Observing Oceans & Freshwater from Space

Learning Objectives

- Oceans & freshwater
  - What is it?
  - Why monitor it?
  - Historical monitoring
  - Remote sensing technologies used to monitor oceans & freshwater
  - Applications/examples

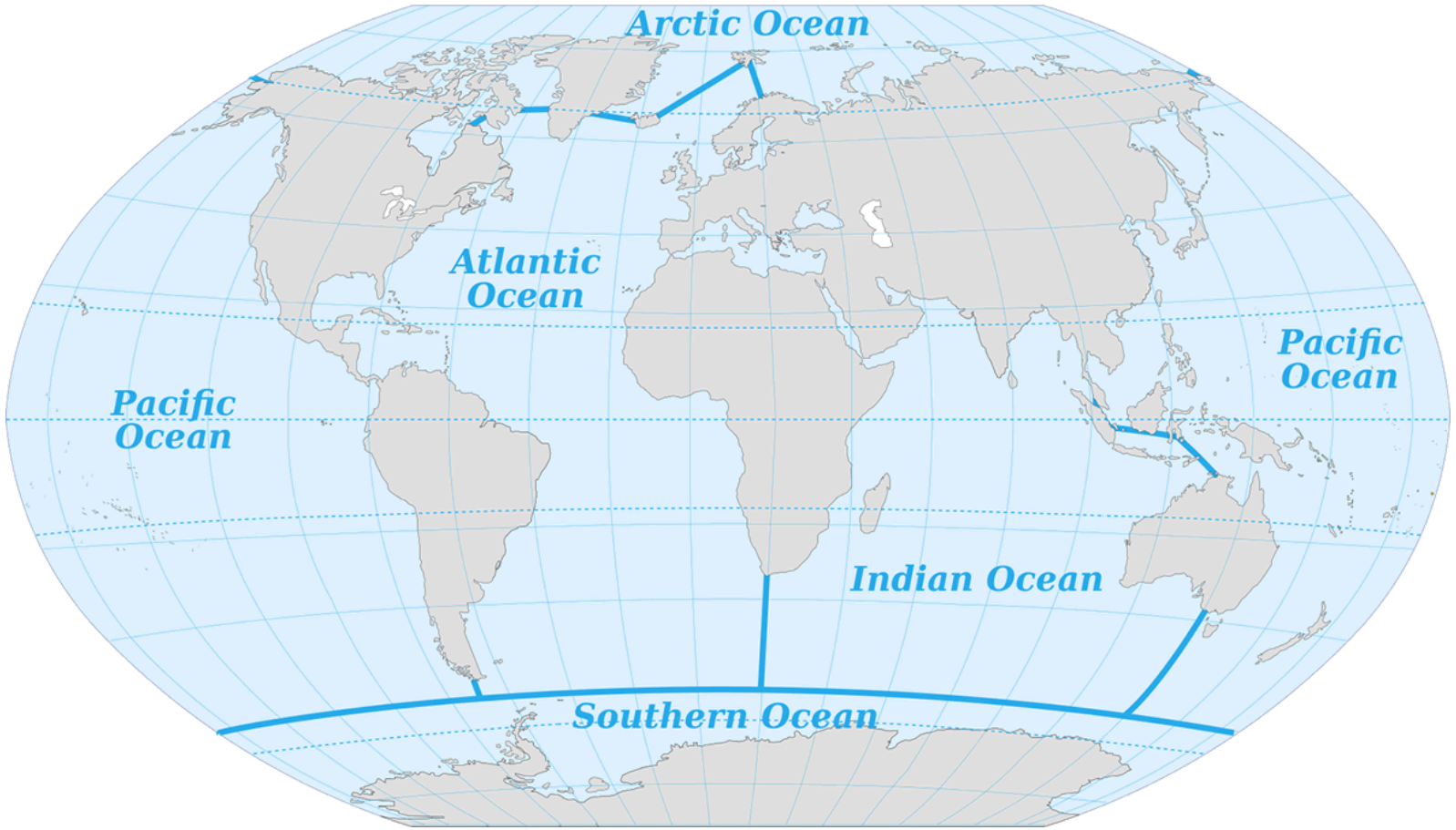
Quick Definitions

Oceans

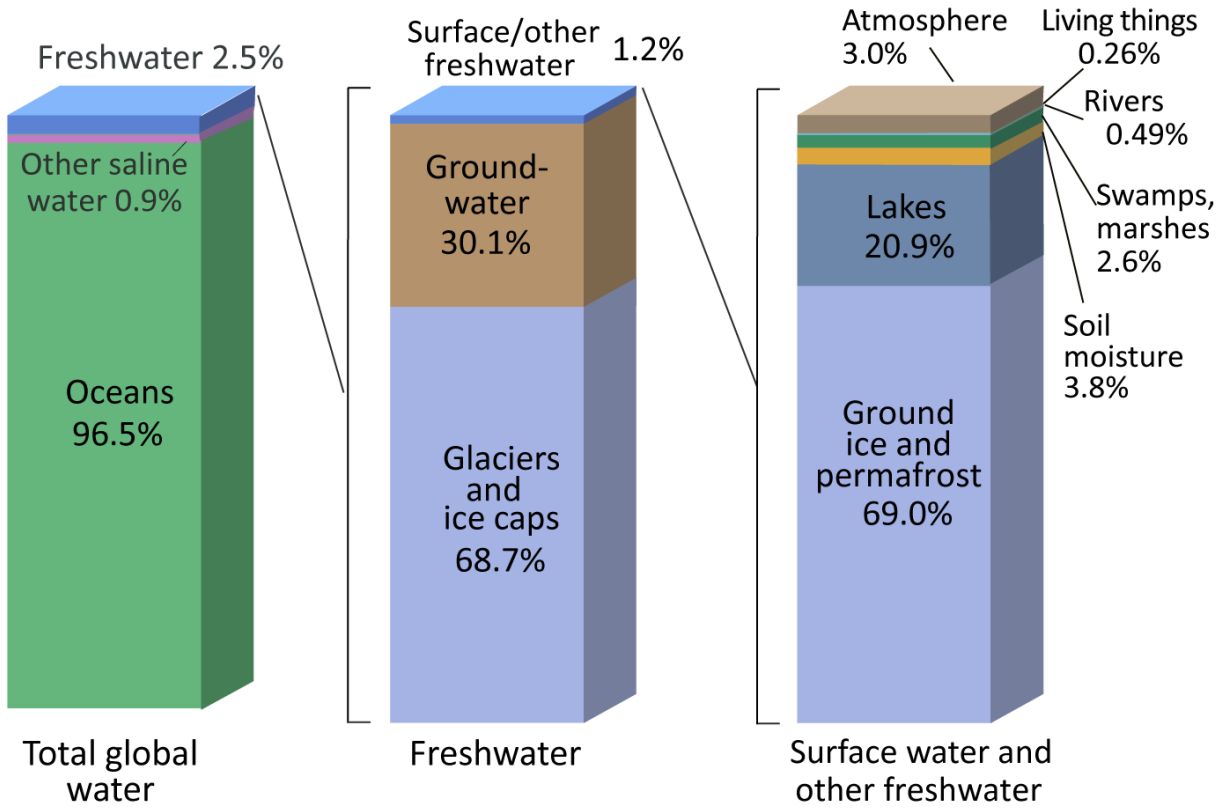
- The body of saltwater that covers 70% of the Earth's surface
  - Contains 97% of Earth's water
  - Atlantic, Pacific, Indian & Arctic
  - Southern is the newest ocean
    - Not recognized worldwide

Freshwater

- Naturally occurring liquid (or frozen) water containing low concentrations of dissolved salts
  - Glaciers, lakes, reservoirs, ponds, rivers, streams, wetlands and groundwater
  - Only 3% of Earth's water
  - Less than 1% of Earth's total surface area


Arctic Ocean
Atlantic Ocean
Pacific Ocean
Pacific Ocean
Indian Ocean
Southern Ocean

Where is Earth's Water?



