OSRI Balloon-Based Spill Surveillance System Operations and Testing Results

Report to Prince William Sound Regional Citizens' Advisory Council

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This report includes contributions from Prince William Sound Regional Citizen's Advisory Council, BP Exploration Alaska, Inc., and Alaska Clean Sea, Prince William Sound Science Center, and the Oil Spill Recovery Institute.

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Contents

Overview

This document is designed to describe in more detail the use and operation of a balloon surveillance system. A system was purchased by the Prince William Sound Science Center (PWSSC) in 2009 for the purpose of testing its applicability for oil spill surveillance. The original concept for the system was an output of a workshop titled, "Hydrocarbon sensors for oil spill prevention and response" (http://www.pws-osri.org/publications/Hydrocarbon%20Sensors.pdf) that was jointly sponsored by the Oil Spill Recovery Institute (OSRI) and the Alliance for Coastal Technology. The desire was to develop a system to provide aerial observation capability within a response fleet. The tethered balloon system was chosen because it has simpler permitting requirements and operations needs than unmanned aerial vehicles (UAV). This document focuses on the system owned by the Prince William Sound Science Center with discussion about other systems as applicable. There are other vendors of balloons and camera systems. Some additional information on alternative systems is provided in the section on selection criteria later in this document. This document builds upon the operation manual provided by the manufacturer, a lessons-learned document from Brian Green of Alaska Clean Seas related to testing done with him, and lessons learned from other deployments. It benefited from the input of all parties involved in the testing in particular, Brian Green (ACS), Jeremy Robida (PWSRCAC), and Regina Ward (BP Exploration Alaska).

The system owned by PWSSC was selected based on the following criteria.

1. Operate on a 50 foot fishing vessel. These are typically seiners that have 25 feet of flat open deck.
2. Operate in relative wind speeds of 30 knots.
3. View an area of 2 miles around the ship. Further is better.
4. Be able to resolve patches on the water of 3 meters in diameter at two mile range.
5. Transmit the images to the mother vessel. If possible to transmit to surrounding recovery vessels that would be beneficial.
6. A thermal infrared camera system is desired. We would like to be able to exchange for a regular camera during the day or have a combined system.
7. The system should be deployable in light rain. We would like to explore the limits at sub-freezing temperatures. In the future we would like to deploy at -40 degrees, but we will start with temperatures above freezing.
8. Expected cloud ceiling is 500 feet. This is a reasonable limiting case, but we will explore the trade-offs of needing to put the system higher.
9. Image update at least every 15 seconds, but more rapid is preferred.
10. Georeferenced imagery is desired, but not required at this time.

The system selected by PWSSC includes a SkyDoc two-ply model 18 aerostat with a Latitude Engineering Paracam visible and infrared video camera system. The SkyDoc aerostat is a kite-style balloon (Figure 1) that allows it to gain lift with increasing wind speed and is rated for winds up to 80 knots. A model 18 requires 969 cubic feet of helium to fill. The PWSSC system includes a 3 mil balloon contained in a nylon cover. Filled it is approximately 14 feet in diameter and 9 feet in height with 24 pounds of lift in no wind. The amount of lift increases rapidly with wind speed. Three control lines attach to a tether that then runs to the ship. The PWSSC tether is strictly a strength member; however other tethers can include electrical cables to supply power or communications with the camera. More information can be found at: http://www.skydocballoon.com/

Figure 1. The red portion is the balloon that is filled with helium. It has a flattened shape and when there is wind the sail (white cloth below the balloon) orients the balloon into the wind. The balloon will also tilt backwards allowing the flatter bottom section to act as a kite with

For the recent testing in Prince William Sound the BP Exploration Alaska, Inc.'s SkyDoc single–ply model 15 aerostat was used. A model 15 requires 560 cu feet of helium to fill. Filled it is approximately 12 feet in diameter and 8 feet in height with 22 pounds of lift in no wind. The BP balloon was a 3 mil balloon without a cover. There was a change in design and manufacturer used by SkyDoc between the purchase of the PWSSC balloon and the BP balloon. The BP balloon has a single seam between hemispheres versus the multiple vertical seems in the PWSSC balloon. The basic functionality of the balloons did not change, however.

The Latitude Engineering Paracam system used in the PWSSC system includes a CloudCap TASE200 visible and infrared camera and gimbal system that provides pan and tilt, lithium battery, gps, and wireless transmission system for communications with the operating vessel. A deck unit connected to a computer with GimbalUI or Viewpoint software provides the means to control the camera and view and record the video signal (Figure 2). Many aspects of the camera system can be selected at purchase or changed by the manufacturer. These include the strength of communication system, focal length of the camera lenses, and ability to have the system serve multiple receiving stations. The system tested is built upon a CloudCap TASE 200 system with a Sony FCB-EX980 visible camera (full color and 20x zoom) and a FLIR Photon 320 IR camera with 35 mm lens (2x zoom). The communications system is set up short range and for one receiving station. Communications are expected up to five miles along line-of-sight with our system. Limited extension of communication range can be achieved by changing the antennas on the deck system, the camera, or both. Battery life is expected to be eight hours. There is the ability to connect to external power and communications if necessary, but PWSSC does not own the appropriate tether cable. The camera system is attached to a support cradle that is then connected to the three control cables of the balloon. The gimbal also has onboard image stabilization built so as to help steady the video feed images. The gimbal allows for viewing 360° horizontal panning and tilt from straight down up to the camera frame. More information can be found at: http://www.latitudeengineering.net/index.php/products/paracam.html

The camera originally came with GimbalUI as the control software. In that software it is possible to view the video along with several characteristics of the camera such as the pointing angle and view position on the ground. The calculation of the view position requires that a digital elevation model be downloaded prior to operation that covers the area that the balloon is being operated in. A newer version of software called Viewpoint has all of the features of GimbalUI, but is also able to map the viewing location (Figure 2) to provide a more intuitive feel when controlling the camera position. The camera view can be adjusted using either the game controller or using a mouse and keystrokes. It is possible to click on a location and the camera will adjust itself to that point and try to remain focused on it. There are several types of map layers that can be downloaded from the web for displaying in the map view. These can be very large files and need to be downloaded before deploying the sensor.

When the record function in the software is activated it records all of the video and control information into a series of files about one second in length. This allows the entire video to be replayed and the displays can be changed to examine different pieces of information recorded by the system. The small files also provide the potential for sending part of the video signal through the internet to other locations.

