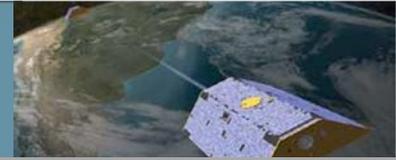


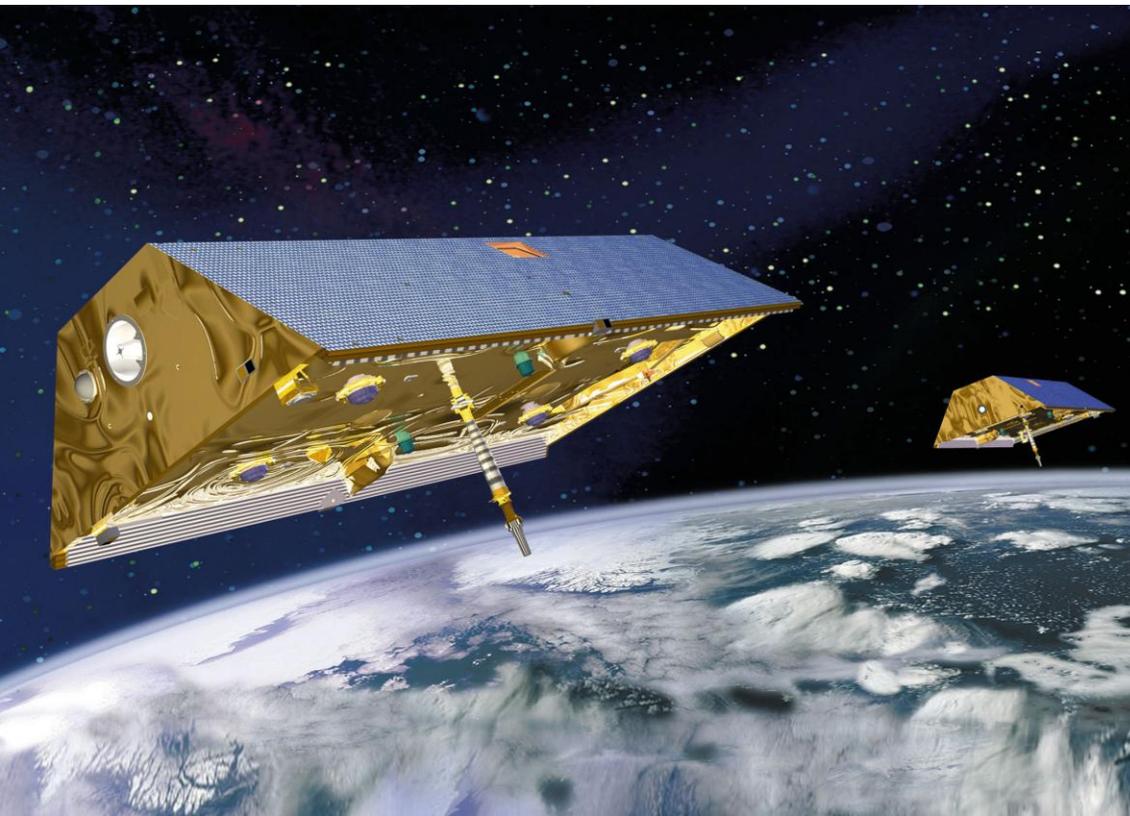
GRACE – Measuring Climate Change with Gravity



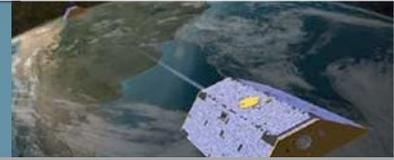
Carmen Boening

Michael M Watkins (Project Scientist)

contributions from John Fasullo, Felix Landerer, Matt Lebsack, Steve Nerem, Graeme Stephens, Josh Willis



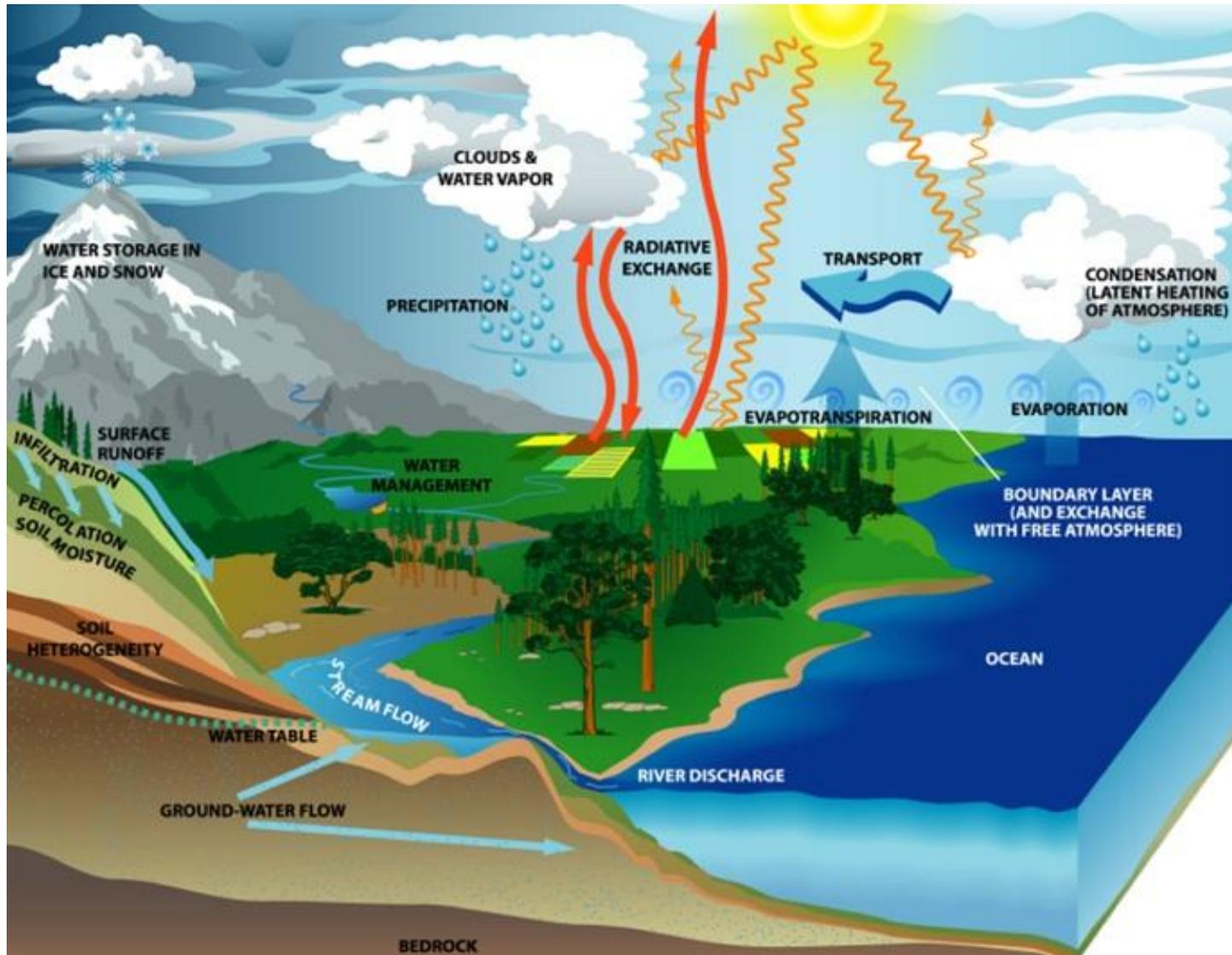
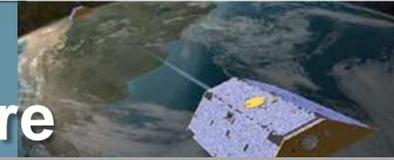
Why Use Gravity Measurements for Climate?



- 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

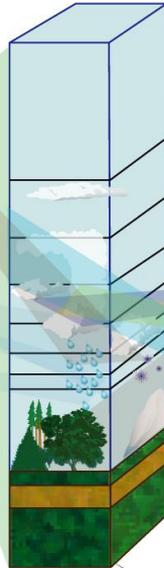
ICESat
- Ice elevation
- Cloud height



GRACE
- Column water-content



TRMM and GPM
- Global precipitation



EOS-Aura
- Atmospheric humidity
- Clouds



EOS-Terra
- Snow and ice
- Vegetation



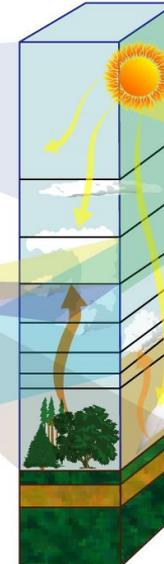
CALIPSO
- Cloud properties



CloudSAT
- Cloud profiler



EOS-Aqua
- Atmospheric humidity
- Water storage
- Clouds
- Snow and ice



TOMS
- Total column ozone



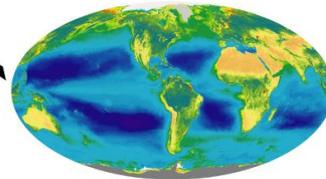
SORCE
- Total Irradiance measurements



SAGE
- Air quality
- Climate change



UARS
- Carbon management
- Air quality



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

Complementary Water and Energy Cycle Missions

QuikSCAT
- Sea-surface wind velocity



EO-1 LANDSAT and NMP EO-1
- Land cover



NPOESS
- Global environmental conditions



GOES
- Weather



Aquarius
- Global sea surface salinity



GRACE: Measurement principle

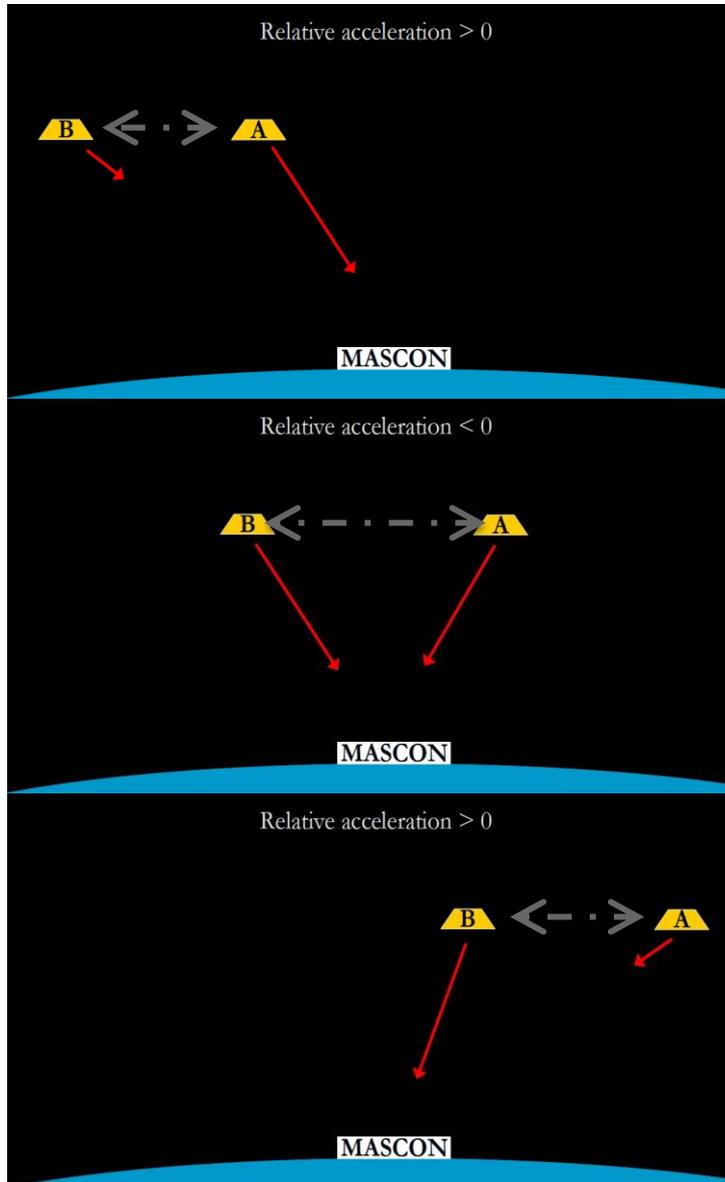
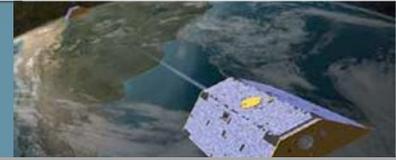
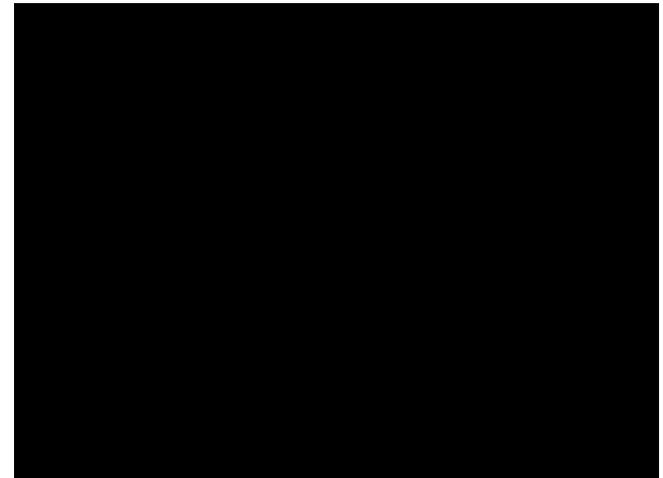
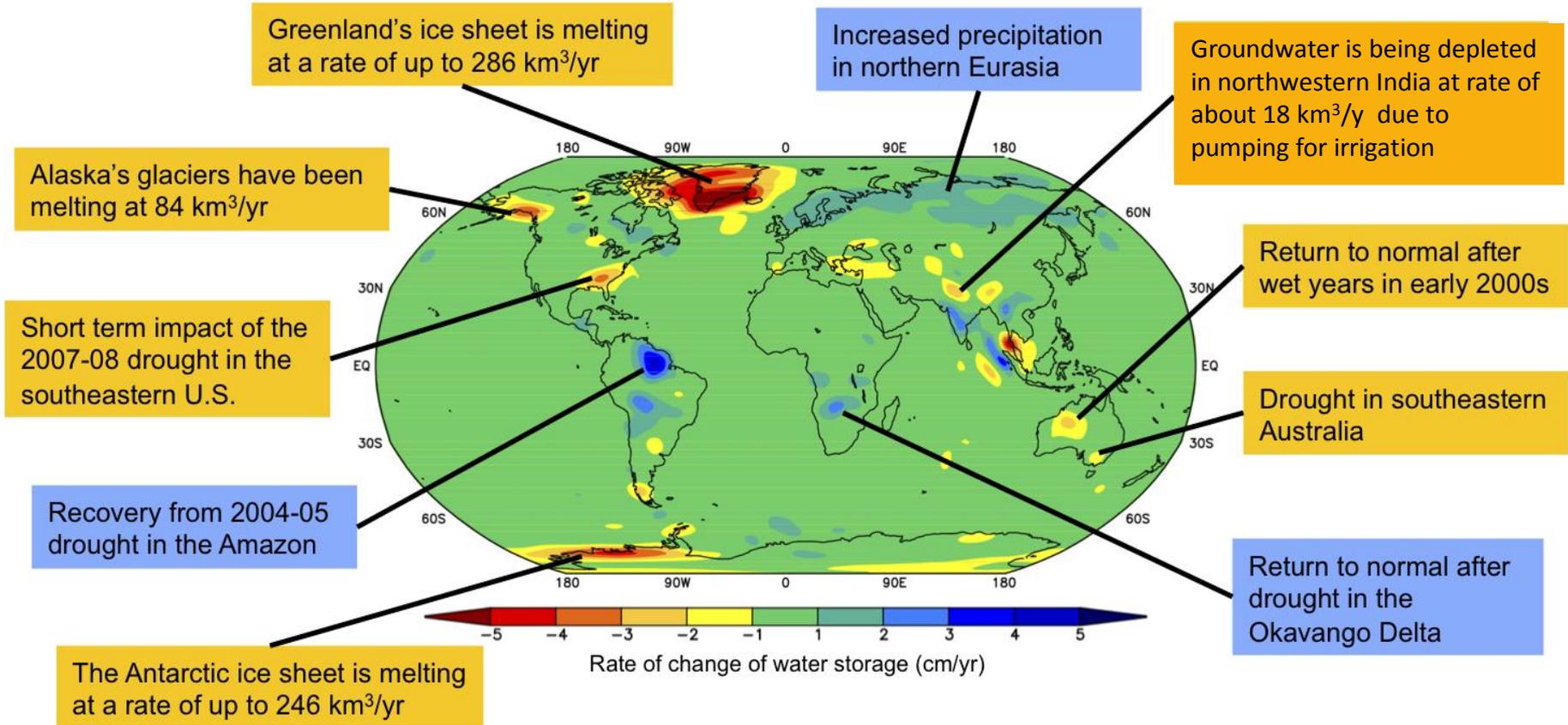
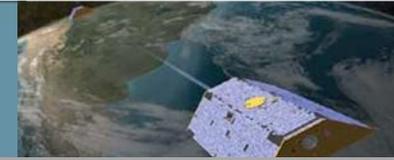