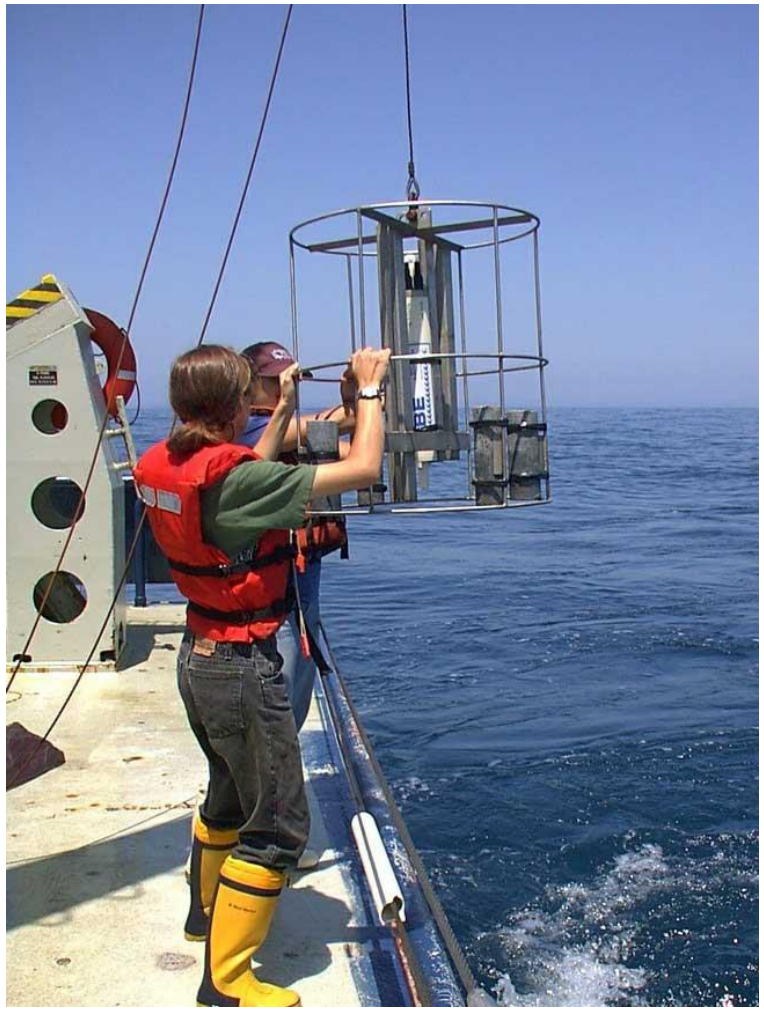
Credit: U.S. Geological Survey, Water Science School. https://www.usgs.gov/special-topic/water-science-school
Data source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources. (Numbers are rounded).

Why Monitor the Oceans & Freshwater?

- Very useful indicator of climate variability and change
  - Community impacts
  - Biodiversity impacts
- Weather and climate prediction
  - Ocean currents
  - Regulation
- Freshwater storage
  - Water resource management
  - Ecosystem
  - Hydrology

Historical Monitoring of Oceans & Freshwater

- People in boats
  - Placing nets or instruments into the water
    - Collecting data on composition (of water and surfaces)
  - Building nautical charts
    - Understand tides, currents, etc.



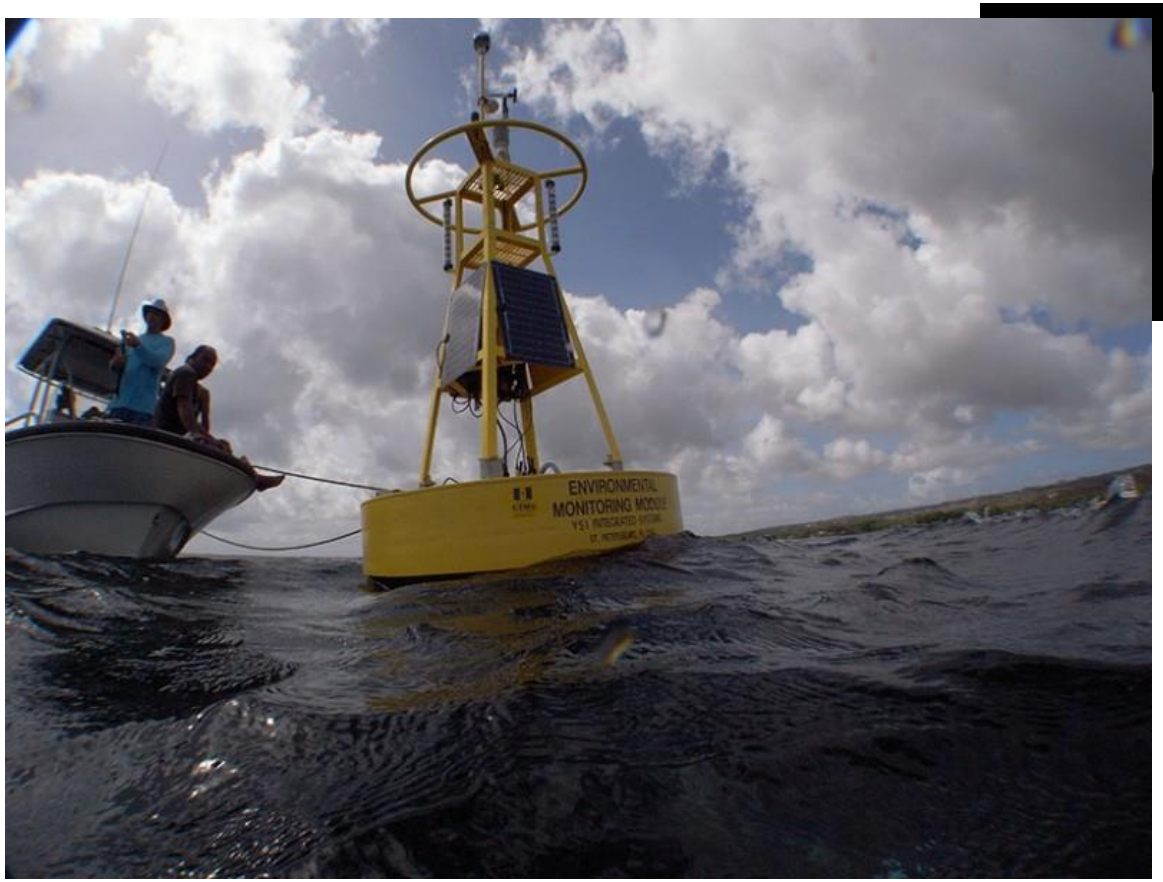
Credit: http://oceanworld.tamu.edu

Monitoring the Oceans & Freshwater from Space

- Characteristics/features measured include:
  - Sea surface temperature
  - Sea levels
  - Freshwater storage
  - Habitat characteristics
    - Coral reefs
    - Salmon habitat in freshwater streams
- Earth observation datasets used include:
  - Landsat
  - MODIS
  - RADAR satellites
  - Lidar (airborne)
  - Plus some new ones

Historical Sea Surface Temperature Measurements

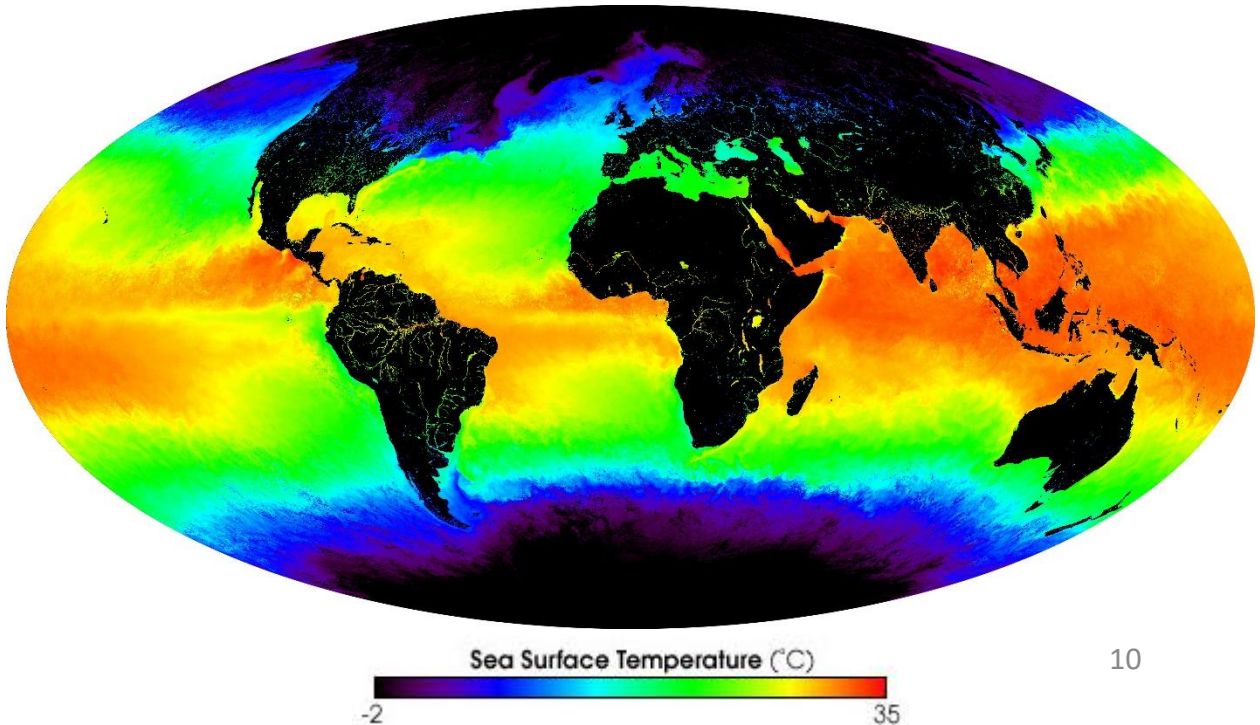
- Before satellites, measurements from buoys were the main tool
- Provides point measurements
- At potentially very fine temporal scales
  - Every hour, minute, second, and millisecond if you'd like
- All weather

