Digital-Elevation and Surface-Classification Maps of the Fish Creek Area, Harrison Bay Quadrangle, Northern Alaska

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Abstract

A set of landform and land cover maps has been completed for the northeastern part of the National Petroleum Reserve, Alaska (NPRA). This set of 1:63,360 -scale maps consists of a color shaded-relief map (5 m resolution data), a surface classification map (30 m resolution data), and a shaded relief-surface classification map generated by fusing the two datasets. Remote sensing data used to compile the maps include Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Interferometric Synthetic Aperture Radar (IFSAR).

Image analysis of the Landsat 7 ETM+ data defined six spectral units for the surface classification and shaded relief-surface classification map. The six spectral units include water/ice, green vegetation, dry vegetated sand, wet vegetated sandy mud, clean sand, and muddy sand. Green vegetation and water/ice were defined by using a band 4/3 ratio and a threshold of band 5, respectively. Dry vegetated sand, wet vegetated sandy mud, clean sand, and muddy sand spectral units were defined by selecting representative image spectra from landforms defined from Landsat 7 ETM+ and IFSAR imagery. Selection of specific landforms was based on inferred sediment types associated with the depositional environment that produced the landform, and from a published USGS 1:250,000 geologic map of the study area. An ENVI matched filtering algorithm was used to map the extent of materials represented by these spectral units.

The dry vegetated sand spectral unit primarily mapped eolian and marine dunes. The wet vegetated sandy mud spectral unit primarily mapped lake sediments. Clean sand and muddy sand spectral units mapped eolian dune blowout features, modern fluvial sands, and deltaic deposits. A combination of dry vegetated sand and green vegetation spectral units mapped flood plain deposits.

The shaded relief-surface classification map was pan-sharpened using IFSAR 5 m data. The composite data illustrate that patterns and combinations of spectral units correspond to specific topographic features such as eolian and coastal ridges, thaw lakes, and river valleys. This correspondence between topographic features and spectral units was investigated in the field and is due to different vegetation types and degree of vegetation stress, which is associated with topography and depth to permafrost.

Introduction

The northeastern part of the National Petroleum Reserve in Alaska (NPRA) has become an area of active petroleum exploration during the past five years. Recent leasing and exploration drilling in the NPRA requires the Bureau of Land Management (BLM) to manage and monitor a spectrum of surface activities that include seismic surveying, exploration drilling, oil-field development drilling, construction of oil-production facilities, and construction of pipelines and access roads. BLM evaluates a variety of permit applications, environmental impact studies, and other documents that require rapid compilation and analysis of data pertaining to surface and subsurface geology, hydrology, and biology. In addition, BLM must monitor these activities and assess the impacts of these

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activities to the natural environment. Timely and accurate completion of these land-management tasks requires elevation, hydrologic, geologic, petroleum-activity, and cadastral data, all integrated in digital formats at a higher resolution than currently available in published formats.

To support these land-management tasks, a series of maps have been generated from remotely sensed data in an area of high petroleum-industry activity (Fig. 1). The maps, extending from 70°00' to 70°30' N latitude and from 151°00' to 153°10' W longitude, include the Alpine oil field on the east, the Husky Inigok exploration well (site of a landing strip) on the west, many of the exploration wells drilled in NPRA since 2000, and the route of a proposed pipeline to carry oil from discovery wells in NPRA to the Alpine oil field. This map area is referred to as the "Fish Creek area" after the prominent fluvial system within the area.

The map series includes a color shaded-relief map (based on 5 m-resolution data, Plate 1), a surface classification map (based on 30 m-resolution data, Plate 2), and a pan-sharpened, shaded relief-surface classification map (generated by fusing the two datasets, Plate 3). Remote sensing datasets used to compile the maps include, IFSAR, and Landsat 7 ETM+ data. In addition, a 1:250,000 geologic map of the Harrison Bay Quadrangle, Alaska (Carter and Galloway, 1985) has recently been released in digital format (Carter et al., 2005), and was used in conjunction with ETM+ and IFSAR data.

