Oil Spill Response Uncrewed Aircraft Systems (UAS) Guidance and Training

September 2024

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A Guide to best practices for flying Uncrewed Aircraft Systems (UAS) during an oil spill or natural disaster response and/or damage assessment.

U.S. DEPARTMENT OF COMMERCE • National Oceanic and Atmospheric Administration • National Ocean Service • Office of Response and Restoration • Emergency Response Division

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Cover Page Photo Credits:
(upper image – Tank Barge) nadir drone image captured by Research Planning, Inc. (RPI), Columbia, SC post Hurricane Ida in support of the USCG and NOAA.
(lower image – Displaced Vessels) oblique drone image captured by USCG post Hurricane Ian.

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Disclaimer

The information contained within this document is intended to provide application-specific guidance for effectively using Uncrewed Aircraft Systems (UAS) to collect data in support of certain emergency and disaster response missions. However, the content is not intended to exhaustively cover or supersede existing regulatory and policy frameworks. This information is provided to help develop and execute the most efficient UAS missions in challenging response environments while also ensuring compliance with existing NOAA policies.

This document supplements but does not replace various standard operating procedures (SOPs) and protocols already in place such as the U.S. Coast Guard (USCG) Short-Range Unmanned Aircraft Systems (UAS) Flight Operations Standard Operating Procedures, USCG Office of Aviation Forces (USCG SR-UAS SOP, 2021); the NOAA Uncrewed Aircraft Systems (UAS) Handbook, NOAA UxS Operations Center (NOAA UAS, 2022); and the NOAA Uncrewed Aircraft Systems Operations Policy, Office of Marine and Aviation Operations (OMAO-UAS, 2022). These and other SOP documents are listed in the resources section of this document.

Purpose

The purpose of this document is to inform the user of best practices for flying UAS during an oil spill or natural disaster response and/or damage assessment. It was specifically designed for small UAS (sUAS) less than 55 pounds but does not preclude applicability to medium and large UAS. It covers a generalized description of equipment, sensors, settings, flight methods, and oiled aerial observations, as well as a decision matrix and description of when to use UAS during response. The intended user is a spill responder that already has a Federal Aviation Administration (FAA) Remote Pilot Certificate as specified by Title 14 Code of Federal Regulations (CFR) Part 107, also known simply as Part 107, and basic flight training as well as any other certification required by their agency or organization. Spill response training is also recommended, as there is only minimal guidance in this document on how to make aerial and shoreline observations of oil. Refer to the Spill Response Resources at the end of this document for more information on spill response operations and training.

A portable and easily deployable UAS is a valuable tool during a response. It can be used for reconnaissance overflights to detect oil or hurricane debris, for viewing areas that are inaccessible due to environmental or hazardous conditions or that are sensitive habitats, and for recording information about oil stranding or derelict vessels. A UAS is also useful for monitoring and recording response strategies, such as shoreline treatment, deployment of boom and sorbents, or removal of vessels and other hurricane debris. It provides a unique perspective and can be used to help plan and direct other response operations. Using UAS can provide significant cost savings, particularly when used in place of traditional aircraft.

Planning Flight Operations

Once a mission has been assigned, there are several questions that can assist with planning the flight operations. What data are you trying to collect (i.e., what is the target)? Where will you be flying? Where is the best launch point? What type of UAS should be employed? When is the best time to fly to collect the data? Who will be part of the operation?

What data are you trying to collect?

Mission Objective

The type of data collected will depend on what the mission objective is and what the target is. The target may be unknown, as is often the case during a reconnaissance flight. Or the target may be the source of the spill once there is general knowledge of where the spill is located. Other potential targets include sheen on water, oiled shoreline, debris, a vessel, or even wildlife. Once the target is identified, the type of data needed can be determined.

Table 1. Data types, descriptions, and use for spill and post-storm response.

Data Type	Description and Use
Video	Most useful when kept under 10 minutes. Beginning and ending nadir photos can capture start and end coordinates for the video if needed. Useful when searching for oil on water and shorelines, detecting and monitoring wildlife, monitoring response activities, and monitoring movement of oil.
Nadir Photo	Photo taken with camera pointed directly downwards from the aircraft. Good for getting a more accurate target location. Used for collecting imagery for mosaics. If taking video, consider also taking a nadir photo at both the start/stop points.
Oblique Photo	Photo taken at an angle other than directly downward - side angle views. Some angles are better than others. Useful for detecting sheens, looking for oil on shorelines, inspecting vessels and debris, wildlife and habitat detection/assessment, and inspecting navigation waterways.
Mosaic	Collection of overlapping nadir photos in a lawnmower pattern. Useful for mapping large areas and thus can be useful when the target is unknown or unspecific. Can be uploaded into a field viewing app such as Field Maps for SCAT and Operations and can be uploaded to a COP such as ERMA.
Thermal Imagery	Pixels represent temperature measurements. Oil usually has a different temperature than water, warmer than water during the day and cooler than water at night. Can be used to highlight/quickly identify oiled areas. Potentially useful for detecting wildlife.
Multispectral Imagery	Pixels represent spectral intensity measurements. Used to estimate oil thickness on water.
Lidar Point Cloud	3D cloud of points representing distance measurements. Used to estimate oil extent on water.
Optical Polarization imagery	Pixels represent polarized visible light measurements. Good for creating high contrast between water and oil.

Data Types

There are several types of data that can be collected with UAS depending on the type of sensor being used. Sensors are described in more detail in the Sensors Section of this document. The most used sensor in spill response is a true-color camera (or just camera) just like a photographer would use. The data products collected by a camera are familiar because they are like what can be collected with a smartphone – photos and video. A mosaic is another true-color camera product that requires some processing. Methods for collecting a mosaic are described in more detail in the True-Color Camera section. A camera collects and records light in the visible range of the electromagnetic spectrum, whereas other sensors may collect and record light from other parts of the spectrum, such as infrared. A list of data types that are useful for spill and post-storm response are listed in Table 1.

Where will you be flying?

There are many things to consider once the mission location is determined: weather/environment, airspace/ground-based restrictions, the ability to maintain line of sight with a small UAS, and wildlife/habitat disturbance. The response might have an Aviation branch that can help.

Weather and Environment

Certain weather conditions are not conducive to flying a UAS. Precipitation in any form (fog, rain, snow, ice) affects most models of UAS and prohibits flying. High winds and extreme temperatures (cold and hot) could prohibit flying. Refer to the manufacturer's specification for the model of UAS being flown to determine the maximum wind speed and maximum/minimum temperatures for operation. Watch the weather forecast and be aware of the potential for rapidly developing storms.

There may be other environmental factors that may affect the takeoff/landing zone or may present a hazard to safely operating the UAS, such as not enough flat open space to operate from, birds flying overhead, electrical wires nearby or overhead, not enough shade or shelter for the operators, or even the presence of other people in the area.

Other factors to be aware of include proximity to structures and objects that could cause electromagnetic (EM) interference such as buildings, vehicles, large gas tanks, and other large metallic objects. Though not as common, EM disruption can also come from surrounding geology (anomalous magnetic rock) or areas of high topography (inside a small canyon or next to a steep cliff wall).

Airspace Evaluation

Know the restrictions for controlled airspace such as around airports. Several apps are available to help determine the type of airspace along with potential restrictions or hazards. Approval to fly in restricted airspace at or below an altitude of 400 feet above ground level (AGL) around some airports can be granted in near real-time using the Low Altitude Authorization and Notification Capability (LAANC) system. Check for foreign airspace, Notice to Airmen notifications (NOTAMs), Temporary Flight Restrictions (TFRs), and general air traffic the area.

Ground Evaluation

Many federal and state lands prohibit the use of UAS (National Parks, Wilderness Areas, Wildlife Refuges, State Parks, etc.). Local municipalities (counties, cities, towns) may also have rules regarding the use of UAS. It is important to check for regulations prior to every mission because they tend to change frequently. Also check for regulations concerning protected habitat in the area such as nesting sites. If flying over private property, contact the landowner. Be mindful to not collect Personally Identifiable Information (PII) or other sensitive personal data without express permission.

When is the best time to fly to collect the data?

Although there isn't always flexibility in choosing when to fly a UAS, there are several environmental factors that should be considered. The altitude of the sun at different times of the day affects imagery in different ways. This effect can also vary depending on location. Generally, during the morning and evening (sunrise to 10 AM and 2 PM to sunset), the sun is high enough to provide sufficient light, but the low sun angles create shadows from objects such as trees, structures, and boulders. During the middle of the day (10 AM to 2 PM), shadows are minimized but highly reflective surfaces will reflect sunlight directly back to the camera.

If flying over water and it can be avoided, do not plan on flying in the middle of the day (10am – 2pm). Any imagery over water will pick up on sun glint and even with a polarized filter may not be mitigated. If this cannot be avoided, be aware of which flight directions cause the most sun glint and try to fly in a direction that minimizes this effect.

When collecting imagery over land, it is best to fly in the middle of the day to minimize the effects of shadows. Shadows result in lost data and a decrease in the quality of optical images. Also, oil is difficult or impossible to detect in shadows.

Be aware of the tidal stage when flying for SCAT and cleanup operations. Attempt to fly during low-falling, low, or low-rising tides to maximize across shore-beach face coverage.

Who will be part of the operation?

All spill operations will require a FAA Part 107 certified Pilot in Command (PIC) with flight experience and a trained visual observer (VO). There will also need to be coordination with the incident commander, whether it is a small incident or a full ICS structure. Also keep in mind that FAA Part 107 rules do not allow for flying over people unless they are part of the operation.

UAS Platforms

There are a variety of UAS platforms available, and they are generally divided into two categories: fixed wing and rotary wing, though there are also hybrids of these categories. These categories are described in more detail below. UAS are further categorized by size, with the most common size category defined as small UAS (sometimes referred to as sUAS) weighing less than 55 pounds. Part 107 covers rules relating to the registration and operation of small UAS, as well as rules for remote pilot certification. Many government agencies and non-governmental organizations (NGOs) are restricted to using only those UAS that have been approved by the Department of Defense (DoD), referred to as "Blue UAS". Some organizations allow UAS that are NDAA-compliant, which has less rigorous qualifications than a Blue UAS. Another distinction for UAS is whether it has swappable payloads so that a variety of sensors can be used with it. Many consumer-grade UAS do not have the ability to change the payload, so it is important to know what sensors are on those platforms.

Fixed Wing

Fixed wing aircraft resemble traditional aircraft, relying on forward motion for lift and stability. They have a major advantage when it comes to range. They tend to be able to fly longer distances than rotary aircraft in the same amount of time. They are also capable of carrying heavy payloads. Some fixed wing UAS have vertical takeoff and landing (VTOL) capabilities (Figure 1).

Figure 1. The WingtraOne has vertical takeoff and landing (VTOL) and has been used for Shoreline Cleanup Assessment Technique (SCAT) operations in Australia. Credit: Wingtra.

Though fixed wing UAS are not typically used in spill or post-storm response, they may be useful for reconnaissance flights or creating mosaics over large areas.

Rotary Wing

Rotary UAS typically have multiple sets of rotor blades (propellers) mounted on vertical masts, though there are also UAS that have a single rotor. The rotation of the propellers around the mast generates lift. A rotor UAS is significantly more maneuverable than a fixed wing UAS. The most common multi-rotor UASs are a hexacopter with six propellers or quadcopter with four propellers (Figure 2). The larger ones often have a swappable payload, allowing for a variety of sensors to be mounted on the aircraft.

Rotary UAS are commonly used in spill and post-storm response. They are generally more portable, easier to launch, and often less expensive than fixed-wing UAS.

Figure 2. Left: Parrot Anafi USA quadcopter. Credit Pilot Institute; Middle: Yuneec Typhoon H Plus hexacopter. Credit: Drone DJ; Right: DJI Matrice 350 quadcopter. Credit: RPI.

Sensors

A sensor is a device which detects or measures a physical property and records, indicates, or otherwise responds to it. Sensors used for remote sensing are found on satellites, traditional aircraft, uncrewed systems (aerial, underwater, and surface), and structures on the ground such as towers and buildings. Sensors are designed to record EM radiation within discrete ranges, or bands (Figure 3). The exact range of wavelengths recorded for each band varies by sensor.

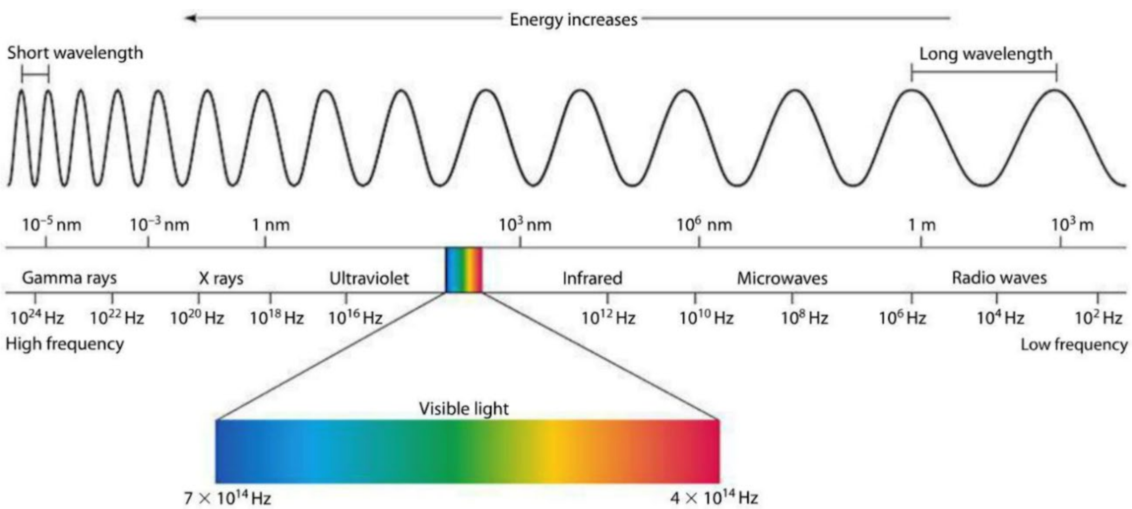


Figure 3. The electromagnetic spectrum. Credit: Descartes Labs.

A variety of sensors are used for oil spill detection and observation. The most used sensor for rapid deployment during spill response is a true-color camera like photographers use. Nearly all commercially available UAS have a true-color camera and common settings to consider will be described in detail. Thermal infrared sensors are also used regularly, mainly for detecting oil on water, and have the advantage of working during night operations. Table 2 lists the types of sensors that have been used for spill response, though not all of them are available for UAS applications. Those that have been mounted as a payload on UAS include true-color, thermal infrared, multispectral, UV, lidar, and optical polarization.

