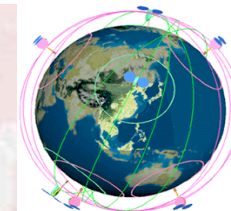
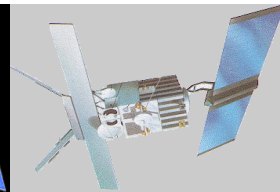
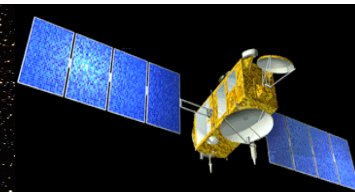
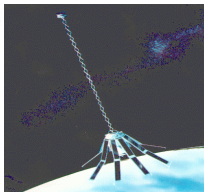
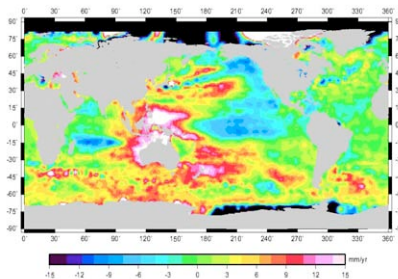


Global Sea Level Trend Observed by GEOSAT, ERS-1/2 and T/P (1985-2001)



Observations and Geophysical Causes of Global Sea Level Rise

C.K. Shum¹, Chungyen Kuo²

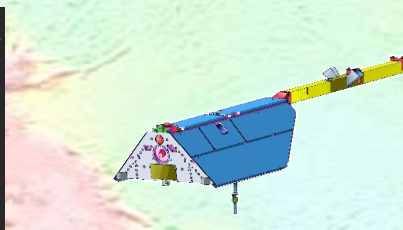
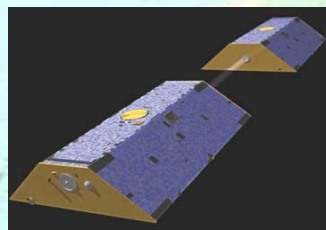
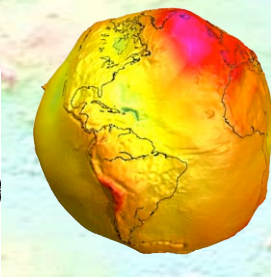
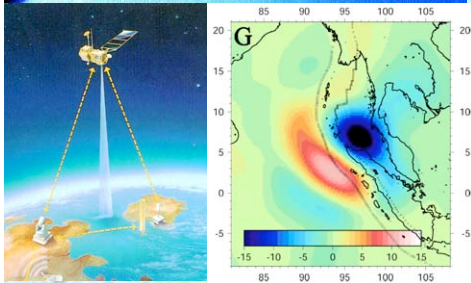
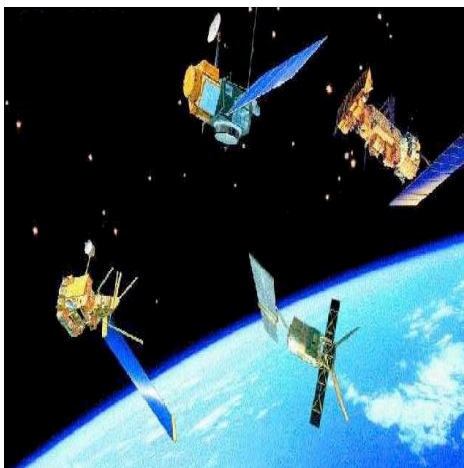
¹School of Earth Sciences, Ohio State University, USA

²Department of Geomatics
National Cheng Kung University, Taiwan

International Symposium on Climate Change
& Food Security in South Asia

Dhaka, Bangladesh

25–30 August 2008



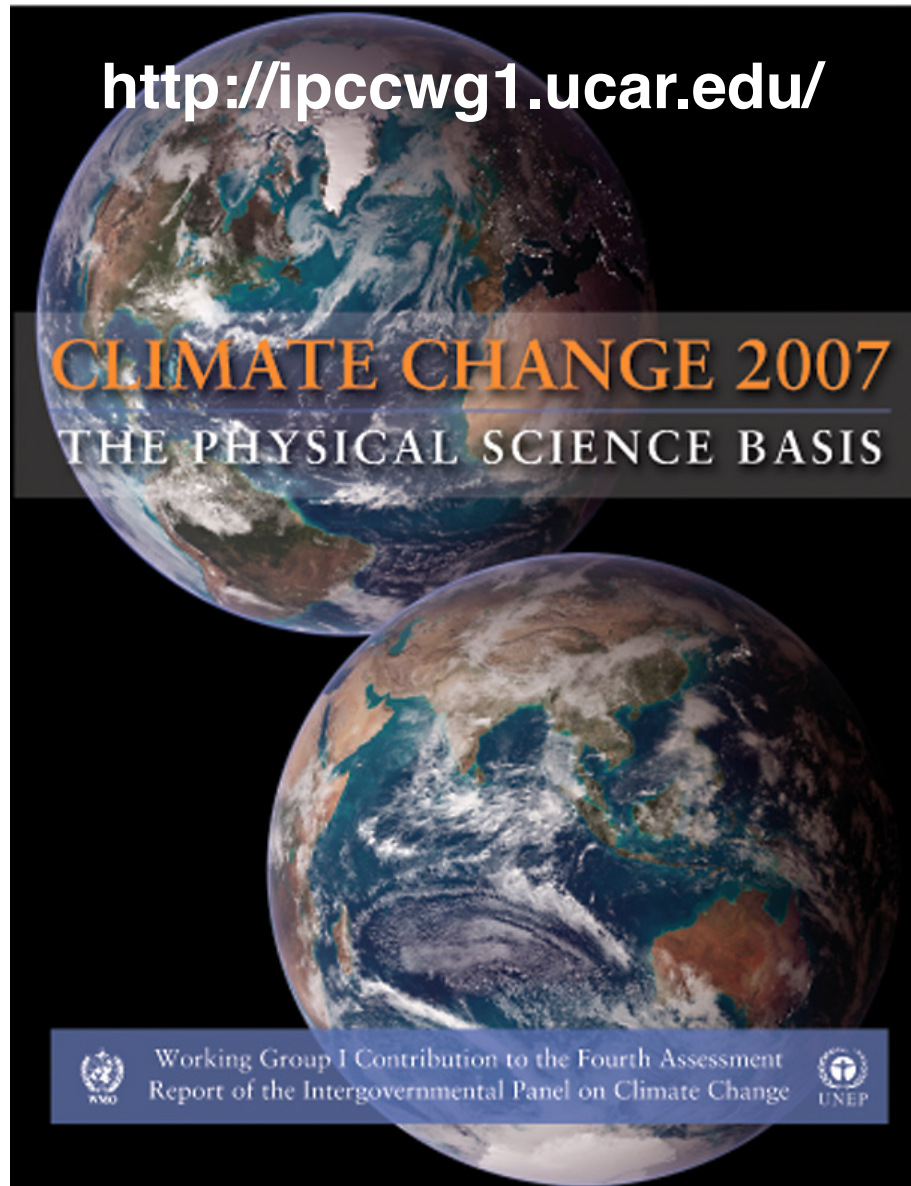
Observations and Geophysical Causes of Global Sea Level Rise

- Intergovernmental Panel for Climate Change, IPCC, Assessment Reports, 1990, 1996, 2001 Third Assessment Report (TAR), 2007 Fourth Assessment Report (FAR): **concise summary on climate change and sea level rise**
- **The 2007 FAR:** “Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level” (sea level assessment: **Bindoff et al., [2007]**)
- Contemporary results on observed sea level rise (**$\sim 1\text{--}2$ mm/yr**) & the associated geophysical and anthropogenic causes
- This study: a post-IPCC 2007 sea level assessment & current outstanding science questions



- Is global sea level rise accelerating since the 1990s?
- Can we measure and explain causes of sea level rise?
- Can we improve the accuracy of predicted sea level rise in the 21st Century?

The IPCC Working Group I Report (2004–2007)



IPCC - WGI, Modified from Solomon [2007]

- Technical Summary, 11 Chapters, 152 Authors, ~450 contributors, ~600 expert reviewers, FAQ

 [Nobelprize.org](http://nobelprize.org)




The Nobel Peace Prize 2007

"for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change"



**Intergovernmental
Panel on Climate
Change (IPCC)**

 1/2 of the prize


Geneva, Switzerland

Founded in 1988



Photo: Scanpix/Tom Hevezi

**Albert Arnold (Al)
Gore Jr.**

 1/2 of the prize

USA

<http://nobelprize.org>

The IPCC Sequence of Key Findings.....

IPCC (1990) Broad overview of climate change science, discussion of uncertainties and evidence for warming.

