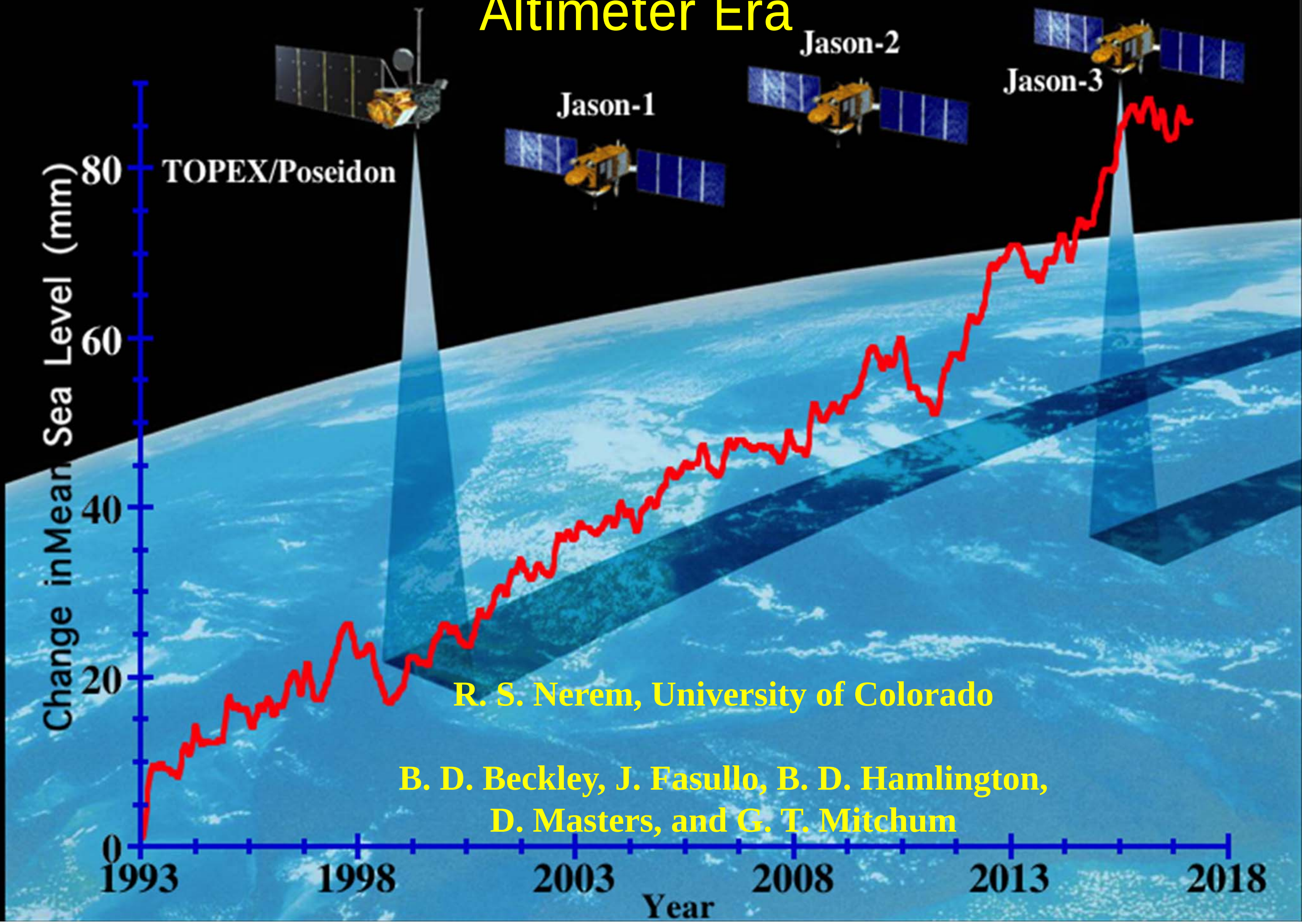
Understanding the Acceleration of Sea Level Rise During the Altimeter Era



R. S. Nerem, University of Colorado

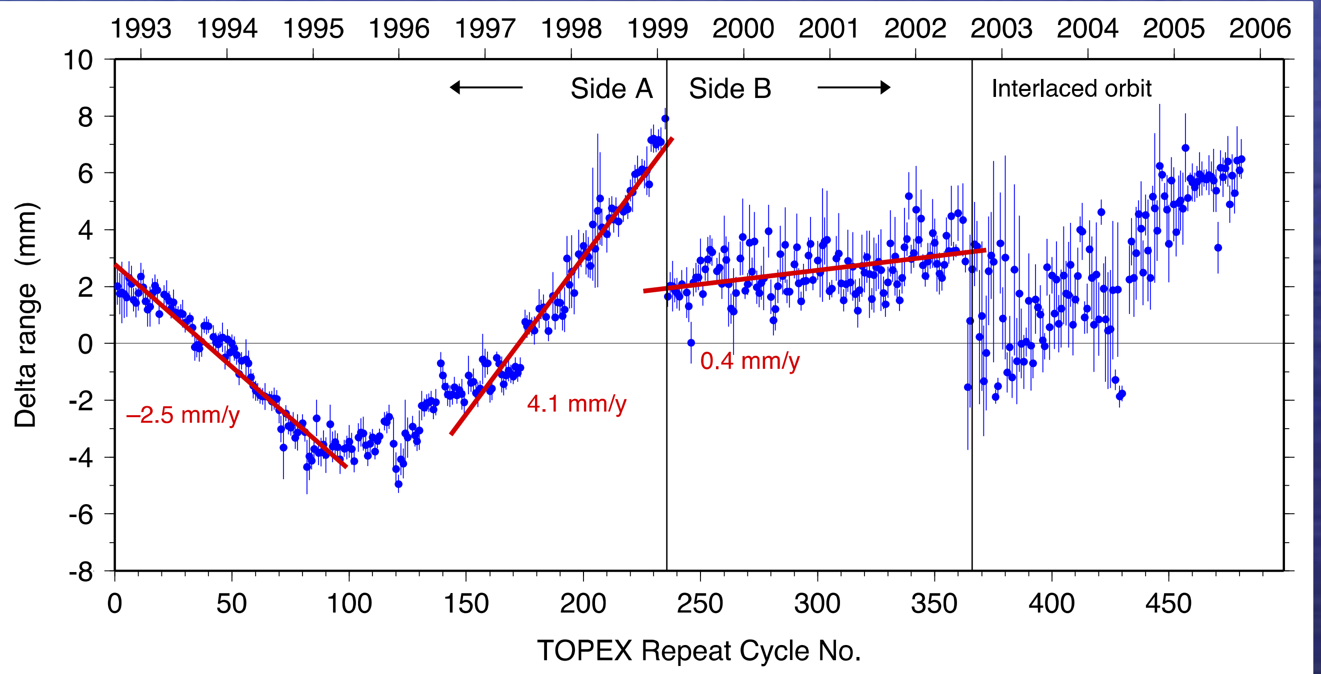
B. D. Beckley, J. Fasullo, B. D. Hamlington,
D. Masters, and G. T. Mitchum

Can we estimate an acceleration in the altimeter record?

- Detecting a significant acceleration is made challenging due to:
  - The length of the altimeter record
  - Errors in altimeter data, particularly drifts in the instruments over time
  - Episodic variability driven by large volcanic eruptions.
  - Interannual variability in GMSL due to changes in TWS
  - Decadal variability in TWS, thermosteric variability and ice sheet mass loss.
- By accounting for each of these (some directly, some by adding to error estimate), we can attempt to extract an acceleration from the altimeter record.