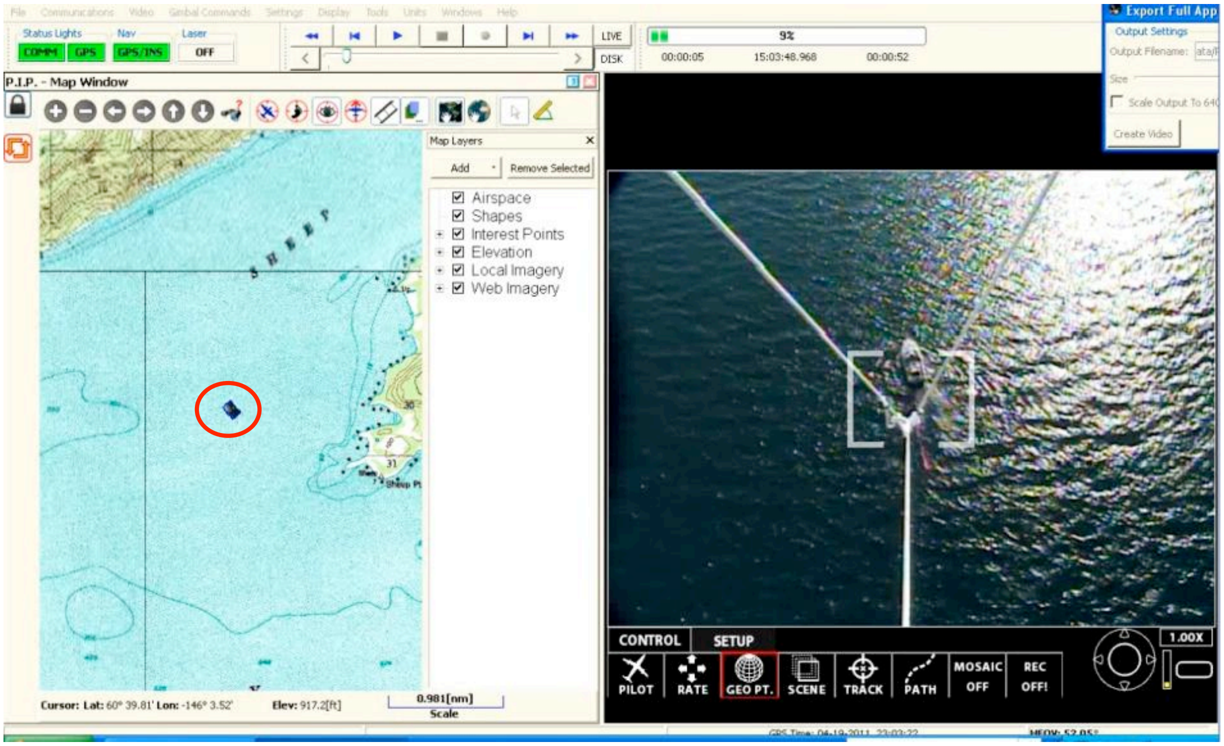

Figure 2. Shown is a screen shot of the Viewpoint software. The left panel shows the point being viewed (red circle). The right shows the video and some of the camera characteristics. For instance the zoom level is in the bottom right. Other views are available that give more information about the camera and area being viewed.

The system was developed with the idea of connecting to a ship with a winch or capstan system to deploy the balloon. It has also been deployed from a truck for observations over land. A winch system is required as the balloon lift will exceed the capability to control it by hand at wind speeds as low as 10 knots.

Operations regulations

Operation restrictions are listed in Federal Aviation Administration CFR 14 Part 101.

Title 14: Aeronautics and Space
PART 101—MOORED BALLOONS, KITES, AMATEUR ROCKETS AND UNMANNED FREE BALLOONS

Subpart B—Moored Balloons and Kites

Source: Docket No. 1580, 28 FR 6722, June 29, 1963, unless otherwise noted.

§ 101.11 Applicability.

This subpart applies to the operation of moored balloons and kites. However, a person operating a moored balloon or kite within a restricted area must comply only with §101.19 and with additional limitations imposed by the using or controlling agency, as appropriate.

§ 101.13 Operating limitations.

(a) Except as provided in paragraph (b) of this section, no person may operate a moored balloon or kite—

(1) Less than 500 feet from the base of any cloud;

(2) More than 500 feet above the surface of the earth;

(3) From an area where the ground visibility is less than three miles; or

(4) Within five miles of the boundary of any airport.

(b) Paragraph (a) of this section does not apply to the operation of a balloon or kite below the top of any structure and within 250 feet of it, if that shielded operation does not obscure any lighting on the structure.

§ 101.15 Notice requirements.

No person may operate an unshielded moored balloon or kite more than 150 feet above the surface of the earth unless, at least 24 hours before beginning the operation, he gives the following information to the FAA ATC facility that is nearest to the place of intended operation:

(a) The names and addresses of the owners and operators.

(b) The size of the balloon or the size and weight of the kite.

(c) The location of the operation.

(d) The height above the surface of the earth at which the balloon or kite is to be operated.

(e) The date, time, and duration of the operation.

§ 101.17 Lighting and marking requirements.

(a) No person may operate a moored balloon or kite, between sunset and sunrise unless the balloon or kite, and its mooring lines, are lighted so as to give a visual warning equal to that required for obstructions to air navigation in the FAA publication “Obstruction Marking and Lighting”.

(b) No person may operate a moored balloon or kite between sunrise and sunset unless its mooring lines have colored pennants or streamers attached at not more than 50 foot intervals beginning at 150 feet above the surface of the earth and visible for at least one mile.

(Sec. 6(c), Department of Transportation Act (49 U.S.C. 1655(c)))

[Doc. No. 1580, 28 FR 6722, June 29, 1963, as amended by Amdt. 101–4, 39 FR 22252, June 21, 1974]

§ 101.19 Rapid deflation device.

No person may operate a moored balloon unless it has a device that will automatically and rapidly deflate the balloon if it escapes from its moorings. If the device does not function properly, the operator shall immediately notify the nearest ATC facility of the location and time of the escape and the estimated flight path of the balloon.

A description of the required markings and lightings are provided below.

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CHAPTER 11. MARKING AND LIGHTING MOORED BALLOONS AND KITES

110. PURPOSE

The purpose of marking and lighting moored balloons, kites, and their cables or mooring lines is to indicate the presence and general definition of these objects to pilots when converging from any normal angle of approach.

111. STANDARDS

These marking and lighting standards pertain to all moored balloons and kites that require marking and lighting under 14 CFR, part 101.

112. MARKING

Flag markers should be used on mooring lines to warn pilots of their presence during daylight hours.

a*. **Display.*** Markers should be displayed at no more than 50-foot (15m) intervals and should be visible for at least 1 statute mile.

b*. **Shape.*** Markers should be rectangular in shape and not less than 2 feet (0.6m) on a side. Stiffeners should be used in the borders so as to expose a large area, prevent drooping in calm wind, or wrapping around the cable.

c*. **Color Patterns**.* One of the following color patterns should be used:

1. ***Solid Color***. Aviation orange.

2*. Orange and White.* Two triangular sections, one of aviation orange and the other white, combined to form a rectangle.

113. PURPOSE

Flashing obstruction lights should be used on moored balloons or kites and their mooring lines to warn pilots of their presence during the hours between sunset and sunrise and during periods of reduced visibility. These lights may be operated 24 hours a day.

a*. **Systems**.* Flashing red (L-864) or white beacons (L-865) may be used to light moored balloons or kites. High intensity lights (L-856) are not recommended.

b*. **Display**.* Flashing lights should be displayed on the top, nose section, tail section, and on the tether cable approximately 15 feet (4.6m) below the craft so as to define the extremes of size and shape. Additional lights should be equally spaced along the cable's overall length for each 350 feet (107m) or fraction thereof.

c*. **Exceptions.*** When the requirements of this paragraph cannot be met, floodlighting may be used.

114. OPERATIONAL CHARACTERISTICS

The light intensity is controlled by a device that changes the intensity when the ambient light changes. The system should automatically turn the lights on and change intensities as ambient light condition change. The reverse order should apply in changing from nighttime to daytime operation. The lights should flash simultaneously.

FAA Policy/Request. For operations the FAA has requested that a waiver/application form 7711-1 be submitted to FAA Western Service Center, Operations Support Group, AJV-W2, 1601 Lind Ave. SW, Renton, WA 98057. They want the form to help determine who should be contacted. It is valuable in determining if there are airstrips that may be in the operating area.

For operations in Prince William Sound it was requested that the operator:

1. Between 6 and 24 hours prior to launch: Contact the Juneau Flight Service Station at 907-586-7385 and ask to issue a Notice to Airmen
2. Between 6 and 24 hours prior to launch: Contact the Anchorage Air Route Traffic Control Center at 907-269-1108
3. When the balloon has been retrieved and the operation completed to contact both centers and let them know of the termination in operations.

When notifying the facilities be prepared to provide the information listed under section 101.15.

Assembly

The balloon comes preassembled. It may be necessary to ensure the sail is firmly attached to the keel control line. The sail should be able to fill, but not ride up the control line. The only other assembly typically required is the addition of tag lines to allow personnel to control the balloon when it is at ground level. The tag lines should extend down so they will reach the ground at about the same point as the three control lines on the balloon (Figure 3). After preliminary field testing, small line grips were added (Figure 4) along the control lines for suspending the camera. This addition made it much easier to adjust and level the camera. The line grip should be installed so it tightens when pulled downward.

The camera requires the installation of its lithium battery, connection of communication, video, gps cables, and mounting on a support to connect to the balloon (Figure 5). The lithium battery is rechargeable and fits in a compartment to the side of the camera. Different types of antennas can be used in the video (2400 MHz) and communications (900 MHz) to increase range. Thus far, only omni-directional antennas have been used on the camera, although PWSSC owns directional antennas. The camera attaches to a mounting system by four bolts on the top of the camera.

The deck unit (Figure 6) requires installation of two antennas for video and one for communications. PWSSC testing used both omni-directional and external antennas. The external antennas provide a better signal when operating within a vessel. The deck unit requires 120 volt ac power. During testing in PWS a 600 watt inverter connected to the vessel's D.C. buss powered the video system. A video out cable connects to a video capture card on a laptop computer. A serial output cable connects to the laptop for communications with the control software.

