Session L8: How Can Remote Sensing Be Used for Water Quality Monitoring?

May 1, 2014

Christine M. Lee, NASA Applied Sciences Program
Blake Schaeffer, US Environmental Protection Agency

Do you identify your primary role in your office as a:

manager?

policy maker?

scientist or researcher?

Other?

Goals of this session

- (Help) familiarize attendees with remote sensing concepts
- For NASA Applied Sciences to better understand the operational challenges related to data
  (can we identify the top 3 from this group)?
- Identify concrete ways remote sensing can help address those challenges

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Not a research talk!

What is remote sensing?

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- For the most part, it is a “snapshot” of conditions (not continuous monitoring)

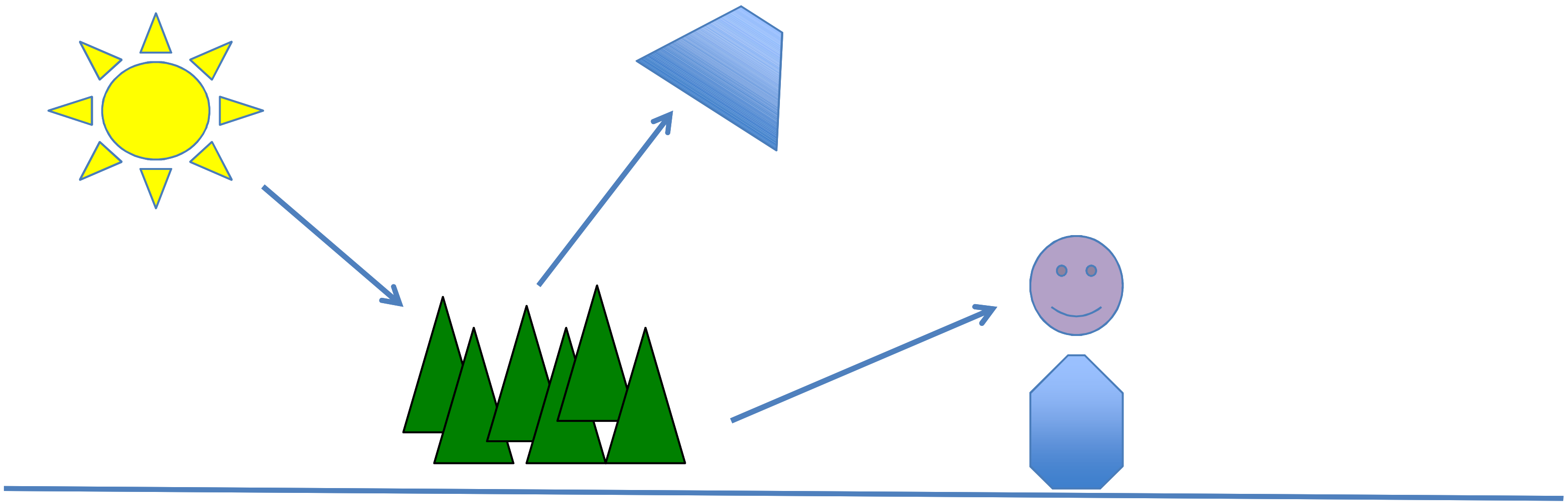
- There are trade-offs between important types of resolutions (spatial, temporal and spectral)

- While USG data is free, still requires some investment to learn how to analyze and interpret the data

- It is NOT a silver bullet for water quality monitoring, but a supplement to existing efforts

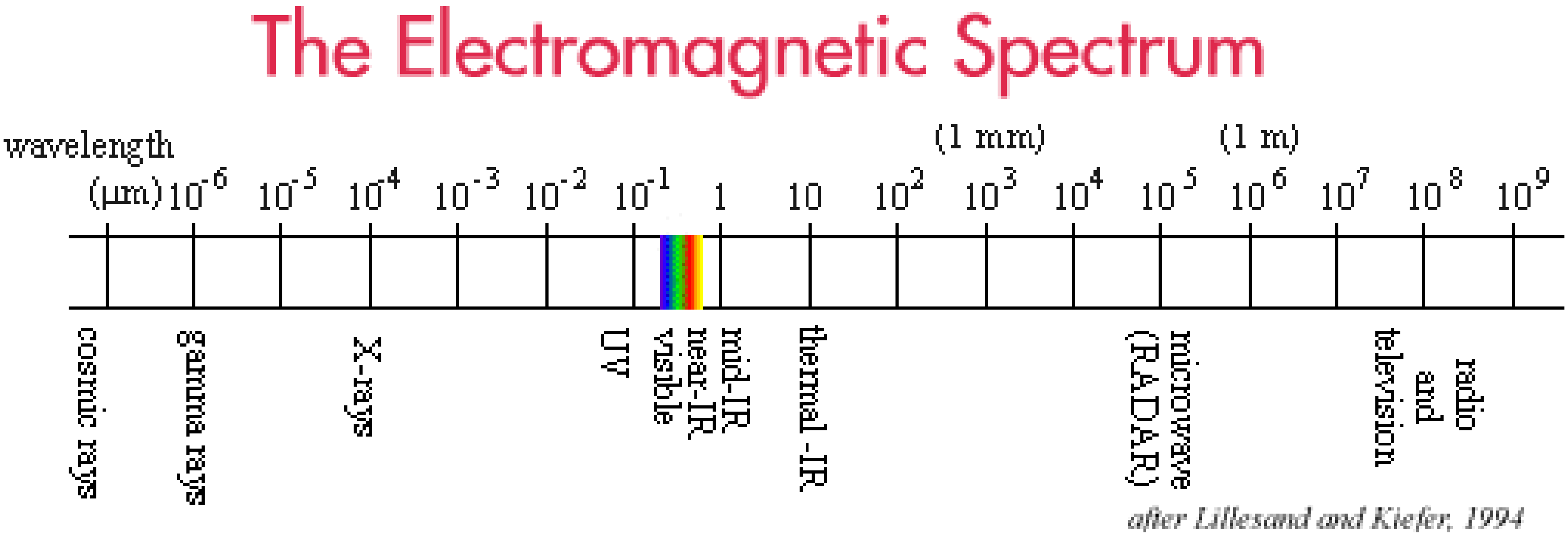
(continued) what is remote sensing?

- Way to measure something or infer information about an object without physically interacting with it
  - For example: Your eyes, Digital Camera, Satellite



Electromagnetic Spectrum: The Photon and Radiometric Quantities

The **underlying basis** for most **remote sensing** methods is the **measurement** of **varying energy levels** of a single entity, the fundamental unit in the electromagnetic (EM) field known as the **photon**.



