Satellite 101

Cara Wilson

NOAA Coastwatch Satellite Course

Anchorage, Alaska

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Versioning

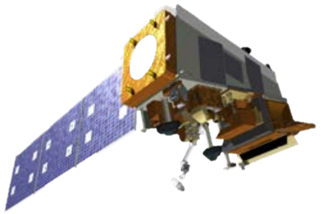
-Wilson, 2017, WCN

-Tomlinson and Vogel, 2018, ECN

-Abecassis and Howell, 2018, PIN

-Wilson and Robinson, 2019, WCN

What is covered in this presentation



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

Sausage Making vs Sausages

What goes into making satellite products: EMR, wavelength bands, IOPs, radiances, atmospheric correction, lunar calibration, absorption spectra, cloud masks…

Using the data for your specific application

What do satellites measure?

- Sea Ice
- Sea Surface Temperature (SST)
- Sea Surface Height (SSH)
- Chlorophyll (ocean color)
- Rainfall
- Surface Vector Winds (SWV)
- Salinity

For how long?

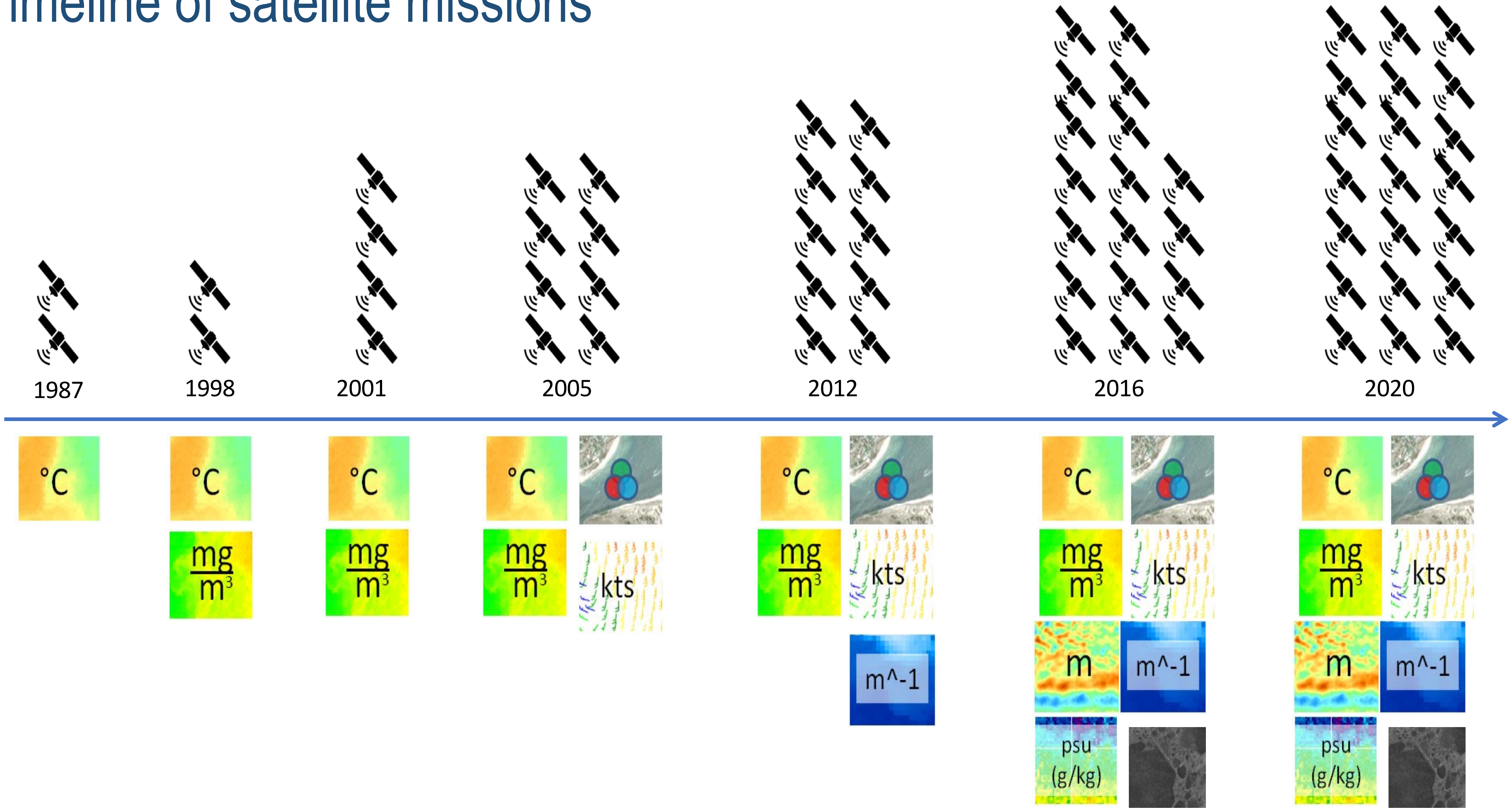
What do satellites measure?

• Sea Ice	since 1978*
• Sea Surface Temperature (SST)	since 1981
• Sea Surface Height (SSH)	since 1992
• Chlorophyll (ocean color)	since 1997
• Rainfall	since 1997
• Surface Vector Winds (SWV)	since 1999
• 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

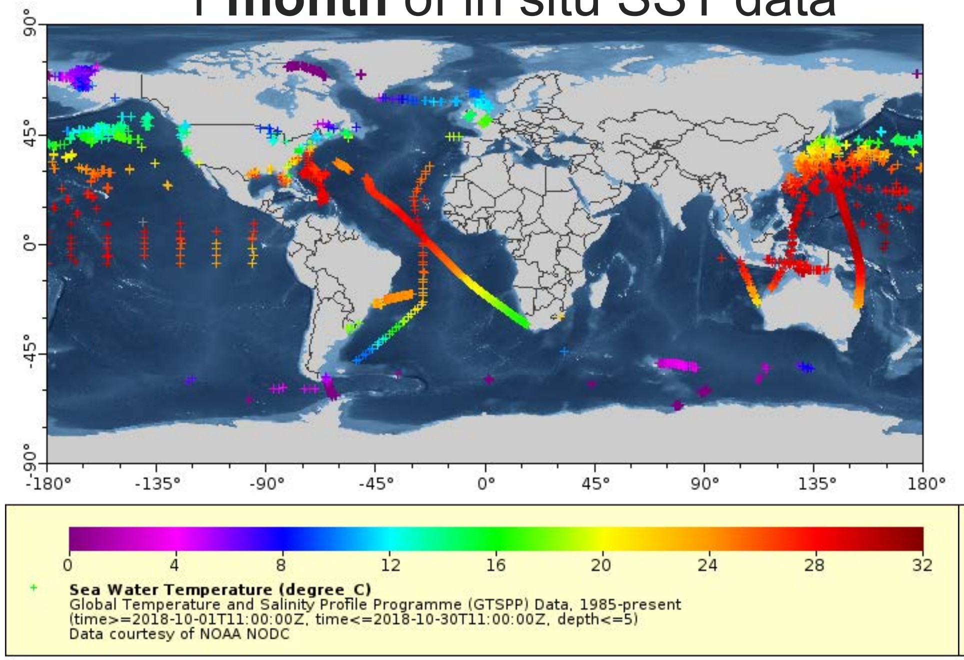
*The *consistently processed* satellite passive microwave record of sea ice concentration begins in 1978, but other data extends to 1966