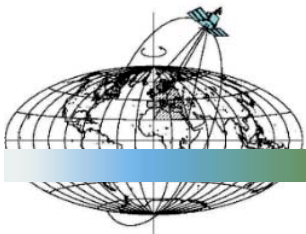
IPCC (1995) “The balance of evidence suggests a discernible human influence on global climate.”

IPCC (2001) “Most of the warming of the past 50 years is likely (>66%) to be attributable to human activities.”

- Observed 20th century sea level rise rate: 1–2 mm/yr(**1.8 mm/yr**);
- Explained (ice source: 0.2 mm/yr, thermal expansion: 0.5 mm/yr),

Unexplained: 0.3–1.3 mm/yr

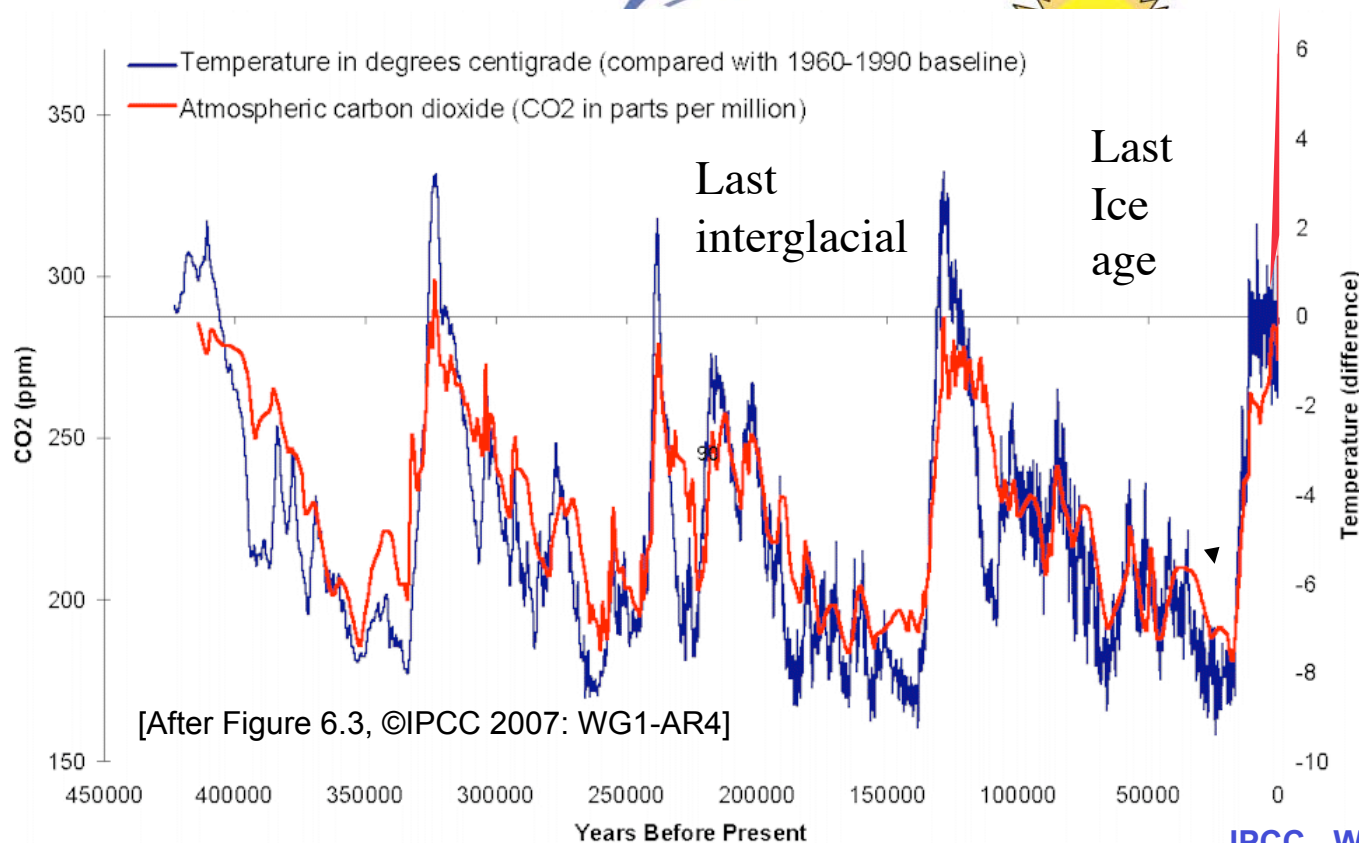
IPCC (2007) “Warming is unequivocal, and most of the warming of the past 50 years is very likely (90%) due to increases in greenhouse gases.”



Ice Age Forcing and Response

Milankovitch Cycles

Natural Climate Forcing:
Rahmstorf & Schellnhuber [2006]



CO₂ concentration was **280 ppm** for the last 400,000 years before 1900. Since 1900, CO₂ concentration has risen to **378 ppm**, indicative of human activities causing its rise.

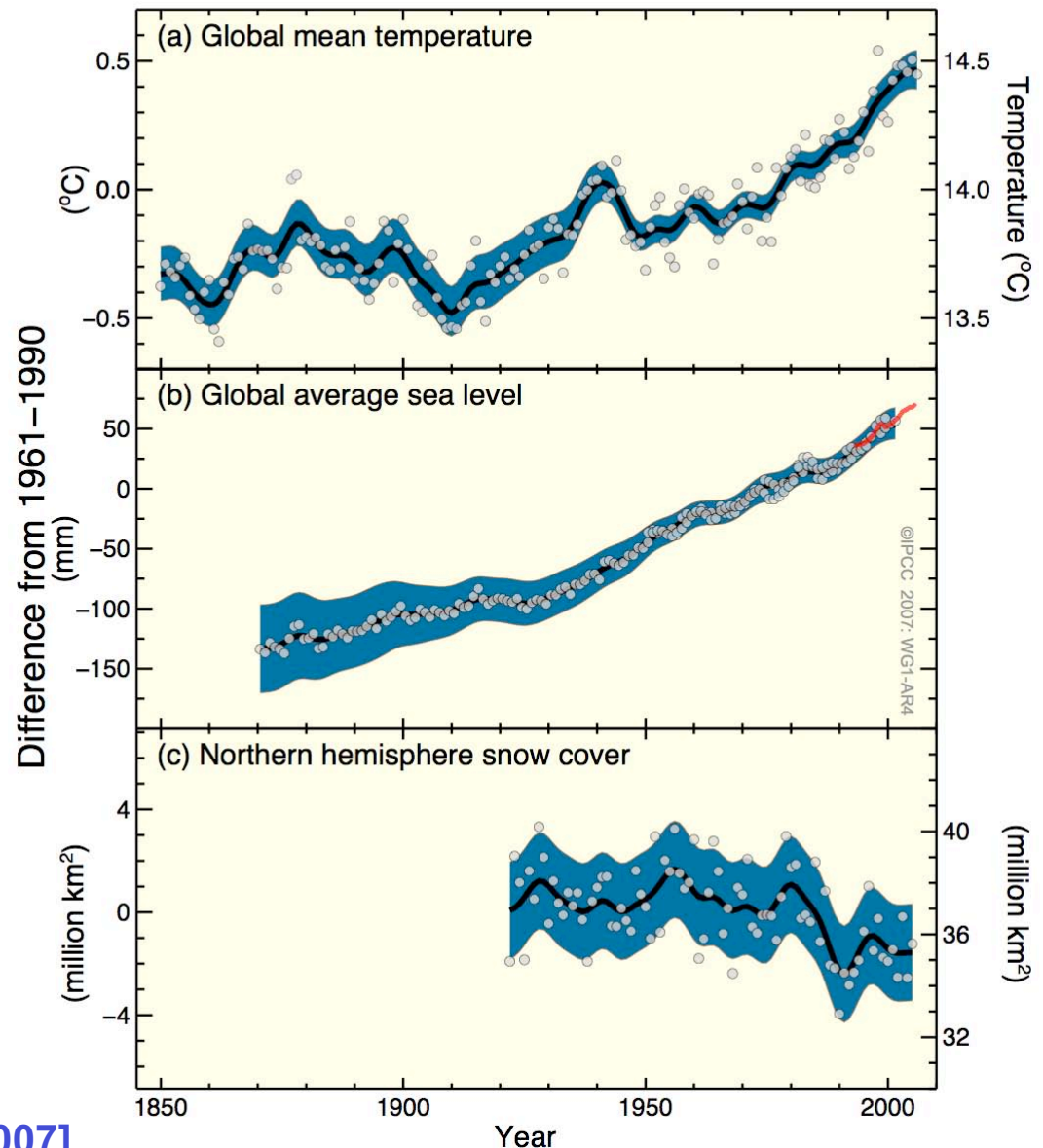
IPCC - WGI, Modified from Solomon [2007]

