Satellite 101, Part 1

2025 Long Island Sound CoastWatch Class

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What is covered in this presentation

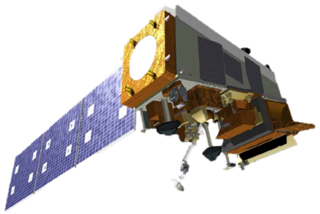
Part 1:

- Overview of available satellite products
- Different Types of Orbits
- Different Resolutions and Spatial Coverages
- Levels of Data Processing

Part 2:

- Types of Sensors and Measurements

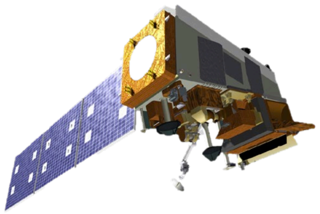
What oceanographic measurements are made by satellites?



- Sea Ice
- Sea Surface Temperature (SST)
- Sea Surface Height (SSH)
- Ocean Color (chlorophyll a, Kd, PAR, etc)
- Rainfall
- Surface Vector Winds (SWV)
- Sea Surface Salinity

For many applications we want to know how the oceans are changing over time, so we need long timeseries of consistent measurements

What oceanographic measurements are made by satellites?

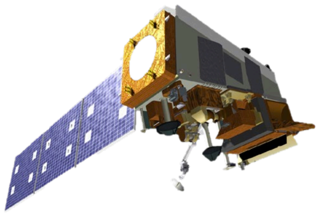


• Sea Ice	since 1978[1]
• Sea Surface Temperature (SST)	since 1981
• Sea Surface Height (SSH)	since 1992
• Ocean Color	since 1997[2]
• Rainfall	since 1997
• Surface Vector Winds (SWV)	since 1999[3]
• Sea Surface Salinity	since 2011

For many applications we want to know how the oceans are changing over time, so we need long timeseries of consistent measurements

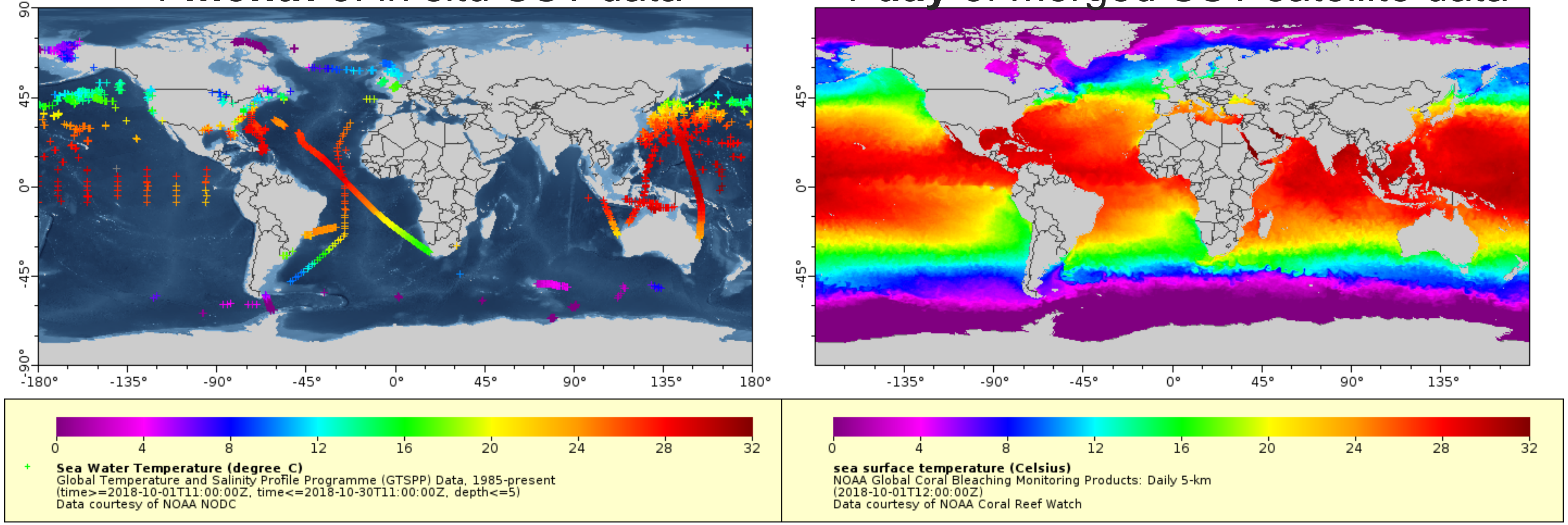
[1]The *consistently processed* satellite passive microwave record of sea ice concentration begins in 1978, but other data extends to 1966.
[2]The continuous record of ocean color sensors extends back to 1997, but the CZCS mission flew from 1979-1986.
[3] Wind speed, without direction, dates back to 1988

Benefits of satellite data



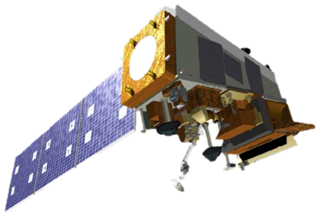
1 **month** of in situ SST data

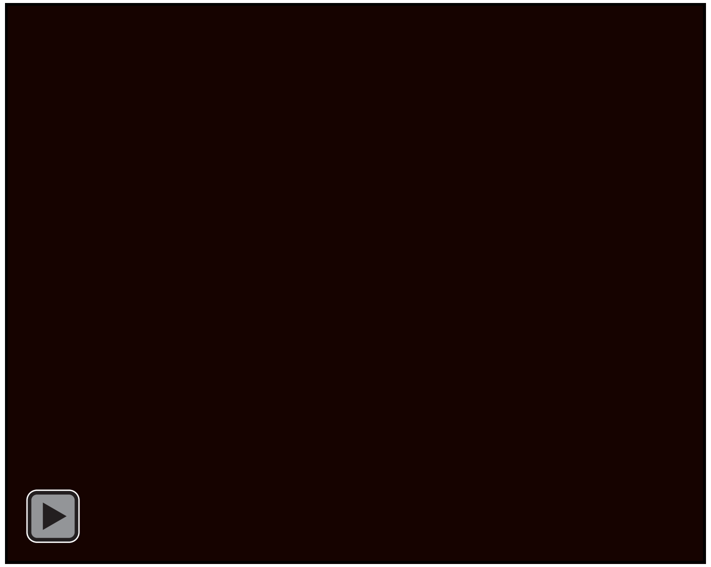
1 **day** of merged SST satellite data



- Satellite data provides observations of the ocean at temporal and spatial scales that are impossible to achieve with traditional in situ measurements
- Timeseries of satellite data make it possible to detect anomalous conditions and 'observe' past events

