Understanding sea-level change and variability during the last decades (1960-2009): from global to regional scales

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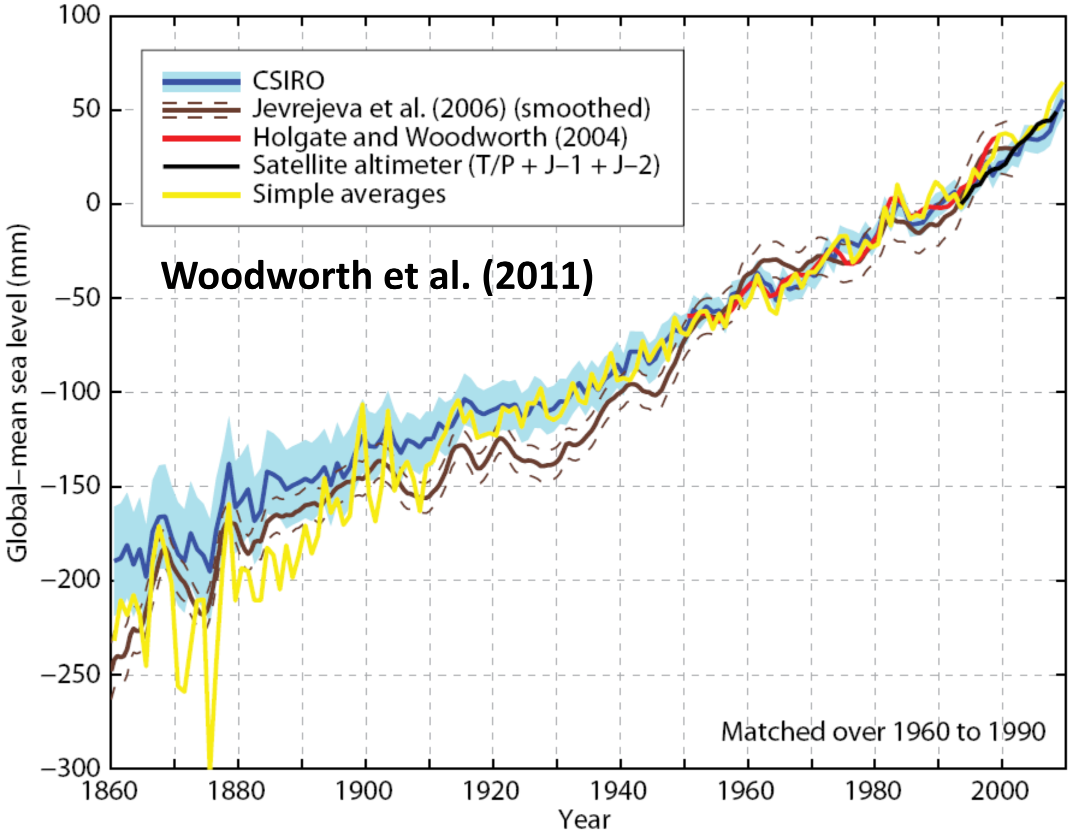
ANTARCTIC CLIMATE & ECOSYSTEMS CRC

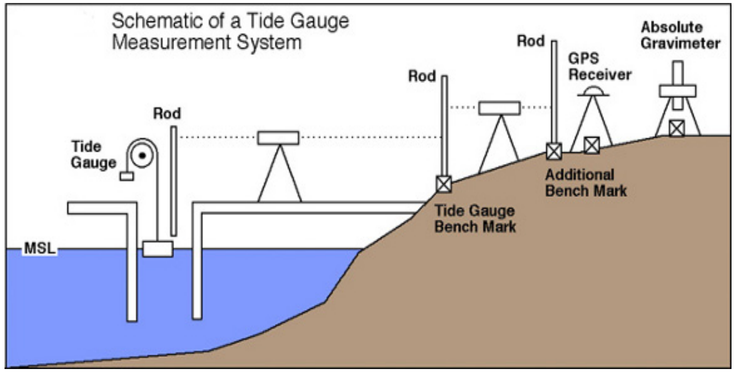
www.acecrc.org.au

Global mean sea-level rise (1860-2009)

Yearly sea level anomalies (mm)



Tide gauges (PMSL)



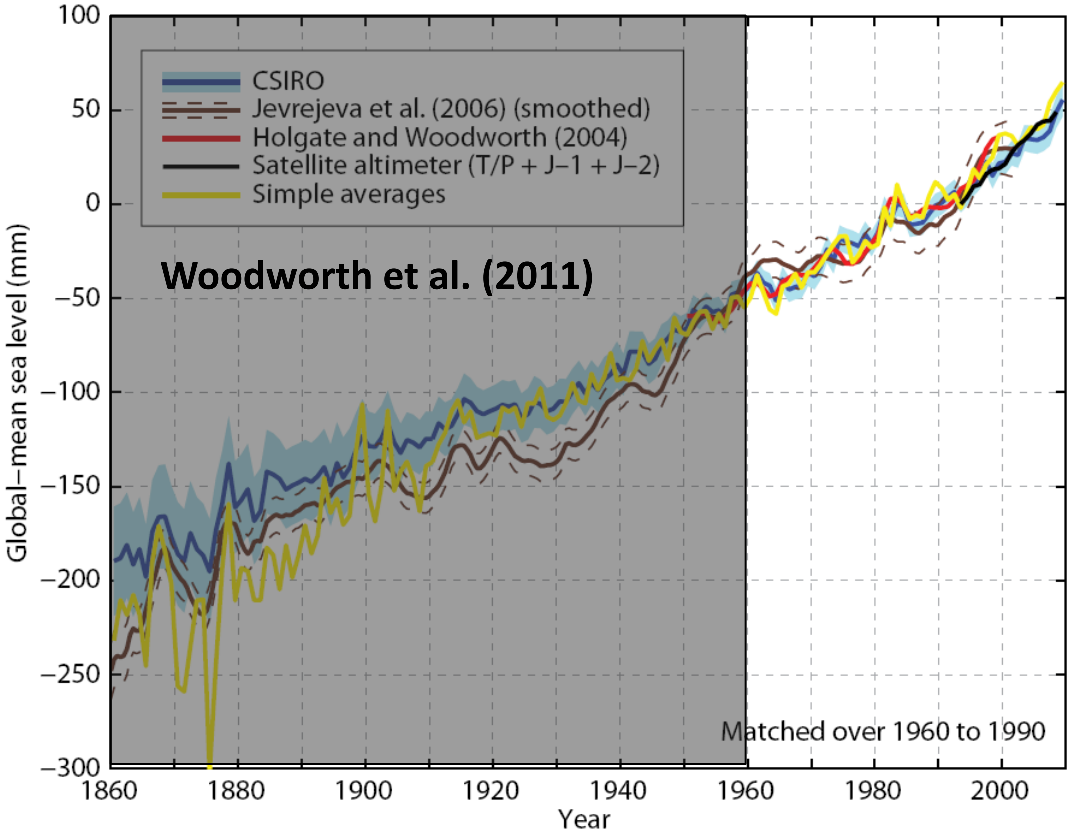
http://sealevel.colorado.edu/content/tide-gauge-sea-level

Multi-decadal (>10 yrs), decadal (~10 yrs) and interannual variability (<10 yrs) superimposed on a **multi-century rising trend** (**1880-2009**) of about **2.1 mm/yr (Church and White, 2011)**.

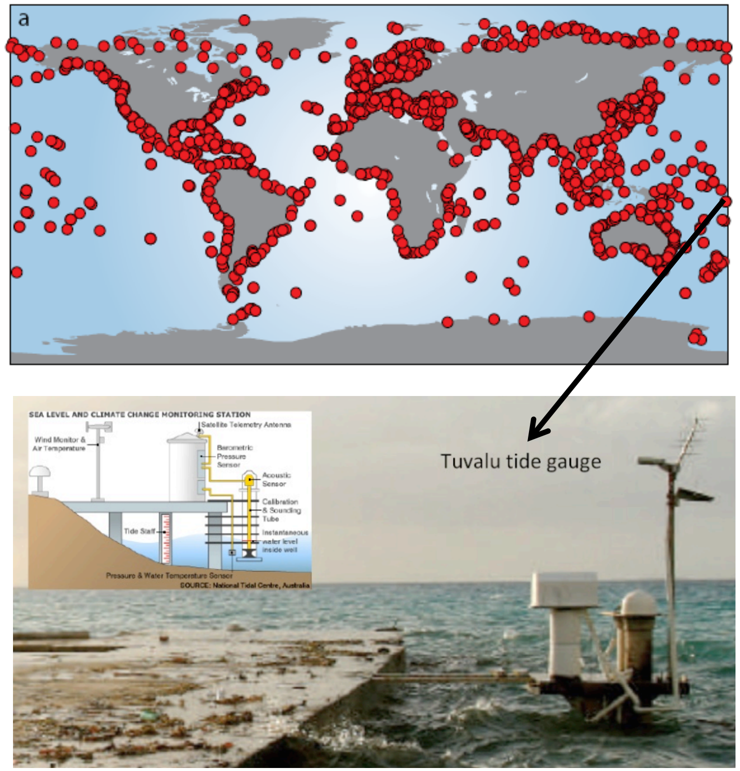
Larger uncertainties (less observations) in the earlier part of the record.

Global mean sea-level rise (1960-2009)

Yearly sea level anomalies (mm)



Tide gauges (PMSL)



Larger number of tide gauges for most recent years, particularly in the Southern Hemisphere and at low-lying island locations (e.g., Tuvalu).

The linear trend for multi-decadal sea-level rise (**1960-2009**) is about **1.9 mm/yr (Church and White, 2011)**.

