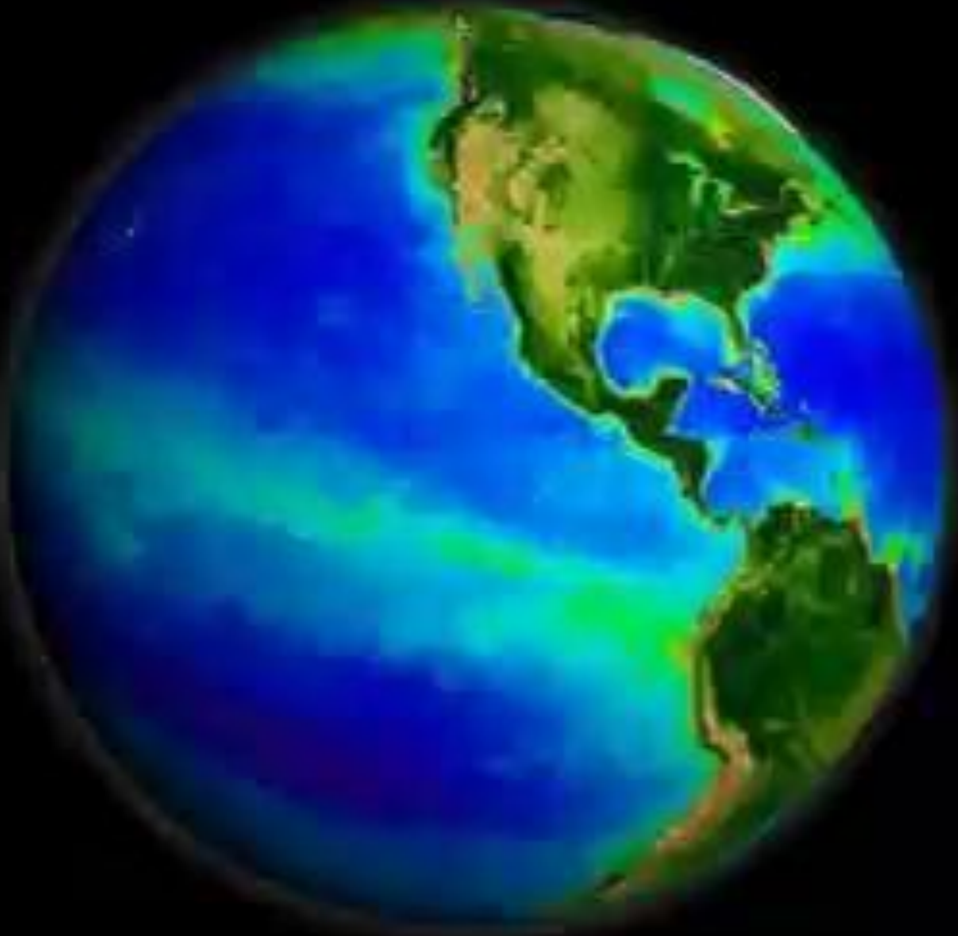
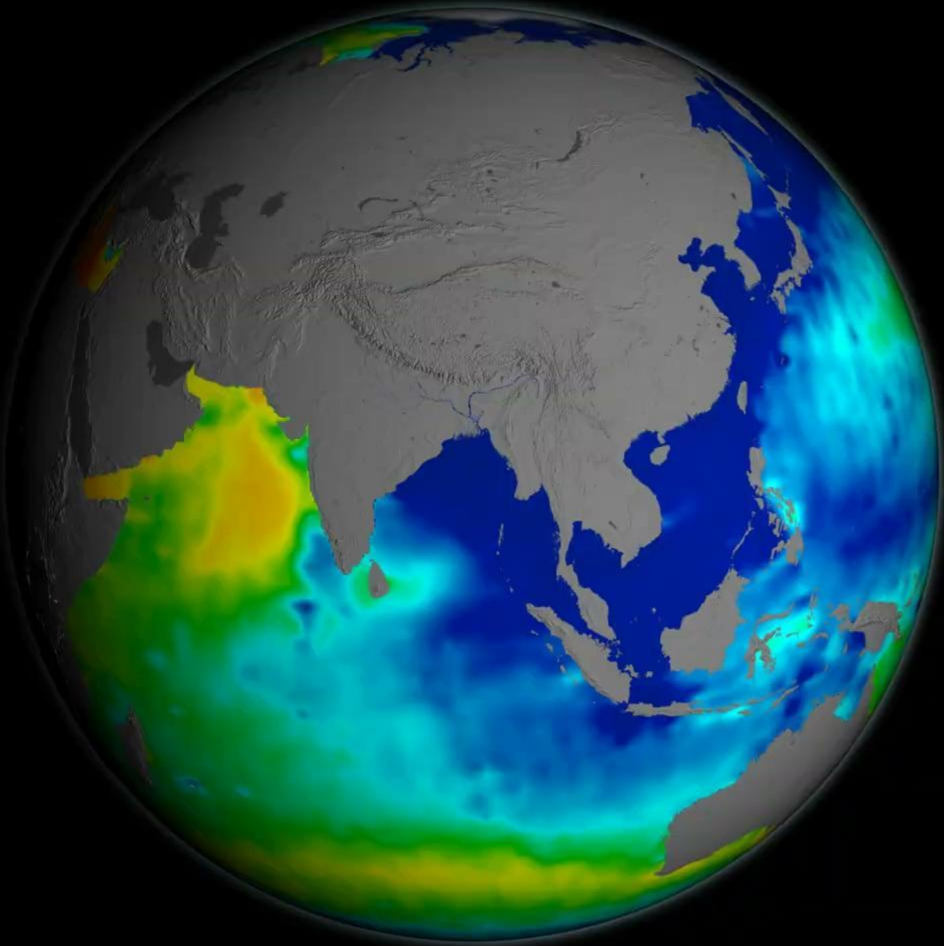




Sep 02, 2011

Brief Overview of Oceanographic Satellite Data

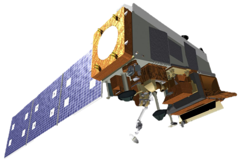
Cara Wilson[1] and the CoastWatch Training Team

[1]NOAA Southwest Fisheries Science Center, Monterey CA

ATN Animal Telemetry Data Course - Oct 25, 2024

coastwatch.info@noaa.gov

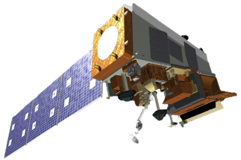
For how long have these measurements been made?



- Sea Ice
- Sea Surface Temperature (SST)
- Sea Surface Height (SSH)
- Chlorophyll (ocean color)
- 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

For how long have these measurements been made?



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

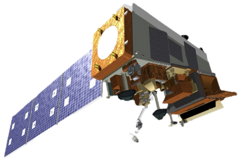
For many applications we want to know how the oceans are changing over time, so we need long timeseries of consistent measurements

[1] The *consistently processed* satellite passive microwave record of sea ice concentration begins in 1978, but other data extends to 1966.

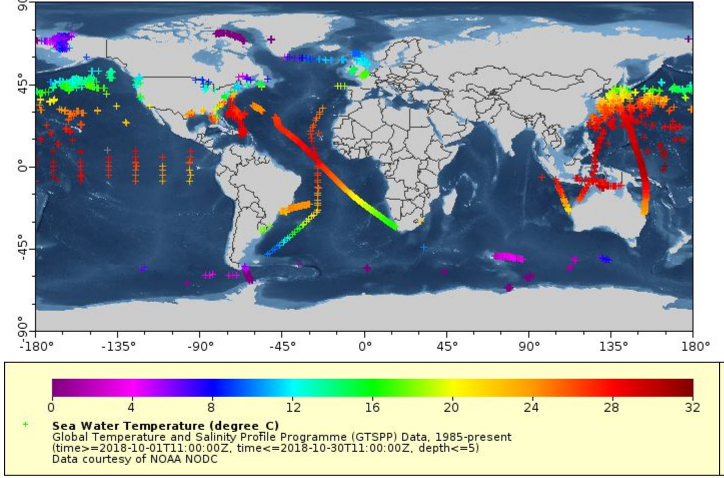
[2] The continuous record of ocean color sensors extends back to 1997, but the CZCS mission flew from 1979-1986.

[3] Wind speed, without direction, dates back to 1988

Benefits of satellite data

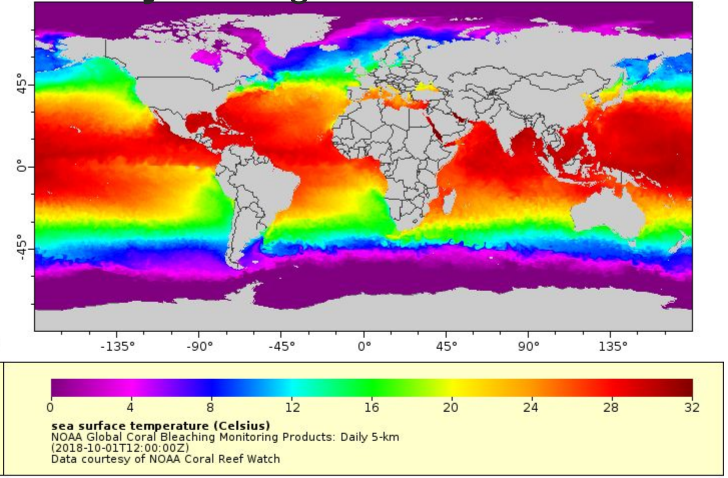


1 **month** of in situ SST data



Sea Water Temperature (degree_C)
Global Temperature and Salinity Profile Programme (GTSPP) Data, 1985-present
(time>=2018-10-01T11:00:00Z, time<=2018-10-30T11:00:00Z, depth<=5)
Data courtesy of NOAA NODC

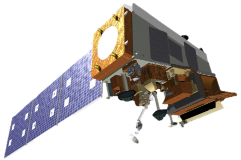
1 **day** of merged SST satellite data

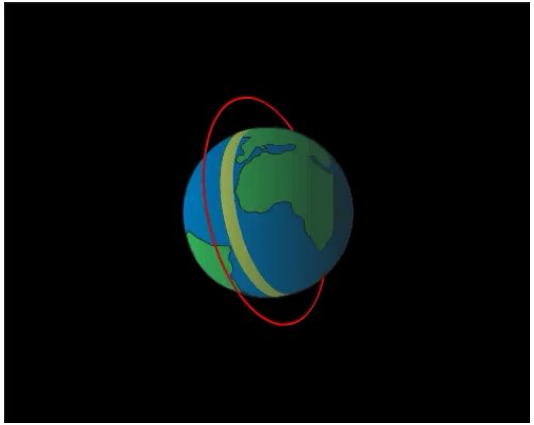


sea surface temperature (Celsius)
NOAA Global Coral Bleaching Monitoring Products: Daily 5-km
(2018-10-01T12:00:00Z)
Data courtesy of NOAA Coral Reef Watch

