Is the Altimeter-Era Acceleration of Global Mean Sea Level Rise Being Masked by the 1991 Eruption of Mt. Pinatubo?

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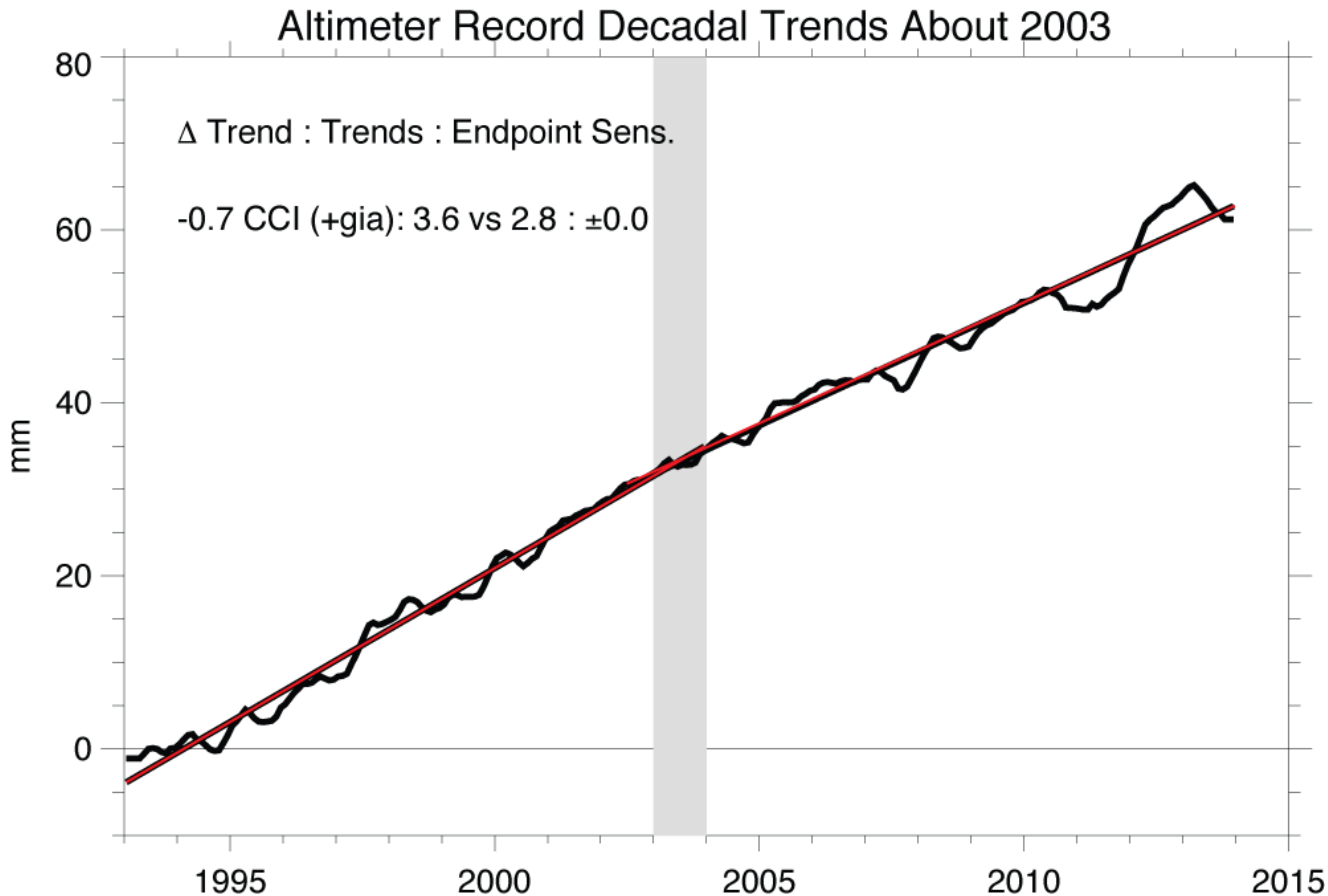
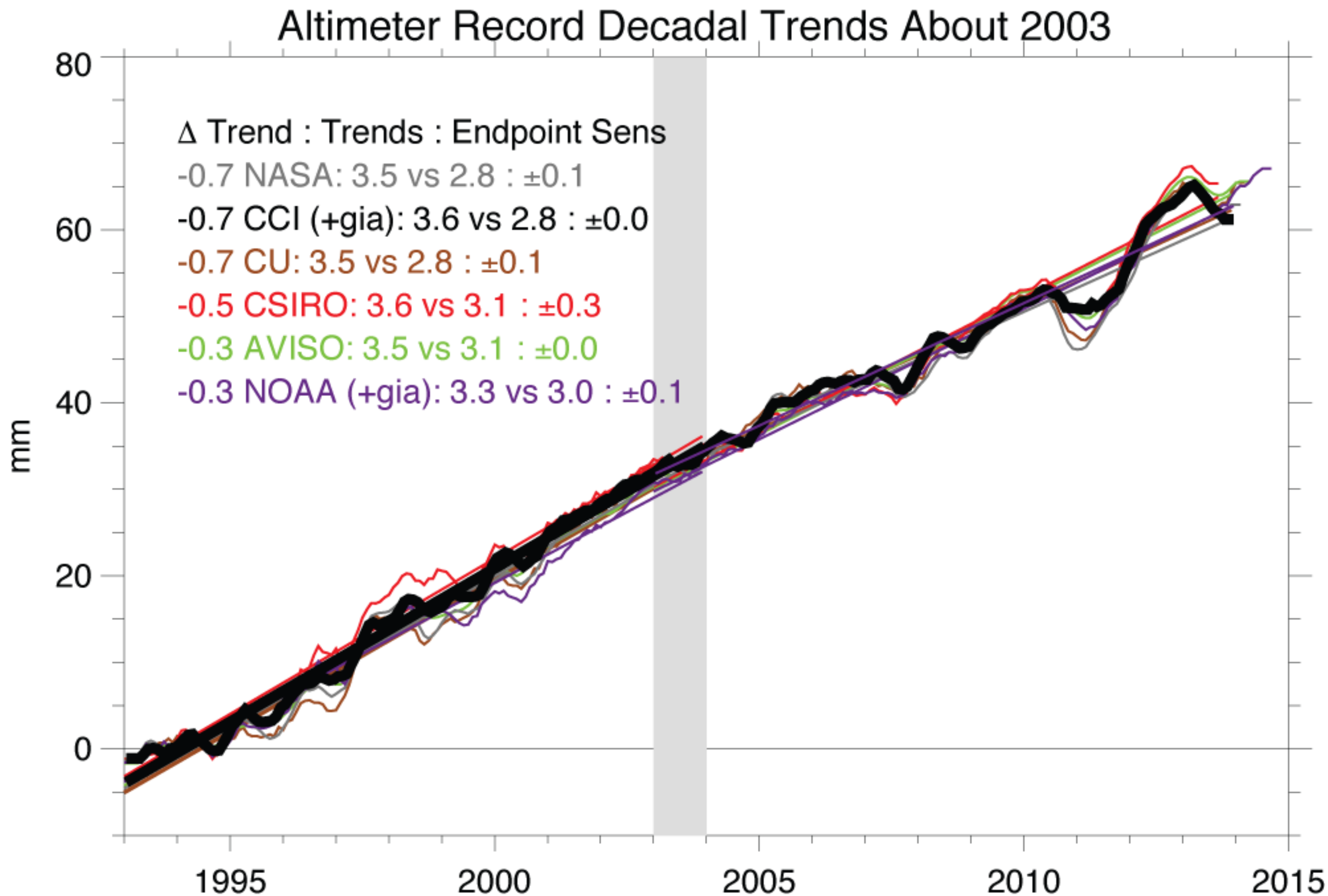
Outline

