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An Introduction to Precision Agriculture: An Educator's Guide to Agricultural Earth Observation

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EXPERT REVIEWED

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Disclaimer

Drone operations are conducted with inherent risk. We have provided several safety tips and suggestions to help mitigate risk. Remote Pilots in Command (RPIC) should always follow all federal, state, and local regulations during flight operations. We also recommend following all manufacturer's recommendations and maintenance schedules for equipment. All information presented in this manual is intended for educational and informational purposes. It is not a substitute for legal or other professional advice. All exercises, learning lessons, flight operations, fieldwork, and associated missions are conducted at your own risk.

Permitted Uses of Materials

These educational materials were developed with support from VirginiaView, which is a member of the AmericaView consortium.

Access

This educational resource (and a broader collection of educational resources) is available either as a hardcopy version or ePublication through VirginiaView, GeoTEd-UAS and Virginia Cooperative Extension at https://virginiaview.cnre.vt.edu/tutorials/.

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How to Use this Workbook

This workbook was developed "by educators, for educators." It is intended to provide introductory information and resources for middle school students, who represent the future generation of agricultural practitioners. We view this document as a "starting point," not an ending point, to support new approaches associated with agricultural operations, and we suspect that this will become somewhat of a living document.

The workbook provides some information to assist educators and their students to develop a basic foundation of knowledge about precision agriculture. This information is supported by examples of precision agriculture workflows.

In addition, the workbook incorporates examples that include uncrewed aircraft (also known as "small uncrewed aircraft systems," sUAS, or drones), associated sensors, and imagery collected by the platforms. We have found that the vehicles themselves can often serve as an educational hook to facilitate the further exploration of other areas of STEAM (science, technology, engineering, arts, and mathematics), including earth observation through remote sensing. While the unmanned aircraft serve as an educational hook, it is the sensor platforms that contribute to the collection of data "on demand." Information and decisions that are a result of this data will ultimately transform agricultural operations.

In addition to providing basic background information associated with precision agriculture, this workbook also provides additional resources, including:

- **PowerPoint presentations** for each section to support educational delivery of information. Please feel free to adapt and modify these resources to support your local needs.

- **Narrated videos** of PowerPoint presentations for many sections. These short videos are provided for educators who may not be comfortable delivering information content. These are generally less than 15 minutes long.

- **Activities** associated with each section. Some activities are indoor; some are outdoor. Some only require a pencil, while other activities may require a drone with a sensor. Educators should thoroughly work through each activity ahead of time to ensure that it is appropriate for the lesson's learning objectives. And of course, every activity can be modified to better target local needs.

- **Discussion questions**, provided in the orange text boxes. Some potential answers to these discussions are provided in the Appendix of this document.

- **A Glossary**, provided in the appendix. Words listed in the glossary are presented in italics in the curriculum's text.

The information and activities in this workbook are provided as an "educational buffet." These materials do not need to be consumed all at once. Educators can sample, take, modify, and serve up topics, activities, and resources of this workbook as needed.

Forward

Agricultural operations are experiencing profound changes that will continue to affect how producers approach the management of their crops and livestock. This shift in operations is increasingly viewed as an agricultural transformation and is often referred to as *precision agriculture* or "smart farming." While these terms are relatively new, the practices associated with precision agriculture may be viewed as an extension of the Green Revolution of the 1960s, which was associated with similar types of technology transfer. Some examples of early Green Revolution initiatives include the development of hybridized seeds and genetically modified organisms (including plants designed for higher yields), the widespread adoption of agricultural chemicals (including fertilizers, herbicides, pesticides, etc.) and new irrigation techniques, and the further development and proliferation of mechanized farming tools. Many of the initiatives associated with the Green Revolution were exported across the world with different levels of success.

Virginia's agricultural industry consists of more than 43,225 farms that cover 7.8 million acres and generates annual economic impacts of over $70 billion (Virginia Department of Consumer Services, 2022). Farming (which includes forestry) is Virginia's largest industry. It seems only natural that such a large industry would evolve to become a data- and network-driven industry to maximize yields and profits. And this transformation is happening rapidly. Having a "birds-eye view" of fields is vital to support data collection and guide agricultural decisions. As evidence of this, the agricultural portion of national (and international) commercial drone market is its fastest growing sector and is projected to grow over 30% to $5.19 billion by 2025 (Bacco, 2018; Douglas, 2020).

While data has always been used to support agricultural operations, traditionally it was collected mainly through visual observations. Later, digital data was initially collected at the regional level. Now, due to the increasing breadth and accessibility to digital networks, the innovation and miniaturization of components, user-friendly interfaces (including data formatting, analytics, and report generation), and decreasing costs, specialized sensors are increasingly being deployed at the local level, down to individual farms, individual fields, and even specific locations within those fields. Sensors are being employed on the ground (between the rows), below the terrain (to measure soil moisture), and above the fields (to detect areas of vegetation stress). Sensors are located on livestock and inside barns. It is not difficult to imagine that future farmers will need to understand how to maintain a completely different set of equipment than they currently manage, as autonomous drones and accompanying sensor payloads and software may very well become just as important to a farmer as the traditional tractor.

I view precision agriculture as a natural extension, or a next logical step, of shifting agricultural trends that have been occurring over thousands of years. The seeds of precision agriculture were planted when our ancestors decided that growing food was more effective than hunting game and gathering roots and berries. Later generations continued to tinker and refine agricultural practices to improve harvests. Innovation spurred many of these changes, including the use of machinery and plows, the use of chemical fertilizers, pesticides, herbicides, new seed varieties, and new irrigation techniques. These techniques were all employed to increase yields.

And now our planet is faced with new challenges. As resources (such as prime farmland and water for irrigation) become increasingly constrained, it only makes sense that we start utilizing our land, water, and other inputs even more efficiently. This is exactly what precision agriculture aims to do.

The cover of the October 1965 *Agricultural Education* magazine (fig. 1) shows an image of a "future farm" that was on display at the 1965 New York World's Fair. "This image brings back memories of one of my favorite childhood cartoons: The Jetsons. The caption below this magazine cover image includes the terms Remote Control Farming and alludes to the ability to control plant growth rates by prescribing targeted agricultural inputs with different crops. This agricultural vision is now increasingly utilized through precision agriculture."

– John McGee

Figure 1: A vision of an American Southwest farm of the future from the 1964-65 World's Fair in New York. "Irrigated by desalted water pumped from the seas or artesian wells, the mineral-rich desert sands produce a number of harvests each year. A futuristic farmhouse, a station from which the farmer remotely controls the machines with which he tills his fields." SOURCE: Futurama Caption Text File (used under license from General Motors).

Getting Started

Small uncrewed aircraft systems are the cornerstone of precision agriculture. Every operation of an sUAS is unique due to an infinite number of variables that can impact a flight, including environmental conditions (weather, landscapes, and wildlife, for example), cultural and social issues (which can include other individuals or structures), sUAS project personnel (everyone has good days and bad days), sUAS software issues, and sUAS hardware performance. This section of the manual provides an overview of some safety considerations, an overview of sUAS rules and regulations, and an example of a checklist. These documents are not intended to provide an inexhaustible list of considerations prior to every flight, but they can act as an initial starting point. Instructors are encouraged to expand these documents based on their own experience.

Overview: Drone Rules and Regulations

Disclaimer: Please follow all local, state, and federal regulations for sUAS aircraft operations. Instructors are advised to consult with their administration to ensure all policies and procedures are followed. The following information is provided as suggested guidance. This information is not intended to be the only source for rules and regulations, which frequently change. For up-to-date Federal Aviation Administration regulations, see https://www.faa.gov/uas/. Questions, clarifications, and interpretations concerning regulations should be directed to the FAA.

Certificates and Registration

- All drone pilots should obtain their Remote Pilot Certificate (RPC, aka FAA Part 107 Certificate) or be under the direct supervision of a certificated pilot when operating a drone.
- The *remote pilot in command* (RPIC) will have all decision-making responsibilities during the flight.
  - The RPIC has the final authority and direct responsibility for the safe operation of the drone.
  - The RPIC should contact risk management or other authority before conducting flights on school grounds.
- All aircraft weighing more than 0.55 pounds should be registered with the FAA and the registration number should be placed on the aircraft. See "FAA DroneZone" below for information on registering a drone.

Operating Requirements

- If operating within 30 minutes of morning and evening *civil twilight*, the aircraft must have an anti-collision light that is visible for at least 3 miles.
- Any equipment attached to the aircraft must be secure and not impact the flight performance (e.g., balance). All aircraft should weigh less than 55 pounds at takeoff.
- Airspace
  - Drone flights are permitted only in Class G (unregulated) airspace. Please check FAA Sectional Aeronautical Charts (https://www.faa.gov/air_traffic/flight_info/aeronav/productcatalog/vfrcharts/sectional/) to ensure the entire flight remains in Class G airspace.
  - The maximum allowable altitude is 400 feet above ground level, and the maximum aircraft speed is 100 mph.

- Check for *Notices to Air Missions* (*NOTAMs*) and Temporary Flight Restrictions (TFRs) during flight planning and before takeoff. A few good sources are https://www.faa.gov, https://www.skyvector.com, and https://www.1800wxbrief.com.
- The pilot must always maintain visual line of sight while operating the drone. The use of visual observers as part of a flight plan is beneficial, but a pilot or an observer can only be responsible for one aircraft at a time. Observation must be unaided (no binoculars).
- Be aware that the Virginia High School League (VHSL) has issued a TFR for all sporting events.

FAA DroneZone

- Create an account with the FAA DroneZone (https://faadronezone.faa.gov/#/) to register drones, request a waiver, and/or report an accident.
- Accident Reporting (responsibility of the RPIC).
  - Report drone accidents that involve serious injury, loss of consciousness, or property damage of at least $500 to the FAA within 10 days.
  - Part 107 Accident Reports can be submitted and reviewed through FAA DroneZone accounts.
- FAA Waivers.
  - The FAA can issue waivers to certain requirements of Part 107 when operators demonstrate they can fly safely under the waiver without endangering other aircraft or people and property on the ground or in the air.
  - Some examples are flying at night, beyond visual line of sight, or over people. For more information, see https://www.faa.gov/uas/commercial_operators/part_107_waivers/.
  - Part 107 Waivers/Authorizations can be created and managed through FAA DroneZone accounts.

Sample Checklist

sUAS (Drone): DJI Checklist (GeoTEd-UAS)

This checklist is specifically developed for a DJI MAVIC, but it can be modified and applied to any sUAS.

Preparation: Before you walk out the door

- [ ] Check to make sure that your operational area is in a safe flight zone.
    - Class G: SkyVector and B4UFLy
    - NOTAMS
- [ ] Check DJI's GeoZone to see if the drone requires unlocking (https://www.dji.com/flysafe/geo-map)
- [ ] Check weather conditions - wind, temperature, etc.
- [ ] Check for firmware updates
- [ ] Check for DJI GO 4 app updates
- [ ] Flight planning
    - Plan flight route
    - Review manual flight procedures
- [ ] Make sure flight area is free of obstacles (powerlines, trees, structures, people, etc.)
- [ ] Charge the:
    - Drone batteries
    - Remote controller (RC) batteries
    - Tablet / iPhone
- [ ] Inspections
    - Inspect overall aircraft / props / motors for damage
    - Inspect battery for damage

Make sure items are present

- [ ] Remote Pilot Certificate(s)
- [ ] Mavic Pro Drone
- [ ] Batteries
- [ ] RC
- [ ] Foldable propellers
- [ ] Micro SD card
- [ ] Phone or tablet with DJI GO4 installed
- [ ] Cable to connect RC to phone

Prepare the aircraft

- [ ] Extend propellers
- [ ] Remove gimbal cover(s)
- [ ] Attach camera filters (optional)
- [ ] Insert Micro SD card
- [ ] Unfold the controller antennas
- [ ] On the side of the RC, make sure "Sport" mode is off
- [ ] On the Mavic Pro, make sure the mode switch is set to "RC"
- [ ] Set the drone on a flat, level surface
- [ ] If using a phone, attach to the RC
- [ ] If using a tablet, attach the tablet and tablet adapter to the RC

Powering up

- [ ] Turn on phone and enter the DJI GO 4 app
- [ ] Turn on the RC
- [ ] Turn on the Mavic Pro
    - Lights will flash on the bottom of the Mavic Pro
    - The Mavic Pro will make the "DJI chime" (for lack of a better term)
    - The gimbal will move
- [ ] Connect Mavic Pro to DJI GO 4
- [ ] Adjust camera settings
- [ ] Wait for GPS & Compass
- [ ] Calibrate if needed
- [ ] Set a good return to home point
    - Check "READY TO GO GPS" in upper left of controller
    - Check minimum "RETURN TO HOME ALTITUDE" setting
        - Take into account trees, structures, powerlines, netting

Begin Flight

- [ ] Hold both of the sticks to the middle-center
- [ ] Let Mavic Pro idle and inspect for irregular vibrations or movements
- [ ] To launch the Mavic Pro, press the left stick up and the Mavic will take off.
- [ ] To stop the Mavic Pro, press the left stick down and the propellers will stop.
- [ ] Press "Record"
- [ ] Hover to check for irregular vibrations, movements, &/or sounds

Post Flight

- [ ] Inspect the drone, the batteries and propellers
- [ ] Record anomalies
- [ ] Complete the battery log
- [ ] Complete the flight log

Notes:

Drone Safety

Disclaimer: Please follow all local, state, and federal regulations for drone operations and be sure all school (or other entity) policies are followed. The following information is provided as a set of recommendations and is not meant to be the only source for safety and regulations.

Before Flight

Complete a Preflight Inspection

Follow all manufacturer recommendations before powering on the drone. A sample preflight checklist is provided prior to this section. Note that manufacturer recommendations always take precedence. Items to inspect typically include:

- Propellers – Ensure there are no nicks, cracks, or bends.
  - Damaged propellers should never be flown. Never attempt to repair propellers.
  - Carbon fiber propellers should never be used when flying with students unless a specific mission would require their use. Carbon fiber propellers can cause serious injuries during an accident.
- Battery – Ensure the battery is fully charged and not damaged.
  - Ensure the battery is not swollen or hot.
- Equipment installations – Ensure all equipment is securely attached.
  - Check propellers to ensure they are securely and properly attached.
  - Check the battery to ensure it is properly attached.
  - Secure all panels, doors, or other latching devices.
  - Check the gimbal and camera to ensure they are securely attached.
- Check the aircraft airframe for obvious defects. Be sure:
  - Landing gears are secure and straight.
  - There are no cracks in the airframe.
  - All lights are working.
  - If installed, the anti-collision lights are functional.
- Transmitter/controller functioning.
  - Ensure batteries are fully charged.
  - Ensure software is updated.

Clear the Operational and Flight Areas

- Ensure a safe and clear operational area.
  - Ensure that the RPIC as well as any other flight crew such as Visual Observers (VOs) are in an area where they will not be disturbed or distracted.
  - Consider using caution tape to designate a crew area with a buffer to prevent people from entering the area of operation.
  - Ensure your flight will not travel over people unless they are crew members or an FAA waiver has been obtained.
- Check current and future weather conditions.
  - Ensure at least 3 statute miles of visibility.
  - Be sure the maximum flight altitude is at least 500 feet below clouds.
  - Be sure the flight pattern is at least 2,000 feet horizontally from clouds.
  - Print the most recent METAR (Meteorological Aerodrome Report) for your records.
  - Check to determine if temperatures could be lower than 40 degrees Fahrenheit, which will impact battery performance.
  - Assess the chance for icing at any flight altitude.

- Ensure that you are clear to operate in the airspace.
    - Ensure that you are operating in Class G airspace.
        - If not, acquire a Low Altitude Authorization and Notification Capability (LAANC) through one of the FAA approved LAANC UAS service providers at https://www.faa.gov/uas/programs_partnerships/data_exchange/#approved or a waiver at https://www.faa.gov/uas/commercial_operators/part_107_waivers/.
        - Check for Notices to Air Missions (NOTAMs) (https://notams.aim.faa.gov/notamSearch/nsapp.html#/).
    - Acquire permission from owner if operating over private property.
    - Check for drone restrictions over public lands.

Drone Flight Operations

Indoor Environment

Flying indoors can present different challenges than flying outside. In addition to following all safety recommendations, please be especially mindful of the following circumstances when flying indoors.

- Ensure a safe and clear operational area.
    - Aircraft flight and operational areas need to be kept clear. This can be challenging in a small indoor environment. Make sure to have signage and markers to keep curious observers at a safe distance away from flight areas and operational areas.
    - Walk and scan the flight area before the flight to note any potential safety hazards. Sprinkler nozzles and fire detection equipment can be especially problematic for indoor drone flights.
- Double-check communications signal.
    - Commercial and educational buildings may have strong Wi-Fi signals. These signals can potentially interfere with the communication between the transmitter and the aircraft, most of which communicate on the 2.4 GHz frequency, which is the same as Wi-Fi. If available, use a frequency spectrum analyzer to determine potential interference before a flight.

Outdoor Environment

- Ensure a safe and clear operational area.
    - Many of your missions will focus on natural resources. Therefore, situational awareness will be critical for a safe flight.
    - Walk the flight area before the flight to note any potential safety hazards. Trees and other tall vegetation could create obstructions during your flight. Please note the height of these structures.
    - If your flight path proceeds between tall trees or buildings, please be especially aware of increased wind velocities between these structures.
    - Always maintain visual line of sight with the drone and adhere to other federal and local regulations.
    - Wildlife can create hazards during the flight, but it's important not to impact wildlife negatively – it actually may be illegal to do so. Many species of birds could be territorial or inquisitive. Swallows and martins will often fly near drones. Mockingbirds, crows, and birds of prey could approach or dive at drones. Please be cautious; change flight direction to avoid encountering wildlife.

Safety When Not in Flight

- All equipment should be secured when not in flight.
- Safely store lithium polymer (LiPo) batteries.
    - Store at levels/temperatures recommended by the manufacturer.
    - Use LiPo bags, which are fireproof, during charging and storage.

Module 1: Exploring Precision Agriculture

An Introduction to Agriculture

Agricultural operations are associated with producing goods. Agricultural products can include food for human consumption such as plant-based foods, which can include crops such as wheat, nuts, vegetables, and fruits, as well as meat, including beef (cows), pork (pigs), poultry (chickens), and fish. When domesticated, animals raised for food are referred to as livestock, and livestock needs to eat as well! So, farmers grow plants (corn, grass, hay, etc.) to keep their livestock fed.

In addition to growing food, farming operations also produce other products that people use daily. Cotton and other fibers are grown on farms. Rubber and latex are harvested from plants. Any food purchased at a grocery store was grown on a farm. While it is often taken for granted, it is difficult to overemphasize the importance of agriculture.

Humankind has been engaged with cultivation for approximately 11,000 years. Over this period, agricultural practices have obviously changed. While some of the changes in cultivation practices have been gradual, other changes, often supported through technology, have resulted in abrupt transformations (consider the plow!). These dynamic shifts are sometimes characterized as “agricultural revolutions.” With the onset of precision agriculture, today may be the beginning of such a new agricultural transformation.

Here are links to a couple of videos that provide excellent general information about agriculture and help to set the stage for precision agriculture.

- **Video: “Introduction to Agriculture”** (developed by Dan Swafford, narrated by Chérie Aukland, 10 minutes): https://youtu.be/ICv9o3dexrc.

- **Video: “Introduction to Pesticides and Herbicides”** (developed by Dan Swafford, narrated by Chérie Aukland, 5 minutes): https://youtu.be/kc_Z_itn7Bs.

Overview: What is Precision Agriculture?

In response to increases in world population, which the United Nations estimates will reach 9.7 billion by 2050, traditional agricultural practices and farming operations are experiencing revolutionary changes due to the increasing demand for food and decreasing areas of prime agricultural land (United Nations, 2019). *Precision agriculture* represents a new agricultural approach being implemented by farmers that puts the right amount of resources (water, fertilizer, and pesticides) where they are needed, when they are needed.

In traditional agricultural operations, farmers treat all their fields the same: Agricultural inputs (such as fertilizer, herbicides, pesticides, and/or irrigation) are applied to all areas of an agricultural field, typically with a tractor or aerial sprayer, at the same rate, regardless of whether every area of the field actually requires these inputs.

Soil characteristics within a single field often vary. Some soils may require a particular prescription of nutrients, while other soil types (in the same field) may require different inputs. In addition, different parts of a field can have other characteristics that can impact agricultural production in these areas. For example, the slope or aspect of the terrain can vary across a field. This is especially true along the eastern U.S. and other agricultural regions that involve rolling terrain.

Different aspects and slopes can influence an array of agricultural factors, including water retention, water runoff, temperature, and evaporation rates. Variations in slope may not only impact what is happening above the ground (evaporation) but can also impact what is happening below the surface of the ground (soil composition and characteristics, water, nutrient, and pesticide leaching), as well.

Discussion Topic: Slope and Aspect

Slope and aspect can provide good initial talking points to introduce the concept of variable agricultural conditions across a single field. This is because slope and aspect can often be visually identified (whereas some of the other factors may require closer scrutiny). This lesson might provide a good opportunity to take the students out into a park or playground area and have them visually observe differences in slope and aspect across the terrain.

Slope is the rise or fall of the surface of the land (how steep it is). Here is the formula for calculating slope:

$$\text{Slope} = \frac{\text{The difference in elevation between two points on the terrain}}{\text{The distance between the two points on the terrain}}$$

Aspect is the orientation of the terrain, or the compass direction (cardinal points in degrees) that the terrain faces. Aspect is usually provided using a numeric value, similar to compass direction, with 0 (or 360) representing north, 90 representing east, 180 representing south, and 270 representing west. Flat areas have no aspect. They are typically given a negative value (-1, for example).

How might differences in slope and aspect influence the growth of crops in a field?

Precision agriculture requires accurate data measurements of several characteristics of the area being farmed. One basic characteristic that requires measurement is location. Using accurate location measurements, farmers can measure how much land they have under cultivation.

Farmers also need to obtain additional information about their land, such as variations in soil types and fertility and differences in terrain. Location is important, because farmers need to be able to understand where these differences in soil characteristics and fertility are occurring. And once it is time to harvest, farmers need accurate data about how much crop is harvested and which areas of their fields are producing more abundant yields (i.e., tons of harvested crops per acre), and which areas of the field are producing less than optimal yields. Location and land measurement are essential components associated with precision agriculture. Location solves the question of “where.”

While sensors can provide farmers with basic information, including the “hot spots” (the particular areas of the field that are experiencing vegetative stress), farmers and agricultural specialists must be able to field check and identify the exact problem so they can take the proper measures to correct it. These problems could include soil issues such as pH imbalance or fertilizer imbalance; pest issues, ranging from a fungus and small insects to crop damage caused by larger animals (like bears!); water and irrigation issues (too much or too little); and competition from weeds for nutrients, sunlight, and/or water. In fact, there can be many different issues impacting the same crop on the same field.

Farmers, therefore, need to rely on their experience and knowledge of agronomy. Agronomy is the science (and technology) of producing plants for food and clothes. How well plants grow is dependent on the soil or other substrates where they grow and the nutrients and water available to them. While technology provides increasing amounts of data, it is essential that agricultural operators be able to correctly interpret this data and provide the proper inputs in the proper amounts and at the correct locations to address the needs of the crops and to make their farming operations more efficient.

An Introduction to Land Measurement

Land measurement is an essential component of precision agriculture. Agricultural fields have boundaries; however, humans usually define these boundaries to reflect historic and cultural values (property lines) as opposed to environmental conditions. There are often soil and topographic variations within a single field boundary.

An acre is a standard unit of field measurement in the United States. An acre is based on the imperial foot, as there are 43,560 square feet in an acre. This seems like an arbitrary value, but historically, an acre was defined as the amount of land that a yoke of oxen could plow in a day. Other countries around the world use different units for land measurement. Most other countries use the metric system of hectares, which is 10,000 square meters (i.e., 100 meters x 100 meters). A hectare is equal to 2.47 acres.

In the western U.S., field boundaries often follow historic boundaries that were designated by the U.S. government through the Public Land Survey System (PLSS). The PLSS divides land into sections. A section is a 1-square-mile tract of land. Sections are then divided into quarter sections. PLSS Sections are essentially square and often remain highly visible in many areas of the Western landscape even today. It is easy to observe the 1-square-mile patterns in the landscape from the window of a plane flown over many areas of the Midwest and Western U.S., as these fields may be delineated by roads or windbreaks. Figure 2 illustrates the delineation of land through the PLSS.

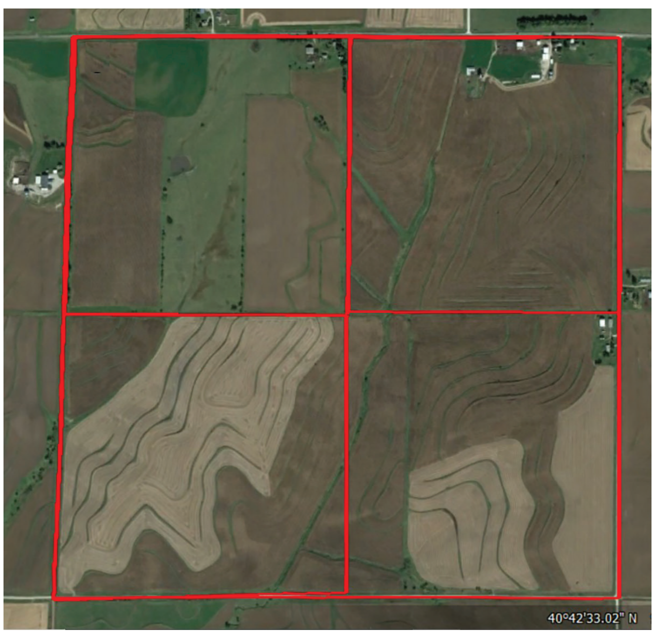


Figure 2: An outline of a PLSS section and quarter sections.

Additional Resources: Overview of Precision Agriculture

Videos:

- **"Introduction to Agriculture"** (developed by Dan Swafford, narrated by Chérie Aukland, 10 minutes): https://youtu.be/ICv9o3dexrc.
- **"Introduction to Pesticides and Herbicides"** (developed by Dan Swafford, narrated by Chérie Aukland, 5 minutes): https://youtu.be/kc_Z_itn7Bs.

PowerPoint Presentation:

- **"Understanding Area Measurements":** https://tinyurl.com/UnderstandingAcreage.

Student Learning Activities:

- Activity 1: Agricultural Inputs
- Activity 2: Exploring Slope and Aspect
- Activity 3: An Introduction to Land Measurement
- Activity 4: Exploring Agriculture Using CROPSCAPE

Notes:

Activity 1: Agricultural Inputs

Refer to these two videos and answer the following questions:

- **"Introduction to Agriculture"** (10 minutes): https://youtu.be/ICv9o3dexrc.
- **"Introduction to Pesticides and Herbicides"** (5 minutes): https://youtu.be/kc_Z_itn7Bs.

1. The three letters on the front of a fertilizer bag represent the percentage of

   ____

   (the answer needs to be in the correct order).
   - N-P-R
   - K-N-P
   - N-P-K
   - P-K-N

2. A bag of fertilizer has the numbers "30-0-10." What do these numbers mean?

3. Explain why N is usually the most important nutrient in producing a corn crop.

4. Explain why N is usually not applied to a soybean crop.

5. Provide an example of a pH value that is:
   - Acidic
   - Neutral
   - Alkaline

6. What element is often applied to a crop when the pH is 5.2 (to raise the pH)?

7. What element is often applied to a crop when the pH is 7.6 (to lower the pH)?

Activity 2: Exploring Slope and Aspect

Let's get familiar with slope and aspect! First, use a formula to calculate the slope of a flat surface indoors. Then, estimate the aspect of that surface. Finally, go outside and estimate the slope and aspect of a nearby hill (or even a slope on playground equipment such as a climbing structure).

