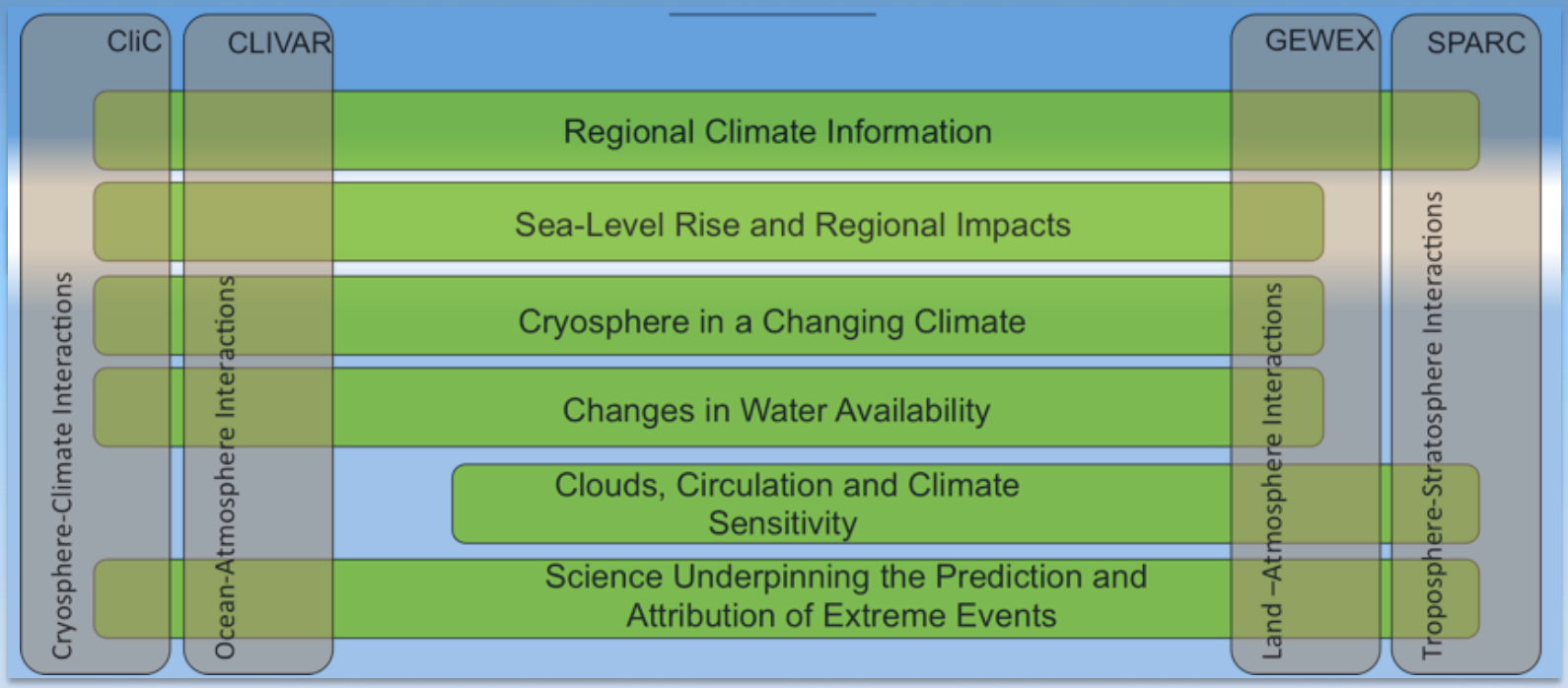
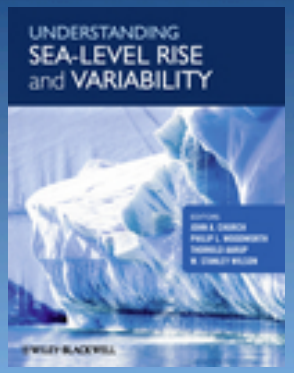
Sea-Level Rise and Regional Impacts



Martin Visbeck

based on input from
Detlef Stammer, Catia Domingues & Claus Böning (CLIVAR)
Jenny Baeseman (CLIC)

Background (2005)



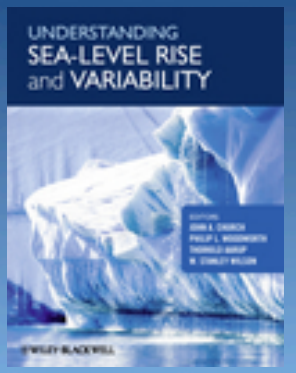
Understanding Sea Level Rise and Variability

A WCRP (World Climate Research Programme) workshop in support of the WCRP's strategy 2005-2015 and a WCRP contribution to the GEOSS (Global Earth Observation System of Systems)

Following discussions at JSC 25 in Moscow and subsequent discussions as part of the COPES Task Force, a proposal to hold a sea-level workshop to bring together all relevant WCRP science with a view to identifying uncertainties and research and observational activities for narrowing these uncertainties was approved the XXVIth session of Joint Scientific Committee for the World Climate Research Programme, Guayaquil, Equador, March **2005**.

The Workshop would require contributions from WCRP projects and activities (CLIVAR, ocean thermal expansion; CliC, glacier and ice sheet contributions; GEWEX, terrestrial water storage; WGCM, coupled climate modelling). In addition, contributions of experts from IGBP, the ESSP GWSP, and other relevant groups would also be valuable.

Background (2005)



Understanding Sea Level Rise and Variability

A WCRP (World Climate Research Programme) workshop in support of the WCRP's strategy 2005-2015 and a WCRP contribution to the GEOSS

Expected Outcome

The major output from the workshop would be a WCRP report summarizing the current state of the science, an outline of future research requirements for improving our understanding of sea-level rise and variability and a description of the observational requirements (both experimental and sustained systematic observations). A careful consideration of uncertainties will be included.

The report would contain sections on requirements for improving present estimates and future projections of:

- sea-level rise and variability,
- ocean thermal expansion,
- non-polar glacier contributions,
- ice sheet contributions,
- vertical motion due to glacial isostatic adjustments and tectonic motions,
- terrestrial (including anthropogenic) water storage contributions,

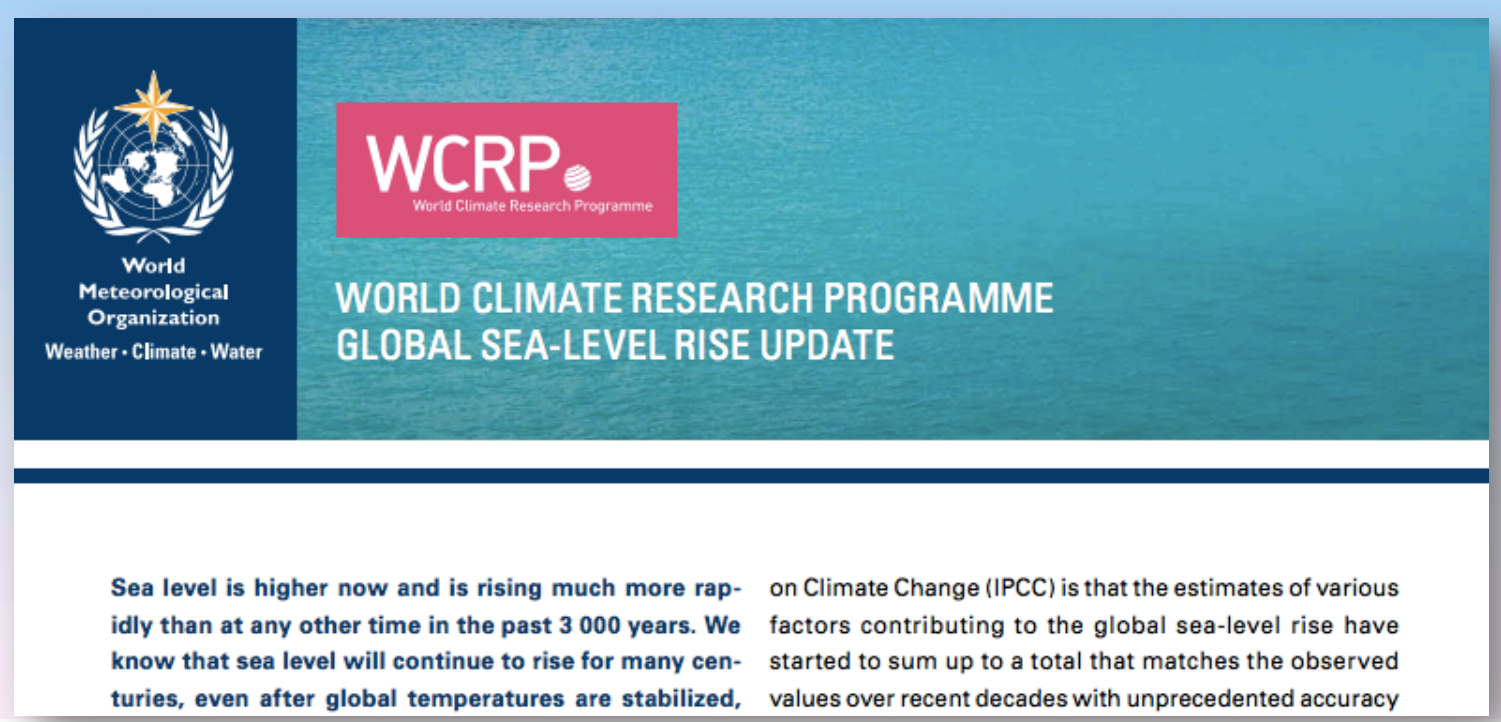
changes in the frequency/intensity of extremes sea level events and waves

The final outcome of the workshop has now been published by Wiley-Blackwells and **is available for purchase** at http://wcrp.ipsl.jussieu.fr/Workshops/SeaLevel/pdf/BookOffer.pdf

Background (2009)

The Joint WCRP/IOC Task Group on Sea-Level Variability and Change

In **2009** the WCRP and IOC (Intergovernmental Oceanographic Commission of UNESCO) established the WCRP-IOC Task Group on Sea-Level Variability and Change. The decision was made by the 30th Session of the WCRP Joint Scientific Committee (6-9 April 2009) and it was endorsed by the 25th Assembly of IOC (16-25 June 2009)


World Meteorological Organization
Weather · Climate · Water

WCRP
World Climate Research Programme

WORLD CLIMATE RESEARCH PROGRAMME
GLOBAL SEA-LEVEL RISE UPDATE

Sea level is higher now and is rising much more rapidly than at any other time in the past 3 000 years. We know that sea level will continue to rise for many centuries, even after global temperatures are stabilized,

on Climate Change (IPCC) is that the estimates of various factors contributing to the global sea-level rise have started to sum up to a total that matches the observed values over recent decades with unprecedented accuracy

Background (2009)