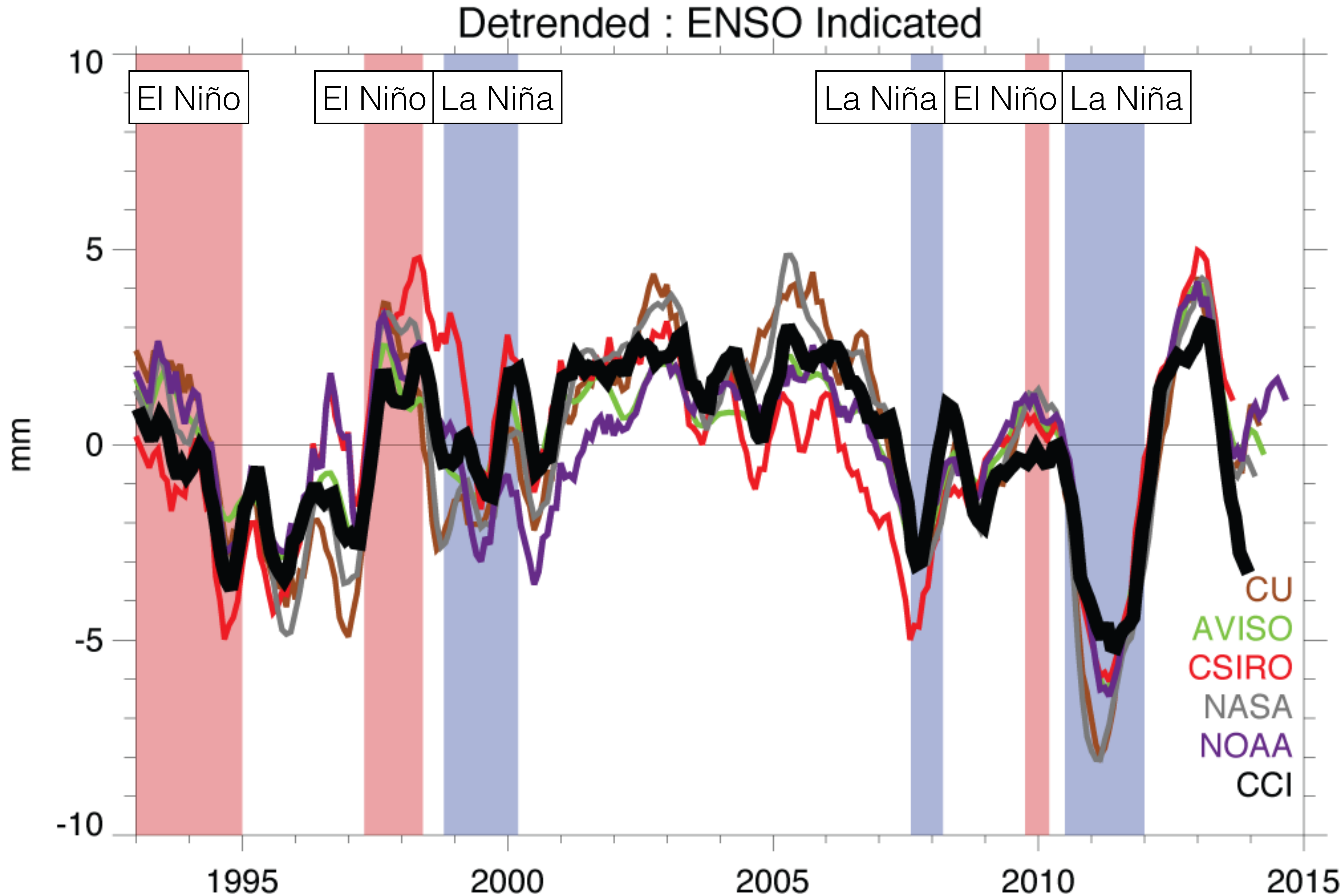
- **GMSL decadal variability:** robust across datasets?
- **The NCAR Large Ensemble:** What is it and why is it needed?
- **Mt. Pinatubo's 1991 Eruption:** the GMSL budget
- **Removing Pinatubo** from the Altimeter Record



1993-2003 mean rate > 2003-2013 mean rate by 7 mm/decade



1993-2003 mean rate > 2003-2013 mean rate by 7 mm/decade for 3 products
Some dataset dependence and endpoint sensitivity exists; (NOAA/CSIRO)
Best-estimate (CCI) shows: 1) > Δ, 2) < endpoint sensitivity 3) < interannual var



Interannual variability (e.g. ENSO) cited as key source of the discrepancy BUT: CCI index has < var, > Δ; 1993-2003 trend reduced by 1993-95 El Niño and 1999-2000 La Niña, 2001-2007 > 0

Causes of Deceleration

- Increases in terrestrial water storage in the past decade (Cazenave et al. 2014,NCC)

- Corrections to altimeter data to account for instrument drift, particularly from 1993-1998 (Watson et al. 2015, NCC)

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The rate of sea-level rise

Anny Cazenave[1*], Habib-Boubacar Dieng[1], Benoit Meyssignac[1], Karina von Schuckmann[2], Bertrand Decharme[3] and Etienne Berthier[1]

