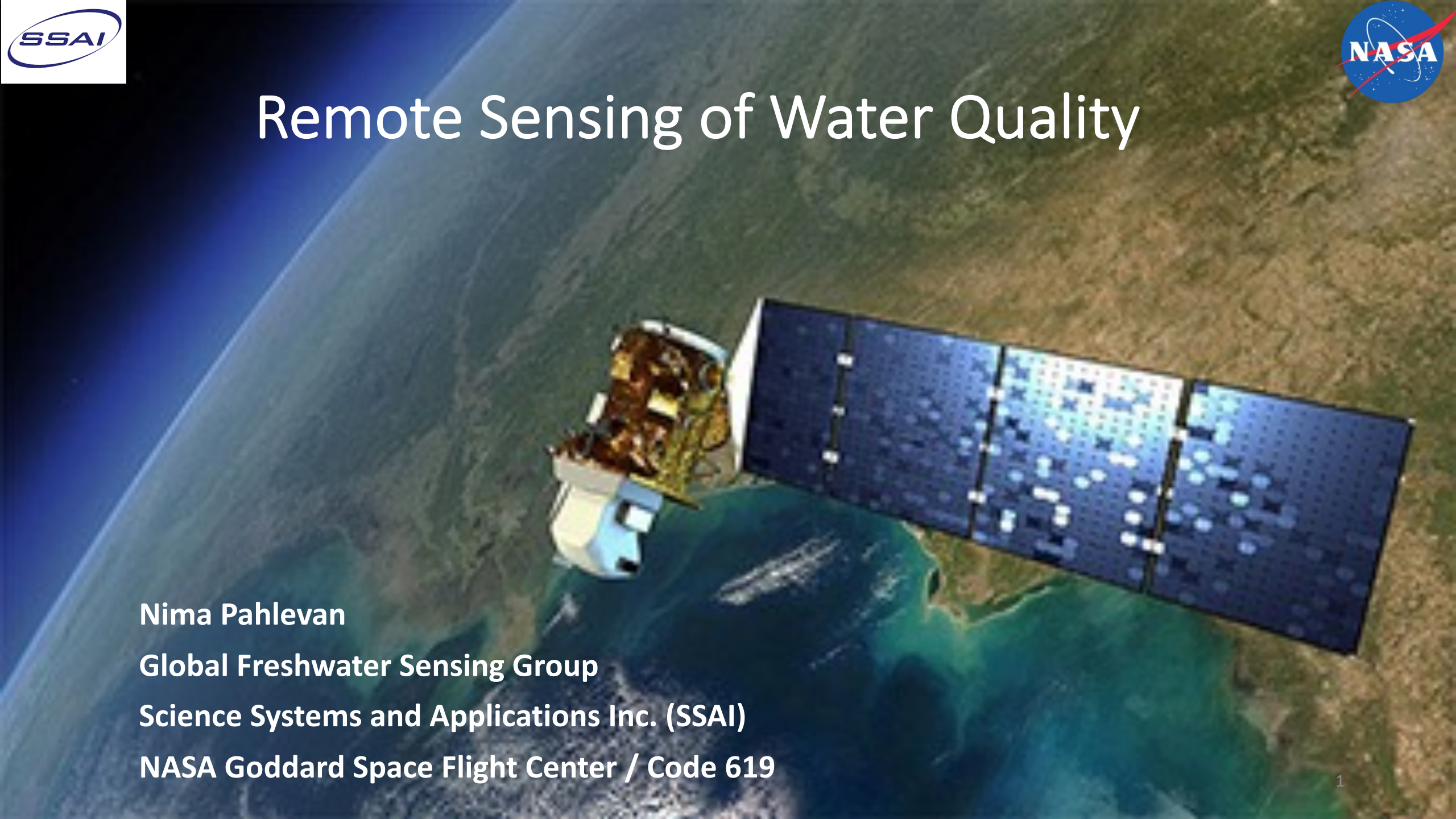
Remote Sensing of Water Quality



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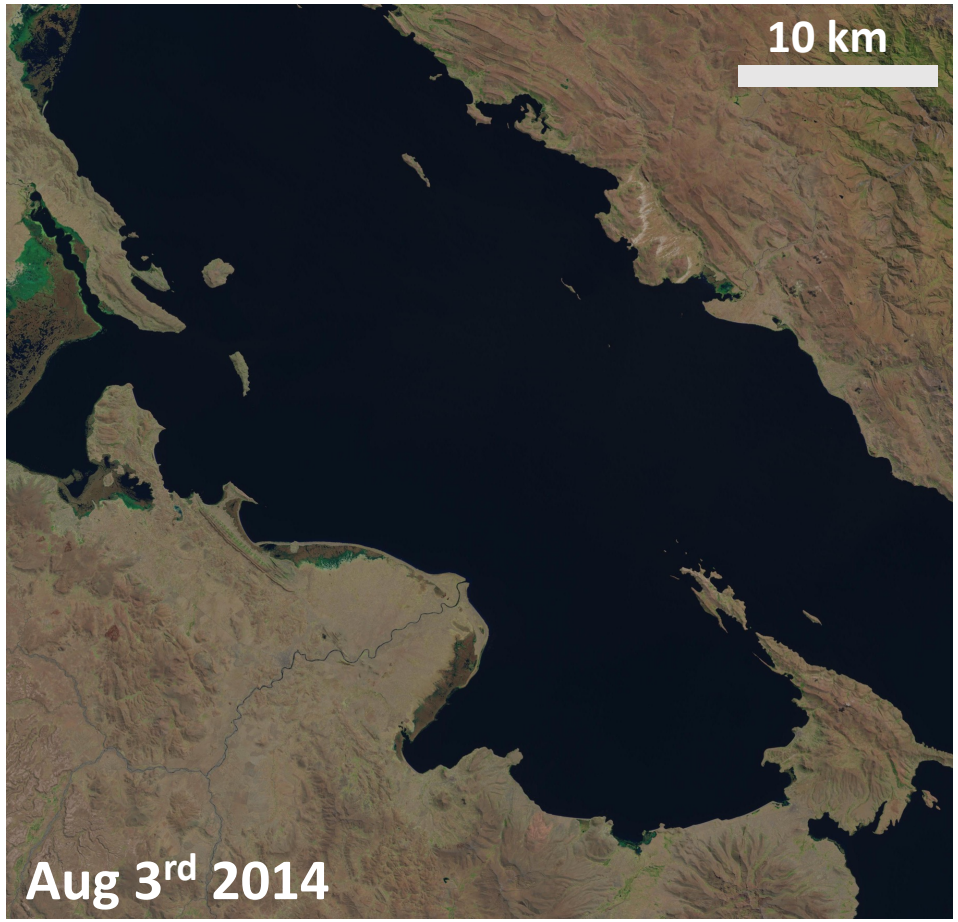
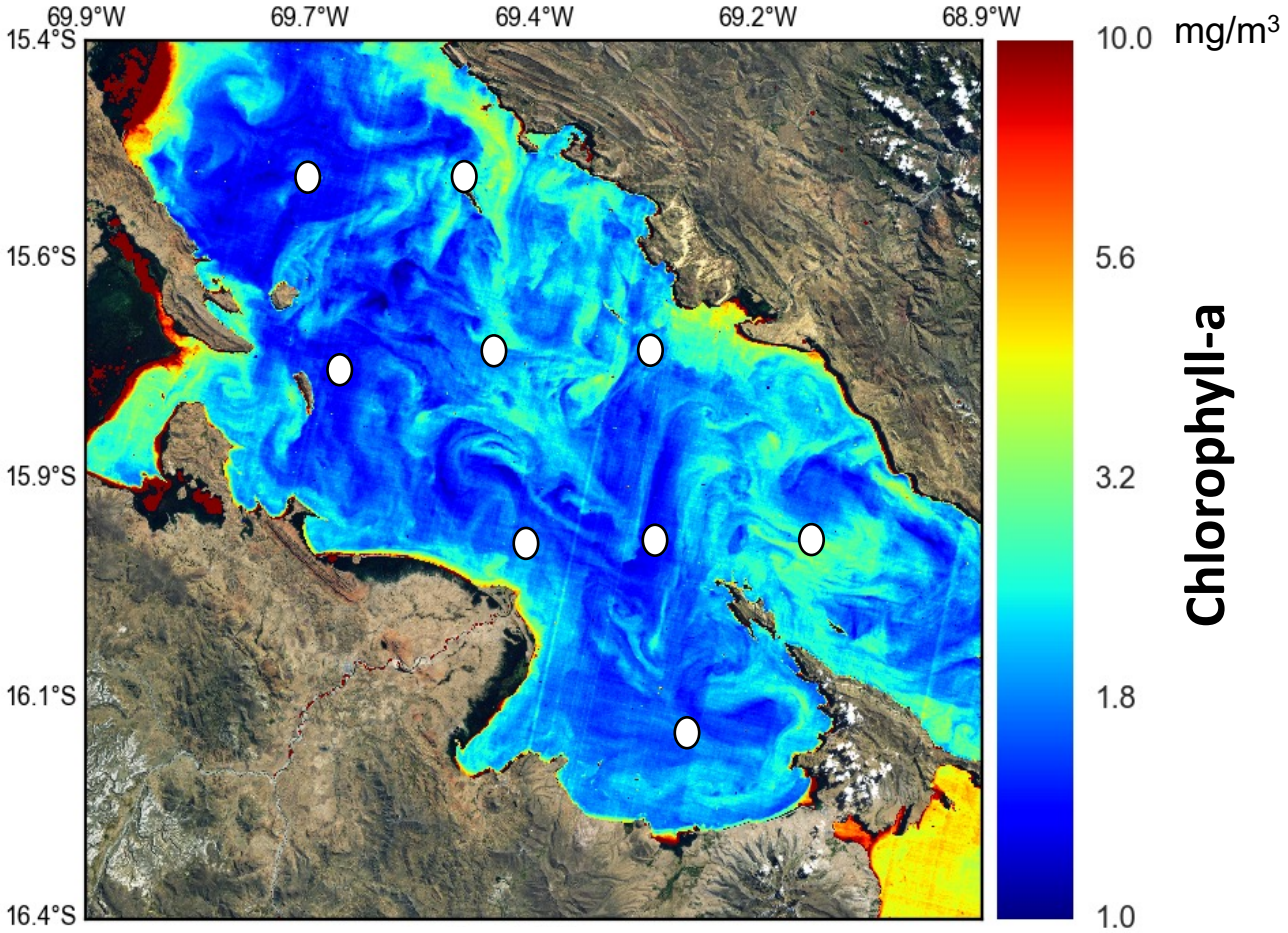
Outline

