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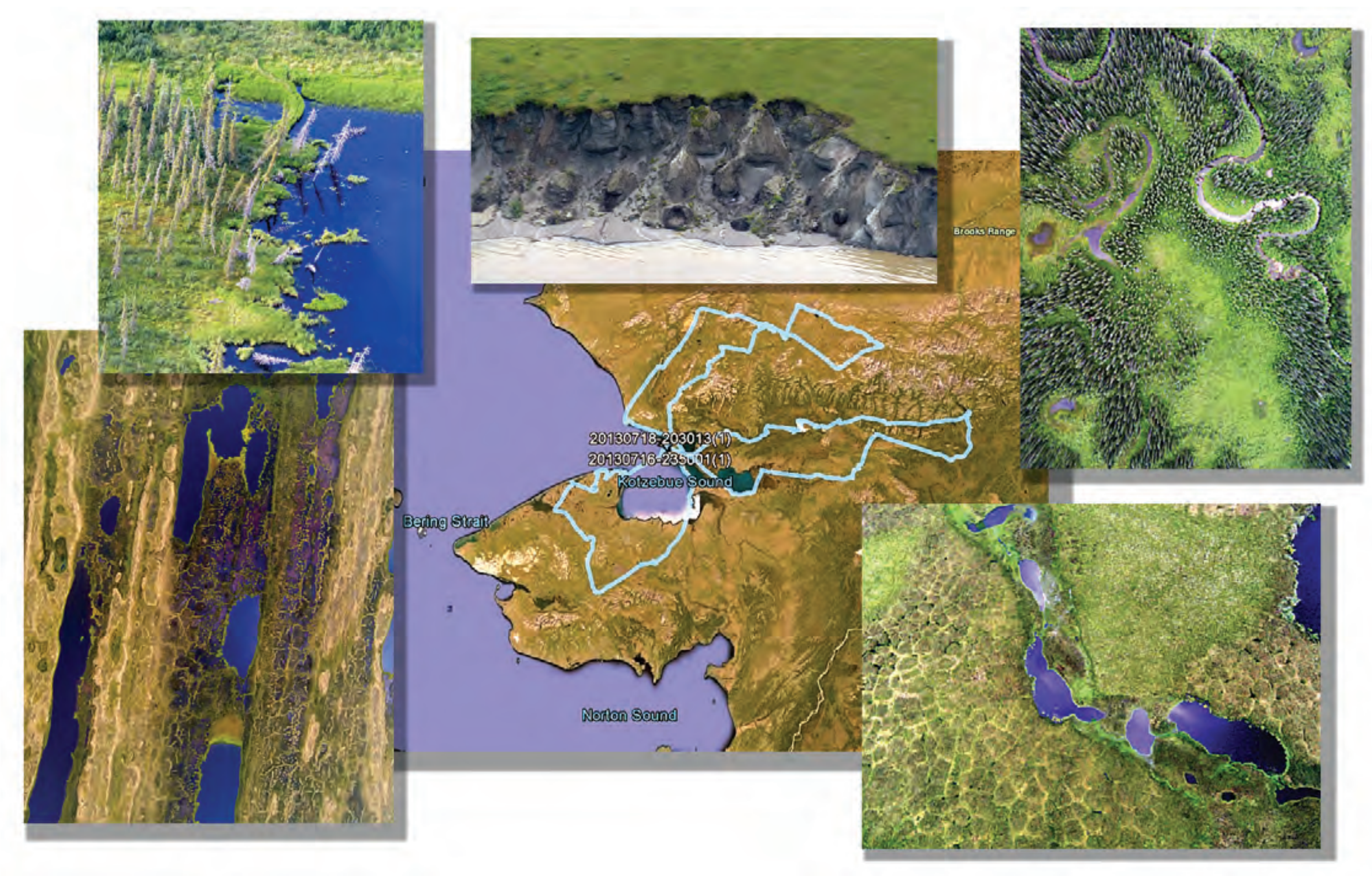
Low-Altitude Photographic Transects of the Arctic Network of National Park Units and Selawik National Wildlife Refuge, Alaska, July 2013



Data Series 846

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

Cover:
Center: transect flight paths in northwest Alaska (Google Earth® map).
Photographs from transect series, clockwise from lower left: coastal water and lowland circumacidic sedge fen, Cape Espenberg, Bering Land Bridge National Preserve (photograph ARCN 130716 Bering, GoPro 0117_pt.jpg); white spruce "drunken trees" and soil subsidence from permafrost melt by tundra lake, Selawik National Wildlife Refuge (photograph ARCN 130717 KobGatSel, Lumix 1116.jpg); coastal erosion, Baldwin Peninsula (photograph ARCN 130717 KobGatSel, Lumix 1331.jpg); riverine white spruce-willow forest and riverine loamy moist alder or willow tall shrub, Noatak National Preserve (photograph ARCN 130718 NoaKru, Drift 2997_pt.jpg); upland organic-rich moist acidic dwarf birch-tussock shrub, Noatak National Preserve (photograph ARCN 130718 NoaKru, Drift 0890_pt.jpg).

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By Bruce G. Marcot, M. Torre Jorgenson, and Anthony R. DeGange

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

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Contents

Figures

Figures–Continued

Tables

Conversion Factors, Datums, and Acronyms and Abbreviations

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
	Area	
hectare (ha)	2.471	acre
hectare (ha)	0.003861	square mile (mi^2)

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Conversion Factors, Datums, and Acronyms and Abbreviations

Acronyms and Abbreviations

AGL	above ground level
ARCN	Arctic Network: Five National Park Service units in northwestern Alaska
csv	comma-separated values, a plain-text database format
DEM	digital elevation model
EXIF	exchangeable image file format
fps	frames per second
GIS	geographic information system
GPS	geographic positioning system
gpx	a file format used by Garmin® GPS eXchange data
jpg	a format for a digital image file based on Joint Photographic Expert Group standards
kmz	Google Earth® compressed location file
mp	megapixel
mp4	a digital multimedia format for video and audio based on MPEG-4 standards
NPS	National Park Service
p	pixel
wmv	Microsoft® Windows Media Video, a digital multimedia format for video and audio
xlsx	a compressed spreadsheet format commonly used by Microsoft® Excel

Low-Altitude Photographic Transects of the Arctic Network of National Park Units and Selawik National Wildlife Refuge, Alaska, July 2013

By Bruce G. Marcot[1], M. Torre Jorgenson[2], and Anthony R. DeGange[3]

Abstract

During July 16–18, 2013, low-level photography flights were conducted (with a Cessna 185 with floats and a Cessna 206 with tundra tires) over the five administrative units of the National Park Service Arctic Network (Bering Land Bridge National Preserve, Cape Krusenstern National Monument, Gates of the Arctic National Park and Preserve, Kobuk Valley National Park, and Noatak National Preserve) and the U.S. Fish and Wildlife Service's Selawik National Wildlife Refuge in northwest Alaska, to provide images of current conditions and prevalence of land-cover types as a baseline for measuring future change, and to complement the existing grid-based sample photography of the region. Total flight time was 17 hours, 46 minutes, and total flight distance was 2,590 kilometers, at a mean altitude of about 300 meters above ground level.

A total of 19,167 photographs were taken from five digital camera systems:

1. A Drift® HD-170 (focal length 5.00 mm);
2. A GoPro® Hero3 Black Edition (focal length 2.77 mm);
3. A Panasonic® Lumix DMC-FZ200 (24× superzoom with variable focal length);
4. A Panasonic® Lumix DMC-SZ7 (10× superzoom with variable focal length); and
5. A Canon® Rebel 3Ti with a Sigma zoom lens (18–200 mm focal length).

The Drift® HD-170 and GoPro® Hero3 cameras were secured to the struts and underwing for nadir (direct downward) imaging. The Panasonic® and Canon® cameras were each hand-held for oblique-angle landscape images, shooting through the airplanes' windows, targeting both general landscape conditions as well as landscape features of special interest, such as tundra fire scars and landslips.

The Drift® and GoPro® cameras each were set for time-lapse photography at 5-second intervals for overlapping coverage. Photographs from all cameras (100 percent .jpg format) were date- and time-synchronized to geographic positioning system waypoints taken during the flights, also at 5-second intervals, providing precise geotagging (latitude-longitude) of all files. All photographs were adjusted for color saturation and gamma, and nadir photographs were corrected for lens distortion for the Drift® and GoPro® cameras' 170° wide-angle distortion. EXIF (exchangeable image file format) data on camera settings and geotagging were extracted into spreadsheet databases. An additional 1 hour, 20 minutes, and 43 seconds of high-resolution videos were recorded at 60 frames per second with the GoPro® camera along selected transect segments, and also were image-adjusted and corrected for lens distortion. Geotagged locations of 12,395 nadir photographs from the Drift® and GoPro® cameras were overlayed in a geographic information system (ArcMap 10.0) onto a map of 44 ecotypes (land- and water-cover types) of the Arctic Network study area. Presence and area of each ecotype occurring within a geographic information system window centered on the location of each photograph were recorded and included in the spreadsheet databases. All original and adjusted photographs, videos, geographic positioning system flight tracks, and photograph databases are available by contacting ascweb@usgs.gov.

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Introduction

Photography of land-cover conditions in arctic and boreal regions of Alaska has proven to be of great value for analyzing landscape changes from various local-to-regional causes (Swanson and Hill, 2010; Swanson 2012a, 2012b; Necsoiu and others, 2013). For example, a systematic 20-km grid of aerial photographs (Swanson, 2013) has provided information for estimating rates and causes of changes in land-cover types (vegetation, water). These estimates of transitional rates have been used in projecting potential effects of climate change on future land cover and implications for wildlife habitat throughout a large arctic and boreal region of northwest Alaska (DeGange and others, 2013). This project was initiated to complement the existing photographic databases by providing a set of high-resolution, natural-light images in continuous coverage along flight transects within the study area of northwest Alaska addressed by DeGange and others (2013).

Description of Study Area

The study area included five administrative units of the National Park Service Arctic Network (Bering Land Bridge National Preserve, Cape Krusenstern National Monument, Gates of the Arctic National Park and Preserve, Kobuk Valley National Park, and Noatak National Preserve), the adjacent area of U.S. Fish and Wildlife Service's Selawik National Wildlife Refuge, and a 10-km buffer around all these administrative units (fig. 1), totaling 162,868 km^2 in an area spanning about 500 km from east to west and about 300 km from north to south. This also is the study area for the U.S. Geological Survey Wildlife Potential Habitat Forecasting Framework Project (WildCast) that projects effects of climate change on future land cover and wildlife habitat (DeGange and others, 2013).

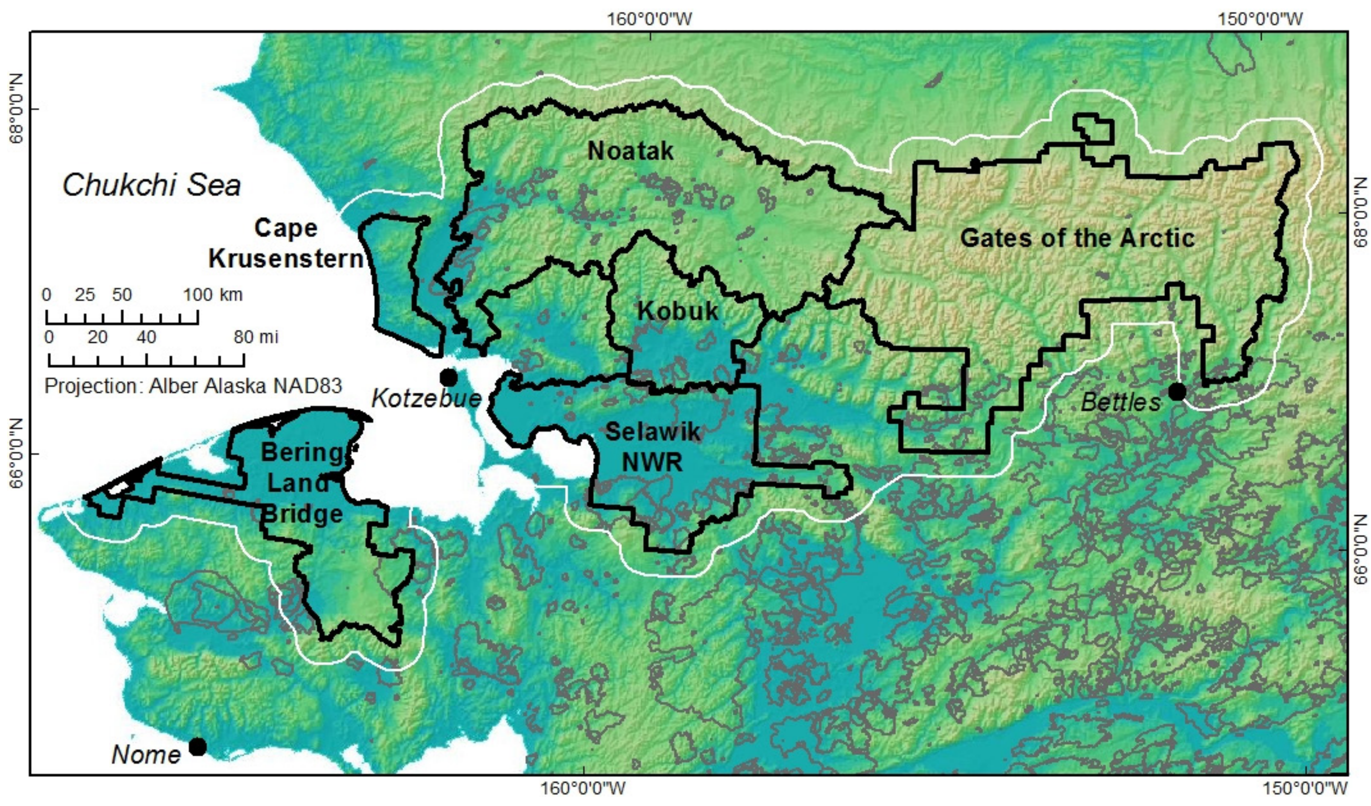


Figure 1. Study area in northwest Alaska comprising five national park units (black outlines) and one national wildlife refuge (NWR) and a surrounding 10-km buffer (white line). Historical fires since 1950 are shown in gray outlines and base map is a shaded-relief map using the U.S. Geological Survey National Elevation Dataset (300-m resolution, lower elevations in blue, higher elevations in yellow).

Methods

Using the village of Kotzebue, Alaska, as a base of operations, we completed the project during 3 days of flights over the study area:

- July 16, 2013—Flight path over Bering Land Bridge National Preserve, with a Cessna 185 equipped with floats (fig. 2);
- July 17, 2013—Flight path over Kobuk Valley National Park, the western edge of Gates of the Arctic National Park and Preserve, and Selawik National Wildlife Refuge, with a Cessna 206 equipped with tundra tires (fig. 3); and
- July 18, 2013—Flight path over Noatak National Preserve and Cape Krusenstern National Monument, with a Cessna 206 equipped with tundra tires (fig. 4).

Figure 2. Flight path with altitude and speed profiles on July 16, 2013, over Bering Land Bridge National Preserve, northwest Alaska. Image source: Google Earth®.

Figure 3. Flight path, with altitude and speed profiles on July 17, 2013, over Kobuk Valley National Park, Gates of the Arctic National Park and Preserve, and Selawik National Wildlife Refuge, northwest Alaska. Image source: Google Earth®.

The specific flight routes were selected to provide a broad representation of ecotypes and land-cover types within each unit, as well as to overfly specific locations with thaw slumps, coastal erosion, and recent tundra fires (figs. 2–4). Each day's flight path consisted of four segments, as three landings were made each day (as shown in the altitude and speed profiles in figs. 2–4), including a landing to inspect and sample ground ice from an exposed pingo core in the northern part of Bering Land Bridge National Preserve.

During all flight segments, global positioning system (GPS) waypoints were recorded automatically at 5-second intervals using an i-gotU® GT-120 GPS waypoint data logger (table 1) mounted on the dashboard of each airplane, resulting in .gpx waypoint computer files (later converted to .csv files for analysis of waypoint statistics; see table 2). The .gpx files were imported into the @trip PC® software (table 3) for locating each flight path, and then the GPS waypoint tracks were exported into Google Earth® (figs. 2–4) and saved as .kmz (compressed GPS route data) format.