Present-day sea-level rise is a major indicator of climate change[1]. Since the early 1990s, sea level rose at a mean rate of ~3.1 mm yr^{-1} (refs 2,3). However, over the last decade a slowdown of this rate, of about 30%, has been recorded[4–8]. It coincides with a plateau in Earth's mean surface temperature evolution, known as the recent pause in warming[1,9–12]. Here we present an analysis based on sea-level data from the altimetry record of the past ~20 years that separates interannual natural variability in sea level from the longer-term change probably related to anthropogenic global warming. The most prominent signature in the global mean sea level interannual variability is caused by El Niño-Southern Oscillation, through its impact on the global water cycle[13–16]. We find that when correcting for interannual variability, the past decade's slowdown of the global mean sea level disappears, leading to a similar rate of sea-level rise (of 3.3 ± 0.4 mm yr^{-1}) during the first and second decade of the altimetry era. Our results confirm the need for quantifying and further removing from the climate records the short-term natural climate variability if one wants to extract the global warming signal[10].

climate sceptics to refute global warming and its attribution to a steadily rising rate of greenhouse gases in the atmosphere. It has been suggested that this so-called global warming hiatus[11] results from El Niño–Southern Oscillation- (ENSO-) related natural variability of the climate system[10] and is tied to La Niña-related cooling of the equatorial Pacific surface[11,12]. In effect, following the major El Niño of 1997/1998, the past decade has favoured La Niña episodes (that is, ENSO cold phases, reported as sometimes more frequent and more intensive than the warm El Niño events, a sign of ENSO asymmetry[19]). The interannual (that is, detrended) GMSL record of the altimetry era seems to be closely related to ENSO, with positive/negative sea-level anomalies observed during El Niño/La Niña events[2]. Recent studies have shown that the short-term fluctuations in the altimetry-based GMSL are mainly due to variations in global land water storage (mostly in the tropics), with a tendency for land water deficit (and temporary increase of the GMSL) during El Niño events[13,14] and the opposite during La Niña[15,16]. This directly results from rainfall excess over tropical oceans (mostly the Pacific Ocean) and rainfall deficit over land (mostly the tropics) during an El Niño[20] event. The

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Unabated global mean sea-level rise over the satellite altimeter era

Christopher S. Watson[1*], Neil J. White[2], John A. Church[2], Matt A. King[1,3], Reed J. Burgette[4] and Benoit Legresy[2]

The rate of global mean sea-level (GMSL) rise has been suggested to be lower for the past decade compared with the preceding decade as a result of natural variability[1], with an average rate of rise since 1993 of +3.2 ± 0.4 mm yr^{-1} (refs 2,3). However, satellite-based GMSL estimates do not include an allowance for potential instrumental drifts (bias drift[4,5]). Here, we report improved bias drift estimates for individual altimeter missions from a refined estimation approach that incorporates new Global Positioning System (GPS) estimates of vertical land movement (VLM). In contrast to previous results (for example, refs 6,7), we identify significant non-zero systematic drifts that are satellite-specific, most notably affecting the first 6 years of the GMSL record. Applying the bias drift corrections has two implications. First, the GMSL rate (1993 to mid-2014) is systematically reduced to between +2.6 ± 0.4 mm yr^{-1} and +2.9 ± 0.4 mm yr^{-1}, depending on the choice of VLM applied. These rates are in closer agreement with the rate derived from

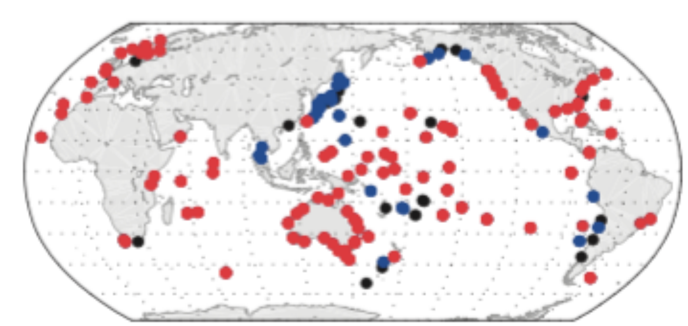

Figure 1 | Map of the initial 122 TGs used in this analysis. Additional quality control procedures (for example, obvious nonlinear VLM) eliminate TGs shown in black, and the earthquake threshold eliminates TGs in blue. The remaining TGs in red are used for bias drift estimation. Distributions by mission are shown in Supplementary Fig. 2.

The NCAR Large Ensemble

- **Motivation**: identifying the forced-response of the climate system requires distinguishing it from internal variability
- **CMIP archives** do not allow for a such a distinction due to model structural differences (ensemble mean ≠ forced response)
- **The NCAR LE** consists of **40 members** of simulation using the CESM-CAM1 from 1920-2100
- Fixed volume ocean - using the Church conversion between OHC and GMSL.
- As variance of internal variability scales as $1/\sqrt{(N-1)}$, the ensemble mean it is << forced response.

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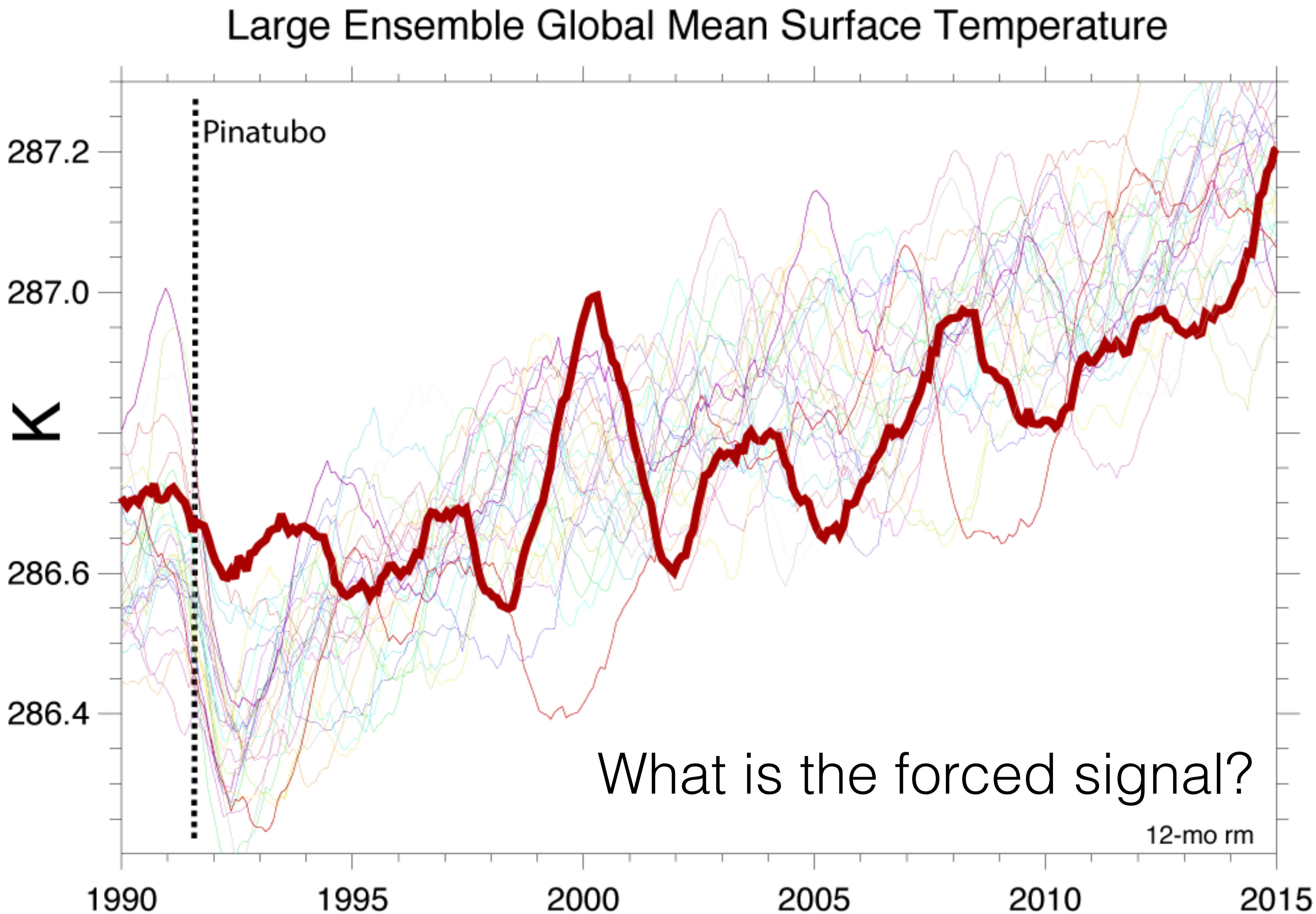
The 1991 Eruption of Mt Pinatubo