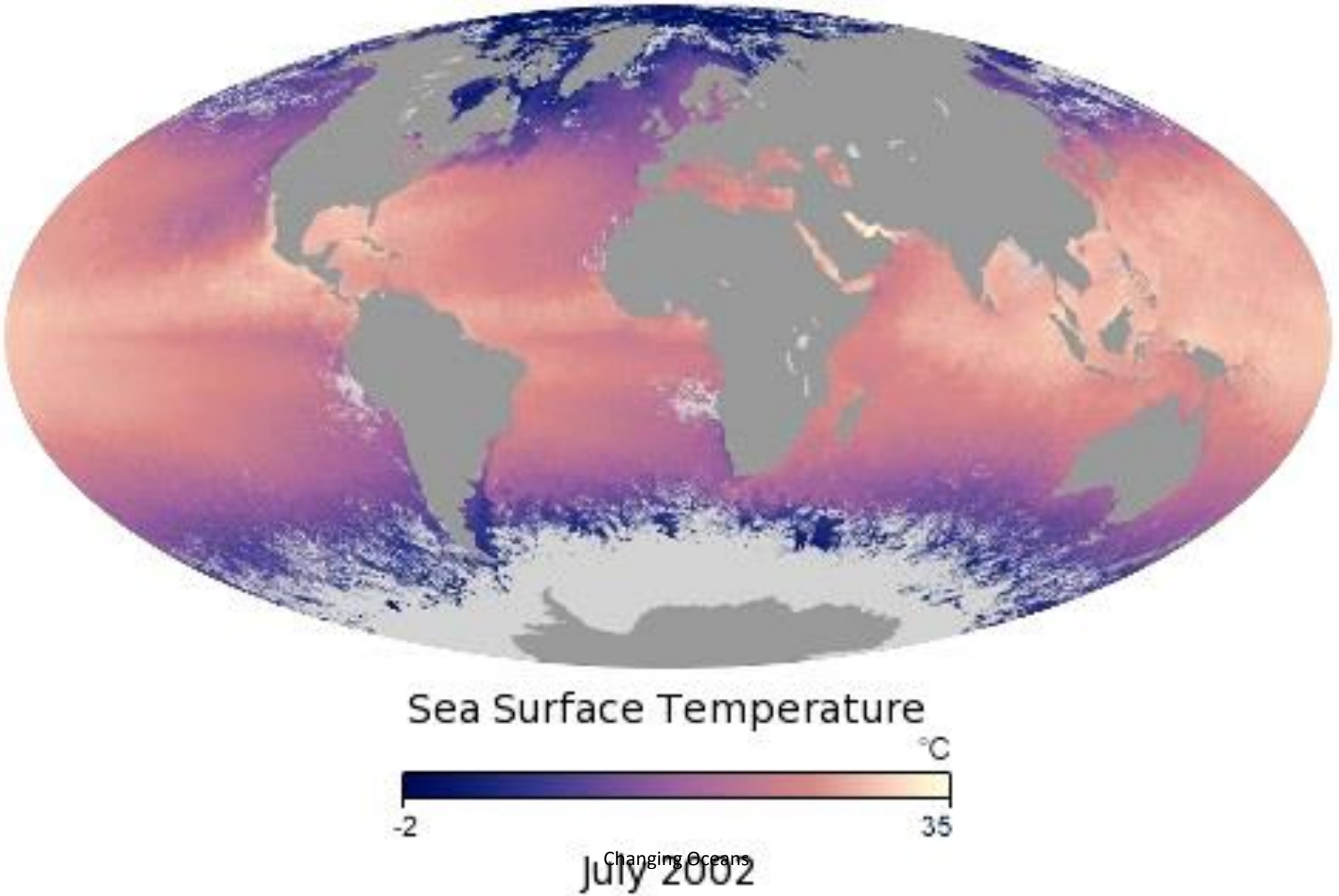


Measuring surface temperature from sea buoys. Credit: NOAA/CREWS.

Sea Surface Temperature

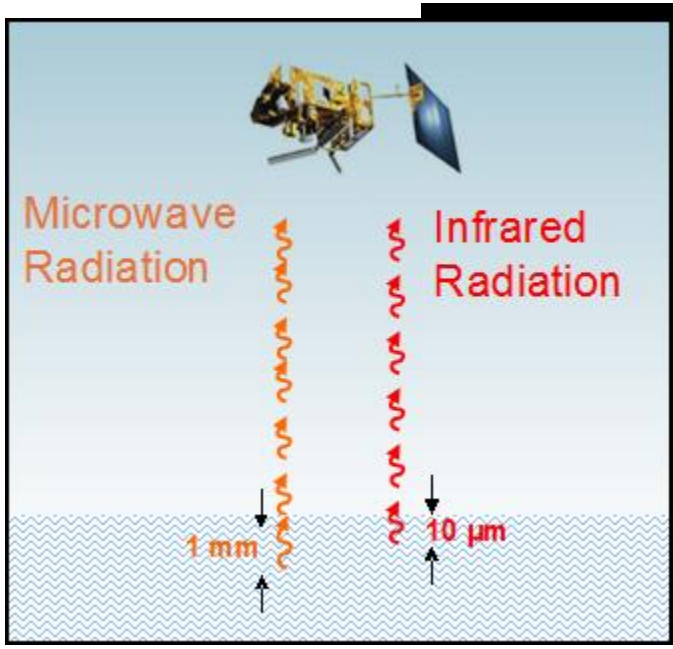
- Provides fundamental information on global climate system
  - Such as identifying El Niño and La Niña cycles
- Typically measured with passive sensors
  - MODIS often preferable
    - Better for coarse spatial scale
    - Better temporal resolution
  - MODIS bands 31 & 32 used
    - Thermal infrared
  - Not all weather




Sea Surface Temperature
°C
-2
35
July 2002

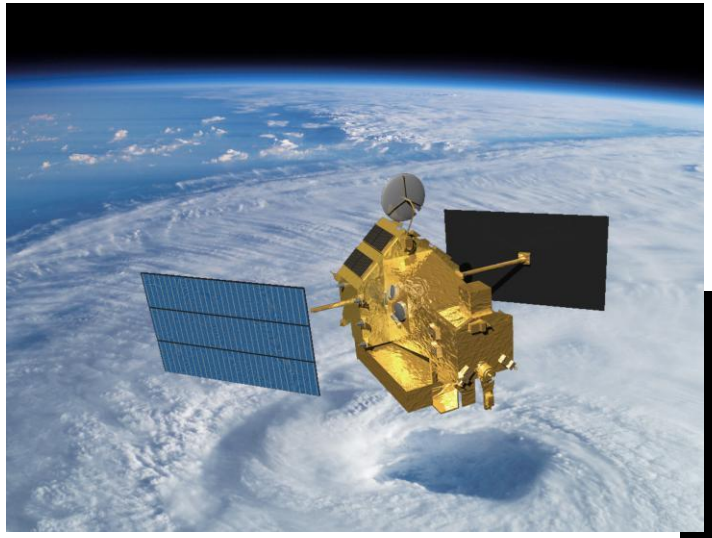
Sea Surface Temperature

- The ocean emits thermal infrared radiation
  - Measured from space by sensors like MODIS
  - And is proportional to sea surface temperature
  - Infrared radiation from the ocean comes from the top 10 microns of the surface
- The ocean also emits radiation in the microwave part of the spectrum
  - Which is also proportional to sea surface temperature
  - Microwave radiation is from the top millimeter of the surface

