The impact of volcanic eruptions on mean sea level

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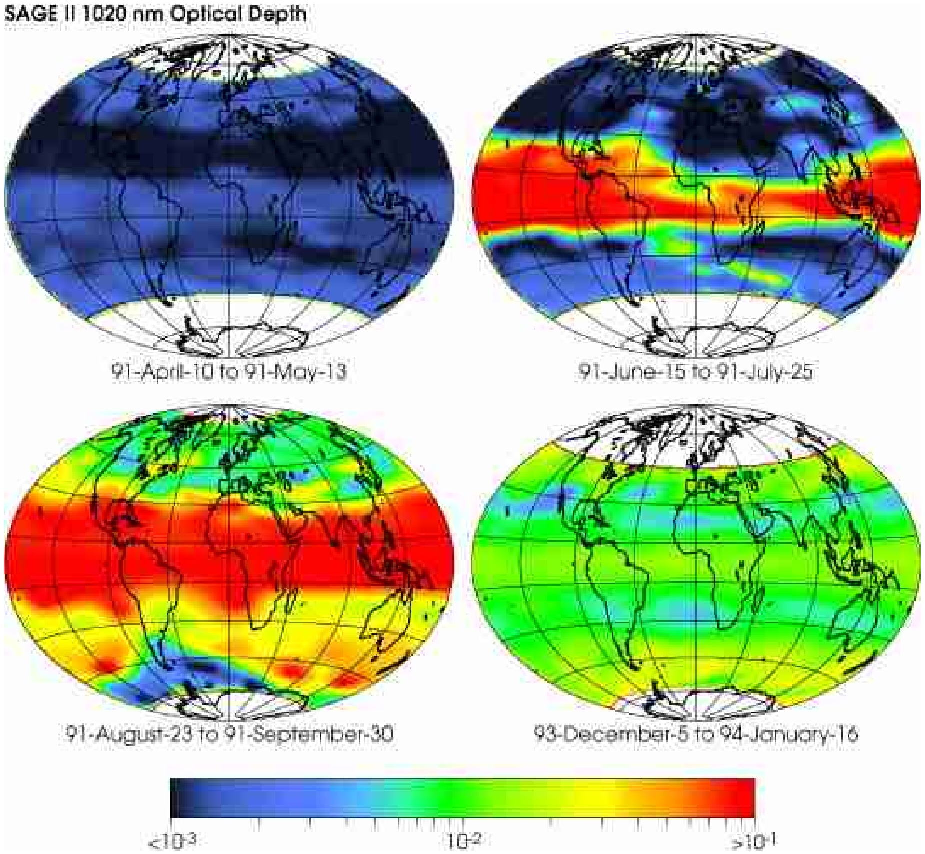
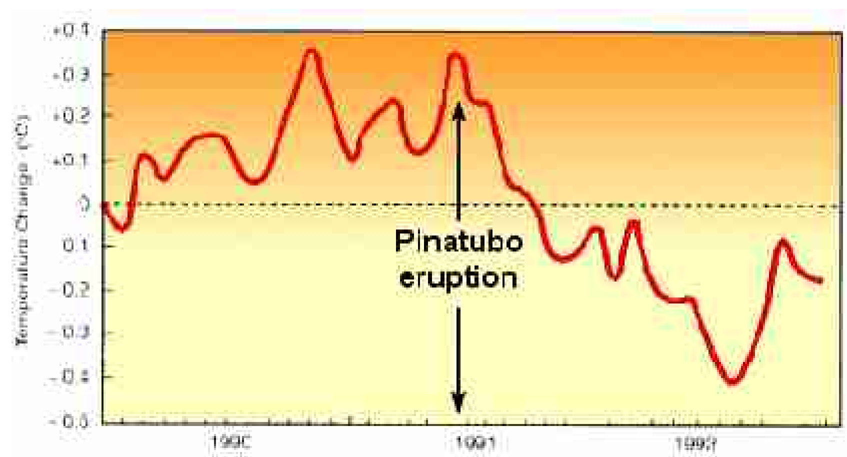
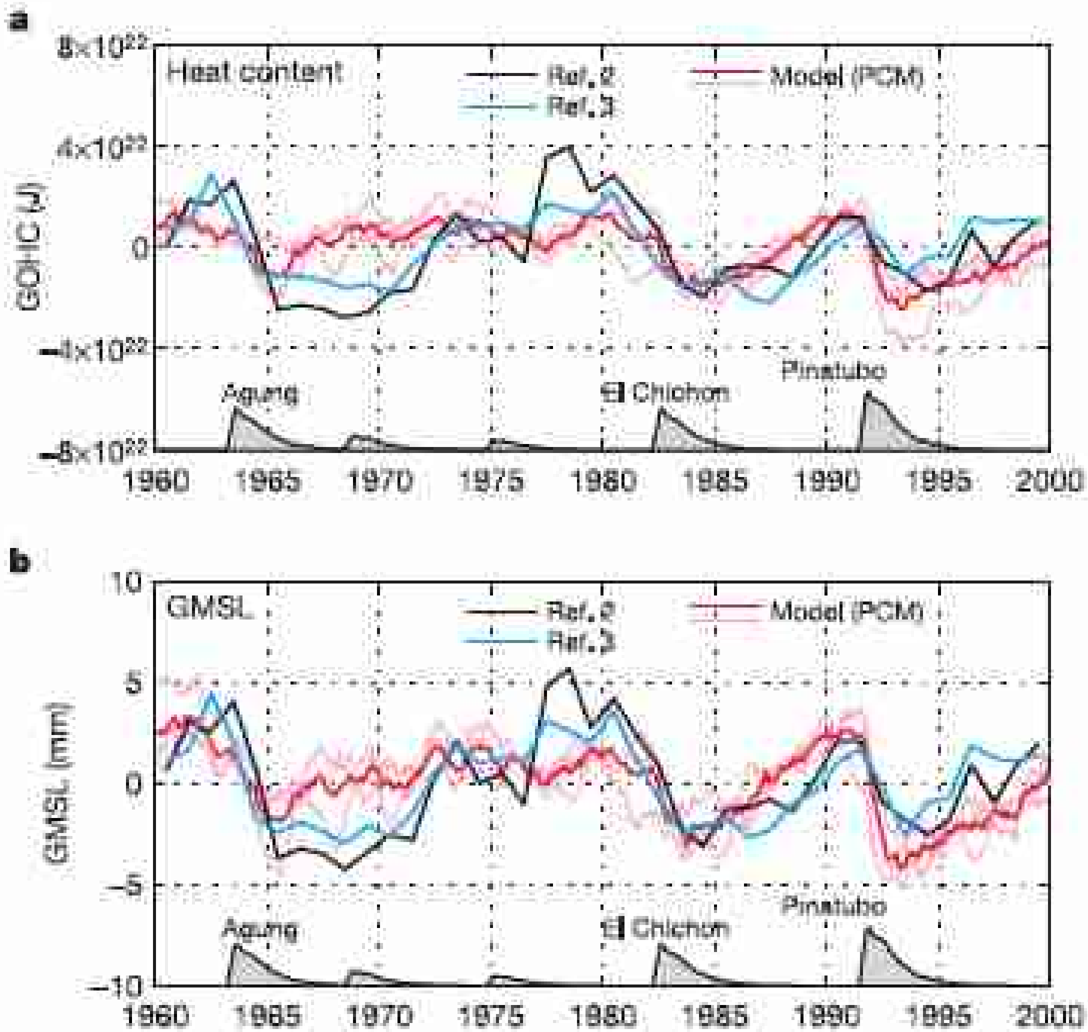


