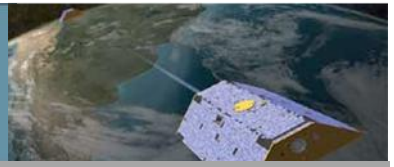
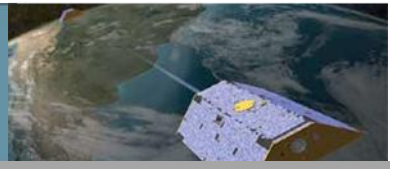
GRACE – Measuring Climate Change with Gravity



Carmen Boening

Michael M Watkins (Project Scientist)
contributions from John Fasullo, Felix Landerer, Matt Lebsock, Steve Nerem, Graeme Stephens, Josh Willis

Why Use Gravity Measurements for Climate?

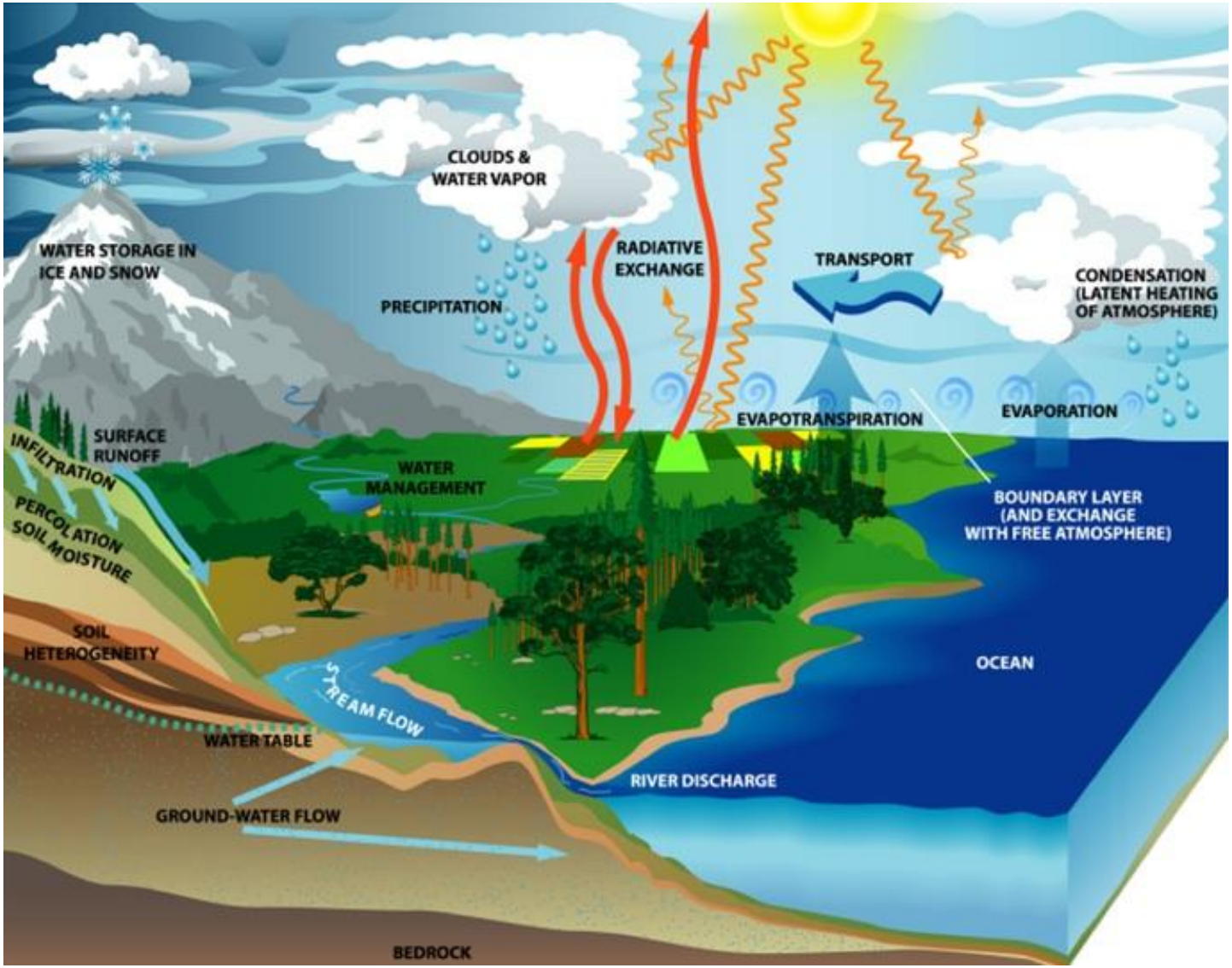


- All components of the Earth system have mass (and hence gravity)
  - Ice sheets
  - Ocean
  - Surface water
  - Ground water

- Can we use this gravity to track their movement and change?
  - If so, we could weigh the ice sheets, see ground water below the Earth's surface, and ocean mass movement

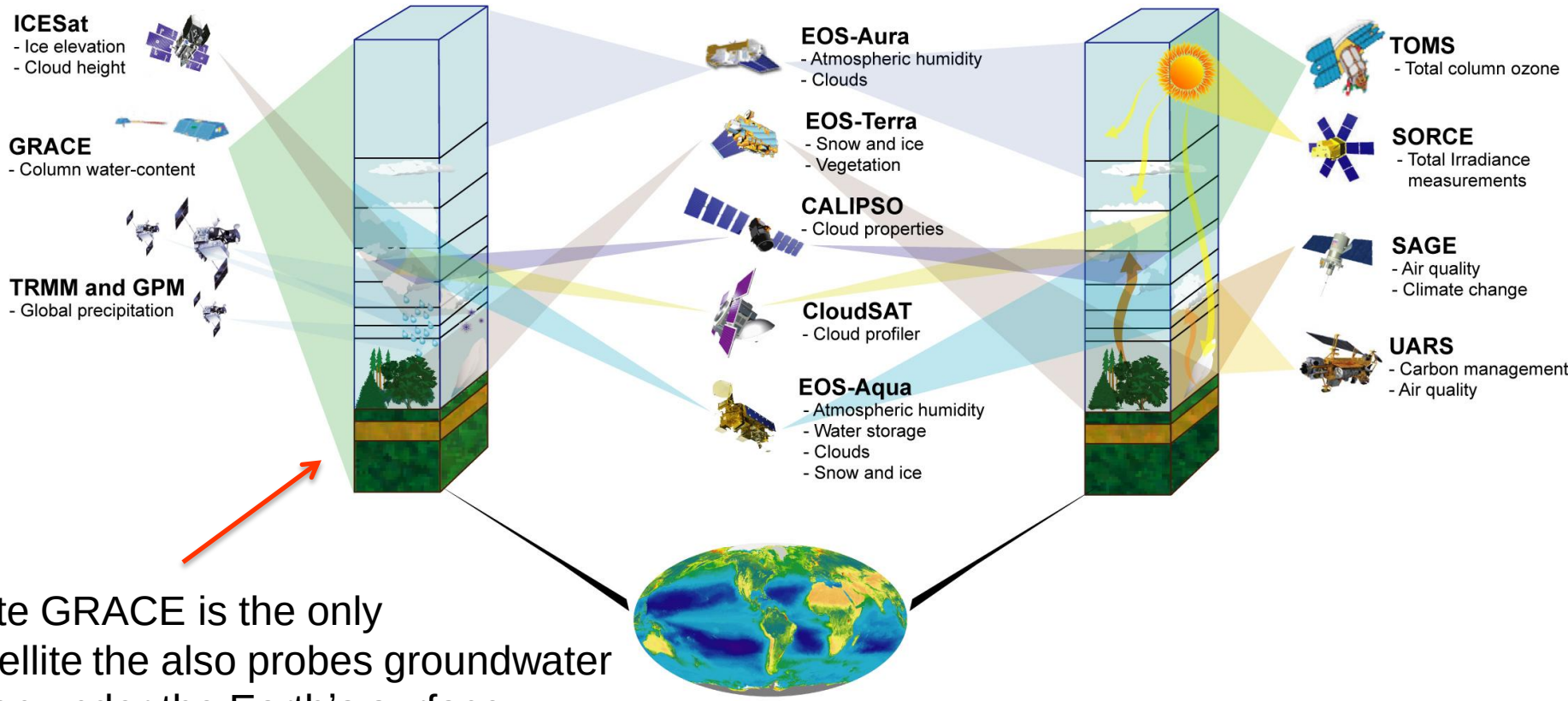
Yes! - This is the purpose of GRACE

Earth's Complex Climate System – Hydrosphere/Cryosphere/Atmosphere/Biosphere



NASA's New Generation of Earth Observing Missions

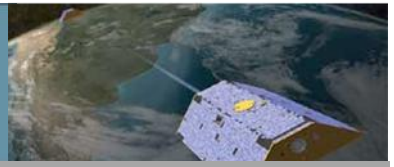
Water Cycle Missions | **Water and Energy Cycle Missions** | **Energy Cycle Missions**



Note GRACE is the only satellite the also probes groundwater deep under the Earth's surface

Complementary Water and Energy Cycle Missions

GRACE: Measurement principle



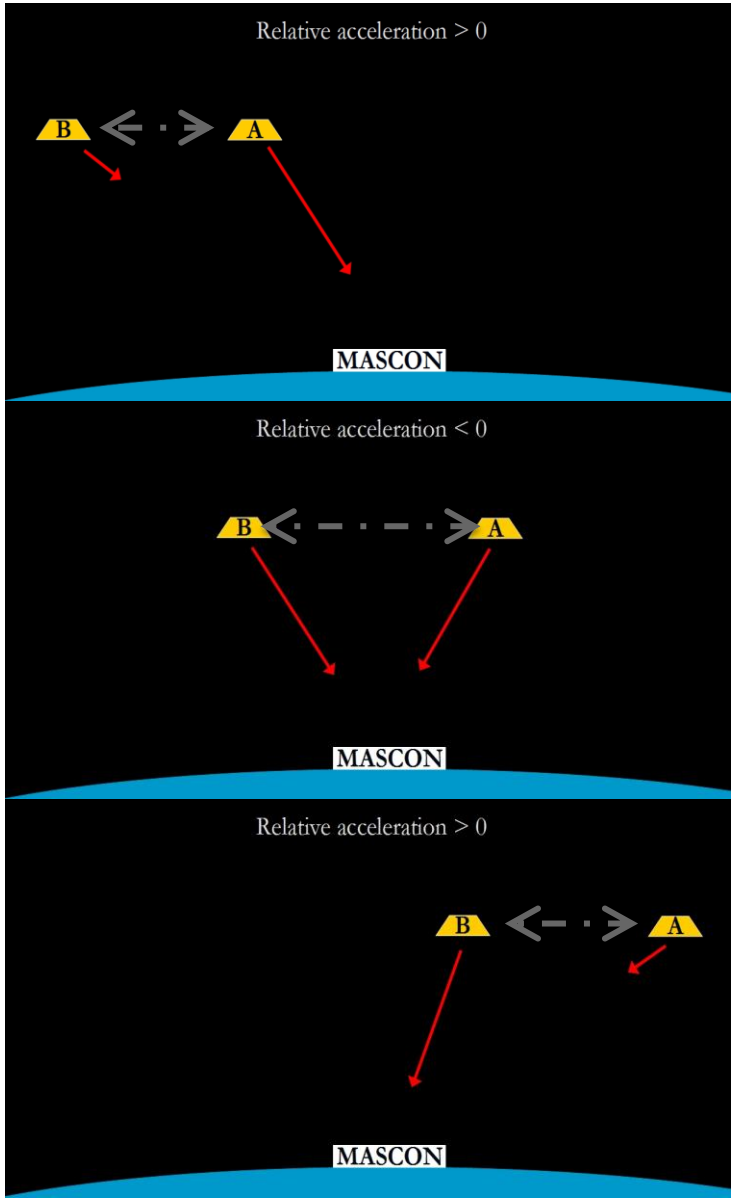
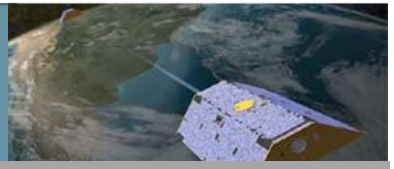


Fig. by
Brian Killett

GRACE 2002-2010 – Major Climate Mass Trends



Greenland's ice sheet is melting at a rate of up to 286 km^3/yr

Increased precipitation in northern Eurasia

Groundwater is being depleted in northwestern India at rate of about 18 km^3/y due to pumping for irrigation

Alaska's glaciers have been melting at 84 km^3/yr

Return to normal after wet years in early 2000s

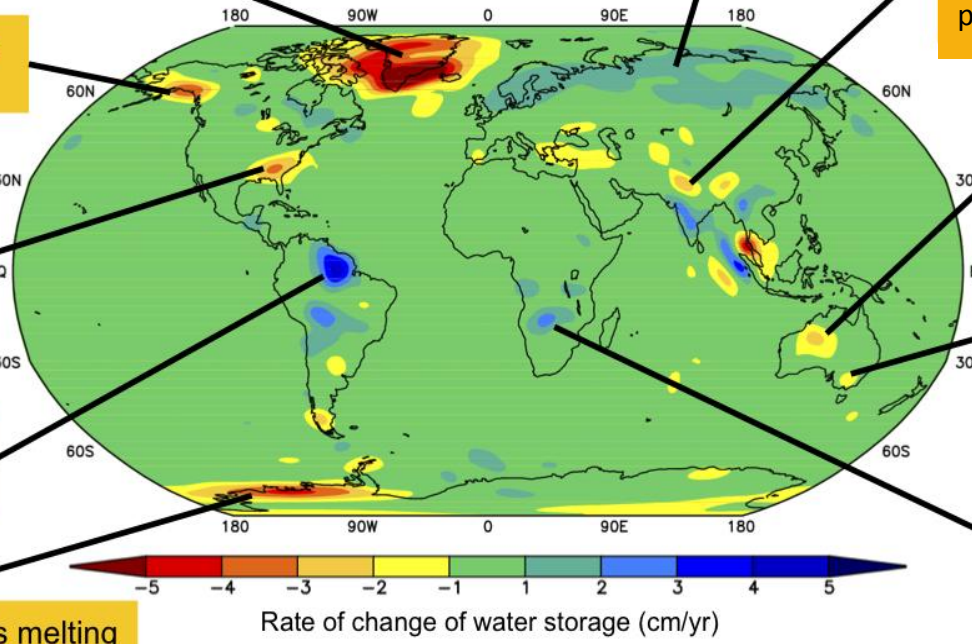
Short term impact of the 2007-08 drought in the southeastern U.S.