- Role of remote sensing in water quality
- Brief theoretical background
- How are water quality maps generated?
  - Satellite sensors
  - Atmospheric correction
  - Algorithms for water quality estimation
  - Product validation
  - Product availability
- Summary

The Art of Remote Sensing Science: Turning an image into information



Lake Titicaca



The Art of Remote Sensing Science: Turning an image into information

Satellite sampling

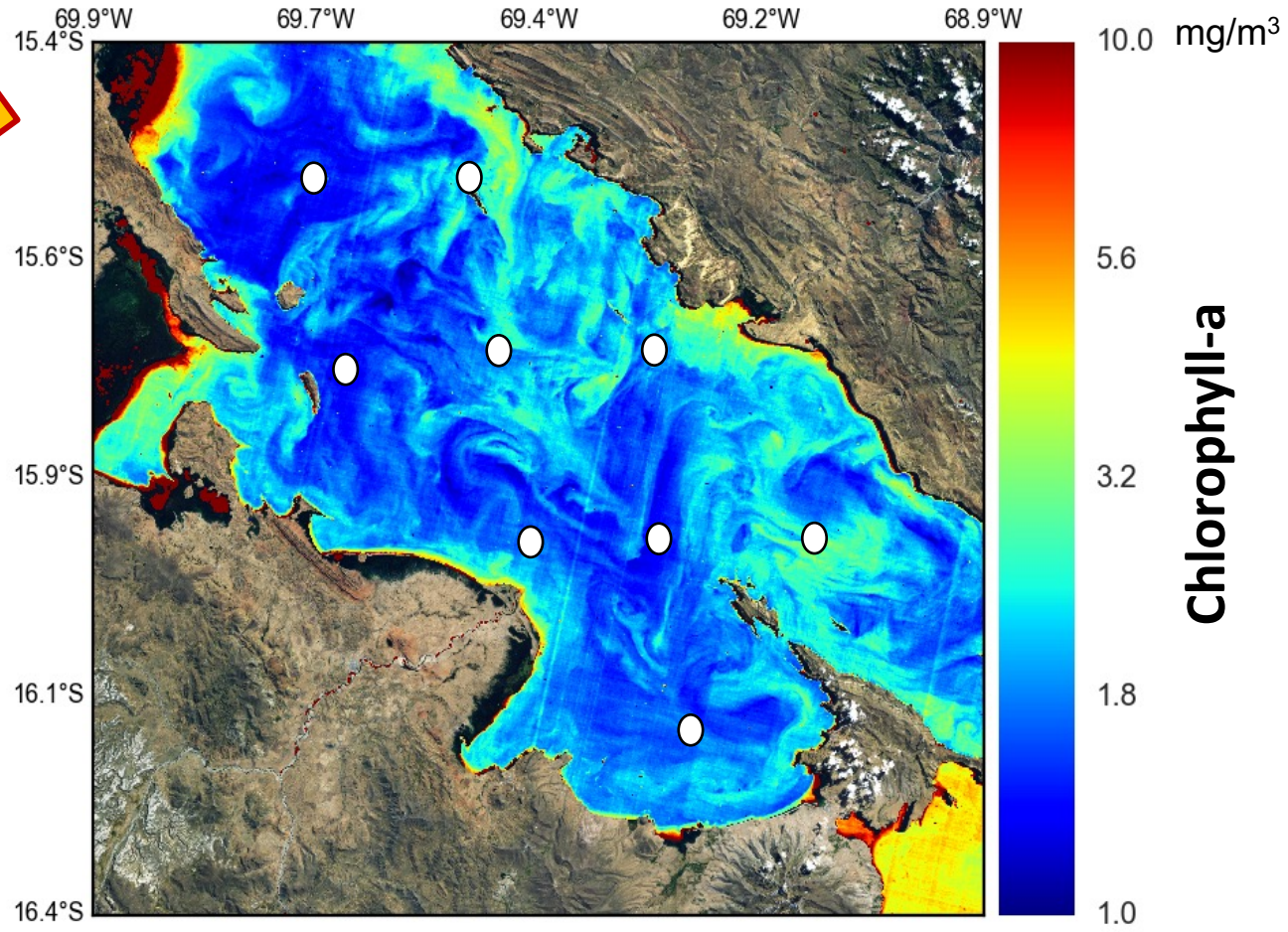
(**Covers Large Areas**)

Vs

ampling

(**Acc ut Limited in Space**)

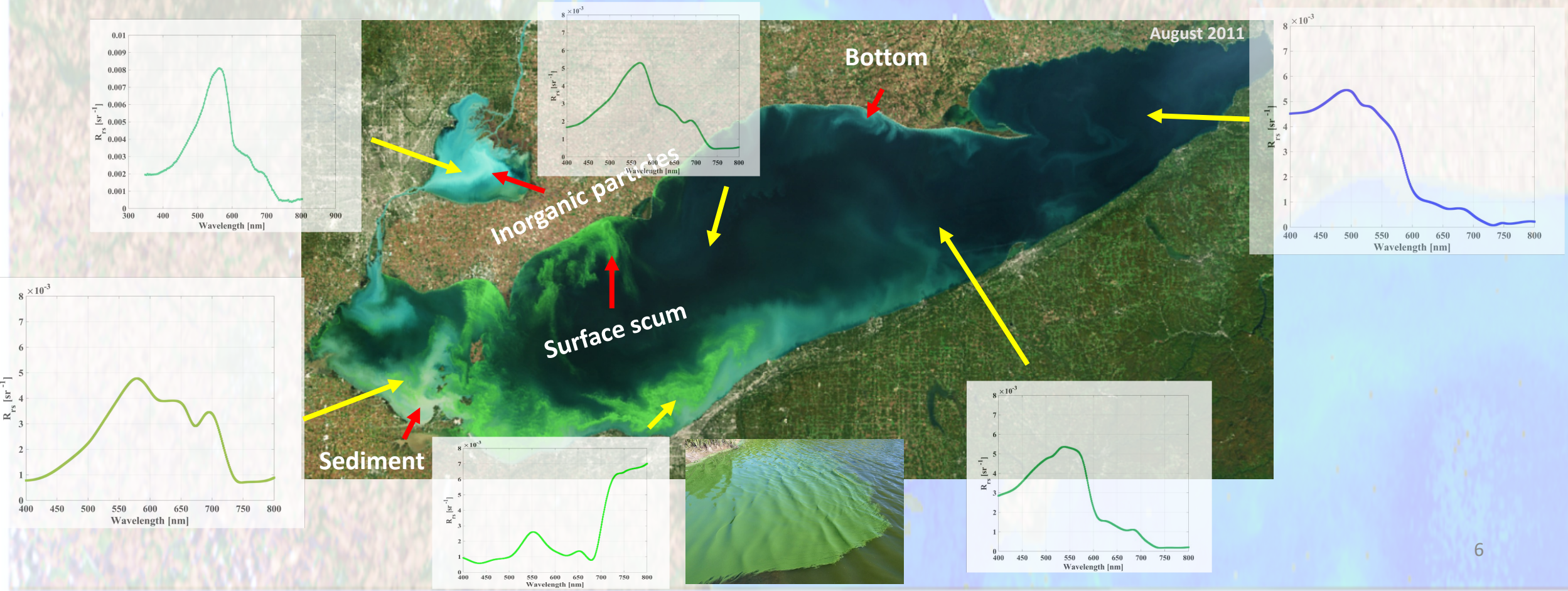
SATELLITE AND FIELD SAMPLING ARE COMPLEMENTARY

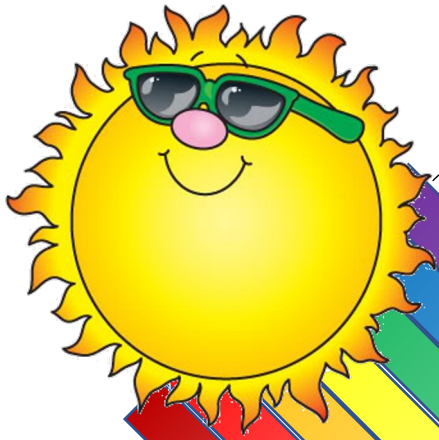


- Satellites in Low-Earth-Orbits (LEOs) travel in near-circular (polar) orbits.
- Each orbit takes ~ 90 minutes to complete.
- As satellite orbits the Earth, onboard sensors (cameras) sweep across track to form images.

