Recent Advances in Satellite Oceanography

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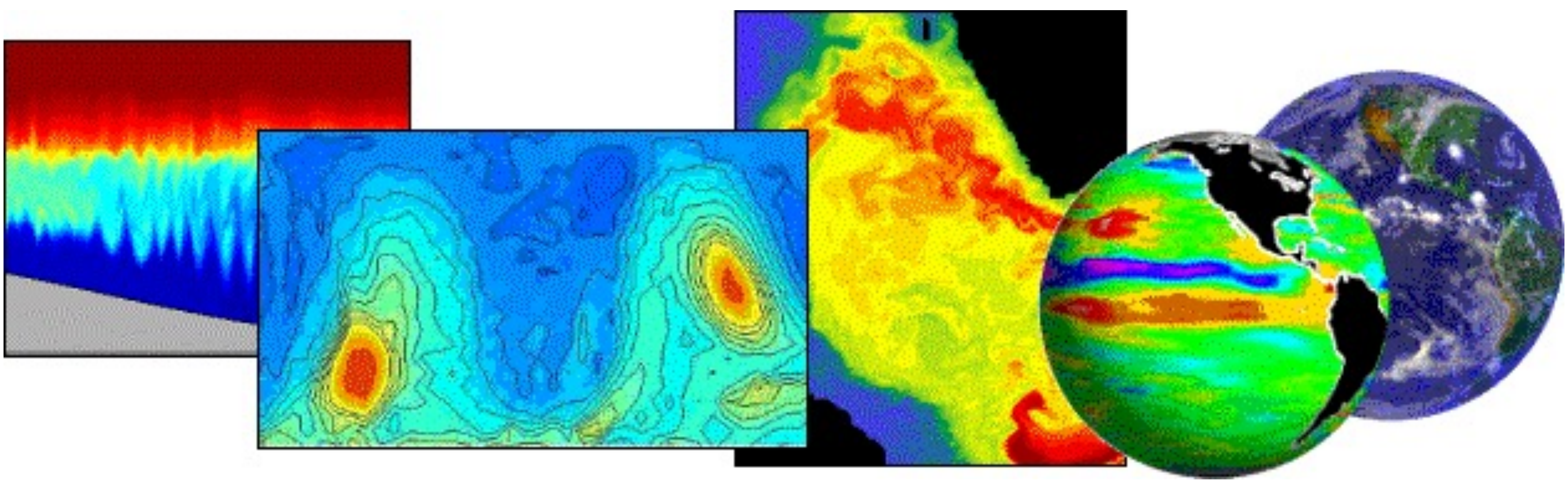
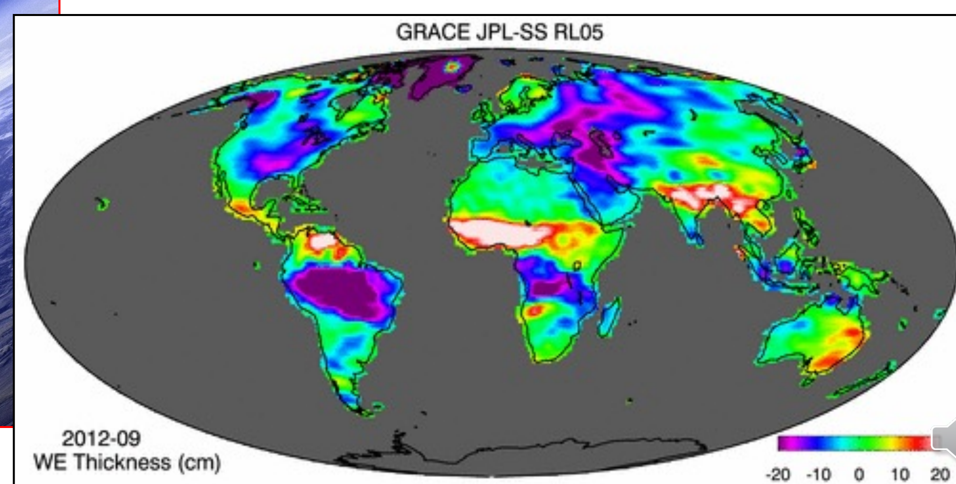


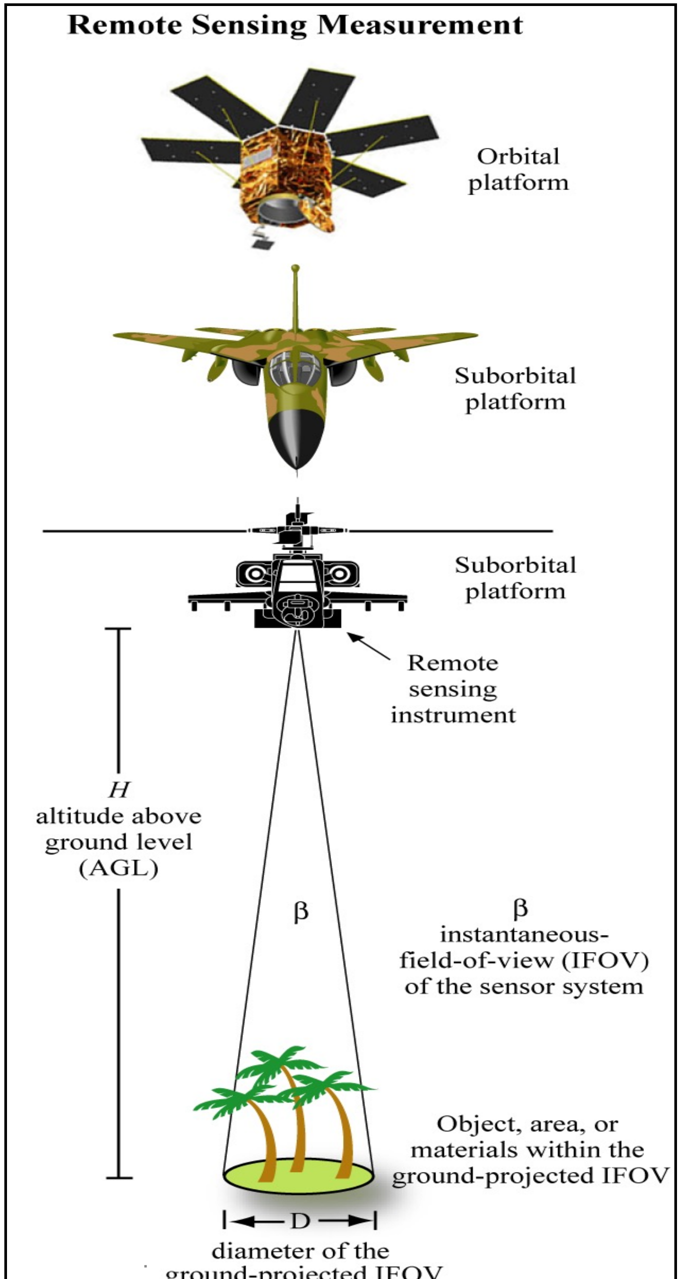
UG-DMFS Summer Program (AUGUST 3-8, 2020)

Outline:

- Remote Sensing: brief intro
- Ocean Color
- GRACE
- Remote Sensing & COVID



Introduction



ASPRS adopted a combined formal definition of *photogrammetry* and *remote sensing* as (Colwell, 1997):

> "the *art*, *science*, and *technology* of obtaining reliable information about physical objects and the environment, through the process of recording, measuring and interpreting imagery and digital representations of energy patterns derived from **noncontact sensor systems**".

Remote Sensing: A brief history

Hot-air Balloons
Invented by the
Montgolfier Brothers
in 1783

Gaspard Felix
Tournachon (Nadar)

1858 Gaspard Felix Tournachon (Nadar) takes first aerial photograph near Paris, using a captive balloon and a collodion plate. Unfortunately, this first aerial photograph did not survive.

Remote Sensing: A brief history

In 1903, Julius Neubronner patented a breast-mounted camera for carrier pigeons that weighed only 70 grams.

A squadron of pigeons is equipped with light-weight 70-mm aerial cameras.

Importance of satellite oceanography

- Observes the distribution of certain ocean surface properties in exquisite spatial detail: allows the true spatial structure to be examined

- Captures a "snapshot" of the spatial distribution. "Freezes" the continually changing ocean

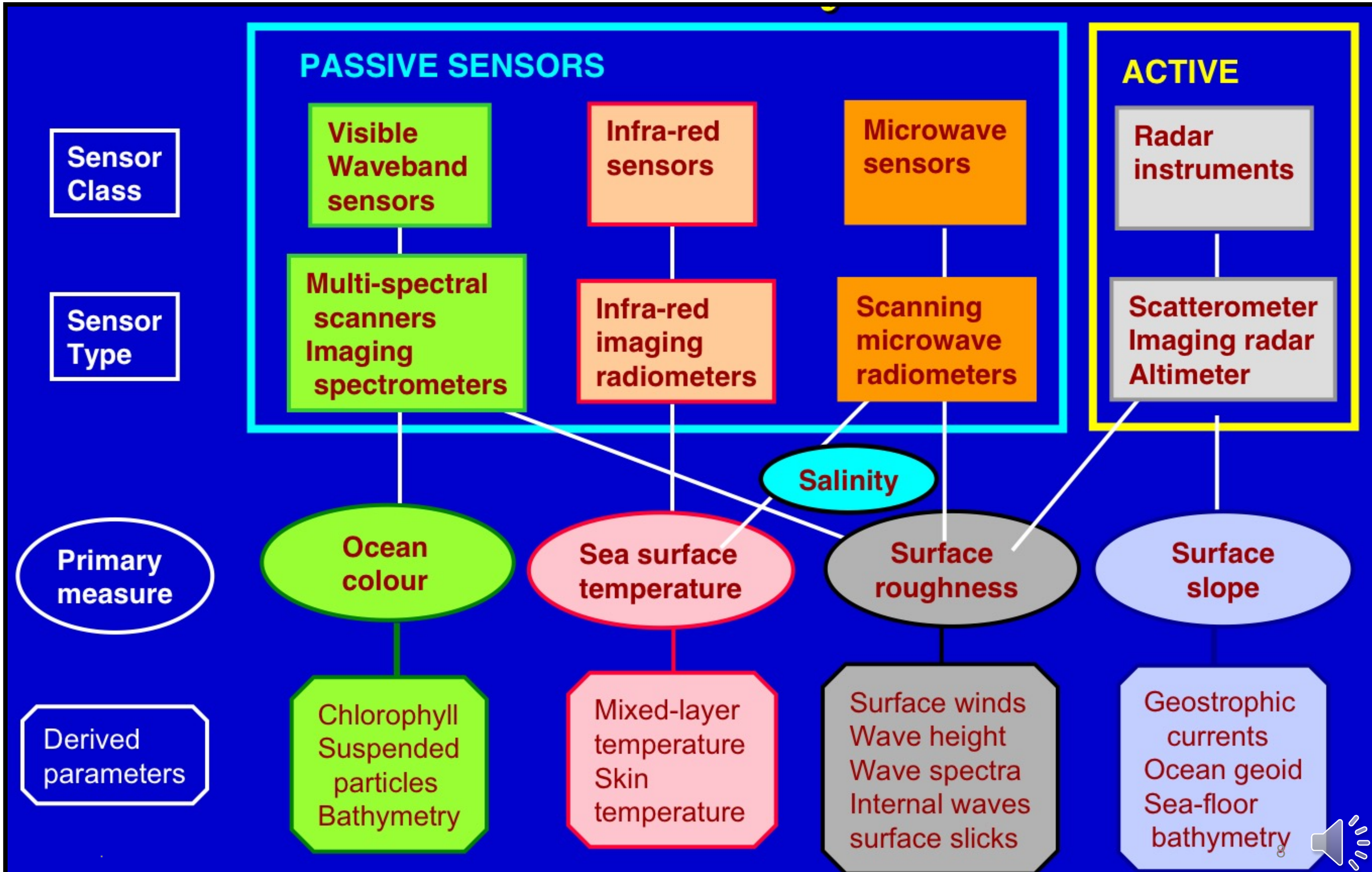
- Offers a repeated view: consistent measurements by a single sensor

- Observes part of the ocean other methods miss
  - Shipping routes are concentrated in certain zones
  - Ships tend to avoid poor weather hazardous regions
  - Drifting buoys tend to avoid regions of divergent currents

Limitations of satellite oceanography

- Can observe only some of the ocean's properties and variables
- Measures the ocean only at or near the surface
  -- Although the surface is the most critical place to measure
- Ocean measurements may be corrupted by the atmosphere
- Some satellites/methods cannot see through clouds at all
- Can make measurements only when the satellite is in the right place at the right time
- All measurements require calibration and validation using in situ data