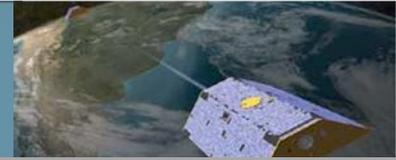
Fig. by
Brian Killett



GRACE 2002-2010 – Major Climate Mass Trends



Sea Level Observations



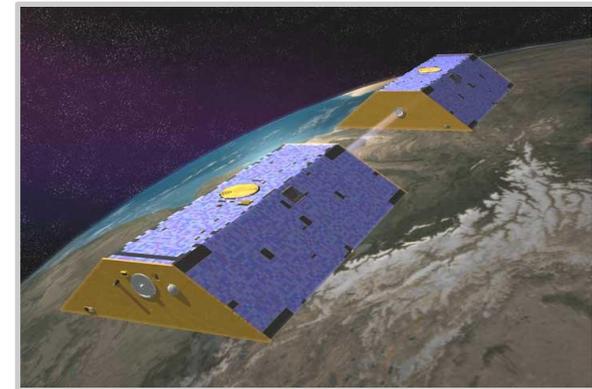
- Altimetry: total sea level

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



- GRACE: mass related changes

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

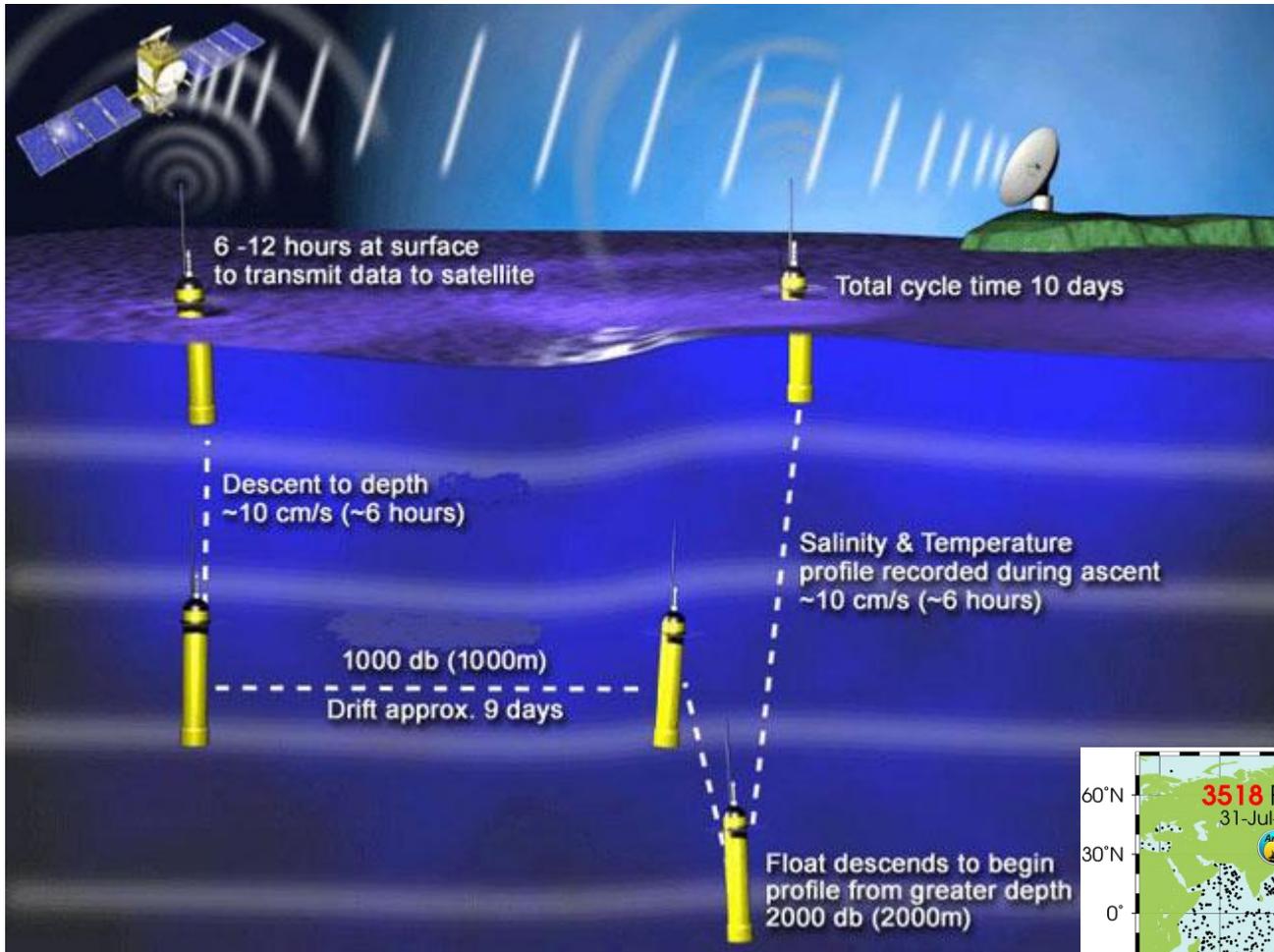
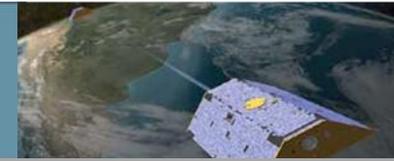


- ARGO floats: thermal expansion and contraction

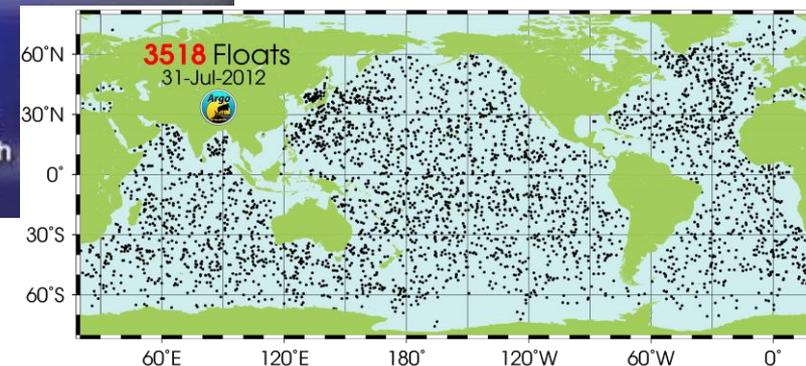
$$h_{\text{total}} = h_{\text{mass}} + h_{\text{density}}$$



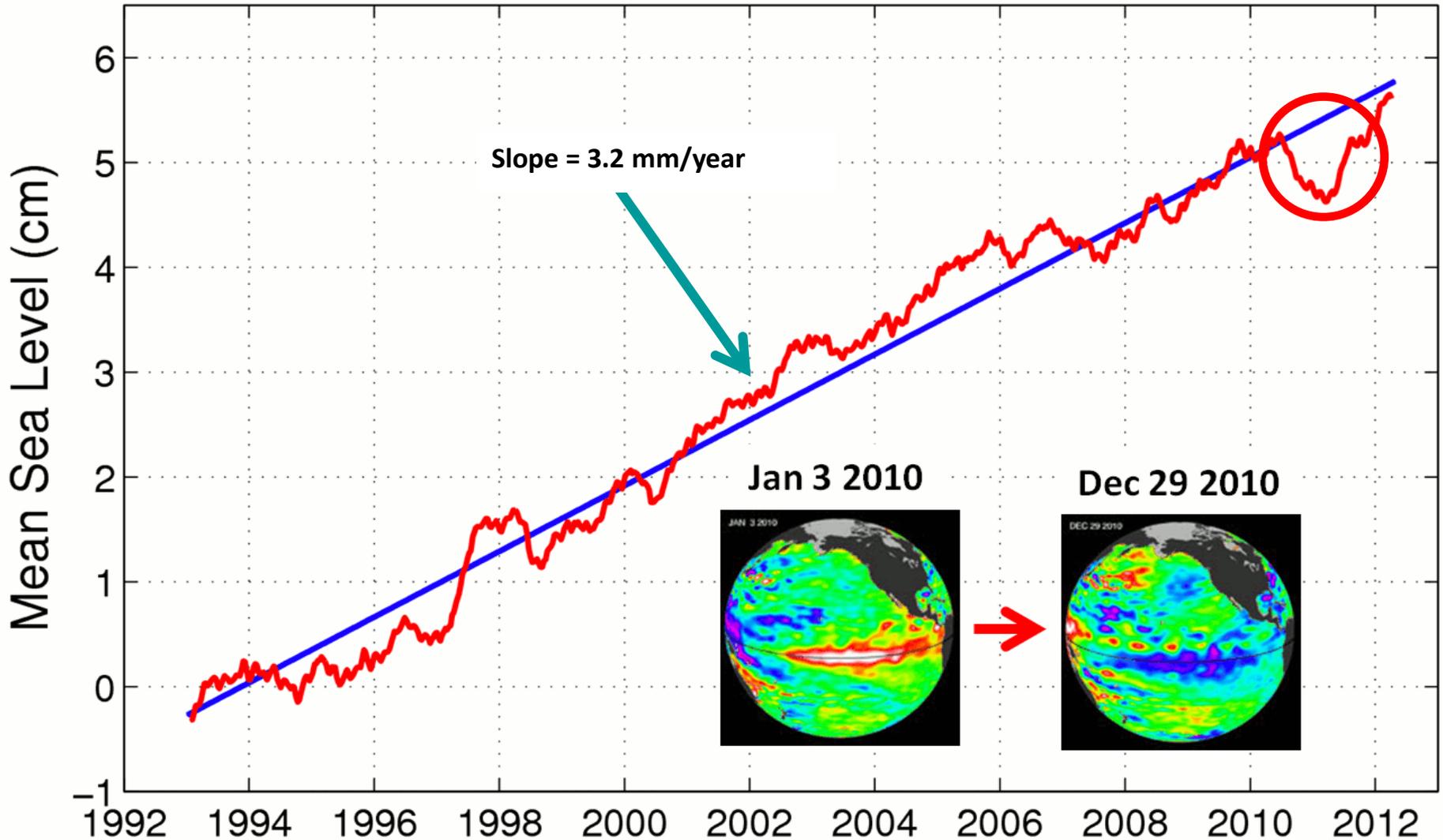
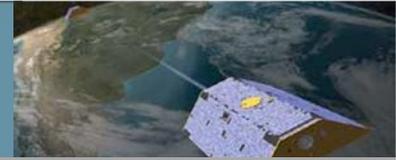
Measuring the Ocean's Temperature



