Drones Rising from the Prairie: Geological Applications of Unmanned Aerial Systems

Fred Anderson and Chris Maike

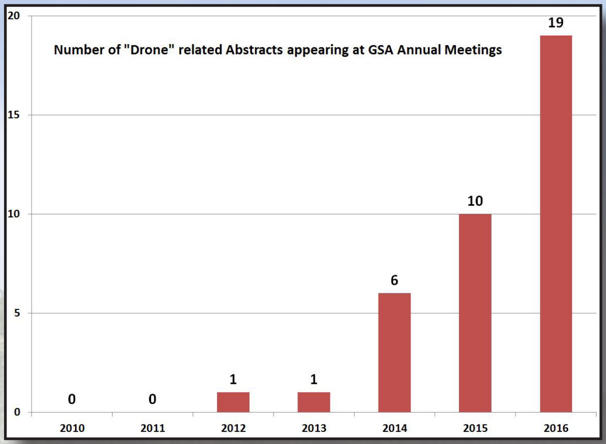

Figure 1. The number of abstracts related to drone use in support of geoscience investigation presented at the Geological Society of America's Annual Meetings over the past six years has steadily been on the rise.

In recent years, the use of Unmanned Aerial Systems (UAS) (i.e. drones) in the geological sciences has steadily been on the rise (fig. 1). Many investigators, geological surveys, and natural resource regulatory agencies across the nation are currently evaluating or already implementing drone platforms to enhance, and provide cost effective alternatives to traditional geologic field investigative work. As of this writing over 15 other state geological surveys in the U.S. (predominantly in the Midwest and Rocky Mountain West) are also using drones to support their regulatory and/or investigative missions. Many others are currently evaluating their use (Anderson, 2017).

A number of Geological Surveys have been using drones for improved characterization of geological hazards over the past few years. They have been using drones to collect high-resolution topographic data for the creation of detailed 3D models that can be used to monitor landslide deformation in lieu of traditional methods such as inclinometry or labor-intensive manual surveying. Daily drone surveys of isolated landslide features can be completed in a few hours and provide investigators with quantifiable data on their movement over time and forewarn the emergence of new landslides after high rainfall events.

Remote Sensing Acquisition Platforms

In the remote sensing environment, which ranges from just above the land surface to the first reaches of space, the realm of the drone for geological applications has been mostly at relatively low-altitudes of 1,000 feet or less. This is the zone where much of the airborne surveying work including imagery collection and airborne geophysical surveying such as gravity and magnetometer surveying is conducted (fig. 2). Traditional aerial photography and today's aerial digital imagery is usually flown at altitudes under four miles above the land surface. Traditional aerial photographs are most commonly available at scales of 1:40,000 and 1:20,000, which are flown at altitudes of 20,000 and 10,000 feet respectively. Satellite imagery collected by the joint National Aeronautics and Space Administration's/USGS LANDSAT program is also frequently utilized in earth science investigations. For more than four decades LANDSAT program satellites (now including LANDSAT 7 and LANDSAT 8) have acquired Earth imagery of the planet. Today,

