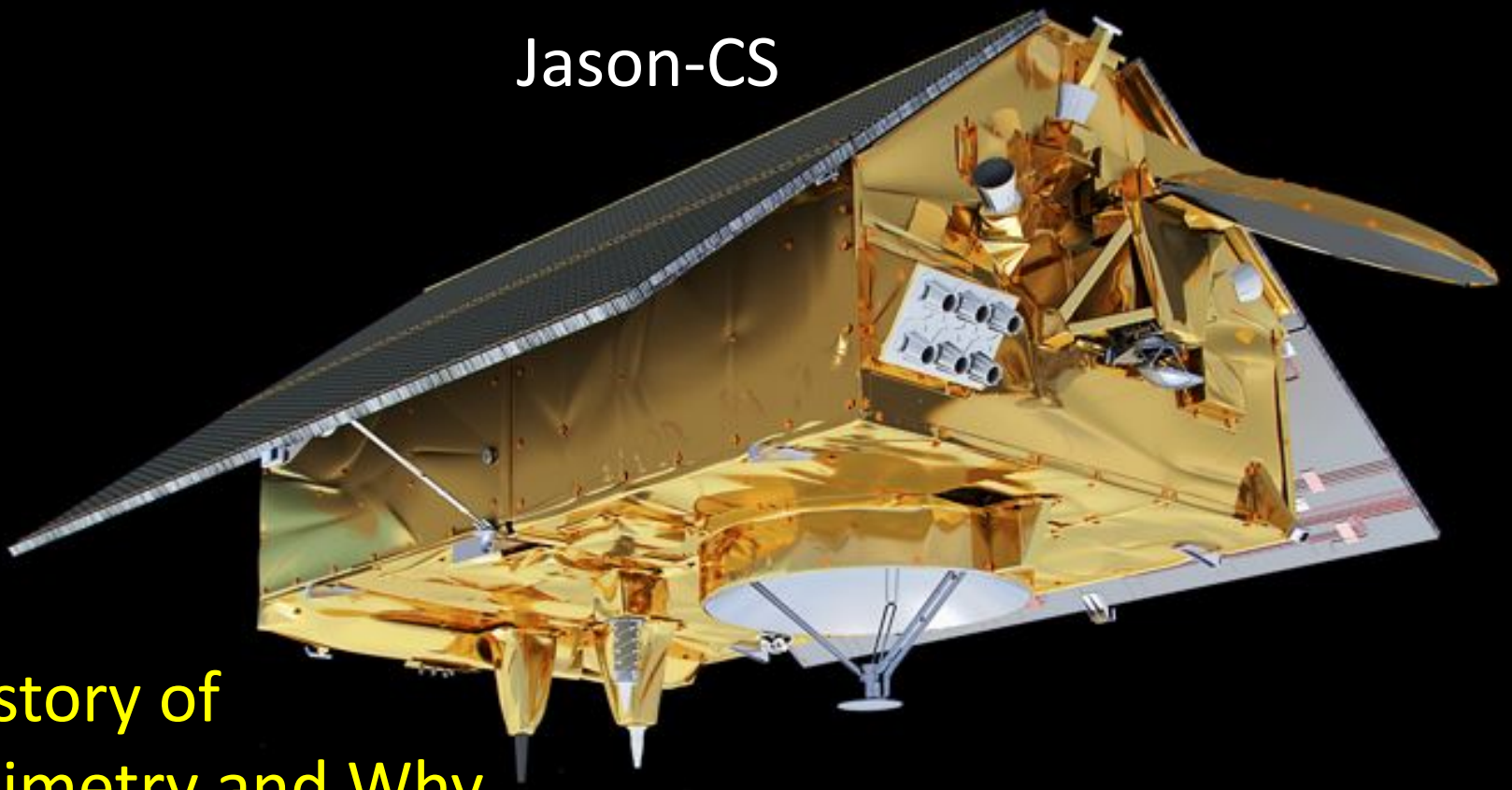


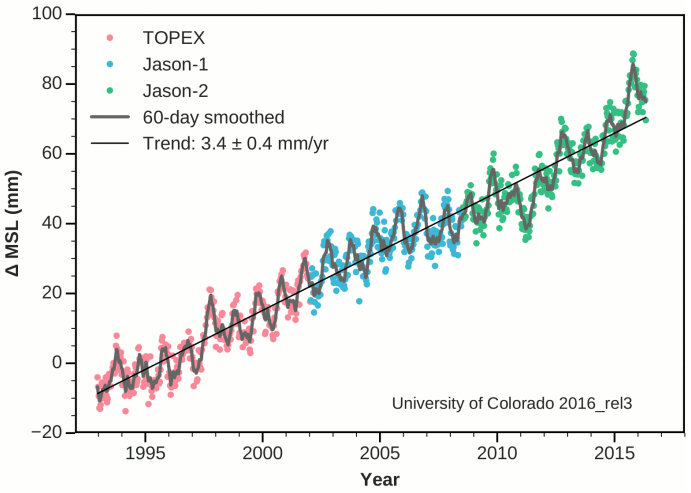
A Brief History of Ocean Altimetry and Why It's the Most Important Mission Ever

Josh K. Willis
joshua.k.willis@jpl.nasa.gov
Jet Propulsion Laboratory

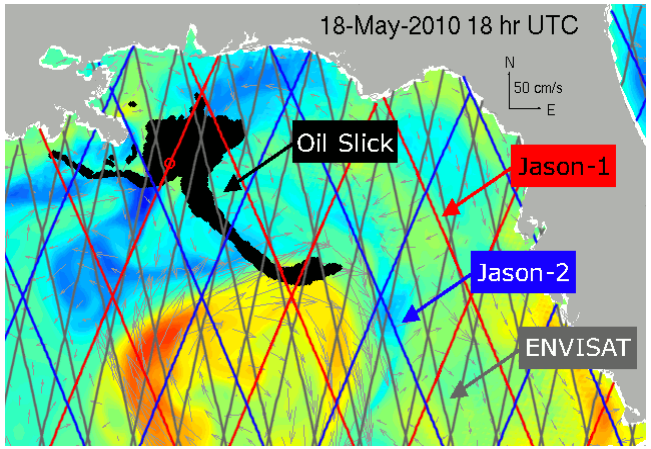
Jason Science Overview

- Continue the time series of global sea level rise
- Seasonal, inter-annual and decadal ocean variability
- Coastal variability and its impact on ecosystems
- Ocean weather-operational oceanography
- Surface wave forecasting and evaluation
- Hurricane intensity forecasting

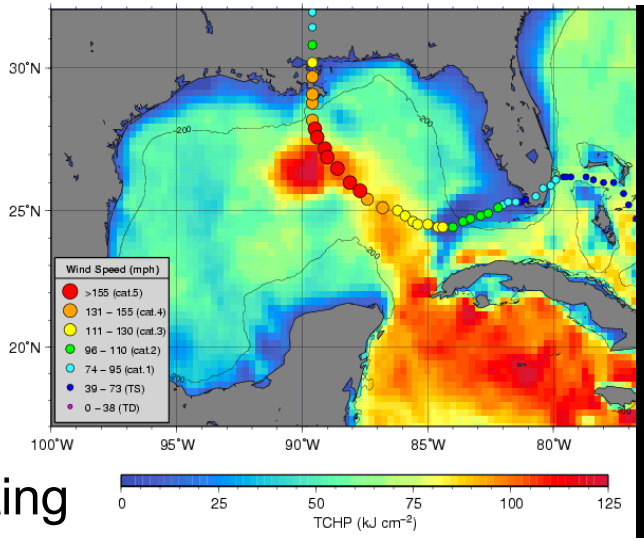
Globally Averaged Sea Level Rise



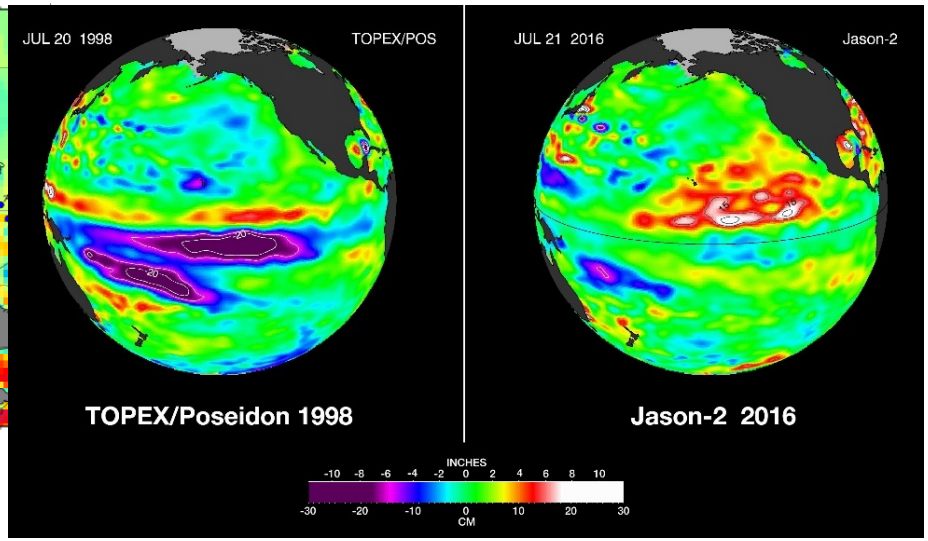
Near Real Time Surface Currents



Ocean Heat Content & Tropical Cyclones

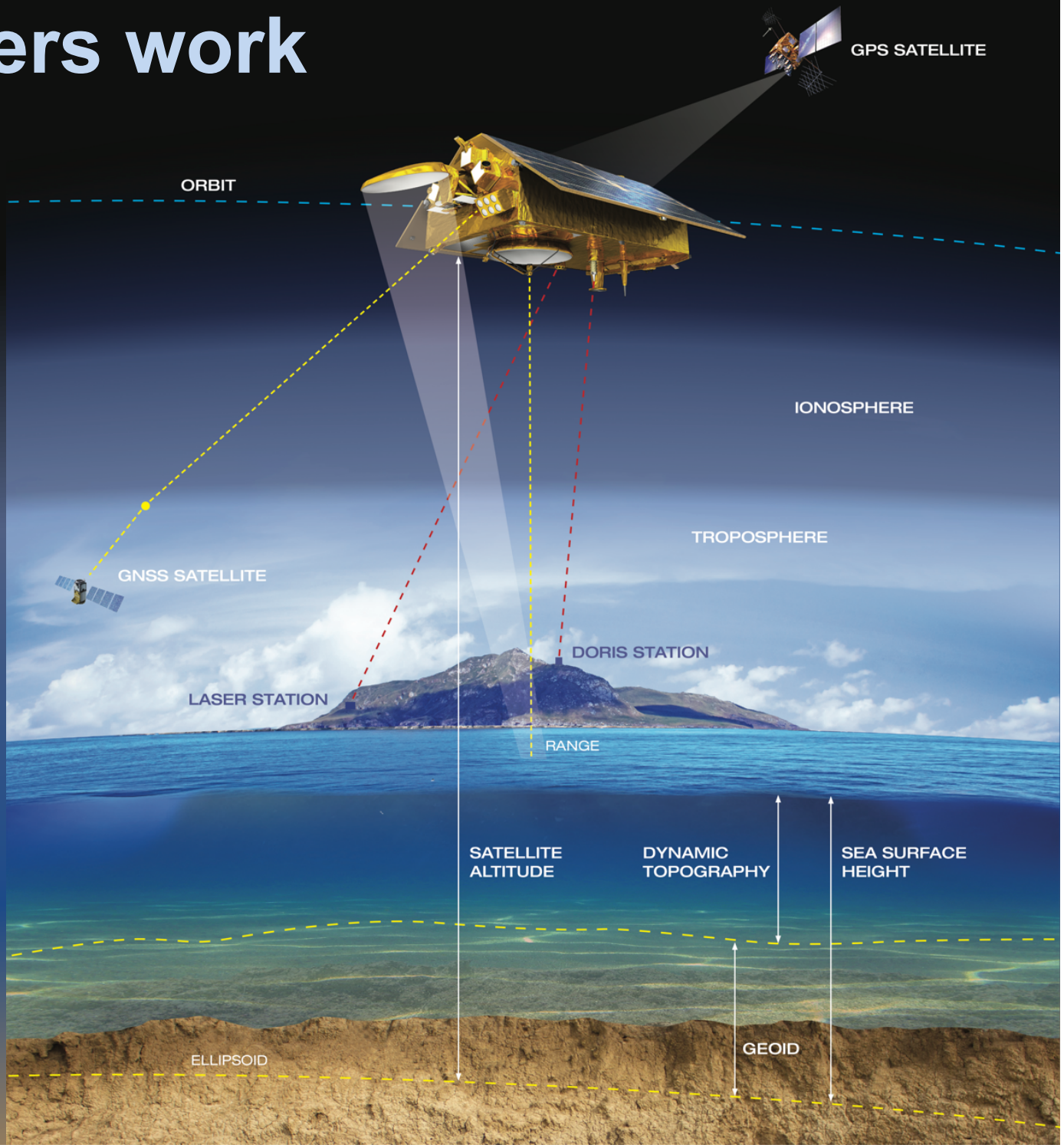


El Nino/La Nina monitoring



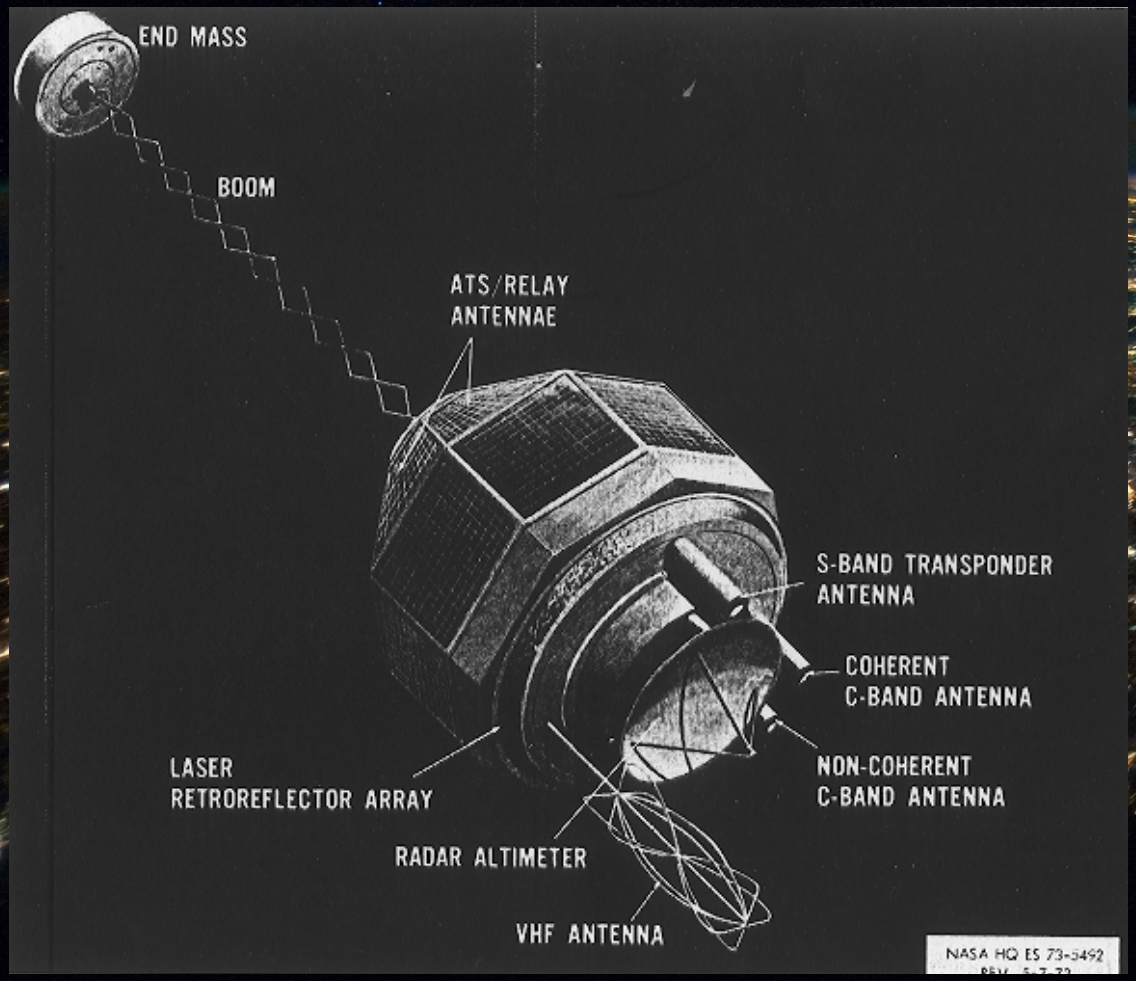
How altimeters work

- Jason satellites measure range using altimeter
- Correct for wet-path delay with radiometer
- Locate satellite using DORIS, Laser Ranging and GPS
- Position and Range give sea surface height.



