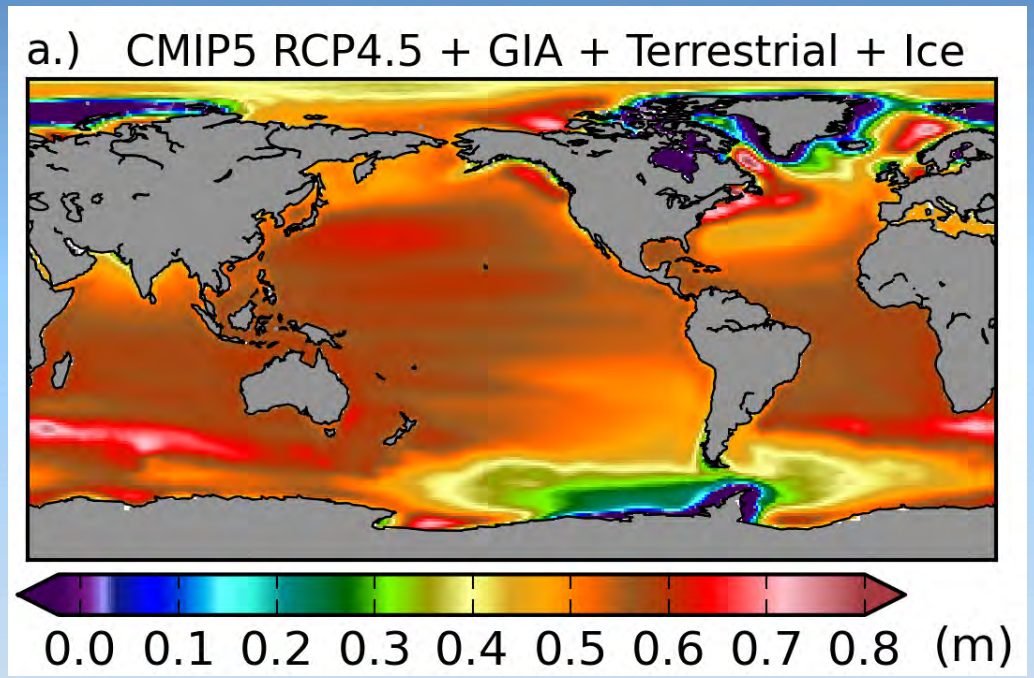
Sea-Level Rise and Regional Impacts



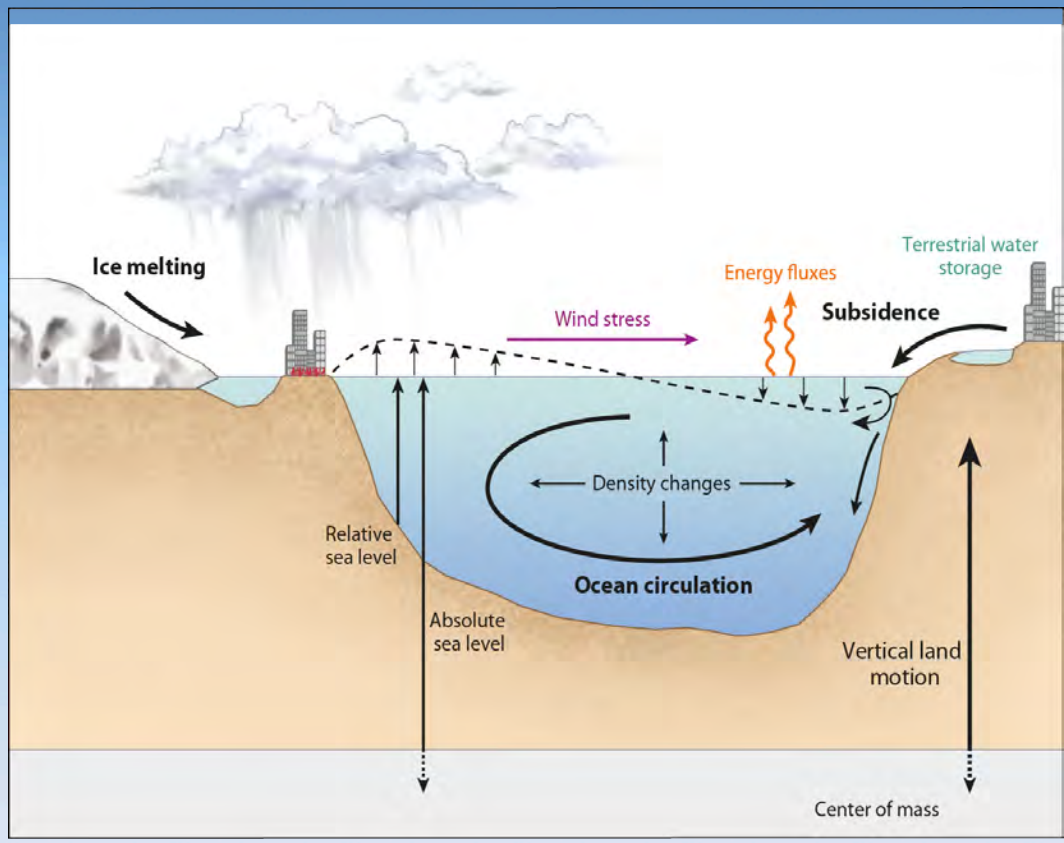
Detlef Stammer and Catia Domingues
GC Sea Level Scoping Team

WCRP World Climate Research Programme

CLIVAR

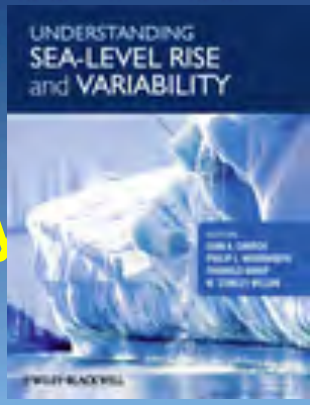
Regional Sea Level

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



Dealing with sea level requires interaction with many communities

Some History



2006: 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

Outcome

WCRP report summarizing the at that time current state of the state, 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).

The report contains 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 was published by Wiley-Blackwells

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

2009: 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

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

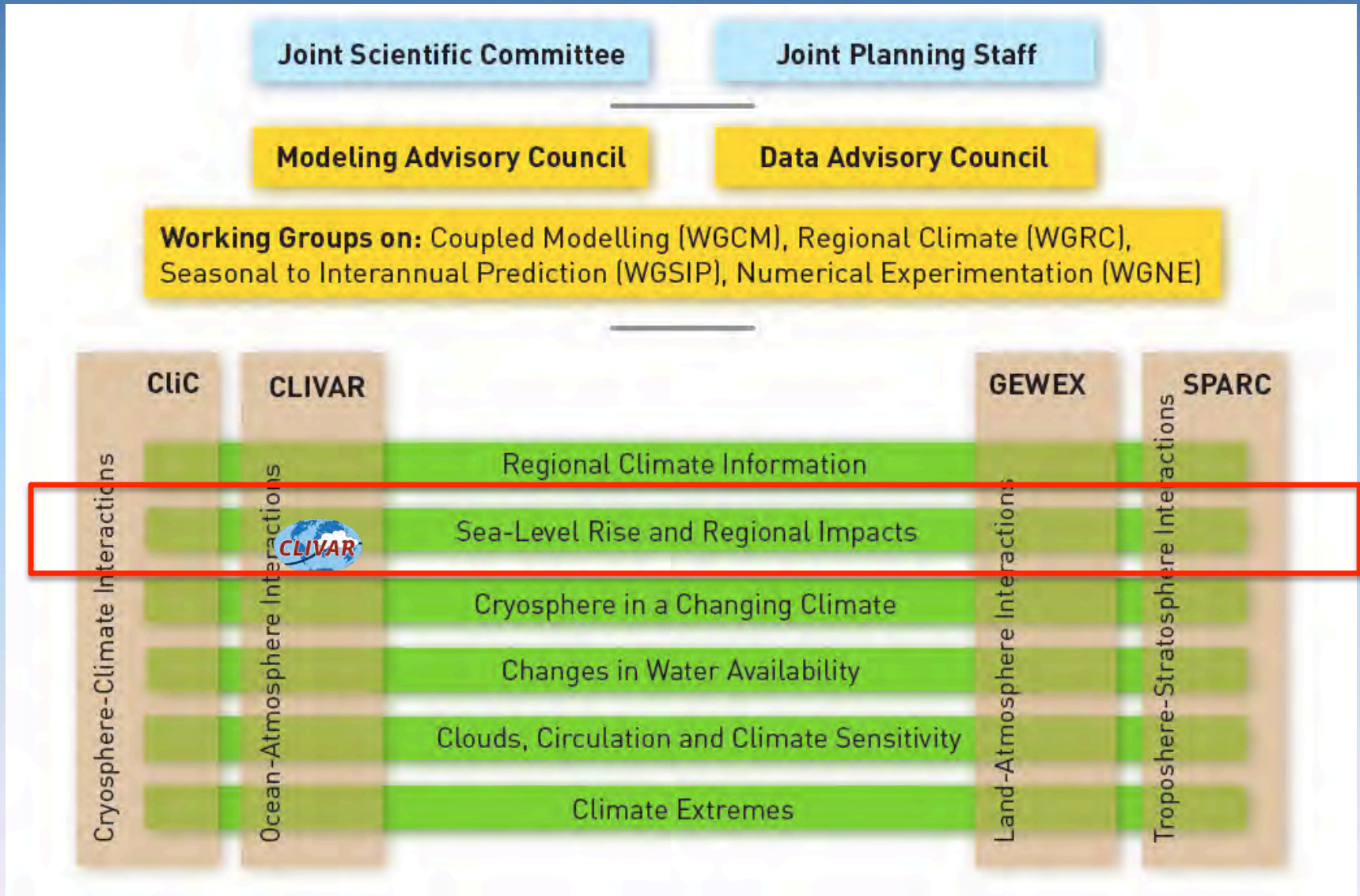
Task Group Activities
24 March 2010 1st session of the Executive Committee of the Task Group,
Bern, SWITZERLAND

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

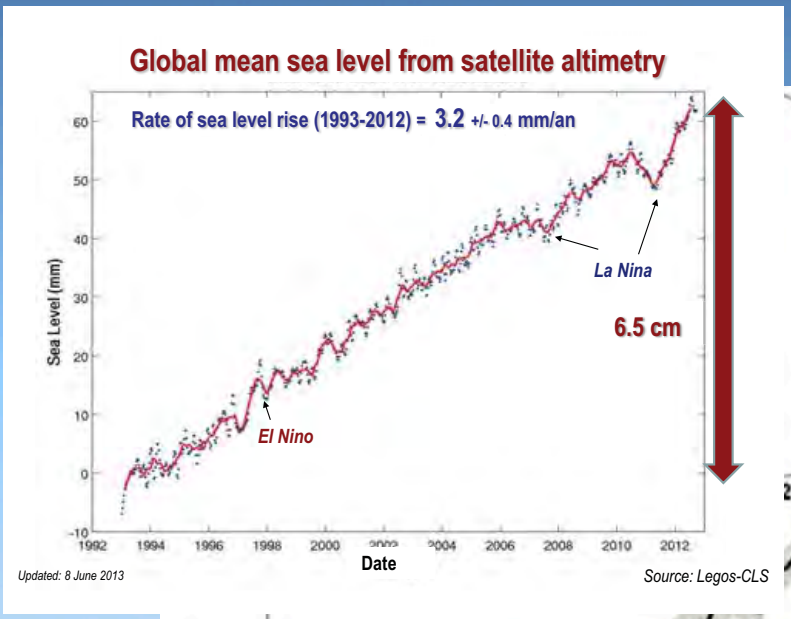
Members of the Executive Committee
- John Church (co-Chair), CSIRO Marine and Atmospheric Research, Hobart, AUSTRALIA
- Konrad Steffen (co-Chair), CIRES, Boulder, Colorado, USA
- Anny Cazenave, LEGOS, Toulouse, FRANCE
- Jonathan Gregory, NCAS and UK MetOffice, Reading UK
- Philip Woodworth, Permanent 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

The WCRP/IOC task group still exists in some stage of activeness and in parallel to GC Sea Level. Why did it not become the GC team?