The Joint WCRP/IOC Task Group on Sea-Level Variability and Change

Task Group Activities

24 March 2010 1st session of the Executive Committee of the Task Group, Bern, SWITZERLAND

Relevant Activities

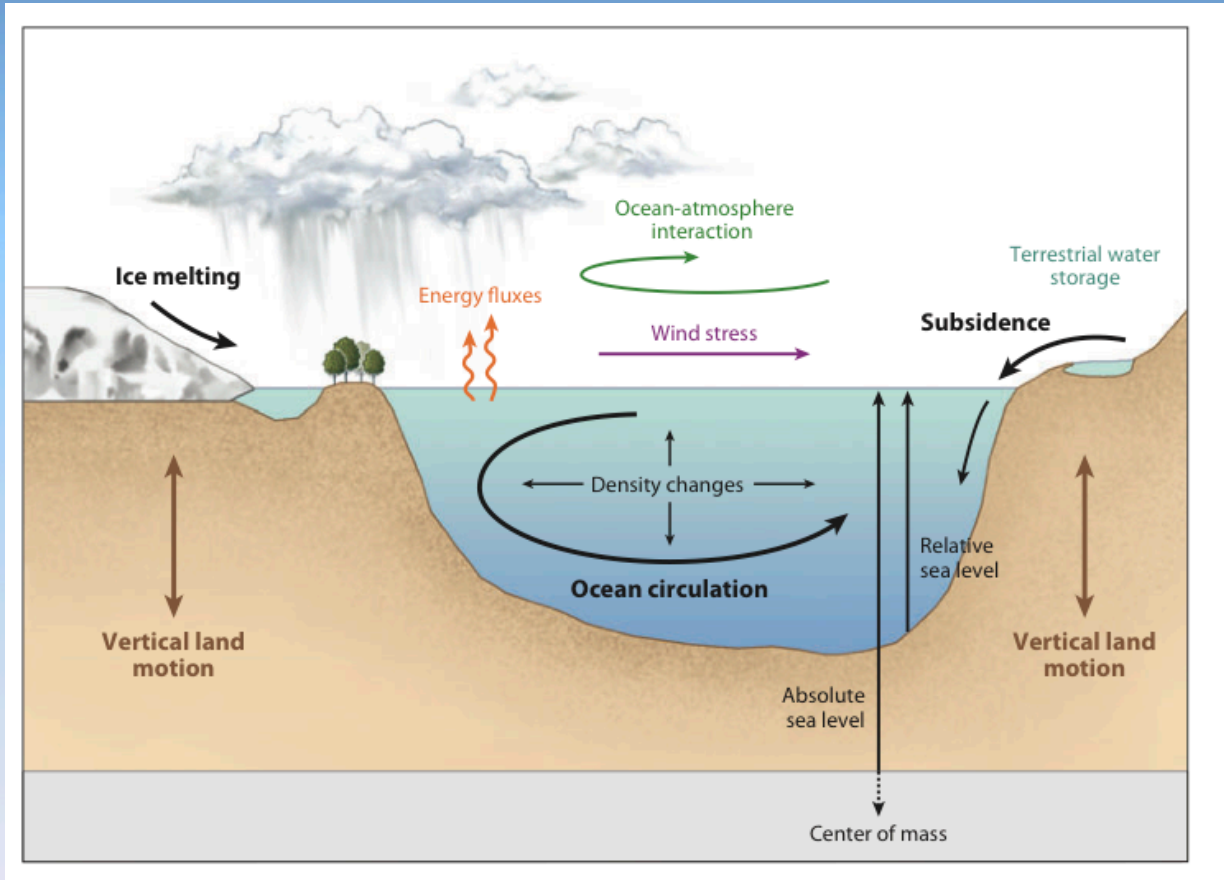
- 21-24 June 2010 IPCC workshop on Sea-Level Rise and Ice Sheet Instabilities, Kuala-Lumpur, MALAYSIA
- 29 Sept.-1 October 2010 Conference on Deltas in Times of Climate Change, Rotterdam, THE NETHERLANDS
- 7-9 February 2011 WCRP/IOC Workshop on Regional Sea-Level Change, Paris, FRANCE

Members of the Executive Committee

- John Church (co-Chair), CSIRO Marine and Atmospheric Research, Hobart, AUSTRALIA
- Konrad Steffen (co-Chair), CIRES, Boulder, Colorado, USA
- Anny Cazenave, LEGOS, Toulouse, FRANCE
- Jonathan Gregory, NCAS and UK MetOffice, Reading UK
- Philip Woodworth, Permanent Service for Mean Seal Levl POL, Liverpool, UK
- Stanley Wilson, U.S. National Oceanic and Atmospheric Administration, USA
- Vladimir Ryabinin (WCRP rep.), WMO Geneva, SWITZERLAND
- Thorkild Aarup (IOC rep.), UNESCO, Paris, FRANCE

Outline (2013)

Sea-Level Rise and Regional Impacts



Dynamics of regional sea level variability (**CLIVAR** research opportunity)

CliC Contributions to Regional Sea Level Rise Grand Challenge

Outreach opportunities (**CLIVAR** and **CLIC**)

Dynamics of regional sea level variability

- Scientific background
- Main challenges
- Suggestions for new research activities

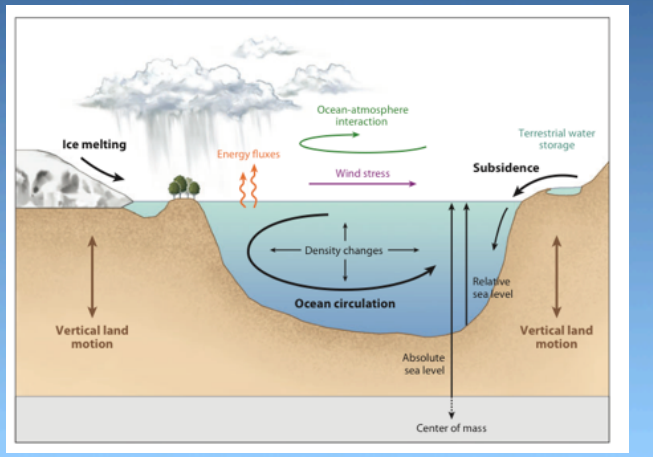
Slides prepared by Claus Böning

based on

- Tiger Team (*Catia Domingues and Detlef Stammer)*
- Draft WCRP White Paper (WCRP Workshop 2011)
- Notes from WGOMD Workshop, Hobart Feb 2013

- … and my take of the recent literature

Regional sea level



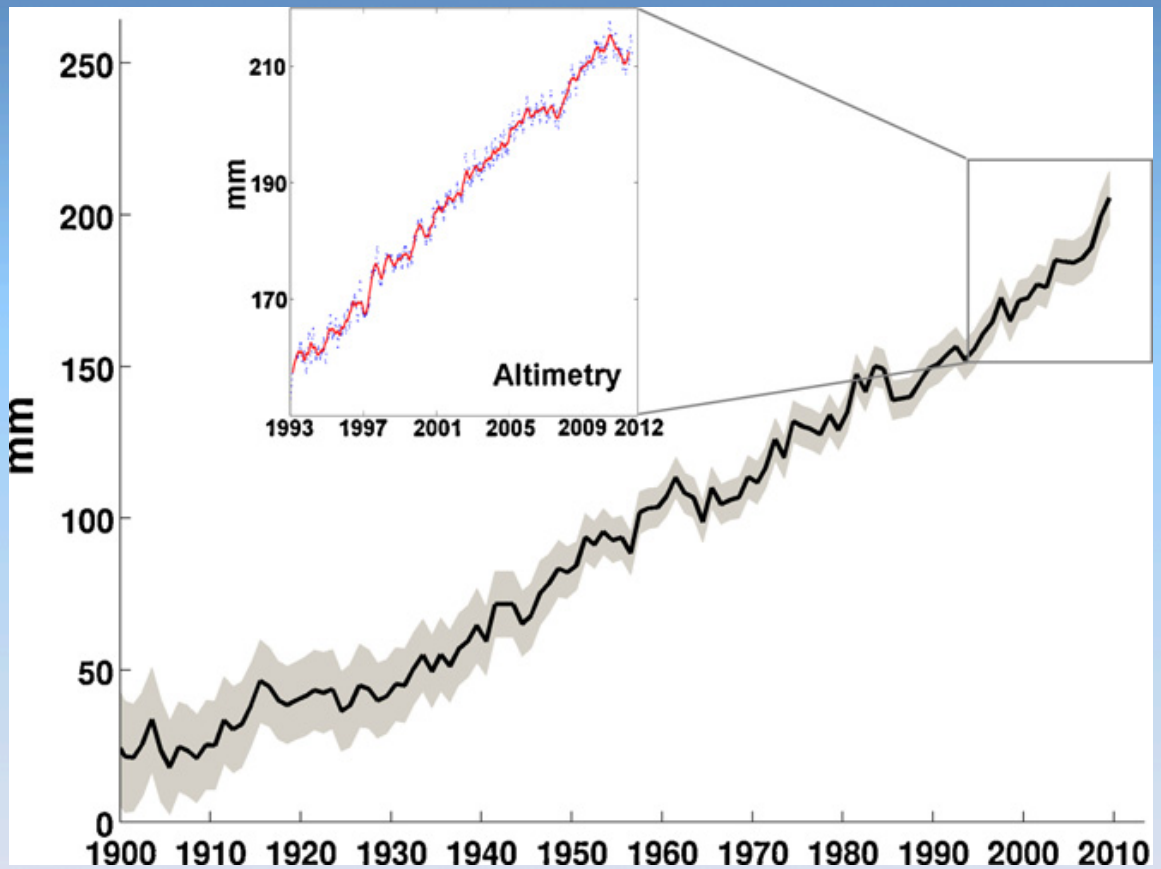
is one of the climate parameters with immediate societal relevance

is affected by all climate components: its changes are an integral measue of climate change

but it has also strong contributions not related to climate (not covered by WCRP)