Materials required

- A flat surface, such as a book or piece of cardboard. This surface should be between 12 inches and 24 inches long.
- Something to prop the book/cardboard up on one end. Blocks, other books, or a small box will work.
- A tape measure or ruler:
    - A short ruler will work for the indoor activity.
    - Tape measures are better suited for the outdoor activity

Estimating slope (indoors)

1. Prop your flat surface as shown in figure 3 below. Measure the height of the highest point of the surface. This height is also known as the rise.

Now measure the length of the surface to the edge of the hypotenuse as shown in figure 3. This length measurement is known as the run.

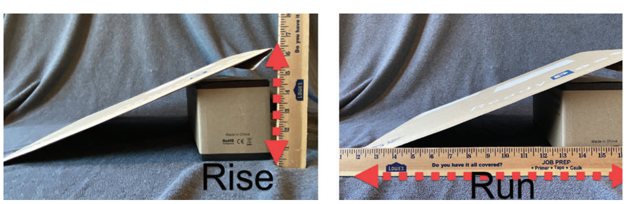


Figure 3: Measuring the rise and run of a slope.

2. To calculate the slope of your surface, complete this equation

$$\text{Percent Slope} = \frac{\text{Rise}}{\text{Run}} \times 100$$

3. Percent slope = ______________

Estimating Slope (outdoors)

Materials needed:

- String or rope.
- Wooden stakes or poles (could be used in lieu of participants holding the string level).
- Tape measure.
- Level (optional)

Activity:

1. Break into groups of three or four participants.
2. Each group should have a line of string 10-30 feet long (flatter terrain may require longer lengths of string).
3. Have one individual stand at the bottom/middle of the slope, holding one end of the string (fig. 4).
4. Have one individual stand at the top of the slope, holding the other end of the string.
5. Participants will need to either use a level or "eyeball" the string to ensure that it is level.
6. One student should measure the height of both ends of the string above the terrain (heights A and B in figure 4).
7. One student should measure the distance of the string (a straight and level line) between A and B.

Use the following formula to calculate the slope:

$$\text{Percent Slope} = \frac{\text{Rise}}{\text{Run}} \times 100$$

$$\text{Percent Slope} = \frac{(\text{Height B} - \text{Height A})}{\text{Distance from A to B (along a straight and level line)}} \times 100$$

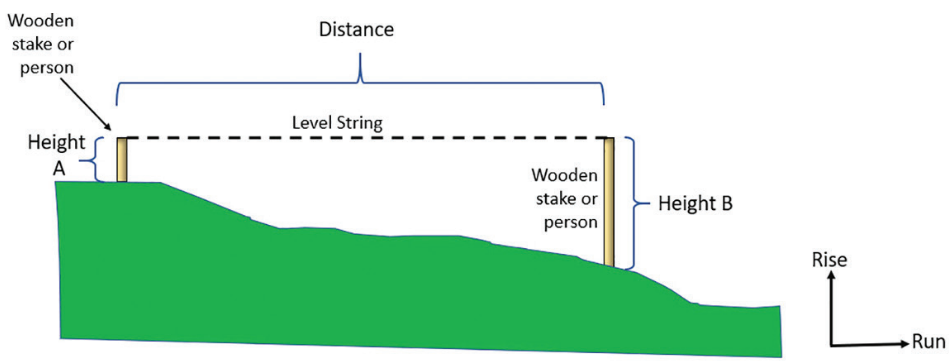


Figure 4: Determining slope in the field. Note that a small string level can be used to ensure that the string is level (or you can eyeball it).

Determining Aspect

Aspect relates to the orientation (or the compass direction) of the slope. Keep in mind where the sun rises (in the east) and sets (in the west) to help to orient yourself and your slope (fig. 5). Aspect can be expressed in cardinal direction (northwest), or it can be more precisely measured using cardinal degree, with north equaling 0 (or 360); east, 90; south, 180; and west, 270. If you have access to a compass, then use it! A compass can provide you with a more precise determination of aspect.

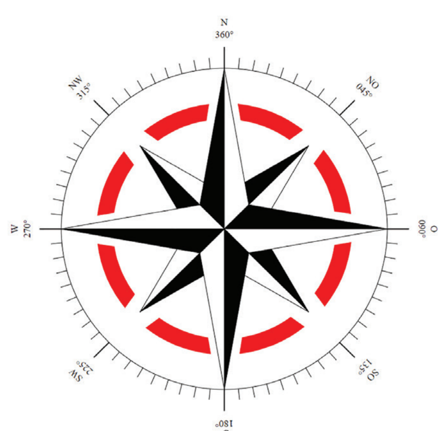


Figure 5: Compass rose with the eight principal winds.

What is the aspect of your slope? ________________

Discussion Box 1: Slope and Aspect – Questions for Further Exploration

- What if you cut your flat surface (so that the run was shorter) in half? Would you expect the percent slope be the same, higher, or lower?
- What if you cut your rise in half (to create a shorter rise)? Would your percent slope be the same, higher, or lower?
- What do you think that the best aspect might be for a sledding hill or a ski slope?
- What do you think that the best aspect might be to support a solar farm?
- Based on the aspect of the slope that you observed (either the indoor or outdoor activity), can you speculate about some of the impacts that the aspect of this slope might have for agricultural production?
- How might the slope of the landscape impact crop production?
- How might slope and aspect influence tree growth on hillsides and mountains?

Activity 3: An Introduction to Land Measurement

Let's Practice Calculating Acreage!

Cool Acre Facts (and a review!)

- An acre of land (historically) was the amount of land that could be plowed by two oxen in a single day.
- An acre is still the basic measurement for a unit for land in the United States (even though we use tractors now!).
- One acre is equal to 43,560 square feet (that's a lot of shoes!).
- Knowing farm acreage is important information for farmers. Farmers need to know the size of their field to estimate how many pounds of seeds to purchase and to estimate other crop inputs (fertilizer, water, herbicide, etc.).
- **Two easy steps for determining acreage:**

    1. Length of Field (ft) x Width of Field (ft) = # square feet.

    2. square feet/43,560 = # acres.

- **How large is a farm?**

According to the U.S. Department of Agriculture's Farms and Land in Farms 2019 Summary, the average farm size in the U.S. is 444 acres. The average farm size in Virginia is about 184 acres. Which state do you think has the largest average farm size? (See the answer at the bottom of the last page of this activity.)

Read the article "Homestead Act," online at https://www.history.com/topics/american-civil-war/homestead-act, and answer the following questions.

1. When the Homestead Act of 1862 was passed, settlers in the West were given a section of land. How many acres did a settler receive?

    a. 40 acres
    b. 160 acres
    c. 640 acres
    d. 1,000 acres

2. One of the requirements of the Homestead Act was to live on the land and establish residency. How many years were settlers required to live on their claims before they were granted ownership?

    a. One year
    b. Three years
    c. Five years
    d. 10 years

3. A farmer has a field that is 600 feet long and 200 feet wide. Determine the number of acres in the field.

4. A farmer has field that is 1,250 feet long and 430 feet wide. Determine the number of acres in the field.

5. Calculate the acreage for the following field (fig. 6, not to scale):

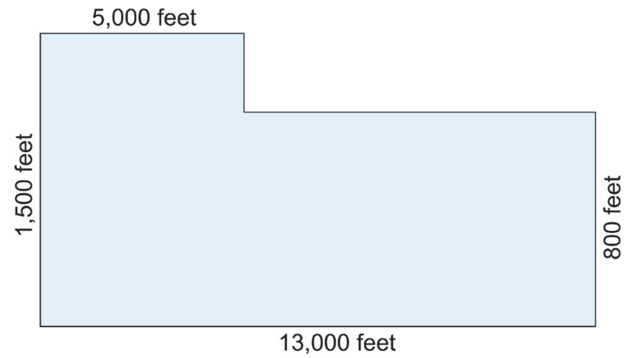


Figure 6: Determine the acreage of this field.

6. In the Midwest, the soil is nutrient-rich, but farmers often depend on irrigation to help their crops mature. Farmers often use center point irrigation (sometimes called circle irrigation). Using circle irrigation, a sprinkler arm rotates around a center pivot point and waters the fields. These arms can be as long as 3,000 feet! Circle irrigation fields are therefore perfectly round. The formula to calculate the area of a circle is $A = \pi r^2$. Calculate the acreage of a central pivot field with a sprinkler arm that is 1,500 feet long (fig. 7).

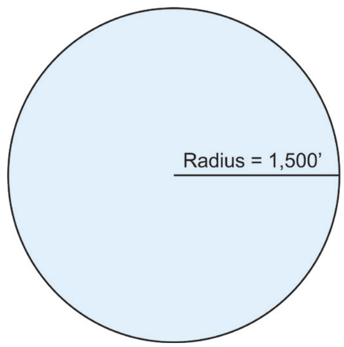


Figure 7: Determine the acreage of a circular field with a radius of 1,500 feet.

$\pi = 3.14$

Radius (r) = ____________

r^2 = ___________

Area of the field in square feet ($\pi \times r^2$) = _____ sq. ft.

Area of the field in acres = ______

(Remember to divide the number of square feet by 43,560 to get acres!)

7. Walk outside your home (your yard or a nearby park) or your school (baseball field or playground) and pick an area to measure. Pick a polygon area that is rectangular in shape (fig. 8).

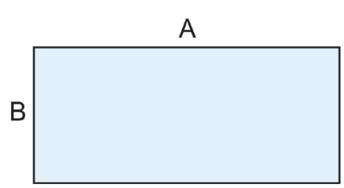


Figure 8: “A” indicates length, while “B” indicates width.

Using a normal step, walk off the length of your chosen polygon (side A).

Enter number of steps here: ________ (the number of steps alongside A)

The average step is about 2.5 feet long. Multiply your answer above by 2.5 to convert the length of your polygon from steps to feet. Note: If you are less than 5 feet 5 inches in height, use 2 as your multiplier instead of 2.5. If you take short steps, use 2 as the multiplier. If you want to get really accurate, you can measure the length of your step (your stride), and use this more precise value as your multiplier!

Enter your answer here: ____________ (the estimated length in feet of side A)

Using a normal step, walk off the width of the polygon (side B).

Enter number of steps here: ____________ (the number of steps alongside B)

Multiply the number of these steps by the same multiplier (2.5, 2, or a more precise figure based on your personal stride) as you did to measure side A.

Enter your answer here: __________ (the width in feet of side B)

Let’s convert your measurements to square feet. Multiply the number of feet associated with the length of the polygon that you measured by the number of feet associated with the width of the polygon (side A feet x side B feet).

________ x _________ = _________ total square feet

An acre is 43,560 square feet. To convert to acreage, divide your answer (total square feet) by 43,560.

How large (in acres) is the area that you measured?

_________ acres

Answer from the first page of this activity: Wyoming has the largest average farm size in the U.S. at 2,437 acres.

Activity 4: Exploring Agriculture Using CropScape

Note: See the appendix for guidance on the Discussion Boxes in this activity.

Core Competencies

This activity covers the following core competencies:

- Explain the importance of agriculture to Virginia and other states in the United States.
- Describe the impact of agriculture on the economy.
- Identify the key factors that have shaped the agricultural industry.

Overview

In this exercise, you will explore agricultural production across the United States through a freely available web mapping application called CropScape, which is available from the U. S. Department of Agriculture (USDA). In this activity, we will explore, visualize, and quantify cropland cover and crop types over time in different areas of interest. We will also compare cropland cover from across different regions of the U.S.

Discussion Box 1: Fun Facts About Agriculture in the USA!

- There are about 2 million farms in the U.S.
- 90% of U.S. farms are classified as small (grossing $350,000 or less a year).
- One U.S. farm can feed 166 people.
- Arizona alone grows enough cotton each year to make more than one pair of jeans for every American.
- Soybean production is key to making crayons.
- Over 92% of the land in Nebraska is farmland.
- Women comprise about one-third of all U.S. farm operators.

Source: https://stacker.com/stories/3554/50-fascinating-facts-about-farming-america.

Farming in the United States is driven by location – **GEOGRAPHY**! The crops that can grow successfully in a specific region depend on a variety of environmental factors and ecosystem services that are location-based: land availability, soil types, weather and climate, elevation, water availability and quality, air quality, pests and diseases, and more. Sometimes these environmental factors can even differ across a single field!

There are also different types of crops that contribute to farming operations and the overall economy in different ways:

- **Feed** crops – food for livestock (e.g., oats and alfalfa).
- **Fiber** crops – for clothing (e.g., cotton and flax).
- **Oil** crops – for consumption or industrial uses (e.g., canola and corn oil).
- **Ornamental** crops – landscape gardening (e.g., roses and tulips).
- **Industrial** crops – for consumer products (e.g., rubber and tobacco).
- **Harvesting** crops – rotational crops (e.g., wheat and barley).
- **GMOs** – genetically modified organisms (e.g., corn and soy).

Source: https://www.nationalgeographic.org/encyclopedia/crop/.

The best way to explore agricultural trends is using maps and charts. We will be using the CropScape web application for this activity. CropScape is a web-enabled mapping application, and it offers several advantages. The data associated with this application has already been collected. This data is served online (so you do not have to locate, format, maintain, and update the data). The application is also maintained "in the cloud" so you need not worry about downloading, installing, and updating software. (However, internet connectivity and a browser are required!)

What is CropScape?

From the U.S. Climate Resilience Toolkit:

CropScape displays data from the United States Department of Agriculture (USDA) Cropland Data Layer (CDL), an annual, remote-sensing snapshot of crop cover during the main growing season across the contiguous United States. Developed within the USDA's National Agricultural Statistics Service (NASS), CropScape is a web-based interactive map visualization, dissemination, and querying system for U.S. cropland. CropScape provides crop-specific land cover data layers created annually for the continental United States using moderate resolution satellite imagery and extensive agricultural ground truthing. Decades of work digitizing field boundaries and confirming crop types led to an automated process by which a computer algorithm interprets the type of crop growing in each field from satellite data.

Within CropScape, users can find data on the type of crop planted in fields each year dating back to 1997. Viewing CropScape within an Internet browser brings the power of geographic information systems (GIS) software to desktop computers, eliminating the need for specialized software, extra computing power, and lengthy training courses. Experienced GIS users who want to download data files and perform their own analyses can do so, but these skills and assets are not necessary to use these valuable tools.

Source: https://toolkit.climate.gov/tool/cropscape.

CropScape (fig. 9) is available online at https://nassgeodata.gmu.edu/CropScape/.

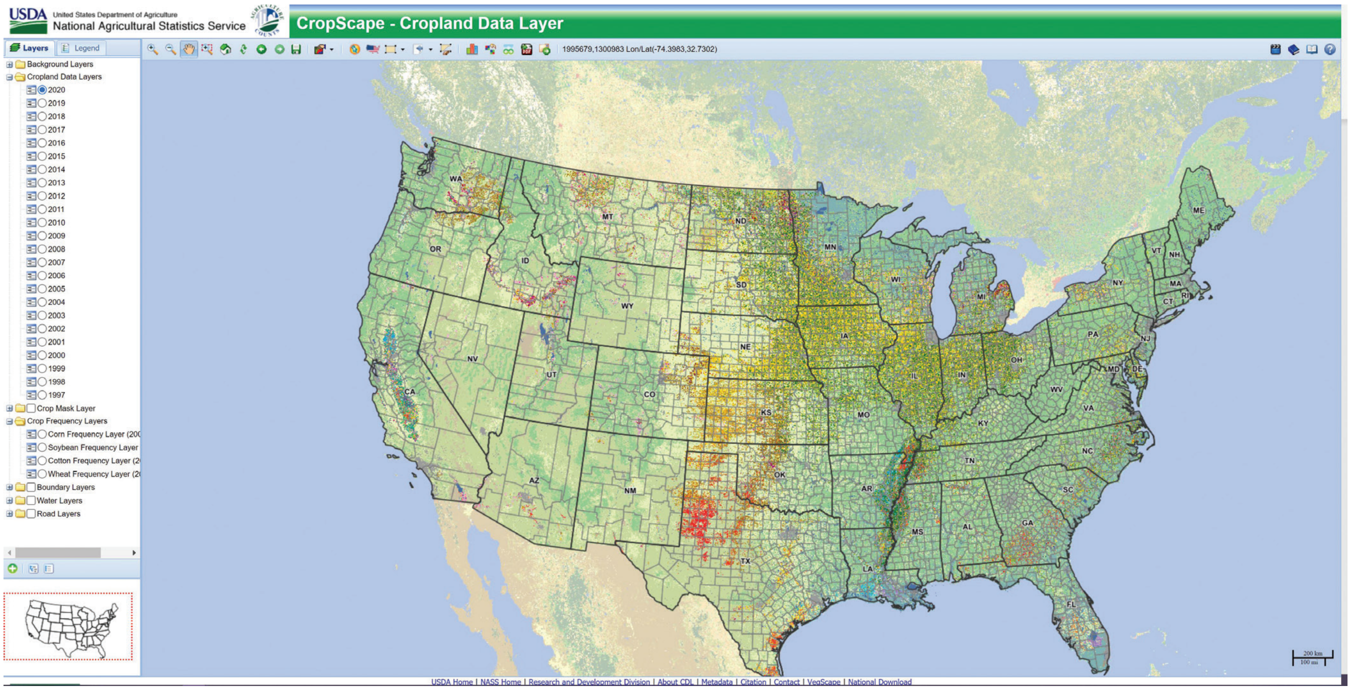


Figure 9: Screenshot of the CropScape – Cropland Data Layer website funded by the USDA National Agriculture Statistics Service.

Before we begin with this activity, let's get familiar with the CropScape Toolbar (fig. 10), Layers (fig. 11), and Legend (fig. 12).

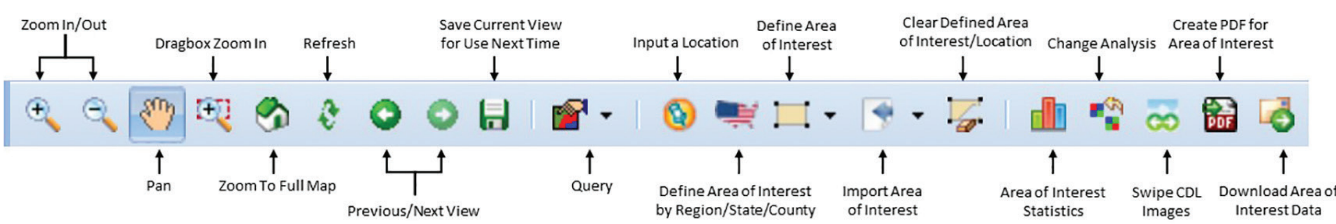


Figure 10: CropScape Toolbar.

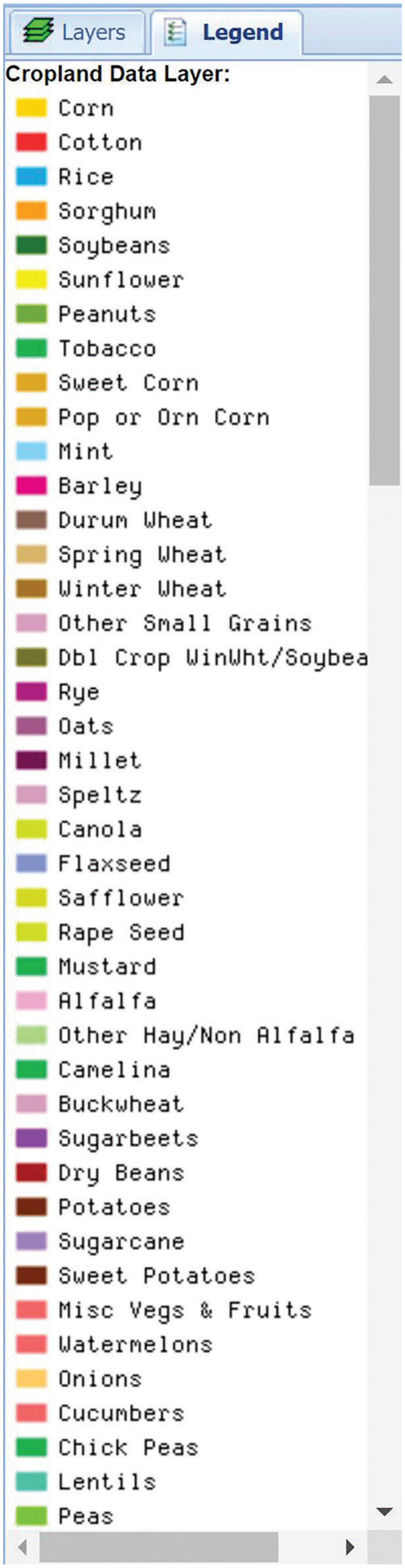


Figure 11: CropScape Layer legend.

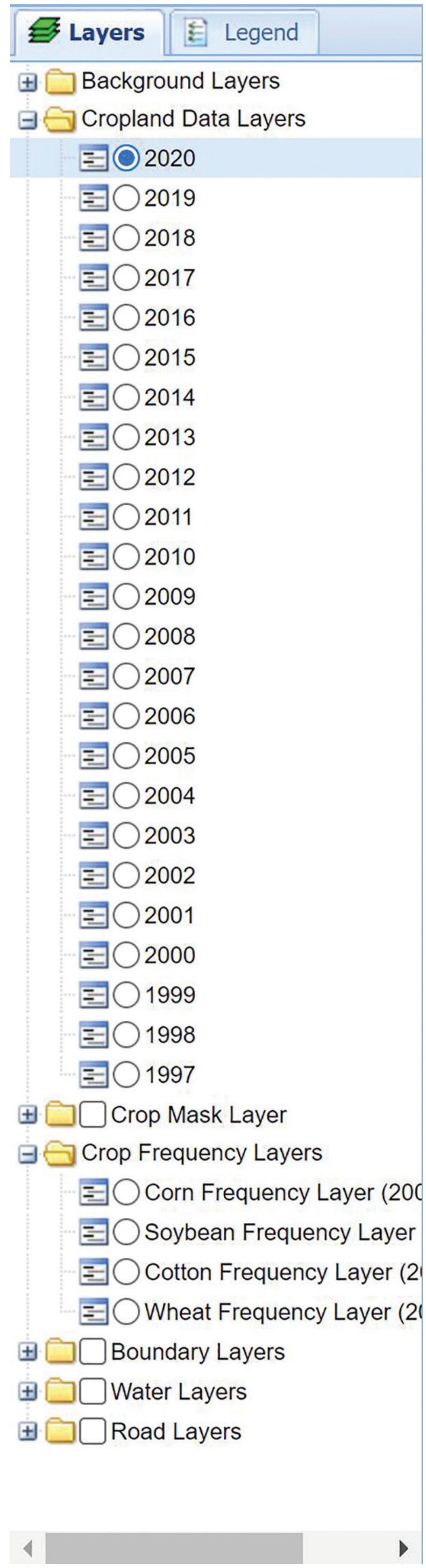


Figure 12: Cropland Data Layer legend.

Getting Started with CropScape

First, we will set up our map for better visualization. Follow these steps or explore on your own!

Go to CropScape at https://nassgeodata.gmu.edu/CropScape/. In the left panel, "Layers," we will do the following:

- Keep the 2021 Cropland Data Layer selected.
- Under the Crop Mask Layers option, check the box for the Crop Mask Layer. Checking this box will only show the cropland pixels, creating a gray background that makes it easier to visualize the data.
- Under the Boundary Layers option, check only the box for State to show state lines for better visualization of the underlying cropland data layers.

After selecting the Layers, your map should look like the image below (fig. 13).

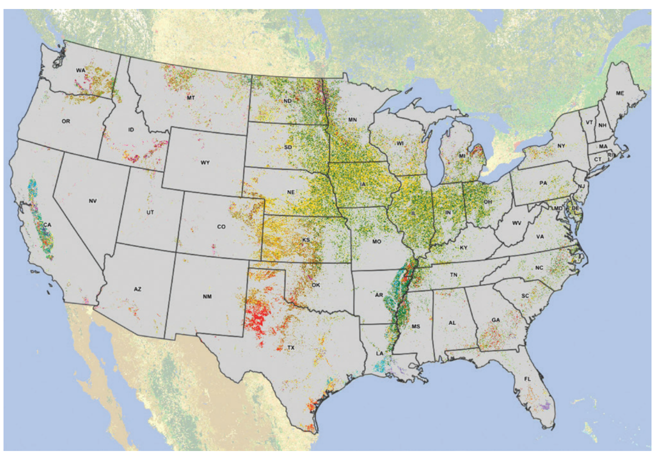


Figure 13: Screenshot showing CropScape map after changing the selections under the Layers panel.

Discussion Box 2: Explore the CropScape Map and Legend

- What are some features that can be identified?
- Do you see the corn and soybean fields in the Midwest?
- Why would there be a cluster of different crop types along the Mississippi River?
- What geographic features cause the strip of cropland running from north to south in California? What is this region called?
- Why might there not be a lot of cropland in Nevada?
- Do you see the dense area of cotton fields in northwestern Texas?

Exploring Cropland in Virginia

1. In the Toolbar, click on the **Define Area of Interest by Region/State/County** tool.
2. In the pop-up box, under the "Select a Level" option, **State** should be automatically selected; if not, choose **State**.
3. Under the "Select a State" option, scroll through the pulldown menu to select **Virginia**.
4. Click **Submit**.

   After the request has been processed, we can view the statistics.

5. In the Toolbar, click on the **Area of Interest Statistics** tool.
6. In the Statistics window, check the box next to **"Display Crop Categories Only."**
7. Double-click on the **"Acreage"** column to organize the list into descending order (biggest to smallest).
8. In the Statistics window's toolbar, click the **Pie Chart** option or the **Bar Graph** option to view graphs of the cropland statistics to answer some discussion questions (figs. 14 and 15).

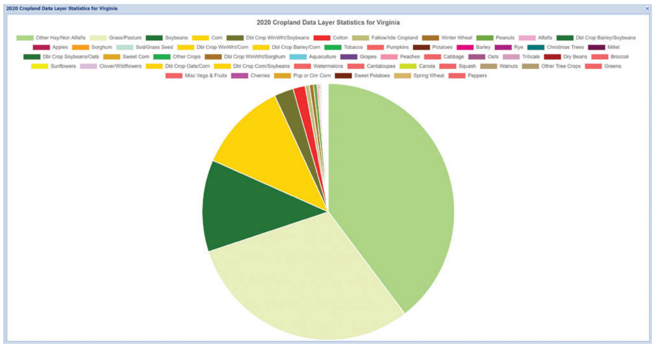


Figure 14: Pie chart of Virginia cropland statistics from 2020.

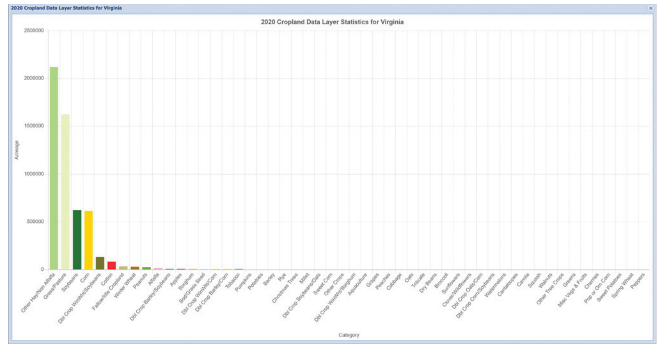


Figure 15: Bar graph of Virginia cropland statistics.

Discussion Box 3:

2020 Cropland Data Layer Statistics for Virginia

- What is the most prominent crop type in Virginia?
- What is the second-most prominent crop type in Virginia?
- What is the least prominent crop type in Virginia?
- What percentage of Virginia's cropland is corn?

Other Interesting Farm Facts About Virginia

- The average farm size in Virginia is 184 acres, which is about the size of Disneyland.
- Virginia has about 43,225 farms.
- Approximately 36% of Virginia primary farm operators are female (that is slightly above the national average!).

Source: Virginia Department of Agriculture (http://www.vdacs.virginia.gov/markets-and-finance-agriculture-facts-and-figures.shtml).