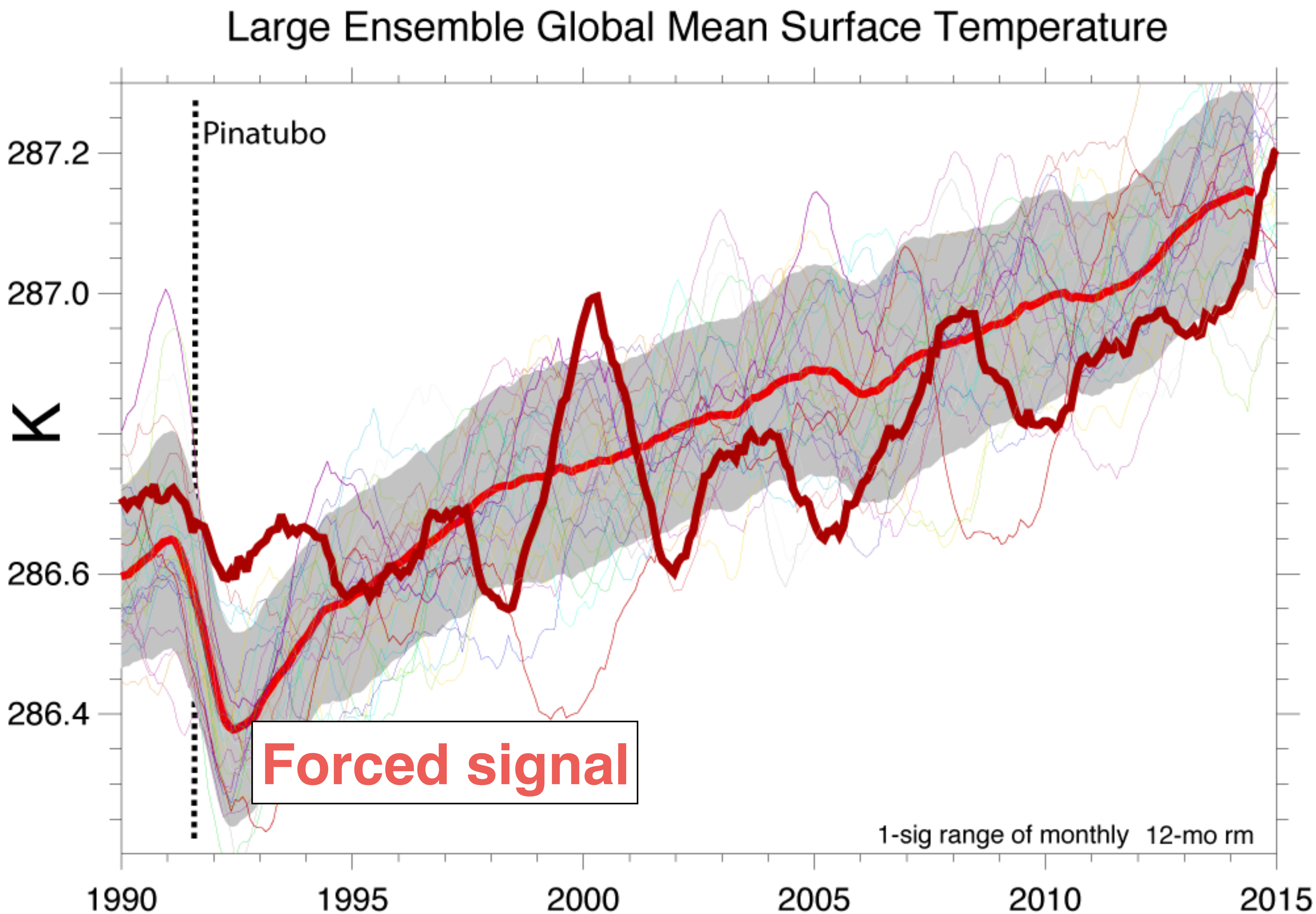
- June 15, 1991
- 2nd largest eruption of the 20th Century
- ~25 Tg of stratospheric aerosol loading
- Global cooling of ~0.5 C, substantial ozone depletion