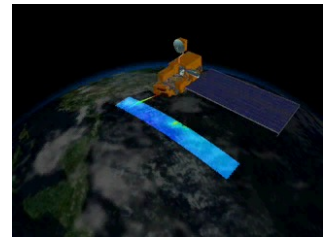
Quantity of Interest

- Water color is physically quantified by measuring water-leaving radiance (L_w), which is commonly normalized by downwelling solar irradiance to arrive at remote-sensing reflectance (R_{rs}; sr^{-1}).





*Measurements of water color are based on electromagnetic energy emitted by sunlight, transmitted through atmosphere, and **reflected** by Earth's surface.*



Downwelling Irradiance, E_d

UV

B

G

Y

O

R

NIR

Water-leaving Radiance, L_w

AIR

Water

There are two possible things that can happen to a photon in water

BACKSCATTERING (b_b)

Algal Particles

Non-algal Particles

Organic Matter

ABSORPTION (a)

$R_{rs} \sim L_w/Ed$

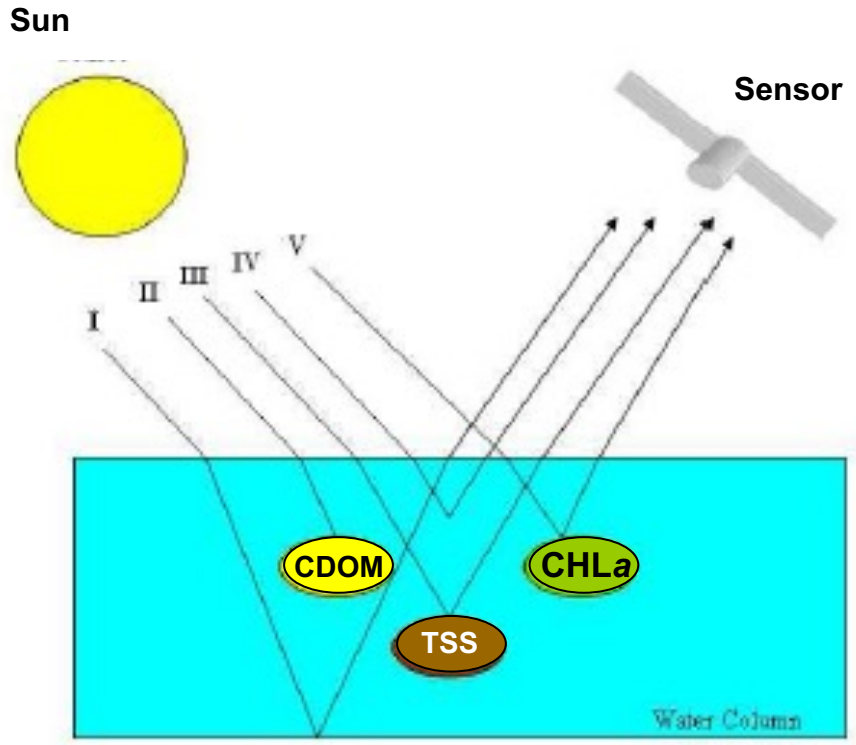
Which Water Quality (WQ) Indicators Can Be Quantified?

- Pigments (e.g., Chlorophyll-a (Chl*a*), Phycocyanin (PC))
- Total Suspended Solid (TSS)
- Colored Dissolved Organic Matter (C
- Turbidity
- Secchi Disk Depth (SDD) clarity/transparency

  - **Inverse Mod**

$$=F\left(\frac{b_{\mathrm{b}}(\lambda)}{a_{\mathrm{t}}(\lambda)+b_{\mathrm{b}}(\lambda)}\right)$$

There is also surface temperature!!

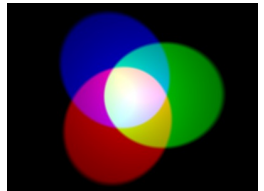


b_b Total backscattering

a Total absorption

R_{rs} Remote Sensing Reflectance

Note: Remotely sensed WQ estimates correspond to near-surface waters



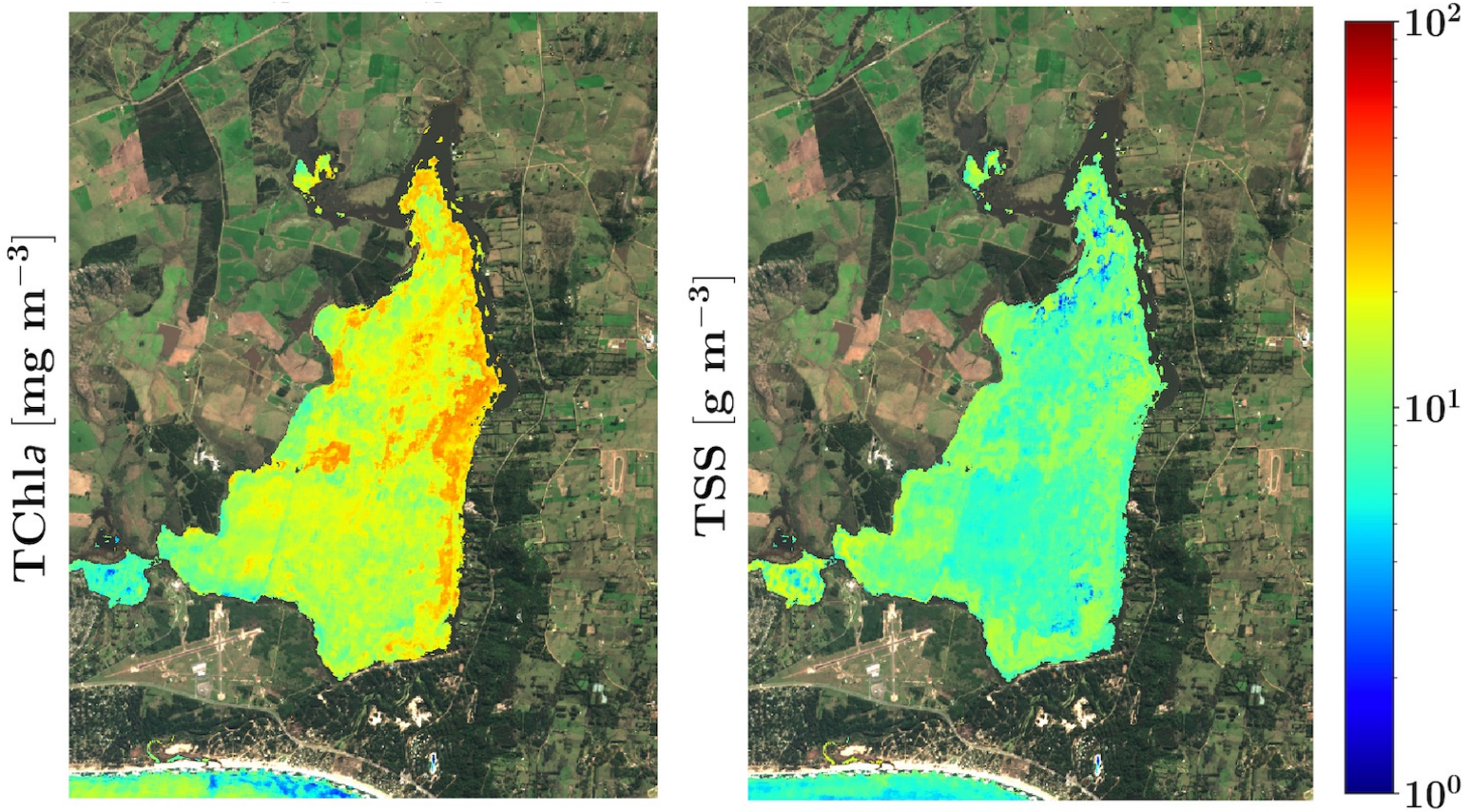
How About Other WQ Indicators?