Exploring Agricultural Trends: Iowa

1. In the Toolbar, click on the **Define Area of Interest by Region/State/County** tool.
2. In the pop-up box, under the "Select a Level" option, **State** should be automatically selected; if not, choose **State**.
3. Under the "Select a State" option, scroll through the pulldown menu to select **Iowa**.
4. Click **Submit**.

   After the request has been processed, we can view the statistics.
5. In the Toolbar, click on the **Area of Interest Statistics** tool.
6. In the Statistics window, check the box next to **"Display Crop Categories Only."**
7. Double-click on the **"Acreage"** column to organize the list into descending order (biggest to smallest).
8. In the Statistics window's toolbar, click the **Pie Chart** option or the **Bar Graph** option to view graphs of the cropland statistics to answer some discussion questions (figs. 16 and 17).

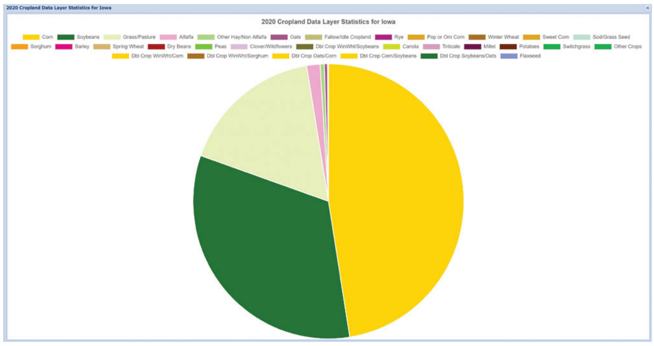


Figure 16: Pie chart of Iowa cropland statistics.

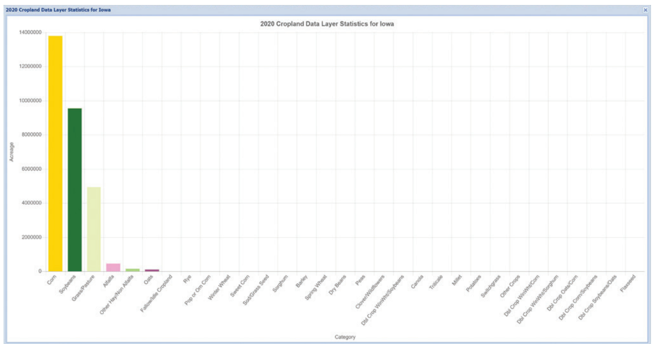


Figure 17: Bar graph of Iowa cropland statistics.

Discussion Box 4:

Discussion Questions on 2020 Cropland Data Layer Statistics for Iowa

- What is the most prominent crop type in Iowa?
- What is the least prominent crop type in Iowa?
- What percentage of the cropland is corn in Iowa?

Other Iowa Farm Fun Facts

- Compared with Virginia, Iowa has less of a variety of crop types, and the majority of cropland is corn.
- The average farm size in Iowa is 359 acres, which is double the size of Virginia farms!
- Why do you think size of farms in Iowa is significantly different than in Virginia?

Exploring Agricultural Trends: The Central Valley of California

Let's try a different area of interest – the Central Valley region of California. This valley stretches from Sacramento to Southern California. Follow the steps from the previous examples to explore agricultural production in California's Central Valley, which is easily seen in CropScape as a densely packed and highly diverse agricultural region that runs from north to south.

In the Toolbar, use the **Zoom** In tool to focus on California.

1. Click on the **Polygon** option under the **Define Area of Interest** tool.
2. Using your mouse, click on the map to draw a polygon around the Central Valley. Click your mouse every time you want the line to change direction. To finish and close the polygon, simply double-click.

   Your new area of interest should look similar to the screenshot below (fig. 18).

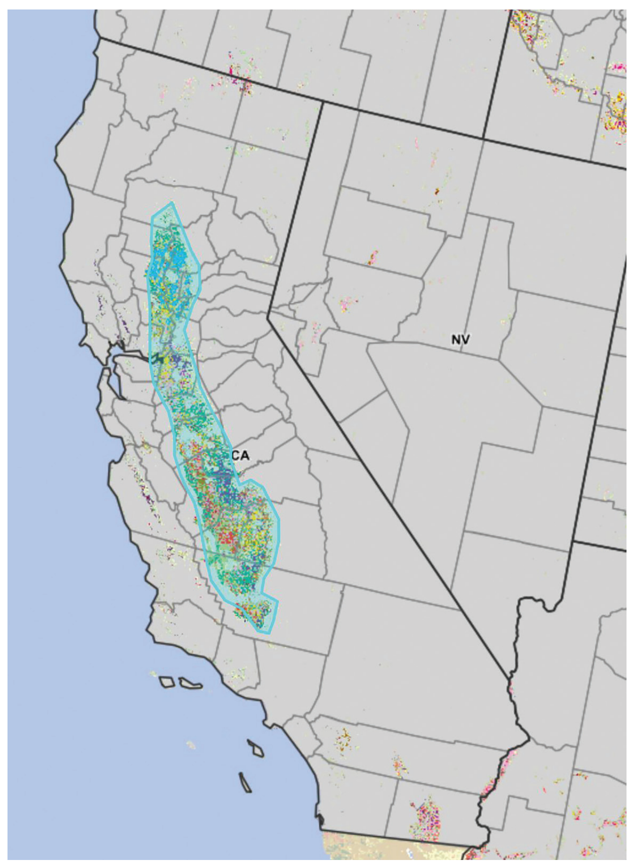


Figure 18: Example polygon of the Central Valley of California.

3. In the Toolbar, click on the **Area of Interest Statistics** tool. 

4. In the Statistics window, check the box next to **"Display Crop Categories Only."**

5. Double-click on the **Acreage** column to organize into descending order (biggest to smallest).

6. In the Statistics window, click the **Pie Chart** option  or the **Bar Graph** option  to view graphs of the cropland statistics to answer some discussion questions. Note that the polygon that was delineated around the Central Valley will differ from person to person. Since the statistics and charts are associated with this polygon, these will also vary from person to person. See figures 19 and 20 for examples.

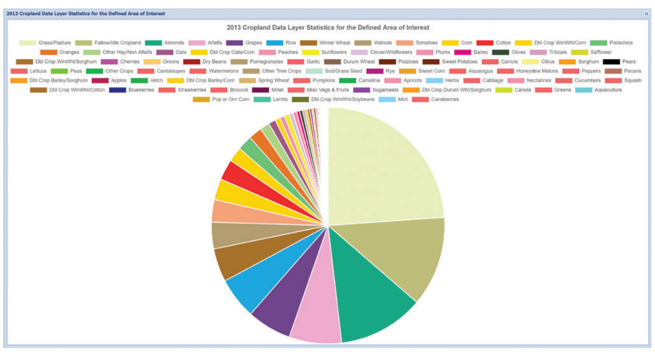


Figure 19: Pie chart of the Central Valley's cropland statistics.

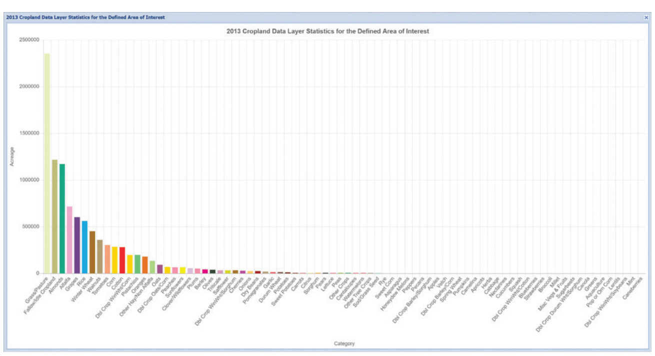


Figure 20: Bar graph of the Central Valley's cropland statistics.

Discussion Box 5:

Discussion Questions on 2020 Cropland Data Layer Statistics for California

- What is the most prominent crop type in the Central Valley of California?
- What is the least prominent crop type in the Central Valley of California?
- What is the Grass/Pasture class used for?

Other California Farm Fun Facts

- Compared with Virginia and Iowa, California's Central Valley has a higher variety of crop types. They are similar to Mediterranean crops (like almonds, grapes, olives, etc.)
- The average farm size in California is 348 acres, which is similar to Iowa, although land is way more expensive in California.
- The Central Valley produces about one-quarter of the nation's food. California produces 66% of the entire nation's fruits and nuts.

Agricultural Exploration - FreeStyle!

Lastly, let's freestyle! Pick your own area of interest (state or region) and explore the agricultural production in that region. With the steps outlined above, choose a new area of interest. Here are a few ideas of what to choose:

- Something local to you – hometown, family farm, or state of residence.
- A meaningful place to you – vacation spot, dream destination, or historical place.
- Interesting anomalies in agriculture across the U.S. – Nebraska is majority farmland while Nevada barely has any farmland, or compare farmland in upstate New York vs. New York City.

CropScape: Other Supporting Resources

- More facts about farming in the U.S.: https://stacker.com/stories/3554/50-fascinating-facts-about-farming-america.

- Download a PDF with U.S. farm reports: https://www.nass.usda.gov/Publications/Todays_Reports/reports/fnlo0220.pdf.

- An overview of CropScape: https://toolkit.climate.gov/tool/cropscape.

- Video demo for CropScape (Zhang, 2021): https://nassgeodata.gmu.edu/CropScape/demo/demo.htm.

- User Guide for CropScape: https://nassgeodata.gmu.edu/CropScape/help/help.html.

- Regional characteristics of California's Central Valley: https://ca.water.usgs.gov/projects/central-valley/about-central-valley.html.

- Download a very detailed PDF explaining the NLCD and CDL layers that are used in CropScape: https://www.nass.usda.gov/Research_and_Science/Cropland/Method/cropland.pdf.

Module 2: Precision Agriculture – Understanding Data

Precision agriculture offers a novel approach compared with traditional agricultural operations. With precision agriculture, farmers use data collected from sensors. These sensors may be located in many different areas of a single field and often are airborne, collecting information from above. Some sensors collect data below the ground (soil sensors), while local weather stations collect rainfall, humidity, and solar insolation data from around the field. Data is also collected from above the ground from sensor *platforms* mounted on tractors, drones, airplanes, and satellites. Data from these various sources is collected and analyzed constantly. When analyzed together, this data serves as the foundation for reports and recommendations that are provided to the farmer to help improve ***agricultural yields***. Simply put, precise agriculture data helps farmers get more agricultural production out of their land.

These reports and recommendations are often provided to a farmer in the form of a map. Maps may show the regions, or grids, of the field where the plants are less vigorous (or less productive), as well as the areas of the field where the plants are growing and thriving more vigorously. This is vital information, as less vigorous or stressed plants produce fewer crops, or lower yields, than healthier plants. Many factors can limit a plant's productivity, such as moisture, nutrients, and pests. When data is collected frequently, the farmer can monitor the status of the fields over time and can therefore identify and quickly respond to problem areas on the field.

Discussion Box 1

Discussion Topic: Why is data Collection Important?

Data collection is the process of recording and collecting observations and information about surrounding conditions. For a farmer, this would include information about conditions in the field. Without collecting data, farmers must rely on visual observations, past experiences, or even a best guess (or a "hunch").

Visual observation is vital in farming and serves as an important source of data. Farmers can visually observe the results of pest infestations on crops and the consequences of a lack of water or nitrogen on crops. However, sensors can often provide information about these issues (pests, water stress, nitrogen deficiency, etc.) before the stress is visually apparent. This enables farmers to isolate the problem and provide proper treatment before it spreads to other parts of the field. Using sensors, farmers can almost look into the future! Farmers are also often dealing in fairly large areas. It may be difficult for them to identify small problem areas from the ground because so many areas are overlooked. Perspective is also important. A farmer can learn a lot about the field just by looking at it from above as opposed to looking horizontally at it while standing on the ground.

Some examples of data that might be important to farmers include precipitation and/or irrigation amounts, soil moisture levels, soil type and texture, nitrogen levels, soil pH, air temperature, soil temperature, humidity, evapotranspiration (water loss from the plant to the air), disease and the presence of other pests, and overall plant health. Each of these factors can affect farmers' ability to get the most out of their land. And as mentioned, data associated with each of these variables is typically not consistent across a given field.

Recommendations that lead to informed decisions that are supported by data are referred to as "data-driven decisions." Data helps farmers make better decisions that can increase yield. This results in lowering costs and increasing yields.

Using map images as prescriptive guides, the farmer can identify and locate the areas of the field that are less productive (fig. 21). This information provides an initial filter and directs the farmer's attention to the areas in the field that may require attention. The farmer, and potentially other agricultural specialists, may need to physically visit the highlighted areas of the field to determine the specific issues that are causing plant stress. For example, plants in a certain location of the field may be infested with insect pests. While the sensor can show that these plants are stressed, the sensors cannot necessarily provide information about what is causing the stress, or, in the case of insects, which species is causing the stress. In this example, identifying the general issue (insect infestation) and the specific species (of the pest) through field visits is critical to identify the correct treatment application. Based on all this collected information (from both the map imagery collected and the field visits), the farmer can prescribe specific techniques to help maintain vegetation vigor and maximize yield. These prescriptions are site specific, as the inputs and techniques can vary from one part of the field to another.

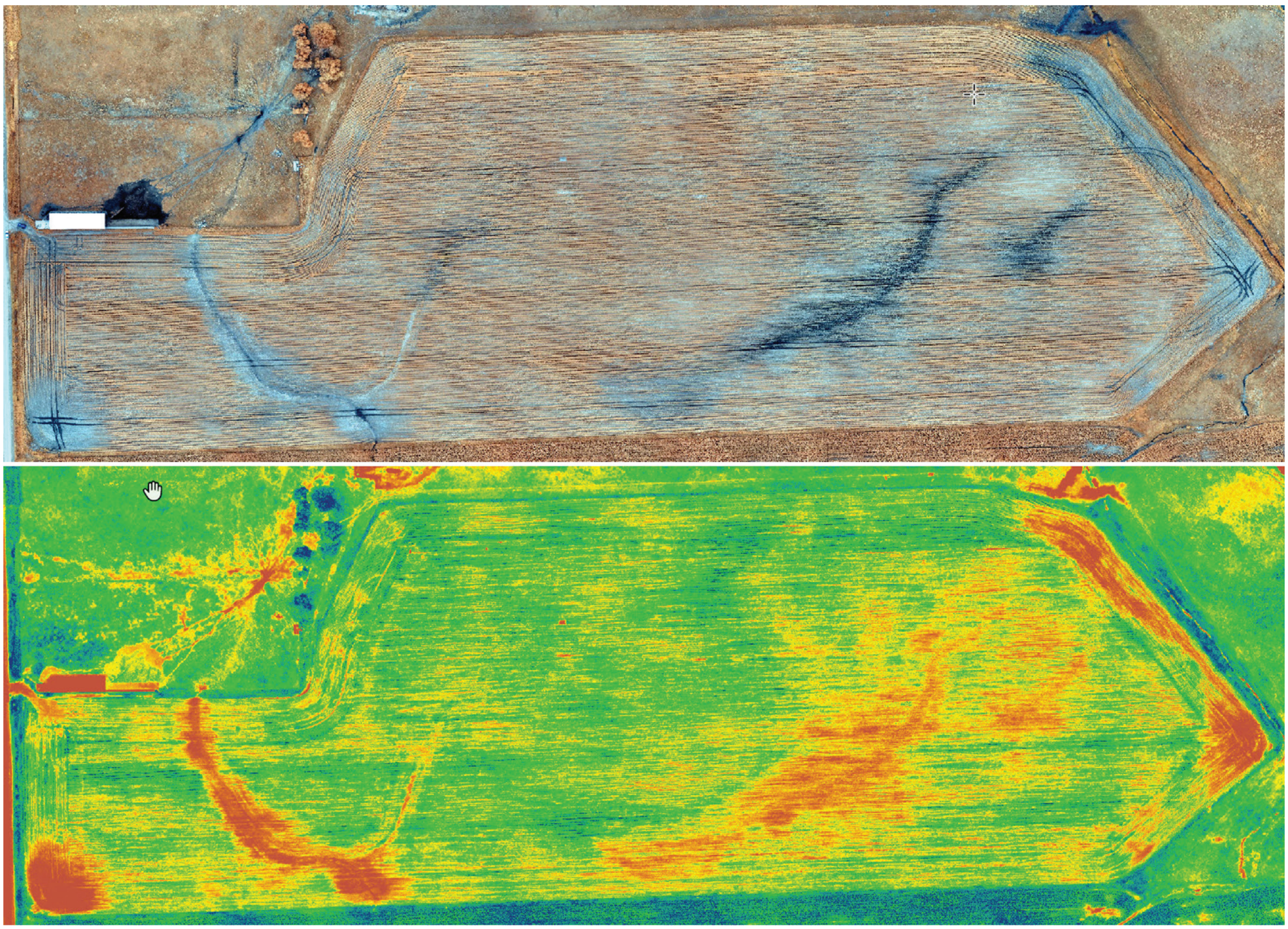


Figure 21: Images of the same field visualized in different band combinations. The upper image is a composite image consisting of the blue, green, and the NIR (near-infrared) bands. In this image, these bands are illuminated by using different intensities of blue color, green color, and red color, respectively. In the image, exposed soils appear as grayish blue. The lower image shows a classified map that was generated using the Green Normalized Difference Vegetation Index (GNDVI: NIR band - Green band/NIR band + Green band). A GNDVI image uses data from outside of visible wavelengths (including near infrared light reflectance) to measure variations in photosynthetic activity over a given field. This index may be used to determine the need for additional water and/or nitrogen. Areas of the field in red (in the lower image) represent wet, bare earth, residues of previous crop the plants, and higher stressed plants, whereby areas in green represent higher levels of vegetation vigor. This information is used to inform farmers about fertilizer and other soil enhancement requirements within a given field. *(Source: Jiyul Chang, South Dakota State University. Used with permission.)*

Through precision agriculture, fields are often divided up into zones or grid cells (Figure 22). Depending on the size of the field, the type of crop, and the technology being used, grid cells can vary in size. Some farming operations and applications use a grid size of 100 feet by 100 feet or larger, while others may implement grid sizes of a few square yards, a few square feet, or even smaller. Even though the same crop is being grown across the entire field, different quantities of inputs, such as nitrogen (for example) can be applied to each grid cell. These quantities are all driven by the integration of data that is collected by sensors. **Precision agriculture, when properly utilized, can increase *crop yields*. These techniques are implemented in order to fine-tune growing conditions to help the farmer in *maximizing yields* while minimizing costs.**

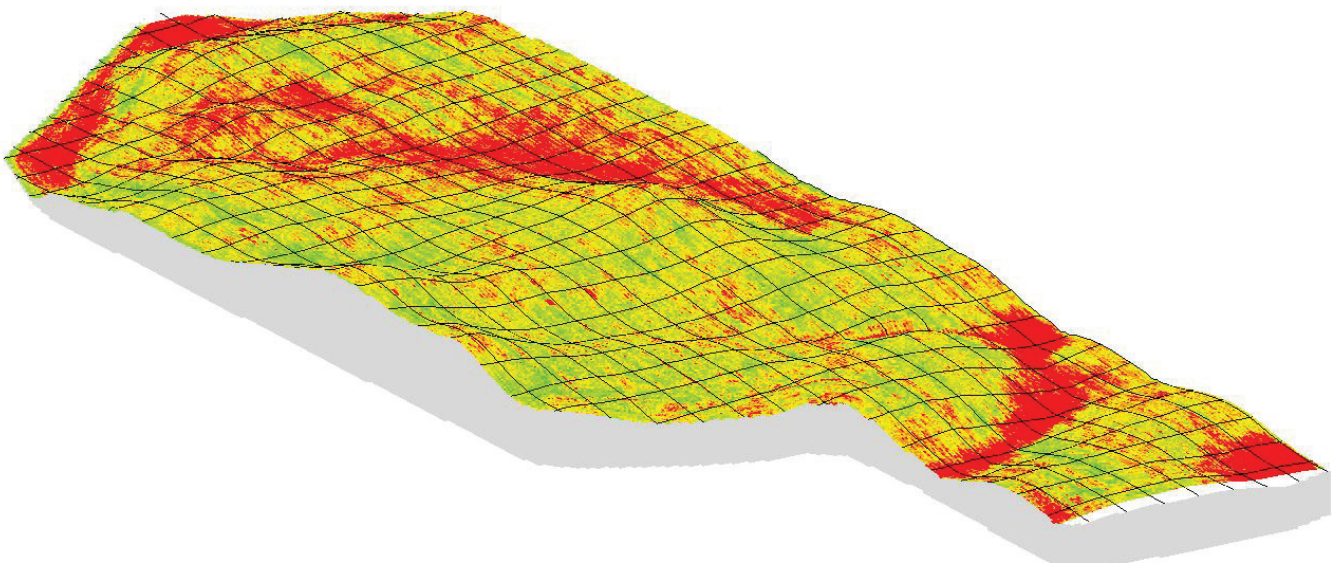


Figure 22: An example of a gridded field that includes topography. This field, which is the same field as in figure 21 but shown from a different orientation, has been classified using the GNDVI index. It shows crop density variations of a soybean field. Green areas are those with higher plant densities. Red areas are areas of plant residue or wet soil, not green plants. Note the correlation between lower topography and lower plant densities. Different applications can be precisely applied by grid cell to target the needs of the plants most efficiently *(Source: Jiyul Chang, South Dakota State University. Used with permission.)*

The Benefits of Precision Agriculture

In addition to increasing agricultural production, precision agriculture can be a good economic tool for farmers. Applying agricultural inputs such as fertilizers, pesticides, herbicides, and water is an expensive process. Farmers can save money by applying these inputs only in prescribed amounts to the portions of the field, or grids, where they are needed, instead of applying inputs at the same rate/amount across the entire field. This practice is often referred to as *variable rate application*. Variable rate application is an important component of precision agriculture.

Variable rate application has several benefits, and these benefits can extend from the farmer to the environment, and even to the consumer. If farmers use variable rate application technology effectively, they will likely need to use less fertilizer or other inputs because they are only spot treating parts of the field with the amounts necessary instead of treating the entire field with the same application amount. Doing this can result in tremendous cost savings, as fewer inputs (e.g., pounds or even tons of fertilizer) would need to be purchased. Farmers who successfully implement precision agriculture can realize cost savings of many thousands of dollars each year, while at the same time maintaining or even increasing yields. This can result in higher profits for the farmer, and a portion of these cost savings can potentially be extended to consumers through lower food prices.

In addition to providing economic benefits to the farmer (and potentially to the consumer), precision agriculture can also benefit the environment. The overuse of agricultural chemicals (also known as agrochemicals, which can include chemical fertilizers, herbicides, insecticides, fungicides, algaecides, nematicides, and rodenticides) or organic inputs such as manure can result in *agricultural runoff*, which can pollute surrounding soil and waterways.

Some of these inputs can leech into the soil and accumulate over time, negatively impacting soil quality. Some inputs become airborne and can drift with the wind. These inputs can affect the health of nearby wildlife, including fish, frogs, birds, and mammals, and of people, as well. When correctly implemented, precision agriculture results in more sustainable and environmentally friendly agricultural practices through less agricultural runoff. Thus, precision agriculture can benefit the farmer, the consumer, and the environment.

How Does Precision Agriculture Work?

The cornerstone of precision agriculture is accurate data and information. Without accurate information about the conditions of the soil, crops, and field, and without good *spatial information* about the field (knowing exactly where in the field the collected data is from), a farmer would not be able to identify and isolate the areas of fields that are stressed. Accurate spatial information is vital for a farmer to effectively implement precision agriculture techniques.

Discussion Box 2

Questions for Discussion: Data Collection

- Can you name several informational items (several types of data) that a farmer might want to collect in order to manage fields and potentially increase crop production?
- How might this data best be collected (procedures, frequency, resources required, etc.)?
- How could the farmer automate the data collection process?

One important piece of data that supports precision agriculture practices is spatial data. Spatial data is information that provides a location tied to the surface of the Earth through *coordinates*. *Geographic coordinates* are the foundation for *spatial location* information. Just as every home has a street address, every mountaintop, every tree, every rock, and every plant on the Earth's surface has a coordinate address! These coordinates are essential to developing maps and to providing reports for farmers.

Coordinates are often provided using *satellite constellations* in Earth's orbit, including the *Global Positioning System* (GPS). GPS, along with other satellite navigation systems, comprise the *global navigation satellite system* (GNSS) that supports vehicle navigation (including applications like Waze, Apple Maps, Google Maps, Uber, and other digital navigational aids) and handheld devices used for geocaching or hiking. These satellites orbit at roughly 12,000 miles above the Earth's surface. Coordinate information, provided by GNSS, is increasingly being used in agricultural machinery, including tractors and harvesters, for *auto-steering* and to support planting and crop management. *Latitude and longitude* coordinates are associated with all the data sensors in and around a field. The data collected by these sensors are also associated with the coordinate address information, so that the data collected can be traced back to a specific location in or around the field. Even data collection platforms located on moving vehicles, including tractors operating on and around the fields, and/or small uncrewed aircraft systems (also known as drones) operating above the fields, collect latitude and longitude data. Since all the collected observations, such as plant stress, are imprinted with coordinate information, this data can be easily integrated together on a map. Farmers who practice precision agriculture rely on these coordinates to navigate to problem areas in their fields in order to conduct field verification using the map coordinates, which are most often expressed in latitude and longitude.

A farmer needs to know exactly which areas of the field are performing poorly. With this information, the farmer is able to focus inputs just on these particular areas. A farmer, therefore, uses coordinates, provided by GNSS, to identify these areas on the field (identified on a map or in a report) and then uses these coordinate values to travel (on foot or tractor) to this exact location in the field for further inspection and to verify the source of the vegetation stress. So, even though the sensors identify the areas of stress, there is a human element that is vital – the farmer or other agricultural specialist must be able to identify what is causing the stress in the vegetation and how this stress can be mitigated in order to provide corrective measures.

Discussion Box 2

Questions for Discussion: Data Collection

Most people have heard about the Global Positioning System (GPS). But what is GNSS, and how does GNSS relate to GPS? GPS is a satellite constellation system that was developed by the U.S. government to aid with navigation, and it was the first satellite navigation system. However, GPS is not the only game in town, as other countries (and other international organizations) have developed their own satellite navigation systems. These include (but there are others):

- Galileo – developed by the European Union.
- GLONASS – developed by Russia.
- Beidou – developed by China.

GPS refers to the American-designed satellite navigation system, but GNSS is a general term that covers all satellite navigation systems. This distinction can be important, because most of today's "GPS receivers" are actually GNSS receivers since they receive signals from multiple satellite constellations including GPS, Galileo, and GLONASS satellite constellations. Most car navigation systems and smartphones receive signals from GPS as well as other satellite constellations, so these are also GNSS receivers. Most drones also contain GNSS receivers. This is good for the consumer because data from additional navigation satellites results in increased accuracy.

Additional information on this topic is available from https://www.gps.gov/systems/gnss/.

Precision agriculture relies on data. Sensors provide information about the conditions of the soils and crops. Data sensors are coupled with spatial data (coordinates). The spatial data ties the conditions with exact locations in the field. The coordinate data (latitude and longitude) provides the farmer with location information about the conditions of specific areas of the field. Even data collected from above the field (on a drone) contains spatial information. This means that every pixel associated with each image can relate to a specific, identifiable location in the field. All the collected information is then assigned to a grid cell. The center and corners of the grid cell also have coordinate information to precisely locate the virtual grid network on the field. This is why spatial data is the foundation of precision agriculture. Without accurate spatial data and location information, precision agriculture just does not work.

Precision agriculture can compare data that is collected over time to identify trends in the fields. These data are often called temporal data, as they represent agricultural conditions at a specific date in time. Farmers will collect data over different time periods and will compare this data. This is an important tool to monitor the changes in health of plants over time. *Temporal data* is extremely important to help identify the early emergence of diseases and pests and track the spread of diseases or other pests over a field. Epidemics are driven by spatial and temporal changes.

Additional Resources: Understanding Data

PowerPoint Presentations:

- "Introduction to GNSS," https://tinyurl.com/IntroGNSS.
- "Maps and Coordinates," https://tinyurl.com/MapCoords.