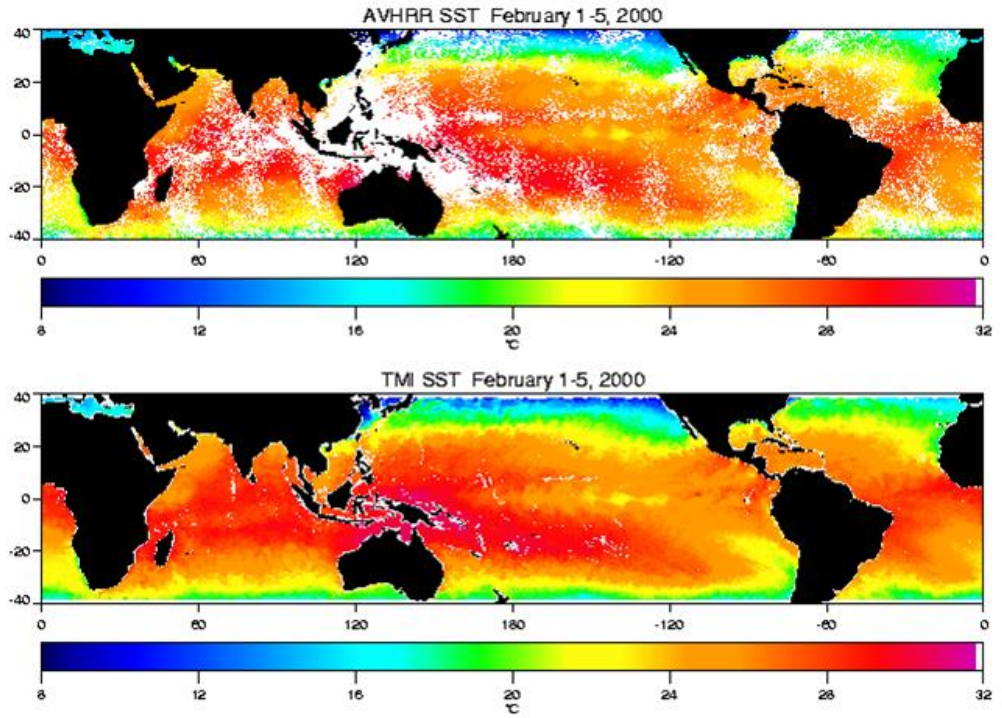


https://resources.eumetrain.org/data/6/619/navmenu.php?tab=6&page=1.0.0

Sea Surface Temperature

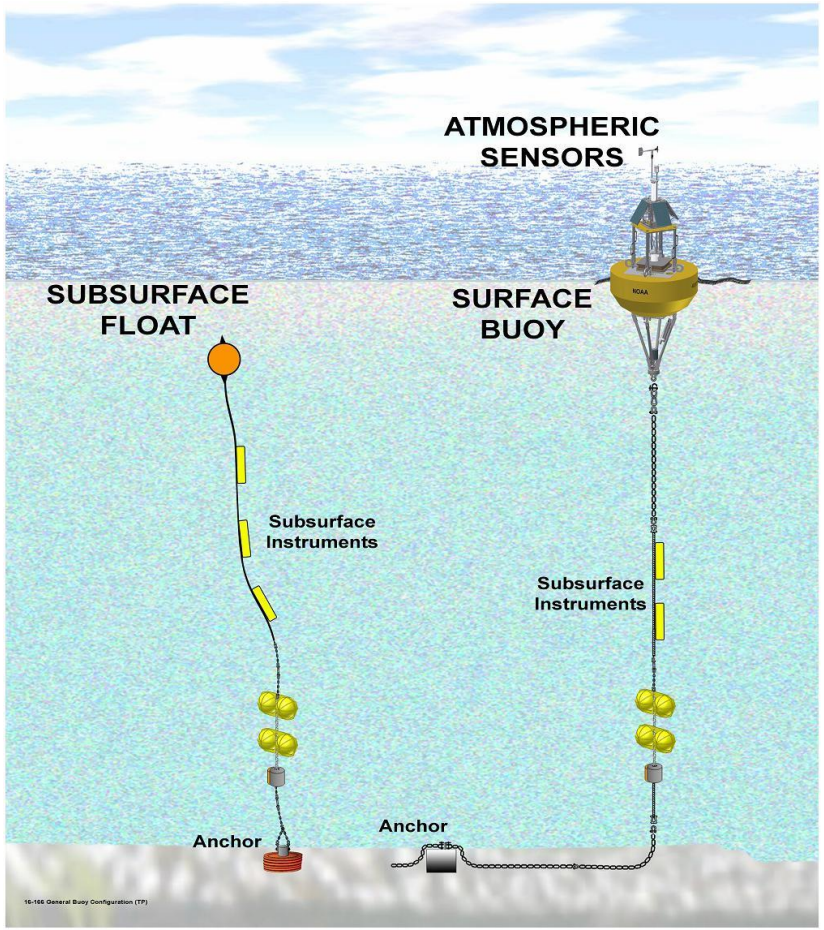


- Tropical Rainfall Measuring Mission (TRMM)
  - Has a Microwave Imager (TMI)
    - Still a passive sensor
  - Allows for sea surface temperature estimates in all weather conditions
  - Representative of the top 1mm of the surface
  - Orbit restricted to +/- 30° of the equator



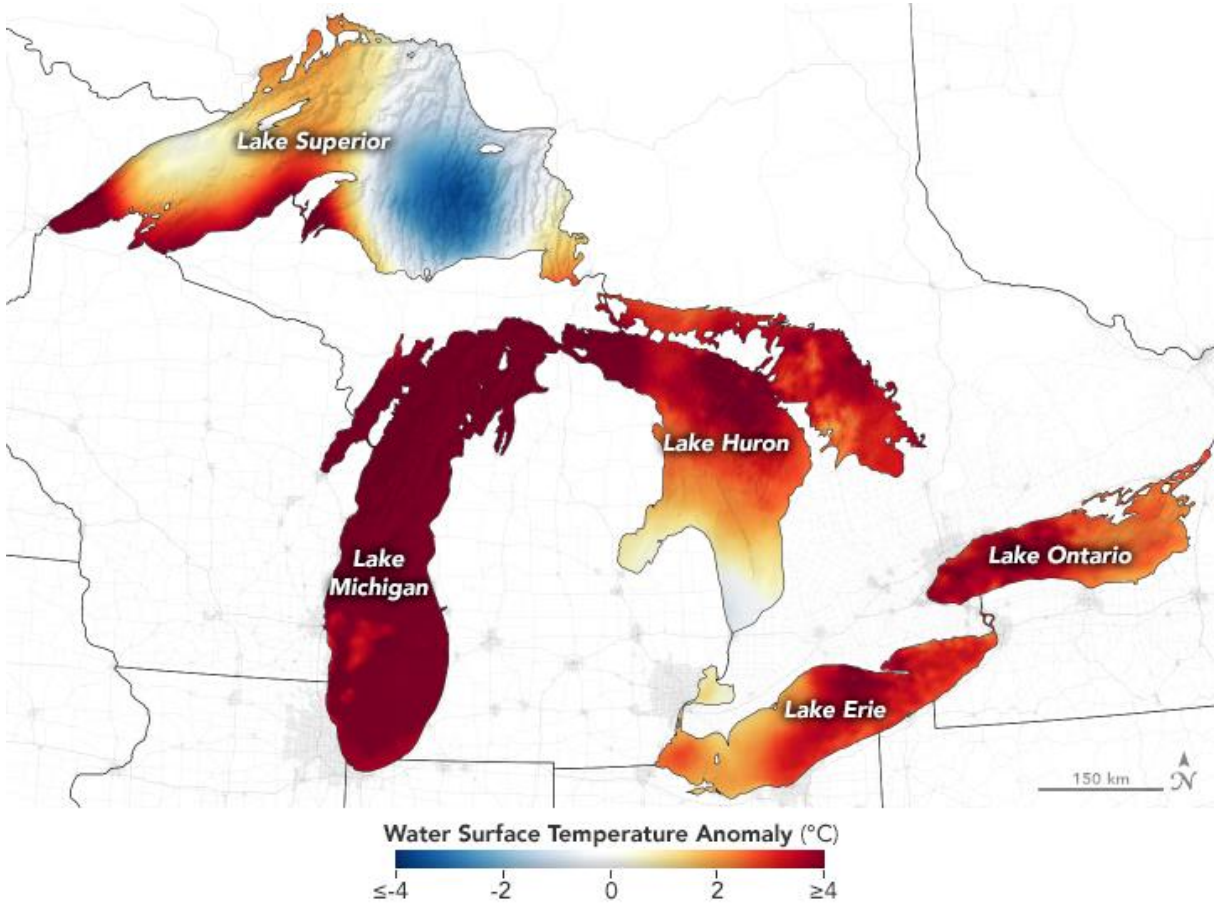
What about below the surface?