The 1991 Eruption of Mt Pinatubo



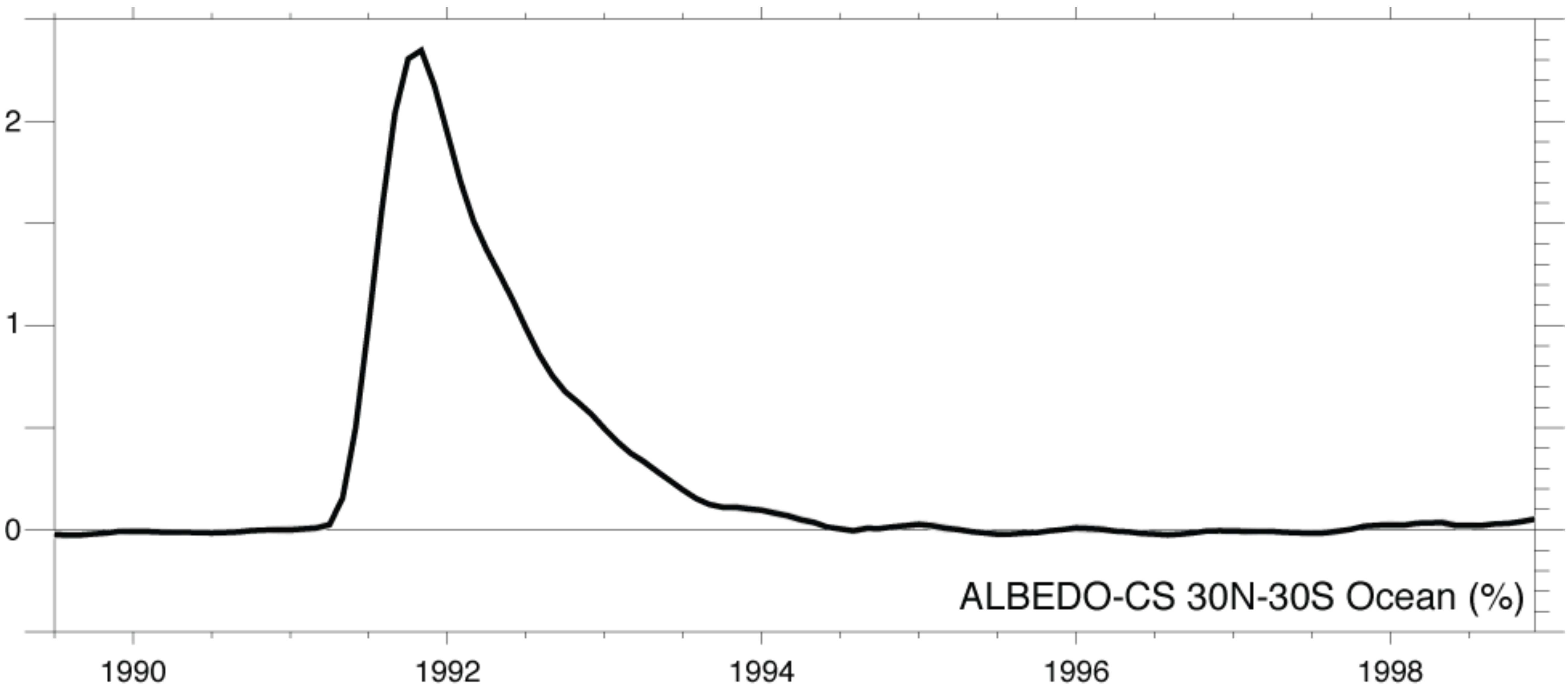
- from examining a single member (also obs), it is not possible to quantify forced response
- significant spread across ensemble members, including in any apparent “response”

The 1991 Eruption of Mt Pinatubo



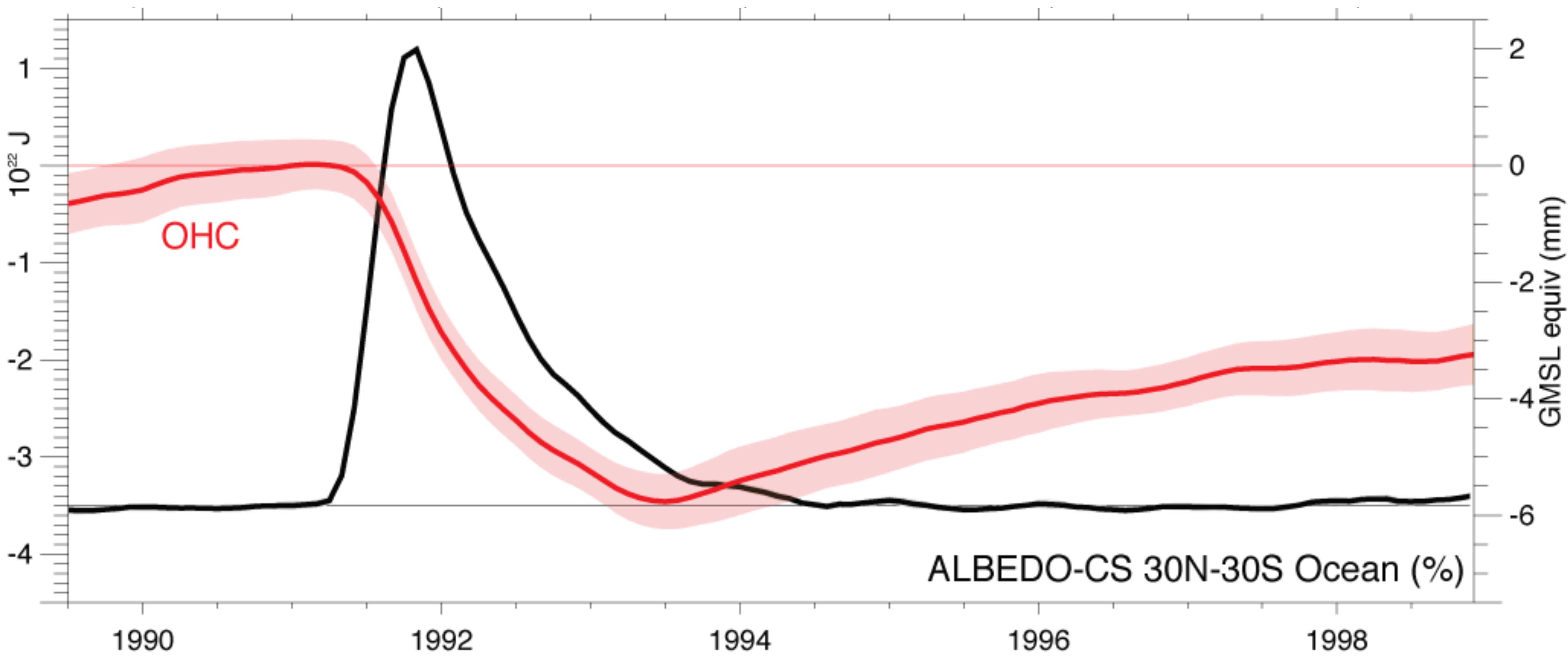
- Temperature Response (ensemble mean, 2 sigma)

