Ocean Remote Sensing from Satellites

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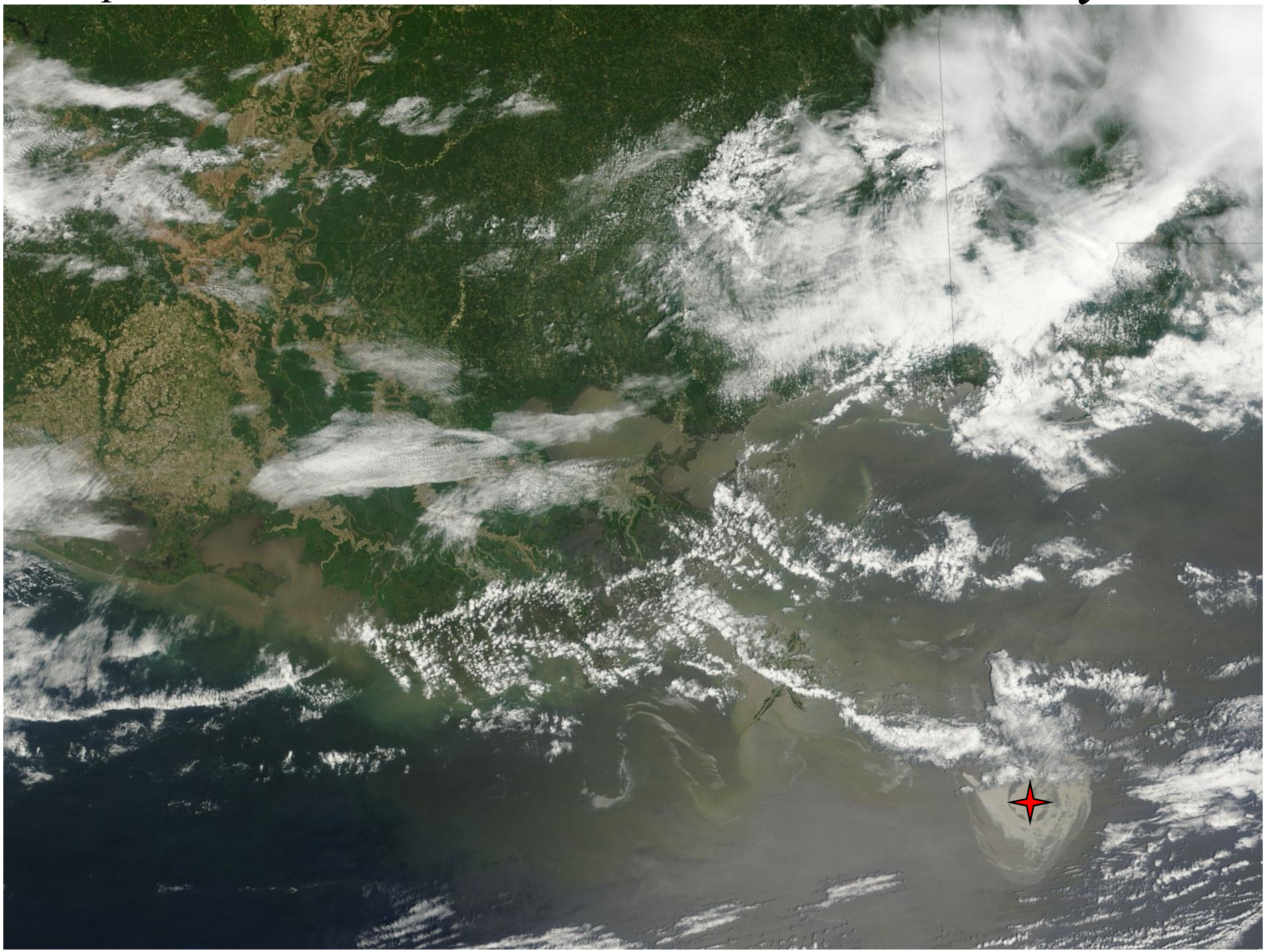
- General Background
- Examples, Measuring
  - Surface Temperature
  - Ocean Color/Optics
  - Sea Surface Height & Currents
  - Surface Wind Stress
- New technology

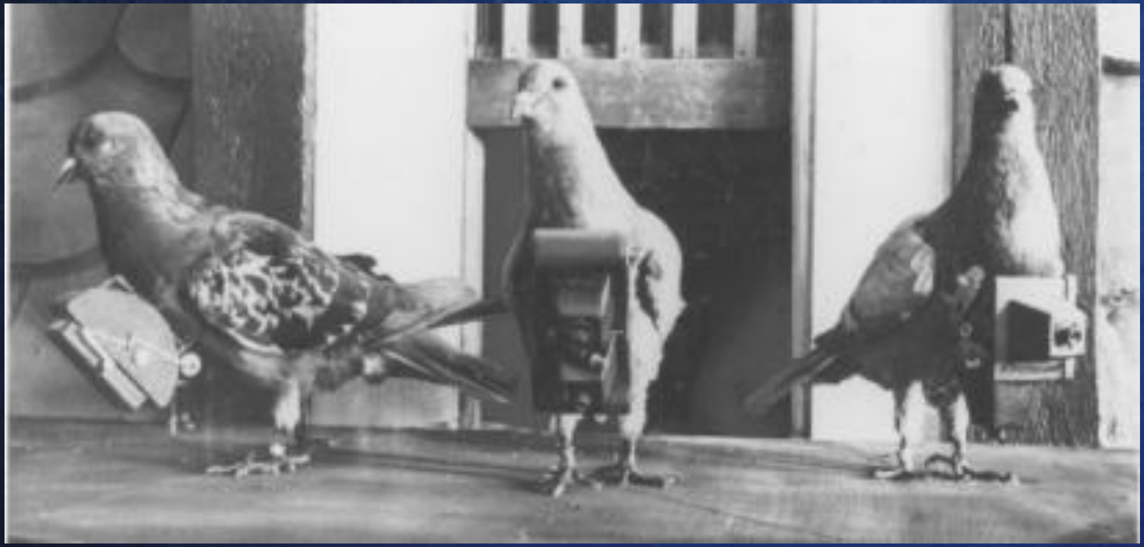
http://response.restoration.noaa.gov/

Gulf Coast oil spill: Satellite "images" may "track" surface features: IR surface temperatures, visible features, …??? ***What can we really see?***



Remote Sensing Pioneers

Early Days 1888



Why Satellites?

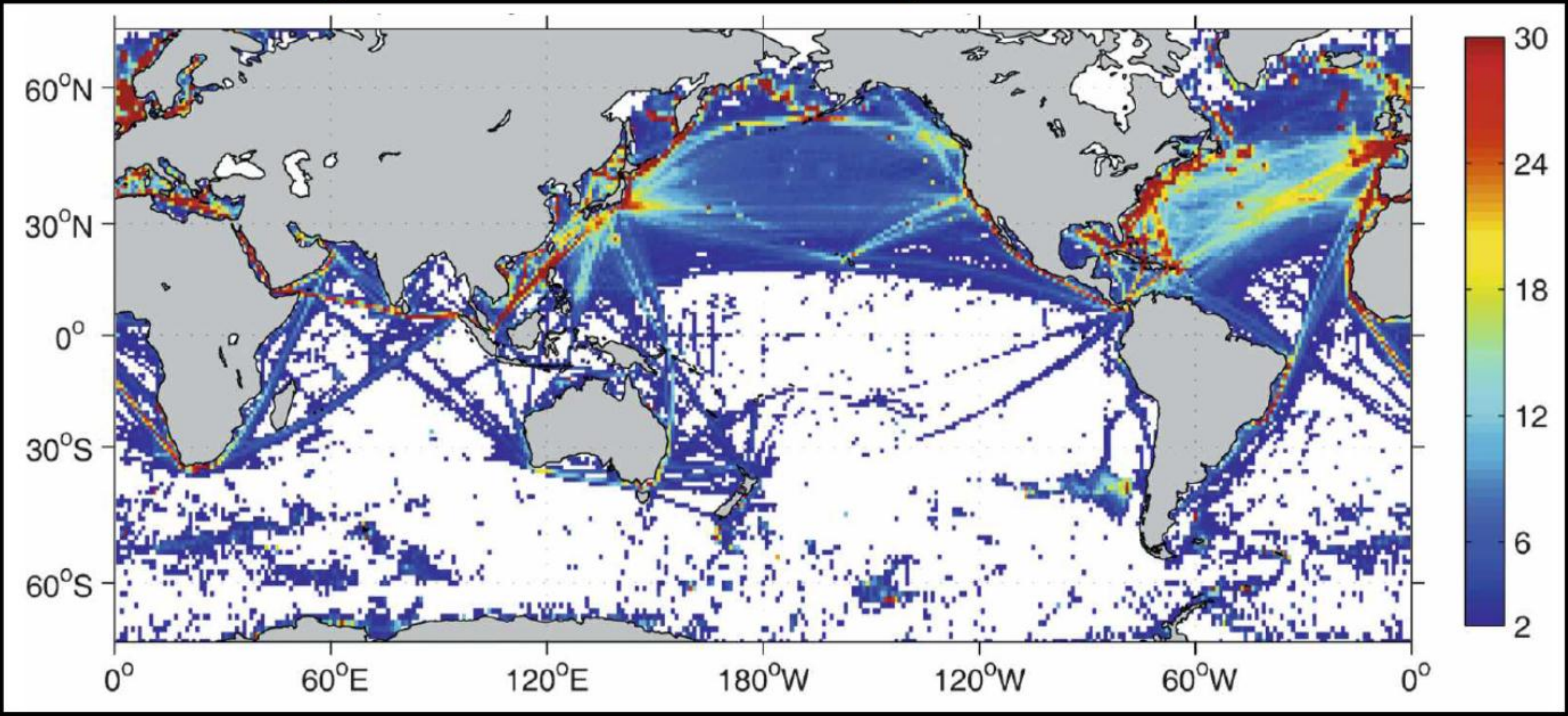
- Oceans are vast, sparsely occupied – satellites provide uniform sampling, daily-to-monthly fields.
- Ship time is expensive
- Satellites can acquire measurements quickly over large areas

BUT…

- Space: a harsh environment for acquiring measurements
- Cost – Satellites are also expensive, but “global” (international)
- Risk – If satellites fail, service calls are even more expensive
- Must measure through intervening atmosphere
- Can’t acquire sub-surface measurements
- Can only measure a half-dozen variables, at the “surface” –
- <u>*But: We can measure wind forcing and response*</u>

Why satellite remote sensing of the ocean?

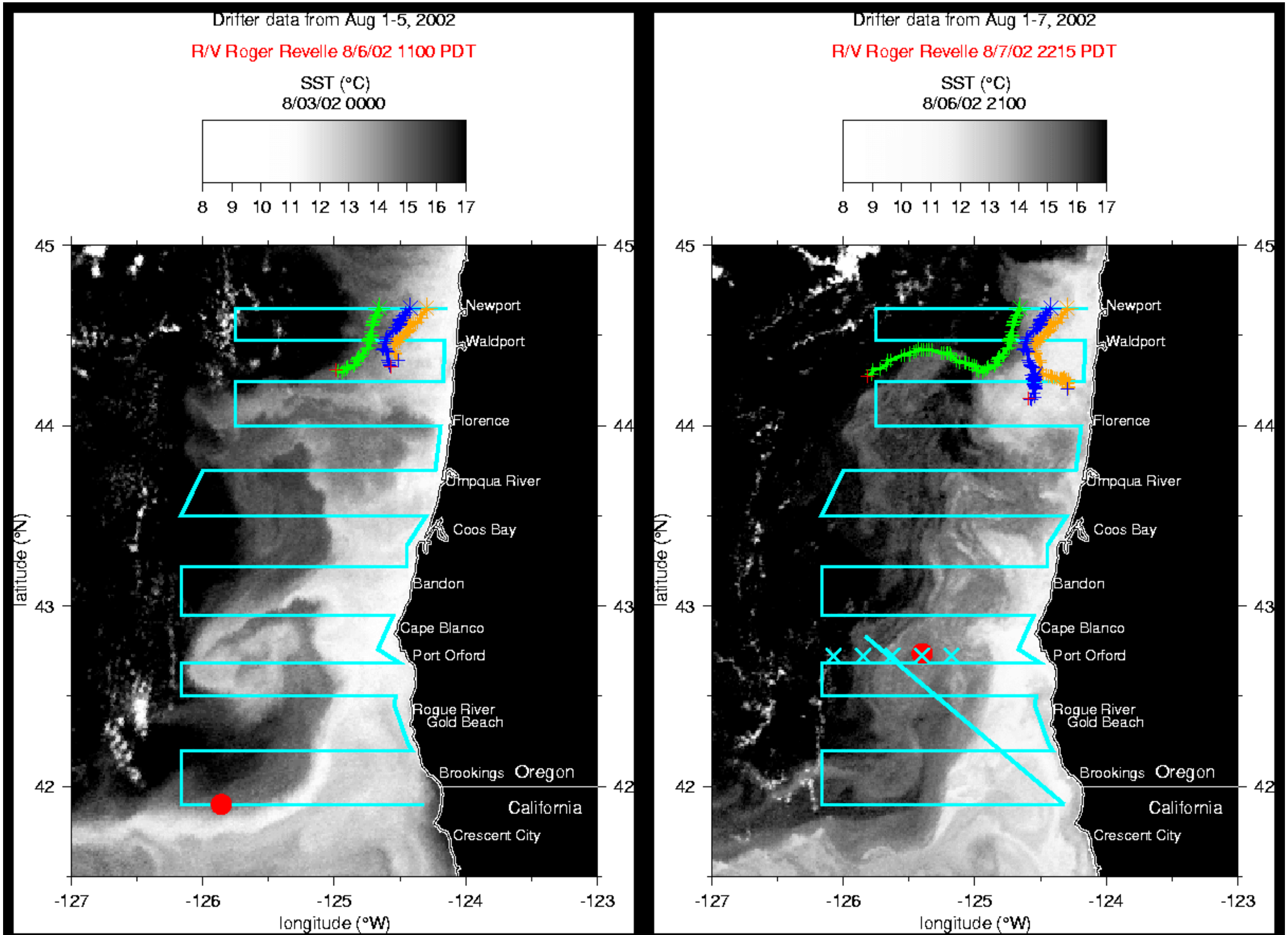
Average Number of Ship Observations per Month
During the Northern Hemisphere Wintertime



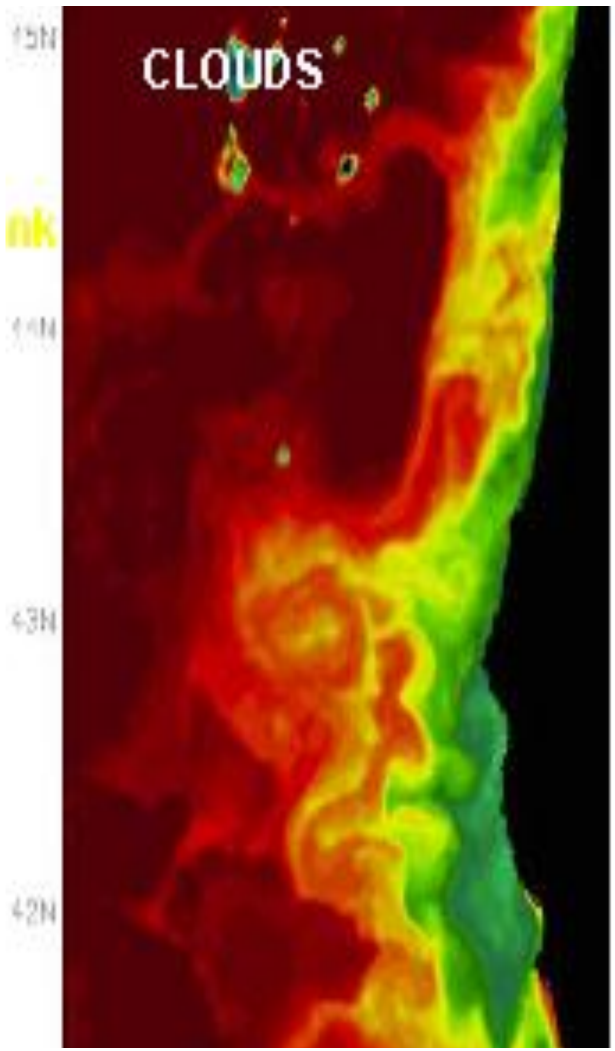
- Vast expanses of the Ocean are seldom sampled by ships.
- Even the “well-sampled” regions are only sampled about once per day.

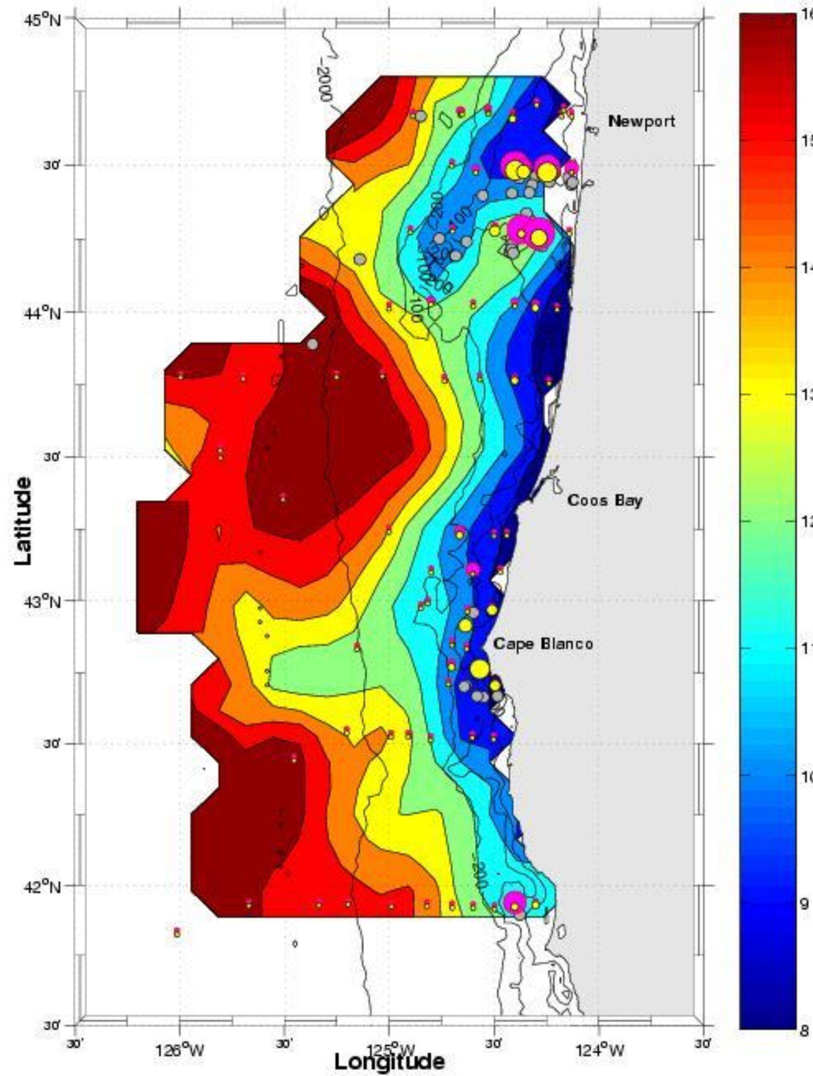
Ships take time to “map out” an area.