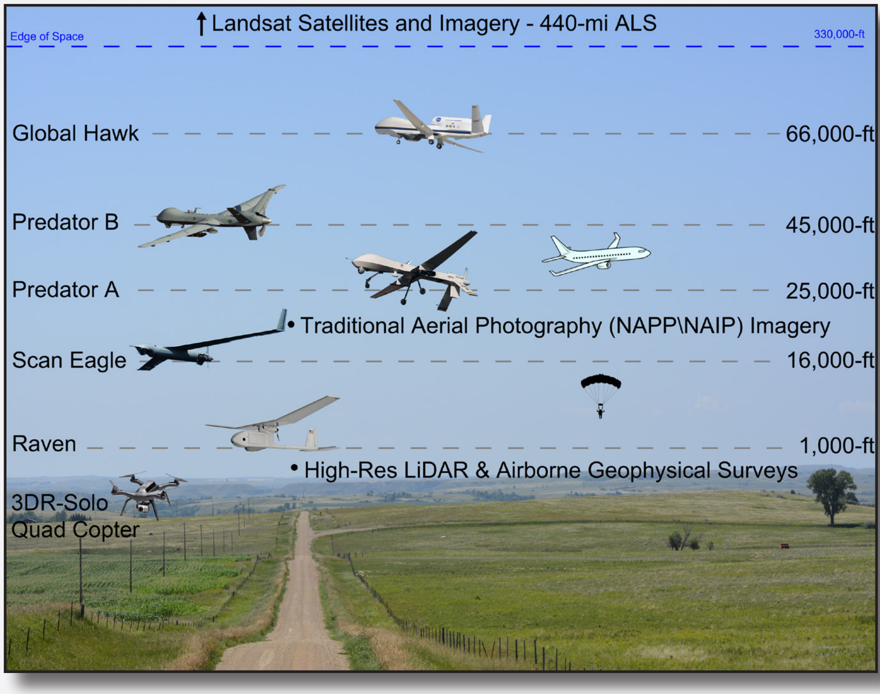

Figure 2. Common drones and operating altitudes within U.S. airspace. The more familiar altitudes of general commercial airliner operation and recreational skydiving are also shown for comparison. The bulk of recent drone work in the geosciences is commonly conducted within the airspace envelope between the ground surface and altitudes of 1,000 feet or less.

about every hour and a half, imagery and a broad range of other data from across the electromagnetic spectrum is collected across the entire globe (USGS, 2015).

Drone Capabilities in North Dakota

North Dakota has numerous drone capabilities within both the military and civilian sectors, predominantly in the Red River Valley. Over the last decade, Grand Forks has continued to grow as the nation's leading drone innovation and development center on three fronts: the opening, in 2015, of the Grand Sky UAS business park at the Grand Forks Air Force Base (currently home to the Global Hawk and the 348th Reconnaissance Squadron); the Northern Plains UAS Test Site, one of seven FAA UAS test sites across the nation tasked with the integration of drone platforms into U.S. airspace without detriment to the general and commercial aviation industries; and the University of North Dakota's Center of Excellence in UAS Training, Research, and Education; within the John D. Odegard School of Aerospace Sciences. Together they provide avenues for collaboration across disciplines and opportunities to develop new applications for drones in North Dakota.

Drone industry leaders at Grand Sky will also be spearheading the development of anti-drone technologies in addition to continuing to provide excellent testing environments for the beyond visual line of sight (BVLOS) mission in cooperation with the Northern Plains UAS Test Site (NPUASTS, 2017). Anchored by Northrop Grumman, which supports the U.S. Air Force Global Hawk mission, the park is expected to grow and develop with companies like General Atomics (manufacturer of the Predator) continuing to expand flight operations and training capabilities. Drawing from the academic and extensive simulation resources at the Center for Unmanned Aircraft Systems at UND and the local drone industry, new projects, like the recently awarded NASA-sponsored UAS Traffic Management Project, will also continue to emerge (UND Aerospace, 2017).

In the southern Red River Valley, the North Dakota Air National Guard's 119th Wing, located in Fargo, provides direct military mission support for the U.S. along with air reconnaissance capabilities for the state (fig. 3). The 119th Wing is the home of North Dakota's "Happy Hooligans" where until recently; the Predator (MQ-1) Unmanned Aerial Vehicle (UAV) was flown. This summer the 119th Wing will be flying MQ-9 Predator Bs (also known as "Reapers") as their current aerial services platform (NDANG, 2017).

Over the past decade, the State of North Dakota and North Dakota Department of Emergency Services have leveraged the use of U.S. Customs and Border Protection drones for data and imagery acquisition in response to disastrous flooding events in the Red River Valley. U.S. Customs and Border Protection operate two Reapers in support of the mission to secure the northern U.S. border (fig. 4). These drones call the Grand Forks AFB home and patrol more than an 800-mile stretch of the international border between the U.S. and Canada. Each Reaper costs $20 million, and is operated at a cost of about $12,000 an hour, according to cost evaluations compiled by the U.S. Office of Inspector General (USOIG, 2014). The Reaper has an altitude ceiling of 50,000 feet and can fly for as long as 20 hours at speeds of up to 276 mph, roughly half the speed of a commercial jet. Reapers are also used by the U.S. Air Force, the U.S. Navy, NASA, and the CIA.