Timeline of satellite missions

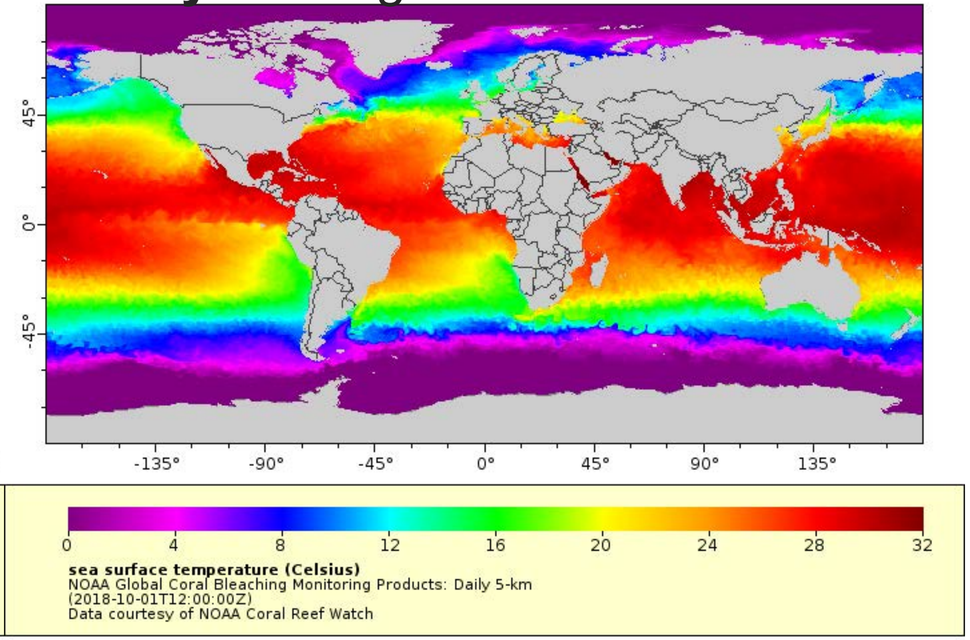


Benefits of satellite data

1 **month** of in situ SST data

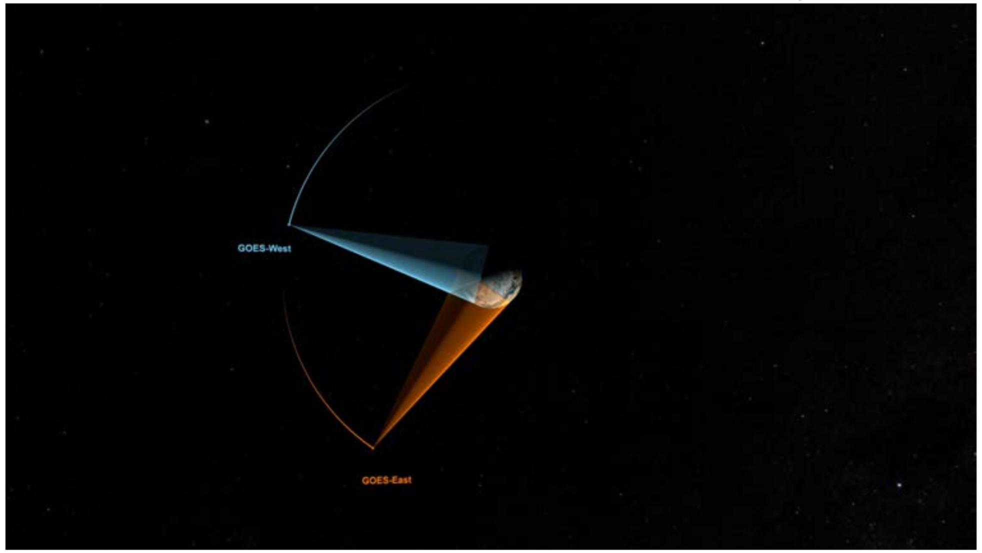


1 **day** of merged SST satellite data



- 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

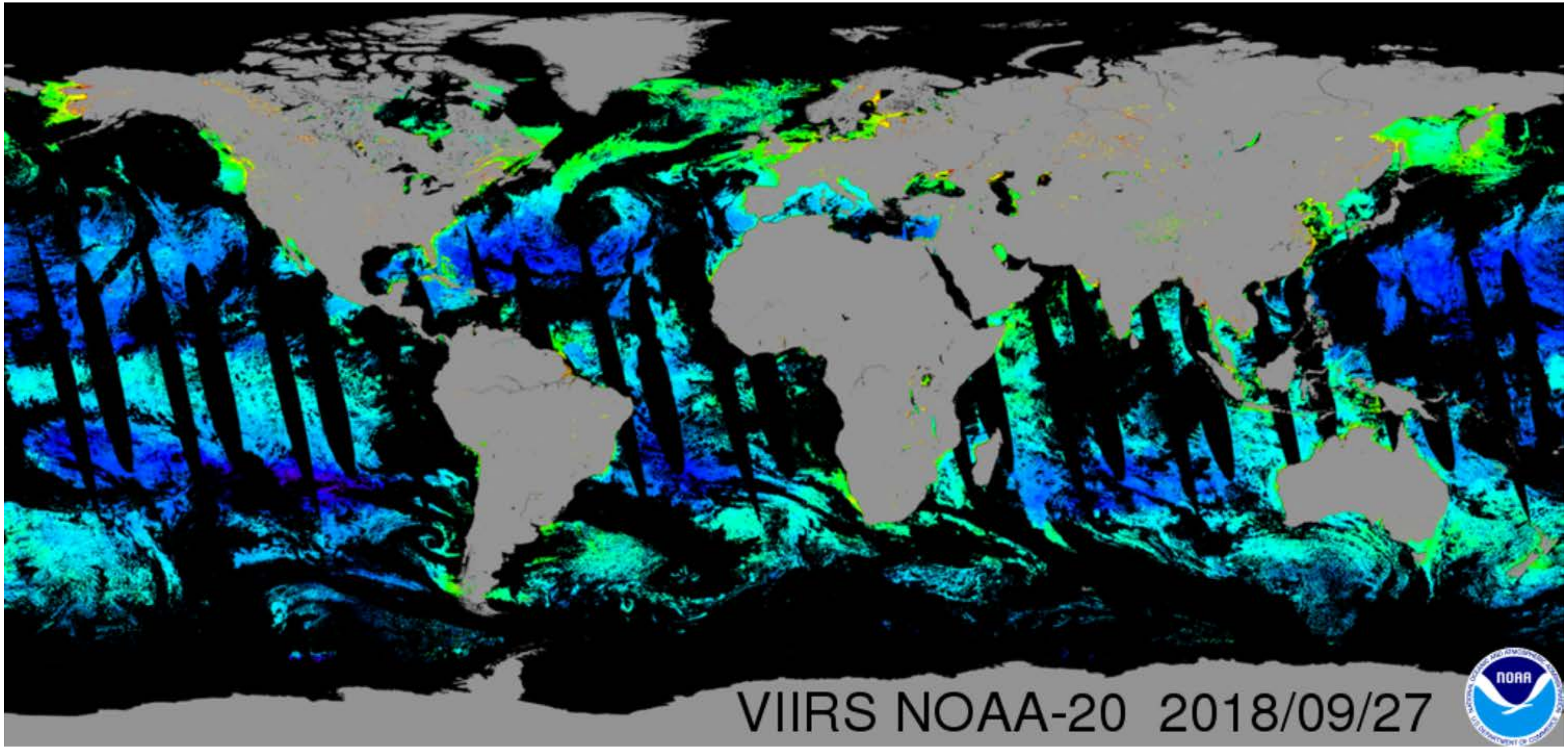


Polar-orbiting satellites view most of the earth once a day

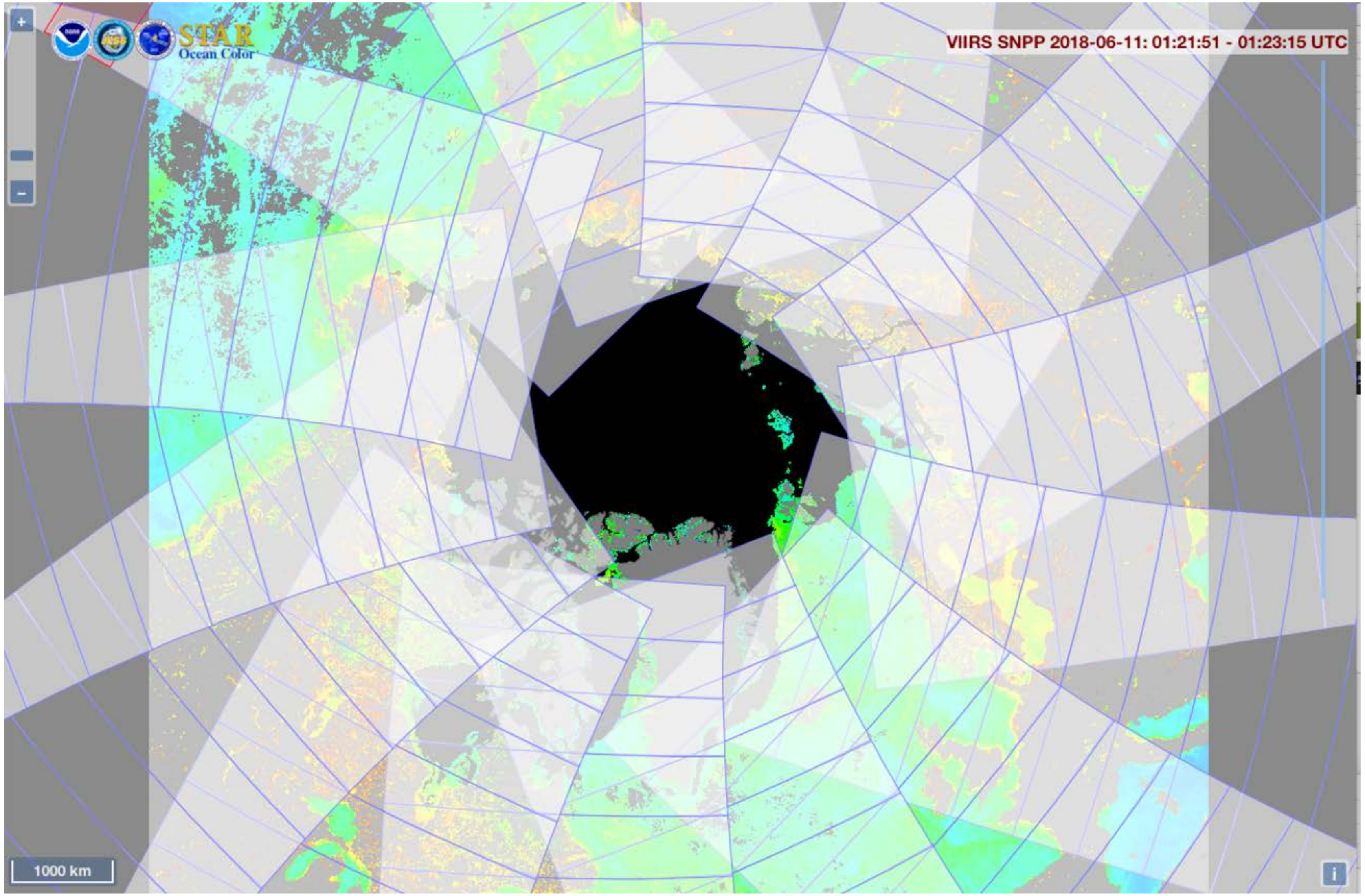
Geostationary satellites view a limited region of the earth, but do so continuously throughout the day

