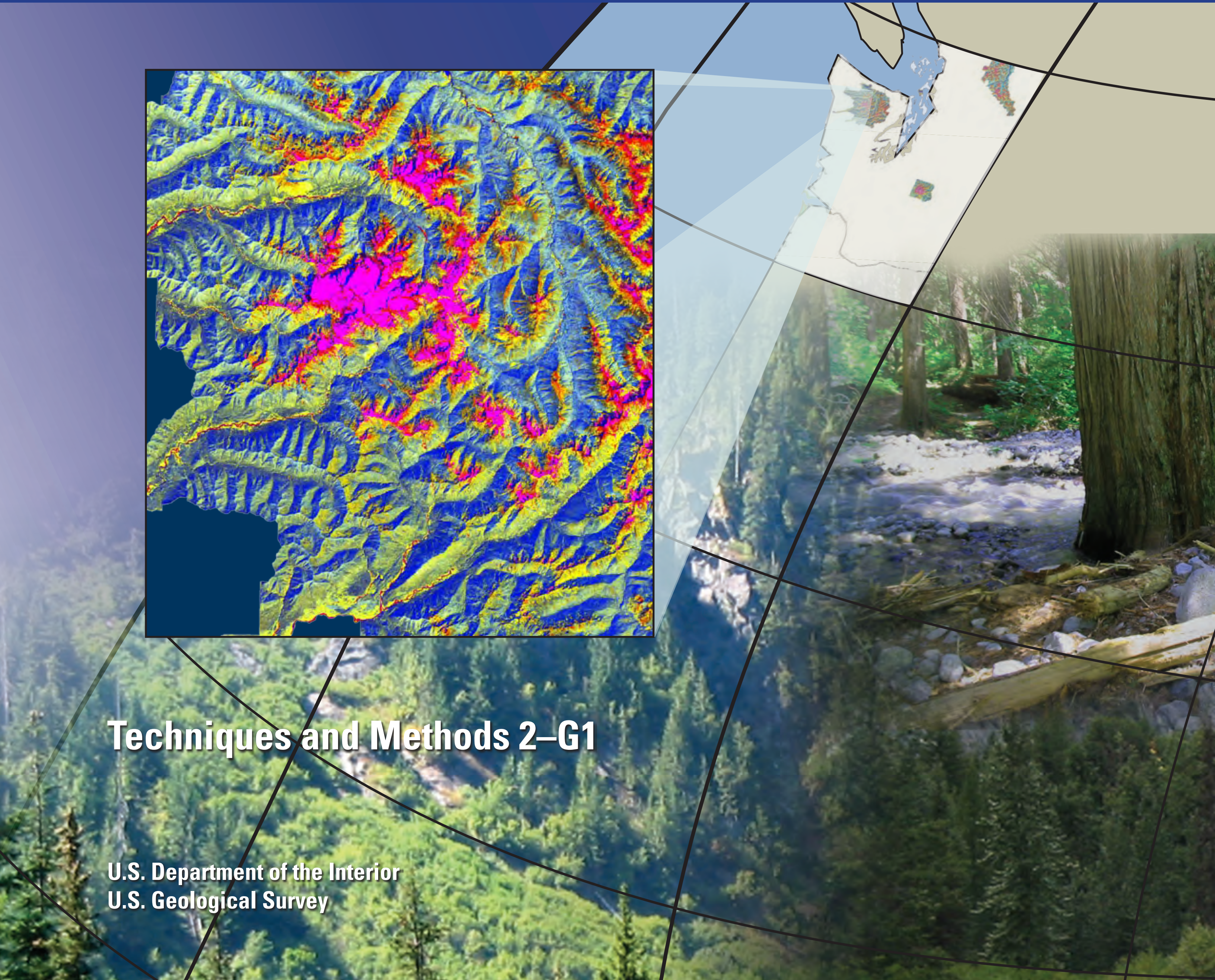
Prepared in cooperation with the NORTH COAST AND CASCADES NETWORK,
NATIONAL PARK SERVICE

Protocol for Landsat-Based Monitoring of Landscape Dynamics at North Coast and Cascades Network Parks

Chapter 1 of Book 2,
Collection of Environmental Data
Section G, Remote Sensing



Techniques and Methods 2–G1

U.S. Department of the Interior
U.S. Geological Survey

Protocol for Landsat-Based Monitoring of Landscape Dynamics at North Coast and Cascades Network Parks

By Robert E. Kennedy, Warren B. Cohen, Alan A. Kirschbaum, and Erik Haunreiter

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Protocol for Landsat-Based Monitoring of Landscape Dynamics at North Coast and Cascades Network Parks

By: Robert E. Kennedy,[1] Warren B. Cohen[1], Alan A. Kirschbaum[2], and Erik Haunreiter[2]

Narrative

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I. Background and Objectives

As part of the National Park Service's larger goal of developing long-term monitoring programs in response to the Natural Resource Challenge of 2000, the parks of the North Coast and Cascades Network (NCCN) have determined that monitoring of landscape dynamics is necessary to track ecosystem health (Weber and others, 2005). Landscape dynamics refer to a broad suite of ecological, geomorphological, and anthropogenic processes occurring across broad spatial scales. The NCCN has sought protocols that would leverage remote-sensing technologies to aid in monitoring landscape dynamics. The parks' personnel considered remote sensing necessary for several reasons (adapted from Woodward and others, 2002):

1. Monitoring must cover large areas often inaccessible by foot travel.
2. Some large-area processes are best viewed from the landscape perspective afforded by remote sensing.
3. Some small-area events are captured more efficiently and consistently with repeat viewing using remote sensing.

At a workshop organized by Andrea Woodward (U.S. Geological Survey-Biological Resources Division/Forest and Rangeland Ecosystem Science Center), October 2002, a variety of remote sensing experts were convened to develop strategies for remote-sensing based monitoring (Woodward and others, 2002). Several factors were considered potential challenges to application of remote-sensing methods to the parks in the Pacific Northwest, including frequent cloud cover and dense coniferous vegetation. Considering costs and benefits of a wide range of active and passive remote-sensing systems, one of the central conclusions of the workshop was that Landsat Thematic Mapper/Enhanced Thematic Mapper (TM/ETM+) data should serve as the core tool for monitoring landscape dynamics. This protocol describes a strategy for monitoring a wide range of landscape dynamics using such data.

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The project was conducted under an interagency agreement between the U.S. Department of Agriculture Forest Service and the U.S. Geological Survey Biological Resources Division/Forest and Rangeland Ecosystem Science Ccenter program (Interagency Agreement 03WRPG0008), and was divided into four tasks. Task 1 was development of a study plan between January and June 2004. Between June 2004 and February 2005, the authors did field and remote sensing analysis for Task 2, which was the testing and evaluation stage. Task 2 finished in February 2005 when the authors presented their findings to the National Park Service (NPS) and BRD personnel. Three meetings were held during Tasks 1 and 2 to allow NPS personnel to prioritize goals and evaluate options for inclusion of methods in the final protocols. Task 3 was the writing of this protocol, and Task 4 is the revision of the protocol according to comments gathered in the anonymous peer review process.

The authors' original proposal to the USGS BRD/FRESC and the NPS (hereafter, the "parks") had several themes. First, the remote-sensing monitoring program would be built around the TM and ETM+ sensors (Cohen and Goward, 2004). Second, the original strategy for monitoring change was to identify a baseline landcover map from among several already available at the parks, use various change detection methods to identify areas of change, and remap only the changed areas. The remapped areas could then be field tested for accuracy, allowing comparison across different baseline maps and change-detection methods. Following the first meeting with the parks (January 14, 2004), this approach was altered substantially. The resulting strategy is discussed in the section, "Strategy for Monitoring."

The third major theme of the original proposal was the goal of articulating the cost, confidence, and utility of using remote-sensing technology to address specific landscape monitoring goals. Some attributes can be tracked by remote-sensing technologies with relatively high confidence even at relatively low cost (Type I), while others are difficult to monitor even with substantial outlays of time and money (Type II; fig. 1*A*). In general, confidence in results is related positively to investment costs, but the confidence/cost ratio (the slope of the increase) varies by the attribute being tracked.

Predicting whether a given ecological phenomenon or landscape attribute is more likely Type I or Type II requires a basic understanding of core remote sensing and scale concepts. Remote sensing instruments measure electromagnetic energy emanating from or being reflected by an object. The sensitivity of an instrument is determined primarily by its engineering design, which represents a strategy to balance tradeoffs between sensor grain size, temporal frequency, and spectral response. Grain size is the spatial property describing the smallest footprint on the ground over which the sensor measures electromagnetic energy (corresponding roughly to the "pixel size" reported for many sensors). The smaller the grain size, the more sensor elements or the more measurement occasions are needed to map a given geographic area, which means that the same location can be mapped less frequently (with a coarser temporal grain). Spectral response describes both the region of the electromagnetic spectrum over which the sensor measurements electromagnetic energy, and the sensor's physical sensitivity across that region. The larger the region of the electromagnetic spectrum over which a sensor measures energy, the more energy it can capture per time period, which tends to increase the signal relative to ambient noise levels. Taken together, these design specifications define an instrument's measurement properties.

At the most basic level, a landscape phenomenon can be considered Type I when its physical properties match well with an instrument's measurement properties. A good match sets the upper limit on the theoretical confidence with which that attribute can be sensed. This confidence level is diminished by grain mismatch between the sensor and the object (spatial, temporal), by uncoupling between the landscape phenomenon and its detectable physical properties, by inappropriateness of the analysis tools applied to the problem, or by poor quality of reference data used to build and test models. Note this important implication: *Improving grain size match, analysis techniques, or reference data cannot boost detection confidence above the theoretical maximum level determined by an instrument's measurement properties*. Often, however, actual confidence levels are far lower than this theoretical maximum, and thus increased effort (cost) applied toward analysis and reference data collection can achieve higher confidence.

Although confidence depends to some degree on cost, utility to the parks may not depend entirely upon confidence (fig. 1*B*). In some cases, attributes that can be measured with high confidence through remote-sensing methods may not be useful to the parks (curve labeled "irrelevant information" in fig. 1*B*), while others may be extremely useful to monitor even if confidence in their accuracy is relatively moderate (curve labeled "relevant information" in fig. 1*B*). Often, it is possible to attain higher ultimate *utility* to the parks by monitoring a slightly different attribute than the parks might originally have intended, simply because its confidence can be much higher at a given cost than for the original attribute.

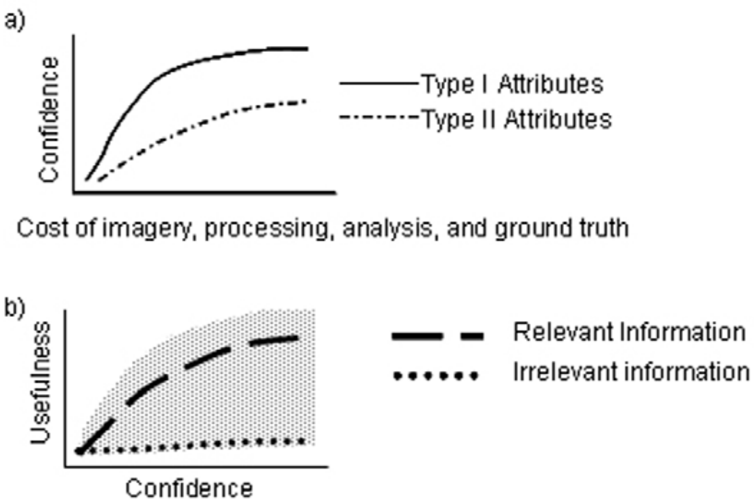

Figure 1. Conceptual relations affecting the choice of remote-sensing technologies and methods for monitoring different ecological phenomena. (*A*) Confidence in an ecological remote-sensing product generally increases as increased resources are applied to imagery, processing, analysis, and collection of ground-truth data. Some ecological attributes can be mapped with high confidence at minimal expense (Type I), while others are extremely difficult to map with a given class of remote-sensing technology, even with significant expense (Type II). (*B*) Usefulness to a park depends, in part, on the confidence with which the attribute can be determined and mapped, but not always. Some attributes that can be derived from remote sensing are irrelevant for the National Park Service, and will be of little utility even when confidence in their measurement is high. Others are relevant, even at relatively low confidence levels.

Narrowing Goals

The first phase in the project was to narrow and articulate monitoring goals. At the January 14th, 2004, meeting in Seattle, the authors aided the parks in articulating their monitoring goals in the framework of remote-sensing technology. Monitoring goals were grouped into broad monitoring themes: **Alpine vegetation, Forested vegetation, Disturbance and recovery, Riparian areas and rivers, Land use and land cover, and Snow and ice.** Key monitoring goals were then described in terms of their relevant spatial and temporal grain and extent, which were then matched to the appropriate remote-sensing technology. Considering these scale issues, as well as the authors' recommendations on relative difficulty of monitoring, the parks prioritized which monitoring goals were to become the foci of protocol development testing of Task 2. These priorities were revisited at the May 13, 2004, meeting in Seattle, resulting in a slight adjustment of some priorities. The combined result of group prioritization of monitoring goals from the January 14 and May 13 meetings is listed in table 1.

Only monitoring goals identified as "Achievable Monitoring Goals" in table 1 were considered for testing in Task 2 of this study. By narrowing monitoring objectives to those likely to be achieved with TM/ETM+ imagery, the parks began defining the cost/confidence/utility envelope for their goals. Several monitoring goals were considered unachievable under the current protocol development. These included goals that required information at a finer grain size than Landsat (for example, many riparian monitoring goals) or involved changes with minimal spectral manifestation (changes between herbaceous communities in the alpine). Other goals to be skipped under this protocol include those already being tracked by other agencies (volcanic eruptions and shoreline change). Encroachment of trees into the alpine, although a high priority, was acknowledged to be particularly challenging. Snow and ice monitoring are discussed separately in the following sections.

For additional clarity, the monitoring goals were grouped according to the time period of observation needed to capture them. Fast processes, such as disturbance, must be monitored yearly because post-event recovery can obscure the original signal if intervals of monitoring are too great. Slow processes require a long period to manifest themselves. Most of the achievable monitoring goals are regrouped in table 2.

The goals for monitoring snow, ice, and glaciers fell into an entirely different temporal scheme. Here, important monitoring questions involve attributes such as the maximum extent of snow cover in a year, duration of snow cover across the landscape, and spatial distribution of glacial snow and ice at the snow-minimum time of year. In all three cases, observation must occur many times within a single year, yet the time period over which these attributes change spans many years. Landsat TM/ETM+ data lack the high-temporal frequency needed to answer these questions alone. Moderate Resolution Imaging Spectrometer (MODIS) and Advanced Very High Resolution Radiometer (AVHRR) data have an appropriate temporal frequency, and the MODIS sensor has a standard product of an 8-day map of snow extent (with both daily and aggregate snow-cover information). The confidence at which fine-grained properties of snow cover could be mapped with MODIS was expected to be relatively low, but the information was important enough even at a coarse grain that exploration of this topic was desired (an example of highly "relevant information" in fig. 1*B*).

Table 1. Ecological monitoring goals of the North Coast and Cascades Network Parks evaluated at three project meetings, 2004 and 2005.

[All goals are characterized in terms of spacial and temporal grain. Based on spatial and temporal grain, as well as importance to the NCCN parks, each goal was assigned a priority for consideration in the study plan. **Priority:** Topics marked "advise" indicate goals that likely were not achievable within this protocol using Landsat TM/ETM+ imagery, but on which the parks sought separate guidance on possible approaches. Those that were thought likely to be achievable using Landsat-based satellite data are noted. **Abbreviations:** USGS, U.S. Geological Survey; NCCN, North Coast and Cascades Network; m, meter; ?, uncertain; >, greater than; <, less than]

Topic	Subtopic	Spatial grain	Temporal grain	Priority	Achievable monitoring goal?
Alpine vegetation	Bare ground impacts	1 m	5 year	Skip (need higher resolution)	
	Interface with forest	1 m / 30 m	Decadal	High/Advise	Yes
	Vegetation communities	1 m	> Annual	High	Advise
Forested vegetation	Hardwood/conifer	30 m	> Annual	High	Yes
	Forest structure (classes)	1 m / 30 m	> Annual	High	Yes
Disturbance and recovery	Vegetation disturbance in avalanche chutes	1 m / 30 m	5–10 years	High	Yes
	Landslides	1m / 30 m	Annual / > Annual	High	Yes
	Fire	30 m	Annual / > Annual	High	Yes
	Insect/disease	1 m / 30 m	Annual / > Annual	High	Yes
	Windthrow	1 m/ 30 m	Annual / > Annual	High	Yes
	Pollution	?	?	Low (important in future; impacts are not extensive enough to detect at present)	
	Shoreline change	1 m	Annual / > Annual	Skip (problematic and already being done)	
	Developed areas (within parks)	1 m / 30 m		Skip (accessible and need higher resolution)	
	Forest harvest	30 m	Annual	High	Yes
	Volcanic	500 m–1,000 m	> Annual	Skip (already being done by USGS)	
Riparian areas and rivers	Riparian vegetation	1 m (30 m)		High (hardwood/conifer distinction)	Yes (30 m)
	Riparian width	1 m		Advise (Landsat not useful)	
	Floods and channel	1 m		Advise	
	Wood	? 1 m Lidar ?		Advise	
	Lake shoreline	1 m		Advise	
	Land use	1 m		Advise	
	Sedimentation	1 m		Advise	
Land use and land cover	Various (primarily outside of parks, including clearcuts)	30 m for most	> Annual	High	Yes
Snow and ice	Glaciers	1m / 30 m	> Annual	High	Yes
	Snow cover	30 m / 500–1,000 m	Annual	High (integrating Landsat with MODIS)	Yes
	Ice out (lakes)	1 m / 30 m	Annual	High	Maybe

Table 2. North Coast and Cascades Network monitoring goals grouped by change interval needed for detection.

Type 1: Monitor yearly
Avalanche chute clearing
Landslides
Fire
Insect/disease defoliation in forest
Windthrow
Riparian disturbance
Clearcuts
Rural development
Type 2: Monitor decadally
Alpine tree encroachment
Hardwood/conifer forest composition
Forest structure

Strategy for Monitoring

The authors' original plan relied on the identification of baseline maps from which change areas could be mapped forward in time for monitoring. At the January 14, 2004, meeting in Seattle, a key problem became apparent: Among the parks there is a sense that the mid-1990s era Pacific Meridian Resources (PMR) maps, which are the most detailed of the available maps, have inadequate detail to be useful to field ecologists, and that these maps should not form the basis of a monitoring plan. Roger Hoffman (OLYM; Olympic National Park) raised an idea that evolved into a new direction for evaluation. Rather than build a change map based on a particular base map, the focus should be instead a methodology for detecting change that is —to the maximum extent possible—separated from any particular baseline map. The goal of protocol development would shift from creation of new maps of landcover to development of maps strictly focusing on areas that have changed (see notes in app. 1 from the January 14, 2004, meeting). Under this “change-focused” strategy, the remote-sensing data would serve as a filter for the Parks, highlighting areas that appear to be changing and which can be investigated in further detail either on the ground or with more detailed imagery (airphotos, high resolution satellite data, etc.).

The change-focused approach is attractive for several reasons:

- Errors in baseline maps are not incorporated into the analysis—all errors will be traceable solely to the change detection methodology. Although the end goal may be to attach the change products to a particular map, which will have errors, the errors will be separable.
- By focusing on areas that have changed, field sampling of the landscape may be more efficient. Nevertheless, the need to validate areas labeled “no-change” still may require considerable sampling effort.
- By making the change methodology as modular as possible, it can be “bolted on” to any map or maps at either the beginning or ending of a given change-detection interval. This gives substantial flexibility to adapt the change products to the needs of different users within the parks, or as new maps become available.

Challenges to Utilizing a Change-Focused Approach

There are several challenges to the change-focused approach. In remote-sensing technology, the changes seen over time are spectral, which have no inherent meaning ecologically, as they represent relative quantities of reflected light energy. While the goal of the change-focused approach was eliminating dependence on any particular landcover map, it is not possible to understand the spectral changes without reference to some sort of reality or truth.

The importance of “truth” data is illustrated in figure 2, which lists the conceptual steps needed to move from remote-sensing data to actual ecological information. The base layer in figure 2 represents the digital numbers returned from a remote device. These raw data have no inherent physical meaning or location information. They also incorporate undesirable effects of atmospheric conditions, sun illumination and surface orientation, that are often unrelated to the properties of the surface materials that are the ultimate target of sensing. Raw images must undergo several so-called preprocessing steps to move them from a raw to a clean format that better characterizes actual surface conditions. These clean data are still one step removed from the information content required in this project, because they characterize the surface only in terms of its reflectance properties. Assigning meaningful labels to those reflectance qualities requires that the clean data be linked through models or rules to observations made at the surface. The result of this process is a map of surface properties, such as a landcover characterization, that has meaning to the end user. Change detection and labeling involve tracking these properties over time, resulting in maps of landscape change. Without reference to maps, some other source of truth data must be used to link reflectance information to surface conditions.

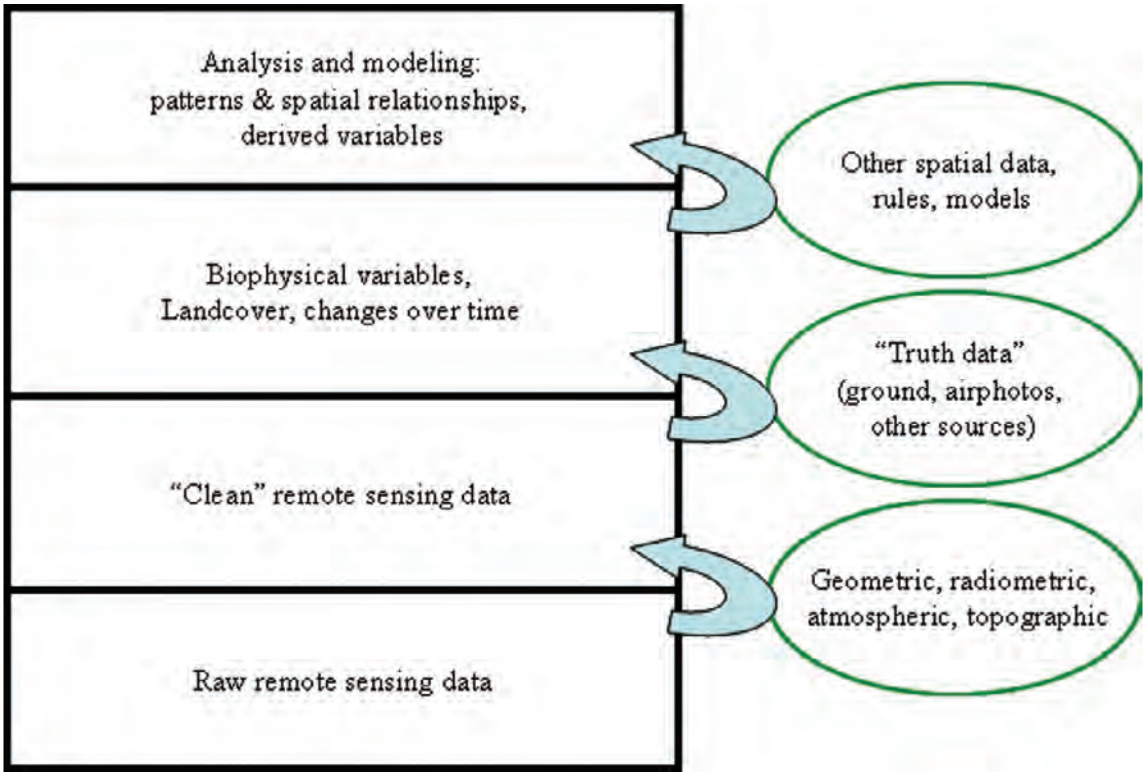

Figure 2. A schematic view of the steps needed to convert raw remote-sensing data into information useful to natural-resources professionals. Raw remote-sensing data are digital numbers arriving from satellite or other digital-recording devices, and have no inherent physical meaning. Cleanup of these data requires information on engineering specifications of the instrument and on conditions of the atmosphere, sun, and surface at time of data collection. These clean remote-sensing data are related to surface conditions with the aid of ancillary data from ground measurements or from basic models. In some cases, further application of models and rules is needed to infer spatial pattern and underlying processes.

The processing steps illustrated in figure 2 expose another challenge to change-detection studies in the parks of the NCCN. Moving from raw to clean remote-sensing data in a single date requires that the effects of sensor, atmosphere, illumination, and topography be removed from the signal. As noted in the October 2002 meeting that preceded this study (Woodward and others, 2002), the parks of the NCCN experience frequent cloud cover and contain steep terrain. Atmospheric and terrain correction were considered potentially very challenging steps, but necessary. These challenges are amplified when changes over time are sought. Conceptually, when images from different dates have different spectral values, those different spectral values could be the result of artifacts in either sensor or viewing condition (the result of technological noise that cannot be cleaned, or of atmospheric, illumination, or topographic effects that change apparent spectral properties of the surface), the result of changes on the ground that are spectrally real but that are uninteresting for the change analysis (for this study, phenological changes), or the result of real changes of interest for the analysis (fig. 3). Separating real changes from the other two categories can be difficult.

A third challenge arises when change detection maps are completed. Since the product being tested is a map of change, not a map of landcover, validation requires an accurate assessment not only of current conditions, but also of conditions at some point in the past. Thus, field measurements of current conditions alone will not be sufficient, and other approaches must be included.

Finally, the parks require monitoring of a suite of landscape dynamics simultaneously (tables 1 and 2). The multiple goals of ecological monitoring contrast with much of the remote-sensing research literature in change detection, where typically only a single attribute is tracked (Bradley and Mustard, 2005; Cohen and others, 2002; Collins and Woodcock, 1996; Coppin and others, 2004; Gumbricht and others, 2002; Hayes and Sader, 2001; Michener and Houhoulis, 1997; Muchoney and Haack, 1994; Roy and others, 2002; Royle and Lathrop, 2002; Sader and others, 2003; Trigg and Flasse, 2001; Viedma and others, 1997; and Wilson and Sader, 2002). In many methods documented in the literature, analytical tools appropriate for one type of monitoring goal would not be appropriate or useful for another monitoring goal. Additionally, future monitoring questions may require retrospective analysis of as-yet-unknown processes or attributes. Therefore, any tools developed for this protocol must be flexible and retain as much information as possible, even if beyond the currently recognized monitoring goals.

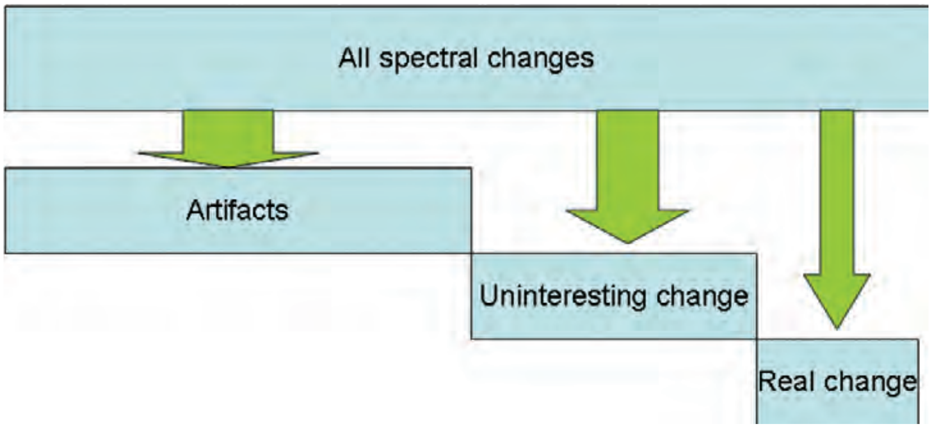

Figure 3. Conceptual description of the relation between apparent spectral change and real, meaningful change on the ground. Some spectral changes are artifacts caused by variation in illumination, atmospheric, sensor calibration, or geometric-registration conditions. Some spectral changes are real changes to the spectral condition of the cover on the ground, but which are not of interest in monitoring (i.e. phenological state at the date of image acquisition). Finally, some spectral changes are real and of interest to the parks.

Tracking Change in Physiognomic Types

At the second project meeting in May 2004, the authors and the parks agreed on a general strategy for implementing the change-focused approach. Rather than derive truth information from existing landcover maps or from expensive new photo- or field-interpretation programs, cover-type labels would be defined in broad physiognomic categories that could be interpreted directly from spectral data alone. The strategy was based on the tasseled-cap transformation of TM/ETM+ data. The tasseled- cap transformation compresses the six nonthermal bands of Landsat TM and ETM+ imagery into three spectral axes, originally named brightness, greenness, and wetness (Crist and Cicone, 1984). Although spectral interpretation of Landsat TM and ETM+ imagery can be achieved by trained interpreters in any spectral space, the tasseled-cap transformation's use of three standardized axes makes it especially useful for interpretation using standard three-color theory. Based on the authors' experience with tasseled-cap imagery from many different biomes, it appears possible to make general interpretations of landcover based on tasseled-cap spectral character alone in every system (Cohen and others, 1998; Cohen and Spies, 1992; Maiersperger and others, 2001; Oetter and others, 2000; and Parmenter and others, 2003). For example, conifer and broadleaf forest, soil and rock, water, and snow and ice display predictable spectral characteristics in every ecosystem examined (fig. 4). As cover-type definitions become more finely described for a particular ecosystem, spectral ambiguity increases. If definitions of physiognomic character are kept relatively generalized, however, changes likely are to be tracked with relatively high confidence. The theme of the change-focused approach, then, becomes one of tracking changes among physiognomic types using general knowledge of the spectral properties of those types. Several broad categories of change detection based on tasseled-cap imagery were to be evaluated in Task 2.

A second theme of testing in Task 2 involved preprocessing. As figure 2 shows, each successive step in processing is built on the layer below it. Many monitoring objectives require detection of changes with very small footprints (windthrow) or with linear features that contrast with their surroundings (rivers, avalanches). Therefore, geometric registration was presumed to be of paramount importance. Additionally, the change-focused approach requires that the spectral space of images from the two dates be aligned. Radiometric correction, which accounts for effects that cause misalignment of spectral space, including engineering, sun angle, and atmospheric effects, thus also was expected to be critically important. Radiometric correction also is necessary to build consistent and robust long-term datasets.

Therefore, the goals of Task 2 were to develop pilot studies to examine approaches to implement the change-focused strategy and to investigate best practices for preprocessing of Landsat TM/ETM+ imagery in support of the parks' monitoring goals. Additionally, because snow and ice questions were acknowledged to require more than Landsat TM/ETM+ data alone, a separate pilot study investigating the potential use of MODIS snow products was needed.

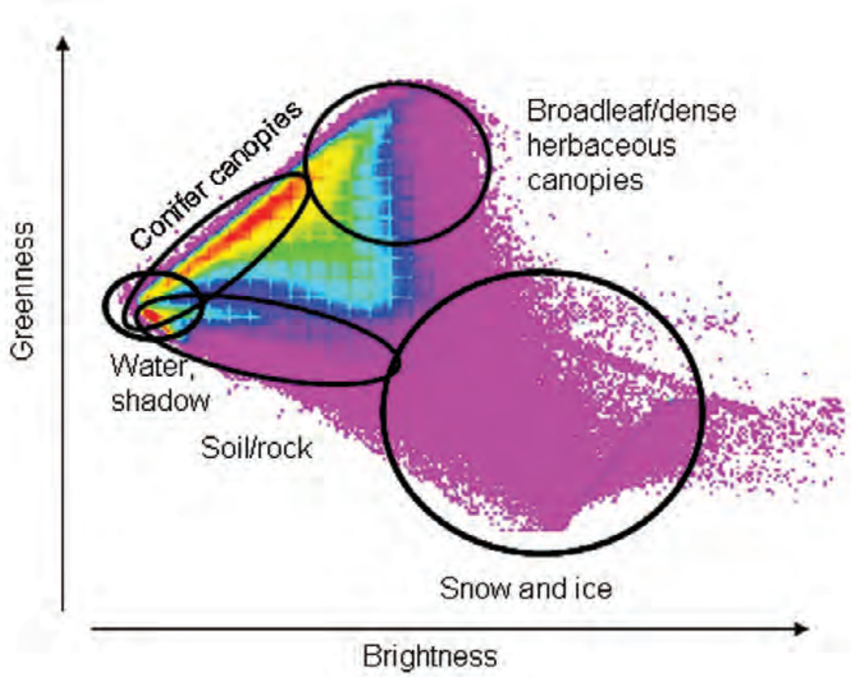

Figure 4. Tasseled-cap spectral space, showing regions where physiognomic types approximately are consistent across ecosystems.

Key Findings of the Pilot Studies in Task 2

A brief overview of the findings of Task 2 is relevant. First, the authors determined that typical tolerances for geometric coregistration of images (Richards, 1993) are often inadequate for the monitoring goals desired by the parks. The authors have included specific recommendations for ordering and processing imagery standard operating procedures 1 and 2 (SOP 1 and 2) that improve geometric properties of coregistered images. Included is a version of automatic tie-point software that finds hundreds of image tie points quickly, allowing excellent coregistration of images. These approaches will minimize, but never entirely eliminate, artifacts of misregistration.

Second, detecting subtle changes caused by insect defoliation, encroachment of woody vegetation into herbaceous zones, and recovery or transition in forest type requires that radiometric and atmospheric differences between images be removed. The authors found that excellent radiometric normalization of images can be achieved with the MADCAL algorithm (Canty and others, 2004), an implementation of which is included with this protocol (SOP 2).

Third, spectral separation of forest age and structure information requires large sets of photo-interpreted reference data, which was determined by the parks to be beyond the scope of the work desired under this protocol. Therefore, changes in forest structure would not be modeled explicitly in terms of objective age or structure attributes. Rather, they would need to be wrapped into general change-detection procedures and separated in a relative sense.

Fourth, the authors found that standard change detection approaches in the literature must be adapted to handle the diversity of changes being sought. The change-detection method most attractive to the parks at the February 2005 meeting was a directed change-vector approach, which allowed more intuitive labeling of change than the standard change-vector approaches in the literature (Lambin and Strahler, 1994 and Malila, 1980). The method ultimately was considered inadequate because of the lack of connection to real quantities on the ground. Therefore, it was used as the model for development of a final method for change detection based on fuzzy classification approaches (see "Methods" section below, as well as details in SOP 3).

Fifth, validation methods must be based on direct interpretation of satellite imagery because airphotos will not be available for yearly assessments, and because exhaustive field validation is too costly for the future budgets of the parks. Therefore, the authors have described an approach to validate directly from satellite imagery (SOP 4) that allows followup with airphoto or field validation.

Finally, monitoring goals for rural development and snow and ice extent were determined infeasible with Landsat technology alone. Rural development, especially near the smaller parks of the NCCN, likely is better achieved through more focused investigations that revolve around tax-lot information and monitoring of specific locales of interest to the parks. The authors showed that raw MODIS data may be useful for tracking regionwide temporal and spatial patterns of snow extent, but that the MODIS snow product itself was not suitable for the parks' needs. In a pilot study for a year of MODIS imagery (water year 2002/MODIS data version 4, obtained from EDC in November 2004), the 8-day maximum snow extent product contained significant false positives and false negatives distributed across the landscape, and these patterns of error changed for each 8-day period visually examined, indicating that there was no predictable bias that could be corrected. Examination of individual day data indicated that cloud cover may have been a significant complicating factor. A detailed snow-extent mask was extracted for two single dates that coincided with Landsat 7 imagery (one in 2001 and one 2002). Relative to the fine-grained Landsat data, the MODIS snow product underestimated snow extent significantly. However, a simple unsupervised classification of the raw MODIS imagery from those same dates suggested that the snow signal was present in the spectral information of the MODIS imagery, indicating that its use may be appropriate if specialized products can be developed for the NCCN. Further development of snow-monitoring goals with MODIS will need to be addressed separately.

II. Sampling Design

Because the maps of change are produced for every pixel in a park, the sample used for the final product is spatially exhaustive. Temporal sampling of imagery depends on the type of monitoring goal being tracked: Type 1 monitoring goals require yearly sampling of imagery, while Type 2 monitoring goals require decadal sampling.

Various parts of the processing methodology (see Methods below) require that sample sites be used for training and validation. For example, the radiometric-normalization approach requires identification of many thousands of pixels that have not changed over time and the validation approaches require sampling of the landscape for intensive satellite-to-satellite (S2S) validation or field sampling. These sampling issues are confined to the discussions within each SOP.

III. Methods

Overview of Methodology

At the end of the February 2005 meeting, the parks and the authors agreed upon a general structure for Landsat-based monitoring of landscape dynamics. The structure was an amalgam of approaches tested in Task 2, with several new components determined at the end of the February meeting. The basic purpose for the change-focused approach would remain as it had throughout much of the project: create maps of change in cover type that could be used as an alarm to indicate where more focused monitoring should occur. Of the methods tested in Task 2, the directed change-vector approach was attractive to the parks because it captured the complexity of change on the landscape in a manner that was relatively intuitive to understand. The primary drawback was that the relative changes captured by this approach had no inherent meaning, either in terms of physical quantities or class-based membership. For many management needs, resource managers would need summarized versions of these changes that sorted the information according to change type and labeled it according to certainty thresholds. Traditional classification-based change methods were attractive in their ability to describe spectral space in terms of membership in classes with physical or ecological meaning. However, these approaches did not capture the complexity of change adequately, and were too constrained to allow later reinterpretation if monitoring needs were to change. Therefore, the desired approach was one that would retain the key characteristics of the directed change-vector approach while allowing more explicit characterization of the physical characteristics of the changes being captured.

Core Approach

After the February 2005 meeting, the authors developed an approach to meet those needs. Geometric and radiometric preprocessing steps are defined according to those found most useful in Task 2. Images on either end of the change interval are normalized using the MADCAL approach of Canty and others (2004). For a baseline image, expert interpretation of a *k*-means, nonparametric-classification procedure is used to partition tasseled-cap space into broad physiognomic classes. These classes can be mapped onto the landscape, and thus can be linked with any appropriate reference dataset (ground plot, airphoto interpretation, etc.) to describe the classes in terms deemed relevant to managers.

More importantly, these spectral classes also are used to develop multivariate-normal probability distributions for the baseline image. Based on the multivariate-normal distribution, probability of membership (POM) in all physiognomic classes is calculated for every pixel in the baseline image. Because the original *k*-means classification is based on image data, classes are distributed across the entire spectral space, such that few points on the landscape are far in spectral space from a class centroid. With robust radiometric normalization, the second image in the change interval can be mapped directly into the POM space of the baseline image. By subtracting POM images from the two dates, changes on the landscape are expressed in terms of changes in the POM classes.

The method is based on well-established classification approaches. The POM calculation comes directly from a standard maximum likelihood classification process (Richards, 1993). In the typical incarnation, however, each pixel would be assigned to the class in which it had the highest POM. In a fuzzy-classification approach for single-date mapping, the POM in all classes are retained, allowing pixels to take on fuzzy membership in several classes (Wang, 1990; Foody, 1996). Here, we extend the single-date, fuzzy-mapping paradigm into two-date change mapping. When events on the ground result in a spectral change, those changes are expressed as *n*-dimensional vectors of changes in class membership likelihood, where *n* is the number of physiognomic classes. Essentially, changes in spectral space are converted to changes in an *n*-dimensional POM space, where probability is expressed on a 0.0 to 1.0 basis. It is important to emphasize our method does *not* ascribe a single-class label to the class with the highest POM; these POM values are carried forward for all classes. This avoids the problem of a typical hard classification, where change is captured only if it happens to cross a discrete boundary in spectral space. Because the POM space is defined according to easily grasped physiognomic classes, this method provides a descriptor that is more intuitive to a nonspecialist audience than descriptors based solely on spectral values.

One of the attractive properties of this approach is its ability to produce maps of change at different levels of probability. By accepting only changes where probability of class membership changes dramatically, only high-certainty changes are mapped. Lowering the threshold includes changes that are increasingly more ambiguous. An example from Mt. Rainier National Park is shown in figure 5, where change maps at two levels of thresholding are shown (figs. 5*B* and 5*D*). As long as the POM threshold is stated explicitly, there is no one correct threshold for change detection. In practice, it is likely that only one or two thresholds are of actual interest to individual parks, but until this protocol has been implemented over time and at different parks, the authors will not prescribe a particular threshold for change. Regardless of the threshold of change chosen, it must be validated.

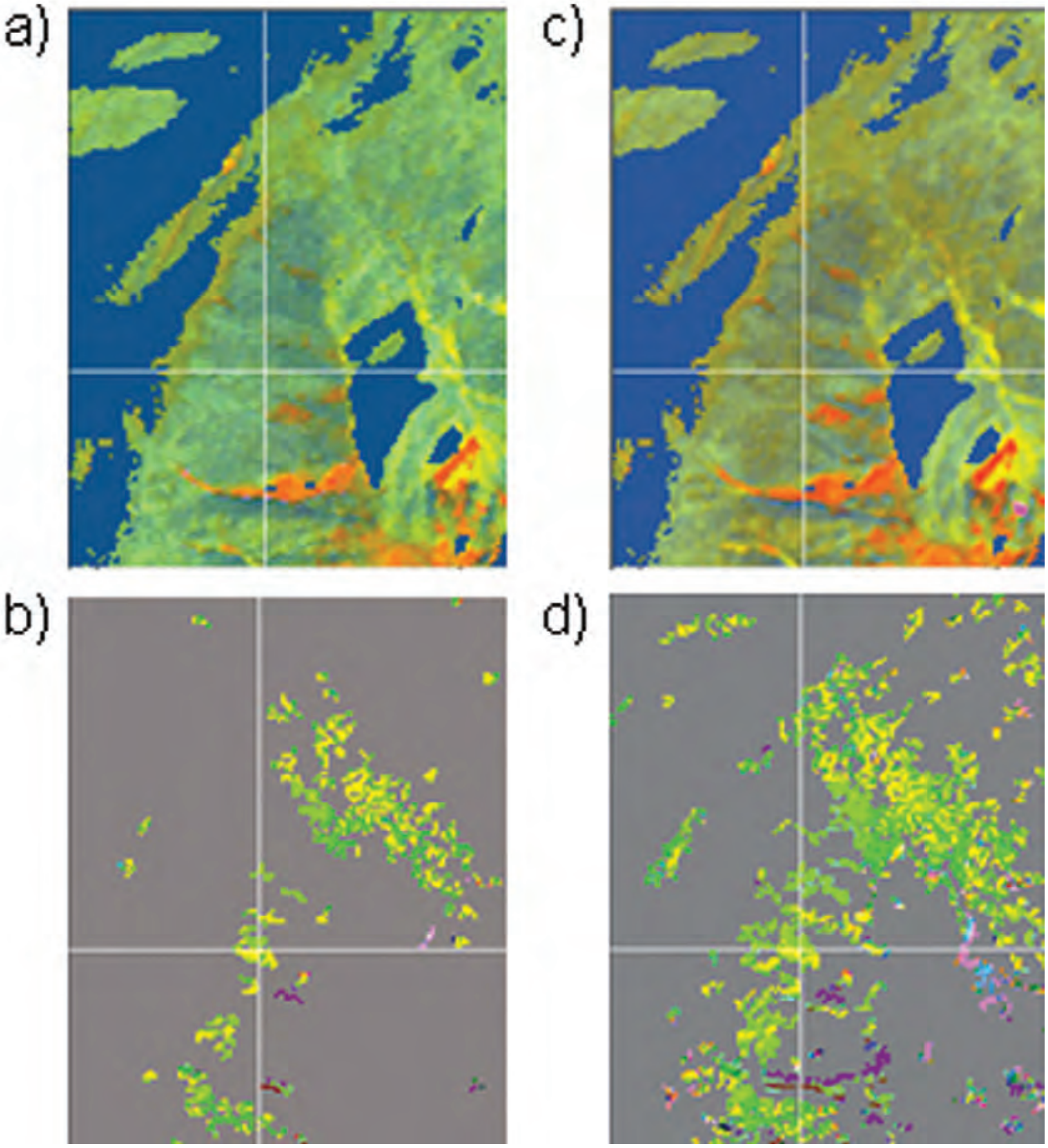

Figure 5. Tasseled-cap images and associated change products for an area adjacent to Mount Rainier National Park. (*A*) Tasseled-cap imagery from 1996. Aspect classes are processed separately; this imagery shows only northwest aspects. Tasseled-cap brightness is shown in red, greenness in green, and wetness in blue. Conifer forest appears as light cyan to dark blue, broadleaf vegetation as yellow, and open areas as red or orange. (*B*) The product of the fuzzy-change-detection approach for the 1996 to 2002 period, shows only areas where probability of membership (POM) in a given class has changed by more than 70 percent. Red, green, and blue color guns correspond to bare soil, broadleaf, and conifer physiognomic types. Insect mortality results in negative conifer values and broadleaf values, leaving yellow (G+R color guns positive) or green (only G color gun positive) tones. (*C*) As in part *A*, but for the year 2002. (*D*) As in part *B*, but for a change threshold of 50 percent rather than 70 percent.

Translating POM Images

Validation of the POM change image is difficult. Quantitative validation of a continuous-variable, *n*-dimensional product requires independent estimates of a similar *n*-dimensional space, which is largely impractical. Even if these spaces could be validated, the changes in physiognomic class membership do not correspond directly to the monitoring goals of the parks listed in tables 1 and 2. Therefore, to increase utility to the parks, physiognomic changes expressed in the POM difference images should be translated into change labels that can be validated and that can be linked more logically to monitoring goals.

For the purposes of both validation and linkage to monitoring goals, differences in POM are compressed into 15 categories of change (table 3) that can be interpreted directly from interpretation of tasseled-cap data. Rules for linking changes in physiognomic class POM to S2S change classes (see below) are presented in SOP 3. Using these rules, an image of S2S change class is created from the difference in POM images. This categorical map of change labels greatly simplifies use of the change products for nonspecialists.

Additionally, the S2S categorical maps can be validated directly from satellite imagery. The classes in table 3 form the core of the S2S validation approach (described in SOP 4). Validation is achieved by visual interpretation of tasseled-cap imagery at the start and end of the change interval, as well as a tasseled-cap-difference image and a high-resolution digital orthoquad (DOQ). Rules are used to aid in interpretation and to score the confidence of the interpreter in change calls.

S2S change classes encompass two types of change. S2S classes two through seven all involve change to or from water. These changes are categorical: if water was present at one time period and not the other, the change falls into one of these classes. These changes refer entirely to changes in riparian areas, not to shoreline changes in stationary water bodies. The remaining classes describe changes occurring elsewhere on the landscape, and are considered to be relative-change types. Classes 10 and 13 are used if vegetation quantity is changing, but cannot be determined to be solely change in conifer or broadleaf types. As defined here, broadleaf types encompass not only broadleaf-forest vegetation, but all non-needleleaf herbaceous and woody vegetation.

The S2S classes listed in table 3 represent just one approach to labeling change from imagery, and are described in more detail in SOP 4. Although suggested for use in this protocol, future evaluation of products may lead to addition or subtraction of some categories.

Most of the monitoring goals in tables 1 and 2 can be described according to labels used in the S2S change classes (table 4). As table 4 lists, the physiognomic cover-type changes associated with many monitoring goals are the same. Loss of vegetation broadly describes many disturbances, for example. Ascribing agents of change requires analysis of the spatial pattern of the change and its context, as well as understanding of the processes that drive landscape dynamics. These require contextual pattern analysis and process-based rule building, the algorithms for which are not included as part of this protocol. Rather, the goal of this protocol is to produce maps that highlight and label changes in terms of their physiognomic type. These form a strong foundation on which to build any number of spatial analyses.

Table 3. Satellite-to-satellite interpretation change classes.

Satellite-to-satellite code	Description
1	No change
2	Water to rock/soil
3	Water to partial vegetation cover
4	Water to complete vegetation cover
5	Rock/soil to water
6	Partial vegetation to water
7	Complete vegetation to water
8	Increase in broadleaf
9	Increase in conifer
10	Increase in vegetation
11	Decrease in broadleaf
12	Decrease in conifer
13	Decrease in vegetation
14	Increase in snow
15	Decrease in snow

Table 4. Linking monitoring goals to satellite-to-satellite interpretation classes.

Agent	Description of change	Satellite-to-satellite interpretation class
	Group 1: Monitor yearly	
Avalanche chute clearing	Avalanche occurs in a chute with broadleaf shrubs	↓ Broadleaf, ↓Vegetation
	Avalanche occurs in a chute with conifer stands	↓ Conifer, ↓ Vegetation
Landslides	Landslide clears broadleaf trees or shrubs	↓ Broadleaf, ↓ Vegetation
	Landslide clears conifer forest	↓ Conifer, ↓ Vegetation
Fire	Fire occurs in herbaceous, shrub, or broadleaf tree community	↓ Broadleaf, ↓ Vegetation
	Fire occurs in conifer-shrub/conifer-tree community	↓ Conifer, ↓ Vegetation
Insect/disease defoliation in forest	Defoliation occurs in broadleaf forest	↓ Broadleaf, ↓Vegetation
	Defoliation occurs in conifer forest	↓ Conifer, ↓ Vegetation
Windthrow	Windthrow occurs in broadleaf forest	↓ Broadleaf, ↓ Vegetation
	Windthrow occurs in conifer forest	↓ Conifer, ↓ Vegetation
Riparian disturbance	Shifting stream channel removes or covers sandbar/rock/gravel	↓ Rock/soil → Water
	Shifting stream channel builds sandbar/rock/gravel	↓ Water → Rock/soil
	Shifting stream channel removes broadleaf trees or shrubs or conifer trees	↓ Partial vegetation → Water, ↓ Complete vegetation → Water
	Shrub/grass cover quickly recovers on newly deposited sandbar	↓ Water → Partial vegetation cover ↓ Water → Complete vegetation cover
	Shifting stream allows recovery of shrub cover on gravel bars	↑ Broadleaf, ↑ Vegetation
	Longer term recovery of conifer occurs along riparian corridor	↑ Conifer
Clearcuts	Clearcut in broadleaf forest	↓ Broadleaf, ↓ Vegetation
	Clearcut in conifer forest	↓ Conifer, ↓ Vegetation
Rural development	Conversion from agriculture to developed	↓ Broadleaf, ↓ Vegetation
	Conversion from broadleaf to developed	↓ Broadleaf, ↓Vegetation
	Conversion from conifer to developed	↓ Conifer, ↓ Vegetation
	Group 2: Monitor decadally	
Alpine tree encroachment	Broadleaf shrub encroachment into rocky glacial outwash	↑ Broadleaf, ↑ Vegetation
	Conifer shrub/tree encroachment into rocky areas	↑ Conifer, ↑ Vegetation
Hardwood/conifer forest composition	Succession from broadleaf shrub to broadleaf tree	↑ Broadleaf
	Succession from broadleaf shrub or tree to conifer shrub/tree	↑ Conifer
	Conversion from conifer to broadleaf	↑ Broadleaf
Forest structure	Transition from broadleaf shrub to broadleaf tree	↑ Broadleaf
	Transition from semi-open to closed conifer canopies	↑ Vegetation
	Transition from young, dense conifer stands to vertically structured older stands	↑ Conifer

Detailed Flow of Methods

In a general sense, the flow of methods of image processing is captured in the sequence of the first four SOPs provided with this document. Preprocessing is applied to images at the start and the end of the change interval, and includes geometric and radiometric processing (Canty and others, 2004; Kennedy and Cohen, 2003; Richards, 1993). The change interval is only 1 year for Type 1 monitoring goals and a decade or more for Type 2 goals. The change-detection approach described above is applied to the images to produce a map of changes in POM in nine physiognomic classes (SOP 3). Thresholds are applied to the map of change in probability, and change types are compressed into one of the 15 S2S classes listed in table 3. Validation (SOP 4) requires independent interpretation of the imagery at a sample of areas across the park, and can be followed by airphoto-based or field validation.