Drought in southeastern Australia

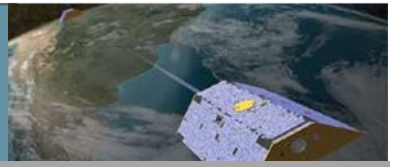
Recovery from 2004-05 drought in the Amazon

Return to normal after drought in the Okavango Delta

The Antarctic ice sheet is melting at a rate of up to 246 km^3/yr



Sea Level Observations

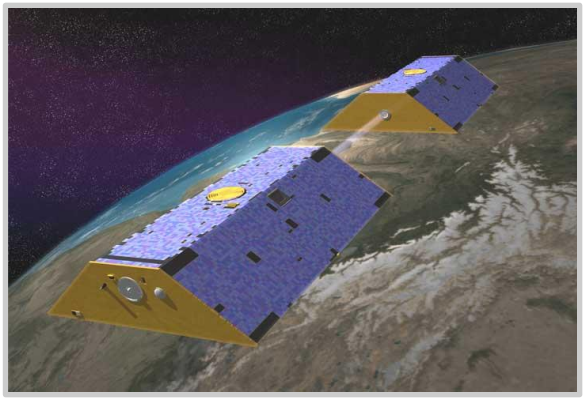


- Altimetry: total sea level

$$\mathbf{h_{total}} = h_{mass} + h_{density}$$

- GRACE: mass related changes

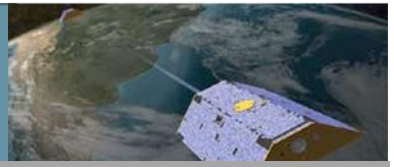
$$h_{total} = \mathbf{h_{mass}} + h_{density}$$