A laptop computer is connected to the deck box with the video and communications cables. A game controller is also connected for controlling the camera functions (Figure 6).

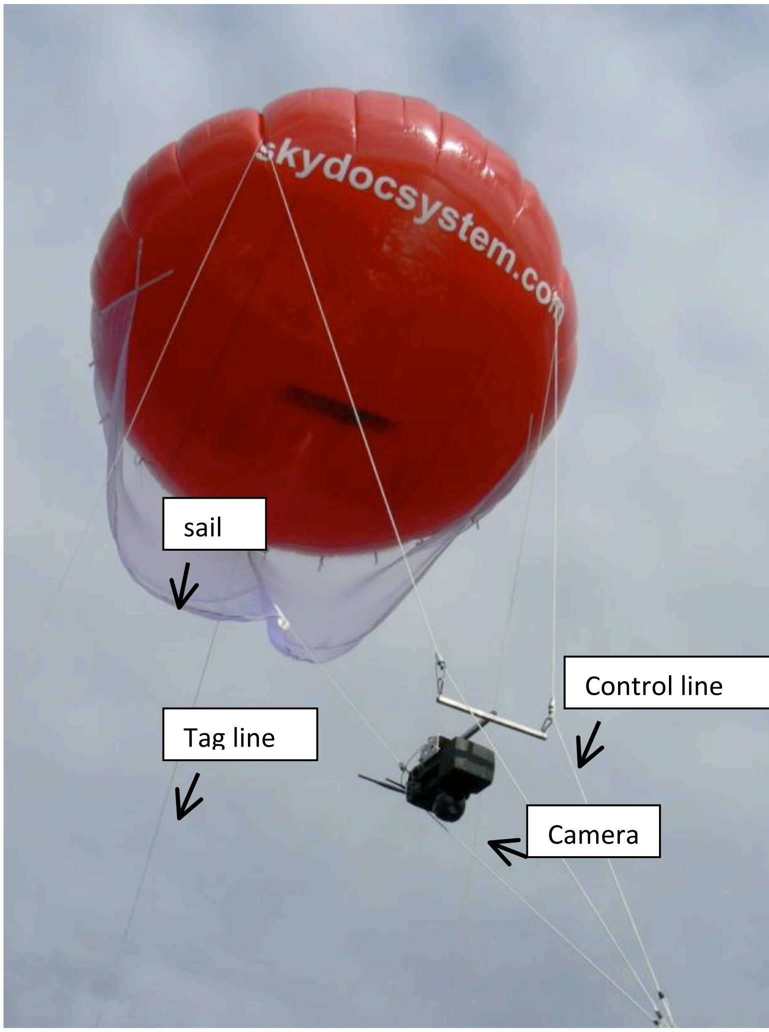

Figure 3.

The balloon system assembled and deployed. The three white lines that connect to the camera and merge together to connect to the tether are control lines. Three lines that are loose are tag lines to control the balloon when it is near the ground.

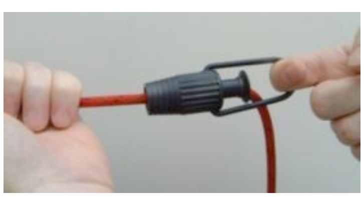

Figure 4. Buckmaster Line grip system.

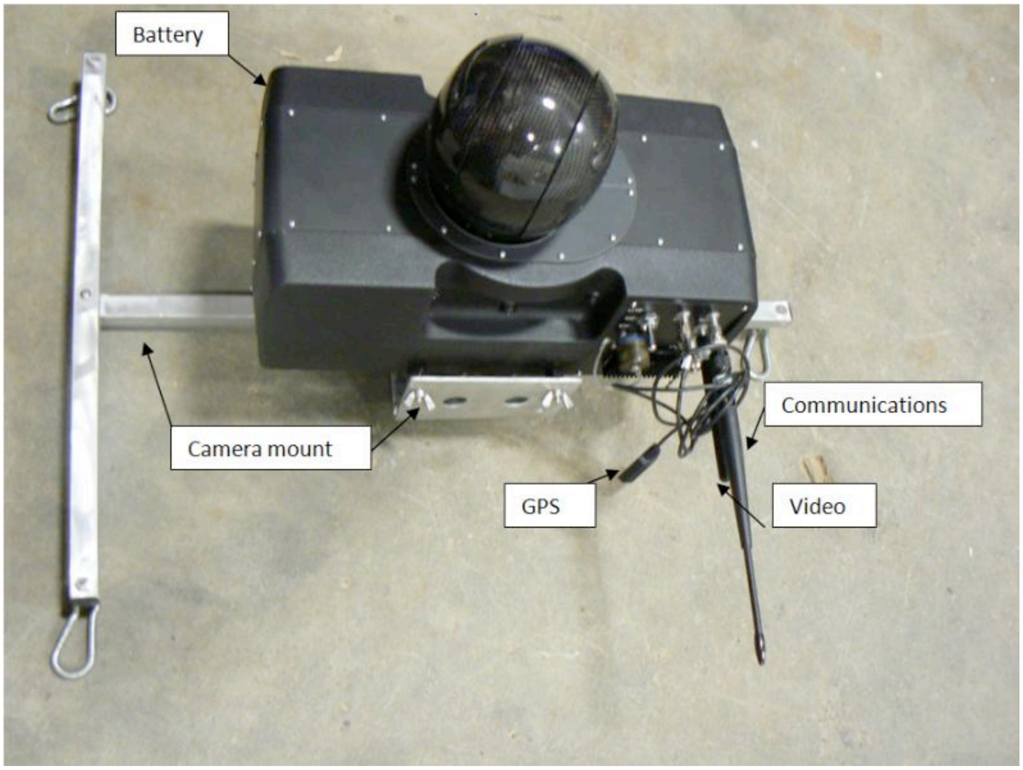

Figure 5. The camera system assembled for deployment.

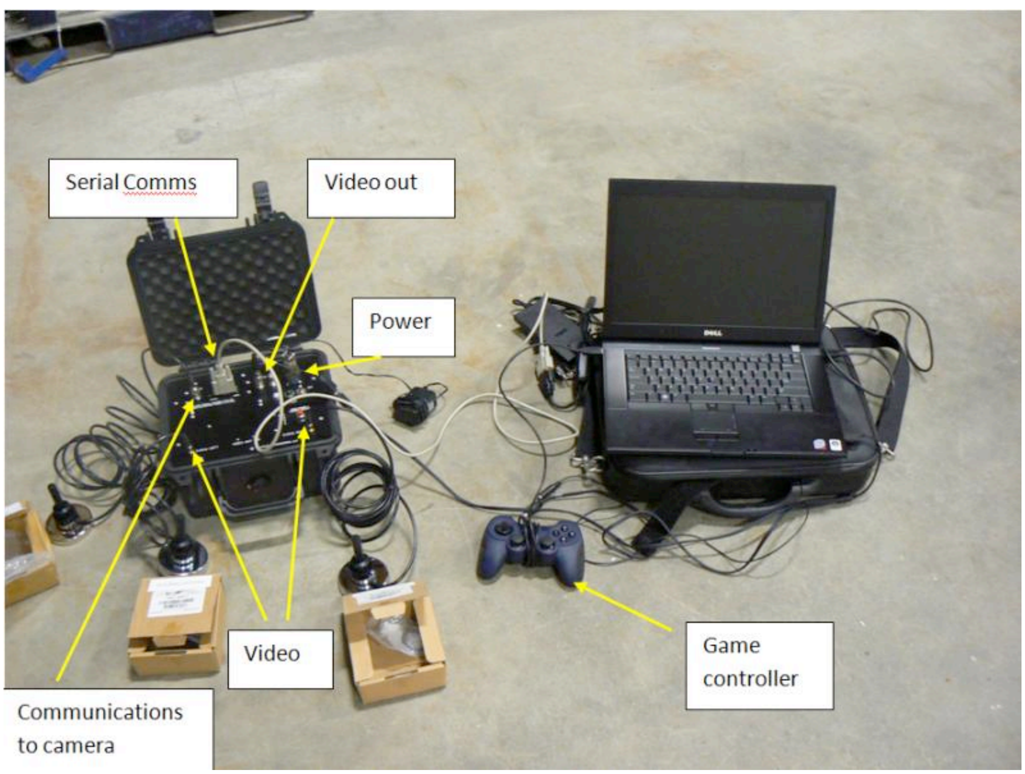

Figure 6. The deck unit is on the left and laptop on right showing antennas and other cables.