RS

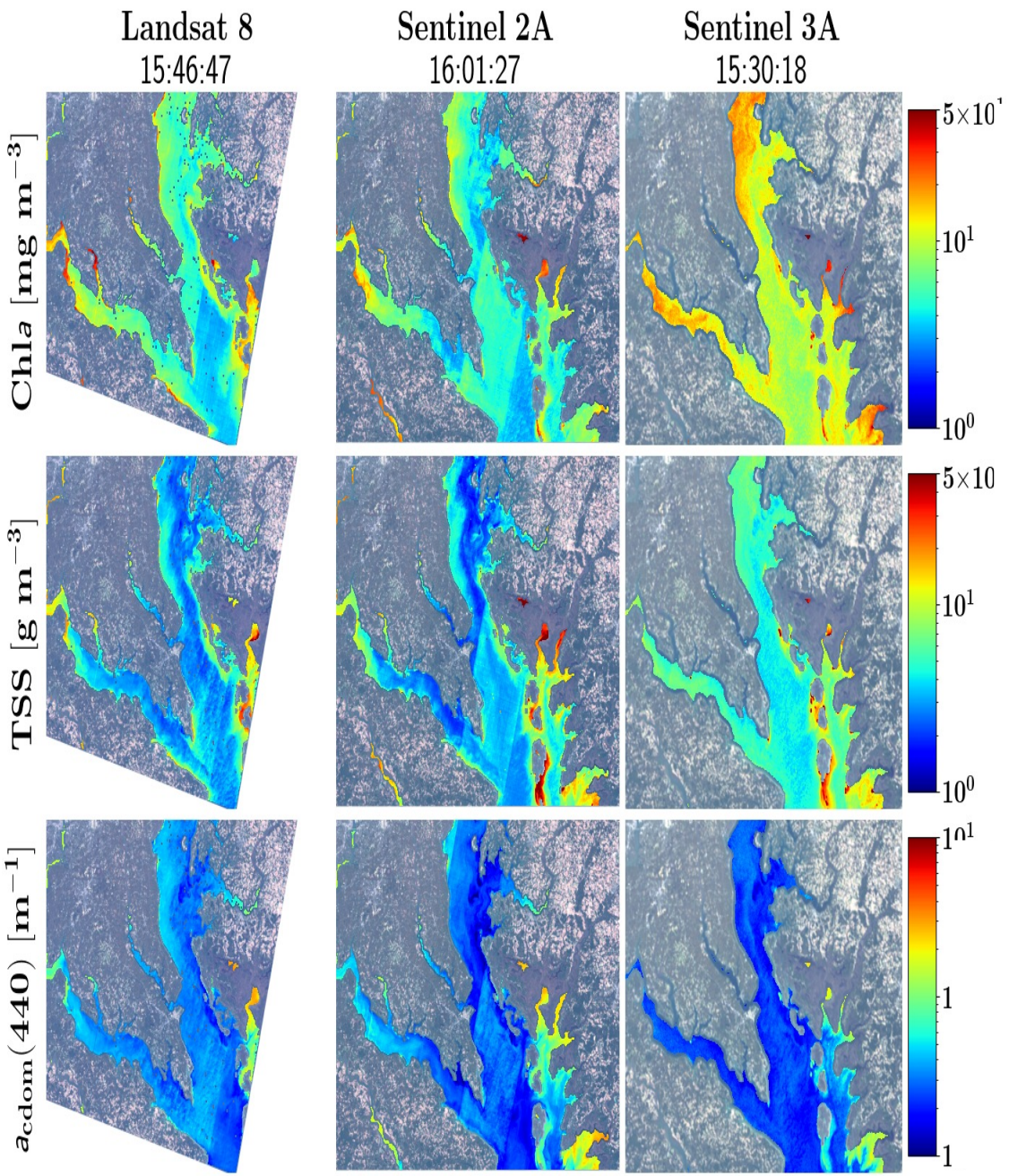
Turbidity
Chlorophyll-a
Total Suspended Solids

Dissolved Oxygen
Electrical Conductivity
pH
Nitrate
Phosphorous

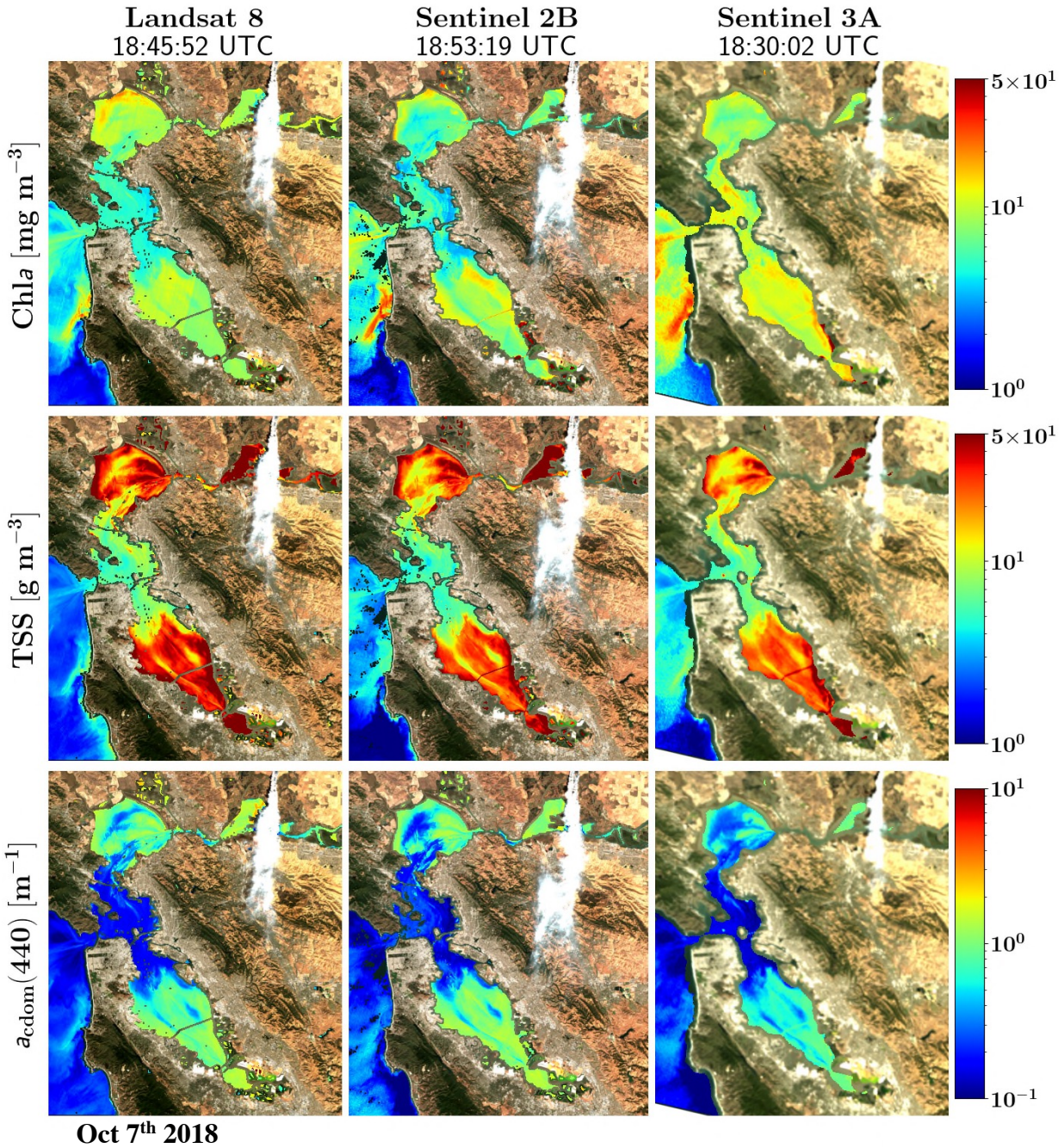
July 11th 2020



RS: Remote Sensing



Nov 7th 2016

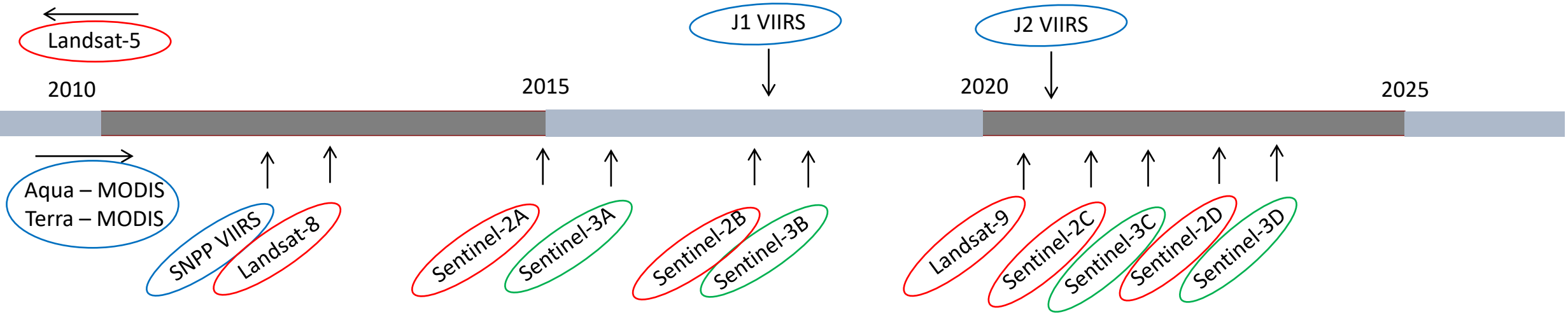


Oct 7th 2018

How are satellite images processed to WQ products?