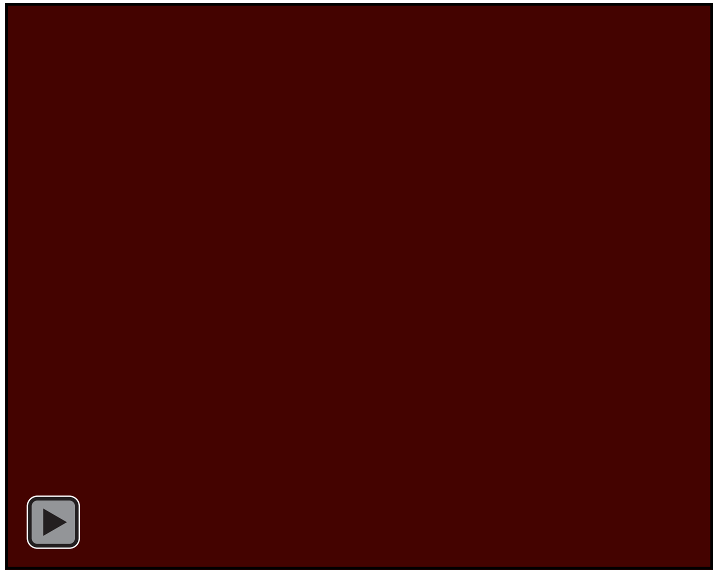
Satellite orbits





Polar-orbiting satellites view most of the earth once a day

Altitude: 700-800 km



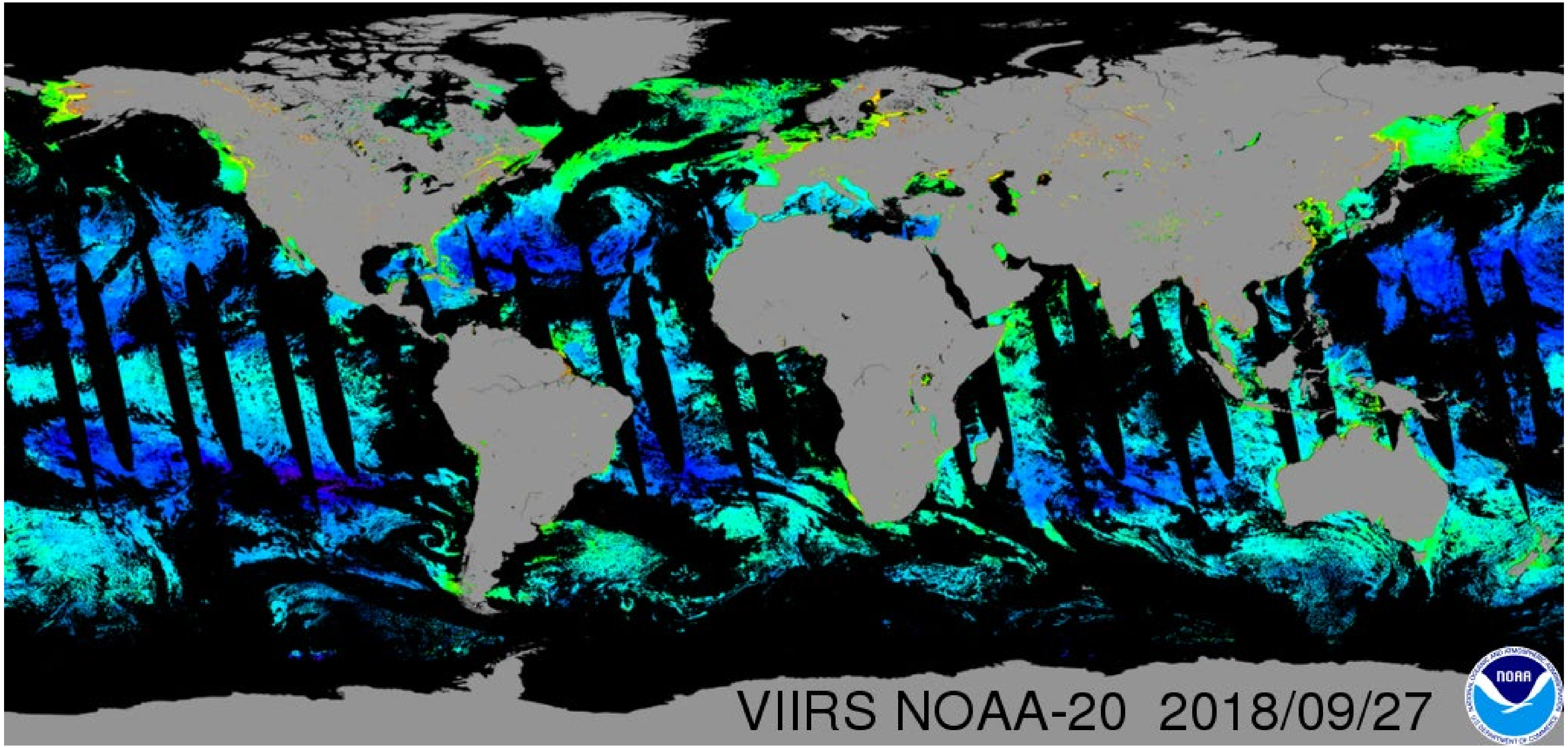
Geostationary satellites view a limited region of the earth, but do so continuously throughout the day

Altitude: 35,800 km

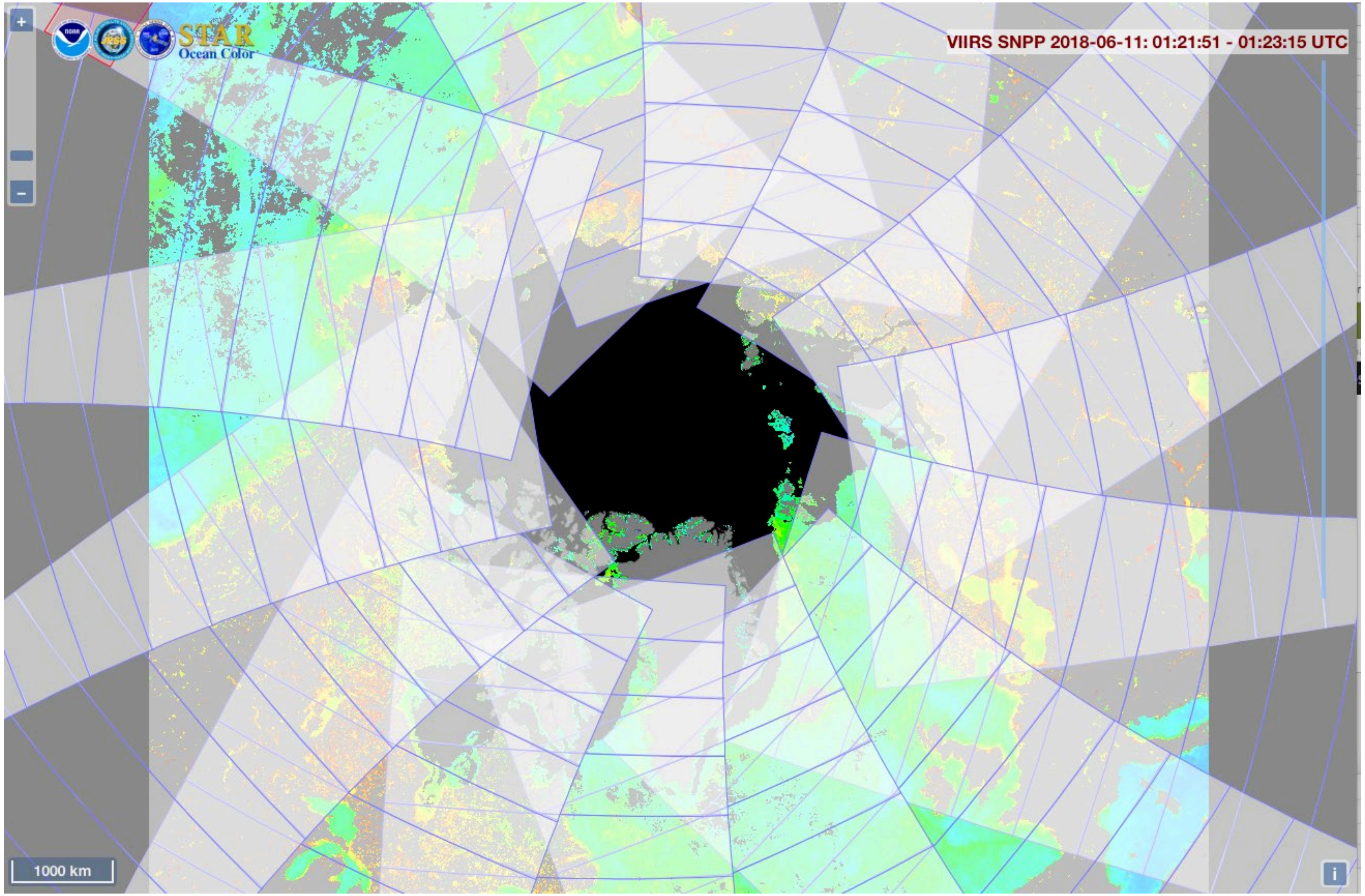
- Most oceanographic satellite measurements come from polar-orbiting satellites
- Some SST measurements are made from geostationary satellites
- South Korea has an ocean color sensor on a geostationary satellite

US will be getting ocean color on GEO!
NASA to launch GLIMR ~2027
NOAA to launch GEO-XO ~2032