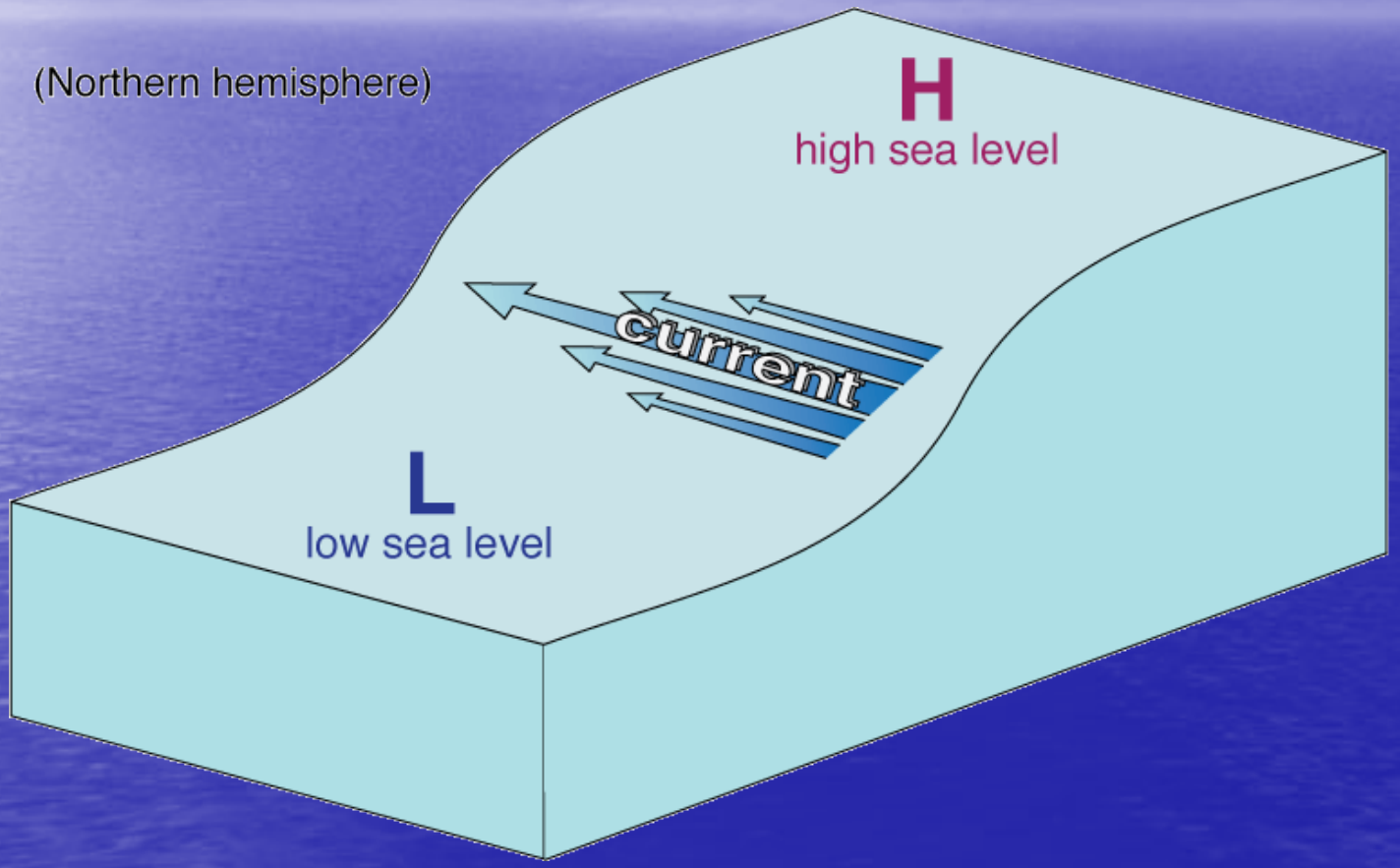
SkyLab
1973

GEOS-3
1974

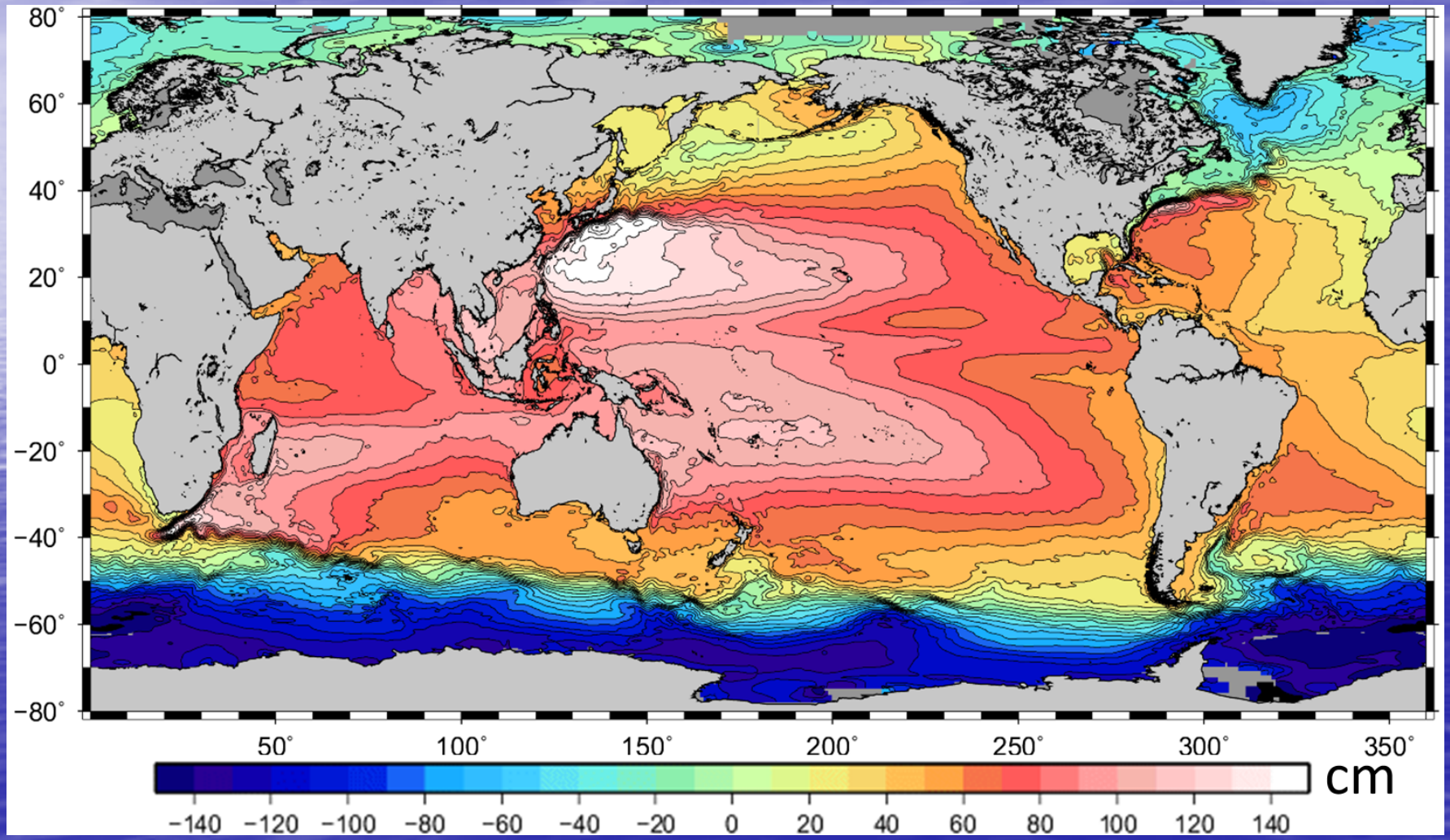


SeaSat
1978

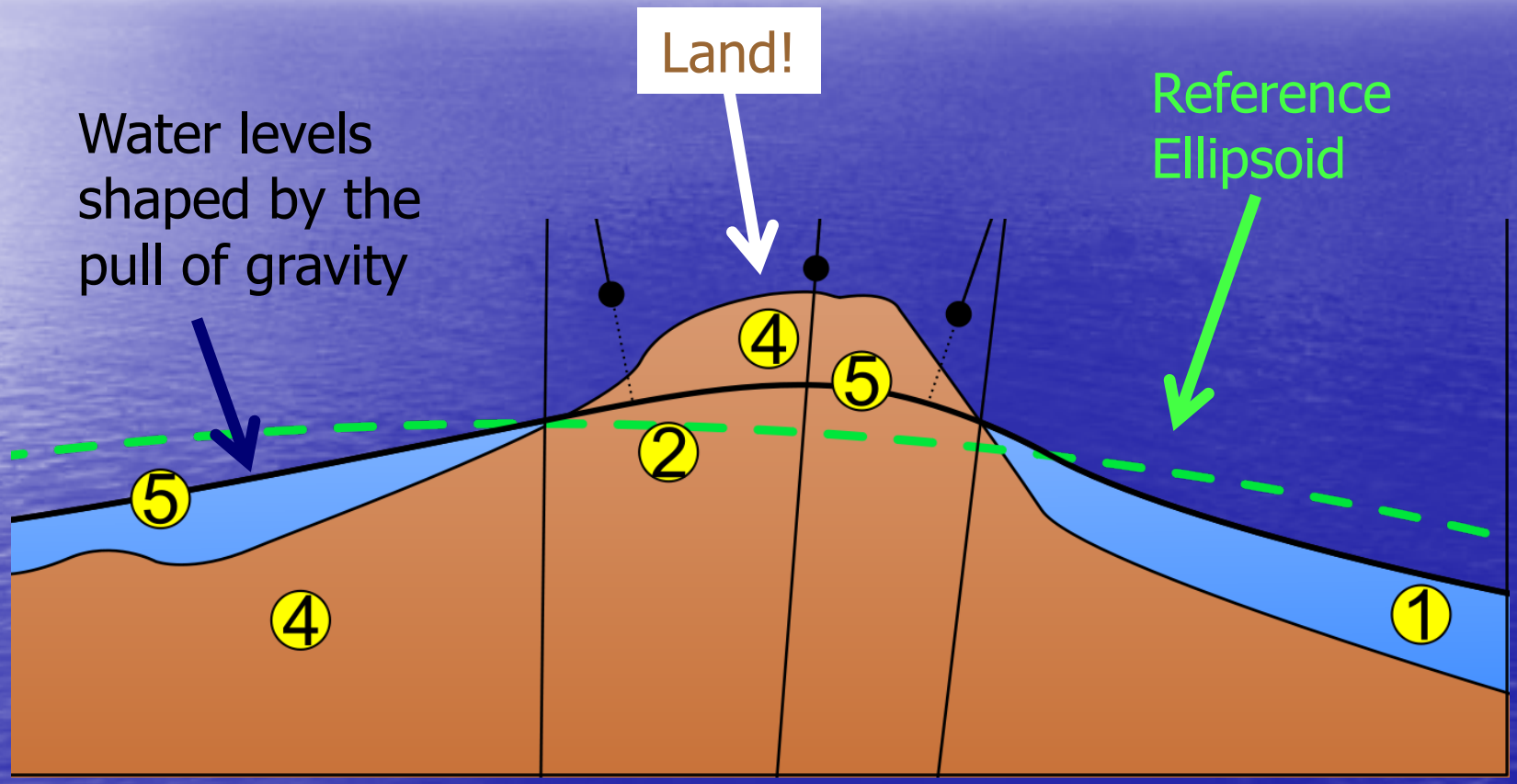
The slope of the ocean tells us the currents at the surface



"Dynamic topography" – tells us the surface currents!

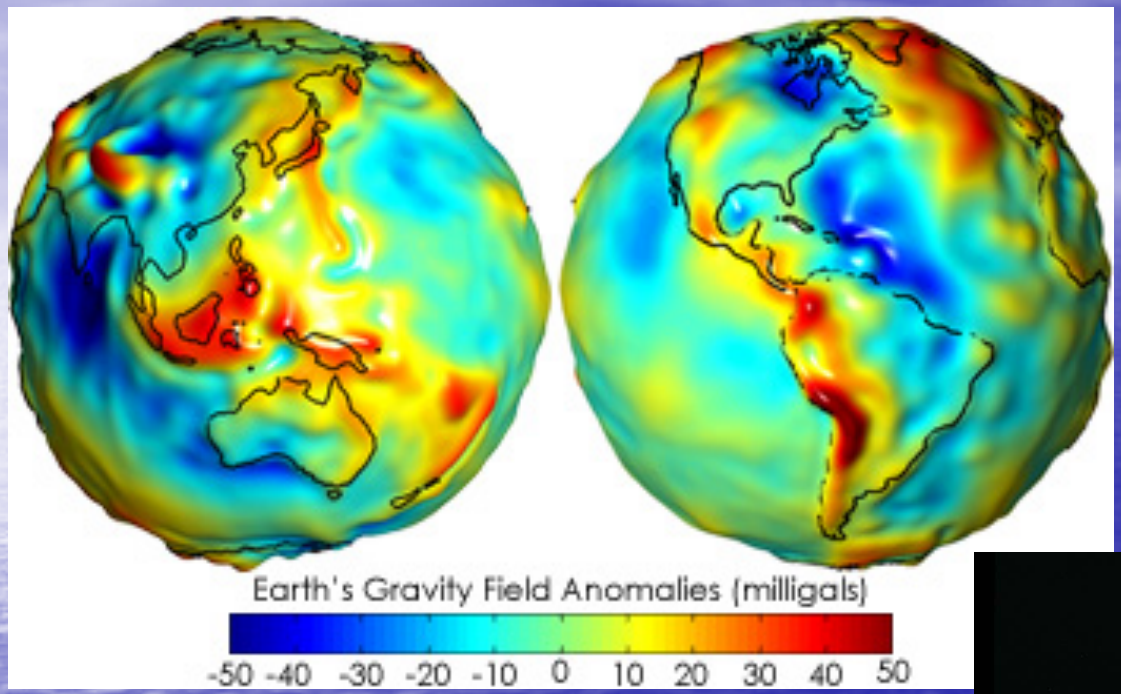


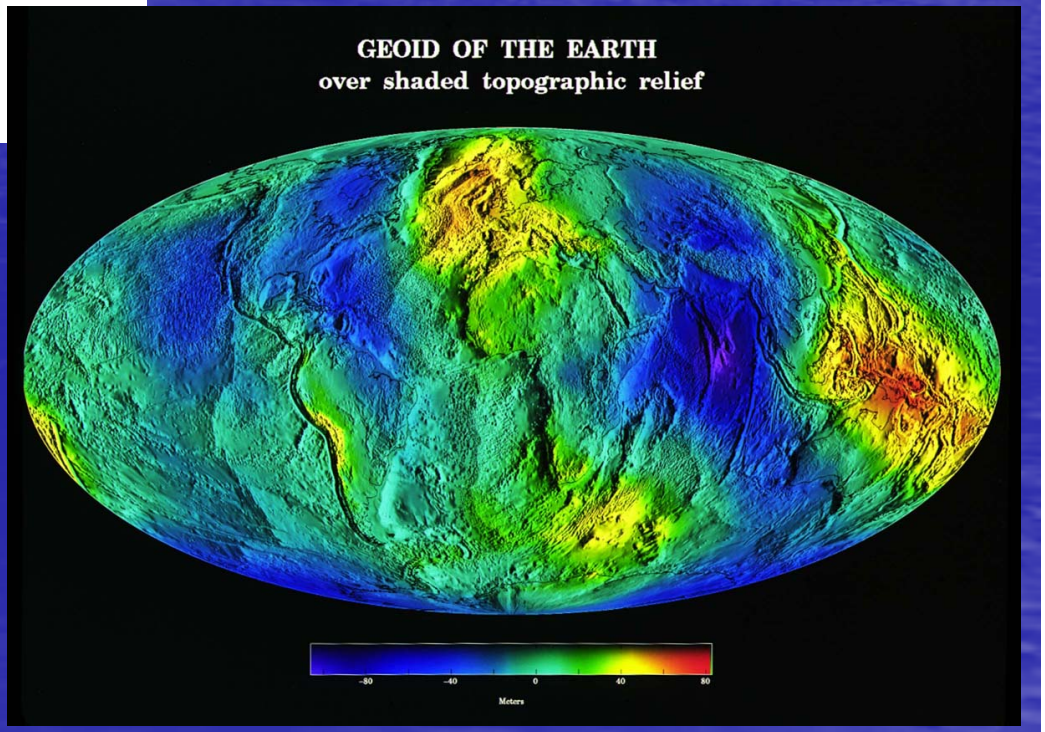
What shapes the sea surface?