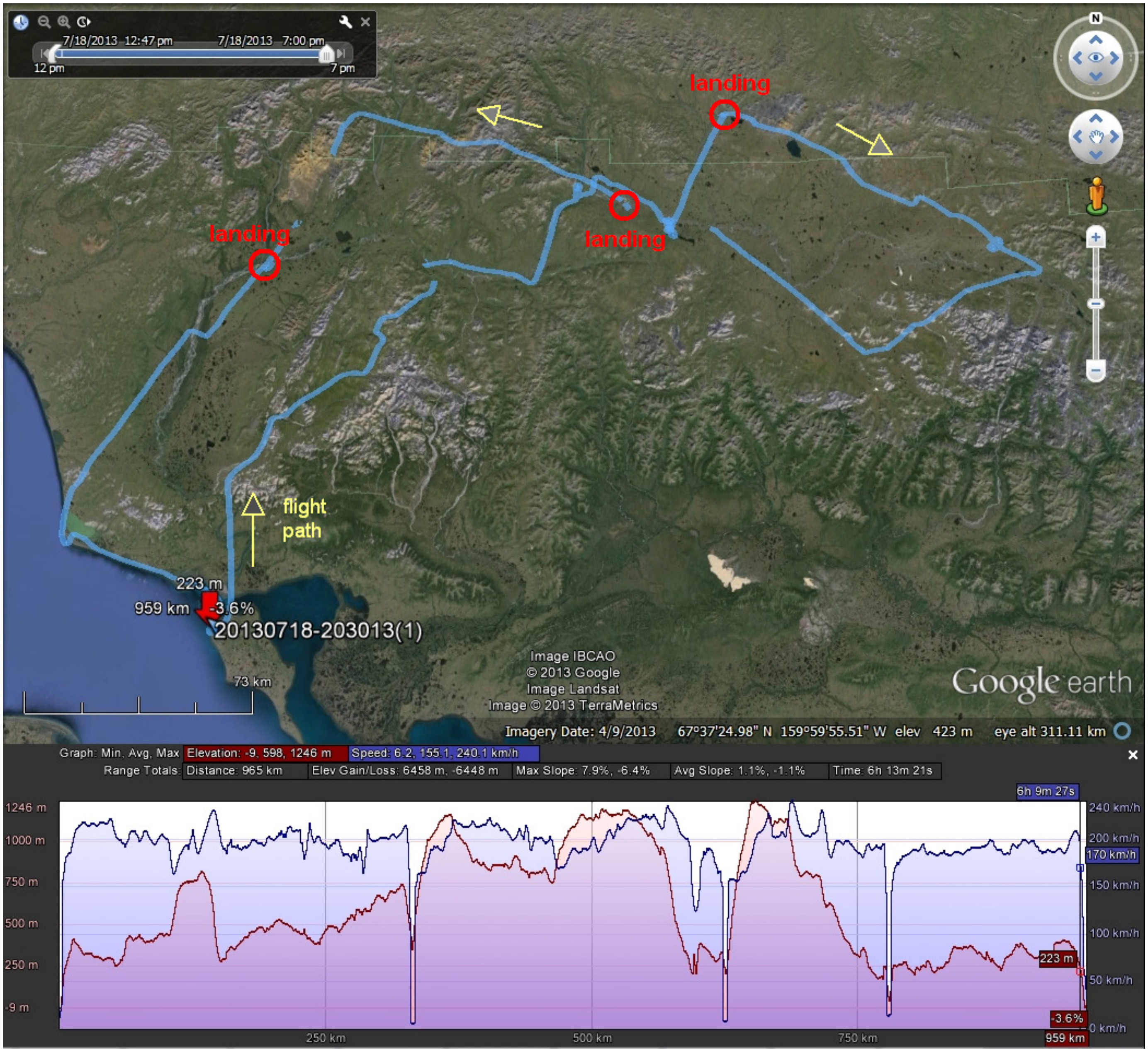


Figure 4. Flight transect route with altitude and speed profiles on July 18, 2013, over Noatak National Preserve and Cape Krusenstern National Monument, northwest Alaska. Image source: Google Earth®. (The flight path is continuous; apparent interruptions are because of Google Earth® presentation.)

Five cameras were used for imaging (table 1):

1. A Drift® HD-170 (focal length 5.00 mm, 5 mp resolution, 2592 × 1944 p, 4:3 aspect ratio, 24-bit color depth);
2. A GoPro® Hero3 Black Edition (focal length 2.77 mm, 12 mp resolution, 4000 × 3000 p, 4:3 aspect ratio, 24-bit color depth);
3. A Panasonic® Lumix DMC-FZ200 (24× superzoom with various focal lengths, 12 mp resolution, 4000 × 3000 p, 4:3 aspect ratio, 24-bit color depth);
4. A Panasonic® Lumix DMC-SZ7 (10× superzoom with various focal lengths, 14 mp resolution, 4320 × 3240 p, 4:3 aspect ratio, 24-bit color depth); and
5. A Canon® Rebel 3Ti (with Sigma zoom lens 18–200 mm focal length, 18 mp resolution, 5184 × 3456 p, 3:2 aspect ratio, 24-bit color depth).

Table 1. Hardware used for global positioning system (GPS) and photography.

Unit	Positioning
GPS	
i-gotU GT-120 GPS waypoint data logger (http://global.mobileaction.com/product/product_i-gotU_USB.jsp), with external battery pack (Brunton Inspire, www.brunton.com/products/inspire, 1000mA, 11.8Wh)	Positioned on the cockpit dashboard under the windshield for unobstructed access to GPS satellite signals
Garmin Oregon 550t hand-held GPS unit	Used on the ground and for backup GPS waypoint data
Cameras	
Drift® HD-170, with extra battery pack	Clamped onto the step strut for nadir imaging
GoPro® Hero3 Black Edition, with supplemental battery unit and extra battery packs	Mounted on the tail strut (Cessna 185 with floats) or on the underwing (Cessna 206 with tundra tires) for nadir imaging
Panasonic® Lumix DMC-FZ200 24× superzoom	Hand-held within the cockpit for oblique to near-nadir photos
Panasonic® Lumix DMC-FZ7 10× superzoom	Hand-held within the cockpit for oblique to near-nadir photos
Canon® Rebel 3Ti with Sigma zoom lens (18–200 millimeter focal length)	Hand-held within the cockpit for oblique to near-nadir photos

Table 2. Number of global positioning system (GPS) waypoints, number of photographs, and flight time and distance.

	Track names	**ARCN 130716 Bering LBNP**	**ARCN 130717 KobGatSel**	**ARCN 130718 NoaKru**	**Totals**
	Flight date	07-16-13	07-17-13	07-18-13	***3 days***
	Number of waypoints[1]	1,354	9,902	9,905	***21,161***
Waypoint times (hh:mm:ss)	Start	23:15:05	23:53:52	19:47:04	
	End	04:34:14	06:07:09	02:00:30	
	Elapsed	5:19:09	6:13:17	6:13:26	***17:45:52***
Number of photos by camera[2]	Drift®[3]	2,427	2,839	3,460	***8,726***
	GoPro®[3]	965	2,251	3,265	***6,481***
	Lumix FZ200	785	1,337	927	***3,049***
	Lumix S27	20	8	10	***38***
	Canon® Rebel	224	352	297	***873***
	Totals	***4,421***	***6,787***	***7,959***	***19,167***
Flight distance	kilometers	645	980	965	***2,590***
	miles	401	609	600	***1,609***

[1]From the i-gotU GT-120 GPS waypoint data logger (see table 1).

[2]After deleting extraneous images.

[3]These cameras were affixed to the plane and set to 5-second time-lapse operation (see appendix 1).

Table 3. Software used to process project data.

Application and source	Use
@trip PC, v. 5.0.1305.871 (http://www.a-trip.com/)	Importing .gpx global positioning system (GPS) waypoint files and displaying flight routes on maps and over satellite images; geotagging photographs, displaying flight routes with photographs.
ArcMap, v. 10.0 (http://www.esri.com/software/arcgis/arcgis10)	Overlaying photograph latitude-longitude exhangeable image file format (EXIF) data onto the ecotype maps.
ArcSoft Panorama Maker v. 3 (http://www.arcsoft.com/panorama-maker/)	Stitching sequential, overlapping digital images into contiguous panoramas.
BR's EXIFextracter, v. 0.9.10 beta (http://www.br-software.com/download.html)	Extracting EXIF and GPS location data into .csv files.
Bulk Rename Utility, v. 2.7.1.2 (http://www.bulkrenameutility.co.uk/Main_Intro.php)	Renaming photograph files into unique, sequential file names so as to plot them onto single GPS tracks for each camera.
EXIF Date Changer, v. 3.0.1.2 (http://www.relliksoftware.com/)	Correcting internal date and time stamps, and adding consistent EXIF data on camera, location, etc., to document each photograph file.
Freemake Video Converter 4.0 (http://www.freemake.com/)	Conversion of .mp4 video files (produced by the cameras) into .wmv video file format.
GoPro® Studio 2.0 (http://gopro.com/support/cineform-studio-software-support)	Processing of flight videos from GoPro® camera for lens distortion correction and enhancement (ProTune function).
Irfanview, v. 4.35 (http://www.irfanview.com/)	Batch-adjusting color and gamma of each photograph.
Microsoft® Excel, v. 2010 (http://www.microsoft.com/en-us/default.aspx)	Converting .csv files to, and manipulating, .xlsx files.
PTLens, v. 8.9 64-bit (http://www.epaperpress.com/ptlens/)	Correction of each Drift® and GoPro® photograph for wide-angle lens distortion.
TimeCalc, v. 1.04 (application used on Android tablet) (https://play.google.com/store/apps/details?id=com.senecacreeksoftware.timecalculator)	Date and time calculations used to set EXIF time data to correct some clock-setting errors from the cameras.

The Drift®HD-170 and GoPro® Hero3 cameras were secured to the struts and underwing for nadir (direct downward) imaging (fig. 5). The Panasonic® and Canon® cameras were each hand-held for oblique-angle landscape images, shooting through the airplanes' glass windows, targeting both general landscape conditions as well as landscape features of special interest, such as tundra fire scars and landslips.

The Drift®and GoPro® cameras were affixed to the airplane exteriors, and each was set for time-lapse photography at 5-second intervals (figs. 6–8) using their highest available resolution (5- and 12-mp, respectively). The 5-second time-lapse interval was calculated (appendix 1) as a function of the expected 300-m flight altitude above ground level (AGL), ground speed, the effective camera focal length after correction for lens distortion and cropping, and the desire to have about one-third overlap of adjacent photographs. Given the mean flight AGL and camera focal length, each resulting Drift®and GoPro® image covered about 71 ha of ground area (see appendix 3 for details on image and pixel sizes).

Additionally, as a demonstration of full continuous coverage, the GoPro® camera was set to video (movie) mode (focal length 2.77 mm, 1280 p × 720 p, 16:9 aspect ratio, 60 fps) for flight segments in Bering Land Bridge National Preserve (fig. 6*B*) and Selawik National Wildlife Refuge (fig. 7*D*). The videos provided the opportunity for extracting individual frames for further analysis.

All photographs were processed as follows (see appendix 2 for details). First, photograph files were separated into folders on the computer, and renamed by flight date and camera type (table 4). Video files (.mp4 format also converted to .wmv) were processed separately from photographs. Next, extensively redundant or extraneous photographs were deleted, such as time-lapse images taken when the planes were stationary, long sequences taken over deep water (for example, over Kotzebue Sound), and other images with no usable content.

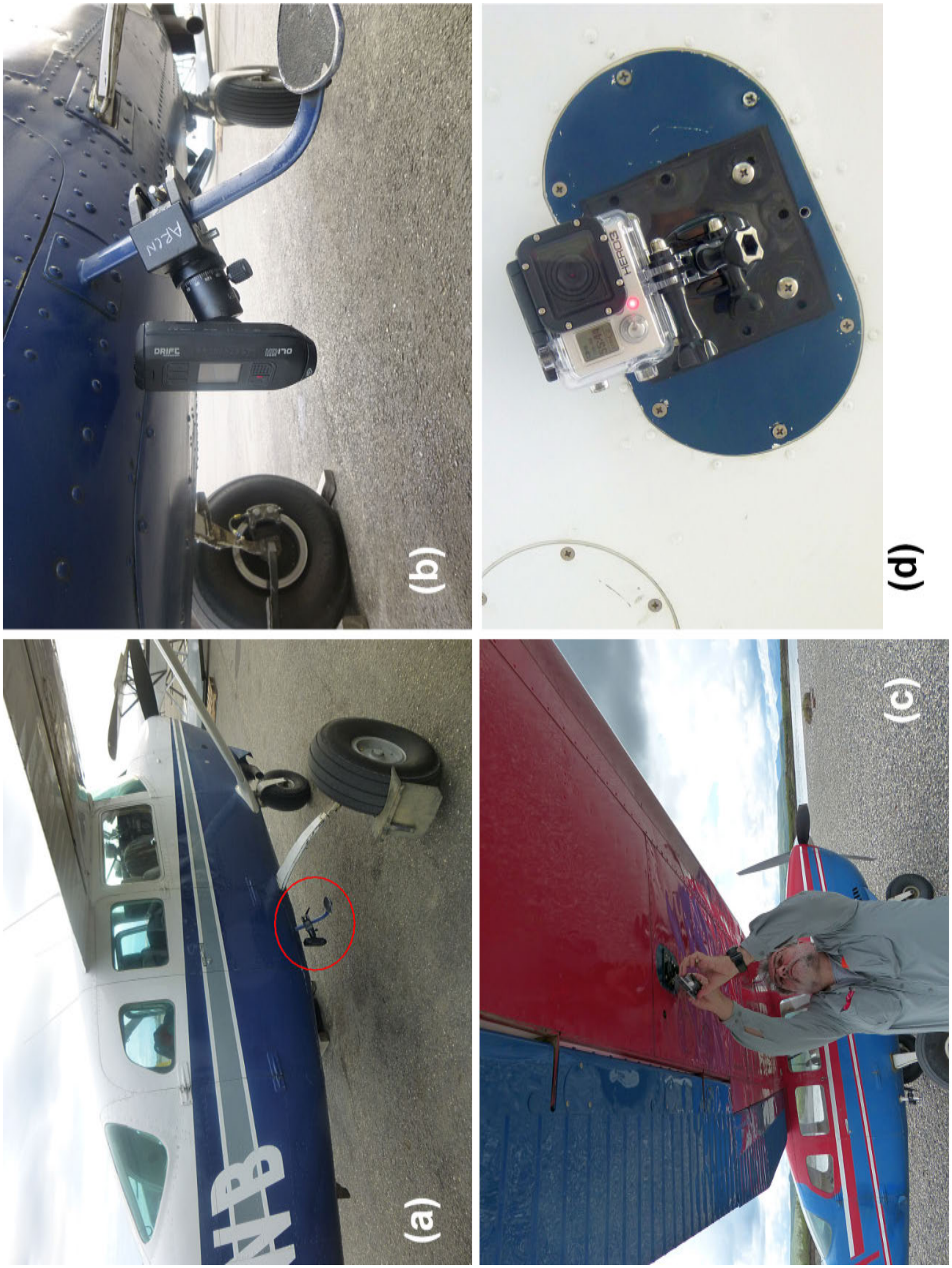
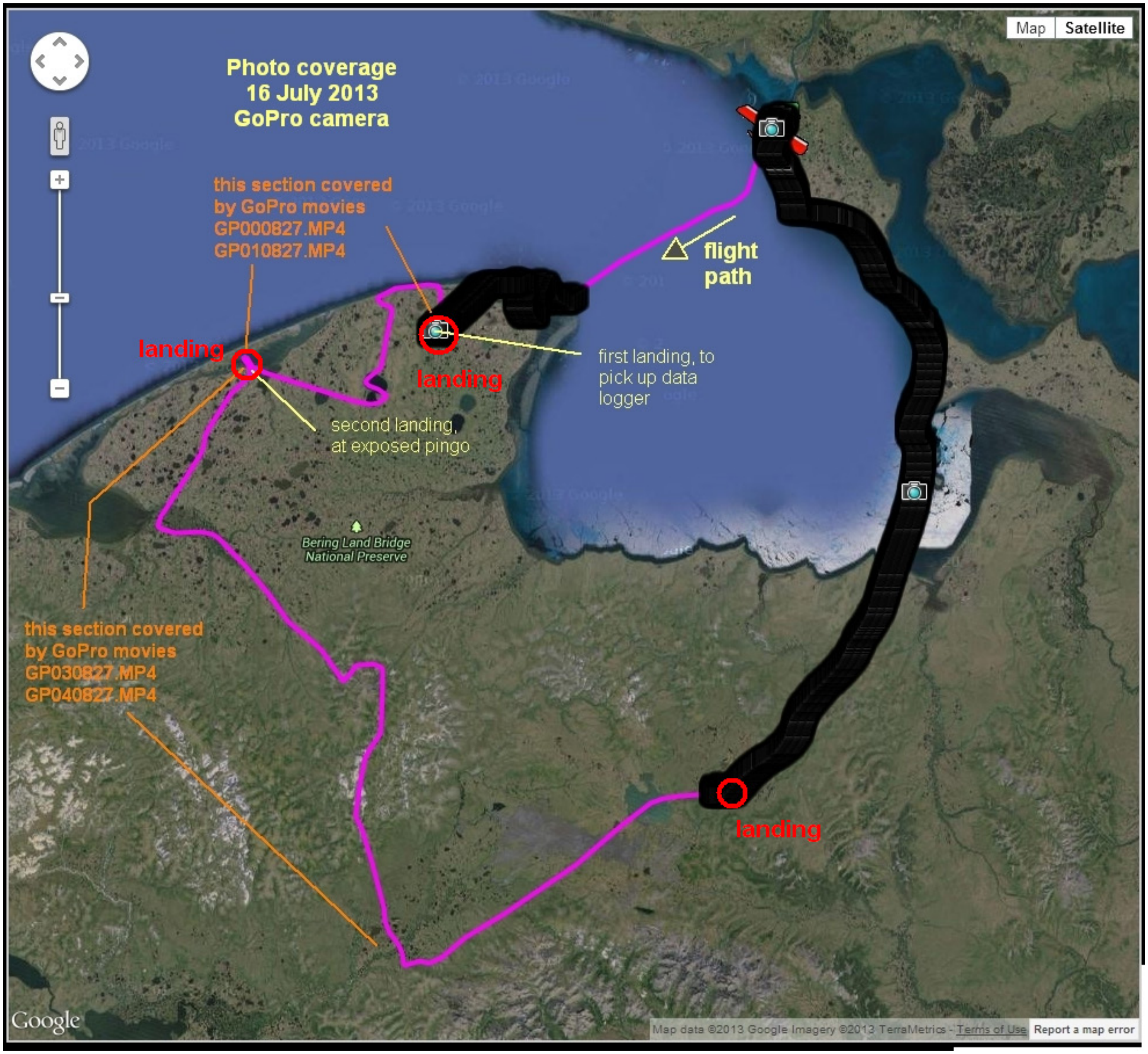


