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Digital Elevation Model Technologies and Applications: The DEM Users Manual, 3rd Edition

Edited by David F. Maune, PhD, CP and Amar Nayegandhi, CP, CMS

To order, visit https://www.asprs.org/dem

The 3rd edition of the DEM Users Manual includes 15 chapters and three appendices. References in the eBook version are hyperlinked. Chapter and appendix titles include:

1. Introduction to DEMs
   David F. Maune, Hans Karl Heidemann, Stephen M. Kopp, and Clayton A. Crawford
2. Vertical Datums
   Dru Smith
3. Standards, Guidelines & Specifications
   David F. Maune
4. The National Elevation Dataset (NED)
   Dean B. Gesch, Gayla A. Evans, Michael J. Oimoen, and Samantha T. Arundel
5. The 3D Elevation Program (3DEP)
   Jason M. Stoker, Vicki Lukas, Allyson L. Jason, Diane F. Eldridge, and Larry J. Sugarbaker
6. Photogrammetry
   J. Chris McGlone and Scott Arko
7. IfSAR
   Scott Hensley and Lorraine Tighe
8. Airborne Topographic Lidar
   Amar Nayegandhi and Joshua Nimetz
9. Lidar Data Processing
   Joshua M. Novac
10. Airborne Lidar Bathymetry
    Jennifer Wozencraft and Amar Nayegandhi
11. Sonar
    Guy T. Noll and Douglas Lockhart
12. Enabling Technologies
    Bruno M. Scherzinger, Joseph J. Hutton, and Mohamed M.R. Mostafa
13. DEM User Applications
    David F. Maune
14. DEM User Requirements & Benefits
    David F. Maune
15. Quality Assessment of Elevation Data
    Jennifer Novac

Appendix A. Acronyms
Appendix B. Definitions
Appendix C. Sample Datasets

This book is your guide to 3D elevation technologies, products and applications. It will guide you through the inception and implementation of the U.S. Geological Survey's (USGS) 3D Elevation Program (3DEP) to provide not just bare earth DEMs, but a full suite of 3D elevation products using Quality Levels (QLs) that are standardized and consistent across the U.S. and territories. The 3DEP is based on the National Enhanced Elevation Assessment (NEEA) which evaluated 602 different mission-critical requirements for and benefits from enhanced elevation data of various QLs for 34 Federal agencies, all 50 states (with local and Tribal input), and 13 non-governmental organizations.

The NEEA documented the highest Return on Investment from QL2 lidar for the conterminous states, Hawaii and U.S. territories, and QL5 IfSAR for Alaska.

Chapters 3, 5, 8, 9, 13, 14, and 15 are "must-read" chapters for users and providers of topographic lidar data. Chapter 8 addresses linear mode, single photon and Geiger mode lidar technologies, and Chapter 10 addresses the latest in topobathymetric lidar. The remaining chapters are either relevant to all DEM technologies or address alternative technologies including photogrammetry, IfSAR, and sonar.

As demonstrated by the figures selected for the front cover of this manual, readers will recognize the editors' vision for the future – a 3D Nation that seamlessly merges topographic and bathymetric data from the tops of the mountains, beneath rivers and lakes, to the depths of the sea.

Co-Editors

David F. Maune, PhD, CP and
Amar Nayegandhi, CP, CMS

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ANNOUNCEMENTS

NV5 Geospatial is transforming the way utilities manage their distribution networks with remote sensing data analysis. Having mapped more than 5.5 million miles of utility distribution networks in the U.S., NV5 Geospatial offers proven solutions that combine a variety of lidar and orthoimagery sensors on mobile and airborne platforms to acquire data for both asset and vegetation management. Analysis of this geospatial data then enables electric utilities to minimize risk and maximize reliability, while increasing efficiency.

"An aging grid, workforce shortages, increasing energy demands and an uptick in major weather events are combining to create a perfect storm that could impact reliability, customer service and safety for electric utilities across the country," said Eric Merten, Vice President, Commercial Group at NV5 Geospatial. "A boots-on-the-ground approach to management cannot keep up with demands related to aging equipment, compliance, pole loading and vegetation encroaching on infrastructure. NV5 Geospatial's innovative remote sensing applications and data analysis tools give utilities the power to proactively address problems in their distribution network before they impact operations or customers."

Built on the success of its remote sensing applications for utility transmission networks, NV5 Geospatial's distribution management solutions offer end-to-end capabilities – from acquiring accurate, high-quality geospatial data to data analysis and visualization using custom viewers and enterprise GIS – and can be customized to meet utilities use cases and budgets.

With a single data collection via remote sensing, NV5 Geospatial makes it easier for utilities to manage, maintain and monitor their distribution networks, whether it relates to their assets and infrastructure, or vegetation that may interfere with it.

Asset Management — NV5 Geospatial remote sensing processes involve more than 25 asset measurements, quickly delivering a comprehensive inventory of utility pole capacity with greater accuracy than traditional boots-on-the-ground surveys. Using NV5 Geospatial's tools, distribution network asset managers can:

- Achieve compliance with National Electrical Safety Code (NESC) clearance guidelines
- Get clear visibility into joint use of poles to prevent pirating, which can be a safety risk because of overcapacity issues, and increase revenue opportunities if poles are capable of supporting attachments of additional communications wires and equipment
- Ensure safe pole loading through analysis of weight load on each pole to prevent breaking or falling during severe weather and get insight into whether the pole can handle more joint use applications

Vegetation Management — NV5 Geospatial's remote sensing data also can help vegetation managers quantify vegetation with distribution rights-of-way and determine risk based on proximity to wires and poles. With customized data inputs and analysis parameters, vegetation managers can improve decision-making and prioritize tree trimming work where risks are greatest. NV5 Geospatial's vegetation management analytics also play a key role in helping utilities save millions of dollars during contractor negotiations and bidding processes by clearly identifying where work needs to be done.

To learn more about NV5 Geospatial Distribution Solutions, go to: https://www.nv5.com/distribution-solutions/.

UP42 made the first major announcement of its new partnership with the introduction of the UP42 ArcGIS Pro Add-in. Available on the **Esri ArcGIS Marketplace**, the UP42 add-in allows users to access UP42 data sets and projects from within ArcGIS Pro.

UP42, a Silver Partner in the Esri Partner Network (EPN), unveiled the add-in today in stand C1.020 at the INTERGEO 2022 Conference this week in Essen, Germany.

Esri's ArcGIS Pro is a standalone application extensively used by geospatial solution builders, GIS professionals and developers to visualize, analyze, compile, and share geospatial data. The UP42 marketplace currently contains over 160 satellite and aerial image products and derived data sets along with dozens of processing algorithms from leading geospatial organizations.

"By integrating UP42 and Esri, we have given users a streamlined way to access the data and analytics products they purchase on UP42 directly from ArcGIS Pro," said UP42 CEO Sean Wiid. "This dramatically simplifies imagery analysis workflows and facilitates advanced geospatial visualization."

The UP42 add-in will significantly reduce the time it takes to access data, build visualization workflows, and develop geospatial solutions. Without leaving the Esri ArcGIS environment, customers can use the new add-in to access the UP42 platform where they can open projects they are already working on, download purchased data sets into ArcGIS and view metadata. New geospatial data products will soon be available for order through the add-in.

The UP42 ArcGIS Pro Add-in is available at no cost and can be downloaded from the UP42 Marketplace or the Esri ArcGIS Marketplace.

Teledyne FLIR Integrated Imaging Solutions is pleased to announce the all new Ladybug6— the latest addition to its field proven Ladybug series. Ladybug6 is the leading high-resolution camera designed to capture 360-degree spherical images from moving platforms in all-weather conditions. Its industrial grade design and out-of-the-box factory calibration produces 72 Megapixel (MP) images with pixel values that are spatially accurate within +/- 2 mm at 10-meter distance.

"The new Teledyne Ladybug6 is designed for mobile mapping and all-weather inspection projects requiring excellent image quality and high resolution," said Mike Lee, Senior Product Manager at Teledyne FLIR. "With the addition of Ladybug6, we are now pleased to offer a wider variety of spherical cameras with higher resolutions ranging from 30 MP to 72 MP."

The new Ladybug6 builds on Teledyne's machine vision heritage with increased image resolution, enhanced on-board processing, and robust IP67-rated connectors. Building on the field proven Ladybug5+, the Ladybug6 captures, compresses, and transmits 8-bit or 12-bit pixel data delivering outstanding images across a wide range of lighting conditions with excellent color response, low noise, and a high dynamic range. Designed from the ground up to capture images from moving platforms in outdoor environments, the Ladybug6 features a wide operating temperature range (-30° C to 50° C), support for additional Global Navigation Satellite Systems, and trigger control by hardware or software with advanced APIs for complete camera control.

Ladybug6 cameras are engineered to deliver high-accuracy, high-resolution, and dependable results for applications such as HD mapping, asset management, roadside inspection, panoramic street image production for street view, road surveying, heritage scanning, building management, among several others.

For more information about Ladybug6 models www.flir.com/products/ladybug6/.

CALENDAR

- 27 January, **ASPRS GeoByte — Allen Coral Atlas: A New Technology for Coral Reef Conservation**. For more information, visit https://www.asprs.org/geobytes.html.
- 15-17 February, **ASPRS Annual Conference at Geo Week**, Denver, Colorado. For more information, visit https://my.asprs.org/2023conference.
- 5 May, **ASPRS GeoByte — SeaSketch 2.0: A New, Free and Open Source software Service for Map-based Surveys and Collaborative Geodesign.** For more information, visit https://www.asprs.org/geobytes.html.

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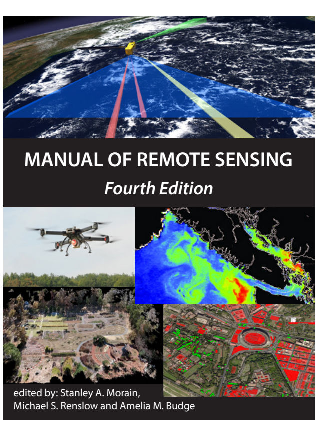
The 4th Edition of the *Manual of Remote Sensing!*



The *Manual of Remote Sensing, 4th Ed.* (MRS-4) is an "enhanced" electronic publication available online from ASPRS. This edition expands its scope from previous editions, focusing on new and updated material since the turn of the 21st Century. Stanley Morain (Editor-in-Chief), and co-editors Michael Renslow and Amelia Budge have compiled material provided by numerous contributors who are experts in various aspects of remote sensing technologies, data preservation practices, data access mechanisms, data processing and modeling techniques, societal benefits, and legal aspects such as space policies and space law. These topics are organized into nine chapters. MRS4 is unique from previous editions in that it is a "living" document that can be updated easily in years to come as new technologies and practices evolve. It also is designed to include animated illustrations and videos to further enhance the reader's experience.

MRS-4 is available to ASPRS Members as a member benefit or can be purchased by non-members. To access MRS-4, visit https://my.asprs.org/mrs4.

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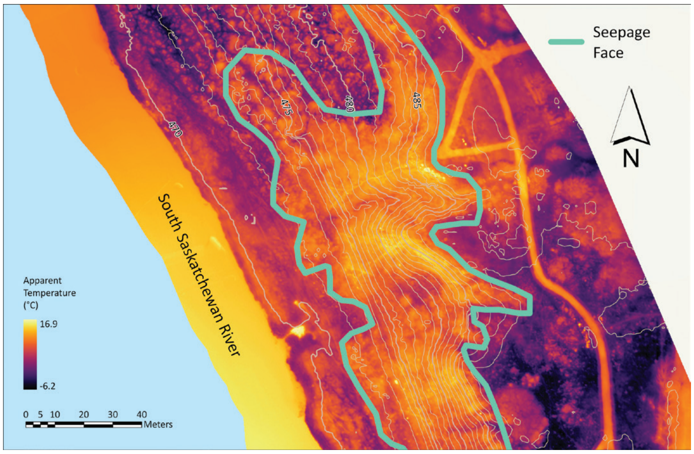

COLUMNS

ANNOUNCEMENTS

DEPARTMENTS

Both UAV photogrammetry and lidar have become common in deriving three-dimensional models of urban scenes, and each has its own advantages and disadvantages. However, the fusion of these multi-source data is still challenging, in which registration is one of the most important stages. In this article, we propose a method of coarse point cloud registration which consists of two steps. The first step is to extract urban building facades in both an oblique photogrammetric point cloud and a lidar point cloud. The second step is to align the two point clouds using the extracted building facades.

Over the last two decades, urban growth has become a major issue in Lahore, accelerating land surface temperature (LST) rise. The present study focused on estimating the current situation and simulating the future LST patterns in Lahore using remote sensing data and machine learning models.

The permanganate index (CODMn), defined as a comprehensive index to measure the degree of surface water pollution by organic matter and reducing inorganic matter, plays an important role in indicating water pollution and evaluating aquatic ecological health. However, remote sensing monitoring of water quality is presently focused mainly on phytoplankton, suspended particulate matter, and yellow substance, while there is still great uncertainty in the retrieval of CODMn. In this article, the Landsat-8 surface reflectance data set from Google Earth Engine and in situ CODMn measurements were matched. The support vector regression (SVR) machine learning model was calibrated using the matchups.

The Yangtze River Delta urban agglomeration (YRDUA) is one of the most active economic development regions in China. However, the YRDUA is facing a severe test of sustainable development. Therefore, this study evaluates the urban comprehensive carrying capacity (UCCC) of cities in the YRDUA from 2009 to 2019 from natural, social, and economic perspectives, and uses the Geographically and Temporally Weighted Regression model to analyze driving factors of spatiotemporal variations of the UCCC.

See the Cover Description on Page 744

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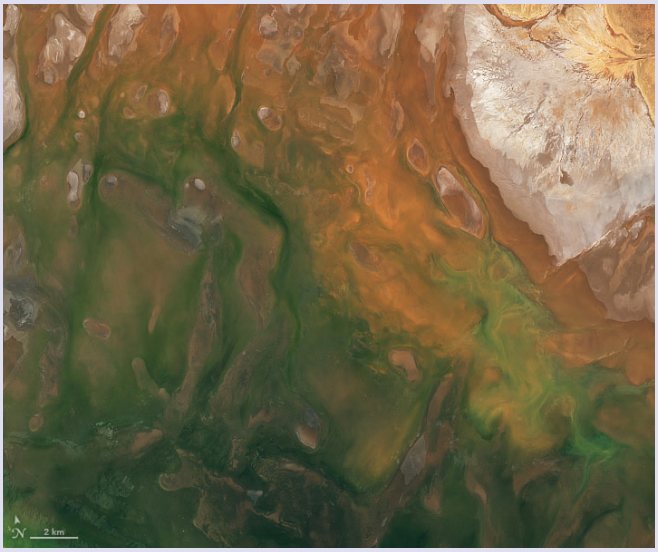
COVER DESCRIPTION

On most days, South Australia's Lake Torrens shows up in satellite images as a relatively dry salt and mud flat. But in October 2022, a substantial amount of water returned to this ephemeral lake.

The Operational Land Imager-2 (OLI-2) on Landsat 9 acquired these images on October 28, 2022, when water spanned much of the lakebed. Wet areas are green-brown, salty surfaces are white, and land is red-brown.