Polar Orbit



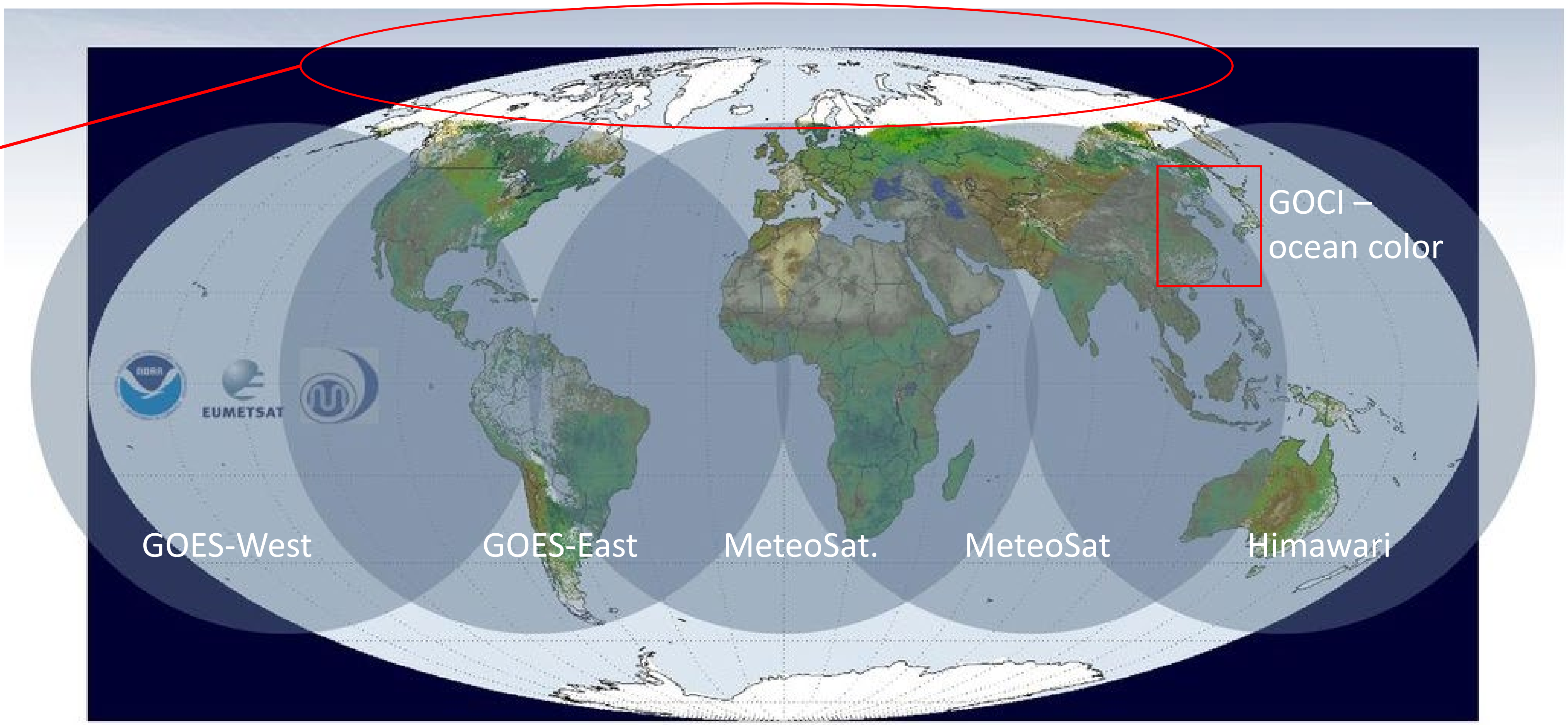
Polar Orbit



from https://www.star.nesdis.noaa.gov/sod/mecb/color/ocview/ocview.html

Geostationary coverage

Geostationary satellites aren't much use in polar regions!



GOES-West (US), GOES-East (US), MeteoSat x2 (Europe), Himawari (Japan)
-> 5 satellites for global coverage, GOCI first geostationary ocean color

Polar vs Geo Orbits

Polar

- Altitude: 700-800 km
- ~ 14 orbits a day
- Global coverage
- High spatial resolution (< 1 km)
- Low temporal resolution (≥ 1 day)

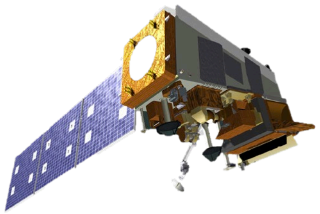
Geo

- Altitude: 35,800 km
- Poor coverage of the poles
- Regional coverage only
- Low spatial resolution (2-4 km)
- High temporal resolution (< hour)

Higher spatial resolution generally means lower temporal resolution, and vice-versa.

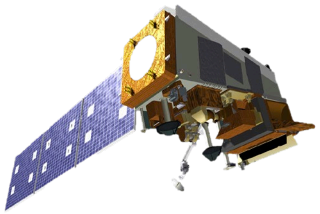
You can't have everything!

What Resolution?



- **Spatial resolution** is the pixel size of the image. The resolution of oceanographic satellite products ranges from 250 m – 25 km.
- **Temporal resolution** is the amount of time that passes between subsequent images at the same point.
- **Spectral resolution** refers to how many bands the sensor has.
- **Swath width** refers to the width of the area observed by the satellite (polar-orbiting). Satellites with larger swath widths will take less time to acquire global spatial coverage.

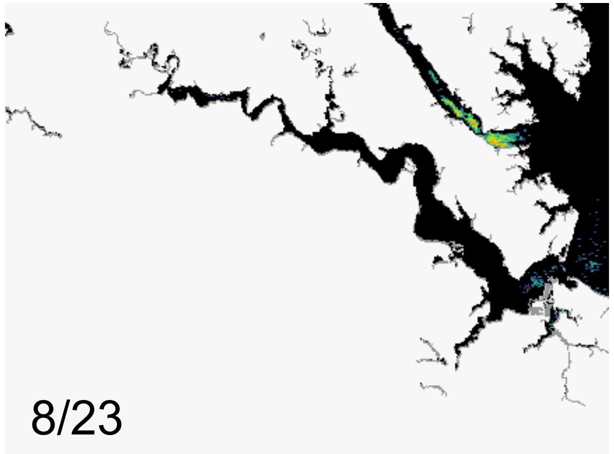
High Spatial Resolution Satellites



- There are a number of high spatial resolution imaging sensors, ~1-30 m, e.g. SPOT, QuickBird, IKONOS, OrbView-3, Hyperion, WorldView, Landsat, Sentinel 2, Planet SuperDove
- The trade-off is temporal resolution, and these sensors generally have very long repeat-times. Some don't have regular repeat times, but rather work on a system of scheduled, on-demand acquisitions.
- These data are generally better suited for land applications than for ocean applications.
- Most of the data has to be purchased, or is difficult to get a hold of.
- These data are generally not offered as part of this course.