Figure 5. Locations of external cameras secured to the airplanes for low-level aerial photography. (a,b) Drift® HD-170 camera clamped to step strut on the Cessna 206; (c,d) GoPro® Hero3 camera bolted to underwing (both Cessna 205 and 206).

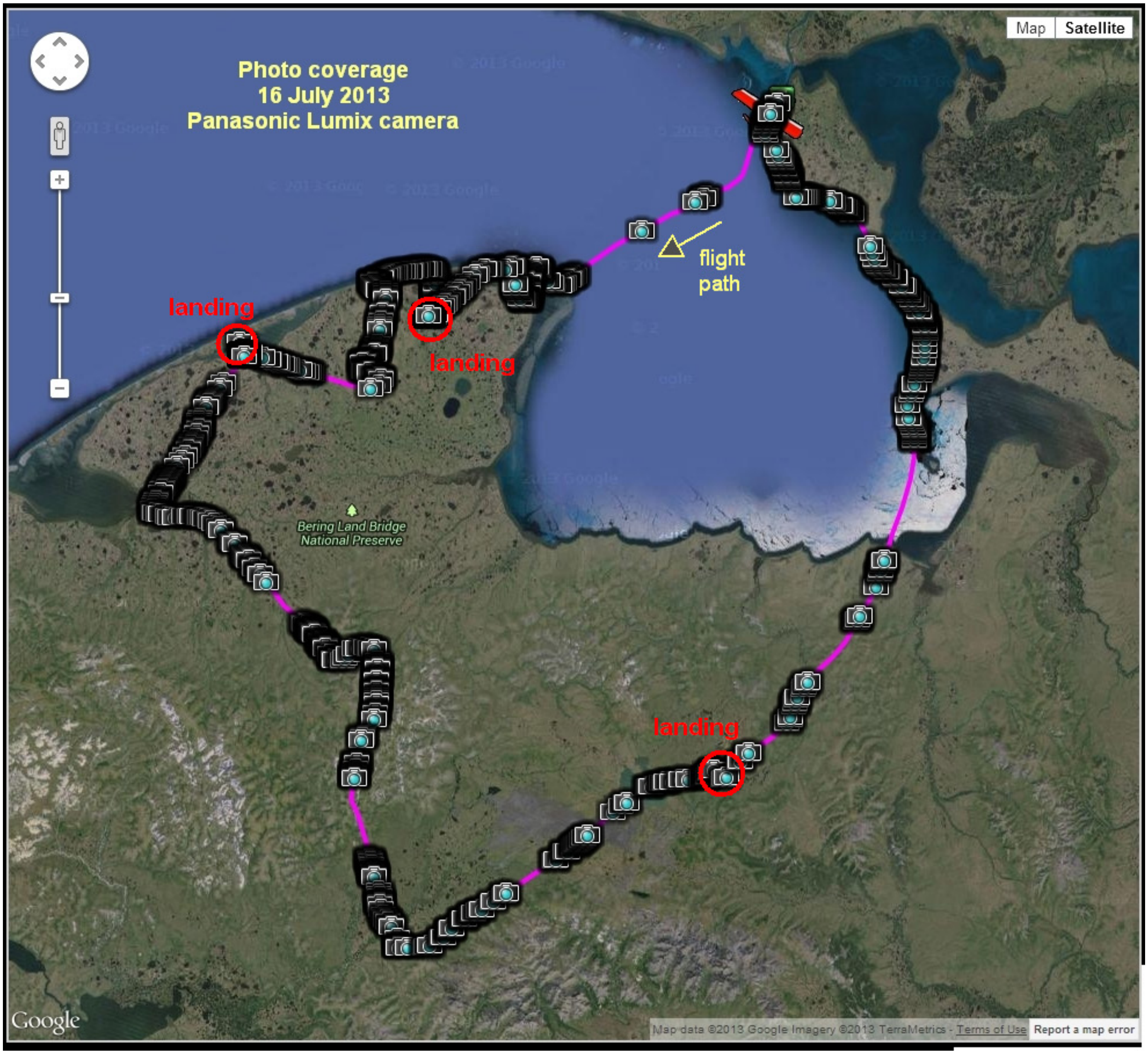
A. Drift® HD-170 camera

Figure 6. Photographic coverage for July 16, 2013, of Bering Land Bridge National Preserve, northwest Alaska. (*A*) Drift® HD-170 camera, (*B*) GoPro® Hero3 Black Edition camera, (*C*) Panasonic® Lumix DMC-FZ200 camera, (*D*) Canon® Rebel camera. Image produced by the software @trip PC® (see table 3). The dark black line denotes contiguous photography at 5-second intervals (small camera icons denote photography and are placed at random by the @trip PC® software).