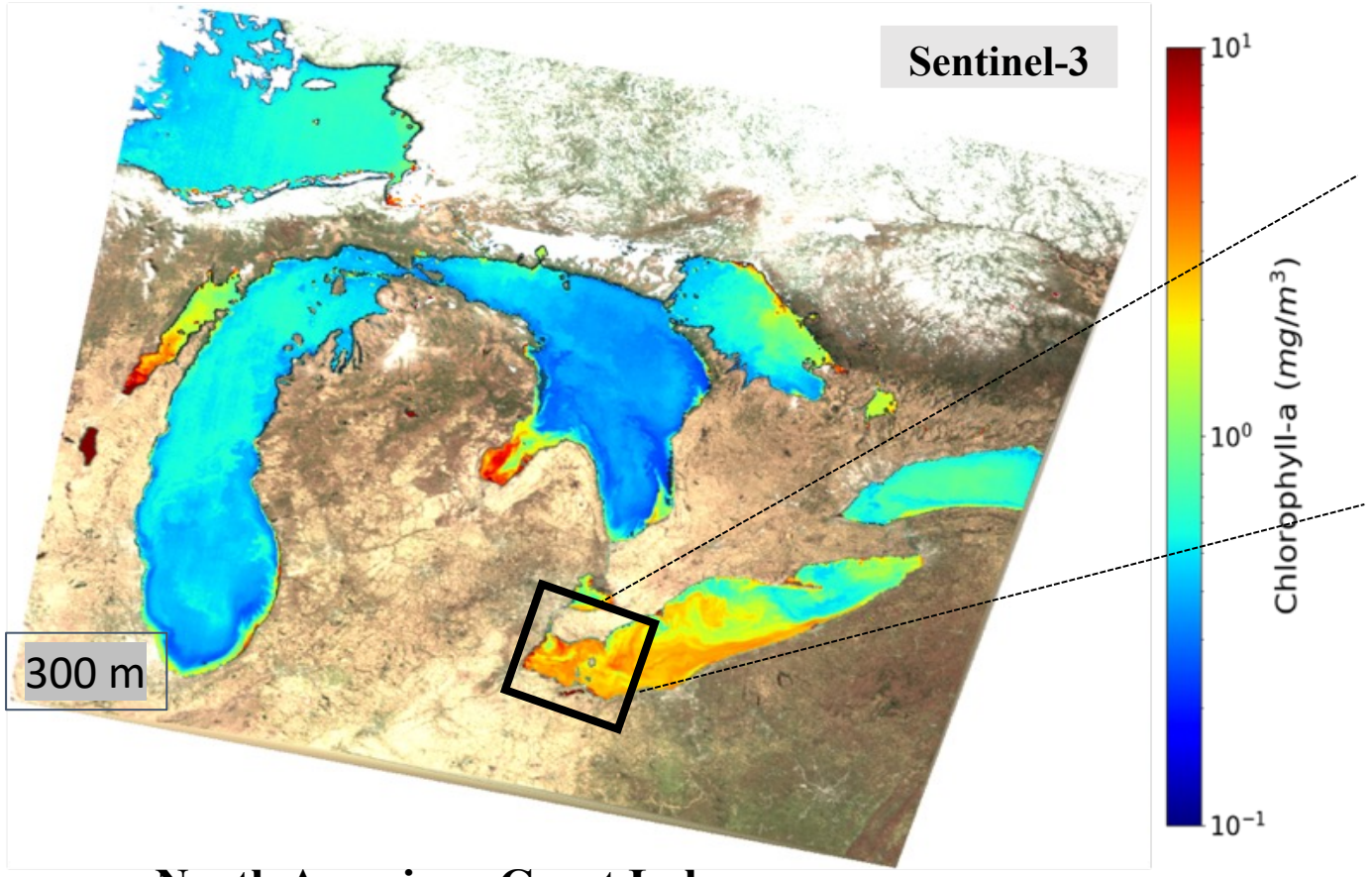
A. Satellite Sensors

- Make high-quality measurements of light within the visible & near-infrared spectrum

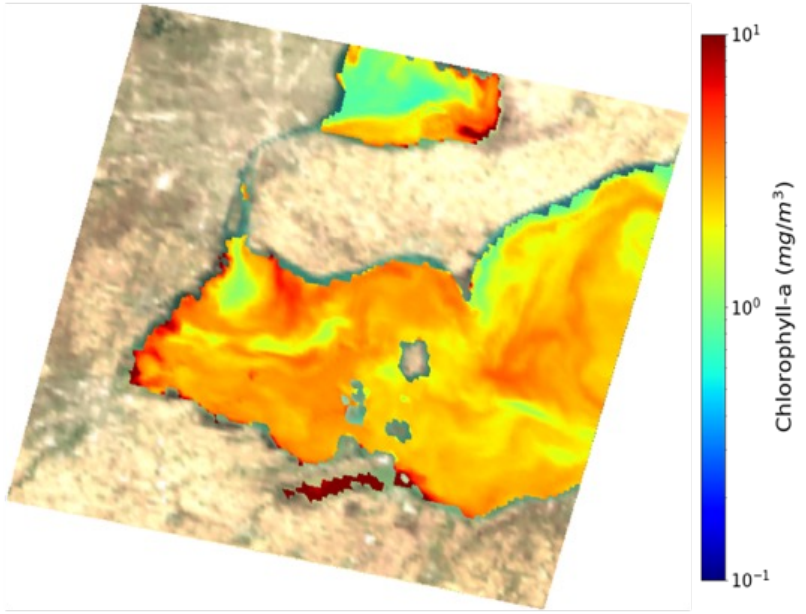


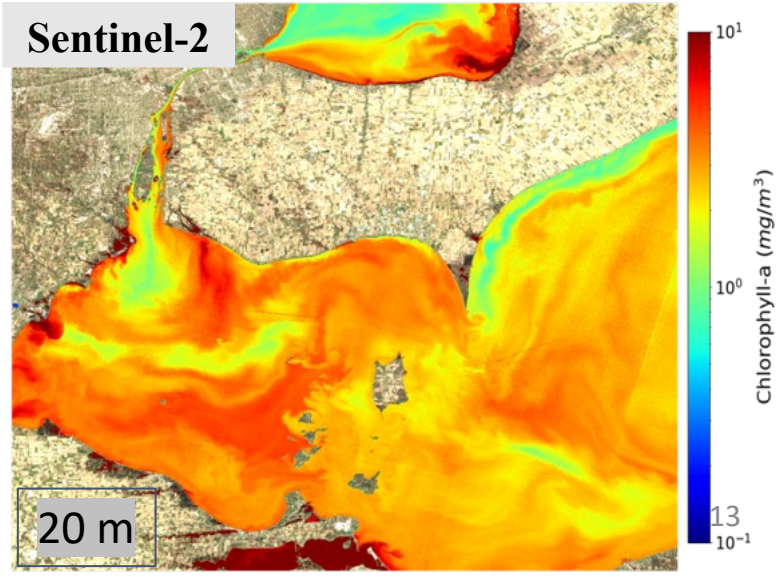
Spatial Resolution	Temporal Resolution
10-30 m	5-16 days
300 m	Alternate day
750 - 1000 m	Daily

Spatial Resolution Example (20 m Vs. 300 m)



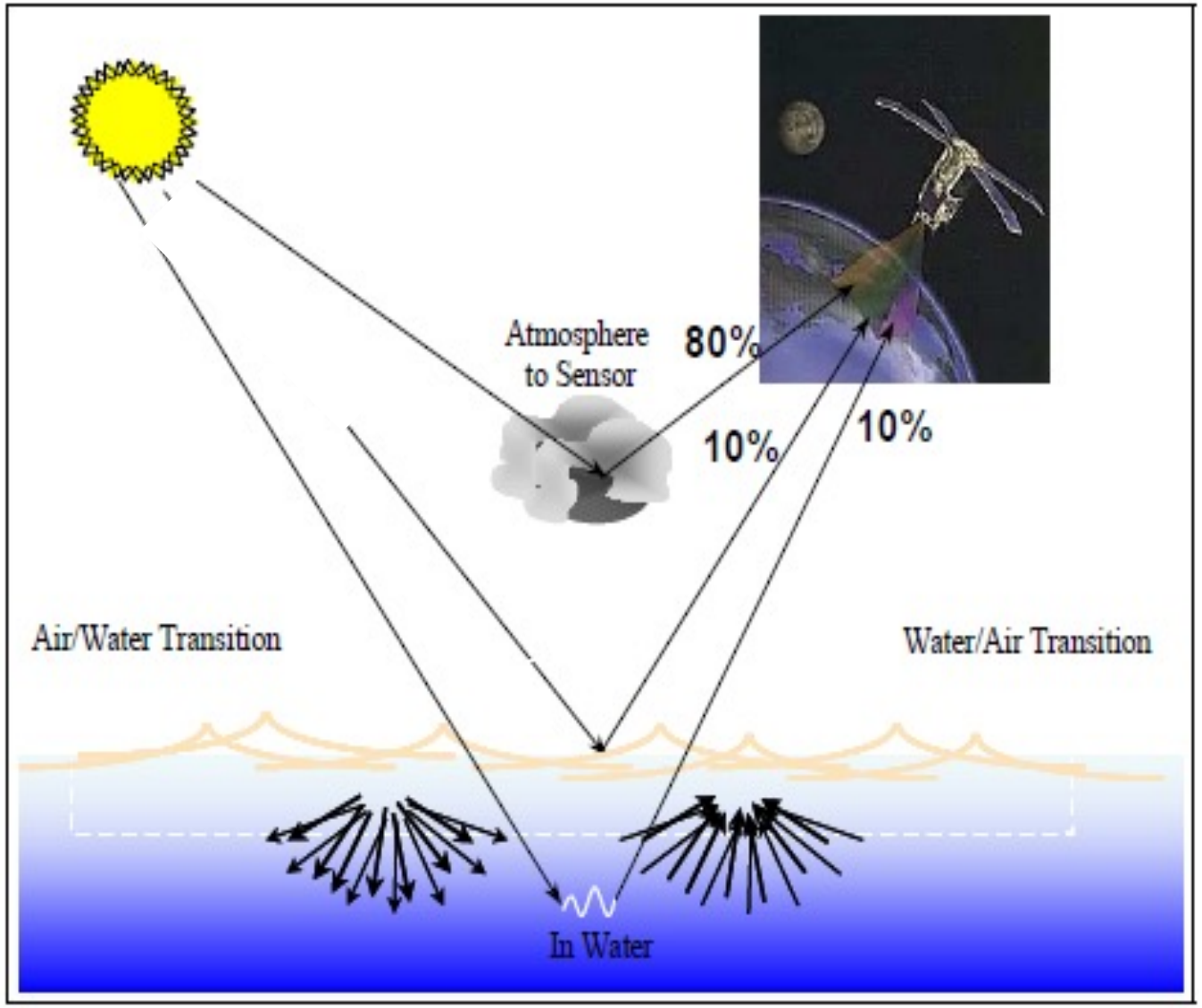
North American Great Lakes
April 30th 2018