The system tested does not have a dedicated winch. A capstan or winch of some variety is necessary for deployment. If a vessel's winch (e.g. net reel) is used then the tether will need to be wound onto the winch. If a balloon docking station is used it will require assembly as well.

Deployment

Make sure to notify the F.A.A. approximately 24 hours in advance before beginning balloon operations. The exception for notification is if the deployment meets the obstructed (shielded) deployment criteria or the balloon remains below 150 feet as listed in the regulations.

Filling the balloon requires four people. Deployment and retrieval of the camera requires at least two people. Ideally, five people would be used to fill the balloon and three for deployment/retrieval. Wind complicates things, so it is ideal to fill, deploy, and retrieve the balloon in calm conditions. That being said, it's not always practical or possible to do this, and the equipment is designed to handle such conditions anyways. Extra personal may be required under challenging conditions. **When filling under windy conditions ensure the sail cannot catch the wind by having the side with the sail pointing into the wind.**

Begin by filling the balloon. It is recommended that a tarp be laid down below where the balloon is inflated to help protect it from rocks and other sharp objects. Close any release plugs on the balloon. Connect a hose (hand tight) to a helium tank and ensure the hose can reach the fill nozzle of the balloon. Note that there are several sizes of helium bottles; make sure to check to ensure you have enough helium to fully inflate the balloon based on the number of cubic feet of volume for the model of balloon. It is best to ensure the balloon is connected to the tether, and the tether is attached to the vessel before beginning to fill.

To fill the balloon one person should insert the hose into the fill connection of the balloon (Figure 7) while a second person slowly opens the valve on the helium tank. At least two other people should be available to help control the balloon as it fills. Care should be taken to reduce directly blowing helium onto the balloon material. Fill the balloon slowly until a bubble forms that the helium can flow into. The person at the helium tank can slowly increase the flow speed as the balloon fills. The connector at the helium tank will become very cold as the bottle empties. This may cause the connector to freeze onto the tank so a wrench may be necessary to disconnect the hose. Several helium tanks are going to be needed to fill the balloon so care should be taken to reduce helium loss while changing the hose between tanks. Fill the balloon until it is taunt. Newer balloons may have a strap that becomes tight when the balloon is full. When the balloon is full remove the fill hose and twist the fill connector to prevent helium loss. The twisted fill connector can be held shut with a rubber band, hair scrunchy, or a large binder clip (Figure 8).

Figure 7. Beginning to fill the balloon. The yellow hose connects the fill nozzle (in hand) with the helium tanks on the truck.

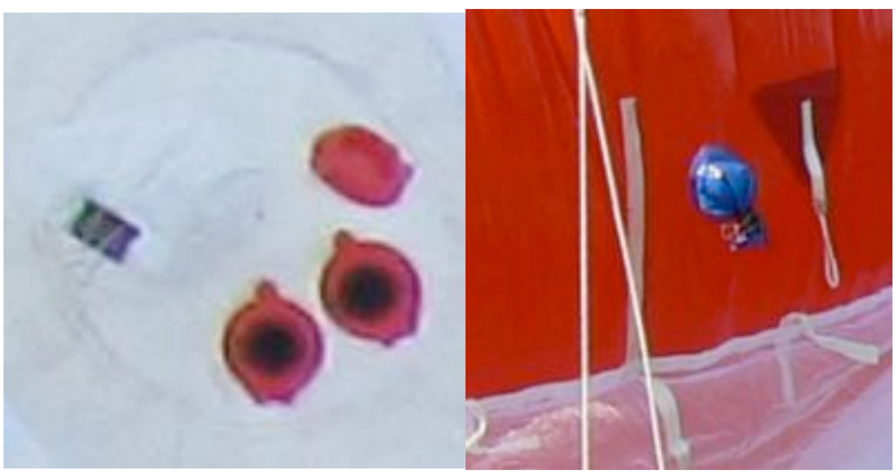

Figure 8. Binder clip used to close the fill hose.

With the balloon filled the handlers on the tag lines can move it to the vessel or let it up until the tether tightens (Figure 9). When handling the balloon it is important to ensure the side with the sail points toward the wind. Care must be taken to not fill the sail with air, thus making the balloon into a large kite while it is being held. Once control is transferred to the tether it can be pulled down to a mounting platform on the vessel, or if operating in a fairly open area it can be left 20 to 30 feet above the vessel during transport. Care must be taken to ensure the balloon and lines do not foul in any rigging on the vessel.

Figure 9. Balloon handlers let the balloon up while the tether to the vessel (below the dock) tightens the tether to the control lines.

Note that when the balloon is below 100 feet it may be influenced by ground turbulence, which will cause the balloon to move erratically. This hasn't been an issue in marine deployments once the balloon is above any turbulence caused by the vessel's superstructure.

For the first deployment it is likely that the control lines will need to be adjusted for the balloon to fly properly. There are three control lines (keel, port, and starboard). The keel line attaches to the back of the balloon and should be attached to the sail on the balloon. With no wind the front of the balloon should point down about six degrees. To determine the proper lengths of the port and starboard control lines the balloon should be put up about 100 feet and towed at about six to eight knots. If the balloon veers to one side it will need to be retrieved and the control line on that side lengthened (or the other side shortened) about an inch and then repeat the towing test. Remember that changing the length of the port and starboard control lines can influence the pitch of the balloon so it may be necessary to recheck the keel line once the forward control lines are adjusted.

The deck unit, computer, and camera should be set up as described earlier. Care should be taken to ensure the antennas have a good view of the expected balloon position. It may be best to put the two video antennas attached to the deck box pointing at right angles to each other to maximize the potential video reception. With everything assembled the software should be started and the camera turned on to ensure proper operation before attaching the camera to the balloon. It is necessary to push the red button on the deck unit to select the proper video channel before the picture can be viewed. Once the camera is verified to be operating properly it should be attached to the three control lines of the balloon and the balloon sent aloft.

During retrieval the balloon should be reeled in as close as possible. Under windy conditions the front end of the balloon will need to be pulled down or the balloon turned around to remove the kite effect. At this point it still is a very large object subject to being blown by the wind and care is needed to try and keep the balloon flat so it does not flip over or catch the wind.

When deflating the balloon the fill nozzle should be opened and pointed upward to allow the helium to escape. Good ventilation in the deflation area is required. A vacuum can be used to help pull residual helium out after the bulk of the pressure has been relieved. Care must be taken not to damage the balloon if using a vacuum.

Maintenance

The primary maintenance tasks are charging the battery and keeping the balloon filled with helium. The camera battery must be removed from the camera by removing the six screws on the battery cover and removing the battery. Caution must be taken as this is a lithium battery that requires careful charging. The PWSSC system has an Ultralife battery charging station that is connected to the battery and then plugged unto an ac power socket (Figure 10). The lights on the charger will blink while the battery is charging and stay on once charging is complete (several hours). There are two battery charge indicators on the battery as well. With multiple batteries it is possible to replace batteries and redeploy the camera system within an approximate half-hour of out of service time. The time required to completely recharge a battery is several hours.

Figure 10. The battery connected to the battery charger.

The balloon specifications are for approximately one percent loss of helium per day. Tests in Cordova using a balloon filled with air verified this loss rate. With a balloon operating in this condition it should only be necessary to retrieve the balloon to add helium approximately once a week.

Leaks in the balloon will lead to higher helium loss rates and necessitate patching the balloon. A Tear-aid patch Type-B is recommended for patching (www.tear-aid.com). This is a clear tape for patching vinyl products. The balloon can be patched using Duct tape if necessary.

To find a leak the balloon should be filled with air using a high volume air pump. Once the balloon is taunt the hole may be found using a soapy water solution and look for bubbles forming or by feeling along the balloon for the air leak. Once a hole is located the area should be cleaned using an alcohol pad, dried, and then an appropriate size patch applied.

Before any deployment all lines should be inspected to ensure they are in good working order. The balloon can pull with a lot of force so frayed lines should be replaced.