The images involved in these steps will differ during three distinct phases of the project. The "startup" phase focuses on establishing a foundation image that can be linked with the field data collected by the NPS in the current era under a project designed to validate maps developed in the past by PMR (henceforth named "field-collection era." around 2005). Figure 6 provides a flow diagram describing this process. First, a Landsat image most appropriate for linkage with the field data is identified, purchased (SOP 1), and is normalized to a reference ETM+ image acquired from the LEDAPs (using methods of SOP 2; LEDAPS reference: http://ledaps.nascom.nasa.gov/ledaps/products2005_new.html). The resultant image becomes the reference image

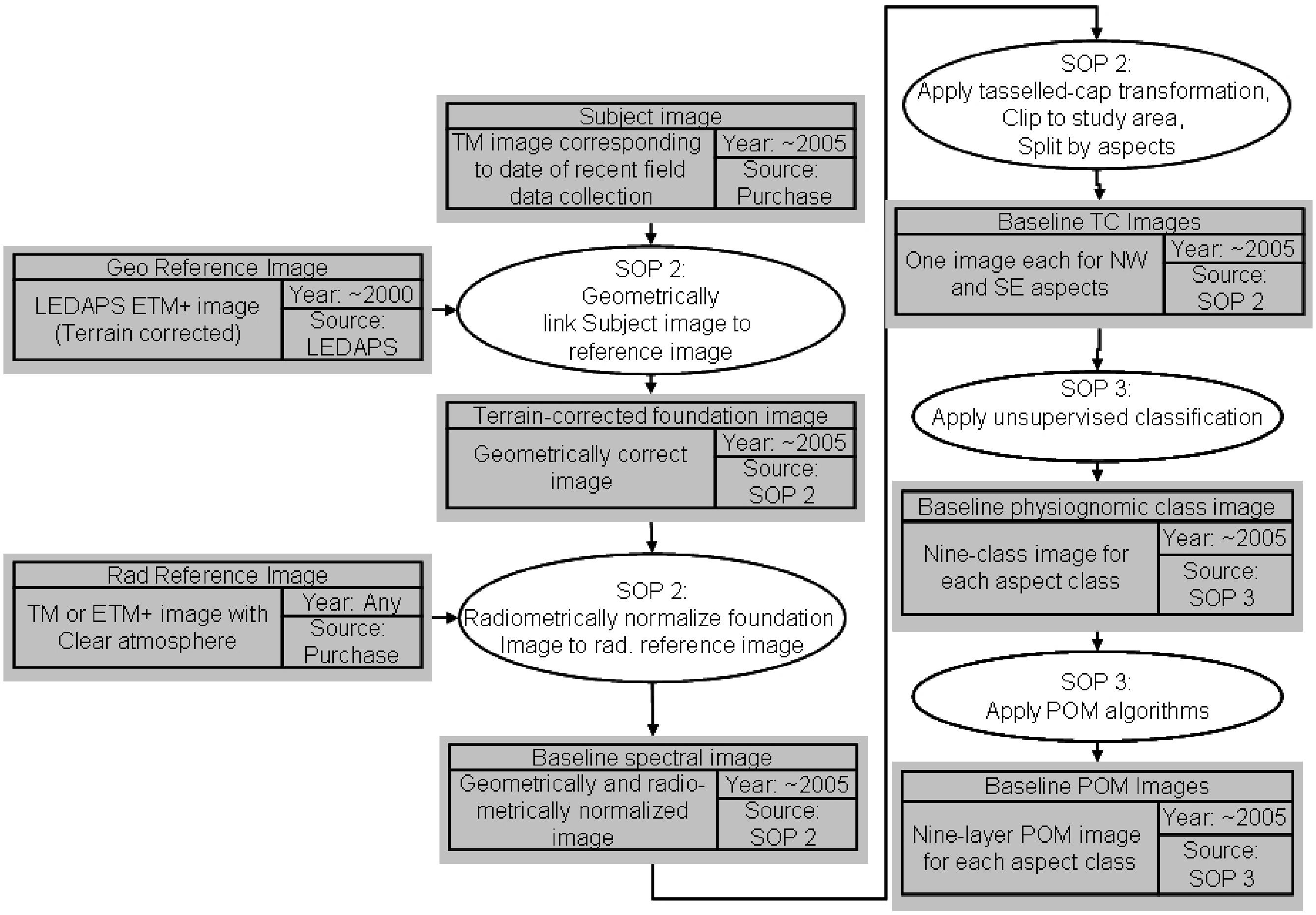

Figure 6. Steps in the startup phase. An image from the era corresponding to the date of recent field validation (approximately 2005) is normalized to reference images, classified, and translated into probability-of-membership (POM) images for two aspect classes. These baseline POM images are then used in Type 1 and Type 2 change-detection phases (figs. 7 and 8).

against which all future images will be referenced for radiometric and geometric normalization. This image is then split by aspect, clipped to the study area, and applied to a tasseled-cap transformation (SOP 2). For each aspect class, the methods of SOP 3 are applied to create a map of physiognomic classes for this image. These classes are then summarized using the field data collected in approximately the year 2005. The classes also are used to build the POM image for each aspect class for the field-collection era. These two POM images become the baseline images on which all further change detection will be based.

Once the startup phase is complete, the "Type 1 change detection" phase begins (fig. 7). Each year, a new image is purchased (SOP 1), preprocessed (SOP 2), and the POM rules for the baseline field-collection era image applied (SOP 3). These POM images are compared to the existing POM images from the prior year for detection and labeling of Type 1 changes, and then validated using S2S (SOP 4).

When a new airphoto mission is acquired, the "Type 2 change detection" phase can begin (fig. 8). In this case, the two images being compared must match the years of airphoto acquisition. The image for the year corresponding to the new airphoto mission already will have been processed under ongoing Type 1 change detection. The image for the year corresponding to the prior airphoto mission must be processed, however. The most recent year of airphoto acquisition is 2003, 2002, and 1998 for Olympic, Mt. Rainier, and NCCN parks, respectively. Images from these years must be identified and processed to POM images, and the POM images compared with those derived for the year of the new airphoto acquisition.

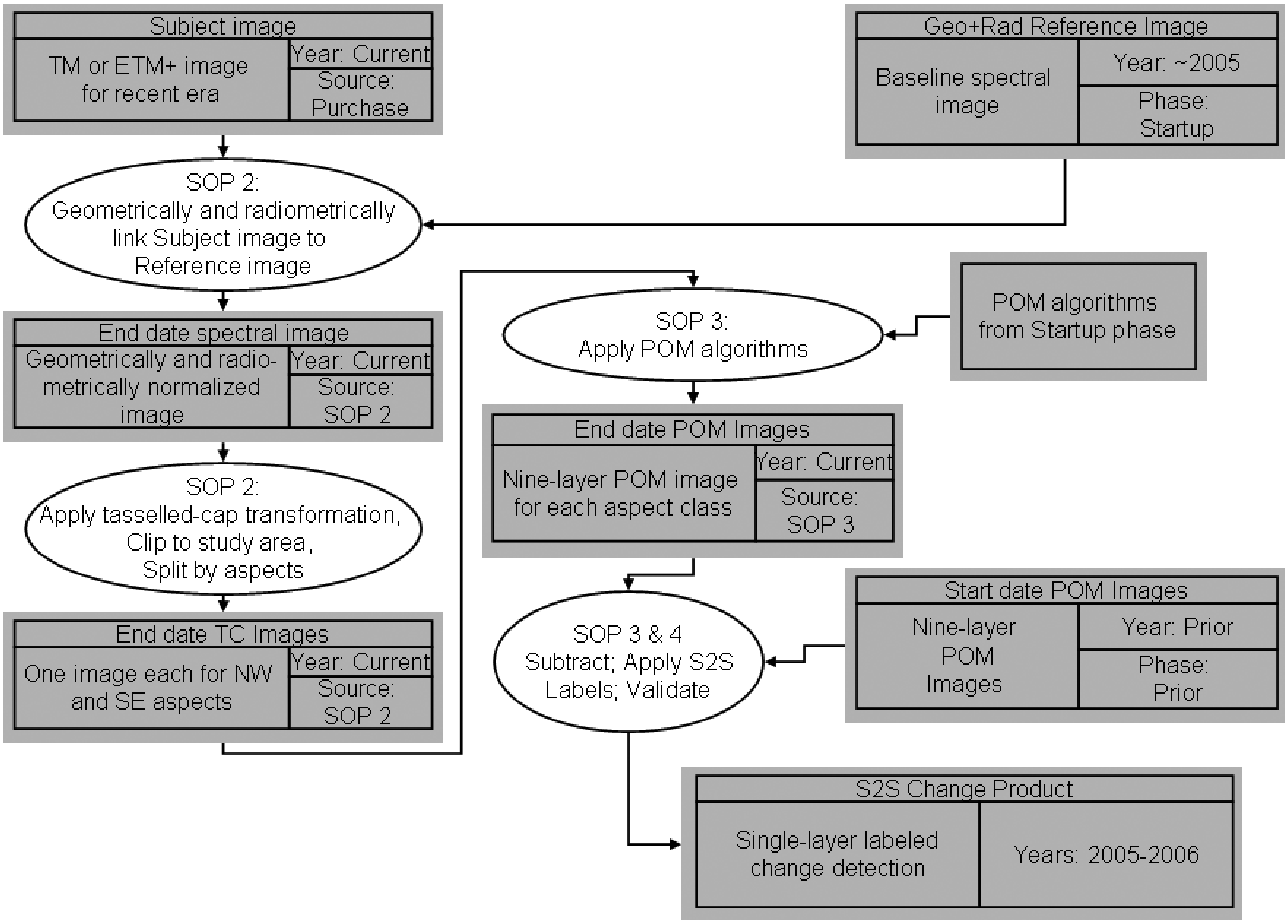

Figure 7. Steps in Type 1 change detection. An image from current year is normalized and applied probability-of-membership (POM) algorithms developed for the baseline images. From these POM baseline images, the POM images from the prior year are subtracted, creating POM difference images. These are translated into satellite-to-satellite (S2S) labels, which allows direct S2S validation.

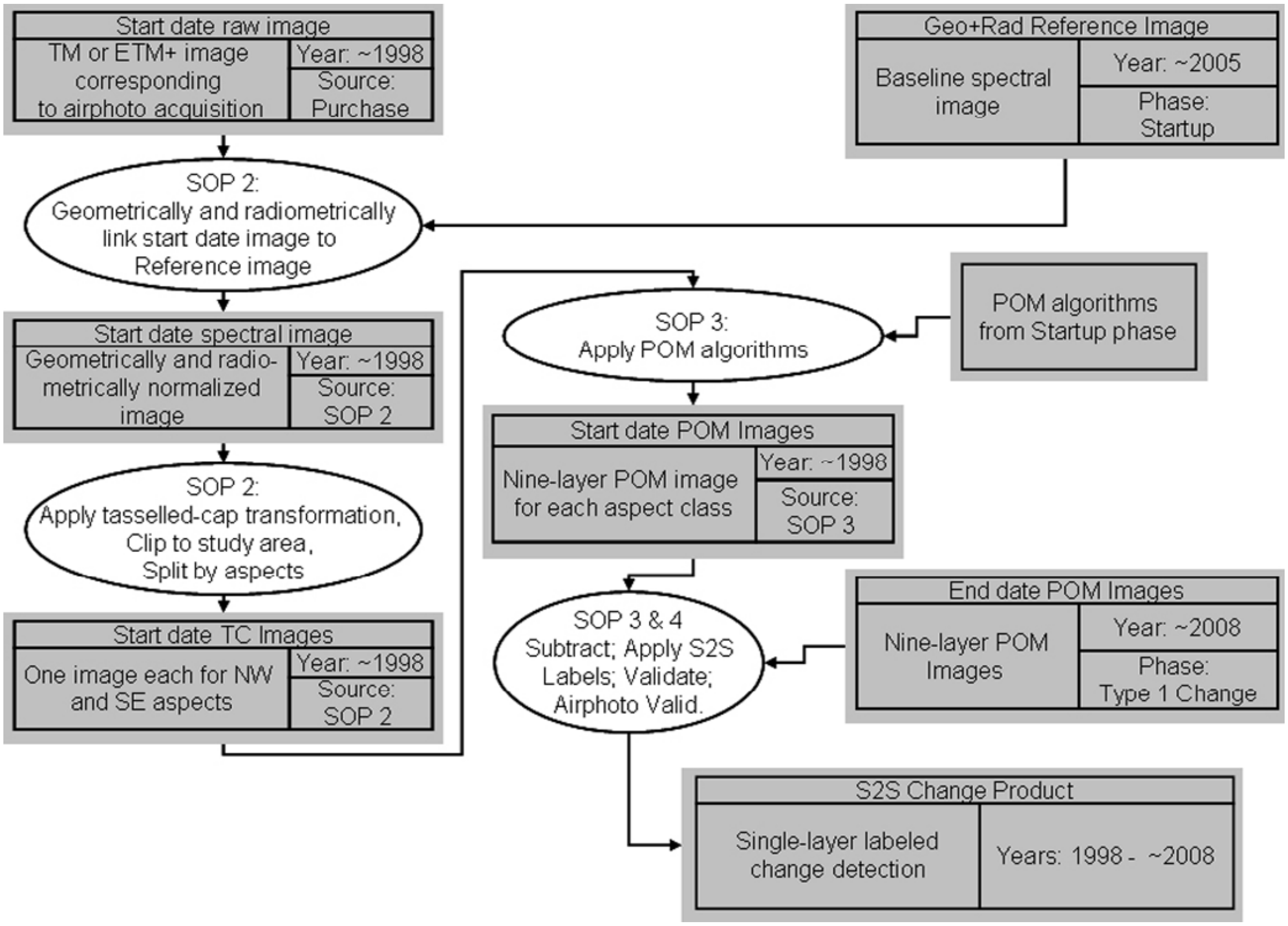

Figure 8. Steps in Type 2 change detection. When a new airphoto mission occurs in the current year, Type 2 change detection occurs in addition to Type 1 change detection. The end date POM image from Type 1 change detection in the current year is compared to a POM image developed for the year corresponding to the prior airphoto acquisition (see text for dates of prior airphoto acquisition). Validation can include both S2S validation for Type 1 changes as well as airphoto validation for Type 2 changes.

Standard S2S interpretation will be conducted on this decadal difference POM image (SOP 4). By matching images and airphotos, direct airphoto interpretation (SOP 4) also can be used for validation of Type 2 changes, which are by nature more difficult to unambiguously interpret from satellite imagery alone.

The steps are summarized in table 5. Although the details of the imagery years may vary slightly depending on availability of imagery and airphotos, the flow of the overall monitoring program should be very similar to the steps detailed in table 5.

Table 5. Sequential phases in the monitoring program.

[**Abbreviations:** POM, probability of membership; NA, not applicable]

Phase	Description	Type of change monitored	Baseline image year	POM	
				Start year	End year
Startup	Establish baseline image	NA	2005		
Type 1 change detection	Change detection	Type 1	2005	2005	2006
Type 1 change detection	Change detection	Type 1	2005	2006	2007
Type 1 change detection	Change detection	Type 1	2005	2007	2008
Type 2 change detection	Change detection	Type 2	2005	1998	2008
Type 1 change detection	Change detection	Type 1, etc.	2005	2008	2009

IV. Data Handling, Analysis, and Reporting

Because final change maps are the result of a long cascade of processing steps, accurate data handling is critical to the success of this protocol. Each step in the processing flow has different requirements.

Metadata

Metadata requirements for all steps in the image processing flow are in SOP 5. The goal of the metadata is to provide a means of replicating the processing steps. This allows better error tracking when problems arise.

Database Design

Image processing does not use a database design. However, S2S interpretation (SOP 4) occurs within the confines of an ArcGIS geodatabase. Data entry within this database contains fields that allow full reconstruction of steps. Details of the database setup are in SOP 4.

Error Reporting

Reporting of error is an important consideration in validation. Error rates are often reported as summarized statistics, but many of these are deceptive and do not provide a full picture of true accuracy of a map (Congalton and Green 1999). Therefore, full error matrices must be reported at the end of S2S interpretation. These are generated in SOP 4 using the ERDAS Imagine accuracy assessment tool, and can be summarized in a grid format (error matrix) as in shown in figure 9. Error matrices describe the counts of occurrences of agreement and disagreement between two types of classification.

		Satellite Classification															
	Change Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Sum
Photo Classification	1	66	0	0	0	0	0	0	1	6	6	5	0	0	0	0	84
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	3
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2
	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10	10	0	0	0	0	0	0	2	13	27	5	0	0	0	0	57
	11	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	13	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2
	14	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
	15	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
	Sum	82	0	0	0	0	0	0	6	19	33	14	0	0	0	0	154

Figure 9. An example of a full error matrix used to report validity of a change product.

Data Archival Procedures

Because of the large size of images, archiving of data is often necessary when immediate processing has finished. Final products (as defined in SOP 5) should be retained in their original format. Original imagery and intermediate products should be compressed and archived rather than deleted. This is especially important if later comparison reveal errors or new comparisons that require reprocessing of part or all of the image stream.

V. Personnel Requirements And Training

This protocol involves a wide range of detailed remote-sensing interpretation, image processing, data analysis, field measurement, and photo interpretation. The authors have attempted to provide sufficient detail in the steps that personnel with moderate familiarity with computers and remote sensing can undertake most steps. Many of the detailed steps can thus be carried out by nonspecialists. However, the level of detail needed for image processing provides many opportunities for error that can be solved only with significant understanding of the satellite imagery being examined and the methods being used for its analysis. Moreover, integration of field, remote sensing, and other datasets requires significant understanding of each component.

Therefore, the authors envision a personnel structure that involves a single specialist who can provide overall guidance for processing teamed with other nonspecialists who can carry out many of the steps for each park. In the multipark setting of the NCCN, it may be efficient for a single group to take primary responsibility for technical processing of all imagery, and for pieces of the validation or interpretation to be carried out by each individual park. Because interpretation of change signals requires an understanding of the mechanisms causing the change, park ecologists, geomorphologists, and other specialists should be involved in the interpretation process at early stages.

Qualifications for a specialist overseeing this work include significant direct expertise in satellite-image processing and analysis, in geographic information-system processing, and in basic multivariate and univariate statistics.

The specialist also must have significant experience in airphoto interpretation. Nonspecialists will need less direct experience with image processing, but experience with geographic information systems and basic statistical knowledge are critical. Field technicians must be familiar with basic map concepts, and must have enough familiarity with geographic information systems and aerial photography to be trained in the interpretation of satellite imagery for field analysis.

The specialist can receive sufficient training from the protocol itself and from the image library associated with the protocol. The specialist will then take responsibility for training nonspecialists and field technicians in image interpretation, which forms the core of much of the processing. The specialist also must train nonspecialist and field technicians in airphoto interpretation, to the extent that each will be using it.

VI. Operational Requirements

Equipment

The primary requirement of this protocol is a computing system that can be used to carry out the image analysis. The protocol requires the following software: ERDAS Imagine, ESRI ™ ArcGIS, Microsoft Access (or equivalent), Microsoft Excel (or equivalent), and Microsoft Word (or equivalent). ERDAS Imagine should be purchased with the Vector Module, if at all possible. To allow processing of large image datasets, computers should have memory of at least 1Gb (gigabyte). Image processing requires the production of many intermediate image products, each of which can be hundreds of megabytes, making hard disk storage of many 10s of gigabytes essential. Facilities for printing of color maps are essential, especially for field validation efforts. Large-area plotters (≥36 in.) are extremely useful for production of maps, but are not essential.

Airphoto interpretation requires facilities for storing and analyzing large numbers of airphotos. Stereo interpretation of photos is essential. Good quality stereoscopes make for good stereo interpretation, and are thus desirable.

Field validation requires basic field equipment (SOP 4), plus a Global Positioning System (GPS) and a digital camera. Good quality GPS units may work better under poor conditions (such as in dense canopies), but even recreational-grade GPS units can be sufficient for the accuracy of pixel location required here. A digital camera is needed only for field documentation, and thus can be an inexpensive unit designed for recreational use.

Startup Costs and Budget Considerations

Startup costs primarily involve purchase of data and software for image processing. Landsat imagery is currently $425 per image for historical data, and purchase of a mid-1990s image likely is necessary for each park. Except for the extreme northwest coastal section of OLYM and, in certain TM images, the extreme southeast portion of North Cascades National Park, each park can be captured within the footprint of a single Landsat TM/ETM+ scene. ERDAS Imagine is an expensive software package, but has been purchased already by at least one GIS shop (Roger Hoffman, OLYM). Costs of airphoto acquisition may not be included as part of this protocol, since decadal airphoto acquisition already is planned for the airphoto-based monitoring program.

Annual Workload

The initial workload will be higher than the sustaining workload, as the specialist overseeing this work trains on each of the steps. After Landsat images have been acquired, initial processing of the first set of change images for a single park may take 2 months or more. Once this has occurred, several of the time consuming steps are reduced, and familiarity with the process should increase the proficiency of the specialist and nonspecialists in the processing. The time required for S2S validation will depend on the size of the park and the number of samples needed (determined in SOP 4). In testing for this project, nonspecialists trained in validation were able to validate eight validation box areas, each 1.5 by 1.5 km in size, in 1 day. Airphoto interpretation will take about twice as long. Final data analysis and map preparation will require approximately 1 month of the specialist’s time. Therefore, initial workloads for yearly change detection may be as much as four- or five-person months in the first year, but this should be reduced to 3 or fewer months in subsequent years. At the decadal scale, when airphoto interpretation is undertaken, an extra month or more will need to be added.

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Protocol for Landsat-Based Monitoring of Vegetation at North Coast and Cascades Network Parks

Standard Operating Procedure (SOP) 1

Acquiring Landsat Imagery

Version 1.01 (September 15, 2006)

Revision History Log:

Previous VersionNumber	Revision Date	Author	Changes Made	Reason for Change	New Version Number
n.a.	07-05-06	REK		Final version under agreement	1.0
1.0	09-15-06	REK	Minor wordsmithing; separation of figures for publication	Preparation for publication	1.01

This SOP explains the procedures for acquiring Landsat Thematic Mapper (TM) imagery for use in image-based monitoring. Procedures are provided for ordering imagery from the EROS Data Center (EDC).

I. Choosing Landsat Imagery

For the purposes of this protocol, we assume that image orders are for continuation of monitoring forward from the year 2005, and that images prior to 2005 already are in the possession of the parks. Two options for future Landsat imagery exist: Landsat 5 and Landsat 7. Landsat 5 has been in operation well beyond its planned mission, and is therefore soon to be retired. Despite its age, it still provides reliable imagery, although slow deterioration of its mechanical components has required continual monitoring and readjustment (see http://edc.usgs.gov/products/satellite/tm.html). Indeed, it was taken offline for 2 months at the end of 2005 to deal with a solar-array problem, but has been reinitiated as of January 30, 2006. Landsat 7 has superior technical specifications, but unfortunately suffered a major instrument malfunction in May 2003 that diminishes its utility. The choice of imagery will thus depend on whether Landsat 5 imagery is available, and on the characteristics of the available Landsat 7 imagery. Landsat data continuity is mandated by statute, and plans exist for data continuity after Landsats 5 and 7 cease functioning (http://ldcm.usgs.gov/). The Operational Land Imager (OLI) will be the immediate successor to Landsat 7, and is planned for launch in 2010.

For the present, Landsat 5 imagery is preferable to Landsat 7 imagery because all pixels in a given scene will be from a single acquisition date. Imagery purchased as recently as 2004 has been reliable and geometrically robust. Eventually, Landsat 5 will no longer be functional. This could happen at any moment, and may be soon (although it has enough fuel to stay in orbit until 2008). Even if Landsat 5 imagery is still available, it may not be sufficiently free of clouds to be usable. In either case, Landsat 7 imagery likely will need to be used (although see note at the end of this section on Advanced Land Imager (ALI) and Advanced Spaceborn Thermal Emission and Reflection Radiometer (ASTER).

Therefore, discussion of the malfunction of the Landsat 7 instrument is necessary. The instrument malfunction was the failure of the scan-line corrector of the satellite, and is discussed at http://landsat.usgs.gov/slc_enhancements/slc_off_background.php. The following is taken directly from that web site:

> “An instrument malfunction occurred onboard Landsat 7 on May 31, 2003. The problem was caused by failure of the Scan Line Corrector (SLC), which compensates for the forward motion of the satellite. Subsequent efforts to recover the SLC were not successful, and the problem appears to be permanent. Without an operating SLC, the ETM+ line of sight now traces a zig-zag pattern along the satellite ground track” (fig. 1).

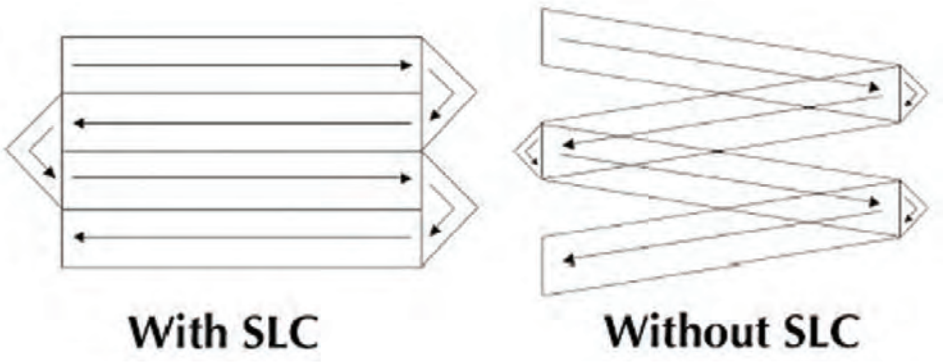

Figure 1. Effect of the Landsat 7 scan-line correction error. Taken from http://landsat.usgs.gov/slc_enhancements/slc_off_background.php.

> “The Landsat 7 Enhanced Thematic Mapper Plus (ETM+) is still capable of acquiring useful image data with the SLC turned off, particularly within the central portion of any given scene. Landsat 7 ETM+ therefore continues to acquire image data in the “SLC-off” mode. Please note that all Landsat 7 SLC-off data will be of the same radiometric and geometric quality compared to data collected prior to the SLC failure.
>
> “The SLC-off impacts are most pronounced along the edge of the scene and gradually diminish toward the center of the scene ….. The middle of the scene (approximately 22 kilometers with a L1G product) contains very little duplication or data loss, and this region should be very similar in quality to previous (“SLC-on”) Landsat 7 image data.”

USGS is continually updating approaches to deal with the gaps caused by the SLC failure. The general strategy is to merge image pixels from two or more different dates to provide a composite image without gaps. Because this results in a single image with pixels from different points in the growing season, it may introduce errors because of phenological progression of vegetation through the season. The effect of this gap filling is not known in advance for any given scene, since it depends on the images used to fill the gaps.

After November 18, 2004, gap filling was provided using the so-called “Phase 2” approach, which allows for filling from multiple scenes. A detailed description of this process is found at http://landsat.usgs.gov/documents/L7SLCGapFilledMethod.pdf.

That document provides guidance on choosing which scenes should be used for gap-filling:

> “The following scene selection guidelines are roughly in order of priority:
>
> 1. Select fill scenes that are as free of clouds as possible and that contain as few obvious changes in scene content (e.g., different snow cover, waterbody ice cover/sun glint differences) as possible.
> 2. Select SLC-off scenes that are as close in time to the primary scene as possible to minimize changes in vegetation conditions. Failing this, select fill scenes (SLC-off or SLC-on) that are as close to an anniversary date as possible to take advantage of the similarities in seasonal-vegetation cycles.
> 3. Select scenes that provide good predicted gap coverage based on the gap phase statistics. These statistics predict the locations of the scan gaps in each scene relative to the Worldwide Reference System (WRS) scene center. Computing the difference between the fill scene gap phase and the primary scene gap phase makes it possible to predict (to within a few pixels) the gap overlap geometry.

4. Select SLC-off fill scenes that are within +/- 4 WRS cycles of the primary scene, if possible. Since the ETM+ scan period increases slowly with time, the primary/fill scene relative scan gap phase will vary across the scene if the acquisition dates are too far apart. Thus, even an apparently "perfect" scan gap phase match will not provide complete gap coverage.
5. For Phase 2 products with multiple SLC-off scenes, including an anniversary date SLC-on scene as the final fill scene is recommended as a way of ensuring good image registration performance and providing complete gap coverage."

For the purposes of monitoring at the parks, gap-filled products may introduce several errors.

First, pixels in a single image could be from different acquisition dates within a season. Phenological changes in vegetation thus may be mingled within a single date, exacerbating the potential for false positives in the change detection.

Second, pixels in a single image may be from different years. This situation is to be avoided, since detecting interyear differences is the crux of the monitoring effort. However, at some parks it may be unavoidable because of frequent cloud cover.

Third, because of the matching algorithms used to bring the gap-filled pixels into radiometric consistency with the reference image, gap-filled pixels may introduce radiometric noise that will affect normalization algorithms later on in processing (SOP 2).

These potential problems unfortunately are unavoidable, but their actual effect is unknown at present for the parks of the NCCN. It likely will be useful to re-examine the effects of the gap-filling on change-detection projects in 5 years as research in this particular question emerges in the remote sensing literature. As practical knowledge is gained about these effects, this protocol may need to be updated (SOP 6). One of the more promising approaches to dealing with this problem may be to consider only areas in the imagery that does not fall in gaps; i.e. use imagery from only one date, and consider this to be a large sample that does not exhaustively characterize the parks.

Potential Use of ASTER or ALI Data

Two other sources of potentially compatible image data may be available: ASTER and ALI.

ASTER (http://asterweb.jpl.nasa.gov/) is an instrument mounted on the Terra spacecraft, which also houses MODIS (MODerate-resolution Imaging Spectroradiometer). ASTER obtains images that are similar enough to Landsat data to be comparable, although there are differences. ASTER obtains only two visible bands where Landsat obtains three, but ASTER's pixel size is 15 m where Landsat's is 30 m. ASTER collects better data in the short-wave infrared region, particularly in the region overlapping with Landsat's Band 7. The swath width of the ASTER instrument is 60 km pointable on either side of center by 106 km. ASTER is a request-only instrument, meaning that the Parks would need to submit an acquisition proposal and make requests for particular image acquisitions.

ALI is a satellite designed to test and illustrate new technical approaches to imaging after the current era of Landsat imagers ends. To facilitate comparison with Landsat imagery, ALI data are designed to be spectrally and spatially similar to Landsat data. Additionally, ALI is a pointable instrument that can be tasked to acquire imagery of a particular location. This is necessary because the swath width of an image is 37 km, as compared to 185 km for a typical Landsat TM image. If gap filling in Landsat 7 data create significant problems, then ALI may be a plausible substitute.

If either ALI or ASTER are determined to be necessary, details of ordering and initial processing will need to be developed that are logically consistent with the existing methods described in this protocol. Currently this is not known, however, requests would need to be placed to acquire imagery at the end of the growing season for the parks. Because the swatch width of both instruments is less than that of Landsat, two or more adjacent images likely may be needed to image some of the parks.

II. Ordering Imagery From Eros Data Center

Landsat imagery is acquired at the satellite as it orbits the Earth, and then is downloaded to various ground-receiving stations. For the most recent Landsat sensor, Landsat 7 or the Enhanced Thematic Mapper Plus (ETM+), these images are gathered at a central repository in South Dakota, the EROS (Earth Resources Observation Systems) Data Center (EDC). Information on the center can be obtained at that center's web site: http://edc.usgs.gov/about/background.html. Through EDC, various other satellite and spatial databases also are available. EDC also maintains a full archive of historical Landsat data, including Landsat 5, which is still active as of August 2005, but which will reach the end of its life by 2008. Information about the Landsat family of sensors is found at http://landsat.usgs.gov/. Landsat imagery is best searched and ordered through EDC's "EarthExplorer" interface.

Using EarthExplorer

EarthExplorer is found at http://edcsns17.cr.usgs.gov/EarthExplorer/, and also can be reached from EDC's main web site (http://edc.usgs.gov/) by following the Products/Satellite Imagery Link and selecting either ETM+ or TM from the table of products listed at (http://edc.usgs.gov/products/satellite.html).

All data can be ordered from EarthExplorer as a guest. Alternatively, users may desire to register (available as a link from the main EarthExplorer web page). Registration is free. The advantage of registration is that user address and order information is saved for future sessions, reducing redundancy later.

Steps for Ordering Imagery

1 Log in to EarthExplorer as a guest or registered user at http://edcsns1cr.usgs.gov/EarthExplorer/

2. In the "Data Set Selection" box, select "Landsat 4-5 TM" or "Landsat 7 ETM+ SLC-off," depending on availability of Landsat 5 data.
    a. If the availability of Landsat 5 is not known, select it first, continue through the steps below to determine if cloud-free imagery is available for the desired park. If not, return to this step and select Landsat 7 imagery instead of Landsat 5 data.

3. The next window is the "Search Criteria" window.
    a. Confirm that the dataset you wanted is in the "Data set" window.
    b. Do not enter anything in the "Spatial Coverage" window. Search will be by WRS path and row, below.
    c. In the Acquisition Date box, select an appropriate date window.
        i. Conditions for appropriate date windows.
            (1) The date window should be for a single year.
            (2) The date window should be approximately consistent with imagery from the year against which this imagery is to be differenced. That imagery already must exist in house. Typically, a good starting point for the parks of the NCCN is a data window that spans June 1 to October 1 of the year. If multiple cloud-free scenes are available (see below), then choose the date of imagery closest to the imagery already in house. The ideal window is late July to mid-August, as vegetation is in full display for most of the parks at most elevation in most years, and the sun is still high enough in the sky to reduce the effects of illumination-induced shadowing.
            (3) Assuming that only 1 year has been selected, the button "Linear" can remain selected. If multiple years are selected, it is advantageous to select the "Seasonal" button, as it only will examine the date window within each year, rather than extending across the nondesired portions of the year in between date windows.
    d. For the WRS Path and Row boxes, select the following according to the park for which imagery is to be ordered:
        i. Olympic: 47/27 (for the bulk of the park) and 47/28 (for the NW coastal section)
        ii. Mt. Rainier: 46/27
        iii. North Cascades: 46/26
            (1) The following parks may not use this protocol at this time, but path/row information is provided for reference in the future.
                (a) San Juan: 47/26
                (b) Ebey's Landing: 47/26
                (c) Ft. Vancouver: 46/28
                (d) Lewis & Clark: 47/28
    e. In the "Results Restrictions" box at the bottom of the screen, change from 10 to 100 records.
    f. Start the search.
        i. The results page will run for a few seconds or minutes.
    g. Once the "Results Summary" page has appeared and the "Status" column reads "Complete," select the "Results" icon to see a table of the images.
        i. The list of images will appear with information on the cloud cover of each image and the date of the image acquisition.
    h. After viewing browse images, select one image by checking its box in the "Order Qty" column, and then selecting "Add selected items to shopping basket."

i. It is critical that browse images be viewed, as the cloud-cover estimate, while relatively accurate, does not describe where in the image clouds may reside. Some images with low cloud cover may have clouds directly over the park, while others with moderate cloud cover may be cloud free over the parks. The goal is to pick an image with the most cloud-free area within the park of interest. In some cases, thin cirrus clouds will not be visible in the browse images, however, so if the cloud-cover estimate provided in the table is higher than appears obvious visually, consider whether another image is available (see criteria below). Also, it is helpful to become familiar with the browse-image format for many dates of imagery. After looking at many images spanning the continuum from cloud covered to absolutely clear, the interpreter begins to build an image of what the landscape looks like when clear, and is better able to catch the subtle effects of thin clouds.

ii. For many years, it may be necessary to choose between several nonoptimal conditions. Follow these guidelines on choosing images.

    (1) Avoid choosing imagery from very early in the season (generally before mid-June), even if cloud free. Early in the season, too much of the relevant area of the parks are still snow covered and vegetation phenology will be quite different. These two factors will cause so many false positives in the change detection later on (SOP 3) that they should be avoided.

        (a) Images from July and August are preferred, even if some of the park is obscured by clouds. Evaluate browse images for location of clouds over the parks. Accept a July or August image if less than approximately 10 percent of the park is cloud covered, as estimated through simple visual estimation (do not use the percent cloud-cover estimate for the whole scene).

        (b) Evaluate whether images from the other sensor (Landsat 5 or 7) are available before moving forward to other dates. Go back to step 2 and choose the other sensor. If not, proceed to (c).

        (c) Avoid images with "Image Quality" flags.

        (d) Images from early September are nearly as good as those in August, especially as they tend to be the best snow-free images, but ultimately are less desirable than those slightly earlier in the season because of sun angle considerations. Also, spectral artifacts caused by rapid fall vegetation senescence likely are increasingly in September. Choose September images if the criteria for July and August images are not met.

        (e) Images in June or October should be chosen only if no other images are available and if these images essentially are cloud-free.

i. Once an image has been selected and added to the shopping basket, proceed to the checkout by selecting "View Shopping Basket."

j. Select the appropriate product type in the next screen ("USGS Shopping Basket").

  i. For Landsat 5.

    (1) In the USGS Shopping Basket select "L4-5 TM LIG Single NLAPS."

    (2) On the next screen, "Processing Options for L4-5 TM L1G Single NLAPS," select options as follows:

        (a) For pixel size for the reflective bands, choose 28.5 m

            (i) This is as close to the native pixel size of the sensor. This will later be resampled to 25 m, but ordering the imagery at 28.5 m maintains the maximum level of geometric integrity of the imagery.

        (b) Resampling method: Use nearest neighbor (NN).

            (i) By selecting 28.5 m and using NN, pixels are as close to the original condition as possible. Effects of later resampling (SOP 2) always can be compared back to this original condition to understand potential artifacts.

        (c) Image Orientation: MAP

        (d) Datum: ensure WGS84

        (e) Output format: NDF

        (f) Projection: UTM

(g) Zone number: leave at default (should be zone 10 for all parks).

(h) Submit, and proceed to item “k” in the outline below.

ii. For Landsat 7, select “ETM+ SLC-off gap filled LPGS”

(1) Once this option is selected, the browser will move to the screen that allows you to determine which scenes to use for the gap filling: “ETM+ SLC-off Gap-filled Products: Fill Scene Selection.”

(2) Instructions on the choice of scenes for gap-filling are available as a link from this window (see http://edcsns17.cr.usgs.gov/helpdocs/landsat/instructions.html). They are recreated here for reference:

Instructions for Selection of Fill Scene(s)

For best results, any scene selected for gap-fill should be cloud-free and as close as possible to the anniversary date of the primary SLC-off scene. For more information on the influence of scene content on the gap-filled results, see Tips for choosing a fill scene.

Section 1 - SLC-off Scenes

The most recent potential fill scenes are listed in this section (“SLC-off scenes”). Note that the fill scenes also contain data gaps, so a variable number of SLC-off scenes (generally 2-3) will be required to obtain a complete fill in the final product.

Up to four SLC-off fill scenes may be selected from the SLC-off section.

“Fill Sequence” refers to the order in which the selected fill scene will be used to contribute to the final gap-filled product. The scene with a value of “1” will be used first to fill all possible gap in the original primary scene. The scene with a value of “2” will be used to fill any remaining gap, after initial fill has been contributed by the “1” scene. The scene with a value of “3” will be used to fill any remaining gap (after “1” and “2”), etc.

Due to small potential errors in the residual gap estimation tool, there may still be a gap remaining in the final processed product. Selection of an additional SLC-off scene (after reaching a residual gap of 0 pixels) will help to assure complete coverage. You may also wish to select an SLC-on scene (Section 2) for an additional “final fill”, to assure that all residual gap has been eliminated in your final product.

Section 2 - SLC-on Scenes

Potential SLC-on scenes are listed in the second section (“SLC-on scenes”). These scenes were collected prior to the SLC failure, and the contributing data will therefore not contain any gaps. Selection of a scene from the SLC-on section will always insure a fully populated gap-filled image. Only one scene may be chosen from the SLC-on section.

If the user selects an SLC-on scene in addition to one or more SLC-off scenes (from Section 1), the SLC-on scene will always be the last scene used for the gap-fill during Level 1G processing.

(a) Because of cloud-cover characteristics in the Pacific Northwest, it likely is that few scenes will have less than 10 percent cloud cover. From the perspective of monitoring across years, prioritize obtaining fill imagery from the same year over obtaining cloud-free imagery. Where clouds exist, it will be explicit that no conclusions can be drawn. Filling those areas with cloud-free imagery from a prior year may lead to misleading conclusions about change.

(b) Nevertheless, it will often be necessary to include prior-year imagery in the gaps. Additionally, it will be necessary to include imagery from 2003 or before in the SLC-ON section of the window. Because the gap mask included with the imagery contains information on which scene was used for a given pixel, it is possible to later selectively eliminate the gap-filled data.

(c) NOTE: If purchasing imagery for the year 2005 onwards, do not choose the SLC-on scene option, because these scenes will be at least 2 years out of date. If there are gaps after other recent SLC-off images have been added, these will be areas where no conclusions about change can be drawn for the period of interest.

(d) Once images are selected, select “Submit fill scenes.”

(3) Once gap-filling scenes have been selected, proceed to the next screen, “Processing Options for L7 ETM+ SLC-OFF Gap-fill L1G Systematic LPGS.”

  (a) For pixel size for the reflective bands, choose 28.5 m.

    (i) This is as close to the native pixel size of the sensor. This will later be resampled to 25 m, but ordering the imagery at 28.5 m maintains the maximum level of geometric integrity of the imagery.

  (b) Resampling method: Use NN.

    (i) By selecting 28.5 m and using NN, pixels are as close to the original condition as possible. Effects of later resampling (SOP 2) always can be compared back to this original condition to understand potential artifacts.

  (c) Image Orientation: NUP

  (d) Output format: Select Fast L7

  (e) Datum: ensure WGS84

  (f) Projection: UTM

  (g) Zone number: leave at default (should be zone 10 for all parks).

k. The next screen, USGS Shopping Basket, will show the results of the selections just made in the “Product Type” column. Confirm that image dates for the Off Fill are as desired.

  i. For the media type, select either CD or FTP.

  ii. Proceed to the payment screen.

l. On the next screen, enter contact information, if registered as a guest.

m. Select appropriate payment options.

n. When the order confirmation appears, select all of the text with details of the order, copy them using Ctrl-C for Windows machines, and paste into a text or word-processing document for archiving. The following information is critical to save for the order:

  i. Date of image.

  ii. Sensor (5 or 7).

  iii. Date of gap-filling images and the order in which they fill the gaps.

  iv. Pixel size and resampling mode.

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Protocol for Landsat-Based Monitoring of Vegetation at North Coast and Cascades Network Parks

Standard Operating Procedure (SOP) 2

Preprocessing Landsat Imagery

Version 1.0 (July 5, 2006)

Revision History Log:

Previous VersionNumber	Revision Date	Author	Changes Made	Reason for Change	New Version Number
n.a.	07-05-06	REK		Final version under agreement	1.0
1.0	09-15-06	REK	Figures and captions extracted	Preparation for publication	1.01

This SOP explains the procedures for processing data acquired in SOP 1 into a geometrically robust, radiometrically standardized-reflectance product that can then be used for change detection (SOP 3). Preprocessing is a critical step in any change-detection study, but is especially so for the types of phenomena being sought by the parks.

Processing Datasheet

Many detailed and sometimes complicated steps are in this SOP. Because the analyst may need to split work between this work and other responsibilities, we provide table 1 that can be printed out separately for the analyst to keep track of steps that have been completed. This should facilitate easier recovery from interruptions.

I. Conventions For Describing Software Methods

Two main types of software package are discussed in this SOP: ERDAS Imagine and IDL-Virtual Machine (VM). The former is an industry standard image processing software package. While the work described in this protocol was done using ERDAS, much of the functionality it encompasses may be found in other software packages. However, because the goal of an SOP is detailed description of methodology, one software package has to be described in detail, and we have chosen ERDAS Imagine because of its widespread use and ease of integration with ESRI Arc products, which also are industry standards and in use at the parks.

Table 1. Datasheet to keep track of steps in Standard Operating Procedure 2.

[**Abbreviations:** IMG, Erdas Imagine file; AOI, area of interest; DEM, digital elevation model; ITP, image tie point; XLS, Microsoft© Excel file; TXT, text file; BSQ, BINSCII-encoded file; SE, Southeast; NW, Northwest]

General information	
Park being processed	
Analyst	
Change interval being processed	
Start of processing	
End of processing	

Section	Step	Filename
Section II	Establish geometric-reference image	IMG:
	Establish radiometric-reference image	IMG:
Section III	Import subject image (if necessary)	IMG:
Section IV	Reproject reference-geometric image (if necessary)	IMG:
Section V	Define study area	AOI:
		Vector:
	Clip geometric-reference image to study area	IMG:
	Clip DEM to study area	DEM:
Section VI	Name of input image	IMG:
	Run ITPFind to match input image to geometric-reference image	ITP Readme:
	Terrain-corrected input image	IMG:
	Clip input image to study area	IMG:
Section VII	Fill out COST processing spreadsheet for subject image	XLS:
	Apply COST model to subject image	IMG:
Section VIII	Develop MADCAL runtime file	TXT:
	Run MADCAL on subject image	BSQ:
	Import MADCAL subject image	IMG:
Section IX	Convert radiometric-reference image to tasseled-cap values	IMG:
	Convert input image to tasseled-cap values	IMG:
Section X	Develop SE and NW aspect AOIs from DEM	SE Aspect AOI:
		NW Aspect AOI:
	Split reference image tassel cap by aspect	SE Aspect IMG:
		NW Aspect IMG:
	Split input image tassel cap by aspect	SE Aspect IMG:
		NW Aspect IMG:

The second software package is built on the Interactive Data Language (IDL). IDL is common in remote sensing research labs but less common in the general image processing industry community, and also is fairly expensive (around $1,500 for a license currently). Because only a few key pieces of the SOP involve IDL programs written for image processing, these can provided as compiled code that can be run in a free version of IDL called Virtual Machine (VM). The code cannot be altered in the VM, but can be utilized for the specific purposes described herein. Alternatively, the image processing system Environment for Visualizing Images (ENVI) could be purchased instead of ERDAS Imagine, since ENVI is built on IDL and includes IDL in its shipping package. This latter step is less conventional, though, and thus the current protocol is for the use of Imagine for image processing and IDL-VM for specific tasks. The code for IDL-VM is supplied as a part of this protocol.

Figure 1. Main console of Imagine.

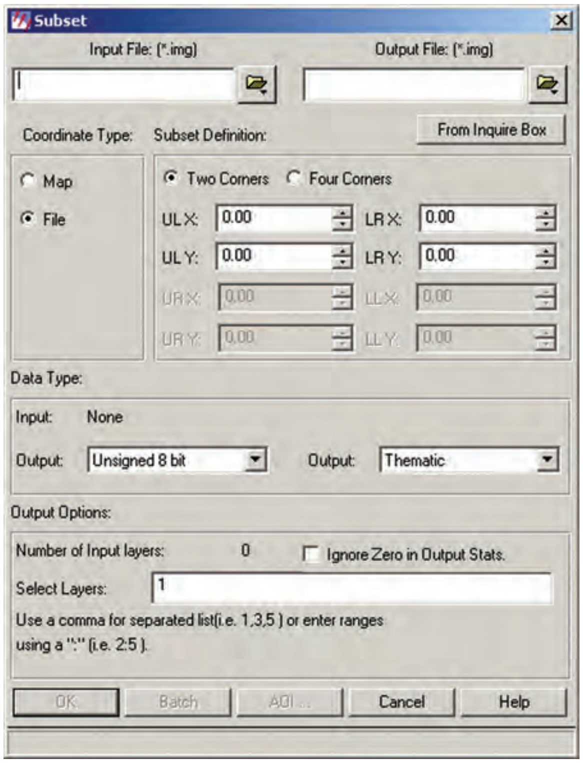
Conventions for describing steps in ERDAS Imagine (from here forward, simply referred to as “Imagine,” with a capital “I”) are straightforward. Imagine is a menu-driven software package that begins with a “Main Console,” shown in figure 1.

The buttons arranged horizontally refer to the main modules of the program. Actions are taken by selecting a button, which then either starts an action or brings up a pull down menu with several options, some of which have pull down options of their own. Actions will be referred to by the box in the main console, followed by a forward slash (“/”) and the name of the option from the pulldown menu. A second slash and pulldown option will be listed as necessary. For example, image subsetting is in a pulldown menu from a pulldown menu from the Interpreter button on the main console, referred to as “Interpreter/Utilities/Subset.”

Once an action is selected, an action window typically appears that provides a suite of options for a given action. The “Subset” action window, for example, is shown in figure 2.

Instructions for filling in boxes and checking options on these action windows are referenced by the name on the window followed by a colon. For example, to switch the default Output type in the subset window above to Signed 16 bit, the instruction in this SOP would read “Output: select Signed 16-bit.”

Instructions for IDL-VM code is described in detail as it is relevant. Go to http://www.rsinc.com/idlvm/index.asp to download the current version of IDL-VM. When installed, the virtual machine will be represented as an icon on the desktop of the computer. Programs developed by the authors are provided as VM-enabled code that is simply dragged with the pointing device on top of the IDL-VM desktop icon to execute the code.



Input File: (*.img)

Output File: (*.img)

Coordinate Type:
○ Map
● File

Subset Definition:
● Two Corners ○ Four Corners

ULX: 0.00 LRX: 0.00
ULY: 0.00 LRY: 0.00
URX: 0.00 LLX: 0.00
URY: 0.00 LLY: 0.00

Data Type:
Input: None
Output: Unsigned 8 bit Output: Thematic

Output Options:
Number of Input layers: 0 ☐ Ignore Zero in Output Stats.
Select Layers: 1
Use a comma for separated list(i.e. 1,3,5) or enter ranges using a ":" (i.e. 2:5).

Figure 2. Subset window.

II. Establish Reference Images

Two categories of preprocessing are to be carried out in this SOP: geometric and radiometric. In each category, the user must define an image acquired on a specific date to be a reference towards which all other images will be matched. Thus, a reference geometric image and a reference radiometric image are needed.

The geometric-reference image is one whose geometric properties are well characterized. Each pixel in the image can be linked directly with a map coordinate on the ground, in coordinates determined by a map projection and an associated spheroid and datum. The spheroid represents a model of the Earth and the datum a set of coordinates developed through actual measurements of points on the ground.

A key step in linking the geometric properties on the ground to a given image is accounting for the potential distortion effects of topography and the curvature of the Earth. When Landsat TM measures reflectance in a particular pixel at the center of the image, it is viewing that pixel straight down, but when it measures reflectance at the edge of the image, it is viewing that pixel at an angle. In the latter case, the elevation of the land can cause distortion in the apparent position of the pixel from the perspective of the sensor: pixels at the tops of mountains will appear to be farther away than they really are, and pixels in valleys will appear closer. The curvature of the Earth also interacts with the view angle to affect apparent position of the pixel. Therefore, a geometric model that includes both curvature and the effects of surface topography is needed to link the observed pixels with their actual locations on the ground. Once the effects of topography and view angle have been accounted for, the image is said have been terrain corrected.

The NASA sponsored GeoCover project resulted in orthoimagery of Landsat TM for the entire globe. Only one image for the 1990 era and one image for the 2000 era are available under this project. For the United States, versions of these GeoCover images can be downloaded easily and cheaply from the NASA-sponsored project Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) available at http://ledaps.nascom.nasa.gov/ledaps/ledaps_NorthAmerica.html). The authors recommend using the appropriate 2000-era Landsat ETM+ image as the geometric-reference image (in the Startup Phase of monitoring; see Narrative).

The radiometric-reference image is one whose radiometric properties will anchor the radiometric properties of later images. The radiometric properties simply refer to how the spectral reflectance of objects on the ground surface are represented as numbers in the image, and takes into account both the sensor engineering design and the state of the atmosphere that interferes with the reflected light from the ground as it travels to the satellite. The radiometric-reference image is one whose radiometric properties are well defined.

In practice, choice of a good radiometric-reference image comes down to a clear atmosphere during image acquisition and a date of acquisition similar to that of most of the other images for which the image is to be used as a reference. This latter condition is useful because a key step in preprocessing is normalizing later images to the spectral properties of the radiometric-reference image. Differences caused by phenological state of the vegetation could confuse the normalization if the reference image were obtained during a point in the season completely unusual relative to the other images desired for use.