Table 2. Sensors used for spill response. Adapted from Garcia-Piñeda et al., 2022.

Sensor	Detection of Oil Mechanism	Application on Water and Ice
True-color (RGB, Visible, Electro-Optical)	Detects the reflected visible light as physical and chemical properties of oil absorb parts of the electromagnetic spectrum.	Contrast between oil and surroundings (ice, snow, water) for detection of oil extent and estimated layer thickness classification.
Thermal Infrared / Forward-looking Infrared	Thermal emissivity differences between oil and surrounding ice/water based on the thermal reflectivity.	Detection of oil extent before thermal equilibrium is achieved, estimated layer thickness classification.
Multispectral / Hyperspectral	Multiple bands of sensors with defined channels of wavelengths will capture hydrocarbon signals depending on absorbance/reflectance spectra of each target.	Difference between non-emulsified oil and emulsified oil, also for detection of false positives (e.g., biogenic oils, sargassum).
Ultraviolet (475 nm)	Reflected ultraviolet contrast between oil, water, and ice.	Detection of oil extent and detection of thin oil slicks and sheens
Lidar	Laser reflection contrast between oil, water, and ice.	Detection of oil on or just below the sea surface and estimated layer thickness.
Fluorosensor and Lidar System	Fluoresced emissions from light and aromatic components of oil.	Detection of oil on or just below the sea surface and estimated layer thickness.
Synthetic Aperture Radar (SAR)	Differences in the backscatter signals generated by viscoelastic properties of oil.	Detection of oil and extent on the sea surface. Advanced SAR sensors (quad-pol) can detect oil thickness.
Optical Polarization	Differences in the polarization of oil, water, and ice.	Detection of oil and extent on the sea surface.

True-Color Camera (RGB, Visible, Electro-Optical)

As mentioned above, the true-color camera is the most used sensor for oil spill response operations and is commonly available on many UAS platforms. They are also referred to as RGB sensors because they detect three frequencies in the visible light spectrum, red (R), green (G), and blue (B). To collect the best imagery possible, it is important to be familiar with your camera settings. Some common ones are File Format, High Dynamic Range (HDR), White Balance, Shutter Speed, ISO, and Aperture. Some cameras have filters that can be applied to the lens, and it is important to know how and when to use them.

File Format

On most platforms, you will be given an option of what file format you would like your imagery to be stored in. For photographs, the options are generally JPG or DNG (RAW). Most platforms give an option to collect both. A JPG is a digital image format containing compressed image data. This is typically what most cameras will collect, and file sizes are relatively small. A DNG file is a RAW image that is not compressed. These files are larger than JPGs and more post-process editing can be done to the image. For UAS data collection, JPG is usually the best photo format, especially if collecting imagery to mosaic.

High Dynamic Range (HDR)

HDR is a technique where multiple images of the same scene are captured at different exposures and merged together to create a single photo. HDR is useful when flying in environments that range from bright sunlight to shade by offering a wider range of colors, brighter whites, and deeper blacks. Most UAS cameras have an automatic function that allows you to take HDR photos and adjust the number of images that are collected and merged.

White Balance

Balances the color temperature in the photos. In other words, instead of whites appearing blue or orange, they should appear white after correctly white balancing an image. Keeping this setting on auto is fine for most applications. Most UAS cameras have preset options for white balance such as Sunny, Cloudy, Daylight, Shade, etc. (Figure 4).

Figure 4. White Balance presets on a UAS camera. Credit: DroneZon.

Exposure Triangle

The next three settings make up what is known as the exposure triangle (Figure 5). A good image will be balanced between these three settings for the ideal exposure. Keeping them on auto is fine for most applications, but it is important to understand their functions.

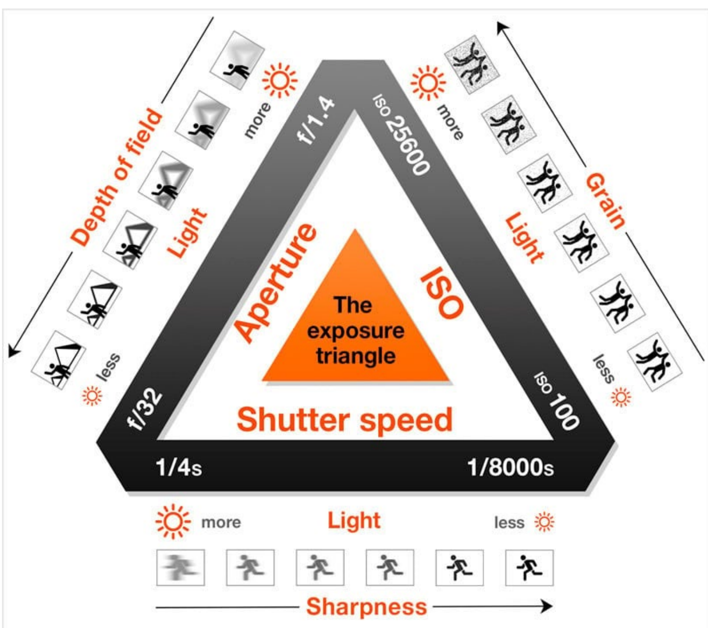


Figure 5. The Exposure Triangle. Credit: PetaPixel (https://petapixel.com/exposure-triangle/).

Shutter Speed

This is the amount of time that the camera's shutter is open. A faster shutter speed is used for faster shots, whereas a slower shutter speed can make images blurry. Choosing a faster rate also limits how much light is absorbed by the sensor. In low light situations, a lower shutter speed will help images have more light. Setting this to auto will likely produce good photographs. Shutter speed is shown in fractions of a second.

Aperture

The aperture is the opening in a camera lens that allows light to reach the sensor. The size of the aperture controls how much light is absorbed as well as the depth of field, i.e. the amount of your photograph that appears sharp (in-focus) from front to back. The aperture is expressed as a number known as "f-stop". The higher the f-stop, the smaller the aperture, the deeper your depth of field. The bigger the aperture (i.e., the smaller the f-stop), the shallower the depth of field.

ISO

ISO is a setting that will brighten or darken a photo. The higher the ISO, the brighter an image will be. However, graininess (noise) also increases with high ISO values. ISO is shown as a number, usually from anywhere between 50 to 5000+. Keep the ISO as low as possible and prioritize the shutter speed/aperture over ISO.

Filters

Sometimes environmental conditions are such that balance is difficult to accomplish within the Exposure Triangle. To aid in better compositions, consider using camera filters if they are available for your platform. There are two types that you will find useful for UAS, Neutral Density (ND) and Polarized filters.

Neutral Density Filters

The primary function of a Neutral Density (ND) filter is to limit the amount of light that enters the lens of a camera without altering the colors in the image produced. They are useful for avoiding over-exposed photos and videos. They are also used to help control depth of field. Conditions during spill response are often very sunny. Using an ND filter can help soften an extreme contrast between the target and a very bright background, allowing you to take a more balanced shot.

ND numbers correlate to the fractional amount the light is reduced by (Table 3). For example, a ND2 filter reduces the light by ½. There is also a relationship between the ND number and f-stop. Using an ND2 filter is equivalent to reducing the f-stop by 1.

Table 3. The most common ND filters used with UAS cameras, the equivalent number of f-stops reduced, and the amount of light that reaches the sensor.

ND #	# of Stops	Intensity Reduction	Conditions *(adapted from the Pilot Institute)*
ND2	1	50%	At dawn or dusk
ND4	2	25%	During overcast or cloudy days
ND8	3	12.50%	Partly cloudy conditions
ND16	4	6.25%	Partly cloudy but mostly sunny conditions
ND32	5	3.10%	Sunny and clear conditions
ND64	6	1.50%	Extremely bright conditions with reflective surfaces

Polarizing Filters

Polarizing filters are used to block horizontal light waves that bounce off highly reflective surfaces. They help to darken over-bright skies, reduce reflected light and haze, and/or suppress glare from water surfaces. They also boost color saturation and contrast. As a result, images appear darker but also crisper and clearer. When collecting imagery over water, a polarizing filter reduces light that bounces off waves, referred to as sun glint, making it easier to see things on or below the surface of the water (Figure 6).

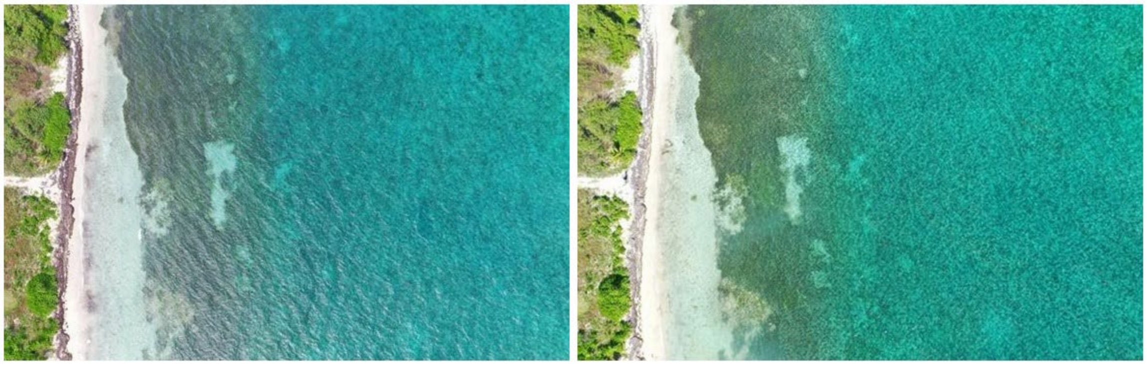


Figure 6. Left: no camera filter over water; right: same location using a circular polarized filter. Credit: RPI.

Polarized filters often come in a configuration called a circular polarizing lens (CPL) where the glass can rotate to calibrate and set the alignment. Note that once the CPL is set, it will work with the camera pointing generally in one direction but will not work if the camera is turned 180 degrees. So, determine the direction to fly (usually away from the sun) and set the CPL for that direction and try to fly only in that general direction while collecting photos or video. Some CPL filters have a mark on them indicating the position the filter should be in for blocking horizontal light (Figure 8). If no mark is present, you can align and mark the CPL yourself.

To properly align a CPL, find a source of vertically polarized light, like a television (computer monitors, cell phones, and tablets do not generally have vertically polarized light). To test your source, hold up a pair of polarized sunglasses. If you can see the image on the screen, rotate the sunglasses 90° (up and down) and if the image is blocked out, that source is emitting vertically polarized light (Figure 7).

Figure 7. Testing for vertically polarized light. Credit: RPI.

Place the aircraft on a flat surface in front of the source, turn it and the controller on. Put the camera in auto exposure mode and rotate the CPL while watching the controller screen until it goes black. Use a paint pen and mark the edge of the lens filter at the 3 o’clock or 9 o’clock position (90°/270°) (Figure 8, left).

When in the field, rotate that mark to the 12 o’clock or 6 o’clock position (0°/180°) to get the most effective use of the CPL (Figure 8, right). Collecting data during the highest degree of sun angles will negate the polarized effect to an extent.

Figure 8. Marking and setting a circular polarizing filter with a mark for setting the horizontal blocking position. Credit: John Daws.

Collecting a Mosaic

A mosaic is the result of many individual photos that are stitched together to form a larger image (Figure 9). It is a great way to capture and visualize imagery for a large area. An orthorectified mosaic, or orthomosaic, has been corrected for perspective, lens distortion, and camera angle to create a perfectly straight-down view of all objects in the frame, tying each pixel to a real location on the Earth’s surface (like the imagery you see in Google Earth). Orthorectification of a mosaic or single image requires significant processing.

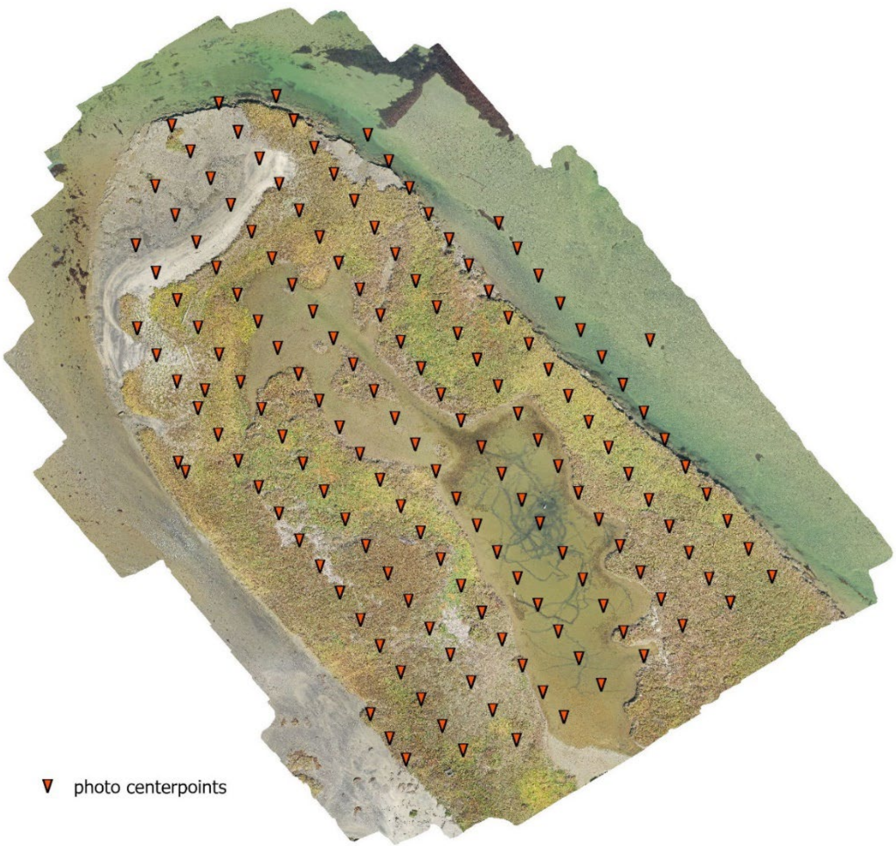


Figure 9. Orthomosaic in Los Peñasquitos Lagoon, CA showing individual photo locations. Credit: RPI.

The best way to collect a mosaic is to use automated flight patterns in the flight control application, if available. Some manufacturers have more automation than others, but the process is similar. These automated patterns create a waypoint for each image that needs to be collected based on several criteria. Due to edge distortion and other factors, collect a slightly larger area than desired so the imagery is more accurate around the desired perimeter.

There are often two different patterns to choose from, a lawnmower pattern or a grid pattern (sometimes called a crosshatch). A lawnmower pattern is shown in Figure 10a. A grid pattern is a lawnmower pattern with a second one over the same area but rotated 90 degrees (Figure 10b). This adds significantly more images, flight time, and post-processing time and is generally not necessary for a response.