GEOSAT
1985
U.S. Navy GEOdetic SATellite
TOP SECRET

The Geoid

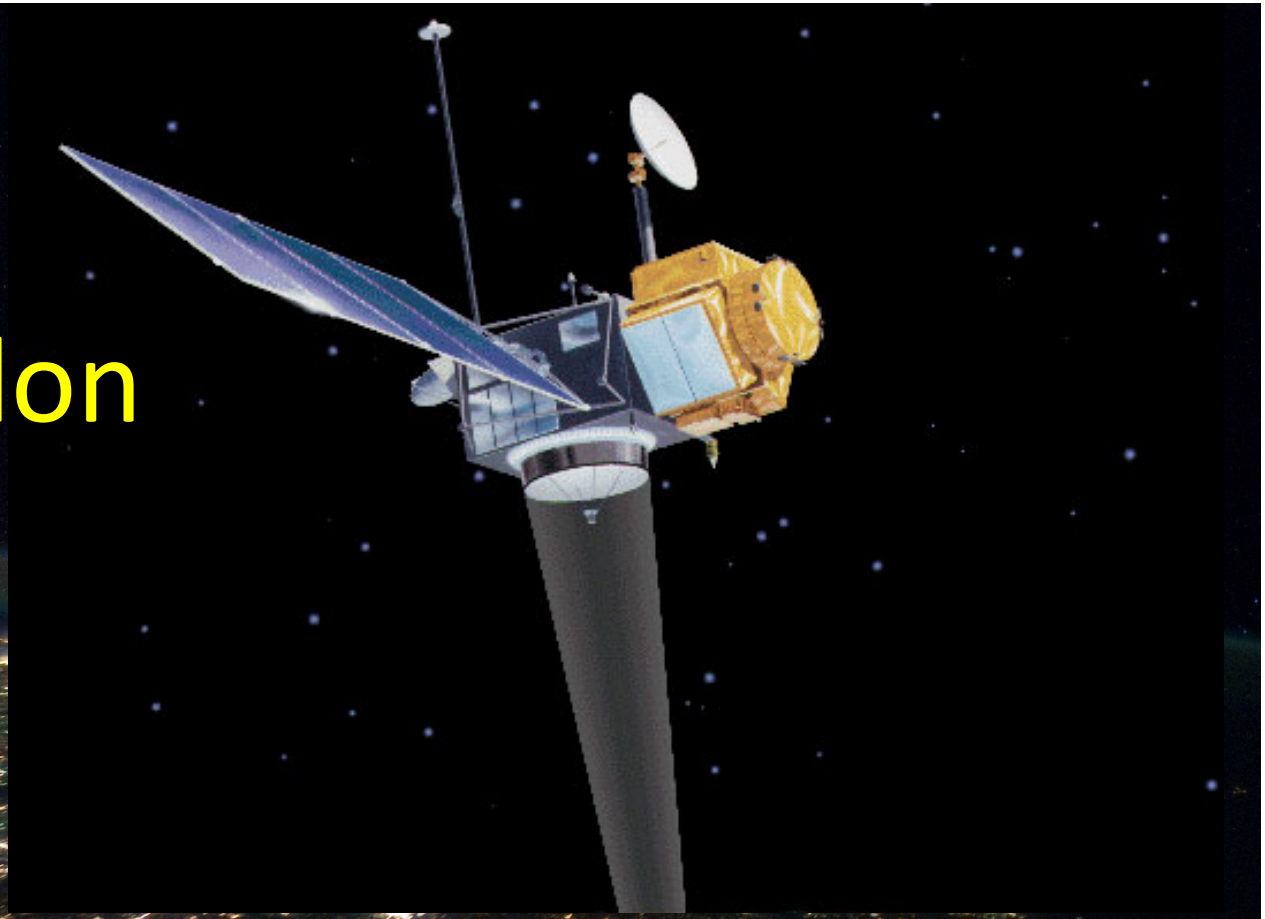

Earth's Gravity Field Anomalies (milligals)
-50 -40 -30 -20 -10 0 10 20 30 40 50


GEOID OF THE EARTH
over shaded topographic relief
-80 -40 0 40 80
Meters


ERS-1
1991

Satellite	Launch	Altitude	Agency	Accuracy
Skylab	1973	435 km	NASA	1 m
GEOS-3	1974	845 km	NASA	25 cm
SeaSat	1978	800 km	NASA	5 cm
GeoSat	1985	800 km	US Navy	4 cm
ERS-1	1991	785 km	ESA	*3 cm

TOPEX/Poseidon
1992



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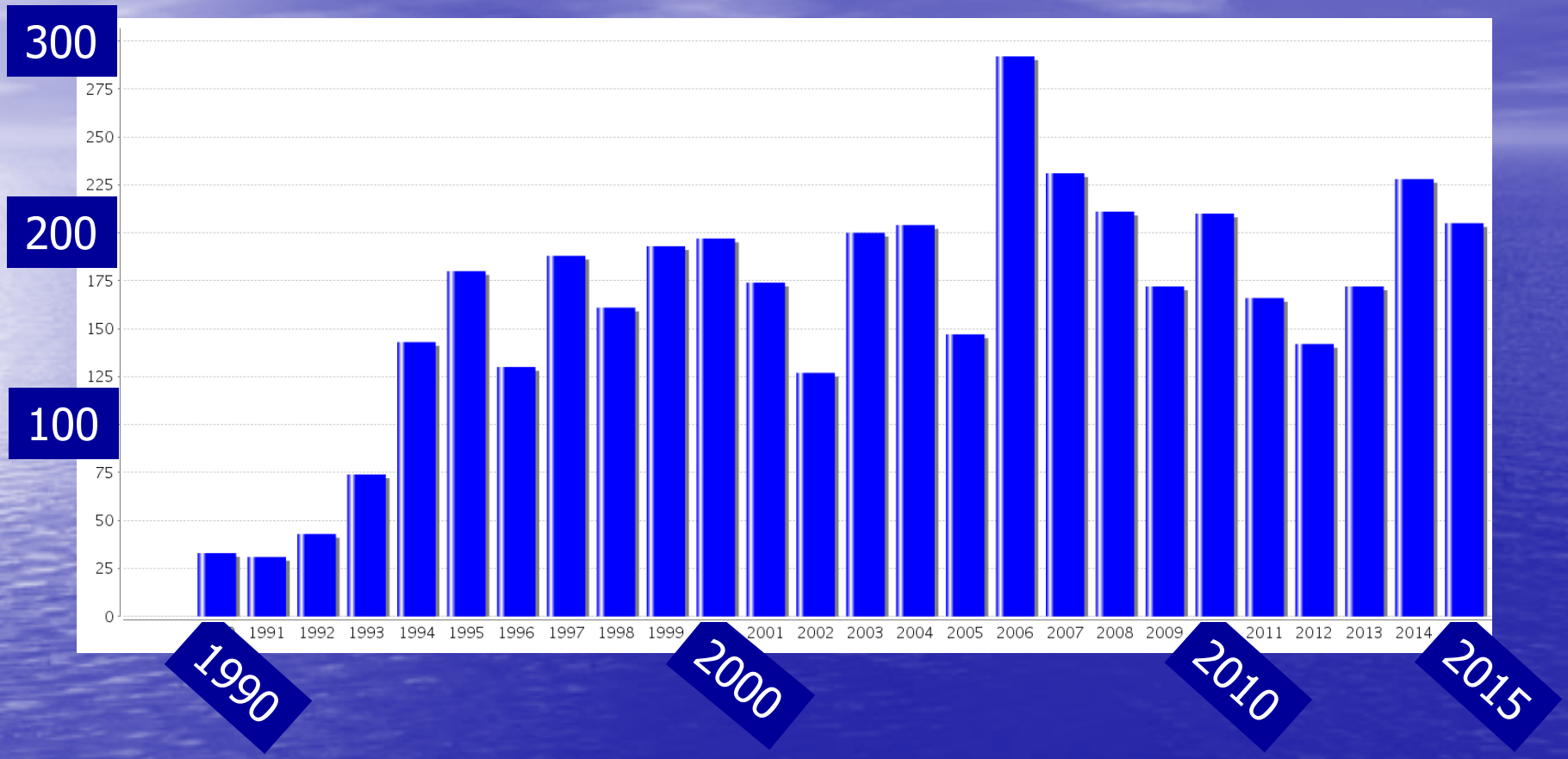
ERS-1	1991	785 km	ESA	*3 cm
TOPEX/ Poseidon	1992	1336 km	NASA/ CNES	2 cm