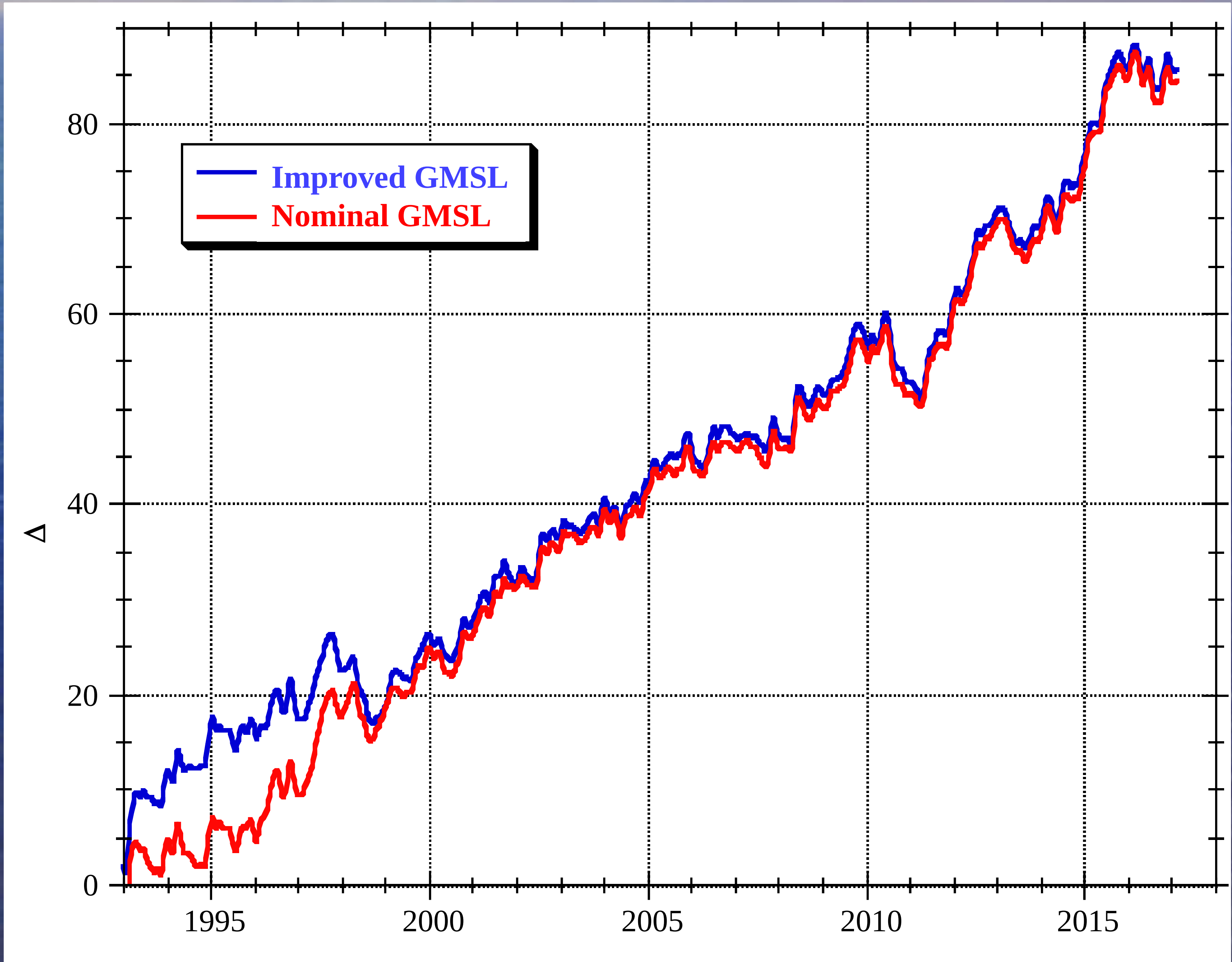
Effect of Cal-Mode Correction on TOPEX GMSL

- As a starting point, following analysis and discussion in Beckley et al. (2017), the Cal-mode correction on TOPEX GMSL was removed.
  - Correction associated with internal path delays.
  - Removal resulted in improved comparisons with tide gauge measurements.



[Beckley et al., 2017]

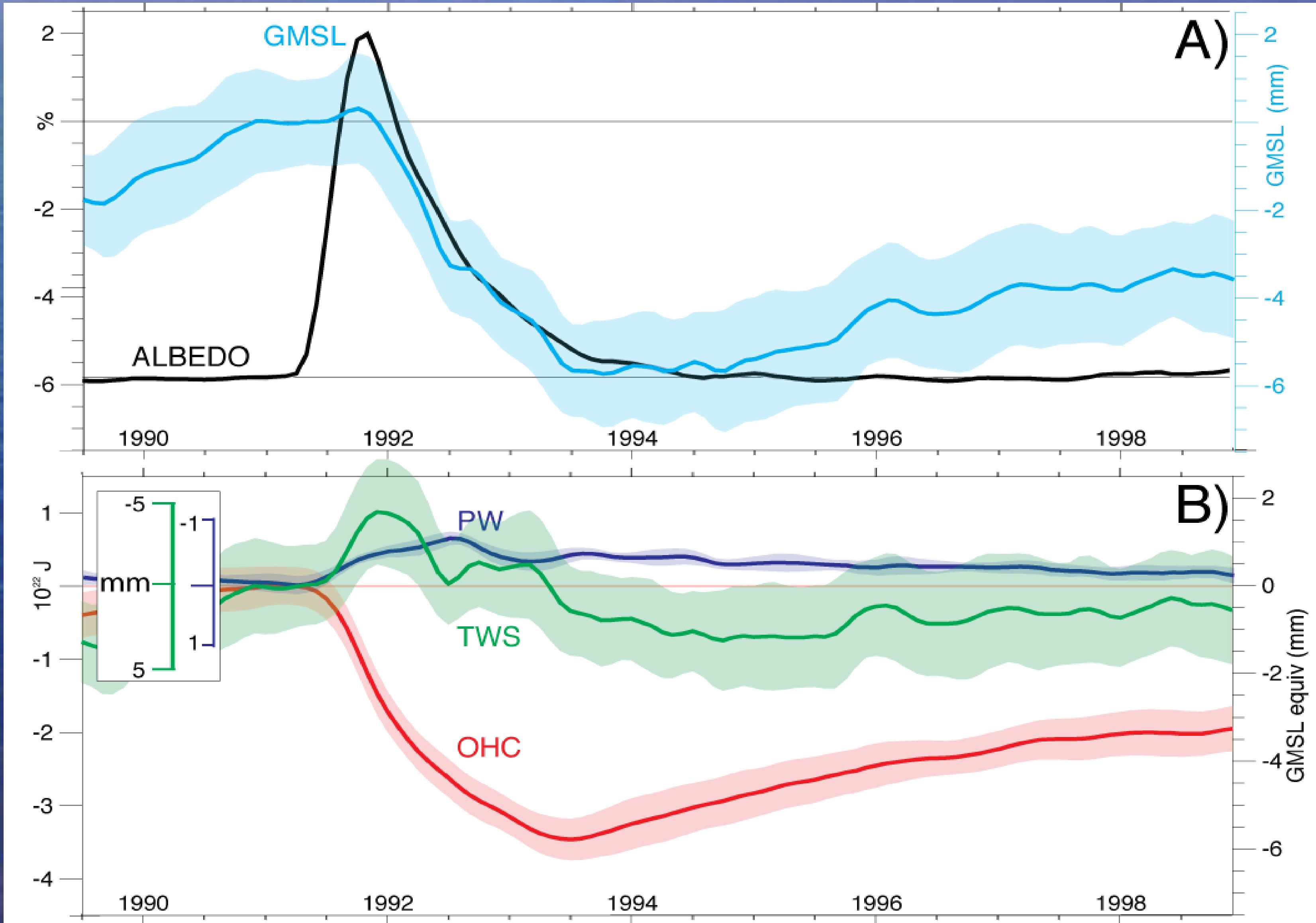
Effect of Cal-Mode Correction on TOPEX GMSL