Algal bloom monitoring with higher spatial resolution

Sentinel 3 Fluorescence algorithm (RBD) from EUMETSAT processed at NCCOS, 300 m every day


8/23

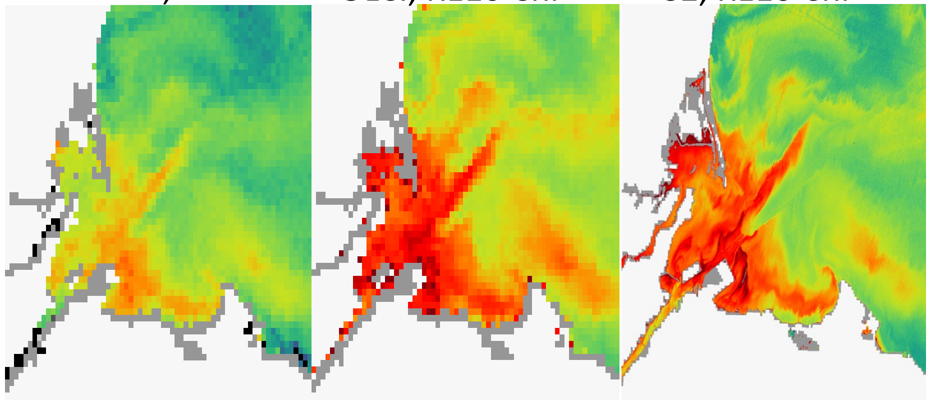

8/28

*Resulted in NCCOS Event Response funds to support additional sampling

Sentinel 2 provides 20 m imagery every 5 days

False color image of rust tide bloom
from EO Browser at European Space Agency (ESA)
https://apps.sentinel-hub.com/eo-browser/

OLCI, CI | OLCI, RE10 Chl | S2, RE10 Chl



Lake Erie cyanobacteria bloom Sept 5, 2024

*Better resolution of bloom patchiness and in narrow rivers and tributaries

Levels of Data

- Level 0: Raw data received from satellite, in standard binary form
- Level 1: Unprocessed data in sensor's geographic coordinates, containing calibration information
- Level 2: Derived geophysical variables atmospherically corrected and geolocated, but presented in sensor's geographic coordinates (granules).
  Also sometimes referred to as "along-track" data.
- **Level 3:** Derived geophysical variables mapped on uniform space-time grid scales.
  Spatial and temporal composites.
- **Level 4**: Model output or results from analyses of lower-level data
  e.g., variables derived from multiple measurements, like primary productivity or interpolation to provide cloud-free product

This course focuses primarily on level 3 and level 4 data

Temporal Composites

Composites product are the best way to deal with missing data due to cloud coverage

- **Level 3C**: Collated, or Temporal Composites
  Data from different time periods from the same sensor are collated together
  Example: Blending 7 (or 8) days of VIIRS Chl data into a weekly composite

- **Level 3S**: Super-collated or Blended Products
  Data from different time periods and different sensors are collated together.
  Example: Blending data from geostationary and polar-orbiting IR sensors

Example of Temporal Compositing

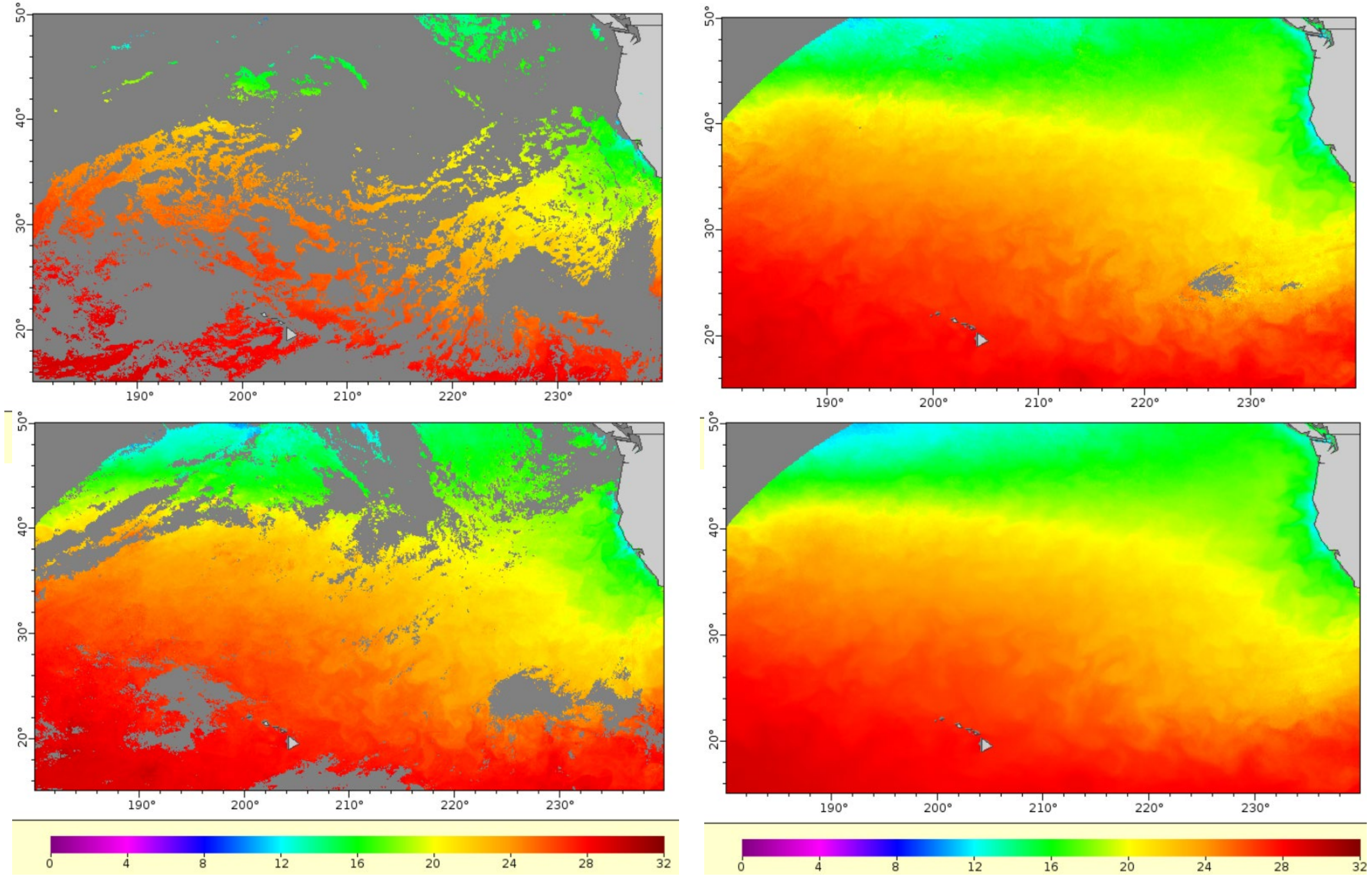
GOES West SST – September 2018

Sept 15
Hourly
Image

Sept 12-18
Weekly
Composite

Sept 15
Daily
Composite

Sept
Monthly
Composite



Cloud Masking

- Cloud masks are necessary for measurements that can’t see through clouds, such as SST and ocean color
- Since cloud masks are usually made from visible imagery, cloud masks for nighttime retrievals of SST are less accurate than for daytime retrievals
- Different agencies and different satellite product producers use different cloud masks.