Lake Torrens is located within in the east-central part of South Australia, just over 100 kilometers (60 miles) south of the Lake Eyre and 450 kilometers (280 miles) north of Adelaide. It lies between the Arcoona Plateau to the west and the Flinders Ranges to the east. The lake arose from a depression that formed east of the Torrens Fault about 70 million years ago. Today, it is one of Australia's largest inland salt lakes, and is a sacred site to nearby Aboriginal nations.



The region is generally very dry, averaging only a few hundred millimeters of rain each year. Unlike Lake Eyre, which receives most of its water from runoff during the summer monsoon, water in Lake Torrens depends primarily on rainfall from the southern hemisphere westerlies during winter.

Across South Australia, an unusually wet winter in 2022 has extended into spring, with the state seeing its wettest October on record (since 1900). Some areas, including the Flinders district, received more than 100 millimeters (4 inches) of rain, making it the wettest October on record. Areas around Roxby Downs, about 30 kilometers southwest of Andamooka, recorded more than eight times their average monthly rainfall for October.

Lake Torrens is typically endorheic, which means that the lake has no outflow and instead loses water via evaporation or seepage into the ground. That was probably still the case this year. But on rare occasions, most recently in 1989, extreme rainfall fills the lake with so much water that it flows south across the Pirie-Torrens corridor and into the Spencer Gulf.

To see the full image, visit https://landsat.visibleearth.nasa.gov/view.php?id=150566

NASA Earth Observatory images by Lauren Dauphin, using Landsat data from the U.S. Geological Survey. Story by Kathryn Hansen.

PHOTOGRAMMETRIC ENGINEERING & REMOTE SENSING

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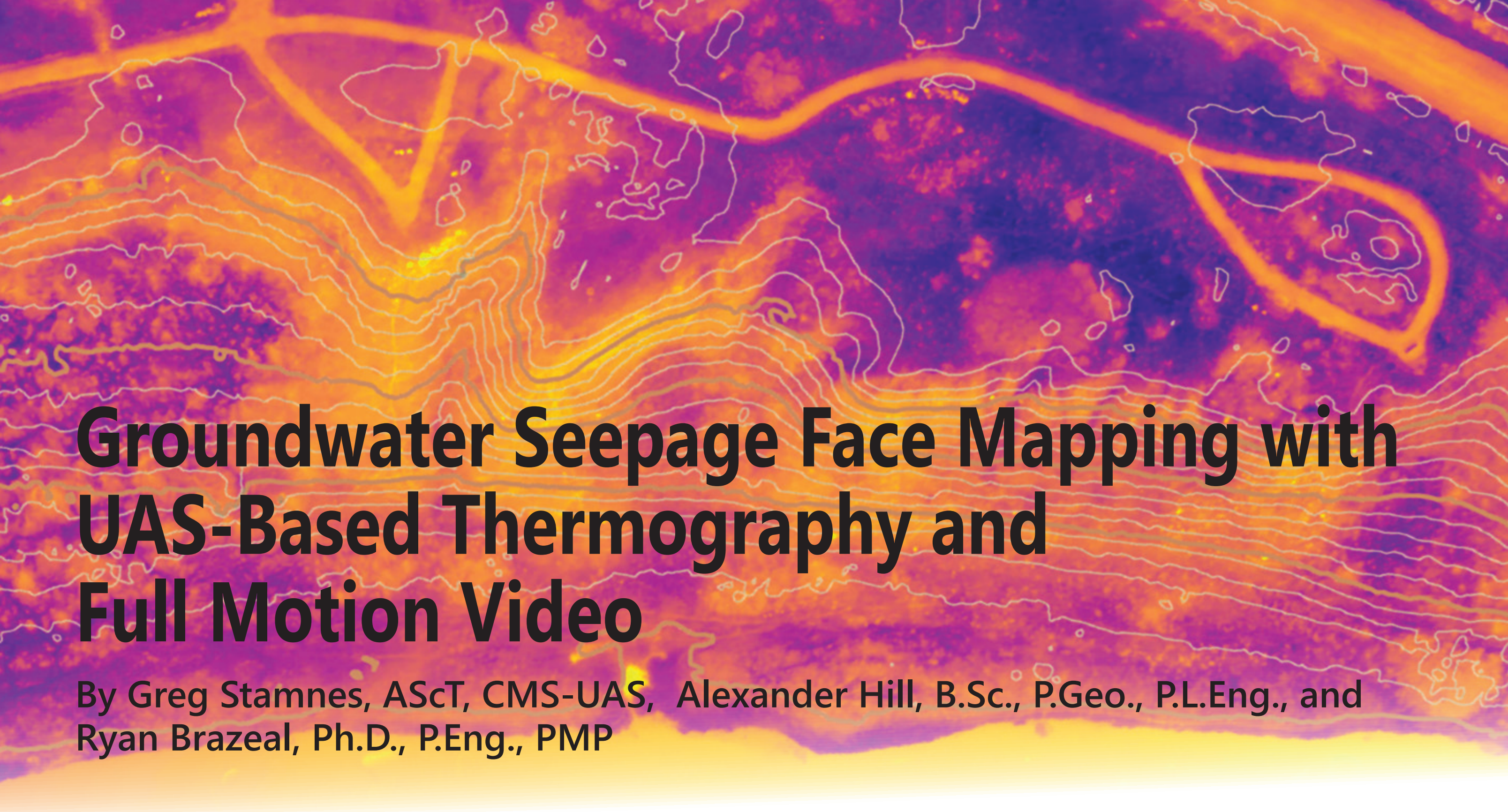

Groundwater Seepage Face Mapping with UAS-Based Thermography and Full Motion Video

By Greg Stamnes, AScT, CMS-UAS, Alexander Hill, B.Sc., P.Geo., P.L.Eng., and Ryan Brazeal, Ph.D., P.Eng., PMP

Introduction

Groundwater seepage is a geohazard which can be difficult to detect visually that contributes to terrain instability and possibly catastrophic failure (Budhu & Gobin, 1996; Alberta Environment, 2022). When terrain instability occurs near dams, highways, and other critical infrastructure, groundwater seepage can have immense economic, environmental, and public safety implications.

Groundwater seepage can be found by identifying the seepage face; the boundary where the flowing groundwater meets the atmosphere (Scudeler, et al., 2017). Identification is often achieved using remote sensing techniques and/or visual assessment via boots-on-the-ground survey. A variety of remote sensing techniques including image interpretation of stereo aerial images (e.g., terrain analysis of current and historical aerial photos), digital orthoimages, and more recently via thermography are utilized by hydrologists, geomorphologists, and geotechnical engineers to locate groundwater seepage faces (USGS, n.d.).

The use of thermographic sensors carried by Unoccupied Aerial Systems (UAS) can be an efficient alternative for identifying groundwater seepage faces. However, the method does have some limitations if the common practice of using a Structure from Motion (SfM) software package to produce a single orthorectified thermal index map from UAS-collected imagery is all that is utilized. This article highlights using Full Motion Video (FMV) to visually identify and georeference groundwater seepage locations using thermography.

There are also limitations of visual interpretation for groundwater seepage identification. Terrain analysis begins with the identification and distinguishing of elements of the landscape. These elements can typically be categorized as; topography or landform, drainage and erosion, vegetation and land-use (Mollard & Janes, 1984). This process requires the skills and knowledge of an analyst to determine the importance and significance of the identifiable features and elements of an observed landscape within the imagery, such as stereoscopic aerial photography.

A common approach is to conduct aerial photography analysis using softcopy photogrammetry. One of the many advantages to this approach is the ability to incorporate and overlay different sources of data and imagery including high-resolution digital aerial photography, orthorectified imagery, and Digital Elevation Models (DEM) to aid in the identification and interpretation of the landscape. This allows the analyst to navigate digitally in 3-Dimensional (3D) space without nominal scale constraints, which is especially important for viewing possible seepage faces. In the identification of groundwater seepage and drainage patterns using this method, the analyst is still reliant on visual cues, especially recognizing tone, shape, vegetation type and terrain relief.

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Analysts must acknowledge that site conditions may differ significantly when comparing conditions at the time of capture of the aerial photography to those currently being assessed. The occurrence of groundwater seepage at a particular area or site may be a function of other variables such as geology, ground stability, vegetation cover, human activity or be seasonal in nature. It is therefore possible that seasonal seepage issues may not be recognized by the analyst when conducting image interpretation of aerial photography alone. In Figure 1 this is illustrated by overlaying seepage identified from 1991 dated aerial photography interpretation (pink hatch), with more recent aerial photography interpretation (green hatch).

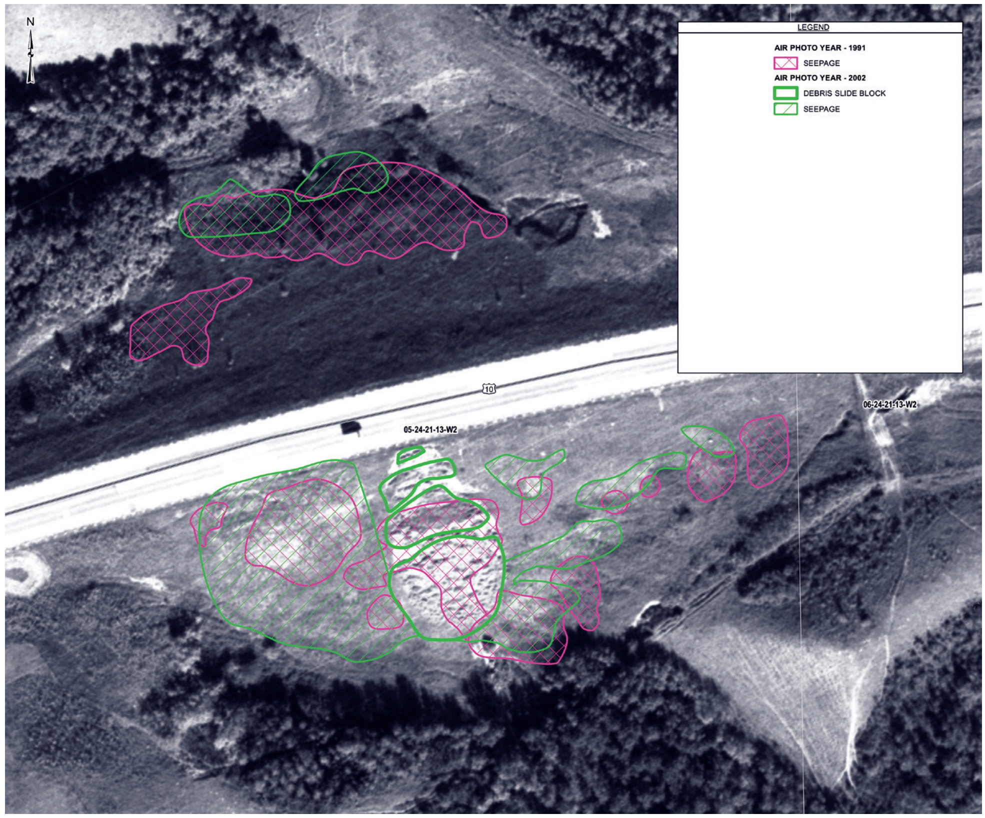

Figure 1: Typical black and white aerial photography used for terrain analysis and identification of potential seepage locations.

Analysis should include on-site ground truthing to validate the findings of the image interpretation phase and order to check the accuracy and relevancy of the mapped terrain features as shown in Figure 1. This is especially important when theorizing what relationships exist between landforms. Answering this question may also provide clues to where groundwater seepage may occur if not obvious from the aerial photography interpretation alone.

> ***Aerial thermography can be used in the context of groundwater seepage to answer two questions: firstly, are there radiometric indications when seepage is occurring within an area of interest, and secondly, where (geographically) is the seepage occurring?***

Aerial Thermography for Groundwater Seepage

Aerial thermography can be used in the context of groundwater seepage to answer two questions: firstly, are there radiometric indications when seepage is occurring within an area of interest, and secondly, where (geographically) is the seepage occurring?

Aerial thermal data acquisition for identifying seepage faces should be timed to commence when the greatest temperature difference occurs between the groundwater flow and the surrounding ground (Ozotta, 2021). This could be during late summer when the flowing groundwater is cooler than the surrounding warmer soil, or in the spring and autumn when the flowing groundwater is warmer than the cooler ground. However, there should not be snow cover on the ground, and the ground should not be deeply frozen during the acquisition of the thermal data (Harvey, et al., 2019). Data collection should occur at night with optimum meteorological conditions, including low wind speeds of less than 24 km/hr, humidity less than 50%, and no precipitation within the previous 24 hours (Infrared Training Center, 2019). Thermal sensors are a passive type of sensor and therefore suffer from environmental factors such as the effects of vegetation occlusion when mapping the ground surface (Ozotta, 2021; Infrared Training Center, 2019). As a result, it is recommended to conduct thermal imaging missions for groundwater seepage detection and mapping during the spring months before seasonal vegetation growth.

Figure 2: Location of the research at the South Saskatchewan River. The study area along the river is about 650m long and 100m wide.

Our research was conducted on the riverbanks of the South Saskatchewan River near Saskatoon, SK, Canada in May, July, and October of 2020, and April, July, and November of 2021 in an area with known groundwater seepage.

The surficial geology of the test site comprises alluvial floodplain deposits and glaciofluvial kame terrace deposits (Christiansen, 1992). However, no forms of intrusive or non-invasive geotechnical/geological investigations were undertaken prior to thermal imaging of the test site.

Thermal imagery datasets were collected using a DJI M200 UAS with a DJI Zenmuse XT2 payload with 13mm lens. The XT2 is a long-wave infrared (LWIR) camera with an uncooled VOx microbolometer, 640 x 512 resolution, and 30 Hz full frame rate. The total project area was approx. 65,000m². During an additional flight, UAS-based lidar data was also collected for orthorectification of the thermal images with Pix4DMapper and to create a DEM of the area for higher accuracy video frame reprojection. Our research concluded that the ideal time to collect data in this region was shortly after spring snow melt when the ground was thawing, and groundwater flow levels were above average.

SfM for Thermal Index Maps

Completing SfM mapping from thermal imagery has the advantage that the produced orthorectified thermal index map can be used in Geographic Information System (GIS) software to correlate areas of increased thermal index (i.e., temperature) with slope, as seepage typically occurs where groundwater zones intersect the faces of slopes (Winter, et al., 1998).

Figure 3 shows contour lines of the ground surface overlaid on an SfM-generated thermal index map created from the data collected on May 7, 2020, shortly after snow melt. The thermal imagery was collected over the course of multiple UAS flights totaling 4 hours in duration from an altitude of 121m above ground level (AGL) resulting in an average Ground Sample Distance (GSD) of 16.9 cm/pixel.

There is a distinct temperature increase noticeable near the top of the riverbank as identified in Figure 3, but it is difficult to confidently delineate where the seepage exists using only the thermal index map and contours. This is primarily due to the lower resolution of the input thermal imagery and the color blending applied to each pixel as part of the SfM orthorectification process. Because of the color blending, other objects with elevated temperatures in relation to the ground, such as trees, contribute to the elevated index values surrounding them and falsely represent the elevated ground temperatures.