The 1991 Eruption of Mount Pinatubo

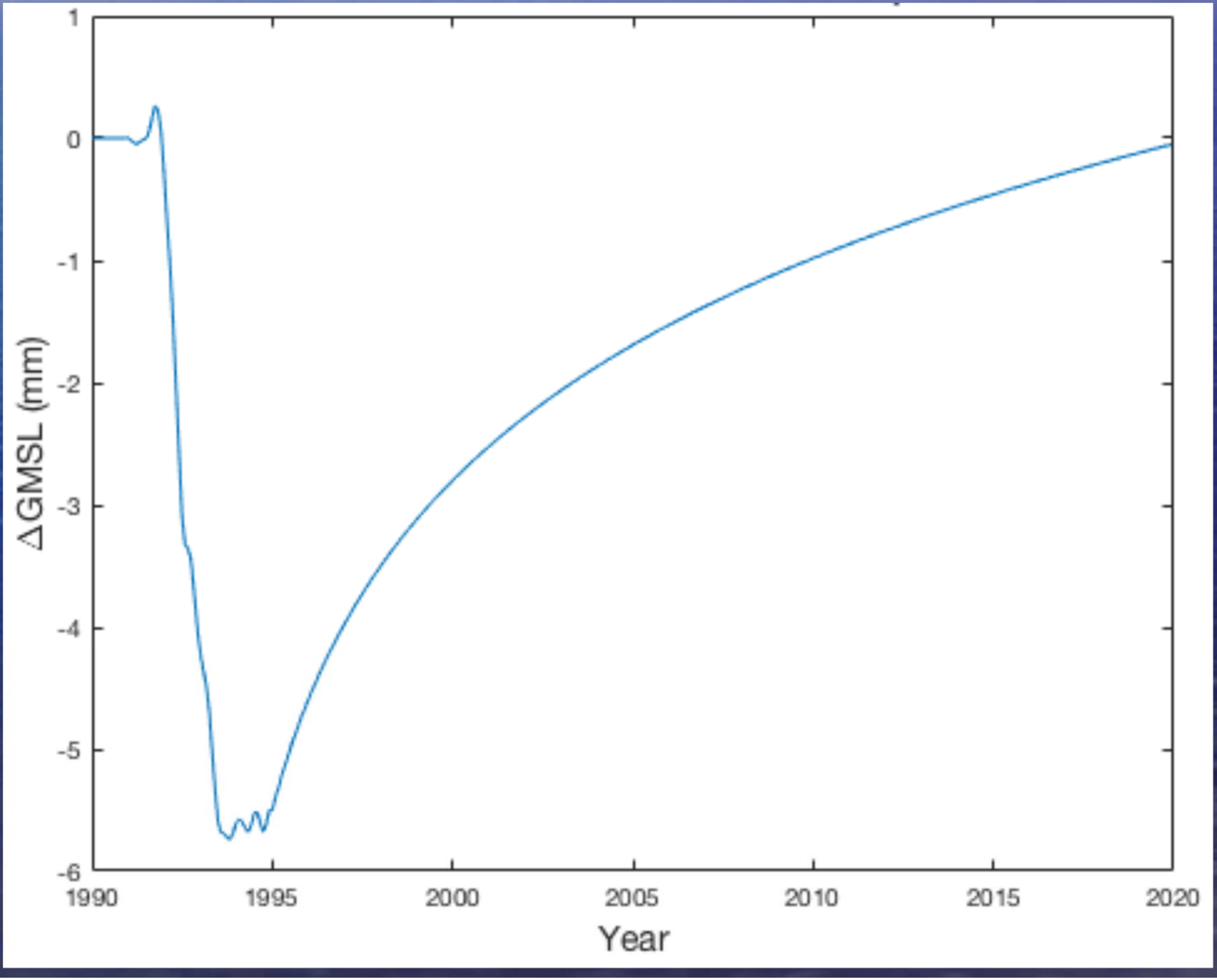
- June 15, 1991
- 2nd largest eruption of the 20th Century
- ~25 Tg of stratospheric aerosol loading
- Global cooling of ~0.5 C, substantial ozone depletion

Effects of Mt. Pinatubo Eruption in 1991



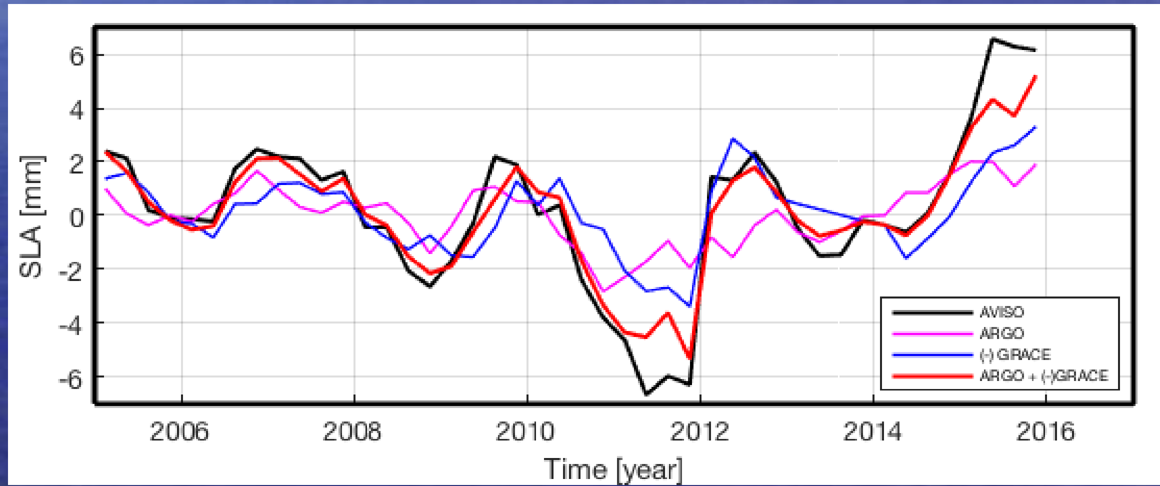
[Fasullo et al., 2016]

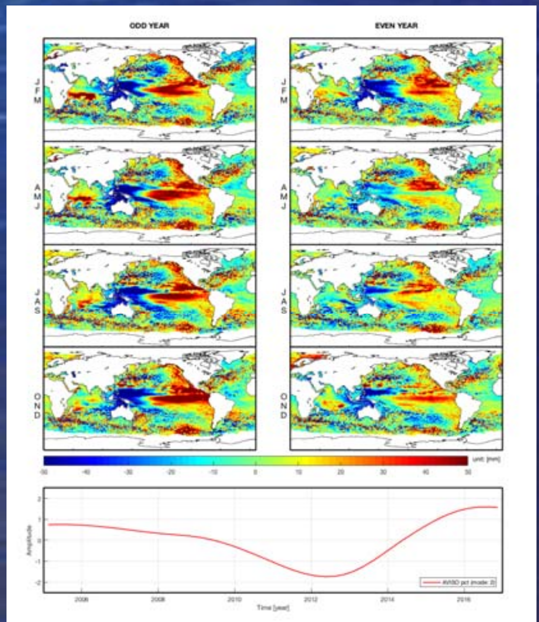
Effect of Pinatubo Eruption on GMSL

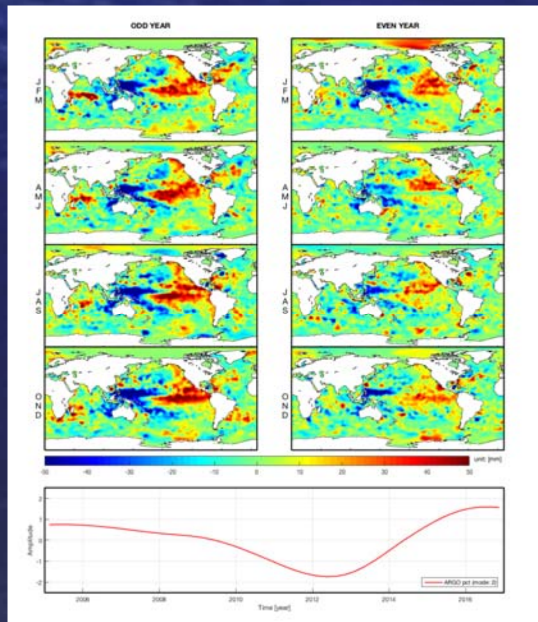


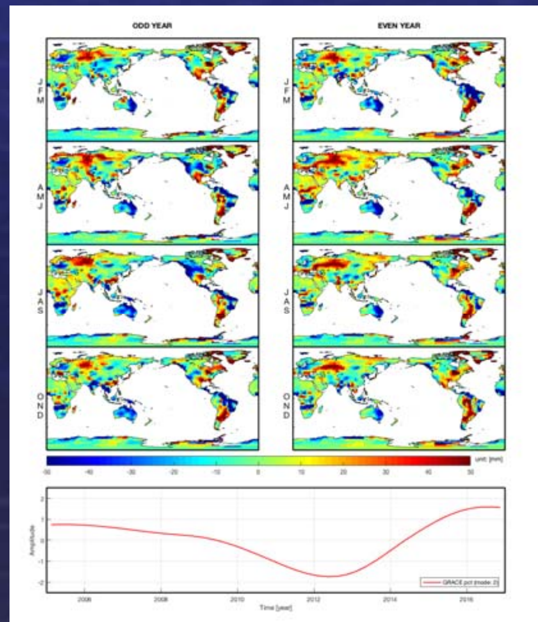
ENSO/PDO GMSL Correction

- Combined CSEOF analysis of GRACE, Argo, and altimetry to look for shared modes of variability.
- Leads to improved ability to physically interpret statistical modes.
- Project back onto full altimetry record.