- 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

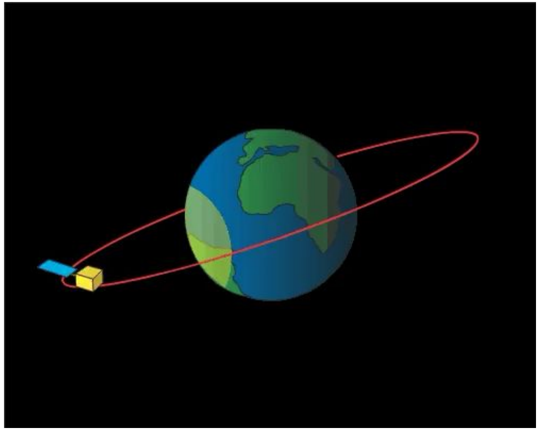
Satellite orbits





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

Altitude: 700-800 km



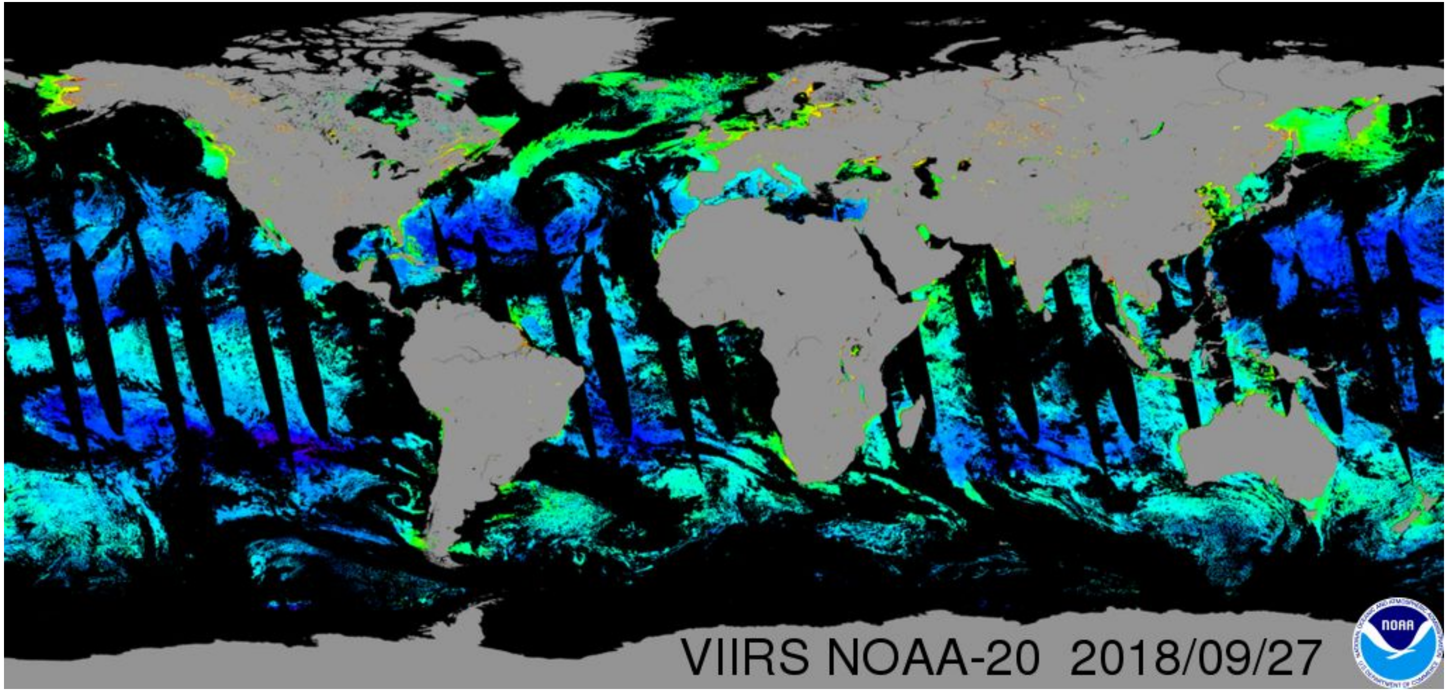
Geostationary satellites view a limited region of the earth, but do so continuously throughout the day

Altitude: 35,800 km

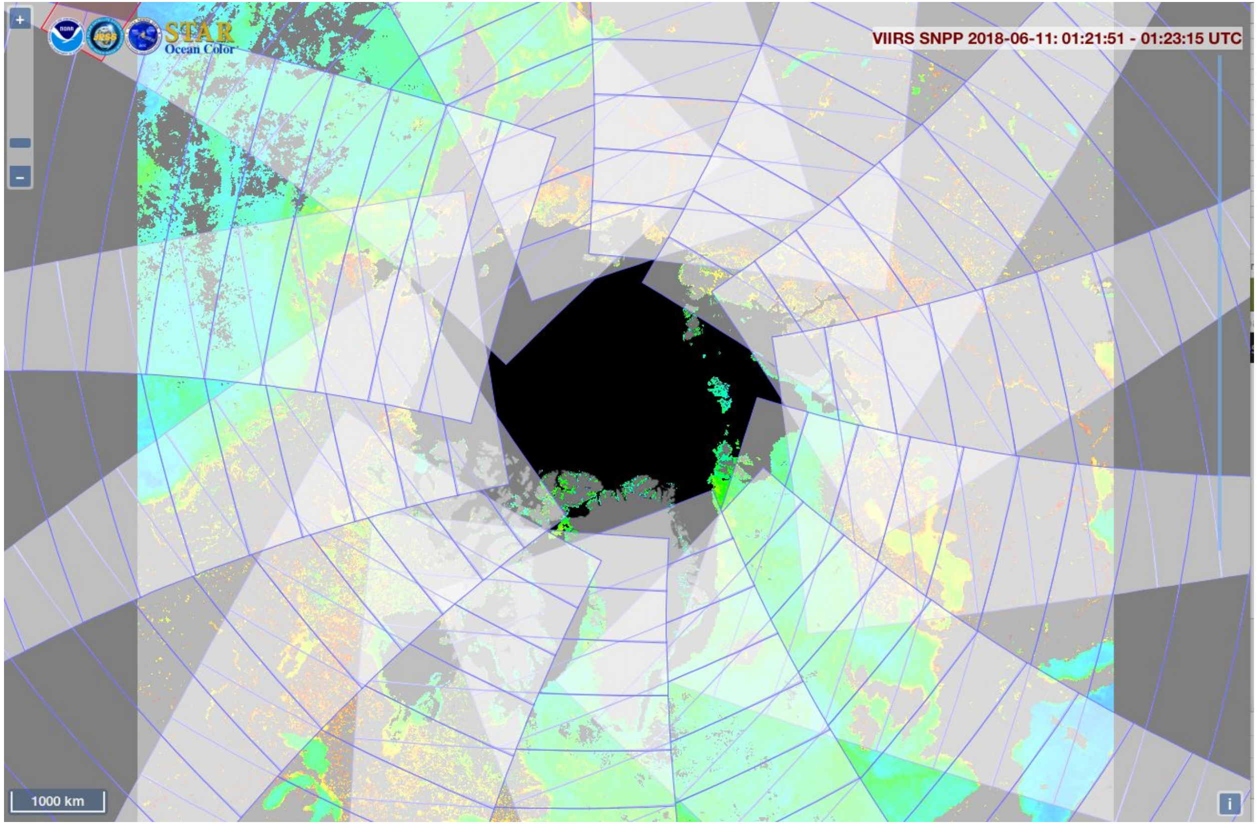
- Most oceanographic satellite measurements come from polar-orbiting satellites
- Some SST measurements are made from geostationary satellites
- South Korea has an ocean color sensor on a geostationary satellite.

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

Polar Orbit



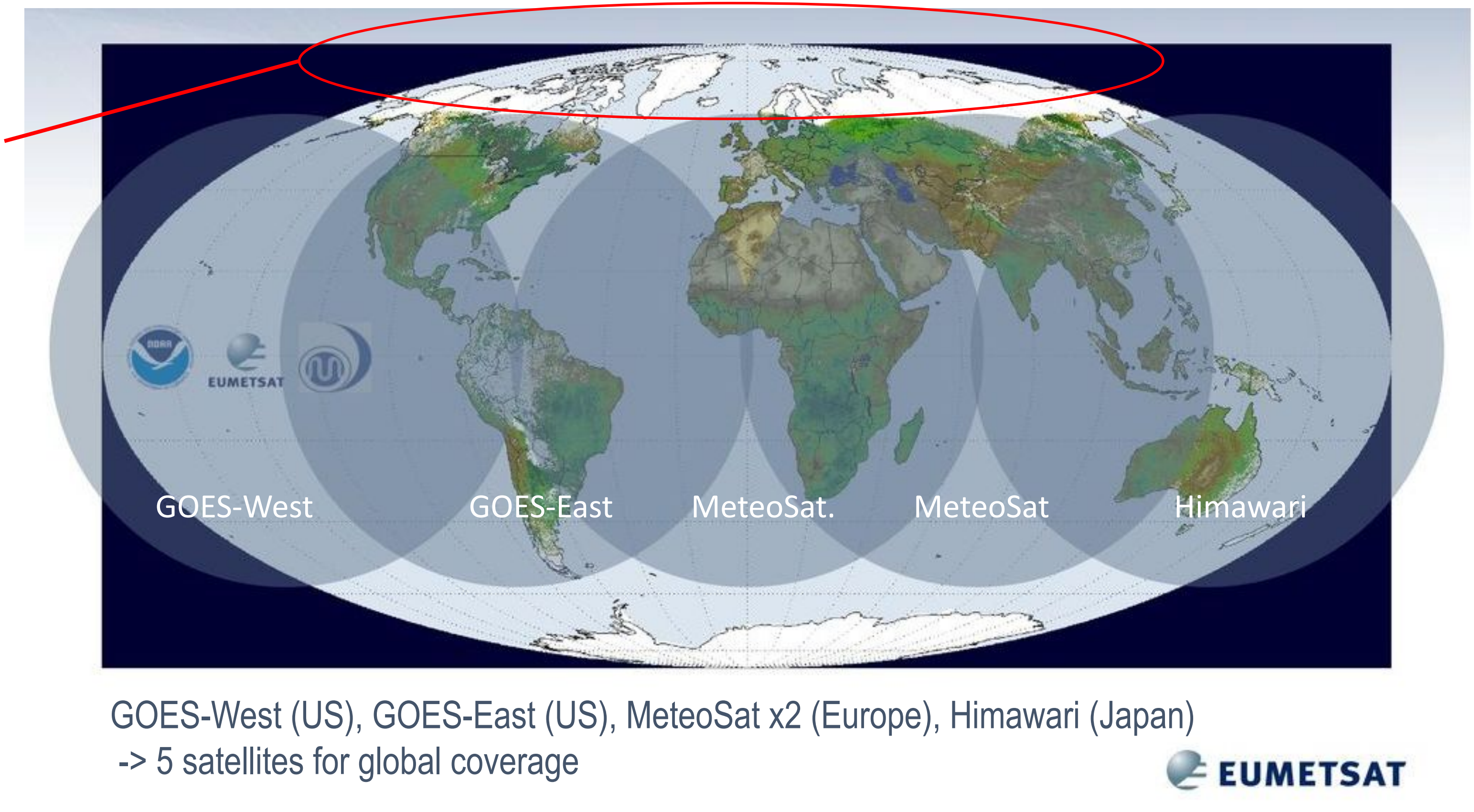
Polar Orbit



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

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)

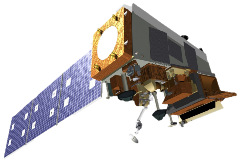
Geo

- 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.