WCRP Grand Challenges



Global Mean Sea Level is Rising



20th-century:
~ 1.7 mm/yr

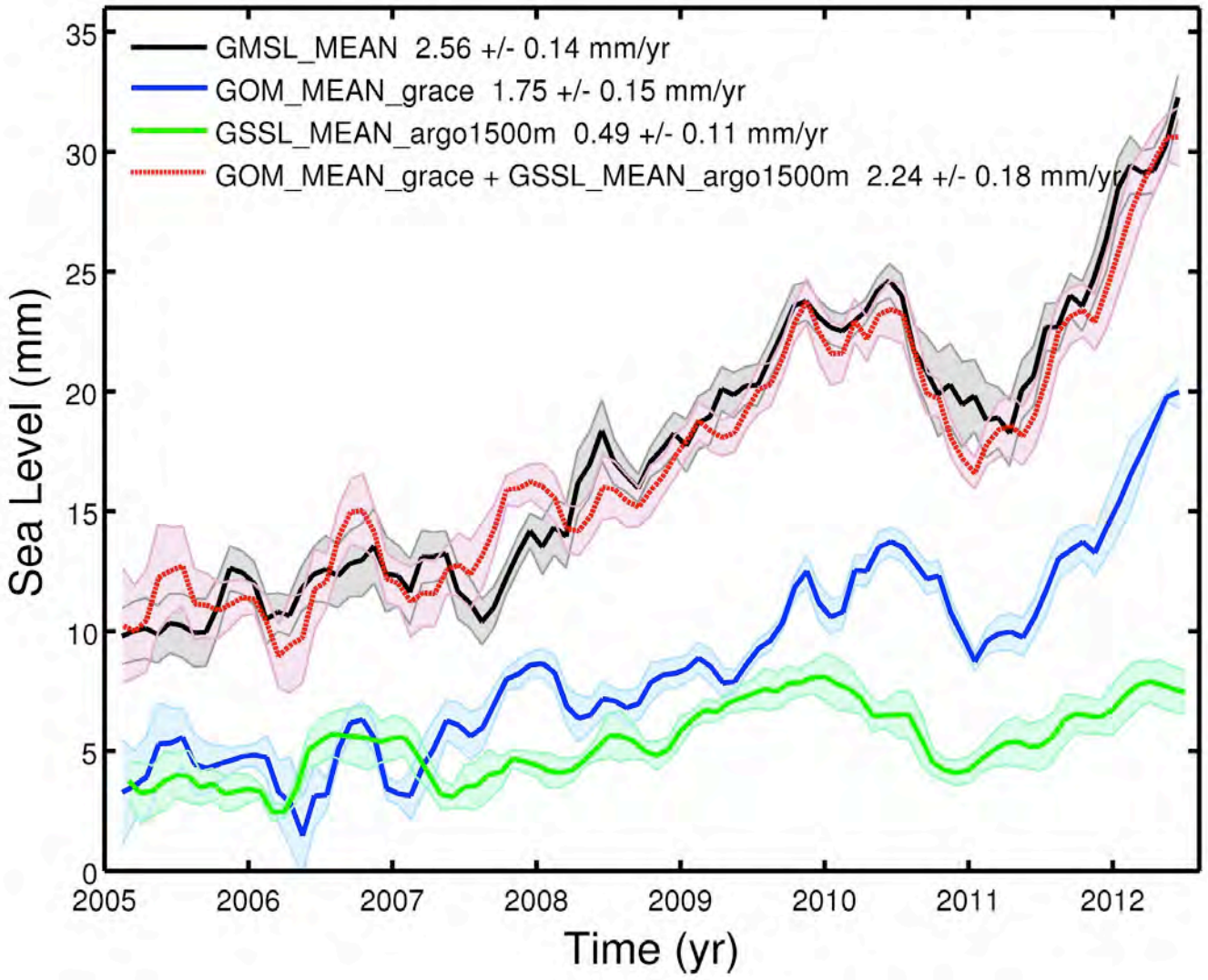
Altimetry (since 1993):
~ 3.2 mm/yr

Causes (last 20 yrs):