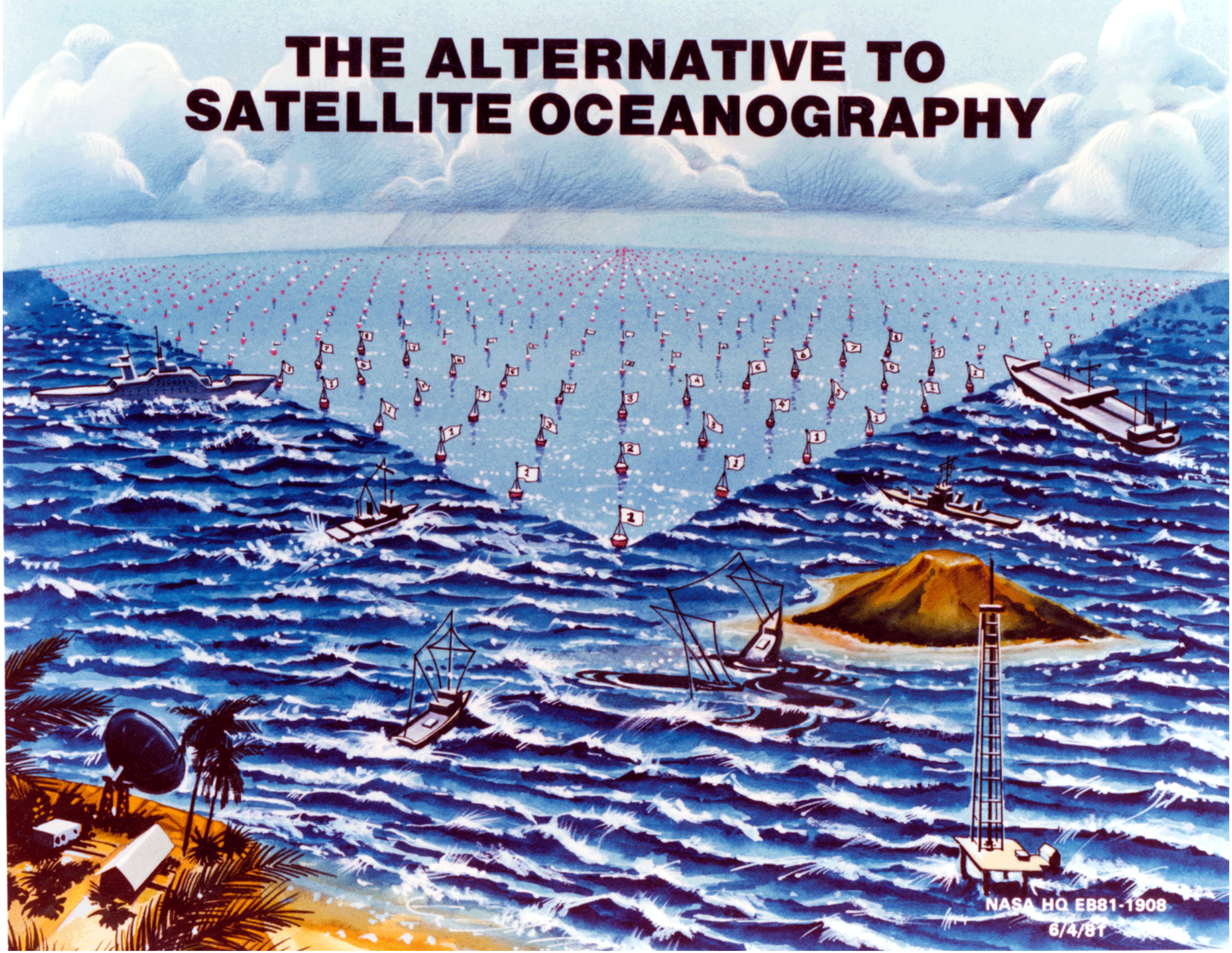
The blue ship tracks take ~ 1-2 weeks in the case below. Patterns of cold water (whiter shades) and currents change in 4 days between images.



The temperature field constructed from ship observations (circles, below right) over a 1-week period shows some of the features evident in the instantaneous satellite image (below left), without the detailed filaments and swirls caused by jets and eddies in the currents, which the satellite field captures in a “snapshot” (clouds allowing?) (August, 2000).



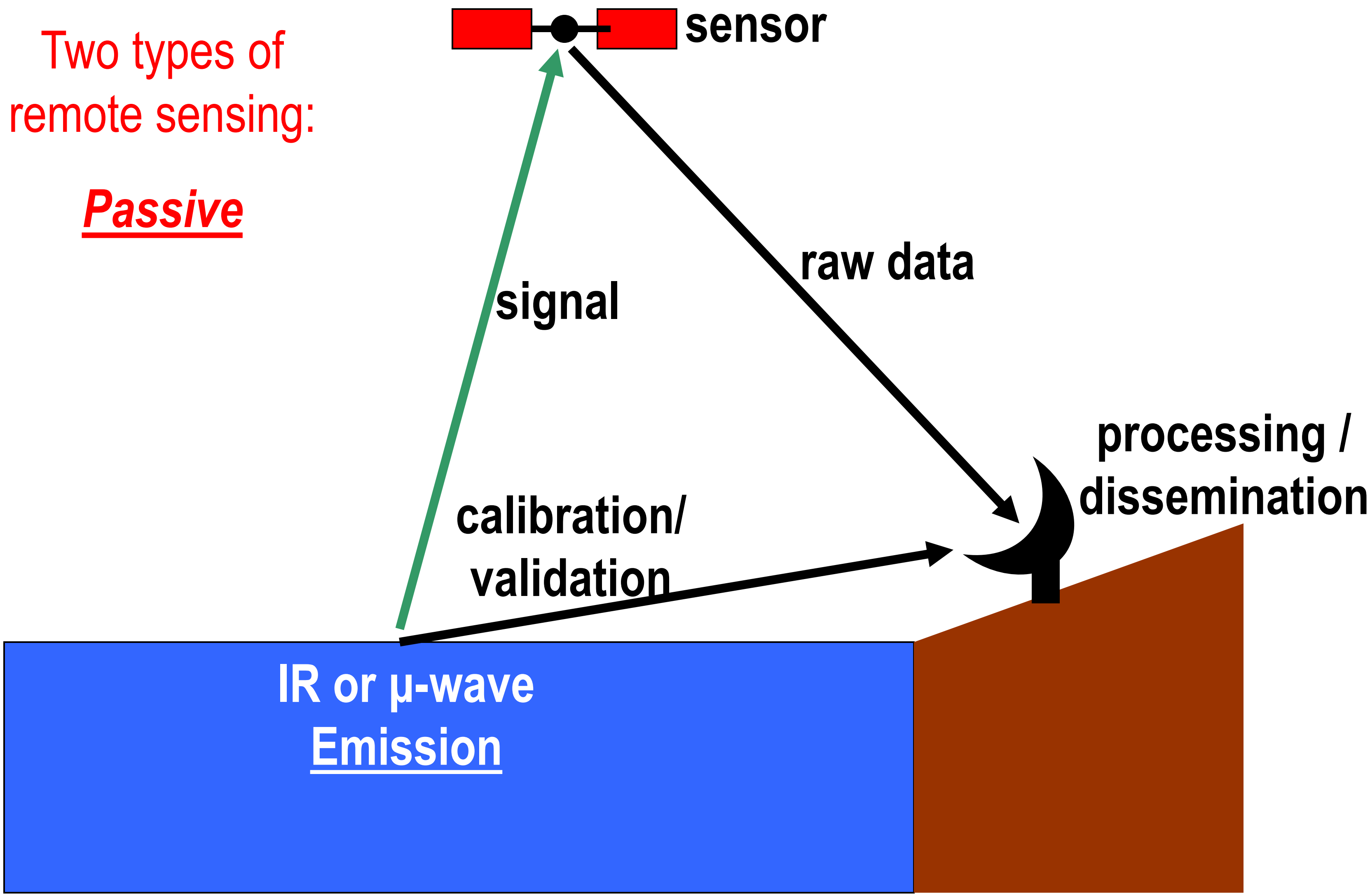



THE ALTERNATIVE TO
SATELLITE OCEANOGRAPHY
NASA HQ EB81-1908
6/4/81

Components of a passive "SST" remote sensing system Using IR or Microwave Wavelengths

Two types of remote sensing:

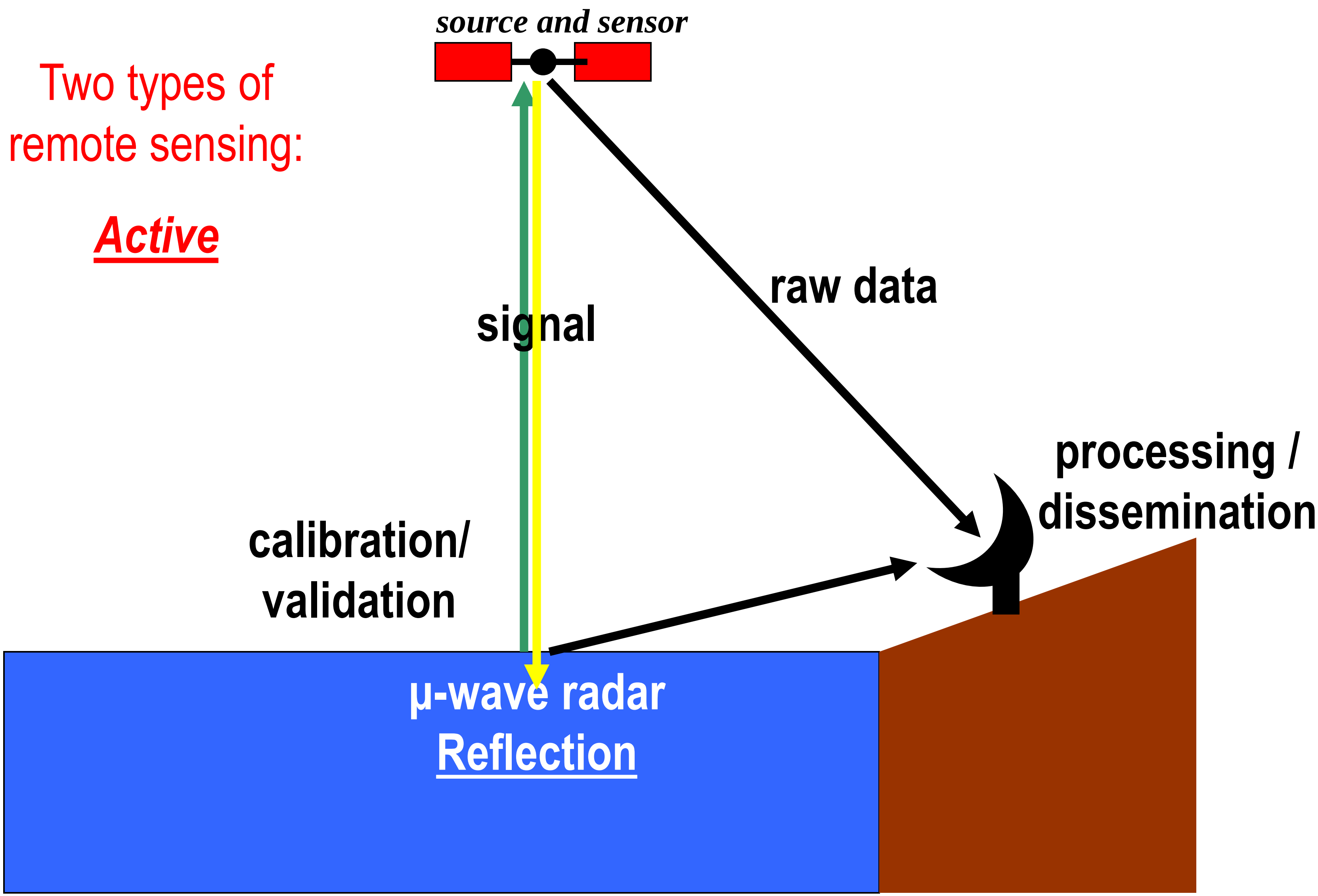
Passive



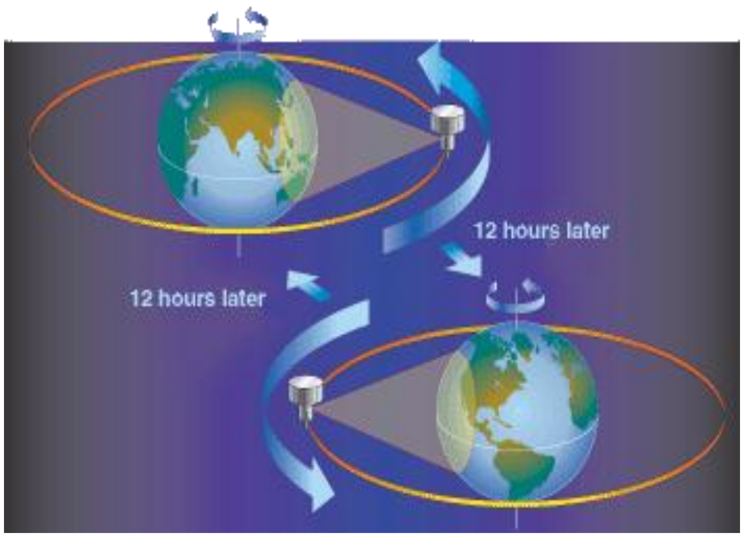
Components of an active radar "altimeter" system
For sea level: Transmit at nadir (directly beneath satellite)

Two types of remote sensing:

Active



Orbits Determine Sampling



Geostationary Orbit - GEO

36,000km altitude (wide view)
Stays over same location
Can document evolving systems
High temporal resolution
Lower spatial resolution?
Not necessarily – can "stare" for longer exposures.
No polar coverage

"Polar" Orbit (Low Earth Orbit LEO)

850-1000 km altitude
Travels nearly over poles
Sees almost whole globe
Lower temporal resolution
Higher spatial resolution?
Not necessarily – limited time over each point.

Examples of several types of orbits.

The Earth's center of mass must be in the orbital plane – so Geostationary orbits must be in the Equatorial plane. Low Earth Orbits are inclined from the equatorial plane. Specialized orbits are used for different purposes.

- Sun-synchronous orbits cross the equator at the same time each solar day.
- Low inclination orbits are used to look more closely at tropical processes.
- Exact-repeat orbits fill in a grid of orbit tracks over X days, then repeat exactly.

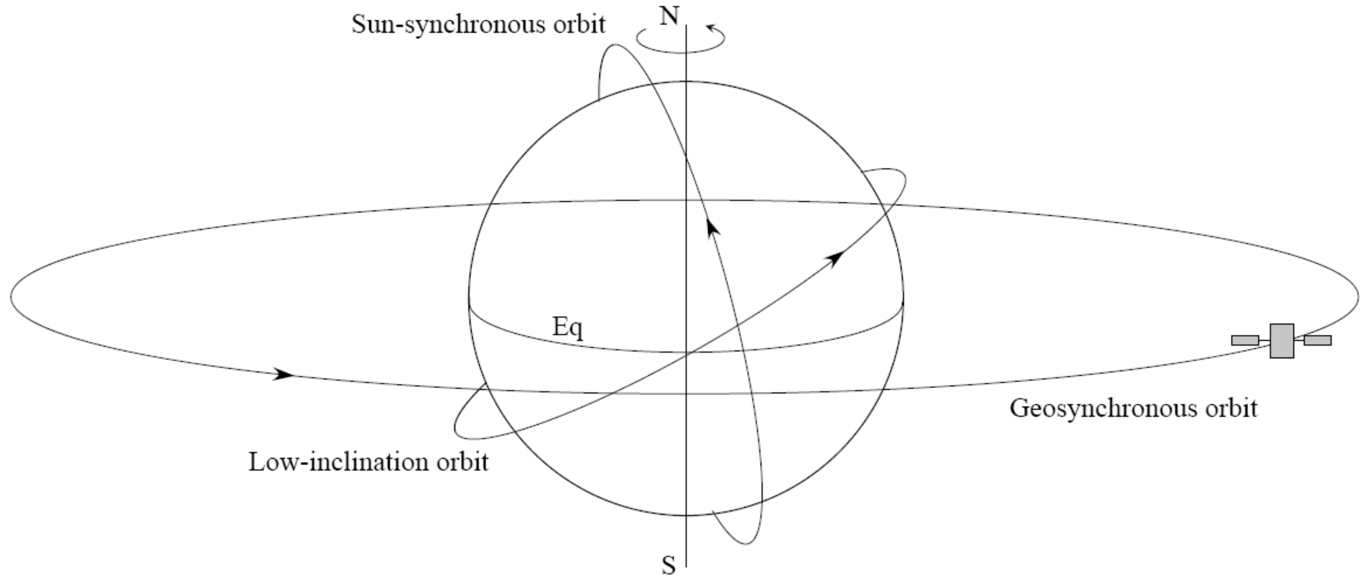


Fig. 1.3. Examples of the sun-synchronous, geosynchronous and low inclination orbits, where 'Eq' is the equator (Adapted from Asrar and Dozier, 1994, Figure 3).

A Global System of Geosynchronous Satellites

Geostationary Sampling: Easy to picture – a sequence of images/fields from a fixed viewing geometry. Five satellites cover the globe, maintained by nations that need the data. The first "weather satellites" were essentially TV cameras in space. For the first time, we could see distant storms developing and approaching. The very first satellites carried film cameras and were not looking at weather. How did the film get to earth?

