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# Adapting Low-Cost Drone Technology to CubeSats for Environmental Monitoring and Management: Harmful Algal Bloom Satellite-1 (HABsat-1)

Richard Beck, Hongxing Liu, Richard Johansen, Min Xu
University of Cincinnati, Geography and GIS, Braunstein Hall, University of Cincinnati,
Cincinnati, Ohio, 45221-0131; 513-556-3426
richard.beck@uc.edu

Catharine McGhan, George Thomas Black, Ou Ma, UC CubeCats
University of Cincinnati, Aerospace Eng. and Eng. Mechanics, Rhodes Hall, 2850 Campus Way,
University of Cincinnati, Cincinnati, OH 45221-0070, 513-556-3032
cat.mcghan@uc.edu

Molly K. Reif
US Army Engineer Research and Development Center, Environmental Laboratory, Joint
Airborne Lidar Bathymetry Technical Center of Expertise, 7225 Stennis Airport Rd, Suite 100,
Kiln, MS 39556, 228-252-1134/228-252-1133
molly.k.reif@usace.army.mil

Erich B. Emery
US Army Corps of Engineers, Great Lakes and Ohio River Division, 550 Main Street, Room 10-032, Cincinnati, OH, 45202, 513-684-3041/ 513-684-3063
erich.b.emery@usace.army.mil

Richard Stumpf
National Oceanic and Atmospheric Administration, National Ocean Service, 1305 East-West
Highway code N/SCI1, Silver Spring, MD, 20910, 301-713-3028
richard.stumpf@noaa.gov

Greg Emerick, Ryan Nelson
Sentera
6636 Cedar Avenue South
Minneapolis, MN 55423, 763-381-1359
greg.emerick@sentera.com

## ABSTRACT

HABsat-1 is designed to improve our understanding of algal bloom dynamics and their causes on land by addressing several current limiting factors for this application using existing satellites. For example, there is suboptimal imager design for water, insufficient spatial resolution for precise co-registration of surface observations, and too few satellites with such capabilities to defeat cloud cover in maritime, tropical and temperate climates. We will overcome these problems by merging a new low-cost multispectral imaging technology with a low-cost CubeSat bus. CubeSats cost roughly 1/100th to 1/1000th of most current long-life imaging satellites. Such cost decreases are necessary to improve upon the temporal coverage (number of appropriate satellites) and spatial resolution of current imaging satellites, such as Landsat-8, Sentinel-2 and Sentinel-3 (MERIS/OLCI). Numerous low-cost satellites

reduce both overall mission cost and individual launch risks associated with large production satellites, such as Landsat, while providing the temporal and spatial resolution necessary for the study of highly dynamic and spatially variable algal blooms. A team of undergraduate aerospace engineers (the UC CubeCats), computer scientists and aerospace and geographic information science faculty have been funded by the Ohio Department of Higher Education and NOAA to adapt low-cost multispectral imagers designed for use on small drones to 3U CubeSats to further reduce the cost of environmental monitoring. This team will create a working on-orbit prototype for a constellation of CubeSat's for routine drinking water monitoring known as Harmful Algal Bloom Satellite 1 (HABsat-1).

## BACKGROUND

New high spatial resolution "sea surface temperature" and "ocean color" capabilities are required to detect, monitor and predict increasingly common and costly harmful algal blooms (HABs) that contaminate drinking water supplies and fish in smaller freshwater lakes, reservoirs and large rivers and in fish and shell fish in the near-coastal oceans. Our goal is to create cost-effective operational warning and prediction systems of the HAB problem to protect citizens from heart, nerve and liver poisoning, paralysis, memory loss, respiratory failure, and sometimes death. HABs have caused a US economic cost of approximately $2.2 billion per year.1,2

Toxic cyanobacteria thrive in warm slow moving water.3,4 All four of the most toxic freshwater cyanobacteria species and all three of the most toxic freshwater diatom species show enhanced growth with increasing temperature.4 The third important factor for HAB prediction is wind speed derived from meteorological stations.5

The increased presence of HABs is reaching a crisis point in the Earth's largest freshwater supplies, the Great Lakes of North America and Africa, and now threaten the drinking water systems of several large cities along their shores. In August of 2014, the City of Toledo shut down its water supply for 400,000 people due to a severe HAB event (Fig. 1).