Applications

This system is intended to function in a similar manner to aerial observers in planes. The strength of the approach is in being able to remain aloft with the vessel for much longer periods of time than is possible with aircraft. It provides a means to reduce risk to personnel by reducing the need for manned aircraft, particularly in marginal flying conditions. It provides an ability to detect oil within a couple miles of the system and instantly relay that information to vessels within that area. It is also relatively simple to deploy from vehicles like trucks as well as boats.

The balloon is merely a deployment platform and the application it is used for will depend on the sensor payload. The payload of the system is dependent on the ability of the balloon to carry it and supply the required power. This allows sensors other than visible optics to be deployed. As described the system tested has visible optics and thermal infrared capabilities. The IR system provides the same information as Forward Looking Infrared (FLIR) cameras on aircraft and helicopters. There is the possibility to carry radar systems, but not systems that require the sensor to be moving with some speed like the synthetic aperture radar (SAR). There is the possibility to carry other types of sensors like spectral radiometers or a laser fluorometer, and gas/vapor detectors; however these may require development work to build the appropriate sensors.

Besides oil detection it may provide a valuable tool for resource management. It would allow a task force leader to observe the vessels in the task force and see if they are in the correct location and correctly implementing the tactics they were assigned. From a fixed point deployment (e.g. over a spill on land) they can also help in keeping track of personnel and the boundaries of the spill. In a towed mode it could be used to map a shoreline. It could also be used for wildlife observations.

The balloon could also be used to develop a communication relay system by carrying repeating equipment. In new development it needs to be remembered that the balloon may not need to carry all the equipment. For communication it may only need to carry the antenna and have it connected to other electronics on the ground through an electrical tether.

Testing

To date the PWSSC system has been deployed on five occasions. These deployments have focused on learning the basic operation of the system and testing specific characteristics of it. No formal training in the assembly and operation of the balloon or camera system was provided before deployment during the tests. Only in the last set of tests was a representative of the surveillance system manufacturer available to provide additional training on system operation. In spite of the lack of formal training it has been possible to assemble and operate the system based on limited notes (basis for earlier sections of this document) within a couple hours.

The first deployment was in 2009 at industry appreciation day in Nikiski, Alaska. During transport on the truck back from the event the single ply balloon popped. It is suspected that the cause of the failure was the balloon snagging a sharp edge of a set screw used on the docking cradle.   The balloon was subsequently replaced with a larger balloon that included a cover as described as the PWSSC system in the previous text.

The replacement balloon was deployed off the Cook Inlet Spill Prevention and Response Inc. (CISPRI) response vessel M/V Perseverance in April of 2010.   The system was inflated on the vessel and deployed from the stern. No capstan or winch was available so it had to be deployed and retrieved by hand, which was only possible due to the light winds during the testing period. The testing occurred during a CISPRI training event where different observation technologies were being used. Brian Reith and Brian Hack were the CISPRI contacts for that testing.

Further testing occurred in October 2010 with Alaska Clean Seas (ACS) in Prudhoe Bay. Brian Green and Lee Majors were the primary contacts at ACS for these tests.   Two sets of tests occurred over a three day period. The first tests were deployment was from their response vessel Harrison Bay. The balloon was inflated next to the road and walked to the vessel where it was suspended at low altitude for transportation (Figure 11). The balloon was deployed and retrieved using a small capstan on the vessel. Power for the computer and camera controller was provided by the vessel's a.c. power system. Testing included deployment and retrieval, camera system basic capabilities (Figure 12), viewing across a band of sea ice, testing the distance objects could be seen, and searching for a seal on ice with both visible and IR camera systems. Wind conditions were light during these tests.

Figure 11. Pictured is the balloon system being deployed off the Alaska Clean Seas vessel Harrison Bay. A capstan was used to deploy and retrieve the balloon. During that test, no docking station was used, but rather the balloon was kept aloft at low altitude while underway. Photo courtesy of Alaska Clean Seas.

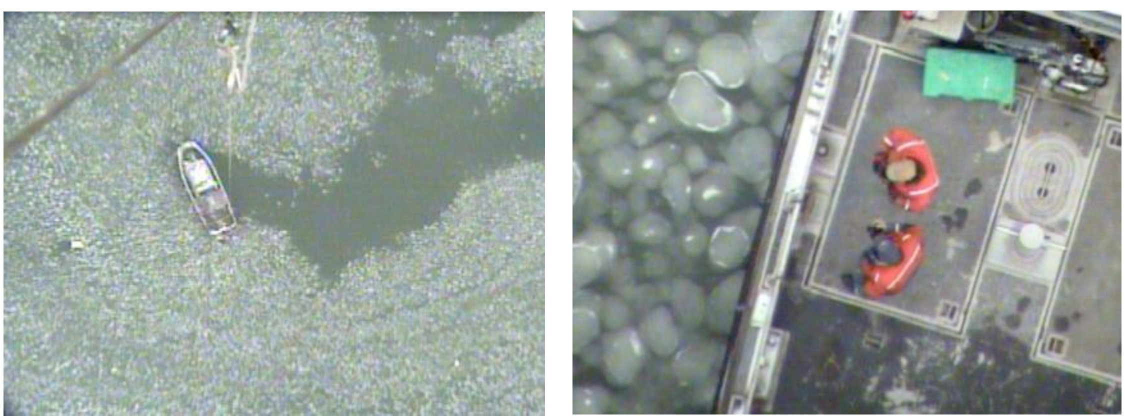

Figure 12. On left is the boat as pictured with no zoom. On right is the same scene at full zoom.

Upon completion of the vessel tests we moved the balloon to a docking station on the back of a flatbed truck for transport and land based deployments (Figure 13). On the first day we attempted to deploy the balloon using a hand activated hose reel winch in winds over 20 knots. It was obvious that at those wind speeds we would not be able to retrieve the balloon using the hand winch so the balloon wasn't deployed. The following day the hand winch was replaced with a hydraulically activated boom reel and the system was deployed in winds of 15-25 knots. The balloon was only deployed to approximately 200 feet due to leakage issues with the balloon (described in later in this document). Testing focused on land deployment and retrieval and the capabilities of the IR camera system. In particular, warm water was poured on the ground so that it could travel under the snow and the camera was used to detect the spread of the water (Figure 14). We also observed the movement of a pickup truck (Figure 15) at distance.

Figure 13. The balloon system was also tested by deploying it from a vehicle. Pictured are the balloon, camera being mounted, a docking station, and boom reel used as a winch. Photo courtesy of Alaska Clean Seas.

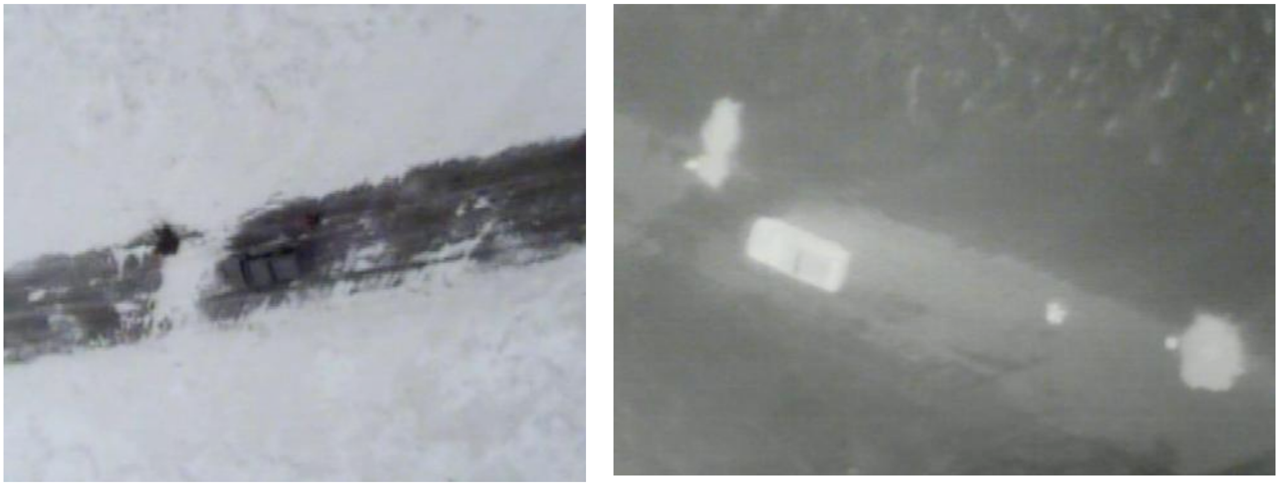

Figure 14. On left is a visible picture of a warm water spill, truck (second warm spill at the far right of picture), and person. On right is the same scene in IR. Cones at the location of the warm water can also be seen. The warm water goes under the snow yet remains visible because it can warm the snow up to freezing and the surrounding snow remains at air temperature.