Stratospheric Aerosol and Gas Experiment II (SAGE II)

The 1.02-micrometer stratospheric optical depth observed by SAGE II just after the Pinatubo eruption (June-July 1991) with that observed a year later. The Pinatubo aerosol layer had warmed the local subtropical stratosphere by about 2.5-3 degrees Celsius within three months after the eruption, and a statistically significant global average surface cooling was predicted by the end of 1992 (lower image).

$$\frac{I}{I_0} = e^{-\tau}$$



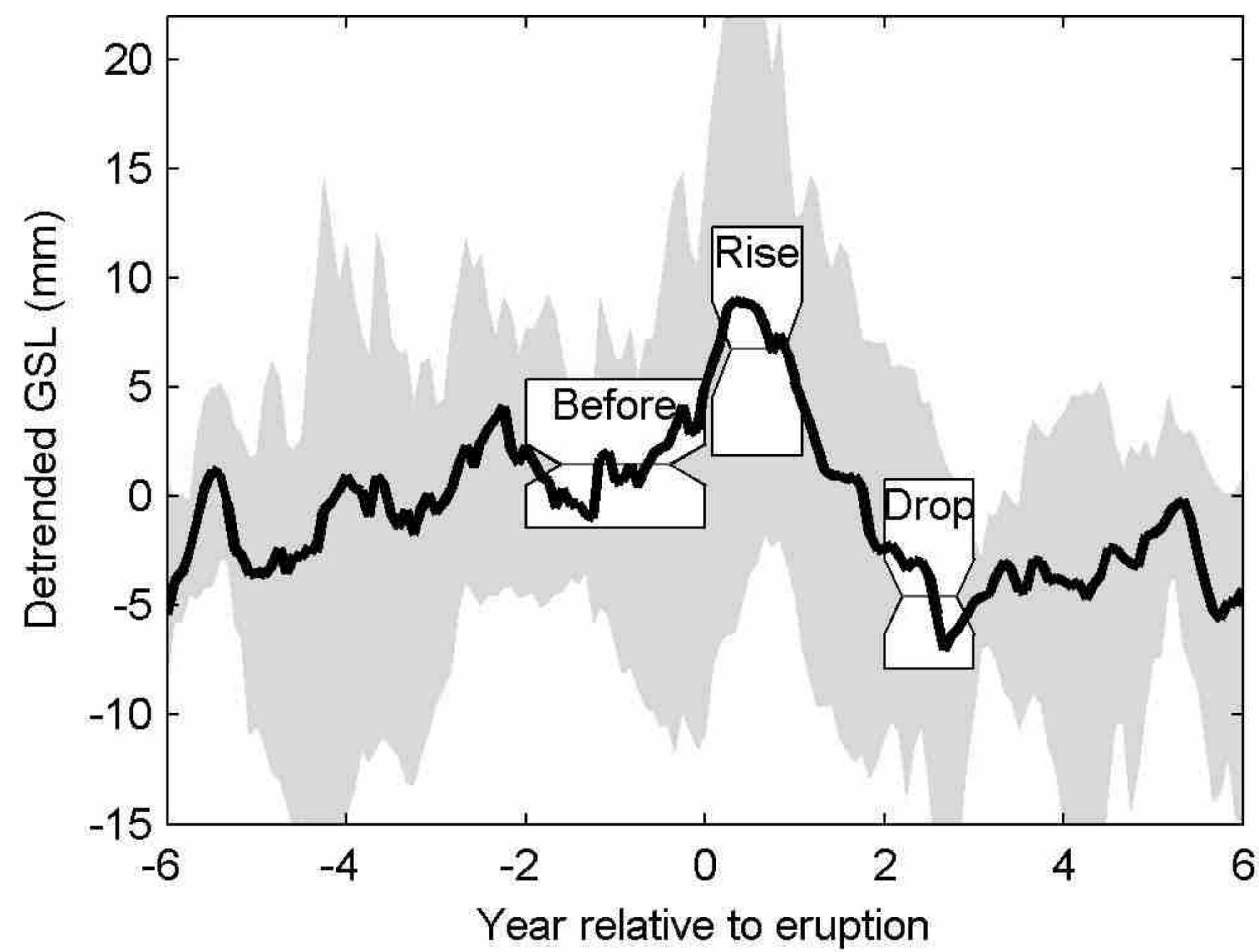


Ocean thermal expansion contributes significantly to sea-level variability and rise[1]. However, observed decadal variability in ocean heat content[2,3] and sea level[4] has not been reproduced well in climate models[5]. Aerosols injected into the stratosphere during volcanic eruptions scatter incoming solar radiation, and cause a rapid cooling of the atmosphere[6,7] and a reduction in rainfall[6,8,9], as well as other changes in the climate system[7]. Here we use observations of ocean heat content[2,3] and a set of climate simulations to show that large volcanic