GNSS Student Learning Activities:

- Activity 5: GNSS Exploration
- Activity 6: Reviewing Global Navigation Satellite Systems (GNSS) Concepts
- Activity 7: GNSS Word Search
- Activity 8: GNSS Activity: Play Ball!

Activity 5: GNSS Exploration

1. The instructor(s) will take participants outside and mark a rectangle on the ground (fig. 23). Each side of the rectangle should be between 50 and 100 feet long.

2. Divide participants into groups from one to four members. Each group will have one hand-held GNSS receiver.

3. Give instructions to participants on the basic operation of a GNSS receiver, including:

   a. Turning the receiver on and off.

   b. Identifying satellites.

   c. Navigating to the compass window and learning how to read the compass.

   d. Identifying coordinates (latitude and longitude).

   e. Marking and saving a waypoint.

   f. Navigating to a waypoint or a provided latitude and longitude coordinate.

Note: It may be helpful to reference the GNSS educational handbooks for assistance with the Garmin eTrex series. These handbooks were designed for educators and are available for download online at https://virginiaview.cnre.vt.edu/tutorials/.

4. Walk with participants around the rectangle showing students how to record locations of each corner.

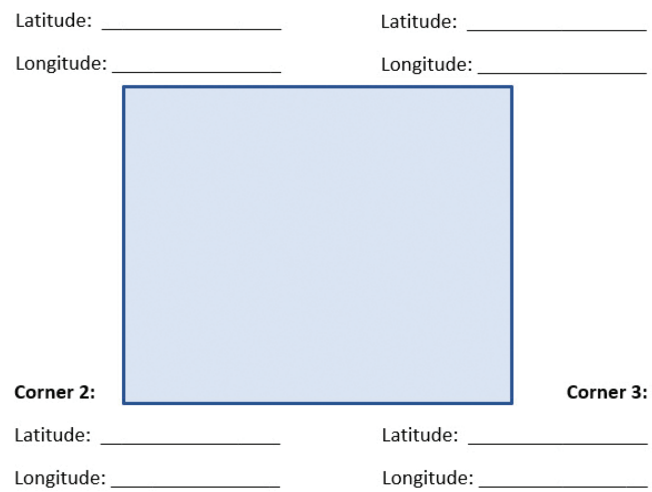


Figure 23: Determining latitude and longitude coordinates for a rectangle.

5. Tell participants to measure the length of each of the four sides of the rectangle and estimate the area of the rectangle using these measurements. Provide their answer here:

6. Using either the digital compass on the GNSS receiver or a compass provided by the leader, tell the participants to identify the compass directions of the four corners of the polygon. Compass directions should be expressed by ordinal name (north, northeast, south, etc.) or by an angle (expressed in degrees, with north = 0 degrees [or 360 degrees], east = 90 degrees, south = 180 degrees, and west = 270 degrees). Note that the digital compass on most GNSS receivers needs to be calibrated. To orient the compass on a GNSS receiver, navigate to the "compass page" and hold the receiver in front of you (face up), and walk in a straight line for about 10 steps (without flipping the receiver around in your hands).

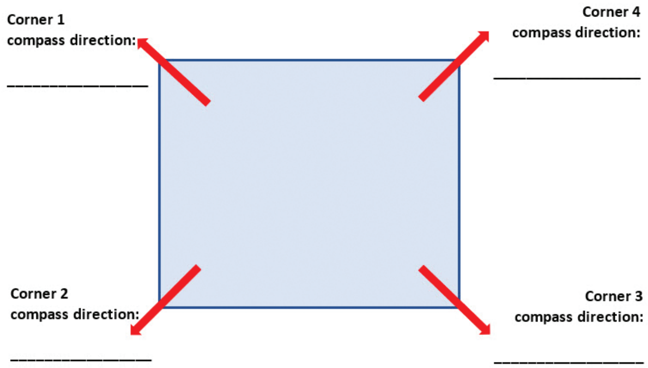


Figure 24: Corner compass directions.

7. After measuring the area and perimeter of the polygon using a tape measure, ask participants to measure the area and perimeter of the same polygon with the GNSS receiver. (Need a refresher? A GNSS tutorial is available from https://virginiaview.cnre.vt.edu/tutorials/.)

8. Write the measurements found using the GNSS receiver here:

   Perimeter (feet): ____________________

   Area (square feet): ____________________

9. Now try the activity using a new shape (a triangle, square, or pentagon, for example). Cones, landscaping flags, the bases on a baseball field, markings on football fields, markings on tracks, etc., can be used to establish boundaries. Tell participants to walk the boundary of the new shape on their own and collect the coordinates of the corners. (Note that this needs to be a polygon with defined corners with an area, not a line or unclosed polygon.) Write down the coordinates in Table 1 (add rows if more are needed).

Table 1	Latitude	Longitude
Corner #1		
Corner #2		
Corner #3		
Corner #4		

10. Tell participants to draw a map of the new shape.

    a. Identify any nearby landmarks (trees, fences, benches, buildings, etc.) on the map.

    b. Label each corner of the polygon shape (similar to the example above: corner 1, 2, 3, etc.).

    c. Use an arrow on the map to identify which direction is "north."

    d. Provide coordinates for each corner of your polygon. Make sure that the corner numbers on your map match the corner numbers below.

    e. Be a Super Mapper! Include a scale bar on your map.

Draw your map below.

Activity 6: Reviewing GNSS Concepts

Note: Students will need to be familiar with the information introduced in this module ("Module 2: Precision Agriculture – Understanding Data") before completing this activity.

1. Explain the GNSS system.

2. Another term for GNSS is ____________________.

3. Explain the difference between GPS and GNSS.

4. What nation created the Global Positioning System (GPS)?

5. Name the three major components of a GNSS.

6. What year was the first GPS satellite launched?

7. Each GPS satellite circles the Earth ____________ times each day.

8. GNSS receivers obtain information from the

   __________________________.

9. What is the basis of GNSS?

10. For a GNSS receiver to determine its elevation, it needs to receive information from how many satellites? (circle the answer)

Two	Five
Three	Six
Four	Ten

Activity 7: GNSS Word Search

Find and circle the following words in the Word Search below.

Precision Agriculture

T	G	A	A	N	R	O	I	A	A	I	I	R	E
O	P	A	O	O	S	R	N	G	M	Y	R	O	T
V	S	U	D	R	U	B	R	R	U	R	A	B	A
N	L	S	A	E	O	I	S	I	A	A	G	O	R
O	A	S	S	V	M	T	M	C	C	T	S	T	E
P	A	N	A	I	O	S	F	U	R	I	O	I	L
R	A	G	T	E	N	B	A	L	G	L	R	C	B
E	M	R	E	C	O	G	R	T	G	I	E	S	A
C	A	L	L	E	T	S	M	U	N	M	T	U	I
I	P	A	L	R	U	B	I	R	N	U	T	L	R
S	P	V	I	M	A	S	N	E	P	I	E	M	A
I	I	I	T	U	N	A	G	N	R	P	M	R	V
O	N	R	E	N	A	V	I	G	A	T	I	O	N
N	G	N	C	E	P	T	C	D	R	O	N	E	I

PRECISION
GNSS
INPUTS
UAV
AGRICULTURE
UAS
FARMING
NAVIGATION
MAPPING
RECEIVER
ORBITS
AUTONOMOUS
DRONE
GPS
SATELLITE
VARIABLE RATE
MILITARY
ROBOTIC

Activity 8: Play Ball with Latitude and Longitude

Determine the latitude and longitude of the infield of a baseball or softball field and map these points on Google Earth. You should capture coordinates in either a decimal degree (DD) format, or degrees, minutes, and seconds (DMS) format.

Latitude and Longitude: What is the difference between decimal degrees (DD) and degrees, minutes, seconds (DMS)?

Just like there are many different ways to represent distance (e.g., inches, feet, yards, miles, meters) there are also many different ways to represent latitude and longitude coordinates. *Degrees, minutes, and seconds* and *decimal degrees* are two options.

Degrees, Minutes, Seconds

Latitude: 37º 12′ 45.32″ N

Longitude: 80º 27′ 59.41″ W

Decimal Degree Equivalent

Latitude: 37.2126º N

Longitude: 80.4665º W

Part 1: Data Collection

A. Travel to the home plate of a nearby baseball or softball field and record the latitude and longitude of its location:

Latitude: ______________________

Longitude: ______________________

B. Go to first base and record the latitude and longitude of its location:

Latitude: ______________________

Longitude: ______________________

C. Go to second base and record the latitude and longitude of its location:

Latitude: ______________________

Longitude: ______________________

D. Go to third base and record the latitude and longitude of its location:

Latitude: ______________________

Longitude: ______________________

E. Head for the pitcher's mound and record the latitude and longitude of its location:

Latitude: ______________________

Longitude: ______________________

Part 2: Data Conversion

Return to the classroom. If you calculated your latitude and longitude in degrees, minutes and seconds, then convert the coordinates to decimal degrees using an online converter ("Satellite Signals" is one of many options: https://www.satsig.net/degrees-minutes-seconds-calculator.htm).

Part 3: Data Visualization

Using Google Earth, enter each coordinate pair into the Google Earth search bar (fig. 25). Make sure that the format of your latitude and longitude coordinates are correct. These can be expressed in degrees, minutes, seconds, or decimal degrees. Latitude always comes first! Also, longitude might be expressed as a negative value in the Western Hemisphere (instead of being delineated as “W”).

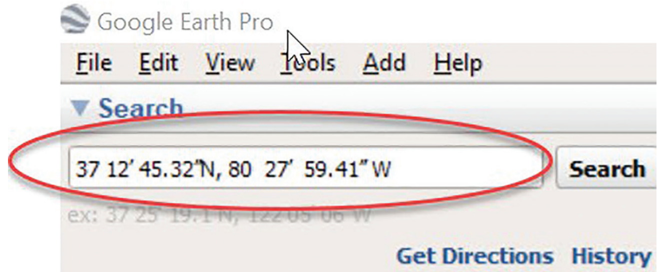


Figure 25: Google Earth search bar with sample of coordinates.

Examine the location provided in Google Earth (see example in figure 26). Did the coordinates that you collected match their real-world locations when mapped onto the Google Earth image? Why or why not?

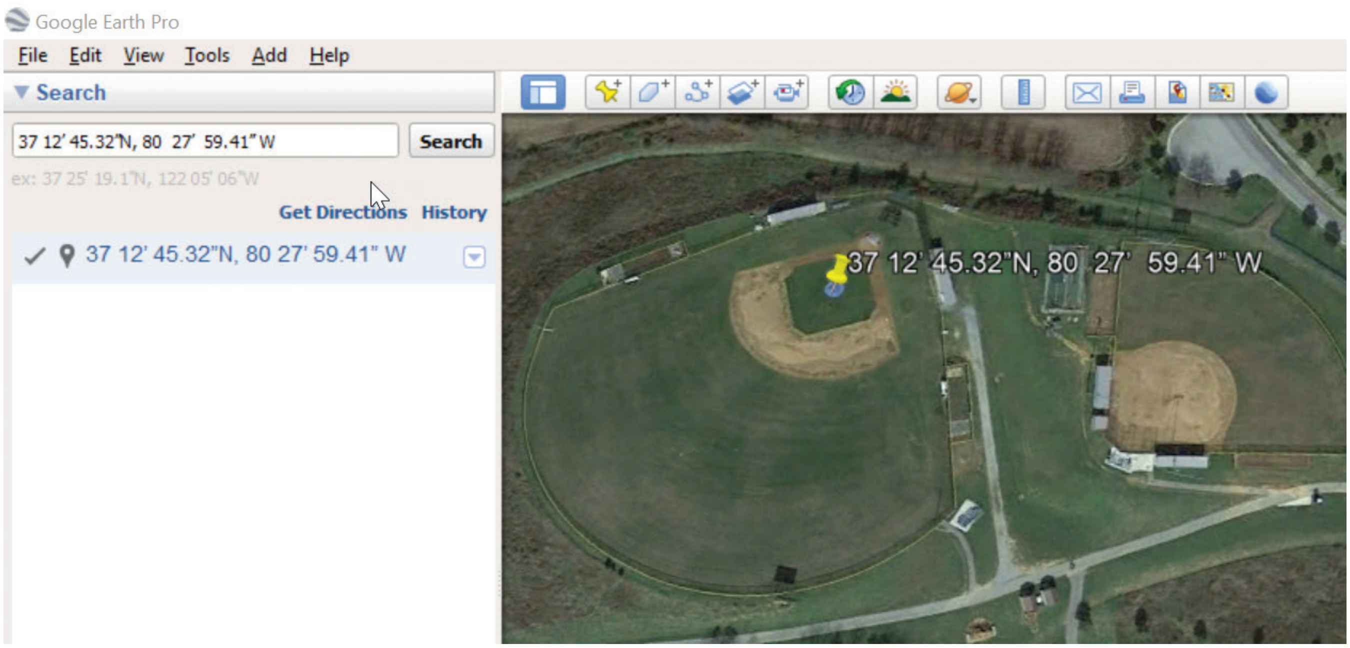


Figure 26: Using Google Earth Pro to open coordinate location.

Notes:

Module 3: Drones in Agriculture

Uncrewed systems are often referred to as *autonomous systems*, or drones. *Drones* can include both airborne systems and systems that are not airborne. Airborne systems are often called uncrewed aircraft, or UA; uncrewed aircraft systems, or UAS; or uncrewed aerial vehicles, or UAV. Systems that are not airborne include terrestrial vehicles that navigate on the land, such as autonomous cars and autonomous tractors, and systems that operate on the surface of the water or underwater, such as autonomous underwater vehicles (AUV) or autonomous aquatic vehicles.

Discussion Box 1

Drones and More Drones

While there are several terms associated with airborne "drones," each term has a slightly different meaning.

- "Uncrewed aircraft" (UA) and "uncrewed aerial vehicles" (UAV) refer only to the aircraft.
- "Uncrewed aircraft systems" (UAS) refers to a collection of components that are required to operate an aircraft. These components may include the aircraft, communication equipment, flight planning software, autonomous flight software, sensors or other payloads, image processing software, etc.
- "Small uncrewed aircraft systems" (sUAS) refers to an aircraft and associated payload (sensor) that weighs less than 55 pounds.
- Drones can be aerial, terrestrial, or aquatic platforms, even though people often associate the term "drones" with airborne aircraft (quadcopters!).

Uncrewed aircraft systems (UAS) are often used to monitor fields to support terrestrial precision agriculture. Can you speculate how farmers might implement uncrewed terrestrial systems (autonomous vehicles) to support precision agriculture? How might farmers use autonomous underwater vehicles (AUVs) to manage agricultural production? What types of farms might be more suitable for AUVs?

Currently, the most important of all these drone platforms is the sUAS (aquatic, terrestrial, and airborne) for traditional precision agriculture applications. When combined with sensor payloads, drones represent the cornerstone of precision agriculture. Although sUAS are used in many different industries, including inspections (buildings, bridges, rooftops, cell towers, etc.), real estate, public safety (search and rescue), natural resource management, and various other industry and economic sectors, precision agriculture represents one of the fastest growing and most promising applications for sUAS, which are most often referred to as drones (Maes & Steppe, 2019).

Using precision agriculture, drone-mounted sensors can serve as an early warning system for problem issues in an agricultural field. Drone-mounted sensors highlight the spatial extent of plant stress in a field. Potentially, these areas of stress can be detected with special sensors before these issues can be visibly detected by humans. It's important to remember that, while sensors can identify areas of the field with stressed vegetation, the sensors are unable to identify the exact reason for the stress (pests, nutrient deficiencies, irrigation requirements, etc.). However, sensor data can be coupled with other data (temperature, humidity, evapotranspiration rates, etc.) and can be employed to estimate the most likely cause of stress. Therefore, precision agriculture requires knowledge about sensors, data, farming operations, and agriculture. A drone alone is not enough! Farmers must also have a command of field management options and of agricultural inputs. Field inspections are critical.

Discussion Box 2

Drone Rules and Regulations

The Federal Aviation Administration (FAA) is the government agency that enforces regulations regarding the operation of aircraft in the National Airspace (NAS). These regulations cover both crewed and uncrewed aircraft. There are rules associated with the operation of drones (even small drones) in the U.S. For a comprehensive list of rules regarding the operation of drones, see https://www.faa.gov/uas/.

Discussion topic: Since drones are so small, why do they require regulation?

A drone is just the vehicle that is used to support precision agriculture. Surprisingly, the most important part of uncrewed data collection is not the vehicle (the drone). The most important part of the vehicle is the **sensor** that is mounted on the drone!

Humans have very accurate and complex sensors. We use our eyes (sight), skin (touch), ears (hearing), and nose (smell) to collect information about our surroundings. Drones can carry some complex electronic sensors as well. These sensors are called *payloads*. Using data collected from these electronic sensors, we can observe and collect data that humans may not be able to see.

Discussion Box 3

Human Observations in Agriculture

- What natural senses do humans use to collect information about agricultural fields?
- What types of observations may give us clues about whether a field is healthy or stressed?
- What are some of the limitations of a purely human approach to sensing?

The Electromagnetic Spectrum

Humans have designed electronic sensors to expand the ability to observe surroundings, to monitor the environment, and to collect additional data that would otherwise not be observable. These digital sensors can be placed around a field or can be placed on drones. Terrestrial drones can continuously move around the field on the ground. Drones can also be airborne and collect data from above the field from a bird's-eye perspective. Some of these airborne sensors detect information and collect data about objects that cannot be detected by the human eye. These airborne drones collect data about fields from a distance, without being in direct contact with the field. This is an example of *remote sensing*. Remote sensing is the observation of an area (or a feature) without coming into direct contact with that area or feature. Since airborne drones (uncrewed aircraft, helicopters, or quadcopters) collect data about the field from above, they are collecting data remotely.

While humans "see" in the visible electromagnetic spectrum, many sensors are able to see beyond this relatively narrow perspective and can therefore extend the range of data collection beyond the human visible spectrum (fig. 27). Sensors, for example, cannot only "see" (and collect data) associated with the human visible spectrum, but these sensors can also "see" (and collect data) in other regions of the electromagnetic spectrum as well. This is important, because the early clues that plants are stressed often are observable only outside of the human visible spectrum. Without sensors, humans would be unable to detect these early signs of stress in plants. This additional information gathered by electronic sensors can provide farmers with an advance warning that some of their crops are not healthy. The advanced notice enables the farmer to quickly identify the source of the plant stress and respond to the specific needs of the plants. Beyond the advanced notice, expanding what the sensor can "see" greatly improves the ability to differentiate the specific cause of plant stress. For example, certain wavelengths are closely associated with moisture stress (plants need water) while others are more closely associated with chlorophyll content (plants need nutrients, such as nitrogen). This early detection is necessary to maximize yields.

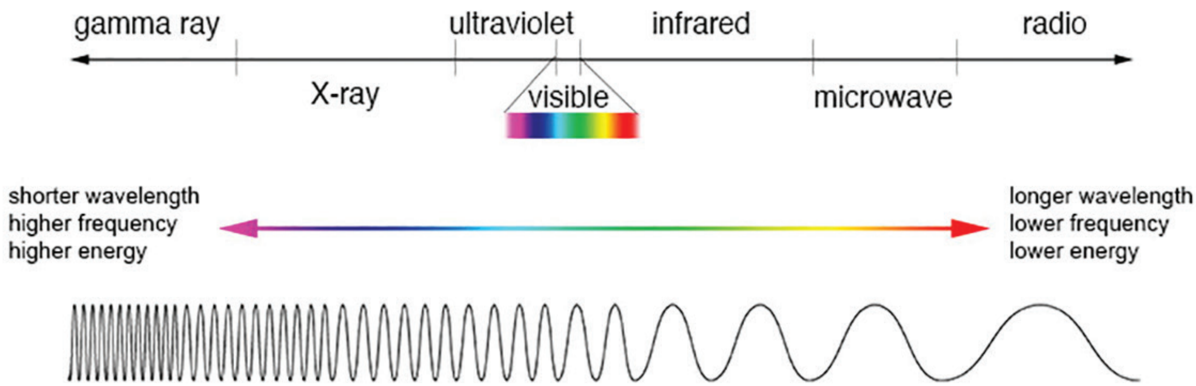


Figure 27: The visible and invisible range of the electromagnetic spectrum.

Discussion Box 4

The Electromagnetic Spectrum

The electromagnetic spectrum (EMS) catalogs a range of all types of energy. Some of this energy can be felt (thermal). Some of this energy can be "seen" (visible energy). When energy hits an object, the energy is either absorbed by the object or the energy is reflected off the object. Different types of energy are absorbed and reflected by different objects in different amounts!

For example, leaves on a tree look "green" to the human eye because of the absorption and reflection of different types of energy. Healthy leaves absorb red (visible) and blue (visible) energy, while they reflect green (visible) energy. This green reflection is what humans see and is the reason leaves look green. Our eyes can tell us that the tree leaf is reflecting green energy, but since we are unable to see thermal, near infrared, or other wavelengths, humans are unable to collect information about the interaction of these energy waves with the leaf without the use of a sensor. The interaction of these other wavelengths (outside of the human visible spectrum) can provide important information about the health of a plant. Sensors can measure these other wavelengths.

For more information on the electromagnetic spectrum and electromagnetic energy, see the NASA (National Aeronautics and Space Administration, 2010) video "Introduction to the Electromagnetic Spectrum" online at https://science.nasa.gov/ems/01_intro.

In what ways do you interact with the electromagnetic spectrum each day?

Sensor Overview

Many different types of sensors can be attached to drones to produce images (digital pictures) that are used help farmers make sound decisions about their harvests. A few examples include:

- **True color sensors** capture images about the field in "true color," which mimics the colors that humans see. True color images captured by a drone will look similar to what you might see when you look out the window of an airplane. True color sensor data show RGB (red, green, and blue) digital values. Those three values can provide approximately 16.5 million different colors on most digital true color sensors or cameras!

- **Near Infrared (NIR) sensors** capture data in the NIR spectrum, which is outside of the human visible spectrum and has longer wavelengths (less energy) than visible light energy. Healthy plants reflect NIR energy. If plants reflect less NIR, they are likely to be stressed. NIR can therefore serve as an early warning signal for plant stress, but this alone doesn't indicate the type of stress. This video from AgEagle Aerial Systems provides a comparison of true color and NIR sensors (AgEagle Aerial Systems, 2016): https://www.youtube.com/watch?v=XLsaYY631ao.

- **Thermal sensors** capture reflected data in longer wavelengths. Since these wavelengths are longer, the image resolution is often coarser. Thermal sensors detect heat. They are often used early during a drought since higher temperatures are often associated with reduced transpiration (and increased plant temperature). Thermal imagery is sometimes used for early disease detection in some crops. Livestock operations also may use thermal imagery to detect temperature anomalies in individual livestock.

- **Multi-spectral sensors** typically collect data from several different regions of the electromagnetic spectrum all at one time. These sensors may collect RGB, NIR, thermal, and other slices of the electromagnetic spectrum. Multi-spectral sensors may collect data from as many as 12, 15, or even 30 regions (bandwidth slices) of the electromagnetic spectrum. As technology improves, the number of potential bands associated with the multi-spectral definition tends to grow.

- **Hyperspectral sensors** are even more specialized and can collect reflectance data from as many as several hundreds or even thousands of slices of the electromagnetic spectrum. This additional information can provide more detailed information about vegetation, including weed detection. Hyperspectral remote sensing is also referred to as imaging spectroscopy. More information is available from the National Ecological Observatory Network (2015) in this video: https://www.youtube.com/watch?v=3iaFzafWJQE.

- **Lidar sensors** do not rely on reflected energy from the sun to collect data (like the other options above). "Lidar" stands for *light detection and ranging*. This type of sensor uses an internal energy source known as "active remote sensing," similar to a pulsing beam of light. These pulses of light (tens of thousands or even hundreds of thousands of light pulses) are emitted every second. The light pulses are emitted from the bottom of the aircraft (could be a crewed or uncrewed aircraft) towards the ground. The light pulses strike the top of the vegetation (and the ground) and are reflected back up to the sensor. Lidar sensors act like sonar sensors. Lidar sensors are used to measure the elevations in terrain (creating 3D models) and can measure the height of vegetation. These sensors are also valuable to identify drainage patterns in fields to help mitigate soil erosion. More information is available from Geospatial World (2017) in this video: https://www.youtube.com/watch?v=zREAEdXzOcw.

All these sensors collect and store data. However, collecting data alone is not enough to guide the decisions driving precision agriculture. Data analysis and image processing converts "raw numbers" (the data) into digestible information that can inform decisions. There are many parameters that can guide image analysis. These parameters can include:

- Texture
- Patterns
- Shapes
- Size
- Color
- Relative location

Discussion Box 5

Remote Sensing Processing and Analysis

Image analysis is critical in order to properly interpret remote sensing imagery. An image analyst serves much like a detective and looks for informative clues in the image. These clues provide a better understanding of real-world conditions on the ground. Different approaches can be used to decipher an image. An analyst can conduct a visual analysis of a remote sensing image. Often shapes, patterns, sizes, colors, locations, and textures can be used to better observe and understand features.

There are many remote sensing analysis techniques. Since a single remote sensing image may be comprised of thousands or even millions of pixels (and since each pixel is associated with a spectral value and spatial coordinates), image analysis software is often used to help farmers to efficiently identify potential agricultural issues in their fields.

In addition to collecting information, such as images, of the terrain, sensors also collect coordinate information. Coordinate information connects collected data to its location on the surface of the Earth. This ensures that the farmer can retrace issues identified through remote sensing back to a specific location on the ground.

When these sensors are collected with autonomous systems (aircraft or drones), the drones can be programmed to refly and recollect data over the same area on a consistent basis every week or month, for example, through the establishment of a *flight plan* (fig. 28). The flight plan should consider many different variables, including the field boundaries, the altitude of the flight, the characteristics (type, resolution, etc.) of the sensor, the structure of the terrain (flat or sloping), as well as other terrain parameters (including nearby trees, buildings, or other structures such as cell phone towers, electric lines, etc.), and local weather patterns, particularly wind. In addition, flight plans must closely consider safety concerns, and flight plans must strictly adhere to government regulations. Flight plans are often delineated by *flight paths*. A flight path is the actual path that a drone will take when operating.

Figure 28: A flight plan for an autonomous operation.

The flight paths and data collection requirements associated with these systems only need to be established once. Once these data collection parameters have been saved, the agricultural fields can be consistently reflown, and data can be collected over and over. Of course, the remote pilot in command (RPIC) can easily modify the saved flight plan to account for changes in weather, such as wind speed or direction, and other variables, such as flight elevation and different sensors. This allows the farmer to consistently monitor the field and effectively respond to changes in the field as needed. Using drones and associated software, the data collection process is becoming increasingly automated. Drones can operate over a field and can monitor crop health using the same flight paths and sensors each week. In addition, different sensors can be mounted on a drone to collect different data perspectives (fig. 29). When information collected by different sensors are combined to help solve a problem (for example, lidar data and multispectral data), it is called *multi-sensor data fusion*.

Figure 29: Example of an oblique perspective of a digital flight plan.

Many aerial drone operations are currently conducted autonomously, meaning that there is often minimal interaction between the drone pilot and the drone once it takes off. Flight plans are created using specialized software. These flight plans are then downloaded into the drone. The flight lines contain latitude and longitude information, which is then used to guide the drone (using GNSS-derived coordinates collected by the drone in real time). The GNSS coordinates are also associated with any data (images) that are collected by the drone. The human involvement with autonomous flights is also extremely important. Humans plan the flight. Humans must also be ready to take over the controls in the event of an emergency or in case an autonomous flight does not go as planned. Human experience and knowledge are critical during the planning and operation of *autonomous drone flights*.

Additional Resources: Drones in Agriculture

Videos:

- Virginia Geospatial Extension's **"sUAS Flight Planning."** This is a seven-part video series on sUAS flight planning (each video is approximately 12 minutes long) (Cross, 2018): https://www.youtube.com/user/VaGeoExtension/playlists.