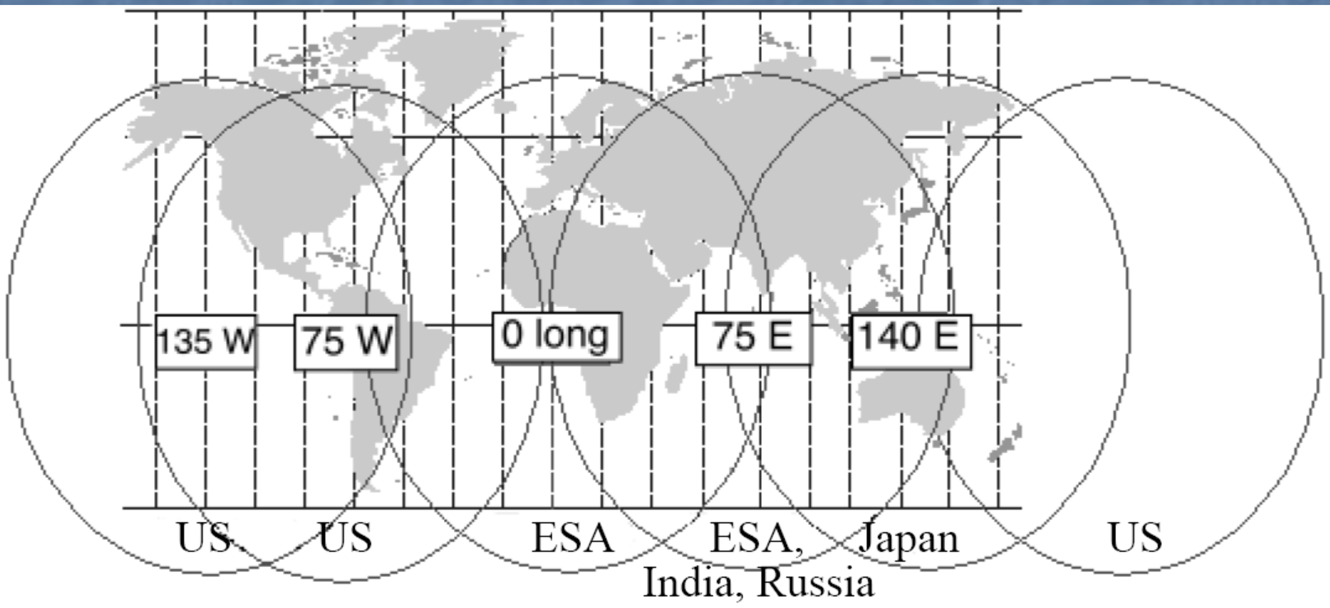
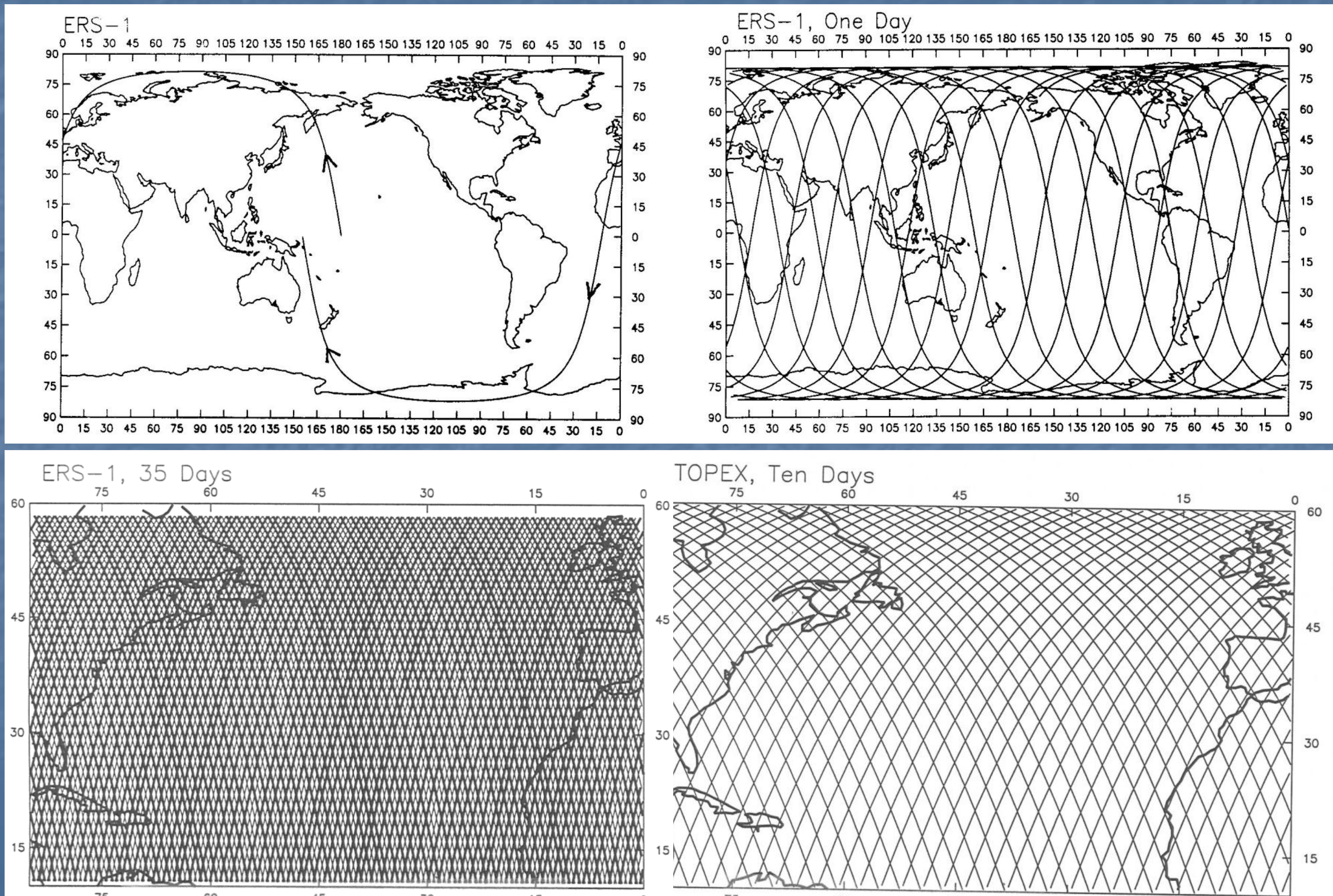
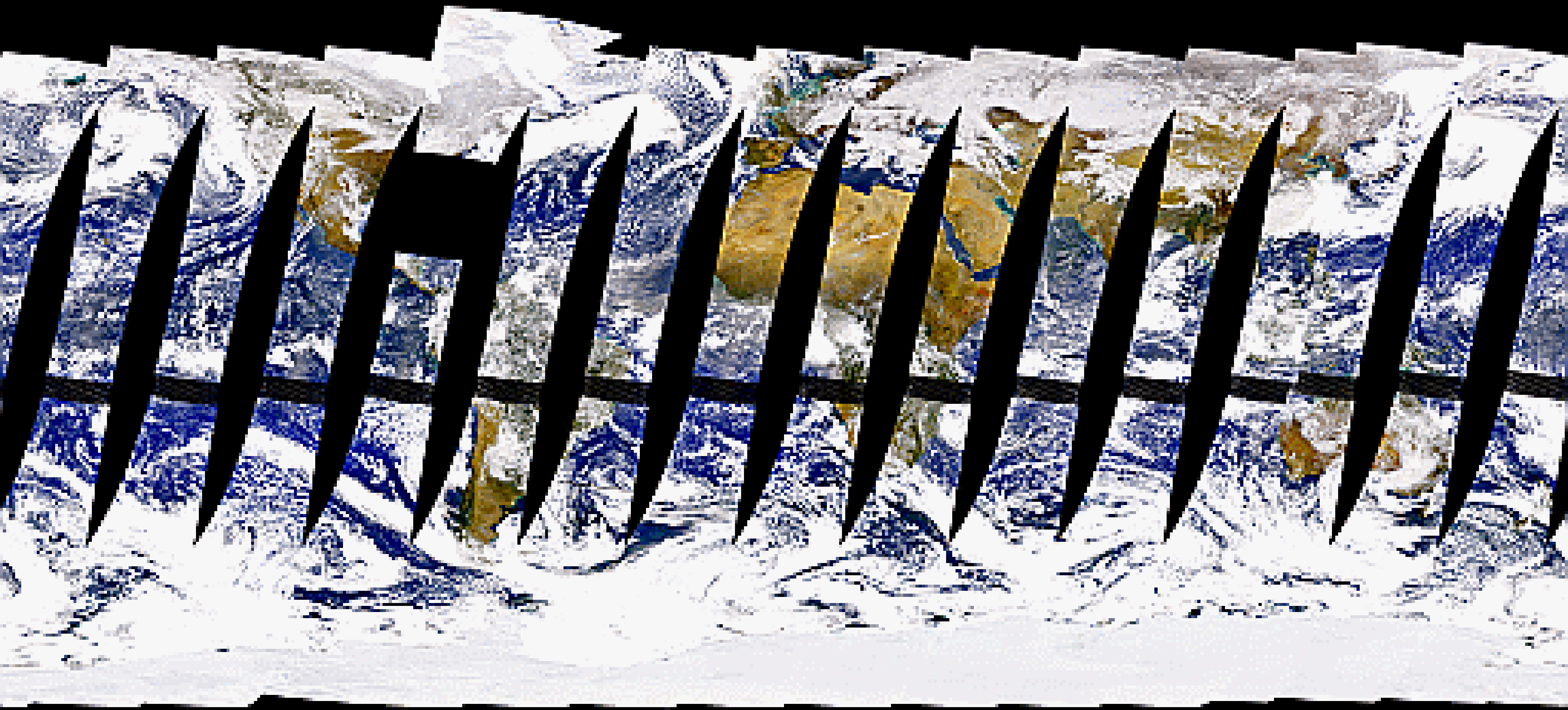


Fig. 1.6. The fields-of-view of five geostationary satellites, which provide near-global coverage.

Low Earth Orbits ("Polar Orbiting"): The orbital plane of the satellite remains fairly constant while the earth rotates toward the east. Subsurface tracks migrate to the west, ~ 25º longitude (2750 km).



What SeaWiFS (visible) sees in one day:
Swaths leave gaps at low latitudes:
Clouds cover >50% of the ocean and obscure visible and IR radiation.



“Space Junk”
1958-2008

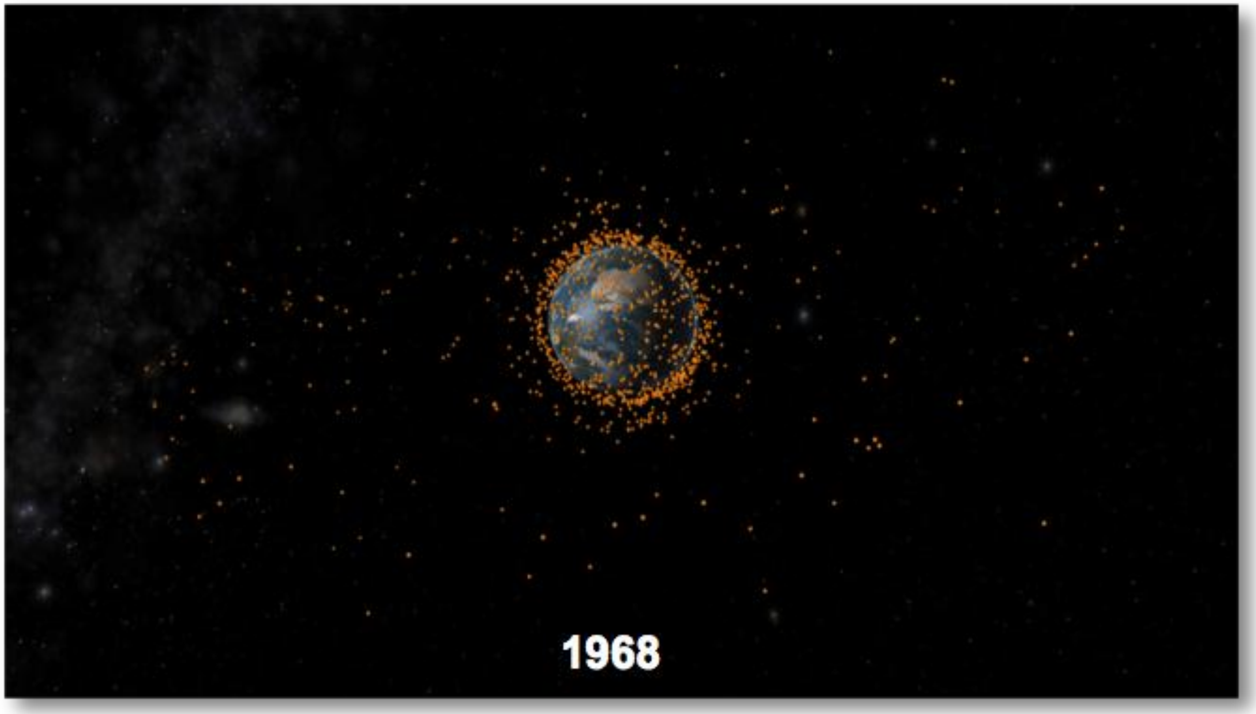
50 Years of Orbital Trash

“Who you gonna call?”