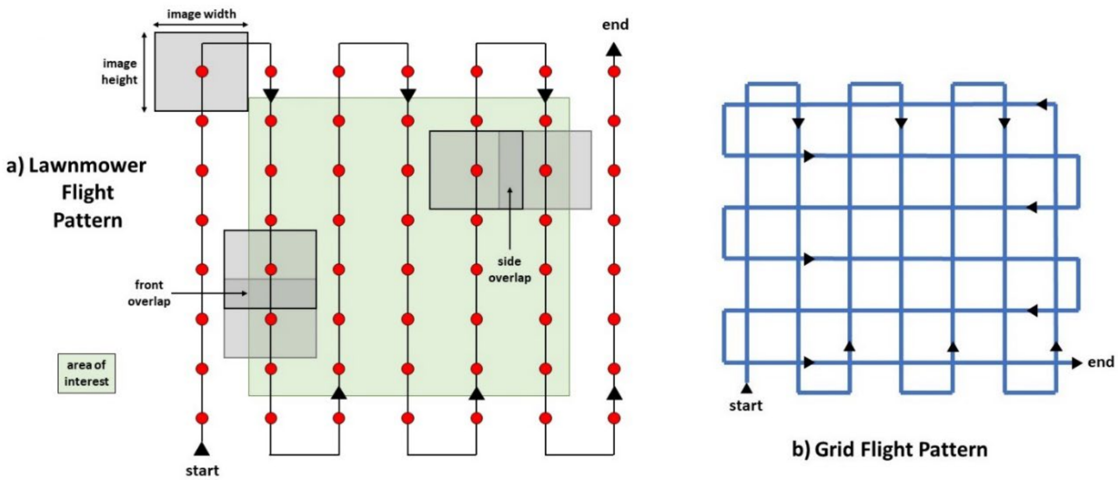


Figure 10. a) Lawnmower pattern for collecting mosaic and lidar imagery, b) grid pattern. Credit: RPI.

The settings that need to be considered to capture adequate data to make a mosaic are altitude, speed, and side/front image overlap (Table 4). Images for a mosaic should be collected with the camera pointed straight down (nadir).

Table 4. Settings required for creating mosaics.

Lawnmower Pattern	Settings
GSD/Altitude	1-3 cm/100-400 feet
Front/Side Overlap	75%/75%
Speed	10-15 mph
Gimbal/camera angle	Nadir (straight down)

Aircraft altitude will directly affect the resolution of the images, the number of images needed to cover an area, and the amount of time required for collection. Image resolution correlates with the Ground Sample Distance (GSD) – the distance between the center of two consecutive pixels as measured on the ground. Some flight applications will have the user adjust the GSD, while others will have the user adjust the altitude, or both altitude and GSD, or let the user switch between the two. A GSD between 1 and 3 centimeters will be adequate for most spill response applications.

Image overlap is the area that is shared between successive images acquired during flight. Sufficient overlap is required for the post-processing software to find enough tie points (common features in overlapping areas) to stitch the images together. For this reason, collecting mosaic imagery over water is very difficult and is discussed in more detail in the Mosaics Over Water section. Front overlap specifies the shared area between consecutive images captured along the drone's trajectory. Side overlap indicates the shared area between images captured along parallel flight paths. An overlap of 75% for each will ensure a good mosaic in most environments.

Some flight applications will automatically determine the speed of flight for the user. If it does not, set it to between 10-15 mph. Some UAS models will also let the user choose to stop the aircraft at each photo waypoint before it captures an image which can help reduce distortion, however it can add a significant amount of time to the flight.

Infrared Thermography

Infrared (IR) thermal cameras are used to measure the thermal radiation emitted by objects – the hotter something is, the more thermal energy it emits. This emitted thermal energy is called a "heat signature." Thermographic cameras detect radiation in the long wave infrared (LWIR) range of the electromagnetic spectrum (roughly 8–15 µm) and produce a thermal image where each pixel represents a temperature value (Figure 11). If the variation in heat signatures between adjacent objects in a thermal image is even subtly different, those objects can be differentiated regardless of lighting conditions. This allows thermal cameras to see in complete darkness and through smoke. Fog and rain have the potential to severely limit the range of a thermal camera due to the scattering of radiation off water droplets. However, in many circumstances, thermal cameras can penetrate fog much more successfully than visible light cameras or the human eye.

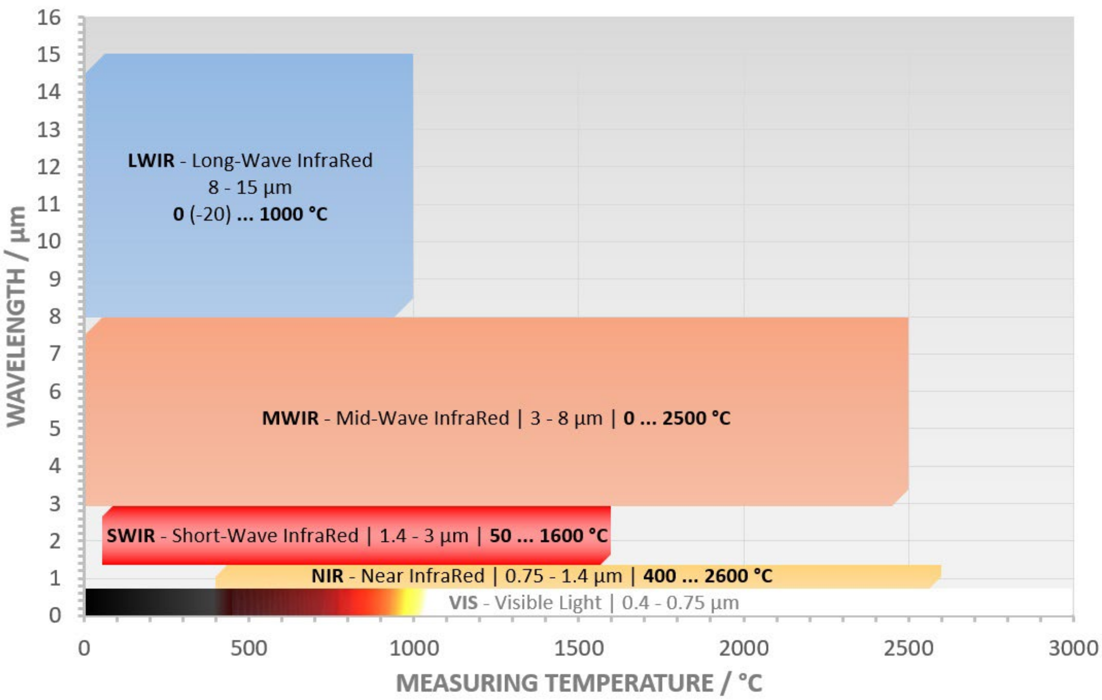


Figure 11. Typical temperature ranges covered by different spectral responses of IR temperature measurement devices. Credit: AMETEK Land.

Thermal cameras are useful for oil spill response because oil often has a different heat signature than the ground, water, and ice. Oil on water will be warmer than the water during the day and colder than the water during the night, making a thermal sensor a useful tool for night detection and observation of oil in offshore environments (Figure 12 and Figure 13). The temperature of oil on water also increases with thickness (Garcia et al., 2019a).

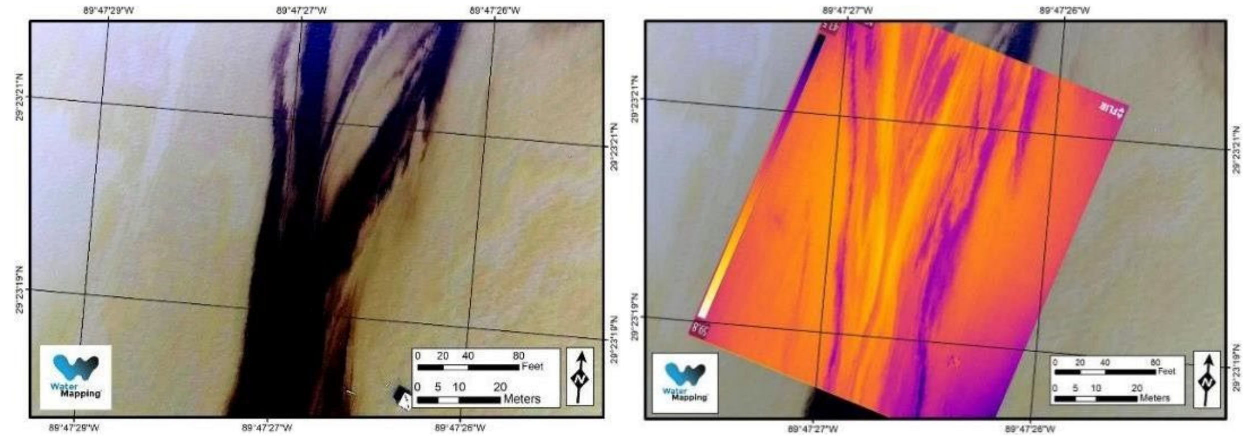


Figure 12. Thick oil on water imaged by visible (RGB) camera on the left and thermal (LWIR 7µm) on the right. Credit: Water Mapping.

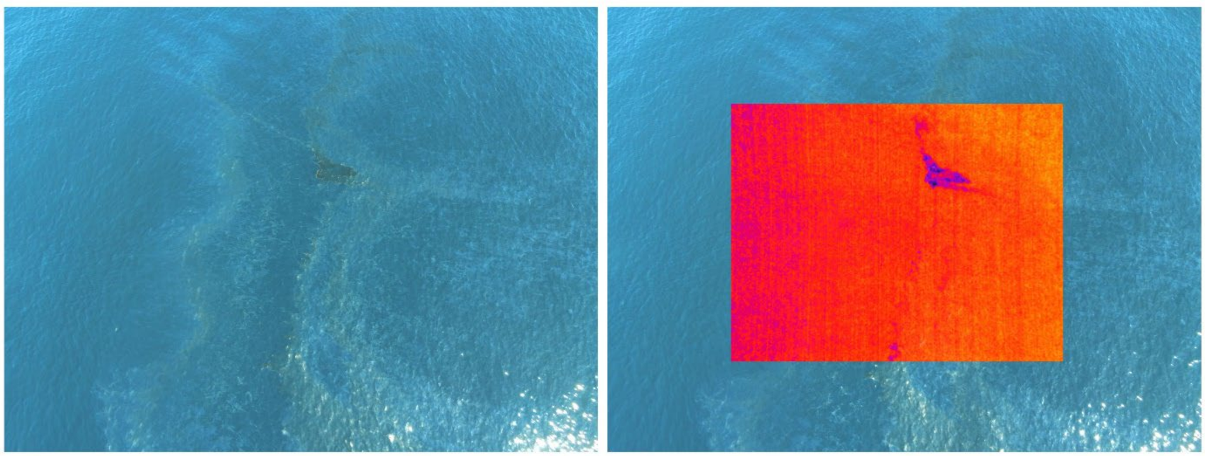


Figure 13. Left: Aerial image of oil on water taken from a Parrot drone. Right: Thermal image from a Parrot drone overlaid on the aerial image. The oil appears purple due to a different thermal signature from the surrounding water. Credit: NOAA.

Multispectral and Hyperspectral Sensors

Multispectral sensors are any sensor that can detect two or more ranges of frequencies or wavelengths in the electromagnetic spectrum. True-color (visible light) cameras would technically fall into this category because they detect three visible wavelengths (red, green, and blue). True-color cameras are usually available on many UAS models and often used in tandem with other sensors. Thus, they have been addressed separately above. The primary difference between multispectral and hyperspectral sensors is the number of spectral bands and their width or range. Hyperspectral sensors have more but narrower spectral bands than multispectral sensors.

The most common spectral frequencies (besides the visible wavelengths) used for oil spill response are listed in Table 5 and include the visible wavelengths. Multispectral sensors are generally used to determine oil spill density and thickness. Satellite applications of multispectral and hyperspectral sensors are more commonly used than UAS for oil spill characterization.

Table 5. Spectral frequencies commonly used for oil spill response.

Band	Frequency/Range (nm)	Oil Spill Frequencies (nm)
Blue	450-520	475
Green	520-600	560
Red	630-690	668
Red edge	705-745	717
NIR-1	750-900	840, 880
NIR-2	860-10400	940
SWIR-1	1550-1750	1700
SWIR-2	2080-2350	2300
LWIR (thermal)	3000-12500	10600-12500

Lidar

Light detection and ranging (lidar) sensors emit laser pulses and measure how long they take to come back after hitting and reflecting off objects. The distance to each object can be calculated precisely based on the time between the output laser pulse and the returned (reflected) pulse. Hundreds of thousands to millions of these precise distance measurement points are being collected each second, producing a 3D point cloud model of the entire area being captured.

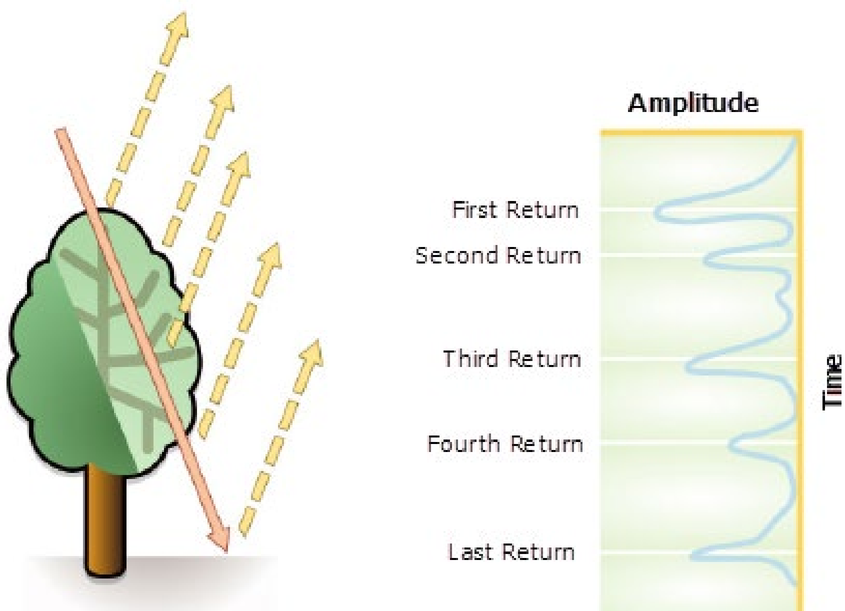


Figure 14. Illustration of lidar returns. Credit: Esri ArcGIS Resources.