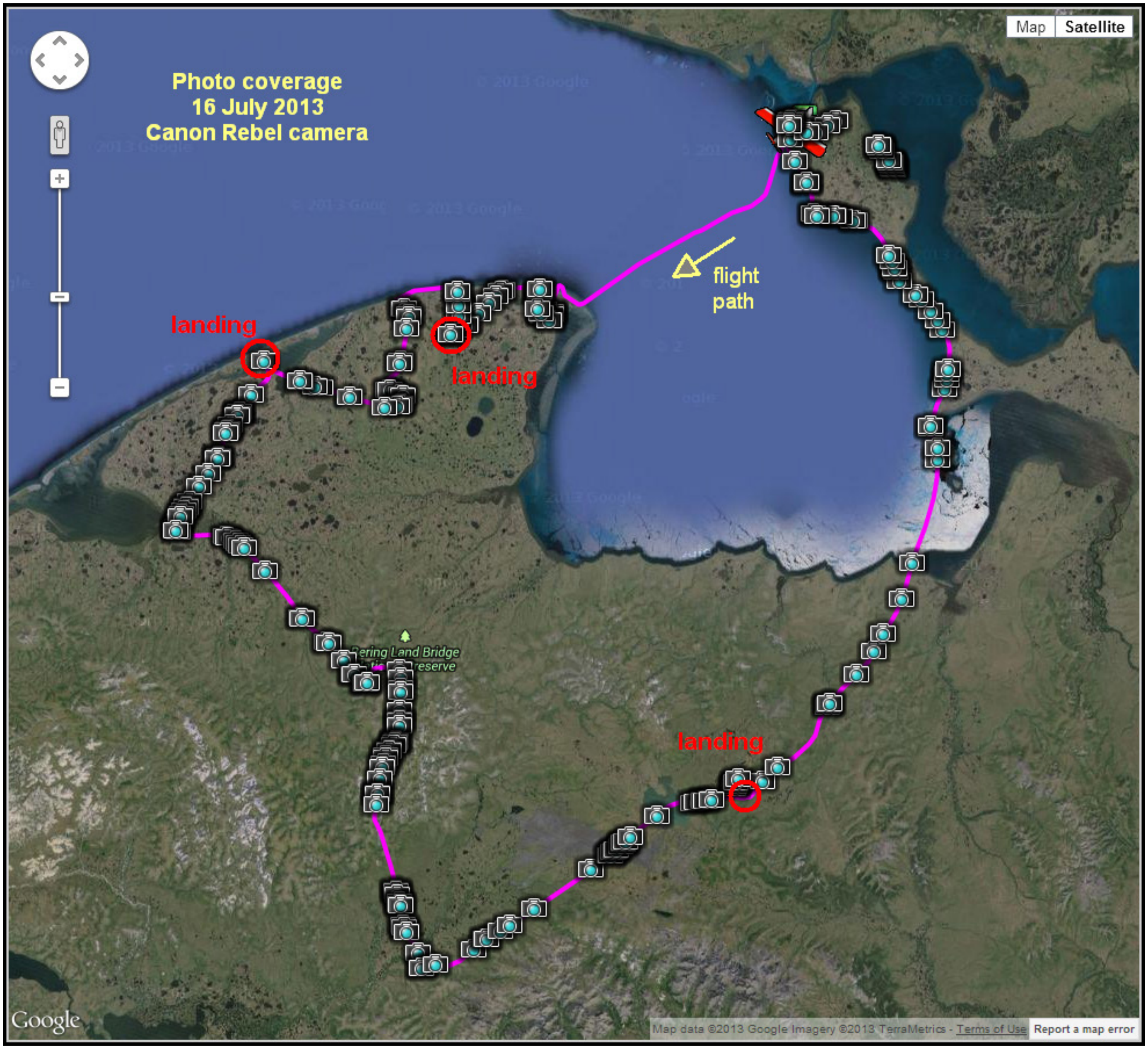
B. GoPro® Hero3 Black Edition camera

Figure 6.—Continued



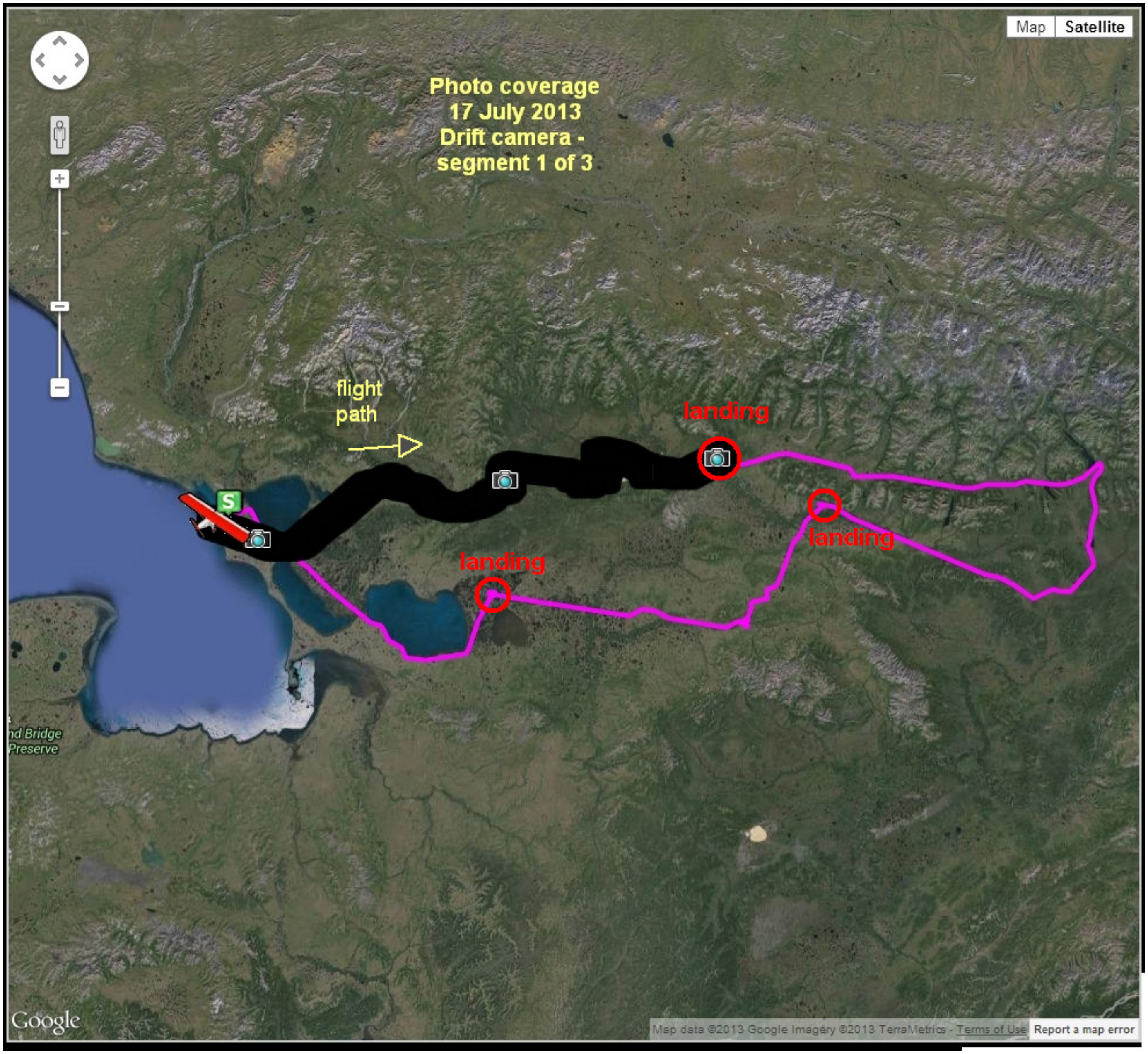
C. Panasonic® Lumix DMC-FZ200 camera

Figure 6.—Continued



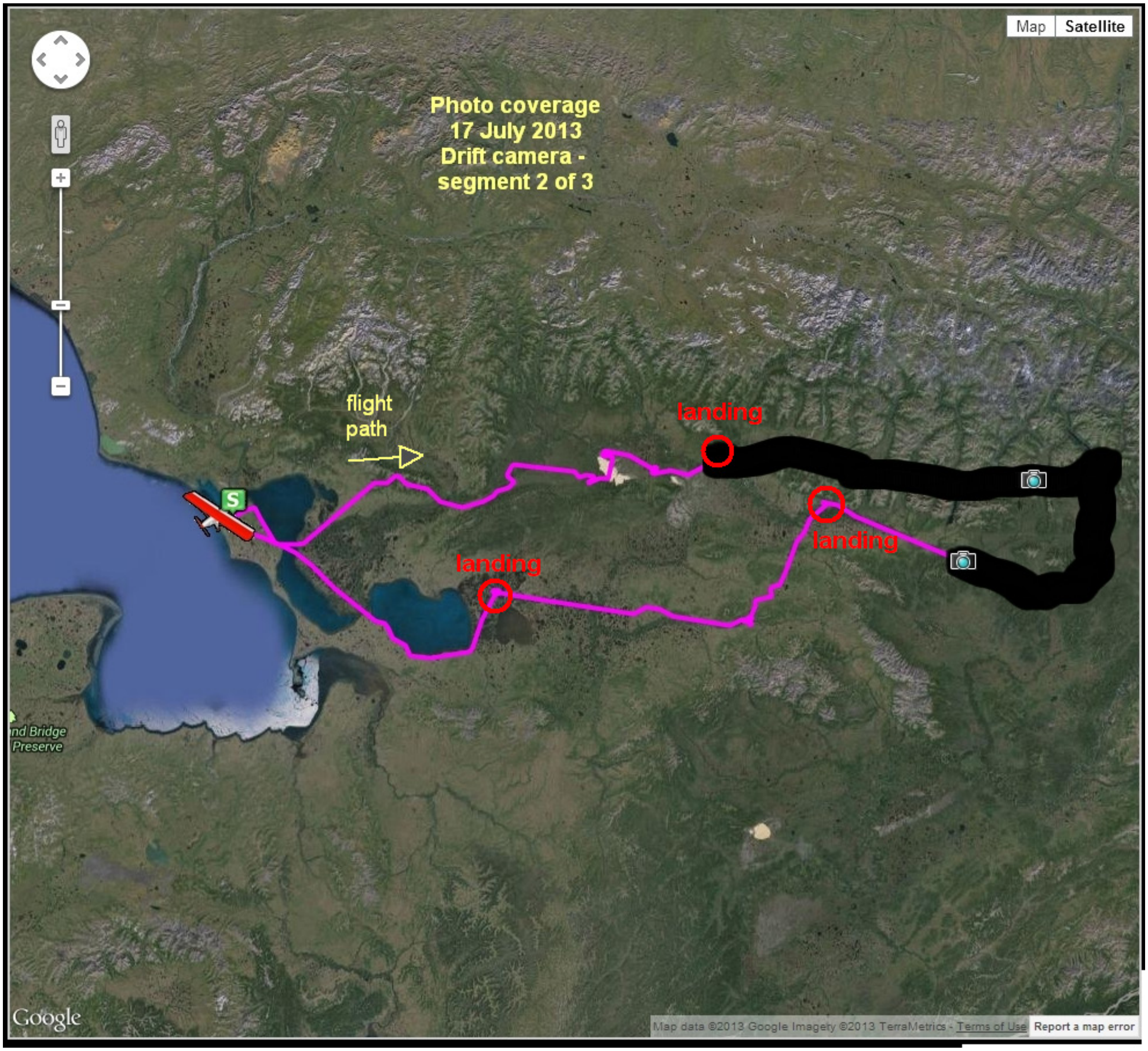
D. Canon® Rebel camera

Figure 6.—Continued



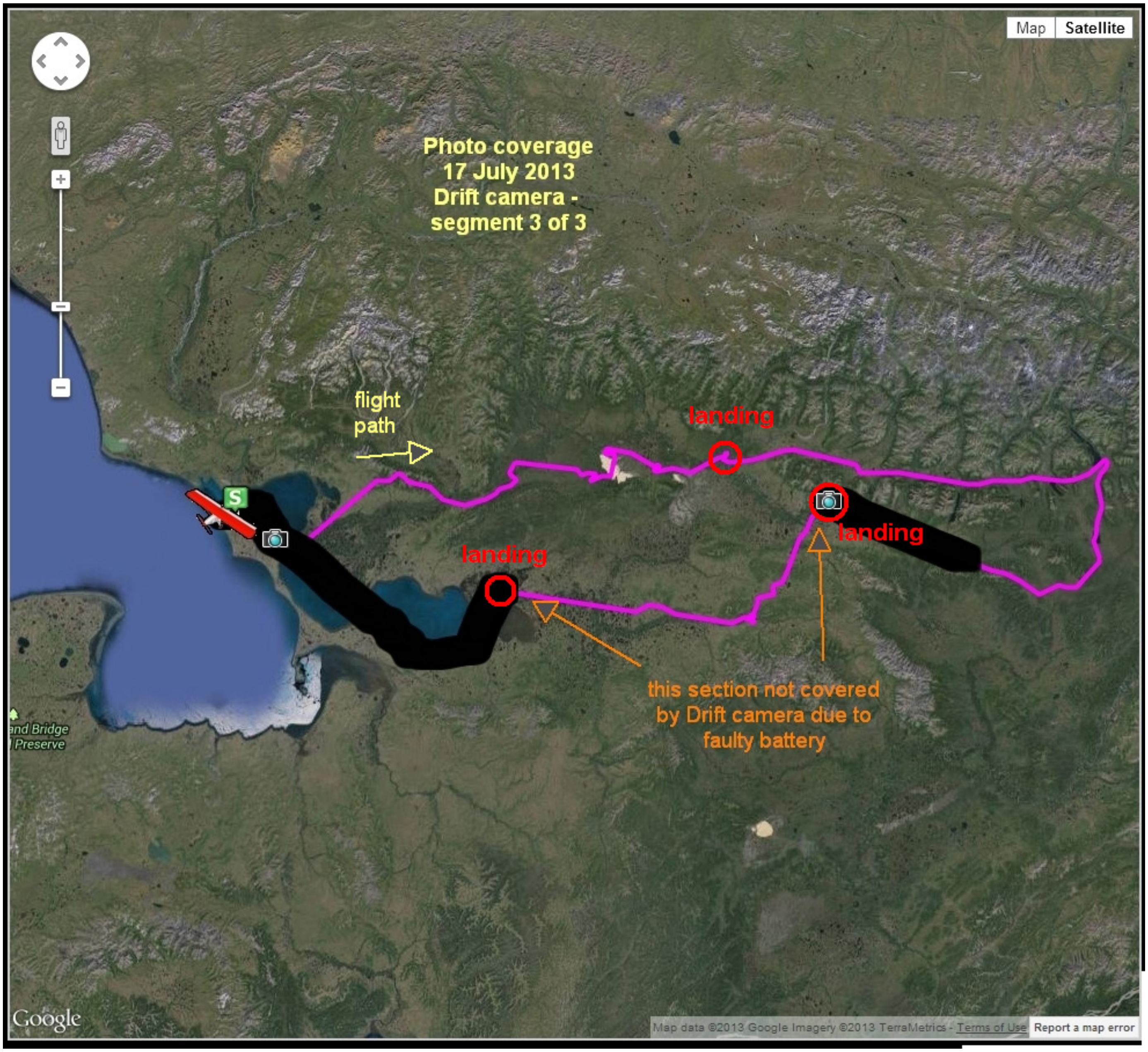
A. Drift® HD-170 camera, segment 1

Figure 7. Photographic coverage on July 17, 2013, of Kobuk Valley National Park, Gates of the Arctic National Park and Preserve, and Selawik National Wildlife Refuge, northwest Alaska. (*A*–*C*) Drift® HD-170 camera, (*D*) GoPro® Hero3 Black Edition camera, (*E*) Panasonic® Lumix DMC-FZ200 camera, (*F*) Canon® Rebel camera. Image produced by the software @trip PC® (see table 3). The dark black line denotes contiguous photography at 5-second intervals (small camera icons denote photography and are placed at random by the @trip PC® software).