Therefore, for the parks of the NCCN, a radiometric reference image should be chosen from the same late-summer date-windows that are recommended for all images (SOP 1). The clarity of the atmosphere for a given image typically cannot be known, but can be inferred. First, minimal cloud cover is preferred, since cloud cover indicates presence of increased levels of moisture in the atmosphere. A dry atmosphere is preferred. Cloud-free images can still have significant levels of atmospheric haze, which also is to be avoided. Haze levels can be inferred from the spectral response of pixels across the six visible bands of the Landsat imagery. Haze affects the bands at shorter wavelengths more than longer wavelengths because of the relation between the size of the particle causing the haze and the wavelength of light passing through it. Therefore, images with the least inferred scattering in Band 1 (the blue band of Landsat, with the shortest wavelength) are the images least affected by atmospheric haze. Thus, if there is a choice of several images for potential radiometric reference image, then it is recommended that the images be processed through to the level of COST processing, detailed below, and then the image with the lowest overall dark-object value in Band 1 be used as the radiometric-reference image.

III. Importing Images Into Imagine

For the methods described in this protocol, all images, whether reference or not, must be converted into the ERDAS Imagine format. The Imagine format is indicated with the filename extension ".img" and is a proprietary, hierarchical spatial data format. Conversion from other file formats into imagine format is best done within Imagine, where the process is named "importing" of external image formats.

Images from a wide range of sources can be imported into Imagine through the Imagine Import/Export action window. This action window is accessed through the second box on the main console (fig. 3).

Figure 3. Button used to access the import/export action window.

Once the import/export button is selected, the Import/Export dialog box will pop up (fig. 4).

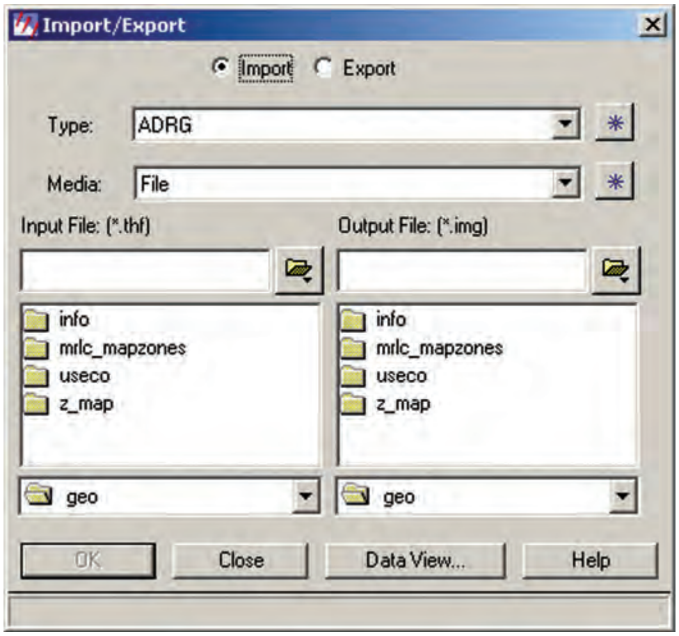
To import an image, first choose the type from the pulldown menu "Type:". If files are purchased from EDC and are Landsat 7 images, then the appropriate choice should be Landsat 7 Fast-L7A EROS. If images are taken from other sources, then other options may be appropriate. For example, many images from NASA sources are provided in an open-source hierarchical-data format (HDF), which has various options on the Imagine import/export dialog. If images are from the LEDAPS site, they are in HDF format, which is a public-format heirarchical data type used by NASA. Select "HDF Scientific Data Format (Direct Read)" as the data type.

Once the appropriate input file type has been chosen, fill in the "Input file:" box, either by manually typing the full path name, or navigate with the mouse using the open folder button just to the right of the blank input-file field. Clicking the "Open folder" button to the right of each filename brings up a file finder window (fig. 5) that allows quick access of files.

The "recent" and "goto" buttons on the right are particularly useful, as they allow quick reference to recently accessed files and folders, respectively.

Setting the default data directories: If the same directory folder is to be used often, it is advantageous to set that directory as the default directory in Imagine. To do this, select "Session/Preferences" from the Imagine main console to bring up the "Preference Editor" window. Select "User Interface & Session" from the "Category" list, and then manually type in the desired path name into the Default Data Directory and Default Output Directory fields. Choose "User Save" to register these preferences for this user for this and all future sessions.

When the input filename is chosen, Imagine will place a default output filename in the "Output File" field of the Import/Export window. Unless specifically overridden, this file will be in the default directory folder. Since the default directory is not typically the desired folder for the output image, it will often be necessary to navigate in the output file field to the desired directory, and then retype the name of the output file. A workaround for this process is to navigate in the Output File field to the desired directory *before* the input file is chosen, and to simply type in a dummy filename in the output file field, and thereafter to select the input file as desired. This will ensure that the default name chosen by Imagine for the output file will be placed in the desired output directory.

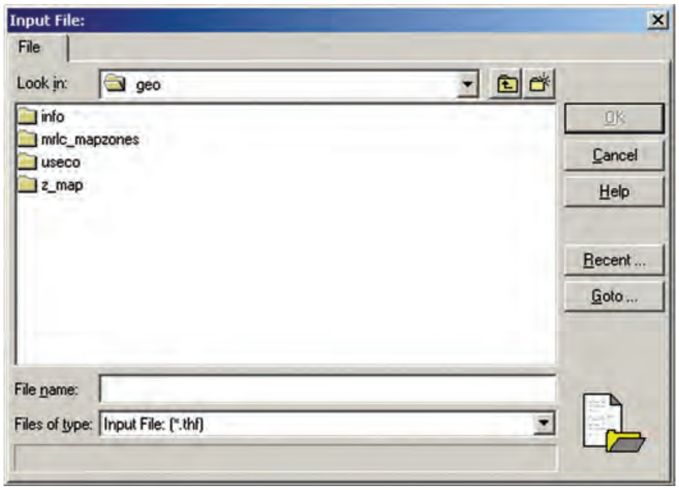


● Import ○ Export

Type: ADRG

Media: File

Figure 4. Import/export action window.



Look in: geo

Files of type: Input File: (*.thf)

Figure 5. File finder window.

IV. Reprojecting and Resampling Images

It is critical that all images and vector coverages be in the same projection, spheroid, and datum before any radiometric or change-detection processing is begun! Although Imagine will tolerate different projections and spheroids when processing, it is best *not* to allow Imagine to reproject "on-the-fly" without knowing explicitly that images are aligned as they should be. Only by viewing spatial data and ensuring that spatial relations are as expected can robust results be achieved.

The geometric reference image is the base of all geometric processing, and thus it is important that it have the appropriate map properties before any further processing is done. Therefore, after the reference image has been imported to the Imagine format, it frequently must be reprojected and resampled.

The NCCN standard spheroid/datum pair is GRS80/NAD83, which should be used for all spatial data. Although many existing Digital Elevation Models and some vector coverages are in the Clarke 1866/NAD27 Spheroid/Datum combination, those are based on an older model of the Earth, a poorer datum-measurement network, and thus should be avoided as baselines for future monitoring. The conversion between NAD27 and NAD83, although not perfect, can be achieved with accuracy more than sufficient for Landsat-based investigations.

All Landsat images are to be resampled to the 25 m pixel size. Although the native resolution of the imagery is 28.5 m, experience has shown that the 25 m size is far easier to work with, both for processing and for eventual field validation.

Therefore, it is necessary as a first step to check the condition of the reference image and reproject it if necessary.

1. Start Imagine if that has not been done already.
    a. If Imagine asks whether a Classic viewer or a geospatial light table is desired, select the classic viewer. It may be desirable to choose not to be asked this question again.
2. In Viewer #1, load the geometric-reference image.
    a. Click on the folder icon directly under File on the viewer menu (fig. 6).
    b. Navigate to the folder with the reference image and open it.
        i. Note: This assumes that the reference image has been imported into Imagine's format. If not, go back to section III above.
        ii. The image should come up in the viewer.
            (1) Because of the tilt of the Landsat image relative to the earth, the upper left portion of the image area likely is black; because the viewer defaults to viewing this area, the initial visible area may be black. To see more of the image, navigate around with the sidebar and bottom bars.
            (2) Alternatively, right-click in the viewing space of the viewer to see the viewer options menu, and select "Fit image to window." This option will resize the entire image to fit within the viewing space of the viewer. It may take several seconds for the resizing to finish.

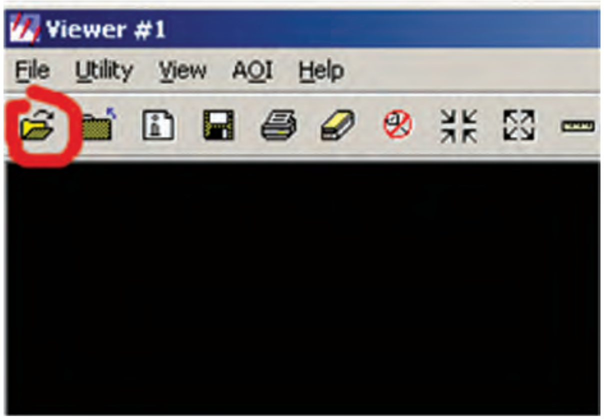


Figure 6. Open-file folder icon, circled.

3. Note the geometric properties of this image.
    - a. Select the ImageInfo icon (a white box with a lowercase “i” in it (fig. 7).

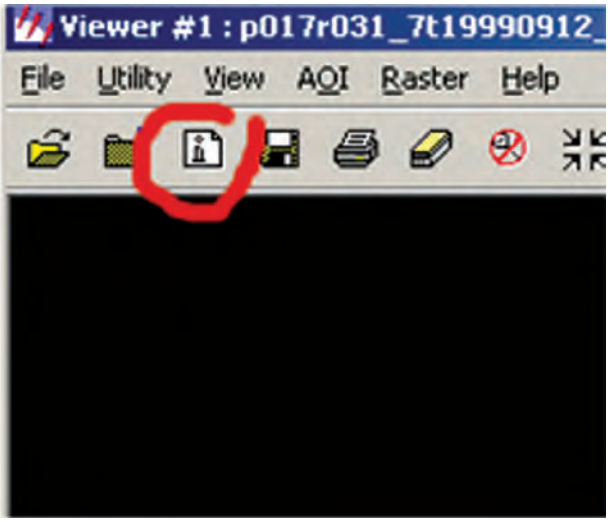


Figure 7. ImageInfo button, circled.

    - b. An ImageInfo window will pop up.
        - i. On the front panel of this window, labeled as the “General” tab, the geometric information about the reference image is shown.
    - c. At the bottom of the ImageInfo box is the Projection Info:
        - i. Ensure that the image is in Universal Transverse Mercator (UTM), in the correct zone (zone 10 for all of the parks of the NCCN), and that the spheroid and datum are as desired (NAD83, unless compelling reasons exist to use a different datum).
            - (1) See Bolstad (2002) for more information on datums and spheroids.
        - ii. Ensure that the pixel size is 25.0 m.
            - (1) If the reference image has been acquired recently, it was recommended in SOP 1 that the image be purchased at 28.5 m. Therefore, it is expected that the pixel size will be 28.5 m, which will need to be resampled to 25.0 m.
    - d. If either the map-projection information or the pixel size is not as desired, then reprojection will be necessary.

4. Reprojecting and resampling images in Imagine
    - a. If the reference-geometric image is in a projection or a spheroid/datum other than desired, it is straightforward to reproject the image in Imagine. Reprojection also can be achieved in Arc programs, but details of the Imagine-based approach are sufficient.
    - b. Steps:
        - i. Ensure that the image to be reprojected is open in a viewer.
            - (1) See step 2 above if not.
        - ii. From within that viewer, select “Raster/Geometric Correction”
            - (1) An action window named “Set Geometric Model” will popup, with a list of options.
        - iii. Scroll down and select “Reproject” from the list.
            - (1) A “Reproject Model Properties” window will pop up, as well as a “Geo Correction Tools” window.
            - (2) In the Reproject Model Properties window:
                - (a) Change grid sampling X and Y to 30 each.
                    - (i) Note that the number 30 is not the size of pixels. This number refers to the density of a grid that Imagine will construct to solve the reprojection equation between different projections. The number 30 in X and Y means that a 30 by 30 grid (i.e. with 900 points) will be used to project between projections.
                - (b) Select the “Projection” tab.
                - (c) Click on “Add/Change Projection.”
                    - (i) A “Projection Chooser” window will come up.
                - (d) Select the desired projection into which the image is to be projected.
                - (e) Click on OK button.
            - (3) In the Geo Correction Tools window, select the “Resample” button, which is a box with four smaller multicolored boxes inside it, tilted on its side (fig. 8).
                - (a) The “Resample” dialog will pop up.
            - (4) For the Output File, navigate to the desired output folder before typing in the name of the resampled output file.
                - (a) Follow naming conventions in SOP 5 Data Management when reprojecting a file.

(5) For the resample method, select "Cubic Convolution."

(a) Note: Nearest-neighbor (NN) resampling is often recommended to maintain the radiometric integrity of the imagery, since it leaves the spectral response within a pixel unchanged. However, experience in monitoring at the NCCN parks has shown that the geometric distortions introduced by the NN resampling cause artifacts in later change detection. Therefore, it is important that the cubic-convolution approach be used. Cubic convolution (see Richards (1993) for a discussion) retains the geometric properties of the image much better, especially when pixel size is changing as in this case, but does introduce some spectral anomalies at the edges of contrasting pixels that must be considered in later steps.

(6) For the output cell sizes, manually type in 25 for both X and Y fields.

(7) Select "Ignore Zero in Stats."

(a) This will make later display of the image work better. Without selecting this option, the large area of no-data around the margins of the imagery is included in the statistics used by Imagine to display the image. Images will appear "washed-out."

(8) Click on OK button.

(a) A progress window will appear and notify when the job is complete.

(9) Close all windows except the Viewer #1, and do NOT save the changes or the geometric model used for the resampling.

(10) The resultant 25 m image will be clipped to the study area in section V below.

5. Reprojecting the Digital Elevation Mode (DEM)

a. A DEM is necessary for a variety of steps in the protocol, and must be in the same projection and datum as the geometric-reference image. Because DEMs typically exist in the NAD27 datum at 30 m, it is often necessary to reproject these into the desired NAD83 and 25 m condition.

Figure 8. Geo Correction Tools window, with the resample icon circled.

i. NOTE: If the DEM is in NAD27 and is a grid coverage, reproject it in an ESRI Arc software product using the NADCON option for reprojection. This method will be more precise than using Imagine's approach in steps b. and c. below.

b. Open the DEM in Viewer #1.

i. Properties of the DEM:

(1) A digital-elevation model for the areas around the parks has been included by the authors, and thus this step will not be necessary unless new DEMs become available, or if the study area around the parks is changed. These steps are provided for that case.

(2) If a digital-elevation model is acquired from another source, or if an in-house DEM from the park is used, it must have metadata describing the map-projection and datum information, pixel size, and units of the vertical dimension (meters or feet).

ii. Open the DEM in a viewer.

c. Reproject the DEM to NAD83 and 25 m.

i. Follow steps in section 4 above in this section, but use the DEM as the base rather than the geometric reference image.

d. If reprojection is done in an Arc software product, it will be necessary to import the reprojected DEM GRID into Imagine. See section III above and follow the instructions for importing images into imagine. The GRID format is listed as one of the import format options.

i. After importing, ensure that the DEM has imported successfully by viewing it in a viewer (see step 2 in this section above).

V. Defining Study Area, Clipping Images and DEMs to the Study Area

This protocol focuses on monitoring in and around the parks, and as such does not require that processing be conducted on an entire Landsat image. Those images are approximately 180 by 180 km, and are located in a manner completely irrelevant to the parks. Therefore, before any processing is done, it is necessary to define a study area in which all image-processing and change-detection activities will take place.

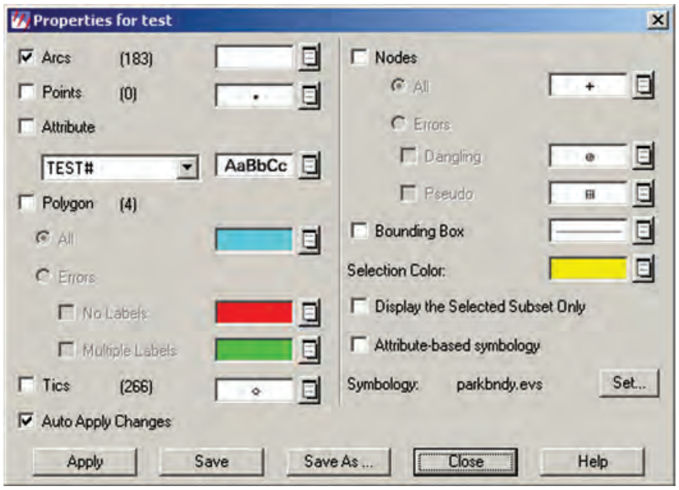
The end goal of study area delineation is to have two geographic coverages representing the same study area boundary: an Imagine-format Area of Interest (AOI) and an ESRI Arc-format vector coverage. Both can be created in Imagine, or, if the study area has been defined elsewhere and is currently in a vector format, Imagine can be used to make an AOI of the vector coverage.

The delineation of the study area is an important step in the long-term success of this protocol, as the study area defined here will be used for reference when creating summary metrics of change over time. Therefore, this step should involve the input of as many interested parties at the parks as possible. As of this writing, there was no agreed-upon rules by which such a designation could be made generic, but there are several components to consider. First, of course, the study area should include the entire park. There may be interest in creating separate study areas in some parks (such as the coastal region at OLYM), but this decision should be approached carefully as it requires more processing. Second, the study area may extend beyond a park by either an arbitrary distance or by some distance defined by ecological or economic factors. It may be difficult to predict these factors at the current time, which argues for a conservatively large study area that could allow future contraction. It will be significantly easier to make the study area smaller in the future than it would be to make it larger.

If the desired study area already exists as a vector layer, the following steps are required:

1. Start Imagine and load the geometric reference image in a viewer (see section IV, steps 1 and 2, if this has not been done already). Ensure that this is the geometric reference image with 25 m pixels.
2. In the viewer, choose “File/Open/Vector Layer” and navigate to the directory where the new study area vector layer is housed.
    a. Open the vector layer, and ensure that it matches with the reference image as expected.
    b. Use the ImageInfo (section IV, step 3 above) to ensure that the vector coverage is in an appropriate projection and datum for the geometric-reference image.
        i. Assuming that the geometric reference will be UTM and NAD83, respectively, then the vector coverage must be in UTM, NAD83.
            (1) NOTE: If a vector coverage is in the Clarke 1866/NAD 27 projection/datum space, it must be reprojected. It is recommended that this projection process occur in ESRI Arc software, using the NADCON transformation approach. Arc/Info documentation on “Projections” provides more information. However, if this approach is not possible, the steps for reprojecting a vector coverage in Imagine are given below.
            (2) If the coverage is not in the appropriate datum, it will be necessary to reproject it into the correct datum. This can be done in various ESRI Arc products and in Imagine. The steps for doing this in Imagine are detailed below. GIS professionals also may prefer to do this in Arc workstation or ArcTools.
        ii. Reprojecting a vector coverage in Imagine.
            (1) In a blank viewer, open the vector coverage.
            (2) Click on the ImageInfo icon (section IV, step 3 above).
                (a) The window associated with the “General” tab will pop up.
            (3) Select “Edit/Reproject the coverage.”
                (a) A “reproject coverage coordinates” window will pop up.
            (4) Name the output vector in such a manner that the distinction in datums can be inferred. Follow data-management considerations in SOP 5 Data Management.
            (5) Click on “Define new projection.”
                (a) The “Projection chooser” window will pop up.
            (6) Use the pulldown menu for the spheroid name field to select NAD83.
            (7) Use the pulldown menu for “Datum name” to pick the NAD83 datum from the list.
            (8) Ensure that zone is 10 and “North or South” is set to north.
            (9) Click OK, then click OK again in the “reproject coverage coordinates” window.
                (a) Save the coverage.

3. With the vector coverage and the geometric-reference image open in the same viewer, select “Vector/Viewing properties.”
    a. The “Properties for test” window for the vector coverage will pop up (fig. 9).
    b. When vector layers are first shown in Imagine, the default is to display them as arcs, not polygons. To manipulate polygons, as will be done below, the polygons must be displayed.
    c. First, uncheck the box for “Arcs” by clicking it.
    d. Then check the box to the left of “Polygon.”
        i. To change the border and fill properties of the polygon, select the box to the right of the colored field to the right of the polygon (in cyan in fig. 9).
        ii. Keep this window open for now.
4. Then from the viewer with the vector coverage in it, select “Vector/Attributes.”
    a. The “Attributes” window will pop up.
        i. Each polygon will have a row in the table of attributes. Select all the rows that include polygons that are desired to defined the study area. Typically, this should be a small number of polygons – often only one – because the study area should be a large, internally connected space.
            (1) To select a row, click on the row number in the left-hand side of the window (the “Record” column in fig. 10).
        ii. To select multiple rows, click and drag down all rows.
        iii. Because polygons are displayed, selecting these rows will change all of the polygons on the viewer to the selection color, which defaults to yellow.

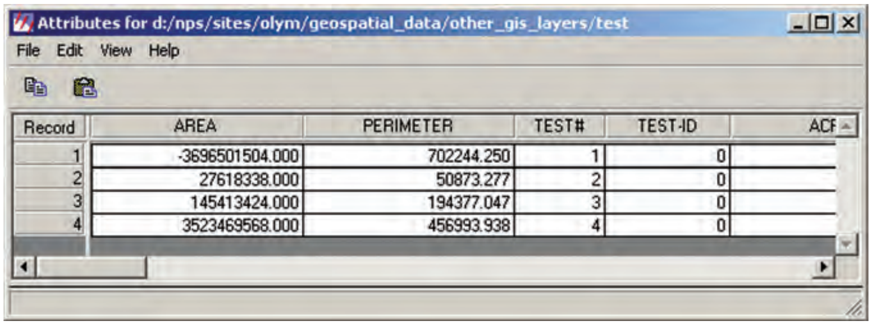


☑ Arcs (183)
☐ Points (0)
☐ Attribute
TEST#
AaBbCc
☐ Polygon (4)
☐ Tics (266)
☑ Auto Apply Changes
☐ Nodes
☐ Bounding Box
☐ Display the Selected Subset Only
☐ Attribute-based symbology
Symbology: parkbndy.evs

Figure 9. Vector viewing properties for test window.

5. With these polygons selected, select “AOI/Copy selection to AOI” from the viewer.
    a. Note: If the coverage and the image are not in the same projection, this step will fail. It is not sufficient to simply remove the image from the viewer to avoid this failure, because the AOI must be associated with the correct datum of the image for all later steps. Therefore, if the coverage is not in the correct datum, it must be either reprojected or the datum must be overruled, as noted in step 2 above.
    b. This step creates a new AOI in the viewer, anchored to the geometric reference image.
6. Save the AOI.
    a. In the viewer, select “File/Save/AOI Layer as.”
    b. Navigate to the appropriate directory and save the AOI layer. Follow the SOP 5 on naming and file location conventions.
7. This AOI is now the base AOI for all subsequent steps that involve clipping of imagery to the study-area boundary, including clipping the DEM.

    If the study area does not exist in vector form and must be created, follow steps 8 through 11.



Record	AREA	PERIMETER	TEST#	TEST-ID	ACF
1	-3696501504.000	702244.250	1	0	
2	27618338.000	50873.277	2	0	
3	145413424.000	194377.047	3	0	
4	3523469568.000	456993.938	4	0	

Figure 10. Vector-attributes window.

8. In a viewer, open the geometric-reference image.
    a. See section IV, steps 1–2 if this is not done already.
9. Draw the study area as an AOI.
    a. Select “AOI/Tools” from the viewer, and then select the polygon drawing button (fig. 11).
    b. When the cursor is moved across the viewer, it will take the form of a crosshair. Clicking with the left mouse button will create a vertex in the developing polygon. Define the vertices that will define the polygon desired to encompass the study area. Double-click when the last desired vertex has been placed to close the polygon-creating process.
        i. NOTE: The study area for ecological monitoring may well extend beyond the boundaries of the parks proper.
10. Save the AOI as the study area AOI.
    a. In the viewer, select “File/Save/AOI layer as.”
    b. Navigate to the appropriate directory and save the AOI layer. Follow the SOP 5 on naming and file-location conventions.
    c. This AOI is now the base AOI for all subsequent steps that involve clipping of imagery to the study area boundary, including clipping the DEM.

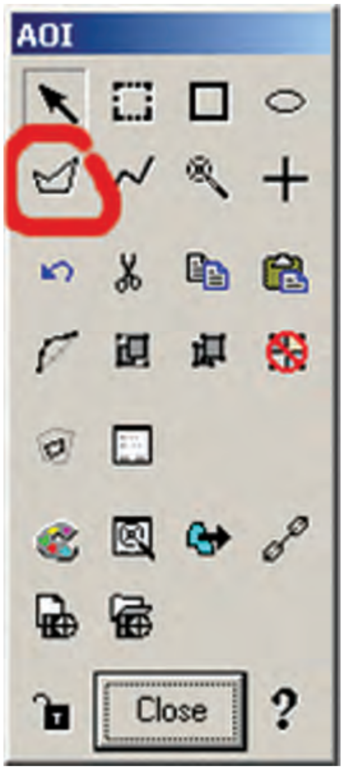


Figure 11. AOI tools window, with the polygon drawing button circled.

11. Copy this AOI to a vector coverage.
    a. NOTE: This step is designed to create a vector coverage of the study area for use in displaying data in ESRI software. It is not strictly necessary, as it will not be used for analysis in any other part of this protocol.
    b. It is first necessary to create a blank vector coverage.
        i. In the viewer, ensure that the geometric-reference image is displayed.
        ii. Select “File/New/Vector layer.”
            (1) A “Create a New Vector Layer” window will pop up.
        iii. Navigate to the appropriate directory and type in the name of the coverage in the Filename field.
            (1) Follow the conventions in SOP 5 Data Management for placement and naming of the coverage.
        iv. Select “single precision” when given the choice between single and double precision.
    c. Once this blank vector layer is open, the viewer should show “Vector” in the list of options at the top of the viewer.
    d. In the AOI tools window, click on the selection arrow icon (upper left icon in fig. 12).
        i. Click in the viewer on the space of the AOI to select it.
            (1) A white box will appear around the outside perimeter of the study area AOI. This indicates that the AOI is selected.

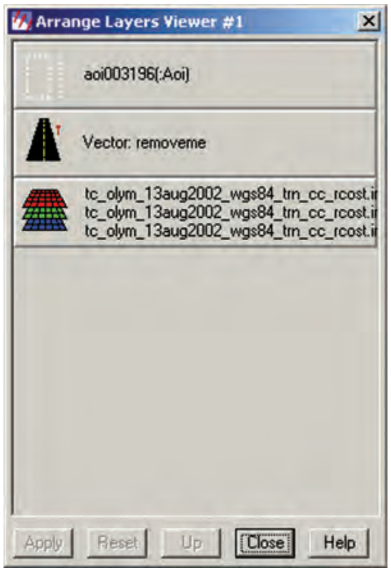
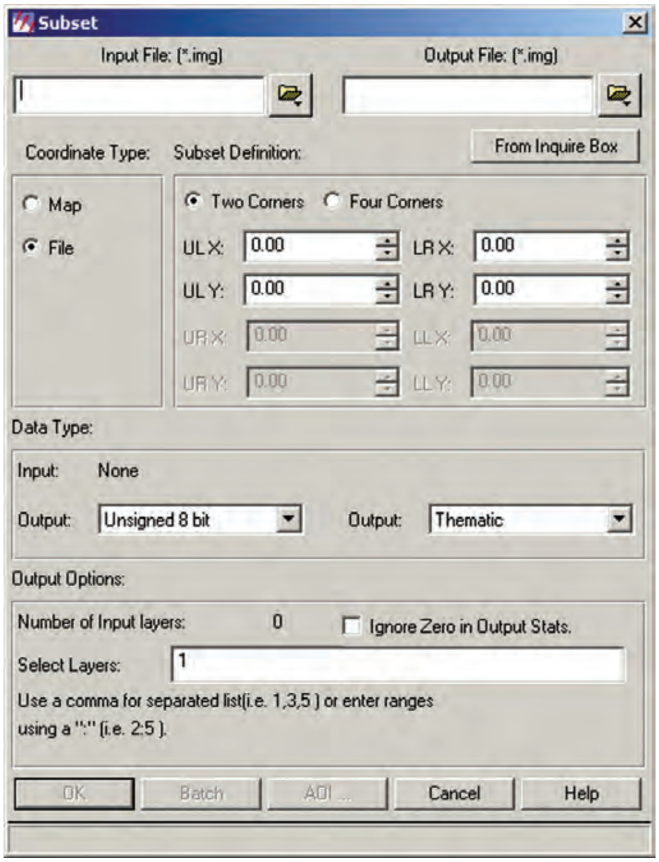


Figure 12. Arrange layers window.

    ii. Select “Vector/Copy selection to vector.”
        (1) Little will seem to have happened. Do not be alarmed.
    iii. Select “File/Save/Top layer.”
e. Confirm that the vector coverage is as expected by removing the study area AOI from the viewer.
    i. Select “View/Arrange Layers.”
        (1) The “Arrange layers” window will pop up.
        (2) Right-click on the top layer, the AOI layer. Select “Delete layer” from the list. Then click on the “Apply” button in the lower left. This will remove the AOI from the viewer. Do not save the AOI layer, since this has been done already in step 10 above.
        (3) After the AOI is removed, the outline of the study area drawn on the screen should remain.
f. Build the vector layer.
    i. In the main imagine console, select the Vector layer utility.
        (1) Note: If the Vector layer utility is not included in the Imagine installation being used, this layer can be built in ArcGIS or Arc workstation. See the documentation for those software packages for assistance on building polygon coverages.
    ii. Select “Build Vector Layer Topology”
        (1) Select the vector coverage just defined.
        (2) Click OK.

Once the study area AOI has been defined, the geometric-reference image and the DEM must be clipped to that area.

12. From the main Imagine icon panel ([fig. 1](#) above), click on the “Intepreter” button.
    a. The “Image Interpreter” window will pop up.
    b. Click on the “Utilities” button from this window.
        i. The “Utilities” window will pop up.
        ii. Select “Subset.”
            (1) The “Subset” window will pop up ([fig. 13](#)).
        iii. In the “Input File” field, navigate to the directory with the geometric-reference image and select it.
            (1) Ensure that the selected image is the one with 25 m pixels and in the NAD83 datum.
        iv. In the “Output File” field, navigate to the appropriate directory for the geometric-reference image.



Coordinate Type: ○ Map ● File

Subset Definition: ● Two Corners ○ Four Corners

ULX: 0.00 LRX: 0.00

ULY: 0.00 LRY: 0.00

URX: 0.00 LLX: 0.00

URY: 0.00 LLY: 0.00

Data Type:

Input: None

Output: Unsigned 8 bit Output: Thematic

Output Options:

Number of Input layers: 0 ☐ Ignore Zero in Output Stats.

Select Layers: 1

Use a comma for separated list(i.e. 1,3,5) or enter ranges using a ":" (i.e. 2:5).

Figure 13. Subset window.

            (1) Follow the conventions in [SOP 5](#) for locating and naming the reference image.
        v. Then click on the “AOI” button at the bottom of the Subset window ([fig. 13](#)).
            (1) In the “Choose AOI” window, select “AOI File.”
            (2) Use the folder button on the right of the AOI file field to navigate to the study area AOI created in step 6 or 10 above in this section.
        vi. Then click on OK button in the Subset window to start the clipping process.
13. Conduct the same process on the DEM (step 12), except use the DEM file as the input file in the Subset window instead of the geometric-reference image.

At the end of the steps in this section, there should be the following:

a. A study area AOI that defines the bounds of the area where all subsequent work will be done.
b. A vector coverage of the same area.
c. A geometric-reference image clipped to the study area.
d. A DEM clipped to the study area.

VI. Geometrically Registering Images to the Reference Image

Images must be aligned so that the information in a pixel at a given coordinate in an image corresponds to the same point on the ground over multiple dates of imagery. To do this, all images must be geometrically aligned to the reference image. Because that image is assumed to be geometrically accurate and registered to a map projection with known coordinates, geometrically registering other images to that reference will result in those new images also being registered to map coordinates. This allows not only direct comparison between images, but also allows connection with other spatially registered datasets, such as GIS layers with information on roads, streams, and trails.

Registration of one image to the reference image is a multistep process (Richards, 1993). First, tie points are in each image. A tie point is a location that can be identified unambiguously in both the reference image and the dependent image, here known as an “Input” image. After a sufficiently large number of tie points is found linking the coordinates in the input image to those in the reference image, a mathematical transformation in the form of a linear equation can be solved that projects a coordinate in the input image into the map system of the reference image. Because of the need to terrain-correct imagery, the process of solving this equation also must take into account the viewing geometry of the sensor and the topography of the land being imaged. Finally, once the equation for transforming coordinates is solved, all of the coordinates of the input image are transformed into their coordinates of the reference image, and resampled to place them on a regular grid in the reference-image map system.

The first step in this process, finding tie points between images, can be done manually or in an automated fashion. Manual location of tie points is time consuming, subject to the interpretation of the individual interpreter and thus not repeatable, and typically results in tie-point populations that are small. Therefore, an automated approach is desirable, and is provided as a module in IDL Virtual Machine (VM) called “ITPFind.”

Locating Image Tie Points Using ITPFind

ITPFind uses image correlation to locate coordinates of image tie points (ITPs) that best match the pixel patterns of small windows in the reference and the input images. It is described in detail in Kennedy and Cohen (2003).

The program is supplied as a module to be run in the IDL-VM. IDL-VM must be installed on a computer before this module can be used (see http://www.rsinc.com/idlvm/index.asp, as noted above, for downloading instructions). Once IDL-VM has been installed, the program can be run by simply clicking and dragging the ITPF module onto the IDL-VM icon. Before this is done, several preparatory files must be setup. The program is named “ITPFind.sav.”

ITPFind requires text files as inputs. These files describe the location and properties of the images to be registered and the parameters used by the program for choosing windows of correlation, grid spacing of tie points, and thresholds for tie-point acceptance. The authors have provided examples of each of these files as part of this protocol, along with the ITPFind VM module. These files must be set up before the program can be used to register images.

1. The first file needed is named “squeet_master.txt”. This file provides the pathnames for all subsequent text files needed by the program. This file can be located anywhere, but it is best to place it in a directory relevant for the files of interest so its location can be found easily. When the ITPFind module is run, it will query the user for the location of this file. The file contains the path and filenames of the two other pointer files required for the program to begin functioning.
    a. One pointer file contains the list of available parameter files (its contents are described in (2.) below). Identify the name of this pointer file using the following syntax: <path/file_here_without_brackets>.
2. The other pointer file contains the list of available image files (its contents are described in (3.) below). Identify the name of this pointer file using the following syntax: <path/file_here_without_brackets>.
    b. File of available parameter files — The filename for this file is specified in squeet_master.txt. This file contains the list of filenames of candidate parameter files. The list of candidate-parameter files starts at the beginning of the file, one file per line separated by carriage returns, with no leading text in the file or on any line. The contents of the parameter files will be outlined below.
3. File of available image files — The filename for this file is specified in squeet_master.txt. This file contains the list of available images and their vital characteristics. For each image file, you must include critical information for the program to run. The following is an example.

Each line will be described below the example. Note that each line ends with a carriage return. Also, there must be a colon and a space between the colon (:) and the first character of the associated information (i.e. Rotation: 0, not Rotation:0 or Rotation 0). Text that does not exactly match the text before the colons will be ignored and will cause errors.

EXAMPLE:

```
Filename: images/exampleInpImage.img
File codename: inputimage
Start point:(x,y): 388, 663
Pixel center to pixel center distance:(x,y): 25, 25
Rotation: -6
Layer to use: 4
Ignore: 0
Mask below: 10
Mask above: 250
```

Description of Each Line:

Filename:

Type in the full pathname of the image without quotes. Currently, the image formats that are accepted are ERDAS Imagine format, or a flat-binary file denoted with a “.bsq” suffix. If the flat-binary option is used, however, there MUST be an accompanying file that describes the geometric qualities of the image. See “Supported Image Types” below.

Currently, the software is designed to accept either ERDAS Imagine 8.3–8.7 images or flat-binary files. Imagine types supported are: Unsigned 8 bit, Unsigned or Signed 16 bit, and IEEE Float.

Flat-binary files must be stored in band sequential format, and the filename must end with “.bsq”. Also, such files must have an accompanying file named the same as the image file, except with “.hdr” swapped in the place of “.BSQ” (i.e. image.bsq and image.hdr). The .hdr file must contain at least the following entries in the following order:

```
BANDS:
ROWS:
COLS:
DATATYPE:
UL_X_COORDINATE:
UL_Y_COORDINATE:
LR_X_COORDINATE:
LR_Y_COORDINATE:
PIXEL_WIDTH:
PIXEL_HEIGHT:
```

Text on other lines will be ignored.

BANDS: the number of bands in the image
ROWS: the number of rows (lines) in the image
COLS: the number of columns (pixels) in each line of the image
DATATYPE: use 3 for 8-bit unsigned, 5 for 16-bit unsigned, and 9 for 32-bit IEEE floating point.

<***>_COORDINATE: All coordinates can be written as decimal values or integer values. These must be in the coordinate system units of the image. If that system is unknown, assume that each pixel is offset from the next by a value of 1.0. It is critical, however, that the coordinates be referenced *as if* they were a UTM-type map coordinate system for the northern hemisphere, where Y-value increases from bottom to top. File-coordinate system coordinates typically work in reverse (Y increases from top to bottom), and this should be avoided.

PIXEL_WIDTH, _HEIGHT: These should be reported in the units of the map system for the image, and should be consistent with the UL_, LR_ COORDINATES given above. For example, if the coordinates given above are in the UTM system with meters as the basis, then pixel dimensions also must be in meters (i.e. 28.5 for raw LANDSAT TM data, or 1000.0 for resampled 1km AVHRR data). Again, if the coordinate system of the image is not known, use 1.0 for both X and Y pixel sizes.

File Codename:

This codename will be incorporated in the output ITP files. It allows later identification of which images were used to find the ITPs. Use some short, unique identifier string without quotes. Because the input and the reference images are stored in this file and there is no distinction in how they are stored, it is sometimes useful to include as part of the codename a reminder about which image is to be used as a reference and which as an input image.

Start Point:(x,y):

The map coordinates of the ‘start point’ of this image. It is simply the approximate location of a point in this image that will match with the ‘Start point’ of its complementary reference or input image. This start point must be in the coordinate system of this image: i.e. in the coordinates of the input image for the input image, and in the coordinates of the reference image for the reference image. Note that the method for location of these coordinates is described in Running the ITPFind Module section below.

NOTE: Typically the Input image has no map coordinates associated with it, since this is the image to be reprojected. Because of a glitch in Imagine, it is necessary to go through the following steps for images that have no map coordinates associated with them *before* the start point is in the viewer.

Open the input image in a viewer (section IV, steps 1–2 above).

Open the ImageInfo for that image (section IV, step 3 above).

Select “Edit/Change Map Model.” The Change Map Model window will appear. Simply click on OK button once this has been done.

Accept changes when prompted.

Close the viewer.

Why do this? For some reason, Imagine has a disconnect between the map info that is used in the viewer when an image is opened that has no geometric information and the map information that is passed to the ITPFind program and to the GCP editor of Imagine (further down in this SOP). By opening the Edit/Change Map model dialog, this forces Imagine to make geometric properties consistent across modules.

Pixel Center to Pixel Center Distance:(x,y):

The distance in a COMMON REFERENCE SYSTEM between the center of adjacent pixel centers in this image. When ITPFind runs, this value will be compared to the parallel measure in the complementary reference or input image to determine how far the program should jump between ITPs. **It must be in the same units for both the reference and the input images** in a given run of the program, typically in units of the reference image. Since the geometric-reference image is a LANDSAT TM image with pixel size 25 by 25 m, its pixel center to pixel center distance should be listed as 25, 25 m. However, assuming that the input image has been ordered from EDC with 28.5 m pixels, its pixel center to pixel center distance should be 28.5 m, even if no map information is associated with the image. Note that if the input image coordinate system is unknown (a likely case, given that ITPs are being sought), the “pixel size” of the input image may be reported in the ImageInfo of ERDAS Imagine as 1.0, 1.0 – but the Pixel center to pixel center distance:(x,y) is still 28.5, 28.5.

Rotation:

The rotation, in degrees clockwise, of this image relative to a stable reference direction. It typically is easiest to set the reference image rotation to zero, and set the input image relative to the reference image. To determine whether the rotation of the input image relative to the reference image is positive or negative, use the following approach:

1. Imagine an arrow pointing north on the ground in the reference image.
2. Imagine an arrow pointing north on the ground in the input image.
3. If the head of the input image arrow is to the left of the reference arrow, the input image rotation is negative. If the head of the input arrow is to the right of the reference arrow, the input image rotation is positive.

Layer to Use:

The layer number of the image to use for the analysis. Only one layer is used. In all likelihood, this should be the same layer number as will be used in the complementary reference or input image. Layers begin with 1. It is best to use a layer of the image with high contrast, such as the near infrared bands. For TM images, band 5 is often good.

Ignore:

If the image file contains unwanted background, give the value of the background here. This is often zero. The programs will recognize background areas and will skip past them, improving performance. Moreover, this method can be used to “work around” popcorn-type clouds or other drastic changes between images. A quick unsupervised classification of the cloudy image can be used to identify the bulk of the clouded areas and the shadows, and all of these can be set to the Ignore value. The program will use only areas between the clouds for calculation of correlation. Note that if this route is chosen, the window size parameter (see below) likely SHOULD be increased to ensure that an adequate number of pixels remain for calculation of correlation when the cloud pixels are removed.

Mask Below, Mask Above (Both Optional)

As of version 2.1, a more useful approach to screening out unwanted areas was added by inclusion of the Mask Below and Mask Above keywords for an image. These are optional – if not used, do not include the keyword on the line (i.e. simply omit the entire line, rather than retaining the keyword “Mask below” and setting it blank). The number attached to either mask below or mask above is the value below or above which pixels will not be used for correlation matching. This was designed for use in cloudy areas, where a mask above value eliminates much of the cloud area and the mask below value eliminates much of the deep cloud shadow. The values must be chosen by the user, so it is best to just look at your image in your favorite image processing system and get a rough guess for the digital number (DN) values of the clouds and shadows. As with the ignore keyword, it is best to increase the window size you are using if you think that a fair portion of each window will be masked out with this feature.

Parameter Files

1. Parameter files are pointed to in the "File of available parameter files" (see above). Each run of the software requires a single-parameter file. An example of the required information is given below, followed by detailed descriptions of each line.

EXAMPLE:

Original Parameters File for use in ITPFind program
Window Size: 150,150
Window Spacing: 400, 400
Number of Iterations: 1
Pixel Aggregations: 1
Search Neighborhoods: 5
Threshold min. steepness: .35
Zoom Factors: 2
Maximum move: 0
Nudgefactor: .20
Postfilter_rms: .025

Window Size:

The size, **in pixel counts of the reference image**, of the window extracted for matching. It is in x,y format. Note that this dimension is *not* in the units of any coordinate system, but referenced by the number of reference pixels. For example, if the reference is a TM image with pixels 28.5 m on a side, then setting the window size to 100,100 means that a window of 100 by 100 pixels will be extracted, equivalent to an area 2,850 by 2,850 m. The equivalent sized window in the input image is calculated by the software based on the Pixel center to pixel center distance:(x,y) given for the reference image and the input images. If they are not the same, the program will resample the input image to match the Pixel center to pixel center distance:(x,y) of the reference image.

Window Spacing:

The approximate desired grid spacing between ITPs, **in pixel counts of the reference image**, between ITPs. Again, the relation between the Pixel center to pixel center distance:(x,y) of the reference and input images will determine the jump in pixels of the input image. Note that the rotation of the input image also will be calculated in the jumping between points. Thus, if the user is unsure of the rotation value of the input image, it is safer to give a smaller window-spacing value, since the error in the rotation value will be multiplied over a shorter distance.

Number of Iterations:

The number of times that the program will refine the ITPs coordinate pair at each point. The next five parameters must each have this many entries, each separated by a comma. For example, if Number of Iterations is set to 2, then each line of the next five must have the keyword parameter followed by ": <n1>, <n2>", where <n1> and <n2> are the values for that parameter.

Typically, this can be set to 1. If set to 2 or higher, the program engages in an iterative process. Using the first entry in each of the next 5 parameters, the program finds an approximate match for the ITP pair. Using that approximate match derived in the first iteration, the program uses the second entry (the number after the first comma) to find a better match for the ITP pair. Typically, this only makes sense if the Pixel Aggregations value is lower for the second iteration than for the first iteration.

Pixel Aggregations:

The number of reference pixels by which to aggregate both images before floating the input image over the reference image. Note that this aggregation occurs AFTER the input image is resampled to match the grain size of the reference image.

If set to 2.0, for example, then the reference image is first aggregated such that a 2 by 2 set of original pixels becomes 1 pixel in an aggregated image. That image—with its doubled pixel center to pixel center distance—is used to develop correlation surfaces and find an ITP. Because of the aggregation, this ITP will have a lower precision than if the ITP were calculated on the images at native resolution, but this aggregation allows a larger area, with more potential for strong spatial pattern, to be used to calculate correlations. Used in conjunction with two or more iterations (set with the Number of iterations parameter above), this can efficiently hone in on ITPs in difficult-to-match image pairs.

Search Neighborhoods:

The number of pixels to float the input image is relative to the reference image. This value is in units of the aggregated pixels—i.e. if the Pixel Aggregations for this iteration were 2, then a search neighborhood of 10 for this iteration actually would mean that the input image has floated an equivalent of 20 original pixels in all directions relative to the reference image.

This parameter greatly influences performance of the software, since increases in the search neighborhood result in squared increases in the number of comparisons necessary. It is thus desirable to keep this number as low as possible. Values between 5 and 7 are optimal, although values as high as 10 or 12 may be necessary.

Threshold Minimum Steepness:

This value is the threshold against which a potential peak in correlation is tested, based on the relation between the peak of correlation and the plane at the "base" of the peak. If the observed value is below this Threshold min. steepness value, the point will be thrown out. A value of 0.35 has been robust across most image situations. If it seems that erroneous ITPs are being accepted too often, increasing this parameter value may help—however, generally it is better to attempt altering other parameters first, i.e. the window size or the search neighborhoods,

Zoom Factors:

The portion of the originally extracted window (determined by the window size) is used for the determination of covariance. A value of 1 means that the entire extracted window is used to determine covariance. A value of 2 means that the window used for covariance calculations will be one-half the size of the original image in both the X and the Y dimensions; i.e. it will be one-quarter the area. The smaller window is extracted from the center of the originally extracted window.

Consider the following example: The window size is set to [400,400], number of iterations set to 2, pixel aggregations set to [2,1], and zoom factors set to [1,2]. In iteration 1, the 400 by 400 window is read from the file, and then aggregated in 2 by 2 blocks to create a 200 by 200 image that captures the spatial patterns across the entire area represented in the original [400,400] image. The spatial matching is run on that image and a preliminary ITP pair located. In the second iteration, the zoom factor of 2 takes the original 400 by 400 image and extracts the 200 by 200 area around the preliminary ITP pair found in iteration 1, and this image (unaggregated, because the pixel aggregation is set to 1 for this iteration) is used to derive a more refined ITP pair.

Maximum Move:

If this value is non-zero, every time the program cannot find a valid covariance peak at a given point, it will try again by searching *nearby* rather than skipping the point altogether. "Nearby" is defined by the next parameter, the Nudgefactor. The pattern of searching nearby is circular; i.e. it will attempt to find a point just to the "right" of the first attempt, then slightly right and down if no match was found there, then down if no match is found, etc., until a complete circle has been traversed. If the Maximum move is 2, this process will continue on a second circle with greater radius.

In most cases, it is more efficient to set this value to zero, since factors that cause difficulty locating peaks at a given location (for example, a bank of clouds in one image) are more likely to exist nearby than far away. However, under certain circumstances the user may require that ITPs be located as close to full-grid pattern as possible, and this option allows this.

Nudgefactor

This value determines how far away from the original point the program should search for covariance values if it cannot find a covariance peak on an initial try. The value is a proportion of the window-size value. If the window size is [400, 400] and the Nudgefactor is 0.5, then the program will extract new windows at a radius of 200 reference pixels away from the original point tried.

Postfilter_rms (Optional)

Some tie points will still be odd, despite the various filters that occur during the search for each individual point. By setting this parameter, the program calculates a simple first-order transformation after all points have been found, and iteratively removes any points whose removal results in an improvement in the overall root-mean-square (RMS) error of the solution. The value of this parameter is the threshold for determining whether improvement has occurred, and corresponds to the proportional improvement in RMS error. Thus, setting it to 0.025 means that points will be removed when their removal improves the RMS error by 2.5 percent or more. This tends to remove the points that clearly are errors (i.e. points over water, etc.). This feature was added with version 2.1.

At a minimum, the squeet_master.txt file must exist, and it must point to a squeet_images.txt file and a squeet_params.txt file. The squeet_images.txt file must contain information for at least two images, one to be used as reference image and one to be used as the input image. The squeet_params.txt file must point to at least one parameter file with all of the necessary parameter fields filled in.

Running the ITPFind Module

To find a good start point of the input and reference images, load each image into an Imagine Viewer (follow steps 1 and 2 of section IV above). In the reference image, use the side bars on the viewer to navigate to approximately the center of the image, and visually locate a feature on the landscape that is recognizable and likely to change little over the time period of the two images. In the viewer, select the crosshair icon (it looks like a plus sign, and is just to the left of the hammer symbol) to start the coordinate-crosshair tool.

The X and Y coordinates of the crosshair are shown in the X and Y fields (fig. 14). Grab the center of the crosshairs by clicking with the mouse point, and drag it to the feature desired. In the viewer for the input image, use the sidebars to navigate to approximately the same area of the image, locate the landscape feature that was identified in the reference image, start a coordinate-crosshair tool in the input image, and click and drag its center point to approximately the same location on the landscape as the crosshairs in the reference image.

Record the X and Y position of the respective crosshairs in the squeet_images.txt file for the reference and the input images.

Once pointer files, image files, and parameter files have been defined, drag the ITPFind icon over the IDL-VM icon to start the program. It will query immediately for the location of the squeet_master.txt file that was created above. Navigate in the file-finding dialog box to the appropriate directory and select the file.

An action window will pop up. The list of available image files will be on the left, the list of available parameter files on the right. On the bottom is an empty table. This table is where reference and input images will be paired and associated with a parameter file.

Click on an available image that is the reference-geometric image. Its name will appear in the ‘Currently Selected’ box. Then click in the first box (first row) of the reference column (the left-hand column) in the bottom table.

For the reference image in ITPFind, use the 25-m geometric-reference image that has been clipped to the study area (section IV, step 12 above). This will ensure that tie points are located only within the study area where terrain information in the form of the DEM also is available.

Pick the input image from the same available image list in the same manner and place it in the middle column below, and finally pick a parameter file and place in the parameter column below. At this point, the ITP program can be run by clicking on the ‘Submit for processing’ button.

Alternatively, additional sets of reference/input image and parameter files can be placed in the second row of the bottom table. After the ITP program has found ITPs for the first set, it will move to the second set, third set, in order.

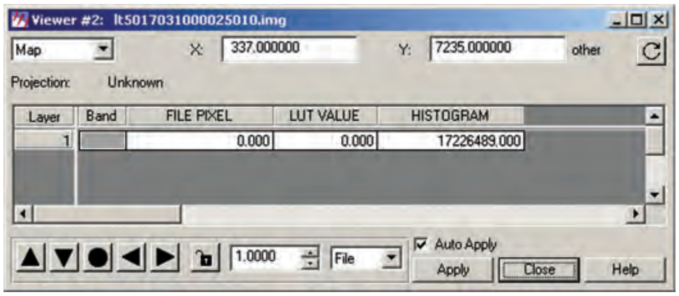
While the program is running, it will display two windows: one shows the growing grid of ITPs, the second shows the image chunks and correlation surfaces for the points being processed currently.