Anomaly Products and Climatologies

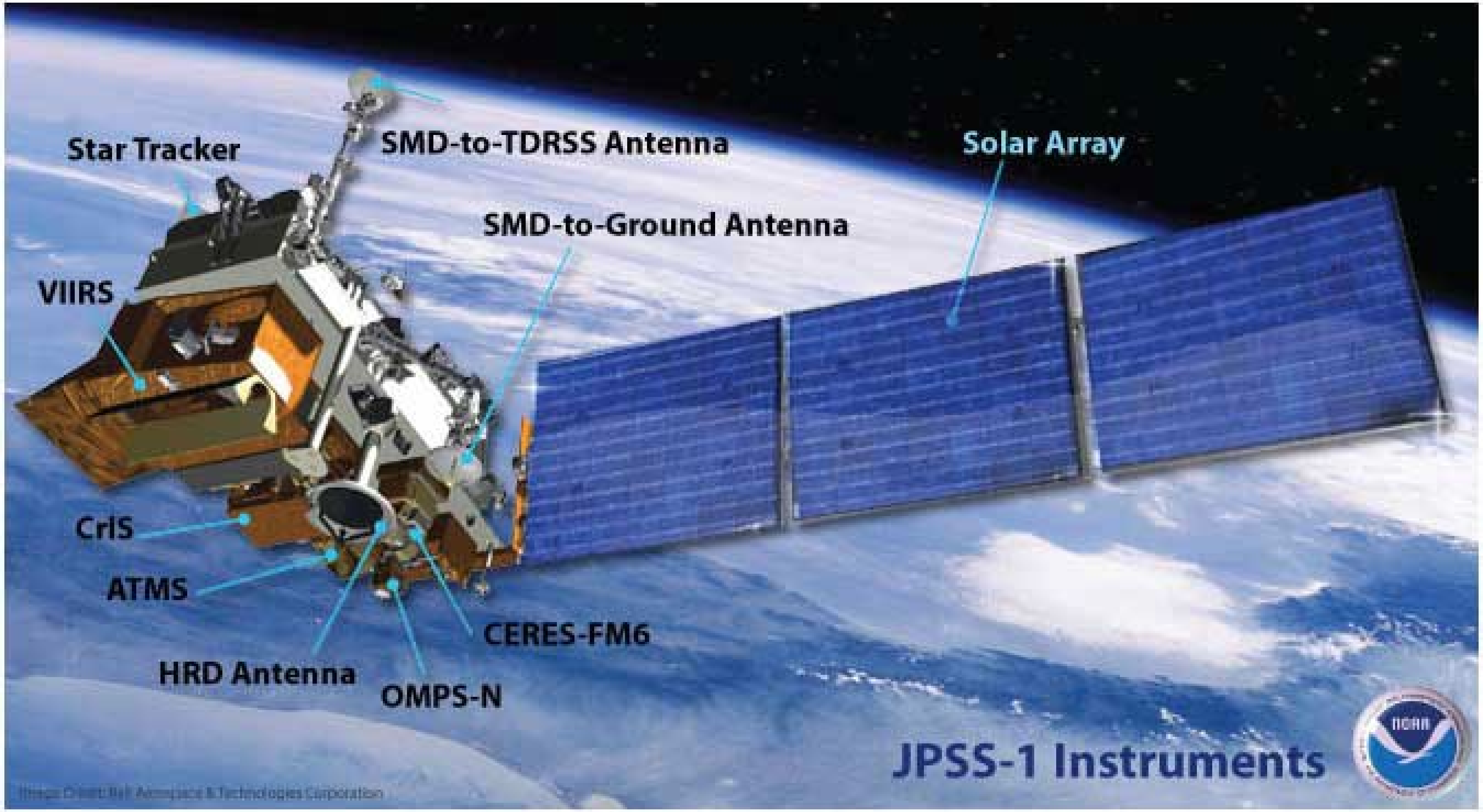
- For many applications an anomaly is more useful than the actual parameter. Anomalies are generated by subtracting a climatology of that parameter.

- We have a limited number of products with anomalies:

	MUR	NOAA Global Coral Bleaching	OSU SST and Chlorophyll Anomalies (MODIS)
Temporal Coverage	2002 - now	1985 - now	2003 - now
Temporal Resolution	Daily & Monthly	Daily	Monthly
Spatial Resolution	1 km	5 km	2 km, West Coast only
Products	SST	SST	SST and Chlorophyll
ERDDAP link	https://coastwatch.pfeg.noaa.gov/erddap/griddap/jplMURSST41anommday.graph	https://coastwatch.pfeg.noaa.gov/erddap/griddap/NOAA_DHW.graph?CRW_SSTANOMALY	https://coastwatch.pfeg.noaa.gov/erddap/griddap/osu2SstAnom.graph https://coastwatch.pfeg.noaa.gov/erddap/griddap/osu2ChlaAnom.graph