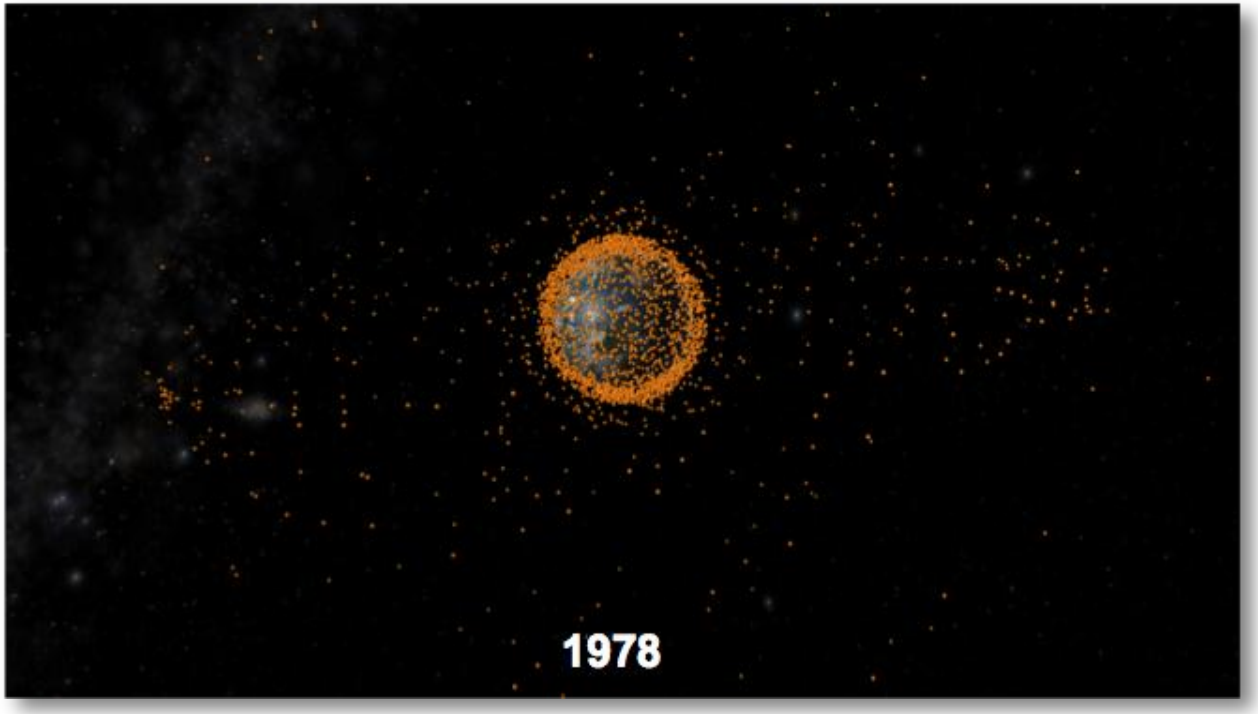
WALL-E

Space Debris

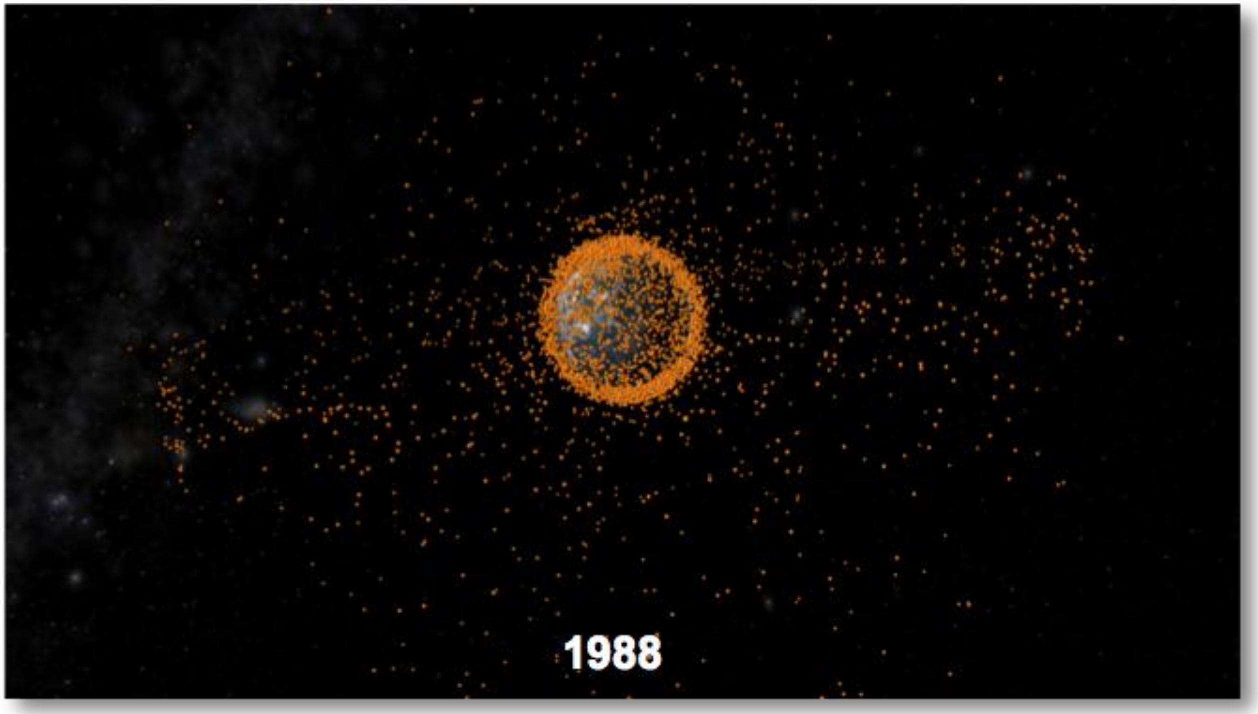
Space Debris



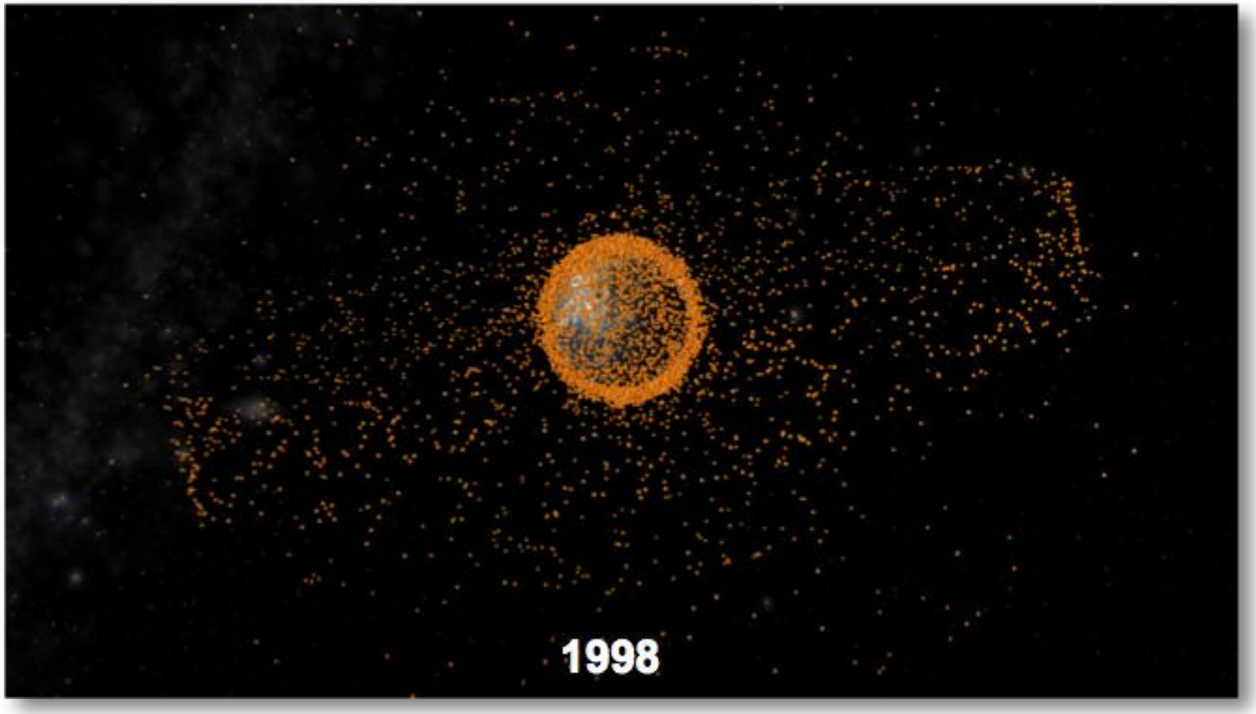
Space Debris



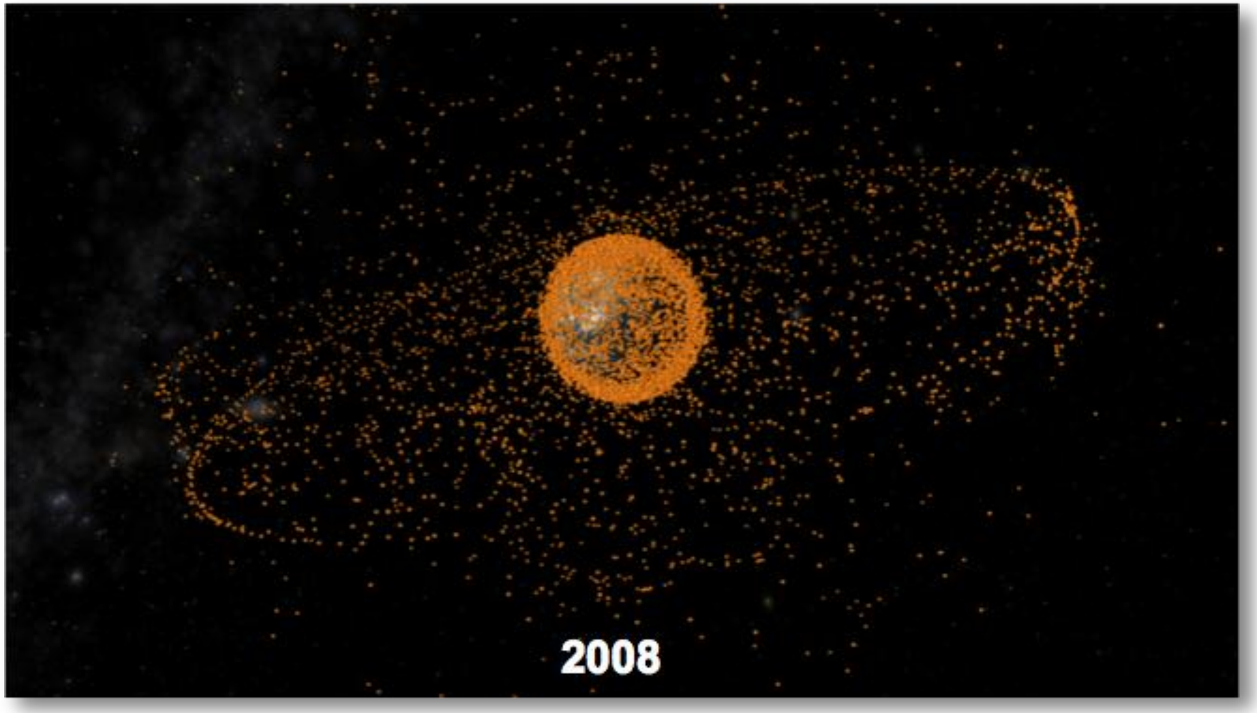
Space Debris



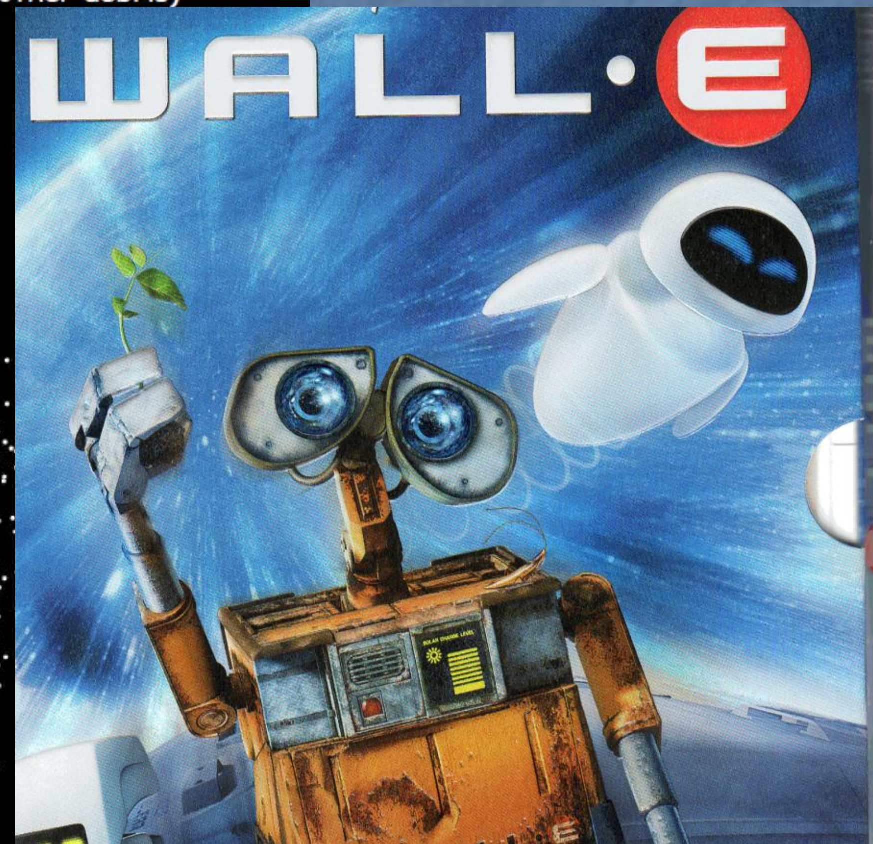
Space Debris



Space Debris




50 years after Sputnik-1: 15,300 orbiting objects
(including dead satellites, spent rocket stages, a wrench that was inadvertently left inside the cowling of a satellite, a camera dropped by an astronaut and various other debris)
Source: NASA


WALL·E

Specific Examples
Sea Surface Temperature (SST)

Perhaps the most ‘standard’ measurement from satellites

Passive meaurement. Traditionally used infrared (IR) emission

- strong signal, obscured by clouds

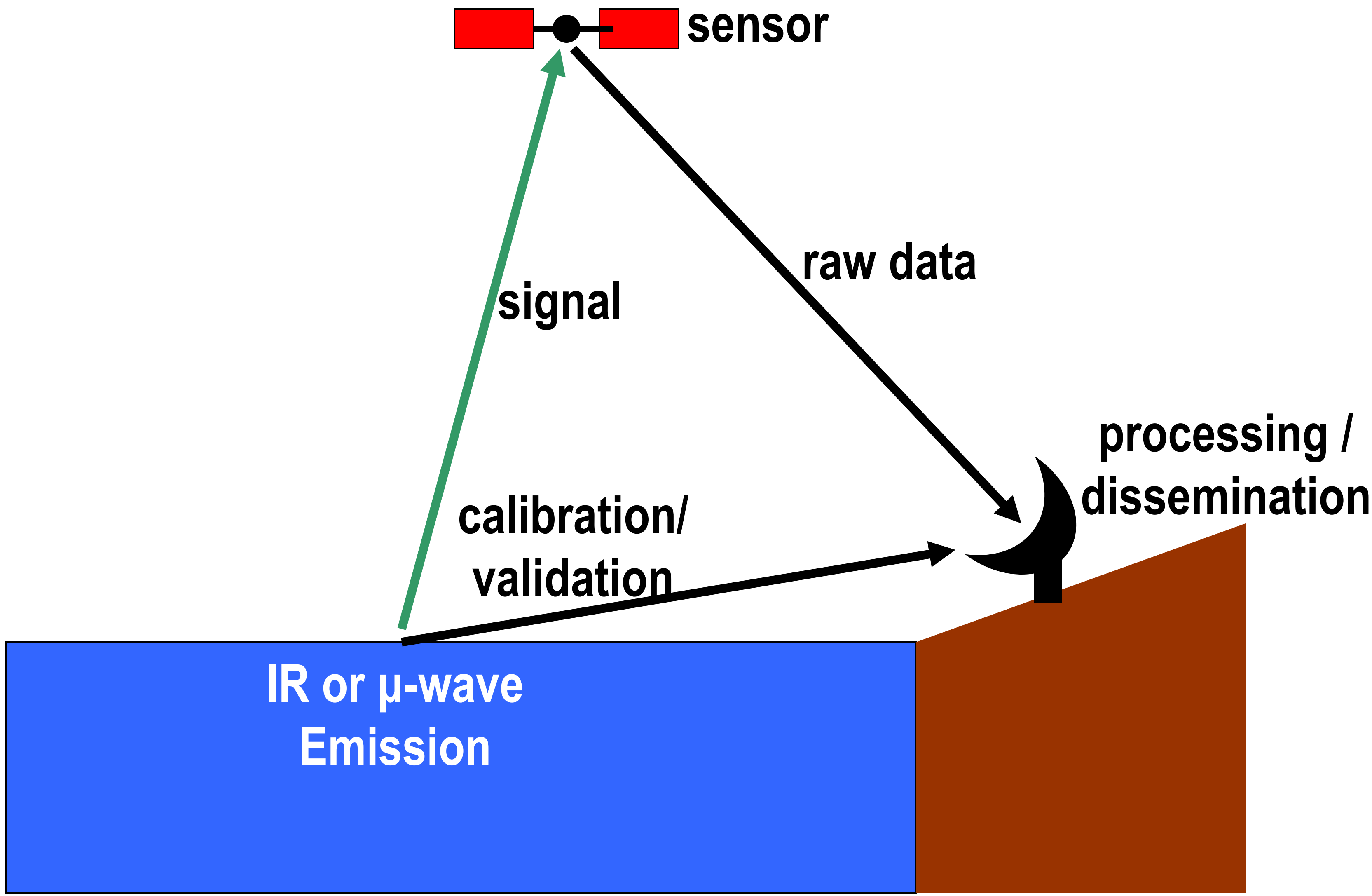
More recently using Microwave

- can see through clouds, but the signal is weak

- microwave also provides other data such as wind speed, water vapor, rain, ice

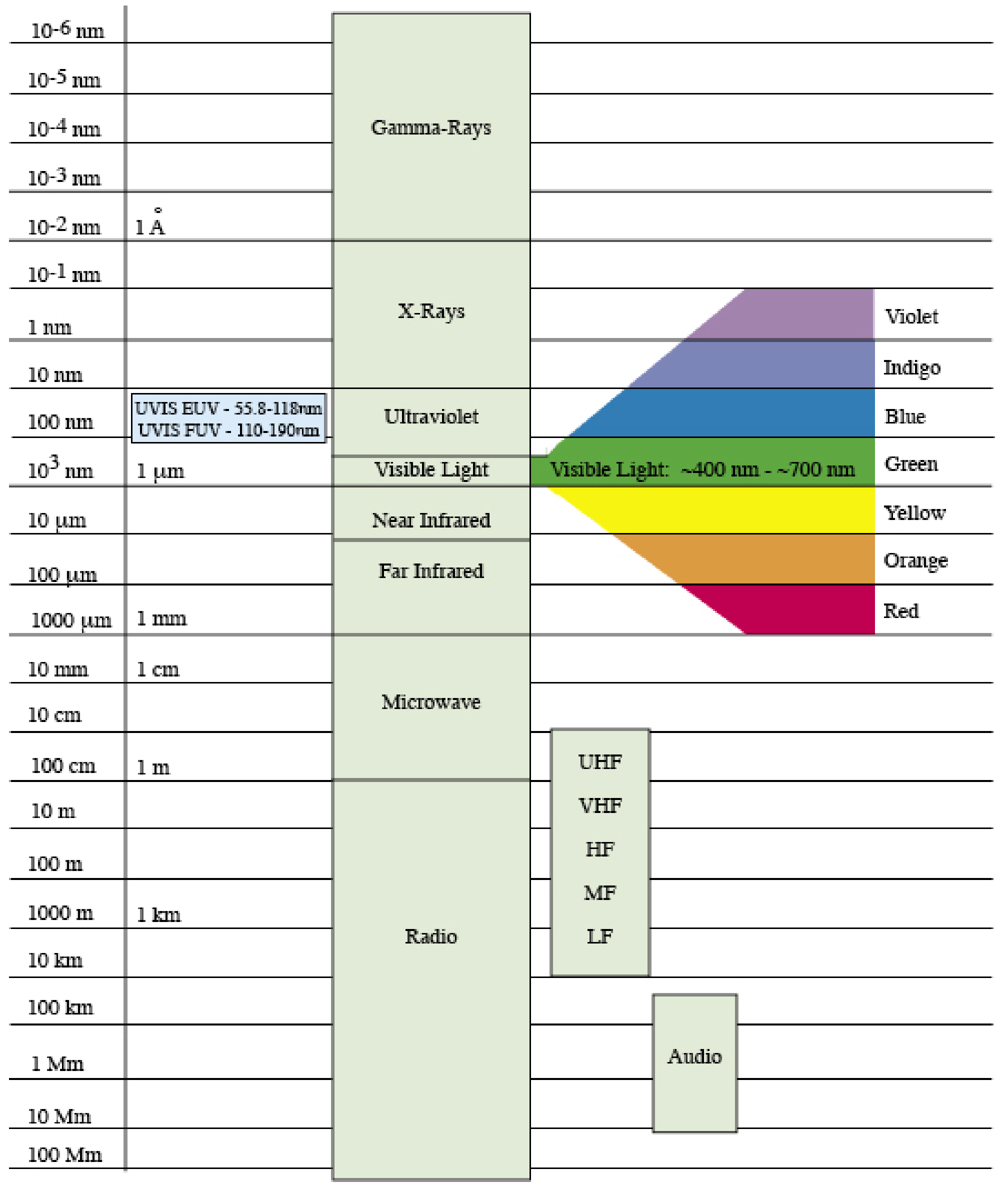
Temperature is important because of its relationship to the heat budget (global warming) and because it’s diagnostic of currents, upwelling etc…

Components of a passive “SST” remote sensing system Using IR or Microwave Wavelengths

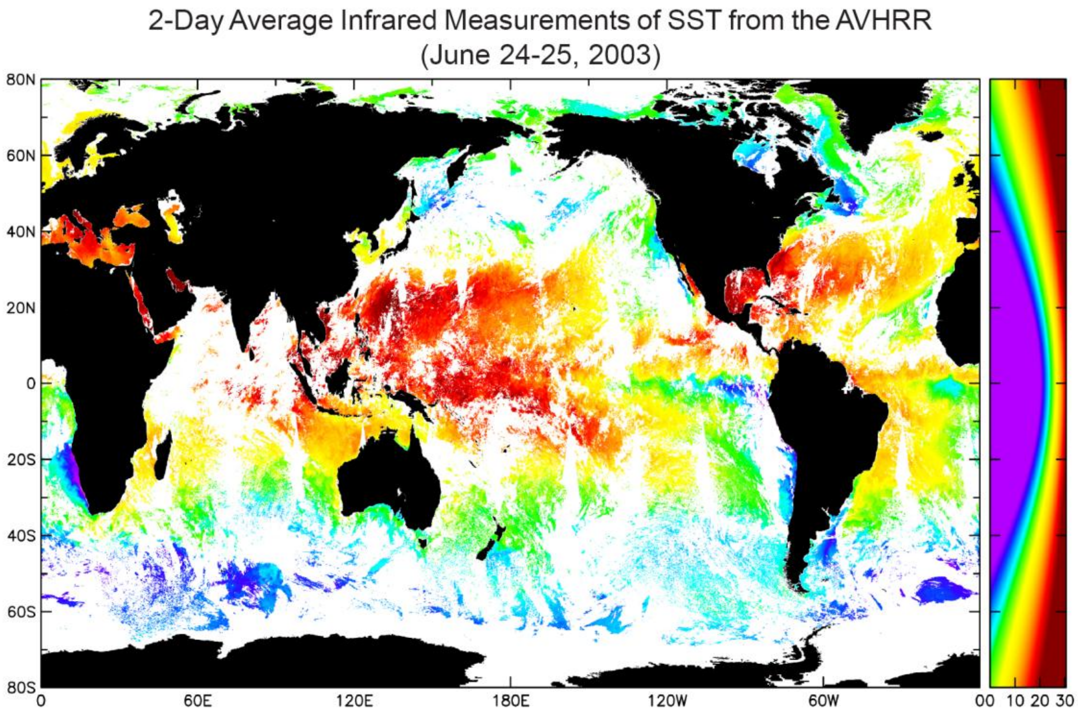


The Electromagnetic Spectrum

Chart by LASP/University of Colorado, Boulder



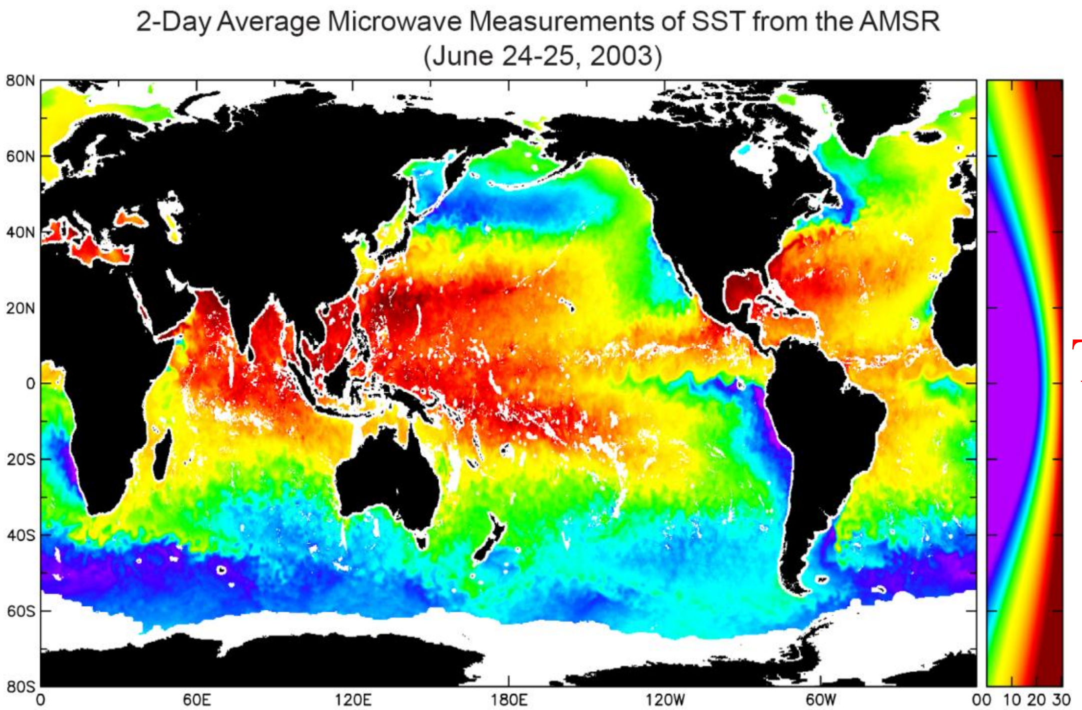
nm=nanometer, Å=angstrom, µm=micrometer, mm=millimeter, cm=centimeter, m=meter, km=kilometer, Mm=Megameter



Why Use Microwave?