→ requires interaction with other comunities

Global mean sea level is rising…



Church and White, 2011

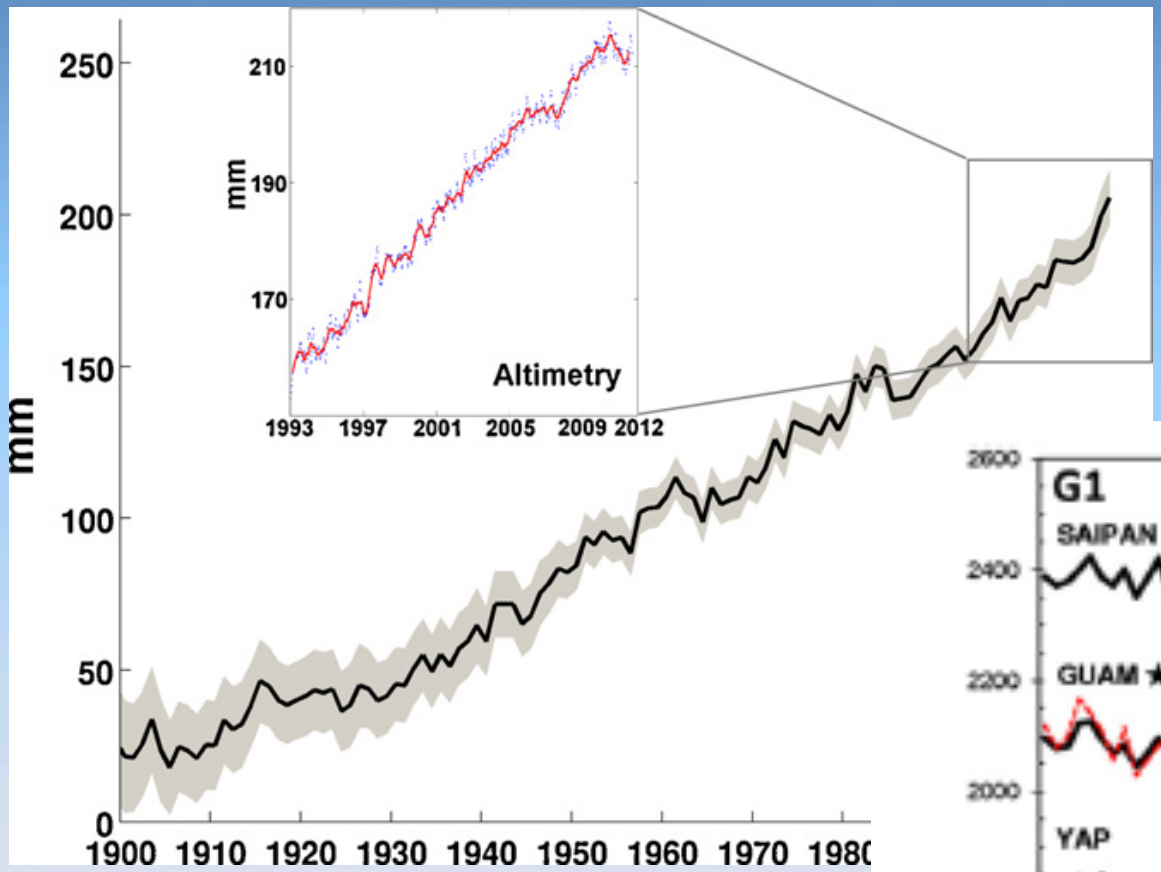
20th-century:
~ 1.7 mm/yr

Altimetry (since 1993):
~ 3.2 mm/yr

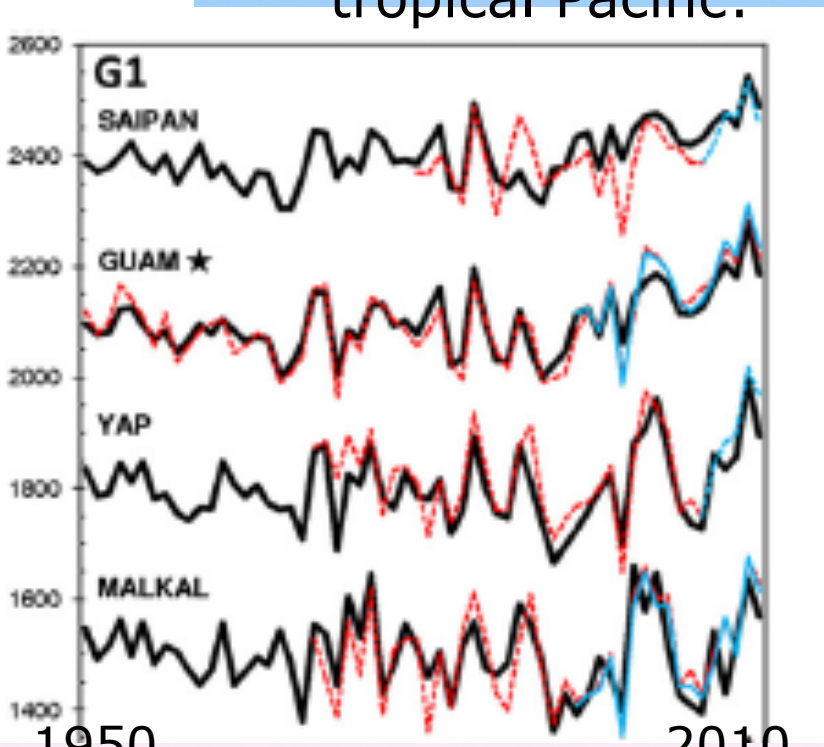
Causes (last 20 yrs):

- ocean warming
  ~ 30-40 %
- glaciers melting
  ~ 30%
- ice sheets:
  recent increase
  to >25%

… but there is strong spatial inhomogeneity

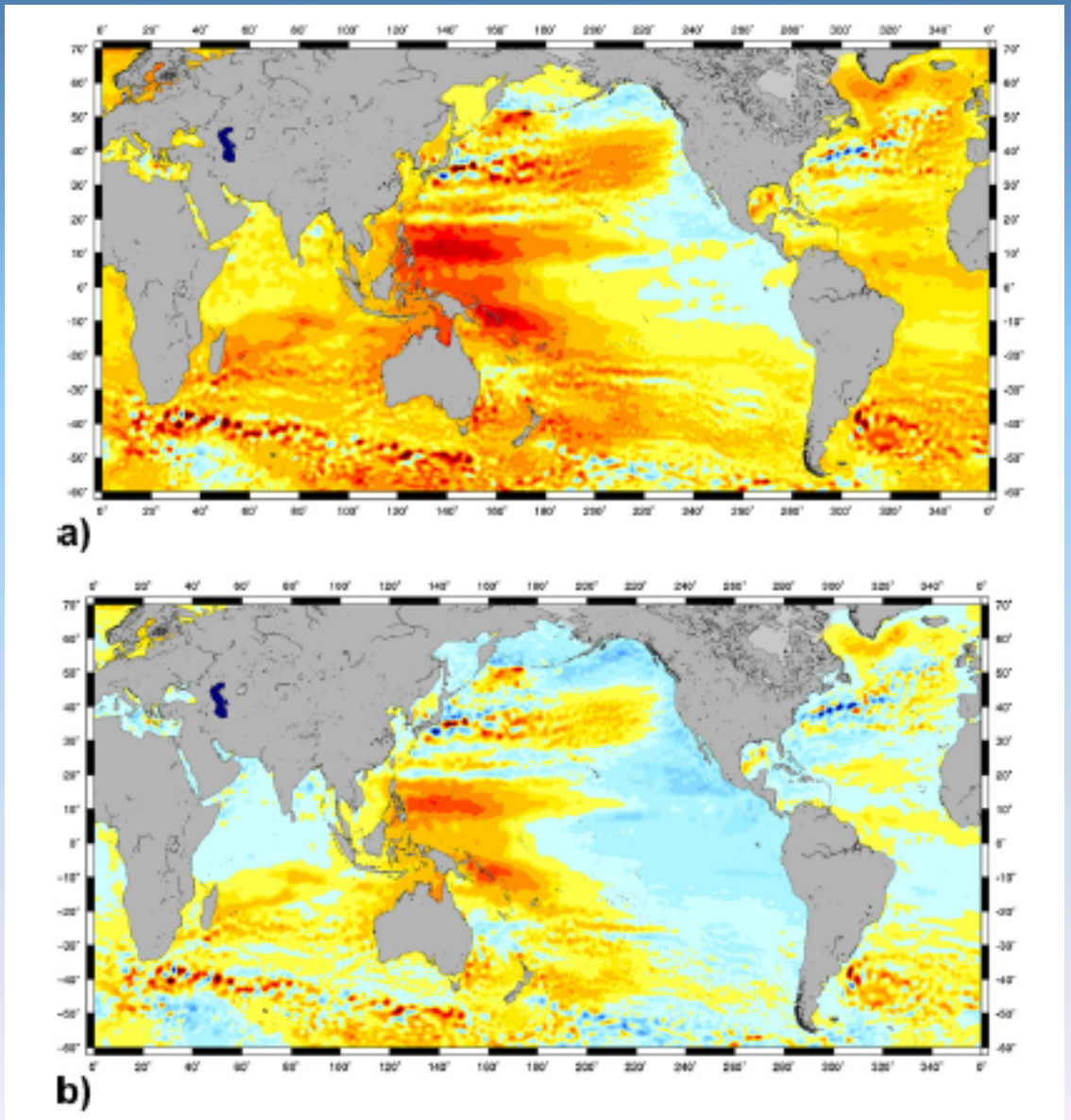


Example: tide gauges (red), altimetry (blue), tropical Pacific:



Becker et al., 2012

Spatial pattern of sea level change



1993 - 2001

1993 –2010

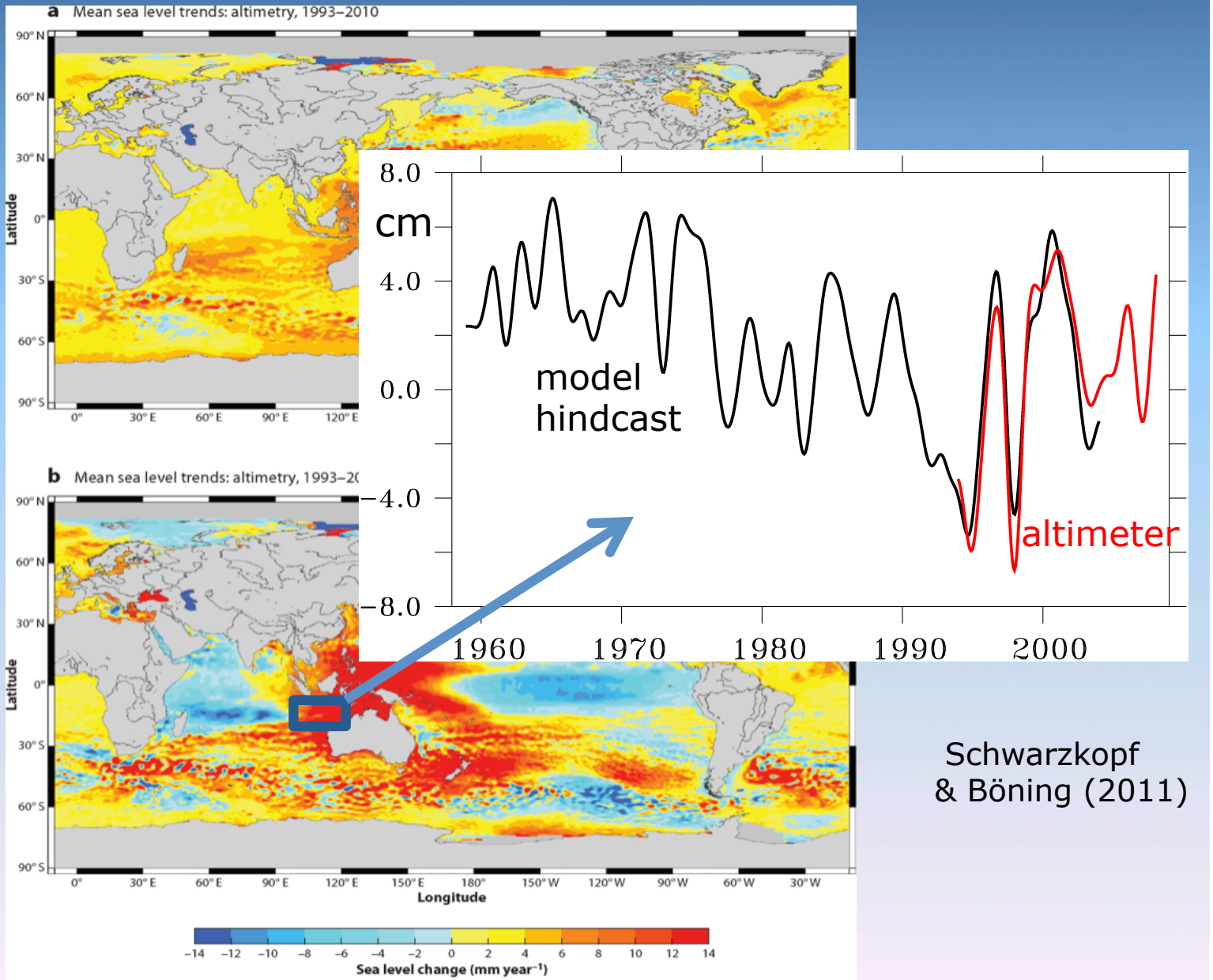
relative to the global mean

Meyssignac and Cazenave (2012)