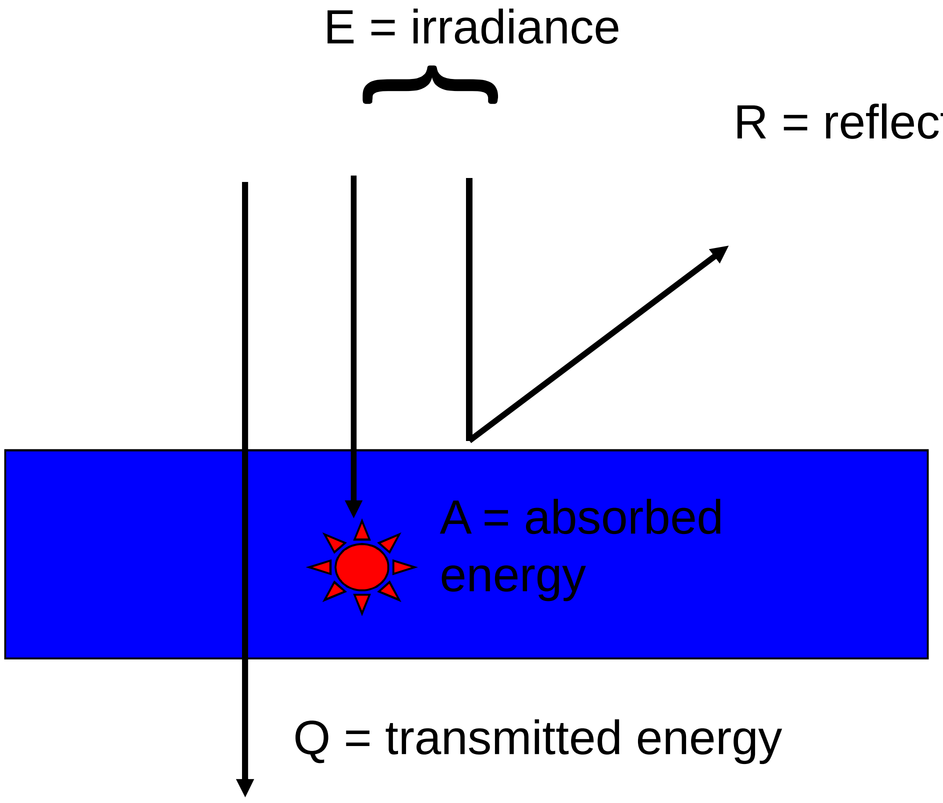
NASA space observatory telescopes (some of them)

Your eyes

Earth observing satellites such as USGS/NASA Landsat, Aqua and Terra (MODIS), others

Conservation of Radiant Energy

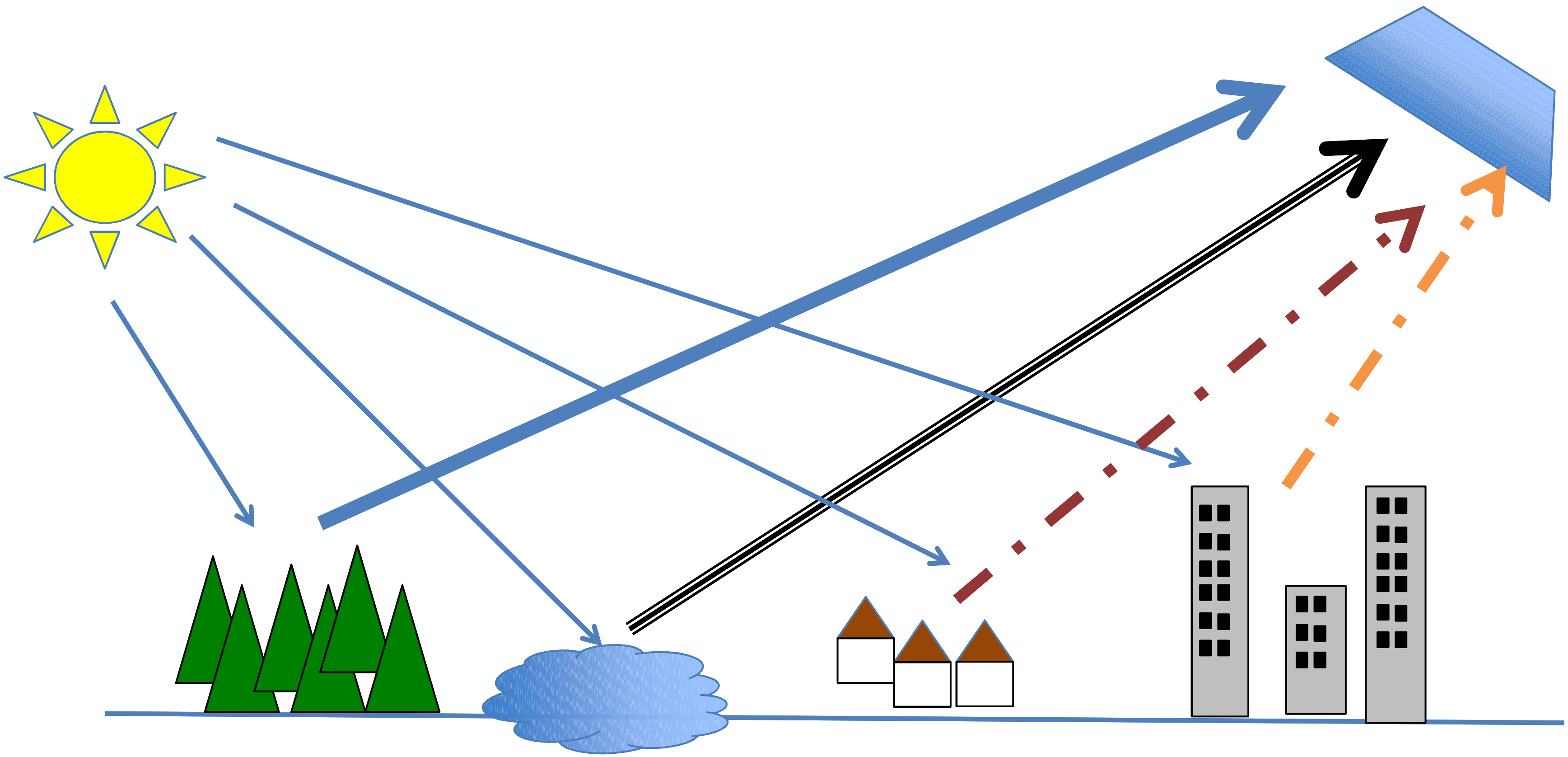
Radiation energy cannot disappear when interacting with matter – it must be conserved and accounted for. Possible energy paths:



DIFFERENT MATERIALS/SURFACES absorb and reflect energy in different ways, but because energy is conserved, we can study the differences between these materials based on what can be measured using satellite remote sensing.

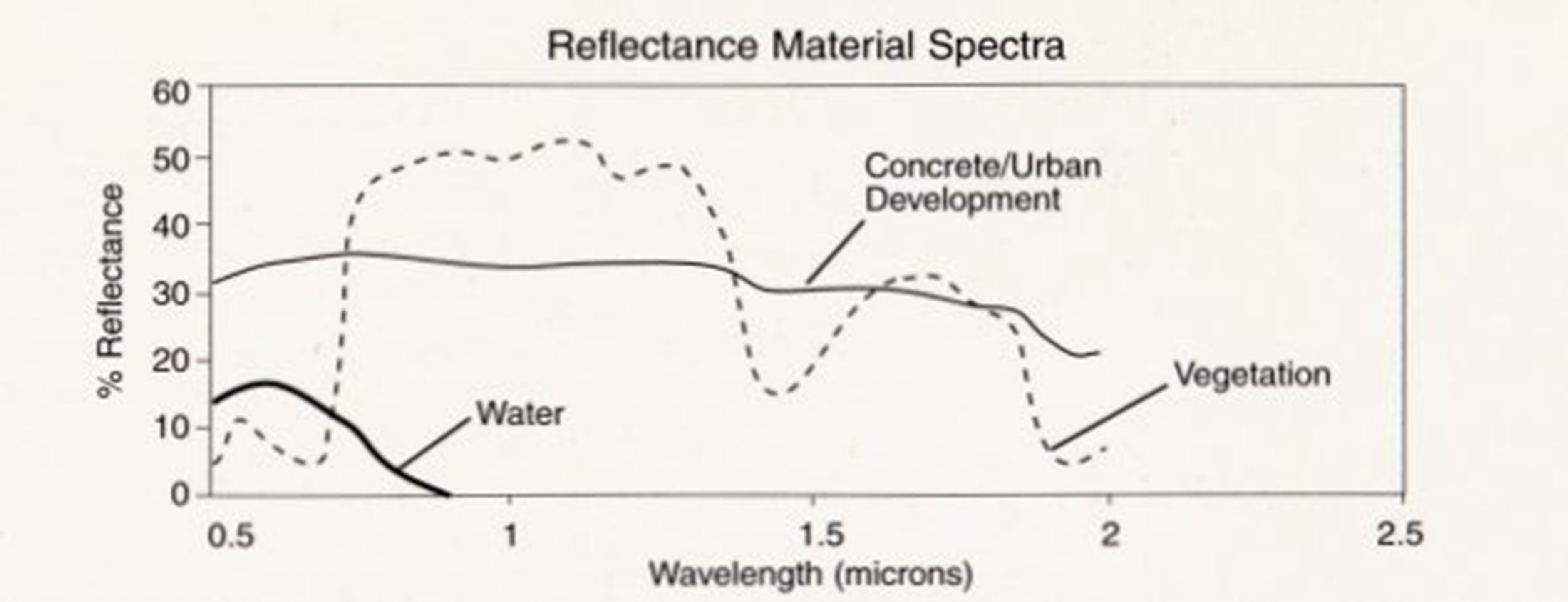
Electromagnetic Spectrum: The Photon and Radiometric Quantities

For example, land surfaces will emit different wavelengths of electromagnetic energy based on their material properties, which can be observed using satellite remote-sensing.