eruptions result in rapid reductions in ocean heat content and global mean sea level. For the Mt Pinatubo eruption, we estimate a reduction in ocean heat content of about 3×10^{22} J and a global sea-level fall of about 5 mm. Over the three years following such an eruption, we estimate a decrease in evaporation of up to 0.1 mm d^{-1}, comparable to observed changes in mean land precipitation[6,8,9]. The recovery of sea level following the Mt Pinatubo eruption in 1991 explains about half of the difference between the long-term rate of sea-level rise[4] of 1.8 mm yr^{-1} (for 1950–2000), and the higher rate estimated for the more recent period where satellite altimeter data are available (1993–2000)[4,10].

Church et al. (2005)

Ref2: Levitus et al. (2005)
Ref3: Ishii et al. (2003)
PCM: Parallel Climate Model (Meehl et al., 2004)

Grinsted, Moore and Jevrejeva (2007)



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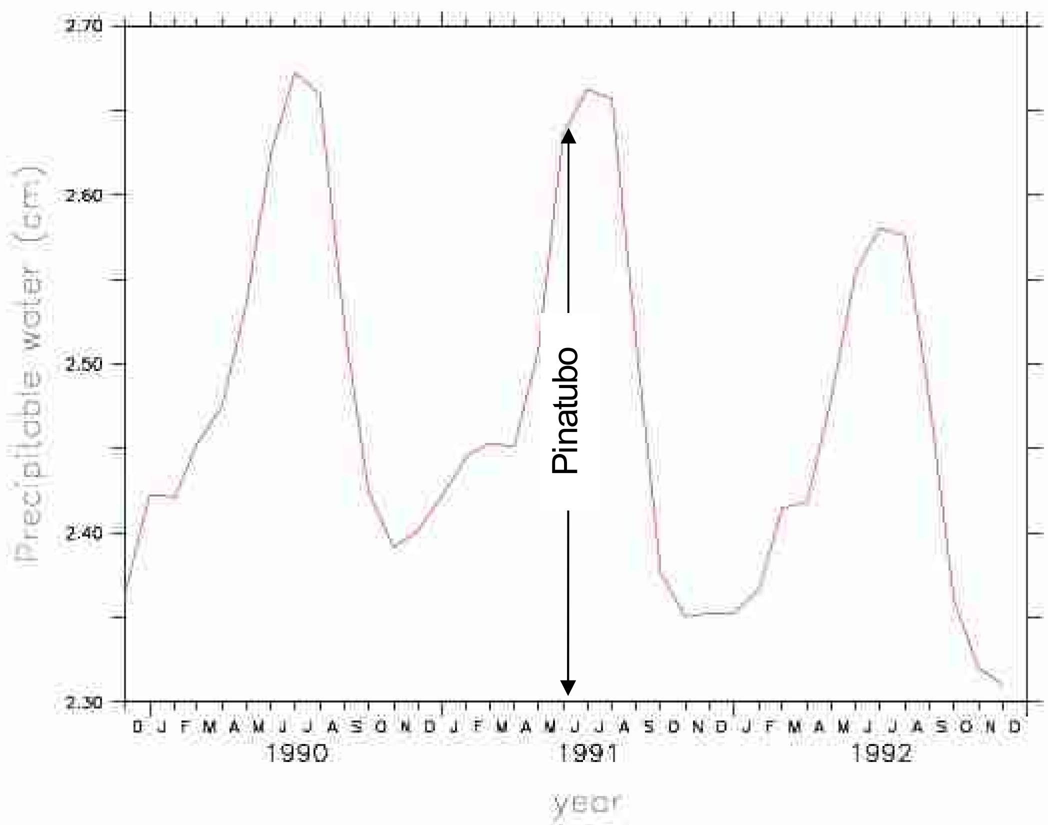
Eruptions: Colima (Feb. 1890), Santa María (Oct. 1902), Agung (March 1963), El Chichón (Apr. 1982), Pinatubo (June 1991). ENSO removed.