- Below surface measurements are primarily taken from mooring and drifter buoys
  - Mooring buoys are good for measuring time series through the depths of the water column
  - Most deeper ocean temperature data are measured from drifter buoys



What about Freshwater?

- We use similar methods for monitoring lake surface temperature
  - MODIS frequently used
  - Landsat used for smaller lakes



An Example of Efficient Data Collection

By Satellite

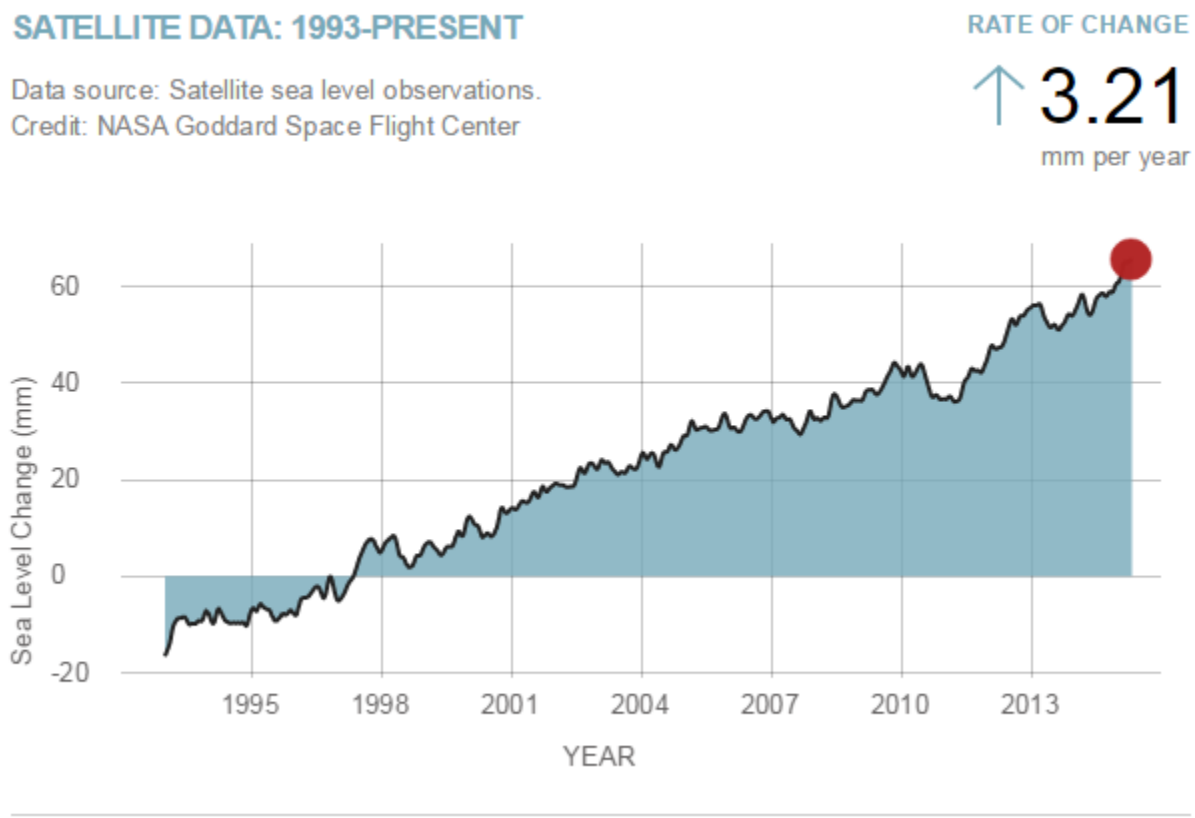
- In the Mid Atlantic, a passing satellite measuring sea surface temperature may contain around 600,000 pixels of data
  - Covering an area of over 250,000 square miles

By Buoy

- Meanwhile, there are only about a dozen buoys in the same area
  - Given the vast size and variability of the ocean, the applications of these measurements are limited
  - But they are still needed to validate satellite data

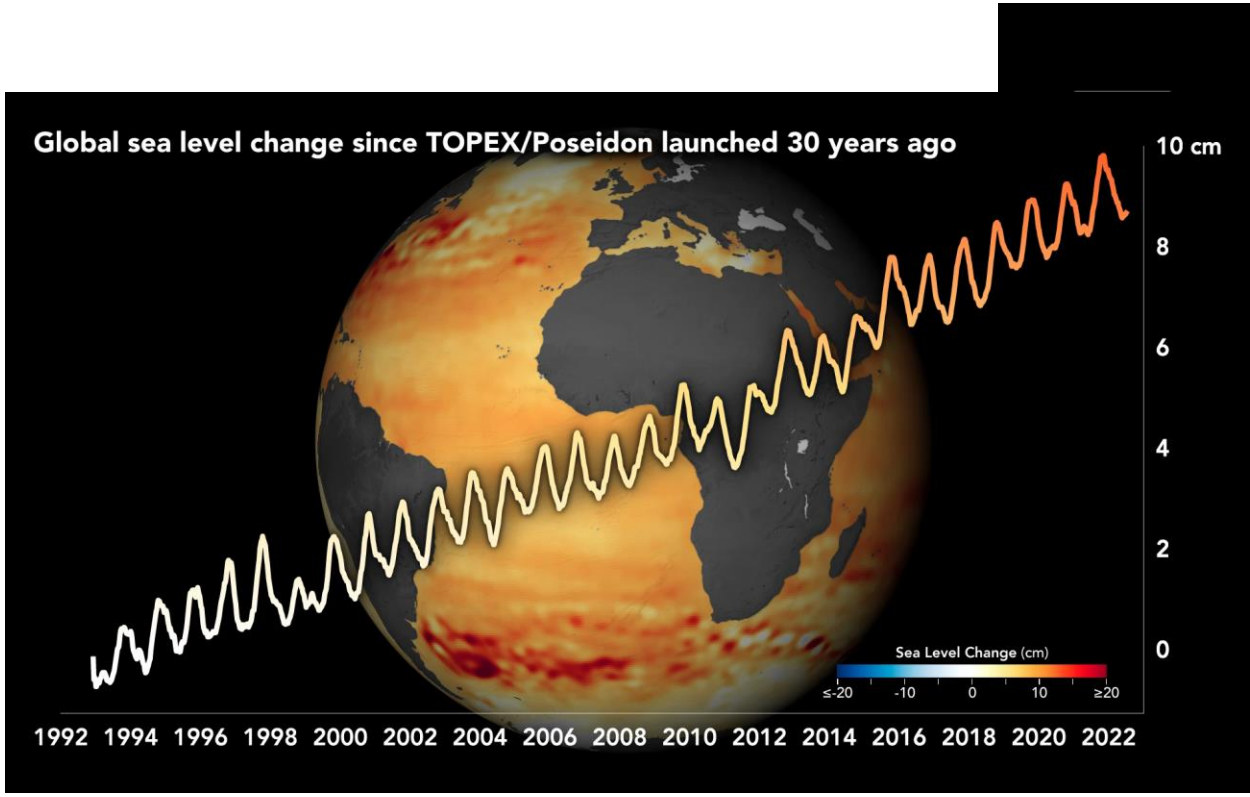
Sea Level

- Rising sea levels are from two primary factors:
  - Thermal expansion of water from increased temperatures (water expands as it warms)
  - Increased melting of land-based ice (glaciers and polar ice caps).