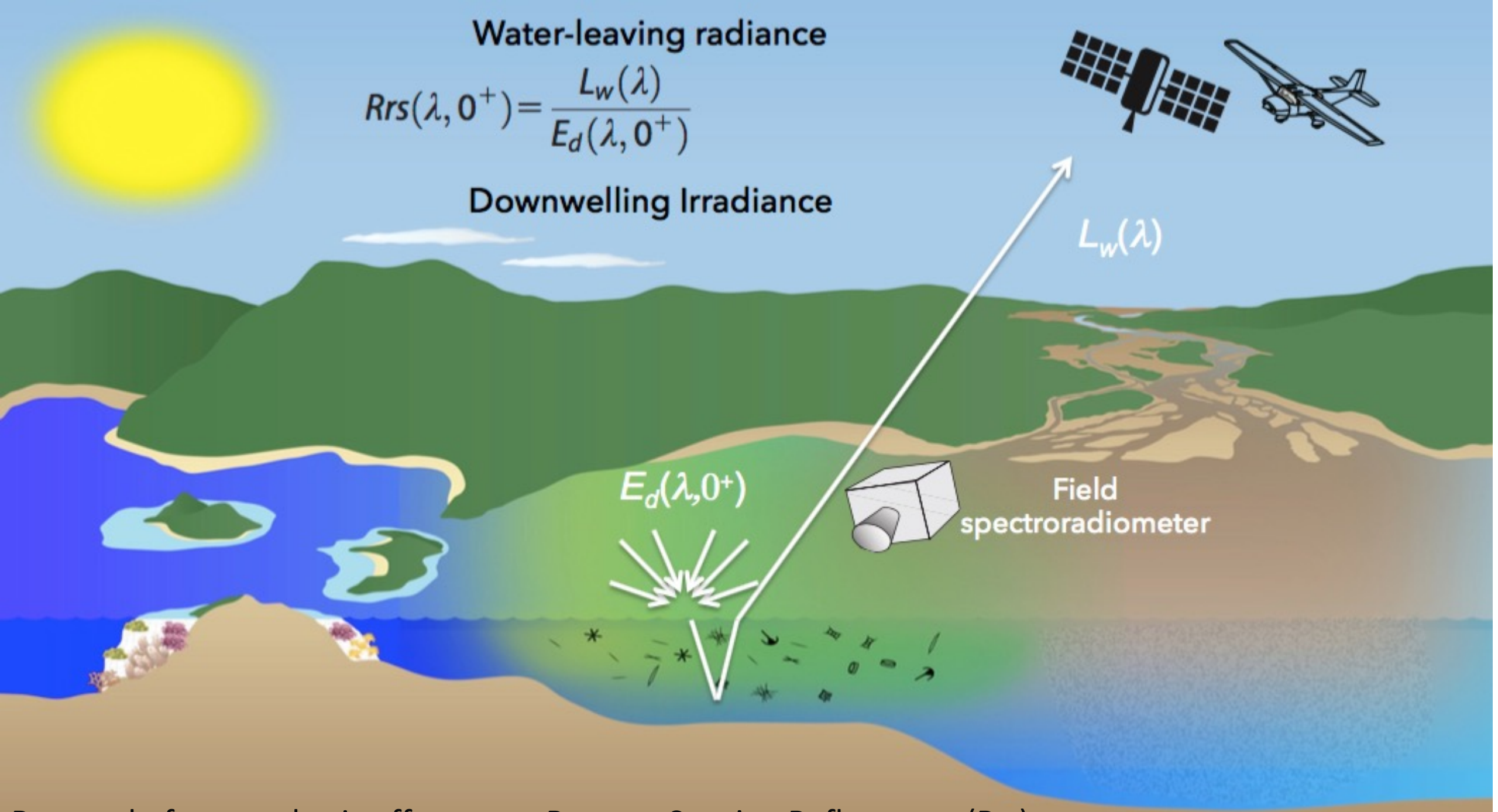




B. Atmospheric Correction

- Most challenging step for generating WQ products
- A large fraction of light reaching satellite sensors originate from atmospheric scattering and absorption
- Several atmospheric correction methods are available – but none are ideal.

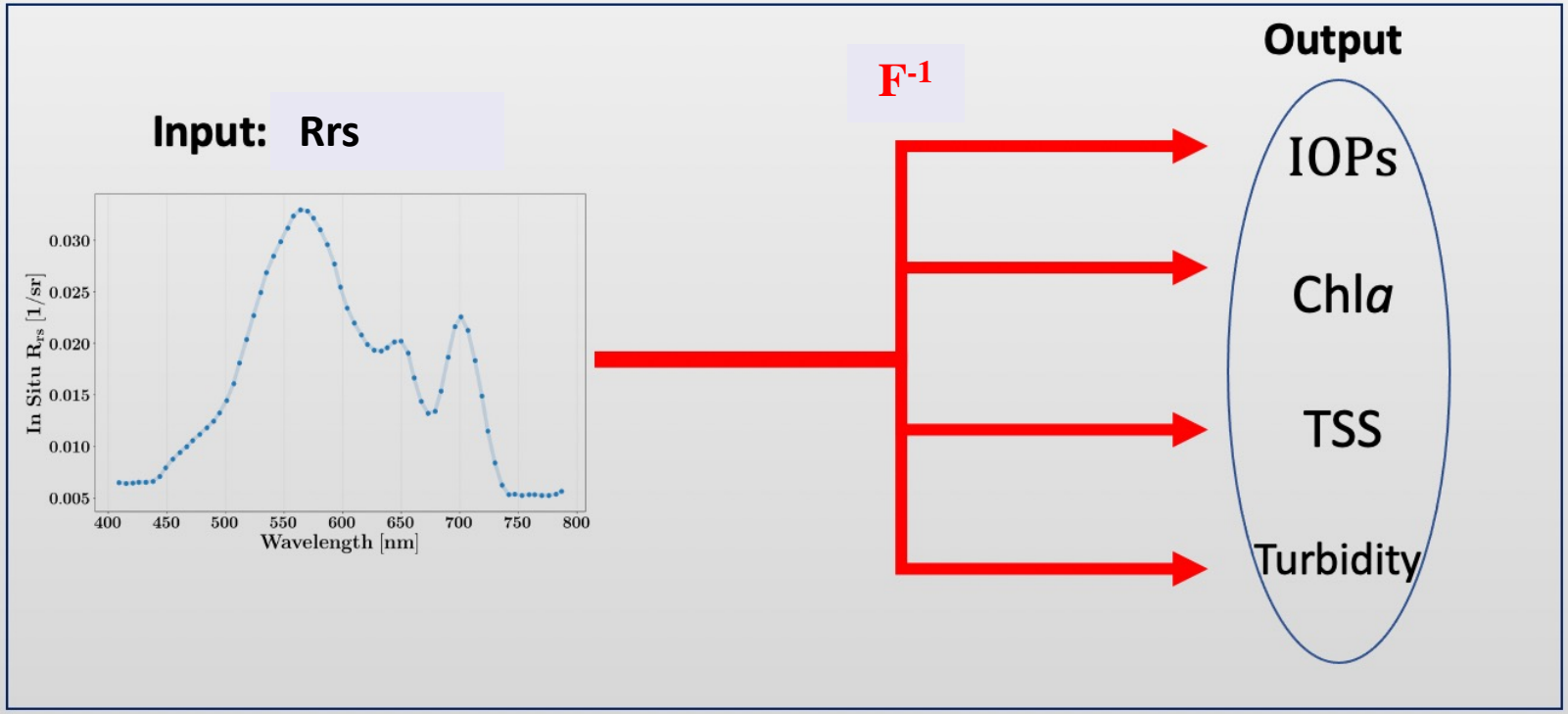




Removal of atmospheric effects --- > Remote Sensing Reflectance (R_{rs})

Credit: https://arset.gsfc.nasa.gov

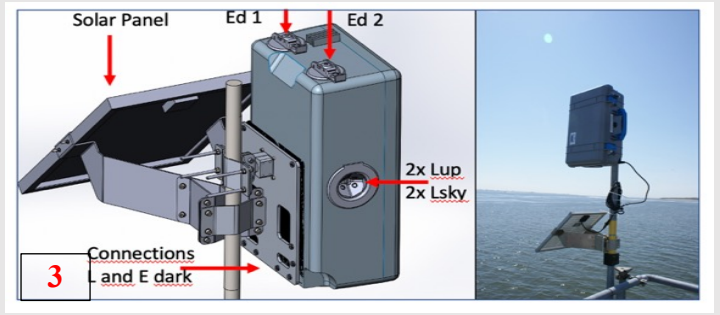
C. Algorithm development for estimating WQ variables