Data and Methods

ETM+ Classification Map

The Landsat 7 ETM+ radiance-at-the-sensor data were acquired on June 6, 2003, and consist of six bands at 30 m resolution in the 0.4 to 2.5 µm region, one band at 90 m resolution centered at 11.45 µm, and one 15 m resolution panchromatic band. The thermal infrared and panchromatic bands were not used in this study. The Landsat 7 ETM+ scene was calibrated to reflectance using an ENVI (Environment for Visualizing Images) reflectance algorithm (RSI, 2000). Evaluation of the reflectance data indicated that values in bands 1-4 were anomalously high, and thus, a dark object subtraction method (Crain, 1971) was used to correct for the optical scattering of light in bands 1-4. A subset of the reflectance Landsat 7 ETM+ scene was then extracted to cover the NPRA study area.

Spectral analysis of target training areas was used to define spectral map units referred to in this report as "spectral units". Landsat 7 ETM+ data were used to identify specific materials or mixtures of materials on the basis of their spectral characteristics and ground truth data obtained from the study area in July 2004. Library spectra (resampled to Landsat 7 ETM+ bandpasses), of typical materials found at NPRA such as green vegetation, quartz sand, dead vegetation, and clay (montmorillonite), have distinct spectral signatures that can be mapped using spectral shape-fitting algorithms (Fig. 2). Image spectra used to define spectral units contain mixtures of green vegetation, quartz sand, dead vegetation, and clay and thus have spectral signatures that consist of multiple spectral features.

The thaw lakes still contained a substantial amount of ice as well as water when the image was acquired in June 2003. Reflectance image spectra of ice, water, vegetation and soil illustrate that ETM+ band 5 (1.65 micrometers) digital number (DN) values are lower for ice and water, than band 5 DN values for vegetation and sediment spectra (Fig. 3). Thus, on the basis of water, ice, and vegetated sediment spectra, a threshold of ETM+ band 5 was used to map the thaw lakes and other water and ice bodies (Fig. 4).

An image spectrum from the study area and a resampled spectrum of green vegetation from a spectral library both indicate a chlorophyll absorption feature at 0.66 micrometers (Figs. 2 and 5). A Landsat 7 ETM+ band ratio of 4/3 produces an image with high DN values where there are relatively strong chlorophyll absorption features, and thus, the green vegetation spectral unit was mapped by applying a threshold to an ETM+ band ratio 4/3 image. Field observations indicate that areas that contained more than 50 percent green vegetation classified as the green vegetation spectral unit.

In order to map additional surficial units, a false color composite (R=7, G=4, B=2) ETM+ image was assessed to select image spectra (Fig 6A). Due to high spectral contrast, a water/ice mask was applied to the false color composite (R=7, G=4, B=2) ETM+ image to improve spectral variability. Spectral units other than green vegetation and water were defined by examining the spectral characteristics of image spectra (Fig. 6B) associated with specific geomorphic features such as dunes, river bars, and lake shorelines (Fig. 6A). Selection of specific landforms was based on inferred sediment types associated with the depositional environment that produced the landform, and from the USGS 1:250,000 -scale engineering geologic map of the study area (Boggs, 1995; Carter and Galloway, 1985; Fig. 6A). Approximately 20 image spectra were selected from the false color composite ice and water masked image. Interpreted spectral units using this process include, vegetated dry sand from linear ridges, clean sand from active dunes around thaw lakes, muddy sand from sand bars in rivers, and wet vegetated sandy mud from lake sediments in thaw lakes (Fig. 6).

Matched filtering, an algorithm for detecting target spectra in the presence of spectral mixtures (Harsanyi and Chang, 1994; Farrand and Harsanyi, 1997), was used with the image spectra to produce a series of gray scale images (Figs. 6B, and 7). The images were qualitatively assessed for spatial coherence and accuracy (Fig. 7). Four images were selected and interpreted to represent mixtures of sediment, water, and vegetation on the basis of their spectral properties, similar distribution in relation to lithologic units of the geologic map (Carter and Galloway, 1985), a 5 m digital terrain model of the IFSAR data, and the water-masked false color composite RGB Landsat 7 ETM+ image (Figs. 2, 3, 5, and 6; Plate 1). A threshold was applied to each grayscale image to remove noise, poor matches and similar mapped pixels. Each processed image was then combined to produce a provisional classification map.