Clouds!

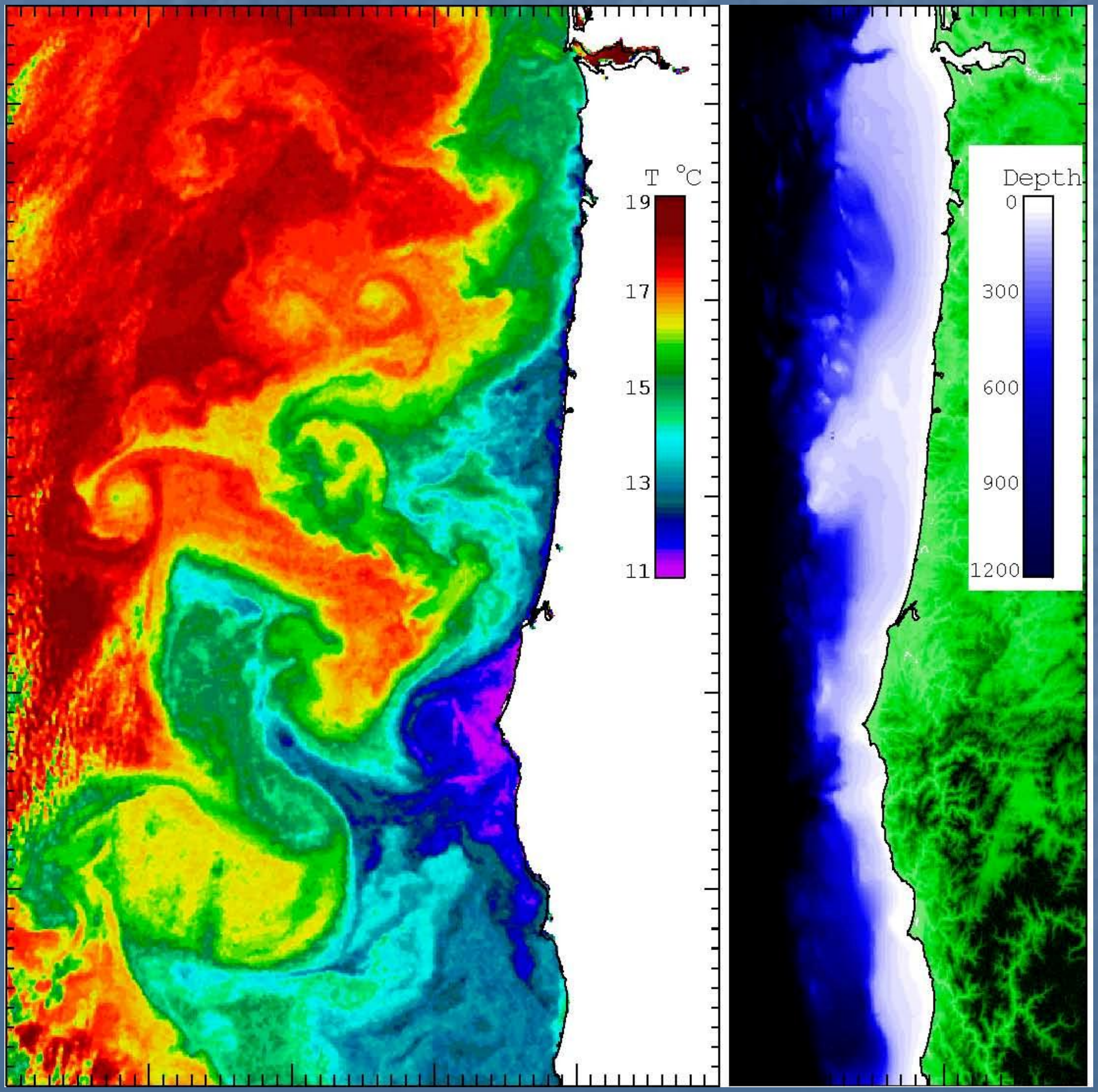
Two-days of Infrared



Two-days of Microwave

Surface Temperature: 1 km

IR SST: 26 Sept. 1998 Bathymetry



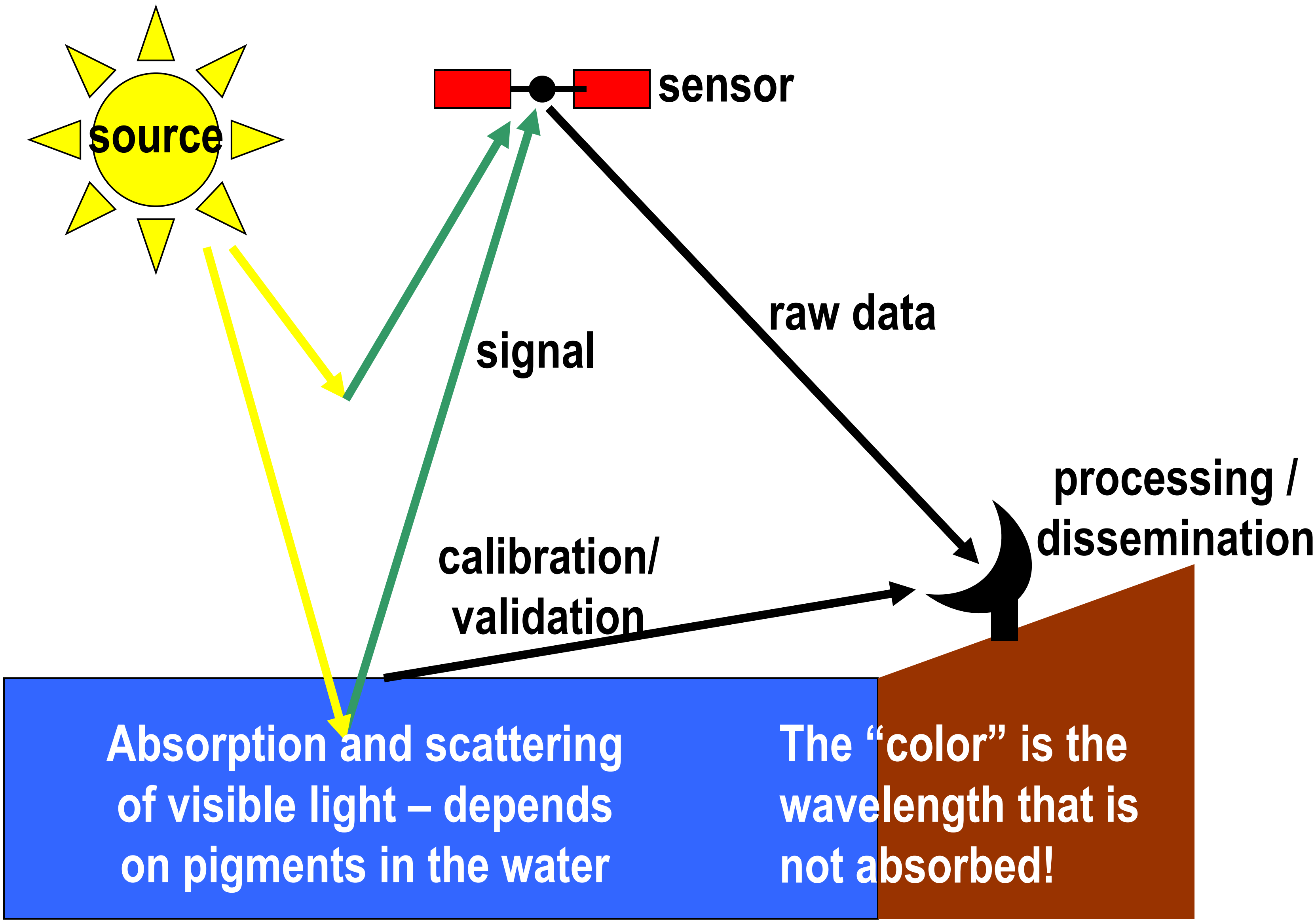
Specific Examples
Ocean color (chlorophyll)

Passive measurement

Measures light scattered and transmitted upward through the ocean surface - its ‘color’ (careful to distinguish between ‘transmission’ and ‘reflection’)

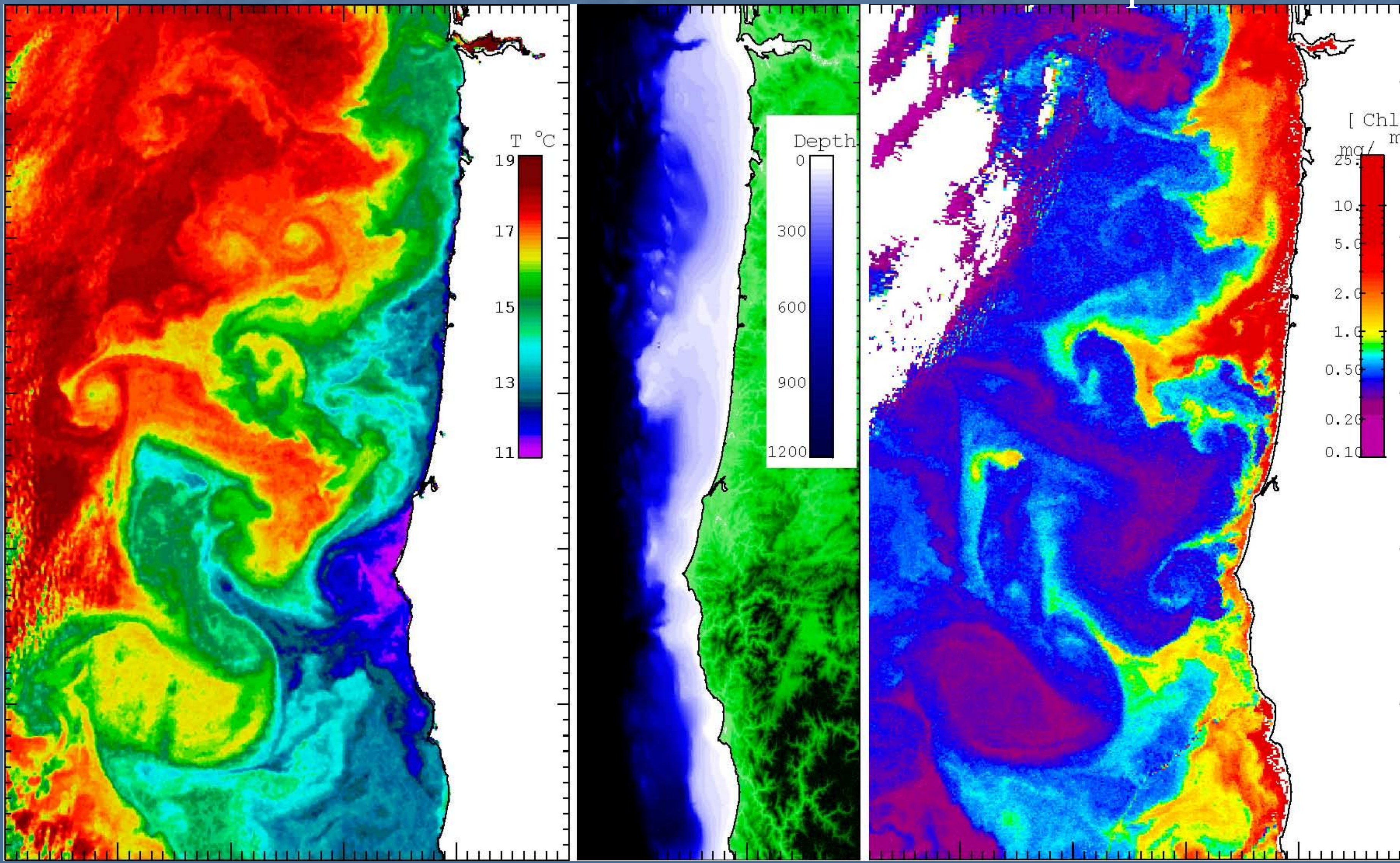
PROBLEM: Most of the signal (>90%) at the satellite is NOT ocean color – It is atmospheric interference: sunlight that has been scattered or reflected by molecules or aerosols in the atmosphere back into the satellite’s field-of-view.

Components of a passive "ocean color" remote sensing system
Using Visible wavelengths



Surface Temperature and Chlorophyll: 1 km

SST: 26 Sept. 1998 | Bathymetry | Chl-a Pigment: 26-27 Sept. 1998



Specific Examples
Sea Surface Height (SSH)

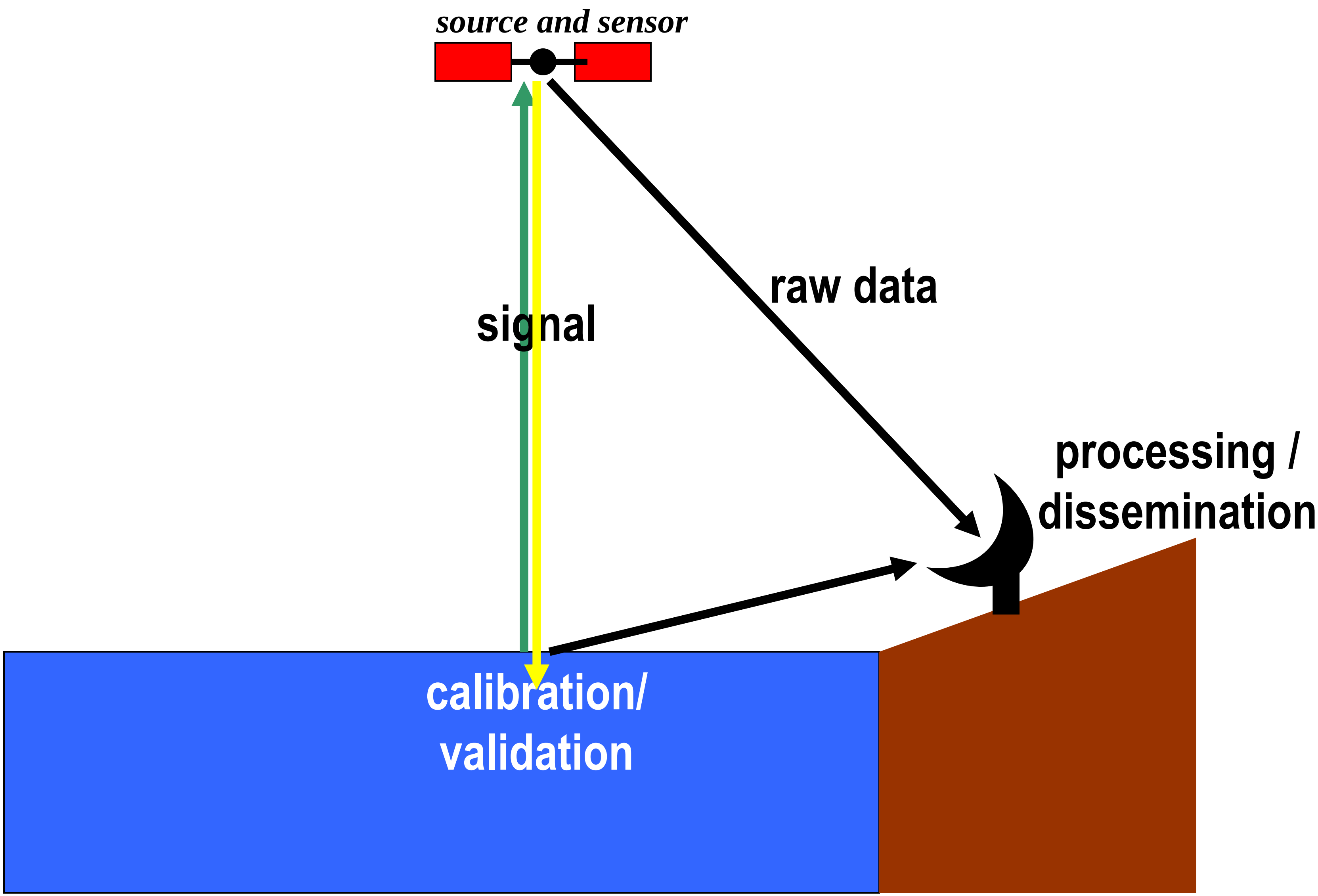
Active measurement using microwave radar

Pulse sent from satellite to earth, measure return time

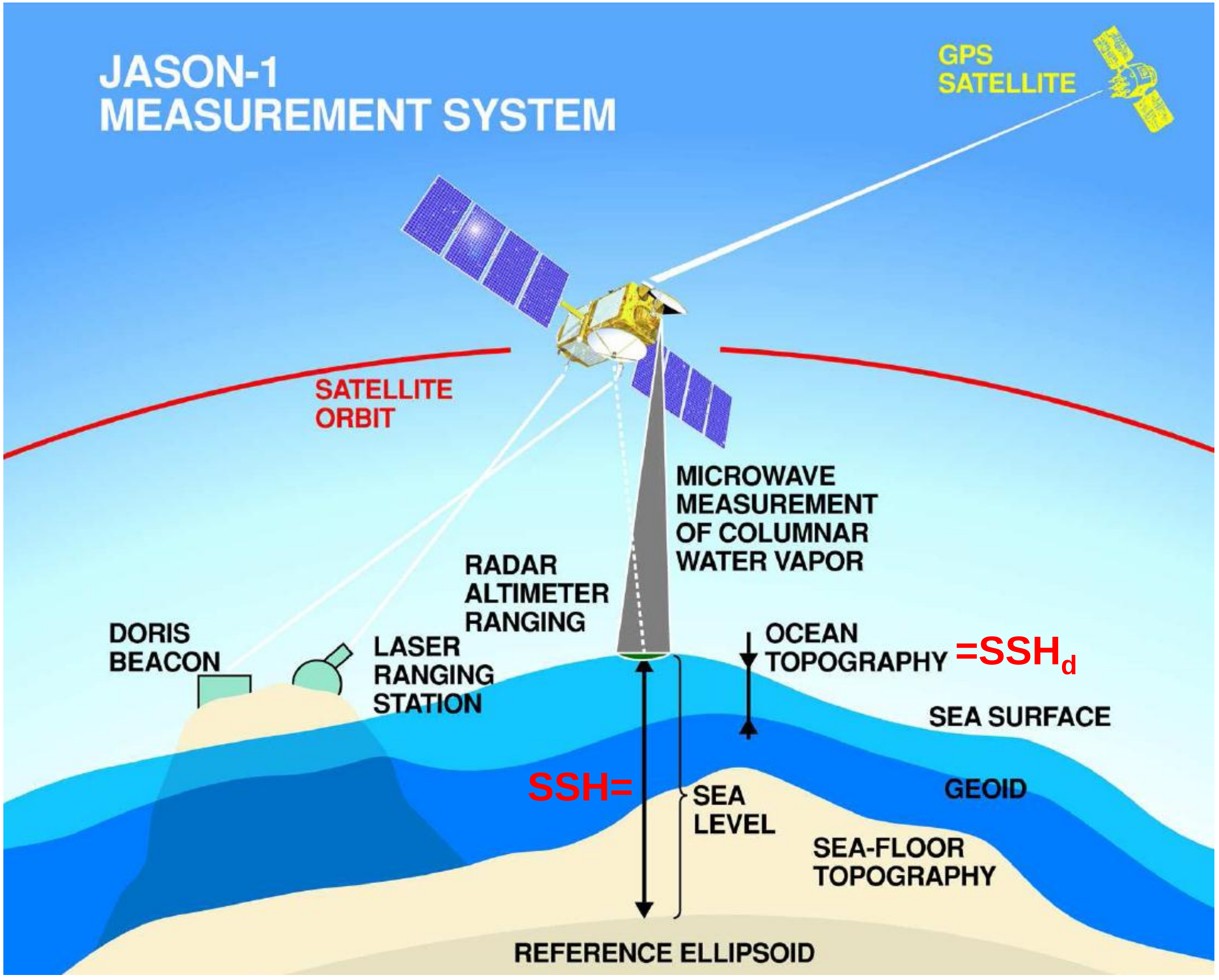
With appropriate processing and averaging, it is possible to calculate:

- Ocean currents, eddies (scales > 60-100 km)
- Deviations in ocean surface due to bathymetry
- Gradual sea level rise due to global warming
- Deviations in ocean surface due to internal physical variability (heat, salinity)

Components of an active radar "altimeter" system
For sea level: Transmit at nadir (directly beneath satellite)



Active Radar – Altimeter: Measures SSH ?what is that?