B. Drift® HD-170 camera, segment 2

Figure 7.—Continued



C. Drift® HD-170 camera, segment 3

Figure 7.—Continued

D. GoPro® Hero3 Black Edition camera

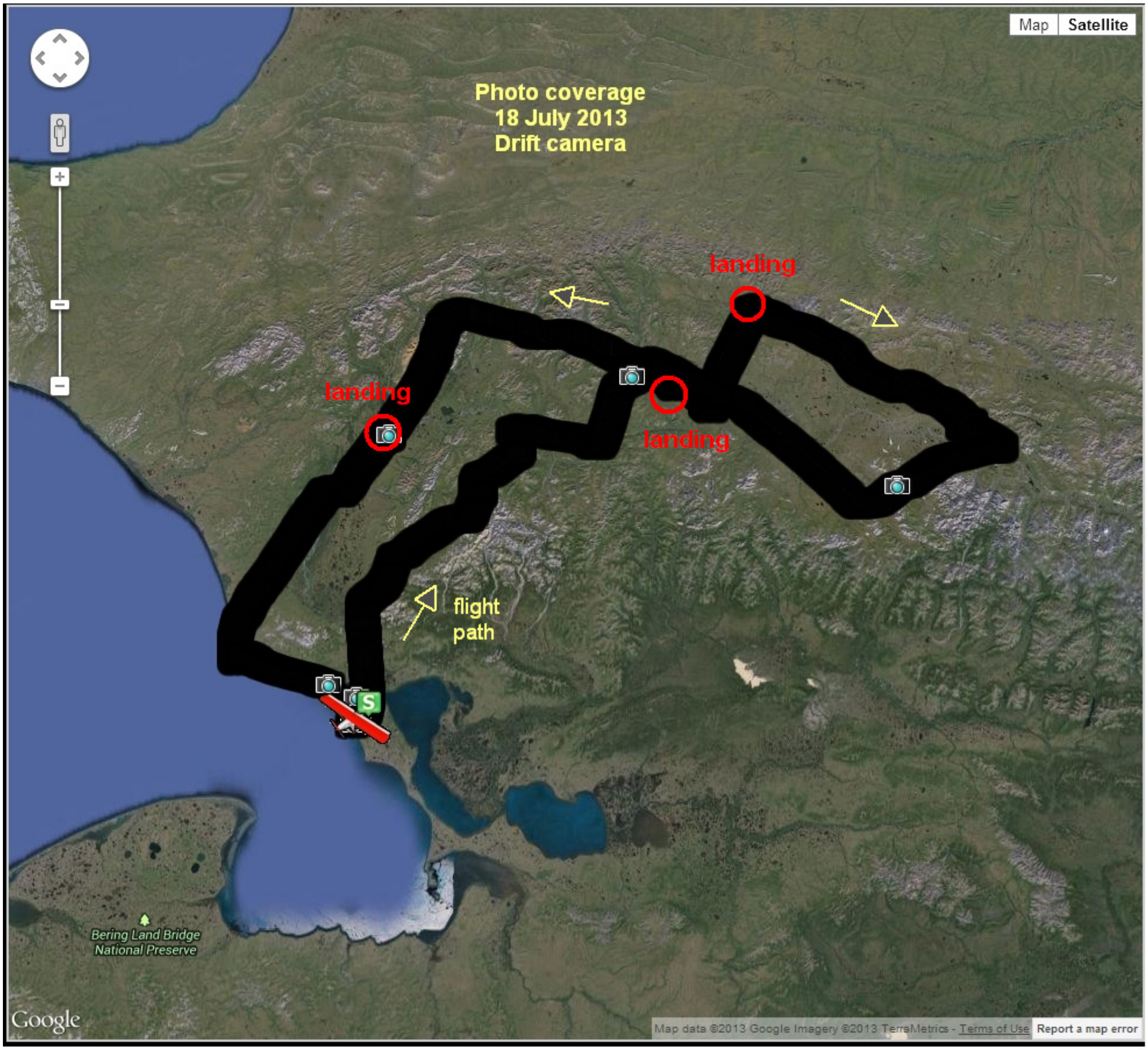
Figure 7.—Continued

E. Panasonic® Lumix DMC-FZ200 camera

Figure 7.—Continued

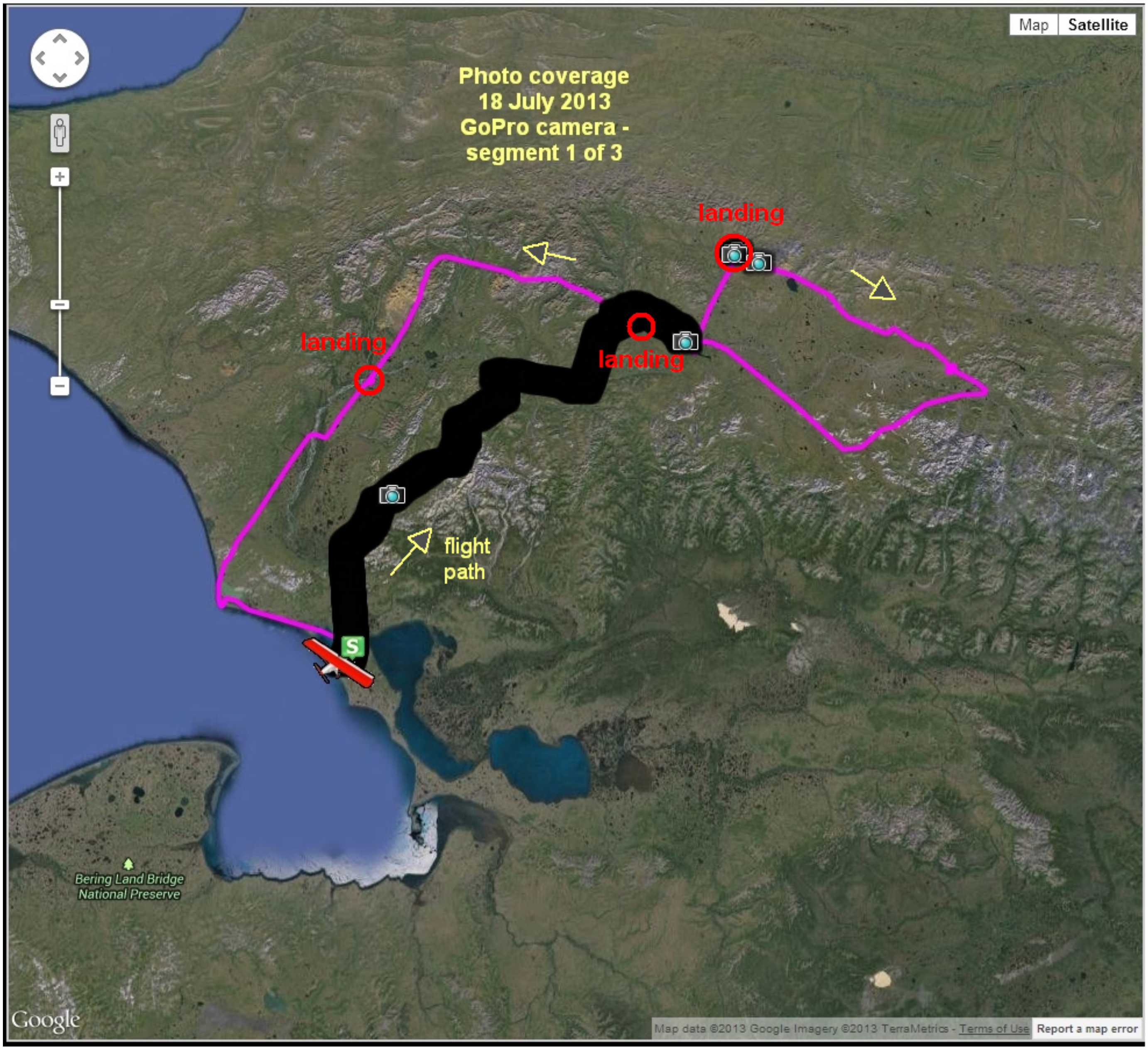
F. Canon® Rebel camera

Figure 7.—Continued



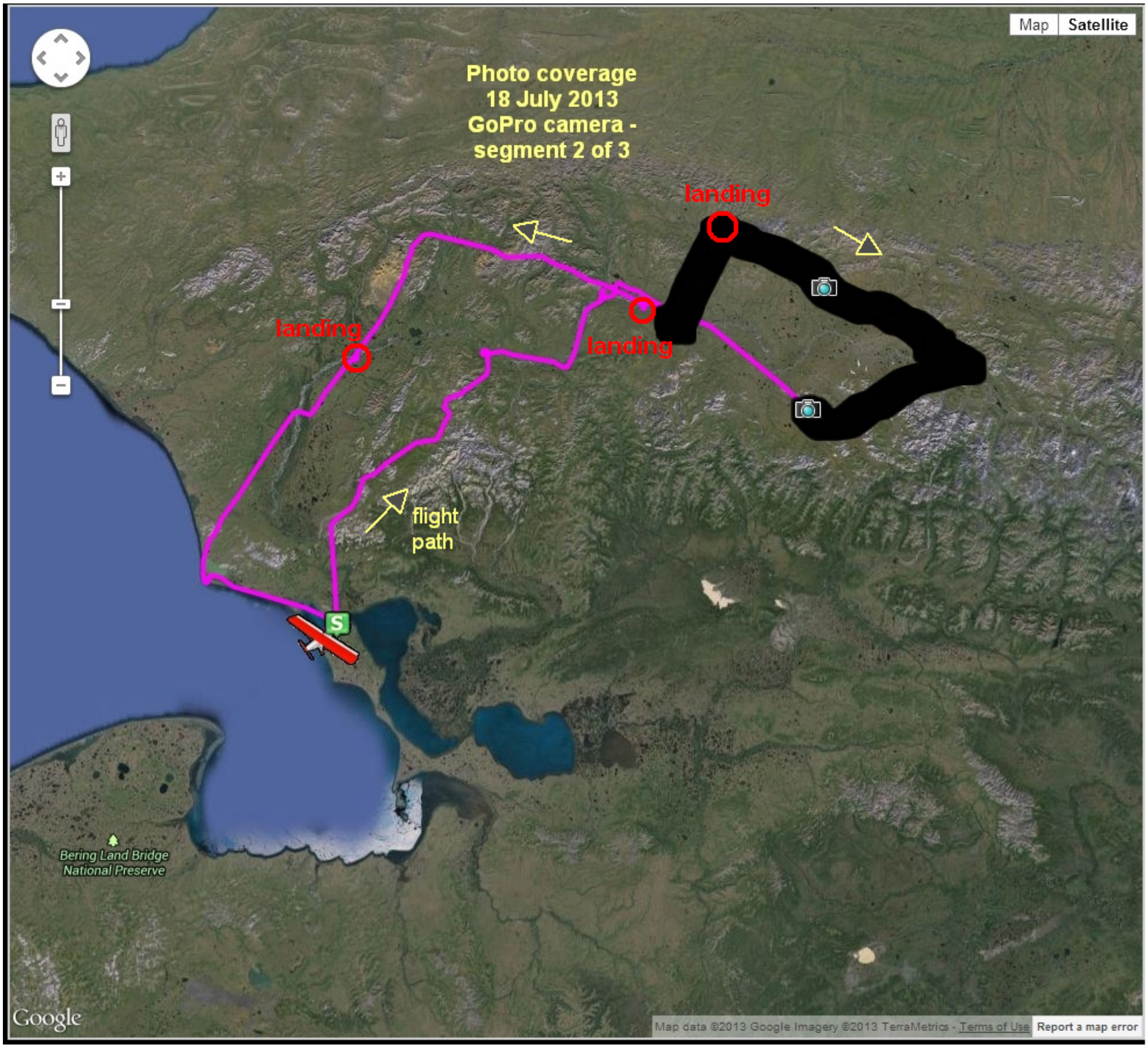
A. Drift® HD-170 camera,

Figure 8. Photographic coverage, on July 18, 2013, of Noatak National Preserve and Cape Krusenstern National Monument, northwest Alaska. (*A*) Drift® HD-170 camera, (*B–D*) GoPro® Hero3 Black Edition camera, (*E*) Panasonic® Lumix DMC-FZ200 camera, (*F*) Canon® Rebel camera. Image produced by the software @trip PC® (see table 3). The dark black line denotes contiguous photography at 5-second intervals (small camera icons denote photography and are placed at random by the @trip PC® software).



B. GoPro® Hero3 Black Edition camera, segment 1

Figure 8.—Continued



C. GoPro® Hero3 Black Edition camera, segment 2

Figure 8.—Continued

D. GoPro® Hero3 Black Edition camera, segment 3

Figure 8.—Continued

E. Panasonic® Lumix DMC-FZ200 camera

Figure 8.—Continued

F. Canon® Rebel camera

Figure 8.—Continued

Table 4. Naming convention of photographs and their computer subdirectories.

[**Computer subdirectory name:** *Location* Bering, Bering Land Bridge National Preserve; Gat, Gates of the Arctic National Park and Preserve; Kob, Kobuk Valley National Park; Kru, Cape Krusenstern National Monument; Noa, Noatak National Preserve; Sel, Selawik National Wildlife Refuge. *Cameras used:* Drift, Drift® HD-170 camera; GoPro, GoPro® Hero3 Black Edition camera; Lumix, Panasonic® Lumix DMC-FZ200 superzoom camera; LumixSZ7, Panasonic® Lumix DMC-SZ7 superzoom camera; Canon, Canon Rebel 3Ti. **File name template:** ARCN, National Park Service Arctic Network; 13071d, yymmdd flight date (130716, 130717, 130718); xxxx, photograph file number (0001, 0002, ...)]

Computer subdirectory name	File name template
\ARCN Photos 130716 Bering\Drift® HD170	ARCN 130716 Bering, Drift® xxxx
\ARCN Photos 130716 Bering\GoPro® Hero3	ARCN 130716 Bering, GoPro® xxxx
\ARCN Photos 130716 Bering\Panasonic® Lumix DMC-FZ200	ARCN 130716 Bering, Lumix xxxx
\ARCN Photos 130716 Bering\Panasonic® Lumix DMC-SZ7	ARCN 130716 Bering, LumixSZ7 xxxx
\ARCN Photos 130716 Bering\Canon® Rebel	ARCN 130716 Bering, Canon® xxxx
\ARCN Photos 130717 KobGatSel\Drift® HD170	ARCN 130717 KobGatSel, Drift® xxxx
\ARCN Photos 130717 KobGatSel\GoPro® Hero3	ARCN 130717 KobGatSel, GoPro® xxxx
\ARCN Photos 130717 KobGatSel\Panasonic® Lumix DMC-FZ200	ARCN 130717 KobGatSel, Lumix xxxx
\ARCN Photos 130717 KobGatSel\Panasonic® Lumix DMC-SZ7	ARCN 130717 KobGatSel, LumixSZ7 xxxx
\ARCN Photos 130717 KobGatSel\Canon® Rebel	ARCN 130717 KobGatSel, Canon® xxxx
\ARCN Photos 130718 NoaKru\Drift® HD170	ARCN 130718 NoaKru, Drift® xxxx
\ARCN Photos 130718 NoaKru\GoPro® Hero3	ARCN 130718 NoaKru, GoPro® xxxx
\ARCN Photos 130718 NoaKru\Panasonic® Lumix DMC-FZ200	ARCN 130718 NoaKru, Lumix xxxx
\ARCN Photos 130718 NoaKru\Panasonic® Lumix DMC-SZ7	ARCN 130718 NoaKru, LumixSZ7 xxxx
\ARCN Photos 130718 NoaKru\Canon® Rebel	ARCN 130718 NoaKru, Canon® xxxx

The next step entailed ensuring that date and time in each photograph file's EXIF (exchangeable image file format) data were accurate, as these data linked to the GPS waypoints for geotagging each photograph. Next, each photograph was adjusted for color saturation and gamma (appendix 2), which highlighted many details. Each nadir photograph (Drift® and GoPro® cameras) then was corrected for lens distortion to adjust for the wide-angle (170° fisheye) distortion that occurred from the small focal lengths, and was cropped to exclude blank portions of the image that occur after fisheye correction (fig. 9). Images from the hand-held Panasonic® and Canon® cameras were not corrected for lens distortion, as those photographs were taken at various oblique angles and focal lengths (zoom levels) from inside the airplane cabin. Each nadir video from the GoPro® camera also was processed for lens distortion correction and color and gamma enhancement.

Next, EXIF data from all photograph files—including photograph file name and computer directory name, photograph date and time, camera type and settings, geotagged digital latitude and longitude, and altitude above mean sea level—were extracted into spreadsheet files (.xlsx formats) by flight date and camera type.

The geolocation (latitude and longitude) of each nadir photograph from the Drift® and GoPro® cameras was overlaid in GIS (ArcMap® 10.0; table 3) onto a map of 44 ecotypes of the ARCN region (Jorgenson and others, 2009). Presence and area of each ecotype within a square window centered on each photograph location were recorded and included in the EXIF spreadsheet files (see appendix 3 for details). Because of the continual time-lapse coverage along the flight routes, not every nadir photograph was taken within the ARCN study area (fig. 1); therefore, not every nadir photograph has associated mapped ecotypes. An example of nadir photographs without associated ecotypes are those taken during the portion of the flight route on July 16, 2013, in Bering Land Bridge National Preserve that occurred east of that area's buffer en route north back to Kotzebue (fig. 2).

The individual photograph geolocations also were intersected in GIS with a digital elevation model (DEM) of the ARCN study area so that ground-level elevation could be determined for each photograph location (appendix 4). Finally, the difference between flight altitude above mean sea level (determined en route by the on-board GPS unit) and ground-level elevation gave flight altitude above ground level for all photographs, which was used to verify the mean flight altitude used in the calculations of photograph time-lapse intervals and areal coverage of each photograph.

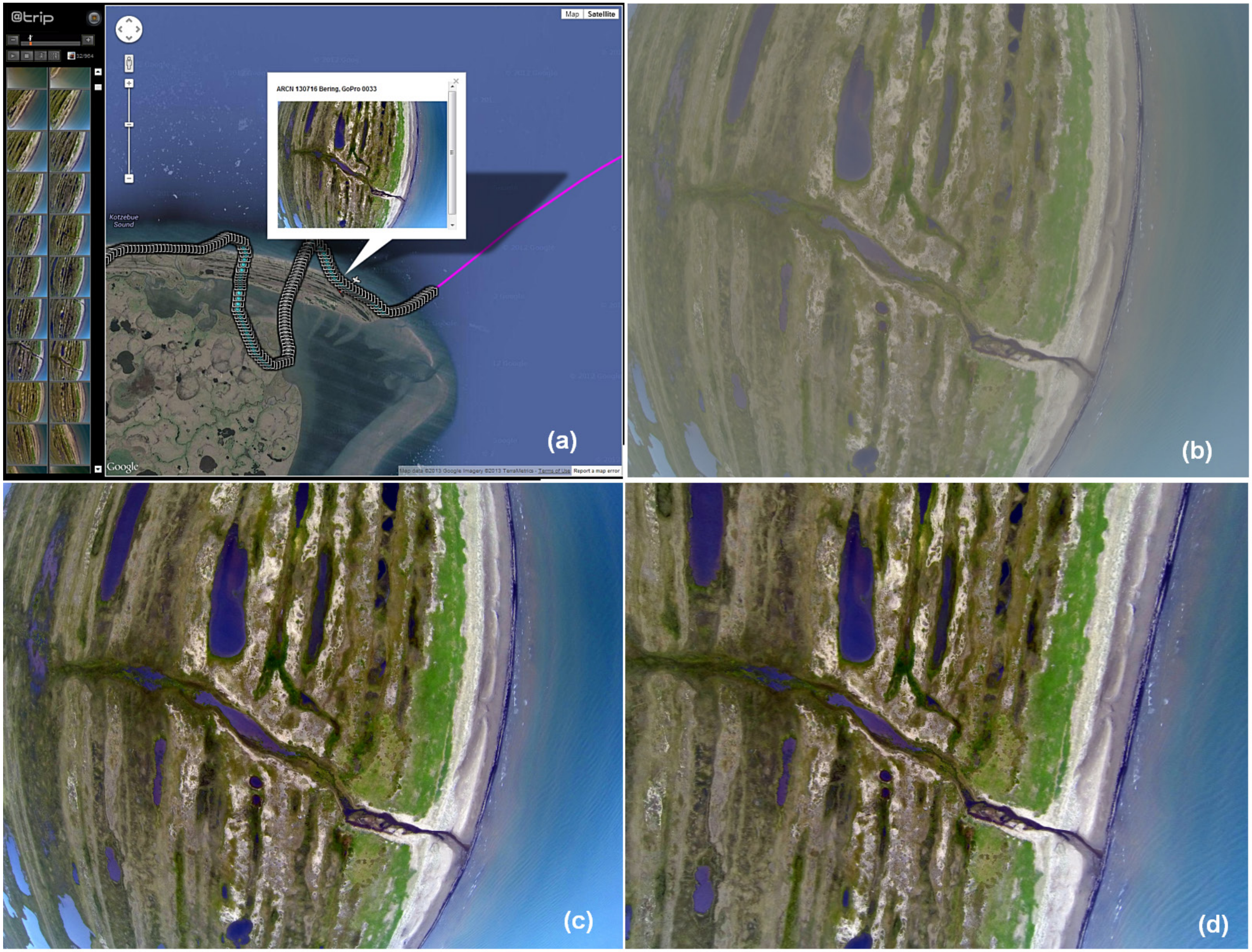


Figure 9. Example of photographic enhancement and correction for lens distortion, of one photograph taken by GoPro® Hero3 camera in northeast coastal section of Bering Land Bridge National Preserve, northwest Alaska, on July 16, 2013. (*A and A inset*) Location of the example photograph, (*B*) original photograph appearance, (*C*) color and gamma adjustment; (*D*) correction for distortion of the wide-angle (fisheye) distortion.

Results

The 3 days of transect flights through the Arctic Network and Selawik National Wildlife Refuge totaled 17 hours, 45 minutes, of flight time and 2,590 km of linear coverage. A total of 21,161 GPS waypoints were recorded from the i-gotU GT-120 GPS waypoint data logger, and 19,167 still photographs were recorded from the five cameras (table 2). Some example photographs are presented in figures 10 and 11. Given the significant overlap between adjacent photographs (see appendix 1), sequential images can be stitched to produce panoramas (fig. 12, appendix 2), which can provide a far broader view of the landscape with no loss of resolution or rectification. Other manipulations also are possible, such as providing three-dimensional views using sequential, overlapping images.

Numerous digital videos also were produced, including six videos taken with the GoPro® Hero3 camera affixed to the airplane struts or underwing (see figs. *6B* and *7D* for video locations). The six GoPro® videos totaled 1 hour, 20 minutes, and 43 seconds of usable coverage and, at a frame rate of 60 fps, totaled 290,580 individual extractable frames (table 5). Video frames could be located geographically by comparison with the Drift® camera photographs that were taken simultaneously. Video frame extracts from the enhanced versions of the video files were color- and gamma-adjusted and corrected for lens distortion following procedures and software settings presented in this report to provide high-resolution detail (for example, fig. 13). An additional 105 short videos, not geotagged, were taken with the two hand-held Panasonic® Lumix cameras of various landscape scenes, airplane takeoffs and landings, and the ground exploration of an exposed pingo ice core in Bering Land Bridge National Preserve.

Nearly all 44 mapped ecotypes were represented in the photograph transects (fig. 14) with the minor exceptions of Human Modified Barrens, Shadow/Indeterminate, and Snow categories. Each of the three flight routes emphasized a different set of ecotypes, with the most commonly represented ecotypes including coastal water, tussock-shrub and low shrub types, sedge-dryas meadow, and white spruce forest (fig. 14). Although the specific ecotypes and their coverage denoted in the databases for individual photographs may be subject to the accuracy of the original ecotype map (estimated to be 65–80 percent by Jorgenson and others, 2009) at that fine scale, this information is nonetheless useful for determining dominant ecotypes and broader locations along the flight transects where specific ecotypes may be found for future change comparison.

Along all three flight routes, among all 12,395 nadir photographs that were geotagged and intersected with the ecotype map and with the DEM map, the overall average flight altitude AGL was 295 m (± 122 m SD; table 6). Adjusting for elevations during takeoff and landings resulted in an average flight altitude AGL essentially identical to the ideal 300 m used in time-lapse and areal coverage calculations (appendixes 2 and 3), thereby verifying the appropriate use of that value in the calculations.

