Introduction to Remote Sensing for Harmful Algal Blooms

Please type your questions in the Question Box. We will try and get to all your questions, but if we don't, feel free to email Sherry Palacios your question at sherry.l.palacios@nasa.gov

Session 1

Question 1: Is sample collection necessary for algal bloom identification or are RS images enough for analysis?

Answer 1: An algal bloom can be identified in remote sensing imagery by seeing an increase in chlorophyll concentration. Determining the taxonomic composition of the bloom from RS imagery is more complicated. As mentioned in the webinar, RS imagery can be used to estimate chlorophyll concentration. In some specific cases, algorithms exist for identification to taxonomic group.

One example is with *Karenia brevis*, the Florida Red Tide organism. It is a rather chubby phytoplankton, so it is different optically from phytoplankton typically living in the same environment. Because it is different optically, it can be approximately discriminated. We will talk more about this idea in week 3 when we review NOAA HAB Bulletin for the Gulf of Mexico. Another example is with *Microcystis aeruginosa*, the cynoHAB organism. It contains vesicles that cause it to float towards the surface. While RS imagery cannot tell us which organism it is, it can be used to inform managers that there is a likely *Microcystis* bloom, and they can use this information to send out people to sample.

Question 2: Can you elaborate glint correction?

Answer 2: When you took fundamentals of remote sensing, it mentions atmospheric correction There are other pre-processing steps you need to take for imagery for water surfaces. One of them is glint correction. Depending on the angle, sometimes the specular reflectance of light off the surface shines right back up to the satellite's sensor, and you can an erroneous measure. What you need to do is find techniques to get rid of the "glint" or light reflection. One of the ways is to subtract a value (e.g., at 750 nm) in the spectrum from the total value, but that only works to some extent. This is an issue for all aquatic RS - sometimes the imagery collected isn't at the best time of day or seasonal cycle. Satellite imagers are scheduled to detect those surface reflections at the best time of day, but it can be an unavoidable issue.

The scheduling of some of these sensors will flag to say that we know this day will have too much glint in a particular region, and they do this for MODIS.

Question 3: Can you please elaborate the fourth order polynomial equation for chlorophyll estimation

Answer 3: https://oceancolor.gsfc.nasa.gov/atbd/chlor_a/ See this link for a more detailed description of the chlorophyll algorithm(s) commonly used with NASA sensors.

Question 4: Which types of HABs are currently monitored with remote sensing?

Answer 4: We have active areas of research for HAB identification, as well as operational tools (in the U.S., especially). There's a lot of research being done to ID HABs, and we're going to be talking about some of these operational approaches. Some of this work that's making its way into operational is the Cyanobacteria Index (CI). CI will be referenced in week 4, and that's to help us ID surface scums of *Microsystis* and other algal blooms.

Other research is being done to ID certain pigments related to cyanobacteria. Cyanobacteria contain phycocyanin, an accessory pigment for photosynthesis and it has a specific impact on the shape of the Rrs spectrum. This spectral characteristic can be used to help identify cyanobacterial using aquatic remote sensing algorithms.

Some citations related to these are in Question 5 below.

In week 4 we'll be talking about the NOAA HAB bulletin. Our guest speaker will also be talking about her online tool, as well.

Question 5: You mentioned that algorithms exist to help identify cyanobacteria. Where can we get these?

Answer 5: Below are two paper references that are a good start on this topic. Within each of these, there are citations that may help further. Also, if searching for more recent literature, these may be good 'seeds' for searching for more recent literature that has cited them.

Wynne, TT, Stumpf, RP, Tomlinson, MC, Warner, RA, Tester, PA, Dyble, J and Fahnenstiel, GL. 2008. 'Relating spectral shape to cyanobacterial blooms in the Laurentian Great Lakes', International Journal of Remote Sensing, 29:12, 3665 — 3672

S Mishra and D R Mishra 2014. A Novel Remote Sensing Algorithm to Quantify Phycocyanin in Cyanobacterial Algal Blooms. Environ. Res. Lett. 9 114003.

Question 6: Do the HABs that cause shellfish poisoning also pose a drinking water quality risk? Or is the risk not so high because the algae can be filtered, etc?