Findings: The IPCC Working Group I Report (2004–2007)

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level

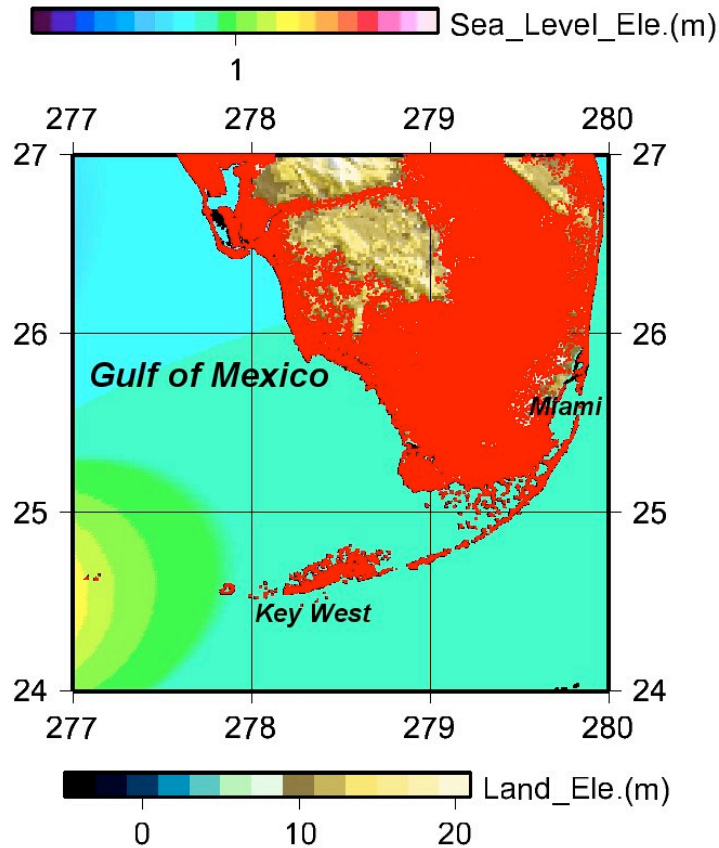
- Snow cover, March–April changes with respect to 1961–1990 average
- Uncertainty (blue), 10-yr average (black curve), yearly average (circle)
- Satellite observed sea level (red)

Changes in Temperature, Sea Level and Northern Hemisphere Snow Cover

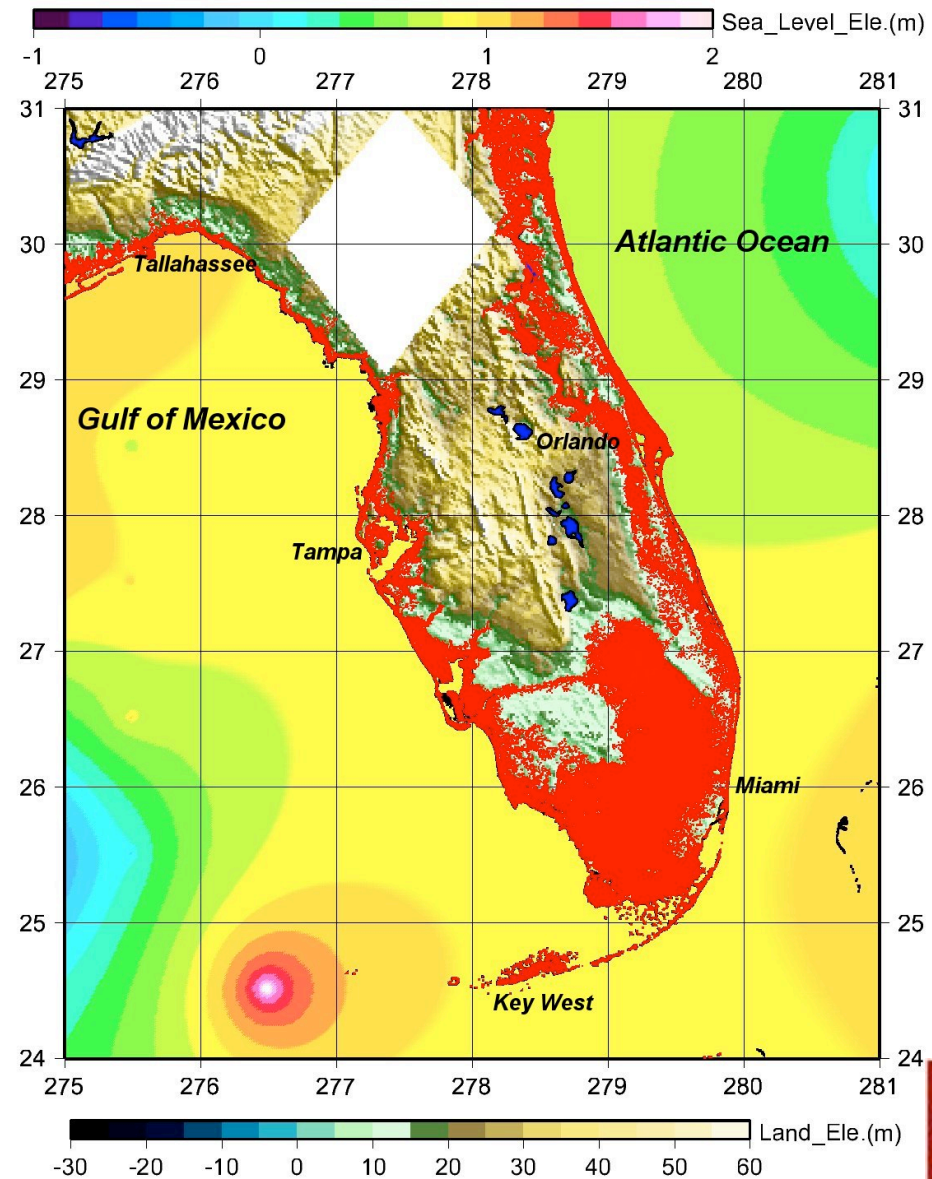


LAND LOSS DUE TO 5 METER SEA LEVEL RISE

Land Elevation Modeled Using SRTM 50-m DEM



Sea Level Modeled Based on Altimetry Determined Trend



C. Shum, 1/07

Sea Level Since the Last Glacial Maximum Between 20,000 to 25,000 Years Ago

Lambeck et al., *Nature*, 2002

Sea level (based on isostatically adjusted sea-level data from various sediment cores) is ~150 m lower than present during the last Ice Age (~25,000 yr ago).

Sea level rise during 1500–1900 is estimated to be ~0.1 mm/yr, while the 20th century sea level rise is: ~1.8 mm/yr