Spectral Reflectance Curves for Various Materials

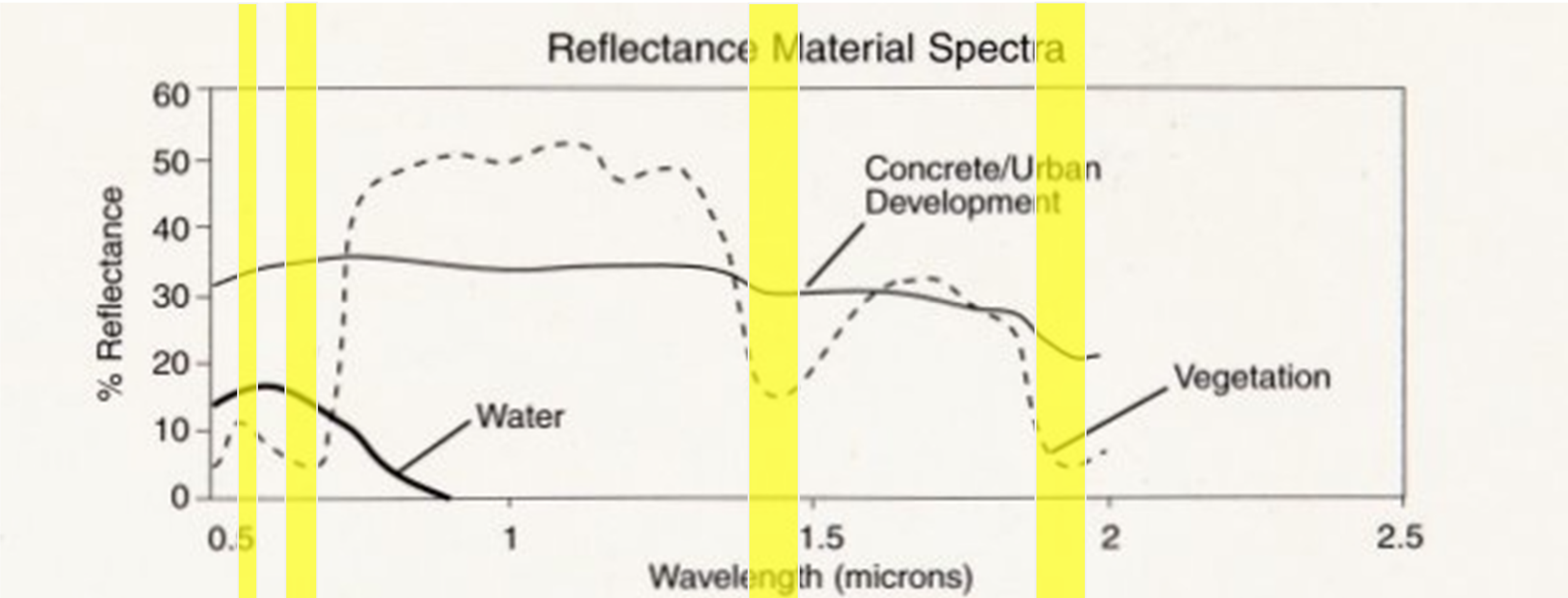
Another way to look at the previous cartoon is by looking at the spectral curves of different materials. This shows the respective spectra for materials from visible to mid IR range of the EM spectrum.



If you were to use a spectrophotometer to obtain spectral signatures of each surface.

Once these materials are well-characterized, it can be used as one of the factors for designing satellite instruments.

Spectral Reflectance Curves for Various Materials



Most satellite instruments (except hyperspectral) target specific spectral sections of the electromagnetic spectrum.

Four considerations for satellite properties (or when you are thinking about using satellite remote sensing for your applications)

Four types of resolution:
Spectral – using spectral signatures to determine which bands or sections of the EM that an instrument should collect information about

Spatial – coverage per pixel (4m vs 30m vs 1km)

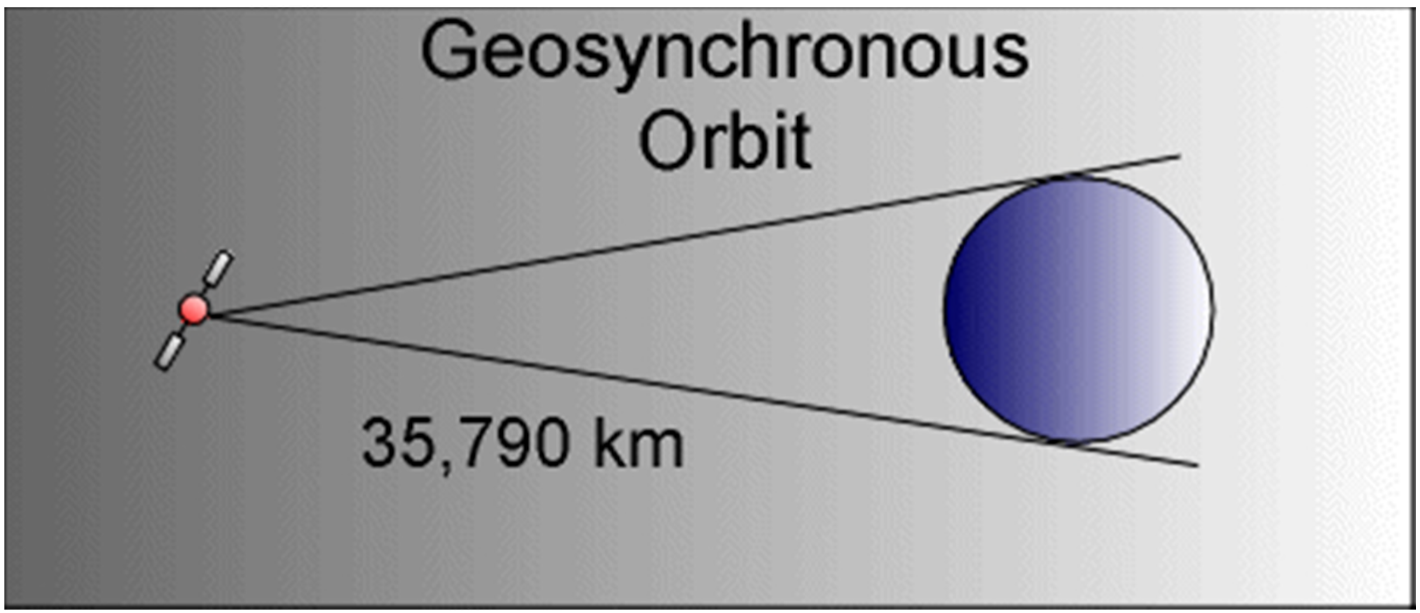
Temporal – time delay between sampling

Radiometric – the amount of data allotted for storing information (more data = more precision and greater amts of info stored for a pixel)

Temporal vs spatial resolution trade-off

<u>Geostationary satellite</u> – stays pointed at the same geographic region; orbits in sync with the Earth's rotation

Enhanced temporal resolution; reduce spatial resolution.