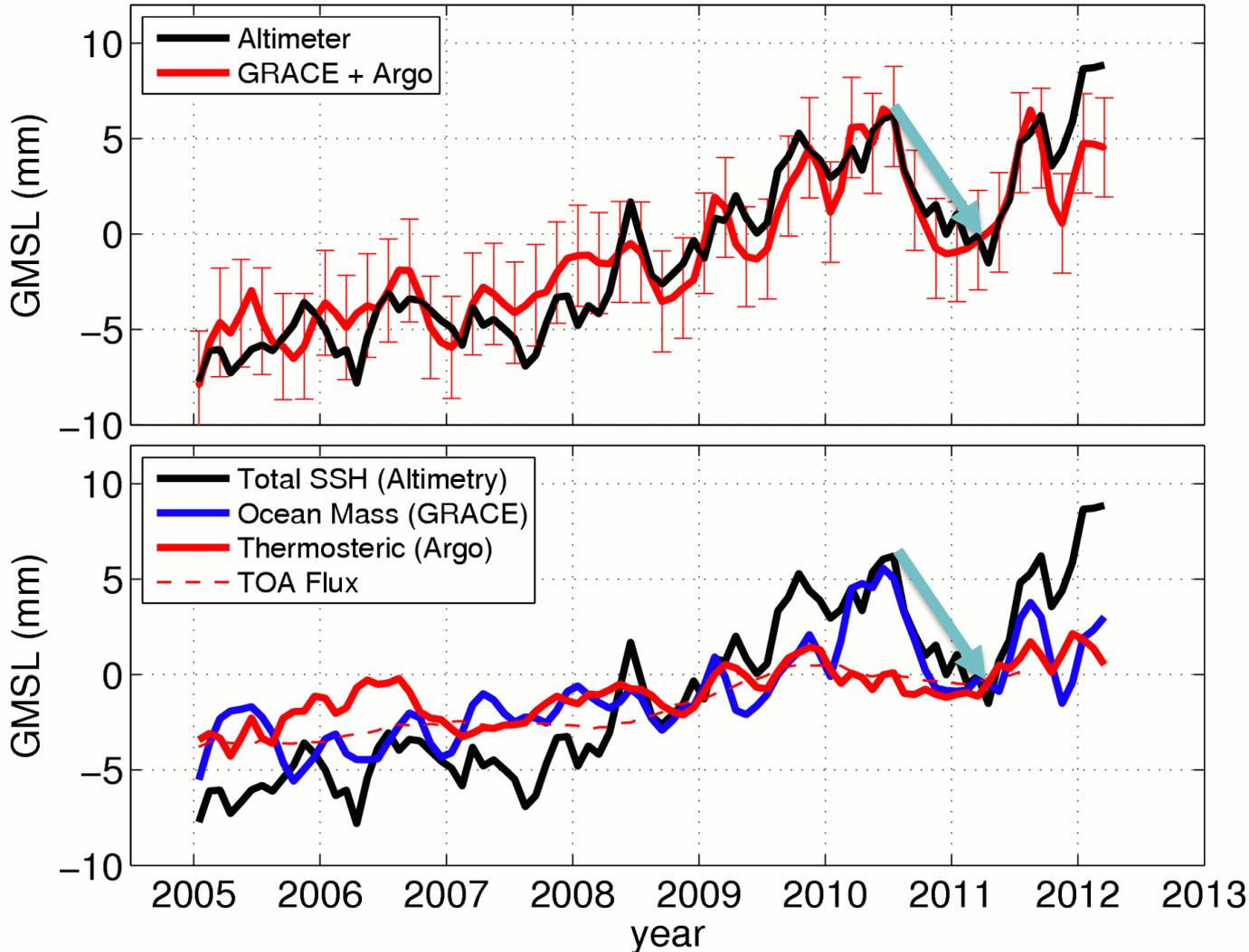
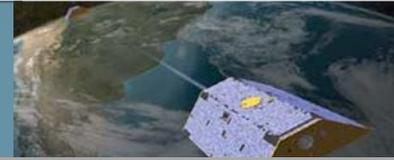
ARGO floats measure the temperature of the ocean down to 2 km (1.4 miles)



Global Sea Level Drops 5 mm

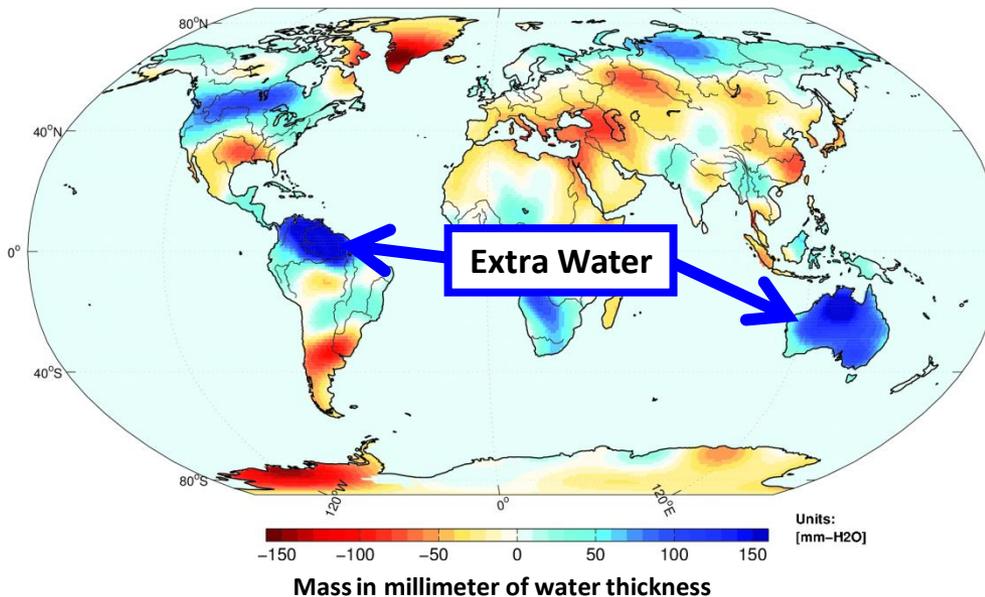
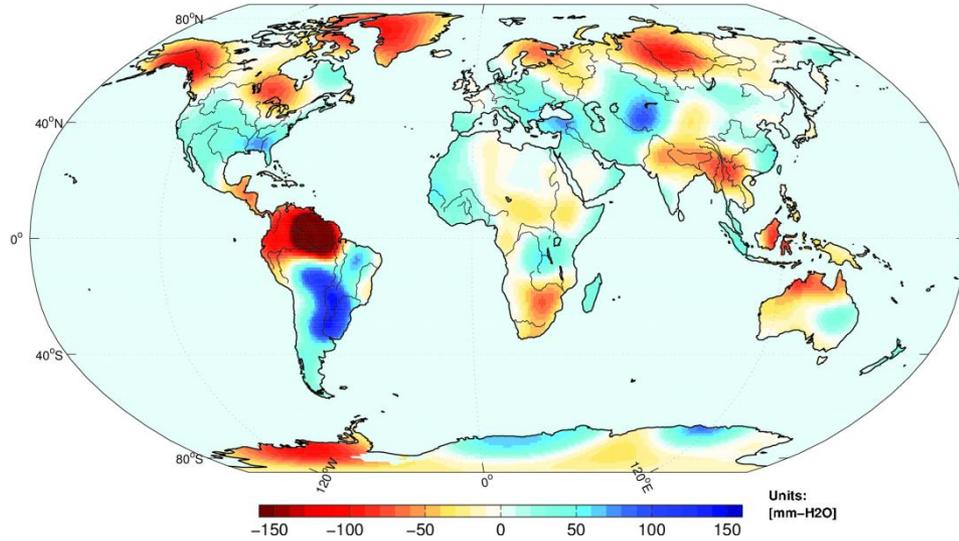
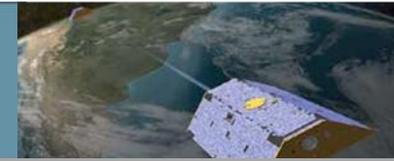


Global Sea Level Drops 5 mm in 2010/11



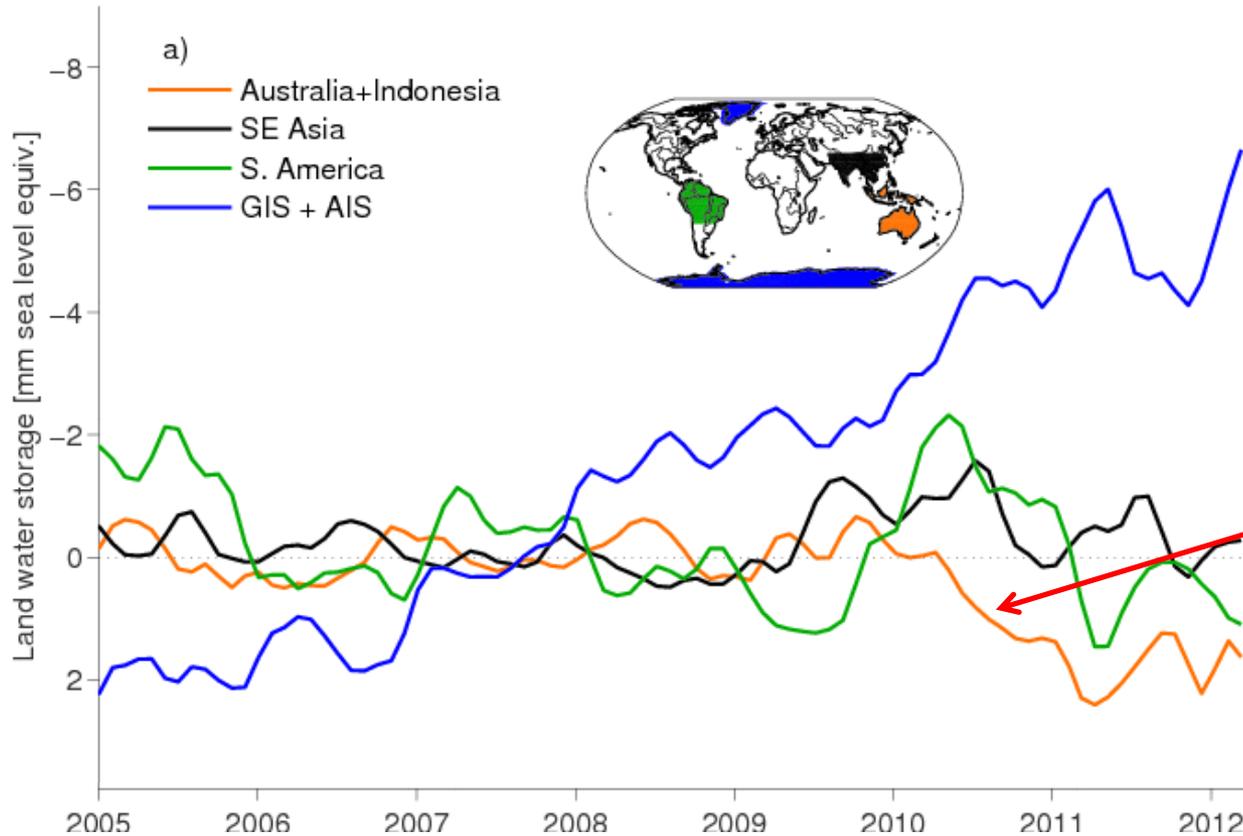
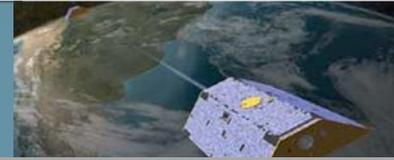
- Altimetry shows drop in global mean sea level.
- Significant part can be attributed to “missing mass from the ocean”