- 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

Polar Orbit

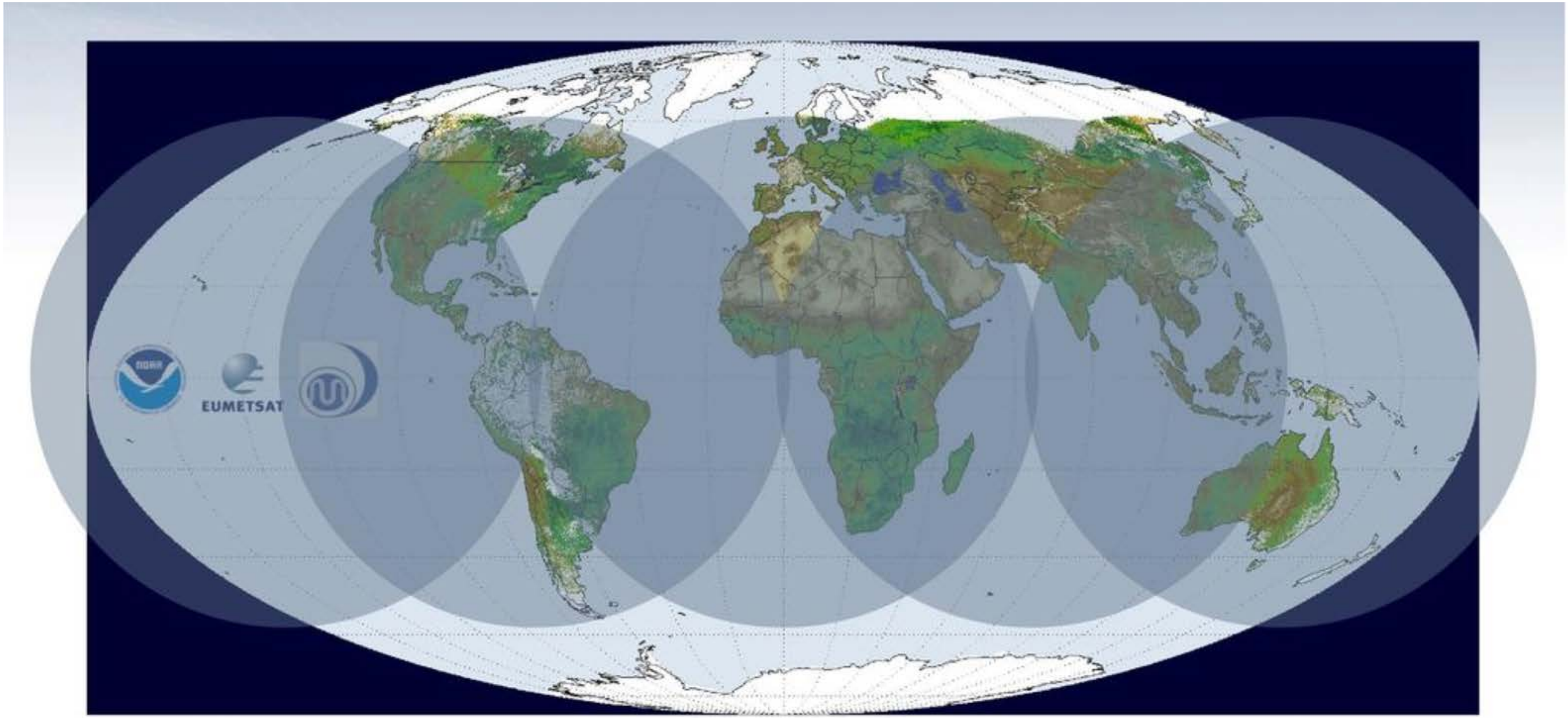


Polar Orbit



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

Geostationary coverage



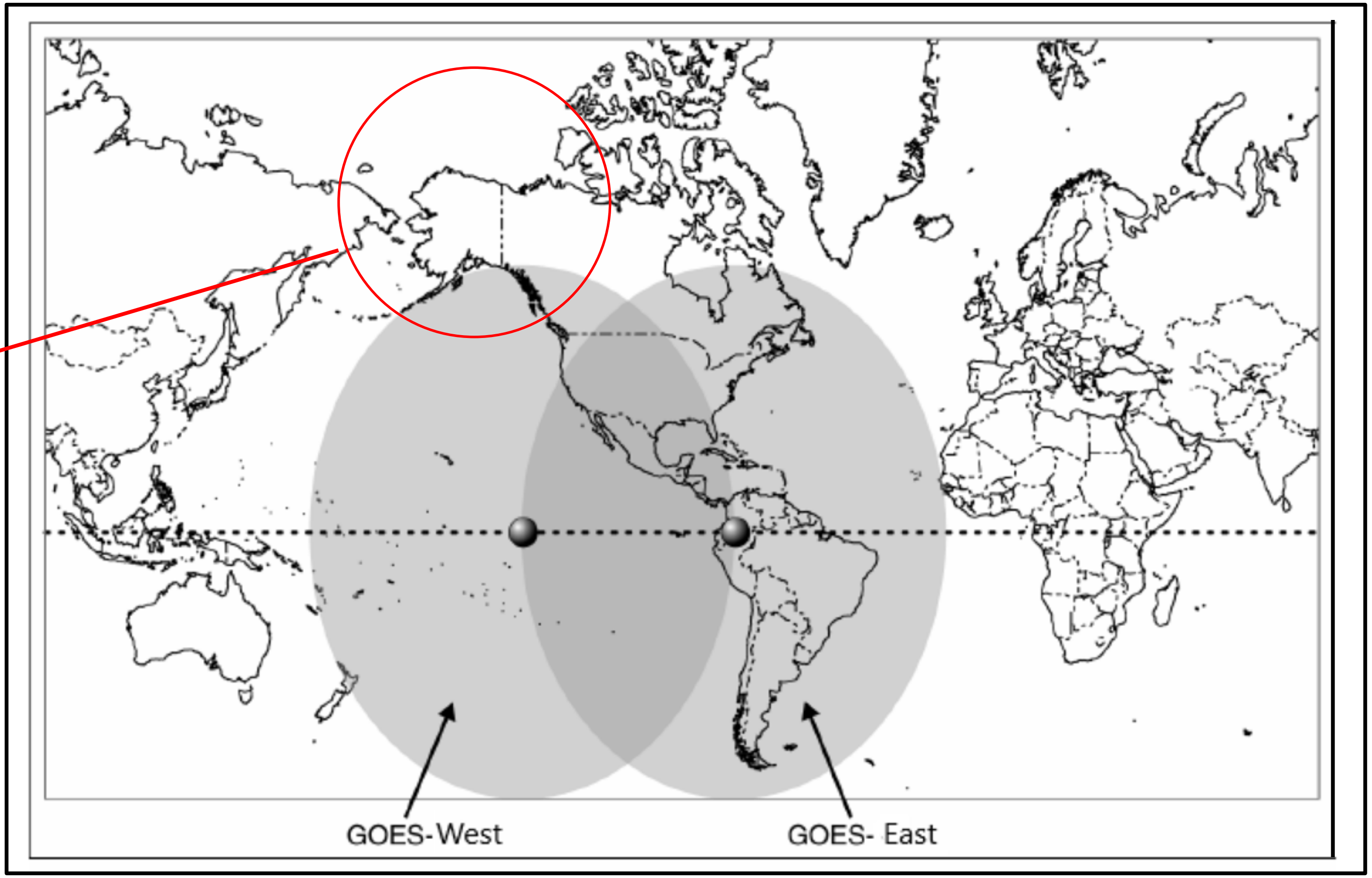
GOES-West (US), GOES-East (US), MeteoSat x2 (Europe), Himawari (Japan)

> 5 satellites for global coverage

EUMETSAT

GOES footprints

Geostationary satellites aren't much use in polar regions!



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. Satellites with larger swath widths will take less time to acquire global spatial coverage.

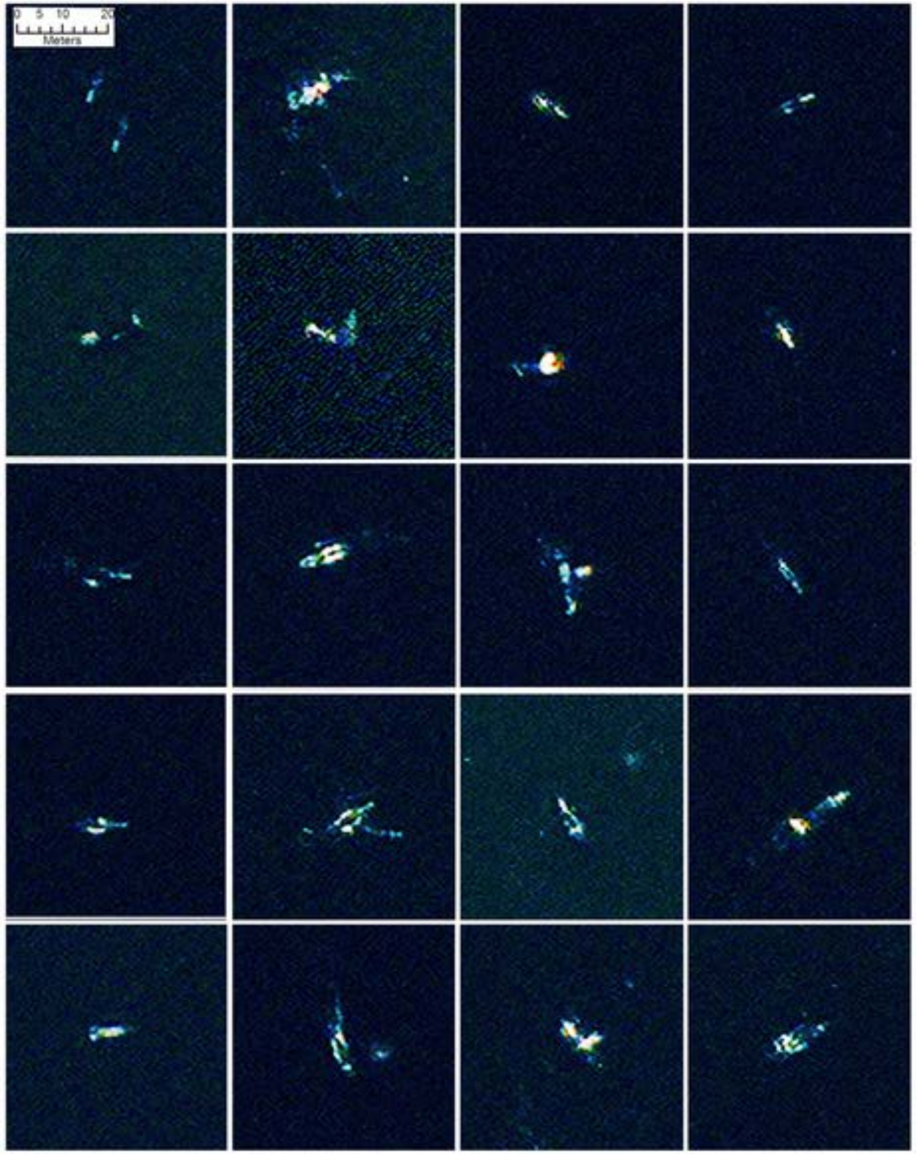
High Spatial Resolution Satellites

- 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.
- Most of the data has to be purchased, or is difficult to get a hold of.
- These data are not offered as part of this course.

Whales from Space

Figure 2. A selection of 20 comparable false colour image chips (bands 1-8-5) of probable whales found by the automated analysis.

"The WorldView2 satellite has a maximum 50 cm resolution and a water penetrating coastal band in the far-blue part of the spectrum that allows it to see deeper into the water column. Using an image covering 113 km^2, we identified 55 probable whales and 23 other features that are possibly whales, with a further 13 objects that are only detected by the coastal band."



Fretwell PT, Staniland IJ, Forcada J (2014) Whales from Space: Counting Southern Right Whales by Satellite. PLoS ONE 9(2): e88655. doi:10.1371/journal.pone.0088655
http://www.plosone.org/article/info:doi/10.1371/journal.pone.0088655

PLOS ONE

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 focusses 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