Answer 6: Most of the HABs mentioned in this series that cause the shellfish poisoning - mostly the marine ones - typically those do not pose a risk to drinking water. Partly because they're marine, but you cannot consume enough of that toxin for it to be dangerous, typically. Even if you could drink salt water, you likely wouldn't get to a dangerous level. Consuming the shellfish is dangerous because the organisms concentrate the toxin when they filter the phytoplankton out of the water. With the drinking water - there are toxins that can be dangerous even at small levels.

Question 7: I would like to know how I can apply remote sensing monitoring in places that are located in high elevation, more on less 2650 msnm, in Bogota. I would like to do it with a Bogota wetland. What do you recommend?

Answer 7: The question gets to the question of RS vs. in situ monitoring. With any question you're asking with RS, it's the size of the surface - the lakes, wetlands - and the amount of open water in those wetlands that you can see. If you're using Landsat, which has 30 m/pixel resolution and you can still pick up chlorophyll, it might be possible to use that tool. But the cloud cover might also cause issues in these environments.

A question: what spatial resolution do you need? What temporal resolution do you need? Would the satellite data be at a resolution you can use. If you're using airborne imagery that you can control, then that gives you the opportunity to have control over when those images are collected. A lot of the same concepts, but then it would be on a different platform. If people have access to these wetlands, there might be an opportunity for citizen science to help with inputs.

Week 4 will mention an app that people can use so that you can use citizen science to help with monitoring chlorophyll concentration.

Question 8: Are lakes able to be monitored for HABs using methodologies presented today?

Answer 8: It depends on the resolution of the sensor and the size of the lake, it also depends on how shallow the water is and how much the lake bottom affects the Rrs signal.

Question 9: Is there a technical/ ecological distinction between "HAB" and a non-harmful algal bloom?

Answer 9: This depends on the organization, its goals, and the context.

Question 10: If chlorophyll value is high, does it mean blooms are present?

Answer 10: Yes, but it could be a non-harmful algal bloom. Additionally, it is still possible to have a harmful toxic bloom even when chlorophyll values are low. This is a limitation of remote sensing. In situ will still be needed in such cases.

Question 11: Is there any species-specific algorithm for detecting Pseudo-nitzschia bloom?

Answer 11: No. Not yet. Down to the genus level is still not possible.
A helpful participant provided this information
Peter Miller (PML):
On detecting Pseudo-nitzschia blooms: We are working on this for the UK ShellEye project (www.shelleye.org).
See some provisional results in this recent poster:
https://drive.google.com/file/d/0ByCVOlnGoUmgT0tnazlaLW5UdkU/view?usp=sharing

As Sherry says, it is only an indication of HAB risk, not conclusive.

Question 12: Are there any means of using sensors on unmanned aircraft such as drones or other operations that may be used from the ground?

Answer 12: Yes, one limitation may be the sensors included on the UAV. More than the traditional RGB wave bands may be needed.

Question 13: Can hyperspectral remote sensing give better accuracy in detecting algal species?

Answer 13: Possibly. Hyperspectral imagery contains more information (because it has more bands) and so it may be possible to discriminate more types of algae and arrive at a better estimate of which organism is causing the bloom. It is still necessary to do accuracy assessment for any algorithm used.

Question 14: I understand that NASA's chlorophyll-a product is free - could you provide specific examples of its applications in the U.S.? Who issues HAB warnings? NASA? States?
Answer 14: Chlorophyll-a product is free and can be obtained from Level 1 & 2 browser at NASA (Amita will talk about this in week 2).

This product is used pretty widely, it depends on which algorithm you're using for what environment. HAB warnings come from a variety of different entities. In CA the California Dept of Fish & Game will provide them, the EPA provides warnings, NOAA provides warnings - a lot of different entities provide them. NASA does not issue warnings. There's been work to streamline them and to be sure the models they're using have the skill to predict a HAB with

some confidence. Then trying to work with resource managers to make the call of if the warning needs to be broadcast - do we trust the model is accurate? In Week 3 our guest speaker will talk more about skill assessment of her forecasting model.

Question 15: What is the minimum size of water body we can assess harmful algal blooms for with high accuracy?