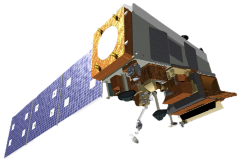
You can’t have everything!

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.

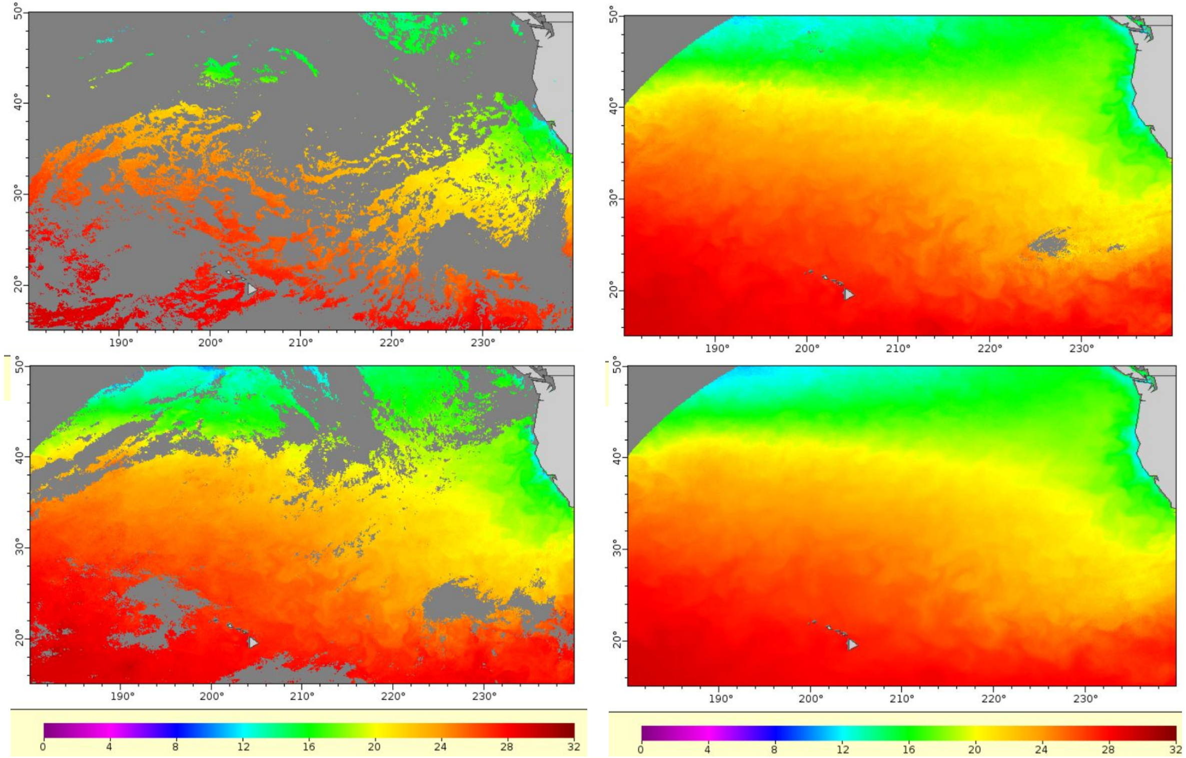
High Spatial Resolution Satellites



- There are a number of high spatial resolution imaging sensors, ~1-30 m, e.g. SPOT, QuickBird, IKONOS, OrbView-3, Hyperion, WorldView
- 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.
- Traditionally these data had to be purchased, and are generally more difficult to access
- These data are generally not offered as part of this course.

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

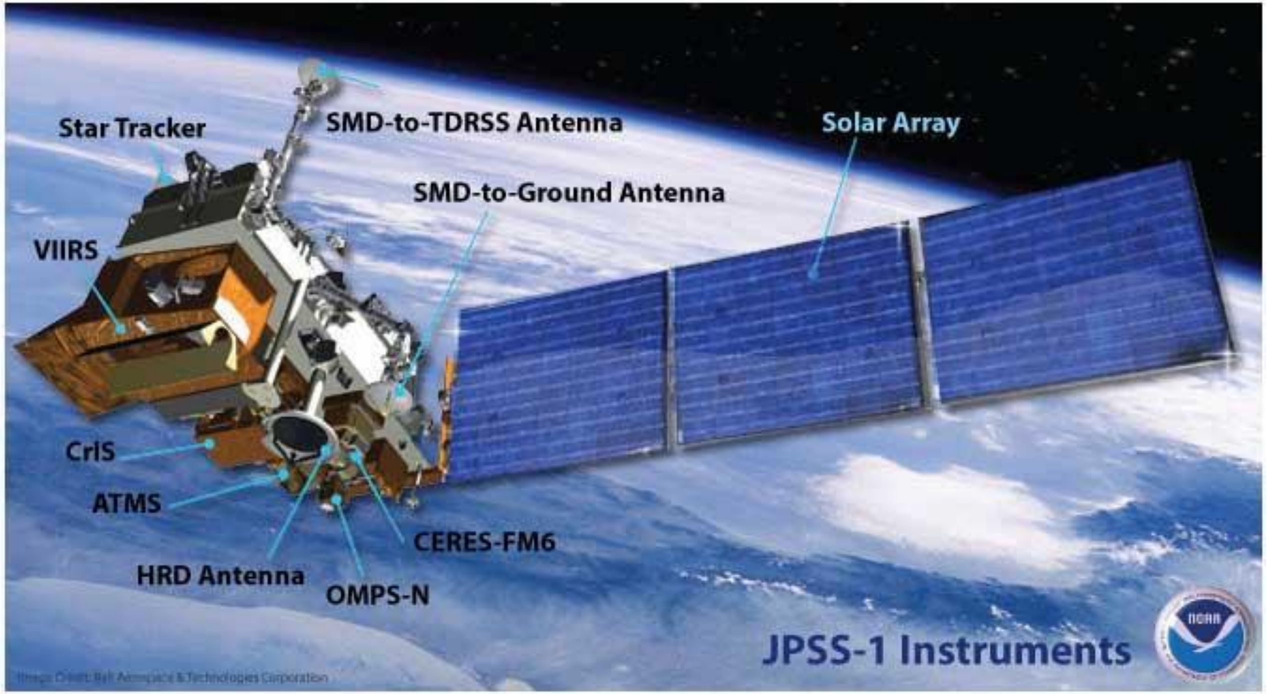
- For many applications an anomaly is more useful than the actual parameter. Anomalies are generated by subtracting a climatology of that parameter.

- We have a limited number of products with anomalies:

	MUR	**NOAA Global Coral Bleaching**
Temporal Coverage	2002 - now	1985 - now
Temporal Resolution	Daily & Monthly	Daily
Spatial Resolution	1 km	5 km
Products	SST	SST
ERDDAP link	https://coastwatch.pfeg.noaa.gov/erddap/griddap/jplMURSST41anommday.graph	https://coastwatch.pfeg.noaa.gov/erddap/griddap/NOAA_DHW.graph?CRW_SSTANOMALY

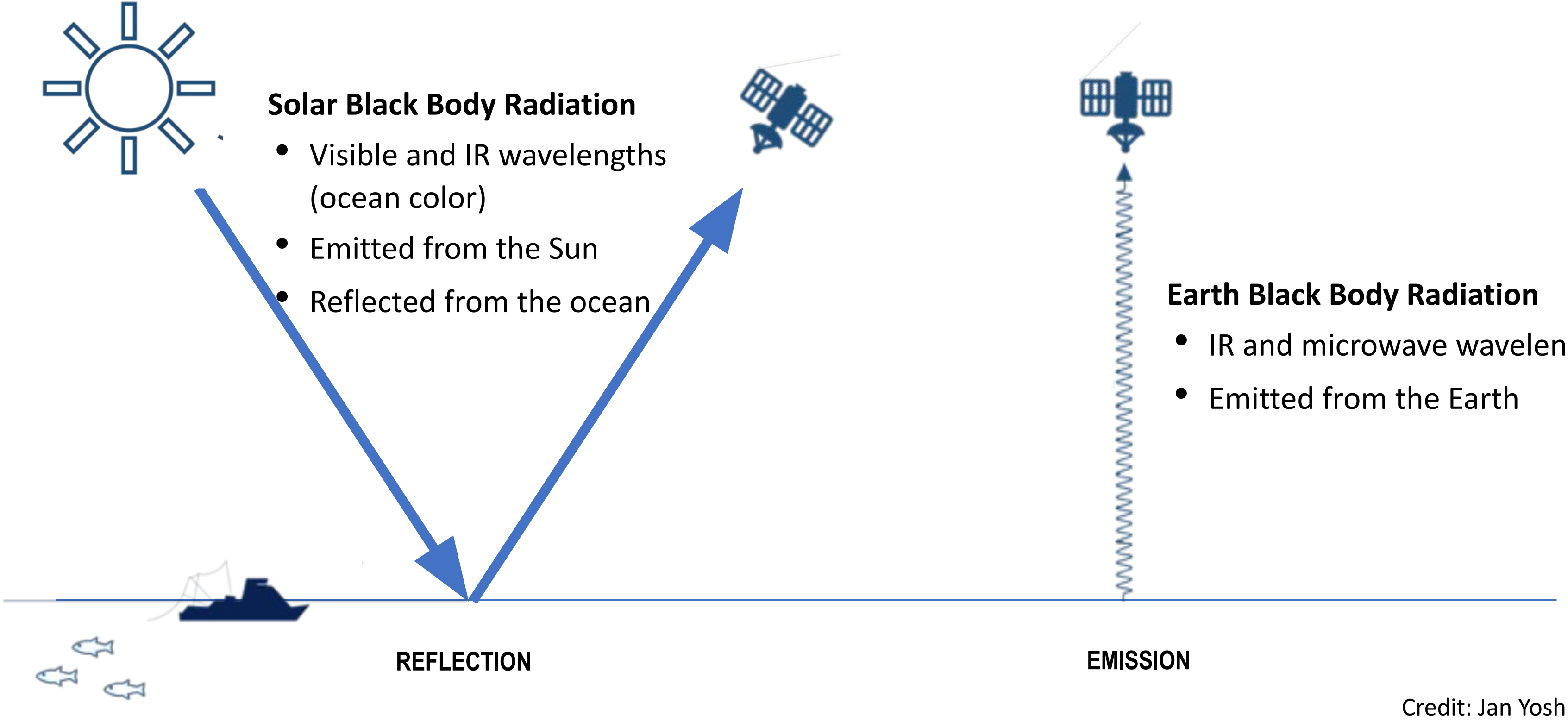
Satellite vs Sensor

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, NOAA-20 and NOAA-21

Satellite measure electromagnetic radiation (EMR)