Terrestrial Water Storage in 2010 and 2011



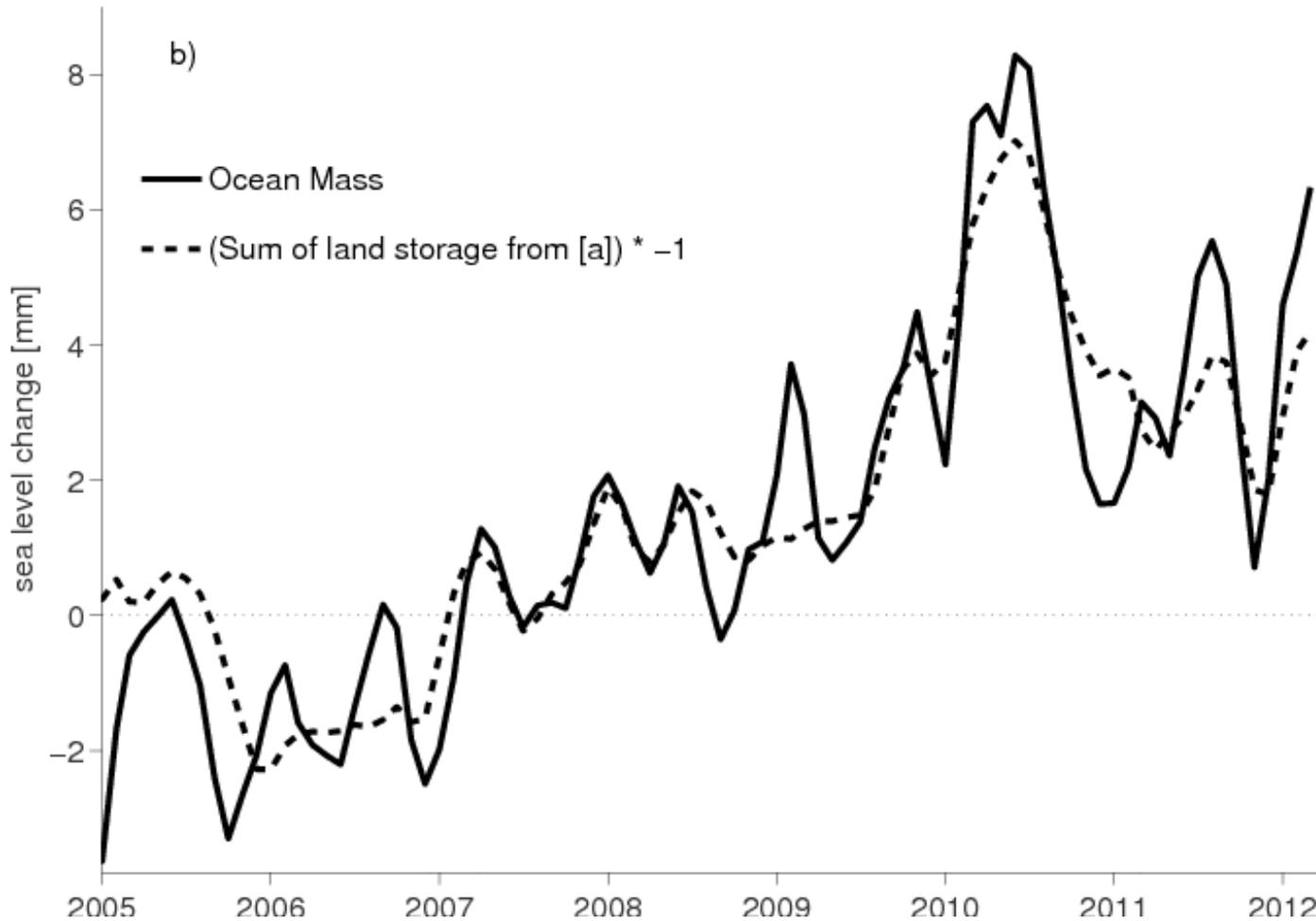
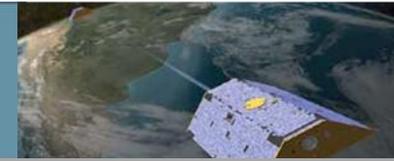
Comparing GRACE mass anomalies from 2010 and 2011 indicates more water over **Australia and northern South America.**

Quantifying the amount of water



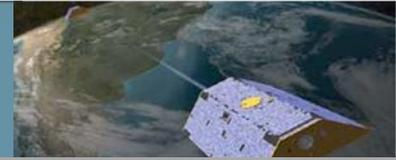
Looking at the contributions from Australia, South America, and SE Asia indicates that the **largest increase** in water mass happened over **Australia**.

Terrestrial Water Storage vs. Sea Level

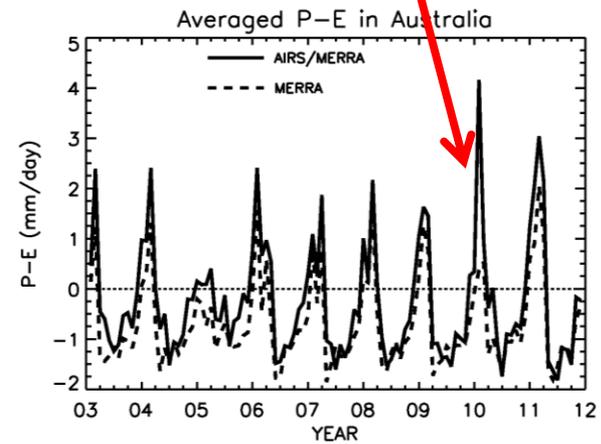
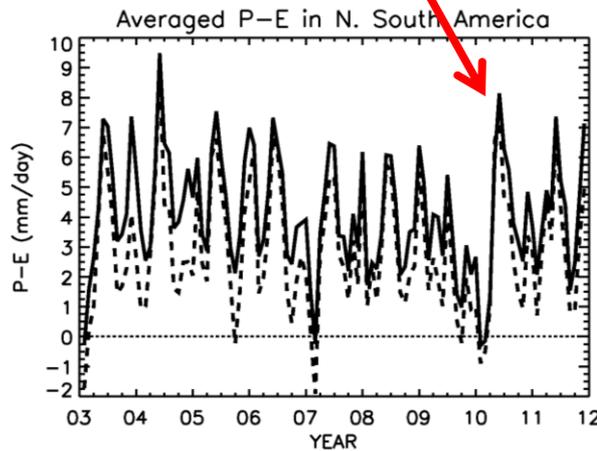
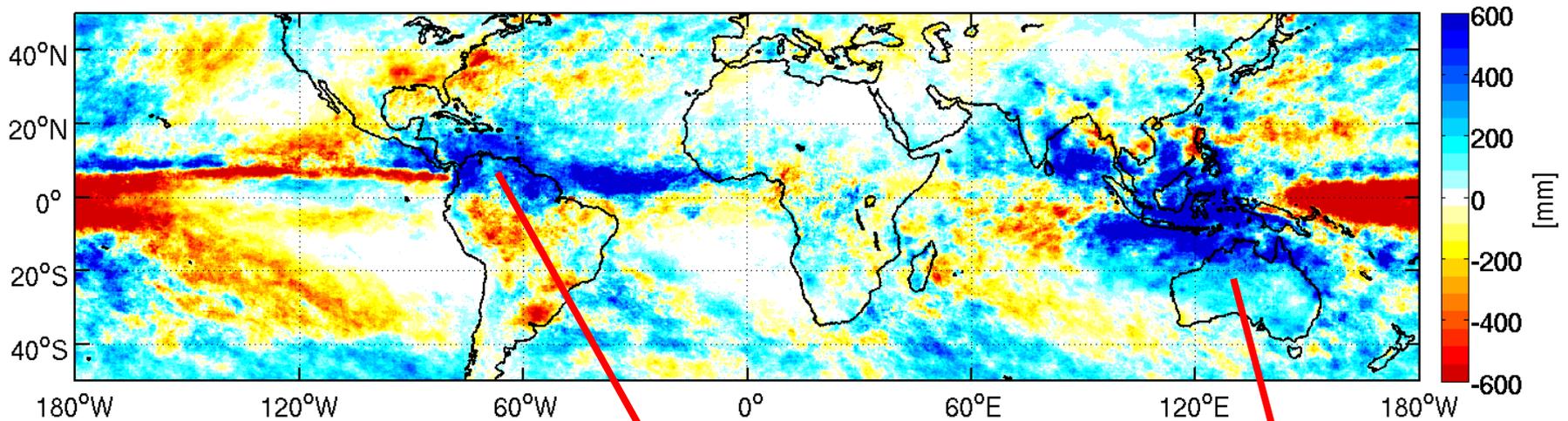


The (negative) sum of contributions from Australia, South America, and SE Asia **explains a large part of the sea level drop.**

Increased Rainfall over Land?

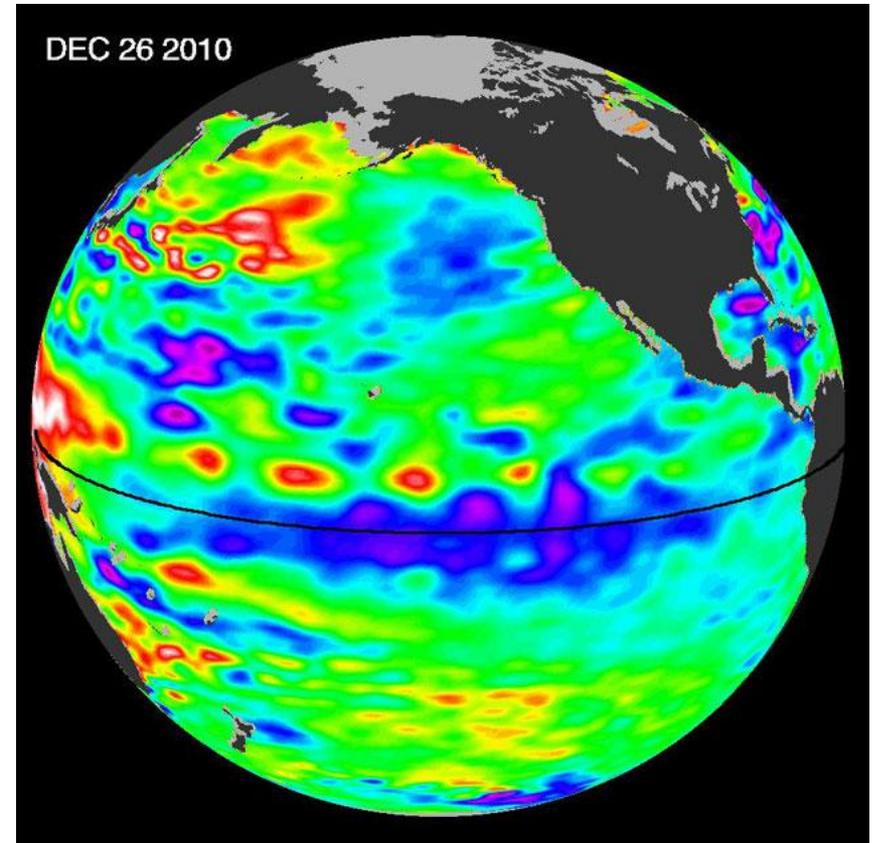
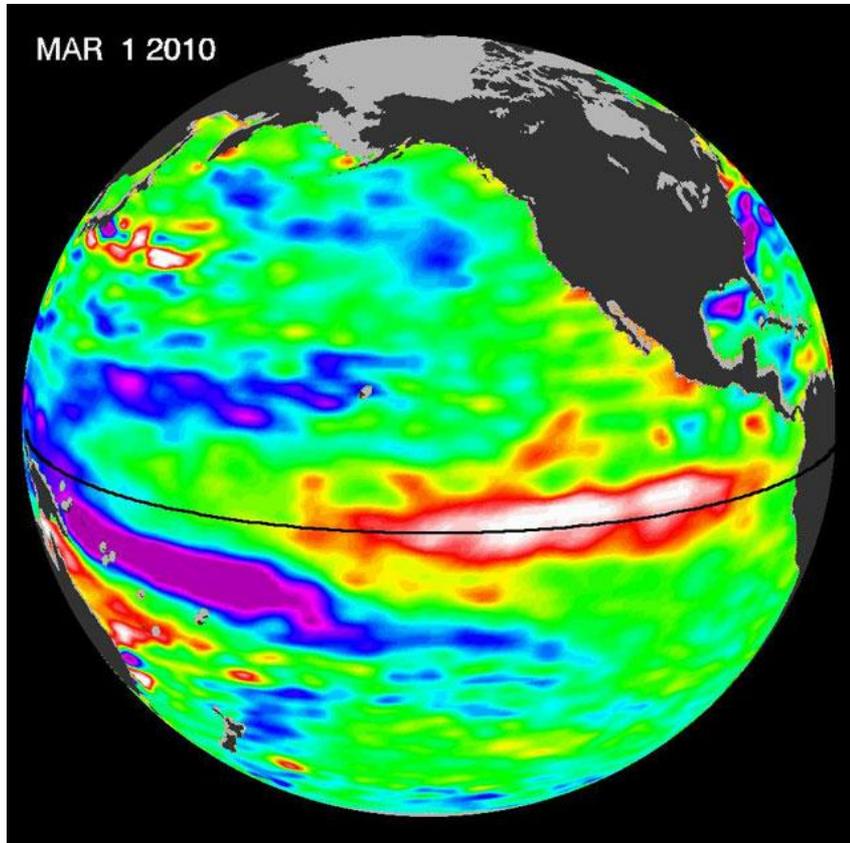
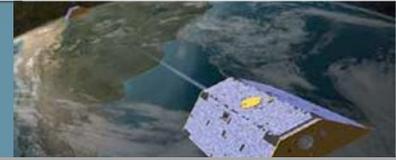


TRMM precipitation

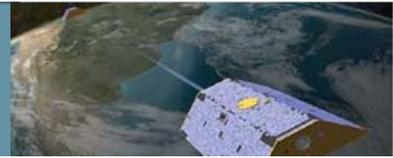


AIRS/MERRA
results by courtesy
of Sun Wong

El Nino Southern Oscillation (ENSO)