The GoPro® Hero3 Black Edition camera greatly outperformed the Drift® HD-170 camera for taking better-quality and higher resolution nadir photographs, although both cameras had similar time-lapse capabilities. Mounting a camera on the landing strut structure on the airplane equipped with floats (as was done for the Bering Land Bridge National Preserve flight path) resulted in the floats blocking nearly one-half of each image; thus, an under-wing mount (as was used on other flight routes) is recommended instead for unobstructed views. For hand-held cameras used to take oblique photographs from inside the airplane cockpit, the Canon® Rebel 3Ti digital SLR (single-lens reflex) and the Panasonic® Lumix DMC-FZ200 superzoom cameras provided higher quality images , although the pocket-size Panasonic® Lumix DMC-SZ7 camera also was handy and useful for taking informal short videos of within-cabin, landing, and takeoff sequences.

The GoPro® nadir videos provided some spectacular views as well as numerous individual frames that could be useful for future change comparison studies, particularly from the videos that were corrected for wide-angle lens distortion. Although the individual frames of the videos were not geotagged, the specific scenes could be compared with the static time-lapse photographs of the Drift® camera, which were taken simultaneously, thereby identifying geotag location from the Drift® camera images. It is possible to semi-automate the geotagging of the individual video frames by (1) capturing frames from the videos; (2) identifying from the Drift® camera photographs, the geotagged location and date and time EXIF data for the first frame in the video sequence; (3) applying date and time corrections to subsequent frames by knowing the video frame rate (for example, 60 frames per second) using the EXIF Date Changer® or similar software (table 3); and (4) matching geotag locations of the subsequent video frames to the GPS waypoints taken during the video flight segments. We recommend that any further videos should be taken at the highest possible resolution; resolution is more important than frame rate. For example, the highest video resolution of GoPro® Hero3 Black Edition camera is 4k Cinematic (4096 × 2160 pixels for a 17:9 aspect ratio) at 12 frames per second, which is a fully adequate frame rate. Battery life was the major limitation of the Drift® and GoPro® cameras, which curtailed taking images on a few of the longer flight sequences between landings when we could change batteries.

In conclusion, the set of low-altitude, high-resolution digital photographs gathered in this project is expected to provide a baseline for change comparisons, both future and historical (fig. 15). Results also can complement existing grid-based imaging programs by providing more detailed and continuous images among the grid points.

Figure 10. Photographs taken with the GoPro® Hero3 Black Edition camera in the transect series, northwest Alaska. (*A*) Riverine, lacustrine, and lowland shrub ecotypes in landscape dominated mostly by Lowland Lake, Upland Rocky-loamy Moist Alkaline Sedge-Dryas Meadow, Upland Organic-rich Moist Acidic Dwarf Birch-Tussock Shrub, and Upland Moist Dwarf Birch-Ericaceous-Willow Low Shrub ecotypes, Bering Land National Preserve (latitude 65.666833 N, longitude 162.692919 W, photograph "ARCN 130716 Bering, GoPro® 0328_pt"); (*B*) lowland lake and upland forest ecotypes in a landscape dominated mostly by Lowland Moist Dwarf Birch-Ericaceous-Willow Low Shrub and Upland Moist Dwarf Birch-Ericaceous-Willow Low Shrub ecotypes, Kobuk Valley National Park (latitude 67.070033 N, longitude 158.504347 W, photograph "ARCN 130717 KobGatSel, GoPro® 0881_pt"); (*C*) tundra thaw slump or retrogression in landscape dominated mostly by Upland Rock-loamy Moist Alkaline Sedge-Dryas Meadow and Upland Organic-rich Moist Acidic Dwarf Birch-Tussock Shrub ecotypes, Noatak National Preserve (latitude 67.957000 N, longitude 156.821789 W, photograph "ARCN 130718 NoaKru, GoPro® 1622_pt"); (*D*) detail of thaw slump or retrogression also showing face slips and patterned ground.

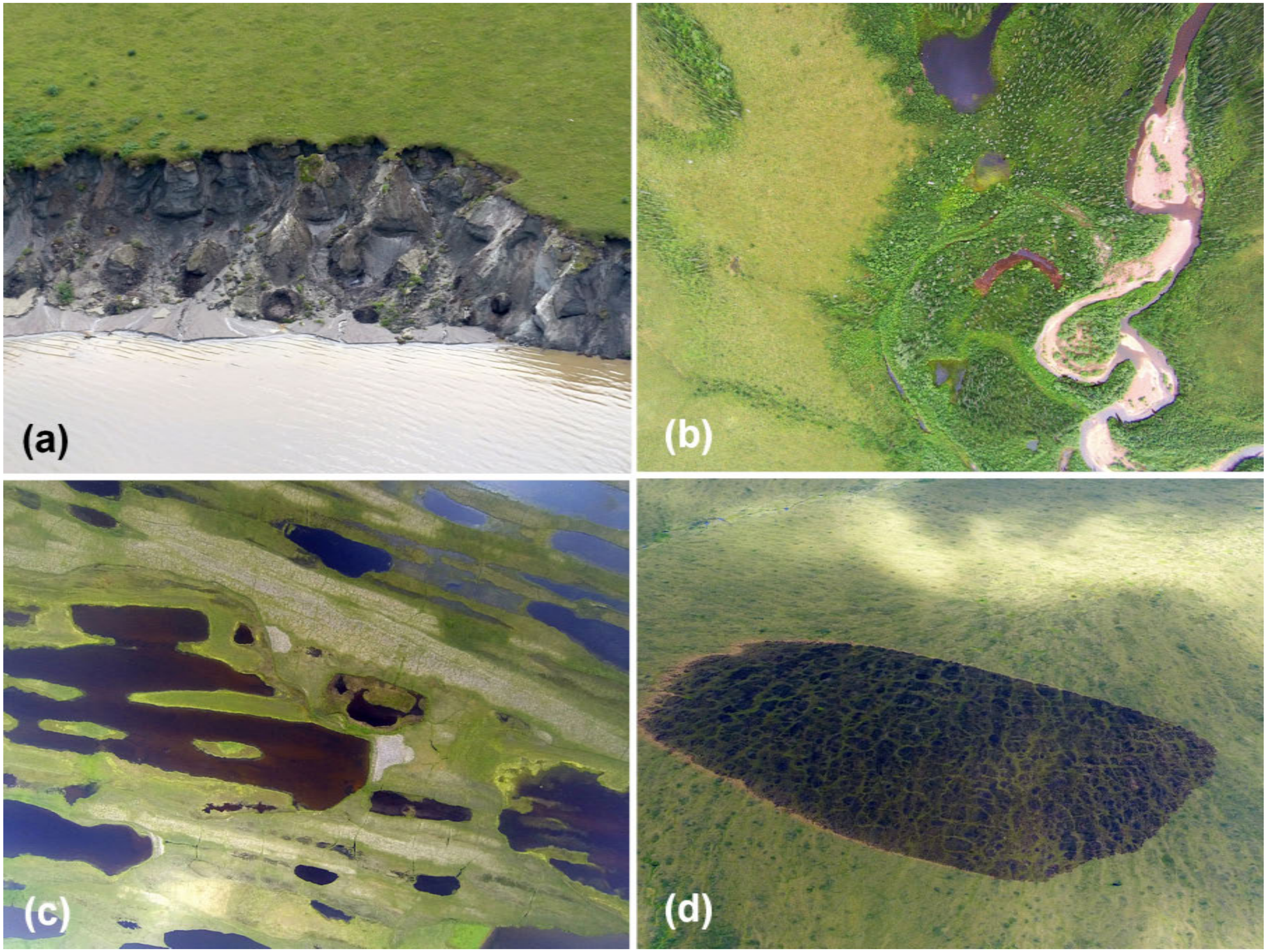


Figure 11. Photographs of disturbance and dynamic processes available in the transect series, northwest Alaska. (*A*) Coastal erosion, Baldwin Peninsula (Panasonic® Lumix DMC-FZ200 camera, latitude 66.845917 N, longitude 162.177881 W, photograph "ARCN 130717 KobGatSel, Lumix 1331"); (*B*) old river floodplain with filled-in oxbows and white spruce forest, Noatak National Preserve (Drift® HD-170 camera, latitude 67.645322 N, longitude 163.012778 W, photograph "ARCN 130718 NoaKru, Drift® 3024_pt"); (*C*) ancient coastlines, Cape Krusenstern National Monument (GoPro® Hero3 Black Edition camera, latitude 67.119022 N, longitude 163.675864 W, photograph "ARCN 130718 NoaKru, GoPro® 3178_pt"); (*D*) recent tundra lightening fire scar, Noatak National Preserve (Panasonic.

Figure 12. Panoramic images stitched from multiple, adjacent photographs along the photographic transect routes, illustrating stitching from 3 images (top) and 5 images (bottom), northwest Alaska.

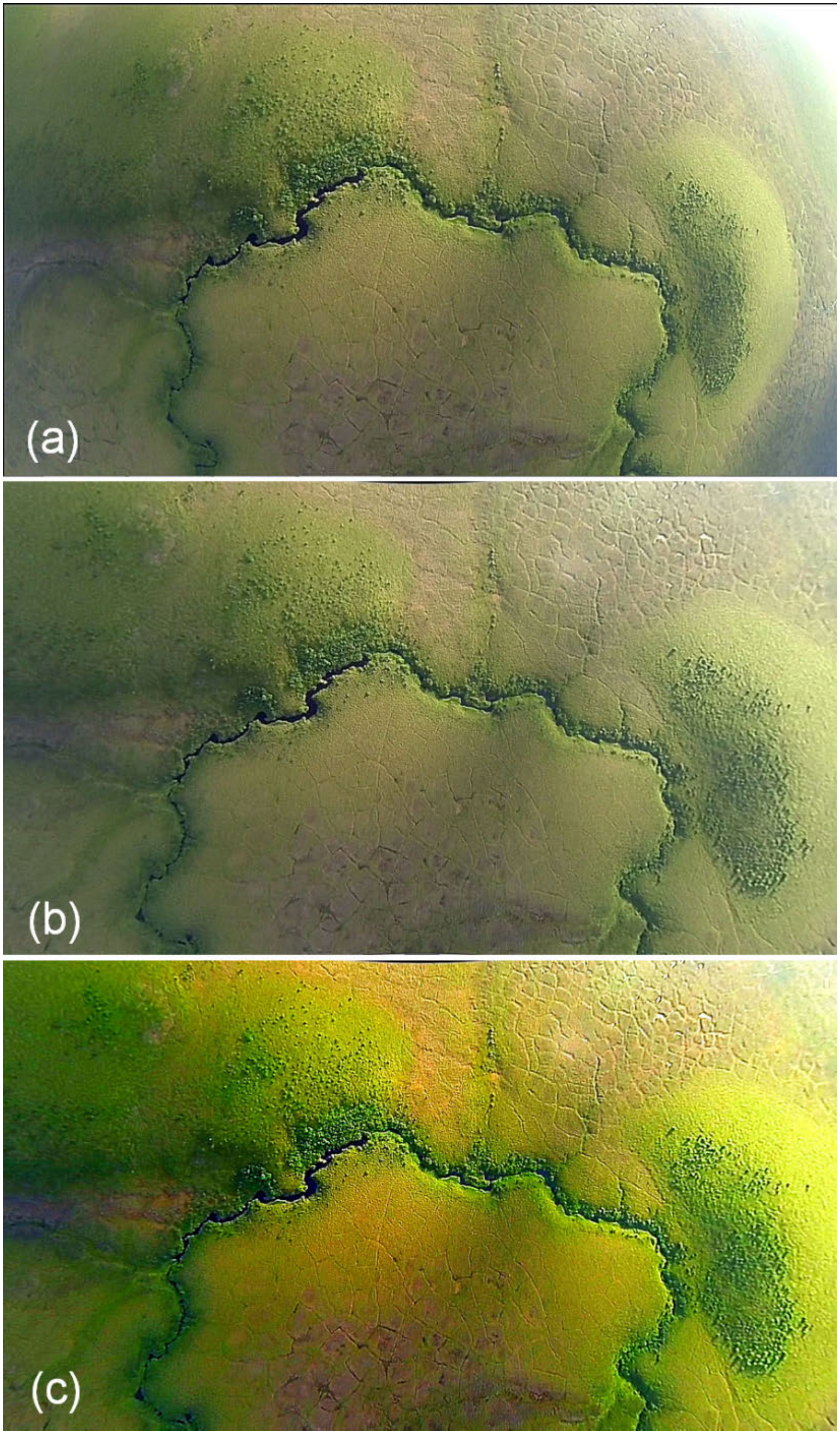


Figure 13. Individual frame-capture from one of the continuous GoPro® Hero3 camera video segments (figs. 6*B*, 7*D*), northwestern Alaska. (*A*) individual frame from one of the videos, (*B*) correction for lens distortion and cropped to eliminate blank areas, (*C*) color-enhanced to emphasize patches and boundaries of vegetation and substrate conditions.

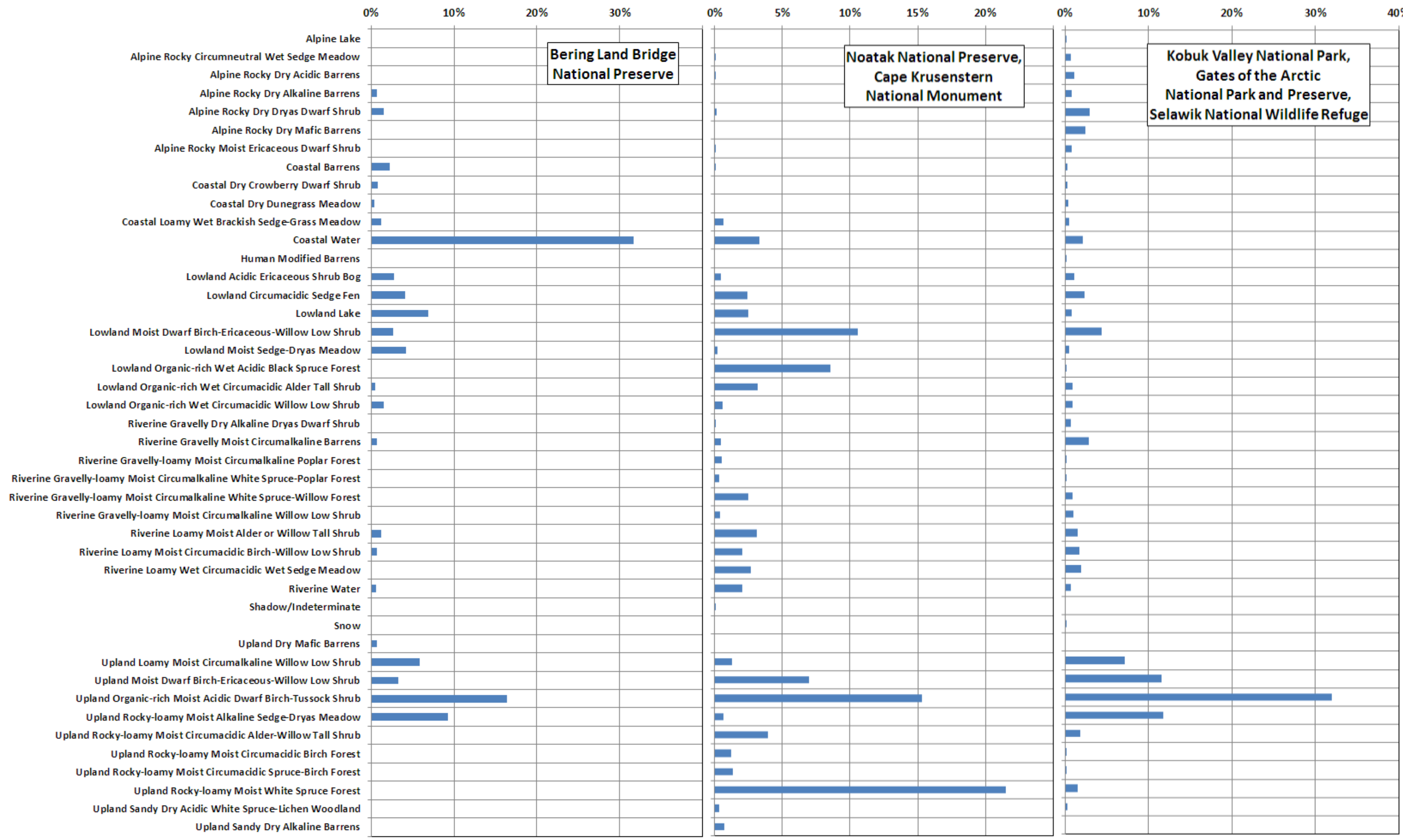


Figure 14. Ecotypes represented in all photographs in each of the Arctic Network flight transect routes on July 16–18, 2013. Full list of all 44 ecotypes as mapped by Jorgenson and others (2009) is shown. For each flight transect route, percentage of total coverage among all nadir photographs (from the Drift® HD-170 and GoPro® Hero3 Black Edition cameras) is shown for each ecotype.