A summary of sensor types & what they measure

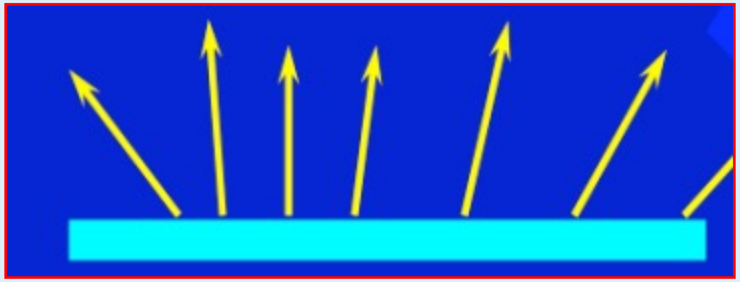


Basic physics and principles

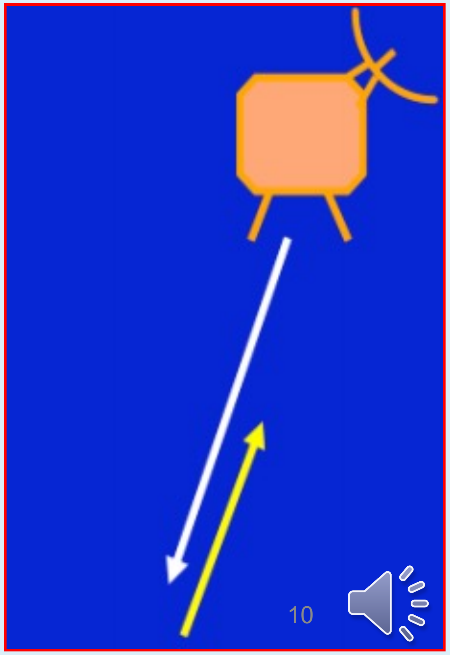
Sources of energy for remote sensing

- The Sun
  - --- Visible waveband
  - --- Near Infra red waveband

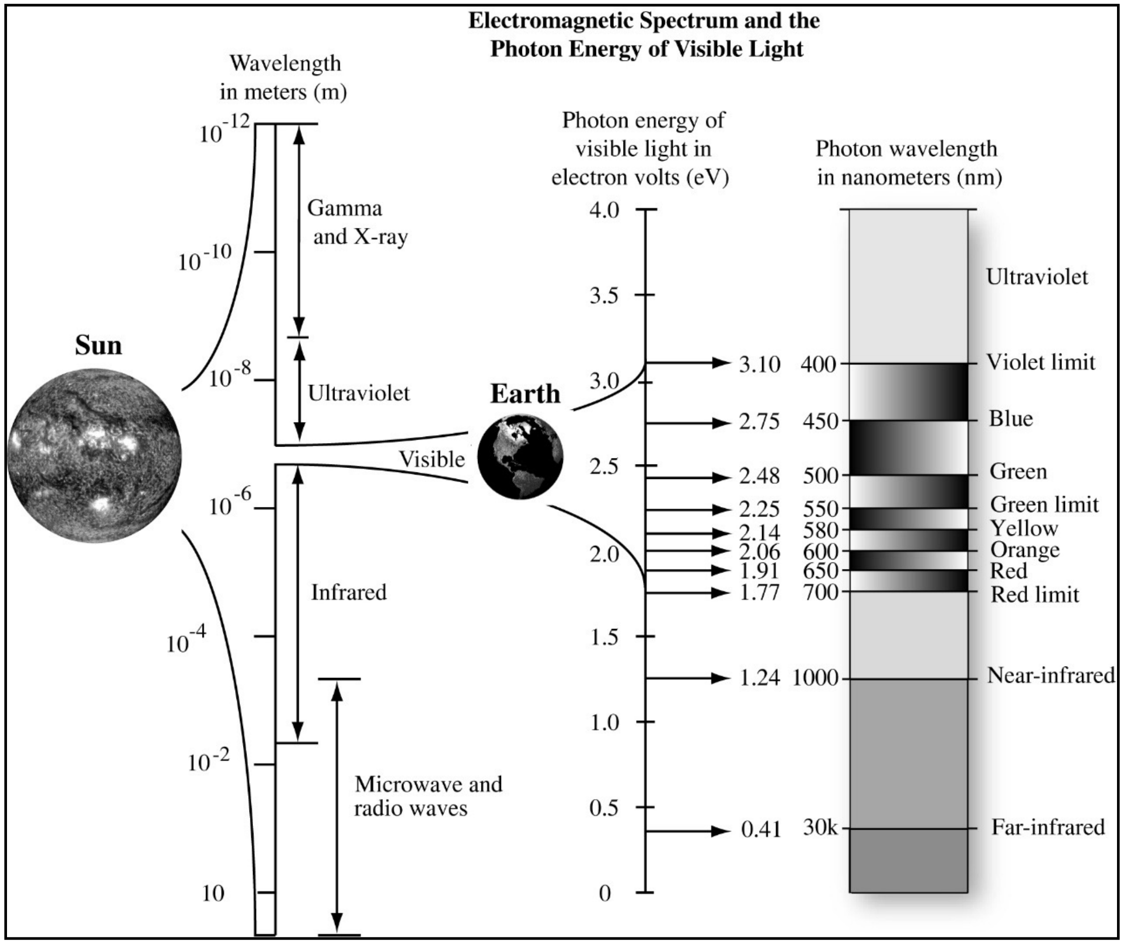
- Thermal emission by the ocean surface
  - --- Thermal infra red
  - --- Microwaves



- Energy source on the satellite
  - --- Microwaves (Radar)
  - --- Visible (Lidar)



Electromagnetic Spectrum

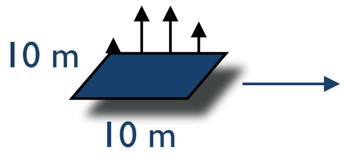


The Sun produces a *continuous spectrum* of energy from gamma rays to radio waves that continually bathe the Earth in energy.

The visible portion of the spectrum may be measured using wavelength (micrometers or nanometers) or electron volts (eV).

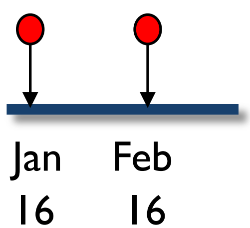
All units are interchangeable.

Remote Sensor Resolution Considerations

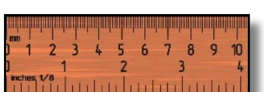


- Spatial - the size of the field-of-view, e.g. 10 × 10 m.

- Spectral - the *number* and *size* of spectral regions (or frequencies) the sensor records data in, e.g. blue, green, red, near-infrared, thermal infrared.



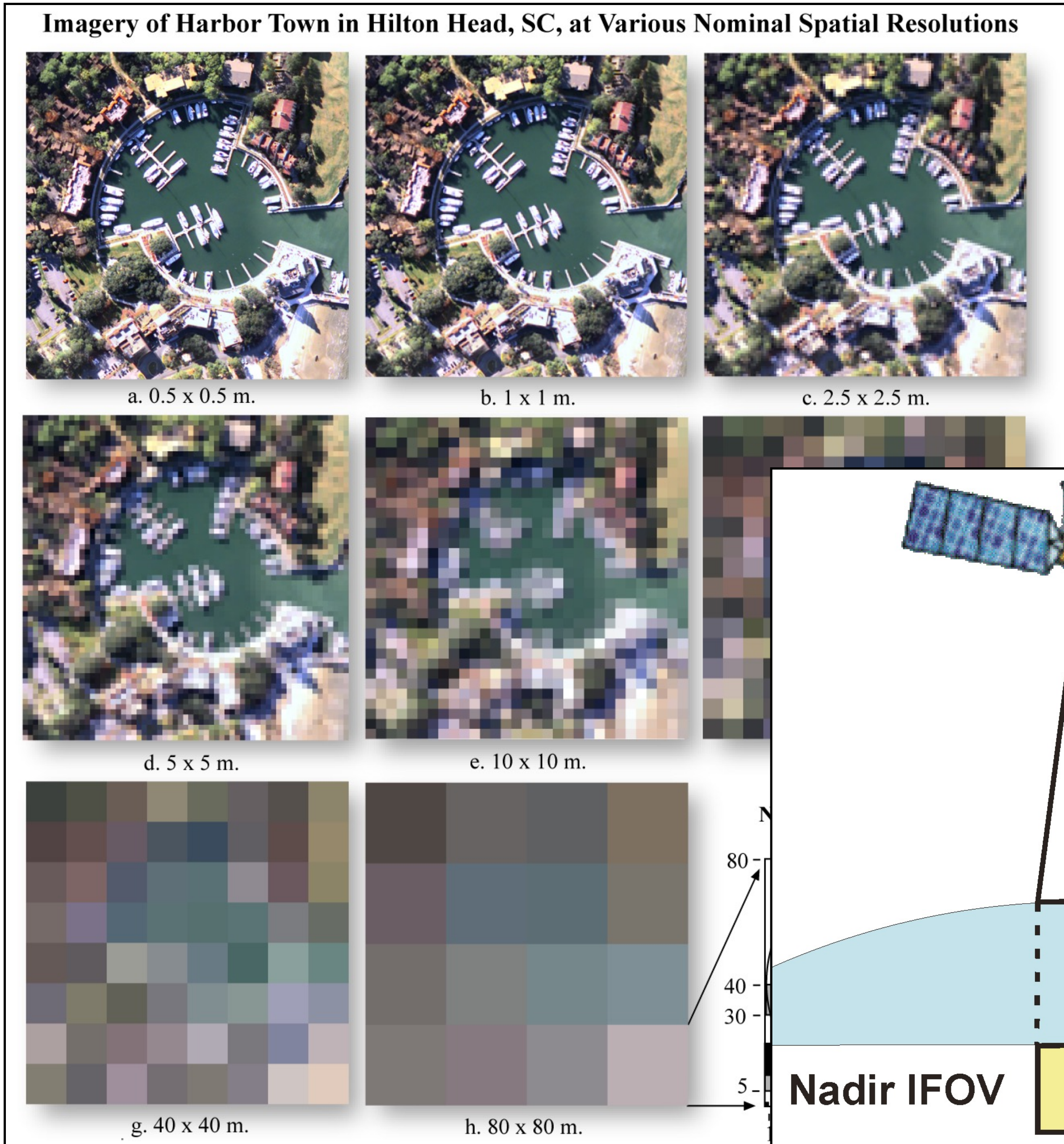
- Temporal - how often the sensor acquires data, e.g., every 30 days.

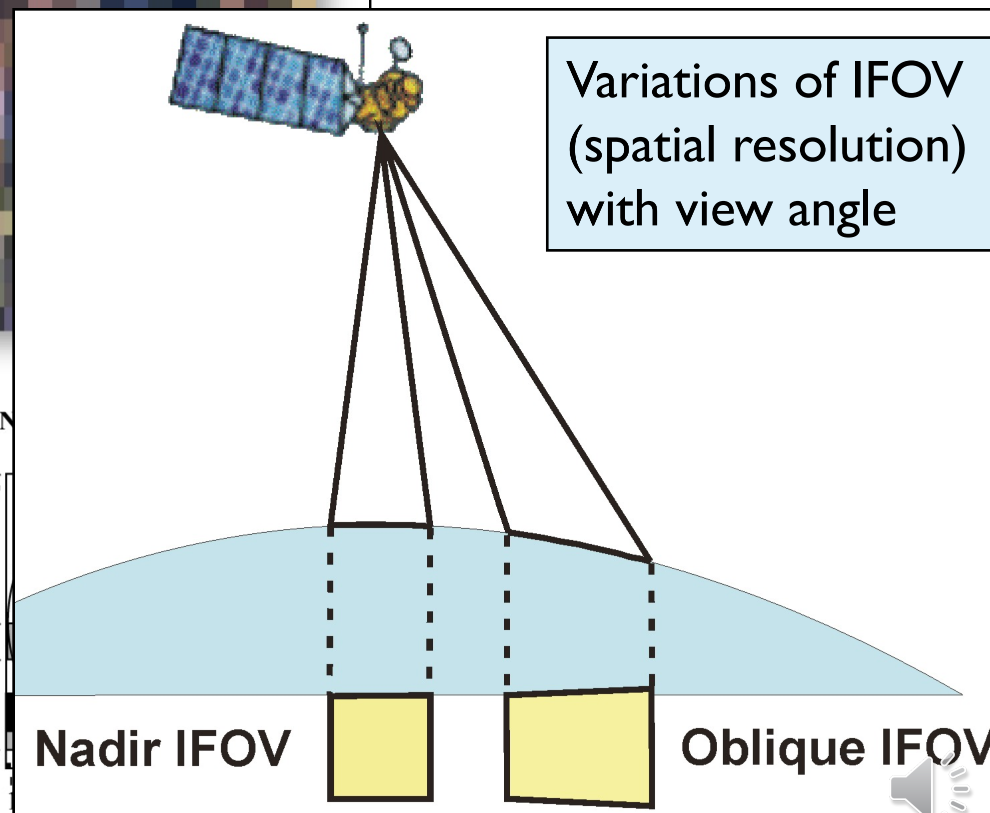


8-bit
(0 - 255)
10-bit
(0 - 1023)

- Radiometric - sensitivity of detectors to small difference in electromagnetic energy.