Figure 4. An MQ-9 Predator B Drone (Reaper), manufactured by General Atomics Aeronautical Systems. This is one of two Reapers operated by the U.S. Customs and Border Protection in support of the mission to secure the northern U.S. border. These drones have also supported flood-fighting efforts in the Red River Valley (USCBP, 2017).

Opportunities for Implementation

There are numerous opportunities for implementation of drones in North Dakota's natural resource regulatory and investigative landscape. Key among these are enhanced inspection and monitoring of oil and gas activities, geologic hazards such as flooding and landslides, abandoned mine land reclamation, and North Dakota's hydrologic systems and infrastructure. The following is just a sample of both proven and potential applications.

Locating Legacy Abandoned Oil and Gas Wells

Finding oil and gas wells when information on their whereabouts is sparse or non-existent is an application of using drones equipped with geophysical instrumentation to detect the location of a "lost" well collar. Detailed surveys of candidate legacy well locations can be completed by equipping a drone with a magnetometer to relocate lost wells so they may be properly abandoned and reclaimed. In the State of New York for example, it is estimated that the locations of more than half of the wells drilled for oil and gas since the 1800s are unknown (Adamson, 2016). Fortunately, here in North Dakota, our oil plays started much later, and well locations are not a common problem.

Figure 3. The MQ-1 "Predator" UAV has flown in North Dakota as a part of the North Dakota Air National Guard's 119th Wing also known as the "Happy Hooligans."

General Electric has recently built a new drone platform called the Raven, which is equipped with instrumentation to directly detect methane leaking from wells and pipelines. This innovative drone successfully completed a test project on oil and gas wells in Arkansas last summer (Moon, 2016). Drone platforms like these could be used to conduct high-resolution surveys for pipeline inspections more efficiently than with vehicular-based or traditional walking inspections.

Interestingly, NASA's Jet Propulsion Laboratory (JPL) has also recently completed the construction of a similar drone with methane-detecting instrumentation that is far more sensitive than traditional hand carried instruments (fig. 5). For example, the hand-held field instrumentation used by the NDGS to detect the presence of methane in groundwater wells in a 2006-2010 statewide study could detect methane in the parts per million range. To visualize such a small concentration, one part per million is about equivalent to 10 bricks in the entire construction of the empire state building (TED-Ed, 2017). NASA's new Open Path Laser Spectrometer (OPLS) has the capability to detect methane concentrations in the parts per billion range, which could help to locate leaking pipelines much earlier (NASA, 2016), resulting in less costly repairs and remediation.

Figure 6. Pseudo-oblique images rendered in Google Earth of landslide features along County Road 80 just west of Huff, ND show the emergence and continued movement of these slides over an 18-year time period from 1997 to 2014. Employing a drone to periodically monitor areas like these along transportation corridors across the state could provide additional cost savings by detecting changes along engineered slopes prior to large scale failure.

Measuring Landform Change over Time in Support of Slope-Stability Analyses

Another drone application is the high-frequency repeat aerial surveying of landslides in western North Dakota (fig. 6). One way to monitor slope stability at a newly engineered site is through the completion of repeat localized low-level drone surveying. By flying the drone over the project location and nearby areas of concern on a daily, weekly, or monthly basis, depending on the type and characteristics of the slide area, detailed topographic surveys can be completed rapidly and compared to previous surveys for signs of movement within the slope mass. Performing this relatively low-cost style of monitoring can provide companies and regulatory agencies with an added level of assurance that a questionable location is structurally and environmentally sound.

Mine Surveying and Abandoned Mines Reclamation

An economically and environmentally valuable way of using drones in the mining industry is in the facilitation of hyper-accurate surveying in order to better quantify operational mining models and volumetrics and to conduct detailed topographic surveys of pre- and post-mining conditions. North American Coal Corporation's Falkirk Mine near Underwood in southeastern McLean County is leading the nation in drone-based mine surveying techniques. Falkirk was recently touted (Schmidt, 2016) as the first surface coal mine in the nation to operate a survey drone with federal approval (fig. 7).