The provisional surficial classification map was assessed in the field for consistency and accuracy of the spectral units with respect to surficial material assignments such as sediment, water and vegetation content. An Analytical Spectral Devices (ASD) field spectrometer was used to collect reflectance spectra in the field and was used to collect reflectance spectra from field samples in the laboratory. The ASD field spectrometer collects reflectance data at 1 nanometer spacing from 0.35 μm to 2.5 μm. Comparison of field and lab spectra from selected calibration sites consisting primarily of windblown quartz sands indicated that no additional calibration of the ETM+ dataset was necessary. In addition, field and lab spectra were also compared to image spectra for evaluation of material content and accuracy of spectral units.

IFSAR Datasets

IFSAR data used in the study were collected by the STAR-3i airborne synthetic aperture radar system. STAR-3i is a high-resolution, single-pass, across-track IFSAR system, which uses two apertures to image the surface. The path length difference between the apertures for each image point, along with the known aperture distance, is used to determine the topographic height of the terrain. The IFSAR system is capable of collecting data with a vertical accuracy of <1 m and a horizontal accuracy of <3 m.

Data are delivered as three core products: orthorectified radar images (ORRIs), digital surface models (DSMs), and digital terrain models (DTMs). ORRIs are 8-bit grayscale GeoTIFF images that show the radar reflectance intensity of various earth surface materials. These images are commonly used to identify and extract drainage networks and cultural features such as pipelines, roads, and buildings. The ORRIs used in this study had a pixel size of 1.25 m and a horizontal accuracy of 2.5 m. The DSMs, or "first-return" elevation data, display the first surface on the ground that the radar strikes. These images consist of measured points collected by the sensor, including the z-values of structures (e.g., building and towers) and vegetation (e.g., trees and crops). These elements are removed from the DSM through filtering techniques to create a DTM. The DTMs, or "bald-earth" elevation data, are similar to Digital Elevation Models (DEMs) in that non-terrain elements are absent. However, unlike the regular array of elevation values that are characteristic of a DEM, a DTM defines topographic elements by irregularly spaced breaklines, or abrupt changes in surface smoothness, like shorelines, roads, streams, and slope breaks. The result is a more accurate depiction of the terrain, useful for contouring, triangulated irregular network (TIN) calculations, and other terrain modeling.

IFSAR, Color Shaded-Relief, and IFSAR-ETM+, Shaded Relief-Surface Classification Maps

Computer-based analytical hillshading has become a widely used tool to visualize three-dimensional topography on a two-dimensional surface. Unlike manually-produced shaded-relief maps, analytical hillshade images often reveal imperfections in the elevation data used to render the image. The IFSAR data contained flaws in some areas because excess motion in the aircraft caused visible ripples in the dataset. A regular banding pattern was apparent along sensor swath boundaries when elevation data were viewed at small-scales. This aside, the DSMs and DTMs derived from the IFSAR system proved to be an excellent data source for generating the shaded-relief surficial classification images (Garrity, 2004).

Large-scale (1:20,000) shaded-relief images were generated from DTM data to identify the location of surficial objects with greater accuracy. Initial image rendering revealed potential challenges related to the portrayal of surface features in an area devoid of any significant relief. When rendered with no vertical exaggeration, the shaded-relief image was essentially flat. Using 5X vertical exaggeration the shadows appeared blocky and generally became unsightly at the desired map scale. To give the landscape images a more natural appearance, DTM surfaces were slightly bump-mapped (Garrity, 2004). Because the images were used for surface delineation, a random height map was unsuitable for fear of compromising data integrity. Instead, the corresponding DSM was used as a height map to generate the bumped surface. The natural "roughness" of the DSM gave the hillshaded DTM a subtle texture without obscuring the DTM surface with unnecessary detail.