Answer 15: It depends on the spatial resolution of the sensor that you're using - It is up to the user to look up the sensor specifications and evaluate its suitability for the application. For example, if working with MODIS, your water body would need to be (at minimum) 9 km at least to trust the sensor. For whatever application, it is incumbent on the user to determine that enough pixels (4 - 5 minimum) fall entirely within the water body and do not include land pixels or mixed pixels (a pixel that has both land and water in it). What's exciting is that ESA is putting up sensors with finer spatial resolution. That series of imagers will be quite a bit more effective than some of the current US sensors at imaging inland water bodies. Amita will be talking about that a bit more in week 2.

Question 16: For more detail and to discriminate chlorophyll, water, and sediments, is it necessary to apply a supervised classification in the water area or discriminate automatically?

Answer 16: There are a number of empirical, semi-analytical, and analytical models to separate these constituents from the Rrs spectra of the water surface. Commonly used methods are the Quasi-Analytical Algorithm (QAA) and the Garver-Siegel-Maritorena (GSM) algorithms which are included as a part of the SeaDAS image processing software package freely available from NASA. It is less common to use classification schemes often used in terrestrial remote sensing applications to identify such things are chlorophyll, colored dissolved organic matter (CDOM), or particles in the water.

Question 17: How practical is to assess HAB in a river or stream with the width of 10-15 meters?

Answer 17: With a satellite sensor, even with many airborne systems, the spatial resolution would be too coarse, so it would not be practical. It might be possible with drone/UAS/UAV technology.

Question 18: In slide 48, you point that "Anomaly shows where the daily chlorophyll concentration differs from a mean computed over a 60-day period ending two weeks prior to the sample date." Why do you stop 2 weeks before the sampling date?

Answer 18: See publication for more details on why they chose this time period: Stumpf, RP, ME Culver, PA Tester, M Tomlinson, GJ Kirkpatrick, BA Pederson, E Truby, V Ransibrahmanukul, and M Soracco. 2003. Monitoring *Karenia brevis* blooms in the Gulf of Mexico using satellite ocean color imagery and other data. Harmful Algae: 2:147 – 160.

Question 19: When I first used SeaDAS, in 1999-2000, it was necessary to have a computer with a unix operating system. Is it possible now to run SeaDAS to make calculations on level 1b data using a computer with a Windows operating system?

Answer 19: SeaDAS has gone through a huge improvement over the last 5 years. In 2013, they released a completely new SeaDAS and the UI is much more intuitive now and is less complicated. Link: https://seadas.gsfc.nasa.gov/ Amita will be talking about it more next week. SeaDAS is a really intuitive way to access that data. Unfortunately, however, it is still required to have Linux or Mac OS X to process between levels using SeaDAS. The Windows functionality is limited in this respect.

Question 20: Is it possible to obtain a time series of chlorophyll for a particular location?

Answer 20: Yes, NASA's Giovanni tool permits this type of time series analysis (for some sensors) and will be discussed in week 2.

Question 21: Can you please explain cell enumeration of in situ monitoring methods of HABs?

Answer 21: Cell enumeration means cell counts. An example in microscopy is the use of a hemocytometer slide that has a calibrated grid as background and the cells in the sample are counted and an estimate of cell-size documented. Methods such as the Flo-Cam and the Imaging Flow CytoBot count cells within a particular volume of sample water. In all of these cases, an estimate of cell taxonomy and cells per liter of volume are determined.

Question 22: How far can we use remote sensing to detect HABs in estuaries?

Answer 22: Again, gets back to the question of spatial scale. Also, a consideration in this and other shallow bottom environments, how much of the bottom is influencing the remote sensing reflectance signal? If the estuary is 'optically deep' or deep enough that the bottom is not influencing the Rrs signal, then the constraints are spatial and temporal resolution. If the sea floor of the estuary is shallow and having an impact on Rrs, then it may not be possible to use remote sensing as there are other environmental considerations that will affect Rrs and provide inconclusive evidence for the algal bloom.

Question 23: Remotely detecting chlorophyll using an unmanned aerial system seems to be a solution for spatial/temporal limitations, cloud cover, and high costs. Has this been explored and if so, to what extent?

Answer 23: This is still in its early stages. If the camera system is adequate for aquatic remote sensing, e.g., it has the spectral resolution and radiometric calibration appropriate for dark water targets, and if the operators have adequate geometric and GPS data collection coincident with the image capture, it is likely that data from UAV/UAS would be acceptable for aquatic remote sensing.

Question 24: What representativeness do the images of chlorophyll a have on the water column? A few centimeters, a couple of meters?