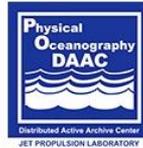


El Nino becomes La Nina



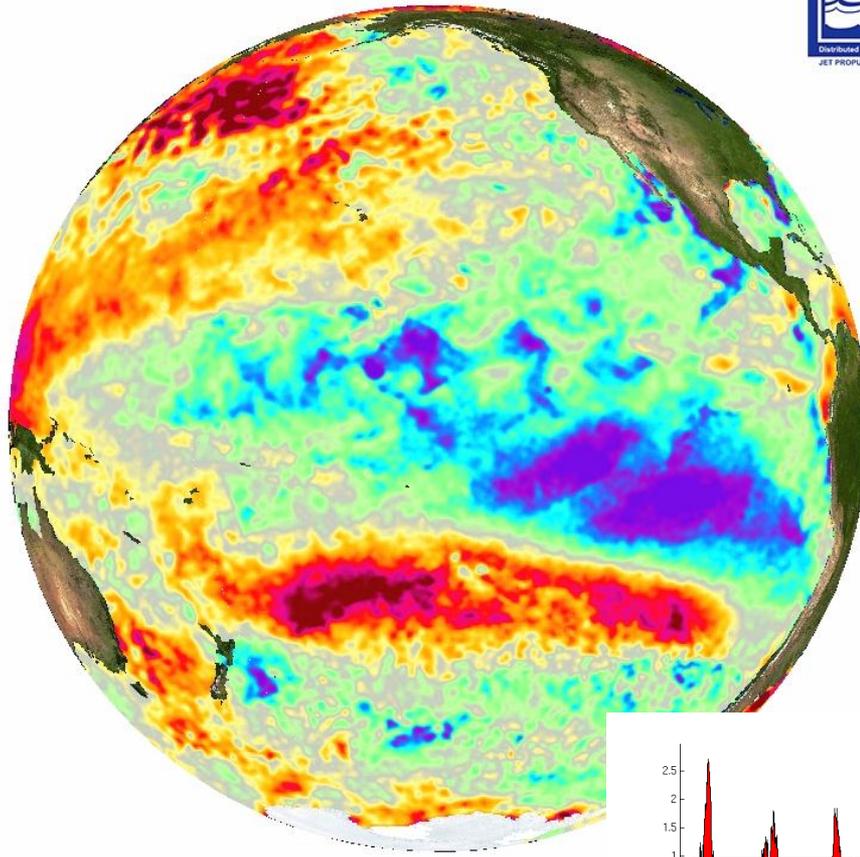
Sea Surface Temperature Anomaly

February 7, 2011

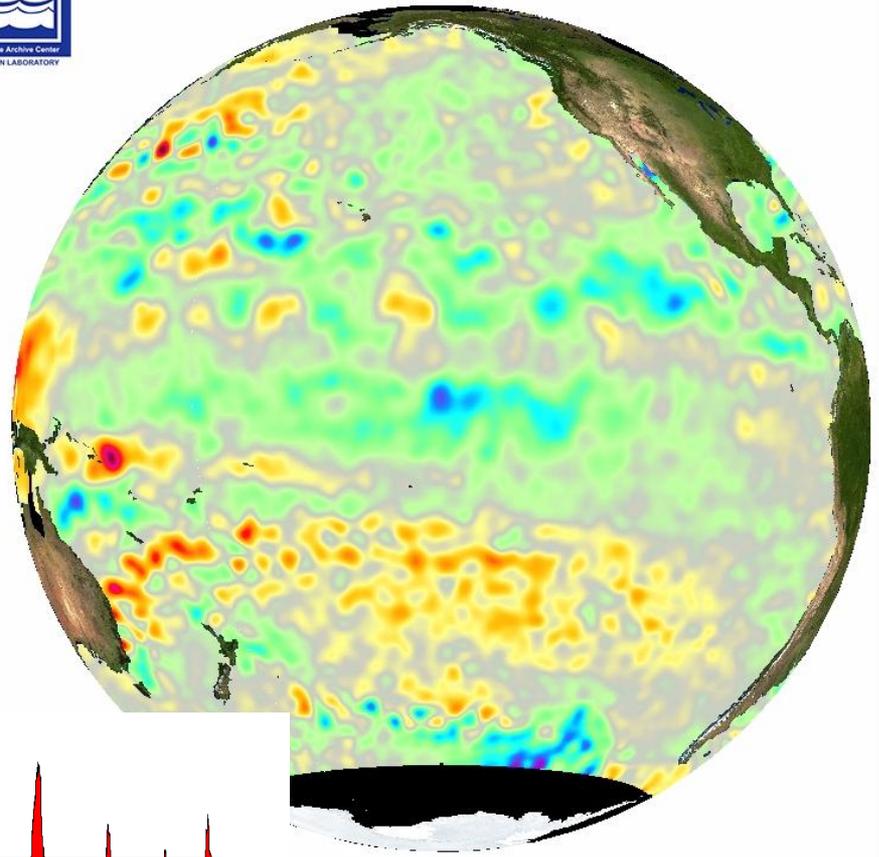


Sea Surface Height Anomaly

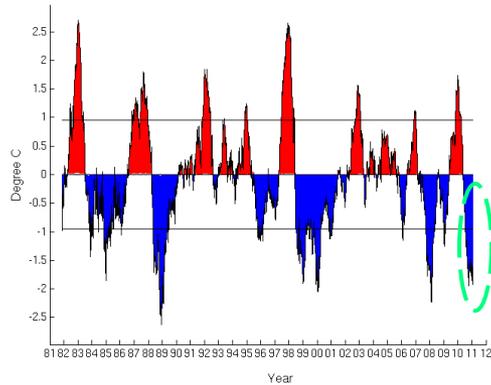
February 7, 2011



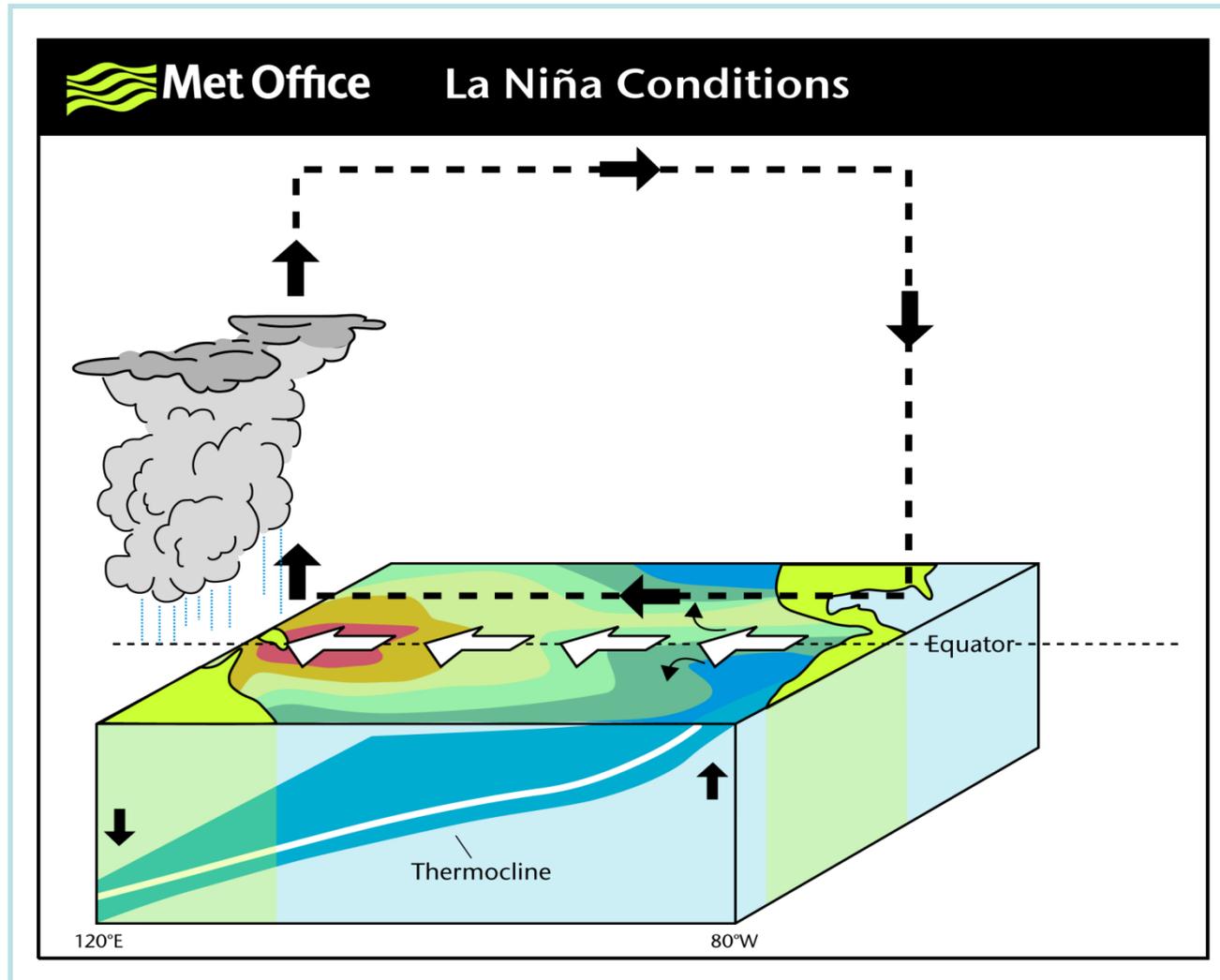
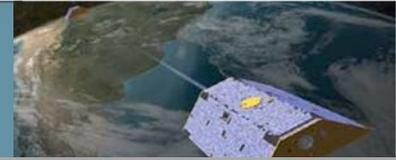
degrees C



cm



La Nina Conditions



[72 Hour Survival Kit](#) Prepare Now For Any Disaster With a 72 Hour
[Relief Pod Emergency Kits](#) Color-Coded, Organized, & Compact. Life is u
[Emergency Medical Tech](#), Emergency Medical Technician Accelerated C

Queensland flooding linked to La Nina phenomenon

Article

Take the International Business Times Readers Survey Now
And See the Results Immediately

Share 4 retweet 1 Buzz up! Share

Print Email Order Reprints

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, 105 km (65 miles) west of Brisbane, January 10, 2011.

Related Articles

- Dynamic Precious Metals Fund
- SGX's A\$7.3 billion bid for ASX falters on



This has led to Queensland having its wettest year to date and the country recording its third wettest year on 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

guardian.co.uk

News Sport Comment Culture Business Money Life & style

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

BBC

Mobile

News Sport

NEWS ASIA-PACIFIC

Home US & Canada Latin America UK Africa Asia-Pac Europe Mid-East Sou

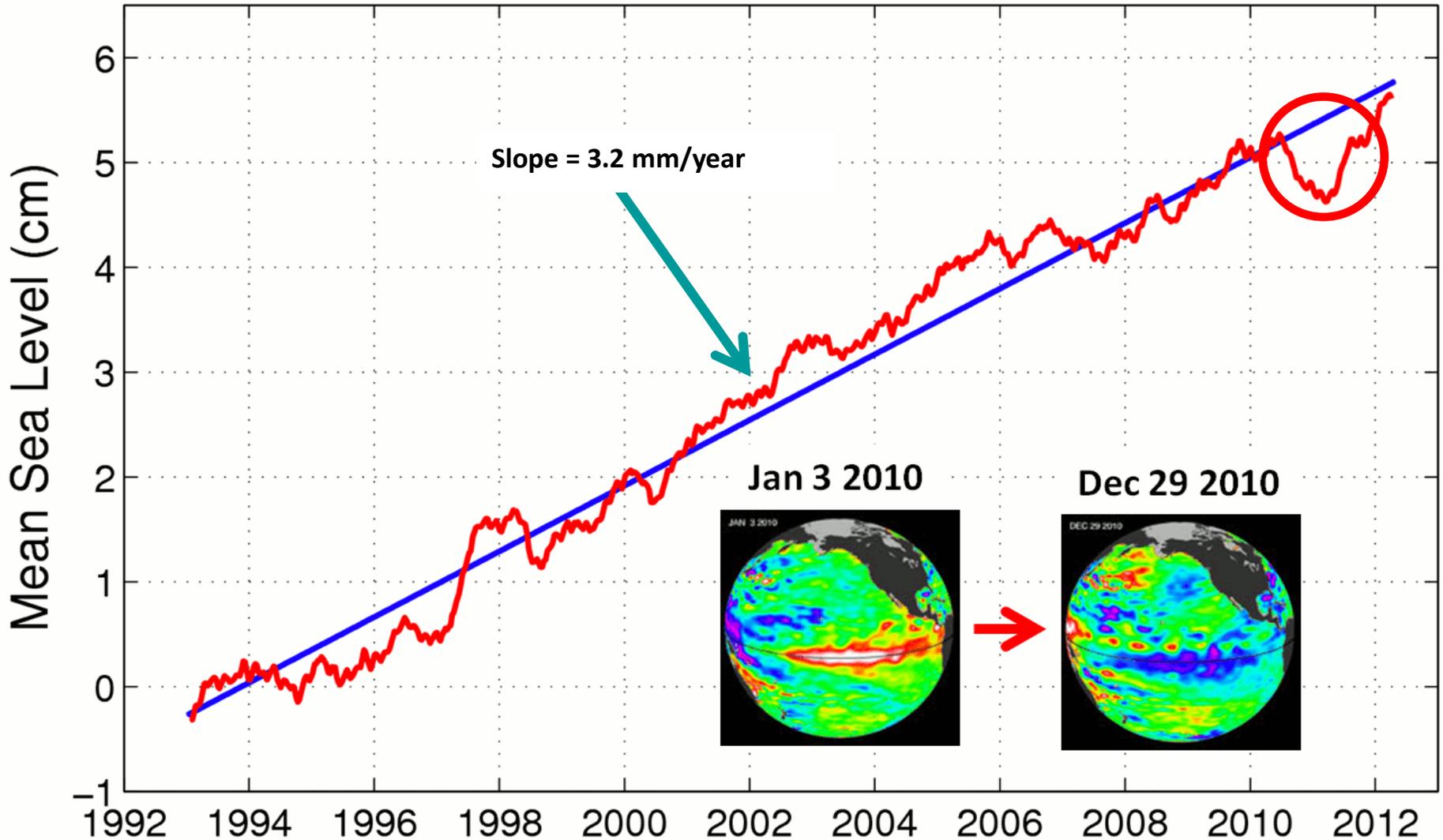
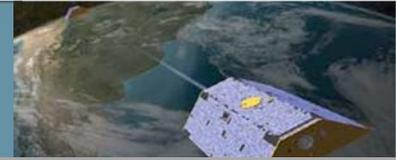
29 December 2010 Last updated at 07:34 ET