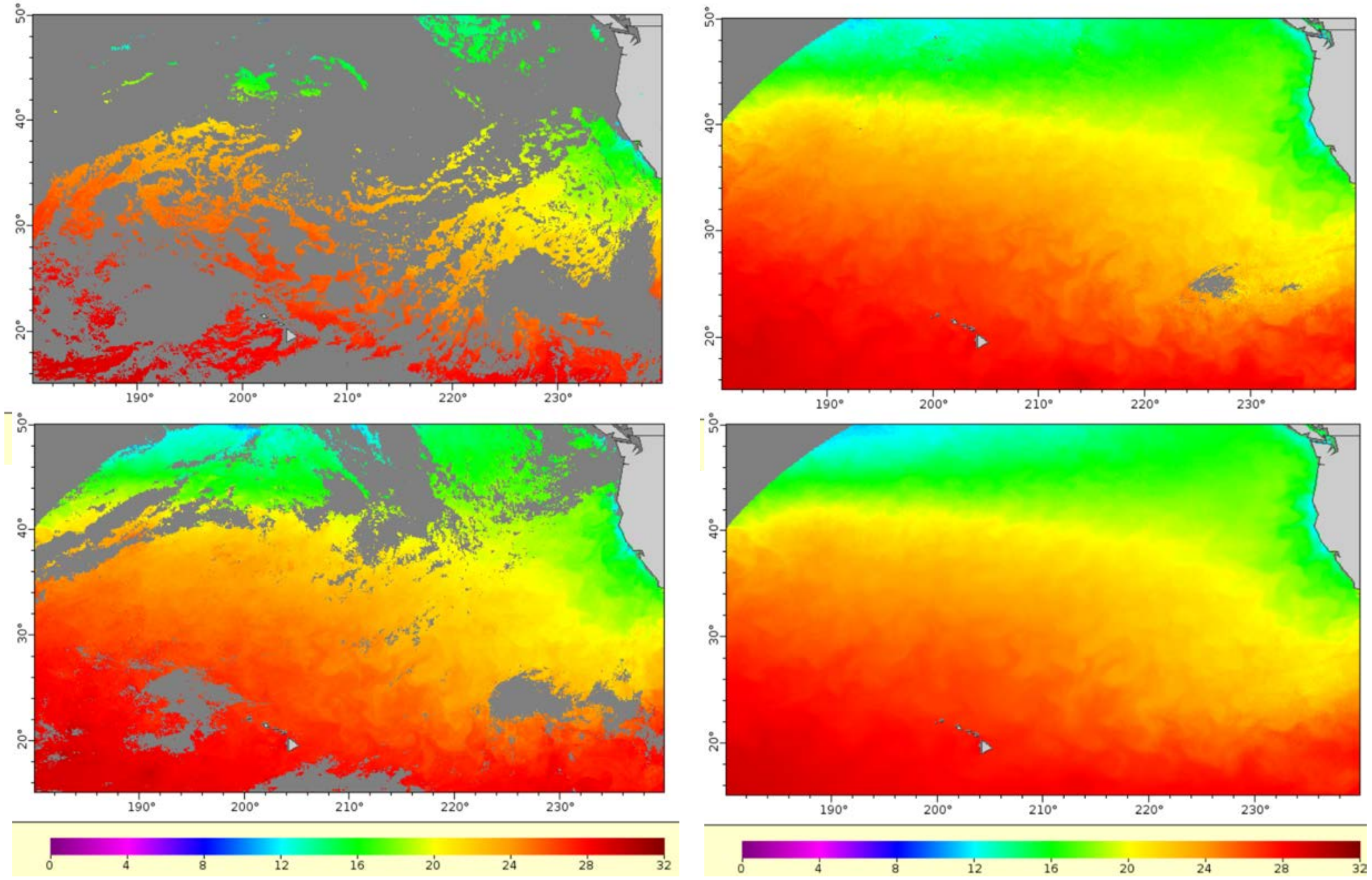
GOES West SST – September 2018

Sept 15
Hourly
Image

Sept 12-18
Weekly
Composite

Sept 15
Daily
Composite

Sept
Monthly
Composite

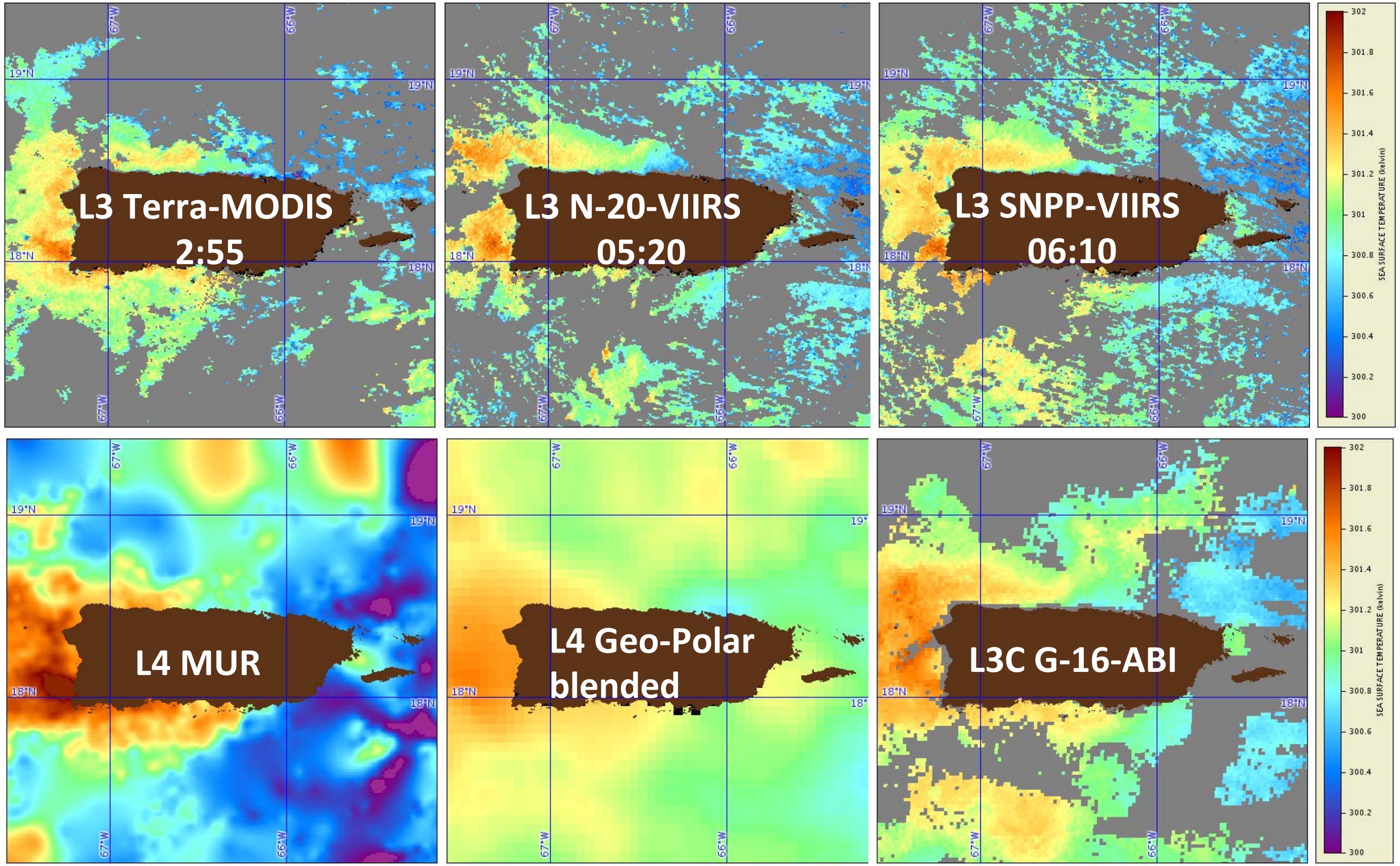


Cloud Masking

- 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.

To interpolate or not?

Slide from Irina Gladkova



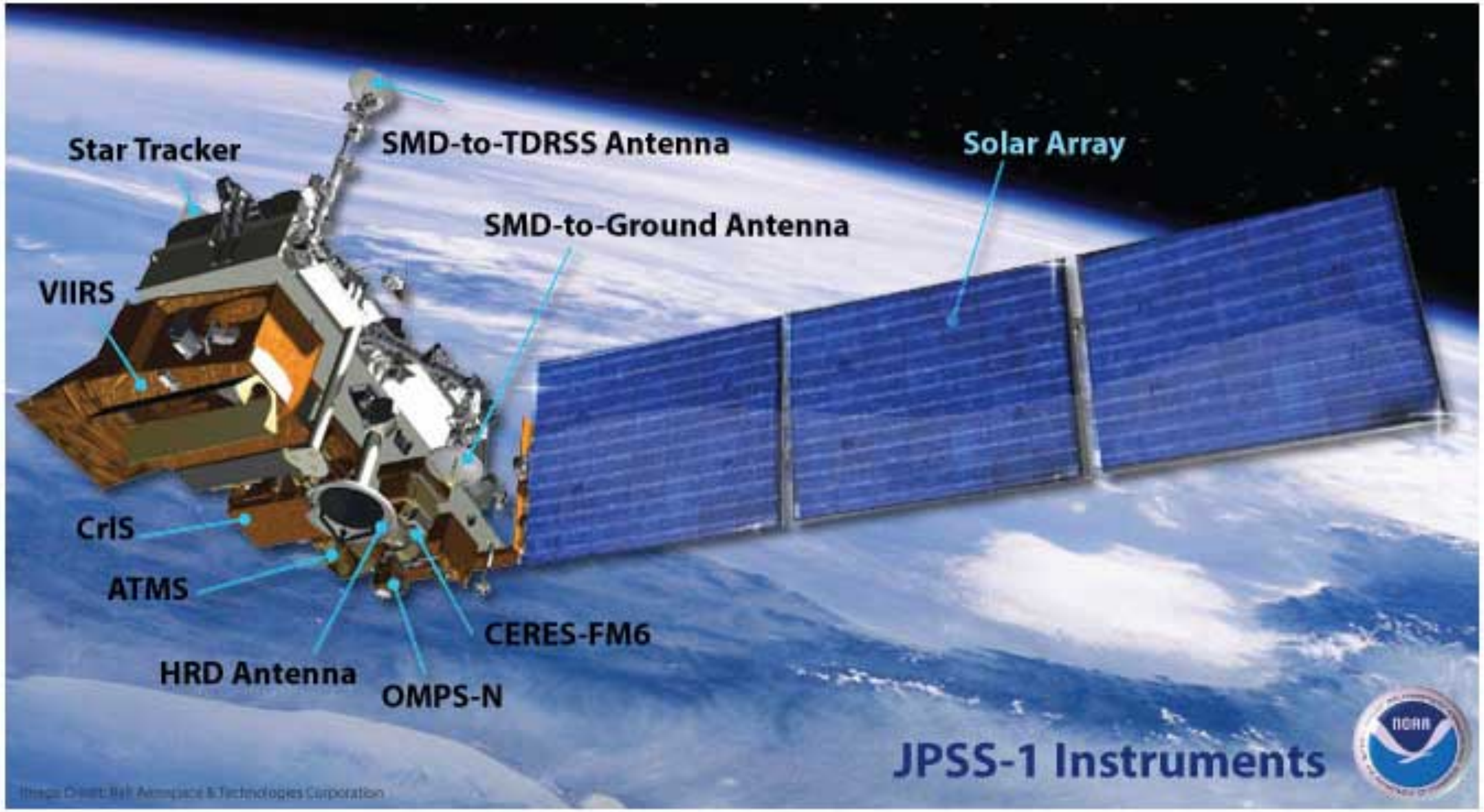
Anomaly Products and Climatologies

- 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

A note on satellite names …

- NOAA renames satellites once they have achieved orbit.
- JPSS-1 was designated NOAA-20 when it reached its orbit.
- GOES satellites are designated by letters pre-launch, and numbers post-launch. GOES-R became GOES-16 and GOES-S became GOES-17.
- The switch from pre-launch to on-orbit names keeps the name series intact for on-orbit constellations

US Satellite Agencies

NASA

National Aeronautic and Space Agency

Responsible for satellite research and development

NOAA

National Oceanic & Atmospheric Administration

Responsible for operational satellites

routine uses, such as weather forecasting

Joint Polar Satellite System (JPSS):

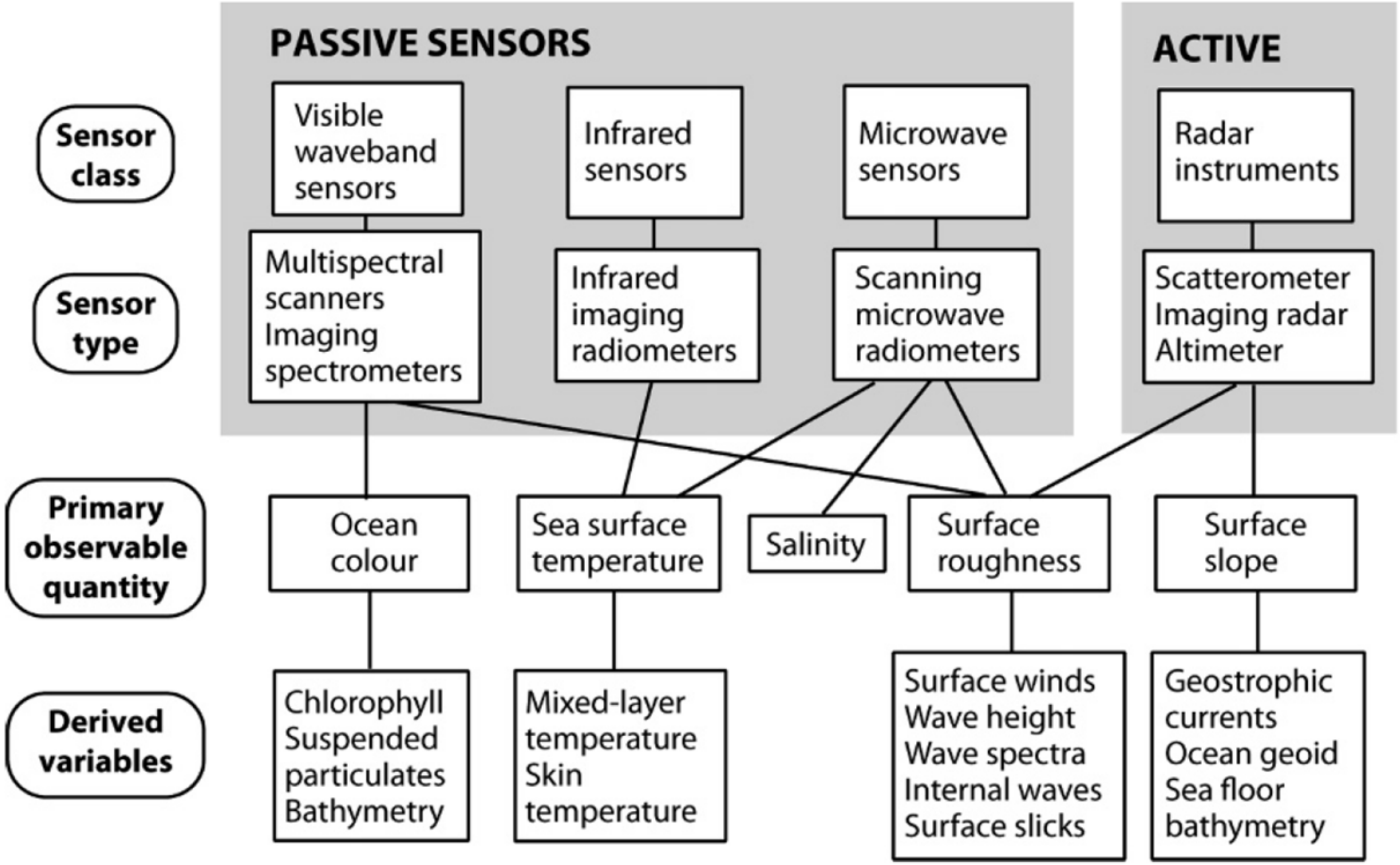
a collaborative multi-satellite mission between NOAA and NASA