Global mean sea-level rise (1993-2009)

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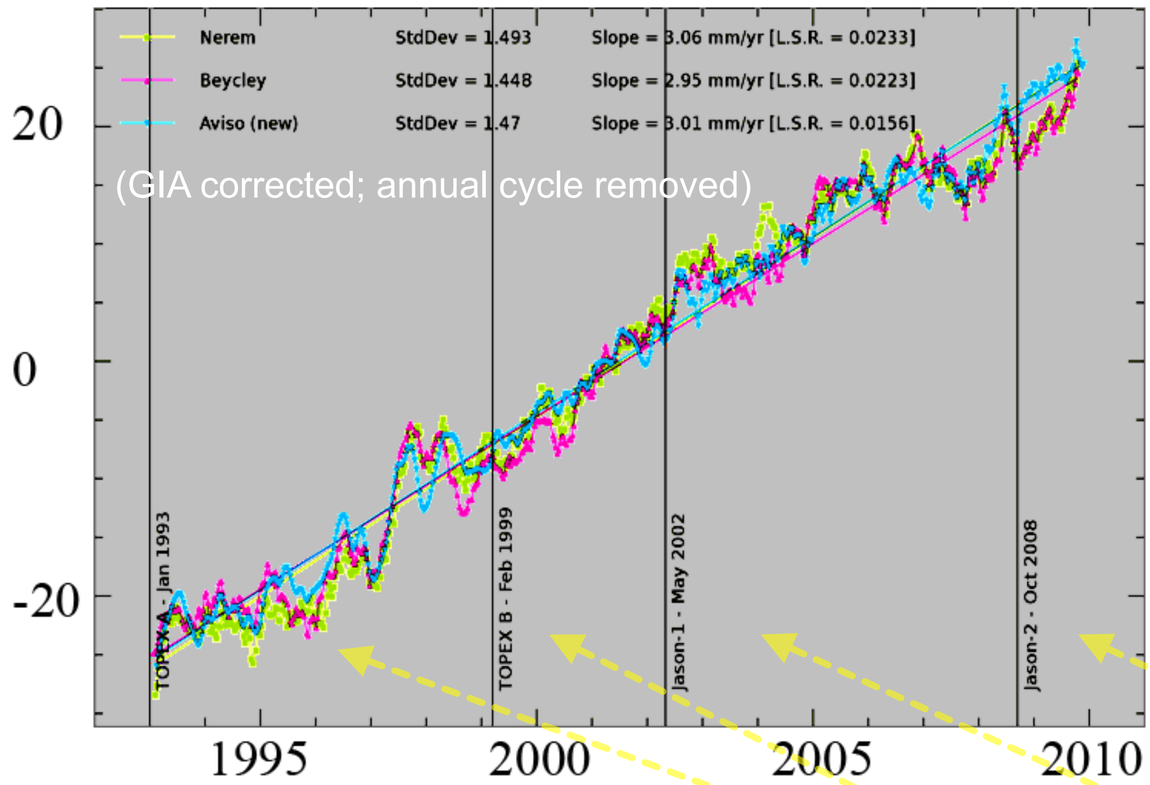
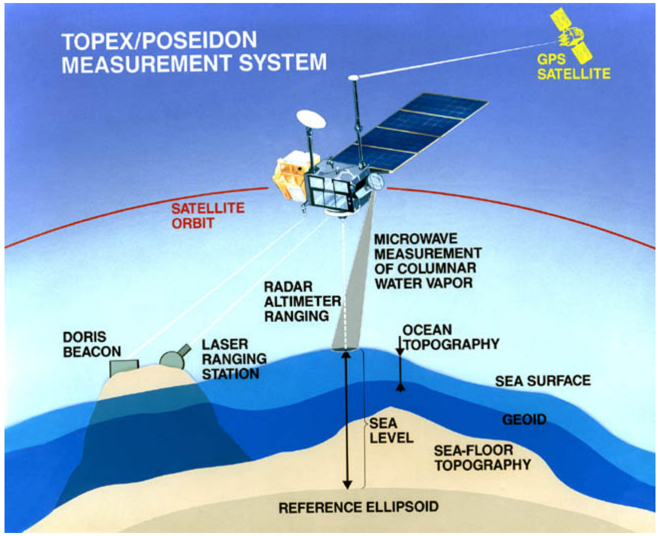
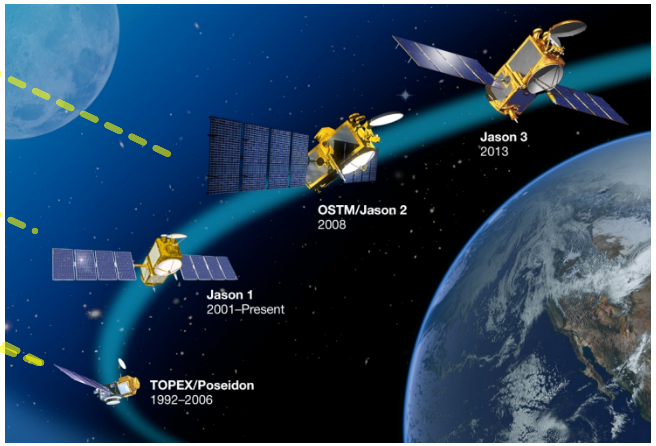
Monthly sea level anomalies (mm)



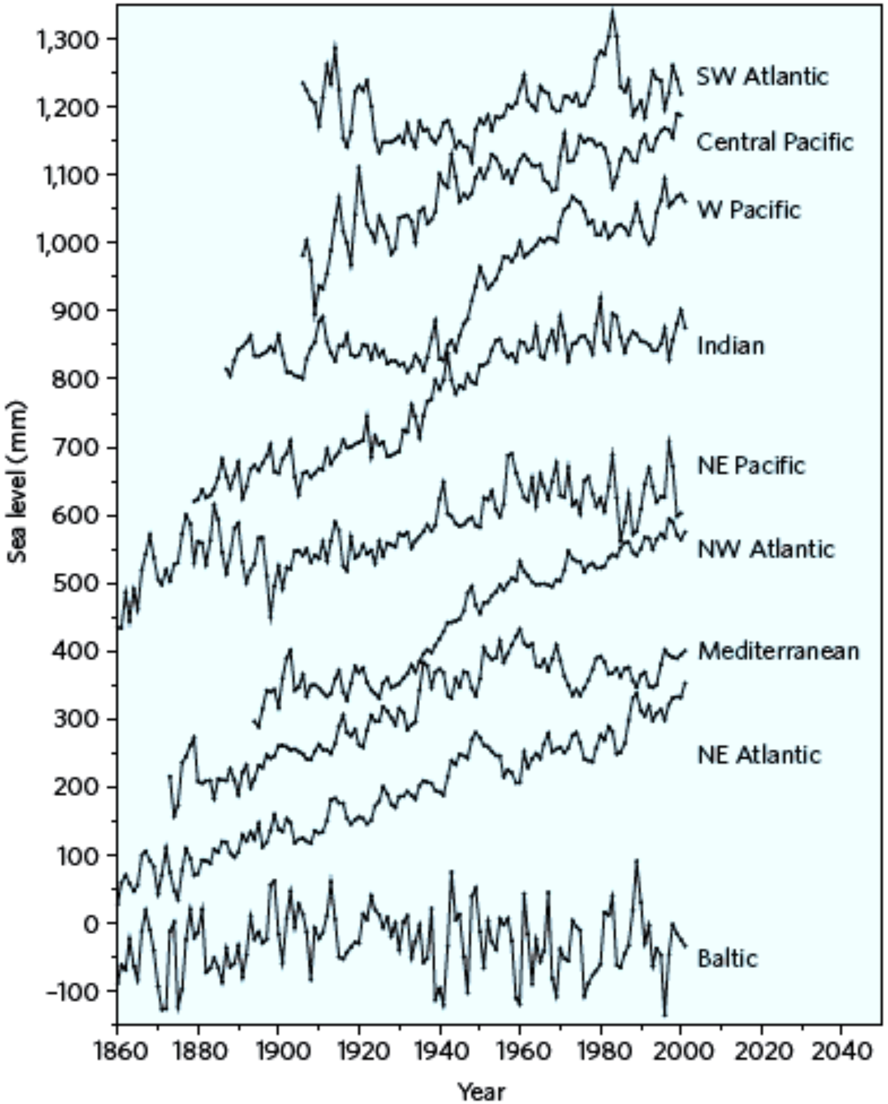
Satellite Altimeter





Interannual to decadal variability superimposed on a 17-year linear trend (**1993-2009**) of ~**3.2 mm/yr** **(Church and White, 2011; Leuliette and Willis, 2011)**.

However ... Global mean is not the whole story...



Jevrejeva et al. (2006)

We do not expect
sea level to (vary and) change
the same way everywhere!

The global mean represents an averaged response of distinct variability and change from various locations.

Regional sea level variations matter to society !!

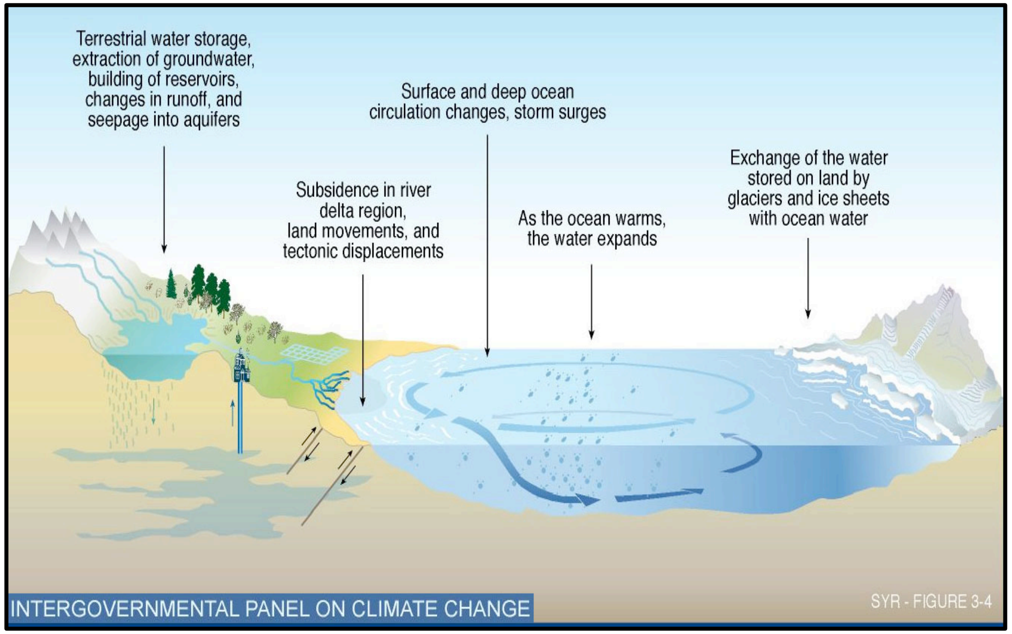
Within 1 m above current sea levels:

- 150 million people living
- 1 trillion dollars worth of assets

Milne et al. (2008); Nicholls (2010)

What causes regional sea level variability and change?