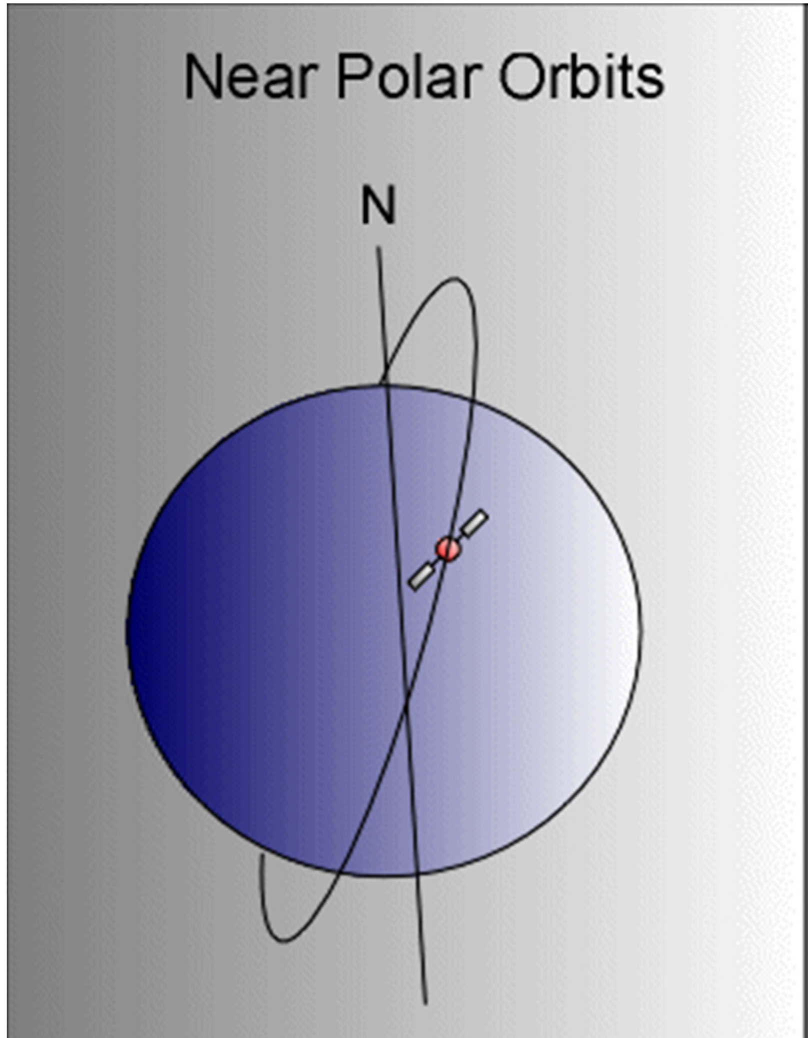
<u>Examples:</u>
NOAA weather satellites

Img credit: marine.rutgers.edu

Temporal vs spatial resolution trade-off

<u>Polar-orbiting satellite</u>
Orbits the Earth near the poles, which allows the satellite to see virtually every part of the Earth underneath it.

Enhanced spatial resolution; reduced temporal resolution.



<u>Examples:</u>
Landsat

Image credit: marine.rutgers.edu

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Atmospheric correction!

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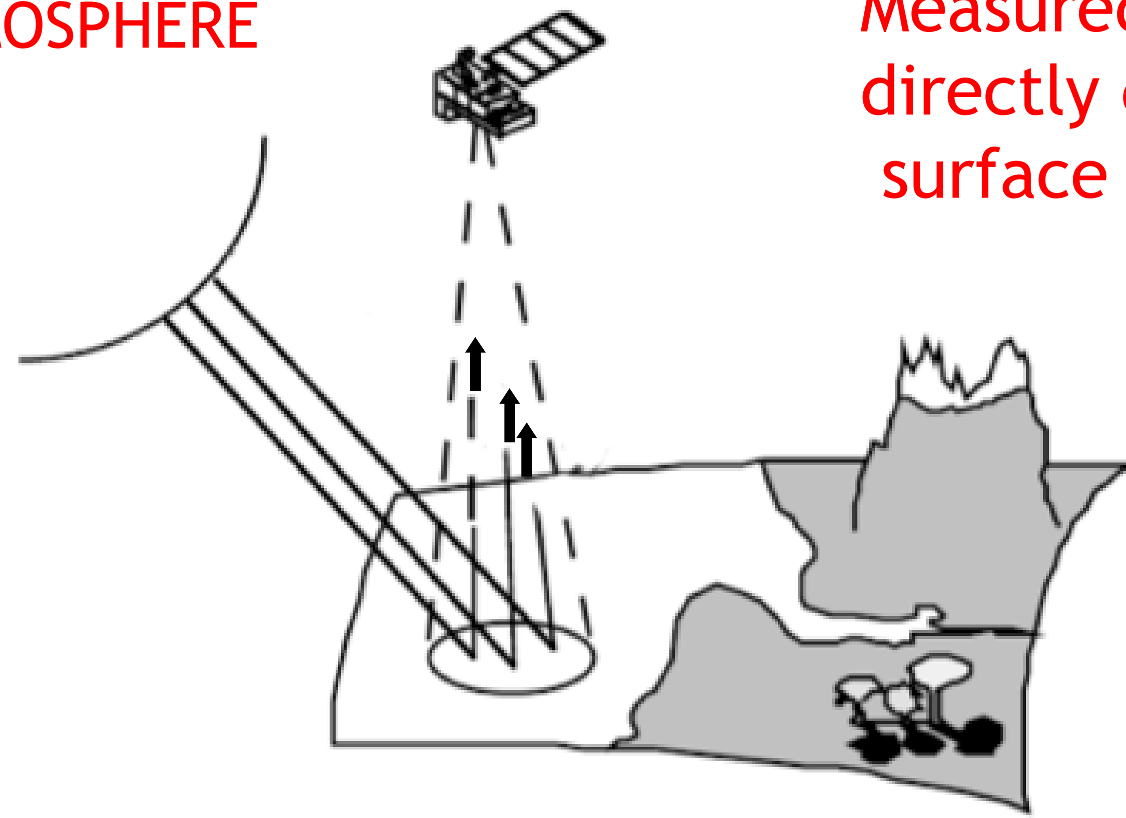
In an ideal situation with no atmosphere all of the incoming radiation would reach the surface. A portion of the photons would be absorbed at the surface. The remaining photons reflect back up into space.