DOD

Department of Defense

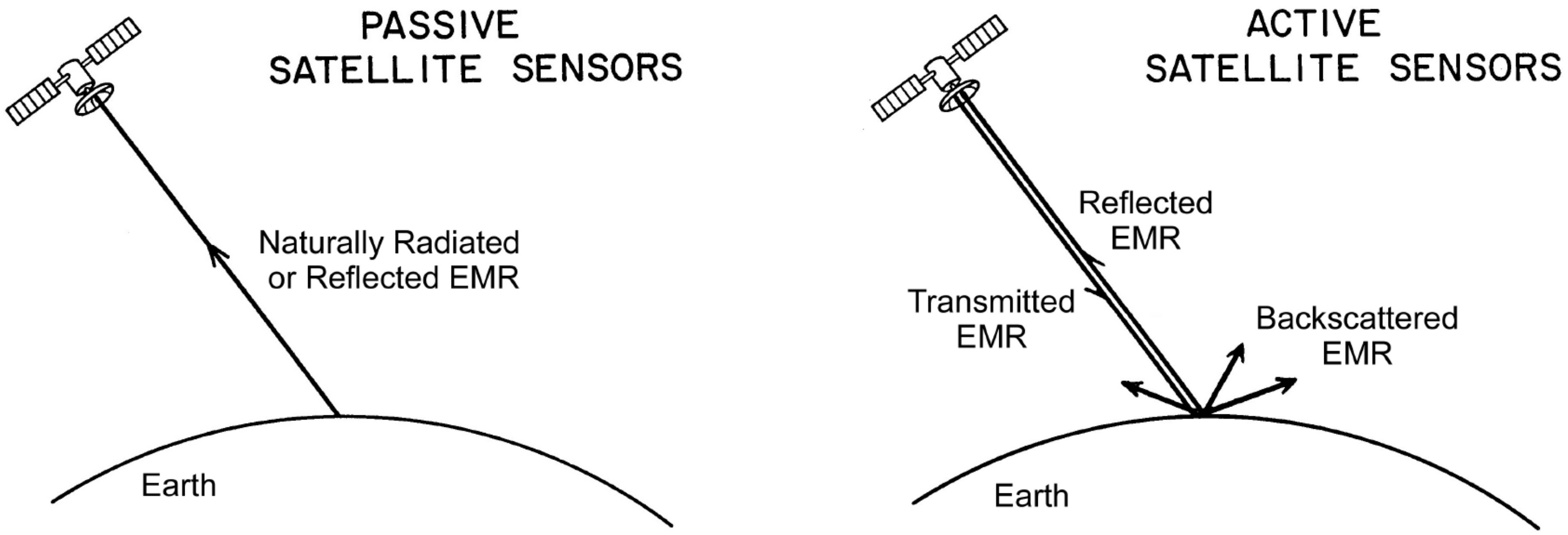
Responsible for military satellites

Types of Sensors and Products



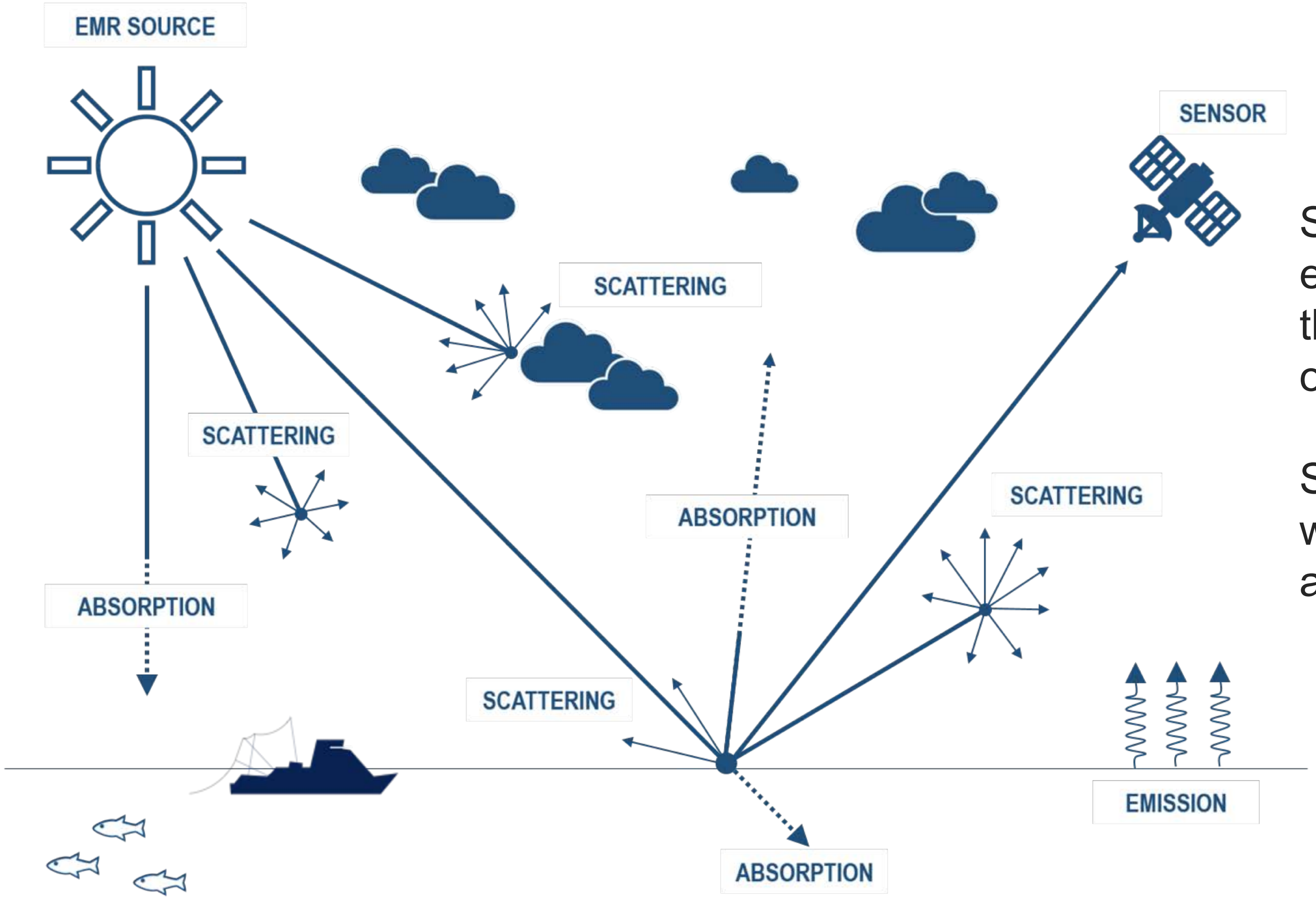
From Robinson, Discovering the Ocean from Space

Passive vs Active Sensors



- **Passive Remote Sensing:** Reception of emitted, reflected or scattered EMR
  Used with UV, visible, IR and microwave wavelengths/frequencies.
- **Active Remote Sensing:** Reception of the reflection of a transmitted pulse of EMR
  Examples include altimeters, scatterometers, lidars, radars.

Satellites and Electromagnetic radiation (EMR)



Satellite sensors measure electromagnetic radiation (EMR) that is emitted or reflected by the ocean (and land).

Sensors target specific wavelengths depending on their application

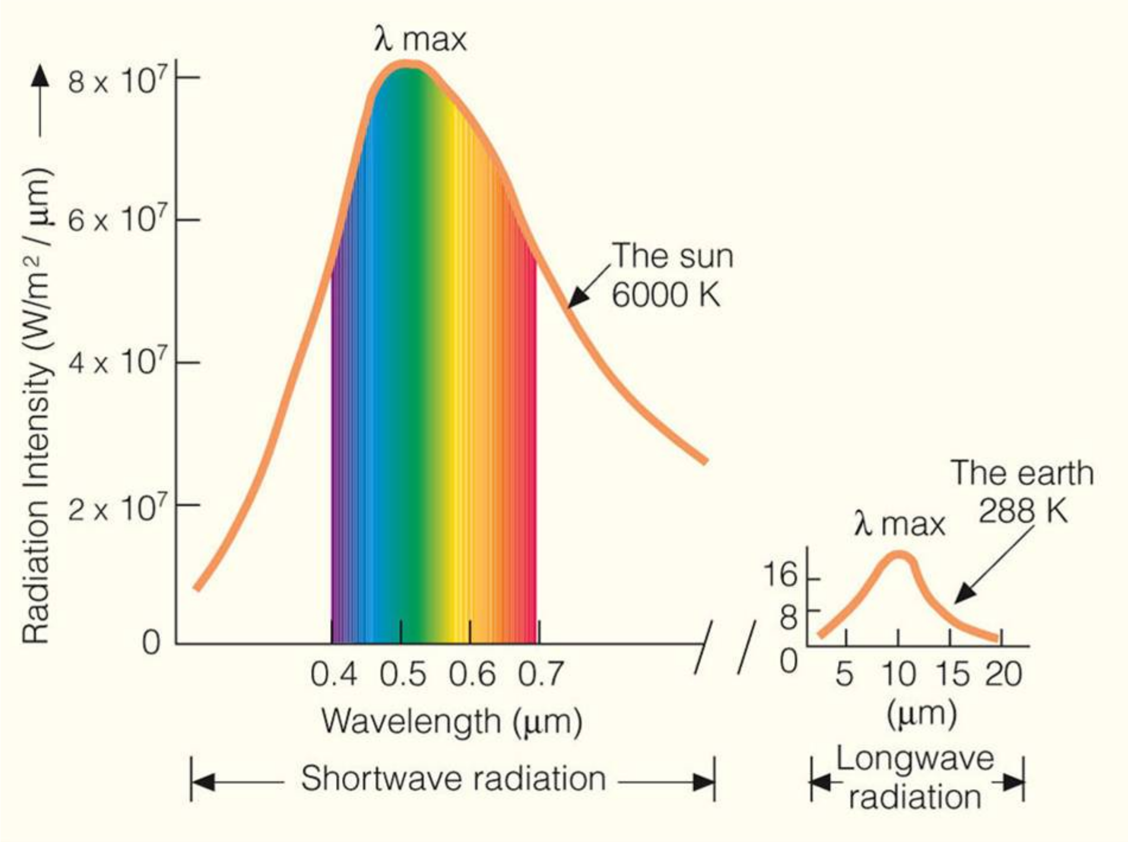
Credit: Jan Yoshioka, CI

Emissivity (e)

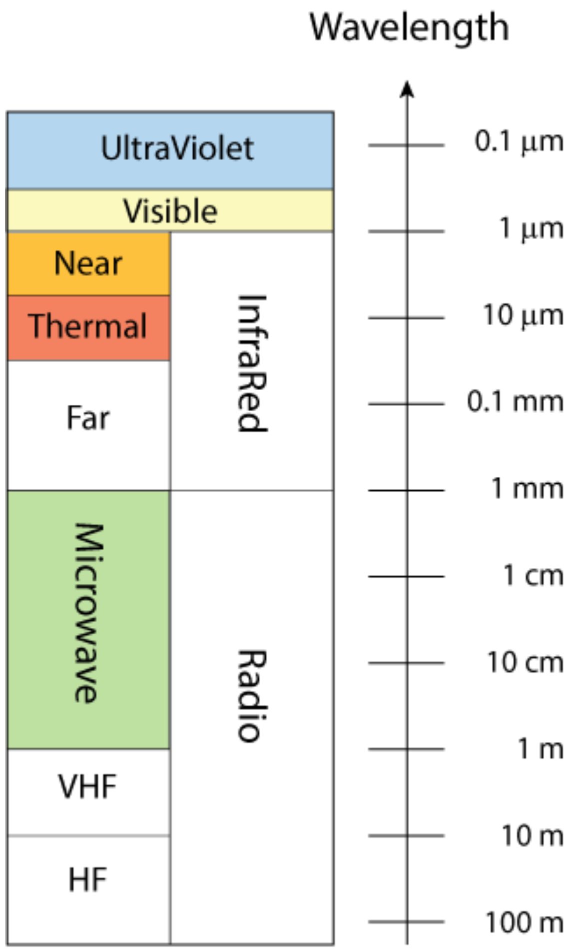
All “things” emit Electromagnetic Radiation (EMR), with characteristics determined by their temperature (Planck’s Function) and emissivity.