Floods force mass evacuations in Queensland, Australia

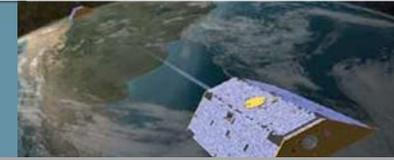


Quickflix on FREE rental titles. Regis

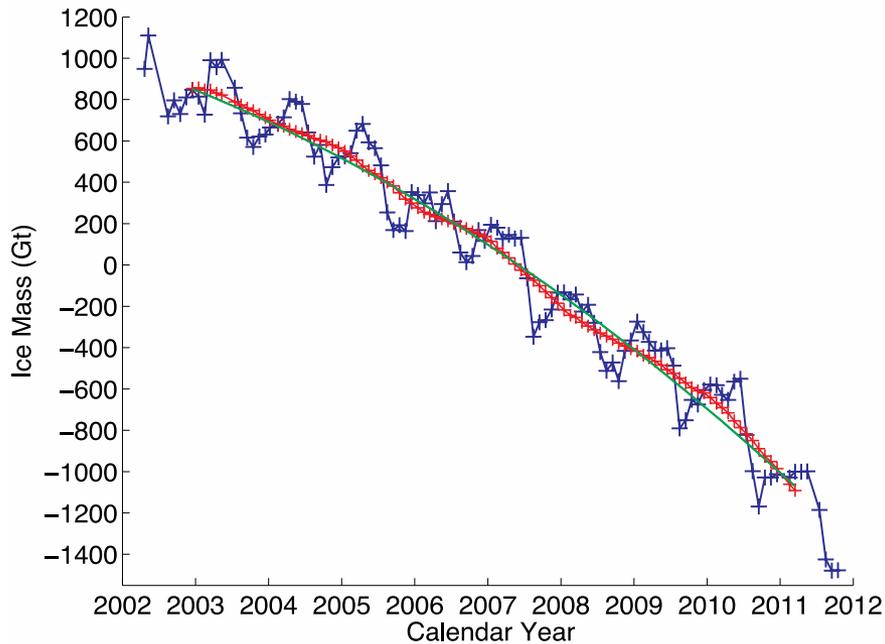
Global Sea Level Drops 5 mm



Ice Mass Loss Observed by GRACE 2002-2011

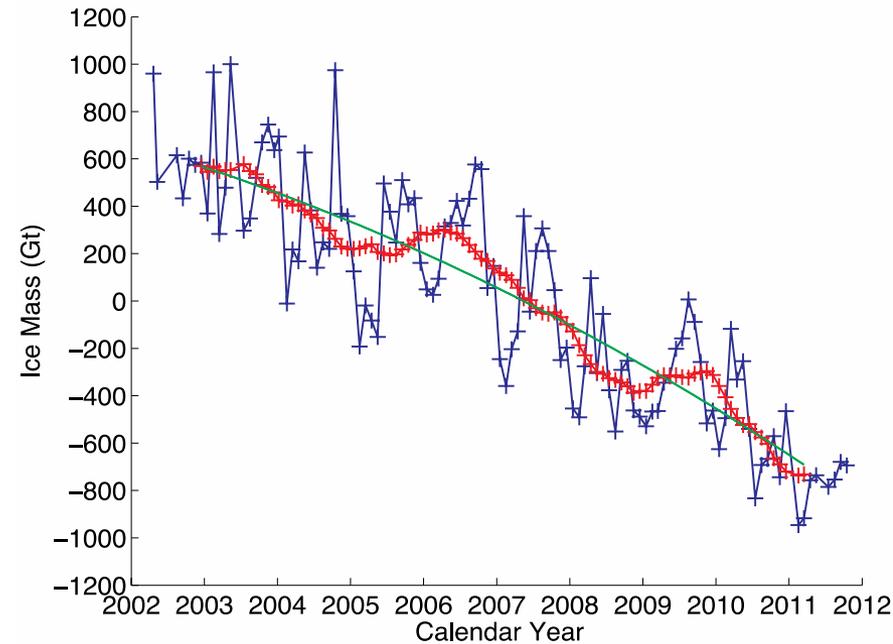


Greenland



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

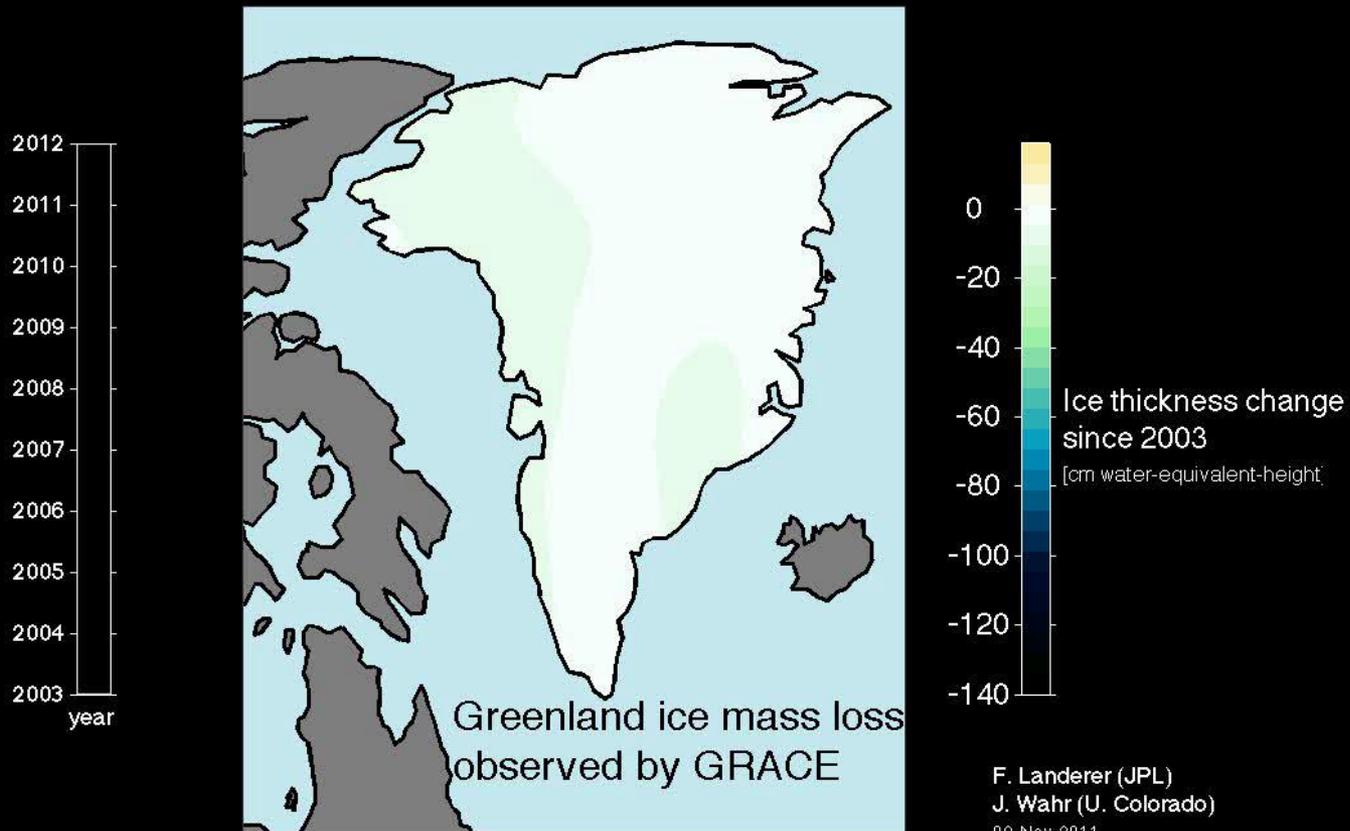
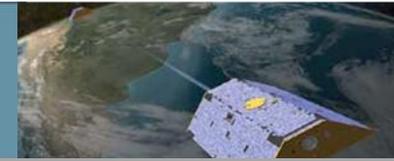
Antarctica



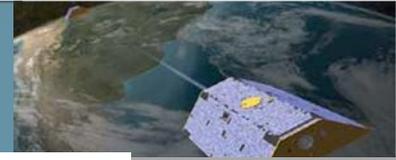
Trend Apr 2002-Oct 2011:
 -152 ± 33 Gt/yr

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

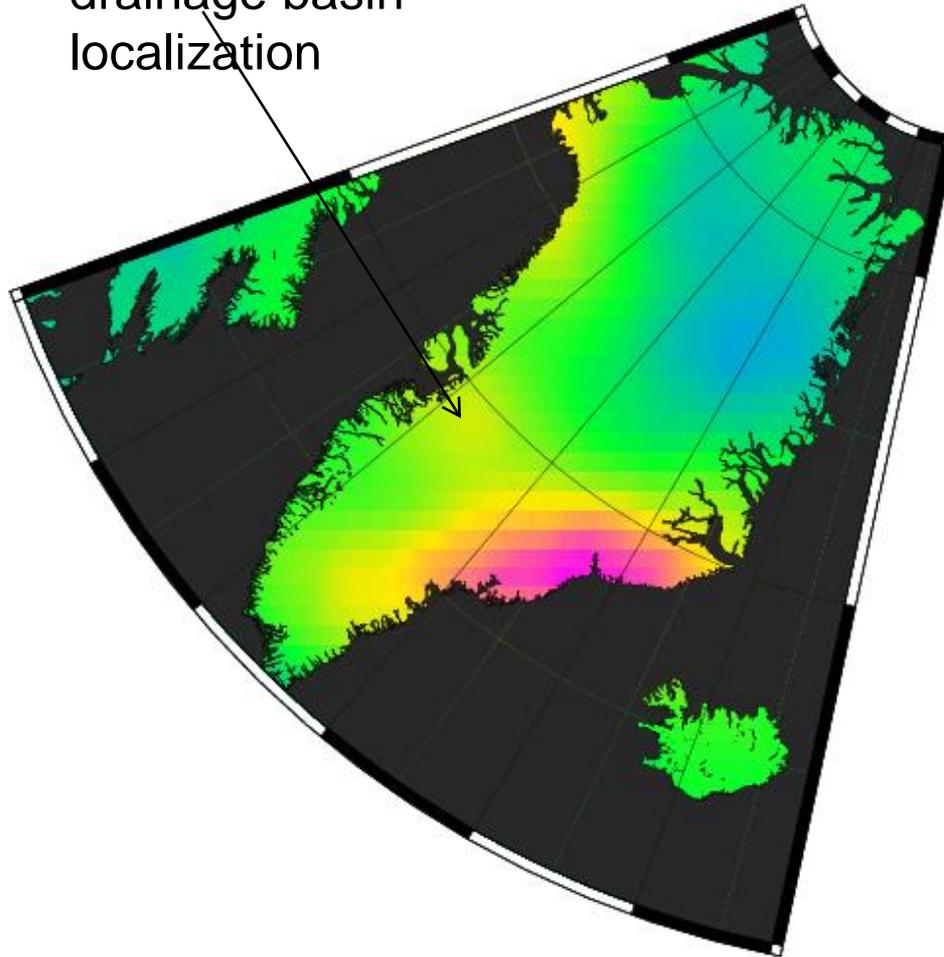
Greenland – Ice Mass Change



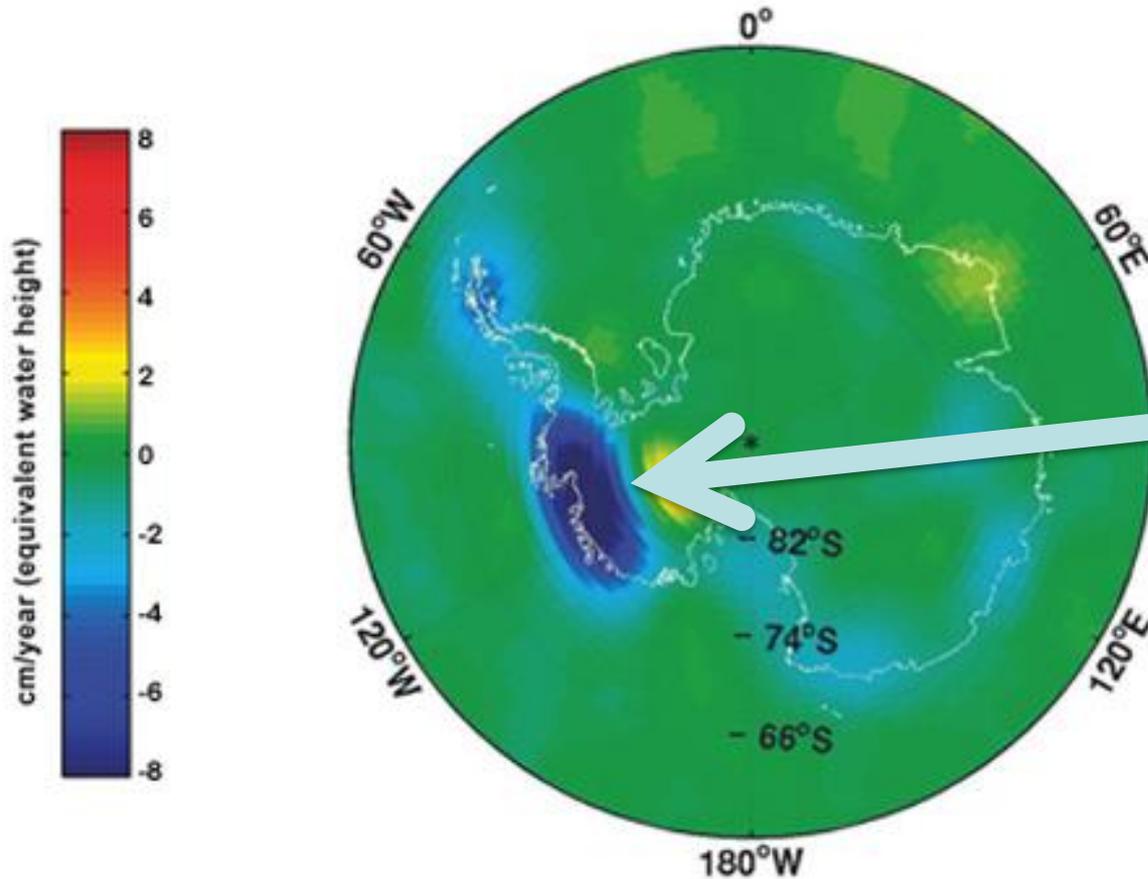
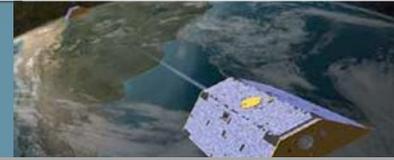
GRACE Analysis Trends— Improving GRACE spatial resolution