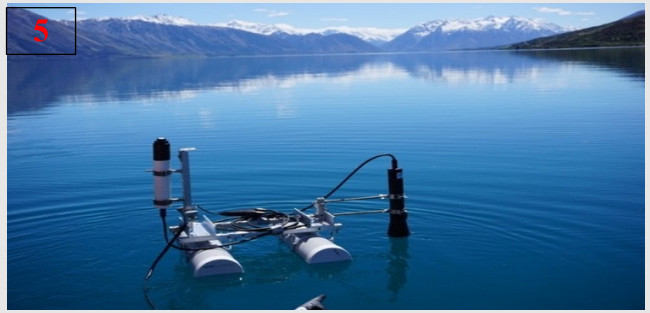


- Inherent Optical Properties (**IOPs**)
  - a_{ph}, b_{bp}, a_{nap}, a_{cdom}, VSF, …
- *Pigment concentrations*
  - Chl*a*, phycocyanin *(PC), phycoerythrin (PE), …*

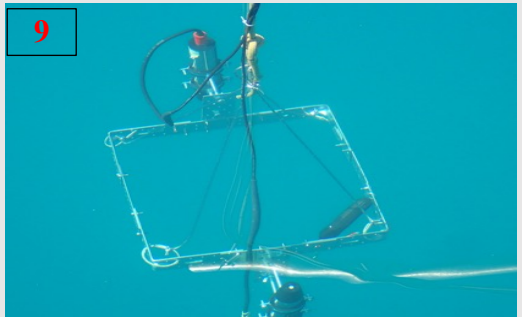
- Other quantities/parameters
  - Acquisition geometry

Field Data Collection

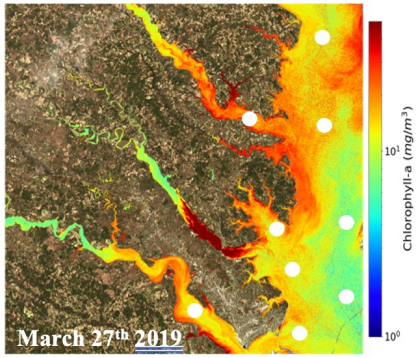




Co-located measurements of radiometry (R_{rs}), Chla, IOPs, Turbidity, and other non optically relevant parameters are required



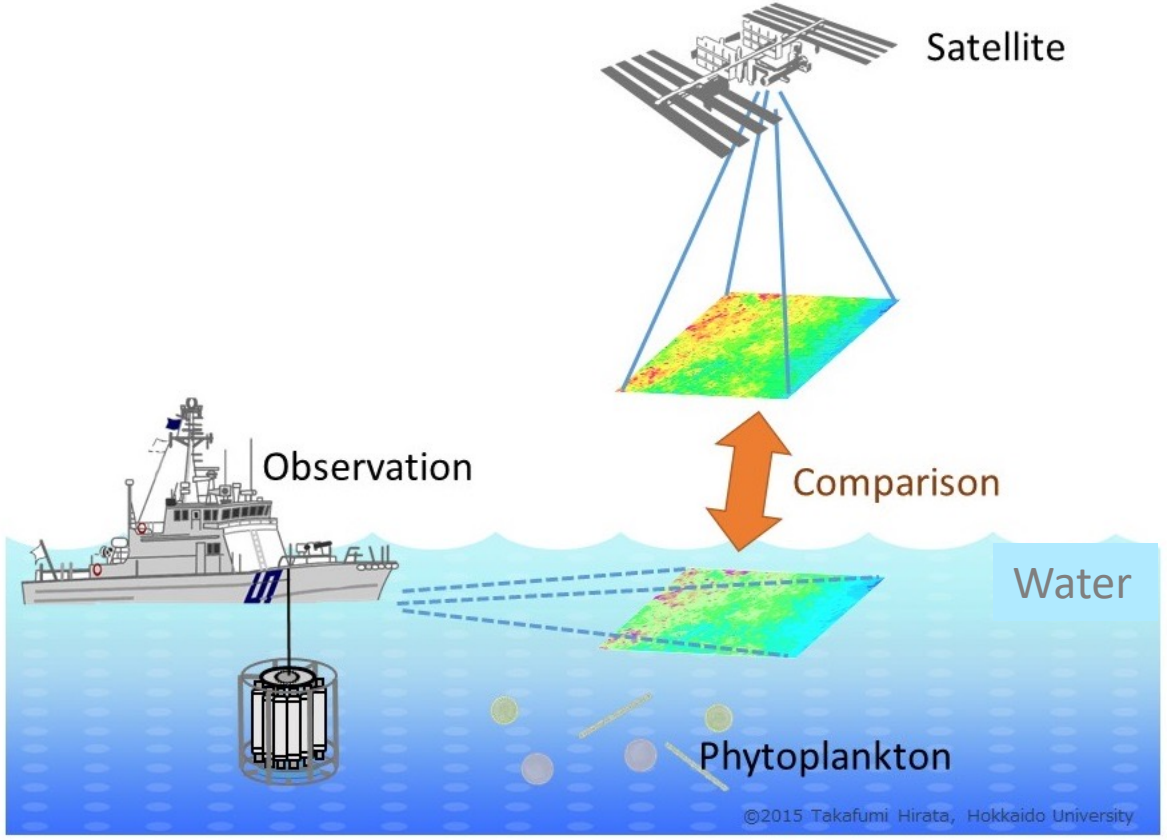
D. Validation



- To determine the quality of satellite-derived water quality products

1. **Quantitative**
   - In situ measurements of near-surface conditions are made ideally **one hour** before or after satellite overpass
   - Depending on the temporal variability of the ecosystem, +/- 24 hours may be practical.

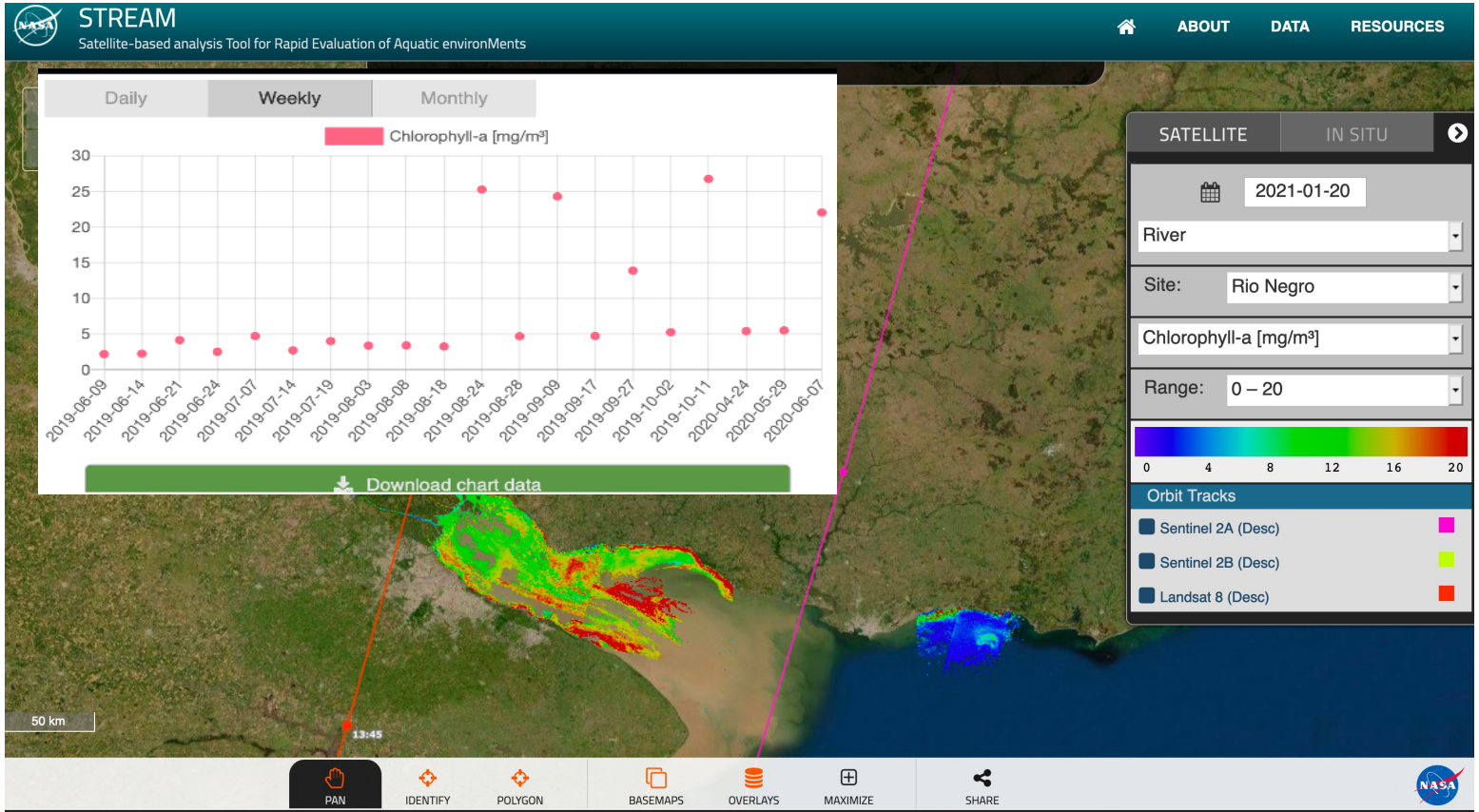
2. **Qualitative**
   - Evaluate time-series data via experts' knowledge