A single laser pulse emitted from the sensor will bounce off many objects with different reflective properties. Each of these reflections comes back to the sensor as described previously – this is called a return. There will be as many returns as there are reflective surfaces for that laser pulse to bounce off (Figure 14). The first return is the most significant and is associated with the highest feature in the landscape (for aerial lidar) which could be the ground surface. With multiple returns, lidar can detect the height of several objects in the field of view including vegetation structure and the elevation of the underlying surface. Most UAS lidar sensors allow for a limited number of returns to be recorded and may have a selection for how many returns are desired.

Lidar can emit different types of laser pulses, such as infrared, visible, and ultraviolet light, and each comes with its own advantages and disadvantages. While visible light would be the best for providing detailed images of objects, it does not penetrate fog or smoke very well. Laser pulses in the infrared range are used for determining oil spill thickness. The use of lidar for oil slick characterization is still being developed. Results from Gould et al. (2019) indicate lidar can penetrate oil slicks with a thickness up to 3 ± 1 mm and suggest that "lidar is able to retrieve a very wide range of oil thickness, going from the micrometer to the millimeter scale and with its best resolution power in the 0 to 1 mm range." Results from Garcia et al. (2024) using infrared lidar indicate that the point density of lidar returns changes with oil slick thickness as well as with temperature. "If the temperature is known at the time of the survey, the point density can be used as a predictor for oil thickness."

Processing raw lidar data requires special computer programs. However, viewing the 3D point cloud is intuitive and expert interpretation is not required, especially when collected simultaneously with a true-color camera. A reference station (CORS or local base station) and special software are needed to process lidar point clouds.

Optical Polarization

Polarization describes the direction in which the electric field of light oscillates. The sun, like most light sources, emits unpolarized light – light that is composed of many waves with all possible directions of polarization. In the same way that polarizing camera filters work (described in the section on True-Color Cameras), a linear polarizer filters out all but the desired direction of polarization. An optical polarization sensor is made up of a grid of linear polarizers (Figure 15) to filter out all glares and identify the angle of polarization of reflected light.

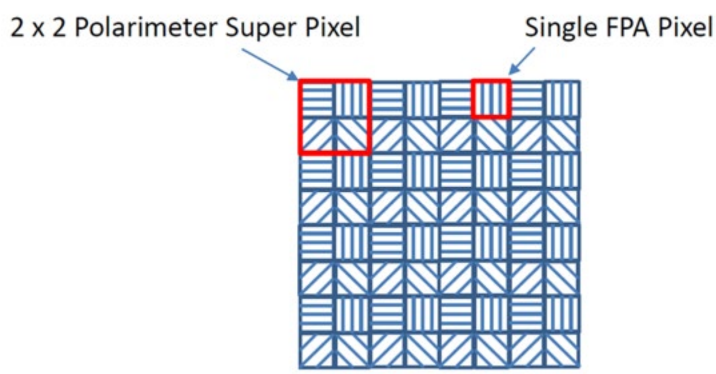


Figure 15. An optical polarization sensor uses 2×2 polarizer super pixels as compared to a single focal-plane array (FPA) pixel such as is used with a true-color camera. Credit: NNTC https://nntc.digital/blog/oil-spill-detection-with-polarization/.

Imagery from an optical polarization sensor shows great contrast between oil and water and thus improves detection of oil. The fusion of imagery from a thermal camera with imagery from an optical polarization sensor can greatly improve oil detection and works even with wave action and dispersion or emulsification of oil (Figure 16 and Figure 17).

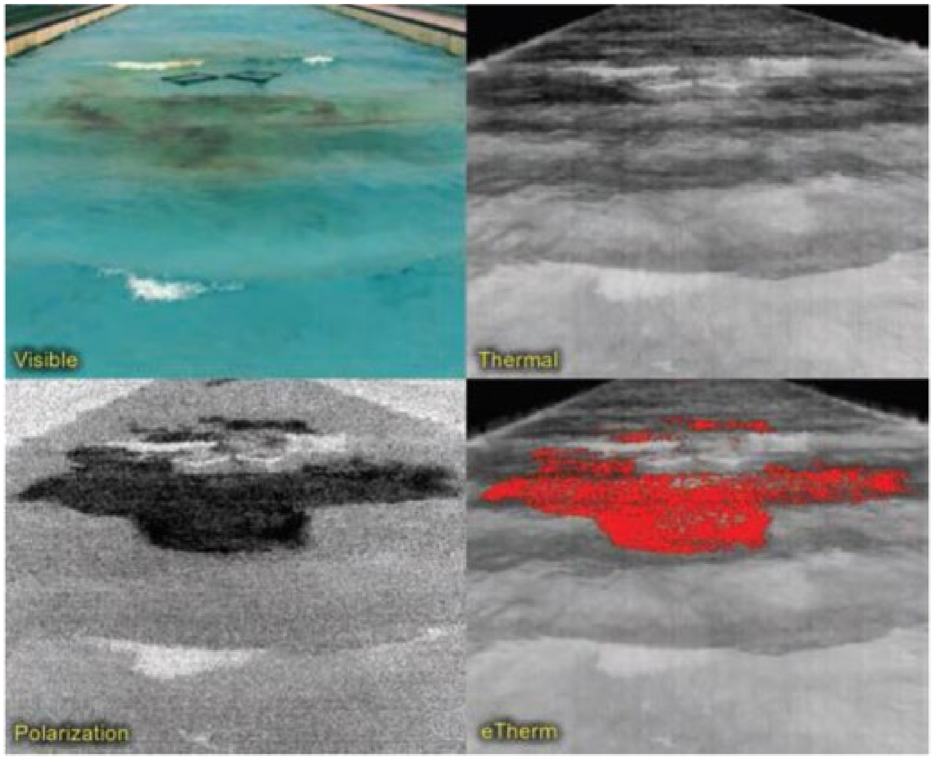


Figure 16. Detection capability of visible (upper left), thermal (upper right), polarization (lower left) and the combined IR/polarization signal (lower right) in breaking waves. Credit: Nedwed et al., 2020.

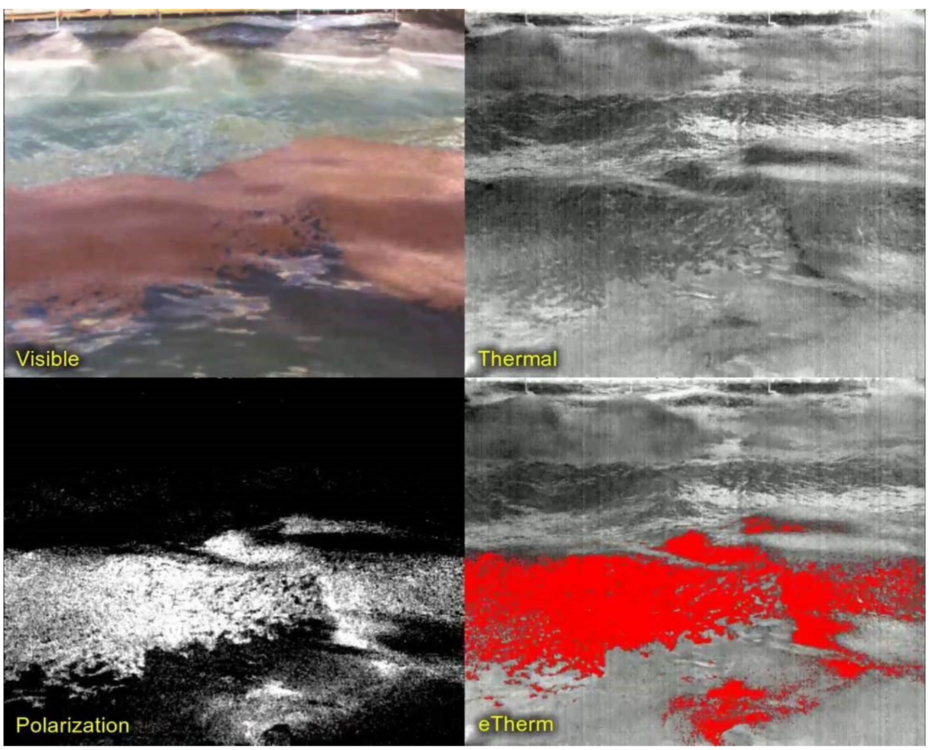


Figure 17. Detection capability of visible (upper left), thermal (upper right), and polarization (lower left) and the combined IR/polarization signal (lower right) of emulsified oil. Credit: Polaris Sensor Technologies.

Synthetic Aperture Radar (SAR)

Synthetic aperture radar (SAR) is a system in which a pulse of energy is directed from the sensor to the surface at an oblique angle (off-nadir). At the surface, radar energy from the pulse is scattered in all directions, with some reflected back toward the sensor antenna. If a surfactant film is present on the ocean surface, it will dampen the effect of wind-generated waves (ripples). Thus, for SAR to be successful, there must be some surface wind present with speeds of 5-20 knots. If the windspeed is greater than 20 knots, the ocean surface is too rough for dampening to occur. Once oil slicks are in shallow waters, a time series of SAR images can be used to estimate the speed and trajectory of the drifting oil. There can also be false positives from natural conditions that dampen the ripples such as kelp beds, plankton blooms, and freshwater fronts.

UAS SAR sensors tested at the Deepwater Horizon (DWH) oil spill in 2010 have demonstrated their ability to detect oil near shorelines (Garcia-Piñeda et al., 2017). SAR observations were collected by UAS (Figure 18A, B) in a small subset of the area covered by the RADARSAT-1 image (outlined in red in Figure 18C). The green areas in Figure 18B show average intensity, and red areas show entropy from the Cloude-Pottier polarimetric decomposition. These red areas indicate an offshore oil mass as well as oil along the beaches. UAS SAR sensors continue to be developed and tested (Svedin et al., 2021) for use in spill response.

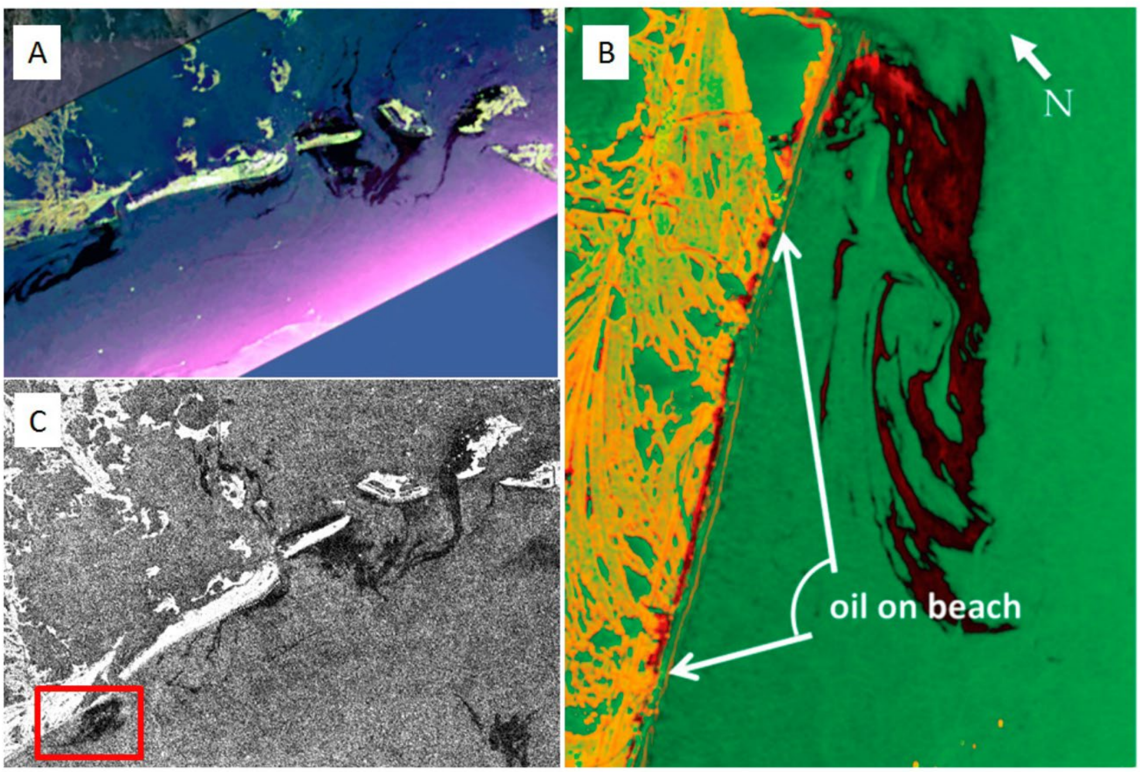


Figure 18. Sequence of SAR observations by UAS SAR on 23 June 2010 (A,B); and RADARSAT-2 on 25 June 2010 (C). Both UAS SAR and RADARSAT were ale to detect the oil in the nearshore environment. Credit: Garcia-Pineda et al., 2017.

Other Equipment

Batteries

Familiarize yourself with the manufacturer's battery specifications and maintenance recommendations. When planning flights, consider the factors that might reduce the maximum flight time of the batteries, such as wind resistance, payload weight, and accessories drawing from the battery, to ensure you have enough batteries to accomplish your work. If covering a long, linear distance make sure to leave enough time and battery life to fly back to your location and remember, if returning with a head wind, the battery will be used up faster.

Be sure to inspect the battery before each mission. It should be fully charged. Look for damage such as cracks or swelling, and if you see any, the battery is no longer safe to use. Monitor the battery charge while flying and note any rapid discharge or other abnormal behavior. Plan to bring the aircraft back to land when the battery charge is reduced to 25-30%. Always pay attention to any alerts on the remote controller, and if Return to Home (RTH) is automatically initiated due to low battery charge, allow RTH to proceed or cancel it if necessary (such as over water) and land the aircraft as soon as possible in a safe manner.

Batteries should be stored at 50% charge to maintain maximum lifespan. Many also have a maximum charging cycle count before severe degradation may occur. Consult the manufacturer's manual for model specific information.

Do not allow batteries to get overheated when not in use. Do not leave them sitting in the sun (even if in a case) or in a hot vehicle. Also, do not attempt to charge batteries immediately after use. Allow them to cool down, or if needed, put them inside a waterproof bag in a cooler of ice to cool down more quickly.

Lights

There are various types of lights that may be used on a UAS, including navigational, anti-collision, and search lights. Lights make your UAS visible to other aircraft in the sky especially with adverse lighting conditions, and lights help the pilot and visual observer(s) maintain sight of the aircraft.

Navigation lights can assist the UAS Pilot and Visual Observers in seeing the UAS and, with different colors at the front and rear of the aircraft, which way it is oriented. These lights can be any color, but the recommended application is to have red on the left and green on the right (Figure 19). Navigation lights are typically solid (i.e., do not blink or strobe) and can be used at the same time as anti-collision lights. There is no rule mandating how bright these lights must be. Many UAS have them built into their arms.

Figure 19. Navigation lights on a drone: red in the front and green in the rear. Credit: DJI.