The dominant contributor to sea level rise is the melting of the ice sheet

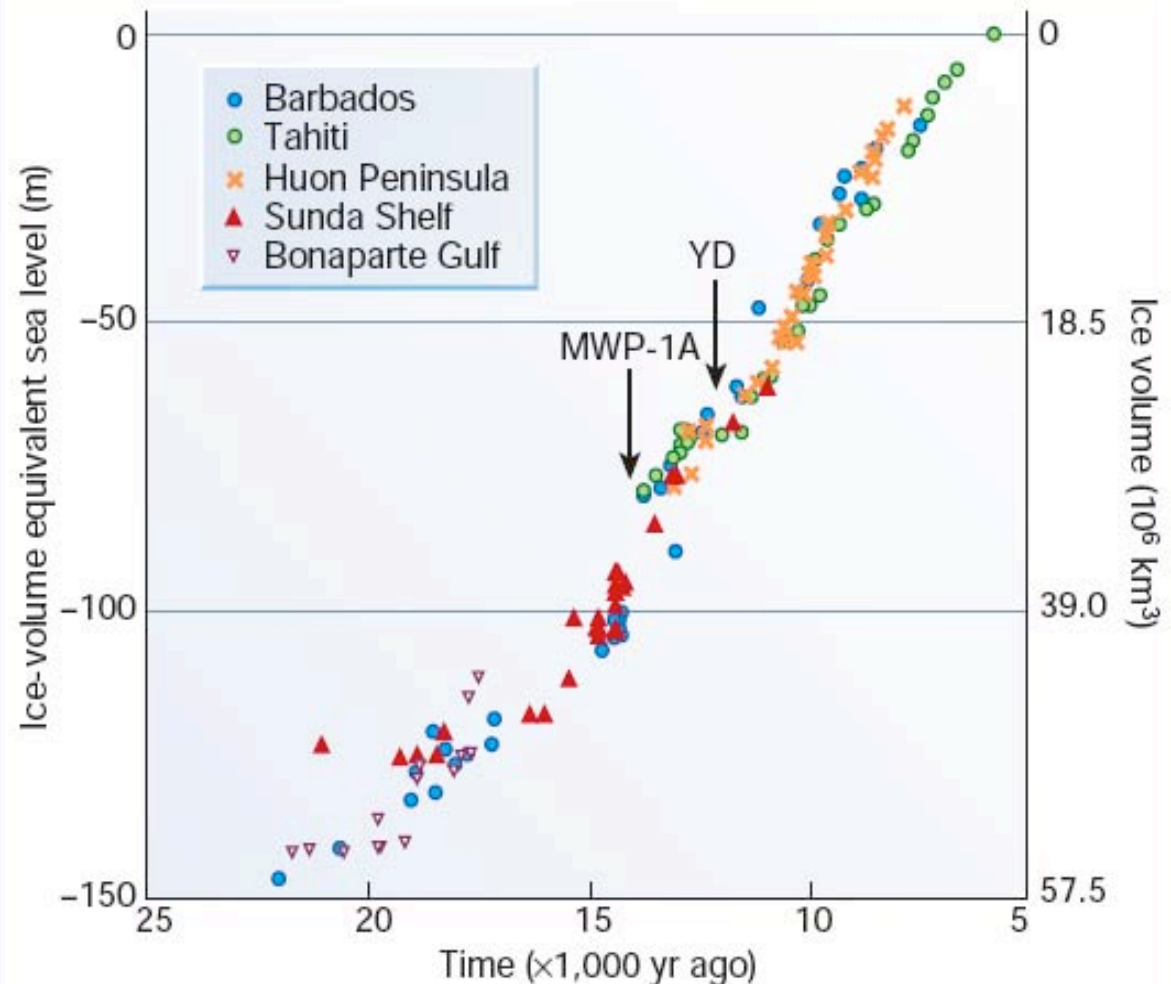
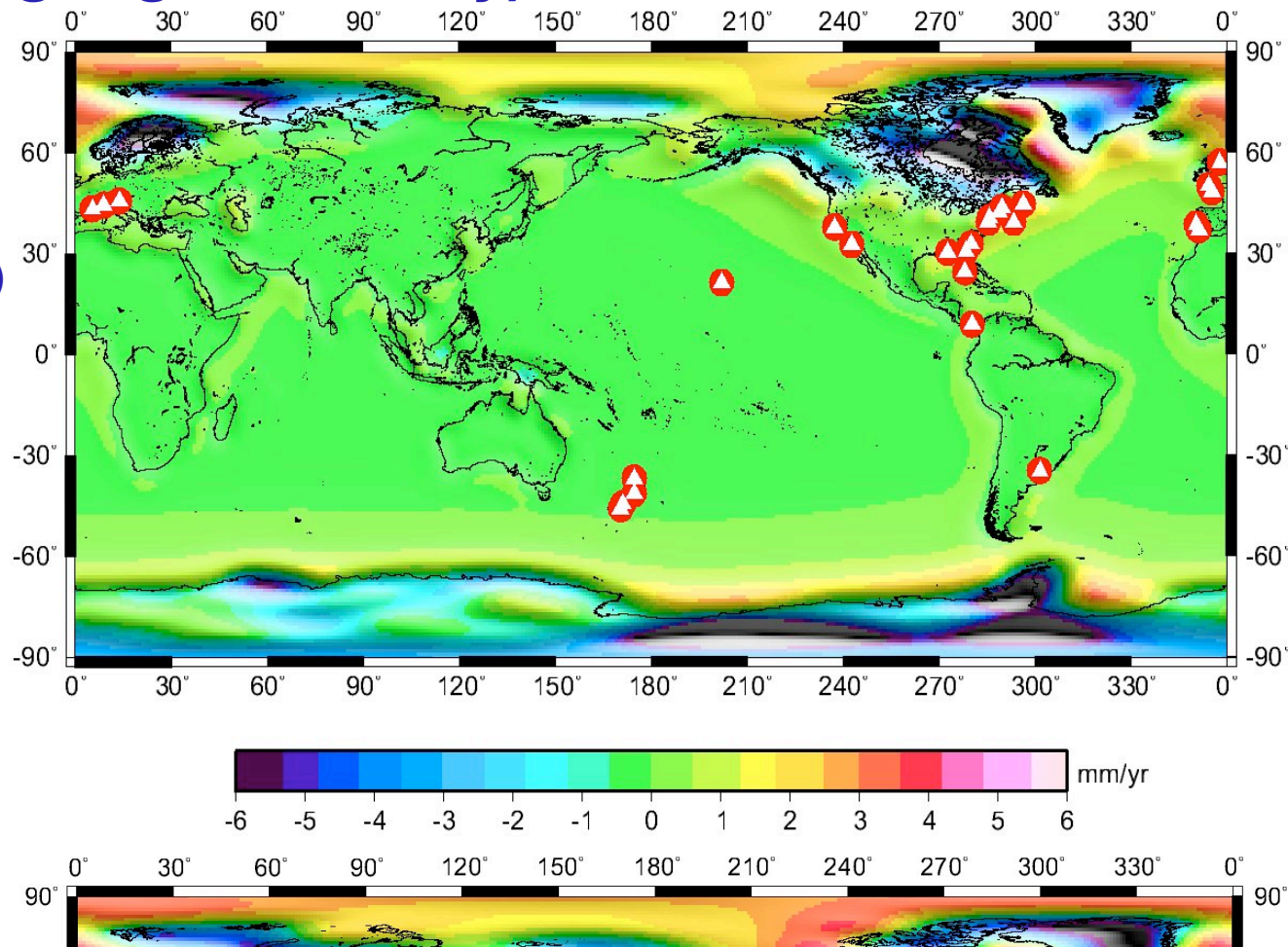
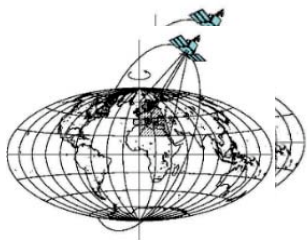


Figure 5 Changes in global ice volume from the time of the LGM to the present. The figure shows ice-volume equivalent sea level for the past 20 kyr based on isostatically adjusted sea-level data from different localities^{73,93–96}. Because of spatial

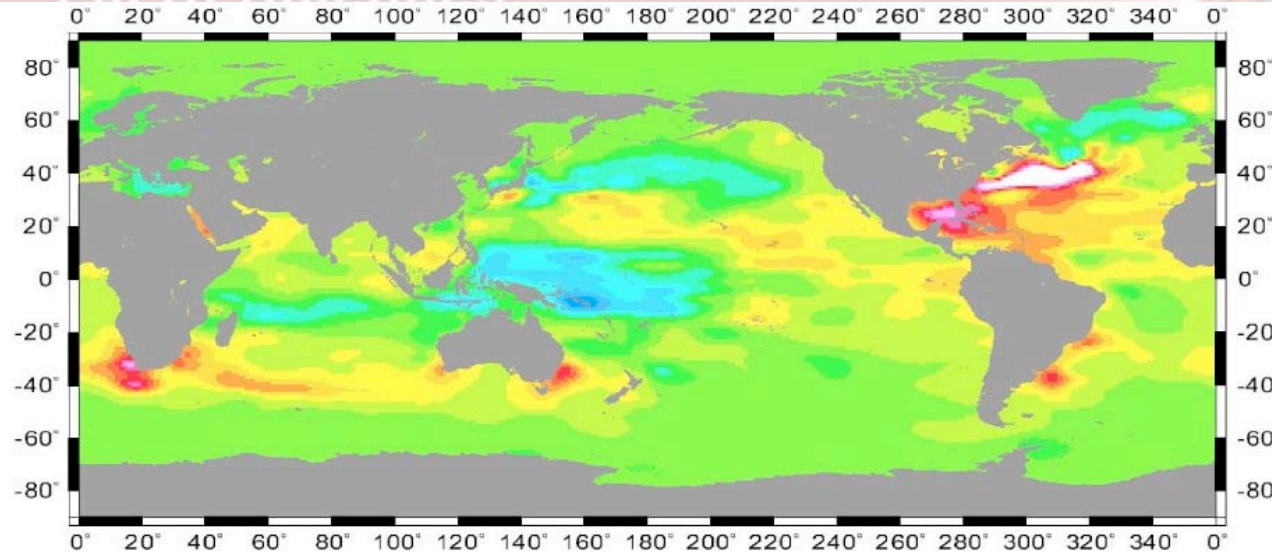
Glacial Isostatic Adjustment

The phenomena of solid Earth visco-elastic rebound due to deglaciation from the last Ice Age (Last Glacial Maximum, 18,000 yr ago, melting ended ~6000 yr ago).
GIA changes land and ocean basins to which instrument (tide gauge/altimetry) are based and referenced.