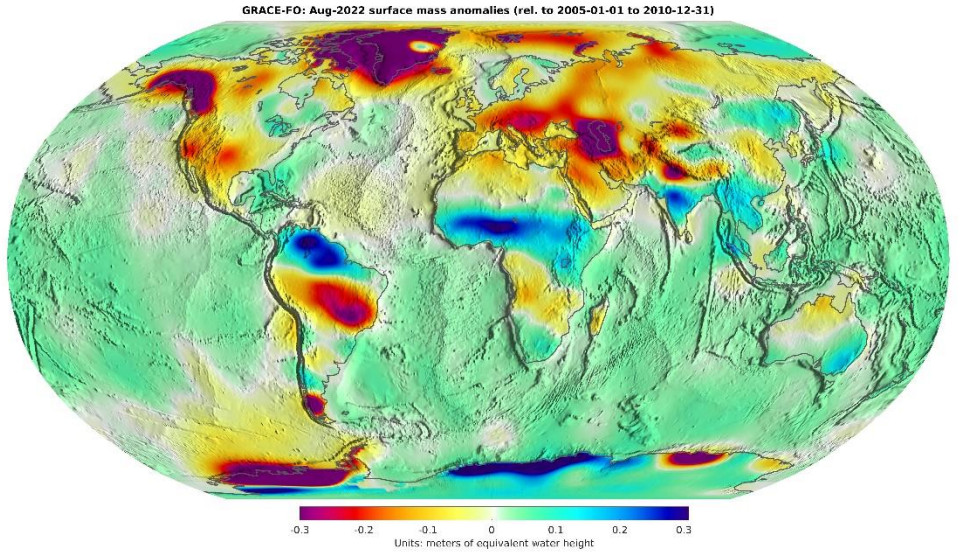
Satellites Used for Sea Level Measurements

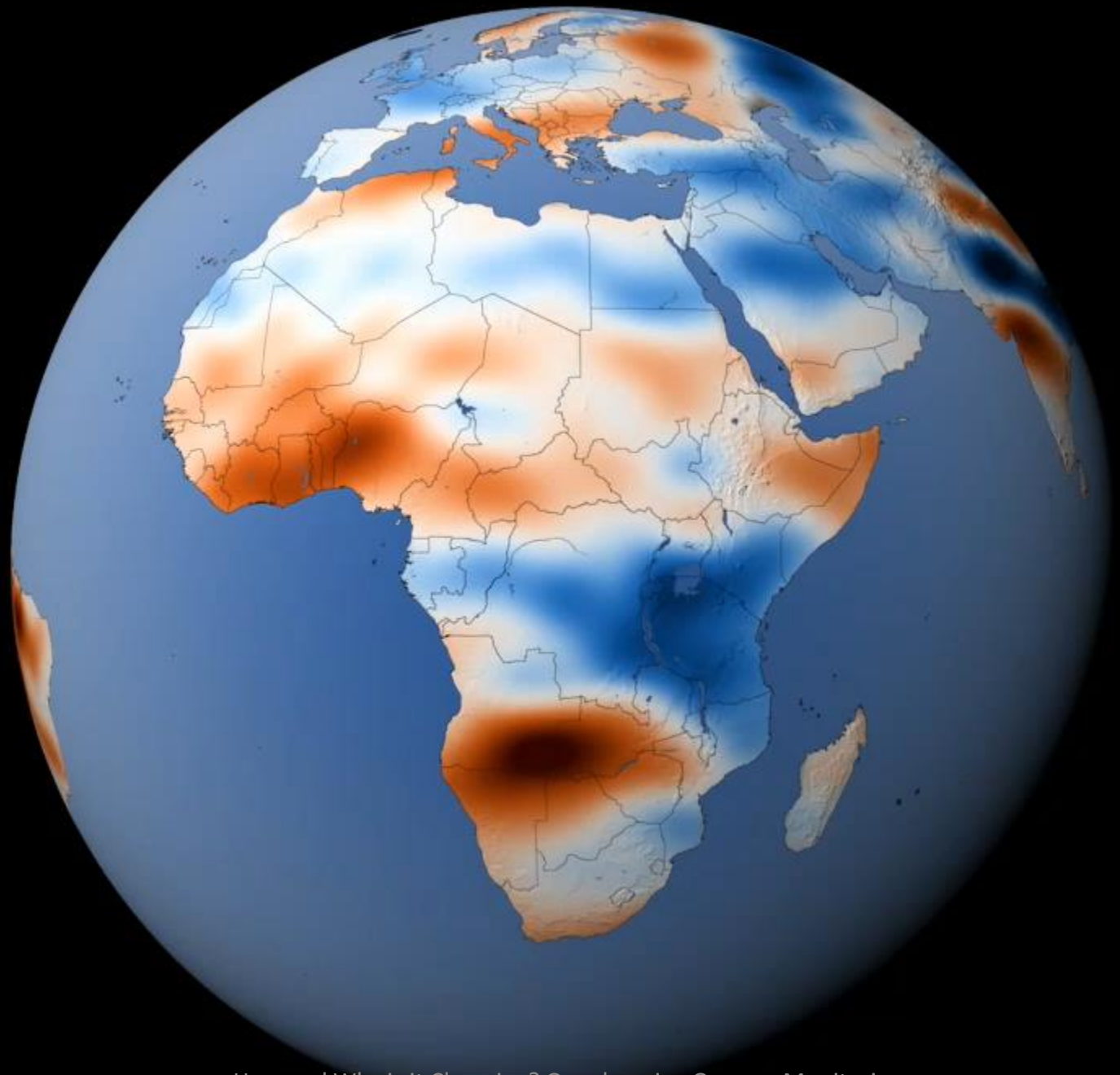
- Topex/Poseidon Mission
  - 1992 – 2006
  - Joint mission between CNES (the French space agency) and NASA
  - The first time scientists were able to map ocean topography with accuracy
- Jason Series
  - Jason 1, 2001 – 2013
  - Jason 2, 2008 – 2019
  - Jason 3: Launched 2016



Satellites Used for Sea Level Measurements

- Gravity Recovery and Climate Experiment (GRACE)
  - Satellite mission that measures gravitational pull across the surface of the Earth
  - Which it relates to mass balance
  - Capable of:
    - Measuring sea level
    - Freshwater storage
    - Land mass storage
      - Main tool used to calculated geoid




Jun 21, 2002

Habitat Characteristics

- Two examples:
  - Coral Reefs with Landsat
  - Salmon habitat with Lidar

Coral Reefs

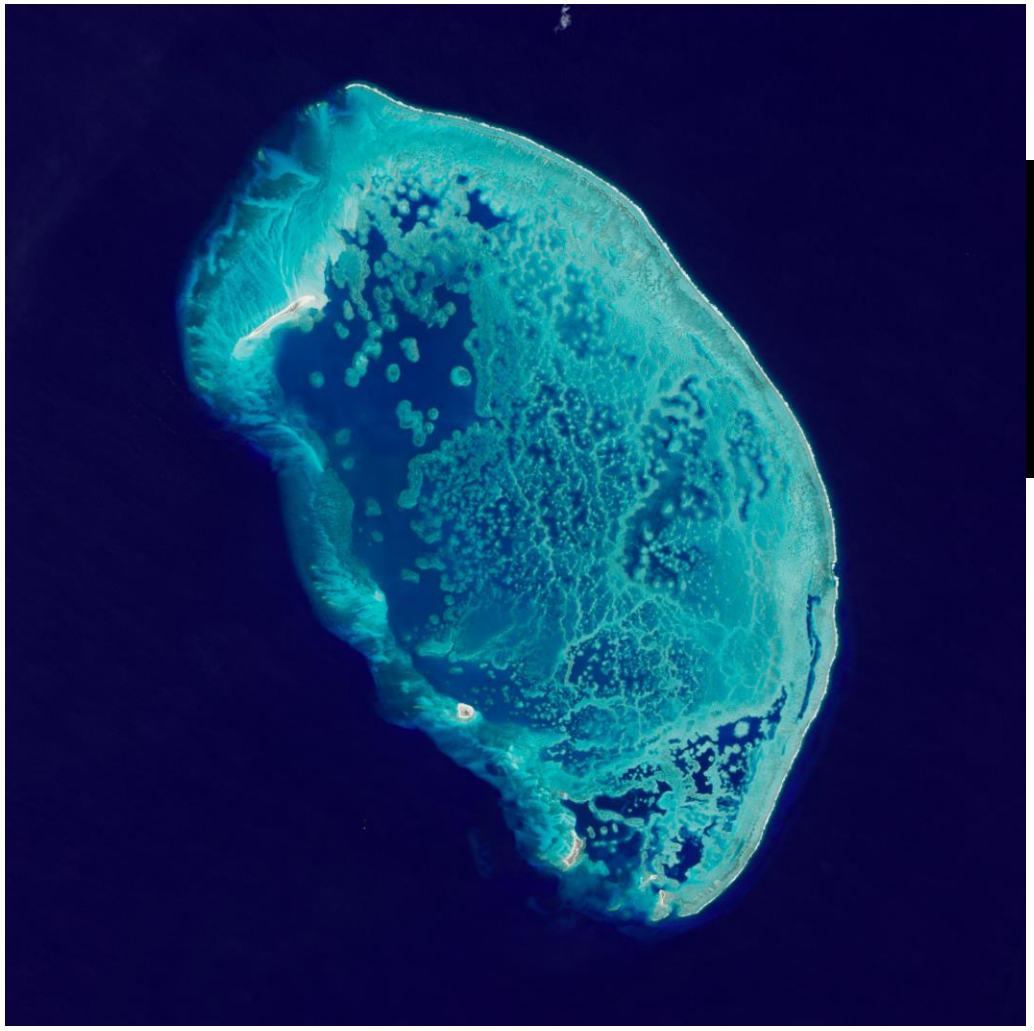
- Coral reefs cover less than 0.01% of the total surface of the ocean
  - But are home to 5% of the global biota
  - And 25% of all marine species
- Increase sea surface temperatures (among other causes) have led to increased coral bleaching
  - Bleaching makes reefs susceptible to:
    - Stress & disease
    - And increases the possibility of death