Note clear
drainage basin
localization

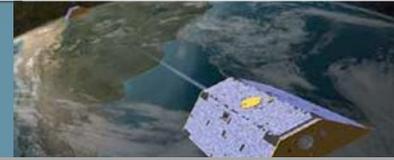


Antarctica – Ice Mass Change



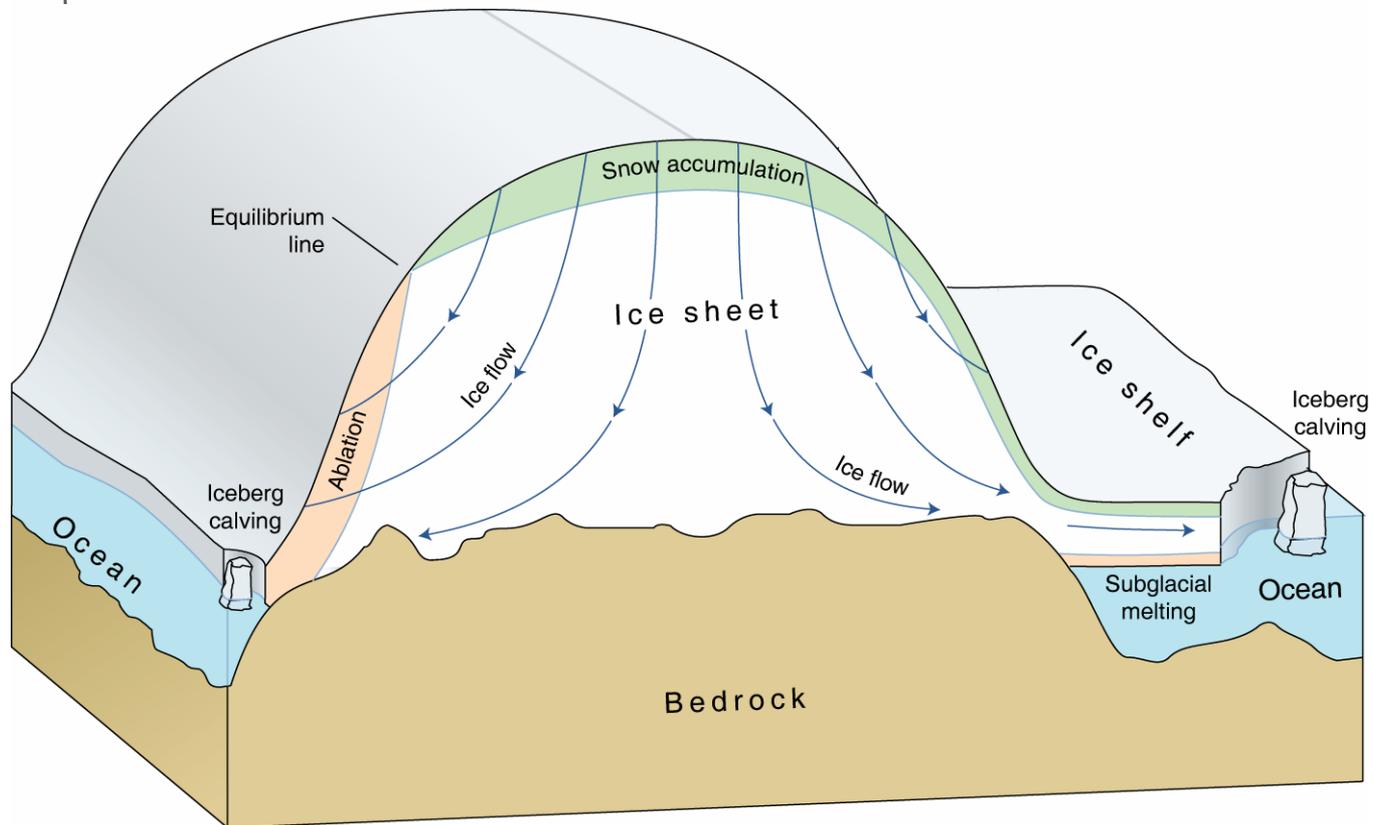
- Ice mass loss primarily in Western Antarctica (Pine Island Glacier and Antarctic Peninsula)

Ice Sheets losing and gaining mass

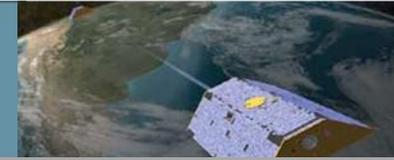


Greenland
Melting on the lower parts of the surface, icebergs calve off from ice sheet edges into ice fjords and the sea

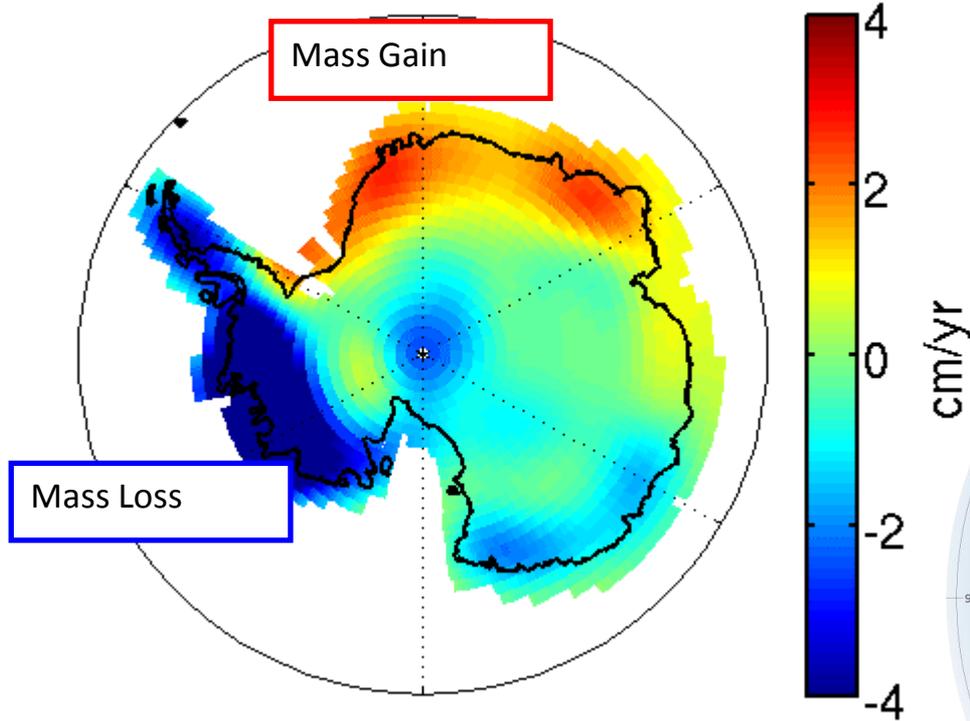
Antarctica
Ice shelves, with subglacial melting. Icebergs calve off from ice shelves



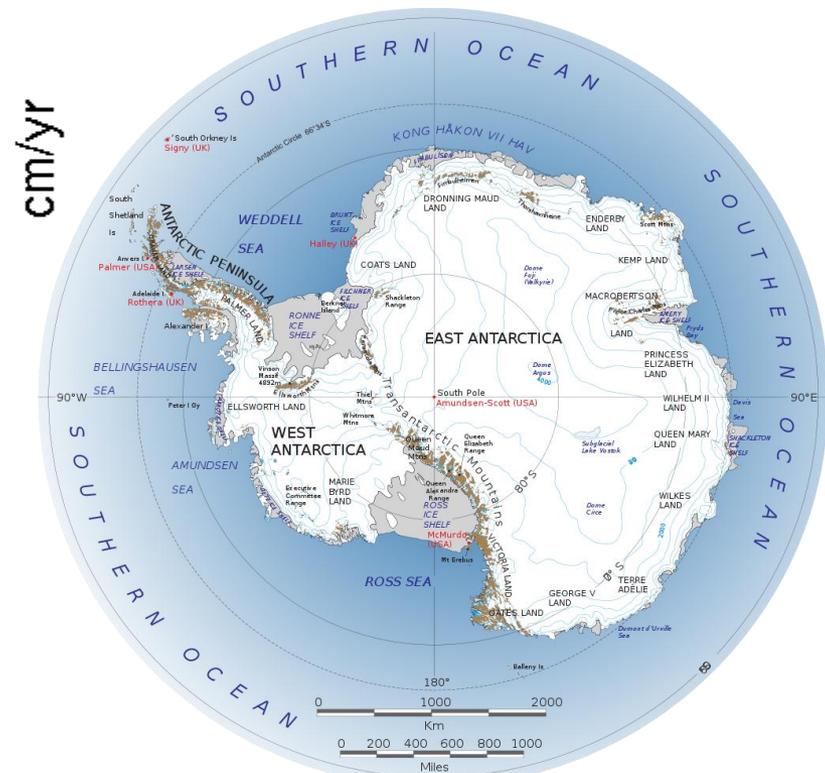
Ice Mass Increase in East Antarctica



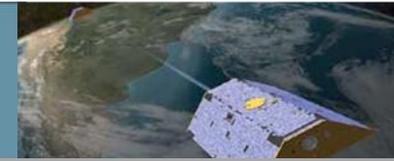
GRACE Mass Trend 2004-2011



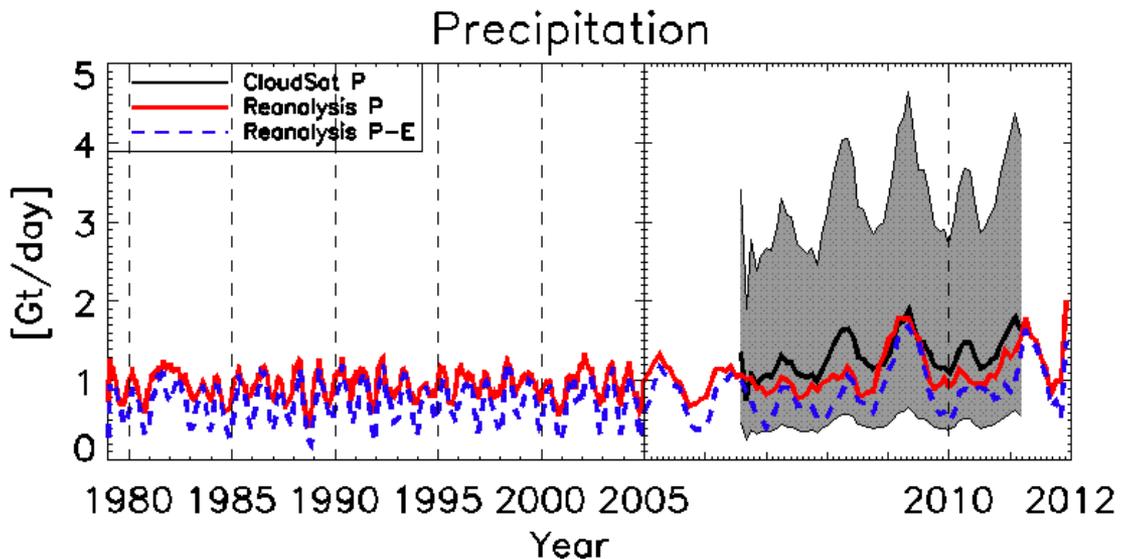
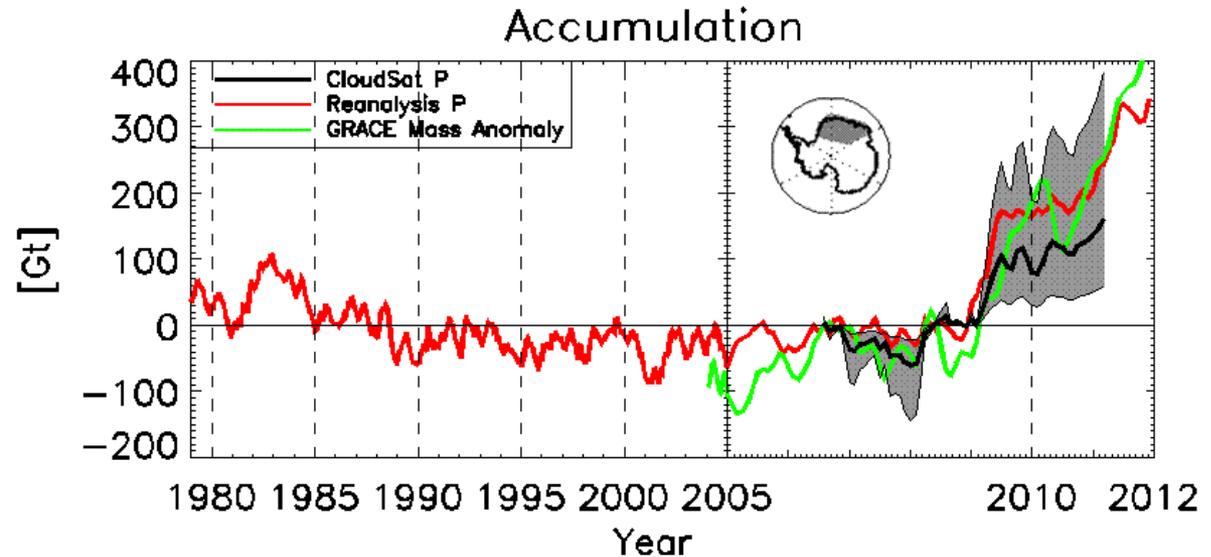
- GRACE satellites observe mass gain along the northern coast of East Antarctica in 2009-2011
- What happened? More ice, more snow?