Solar Black Body Radiation

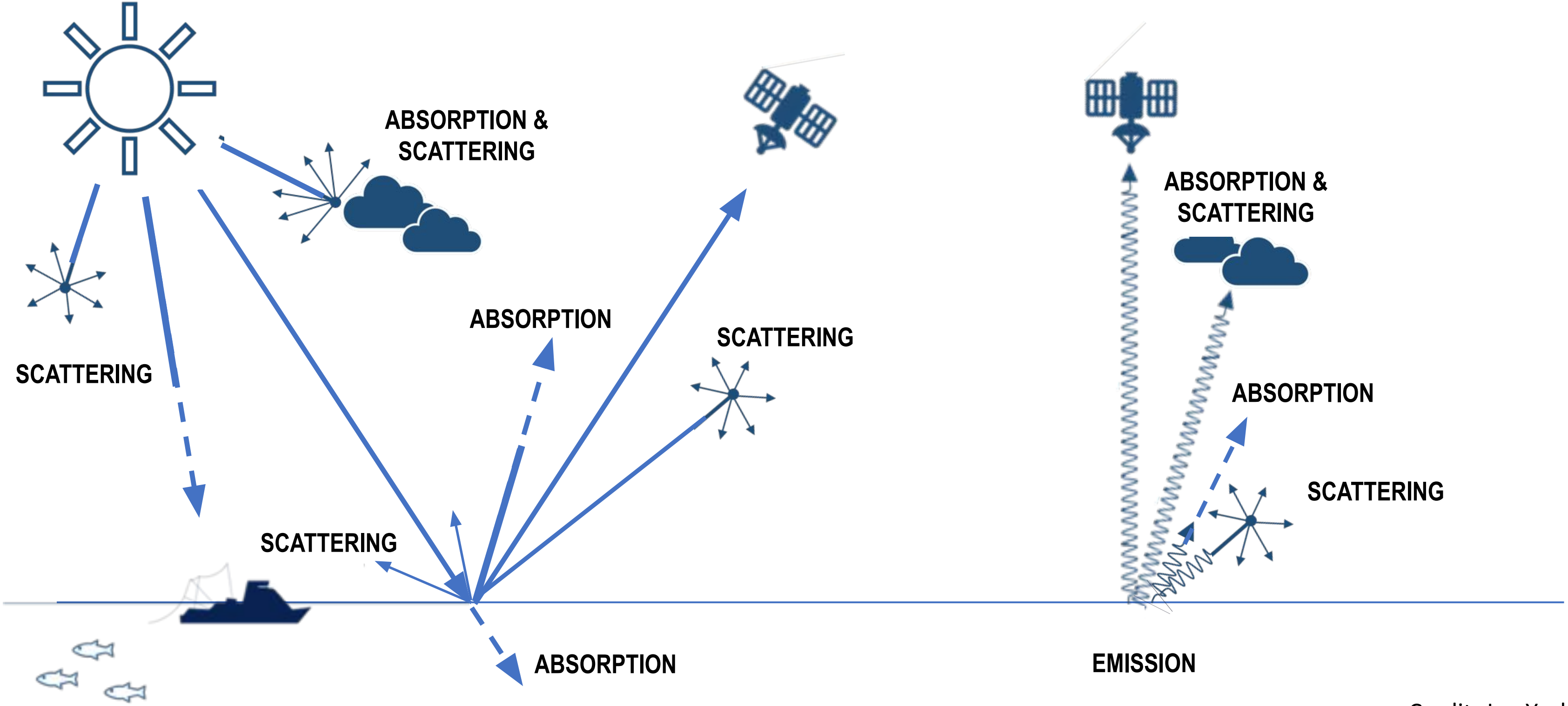
- Visible and IR wavelengths (ocean color)
- Emitted from the Sun
- Reflected from the ocean

Earth Black Body Radiation

- IR and microwave wavelengths
- Emitted from the Earth

Credit: Jan Yoshioka, CI

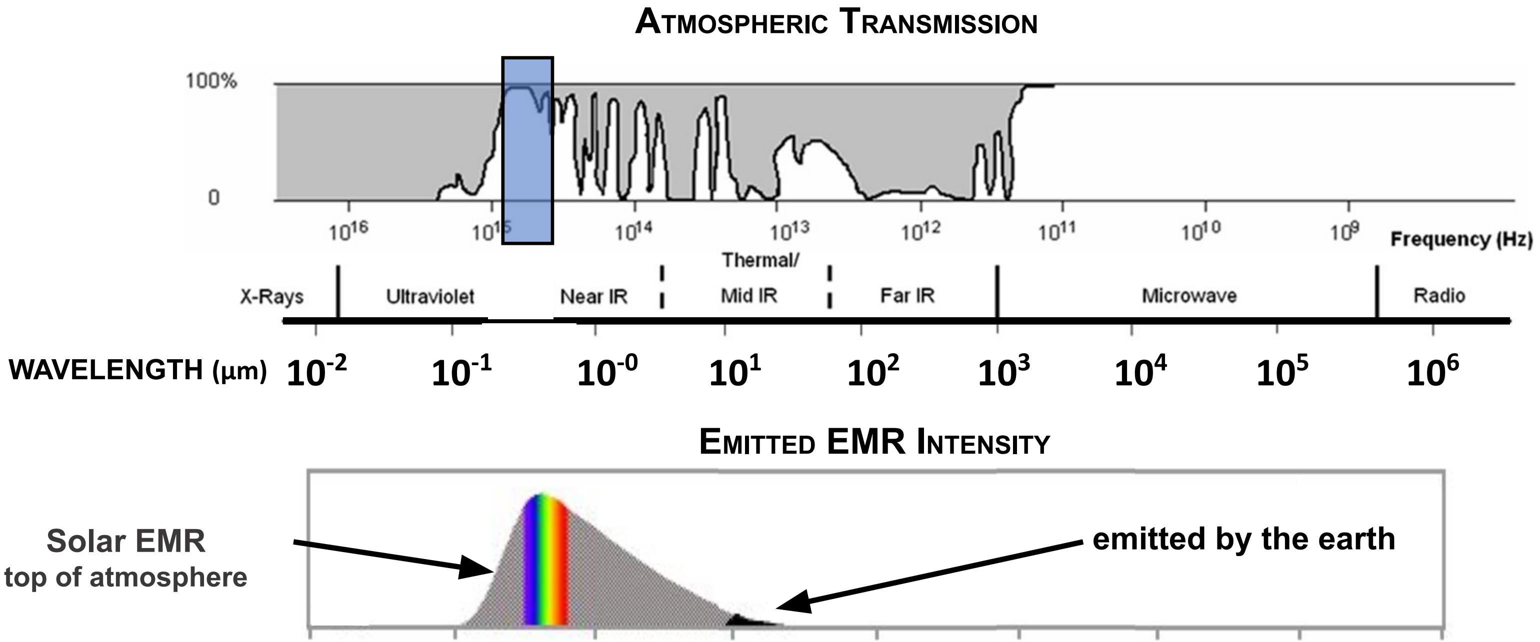
Processes alter the EMR signal as it passes through the atmosphere



Credit: Jan Yoshioka, CI

Visible light passes through the atmosphere without much attenuation

Atmospheric transmittance is high in **visible bands**, where solar EMR emission is highest

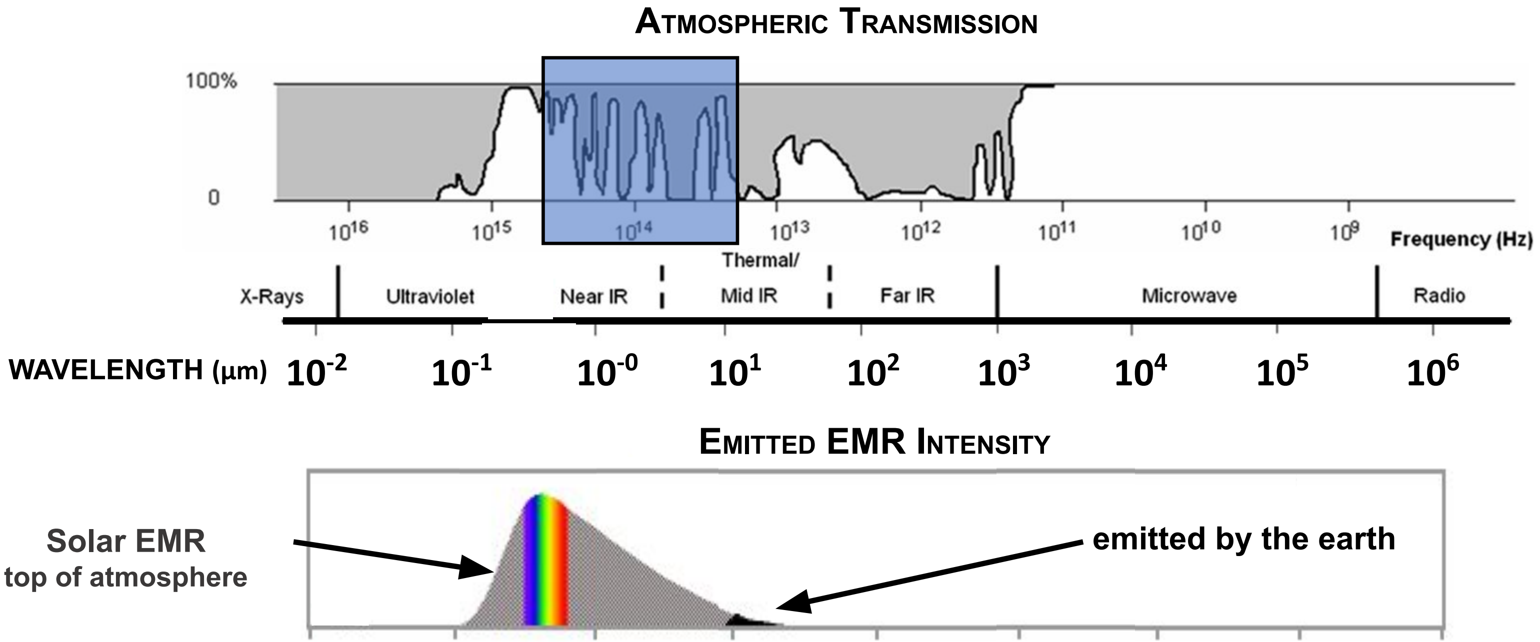


Solar EMR
top of atmosphere

emitted by the earth

Infrared passes through narrow atmospheric windows

In the infrared, high transmittance occurs in narrow bands. This includes the optical windows in the thermal **infrared**, where the Earth's surface emits radiation.