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

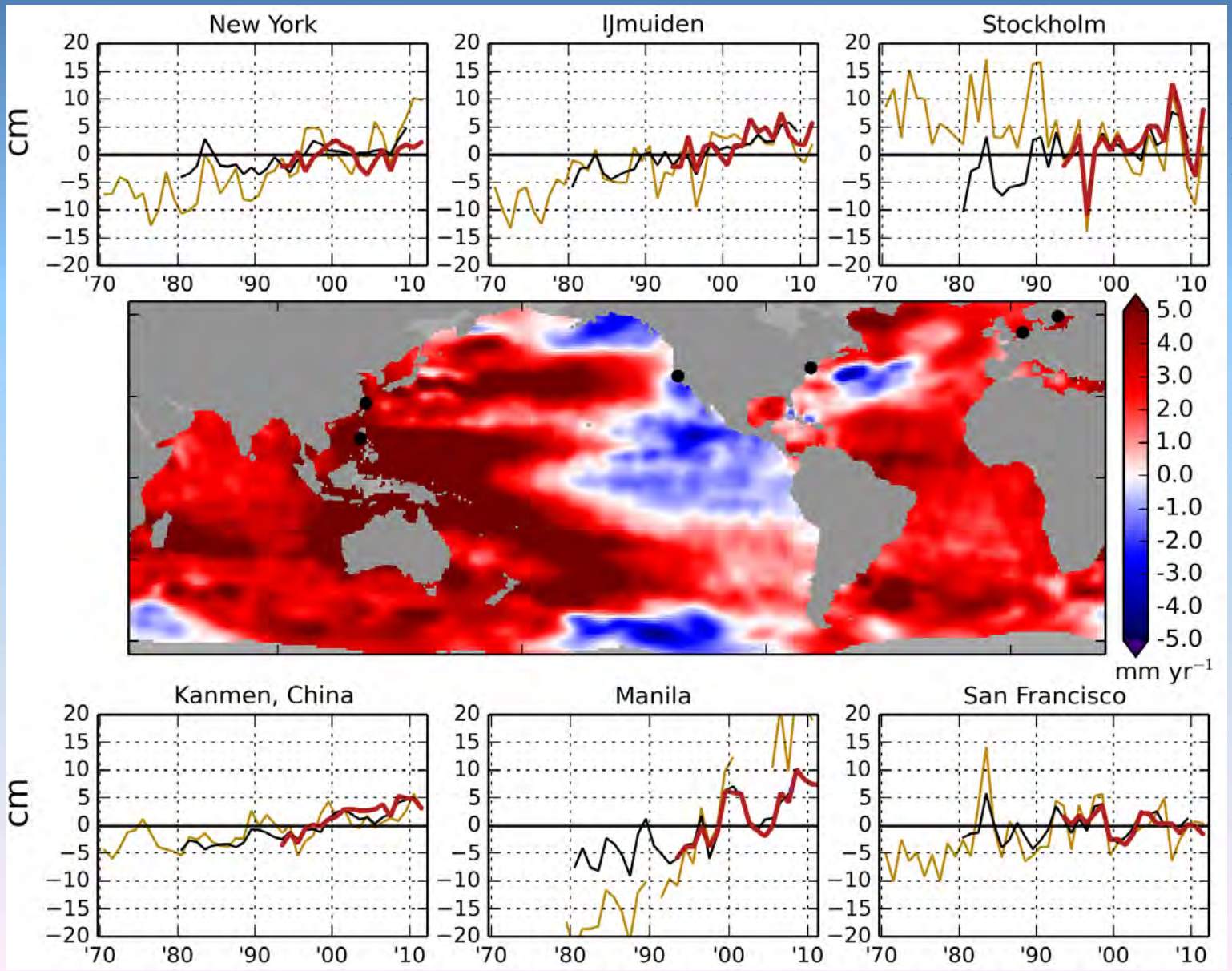
Church and White, 2011, A. Cazenave

Contributions to global Sea Level Change



K. v. Schuckmann
A. Cazenave

Strong Spatial Inhomogeneity

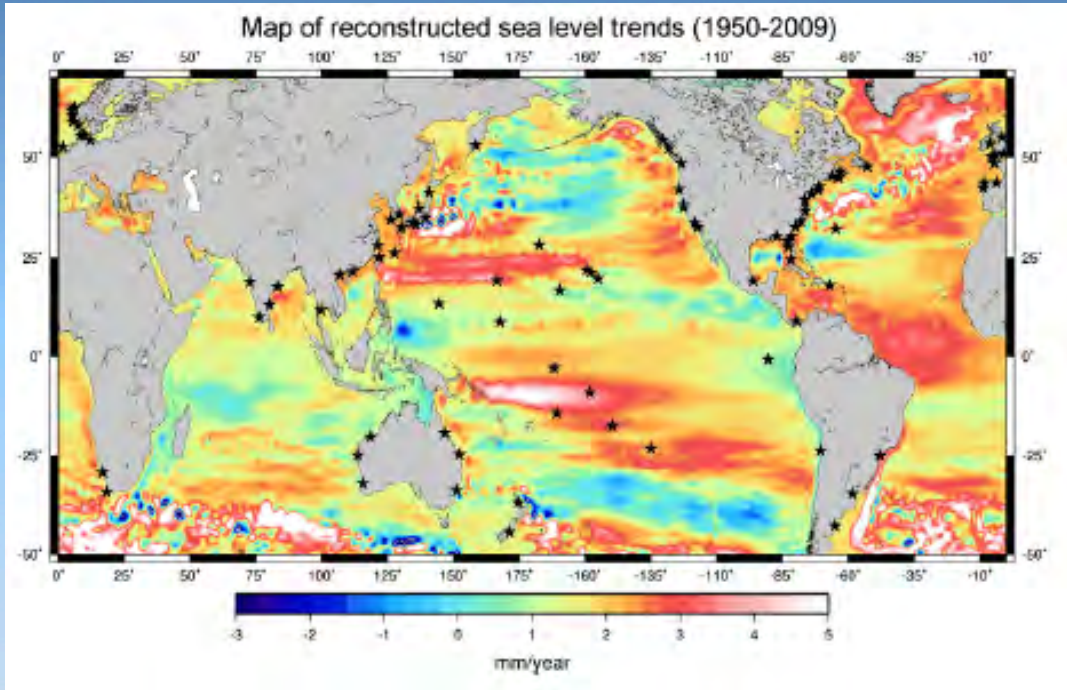


- Tide gauges
- Reconstruct.
- Altimetry

Altimetry
1993-2012

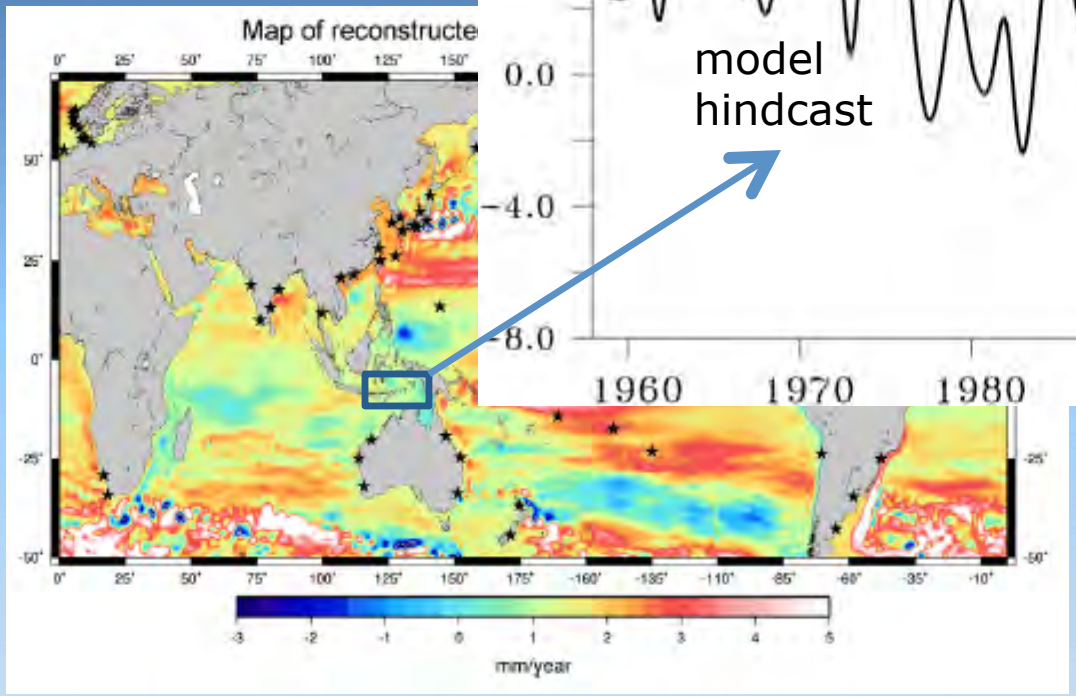
GIA not
removed

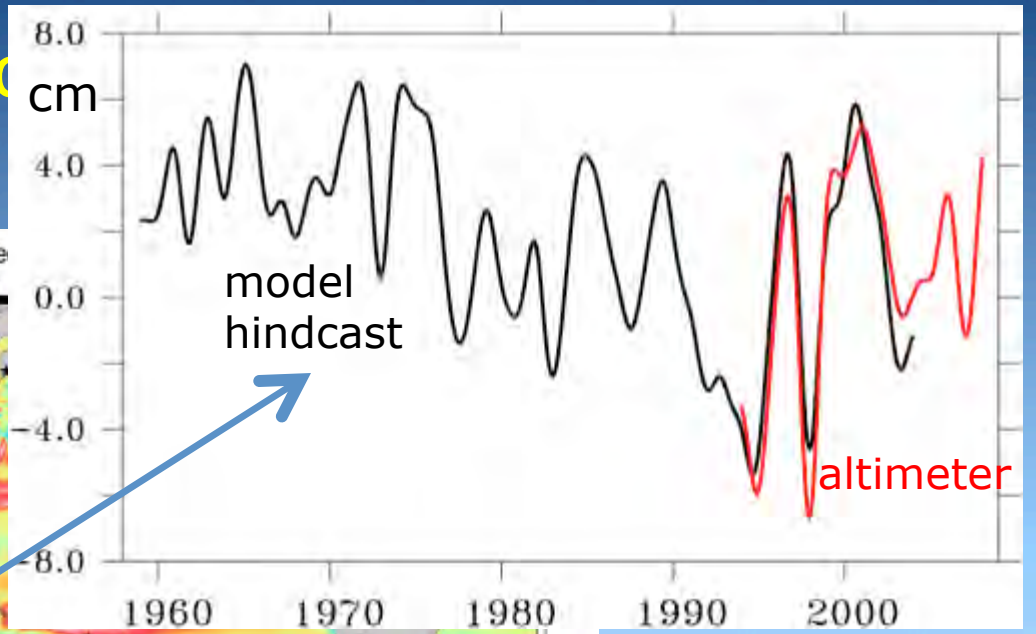
Reconstructions suggest (1950 – 2009):



Becker et al. (2012)

Reconstruc

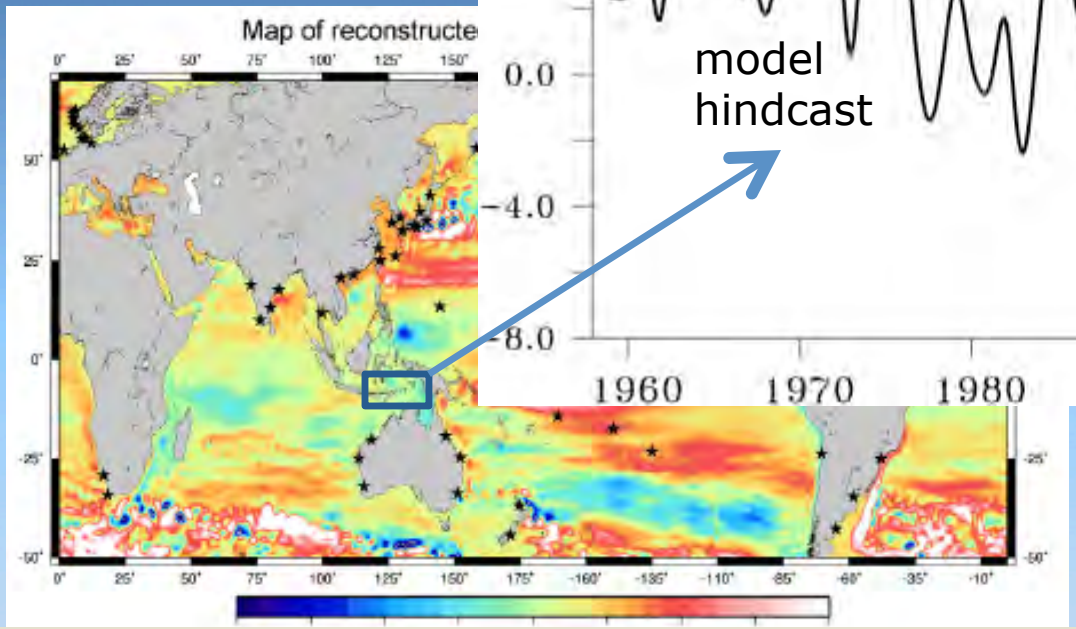


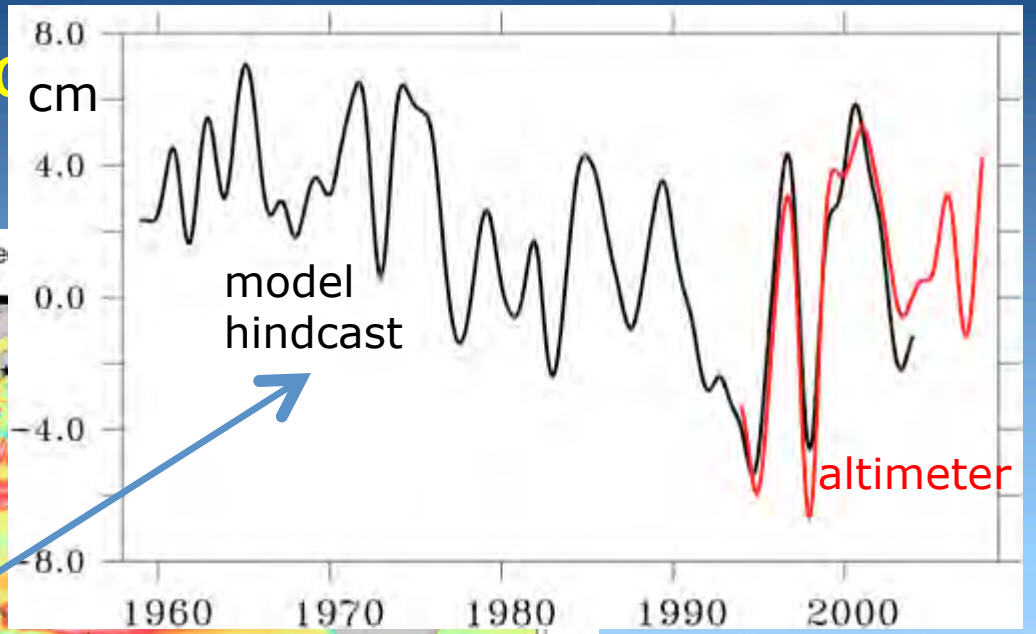


Schwarzkopf
& Böning (2011)

Becker et al. (2012)