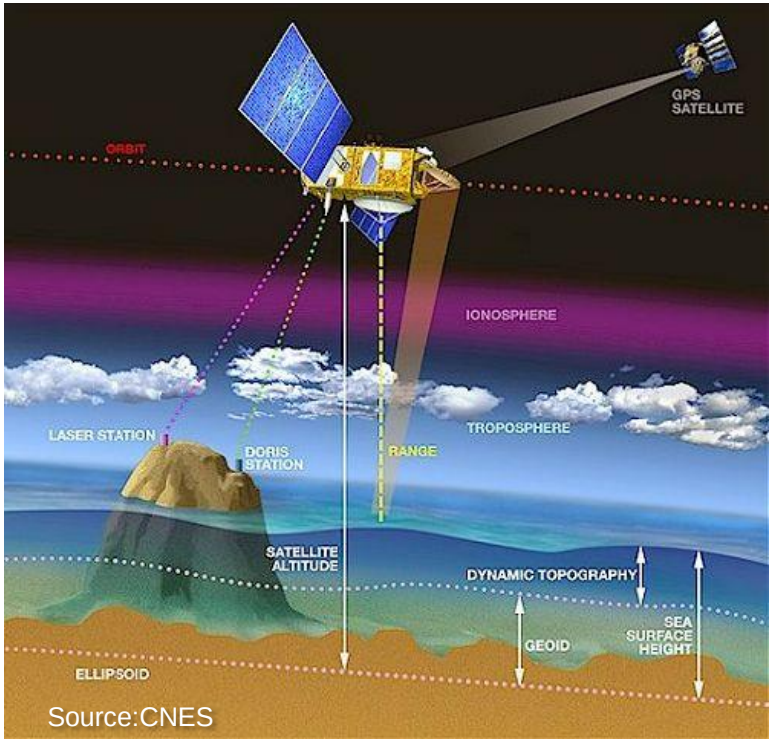


- ARGO floats: thermal expansion and contraction

$$h_{total} = h_{mass} + \mathbf{h_{density}}$$

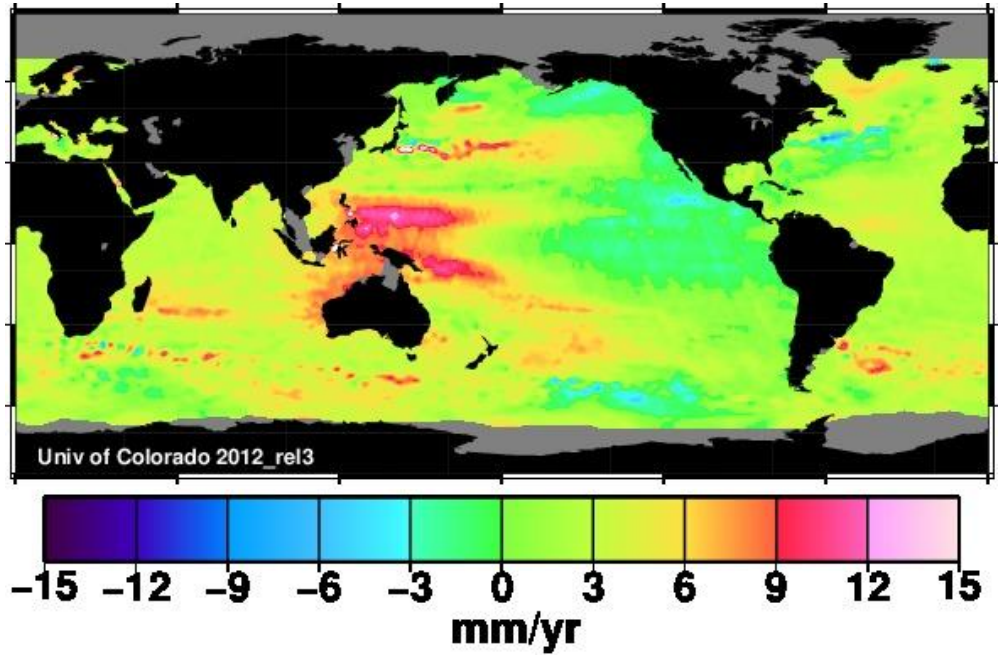
Measuring the Ocean's Height



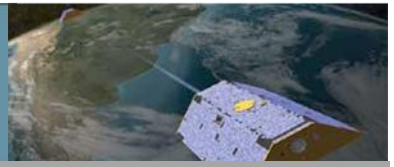


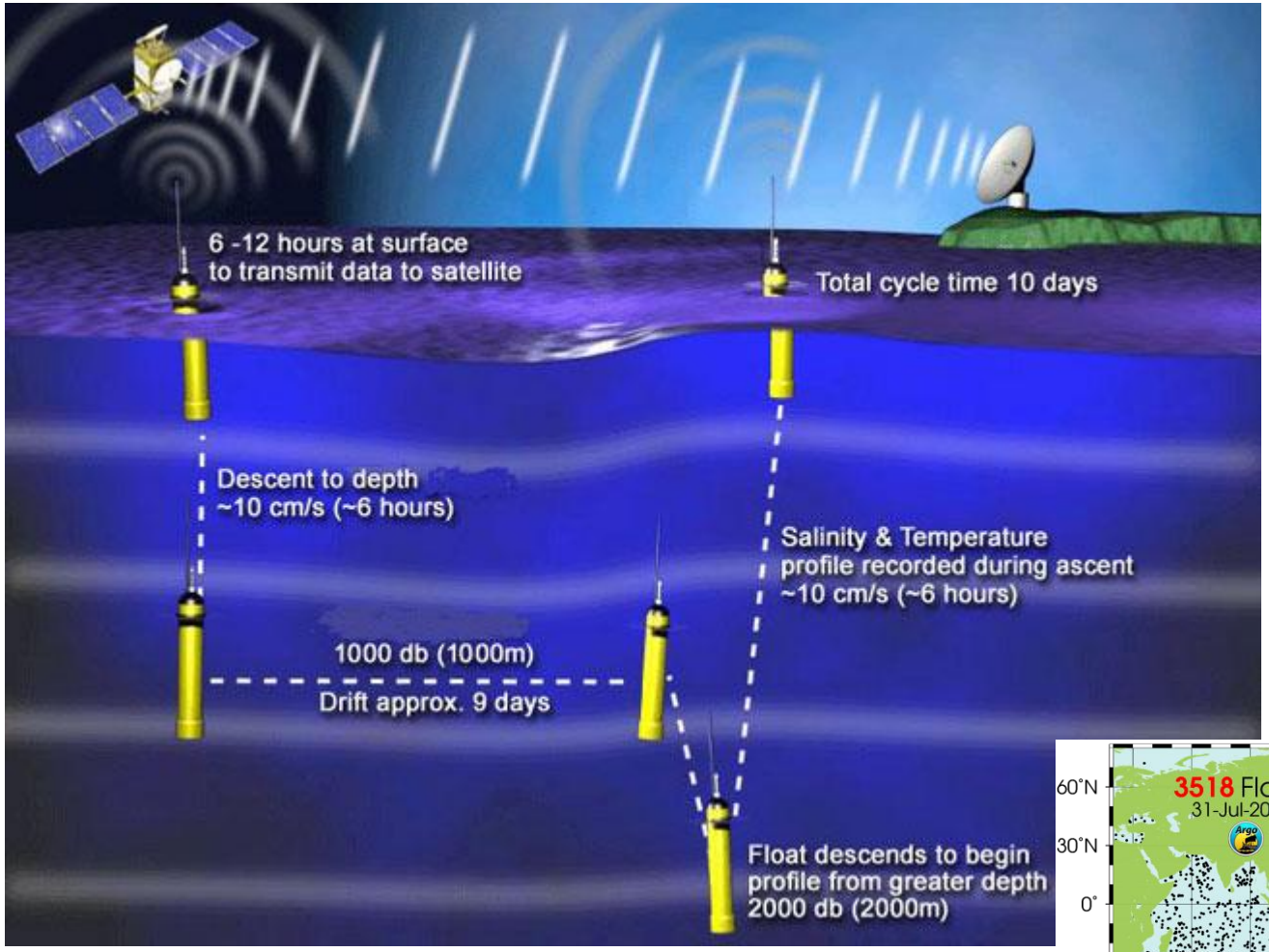
Source:CNES

Satellite Altimetry measures the surface elevation of the ocean

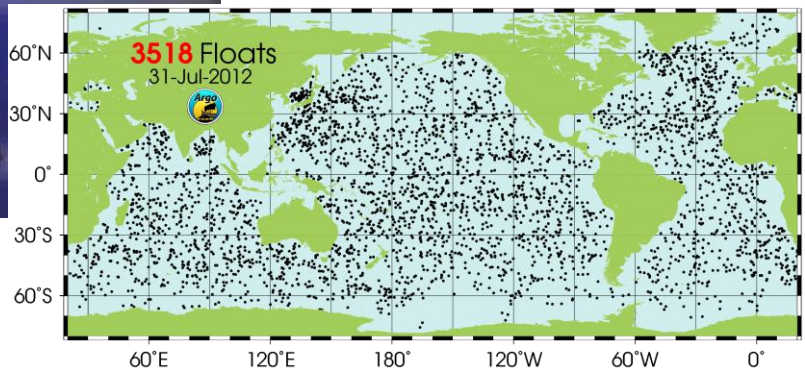


Measuring the Ocean's Temperature

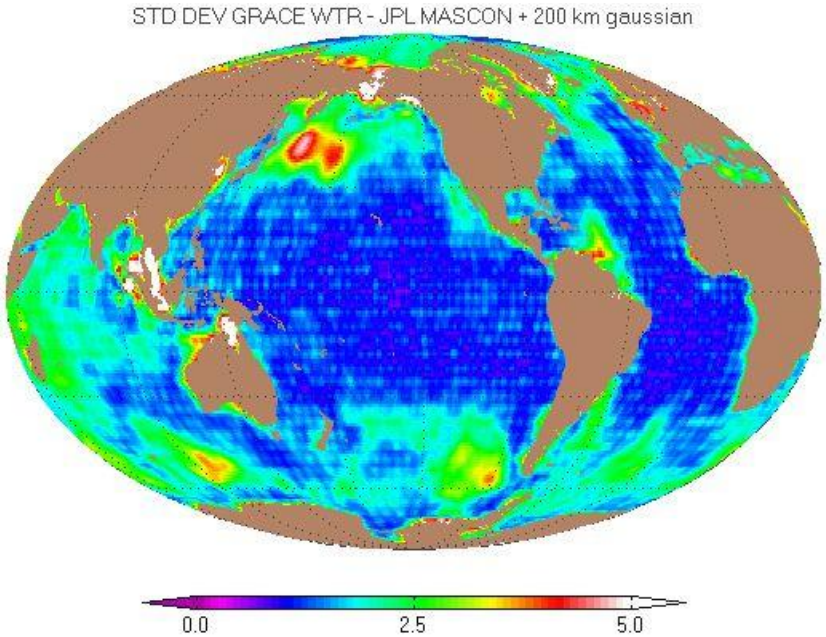


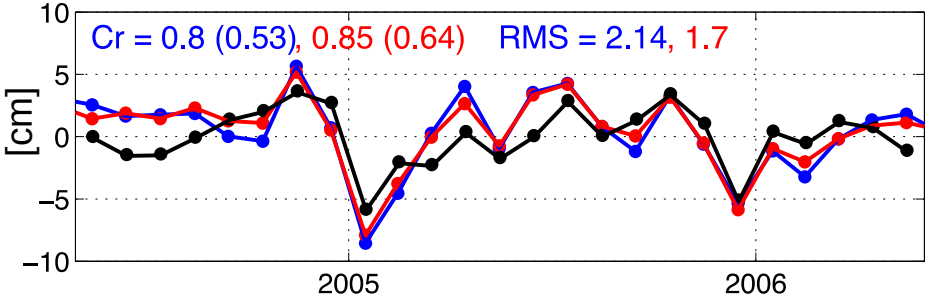


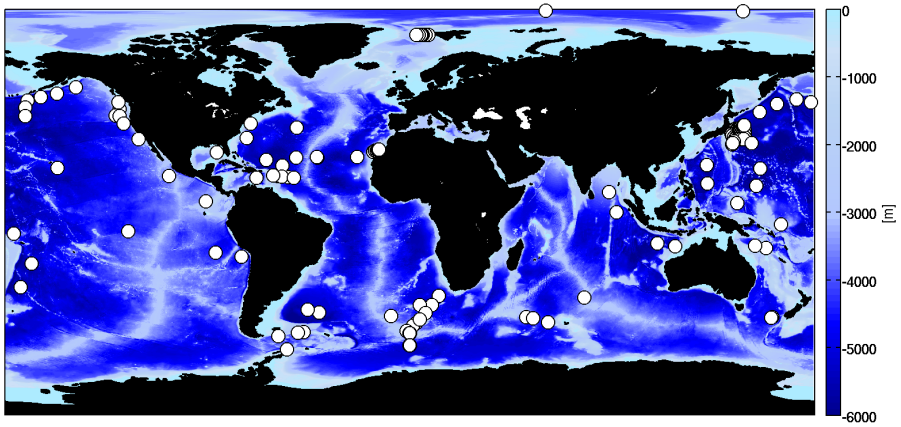
ARGO floats measure the temperature of the ocean down to 2 km (1.4 miles)



Measuring the Ocean's Weight

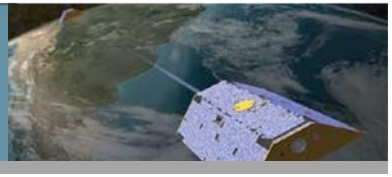


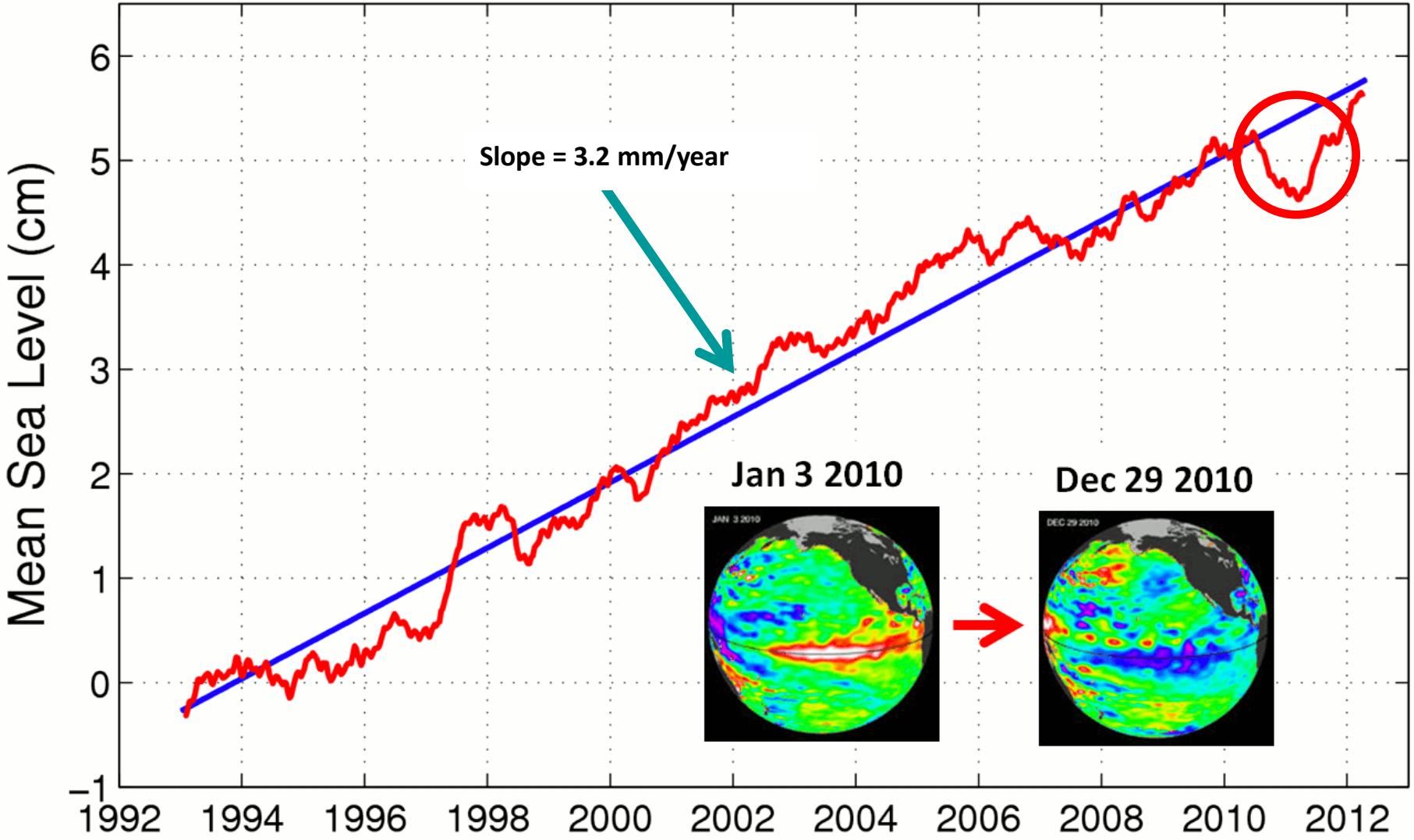




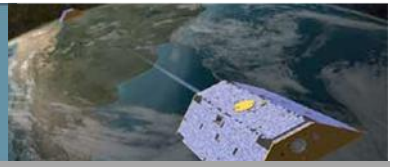
Ref.: Park et al. (2008)