**Figure 1: Supervised classification of visible to near-infrared (VNIR) image showing harmful (toxic) algal bloom near the City of Toledo Water Intake on Lake Erie, August 2009, before the August 2014 drinking water crisis.**

The National Oceanographic and Atmospheric Administration (NOAA) and universities conservatively estimated in 2007 that HABs cost US taxpayers $82M per year "due to impacts on public health, tourism, and the seafood industry".6,7,8 Ohio lost more than $13M in tourism revenue in just 2 years due to HABs. The U.S. Centers for Disease Control (CDC) notes that HABs potentially cost the United States "economy billions of dollars each year" with single HAB events costing up to $47M. Known health risks include skin contact with HABs, ingestion of contaminated drinking water or seafood, and inhalation of airborne droplets or mist contaminated with HAB toxins. The CDC recently (June 2017) began to track HAB exposure to assess the long-term epidemiological impacts of HABs via their new One Health Harmful Algal Bloom System (OHHABS).

Nationwide, 38 states have reported annual HABs. For coastal states such as Texas, Louisiana, Mississippi, Alabama, Georgia, Florida, and Ohio, HABs are already a major threat to drinking water, recreation and tourism, the fishing industry, livestock, wildlife, and perhaps to public health (Fig. 1). HABsat-1 is designed to decrease the cost and increase the capabilities of NASA and NOAA visible to near-infrared (VNIR) imaging satellites for water quality studies in general and to study both the causes and effects of HABs in particular. Although HABsat-1 will be optimized for use over coastal waters (ocean and Great Lakes), we expect that it will also have applicability for smaller inland reservoirs and rivers that contribute nutrients to coastal oceans and the Great Lakes.

Nutrient runoff, especially nitrogen and phosphorous from farm fields, impacts many water bodies beyond the coasts of the Great Lakes. Numerous sources of drinking water, including smaller inland reservoirs and lakes, linked by rivers to our coastal ocean environments, are also experiencing more frequent and more severe HABs. Large quantities of these excess nutrients are transported onward to coastal ocean environments such as the Mississippi Delta and Gulf Coast, which are also experiencing HABs due to nutrient fluxes from inland watersheds (Fig. 2). These coastal ocean algal blooms may also be toxic and contribute to “dead zones” due to hypoxia caused by the decay of phytoplankton blooms. The August 2017 Gulf of Mexico “dead zone” was the largest on record.

Given the strong ecological links between nutrient pollution, drinking water supplies, the fishing industry, and public health, NASA’s remote sensing capability is a major contributor to the U.S. Federal Interagency Working Group on the Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA). The design for HABsat-1 builds on several million dollars of previous U.S. Army, NASA, NOAA and USGS-sponsored remote sensing research in western Lake Erie and other Ohio water bodies.

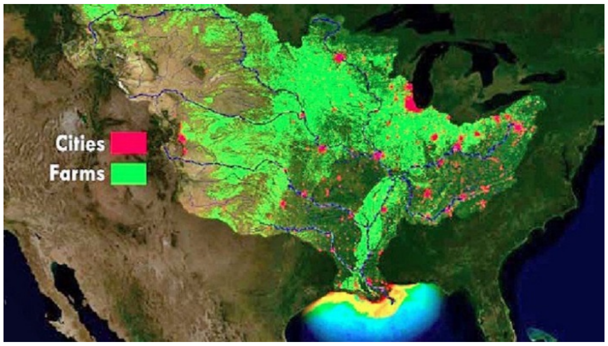

**Figure 2: Image map of nutrient sources contributing to the US Gulf Coast Dead Zone. Coastal environments receive nutrients from inland water bodies including the Great Lakes, major rivers and their watersheds.**

This research has shown that hyperspectral or custom narrowband multispectral imagers with radiometric thermal imagers are the preferred instruments for predicting, detecting, identifying potential HABs in the oceans, Great Lakes and inland water bodies, including reservoirs, natural lakes, and rivers.9-21 This research has also shown that sources of such imagery are rare and need to become less costly and more numerous (≈8-16 satellites) to defeat cloud cover issues at finer resolution.