Anti-collision lights aid other airspace users (traditional and uncrewed) to be able to see your UAS from the air or ground. Under Part 107 rule 107.29, these lights are required to fly during twilight and night-time operations, in other words, 30 minutes before official sunrise to 30 minutes after official sunset. The FAA requires strobe lights that must be visible at a range of 3 statute miles. Many though not all UAS come equipped with anti-collision lights, however they may not be powerful enough. It is recommended that anti-collision lights be white or red to maintain regularity of color with other pilots. While not mandated for daytime use, it is recommended to use anti-collision lights during the day when conditions are cloudy, smoggy, smoky, or under any other degraded visual environment (DVE) conditions where they could help other pilots see your aircraft.

Anti-collision lights can be used in place of navigation lights, but non-blinking lights cannot be used as anti-collision lights. If purchasing an aftermarket light, ensure it is water resistant and that the added weight won't affect the flying capabilities of your UAS.

Search lights attach to the aircraft body facing forward and are used to illuminate objects. To be effective, they should be able to illuminate objects up to 75 feet away. Because search lights are intentionally very bright, be cautious when using one and do not direct it towards other aircraft.

Propellers

After placing the aircraft on the launch pad, unfold all the propellers to reduce resistance on the motors before you start them. You should check your propellers before each flight for any cracks or excessive wear. Feel each propeller for nicks and cracks and gently bend it while listening for pops that indicate microcracks. Then hold the aircraft firmly and spin each propellor manually. You are looking for any resistance, friction, or wobbling.

When spinning up the propellors, listen for any grinding, squeaking, rattling, or other unusual sounds, and look for any wobbling. Carry spares with you and know how to change them. Make sure to be thorough after a crash or rough landing.

On-Water Operations

On-water operations pose a series of challenges that are different from land-based flights. Operations over water could result in the aircraft crashing into the water and be a total loss, even if recovered. There are steps that can be taken to reduce this risk, such as turning off downward obstacle sensors and learning how to launch and catch an aircraft by hand. Since water is very reflective, consider using a polarized filter over your lens for daytime operations over water when using a true-color camera.

Launching and Landing from a Vessel

When launching from a vessel, turn off the RTH function or set it to be the remote control (RC) so the aircraft does not return to its initial takeoff location in case the vessel drifted or was moved elsewhere. Ensure you give yourself enough time and battery charge (~25-30%) to bring it back to your location and safely land or manually recover it by hand. Landing on a small vessel may be difficult to impossible if the obstacle avoidance sensors cannot be disabled, and you may have to catch it. It is highly recommended that hand launch and recovery are performed by two people, the pilot and a trained observer, and that the maneuvers are practiced on land before attempting them on a vessel.

Landing a UAS aircraft or uncrewed aerial vehicle (UAV) on a vessel that is being affected by high waves or swells is very challenging, and in this case, catching it by hand can be dangerous and is not recommended. Do not takeoff during high wave action and if the aircraft has already been launched and waves begin to build, return the UAV and land safely as soon as possible.

The electronic components, GPS, and navigation systems (compass, Inertial Measurement Unit or IMU) in a UAS are highly sensitive to magnetic fields. Many vessels are made of or have components composed of metal and even the vibrations of the motor when running can cause magnetic interference. It is important to ensure that the UAS is minimally exposed to sources of magnetic interference. The PIC should survey the vessel for the best areas for operating the UAS and have at least two alternatives.

When launching from the deck of a vessel, be aware that the wind (or lack of) near the deck can be quite different than just above the deck and to the sides of the vessel. The UAS may encounter a sudden shift in wind direction shortly after takeoff. Keep the direct launch area clear of people as much as possible and fly the aircraft directly upwards until safely past the wind shear before hovering to perform flight control checks.

Hand Launch and Recovery

Although hand launch and recovery can be very useful while operating from a vessel, there may be other situations where these methods may be better than normal procedures. For example, when flying in a steep and narrow channel or from a cliff or other high point, the wind near the surface could make normal takeoff or landing very difficult. Practice and become comfortable with hand launch and recovery in a stable environment before attempting in a difficult environment. Make sure all personnel including the person launching or catching the UAV by hand are upwind of the aircraft. Refer to the manufacturer's instructions on how to safely perform these maneuvers. If this information is not available in the instruction manual, use the following guidelines.

Hand Launch

Although some UAVs require launching by hand, including many fixed wing platforms, environmental conditions or lack of appropriate launch space (such as a very small deck or not enough distance from people on board) may make it necessary to hand launch an aircraft that normally takes off vertically.

To hand launch a rotary wing UAV:

- *As the person holding the aircraft*,
    - Hold the aircraft from underneath while keeping it level and away from the body (Figure 20).
    - Face the camera away from the body.
    - Keep your fingers and other body parts away from the propellers.
- *As the pilot*, engage the motors and either perform an automated takeoff or takeoff manually.
- *As the person holding the aircraft*, relax your grip and allow it to take off under its own power.
- *As the pilot*, quickly get the aircraft up above everyone and away from any obstacles.

Figure 20. A U.S. Coast Guard Pilot hand launches a UAV. Credit: U.S. Navy.

Hand Recovery

It is sometimes easier and safer to catch a UAV on a vessel than it is to land it on the deck or elsewhere due to factors such as different wind speeds just above the deck of the vessel and small or inappropriate landing space. If the UAV must be hand caught when the vessel is rolling due to high waves, exercise extreme caution and wear protective gear (helmet, gloves, eye protection, arm protection, etc.). Do not flip the UAV to kill the motors once it has been caught. Although this is an effective way to stop the propellers, over time it can cause damage to the motors and the risk of injury is increased.

To manually recover a rotary wing UAV:

- *As the pilot*,
    - Deactivate the obstacle sensors if possible.
    - Hover the aircraft above and slightly downwind of the person that will be catching it.
    - Rotate the aircraft so the camera faces away from them.
    - Begin landing the aircraft either by pressing a “land” button or by descending until the aircraft starts its landing sequence.
- *As the person catching the aircraft*,
    - Hold your hand away from your body at arm’s length and at or above shoulder height (Figure 21, left).
    - Ensure you have solid footing and no obstacles around you.
    - As the aircraft descends in landing mode, move your hand underneath it, keeping fingers and other body parts away from the propellers.
    - Once you have caught it, hold onto it from underneath and wait for the motors to stop and the propellers to stop spinning (Figure 21, right).

- *As the pilot*, once the catcher has a secure hold on the aircraft, power down the motors.

Extreme caution is required and do not attempt hand launch or recovery with strong winds or waves, on a rapidly moving vessel, or if you have encountered any problems with the aircraft during flight. Do not attempt to catch the aircraft before initiating landing. This skill must be practiced in as safe a manner as possible. Consult your aircraft user manual for model specific instructions.

Figure 21. Left: A U.S. Coast Guard VO catches a Parrot Anafi USA. Credit: USCG. Right: A VO catches a Matrice 300. Credit: Water Mapping.

Salt Water and Ice

Salt water and ice environments require more consideration than freshwater environments. Operations over salt water will require extra cleaning afterwards to keep salt buildup off delicate sensors and lenses.

Be aware of aircraft operating temperatures, and that batteries may not last as long in cold weather. If launching from on top of the ice, be aware and take precautions in the event of thin ice. Additionally, small ice particles may be disturbed by the propeller, so either launch and recover manually (by hand) or use a landing pad to protect the aircraft. Due to the high albedo (or reflectivity) of ice, be sure to counter that brightness either in the camera settings or with lens filters and turn on the HDR setting if available.

Mosaics Over Water

Collecting imagery over water for a mosaic is complicated and currently is not possible for most software to process. Mosaic processing software relies on distinct features in overlapping areas of images to tie them together (tie points). Because water is indistinctive when calm and flat and otherwise moving too much with wind and waves, there are no distinctive features except possibly the vessel, a buoy, or oil if present. However, methods to stitch together images over water are currently being tested and evaluated (Román et al., 2024), and, in some cases actively being used for spill response (Garcia et al., 2021). Mosaics over areas that include calm lakes and ponds have been created with varying degrees of success, though solar glare can be an issue.

Oil Observations on Water

Even if the operator is not a trained aerial observer, it is important to be familiar with accepted and widely used terminology for open water aerial identification of oil (Figure 22 and Figure 23). The following descriptions come from the NOAA Open Water Oil Identification Job Aid (see Spill Response Resources).

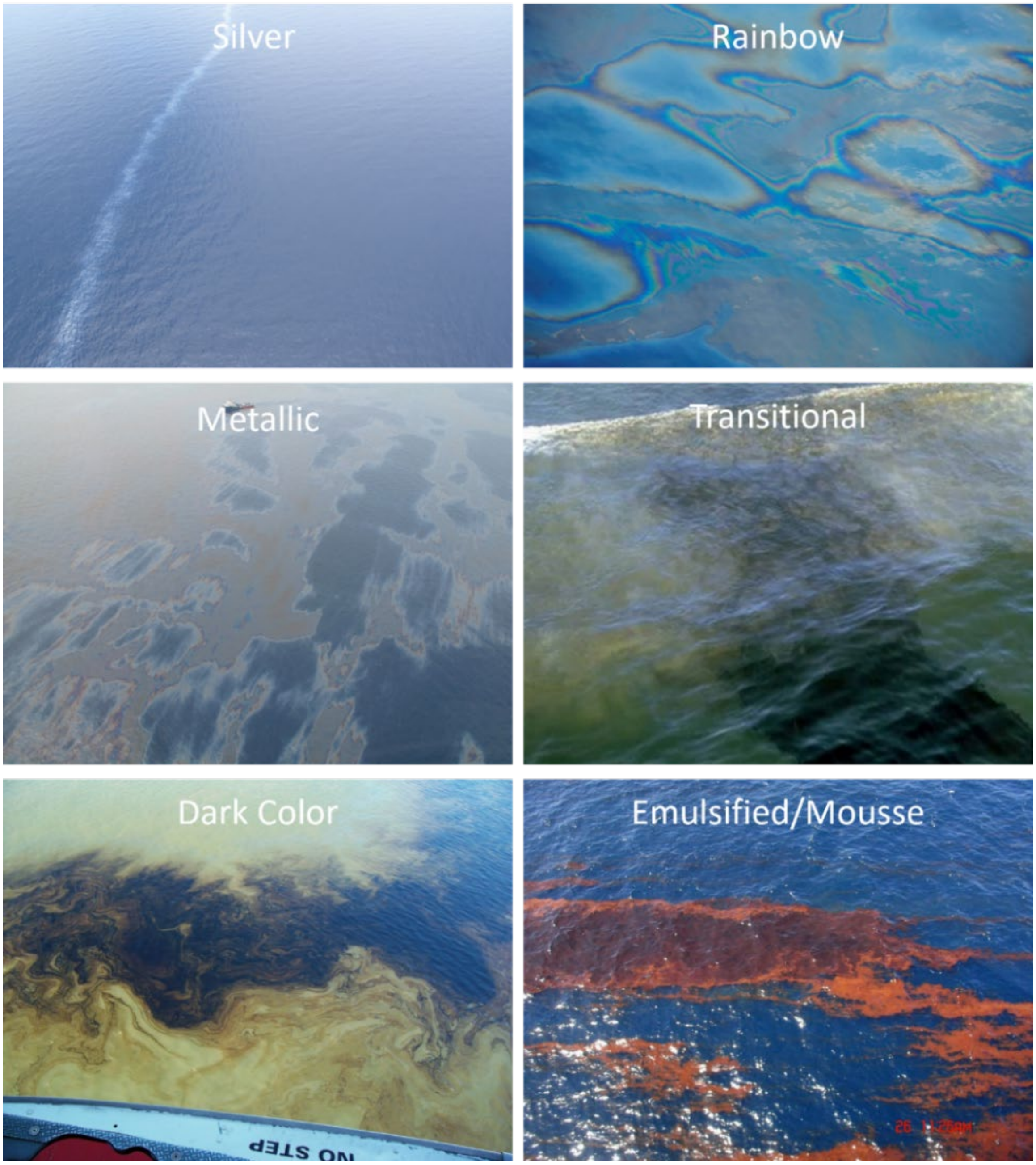


Figure 22. Oil on water descriptions. Credit: NOAA.

Thickness/Color

Sheen: Sheen is a very thin layer of oil floating on the water surface and is the most common form of oil seen in the later stages of an oil spill. Metallic, Rainbow, Silver/Grey, and Transitional are all used to describe the color of a sheen, and each relates to the thickness of the oil. The largest area of an oil slick can be made up of sheen, as it is the thinnest layer and tends to spread the farthest. Sheen is not considered recoverable oil in on-water operations.

Dark Color: This represents a continuous true oil color and occurs at thicknesses of at least a hundredth of an inch. This is the heaviest color of oiling on water and will often represent the true color of the oil. Dark oil can take up the least amount of area in an oil slick but contains most of the oil. Dark oil will usually be at the leading edge of a slick. Dark oil is considered recoverable and will be where most efforts to contain and remove oil are concentrated.

Emulsified Oil or Mousse: Water-in-oil mixture that appears as various shades of orange, brown, and/or red. Emulsification is a weathering process and is a result of oil droplets breaking apart and mixing with water molecules. Mousse is often seen in convergence zones where waters of different densities meet. Rough weather can also emulsify oil through wave action and agitation.

Figure 23. Oil on water structures. Credit: NOAA.

Structures

Streamers: Narrow bands or lines of oil (sheen, dark, or emulsified) with relatively clean water on each side. Streamers may be caused by wind and/or currents but should not be confused with multiple parallel bands of oil associated with windrows, convergence zones, or lines commonly associated with temperature and/or salinity discontinuities.

Windrows: Multiple bands or streaks of oil (sheens, dark, or mousse) that line up nearly parallel with the wind.

Convergence Zone: A long narrow bank of oil (and possibly other materials) often caused by the convergence of two bodies of water with different temperatures and/or salinities. Unlike streamers or windrows which are commonly associated with wind, convergence zones are normally associated with the interface between differing water masses, or the effects of tidal and depth changes that cause currents to converge.

Patches: Reflects a broad range of shapes and dimensions.

Tarballs: Discrete globules of weathered oil, ranging from mostly oil to highly emulsified. Can range in size from millimeters to 30 cm. Sheen may or may not be present. Will likely be very difficult to see from the air.

No Structure: Random eddies or swirls of oil at any thickness. This is normally the result of little to no wind and/or currents.