NO ATMOSPHERE

Measured radiance directly depends on surface properties



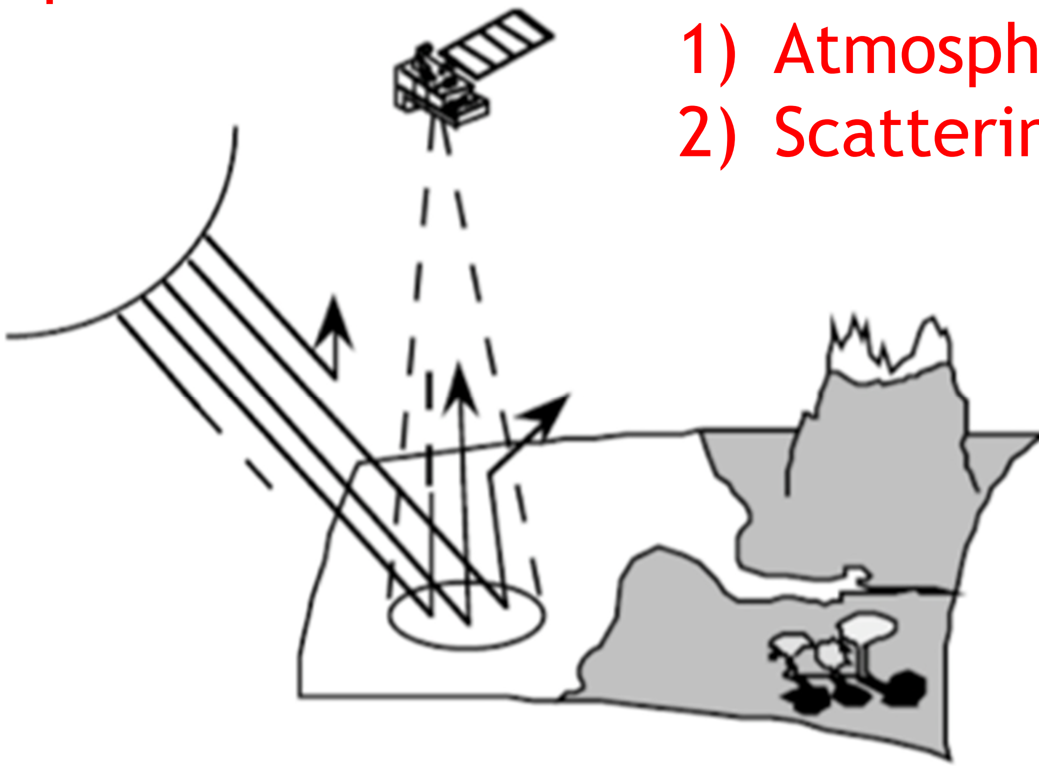
Diagrams from E. Vermote et. al, 6S manual

The real atmosphere complicates the signal. Only a fraction of the photons reach the sensor so that the target seems less reflective.

Real Atmosphere

Photons lost due to

1) Atmospheric absorption
2) Scattering



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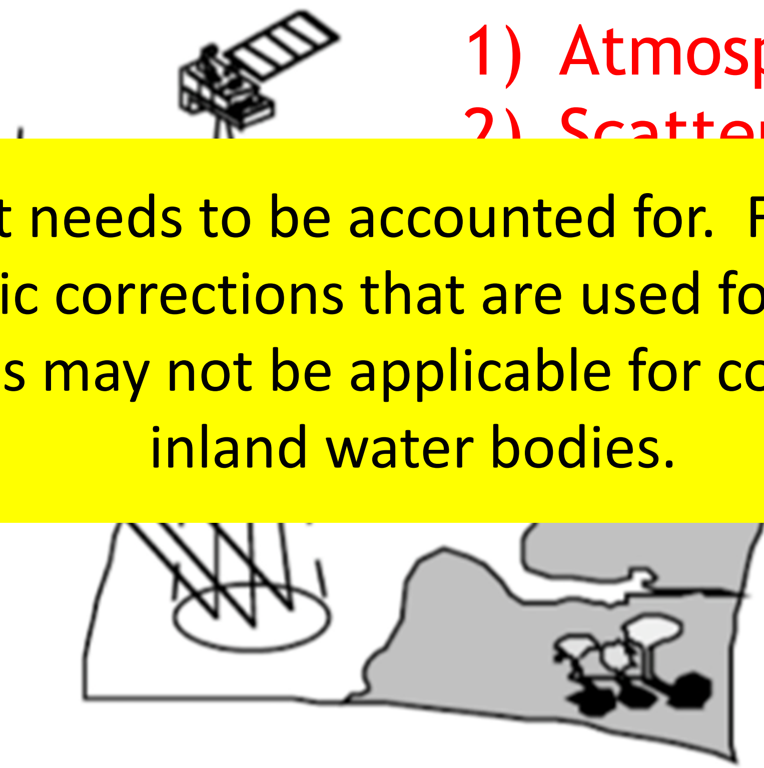


This effect needs to be accounted for. For example, atmospheric corrections that are used for open ocean measurements may not be applicable for coastal systems or inland water bodies.

Diagrams from E. Vermote et. al, 6S manual

Applications for water quality

Water Properties: Indicators of Water Quality

Physical Properties: CDOM, Temperature, (Density, Heat Capacity), Turbidity, Suspended Sediment, Light Attenuation

Chemical Properties: Salinity, Dissolved Oxygen, (Hardness, pH)

Biological Properties: Algal Blooms, Microorganisms, Primary Productivity

Remote Sensing of Water Quality Indicators

Recall: Satellite remote sensing measures electromagnetic radiation – essentially reflected radiation from the Earth's surface from the sun (mostly)

- Constituents that alter the thermal or optical properties of a water body considerably can be detected using satellite remote sensing

- These constituents include:
  - Algae
  - Suspended sediments
  - CDOM
  - Oils
  - Vegetation
  - Temperature

- NOTE: Many chemicals and pathogens do not directly affect or change the spectral or thermal properties of surface waters -- can only be inferred indirectly from measurements of other water quality parameters affected by these chemicals

Remote Sensing of Water Quality Parameters

Spectral Bands useful for Water Quality

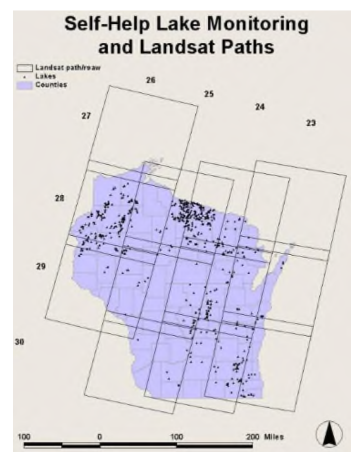
Suspended Sediments or Turbidity	700-800 nm
Chlorophyll	460-520 nm
Water Clarity	450-515 and 630-690 nm
Algal Bloom	760-900 nm and 1.55-1.75 μm

These spectral bands are available on NASA Terra and Aqua-MODIS and Landsat-TM

Example 1: Secchi Depth/Water Clarity

- 15,000 lakes in WI
- Secchi disk measurements used to assess lake water clarity
- Developed empirical relationship between remote sensing data and Secchi disk measurements (obtained by citizen monitors)
- Used two bands from Landsat; data is publicly accessible, free, and open
- Greb et al. notes multiple years of historical data required to properly calibrate the relationship to remote sensing data

$$\text{Ln(Secchi Disk)} = a(TM_1/TM_3)+b(TM_1)+c$$



Credit: S. Greb, WI DNR

Example 1: Secchi Depth/Water Clarity

- Recalibrated on a yearly basis
- After SD generated, data assessed with consideration towards lake size, lake classification (grouping lakes by hydrology, morphometry, landscape position)
- Convert SD to Carlson's trophic status (TSI), rel. to phosphorus, nutrient, chlorophyll, SD
- Lake then assessed on a scale (Excellent, good, fair, poor) based on classification type and TSI
- Enabled 8000 lakes to be evaluated for water clarity over multiple time periods