The program will output five text files: one file for X coordinates of the input image, one for Y coordinates of the input image, one for X coordinates of the reference image, one for Y coordinates of the reference image, and one readme file. **All files are placed in the directory of the INPUT IMAGE. They will be named with an identical root based on the image codenames used to find the ITPs and the time at which the program commences**. The files with the X and Y coordinates will be imported into the ground-control-point (GCP) editor of Imagine below (see step 4.b. below).

These files are only the coordinates of the ITPs. From this point, Imagine must be used to conduct the terrain correction.

Conducting Terrain Correction

1. Load the geometric-reference image that has been clipped to the study area.
    a. The image was created in section IV, step 12 above.
    b. To load the image into the viewer, see section IV, steps 1 and 2 above.
2. In the main icon panel of Imagine, select the viewer button (fig. 15).
    a. Viewer #2 will come up.
        i. Open the Input image in Viewer #2.
            (1) Again, click on the folder icon of the viewer and navigate to the appropriate folder. This assumes that the input image has been imported into Imagine format. If not, it is necessary to import this image into the Imagine format (section III above).



Viewer #2: lt5017031000025010.img

Map X: 337.000000 Y: 7235.000000 other

Projection: Unknown

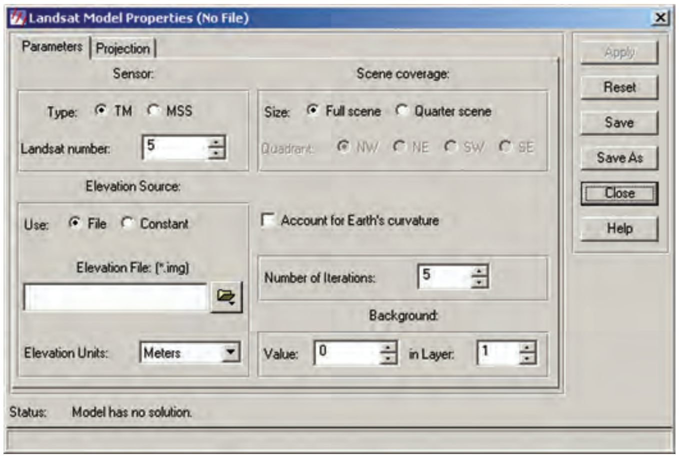
Layer	Band	FILE PIXEL	LUT VALUE	HISTOGRAM
1		0.000	0.000	17226489.000

1.0000 File ☑ Auto Apply

Figure 14. Coordinate-crosshair window.

Figure 15. A portion of Imagine’s main icon window, with the button that starts Viewers circled.

3. From within Viewer #2 (with the input image), select “Geometric correction.”
    a. An action window named “Set Geometric Model” will pop up, with a list of options. Another action window labeled “Geo Correction Tools” will pop up (see fig. 8 above).
    b. In the Set Geometric Model window, select Landsat and click on the OK button.
        i. The “Landsat Model Properties” window will pop up (fig. 16).
    c. For sensor type, ensure that TM is selected, and that the Landsat number: field is correct.
        i. The information on which Landsat sensor acquired an image can be found in the header file (a file ending with .h1) that came with the original Landsat image from EDC (see SOP 1 Ordering Imagery).
    d. In the “Elevation File: (*.img)” field, use the folder icon to navigate to the DEM that has been clipped to the study area (this step is discussed in section V, step 13, above).
    e. Ensure that the elevation units are correct.
        i. This information should be found in the metadata associated with the original DEM file.
        ii. If there is no such information on the vertical units of the DEM, it can be inferred in many cases.
            (1) Open the DEM in a viewer (see section IV steps 1–2).
            (2) Open the ImageInfo for that viewer (see section IV step 3).
            (3) In the Statistics info section of the ImageInfo window, note the value of the “Max:” field. This value should approximately represent the maximum elevation in your study area. Since units of feet and meters differ by a factor of three, this maximum value should indicate which unit is used for the DEM. Other vertical units (decimeters) have sometimes been used; if neither feet nor meters seem likely, then it will be necessary to track down the source of the DEM and determine the appropriate units.
    f. Leave the rest of the fields in the default position.
4. Setup the coordinates for the terrain correction by importing the image tie-point text files that were created by ITPFind above.
    a. Click on the “Projection” tab of the Model properties page.
        i. Click on the button labeled “Set Projection from GCP Tool.”
            (1) The “GCP tool reference setup” window will pop up, with the “Existing viewer” line selected with a circular radio button. This is the desired choice, so simply click on the OK button.
                (a) The “Viewer selection instructions” window will pop up, instructing user to left-click the mouse in the viewer with the reference image. Place the mouse in Viewer #1 and left-click the mouse button.
                (b) The Reference Map information window will pop up, with a list of the geometric properties of the reference image. Click on the OK button.
                (c) Imagine will then rearrange windows and add windows.
    b. All of the steps below occur in the “GCP Tool” window.
        i. First, turn off the automatic calculation and display mode by clicking on the “Toggle fully automatic GCP editing mode” button on the left-hand side of the window (fig. 17).


Landsat Model Properties (No File)

Sensor:
Type: ● TM ○ MSS
Landsat number: 5

Scene coverage:
Size: ● Full scene ○ Quarter scene
Quadrant: ● NW ○ NE ○ SW ○ SE

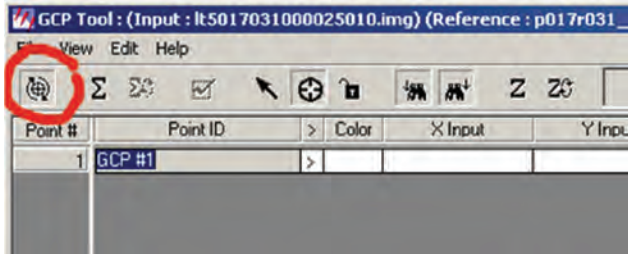
Elevation Source:
Use: ● File ○ Constant
Elevation File: (*.img)
Elevation Units: Meters

☐ Account for Earth's curvature
Number of Iterations: 5

Background:
Value: 0 in Layer: 1

Status: Model has no solution.

Figure 16. Landsat model properties page, used to reproject images acquired by the Landsat sensors.


GCP Tool : (Input : lt5017031000025010.img) (Reference : p017r031_

Point #	Point ID	>	Color	X Input	Y Inpu
1	GCP #1	>			

Figure 17. GCP tool, with the automatic GCP mode button circled.

(1) With the mouse over the title of the "X Input" column, left-click on the mouse to select that column. The first cell should be highlighted and the shaded title box of the column inverted, indicating that the column has been selected.

(2) Right click from the same position over the title box to see the column options window. From the list of options, select "Import."

  (a) The "Import column data" window will appear. Navigate to the directory where the Input image used in the ITP find program above is stored. This is where ITPFind puts tie-point files.

    (i) Select the file whose filename ends with "…_xinput.txt" and click on the OK button.

      (1) Note: The first part of the file name corresponds to the image code names that were included in the available image text files used as input to the ITP program, the second part corresponds to the time stamp when the ITP program was run.

    (ii) The X coordinates of the input image tie points should appear in the X-input column.

(3) Repeat this process for the Y input column, this time selecting the filename ending with "…_yinput.txt".

(4) Repeat for the X ref and Y ref columns as well.

(5) When all the tie points have been located, the elevation values in the Z ref column should appear. If not, click on the "Z" icon in the GCP Tool window to load them. If no values appear, return to the Landsat Model properties dialog (fig. 16) and ensure that the DEM has been identified properly, and then click on the Apply button again.

  (a) If no values appear after this step, open new viewers and ensure that the coordinates of the DEM correspond to the same area as the image.

    (i) Open a new viewer.

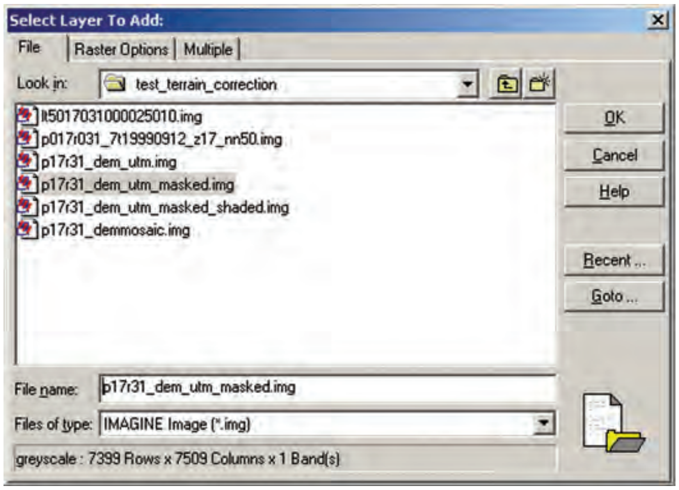
    (ii) Load the reference image.

    (iii) Load the DEM, but when loading the image in the "Select Layer to Add" dialog (fig. 18), click on the "Raster Options" tab.

    (iv) Uncheck the "Clear display" box. Now the DEM will load into the same viewer as the reference image.

    (v) Once the DEM has loaded, right-click in the viewer and select "Fit image to window" from the pulldown list.

    (vi) The viewer should redraw. The image should appear first, then the DEM should appear over it. If the two are in entirely different portions of the viewer, this indicates that coordinates or projections have been in error. Double-check all resampling and reprojecting steps above.


Select Layer To Add:

Look in: test_terrain_correction

lt5017031000025010.img
p017r031_7t19990912_z17_nn50.img
p17r31_dem_utm.img
p17r31_dem_utm_masked.img
p17r31_dem_utm_masked_shaded.img
p17r31_demmosaic.img

File name: p17r31_dem_utm_masked.img
Files of type: IMAGINE Image (*.img)
greyscale : 7399 Rows x 7509 Columns x 1 Band(s)

Figure 18. Window where files are chosen to add to a Viewer.

(6) Calculate the solution for the reprojection.

(a) Hit the sigma symbol on the left-hand side of the GCP Tool window.

(i) The columns X residual, Y residual, RMS error, and Contrib. all will be populated. Additionally, the field in the center top of the GCP tool will display the “Control point error” for X, Y, and total. This is the total RMS error. See Richards (1993) for more information on the calculation of the RMS error. These will be in units of the input image. If the input image is without map information and has pixels of size 1.0, for example, then a total error of 0.5 would indicate a RMS error of half a pixel.

(7) Screen out any tie points that are outside the edge of the DEM.

(a) With the mouse over any row in the GCP tool, right click to get the row-selection tool. Select “Criteria” to bring up the “Selection Criteria” window (fig. 19).

(b) Using the mouse and the left mouse button, select from the Columns: field the “Z Ref.” row.

(i) Imagine will place $“Z Ref.” in the “Criteria:” field at the bottom of the window, and will continue to build the criterion expression as more values are selected below.

(c) Select from the “Compares” field the double-equal-sign (==).

(d) Select from the keypad the number 0.

(i) Ensure that the final expression is $“Z Ref.” == 0.

(e) Click on the Select button. All of the rows in the GCP tool where Z Ref. is zero will be highlighted in yellow.

(f) Ideally, there should be none of these rows. But in case there are, place the cursor over any row number in the left-hand side of the GCP tool and right-click. Select “Delete selection.” This will eliminate any points where the elevation is zero.

(i) Why? Elevations of zero would otherwise be incorporated in the general solution relating the images to each other, and false zeros will cause large distortions in the solution.

(8) Recalculate the solution for the reprojection.

(a) This must be done twice, once before and once after taking out points with zero elevation, or else Imagine will crash.

(9) The control-point error should be well below 1 pixel in size, ideally less than one-half of a pixel. If it is significantly greater than this, examine the control points in the table to see if there are any extremely unusual points, as indicated by the value in the “Contrib.” column.

(a) These can be selected using the criterion window, as in step 7 above, but in this case select “Contrib. >2.0,” etc. to find the points.

(i) To view individual points, select the two binocular icons to have the viewers zoom to the selected tie points to examine particularly unusual points. If a visual examination shows that a given tie-point pair is wrong – i.e. that the points correspond to entirely different points on the landscape, then right-click on the row of the offending point and select “Delete selection” to remove it. This will delete all the points currently selected, so make sure that only the desired point is selected.

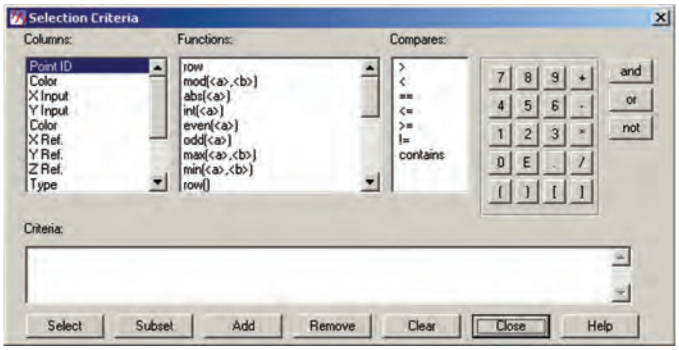


Figure 19. Selection criteria window for the GCP tool.

            - (ii) After deleting a point, recompute the solution by hitting the sigma function button again. This will compute the overall error without the offending point, and will redistribute error among the remaining points. Check for unusual points again.
                - (1) This iterative process is done automatically in the ITPFind program, so this process likely should be unnecessary.
        - (c) Once the reprojection solution has been computed from the tie points, the input image can be resampled.
            - (i) First, record the Control Point Errors computed in the GCP Tool window, both for X and Y and for the total. These should be attached to the metadata for the resampled input image. See SOP 5 Data Management.
            - (ii) Click on the resampled icon in the "Geo Correction Tools" window (see fig. 8 above).
            - (iii) Follow the instructions in section IV, step 4.b. iii.(3)–(9) above for resampling.
        - (d) When resampling has concluded, close all windows and do not save the projection parameters or model. These would become attached to the images, which causes confusion if later images are to be registered to these same images.

At this point, the input image should be in the same projection as the geometric-reference image. To check this, follow these steps.

5. Checking for geometric matching of images.
    - a. Open a viewer.
    - b. Open the reference image using the standard file opening procedure (section IV, steps 1–2 above).
    - c. In the same viewer, use the open folder icon to start the "Select Layer to Add" window (fig. 18) and navigate to the input image and select it, but do NOT click on OK.
        - i. Click on the "Raster Options" tab in the Select Layer to Add window, and uncheck the box next to "Clear display."
        - ii. Click on OK button.
    - d. Both images should be displayed in the same viewer.
    - e. In the viewer, select "Utility/Flicker."
        - i. The Viewer Flicker dialog will open.
        - ii. Hit the "Manual filter" button to toggle between the two images in the viewer.
        - iii. Alternatively, click the box "Auto Mode" to have the toggling occur automatically.
        - iv. When the two images are toggled, there should be minimal apparent "jumping" of pixels back and forth across dates. The flickering image should appear geometrically stable, although radiometric changes may cause the illusion of some motion as the images flicker.
        - v. Scroll around the image and ensure that the image is stable across the entire range.
        - vi. Zoom in on some locations and view the flicker closely.
        - vii. Pay particular attention to mountainous areas. If the automatic flicker mode is on, if there is a problem with the terrain correction, the flicker will reveal distortions that are correlated with the position of hills and mountains, creating a pseudo-three-dimensional effect as flickering occurs.
            - (1) If this is the case and terrain correction has been done in Imagine, this suggests that either the terrain correction was inaccurate, or that the original reference image was in fact NOT terrain corrected.
                - (a) Check the elevation units of the DEM and make sure these are in the appropriate units. If not, redo the terrain correction of the input image.
                - (b) Check the history of the geometric reference image to confirm that it was terrain corrected or orthorectified.
                - (c) Repeat the reprojection of the input image process to the point where tie points have been loaded in the GCP tool, and check carefully for unusual tie points. Check each tie point with high RMS error and ensure that all points make sense visually.

Once the input image has been reprojected to the geometric properties of the geometric reference, and once it has been confirmed to be accurate, **the input image must be clipped to the study area.** Follow the steps in section V to clip the input image. Use the naming conventions in SOP 5 (Data Management) to name the clipped, terrain-corrected input image.

VII. Compensating for Sensor and Atmospheric Influences in Reference and Input Images

The atmosphere affects the reflectance signal that impinges on the sensor from the surface of the Earth. Differences in atmospheric conditions between dates of imagery will cause differential artifacts in the images that will confuse later change detection. Therefore, all reasonable efforts must be made to compensate for these effects. The first step is to bring both images into a common system of measurement, reflectance.

The units of a Landsat image are simply digital numbers (DNs), corresponding to the magnitude of energy being measured by each of the sensor elements in the satellite. Because the engineering properties of the sensor are known, the DNs can be converted into physical units of radiance. Knowing the emission spectrum of the sun entering the atmosphere, these units of radiance can further be quantified as a proportion of the incoming radiation ranging from 0 to 1.0. This is known as "top-of-atmosphere reflectance." It does not take into account the effects of the atmosphere.

Without direct measurements of atmospheric absorption at the moment of image acquisition, it is impossible to know this atmospheric effect directly, but it can be approximated. To approximate the effects of the atmosphere, it must be assumed that there are some objects on the surface with little to no reflectance. These so-called "dark objects" should indicate a reflectance of zero or near-zero. Because the atmosphere introduces scattering between the objects and the sensor, the apparent reflectance of these objects from the sensor's perspective is non-zero and positive. The additive effect of this scattering can be removed by simply subtracting the offset above these dark objects from all pixels in the image. The multiplicative effects of the atmosphere can be approximated simply by a correction factor that scales with the path length through the atmosphere, which requires only that the sun angle and elevation be known. All of these steps can be incorporated in a single-transformation process and placed in a graphic model in Imagine. Because these were best described in (Chavez, 1996) as COS-theta or COST methods, these steps are referred to here as COST processing.

1. Selecting dark-object values for each band:
    a. The first part of the COST processing is selection of dark-object values for each of the six visible bands in Landsat.
    b. An Excel spreadsheet is in the appendixes and serves as a template for which the relevant values for COST processing can be stored.
        i. This spreadsheet file is named "COST_processing_template.xls."
        ii. Save this Excel file under a new name that corresponds to the name of the image, so that it can be connected easily with that image in the future.
        iii. Make a note of this filename in the metadata associated with this image.
            (1) Follow the conventions in SOP 5 Data Management for naming convention.
    c. It is helpful to use the entire image area, not just the area within the study area of the park, for locating potential dark objects because the population of potential targets is much higher. Therefore, for a given image, go back to the first version of the image that includes the entire footprint of the original Landsat image directly after importing into Imagine format.
        i. This image should be the one that was imported in section III above. It need not be geometrically referenced for selection of dark-object values.
    d. Open the image in a viewer using the Pseudocolor option:
        i. Use the open-folder icon to bring up the "Select layer to Add" window (shown in fig. 18 above).
            (1) Navigate to the desired image folder, select the image from the available files list so that its name appears in the "File name:" field. Do NOT click on OK yet.
        ii. Click on the "Raster options" tab.
            (1) In the field labeled "Display as:" select "Pseudo color."
            (2) Choose the desired layer. If just starting, select 1 for band 1, which corresponds to the blue wavelengths in Landsat.
            (3) Retain defaults for the other options.
        iii. Click on OK button.
        iv. Right-click in the viewer and select "Fit image to window."
        v. Select "Raster/Attributes."
            (1) The Raster Attribute Editor will popup.
                (a) There are three columns: Histogram, Color, and Opacity. The important columns for this exercise are the Histogram and the Color columns.
                (b) The Histogram column indicates the count of pixels that have the value indicated in the row value on the left-hand side of the attribute editor. For Landsat images, these range from 0 to 255.

- (c) There is a high histogram count in the row with value 0. These are the pixels outside the edge of the image area, and should be ignored.
- (d) For bands 1–3 and often 4, the row number with the lowest non-zero histogram value is not the row 1, but rather another row with a higher value. This indicates that even the darkest objects in the scene have non-zero reflectance, and indicates the level of atmospheric scattering. It is not wise to simply take the row number of the lowest non-zero histogram count as the dark-object value, however, because these low values could be artifacts of processing upstream of image acquisition or even of steps conducted in Imagine.
  - (i) It is most robust to use images that only have been resampled using the NN method, which is why SOP 1 recommends ordering imagery using the NN option from EDC.

2. Start with the lowest non-zero histogram value and examine the location of the pixels corresponding to that value using step 1.a.i.–vii. below, and step sequentially to higher values until a pixel value is identified whose pixels reside in the landscape, and which correspond to features that are expected to be dark-objects step 1.b.i.–ii. below.
   - a. To examine where pixels at a given pixel value reside on the image, do the following:
     - i. Select the row with the desired pixel value. For example, select the row with the first non-zero histogram value.
     - ii. Then place the mouse over the box in the column labeled “Color” for this row, and right-click.
       - (1) A small window with a variety of color options will pop up. Select a color that allows easy contrast with the grey tones of the image, perhaps red or yellow.
     - iii. Look in the viewer at the image and see where the red pixels reside.
     - iv. Evaluate these pixels according to the criteria in step b. below.
     - v. If these pixels are not considered valid dark objects, select “Edit/Undo Last Edit” in the Raster Attribute Editor to change the color patch back to its original nonhighlighted shade. Then move to a pixel value one step higher and repeat this process.
     - vi. If these pixels are considered legitimate dark objects, then take this value as the approximate dark-object value.
       - (1) Because few objects are truly nonreflective, it is typical to assume that the observed dark objects have an actual reflectance on the ground of roughly 1 percent. Therefore, the true value for zero reflectance will be somewhat lower than the observed value in the image. The correction factor can be approximate, since these dark objects are an approximation of the actual atmospheric effects. Therefore, take the tentative dark object value and adjust it as follows to calculate the actual dark-object value for the band:
         - (a) For bands 1–3 and band 7, subtract 1 from the observed value.
         - (b) For bands 4 and 5, subtract 2 from the observed value.
           - (i) In both cases, however, the minimum allowed dark-object value is zero.
     - vii. Enter this value in the dark-object value column for the row corresponding to the band in the Excel spreadsheet saved in step 1.b. above.
   - b. Evaluating dark-object pixels.
     - i. Characteristics of valid dark-object-type pixels.
       - (1) The pixels reside on the landscape, not on the margins of the scene area.
       - (2) The pixels are in areas where dark reflectance is expected:
         - (a) Water bodies.
         - (b) Topographic shadow.
         - (c) Deep shadow on shaded aspects of forests.
     - (ii) Characteristics of dark objects that are artifacts:
       - (1) The pixels reside on the very margin of the active area of the image.
         - (a) These typically are formed because of bilinear or cubic convolution of zero values outside the image with non-zero values inside the image.
       - (2) The pixels reside directly next to a very bright pixel and the image has been subjected to cubic convolution resampling beforehand.

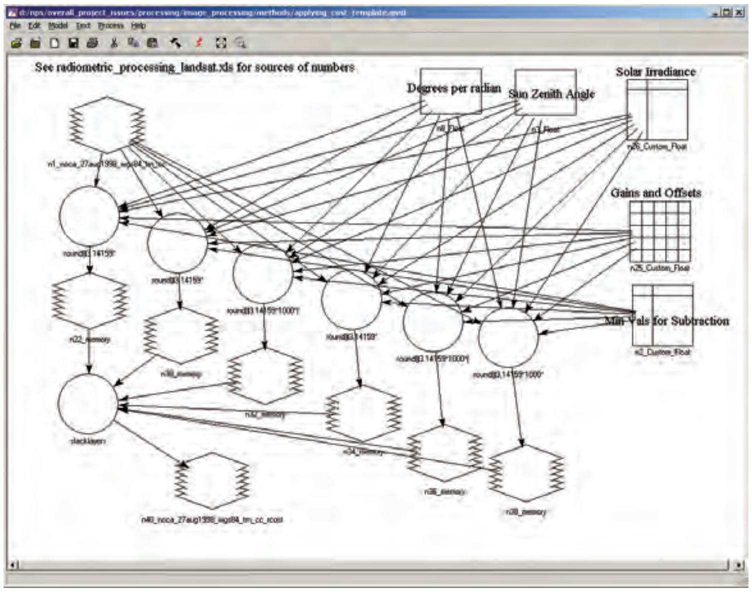
            (a) Cubic convolution can depress values of pixels neighboring bright objects, and thus can force otherwise dark objects to even darker values that are an exaggeration of the actual dark-object value.

    c. Repeat this process for all six of the visible bands in the Landsat image. Record each dark-object value in the Excel file from step 1.b. above.
        i. When this has been done for all bands, evaluate the relation between dark-object values across bands.
            (1) The effect of haze is greatest at shorter wavelengths in the blue bands of the image, and tapers off as band number increases. Therefore, the dark-object values should be highest in band 1, lower in band 2, etc. The dark-object values of each band should be no higher than the band number lower than it. If this is not the case, then it indicates that the dark-object value for the lower-numbered band may have been too low. Review the dark-object pixels for that band.
            (2) Bands 5 and 7 may have almost no scattering, and therefore may have dark-object values of 1 or 0.

3. Identifying sun elevation and angle:
    a. When an image is ordered from EDC, the associated header contains information on the sun elevation and sun azimuth.
    b. These values should be entered into the excel spreadsheet noted above. Note that the formula for the COST processing requires the sun zenith, which is 90 degrees minus the sun elevation.

4. Identifying gains and offsets:
    a. The DN values reported in a band from Landsat do not correspond to actual physical quantities. To convert the DNs to physical values of radiance, the gains and offsets of the sensors in the satellite must be taken into account. The gain of a sensor is akin to the amplification factor needed to convert it from one set of units into another—the slope of the line relating the DNs to radiance values, in this case. The offset or bias is simply the equivalent of the intercept of the same line. As a sensor ages, these translation factors will drift, and thus it is necessary to know them for each specific image being processed.
        i. For Landsat 7 (ETM+) imagery, the gains and offsets are listed for each band in the header file. These should be entered into the Excel spreadsheet.
        ii. For Landsat 5 imagery *ordered* after May 4, 2003, the gains and offsets in the header can be used and entered into the Excel spreadsheet.
        iii. For Landsat 5 imagery that was acquired by the satellite before 1989 and processed before May 4, 2003, use the gains and offsets (table 2) found in Chander and Markham, 2003.

4. Entering data into an Imagine spatial modeler
    a. An Imagine graphic model appears in the appendix that will apply the values collected in steps 1–3 to an image to create a COST-processed version of the image. This model is named **applying_cost_template.gmd**
        i. From Imagine's main icon panel, select the icon labeled "Modeler."
        ii. Select "Model Maker."
        iii. In the Model Maker, use the open folder to navigate to the template model and open it (fig. 20).
        iv. Save this file under a name that links it to the image being processed. Do this using File/Save As. Use the naming conventions of SOP 5 Data Management.
    b. Conventions of the spatial modeler in Imagine.
        i. See figure 20.



See radiometric_processing_landsat.xls for sources of numbers

Figure 20. Graphic modeler in Imagine, with the template for COST processing.

Table 2. Gains and offsets for Landsat 5 imagery acquired before 1989.

[From Chander and Markham (2003)]

	Gain	Bias
Band 1	0.602431	-1.52
Band 2	1.1751	-2.84
Band 3	0.805765	-1.17
Band 4	0.814549	-1.51
Band 5	0.108078	-0.37
Band 7	0.05698	-0.15

ii. All spatial data and actions applied to it are represented as shapes linked with arrows that indicate the flow of processing.

iii. Double-click on any shape to see information about the spatial data, numerical data, or function contained in the shape.

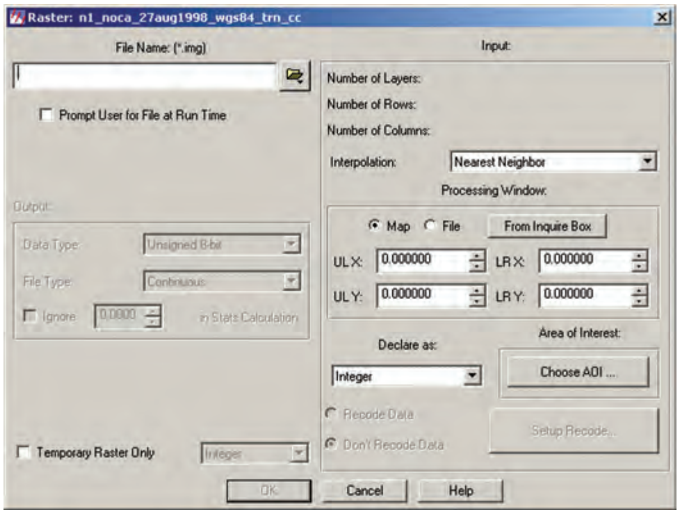
iv. Click on the hammer symbol to show a window of tools that can be used to update or build a graphic model.

v. Circles correspond to functions. For a function to operate, it must have an arrow leading to it from some data object, such as an image or a table.

vi. Stacked oblique squares represent spatial data. These are used as inputs to functions.

vii. Squares correspond to data that must be entered manually or that is not spatial, such as tables taken from external text files.

c. Enter data accumulated in the Excel spreadsheet into the modeler.


Raster: n1_noca_27aug1998_wgs84_trn_cc

File Name: (*.img)

☐ Prompt User for File at Run Time

Input:

Number of Layers:

Number of Rows:

Number of Columns:

Interpolation: Nearest Neighbor

Processing Window:

● Map ○ File

ULX: 0.000000 LRX: 0.000000

ULY: 0.000000 LRY: 0.000000

Declare as: Integer

○ Recode Data

● Don't Recode Data

Output:

Data Type: Unsigned 8-bit

File Type: Continuous

☐ Ignore 0.0000 in Stats Calculation

☐ Temporary Raster Only Integer

Figure 21. Raster information layer that is used to specify image files for modeling.

i. In the upper-left of the model, double-click on the image-stack symbol labeled “Image to be converted.” The Raster information layer will pop up (see fig. 21).

ii. In the filename field, use the open folder icon to navigate to the appropriate image and select it.

(a) NOTE: Even though the dark objects were chosen using the entire original Landsat image footprint, the actual correction model should be applied to the image that has been clipped to the study area! The use of dark objects outside the study area is justified on the simplifying assumption that atmospheric conditions are stable across the entire image, even though this assumption is technically false. However, dark objects are critical to this correction and also are rare, so the use of the entire image allows inclusion of more dark objects, which outweighs the potential problems in variable atmospheric conditions. If enough dark objects are viewed across the image, then these conditions should approximately average out.

iii. All of the other values in the window can be left in their default conditions.

d. In the box near the top center labeled “Sun Zenith Angle,” enter the sun zenith angle from the Excel spreadsheet. **Recall that this is 90 degrees minus the sun elevation, which typically is what is listed in the header for the file.**

e. In the box on the right-hand side of the model labeled “Gains and Offsets,” double-click and enter the gains and offsets recorded in the Excel file. Note that the matrix window that appears will have six rows. Rows 1–5 correspond to bands 1 through 5, while row 6 corresponds to band 7 of Landsat.

f. In the box labeled “Min Vals for Subtraction,” enter the dark-object values from the excel spreadsheet that were determined in step 1 in this section above.

g. At the bottom of the model, click on the image stack shape labeled “Output COST image.”

h. Save the model, ensuring that the name can be linked easily to the image on which the processing is to be conducted.

i. Run the model by clicking on the red lightning bolt icon in the icon row at the top of the graphic model window.

5. The result of this process is an image in units of apparent reflectance on the surface of the Earth. It likely will not correspond to true reflectance on the ground because the approximation for atmospheric effects is not perfect, and because the illumination angle of slope facets on the landscape is not considered. Nevertheless, the gross effects of atmospheric scattering and atmospheric patheffects have been addressed. This image will be referred to as the COST version of an image.
    a. Note that the units of this image are in scaled reflectance. True reflectance is considered a proportion from 0 to 1.0. Representing these values requires the use of the floating-point data type, which requires twice as much space on the disk as the integer type. Therefore, all of the reflectances have been scaled to run from 0 to 1000, with 1000 equal to 1.0 reflectance. Note also that some pixels will have reflectances less than zero—these correspond to the pixels that were noted as artifacts in the dark-object-identification step above.

VIII. Radiometric Normalization

In most cases, COST processing will not take care of all of the atmospheric effects that could cause confusion when change detection is conducted later. Two COST-processed images likely will differ somewhat in their claimed reflectances for a given pixel, even if no real change has occurred, because the true nature of the atmosphere above every pixel is not known. Because some of the parks' monitoring goals require distinction of subtle spectral difference, even these slight artifacts could be problematic. Therefore, it is necessary to further normalize images before change detection can take place.

Many approaches exist in the remote sensing literature to normalize the radiometric and spectral qualities of one image to another. The authors tested a variety of these approaches and determined that a recently published approach known as Multiple Alteration Detection Calibration (MADCAL) works extremely well for the parks of the NCCN, and has the great advantage of being automated.

The authors have supplied IDL-VM software that will perform the MADCAL normalization between two images. Follow the steps below for normalization.

1. Identify the radiometric-reference image and the radiometric-dependent image.
    a. As noted above in section II, the radiometric-reference image need not be the same image as the geometric-reference image. However, both the reference and dependent images must have been registered geometrically to the reference- geometric image.
    b. The reference-radiometric image ideally should be as close to clear-sky conditions as possible.
2. To run the MADCAL software, a text file with run parameters must be constructed.
    a. An example file has been provided, named "madcal_runfile_template.txt". Save this file under a new name that will identify it specifically to the images being used. It is advisable that the runtime file be placed in the same folder as the dependent image, since it is that image that will be altered.
    b. The following are the fields that must be present in that file:

```
Reference file:
D:\NPS\sites\mora\geospatial_data\mora_1996_2002\
radiometric\tm_mora_14aug2002_nad83_cc_rcost.img
Dependent file:
D:\NPS\sites\mora\geospatial_data\mora_1996_2002\
radiometric\tm_mora_21aug1996_nad83_cc_rcost.img
Run name: test1
Subset size in pixels: 1000
Subset upper left coordinate: 569949, 5192068
Subset upper left coordinate: 576724, 5217368
Subset upper left coordinate: 602174, 5217368
Subset upper left coordinate: 604374, 5187943
```

    c. Key phrases are those that appear to the left of the colon (:) symbol. They must exist exactly as shown above, followed immediately by the colon symbol, followed by a space, followed by the relevant field information. To view the file and set the parameters, use a generic text editor such as Notepad.
    d. Description of key phrases above.
        i. Reference file:
            (1) Provide the full pathname to an imagine-format file that corresponds to the radiometric-reference image.
        ii. Dependent file:
            (1) Provide the full pathname to an imagine-format file that corresponds to the image that will be matched to the radiometric-reference image.
        iii. Run name:
            (1) Provide a unique name for this run that will identify outputs in case other runs are done on the same dependent image. This run name will be attached to the file name of key files to distinguish it from other runs.

iv. Subset size in pixels:

(1) The MADCAL program extracts a subset from the two images to be matched and conservatively identifies pixels that have not changed substantially between the two images. Because of the calculations needed to identify the no-change pixels, memory sizes may constrain the size of the subset that can be extracted. We have found that a subset size of 1000 pixels works well.

v. Subset upper left coordinate:

(1) Because of the limitation of individual subset size, our implementation of the MADCAL approach allows for multiple subsets. Pixels that have not changed in each subset are identified, and then all of the no-change pixels are combined to produce a large no-change pixel sample that is used to develop bandwise regressions that link the reference and dependent images.

(2) Therefore, the position of the different subsets must be provided to the program. To identify these subsets, do the following:

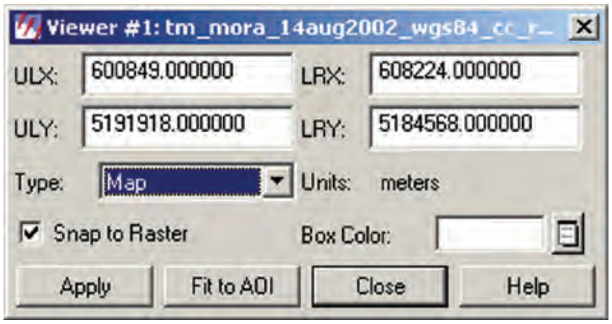
(a) Open a viewer in Imagine (see section IV, steps 1 and 2).

(b) Load the radiometric-reference image that has been clipped to the study area for the park.

(c) Anywhere in the viewer space, right-click and select “Fit image to window” from the pulldown menu.

(d) Anywhere in the viewer space, right-click and select “Inquire Box” from the pulldown menu.

(i) A small window with coordinates for the inquire box will popup (fig. 22).


Viewer #1: tm_mora_14aug2002_wgs84_cc_r...

ULX: 600849.000000

LRX: 608224.000000

ULY: 5191918.000000

LRY: 5184568.000000

Type: Map

Units: meters

☑ Snap to Raster

Box Color:

Figure 22. Inquire-box window.

(3) The goal is to use this inquire box to visually delineate the areas on the image that are to be used for the MADCAL subsets. Therefore, the first step is to make the inquire box equal in size to the subsets that will be used in the MADCAL routines. If the recommended size of 1000 pixels is used, follow these steps. Alter the number 1000 if a different subset size is chosen.

(a) In the inquire box, from the “Type” pulldown menu select “File”, rather than the default “Map” value.

(i) The coordinates change from map coordinates to file coordinates.

(b) With the mouse, highlight the value in upper left field box labeled ULX: and type 0 to overwrite the value to 0.

(c) Do the same for the ULY value, setting it to 0.

(d) For the LRX and LRY fields, set each field to 1000.

(e) Click on the Apply button.

(i) The inquire box should be resized to the size of the subset, and should reside in the upper left of the viewer.

(f) In the inquire box, from the “Type” pulldown menu select “Map.” The box will be of the same size, but now the coordinates will be map coordinates.

(g) With the mouse, click and drag in the center of the inquire-box area to move it across the image. Do NOT resize the box by pulling the corners, as this will require repeating steps (a)–(e) above.

(4) Move the inquire box over the reference image and locate subsets. When an area has been located, note the values in the inquire box in the ULX and ULY fields. Ensure that these are in map coordinates, not file coordinates.

(a) Enter these values in the MADCAL control text file for the Subset upper left coordinate field. The format is <X coordinate>, <Y coordinate>.

(b) Repeat this process for as many subsets as desired. Four such subsets are shown in the example above, but any number from 1 to as many is allowed.

(c) If more than four subsets are chosen, copy the key phrase “Subset upper left coordinate: ” text to a new line directly under the prior subset.

(d) If fewer than four subsets are chosen, make sure to erase the entire line for the nonused subsets. The key phrase “Subset upper left coordinates: ” only should appear if valid coordinates follow it on the same line.

(5) Tips on locating subsets.

(a) The subsets should be well distributed across the area of the image.

(b) Make sure that subsets represent all of the types of landcover conditions present in the image.

(c) Avoid subsets that have a majority of their area in conditions that likely are to change drastically between images, such as cloudy areas in one image or large snow areas.

3. Once the MADCAL run parameters have been entered, the program can be run.

a. Locate the “madcal.sav” file that has been provided with this protocol.

b. Click and drag this file over the IDL-VM.

c. The program will produce a “splash screen” advertising IDL. Click on it to make it go away.

d. The program will then prompt for the location of the MADCAL control file.

i. Navigate to the file created in step 2 and click on the OK button.

e. The program will then run.

i. A window will appear noting that MADCAL has begun, and noting the location of the diagnosis file. This diagnosis file is a text file that keeps track of programmatic flow, in case of errors.

ii. There will be no other initial indicator of progress for the file.

(1) The diagnosis file will be updated as the program runs, so occasional checks of this file’s time stamp, or re-opening of this file, will provide an idea that the program is still running.

iii. Eventually, a cascade of new windows will pop up, each with a scatterplot of the reference and dependent image pixels, as well as the regression line fit to them, for each band, for the first subset.

iv. This will repeat for each of the subsets identified in the MADCAL control file

v. Finally, a set of similar windows will pop up that will cycle through the bands more slowly. This is the set that combines all of the no-change pixels across subsets, and takes longer for each set.

vi. When the last one is done, the windows will disappear. This indicates that the program is complete.

f. View the log file. It defaults to the C:\temp directory. Open this file with a simple text editor.

i. In that file, the location of the MADCAL results file is noted. This is the file that contains all of the relevant information on the run, including correlation coefficients for the regressions between the reference and dependent images.

(1) It is listed in the log file as:

```
Setting up results file:
D:\NPS\sites\mora\geospatial_data\mora_1996_2002\
radiometric\tm_mora_21aug1996_nad83_cc_rcosttest1_
madcaloutputs.txt
```

g. Open the results file.

i. Listed at the top of this file are the reference image, dependent image, and subset coordinates. These should be included with metadata on the dependent file. See SOP 5 Data Management for components of the metadata to be included with each file.

ii. Information on the fitting of subsets is provided for reference, but can be ignored for the final image file because the subset-specific fitting parameters are not used.

iii. The important fitting information begins in the file after the point labeled as follows:

“Performing final calibration
using all no-change pixels.”

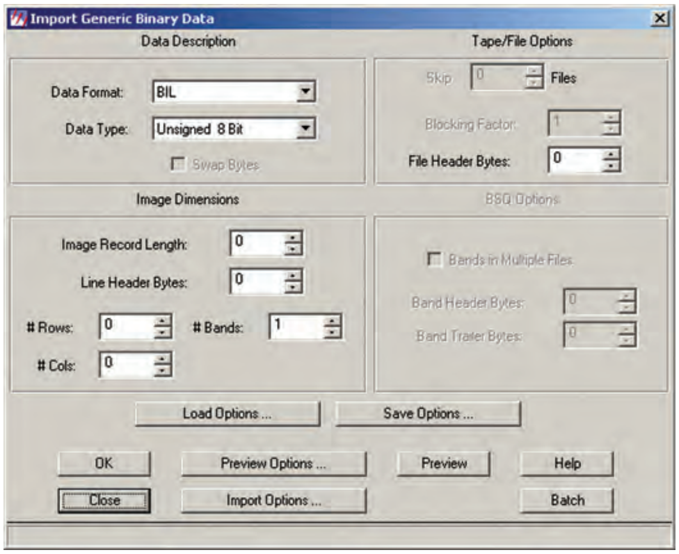
h. The program will write a calibrated version of the dependent image. The name of this file is noted at the end of the results file, and is based on the original name of the dependent file, with “_madcal.bsq” added at the end of the filename.

i. This file is a “flat binary” file. It must be imported into Imagine.

4. Importing the MADCAL adjusted image into Imagine (referenced in SOP 3, Probability Differencing).
    - a. Open the header file associated with the calibrated image. This header file has the same name as the file noted in h) above, but with the extension “.hdr” instead of “.bsq”.
        - i. This is a text file with information on the flat binary file that is relevant for importing into imagine. An example is shown here:

```
BANDS: 6
ROWS: 2930
COLS: 3228
DATATYPE: S16
UL_X_COORDINATE: 557599.00
UL_Y_COORDINATE: 5228568.0
LR_X_COORDINATE: 638274.00
LR_Y_COORDINATE: 5155343.0
PIXEL_WIDTH: 25.000000
PIXEL_HEIGHT: 25.000000
```

    - b. See section III above (Importing images into Imagine). Open the Import/Export dialog
        - i. Select “Generic Binary” from the “Type” pulldown menu.
        - ii. In the Input File field, navigate to and select the madcal calibrated image with extension “…bsq”, noted in step 3.h. above.
        - iii. In the Output File field, navigate to the same directory and type in the desired name of the output file.
            - (1) Follow the conventions in SOP 5 Data Management.
        - iv. Click on the OK button. The “Import Generic Binary Data” window will popup (fig. 23).


Import Generic Binary Data

Data Description

Data Format: BIL

Data Type: Unsigned 8 Bit

☐ Swap Bytes

Tape/File Options

Skip: 0 Files

Blocking Factor: 1

File Header Bytes: 0

Image Dimensions

Image Record Length: 0

Line Header Bytes: 0

Rows: 0

Bands: 1

Cols: 0

BSQ Options

☐ Bands in Multiple Files

Band Header Bytes: 0

Band Trailer Bytes: 0

Figure 23. Import generic binary data window.

    - c. Use the information in the header file to fill in the appropriate fields.
        - i. Data Format: Select “BSQ.”
        - ii. Data Type: Select “Signed 16 Bit.”
        - iii. # Rows: Type in the value from the “Rows” line in the header file.
        - iv. # Cols: Type in the value from the “Cols” line in the header file.
        - v. # Bands: Type in the value from the “Bands” line in the header file.
        - vi. Click on the “Import Options” button.
            - (1) The Import Options window will appear (not shown).
            - (2) Select “Run-Length Encoding (ESRI)” from the “Output Data Compression” field. This will conserve significant file space, since it reduces the large areas of background to compressed data.
                - (a) Do not select “Ignore zero in stats.”
            - (3) Click on OK button.
        - vii. In the “Import Generic Binary Data” window, click on the OK button.
            - (1) A progress meter will show the progress on the import.
            - (2) When it is done, click on the OK button.
    - d. Update the map model and geometric information for the imported image.
        - i. The imported image has no geographic information. Therefore, it is necessary to manually enter this once the image has been imported. It is identical to the map model and geometric information for the dependent image. Therefore, use it to fill in the appropriate fields.
        - ii. Open a viewer and load the dependent image (the original, noncalibrated image, entered in the MADCAL control file in step 2d above in this section). This image will serve as the template for entering geographic information in the recently imported image.
            - (1) Open the ImageInfo for this viewer (see fig. 7 above to find the appropriate icon to start the ImageInfo).
        - iii. Open a second viewer and load the calibrated

image that was just imported.

        (1) Open the ImageInfo for this viewer. Arrange the two ImageInfo windows so that both can be seen on the screen at the same time.

    iv. In the ImageInfo for the calibrated image, select "Edit/Change Map Model."

        (1) The Change Map Info window will pop up. Manually fill in the fields, using the ImageInfo of the original image as reference:

            (a) Upper Left X: Use the value of Upper Left X in the ImageInfo of the original dependent image.

            (b) Upper Left Y: Again, use the value from the Upper Left Y in the ImageInfo of the original dependent image.

            (c) Pixel size X and Y: Use the values from the fields named the same in the ImageInfo of the dependent image.

            (d) Units: meters

            (e) Projection: UTM

            (f) Click on OK button, and then accept the changes for all layers when prompted.

    v. In the ImageInfo for the calibrated image, select "Edit/Add/Change Projection."

        (1) Again, use the information in the "Projection Info" of the original dependent image to update the spheroid, datum, UTM zone, and north/south fields.

e. For these changes in the map model to take effect, the image must be closed. Close all of the viewers.

At the end of this section, the dependent image will be as radiometrically close to the radiometric reference image as possible. Both images will be in units of scaled reflectance, for all six nonthermal bands of Landsat thematic mapper. These images must then be converted to tasseled-cap values, and then split by aspect, before preprocessing is complete and change detection can commence.

IX. Converting Imagery to Tasseled-Cap Values

The tasseled-cap transformation is a linear transformation of the six-dimensional space of the original Landsat bands into three new bands known as brightness, greenness, and wetness. (Note: The original tasseled cap actually converts into six new bands, but in practice only the first three bands are used because they capture more than 90 percent of the variation of the 6-band images.) The tasseled-cap space can be interpreted in physiognomic terms in most terrestrial systems, and thus forms the core of the change-focused approach to monitoring that is the central theme of this protocol.

The authors have included an Imagine graphic model that converts reflectance-based COST-processed images into tasseled-cap values. Note that the tasseled-cap coefficients for reflectance band inputs, such as those resulting from the COST processing, are different from those originally published. The reflectance coefficients were published in a later article (Crist, 1985).

To run the tasseled cap, follow these steps.

1. Open Imagine's graphic modeler.

    a. In the main icon panel, select "Modeler," and then "Model Maker."

    b. When the blank spatial modeler window appears, use the open-folder icon and navigate to the graphic model that is included in the appendix for this protocol.

        i. The graphic model is entitled Landsat_refl_tasselcap.gmd.

    c. When the model is open, click on the red lightning bolt to run the model.

    d. The graphic model will prompt for the name of the input file by creating a dialog window with the title "Select Existing File for Raster: n1_Prompt_user."

        i. Navigate to the COST-processed image, select it, and click on the OK button.

    e. The graphic model will then create a nearly identical looking window titled "Enter New File for Raster: n9_Prompt_user."

        i. Navigate to the desired directory, and type in the name of the desired output file.

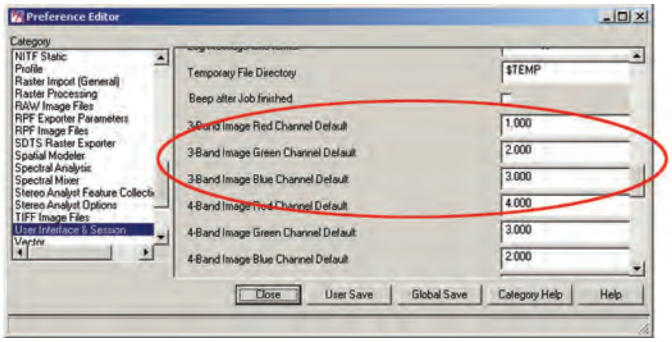
            (1) Use the conventions in SOP 5 Data Management for naming and location conventions.

        ii. Click on OK button once and the appropriate folder and name will be entered.

   f. The model will run and show a progress meter.
   g. When the model is complete, click on the OK button.

2. Run the tassel-cap model on both dates of imagery that will be used for change detection.
   a. These images need not be the geometric nor the radiometric reference images. However, it is imperative that these images be referenced to the designated geometric and radiometric reference images as detailed in sections II through VIII above.

3. Reset the default band combinations in Imagine for 3-band images
   a. The three color guns on a color screen or monitor are red, green, and blue. When displaying images, Imagine must be told which band of an image is to be displayed in each of the three colors. NOTE: Unless otherwise specified, Imagine will default to displaying 3-band tasseled-cap images with brightness in blue, greenness in green, and wetness in red. This is the reverse of the color tones to be used throughout the rest of the protocol, and thus the defaults must be changed.
      i. From the main console, select “Session/Preferences.” In the “User interface & session” category of the Preference Editor, scroll down on the right-hand portion of the panel to the point where 3-Band Image defaults are listed (see fig. 24).
      ii. Set the 3-band Image Red Channel Default to 1, Green Channel Default to 2, and Blue Channel Default to 3.
      iii. Click “User Save.”
      iv. Close the preference editor.



Temporary File Directory: $TEMP
Beep after Job finished: ☐
3-Band Image Red Channel Default: 1.000
3-Band Image Green Channel Default: 2.000
3-Band Image Blue Channel Default: 3.000
4-Band Image Red Channel Default: 4.000
4-Band Image Green Channel Default: 3.000
4-Band Image Blue Channel Default: 2.000

Figure 24. Setting bank-display preferences for viewing tasseled-cap image with brightness in red, greenness in green, and wetness in blue.

X. Splitting Imagery by Aspect

The Landsat Thematic Mapper passes over a given point in the northern hemisphere in late morning, around 10:30 a.m. local sun time. At this time of day, the sun azimuth approximately is southeast, depending on the day of the year. Because of this, hillslopes that face southeast are illuminated directly with the maximum sunlight, while hillslopes that face northwest are least illuminated. In the remote sensing literature, various approaches have been proposed to equilibrate the effects of terrain-related variable illumination.

The key challenge in these approaches is that the bidirectional reflectance-distribution function, which describes variation in reflectance as a function of viewing and illumination angle and on which illumination correction must depend, differs substantially by type of material being illuminated (Egbert and Ulaby, 1972; Kimes, 1983; Kriebel, 1978; Norman and others, 1985; Ranson and others, 1994). Thus, an illumination-angle correction must apply a different correction for every type of surface, and the correction must be based on detailed measurements made in those conditions. Approximations exist, but few have emerged as generically applicable. Moreover, atmospheric effects change the ambient illumination, which varies by image acquisition. For this reason, topographic correction has remained a challenging prospect (Civco, 1989; Conese and others, 1993; Holben and Justice, 1980; Teillet and others, 1982). For this project and for prior projects, the authors evaluated a promising recent entry in this field (Gu and Gillespie, 1998), but found it unacceptable for the variety of surface and illumination conditions encountered in the parks of the NCCN. Overcompensation was a common outcome of illumination correction (as has been found in most of the papers cited previously), resulting in reflectance values whose true meaning was even less well known than those resulting from sections II through IX above.

