CHAPTER 2

Photogrammetry and Remote Sensing

2-1. Introduction. This chapter provides an introduction to aerial and satellite photogrammetry and other metric remote sensing technologies, including Light Detection and Ranging (LiDAR) and Interferometric Synthetic Aperture Radar (IFSAR), which the U.S. Army Corps of Engineers might use for mapping of geospatial information. This chapter primarily serves to compare the products from various technologies and to summarize their respective advantages and disadvantages. Chapter 4 provides detailed explanations of aerial photogrammetry; Chapter 5 provides detailed explanations of satellite photogrammetry; Chapter 6 provides detailed explanations of aerial topographic LiDAR, and Chapter 7 provides detailed explanations of aerial bathymetric LiDAR.

2-2. Aerial Photogrammetry. For most of the past century, aerial photogrammetry has been relied upon for stereo-compilation of 2D planimetric maps and 3D topographic maps including contours. Since the early 1990s, digital orthophotos have become the most popular product of aerial photogrammetry.

a. Photogrammetric Products. The most common products from aerial photogrammetry include digital orthophotos (Figure 2-1), digital planimetric maps (Figure 2-2), digital topographic maps (Figure 2-3), digital orthophotomaps (Figure 2-4), or printed topographic maps (Figure 2-5), or variations of any of these products. All of these photogrammetric products require completion of Aerial Triangulation (AT) explained in Chapter 4 which also includes the detailed workflow for aerial photogrammetric mapping tasks.

b. Advantages of Aerial Photogrammetry. Advantages of aerial photogrammetry include the following:

(1) Calibrated metric cameras are used in order to achieve extremely high spatial accuracy. The precise focal length, principal point coordinates, and various forms of lens distortion are carefully calibrated so that systematic distortions can be corrected/eliminated. All components of a metric camera system must be stable and consistent for extremely accurate repeatability.

(2) Panchromatic, natural color or color infrared aerial photographs can be acquired from metric film cameras, or multispectral digital imagery can be acquired from digital metric cameras. Such aerial imagery allows users to realistically see the landscape from above and to resolve disputes that might occur from other technologies.

Figure 2-1. Digital orthophoto, showing visible features even in dark shadows.

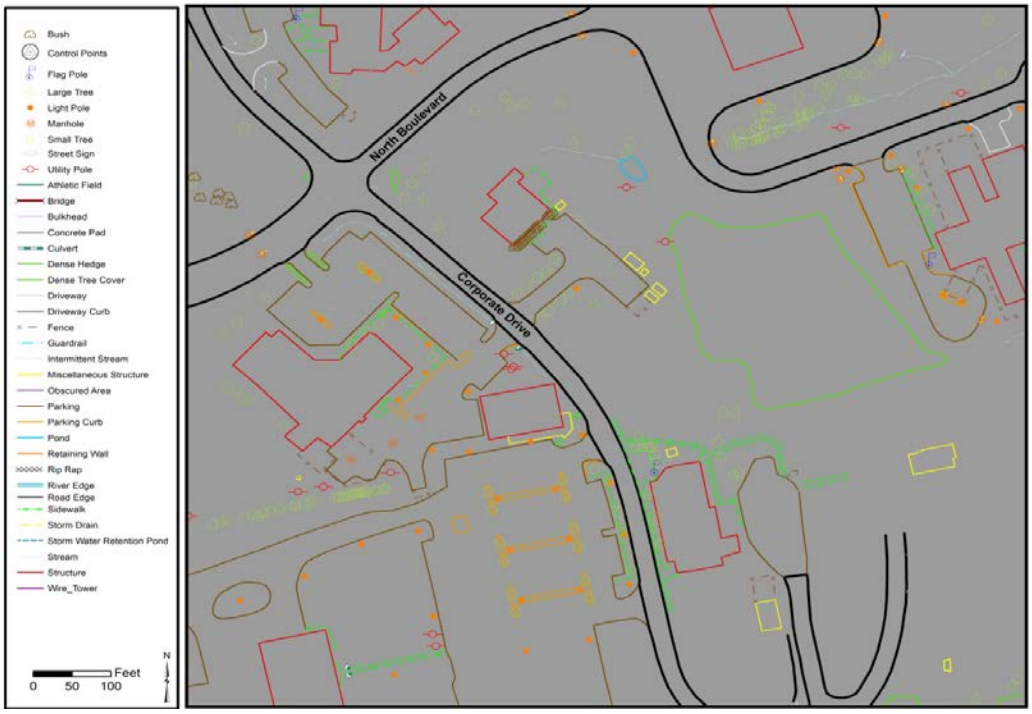

Figure 2-2. Planimetric map, showing selected features without elevation data.