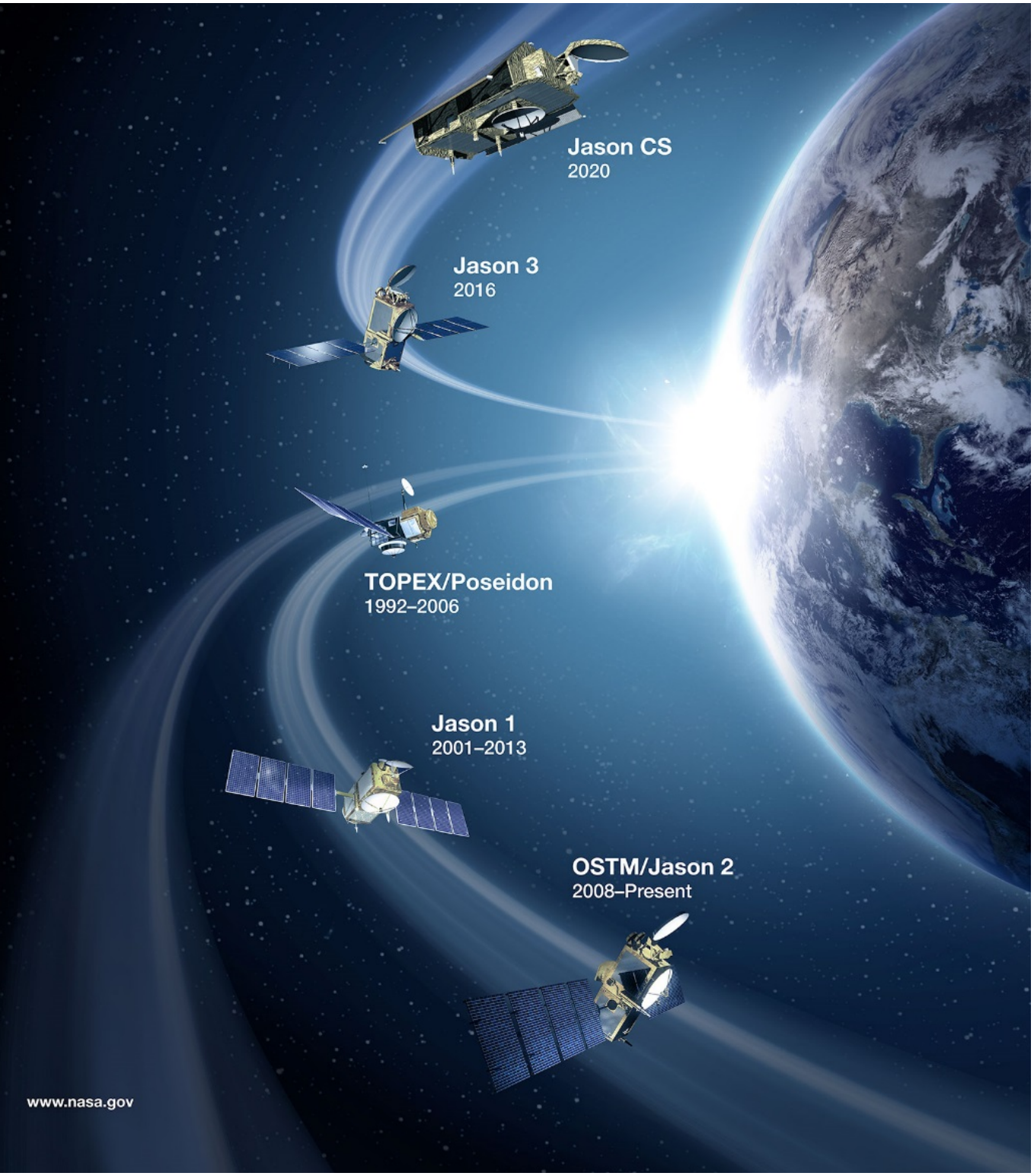
Publications using altimeter data



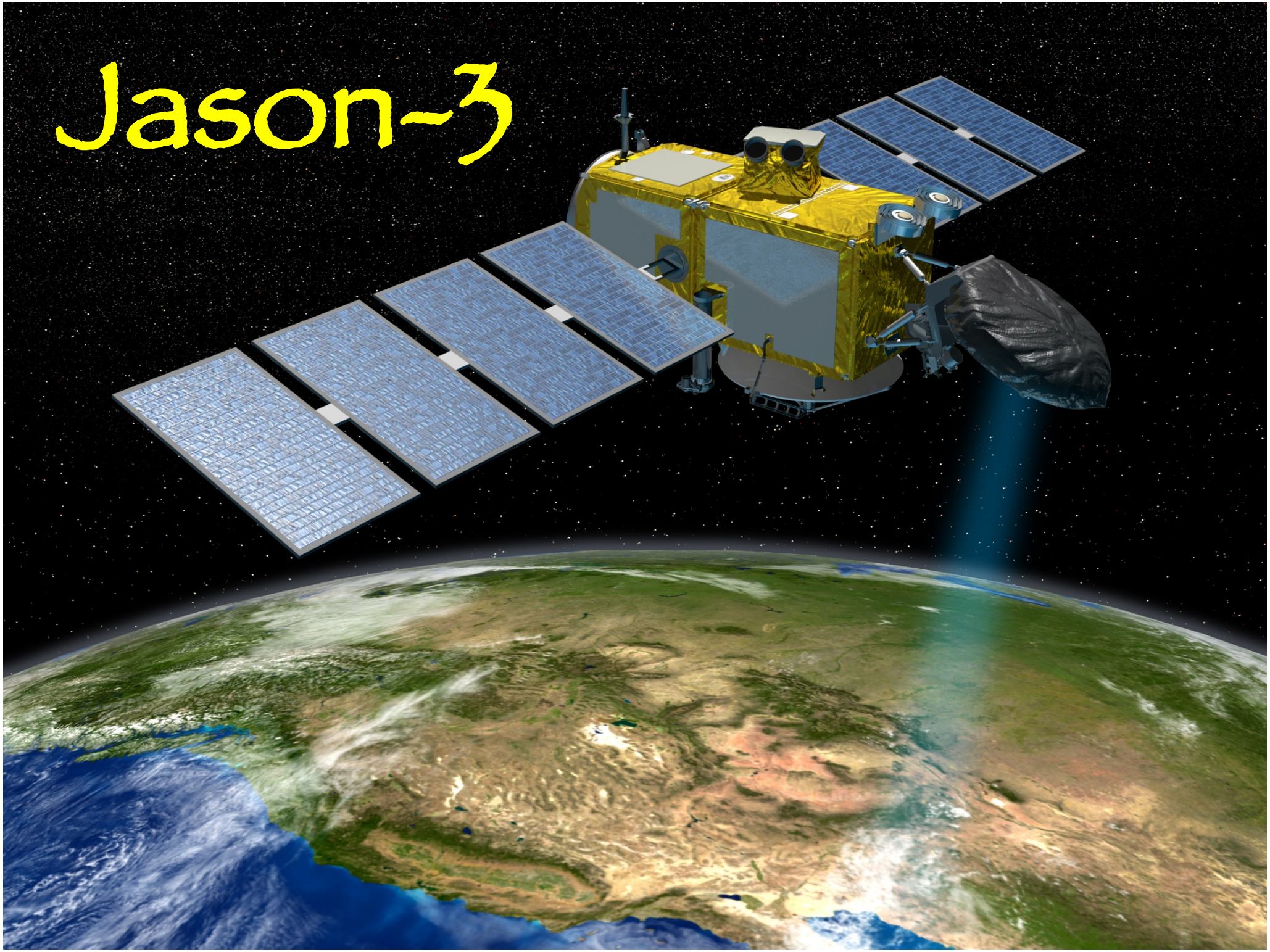
The Scientific community has published more than 4300 peer-reviewed articles using altimeter data, and still produces papers at a rate of about 200 papers per year. Most are published by members of the OSTST, which is respoinstibel


CNES
JASON
NASA

The era of modern altimetry



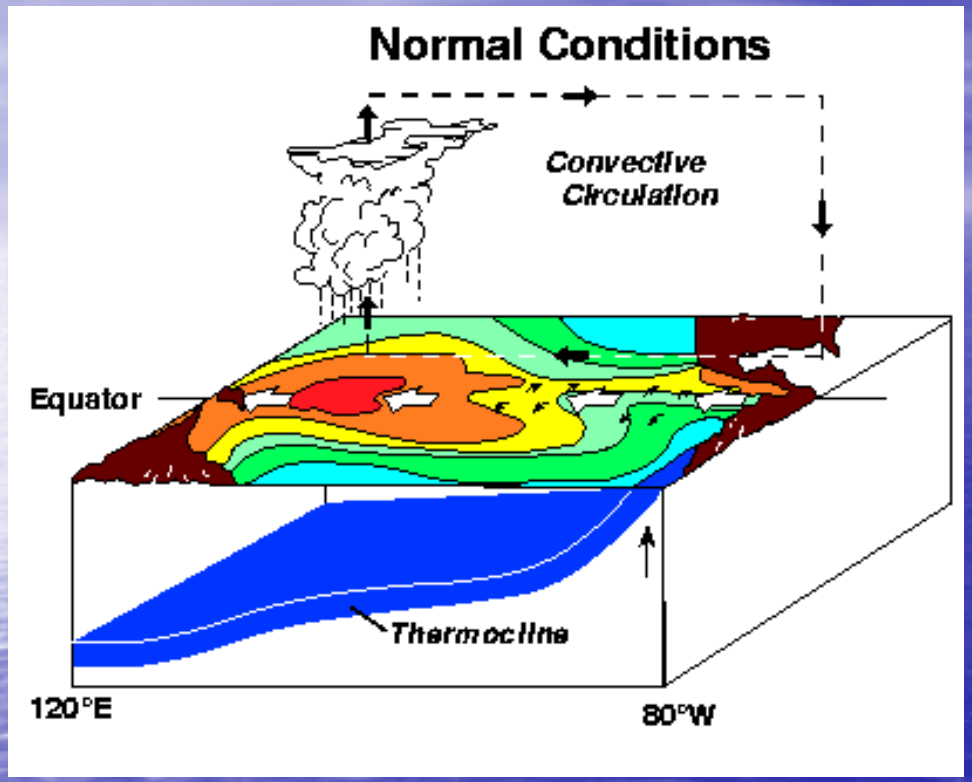

Jason
Part III


Jason-3

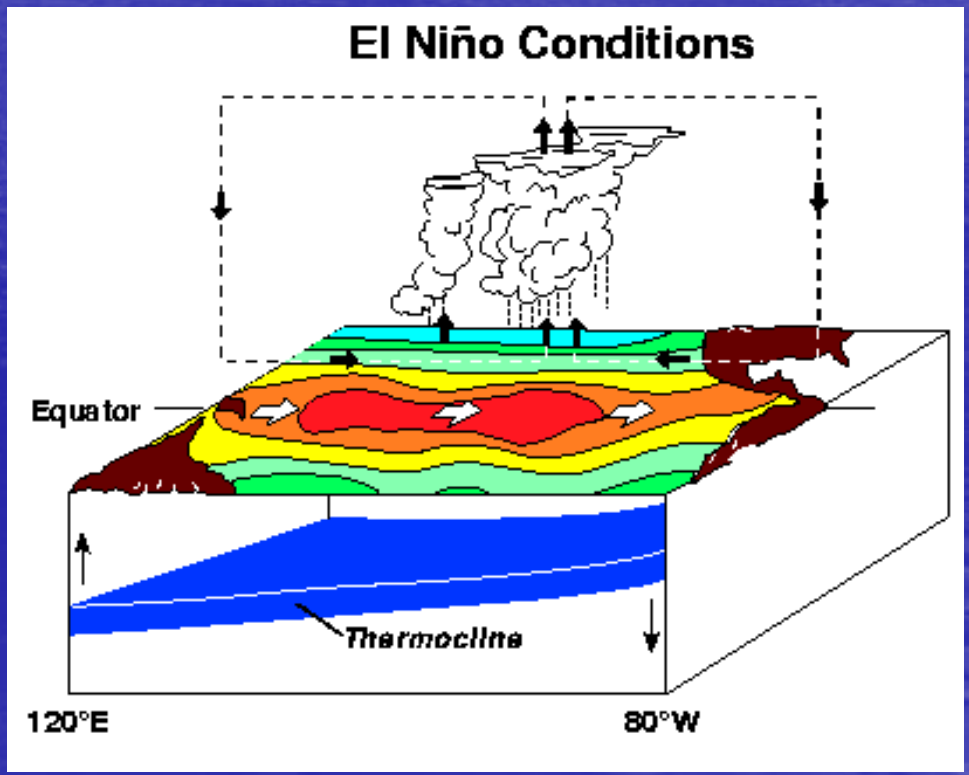

El Niño
THE WEATHER CHANNEL
EL NIÑO


GODZILLA
El Niño

El Niño 101



Strong Trade Winds
Warm H_20 Piles Up off Asia
Cooler H_20 off Americas

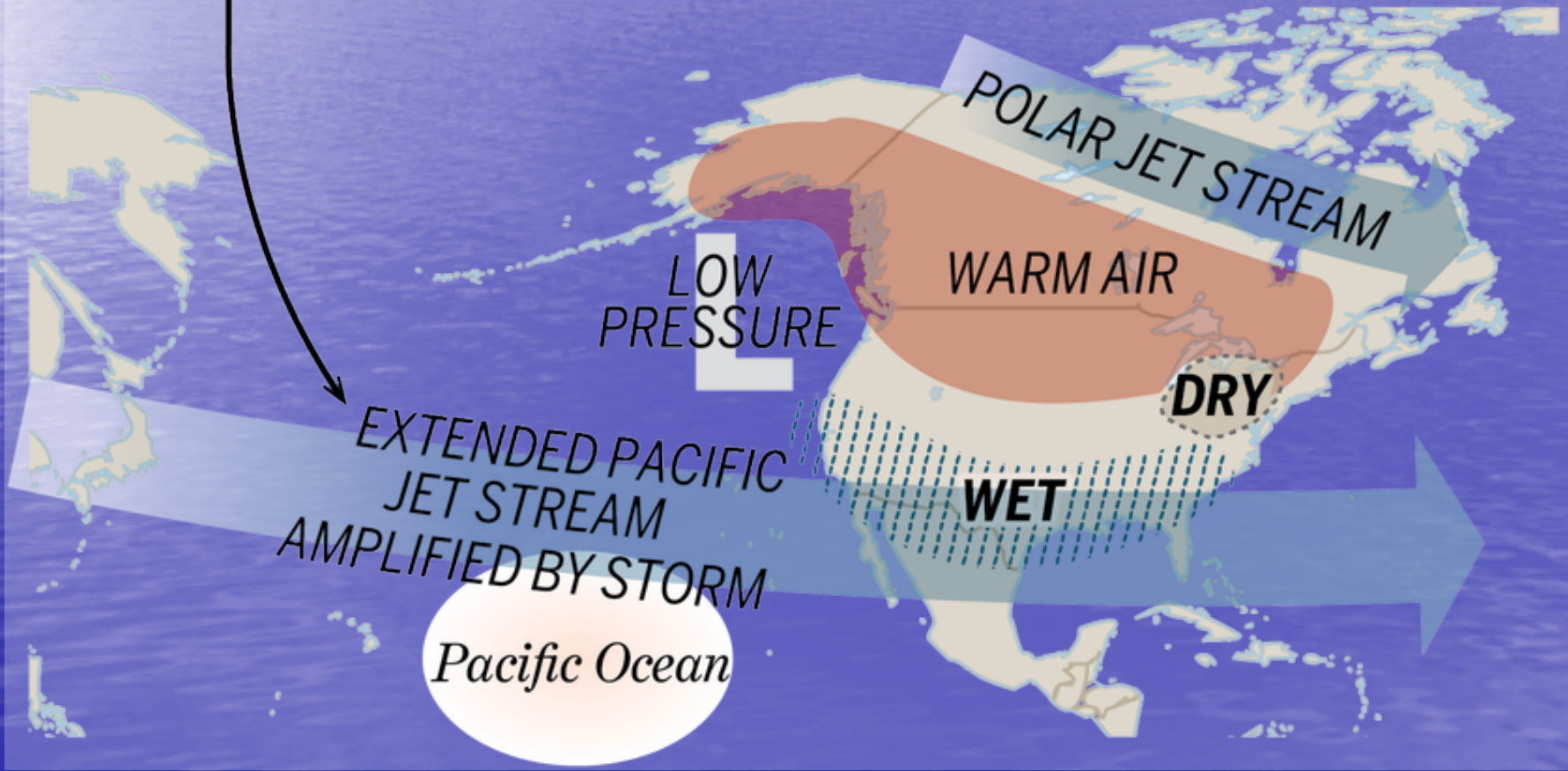


Weakening Trade Winds
Warm H2O off Asia
Moves toward Americas

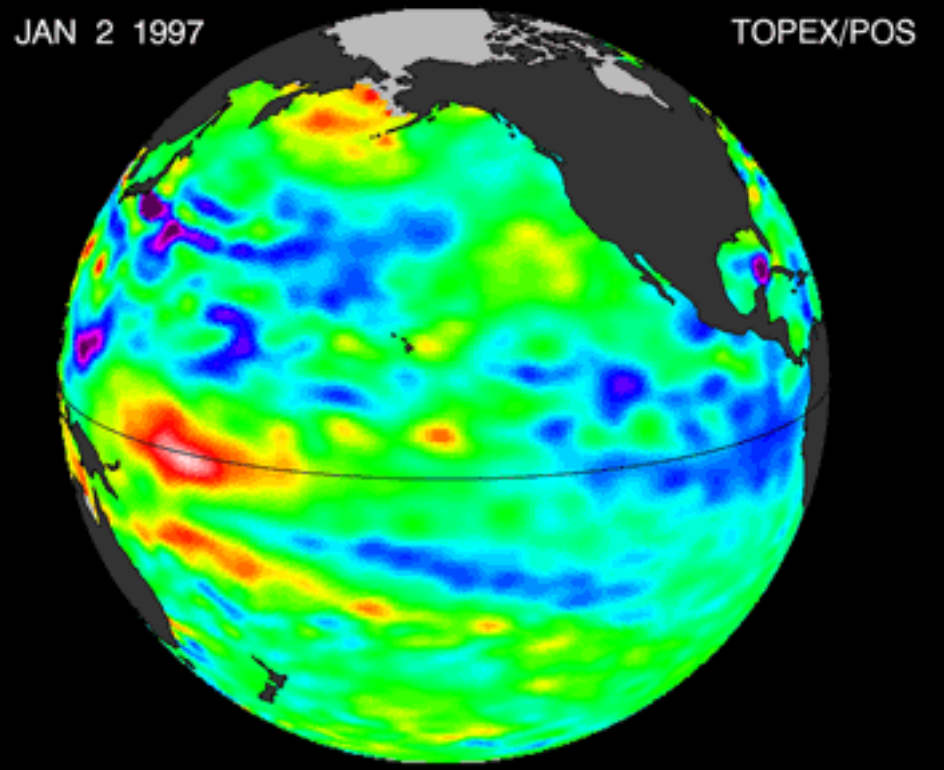
El Niño impact

During an El Niño year, the jet stream, which ushers storms across North America, intensifies and moves farther south than usual.

The result can be abnormally wet winters in California and dry and warmer-than-usual winters in the Pacific Northwest.