Answer 24: Typically the first optical depth, of which the actual distance is dependant on how much material is in the water and the attenuation of light by that material. A good reference for the details of this topic is in J.T.O. Kirk “Light and Photosynthesis in Aquatic Ecosystems”, 2nd Edition, Chapter 1, Section 1.6 “Optical Depth”, p. 24. Another source that is freely available is the Ocean Optics Web Book (http://www.oceanopticsbook.info/).

Question 25: Are remote sensing techniques practiced in all parts of the globe to monitor HABs?

Answer 25: Remote sensing of HABs is in its early stages. Currently, it is used in Europe, Australia, the southwestern coast of Africa, the Arabian peninsula, the US, some countries in South America. It is also gaining wider use for monitoring of water quality in some countries, and global initiatives for drinking water such as CyanoLakes (http://www.cyanolakes.com/). Some of these are research-level (meaning not fully tested for decision makers) and some are operational.

Question 26: Do the satellite sensors also detect water temperatures?

Answer 26: Yes. Temperature is inferred from the reflectance data in the thermal range.

Question 27: In regards to in-situ sample correlation to Rrs, what is an appropriate "time-window" (e.g., time between sampling and remote imagery collection)? I believe in the seminar you said approximately an hour, but what would be the "maximum"?

Answer 27: We typically try to sample within one hour on either side of the overpass. Sometimes we aim for an even tighter time window. Water moves and in the systems we are sampling, the water movement is dynamic enough that beyond one hour increases the

likelihood that the water mass measured by the imager is no longer the one being measured in situ at that particular location.

Session 2

Question 1: How do you discriminate different types of algal blooms?

Answer 1: It depends on the algal taxa and the environment where it is taking place. Sometimes, the best we can do is to determine that a sudden increase in algae occurred (using chl-a anomaly). Sometimes this information is good enough for making a decision to focus sampling effort.

It is possible to differentiate some algal groups because of their optical properties. Examples include *Microcystis aeruginosa* which float due to gas vesicles and also *Karenia brevis* because it is so different optically (low backscattering) from the algae that normally grow in the environment. Even with these, it is still necessary to do sea-truth measurements.

Question 2: Can remote sensing data be used to forecast or predict HABs so that field teams can prepare for a field data gathering session?

Answer 2: Yes, many groups are working on this. Often these forecast systems couple the use of remote sensing imagery with geophysical models. Our week 3 guest speaker will talk about her forecasting model.

Question 3: Is there a historical database connecting disease with population so water resource professionals can communicate with the public?

Answer 3: CDC [link]

Question 4: Given Hurricanes Harvey and Irma, are there satellites that have higher temporal resolution than 16 days?

Answer 4: yes - geostationary satellites have much higher temporal resolution. GOES-16 (GOES R), for instance, takes full disk images every 15 min, an image of the continental U.S. every 5 min, and smaller, more detailed images of areas where storm activity is present every 60 seconds. (Source: GOES-R ABI Instrument Page)

Other polar orbiting satellites also have higher temporal resolution - MODIS (on board Terra and Aqua) do daily observations, and Suomi NPP also does daily observations.

Question 5: Bandwidths of Landsat 8 and Sentinel are different. How does this affect using Sentinel to fill data gaps of Landsat 8? Is there any protocol to follow when supplementing data between sensors?

Answer 5: We encourage you to look at this experimental product being developed to harmonize Sentinel and Landsat-8 https://hls.gsfc.nasa.gov/

Question 6: How accurate are remote sensing methods to forecast HAB outbreaks, using in-situ data with modeling?

Answer 6: This is partly the subject of week 3 - skill assessment with respect to forecasting models.

Question 7: Are there populations of algae that directly correlate with sickness of humans/mammals/benthic organisms?" ie. “at this concentration of algae, sea lion pups were affected for ocean data; or “at this concentration, the reservoir produced sickness effects in humans”?

Answer 7: There are types of algae that can sometimes contain certain toxins which result in sickness of organisms. Typically, the outcome is determined by how much toxin entered the affected organism, and less so on the concentration of the phytoplankton cells themselves. Different toxins enter the food or drinking water system in different ways. Reporting of toxins is typically as dissolved, particulate, and/or total toxins in the environment, and less so on the amount of toxin per phytoplankton cell.