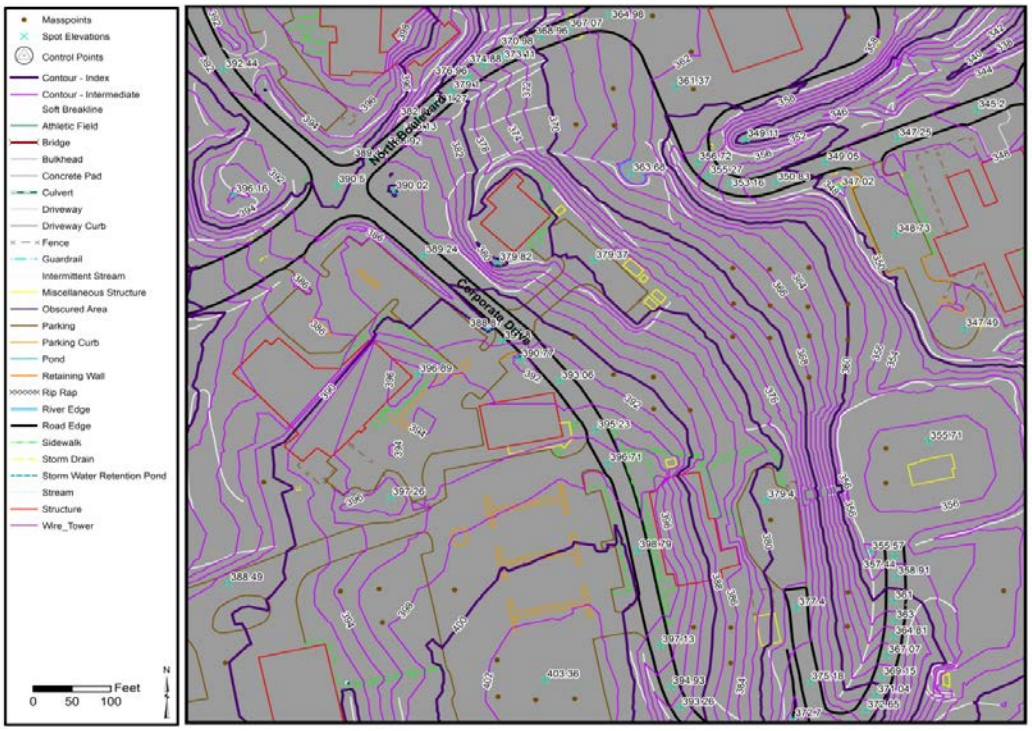

Figure 2-3. Topographic map, showing planimetric features plus topographic contours and spot heights.

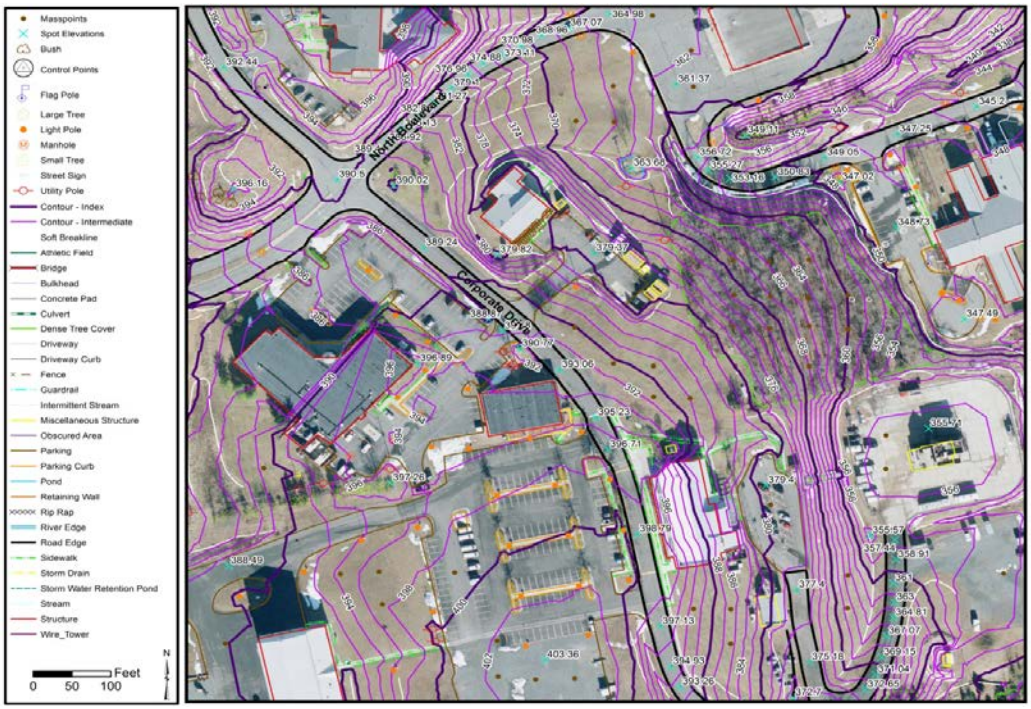

Figure 2-4. Topographic map with orthophoto base map.

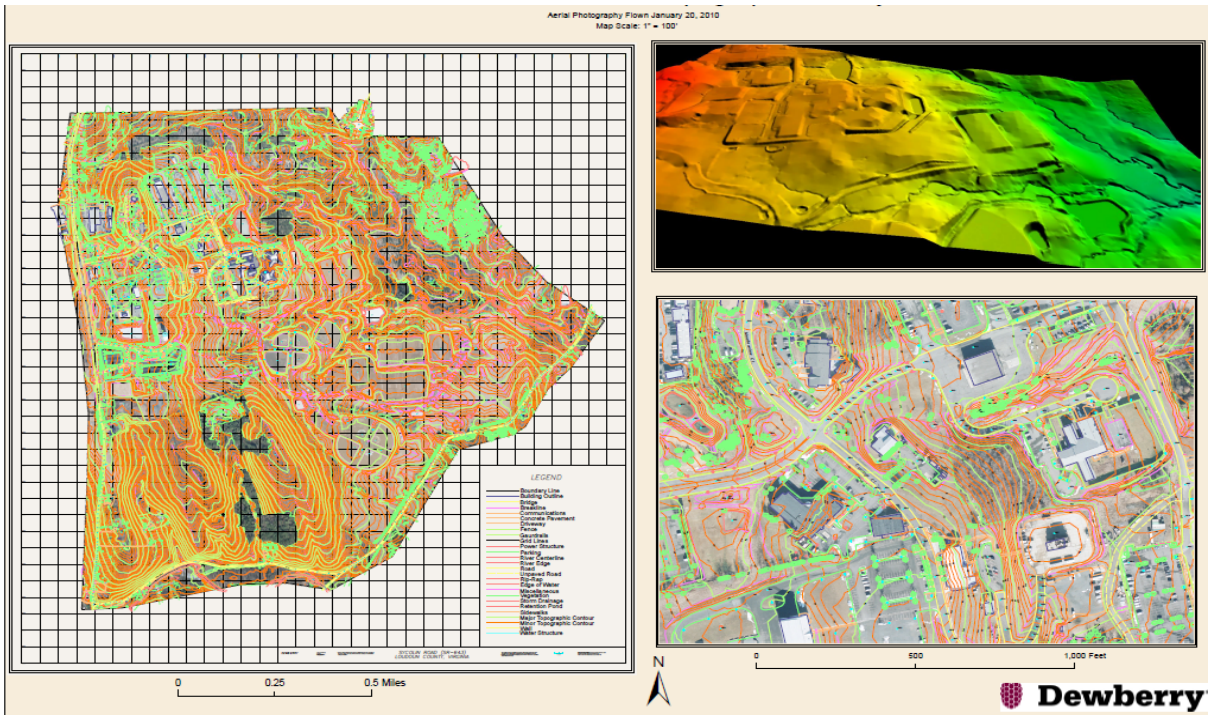

Figure 2-5. Printed topographic map of larger area (left), including map scale. The hillshade map (upper right) shows the 3D topographic surface only. The topographic map (lower right) is similar to Figure 2-4 but with different colors and highlights.