Water reservoirs

Atmosphere			-1 mm
Ocean	+7 mm	Land	-6 mm



NCEP/DEO Reanalysis 2

Response to heat, salt & freshwater fluxes in a slab ocean

$$(h\rho)_t = \rho_0 F_s$$

$$(h\rho T)_t = Q_s / c_p\,, \quad (h\rho S)_t = 0$$

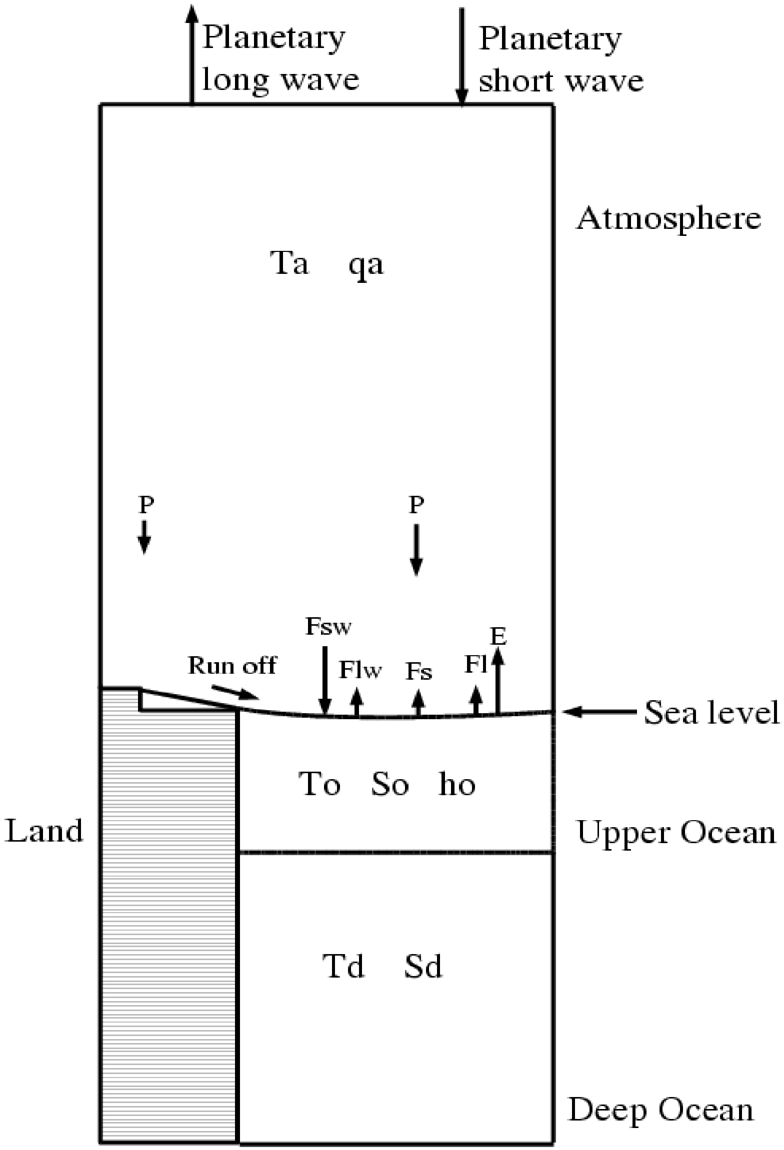
$$\rho = \rho(S, T)$$

$$d\rho = -\alpha\, dT + \gamma\, dS$$

$$h_t = \alpha \frac{Q_s / c_p}{\rho^2} + \frac{\rho_0 F_s}{\rho}\left(1 + \frac{-\alpha T + \gamma S}{\rho}\right)$$

$$\approx \alpha \frac{Q_s / c_p}{\rho^2} + \frac{\rho_0 F_s}{\rho}$$

CONCEPTUAL CLIMATE MODEL



- Atmosphere: Energy-moisture balance

- Ocean: "one-and-a-half reduced gravity" + entrainment/detrainment at the base of the mixed layer