Reconstruc



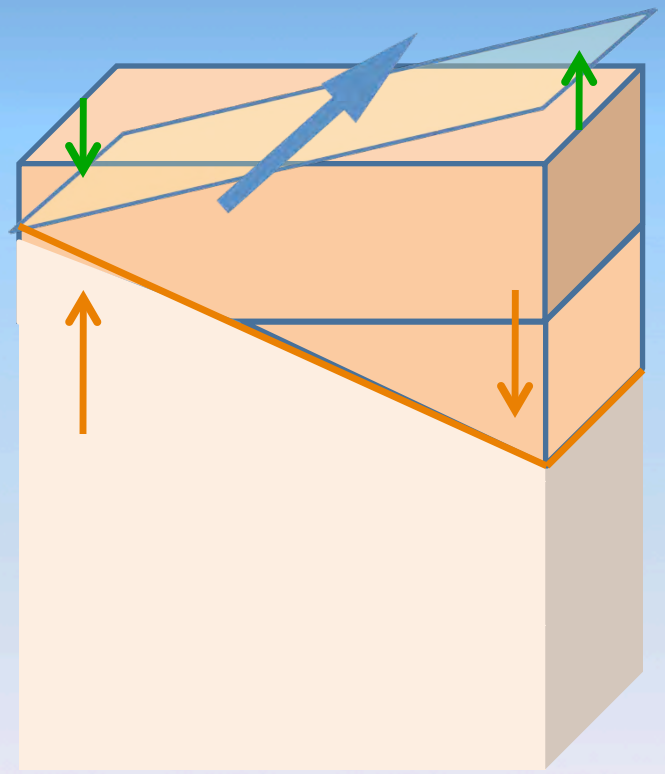


Schwarzkopf
& Böning (2011)

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

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

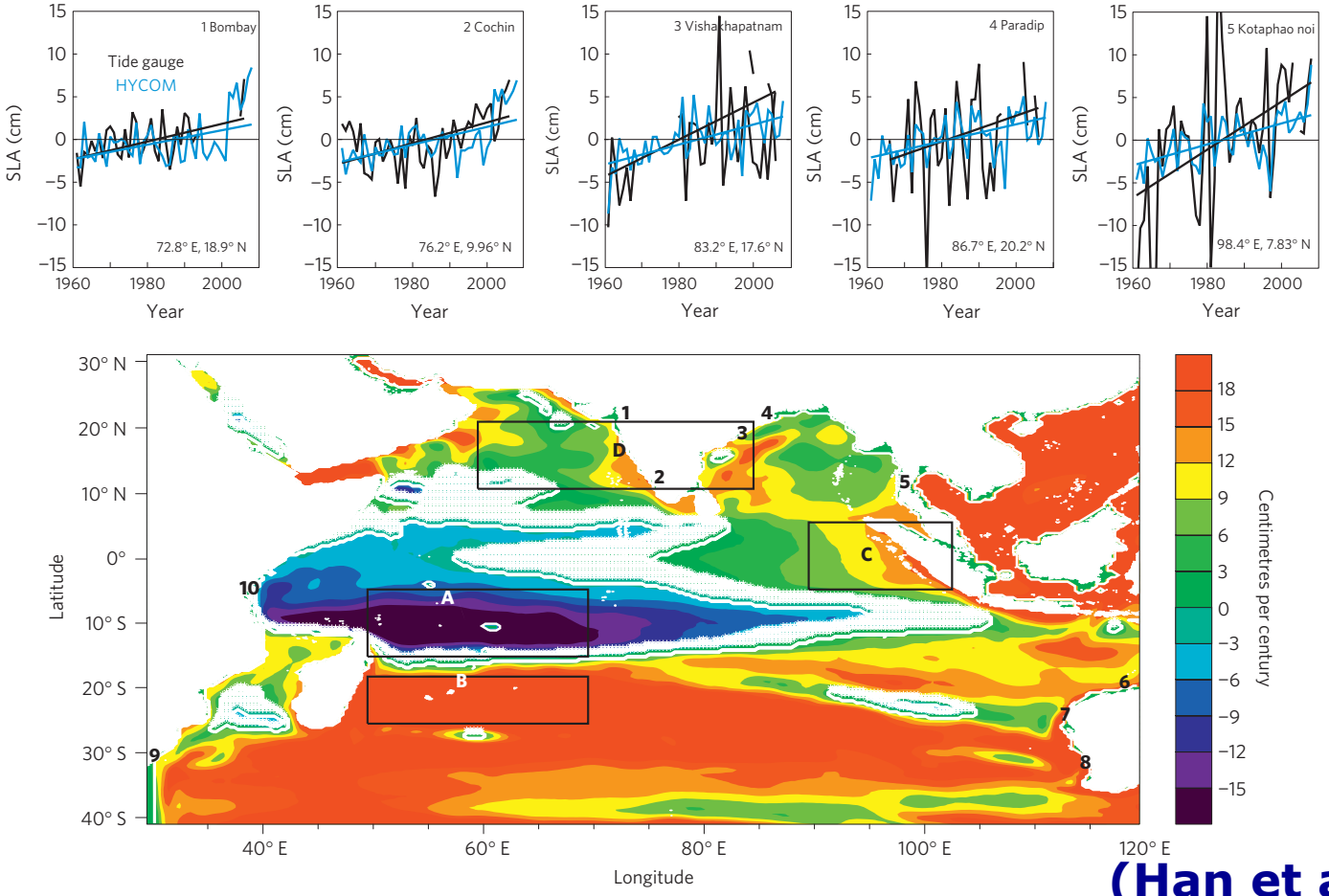
→ first baroclinic mode(s) dominate:

close link between SL and pycnocline depth;

pressure gradients do not extend to the bottom

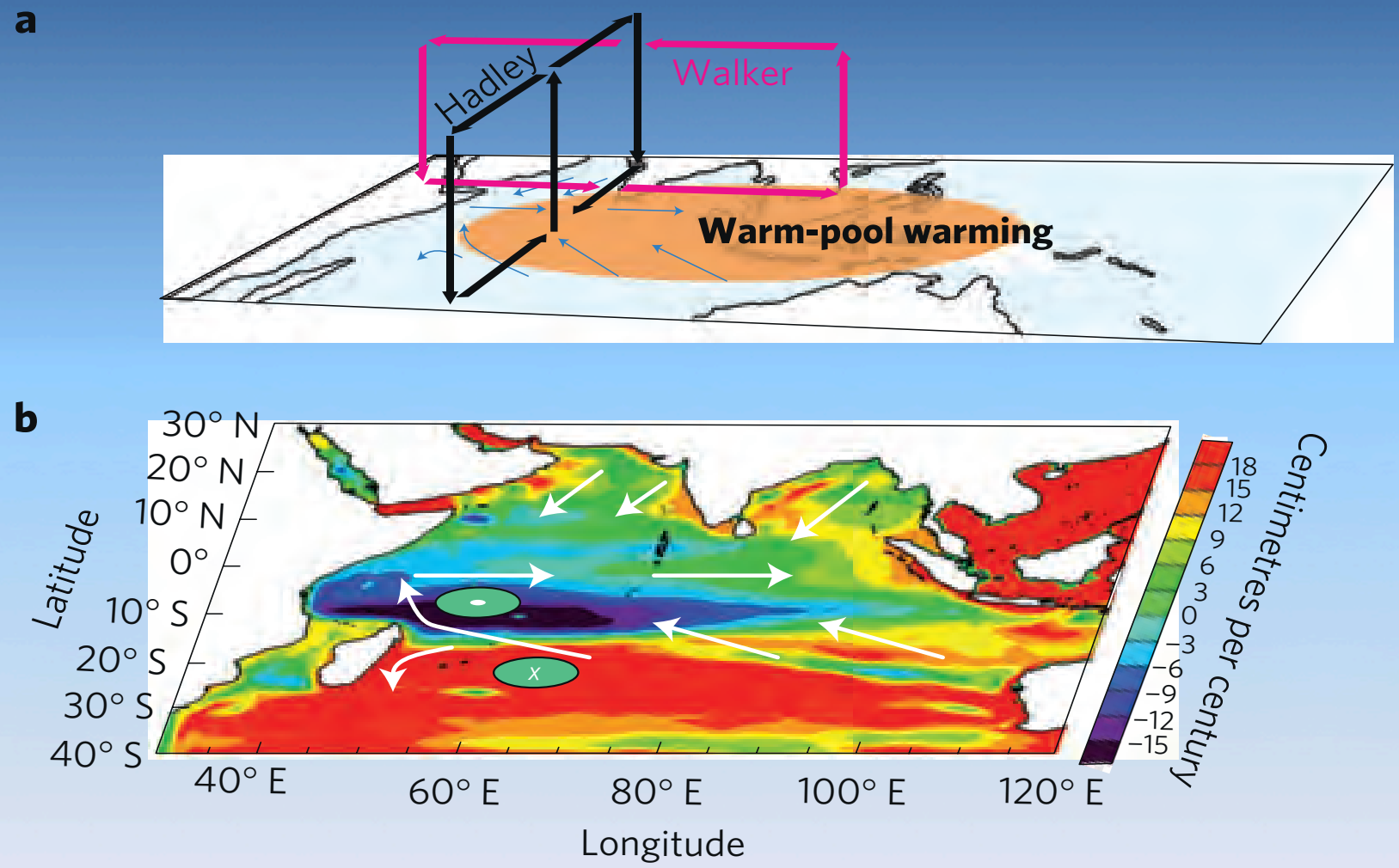
… commonly described as: „steric"

HYCOM, tide gauge SSH changes 1961 - 2008



(Han et al., 2010)