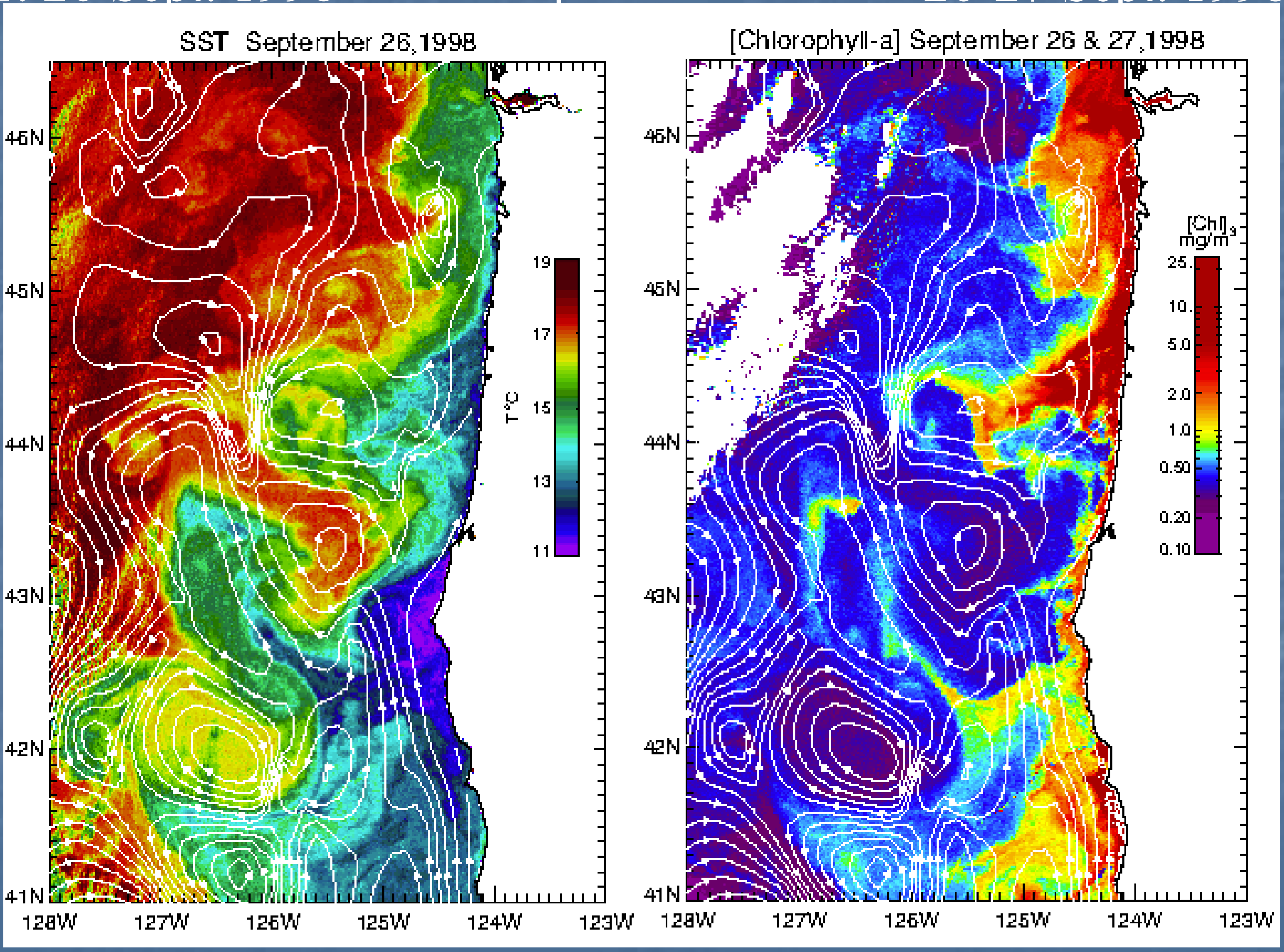


Surface Height, Temperature and Chlorophyll: 1 km

SST: 26 Sept. 1998

SSH: 2 Altimeters Sept. 1998

Chl-a Pigment: 26-27 Sept. 1998

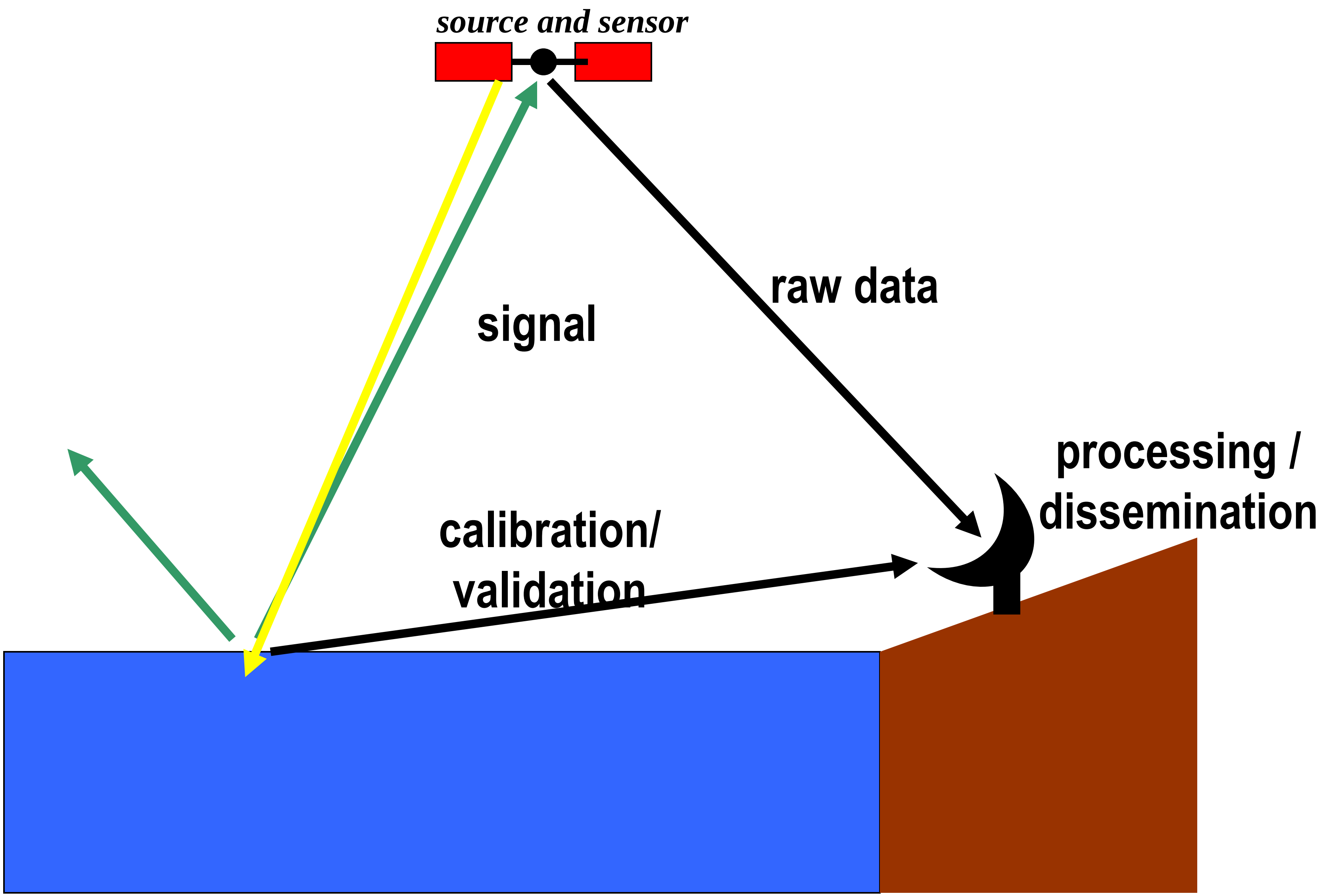


Specific Examples
Wind & Wind Stress (“tau” - τ)

Active measurement, using microwave radar to get “vector winds” – speed and direction.

- Pulse sent from satellite to ocean surface, then scattered depending on surface roughness
- Surface roughness (capillary waves) depends on wind stress
- Strength of return to satellite gives wind stress and direction

Components of an active radar "scatterometer" system
For wind: Transmit at an angle



Radar Scatterometry

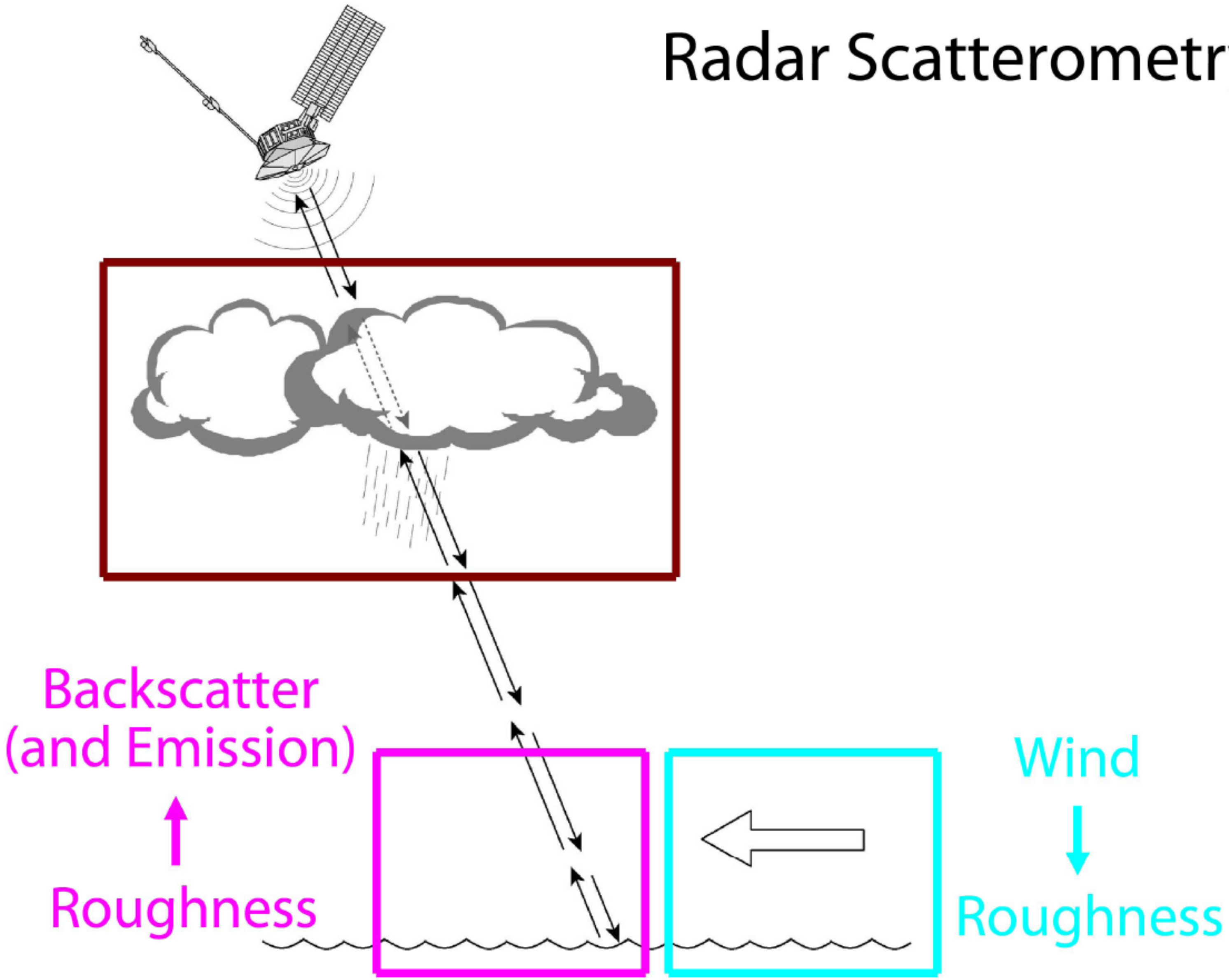
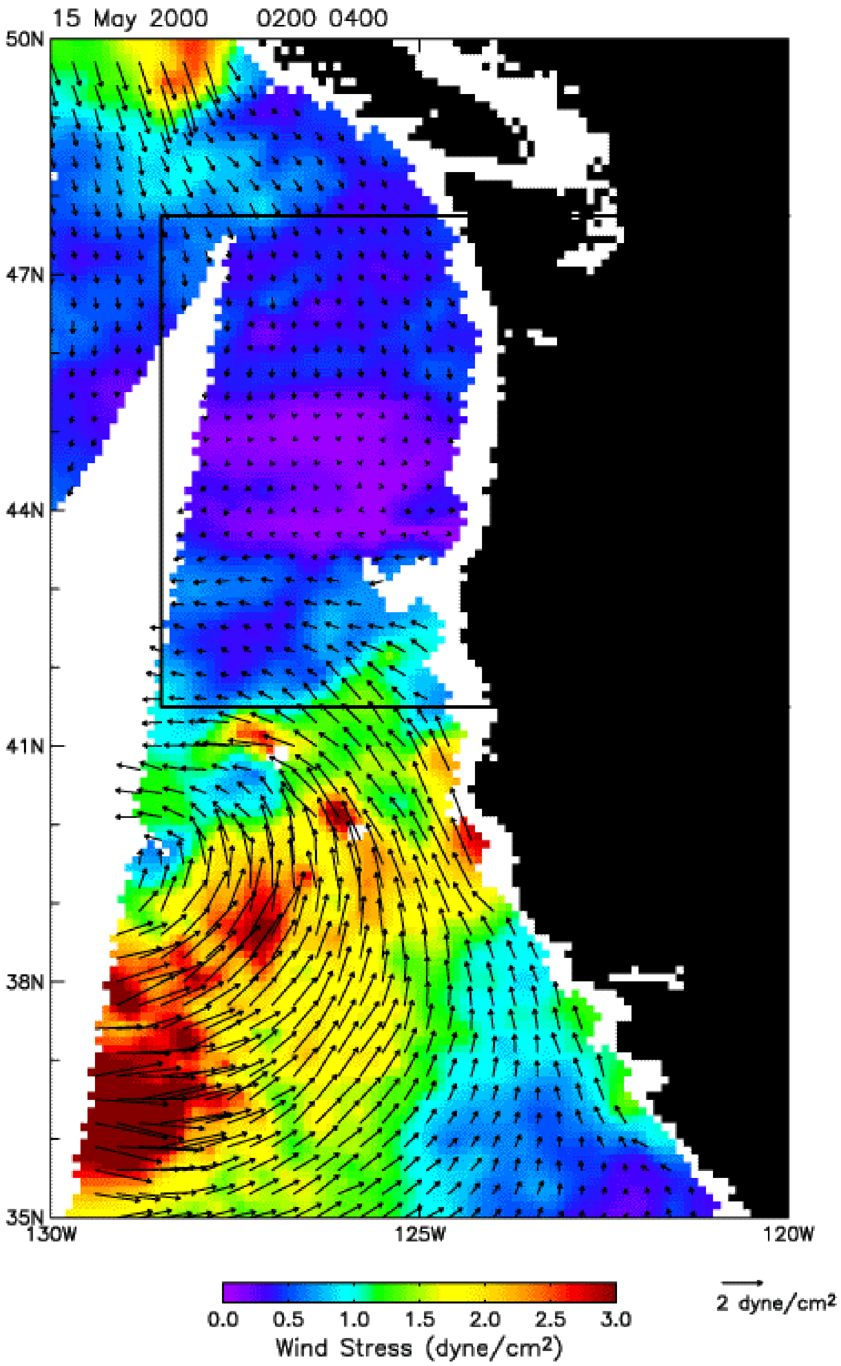