Our experience reveals that thermal mapping using SfM has several limitations. Groundwater seepage faces are commonly composed of homogeneous earth with similar geological properties and/or permeability characteristics that heats and cools at similar rates resulting in low thermal contrast. This low thermal contrast in turn results in featureless imagery which can lead to SfM key point generation failure. SfM software developers have thermal data collection recommendations including 90% front and side overlap, low flight speeds of 2-3 m/s, using a gimballed camera, and flying higher to assist key point matching (Pix4D, 2019; Pix4D, 2018a; Pix4D, 2018b). However, by following these guidelines challenges arise due to the volume of image data from acquiring imagery with high overlap. To reduce data volume the solution is to fly higher, but this reduces the image resolution. Flying at higher altitudes increases the volume of atmosphere between the ground and the sensor, resulting in thermal energy loss due to atmospheric attenuation (Infrared Training Center, 2019). Flying at very slow speeds increases image quality by reducing motion blur but contributes to the impractical data acquisition and processing limitations of UAS mapping.

Another issue with SfM-based thermal mapping is the inconsistency of input data due to the loss of thermal energy over time. On larger projects that require multiple UAS flights and span several hours in duration, the data collected at the beginning of the acquisition period may have different thermal energy than the data collected near the end of the period over the same geographical area. In addition to all the above noted problems, thermal cameras onboard UAS will typically automatically adjust their measurable temperature range throughout the flight depending on the thermal energy that reaches the sensor. This is synonymous with collecting color imagery while adjusting the ISO light sensitivity setting significantly throughout acquisition. The resultant imagery can be difficult to process within SfM software in order to produce meaningful mapping products.

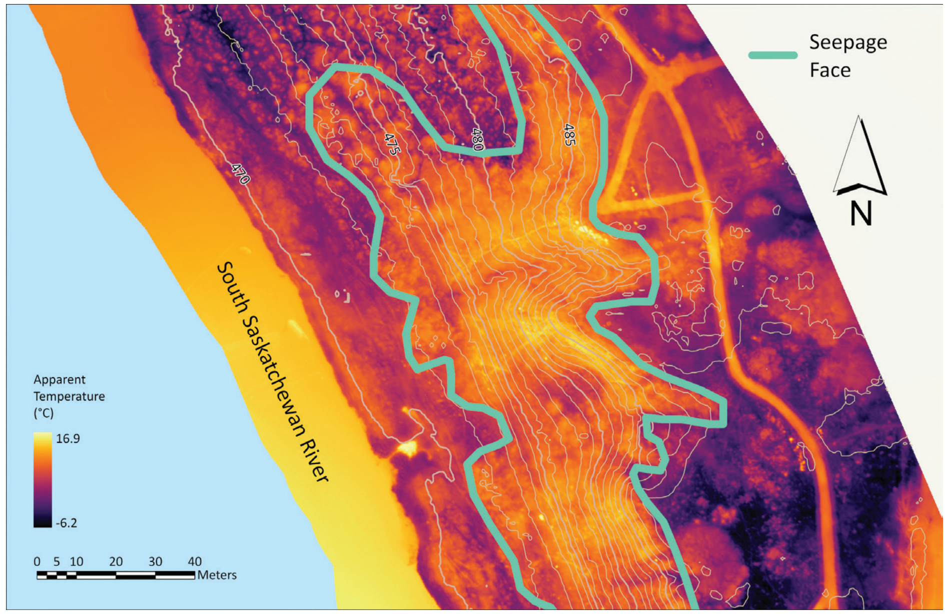

Figure 3: Thermal index map with elevated temperature on riverbank slopes. The contour interval is 1m. Date of data collection: May 7, 2020.

> *FMV is similar to Augmented Reality in that it combines real-world video data with georeferenced digital data such as point, polyline, and area features. Contour lines can be used to assist with the visualization of elevation change during FMV video review to identify temperature changes in areas of slope change.*

FMV for Identifying Groundwater Seepage

In addition to the high-altitude UAS flights, a single lower-altitude flight (45m AGL) was performed over the known seepage locations in order to investigate the practicality of using close-range thermal video for identifying groundwater seepage. This reduction in altitude subsequently increased the image resolution and reduced the volume of atmosphere between the thermal camera and the ground. This in turn resulted in an improved level of discernable temperature difference between the seepage faces and the surrounding ground. In order to georeference the features of interest identified within the thermal video, tests were conducted using FMV. FMV refers to a video file which has been combined with geospatial metadata to make the video file geospatially aware (Esri, n.d.). FMV is similar to Augmented Reality in that it combines real-world video data with georeferenced digital data such as point, polyline, and area features. Contour lines can be used to assist with the visualization of elevation change during FMV video review to identify temperature changes in areas of slope change.

To create a thermal index map with accurate absolute temperature values for each pixel, thermographic imagery collected with a radiometric camera needs to be corrected for emissivity and bias (Abdullah & Turek, 2021). This procedure presents challenges for FMV. However, in the case of locating seepage faces, apparent temperature differences are sufficient due to its qualitative nature (Harvey, et al., 2019). The non-disruptive nature of low-altitude UAS flights in comparison to using occupied aircraft, along with the suitability of using apparent temperature differences, favors the use of FMV from UAS for identifying and mapping groundwater seepage faces.

Site specific variables such as (but not limited to) geology, terrain, thermal characteristics, and slope aspect may dictate that FMV for groundwater seepage mapping be used in conjunction or at least supported by more conventional forms of terrain analysis (such as aerial photography analysis). Possible correlation between these variables and the findings of the FMV mapping and thermal imaging data may be drawn such that analysis can reliably map potential groundwater seepage areas.

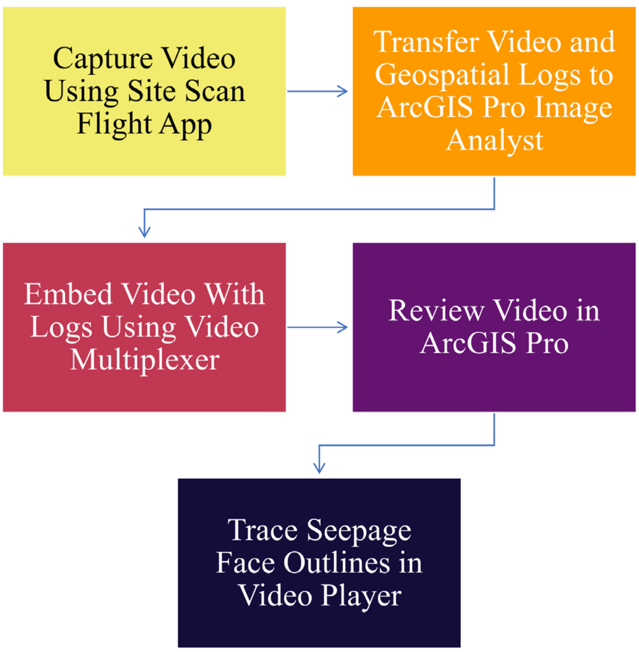

Figure 4: FMV Flow Chart (ArcGIS, 2020).

To create FMV, video data, along with position and orientation metadata of the UAS and gimbal orientation stored in geospatial flight logs created by Esri's Site Scan Flight app software, is combined using the Video Multiplexer tool within ArcGIS Pro. Areas of temperature change representing seepage can then be manually digitized to create vector feature classes, directly from the video frame within the Video Player similarly to how the area was manually digitized using the thermal index map as shown in Figures 3 and 5. The area of traced groundwater seepage in Figure 5 appears to coincide with the outcropping of more permeable soil deposits which may promote groundwater flow.

Another useful tool is the Frame Export tool which projects a single video frame onto the Esri map. Figure 5 shows an FMV frame that was overlaid onto the ArcGIS map view with the Frame Export tool.

Using ArcGIS Pro, the FMV can be displayed and a line feature displaying the UAS position during the flight will be shown in the map view (red parallel lines in Figure 6), as well as the position of where the video frame was recorded and the projected outline of the video frame on the ground. Feature classes that appear in the map or scene view can be displayed in the video frame, such as contours, cadastral boundaries, or manually digitized features by enabling the "Display Features" function. Such ability to view contours in the video frame assists reviewers in visually correlating changes in slope to the seepage faces. It also functions to ensure that all identified areas of interest within the video have been delineated. Once the FMV review has been completed, the feature classes can be easily exported as vector features for downstream GIS and CAD visualization and analysis.

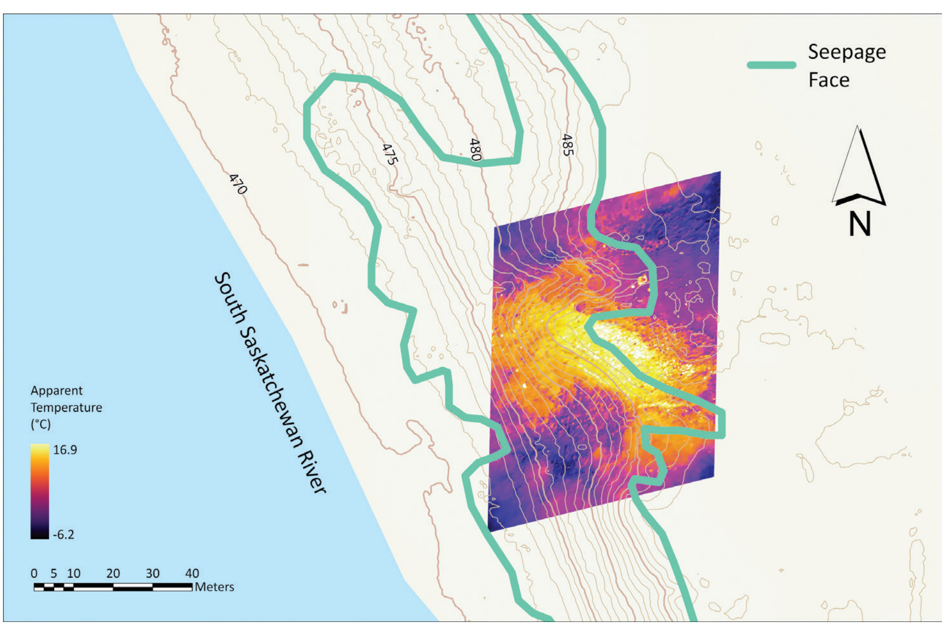

Figure 5: FMV Frame Export showing seepage face locations overlaid with contours – see the comments for Figure 3. Date of data collection: April 24, 2021.

In summary, there are many benefits to using FMV. It allows for reduced UAS flying height and distance from the sensor to the ground, reducing the effects of wind and other atmospheric conditions (e.g., humidity) within the thermal data. As a result, the FMV data are of more detail and higher resolution, and there is less thermal energy loss between the sensor and the ground. Parallel flight lines can be flown further apart as the high overlap for successful SfM processing is not required. The camera can be pointed in a nadir direction to reduce oblique distortion, and linear corridors can be mapped in a single pass, which is not successful when using SfM-based thermal mapping.

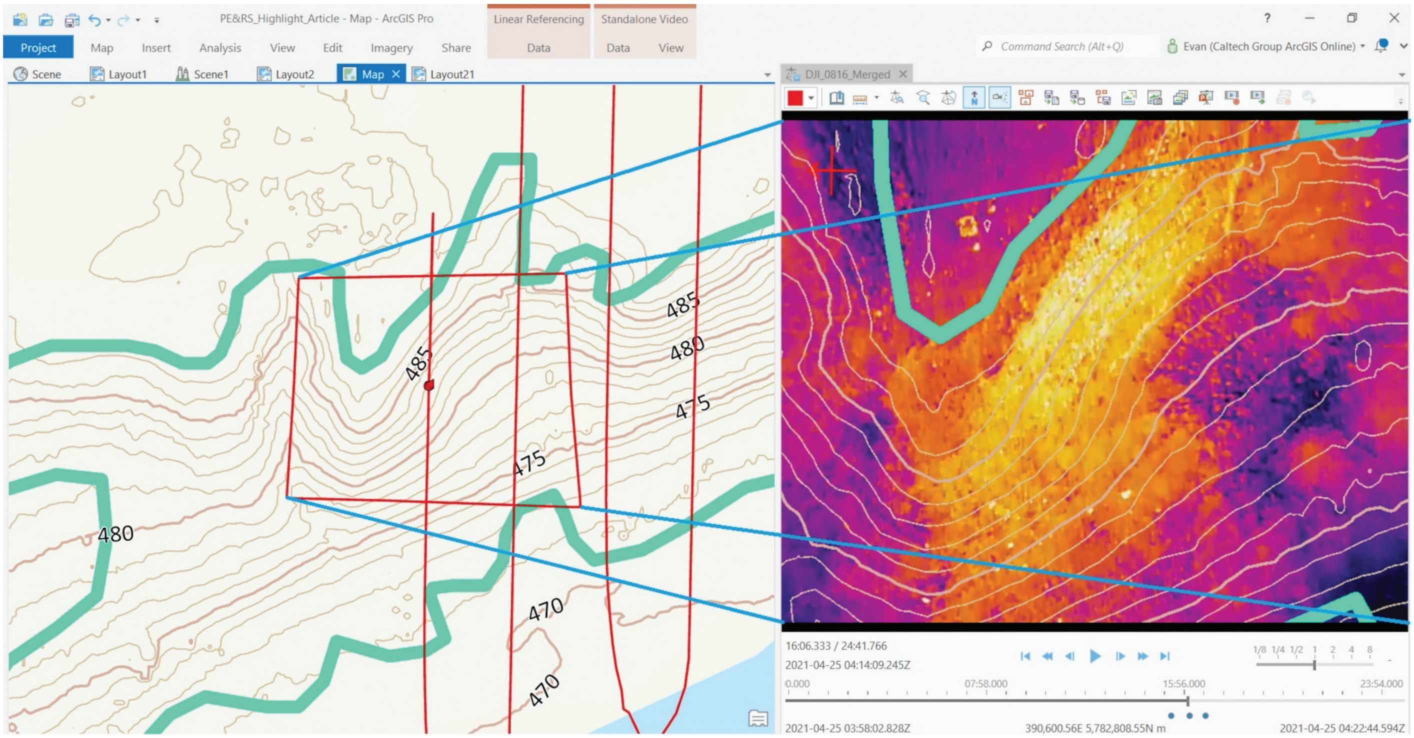

Figure 6: FMV Review in Esri's ArcGIS Pro Identifying Groundwater Seepage Face.

Although video files are typically large in size, the thermal video data collected over the research area was only 25% of the total size of the still thermal imagery collected. The total data collection time for the thermal video data was 40 mins, compared to 4 hours for still thermal imagery. Because the thermal data is collected faster, there will be less temperature variation from the beginning to the end of data collection. FMV data collection using UAS can be completed with high temporal frequency and in conjunction with aerial photography during sunlight to identify correlations. Lastly, groundwater seepage faces can still be identified in areas with reduced thermal contrast using FMV.

Similar to image interpretation of aerial photography (i.e., stereoscopic images), interpretation of FMV videos is required in order to identify and evaluate possible groundwater seepage areas. Misinterpretation of groundwater seepage due to vegetation cover and other land-use issues while using FMV increases without a fundamental understanding of the terrain.

> *"In summary, there are many benefits to using FMV."*

Future studies are to incorporate geology as a variable as it relates to thermographic mapping of potential groundwater seepage areas. Geology, specifically the physical characteristics of a soil or rock have influence over the thermal characteristics that will develop within a particular soil or rock. Heat transfer within a soil (other than conduction) may only be a factor in more permeable soils where groundwater flow is apparent (The Canadian Geotechnical Society, 2006).