ATMOSPHERIC TRANSMISSION

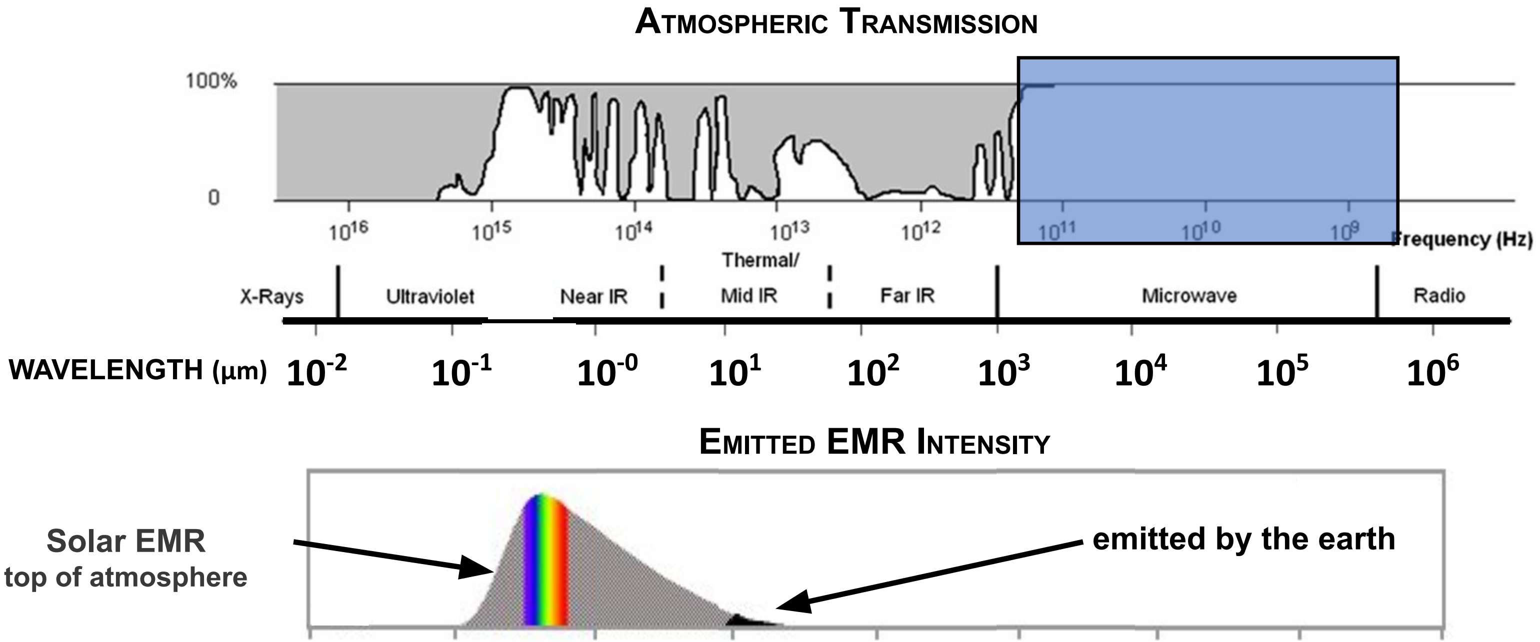
EMITTED EMR INTENSITY

Solar EMR
top of atmosphere

emitted by the earth

Microwaves passes through the atmosphere without much attenuation

In the **microwave**, atmosphere transmission is near 100%.
But emission in the **microwave by** are relatively weak, so large antennas and large sensor footprints are needed to collect enough radiation for measurements.



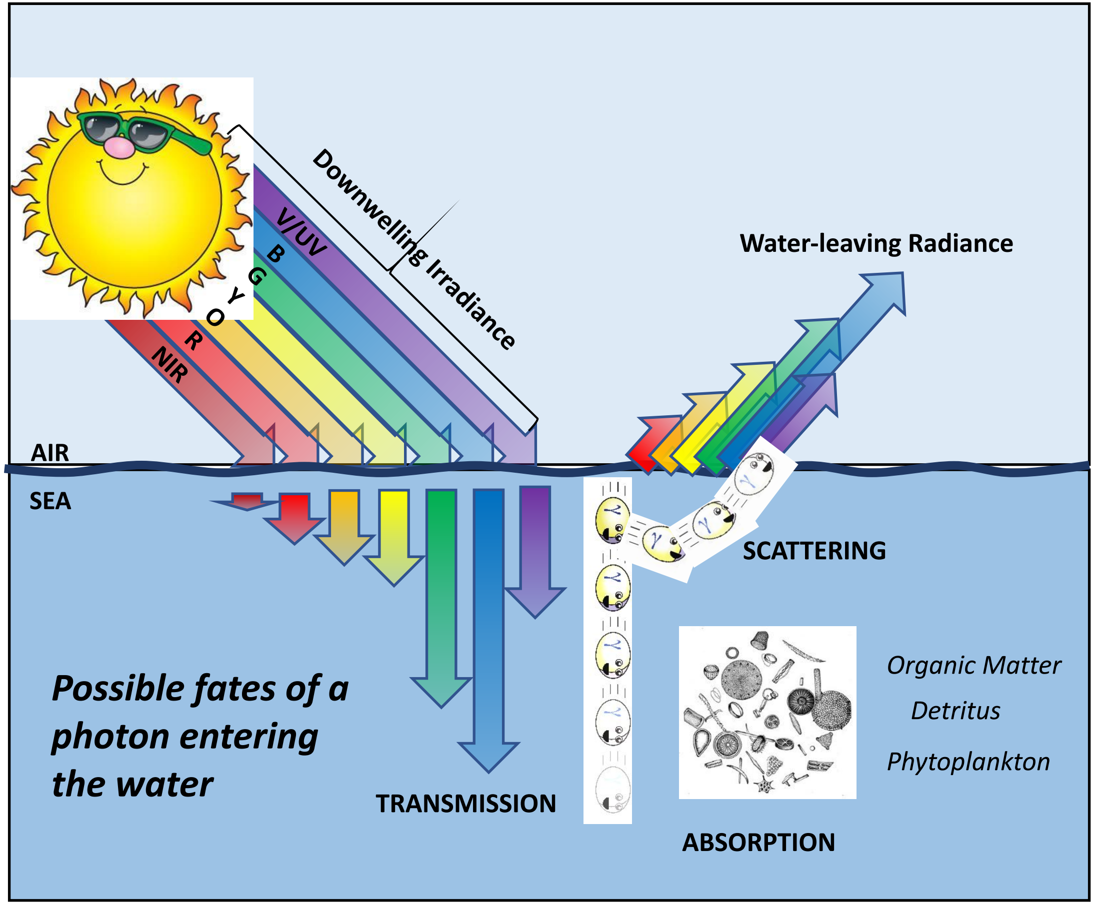
EMR is also affected by the water properties

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



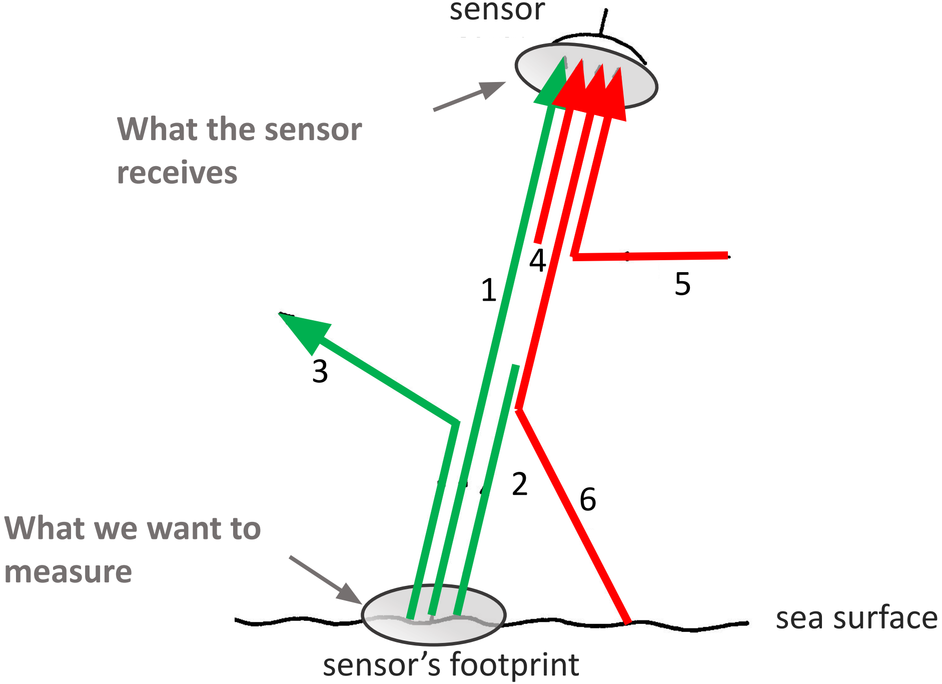
Atmospheric Pathways of EMT between the ocean and the satellite

Emitted from the sea within the sensor's footprint

Ray 1 - the useful signal, radiation leaving the ocean and measured by the sensor
Ray 2 - radiation leaving the ocean that is absorbed by the atmosphere
Ray 3 - radiation that is scattered by the atmosphere out of the sensor field of view

Reaching sensor from sources outside its footprint

Ray 4 - radiation emitted by the constituents of the atmosphere
Ray 5 - radiation reflected by scattering into the field of vision of the sensor
Ray 6 - radiation from the ocean but from outside the field of view.