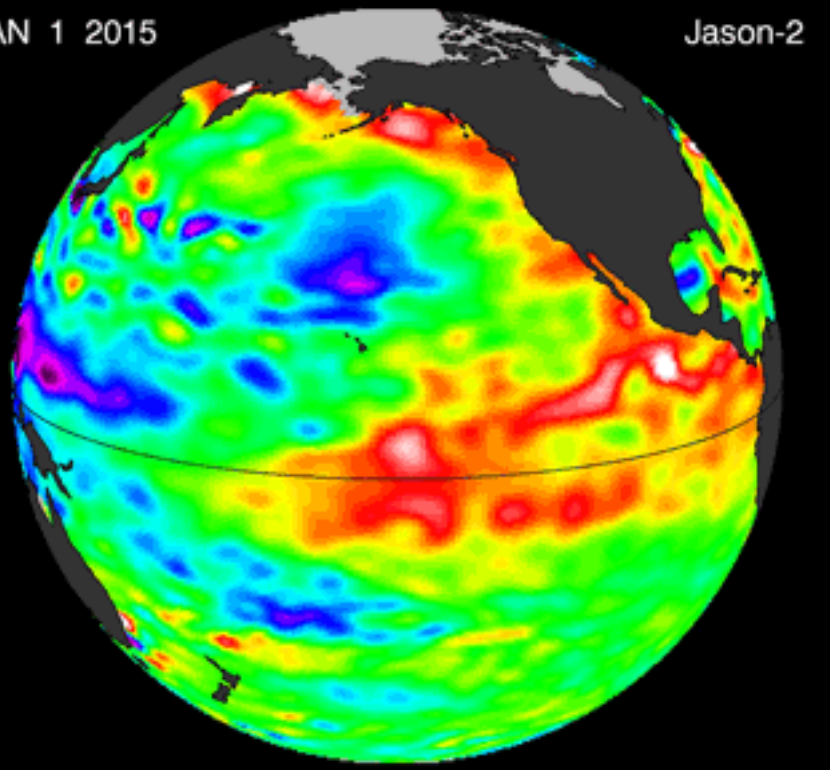


El Niño 1997



TOPEX/Poseidon 1997

El Niño 2015



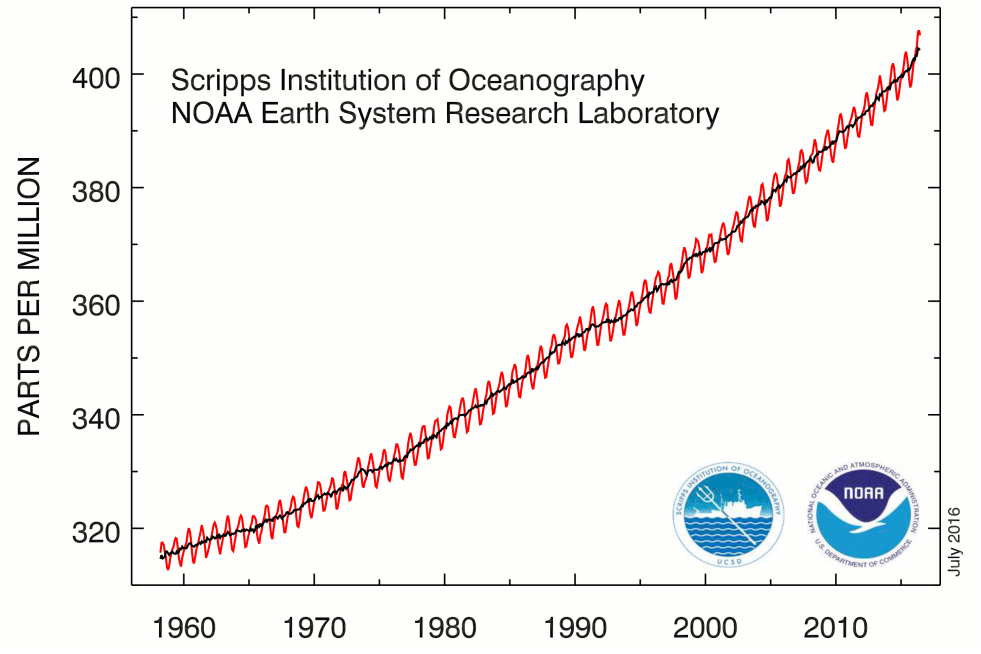
Jason-2 2015

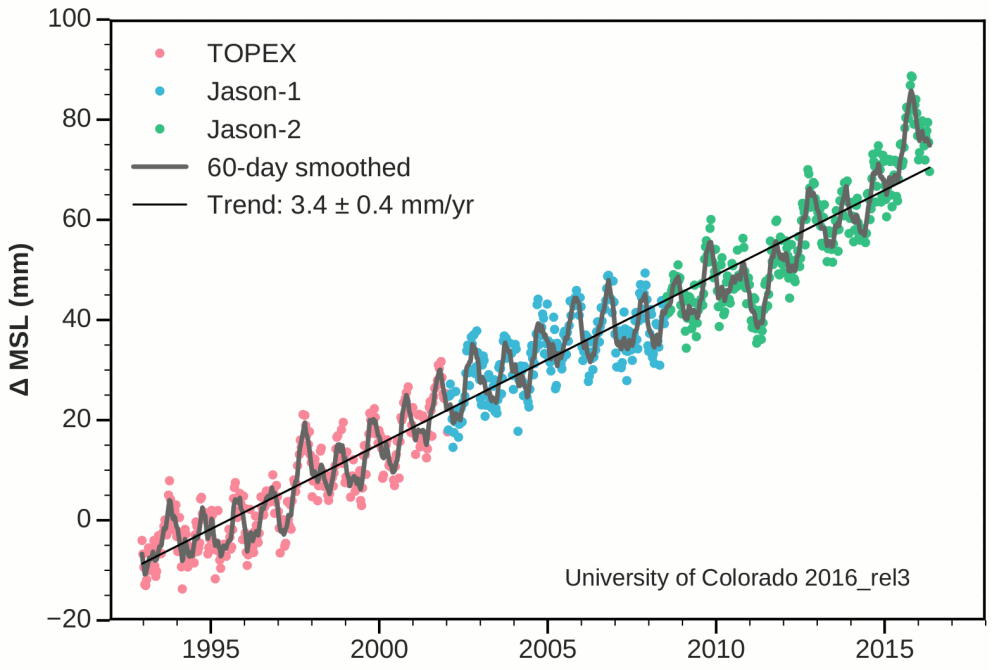
sealevel.jpl.nasa.gov

Satellite Altimeters Measure Sea Level Rise

Cause

Effect





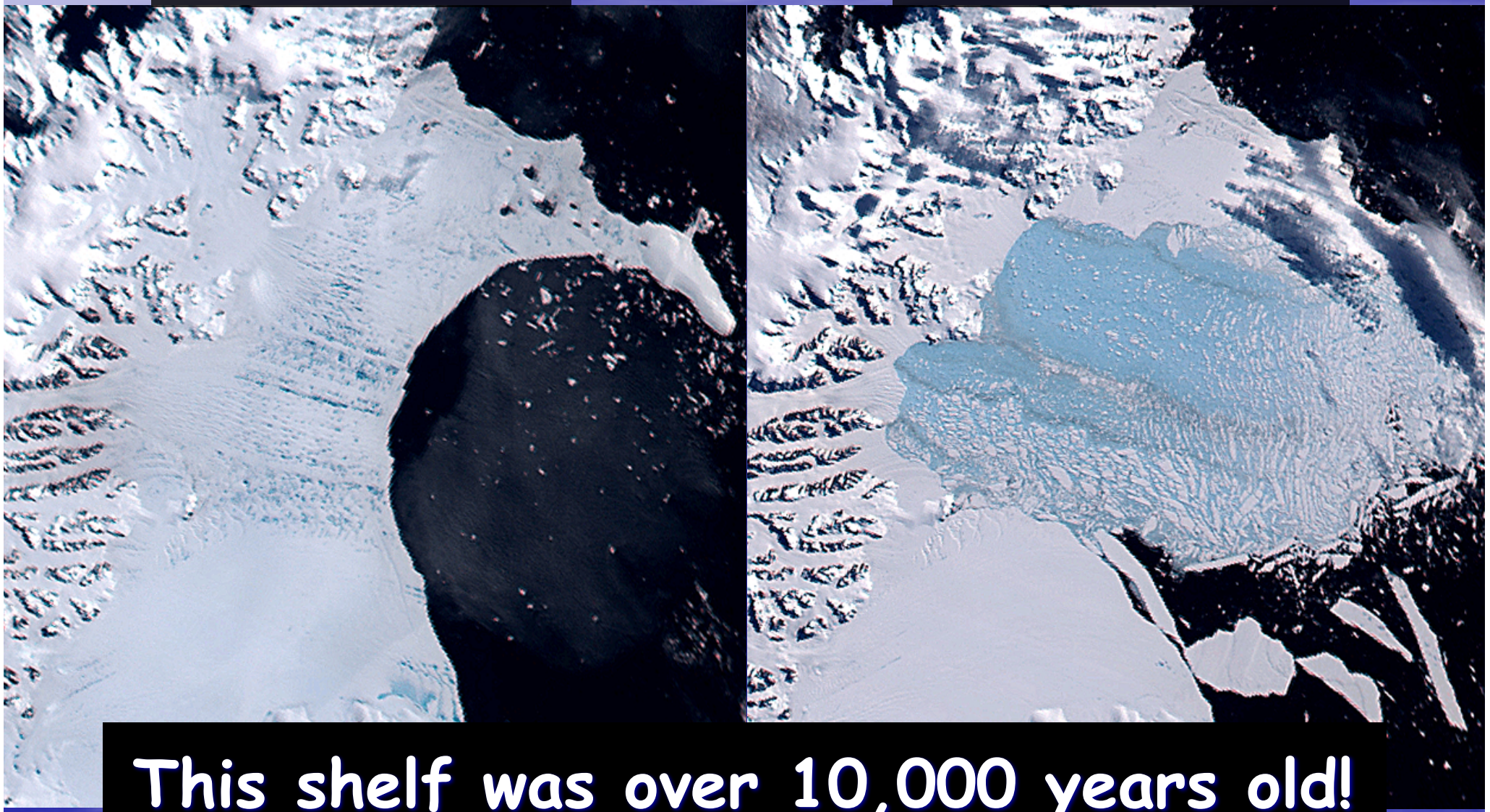
CO_2

Global Sea Level Rise

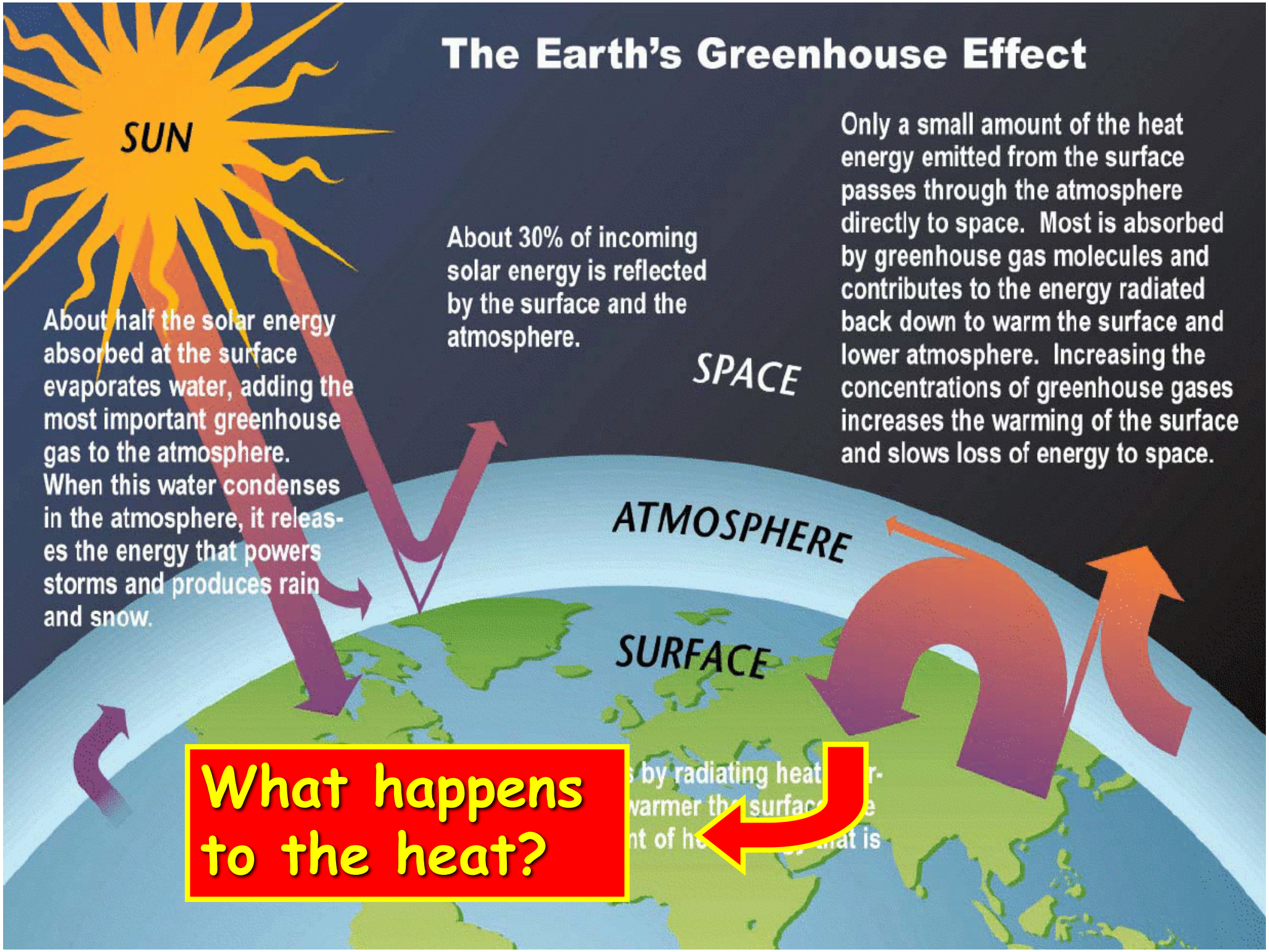
Larsen B Ice Shelf

Jan 31, 2002

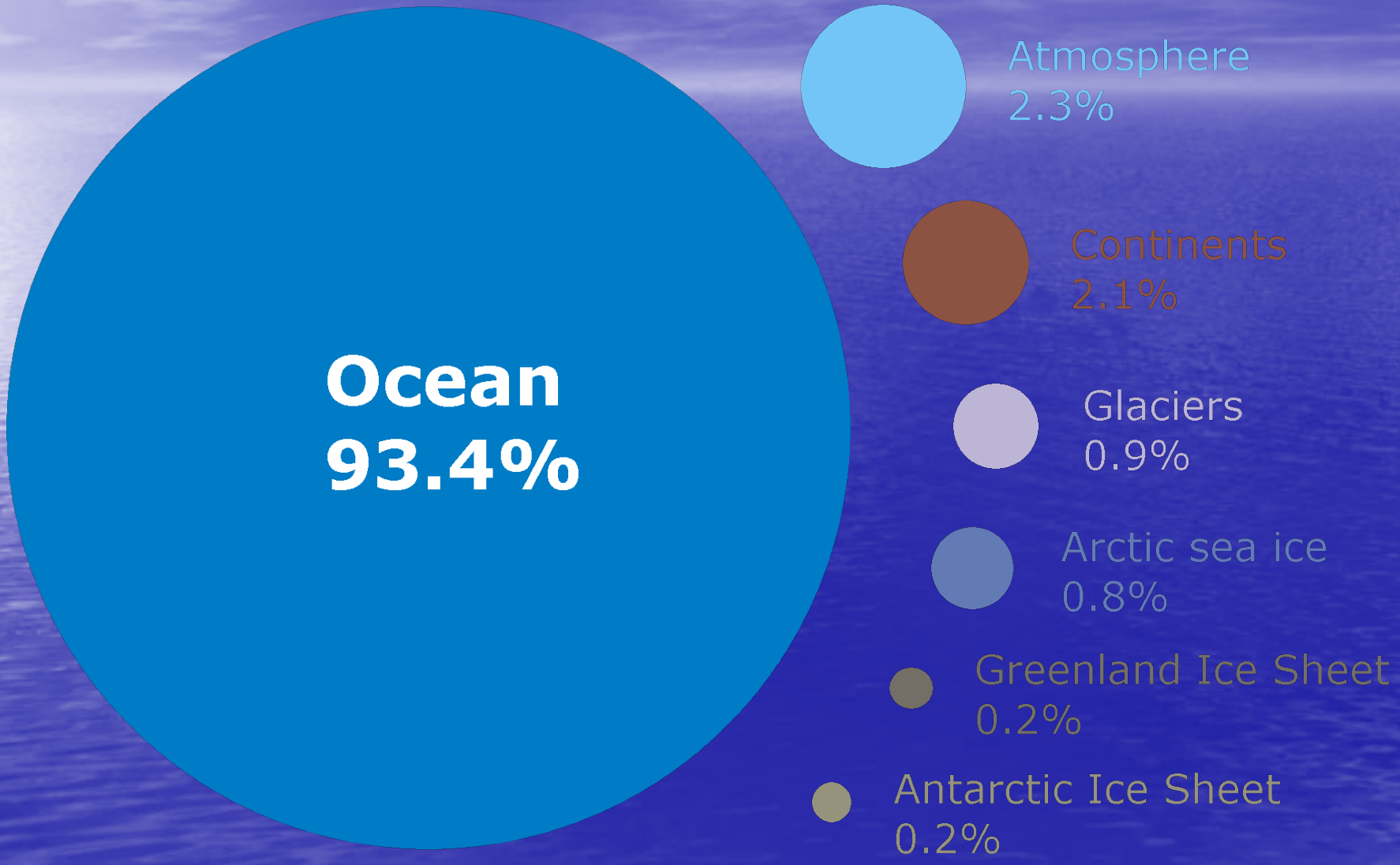
March 7, 2002



This shelf was over 10,000 years old!