The Future of FMV for Groundwater Seepage

One of the current trends in UAS industry is the integration of network connectivity for near real-time data transfer of imagery and video. Presently, some systems, such as the Freefly Systems Astro UAS, offer real-time viewing of data from several sensors including the Workswell WIRIS Pro or Flir Duo Pro R radiometric thermal cameras via the Auterion Suite. This allows for analysts to remotely view the thermal imagery from a live video dashboard and identify potential areas of interest to be further investigated while the UAS pilots are still in the field. The real-time data is not FMV, as it is not multiplexed with the position and orientation data streaming from the UAS and gimbal sensors. With the present ability to stream high-resolution video data to a remote viewer in real-time, it is perceivable that in the future it may be possible to perform the multiplexing of the video data and the position and orientation data for real-time FMV.

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GIS Tips & Tricks

Al Karlin, Ph.D. CMS-L, GISP

Getting your bearings in GIS?

In the September 2022 issue of *PE&RS*, this column asked “Which Way is Up?”, discussed three definitions of “North”, and provided tips on how to symbolize each on your map. This month’s tip focuses on a similar issue, how to calculate the bearing (i.e., compass direction) of a line.

As with “North”, there are several ways to define a “bearing.” In navigation and GIS-mapping, a bearing is the horizontal angle, measured in degrees, between the direction of an object and another object, or between that object and that of “true” (i.e. celestial) north. The “absolute bearing” refers to the angle, measured in degrees, between magnetic north (i.e. the magnetic bearing) and an object, while the “relative bearing” refers to the angle, again, measured in degrees, between a craft’s forward direction and the location of another object. Bearings are frequently referred to as “azimuths” which can be measured in degrees clockwise from “north” as geodetic (from celestial north), magnetic (measured from magnetic north) astronomic (from the south) or assumed azimuths. So, when reporting bearings (or azimuths) it is always a good idea to specify which is being reported. For additional information, https://theconstructor.org/surveying/azimuths-bearings-surveying-difference-determination/38494/, is a good general reference.

While calculating a bearing in an Esri GIS system seems like it should be a simple matter, the bearing is not one of the properties that is recorded in the standard line-attribute table. Furthermore, the bearing is also not one of the seven geometric features of a line that can be calculated by the “Calculate Geometry” function in the linetable field functions. Then, to make matters even more complex, when displaying or calculating a bearing in ArcGIS Desktop, the bearing is reported counterclockwise from East but calculated by the Add Geometry Attributes script as clockwise from North! So, here are some tips for getting your bearings.

In ArcGIS Desktop

Method 1—Interactive when editing/creating a line feature without point snapping – When in an editing session and creating a line feature, start the line, and move the cursor to the end-point. Before clicking the end-point, right-click on the mouse or use the key combination Crtl-A to reveal the “Direction …” of the line as in Figure 1. The Direction… window will display the bearing as in Figure 2. IMPORTANT NOTE: This “direction” is measured counterclockwise from the EAST (East=0, North=90, West =180, South=270) so to derive the compass bearing, you may want to adjust the value to North. In this case (Figure 2), the reported bearing of 27.2269º, is converted to the compass direction 62.7731º from North.

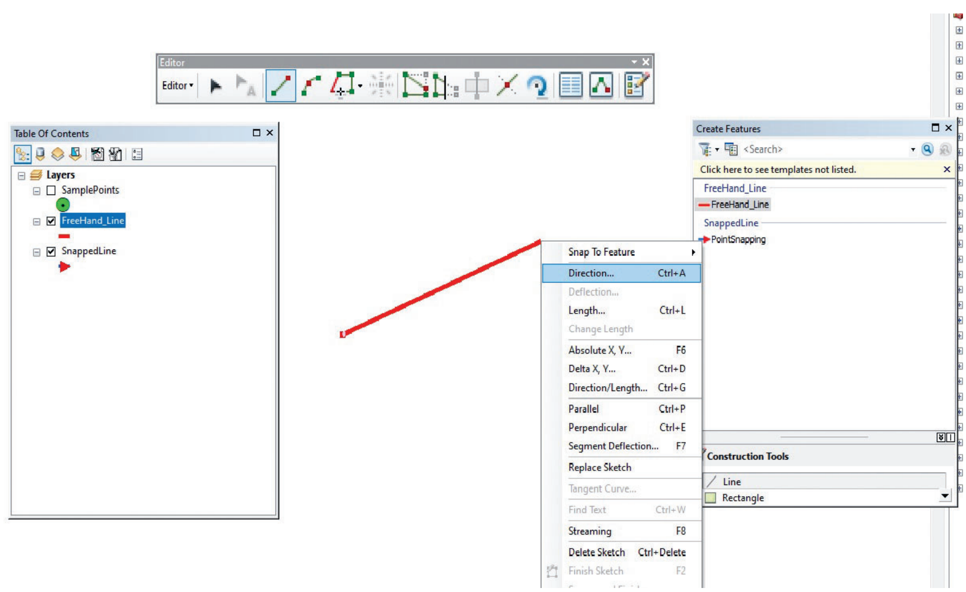

Figure 1. Using the key combination Ctrl-A (or right-mouse clicking) on the end-node of a freehand drawn line feature to start the Properties menu, then selecting the Direction… property.

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METHOD 2—Interactive when **editing/creating a line feature with feature snapping**. When in an editing session and constructing line features by snapping to points, the direction of any segment can be revealed as in Method 1. After snapping to the node, use the Ctrl-A sequence to show the direction. Again, the direction is measured counterclockwise from East. So, in this example (Figure 3), the reported bearing of 158.9755° is converted to 291.0245° from North.

METHOD 3— Using the Add Geometry Attributes script from ArcToolbox to **add the bearing to a line feature class**. Finally, with ArcGIS 10.8, there is an "Add Geometry Attributes" script in the Data Management Tools | Features Toolset that will add additional geometric attributes, including the bearing, to line feature classes (and/or shapefiles). In the example below, I added three lines to the SnappedLine feature class. Opening the Add Geometry Attributes tool (Figure 4) and check the desired attributes, indicate the linear units and Coordinate Reference System; running the tool will result in those attributes being added to the feature class table (Figure 5). Of course, the direction of the line is From_Node toward To-Node BUT the BEARING is reported from CELESTIAL NORTH!

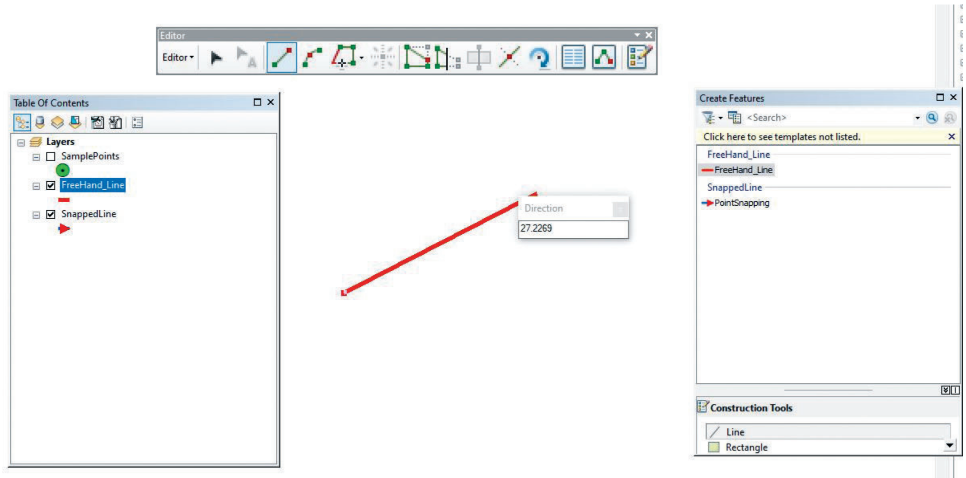

Figure 2. The Direction Window showing the bearing of the line feature. Note: this angle is computed counterclockwise from East.

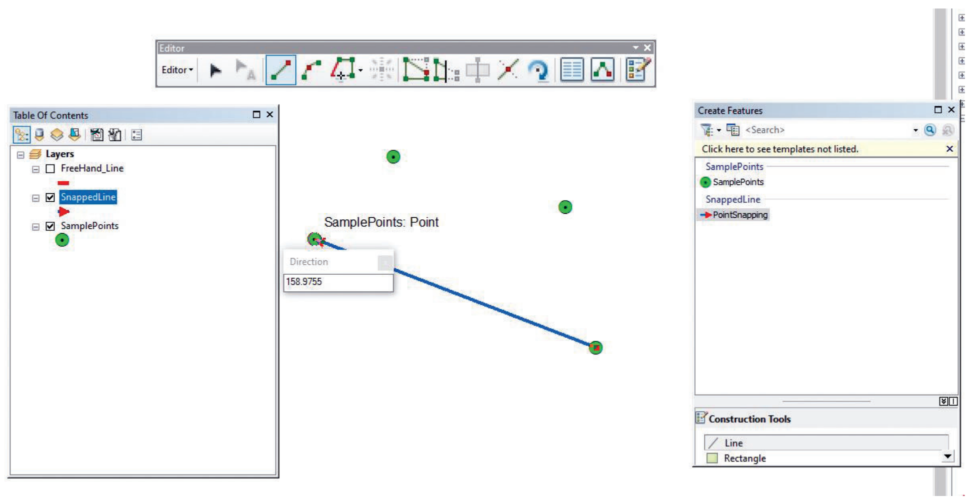

Figure 3. Using the key combination Ctrl-A after snapping a line feature to an end-point to show the Direction window. Again, note that the Direction is reported from East.

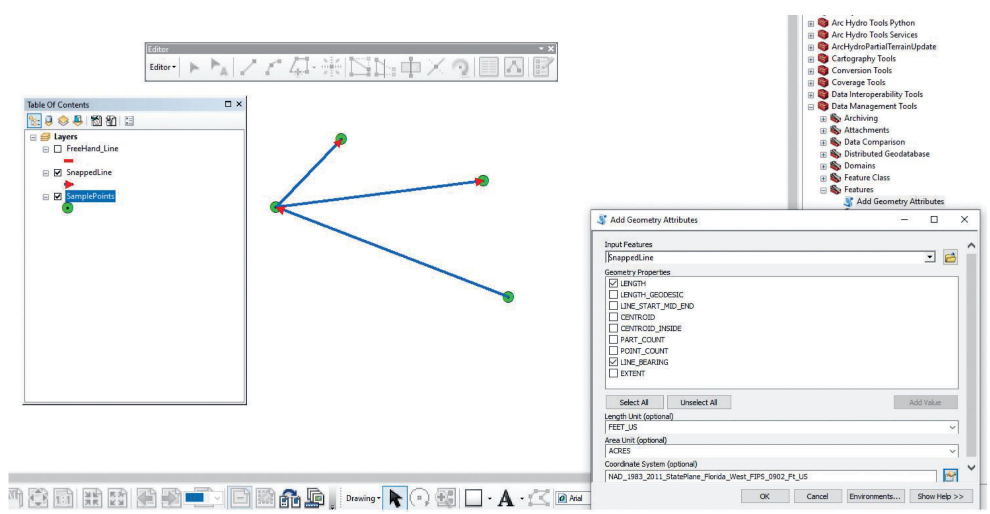

Figure 4. Using the Add Geometry Attribute script found in the Data Management Tools | Features toolset and choosing to add the LENGTH and LINE_BEARING attributes to the SnappedLine feature class.

In ArcGIS Pro

The same interactive and tabular methods described for ArcGIS Desktop also work in ArcGIS Pro. The only difference is that the interactive methods now give you options (Figure 6. drop down arrow) of displaying the direction as NAz (North=True Azimuth), SAz (South = Astronomic Azimuth), P (Polar Azimuth), or QB (Quadrant Bearing). The Add Geometry Attributes tool is again found in the Data Management Tools | Features Toolset.

While not as straight-forward as a user might hope, determining the direction of a line or a line feature class is not that challenging once you get your bearings.

Send your questions, comments, and tips to GISTT@ASPRS.org.

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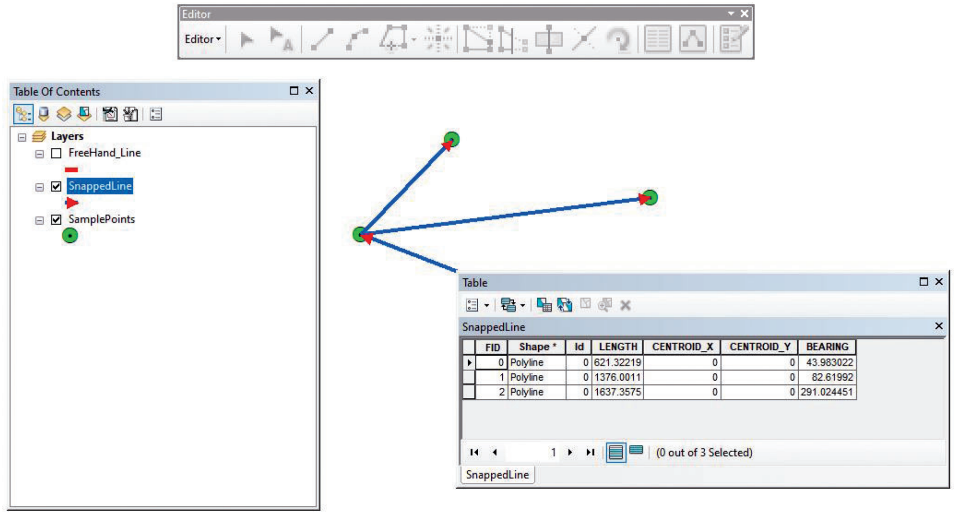


Figure 5. The resulting feature attribute table after running the Add Geometry Attributes script. Note that the script added the CENTROID_X and CENTROID_Y field but did not calculate these values. Use "Calculate Geometry" to populate these fields. Also note that the BEARING values are reported from Celestial North!

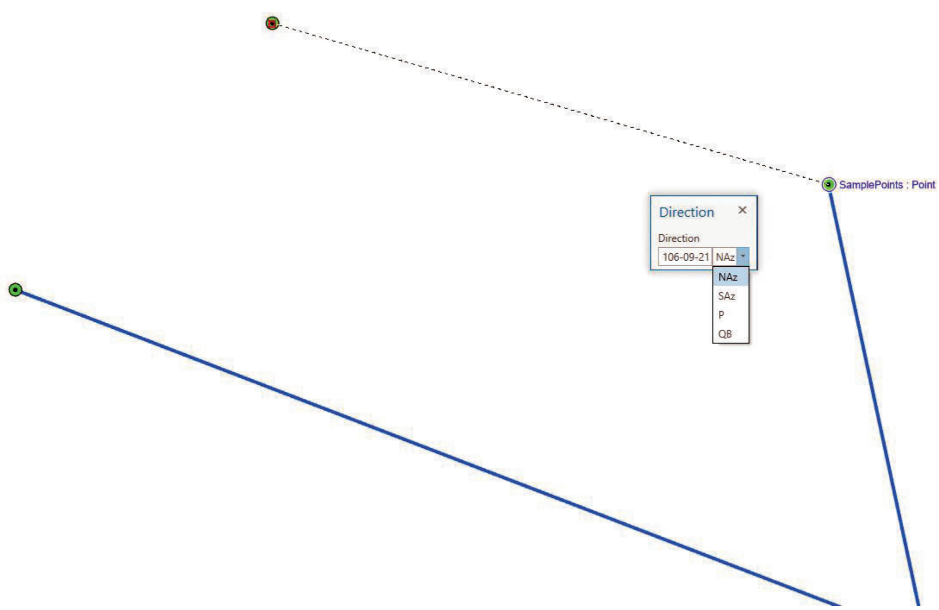
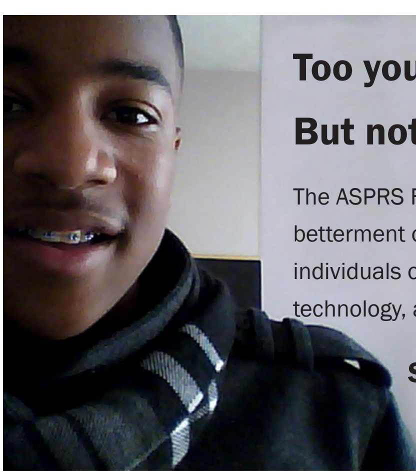


Figure 6. In ArcGIS Pro, the interactive (Ctrl-A) Direction property provides optional reports for the bearing.