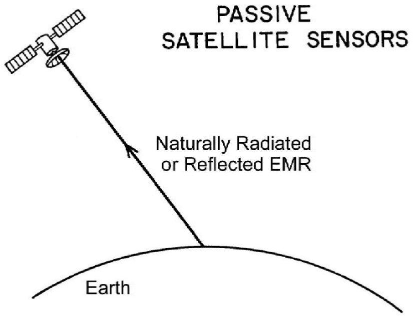
ATMOSPHERIC CORRECTIONS ARE NECESSARY TO DERIVE ACCURATE SATELLITE DATA PRODUCTS.

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.

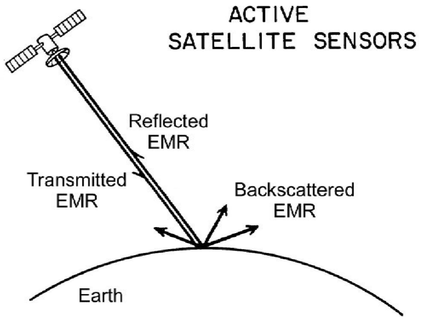
Atmospheric correction is necessary to derive accurate satellite data products.

Passive vs Active Sensors



Passive Remote Sensing

- Reception of EMR signals from natural source
- Either EMR from the Sun that is reflected off of the earth or EMR emitted by the Earth

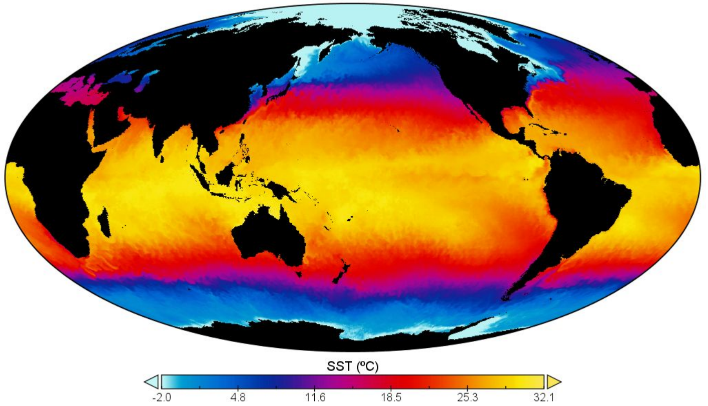


Active Remote Sensing

- Reception of EMR signals from a pulse emitted by a satellite
- The pulse is directed to the earth and the reflected signal is captured by the satellite sensor

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:

- $\text{SST}_{\text{subskin}}$ 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)
- CDOM (Colored Dissolved Organic Matter)
- Primary Productivity
- Fluorescence,
- Photosynthetically Available Radiation (PAR)
- Water Clarity

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 (NOAAA-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

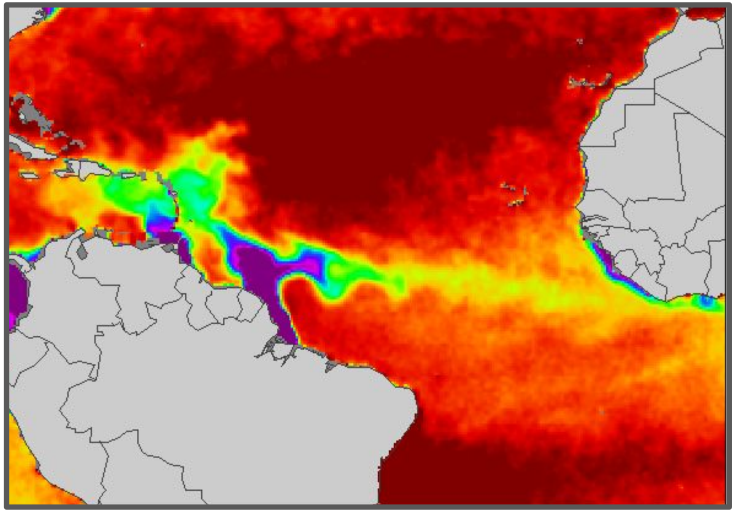
1990 - present
Daily global coverage
Accuracy ~ 3 cm

Uses for satellite salinity

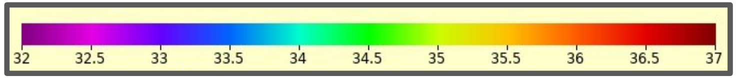
Global thermohaline circulation

Dynamic ecosystem modeling

Tracking surface salinity events



SMOS data – 0.25° resolution



Practical Salinity Scale

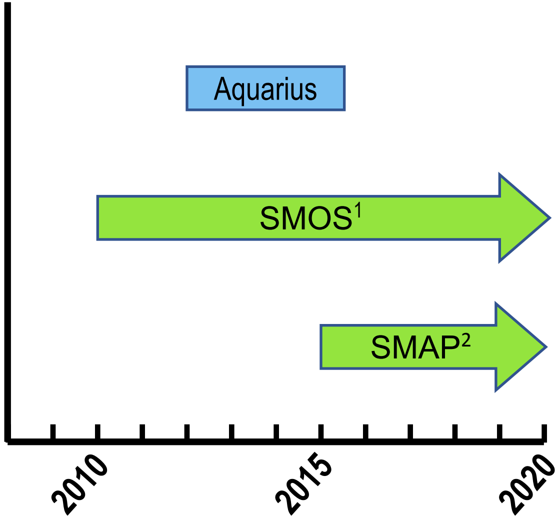
Temporal coverage: 2010 - Present

Spatial resolution: 0.25 – 1 degree

Global coverage: 3 – 8 days

Accuracy: 0.15-0.25 PSS

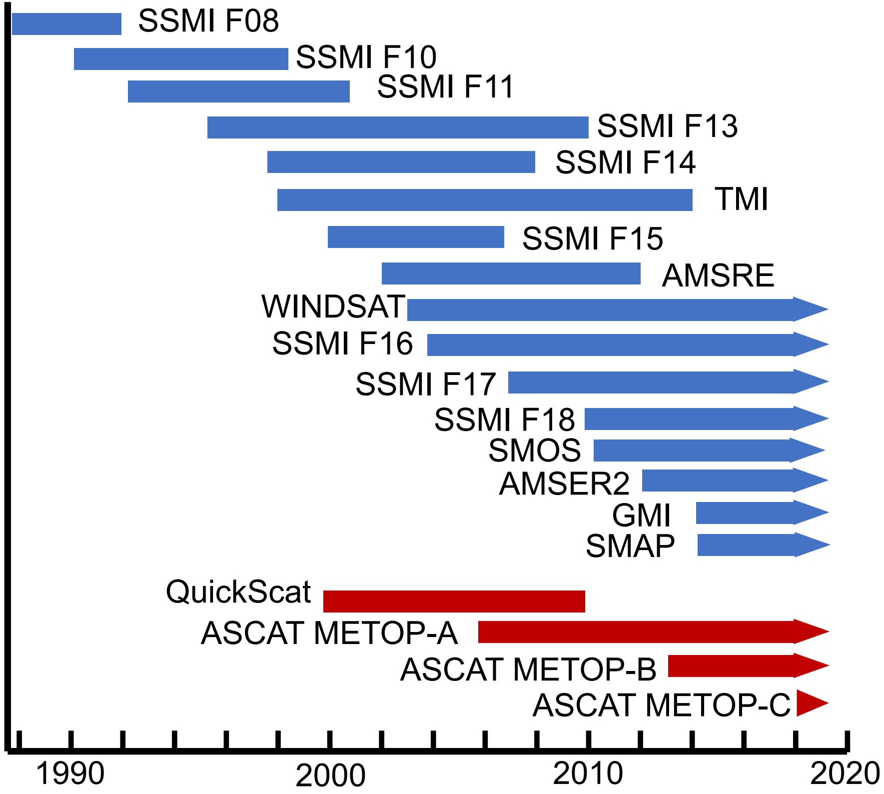
Depth: 1–2 cm

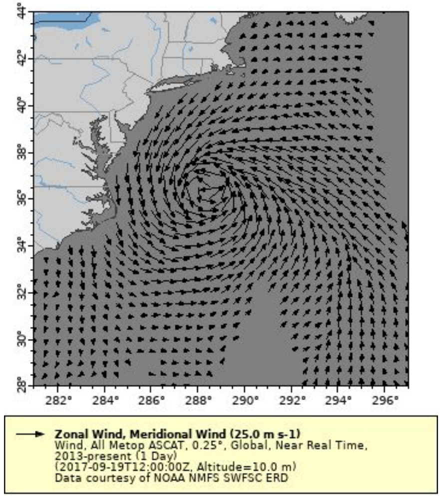


[1] Soil Moisture and Ocean Salinity mission

[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)

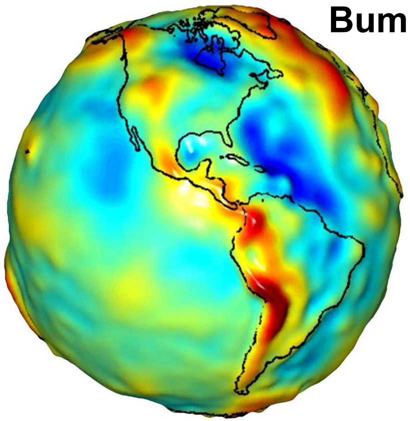
Active sensors (wind speed & direction)