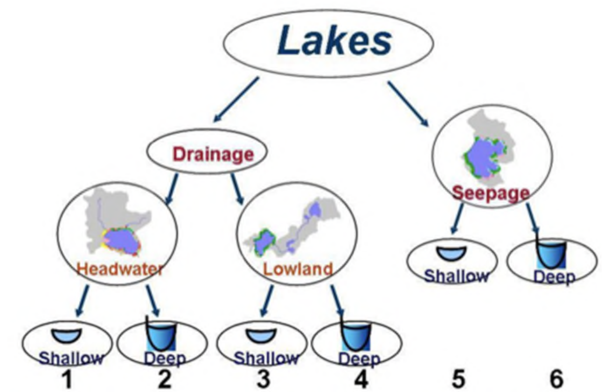
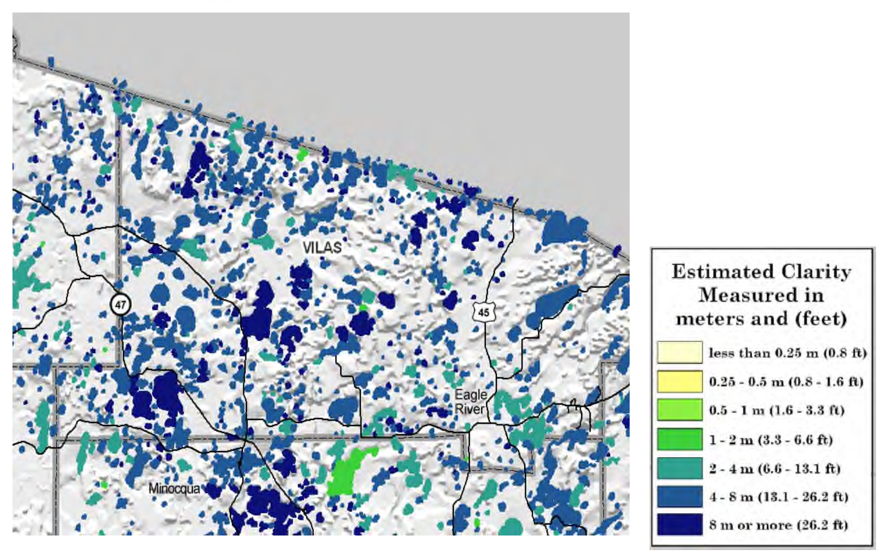


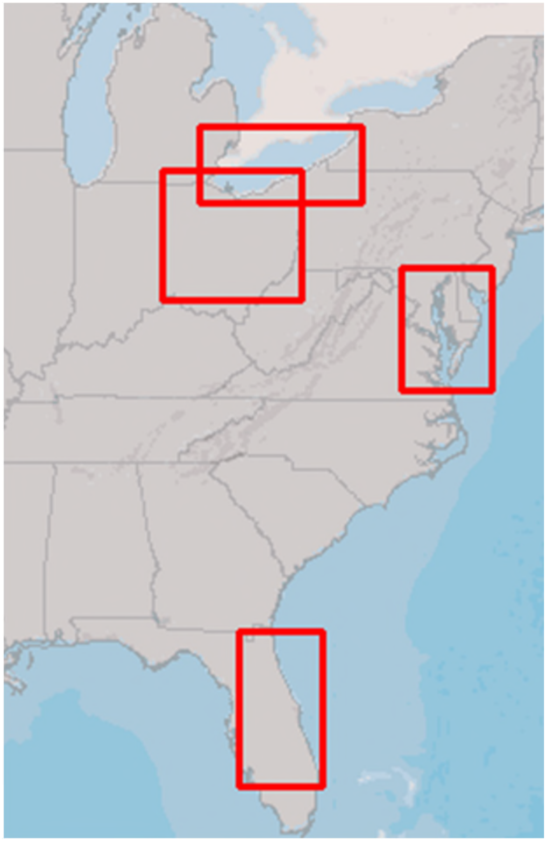
Figure 1. Lake Classification based on hydrologic connection and landscape position



Greb et al, IJSRE

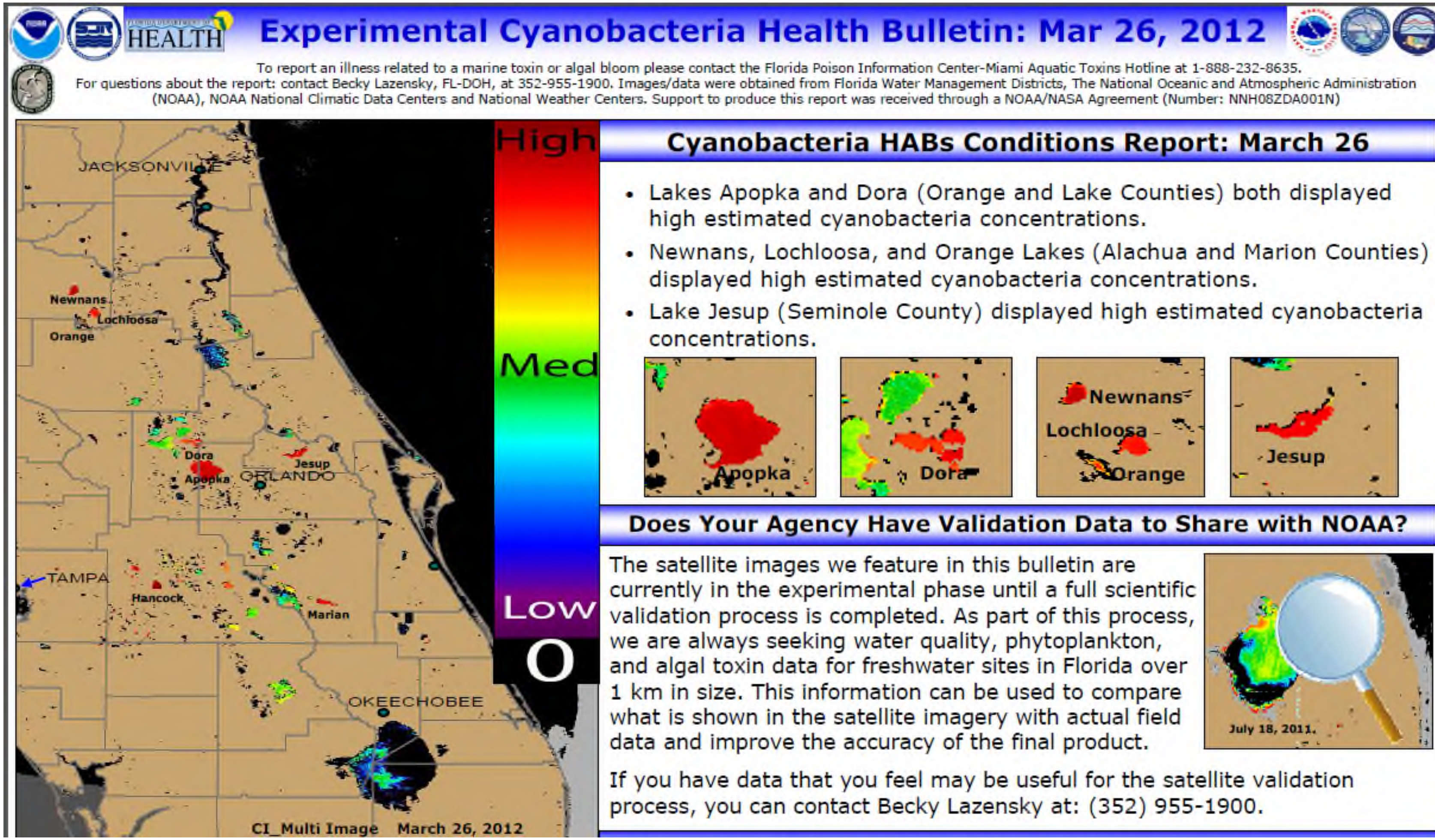
Example 2: Chlorophyll / Algal Bloom Monitoring

- NOAA Harmful Algal Bloom Data Viewer using 678 nm band on MODIS to evaluate chlorophyll concentrations, validated using 3 years of data
- Bulletins available for chlorophyll and algal blooms in Great Lakes, Gulf of Mexico
- Bulletins available for Kd for New York, New Jersey, North Carolina, West Florida



Stumpf et al., Bulletin:
http://www2.nccos.noaa.gov/coast/HABViewer.html

Satellite Health Bulletin, Florida Dept. of Health and NOAA, continuing with MODIS



Experimental Cyanobacteria Health Bulletin: Mar 26, 2012

To report an illness related to a marine toxin or algal bloom please contact the Florida Poison Information Center-Miami Aquatic Toxins Hotline at 1-888-232-8635.
For questions about the report: contact Becky Lazensky, FL-DOH, at 352-955-1900. Images/data were obtained from Florida Water Management Districts, The National Oceanic and Atmospheric Administration (NOAA), NOAA National Climatic Data Centers and National Weather Centers. Support to produce this report was received through a NOAA/NASA Agreement (Number: NNH08ZDA001N)

Cyanobacteria HABs Conditions Report: March 26

- Lakes Apopka and Dora (Orange and Lake Counties) both displayed high estimated cyanobacteria concentrations.
- Newnans, Lochloosa, and Orange Lakes (Alachua and Marion Counties) displayed high estimated cyanobacteria concentrations.
- Lake Jesup (Seminole County) displayed high estimated cyanobacteria concentrations.