Spatial Resolution





RECAP: Satellite data sources

- **Radiometers:** sea surface temperature

-- Envisat (AATSR)   -- NOAA (AVHRR)

- **Spectral sensors:** ocean color and water quality

-- Envisat (MERIS)   -- Aqua (MODIS)   -- Quickbird

- **Altimeters:** SSH, SWH, surface wind speed, ocean currents

-- Envisat   -- Jason-1   -- Jason-2   -- GFO-- ERS-2

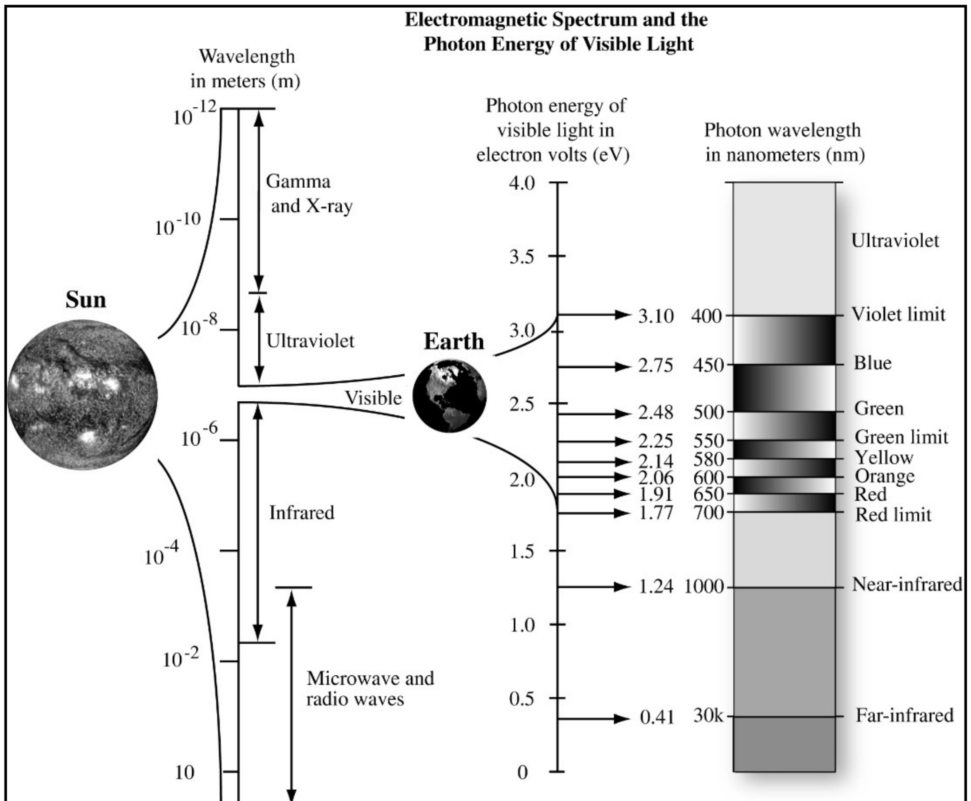
- **Scatterometers:** surface wind speed and direction.

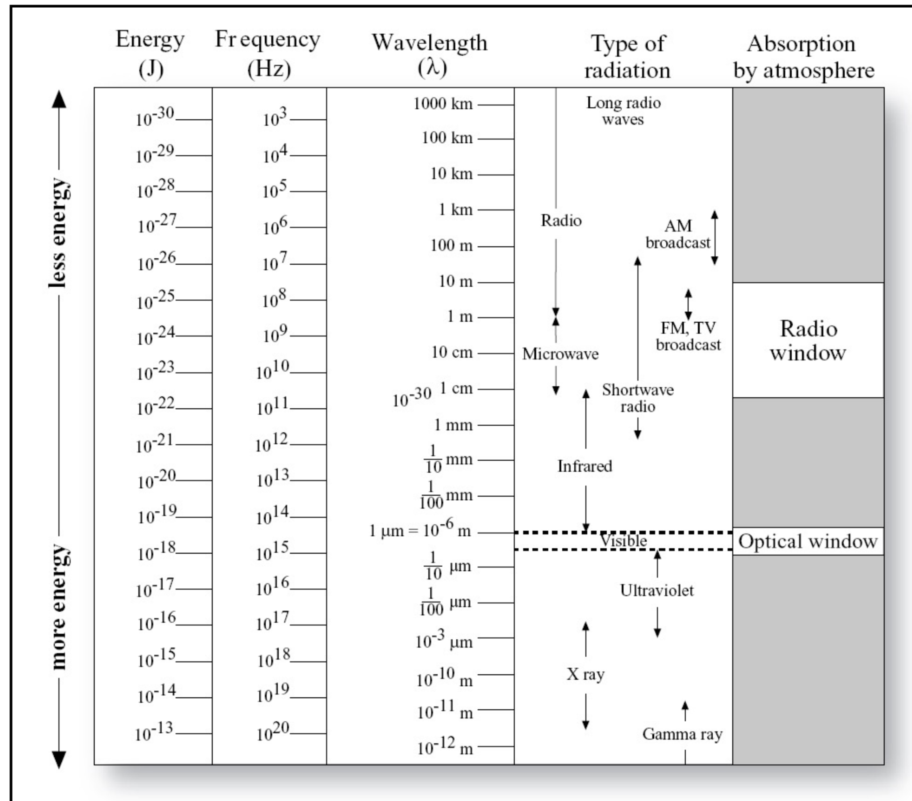
-- QuikSCAT   -- ASCAT   -- ERS-2

- **Synthetic Aperture Radars** (SAR): winds, waves, currents, oil slicks and ship detection.

-- Envisat (ASAR)   -- Radarsat   -- TerraSAR-X

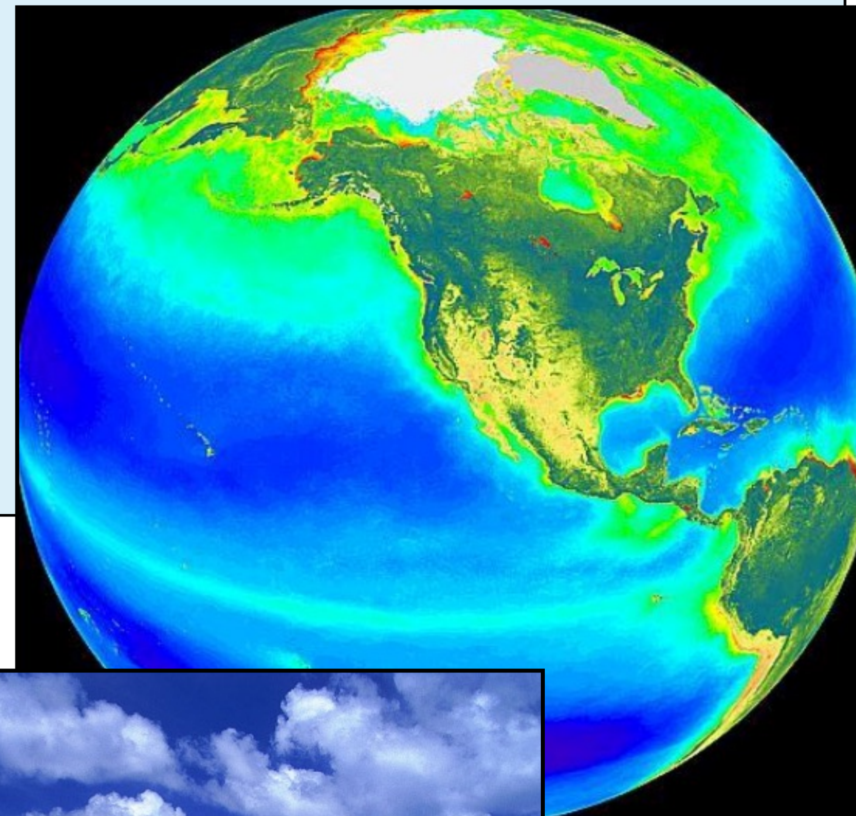
Visible waveband: Ocean color

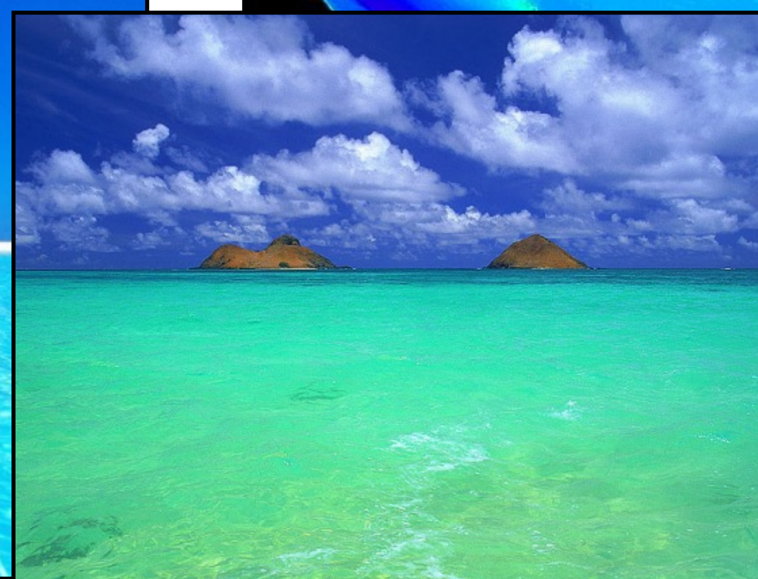




What is the color of the ocean?

- The color of the ocean appears BLUE in clear water.
- But it changes due to :
  -- Phytoplankton patchiness
  -- Inorganic/Organic matter





What is the color of the ocean?

- Clean ocean water absorbs red light, i.e., sun radiation of long wavelength and transmits and scatters the light of short wavelength. That is why ocean surface looks blue.

- Phytoplankton cells contain chlorophyll that absorbs other wavelengths and contributes green color to ocean water.

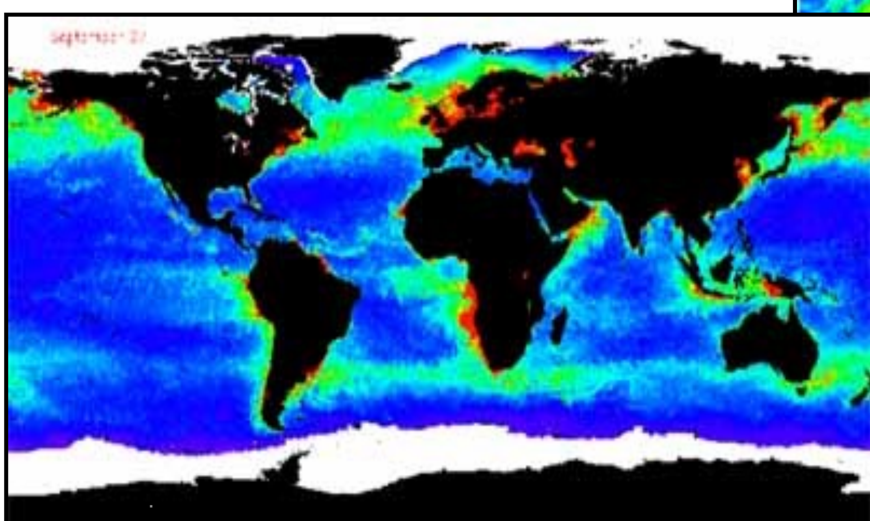
- In coastal areas suspended inorganic matter backscatters sunlight, contributing green, yellow and brown to water color.

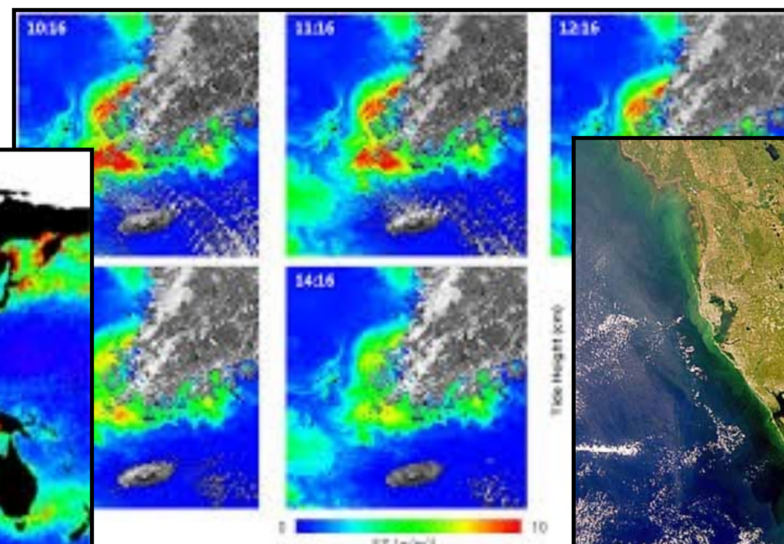
Why ocean color from space?

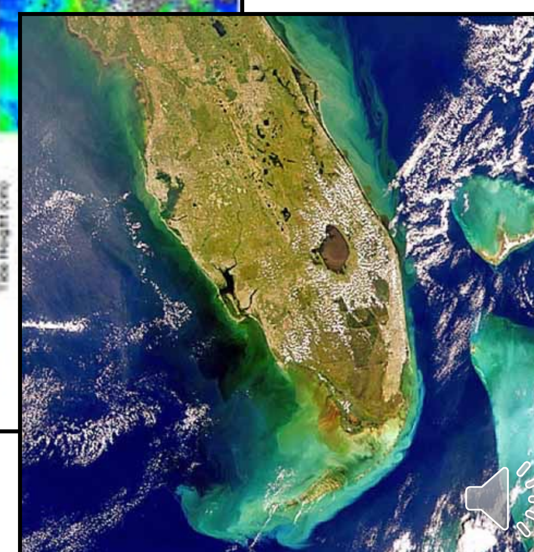
- ☐ Locates and enables monitoring of regions of high and low bio-activity. Synoptic Scales of Pigments
- ☐ Food–primary production (phytoplankton linked with chl); marine fisheries
- ☐ Climate (phytoplankton, possible CO_2 sink-carbon budget)
- ☐ Seasonal influences; phytoplankton blooms; upwelling
- ☐ River and Estuary plumes and influences
- ☐ Boundary currents. Reveals current structure & behavior.
- ☐ Reveals Anthropogenic influences (pollution); oil spills
- ☐ Remote sensing reveals large and small scale structures that are very difficult to observe from the surface.