In the ocean emissivity is a function of wind speed, temperature, salinity. By detecting changes in emissivity we can determine the wind speed temperature, salinity.

a perfect blackbody has an emissivity of 1
highly polished silver has an emissivity of 0.02
In the infrared, open water and sea ice have e = .98
In the microwave, ocean e = .4 and sea ice e = .8

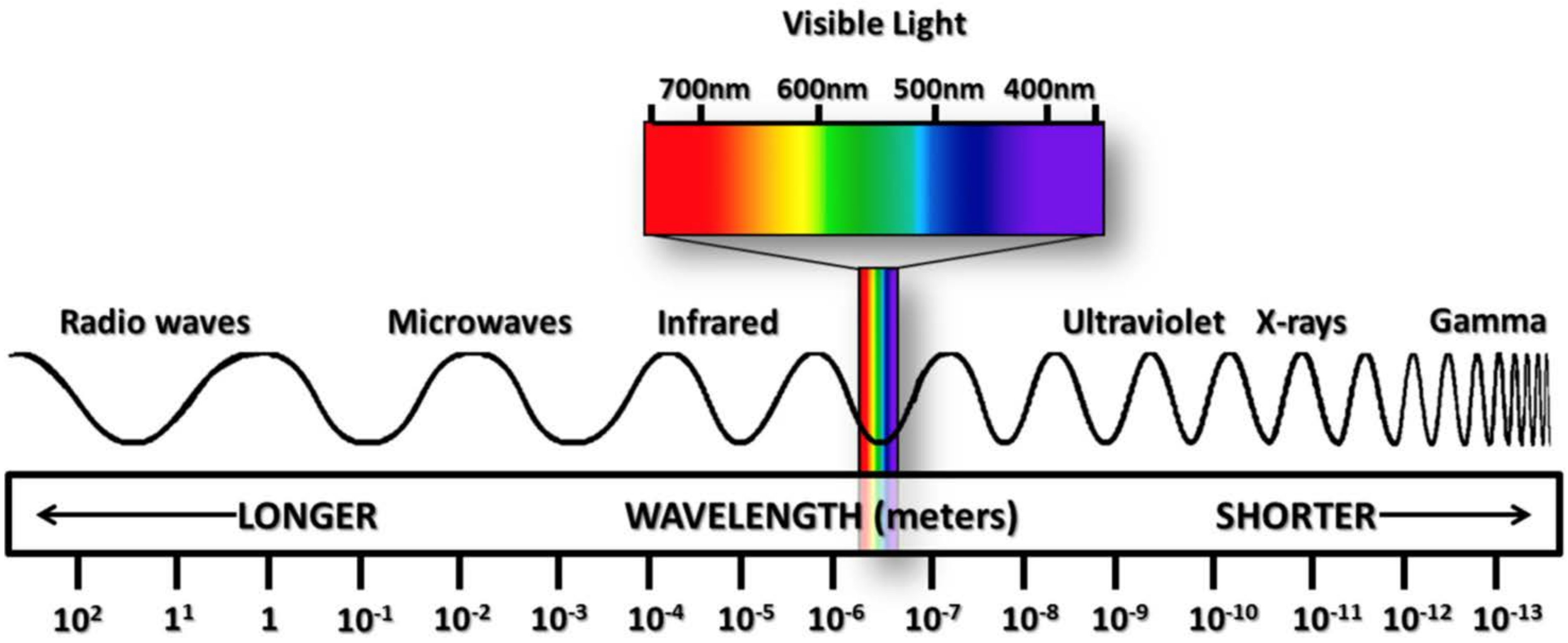


EMR Spectrum and Applications



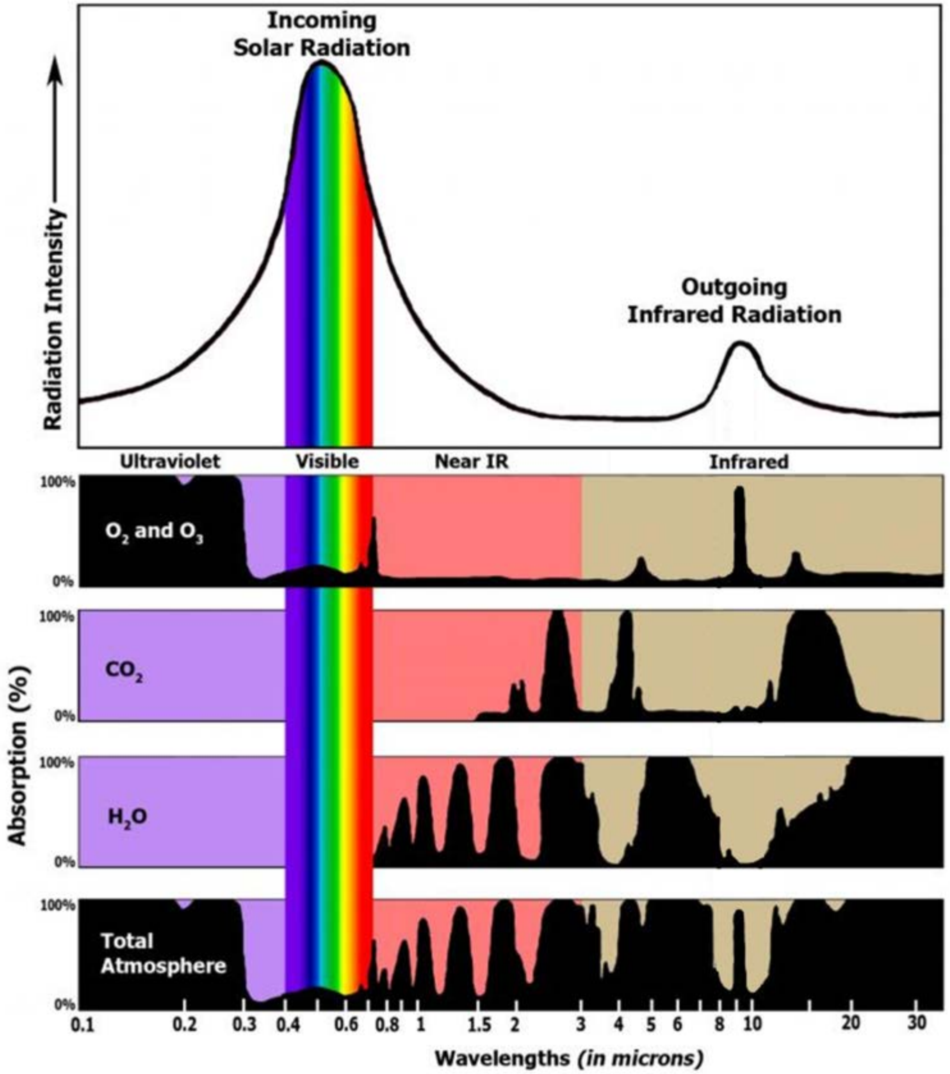
Sensor	Application
TOMS, OMPS	Ozone conc.
DMSP OLPS NOAA AVHRR GOES-R ABI	Weather
Landsat MSS/TM SPOT HRV	Land use Geomorphology
CZCS, Seawifs MODIS, VIIRS	chl a conc. turbidity, sediment
NOAA AVHHR GOES-R ABI	vegetation, clouds snow, ice
NOAA AVHHR GOES-R ABI	sea surface temp night-time clouds water vapor
SMMR SSM/I	sea ice conc. snow cover
Altimeters SAR Scatterometers	sea surface height, currents surface roughness wind

Electromagnetic Radiation (EMR) Spectrum



- Visible and IR (Infrared) radiation are typically measured in wavelengths.
- Microwaves are measured in frequency.
- Microwave frequencies are often described by letters, the C-band, the X-band etc.

The influence of the atmosphere



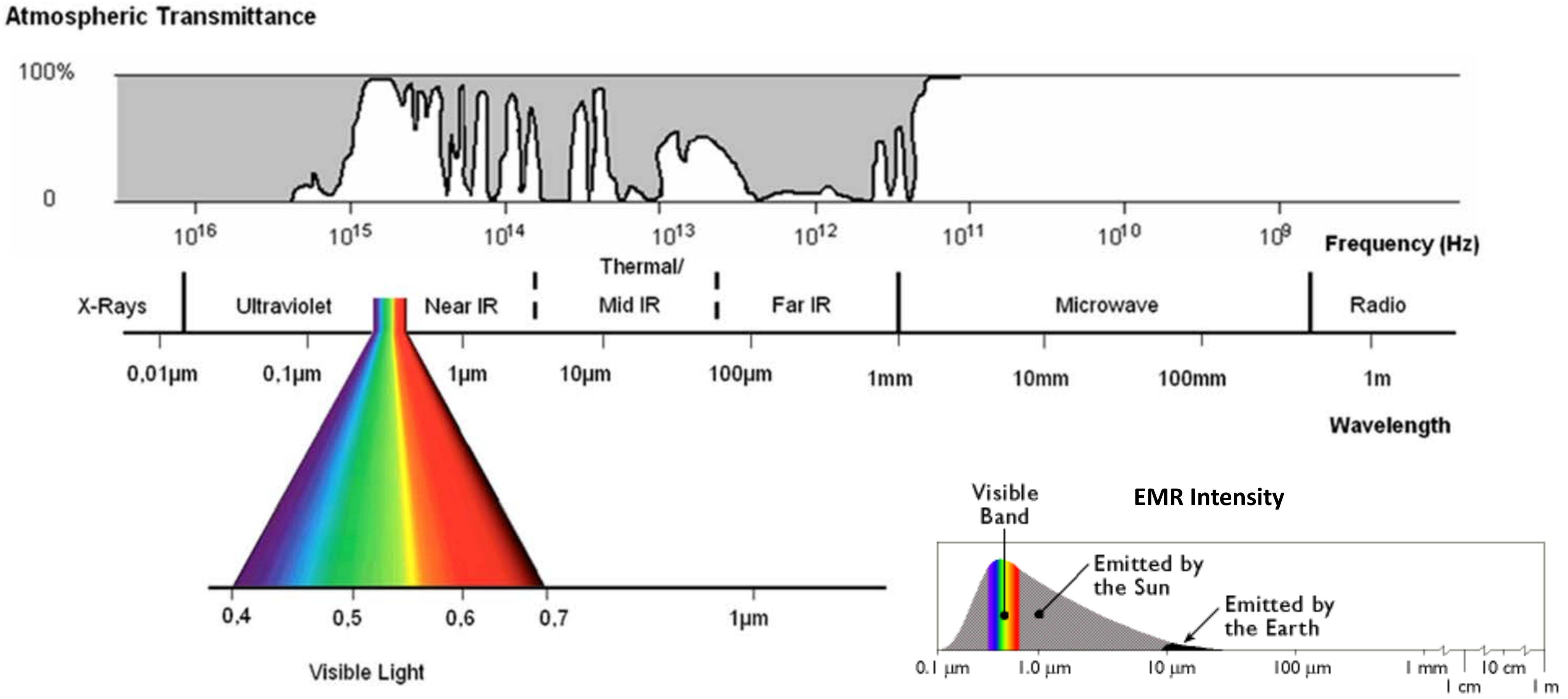
The atmosphere is opaque to electromagnetic radiation at many wavelengths, due to absorption by atmospheric gases. There are only certain wavelengths through which radiation may be fully or partly transmitted.

Remote sensing focuses on these atmospheric windows.