Figure 5. NASA JPL's OPLS sensor onboard this small drone can detect methane in concentrations in the parts per billion (ppb) range (about equal to one drop of water in an Olympic size pool) and could be an aid to future oil and gas pipeline inspections and surveys.

Drones carrying geoscience-instrumented payloads could provide several exciting opportunities for geological investigations in North Dakota including mining reclamation. Drone-based high-resolution surveying, mapping, and monitoring of the subsidence of abandoned underground coal mines could enhance the identification and reclamation of these potential public hazards.

Figure 7. Technicians at the Falkirk Mine in central North Dakota have been using the Trimble UX5 drone to optimize mining operations since the fall of 2015.

Traditionally, when measuring a stratigraphic section, the field geologist traverses the outcrop by walking up the section and measuring the thickness of particular beds of rock and writing detailed descriptions of the lithologies along the way. With a drone, one can conduct a detailed topographic and imagery analysis of the entire outcrop, not just one measured path along it, without risking the safety of the geologist. Employing multiple cameras or different types of sensors on the drone, such as thermal cameras, Geiger counters, gravimeters, or magnetometers, can also increase the variety of geological data that can be collected. Detailed data and imagery analysis can reveal new insights into mineral assemblages and stratigraphic divisions traditionally obtainable only after weeks of field investigation and costly laboratory analysis (fig. 8).

Measuring and Monitoring Paleontological Sites
Identifying and mapping newly uncovered paleontological sites is a time-consuming and laborious process. Utilizing drone mapping and imaging technologies can offer opportunities for enhanced mapping of key fossil beds and surveying of accurate specimen distribution across a key fossil locality. In addition, cost-effective repeat surveys can be completed to better preserve and manage these sites (fig. 9).

Using drone-based surveys for mapping mine subsidence features greatly increases the level of field safety for the geologist. Drones are effective substitutes for human observers and eliminate the necessity of “boots on the ground” in areas where there may be unseen or unknown hazards. Regulators “across the pond” in the United Kingdom experienced just these conditions while investigating their legacy mining sites (DroneApps, 2017). They have been implementing drones in their continuing investigations and reclamation of abandoned mine lands by coupling drones with geophysical methods like microgravity surveying to improve remedial activities at legacy sites. Microgravity surveying is a geophysical investigative method whereby very small variations in the gravitational field of Earth are measured in order to determine the location of voids in the subsurface, such as abandoned mines or dissolution features such as traditional sinkholes (Reynolds, 1997).

Perhaps one of the greatest advantages of using drones in support of geoscience investigation is their ability to complete highly accurate repeat surveying and imagery collection missions at nominal costs on any desired temporal span. The time span (e.g. hours, days, weeks, months, etc.) can best be set to capture the characteristics of the geologic target of interest.

Measuring Stratigraphic Sections and Inaccessible Outcrops
Another excellent geological application of drones is in the measuring of hard-to-reach or inaccessible outcrops of stratigraphic interest.

Figure 8. A drone photo of an outcrop of the Tertiary age Cannonball Formation (deposited by the last sea to cover North Dakota) exposed along the Heart River southwest of Mandan. This outcrop is difficult to access for detailed examination owing to its proximity to the river, steepness of slope, and loosely consolidated nature of these particular sedimentary rocks. Employing a drone to survey hard-to-reach outcrops like this can reveal new geologic insights and provide unprecedented detail of key outcrops and type sections while considerably improving the safety of the geologist.

Figure 9. Drone photo of a NDGS public fossil dig southwest of Dickinson.

Surveying the Health of Dam Construction across the State

It is estimated that many of the dam structures across the United States are in need of repair since a vast majority of them were built in the early 20th century (Pupovac, 2015). As of 2015, there were 1,223 North Dakota state-regulated dams, 48 classified with a high hazard potential (meaning if the dam failed there could be significant economic consequences and potential loss of life) (NDSWC, 2017). Periodic surveys using unmanned aerial systems equipped with LiDAR, photogrammetric, or perhaps even thermally sensitive instrumentation, could provide clues to aging structures needing repair or replacement. These cost-effective measures would be beneficial for safety and regulatory programs with insufficient investigation and inspection resources. Also, monitoring reservoir volumes and sedimentation rates in retention structures via drone mapping can lead to more cost-effective management and overall performance. Adapting aerial drone technology for use in the surface aquatic environment, such as in the surveying of difficult-to-access water bodies like volcanic lakes has proven to be achievable and surprisingly affordable (McFarlane et al., 2017).