The Earth's Greenhouse Effect
SUN
About half the solar energy absorbed at the surface evaporates water, adding the most important greenhouse gas to the atmosphere. When this water condenses in the atmosphere, it releases the energy that powers storms and produces rain and snow.
About 30% of incoming solar energy is reflected by the surface and the atmosphere.
SPACE
Only a small amount of the heat energy emitted from the surface passes through the atmosphere directly to space. Most is absorbed by greenhouse gas molecules and contributes to the energy radiated back down to warm the surface and lower atmosphere. Increasing the concentrations of greenhouse gases increases the warming of the surface and slows loss of energy to space.
ATMOSPHERE
SURFACE
What happens to the heat?

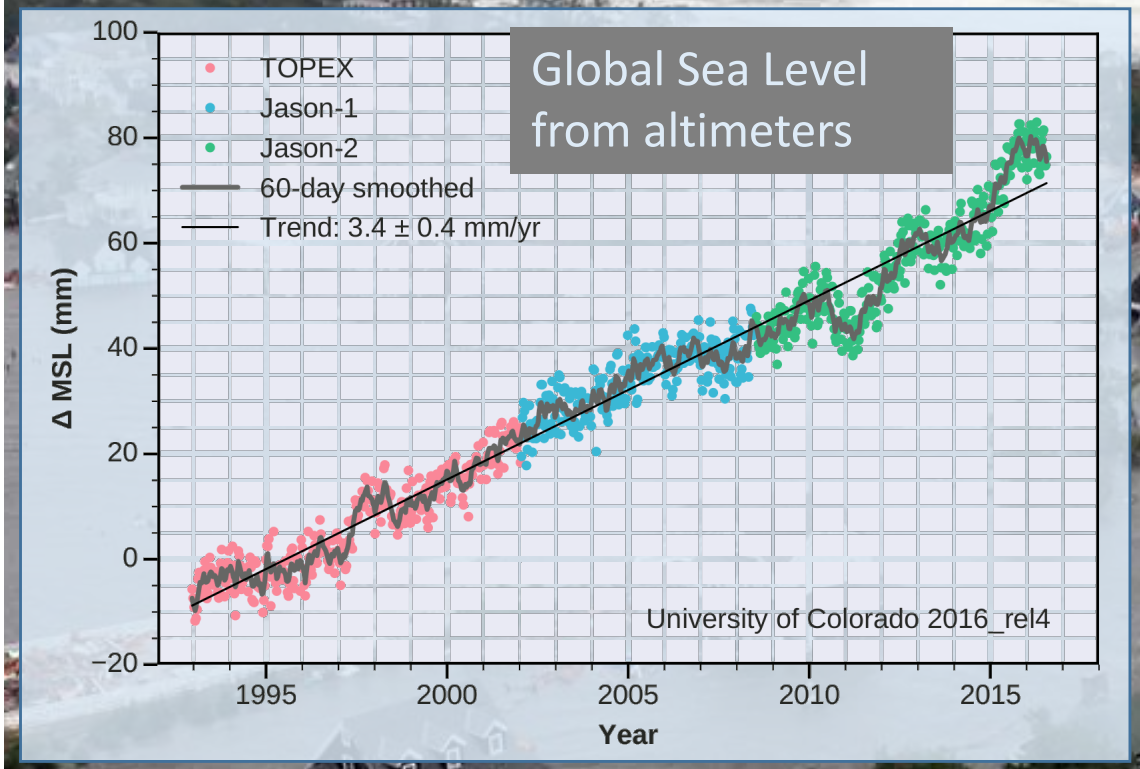
Where is global warming going?



Muir Glacier, SE Alaska

August, 1941 (photo by William Field) August, 2004 (photo by Bruce Molnia)

Altimeters measure the rising ocean

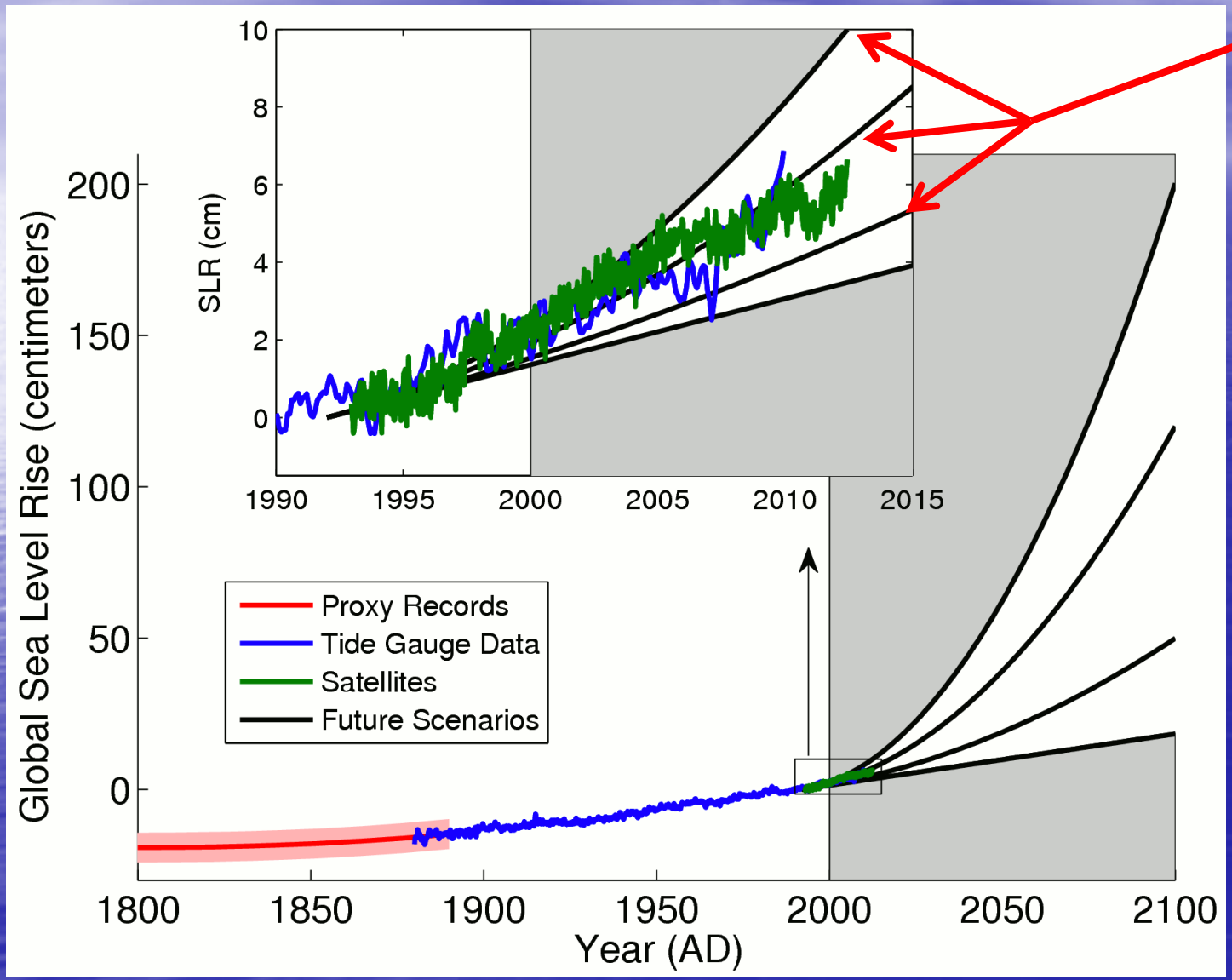


Worldwide, 200 million people live on land that will be regularly flooded or below sea level by 2100

Hauer et al., Nature Climate Change, 2014

Photo of New Jersey shoreline after Superstorm Sandy in 2012

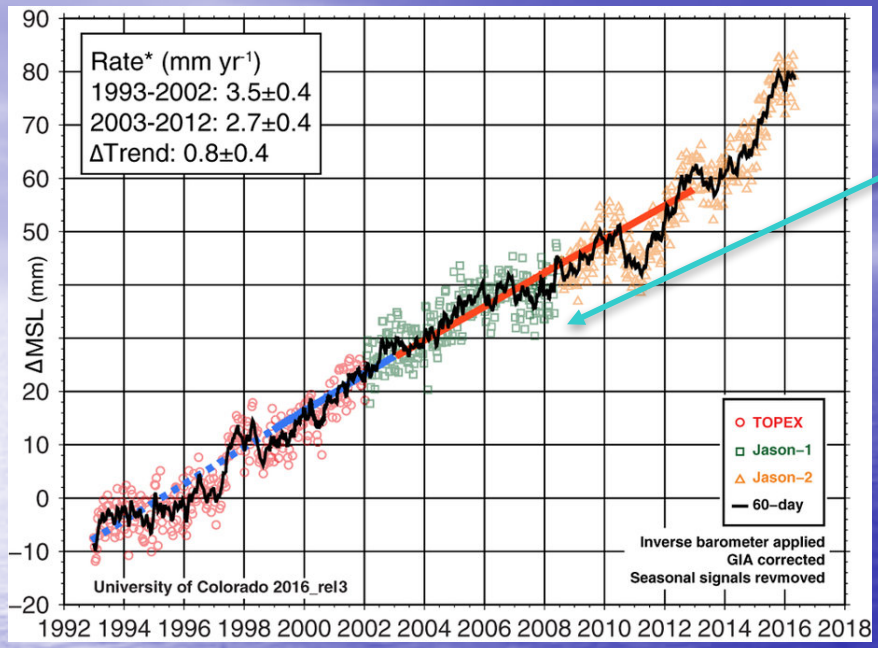
Future Rise



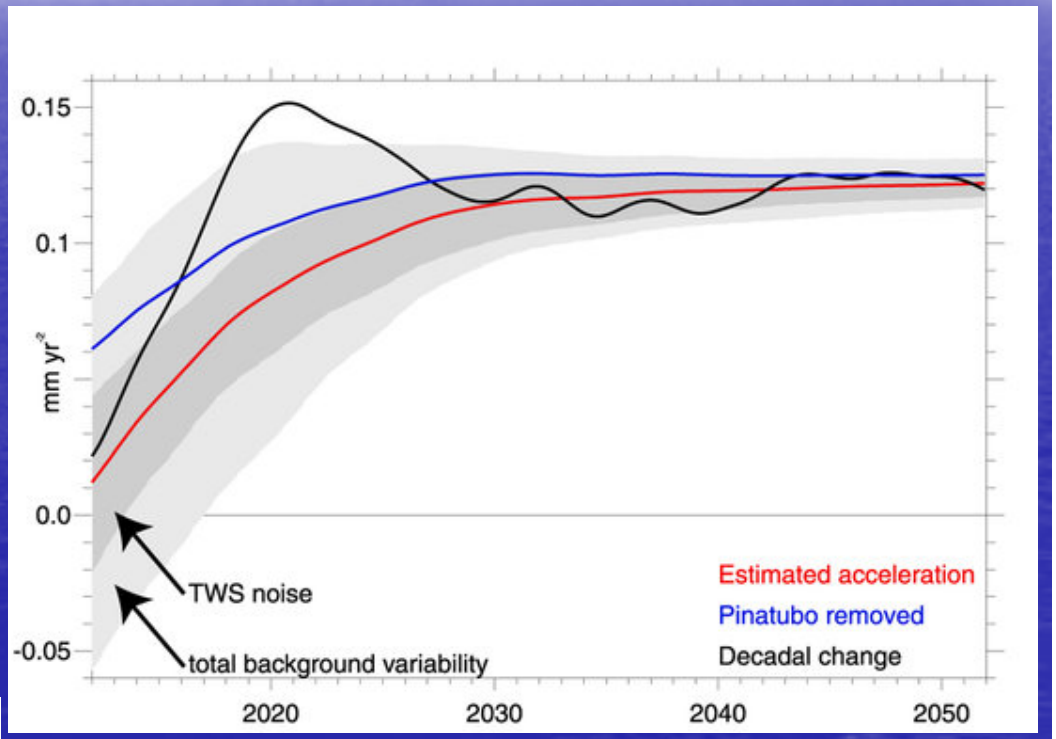
Which path are we on?

Satellite altimetry is our "canary"

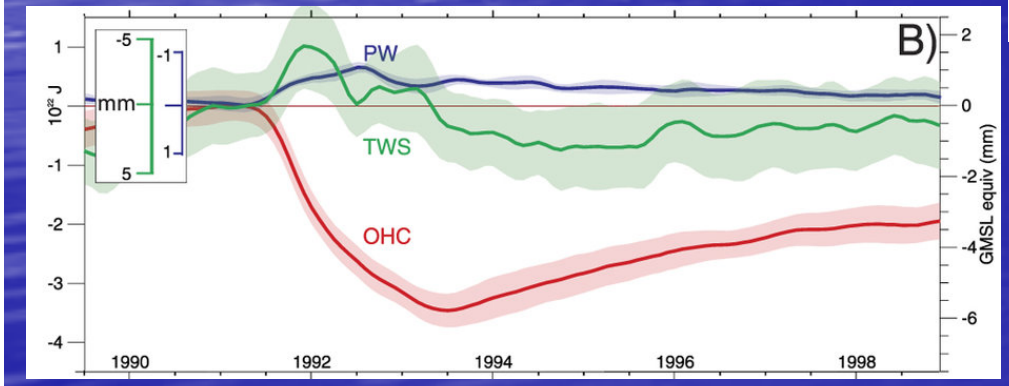
When will sea level rise accelerate?



Global sea level has risen steadily over the last 23 years, but ice melt has accelerated….



IPCC simulations suggest ocean cooling after Pinatubo eruption in 1992, and 'recover' caused faster than normal rise in the early 1990s.



Results suggest that acceleration will become detectable within the next 5 years!