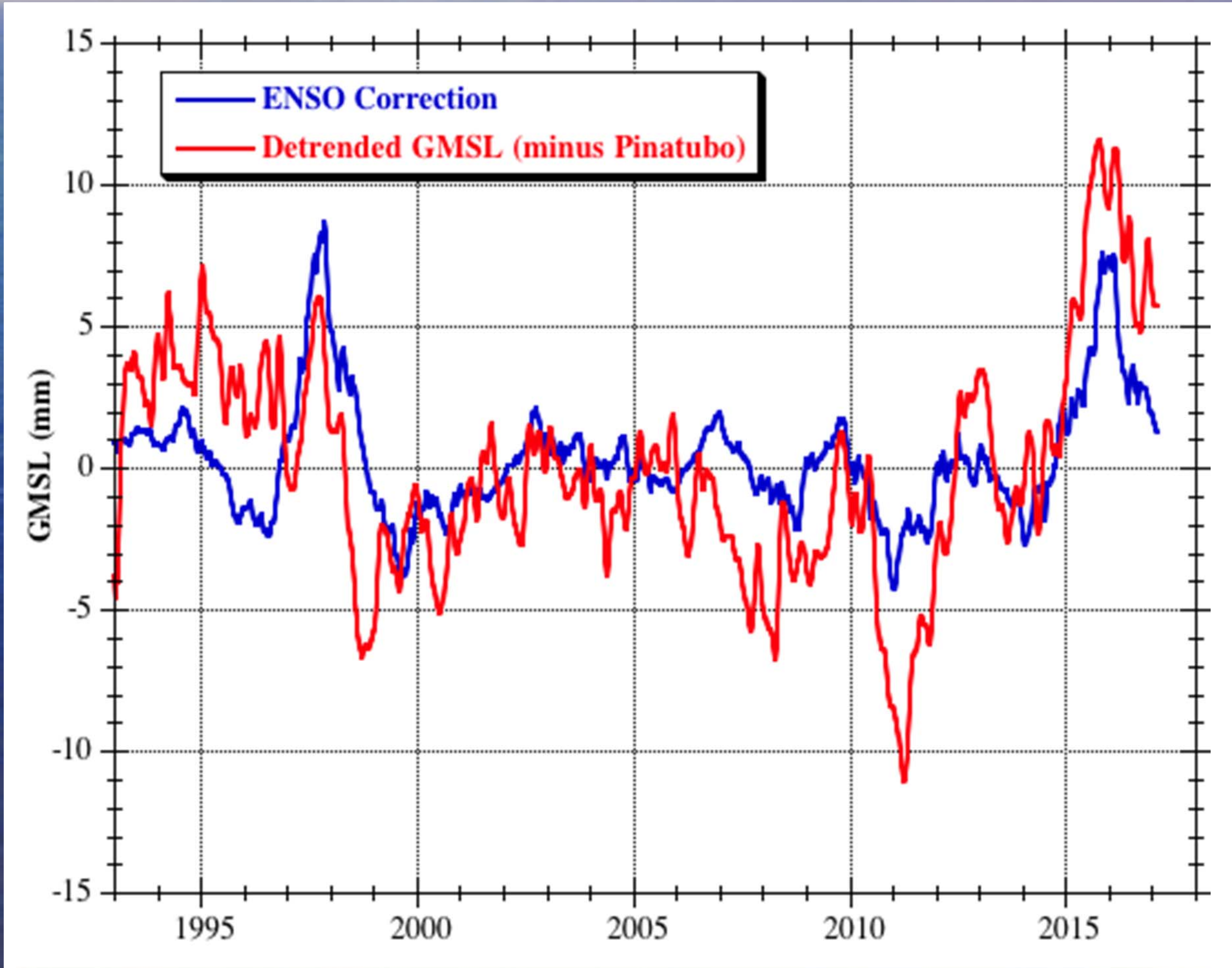




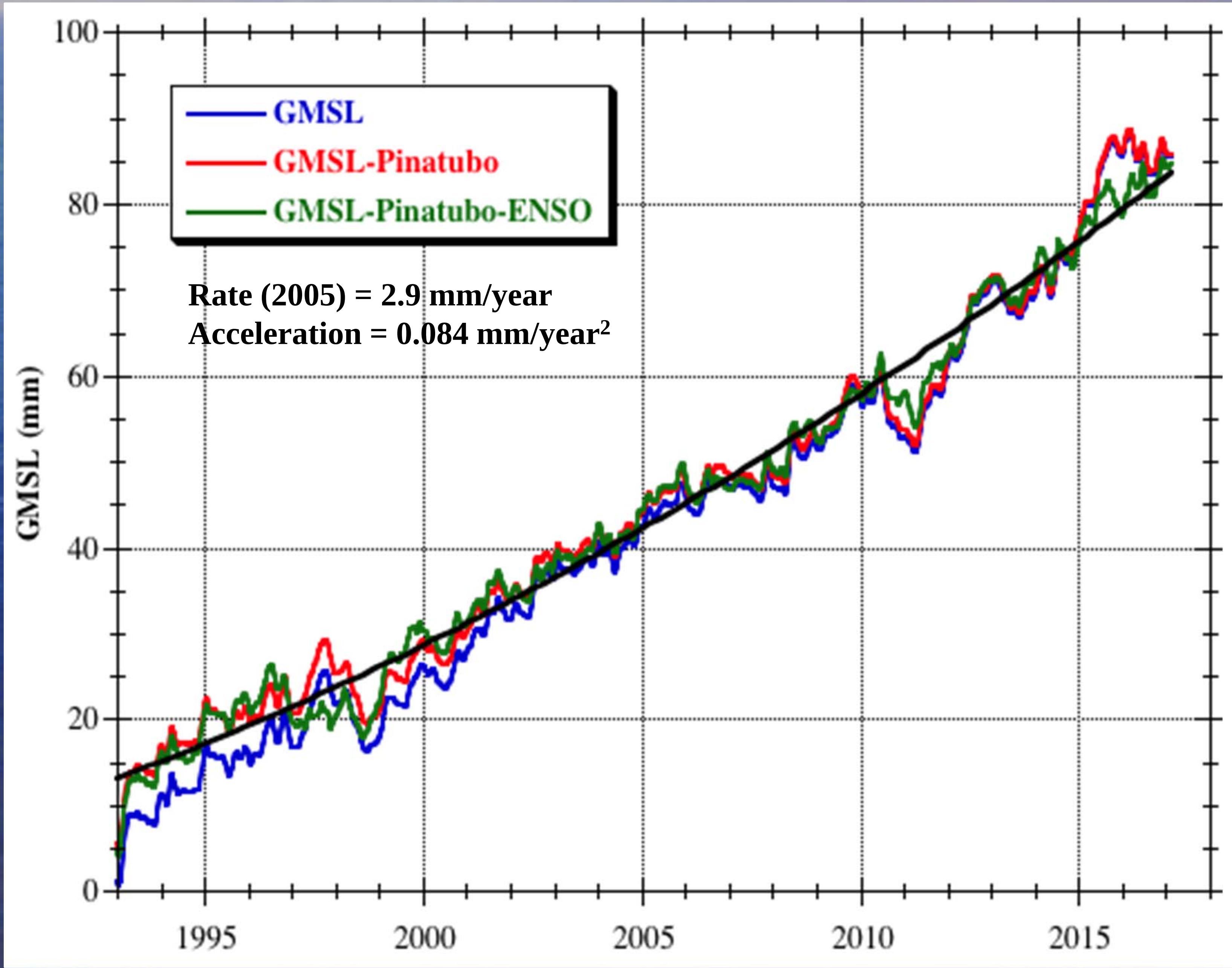




ENSO GMSL Correction



Correcting GMSL for Pinatubo and ENSO



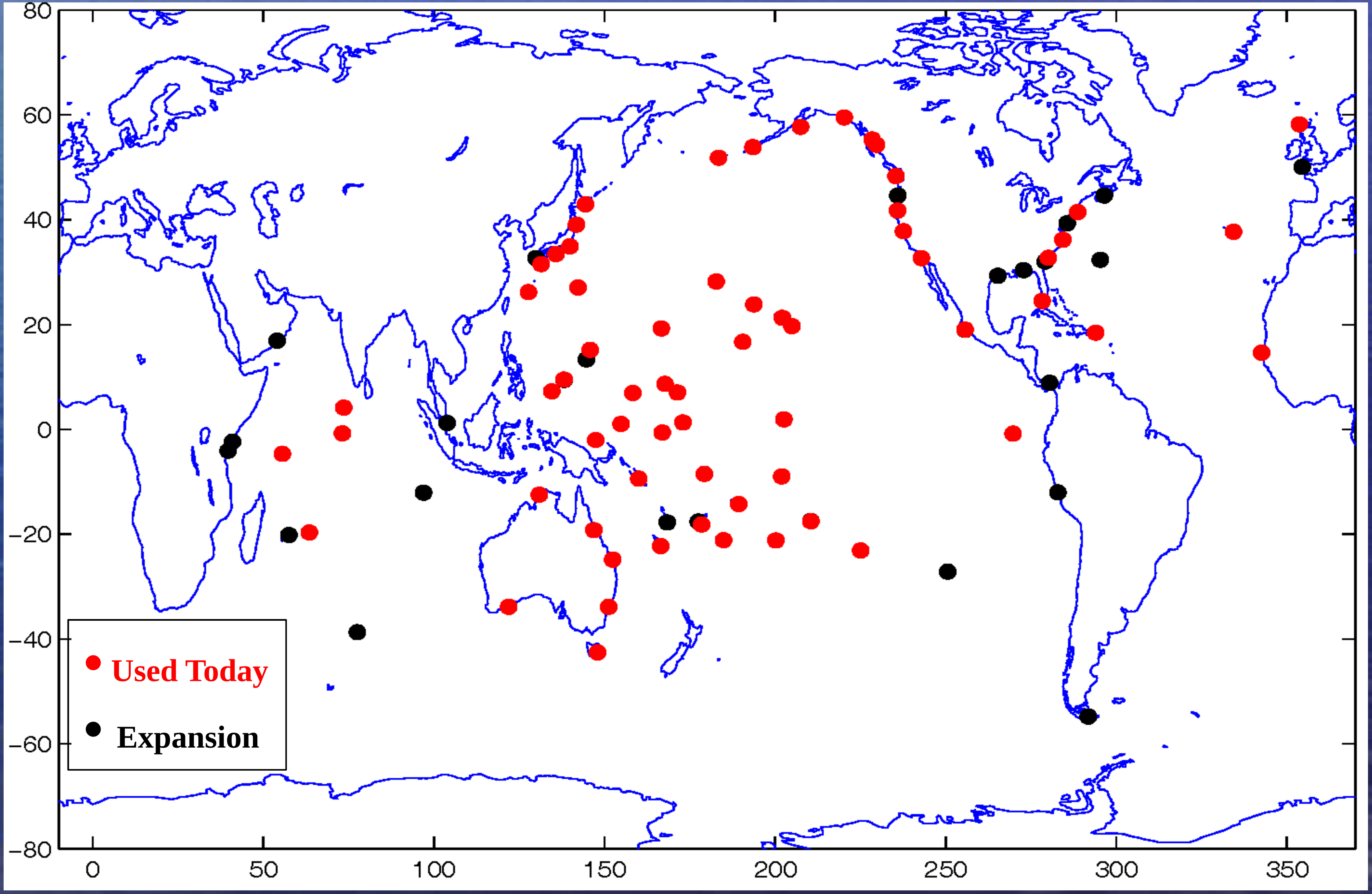
GMSL Acceleration Estimates

Case	Acceleration (mm/yr^2)