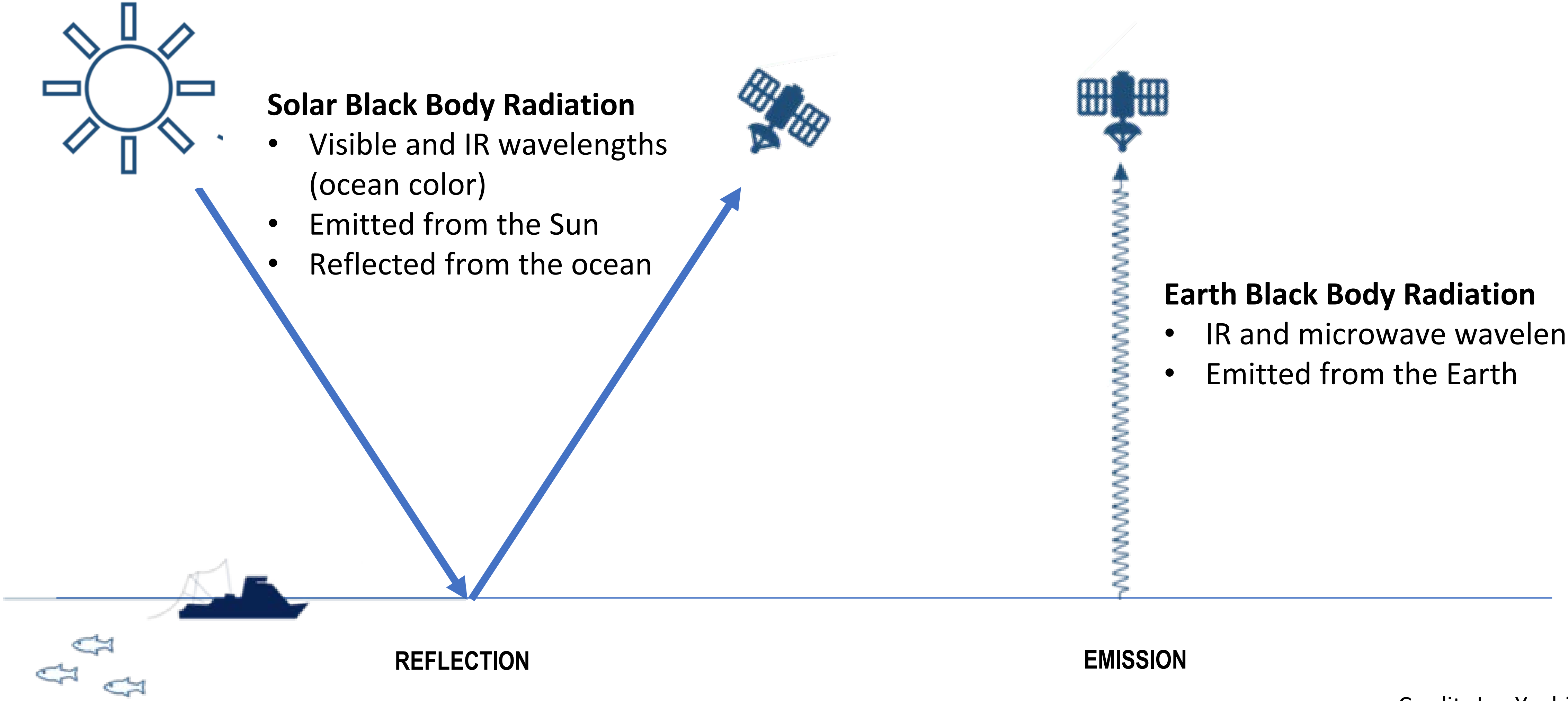
Satellite vs Sensor

VIIRS:
Visible
Infrared
Imaging
Radiometer
Suite



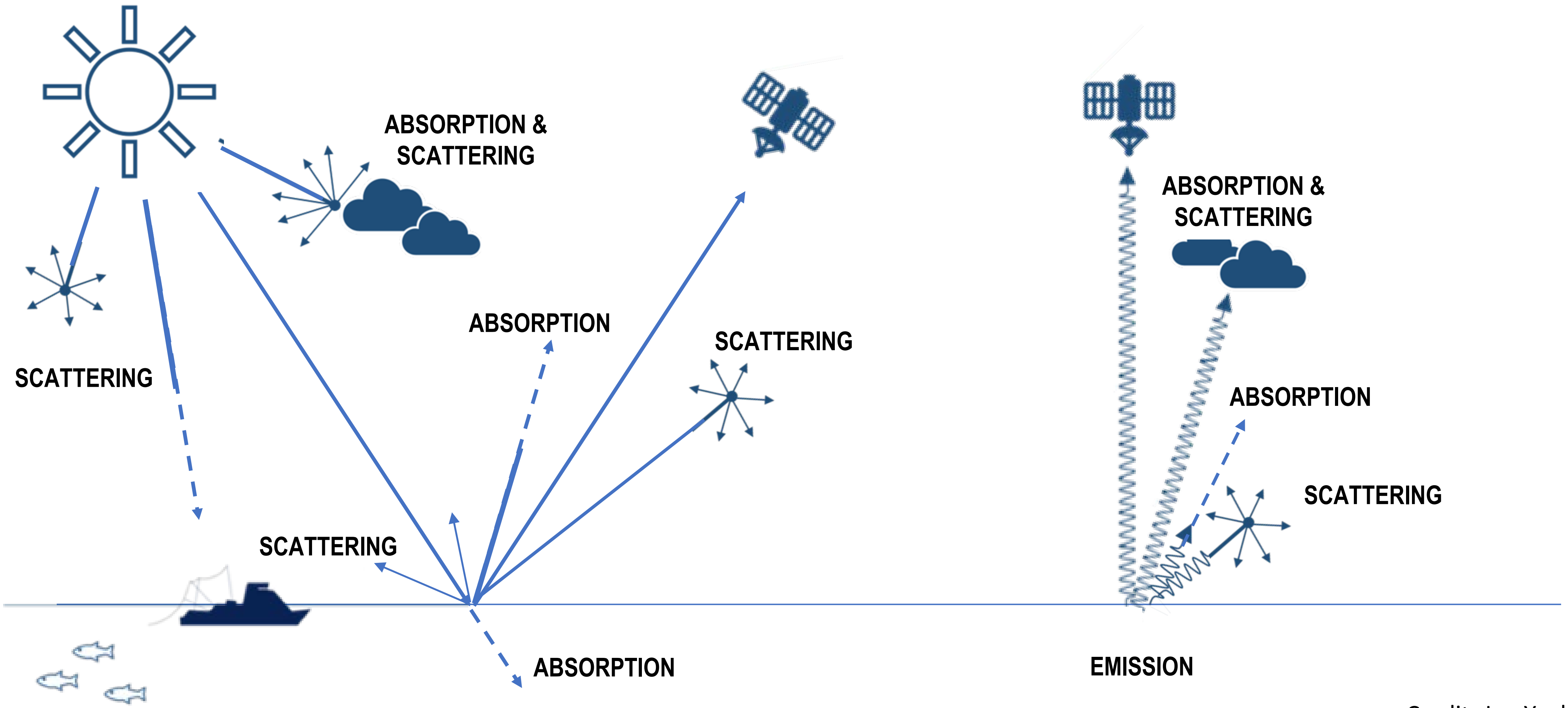
Some satellites are single-mission, carrying only one sensor, e.g. the SeaWiFS sensor on the GeoEye/OrbImage satellite. Other satellites have multiple sensors on them, as the JPSS satellites do. The same sensor can be on multiple satellites, ie VIIRS on SNPP and NOAA-20

Satellite measure electromagnetic radiation (EMR)



Credit: Jan Yoshioka, CI

Processes alter the EMR signal as it passes through the atmosphere



Credit: Jan Yoshioka, CI

Atmospheric Correction

- Most of the absorption/re-emission of IR in the atmosphere is caused by a few gases (O_2, N_2 and trace gases) that are relatively well-mixed, and by water vapor, ozone and aerosols, that are not well mixed.
- The well-mixed components cause a constant difference in temperature between the surface and the satellite.
- The variable components must be detected and corrected for using multiple wavelengths.

Atmospheric correction is necessary to derive accurate satellite data products.

EMR is also affected by the water properties

EMR emitted by the sun is transmitted through the atmosphere to the ocean.

EMR interacts with elements in the ocean, where the spectral characteristics are changed

EMR reflected from the ocean is transmitted through the atmosphere and reaches the sensor

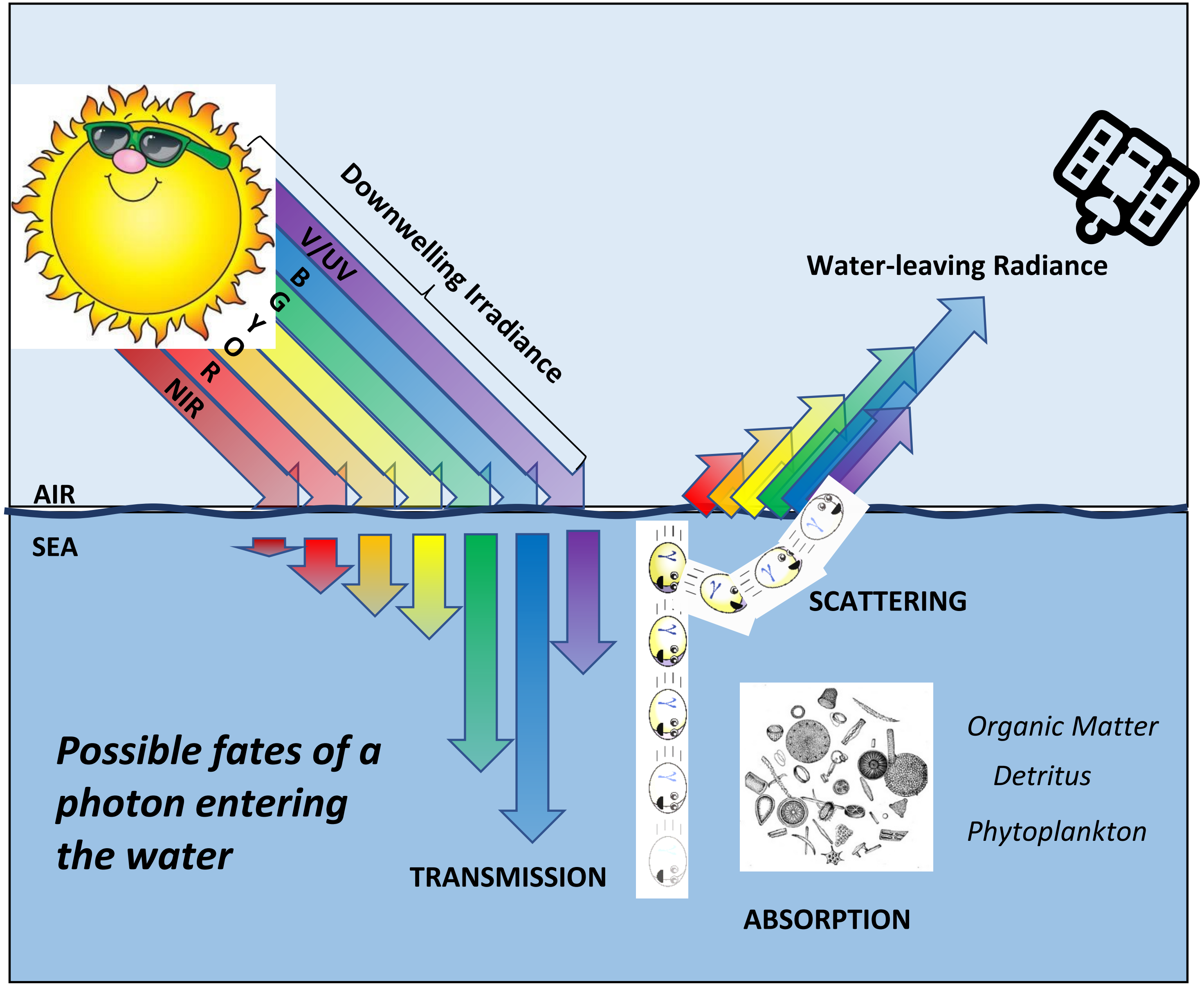


Image Credit: jeremy.werdell@nasa.gov

Sea Surface Temperature

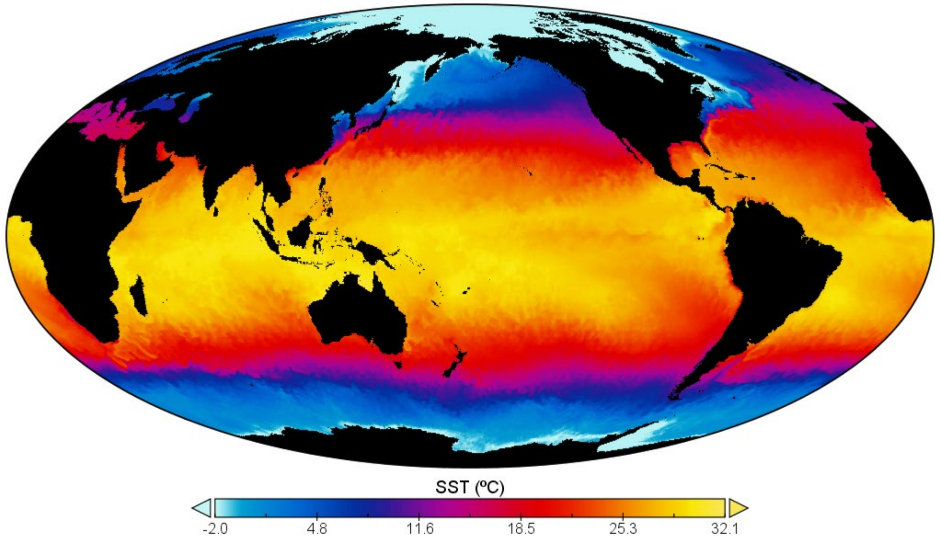
Continuous satellite data record goes back to 1981