(3) Stereo imagery can be acquired with the least expensive single-engine aircraft or even unmanned aerial systems (UAS) when approved for use by the Federal Aviation Administration (FAA).

(4) Aerial triangulation (AT) is so mature that photogrammetrists can reliably predict the accuracy of their products from AT results, normally without independent accuracy testing, enabling the metadata to use the "Compiled to meet …" accuracy statements from the National Standard for Spatial Data Accuracy (NSSDA).

(5) The same imagery can be used for multiple applications, i.e., digital orthophotos, planimetric and/or topographic maps.

(6) With stereo imagery having at least 60% forward overlap, automated image correlation can be used for development of Digital Surface Models (DSMs).

(7) Modern high-resolution digital mapping cameras can capture imagery with ground sample distance (GSD) as small as a few centimeters.

(8) Advanced 12-bits per pixel digital data capture provides much higher radiometric resolution (4,096 levels of grayscale vs. 256 levels in standard 8-bit imagery) providing a wider tonal range and provides better visual detail, especially at the extremes of highlight and shadow. Digital imagery is now often collected between sunrise and sunset rather than during only a few hours near mid-day as with film.

(9) The same AT solution can and should be used for production of digital orthophotos, planimetric and topographic maps from the same imagery, insuring that all products will be accurately geo-registered and fit together seamlessly.

(10) Imagery can always be used to correct errors of commission or omission at a later time.

(11) Steps such as editing and finishing can always rely upon a stereo model to resolve discrepancies and correct errors to the highest accuracy the system provides.

(12) For special applications, hyperspectral imagery and oblique imagery can both be processed photogrammetrically to accurately map an area of interest from different spectral frequencies or different viewing perspectives.

c. Disadvantages of Aerial Photogrammetry. Disadvantages of aerial photogrammetry include the following:

(1) Aerial imagery cannot be acquired through clouds, haze, fog or smoke. “No-fly” zones, safety or logistical issues may limit aerial access.

(2) Aerial imagery, especially film imagery, can also be limited by dark shadows. To minimize such shadows, film imaging is typically limited to 4-6 hours each day when the sun angle is 30 degrees or greater above the horizon.

(3) Production of digital elevation models (DEMs) or contours are severely hampered by dense vegetation when the photogrammetrist cannot see the bare-earth terrain in stereo from two different perspectives. Because of this, contour lines through forests are either mapped as dashed lines or not shown at all. Leaf-off image acquisition does not always solve this challenge, though this problem is reduced in deciduous forests with leaf-off imagery typically acquired between December and March in the northern hemisphere.

(4) Except for the so called more-expensive “true orthophotos” that do not show the sides of buildings, most digital orthophotos have some amount of “building lean” where the sides of buildings are visible. This also causes “building footprints” compiled from stereo images to not exactly fit the underlying orthophoto which slightly displaces the image of building rooflines. Imagery acquired from higher altitudes with a camera lens with a longer focal length helps to reduce, but not eliminate, “building lean.”

d. Aerial Photogrammetry References. In addition to Chapter 4, additional references include:

(1) American Society for Photogrammetry and Remote Sensing. 2013. "Manual of Photogrammetry," 6th ed., J. Chris McGlone, ed., Bethesda, MD.

(2) American Society for Photogrammetry and Remote Sensing. 2007. "Digital Elevation Model Technologies and Applications: The DEM Users Manual," 2nd ed., David F. Maune, ed., Bethesda, MD.

(3) Wolf and Dewitt, "Elements of Photogrammetry with Applications in GIS," 3rd ed, McGraw Hill, 2000.

2-3. Satellite Photogrammetry. Satellite photogrammetry products include large coverage orthophotos and orthomosaics; stereo products that can be used to create elevation models; and other digital products such as planimetric maps, parcel maps, land cover maps, and bathymetric charts (in clear water), etc. are routinely produced from satellite images. Satellite photogrammetry has truly emerged since the launch of the high resolution Ikonos-2 satellite in 1999. Figure 2-6 shows an example with ½-meter pixel resolution. Chapter 5 shows other high resolution imaging satellites (e.g., WV-3 with 30-cm resolution) that have been subsequently launched and provides expanded details on satellite photogrammetry.

Figure 2-6. WorldView2 image (1/2-meter pixel resolution) of the Olympic Stadium, Sydney, Australia, acquired on 10/20/2009, shortly after the satellite was launched.

a. Advantages of Satellite Photogrammetry. Costs, global coverage, timeliness and frequent revisits are major advantages. Policies (e.g., no-fly zones) and logistical problems on land do not hinder satellite image acquisition. Stable satellite systems can be used to create accurate digital orthophotos, up to 1:2,000 to 1:5000 scale, per Figure 2-6, with good elevation models and control. When a natural or manmade disaster occurs, satellites are normally the first on the scene to capture post-event imagery which can be quickly paired with pre-event imagery for before/after image comparisons, as shown in Figure 2-7. As explained in Chapter 5, stereo imagery can also be collected with multiple convergence angles allowing the creation of elevation models that can be used to create 2-meter contours. Figure 2-8 shows an example of a Digital Surface Model (DSM) produced from satellite stereo imagery. Satellite imagery has also been used to develop 3D models by taking advantage of different viewing geometries of the same area in multiple orbits.