Nominal	0.082
Cal Mode Removed	0.097
Pinatubo Removed	0.117
ENSO/PDO Removed	0.084

What are the errors in this acceleration estimate?

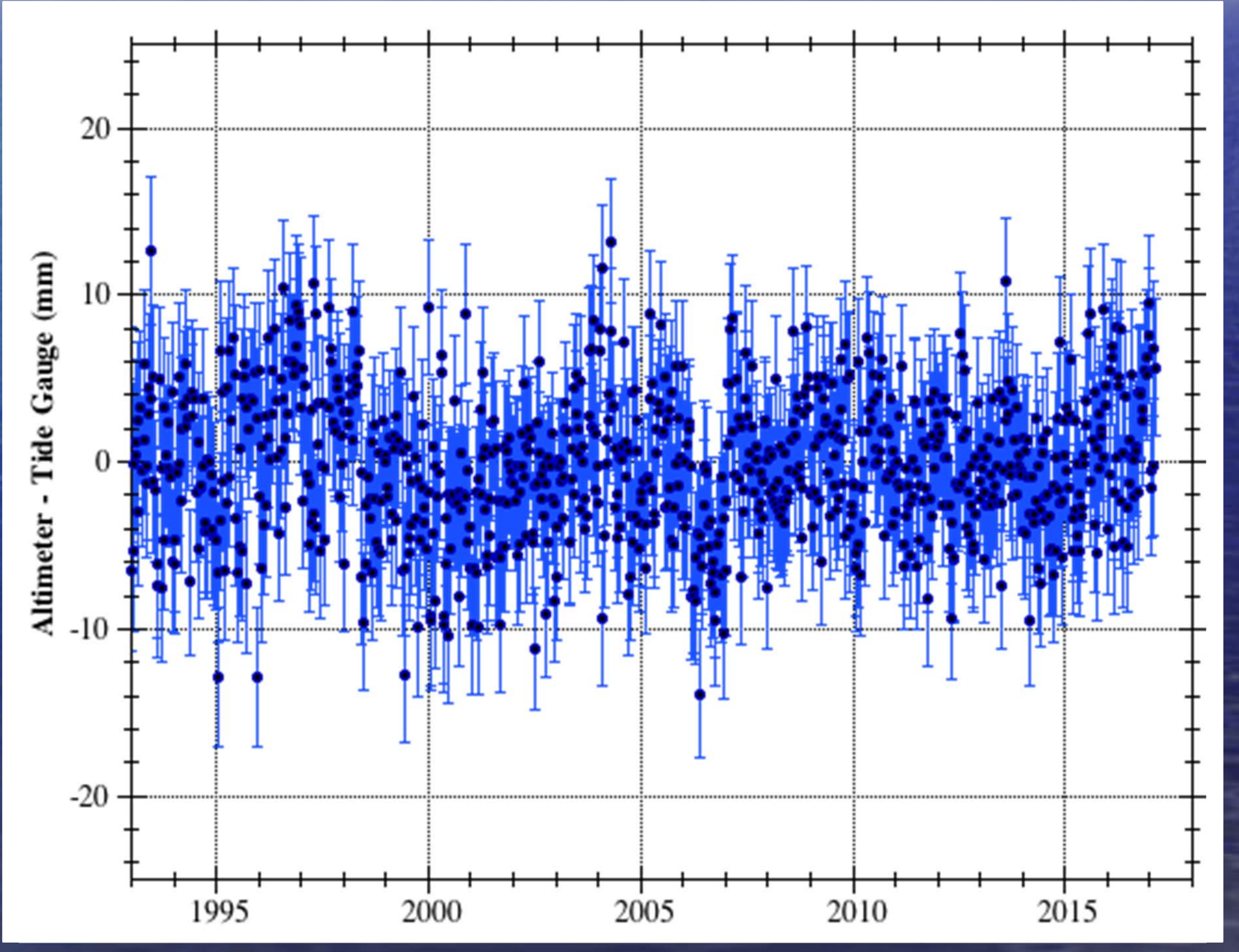
Tide Gauges

Tide Gauges Used for Cal/Val



Updated from [Mitchum, 2000]