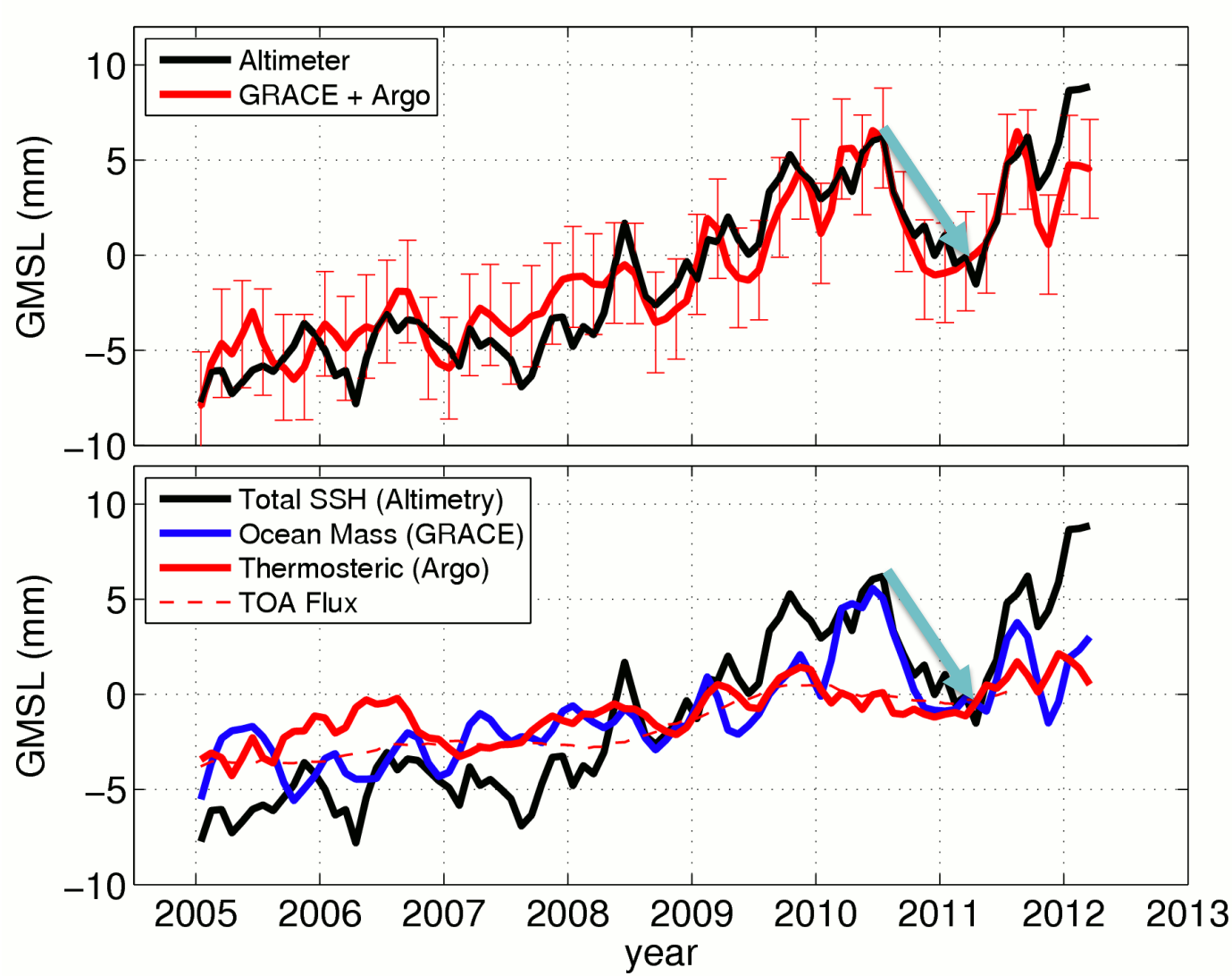
Global Sea Level Drops 5 mm





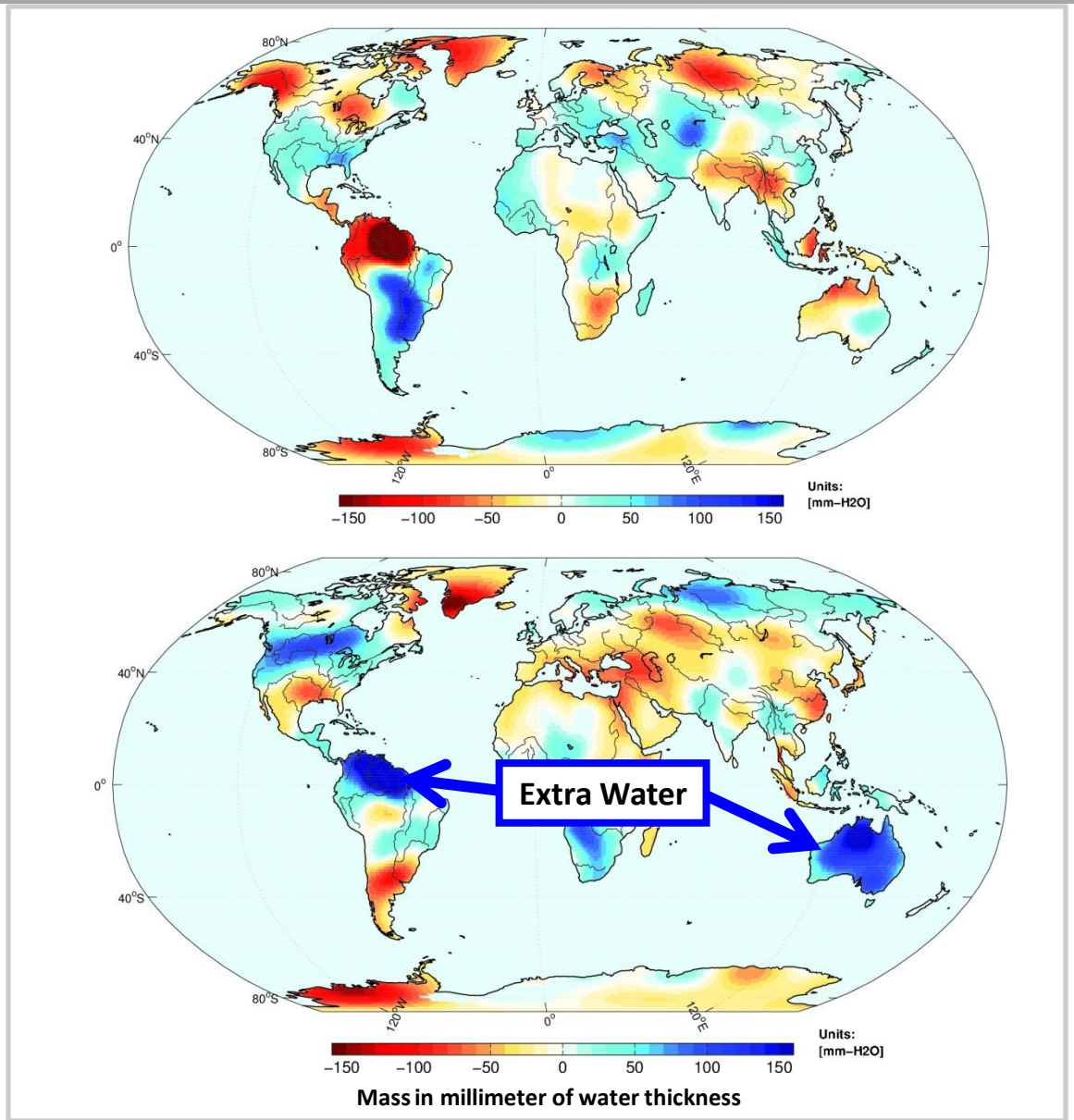
Global Sea Level Drops 5 mm in 2010/11





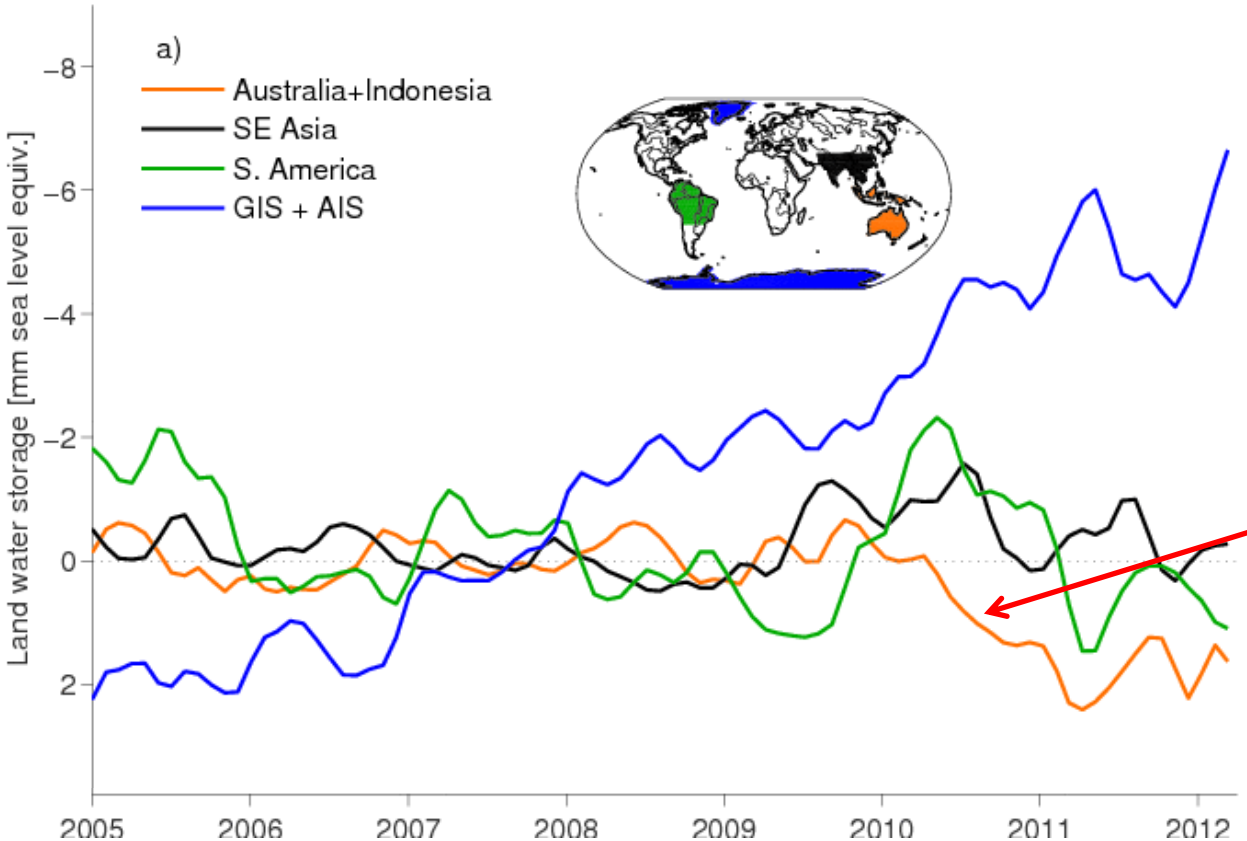
- Altimetry shows drop in global mean sea level.
- Significant part can be attributed to "missing mass from the ocean"

Terrestrial Water Storage in 2010 and 2011



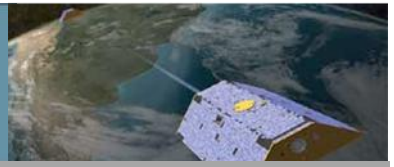
Comparing GRACE mass anomalies from 2010 and 2011 indicates more water over **Australia and northern South America**.

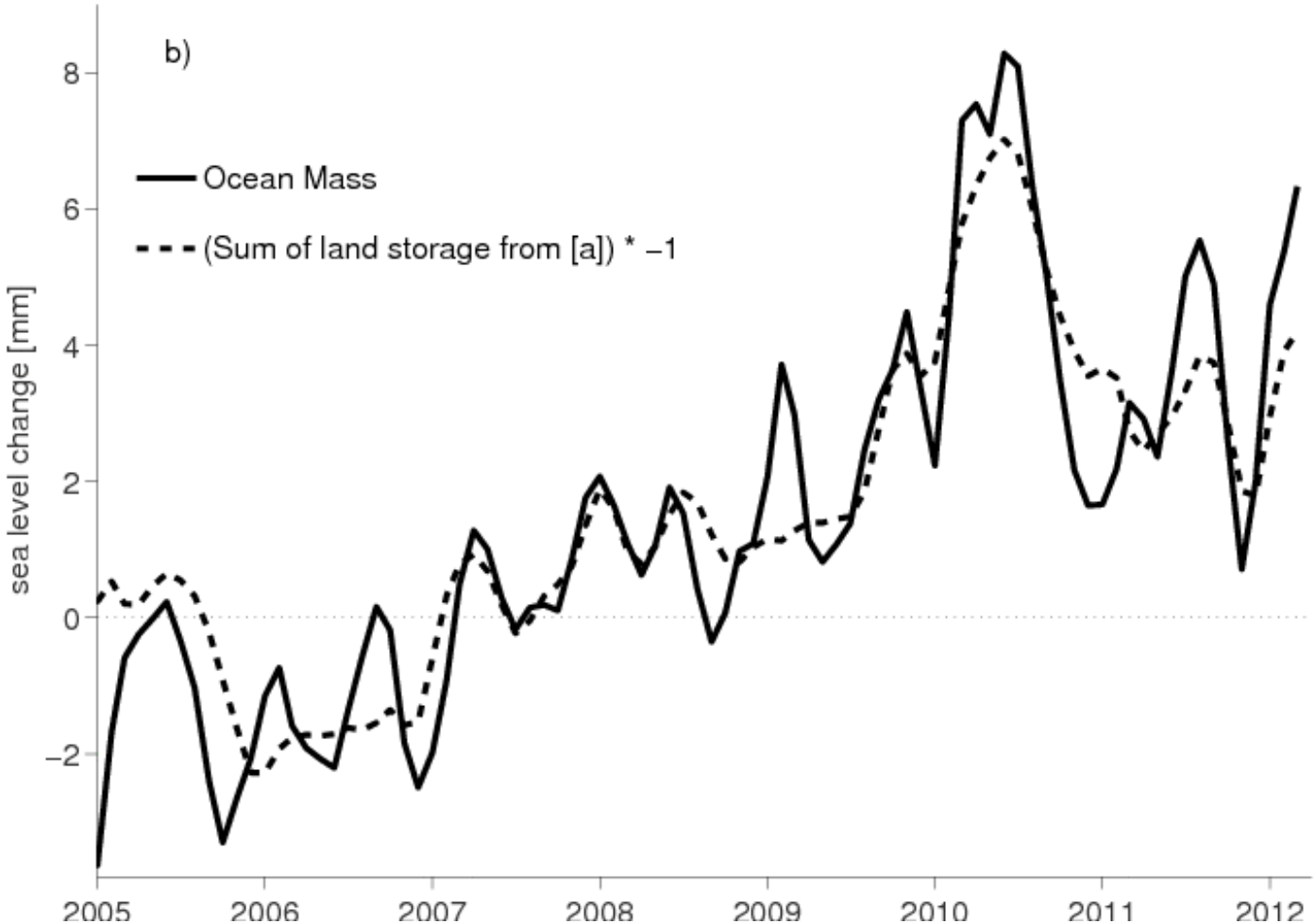
Quantifying the amount of water



Looking at the contributions from Australia, South America, and SE Asia indicates that the **largest increase** in water mass happened over **Australia**.

Terrestrial Water Storage vs. Sea Level

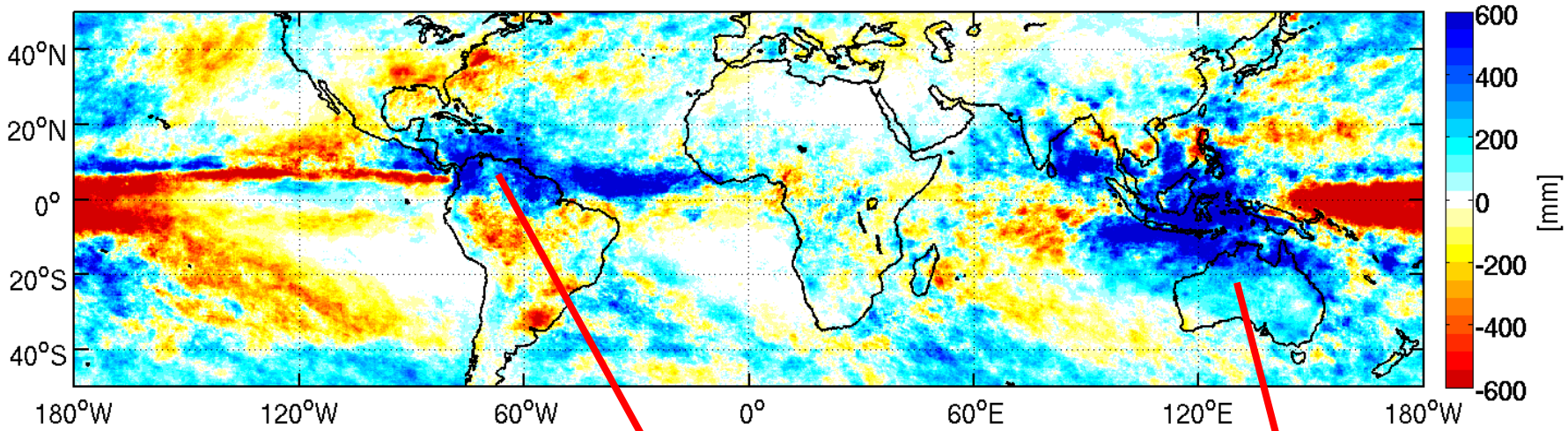




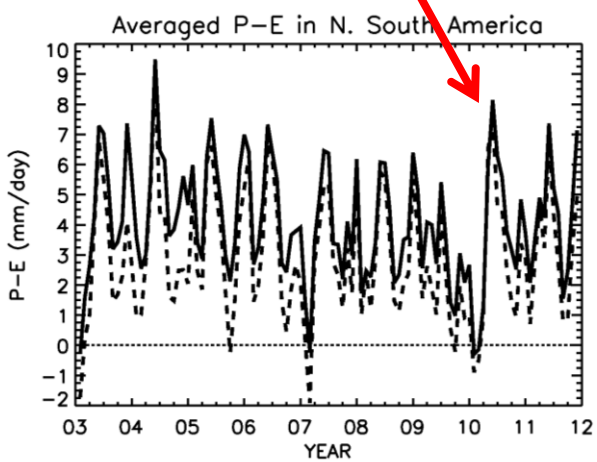
The (negative) sum of contributions from Australia, South America, and SE Asia **explains a large part of the sea level drop**.

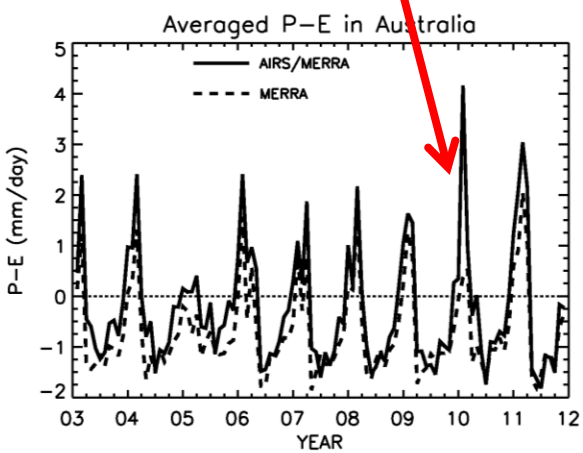
Increased Rainfall over Land?