Table 5. Video files of land cover from GoPro® Hero3 camera.

[Video locations during flight paths are shown in figures 6*B* and 7*D*. **Time data:** Pertain to original videos; processed versions (correction for lens distortion and image-enhanced) include clipping out extraneous material. **Number of frames:** Number of frames of land cover conditions at video rates of 60 fps, excluding extraneous material (see **Comments**). **Abbreviations:** mm, minutes, ss, seconds, fps, frames per second]

Folder and file name	Start time mm:ss	End time mm:ss	Total time mm:ss	Number of frames	Comments
\ARCN videos\ARCN videos 130716 Bering\GoPro® Hero3					
GP000827 flight segment	07:15	26:04	18:49	67,740	Begins with plane in water and takeoff; land coverage starts at 07:15.
GP010827 flight segment	00:00	06:30	06:30	23,400	Begins during flight; water landing starts at 06:30; remainder is plane at rest on water.
GP030827 flight segment	21:00	26:04	05:04	18,240	Begins with plane in water and takeoff; land coverage starts at 21:00.
GP040827 flight segment	00:00	02:02	02:02	7,320	Short segment, all over land.
\ARCN videos\ARCN videos 130717 KobGatSel\GoPro® Hero3					
GOPR0938 flight segment	03:50	26:04	22:14	80,040	Takeoff from Selawik, coverage starts 03:50; includes some segments over water.
GP010938 flight segment	00:00	26:04	26:04	93,840	Includes some segments over water.
Totals			1:20:43	290,580	

Table 6. Average and standard deviation (SD) of flight altitude of geotagged nadir photographs taken with the Drift® HD-170 and GoPro® Hero3 Black Edition cameras.

[**Area:** Bering, Bering Land Bridge National Preserve; KobGatSel, Kobuk Valley National Park, Gates of the Arctic National Park and Preserve, and Selawik National Wildlife Refuge; NoaKru, Noatak National Preserve and Cape Krusenstern National Monument. **Abbreviations:** AGL, above ground level; m, meter]

Area	Average flight altitude AGL (m)		N (number of photographs)			Overall average flight altitude AGL (m)	Standard deviation flight altitude AGL (m)	
	Drift®	GoPro®	Drift®	GoPro®	Total	Weighted means	Drift®	GoPro®
Bering	295	311	1,820	632	2,452	299	88	106
KobGatSel	298	289	2,325	2,102	4,427	294	90	85
NoaKru	291	298	2,950	2,566	5,516	295	147	157
Totals					12,395	295	122	

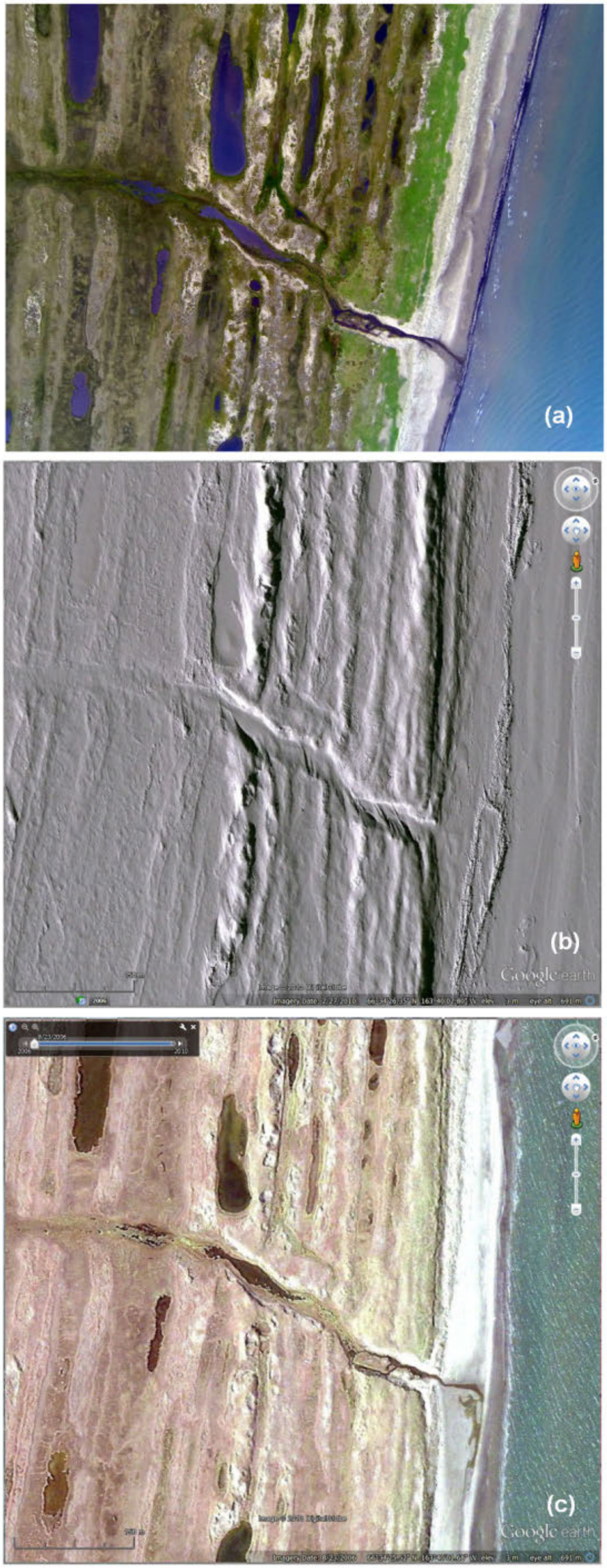


Figure 15. (*A*) Color- and gamma-adjusted and lens distortion-corrected GoPro® photograph (July 16, 2013; see [fig. 9](#)) compared with IKONOS and Worldview images (with 1-meter and 0.5-meter resolutions, respectively), taken on (*B*) February 27, 2010, and (*C*) August 23, 2006 (image source: Google Earth®, accessed August 25, 2013).

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Appendix 1. Calculations of Time-Lapse Interval Needed for Continuous Flight Line Photography

Following are the calculations made to determine the frequency of the time-lapse interval settings on the Drift® HD-170 and GoPro® Hero3 Black Edition cameras, to ensure overlapping coverage of photographs along the flight transects.

The cameras were secured to the underwing and undercarriage of the Cessna 185 and 206 airplanes, for nadir (direct downward) imaging. Each camera was set to its wide-angle (170°) mode. Later, correcting for lens distortion and cropping of the images reduced the coverage angle to about two-thirds of the original image, resulting in an effective image coverage of about 115°. The airplanes flew at an average altitude a of about 300 m above ground level (AGL). Thus, effectively, a cross-section triangle was formed as shown in figure A1.

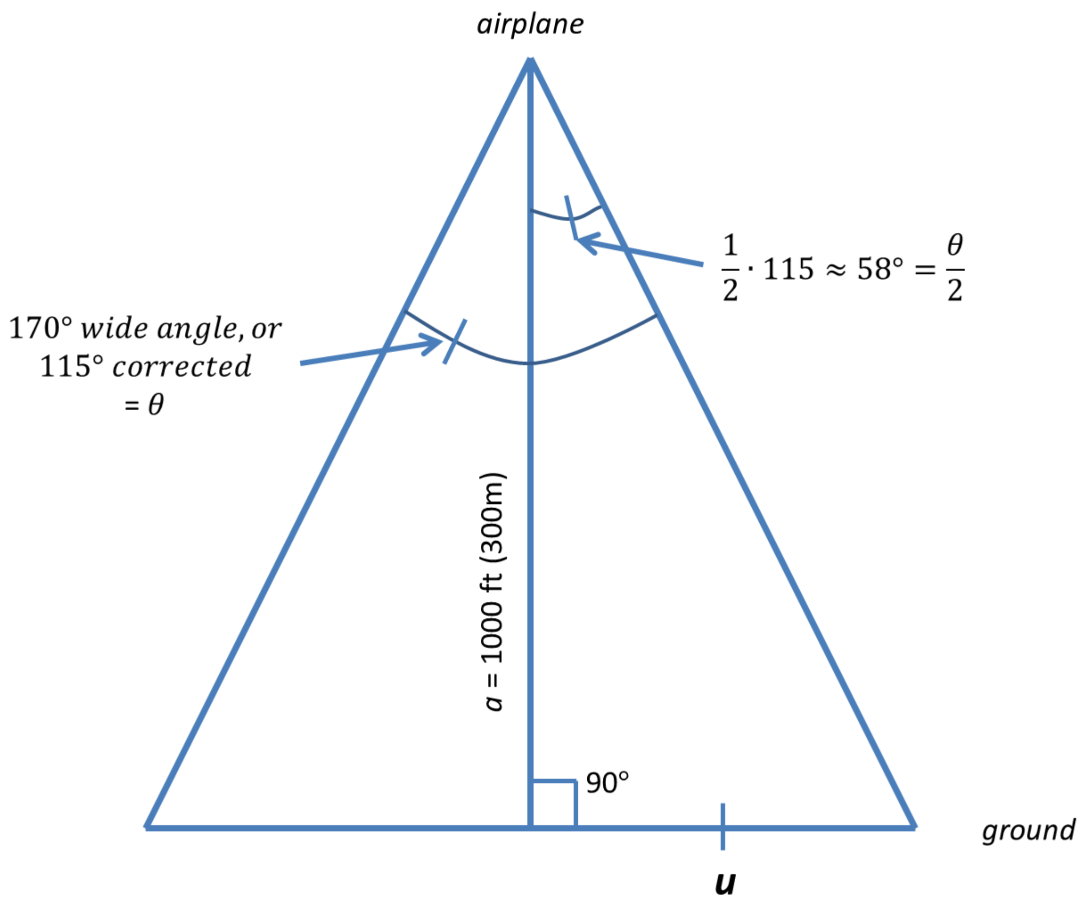

Figure A1. Schematic of the geometry used to calculate ground distance covered during flights with known altitude *a* and known ground speed.

In figure A1, the ground distance u represents one-half the span covered by each photograph, and is calculated as:

$$\tan\left(\frac{\theta}{2}\right) = \frac{u}{a} = u1000 \qquad \text{(A1)}$$

where, solving for u,

$$u = a \times tan\left(\frac{\theta}{2}\right) = (1000 \text{ ft}) \times tan\ (58°) = 488\text{m} \qquad \text{(A2)}$$

Next, to determine the time elapsed when the airplane would arrive at the next photograph point with no overlap in ground image, we needed to know the ground speed of the airplane and the distance to be covered, shown as $2u$ in figure A2.

The airplane flew at an average ground speed of about 190 kph (104 kt or 54 m/s). At this rate, covering a distance of $2u$ = 975 m would take (975 m)/(54 m/s) = 18 seconds.

To account for wide-angle distortion and to enable adjacent photographs to be stitched into panoramic images (see fig. 12), we wanted approximately one-third overlap between adjacent photographs. Therefore, setting the cameras to (1/3)(18 seconds) resulted in a time-lapse interval of (rounded) one photograph every 6 seconds; the two cameras used for time-lapse photography had settings only at 5-second intervals, so we chose an interval of one photograph every 5 seconds. This meant that for every traverse of 975 m between exclusive photographic coverage points, there would be a mean of (18 seconds) / (5 seconds/photograph) = 3.6 photographs, which is generally what was observed in the final product.

The airplane did not fly perfectly at 300 m altitude AGL and at a 54 m/s velocity, but deviations—such as 450 m altitude AGL and slightly higher velocities—did not significantly affect the final product. For instance, a flight altitude of 450 m AGL meant that the distance between exclusive photographic area coverage would be 732 m, so that there would be (2)(732 m)/(54 m /s) = 27 seconds elapsed between exclusive photograph points, and at a 5-second photograph time-lapse interval, (27 seconds)/(5 seconds/ photograph) = 5.4 photographs would be taken, again providing adequate area overlap between adjacent images. We rarely if ever flew below 300 m altitude AGL for any sustained time period.

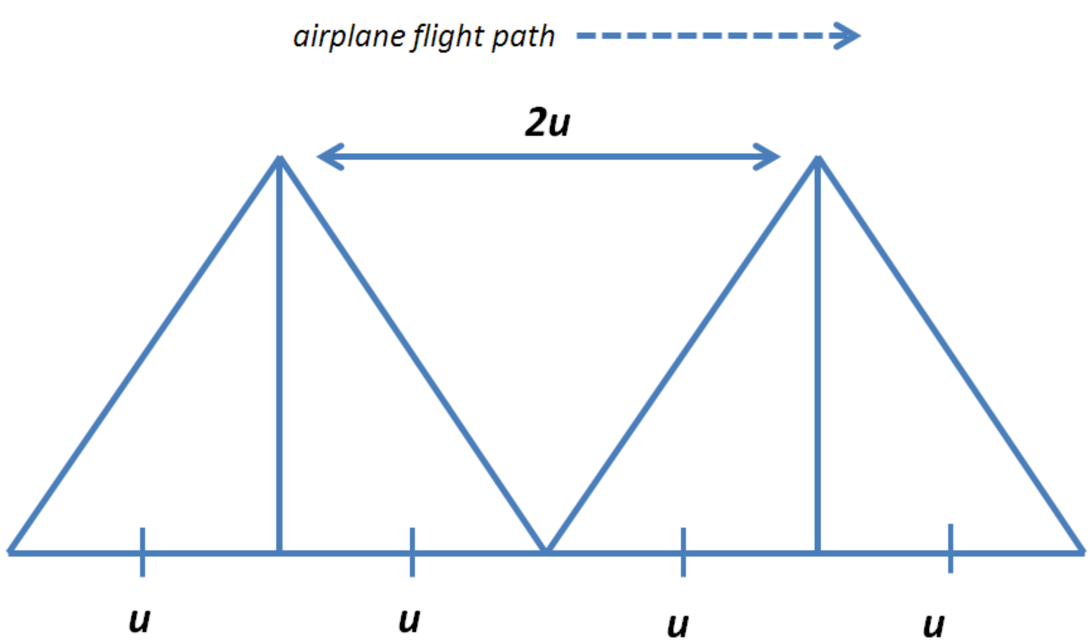

Figure A2. Schematic of the geometry used to calculate distance 2*u* and the timing between successive time-lapse photographs.

Appendix 2. Details of Photograph Processing

The following eight steps were followed in processing the photographs from this project. Methods are presented here in detail—including problems encountered and solutions devised—to potentially aid future photographers engaged in similar project work. See tables 1 and 3 for information on hardware and software used.

STEP 1: Downloading and sorting photographs from cameras.

Photographs were downloaded from each camera and each day's flight and were stored in separate subdirectories (folders) on a computer. Photographs (.jpg files) and videos (.mp4 files, later converted into .wmv files) were sorted into different folders.

The cameras automatically created new folders on the SD cards when the cameras were shut off and turned back on (upon landing or takeoff), when batteries were replaced, and when 999 photographs were taken on a camera for any continuous time-lapse series. This resulted in the cameras automatically creating files with the same names (which were placed automatically in different subdirectories on the cameras' memory cards).

Redundant photographs in each photograph set were deleted, such as time-lapse images taken when the airplane was stationary, long sequences taken over water, and other photographs with no usable content.

Note that photographs from the Drift® camera from the July 16, 2013 flight tracks in Bering Land Bridge National Preserve are only partial images. The Drift camera could be secured on that airplane only to the struts of the external step where the nadir orientation of the lens was partially obscured by one of the airplane floats.

Resulting photograph file directory name: WildCast ARCN photo study 01 ORIGINAL

STEP 2: Correcting EXIF (exchangeable image file format) date and time stamps to fix erroneous date-time stamps.