These same research efforts show that the type of imagery (ideally VNIR, narrow bands, 30-90 m GSD) and timing of water quality parameter measurement are more important than the exact choice of algorithm used to process the imagery, although the NOAA cyanobacterial index (CI) algorithm and some variants are consistently promising in the Great Lakes, inland Midwest waters, and coastal oceans. HABsat-1builds on a current NASA Glenn Research Center (GRC) led collaboration by several NASA partners for the future of the Great Lakes, coasts and oceans including NASA, the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JABLTCX), U.S. Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC), NOAA’s Great Lakes Environmental Research Laboratory (GLERL), universities, and several small business contractors focused on refining VNIR hyperspectral and narrow band multispectral imagers for water quality monitoring. These groups are also working together to refine the algorithms necessary to translate the imagery into useful information for water quality monitoring and management (decision support) by NASA and its federal HABHRCA partner agencies.

## APPROACH

HABsat-1 will modify an off the shelf four-band multispectral imager designed for use on unmanned aerial system (UAS) platforms for agriculture and adapt it to a standardized 3U CubeSat chassis and bus to decrease the cost and increase the spatial resolution of NASA, DoD and NOAA satellites for inland and near-coastal water quality prediction and monitoring (Fig. 3). Decreasing the cost of water quality satellites is important because cloud cover issues (too few satellites) are the current limiting factor for the application of NASA’s remote sensing technology to NOAA and USACE inland water quality monitoring responsibilities for public health protection.17,18

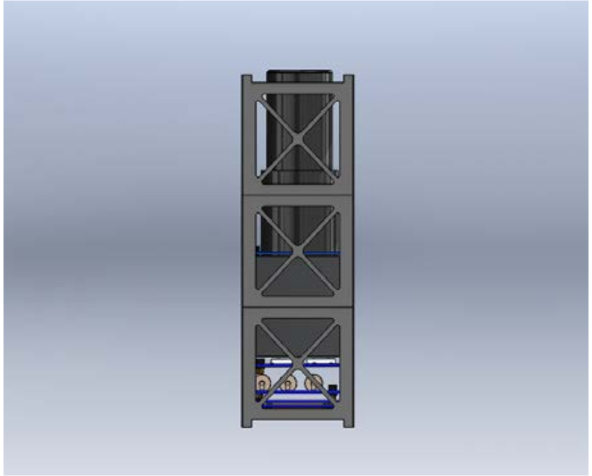

**Figure 3: HABsat-1 Preliminary Design**

HABsat-1 will mitigate several factors that limit the application of existing satellites to NASA’s Mission Focus on *Human Health and Security: Algal Blooms and Waterborne Infectious Diseases*.23,24 These limiting factors include spatial resolution for, “ocean color” and “SST” capabilities for near-coastal and inland waters and poor temporal resolution due to too few satellites (cost).17,18 HABsat-1 will also help to map the causes of HABs on land via VNIR mapping of adjacent watersheds and reduce costs and risks associated with water quality prediction and monitoring. For example, there is suboptimal imager design for inland and coastal water quality monitoring, insufficient spatial resolution for precise co-registration of surface observations, and too few satellites with such capabilities to defeat cloud cover in humid temperate, humid tropical, and maritime subpolar climates.

Such cost decreases are necessary to improve upon the temporal coverage (number of appropriate satellites) of current imaging satellites, such as Medium Resolution Imaging Spectrometer/Ocean Land and Color Instrument (MERIS/OLCI) and Sentinel-2A/B. Constellations of low-cost satellites reduce both overall cost and launch risks associated with large production satellites, such as Landsat, while providing the temporal and spatial resolution necessary for the study of highly dynamic and spatially variable algal blooms and other coastal events such as hurricanes. HABsat-1 is optimized for the prediction and monitoring of HABs and will be well suited to contribute to additional inland and littoral studies of turbidity, bathymetry, and adjacent wetlands.

A team of undergraduate aerospace engineers (the UC CubeCats), computer scientists and aerospace and geographic information science faculty have been funded by the Ohio Department of Higher Education and NOAA to adapt low-cost multispectral imagers designed for use on small drones to 3U CubeSats to further reduce the cost of environmental monitoring. This team will create a working on-orbit prototype for a constellation of CubeSat's for routine drinking water monitoring known as Harmful Algal Bloom Satellite 1 (HABsat-1).