TRMM precipitation

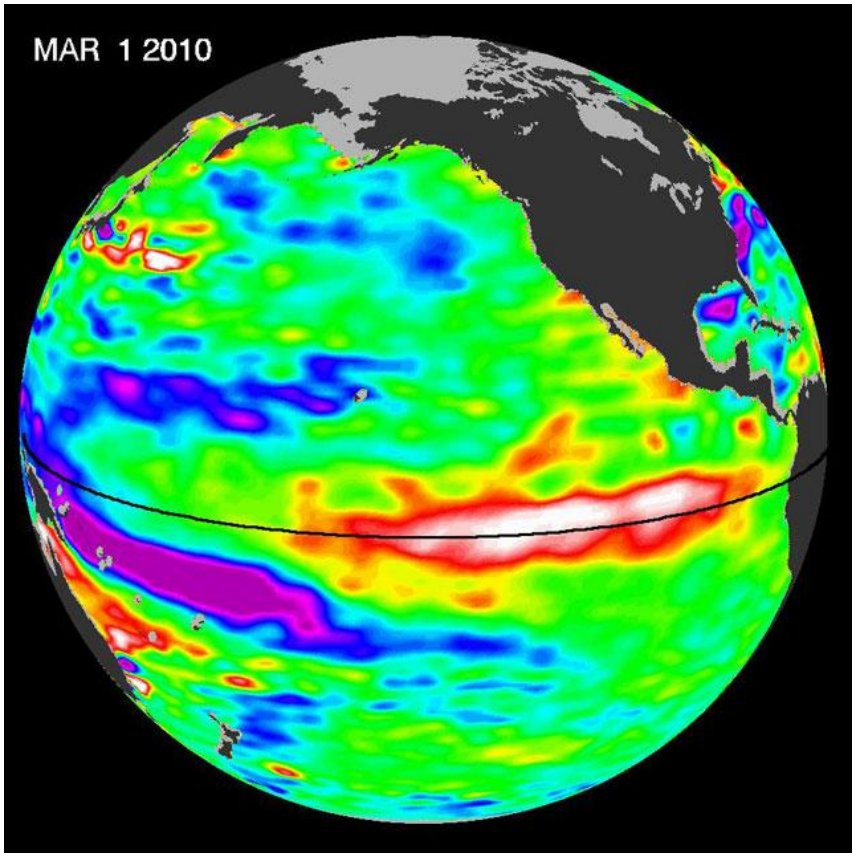


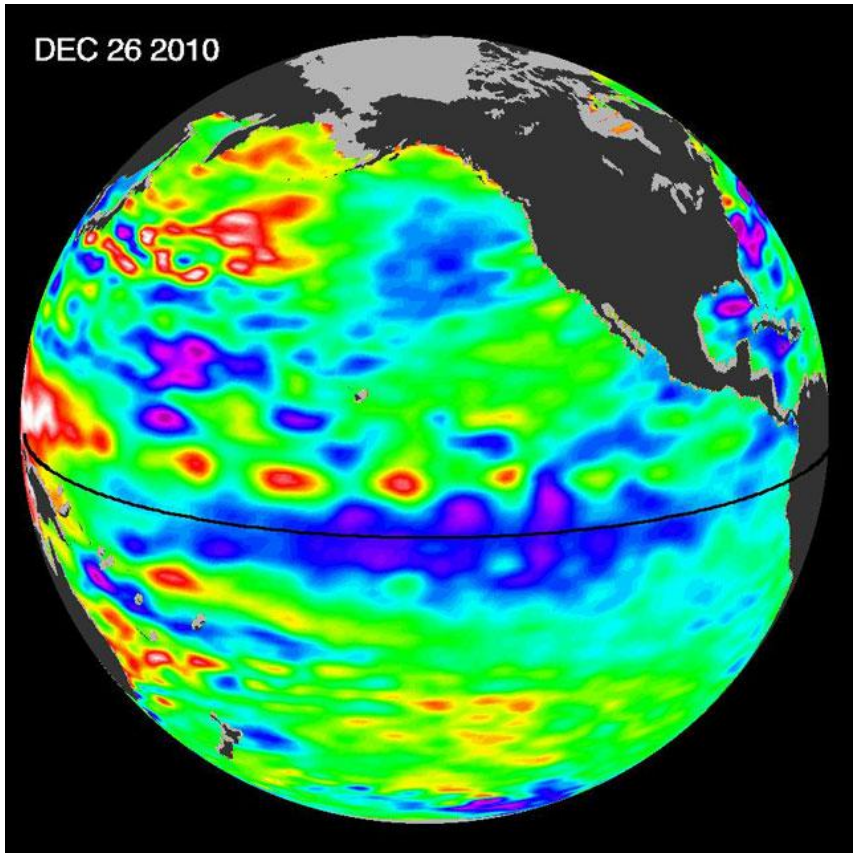
AIRS/MERRA results by courtesy of *Sun Wong*



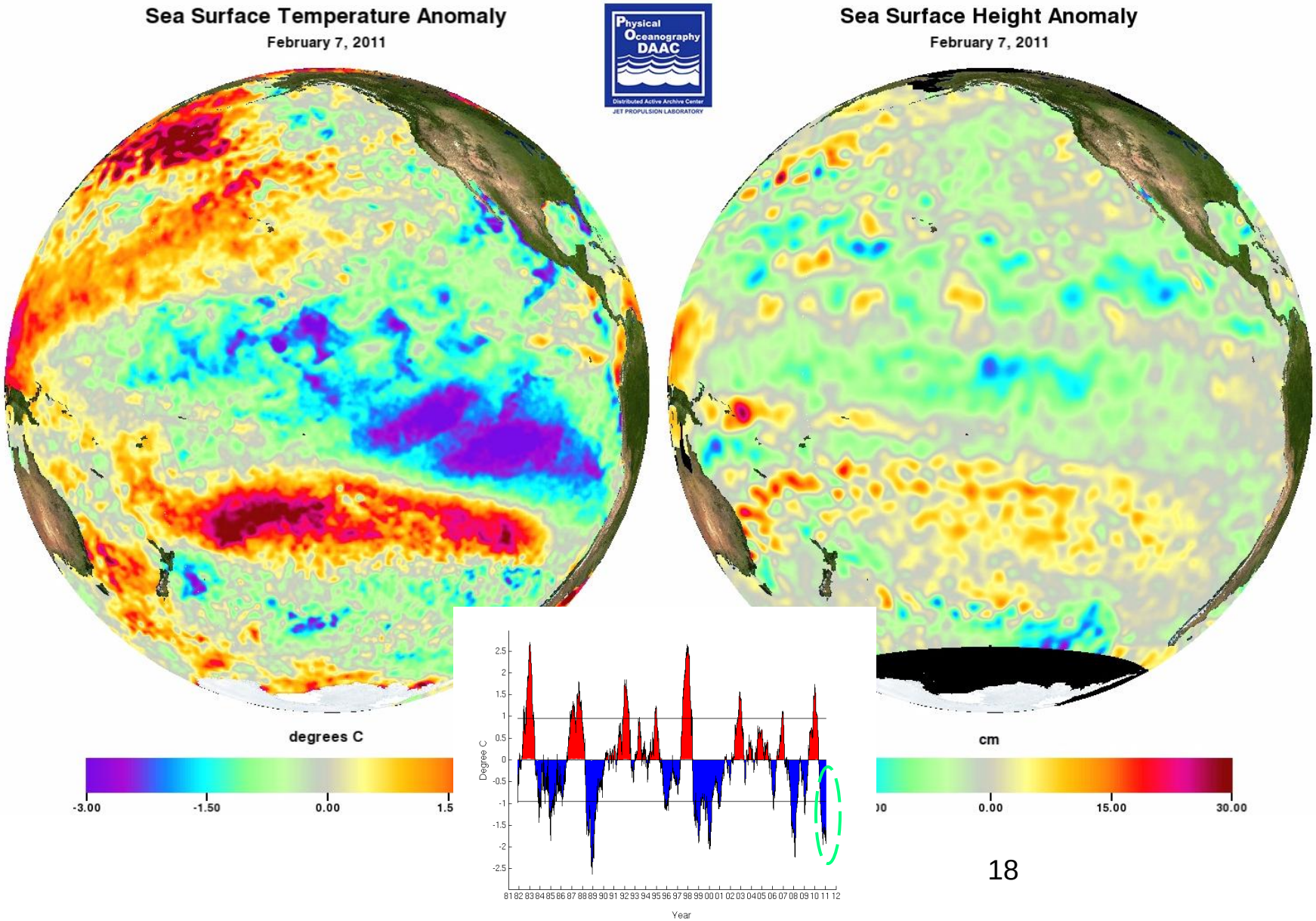


El Nino Southern Oscillation (ENSO)

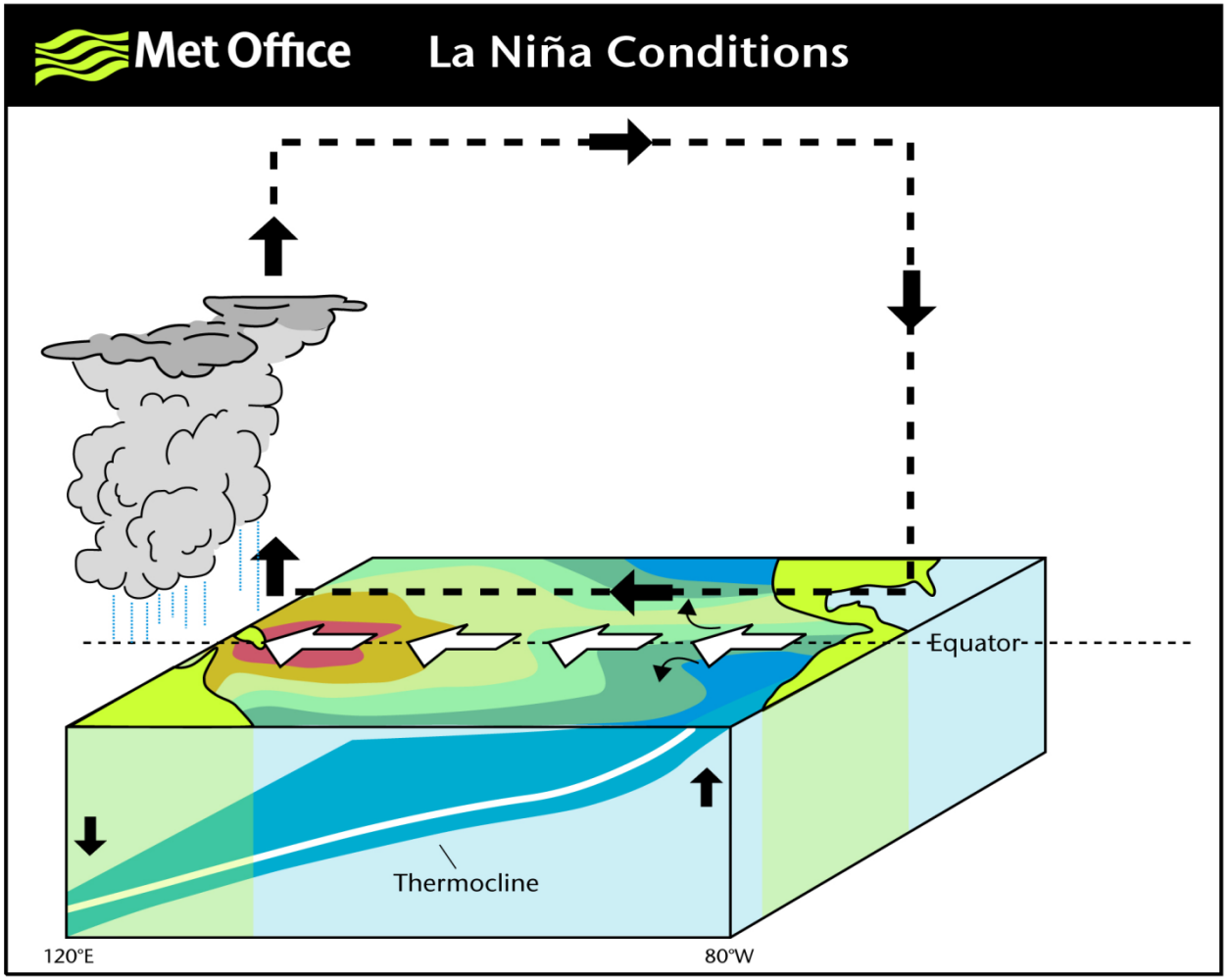




El Nino becomes La Nina


Sea Surface Temperature Anomaly
February 7, 2011
Physical Oceanography DAAC
Distributed Active Archive Center
JET PROPULSION LABORATORY
Sea Surface Height Anomaly
February 7, 2011
degrees C
-3.00
-1.50
0.00
1.5
cm
0.00
15.00
30.00
Degree C
Year

La Nina Conditions



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Queensland flooding linked to La Nina phenomenon

Article

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By Joyce R. | January 12, 2011 1:32 PM AEST

The floods in Queensland are being blamed on one of the strongest "La Niña" weather phenomenon case in the world to date that led to unusually less rain to the South America near along the eastern Pacific and more rain to the western Pacific.

View Full Image

REUTERS

A passenger in a car waves for assistance as a flash flood sweeps across an intersection in Toowoomba, 10 km (65 miles) west of Brisbane, January 10, 2011.