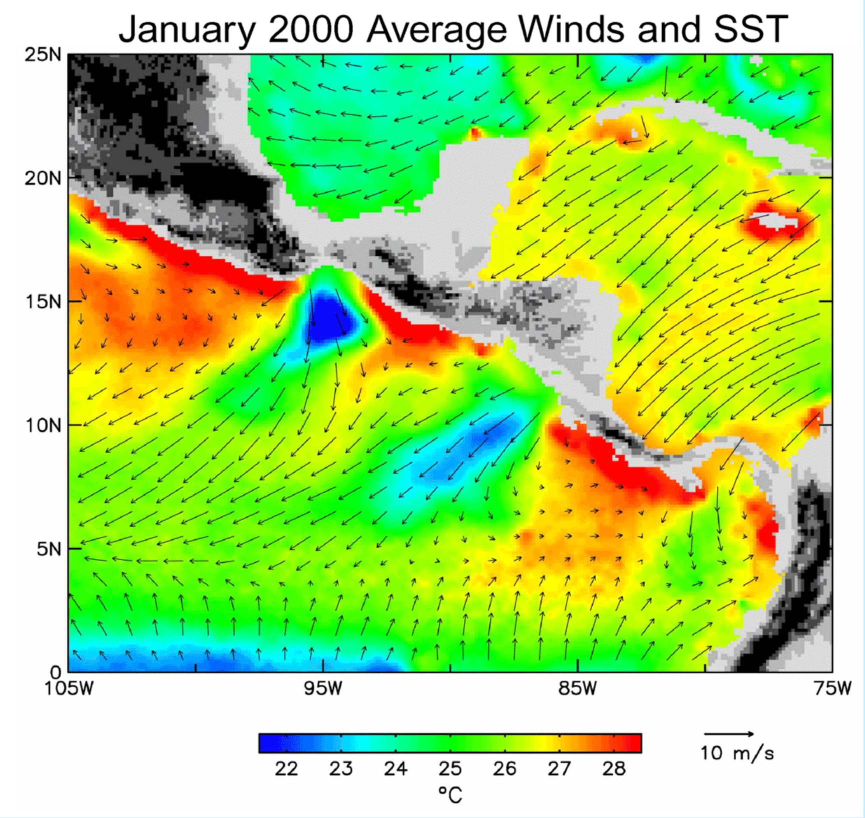
Figure courtesy of M. Freilich


15 May 2000 0200 0400
50N
47N
44N
41N
38N
35N
130W
125W
120W
0.0 0.5 1.0 1.5 2.0 2.5 3.0
Wind Stress (dyne/cm²)
2 dyne/cm²

QuikSCAT Science: *Ocean Circulation*

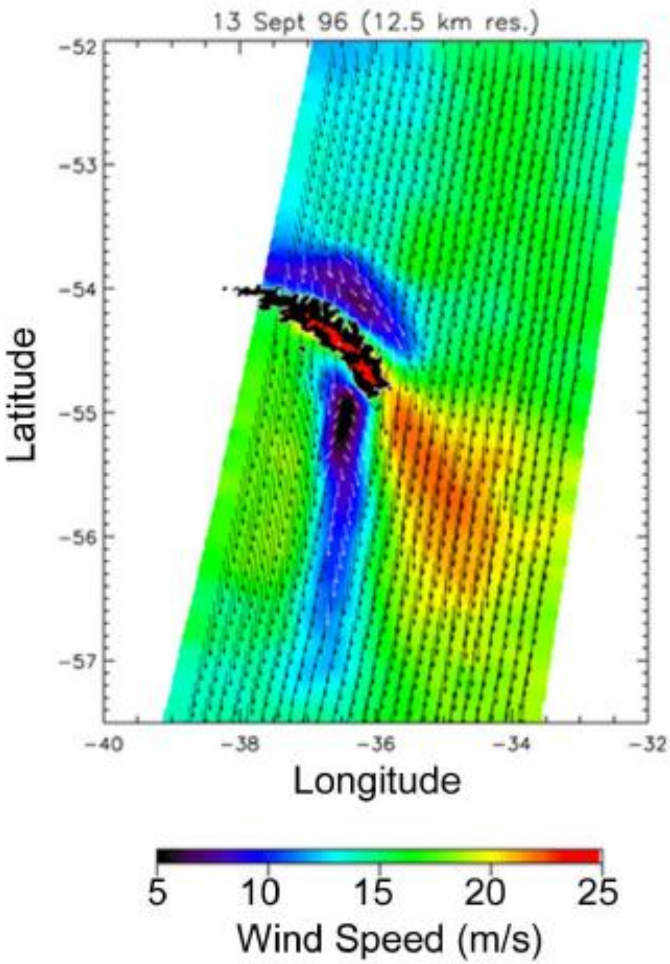
QuikSCAT's high resolution, extensive, and frequent wind velocity measurements are used to understand upper ocean circulation from regional to global scales

- Wind stress is the largest momentum input to the upper ocean
- Wind stress curl drives large-scale surface currents
- Small-scale wind variability modifies large-scale ocean circulation
- Coastal regions exhibit amplified physical/biological response
- Wind forcing complements dynamic and thermodynamic response measurements

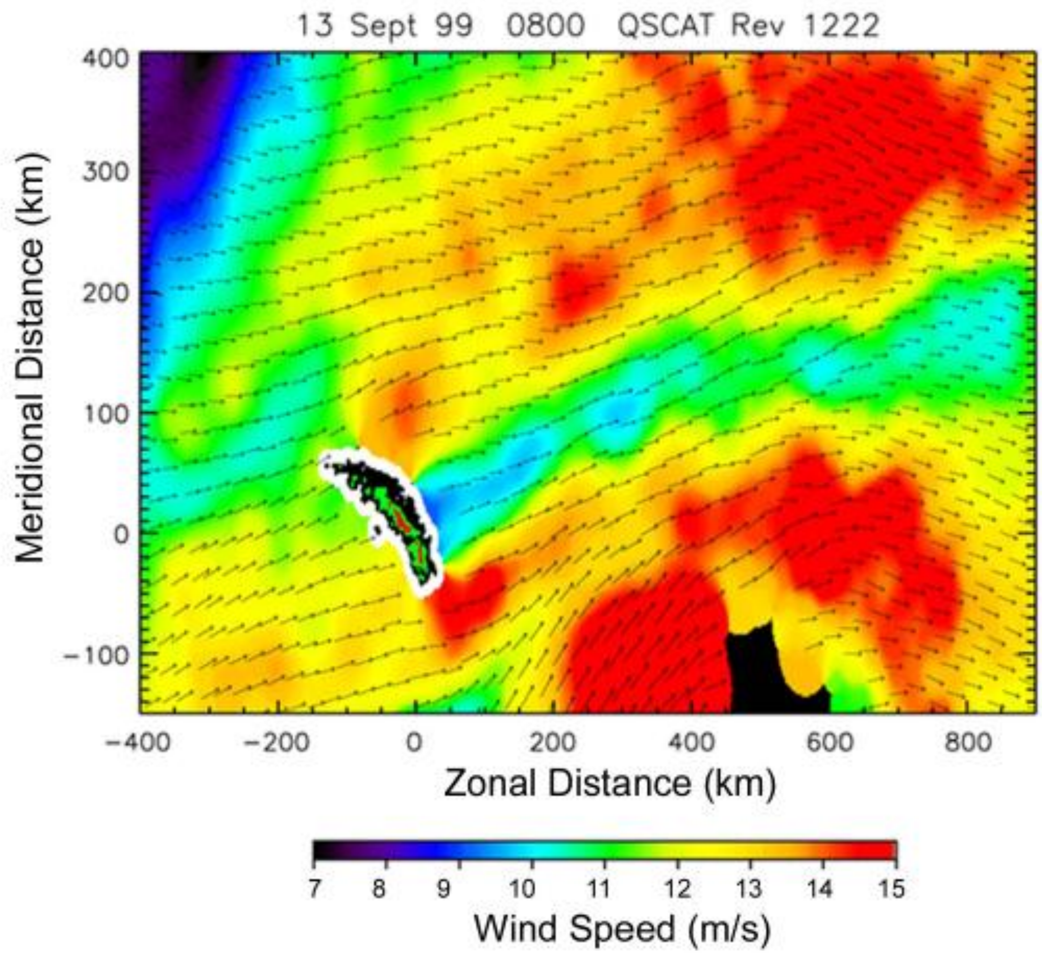


Wind Shadows Behind South Georgia Island

NSCAT Example

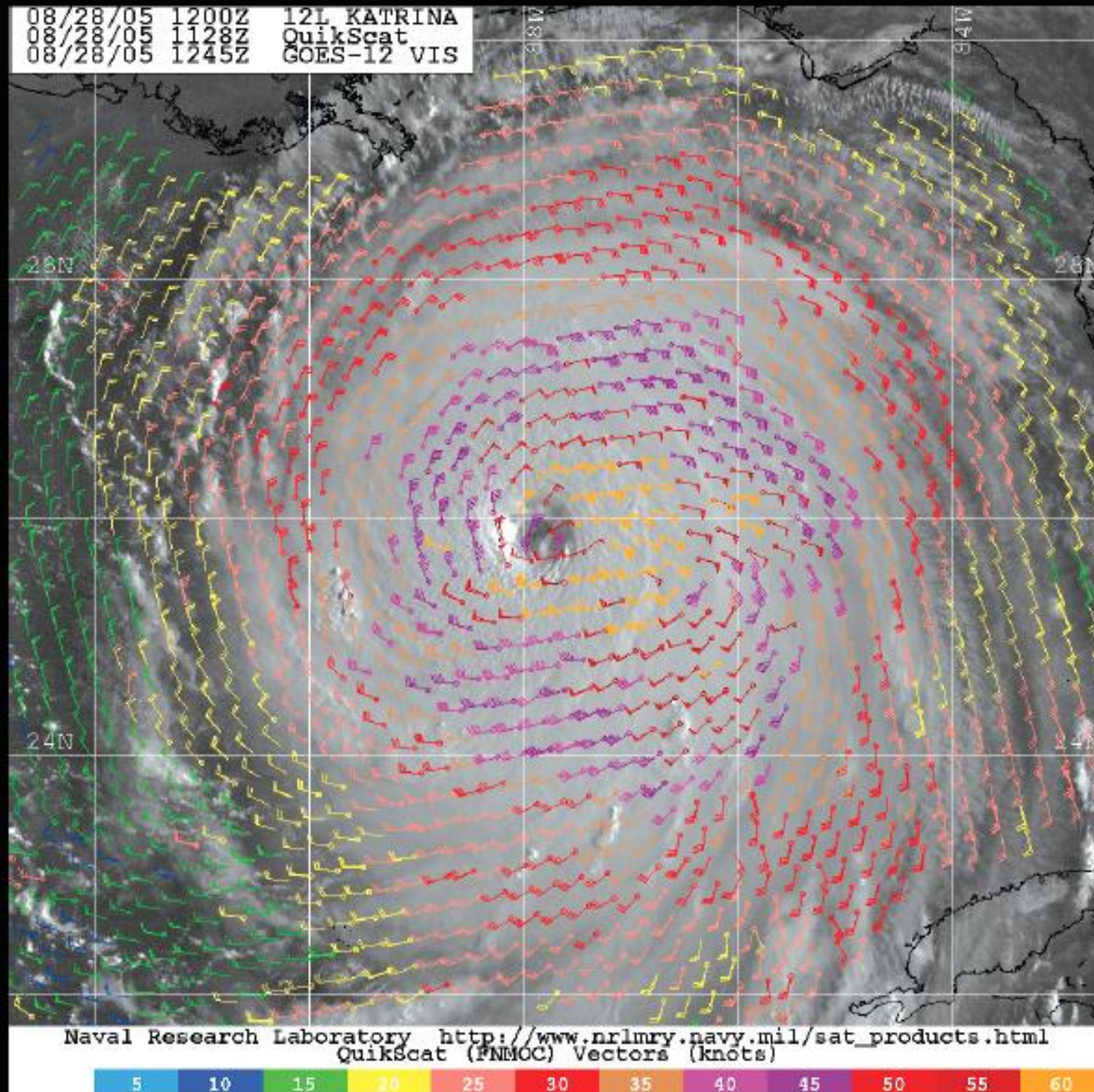


QuikSCAT Example

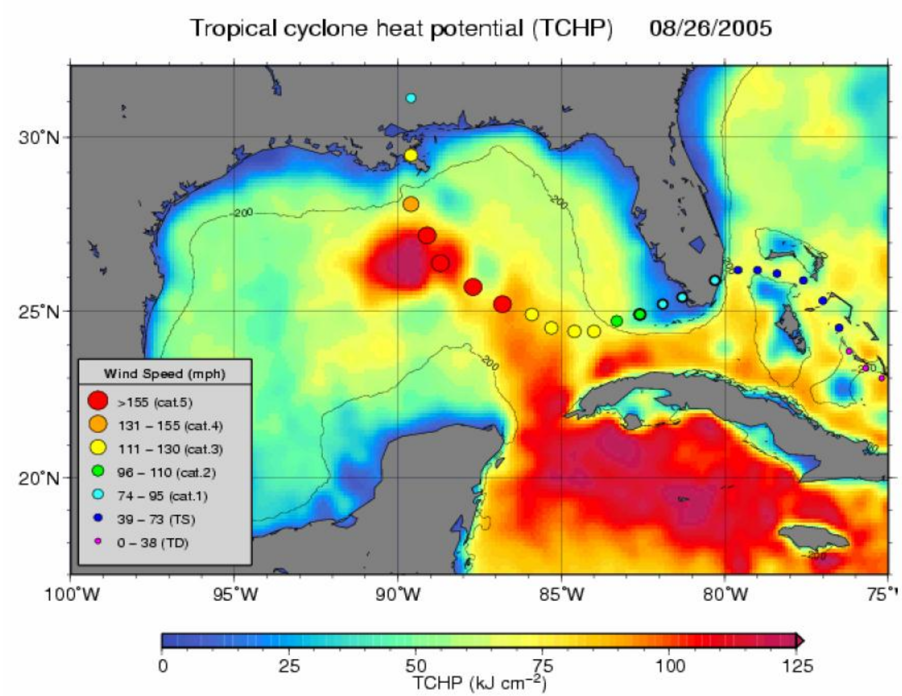


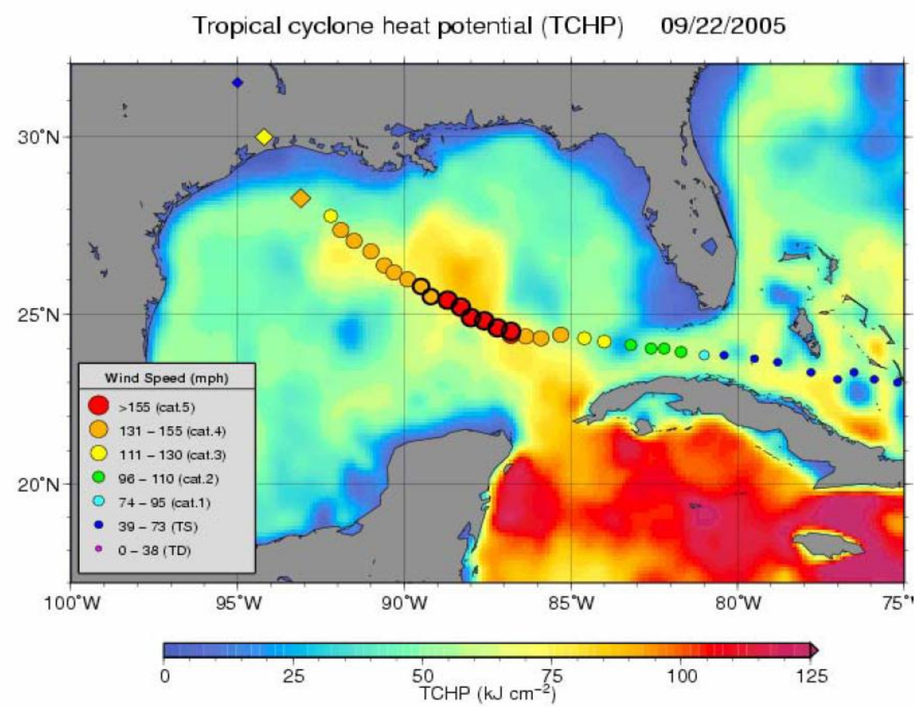
Figures courtesy of M. Freilich

QuikSCAT Measurements of Hurricane Katrina



Packing Heat in the Gulf
Altimeter and Scatterometer

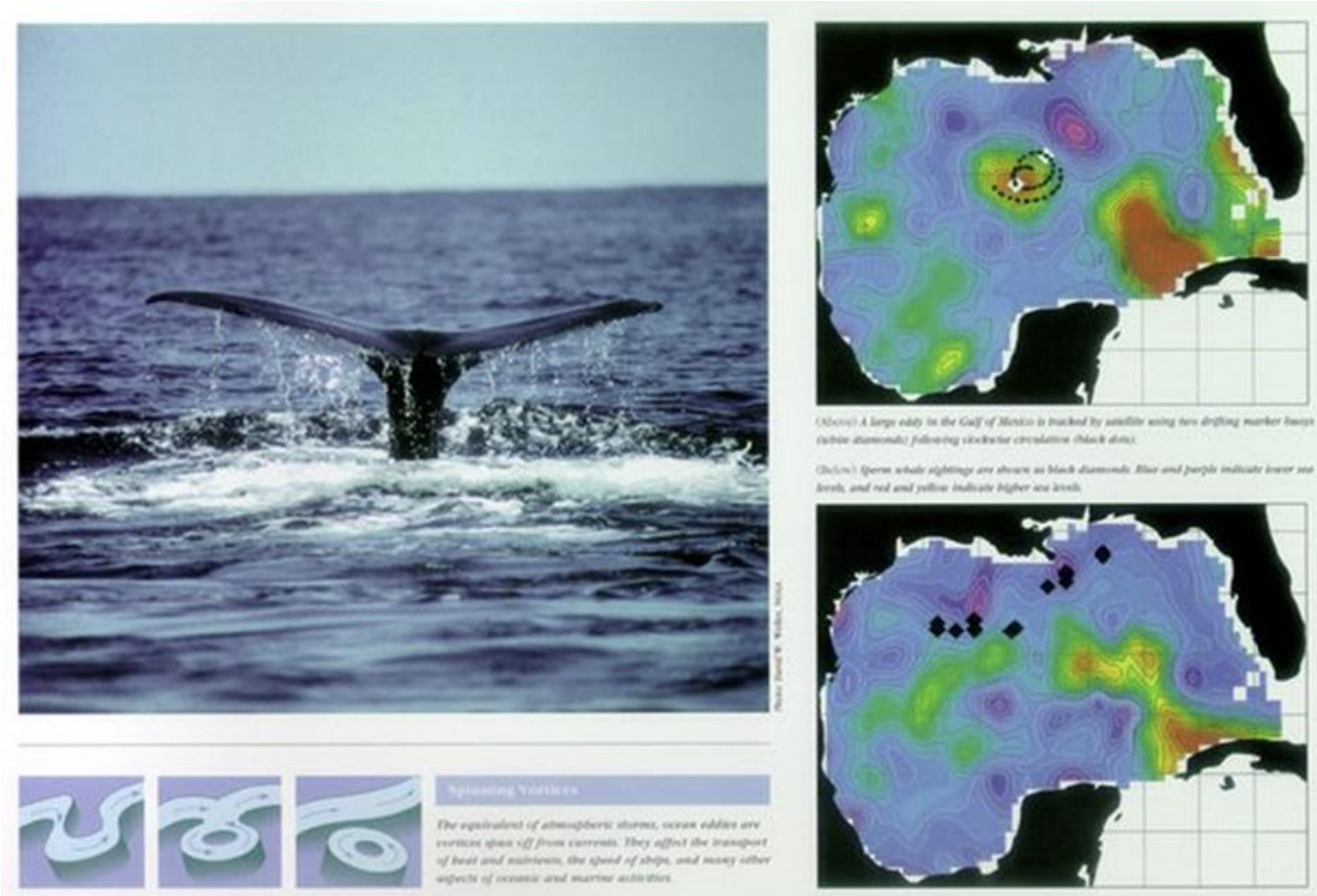


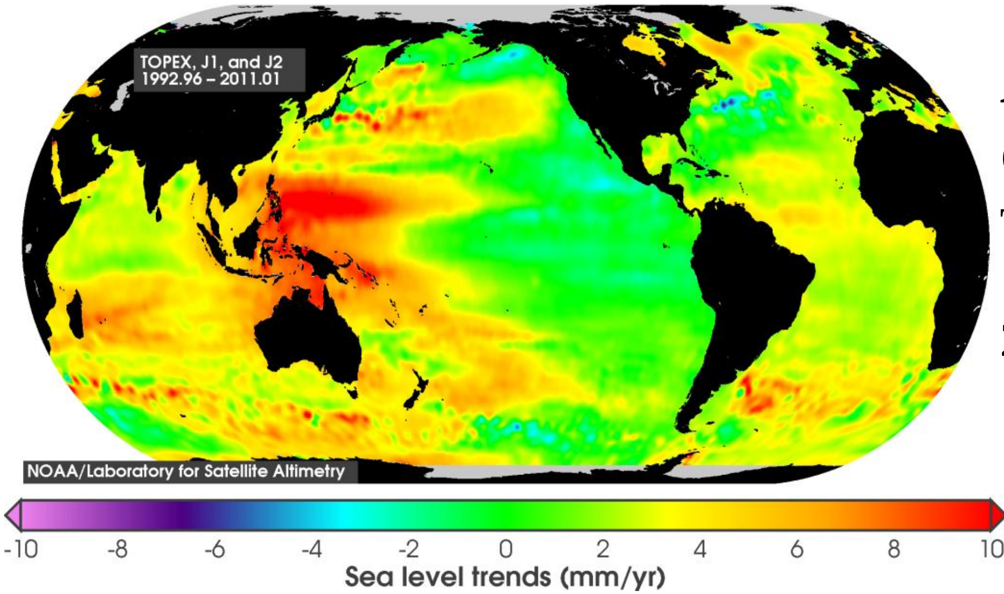


(G. Goni and J. Trinanes, NOAA/AOML)