Major Ocean Color Data Products

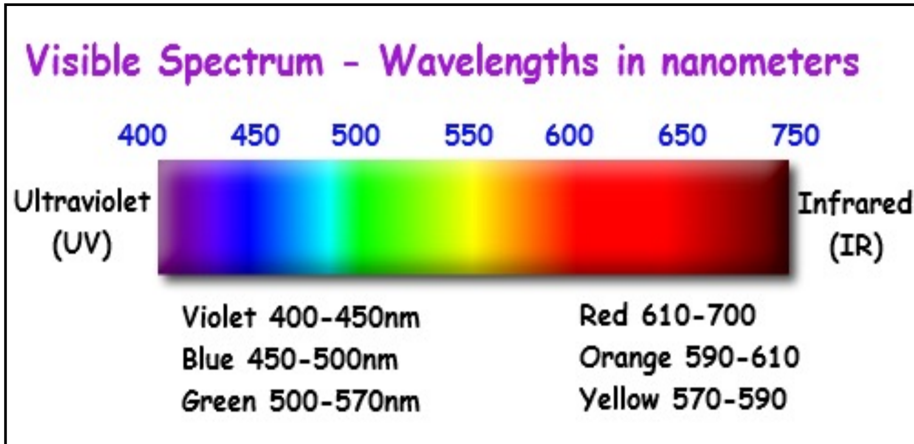
- ✓ Chlorophyll
- ✓ Suspended Sediments
- ✓ Yellow Substances
- ✓ Aerosol

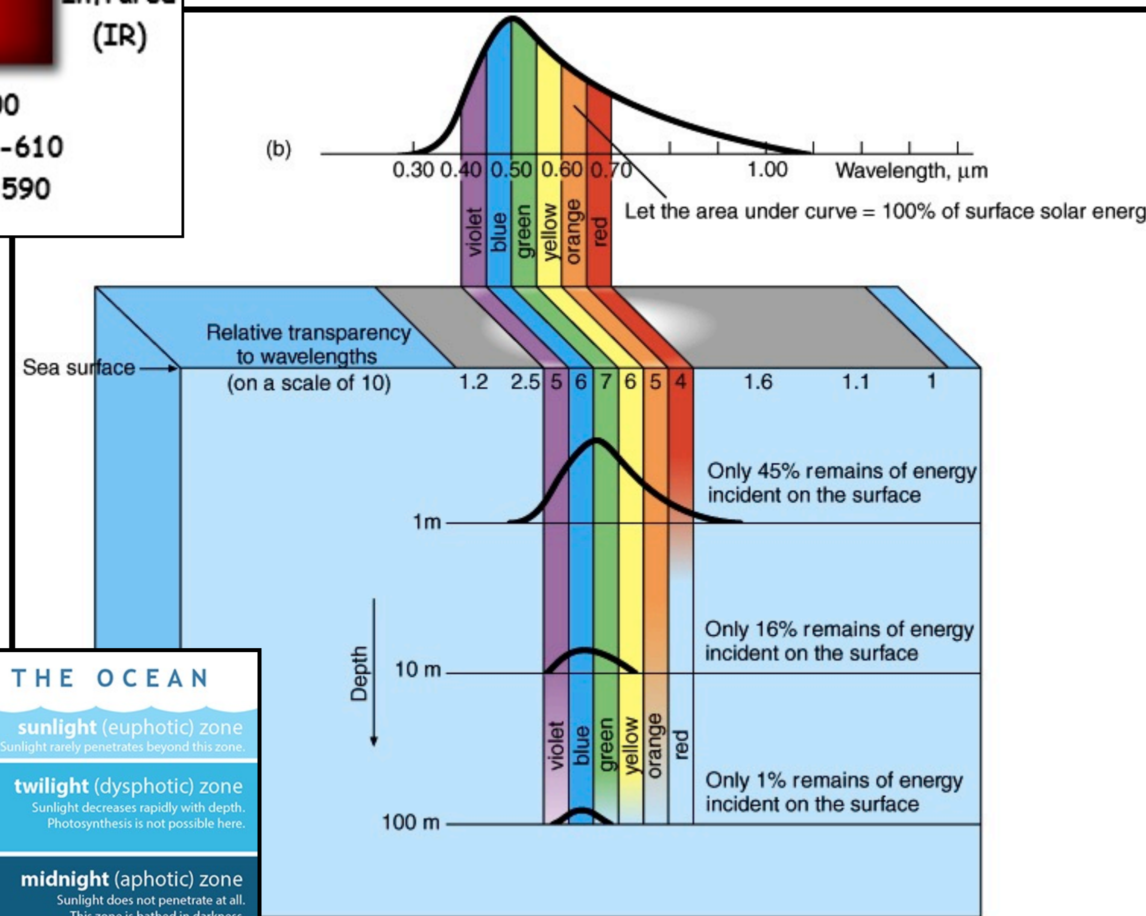


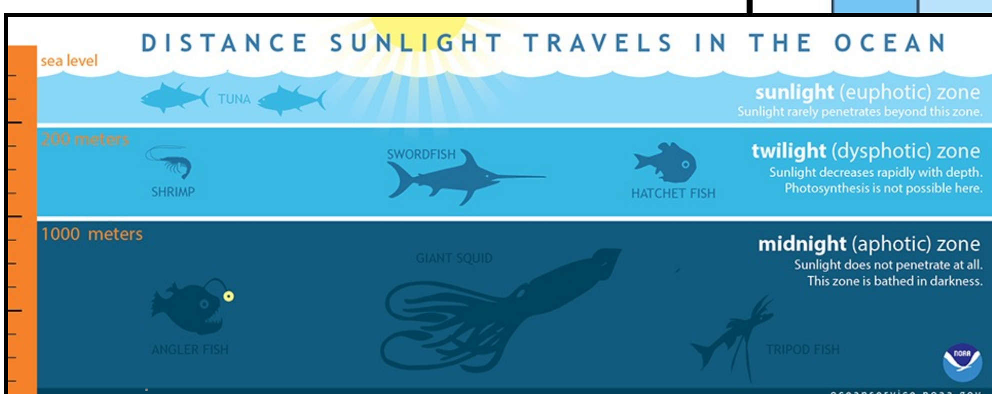




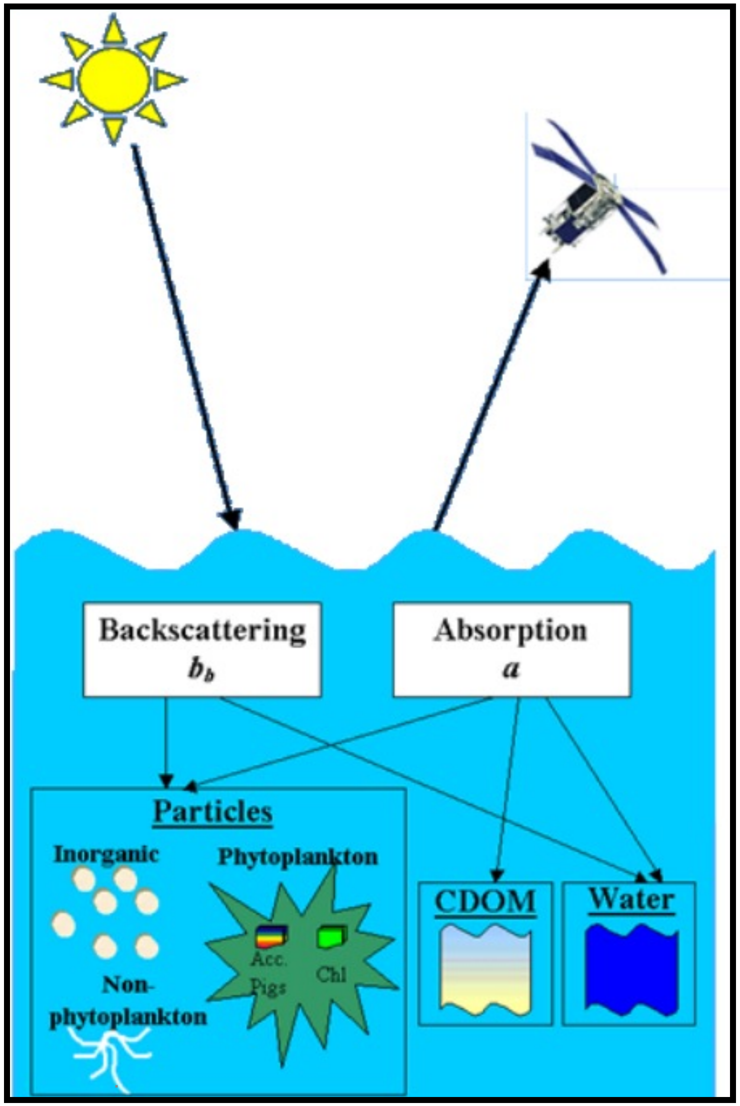
Principles of satellite measurements of ocean color

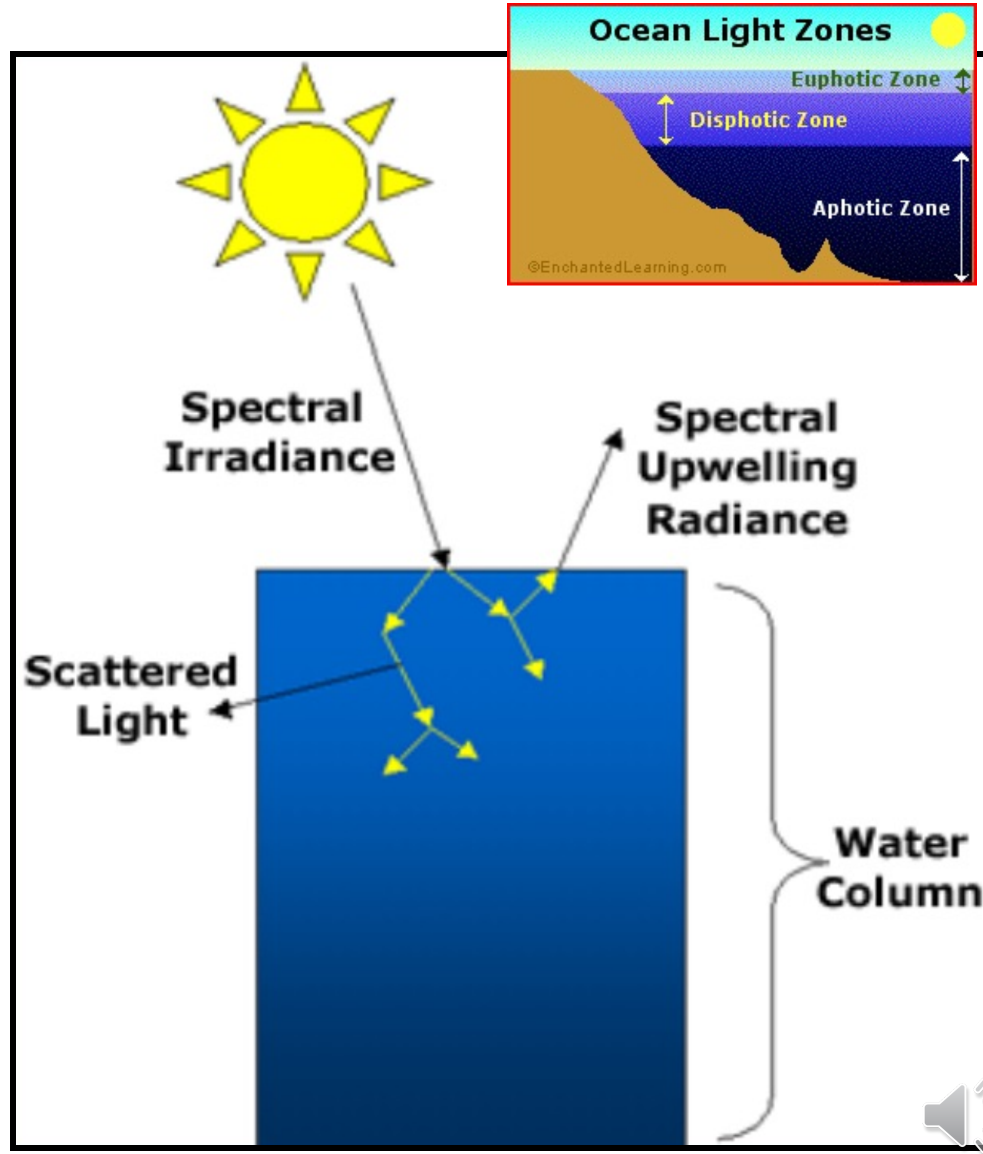




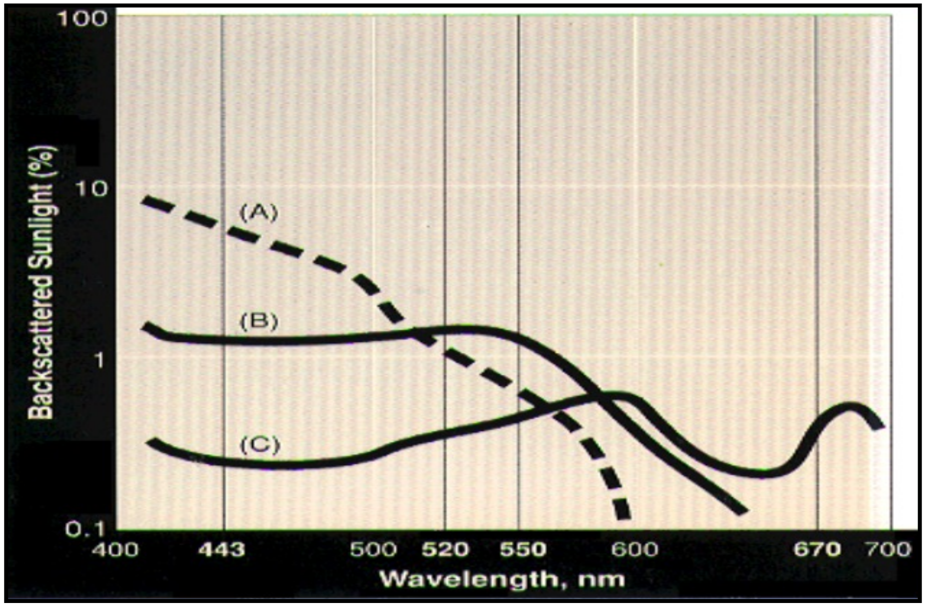


Basic principles of satellite measurements of ocean color





Principles of satellite measurements of ocean color



Ocean color can be measured on the basis of the spectrum of visible light emitted from the study object.