Infrared instruments:

- SST_{skin} – the top ~ 20 um
- High spatial resolution
- Measurements blocked by clouds
- Sensors in both polar and geo orbit

Microwave instruments:

- $SST_{subskin}$ top ~ several mm
- Reduced spatial resolution
- Sees through clouds (fuller coverage)
- No measurements close to land (50-100km)
- Sensors only in polar orbit



Blended Products:

- Data from multiple satellites and/or multiple passes of the same satellite are combined
- Often data-gaps are filled by interpellation

Products Selection

- There are many SST products to choose from
- Before picking a product, select a few and compare them for several time steps and regions.

Ocean Color

Continuous satellite data record goes back to 1997

Measurements are made in the visible wavelengths and can not be made through clouds or at night.

Atmospheric correction is extremely important!

There are a suite of products measured by "ocean color" satellites:

- Chlorophyll (most commonly used)
- Primary Productivity
- Photosynthetically Available Radiation (PAR)
- CDOM (Colored Dissolved Organic Matter)
- Fluorescence
- Water Clarity, Depth attenuation (Kd)

Traditional algorithms were developed for Case-1 (open ocean) waters.

- Care must be taken when using data from Case-2 (coastal) waters.

The most recently launched U.S. OC sensors are VIIRS

- Joint NASA/NOAA missions were launched Oct. 2011 (SNPP), Nov 2017 (NOAA-20) and Nov 2022 (NOAA-21)

Primary US satellites: • SeaWiFS 1997-2010 • MODIS/Aqua 2002- 2016-present • VIIRS 2011-present

European satellites: • MERIS 2002-2012 • OLCI April 2016-present

Sea Surface Salinity, Surface Winds, and Altimetry

Characteristics of microwave measurements

Measured with passive and active microwave sensors

Measurements are taken day and night,
and in nearly all-weather conditions

Spatial resolution (~ 25km) is lower that visible and infrared.