HYCOM, tide gauge SSH changes 1961 - 2008



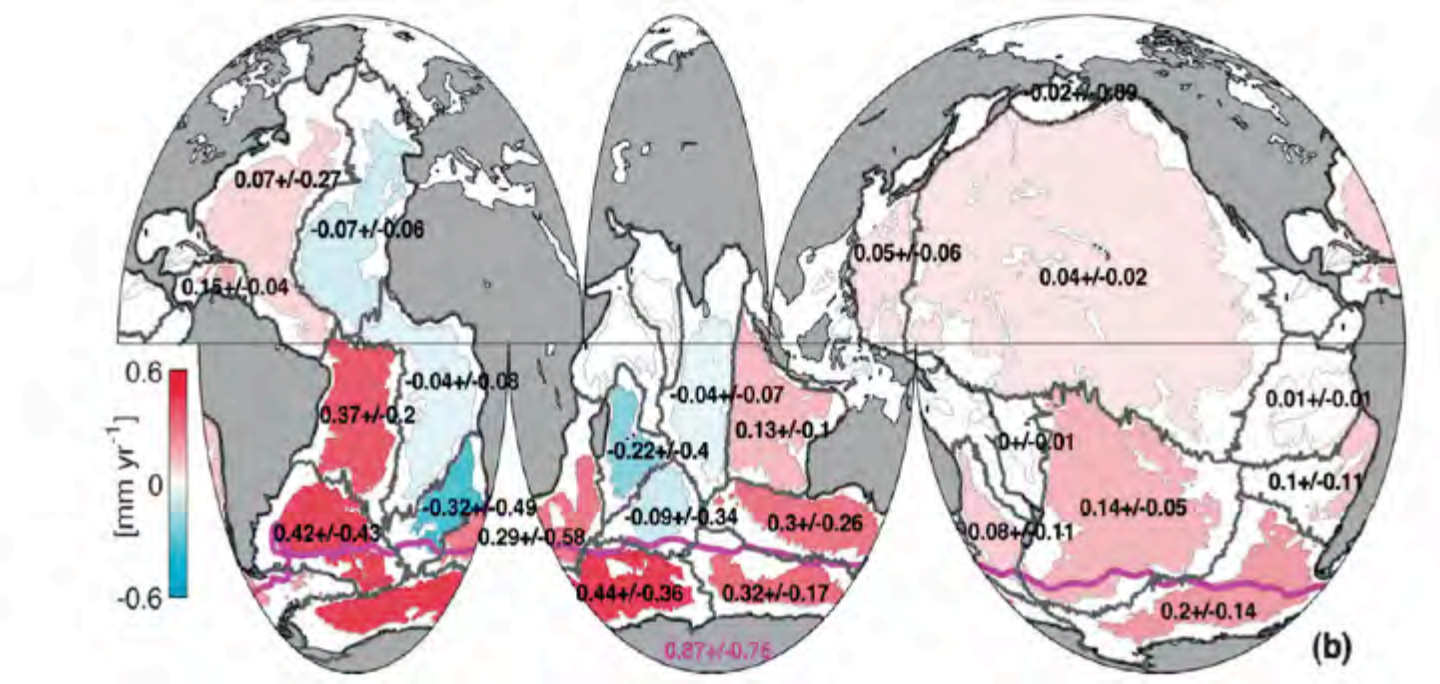
Strong coupling between climate modes and sea level.

Question: what caused this change in the atmospheric circulation?

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)

Other processes become important:

(1) *when considering longer time scales:*

- changes in heat and freshwater uptake

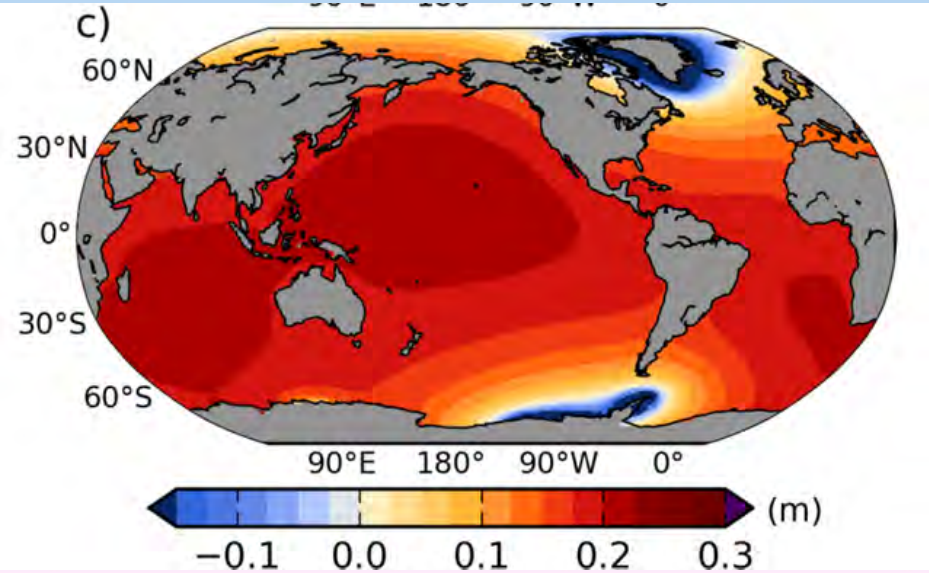
- *future:* additional fw input from glaciers and ice sheets

→ non-uniform distribution due to

- ocean dynamics
- gravitational effects: SL drops near the ice edge ...

… will become a major factor:

here: ensemble-Mean RCP 4.5 change 2100-2000



Slangen et al. (2014)

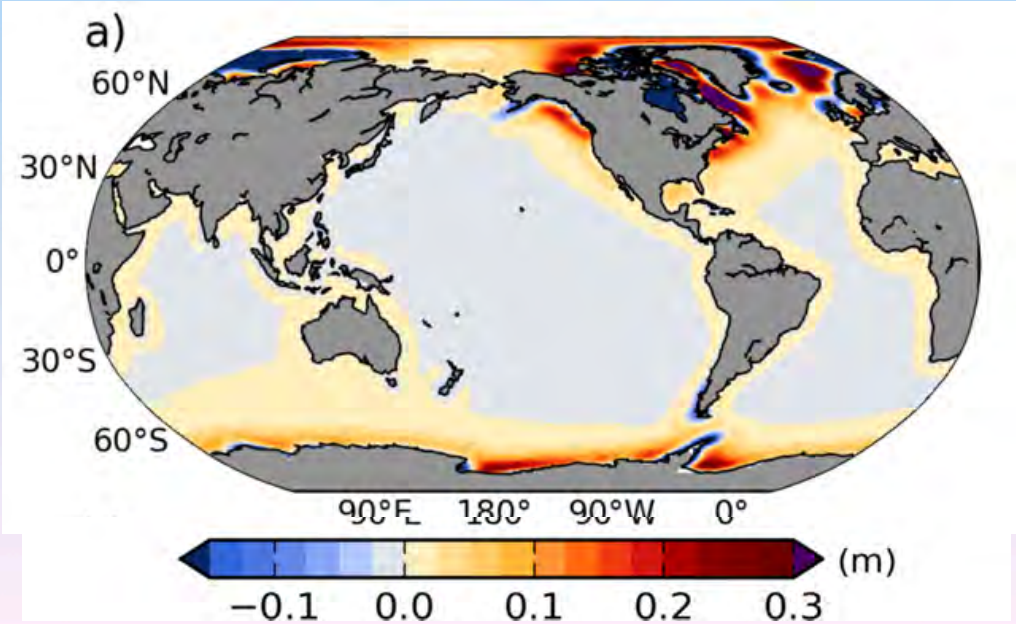
Other processes become important:

(1) *when considering longer time scales:*

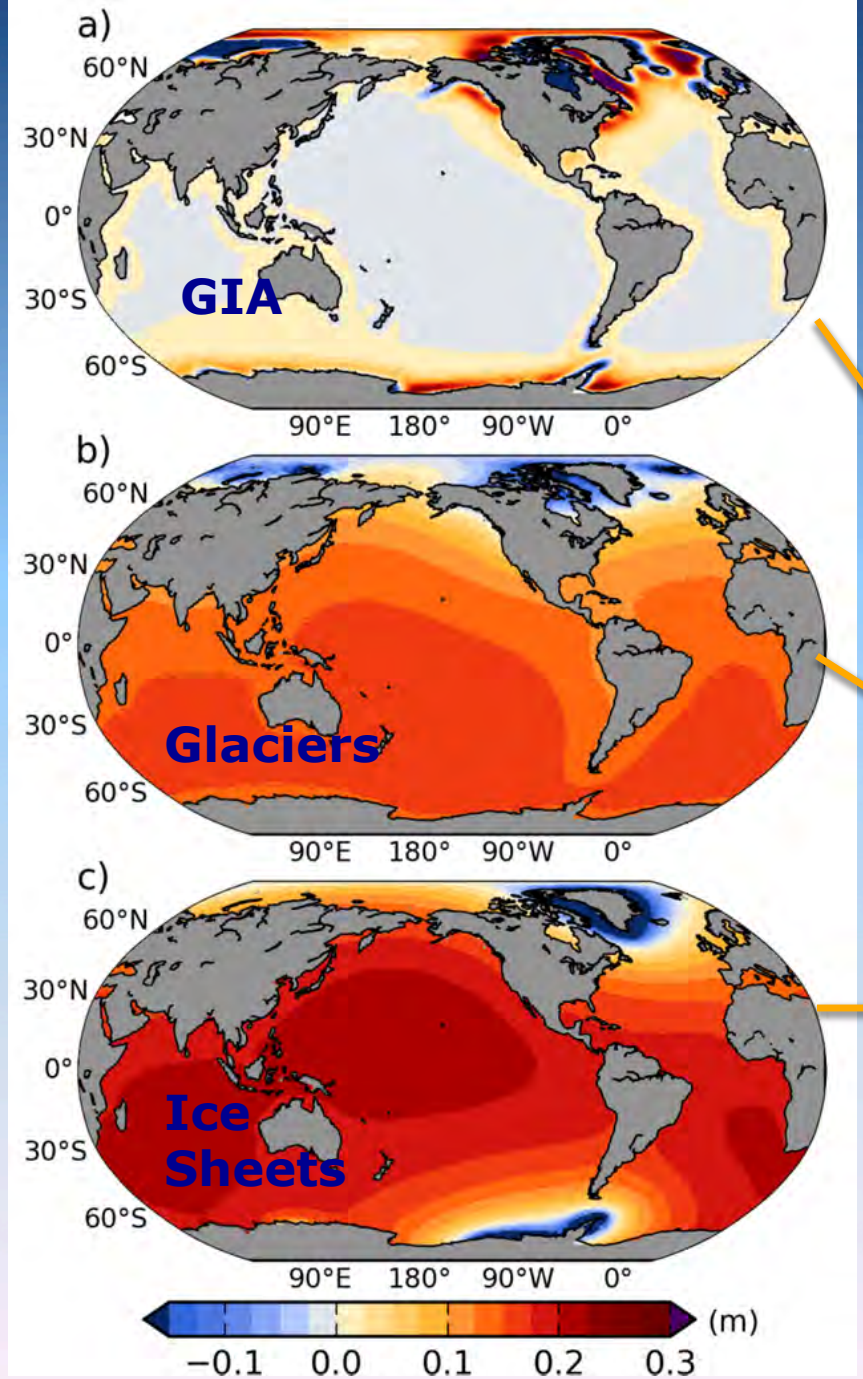
- changes in heat and freshwater uptake

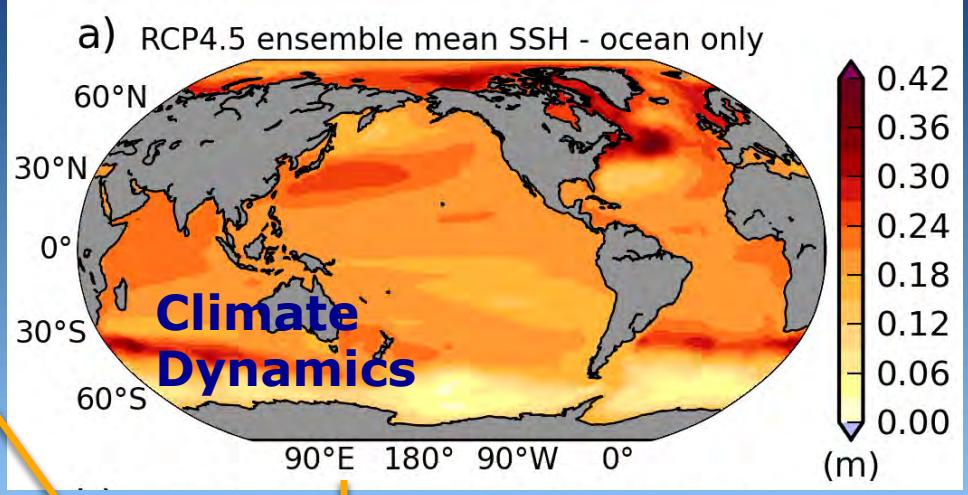
- *future:* additional fw input from glaciers and ice sheets