## SCIENCE PAYLOAD REQUIREMENTS

HABsat-1 will carry a customized, low-cost narrow-band multispectral imager from Sentera, *HAB phycocyanin/chlorophyll*, optimized for the study of algal bloom dynamics. The NOAA Cyanobacterial Index (CI) algorithm will be used to process the data received from HABsat-1. The phycocyanin version of the NOAA CI algorithm requires narrow (10-20 nm) imaging bands near the 620, 665, and 681 nm wavelengths for the appropriate detection of the phycocyanin absorption feature associated with cyanobacteria. Additional information on chlorophyll content is provided by the near infrared bands at 708 nm. Finally, all algorithms benefit from robust atmospheric correction that is facilitated by a narrow imaging band near 708 nm. These wavelengths are currently employed by the European Space Agency's 300-m resolution OLCI imaging spectrometer, which is optimized for earth observation.

However, several groups have observed considerable spatial variation of algal blooms on Lake Erie and other water bodies within large pixels, making "water truthing" (coincident surface observations) difficult, hence the need for higher spatial resolution. The custom imager with associated UHF and S-band communications will be tested for both fitness for purpose and for reliability as part of the complete CubeSat on a light aircraft before launch and against water quality measurements on western Lake Erie after launch.

## SCIENCE MISSION CONSTRAINTS

The HABsat-1 scientific mission requires an operational lifespan of at least one year to be declared successful; our stretch design goal will be a two-year operational lifespan. To meet the Great Lakes observation requirements, the orbital inclination needs to be within 50º-140º for complete coverage of the Great Lakes, and the orbit needs a minimum perigee of 450 km so HABsat-1 does not deorbit in less than one year.

## OBJECTIVE

The objective of HABsat-1 is to build, to launch, to demonstrate, and to use a student-engineered multispectral imaging CubeSat for the study of harmful algal bloom dynamics in the Great Lakes and other Ohio water bodies to provide routine optimum information and new technology for the study of bloom dynamics to aid state and federal agencies with monitoring and mitigation of harmful algal blooms in drinking water sources as part of NASA's *"Remote Sensing of Water Quality"* Project, NOAA's cyanobacterial bloom predication models and the US Army Corps of Engineers national drinking water protection efforts.

## GENERAL METHOD

HABsat-1 will be a 3U imaging CubeSat in Low Earth Orbit (LEO) that will utilize an active attitude determination and control system (ADCS) system to detumble and point the spacecraft at western Lake Erie during imaging phases. The ADCS system will also be used to orient the high-gain S-band antenna towards the University of Cincinnati ground station to ensure proper downlinking of imaging data. An on-board UHF radio in the 70-cm band will beacon the health of the spacecraft, which will also be received by the ground station at the University of Cincinnati. HABsat-1 will utilize solar panels covering five faces of the CubeSat to generate enough power to fulfill the mission requirements. The power will be managed and stored by an EnduroSat power distribution board. Figure 3 shows a preliminary model of the HABsat-1 satellite. For visualization purposes, the solar panels on the top face are not shown so that internal placement of the board stack and imager can be seen. HABsat-1 will carry a low-cost narrow-band multispectral imager, *HAB phycocyanin/chlorophyll (HABpc)*, optimized for the study of algal bloom dynamics. The NOAA Cyanobacterial Index (CI) algorithm will be used to process the data received from HABsat-1.

### *Engineering Method*

HABsat-1 engineering will be led by the UC CubeCats Undergraduate Team with supervision by faculty from UC Aerospace Engineering and UC Geography/GIS. UC CubeCats undergraduates include present and past interns at Pumpkin Space in San Francisco (a major CubeSat component supplier), NASA Johnson Space Center, the NASA Jet Propulsion Laboratory (JPL), Northrop Grumman, GE Aviation, and many other aerospace companies. The UC CubeCats team has recently secured funding for the design and construction of a Helmholtz Cage (Fig. 4) for the simulation of the Earth's magnetic field in orbit, and for the renovation of a UHF/VHF ground station (Fig. 5).