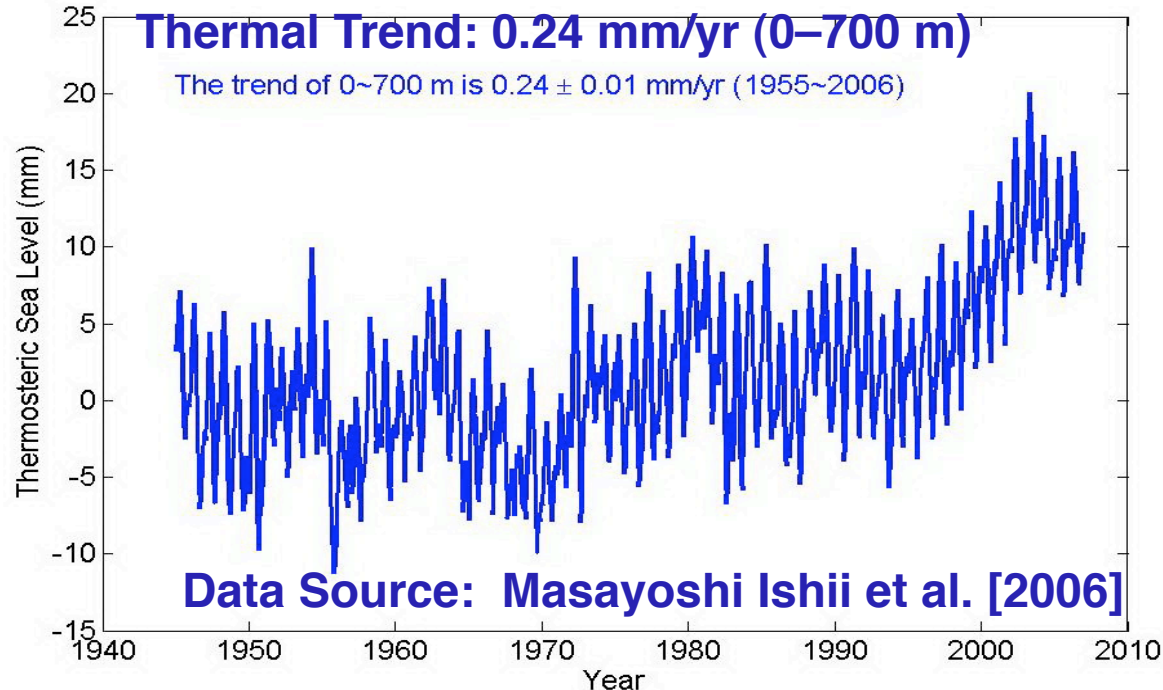
Uplift
predicted by
ICE-4G (VM2)
model
(Peltier, 2000)



Thermal Expansion of the Ocean (1955–2000)



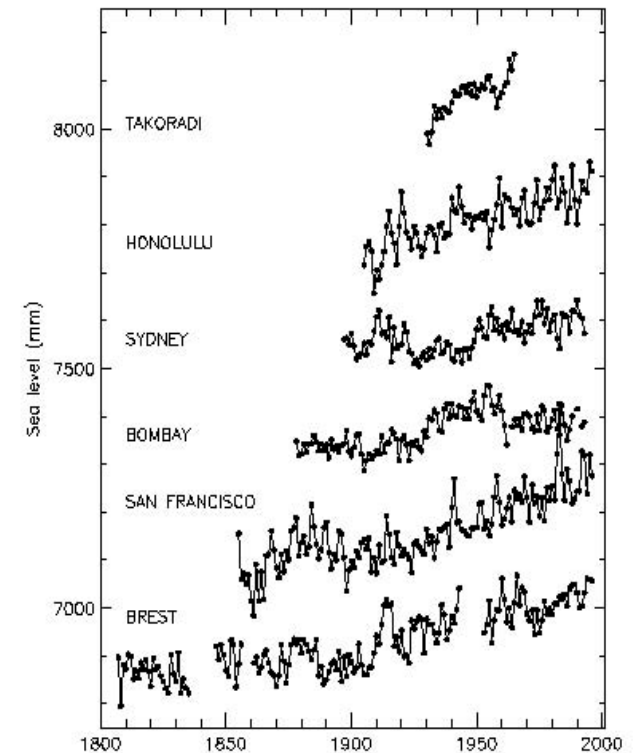
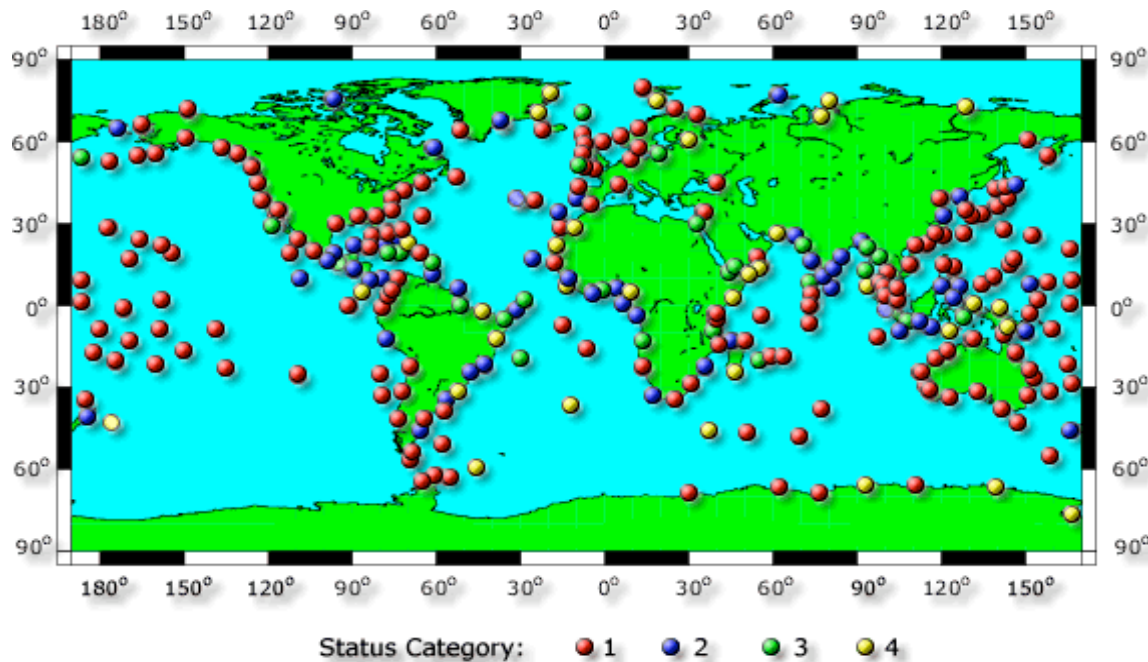
Historic data coverage extremely sparse in the Southern Ocean (improved with ARGOS)



Biases are uncovered in Argos data and XBT data, which could affect the long-term trend

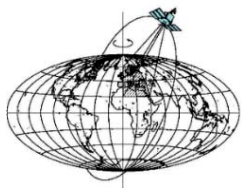


GLOSS/PSMSL Global Tide Gauge Network



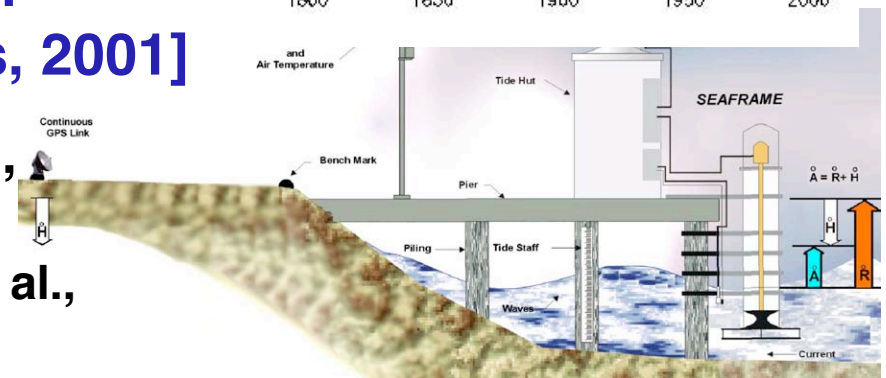
Sea level rise: ~ 1.7–1.8 mm/yr
100–200 year records [e.g., Douglas, 2001]