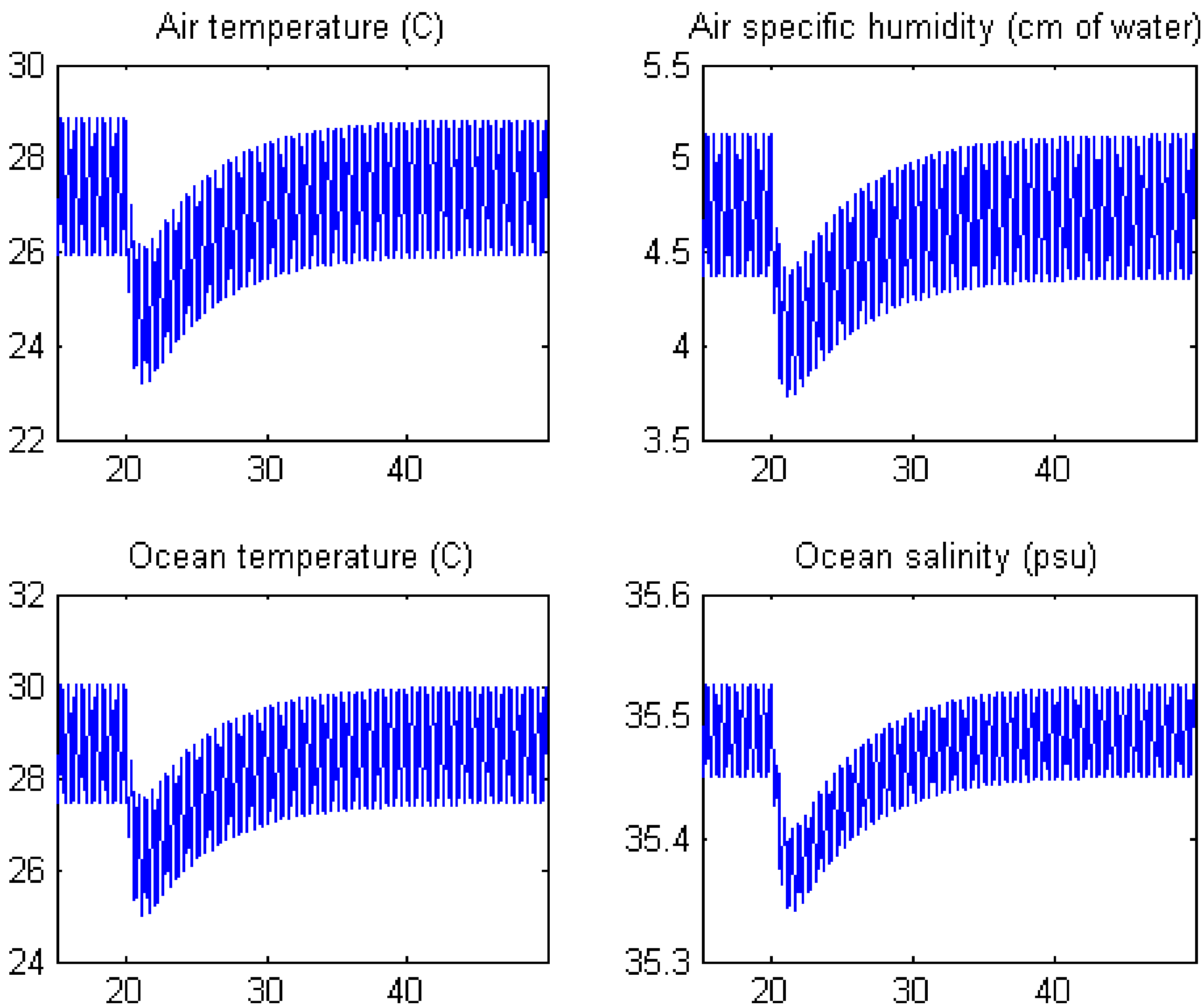
-Land: fresh water reservoir

(The model conserves water heat and salt content and water mass. Lateral transport has been introduced but not yet tested)

Experiments

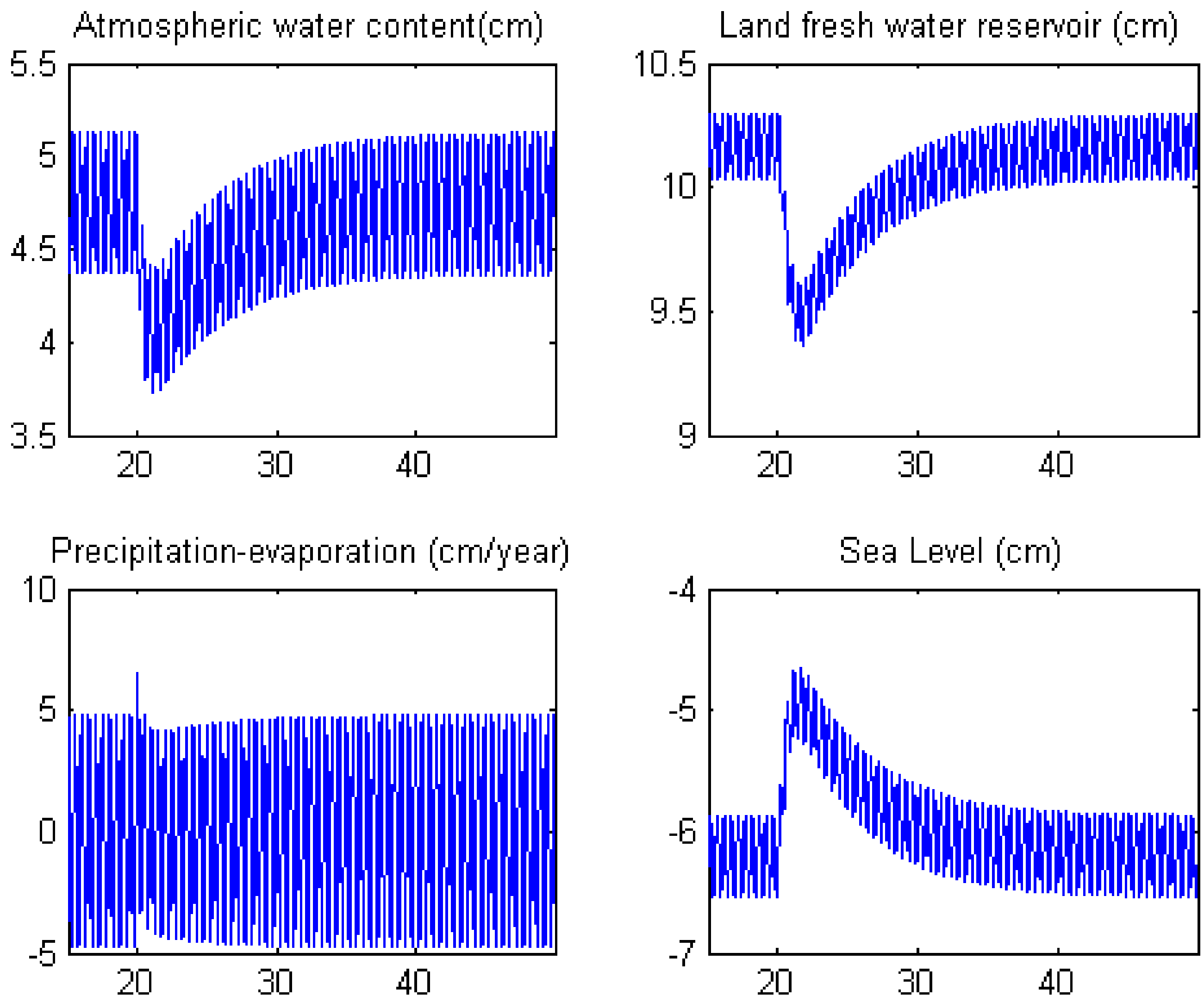
- **Apply a 2.5% reduction to insolation in year 20 of integration. Insolation recovers with an e-folding time scale of 5 years. No entrainment/detrainment in these experiments.**
  - **Low latitude insolation (equator)**
    - **ho = 5 m (Eq-SML)**
    - **ho = 50 m (Eq-DML)**
  - **Mid latitude insolation (30 N)**
    - **ho = 5 m (ML-SML)**
    - **ho = 50 m (ML-DML)**