Figure 2-7. Satellite images before (left) and after (right) the Moore, OK tornado on May 20, 2013. The swipe tool is used to compare before/after views of the tornado. Source: Esri, Digital Globe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, Swisstopo and the GIS User Community | Bearing Tree Land Surveying (http://www.btls.us/)

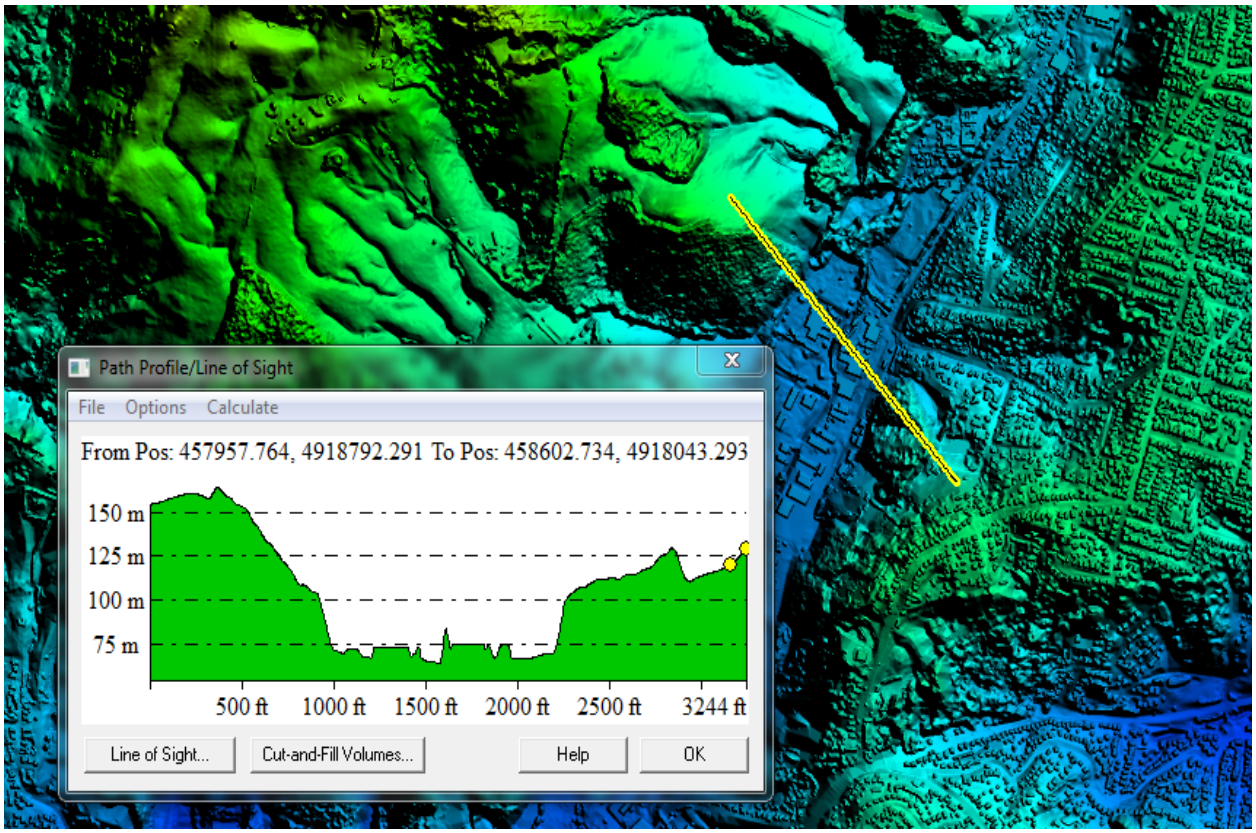

Figure 2-8. Digital Surface Model (DSM) derived from satellite stereo imagery, shown with profile drawn between two selected points.

b. Disadvantages of Satellite Photogrammetry. Satellites collect images with differing view geometries that can affect the quality of mosaics as well as associated positional accuracies with increasing off-nadir angles of collection geometry. Further, fixed orbits of satellite constrain the collection time to specific local time anywhere across the globe and can be impacted by cloud cover in those regions.

2-4. Aerial LiDAR. Since approximately 1998, Light Detection and Ranging (LiDAR) has emerged as the most popular and accurate technology for all forms of digital elevation modeling (used for many forms of automated terrain analyses, including hydrologic and hydraulic modeling used by USACE) as well as contours, hillshades and other "elevation derivatives" used for manual and/or semi-automated terrain analyses.

a. Products of Aerial LiDAR. Typical products of aerial LiDAR are shown in Figures 2-9 through 2-24 below.

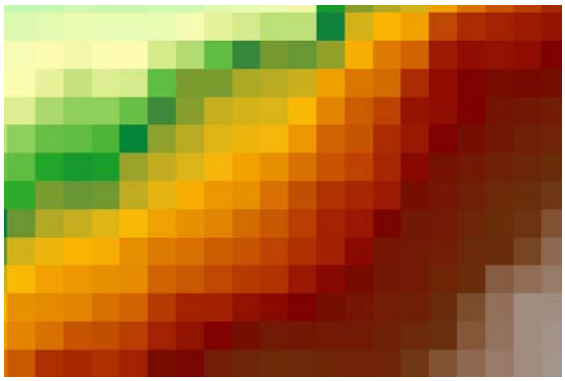

Figure 2-9. Gridded DEM viewed as pixels, color-coded by elevation for 3D visualization with hillshades such as shown at Figure 2-20 below.

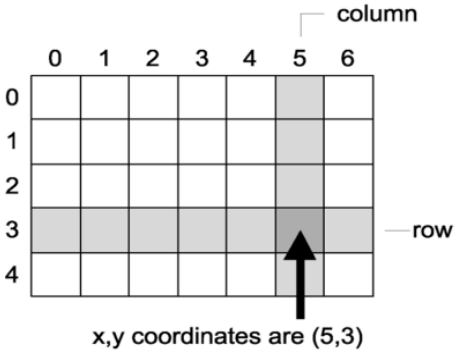

Figure 2-10. DEM files are small and efficient because individual x/y coordinates do not need to be stored.