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

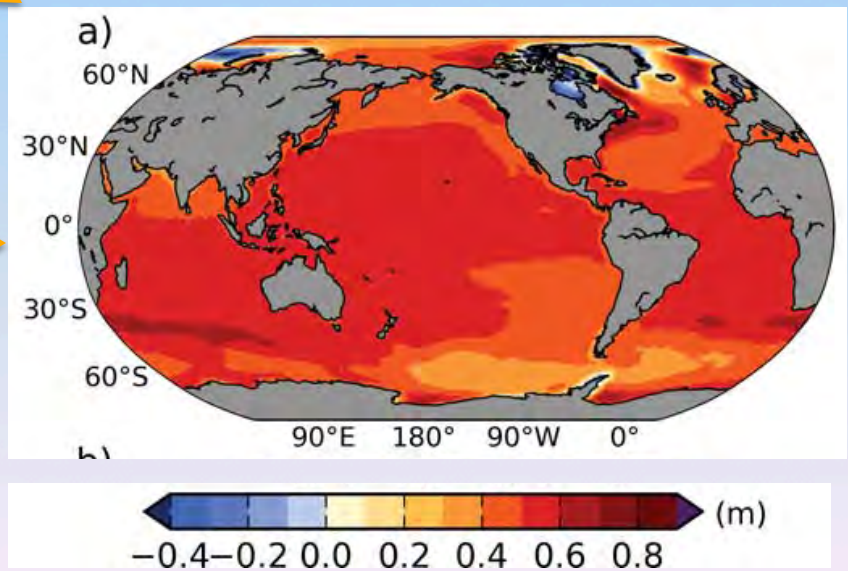


Slangen et al. (2014)



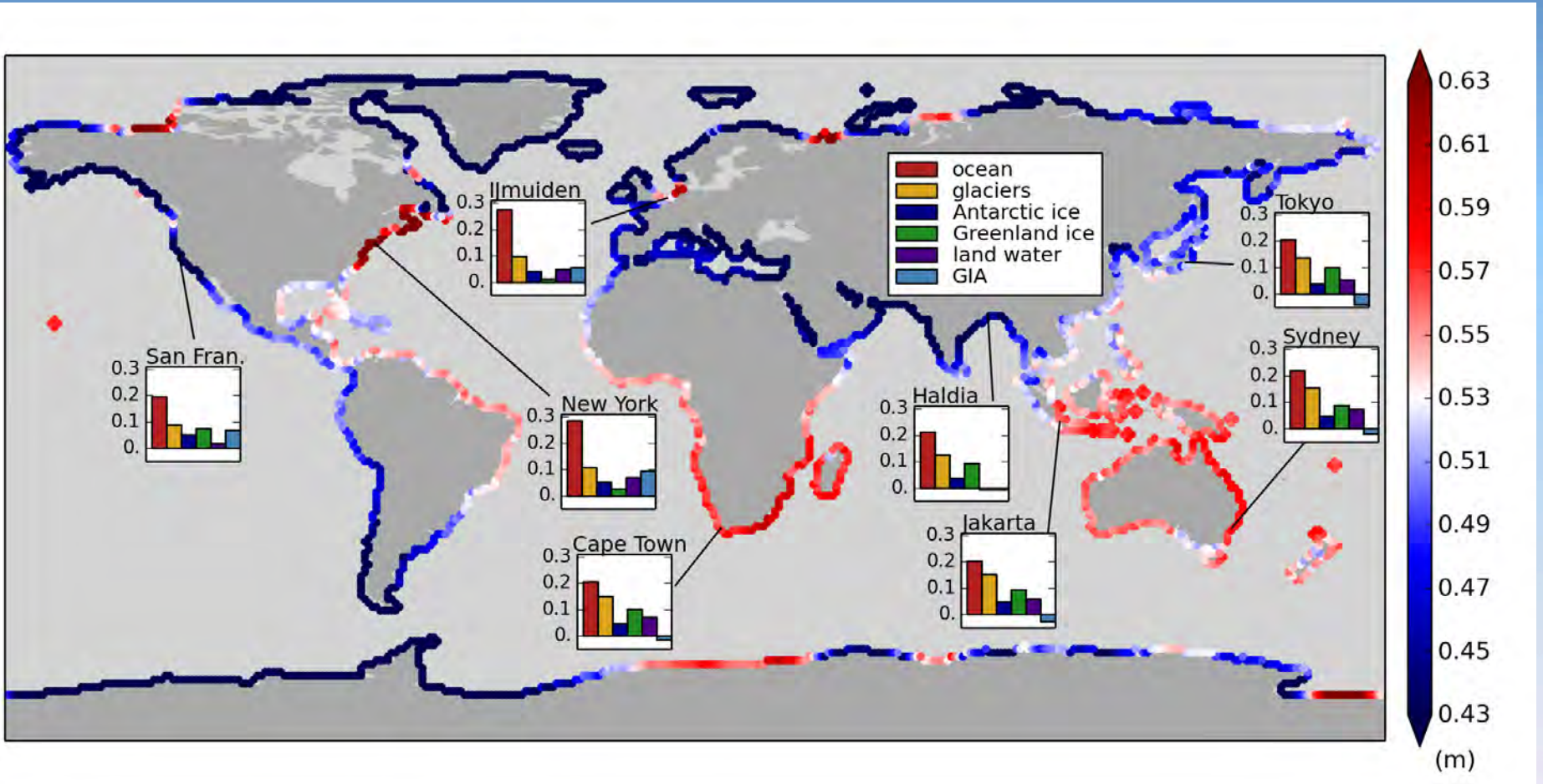


Net Sea Level Change
(plus a few other terms)



Slangen et al.(2014)

Coastal sea level:
relative to global mean, and by component.



(Carson et al., 2014)

Other processes become important:

(2) *when considering shelf regions:*

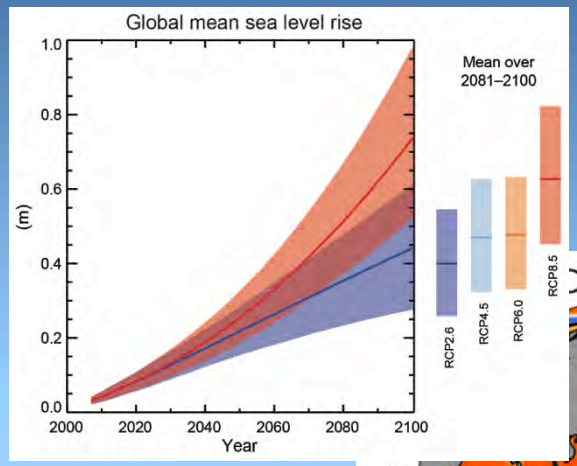
- coastal sea level can be decoupled from deep ocean through shelf sea and coastal dynamics

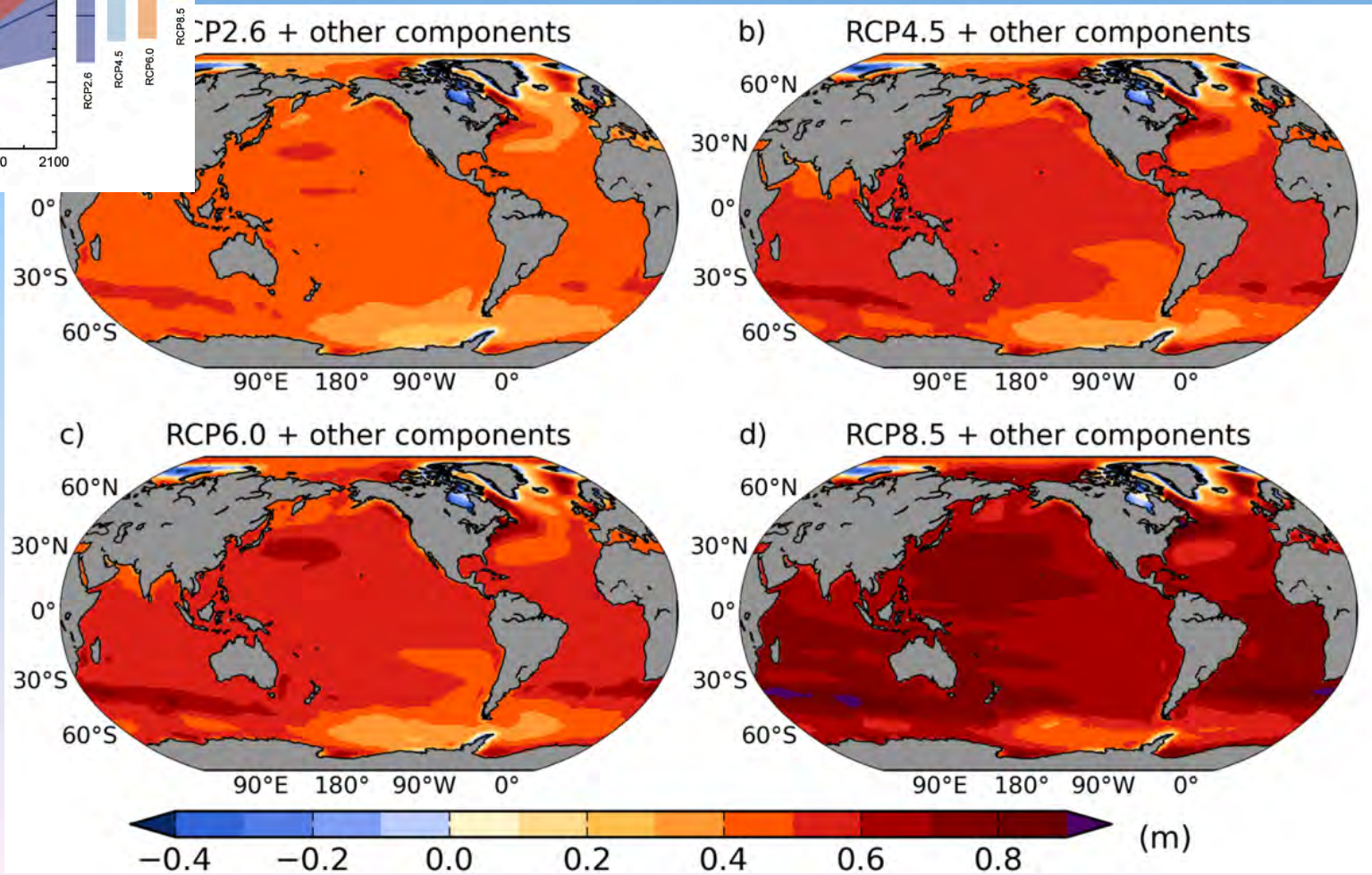
Bingham and Hughes 2012; Calafat et al. 2013