… strong temporal variability

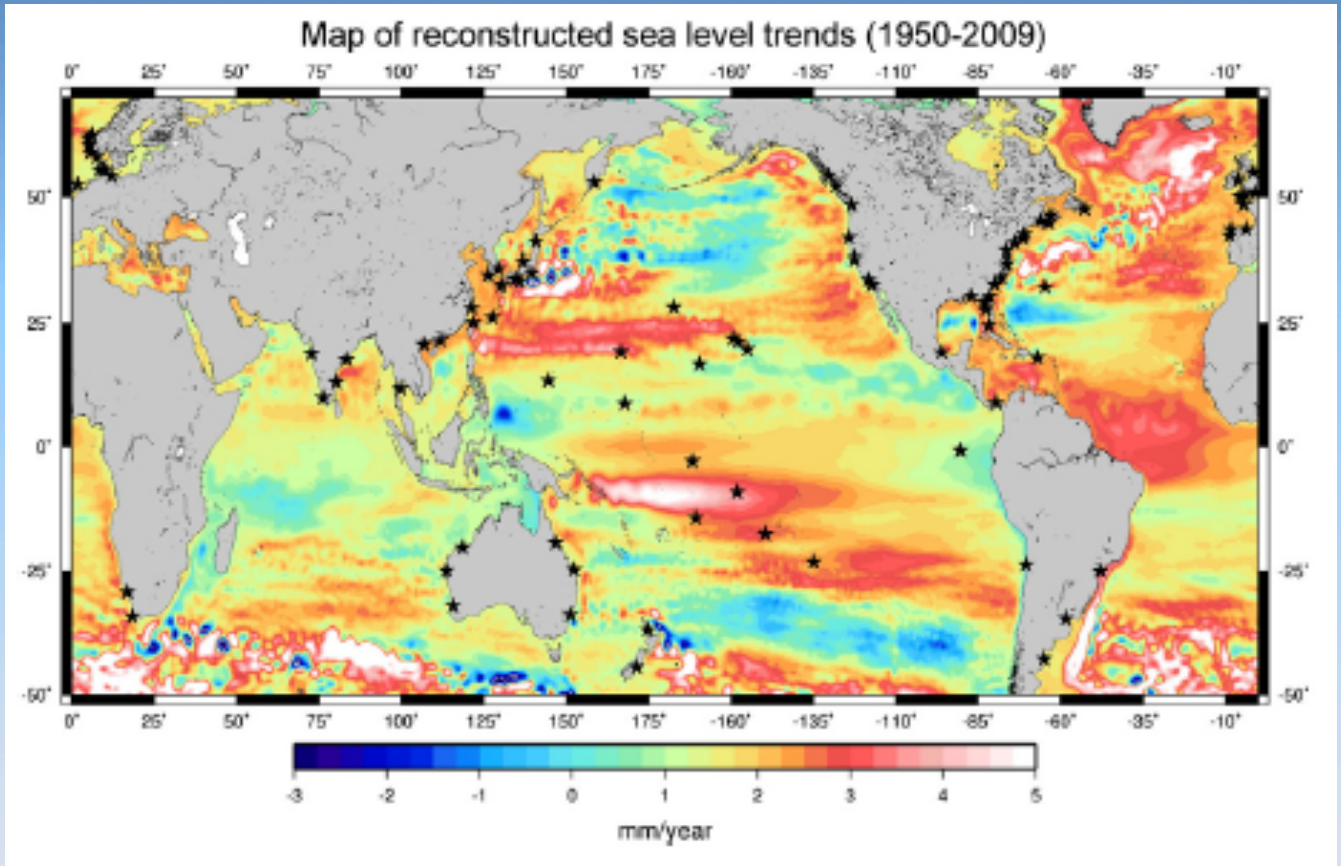
1993 - 2010

1993 - 2001



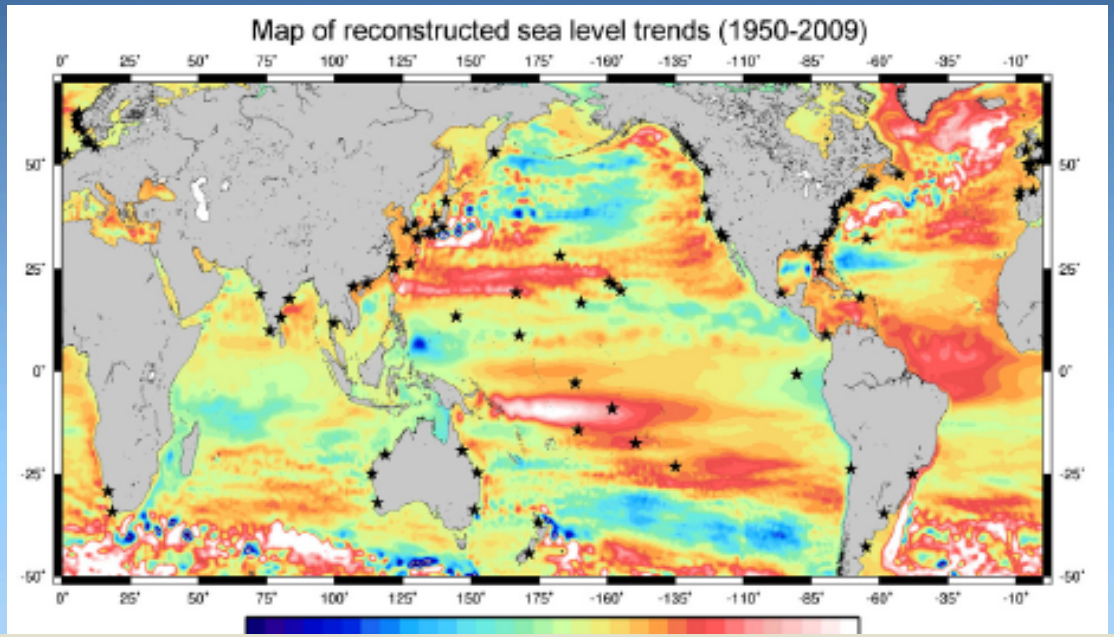
Schwarzkopf
& Böning (2011)

Reconstruction of multi-decadal changes



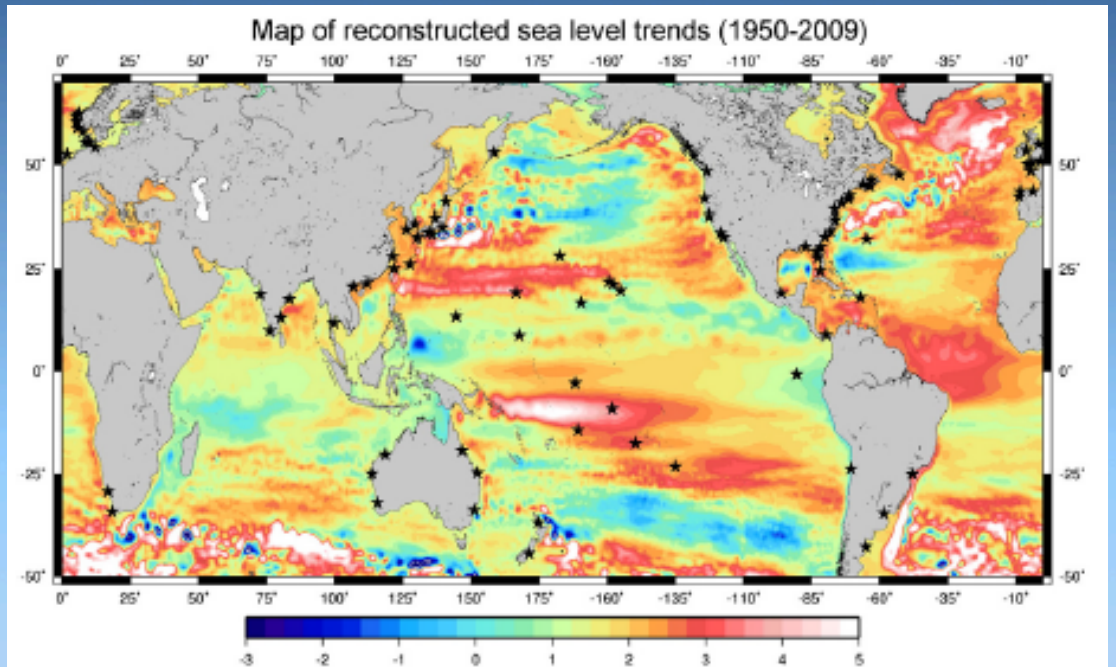
Becker et al. (2012)

Reconstructions suggest:

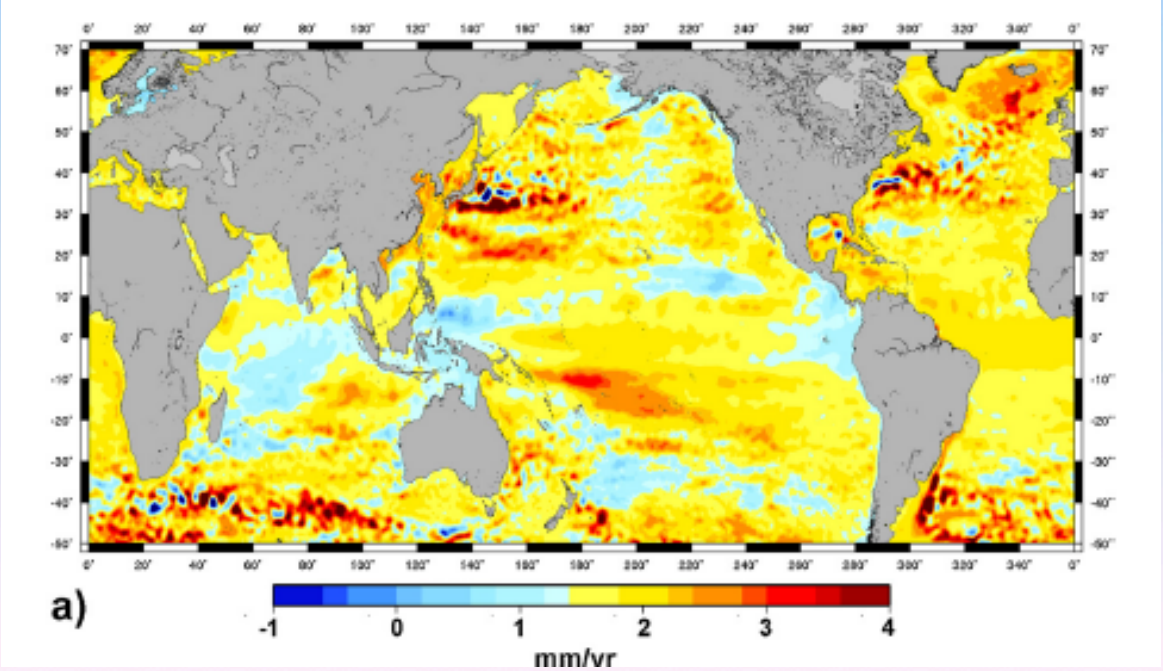


- non stationarity of spatial trend patterns
- linkage to natural climate modes (ENSO, PDO, NAO,..)
- for many regions: natural variability > anthropogenic trend

…but spatial patterns are uncertain!



Becker et al. (2012)



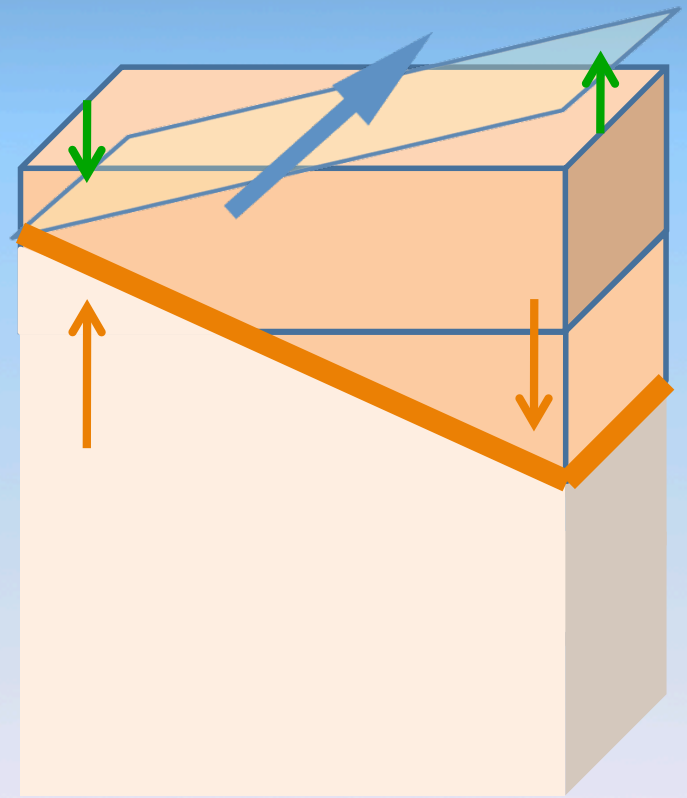
Meyssignac & Cazenave (2012)

Processes

Main factor on interannual-decadal time scales:

adiabatic re-distribution of upper-layer water:

(wind-driven) currents associated with climate modes



sea surface height

pycnocline

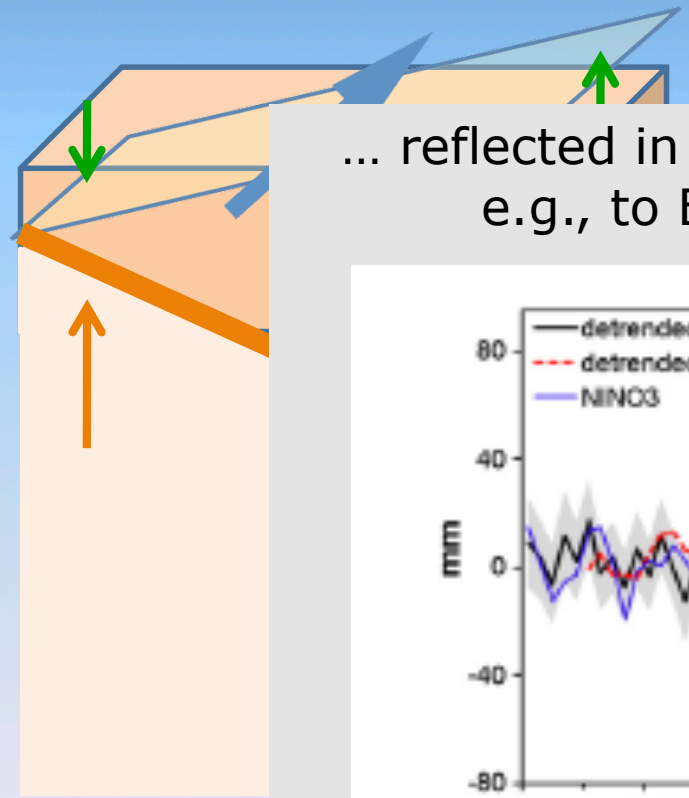
⟹ first baroclinic mode(s) dominate:

close link between SL and pycnocline depth;

pressure gradients do not extend to the bottom

… commonly described as: „steric"

Main factor on interannual-decadal time scales:
wind-driven (adiabatic) re-distribution of upper-layer waters



sea surface height

… reflected in close linkage to climate modes:
e.g., to ENSO in the tropical Pacific:

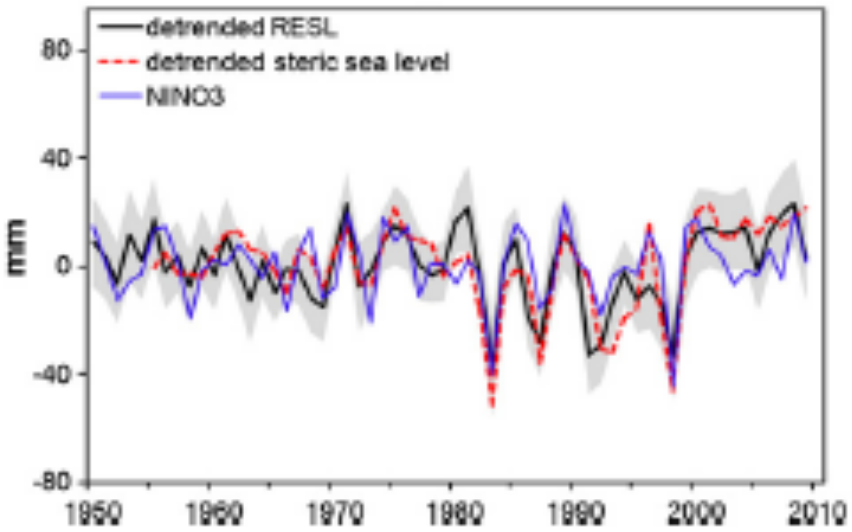
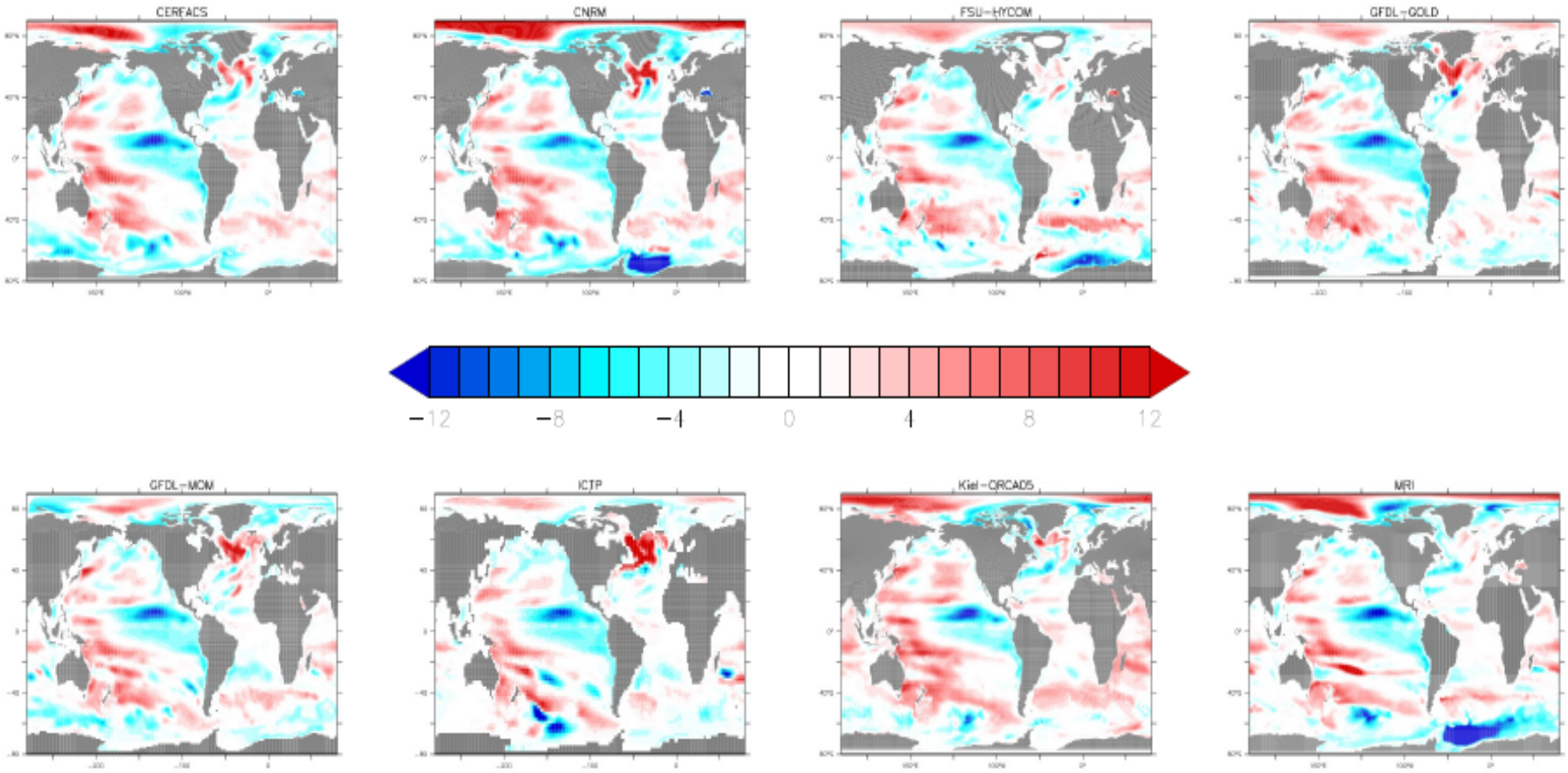


Fig. 4. Reconstructed and steric mean sea level time series for 1950–2009. The detrended RESL is the black line and its uncertainty is in gray. The detrended steric sea level is the red line. The inverse NINO3 index (shifted by half a year) is superimposed in blue.