Source: NASA

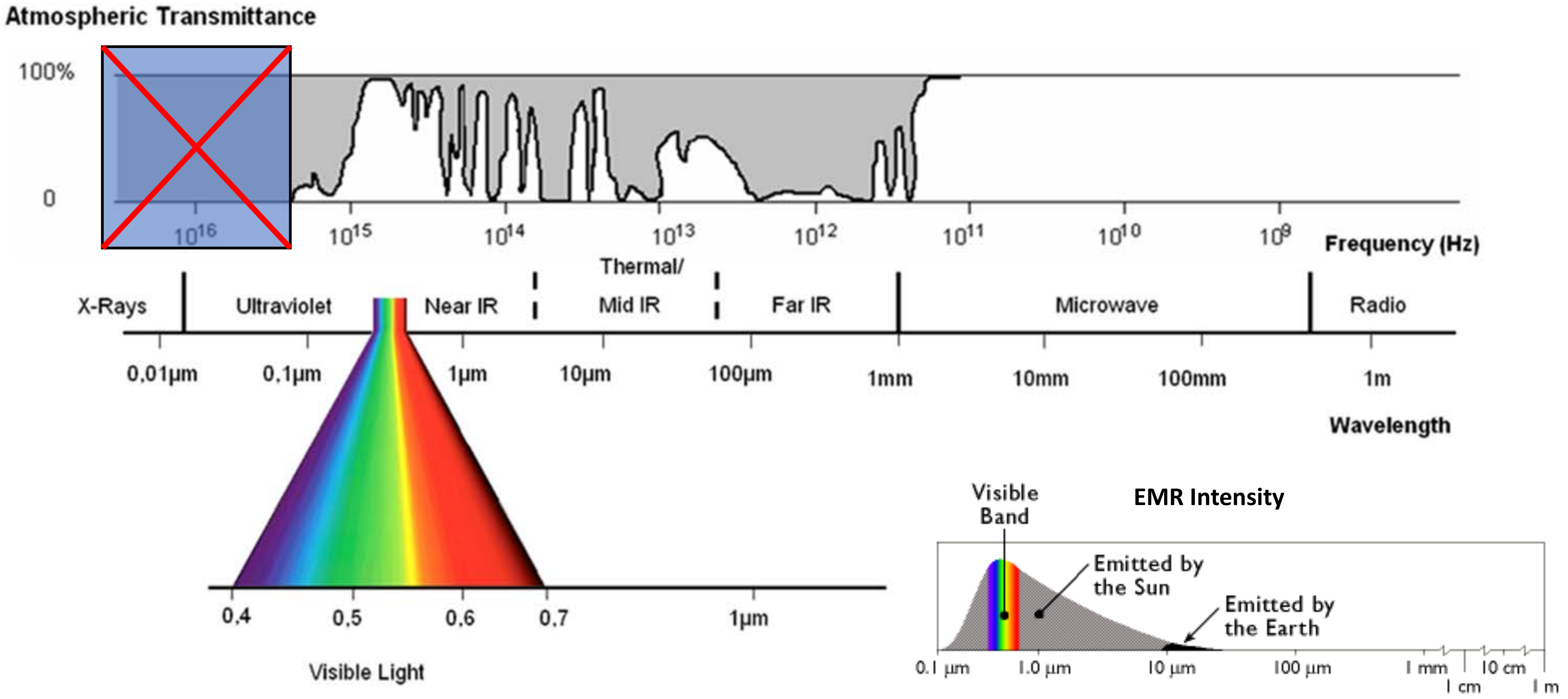
The effect of the atmosphere

Satellites can ‘see’ the earth in the regions of high atmospheric transmittance



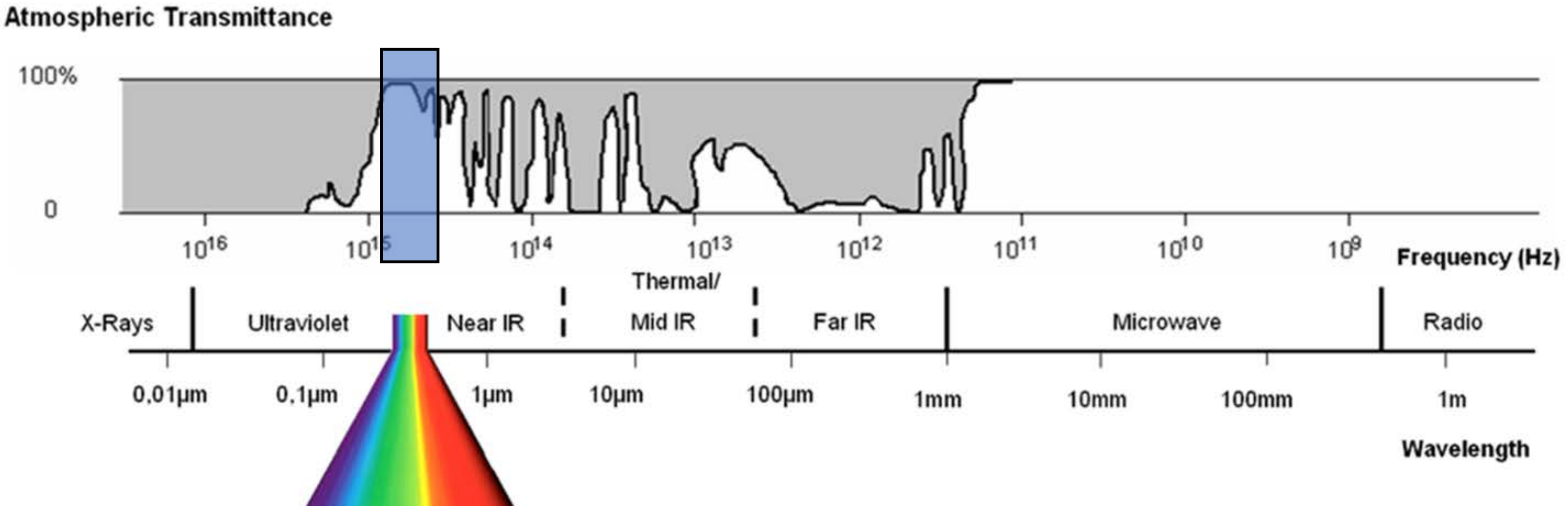
Atmospheric windows

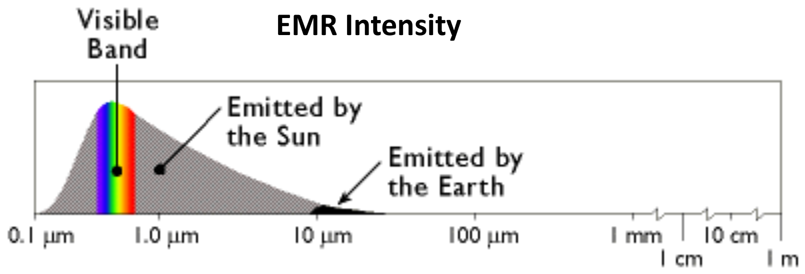
Wavelengths shorter than the ultraviolet are nearly totally absorbed by the atmosphere and are therefore less relevant for remote sensing.



Atmospheric windows

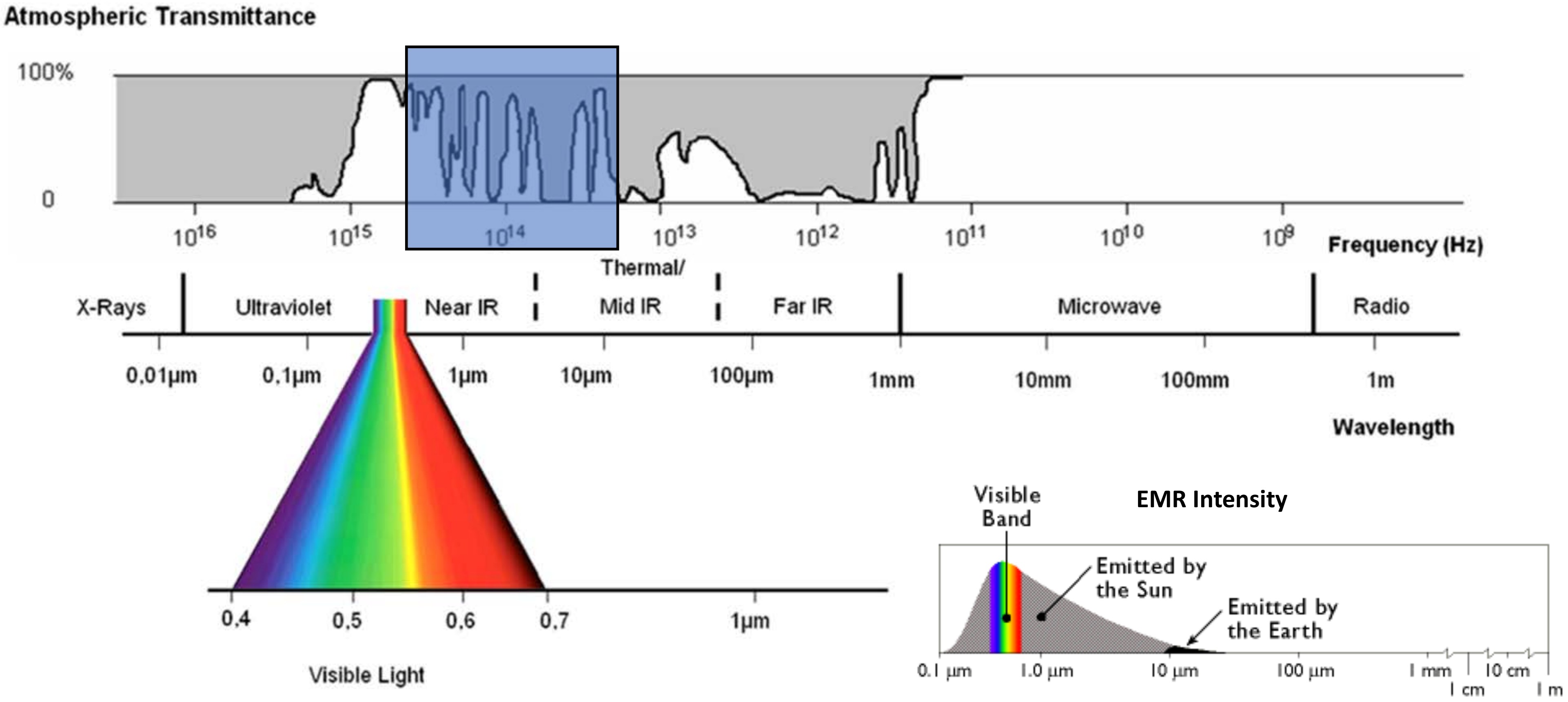
In the **visible**, where the sun emits at the highest intensity, atmospheric transmittance is high.





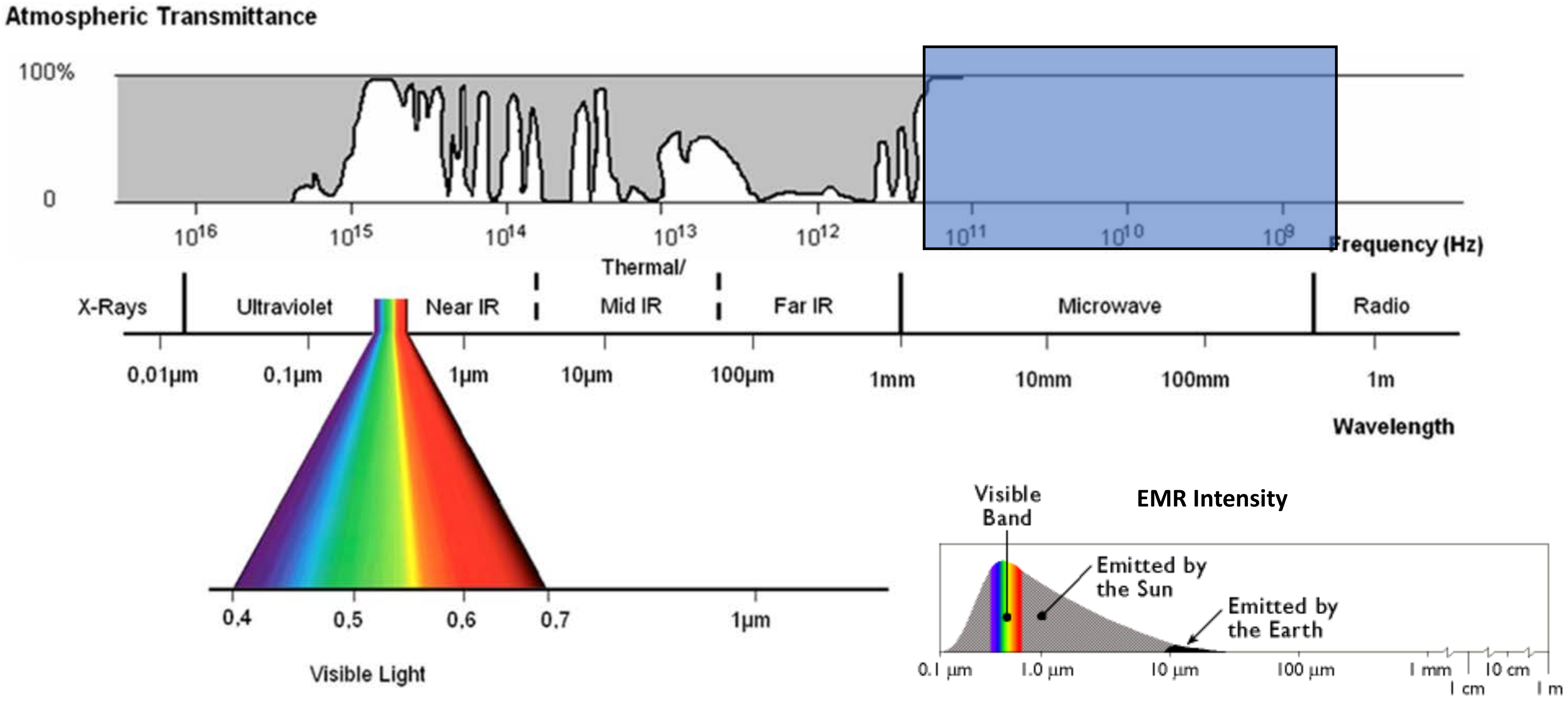
Atmospheric windows

At higher wavelengths, transmittance is reduced to narrow bands. This includes the optical windows in the thermal **infrared**, where the Earth's surface emits radiation.