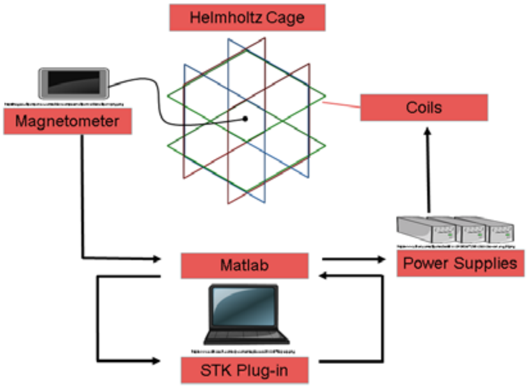

**Figure 4: Helmholtz Cage Block Diagram**

A Helmholtz Cage will be designed and constructed by Fall 2018 and used to test and ensure the magnetorquer based ADCS functions properly before launch.

**Figure 5: UHF/VHF Ground Station**

The refurbished UHF/VHF Ground Station will provide communications during de-tumbling and backup communications for a new S-band downlink station (Fig. 6). Funding for this project will be used to add S-band downlink capabilities to the ground station, so that it can receive health beacons, send the CubeSat commands, and receive imagery data.

**Figure 6. S-band Ground Station Upgrade**

Figure 7 shows a functional block diagram of the HABsat-1 CubeSat. This block diagram describes how the different subsystems and components within the CubeSat interact with one another. The functions and interfaces of each subsystem are detailed in Table 2.

A preliminary mass budget was developed from the functional block diagram to ensure the desired system was feasible from a mass standpoint. The total mass estimation falls within the 3.96 kg limit. An analysis was performed on the power system of the CubeSat. In standby mode, the CubeSat will only consume 2 W of power. The maximum power draw, 6 W, occurs during the S-Band downlinking of data. These minimum and maximum power values are close to the calculated range of 4.5 – 5.4 W produced by the solar panels. The use of batteries allows for additional power to be stored

**Table 1: Spectral Characteristics of the HAB phycocyanin sensor developed in collaboration with NOAA**

| HAB phycocyanin | Band | Band Center (nm) | GSD (m) | FWHM (Band Width) nm |
|---|---|---|---|---|
| Phycocyanin | 1 | 620 | 72 | 10 |
| Phycocyanin Shoulder | 2 | 650 | 72 | 10 |
| Chlorophyll Shoulder | 3 | 680 | 72 | 10 |
| Chlorophyll (NIR) | 4 | 708 | 72 | 10 |

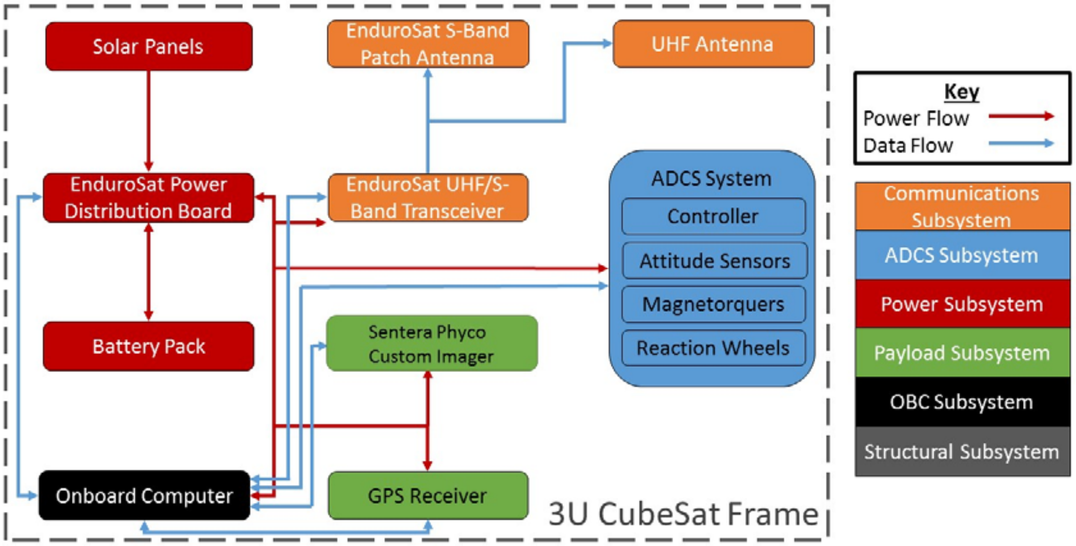

**Figure 7: HABsat-1 Functional Block Diagram**

**Table 2: Subsystem Functions**

| Subsystem | Function |
|---|---|
| Communications | Transmit data and receive commands from UC ground station. |
| ADCS | Attitude Determination and Control System to detumble/orient CubeSat. |
| Power | Capture and store solar power for use by all subsystems. |
| Payload | Capture multispectral imagery and send to the onboard computing system. |
| Onboard Computing (OBC) | Manage activity and send commands to all CubeSat subsystems. |
| Structural Subsystem | Ensure all components survive the launch/operational environments. |