This has led to Queensland having its wettest year to date and the country recording its third wettest year record. La Niña is likely to remain into the southern hemisphere autumn with the possibility of stronger rains says the Australian Bureau of Meteorology. La Niña comes every few years and lasts for about one to two years with its cause largely still a mystery. Experts speculate it stems from the interaction between the ocean and atmosphere.

"This is one of the strongest La Niña events in the past half century," Bill Patzert, a climatologist at Nasa's Jet Propulsion Laboratory told the Guardian. "Impacts include heavy rains and flooding, which has damaged crops and flooded mines in Australia and Asia. It also has resulted in flooding in northern South America and

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Environment > Flooding

Australia floods: La Niña to blame

The country is in the in the grip of an unusually strong periodic climate phenomenon that brings heavy rains

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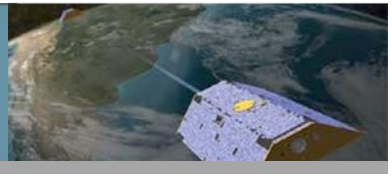
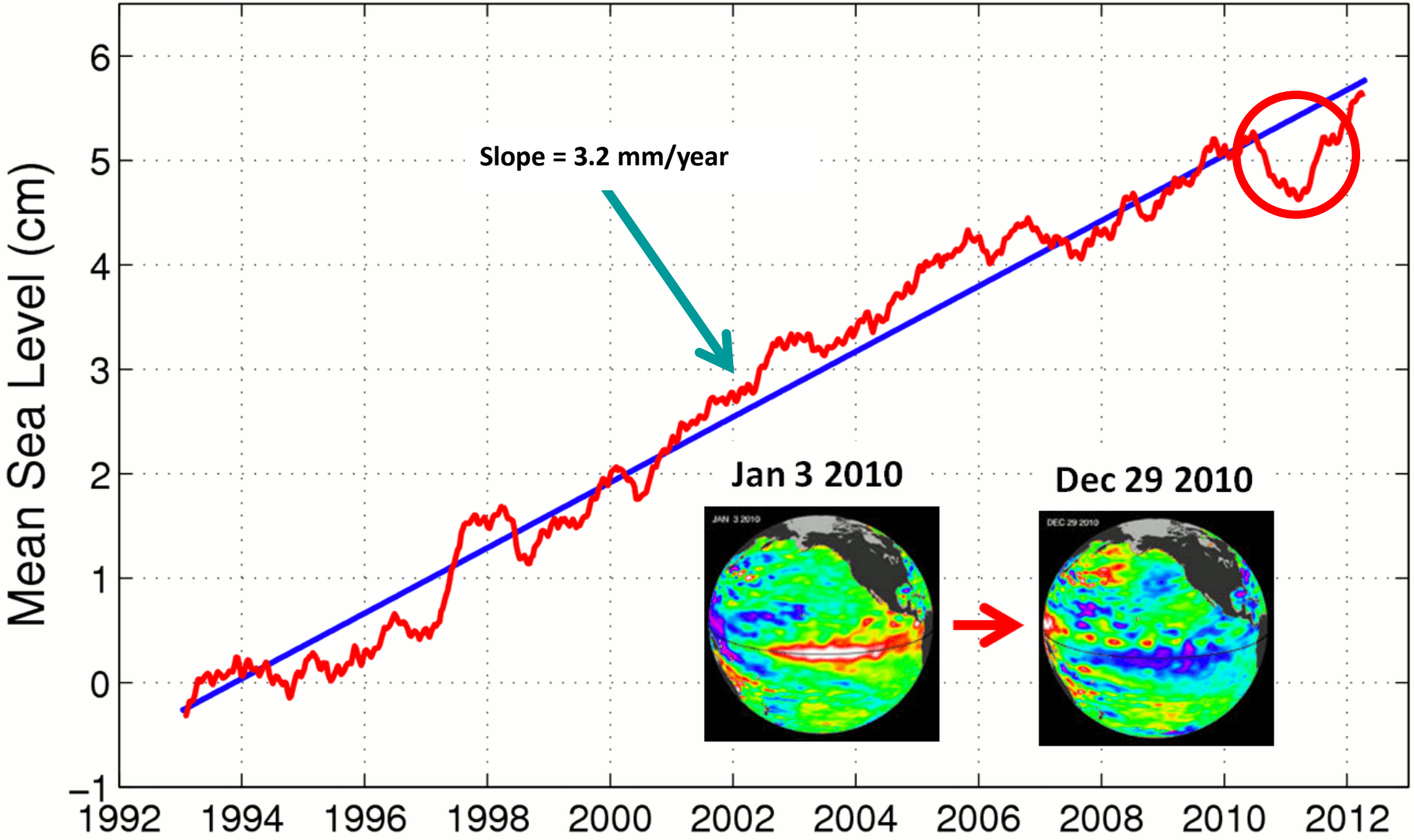
29 December 2010 Last updated at 07:34 ET

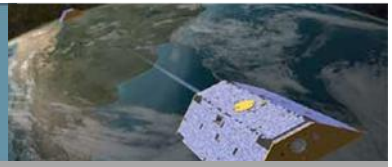
Floods force mass evacuations in Queensland, Australia

Global Sea Level Drops 5 mm

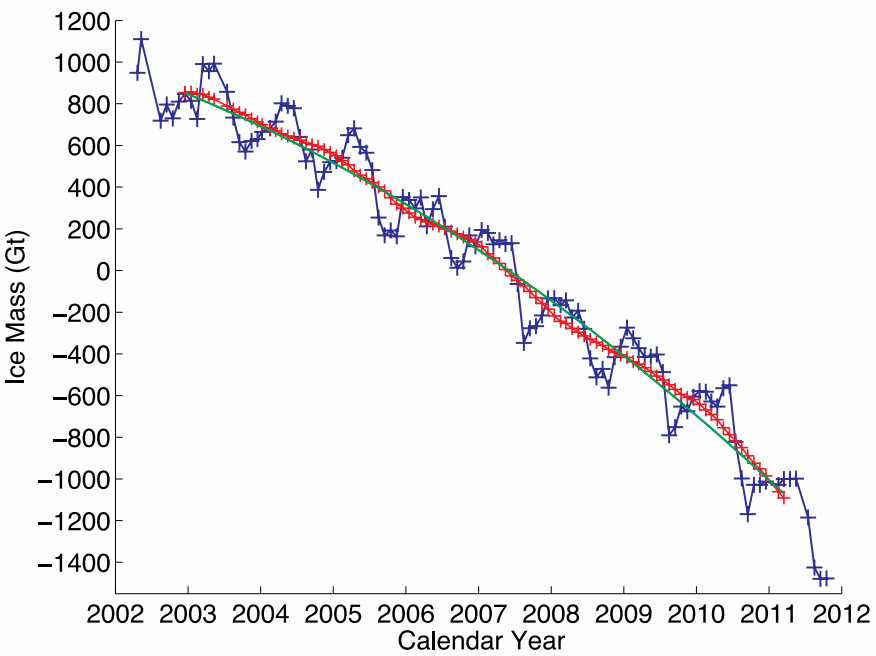




Ice Mass Loss Observed by GRACE 2002-2011

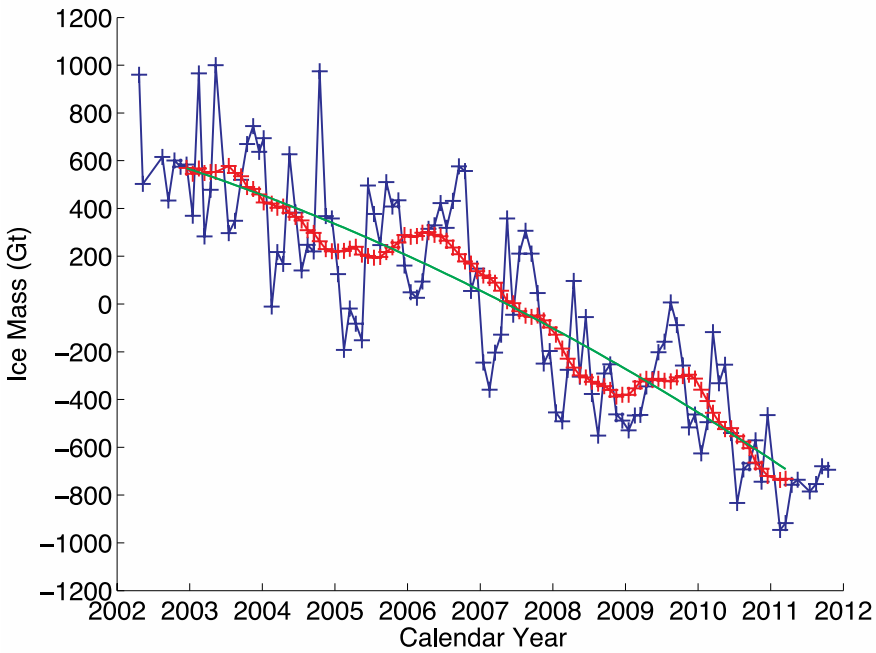


Greenland



Trend Apr 2002-Oct 2011:
-220±33 Gt/yr

Antarctica

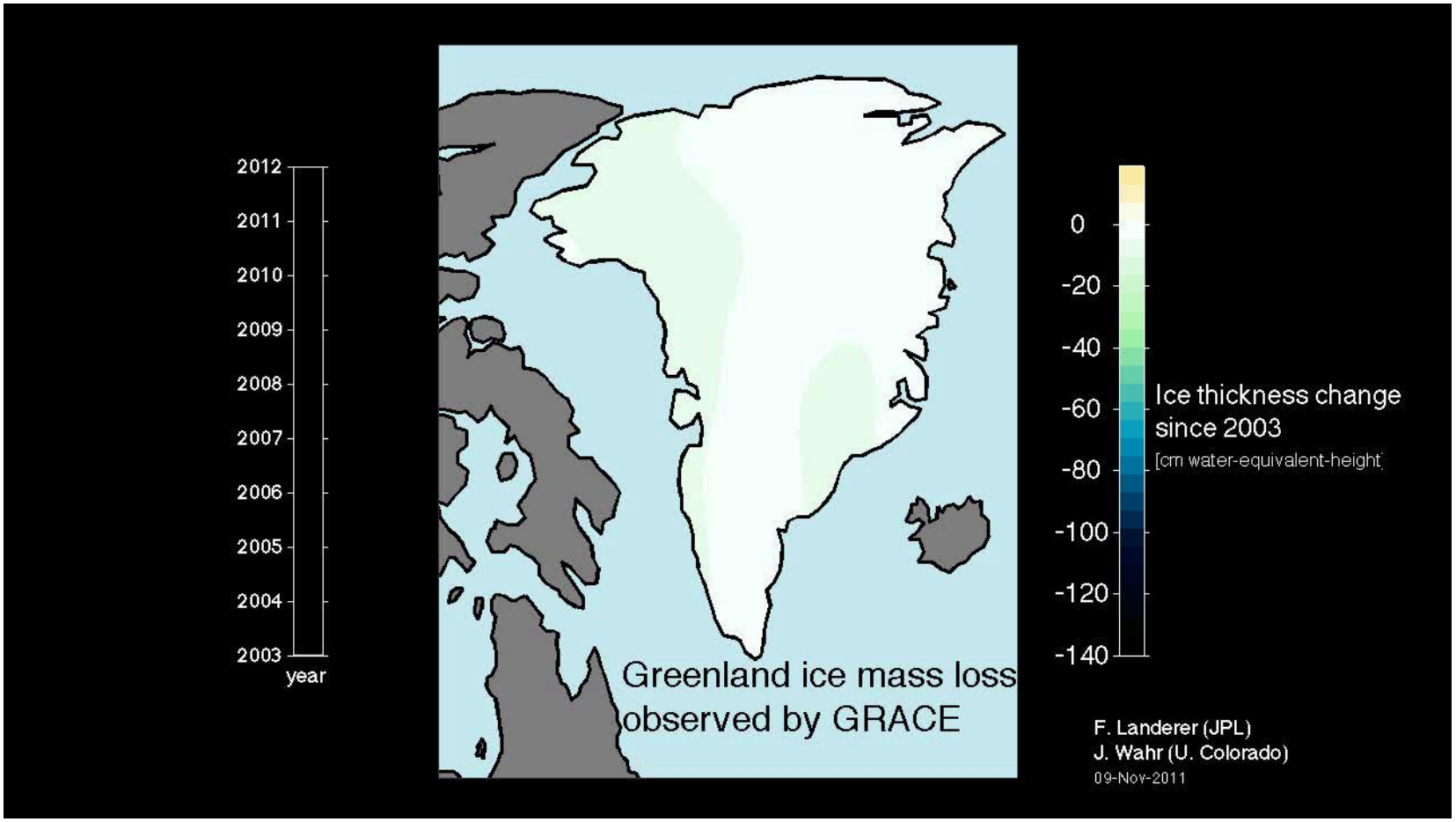


Trend Apr 2002-Oct 2011:
-152±33 Gt/yr

Units of Mass Loss are Gigatons/year (and corrected for GIA)