Becker et al., 2012

… reflected in robust ocean model hindcast simulations of (sub-)tropical SSH variability (CORE II of WGOMD):

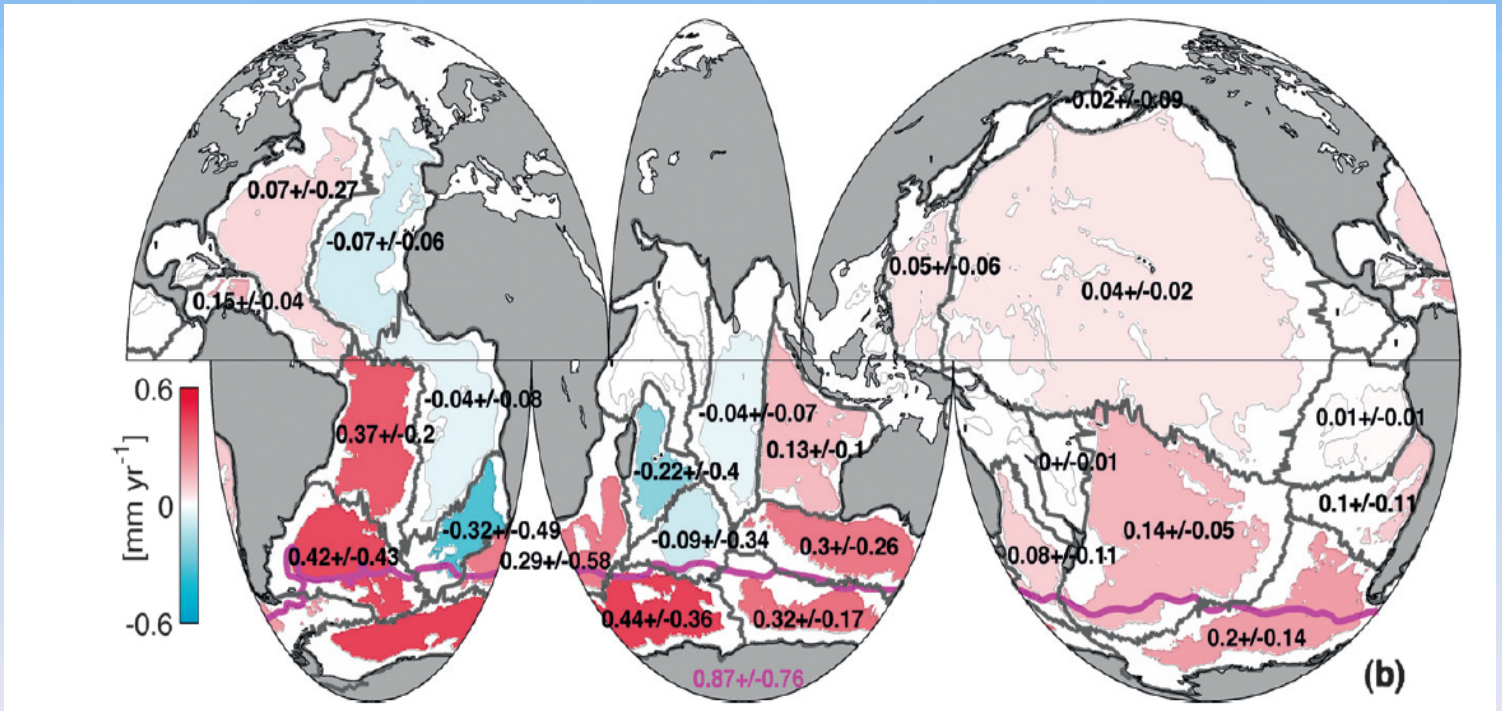


(Griffies et al., 2013 subm.)

…but other processes become important:

(1) when considering longer time scales:

- changes in heat and fw uptake (changes in water masses)



Basin means of SL rise (mm/yr) since 1990 due to observed abyssal warming (>4000m depth) and in the Southern Ocean from 1000-4000m

(Purkey & Johnson, 2010)

…but other processes become important:

(1) *when considering longer time scales:*

- changes in heat and freshwater uptake

- *future:* additional fw input from glaciers and ice sheets

→ non-uniform distribution due to
- ocean dynamics
- gravitational effects: SL drops near the ice edge

…but other processes become important:

(1) *when considering longer time scales:*

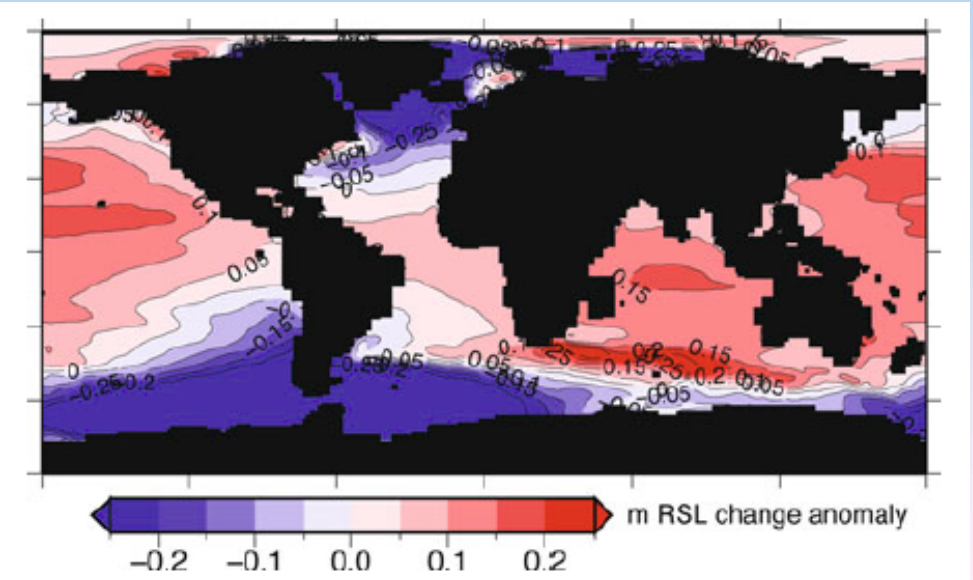
- changes in heat and freshwater uptake

- *future:* additional fw input from glaciers and ice sheets

→ non-uniform distribution due to
- ocean dynamics
- gravitational effects: SL drops near the ice edge

…could become a major factor:

here: ensemble-mean A1B with 0.22m from GIS, 0.41m from AIS



Slangen et al. (2012)

…but other processes become important:

(1) *when considering longer time scales:*

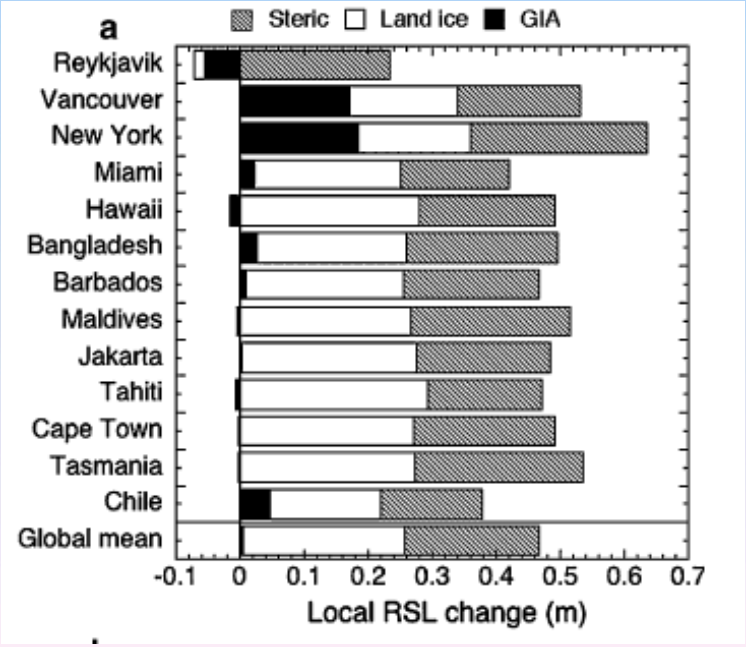
- changes in heat and freshwater uptake

- *future:* additional fw input from glaciers and ice sheets

- vertical land motion, e.g.: Glacial Isostatic Adjustment (GIA)

21st century projections for A1B scenario

Slangen et al. (2012)



…but other processes become important:

(1) *when considering longer time scales:*

- changes in heat and freshwater uptake

- in the future: additional fw input from glaciers and ice sheets

- vertical land motion (e.g., uncertainties in GIA)

(2) *when considering shelf regions:*

- coastal sea level is decoupled from deep ocean at higher latitudes (as an effect of wave characteristics)

Bingham and Hughes 2012; Calafat et al. 2013

- mass redistribution (shelf mass loading)

Landerer et al. 2007; Richter et al. 2013

… deep ocean density changes → cross-shelf pressure gradient → mass redistribution („shelf mass loading“)