A **complex interplay** of various dynamical **components of the climate system** (e.g., ocean, atmosphere, cryosphere, Solid Earth), operating on a **wide range of spatial and temporal scales**.



It can be explained by …

- **"Container"**
  (e.g., changes in the shape of the ocean basins via deformation of the solid Earth along with gravitational and rotational effects)

- **"Liquid volume"**
  (e.g., changes in volume of seawater via mass exchange with atmosphere, cryosphere, land, and/or via temperature and salinity (density) transformations)

A major and truly interdisciplinary challenge:

To better understand how each dynamical process has contributed to observed sea level changes and how it will contribute in the future.

Need to reduce current uncertainties to improve impact assessments, and so help to optimize the type and timing of policy decision-making.

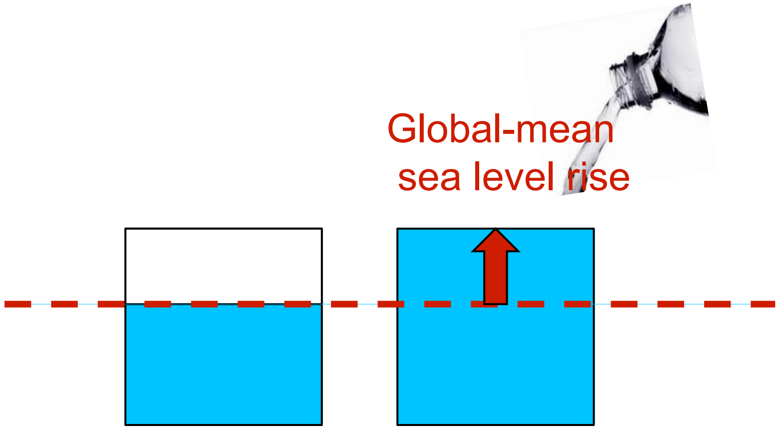
Meehl al. (2007); Lowe et al. (2011)

Changes in ocean volume – mass contribution

Net change in volume.

Adding (or removing) water into (from) the global ocean.

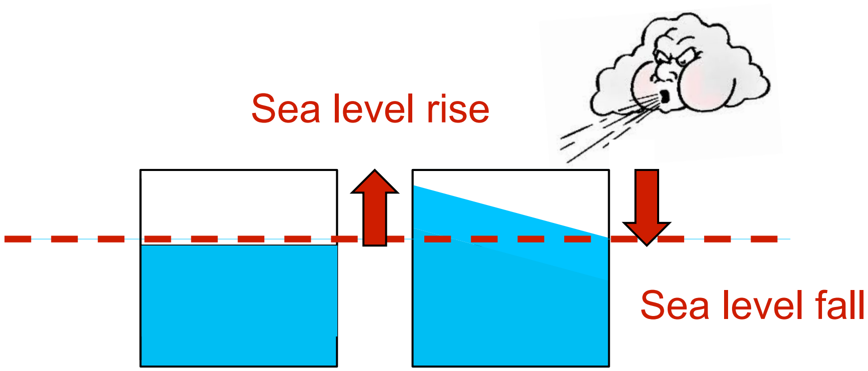
(e.g., precipitation/evaporation; melting of land-based ice)



No net change in volume.

Only regional mass redistribution within the oceans.

(e.g. , wind-driven mass redistribution)



Changes in ocean volume – steric contribution

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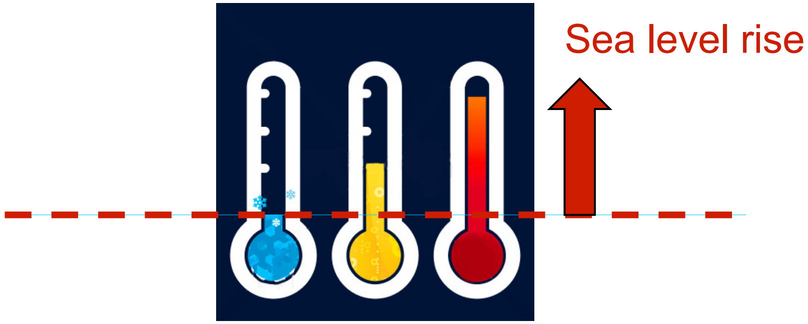
Net change in volume.

Increasing (or decreasing) the averaged density of water masses.

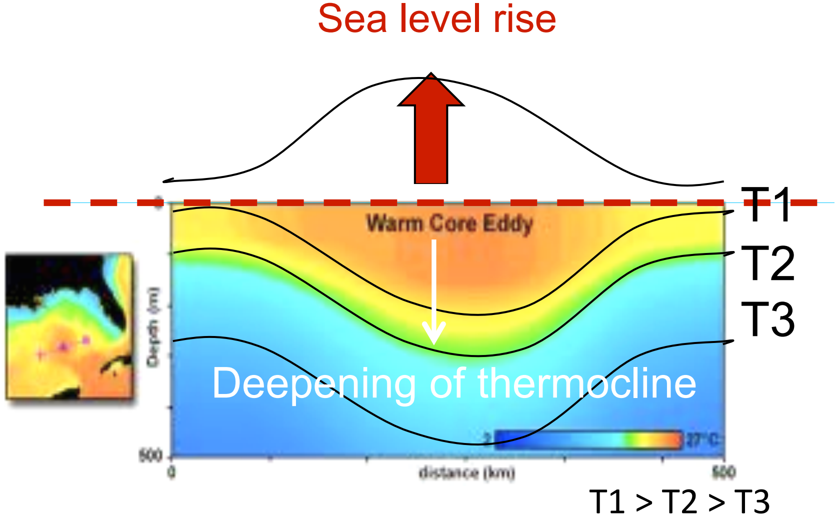
(e.g., thermal expansion due to heat uptake)

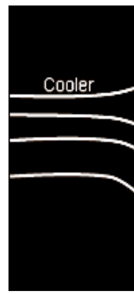


No net change in density.

Only regional density redistribution within the oceans.

(e.g., ocean circulation processes)

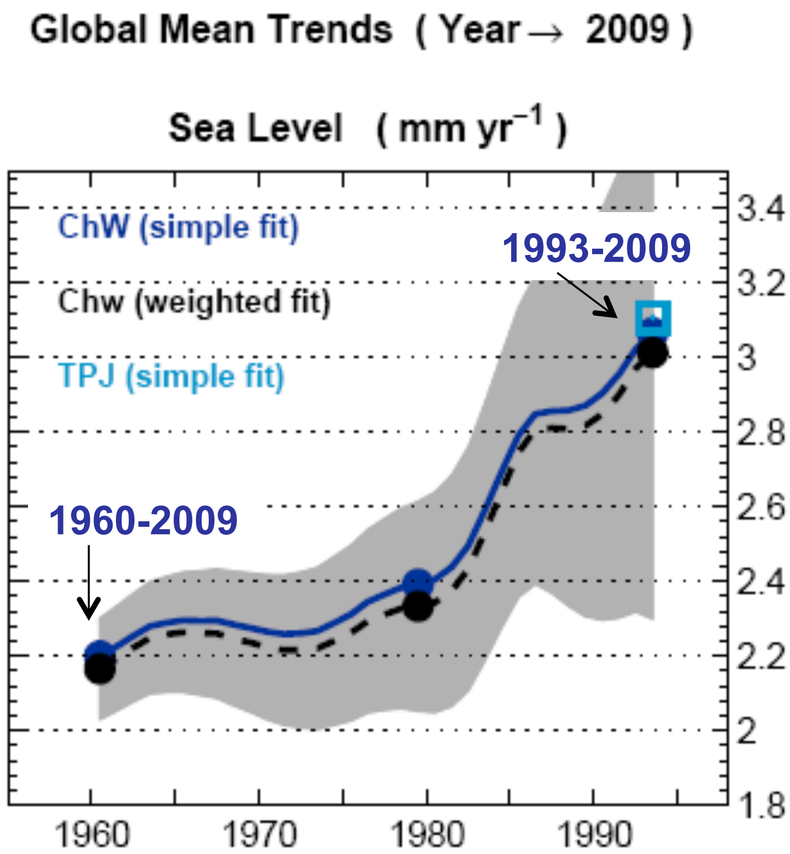


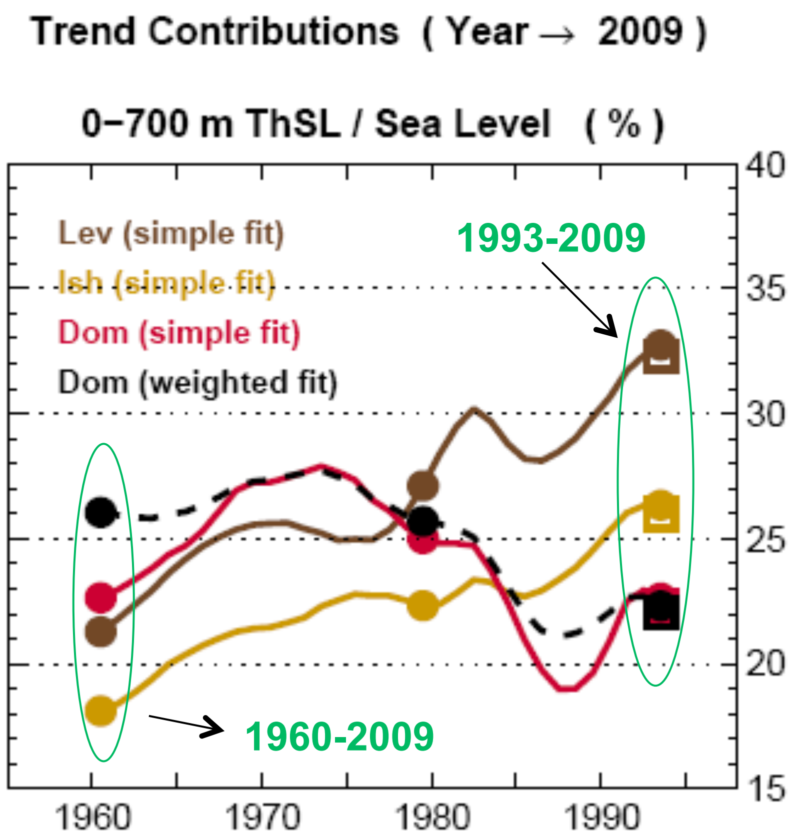


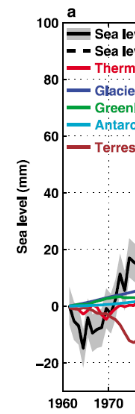
Density is a function of **temperature**, **salinity** and **pressure** (depth).