- **"An Introduction to the Electromagnetic Spectrum"** (about five minutes long) (National Aeronautics and Space Administration, 2010): https://science.nasa.gov/ems/01_intro.

- **"How One NASA Image Tells Dozens of Stories"** (Neo, about six minutes) (NEO, 2019): https://www.youtube.com/watch?v=ZYGd-llxHJE.

- **"Comparison of True Color and Near Infrared Sensors"** (AgEagle Aerial Systems, five minutes) (AgEagle Aerial Systems, 2016): https://www.youtube.com/watch?app=desktop&v=XLsaYY631ao.

- **"Mapping the Invisible: Introduction to Spectral Remote Sensing"** (about six minutes) (National Ecological Observatory Network, 2015): https://www.youtube.com/watch?app=desktop&v=3iaFzafWJQE.

- **"Lidar: Light Detection and Ranging"** (about three minutes) (Geospatial World, 2017): https://www.youtube.com/watch?v=zREAEdXzOcw.

- **"5 Human Activities You Can See from Space"** (about three minutes) (VOX Media Inc., 2015) : https://www.youtube.com/watch?v=MNQ9z_Eb-Jc.

- **"Behind the Scenes: Verge Aero Drone Light Show During Covid-19,"** a short documentary that shows how a drone light show is created (about 13 minutes) (Nick Lang Media Inc., 2020): https://www.youtube.com/watch?v=rnwwXGYF3r0.

- **"Behind the Scenes: How to Make a Drone Show"** (about six minutes) (UcGSTV Media, 2019): https://www.youtube.com/watch?v=YW_VR3Yx0DE.

- **"Introduction to Tello Drone Programming,"** a tutorial series of seven videos (about one to three minutes each) that covers everything from installation to coding. (creation of free account required to view) (DroneBlocks, 2021): https://learn.droneblocks.io/p/introduction-to-drone-programming-with-tello.

PowerPoint Presentation:

- **"Introduction to Remote Sensing,"** https://tinyurl.com/IntroRS.

Student Learning Activities:

- Activity 9: An Exploration of Satellite Imagery Using StoryMaps

- Activity 10: Exploration with sUAS Imagery

- Activity 11: Game of Drones

- Activity 12: Tic Tac Toe Drone

- Activity 13: Drone Relay Race

Notes:

Activity 9: An Exploration of Satellite Imagery Using StoryMaps

Note: See the appendix for guidance on the Discussion Boxes in this activity.

Objective

Precision agriculture is based on data collected from various sensors. Sensors can be terrestrial (land based) or airborne. Airborne sensor platforms can be associated with different types of aircraft including balloons, drones, airplanes, and satellites. In this activity, students will be introduced to remotely sensed imagery acquired from Earth observation satellites, including the Landsat program, which has been in operation since 1972.

Requirements

This activity requires the use of a tablet, Chromebook, or computer (laptop or desktop), and internet access.

Concepts covered

This activity will incorporate the use of a StoryMap, which is an interactive presentation and web-mapping application produced by the geographic mapping company Esri. The StoryMap is divided into general sections that include:

- Introduction to satellite imagery
- Day vs. night imagery
- Summer vs. winter imagery
- Clouds
- Detecting change over time

Note that there are discussion points provided below for each section in the StoryMap.

This online StoryMap was prepared and published by Virginia Tech doctoral student Paige Williams. The StoryMap is available online at https://arcg.is/nSbjf.

Discussion Box 1

Here is an interesting video that provides and overview about how satellites support Earth observation (National Aeronautics and Space Administration, 2021).https://www.youtube.com/watch?v=WpJT54UrM00&list=PL2aBZuCeDwlSXza3YLqwbUFokwqQHpPbp&index=4

Discussion question:

- What kinds of issues in your community may be supported by Earth observation satellites?
- Why might satellite observations provide better data and information than ground-based observations?

Go online to StoryMaps at https://arcg.is/nSbjf and follow along through the different sections of this StoryMap. This activity will incorporate discussion questions that coincide with the content throughout this StoryMap.

Image of the Earth from Satellite Imagery

- This section of the StoryMap shows OpenStreetMap and satellite imagery.
- The maps provided are zoomed into the central area of **Washington D.C.** with historical monuments and other important governmental buildings.
- Use the Swipe tool to move back and forth across the maps.

Discussion Box 2

Tips for using a StoryMap

- Use the scroll wheel on the mouse to move you through the website.
- Any map is interactive!
  - The Zoom is in the lower right corner.
  - To pan (drag the map around), drag while holding down your left mouse button.
  - The Home button will take you back to the original location.
  - Make the map full screen by pressing the icon in the upper right corner.
- The Swipe tool is interactive and allows you to swipe between two images or maps.
- To watch the YouTube videos, simply press play. (There is also an option to view the videos on YouTube's website in the lower left corner of each video.)
- The StoryMap website link is sharable and publicly available.

Discussion Box 3

Take time to explore the maps of Washington D.C. What are some features that can be identified?

- Do the roads and buildings from OpenStreetMap line up with the satellite imagery?
- Can you locate the U.S. Capitol and the White House?
- Why might some of the buildings be slanted in the satellite image?

Satellite Imagery at Different Times of the Day

This section shows day vs. night imagery.

The maps provided are zoomed into the contiguous United States of America.

Use the Swipe tool to move back and forth across the maps.

Watch the video in this section, “How One NASA Image Tells Dozens of Stories” (about six minutes) (NEO, 2019). The video is also online at https://www.youtube.com/watch?v=ZYGd-IlxHJE.

Discussion Box 4

Take time to explore the maps and video provided. What are some features that can be identified?

- What is the light source for imagery during the day?
- What is the light source for imagery at night?
- How are light sources at night associated with human activity?
- Which light sources at night might be associated with natural causes?
- Can you locate some highly populated areas in the United States?
- What are some things that might be happening in the dark places of the night imagery?

Satellite Imagery at Different Times of the Year

This section shows **summer vs. winter** imagery, including how **clouds** affect imagery.

The maps provided are zoomed into the extent of Europe and Asia.

Use the **Swipe** tool to move back and forth across the maps.

Scroll below the Swipe tool to view the satellite image blocked by clouds.

Discussion Box 5

Take time to explore the maps provided. What are some features that can be identified?

- What is the main difference in the summer vs. winter imagery?
- What are some other differences in the summer vs. winter imagery?
- What is between the satellite and the ground?
- In what specific places of the world would clouds be an issue at certain times of the year?

Satellite Imagery Used to Detect Change Over Time

- This section shows how we visualize satellite images through time.
- The first image is a GIF of a river in Peru changing every year from 1985 to 2013.
- Watch the Vox Media video “5 Human Activities You Can See from Space” (VOX Media Inc., 2015) (https://www.youtube.com/watch?v=MNQ9z_Eb-Jc).

Discussion Box 6

Take time to explore the maps and video provided. What are some features that can be identified?

- What has happened to the river in Peru over time?
- What are some other examples of change that we can monitor from space?
- What causes shifting shorelines of bodies of water?
- Where in the world is a good example of fast urbanization (population shift from rural to built-up)?

Discussion Box 7

Final Discussion Points on the Pros and Cons of Satellite Imagery:

Benefits of satellite imagery:

- Satellite imagery can help monitor weather and the vegetation trends on Earth.
- Satellites can capture data over large areas of the Earth quickly.
- Satellites can revisit areas of the Earth fairly quickly, so that changes can be monitored over short periods of time.
- Satellites are also used to efficiently monitor an array of conditions and events, including wildfires, pollution, deforestation, and land use transitions.

Cons of satellite imagery:

- Most satellites cannot see everything all the time. Clouds can block the view of the ground (as do treetops).
- Ground verification is used sometimes to double-check information in the satellite images. This can be resource (and time) intensive, especially in remote locations.

Notes:

Activity 10: Exploration with Drone Imagery

Map fields in minutes to conduct stand counts, identify variability, and make in-field recommendations, all offline at the field's edge.

Overview

One of the cornerstones of precision agriculture is the use of small uncrewed aircraft systems (drones) to monitor agricultural fields and operations, since these platforms provide a unique perspective – looking down from above. Drones carrying various sensor payloads can help farmers assess plant health, which can vary across a field. Differences in plant heath can be attributed to the presence of small pests (insects and diseases), soil variations (differences in organic matter, pH, nitrogen, or other soil characteristics such as aspect and slope), irrigation patterns, damage due to weather (hail, wind, hard rain), and damage attributed to larger pests (bears, deer, boar, etc.). Areas within a field that have been identified as stressed are often referred to as "hot spots."

The exploration of plant health should begin with identifying an area to survey. What are you looking at – specific crops, livestock, pasture? And what are you looking for? This activity provides an example of how to observe the health and growth differences of a hay field on a local farm.

Hay is a standard crop grown nationwide and is a fundamental crop for most livestock farmers. Some farmers will grow and harvest alfalfa or clover, while others stick to timothy or brome grass hay. Alfalfa and clover have special harvesting criteria based on the flowering of the plant. The field that is observed in this example is orchard grass. We encourage participants in this activity to research the fields, crops, and local conditions such as water, soils and slopes, that you are monitoring to help you make more informed decisions about your observations and make more effective recommendations. Farmers and educators have a wealth of knowledge that they would be glad to share with you!

Prepare for Takeoff!

Several steps are required when operating a drone over an agricultural field:

1. Mission planning.
2. Operations and data collection.
3. Image processing.
4. Image Interpretation and analysis.

> To find out if your drone is compatible with DroneDeploy, check out its "Recommended and Supported Drones" article online at https://support.dronedeploy.com/docs/recommended-and-supported-drones (Drone Deploy, 2022).

Operating a drone with a sensor payload such as a camera or other imaging sensor will provide you with valuable perspective and information (data) captured from "above." In this module, you will learn how to plan a flight, conduct an autonomous flight, and process the data (imagery in this case) collected by the sensor on your drone using DroneDeploy. DroneDeploy is a cloud-based software option that will support mission planning for autonomous flights and also image processing. You can obtain a free 14-day evaluation version of DroneDeploy. Note that software evaluations are limited to one trial copy per email address. Otherwise, you can purchase a license of this software as needed or use other free software options such as Pix4d Capture or Drone Harmony. The Virginia Geospatial Extension Program maintains an up-to-date list of autonomous flight planning software (both free and for purchase) and image processing software (also free or for purchase) via the VirginiaView Website (https://virginiaview.cnre.vt.edu/software-apps/).

Let's begin by going to https://www.dronedeploy.com/ or download its mobile app from your app store (iPhone or Android) and register for a free trial account (figs. 30 and 31). Trial accounts can be accessed directly from https://www.dronedeploy.com/signup-v2.html . If prompted for a company name feel free to provide your school or other organization. If you are not associated with a company, feel free to identify as 'Independent'.

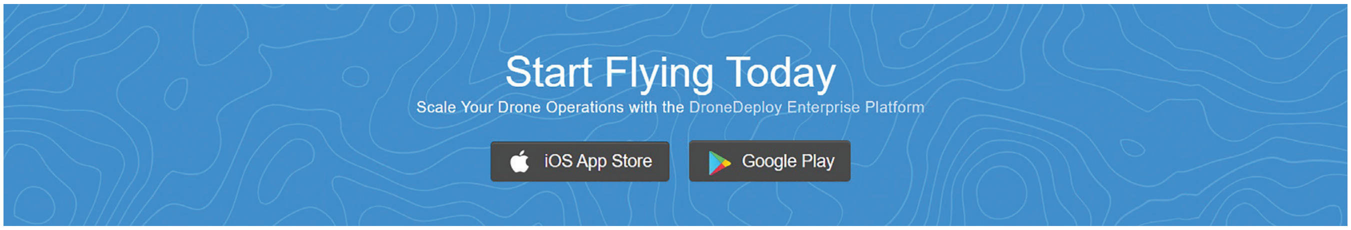


Figure 30: DroneDeployMobile Apps.

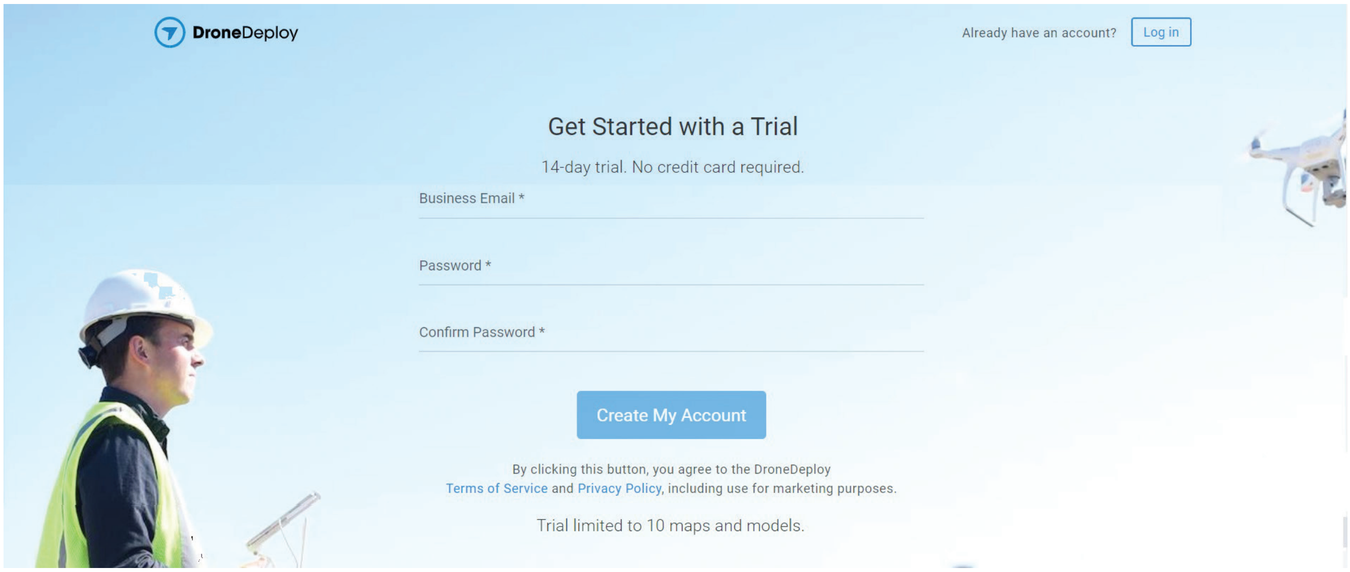


Figure 31: Drone Deploy trial webpage.

Flight Planning

To begin a new project, log in on your mobile device or your desktop browser. The following directions apply to the desktop browser version, but you will find the mobile app very similar.

When you log in, you will be taken to the DroneDeploy dashboard showing your current projects (fig. 32). Select the New Project option. Your current location may be chosen as the default location of your project. You can also navigate to any other location on the map to start your project (fig. 33).

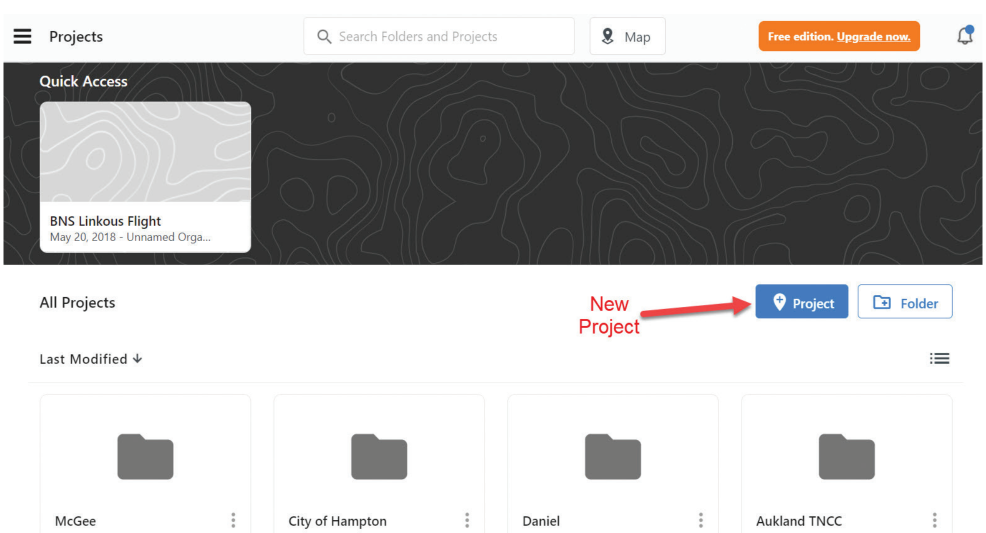


Figure 32: Starting a new project.

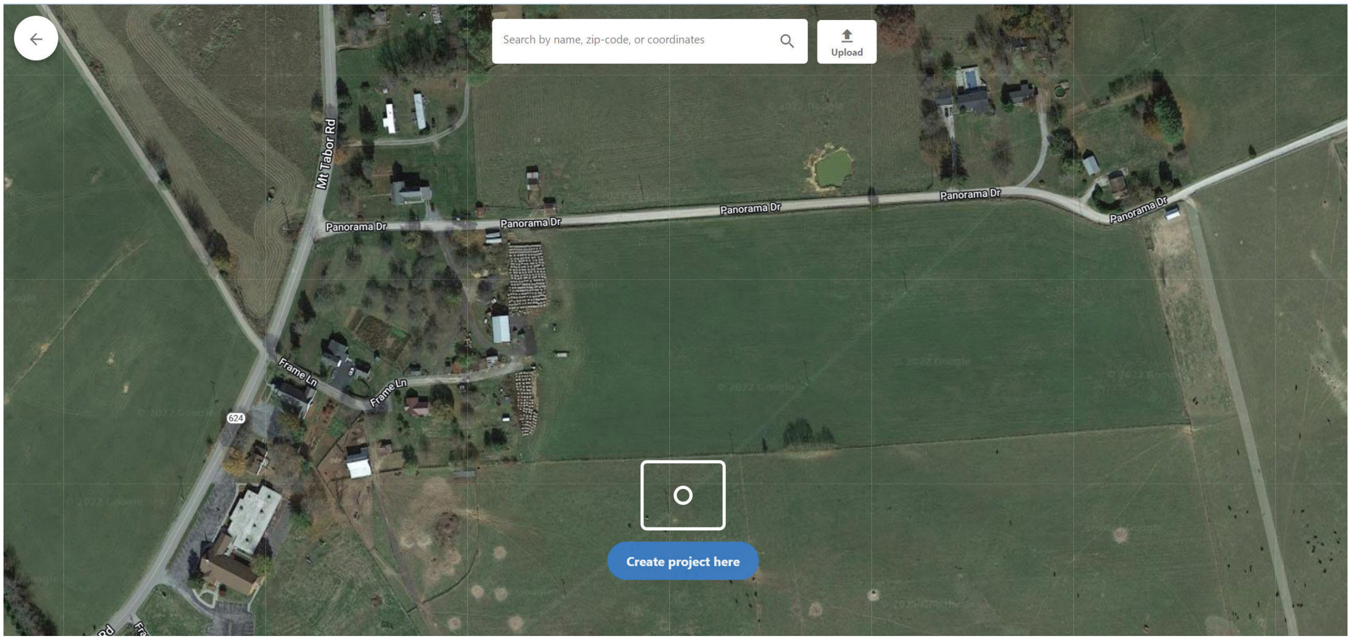


Figure 33: Creating a new project.

For this project we will create an autonomous flight plan by first Creating a Project (select the Create project here button and provide a name for your project). Next, select the Standard-Create a map and model option. For your field flight, choose the highest legal flight altitude that you are comfortable with. You can experiment with the various options (altitude and overlap settings which are under the advanced settings) to identify appropriate parameters for your project. (fig. 34). You can also turn off the "Enhanced 3D" option. It is active by default on new projects but is only necessary when 3D imagery is being captured. Turning it off will save time for your flight. Note that changes to flight parameters (flight altitude, overlap, etc.) can directly impact flight times and the number of images captured.

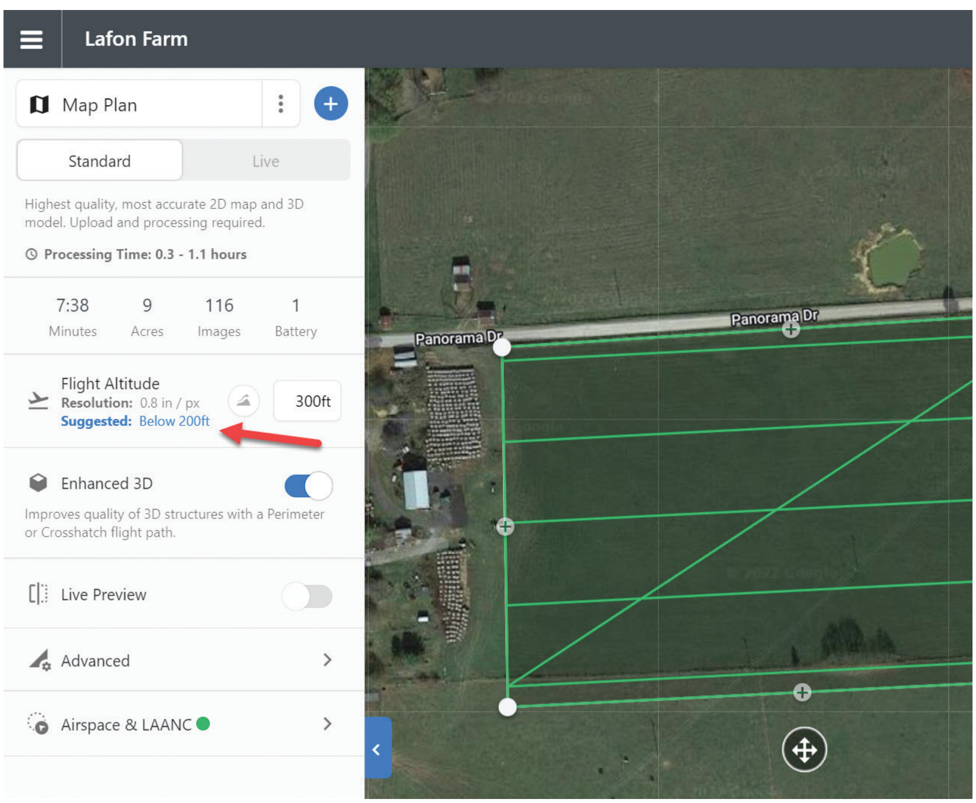


Figure 34: Autonomous Flight Planning in DroneDeploy.

DroneDeploy will prompt you with any "Airspace & LAANC" (Low Altitude Authorization and Notification Capability) warnings for your flight area (fig. 35), but you are responsible for knowing the airspace that you will be flying in and following all regulations, both from the FAA and locally. You may want to reference aeronautical charts (www.skyvector.com) and other resources, including smartphone apps such as "B4UFly" to make sure that you are in full compliance with Part 107 regulations. Resources regarding sUAS are available from the FAA online at https://www.faa.gov/uas/commercial_operators/ and from VirginiaView at www.virginiaview.net.

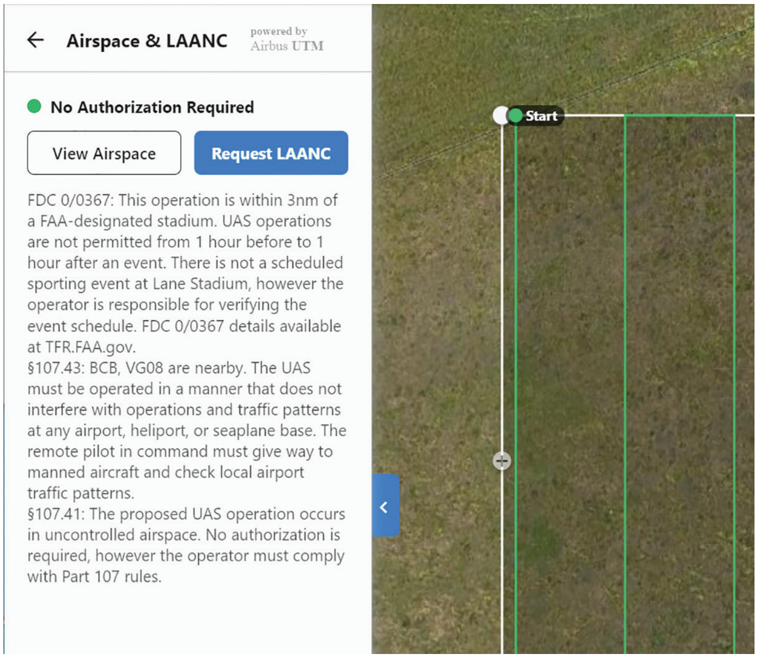


Figure 35: Airspace and Low Altitude Authorization and Notification Capability warning page from DroneDeploy.

In the map window, you can customize a boundary around the area that you would like to establish as your flight plan by clicking and dragging the white circles to the corners of the area of interest. Use the + button to add vertices to the standard rectangle if the field that you are interested in capturing has more than four corners. Once you have fine-tuned your flight parameters, your flight plan is complete (fig. 36).

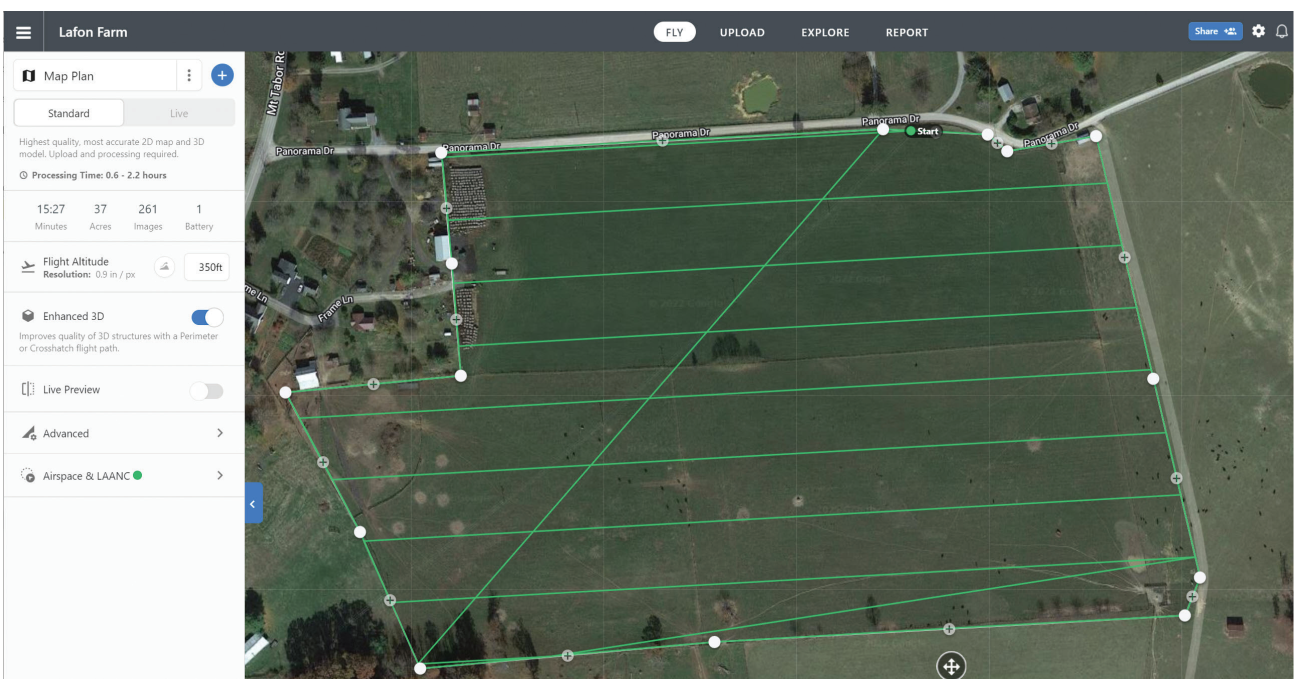


Figure 36: Sample completed flight plan.

Safe operations!

Remember to adhere to all FAA regulations as outlined in Part 107. A summary of these regulations is provided on the FAA's UAS fact sheet available online at https://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=22615.