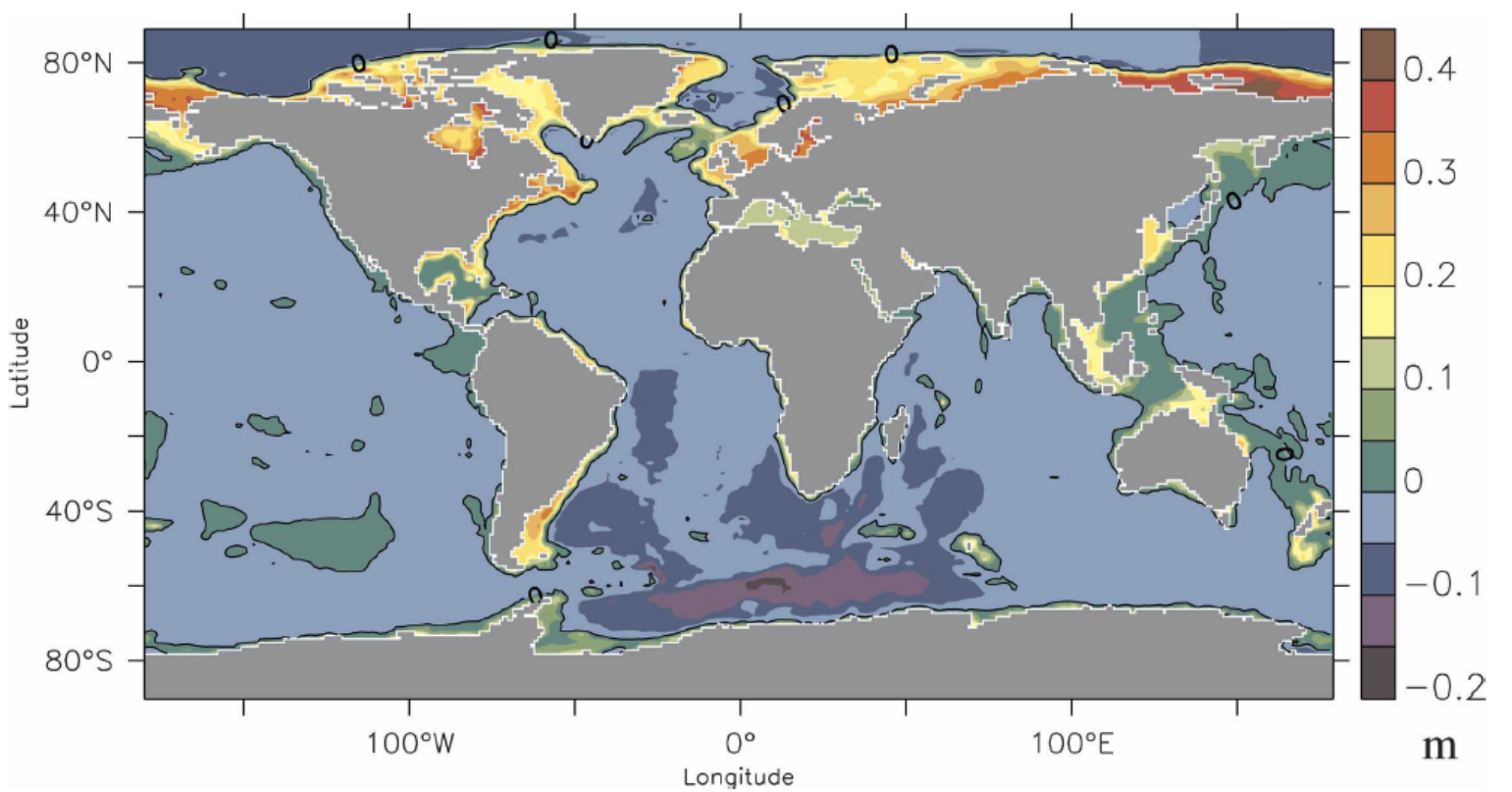


FIG. 6. Mean bottom pressure changes $p'_b g^{-1} \rho_0^{-1}$ (m water column equivalent) for the decade 2090–99 relative to the control simulation, as defined in Eq. (4).

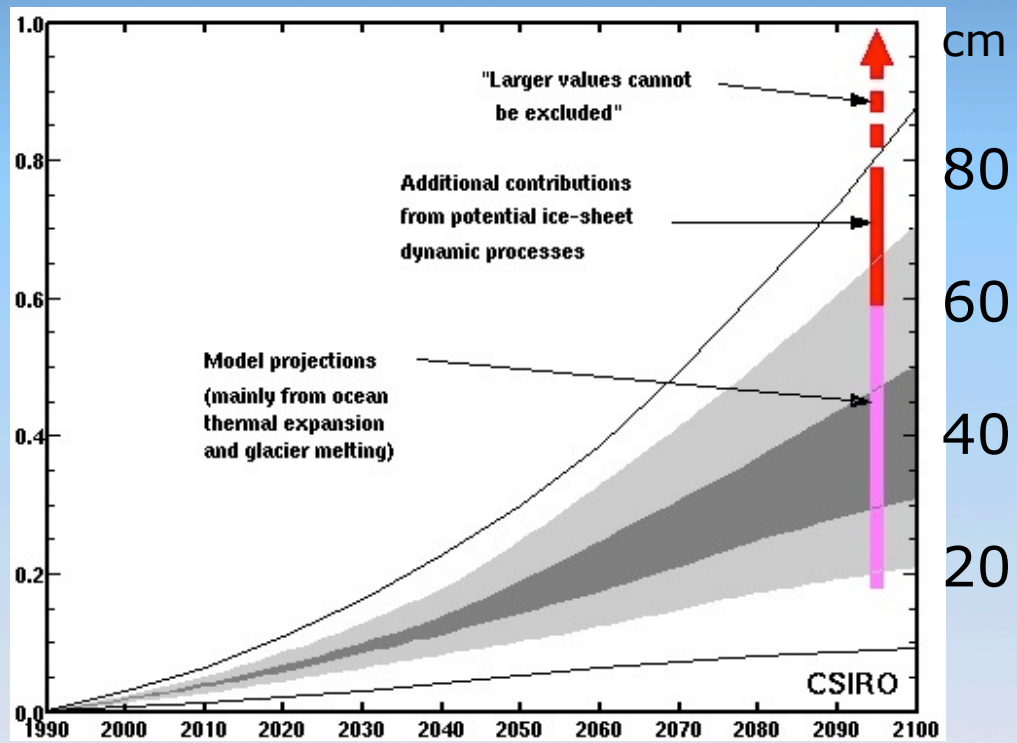
Landerer et al. (2007)

→ coastal sea level rise increased relative to the deep ocean

Projections of regional sea level changes for the 21st century:

Main challenges

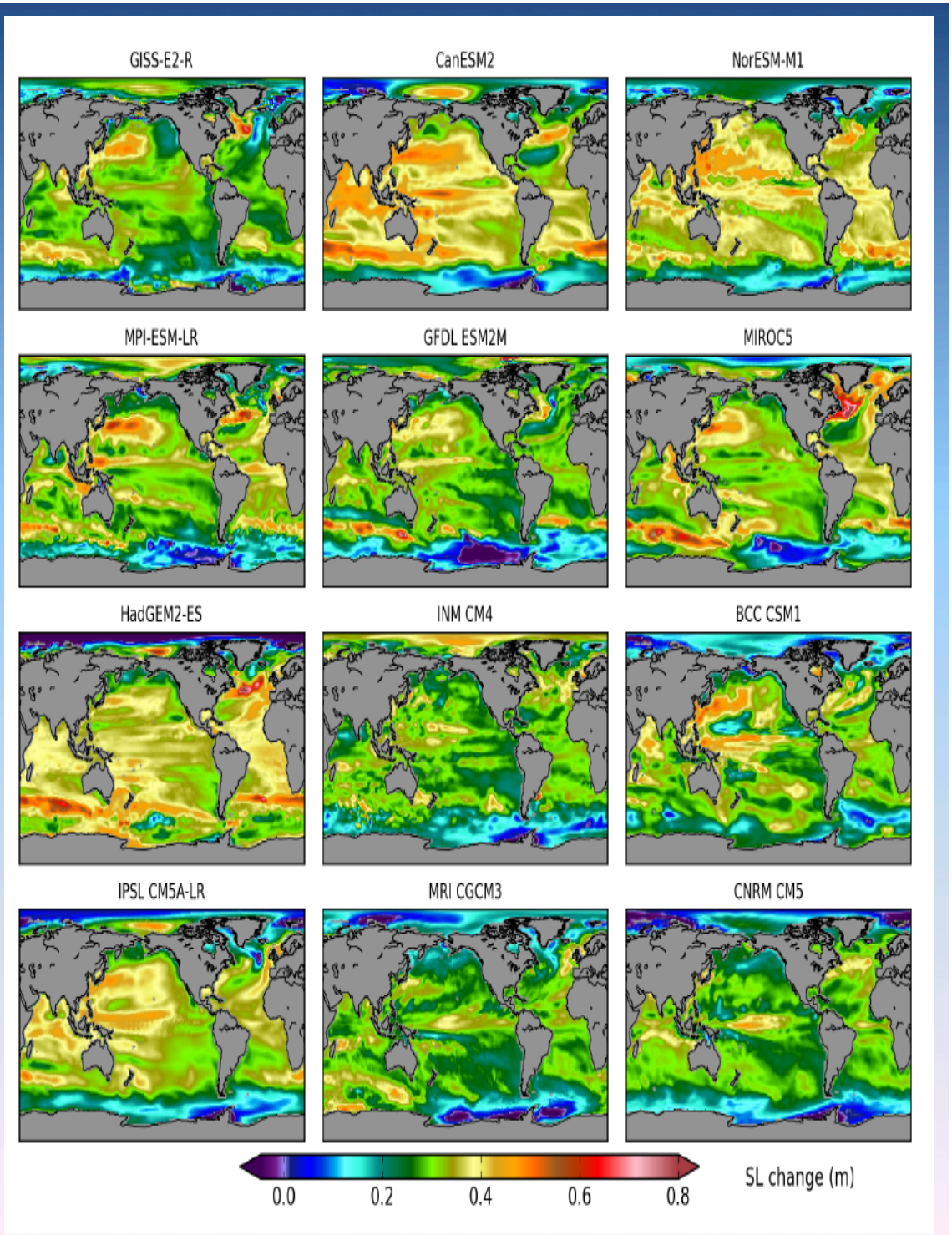
(1) Scenario uncertainty / global mean SL



J. Church

(2) Inter-model spread

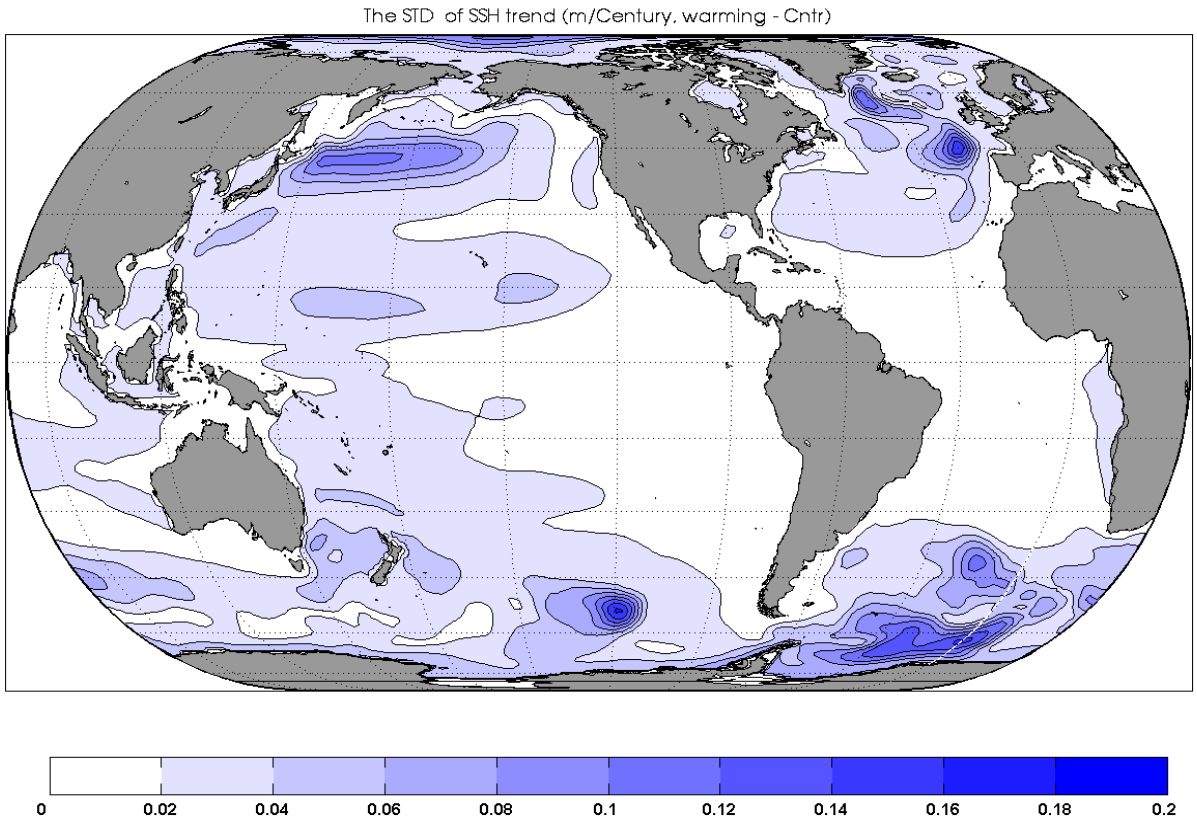
… reflecting strong differences in ocean circulation changes (steric changes)