More importantly, no illumination correction can compensate for the simple fact that slopes with lower illumination have less reflective signal to be measured (Conese and others, 1993). For Landsat TM images, hillslopes facing northwest have lower signal-information content relative to the constant levels of background noise. Even if an illumination correction were to be developed that could produce images that appear visually appealing, they would imply that the image-information content were consistent across the entire area, which is false.

Therefore, all change detection for this protocol must be split into two broad aspect classes: those that face the sun at the time of image acquisition, and those that face away from the sun at the time of image acquisition. This approach makes explicit the fact that the two aspect classes inherently have different signal-to-noise ratios. This section describes how the images produced thus far can be split in preparation for the change detection.

1. First, the DEM must be split into different aspect classes.
    a. Create an aspect image.
        i. From the main icon panel in Imagine, click on the Image Interpreter button, and select “Topographic Analysis/Aspect.”
        ii. In the “Surface Aspect” window that appears next, do the following:
            (1) In the Input DEM field, navigate to the DEM that was clipped to the study area in section V, step 13 above.
            (2) In the Output file field, navigate to the same directory, and name the output file according to the conventions in SOP 5 Data Management.
    b. Create a slope image
        i. From the main icon panel in Imagine, click on the Image Interpreter button, and select “Topographic Analysis/Slope.”
        ii. In the “Surface Aspect” window that appears next, do the following:
            (1) In the Input DEM field, navigate to the DEM that was clipped to the study area in section V, step 13 above.
            (2) In the Output file field, navigate to the same directory, and name the output file according to the conventions in SOP 5 Data Management.
    c. The authors have provided an Imagine graphic model to create the aspect class masks that will be used to split the images.
        i. The model provided is named: make_aspect_masks_mora.gmd. See figure 25.
            (1) This model was applied to the DEM at MORA on the computer system of the authors. Therefore, all file names and paths must be adapted when the parks conduct this processing.
            (2) First, save the graphic model under a new name using File/Save As. Follow the naming conventions in SOP 5 Data Management.
            (3) Changing filenames:
                (a) Double-click the image stack icon in the upper left of the graphic model, and enter the appropriate name in the filename field. The file is the aspect image created in section X, step 1a above.

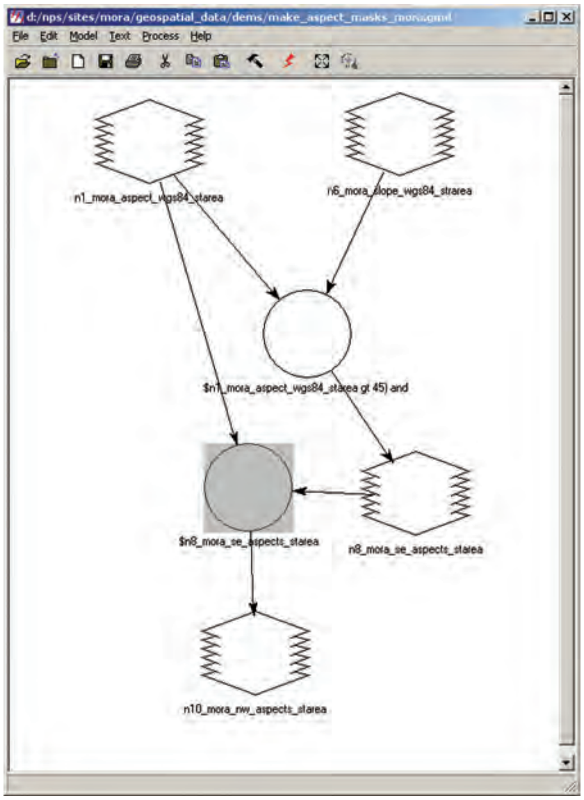


Figure 25. Imagine graphic model for making aspect mask images at MORA.

                (b) Do the same procedure to change the name of the input slope image in the image stack icon in the upper right of the model.
                (c) Double-click on the icon on the right-hand side of the image. Enter a name in the filename field for the mask corresponding to southeast aspects. It is recommended that a naming convention similar to that provided be used, where the filename includes the name of the park and the fact that the mask is for the southeast aspects.
                (d) Double-click on the icon on the bottom of the mask, and name the output for the NW aspects.
            (4) Run the model by clicking on the lightning bolt icon in the modeler icon row.
    d. Convert the masks into AOIs.
        i. Open a viewer, and open the NW aspect mask that was just created.

    ii. In the viewer, select “Raster/Attribute editor.”
        (1) The Raster attribute editor window will open. There will be two rows, 0 and 1.
    iii. Select the row with the value 1 by left-clicking on the shaded box with the value “1” in it on the left-hand side of the table in the window.
        (1) This selects all of the pixels that have value 1, which are those that are within the NW aspect mask.
    iv. In the Viewer, select “AOI/Copy selection to AOI.”
        (1) This will copy those pixels to a new, unnamed AOI.
    v. In the Viewer, select “File/Save/AOI layer as,” and save the AOI with a name based on the conventions described in SOP 5 Data Management.
        (1) **This mask AOI will be relevant to all processing done at a given park, so it is critical that it be named and located for further use.**
        (2) NOTE: In some cases, the authors have found that Imagine will not know how to use an AOI if the parent image from which it is drawn does not exist. This is even the case when the parent image exists but *simply has been moved from its original location*. It is therefore important to retain the original pixel-level aspect masks in their original directory. This also makes it advantageous for the user to refer back to them to recreate the masks if needed.
    vi. Repeat this process for the SE aspect mask.

e. The result of this process are two image masks, one for each of the two aspect classes. In the mask image, a value of 1 indicates membership in the aspect class and a value of 0 indicates nonmembership. These images can be multiplied by any other image on a pixel by pixel basis to eliminate areas not in the mask, which is the next step below.

2. Splitting images by aspect mask.

a. The authors have provided a graphic model to multiply tasseled-cap images by the aspect masks to create tasseled-cap images split by aspect (named **split_imagery_by_aspect.gmd**). (see fig. 26)

    i. This model was applied to imagery and aspect masks at MORA on the computer system of the authors. Therefore, all file names and paths must be adapted when the parks conduct this processing.

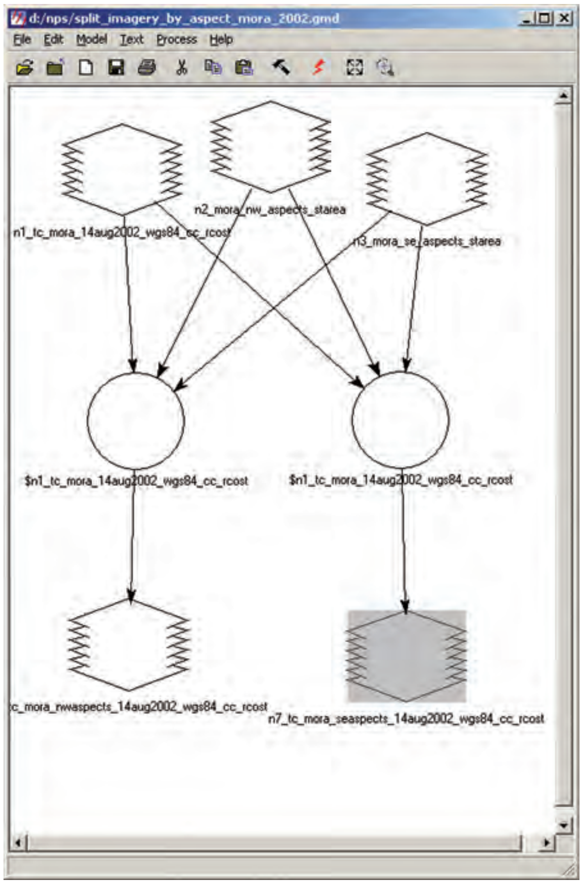


Figure 26. Graphic model to split tasseled-cap imagery by aspect class.

    ii. First, save the graphic model under a new name using File/Save As. Follow the naming conventions in SOP 5 Data Management.
    iii. Changing file names:
        (1) Double-click the image stack icon in the upper left of the graphic model, and enter the name of one of the two tasseled-cap, study-area clipped images from section IX above.
        (2) Rename the files for the top-center and top-right image stacks. These correspond to the aspect images that were created in step 1 above in this section. The top center image is for the NW aspects mask and the top right for the SE aspects mask.
        (3) Follow the conventions in SOP 5 Data Management for naming the output files.
    iv. Run the model by clicking the lightning bolt icon in the modeler icon row.

3. Repeat step 2 for all tasseled-cap images that are to be used in change detection.

XI. Summary

The processing steps described in this document take Landsat TM imagery from its original state when purchased from EDC (at the end of SOP 1) to the state that can be used in change detection (SOP 3). The following files are to be used in later steps:

1. Study area AOI and vector coverages (section V).
2. DEM clipped to the study area (section V).
3. Aspect masks (both raster and AOI) for the NW and SE aspects (section X).
4. Tasseled-cap imagery, split by aspect, for the study area (section X).

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Protocol for Landsat-Based Monitoring of Vegetation at North Coast and Cascades Network Parks

Standard Operating Procedure (SOP) 3

Physiognomic Change Detection

Version 1.0 (July 5, 2006)

Revision History Log:

Previous VersionNumber	Revision Date	Author	Changes Made	Reason for Change	New Version Number
n.a.	07-05-06	REK		Final version under agreement	1.0

This SOP explains the procedures for detection changes in the physiognomic properties of the surface over time. It follows and relies on outputs from SOP 2 (Preprocessing Imagery).

This SOP describes three phases in change detection. In the startup phase, the spectral space of a reference image for the parks is converted into probability-of-membership in physiognomic classes, and this forms the basis for all change detection in all subsequent years. For the type 1 phase of change detection, yearly changes are converted to that reference probability-of-membership space and converted to S2S classes for interpretation (SOP 4). For the type 2 phase of change detection, images from years corresponding to dates of airphoto acquisition are referenced to that probability-of-membership space, differenced, converted to S2S classes, and then optionally backed up with direct airphoto interpretation.

Processing Datasheet

There are many detailed and sometimes complicated steps in this SOP. Because the analyst may need to split work between this work and other responsibilities, we provide table 1 that can be printed out separately for the analyst to keep track of steps that have been completed. This should facilitate easier recovery from interruptions

Table 1. Datasheet to keep track of steps in Standard Operating Procedure 3.

[**Abbreviations:** SOP, standard operating procedure; TC, tassel cap; IMG, Erdas Imagine File; POM, probability of membership; CSV, comma-delimited text file; TXT, text file; PMR, Pacific Meridian Resources; S2S, satellite to satellite]

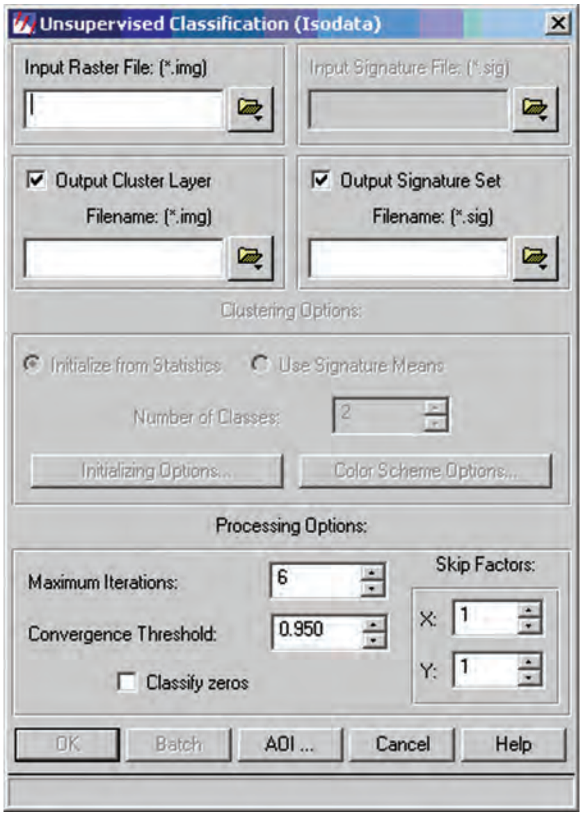
General information		
Park being processed		
Analyst		
Change interval being processed		
Start of processing		
End of processing		
Section	**Step**	**Filename**
	SE	
Section II (Startup Phase Only)	Identify baseline TC image from SOP 2	IMG:
	Create 25-class unsupervised classification image	IMG:
Section III (Startup Phase Only)	Collapse 25-class image into 9-class physiognomic image	IMG:
Section IV	Develop POM spreadsheets (Startup Phase only)	CSV:
	Set up POM runfile template	TXT:
Section V	Calculate POM difference image	IMG:
	NW	
Section II (Startup Phase Only)	Identify baseline TC image from SOP 2	IMG:
	Create 25-class unsupervised classification image	IMG:
Section III (Startup Phase Only)	Collapse 25-class image into 9-class physiognomic image	IMG:
Section IV	Develop POM spreadsheets (Startup Phase only)	CSV:
	Set up POM runfile template	TXT:
Section V	Calculate POM difference image	IMG:
	Merged aspects	
Section VI	Merge aspects	IMG:
Section VII	Tabulate plot data from PMR database (Startup phase only)	Plot Database:
	Link PMR data with physignomic classes (Startup phase only)	Summarized data:
Section VIII	Create S2S images	IMG:
Section IX	Sieve S2S images	IMG:
Section X	Convert to vector layer	Vector:

I. Required Input Imagery From SOP 2

Several of the images and associated spatial datasets from SOP 2 are required for SOP 3. They are listed here again for clarity:

1. Study area AOI and vector coverages (section V).
2. DEM clipped to the study area (section V).
3. Aspect masks (both raster and AOI) for the NW and SE aspects (section X).
4. Tasseled-cap imagery, split by aspect, for the study area (section X). One image must be defined as the baseline image (the early image) and one as the changed image (see Narrative, table 5, for more detail).

Confirm that these files exist and that the locations are known.



Unsupervised Classification (Isodata)

Input Raster File: (*.img)

Input Signature File: (*.sig)

☑ Output Cluster Layer Filename: (*.img)

☑ Output Signature Set Filename: (*.sig)

Clustering Options:

● Initialize from Statistics ○ Use Signature Means

Number of Classes: 2

Processing Options:

Maximum Iterations: 6

Convergence Threshold: 0.950

☐ Classify zeros

Skip Factors: X: 1 Y: 1

Figure 1. Unsupervised classification window.

II. Unsupervised Classification of Baseline Image

The baseline image must first be classified according to the spectral variation present in the image. This step will occur only in the Startup Phase of monitoring, and should be applied only to the baseline image (see Narrative, Methods section). Unsupervised classification using the *k*-means classifier is a common nonparametric approach to split a multivariate space into an arbitrary number of regions. For conventions on describing the steps and methods in Imagine, see section I of SOP 2.

Carry out the steps in this section separately for both NW and SE aspects.

1. From the main Imagine icon panel, select “Classification” and then “Unsupervised Classification” from the list of options.
    a. NOTE: The following assumes that the tasseled-cap image has been displayed in your viewer with brightness in red, greenness in green, and wetness in blue. If you did not change the defaults for display of three-layer images in SOP 2, section IX, change the default first, and then restart the classification.
    b. The “Unsupervised Classification” window will pop up (fig. 1).
    c. In the “Input Raster File:” field, navigate to the aspect-appropriate baseline tasseled-cap image.
        i. This image is the baseline tasseled-cap image created in the Startup Phase of monitoring (fig. 5 in the Narrative). Ensure that this image has been clipped to the study area and aspect masks (SOP 2).
    d. In the Output Cluster Layer field, navigate to the desired directory and name the output file.
        i. Follow the conventions in SOP 5 Data Management for naming and locating this file.
    e. Uncheck the box for “Output signature set.”
    f. Click on the “Initializing Options” button.
        i. Select “Initialize from Principal Axis.”
            (1) This option finds the dominant axis of variation in the spectral data and seeds the classes along that axis.
        ii. Other options can be left as default values.

g. Click on “Color Scheme Options.”
   i. Select “Approximate True Color” and leave the band combinations as default.
h. In the Number of Classes field, type “25”.
   i. This will create 25 classes in this spectral space. The choice of 25 classes is somewhat arbitrary, since these classes will be collapsed later, but experience shows that it is a large enough number to separate real classes on the ground and yet small enough to interpret and integrate later.
i. In the Maximum Iterations field, type in “20”.
j. Leave the convergence threshold at 0.950.
k. Click on the AOI button.
   i. In the window that appears, select the button for “AOI File.”
      (1) The file-field dialog will become active.
      (2) Navigate to the NW aspects AOI that was created in SOP 2, section X.
l. Click on OK button.
   i. The progress meter will run as Imagine processes the image. It will take several minutes.

2. Repeat this process with the baseline image, but use the SE aspects AOI instead of the NW aspects AOI, and name the output file accordingly. All other options are the same.
3. The result of this process will be two images, each with 25 spectral classes.

III. Collapsing Spectral Classes Into Simple Physiognomic Classes

The 25 spectral classes in section I must be compressed down to 9 simple physiognomic types (table 2).

These types occupy distinct regions of tasseled-cap spectral space. To collapse the 25 classes into the simplified classes, the tasseled-cap spectral space must be visualized, nearby classes noted, and then classes recoded into physiognomic classes.

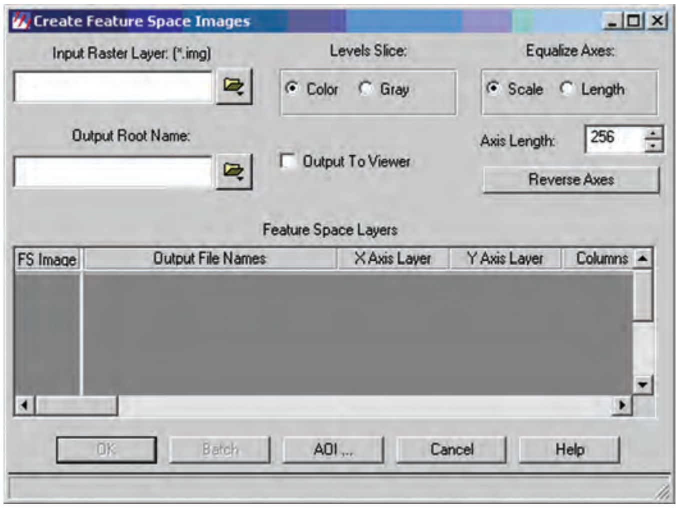
Conduct the following steps for both aspect classes. The examples below show the NW aspects case.

1. Viewing spectral space of NW aspects using feature space images:

a. From the main icon panel in Imagine, click the Classification button, and then select “Feature space image” from the list of options that appears.
   i. The “Create Feature Space Images” window will pop up (fig. 2).
b. Input raster layer field:
   i. Use the open-folder icon to navigate to the **baseline** tasseled-cap image that has been clipped to the study area and to NW aspects.
      (1) Recall that the baseline image is the one at the beginning of the desired change interval.
      (2) This image was created in section X of SOP 2.

Table 2. Physiognomic classes for the North Coast and Cascades Network Parks.

Class number	Class description
1	Water/deep shade
2	Closed-canopy conifer
3	Conifer-broadleaf mix
4	Dense broadleaf/grass
5	Broadleaf tree/shrub
6	Mixed
7	Open: dark
8	Open: bright
9	Snow and ice



Levels Slice: ● Color ○ Gray
Equalize Axes: ● Scale ○ Length
Axis Length: 256
☐ Output To Viewer

Figure 2. Create Feature Space Images window.

c. Output root name:

  i. Imagine will produce a root name in the default output directory, which likely is not where it belongs. Thus, it is necessary to specifically indicate the directory to which the output feature space image should be placed.

    (1) Navigate to a desired output directory. Follow the conventions of SOP 5 Data Management for placement of the output file.

    (2) Click on OK button.

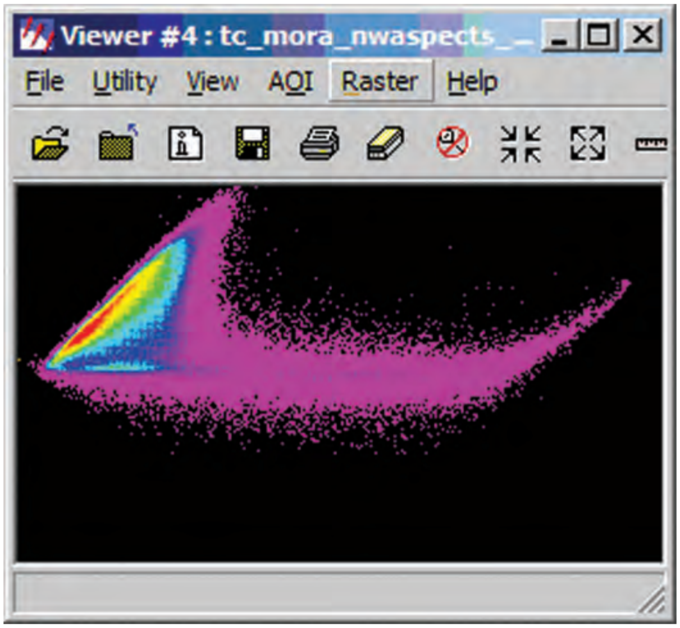


Figure 3. An example of a greenness/brightness feature space image.

d. Click on the AOI button

  i. Select "AOI File."

    (1) The "Select the AOI file" field will become active.

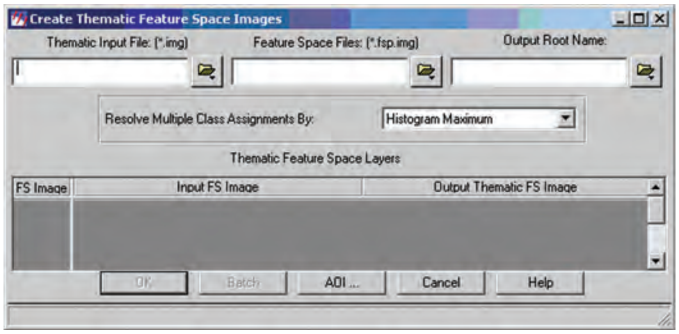
  ii. Navigate to the NW aspects AOI created in SOP 2 section X.

e. Left-click and drag down through the three rows in the table at the bottom of the Create Feature Space Images window. All three rows (label 1,2,3) should be highlighted in yellow.

f. Click on the OK button.

g. Examine the image outputs. For example, the feature space image for bands 1 and 2 – tasseled-cap brightness and greenness – are shown in figure 3.

h. In figure 3, brightness (band 1) values are arranged from left to right, and greenness values are arranged from bottom to top. Color intensity corresponds to pixel count—red indicates the greatest number of pixels, magenta the fewest. Snow and ice are relatively rare and are high in brightness but low in greenness, and thus occupy a sparse population spread out in a tail from left to right in figure 3. Most of the pixels in this image (taken from the area around Mt. Rainier National Park) are forested and fall along a diagonal running from lower left to upper center in figure 3.



Resolve Multiple Class Assignments By: Histogram Maximum

Figure 4. Create thematic feature space images window.

2. View the 25 spectral classes in this spectral space.

  a. From the main icon panel in Imagine, click the "Classification" button, then select "Feature Space Thematic" from the list that appears.

    i. The "Create Thematic Feature Space Images" window will popup (fig. 4).

  b. Thematic Input File:

    i. Use the folder icon to navigate to the unsupervised classification image for the NW aspects that was created in section II above.

  c. Feature Space Files:

    i. Use the folder icon to navigate to the brightness-greenness feature space image created in step 1 above in this section.

      (1) The brightness-greenness feature space image is noted by the phrase "_1_2.fsp.img" in the file name.

d. Output Root Name:

i. Use the folder icon to open the file navigation dialog.

ii. As in step 1c above, it is useful to copy the default “output root name” onto the clipboard before navigating to the desired output folder.

iii. Navigate to the same folder in which the feature space images were placed.

iv. Follow naming and file location conventions in SOP 5 Data Management.

e. In the Feature Space Files field, navigate and select the greenness-wetness feature space image

i. This is the feature space image with “_2_3.fsp.img” in the filename.

ii. When this is selected, a second row of filenames should appear in the table at the bottom of the window.

(1) This second set of files will be placed in the correct directory, assuming it has been changed in step 2.d. above prior to this step.

f. Click on the AOI button and navigate to the AOI for NW aspects. Click OK.

g. In the “Create Thematic Feature Space images” window, select both rows by clicking and dragging the numbers on the left-hand side of the table.

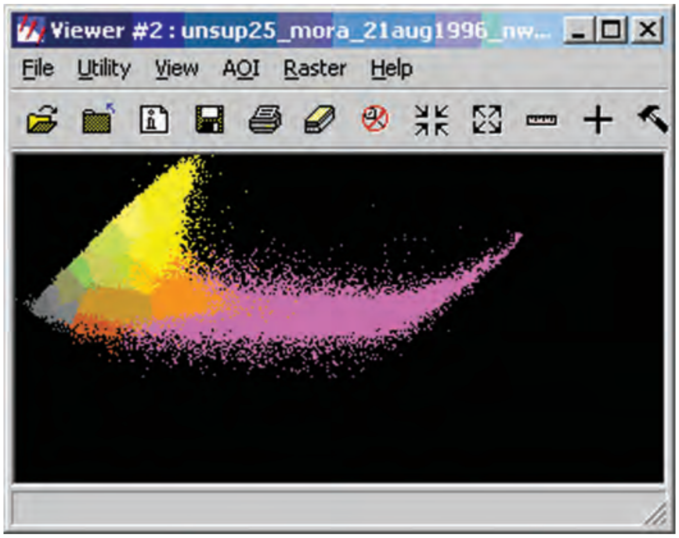


Figure 5. Feature-space thematic image corresponding to the feature space image in figure 3.

h. Click OK.

i. View the results.

i. In a viewer, open the feature space thematic image. Figure 5 shows an example of the output for the same image shown in the feature-space image in figure 3.

j. The colors in figure 5 correspond to the colors of the classes in the 25-class unsupervised classification image from section I.

k. To see which class numbers correspond to a given color in the feature space thematic, use the cursor utility.

i. Click the plus sign icon in the viewer (just to the left of the hammer symbol; fig. 5). The cursor utility window will pop up.

ii. A crosshair will appear in the viewer. Click and drag at the center of that crosshair to move it through the feature space. The class number will be reported in the “Pixel Value” column of the cursor window.

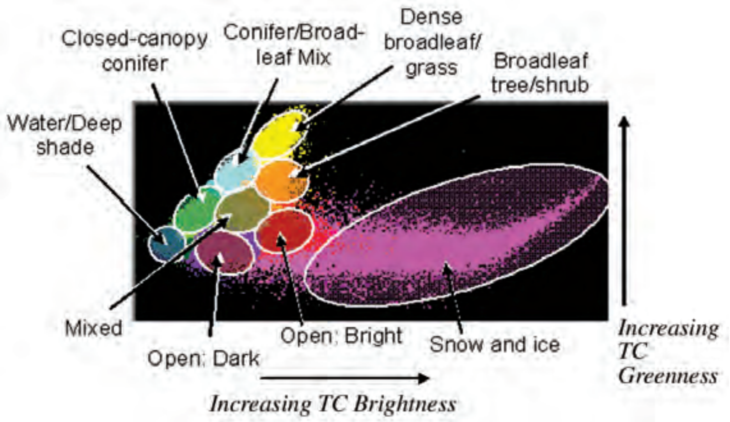


Figure 6. Approximate locations of physiognomic cover classes in the brightness/greenness space.

3. Identifying classes to combine.
   a. Each of the nine physiognomic classes listed in table 2 will be composed of several spectral classes. A table of the nine classes and the spectral classes that make them up must be determined by the interpreter. Two tools can be brought to bear on this.
      i. The shape of the brightness-greenness feature space in figures 3 and 5 is typical. The physiognomic classes can be identified based on their approximate locations in this feature space. Indeed, the relative stability of these broad physiognomic classes across different systems is one of the key reasons that the tasseled-cap transformation was chosen as the base for change detection. Figure 6 shows the approximate regions of these physiognomic classes in brightness/greenness space, while figure 7 shows the same in greenness/wetness space. These general locations serve as the starting point for determining how to aggregate spectral classes.

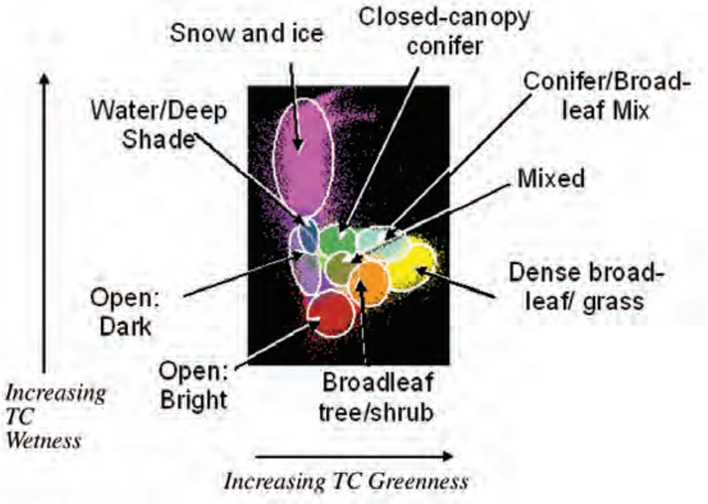
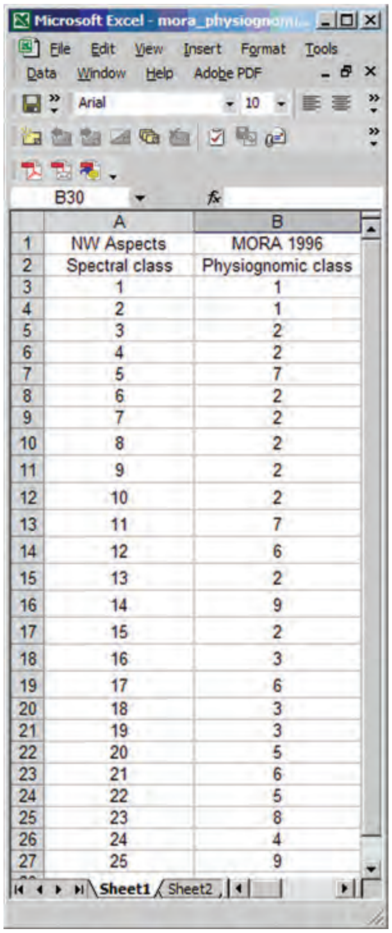


Figure 7. Approximate locations of physiognomic cover classes in the greenness/wetness space (greenness on X axis)

      ii. In addition to noting the position in spectral space of the physiognomic classes, it also is useful to use direct interpretation of the imagery to aid in labeling the spectral classes.
         (1) Load the image of the 25 spectral classes into a new Imagine viewer.
         (2) Select Raster/Attributes.
            (a) A Raster Attribute window with a table of the 25 spectral classes will appear, with a column for the color of each class in the image.
            (b) To see where on the landscape a given class falls, use the left-mouse button to select the row of the given class, and then right-click on the color patch of that row to change the class colors. Pick a new color that is unlike most of those already on the image–often white or black are useful.
            (c) Examine where on the landscape the class falls to aid in interpreting the class. Take into consideration known elevation patterns, as well as a general knowledge of the cover types in the system. See the section in SOP 4 Validation on S2S interpretation (section VI) for tips on interpreting directly from tasseled-cap images.
            (d) When done with viewing the class, select “Edit/Undo last edit” to return the class to its original colors.
               (i) When exiting the raster attribute editor, do **not** save changes.
         (3) If desired, link the 25-class image with the original tasseled-cap image from which it was formed to aid in interpretation.
            (a) In a separate viewer, load the tasseled-cap image for the NW aspects.
            (b) Right-click anywhere in the classified-image viewer, and select “Geo. Link/Unlink.”
               (i) Left-click in the viewer with the tasseled-cap image.
            (c) Open a cursor window in the classified image, if one is not open already.
               (i) Select the “+” symbol in the viewer with the 25-class spectral image.
               (ii) Click the center of the crosshairs in the viewer to move the crosshairs around, and note spectral patterns in the tasseled-cap image to aid in interpretation of the imagery.

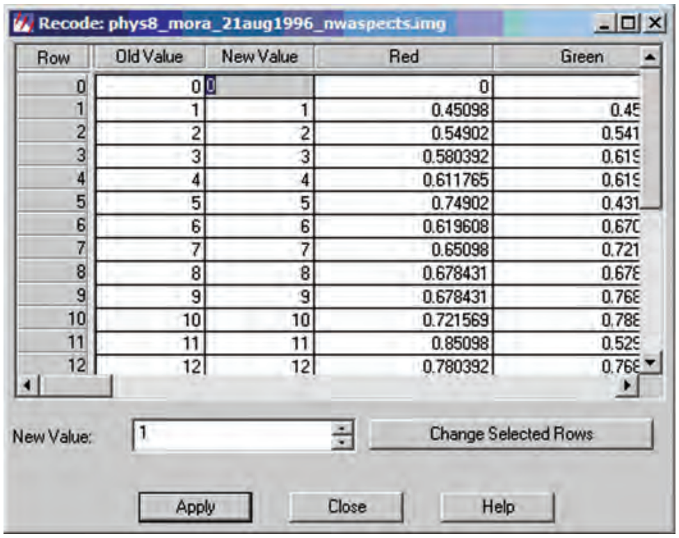
(d) Use the interpretation aids in the supplied "spectral library" that the authors have provided in an appendix to see examples of different cover classes on airphotos, in the field, and on imagery.

iii. In practice, class calls will not always be clear cut, especially for the physiognomic classes that involve mixtures of types. While good class calls will improve the quality of later change detection, the method does not assume that the physiognomic classes will be perfect. The classes will be converted later into a statistical representation based on these classes, adjusting the boundaries of the classes, and that statistical representation will further be described by ground and/or airphoto interpretation data to characterize within-class variability. Finally, the method works on directional variation in spectral change and assumes overlap of classes. Therefore, the precise definitions of the classes are less critical than in a project where the classified image was the single outcome. Nevertheless, the definitions of the class groupings may affect outcomes, and it is assumed that lessons learned about class grouping for each park eventually will need to be incorporated in a later revision of this Protocol. See the Narrative section for a broader discussion of this topic.



	A	B
1	NW Aspects	MORA 1996
2	Spectral class	Physiognomic class
3	1	1
4	2	1
5	3	2
6	4	2
7	5	7
8	6	2
9	7	2
10	8	2
11	9	2
12	10	2
13	11	7
14	12	6
15	13	2
16	14	9
17	15	2
18	16	3
19	17	6
20	18	3
21	19	3
22	20	5
23	21	6
24	22	5
25	23	8
26	24	4
27	25	9

Figure 8. An example of record keeping for linking the 25-class spectral image with 9 physiognomic classes. (see [table 2](#)).



Row	Old Value	New Value	Red	Green
0	0	0	0	
1	1	1	0.45098	0.45
2	2	2	0.54902	0.541
3	3	3	0.580392	0.61
4	4	4	0.611765	0.61
5	5	5	0.74902	0.431
6	6	6	0.619608	0.67
7	7	7	0.65098	0.721
8	8	8	0.678431	0.67
9	9	9	0.678431	0.76
10	10	10	0.721569	0.78
11	11	11	0.85098	0.52
12	12	12	0.780392	0.76

Figure 9. Recode window, where the 25-spectral class image is recoded into 9 physiognomic classes.

b. Keep track of the link between the original spectral class number (1 through 25) and the new physiognomic classes (1 through 9).

i. This can be done in a simple word processing document, or in a spreadsheet. An example in Excel is shown in [figure 8](#).

4. Merging classes.

a. Once a physiognomic class is associated with each of the 25 spectral classes, the 25-class image can be recoded into the 9 physiognomic classes ([table 2](#)).

i. Open the 25-class image in a Viewer, if not open already.

(1) NOTE: This is the geographic image of the 25 classes, *not* the feature space image of the type shown in [figure 5](#).

ii. Save this image under a new name that includes “phys9,” or a similar designation that will distinguish it from its 25-class parent
    (1) Use “File/Save top layer as” to give the image a new name
    (2) Follow the naming conventions in SOP 5 Data Management.

iii. Select “Raster/Recode” from the viewer menu.
    (1) The “Recode” window will pop up (fig. 9).
    (2) Keep the row 0 the same.
    (3) Starting with row 1, use the table or document where the class linkages were stored to type in the appropriate physiognomic class for a given spectral class.
        (a) The spectral class is the “Old Value” column.
        (b) The physiognomic class is the “New Value” column.
    (4) After typing in the values in the New Value column, click on the Apply button.
        (a) The colors on the image should change. The color scheme will remain the same as in the original 25-class image, but now the new classes only occupy the first 9 classes. Therefore, the colors of the first 9 classes in the 25-class image will be “painted” across the entire image.
    (5) Select “File/Save Top Layer”
        (a) Imagine will warn that pixel values could change permanently; this is okay. Continue.
        (b) NOTE: To see the effects of the change in the raster attribute editor, it is necessary to reload the image into the viewer; only then will statistics be calculated for the new physiognomic classes.

b. The image at this stage is a representation of the physiognomic classes on the landscape. It may be desirable to view this image and confirm that the patterns on the landscape make sense, using direct image interpretation and knowledge of the landscape as a guide. Follow step 3.a.ii. above to link with the original tasseled-cap imagery.
    i. While it is important that the general patterns on the landscape make sense, it must be kept in mind that these represent broad physiognomic classes, and that there is often a mixture of a variety of land types within one physiognomic class. See note 3.a.iii. above.

5. If it is thought necessary to change or regroup the 25 classes differently, repeat step 3, adjusting class linkages as deemed necessary. Repeat steps 1 through 4 for the SE aspects.
    a. Where the NW aspects AOI is indicated, choose the SE aspects instead.
    b. Where the NW aspects classification or tasseled-cap image is indicated, choose the SE aspects version of the same instead.

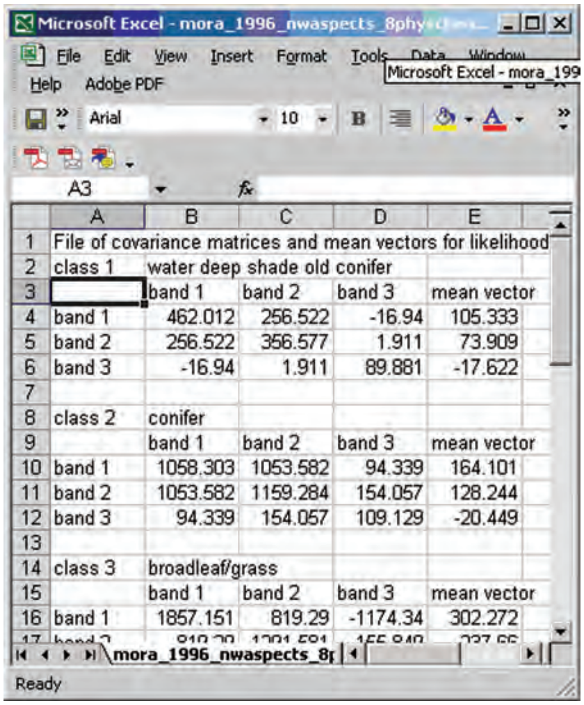
IV. Probability Surfaces for Physiognomic Classes

The change-detection approach used here relies on the concept of likelihood of class membership, a concept well established in the common “maximum-likelihood” classification process. In the maximum-likelihood classification process, training samples are used to characterize the spectral properties of each of several classes, on the assumption that class membership is a Gaussian probability surface in the multiple spectral bands of the training image. Each pixel in a spectral image can then be scored according to its probability on that probability surface for each class; a pixel is labeled according to the class in which it has the maximum probability of membership. See Richards (1993) for details on the maximum-likelihood approach. Rather than using the maximum-likelihood probabilities directly, we consider each pixel to have the potential for partial membership in several classes, which makes the method an essentially fuzzy classification approach (Foody, 1996).

Although maximum-likelihood classification is a built-in component in Imagine, the built-in module cannot be used here. First, for each pixel Imagine provides the single or, in the case of fuzzy classification, multiple-class calls, but does not provide a multilayer POM image. Imagine *will* provide a single “distance image,” the Mahalanobis distance. The Mahalanobis distance is a component of the likelihood function, and could be converted to a POM using fairly straightforward linear-algebra techniques implemented in an Imagine graphical model. Unfortunately, the distance image provided by Imagine represents the distance of each pixel from the class to which it was assigned, so class-level-distance images can be achieved only if the classification is done with a single training class at a time. This is cumbersome, but would be manageable if it were not for the second challenge: the probability calculations in a typical likelihood calculation are the likelihood of the unique point in spectral space being in a given class, which is a very small number because a point occupies a very small portion of the space. What is envisioned in our change-detection approach is to evaluate where a given pixel resides on a cumulative-probability surface ranging from 0 to 1.0, with the probability of 1.0 indicating the mean spectral position of a class. This requires an integration of the probabilities of all points in spectral space at a similar probability contour level, relative to all probabilities greater than the value at that point. Such an integration is not achieved easily in Imagine.

Therefore, the process for producing likelihood surfaces was developed in IDL and transferred to IDL-VM for implementation. It involves several steps. First, spectral signatures for the nine physiognomic classes are gathered in the signature editor of Imagine. These are then copied and pasted into a comma-delimited text file for use as input to the IDL-VM routine. The IDL procedure takes the signature information and produces a lookup table that assigns a cumulative probability of membership in each of the nine classes for a given combination of tasseled-cap values. A second IDL procedure then applies that lookup table to any image, either the baseline image or a changed image, to produce an image of probabilities. This image is then imported back into Imagine, where it can be differenced and further processed.

1. Characterize the statistical properties of each of the nine physiognomic classes. Do this process for the NW aspect images first, then the SE aspect images.
    a. Open in a viewer the nine-physiognomic-class image from section III.
    b. Open the tasseled-cap image from which the 25-class image was derived (see section I).
    c. Open the template spreadsheet for recording the covariance matrix information.
        i. This file has been provided with this protocol, and is named:
            (1) "Physclass_covariance_matrix_template.csv".
                (a) The file is comma-delimited, which means it can be viewed in any text editor, but is most easily manipulated in Excel, where each cell can be entered separately.
    d. Save this file – AS COMMA DELIMITED FORMAT – under a new name for the particular park, year, and aspect class for which the physclass image above was created.
        i. Follow the naming and file locations in SOP 5 Data Management.
        ii. Note the following example to understand the key components of this file (fig. 10).
            (1) The covariance-matrix file must have the same format as noted above to be intelligible to the IDL routines later on.
                (a) Each class is noted by a cell labeled "class <x>", where <x> is 1, 2, 3, etc. Note the lack of capitalization.
                (b) In the cell immediately to the right of that cell, the name of the class can be entered, of any arbitrary length, but be careful NOT to include any commas in the description!
                (c) The next row should include cells in this sequence:
                    (i) Blank, "band 1", "band 2", "band 3", "mean vector".
                (d) The first cell in the next row must have the name "band 1" followed by four cells of numbers (to be entered below).
                (e) The first cell in the next row must have the name "band 2", followed by four cells of numbers (to be entered below).
                (f) The first cell in the next row must have the name "band 3" followed by four cells of numbers (to be entered below).



	A	B	C	D	E
1	File of covariance matrices and mean vectors for likelihood				
2	class 1	water deep shade old conifer			
3		band 1	band 2	band 3	mean vector
4	band 1	462.012	256.522	-16.94	105.333
5	band 2	256.522	356.577	1.911	73.909
6	band 3	-16.94	1.911	89.881	-17.622
7					
8	class 2	conifer			
9		band 1	band 2	band 3	mean vector
10	band 1	1058.303	1053.582	94.339	164.101
11	band 2	1053.582	1159.284	154.057	128.244
12	band 3	94.339	154.057	109.129	-20.449
13					
14	class 3	broadleaf/grass			
15		band 1	band 2	band 3	mean vector
16	band 1	1857.151	819.29	-1174.34	302.272

Figure 10. An example of the covariance-matrix template file to keep track of the spectral properties of the nine physiognomic classes.

e. From the main Imagine icon panel, select “Classification/Signature Editor”.
    i. The “Signature Editor” window will pop up (fig. 11).

f. Select “Edit/Image Association.”
    i. A window will appear prompting for the name of the associated image file. Navigate to the tasseled-cap image noted in step 1.b. above. Be careful to select the tasseled-cap image for the same aspect group (NW or SE aspects).

g. Next, have Imagine extract the spectral properties for each of the nine physiognomic classes:
    i. Select “Edit/Extract” from thematic layer.
    ii. The “Signature Extract from Layer” dialog will pop up (fig. 12).
    iii. Use the folder icon to navigate to the nine physiognomic-class image (created in section III above) for the desired aspect class.
    iv. Name the output-signature file according to the conventions in SOP 5 Data Management.
        (1) Note this file name for use in the probability calculations later.
    v. Click on the “AOI” button.
        (1) Navigate to the AOI for this aspect class, created in SOP 2, section X.
            (a) Recall that an AOI is an area of interest in Imagine terminology. This confines the signature gathering to only the NW or SE aspects.
    vi. Click on OK button to run the signature collection.

h. In the Signature Editor, select “File/Open.”
    i. Use the folder icon to navigate to the signature file just created.
        (1) Recall that the “Recent” button in the file navigation window can be used to quickly access recently used files (fig. 13).

i. Click on Ok button to load the signatures.
    i. The Signature Editor should now show nine rows of signatures, with colors corresponding to the colors chosen for the nine physiognomic classes in the classified image (section III above). See figure 14 for an example.

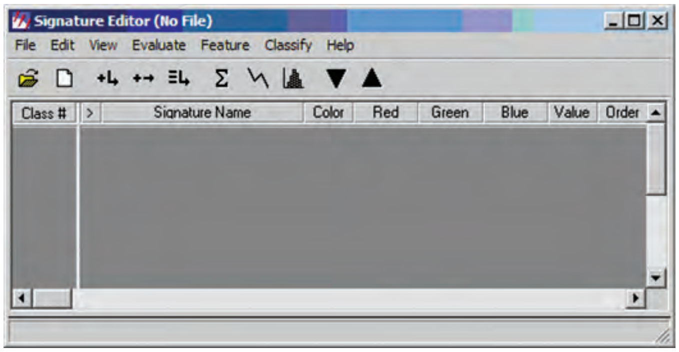


Figure 11. Signature Editor window.

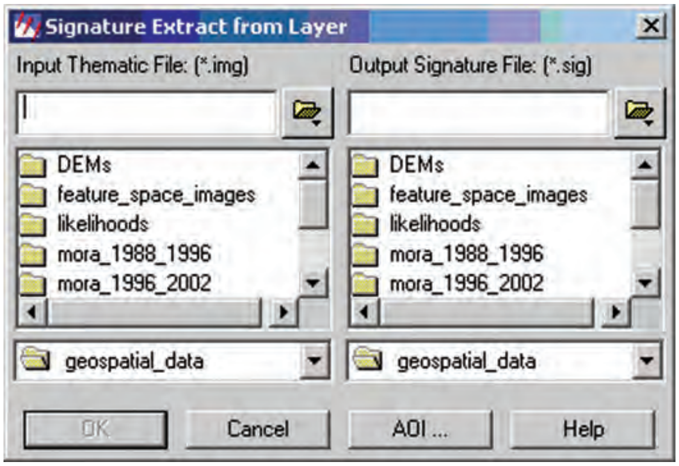
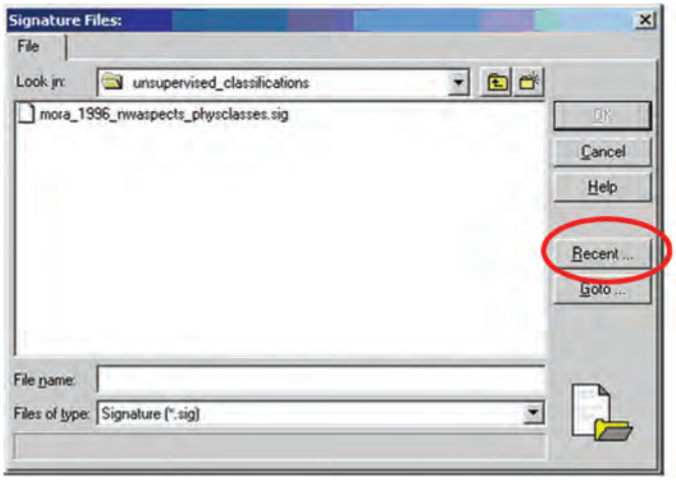


Figure 12. Window to specify signature extraction from thematic layers.



Look in: unsupervised_classifications

mora_1996_nwaspects_physclasses.sig

File name:

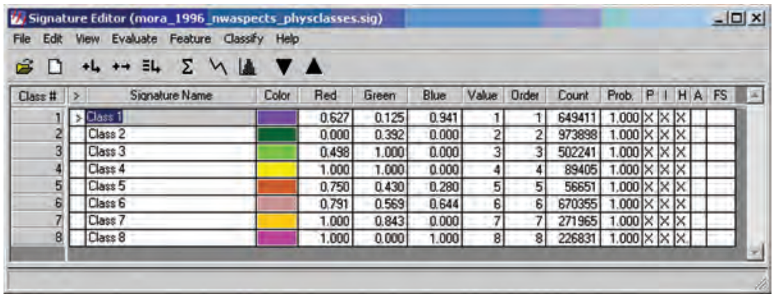
Files of type: Signature (*.sig)

Figure 13. Screen capture with drawn circle illlustrating the Recent button in the file-navigation dialog, which allows quick access to recently opened Imagine files.

j. The goal now is to transfer the covariance-matrix and mean-spectral values from each of these nine classes into the covariance-matrix file created in step 1.d. above.

  i. In the Signature Editor, note the column to the left of the Signature Name. The column is headed with a greater-than sign (>). In the first row, there also is a greater-than sign, indicating that the first class is the active class.

  ii. Select View/Statistics from the Signature Editor



Class #	>	Signature Name	Color	Red	Green	Blue	Value	Order	Count	Prob.	P	I	H	A	FS
1	>	Class 1	🟪	0.627	0.125	0.941	1	1	649411	1.000	X	X	X		
2		Class 2	🟩	0.000	0.392	0.000	2	2	973898	1.000	X	X	X		
3		Class 3	🟩	0.498	1.000	0.000	3	3	502241	1.000	X	X	X		
4		Class 4	🟨	1.000	1.000	0.000	4	4	89405	1.000	X	X	X		
5		Class 5	🟧	0.750	0.430	0.280	5	5	56651	1.000	X	X	X		
6		Class 6	🟥	0.791	0.569	0.644	6	6	670355	1.000	X	X	X		
7		Class 7	🟨	1.000	0.843	0.000	7	7	271965	1.000	X	X	X		
8		Class 8	🟪	1.000	0.000	1.000	8	8	226831	1.000	X	X	X		

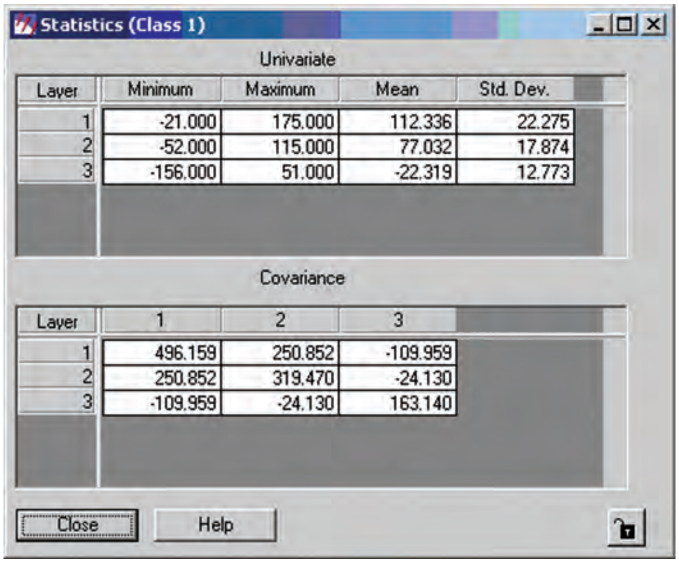
Figure 14. Signature editor window, with spectral signatures from nine physiognomic classes.