Clean ocean water (A) has maximum in short (blue) wavelength and almost zero in yellow and red.

Higher is phytoplankton (i.e., chlorophyll and other plant pigments) concentration, more is contribution of green color (B).

In coastal zones with high concentration of dead organic and inorganic matter light spectrum has maximum in red (C).

Sources of ocean color change

- Phytoplankton and its pigments
- Dissolved organic material

  -- Colored Dissolved Organic Material (CDOM, or yellow matter, or gelbstoff) from decaying vegetable matter (land) and phytoplankton degraded by grazing of photolysis.
- Suspended particulate matter

  -- The organic particulates (detritus) consist of phytoplankton and zooplankton cell fragments and zooplankton fecal pellets.

  -- The inorganic particulates consist of sand and dust created by erosion of land-based rocks and soils. These enter the ocean through:

  -- River runoff.

  -- Deposition of wind-blown dust.

  -- Wave or current suspension of bottom sediments.

MODIS--Moderate Resolution Imaging Spectroradiometer

- Two MODIS sensors:
  -- **Terra** satellite launched December 18th, 1999

  -- **Aqua** satellite launched May 4th, 2002.

- Both have sun-synchronous near-polar orbit.

- Terra's orbit around the Earth is timed so that it passes from N to S across the equator in the morning (10:30 a.m., descending node)

- Aqua passes S to N over the equator in the afternoon (1:30 p.m., ascending node).

New Ocean Color Missions:

VIIRS: Visible Infrared Imaging Radiometer Suite.
Part of Joint Polar Satellite System

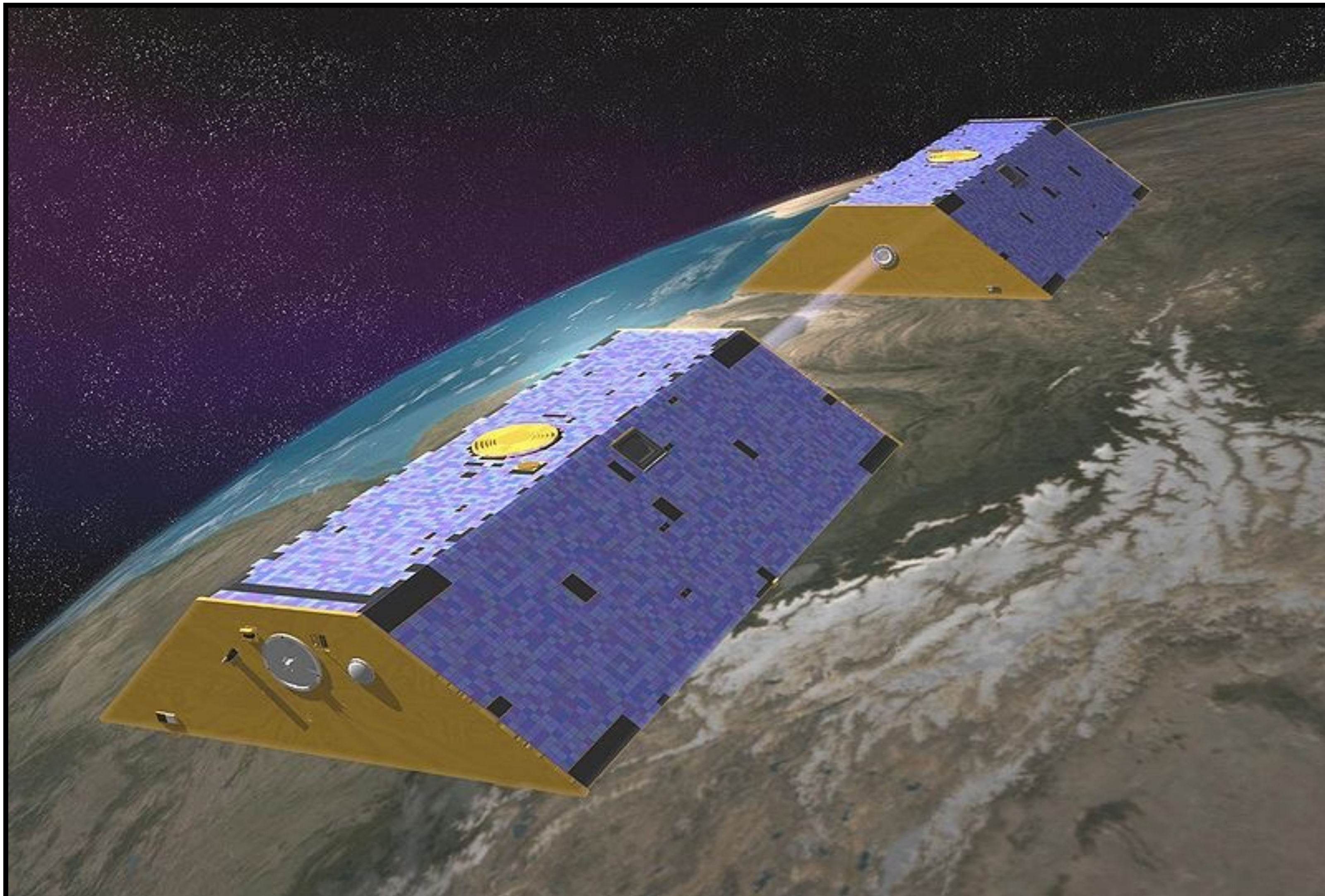
- launched October 28, 2011
- on board Suomi National Polar-orbiting Partnership (Suomi NPP) and NOAA-20 weather satellites
- instrument is a scanning radiometer
- measures in the visible & infrared bands of the EM spectrum
- has swath width of 3060 km at the satellite's average altitude of 829 km
- can collect data in 22 different spectral bands of the electromagnetic spectrum, in the wavelengths between 0.412 μm and 12.01 μm
- benefits: monitor changes and properties in surface vegetation, land cover/use, hydrologic cycle, and the earth's energy budget

New Ocean Color Missions:

PACE: Plankton, Aerosol, Cloud, ocean Ecosystem.

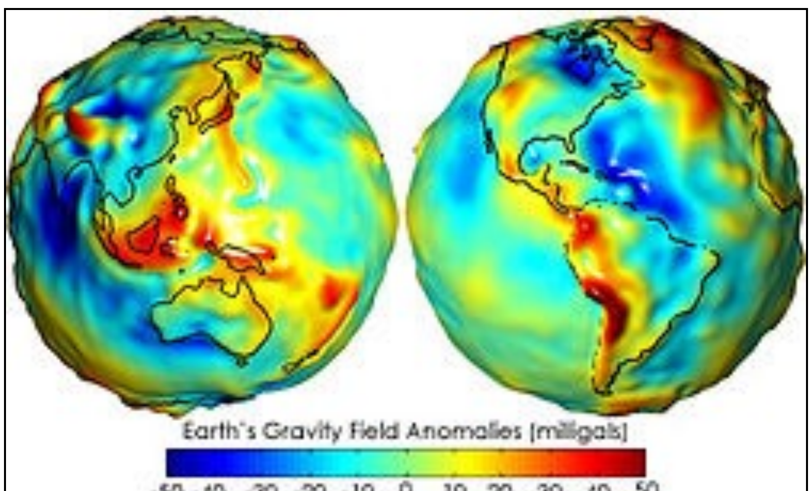
- to be launched 2022
- global ocean color, biogeochemistry, ecology, & carbon cycle
- Ocean Color Instrument (OCI) – the primary sensor
- OCI - optical spectrometer; measures ocean color from UV to shortwave infrared.
- wavelengths UV (350-400 nm), visible (400-700 nm), and near-infrared (700-885 nm), as well as several shortwave infrared bands

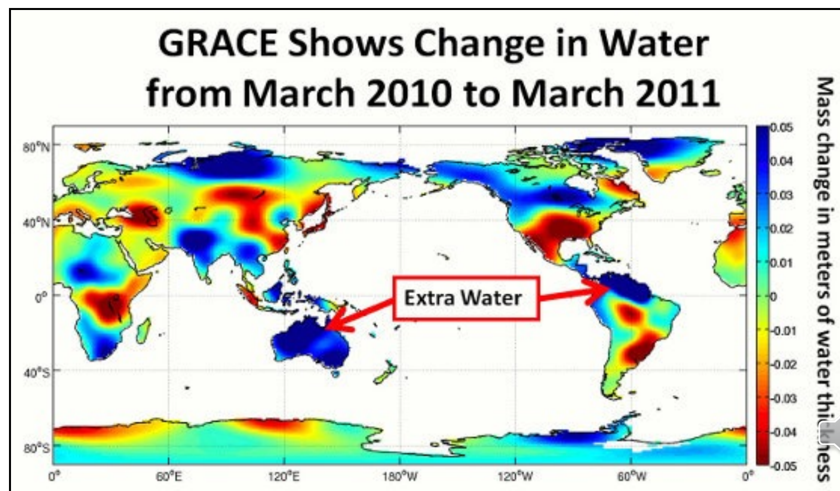
GRACE



GRACE

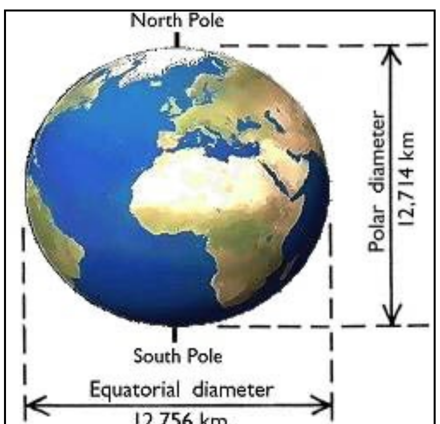
- **GRACE:** Gravity Recovery And Climate Experiment
- NASA & German Aerospace Center. Launched March 17, 2002
- GRACE makes detailed measurements of Earth's gravity field anomalies
- Measure time variable gravity field to detect changes in the water storage and movement from reservoir to another (e.g., from ice sheets to ocean)

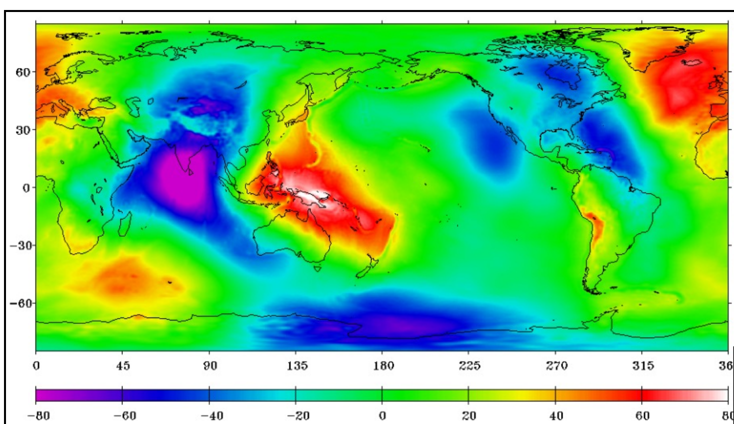




Shape of the Earth

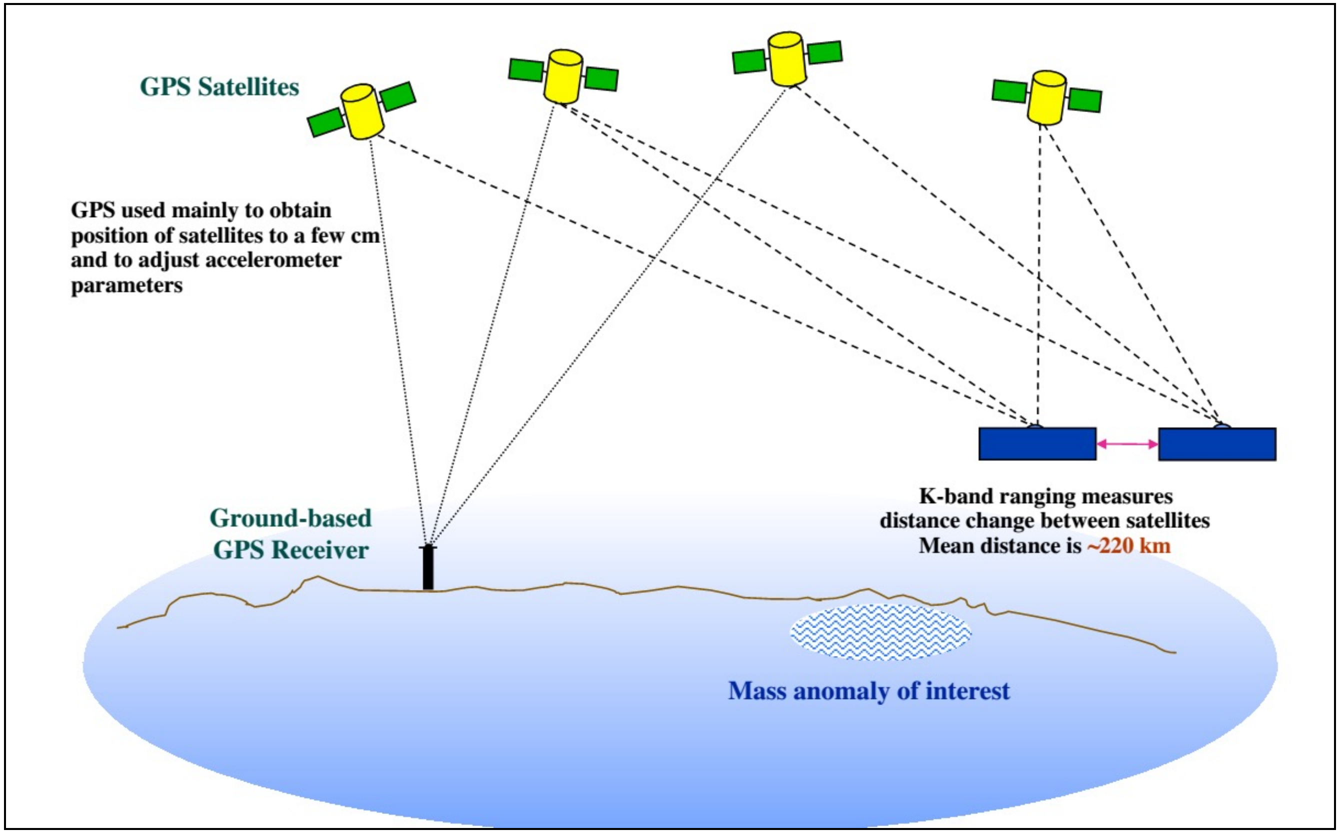
- Earth is not a perfect sphere
- Poles are ~ 21 km (13 mi) closer to the center of the Earth than the Equator (shape of an ellipsoid)
  -- Only a 0.3% difference
- 99.99% of the sea surface height measured by an altimeter is due to this gravitational shape of the Earth (or geoid)
- If we remove the ellipsoid shape, there are still ± 100 m deviations in the SSH or geoid