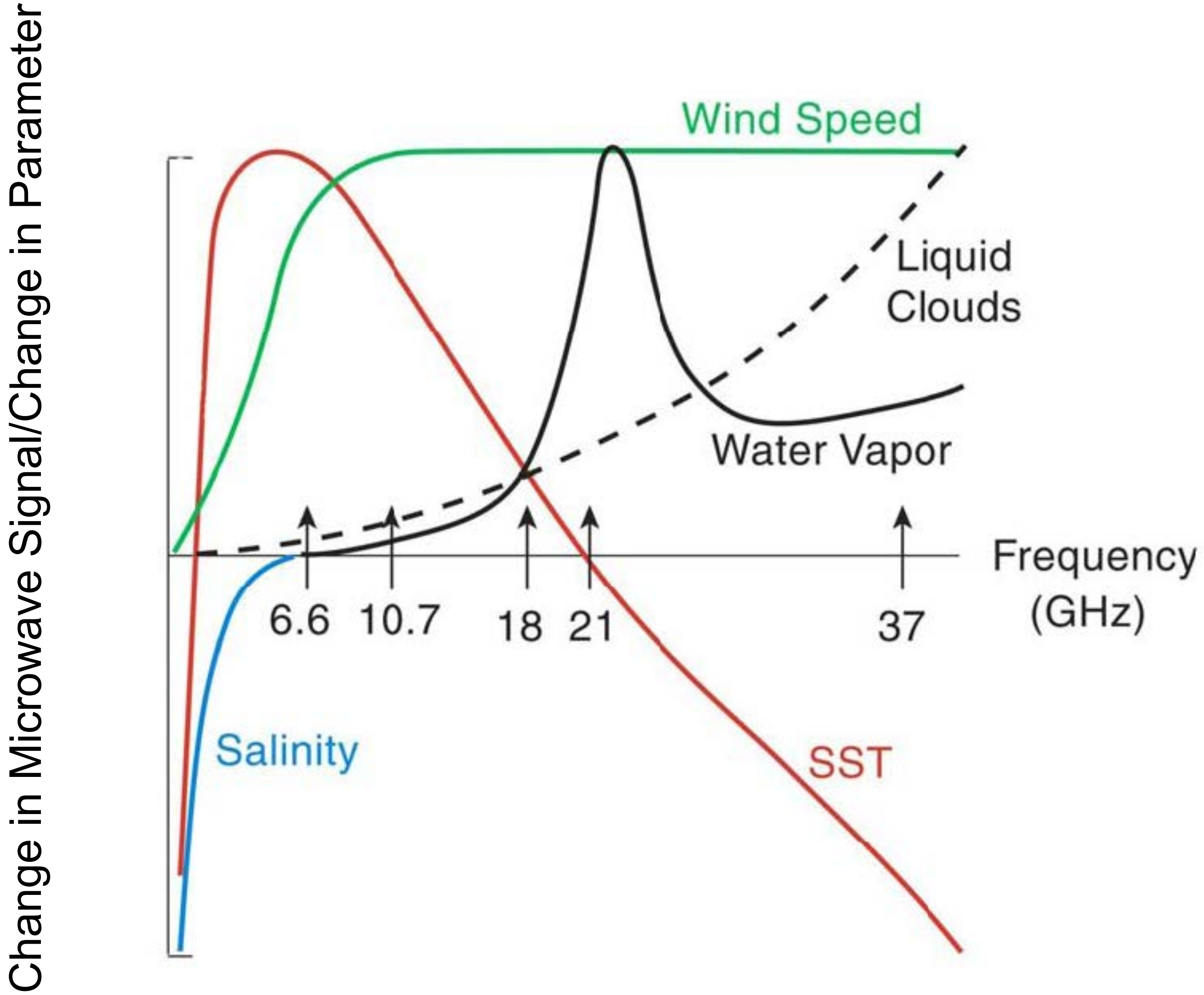


Atmospheric windows

In the **microwave**, the atmosphere is nearly transmissive. But the sun and earth's radiation are weak and large antennas are needed to collect enough radiation



Microwave Ocean Surface Emissions



Atmospheric Pathways

Ray 1 - the useful signal, radiation leaving the ocean and measured by the sensor

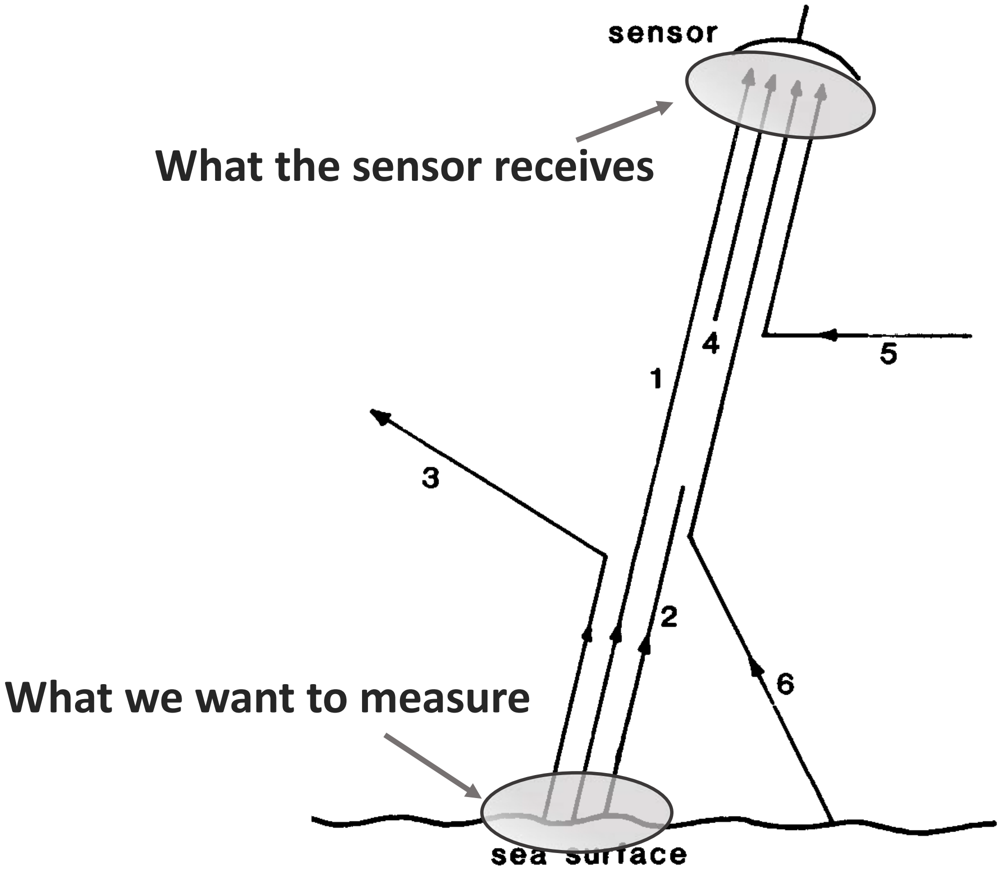
Ray 2 - radiation leaving the ocean that is absorbed by the atmosphere

Ray 3 - radiation that is scattered by the atmosphere out of the sensor field of view

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 pathways of EMR between the ocean and the satellite.

Atmospheric correction of the satellite data is necessary to derive accurate satellite data products.

Atmospheric Pathways

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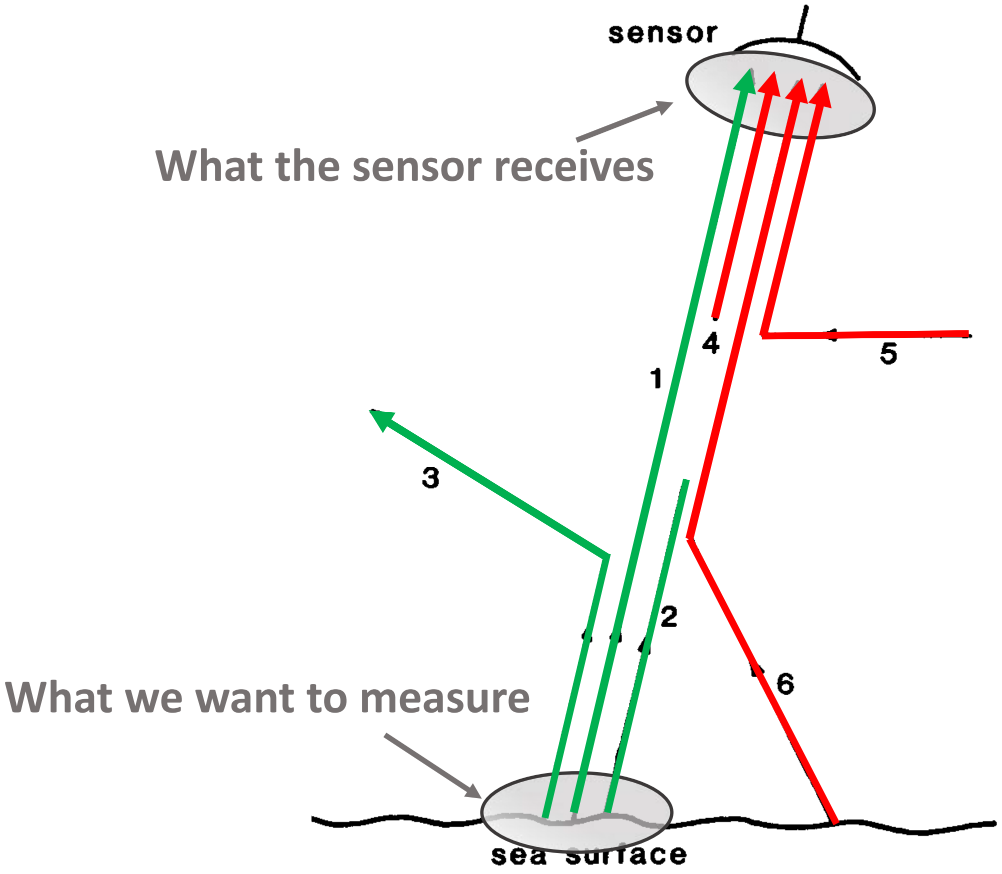

Atmospheric pathways of EMR between the ocean and the satellite.

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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.

NRT vs Science Quality

- Near-Real time (NRT) data, is data with the shortest latency possible, hours to days.
  To achieve this short latency these datasets have undergone minimal Quality Control (QC)
- Science Quality data has undergone better quality-control (QC), and has latency periods of several weeks to several months. These data are typically are used to look at trends over time, and for use in publications
- For datasets that are periodically reprocessed, the older versions should be labelled “deprecated” on data servers (i.e. ERDDAP).