Does Your Agency Have Validation Data to Share with NOAA?

The satellite images we feature in this bulletin are currently in the experimental phase until a full scientific validation process is completed. As part of this process, we are always seeking water quality, phytoplankton, and algal toxin data for freshwater sites in Florida over 1 km in size. This information can be used to compare what is shown in the satellite imagery with actual field data and improve the accuracy of the final product.

If you have data that you feel may be useful for the satellite validation process, you can contact Becky Lazensky at: (352) 955-1900.

Example 3: Nutrients

- Considerable in situ data for Florida coast, but still some gaps in data
- Remote sensing-derived measurements could help populate data history
- Used SeaWiFs data to resolve chlorophyll concentrations along Florida coast
- Inferred nutrient concentrations using response relationship between nutrients and algal densities
- Remote sensing measurements were validated using ground-based data
- Supported development of reference condition for nutrient criteria and monitoring

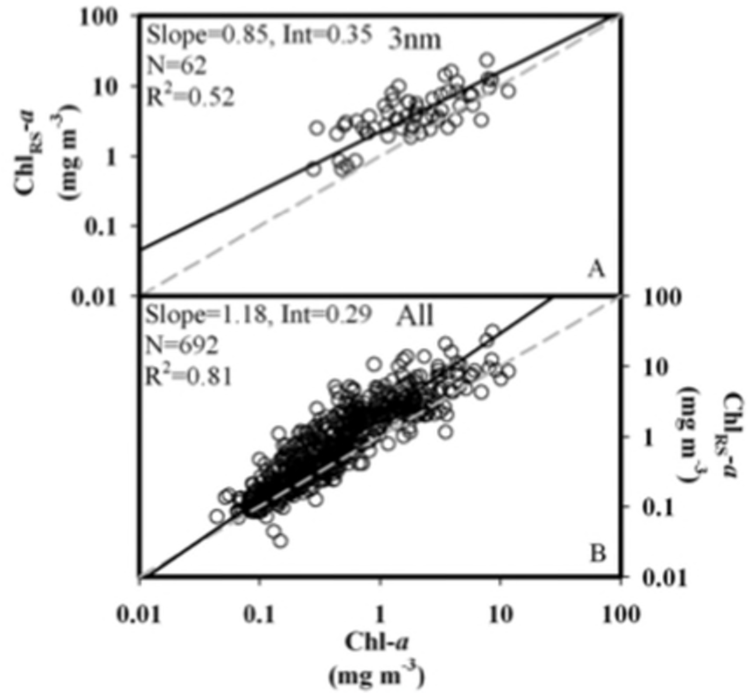


Figure 2. SeaWiFS observations of Chl_{RS}-*a* compared to in situ Chl-*a* from stations within coastal segments (A) and for all the stations (B). Gray dashed line is 1:1 fit and black line is regression slope. Plots are presented in log space, but regression coefficients have been converted to linear space to represent a linear regression formula of y = slope*x + intercept.

Schaeffer et al 2012, ES&T

Resources

NASA Applied Sciences Programs

http://appliedsciences.nasa.gov

Applied Remote SEnsing Training (ARSET)

Provides *free* webinar and hands-on training to access/use NASA data and products; http://water.gsfc.nasa.gov

NOAA Harmful Algal Bloom Bulletin http://www2.nccos.noaa.gov/coast/HABViewer.html

NASA data/product websites (free and available)

Reverb – the NASA Earth Science data and discovery tool

- Home page - http://reverb.echo.nasa.gov/reverb/
- Tutorial - http://www.echo.nasa.gov/reverb/tutorial/Tutorial.html

EOSDIS – NASA's Earth Observing System Data and Information System http://earthdata.nasa.gov/

NASA ocean color (ocean biology/biogeochemistry) http://oceancolor.gsfc.nasa.gov

NASA interactive visualizer and analyzer, Giovanni tool

http://disc.sci.gsfc.nasa.gov/giovanni

Bruce Monger Cornell Ocean Color Course (May 30-Jun 13, 2014) – (cost $, not a NASA endorsed course but it has excellent reviews) http://www.geo.cornell.edu/ocean/satellite/index.html

A few last thoughts…

- Research satellites (NASA is a research agency, not operational)
- NASA Applied Sciences works to bridge research to operations and support resource managers/operational partners in applications development and transition

Contact info slide

- Christine Lee (christine.m.lee@nasa.gov)
- Blake Schaeffer (schaeffer.blake@epa.gov)

Discussion

For each group (15-25 min)

Please have each person respond to these questions:

Quick questions:

- What is the purpose of your office and your role in your office? (summarize in the report out)

- What kinds of information do you rely on to respond to your water quality mandate? (% in situ; % models; % satellite imagery; % other)

- What about remote sensing appeals to you / how could it relate to your existing practices?

- What would you be interested in exploring with regards to remote sensing in the short term? In the long term?

- If your office were able to pilot a project to test the utility of remote sensing, what would need to be demonstrated in order to consider further consideration or investment? (In other words, what are your parameters for a successful demonstration of remote sensing for your application?)

Question 1

- Summarize the distribution of roles in your group? Were you mostly managers? Researchers?

Question 2

- Summarize: what kinds of information do you rely on to respond to your water quality mandate? (% in situ; % models; % satellite imagery; % other)

Question 3

- Summarize: What about remote sensing appeals to you / how could it relate to your existing practices?

Question 4

- Summarize: What would you be interested in exploring with regards to remote sensing in the short term? In the long term?

Question 5

- Summarize: If your office were able to pilot a project to test the utility of remote sensing, what would need to be demonstrated in order to consider further consideration or investment? (In other words, what are your parameters for a successful demonstration of remote sensing for your application?)

NASA DEVELOP Applications

- Let’s explore some of these ideas. Can any of them fit a 10-week timeframe? Please keep this in mind during Tiffani’s presentation.