Landsat 7 - ETM+ image of the archipelago, Vanatinai. Credit: NASA

Mapping Coral Reefs

- Landsat has emerged as a key tool for mapping and monitoring coral reefs

- Can you brainstorm some reasons Landsat would be ideal for mapping/monitoring coral reefs?

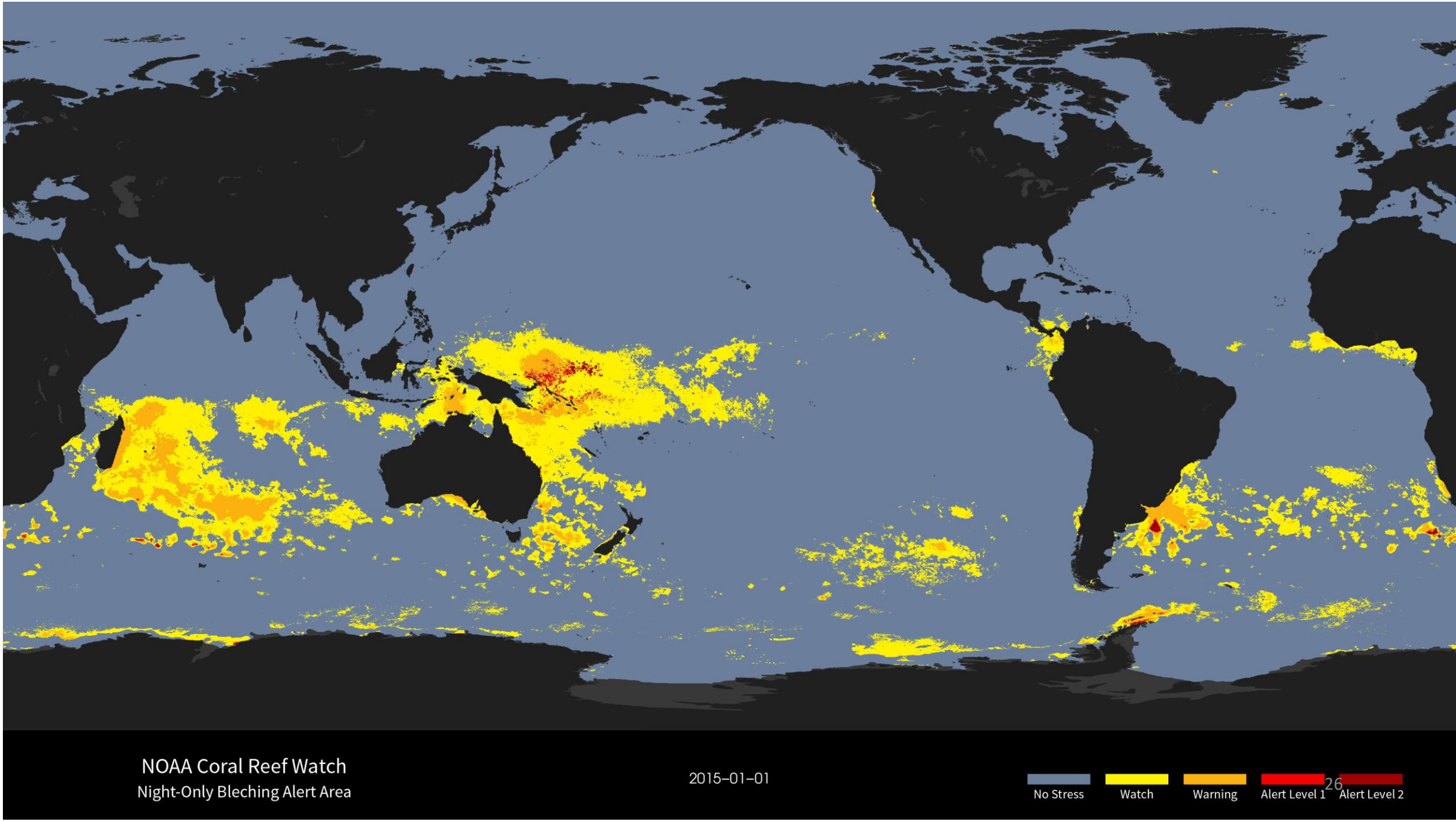


Five small islands within the largest coral structure in the southern Gulf of Mexico. These images were acquired on November 5, 2014, by the Operational Land Imager (OLI) on Landsat 8. Credit: NASA Earth Observatory image by Jesse Allen.

Mapping Coral Reefs

- Landsat has emerged has a key tool for mapping and monitoring coral reefs
  - Fine/moderate spatial resolution
  - Longest record through time
  - Free dataset
  - Landsat 8 (and 9) has ideal spectral bands
    - Extra band in VIS blue
    - Extra sensitivity
    - Better signal to noise ratio

Landsat 8 image just north of Cairns in August 2022 after a bleaching event.
Credit: NASA

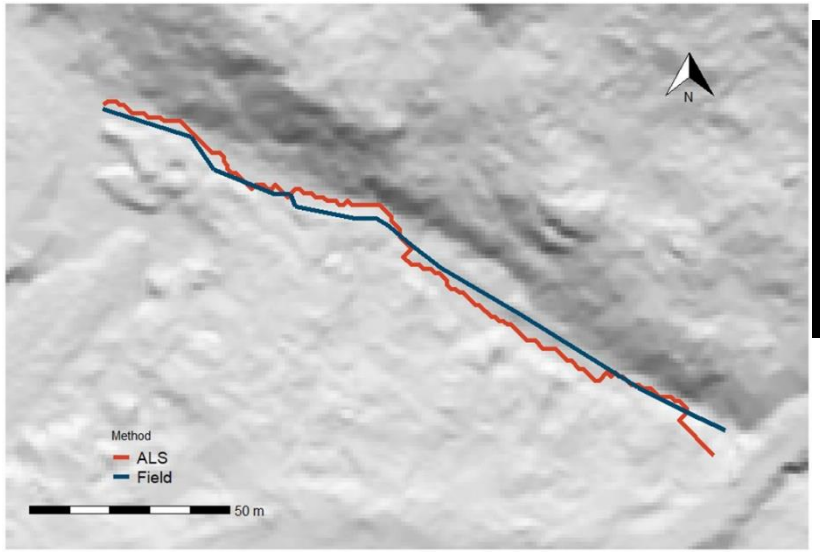

NOAA Coral Reef Watch
Night-Only Bleching Alert Area
2015–01–01
No Stress
Watch
Warning
Alert Level 1
Alert Level 2

Mapping Salmon Habitat with Lidar

- Salmon are a keystone species linked to:
  - Greater ecosystem diversity
  - Important ecosystem energy cycles
  - Economies & sustenance
- They are vulnerable to many stressors and threats:
  - Climate change
  - Habitat degradation
  - Pollution

Mapping Salmon Habitat with Lidar

- Mapping habitat units is important for understanding salmon behaviour and abundance
- Lidar allows for efficient data collection and mapping of:
  - Riffles
  - Pools
  - Cascades
  - Glides