Removal of jagged shading was accomplished by generalizing the raw data grids, isolating their shaded pixels, and then merging the generalized shade layer with the original grid. To generalize the raw data grids, softening techniques were applied in ArcInfo Workstation using focal functions. The amount of softening was regulated by adjusting the neighborhood configuration (shape, size) in the focal command. In all instances, a very small neighborhood was used and care was taken not to over-generalize the softened grids. Isolation of shaded pixels within the generalized grids was accomplished in Adobe Photoshop via the "Curves" tool, while the remaining pixels were converted to white. Finally, the adjusted softened hillshade and original hillshade were merged by multiplying the two images in Photoshop. Multiplying the images caused the converted white pixels of the softened image to drop out, resulting in a softening effect restricted to the darkest shades of the merged image. The resulting hillshade image had a more natural appearance, devoid of any jagged shading.

The 30 m surficial classification map was resized to match the dimensions of the 5 m DTM hillshade image in ERDAS Imagine. A median filter was applied to the 30 m dataset to minimize pixelization when viewed at full resolution. Datasets were fused (merged) using raster arithmetic operators in ArcGrid and then downsampled appropriately based on the desired map scale.

Interpretation of Data Products

ETM+ Surface Classification Map

The spectral units of the ETM+ surficial classification map are: water (blue), green vegetation (green), dry vegetated sand (yellow), wet vegetated sandy mud (red), clean sand (white), and muddy sand (cyan) (Plate 2). In addition, unclassified pixels (black) are also illustrated on the classification map.

The average spectrum of the wet vegetated sandy mud spectral unit (red, surficial classification map) has a strong band 3 absorption feature, high reflectance in band 5, low reflectance in band 7, and a relatively low albedo when compared to other spectral units (Fig. 8). Field observations indicate that the wet vegetated sandy mud spectral unit consists of approximately 45 to 50 percent water, approximately 45 to 50 percent dead or senescent (brown, no chlorophyll) and live (green, chlorophyll) grass, and <5 percent sandy mud at the surface (Fig. 9). Field spectra resampled to ETM+ bandpasses are very similar to image spectra taken from parts of the image classified as wet vegetated sandy mud. The field spectra illustrate a strong 0.7 μm chlorophyll absorption feature, and a low reflectance in the 2.0 μm to 2.5 μm region due to cellulose absorption from dead and live vegetation and water (Figs. 9 and 10, red curve). The field spectra also have a lower albedo than other field spectra due to the presence of water (Figs. 3 and 9). Thus, the spectral characteristics of wet vegetated sandy mud spectral unit are due to a mixture of live (green) and dead or senescent (brown) vegetation (low bands 3 and 7, respectively), and water (relatively low albedo compared to other spectral units).

The average spectrum of the dry vegetated sand spectral unit has a slight chlorophyll feature, high band 5 reflectance, low reflectance in band 7 and the highest albedo of all of the spectral units (Fig 8). Field data indicate that the dry vegetated sand unit consists of approximately 20 percent live (green) vegetation, 75 percent dead (brown) vegetation, and < 5 percent bare sand (Fig. 11). In some areas such as on parabolic dunes, the dry vegetated sand spectral unit consists of up to 20 percent lichen and up to 20 percent bare sand (Fig. 11). A field spectrum illustrates a 0.7 μm (ETM+ band 3) chlorophyll absorption feature. The field spectrum also illustrates high reflectance in the 1.4 to 1.8 μm region and low reflectance in the 2.0 to 2.5 μm region which is due to cellulose absorption (Fig. 10 A and 8, yellow curve). Quartzose sand also has high reflectance in the 1.4 to 1.8 mm region (Figs. 2 and 10), which is partially responsible for the high band 5 reflectance of image spectra from the dry vegetated sand spectral unit. The spectral characteristics of the dry vegetated sand spectral unit are due small amounts of live (green) vegetation mixed with large amounts of dead (brown) vegetation, sand, and lichen.