Once you have established your perimeter and flight settings, DroneDeploy will give you an estimated time and number of batteries needed to complete your mission, as well as the number of images that will be taken during flight. You are then ready to connect your drone to the software and start the preflight checklist.

If you have trouble successfully connecting your drone in the mobile application, you can open the drone-specific application (e.g., DJI GO) to be sure that the drone is in "ready to fly." condition before starting the mission in DroneDeploy.

As you can see, the DroneDeploy software provides you with some important information, such as minutes of flight, acres to be captured, the total number of images that will be acquired during the operation, and the number of batteries required to complete the project (fig. 37). Make sure that you are comfortable with your flight altitude. Lower flights will result in more images (and more image processing). Note that more data can sometimes result in "data overload" – more is not necessarily better!

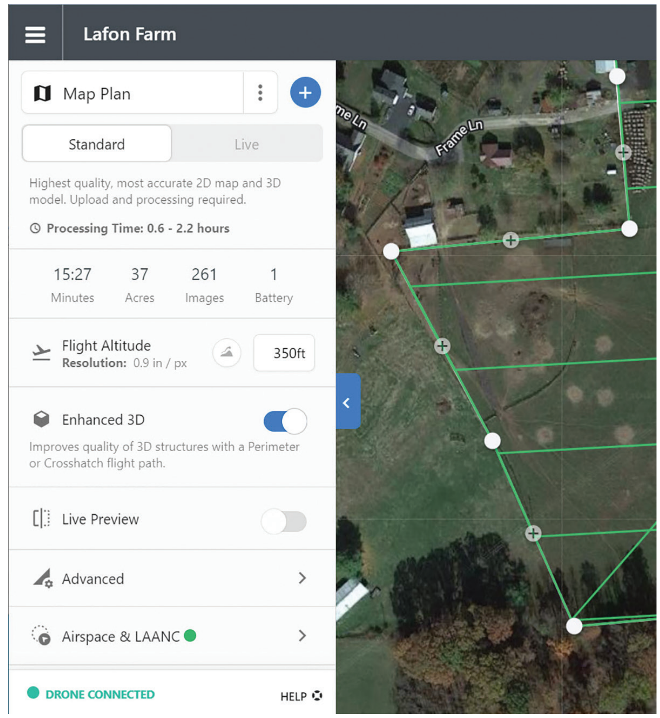


Figure 37: The DroneDeploy screen once the drone has been connected.

Take note of the items in the preflight checklist (fig. 38). If you are missing any component of this checklist, your mission cannot be executed.

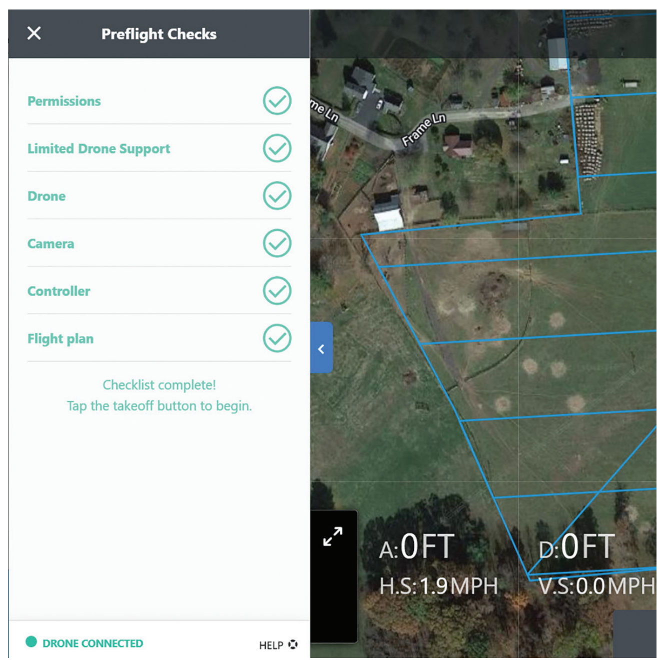


Figure 38: Preflight checklist.

Flight Operations

Once you start your flight, you will be able to watch your drone navigate along the preplanned flight path. You will be able to switch between the flight path and the camera view during the mission by clicking on the **expand image** icon . You can monitor various aspects of the mission including the altitude and battery level, as well as the receiver and satellite signal strength (fig. 39). With all this information, it is important to remember that, as stated in the FAA's Part 107 rulemaking, the remote pilot in command (RPIC) must maintain visual contact (also known as "visual line of sight") with the drone during the entire mission.

Figure 39: DroneDeploy screenshot taken during a mission.

Image Processing

Once the mission is complete, you will upload the images to DroneDeploy for processing by following these steps:

1. Copy the images from the SD card on the drone to a folder on your local computer. It's also possible to upload the images directly from your mobile device to DroneDeploy, but this could take up a lot of data, which could be a concern if your mobile device is on a limited data plan.

2. Log in to DroneDeploy through a browser.

3. Select **Upload**, browse to the folder that contains your images, and select all of the images to upload to DroneDeploy for processing. Be sure to review your images prior to selecting them (fig. 40). DroneDeploy takes one image from the home point, prior to taking off, and this image should not be included in your upload.

Figure 40: Selecting photos to upload.

Once your images have been uploaded, it takes a little time for DroneDeploy to process them (fig. 41).

Figure 41: The Upload Images screen on DroneDeploy. Each blue dot represents an image that is being uploaded.

Various settings can be adjusted to reduce processing time, but they affect the quality of the image. Once the images have been processed, you will receive an email from DroneDeploy telling you that processing is complete. The processing speed can vary from day to day, and since you are using a trial version of DroneDeploy, your processing request will likely receive lower priority than someone with a professional or business version of the software. In any event, your image processing request may take anywhere from a half an hour to a half a day.

Image acquisition and image processing are vital components of precision agriculture. But the image interpretation is what provides agricultural producers with visual information that can be used to support data-driven decisions. These decisions are based not on a hunch, but on actual observations.

Discussion Box 8

Take time to explore your images and look for features to discuss with the class. Review figure 42. What are some features that can be identified?

- Do you see any power lines?
- What are those dark shadows on the ground?
- Can you tell by looking at this image which field is a pasture field and which one is a crop field?
- Do you see any water features?

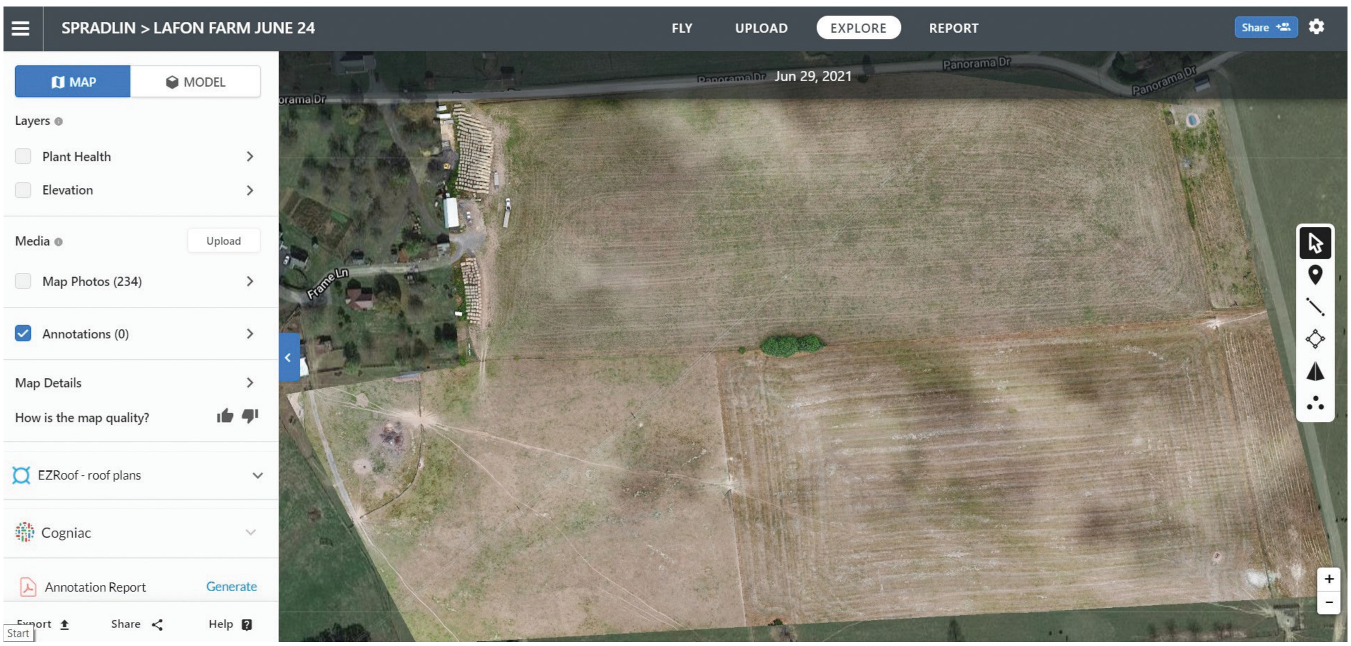


Figure 42: Example of a DroneDeploy processed image.

Using DroneDeploy, turn on Plant Health, and let's take a look at the same image with some adjustments to the color bands. Most standard cameras take images using the RGB (red, green, blue) color band filters because that represents a true color in the visible light spectrum, and it looks like a normal photo to our sensors (our eyes). However, when we are looking for plant health, it can be beneficial to compare the near infrared and green light to measure healthy green vegetation. If near-infrared light is not an option with your sensor or camera, a simple green to red pixel ratio can also be more telling than the true color image. Farmers will often use a vegetation index to help guide decisions about their fields and to help identify vegetation health trends over time by collecting data over the same field on a regular basis. There are many different types of vegetation indices. DroneDeploy offers a VARI (Visible Atmospherically Resistant Index) processing option that will alter a standard RGB image to "mimic" an NDVI (Normalized Difference Vegetation Index) image, which measures live vegetation in an area and is commonly used in agricultural assessments.

Want to learn more about vegetation indices?

A tremendous amount of information is available about vegetation indices. These indices use a combinations of band wavelengths (red, green, blue, near infrared, etc.) to enhance certain properties of the terrain (areas of vegetation vigor, areas of vegetation stress, water, moist soils, etc.). Vegetation indices can provide important information and insights to the farmer.

PrecisionHawk provides a good overview and summary of some common vegetation indices online at https://www.precisionhawk.com/agriculture/vegetation-indices.

Figure 43 is an example of a transformed image using VARI. In this image, you can see hot spots (red) where the crop is showing signs of stress. This could be due to lack of moisture or low fertilization. This information would be difficult to determine from a standard RGB image.

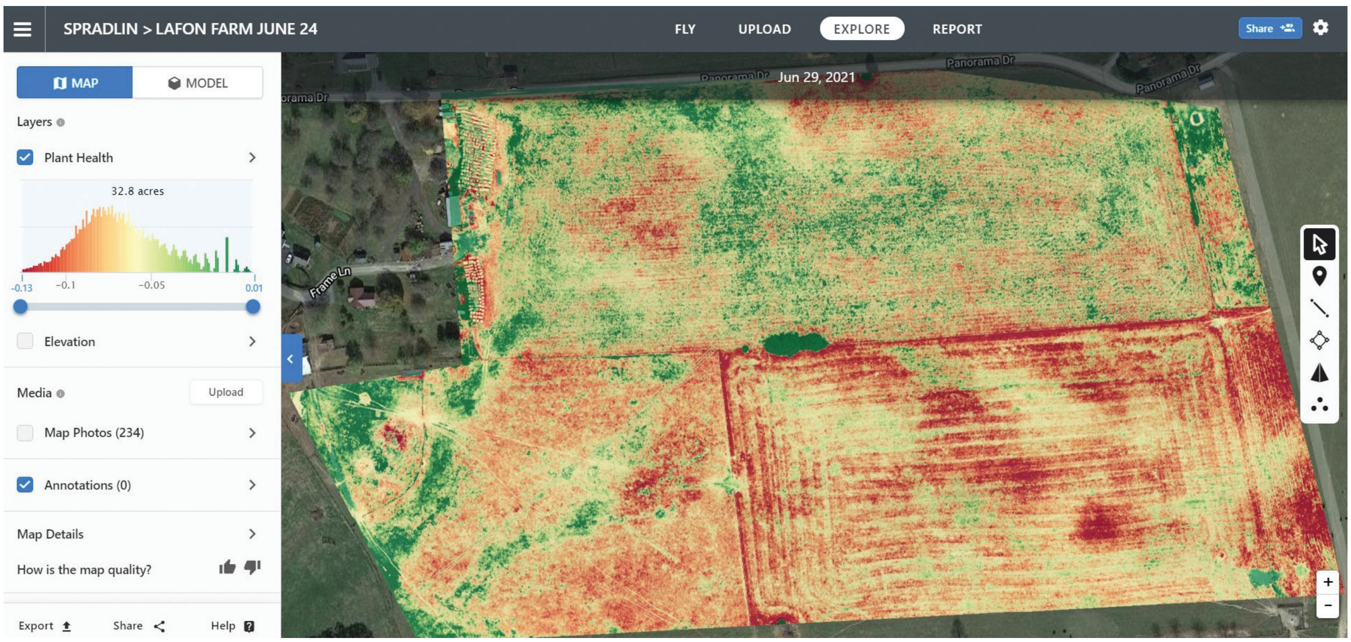


Figure 43: VARI image showing differences in plant health.

Figures 44 and 45 were taken prior to harvesting the crop, immediately following fertilization. It was taken in the same field three years and two months prior to the images above. The plant health imagery of the crop field is very different than the images and analysis done after harvest of the crop. Both images can be beneficial to the farmer, but timing of the flight is important to understanding the results.

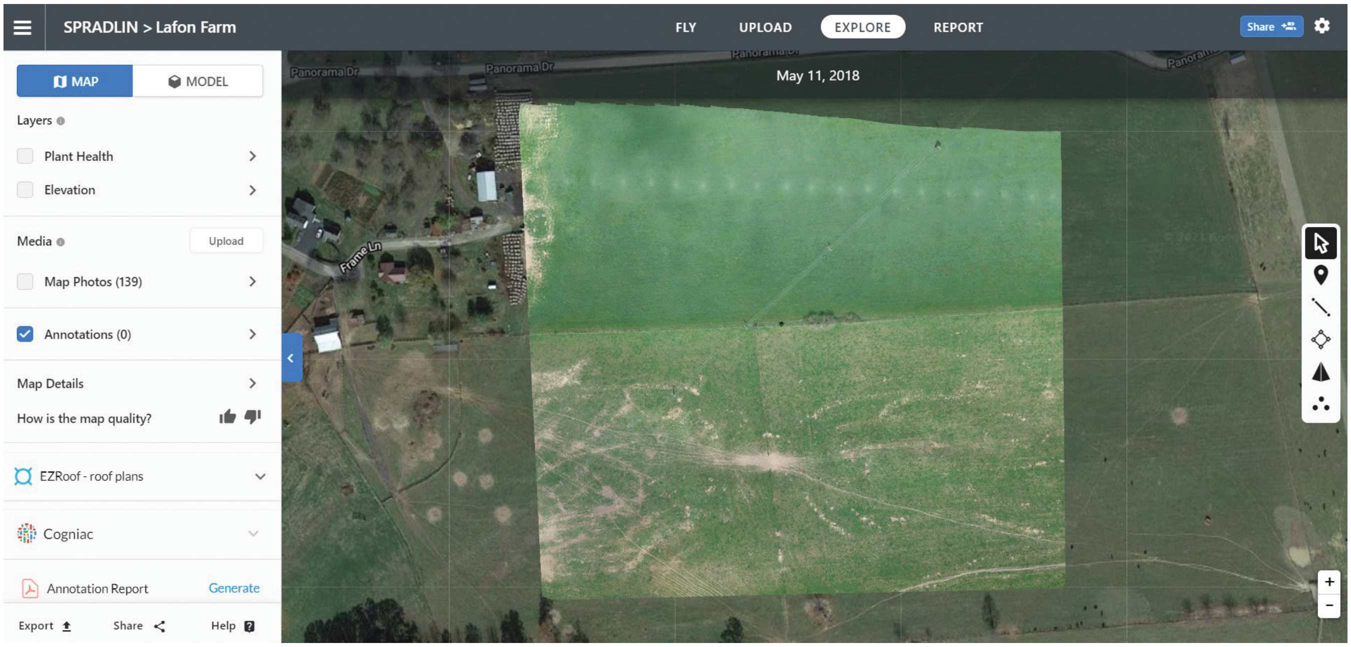


Figure 44: After fertilization (RGB).

Figure 45: After fertilization (Plant Health).

After processing your imagery, identify areas of the field that appear:

- Healthy (green).
- Stressed (red).

Note that drone-based sensors can help determine the locations of vegetation stress (hot spots). However, these sensors are not necessarily able to identify the cause of the vegetation stress. Understanding the cause of the stress is vital in order to prescribe the proper treatment. After identifying the hot spots within a field, what would be the next steps for a producer?

Activity 11: The Game of Drones

When students have mastered the basic controls of their drone, they can move on to more complicated and controlled activities. Most of the activities associated with the "Game of Drones" can be used indoors in a controlled environment.

The activities in this module introduce basic programming concepts to students. These skills are essential when programming and coordinating communication between sensors for data collection and data analysis. In addition, programming is essential for precision agriculture vehicles, both terrestrial and airborne, and other production systems such as irrigation, to effectively respond to issues and hotspots in the field.

Show Drones

In this section, students will explore the art of drone light shows. Drone light shows are growing in popularity and new software makes programming them much easier. After taking the time to demonstrate how a professional show is created, you can lead the class in a group activity where teams will program and sync their drones to create their own show.

Some examples of drone light shows are provided below, with many more examples available online. Figure 46 provides an example image of a drone light show in China, where 600 drones transform images of tea and tea-picking girls to creatively display the culture of the Jiujiang tea harvest.

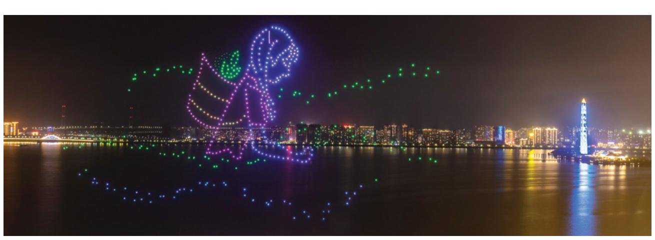


Figure 46: On the night of May 29, 2019, a light show using 600 drones depicted images of tea and tea-picking over Balihu Lake in Jiujiang, China.

In addition, a video documentary, "A Behind-the-Scenes Look at the Verge Aero Drone Light Show During Covid-19" (about 14 minutes), demonstrates the work that goes into developing a drone light show with 136 individual drones working in tandem. This video provides an overview of planning and design, safety and security issues, risk management, and program execution. At the end, students can enjoy watching a video that shows how all the components come together. The video is online at https://www.youtube.com/watch?v=rnwwXGYF3r0. (Nick Lang Media Inc., 2020)

Another video, "Behind the Scenes: How to Make a Drone Show?" (about five minutes) provides students with step-by-step instructions needed to create a drone show with DroneShowSoftware.com. It covers using animation software including speed considerations, viewshed parameters, collision risk avoidance, virtual testing, virtual environments, and risk management (with virtual fences and other tools) and logistics. The video is online at https://www.youtube.com/watch?v=YW_VR3Yx0DE. (UcGSTV Media, 2019)

Dancing Drones in the Classroom

After reviewing the steps required to put together a large-scale drone light show, your students can begin to think about ways to coordinate drone flights with music. Your students will essentially be "Dancing with Drones." The Dancing with Drones exercise will be accomplished by students programming drones. To complete this exercise, you must have programmable drones and software. Many different types of drones can be programmed. We've had good experience using the DJI Tello drones as they are relatively small. With this in mind, you do need to ensure that students and all participants adhere to safe operation standards.

DroneBlocks is an open-sourced block-based programming language that students can use to program missions for many different types of drones. Programming with DroneBlocks is an easy way to develop an autonomous mission. By keeping distances small, these missions can be used in a small open indoor area, such as an auditorium. DroneBlocks works on iOS, Android, and Chrome, and is available for download from the iOS App Store, Google Play Store, and Chrome App Store. At this time, the Android version supports only the DJI Tello drones, but refer to the DroneBlocks website for more information at https://www.droneblocks.io/app.

DroneBlocks provides a free online instructional tutorial course (for educators) that introduces some fundamentals of programming with Tello drones using DroneBlocks. This course is comprised of seven short (typically less than three minutes) videos. The course requires that users establish a (free) DroneBlocks account. Use this URL to setup a DroneBlocks account (https://learn.droneblocks.io/p/introduction-to-drone-programming-with-tello). In addition, there are other DroneBlocks instructional resources available on YouTube.

The key to DroneBlocks is to start simply and work up from there!

DRONEBLOCKS

Suggested approach for the Game of Drones:

1. Divide students into groups of four, each student with their own drone and software access.

2. Provide each group with a song that has a strong beat. The song should be approximately 30-60 seconds long. Optionally, you can have students look for their own song, but this can become a distraction.

3. Have students listen to the song together and identify at least six different changes in the beat to coordinate movement. Have them note the times of the changes.

4. Group Storyboard students work as a group to plan the drones' movements in sync with the music and write the plan out in a storyboard (see example in figure 47). Note that the drones should complement each other but not be the exact same as each other.

5. Each student should then write the program for their drone's movement. Once they have their program written, the group can practice synchronization. See an example program in figure 48.

The synchronization part of this activity can take a lot of time. Allow a set amount of time for students to achieve their best run and video it.

You should emphasize that this is not just a programming mission. Students should be prepared for safe flight operations. Ensure that:

- The drones are spaced far enough apart so they will not crash into each other.

- Students and other observers are located a safe distance from the operation.

- Everyone knows what to do in the event of a flight anomaly, like how to quickly abort the mission!

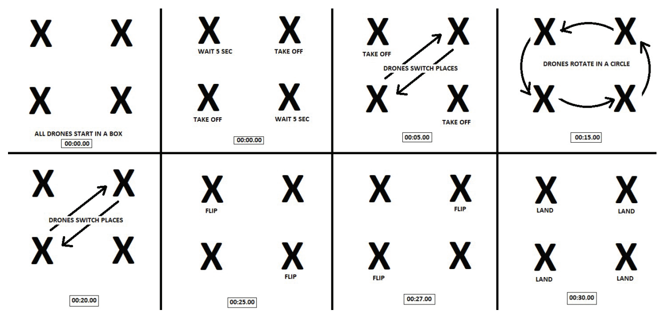


Figure 47: An example story board for a coordinated Drone Dance using four drones.

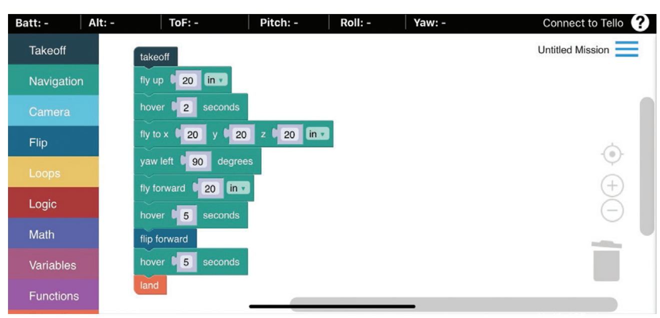


Figure 48: Drone Blocks program.

Activity 12: Tic-Tac-Drone

This activity provides a fun way to practice controlling your drone. This exercise can be conducted either outside or inside in a gymnasium or large open area.

Use drones that have an appropriate amount of lift (most 450 mm-frame drones are adequate). Attach bean bags to the drone using drone drop clips. You can use a manufactured clip or design your own clip (fig. 49). Some of these clips can be 3-D printed. Please check drone manufacturer guidelines for weight of payload and adjust the beanbag design accordingly.

Figure 49: Top Race Drone Clip with Remote Control, Release and Drop Drone Delivery Kit.

Students should then operate the drone and drop the bean bags onto a large tic-tac-toe board sketched out in a parking lot (fig. 50). The board game can be laid out with sidewalk chalk, tape, or using line or string. Students should work in teams of two to complete the game. Be sure to secure the parking lot so that cars are not moving through your game area. You can also spray paint a board in a grassy area.

Figure 50: Playing Tic-Tac-Drone using a DJI Inspire drone.

This game should be conducted in manual mode. An advanced version of this game would be to play it using an automated mode using a program such as DroneBlocks.

You can also elevate this activity to be a game of cornhole instead of tic-tac-toe, which requires more precise placement and coordination of the drop.

Notes:

Activity 13: Drone Relay Race

The goal of the Drone Relay Race is for players to fly through obstacles and reach the other side without crashing. See figure 51 for ideas on different obstacles to create.

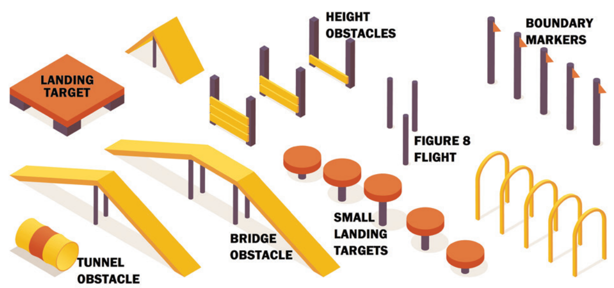


Figure 51: Sample obstacles.

Participants who miss an obstacle or crash are disqualified. You can elevate the requirements for this activity by setting a minimum completion time or by having students complete the course against an opponent. The better option is probably to choose a timed event in order to prevent drones from crashing into each other in midair.

Suggested Materials for Obstacle Course Construction

- PVC Pipe and Connectors
- Pool Noodles
- Hula Hoops
- Traffic Cones
- Caution or Flagging Tape

Notes:

Module 4: Precision Agriculture Workflows – Bringing It All Together

Just as no two chefs follow the exact same recipes, ingredients, cooking tools, or utilize the exact same techniques when cooking a three-course meal, there is no single methodology that farmers use when practicing precision agriculture. Every crop and every field may have unique characteristics and requirements, and farmers have different types of resources available. However, the following outline provides a summary of precision agriculture processes that a farmer might follow.

1. Soil sampling – Farmers determine their soil characteristics, provide general soil amendments, and condition the soil.

2. Farmers plant their seeds.

3. The seeds start to grow!

4. Airborne drones and their sensor payloads provide "eyes in the sky" to help monitor the status of the crops. Using sensors, including near-infrared sensors, these drones collect data that can identify areas of the fields that might be stressed.

   a. Drone-collected data can be captured on a regular basis – weekly, biweekly, monthly, etc.

   b. All collected data includes coordinate information so that the farmer is able to precisely navigate to areas where problems have been identified by the drone sensor. These problem areas are often referred to as "hot spots."

   c. The drone-captured data may be augmented with data from other "smart sensors" that are located around the farm. These sensors wirelessly transmit data to the farm management software.

5. Fieldwork is conducted. The farmer and/or other specialists may use a GNSS receiver to precisely locate the areas of the field with stressed crops, or hot spots. Fieldwork is required to identify the cause of the vegetation stress, which could include insects, soil enhancement needs, weeds, weather damage, or other issues.

6. Based on the data and evidence collected and by the fieldwork, an application plan is developed with a prescription of targeted inputs such as fertilizer, water, pesticides and/or herbicides.

7. A tractor supported by GNSS receivers and "smart sprayers" travels to the exact locations in the field where the stressed crops are located. These specific areas are treated according to the prescribed management plan.

8. Airborne drones continue to monitor the field on a regular basis to evaluate the success of previous treatments and identify new emerging issues that could impact crops. Sometimes these crop-related issues may appear in areas that have already been treated, and sometimes new issues may appear in other areas of the field.

9. At harvest time, tractors (harvesters) collect data including GNSS coordinate data and harvest data to determine which areas of the field produced the most and which produced the least harvest per unit. This production metric can be expressed as tons of harvest per acre or number of bushels per acre, for example. This information can be vital for a farmer by identifying areas of the field that may require additional attention in the off-season, perhaps improving drainage in an area that did not produce as much harvest per acre due to saturated soils or that might require other inputs to increase yields in the future.