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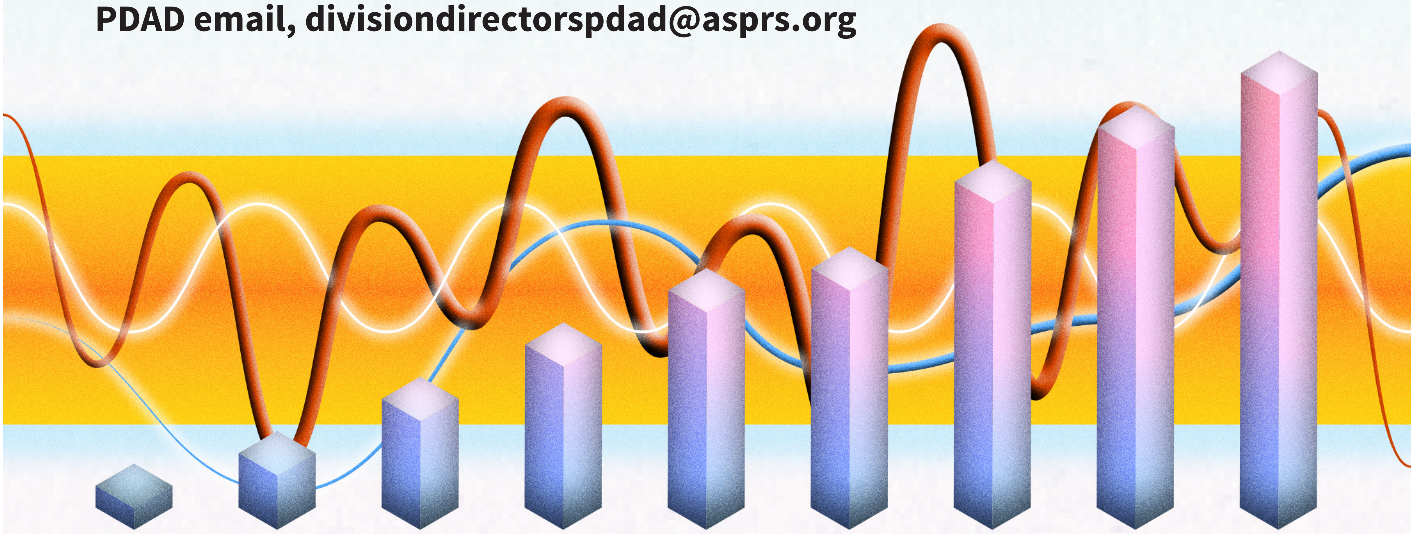

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Mike Zoltek

The Impact of Certification/Licensure on Your Geospatial Career

Certification and Licensure directly impacts all practicing Geospatial professionals. However, it is a challenge in the current environment of fast-paced technological advancement to ensure those providing geospatial products and services are both capable and qualified to fulfill the needs of clients and customers. How do users of current and future technologies choose providers? How do they know that the product or service they are receiving will have a reasonable expectation for correctness and completeness? Certification and licensure have provided traditional paths for demonstrating knowledge and technical proficiency. "Certification" has historically been used to evaluate and ensure technical competence, while "licensure" has traditionally been the mandate of legislation (at both the state and federal level) premised by the need to ***"protect the public health, safety and welfare."*** Traditional requirements to become licensed include a combination of a defined level of formal education, experience, and testing.

Licensing has long been a requirement for doctors, lawyers, engineers, and land surveyors. As technologies have advanced, many states have realized the need to license photogrammetrists, providers of a variety of geospatial information (e.g., GIS practitioners), and those providing lidar data collection and processing services (a.k.a. topographic mapping products & services). As more states enact legislation relating to existing and new geospatial products and services, it is difficult for practicing professionals, state and national organizations, and the public to keep up with changes to existing rules and regulations. The American Society for Photogrammetry and Remote Sensing (ASPRS), as the leading scientific organization representing the photogrammetry and remote sensing profession, provides a resource to readily access this new and changing information through its published maps and variety of geospatial mapping products and services.[1] The "Licensure Maps and Regulations" website1 shown in Figure 1 provides metadata on State Surveying Regulations; State Licensure Map for GIS Services, Lidar and Topographic Products, Georeferenced Imagery and Authoritative Imagery, respectively, with references to each state's existing Regulations, Board Websites, Individual State Regulations and also provides a Composite State Regulation Document.

Currently there are twenty-one (21) states that have existing regulations relating to georeferenced imagery products and services, thirty-three (33) that have existing regulations relating to authoritative imagery products and services, forty-seven (47) states with regulations relating to topographic mapping-related products and services (which includes lidar services), and fifteen (15) states with existing regulations relating to GIS-related products and services.

Having a list of the current regulations is just the first step. Every provider of a potentially regulated product or service should be aware of and understand how specific state regulations impact their practice because each state regulates geospatial products and services differently. Products or services that are regulated in one state may not be regulated the same way (or at all) in another state. For the practicing geospatial professional (whether it be an engineer, surveyor, photogrammetrist, GISP or UAS pilot), knowledge of an individual area of practice is essential. Knowledge of state, local and possibly even federal regulations are required to properly perform services, provide products, and fulfill contractual requirements for clients.

As mentioned earlier, the geospatial industry is constantly going through rapid changes as advancements are made in measurement technologies and capture platforms. The lower cost and easy access to measurement technologies (e.g. imagery and lidar systems) combined with the new and readily available low-cost UAS have allowed for an unprecedented opportunity for both individuals and firms to get into the business of collecting data to support an ever-expanding variety of geospatial products and services. The field-to-finish (e.g., black box) software solutions supporting these new advancements allow for virtually anyone to provide products that appear to be the same as those that have historically been created utilizing validated geospatial methodologies.

At almost every major geospatial conference in the last few years, the "big" giveaway is a UAS. Does this mean that

[1]http://www.asprs.org/PPD-Division/Licensure-Maps-and-Regulations.html

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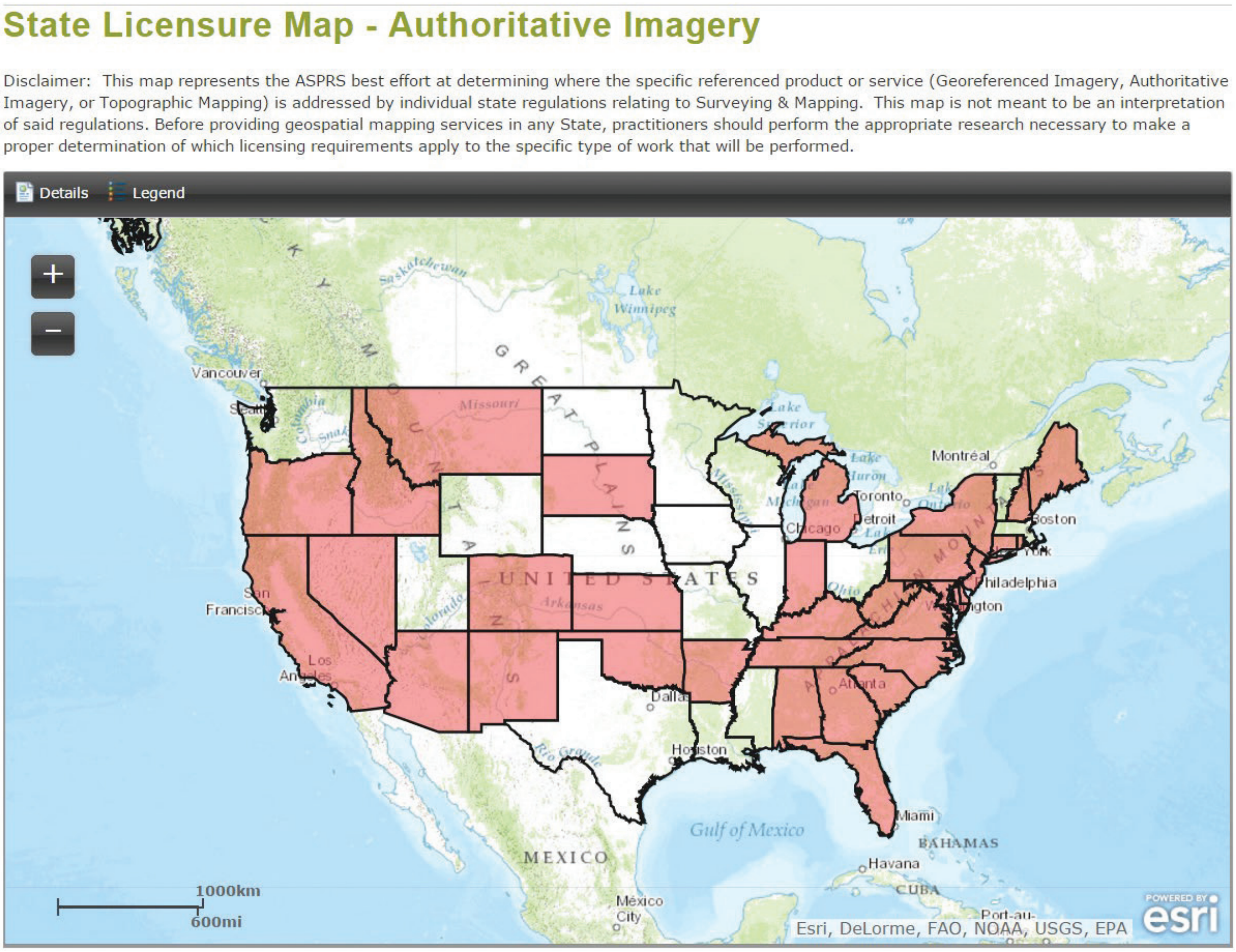

Figure 1. From the "Licensure Maps and Regulations" in ASPRS Profession Practice Division: The State Licensure Map—Authoritative Imagery

anyone can use this technology to create and provide services to the public? Various states have proposed or enacted legislation that clearly states otherwise. Over the last few years, there have been regulations enacted by over twenty (20) states regarding UAS use.[2] The 2012 FAA enacted its Section 333 exemption policies,[3] and in November 2015 published its report, Unmanned Aircraft Systems (UAS) Registration Task Force (RTF) Aviation Rulemaking Committee (ARC) Task Force Recommendations Final Report,[4] in which it recommended that all UAS flying within U.S. airspace that have a mass of more than 250 grams (~0.55 pounds) be registered with the FAA.

The new legislation and rules are examples of how the landscape of certification and licensure is being affected by new technologies. Rapid changes in technology require us to continually ask the questions as to which geospatial products and services should require certification and which should require licensure. How will the current and future practice of certified and/or licensed professional practice be affected by these changes? The answers to these questions will define the future of all practicing geospatial professionals, whether they are engineers, surveyors, photogrammetrists, GISPs or UAS pilots.

To help facilitate appropriate regulations regarding certification and licensure, the ASPRS Professional Practice Division (PPD)[5] proactively engages states to discuss potential legis-

[2]*Current Unmanned Aircraft State Law Landscape*, by National Conference of State Legislators, November 25, 2015: http://www.ncsl.org/research/transportation/current-unmanned-aircraft-state-law-landscape.aspx

[3]*FAA Modernization and Reform Act*, of 2012, HR 658, by Federal Aviation Administration (FAA): https://www.faa.gov/uas/media/Sec_331_336_UAS.pdf and https://www.faa.gov/uas/legislative_programs/section_333/

[4]*Unmanned Aircraft Systems (UAS) Registration Task Force (RTF) Aviation Rulemaking Committee (ARC) Task Force Recommendations Final Report* November 21, 2015: https://www.faa.gov/uas/publications/media/RTFARCFinalReport_11-21-15.pdf

[5]http://www.asprs.org/Divisions/Professional-Practice-Division.html

[6]http://www.asprs.org/Divisions/Unmanned-Autonomous-Systems-Division.html

lative changes and assists states by reviewing current and proposed state licensure laws related to geospatial products and services. ASPRS PPD works with individual states to ensure that there is an available licensure path for appropriately educated and experienced professionals. ASPRS PPD also actively engages other national geospatial organizations (URISA, NSPS, MAPPS, etc.) to coordinate efforts of regulation review and interpretation, with the goal of appropriately advising legislative bodies on legislation relating to existing and future geospatial products and services. Additionally, ASPRS has formed its Unmanned Aerial Systems Division whose "objectives include outreach and education, liaising with UAS-interested parties outside the Society, development and promotion of standards and best practices, establishment of calibration and validation sites, and credentialing and certification activities…"[6]

While it is in the best interest of every practicing professional to be active in their individual national organizations, it is incumbent upon every practicing geospatial professional to stay up to date on the specific rules affecting their practice. This combination of these two items is the only way to ensure the appropriate implementation of certification and licensing requirements, while also ensuring the protection of the health, safety, and welfare of the public in our fast-paced geospatial world.

Author

Mike Zoltek is a land surveyor, photogrammetrist, and GIS professional with over 30 years of geospatial experience. As the National Geospatial Program Director at GPI Geospatial, Inc (GPI), Mike is responsible providing operational oversight while leading new geospatial initiatives for the firm. A licensed surveyor who holds active surveying/photogrammetry registrations in 26 states, Mike has extensive experience with a wide variety of geospatial services, ranging from boundary surveying to remote sensing services. Mike currently serves as a member of Florida's State Board of Professional surveyors & Mappers, is the chair of the ASPRS Evaluation for Certification Committee and serves on the ASPRS Standards Committee that is currently updating the ASPRS standards for geospatial products and services. Mike has presented numerous technical seminars at universities and community colleges, as well as at industry conferences, and as has served as expert witness in boundary litigation cases in the state of Florida.

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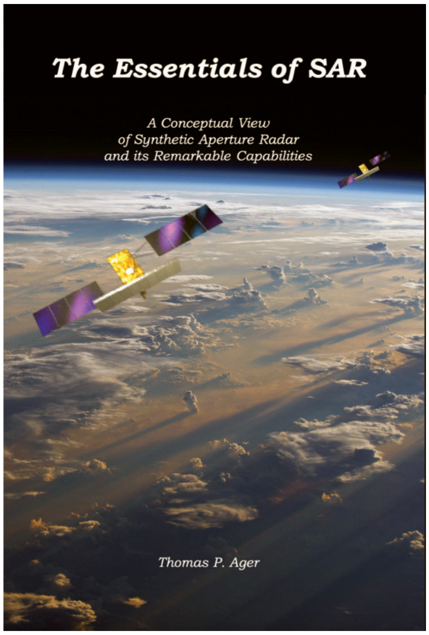

The Essentials of SAR, A Conceptual View of Synthetic Aperture Radar and its Remarkable Capabilities

By Thomas P. Ager

Independently published, August 2021. 309 pp. ISBN-13 979-8512864487, ASIN B09CGKTLZV.