Fasullo et al., ***Science***, *2016*

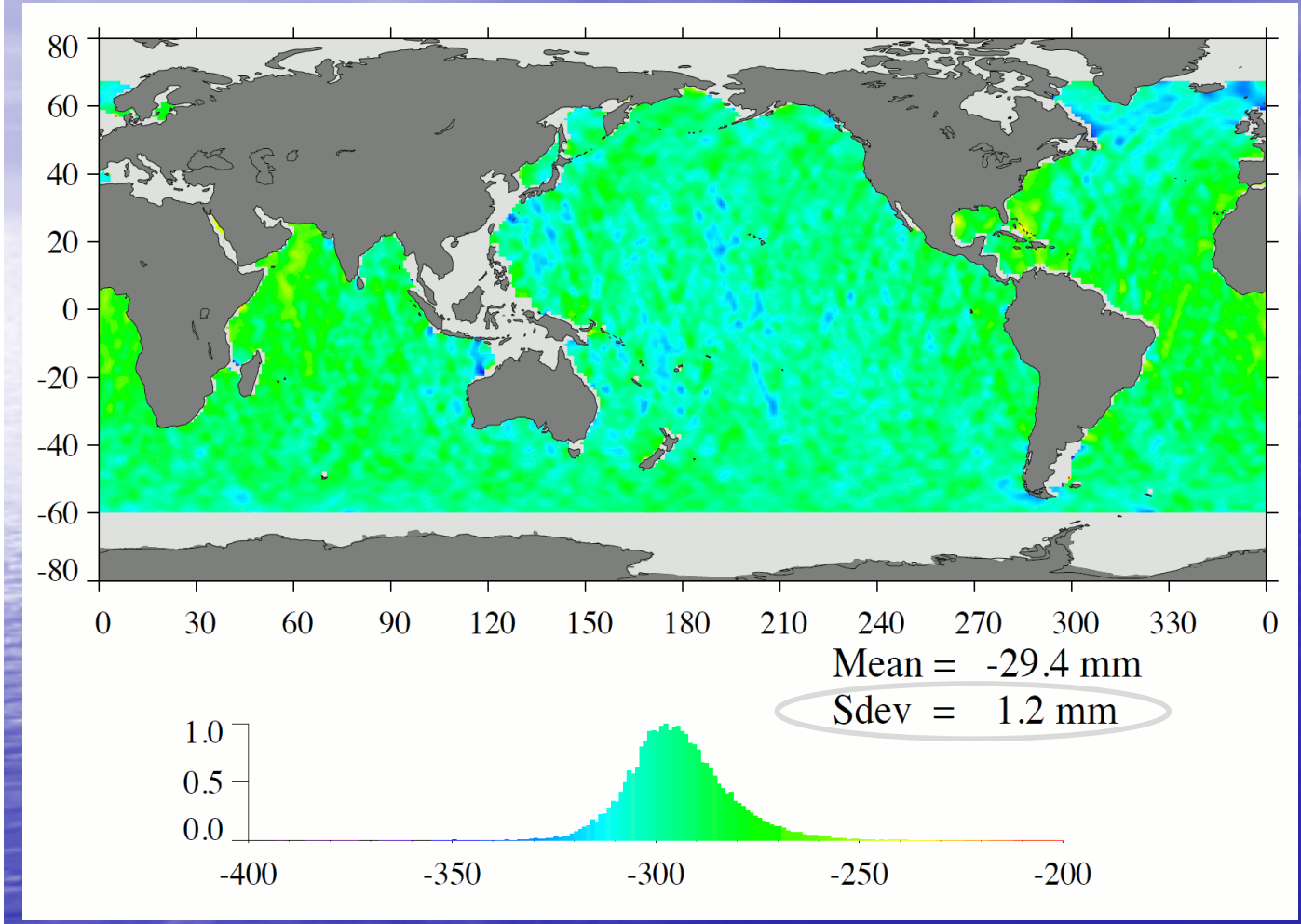
2016 Meeting La Rochelle, France, ~250 Participants

The OSTST

<u>Official OSTST Recommendation</u>:

The OSTST recognizes the importance of maintaining the climate record of sea level change. Because long-term stability of the AMR is required in order to achieve this, the OSTST is willing to *<u>accept the additional risk</u>* of… blah, blah blah.

Key Work done by OSTST

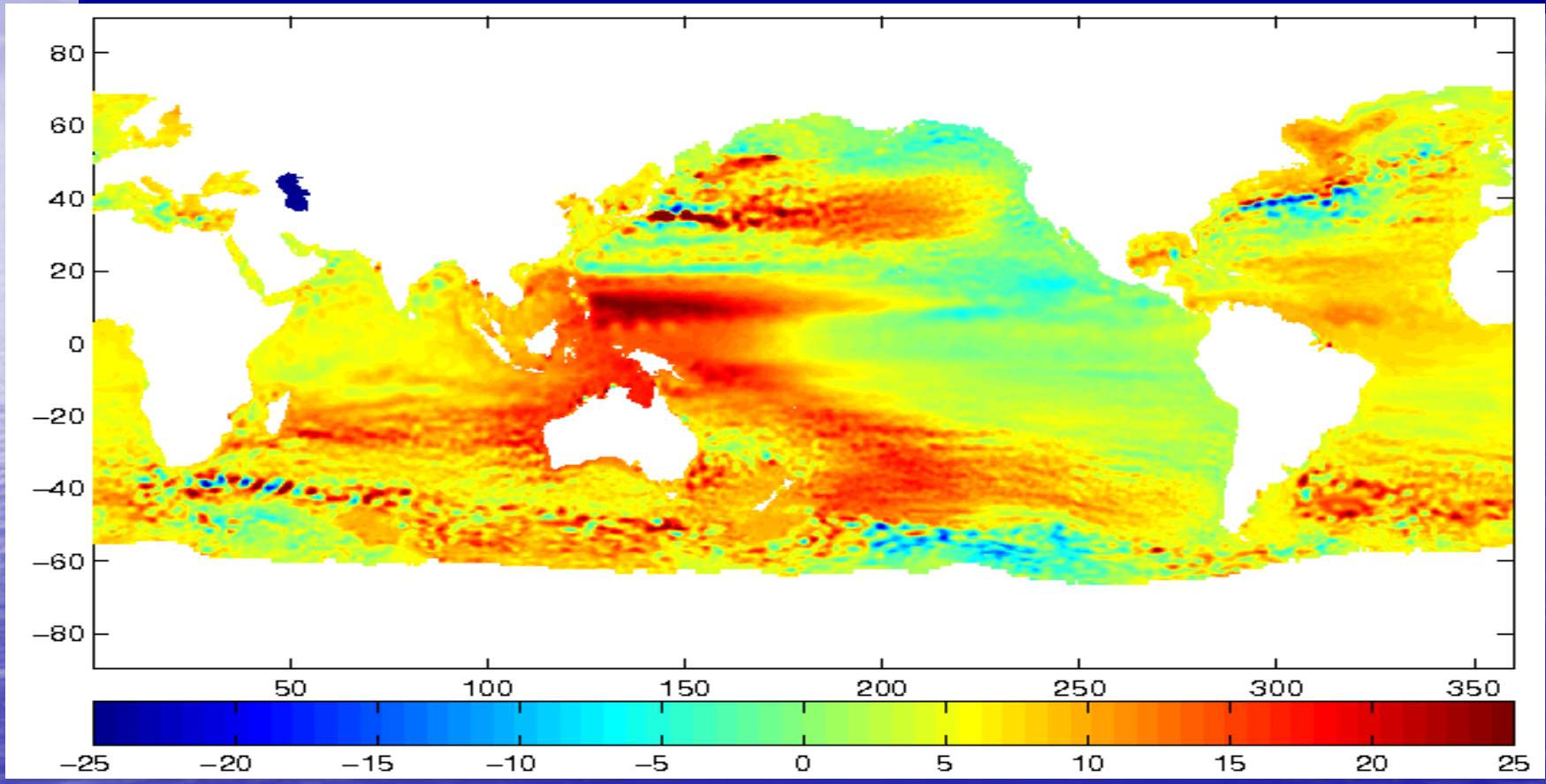


Difference between Jason-2 and -3 The RMS difference between the two (see bottom for the histogram of the differences) is only 1.2 mm! **Image credit:** Frank Lemoine

For 6 months, Jason-2 and 3 flew 80 seconds apart measuring the same ocean, so they could be cross calibrated

Patterns of Global Sea Level Change

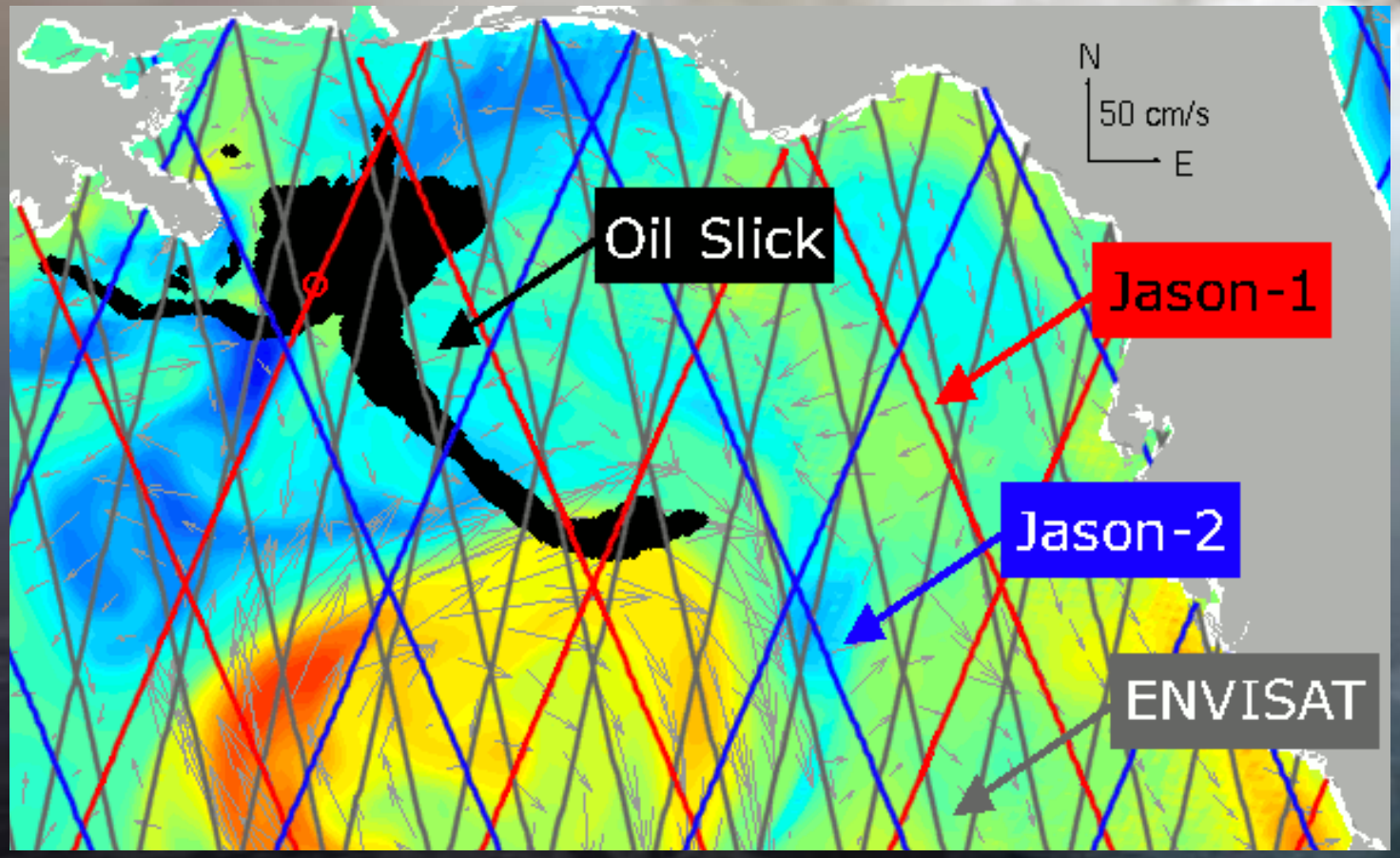
1993-2015 trend in Sea Level



Although global sea level rise tells a simple story, the regional pattern reveals a complicated one. Sea levels rise in some places and fall in others as natural cycles push heat from one place to another within the ocean. The satellites make it possible to keep track of the global picture

Deep Water Horizon Oil Spill

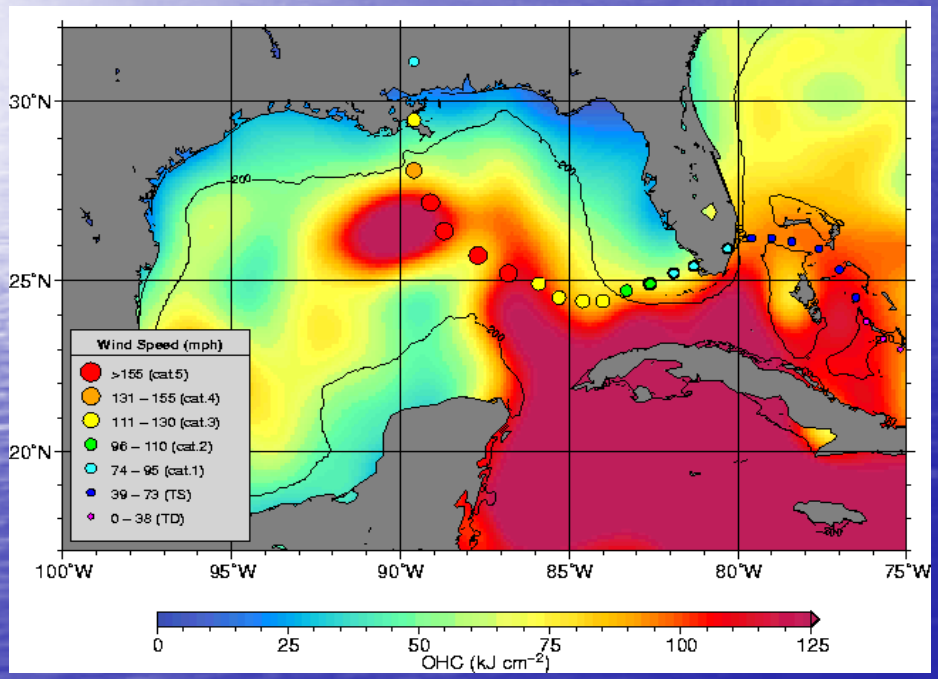
April 2010



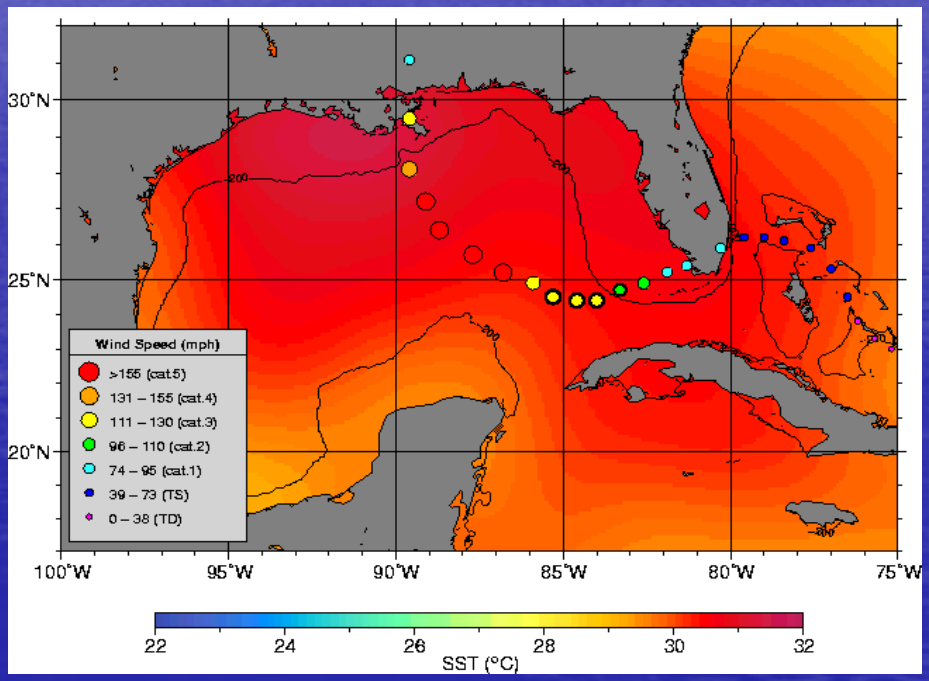
Altimeters tell us about currents in real time