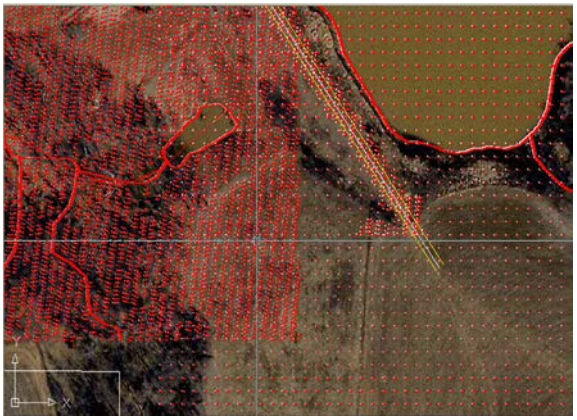

Figure 2-11. Irregularly-spaced LiDAR mass points (left), breaklines, and gridded DEM (right) viewed as "elevation posts," interpolated from surrounding mass points.

Figure 2-12. LiDAR intensity returns from laser pulses. White streaks on the river show separate flight lines. With topographic LiDAR, laser pulses are absorbed by and are unreliable on water.

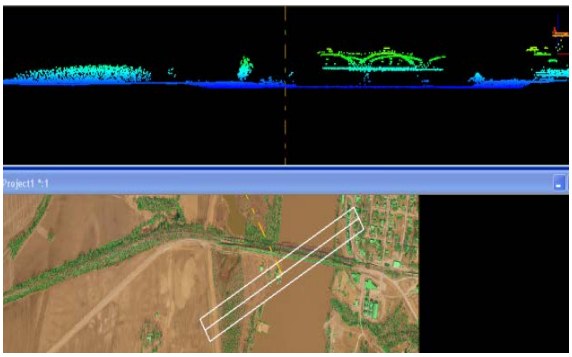

Figure 2-13. Topographic LiDAR profile (top) showing elevations along the transect (bottom) that crosses the river and bridge.

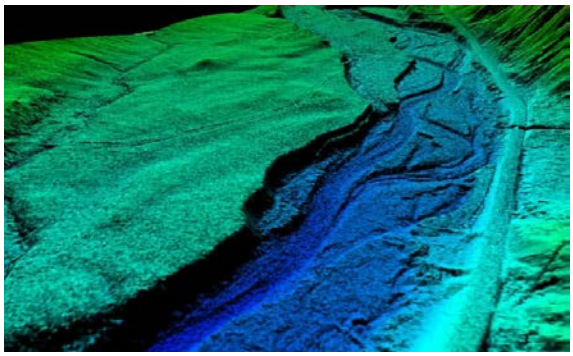

Figure 2-14. Topobathymetric LiDAR also maps subsurface bathymetric surfaces, depending on water clarity / turbidity.

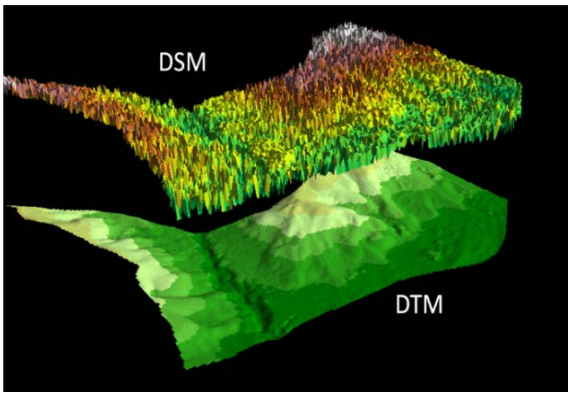

Figure 2-15. Digital Surface Model (DSM) at top and Digital Terrain Model (DTM) at bottom.

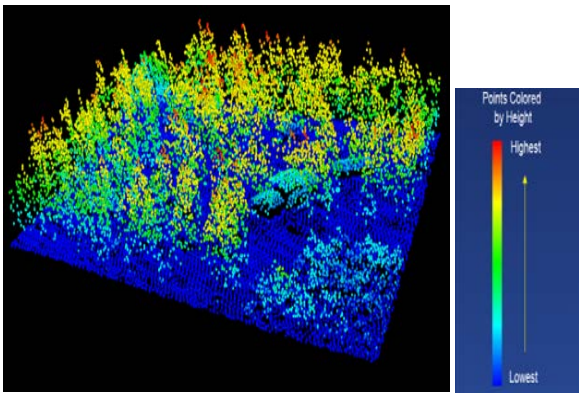

Figure 2-16. LiDAR point cloud tree height map subtracts DTM elevations from DSM elevations.

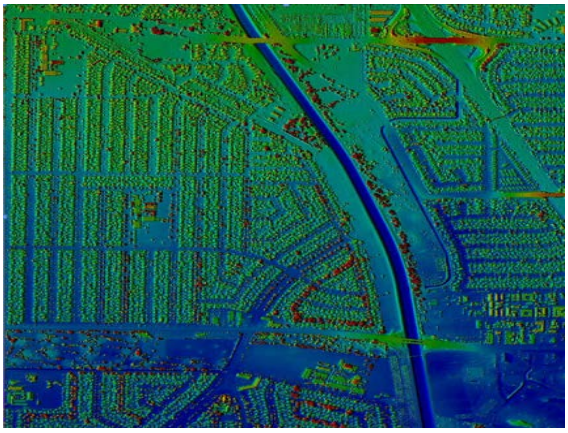

Figure 2-17. LiDAR DSM of urban area, includes elevations on treetops, buildings, bridges, etc.