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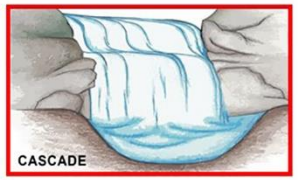
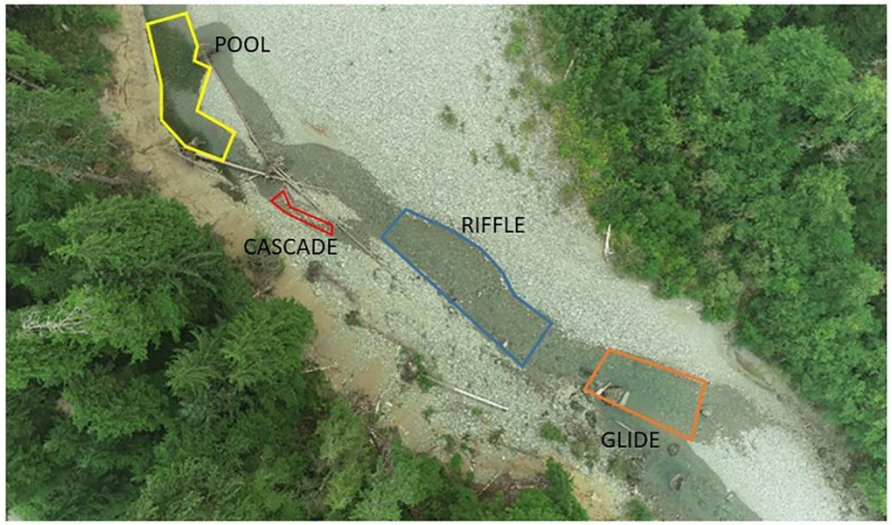
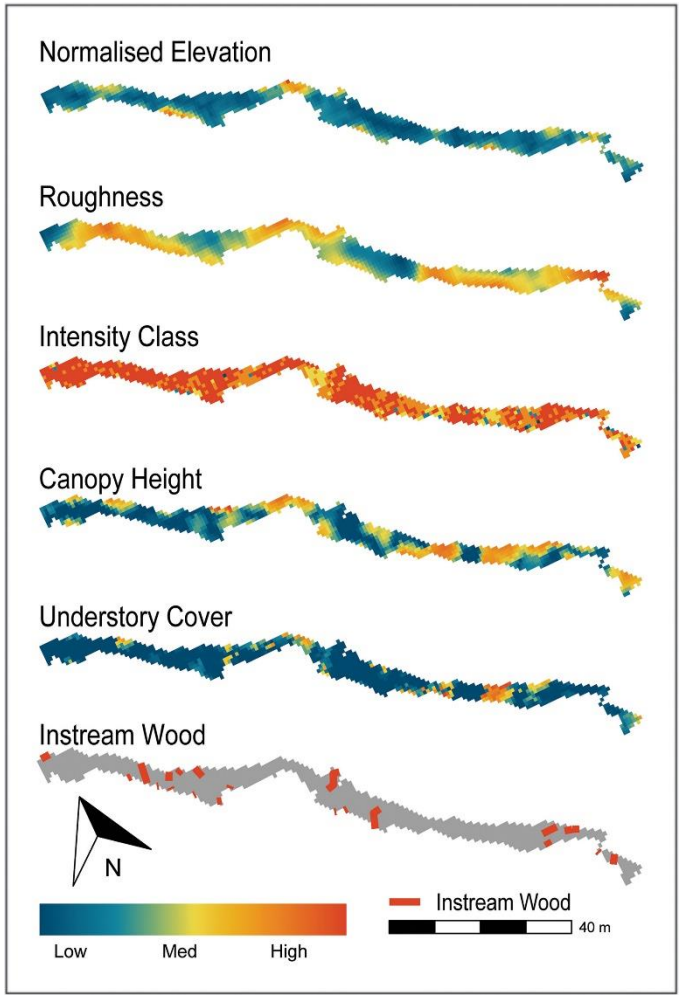
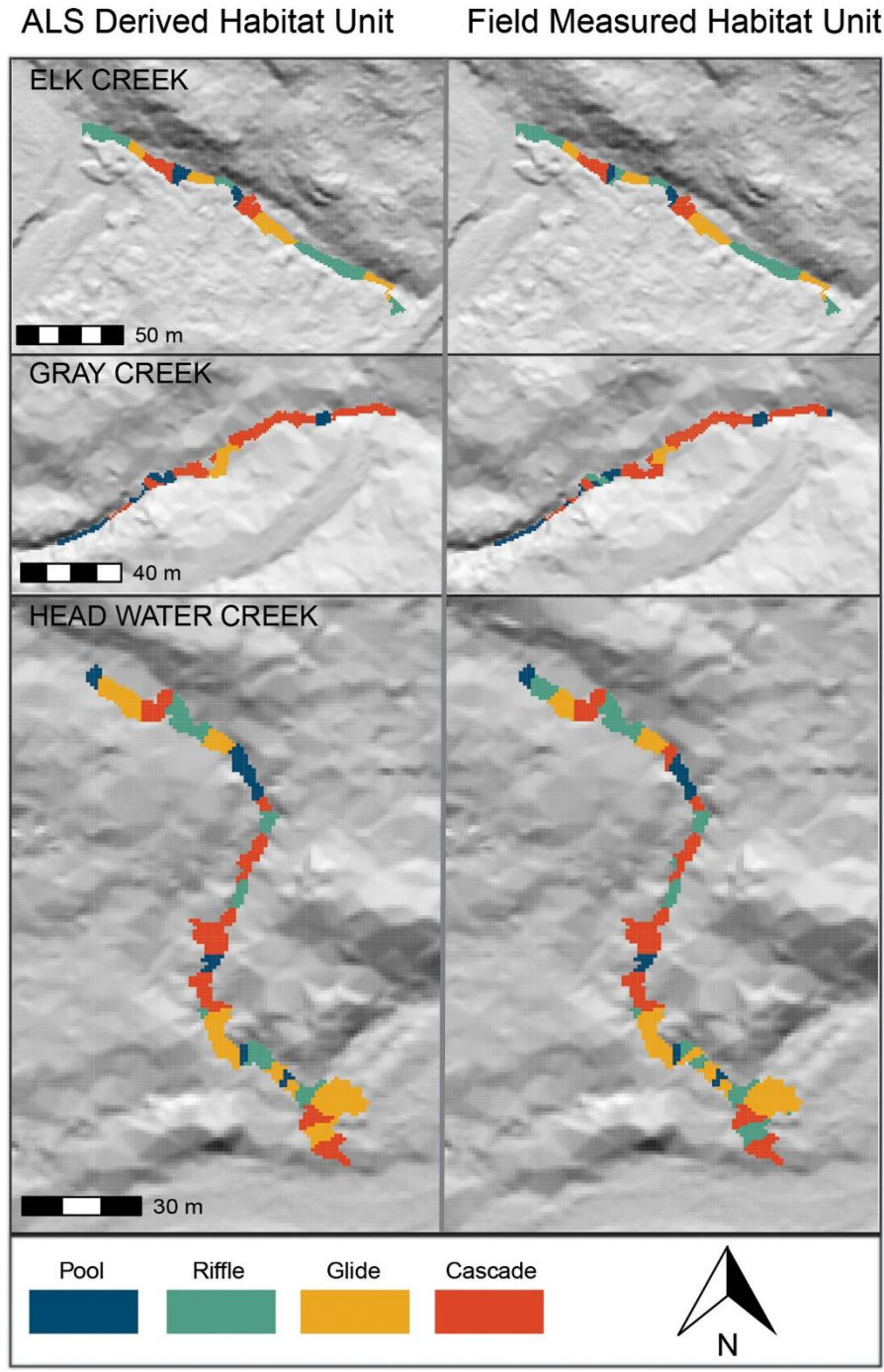




How and Why is it Changing? Our cl
Sea Ice from

- Lidar can use terrain and structural data
  - To map salmon habitat units
  - With very high accuracy
    - Up to 96% accuracy





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Summary

- Sea Surface Temperature
  - MODIS
    - Thermal infrared bands
  - TMI sensor onboard TRMM satellite
    - Microwave bands
- Sea Level
  - Topex/Poseidan
  - Jason Series
  - GRACE
- Habitat Characteristics
  - Coral reefs with Landsat
  - Salmon habitat with airborne Lidar

Advantages of Earth Observation Data for Oceans & Freshwater

Depending on the dataset:

- Standardized data
- Efficient collection
- Coverage
- Resolutions
  - Spatial
  - Temporal
  - Spectral

Seeing a pattern yet?

Important Topics

- How was sea surface temperature measured historically?
  - Is that method still used today? For what purpose?
- What is one advantage of using satellite data to monitor sea surface temperature when compared to historical methods?
- What was the purpose of the Topex/Poseidan and Jason Series of satellites?
- What is a newer/useful satellite for coral reef mapping?
- Name an example of freshwater habitat mapping using Lidar?