Tropical Cyclone Heat Potential (TCHP) fields are derived from altimetry data for hurricanes Katrina (left) and Rita (right) in 2005. The path of each hurricane is indicated with circles, their size and color representing intensity (see legend), as the storms made their way across the Gulf of Mexico. Both hurricanes rapidly intensified to category 5 as they passed over the Loop Current and a warm ring, then diminished to category 4 and category 3, respectively, by the time they traveled over cooler waters outside the warm ring. NOAA's Atlantic Oceanographic and Meteorological Laboratory uses blended satellite altimetry data, including those from NASA's TOPEX/Poseidon and Jason-1 missions, to estimate TCHP (a measure of the oceanic heat content from the sea surface to the depth of the 26°C isotherm) in the Gulf of Mexico in near-real time. High values of TCHP may be linked to hurricane intensification. These fields are critical to scientists and forecasters in better understanding the link between the ocean and the intensification of hurricanes. See http://www.aoml.noaa.gov/phod/cyclone/data/ for more information.

Ocean Eddies as Habitat for Marine Mammals, Turtles, …

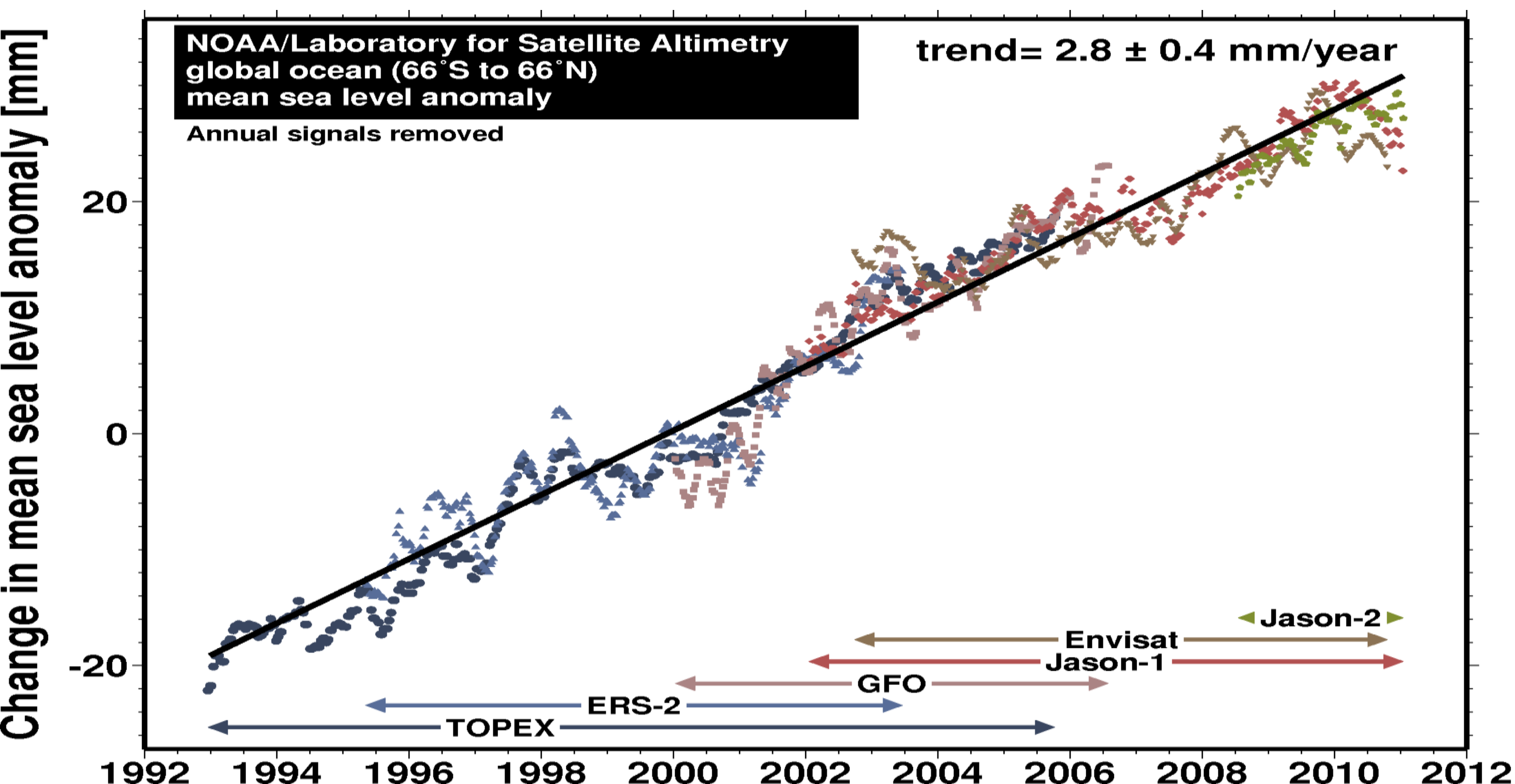




Altimeter Estimates of Global Sea Level Rise:

This signal (the rise) is due to two effects:

1) Thermal expansion as the water heats;
2) Increased volume of water as the glacial ice melts.



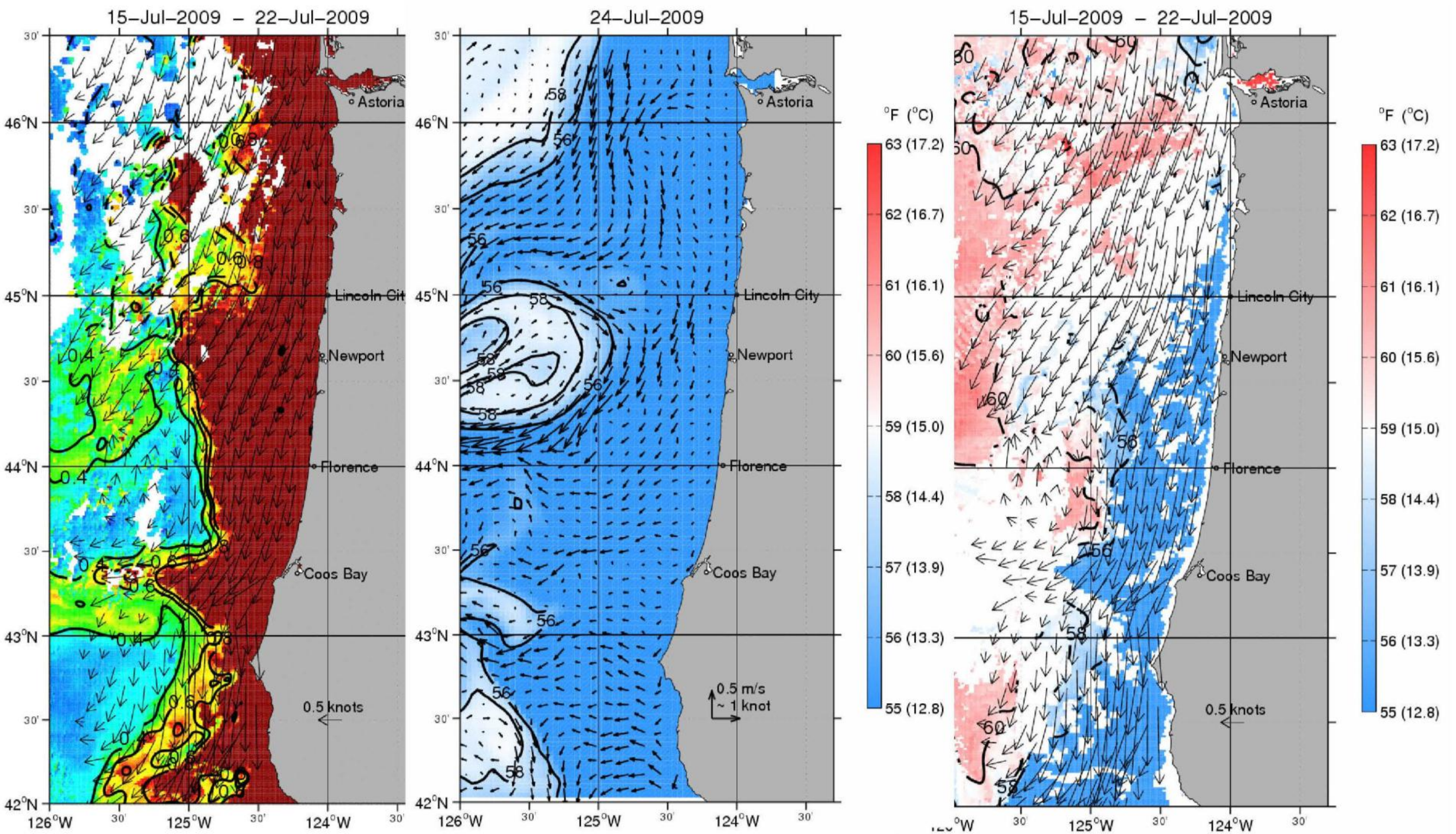
Animations of Ocean Sea Surface Heights:

- "3-Pacific_SSH_1993-2011.mpg" This animation from NASA of sea surface height (SSH) in the Pacific from 1993-2010 shows the eastward movement of high SSH along the equator during the onset of El Niño conditions (1997-98, 2006, 2009) and the westward movement of eddies nearly everywhere else.

The animations described below may be available from Dudley Chelton (dchelton@coas.oregonstate.edu)

- An eddy next to California traps a subsurface float and carries it with the eddy as it moves to the west. Passive plankton ecosystems are also carried in this same fashion.
- Eddies in the global ocean are everywhere, mostly moving from east to west, unless they are caught in a current moving more quickly to the east.

Computer Models of 3-D Currents and Temperature: Fishermen at Coos Bay use these fields to direct cruises

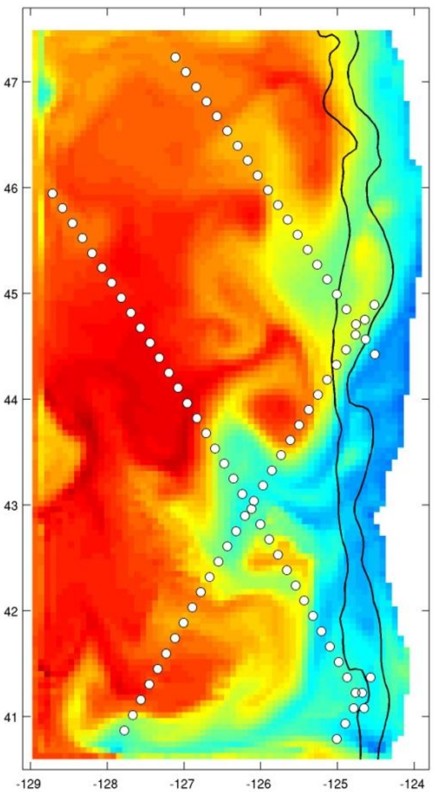


8-day composites of GOES SST (right) and MODIS chlorophyll (left) over radar surface velocities during the period leading up to the forecast. (Middle) 2-day forecast SST and surface velocity (without data assimilation).

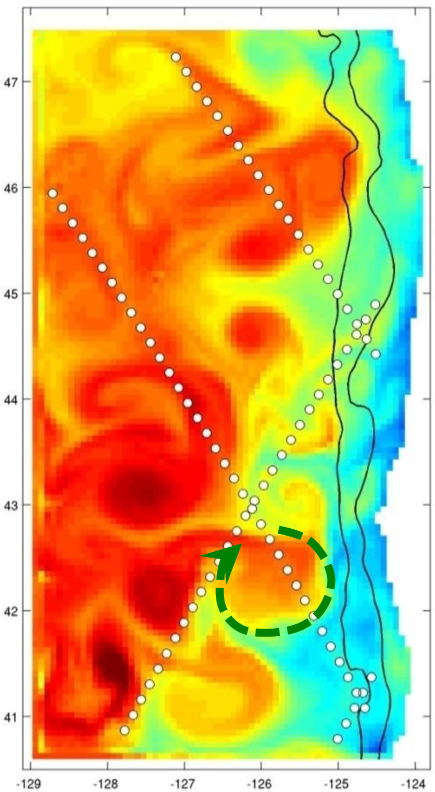
Computer Models of 3-D Currents and Temperature

Alongtrack altimeter SSH data (dots) are used to "correct" the model. GOES satellite SST is used to verify the improvement of the model SST fields.

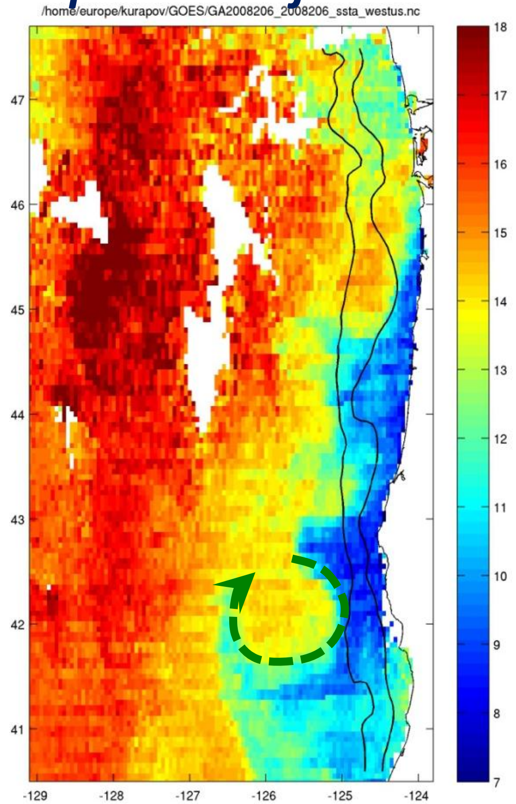
prior (free-run) model SST



model SST after SSH assimilation



GOES daily SST (7/20/08), independent of model.



Future Technologies

"Next generation" satellite sensors are being developed by NASA and NOAA.

- "Swath altimeters" will provide higher resolution SSH fields, closer to the coast.
- "Interferometer" scatterometers will provide higher resolution wind fields, closer to the coast.
- "Hyper-spectral" ocean color sensors will sample the full visible radiation spectrum, allowing the identification of different types of phytoplankton, including those responsible for "harmful algal blooms" that close regions to the harvest of shellfish. These will also have higher resolution to retrieve data farther up into rivers and estuaries.
- SST sensors will combine the IR and Microwave channels to provide all-weather SST fields with higher resolution.
- These satellite data and in-water data from subsurface "observatories" will be "assimilated" into 3-D models of the ocean's circulation to provide predictions of currents, temperatures, oxygen (to warn of "dead zones").

Need more skilled people to analyze data from these systems!!

Summary

Oceanography has traditionally faced a sampling limitation.

Satellites allow us to observe large areas quickly, but:

- Only see the ocean surface;
- Careful data calibration required for long term data sets.

Parameters include: SST, Surface Height, Winds, Ice, Chlorophyll, Fluorescence (Productivity).

In the Atmosphere: Profiles: Temperature, Water Vapor, Rain, Ozone, CO_2.

Recent Advances: Salinity (this year), Wind and Height data closer to the coast and higher resolution; All-Weather SST; Hyperspectral data

New technologies collect subsurface data in the water – gliders, AUV.

Smaller and more power efficient sensors, more chemistry, more biology.

Computer models use all of these to predict accurate currents and temperatures

Need skilled people to analyze data and advance the science!!

Web Sites

OSU/COAS: Cooperative Institute for Oceanographic Satellite Studies

http://cioss.coas.oregonstate.edu/CIOSS/

OSU/COAS/Ocean Optics/Color:

http://picasso.coas.oregonstate.edu/ORSOO/

NOAA Global Sea Level Rise: http://ibis.grdl.noaa.gov/SAT/slr/

U. Wisconsin Madison: Coop. Institute for Meteorological Satellite Studies

http://cimss.ssec.wisc.edu/

Jet Propulsion Laboratory (JPL/NASA) Physical Oceanography Data Center

http://podaac.jpl.nasa.gov/

NOAA Satellite Research & West Coast Satellite Data: "CoastWatch"

http://www.star.nesdis.noaa.gov/star/ & http://coastwatch.pfel.noaa.gov/

NASA Goddard Science Center – Satellite Data and Info & Ocean Color

http://disc.sci.gsfc.nasa.gov/ & http://oceancolor.gsfc.nasa.gov/

NASA Tutorial: http://rst.gsfc.nasa.gov/Front/overview.html


THE END