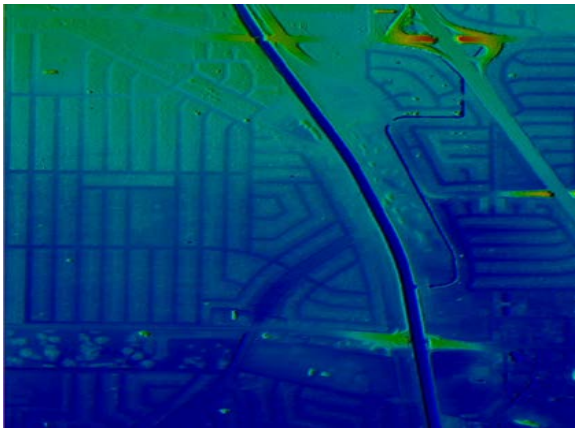

Figure 2-18. LiDAR DTM of urban area, excludes elevations on trees, buildings, manmade features.

Figure 2-19. Produced from LiDAR, traditional contours remain popular for human visualization.

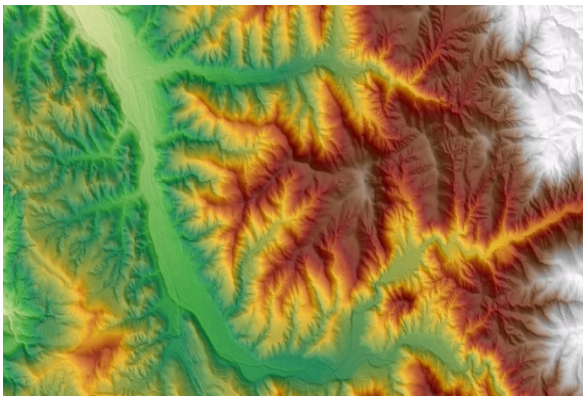

Figure 2-20. LiDAR hillshade maps are gaining popularity for human 3D visualization.

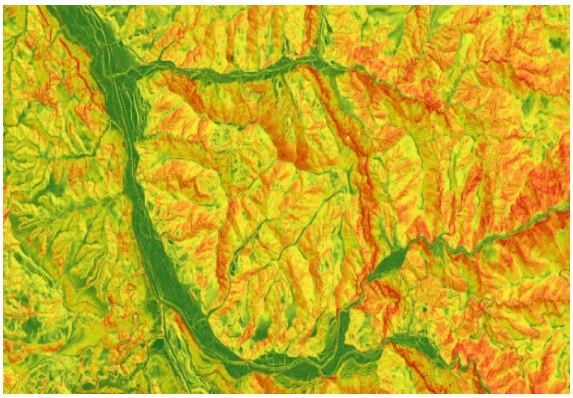

Figure 2-21. LiDAR slope map. Steepest slopes are red; shallowest slopes are green.

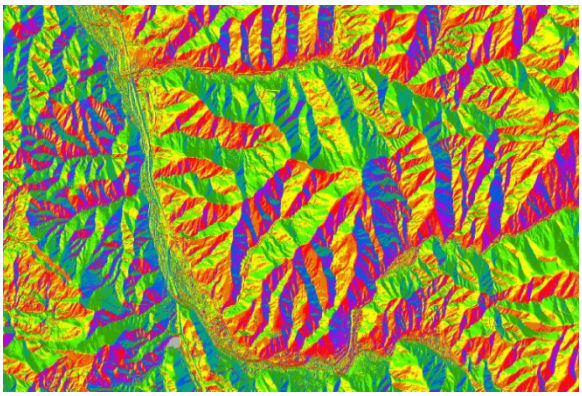

Figure 2-22. LiDAR aspect map. Hottest aspects facing south, toward the sun, are in red.

Figure 2-23. LiDAR viewshed map shows what can be seen (red) and not seen (green) from an antenna 9.5 ft. tall.

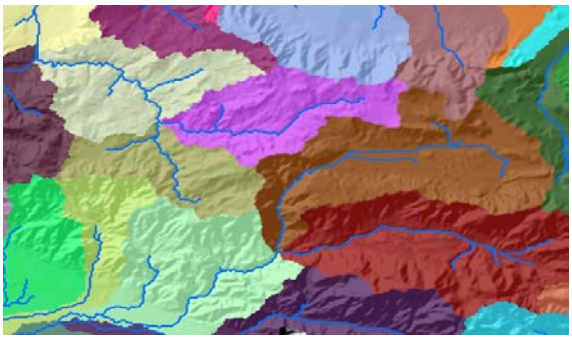

Figure 2-24. Watersheds and stream networks delineated from LiDAR. Hillshading has been added to show the underlying terrain.

b. Advantages of Aerial LiDAR. Advantages of aerial LiDAR include the following:

(1) The major advantage of aerial LiDAR is its ability to map the bare earth DTM beneath forest canopy, as shown in Figures 2-25 and 2-26. If a person walking through a forest can see some sky overhead looking up through the canopy, there is a good chance that individual LiDAR pulses can also penetrate that canopy looking downward to map the ground beneath.

(2) With new LiDAR sensors, point density is increasing, which improves its ability to penetrate forest canopy, while the cost of LiDAR datasets is decreasing.

(3) Similar to photogrammetry or radargrammetry, lidargrammetry enables 3D breaklines to be compiled from overlapping stereo pairs from LiDAR data. Two pseudo images called a pseudo stereo pair can be constructed from LiDAR data, allowing a photogrammetric system operator to “see” in 3D and use lidargrammetry to better determine the location of ground features.

Figure 2-25. In spite of dense vegetation shown on this orthophoto in Florida, LiDAR data collected with point density of 4 points/m^2 was able to map contours and establish a hydro flow line for the dry drainage feature in this forest.