Altimeter – Tide Gauge Sea Level



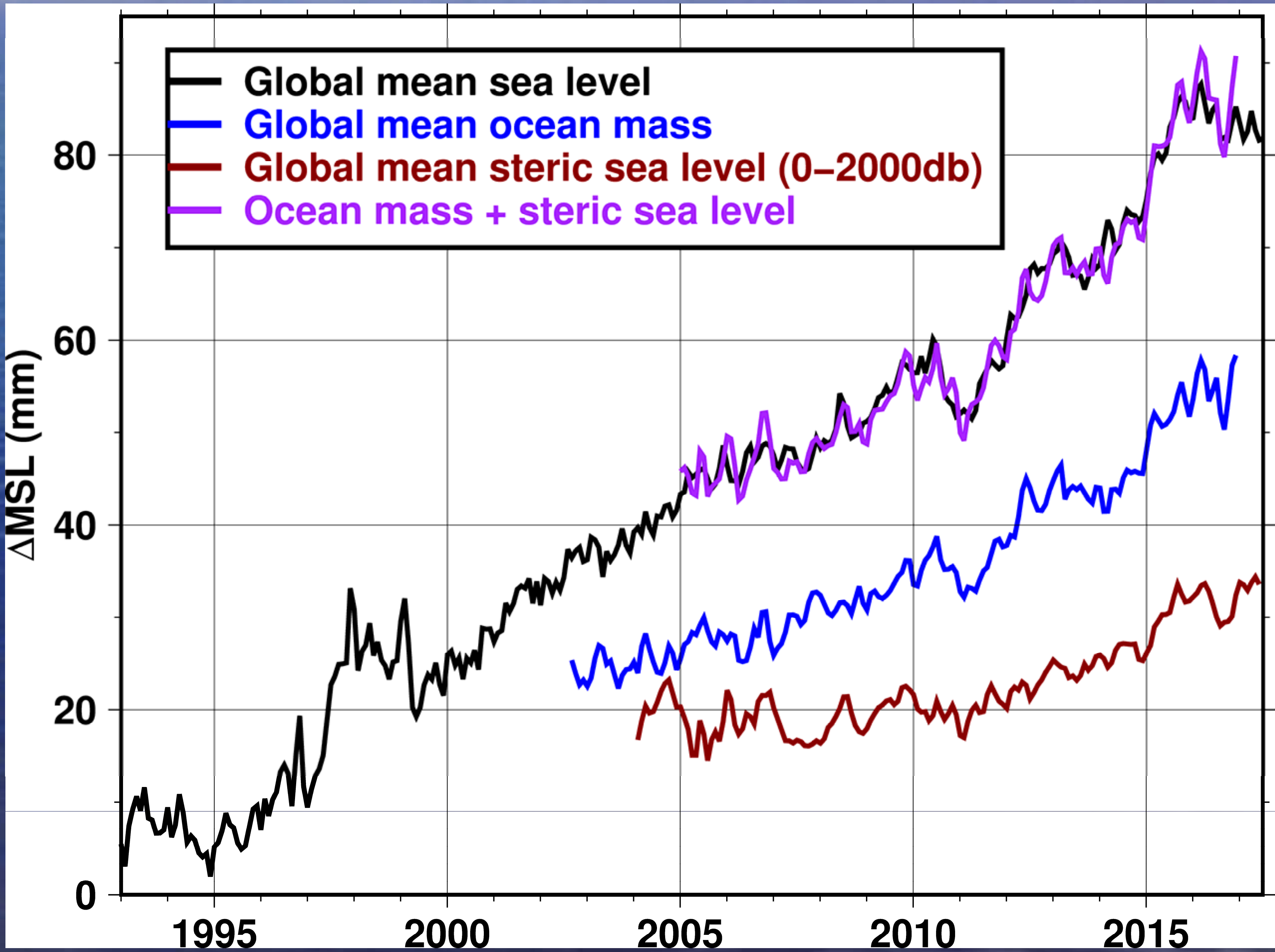
Acceleration Error Assessment

Error	Source	Acceleration Error (mm/yr^2) 1σ
Altimeter Measurement Errors	Tide Gauge Calibration	0.011
Decadal Variability	Cryosphere (Wouters et al., 2013)	0.014
	TWS (NCAR LE)	0.0054
	Thermosteric (NCAR LE)	0.0075
	Precipitable water (NCAR LE)	0.0013
Pinatubo Correction Error	NCAR LE	0.01
ENSO/PDO Correction Error	Coupled CSEOF Analysis	0.01
T		

Can we validate this acceleration estimate using other data sources?

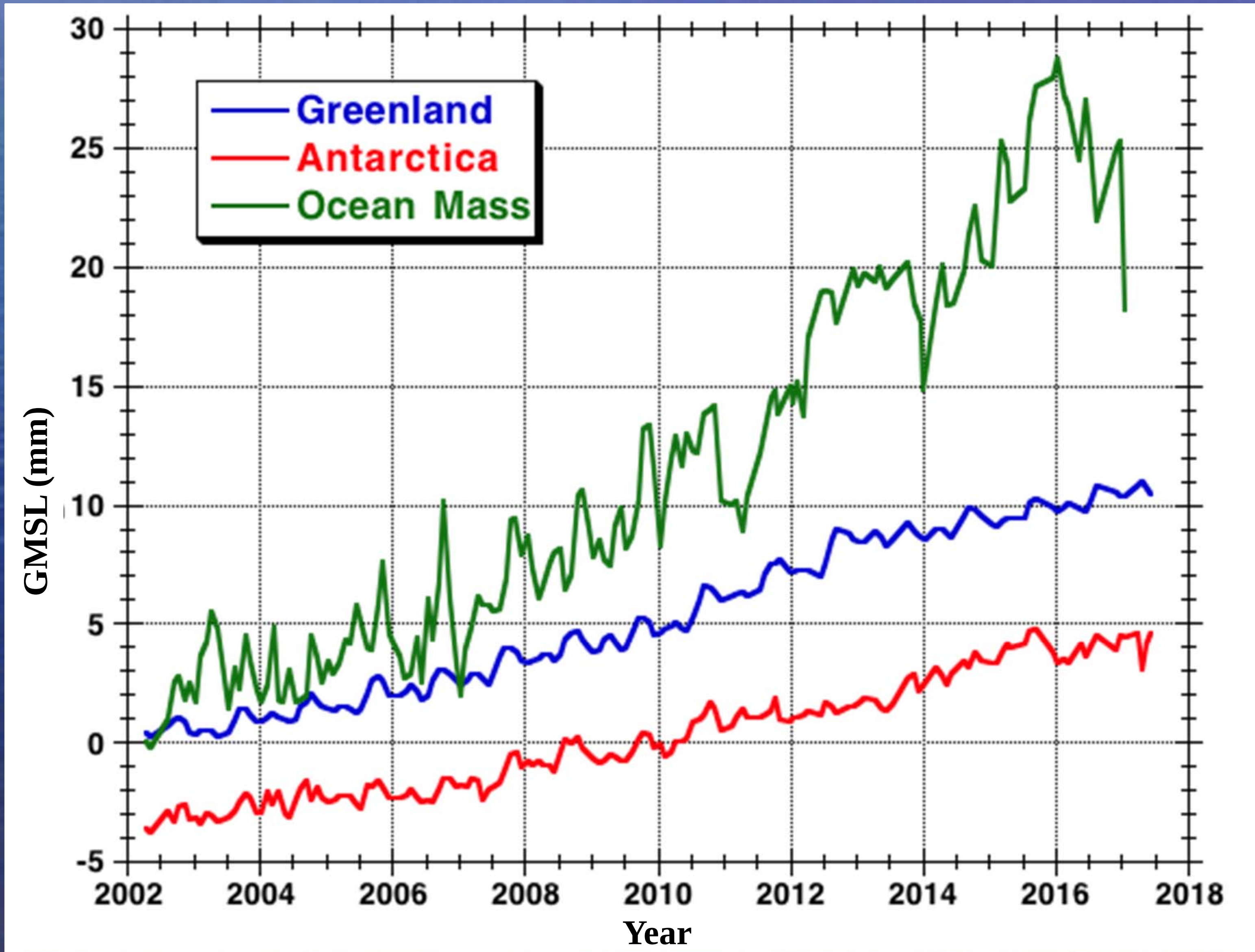
Climate-Driven GMSL Acceleration = 0.084 ± 0.025 mm/yr^2