Other Terms

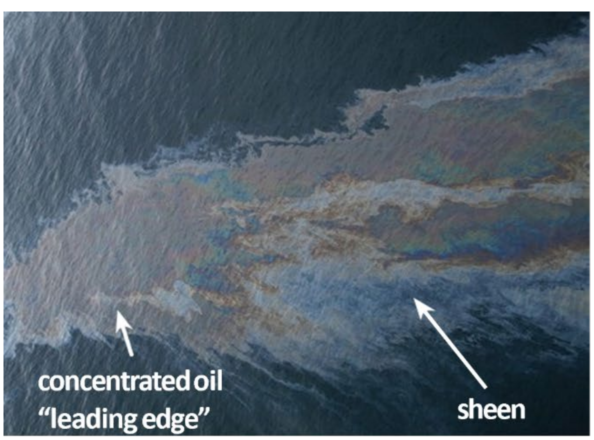
Entrainment: The loss of oil from containment when it is pulled under a boom by the current. Entrainment typically occurs from booms deployed perpendicular to currents greater than ¾ knot.

Recoverable Oil: Oil that is in a thick enough layer on the water to be recovered by conventional techniques and equipment. Only black or dark brown oil, mousse, and heavy metallic layers are generally considered thick enough to be recovered by skimmers.

Weathering: A combination of physical and environmental processes such as evaporation, dissolution, dispersion, photo-oxidation, and emulsification that act on oil and change its physical properties and composition.

Leading Edge: thicker oil concentrated at the leading edge of the slick that is being driven by wind and/or currents. 90% of the oil is located in 10% of the observable oil (Figure 24).

Trailing Edge: The point at which the floating film has dissipated and no longer produces a sheen.



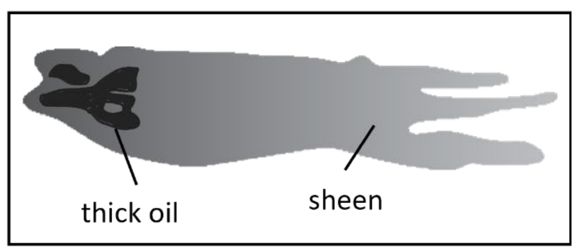


Figure 24. Leading Edge graphics. NOAA Open Water Oil Identification Job Aid for Aerial Observation.

Nearshore and Shoreline Operations

Shoreline Environments

Shorelines are grouped and categorized by how sensitive they are to oiling. Oil may present differently depending on the type of shoreline it impacts. The following shoreline types are commonly encountered during spill response.

Rocky Shores and Exposed Manmade Structures

These are the least sensitive of shoreline types. Oiling will cause the least amount of damage. Look for oil and staining along the intertidal zone (Figure 25).

Figure 25. Oil on rocks and sand along a portion of soiled coastline near Refugio State Beach, on May 23, 2015. Credit: U.S. Coast Guard.

Sand Beaches

Fine to medium-grained sand beaches are less sensitive than coarse-grained, mixed sand and gravel, and gravel beaches due to the sediment size making it more difficult for oil to seep between the grains. Be aware that some bird species nest in low spots in the sand.

Oil will be found in the intertidal zone, the area on a beach that covers the low tide water mark and the highest tide mark. The high tide mark is indicated by wrack (an accumulation of organic material such as seagrass, kelp, driftwood, sponges), vegetation, and other debris that washes up onto the shoreline during these tide periods. In areas without tides or areas with very weak tidal influences, this will be denoted by wind and wave action and will be narrower on the beach face. Determining the presence of oil can be difficult if wrack and/or other vegetation is present (Figure 26).

Be sure to use a launch pad during take-off and landing so sand isn't picked up by the prop wash. Sand can also have a higher albedo, so consider using camera filters and turning the HDR setting on, if available for your aircraft.

Figure 26. Small tar patties and vegetation on Rincon Beach, Santa Barbara, CA. Credit: RPI.

Riprap and Sheltered Manmade Structures

Riprap structures are composed of cobble- to boulder-sized quarried rocks or concrete and are placed as protection behind beaches, along harbors, and as groins or jetties to protect the shoreline from erosion. Walking along riprap can be difficult, especially since oiling will either be between boulders or adhered to their surface (Figure 27).

Figure 27. Tar on riprap, Rincon Beach, Santa Barbara, CA. Credit: RPI.

For oiling that is on the surface, a UAS should be flown along the outside with its camera pointed at an oblique angle to the riprap. Photos and short videos are appropriate for this type of survey. Note that it is highly unlikely that oil between boulders and rocks will be detectable from the air.

Wetlands

Wetlands are the most sensitive shoreline habitats. They are subclassified into salt- and brackish-water marshes, freshwater marshes, swamps, and scrub-shrubs/mangroves. They are often flooded during high tide or during extended periods of rain, when there is no tidal influence. As a result, oiling will often be found on vegetation stems instead of the substrate (Figure 28).

Wetlands may have pools of water in them that can be very reflective. Recommend using a polarizing lens filter if using a visible light camera. Be aware of birds in the area, especially if the noise of the aircraft flushes them from the marsh.

Figure 28. Banded oil on salt marsh in St. Simon Sound, GA. Credit: RPI.

Using a UAS to survey swamps and mangroves for oil will likely be of little value due to the height of vegetation and the fact that oiling will be low down around the waterline. Marshes could benefit from utilizing a remote aircraft. Oblique photos and video will show oiling as bands on the vegetation. Nadir photos and mosaics are useful to help quantify the extent of oiling for possible treatment (Figure 29), especially if there is oil on the substrate and vegetation is sparse.

Figure 29. Mosaic (left) and oblique (right) imagery of oil on marsh, Bayou Perot, LA. Credit: RPI.

Oil Observations on Shorelines

Shoreline Cleanup Assessment Technique (SCAT) is a systematic method for surveying an affected shoreline after an oil spill. If you are unfamiliar with SCAT, there are a few things you should be familiar with, such as shoreline type, oiling characteristics, and how to estimate percent distribution.

SCAT is used to not only identify shoreline oiling, but also to quantify it. As a UAS pilot, your main job will be to note presence/absence of oiling, as well as estimate percent coverage. The following graphic is from the NOAA SCAT Manual. At the very least, you can use the terms Trace (<1%), Sporadic (1-10%), Patchy (11-50%), Broken (51-90%), and Continuous (91-100%) when describing oiling coverage (Figure 30).

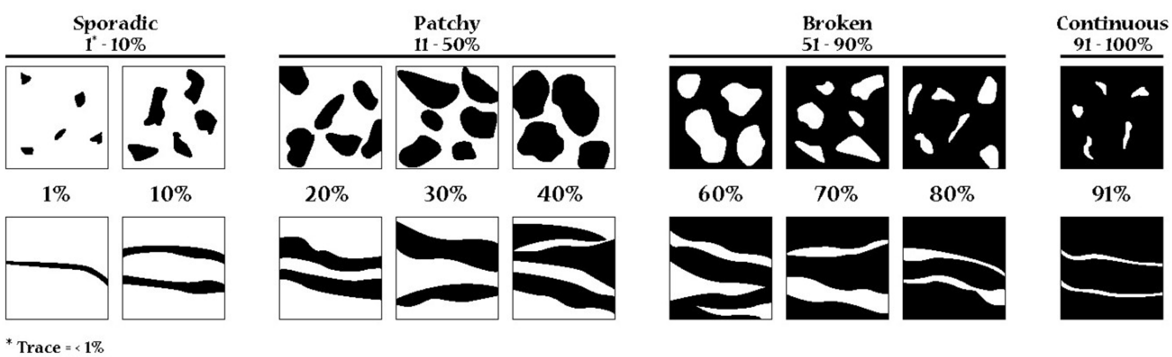


Figure 30. Shoreline oil coverage (black areas) estimation chart. Source: Owens and Sergy, 2000.

When to Use UAS

When responding to an incident, it is helpful to know which platform will be the most useful for a specific operation. Generally, if the potentially impacted area of the incident is very large and the location is vague, satellite-based sensors may help narrow down the location and provide some initial information. If there is a better understanding of the general location but the area to be searched is still very large, traditional aircraft platforms will be the most useful. UAS platforms are best suited for smaller areas and when detailed information is needed. This is summarized in the decision matrix in Figure 31.

	PLATFORMS			SENSORS ✓= frequent use, ○ = infrequent use				
Operation	**Satellite**	**Aerial**	**UAS**	**Optical**	**Thermal**	**Multispectral**	**Polarization**	**Lidar**
Reconnaissance	Very large area with vague idea of location	Large area with some idea of location	Smaller area with good idea of general location	✓	✓	✓	✓	
Supplemental/ Hotspot		Large area that cannot be accessed with UAS due to VLOS limitations	Smaller area with known location	✓	○	○	○	
Detecting/ Imaging Sheens	Large area with vague idea of location	Large area with good idea of location	Smaller area with good idea of general location	✓		○		
Vessel/Debris Inspection			Smaller area with known location	✓				
Wildlife Detection		Large area with some idea of location	Smaller area with good idea of general location	✓	○			
Environment Assessment		Large area with known location	Smaller area with known location	✓	○	○		
Aids to Navigation		Large area with some idea of location	Smaller area with some idea of location	✓				
Oil Characterization		Large area with known location	Smaller area with known location	✓	✓	✓	✓	✓

Figure 31. Decision matrix for which platform to use and when. Credit: RPI.

Reconnaissance/Surveillance Overflights

Reconnaissance (or recon) often requires overflights for making initial assessments. UAS can be used in place of traditional aircraft for these overflights to search for moderate to heavy contamination. Long distances may need to be covered, thus indicating the type of UAS that should be used (fixed wing or multi-rotor). For flights that will take less than 40 minutes and do not need to cover long distances, a multi-rotor aircraft is sufficient.

The main objective of an initial assessment overflight over water is to identify the location and extent of floating oil. Once the location has been determined, other factors can be assessed including direction of travel, type of oil, and potentially the oil thickness as well as weathering and emulsification of the oil.

The objectives of a shoreline recon survey are 1) Obtain overall perspective on shoreline types and degree of contamination in the impacted area, 2) Determine the areal extent of oiling on the shoreline, and 3) Identify logistical constraints to shoreline access for both shoreline assessment (before committing a full SCAT team) and cleanup teams. Logistical constraints include mudflats, oyster reefs, or other obstacles that may impede being able to survey at low tide and may not be apparent in aerial imagery. A full SCAT team is not needed for recon, and a UAS operator and visual observer can be assigned an area on their own (one of them must be Part 107 certified). If oil or some other hazardous material is detected during an overflight, the UAS can easily be flown in for a closer look before returning to base. Surveillance overflights are for detecting, monitoring, and tracking the spill as well as for identifying the presence of wildlife.

A reconnaissance/surveillance overflight requires high resolution true-color cameras and thermal sensors. This operation is also time-sensitive, and information needs to be sent to the command post as soon as possible to provide situational awareness for reporting or documenting the nature of the spill and for planning subsequent missions. Collecting real-time video is the fastest way to get data to the decision makers. Oblique and nadir imagery with GPS information is also useful for documenting, reporting, and posting to the common operating picture (COP) such as ERMA.

Orthomosaic products are useful for capturing the footprint of oiling, including the leading and trailing edge. However, creating orthomosaics from images captured over water can be challenging (see section on Mosaics Over Water).

Specifications

- Target may be unknown; if a spill, could be oiled vegetation, sand, habitat, or oil on water; if post-storm, could be derelict vessel(s) or other pollution hazard.
- Reconnaissance flight requires high resolution true-color cameras and thermal sensors.
- Surveillance flight requires high resolution true-color cameras and thermal sensors but may also require multispectral sensors.
- Collect shoreline data at low tide, if possible, to maximize the potential to observe intertidal features and stranded oil.
- Collect real-time (instantly delivered) video if possible and nadir/oblique photos or provide products to the COP immediately upon return. If real-time video is not possible, collect short videos of any oiling found along a linear flight along a beach, riprap, or other similar shoreline.
- A complex environment like a marsh would be a good candidate to fly a lawnmower pattern and compile a mosaic image for further analysis. For mosaics, provide COP with raw images immediately upon return; process images to create an orthomosaic and deliver to COP in full resolution.
- Download and deliver flight tracks to COP for location information.

Shoreline Cleanup and Assessment Technique (SCAT)

There are four areas of the SCAT process where UAS is particularly useful for supplementing shoreline surveys and clean-up operations: reconnaissance (described in the previous section); SCAT shoreline surveys (including marsh interiors); operations treatment (i.e., sorbent, boom, vegetation cutting); and post-treatment shoreline inspection.

Once the shoreline is segmented and SCAT teams are deployed, teams can use UAS to create overview maps of segments to be used later in the planning process. A complex environment like a marsh would be a good candidate to fly a lawnmower pattern and compile a mosaic image for further analysis. UAS can also be deployed to survey shorelines that are otherwise inaccessible due to tides, hazardous terrain, sensitive habitat (e.g., marsh interiors), etc. Be aware that you will only be able to identify areas of significant oiling and will likely not see trace/tarball oiling.

Imagery and video collected by UAS are also valuable tools for planning operations treatment and can be used to monitor and record treatment application as well as inspection of areas post-treatment.

Specifications

- Target could be oiled vegetation, sand, habitat, or manmade structures such as a seawall or riprap.
- Requires high resolution true-color cameras. Thermal sensors could be useful if the oil is a different temperature than whatever it has become stranded on.
- Collect data at low tide, if possible, to maximize the potential to observe intertidal features and stranded oil.
- Collect nadir/oblique photos and video to document the presence of oiling and precent coverage.
- A complex environment like a marsh would be a good candidate to fly a lawnmower pattern and compile a mosaic image for further analysis. Mosaics could also be useful for creating documentation of SCAT segments such as an overview map. For mosaics, provide COP with raw images immediately upon return; process images to create an orthomosaic and deliver to COP in full resolution.
- Download and deliver flight tracks to COP for location information.

Supplemental Information and Hotspot Assessment

Flights to gather supplemental information are usually conducted locally, with shorter flight distances. Supplemental information could be identifying the nature of oil (localized oil spill inspections), obtaining more information about a derelict vessel, or getting more information about impacted wildlife and habitat. Hotspot assessment is getting more details about an area that is severely impacted, such as vessels piled up on sensitive habitat like mangroves (Figure 32) or extensive oiling of sensitive habitat (Figure 29). Typically, the UAS is used to get close to objects or other targets, so a multi-rotor aircraft with hover capability is the best option. True-color cameras are required for this operation. For oil characterization, thermal, multispectral, and optical polarization sensors may be useful if available.

Figure 32. UAV photo showing a hotspot with multiple boats and other debris in mangroves after Hurricane Ian. Credit: USCG.