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

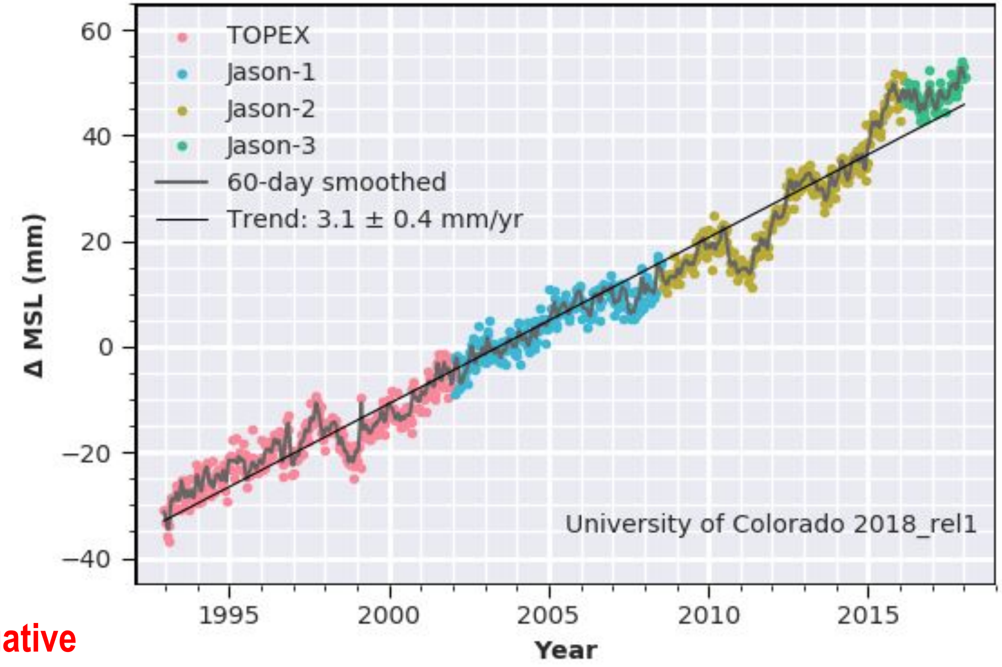
Altimetry

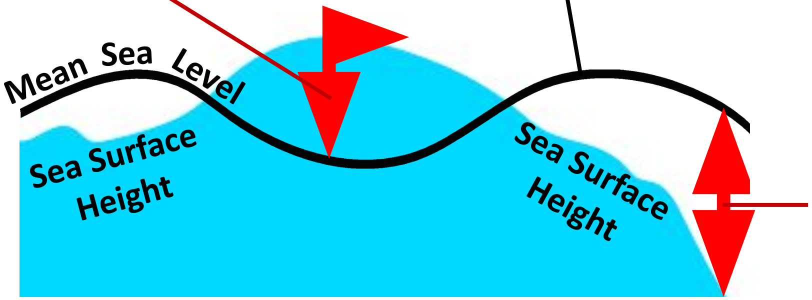
Main variables:

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



Bumpy Earth





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

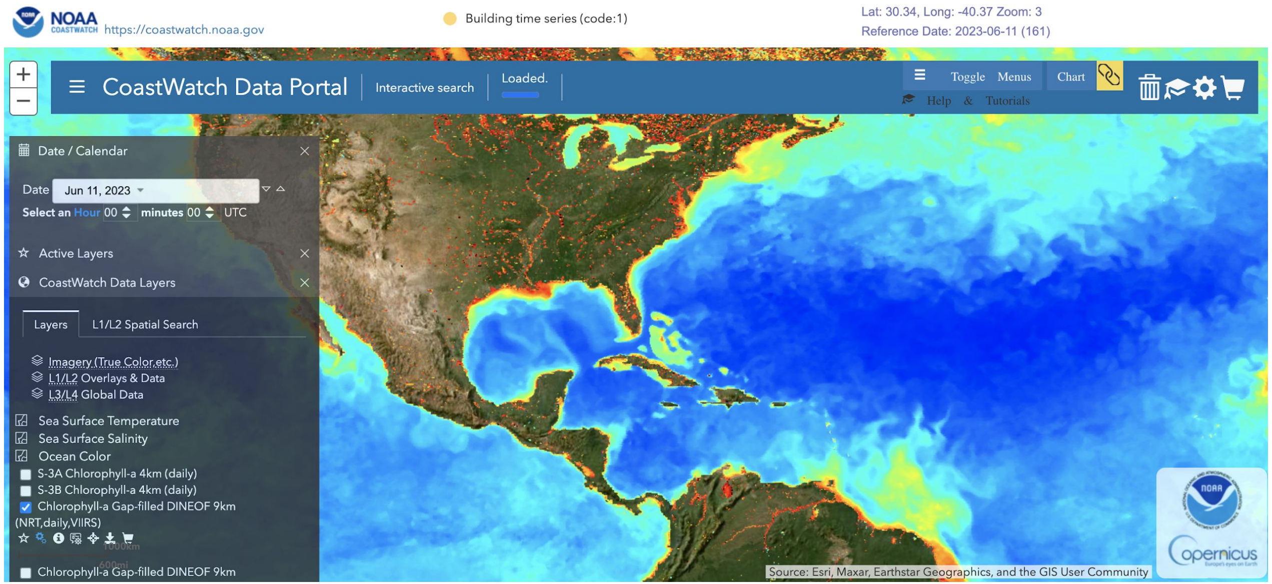
Positive
Sea Level Anomaly

Negative
Sea Level Anomaly

Data Access/Discovery

- Websites:
  - CoastWatch (https://coastwatch.noaa.gov)
  - CoastWatch Regional Nodes (https://coastwatch.noaa.gov/cw/nodes.html)
- FTP Server:
  - ftp://ftpcoastwatch.noaa.gov
- THREDDS/ERDDAP:
  - https://coastwatch.noaa.gov/thredds
  - https://coastwatch.noaa.gov/erddap
  - CoastWatch West Coast Node ERDDAP Catalog of Catalogs:
    - https://coastwatch.pfeg.noaa.gov/erddap/download/setup.html#organizations
    - erddap.com

CoastWatch Data Portal


https://coastwatch.noaa.gov

Building time series (code:1)

Lat: 30.34, Long: -40.37 Zoom: 3
Reference Date: 2023-06-11 (161)

Loaded.

Date Jun 11, 2023
Select an Hour 00 minutes 00 UTC

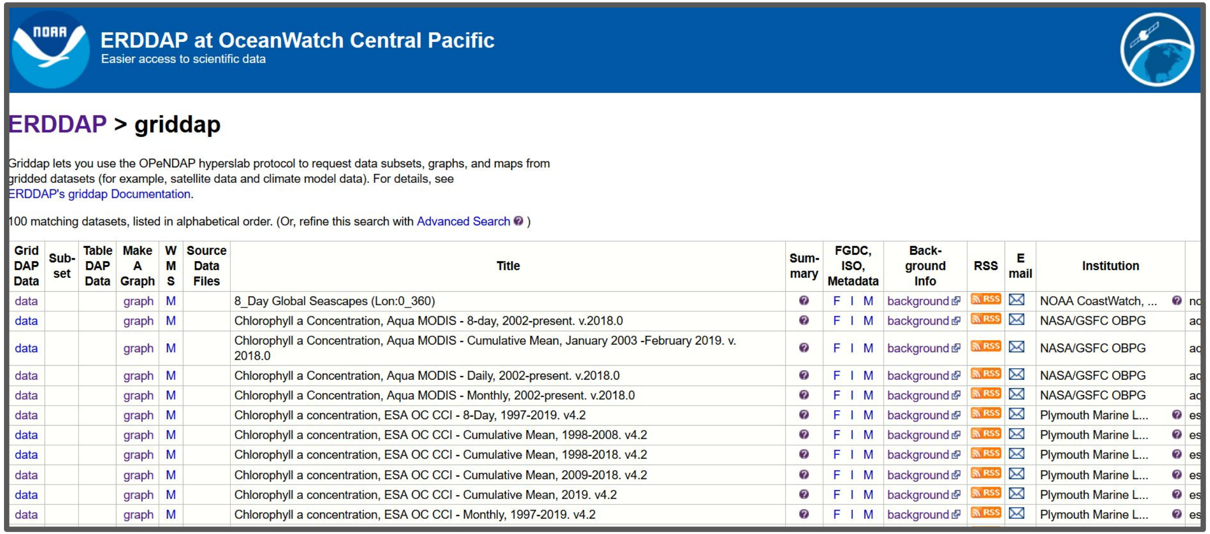
☐ S-3A Chlorophyll-a 4km (daily)
☐ S-3B Chlorophyll-a 4km (daily)
☑ Chlorophyll-a Gap-filled DINEOF 9km (NRT,daily,VIIRS)
☐ Chlorophyll-a Gap-filled DINEOF 9km

Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community

- Visualize data layers
- Make time series
- Download data for region/range of dates
- Special user tools for specific applications

https://coastwatch.noaa.gov/cw_html/cwViewer.html

The web interface for the ERDDAP data catalog



ERDDAP at OceanWatch Central Pacific
Easier access to scientific data

ERDDAP > griddap

Griddap lets you use the OPeNDAP hyperslab protocol to request data subsets, graphs, and maps from gridded datasets (for example, satellite data and climate model data). For details, see ERDDAP's griddap Documentation.

100 matching datasets, listed in alphabetical order. (Or, refine this search with Advanced Search ?)

Grid DAP Data	Sub-set	Table DAP Data	Make A Graph	W M S	Source Data Files	Title	Sum-mary	FGDC, ISO, Metadata	Back-ground Info	RSS	E mail	Institution	
data			graph	M		8_Day Global Seascapes (Lon:0_360)	?	F I M	background	RSS	✉	NOAA CoastWatch, ... ?	no
data			graph	M		Chlorophyll a Concentration, Aqua MODIS - 8-day, 2002-present. v.2018.0	?	F I M	background	RSS	✉	NASA/GSFC OBPG	ac
data			graph	M		Chlorophyll a Concentration, Aqua MODIS - Cumulative Mean, January 2003 -February 2019. v. 2018.0	?	F I M	background	RSS	✉	NASA/GSFC OBPG	ac
data			graph	M		Chlorophyll a Concentration, Aqua MODIS - Daily, 2002-present. v.2018.0	?	F I M	background	RSS	✉	NASA/GSFC OBPG	ac
data			graph	M		Chlorophyll a Concentration, Aqua MODIS - Monthly, 2002-present. v.2018.0	?	F I M	background	RSS	✉	NASA/GSFC OBPG	ac
data			graph	M		Chlorophyll a concentration, ESA OC CCI - 8-Day, 1997-2019. v4.2	?	F I M	background	RSS	✉	Plymouth Marine L... ?	es
data			graph	M		Chlorophyll a concentration, ESA OC CCI - Cumulative Mean, 1998-2008. v4.2	?	F I M	background	RSS	✉	Plymouth Marine L... ?	es
data			graph	M		Chlorophyll a concentration, ESA OC CCI - Cumulative Mean, 1998-2018. v4.2	?	F I M	background	RSS	✉	Plymouth Marine L... ?	es
data			graph	M		Chlorophyll a concentration, ESA OC CCI - Cumulative Mean, 2009-2018. v4.2	?	F I M	background	RSS	✉	Plymouth Marine L... ?	es
data			graph	M		Chlorophyll a concentration, ESA OC CCI - Cumulative Mean, 2019. v4.2	?	F I M	background	RSS	✉	Plymouth Marine L... ?	es
data			graph	M		Chlorophyll a concentration, ESA OC CCI - Monthly, 1997-2019. v4.2	?	F I M	background	RSS	✉	Plymouth Marine L... ?	es

- Make simple graphs
- Download data for region/range of dates
- Use API in programming language to download data

For satellite data: Visit the NOAA CoastWatch data catalog pages

EACH OF THESE CATALOGS PROVIDE INFORMATION ABOUT DATASETS TO HELP YOU DECIDE WHICH TO USE

NOAA CoastWatch • OceanWatch
Central Office
coastwatch.noaa.gov

NOAA COASTWATCH WEST COAST REGIONAL NODE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
coastwatch.pfeg.noaa.gov/data.html