- mass redistribution (shelf mass loading)

Landerer et al. 2007; Richter et al. 2013

(1) Scenario uncertainty / global mean SL



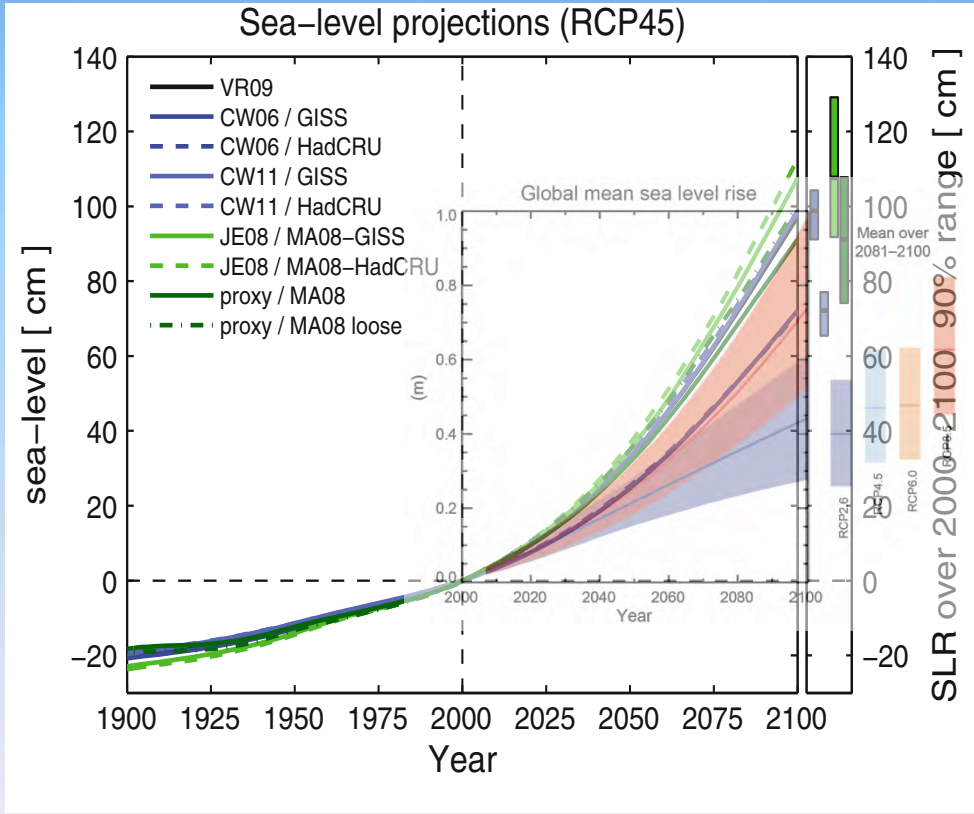


Difference Process-oriented vs. Semi-empirical Sea Level Projections

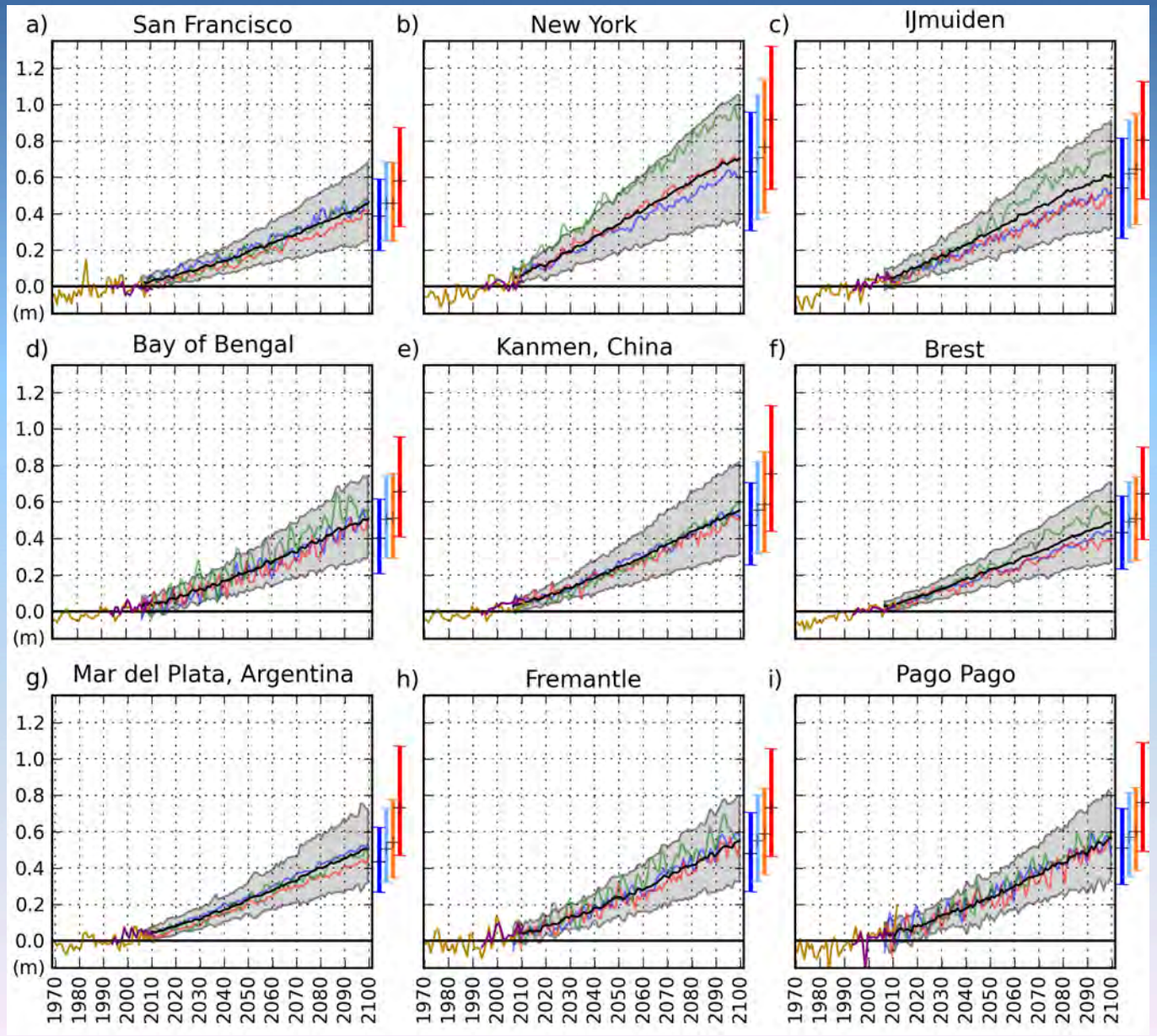
Semi-empirical models:

$$dH/dt = a(T(t) - T0) + b\, dT/dt + \ldots.$$

The gap between climate models and semi-empirical projections reduced but remains!

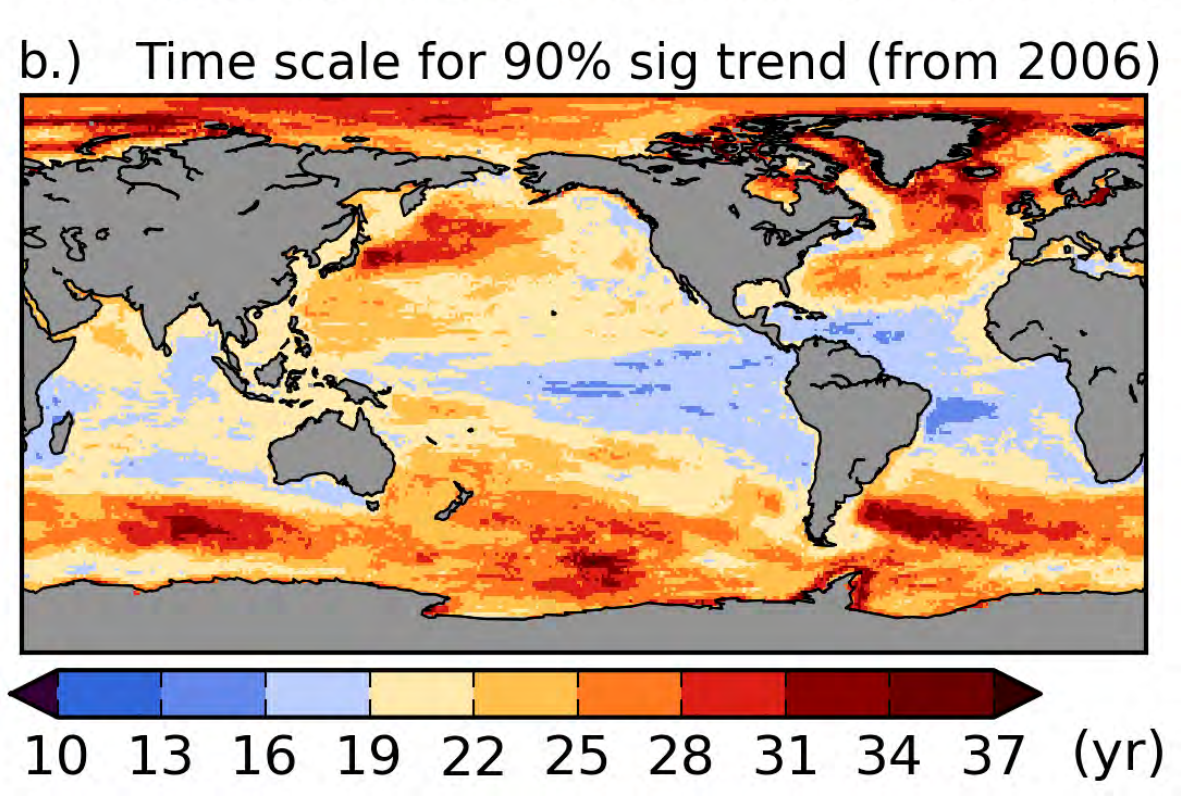


(2) Variability uncertainty / climate modes



(Carson et al., 2014)