Steric = TEMP + SAL; **Thermosteric** = only TEMP; **Halosteric** = only SAL.

Thermosteric contribution to global mean sea level rise
(for various trend periods)







On average, **upper-ocean thermosteric sea level contribution** explains about **20 to 30%** of **global mean sea level rise**, from 1960, 1961, … , 1992, 1993 to 2009. **(Domingues et al., in prep.)**.

Levitus et al. (2009)

Ishii and Kimoto (2009)

Domingues et al. (- - -)

Thermosteric contribution to regional sea level trends

Sea level (mm/yr)

1993-2009

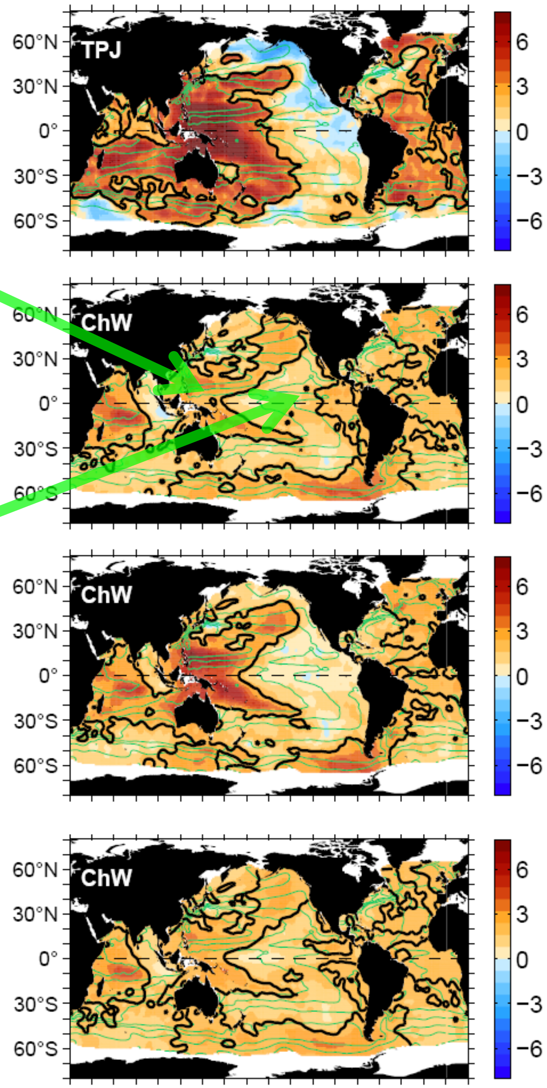
Above global mean

1980-2009

Below global mean

1970-2009

1960-2009



Sea level trends for shorter periods (e.g., 1993-2009) **differ** from longer-term periods (e.g., 1960-2009).

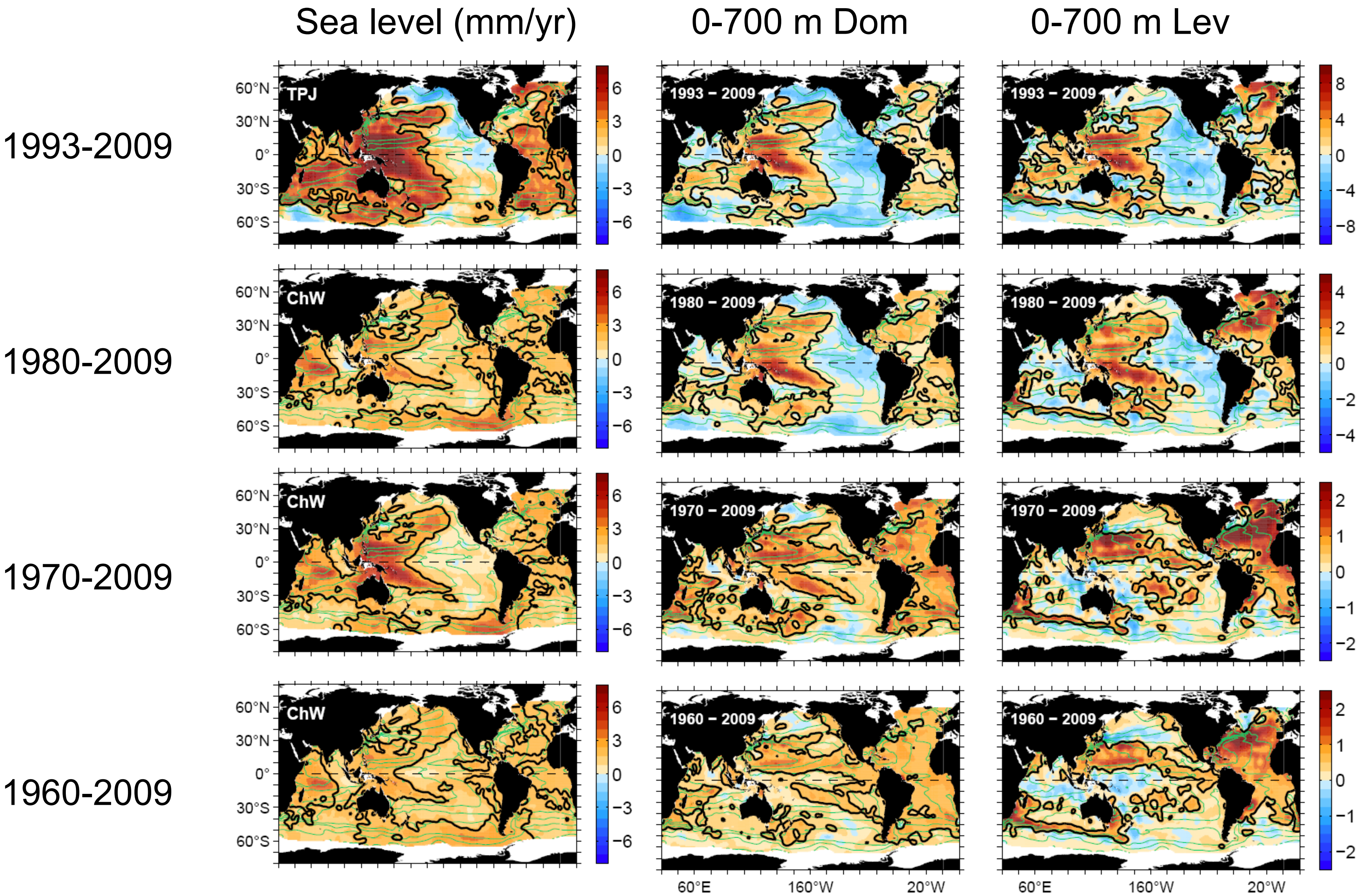
This is be expected because of natural climate variability ranging from interannual, decadal to multi-decadal timescales.
(e.g., **modes of variability**: ENSO, PDO, IOD, NAO, SAM, AMO, etc)

Natural climate variability can mask anthropogenic sea level changes.

Global mean = black bold line

Domingues et al. (in prep.)

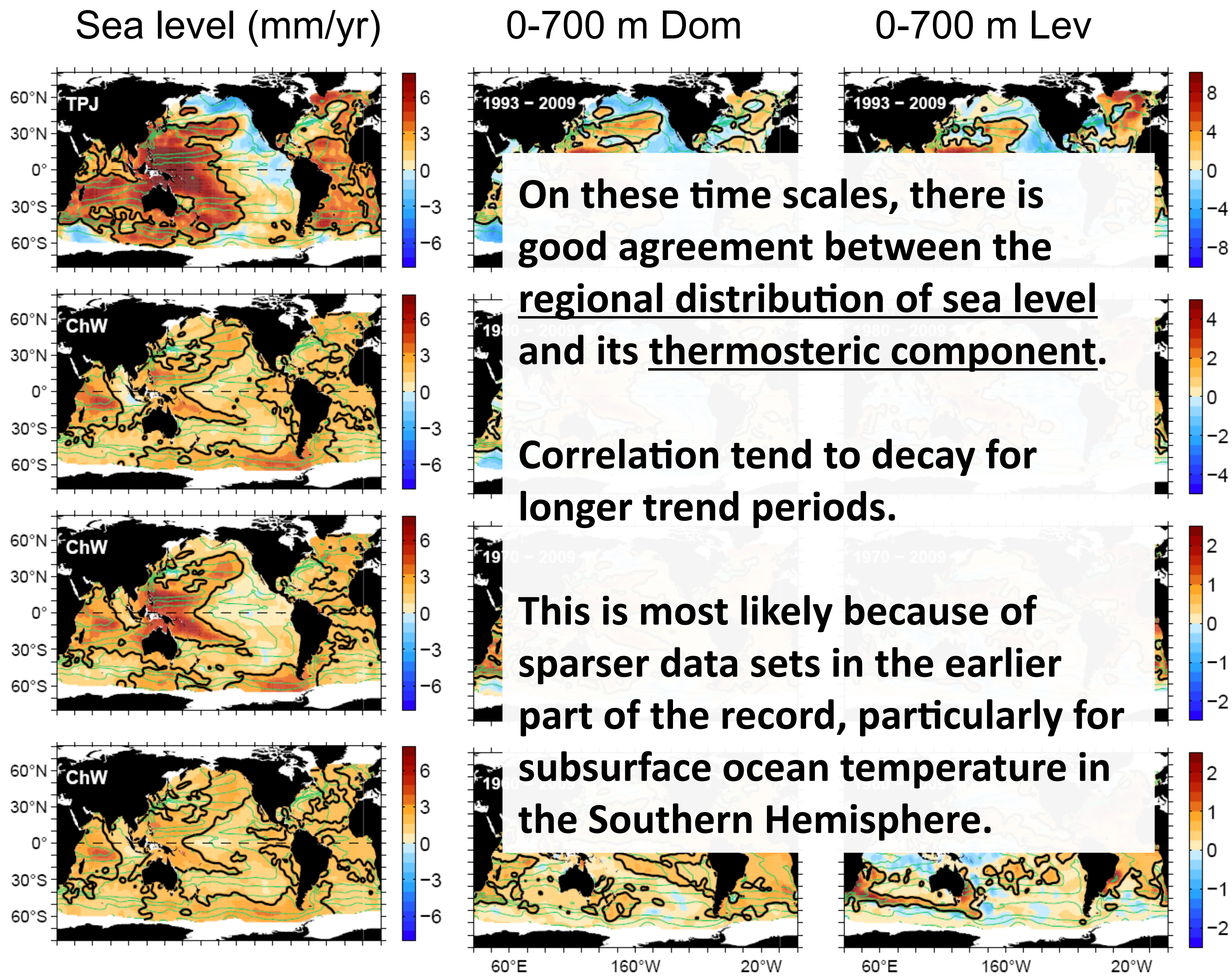
Thermosteric contribution to regional sea level trends



Global mean = black bold line

Domingues et al. (in prep.)