    (1) The “Statistics” window will open showing with the name of the active class in the title bar (typically class 1 on startup). See figure 15.

  iii. First, copy and paste the covariance-matrix values into the spreadsheet.

    (1) Select all three rows in the covariance matrix in the bottom half of the window (fig. 15) by clicking and dragging the grey boxes on the left-hand side of the table. The rows should be highlighted.

    (2) Select all three columns in the same table by clicking and dragging left to right across the boxes at the top of the table. The columns should be highlighted (fig. 16).



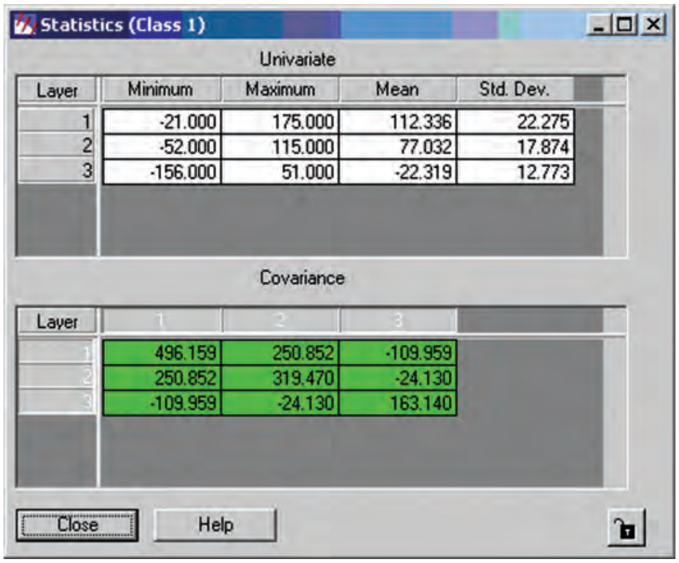
Univariate

Layer	Minimum	Maximum	Mean	Std. Dev.
1	-21.000	175.000	112.336	22.275
2	-52.000	115.000	77.032	17.874
3	-156.000	51.000	-22.319	12.773

Covariance

Layer	1	2	3
1	496.159	250.852	-109.959
2	250.852	319.470	-24.130
3	-109.959	-24.130	163.140

Figure 15. Class statistics window, from which values will be entered into the covariance-matrix spreadsheet.



Univariate

Layer	Minimum	Maximum	Mean	Std. Dev.
1	-21.000	175.000	112.336	22.275
2	-52.000	115.000	77.032	17.874
3	-156.000	51.000	-22.319	12.773

Covariance

Layer	1	2	3
1	496.159	250.852	-109.959
2	250.852	319.470	-24.130
3	-109.959	-24.130	163.140

Figure 16. Highlighting of covariance-matrix cells.

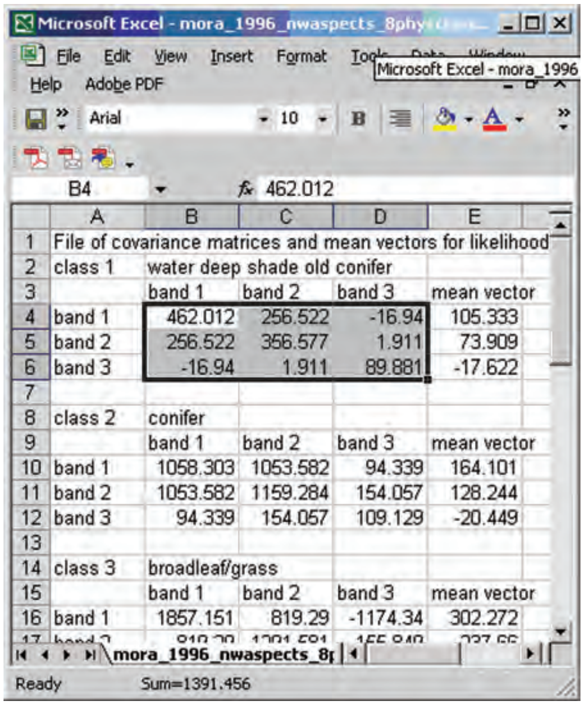
    (3) Right-click in any of the three column header number boxes (1, 2, or 3)

      (a) Select ‘copy.’

  iv. In the Excel spreadsheet from section 1.d. above (fig. 10), click and drag to select the 3 by 3 set of cells in the class 1 section of the spreadsheet corresponding to bands 1, 2, and 3 (fig. 17).

    (1) Right-click in those cells and select “paste.”

      (a) Confirm that the values in the spreadsheet match those in the covariance matrix in the Imagine Statistics window.



B4 = 462.012

	A	B	C	D	E
1	File of covariance matrices and mean vectors for likelihood				
2	class 1	water deep shade old conifer			
3		band 1	band 2	band 3	mean vector
4	band 1	462.012	256.522	-16.94	105.333
5	band 2	256.522	356.577	1.911	73.909
6	band 3	-16.94	1.911	89.881	-17.622
7					
8	class 2	conifer			
9		band 1	band 2	band 3	mean vector
10	band 1	1058.303	1053.582	94.339	164.101
11	band 2	1053.582	1159.284	154.057	128.244
12	band 3	94.339	154.057	109.129	-20.449
13					
14	class 3	broadleaf/grass			
15		band 1	band 2	band 3	mean vector
16	band 1	1857.151	819.29	-1174.34	302.272

Figure 17. Selecting the cells in the covariance matrix of Class 1 to be written over by the values calculated in the Statistics window.

v. In the Signature Editor, left-click in the “>” column in row 2 for the second class. The “>” symbol should move to that cell, indicating that class 2 is now the active class. The statistics window should be updated to show the statistics for class 2.

  (1) Because the cells are still selected in the Statistics window for the covariance matrix, simply right-click in the column header of any of the three columns of the covariance matrix, and select “copy.”

vi. Paste these into the 3 by 3 set of cells of the covariance matrix spreadsheet (follow steps iv. and v. above).

vii. Repeat this for all nine classes.

viii. Then return to class 1 in the signature editor.

  (1) Click in the “>” column next to class 1.

ix. In the Statistics window, select all three rows in the top half of the window this time (the “Univariate” half).

x. Select just the single column title “Mean.”

xi. Copy and paste these cells into the class 1 “Mean Vector” column of the spreadsheet.

xii. Repeat this process for all nine classes.

xiii. Save the file. Excel will alert the user about .csv having properties that may be saved in the file. Save anyway.

xiv. This covariance-matrix file will be used by the IDL VM program “PROBDIFF” to calculate POM in each of the nine classes.

2. Set up the text format “runfile” in preparation for running the IDL-VM program.

  a. The authors have provided a template runfile for PROBDIFF program.

    i. The runfile template is named: **probdiff_runfile_template.txt.**

    ii. This file controls the PROBDIFF program, telling it where to find files, the covariance matrix, etc.

  b. Before making changes, first save this file under a new name that allows unique connection with the park, aspect class, and occasion of this run.

    i. The occasion refers to the current implementation of change detection, recognizing that in future years a new change-detection run will be done, and thus will need to be distinguished from the current run.

  c. The file must have these fields. Each file must end with a colon, and have exactly one space following the colon.

    i. NOTE: It is critical that you use exactly the same names for the key phrases on each line (i.e. Apply to file: must be written exactly as shown), that a single space follow the colon of each key phrase, and that the filename, etc. entered for that phrase be entirely on the same line in the file – do NOT press return/enter anywhere between the phrase and the end of the characters specifying the filename.

    ii. “Covariance matrix file: ”

      (1) This must have the full pathname of the comma-delimited file to which the covariance-matrix values have been copied in step 1.

    iii. “Output probability lookup file: ”

      (1) This file will retain the IDL-code designating the lookup values to link spectral values with the cumulative POM. It can be used only by the IDL program, but the naming should be determined by the user to include as a reference in the metadata.

        iv. “Run name: ”
            (1) This is a string identifier that will be attached to the image file names to name the output nine-layer probability images, and to the current occasion of the change detection.
        v. “Apply to file: ” → repeated for as many images as desired, with a separate entry on each subsequent line
            (1) This is the full pathname of the tasseled-cap images for which this lookup table is to apply.
            (2) At a minimum, the baseline and the changed image should be listed here. But there is no limit to the number of images to which this can be applied. Thus, several years of imagery could be processed in succession, all referenced to the baseline-image condition. At present, this protocol simply assumes that two images, one at each end of a change interval, are being processed.
            (3) NOTE: It is critical that you use exactly the same names for the key phrases on each line (i.e. Apply to file: must be written exactly as shown), that a single space follow the colon of each key phrase, and that the filename, etc. entered for that phrase be entirely on the same line in the file – do NOT press return/enter anywhere between the phrase and the end of the characters specifying the file name.

3. Run the PROBDIFF program
    a. Ensure that the IDL-VM has been installed on the computer.
        i. See SOP 2 section VI for information on installing Virtual Machine.
    b. Find the PROBDIFF.sav file provided in the appendices.
        i. Drag the file onto the IDL-VM icon.
        ii. On the IDL-VM splash screen, click OK to continue.
        iii. The PROBDIFF program will notify you that it is beginning by showing a small information screen. Click OK to start the program.
    c. A window will pop up asking for the location of the runfile-template text file.
        i. This is the text file that was just created in the prior step.
    d. The program will begin.
        i. There will be no direct indicator icon showing progress of the program. However, the program continually writes out a diagnosis file for error analysis, should the program cease functioning. This diagnosis file is placed by the program in the same directory as the PROBDIFF control file that was used to run it. The name is based on the PROBDIFF control file name, but has added a unique time stamp identifier and the word “_diag.txt”. By watching this file (either reloading it over time or simply refreshing a Windows Explorer window viewing the file and its time stamp), the user can ensure that the program is running. As long as the file is updated frequently, the file is running. If there are any problems, the text file can be used to determine where in the program flow the problem occurred.
        ii. The program first uses the covariance-matrix data from the nine classes to build a lookup table for the POM for each combination of spectral values in the baseline image from which the covariance matrix was built. This program will take significant time to run.
        iii. Then the program applies this lookup table to all of the files that are listed in the runfile. These are the files listed as “Apply to file:” noted in step 2.c.iv. above.
4. When the program is done, import the probability images into Imagine. These images are named Probability of Membership (POM) images, because they describe the POM in each of the nine physiognomic classes.
    a. See details on importing BSQ images into Imagine in SOP 2, section VII, step 4. Briefly, use Imagine’s Import/Export dialog to navigate to the directory of each of the “Apply to file” images. The probability image name will follow the name of the image from which it is calculated, with a modifier associated with the unique name provided in the runtime file.
        i. Name the Imagine format file according to the naming conventions in SOP 5 Data Management.
    b. There also will be a file with the extension “.hdr”.
        i. Open that as a text file, and use it to find the appropriate fields for the Imagine importer.
        ii. Once the image is imported, use that file to fill out the map-projection information in the ImageInfo of the imported image.
5. The result of this process is an aspect-appropriate POM

image with nine layers (one for each class listed in the covariance-matrix file) for each image listed in the PROBDIFF control file. For a given year of image, the nine values associated with each pixel correspond to the probabilities of that pixel belonging in each of the nine physiognomic classes for that year. The next step is to subtract probabilities of class membership across years to identify areas of change.

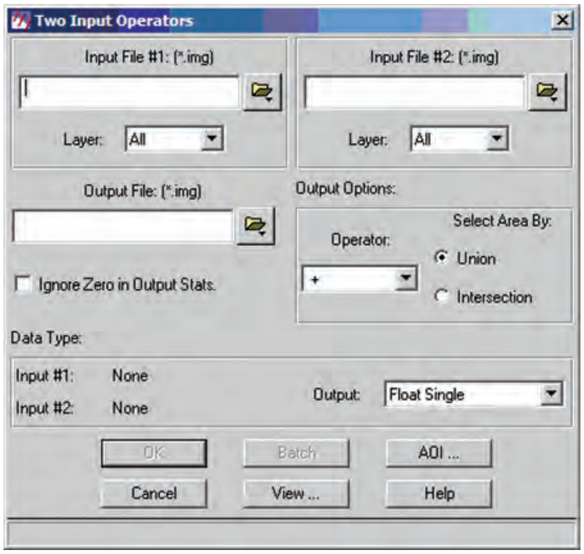
a. NOTE: These images represent probabilities scaled by 100 and transferred into byte type (to make the file sizes manageable). Thus, the probabilities will range from 0 to 100.

At this point, repeat all of the steps in this section for the SE aspect-image class.

V. Calculating Difference Image

At this stage, we focus on POM images for the baseline and the change image for one aspect class. In section IV, POM in each of the physiognomic classes was calculated for each pixel. In this section, the POM values for each class are subtracted on a pixel-wise basis to identify changes in POM over the change interval. Here again, we refer to the earlier date image as the “baseline” image and the later date image as the “change” image. Again, conduct every step here for the NW aspects, then repeat for the SE aspects.

1. Confirm that the map information entered for the imported images is correct (these steps referred to several other points earlier in the SOPs)
    a. In two viewers, open the two POM images that will be subtracted. The images should be from the same aspect class (either NW or SE). One image should be the POM image associated with the baseline year and one the POM image associated with the change year.
    b. In a third viewer, open the tasseled-cap version of the baseline image. This will serve as a visual reference.
    c. In the tasseled-cap viewer, right-click and select “Geo Link/Unlink,” and link with one of the other viewers, then do it again and link with the last viewer.
    d. Open a cursor (click on the “+” cursor icon in either viewer), and then click and drag it around, making sure that all three images are lined up geographically.
        i. If not, use the ImageInfo to examine the geographic-map model and projection information. Use discrepancies to trace back to the source of the potential mismatch. Since these are all derived from the same images, errors are most frequently associated with mistypings, etc. in the manual importing of the images.
    e. Once these have been confirmed, close all viewers.
2. In Imagine’s main console, select the “Image Interpreter” button, then select “Utilities\Operators”
    a. The “Two Input Operators” window will pop up (fig. 18).
    b. The “Input File #1” image is the POM image created by PROBDIFF for the “Change image” (the later of the two dates).
    c. The “Input File #2” image is the POM image created by PROBDIFF for the “Baseline image.”
    d. Name the output file according to the SOP 5 Data Management.
    e. Change the “Operator” to the minus sign.
    f. Change the “Output” to “Signed 16-bit.”
    g. Select the AOI button.
        i. Navigate to the aspect AOI (nwaspects.aoi or seaspects.aoi) file corresponding to this aspect image. This AOI was created in SOP 2, section X.
    h. Click on OK button to run the differencing.
        i. This image will take the two 9-layer POM images, subtract each band from the same band, which will result in a 9-layer difference-in-POM image.
3. Examine the difference image to make sure it makes sense.



Layer: All

Layer: All

Operator: +

Select Area By: ● Union ○ Intersection

☐ Ignore Zero in Output Stats

Input #1: None

Input #2: None

Output: Float Single

Figure 18. Two input operators window, used to subtract two images.

a. In two new viewers, open the baseline and change tasseled-cap images on which the POM images were based.
    - i. These images are the tasseled-cap images listed in the “Apply to file:” lines of the PROBDIFF control file (see section IV, step 2.c.v. above).

b. In two additional viewers, open the predifferencing POM images.
    - i. These are the nine-layer images corresponding to the POM in each of the physiognomic classes.

c. In a fifth viewer, open the POM difference image

d. In any of the viewers, select “View/Tile Viewers” to better distribute all five viewers on the screen.

e. Geolink all viewers to the POM difference image.
    - i. Right-click in the POM difference image, select Geo Link/Unlink, and then select another viewer. Repeat for all four other viewers.

f. Start a cursor using the “+” icon.

g. Move the cursor around and ensure that the patterns in the difference image make sense.

h. How to interpret the images:
    - i. There are nine bands in these POM images, only three of which are shown. Depending on the configuration of Imagine, the three shown initially may differ, but are typically bands 4, 3 and 2 for Red, Green, and Blue on the screen, respectively. Each band corresponds to a physiognomic class, with band 1 corresponding to the first physiognomic class. The order of the classes is the same as the order they were entered in the covariance matrix file passed to the PROBDIFF program.
        - (1) The choice of which bands are displayed can be changed using Raster/Band Combinations in the viewer. There, the bands associated with each color gun (red, green, and blue) on the screen can be chosen.
        - (2) No-change: If an area has not changed in any of the three bands currently displayed in the viewer, it will appear grey because all three bands are zero. Grey is roughly midway between the negative and positive ranges of the changes seen across the image.
        - (3) Change: Colors other than grey involve some change in the combined probabilities of the three classes being displayed. Because the color reflects potential positive and negative changes in each of the three displayed classes as well as no-change, the exact interpretation requires some careful thought.
            - (a) Consider the case where classes 1, 2, and 3 are represented by the red, green, and blue color guns on the screens.
            - (b) If a pixel shows up red, it could be the result of two distinct processes. The more intuitive process is where class 1 has increased in POM, and classes 2 and 3 are unchanged. The less intuitive process is where classes 2 and 3 have decreased dramatically, and class 1 has remained the same. Thus, the color combination represents the relative change among the three classes currently displayed.
        - (4) It is safest to use the colors as a preliminary indicator of change, and then to use the cursor (crosshairs) to query individual pixels in a changed area to confirm the direction of change (positive or negative) of each class.

If the difference image appears to have many geometric artifacts, it may be that the map information was entered incorrectly, or that the registration of the images was insufficient.

        - (5) In the case of the latter problem, it is necessary to confirm that the terrain correction in the geometric registration was done correctly, and that the tie points were located correctly. See SOP 2, section VI on geometric correction.
    - ii. If there appear to be many false positives—areas where change is claimed in the difference image but where there is no apparent cause in the source tasseled-cap images—then the patterns of the false positives must be examined to develop hypotheses about what might be going wrong.
        - (1) Note that low probability changes in class membership are often due to normal noise in illumination, processing, etc. False positives should be considered as those changes where a high probability (>50) of change is indicated, but where there is no obvious change in the parent images.
        - (2) If false positives appear to have no

relationship to the patterns on the actual landscape, it may be that the radiometric normalization has not been achieved appropriately. Go back to the SOP 2 section VIII on radiometric normalization and check the output images to make sure that the normalization has not failed.

(3) If false positives are restricted to particular features on the landscape, first check to determine if those features are always located in one of the physiognomic classes. If so, first check to make sure that the covariance matrices of the classes were entered correctly into the covariance matrix comma-delimited file (see section IV, step 1 above).

The steps in this section need to be repeated in their entirety for the other aspect class.

The difference POM images at this point can be used in one of three ways. First, they can be used directly as visual estimates of the continuous-variable probability of change across all classes. This directly fulfills one of the objectives of the protocol, and makes this image a final product (see SOP 5). Secondly, these nine-layer probability-of-change images can be masked to only include areas where a certain threshold of change has occurred, to simplify viewing and interpretation. Finally, these continuous-variable images can be categorized according to rules deemed as useful for an individual park's needs. This will be described in section VIII below.

VI. Merging Aspects

Sections II through V must be done separately for each of the two aspect classes (SE and NW). Once this has been done, the POM difference images should be merged for further analysis.

In Imagine's main icon panel, click on the Interpreter button, and select "Utilities/Operators." The operator window will popup. Enter the SE aspect image as Input File #1, the NW aspect image as Input File #2. Retain the "+" as the operator. This will add the two POM difference images together on a pixel-wise basis. Because the two images have zeros where their aspect class is not present, this approach is a simple approach to merge the two aspect classes. Name the output according to the conventions in SOP 5 Data Management.

VII. Using Pacific Meridian Resources Data to Describe Physiognomic Class

The physiognomic classes created in section IV above were based on a direct understanding of the physical basis for the distribution of reflectances in spectral space. Broadly speaking, regions of spectral space describe vegetation physiognomic properties anywhere in the world. While changes in these classes can often be used to describe where disturbance is occurring and generally how that disturbance affected the vegetation, the physiognomic classes contain no information on park-specific vegetation-community types that they represent.

In the parks of the NCCN, field data were recorded for the purposes of Landsat-based mapping by the private consulting company Pacific Merdian Resources (PMR) in the mid-1990s. While these field data do not cover enough of the spectral space to be used as the basis for statistical class *building*, they can be used as a first approximation of the park-specific vegetation within each of the physiognomic classes. This step only need be taken during the startup phase of monitoring, when the image from the era near collection of ground data from PMR is being processed.

Using the PMR field data to describe the physiognomic classes consists of three steps. First, the database with the field data must be summarized to the plot level with summary statistics that are desirable to the user. An example is described below, but any statistics could be used. The key is simply that each plot with a unique geographic location have a set of numeric descriptors. This is done in Microsoft© Access, or could be done in any similar database-software package. The second step is to extract the physiognomic class associated with each plot. This is done in Imagine using the geographic coordinates in the database. Finally, the plots are grouped by physiognomic class and summarized to provide a description of that class.

1. Summarizing PMR data in the database.
    a. This can be done to any level of detail desired. Below, we provide a sketch of the process.
    b. The PMR data were provided to the authors in the form of an MS Access database called "PMRPlotData." Each tree or each cover component is stored as a separate entry. The goal is to collapse all tree observations and cover observations into a single entry per plot.
        i. A query with all plots and measures for the NCCN existed in that database. From it, a simple query was used to develop a new table with the plots and measures for a single park.

(1) Record cleaning involved filling in values in the FIXED column for trees where no entry was made. The FIXED value was inferred from the DBH of the observed tree.

(a) if DBH is between 4 and 18, assign 40.

(b) if DBH is between 18 and 36, assign 10.

(c) if DBH is >36, assign 5.

(2) A select query was then used to extract only the live-tree observations.

(3) Conifer and broadleaf components were separated.

(a) The broadleaf and conifer species were assigned manually in the species table of the database, and linked to the live-tree observations.

(b) This was then linked to the result of the query of live tree observations (step (2)).

(c) A query could then be made on conifer and hardwood designation. In this query, the DBH was converted to area per acre using the expansion factor (the FIXED value) in the formula: [exp_factor]*((0.5*[DBH])^2)*3.14159/144.

(i) A new column with area per acre was created in the query.

(d) The results were two queries, one for broadleaf and one for conifer, where each tree's DBH was scaled to a plot-level basal area.

(e) Then a crosstab query was used to add up the total basal area by broadleaf and conifer per plot.

ii. For all components where the COMPCODE was not LT (live tree), a crosstab query was used to add the cover percentages by plot number.

iii. This was combined with the conifer and broadleaf tree components to result in a single table that had all plot coordinates from the original plot file, along with the broadleaf and conifer basal area and the percentages of the nontree components.

2. Extracting these points in Imagine.

a. Copy the X,Y coordinates of the plots into a separate spreadsheet.

i. In the database program, select all of the plot X and Y coordinates. In Access, the column headers X_coord and Y_coord are selected, and the Edit/Copy function selected.

(1) NOTE: It is critical that these coordinates be listed in the same coordinate system as the image (i.e. NAD83, if standard NCCN conventions are used). The images in the PMR database are in NAD83 already, so this should not be an issue.

ii. Paste these into an empty Excel spreadsheet.

iii. Remove any leading text rows, so that only two columns have data.

iv. Save this as a comma-delimited file.

v. In the Windows Explorer, change the extension of this file to .dat (this is so that Imagine will accept it).

b. In Imagine's main console, select "Utilities/Pixels to ASCII."

i. The Pixel to Table window will pop up (fig. 19).

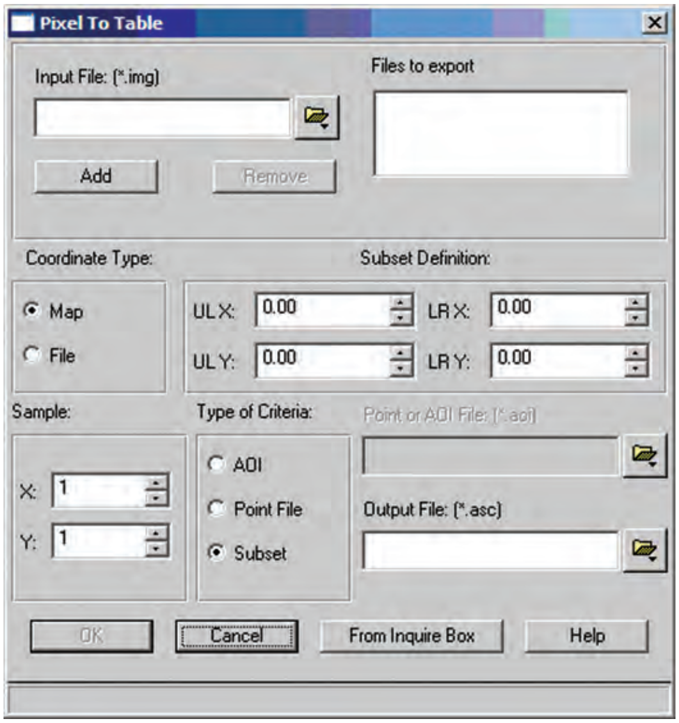
ii. The Input Image is the nine-class physiognomic image created by recoding the 25-class image in section III above.

(1) Once the file is located and shows in the Input File field, the "Add" button must be clicked.

iii. Under "Type of Criteria:" select "Point File," and then find the ".dat" file just created.

iv. The Output File (ending in .asc) should be placed in this park's folder.

v. Click on OK.



Coordinate Type: ● Map ○ File

ULX: 0.00 LRX: 0.00

ULY: 0.00 LRY: 0.00

Sample: X: 1 Y: 1

Type of Criteria: ○ AOI ○ Point File ● Subset

Figure 19. Pixel to Table window.

   c. Copy the extracted class values back into the database.
      i. In a Windows Explorer window, change the extension name of the .asc file to ".txt."
      ii. Open the file in Excel.
         (1) Fixed width formatting will be necessary.
      iii. Copy and past the column under "B1" (band 1). It should contains numbers from 1 to 9, maximum (the nine physiognomic classes). It likely is that some of the classes will be underrepresented or absent because those regions of spectral space were not field sampled.
      iv. Paste the values into a new column in the database.
3. Group by the class.
   a. The easiest approach is to conduct a crosstab query in the database software to summarize by the class of each plot.
      i. Summarize both by mean and variance of each of the plot metrics (conifer DBH, broadleaf DBH, percent cover of live vegetation, etc.).

VIII. Converting Change to Satellite-to-Satellite Classes

Changes in the physiognomic classes can be viewed directly as continuous-variable probability-change images, which provide insight into the range of spectral change occurring. However, these continuous-variable images are difficult to summarize visually or statistically. Moreover, they are difficult to validate directly without substantial, quantitative airphoto interpretation that is beyond the budget or scope of the NCCN parks. Validation of year-to-year changes must occur without photos, and thus for this protocol, direct interpretation of satellite images will form the core of validation (see SOP 4). The authors have developed a structure for S2S image interpretation of changes (SOP 4) that relies on 15 classes of interpretable change and no-change (see table 3). To achieve later validation, then, the continuous-variable, nine-layer POM images must be converted into classified S2S images.

To link changes in POM to S2S, a matrix of pairwise increases and decreases POM of the nine physiognomic classes is developed (table 4).

Each cell in table 4 can be viewed as an hypothesis of change. For example, the greater the positive change in POM for the closed-canopy conifer and the greater the negative change in POM for the open: dark conditions, the more likely that S2S change class 9 is occurring ("Increase in conifer," see table 3). By adding the positive POM change for the physiognomic class in each cell's column header with the negative of the POM change for the physiognomic class in the cell's row header, a score for that cell is calculated that is more positive as support for that cell's hypothesis grows. This score is the total probability change in support of a given cell's hypothesis.

Table 3. Satellite-to-satellite interpretation change classes.

Satellite-to-satellite code	Description
1	No change
2	Water to rock/soil
3	Water to partial vegetation cover
4	Water to complete vegetation cover
5	Rock/soil to water
6	Partial vegetation to water
7	Complete vegetation to water
8	Increase in broadleaf
9	Increase in conifer
10	Increase in vegetation
11	Decrease in broadleaf
12	Decrease in conifer
13	Decrease in vegetation
14	Increase in snow
15	Decrease in snow

For each pixel in the study area, all cells from table 4 that support a given S2S change-class hypothesis are compared, and the single best score is taken as the score for the hypothesis of that type of S2S change occurring in a given pixel. This is done for all 14 S2S change classes for each pixel, resulting in a 15-layer image with a 15-dimensional S2S score for each pixel. Then, a separate algorithm is used to identify the highest score and use it to label the type of S2S change occurring. If that highest score does not pass a minimum threshold, then no-change is likely to have occurred and the S2S class 1 is assigned.

These steps of detecting and labeling changes have been distilled into two graphic models in Imagine. Therefore, the steps for conducting this process are achieved easily in Imagine using graphic models supplied by the authors.

1. Calculate scores for the S2S change classes by applying the rules from table 4 to the POM difference image created in section VI.
   a. In the main Imagine icon panel, click on the modeler button, and select "Model Maker."
   b. Load the graphic model named "assign_s2s_labels_to_9physclass_difference.gmd".
   c. The model is shown in figure 20.

Table 4. Linking observed increases and decreases in probability of membership with satellite-to-satellite change classes.

[na, not applicable]

		Inceasing									
		No increases	Water/deep shade	Closed-canopy conifer	Conifer-broadleaf mix	Dense broadleaf/grass	Broadleaf tree/shrub	Mixed	Open: dark	Open: bright	Snow and ice
Decreasing	No decreases	1	1	9	10	8	8	10	1	1	14
	Water/deep shade	1	na	4	4	4	4	3	2	2	14
	Closed-canopy conifer	12	7	na	8	8	8	12	12	12	14
	Conifer-broadleaf mix	13	7	9	na	8	8	13	13	13	14
	Dense broadleaf/grass	11	7	9	9	na	11	11	11	11	14
	Broadleaf tree/shrub	11	7	9	9	8	na	11	11	11	14
	Mixed	13	6	9	10	8	8	na	13	13	14
	Open: dark	1	5	9	10	8	8	10	na	1	14
	Open: bright	1	5	9	10	8	8	10	1	na	14
	Snow and ice	15	15	15	15	15	15	15	15	15	na

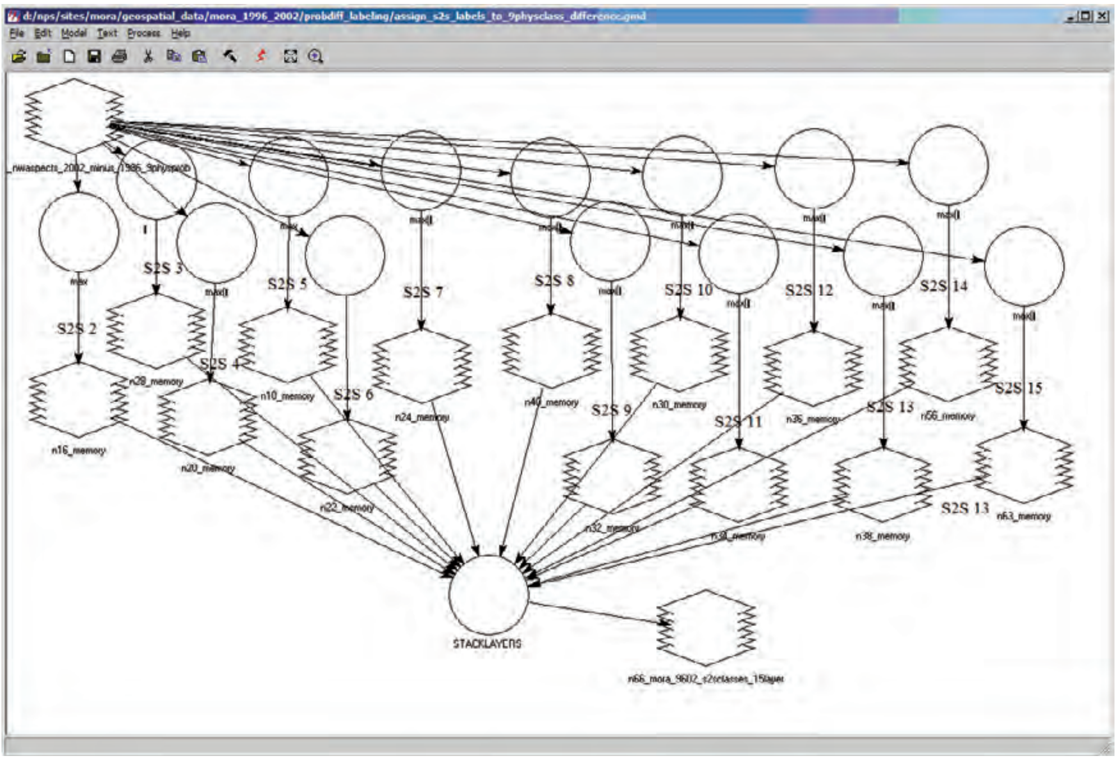


Figure 20. Model used to calculate satellite-to-satellite scores based on probability-of-membership difference-image values.

d. Save this model under a different name that is specific to the park and year of change being investigated.

    i. Follow guidelines in SOP 5 Data Management for naming and placing the model.

e. Update filenames in the model.

    i. In the upper left, double-click on the raster object and change the name to the difference image created in section VI.

    ii. In the lower right, change the filename to the appropriate filename for the “POM to S2S class image” listed in SOP 5, Data Management.

f. Run the model by clicking on the lightning bolt.

2. In the model, select “File/Open” and open the second model in the sequence: “detect_and_label_s2s.gmd” (fig. 21).

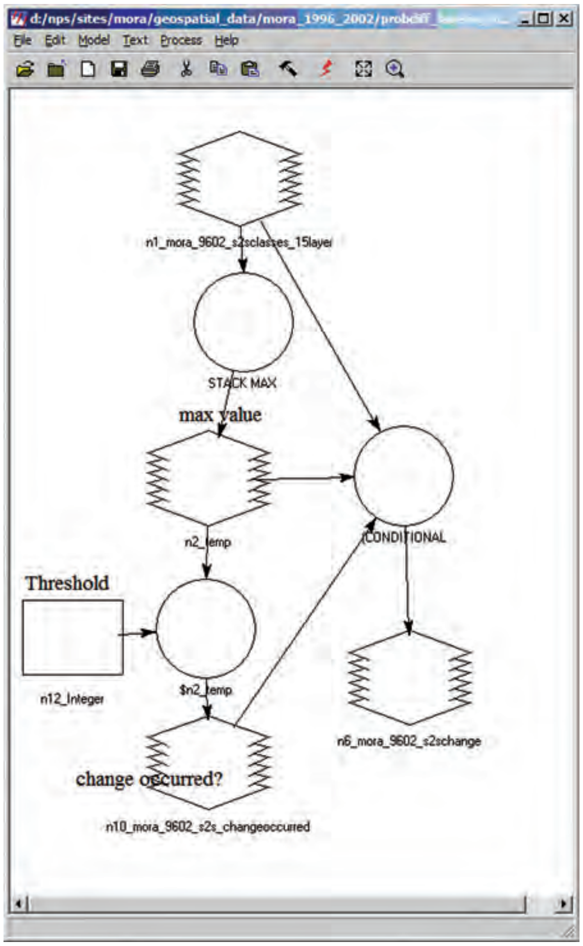


Figure 21. Model used to create a change-label layer.

a. Save this model under a new name, again specific to the park and years of the images used for change detection.

    i. In the raster layer at the top of the model, change to the file just created by the model in step 1 (the 14-layer S2S score image).

    ii. On the left is a box containing the scalar value that will be used as the threshold of change for change labeling. This value can be changed. It currently is set at 80, which means that any pixels where the combined POM change exceeds 80 for any cell in table 4 will be labeled as change.

        (1) NOTE: As noted in the Narrative, there is no single threshold of change value that is “correct.” As long as maps of change explicitly describe the threshold used to make them, and as long as the error of a given map has been assessed using S2S (SOP 4) or other similar methods, they are legitimate. It may be useful for parks to initially experiment with different probability thresholds to determine which thresholds appear useful. In practice, the parks may find that some threshold values are more useful over time for actual implementation and use by the various users at the parks. Additionally, the parks may find that some high thresholds are useful for some monitoring goals and lower thresholds for others. In either case, suggested values for change thresholds could be added to this protocol later (see SOP 6).

    iii. At the bottom are two raster layers that should be changed. The lower-left image will be a single-layer file that records with ones and zeros if change has occurred or not, based on the threshold value. The lower-right image is the labeled change image. Name this image to include the park, the year of the change interval, and the string “_S2Slabel_”.

        (1) Follow guidelines in SOP 5 Data Management for location of the images.

b. Run the model.

IX. Sieving Out Small Changes Based on Satellite-to-Satellite Class

The result of the change thresholding and labeling process is an image that often contains “speckle”: individual pixels that pass the threshold-of-change rule spectrally, but whose change likely is the result of small misregistration errors. Typically, change-detection products are sieved to a minimum mapping unit that is large enough to eliminate most of these small occurrences, often 2 ha or more. In this case, many monitoring goals require that small events be retained. Therefore, a minimum mapping size of only 6 (0.375 ha) pixels is recommended.

Because there are 14 classes of S2S change, patches where change has occurred often contain a mosaic of similar S2S labels. For example, regrowing clearcuts may include pixels labeled as increasing in broadleaf, conifer, and general vegetation. When individual pixels lie in a matrix of similarly themed pixels, they should not be sieved away. Therefore, the 14 S2S classes are first grouped before sieving. The original labels will be reassigned after sieving.

1. Group S2S labels by theme.
    a. Open the graphic model “group_s2s_for_sieving.gmd” (fig. 22).
        i. Save this model under a new name specific for the image being sieved. See SOP 5 Data Management for details.

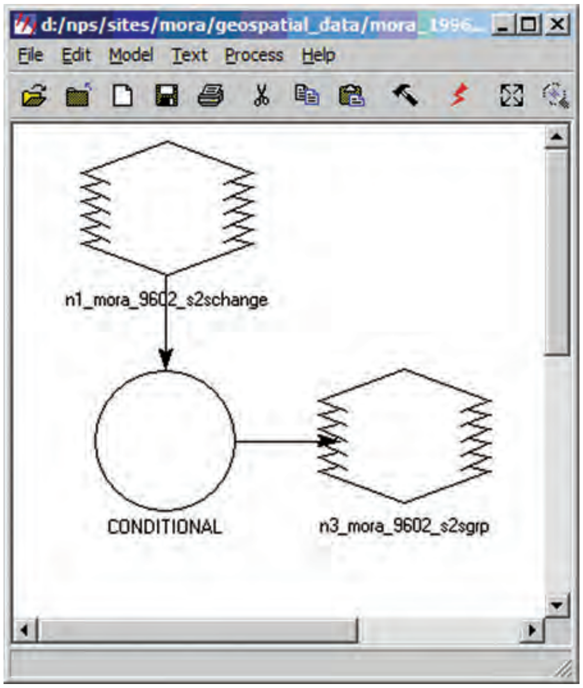
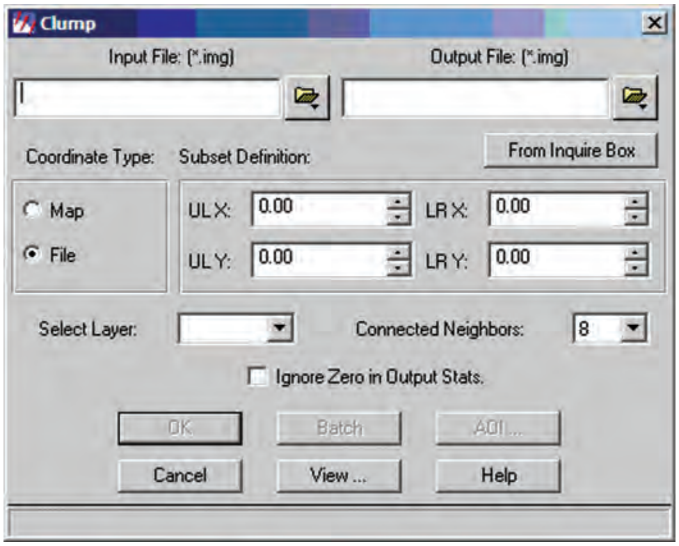


Figure 22. {Screen capture showing} model to group satellite-to-satellite labels by theme.

    b. Change the name of the two files.
        i. The top file is the S2S change-label image from the prior section.
        ii. The output will be a classified image with four classes. These four classes are regroupings of the 15 S2S classes into common thematic elements: no-change, increase in any vegetation type, decrease in any vegetation type, and conversion of snow. Place this in a directory below the level of the change-detection files named “sieving” (create this directory if it has not been done before). This file will be used only for sieving.
            (1) Click on the AOI button, and navigate to the study area AOI (the entire study area, not just one of the two aspects) created in SOP 2.
                (a) NOTE: If this AOI step is not done, the entire area outside of the study area will be assigned a value of 1, indicating no-change.
    c. Run the model.
2. Filter out pixel groups that are smaller than 6 pixels.
    a. Hit the Image Interpreter button in the main Imagine icon panel.
        i. Select “GIS Analysis/Clump.”
            (1) The Clump window will pop up (fig. 23).
            (2) The input file is the image created in step 1.
            (3) The output file should be placed in the subdirectory named “sieving.”
                (a) This is a temporary image that can be erased after this SOP is complete.



Coordinate Type: ● File
UL X: 0.00
LR X: 0.00
UL Y: 0.00
LR Y: 0.00
Connected Neighbors: 8

Figure 23. Clump window.

(4) Click on OK.

(a) This will create an image where all connected pixels are assigned a clump number.

ii. Select "GIS Analysis/Sieve."

(1) The Sieve window will pop up. (fig. 24).

(a) The input file is the clumped image from the prior step.

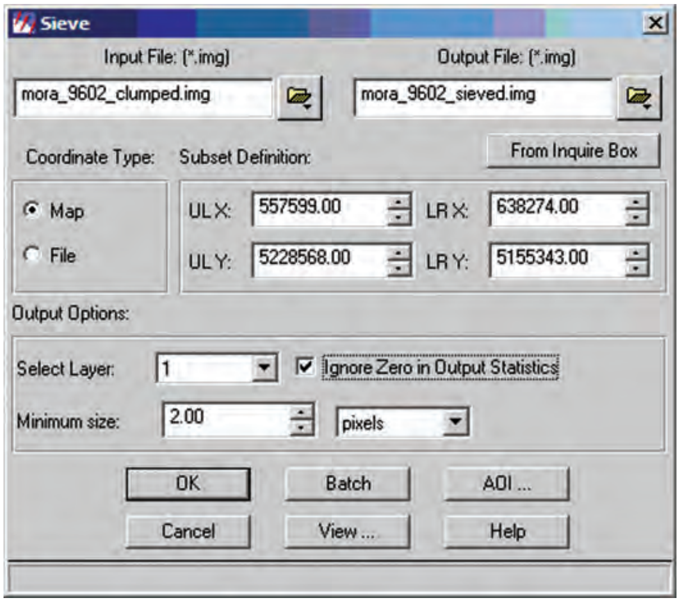
(b) The output file should be placed in the same "sieving" folder.

(c) Set the minimum size to 6 pixels.

(i) This is equivalent to a minimum mapping unit of 0.375 ha.

(d) Click on OK.

(2) The result of this process is an image with pixels labeled with the clump number. This number is uninteresting. But any pixel that has a non-zero value is one that survived the clumping. By treating this as a mask, the original S2S class image can be sieved using a simple graphic model. Areas that did not have more than six adjacent S2S change pixels will be assigned a value of zero. By multiplying this image by the original S2S class image, the zeros will eliminate any pixels in the original 15-class S2S image that are isolated. This multiplication is carried out in the next step.


Sieve

Input File: (*.img) mora_9602_clumped.img

Output File: (*.img) mora_9602_sieved.img

Coordinate Type: ● Map ○ File

Subset Definition:

UL X: 557599.00 LR X: 638274.00

UL Y: 5228568.00 LR Y: 5155343.00

Output Options:

Select Layer: 1

☑ Ignore Zero in Output Statistics

Minimum size: 2.00 pixels

Figure 24. Sieve window.

3. Apply the sieve filter to the original S2S image.

a. Open the model "sieve_s2s_labels.gmd" (fig. 25).

i. Save this model using naming conventions in SOP 5 Data Management.

ii. This model multiplies the mask resulting from the sieve process by the S2S change-labeled image. Where individual pixels have been masked out in the sieved image, they are erased from the change-labeled image.

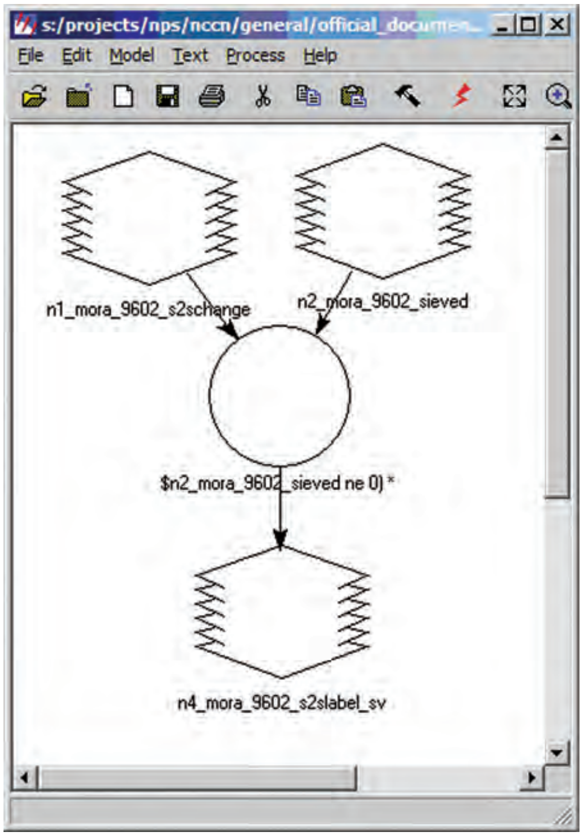
iii. Change the input files. The upper-left file is the change labeled image from section VIII. The upper-right file is the product of step 2 (the sieved image).

iv. Change the output file (at the bottom of the model).

(1) Name the output file using the conventions in SOP 5 Data Management.

(2) NOTE: The output type should be forced to thematic.

b. Run the model.


s:/projects/nps/nccn/general/official_documen...

n1_mora_9602_s2schange

n2_mora_9602_sieved

$n2_mora_9602_sieved ne 0) *

n4_mora_9602_s2slabel_sv

Figure 25. Model to sieve Satellite-to-Satellite labels.

The result of these steps is an image of S2S change labels. Pixels that are labeled with one of the 14 S2S change labels are those that meet the threshold of change criterion determined in the “detect_and_label_s2s.gmd” model and that are labeled according to the observed spectral changes. This product will be validated in SOP 4. Keep track of the name and location of this file. NOTE: This file directly fulfills one of the objectives of the protocol, and as such is considered a final product (see SOP 5).

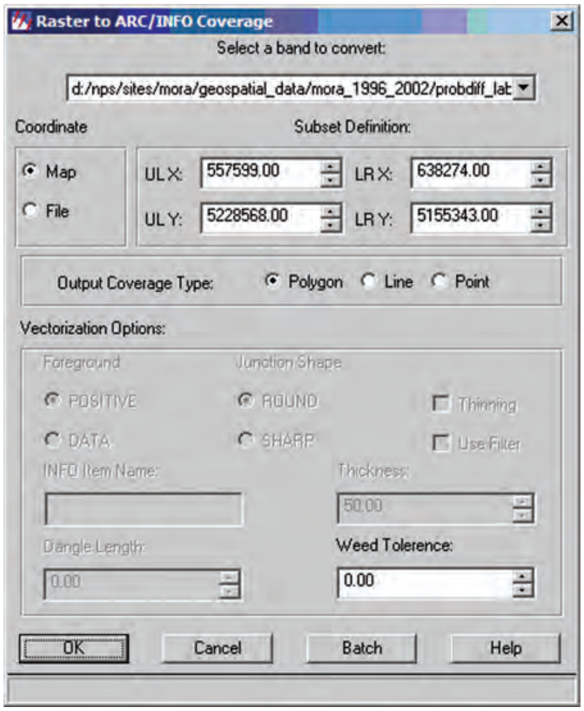
Errors in this product will be caused by several important factors. Illumination differences, caused by changes in the date of image acquisition, will cause the change labeling approach to indicate changes to or from the water/shadow class when no real change has occurred. Geometric misregistration will cause false positives in all classes when contrasting spectral type are adjacent to each other. Phenological change will cause the broadleaf classes to either increase or decrease in one image, resulting in labels that indicate changes in those classes. Note that this effect will be widespread if the cause is a phenological difference; therefore, if an individual patch shows a label of increase or decrease in broadleaf component, and surrounding patches do not, then the label likely is real.

X. Converting to ArcInfo Polygon Formats

When change products are to be used in the field or in conjunction with other GIS data, it is convenient to convert them into an ArcInfo polygon-vector coverage.

1. Click on the Vector Utilities button in the main icon panel of Imagin.
   a. Select “Raster to vector.”
      i. For the Input Raster, select the file created at the end of section IX—the labeled and sieved thematic layer.
      ii. Name the output vector layer and click on OK.
      iii. The Raster to Arc/Info Coverage window will popup (fig. 26).
      iv. Click on OK.

This is the final-change product in this SOP.



Raster to ARC/INFO Coverage

Select a band to convert: d:/nps/sites/mora/geospatial_data/mora_1996_2002/probdiff_lat

Coordinate: ● Map ○ File

Subset Definition:

UL X: 557599.00 LR X: 638274.00

UL Y: 5228568.00 LR Y: 5155343.00

Output Coverage Type: ● Polygon ○ Line ○ Point

Vectorization Options:

Foreground: ● POSITIVE ○ DATA

Junction Shape: ● ROUND ○ SHARP

☐ Thinning ☐ Use Filter

INFO Item Name:

Thickness: 50.00

Dangle Length: 0.00

Weed Tolerence: 0.00

Figure 26. Window for converting an Imagine image to a polygon coverage.

XI. Summary

The steps described in this SOP 3 take tasseled-cap imagery derived from SOP 2 to a state that describes change on the landscape in several ways. Key products in this SOP are:

1. POM lookup values.
2. Nine-layer POM difference images from the two dates of imagery.
3. S2S-labeled change image(s).

Protocol for Landsat-Based Monitoring of Vegetation at North Coast and Cascades Network Parks

Standard Operating Procedure (SOP) 4

Validation of Change-Detection Products

Version 1.0 (July 5, 2006)

Revision History Log:

Previous VersionNumber	Revision Date	Author	Changes Made	Reason for Change	New Version Number
n.a.	07-05-06	REK		Final version under agreement	1.0

This SOP explains the steps for validating polygon-based maps of vegetation change and disturbance created in SOP 3. Because reference sources are variable among parks and depend on unknown future budgets, the validation strategy chosen is hierarchical. Direct validation from satellite imagery is the minimum validation that is necessary for change products, and requires minimal additional financial outlay. This approach allows yearly validation for the group of monitoring goals that must be monitored on a yearly or near-yearly basis (type 1 monitoring objectives; see Narrative). Photo and field validation of the those satellite-based validation steps can follow and provide a better understanding of actual error rates. Field validation is best for type 1 monitoring goals, photo validation for type 2 validation.

Note that SOP 3 will produce a variety of continuous-variable-change products that precede the steps needed to produce polygons of change. Validation of such continuous-variable products would require many more field- or photo-validation plots than the methods for polygon-based validation, and thus are not considered part of this protocol.

I. Overview

Validation is the process of determining how accurately the product from SOP 3 detects and labels changes. Typically, an accuracy assessment is conducted using a large number of sample plots where the labels from a change product are compared with labels determined by another, more reliable method. For single-date landcover products, accuracy assessment can be achieved through a random sample of small plots. This is not necessarily the case for change detection. Most of a landscape does not change, so randomly placed small plots would primarily occur in no-change areas. To adequately test whether a change-detection method is accurate, a sample design balanced across change and no-change areas is desirable.

Our approach is to use direct human intepretation of imagery to exhaustively label change within boxes that are much larger than the grain size of most disturbances on the landscape. Here, we use boxes 1.5 km by 1.5 km in size. Most of the area in these validation boxes will be unchanged, but the large size of the boxes will increase the chance of capturing change events. Once these events are digitized, random samples can be drawn equally from the change and no-change areas and used for actual accuracy assessment.