Equatorial insolation, ho = 5 m



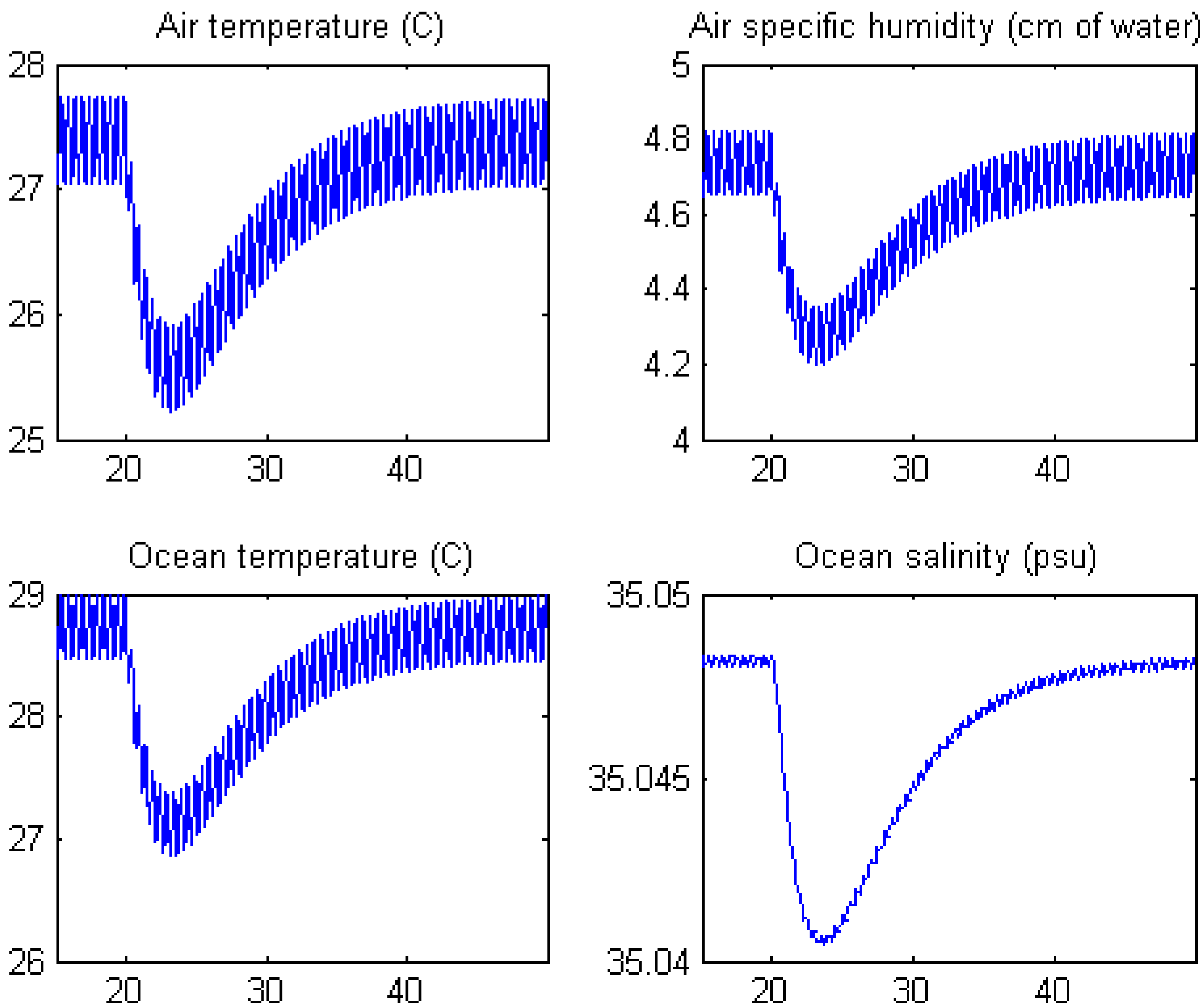
X-axis is time in years

Equatorial insolation, ho = 5 m



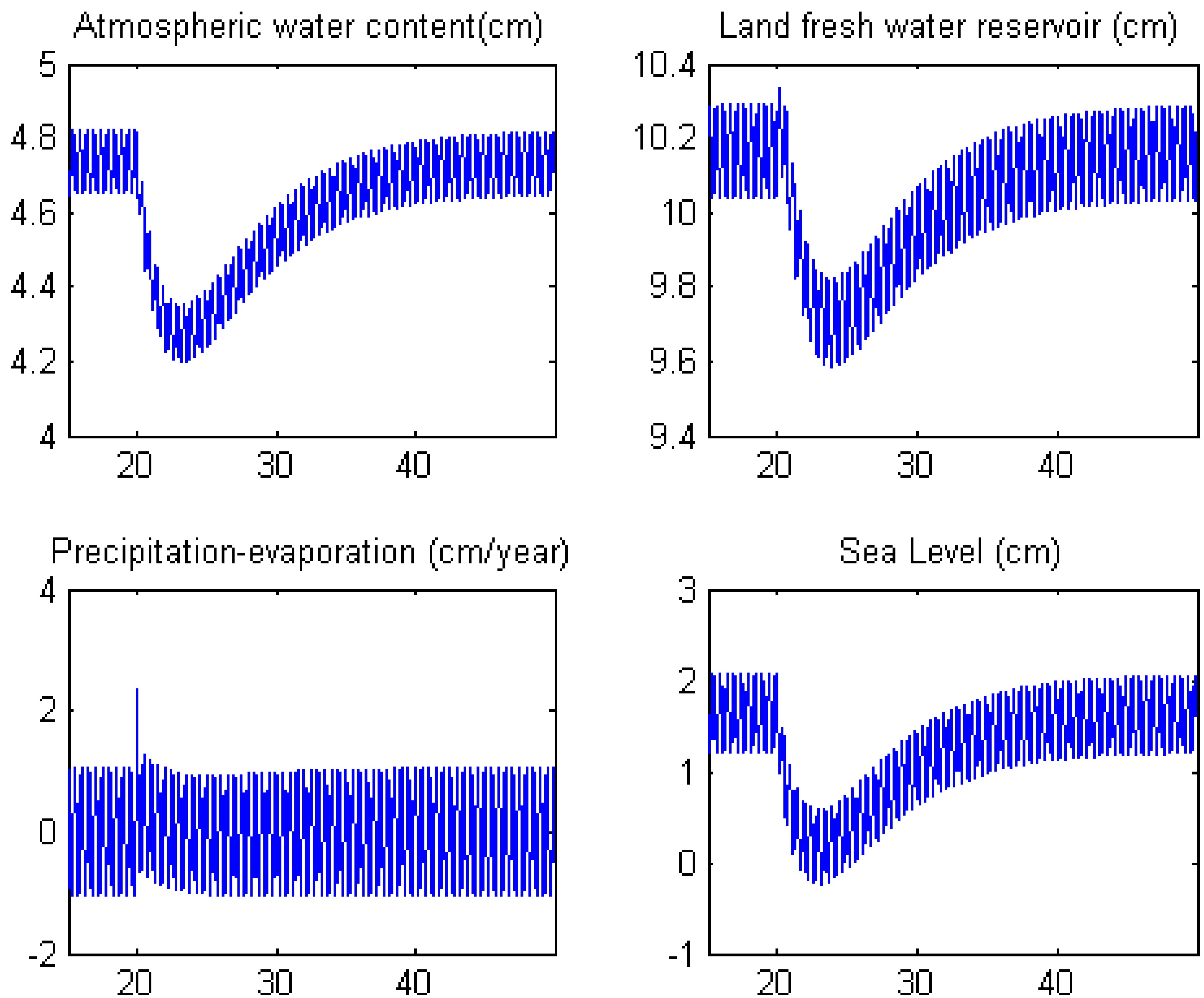
X-axis is time in years