NOAA CoastWatch
Caribbean and Gulf of Mexico Regional Node
cwcaribbean.aoml.noaa.gov

NOAA OCEANWATCH CENTRAL PACIFIC NODE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
https://oceanwatch.pifsc.noaa.gov/doc.html

NOAA CoastWatch EAST COAST NODE
eastcoast.coastwatch.noaa.gov

NOAA POLARWATCH COASTWATCH REGIONAL NODE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
https://polarwatch.noaa.gov/catalog/

NOAA CoastWatch Great Lakes
coastwatch.glerl.noaa.gov

Preview sample images

Find out the geographical coverage

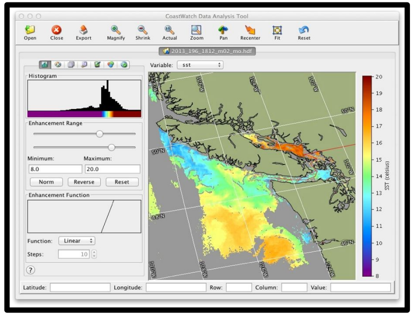
Find out the temporal range coverage

Review metadata for details about datasets

Tools for data processing

COMPREHENSIVE SOFTWARE PACKAGES

NOAA CoastWatch Utilities



Variable: sst

Minimum: 8.0

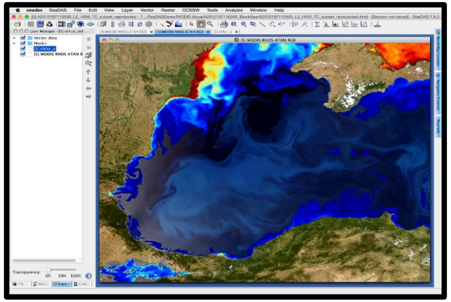
Maximum: 20.0

Function: Linear

Steps: 10

coastwatch.noaa.gov/cw/user-resources/coastwatch-utilities.html

NASA SeaDAS



seadas.gsfc.nasa.gov

Comprehensive software packages for satellite data:

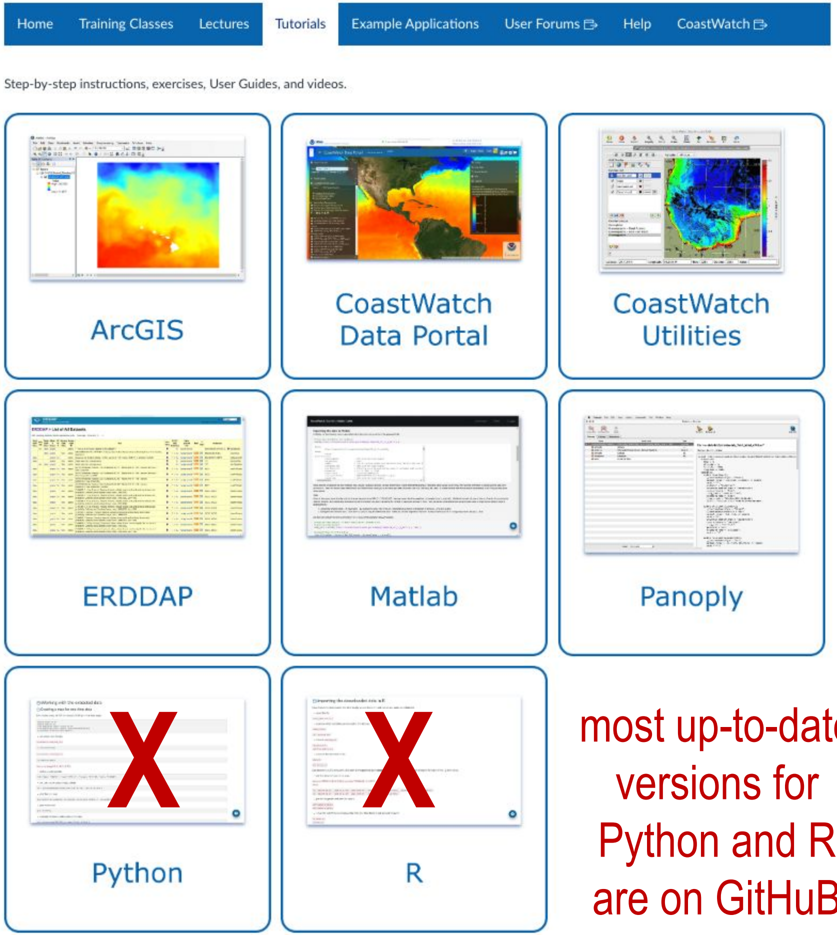
- Processing
- Graphics and Visualization
- Analysis
- Format conversions
- Quality control

Not shown, ESA SNAP

Tutorials are Available on the CoastWatch Learning Portal

Presently housed on the University of Maryland learning management system :

https://umd.instructure.com/courses/1336575/pages/all-lectures



Step-by-step instructions, exercises, User Guides, and videos.

most up-to-date versions for Python and R are on GitHuB

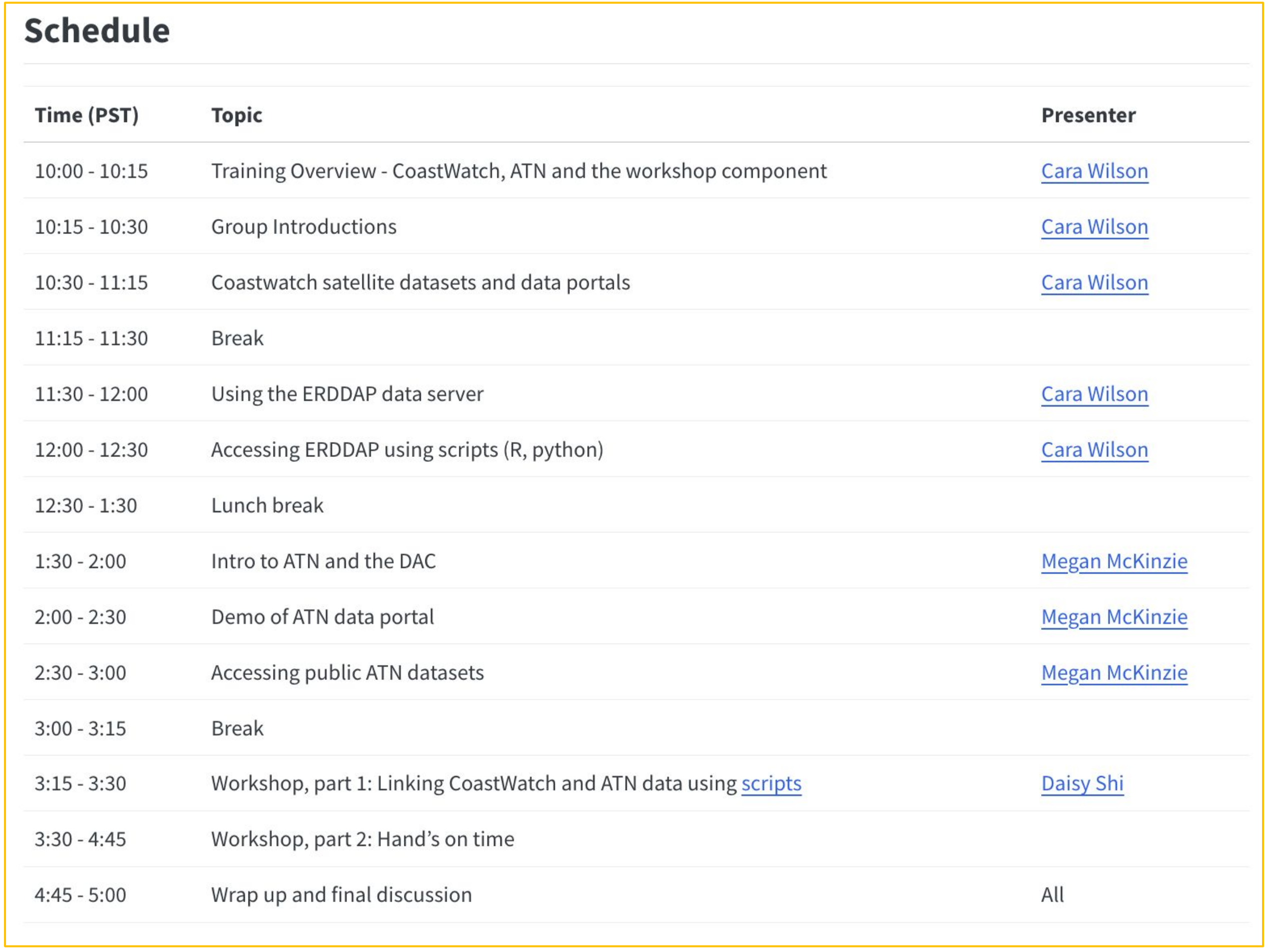
We will be using Slido to interact with participants:

Go to www.slido.com

#ATN

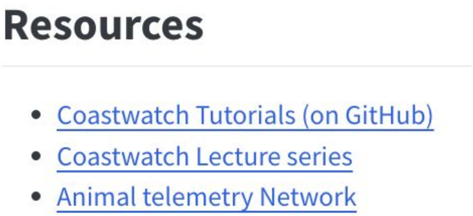
2024 ATN Training

October 25, 2024 Virtual 10am - 5pm (Pacific Time)



Schedule

Time (PST)	Topic	Presenter
10:00 - 10:15	Training Overview - CoastWatch, ATN and the workshop component	Cara Wilson
10:15 - 10:30	Group Introductions	Cara Wilson
10:30 - 11:15	Coastwatch satellite datasets and data portals	Cara Wilson
11:15 - 11:30	Break	
11:30 - 12:00	Using the ERDDAP data server	Cara Wilson
12:00 - 12:30	Accessing ERDDAP using scripts (R, python)	Cara Wilson
12:30 - 1:30	Lunch break	
1:30 - 2:00	Intro to ATN and the DAC	Megan McKinzie
2:00 - 2:30	Demo of ATN data portal	Megan McKinzie
2:30 - 3:00	Accessing public ATN datasets	Megan McKinzie
3:00 - 3:15	Break	
3:15 - 3:30	Workshop, part 1: Linking CoastWatch and ATN data using scripts	Daisy Shi
3:30 - 4:45	Workshop, part 2: Hand's on time	
4:45 - 5:00	Wrap up and final discussion	All



Resources

- Coastwatch Tutorials (on GitHub)
- Coastwatch Lecture series
- Animal telemetry Network

https://coastwatch-training.github.io/CoastWatch-Workshops/courses/seaice24.html