### Table 3: Estimated Mass Budget

| **CubeSat Components** | **Unit Mass (kg)** | **Quantity** | **Total Mass (kg)** |
|---|---|---|---|
| 3U CubeSat Frame / Radiation Shielding Materials | 0.347 | 1 | 0.347 |
| Solar Panels (13 1U faces) | 0.026 | 13 | 0.338 |
| CubeSat Power Module (including Batteries) | 0.278 | 1 | 0.278 |
| Sentera Phyco Custom Imager | 0.150 | 1 | 0.150 |
| Lens – 25 mm M12 - f1.2 | 0.130 | 1 | 0.130 |
| Onboard Computer | 0.040 | 1 | 0.040 |
| ADCS Computer | 0.060 | 1 | 0.060 |
| GPS Receiver (ADCS sensor) | 0.047 | 1 | 0.047 |
| GPS Antenna (ADCS sensor) | 0.010 | 1 | 0.010 |
| Micromotors (ADCS actuator component – momentum wheel) | 0.007 | 3 | 0.020 |
| Fly Wheels (ADCS actuator component – momentum wheel) | 0.022 | 3 | 0.066 |
| Magnetorquer (ADCS actuator, two rods and one coil)) | 0.074 | 1 | 0.074 |
| Magnetometer (ADCS sensor) | 0.001 | 1 | 0.001 |
| Coarse Sun Sensor (ADCS sensor) | 0.001 | 10 | 0.010 |
| Rate Sensor (ADCS sensor, single-axis) | 0.001 | 3 | 0.003 |
| Fine Sun and Nadir Sensor (ADCS sensor) | 0.080 | 1 | 0.080 |
| Actuator Mounting Board | 0.140 | 1 | 0.140 |
| UHF/S-Band Transceiver | 0.114 | 1 | 0.114 |
| S-Band Patch Antenna | 0.064 | 1 | 0.064 |
| UHF/VHF Antenna | 0.010 | 1 | 0.010 |
| Wiring, connectors, fasteners, thermal isolation material | 0.250 | 1 | 0.250 |
| **Total** | | | **2.232** |

during standby mode, which can be used during more power-intensive modes to achieve mission objectives.

### *Testing Method*

Prototype testing for initial integration of the HABsat-1 components will be conducted on the ground (e.g., using the satellite GNC test rigs being constructed in UC Aerospace lab facilities). Then, these will be combined into a fully-integrated engineering model and launch provider for final launch checkout. Significant software testing will also occur to ensure proper integration of components before launch.23,24

## SATELLITE LAUNCH

Once the CubeSat has been constructed, the UC CubeCats team will apply to NASA's CubeSat Launch Initiative for HABsat-1 launch support. The NASA program plans to launch 34 satellites in 2017, but cannot guarantee a launch until acceptance into CSLI, and one needs to have a real satellite ready for launch to be in contention for launch support. Strong scientific merit, a strong engineering foundation, funding from ODHE, agency support, and a demonstrated ability to design, build, and test a CubeSat would greatly increase the chances of HABsat-1's acceptance into CSLI.

## SATELLITE ORBIT

We expect the HABsat-1 prototype to inherit the International Space Station (ISS) orbital inclination of 51.6 degrees from a Nanoracks launch. NASA orbital modeling and our own lead us to expect a resulting orbital period of 90-93 minutes, with 15-16 daylight orbits per 24 hours. A map of likely daylight ground tracks from an ISS-like orbit over a 24 hour period is shown in Figure 8.