Specifications

- Target could be stranded or floating oil, derelict vessel(s), wildlife, habitat, etc.
- Requires high resolution true-color cameras. Other sensors such as thermal, multispectral, and optical polarizers may be useful for oil characterization.
- Consider what the target is and determine the best time of day for collecting imagery. Factors to consider might be tidal cycles, wildlife behavior, water turbidity, etc. To maximize the potential of observing intertidal features and stranded oil, collect data at low tide.
- Be aware of any wildlife in the area and follow any local/federal ordinances regarding flying near wildlife.
- Collect nadir/oblique photos and video, though mosaics could be useful for a situation such as dozens of vessels and other debris piled into one location.
- Download and deliver flight tracks to COP for location information.

Detecting and Imaging Sheens

Sheens, as described previously, consist of very thin films that are distinguishable because sheen forms a surface that reflects light and can appear to be relatively brighter than the clean water surface depending on the viewing angle between the observer and the ambient light source (Garcia-Piñeda et al., 2020). It is best to use a true-color camera and collect images from varying angles. Also, a polarizing filter may be helpful if set in the correct orientation. Sheen color can be influenced by several factors, including the reflection of the sky, position of the sun, underlying water color, sea state, and wind conditions (Figure 33).

Figure 33. Sheen on water in front of a barge in Bayou Perot, LA, seen from four different angles. Reflections on the water from clouds make it difficult to see the sheen from some angles. Credit: RPI.

Specifications

- Target is unknown or a suspected sheen on water.
- Requires true-color cameras. Thermal sensors are not good at picking up sheens because they are so thin they tend to be in thermal balance with the water underneath. Multispectral sensors may be used to detect different aspects of sheens (Garcia et al., 2019b).
- Sheens are most easily detected from the side with a highly oblique view. Take photos from varying oblique angles and aircraft locations.
- Sheen color is most accurately characterized in a nadir photo taken from directly overhead. Though, some of the thinnest sheens may become transparent and disappear when you fly directly overhead. If that occurs, look for a source area or region with a darker color to confirm that the sheen represents oil and not a naturally occurring false positive.
- The potential for false positives is very high when looking for sheens. Biogenic sheens look very similar and floating algae or vegetation can be mistaken for a sheen.
- Collect real-time (instantly delivered) oblique and nadir photos if possible or provide products to the COP immediately upon return. Include photos that capture the extent of the sheen.
- Download and deliver flight tracks to COP for location information.

Post-Storm Vessel and Debris Inspection

When assessing post-storm derelict vessels or other hazardous debris, get in close to look for pollution sources and to gather identifying information such as vessel registration numbers or hazardous material markings.

Figure 34. Derelict vessel from Hurricane Ian where a UAS was used. Note that the Registration Number is visible. Credit: USCG.

Derelict vessels can be high in the mangroves or marsh and difficult to access during field assessments. Using a UAS, you might be able to get close enough to get identifying information such as registration numbers (Figure 34) or the vessel name. For state registered vessels, the registration numbers will be on the forward half of the vessel and will start with the state prefix, followed by numbers and letters. (EX: FL 1234 AA). Working with state waterways law enforcement, the vessel owners should be able to be identified and contacted. Vessels that are federally documented will have their name on either transom or either side of the vessel, along with the home port of the vessel.

In addition to identifying information, take photos of the surrounding environment, especially if there is any damage to marsh or mangrove from the vessel settling there. Ensure the photos get uploaded to a database management system (VADR, NDOW, ERMA, etc) so they can be used by the response to find owners and plan any salvage activities.

Specifications

- Target is a vessel or other hazardous debris.
- Requires true-color cameras. Camera filters may be useful, especially over water.
- Get in close to look for pollution sources and to gather identifying information such as vessel registration numbers or hazardous material markings.
- Collect oblique/nadir photos, making sure that the camera is focused on the vessel, so the registration numbers are clearly visible. State registration numbers are 3 inches in height.
- Collect photos/video of the surrounding environment.
- If uploading photos to a field app (VADR), do not upload screenshots of the UAS RC screen (Figure 35), because the resolution is usually not sufficient and there may be glare obscuring important information.
- Download and deliver flight tracks to COP for location information.

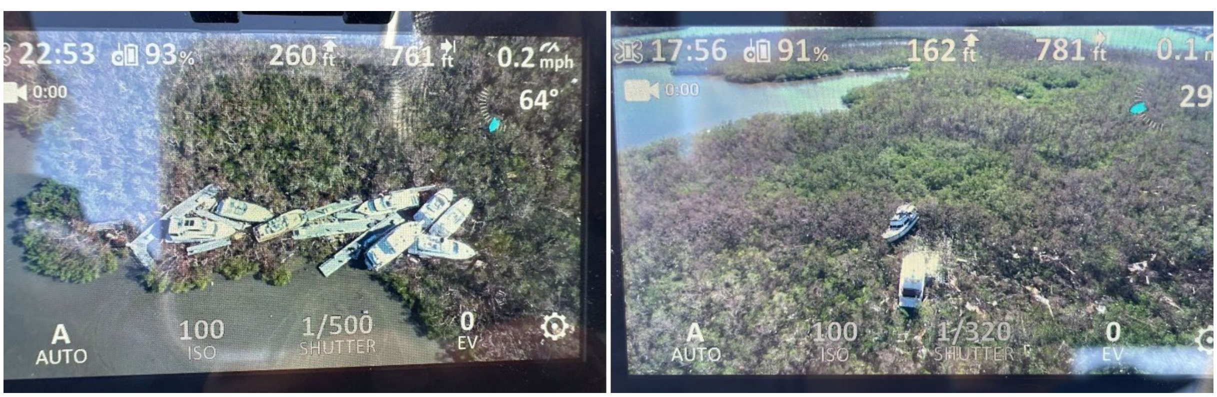


Figure 35. Screenshots of a UAS remote controller screen uploaded to VADR have glare and are low-resolution. Credit: USCG.

Nearshore and Shoreline Wildlife Detection and Identification

There may be wildlife activities happening in and around the area of an oil spill. Use UAS to do a reconnaissance flight to detect and identify wildlife (Figure 36). Follow Best Management Practices (BMPs) established by the Incident Command to avoid and/or minimize impacts to fish, wildlife, marine mammals, and other natural resources.

Specifications

- Target may be unknown or could be wildlife species known to be in the area at the time of the mission.
- Requires true-color cameras, though thermal sensors may aid in detection.
- Avoid unnecessarily disturbing wildlife. There may be guidelines and regulations regarding the use of UAS near certain wildlife, such as bird nesting sites. Follow established BMPs. See the resources section for more information.
- Collect real-time (instantly delivered) video and nadir/oblique photos if possible or provide products to the COP immediately upon return.
- Download and deliver flight tracks to COP for location information.

Figure 36. Pelicans, terns, and gulls rest on Chester Island in Matagorda Bay, Texas. Credit: Hank Arnold, Audubon.

Environment/Habitat/Wildlife Assessment

There are potential impacts to wildlife and habitats caused by oil spills, storm damage, and vessel groundings. During a response, there will be a preliminary assessment to determine whether any such impacts have occurred. The preliminary assessment also establishes a baseline for continued monitoring including for Natural Resources Damage Assessment (NRDA) – a process to determine the appropriate type and amount of restoration needed to offset these impacts. Assessment flights are usually performed locally. Imagery from these flights could also be used to determine access points to impacted areas for any prescribed cleanup operations.

Specifications

- Target is an environment that may include wildlife and/or sensitive habitat.

- Requires true-color cameras, though thermal sensors may aid in detection.
- May need to collect imagery even if there is no observable impact for documentation purposes.
- For wildlife, capture as far away as possible while still getting the information needed so as not to further disturb the wildlife. There may be guidelines and regulations regarding the use of UAS near certain wildlife, such as bird nesting sites. Follow established BMPs. See the resources section for more information.
- For sensitive habitat, capture imagery beyond the boundary of the impacted area. Follow any regulations in place and do not takeoff/land in sensitive habitat.
- Collect real-time (instantly delivered) video and nadir/oblique photos if possible or provide products to the COP immediately upon return.
- For mosaics, provide COP with raw images immediately upon return; process images to create a georeferenced mosaic and deliver to COP in full resolution.
- Download and deliver flight tracks to COP for location information.

Aids to Navigation

Navigation pathways may be obstructed during an oil spill or after a storm. Use UAS to do a reconnaissance flight to determine if navigation pathways are obstructed and to find alternate routes. A UAS might be able to provide a better perspective for identifying and characterizing submerged debris. For example, the submerged object in Figure 37 is not identifiable in an image taken with a smartphone. It was necessary to get closer (by boat) to the object to determine it was a submerged car. Flying a UAV out to the object would have been safer and it could have potentially collected images showing the size of the vehicle.

Specifications

- Target is navigation pathways and routes.
- Requires true-color cameras.
- Collect real-time (instantly delivered) video and nadir/oblique photos if possible or provide products to the COP immediately upon return.
- Download and deliver flight tracks to COP for location information.

Figure 37. A submerged object is a navigational hazard. Credit: USCG.

Appendix

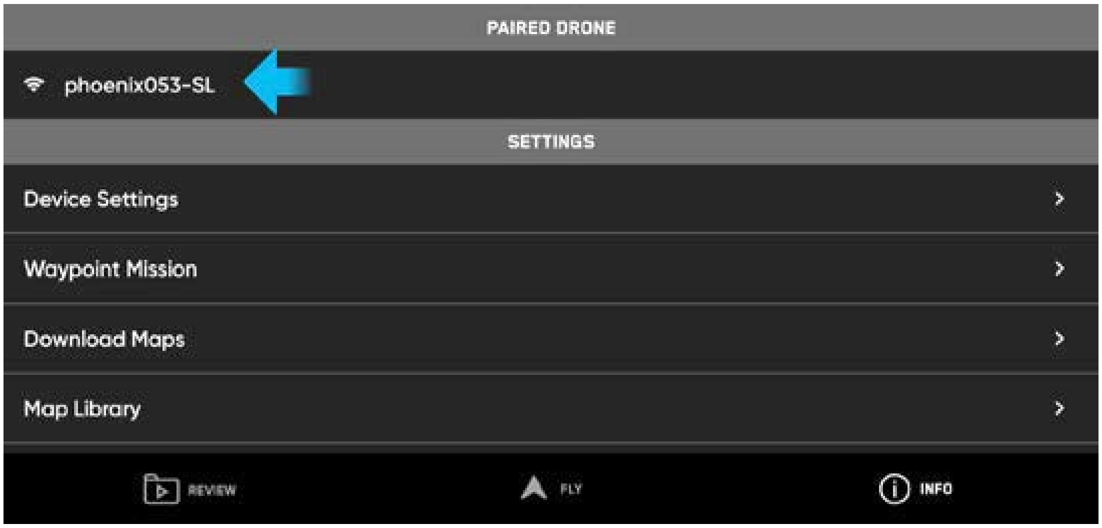
Downloading Flight Tracks

Flight tracks are an essential data deliverable. They provide the best record of where all imagery was collected. The process for downloading flight tracks (also called flight/track logs) varies by manufacturer. Consult the manufacturer's manual for how to download track logs for your aircraft. Methods for some of the most common UAS are described here.

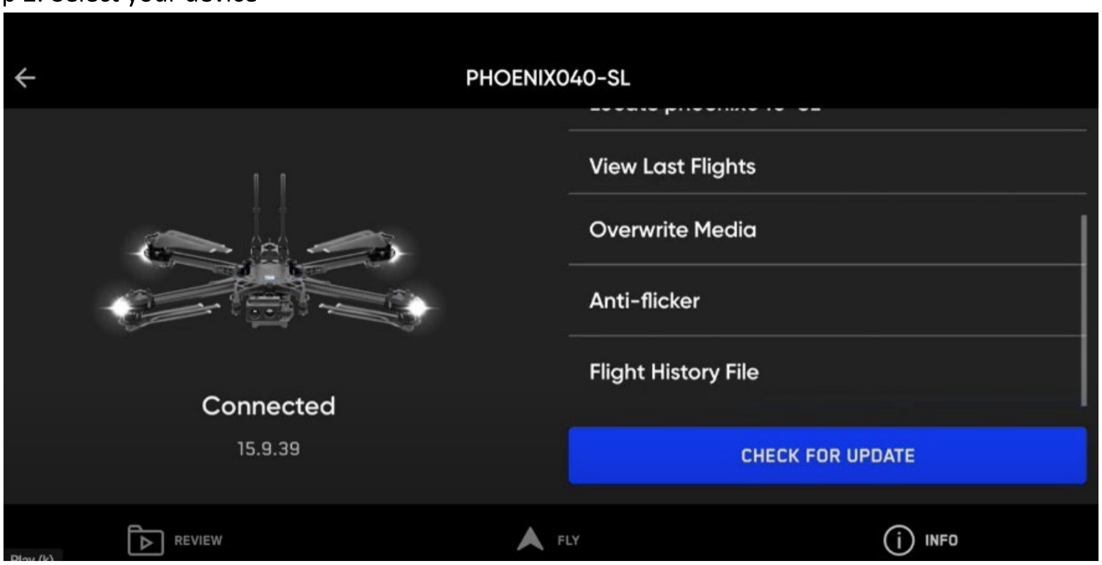
Skydio X2E

On the Skydio Enterprise Controller (referenced from the Skydio X2E Operator Manual 24.10 A0118):

Step 1. Select the **INFO** menu

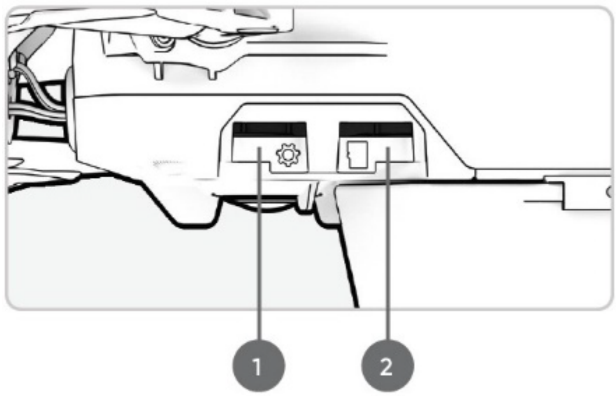


Step 2. Select your device



Step 3. Select **Flight History File**

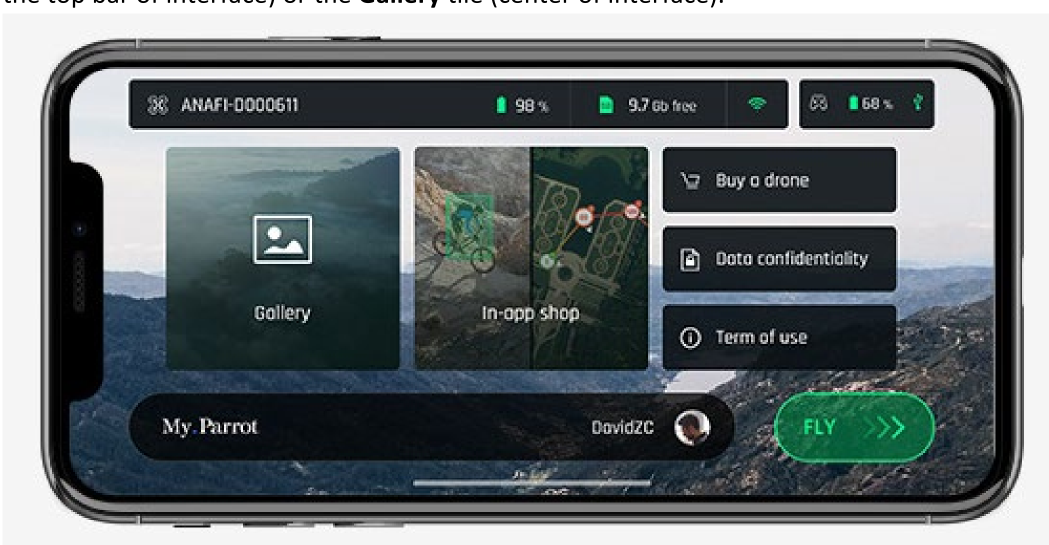
Step 4. Select **Store Flight History** – The flight history log will be stored on the SD logs memory card (number 2) and available for download as a CSV file.