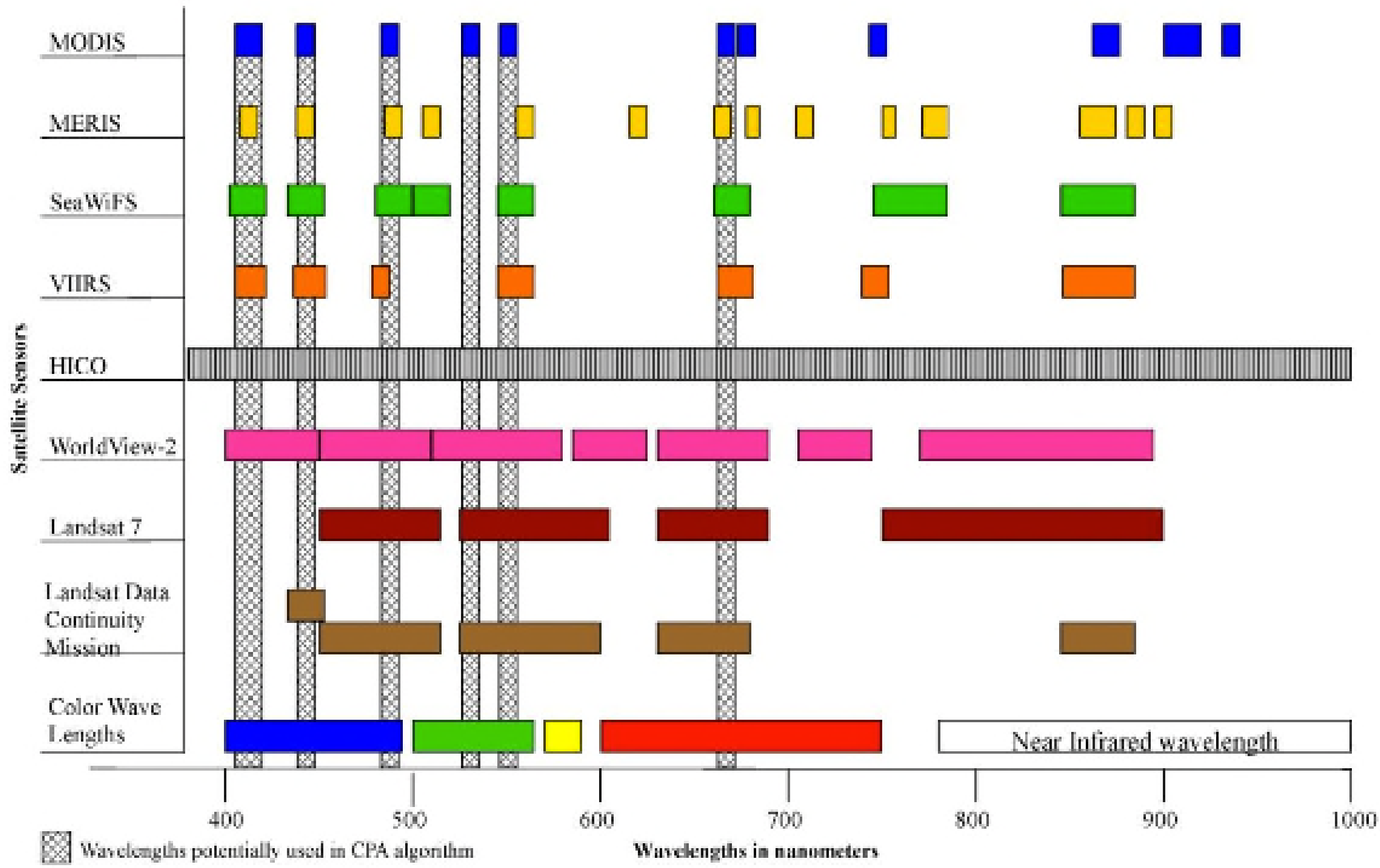
Summary of Satellite Systems for Ocean Color and Water Quality Measurements

Water Quality Measure Product	Sensor	Spatial Resolution	Temporal Coverage	Revisit Time
Lake Surface Temperature (LST)	MODIS	1 km	2002–Present	Daily
Color-Producing Agents (chl,doc,sm)	MODIS VIIRS MERIS CZCS SeaWiFS	250 m–1 km 750 m 330 m 1 km 1 km	2002–Present 2012–Present 2002–2012 1979–1986 1997–2011	Daily Daily 2–3 Days Periodic Daily
Optical Depth (Kd, PAR, Photic Depth)	Landsat MODIS VIIRS	30 m 250 m–1 km 750 m	1975–Present 2002–Present 2012–Present	16–17 Days Daily Daily
Harmful Algal Blooms (HABs)	MODIS VIIRS MERIS	250 m–1 km 750 m 330 m	2002–Present 2012–Present 2002–2012	Daily Daily 2–3 Days
Submerged Aquatic Vegetation (SAV)	Landsat MODIS VIIRS MERIS	30 m 250 m–1 km 330 m 750 m	1975–Present 2002–Present 2002–2012 2012–Present	16–17 Days Daily Daily 2–3 Days
Sediment Plume (TSSIGL)	MODIS VIIRS MERIS CZCS SeaWiFS Landsat	250 m–1 km 750 m 330 m 1 km 1 km 30 m	2002–Present 2012–Present 2002–2012 1979–1986 1997–2011 1975–Present	Daily Daily 2–3 Days Periodic Daily 16–17 Days
Primary Productivity (PP)	MODIS VIIRS MERIS CZCS SeaWiFS	250 m–1 km 750 m 330 m 1 km 1 km	2002–Present 2012–Present 2002–2012 1979–1986 1997–2011	Daily Daily 2–3 Days Periodic Daily

Additional surface wind speed and direction, remote sensing products, wetland maps, lake ice extent and concentration

SOURCE: http://www.mtri.org/workshops/nasagreatlakes2014/assets/for_website/Shuchman_RSalgorithms.pdf

Ocean Color Satellite Band Comparison



http://www.mtri.org/workshops/nasagreatlakes2014/assets/for_website/Shuchman_RSalgorithms.pdf

Regions of the Electromagnetic Spectrum

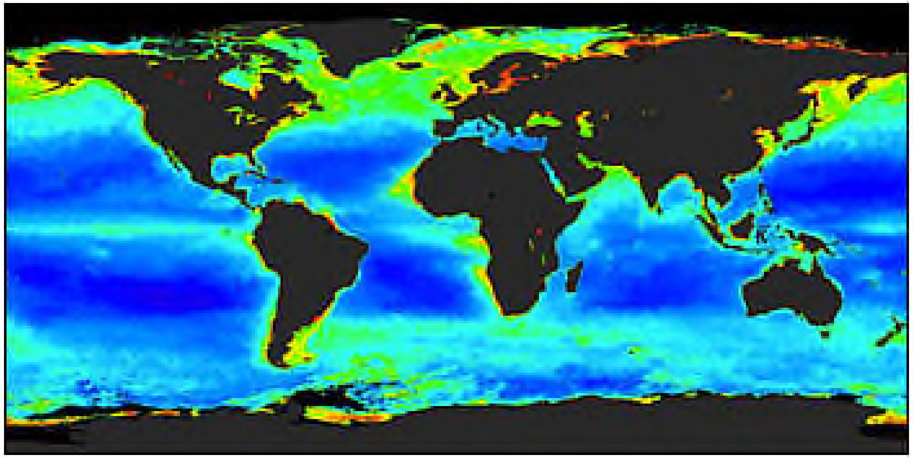
Gamma ray	*<0.03 nm*
X-ray	*0.03 - 3 nm*
Ultraviolet	*3 – 400 nm*
Visible	*400 - 700 nm*
Near infrared	*0.7 - 1.3 mm (micrometers)*
Mid-infrared	*1.3 - 3.0 mm*
Thermal (far) infrared	*3.0 - 5.0 mm AND 8 - 14 mm*
Microwave	*0.3 - 300 cm*
Ultrahigh Frequency (UHF)	*10 – 100cm*
Very High Frequency (VHF)	*1 – 10m*

mm - micrometers (10^{-6} m)
nm – nanometers (10^{-9} m)

Sea-viewing Wide Field-of-view Sensor (SeaWiFS)

http://oceancolor.gsfc.nasa.gov/SeaWiFS/

1997: The Sea-viewing Wide-field-of-view sensor, the only sensor onboard the OrbView-2 satellite, was launched into low-Earth orbit from a Pegasus rocket attached to the belly of a modified Lockheed L-1011 aircraft. Data gathered from SeaWiFS is helping scientists identify oceanic "hot spots" of biological activity, measure global phytoplankton biomass, and estimate the rate of oceanic carbon uptake. This information will yield a better understanding of the sources and sinks in the carbon cycle and the processes that shape global climatic and environmental change.



SeaWiFS ocean chlorophyll data from 1998. Low concentrations of phytoplankton are represented by purple and blue shades, high concentrations are yellow, orange, and red. (Image courtesy NASA SeaWiFS project)