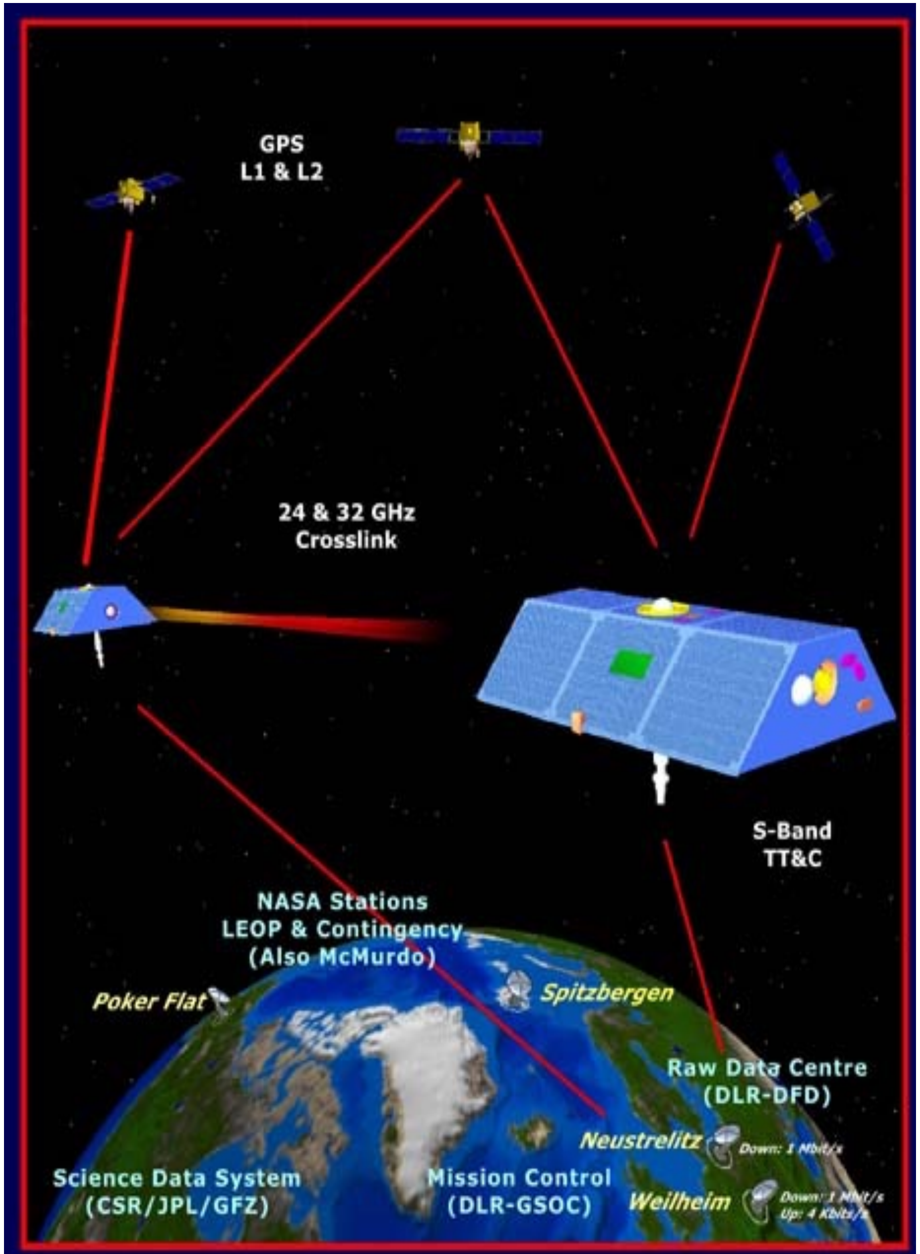
Earth mean sea surface/geoid

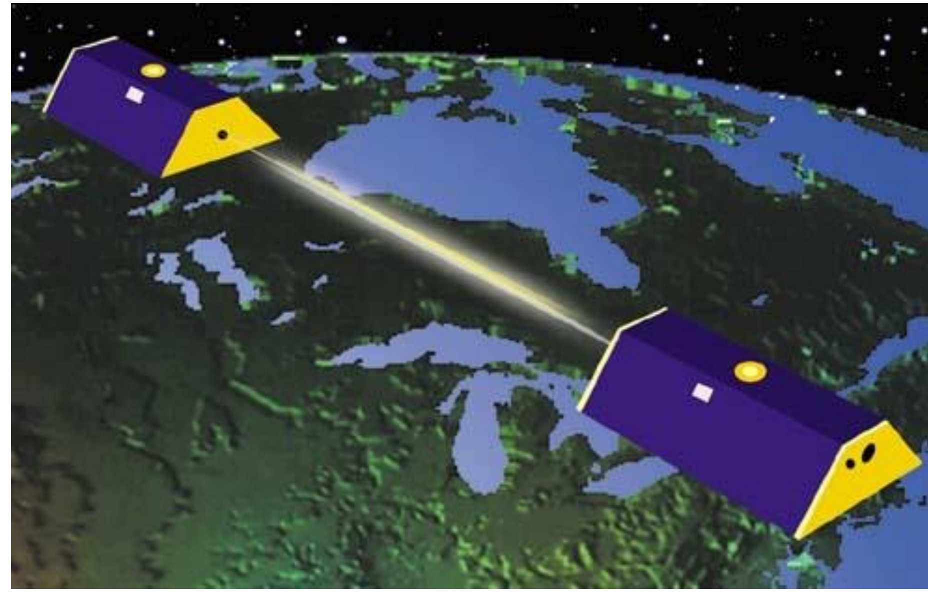
GRACE: Measurement principle



- uses a microwave ranging system to accurately measure changes in the speed and distance between ***two identical spacecraft*** flying in a polar orbit about 220 kilometers (140 mi) apart, 500 kilometers (310 mi) above Earth.

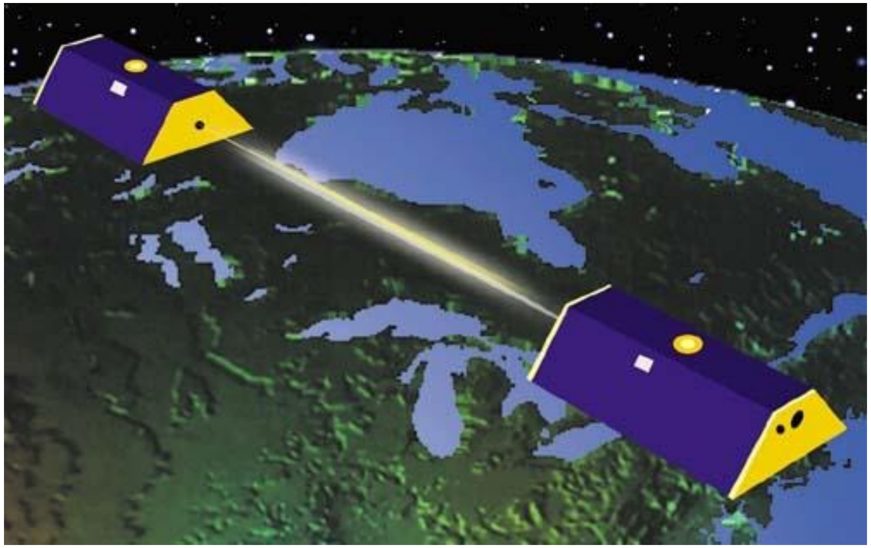
GRACE: Measurement principle





- The ranging system is sensitive enough to detect separation changes as small as 10 micrometers
- (approximately one-tenth the width of a human hair) over a distance of 220 kilometers

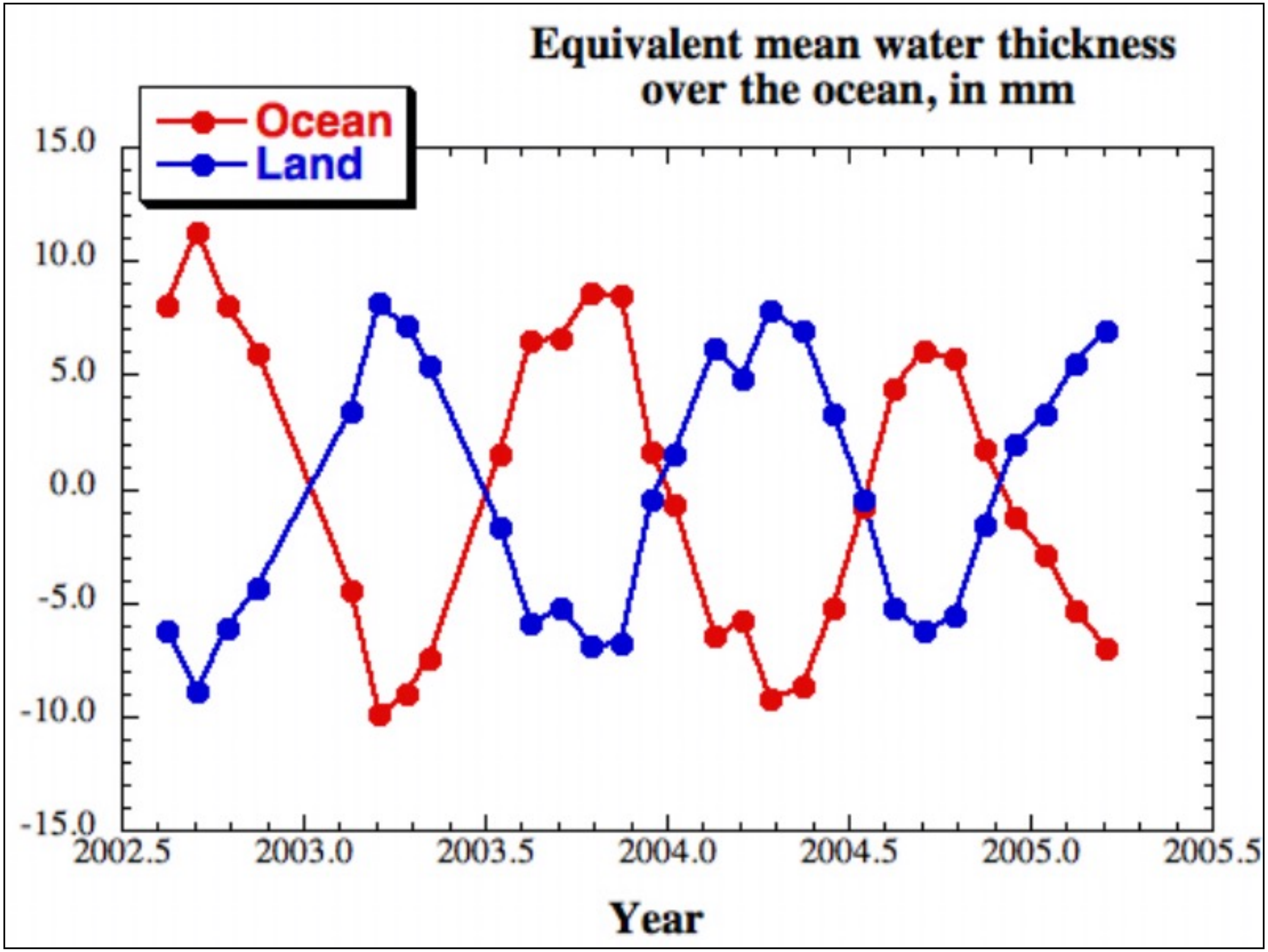
GRACE: Measurement principle



- As the twin GRACE satellites circle the globe 15 times a day, they sense minute variations in Earth's gravitational pull
- When the first satellite passes over a region of slightly stronger gravity, a gravity anomaly, it is pulled slightly ahead of the trailing satellite.