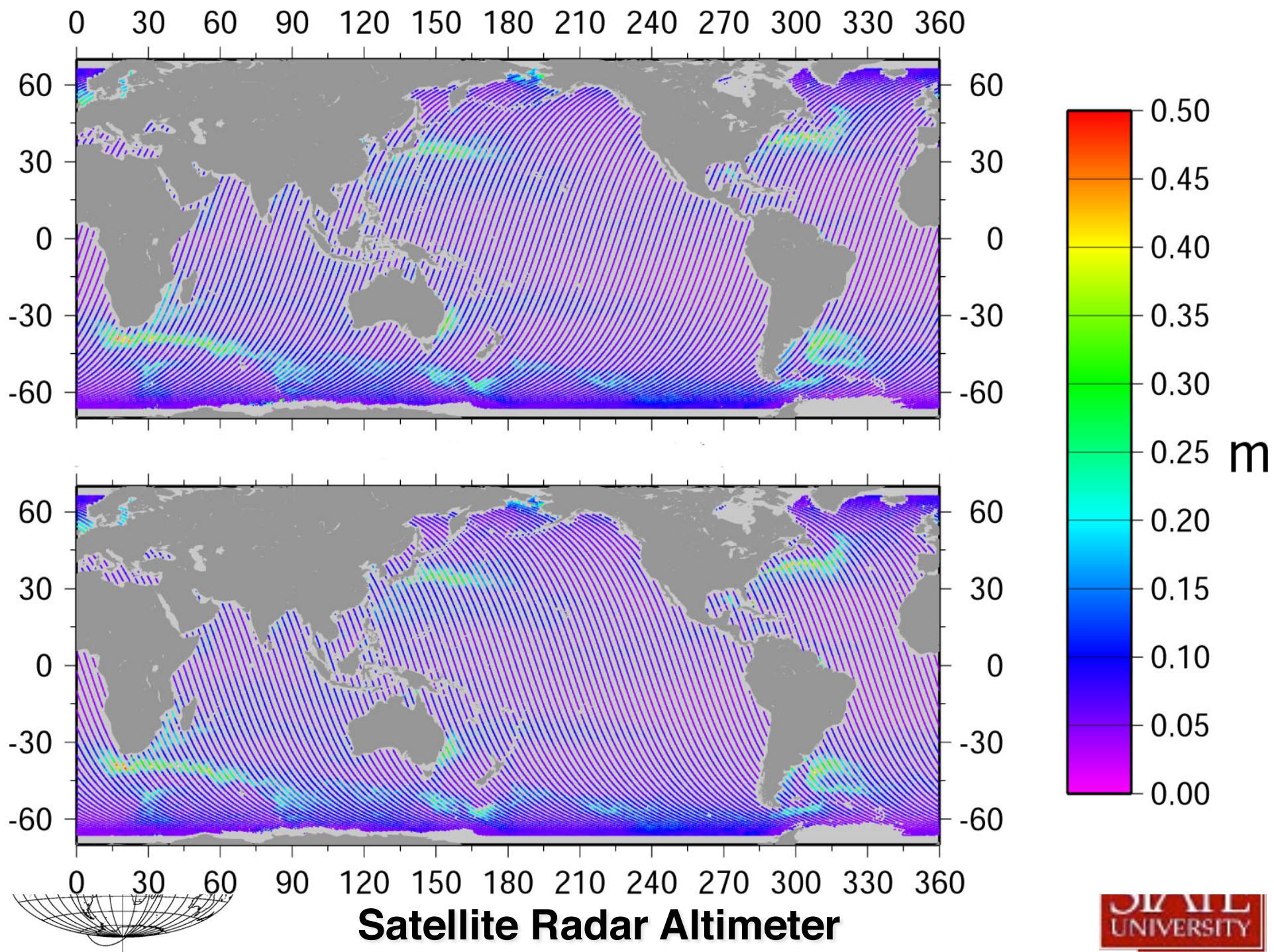
Tide gauges measures **relative sea level**,
 requires GPS for measuring vertical
 motion (**Recent results: 1.8 mm/yr** [Snay et al.,
 2007]: **1.31 mm/yr** [Woppelmann et al.,
 2007], after applying GPS ‘correction’)



Selected RLR gauges used

<http://www.pol.ac.uk>





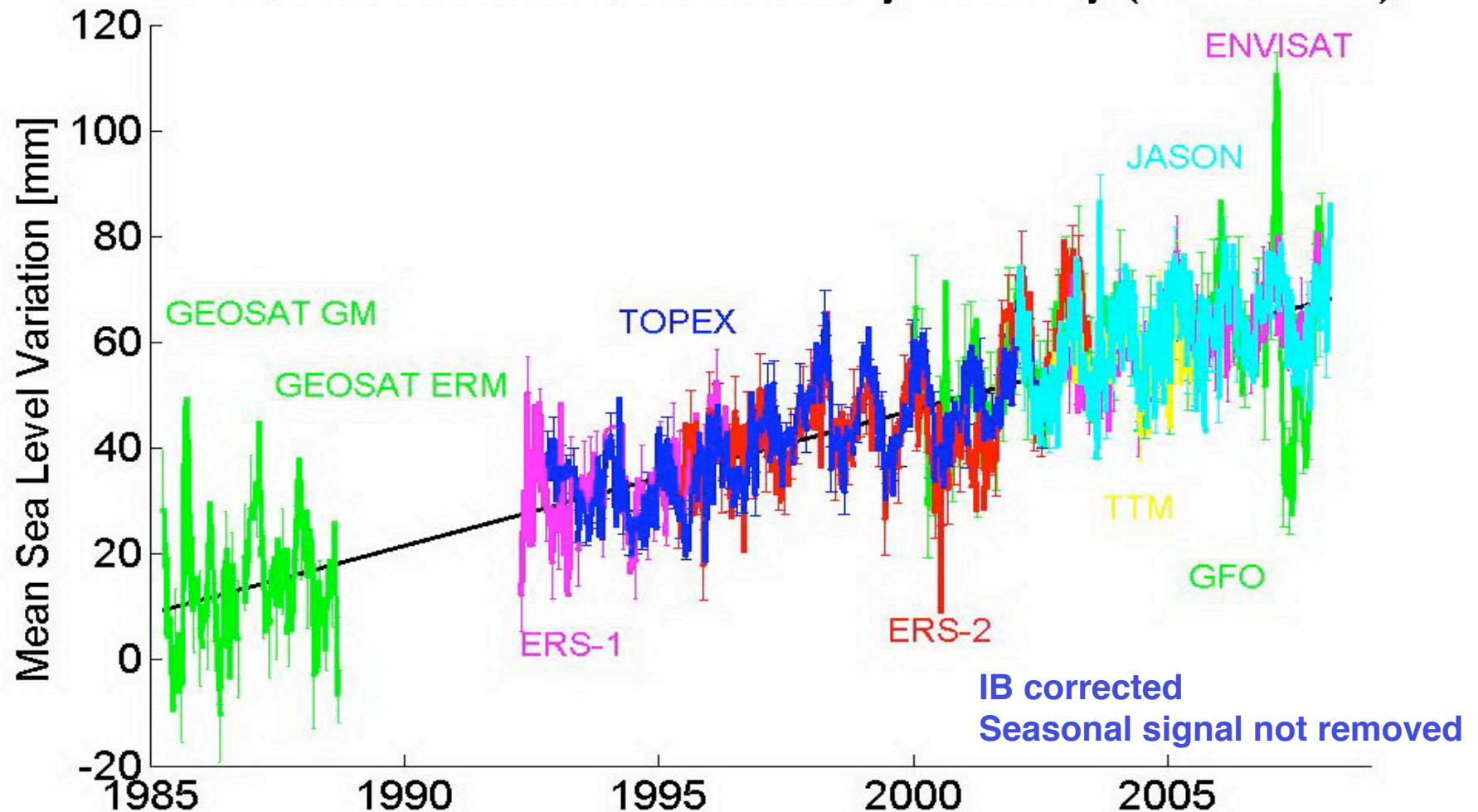
Global Sea Level Rise Observed By Satellite Altimetry (1985–2008)