Agreement of Altimetry, Gravity, and Argo

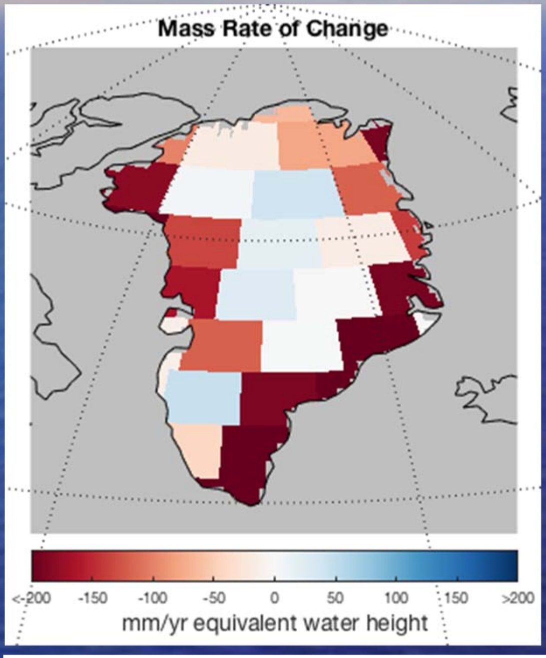


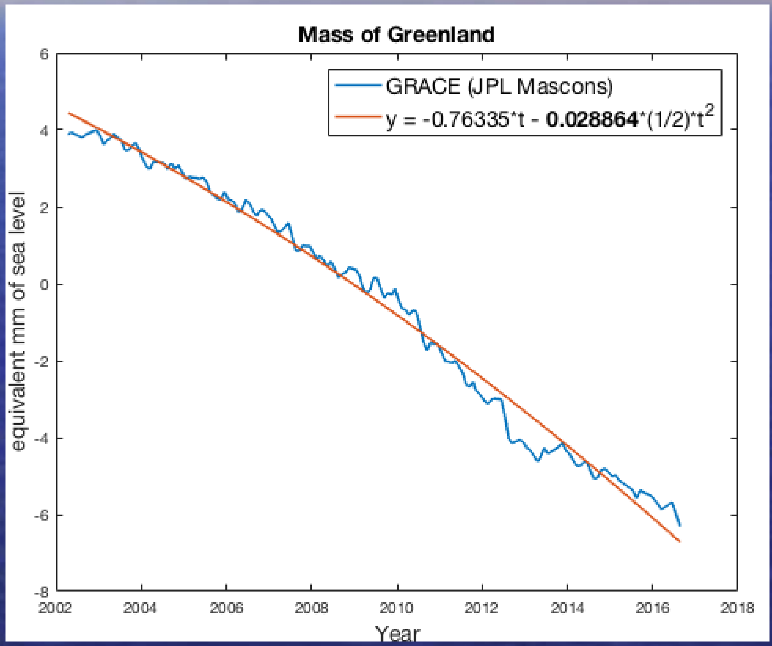
[Leuliette, 2017]

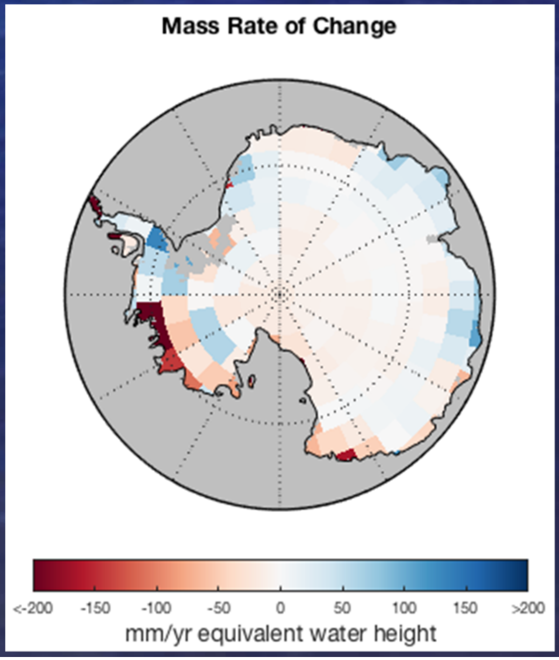
GRACE Mass Estimates (JPL Mascons)

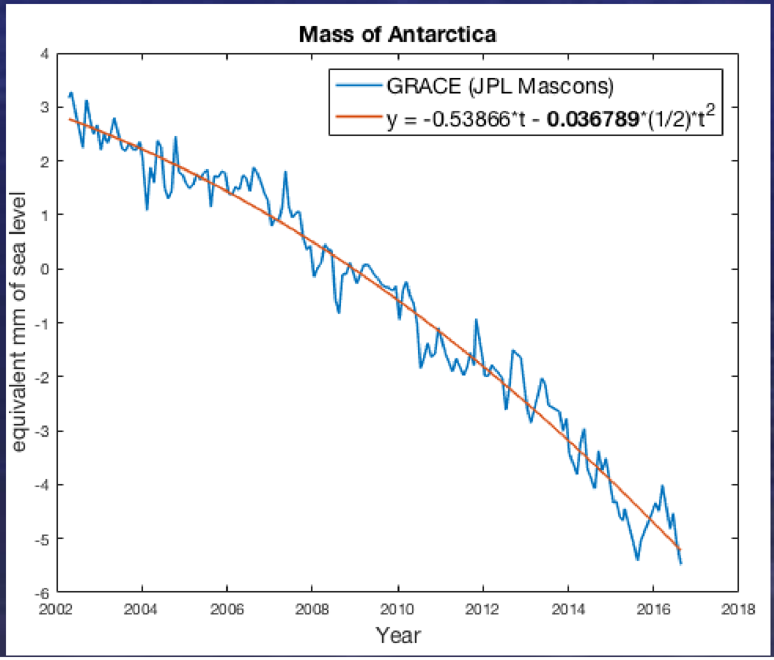


GRACE (2002-present)