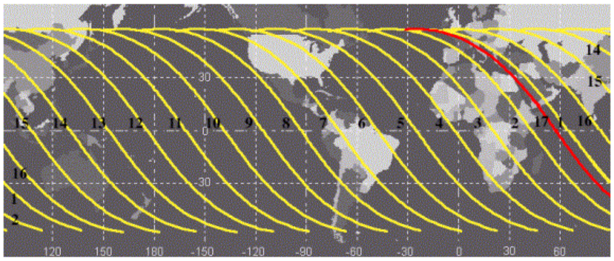

**Figure 8. Daylight tracks for consecutive orbits during one 24 hour period.**

NASA's orbital modeling suggests an approximate repeat of the same Earth surface locations every 3-6 days depending on ISS altitude and the swath width of

flown on a private aircraft. This will provide functional testing and a verification of the payload, onboard computing, power, attitude determination function and communications subsystems; redesign and retesting will occur if necessary. Finally, a separate flight model will be developed that includes all final components (e.g., the full ADCS system). This model will go through the certification process for spaceflight, first by a supplier of qualification testing and then by the

the imager. The 63 day lighting precession associated with the ISS orbit, seasonal variations in illumination due to the tilt of the Earth's axis and the ISS orbit's lack of coverage for the near-polar regions (that also have serious HABs) makes multiple "out of phase" satellites necessary for operational water quality monitoring. Over the longer term we hope to launch the HABsat constellation into a mix of both near-polar and ISS-like orbits for complete global coverage of the Earth's freshwater resources (Fig. 9).

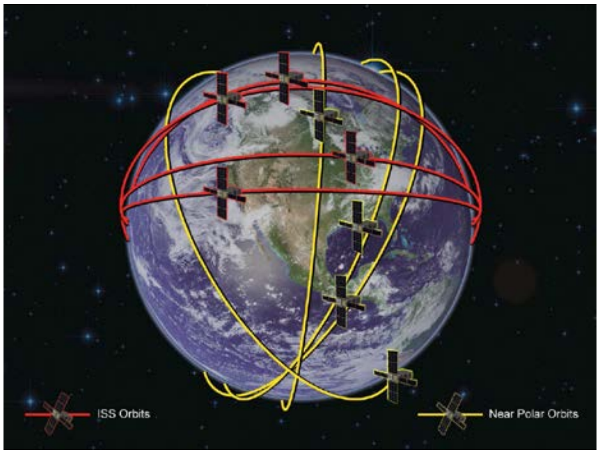

**Figure 9. Proposed mixture of near-polar and ISS-like orbits for HABsat water quality monitoring constellation.**

## IMAGER SIMULATION

The Quad camera fits within a 1U segment of the 3U HABsat-1 chassis (Fig. 10). The expected performance of a Sentera imager (Table 4) with customized band filters (Table 5) for the detection of the 620 nm phycocyanin absorption feature characteristic of cyanobacteria was simulated by spectrally and spatially binning real CASI hyperspectral aircraft data collected by the US Army Corps of Engineers and the NASA Glenn Research Center.

Initial modelling of the space modified 1280 x 960 pixel *framing* imager with 25 mm focal length lenses at an orbital altitude of 450 km suggests a swath width of

86.4 km, a swath "height" of 64.8 km with a ground sample distance (GSD) of approximately 67.5 meters. The real space modified camera specifications will depend upon the focal plane to the new metal imager case and lens mount distances. NASA will adjust the lens specifications to meet a target GSD value of 70-90 meters. This target GSD value is derived from intensive field surveys with USACE, USEPA and NASA hyperspectral overflights, simulations of multispectral satellite imagery (including HABsat-1) and real multispectral satellite data with rigorous atmospheric correction to reflectance.

**Figure 10: Chassis of stock Sentera Quad multispectral imager with custom band filters before modification by Sentera and NASA for use in space.**

**Table 4: Specifications of Sentera Quad Imager before modifications for space.**

| | | |
|---|---|---|
| Sensors | | |
| | Resolution | 1x 1.2MP CMOS RGB<br>3x 1.2MP CMOS Mono<br>• 655nm CWL x 40nm width<br>• 725nm CWL x 25nm width<br>• 800nm CWL x 25nm width |
| | Shutter | Global |
| | Pixel Size | 3.75um |
| | Pixel Count | 1248 x 950 |
| Lens | | |
| | FOV | 50° horizontal / 39° vertical - Low Distortion |
| | GSD @ 200' | 1.8" (4.5cm) |
| | GSD @ 400' | 3.6" (9.1cm) |
| Size | | 3" x 2.45" x 1.9" (76mm x 62mm x 48mm) |
| Weight | | 170 grams |
| Power | | 5 to 26.2VDC, 12W typical |
| Frame Rate | | 1.2MP Stills: 7fps<br>720p Video: 20-24fps |
| Storage | | 32GB SD card per sensor<br>• JPEG, 200,000 images per card<br>• TIFF, 8,000 images per card |
| Interfaces | | Ethernet, Serial/UART |