Estimated sea level trend (1985–2008): 2.6 ± 0.4 mm/yr

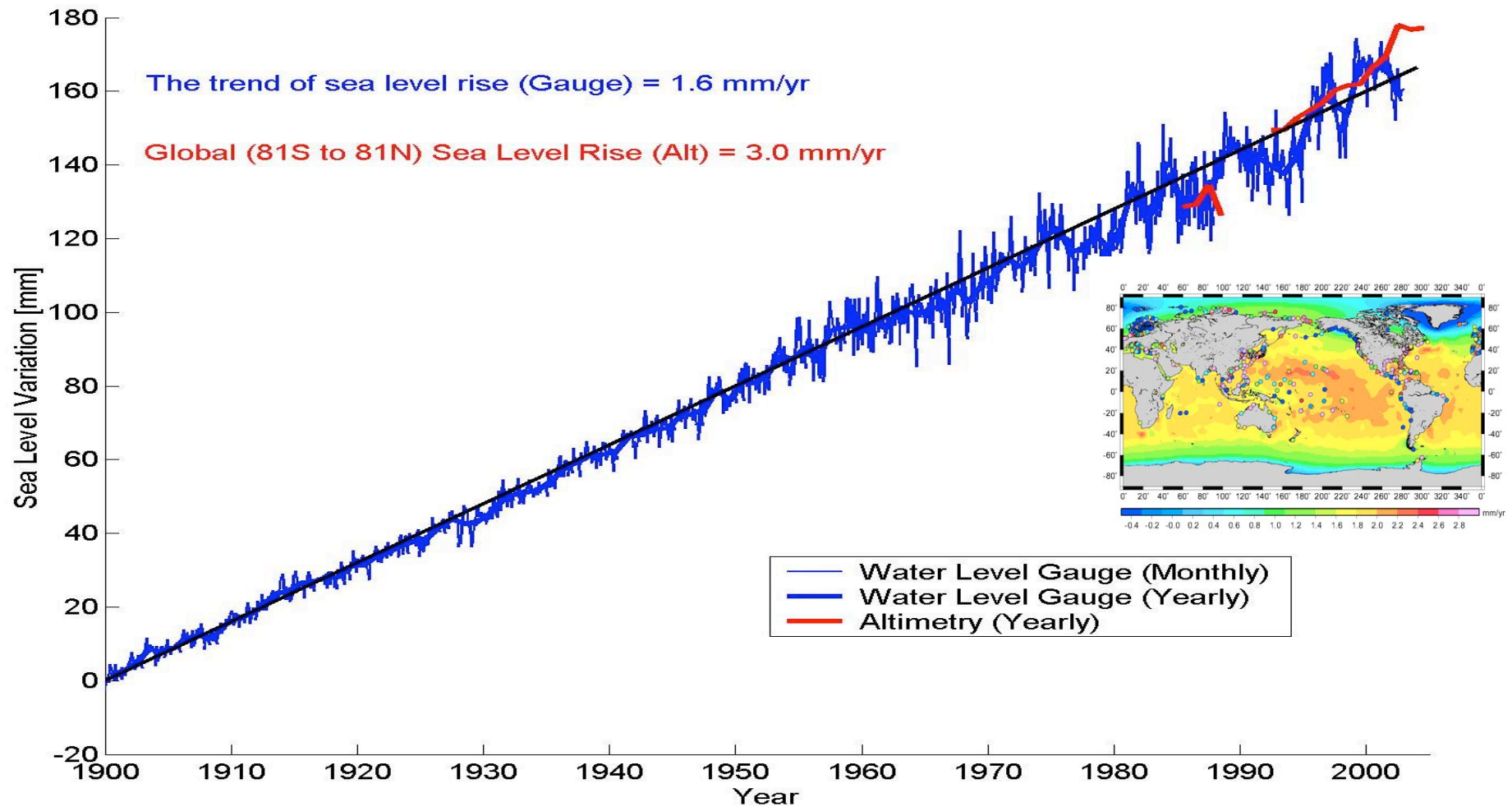
Thermal trend (1985–2006): 0.58 ± 0.02 mm/yr (1955–2006): 0.24 ± 0.01 mm/yr

After sea floor basin “geoid” GIA correction (ICE4G): **Trend = 2.7 mm/yr**

Global Sea Level Rise Estimated by Altimetry (1985-2008)

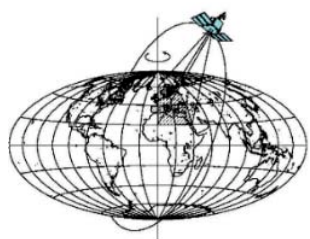
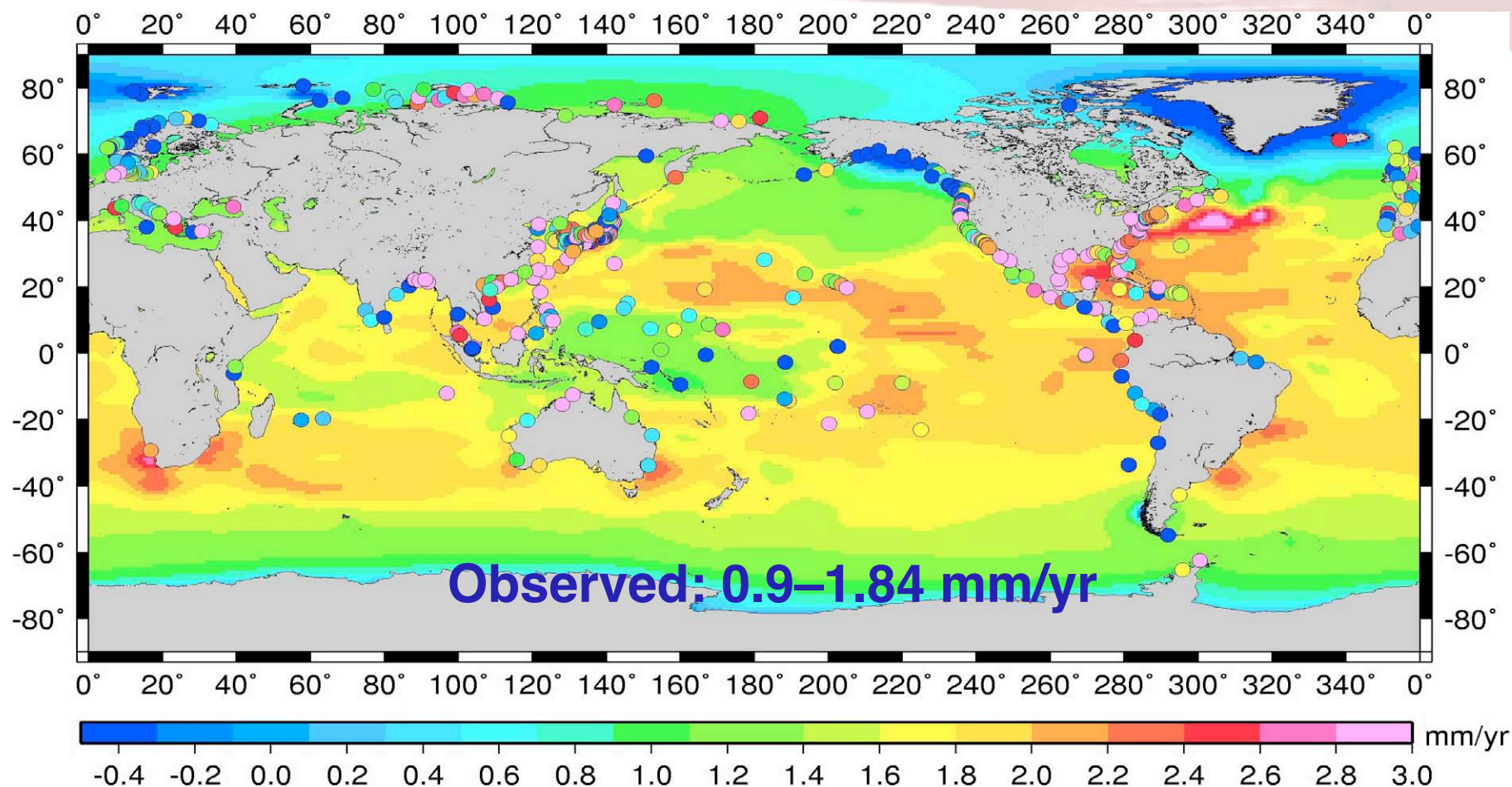


Sea Level from Multiple Altimetry & Tide Gauge (1900-2002)



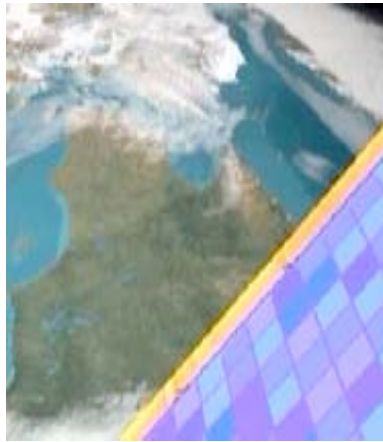
ICE-4G Geoid effect on altimetry (± 81.5) = 0.2 mm/yr
ICE-4G Geoid effect on altimetry (around TG) = 0.1 mm/yr
IB correction (NCEP & ECMWF) applied, 651 tide gauges, ICE-4G nominal GIA model

Estimated Global Sea Level Rise Using Tide Gauges and Satellite Altimetry (1900–2003)