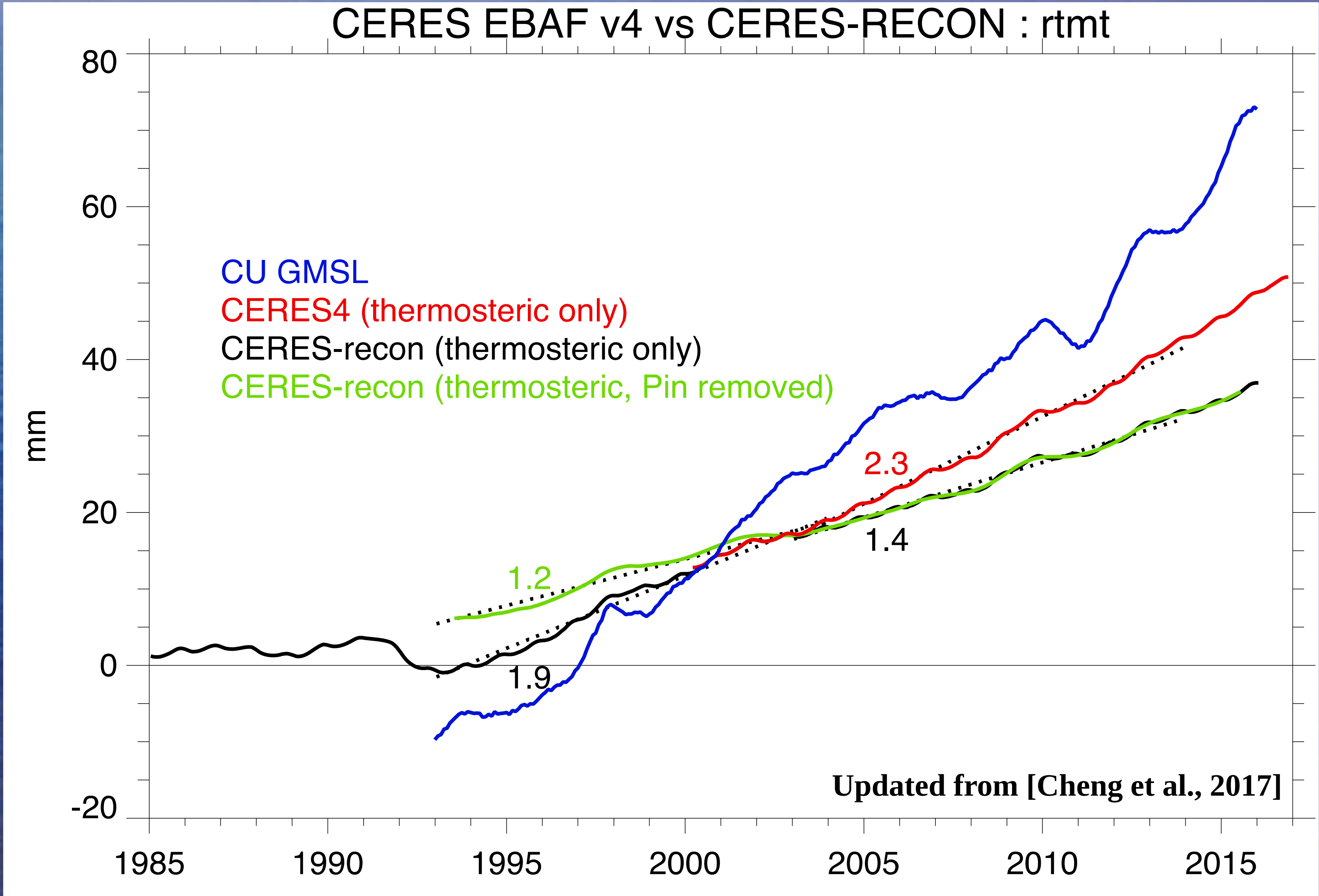
Greenland GMSL Rate & Acceleration

Data Source	End Date	Rate (mm/yr) Epoch 2005	Acceleration (mm/yr^2)
CSR Mascons	2017.44	0.49	0.0131
GSFC Mascons	2016.53	0.72	0.0181
JPL Mascons	2017.44	0.68	0.0194
CSR RL05 SH	2017.06	0.65	0.0226

Antarctica GMSL Rate & Acceleration

Data Source	End Date	Rate (mm/yr) Epoch 2005	Acceleration (mm/yr^2)
CSR Mascons	2017.44	0.30	0.0239
GSFC Mascons	2016.53	0.40	0.0364
JPL Mascons	2017.44	0.42	0.0267
CSR RL05 SH	2017.06	0.32	0.0346

Thermosteric Sea Level Acceleration

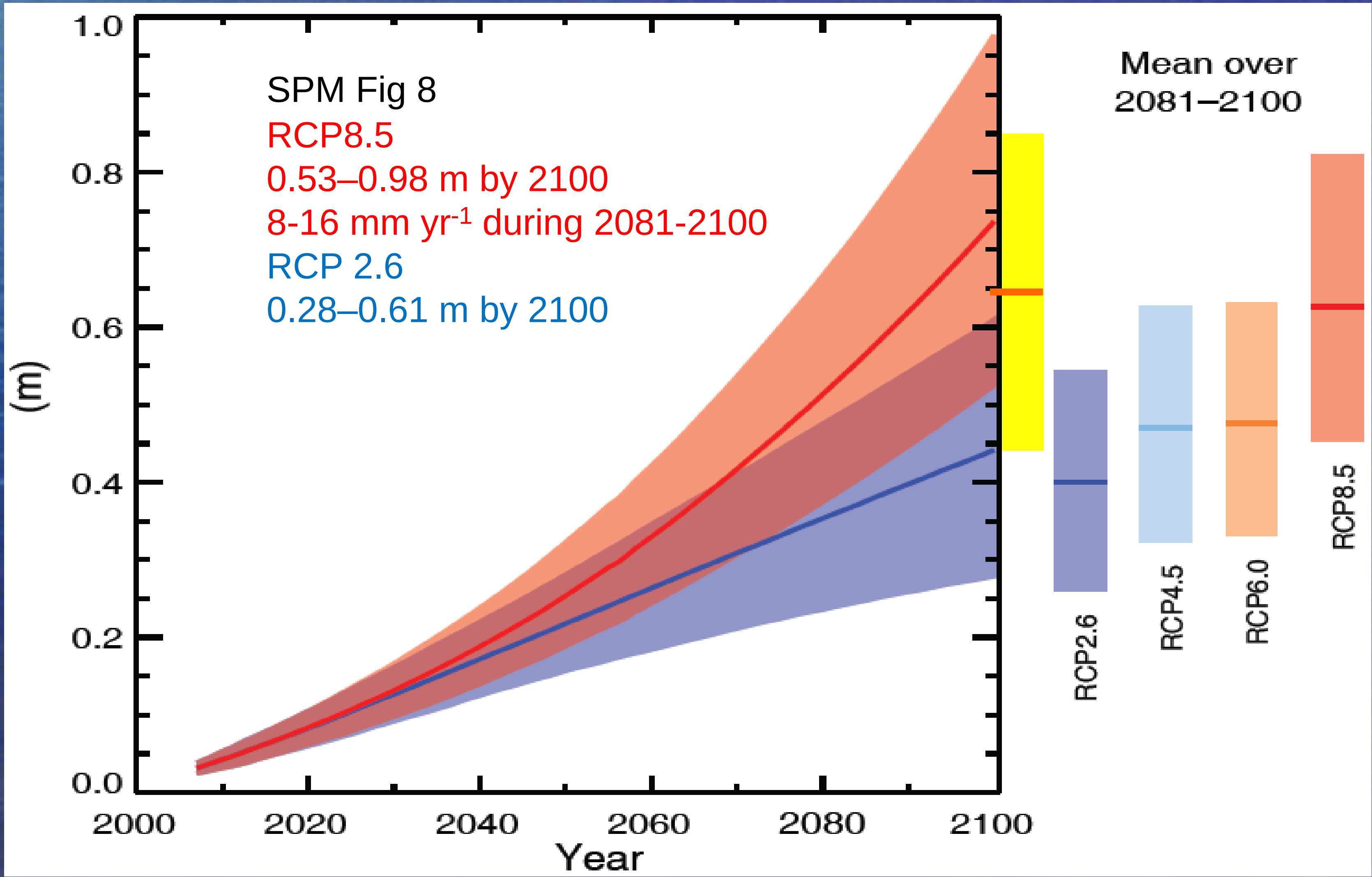


Validating the Observed GMSL Acceleration

Component	Time Period	Rate (mm/yr) Epoch 2005	Acceleration (mm/yr^2)
Greenland	2002-2017	0.68	0.0194
Antarctica	2002-2017	0.42	0.0267
Mountain Glaciers & Small Ice Caps	2002-2017	0.51	0.0104
Thermosteric (no Pin.)	1993-2015	1.43	0.0246
Components Total		**3.0**	**0.081**
Altimeter Observed	1993-2017	**2.9**	**0.084**

Projections of 21st-century GMSLR under Different RCPs from the IPCC 5th Assessment Report

Medium confidence in *likely* ranges. *Very likely* that the 21st-century mean rate of GMSLR will exceed that of 1971-2010 under all RCPs.



Conclusions

- We have detected a small acceleration of global mean sea level in the satellite record of 0.084 ± 0.025 mm/yr^2.
- This acceleration has the potential to double the amount of sea level rise by 2100 as compared to sea level rising at a constant rate of ~3 mm/year.
- GRACE is a critical tool for validating this acceleration and determining its cause.
- Estimates of the acceleration of GMSL will improve as the satellite record lengthens.

Thanks! Questions?