Exhaustive description in 2.25 km^2 areas is difficult by most means. Field validation over such a large area essentially is impossible. Airphoto interpretation was tested as a means of doing such an exhaustive survey, but was found by the authors to be unreliable using typical airphoto-interpretation procedures. Instead, the authors found that direct interpretation of the satellite images, using methods borrowed from airphoto interpretation, proved to be a quick and reliable means of identifying changes on a landscape. We call the method S2S, shorthand for satellite-to-satellite interpretation. The key advantage of this approach is the availability of a difference image (an image of the mathematical difference in spectral values) to highlight areas of potential change. This necessarily limits the accuracy assessment to those changes that can be detected and labeled from spectral-imagery alone. In theory, many small and subtle changes may go undetected. By testing against airphotos, we found that most of the changes of interest to the parks were, in fact, captured.

Once S2S is used to identify change or no-change over a set of 2.25 km^2 boxes, small sample plots for accuracy assessment can be drawn from those areas using random sampling. Additionally, these plots can be validated independently from airphotos if such photos are available.

II. Required Products From Prior SOPs

This SOP requires imagery from SOP 2 and final products from SOP 3.

From SOP 2, the following are needed:

1. Study AOI and vector coverages (section V).
2. DEM clipped to the study area (section V).
3. Aspect masks (both raster and AOI) for the NW and SE aspects (section X).
4. Tasseled-cap imagery, split by aspect, for the study area (Section X).

Confirm that these files exist and that the locations are known.

From SOP 3, the following are needed:

1. Final polygon-based S2S change products (section X).

Note that if two or more thresholds for change are used to create change products in SOP 3 (for example, one at a high threshold and one at a lower threshold), each must be validated independently. Currently, this protocol considers validation of only a single product.

III. Software Used

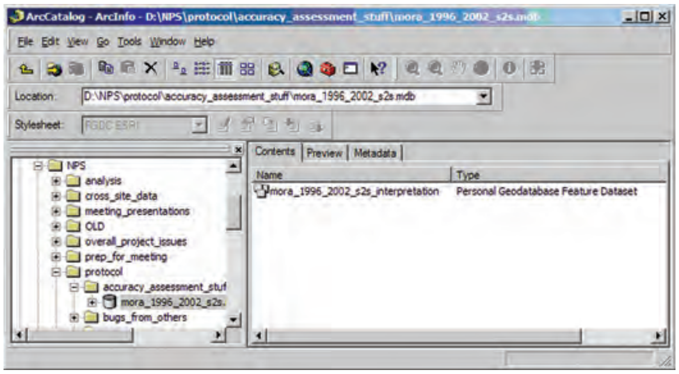
In this SOP, geospatial-database visualization is more important than in prior SOPs. Therefore, here we introduce the use of ESRI ™ ArcGIS software for parts of the SOP. ArcGIS provides easy onscreen digitizing and database updating. Although these functions can be achieved in ERDAS Imagine, they are more efficient in ArcGIS. Moreover, ArcGIS is a software package familiar to most parks because of its ubiquitous use in GIS applications. Therefore, relative to SOP 2 and SOP 3, parts of this SOP will contain less detail about ArcGIS commands and strategies, as local expertise for ArcGIS problem-solving likely is more robust than could be reported effectively in this document. NOTE: Within this SOP, we also assume that the user has installed ArcGIS components (here, version 9.0), specifically ArcCatalog and ArcMap.

IV. Setting Up Validation Database

Validation occurs within validation boxes that are 1.5 km by 1.5 km on a side. The interpreter will use standardized rules (section VI) to fully label the entire 2.25 km^2 area as either no-change or one of 14 other change categories. Interpretation will be based on the satellite image from the two dates of the change interval, a difference image of those images, and a high-resolution digital orthoquad for reference. All of these steps will occur within ArcMap, a module of ArcGIS. The first step is setting up a database within ArcGIS to record and label digitized changes. This involves creation of a geodatabase and the feature datasets that will be used to record interpreted change calls.

1. Set up the database and feature set.
    a. In ArcCatalog, navigate to the desired folder.
        i. Follow guidelines in SOP 5 Data Management for naming that folder.
    b. Right-click on the folder.
        i. Select “New/Personal geodatabase.”
            (1) Name the geodatabase.
                (a) This database will house all of the S2S interpretation for this park. Feature datasets will be created that specify the years within which change is validated. Thus, the name should indicate only the name of the park, and the fact that it is for validation.
                (b) Follow guidance in SOP 5 Data Management for naming and placement of this database.

c. Create an S2S feature dataset for the specific years of change detection.
    i. This feature dataset will house the feature classes (polygon coverage-like datasets) that will house the accuracy assessment for this park and year. Therefore, this dataset should have a name that indicates the park name and the years of change. Because the accuracy assessment may include both S2S and airphoto and other accuracy assessments, the name should only include the park and the years of the validation. See SOP 5.
    ii. Right-click on the new geodatabase.
    iii. Select “New/Feature dataset.”
        (1) Name the feature dataset.
            (a) Follow guidelines in SOP 5 Data Management for naming.
        (2) Assign geographic properties to this dataset.
        (3) Click the Edit button.
            (a) In the Spatial Reference Properties dialog box, select “Import.”
                (i) Navigate to either of the tasseled-cap images that were used for the difference-image processing in SOP 3. We use these images as the reference because digitizing must match the pixel location of these images. **Do not** use another GIS coverage for this purpose.
            (b) Click OK to exit the Edit session.
    iv. Click OK to approve the new dataset.
    v. The new-feature dataset should be listed in the Contents pane of the ArcCatalog window, as shown in figure 1.



Location: D:\NPS\protocol\accuracy_assessment_stuff\mora_1996_2002_s2s.mdb

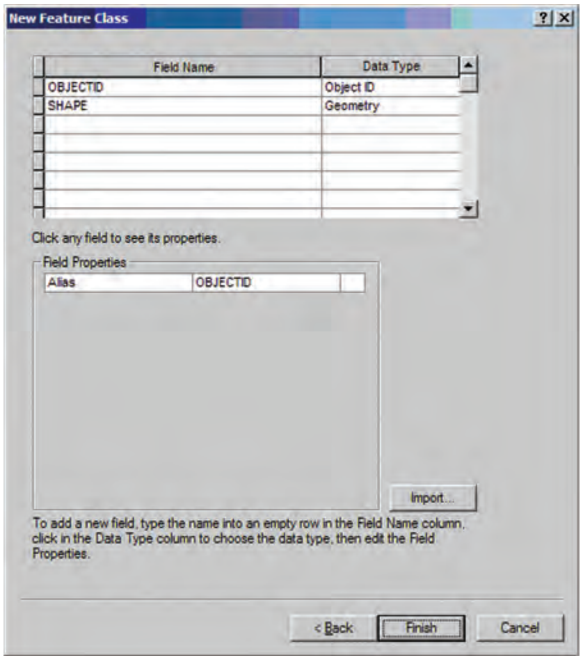
Stylesheet: FGDC ESRI

Name	Type
mora_1996_2002_s2s_interpretation	Personal Geodatabase Feature Dataset

Figure 1. ArcCatalog window showing the contents of a newly created geodatabase.

d. In later steps, new feature classes must be created or imported into this feature dataset. The steps for creating a new feature class are provided here for later reference.

e. Steps for creating a new feature class within the feature dataset:
    i. Right-click on the feature dataset, select “New/Feature Class.”
        (1) Name this dataset to uniquely identify it by park, year of change detection, and the fact that this is an S2S dataset.
            (a) Follow guidelines in SOP 5 Data Management for naming.
            (b) Type remains default (simple features).
            (c) Click next.
    ii. Use default configuration.
    iii. In the next window, new fields can be entered into the database. See figure 2 for an example of the starting point, before user fields have been entered.



Field Name	Data Type
OBJECTID	Object ID
SHAPE	Geometry

Click any field to see its properties.

Alias OBJECTID

To add a new field, type the name into an empty row in the Field Name column, click in the Data Type column to choose the data type, then edit the Field Properties.

Figure 2. New feature class window.

1. New fields can be added by typing directly into empty boxes. Field names indicate the kind of data that will be entered into the fields. When new-feature classes are to be added later, the field name and the data type will be specified, e.g.:
    a. Field name = box_id
        i. Data type = short integer
2. New fields can be added to an existing feature class in ArcMap as follows:
    a. Open the layer in ArcMap.
    b. Right-click on the layer and select "Attributes."
    c. In the Options box of the Attributes window, select "Add Field."
    d. The field name and data type are specified in a pop-up window.
    e. NOTE: The new fields cannot be created if the feature class is open, or if it has been opened recently, in ArcCatalog. It may be necessary to quit from ArcCatalog if ArcMap will not allow a new field to be added because the dataset is locked.

V. Creating Validation Boxes

Validation boxes will be chosen by one of two methods: (1) Grid placement, or (2) placement based on location of airphotos for later validation.

Use method 1 if no airphoto validation is planned or possible. This will be the case more often than not, as airphoto validation will be possible only when appropriate airphotos exists on both ends of the change intervals. Assessments of yearly change-detection products for type 1 validation processes (disturbance, etc.; see Narrative) will use method 1.

Use method 2 if two-date airphoto validation is planned. This will occur only when airphotos are available for both dates of the period.

If aerial photos are available only for a small portion of the desired area of monitoring, it may be necessary to use both methods. Method 2 would be used to create a core set of validation boxes where photo interpretation can be used to validate the S2S interpretation method, while Method 1 can be used to expand the area over which the S2S interpretation can be used to validate the change-detection image from SOP 3.

Method 1: Creating Random Grid-Based Validation Boxes.

1. Create a new map in ArcMap.
    a. Launch ArcMap.
    b. Start ArcMap with a "New empty map" when prompted.
    c. Immediately save this new map under a new name.
        i. It is recommended that a single-map project be used for all validation at a given park. This map ultimately will incorporate layers for image interpretation and validation for many years. Therefore, the name should include the park name and the indication that it is a map for validation purposes.
        ii. Follow guidelines in SOP 5 Data Management for naming.
    d. Load the following layers and images:
        i. Early date tasseled-cap image.
            (1) This typically is the "baseline" image in the change-detection methods (SOP 3).
            (2) For ease of interpretation, use the full image, rather than the aspect-split images.
            (3) Be sure to use the radiometrically normalized images in all cases.
        ii. Late date tasseled-cap image.
            (1) This typically is the "changed" image defined in the change-detection process (SOP 3).
        iii. Study area vector layer.
            (1) This was defined in SOP 2, section V.
2. Create a grid of potential validation boxes.
    a. Open ArcToolbox.
        i. Within ArcMap or ArcCatalog, click on the red toolbox icon.
    b. In the ArcToolbox, select Conversion Tools/To Raster/Feature to Raster.
        i. Input feature: The study area vector layer.
        ii. Field: id field.
        iii. Output raster: Name this according to the conventions in SOP 5 Data Management.
        iv) Output cell size: Type in 1500 (for 1500 m).

c. Convert the grid coverage to a polyline.

i. In ArcToolbox, select Conversion Tools/From Raster/Raster to Polyline.

(1) Input raster: The grid just created.

(2) Output polyline: <park>_1500pl.

d. Convert the polyline to a coverage.

i. In ArcToolbox, select Conversion Tools/To Coverage/Feature Class to Coverage.

(1) Input Feature Class: The polyline dataset just created.

(2) Output coverage: <park>_1500arc

e. Build topology for the Arc coverage.

i. This approach uses Arc Workstation—the command line oriented version of Arc that comes with ArcGIS. If Arc Workstation was not installed with ArcGIS, consult documentation on installing it. Alternatively, users of ArcGIS may be aware of other means of building the topology for the coverage.

ii. Start Arc Workstation.

iii. Change the workspace to the one where the coverage just created exists.

iv. Type: build <park>_1500arc poly

f. In ArcMap, load the coverage into the same map composition.

i. Confirm that the boxes fall within the study area.

3. Select a random subset of those grids.

a. The process above created a polygon coverage where each 1.5-km box has a unique ID. Those IDs can then be used to develop a random subset.

b. Calculate a new column for the IDs.

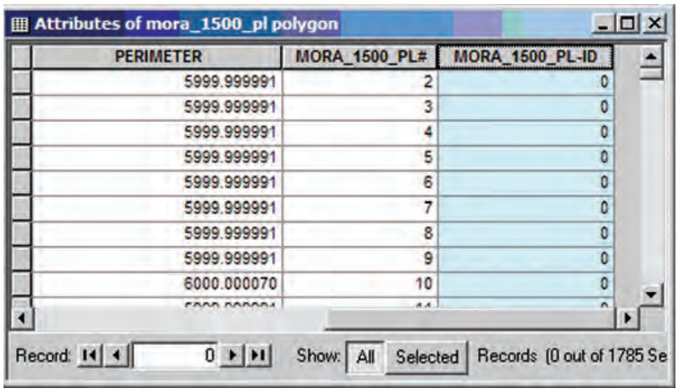
i. In the build in Arc, the polygon IDs were assigned to an item (column header) with the name of the coverage and a # at the end. We want to lock those numbers into the column with the coverage name followed by "-ID", which will be stable (fig. 3). Right now, it is set to zeros.

ii. In ArcMap: With the coverage open in ArcMap, right-click on the name of the coverage in the list of layers on the left of the ArcMap interface, and select "Show Attributes."

(1) The table with the attributes for all of the 1.5 km boxes will pop up. (fig. 3).

iii. Left-click on the title of the column with the ending "-ID".

(1) The column should be selected (see figure 3).



PERIMETER	MORA_1500_PL#	MORA_1500_PL-ID
5999.999991	2	0
5999.999991	3	0
5999.999991	4	0
5999.999991	5	0
5999.999991	6	0
5999.999991	7	0
5999.999991	8	0
5999.999991	9	0
6000.000070	10	0

Record: 0

Records (0 out of 1785 Se

Figure 3: A portion of an attribute window, showing the appropriate column to select.

iv. Right-click on the column header and choose "Calculate."

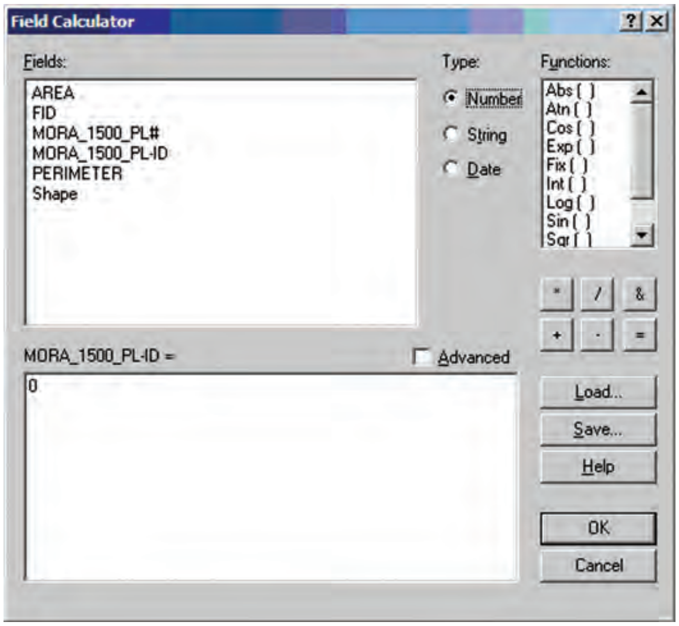
(1) Answer "Yes" when queried about editing outside of the editor.

(2) A Field Calculator window will pop up (fig. 4)

(3) In the "Fields:" area, simply click on the field label with the # symbol at the end.

(a) In figure 4, it is the field "MORA_1500_PL#".

(b) The field should show up in the bottom area, indicating that the "-ID" field will be calculated to be equal to the "#" field.



Fields:
AREA
FID
MORA_1500_PL#
MORA_1500_PL-ID
PERIMETER
Shape

Type:
● Number
○ String
○ Date

Functions:
Abs ( )
Atn ( )
Cos ( )
Exp ( )
Fix ( )
Int ( )
Log ( )
Sin ( )
Sqr ( )

☐ Advanced

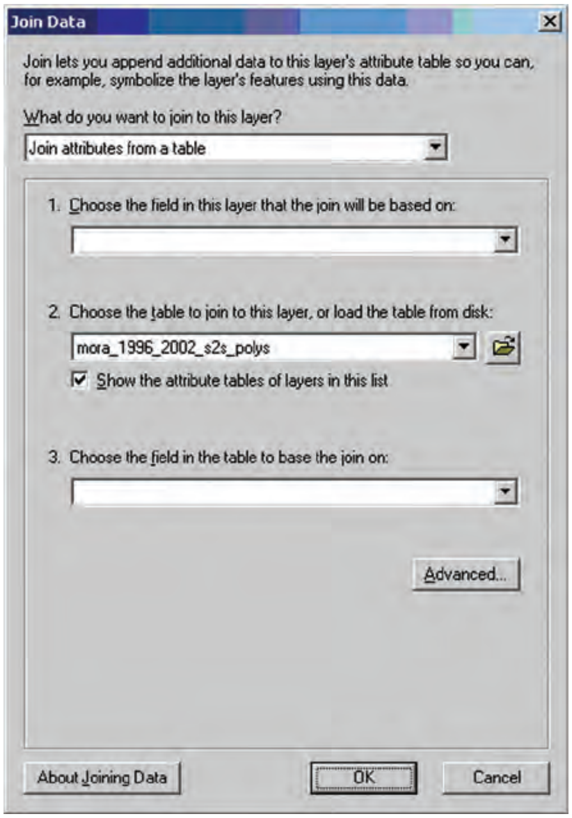
MORA_1500_PL-ID =
0

Figure 4. Field Calculator window.

c. Export the table
    i. Still in the Attributes window, select "Options/ Export." (Options is a button near the bottom on the right.)
        (1) Select "All Records" from the pulldown at the top of the window.
        (2) Click on the folder icon to change the name and type of the output.
            (a) Change the type from .dbf to text.
            (b) Change the name and location of the file to one such as: <park>_1500arc.txt
            (c) Do not add the table to the current map when prompted.
        (1) Optional: In a file explorer, change the name of the exported file.
            (a) Although ArcMap calls this file a text file, and assigns the extension .txt, it actually is a comma-delimited file.
            (b) Using a file explorer, change the filename extension from .txt to .csv
    ii. In Excel or a similar spreadsheet:
        (1) Open the text file.
            (a) If the extension was changed to .csv, it can be read directly into Excel, but if the filename extension is not changed, the import dialog will guide user through the steps.
            (b) Five columns will appear.
            (c) The column with increasing sequential numbers is the one from which random samples will be chosen.
        (2) Create a column of random numbers.
            (a) In a sixth column, type "random_ number" in the first cell.
            (b) In Excel: Type and paste to all cells the function RAND()
                (i) Because this number changes each time it is pasted, it **must** be captured once.
                    1. Once all cells have had a random number generated, copy the entire column, paste special, and select "Paste Values Only."
                        a. The random numbers will become locked.
        (3) Create a column with the rank of the random numbers.
            (a) In a seventh column, type "Rank" in the first cell.
                (i) Copy and paste the rank formula into all cells.
                    1. In Excel: Use ANK(<cell>, <all cells>, 1) to sort ascendingly.
                        a. Or use "Insert/Function," type Rank in the search window, and use the help wizard to select the correct cells.
                        b. Regardless of the method used for the first cell, the address for the range of cells against which to rank must be locked.
                            i. Put dollar signs ($) before the number components of the beginning and ending of the range of cells for the rank calculation.
                            Example: change
                            =RANK(F2,F2: F1786,1) to
                            =RANK(F2,F$2: F$1786,1).
        (4) Determine how many validation boxes will be used for validation.
            (a) Because the size of the change events is small and unknown, and the rate of change is unknown, it is difficult to know how many validation boxes are necessary.
            (b) Aim for a 5 percent sample. If there are 2,000 boxes in the spreadsheet, this would mean 100 boxes for sampling.
            (c) All boxes with a rank from the random number generation less than 101 will be used for validation.
        (5) Create an indicator for those boxes that will be used for validation.
            (a) In a new column, type "Use_it" in the first cell.
            (b) Insert a conditional formula into the next cell .

            i. In Excel: use the formula =IF(rank < 101, 1, 0)
                1. This will set the Use_for_validation column to 1 if the box is to be used for validation, and 0 otherwise.
                2. Copy the entire column and paste special, values only, to lock in the values.
                3. Delete all columns except for the column with unique IDs and the column “Use_it” that was just created.
        (6) At this point, the file should have two columns – one for the unique identifier of the boxes, and one with the “use label.”
        (7) Save this file (maintain it in the .csv format).
        (8) Close the file in Excel.
            (a) This is important! ArcMap will not allow joins if the file is open in the spreadsheet program.
            (b) This Excel file will then be linked to the coverage, once the coverage has been imported into the geodatabase.

4. Import the coverage of boxes into the feature dataset created in section IV.c. above in the geodatabase.
    a. Start ArcCatalog.
        i. Navigate to the directory with the geodatabase created in section IV.c. above.
            (1) Expand the database to see the feature dataset associated with this change interval (i.e. “mora_96_02”).
                (a) Right-click on the feature dataset, and select “Import/Feature Class (single).
                (b) Navigate to the polygon coverage just created in steps 1–3, and select the polygon-feature class from that coverage to import.
                (c) For simplicity, name the Output Feature Class Name in a manner that allows identification of the park, the year of the change detection, and the fact that this coverage is of the validation boxes.
    b. In ArcMap, remove the stand-alone polygon coverage from display by right-clicking on it in the layers window, and then select Delete. This will prevent later confusion.
    c. In ArcMap, bring in the newly imported feature class.
5. Add new fields to this feature class.
    a. See section IV, step 1.e. for how to add an item to a feature class (table 1).
        i. Add these items and types:
6. Then join this feature class to the Excel file indicating which polygons should be used for validation.
    a. In ArcMap:
        i. Join the .csv data back to the original boxes.
        ii. Right-click on the polygon coverage of the 1.5 km boxes, and select “Joins and relates/Join.”
            (1) The Join Data dialog will pop up (fig. 5).
        iii. Choosing answers to the three fields needed.
            (1) The field in this layer that the join will be based on is the one with unique IDs for each box. This is the column whose values were calculated in step 3.b. above.
            (2) The table to join to this layer is the spreadsheet just created.
            (3) The field in the table should be the same name as in the first field, since it was created from the layer in part 1.



Join lets you append additional data to this layer's attribute table so you can, for example, symbolize the layer's features using this data.

What do you want to join to this layer?
Join attributes from a table

1. Choose the field in this layer that the join will be based on:

2. Choose the table to join to this layer, or load the table from disk:
mora_1996_2002_s2s_polys
☑ Show the attribute tables of layers in this list

3. Choose the field in the table to base the join on:

Figure 5. Join data dialog window in ArcMap.

b. After this join, the column with the label “Use It” will contain ones and zeros. The feature class will then be subset so that only the polygons with a use-it value of 1 remain.

  i. In ArcToolbox, select Analysis Tools/Extract/Select.

  ii. The input feature is the feature class on which the join was just done.

  iii. The output feature class is the name of the layer that will be used to do the actual S2S interpretation. Name it with the park, the year of the change interpretation, and “S2S” to indicate that it is for the S2S.

  iv. Use the Expression to select only the polygons that have a Use It value of 1.

    (1) Click on the button with the letters “SQL” on it. In the expression builder, select the “Use It” column by double-clicking (to make it appear in the expression window in the bottom half of the window), then add “= 1” after it. Click OK.

    (2) This will create a new layer with only the randomly selected polygons.

c. Load this layer into ArcMap to ensure that only a subset of polygons remains. (See fig. 6 for an example at MORA.)

d. Indicate in each box the baseline condition of No Change (S2S type 1).

  i. Enable editing on the layer just created (Editor/Enable Editing).

  ii. Open the attribute editor for the layer.

    (1) Click on the first cell in the “Change_type” column, which currently should have the <Null> value.

      (a) Type in the number 1 in this cell.

      (b) Use the down arrow to select the next cell down, and type a 1. Do this for all of the boxes. This sets the background value of 1 to be no-change for all of the boxes that will be interpreted.

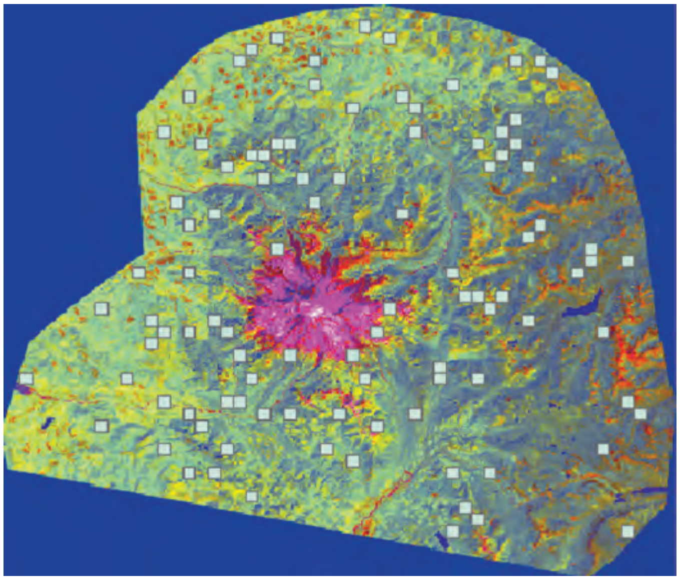


Figure 6. An ArcMap session showing the distribution of randomly selected validation boxes.

Method 2: Selecting Validation Boxes Based on Airphoto Availability

If airphotos are available and are to be used later to validate the S2S process, then S2S must be conducted at locations where airphotos can be used for such a validation.

1. Determine candidate airphoto pair.

  a. If airphotos are to be used to validate the S2S process, airphotos from the same areas must be available in both the early and late image dates. Because of missing airphotos, difficulty matching flightlines, etc., this is not possible for every single photo in a flightline.

  b. Determining the appropriate set of airphotos will be highly dependent on the particular airphotos available at a given park, and thus cannot be written in specific detail. Rather, we present here a sketch of the typical steps.

  c. Locate the center points of all airphotos in both years (early year and late year).

    i. This already has been done for most parks, as digitized flightlines are available for most current airphoto acquisitions. If not, photo-center points must be digitized by hand into a point coverage where the airphoto name and unique identifier on the photo itself are stored as one of the fields in the point-coverage database.

  d. Methodically search through all of the airphotos in 1 year and determine which photos in the prior year cover the same area. These will be candidates from which to draw samples for S2S validation.

    i. The airphoto validation of the S2S process will be matched to the size of the S2S validation boxes, which are 1.5 km on a side. This size was chosen to capture a large enough area on most 1:12,000 airphotos, but not so large as to require sampling on the edges of individual photos, where distortions are greatest.

    ii. Therefore, when looking for overlap areas between years, prioritize areas of overlap that are nearer to the centers of photos from at least one of the 2 years.

        (1) It likely will be useful to produce a mylar overlay with a 1.5-km box on it for reference. It typically is easiest to draw a box in a graphics program where the size of the box in centimeters can be specified, print the box on a piece of paper, then use a photocopier to copy the box onto a mylar or overhead transparency sheet.

        (2) The size of the box will be determined by the scale of the airphotos. For a 1:12,000 airphoto set, the length of 1,500 m on the ground corresponds to a line 12.5 cm long, or a box 12.5 cm on a side. Note that the scale of a given photo will be slightly different than the desired scale of the acquisition for the entire photoset, since the elevation under the plane will change. This will be handled later in the image interpretation, so the point of the mylar box is simply to provide a guide for the approximate area being interpreted later.

    iii. If at all possible, stereo viewing will be used for validation later, so it is best in this process to consider areas where stereo viewing can be achieved in both image dates. This requires that two sequential airphotos along a flightline are needed for an area to be a candidate for selection.

2. Develop a spreadsheet of possible airphoto-candidate pairs.

    a. Each area determined in step 1 will occupy a single row in the spreadsheet. For each of the two airphoto years, keep two columns to list the two photo IDs that will be used for the stereo interpretation of that year.

    b. It may be advantageous to include another column that will allow this area to be found easily again on the landscape, because once the photo areas are subsetted, 1.5-km boxes will be drawn manually for the area of overlap. Thus, the area used to determine possible candidate-airphoto pairs should be stored in some manner.

        i. The flightline information from each photo may be sufficient.

        ii. Or the X and Y coordinates of the upper-left corner of the 1.5-km box may be useful as well. To do this, the airphotos would need to be on a Geo-referenced dataset, such as one of the tasseled-cap images develop in SOP 2.

            (1) Open the tasseled-cap image.

            (2) Open the digitized flightline.

            (3) Use the flightline information to find the point on the landscape corresponding to the candidate area, and then use the cursor to note the X and Y coordinates of the upper-left corner of the box.

            (4) Store the X and Y coordinates in columns for that purpose.

3. Determine how many areas can be photointerpreted under budget considerations.

    a. Again, with no sense for the rate of disturbance, it is impossible to know how many samples will be needed to characterize the accuracy of the S2S process. More is always better, of course, and if only 1 change is captured per validation box, then a sample smaller than 30 likely will be inadequate for anything but the coarsest estimates of error rate. In determining this number, recall that only a small number of plots on any given airphoto will be photointerpreted, so the time per photo is relatively small.

    b. A sample covering approximately 5 to 10 percent of the park is an excellent target.

4. From the spreadsheet, use the random number generation and ranking process described in section 1 to pick a random subset of the candidate airphoto pairs for validation.

    a. In the spreadsheet developed in step 2 in this section, follow the sequence in method 1, steps 3c.(ii) above.

5. Create 1.5-km boxes for the validation areas.

    a. Because the grid of boxes is not available as it was in section 1 above, each 1.5-km box must be drawn in a new feature class in the geodatabase.

        i. Create a new feature class in the S2S feature dataset.

            (1) The S2S feature dataset was created in section IV.1.c.

            (2) Follow the steps for creating a new S2S feature class within this dataset.

            (3) Name this feature class with components of the name that indicate the park, S2S, and the years for which change is occurring. This feature class will first be used to conduct the standard S2S interpretation, and then a copy will be made for later interpretation with airphotos.

    (4) **When creating the feature class, add the same 7 fields that are listed in table 1 above (in method 1).**

b. Bring a single date tasseled-cap image into ArcMap for reference.

c. Bring the new feature class into the ArcMap session and make it editable.

  i. Select the Editor pulldown menu from the ArcMap session (see fig. 7), and select "Enable Editing." Ensure that the new feature class is selected as active in the layers list before enabling editing (i.e. its name is in the "Target:" window).

d. For each area selected for validation, do the following:

  i. Draw a 1.5-km box to delineate the interpretation area. As noted above, because these areas must be found from the spreadsheet of candidate areas, it is useful that those candidate areas have a tag or a coordinate pair that allows easy location.

    (1) To draw the box, ensure that the "Task:" window shows "Create new feature."

    (2) Click on the Pencil icon for sketching.

    (3) Left-click on the image to position the first vertex of the box that will define the first corner.

    (4) Click on the first point of the box. Right-click and select Distance and Direction fields to ensure a square box with lengths of exactly 1,500 m.

      (a) Tip: When the third vertex is drawn, right-click and select 'Square and Finish' to draw the fourth vertex.

    (5) Open the Attribute window for this layer (if not already open), and find the box that was just created (its row will be highlighted).

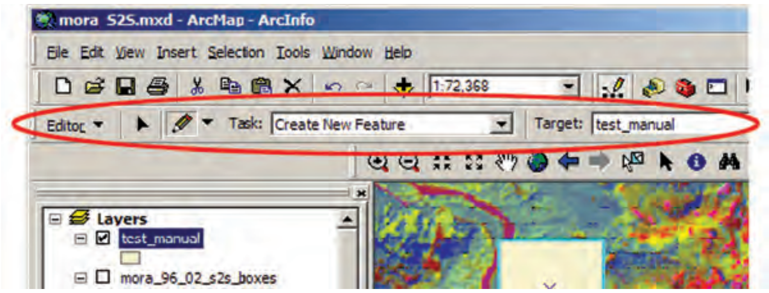
      (a) Click on the cell corresponding to the "change_type" column. Type in the number 1 in this box, indicating that the baseline condition of the box is no-change (see S2S codes in table 2).

  ii. Save after each box is coded.

  iii. At the end of this process, all of the boxes that will be used for S2S validation and the subsequent airphoto validation will be digitized and saved into the feature class within the accuracy assessment geodatabase.

Table 1. Fields to add to feature classes used in satellite-to-satellite interpretation.

Field name	Field type
Change_type	Short integer
Dist_agent	Short integer
Certscore_change	Short integer
Certscore_dist	Short integer
Box_id	Short integer
Event_id	Long integer
Comments	Text
Interpreter	Text



Task: Create New Feature

Target: test_manual

Figure 7. ArcMap interface, with a red oval indicating the area with editing options referred to in this section.

Table 2. Satellite-to-satellite interpretation change classes.

Satellite-to-satellite code	Description
1	No change.
2	Water to rock/soil.
3	Water to partial vegetation cover.
4	Water to complete vegetation cover.
5	Rock/soil to water.
6	Partial vegetation to water.
7	Complete vegetation to water.
8	Increase in broadleaf.
9	Increase in conifer.
10	Increase in vegetation.
11	Decrease in broadleaf.
12	Decrease in conifer.
13	Decrease in vegetation.
14	Increase in snow.
15	Decrease in snow.

VI. Satellite to Satellite (S2S) Interpretation of Changes

Once validation boxes have been located and entered into the geodatabase, interpretation of changes can begin. S2S interpretation is based on the principles applied to airphoto interpretation. The human brain brings in spatial context to help interpret patterns of shape, color, and text to determine what is happening in an image.

The differences between aerial photo and satellite interpretation are the scale of the analysis and the spectral depth of the respective image types. In high-resolution aerial photos, individual elements on a landscape (i.e. trees, small patches of rock, or small streams) are interpretable at a scale familiar to a human. In satellite imagery at the scale of Landsat TM/ETM+, such detailed features individually are not discernible. This requires some degree of retraining for interpretation. Satellite imagery provides an important advantage over aerial photos in its increased spectral depth. Landsat imagery provides spectral information about the surface in the near infrared and midinfrared regions, both of which are extremely useful for distinguishing different cover types. The tasseled-cap transformation captures the variation in the six visible, near-infrared, and midinfrared bands of TM with just three axes, allowing display on standard digital monitors in the three color guns (red, green, and blue). Color-infrared photography, when available, could provide insight into the near-infrared reflectance of the surface, but not typically into the midinfrared reflectance. The added spectral depth and interpretability afforded by the tasseled-cap transformation of TM/ETM+ imagery requires further training to interpret, but increases the ability of an interpreter to describe conditions.

Because of the need for training, the authors have provided an image library to be used in conjunction with the S2S interpretation process. Before S2S interpretation begins, interpreters should use this library to gain familiarity with the main cover types and their representations in tasseled-cap space. The library associated with this version of the protocol is “NCCN_Image_library_v1.0.ppt”.

Table 3. Interpreting tasseled-cap difference images when early image is subtracted from late image.

Color	Direction of tassled-cap change: early to later	Interpretation
Grey	No change	No change
Bright red	Increase in brightness	Dramatic loss in vegetation, either because of disturbance or because of phenology; OR presence of cloud in later date.
Dark red	Subtle increase in brightness	Often associated with loss of vegetation from areas that were very bright and green at early date—a good example is a disturbance in shrub field or young hardwood/conifer plantation
Light blue to white	Increase in all bands, wetness especially	Increase in vegetation, especially conifer. Common in clearcuts that were vegetated partially in early date and which are increasing in HW and conifer; OR an increase in snow from a relatively vegetated starting point; OR presence of cloud in early date and conifer in later date.
Dark blue	Increase in wetness, potential decrease in brightness	Increase in conifer percent cover. Common in clearcuts transitioning from hardwood or shrub dominance to conifer dominance; OR increase in shading in later date (take into account date of image); OR presence of cloud in later date; OR increase in water (channel changes).
Bright yellow	Increase in brightness and greenness	Typically, increase in broadleaf component, either shrub, grass or hardwood tree, caused either by recovery from disturbance or by phenology; OR presence of cloud shadow in the early date and vegetation in the later date.
Bright green	Increase in greenness	Increase shrub/grass/hardwood cover from a condition that was bright before, but not green—typically found when river beds come back to vegetation, but also common where snow was present before and now is gone.

The S2S process also requires that the interpreter understand how to interpret spectral patterns in images of the mathematical differences between two tasseled-cap images. Table 3 provides an interpretation key for difference imagery. This assumes that the image is displayed in a viewer with brightness in red, greenness in green, and wetness in blue. See SOP 2 if this has not been set as the default for viewing.

The interpretations in table 3 provide a first approximation of the likely change that has occurred. The interpreter must then apply knowledge of the conditions before and after the change (using direct interpretation of the tasseled-cap images), knowledge of the ecosystem, and spatial context to further hone the interpretation. Finally, reference to a single-date, high-resolution digital orthoquad can improve understanding of the potential land-use condition in which interpretation is occurring. A final change call is made and categorized into one of 15 categories, listed in table 2. This table can be printed out separately to provide an easy reference when onscreen editing is done.

In addition to determining the change class, the interpreter makes a call about the disturbance agent (table 4). This is drawn from the combination of the spatial context and the observed spectral change.

In assignment of both change class and disturbance agent, the interpreter may have varying degrees of certainty. Degrees of certainty can be quantified using simple rules that describe the elements of the decision-making process when a change call and disturbance agent are identified. Table 5 lists the conditions and scoring for certainty scores in the change calls and the disturbance agents.

Table 4. Satellite-to-satellite disburbance agents.

Satellite-to-satellite disturbance agent code	Agent
1	Landslide.
2	Avalanche chute.
3	Fire.
4	Insect.
5	Fire or insect.
6	River disturbance.
7	Clearcut.
8	Unknown.

Table 5. Certainty scoring for change classes.

[Score is assigned by the relative degree of agreement with the conditions statement, with zero indicating that the condition is not found. **Change call:** Total certainty score ranges from 0 to 4; **Disturbance agent:** Total certainty score ranges from 0 to 3]

Condition	Certainty points
Change call	
Spectral change vector is distinct from change vector of similar starting types in surrounding area	0, 1, or 2
Area of spectral change is large and consistent within “patch”	0 or 1
Spectral condition of endpoints is interpretable and consistent with change call	0 or 1
Disturbance agent	
Shape is consistent with disturbance agent	0 or 1
Size is consistent with disturbance agent	0 or 1
Landscape position and context are consistent with disturbance agent	0 or 1

A variety of factors could lead to false positives in the automated change algorithms, and these must be filtered out by the interpreter. To achieve this, the interpreter must be aware of the factors that can lead to false positives in the automated algorithms. The following is a partial list of four major effects that the interpreter can take into consideration when evaluating the spatial patterns of spectral change.

Geometric Misregistration

Even with excellent image-wide geometric registration of two images, local distortions can remain. These are mostly inconsequential, but if they occur at a boundary with sharply contrasting spectral types, even a small geometric shift can result in large apparent shifts in spectral value. Thus, misregistration will manifest itself most strongly around small patches and linear features that contrast with their surrounding matrix (i.e. avalanche chutes, rivers, or small openings in the forest). A difference image will show that large change has occurred, but examination of the two source images separately will show that the shape and color of the area has not changed. This indicates that misregistration has caused the spectral change. Another clue comes from the shape of the apparent spectral change in the difference image. If the difference is only at the margins of a small patch, and the complementary spectral change occurs on the other side of the patch, then misregistration also is implicated. In cases where it is unclear whether misregistration plays a role, indicate the change type but give a correspondingly low confidence score.

Illumination Differences:

After the summer solstice, the sun is lower at the time of each successive Landsat image acquisition, so the shadows get longer. Landsat images are acquired at approximately10:30 a.m. local sun time, meaning that the sun is approximately in the southeast, although the azimuth of the sun also varies with the seasons. The illumination variability caused by the different angles of the sun is sometimes subtle, but can cause some shadowing effects on the northwest aspects of slopes. For example, a small opening in the forest in 1 year may appear to go away in another year, simply because the patch has fallen into shadow in the latter date. This can happen even with a difference of just a week or 10 days in the date of image acquisition, especially as days change more rapidly in late August and September. If it seems likely that shadow may have caused difference, do not include it.

The decision is not always straightforward. Illumination will cause bulk changes in reflectance for entire hillsides, but so can other effects. For example: Insect infestation can affect entire hillsides in forested areas.

If it is difficult to tell, label the change, but score the certainty appropriately. In this case, because the spectral condition is not interpretable easily and because the signal may or may not be similar to other conditions, table 5 would indicate a certainty score of 2.

Year-to-Year Phenology Changes

Because the date at which cloud-free imagery can be acquired varies from year to year, and because of climatic variations between years, the phenological state of deciduous vegetation often varies from image to image. This is true especially at the alpine/subalpine interface, where snowpack duration drives much of the timing from year to year. Changes in phenological state will have spectral manifestations that, although corresponding to an actual change in the state of the vegetation, do not represent a change in cover type or quality that is of interest in this work. Automated spectral change-detection methods will be fooled by this spectral change, but a human interpreter can often account for such phenological change by comparing the spectral changes in deciduous vegetation in one location with the overall spectral changes of similar vegetation in other similar parts of the landscape. If spectral changes are definitely associated with phenology, change should not be labeled. If the change call is difficult, the certainty score should be adjusted accordingly. If all of the vegetation in a given type is experiencing similar changes, then the first change-call condition in table 5 is not met, so the maximum certainty score is 2, with likely lower scores because the other conditions are not met.

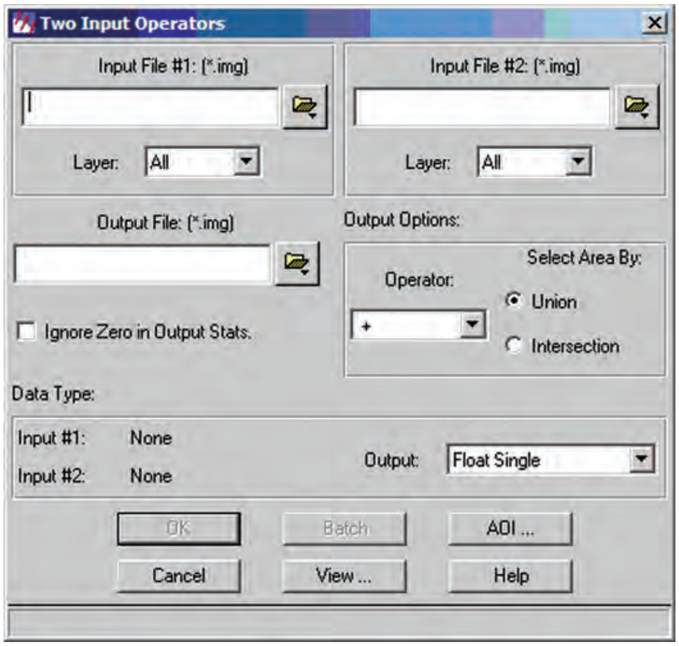
Problems With Radiometric Normalization

Radiometric normalization with the MADCAL algorithm appears to be quite robust, but no automated normalization process is perfect. The magnitude of errors in the fit between the two image years often scales with the brightness of the target. Thus, small errors in radiometric normalization can lead to spectral differences that are quite evident in the difference imagery used for interpretation. When the two end-point images also are referenced, however, there is often no apparent difference in the condition, because each image is displayed according to its own display scaling equation that compensates for the scaled error. Thus, it is often possible to rule out the apparent changes that are caused by radiometric error.

VII. Imagery Setup and Satellite-to-Satellite Interpretation Process

The actual setting up of imagery and S2S interpretation process is as follows:

1. Create a tasseled-cap difference image for interpretation.
    a. In ERDAS Imagine, do the following steps:
        i. From the main icon panel, click the Image Interpreter button.
            (1) This is the icon with the magnifying glass over a small raster box.
        ii. Select Utilities/Operators
            (1) The Two Input Operators dialog window will pop up (fig. 8)
            (2) The “Input File #1:” is the LATER date image (the changed image).
                (a) Use the entire study area, tasseled-cap image used in SOP 3 for the change detection (not the aspect-subsetted image).



Layer: All

Layer: All

☐ Ignore Zero in Output Stats.

Operator: +

● Union
○ Intersection

Input #1: None
Input #2: None

Output: Float Single

Figure 8. Window used to create difference images.

        (3) "Input File #2" is the EARLY date image (the baseline image).
        (4) The output file should be named to indicate both parent images, and should include the word "minus" in it, to clearly indicate that it is a difference image.
            (a) *This image is the "Difference Image" referred to subsequently in this section.*
        (5) Change the "Operator:" to the minus sign.
        (6) Change the output type to Signed 16-bit.
        (7) Click OK.

2. All of the interpretation is done in ArcMap.
    a. Ensure that the following layers are present in the ArcMap project.
        i. The baseline tasseled-cap image (the baseline image was defined in SOP 3).
        ii. The changed tasseled-cap image (the image from the later year).
        iii. The difference image.
        iv. A DOQ specific for the area being interpreted.
            (1) Install the Terraserver add-in to ArcMap.
                (a) Terraserver provides free access to digital orthoquads that will be used to aid the interpreter to understand landuse in an area.
                    (i) If Terraserver is not already installed in ArcMap, see information at the ESRI web site for instructions.
                    (ii) Generally, the steps for ArcGIS 9.0 are as follows:
                        1. At the ESRI support website (support.esri.com), click on downloads and search for Terraserver.
                        2. Download and install according to ESRI instructions
                        3. This will involve the .NET architecture, which, if not already installed, also will need to be installed.
                        4. Once Terraserver is installed, it can be viewed within ArcMap using View/Toolbars/Terraserver.
        v. The feature class that holds the validation boxes.
            (1) Select this layer and then enable editing on this layer, if not done already.
                (a) Select Editor/Enable editing.
    b. Begin with the first validation box where interpretation is to begin (created either by method 1 or 2). It likely is that a systematic interpretation from top to bottom or left to right in the study area will be easiest.
        i. Open the attribute table in the feature class that holds the validation boxes.
            (1) Locate the current validation box in the attribute table.
                (a) The selection tool in ArcMap (a small white arrow next to a square with three small polygons inside) can be used to click and drag over the area of the box, selecting it.
            (2) Fill-in the information on the box itself.
                (a) Label the box with a unique numerical sequential ID, beginning with 1.
                (b) There is no event ID for the box, which is no-change.
                (c) Assign a change type of 1 (no-change; see table 2) by typing directly into the "change_type" cell for the row of this box, if the number is not already there.
                (d) Assign a certainty score of 4.
                    (i) This sets the background to the no-change value.
    c. With the difference image as the visible layer (checkmark in the Layers window), methodically work through the entire 1.5 km by 1.5 km box looking for spectral evidence of change.
        i. In the difference image, no-change is shown with grey tones.
        ii. Bright and colored areas in the difference image indicate large spectral change between years. Examine each patch of such potential change.
            (1) Zoom into the area with the potential change.
            (2) Turn off the difference image by unchecking the box. Note which of the two tasseled-cap images is now visible – it will be the image that is higher up in the list of the layers.
            (3) Then turnoff that image by checking its box

off, and flicker between the two tasseled-cap images by checking and unchecking that box.

            (4) Evaluate whether the change corresponds to real change, or is caused likely by one of the confounding factors listed above (geometric misregistration, illumination difference, year-to-year phenology change, or radiometric-normalization problems).

        iii. **Ultimately, the interpretation of change must occur by viewing the before and after images, not the difference image.** The difference image is useful as a means of focusing on areas that may have changed, but because of the many possible ways that spectral change may occur, it cannot be used to make the change call.

        iv. Disturbance agents (tables 4 and 5) are interpreted using spatial context and the shape of the area experiencing change. Note that S2S classes that involve an increase in vegetation amount are not assigned a disturbance agent, under the assumption that a disturbance agent is used only to describe agents that remove or diminish vegetation.

        v. If change has occurred, digitize it on the screen.

            (1) Select the pencil icon from the ArcMap icon panel just to the right of the Editor pulldown menu.

            (2) Use the pencil to draw the vertices of a polygon that captures, as precisely as possible, the feature that has changed.

                (a) These features will be later turned into a raster layer. Therefore, the polygon boundary should be drawn to incorporate all pixels where change has occured.

            (3) Double-click on the last vertex.

        vi. The new feature will appear in the attribute table for the feature class.

            (1) Enter the box number in the box cell. The box number is the same for all changes that occur within a validation box.

                (a) If method 1 was used to create boxes, then the box number can be taken from the Object ID of the layer. If method 2 was used, then box numbers are assigned sequentially as they are interpreted.

            (2) The event number is the number of the change event occurring within the box. Restart this numbering for each new validation box. Thus, each box with a change event will have a polygon with the box number and an event ID of 1.

            (3) Type in the change type, disturbance agent, and certainty scores in each of the boxes.

            (4) Type in comments on the change call. In particular, reasons for low certainty scores are quite useful for later interpretations.

        vii. In the Editor pulldown menu, select "Save Edits" before moving on to the next change.

    d. Repeat this process for all of the validation boxes.

    e. Select "Edit/Stop Editing" to stop editing the feature class.

VIII. Converting S2S Polygons to Raster

The polygons digitized in section VII will be converted to raster layers so that accuracy assessment can be run.

1. In ArcToolbox, select "Conversion Tools/To Raster/Feature to Raster."

    a. The input feature is the feature class that was just populated with S2S interpretation calls.

    b. The output location is the folder where the S2S interpretation exists. This typically should be in the same folder that holds the parent database.

    c. The name of the output grid should identify the park, the years, and the fact that this is an S2S product. The total name of grids must be 13 characters or fewer.

        i. Example: mora96_02_s2s

    d. Select the cell size to be 25 m. This will match with the pixel size of the imagery.

    e. The value for the grid is the change type.

VIX. Accuracy Assessment of Change Detection

The detection of change is the first step in monitoring. Therefore, the first need for accuracy assessment is determining whether the automated change-detection algorithms from SOP 3 separate areas that have changed from a background of areas that have not changed. To assess this accuracy, both the S2S and the change images from SOP 3 must be collapsed into a change/no-change state, and then a standard accuracy assessment performed.

From the population of cells in the gridded S2S change coverage, a sample of small, 2 by 2 pixel plots will be used to compare the S2S calls to the change product produced in SOP 3. The sampling process will be conducted in ERDAS Imagine.

1. First, the grid must be imported into Imagine.
    a. Click on the Import icon in the main Imagine icon panel.
    b. Select the type to be "Grid" from the pulldown list.
    c. Navigate to the folder where the grid from section VIII was placed in both the input and output-file areas.
    d. Select the grid from the list for the input file.
        i. Imagine automatically will fill-in the name of the output file. NOTE: This is the same as the folder that houses the original grid, so it actually will change folders *without warning*. Manually navigate backup one folder level and manually type in the name of the output file, including the .img, to avoid this automatic change of directories.
    e. Click OK.
        i. In the Import Grid window, select "Import Options," and change the Output Data Compression to "Run Length Compression."
            (1) This will greatly reduce the size of the file, since most of the file is background zero area that can be represented with small file size.
        ii. Change the output-data type to unsigned 8-bit.
            (1) This will allow the image to be viewed as a thematic layer in Imagine, which is necessary for Imagine's accuracy assessment tool.
        iii. Click OK in the Import Options window.
        iv. In the Import Grid window, click OK to start the import.
2. Change the type of the image from continuous to thematic
    a. Open the file in a viewer.
    b. In the viewer, click the ImageInfo button to bring up an ImageInfo button.
    c. Select Edit/Compute statistics.
        i. Change the skip factor to 1 for both X and Y
        ii. Click OK.
    d. Once the statistics have been calculated, the layer can be changed to a thematic type.
        i. Select Edit/Change Layer Type.
        ii. Confirm that the "Type:" field in the Layer Info section of the ImageInfo window now reads "Thematic".
        iii. Close the ImageInfo window.
3. Recode all of the change categories into one of two categories: no-change or change.
    a. Save a copy of the thematic image under a new name.
        i. In the viewer, select File/Save Top Layer As, and save it under the same base name, but add "_chnoch" in the file name.
    b. In the viewer of the change/no change file, select "Raster/Recode."
        i. For all rows 2 through 15, change the New value to 2.
            (1) Change is now indicated with the number 2. No-change has a value of 1, and areas that were not interpreted remain 0.
    c. In the Viewer, select "File/Save Top Layer," and agree when it asks whether the file should be saved since it will change pixel values.
    d. Then reopen the file, using the file open dialog, to force Imagine to recognize the change.
4. Open the change/no-change image in an Accuracy Assessment window.
    a. From the main icon panel, select the "Classifier" icon, then "Accuracy Assessment" from the pulldown menu.
        i. The Accuracy Assessment window will pop-up (fig. 9).
    b. Select File/Open, and open the classified image file of the change_types that was just created above.
        i. No obvious change will take place.