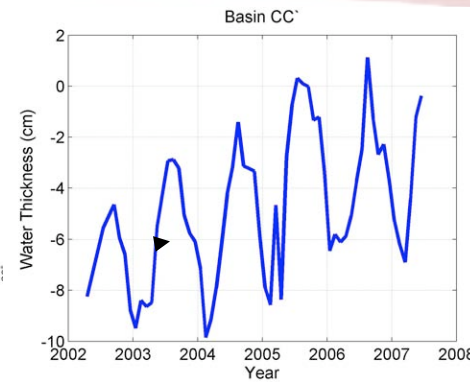
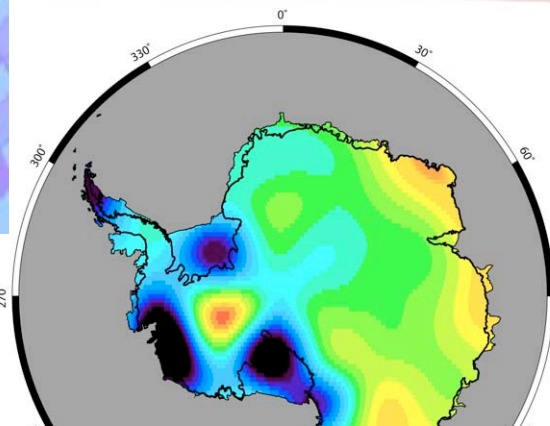
Estimated Sea Level Rise = 1.62 ± 0.22 mm/yr
525 selected tide gauges, multiple satellite altimetry used

Assuming geographical patterns of sea level change due to glacier/ice sheet melt, thermal expansion, and GIA known



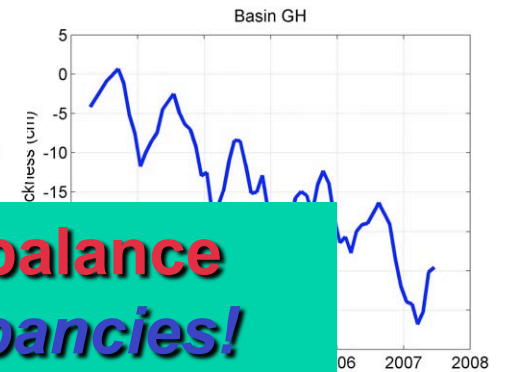
Credit: NASA, CSR

Polar Ice Sheet Mass Balance Observed by GRACE, 2002–2008

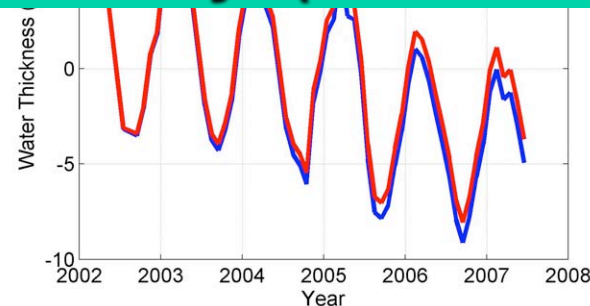
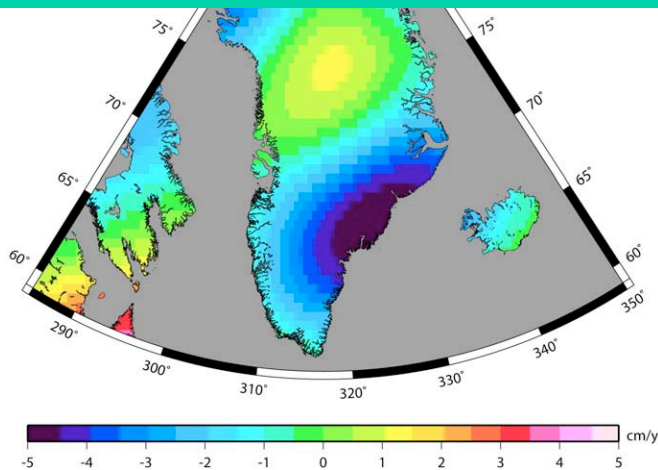


E. Antarctica

W. Antarctica



Current estimate of ice sheet mass balance (equivalent sea level): *Large Discrepancies!*
Antarctica: -0.03 to 0.57 mm/yr (1992–2005)
Greenland: -0.12 to 0.17 mm/yr (1992–2006)

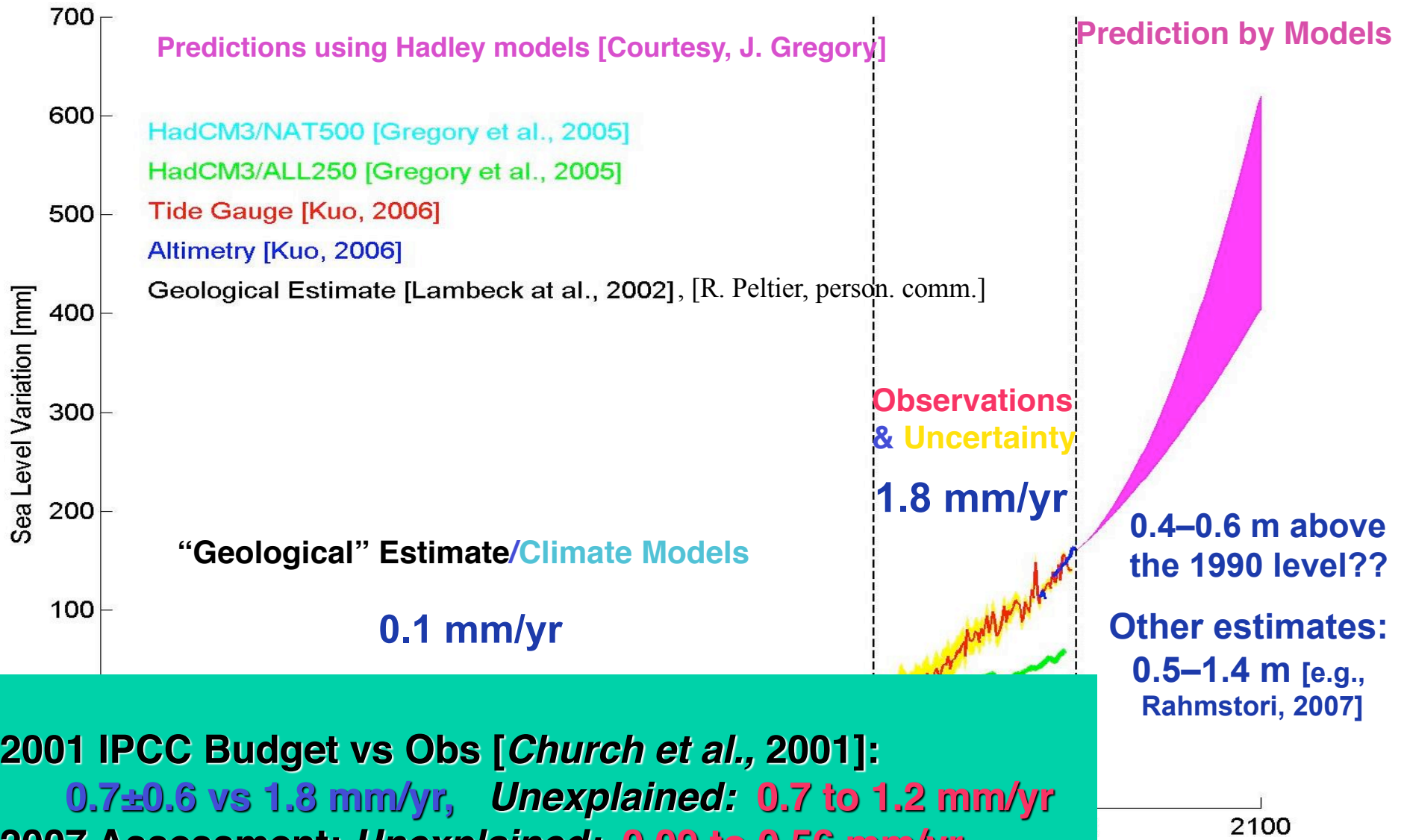


**Averaged
Greenland
mass loss**

**ICE-5G (VM4) GIA correction
model (Peltier, 2004) used**



Global Sea Level Rise: Estimation & Prediction (1500-2100)



2001 IPCC Budget vs Obs [Church et al., 2001]:

0.7 ± 0.6 vs 1.8 mm/yr, Unexplained: 0.7 to 1.2 mm/yr

2007 Assessment: Unexplained: 0.09 to 0.56 mm/yr

CONCLUSIONS

- There is strong evidence that global sea level has accelerated its rise since the industrial revolution, implicating human causes:
 - 20th century (1900–2002) sea level rise is **1.62 ± 0.22 mm/yr**. Sea level rise from 1500–1900 is only **~ 0.1 – 0.2 mm/yr**
 - Known geophysical causes of sea level rise sum up **0.81 to 2.54 mm/yr** (observed 0.9–1.84 mm/yr), which is closer than the last IPCC (2001) assessment. But the agreement could be accidental as some contributors (hydrologic, ice melt) have large error
 - Outstanding scientific questions include: is the sea level rise further accelerating (since the 1990s)? Can we improve the observed accuracy and better understand various geophysical causes of sea level rise?