### *HABsat-1 Imager Band Selection*

The Sentera Quad imager has four bands. Three different NOAA candidate combinations of four band center wavelengths were evaluated. The best performing band combinations used 620, 650, 680 and 708 nm band centers with less than 30 nm full width half maximum (FWHM) band widths (Johansen et al., in prep) (Table 5). The stock filters on the Quad will be modified to NOAA's specifications (620, 650, 680, 710 nm with 10 nm FWHM band widths) by Sentera before the camera is shipped to NASA for modification for use in space. Sentera's new narrow 10 nm FWHM band filters may result in performance even better than our initial conservative simulations.

After the imager case and lenses have been modified for use in space by NASA's Glenn Research Center the completed imager will be tested by UC on a light aircraft over algae laden water as part of ongoing NASA and USACE water quality monitoring research and then integrated with the HABsat-1 chassis for testing and launch preparation.

**Table 5: Expected Band Configuration for the Customized Sentera Quad imager (left) adjusted to leverage the 620 nm phycocyanin feature on HABsat-1 vs. simulation based on real CASI hyperspectral aircraft data.**

| | HABsat-1 | | Synthetic HABsat-1 | |
|---|---|---|---|---|
| **Bands** | **Center** | **FWHM** | **Synthetic Center** | **FWHM** |
| | **(nm)** | **(nm)** | **(nm)** | **(nm)** |
| **B1** | 620 | 10 | 622.2 | 28 |
| **B2** | 650 | 10 | 650.6 | 28 |
| **B3** | 680 | 10 | 679.1 | 28 |
| **B4** | 710 | 10 | 707.5 | 28 |

### *Related Work*

The HABsat-1 imager specifications build on several million dollars of previous US Army, NASA, NOAA, and USGS-sponsored remote sensing research by the Ohio Department of Higher Education (ODHE) universities in western Lake Erie and other Ohio water bodies. This research has shown that hyperspectral or custom narrowband multispectral imagers are the preferred instruments for detecting and identifying harmful algal blooms in Lake Erie and other Ohio water bodies, including reservoirs, natural lakes and the Ohio River.9,10,11-17

The design of HABsat-1 will also build off the past work of the UC CubeCats undergraduate student engineering team. UC CubeCats teaches new members the space systems and mission engineering process through the design, construction, launch, and operations of high altitude weather balloons. The majority of the members of the HABsat-1 team have either participated in or created this program. Project LEOPARD (UC CubeCats first CubeSat mission) is also in development, and the engineering experience gained and processes being created through the design towards launch and operations of Project LEOPARD will support the design of HABsat-1. Specifically, the CubeSat frame designed for Project LEOPARD will be redesigned to accommodate the larger HABsat-1 CubeSat, and the solar panel design will also be revised and applied to the design of the HABsat-1 solar panels. Any testing, integration, and operations experience gained from Project LEOPARD will be applied to HABsat-1.

## GROUND SYSTEM

The UC CubeCats team will be responsible for all data acquisition from the satellite to the ground system. Upon receiving the raw data, UC CubeCats will pass this to the University of Cincinnati Geography and Geographic Information Science Department for data processing. Afterwards, we will leverage the National Science Foundation’s recent $900,000 investment in UCScienceNet and its 100 GB/s connection to the USGS/NASA EROS Data Center and to NASA’s research network via OARnet. We plan to archive HABsat-1 imagery to UCScienceNet for distribution to researchers and agencies, such as the National Oceanic and Atmospheric Administration (NOAA), U.S. Army Corps of Engineers (USACE), and Engineer Research and Development Center (USACE-ERDC) Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX). UC Geography/G.I. Science has servers on UCScienceNet to stage the data.

## ACKNOWLEDGMENTS

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