Parrot Anafi USA

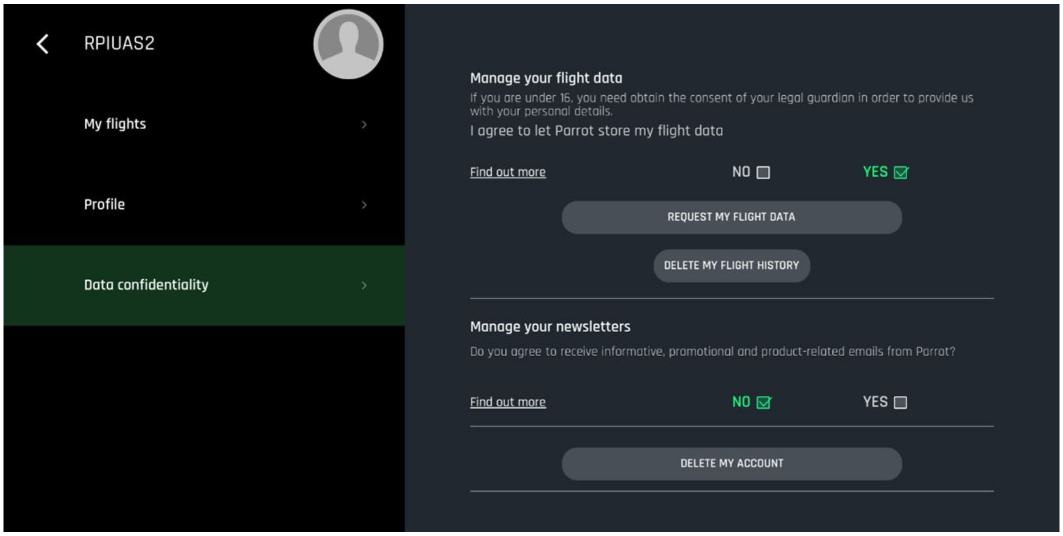
From the FreeFlight 6 USA app (referenced from the Anafi USA FreeFlight 6 USA User Guide):

Step 1. Access the **Gallery** from the FreeFlight 6 USA homescreen – tap either the **microSD card** icon (on the top bar of interface) or the **Gallery** tile (center of interface).

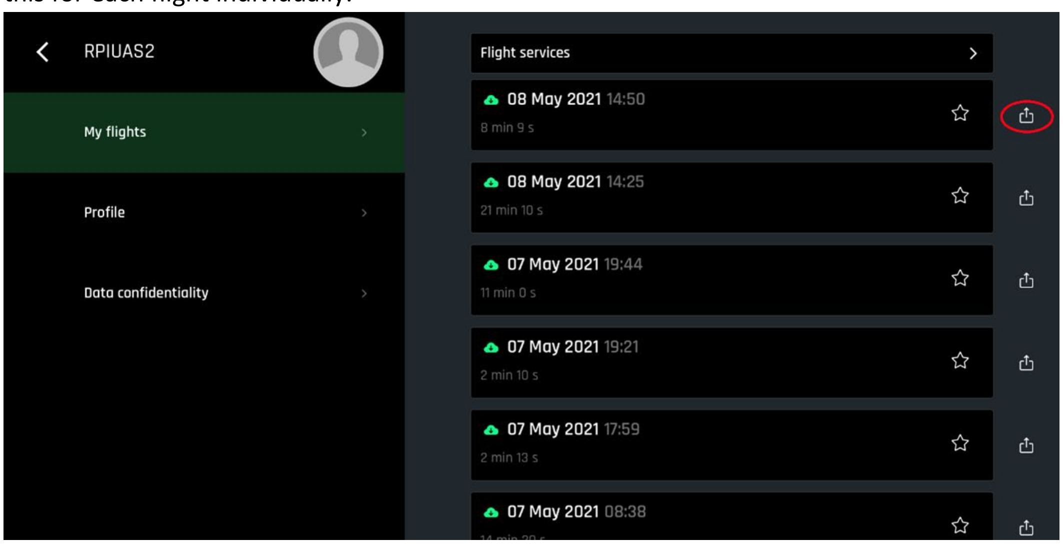


Step 2. Tap the **Data confidentiality** button.

Step 3. Select **Data confidentiality** on the left and check to see if the Yes box is checked under "Manage your flight data"; if so, click on REQUEST MY FLIGHT DATA and it will send the data to the email you are logged in with.



Step 4. If **NO** is checked in the Data confidentiality window, then you must send individual log files; select **My flights** on the left and flights will be listed by date on the right; click the share icon next to the flight you want to send and the iOS share options will pop up (AirDrop, Messages, Mail, etc.); do this for each flight individually.



Checklists and Mission Logs

The following checklists are from the Uncrewed Aircraft Systems Oil Spill Response Job Aid (NOAA, 2021). An example of an offshore oil observations mission log is also provided.

PRE-MISSION

EQUIPMENT PREP:
_____AIRCRAFT BATTERIES CHARGED
_____REMOTE CONTROLLER CHARGED
_____STROBE LIGHTS CHARGED
_____TABLET/PHONE CHARGED
_____UAS FIRMWARE UP-TO-DATE
_____APPS UPDATED
_____MAPS FOR FLIGHT AREAS CACHED IN APPS
_____MICROSD CARD BACKED UP & CLEARED

MISSION PLANNING:
_____FLIGHT PLAN
_____AIRSPACE RESTRICTIONS & APPROVALS
_____NOTAMs/TFRs
_____ORM ASSESSMENT
_____WILDLIFE AVOIDANCE
_____OBSTACLES (RTH, TAKEOFF LOCATION, ETC.)
_____WEATHER
_____SCAT SEGMENT MAP
_____BLANK SCAT SURVEY FORM(S)

PACKING LIST:
_____AIRCRAFT W/ GIMBAL PROTECTOR INSTALLED
_____REMOTE CONTROLLER
_____MICROSD CARD(S)
_____TABLET/PHONE W/ APPS
_____STROBE LIGHTS
_____CAMERA FILTERS
_____PROPELLERS (4 PLUS SPARES)
_____REMOTE CONTROLLER PHONE/TABLET CABLE
_____CAMERA FILTERS
_____LAUNCH PAD

Figure 38. Pre-Mission Checklist

PRE-FLIGHT

AIRCRAFT INSPECTION:
_____CHECKED FOR CRACKS OR SEPARATION
_____CHECKED FOR LOOSE OR DAMAGED SCREWS
_____CHECKED FOR LOOSE OR DAMAGED WIRING
_____PROPELLERS CHECKED
_____CAMERA LENS & OBSTACLE SENSORS CLEANED

BEFORE TAKEOFF:
_____LAUNCH PAD PLACED (OPTIONAL)
_____REGISTRATION NUMBER IS VISIBLE
_____GIMBAL PROTECTOR REMOVED
_____GIMBAL IS LEVEL & CAN MOVE UNOBSTRUCTED
_____CONTROLLER CONNECTED TO TABLET/PHONE
_____FLIGHT MODE SWITCH IS SET (USUALLY P-MODE)
_____ANTENNAS PROPERLY POSITIONED
_____MICROSD CARD INSTALLED
_____STROBE LIGHTS INSTALLED AND TURNED ON
_____CAMERA FILTER INSTALLED (OPTIONAL)
_____AIRCRAFT AND CONTROLLER TURNED ON
_____COMPASS CALIBRATED
_____BATTERY LEVELS CHECKED

BEFORE TAKEOFF (cont.):
_____GPS STATUS CHECKED
_____CAMERA SETTINGS CHECKED
_____LAUNCH SITE CLEARED AND PARTICIPANTS UPWIND
_____RETURN TO HOME (RTH) BEHAVIOR AND ALTITUDE SET

TAKEOFF & HOVER – BEFORE FLIGHT:
_____AIRCRAFT IS STABLE
_____FLIGHT CONTROLS CHECKED
_____START VIDEO RECORDING (OPTIONAL)
_____CHECKED FOR OBSTACLES/INTERFERENCE

Figure 39. Pre-Flight Checklist

POST-FLIGHT

____DATA SYNCED TO REMOTE CONTROLLER APP
____AIRCRAFT TURNED OFF
____REMOTE CONTROLLER TURNED OFF
____CONTROLLER TO TABLET/PHONE CABLE REMOVED
____GIMBAL PROTECTOR SECURED
____CAMERA FILTER REMOVED (OPTIONAL)
____MICROSD CARD REMOVED
____MICROSD CARD BACKED UP
____RECORDED FLIGHT TRACK DOWNLOADED
____RECORDED FLIGHT TRACK BACKED UP
____AIRCRAFT & PROPELLERS INSPECTED
____AIRCRAFT BATTERY REMOVED
____AIRCRAFT BATTERY INSPECTED
____PROPELLERS REMOVED (OPTIONAL)
____MISSION LOG COMPLETED
____LAUNCH PAD RETRIEVED (OPTIONAL)
____EQUIPMENT STORED PROPERLY

Figure 40. Post-Flight Checklist

EMERGENCY PROCEDURES

LOST LINK (CONTROLLER CONNECTION):
- MAINTAIN VISUAL CONTACT
- PAUSE AUTONOMOUS FLIGHT IF NECESSARY
- HOVER UAV FOR UP TO 2 MINUTES
- RTH SHOULD AUTO-INITIATE
- ATTEMPT TO RE-ESTABLISH LINK IF RTH FAILS, MOVE RC TOWARDS AIRCRAFT OR TO HIGHER POSITION, REPOSITION ANTENNAS

LOSS OF GPS:
- MAINTAIN VISUAL CONTACT WITH UAV
- MANUALLY OPERATE UAV UNTIL GPS REACQUIRED
- LAND UAV AS SOON AS POSSIBLE IF STILL NO GPS
- CSC (ENGINE KILL) IF UNABLE TO REGAIN CONTROL

LOSS OF VISUAL CONTACT:
- PAUSE AUTONOMOUS FLIGHT IF NECESSARY
- ATTEMPT TO RE-ESTABLISH VISUAL CONTACT
- INITIATE RTH UNTIL UAV IS VISIBLE OR HAS LANDED

APPROACHING AIRCRAFT:
- IMMEDIATELY DESCEND UAV TO SAFE ALTITUDE

LOW BATTERY WARNING:
- PAUSE AUTONOMOUS FLIGHT IF NECESSARY
- INITIATE RTH OR FLY UAV MANUALLY TO RETURN

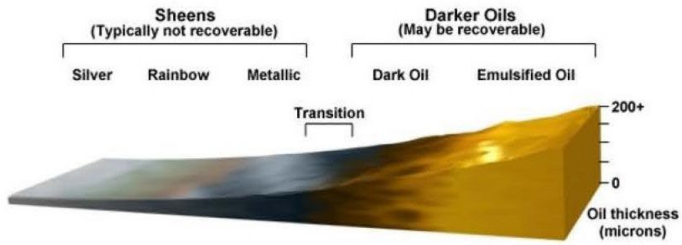
POWER FAILURE:
- WARN ANY PERSONS IN THE VICINITY
- CLEAR THE AREA IF POSSIBLE
- MAINTAIN VISUAL CONTACT WITH UAV
- RETRIEVE AIRCRAFT IF POSSIBLE

Figure 41. Emergency Procedures

Oil Observations

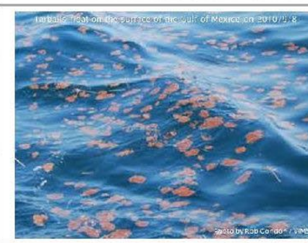
☐ OIL OBSERVED	☐ NO OIL OBSERVED

COLOR



	SHEEN		DARKER OIL
☐	Silver	☐	Black / brown
☐	Rainbow	☐	Yellow / dark brown / red *(emulsified)*
☐	Metallic	☐	Other *(please describe)*

DISTRIBUTION

☐ Streamers Size: Orientation:		☐ Patch Size: Orientation:	
☐ Convergence line Size: Orientation:		☐ Tarballs Size: Orientation:	
☐ Windrows Size: Orientation:		☐ No Structure Size: Orientation:	

Notes:

Figure 42. Example: Aerial Observations of Oil Mission Log. Credit: RPI and WaterMapping.

Resources

UAS Operations

U.S. Coast Guard (USCG) Short-Range Unmanned Aircraft Systems (UAS) Flight Operations Standard Operating Procedures, USCG Office of Aviation Forces (USCG SR-UAS SOP, 2021). https://homeport.uscg.mil/Lists/Content/Attachments/71056/Short-range%20UAS%20USCG%20SOP.pdf

NOAA Uncrewed Aircraft Systems (UAS) Handbook, NOAA UxS Operations Center. https://www.omao.noaa.gov/sites/default/files/documents/NOAA%20UAS%20Handbook.pdf

NOAA Uncrewed Aircraft Systems Operations Policy, Office of Marine and Aviation Operations (OMAO-UAS, 2022) *(internal NOAA access only)*. https://www.omao.noaa.gov/uncrewed-systems

14 Code of Federal Regulations (CFR) Part 107. https://www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-107

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Maritime Environmental Response Oil Mission Guidelines, WaterMapping LLC, NOAA OR&R, USCG, 2023. Available at the University of New Hampshire (UNG) Coastal Response Research Center (CRRC) https://crrc.unh.edu/

Spill Response

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Wildlife and Drones

14 Code of Federal Regulations (CFR) Part 107 https://www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-107

Drones for Conservation, World Wildlife Fund (WWF) Conservation Technology Series Issue #5. https://www.space-science.wwf.de/drones/

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