Spectral shape comparisons of an averaged field spectrum (n-15) resampled to Landsat 7 ETM+ bandpasses and the average image spectrum of the dry vegetated sand spectral unit indicate that band 5 and band 3 reflectance are lower for field spectra, however, overall spectral shapes are similar (Fig 10b). The field spectrum of dry vegetated sand is similar to the field spectra taken from an area that classifies as wet vegetated sandy mud (Fig. 10). The lower band 3 and band 5 reflectance values of the field spectrum resampled to Landsat 7 ETM+ bandpasses are due to the seasonal changes in vegetation. The field spectra were recorded in mid summer when there was more live (green) vegetation than in early summer when the Landsat 7 ETM+ data were acquired. Green vegetation contains more chlorophyll and water than brown (senescent) vegetation, and would result in lower reflectance in bands 3 and 5 (Figs. 2, 10, and 11). The increase in green vegetation later in the summer indicates that acquisition of data by visible to short-wave infrared detectors needs to occur in early summer when vegetation is still senescent.

The average image spectrum for the clean sand spectral unit has a small chlorophyll feature, high reflectance in bands 5 and 7, and lower albedo when compared to the average dry vegetated sand spectrum (Fig. 8). The lower albedo of the clean sand average image spectrum may be due to surface moisture at the time of the Landsat data acquisition. Field observations indicate that the clean sand spectral unit primarily consists of quartz sand (approximately 95 percent) and minor amounts (<5 percent) of live (green) vegetation, silt, and clay (Fig. 12). Quartz is spectrally flat and has high reflectance in the 1.5 to 2.4 μm region (Fig. 2). Laboratory spectra of sand samples from dune blowout features indicate high reflectance from 1.5 μm to 2.5 μm with slight 2.20 μm and 2.35 μm absorption features due to muscovite (Fig. 10). The high reflectance of bands 5 and 7 in the average spectrum of the clean sand spectral unit is due to the high percentage of quartz (>95 percent; Figs. 2, and 10).

The slightly muddy sand spectral unit has a more intense absorption of band 7 than the clean sand spectral unit, and less intense chlorophyll absorption and higher albedo than the wet vegetated sandy mud spectral unit (Fig. 8). Laboratory spectra of all of the sands from the study area have a 2.2 μm absorption feature that is typically associated with either muscovite or clays (Figs. 2 and 10). Field observations also indicate that there is slightly more (>10 percent) silty mud and green vegetation in the muddy sand spectral unit than the clean sand spectral unit (Fig. 13) but less than the wet vegetated sandy mud spectral unit. The greater percentage of clay and (or) muscovite and green vegetation accounts for the deeper band 7 absorption feature in the slightly muddy sand unit than observed in the clean sand spectral unit.

Some pixels did not correlate with any of the spectral unit classifications. Field investigations in June 2004 indicated that some of the non-classified areas contained equal amounts of green and dead vegetation and up to 10 percent standing water (Fig. 14). It was not possible to determine if this is a separate classification unit. Many of the unclassified pixels have different spectral signatures and several different spectral classes may be grouped in the non-classified category.

A single spectral unit, a combination of spectral units, or a combination of spectral units and non-classified pixels form patterns that define eolian, fluvial, deltaic, and marine depositional facies (Plate 2). The dry vegetated sand spectra primarily mapped deposits of eolian and marine sand located in the northwestern part of the study area. The wet vegetated sandy mud spectral unit primarily mapped muddier lake sediments of thaw lakes. Clean sand and muddy sand spectral units mapped recent sand bodies, including eolian blowout features, fluvial sand bars and deltaic deposits. A mixture of dry vegetated sand and green vegetation spectral units, and unclassified pixels mapped flood plain deposits in the eastern part of the study area.

On the basis of field and spectral data most of the spectral characteristics observed in NPRA are due to water, quartz sand, silty mud, live (green) vegetation, and dead or senescent (brown) vegetation. The primary spectral controls on dry vegetated sand are mixtures of live (green) and dead (brown) vegetation. Lake sediment spectral characteristics are primarily due to mixtures of live (green) vegetation, dead (brown) vegetation and water. The clean sand spectral unit is primarily quartz sand and muddy sand spectral unit is primarily quartz with small mixtures of silty mud, and vegetation.

ETM+-IFSAR, Shaded Relief-Surface Classification Map

The shaded relief-surface classification map combines the 5 m IFSAR data and the ETM+ surficial classification map. The color classification scheme is the same as the surface classification map, however, light-gray to black hillshading from the DTM has been added to enhance surface features.