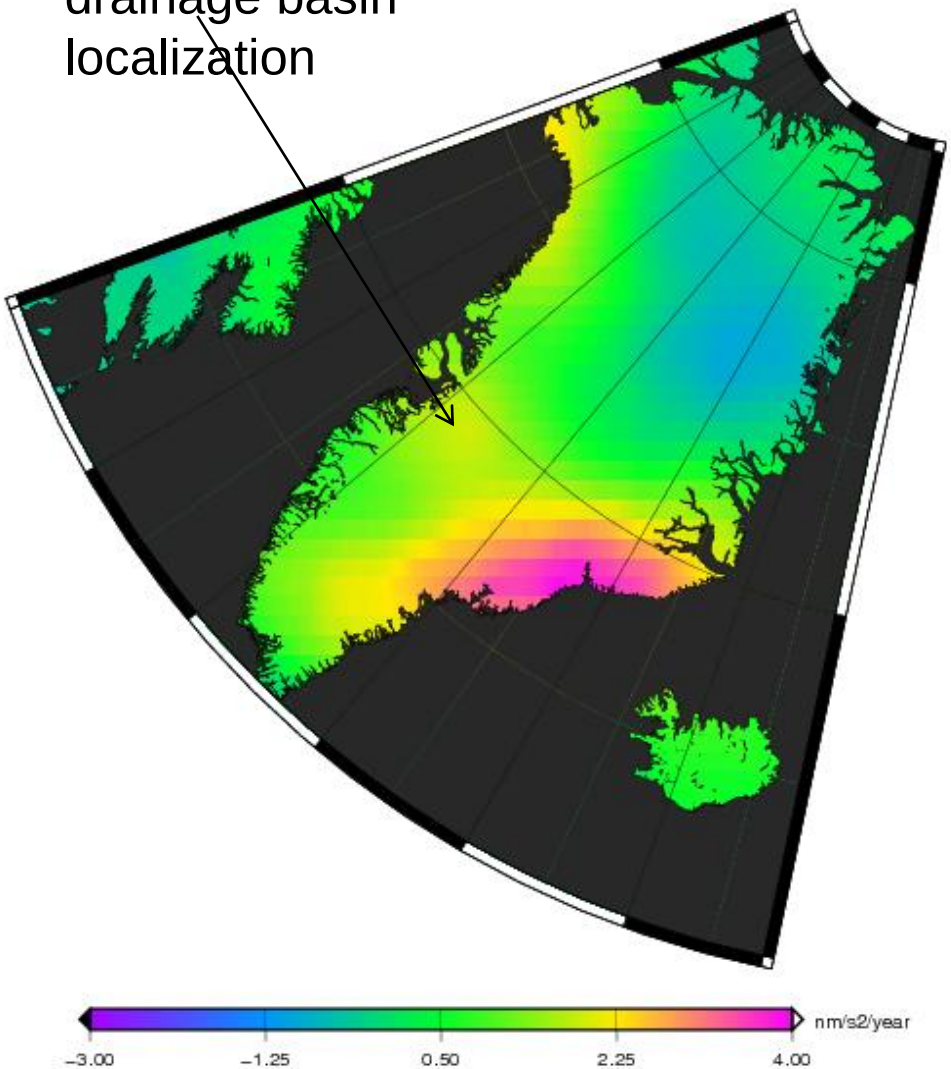
Reference: Velicogna et al, 2012

Greenland – Ice Mass Change

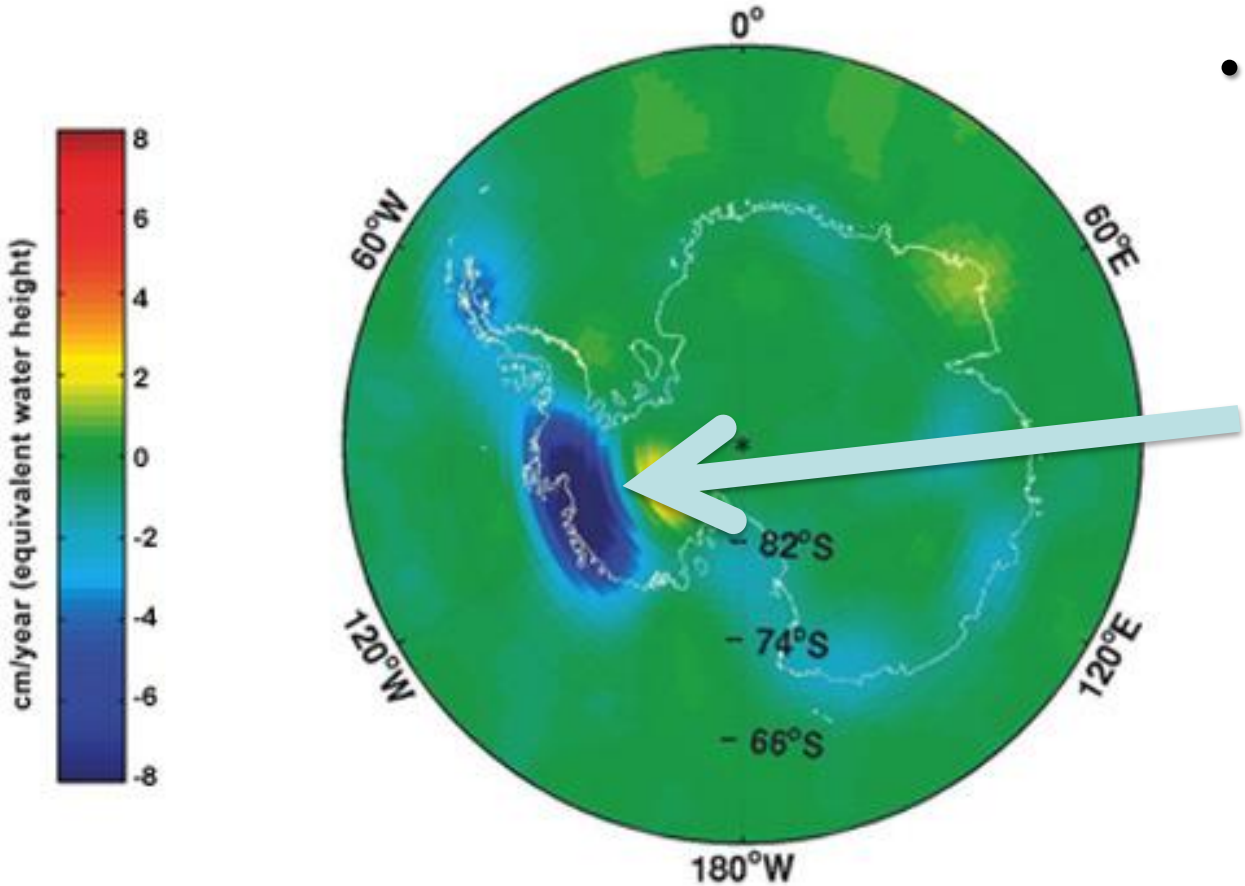


GRACE Analysis Trends– Improving GRACE spatial resolution

Note clear drainage basin localization

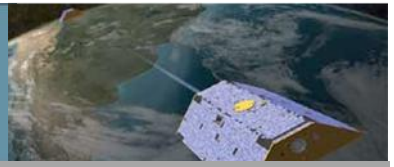


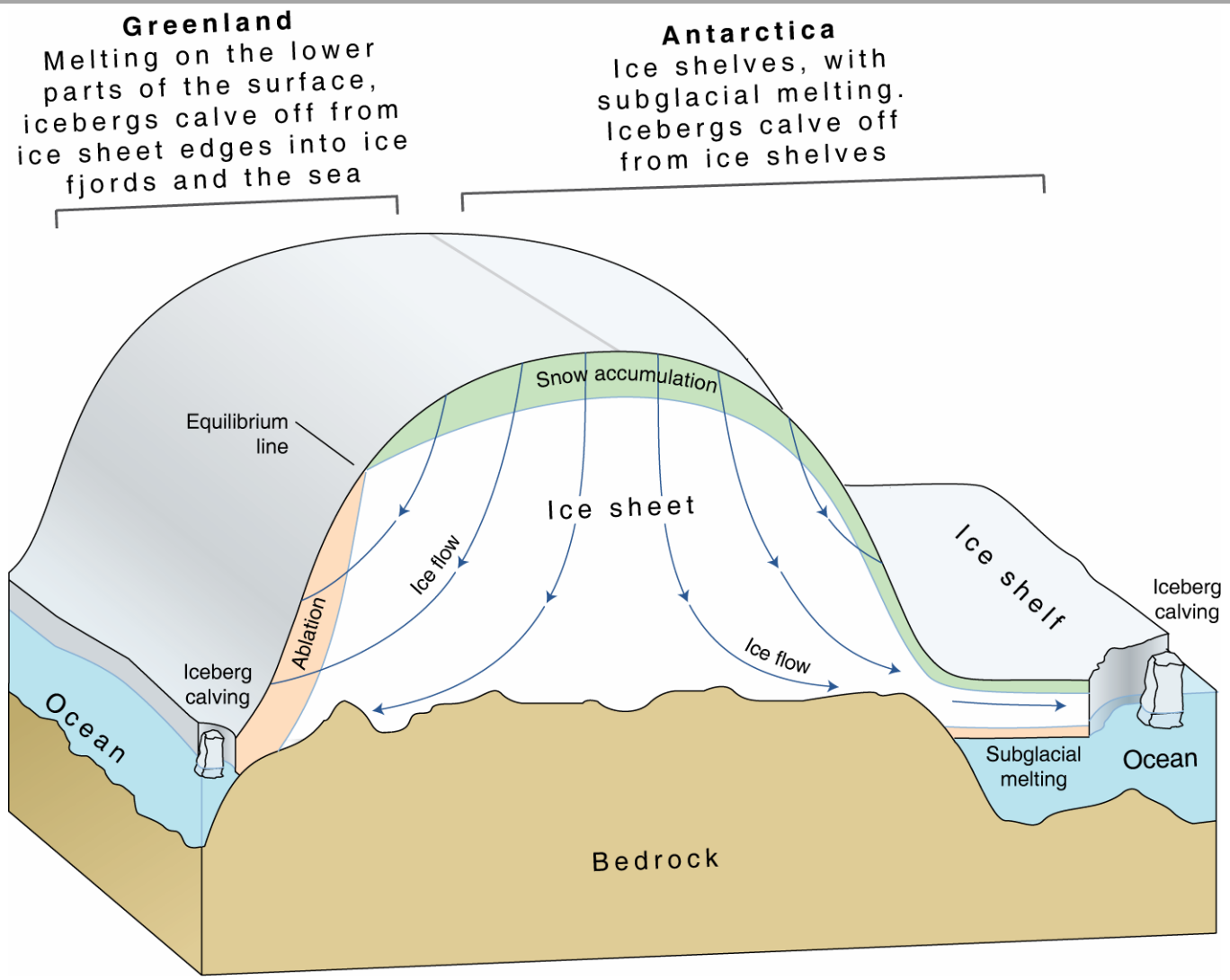
Antarctica – Ice Mass Change



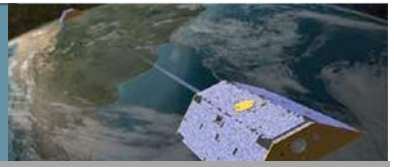
- Ice mass loss primarily in Western Antarctica (Pine Island Glacier and Antarctic Peninsula)