Slangen et al. (submitted 2013)

(3) Strong internal variability

→ Regional SL changes dependent on initial conditions



M. Latif (pers. comm.)

Ensemble standard deviation (m/century) from 22 integrations

(1%-increase: CO2 doubling after 70 years, then CO2 constant for another 30 Years)

Suggestions

… for new
Disciplinary / Interdisciplinary Research Activities

(I) Past Changes in Regional Sea Level

Large remaining uncertainties in reconstructions. Requires dedicated programs:

→ complement the tide gauge record with more (proxy) data
liaise with other communities? (e.g., salt marshes?)

→ a co-ordinated model-data synthesis effort (multi-model, multi-method) analoguous to the CORE effort of *WGOMD*

→ integration of ice sheet modeling, sea level reconstructions, and land motion (*holistic view, also required in topics below*)

(II) Present Sea Level Changes and Processes

Improve understanding of present changes and underlying causes.
Identify forcing functions. Separate natural and anthropogenic changes:

→ Observation of deep ocean T & S changes -- *CLIVAR basin panels*

→ Ocean modeling hampered by spurious drift: explore novel forcing strategies, atmospheric feedbacks… -- *WGOMD*

→ Additional fw input from melting of glaciers -- *glaciology CliC*

→ Climate models: test results against present day changes and processes -- *WGCM*

(III) Future Projections

Inter-model differences in 21st-century projections reflect large uncertainties in (i) future evolution of climate modes, (ii) initialization (phase of internal variations), (iii) changes in regional ocean circulation, (iv) projection of glacier and ice sheet changes, (v) interaction of the ocean with ice sheets:

Need interaction between modeling, glaciology and geodesy to

→ Obtain a better understanding and reduction of uncertainties in climate models with respect to sea level

→ Addition of missing processes and components into climate models: e.g., ice sheet dynamics and ice sheet mass loss, changes in terrestrial hydrology

→ Initiate a coordinated climate modeling effort with improved representation of regional ocean dynamics; ice sheet-ocean interaction; changes in terrestrial hydrology

(IV) Ocean-Coastal and Human Interaction

There is need to systematically account for coastal effects in future projections as well as non-climate related anthropogenic effects:

→ Shelf dynamics: Integration of open ocean and shelf modeling

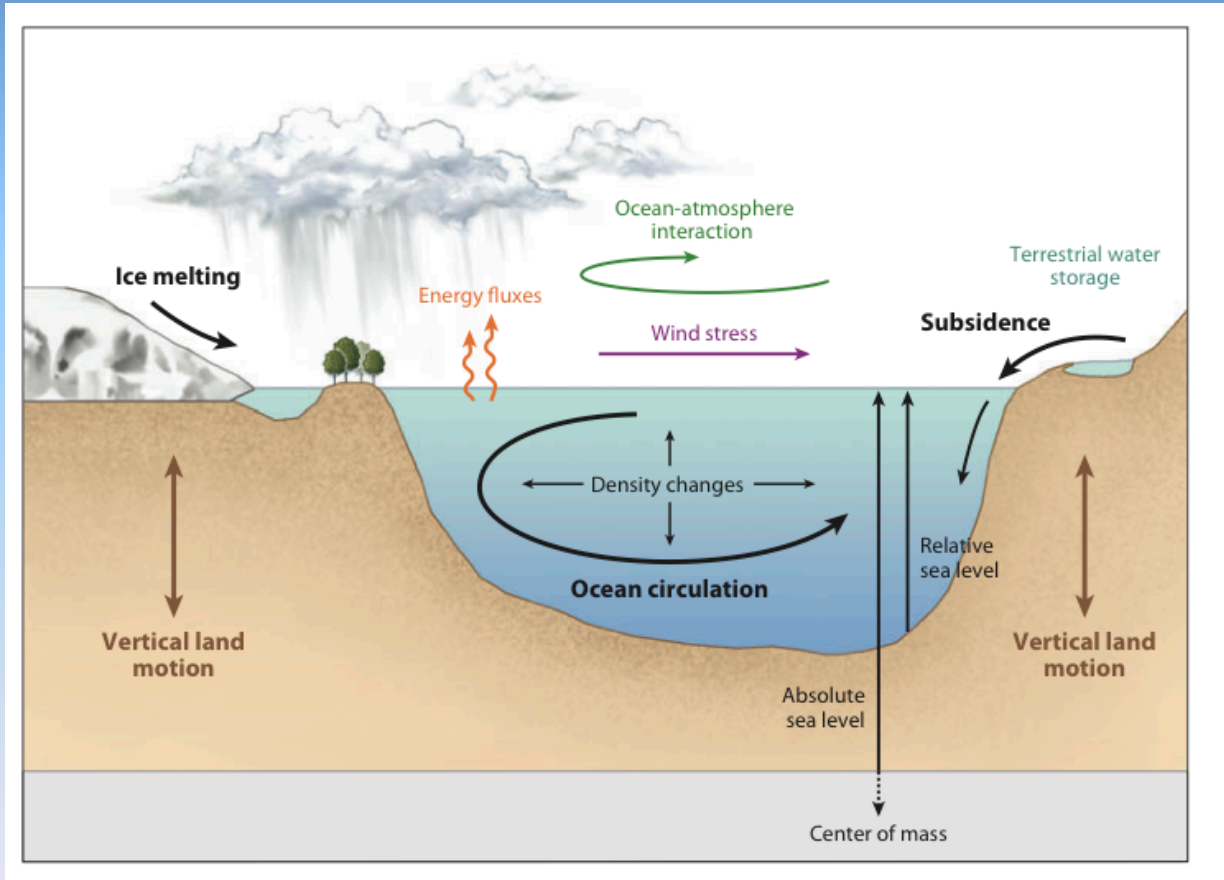
→ Impacts of storm surges and waves?

→ Inclusion of sediment and ground mining effects

-- liaise with coastal community, geodesy and social sciences

Outline

Sea-Level Rise and Regional Impacts



Dynamics of regional sea level variability (**CLIVAR** research opportunity)

CliC Contributions to Regional Sea Level Rise Grand Challenge

Outreach opportunities (**CLIVAR** and **CLIC**)

CliC Contributions

West Antarctic Glacier-Ocean Modeling

- New targeted activity to better assess sea-level contributions from the West Antarctic Ice Sheet (David Holland)

Arctic Freshwater Synthesis

- New targeted activity looking at freshwater movement and changes in the Arctic (Terry Prowse) that will likely to have a piece on any changes of freshwater volume export to Arctic Ocean

Ice Sheet Mass Balance and Sea Level Working Group

- Co-sponsor with SCAR/IASC, Ed Hanna contact. Goals of the new group are varied – CliC will be leading an effort under ISMASS for ice sheet model intercomparisons, development of a ice sheet modeling forum and contributing to workshops for early career scientists, as well as helping with online resources

Workshops

Antarctic Ice Rises Workshop

- Workshop looking at the role of ice rises in stabilizing the Antarctic Ice Sheet

Tidewater Glacier Workshop

- Workshop report from August 2012, and follow up activities to help identify key glaciers to watch and learn about calving, create network, etc.

Sea Level Rise Educational Resources

Joint CliC/CLIVAR organized (Jennifer R/ Jenny B)

Webinars

- Targeted at climate science communicators
- Starting this summer
- 4-6 ~ 1 hour online seminars specifically addressing new concepts since IPCC AR4 to prepare communicators for AR5
- Archived online
- Fact sheet summarizing webinars

Classroom activities for teachers

- Together with Polar Educators International
- Updating existing resources

Graphics Archive

- Online database of high quality images, animations, videos, etc
- Verified by Researchers

Regional sea level variability and change

Areas primed for progress in the next 5-10 years that will benefit significantly from CLIVAR coordination.

(I) Improve Past Regional Sea Level Reconstructions

- Complement the tide gauge record with more (proxy, *e.g., salt marshes*) data *liaise with PAGES*
- Co-ordinated model-data synthesis effort (multi-model, multi-method) Liaise with *WGOMD*
- Integration of ice sheet modeling, ocean modeling, sea level reconstructions, and land motion (***holistic view**, liaise with other groups outside WCRP)*

(II) Improve understanding of present changes and underlying causes

- Separate natural and anthropogenic changes; identify forcing;
- Observation of deep ocean T & S changes *CLIVAR basin panels*
- Explore novel forcing strategies, atmospheric feedbacks… *WGOMD*
- Additional fw input from melting of glaciers -- *glaciology*
- *Test* climate models against present day changes and processes -- *WGCM*

Regional sea level variability and change

Areas primed for progress in the next 5-10 years that will benefit significantly from CLIVAR coordination.

(III) Future Projections (*interaction between modeling, glaciology and geodesy)*

- Obtain a better understanding and reduction of uncertainties in climate models with respect to sea level
- Addition of missing processes and components into climate models: e.g., ice sheet dynamics and ice sheet mass loss, changes in terrestrial hydrology
- Initiate a coordinated climate modeling effort with improved representation of regional ocean dynamics; ice sheet-ocean interaction; changes in terrestrial hydrology
- Liase with WGCM ?, CLIC, ...CMIPX, ...

(IV) Ocean-Coastal and Human Interaction

- Account for coastal effects in future projections as well as non-climate related anthropogenic effects:
- Shelf dynamics: Integration of open ocean and shelf modeling
- Impacts of storm surges and waves?
- Inclusion of sediment and ground mining effect
- *Liaise with social sciences, coastal community, geodesy and social sciences*