Reviewed by Connie Krampf, CP, CMS/GIS-LIS, Senior Geospatial Analyst, DroneView Technologies LLC, Bloomfield Hills, Michigan

The book *"The Essentials of SAR, A Conceptual View of Synthetic Aperture Radar and its Remarkable Capabilities"* is authored by Thomas P. Ager. Mr. Ager is an expert in the SAR (Synthetic Aperture Radar) industry. He provides SAR consulting and teaching services.

This book comprises a total of six parts that the author refers to as "Apertures" – each with several chapters. SAR is not unknown to the imaging industry. As the author stated in the Foreword of the book: "SAR is well known as an imaging technology that can see through clouds and darkness, but SAR remains a confusing and enigmatic sensor for many. Its image is naturally different from the optical views wired into the human visual system, and SAR has an electrical engineering heritage that is incomprehensible to most ordinary people." Adroitly, the author explains the SAR technology to make it a clear and appealing subject for users who do not have advanced degrees in electrical engineering.

The author highlights the values of SAR in the preface, from which the reader can learn and appreciate important characteristics of SAR technology. These characteristics are "cloud penetration", "day and night coverage", "high resolution independent of distance", "variable resolution and coverage", "accurate geolocation", and "coherent illumination and many products".

Aperture, reviews basic sensor design and explains microwave sensors and how a simple form of radar imaging works. He then addresses how these processes enable for SAR imaging thoroughly providing the formulas behind the science. The author provides various examples of SAR theories behind those image phenomenon.

Aperture Three provides an overview of SAR products so readers can learn how SAR products are produced. Aperture Four explains how SAR geolocation works and gives examples of geodetic level accuracy derived from a commercial spaceborne SAR satellite. The author reviews how a radar pulse works and how the echoes, and the sources of all SAR data behave when they arrive at the antenna while also explains why SAR images sometimes have ghostly misplaced features in Aperture Five. The final Aperture describes the SAR's future by reviewing examples of ease, speed and automation in SAR processing of how to access the harmonic depth of SAR by replacing orderable, individual products. The book also includes appendices to discuss further considerations of SAR while reader can also find a list of symbols and acronyms, and an Index in the book.

The book provides basic concepts and explains the practices of SAR technology in great detail. The book is well organized so the reader can follow the contents in a logical way with ease. The book could be used as a text book for undergraduates or graduates who study remote sensing science. It also can be a valuable reference for remote sensing professionals.

SAR is a serious technical topic. To help the reader understand the subject more easily and to keep the discussion interesting, the author uses tables, charts and related pictures, some of them even cartoon-like illustrations, to present the theories of SAR. The book uses some mathematical formulas, stories and even music and

continued on page 764

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Grids & Datums

New Zealand

BY Clifford J. Mugnier, CP, CMS, FASPRS

The Grids & Datums column has completed an exploration of every country on the Earth. For those who did not get to enjoy this world tour the first time, *PE&RS* is reprinting prior articles from the column. This month's article on New Zealand was originally printed in 2005 but contains updates to their coordinate system since then.

New Zealand is the southernmost extent of colonization by Polynesians. It is believed that the colonization took place in at least two major waves, the first of which is thought to have occurred around 950 AD and the second around 1200 to 1400 AD. The first group consisted of hunters who depended for survival on the flightless "Moa" bird that is now extinct. The second Polynesian group was more agrarian, and archeological evidence indicates that the two cultural groups overlapped. Abel Janszoon Tasman, a captain for the Dutch East Indies Company, was the first European to discover the Maori of New Zealand. He sighted a "large land, uplifted high" near the modern day town of Hokitika on the West Coast of South Island on 13 December 1642. He sailed northwards to a bay which he subsequently named Murderer's Bay (now renamed Golden Bay), after four of his men were attacked and killed by Maori warriors. The entire region was once thought by Tasman to be part of Tierra del Fuego, so he named it Staten Landt. Soon after Tasman's voyage it was discovered that it was not Staten Landt, and it was renamed Nieuw Zeeland.

In the late 1800s, modern surveying had begun. Captain James Cook, son of a Scottish migrant farmhand, was apprenticed to a Quaker ship owner and he learned his trade in the difficult waters of the North Sea. He studied mathematics at night during off seasons, and later in Nova Scotia he mastered surveying with the plane table and alidade. He was chosen to command a scientific voyage to the Pacific Ocean. He was commissioned Lieutenant prior to his first survey and he was promoted to the rank of Captain before his third and last survey voyage. On the first voyage (1768-1771), his charter was to first go to Tahiti and observe the transit of Venus. These observations were to be later combined with other simultaneous observations (by others) in different locations in order to establish the magnitude of one astronomical unit (AU), which is defined as the mean distance of the Earth from the Sun. (See "The Republic of Mauritius," *PE&RS*, February 1999). After making these observations, Cook was to sail south and discover or not the supposed Antipodes or great Southern Continent. The East Coast of

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North Island was sighted 07 October 1769. Cook circumnavigated North and South Island while taking almost continual observations. It took six months to produce an "astonishing" chart of New Zealand that mapped 2400 miles of coastline. On this first voyage, Cook did not sail with John Harrison's chronometer but instead used Dr. Maskelyne's Lunar Almanac, published in 1767, which he used to fix his longitudes. However, Cook did use Harrison's chronometer on his two subsequent voyages (1772-1775, 1776-1780); he verified his longitudes to within 30 minutes. Cook's chart was used for the next 100 years as the settlement of New Zealand began. Thanks to Peggy Haeger for the above research done in the late 1990s for a graduate-level course on coordinate systems that I used to teach at the University of New Orleans.

According to L.P Lee in *First-order Geodetic Triangulation of New Zealand 1909-49* and *1973-74*, "In New Zealand, as indeed in many a similar young country, … the settlement survey proceeded well in advance of the triangulation, which should have controlled it. Even the triangulations were done in reverse order, the smaller networks being observed first, the larger and more accurate networks later. Thus, the procedure has been one of successive approximations, and each stage has led to a revision or recalculation of the work done earlier."

The first use of triangulation to control local surveys was by Felton Mathew, the first Surveyor-General in 1840-41; the limited area covered was near Auckland. In 1849 another small triangulation was begun near Christchurch. Both of these were superseded by more accurate surveys. In 1852, six Provincial Governments were formed to administer New Zealand, and later this increased to nine provinces; each of which had its own survey department. (A special department of the General Government conducted Surveys of native Maori lands). Henry Jackson based his land surveys on triangulation in Wellington Province beginning in 1865. The principal sections were in Wellington, Wairarapa, and Rangitikei covering the three districts where settlements were located, and each section was erected upon its own baseline, with several check bases included for verification.

The specifications for surveying the New Zealand public lands with steel tapes originated with experiments on the Thames gold-fields in 1869. The specifications were finally written to require steel tapes only (no chains) by James McKerrow in 1886, which preceded both the Swedish Jäderin steel wire apparatus in 1887, and the U.S. Coast & Geodetic Survey steel tapes in 1891!

"In the Province of Otago a control net of triangulation was not used, but a uniform system to govern the orientation of surveys was introduced by J.T. Thomson in 1856. The Province was divided into for large districts called 'meridional circuits.' Within each circuit an initial station was selected and true meridian was determined by astronomical observation. Bearings, but not distances, were carried outwards by traverse from the initial station to the boundaries of the circuit, following the chief valleys suitable for settlement. Points on these traverses were called 'geodesic stations,' and were usually from 15 to 25 km apart, providing a series of reference points by which any survey within the meridional circuit could be oriented in terms of the meridian of the initial station. Any further control was merely local, being based upon a small triangulation net extending only over the region where is was immediately required, so that a large number of independent triangulations came to be distributed throughout the settled area of the Province. Each such triangulation was regarded as the control for an area around it called a 'survey district,' and each meridional circuit was eventually divided into many such districts, often irregular in shape: although the later additions tended to be bounded by lines parallel to and perpendicular to the meridian of the initial station. Local surveys could be coordinated with reference to the geodetic stations within a survey district."

The original datum for New Zealand was the Mt. Cook Datum of 1883, located in the city of Wellington.

Thompson eventually adopted the meridional circuit system for all of New Zealand in 1877 as modeled by his original system earlier used in Otago. A total of 28 Meridional Circuits were established: nine in the North Island and 19 in the South Island. Those Meridional Circuits with their original initial origins are: Mt. Eden/Mt. Eden, Bay of Plenty/Maketu, Poverty Bay/Patutahi, Taranaki/Huirangi, Tuhirangi/Thuirangi, Hawkes Bay/Hawkes Bay, Wanganui/Mt. Stewart, Wairarapa/Opaki, Wellington/Mt. Cook, Collingwood/Parapara, Nelson/Botanical Hill, Karamea/Karamea, Marlborough/Goulter Hill, Buller/Buller Initial, Grey/Grey Initial, Amuri/Isolated Hill, Hokitika/Hokitika Initial, Okarito/Abut Head, Mt. Pleasant/Mt. Pleasant, Gawler/Gawler Downs, Jacksons Bay/Mt. Eleanor, Timaru/Mt. Horrible, Lindis Peak/Lindis Peak Initial, Mt. Nicholas/Mt. Nicholas, Mt. York/Mt. York, Observation Point/Observation Point, North Taieri/North Taieri, and Bluff/Observation Spot. Computations on these meridional circuits were performed on the plane with the point of origin being the initial point. With the geodetic coordinates known for each initial point, the survey computations were equivalent to using the Polyhedric projection, which is the same as the Local Space Rectangular, commonly used in computational photogrammetry.

In 1901 a new secondary triangulation was started in order to bring all the different nets of triangles into harmony in the Wellington and Taranaki districts. The North Island geodetic triangulation of 1921-1938 started actual field observations in 1923 and continued until being suspended during the Great Depression of the early 1930s. It resumed in 1936. The South Island geodetic triangulation of 1938-1942 started with the observations across Cook Strait in a quadrilateral with one line measuring 120 km from Papatahi to Attempt Hill. Final fieldwork was observed from 1947-1949 including baseline-measuring equipment obtained on loan from Tanganyika (now Tanzania), which was used for three South Island bases. In 1948, 12 LaPlace stations were observed with time signals transmitted from Dominion Observatory especially for this purpose. When the computations were completed, the "New Zealand Geodetic Datum 1949" (NZGD49) was established where the initial station of origin was: Papatahi Trig Station Φ_o = 41º 19´ 08.9000″ S, Λ_o = 175º 02´ 51.0000″ E of Greenwich, azimuth to Kapiti No. 2 α_o = 347º 55´ 02.500″, and the ellipsoid of reference is the International 1924 where a = 6,378,388 m and $^1/_f$ = 297. Papatahi is a centrally situated station of the main net and one of the corner stations of the subsidiary net containing Kelburn. The values of deflection of the vertical for the north-south component at 65 latitude stations and deflection of the vertical for the east-west component at 39 azimuth stations from the first adjustment were known, and the latitude and azimuth at Papatahi were chosen so as to make the means of these differences equal to zero. The longitude adopted for Papatahi was that derived from Kelburn. The stations were coordinated on the National Grids, each island being on an independent Transverse Mercator projection, which had been selected by H.E. Walshe just before WWII. The New Zealand North Island Belt Latitude of Origin φ_o = 39° S, Central Meridian, λ_o = 175° 30´ E, Scale Factor at Origin, m_o = unity, False Northing = 400,000 yards, False Easting = 300,000 yards where 1 foot = 0.304799735. The New Zealand South Island Belt Latitude of Origin, φ_o = 44° S, Central Meridian, λ_o = 171° 30´ E, Scale Factor at Origin, m_o = unity, False Northing = 500,000 yards, False Easting = 500,000 yards. No further first-order work was contemplated for about 25 years, and in 1972-1974, some reobservation and extension was done with theodolites and Geodimeter Model 8 electronic distance meters.

When the metrication of surveys was begun in 1973, a one-projection coordinate system was adopted for topographic maps (the New Zealand Map Grid), but for cadastral surveying it was decided to retain the meridional circuit systems but the Polyhedric coordinates were replaced by Transverse Mercator coordinates referred to the old origins.

In August 1998, "Land Information New Zealand" (LINZ) approved the adoption and implementation of a new geocentric datum, New Zealand Geodetic Datum 2000 (NZGD2000). The new coordinates of points changed by approximately 200 meters relative to the old datum, NZGD49. A one-projection coordinate system was adopted for 1:50,000 scale and 1:250,000 scale topographic maps (the New Zealand Transverse Mercator 2000) that replaces the NZMG. The NZTM2000 Latitude of Origin, φ_o = 0°, Central Meridian, λ_o = 171° E, Scale Factor at Origin, m_o = 0.9996, False Northing = 10,000,000 meters, and False Easting = 1,600,000 meters. For cadastral surveys in terms of NZGD2000 the 28 new meridional circuits replace the existing circuits, which were in terms of NZGD49. The new circuits are referred to as "<name> Circuit 2000," to distinguish them from the old circuits. The origins of latitude and longitude of the NZGD2000 circuit projections are almost the same as their NZGD49 equivalents being rounded down to the nearest arc second. The central meridian scale factors at origin of the NZGD2000 circuit projections are the same as those of their NZGD49 equivalents. The false origin coordinates of NZGD2000 circuit projections are 100 km greater then their NZGD49 equivalents, being 800 km N and 400 km E. This is to reduce the risk of confusion between the NZGD2000 and NZGD49 projections. The NZGD2000 circuit projections are based on the GRS80 ellipsoid of revolution where a = 6,378,137 m and $^1/_f$ = 298.257222101. The SI standard for the meter has been adopted. The NZGD2000 circuit projections have a scale factor at origin of unity except for North Taieri 2000 (0.99996) and Mt. Eden 2000 (0.9999).