The 1991 Eruption of Mt Pinatubo in the Large Ensemble: GMSL Budget



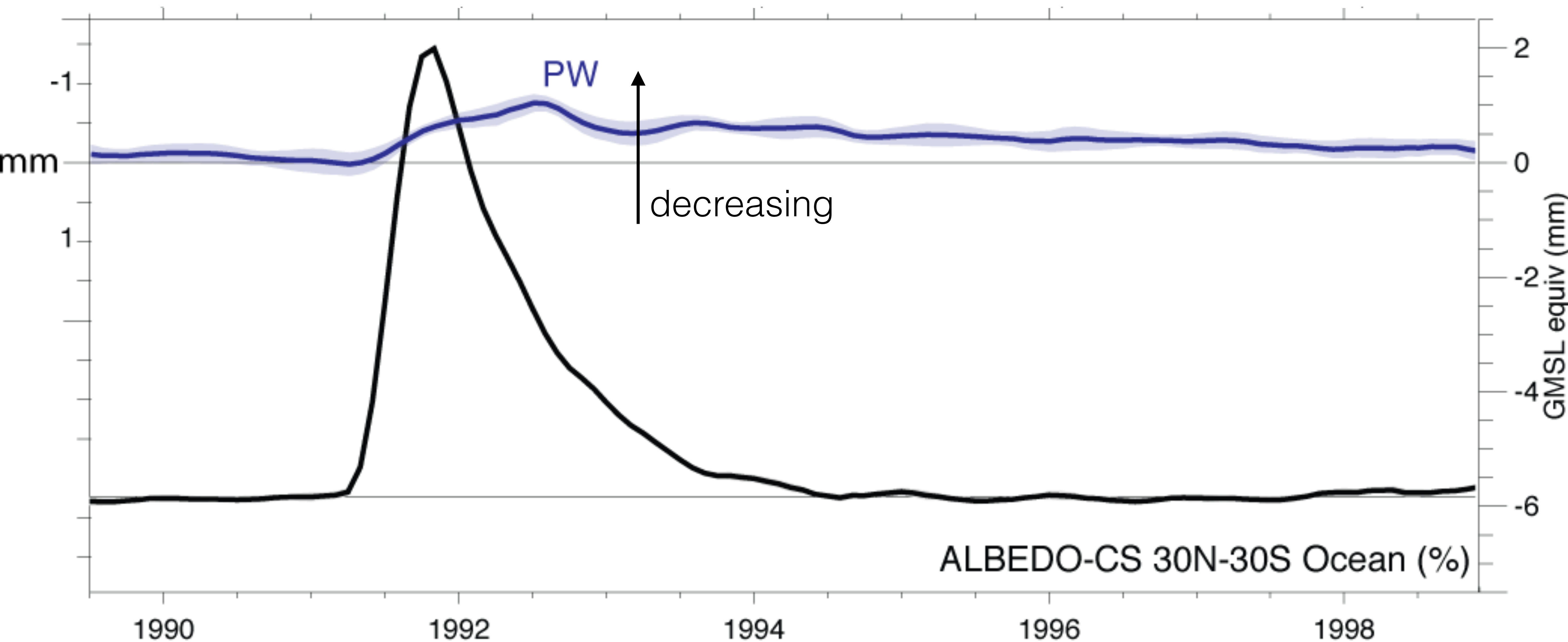
- Ensemble-mean clear sky albedo albedo anomaly is a useful diagnostic for the eruption

The 1991 Eruption of Mt Pinatubo in the Large Ensemble: GMSL Budget



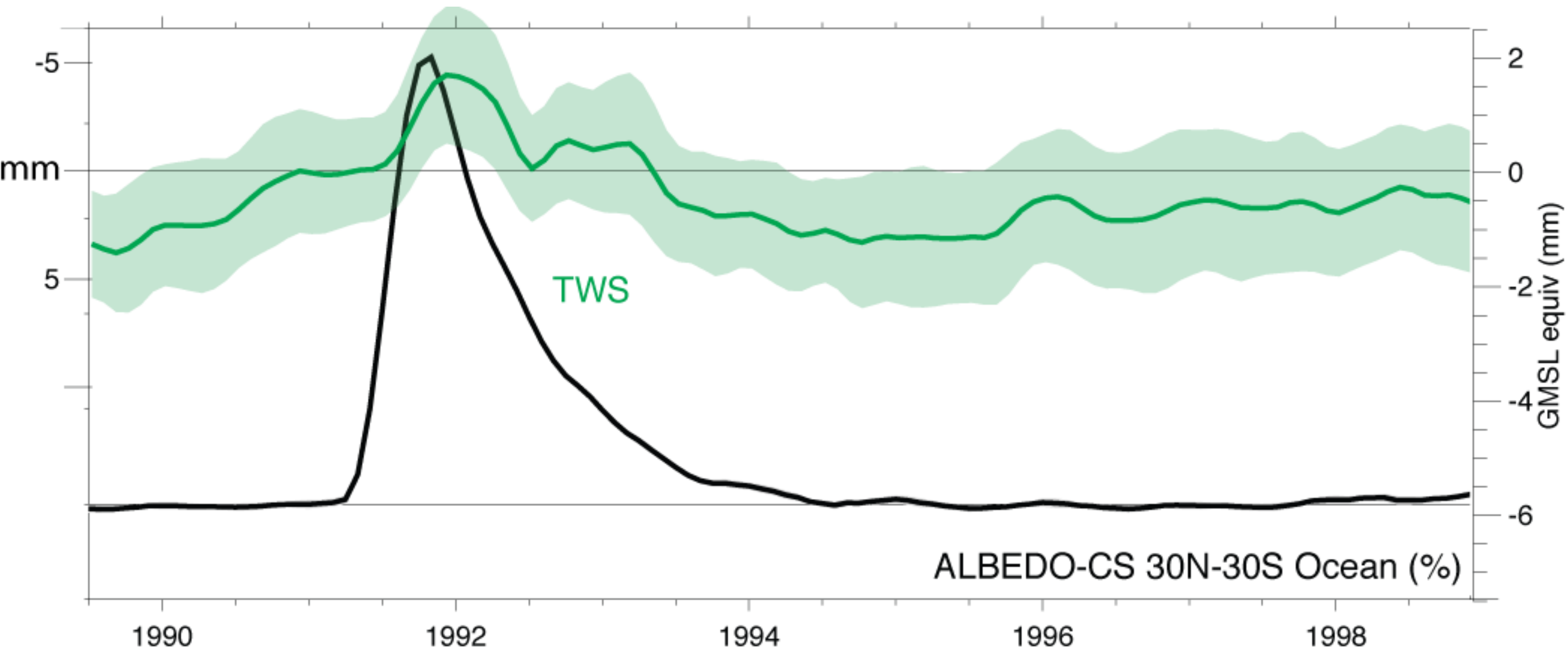
- Ocean heat content drops substantially due to the radiative forcing of the eruption