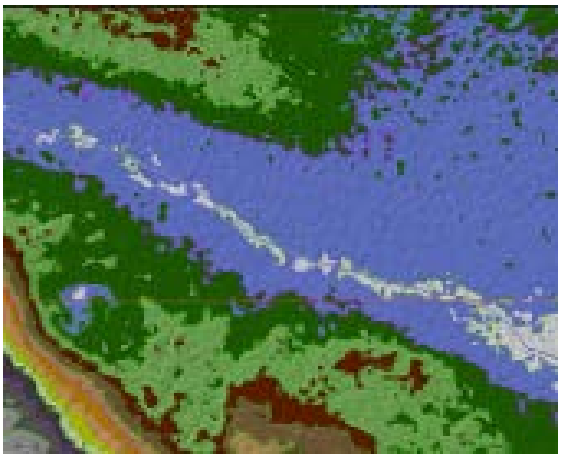

Figure 2-26. Color-coded by 1-foot contour elevation bands, the white polygons define depression contours that show dry puddles. Such topographic mapping in heavily forested areas would be impossible with photogrammetry. Shows same area as Figure 2-25.

(4) Compared with standard discrete return topographic LiDAR, full waveform LiDAR has advantages for mapping forests, wetlands, and short vegetation, as explained in Chapter 6, but full waveform LiDAR is primarily used for research at this time because of the lack of waveform processing tools.

(5) Bathymetric LiDAR and topobathymetric LiDAR sensors, explained in Chapter 7, are also able to map the submerged bathymetric surface in waters that are reasonably clear from turbidity.

(6) For its 3D Elevation Program (3DEP), the U.S. Geological Survey, working with other members of the National Digital Elevation Program (NDEP), has adopted Quality Level 2 (QL2) LiDAR data with 2 points per square meter and vertical RMSEz of 10 cm as the new standard for elevation data in all states and U.S. territories except for Alaska. This means that there is increased opportunity for cost sharing with other agencies and states to acquire QL2 LiDAR data nationwide. QL1 LiDAR, with 8 points per square meter and vertical RMSEz of 10 cm, remains a buy-up option for any user with a requirement for mapping in exceptionally dense vegetation.

c. Disadvantages of Aerial LiDAR. Disadvantages of aerial LiDAR include the following:

(1) Topographic LiDAR provides unreliable elevations of water surfaces and surfaces beneath the water level.

(2) Discrete return LiDAR pulses are limited in their ability to distinguish between two elevation surfaces that are relatively close together, as when the separation between the two surfaces is less than the length of a single laser pulse. Full waveform LiDAR data does not have this issue but is more expensive and difficult to process because waveform file sizes are typically 10 times larger than discrete return file sizes and there is currently no commercial or open source software to process waveform data.

(3) Topographic LiDAR technologies are relatively immature so that system calibration procedures and accuracy testing procedures are still evolving.

(4) Topobathymetric LiDAR technologies are even less mature than topographic LiDAR technologies.

d. Aerial LiDAR References. In addition to Chapter 6, additional references include:

(1) American Society for Photogrammetry and Remote Sensing. 2012. "Manual of Airborne Topographic Lidar," Michael S. Renslow, ed., Bethesda, MD

(2) American Society for Photogrammetry and Remote Sensing. 2007. "Digital Elevation Model Technologies and Applications: The DEM Users Manual," 2nd ed., David F. Maune, ed., Bethesda, MD.

2-5. Interferometric Synthetic Aperture Radar (IFSAR). Both satellite and aerial IFSAR are discussed in the IFSAR chapter of ASPRS, 2007 which explains Synthetic Aperture Radar (SAR) technology in detail. The Shuttle Radar Topography Mission (SRTM) and the TerraSAR family of commercial satellites are satellite-based IFSAR sensors from which relatively low accuracy datasets can be obtained. However, because of USACE requirements for higher accuracy datasets, only aerial IFSAR products, advantages and disadvantages will be discussed in this section.

a. Products of Aerial IFSAR. Four common aerial IFSAR products are shown in Figures 2-27 through 2-30 below.

Figure 2-27. X-band IFSAR collects the top reflective surface to produce a DSM.

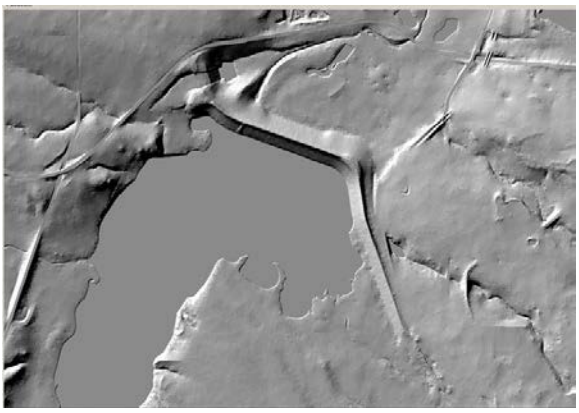

Figure 2-28. The IFSAR DSM is subsequently filtered to produce a bare-earth DTM.

Figure 2-29. IFSAR Orthorectified Radar Image (ORI) used to create hydro masks.

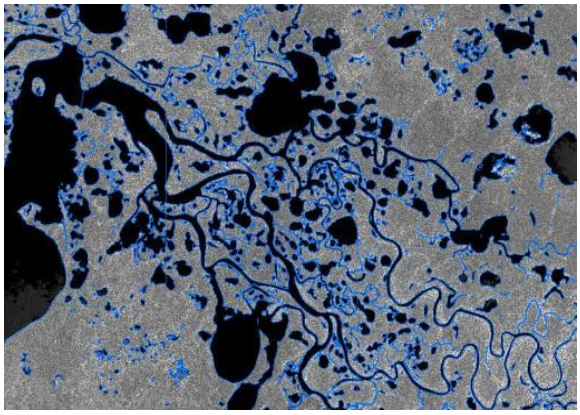

Figure 2-30. IFSAR hydro mask can be used to create hydrographic breaklines (shown in blue).

b. Advantages of Aerial IFSAR. Advantages of aerial IFSAR include the following:

(1) The single greatest advantage of IFSAR is its ability to map through clouds, fog, haze and smoke. See Figures 2-31 and 2-32.

(2) IFSAR orthorectified radar images (ORIs), as shown in Figure 2-29, can be used to pan-sharpen satellite imagery of poorer resolution, as demonstrated in Figure 2-33.