Additional Resources: Precision Agriculture Workflow

Video:

Using GNSS in Agriculture (developed by Dan Swafford, narrated by Chérie Aukland, 7 minutes): https://youtu.be/0951Mdaqzxl.

Student Learning Activities:

- Activity 14: Exploring Plant Health with Remote Sensing
- Activity 15: Identifying Field Issues from Drone Imagery
- Activity 16: Reviewing Remote Sensing Concepts
- Activity 17: Where in the World?

Notes:

Activity 14: Exploring Plant Health with Remote Sensing

Note: See the appendix for guidance on the Discussion Boxes in this activity.

Objective

Explore the capabilities of using remotely sensed data to acquire information on plant health that cannot be seen with the naked eye.

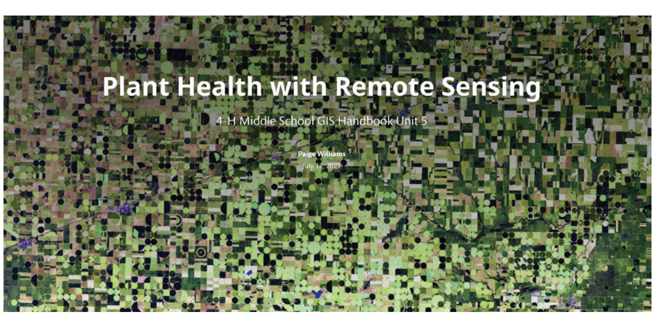
Concepts to Cover

- Healthy vs. stressed plants.
- Electromagnetic spectrum – the visible and invisible part of the spectrum.
- Near Infrared's interaction with vegetation.
- NDVI – Normalized Difference Vegetation Index.

This activity will incorporate the use of a StoryMap, which is an interactive web-mapping application produced by the geographic mapping company Esri. Like the StoryMap in Activity 9, this StoryMap was prepared and published by Paige Williams. This StoryMap provides learners with the opportunity to explore agricultural issues using satellite remote sensing.

The link to the StoryMap is available online at https://arcg.is/1n8m1K.

Follow along through the different sections of the StoryMap. The activity incorporates discussion questions that coincide with the content throughout the StoryMap.



Discussion Box 1

Tips for Using a StoryMap

- Use the scroll wheel on the mouse to move you through the website.
- Any map is interactive!
  - The Zoom is in the lower right corner.
  - To pan (drag the map around), drag while holding down your left mouse button.
  - The Home button will take you back to the original location.
  - Make the map full screen by pressing the icon in the upper right corner.
- The Swipe tool is interactive and allows you to swipe between two images or maps.
- To watch the YouTube videos, simply press play. (There is also an option to view the video on YouTube's website in the lower left corner of the video.)
- The StoryMap website link is sharable and publicly available.

Introduction

To begin this activity, scroll through the introductory slides in the StoryMap to get familiar with the subject. Review the sections entitled:

- Healthy vs. Stressed Plants.
- Understanding the Power of Remote Sensing.
- Using the Electromagnetic Spectrum with Vegetation.

- Remote Sensing Imagery to Detect Plant Health.
- Remote Sensing Images Drive Decision-Making.

Discussion Box 2

Take time to explore the introductory slides to answer the following questions:

- To the naked eye, what color are plants when they are stressed?
- Why is it hard to detect plant stress with the naked eye?
- What do healthy and stressed plants do differently with incoming light from the sun?
- What is the portion on the electromagnetic spectrum that humans cannot see, but is used for detecting plant health?
- What are some things that cause stress on plants?
- How can a farmer use these maps to help make decisions?

NDVI – Normalized Difference Vegetation Index

Using the mouse wheel, scroll through and read the StoryMap content on "Detecting Plant Health Using NDVI." Included in this section are two example maps of true color images compared with NDVI images.

The first set of maps was created from a drone acquisition flown over a cornfield at Kentland Farm in Blacksburg, Virginia.

The second set of maps was created from a drone acquisition flown over a soybean field in South Dakota. This section of the StoryMap also includes an elevation map overlaid with the NDVI map to visualize the field in three dimensions. Red areas of the field are areas with very little, if any, chlorophyll activity. It could be water, dead vegetation, or bare earth. Green areas are regions of healthy vegetation.

Discussion Box 3

Take time to explore the NDVI content and maps of drone acquisitions over crop fields to answer the following questions:

- What bands are used to calculate NDVI?
- Will a healthy plant produce a low or high NDVI value?
- In the cornfield at Kentland Farm, what are some features that pop out when comparing the true color and NDVI images?
- In the alfalfa field in South Dakota, what are some features that pop out when comparing the true color and NDVI images?
- How does the addition of a 3D elevation map help inform our understanding of the stressed areas of the image?
- Can you identify any other instances of stress or poor health in the provided images?

Landsat Viewer

What is Landsat? The Landsat Program is a series of Earth-observing satellite missions jointly managed by NASA and the U.S. Geological Survey. NASA explains:

"Landsat shows us Earth from space. Since the first Landsat satellite launched in 1972, the mission has collected data on the forests, farms, urban areas, and freshwater of our home planet, generating the longest continuous record of its kind. Decision makers from across the globe use freely available Landsat data to better understand environmental change, manage agricultural practices, allocate scarce water resources, respond to natural disasters and more." *(Source: https://www.nasa.gov/mission_pages/landsat/overview/index.html.)*

The Landsat Viewer is an interactive web mapping application that highlights some of the capabilities for accessing Landsat imagery layers. It is powered by ArcGIS for Server, and accesses Landsat Public Datasets running on the Amazon Web Services Cloud.

The layers are updated with new Landsat images on a daily basis.

The Landsat Viewer is embedded into the StoryMap, but here is the link if needed: https://livingatlas2.arcgis.com/landsatviewer/.

First, let's get familiar with the Landsat Viewer tools (fig. 52).

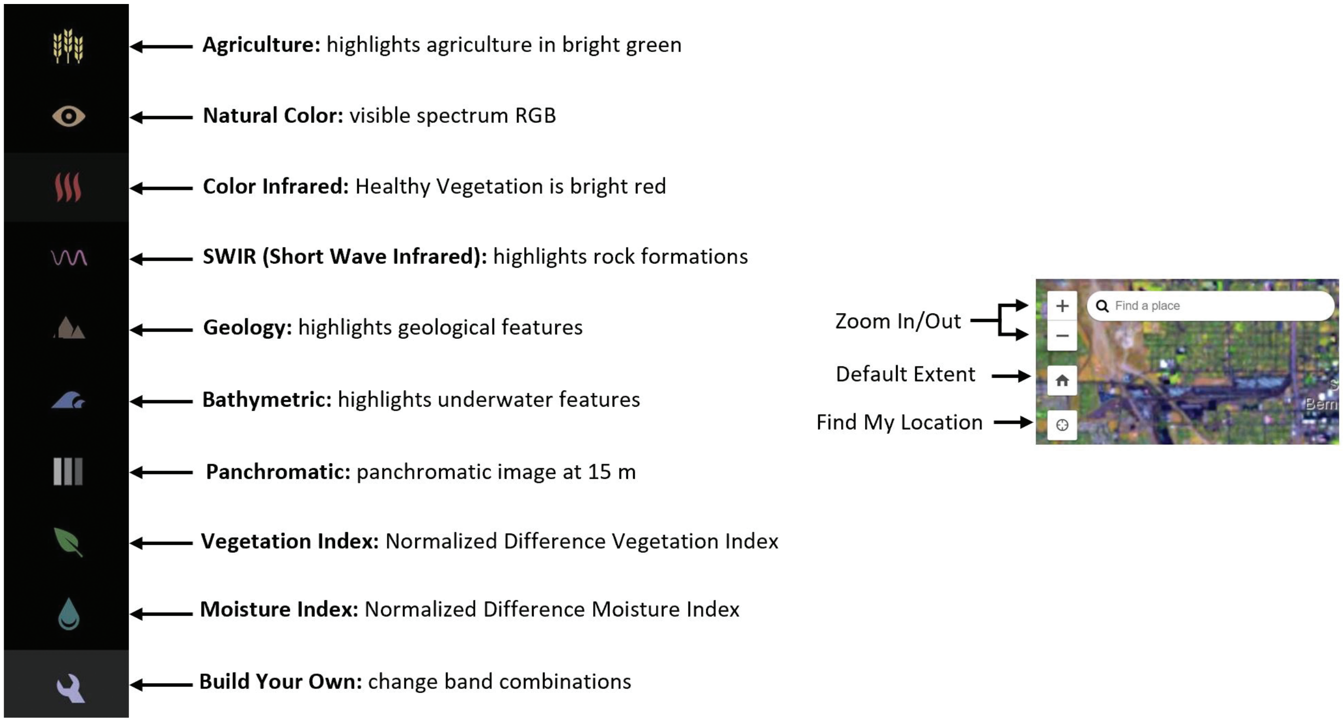


Figure 52: Landsat Viewer toolbar and tools with description.

To begin our activity for this section, simply click on the map to interact with the app.

The map has a default location at ESRI Headquarters in Redlands, California, but let's change our location to your current location now by clicking the "Find My Location" tool in the upper left of the map viewer.

Hint: *To aid in visualization, it can help to go back to the tool showing the Natural Color image to better understand the land features.*

Select the **Color Infrared** tool in the left-hand toolbar. In this example, healthy vegetation is shown in **bright red**.

Discussion Box 4

Take time to explore the Color Infrared map of your current location to answer the following questions:

- What are some identifiable features in your image?
- Can you locate some places with trees?

What color are agricultural fields in this image? What does that color indicate?

Select the **Vegetation Index** tool in the left-hand toolbar. In this image, healthy vegetation is shown in **green**.

Discussion Box 5

Take time to explore the Vegetation Index map of your current location to answer the following questions:

- What are some identifiable features in your image?
- Do you have any dark green pixels on the map of your area?
- Do you see urban areas in orange and red?
- How does this image compare with the Color Infrared map?

Select the **"Agriculture"** tool in the left-hand toolbar. Agriculture is highlighted in **bright green**.

Discussion Box 6

Take time to explore the agriculture map of your current location to answer the following questions:

- What are some identifiable features in your image?
- Can you locate any farms or cropland?
- How does this compare to the Color Infrared and Vegetation Index maps?

Experiment on your own with the other tools and different locations in the Landsat Viewer!

Notes:

Activity 15: Identify Yield Issues from Drone Imagery

Satellite imagery has been used to help assess the extent of agricultural lands and the health of crops for decades. Drone imagery gives analysts an opportunity to inspect crops more frequently and evaluate a smaller area, which gives a sharper, higher-resolution image.

Healthy crops reflect and absorb wavelengths of light differently than plants of poor health. Simply looking at a traditional image of a field in RGB (red, green, blue, also known as “true color” since RGB images are similar to what humans see) can provide the farmer with immediate feedback about the relative health of the crops in a single field or across several fields at once. Crop health is directly related to yield. If a hayfield appears deep green, then stressed brown and yellow pastureland will stand out. Sensors that collect information beyond the visible light spectrum provide additional insight by sensing the reflection and absorption of energy from the agricultural fields that can’t be seen without the help of equipment.

Let’s take a look at some example photographs and examine the plant health issues in this hayfield.

RGB (True Color) Imagery

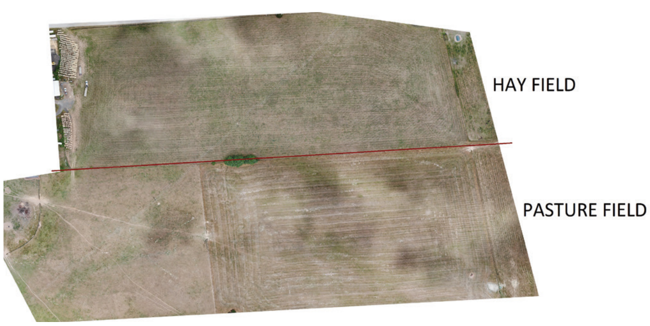


Figure 53: True color imagery of a hayfield.

Examine figure 53, above. What features can you identify?

- Make a list of objects or features that can be identified in the imagery above. Encourage students to zoom in. Some features that they should identify include:
    - Powerlines
    - Trees
    - Hay bales
    - Fence
    - Truck
    - Building/barn
    - Dirt paths
    - Cloud shadows (or clouds)

You can also utilize imagery from Google Earth or any other online map-viewing application to explore remote sensing imagery.

- Example: paste these coordinates into the search bar of Google Earth or similar app:
    - 37.32028, -120.79224

The map-viewing app will navigate you to an agricultural area in California. Your image should look similar to figure 54:

Figure 54: Google Earth image of agricultural area in California.

What features can you identify in figure 54? Feel free to make some good guesses, then you can use the street view function to gain additional perspective about your images.

- What are the round circles in the image above?
- Why are these features round, instead of rectangular?
- Which of the three fields would you consider to have the highest yield?
- Which of the three fields do you think might have a broken irrigation nozzle?

Do you see anything that might distort or introduce error in the plant health analysis?

Clouds can greatly influence image analysis. It can be difficult to acquire and compare data in "true color" if there are special weather conditions or outside influences, especially if conditions are not consistent across a field (like cloud shadows would be).

NDVI (VARI) Imagery Analysis

DroneDeploy offers a VARI (Visible Atmospherically Resistant Index) algorithm that will alter a standard RGB image to mimic an NDVI (Normalized Difference Vegetation Index) image as seen in figure 55.

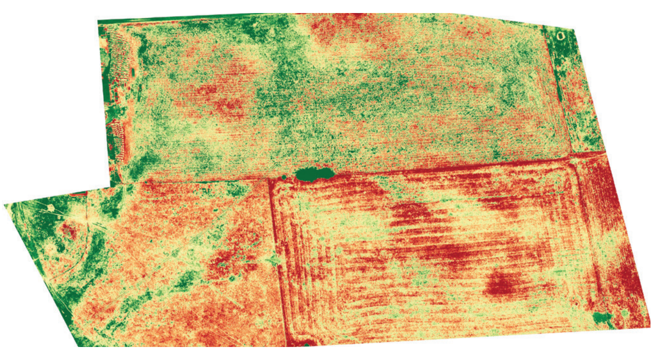


Figure 55: VARI image produced by DroneDeploy of the hay and pasture fields from figure 53.

Guiding Questions for Instructors

Do you think that this is considered a healthy field?

- Healthy" can be a subjective (or relative) term. The goal is for students to recognize that green = healthy and red = dry/dead.
- In figure 55, you can see hot spots where the crop is showing signs of stress. This could be due to lack of moisture or low fertilization. This information would be difficult to determine from a standard RGB image that hasn't been manipulated. Ask students to:
    - Identify the "hot spots" and to hypothesize why these are hot spots.
    - Brainstorm ideas on how a farmer might determine what is causing stress in these identified hot spots.
    - Discuss what a farmer would do in order to mitigate (correct) the issues associated with these identified hot spots.
    - Estimate what percentage of the hay field (top half of figure 55) appears healthy (green).
    - Discuss the deep green color in the middle of figure 55. If they didn't have access to the standard RGB image in figure 53, would they know right away what that deep green represented?

Students can see that while NIR imagery and image indices such as NDVI or VARI can provide important information about the relative health of crops in a field, it can be important to have both images (true color and NIR/index images) to more fully understand what is happening "on the ground." Images can be visually compared side by side. Another method to visually display and compare this imagery is using an ArcGIS Storymap! You can see a preview of these images and use the slider tool online at https://arcg.is/0qrXG1 (fig. 56).

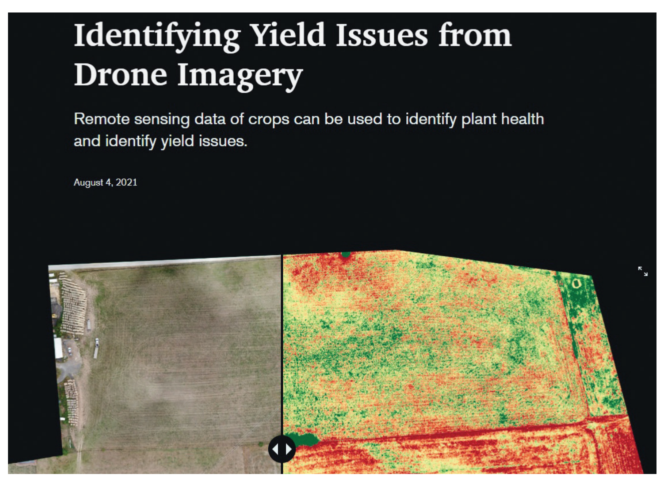


Figure 56: Screenshot of "Identifying Yield Issues from Drone Imagery" StoryMap home page.

On the following pages, figures 53 and 55 are provided in a larger format to copy/print for students or project onto a white board.

Figure 53: True color imagery of a hayfield.

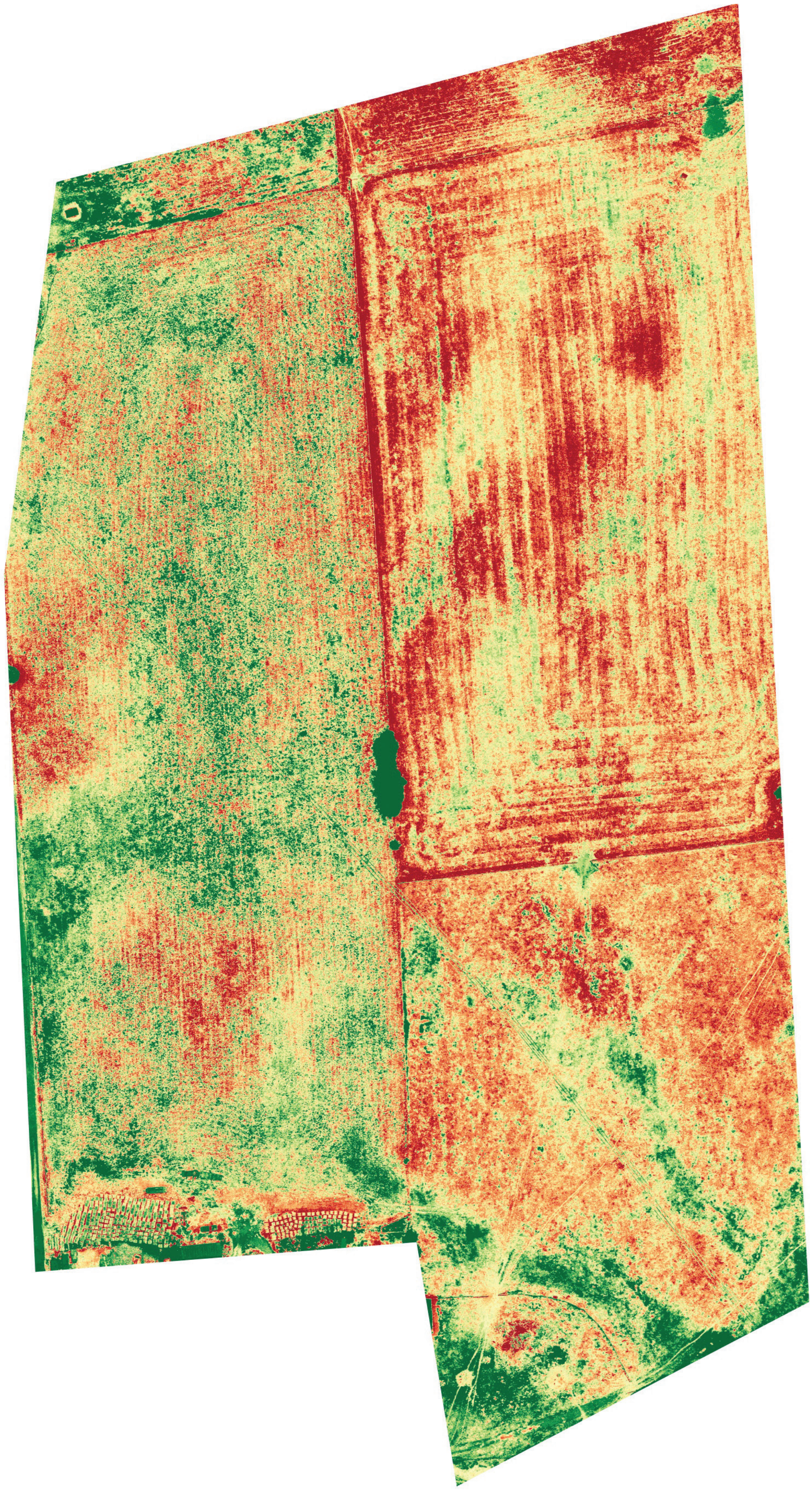


Figure 55: VARI image produced by DroneDeploy of the hay and pasture fields from figure 53.

Activity 16: Reviewing Remote Sensing Concepts

1. What is remote sensing?

2. List two types of remote sensing sensors:

   a.

   b.

3. Discuss the difference between these two types of sensors.

4. What can remote sensing tell us about a crop of corn? (list two)

5. What is a pixel?

6. If you wanted to capture a high-resolution photograph of a cornfield, what size of pixel would you capture?

   a. Large pixels

   b. Small pixels

   c. No pixels

7. Your corn crop is exhibiting stress. List three possible sources of this stress.

   a.

   b.

   c.

8. Give an example of a “hot spot” in your cornfield.

Activity 17: Landsat Puzzle Game

IndianaView, a service committed to promoting the use of public domain remotely sensed image data (from aerial and satellite platforms), has developed an online Landsat puzzle game. The game provides opportunities to identify specific features in the images to complete the puzzle.

What is Landsat?

You are now well aware that special sensors can be placed on drones. Similar sensors can also be placed on other forms of crewed and uncrewed vehicles, including satellites! Landsat, jointly operated by NASA and the U.S. Geological Survey, is a mission that uses satellites to observe the Earth.

Landsat 1 was initially launched in 1972. Since then, additional Landsat satellites have been launched, collecting data and observing the Earth continuously to document the impacts of climate change; wildfire issues; changes in land cover; agricultural issues associated with drought, pests, or floods; growth and changes in urban areas; urban heat islands; and changes in water abundance and water quality. While improvements to the satellites and sensors have been implemented since 1972, Landsat's mission-to-mission goals remain the same.

Learn more about the Landsat program online at https://www.usgs.gov/core-science-systems/nli/landsat.

Accessing the Puzzle

Are you ready to start puzzling? Access the Landsat puzzle at IndianaView's Earth Image Puzzle homepage (fig. 57) at https://www.indianaview.org/image_puzzle.html.

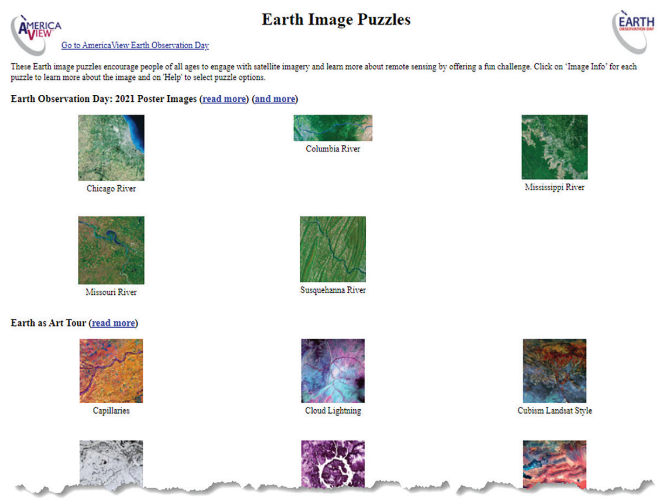


Figure 57: IndianaView's Earth Puzzle home page.

Select a Landsat image that you would like to use as a puzzle. This example uses the "Farms in Kansas" image from the Earth Observation Day 2018 selection. After choosing an image, specify how many puzzle pieces you want to work with (fig. 58).

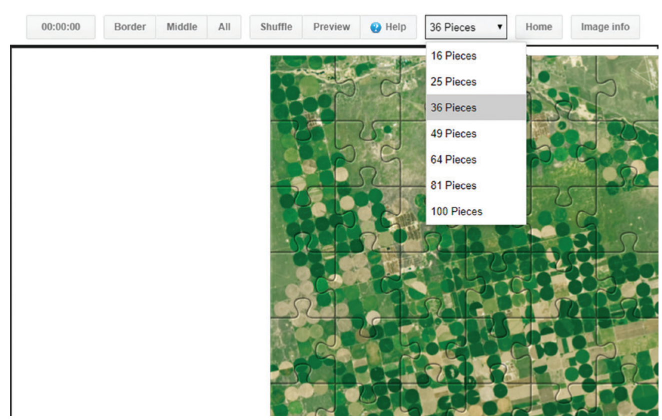


Figure 58: Selecting puzzle options.

Click the "Shuffle" button, and you are now ready to start putting together the puzzle (fig. 59). Use your mouse to drag the puzzle pieces to create your Landsat masterpiece. Use the remote sensing image analysis tools that you have practiced to help you to complete your puzzle. Examine shapes, patterns, sizes, color, locations, and texture to better observe and understand features and help you solve your puzzle! Note that the background in your puzzle might be a different color than what is shown in our picture.

Figure 59: Puzzle pieces.

Note that there is a timer in the upper left-hand corner of the screen. Use the timer to compete against yourself or generate some friendly competition with others!

Notes:

Activity 18: Where in the World

Where in the World (fig. 60) is an exciting and fun opportunity for students to practice their geography and remote sensing visual analysis skills! In this online application, learners are provided with an image (it could be a satellite or other aerial photographic image), and they use deductive reasoning to attempt to identify which country the image is from. Players can choose among three multiple-choice options to guess the answer, working in groups or independently.

Materials required: A computer or tablet and internet are required.

URL: https://eol.jsc.nasa.gov/BeyondThePhotography/WhereInTheWorld/quiz.pl.

Or use this shorter alias: https://tinyurl.com/ImageGuesser.

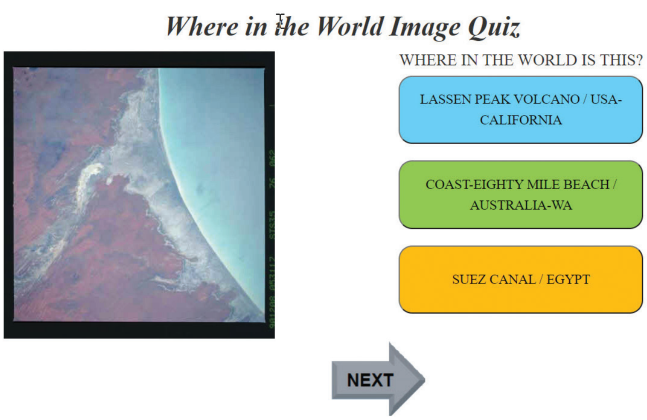


Figure 60: A page from the "Where in the World Image Quiz" website.

Notes:

Appendices

Glossary: Lingo to Know

agricultural yield – May also be referred to as "crop yield" or "crop production"; relates to the amount of produce harvested per unit of land (i.e., per acre or hectare). Examples:

- A total of 40 tons of corn were harvested from a 38-acre field.
- The agricultural yield associated with these five fields averaged 1.3 tons per acre.

agricultural runoff – Associated with water that is deposited on fields (through rain, irrigation, snowmelt, etc.). Some of this water is absorbed and utilized by plants, and some either flows over the top of the ground or can be absorbed into the ground. When water is not directly utilized by plants, it can carry agricultural inputs (fertilizer, pesticides, herbicides, manure) into neighboring streams and waterways, which is the process known as agricultural runoff.

agronomy – The science (and technology) of producing plants for food and clothes. How well plants grow is dependent on the soil or other substrates where they grow and the nutrients and water available to them.

aspect – Also known as "exposure," aspect is the compass direction which an area of land faces.