Figure 15. A pickup truck is pictured in the red square at a distance of 1.5 miles. The Deadhorse airport is in the background at approximately six miles. The truck is more visible in the video than on stills. It is also possible to shift between the white-hot and black-hot displays to find small objects in the IR.

The fourth set of tests were conducted in April of 2011 in Prince William Sound. These tests were conducted as a collaboration between PWSRCAC (Jeremy Robida), BP Exploration Alaska (Regina Ward) and PWSSC/OSRI (Scott Pegau). During a two day period a system consisting of the PWSSC camera and a BP owned balloon was deployed of the PWSSC 40 foot research vessel New Wave. The primary purposes of the tests were to familiarize more people with the system, test new software, and test the capabilities of the camera system. The BP balloon is smaller than the PWSSC balloon and requires only half the helium to inflate. It does not have the cover that the PWSSC balloon uses. The balloon was tethered to a hydraulically operated net real on the stern of the vessel. During transportation the balloon was tied to a framework over the winch (Figure 16). With the balloon well secured we were able to reach speeds of 20 knots during transit. The balloon was deployed up to 500 feet in calm wind conditions. During the day the wind would pick up to approximately 10 knots, which was enough to affect the orientation of the balloon so that it acted more as a kite. Sky conditions were clear to lightly overcast during the tests. One interesting result from the testing was the difference between a boat view and aerial view of a patch of focus "popweed" floating near the boat (Figure 17).

Figure 16. The BP balloon is pictured tied down to a mooring frame for transit.

Figure 17. Pictured is a patch of drifting fucus “popweed seaweed” as observed from the flying bridge of a boat (left) and from the balloon system (right).

The final deployment was as a demonstration at Valdez. In the harbor the balloon was deployed to the height of surrounding light posts (~100 feet).   The boat was open to interested personnel to come and operate the camera system to acquaint them with the potential of the technology. In order to run a large screen display to make the picture easier to see we needed to run the shipboard generator. We were able to use the warmer exhaust water to provide an infrared signal that could be seen flowing through the harbor past a nearby boat (Figure 18).

Later the receiver electronics were shifted to a second vessel with the balloon remaining on the R/V New Wave. Both boats transited to be outside of five miles from the airport and the balloon deployed to 500 feet. The purpose of the deployment was to demonstrate the technology to a wider array of people and test the separation distance that the camera could be controlled. However, water had entered the electronics box (described later) and upon power up the radio transmitter for the balloon control failed. It was possible to get a camera picture, but not control the position of the camera.

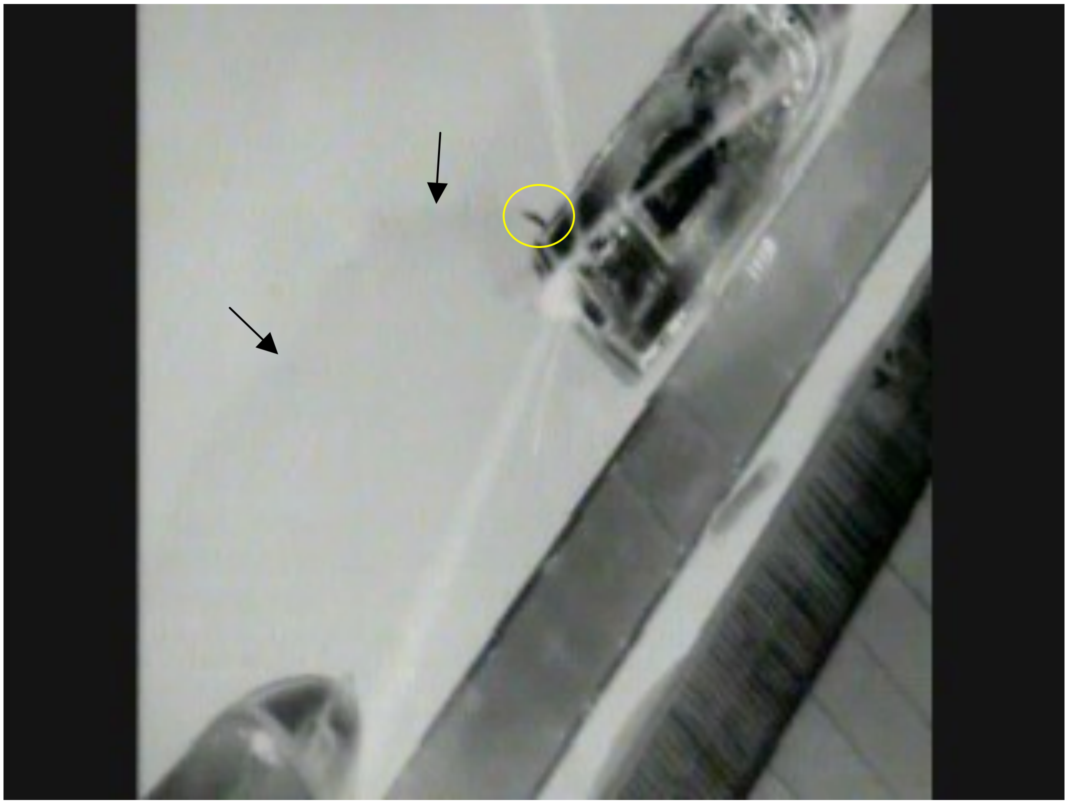

Figure 18. The cooling system plume from the generator is circled in yellow. It is ten degrees above the ambient temperature. The arrows point to the warmer water as it travels back. The temperature gradient is less than one degree between the two water masses. Under IR, PWSSC was able to watch this warmed exhaust water drift into the harbor and eventually, ten feet from the boat, cool back down and become indistinguishable from the surrounding water.

To date most of the testing has focused on learning basic operations of the system. During these tests it has been shown that the system has the ability to detect objects as small as 3' by 3' from 2 miles away using the visible camera. The IR camera was able to detect a 30' vessel from two miles away. It was able to resolve a 1 degree change in water temperature associated with an exhaust plume on a vessel 100 feet below the camera. With the IR system it was possible to detect warm water under a layer of snow as well.

Lessons learned

While PWSSC's operating hours with the system remain low some issues and desired improvements have been noted. The first is the attachment of the camera to the balloon system. Originally pieces of line were used to tie the camera mount into the control lines. That system was replaced with the line grips that allow better control of the position of the camera. Since the balloon changes orientation with increasing wind speed, being fixed to the control lines causes the camera to tilt. When tilted it is more difficult to point the camera using the game controller as its horizon does not match the horizon on the water. It may be possible to run a series of low-friction lines between the line grips and then clip the camera mount to lines and allow the system to gravity level as the balloon changes orientation. It may be best to move the line grips higher on the control lines to give the camera more room to level itself.

It is concerning to mount the camera directly to the flight control lines of the balloon. With the two-ply system there are mounting rings at the base of the balloon. A camera mounting system that is able to utilize these rings may be a better approach than attaching the camera to the control lines.

The two-ply balloon has an outer shell of material that has an opening in the top to allow the inner balloon to be removed from the outer shell. When driving down dirt roads this hole provides an entrance for small rocks to be caught between the shell and balloon. As the rock travels down the balloon it can create a large number of small punctures that need to be repaired. Over 50 small punctures were found in the balloon after testing in Prudhoe Bay where the balloon was transported on a truck several times. It is important to ensure the balloon is fully covered when transporting it. Single-ply balloons must be fully covered to protect from rocks.

The balloon can be tied to a docking structure that allows it to be transported while inflated on a truck or vessel. The balloon will be affected by the wind generated in transport, which can apply stress to the system. It will also tend to rub on the support system. It is critical that the support system be checked for any rough points and they are covered otherwise the balloon may suffer catastrophic failure (pop) when being transported. This is also a value in using a two-ply system that has a layer of protection for the balloon.