Autonomous Underwater Vehicles (AUVs)

In addition to aerial drones, there are also unmanned systems capable of operating in the water. These types of vehicles are called Autonomous Underwater Vehicles (AUVs) and have many of the same capabilities as their airborne counterparts (fig. 10). An AUV is capable of performing costly surveys of submerged utility corridors and collecting high-resolution sonar data that can be used to create three-dimensional models of submerged landscape features such as lakeshore landslides (fig. 11) or detailed profiles of accumulated lake sediment. Much of the lakeshore around Lake Sakakawea has been mapped by the NDGS for landslides. Areas like these, that coincide with locations of utilities and related energy development infrastructure, could be relevant candidates for AUV bathymetric surveys.

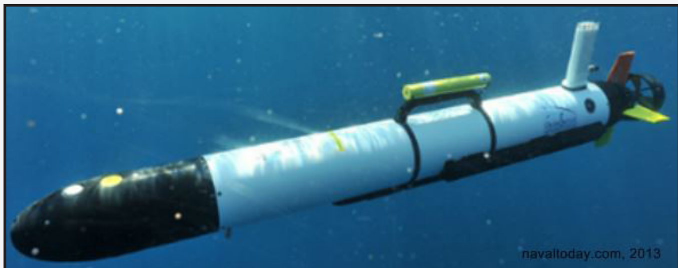

Figure 10. The Iver3-580 is an AUV that can independently conduct detailed acoustic and magnetometer surveying along with collecting underwater imagery that can be used in submerged utilities inspection and in the evaluation of underwater slope stability in lakeshore settings.

Many of the aerial and underwater drones currently in use fall into the Remotely Operated Vehicle (ROV) category. The fundamental difference between ROVs and AUVs is that AUVs operate completely on their own and are not attached or tethered to their deploying platforms or vessels. The National Oceanographic and Atmospheric Administration (NOAA) currently deploys AUVs for hydrographic surveying in order to identify potential underwater hazards to commercial and recreational navigation and is also evaluating their use for bathymetric surveying in support of NOAA's nautical charting mission (NOAA, 2017). There are several relevant applications for using AUVs in North Dakota, including submerged utilities inspection, both pre- and post-construction, and detailed bathymetric studies for higher quality mapping of submerged lake-bed topography and potential identification of submerged historical, archaeological, or potential paleontological sites (C&C Technologies, 2017).

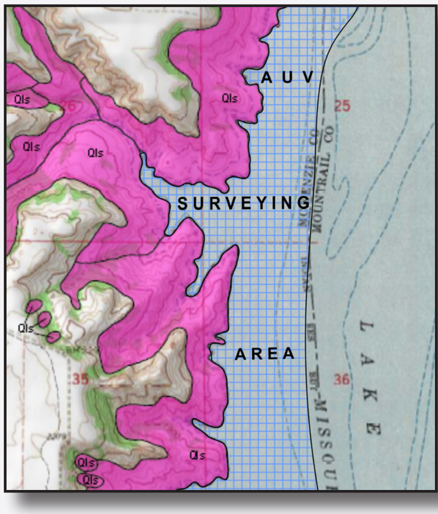

Figure 11. Numerous landslides along the lakeshore of Lake Sakakawea have been mapped with traditional aerial photographic techniques to the water line (Murphy, 2010). AUV bathymetric surveys completed along areas like this (outlined with the cross-hatched light blue pattern) could provide additional detailed information about the continuity and potential reactivation of submerged landslide features and identify potential problem areas not identifiable by traditional aerial mapping methods.