Hurricane Katrina speeds up over warm water

Sea Surface Height



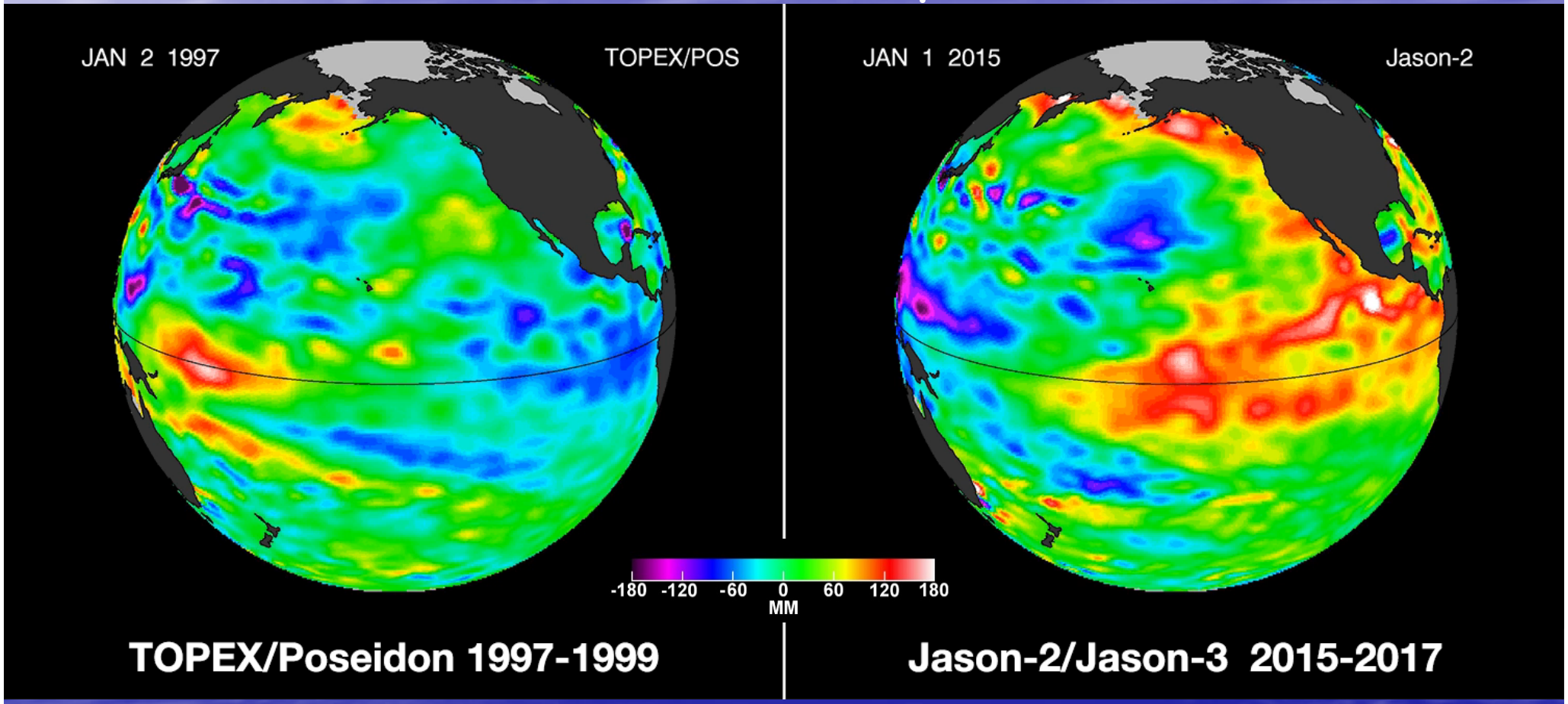
Sea Surface Temperature



Courtesy of NOAA/AOML

Godzilla's Return?

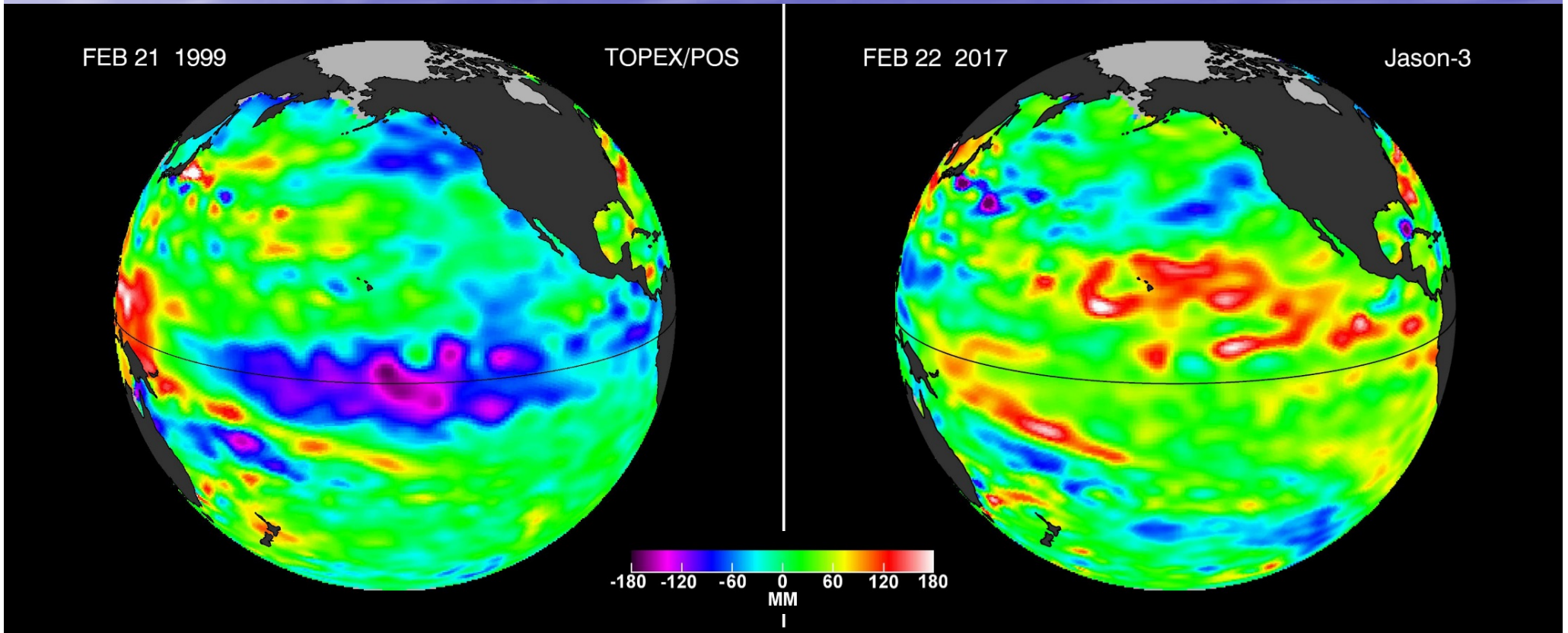
The Jason missions measure ocean height, which is related to ocean temperature



Last year's Godzilla gave SoCal a miss, but compared to the huge 97-98 El Nino, there was a huge difference

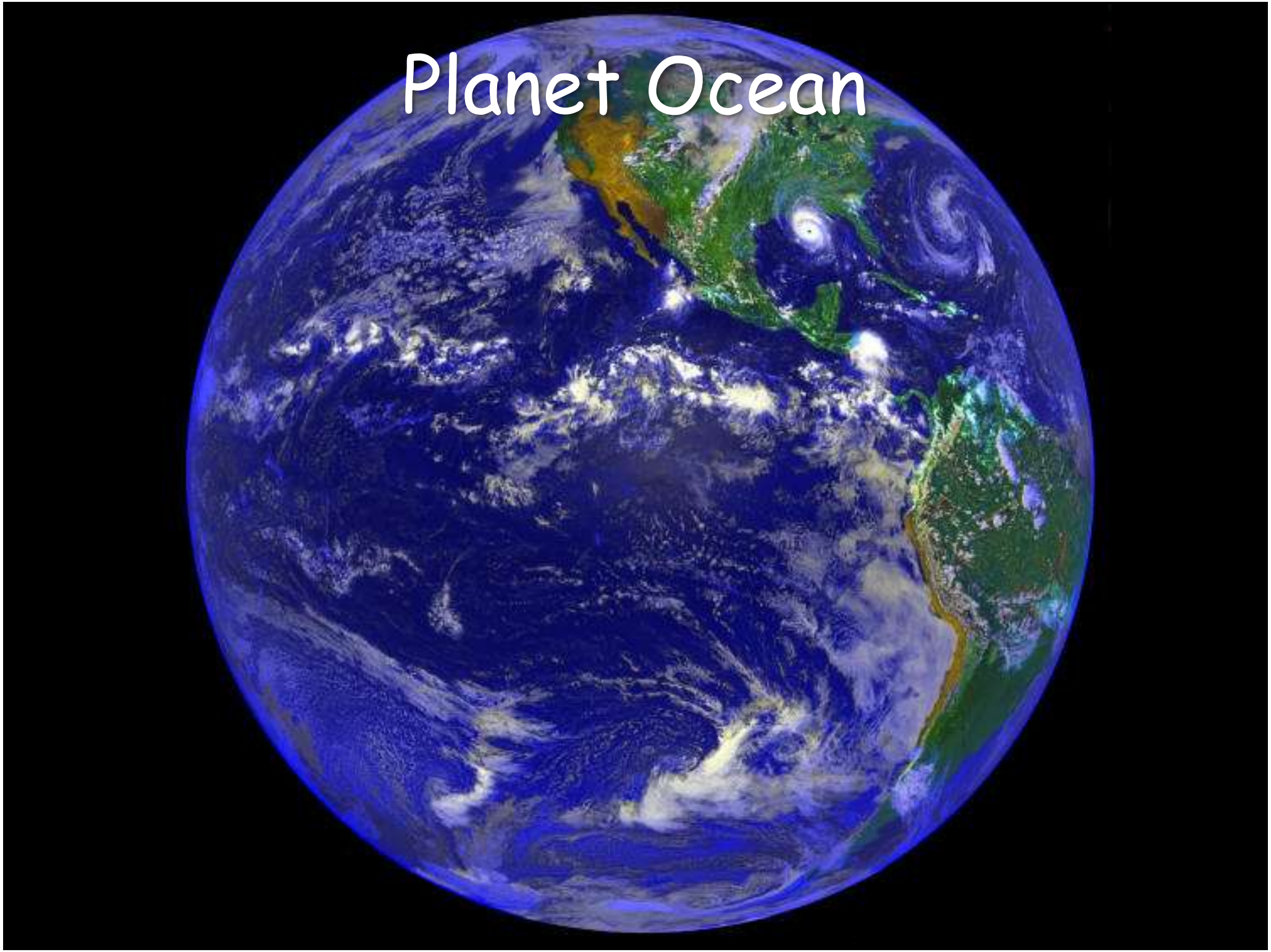
Godzilla's Return?

No Big La Nina in 2016, but leftover warm water could trigger another El Nino NEXT YEAR.



It could ALSO mean the return of the WARM PDO: a new decade of rain?

Planet Ocean



Fisheries and Altimetry

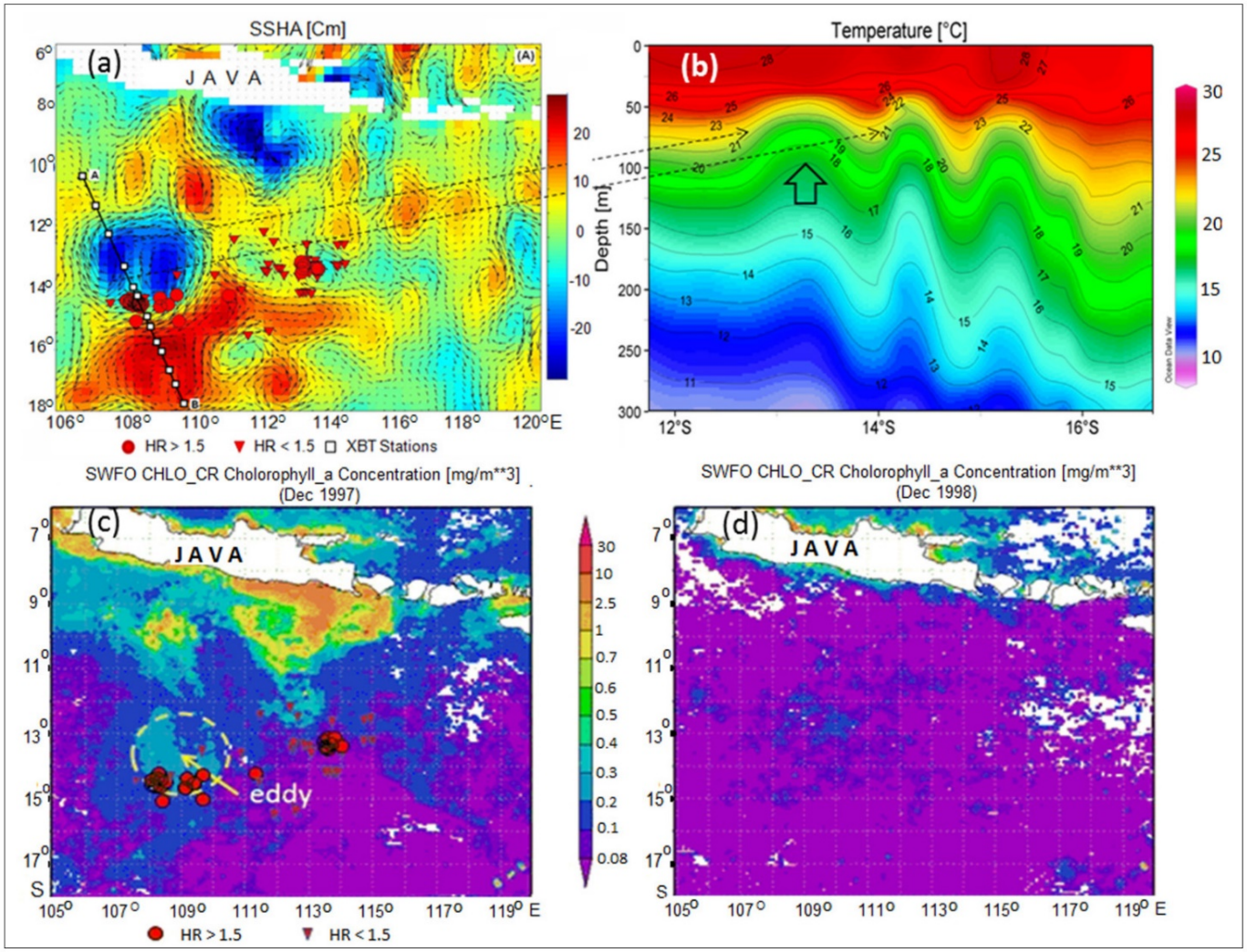


Figure 7 - (a) Bigeye tuna HR overlaid on SSHA, (b) Meridional section of temperature when eddy is well formed (c) Distribution of monthly mean Chl-a concentration at the time of El Niño and IOD positive phase in December 1997, (d) and normal condition in December 1998.

From Lumben-Gaol et al., *Euro. J. of Remote Sensing*, 2015

Tuna fisheries in the Indian Ocean depend on El Niño, the state of the Indian Ocean, and eddies (swirls of ocean currents that persist for weeks or months)

Altimeter data helps track all three of these (El Nino, the Indian Ocean Dipole *and* eddies). This study found tuna catch and chlorophyll where high on the edge of front, where warm and cold water were close together.