Thermosteric contribution to regional sea level trends



On these time scales, there is good agreement between the <u>regional distribution of sea level</u> and its <u>thermosteric component</u>.

Correlation tend to decay for longer trend periods.

This is most likely because of sparser data sets in the earlier part of the record, particularly for subsurface ocean temperature in the Southern Hemisphere.

Global mean = black bold line

Domingues et al. (in prep.)

Thermosteric contribution to regional sea level trends

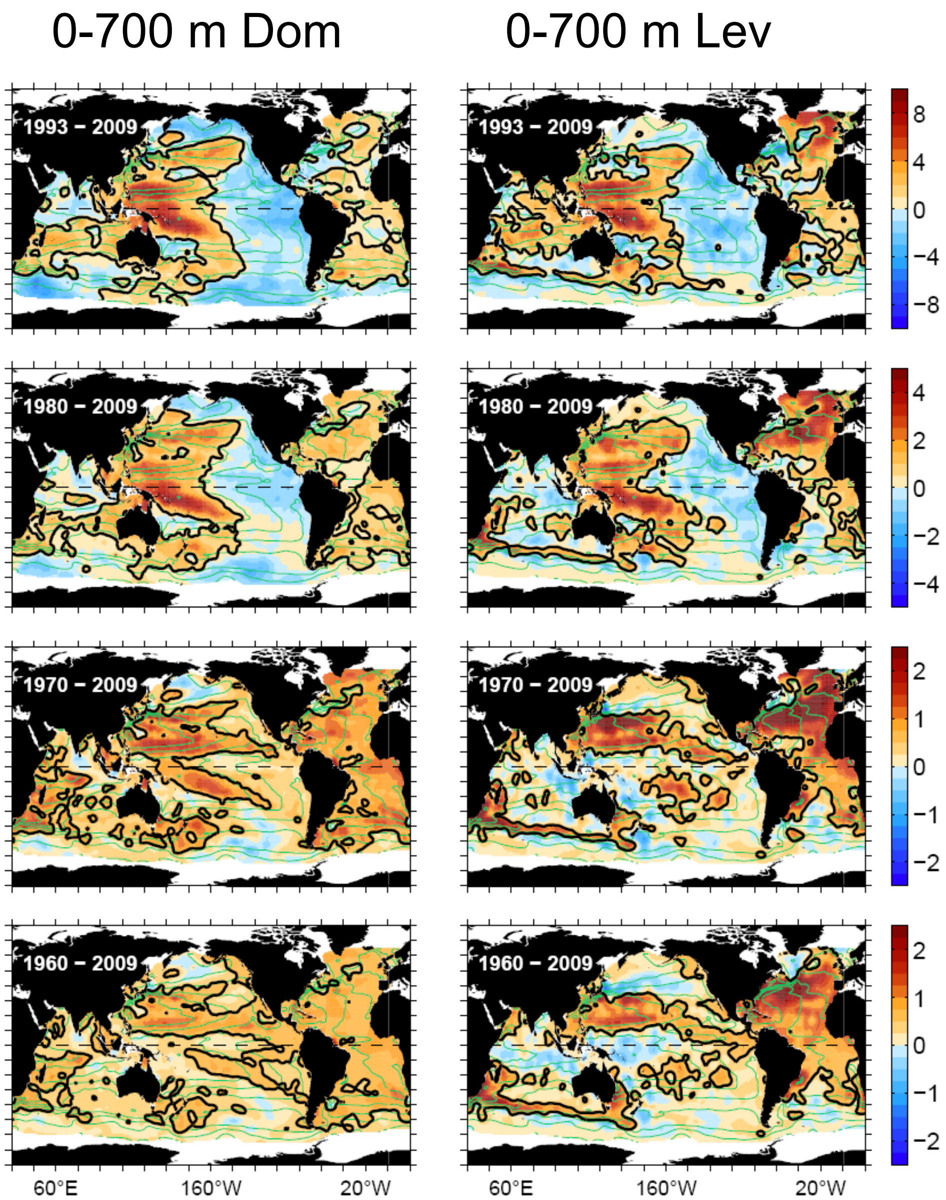
On these time scales, there is some agreement between the regional distribution of the two thermosteric estimates shown.

Correlation decays for longer trend periods.

This is <u>largely due to the individual approaches used to infill data gaps</u> (not shown);

to a certain degree to different instrumental bias corrections (XBTs) (not shown);

and possibly due to influence of density compensation (halosteric contribution) in the Domingues et al. estimates for the North Atlantic.



Global mean = black bold line

Domingues et al. (in prep.)

Mechanisms governing observed regional spatial trend patterns?

A larger number of observational/modelling studies indicate that observed **regional changes** are **steric** in nature, and mostly associated with **redistribution of upper-ocean temperature and salinity**.

Many of the regional changes can be explained in terms of redistribution by **(coupled atmospheric-oceanic) modes of variability**.

Emerging studies suggest (and confirm results of some earlier studies) that **changes in surface wind stress are a major forcing mechanism**. These shorter and longer-term wind effects drive direct/indirect, local/remote **adjustments in ocean circulation**, which then directly manifest **in regional sea level patterns**.

(e.g., Han et al., 2010; Timmerman et al., 2010; Merrifield, 2011; Schwarzkopf and Boning, 2011)

Related WCRP conference talks in this session:

- *Beinot Meyssignac et al.*
- *Weiqing Han*
- *Shayne McGregor and Axel Timmermann*
- *Chris Piecuch and Rui Ponte*

Related WCRP poster session: *Sea-level variability and change*

- *Bouttes and Gregory*
- *Yasuda and Sueyoshi*
- *Suzuki and Ishii*
- *Till Kuhlbrodt*

Mechanisms governing future regional changes (model projections)?

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A larger number of recent modelling studies, including idealised experiments, making reasonable progress in teasing apart the **individual contributions** from **physical mechanisms causing changes in ocean dynamics** (e.g., wind, heat and freshwater fluxes), and therefore their impact on regional sea level patterns.

(e.g., Banks et al., 2002; Suzuki et al., 2005; Lowe and Gregory, 2006; Landerer et al., 2007; Yin et al., 2010; Suzuki and Ishii, 2011)

Related WCRP conference talks in this session:

- *Till Kuhlbrodt*
- *Shayne McGregor and Axel Timmermann*

Related WCRP poster session:
Sea-level variability and change

- *Yin et al.*
- *Yasuda and Sueyoshi*
- *Suzuki and Ishii*
- *Till Kuhlbrodt*

Challenges & Priorities

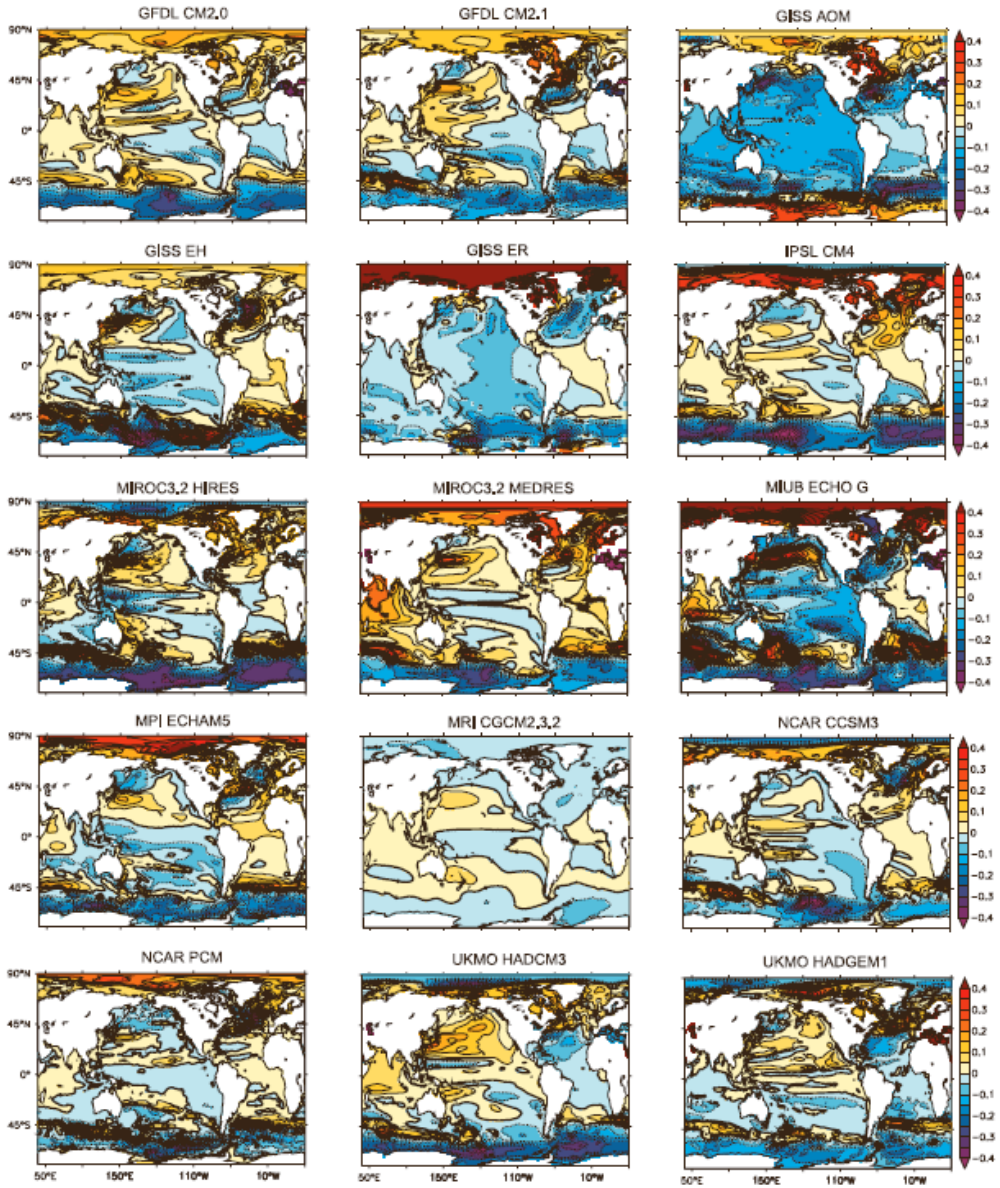
Key priority:

To narrow down spread in 21st century regional sea level projections.