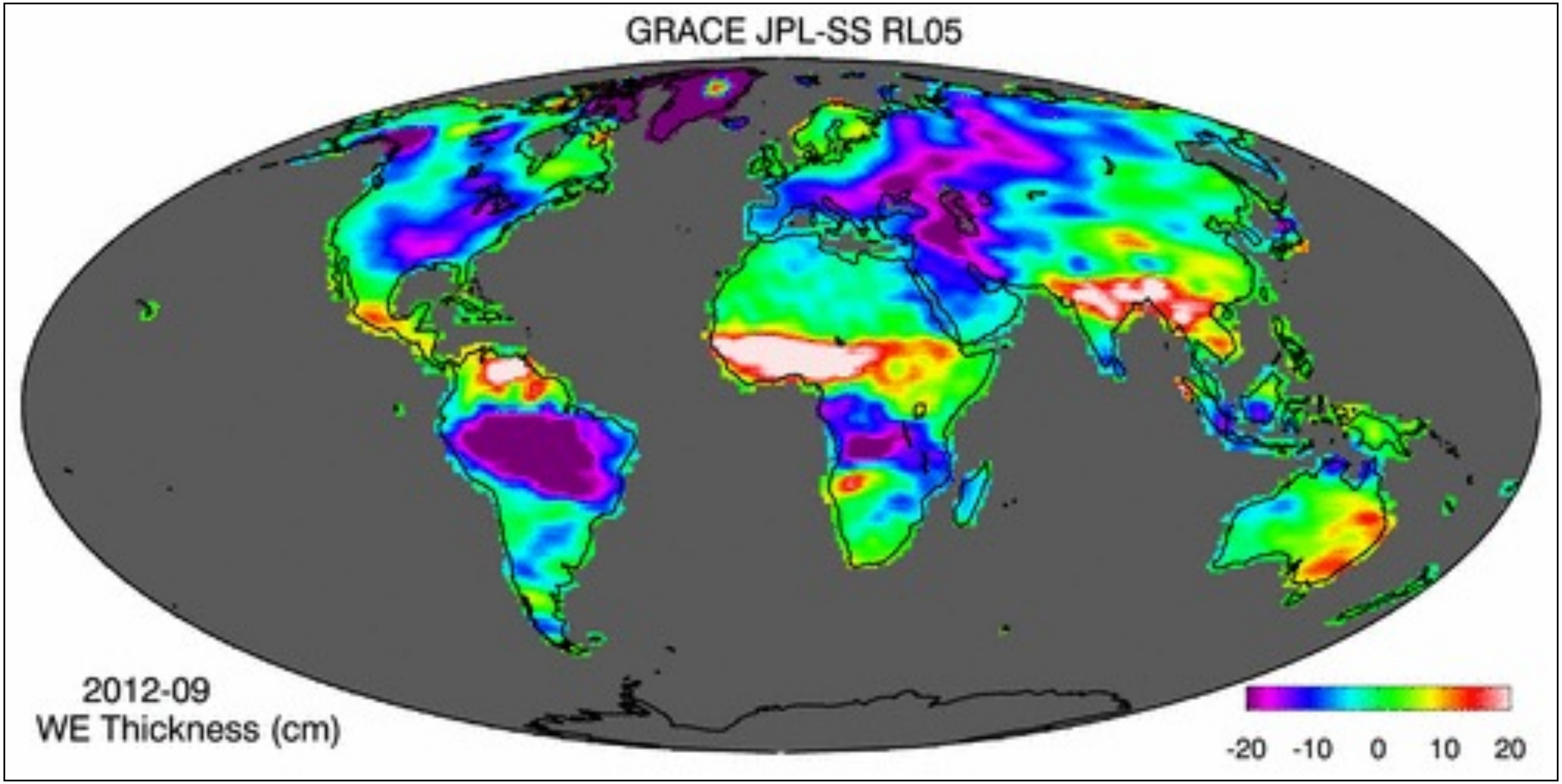
- This causes the distance between the satellites to increase.
- The first spacecraft then passes the anomaly, and slows down again; meanwhile the following spacecraft accelerates, then decelerates over the same point.

GRACE: Water Thickness



- GRACE measures the mass flux over both the ocean and land; these are out of phase

GRACE: Water Thickness



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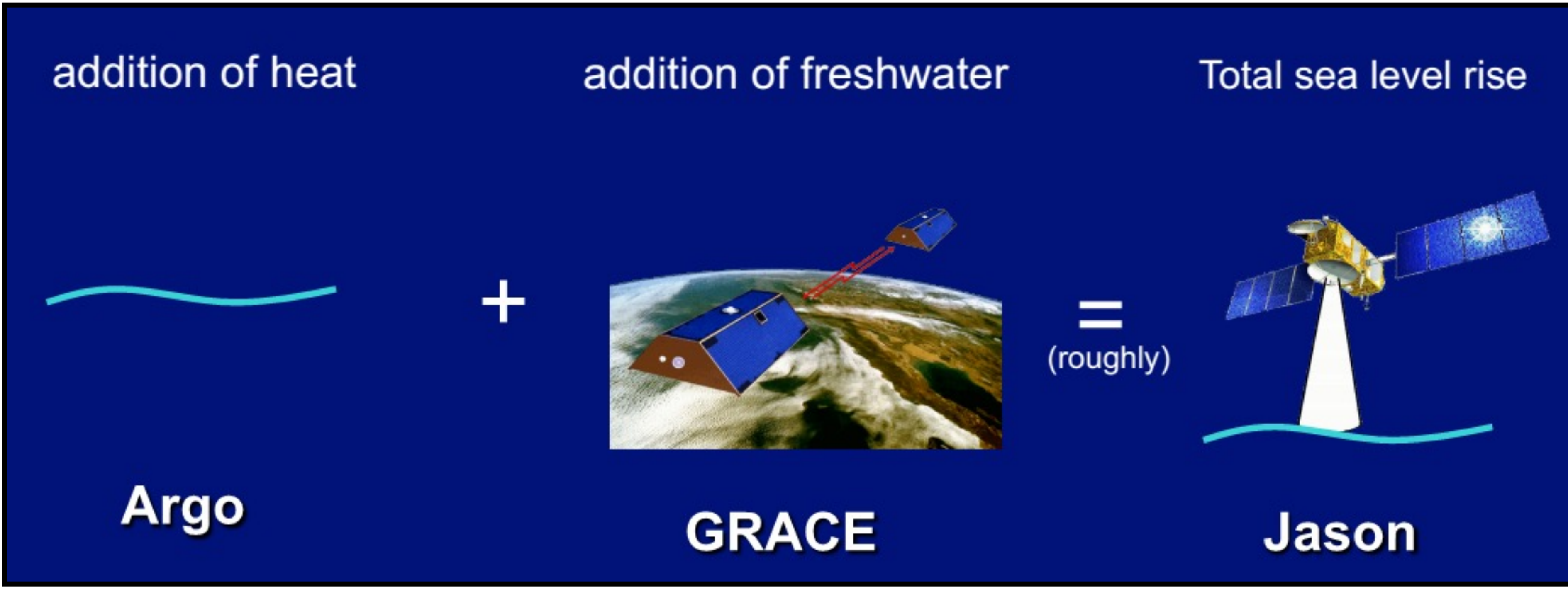
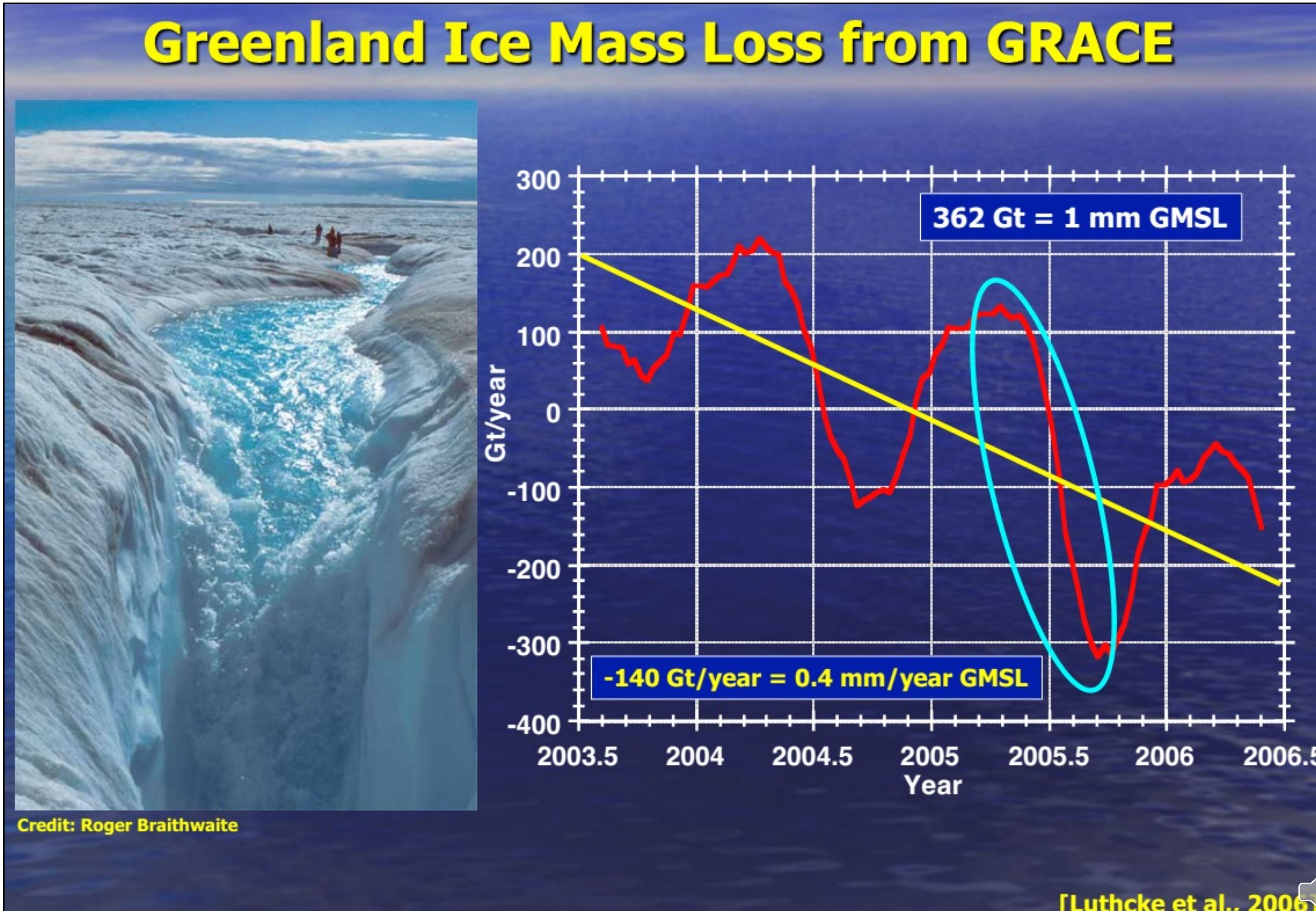
GRACE: Sea level changes