If the sail on the balloon is able to slide up the keel line it will cause the system to lose its ability to orient into the wind. Essentially it becomes a kite without a tail, which will cause it to spin out of control.

The 900 MHz communication channel is also commonly used by WiFi systems and cordless telephones, which may lead to interference, particularly in an urban environment. The 2400 MHz video channel reception is likely to be degraded by high humidity or rainfall.

During field testing in Valdez, water ran down the cables from the external antennas into the deck box installed on the vessel. The water passed through the faceplate of the deck box and accumulated inside. When the wet components were powered up it caused a failure in the deck box. There are several ways that prevent water from flowing down a cable and some effort to keep water from the deck box is necessary. The deck box also needs appropriate gaskets to prevent water from passing through the faceplate. It is better that water accumulates on the outside of the box to indicate the presence of a problem.

The software calculates the image position based on the orientation and altitude of the camera plus the pan and tilt information. The system tested uses GPS for determining the compass direction and altitude. For the compass to work properly the vessel must be moving greater than three knots. The altitude from GPS is not very good, which affects the position estimate. Field testing revealed that the system was able to make reasonable guesses to the image position, but improvements are possible by upgrading hardware and installing a compass and altimeter.

Future work

As stated earlier the testing to date has been limited and several tests and improvements are likely to be needed before the system can be fully integrated into spill response functions. The primary work necessary is to identify the performance specifications for particular applications. With well-defined performance specifications it will be possible to identify the available technology and transfer this style of observation platform into use.

Of the system itself the most important new development is likely to be arranging a system to allow the camera to maintain its orientation while the balloon shifts from nearly level to pointing up as wind speed changes. While the camera still operates when tilted it is difficult to intuitively control the direction that it is pointing. Other simple modifications include adding an electrical tether for operating the payload, and testing smaller winches on vehicles.

The weather resistance of the camera system has not yet been tested. There are obvious places where water may be able to enter the camera at the top of the gimbal system. The battery cover needs to have a gasket added to improve weather resistance. It would probably be best to get an empty camera housing and see how much water is likely to infiltrate the camera system under different rain conditions. It is also possible to test the system with the cameras installed, but power must be disconnected until the camera is fully dried out. The F.A.A permit requires three miles visibility so the system should not be used in extremely heavy rains, but it would be nice to know the limitations. Another weather limitation of importance is the ability to perform at low temperatures. The system should be tested for operation at subfreezing temperatures.

All tests to date have been performed during daylight hours. The visible camera capabilities during low-light periods of time and the performance of the IR camera at night are still areas of interest.

The ability for additional vessels to receive the video signal has been identified as a need and remains to be tested. In particular it is important to determine how far away a vessel can be and still receive the video signal. Providing the basic video signal should have an easy and inexpensive solution. The ability to provide the other data being collected by the balloon may be more difficult.

The ability to transmit information back to the command center is desired. The easiest approach appears to be to in developing software that sends files built by the camera system through the internet. Currently, the camera system saves the data in one-second segments that are about 1.5 MB in size (~130 GB/day). Based on internet connectivity and speed, the software could choose to send a frame every five or ten seconds for example. Given internet connectivity limitations, it is not realistic (or perhaps necessary) to send all of the data and frames collected. Perhaps the software could be used to select the appropriate transfer capabilities and adjust accordingly based on connectivity. Development of this software would need to funded and subsequently tested.

It should be noted that many of the tests described above do not require the full assembly of the balloon and camera system, but can be achieved by simpler testing in a lab or on a building. Testing on the ground can be achieved inexpensively as it does not require the logistical support for balloon deployment.

The existing tests have focused on particular aspects of the system capabilities. It remains to test the system in specific applications where it may be used. This could include testing within a spill response task force, a fixed point deployment for monitoring for changes, or a towed mapping mode. It may be easiest to deploy the system with a task force as part of the annual fishing vessel hazwopper training.

The balloon is just a deployment platform and it may be desirable to develop other packages to be deployed. This might include other sensor suites, such as a laser fluorosensor or microwave radiometer, or other types of packages, such as communication relay stations.

System selection considerations

In selecting a system it is important to match the system to the intended application. The system described here was purchased trying to meet a specific set of operational criteria that was the first guess at what would be best. There are a wide range of systems available with better and worse performance than the one tested. It will be up to the user to determine their minimum specifications, but some considerations based on the tests to date are outlined here.

There are some considerations that apply to any application or payload. One is that the system should be easy to use and maintain. Some level of training is necessary to fully utilize the system, but it is important to remember that the system is likely to be used in a remote location by people with limited experience. Basic in-field troubleshooting should be possible (i.e. patch a leak in the balloon, reboot the system, troubleshoot the loss of signal).

The system should be durable enough to take shipping into remote locations and durable enough to operate in a wide range of weather conditions. Given the types of environments in Alaska the system should be capable of operating in the harshest conditions it is likely to encounter. The system should be able to handle wind, rain, snow, and sub-freezing conditions. Wind gusts of at least 60 knots and continuous wind speeds of 30 knots should be considered minimum conditions for deployment and operation. The tether must be able to handle conditions in excess of these. The deployment and retrieval system should also be adequate for operating under high-wind conditions.

Under some applications the system may need to be deployed without servicing for several days. It will be important that the helium loss rate and the electrical usage be such that allows these longer deployments. In these instances an electrical tether is likely to be required.

The balloon is a lifting platform and needs to checked to ensure it can lift the desired payload. The balloon must meet all of the regulatory requirements, such as emergency helium release and marking. There are different styles, sizes, thicknesses of balloon material, and covers that can be purchased that will affect the amount of lift. To ensure enough lift in low wind conditions it is recommended that 10 pounds be added to the weight of all the payload components, all required marking and lighting systems, and 500 feet of tether cable. The ten pounds of excess lift will help stabilize the balloon when near the ground and provide a margin for small additions to the payload (such as the line grips). A balloon with a cover is preferred to protect it from rocks and sharp points on the vessel. Adding the cover will increase the amount of helium needed.

Camera selection will depend on the application. From 500 feet it is possible to see over 20 miles away, but it is not likely that the system will be useful to that range. From 500 feet it is more likely to be possible to see oil on the surface out to two to five miles because of the large angle to the object. The exact distance will depend on the height of the balloon, the camera focal length, the optical zoom of the camera, and the number of pixels (resolution) of the camera. Increasing the resolution of the camera system will increase the cost and at some point may overwhelm the ability to transmit the signal back to the vessel. At high zoom levels it is difficult to maintain the camera pointed at the object even with stabilization systems.

The system tested included a Sony FCB-EX980 visible camera with a half field of view (HFOV) of 52° to 2.5°. The system has one of the wider angle lenses available and changing the focal length would increase the resolution at distance, but reduce the ability to see a large area during search operations. The 20 x zoom capability seemed more than adequate with this lens to resolve small objects within a couple miles. With this system it was possible to see an object 3 foot by 3 foot from two miles away. It can be difficult to maintain an object in the field of view when at full magnification. Also, despite the onboard image stabilization of the camera, images can get jumpy under high magnification because of the motion of the balloon.

The long-wave infrared system tested is a FLIR Photon 320 with a 25 mm lens providing a 20° HFOV. It has a 2x zoom capability. In the demonstrations the spill responders requested higher zoom capabilities with the IR camera. Cameras with twice the resolution are available and can provide better electronic zoom. With the camera system PWSSC tested, it was possible to detect a 30 foot fishing vessel from more than two miles away. This seems to be the minimum resolution necessary.

With IR systems it is also important to consider the thermal range and resolution. The system must be able to detect all temperatures within the normal operating range. At the same time it is important to be able to resolve small temperature differences. It is desirable to identify less than one degree temperature differences in order to identify oil on the surface. With 0.1° C resolution it is possible to see oil even when there isn't a temperature difference because of the difference in emissivity of oil and water. The influence of the difference in emissivity is dependent on the thickness of the oil so thicker layers (>200 μm) are more evident than thin sheens in the infrared.

When testing the system there seems to be a desire to see how small an object can be seen and forget what size of object needs to be seen during operations. During field trials, testers were eager to zoom in close on objects to test the cameras' abilities. PWSSC's speculation is that under normal response situations though, one would likely run the cameras at wider angles.