Progress understanding:

- Model formulation
  (e.g., mixing parameterizations)
- Simulated internal variability
- Simulated coupled-modes of variability
- Different forcings

Do we need to establish a coordinated effort to "fast track" and systematically investigate the causes of difference in models' responses?



Yin et al. (2010)

Thank You

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COOPERATIVE RESEARCH CENTRE

Acknowledgements: Helpful comments from Nathan Bindoff, John Church .

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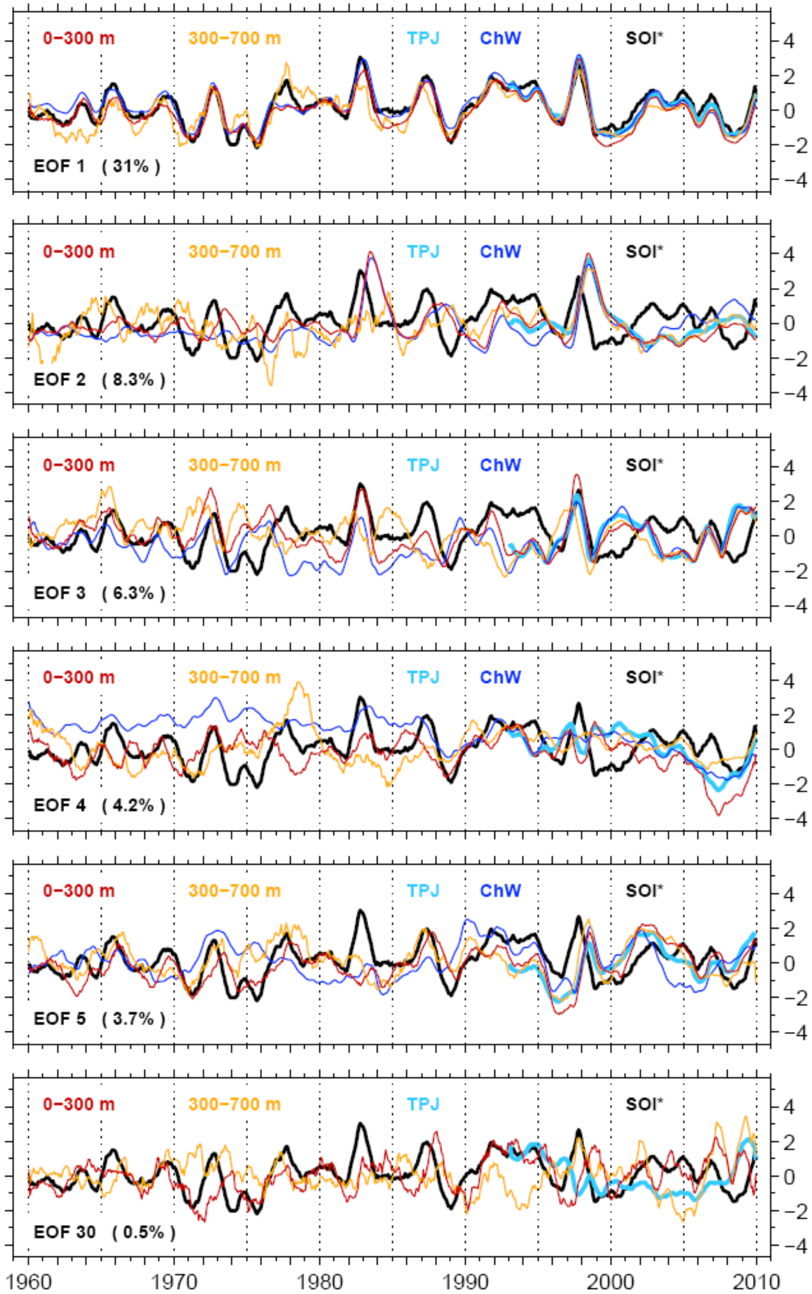
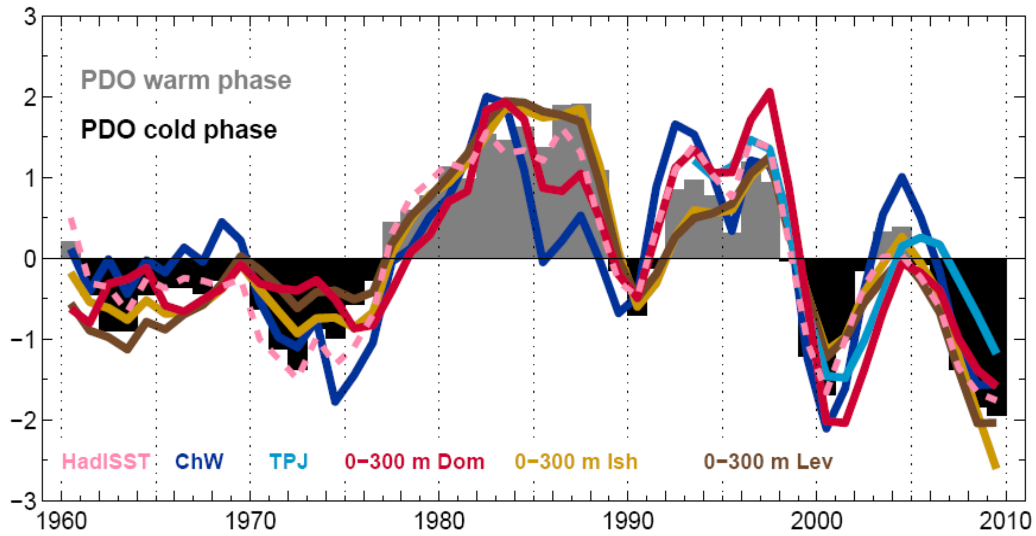
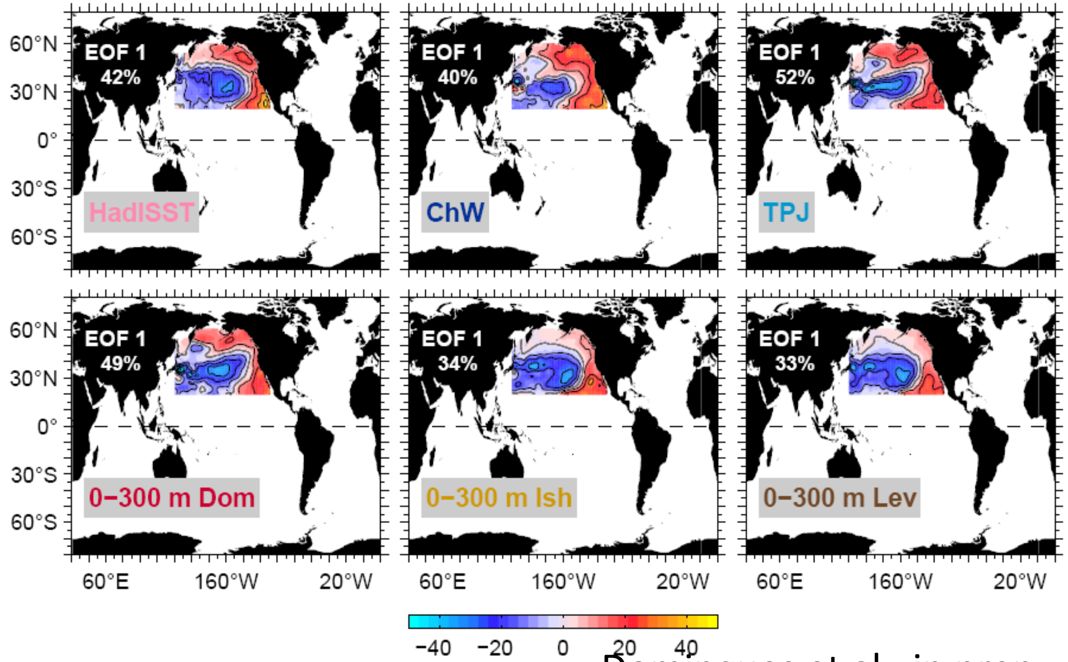
ENSO/PDO ⇔ Sea level, thermosteric sea level