The 1991 Eruption of Mt Pinatubo in the Large Ensemble: GMSL Budget



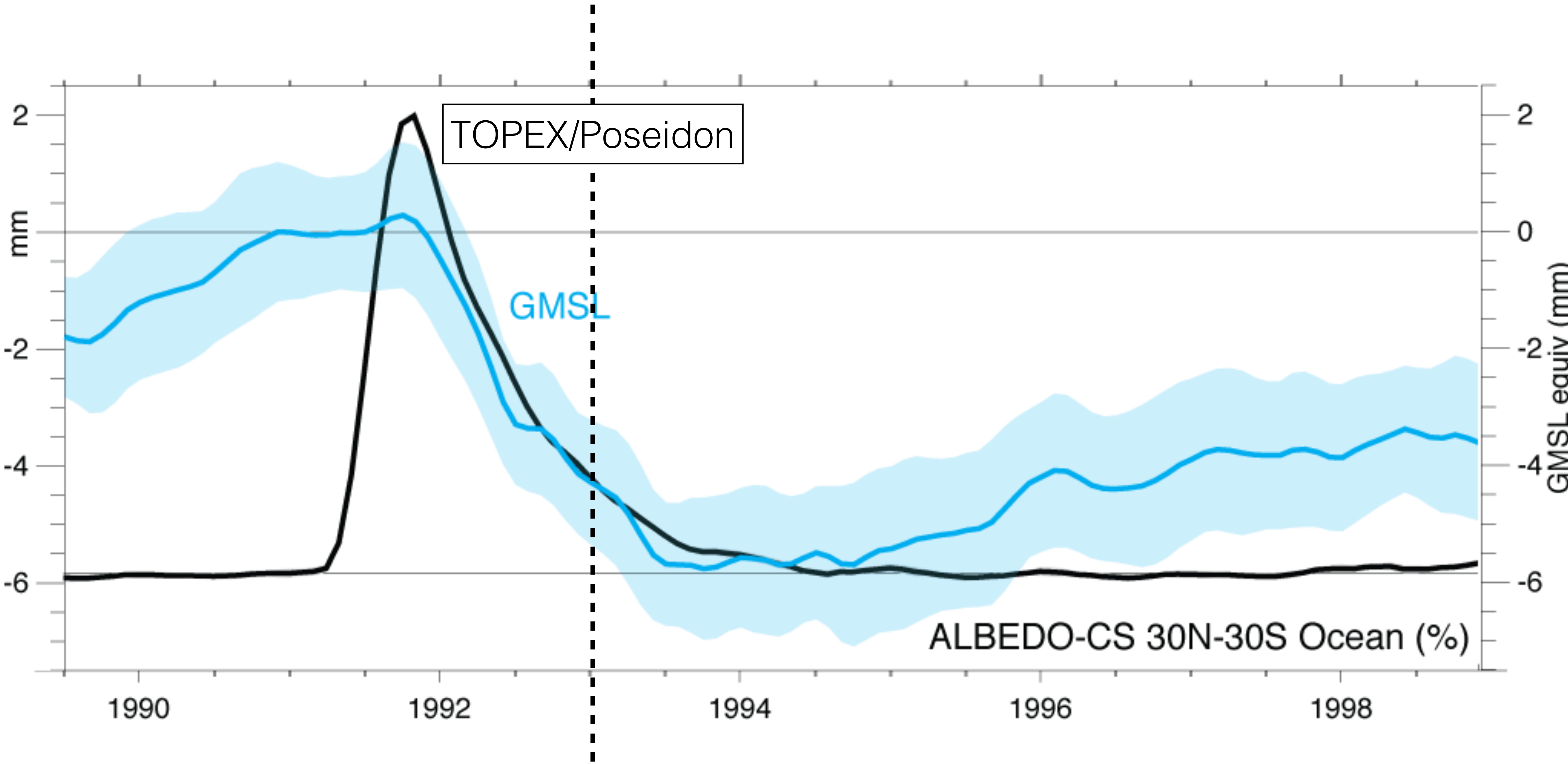
- Atmospheric PW DECREASES, contributing to an INCREASE in GMSL

The 1991 Eruption of Mt Pinatubo in the Large Ensemble: GMSL Budget



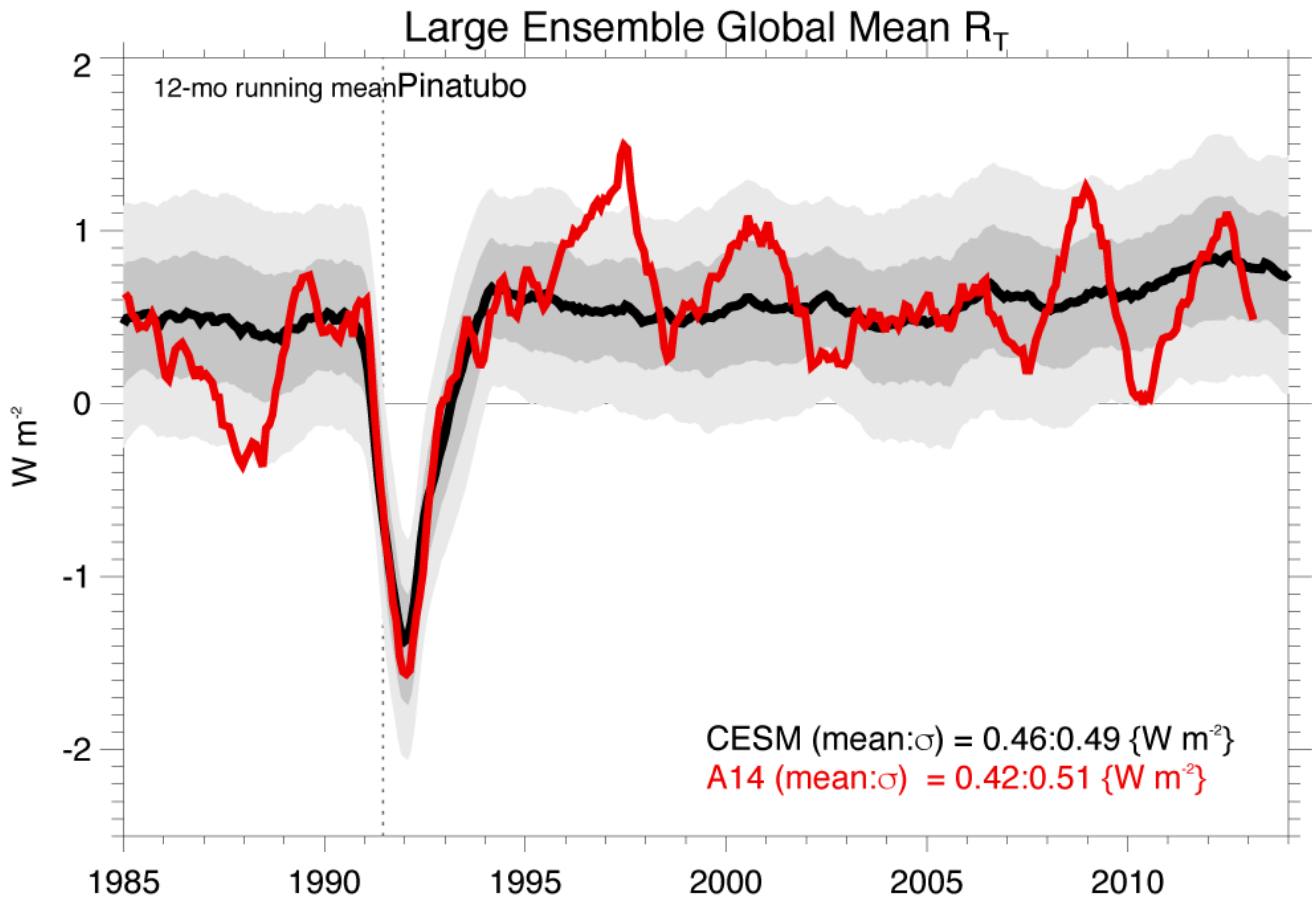
- Terrestrial water also DECREASES, contributing to an INCREASE in GMSL