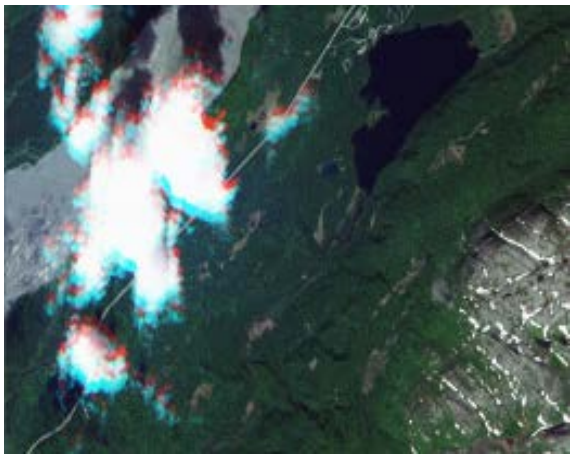

Figure 2-31. This is a RapidEye 5-m color satellite image of Alaska where clouds, fog, haze and/or smoke are common in many locations.

Figure 2-32. As the only technology that maps through clouds, etc., IFSAR pan-sharpened this RapidEye image and mapped beneath the clouds.

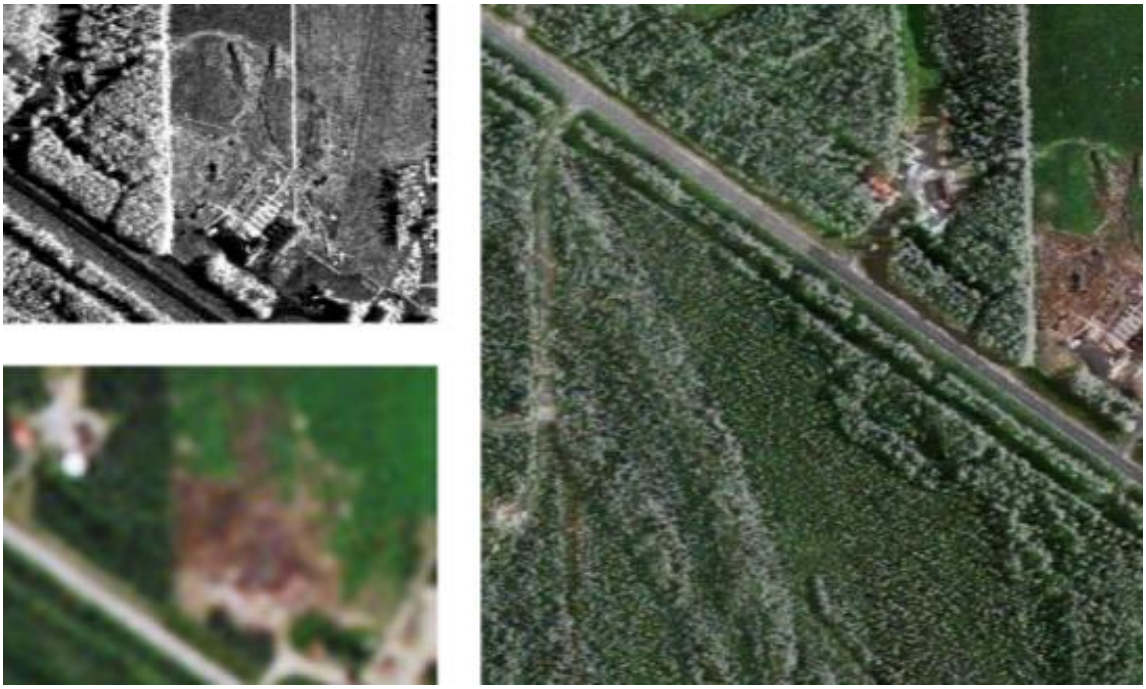

Figure 2-33. IFSAR ORIs can be used to pan-sharpen satellite imagery of poorer resolution. Here, a 62.5-cm IFSAR ORI (upper left) is merged with a 5-m resolution RapidEye satellite color image (lower left) to produce a 62.5-cm pan-sharpened color orthophoto (right) in Alaska.

(3) IFSAR ORIs are automatically geo-registered to fit IFSAR DSMs and DTMs.

(4) IFSAR is ideal for generation of hydro masks that identify water features.

(5) IFSAR data have already been acquired by Intermap for 49 states (all except Alaska) for their NEXTMap USA® program.

(6) IFSAR is the least expensive technology for mapping large areas.

c. Disadvantages of Aerial IFSAR. Disadvantages of aerial IFSAR include the following:

(1) IFSAR elevation datasets are less accurate than elevation datasets from LiDAR or photogrammetry.

(2) IFSAR data cannot be cost-effectively acquired for small areas; this technology works best for large area acquisitions only.

(3) Except for Alaska (in progress), NEXTMap USA® data are licensed rather than owned by the purchaser.

d. Aerial IFSAR References. Additional references include:

(1) American Society for Photogrammetry and Remote Sensing. 2007. "Digital Elevation Model Technologies and Applications: The DEM Users Manual," 2nd ed., David F. Maune, ed., Bethesda, MD.

2-6. Summary. This chapter primarily addresses the comparative advantages/disadvantages of aerial and satellite photogrammetry and aerial LiDAR and IFSAR as pertains to the needs of USACE Divisions and Districts. Chapter 4 provides additional details on aerial photogrammetry and Chapter 5 provides additional details on satellite photogrammetry. Chapter 6 provides details on aerial topographic LiDAR and Chapter 7 provides details on aerial bathymetric LiDAR. No chapter in this manual is provided for airborne IFSAR because this technology, relevant for large area coverage, is normally not acquired for individual projects but is instead licensed from NEXTMap USA and NEXTMap Europe datasets available for most of the U.S. and Europe. Airborne IFSAR data are currently being acquired by USGS for the State of Alaska and will be publicly available without licensing restrictions as deliverables are produced and accepted into the National Elevation Dataset (NED).