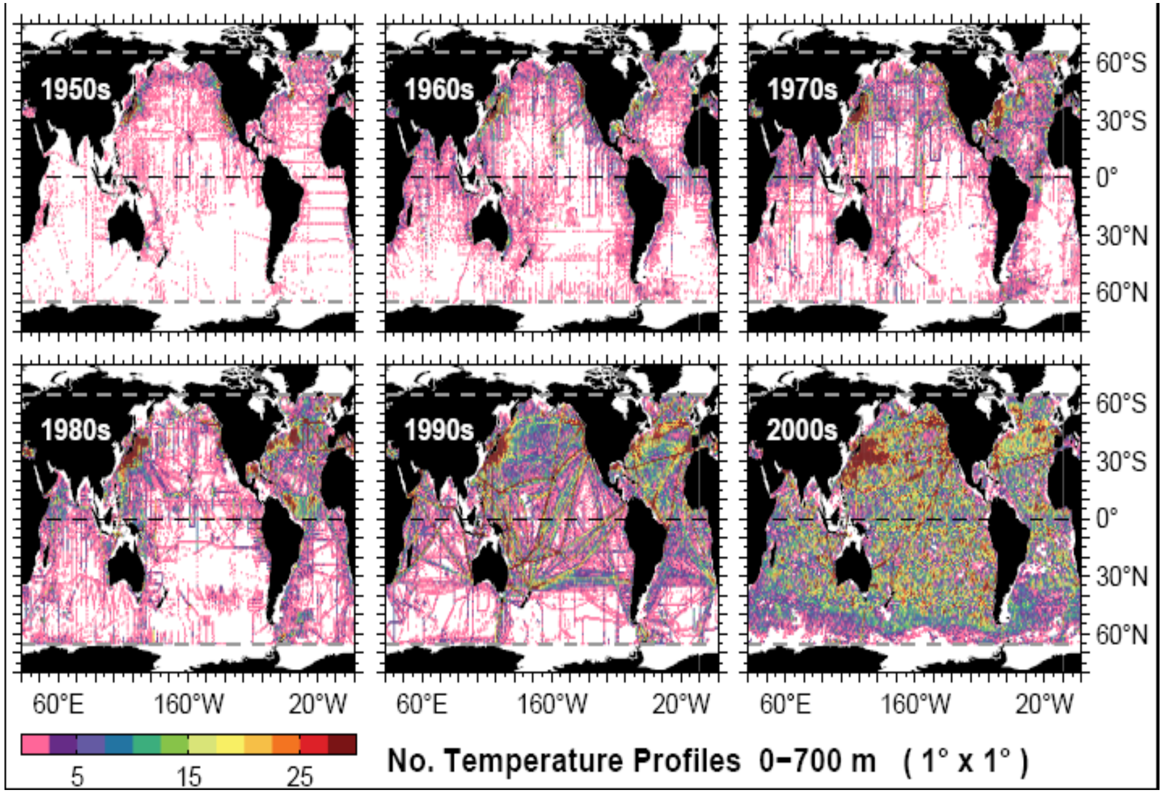


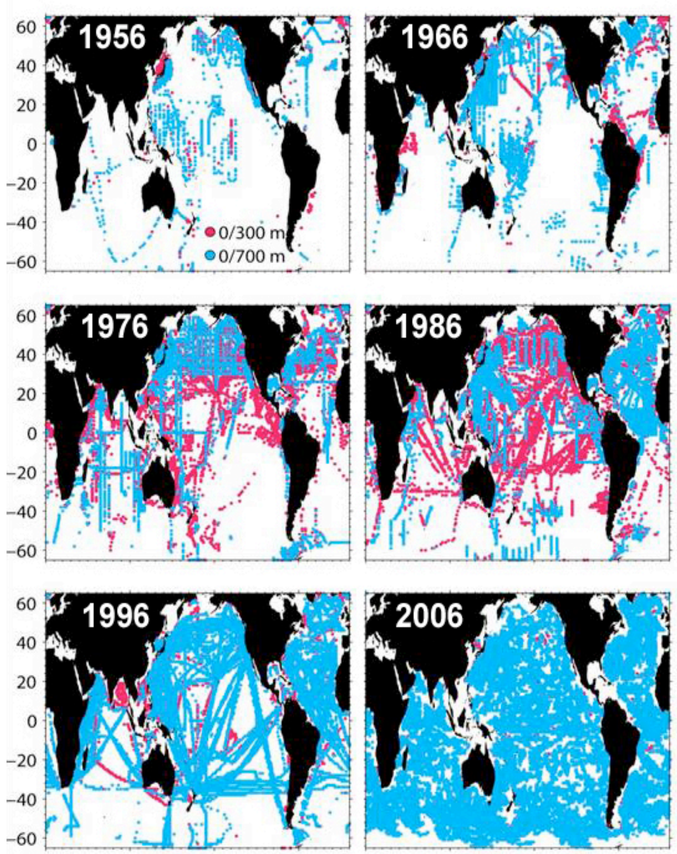




Domingues et al., in prep.

Decadal geographical coverage - subsurface ocean temperature

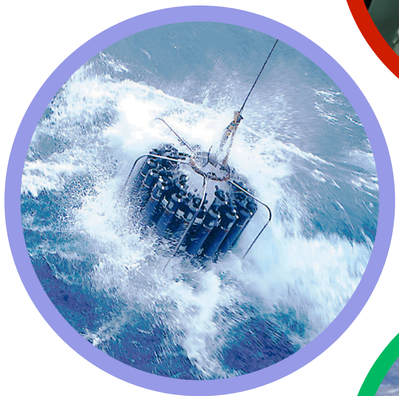




Domingues et al., in prep.

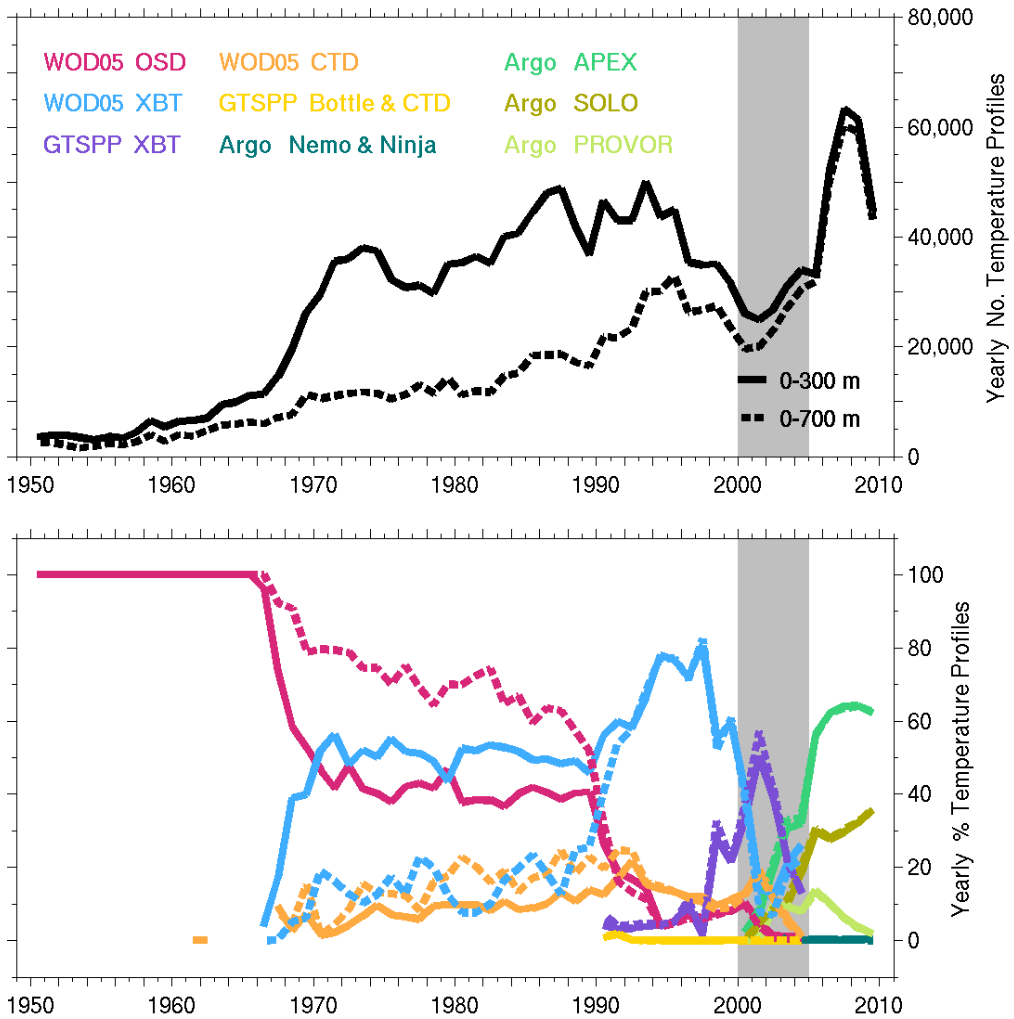
Temporal coverage/Instrumental changes

MBT & XBT
(70% historical data base)



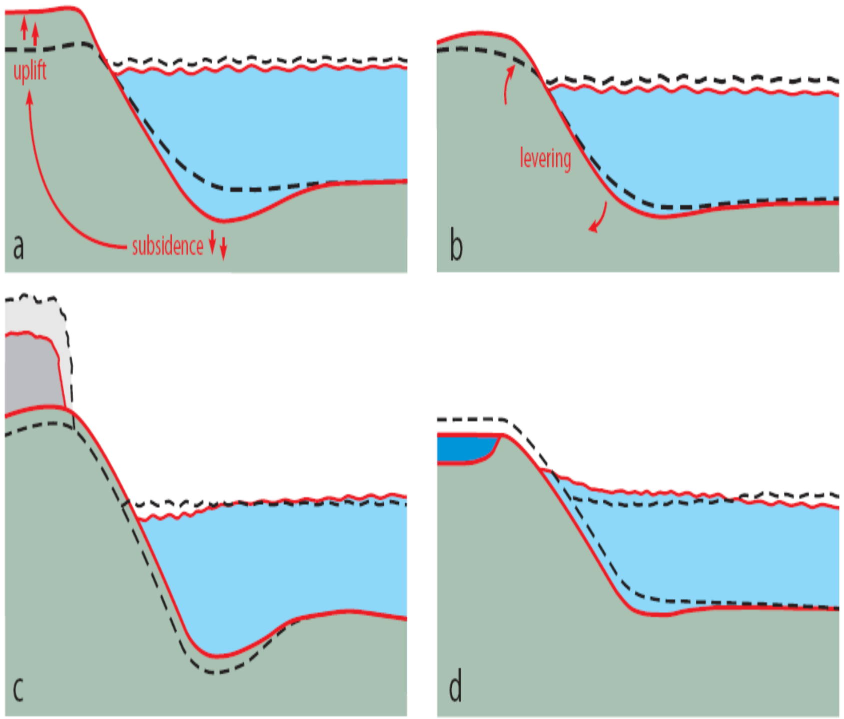
Bottle & CTD
(most accurate & expensive)

Argo float
(recent robot revolution)



Domingues et al., in prep.