Ice Sheets losing and gaining mass

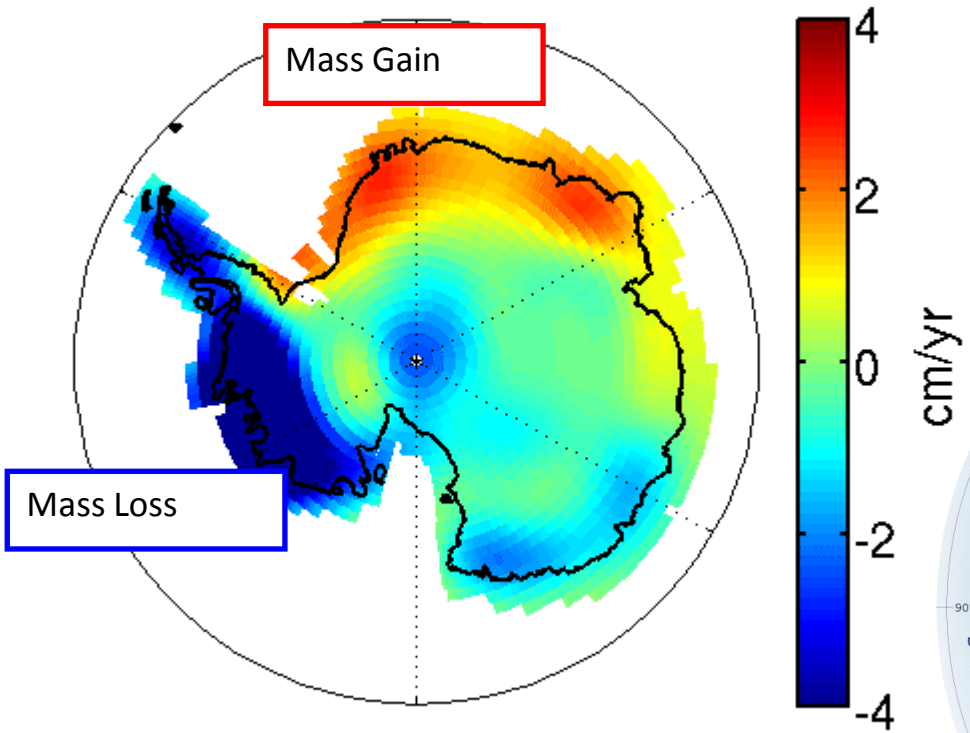




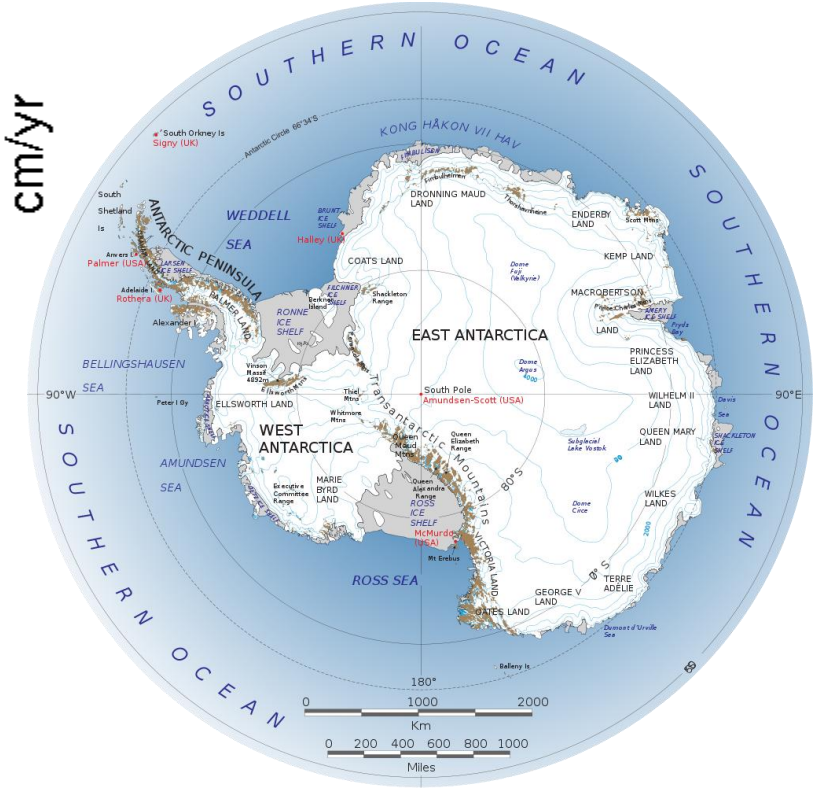
Ice Mass Increase in East Antarctica



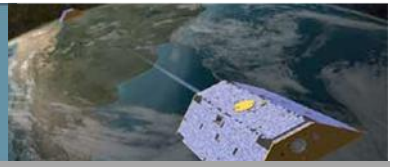
GRACE Mass Trend 2004-2011



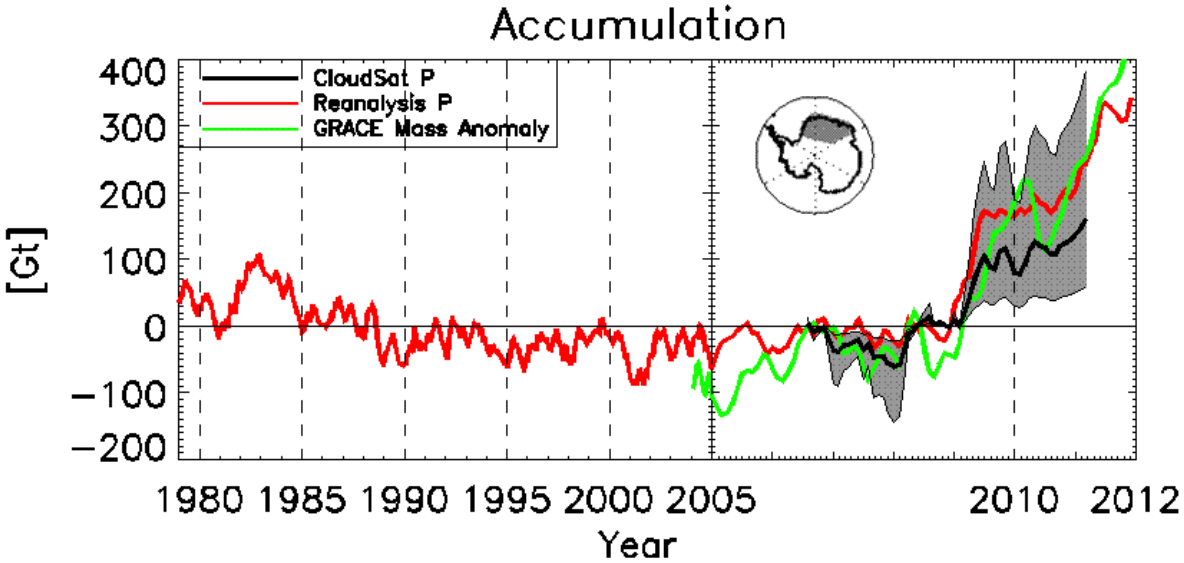
- GRACE satellites observe mass gain along the northern coast of East Antarctica in 2009-2011
- What happened? More ice, more snow?

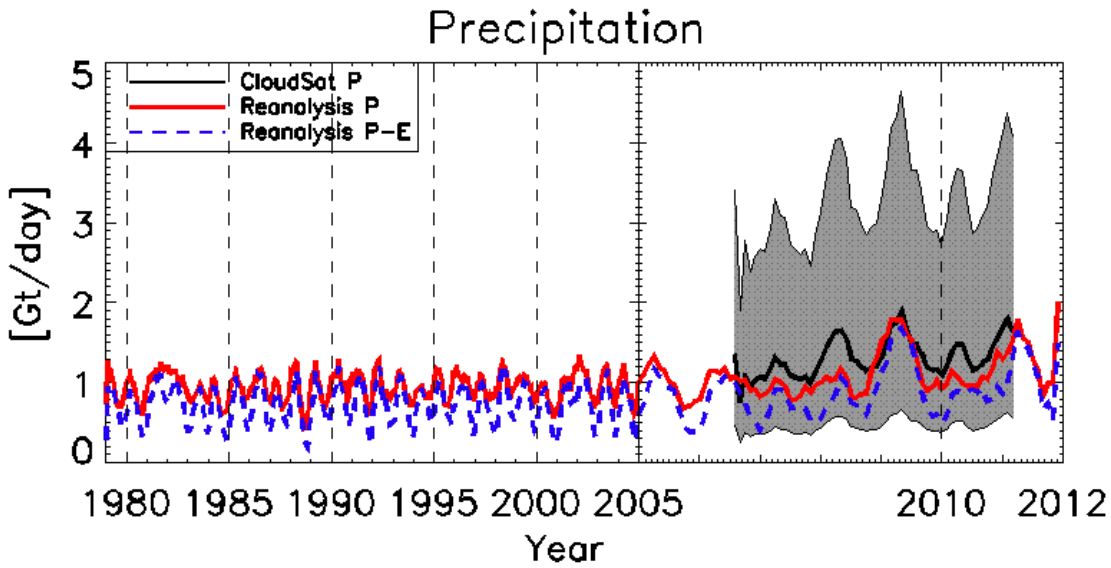


Ice Mass Increase and Antarctic Precipitation



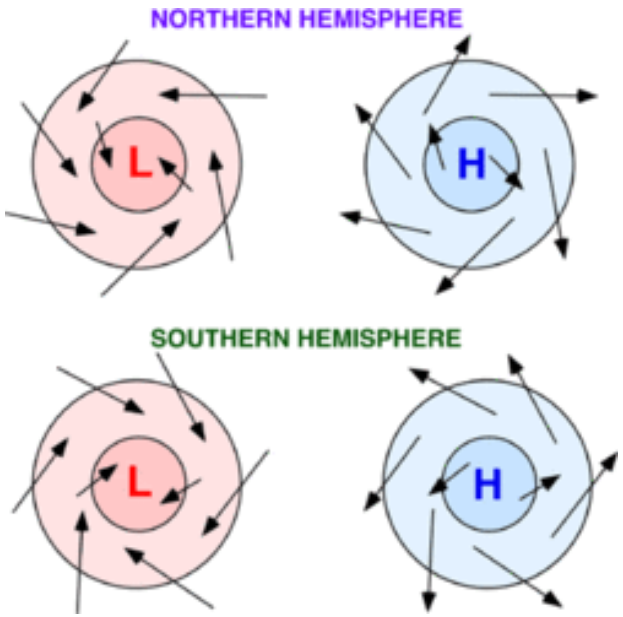
- CloudSat observes snowfall
- Accumulated snow from CloudSat agrees well with GRACE's observed mass
- Independent snowfall data confirms this

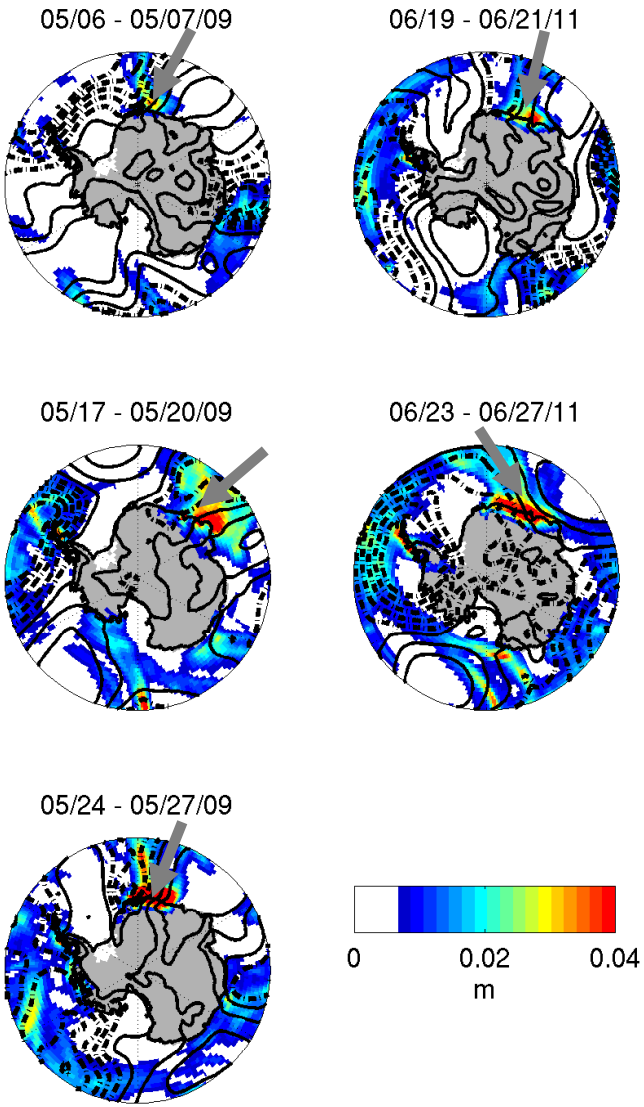




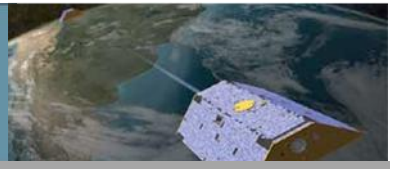
High Precipitation and Southern Ocean Winds

- Strong, stable wind systems occurred over the Southern Ocean in 2009/2011
- The anomalous winds brought moist air from the ocean to East Antarctica and led to intense snowfall



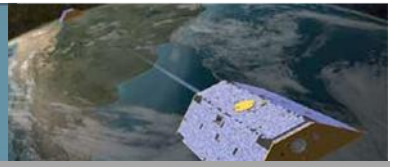


Summary

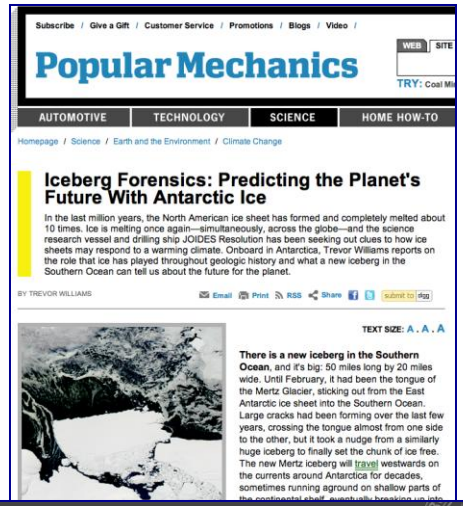


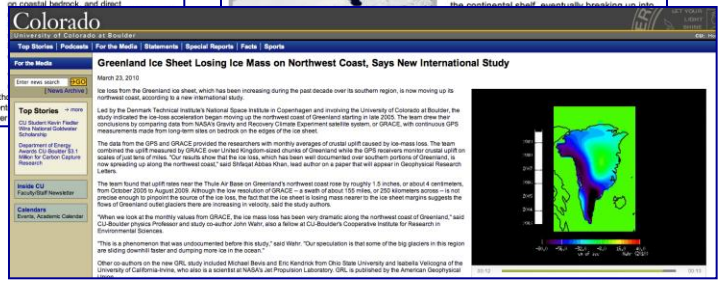
- GRACE “weighs” components of the Earth system (ice sheet, ocean, land…)
- Gravity observations tell us how water – in all its states - moves around the planet
- By combining GRACE with various other satellite observations, we can better understand the processes contributing to sea level rise
  - mass from melting vs. expansion of the ocean due to warming
  - short-term (ENSO) vs. long-term (melting, warming) changes
  - the role of precipitation and evaporation
  - water transport through the atmosphere from the ocean to land
- Sea level change is just one example among many: droughts, groundwater use, hydrologic cycle, but also earthquakes and adjustment of the solid earth to the past ice age…

GRACE Science in the News



- Arctic regions ice melt
- Greenland/Antarctic ice sheet
- Hydrologic studies
- Ocean Circulation/ Sea Level





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