The 1991 Eruption of Mt Pinatubo in the Large Ensemble: GMSL Budget



- The ensemble mean GMSL deficit reaches a minimum in 1993 of 5-7 mm

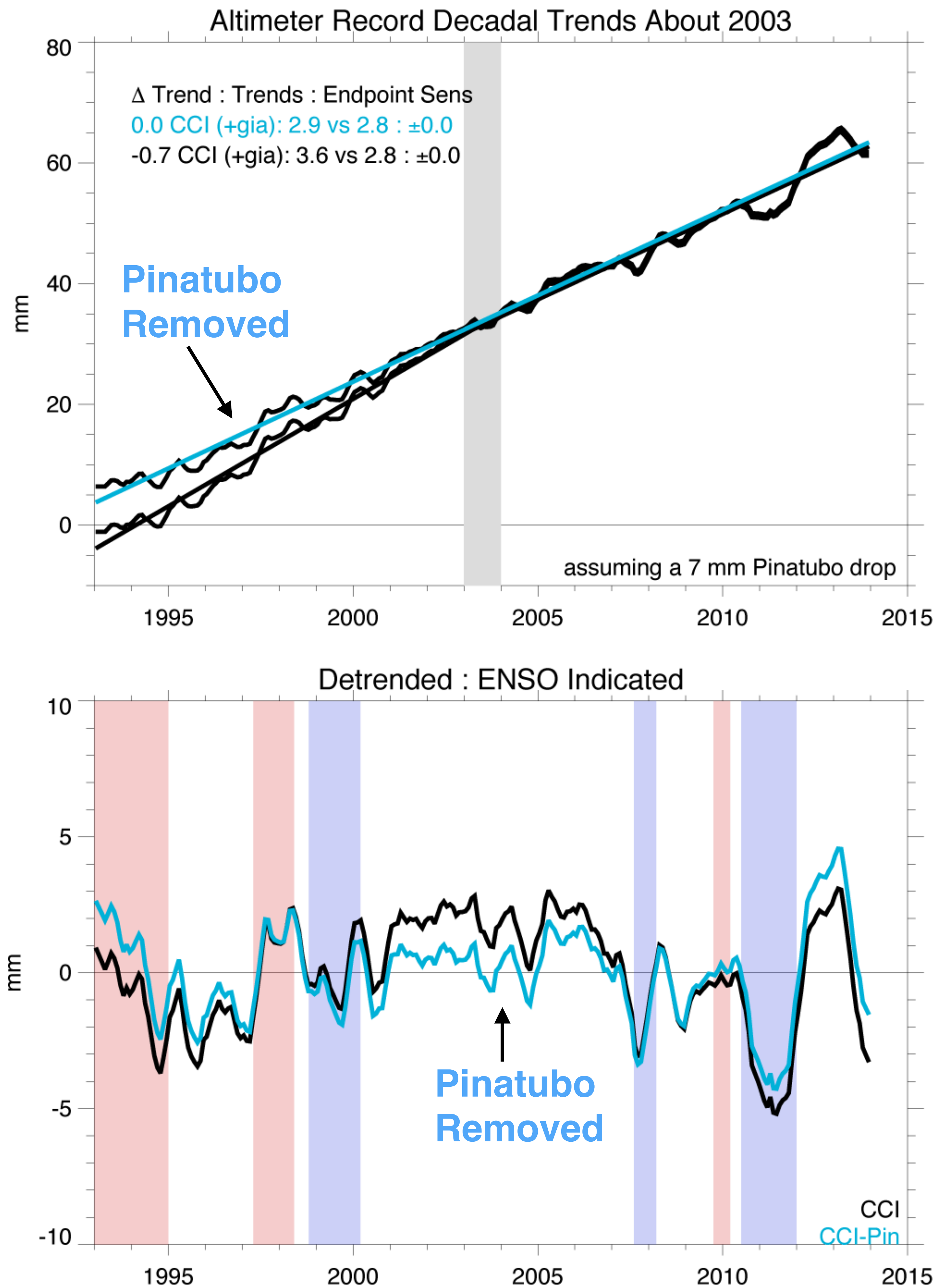
Validation of CESM with CERES



- LE Net TOA flux anomaly matches CERES' blended ERBS-CERES data

Removing Pinatubo From CCI GMSL

- assuming a Pinatubo drop of 7 mm
- Δ decadal trends → 0
- anomaly from 2001 to 2007 is ≅ 0
- 1993-1995 El Niño anomaly > 0



Conclusions

- Inter-decal trends in GMSL suggest an additional 7* mm of sea level rise from 1993-2003 relative to 2003-2013

- The 1991 eruption of Mt. Pinatubo significantly lowered ocean heat content; OHC reached a minimum in 1993 at the start of the altimeter era and recovered gradually through the 1990s

- An anomalous rise of about 6 mm in the decade following 1993 is estimated from the CESM Large Ensemble; due largely to recovery in OHC

- Removing this signal from altimetry substantially reduces *observed decadal variability and improves consistency with ENSO-based expectations of GMSL anomalies.

* some dataset dependence exists