The Circuit Parameters are as follows: Mount Eden 2000 - φ_o = 36º 52´ 47″ S, λ_o = 174° 45´ 51″ E, m_o = 0.9999; Bay of Plenty 2000 - φ_o = 37º 45´ 40″ S, λ_o = 176° 27´ 58″ E, m_o = 1.0; Poverty Bay 2000 - φ_o = 38º 37´ 28″ S, λ_o = 177° 53´ 08″ E, m_o = 1.0; Hawkes Bay 2000 - φ_o = 39º 39´ 03″ S, λ_o = 176° 40´ 25″ E, m_o = 1.0; Taranaki 2000 – φ_o = 39º 08´ 08″ S, λ_o = 174° 13´ 40″ E, m_o = 1.0; Tuhirangi 2000 - φ_o = 39º 30´ 44″ S, λ_o = 175° 38´ 24″ E, m_o = 1.0; Wanganui 2000 - φ_o = 40º 14´ 31″ S, λ_o = 175° 29´ 17″ E, m_o = 1.0; Wairarapa 2000 - φ_o = 40º 55´ 31″ S, λ_o = 175° 38´ 50″ E, m_o = 1.0; Wellington 2000 - φ_o = 41º 18´ 04″ S, λ_o = 174° 46´ 35″ E, m_o = 1.0; Collingwood 2000 - φ_o = 40º 42´ 53″ S, λ_o = 172° 40´ 19″ E, m_o = 1.0; Nelson 2000 - φ_o = 41º 16´ 28″ S, λ_o = 173° 17´ 57″ E, m_o = 1.0; Karamea 2000 - φ_o = 41º 17´ 23″ S, λ_o = 172° 06´ 32″ E, m_o = 1.0; Buller 2000 - φ_o = 41º 48´ 38″ S, λ_o = 171° 34´ 52″ E, m_o = 1.0; Grey 2000 - φ_o = 42º 20´ 01″ S, λ_o = 171° 32´ 59″ E, m_o = 1.0; Amuri 2000 - φ_o = 42º 41´ 20″ S, λ_o = 173° 00´ 36″ E, m_o = 1.0; Marlborough 2000 - φ_o = 41º 32´ 40″ S, λ_o = 173° 48´ 07″ E, m_o = 1.0; Hokitika 2000 - φ_o = 42º 53´ 10″ S, λ_o = 170° 58´ 47″ E, m_o = 1.0; Okarito 2000 - φ_o = 43º 06´ 36″ S, λ_o = 170° 15´ 39″ E, m_o = 1.0; Jacksons Bay 2000 - φ_o = 43º 58´ 40″ S, λ_o = 168° 36´ 22″ E, m_o = 1.0; Mount Pleasant 2000 - φ_o = 43º 35´ 26″ S, λ_o = 172° 43´ 37″ E, m_o = 1.0; Gawler 2000 – φ_o = 43º 44´ 55″ S, λ_o = 171° 21´ 38″ E, m_o = 1.0; Timaru 2000 - φ_o = 44º 24´ 07″ S, λ_o = 171° 03´ 26″ E, m_o = 1.0; Lindis Peak 2000 - φ_o = 44º 44´ 06″ S, λ_o = 169° 28´ 03″ E, m_o = 1.0; Mount Nicholas 2000 - φ_o = 45º 07´ 58″ S,

$\lambda_o = 168° 23' 55''$ E, $m_o = 1.0$; Mount York 2000 - $\varphi_o = 45°$ $33' 49''$ S, $\lambda_o = 167° 44' 19''$ E, $m_o = 1.0$; Observation Point 2000 - $\varphi_o = 45° 48' 58''$ S, $\lambda_o = 170° 37' 42''$ E, $m_o = 1.0$; North Taieri 2000 - $\varphi_o = 45° 51' 41''$ S, $\lambda_o = 170° 16' 57''$ E, $m_o = 0.99996$; and Bluff 2000 - $\varphi_o = 46° 36' 00''$ S, $\lambda_o = 168°$ $20' 34''$ E, $m_o = 1.0$.

Thanks to Graeme Blick of LINZ for a copy of L.P. Lee's monograph on the history of geodetic triangulation in New Zealand and to Mal Jones of Perth Australia for his continuing generous help.

New Zealand Update

"The geodetic system has been and will continue to be upgraded and enhanced. Often this is in response to increased accuracy requirements, but it is also to meet the needs of an increasing range of users. Accurate positioning is increasingly carried out by non-surveyors, often in a fully automated manner. LINZ must therefore consider how the geodetic system can support the needs of applications such as Intelligent Transportation Systems (ITS), indoor positioning and precision agriculture.

"From a user perspective, a geodetic system would ideally provide the highest levels of absolute and relative accuracy without changing coordinates. In a country such as New Zealand, these requirements are mutually exclusive. At the same time, the exploding use of GNSS-enabled technology providing ITRF coordinates through techniques such as precise point positioning (PPP) requires that LINZ provide greater support for the global reference frame.

"To support these diverse user needs LINZ is considering how to implement a two-frame system whereby both national and global datums are actively supported, with well-defined transformations between them (Donnelly et al. 2015). This would effectively be a formalization of existing practice. Applications such as cadastral surveying might continue to use NZGD2000, but other applications could then work directly in ITRF." *From Static to Dynamic Datums: 150 years of Geodetic Datums in New Zealand*, G. Blick & N. Donnelly, 2016. https://www.tandfonline.com/doi/full/10.1080/00288306.2015.1128451.

The contents of this column reflect the views of the author, who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the American Society for Photogrammetry and Remote Sensing and/or the Louisiana State University Center for GeoInformatics (C^4G).

This column was previously published in *PE&RS*.

Book Review

continued from page 760

prose to illustrate technical principles. For example, he makes an analogy to Clapton's "Layla and other Love Songs" to demonstrate a point. He often takes into consideration the reader's perspective to help make technical concepts understandable to the new students. The viewer finds blue insert boxes at chapter endings throughout the book which are very interesting, informational, and fun to read. The author provides more information in those insert boxes to support the points of view presented in each chapter.

The book cover is well designed, the font size of the book makes for easy reading. The illustrations are well placed to keep the subject matter relevant to the chapter content. The print quality of the book is good for the most part, but some minor improvement might be possible. Some of the SAR images in the book could be better colorized and larger size of some image could better convey the author's messages. If used as a text book, the instructor of the course would have to invest his/her time to develop questions for homework for students since no homework exercises are provided in the book. Nevertheless, the book is highly recommended for the student of SAR technology or for the remote sensing professional who wants to enhance his/her knowledge of SAR.

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Innovative Methods for Geospatial Data using Remote Sensing and GIS

Internationally comparable data is a global need for managing resources, monitoring current trends and taking actions for sustainable living. Even though there has been a significant progress on geospatial data availability, extensive data gaps are still a major problem for general assessment and supervise the progress through the years. According to United Nations 2022 The Sustainable Development Goals Report, while health and energy sectors have the highest data available, limited data available for climate action.

The COVID-19 crisis has also shown that there are innovative data collection methods utilizing information and computer technologies. However, only 5% of the countries have benefit from remote sensing technologies to measure the impact of COVID-19. Additionally, novel approaches such as artificial intelligence should be used in conjunction with assessments to make sure they are put to use for critical situations.

The recent developments in remote sensing, geographic information systems and ICT have provided a wide accessibility to create geospatial data for various purposes. The proposed special issue focuses on *"Innovative Methods for Geospatial Data using Remote Sensing and GIS" for wide range of applications. This special issue aims to bring researchers to share knowledge and their expertise about innovative methods to contribute to fill data gaps around the world for a better future.*

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Automatic Registration Method of Multi-Source Point Clouds Based on Building Facades Matching in Urban Scenes

Yumin Tan, Yanzhe Shi, Yunxin Li, and Bo Xu

Abstract

Both UAV photogrammetry and lidar have become common in deriving three-dimensional models of urban scenes, and each has its own advantages and disadvantages. However, the fusion of these multi-source data is still challenging, in which registration is one of the most important stages. In this paper, we propose a method of coarse point cloud registration which consists of two steps. The first step is to extract urban building facades in both an oblique photogrammetric point cloud and a lidar point cloud. The second step is to align the two point clouds using the extracted building facades. Object Vicinity Distribution Feature (Dijkman and Van Den Heuvel 2002) is introduced to describe the distribution of building facades and register the two heterologous point clouds. This method provides a good initial state for later refined registration process and is translation, rotation, and scale invariant. Experiment results show that the accuracy of this proposed automatic registration method is equivalent to the accuracy of manual registration with control points.

Introduction

Point cloud registration is to calculate the rigid transformation relationship between two sets of point cloud data, align the two sets of point cloud data, and construct a complete model. In many instances, there is a need to align point cloud data collected at different times from different platforms. For example, using well-registered lidar point clouds and optical images at the same time can easily improve measurement and interpretation accuracy(Campos-Taberner *et al.* 2016; Kwak *et al.* 2006).

There are two main stages for pairwise three-dimensional (3D) point cloud registration: (i) the coarse alignment and (ii) the refined alignment. The Iterative Closest Point (ICP) algorithm is currently the most widely used registration method. The algorithm can well register two point clouds together after multiple iterations (Besl and McKay 1992; Chen and Medioni 1992; Rusinkiewicz and Levoy 2001). For over two decades, many variants of the ICP algorithm have been developed. Gruen and Akca (2005) proposed an alternative to ICP referred to as "Least Squares 3D Surface Matching". This method gives the opportunity of matching arbitrarily oriented 3D surface patches and fully considers 3D geometry. Bae and Lichti (2008) developed the "Geometric Primitive ICP" method which uses normal vector information together with change in surface curvature for point cloud matching. It improved the precision of the estimated relative transformation parameters by as much as a factor of 5, which provides a window of opportunity to use this automated registration method in practical applications such as terrestrial surveying and deformation monitoring. Bouaziz *et al.* (2013) introduced "Sparse ICP" which is less sensitive to outliers than the classical ICP.

All these methods give meaningful results only if the pair of point clouds have already been coarsely co-registered. More importantly, the performance of these refined alignment methods depends on the quality of the coarse co-registration. Therefore, the coarse point cloud co-registration is a critical step to the final registration results. In this paper, we focus on addressing the initial coarse point cloud co-registration problem. We propose a method that uses specific objects, which can be segmented in the scene, to determine the transformation parameters. Specifically, in the urban scene, this object is determined to be the facade of buildings. By comparing the distribution of surrounding facades, we identify the corresponding facades in the matching, and calculate the similarity transformation matrix of the two point clouds. This method provides a good initial state for later refined registration process and is translation, rotation, and scale invariant.

Related Work

Automated Coarse Point Cloud Registration

Cross-source point cloud registration is very challenging because of the density difference, scale difference, partial overlap, and combination of considerable noise between point clouds. The existing 3D point cloud registration methods can be divided into two categories: (i) descriptor-based methods and (ii) non–descriptor-based methods. The main difference between the two methods is whether they rely on key point based descriptors to represent features.

Descriptor-Based Methods

Many traditional point cloud registration methods rely on the extraction of salient key points. Descriptors are formed by using various types of local neighborhood shape attributes of the point cloud. Similar descriptors on source and target point clouds can then be matched to find corresponding key points. Various three-dimensional point cloud descriptors have been developed, including Fast Point Feature Histograms (Rusu *et al.* 2009), Signature of Histograms of Orientations (Salti *et al.* 2014). When the source and target point clouds have a scale difference, these descriptors will fail during the feature matching process.

To overcome the difference of scale, some descriptors use local scale to define the local region used for descriptor generation. For example, the Scale Invariant Feature Transform (Lowe 2004) detector uses a "Difference of Gaussian" framework for estimating the local

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The Simulation and Prediction of Land Surface Temperature Based on SCP and CA-ANN Models Using Remote Sensing Data: A Case Study of Lahore

Muhammad Nasar Ahmad, Shao Zhengfeng, Andaleeb Yaseen, Muhammad Nabeel Khalid, and Akib Javed

Abstract

Over the last two decades, urban growth has become a major issue in Lahore, accelerating land surface temperature (LST) rise. The present study focused on estimating the current situation and simulating the future LST patterns in Lahore using remote sensing data and machine learning models. The semi-automated classification model was applied for the estimation of LST from 2000 to 2020. Then, the cellular automata-artificial neural networks (CA-ANN) module was implemented to predict future LST patterns for 2030 and 2040, respectively. Our research findings revealed that an average of 2.8 °C of land surface temperature has increased, with a mean LST value from 37.25 °C to 40.10 °C in Lahore during the last two decades from 2000 to 2020. Moreover, keeping CA-ANN simulations for land surface temperature, an increase of 2.2 °C is projected through 2040, and mean LST values will be increased from 40.1 °C to 42.31 °C by 2040. The CA-ANN model was validated for future LST simulation with an overall Kappa value of 0.82 and 86.2% of correctness for the years 2030 and 2040 using modules for land-use change evaluation. The study also indicates that land surface temperature is an important factor in environmental changes. Therefore, it is suggested that future urban planning should focus on urban rooftop plantations and vegetation conservation to minimize land surface temperature increases in Lahore.

Introduction

The land surface temperature has increased globally as a result of increasing urbanization and substantial land-use change. Land surface temperature (LST) is accelerated due to both natural and artificial events and overstresses our environmental system (Girma *et al.* 2022; Zhu *et al.* 2022). Due to rapid urbanization and infrastructure development, most of the vegetation and farmland have been converted into urban centers, escalating the land surface temperature (Naikoo *et al.* 2022; Zhou *et al.* 2021). According to El-Hattab *et al.* (2018) as a result of the expansion of metropolitan regions, LST will increase and more greenery will be converted into man-made infrastructure in the future.

The LST patterns give useful information about the environment and help in understanding climate change (Cai *et al.*, 2018; Sadiq Khan *et al.* 2020). The land surface temperature has an impact on the oceans, weather patterns, plants, and animals that cause ecological uncertainties (Nath *et al.* 2021). But an increase in land surface temperature, especially in urban centers, has a more severe effect on humans and our ecosystem. An increase in LST causes more droughts, melting glaciers, rising sea levels, and changes in snow patterns. Over the previous few decades, megacities have become urban heat islands (UHI) rapidly because of commercial activities, deforestation, and greenhouse gas emission (Rehman *et al.* 2021).

The importance of land surface temperature is rapidly being recognized, and there is growing interest in developing approaches for retrieving LST from satellite remote sensing data. Remote sensing data and GIS technology have provided a wide range of computational modelling for researchers to perform LST development research. Remote sensing technology advancements combined with machine learning and artificial intelligence technologies (Abbas *et al.* 2021; Hamedianfar *et al.* 2020; Talukdar *et al.* 2020) provided prompt and valuable results. Researchers have used a wide range of prediction models (Ghalehteimouri *et al.* 2022; Zhang *et al.* 2022) to predict future LST; for example, Markov Chain, Artificial Neural Network (ANN), cellular automata (CA), and FBprophet. However, CA is a popular and widely used artificial intelligence model and was found to be more reliable in simulating future LST patterns (Al-Darwish *et al.* 2018; Guidigan *et al.* 2019). The cellular automata model works by automatically computing cells based on transitional rules, and algorithmic equations to simulate complex systems such as LST change dynamics in cities (Khan *et al.* 2022; Shafizadeh-Moghadam *et al.* 2021; Zhang and Wang 2021).

This study implemented semi-automatic classification (SCP) and ANN algorithm-based CA models in Quantum Geographic Information System (QGIS) to estimate and predict the LST in the study area. Lahore's surface temperature has risen significantly in recent years (Imran and Mehmood 2020; Mumtaz *et al.* 2020) which has resulted in major environmental issues. As Lahore is Pakistan's fast-rising economic capital, it is confronted with various environmental and socioeconomic complications (Anjum *et al.* 2021). Many studies have been undertaken in the past by researchers for better environmental planning and development (Hussain and Nadeem 2021) in Lahore.

Lahore has significant vegetation loss as a result of urbanization and population growth, resulting in environmental deterioration and a regional rise in temperature. Although the city faces many challenges, including a lack of urban development policies, an increasing population, and rising LST. This study aims to estimate current LST for the years 2000, 2010, and 2020, as well as to model LST trends for the years 2030 and 2040, respectively. This research work has two main goals: (i) assessment of land surface temperature and future projections and (ii) implementation of SCP and CA-ANN models to evaluate LST patterns. This study is noteworthy since no one has before implemented the SCP-machine learning and modules for land-use change evaluation (MOLUSCE) models to predict the land surface temperature in Lahore.