Because of the motion of the balloon it is very important to have image stabilization. At high zoom levels it would be impossible to remain focused on an object without stabilization and interpreting images at low zoom may be difficult if the image moves significantly.

The camera should have full pan and tilt control to ensure it can see the entire water surface within five miles.

Information management is an important consideration when specifying a system. At a minimum the camera signal, associated gps data, and camera positions must be recorded and able to be played back together. A user interface that allows the operator to see where the camera is and where it is pointed at is highly desirable. It is best to be able to see the information on a navigational chart or other map interface.

It is more important to provide a geographic location with the image than first considered when specifying the system used by PWSSC. The image position is calculated based on the altitude, compass position, pan and tilt of the camera system. The system tested uses the gps on the camera for altitude and compass orientation. The camera needs to be moving to provide a gps compass reading and the gps calculation of altitude has limited accuracy. These issues limit the accuracy of the position calculation, which is more apparent the further an object is away. The image position estimate can be improved with the addition of a compass and laser altimeter.

It is desirable to have more than one vessel receive the video signal with a 2400 MHz receiver and video display. For communications to multiple vessels within a task force the balloon should be able to transmit wirelessly at least two miles. To receive all the telemetry information may require an additional full ground system. Additional ground systems would have to be configured to work with the master controller. They then would have the ability to operate the camera. Until it is better understood how the system will be utilized it is not recommended to have multiple control units, but providing the ability to view at least the video feed is desirable. The ability to view the video signal should have a low-cost solution. Being able to combine and view both the camera data and video signal is desirable but likely to be significantly more expensive.

It is desirable to relay information back to the Incident Command, which may require some additional software development. It is unlikely to be able to send the full video signal through existing internet connections so some compression or subsampling may be needed. The large quantity of data generated by the system makes it difficult to transmit more than a portion of the data back to shore.

Of the ground support gear there are two critical components. The first is the computer, particularly the hard drive. The video can generate hundreds of gigabytes of data a day, which requires external hard drives be available for deployments greater than a day if the data is being recorded. The computer must have the available slots for all the connections to the deck unit. The second component is the winch. During different tests we have used ship capstans, boom reel, and net reel. Having a winch, such as a net reel makes deployment and retrieval much simpler than using a capstan. Some type of retrieval system capable of retrieving the balloon under high wind conditions is absolutely required. With winds much greater than 15 knots it may not be possible to retrieve the balloon by hand. If an electrical connection is made through the tether either a dedicated winch with slip rings or an electrical disconnect near the reel is needed. While having a dedicated winch is nice, it may be better to maintain flexibility and reduce shipping requirements by going with an electrical disconnect between the deck unit and the tether cable.

Cost and weight must be considered as factors in selection. A heavier a payload requires a larger balloon and that dictates the amount of helium needed. The helium is often the largest single piece for shipping and can be difficult to obtain in large quantities in many locations. Reducing the weight of the payload, increasing the camera capabilities, improving weather resistance are all possible, but at some point the increasing cost will outweigh the gain in capability.

Best Available Technology selection criteria

The balloon provides a platform that could be used for deploying a wide array of oil detection sensors. The evaluation on best available technology provided here is based on a visible and thermal IR sensor package. This evaluation of best available technology is required under Alaska state statute AK 75.255(k).

1.1. Availability: This system uses off-the-shelf technologies available from multiple vendors. The systems can be put together using various parts or purchased as a turn-key package. Two vendors of the kite-style balloons are SkyDoc (http://www.skydocballoon.com/) and Aerial Products (http://www.aerialproducts.com/). Both vendors also supply a wide range of turn-key surveillance systems.
There are a variety of potential surveillance systems that can be considered for the payload. These range from unstabilized, fixed-view, visible-only cameras to systems with ones with gyroscopically stabilized, dual visible and cooled-IR cameras. This leads to a wide range of price options and capabilities. The mid to high end systems may have export restrictions associated with them because of the level of technology being incorporated.

1.2. Transferability: This technology is ready to be transferred into spill response applications. It has been deployed from boats ranging between 40 and 110 feet long. Additionally, the balloon system has been deployed from smaller flatbed style work trucks. So long as there are winch capabilities, the balloon system is easy to move from platform to platform as control boxes and antennas are easily packed up.

1.3. Effectiveness: This approach allows for long-term aerial observation capabilities. There is the potential for maintaining aerial observational capabilities for several days without needing to retrieve the system. The information is sent directly down to the response team and there is the potential for it to be seen by multiple vessels at the same time.

1.4. Cost: Cost of a complete system is dependent on the size and grade of the balloon, type of camera, communications approach, and ground station components. The approximate cost of a balloon and associated camera system with stabilized gimbal, visible and thermal infrared cameras, communications capabilities of a few miles, and associated control software is $85,000. The operational cost is for the balloon PWSSC tested is about $1500 for helium plus vessel costs. The helium should be able to operate the balloon for more than 10 days. Longer deployments require a small increase in helium used. Additional ground support components, such as a dedicated winch and docking station will add to the estimated cost of the system. A higher end camera system that is more weather resistant, and has greater infrared zoom capabilities will add approximately $60,000. The addition of a laser altimeter and compass will continue to bring the cost of the camera system up. A visible only camera with less stability can greatly reduce the cost of the system as well.

1.5. Age and Condition: This would be new technology.
1.6. Compatibility: This technology should not interfere with other observation techniques. The balloon should be flown below the level that aircraft are used, although coordination with aircraft is necessary.
1.7. Feasibility: The technology has been demonstrated as being feasible. It still requires determining the application and finding the correct sensor payload for that application

Best Available Technology Evaluation:

BAT Evaluation Criteria	Current Method: Aircraft visual observations	Current Method: Satellite observations	Current Method: Aircraft Electro-Magnetic sensors	Alternate method: Balloon based Visible and IR
Availability: Whether technology is best in use in situation or is available for use by applicant	Technology is available and used worldwide	Technology is available and used worldwide	Technology is available, but limited sensor suites available in the US	The technology is available for use
Transferability: Whether each technology is transferable to applicants operations.	Currently in place	Currently in place	Yes	Yes
Effectiveness: Whether there is a reasonable expectation each technology will provide increased spill prevention or other environmental benefits.	Effective as long as planes with observers are able to fly	Visible and IR systems are limited by cloud cover. All systems limited by number of observation oportunities. There can be issues with determining what is being observed	Effective as long as planes are able to fly in the area	The technology allows for greater observation times over other approaches. The information is sent directly to the response vessels decreasing the time necessary to get information to those vessels

Cost: The cost to the applicant of achieving BAT, including consideration of that cost relative to the remaining years of service of the technology in use by the applicant.	Costs are for aircraft and observers	Most sensors are national assets. Some have cost per scene collected. Processing for oil detection may add cost	The cost of initial purchase of aircraft and appropriate sensor suite would be extremely expensive. The operation and maintenance costs are expected to be high	Cost is dependent on the camera system. An approximate cost for balloon with camera is $85,000. Helium is the expendable cost at about $1,500 per deployment
Age and Condition: The age and condition of technology in use by the applicant.	Currently in place	Currently in place	Some sensors available and in good condition. A full suite of sensors would be new	The technology is new
Compatibility: Whether each technology is compatible with existing operations and technologies in use by the applicant.	Compatible with other technologies	Compatible with other technologies	Compatible with other technologies	Compatible with other technologies
Feasibility: the practical feasibility of each technology in terms of engineering and other operational aspects.	Currently in place	Currently in place	Currently in place elsewhere	Has been demonstrated as feasible
Environmental Impacts: Whether other environmental impacts of each technology, such as air, land, water pollution, and energy requirements offset any anticipated environmental benefits.	Limited to aircraft exhaust	None	Limited to aircraft exhaust	None

Safety Considerations	Potential for loss of life if aircraft fails	None	Potential for loss of life if aircraft fails	Minimal impact/overhead hazard
Potential for Property Damage (platform/Ancillary equipment damage)	Possibly total lost of platform/damage to structure/area of impact. Increased number of flights could mean a increase to the possible loss of a plateform. (i.e. mechanical failure, weather conditions)	None - very unlikely that a satellite will lose orbit	Possibly total lost of platform/damage to structure/area of impact. Increased number of flights could mean a increase to the possible loss of a plateform. (i.e. mechanical failure, weather conditions)	Possible lose of camera system & balloon/minimal damage to area of impact