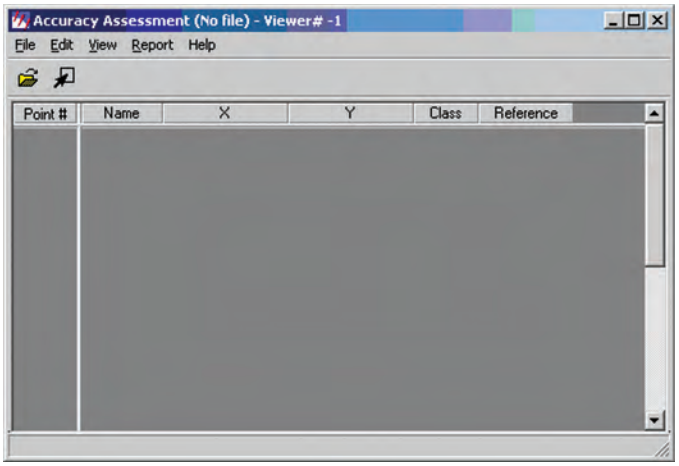


Figure 9. Accuracy assessment window in Imagine.

Window Size: 3

Window Majority Rule:

○ Clear Majority

● Majority Threshold

Threshold: 4

No Majority Action:

● Discard Window

○ Use Center Value

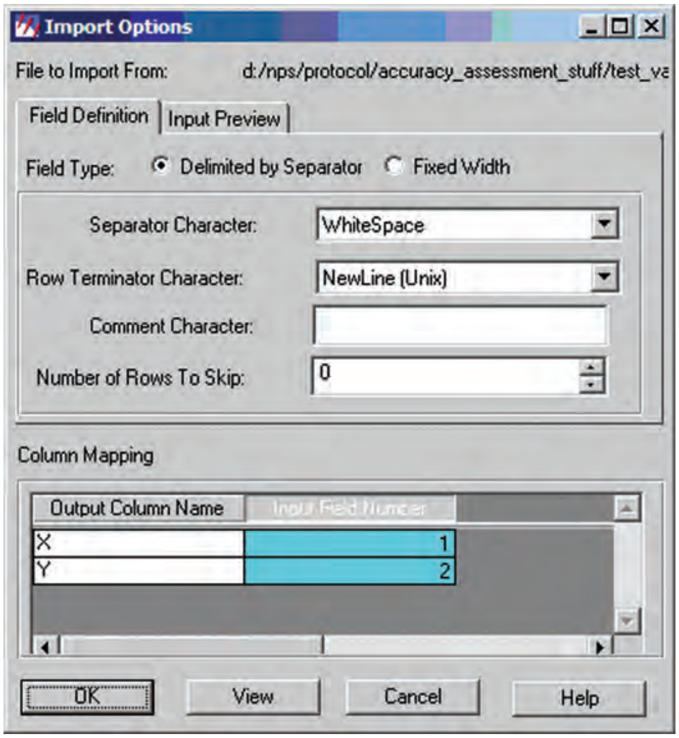
☑ Report Windows

Figure 10. Class-value assignment options window.

5. Select validation points.
   - a. Set-up the options.
     - i. In the Accuracy Assessment window, select “Edit/Class Value Assignment Options.”
     - ii. The Assignment Options window will appear (fig. 10).
     - iii. Retain the window size of 3.
     - iv. Change the Window Majority Rule to “Majority Threshold” and set the “Threshold:” to 4 (as shown in fig. 10). This defines the minimum number of pixels within the 3 by 3 window needed to achieve “majority” class status. By setting to 4, only 4 of 9 pixels need be the same for a potential accuracy assessment plot to be labeled and used.
   - b. Have Imagine find the points.
     - i. Add in the Accuracy Assessment window, select “Edit/Add Random Points.”
     - ii. The “Add Random Points” interface will pop up.
       - (1) The number of points should be as large as possible. It will be guided by the number of change events captured in the S2S interpretation above. The goal is a balanced sample of change and no-change classes. If there are relatively few areas that have changed, there will simply not be much “room” to place change samples.
         - (a) Select the largest number of points that reasonably will fit within the S2S interpreted change areas.
       - (2) Change the distribution parameters to “Equalized Random.”
       - (3) Click the “Select Classes” button.
         - (a) A Raster Editor will appear. Click and drag on the rows for values 1 and 2 (not value 0) to select only the change and no-change classes for picking random points.
       - (4) The routine will search for points. If it runs out of trials before the desired number of points is reached, it will ask if more runs should be done. Repeat this process until the desired number of points is run, or until the increase in points per run is negligible.
   - c. Display the class values for the random points.
     - i. In the Accuracy Assessment window, select “Edit/Show Class Values.”
   - d. Display the points on the images.
     - i. In the Accuracy Assessment window, select “View/Select Viewer.”
       - (1) Click in the viewer with the change/no-change image in it.
       - (2) The points should appear as a set of labeled crosshairs.
   - e. Export the points to a file.
     - i. In the Accuracy Assessment tool, select all of the rows.

        (1) Right-click on any of the greyed-row-number boxes on the left of the table, and select “Select All.” All of the rows should be highlighted (in yellow unless the user has changed preferences).
    - ii. In the Accuracy Assessment tool, select all of the columns.
        - (1) Click and drag across all five columns (Name, X, Y, Class, Reference). Now the entire matrix should be highlighted in a new color.
    - iii. Export the points.
        - (1) Right-click anywhere in the column-headers and select “Export.”
        - (2) Change the format to comma-delimited.
            - (a) Click on the Options button and change the separator character to “comma”.
        - (3) Save the points in the same folder where the accuracy assessment is being conducted.
            - (a) Name the file with the park, year of change, and include a component of the filename “_s2s_validationpts”.
    - iv. Change the extension of the file from .dat to .csv
        - (1) Do this in the Windows Explorer file. Single-click on the filename to highlight it, click the F2 button, and then manually type in “csv” instead of “dat”.
- f. Make a copy of the file with the coordinates only.
    - i. Users will need a version of the file with the coordinates to extract the values from the change image.
    - ii. In the Windows file explorer, single-click on the filename, right-click and select “copy.” Click elsewhere in the Windows folder and paste it.
        - (1) Rename the file (in the same manner that it was changed to .csv in the previous step), adding in “_xyonly_” to the filename.
    - iii. Open the “_xyonly_” file in Excel or a similar spreadsheet.
    - iv. Select and delete all of the columns except the X and Y coordinates.
    - v. Save the file.
    - vi. In the Windows Explorer, change the filename extension on the _xyonly_ file to “.txt” instead of “.csv”, now that it has been changed. This will allow Imagine to read it.
- g. CLOSE the Accuracy Assessment window (File/Close).
    - i. This is necessary to get a fresh start on the difference image.

6. Convert the change image created in SOP 3 into a change/no-change image.
    - a. The change/no-change image from S2S will be used to assess how well the product from SOP 3 detects change. To compare like products, the product from SOP 3 must be collapsed to a change/no-change image.
        - i. Follow steps 2 and 3 above, only apply them to the classified change image from SOP 3.
        - ii. This image will be referred to as the “SOP 3 change/no-change image”
7. Extract change calls from SOP 3 change/no-change image.
    - a. Open the SOP 3 change/no-change image in a new viewer in Imagine.
    - b. Open the Accuracy Assessment tool.
    - c. Select “File/Open” and select the SOP 3 change/no-change image.
    - d. Select “Edit/Import User Defined Points.”
        - i. Navigate to the _xyonly_ file created in step 5 above. Once selected the “Import Options” window will appear (fig. 11).
        - ii Change the “Separator Character:” to a comma.
        - iii Imagine will then import the points and add its own IDs.
            - (1) Confirm that the IDs assigned automatically here are the same as those already saved in the “s2s_validationpts.csv” file from step 5.e. above. Check a few random points through the list in both files and ensure that the X and Y coordinates are the same for a given ID number.
                - (a) If not, this indicates an error in the steps above. Repeat the process and make sure not to resort or otherwise manipulate the points in the spreadsheet or the cell arrays in Imagine.
    - e. Extract the values from the SOP 3 change/no-change image.
        - i. Change the class assignment options
            - (1) Select “Edit/Class Value Assignment Options.”



File to Import From: d:/nps/protocol/accuracy_assessment_stuff/test_va

Field Type: ● Delimited by Separator ○ Fixed Width

Separator Character: WhiteSpace

Row Terminator Character: NewLine (Unix)

Comment Character:

Number of Rows To Skip: 0

Output Column Name	Input Field Number
X	1
Y	2

Figure 11. Import options window for bringing coordinates into the accuracy assessment tool.

            (a) Change the majority rule to 4 pixels.

        ii. Extract the points.

            (1) Select "Edit/Show Class Values."

8. Copy the S2S derived values for change/no-change into the Accuracy Assessment tool.
    a. In the Excel spreadsheet showing the "validationpts.csv" file (step 5.e. above), select and copy the entire column of change/no-change values that were extracted from the S2S image.
    b. In the Accuracy Assessment tool, left-click on the column labeled "Reference," then right-click and select "Paste." The column should be filled with the values just copied from the Excel spreadsheet.
9. Develop an accuracy assessment report.
    a. In the Accuracy Assessment tool, select "Report/Accuracy Report."
    b. Imagine will produce an accuracy assessment text file.
    c. This report will include standard accuracy assessment metrics: Users Accuracy, Producers Accuracy, and the Kappa Statistic.
        i. See the following two references for information on interpreting and reporting accuracy assessments of classified maps: Congalton and Green (1999) and Foody (2002).

X. Accuracy Assessment of Change Labeling

Ideally, the process in SOP 3 will not only detect change well, but will label it correctly. The process of determining accuracy for the change labels is identical to the process in section IX, except that the full 15-class S2S and change products will be used.

Often, many of the 14 classes of change will have few–if any–examples. Thus, the accuracy-assessment matrix will be sparse, and the accuracy of some classes will be based on very few examples. These sparse classes must be interpreted with care.

1. Close any viewers, Excel files, and accuracy assessment tools that are open, to prevent confusion.
2. In a new viewer, open the S2S image imported in step 1 of section IX.
3. Open the Accuracy Assessment tool.
    a. Select "Open" and find the S2S image from step 2.
4. Select Edit/Import User Defined points.
    a. Load the "_xyonly_" points from step 5.f. in section IX.
    b. Change the Options to a majority of 4 for class assignment (step 5.a. in section IX).
    c. Select "Edit/Show Class Values."
5. Export these points (with the class values from the full 15-class S2S image now) to a new excel file, with a part of the file name "_s2svalidationpts."
    a. See step 5.e. in section IX for instructions.
6. Close the Accuracy Assessment tool.
7. In a new viewer, open the SOP 3 change image (with all 15 S2S classes).
8. Open a new Accuracy Assessment tool.
    a. Load the "_xyonly_" points again.
    b. Change the Options to a majority of 4 for class assignment (step 5.a. in section IX).
    c. Select "Edit/show class values,"
        i. The SOP 3 change image values for change are now in the Class column.
    d. For the Reference column, copy and paste the reference values from the "_s2svalidationpts" spreadsheet developed from step 5.
9. Have Imagine conduct a new accuracy assessment.

Again, note that the accuracy of classes with few points can be difficult to interpret because a single point labeled correctly or incorrectly plays a large proportionate role.

XI. Photo-Based Accuracy Assessment

If airphotos are available for both dates of the change interval, an airphoto interpretation is feasible under budget constraints by using the following steps.

1. Overview of process:
    a. Use the validation points developed in section IX as locations for airphoto validation.
        i. Save the points from section IX as an annotation layer.
            (1) In the Accuracy Assessment tool linked to the S2S validation image, with the coordinates and IDs of the validation points visible in the cell array of the window, select "File/Save as Annotation."
        ii. Load this annotation layer into a viewer with the tasseled-cap image from either the early or later year of the change interval.
        iii. The validation points will appear on the image, along with their IDs, in the viewer.
    b. Visit each point in-turn, and record the photo-interpreted condition of the change in a spreadsheet where each row corresponds to a single-validation point.
        i. Locate the points on the image, and then locate the appropriate photos for validation (both the early and later photos). Because the validation boxes were selected with method 2 (section V above), all of the boxes should be readily linked with an airphoto pair that can be used for validation.
        ii. The change calls that are being validated with the airphoto interpretation should follow the S2S change categories. See step 2 below for more information.
    c. Once the points have been assigned S2S-type calls from the airphoto interpretation, the column with the S2S-type calls can be copied and pasted into the Accuracy Assessment tool along with the same calls made from the satellite image (those loaded in step a. above).
    d. Accuracy assessment and reporting follows the approaches described in section IX.
        i. As described here, the accuracy statistics represent the assessment of the accuracy of the S2S interpretation, not the original change product.
2. Suggested rules for photo interpretation.
    a. For consistency with the S2S format, it is suggested that the same 15 classes of change and 8 classes of disturbance agent (tables 2 and 4, respectively) be determined from the airphoto interpretation.
    b. As with the S2S interpretation, it is not always possible to be certain about some types of change. In fact, the process of determining change with airphotos brings with it new uncertainties. Therefore, additional considerations must be taken into account.
        i. First, it is sometimes difficult to take a plot on an image and find its location on an aerial photo. This leads to some uncertainty in position, which can be scored.
        ii. Second, cover type and condition can be ambiguous based on tone alone, sometimes context is needed. Moreover, some changes in condition or quality can be inferred simply from ecological knowledge provided by the high-resolution detail of the spatial context of change. But the certainty of type change versus condition change requires that the S2S change calls be separated into two broad categories: those that involve changes in land-cover type (water to vegetation) and those that involve change in land-cover quality (increase in proportions of broadleaf cover). Table 6 lists how the original 15 classes of S2S change are classified according to type or quality.
        iii. Given this background, table 7 provides a set of rules for assigning certainty scores to changes interpreted from airphotos.

Table 6. Classifying satellite-to-satellite interpretation change classes by type or quality change.

[–, not applicable]

Satellite-to-satellite code	Description	Type or quality?
1	No change	–
2	Water to rock/soil	Type
3	Water to partial vegetation cover	Type
4	Water to complete vegetation cover	Type
5	Rock/soil to water	Type
6	Partial vegetation to water	Type
7	Complete vegetation to water	Type
8	Increase in broadleaf	Quality
9	Increase in conifer	Quality
10	Increase in vegetation	Quality
11	Decrease in broadleaf	Quality
12	Decrease in conifer	Quality
13	Decrease in vegetation	Quality
14	Increase in snow	Type
15	Decrease in snow	Type

Table 7. Certainty scoring for airphoto-based change detection.

[Total score incorporates a score for location uncertainty (1–3) and for either type or quality]

Apply to which type of plots?	Certainty statements	Score
All plots	*Plot can be located only by reference to relatively distant features.*	1
	Plot can be located within a patterned area, but not entirely clear how the satellite patterns match with photos.	2
	Plot can be unambiguously located in both satellite and photos, because of unique patterns in both image and photos.	3
For "type" changes only	*Cover type is ambiguous, and tone and context help only slightly.*	1
	Cover type is somewhat ambiguous in tone, but context helps make a call.	2
	Cover type is unambiguous in terms of tone and patterns, and is confirmed by context.	3
For "quality" changes only	*Direct observation of changes in cover condition is not possible, but ecological knowledge of type indicates that change is likely.*	1
	Direct observation of changes in cover condition is not possible, but knowledge of ecological conditions indicates that change is probable.	2
	Cover change is visible directly either in terms of percent cover or size of individual trees/shrubs in plot.	3

iv. For changes in cover percentages, grid-based photointerpretation of percent cover may be desired. The following methods are suggested:

(1) With reference to the scale of the aerial photos, develop square plots on transparencies. These plots should be small enough to capture a relatively homogeneous cover condition, usually <0.5 ha, but large enough to be located unambiguously on both imagery and photos.

(a) The square plots should include a grid of small points at which cover type is photo interpreted. The number of grid points that can fit within a square depends on the scale of the photos. For 1:12,000 photos, a grid of 20 points (arranged in a 5 by 4 matrix) is sufficient.

(2) For each plot, use the transparency to label cover type at each of the grid points.

(a) Cover types depend on the park, but should at least separate soil/rock, conifer, hardwood trees, shrubs and grass. Further distinction of type may be desired, but would be more than needed for the S2S change validation.

(b) Record the total count of each cover type for each plot.

(c) Do this for the early date photo and the late date photo.

(d) Record these values in a spreadsheet for archiving.

(e) Based on changes on cover type, ascribe the appropriate S2S change class call to the plot.

v. After all photo-interpreted changes have been recorded, the accuracy assessment can be conducted to validate the S2S interpretation.

3. As noted in the introduction to section V, if the aerial photos do not cover enough of the desired area, S2S interpretation may need to be applied both to areas where photos are available and to a larger area where the airphotos are not available. If this is the case, then S2S interpretation for the larger area serves as an estimate of the accuracy of the change product from SOP 3, while the smaller airphoto-interpretation set provides an insight into the accuracy of the S2S process.

XI. Field-Based Validation

Field validation is expensive and thus not considered a primary means of validation for this protocol. True random sampling of the entire park would be prohibitively expensive. Rather, field validation of change calls should be conducted on an opportunistic basis as field crews visit the park for other reasons, or as small funds become available for limited field visits. Because field sampling will be limited to small geographic areas and will be conducted under a time constraint, maximal use of field time is required. This has two implications. First, *all* areas labeled as change by the methods of SOP 3 should be considered possible validation targets, rather than a random subset of those targets that would be encouraged with random sampling. Second, in the interest of acquiring the largest sample size possible, field sampling should focus on areas that are either relatively easy to access or which can be validated from a distance.

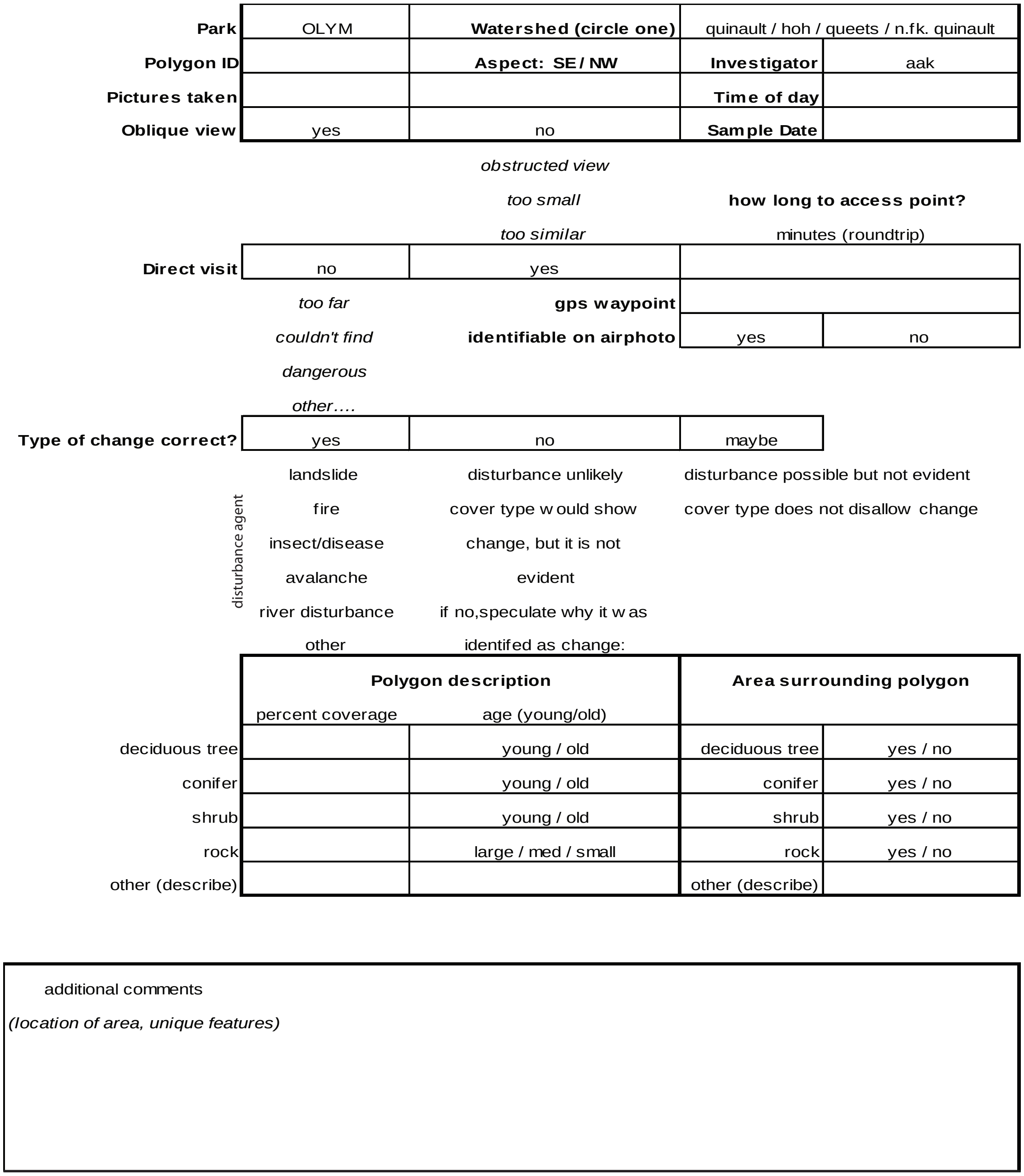
Field validation only can be used reliably to validate change products that track changes occurring in the prior 1–2 years. Author pilot studies confirmed that validation of changes that occurred long ago is essentially impossible, as those changes are often obscured by later recovery or later disturbance events.

Field-based change detection validation typically will be limited to changes that can be detected in a short change detection window (i.e. type 1 monitoring goals).

Table 8. Field equipment for field validation.

Number	Description
Req.	
1	Compass (with declination set for particular park)
1	Digital camera
1	Binoculars
1	GPS unit for navigating to plots
Variable	Data sheets for the number of plots to sample
3	Pencils for marking datasheets
3	Sharpie® marker for making notes on airphoto or imagery
1	Clipboard for holding and marking datasheets
1	First aid kit
1	Sunscreen
1	Insect repellent
1	Watch
1	5-m D-tape for measuring tree diameters
Several	Reference books for tree and plant identification

1. Preparation of validation.
    a. Electronic products needed:
        i. Polygon form of the change product from SOP 3 (section XI in SOP 3).
        ii. Tasseled-cap imagery from the most recent time period possible.
        iii. Digitized aerial photos for the areas where field visits will occur.
        iv. GIS coverages of park trails and roads.
        v. DEMs.
    b. Field materials needed (see table 8).
        i. Some of these materials will require preparation before the field season.
            (1) Prior to the first field season, the most recent set of airphotos should be scanned. Scanning these photos ahead of time will allow for more time in the field (validating during the field season). A digital copy of these photos will greatly reduce the time spent finding and scanning relevant photos.
            (2) Datasheets also should be developed and printed out ahead of time, including 25 percent on Rite in the Rain® paper.
                (a) An example datasheet is shown in figure 12.
            (3) Make sure that the digital camera is fully operational and that download cable works.
            (4) Make sure GPS unit works and that download cable works. Check that the GPS displays in the correct datum (NAD83).
    c. Determination of field routes
        i. To maximize use of field crew time, routes should be chosen for validation that will encounter as many change polygons as possible. The polygon-form change product from SOP 3 should be overlaid on the recent tasseled-cap imagery, along with DEMs and path and road GIS layers, to determine which paths and roads likely will give field personnel the opportunity to either directly visit polygons labeled as change, or to view those polygons from overlooks or distance vantage points.
        ii. Master printouts of the change polygon number and its associated SOP 3 derived change type should be printed out on Rite in the Rain paper. When each polygon is visited in the field, the change call produced by the SOP 3 methods will be compared against conditions noted in the field.



Park	OLYM	**Watershed (circle one)**	quinault / hoh / queets / n.fk. quinault	
Polygon ID		**Aspect: SE / NW**	**Investigator**	aak
Pictures taken			**Time of day**	
Oblique view	yes	no	**Sample Date**	
		obstructed view		
		too small	**how long to access point?**	
		too similar	minutes (roundtrip)	
Direct visit	no	yes		
	too far	**gps waypoint**		
	couldn't find	**identifiable on airphoto**	yes	no
	dangerous			
	other….			
Type of change correct?	yes	no	maybe	
disturbance agent	landslide	disturbance unlikely	disturbance possible but not evident	
	fire	cover type would show	cover type does not disallow change	
	insect/disease	change, but it is not		
	avalanche	evident		
	river disturbance	if no,speculate why it was		
	other	identifed as change:		
	Polygon description		**Area surrounding polygon**	
	percent coverage	age (young/old)		
deciduous tree		young / old	deciduous tree	yes / no
conifer		young / old	conifer	yes / no
shrub		young / old	shrub	yes / no
rock		large / med / small	rock	yes / no
other (describe)			other (describe)	

additional comments

(location of area, unique features)

Figure 12. Sample data sheet.

d. Map making:

i. Before going into the field, maps should be produced with some key characteristics. These include labeled roads and trails, in the same coordinate system as imagery, to assist field-validation crew in finding the correct trail or road. Other helpful layers are isolines for slope and elevation interpretation, scale for distance, labeled polygons with waypoints, and imagery dates for any further interpretation of possible phenology or shadowing problems with the imagery. Scales for maps vary from 1:10000 to 1:20000, depending on scope or AOI.

ii. Maps should include tasseled-cap imagery from both the early and later years for reference. This will help the crew to understand what was there beforehand and what is there currently, and to better diagnose whether false positives in the change product were caused potentially by misregistration or other effects discussed in section VI of this SOP.

(1) If time permits, it is extremely helpful for the field crew to obtain basic training in the interpretation of the tasseled-cap imagery, and to have color printouts of the Image Library for reference.

iii. Airphotos prove to be very helpful provided there is enough detail. To this end, airphotos for use in the field should be at a scale ranging from 1:4000 to 1:12000. Airphotos with detail less than this are not as helpful because of difficulty identifying specific polygons on the landscape and the inability to distinguish relative height of trees or area of polygons. After airphotos have been scanned and printed, polygons should be drawn and labeled on the photos with a black Sharpie® to aid in field identification.

2. Field validation

a. Direct visits:

i. In most cases, a direct visit will be the preferred method to confidently ascertain the accuracy of the change call. Access time to polygons will depend on distance, slope, vegetation, and GPS coverage. On average, in NOCA it took 35 minutes to access plots off trail, while in OLYM the average was much lower at 11 minutes, partly due to large river valleys and areas being validated. In OLYM, it was possible to hike up the river channel, whereas NOCA had less river channel access and more polygons on slopes off trail. GPS coverage is crucial in effectively navigating to plots. If GPS coverage is unreliable or spotty, it will be necessary to note distance and direction of polygon, then pace and shoot a bearing to polygon. Hopefully you will regain GPS coverage along the way, in which case re-assess your position, distance, and direction to target.

ii. Once at a polygon, record a waypoint, fill out field-validation datasheet (fig. 12) and take multiple photos of area. Digital photos will aid in long-term storage of index areas and provide useful information in the instance the imagery does not explain data collected during the field visit. Important characteristics of photos include a photo directly overhead, oblique photo of understory, and any closeups of disease or infection. Record this photo number on datasheet for future reference. It may be advantageous to include in the frame of the photo a handheld whiteboard with key site identifier information (date, ID of change polygon, park name, etc.) for easier labeling later. If there are any other notable features of this plot or area make sure to note these in the 'comments' space of datasheet.

iii. Determination of change call accuracy:

(1) The change type defined as an S2S class is one of physiognomic change, while the condition viewed in the field at a single point in time is one of cover type and condition. Linking the two is necessary.

(a) If the S2S type indicates that a loss of vegetation occurred, then the agent of change should still be visible, and must be consistent with the proposed type of change.

(b) If the S2S type indicates a gain in vegetation, then the process that causes that change (recovery from disturbance, for example) must still be in evidence. Typically, this will require inference of process from the current pattern seen on the ground. Notes regarding the inferences used to make the change call are necessary.

(2) If the polygon-change product indicates change, but none has occurred, then the field crew should speculate why the area was identified as change. With both the prechange and postchange interval tasseled-cap imagery in the maps, the crew can often determine if false positives are caused by geometric misregistration, phenological change, or illumination effects.

b. Oblique views:

i. If change polygons are very far from access routes, they may be viewed from vantage points that allow a reasonable assessment of conditions on the ground.

(1) First, assess whether the correct area is being viewed.

  (a) Locate the current observation point on the photo.

    (i) Visually reference the airphoto to the satellite image on the printed map, and use the trail and access-road layers as reference.

  (b) Locate the desired change polygon on the photo and on the image on the map.

  (c) On the satellite image, which has true (map) north oriented up, estimate the compass bearing of the change polygon from the current location.

  (d) Use that bearing to sight into the polygon in the field.

    (i) Consider obstructions and elevation when making this sightline.

ii. Because field validation is used for type 1 monitoring goals (see Narrative), most of the changes can be observed from a distance. Oblique views are aided by binoculars. Spotting scopes, while useful, were tested and deemed of little value for their extra weight and bulk.

c. Direct field visits for distance plots:

  i. If a plot is far from access, and if an oblique view is not feasible because of obstructed views, distance plots may need to be visited directly.

  ii. Because the spectral data used for the change detection are consistent across large areas, changes that are far away from access, but which are spectrally similar to other changes nearby, have limited value for direct visiting. Because this is difficult to judge in the field, however, it is suggested that direct visits be made to plots that are distant only a part of the time. An easy way to determine this is to flip a coin twice, and only visit a distance plot if heads appear twice (one of four times).

  iii. Distant plots that are to be visited still may be inaccessible because of rivers or topography. In that case, record for that polygon that the plot was not verified because it was dangerous to access.

3. Data entry.

  a. Field-validation calls should be entered into a field-validation database. Fields in the database should include:

    i. Park name.

    ii. Filename of early year image used for change detection.

    iii. Filename of late year image use for change detection.

    iv. Filename of polygon-based, change-detection product used for field validation

    v. Polygon number.

    vi. Polygon centroid X coordinate in NAD83 UTM coordinates.

    vii. Polygon centroid Y coordinate in NAD83 UTM coordinates.

    viii. Photo number of photo used in field to locate change polygon.

    ix. Direct visit in field?

      (1) Yes or no.

    x. Oblique view?

      (1) Yes or no.

    xi. If no visit, reasons.

      (1) Dangerous.

      (2) Not selected by random.

    xii. S2S change call provided by SOP 3 methods.

    xiii. Additionally:

      (1) Include all of the other fields on the field-verification datasheet shown in figure 12.

4. Analysis and reporting.

  a. Analysis is straightforward, and need only involve calculation of simple proportion statistics from the database.

  b. Summary statistics derived from the database should include at least the following:

    i. Percent of change/no-change calls from the SOP 3 product that were correct.

    ii. Breakdown of the correct and incorrect calls by S2S change label.

  c. Additionally, it is helpful to quantify the reasons that the field crew speculated the change call was incorrect.

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Protocol for Landsat-Based Monitoring of Vegetation at North Coast and Cascades Network Parks

Standard Operating Procedure (SOP) 5

Data Management

Version 1.0 (July 5, 2006)

Revision History Log:

Previous VersionNumber	Revision Date	Author	Changes Made	Reason for Change	New Version Number
n.a.	07-05-06	REK		Final version under agreement	1.0

This SOP describes the steps needed to ensure that images, image processing steps, and interpreted data are maintained and documented correctly.

I. Journaling

It is recommended that an electronic text file journal be maintained to keep track of all filenames and decisions made during the steps of this protocol. This journal should be maintained in chronological order, with the date of each entry noted. Whenever a processing step is conducted, all of the relevant information about that step is entered into the journal. Enough detail should be given to fully replicate the step, including the names of all input and output files, the software module and tool used for the analysis, and all processing options (buttons selected, data types, etc.). The use of hyperlinks to other files also can be a useful feature because it provides full pathnames of files that can be used later for interpretation, even if the hyperlinks themselves become out of date because files are moved.

Additionally, the journal should be used to record rationale for making decisions and for noting observations about imagery or datasets that may be useful later for error tracking or evaluation of unexplained results.

Although the key steps leading up to any geospatial product also will be stored in the metadata, this journaling process allows much more flexibility in keeping track of details. Most of the time, these details are not needed later, but occasionally they are the difference between a quick fix and starting from scratch.

II. Metadata

Good metadata will allow complete replication of a product. The processing of imagery requires many steps, each of which requires documentation to be replicable. In table 1, the major steps in image processing through this protocol are listed, along with the resultant image and the information that must be stored in the metadata. These metadata requirements are in addition to those that NPS specifies in its current version of “Specifications for GIS Products and Deliverables” (current version dated August 22, 2005: http://www1.nature.nps.gov/im/units/nccn/dm_docs/NCCN_GIS_Product_Specifications.pdf).

The validation process also requires metadata. Validation windows must be identified according to the method by which they were created. If validation windows are defined using method 2 (based on airphoto flightlines), then the spreadsheet developed to track all possible photo pairs, as well as those randomly selected for the validation, must be noted. S2S-interpretation codes, disturbance-agent codes, and certainty-scoring rules also must be linked to the interpretation database, either by hyperlinking to the files or by inclusion of the text of the rules with each database.

Table 1. Image-processing steps and their metadata requirements.

[**Abbreviations:** TM, Thematic Mapper; ETM, Enhanced Thematic Mapper Plus; EDC, EROS Data Center; NN, nearest neighbor; RMS, root-mean square; COST, cosine theta; MADCAL, MAD calibration; NW, northwest; SE, southeast; AOI, area of interest; DEM, digital elevation mode; POM, probability of membership; S2S, satellite to satellite]

Step	Resultant image	Required metadata
Image purchasing	7-band Landsat TM or ETM+ image	Date of image acquisition; date image was ordered; source for image (EDC, etc.); cell size ordered; resampling format (NN); plus all header information included with image.
Geometric rectification	Terrain corrected image	Name of parent image and of terrain-corrected image used for reference; Number of image tie points found; means of finding tie points (automated; manual); RMS Error X, Y, and total; resampling method (NN, etc.); order of polynomial model for resampling; digital elevation model used for terrain; software used to do terrain correction.
Atmospheric correction	COST corrected image	Dark-object values used for calculations; bandwise gains and offsets used for scaling; sun elevation and azimuth; sun distance; illumination values by band; name of graphic model used to process model.
MADCAL	Radiometrically normalized image	Name of parent image and of radiometric-reference image; calculated gains and offsets relating each band in parent image to reference image; location and size of image subsets used to identify no-change pixels; name of control file used to run MADCAL algorithm.
Application of tasseled-cap coefficients	Tasseled-cap image	Name of parent image; coefficients used for tasseled-cap calculations.
Splitting by aspect	NW or SE aspect tasseled-cap image	Name of parent image; name of AOI file used to split by aspect; name of DEM used to develop aspect-AOI.
Unsupervised classification	25-spectral class image	Name of parent image; source of original classes (principal components or diagonal axis); number of iterations for classification; threshold for stability.
Calculation of feature-space images	Two feature-space images	Name of parent tasseled-cap image.
Assignment of classes to feature space	Two feature-space images	Name of parent tasseled-cap image; name of 25-spectral class image.
Recoding to nine physiognomic types	Physiognomic-class image	Name of parent tasseled-cap image; name of 25-spectral class image; name of Excel file to store from- and to-class numbers; names of physiognomic classes.
Calculation of POM images	POM image	Name of parent tasseled-cap image; name of physiognomic class image; filename of PROBDIFF control file; date of PROBDIFF run.
Calculation of POM change	POM difference image	Name of two parent POM images.
Conversion to S2S classes	S2S class image	Name of POM parent image; name of S2S classes; name of graphic model used to convert the image.
Thresholding S2S images for change	S2S change-detection image	Name of S2S class image; threshold of change used for detection; name of graphic model used to threshold change.
Labeling S2S images	S2S labeled image	Name of S2S class image; threshold of change used for detection; name of graphic model used to threshold change.

III. File Structure and Naming

File naming should follow the conventions of the current version of the NCCN "GIS Naming Conventions" document (current version: August 3, 2005; http://www1.nature.nps.gov/im/units/nccn/dm_docs/ NCCN_GIS_Naming_Conventions.pdf). Final and intermediate products must follow slightly different conventions. The key images and their final or intermediate status are listed in table 2.

During processing, all of the images in table 2 will retain intermediate file-naming conventions. Also, there are a host of other images developed during processing that should follow intermediate file-naming conventions. After completion of all processing, a copy of the final-image products listed in table 2 will be saved under a new name that conforms to the final product naming conventions.

A variety of images, other spatial data, and control files are used throughout this protocol. These are listed in tables 3 through 5, along with the naming conventions that should be used when creating the files. Intermediate naming conventions specify a 13 character filename with the 10.3 file naming structure as follows: cxxxxxxxxc9.ext. The first "c" corresponds to park name, and is referenced in the NCCN naming conventions documentation. The second "c" lists image type, which in the case of image is always "r". The number in the location occupied by the "9" indicates version number for the file. In the middle of these are seven character locations to uniquely identify the filename. Underscores are used to indicate unused portions of the name.

According to the August 3, 2005, version of the "GIS Naming Conventions" document (http://www1.nature.nps.gov/im/units/nccn/dm_docs/NCCN_GIS_Naming_Conventions.pdf), final products must follow a different format. Thus, for normalized imagery ("tc_96__" in the intermediate naming stage), POM difference images ("pdn0296" and "pds0296"), and S2S labeled images ("sln0296" and "sls0296"), formatting should follow the final-product naming conventions. First, a project code must be established in the NCCN tracking database, with a separate subcode for each of these three products. Each code/subcode name will contain five characters. Final names will then follow a 10.3 naming format, beginning with a 4-character prefix code for the park name, the five-character project code/subcode, and a single-character code to separate successive occasions of change detection. This latter single-character identifier begins with "a" and continues up the alphabet. Each year that change detection is carried out, a new letter is added. It is unclear how the name will change when 26 years have passed.

Table 2. Image products listed by final or intermediate status.

[**Abbreviations:** TM, Thematic Mapper; ETM, Enhanced Thematic Mapper Plus; COST, cosine theta; MADCAL, MAD calibration; NW, northwest; SE, southeast; POM, probability of membership; S2S, satellite to satellite]

Step	Resultant image	Final or intermediate?
Image purchasing	7-band Landsat TM or ETM+ image	Intermediate
Geometric rectification	Terrain corrected image	Intermediate
Atmospheric correction	COST corrected image	Intermediate
MADCAL	Radiometrically normalized image	Intermediate
Application of tasseled-cap coefficients	Tasseled cap image	Final
Splitting by aspect	NW or SE aspect tasseled-cap image	Intermediate
Unsupervised classification	25-spectral class image	Intermediate
Calculation of feature space images	Two feature-space images	Intermediate
Assignment of classes to feature space	Two feature-space images	Intermediate
Recoding to nine physiognomic types	Physiognomic-class image	Intermediate
Calculation of POM images	POM image	Intermediate
Calculation of POM change	POM difference image	Final
Conversion to S2S classes	S2S class image	Intermediate
Thresholding S2S images for change	S2S change-detection image	Intermediate
Labeling S2S images	S2S labeled image	Final

Table 3. Codes for intermediate-image products.

[**7-digit code:** Full filename is of format cxxxxxxxc9.ext, where the first "c" is the park letter abbreviation, the "x" is the 7-character core, the second "c" is the format of the file, the number is the version of the file, and the extension depends on the type of image (".img" for the images in this table). Here, the digits "96" are used as a place holder to represent a single year image from 1996, and "02" to represent the year 2002. Any time both occur in the same filename, the file represents combined information from both years. If two filenames are listed, they correspond to different aspect images. If four are listed, they correspond to two instances of files for two aspects each. **Abbreviations:** SOP, standard operating procedure; TM, Thematic Mapper; ETM, Enhanced Thematic Mapper Plus; COST, cosine theta; MADCAL, MAD calibration; NW, northwest; SE, southeast; POM, probability of membership; S2S, satellite to satellite]

SOP	Section	Process	Resultant image	7-digit code
1	II	Image purchasing	Orthorectified TM image (geometric reference) 25 m grain size	tmo02__
1	II	Image purchasing	7-band Landsat TM or ETM+ image (Subject image)	tmp96__
2	V	Clipping to study area	Reference Image clipped to study area	tmo02st
2	VI	Geometric rectification	Image terrain corrected and registered to orthorectified image	tmg96__
2	VI	Clipping to study area	Subject Image clipped to study area	tmg96st
2	VII	Atmospheric correction	COST corrected image	tma96__
2	VIII	MADCAL	Radiometrically normalized image	tmm96__
2	IX	Application of tasseled-cap coefficients	Tasseled-cap image	tc_96__
2	X	Splitting by aspect	NW or SE aspect tasseled-cap image	tcn96__, tcs96__
3	II	Unsupervised classification	25-spectral class image	ucn9625, ucs9625
3	III	Calculation of feature-space images	Two feature space images for each of two aspect classes	fsn96bg, fsn96gw, fss96bg, fss96gw
3	III	Assignment of classes to feature space	Two thematic feature-space images for each of two aspect classes	fun96bg, fun96gw, fus96bg, fus96gw
3	III	Recoding to nine-physiognomic types	Physiognomic class image	p9n96__, p9s96__
3	IV	Calculation of POM images	POM image	pmn96__, pms96__
3	V	Calculation of POM change	POM difference image	pdn0296, pds0296
3	VI	Merging aspects	Final, aspect-merged nine-layer POM difference image	pdf0296
3	VIII	Conversion to S2S classes	POM to 15-layer S2S image	p2s0296
3	VIII	Thresholding S2S images for change	Single-layer S2S change-detection image	s2c0296
3	VIII	Labeling S2S images	Single-layer S2S labeled image (with speckle)	s2l0296
3	IX	Sieving speckle	4-layer S2S themed image	s240296
3	IX	Sieving speckle	S2S class sieved	s2p0296

Table 4. Codes for other intermediate products.

[Full filename is of format cxxxxxxxc9.ext, where the first “c” is the park letter abbreviation, the “x” is the 7-character core, the second “c” is the format of the file, the number is the version of the file, and the extension depends on the type of image (“.img” for the images in this table). Here, the digits “96” are used as a place holder to represent a single year image from 1996, and “02” to represent the year 2002. Any time both occur in the same filename, the file represents combined information from both years. If two filenames are listed, they correspond to different aspect images. **Abbreviations:** SOP, standard operating procedure; DEM, Digital Elevation Model; NAD83, North American Datum of 1983; AOI, area of interest; S2S, satellite to satellite]

SOP	Section	Process	Resultant image	7-digit code
2	IV	Reprojecting DEM	25-m DEM in NAD83	dem_n83
2	V	Defining study area	Study area AOI	starea__
2	V	Defining study area	Study area vector coverage	starea__
2	V	Subsetting DEM	25-m DEM clipped to study area	demst__
2	X	Splitting by aspect	DEM aspect mask images	aspnmsk, aspsmsk
2	X	Splitting by aspect	AOI for each of the aspect classes	aspnmsk, aspsmsk
3	IV	Calculating probability of membership in physiognomic classes	Probability lookup file	pmn96lu, pms96lu
4	IV	Creating S2S geospatial database	Geodatabase	validat
4	IV	Creating S2S geospatial database	Feature dataset within geodatabase for all validation within a given year interval	val0296
4	IV	Creating S2S geospatial database	Feature class for S2S interpretation of change	s2s0296
4	V	Selecting random 1.5 km boxes	Grid of 1,500-m by 1,500-m boxes for later random selection (use for grid, polyline, and polygon formats)	gd_0296
4	V	Selecting random plots	Text file with box labels, Excel file with random numbers	gd_0296

Table 5. Codes for control files and models.

[Full filename is of format cxxxxxxxc9.ext, where the first “c” is the park letter abbreviation, the “x” is the 7-character core, the second “c” is the format of the file, the number is the version of the file, and the extension depends on the type of image (“.img” for the images in this table). Here, the digits “96” are used as a place holder to represent a single year image from 1996, and “02” to represent the year 2002. Any time both occur in the same filename, the file represents combined information from both years. If two filenames are listed, they correspond to different aspect images. **Abbreviations:** SOP, standard operating procedure; COST, cosine theta; MADCAL, MAD calibration; DEM, Digital Elevation Model; POM, probability of membership; S2S, satellite to satellite]

SOP	Section	Process	*Resultant image*	*7-digit code**, **
2	VII	COST calculations	Spreadsheet to keep track of COST numbers	tma96cs
2	VII	COST calculations	Graphic model to apply COST to imagery	tma96cs
2	VIII	MADCAL	MADCAL control file	mad0296
2	X	Splitting by aspect	Graphic model to split DEM by aspect	spDMasp
2	X	Splitting by aspect	Graphic model to split one tasseled-cap image by aspect	sp96asp
3	III	Recoding 25 to 9 classes	Spreadsheet to document-conversion codes	p9n96cc, p9s96cc
3	IV	Assigning POM	Spreadsheet to describe statistics for physiognomic classes	p9n96st, p9s96st
3	IV	Extracting spectral signatures for nine-physiognomic classes	Imagine-signature file	p9n96sg, p9s96sg
3	IV	Calculating POM in physiognomic classes	PROBDIFF control file	pmn96cc, pms96cc
3	VIII	Converting nine-POM layers to S2S class scores	Graphic model to convert 9-layer difference in POM image into 15-layer S2S class image	p2s0296
3	VIII	Detecting and labeling change	Graphic model to convert 15-layer S2S class image into single-layer classified S2S image	s2s0296
3	IX	Sieving speckle	Graphic model to group S2S classes for sieving	s240296
3	IX	Sieving speckle	Graphic model to sieve S2S labeled image	s2p0296

During image processing, file folders and subfolders should provide clear separation of different steps in the image processing. Modules used to create images (graphic models, files to control software packages, etc.) should be placed in the same folders as the files they are used to create. The following structure is suggested for intermediate processing (fig. 1). Each year of imagery contains its own sequence of processing steps in separate folders. Datasets that do not change from year to year (DEMs, Study Area, etc.) are static folders at the same level as the image-year folders. All steps that involve combinations of images from different years (such as difference images, etc.) must be placed in a separate folder clearly labeled with both years over which change is occurring.

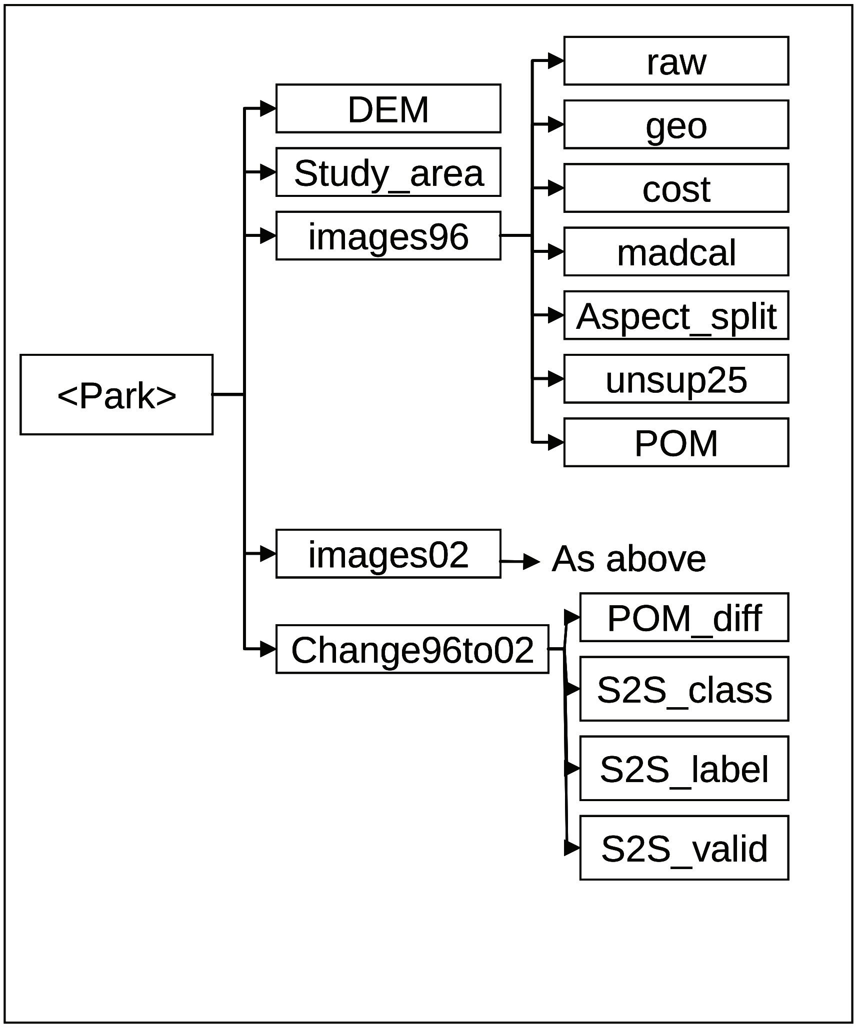

Figure 1. Suggested directory structure for image processing.

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Protocol for Landsat-Based Monitoring of Vegetation at North Coast and Cascades Network Parks

Standard Operating Procedure (SOP) 6

Revising Protocol

Version 1.0 (July 5, 2006)

Revision History Log:

Previous VersionNumber	Revision Date	Author	Changes Made	Reason for Change	New Version Number
n.a.	07-05-06	REK		Final version under agreement	1.0

This SOP explains how to make changes to the protocol for Landsat-based Monitoring of Vegetation at the NCCN Parks. Observers asked to edit the Protocol Narrative or any one of the SOPs need to follow this outlined procedure in order to eliminate confusion in how data are collected and analyzed. All observers should be familiar with this SOP in order to identify and use the most current methodologies.

Procedures

1. This protocol attempts to incorporate the best and most cost-effective methods and technologies in order to produce results that internally are consistent and externally are comparable to other Landsat-based monitoring programs. As new methods and equipment become available these should be incorporated in a timely manner with the appropriate reviews.
2. All edits require review for clarity and technical soundness. Small changes or additions to existing methods will be reviewed by in-house GIS and NPS remote-sensing specialists. However, if a complete change in methods is sought, then a full outside review is required. Experts within and out of the NPS in remote sensing will be utilized as reviewers.
    a. Changes in software are likely. When these changes do not alter the fundamental tasks being conducted, in-house review is sufficient. When sensors change, or software packages disappear or become outdated, full reviews are required.
3. Major edits and protocol versions should be documented in the Revision History Log that accompanies the Protocol Narrative and each SOP. Changes should be noted only in the Protocol Narrative or SOP being edited. Version numbers increase incrementally by hundredths (e.g. version 1.01, version 1.02 …etc) for minor changes. Major revisions should be designated with the next whole number (e.g., version 2.0, 3.0, 4.0 …). Record the previous version number, date of revision, author of the revision, identify paragraphs and pages where changes are made if major changes are undertaken, and the reason for making the changes along with the new version number.
4. Inform the NCCN Data Managers about changes to the Protocol Narrative or SOP so the new version number can be incorporated in the metadata of the project database. The database may have to be edited by Data Managers to accompany changes in the Protocol Narrative and SOPs.
5. Post new versions on the internet and forward copies to all individuals with a previous version of the affected Protocol Narrative or SOP.

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USGS Kennedy and others— **Protocol for Landsat-Based Monitoring of Landscape Dynamics at North Coast and Cascades Network Parks**—Techniques and Methods 2—G1

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