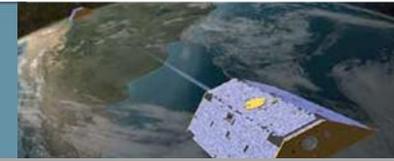
Ice Mass Increase and Antarctic Precipitation



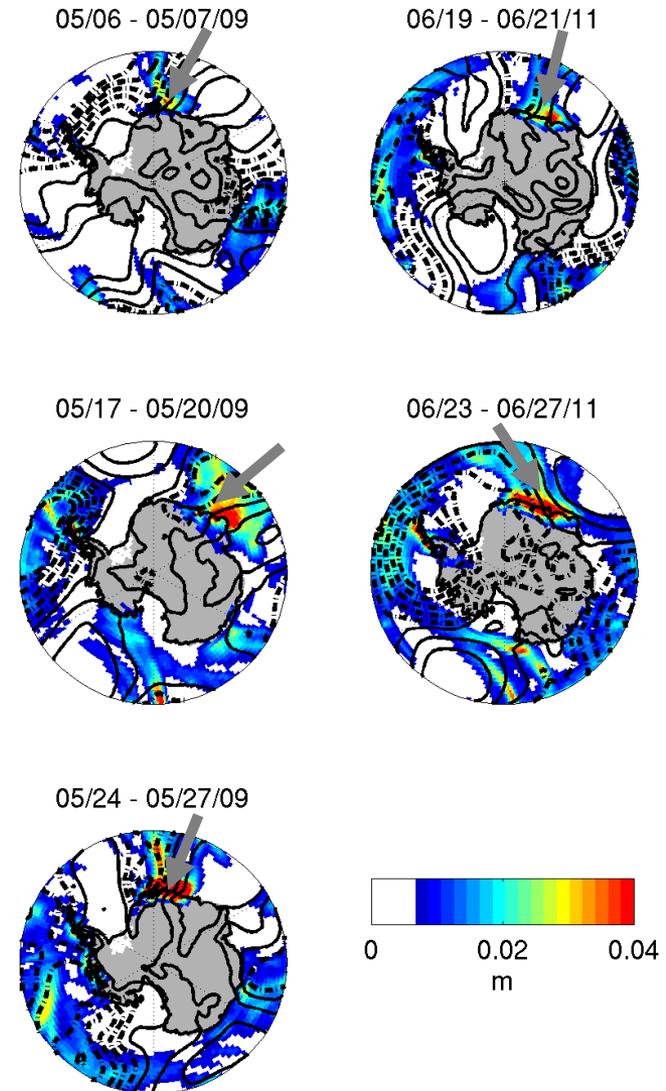
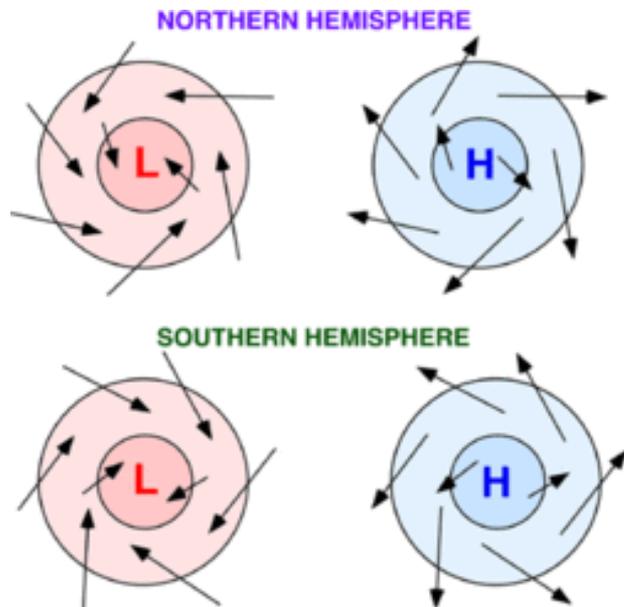
- CloudSat observes snowfall
- Accumulated snow from CloudSat agrees well with GRACE's observed mass
- Independent snowfall data confirms this



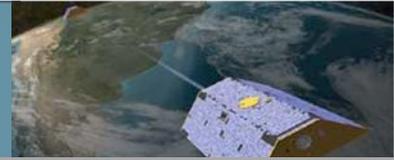
High Precipitation and Southern Ocean Winds



- 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

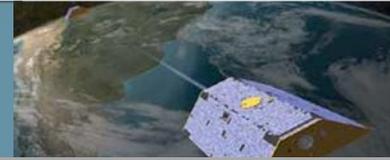


Summary



- 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

DiscoveryNews ... survives cold like woolly mammoths.

EARTH | SPACE | TECH | ANIMALS | DINOSAURS | ARCHAEOLOGY | HISTORY | HUMAN

Discovery News - Earth News - More Greenland Ice Melting Faster

MORE GREENLAND ICE MELTING FASTER

Analysis by John D. Cox
Wed Mar 24, 2010 9:27 PM ET
Comments | Leave a Comment

Sensitive Global Positioning System and other satellite-borne sensors have detected the accelerating northwestern migration of ice loss the length of coastal Greenland since 2005.

Scientists have known for some time that the great ice sheet was losing mass over southeastern portions of Greenland, but a new analysis describes "an on-going northward migration of increasing mass loss" along the western coast from the southern tip to the far north.

The Greenland ice sheet is a vast reservoir, two miles deep in places, containing enough water to fill the Gulf of Mexico -- and to raise sea level 21 feet if it were all to melt.

The new analysis, by an international team led by Shafiq Abbas Khan of the National Space Institute of Denmark, is published this week in the American Geophysical Union journal *Geophysical Research Letters*. The image, courtesy of AGU, shows the average rate of mass loss, measured in centimeters of ice thickness, between February 2005 and June 2009.

(Click on the image and watch a video, courtesy of the University of Colorado-Boulder, that shows the evolution of the melting pattern since January 2003.)

The researchers compared two sets of data -- measurements of "crustal uplift" along the coast detected by three long-term GPS sites on southern Greenland, and data

Subscribe | Give a Gift | Customer Service | Promotions | Blogs | Video |

Popular Mechanics

TRY: Cool Mix

AUTOMOTIVE | TECHNOLOGY | SCIENCE | HOME HOW-TO

Homepage / Science / Earth and the Environment / Climate Change

Iceberg Forensics: Predicting the Planet's Future With Antarctic Ice

In the last million years, the North American ice sheet has formed and completely melted about 10 times. Ice is melting once again--simultaneously across the globe--and the science research vessel and drilling ship JOIDES Resolution has been seeking out clues to how ice sheets may respond to a warming climate. Onboard in Antarctica, Trevor Williams reports on the role that ice has played throughout geologic history and what a new iceberg in the Southern Ocean can tell us about the future for the planet.

BY TREVOR WILLIAMS

TEXT SIZE: A A A

There is a new iceberg in the Southern Ocean, and it's big: 50 miles long by 20 miles wide. Until February, it had been the tongue of the Mertz Glacier, sticking out from the East Antarctic ice sheet into the Southern Ocean. Large cracks had been forming over the last few years, crossing the tongue almost from one side to the other, but it took a nudge from a similarly huge iceberg to finally set the chunk of ice free. The new Mertz iceberg will [float](#) westwards on the currents around Antarctica for decades, sometimes running aground on shallow parts of the seafloor and churning the brackish water

nature geoscience

nature.com | Personal home | archive | home | in the press | full text

NATURE GEOSCIENCE | IN THE PRESS

Bulge in the ocean

Asel Bajajewski
Nature Geoscience 4, 421 (2011) | doi:10.1038/ngt1197
Published online 30 June 2011

Some giants are so big, they are practically invisible. Geophysicists have discovered one of them -- a huge hump of water in the South Pacific that is imperceptible to the naked eye. Satellite rebid scientists in tracking the phenomenon. Carmen Bitting and her colleagues at the California Institute of Technology (Caltech) have reported a bulge in ocean waters that stretched over an area the size of Australia for some months, and measured up to six centimetres in height (C. Bitting et al. *Geophys. Res. Lett.* 38, L04602, 2011). A "record" of an "unusual maximum", say the researchers.

The discovery can be attributed to the satellite programme Gravity Field and Steady State Ocean Circulation Explorer (GOCE) (<http://ftp.igs.fhnw.ch/GOCE/>) and Gravity Recovery and Climate Experiment (GRACE) that measure the Earth's gravitational pull. These programmes have provided the most precise atlas of the Earth's gravitational field so far.

Journal home | Current issue | For authors | Selected feature | Earth designed by plants | Vegetation has been a key part of the Earth's surface for only about 450 million years. With the progression of the terrestrial landscape from bare surfaces to widespread coverage by plants-ground vegetation initiates, then heats and finally-flourishing plants: the Earth's surface and its biogeochemical processes have also changed in this time, we present a collection of articles that explore how the evolution of terrestrial plants and the Earth's surface have affected each other.

year | email | download pdf | water reports | topics and announcements | online benchmark

THE WASHINGTON POST

Politics | Opinions | Local | Sports | National | World | Business | Investigations

Corrections | Energy & Environment | Health & Science | Higher Education | National Security | On Fall

In the News | George Huguely | Jeremy Lin | Ron Barber | Miss Allard | Ben Fostelore

SAVE \$1,000 ON SOLAR 2011

A Post investigation: Coegren and cash | A photographic valentine to D.C. | Plo. Nor

Weather cycles cause a drop in global sea level, scientists find

By Juliet Eljertin, Published: August 25

The global sea level this summer is a quarter of an inch lower than last summer, according to NASA scientists, in sharp contrast to the gradual rise the ocean has experienced in recent years.

The change stems from two strong weather cycles over the Pacific Ocean -- El Niño and La Niña -- which shifted precipitation patterns, according to scientists at NASA's Jet Propulsion Laboratory in Pasadena, Calif. The two cycles brought heavy rains to Brazil and Amazon, along with drought to the southern United States.

Researchers monitored the ocean's width, height, temperature and salinity through satellites and robot-operated floats, and presented their findings Aug. 8 and 9 at the annual Gravity Recovery and Climate Experiment (GRACE) Science Team Meeting in Austin, Tex.

"This year the continents got an extra dose of rain, so much so that global sea levels actually fell over most of the last year," said

Colorado

Top Stories | Profiles | For the Media | Statements | Special Reports | Facts | Sports

Greenland Ice Sheet Losing Ice Mass on Northwest Coast, Says New International Study

March 23, 2010

Ice loss from the Greenland ice sheet, which has been increasing during the past decade over its southern region, is now moving up its northern coast, according to a new international study.

Led by the Denmark Technical Institute's National Space Institute in Copenhagen and involving the University of Colorado at Boulder, the study indicated the ice loss acceleration began moving up the northwest coast of Greenland starting in late 2005. The team drew their conclusions by comparing data from NASA's Gravity and Recovery Climate Experiment satellite system, or GRACE, with continuous GPS measurements made from long-term sites on stations on the edge of the ice sheet.

The data from the GPS and GRACE provided the researchers with monthly averages of crustal uplift caused by ice-mass loss. The team confirmed the uplift measured by GRACE over United Kingdom-sized chunks of Greenland with the GPS measured monthly crustal uplift rates of just one of inches. "Our results show that the ice loss, which has been well documented over southern portions of Greenland, is now spreading up along the northwest coast," said Shafiq Abbas Khan, lead author on a paper that will appear in *Geophysical Research Letters*.

The team found that uplift rates near the Thule Air Base on Greenland's northwest coast rose by roughly 1.5 inches, or about 4 centimeters, from October 2005 to August 2009. Although the low resolution of GRACE -- a swath of about 150 miles, or 250 kilometers across -- is not precise enough to pinpoint the source of the ice loss, the fact that the ice sheet is losing mass where the ice sheet margins suggest the flow of Greenland glacier waters there are increasing in velocity, said the study authors.

"When we look at the monthly values from GRACE, the ice mass loss has been very dramatic along the northwest coast of Greenland," said CU-Boulder physics Professor and study co-author John Wahr, also a fellow at CU-Boulder's Cooperative Institute for Research in Environmental Sciences.

"This is a phenomenon that was undocumented before this study," said Wahr. "Our speculation is that some of the big glaciers in this region are sliding downhill faster and dumping more ice in the ocean."

Other co-authors on the new GPS study included Matthew Bevan and Eric Kendrick from Ohio State University and Isabella Veloso of the University of California, Irvine, who also is a scientist at NASA's Jet Propulsion Laboratory. GPS is operated by the American Geophysical