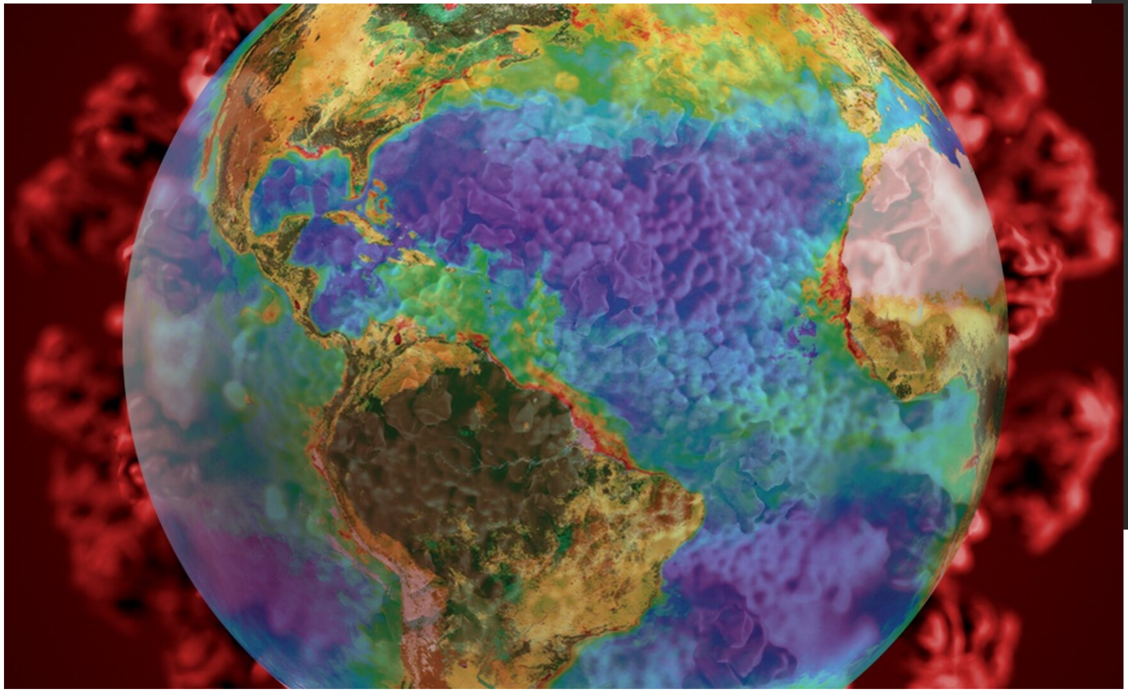


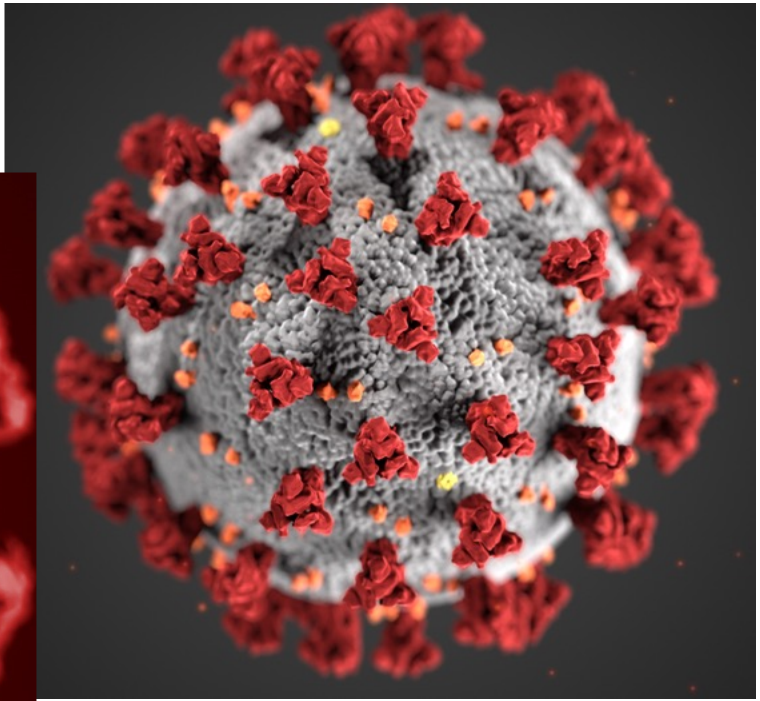
- Globally averaged sea level rise

GRACE: Sea level changes- potential contributions

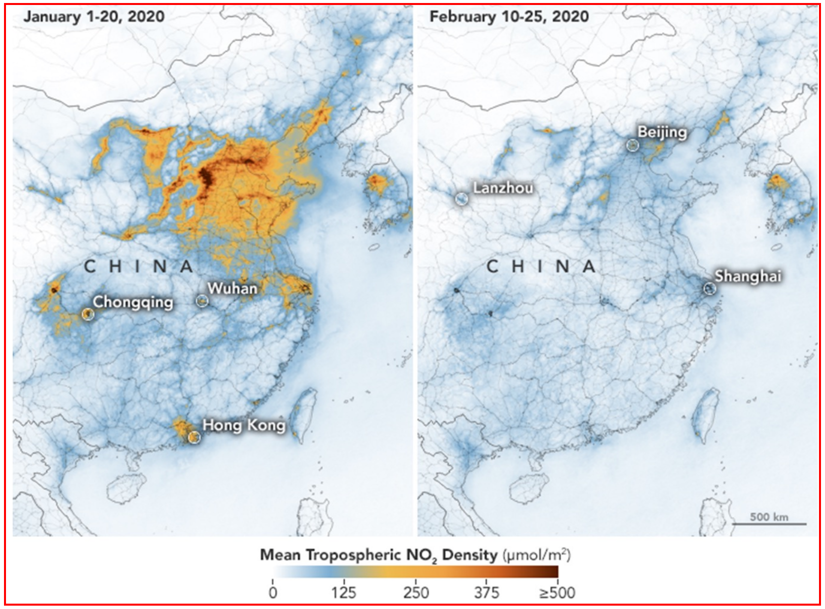


Remote Sensing and COVID-19



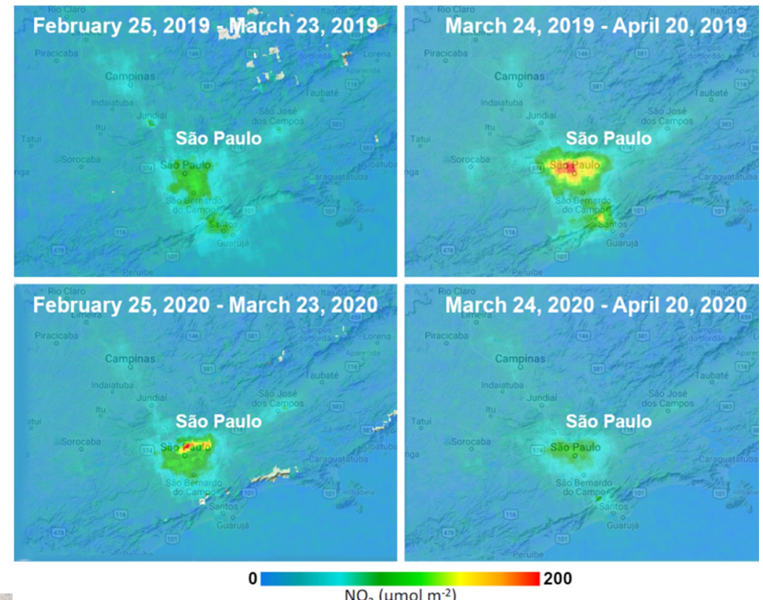


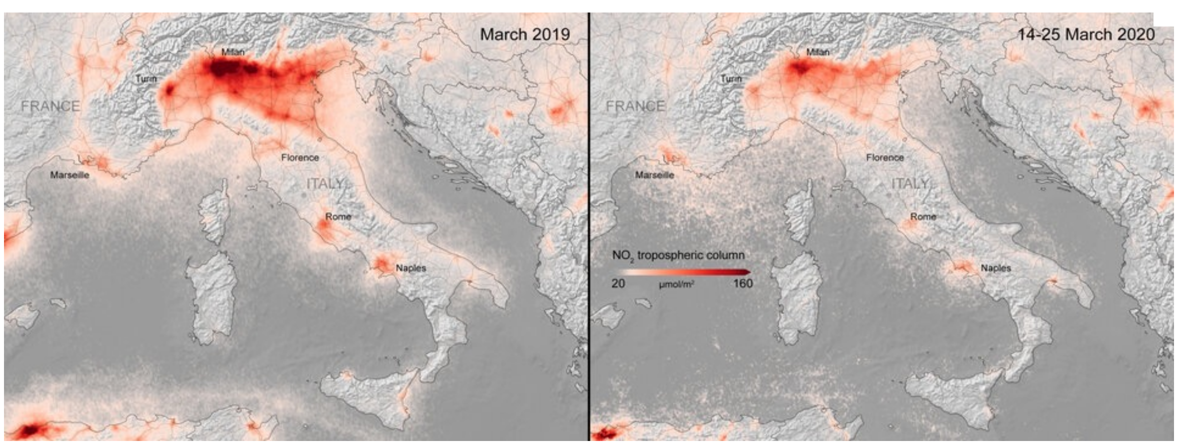
Environmental tracking/ monitoring



Dramatic reduction in China air pollution

NASA satellite image shows steep drop in noxious gas over central, eastern areas of China, as government forces closure of factories, transportation

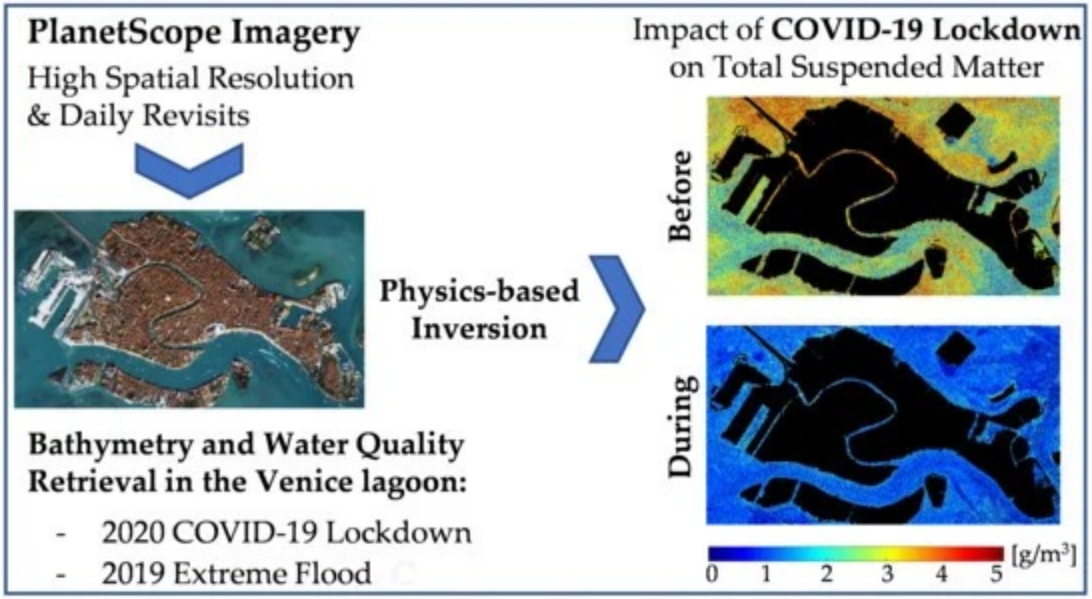




NO_2 reductions over Italy (ESA Copernicus Sentinel-5P satellite)

Mean levels of tropospheric NO_2 measured by the S5p/TROPOMI-ESA both in the four-week before and in the four-week during the partial lockdown in São Paulo, Brazil, compared to the same period in 2019

Water quality



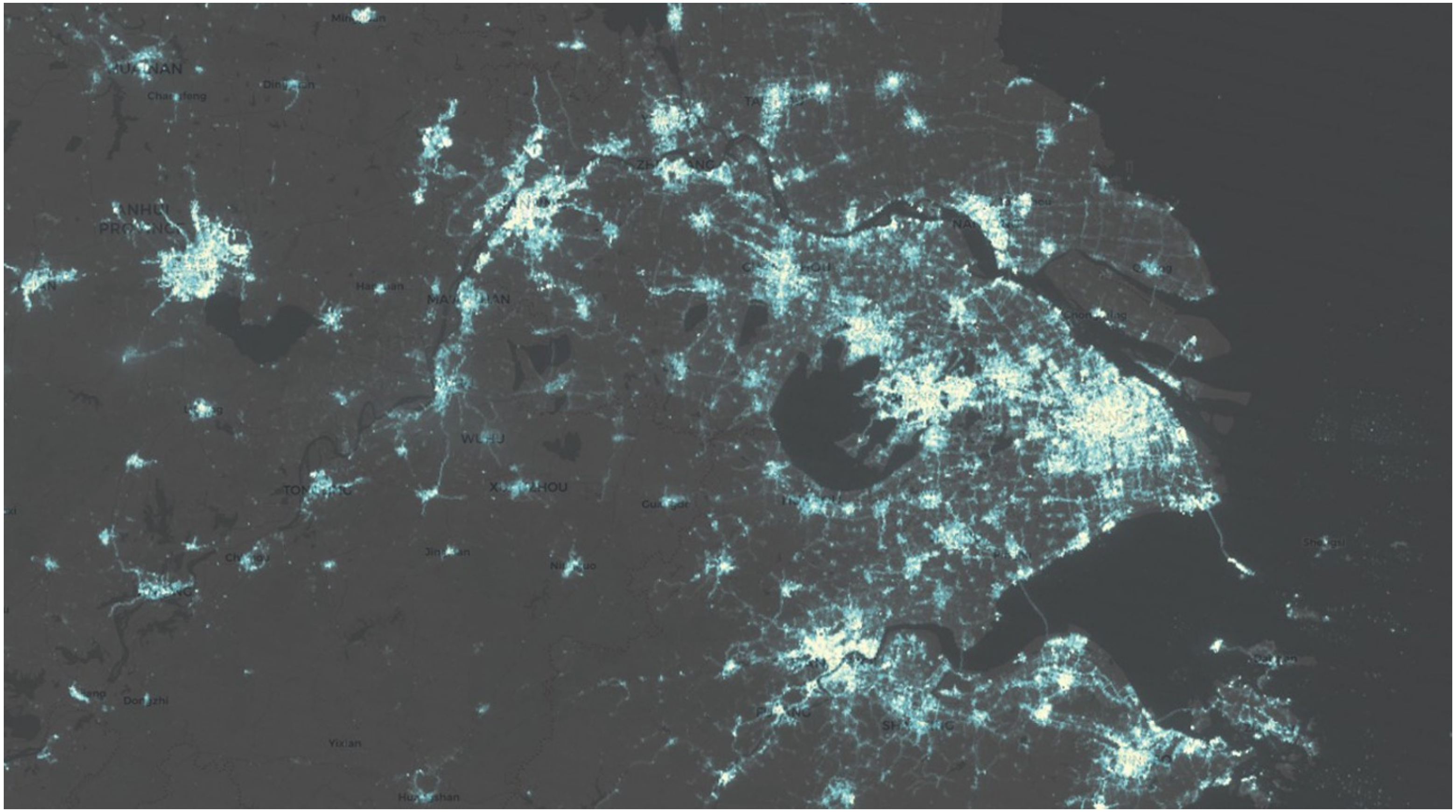
Niroumand-Jadidi et al., 2020

Reduction in TSM (low turbidity, high water clarity) in Venice Lagoon.

Results from PlanetScope constellation (130+ satellites currently in orbit)

Satellites are mainly CubeSats - 10 × 10 × 30 cm^3 carrying sensors with four or five bands. 3m spatial resolution; daily.

Monitoring economic activities



Satellite nighttime light emissions data for Shanghai, China, from Jan. 3, 2020 (before COVID outbreak). Data from NOAA Visible Infrared Imaging Radiometer Suite (VIIRS)