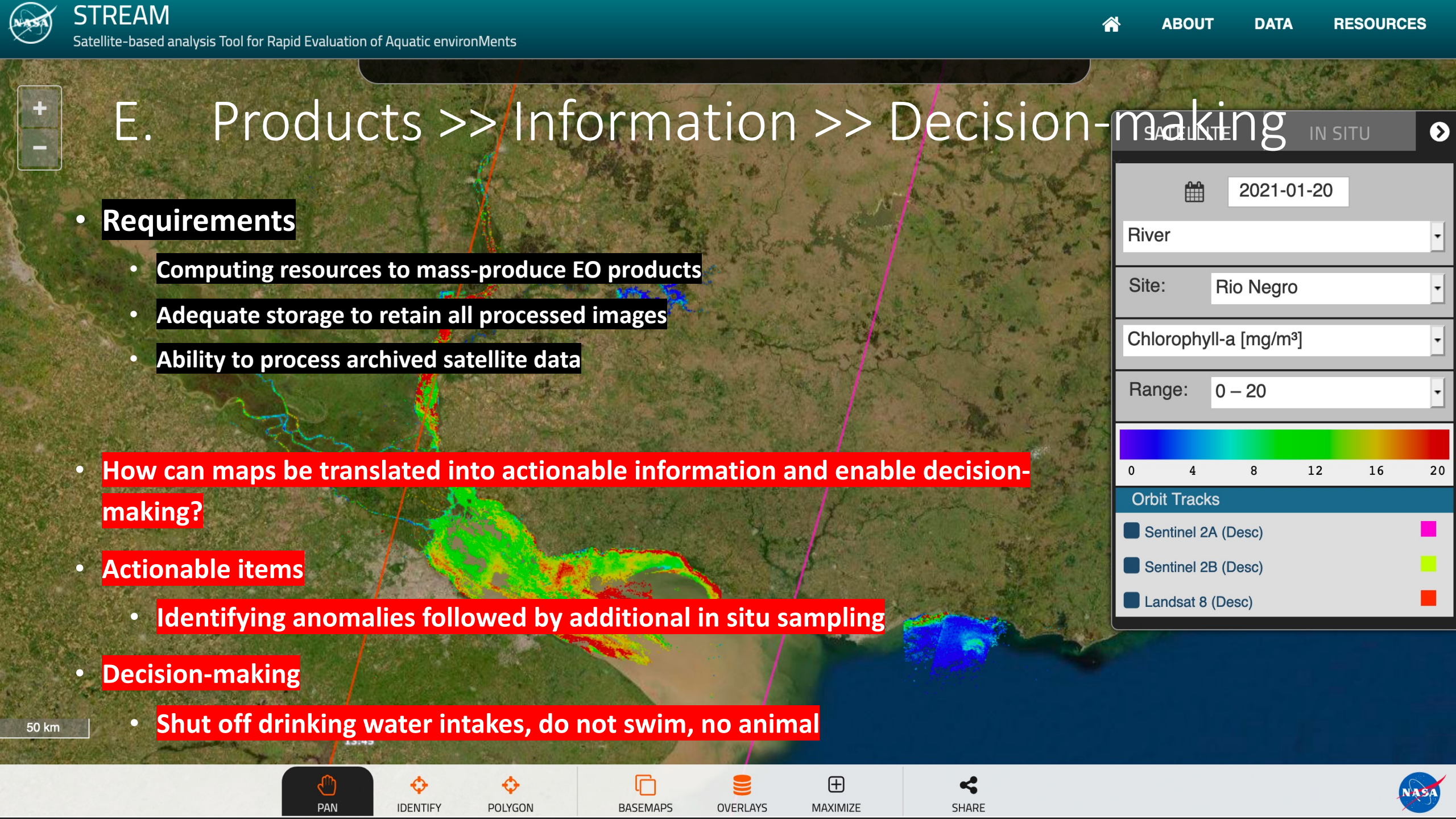


- Satellite overpass times
  - 10:00 – 14:00 (local time)

E. Satellite-based WQ Monitoring Tools

STREAM: **S**atellite-based analysis **T**ool for **R**apid **E**valuation of **A**quatic environ**M**ents





- **Requirements**
  - **Computing resources to mass-produce EO products**
  - **Adequate storage to retain all processed images**
  - **Ability to process archived satellite data**
- **How can maps be translated into actionable information and enable decision-making?**
- **Actionable items**
  - **Identifying anomalies followed by additional in situ sampling**
- **Decision-making**
  - **Shut off drinking water intakes, do not swim, no animal**

Benefits of Remote Sensing for WQ Monitoring

- Save money
  - Guided sampling (**where and when** to sample water)
  - Monitoring remote (hard-to-access) waterbodies

- Others
  - Reporting Sustainable Development Goals 632/661
  - Frequent sampling
  - Large-area monitoring
  - Identify hotspots (e.g., dead zones causing fishkill and harming aquaculture)

Limitations of Remote Sensing for WQ Monitoring

- Products require field validation
- Satellite estimates may not be as accurate as field measurements
- Cloud cover, cloud shadows, and haze
- Estimated variables correspond to near-surface water column
- Product uncertainties in clear waters, where bottom can be seen, increase
- WQ variables generally encompass optically relevant parameters only

Discussion: Integrating Satellite Technology into Decision-making Activity in South America

- What are the pressing issues? HABs?
- What are the challenges in satellite data product uptake?
- What is missing?

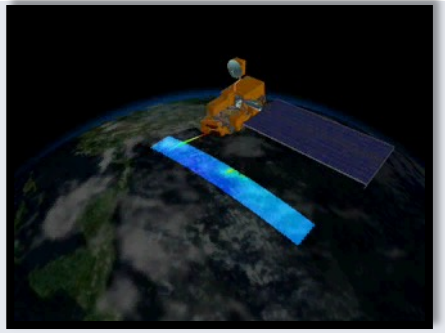
- Propose a pilot study: Focus on specific regions within South America

  - RS community: a) Identify optimal processing approaches, b) Enable access to RS products, c) Facilitate joint research developments, and c) Support training and capacity building

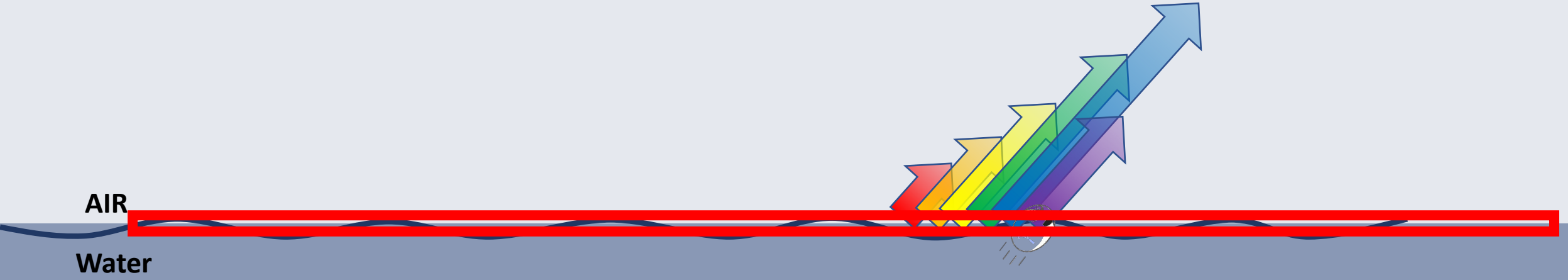
  - Countries: a) Provide in situ data for validation and b) Assist with validation and interpretation of RS products

Backup

Surface Temperature

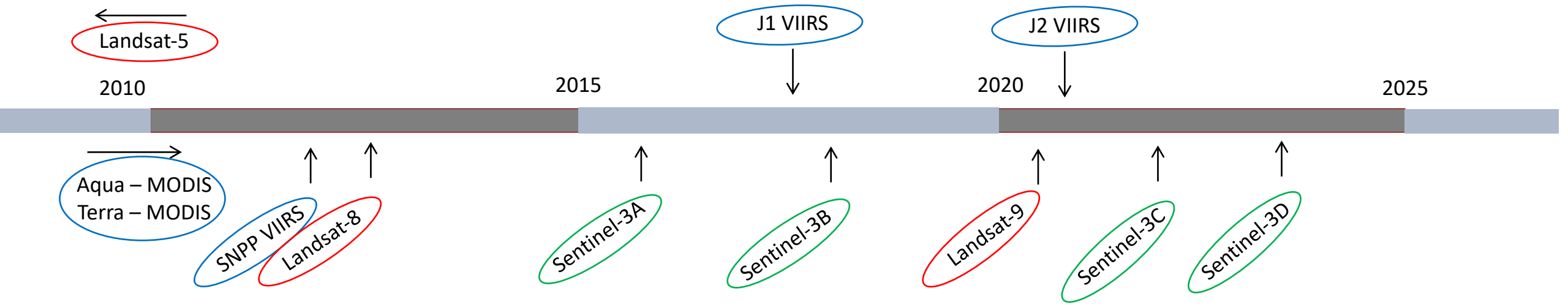


Surface radiation, L_s



Satellite Sensors

- Make high-quality measurements of light within the thermal spectrum



Spatial Resolution	Temporal Resolution
60-120 m	16 days
500 m	Daily
1000 m	Daily

Challenges

1. Landsat-8 & Senitnel-2 measurements are not identical
2. Atmospheric correction must be very robust. Bear in mind, each satellite measurement contains atmospheric scattering and absorption that must be accurately removed
3. Algorithms: More in situ data are required to improve the quality of products
4. Validation: Coordinating field monitoring activities with satellite overpasses