Opportunities for Collaborative Flights

Returning to the sky, one of the most readily identifiable opportunities for implementing drones in geological investigative and regulatory inspection work across large areas of the landscape is the "piggyback" concept of attaching instrument payloads to aircraft that are regularly flying a primary mission, ideally a training exercise. For example, partnering with UND Aerospace to fly tight high-resolution airborne geophysical grids, such as gravity and aeromagnetics, for each county in North Dakota could provide unique opportunities to investigate the geophysical properties of the subsurface geology of North Dakota at unprecedented levels of detail. This information could reveal undiscovered economic geologic prospects and provide unique opportunities for drone pilot training by repetitively holding tight flight lines across a dense, relatively low-altitude geophysical survey grid.

The Future of Drones in the Geosciences

There are certainly many new and exciting opportunities for the implementation of drones in the geosciences that can increase the detail, accuracy, and efficiency of conducting field investigations, all while providing for increased safety to the field geologist. The near future holds even more exciting possibilities with the potential use of swarming autonomous micro-drones (fig. 12) that are effectively pre-programmed for the mission, launched, and then allowed to figure out on their own the most efficient method of completing the programmed assignment (U.S. DoD, 2017). Imagine arriving at your field site in the morning, programming your "birds" for flight, releasing them into the sky on their way to their pre-programmed area of investigation, and then they return to the field site on their own later in the day with all of the needed information collected and ready for processing and evaluation.

Implementing UAS use at the NDGS

We recently acquired the inexpensive Phantom 4 Pro Drone and put it to immediate use in support of the geologic and landslides mapping mission. The Phantom is flown by a single geologist and can fly vertical take-off and landing missions on demand. The drone can fly missions for over twenty minutes at a time. Additional battery supplies allow a geologist to reach several sites in a day. The drone is an effective and cheap method for photography compared to an airplane or helicopter. A site can be photographed in a shorter time frame with a drone than a helicopter or airplane which requires more planning and associated costs.

Our drone is equipped with a 20 megapixel gimbal camera, resulting in stunning still photography. Also, the camera records 4K video (60 frames per second) giving a clear overview of geologic sites. The pilot operates the drone using a remote control and is able to observe the pictures and drone locations via a live feed through a tablet screen (fig. 13).

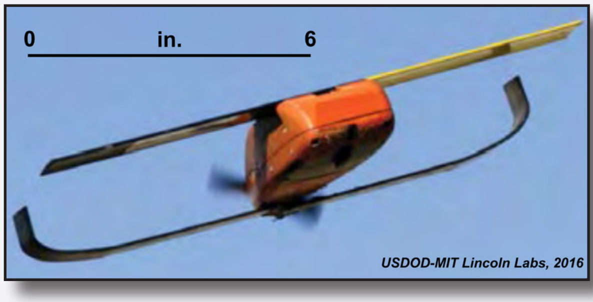

Figure 12. The Perdix autonomous micro-drone, developed by MIT's Lincoln Laboratory, is capable of flying in swarms and has completed naval surveillance missions in a collective and autonomous fashion (Harper, 2016).

Currently, we are using the drone to collect oblique aerial imagery for sites of potential geologic hazard, particularly landslides. Historically, landslides were mapped from aerial imagery and stereo pairs. In more recent years, the addition of Google Earth has allowed the user to view oblique imagery as well. However, lack of quality, distorted models, and years of data acquisition gaps do not do oblique angles justice. High quality oblique aerial photography is very important in natural hazard assessment, which is why drones will feature so prominently in the future for geological mapping (fig. 14).

There is a multitude of remote sensing needs that many different drones can accommodate. At this time, we have found that the cost-efficient Phantom 4 Pro serves many of these. The sharp photography and videography it provides are essential for site and natural hazard assessments. In the future, we will evaluate drones that can handle more rigorous operations such as magnetics, LiDAR, and multispectral sensing, enabling geologists to conduct a variety of Survey missions.

Figure 13. Survey geologist Chris Maike, an FAA Part 107 Certified Drone Pilot, flies the Phantom 4 Pro drone while collecting imagery along the rugged topography of the Missouri River Valley south of Bismarck.

Figure 14. Comparison of pseudo-oblique aerial imagery rendered in Google Earth (above) with recent true oblique imagery (below) collected with the Survey's new Phantom 4 Pro Drone. Fresh weathering of a scarp (S) is visible in the drone imagery of a landslide originating within badlands topography of the Sentinel Butte Formation in western North Dakota.

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