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Permanganate Index Variations and Factors in Hongze Lake from Landsat-8 Images Based on Machine Learning

Yan Lv, Hongwei Guo, Shuanggen Jin, Lu Wang, Haiyi Bian, and Haijian Liu

Abstract

The permanganate index (COD_{Mn}), defined as a comprehensive index to measure the degree of surface water pollution by organic matter and reducing inorganic matter, plays an important role in indicating water pollution and evaluating aquatic ecological health. However, remote sensing monitoring of water quality is presently focused mainly on phytoplankton, suspended particulate matter, and yellow substance, while there is still great uncertainty in the retrieval of COD_{Mn}. In this study, the Landsat-8 surface reflectance data set from Google Earth Engine and in situ COD_{Mn} measurements were matched. The support vector regression (SVR) machine learning model was calibrated using the matchups. With the SVR model, this study estimates the COD_{Mn} in Hongze Lake, presents the historical spatiotemporal COD_{Mn} distributions, and discusses the affecting factors of the change trend of the COD_{Mn} in Hongze Lake. The results showed that the SVR model adequately estimated COD_{Mn}, with a sum squared error of 1.49 mg^2/L^2, a coefficient of determination (R^2) of 0.95, and a root mean square error of 0.15 mg/L. CODMn in Hongze Lake was high in general and showed a decreasing trend in the past decade. Huai River, Xinsu River, and Huaihongxin River were still the main sources of oxygen-consuming pollutants in Hongze Lake. The wetland natural reserve near Yugou had a significant effect on reducing COD_{Mn}. This study provides not only a scientific reference for the management of COD_{Mn} in Hongze Lake, but also a feasible scheme for remote sensing monitoring of COD_{Mn} in inland water.

Introduction

With global warming and the intensification human activities, eutrophication has become a worldwide environmental problem. The deterioration of water quality seriously damages the stability of aquatic ecosystem and threatens the safety of domestic and production water. On the global scale, water quality monitoring of rivers and lakes is usually operated by measuring water temperature, pH, dissolved oxygen, chemical oxygen demand (COD_{Mn}), biochemical oxygen demand, ammonia nitrogen, volatile phenol, cyanide, arsenic, copper, lead, zinc, cadmium, mercury, hexavalent chromium, total nitrogen (TN), total phosphorus (TP), fluoride, transparency, chlorophyll a (Chl *a*), and other indicators on-site for water quality evaluation and management (Liu 1985).

At present, the water quality indicators in China are generally determined by sampling on sites in accordance with the national environmental protection standards (GB 3838-2002; Ministry of Ecology and Environment of the People's Republic of China, 2002). COD_{Mn} effectively indicates the pollution of oxidizable substances in water, and the accurate detection of its spatial distribution is of great significance for aquaculture, aquatic environmental health, and ecological early warning. Therefore, COD_{Mn} is an important indicator for water quality (Li *et al.* 2017). Shang *et al.* (2016) studied the temporal and spatial variation of water environmental factors and found that the main environmental influencing factor of benthic functional feeding groups was total nitrogen in spring and summer, and COD_{Mn} was the main environmental influencing factor in autumn. At the same time, COD_{Mn} was also the main environmental factor of temporal and spatial variation of zooplankton (Shang *et al.* 2016; Shang *et al.* 2021). Rao (2015) measured and obtained high-precision and highly sensitive COD_{Mn} in surface water based on spectrophotometry. A comparative study was conducted on the COD_{Mn} load in the Three Gorges Reservoir area of the Yangtze River between the wet and dry seasons (Huang *et al.* 2021) using in situ measurements. The higher the COD_{Mn} was, the more serious the pollution by organic matter and oxidizable inorganic matter was in water, found by mapping the COD_{Mn} distribution in the Tokyo Bay (Kawabe and Kawabe 1997). Jun *et al.* (2017) found that the main pollution factors in the Hailar River were COD_{Mn} and COD by studying the water quality of the river. All the above studies adopted traditional water quality monitoring methods, namely, field water sample collection and laboratory water quality parameters measurement. Such methods are time consuming and laborious. Meanwhile, these methods are difficult for large-scale water quality monitoring due to the limitation of manpower, material resources, weather, and hydrological conditions.

With the development of remote sensing technology, it is possible to realize water quality monitoring at a large-scale using satellite remote sensing. Compared with the traditional methods, remote sensing provides large-scale, quick-access, and dynamic water quality monitoring. Although the Landsat series of satellites were originally designed for land monitoring, their high spatial resolution (30 m) provides a unique opportunity for monitoring inland water environments with strong spatial heterogeneity and thus have become one of the mostly widely used multi-spectral remote sensing data sources for inland water quality monitoring. Tan *et al.* (2015) constructed empirical models of Chl *a* and

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Exploring Spatiotemporal Variations and Driving Factors of Urban Comprehensive Carrying Capacity in the Yangtze River Delta Urban Agglomeration

Songjing Guo, Xueling Wu, Ruiqing Niu, and Wenfu Wu

Abstract

The Yangtze River Delta urban agglomeration (YRDUA) is one of the most active economic development regions in China. However, the YRDUA is facing the severe test of sustainable development. Therefore, this study evaluates the urban comprehensive carrying capacity (UCCC) of cities in the YRDUA from 2009 to 2019 from natural, social, and economic perspectives, and uses the Geographically and Temporally Weighted Regression model to analyze driving factors of spatiotemporal variations of the UCCC. Besides, this study divides the UCCC into three levels: high, medium, and low. The results indicate that: 1) there is a significant spatial heterogeneity of the UCCC in the YRDUA; 2) the UCCC in the YRDUA is generally at medium level and presents a gradually increasing trend; 3) 10 driving factors significantly affect the UCCC, and the influence intensity is non-stationary in time and space. These findings can provide references for improving the UCCC in the YRDUA.

Introduction

With the rapid development of economy, the population is rapidly aggregating from rural to urban areas, and 68% of people are expected to live in cities by 2050. During the process of rapid urbanization, land covers have changed significantly (Tran 2016; Beck 1992), bringing a series of ecological and environmental problems, such as natural disasters (Allouhi *et al.* 2015), air pollution (Zhang *et al.* 2019), ecological degradation, and resource shortage (Chen *et al.* 2017). Cities are facing the threat of unhealthy development, and the urban carrying capacity is gradually overloaded (Yang and Li 2011). Scholars have been committed to find a sustainable development way that takes into account eco-environmental protection, economic development, and social progress (Tian *et al.* 2021). And comprehensive evaluation of urban carrying capacity is an important link to achieve sustainable urban development.

Up to now, there is no unified concept of the sustainable development (Walz 2000); most views believe that sustainable development should be committed to the coordinated development between human social activities and the ecosystem (Li *et al.* 2011). Under such a background, the concept of ecological carrying capacity was proposed (Fan 2009; Wang *et al.* 2018), which is an objective reflection of the natural system's regulation capacity (Zhang *et al.* 2018). Besides, ecological carrying capacity also reflects the degree of human activities to the use of resources and damage to the ecological environment. With the acceleration of urbanization, urban population expansion, resource and environmental constraints, and serious traffic congestion are becoming increasingly prominent. Many scholars began to study urban adaptation from the urban comprehensive carrying capacity (UCCC) (Zhou *et al.* 2018). The concept of UCCC provides a specific evaluation method and measurable index for the urban sustainable development capacity, and also provides guidance for urban managers to better deploy urban resources (Liu *et al.* 2020; Pandit *et al.* 2017; Wang *et al.* 2019).

Urban agglomeration is a high-level urbanization development pattern. In China, urban agglomerations concentrate 45% of urban population, 50% of Gross Domestic Product (GDP), and 60% of foreign capital (Fang 2015). With the continuous aggregation of urban space, urban diseases such as the depletion of natural resources, ecosystem degradation, and environmental pollution are also highly concentrated in the urban agglomeration (Heikkila and Xu 2013). The Yangtze River Delta Urban Agglomeration (YRDUA) is a typical representative of Chinese urban agglomeration. Although it occupies only 2.1% of China's national area, it accounts for 20% of the GDP and is considered an important engine of China's economic development. At present, the YRDUA is facing the severe test of sustainable development. Therefore, it is of great significance to evaluate the UCCC in the YRDUA and explore the spatiotemporal variations and driving factors of UCCC for the sustainable development of the YRDUA.

Previous carrying capacity studies followed the rule of minimum limiting factors, emphasizing that a single factor has a decisive impact on UCCC, and analyzed from a single key factor such as land cover, population, and transportation (Edmonds 2005). For example, Zhang *et al.* (2019) used the principal component analysis method to analyze the water resources carrying capacity of Huhhot and found that there were great differences in the water resources use capacity of various districts (Liu *et al.* 2019). And Guo and Liu (2011) studied the land carrying capacity of 11 cities in Hebei Province and found that land carrying capacity is positively correlated with the land economy. Besides, Shan and Wang selected three indicators including climate natural capacity, urban climate pressure, and urban coordinated development capacity were selected to evaluate the climate carrying capacity, indicating that improving energy efficiency and reducing undesirable outputs of power were the main ways to improve regional climate carrying capacity (Shan and Wang 2021).

Different regions have different ecological conditions and development patterns. The impact of the same factor on UCCC varies from region to region. In addition, UCCC is affected by various dynamic factors, such as human activities, energy consumption, and climate change, especially in rapidly developing regions like the YRDUA. In the analysis of the driving factors in UCCC, the characteristics of factors including the temporal dynamics, spatiotemporal coupling, and spatial interactions should be taken into account. The least square and

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WHO'S WHO IN ASPRS

Founded in 1934, the American Society for Photogrammetry and Remote Sensing (ASPRS) is a scientific association serving thousands of professional members around the world. Our mission is to advance knowledge and improve understanding of mapping sciences to promote the responsible applications of photogrammetry, remote sensing, geographic information systems (GIS) and supporting technologies.

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Member Since: 11/2004

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www.sanborn.com
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*quantity depends on membership level

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Cover 4	$1,850	$2,000	$2,350	$2,500
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Full Page	$1,000	$1,175	$2,000	$2,350
2 page spread	$1,500	$1,800	$3,200	$3,600
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1/3 Page	$800	$800	$1,000	$1,000
1/4 Page	$600	$600	$750	$750
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1/8 Page	$200	$200	$250	$250
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Dedicated Content Email blast	$3000	$3000	$3000	$3000
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PE&RS Digital Edition Announcement E-Mail	$1000	$1000	$1000	$1000

A 15% commission is allowed to recognized advertising agencies

Ad Size	Width	Height
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Full Page (bleed)	8.625"	11.25"
Full Page (trim)	8.375"	10.875"
2/3 Page Horizontal	7.125"	6.25"
2/3 Page Vertical	4.58"	9.625"
1/2 Page Horizontal	7.125"	4.6875"
1/2 Page Vertical	3.4375"	9.625"
1/3 Page Horizontal	7.125"	3.125"
1/3 Page Vertical	2.29"	9.625"
1/4 Page Horizontal	7.125"	2.34"
1/4 Page Vertical	3.4375"	4.6875"
1/8 Page Horizontal	7.125"	1.17"
1/8 Page Vertical	1.71875"	4.6875"

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A detailed article to enhance your cover image is welcome but not a condition of placing an image. Many readers have asked for more information about the covers and your article is a highly visible way to tell your story in more depth for an audience keenly interested in your products and services. No article is guaranteed publication, as it must pass ASPRS editorial review. For more information, contact Rae Kelley at rkelley@asprs.org.

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Cover 1	$1,850	$2,000	$2,350	$2,500

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VENDOR SEMINARS

ASPRS Sustaining Members now have the opportunity to hold a 1-hour informational session as a Virtual Vendor Seminar that will be free to all ASPRS Members wishing to attend. There will be one opportunity per month to reach out to all ASPRS Members with a demonstration of a new product, service, or other information. ASPRS will promote the Seminar through a blast email to all members, a notice on the ASPRS web site home page, and ads in the print and digital editions of *PE&RS*.

The Virtual Seminar will be hosted by ASPRS through its Zoom capability and has the capacity to accommodate 500 attendees.

Vendor Seminars	
Fee	$2,500 (no discounts)

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When you need to fill a position right away, use this direct, right-to-the-desktop approach to announce your employment opportunity. The employment opportunity will be sent once to all ASPRS members in our regular Wednesday email newsletter to members, and will be posted on the ASPRS Web site for one month. This type of advertising gets results when you provide a web link with your text.

Employment Opportunity	Net Rate
30-Day Web + 1 email	$500/opportunity
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Newsletter vertical banner ad	Net Rate
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Materials	Net Rate
Advertiser supplies HTML, including images.	$3000/ opportunity

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Become a sponsor today!

The e-mail blast sponsorship opportunity includes a **180 x 240 pixel ad** in the email announcement that goes out to our membership announcing the availability of the electronic issue.

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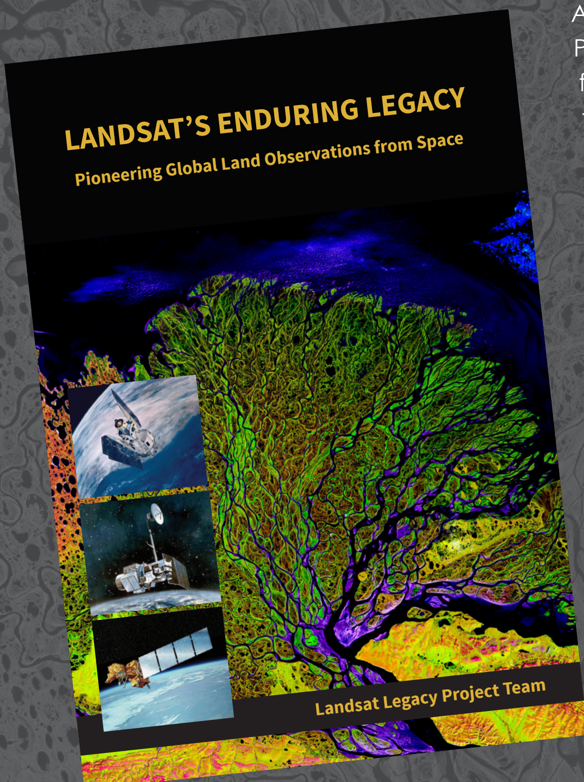

After more than 15 years of research and writing, the Landsat Legacy Project Team published, in collaboration with the American Society for Photogrammetry and Remote Sensing (ASPRS), a seminal work on the nearly half-century of monitoring the Earth's lands with Landsat. Born of technologies that evolved from the Second World War, Landsat not only pioneered global land monitoring but in the process drove innovation in digital imaging technologies and encouraged development of global imagery archives. Access to this imagery led to early breakthroughs in natural resources assessments, particularly for agriculture, forestry, and geology. The technical Landsat remote sensing revolution was not simple or straightforward. Early conflicts between civilian and defense satellite remote sensing users gave way to disagreements over whether the Landsat system should be a public service or a private enterprise. The failed attempts to privatize Landsat nearly led to its demise. Only the combined engagement of civilian and defense organizations ultimately saved this pioneer satellite land monitoring program. With the emergence of 21st century Earth system science research, the full value of the Landsat concept and its continuous 45-year global archive has been recognized and embraced. Discussion of Landsat's future continues but its heritage will not be forgotten.

The pioneering satellite system's vital history is captured in this notable volume on Landsat's Enduring Legacy.

Landsat Legacy Project Team

Samuel N. Goward
Darrel L. Williams
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Laura E. P. Rocchio
James R. Irons
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