Equatorial insolation, ho = 50 m



X-axis is time in years

Equatorial insolation, ho = 50 m



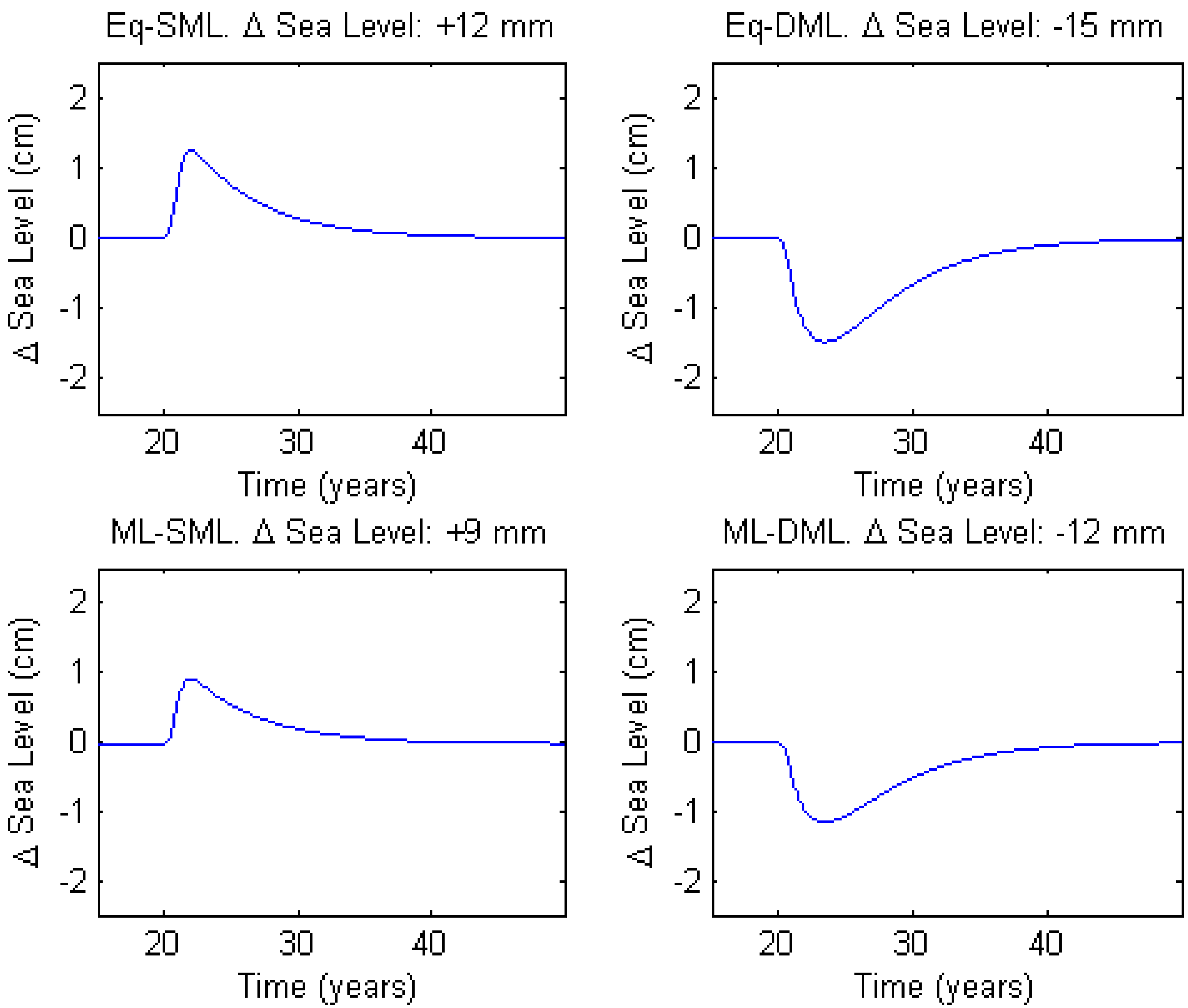
X-axis is time in years

Why does the sign of sea level change depend on mixed-layer depth?