Passive sensors cannot measure close to the coast

Salinity

2010 - present

Global coverage in 1-3 days

Accuracy ~0.2 PSS

Winds

1987 - present

Global coverage 6-hours

Accuracy ~ 0.1 m/s

Altimetry

1990 - present

Daily global coverage

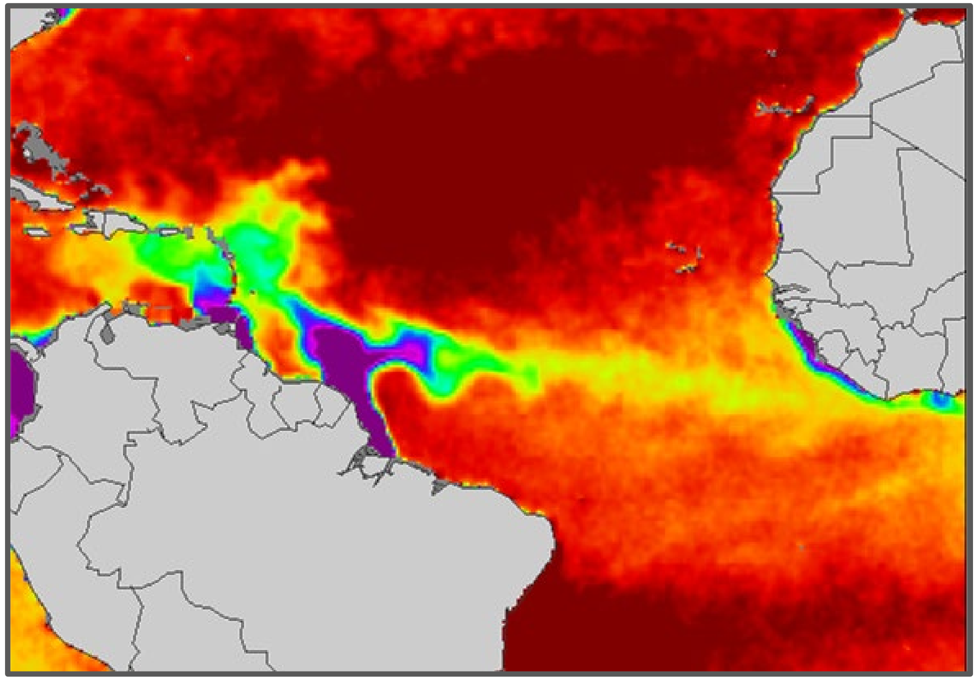
Accuracy ~ 3 cm

Uses for satellite salinity

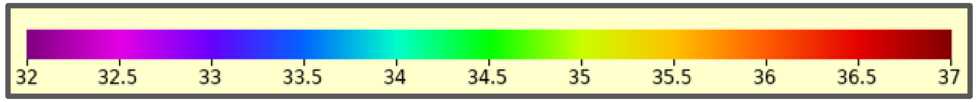
Global thermohaline circulation

Dynamic ecosystem modeling

Tracking surface salinity events

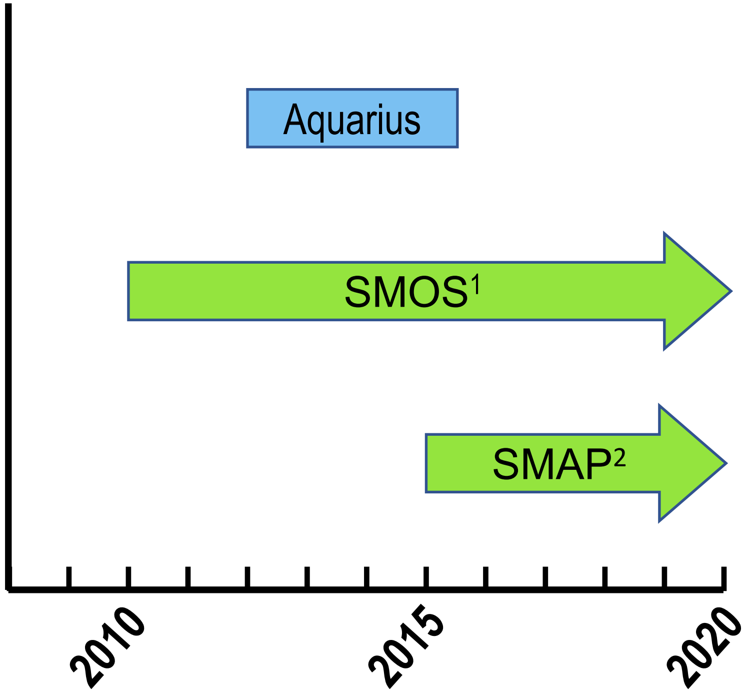


SMOS data – 0.25° resolution



Practical Salinity Scale

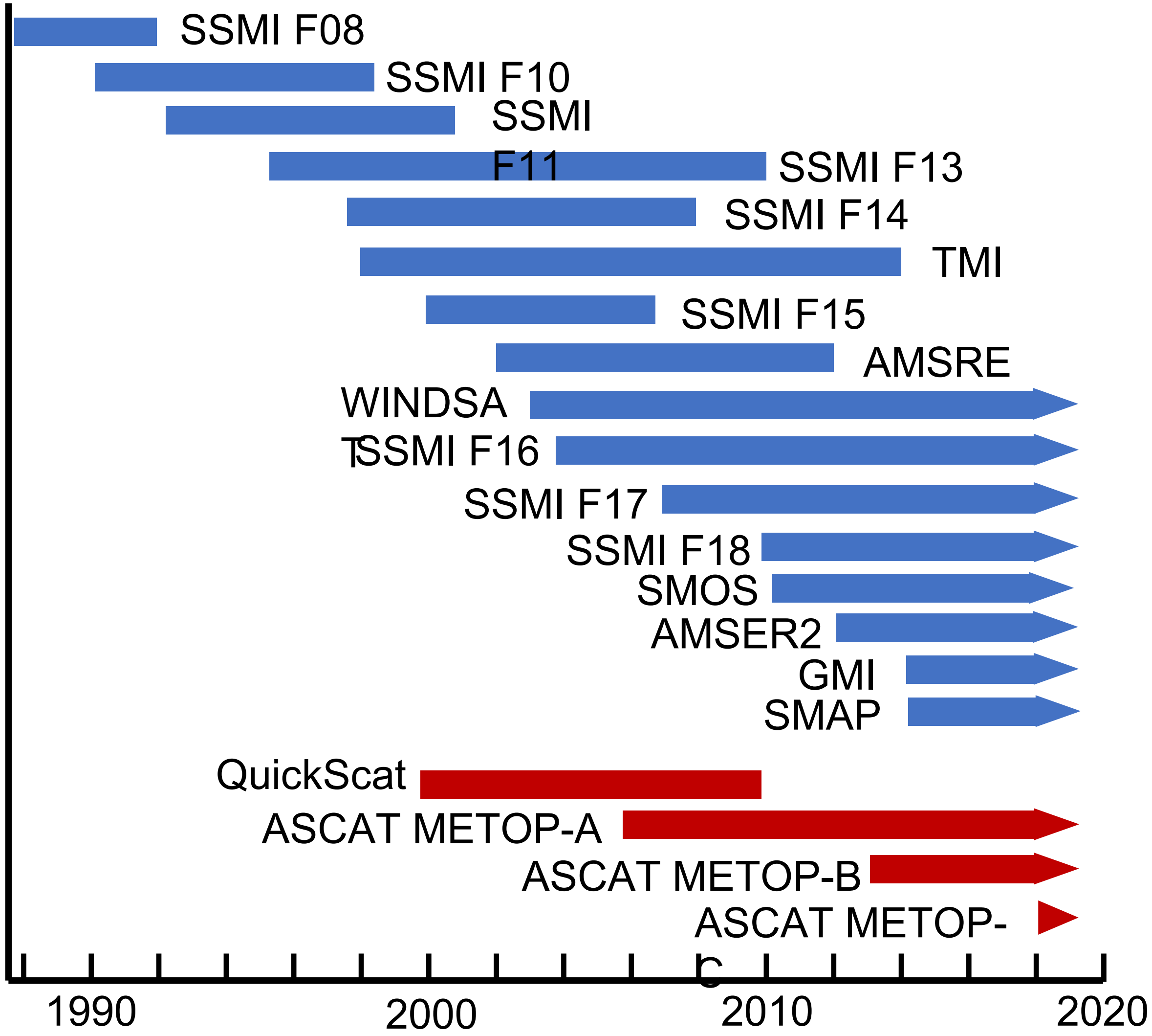
Temporal coverage:	2010 - Present
Spatial resolution:	0.25 – 1 degree
Global coverage:	3 – 8 days
Accuracy:	0.15-0.25 PSS
Depth:	1–2 cm

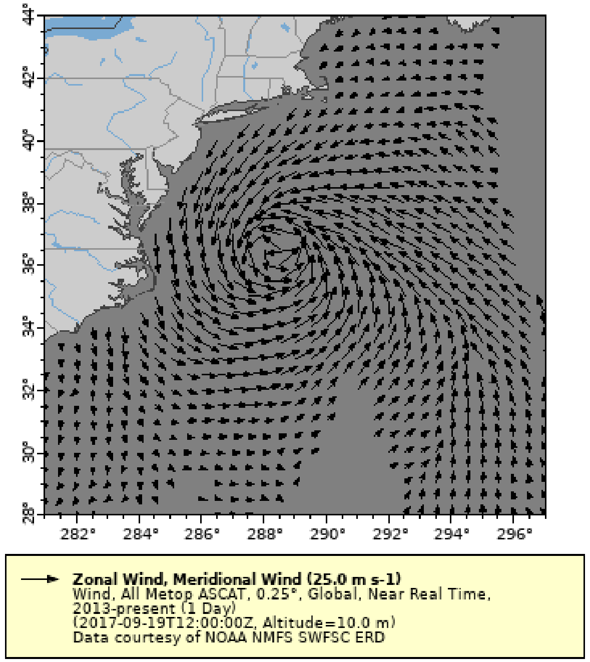


[1]Soil Moisture and Ocean Salinity mission

[2]Soil Moisture Active Passive mission

Wind





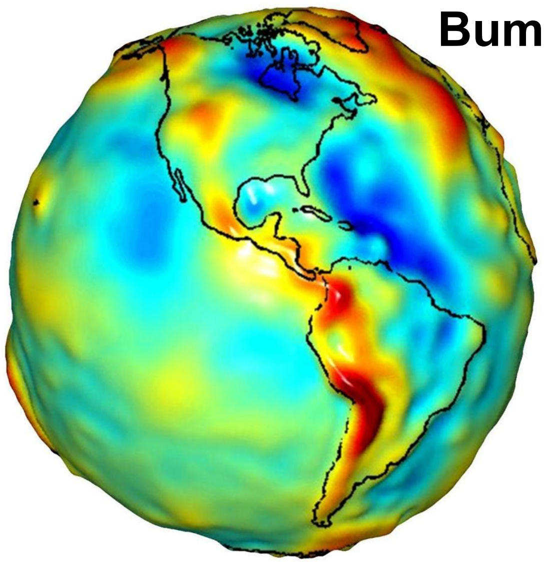
Passive sensors (wind speed only)

Time span:	1987 - Present
Global coverage:	ca. 6 hours - 3 days
Spatial resolution:	1/8° – 1° (12–100km)

Active sensors (wind speed & direction)

Time span:	1999 - Present
Global coverage:	ca. 1 - 3 days
Spatial resolution:	0.25° – 1° (25-100 km)

Altimetry

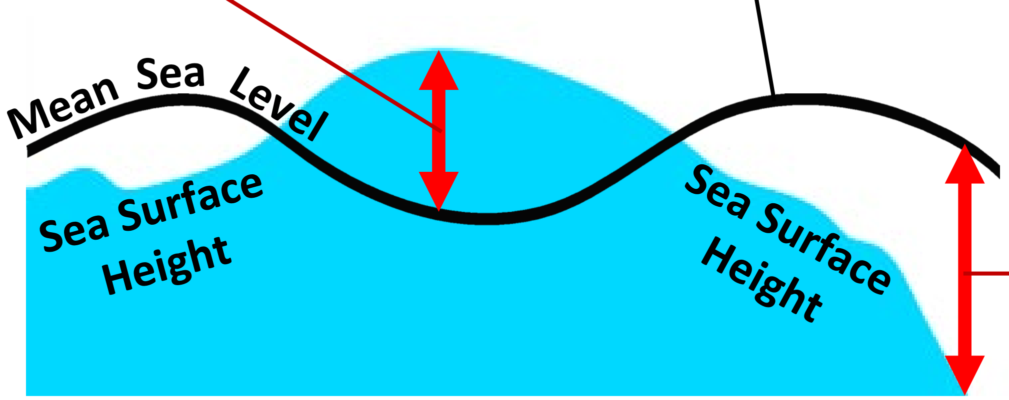

Bumpy Earth

Main variables:

- Sea Surface Height
- Sea Level Anomaly
- Geostrophic Currents
- Eddy Kinetic Energy

Positive
Sea Level Anomaly

Long-term sea level mean
currently the 1993-2012 mean



Negative
Sea Level Anomaly