The internal date and time information on individual photograph runs (flight legs) became reset in the Drift and GoPro® cameras to an incorrect default value when the cameras were switched off and back on or when batteries were replaced (that is, contrary to expectations, the cameras did not retain the correct date and time settings). Having the exact, precise date and time for each photograph is critical to correctly geotagging each image. However, photographs in each "reset" series retained their relative difference in date and time among each other, so what was needed was to determine the correct date and time for any one photograph of the series and then apply that same relative date and time correction to all photographs of that series, and to repeat the process for each photograph series. This entailed going through the photograph folders from all cameras, flight dates, and subfolders thereof, and locating one or several photographs (for accuracy spot checks) and comparing them to the exact date and time (yy:dd:hh:mm:ss) and the exact location (latitude, longitude) when and where they were taken.

This was determined by reading the .gpx GPS waypoint data into @trip PC® software that shows each GPS track and waypoint superimposed over zoomable satellite imagery. When a uniquely shaped tundra lake, a town, or other clearly identifiable landmark centered on a photograph was identified on the Landsat imagery, that same exact spot then was located along the GPS track, at which that GPS data point's date and time were identified. Next, a time calculator was used to determine the difference from the photograph's (incorrect) EXIF date and time for that point. This resulted in determining the specific date and time increment or decrement needed to adjust the EXIF data of the photograph to perfectly match the (correct) GPS data. This was done for each set of photographs from each combination of camera, flight date, and photograph track, and the corrections for each photograph track were verified with spot checks of the alignment of other photographs not used to determine the correction for that track.

It was important to amend the photograph files' EXIF data, not the files' "Windows" date and time such as appears in Microsoft® Windows Explorer in the Windows-based computer used. To amend the EXIF data by incrementing or decrementing a specified yyyy:dd:hh:mm:ss, the software EXIF Date Changer® was used in which yyyy was reset to a specified year if needed (using the software function "set date/time to"), or the time stamp was adjusted by specific decrements or increments (using the function "adjust time by"), at the same time also resetting the Windows file created date and time to the corrected (actual) taken date and time.

Resulting photograph file directory name: WildCast ARCN photo study 02 TIME DATE ADJUSTED

STEP 3: Color adjustment, image enhancement.

Each photograph was adjusted for color and gamma settings to help bring out details, by using the software Irfanview® in batch mode, specifying the "auto adjust color" option and "save with original .jpg quality" option.

GoPro camera videos were adjusted by using GoPro Studio for orientation (flight direction at top of image) and image enhancement (Protune color and gamma), and stored in file directories named "GoPro Hero3 CORRECTED, ENHANCED."

Resulting photograph file directory name: WildCast ARCN photo study 03 IMAGE ENHANCED

STEP 4: Renaming photograph files.

All photograph files then were globally renamed to provide mnemonic names denoting the overall study area, flight date, specific study area units flown, and camera used.

The files were renamed using these name templates:

ARCN 130716 Bering, Drift xxxx
ARCN 130716 Bering, GoPro xxxx
ARCN 130716 Bering, Lumix xxxx
ARCN 130716 Bering, LumixSZ7 xxxx
ARCN 130716 Bering, Canon xxxx
ARCN 130717 KobGatSel, Drift xxxx
ARCN 130717 KobGatSel, GoPro xxxx
ARCN 130717 KobGatSel, Lumix xxxx
ARCN 130717 KobGatSel, LumixSZ7 xxxx
ARCN 130717 KobGatSel, Canon xxxx
ARCN 130718 NoaKru, Drift xxxx
ARCN 130718 NoaKru, GoPro xxxx
ARCN 130718 NoaKru, Lumix xxxx
ARCN 130718 NoaKru, LumixSZ7 xxxx
ARCN 130718 NoaKru, Canon xxxx

where:

ARCN	National Park Service's Arctic Network
Date	
13071x	yymmdd flight date
Location	
Bering	Bering Land Bridge National Preserve
Kob	Kobuk Valley National Park
Gat	Gates of the Arctic National Park and Preserve
Sel	Selawik National Wildlife Refuge
Noa	Noatak National Preserve
Kru	Cape Krusenstern National Monument
Cameras used	
Drift	Drift HD-170
GoPro®	GoPro® Hero3 Black Edition
Lumix	Panasonic Lumix DMC-FZ200
LumixSZ7	Panasonic Lumix DMC-SZ7
Canon	Canon Rebel 3Ti

Resulting photograph file directory name: WildCast ARCN photo study 04 FILES RENAMED

STEP 5: Geotagging all photographs.

Each photograph then was geotagged to the GPS flight paths using the @trip PC software that matched each photograph EXIF date and time stamp to that of the GPS data to determine the exact location of the photograph. This resulted in adding decimal latitude and longitude stamps to the EXIF data of each photograph.

Resulting photograph file directory name: WildCast ARCN photo study 05 GEOTAGGED

STEP 6: Lens distortion correction and cropping of Drift and GoPro photographs.

Photographs from the GoPro® and Drift cameras then were corrected for lens distortion, as those two cameras produced fixed wide-angle images with edge distortion. The program PTLens® was used for this function. Program parameters needed in PTLens to correct for lens distortion were determined by (1) communication with Tom Niemann, author of PTLens, who suggested program settings appropriate for correcting the wide-angle distortion of the GoPro® camera images; (2) inspecting the (commensurate) settings posted by Paul Illsley at his GoPro® Hero2 Aerial Imaging and Mapping Project web site (http://www.paulillsley.com/GoPro/Airphoto/), in which he used PTLens to correct for the wide-angle GoPro® aerial images taken from a small airplane in a fashion quite similar to this project's setup; and (3) testing the settings with images containing known straight landscape lines such as roadways. The PTLens values used to correct the ARCN aerial photograph nadir images were: distortion type = fisheye; fisheye distortion setting = 120; and crop = 20. Also specified were JPEG Quality = 100 under Options to minimize information loss as each corrected image was saved. Note, too, that each image was cropped to exclude the margins containing black parabolic areas that resulted from the image rectification. This cropping excluded from each photograph only a small part containing the most distorted corner images. Note that this procedure to correct the images was essentially a first approximation, as it did not correct for oblique views caused by tilt of the airplane.

The program PTLens creates new files with a common, user-specified file name suffix (default is *_pt). To then delete (or move) the original files, the utility program xplorer2® (a replacement for Microsoft Windows Explorer) was used. In xplorer2, "_pt.jpg" was entered in the "Select" box, which then highlighted all new (corrected for lens distortion) files with that filename suffix, and then Mark / Invert was selected so that all files without _pt were highlighted and then could be easily deleted or moved in batch mode.

Resulting photograph file directory name: WildCast ARCN photo study 06 CORRECTED

STEP 7: Extraction of EXIF data.

All EXIF data in the photographs then were extracted into .csv files by using the program BR's EXIFextracter® and were converted into.xlsx spreadsheet file format by using Microsoft Excel 2010. Separate .xlsx spreadsheet files were created for each combination of flight date, route, and camera. Resulting files (names were coded, as described further in Step 4) were named:

ARCN 130716 Bering, Drift EXIF data.xlsx
ARCN 130716 Bering, GoPro EXIF data.xlsx
ARCN 130716 Bering, Lumix EXIF data.xlsx
ARCN 130716 Bering, LumixSZ7 EXIF data.xlsx
ARCN 130716 Bering, Canon EXIF data.xlsx
ARCN 130717 KobGatSel, Drift EXIF data.xlsx
ARCN 130717 KobGatSel, GoPro EXIF data.xlsx
ARCN 130717 KobGatSel, Lumix EXIF data.xlsx
ARCN 130717 KobGatSel, LumixSZ7 EXIF data.xlsx
ARCN 130717 KobGatSel, Canon EXIF data.xlsx
ARCN 130718 NoaKru, Drift EXIF data.xlsx
ARCN 130718 NoaKru, GoPro EXIF data.xlsx
ARCN 130718 NoaKru, Lumix EXIF data.xlsx
ARCN 130718 NoaKru, LumixSZ7 EXIF data.xlsx
ARCN 130718 NoaKru, Canon EXIF data.xlsx

STEP 8: Overlay with ecotype map.

The set of ecotypes captured in each nadir photograph then were identified and recorded in the EXIF spreadsheet files by overlaying in the ArcMap® geographic information system (GIS; table 3) the latitude and longitude EXIF data of each photograph onto the ecotype map of the study area. The resulting files were named as in Step 7 and appended with "w ecotypes," with ecotype names included as new data fields for each photograph and data entered as the number of ecotype map pixels represented in each photograph. Details of the GIS overlay procedure are explained further in appendix 3.

Additional Photograph Manipulations

We provided examples of stitching together overlapping images to create contiguous panoramic images (see fig. 12). Many computer programs are available for stitching digital photographs, including Irfanview; we used ArcSoft® Panorama Maker version 3 for our examples in this report (see table 3).

Appendix 3. Analysis of Ecotype Coverage in Photographs

Ecotypes (land and water cover types) that were present in the nadir photographs (taken with the Drift HD-170 and GoPro® Hero3 Black Edition cameras; table 1) were determined in GIS (ArcMap 10; table 3) by intersecting the geotagged locations of each photograph with the map of ecotypes developed by Jorgenson and others (2009) for the Arctic Network (ARCN) study area.

Nadir photographs were taken at 2592 × 1944 photographic pixels (5 megapixels) with the Drift camera and 4000 × 3000 photographic pixels (12 megapixels) with the GoPro® camera; thus, with an aspect ratio of 4:3 or 1.33:1. Using the flight geometry applied to determine photograph time-lapse intervals (appendix 1), at a mean flight altitude of 300 m above ground level and an effective lens angle of approximately 115°, each photograph in its corrected and cropped format covered a rectangular area with a width of about 975 m (2*u*, appendix 1). Applying the aspect ratio of each photograph, the coverage length of each photograph was 975 m/1.33 = 732 m. Thus, the area covered by each corrected photograph was 975 m × 732 m = 71 hectares (ha).

Ecotypes were mapped by Jorgenson and others (2009) at a pixel size of 28.5 m × 28.5m (812.25 m^2). Centering the geotagged location (latitude an d longitude) of each photograph on the ecotype map, a GIS window of 25 × 25 map pixels was a tractable means of approximating most of the area covered by each corrected and cropped photograph (J. Terenzi, written commun., February 24, 2014). The resulting GIS window at each photograph location, therefore, covered 51 ha on the ecotype map (= [25 × 25 pixels] × [812.25 m^2/pixel]).

Appendix 4. Metadata Documentation of Arctic Network Photograph Database Files

Following are descriptions of the data fields found within the Arctic Network (ARCN) photograph database and spreadsheet files in the computer folder named "ARCN photo GPS (EXIF) data spreadsheets." The individual ARCN digital photograph database files are named following the convention noted in appendix 2.

The database files are saved as both comma-separated value text (ASCII) format (.csv) and Microsoft® Excel 2010 format (.xlsx).

Each record in the ARCN photograph database files pertains to a specific digital photograph and generally includes information on photograph file name, camera type and settings, and geolocation of the photograph. All this information came directly from each photograph file's exchangeable image file format (EXIF) data (corrected for time and location, as described in appendix 2).

Three sets of ARCN photograph database files were developed for this project, in these computer folder names: (1) "Nadir Photographs All," which provides the above-mentioned EXIF data fields for all photographs taken vertically downward, with the Drift® HD-170 and GoPro® Hero3 Black Edition cameras; (2) "Nadir Photographs With Ecotypes," which is a subset of the "Nadir Photographs All" set that was within the boundaries of the map of ecotypes (land and water cover types) in the ARCN study area (see text for explanation); and (3) "Oblique Photographs," which provides the EXIF data fields for photographs, taken by hand during the photographic transect flights, with the Panasonic® Lumix DMC-FZ200, Panasonic Lumix DMC-SZ7, and Canon® Rebel 3Ti cameras. Database files pertaining to set (2) also include data on flight altitude and on extent of each ecotype category present within each photograph (see text and appendix 3); these additional data fields are noted in the following table.

Data field	Description
Folder	Name of the computer folder containing the digital image files
File name	Name of the photographic image computer file (.jpg)
Date and time	Date (YY:MM:DD) and time (HH:MM:SS) the photograph was taken
Camera make	Make of the camera used to take the photograph
Camera model	Model of the camera used to take the photograph
Height x width	Size of the digital image in pixels
Size of image file	Number of pixels of the digital image (= height × width)
Exposure (sec)	Shutter speed in seconds of the photograph
Aperture (F-number)	F-stop of the photograph
ISO	Sensitivity ("film speed") setting of the photograph (ISO = International Organization of Standardization)
Flash used?	Whether camera flash was used for the photograph (all "no")
Focal length	Focal length (focus distance to object) of the photograph
Latitude	Latitude of the location of the center of the photograph in digital degrees north of the equator
Longitude	Longitude of the location of the center of the photograph in digital degrees west of the prime meridian
All following data fields were added to the "Nadir Photographs With Ecotypes" databases	
Flight altitude ASL	Altitude of the airplane above sea level (ASL) when the photograph was taken, in meters
DEM elevation	Ground-level elevation at the center of the photograph, as taken from a digital elevation model (DEM) map in the ArcMap geographic information system, in feet
Flight altitude AGL	Altitude of the airplane above ground level (AGL) at the center of the photograph, in feet; calculated by: [Flight altitude ASAL in meters] – ([DEM elevation in feet] / [3.281 feet/meter])

The following fields pertain to the 44 mapped ecotypes; data in each field pertain to number of map pixels (1 pixel = 28.5 × 28.5 m = 812.25 m^2) of each ecotype that appeared in a GIS window 51 hectares in area centered on each photograph (appendix 3).

Alpine Lake
Alpine Rocky Circumneutral Wet Sedge Meadow
Alpine Rocky Dry Acidic Barrens
Alpine Rocky Dry Alkaline Barrens
Alpine Rocky Dry Dryas Dwarf Shrub
Alpine Rocky Dry Mafic Barrens
Alpine Rocky Moist Ericaceous Dwarf Shrub
Coastal Barrens
Coastal Dry Crowberry Dwarf Shrub
Coastal Dry Dunegrass Meadow
Coastal Loamy Wet Brackish Sedge-Grass Meadow
Coastal Water
Human Modified Barrens
Lowland Acidic Ericaceous Shrub Bog
Lowland Circumacidic Sedge Fen
Lowland Lake
Lowland Moist Dwarf Birch-Ericaceous-Willow Low Shrub
Lowland Moist Sedge-Dryas Meadow
Lowland Organic-rich Wet Acidic Black Spruce Forest
Lowland Organic-rich Wet Circumacidic Alder Tall Shrub
Lowland Organic-rich Wet Circumacidic Willow Low Shrub
Riverine Gravelly Dry Alkaline Dryas Dwarf Shrub
Riverine Gravelly Moist Circumalkaline Barrens
Riverine Gravelly-loamy Moist Circumalkaline Poplar Forest
Riverine Gravelly-loamy Moist Circumalkaline White Spruce-Poplar Forest
Riverine Gravelly-loamy Moist Circumalkaline White Spruce-Willow Forest
Riverine Gravelly-loamy Moist Circumalkaline Willow Low Shrub
Riverine Loamy Moist Alder or Willow Tall Shrub
Riverine Loamy Moist Circumacidic Birch-Willow Low Shrub
Riverine Loamy Wet Circumacidic Wet Sedge Meadow
Riverine Water
Shadow/Indeterminate
Snow
Upland Dry Mafic Barrens
Upland Loamy Moist Circumalkaline Willow Low Shrub
Upland Moist Dwarf Birch-Ericaceous-Willow Low Shrub
Upland Organic-rich Moist Acidic Dwarf Birch-Tussock Shrub
Upland Rocky-loamy Moist Alkaline Sedge-Dryas Meadow
Upland Rocky-loamy Moist Circumacidic Alder-Willow Tall Shrub
Upland Rocky-loamy Moist Circumacidic Birch Forest
Upland Rocky-loamy Moist Circumacidic Spruce-Birch Forest
Upland Rocky-loamy Moist White Spruce Forest
Upland Sandy Dry Acidic White Spruce-Lichen Woodland
Upland Sandy Dry Alkaline Barrens

Authors M. Torre Jorgenson (left) and Bruce G. Marcot (right) in Gate of the Arctic National Park and Preserve (photograph taken by pilot Anthony Remboldt).

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