- North = 0 degrees
- East = 90 degrees
- South = 180 degrees
- West = 270 degrees

autonomous system – *See uncrewed system.*

autonomous drone flight – *See uncrewed system.*

auto-steering – Also referred to as auto guidance; refers to the guidance, or navigation, of farm vehicles using global navigation satellite systems (GNSS).

civil twilight – The period of the day just before sunrise or just after sunset. This is when the sun is approximately 6 degrees below the horizon, but when there is still enough light to participate in ordinary outdoor activities. The period after civil twilight is considered to be night. Higher latitudes may experience longer civil twilight periods during summer months than lower latitudes.

coordinates – Two numbers that can pinpoint a location. Coordinates use a grid system.

crop yield – The measure of crop harvested per acre of land. It can be expressed by weight (pounds or tons) or volume (bushels) and is stated as a ratio ("170 bushels of corn per acre").

drone – *See uncrewed system.*

ecosystem services – Ecosystems support life for people. For example, plants produce oxygen, keep soils from eroding through their root systems, and help filter water. Bees and wild insects pollinate crops. Worms and bacteria enhance the soil. Some plants and insects deter pests from entering fields. Scientists are gaining an increased understanding of the benefits that ecosystems provide to humans.

flight paths – GNSS waypoints that are connected by flight lines. These flight lines represent the automated flight path of a drone. Flight paths are delineated by the RPIC during the flight planning process.

flight plan – A methodical process led by the remote pilot in command (RPIC). The flight plan takes many variables into consideration that could influence the flight. These variables could include scheduling (time of day, etc.), payload characteristics, altitude, weather, nearby structures, land cover, emergency landing sites, specific safety requirements, regulations, and flight patterns. The data goals of the project help guide the flight plan. RPICs often utilize check sheets to support their flight planning.

geographic coordinates – Coordinates stating latitude and longitude, usually expressed in units of degrees, minutes, and seconds, or in decimal degrees. Geographic coordinate systems are used to pinpoint a location on the surface of the Earth.

global navigation satellite systems (GNSS) – A general term that encompasses all different navigation satellite systems. Global navigation satellite systems associated with GNSS include: GPS (USA), Galileo (European Union), and GLONASS (Russia). Signals from these satellites provide support for navigational services around the world (including those for self-driving vehicles, Uber, etc.). GNSS provides the foundation for autonomous drone operations and auto-steer tractors.

Global Positioning System (GPS) – A global navigation satellite system that was developed by the United States.

grid cell – A unit of area (typically a square) that is superimposed on top of a field. Grid corners are associated with geographic coordinates. These cells are often used to break up an agricultural field into smaller units, so that these smaller units can be monitored and managed to promote higher agricultural yields.

latitude – A geographic coordinate used to measure points north or south on Earth, as measured from the equator.

longitude – A geographic coordinate used to measure the distance of a point east or west of the prime meridian.

maximizing yields – The practice of farmers working to harvest the maximum amount of crop from their field as possible. By maximizing their harvest, they are able to sell more of their crop, which allows them to increase their profit. The concept of maximizing harvest is often referred to as "maximizing yields."

multi-sensor data fusion – Enables the combination and analysis of information from multiple sensors (or other sources) in order to support decision-making.

notice to air missions (NOTAMs) – A statement provided by the U.S. Federal Aviation Administration (FAA) that contains information about a modification or change to the national airspace system. Examples of circumstances that would prompt the issuance of a NOTAM include airshows, balloon festivals, parachute jumps, rocket launches, or controlled airspaces (temporary flight restrictions) that might be associated with large crowds (football games) or the presence of VIPs (such as members of Congress or the president). Note: Until recently, NOTAM referred to "notice to airmen," but this reference is now considered outdated.

payload – Cargo that is carried by a vehicle. UAS payloads are often associated with sensors.

platform – In relation to this curriculum, "platform" refers to the vehicle on which a sensor can be mounted. Examples of sensor platforms might include satellites, manned aircraft, balloons, terrestrial drones, and UAS.

precision agriculture – The farming practice that relies on accurate data collected across a field. Farmers use this data to identify different terrain, soil, and plant characteristics within their field, and then prescribe variable amounts of inputs for different areas of their fields to increase crop production.

profit – The difference between the amount of money that is spent and the amount of money that is earned. In agricultural operations, farmers spend money to purchase seeds, buy farm equipment (tractors, harvesters, sprayers, irrigation, etc.), repair and maintain structures and equipment, purchase agricultural inputs (fertilizers, fertilizers, herbicides, etc.), pay for labor, etc. Farmers use money that is collected through the sale of the harvest to pay for these expenses. The money that is left over after all expenses are paid is the profit.

remote pilot in command (RPIC) – A term associated with the pilot of a drone. The RPIC is responsible for ensuring that the drone is operating safely and in compliance with all regulations. The RPIC is the final authority for the operation of the drone. All drone flights must have a designated RPIC.

remote sensing – The process by which you can observe and collect information about an object without being in direct contact with that object. Remote sensing platforms can include large balloons, kites, sUAS, manned aircraft (airplanes and helicopters), and satellites. Different sensors can be mounted on these different platforms to collect different information about the Earth's surface.

satellite constellation – A group of similar satellites that collectively support an application or common purpose. GPS is an example of a U.S. constellation of satellites that provides users with position and navigation.

slope – The rise or fall of the surface of the land. The formula for measuring slope is:

$$\text{Slope} = \frac{\text{The difference in elevation between two points on the terrain}}{\text{The distance between the two points on the terrain}}$$

spatial information – *See spatial location.*

spatial location – The location of an object on the surface of the Earth relative to other objects. Often, geographic coordinates (latitude and longitude) serve as a cornerstone for spatial location.

temporal data – The collection of data associated with a documented moment in time. Examples might include capturing drone imagery of a field on June 22. This same field can be revisited each week (or each month). The initial data captured could be used as a baseline to compare data captured at later dates.

uncrewed system – Any autonomous vehicle system. This could include autonomous airborne systems such as quadcopters or fixed wing aircraft (airplanes), autonomous terrestrial systems ("robots on the ground"), and autonomous marine systems (including autonomous underwater vehicles (AUV) and autonomous surface vehicle (ASV).

variable rate application – Traditionally, farmers have applied the same amount of inputs (water, fertilizer, pesticide, herbicide, etc.) over an entire field. Variable rate application represents a more modern approach, whereby a farmer will apply an input at different amounts based on the local needs of the plants in the field. Some areas of the field, for example, may require higher amounts of nitrogen than other areas of the field. Variable rate application can save farmers money (because they need to purchase fewer inputs) and can therefore support increased profits. In addition, this approach is also good for the environment, since it can minimize agricultural runoff.

Summary List of Supplemental Resources

Videos

Module 1: Exploring Precision Agriculture

- **"Introduction to Agriculture"** (developed by Dan Swafford, narrated by Chérie Aukland, 10 minutes): https://youtu.be/lCv9o3dexrc.
- **"Introduction to Pesticides and Herbicides"** (developed by Dan Swafford, narrated by Chérie Aukland, 5 minutes): https://youtu.be/kc_Z_itn7Bs.
- **"CropScape Demo Video"** (George Mason University, nine minutes) (Zhang, 2021): https://nassgeodata.gmu.edu/CropScape/demo/demo.htm.

Module 3: Drones in Agriculture

- **"sUAS Flight Planning"** seven-part video series (about 12 minutes each) (Cross, 2018): https://www.youtube.com/user/VaGeoExtension/playlists.
- **"An Introduction to the Electromagnetic Spectrum"** (about 5 minutes) (National Aeronautics and Space Administration, 2010): http://science.nasa.gov/ems/01_intro.
- **"How One NASA Image Tells Dozens of Stories"** (about 6 minutes) (NEO, 2019): https://www.youtube.com/watch?v=ZYGd-IlxHJE.
- **"Comparison of True Color and Near Infrared Sensors"** (5 minutes) (AgEagle Aerial Systems, 2016): https://www.youtube.com/watch?app=desktop&v=XLsaYY631ao.
- **"Mapping the Invisible: Introduction to Spectral Remote Sensing"** (about 6 minutes) (National Ecological Observatory Network, 2015): https://www.youtube.com/watch?app=desktop&v=3iaFzafWJQE.
- **"Lidar: Light Detection and Ranging"** (about 3 minutes) (Geospatial World, 2017): https://www.youtube.com/watch?v=zREAEdXzOcw.
- **"5 Human Activities that You Can See from Space"** (about 3 minutes) (VOX Media Inc., 2015): https://www.youtube.com/watch?v=MNQ9z_Eb-Jc.
- **"Behind the Scenes: Verge Aero Drone Light Show During Covid-19"** (13 minutes) (Nick Lang Media Inc., 2020): https://www.youtube.com/watch?v=rnwwXGYF3r0.
- **"How to Make a Drone Show"** (about 6 minutes) (UcGSTV Media, 2019): https://www.youtube.com/watch?v=YW_VR3Yx0DE.
- **"An Introduction to Tello Drone Programming"** This seven-module tutorial series covers everything from installation to coding. Note that you are required to create a free account to access this tutorial series (each tutorial is approximately 3 minutes) (DroneBlocks, 2021): https://learn.droneblocks.io/p/introduction-to-drone-programming-with-tello.

Module 4: Precision Agriculture Workflows: Bringing it all Together

- **"Using GNSS in Agriculture"** (developed by Dan Swafford, narrated by Chérie Aukland, 7 minutes): https://youtu.be/0951Mdaqzxl.

PowerPoint Presentations

Exploring Precision Agriculture

- **"Understanding Area Measurements"**: https://tinyurl.com/UnderstandingAcreage.

Precision Agriculture: Understanding Data

- **"Introduction to GNSS"**: https://tinyurl.com/IntroGNSS.

- **"Maps and Coordinates"**: https://tinyurl.com/MapCoords.

Drones in Agriculture

- **"Introduction to Remote Sensing"**: https://tinyurl.com/IntroRS.

Discussion Guidance for Activity 4: CropScape

Discussion Box 1 provides fun facts about agriculture in the U.S.

Source: https://stacker.com/stories/3554/50-fascinating-facts-about-farming-america.

Discussion Box 2: Explore the CropScape Map and Legend

Take time to explore your images and look for features to discuss with the class.

Q: What are some features that can be identified?

A: Basically, any item that can be identified in the legend (fig. 12) can be identified on the map. This could include rivers and streams, state boundaries, roads, as well as agricultural areas.

Q: Do you see the corn and soybean fields in the Midwest?

A: Students should be able to identify fields in the Midwest that are associated with corn and/or soybeans.

Q: Why would there be a cluster of different crop types along the Mississippi River?

A: Water availability, soil conditions, access to specific markets, etc.

Q: What geographic features cause the strip of cropland running from north to south in California? What is this region called?

A: This is called California's Central Valley. The Central Valley has several geographic benefits, which include very fertile soils (caused from erosion from the mountains), water availability due to snowmelt in the mountains (of course, this is a relative term), and access to nearby markets and transportation infrastructure (for shipping). Historically, the Central Valley has also had adequate seasonal labor to support this industry.

Q: Why might there not be a lot of croplands in Nevada?

A: The majority of the state is desert and rough mountain terrain.

Q: Do you see the dense area of cotton fields in northwestern Texas?

A: This area accounts for more than 42% of the total cotton production in the U.S.

Discussion Box 3: Discussion questions on 2020 Cropland Data Layer Statistics for Virginia

Q: What is the most prominent crop type in Virginia?

A: Hay/non alfalfa. (Forest or timber could also be considered to be a correct answer.)

Q: What is the second-most prominent crop type in Virginia?

A: Grass/pasture.

Q: What is the least prominent crop type in Virginia?

A: Peppers.

Q: What percentage of Virginia's cropland cover is corn?

A: 2.4%

Q: The average farm size in Virginia is 184 acres, which is about the size of Disneyland.

Source: https://www.nass.usda.gov/Publications/Todays_Reports/reports/fnlo0220.pdf.

Discussion Box 4: Discussion questions on 2020 Cropland Data Layer Statistics for Iowa

Q: What is the most prominent crop type in Iowa?

A: Corn.

Q: What is the least prominent crop type in Iowa?

A: Flaxseed.

Q: What percentage of the cropland is corn in Iowa?

A: 38.3%

Other Iowa farm fun facts:

Compared with Virginia, Iowa has a less of a variety of crop types and majority of cropland is corn.

Virginia has a variety of topography, soils, climate and farm size; therefore crops can be more diverse.

The average farm size in Iowa is 359 acres, which is double the size of Virginia farms!

Source: https://www.nass.usda.gov/Publications/Todays_Reports/reports/fnlo0220.pdf.

Why do you think size of farms in Iowa is significantly different than in Virginia?

Land availability in Iowa. Iowa is relatively flat. Iowa was settled using the Public Land Survey System (PLSS). You could hypothesize that farms have historically been (on average) in Iowa. Virginia is more densely populated and mountainous.

Discussion Box 5: Discussion questions on 2020 Cropland Data Layer Statistics for "The Central Valley" in California

Q: What is the most prominent crop type in the Central Valley of California?

A: This answer is contingent on how students delineate their polygons. Grass/pasture and almonds are often identified as some of the post prominent crop types.

Q: What is the least prominent crop type the Central Valley of California?

A: This answer is contingent on how students delineate their polygons. Blueberries may be identified as one of the least prominent crop types in the Central Valley. Note that blueberries are a fairly water-intensive crop and irrigation in California is expensive due to water shortages.

Q: What is the Grass/Pasture class used for?

A: Cows and livestock feed. The majority is for beef and dairy production.

Other California farm fun facts:

Compared with Virginia and Iowa, California has a higher variety of crop types and similar to Mediterranean crops (like almonds, grapes, olives, etc.)

This is likely due to the climate. The Central Valley has more moderate annual temperatures than Iowa or Virginia.

The average farm size in California is 348 acres, which is similar to Iowa although the land is way more expensive in California.

Source: https://www.nass.usda.gov/Publications/Todays_Reports/reports/fnlo0220.pdf.

The Central Valley produces one-quarter of the entire nation's food.

Source: https://ca.water.usgs.gov/projects/central-valley/about-central-valley.html.

California Produces about 66% of the nation's fruits and nuts.

Source: https://www.cdfa.ca.gov/Statistics/PDFs/2020_Ag_Stats_Review.pdf.

Discussion Guidance for Activity 9: Exploring Satellite Imagery Using StoryMaps

Discussion Box 1 is just fun facts.

Sources: https://blog.maxar.com/earth-intelligence/2011/little-known-facts-about-satellites; https://www.softschools.com/facts/space/satellite_facts/3795/.

Discussion Box 2: This box provides tips for using StoryMaps.

Discussion Box 3: Take time to explore the maps of Washington D.C. What are some features that can be identified?

Q: Do the roads and buildings from OpenStreetMap line up with the satellite imagery?

A: For the most part, yes, but not perfectly.

Q: Can you locate the U.S. Capitol and the White House?

A: Hint: Use the swipe tool to uncover the labelled map and zoom in to reveal additional descriptive text.

Q: Why might some of the buildings be slanted in the satellite image?

A: This is due to the view angle of the satellite sensor passing over the area. When sensors observe features on the ground directly overhead (also known as nadir), there is less distortion. When sensors observe features on the ground from a side angle (also known as an oblique angle), there is increased distortion.

Discussion Box 4: Take time to explore the maps and video provided. What are some features that can be identified?

Q: What is the light source for imagery during the day?

A: The sun. When a sensor measures energy (reflected off of an object) that is emitted by a natural source (light from the sun), this is referred to as passive remote sensing. When an artificial source of energy is used by a sensor to detect reflected energy, this is referred to as active remote sensing. Using a camera with a flash is an example of active remote sensing because a camera flash is an artificial source of light. Sonar, radar, and lidar are also examples of active remote sensing.

Q: What is the light source for imagery at night?

A: Artificial lights from electricity (streetlights, buildings, etc.); the oil extraction generates bright lights; commercial boats; wildfire; flares from refineries; etc.

Q: How are light sources at night associated with human activity?

A: All sources from the previous question are caused by human activity.

Q: Can you locate some highly populated areas in the United States?

A: Look for clusters of lighted areas in the satellite imagery at night map.

Q: What are some things that might be happening in the dark places in the night imagery?

A: Positive: Wildlife sanctuaries, bird migration, fireflies need dark to survive, people stargazers, recreational opportunities,

Negative: Political unrest, human migration, lack of energy infrastructure, illegal fishing zones, etc.

Discussion Box 5: Take time to explore the maps provided. What are some features that can be identified?

Q: What is the main difference in the summer vs. winter imagery?

A: Snow cover.

Q: What are some other differences in the summer vs. winter imagery?

A: Deciduous trees in Europe have leaves in the summer, sea ice expands in the winter, mountains pop out with snow cover. See the Alps – more land features can be seen in the summer. Note: The water appears darker in the winter imagery, but that is just a processing difference not a physical difference in water color at different times of year.

Q: What is between the satellite and the ground?

A: The atmosphere, which contains atmospheric particles and clouds that produce weather.

Q: In what specific places of the world might clouds be an issue at certain times of the year?

A: It depends on the weather and climate of certain regions. Examples include clouds blocking the Amazon rain forest, which is called a "cloud forest"; clouds blocking southern India during the monsoon season; and clouds from hurricanes hitting the Southeastern U.S. at the end of the summer. On the contrary, clouds would rarely be an issue over the Sahara Desert.

Discussion Box 6: Take time to explore the maps and video provided. What are some features that can be identified?

Q: What has happened to the river in Peru over time?

A: It has completed rerouted its course due to the dynamic nature of water flow and created a lake.

Q: What are some other examples of change that we can monitor from space?

A: Deforestation, urban sprawl, changes in agricultural planting patterns (fallow to fields), different types of agricultural practices (pastureland/cropland/fish farming), changes from green space to impervious surfaces, etc.

Q: What causes shifting shorelines of bodies of water?

A: currents, differences of precipitation patterns, climate change, weather

Q: Where in the world is a good example of fast urbanization (population shift from rural to built-up)?

A: Watch the video in the StoryMap for examples of fast urbanization over time.

Discussion Guidance for Activity 14: Exploring Plant Health with Remote Sensing

Discussion Box 1: Tips for using a StoryMap.

Discussion Box 2: Take time to explore the slides to answer the following questions:

Q: To the naked eye, what color are plants when they are stressed?

A: Brown or yellow.

Q: Why is it hard to detect plant stress with the naked eye?

A: Signs of plant stress often aren't visible to the human eye. We see the aftereffects of the stress, and when that appears, it's usually too late to recover the plant back to health. Also, it can be difficult to conduct a visual analysis over large areas, like huge corn fields in Iowa.

Q: What do healthy and stressed plants do differently with incoming light from the sun?

A: Healthy plants absorb and reflect energy differently from stressed plants. This is particularly the case with near infrared energy. Healthy plants reflect more energy than stressed plants in the near infrared bands.

Q: What is the portion on the electromagnetic spectrum that humans cannot see, but is used for detecting plant health?

A: Near infrared.

Q: What are some things that cause stress on plants?

A: Insect infestation, lack of nutrients, lack of water, weeds, disease.

Q: How can a farmer use these maps to help make decisions?

A: Maps can be used to provide the geographic location of stressed crops in the field. When farmers know the location of the stress, they can conduct fieldwork to identify the source of the stress and then prescribe a solution.

Discussion Box 3: Take time to explore the NDVI content and maps of drone acquisitions over crop fields to answer the following questions:

Q: What bands are used to calculate NDVI?

A: Red and near infrared.

Q: Will a healthy plant produce a low or high NDVI value?

A: Healthy plants will produce a high NDVI value.

Q: In the cornfield at Kentland Farm, what are some features that pop out when comparing the true color and NDVI images?

A: Stressed vegetation between the rows of corn; stressed vegetation on the edges of the field; random hot spots throughout the field that we cannot see in true color image; vehicles are red because they do not have plant matter.

Q: In the alfalfa field in South Dakota, what are some features that pop out when comparing the true color and NDVI images?

A: Gray/blue areas in the true color image appear as areas of low chlorophyll in the NDVI image (could be rocks, water, or different soil type); certain edges of the field look stressed or have poor health; tracks from a truck can be seen in both images; trees are blue and green, which depicts vigorous vegetation.

Q: How does the addition of a 3D elevation map help inform our understanding of the stressed areas of the image?

A: The stressed areas seem to be in the lower elevation areas and valleys of the image; this could imply that the health is related to the elevation or slope of the land.

Q: Can you identify any other instances of vegetation stress or poor health in the provided images?

A: Open for discussion.

Discussion Box 4: Take time to explore the Color Infrared map of your current location to answer the following questions:

Q: What are some identifiable features in your image?

A: The answers to these questions will depend on the location. Some features to look for include agricultural fields, residential areas, etc.

Q: Can you locate some places with trees?

A: The answers to these questions will depend on the location. Some features to look for include agricultural fields, residential areas, etc.

Q: Can you see the agricultural fields in pink?

A: Arbitrary to location, these could also be golf courses or anything with vigorous chlorophyll activity.

Discussion Box 5: Take time to explore the Vegetation Index map of your current location to answer the following questions:

Q: What are some identifiable features in your image?

A: Depending on your area you may see agricultural fields actively growing, forests, streets/impervious surfaces.

Q: Do you have any dark green pixels around you?

A: Arbitrary to location, would suggest vigorous vegetation growth.

Q: Do you see the urban areas in orange and red?

A: Arbitrary to location, orange and red is often associated without vegetation such as impervious surfaces.

Q: How does this compare to the Color Infrared map?

A: Arbitrary to location, but based on health, the crop fields should pop out as blue and trees in green or yellow. It's easier to locate healthy cropland.

Discussion Box 6: Take time to explore the agriculture map of your current location to answer the following questions:

Q: What are some identifiable features in your image?

A: Arbitrary to location, look for structures, object uniform in shape (man-made), water, circular/rectangular shapes that indicates fields.

Q: Can you locate any farms or cropland?

A: Arbitrary to location, look for circular/rectangular shapes that indicates fields.

Q: How does this compare to the Color Infrared and Vegetation Index map?

A: Arbitrary to location, but ag and color infrared layer makes the land cover classes more obvious and you can see boundaries of cropland.

Other Supporting Resources

- Landsat Viewer website: https://livingatlas2.arcgis.com/landsatviewer/.
- Further information about NDVI: https://www.planetwatchers.com/whats-the-matter-with-ndvi-you-are/.

Discussion Guidance for Activity 16: Reviewing Remote Sensing Concepts

1. What is remote sensing?

   The process by which you can observe and collect information about an object without being in direct contact with that object. Remote sensing platforms can include large balloons, kites, sUAS, manned aircraft (airplanes and helicopters), and satellites. Different sensors can be mounted on these different platforms to collect different information about the Earth's surface.

2. List two types of remote sensing sensors:

   a. Active sensors

   b. Passive sensors

3. Discuss the difference between these two types of sensors.

   a. Active sensors – use their own energy source to collect energy that is reflected by an object. Lidar and sonar are examples of active sensors. A camera flash is also an example of an active sensor.

   b. Passive sensors – measure energy (reflected off of an object) that is emitted by a natural source (light from the sun), this is referred to as passive remote sensing.

4. What can remote sensing tell us about a crop of corn? (list two)
   There are many potential answers. Here are a few…

   a. Crop damage due to weather (wind, hail, etc.)

   b. Animal damage (bears, deer, etc.)

   c. Areas of less vigorous / more stressed plants

   d. Areas of more more vigorous / more stressed plants

   e. Weeds / ground cover

   f. Standing water

5. What is a pixel?

   A pixel is the most basic unit of an image.
   In remote sensing, pixels are comprised of small grid cells. Each cell is assigned a unique color. Smaller pixels result in sharper, or higher resolution images. However, images with smaller pixels require more storage space than higher resolution images.

6. If you wanted to capture a high-resolution photograph of a cornfield, what size of pixel would you capture?

   a. ~~Large pixels.~~

   b. Small pixels.

   c. ~~No pixels.~~

7. Your corn crop is exhibiting stress. List three possible sources of this stress.
   There are many potential answers. Here are just a few.

   a. Insect damage

   b. Too much rain (water)

   c. Not enough rain (water)

   d. Lacking primary nutrients (nitrogen, phosphorus and/or potassium)

   e. Lacking (or too much of) a minor nutrient (iron, zink, etc.),

   f. Wrong pH

   g. Damage caused by other animals

   h. Weed issues

   i. Heat stress

   j. Too much shade

   k. Too much sun

8. Give an example of a “hot spot” in your cornfield.

   A hot spot is an isolated area in a field that has been identified as an area where plants are exhibiting stress. Hot spots are best identified from above. Typically, farmers need to identify these isolated areas of stress early, before the conditions associated with these hot spots spread to other areas of the field. The drone can only identify a hot spot. It often is unable to identify the precise source of the vegetation stress. Therefore, field work is essential to validating the source of the stress, and to prescribe the proper management techniques to correct the problem.

About the Authors

John McGee, Ph.D., is a faculty member in Virginia Tech's Department of Forest Resources and Environmental Conservation and has served as the Virginia Geospatial Extension Program specialist since 2003. Through the VGEP, John has hosted hundreds of geospatial workshops in response to the geospatial educational needs of Virginia's communities. John serves as a co-principal investigator on the National Science Foundation-funded Geospatial Technician Education-Unmanned Aircraft Systems (GeoTEd-UAS) project and is the state coordinator for VirginiaView. He is the coauthor of several textbooks on the use of GIS and remote sensing, and provides video tutorials that have received over 12,000 hours of views. John has actively served to facilitate geospatial-related initiatives and projects across Virginia since 2003.

John McGee

Dan Swafford is a retired teacher with 40 years of experience teaching Agriculture Education classes to middle and high students. During his last few years of teaching, Dan became very interested in using UAVS in his classroom to motivate students to think about the future of agriculture. Upon his retirement, he accepted a position with the Virginia Cooperative Extension Service at Virginia Tech. In this position, Dan works to support youth development in the areas of 4-H and FFA. For the past four years, he has visited middle and high school students in a 12-county area delivering programs on the use of drones in agriculture. Dan holds an FAA Part 107 Remote Pilot Certificate.

Dan also works in the area of adult education and research with drones in agriculture. From 2017 to 2020, he carried out a study of the effectiveness of using sUAS to monitor sheep flocks. During this time, he also co-authored two Extension publications that explore the use of drones in agriculture. Dan has designed his adult education program for 4-H agents and Agriculture Education teachers.

Dan Swafford

Paige Williams is currently a Ph.D. student in the Department of Forest Resources and Environmental Conservation at Virginia Tech and also a fellow of the Remote Sensing Interdisciplinary Graduate Education Program. Over the past seven years, she has gained extensive research and teaching experience in GIS and remote sensing, specifically to forestry, natural resource management, ecological modeling, and earth system science. She has taught undergraduate courses and workshops including Digital Planet, Introduction to Land and Field Measurements, and Forest Photogrammetry. She has participated as a GIS/remote sensing team member on multiple international research projects in Africa, Panama, and India. Her master's thesis, funded by the NASA Land Cover and Land-Use Change Program, focused on mapping small-holder forest plantations in Andhra Pradesh, India. Her current research with the NASA Goddard Space Flight Center focuses on testing a satellite mission concept on an sUAS to measure the structure and function of forested ecosystems.

Paige Williams

Veronica Spradlin, Certified GIS Professional, is the Drafting and Engineering instructor at Blacksburg High School. She has 13 years of experience teaching grades six through 12. Veronica has an FAA Part 107 Remote Pilot Certificate and has been involved in sUAS operations since 2014. She has led multiple flight operations, including the first UAS operation over Virginia Tech's Lane Stadium as part of a service-learning project. She served as the remote pilot in command of the mission and coordinated all mission requirements, planning with Virginia Tech's safety office. In the summer of 2019, Veronica served as a Master Teacher for Virginia Space Coast Scholars, where she developed and delivered sUAS lessons for students attending the Summer Institute. Veronica served on the 2021 VDOE curriculum review committee for developing statewide curriculum standards for sUAS courses for Career and Technology Education. In 2019, Veronica took the Blacksburg Drone Competition team to Dallas, Texas. The team placed first in the Bell Vertical Robotics Competition.

Veronica Spradlin

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