Changes in the shape of the ocean basins (example)



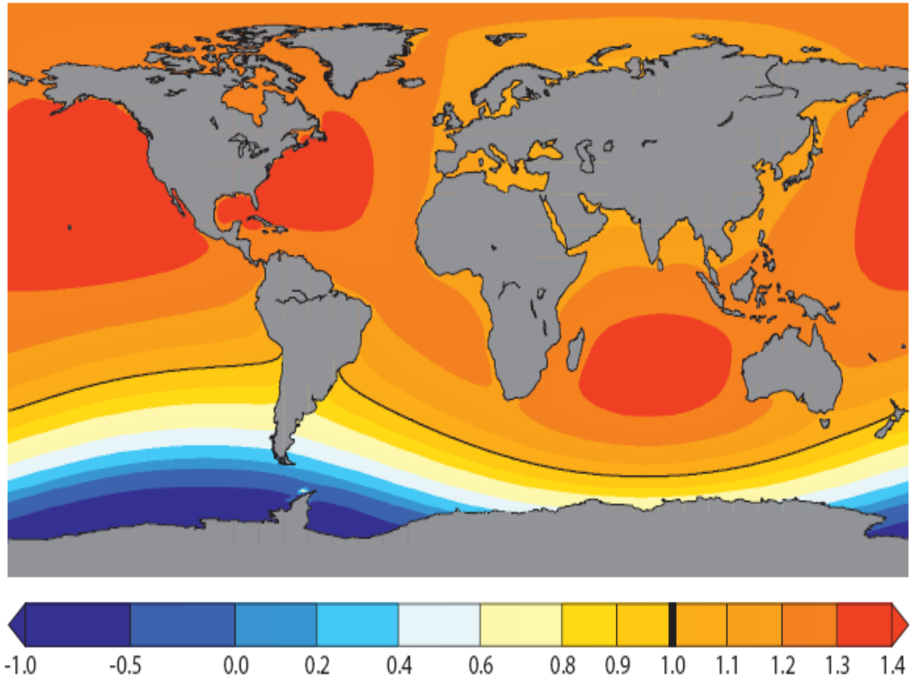


Figure 6. Pattern of relative sea level rise that would result from collapse of the West Antarctic Ice Sheet. The plot has been normalized so that a value of 1.0 corresponds to the average increase in sea level.

Tamisiea and Mitrovica (2011)

Contribution of Pacific wind stress to multi - decadal OHC and sea level variations in the tropical South Indian Ocean

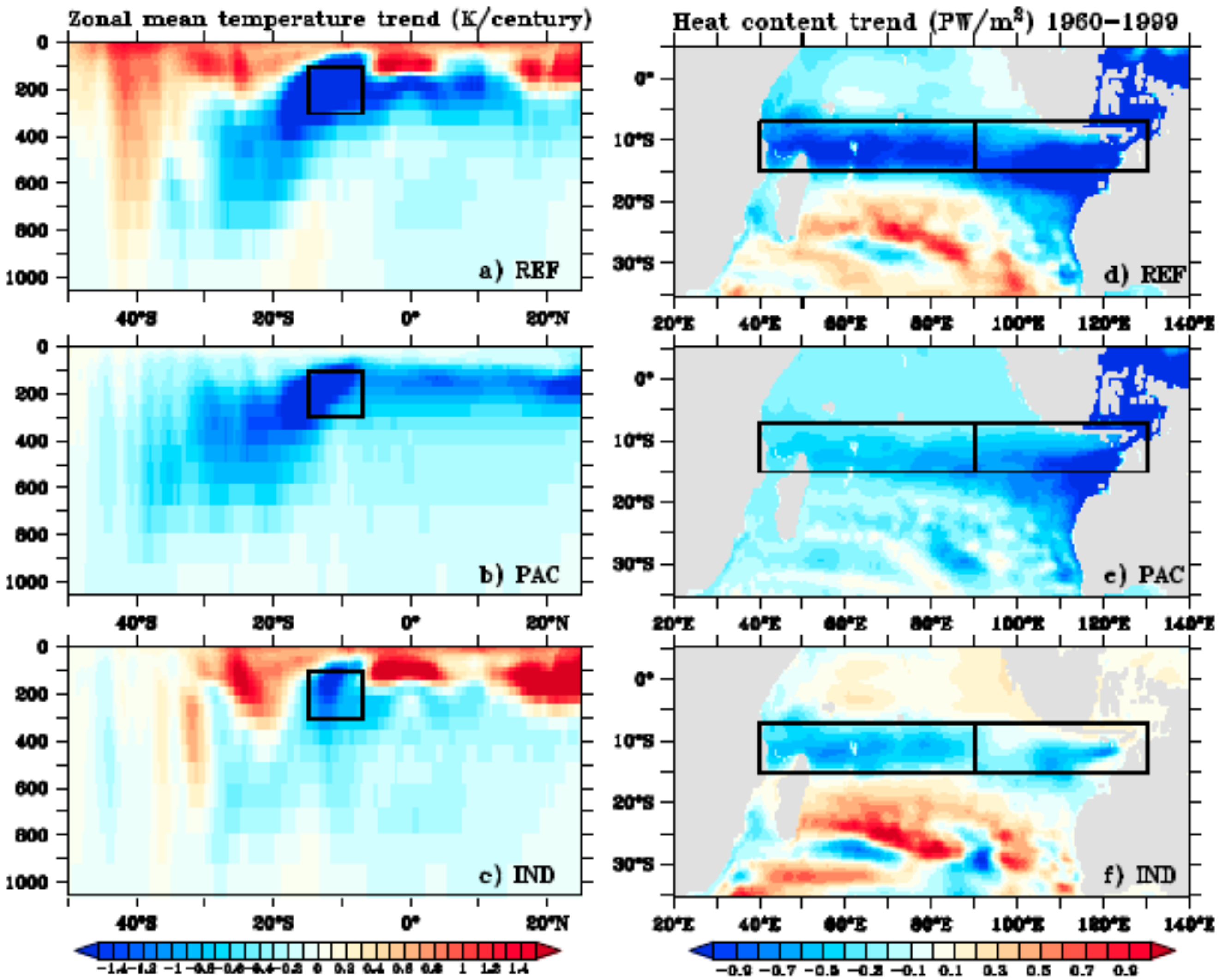
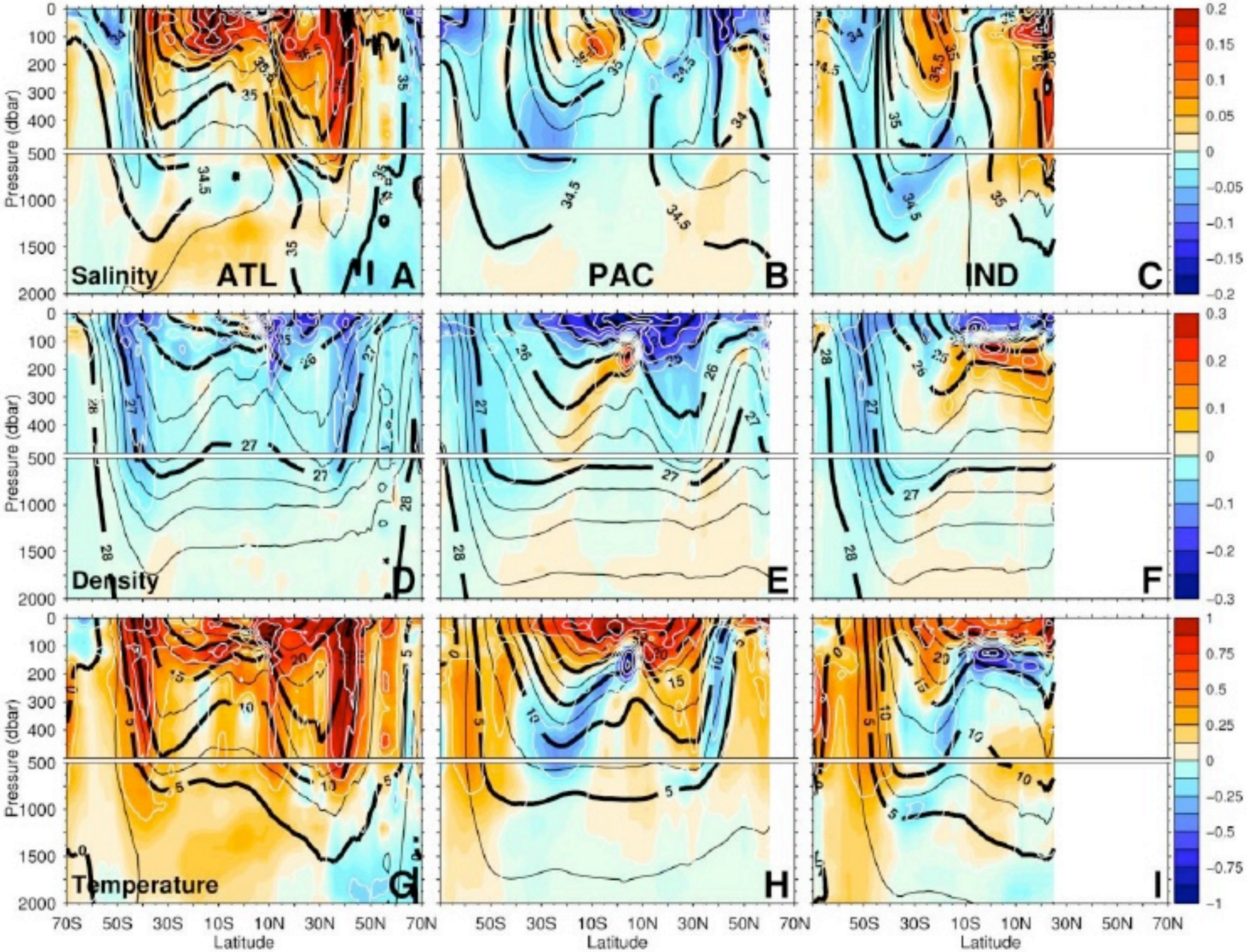


Figure 2. Linear trends (1960–1999) of IO zonal mean temperature (in K/century) for (a) REF, (b) PAC and (c) IND; and of 100–300 m heat content (in PW/m^2) for (d) REF, (e) PAC and (f) IND.

Franziska U. Schwarzkopf and Claus W. Böning, 2011

Zonal mean basin changes



Paul Durack, 2010 – PhD thesis (paper in prep.)