Specific spectral units or combinations of spectral units tend to correlate with specific topographic features such as eolian and coastal ridges and river valleys. A combination of shaded relief, and dry vegetated sand, sandy mud, and unclassified pixels define east to northeast trending ridges capped by parabolic dunes in the western part of the study area (Plate 3). Pixels classified as dry vegetated sand primarily cover the ridges and dunes and unclassified and wet sandy mud pixels dominate the inter-dune and inter-ridge areas (Plate 3).

Low-profile (> 10m) river valleys dominate the eastern part of the study area (Plate 3). Meandering channels are slightly incised and the sediments in active channels are classified primarily as clean and slightly muddy sands. Adjacent to the active fluvial channels are low-profile water and sediment-filled abandoned channels and thaw lakes, which classify as water, and wet vegetated sandy mud (Plate 3). Bordering the active and abandoned channels are low-relief terraces classified as dry vegetated sand (Plate 3). Field investigations indicate that some of the low-relief terraces are capped by eolian reworked fluvial deposits. Flanking the low-relief terraces are broad flat interfluvial plains that are classified as wet sandy mud, dry vegetated sand, green vegetation and unclassified pixels (Plate 3). The broad plain areas contain an abundance of sandy mud and water-filled thaw lakes. Some of the lakes and lake deposits tend to form groups of northeast trending topographically low areas and may indicate locations of older abandoned stream and river channels.

The shaded relief-surface classification map illustrates a close relationship between surficial vegetation and topography, which may be linked to the availability of water for vegetation and depth to permafrost. The DTM shows that the eolian and coastal ridges, which cover the western part of the study area, are up to 500 m wide, average 4 km in length, and have vertical profiles of approximately 18 m (Plates 1, and 3). Up to 60 percent of the vegetation on these dunes was either senescent or dead (brown to light gray in color; Fig. 12). Vegetation types on eolian and coastal ridges included sedges, lichens, and mosses (Fig. 11). Field investigations show that the floodplain and river valley areas in the eastern part of the study area contain up to 80 percent green vegetation, consisting of sedges, dwarf willows and alders, perennials, and mosses (Fig. 14). Thus, field observations suggest that there is significantly more moist vegetation and standing water in the river valleys than the eolian and coastal ridges. Shallow pits dug in the field indicate that depth to permafrost was 0.5 m - 1.2 m in the eolian and coastal dune areas and 0.2 m - 0.4 m in the eastern fluvial dominated topography. The differences in depth to permafrost may be due to either better drainage of the eolian and coastal dune sediments or greater exposed surface area of the dunes, which would increase the rate of melting permafrost. Due to the extremely dry conditions of < 10 cm of precipitation per year (NOAA, 2005), water perched above the permafrost is a major source of water for vegetation. Thus, increased depth to permafrost would create more arid surface conditions favoring stressed vegetation and organisms such as lichens that thrive in relatively arid conditions.

Conclusions

Image and field spectra indicate that acquisition of visible and short-wave infrared remote sensing imagery must be done during early summer. In mid- to late- summer, green vegetation densities increase and obscure some of the spectral variability. Field spectra of dry vegetated sand acquired in mid-summer resembled field spectra taken from lake deposits due to the increase in green vegetation. Image spectra of dry vegetated sand acquired in early summer, however, illustrate less green vegetation and have distinct spectral features that can be mapped.

The IFSAR and Landsat 7 ETM+ data provide complementary information that enhances the ability to map subtle land cover variations in the NPRA coastal plain. The DTM permits identification of landforms using elevation data. The surficial classification map is composed of spectral units that defined different types of sediment such as wet sandy mud, muddy sand, and clean sand. Spectral units of the surface classification map also define areas of green vegetation, dead or senescent vegetation and water during the early summer. The spectral units of the surface classification map form distinct patterns that highlight geomorphic features such as sediment-filled lakes, dune and ridge complexes, and river valleys. The merged data in the shaded relief-surface classification map provides better definition of topographic features than the individual datasets due to the relationship of topographic features, sediment types and vegetation cover to water availability, which may be due to variations in the depth to permafrost for specific landforms.

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