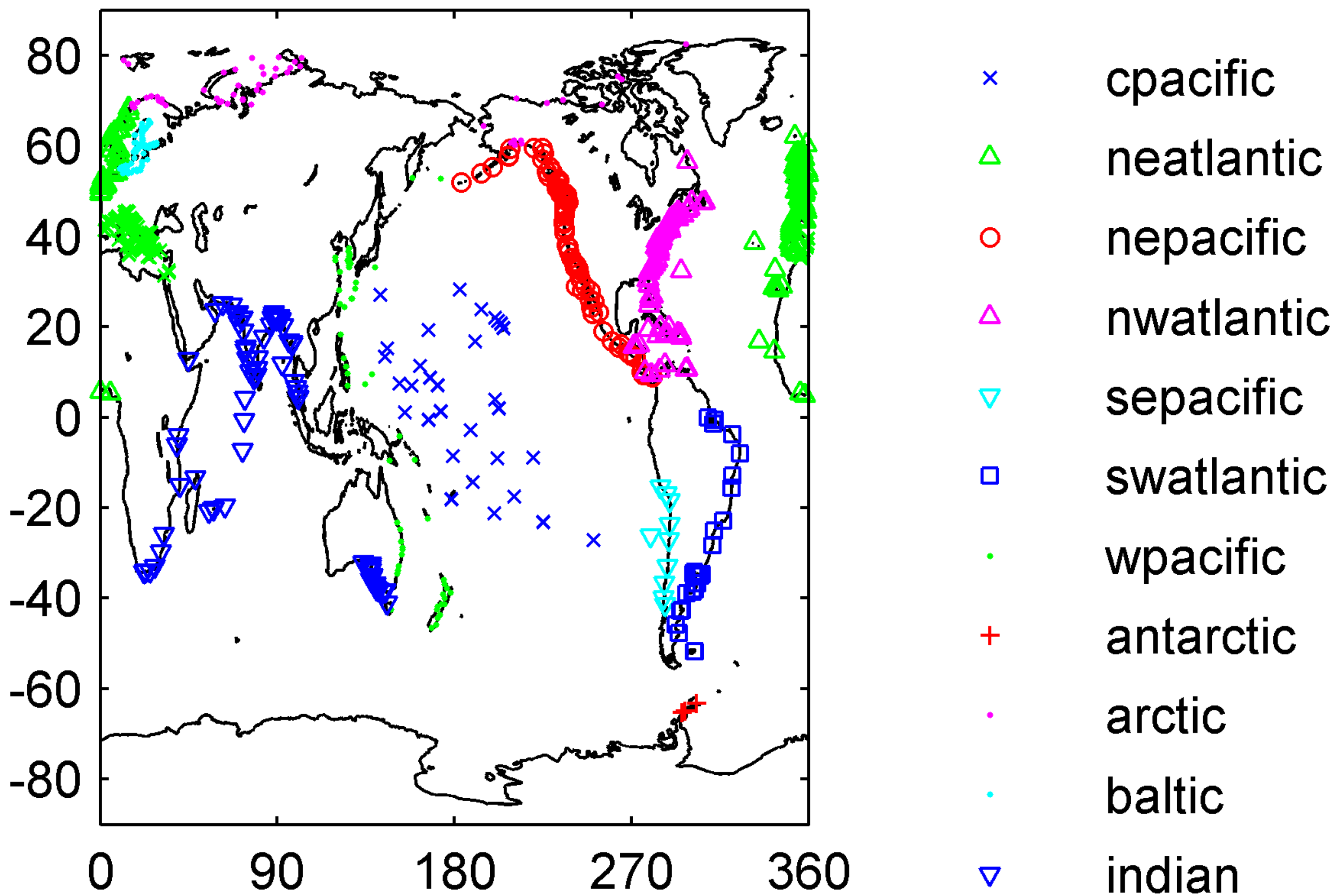
$$h\,\rho = C \Rightarrow \Delta h = \frac{-\Delta\,\rho}{\rho}h$$

For a given density change, sea level change will be larger for deeper mixed layers.

Intercomparison of sea level change (1-year moving average)



X-axis is time in years



Tide gauge stations (from PSMSL)

Volcanic impact on sea level in each of the regions

Region	Before (mm)	Rise (mm)	Drop (mm)
Antarctic	11	-14	2
Arctic	13	27	-8
Baltic	20	47	-23
CPacific	3	-9	-17
Indian	2	0	-7
Mediterr	2	-10	-9
NEAtlantic	1	12	-10
NEPacific	-5	41	3
NWAtlantic	-2	14	-12
SEAtlantic	0	-2	3
SEPacific	-9	41	9
SWAtlantic	3	-4	33
WPacific	-3	-9	0

What should come next?

- Create a zonally averaged version of the model with latitude bands connected through eddy diffusion of heat and moisture in the atmosphere and heat, salt and volume transport in the ocean. This is in progress, but problems with the parameterisation of entrainment...
- Use OGCM to run similar experiments?