(2) Variability uncertainty / climate modes

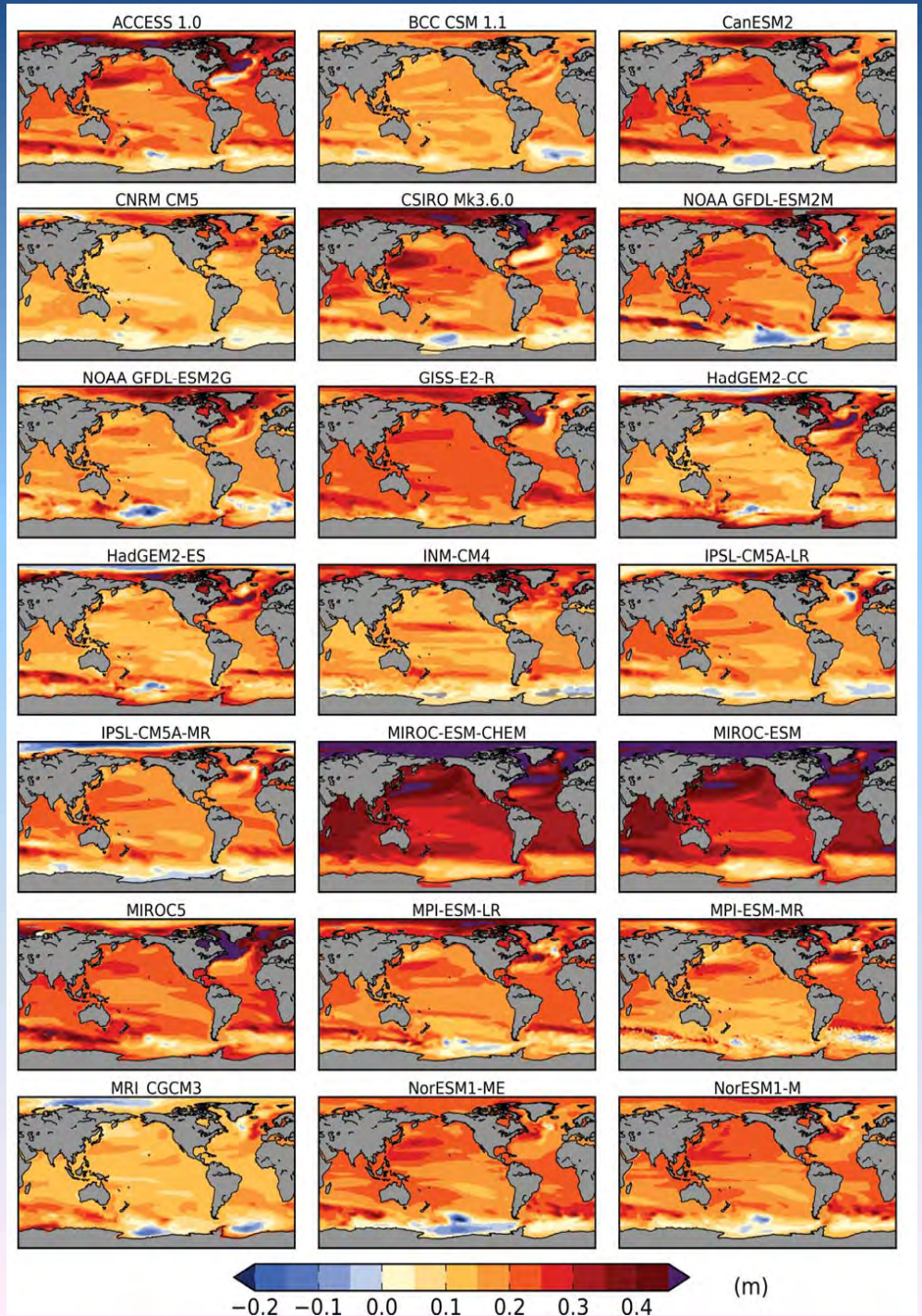


(Carson et al., 2014)

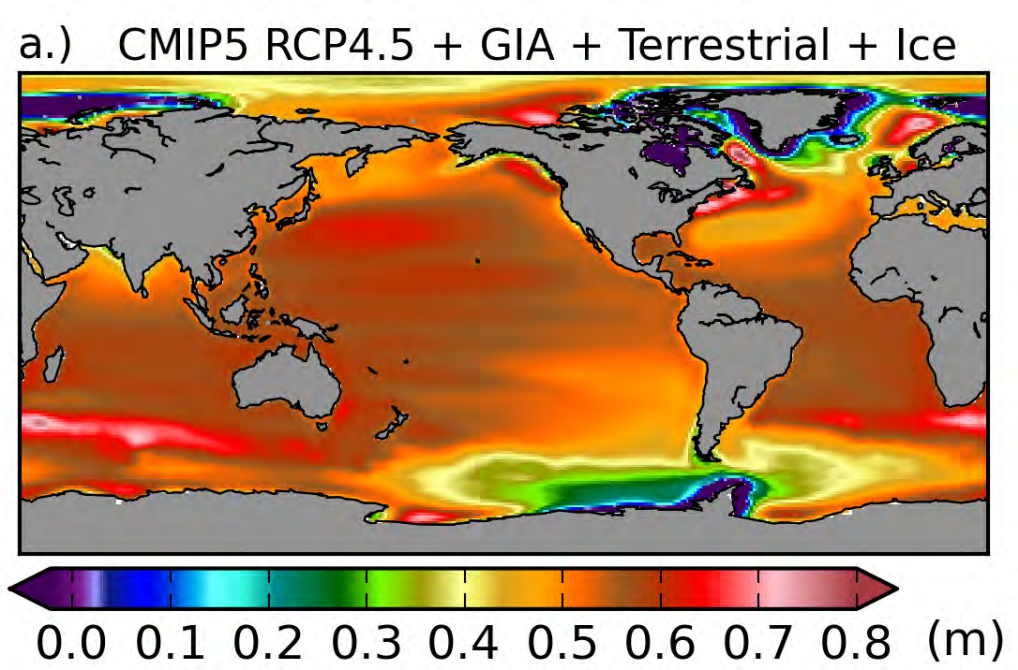
(3) Uncertainty:
Inter-model spread

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

Slangen et al. (2014)



GC:
Sea-Level Rise and Regional Impacts



WCRP World Climate Research Programme

CLIVAR

GC Sea Level Scoping Team

Expertise	Name	Country	Partner Organization
Geodesy/ Geophysics	Natalya Gomez	Harvard, USA	
	Mark Tamisiea	NOC, UK	IAG
Glaciology/ Ice sheets	Roderik van de Wal	U. Utrecht, The Netherlands	
	Tony Payne	U. Bristol, UK	CliC
Regional processes,	Edward Hanna	U. Sheffiled, UK	CliC, ISMASS
	David Holland	Courant, USA	CliC
	Rui Ponte	AER, USA	
	Detlef Stammer	CEN, Germany	SL scoping co-chair CLIVAR
	Catia Domingues	ACE CRC/IMAS/U. Tasmania, Australia	SL scoping co-chair, CLIVAR
Reconstructions	Benoit Meyssignac	LEGOS, France	
Climate modes	Axel Timmermann	IPRC, USA	
	Jianjun Yin	U. Arizona, USA	
Climate modeling	Stephen Griffies	GFDL, USA	CLIVAR
	Jonathan Gregory	U. Reading, UK	
Satellite observations/Terrestrial hydrology	Anny Cazenave	ISSI, Switzerland	WCRP JSC
Extremes, storm surges, waves and coastal impacts	A.S. Unnikrishnan	NIO, India	
	Gonéri Le Cozannet	BRGM, France	

Overarching Goal

- Establish a **quantitative understanding** of the natural and anthropogenic mechanisms of regional to local sea level variability;
- Promote advances in observing systems required for an integrated SL monitoring;
- Foster the development of SL predictions and projections that are of increasing benefit for coastal zone management.
- To meet this challenge, the **scoping team** has developed an **integrated interdisciplinary program** on SL research reaching from the global to the regional and local scales.
- Program aims for **close interaction with coastal communities** to assure that results of the proposed scientific research are incorporated into practices of **coastal zone management, and impacts and adaptation efforts**.

Overarching Goal

- The GC effort will focus on all components of **global to local sea level changes** and will consider the necessary analyses on global and regional **climate change data and simulations**, extreme events and potential impacts, including the evaluation of **sea level rise impacts for coastal zones**.
- Studies related to detailed impact assessments and the development of adaptation plans cannot be performed as part of this WCRP GC on SL.
- There is presently a lack of evidence regarding the role of contemporary sea level rise in coastal erosion, submersion and saline intrusions in aquifers (IPCC WG2 Ch. 18) and this requires attention in future studies.

Structure of the GC Sea Level

- The structure of the GC Sea Level effort will consist of a **GC executive team** and **working groups (WG)** underneath, focusing on individual subjects.
- In each working group, led by up to three co-chairs representing different core disciplines, an **integrated approach** is envisioned, involving theoretical concepts, observations and models.
- Jointly with two co-chairs, the WG leadership would make up the **GC Sea Level executive membership**.
- **GC Sea Level chairs will involve natural and coastal sciences**.
- Membership within each WG will involve members from joint CLIVAR/ CLIC/GEWEX/SPARC, modeling groups, but also from other relevant programs (e.g, PAGES, IAG).
- GC Sea level co-chairs will report to the WCRP JSC and the CLIVAR SSG.

Work Programm

Five parallel, but interconnected, working groups:

1) **An integrated approach to historic sea level estimates (paleo time scale)**
2) **Process understanding of fast ice sheet dynamics (contemporary)**
3) **Causes for contemporary regional sea level variability and change**
4) **Predictability of regional sea level**
5) **Sea level science for coastal zone management**

- The GC team will provide an assessment of the state of affairs of sea level research every 2 years and will use the resulting information to make adjustments of its science plan and recommendations for international sea level research efforts.
- It is also planned that the GC team will write summaries on data and modeling issues, bringing together information and recommendations from all working groups.

WP I: An integrated approach to historic sea level estimates *(paleo time scale)*

Potential lead: Natalya Gomez, Roderik van de Wal, Mark, Tamisiea

Challenges:

- Generating a consistent sea level budget for different time periods:
  - Last Glacial Maximum – far-field sea level indicators in agreement with total ice volume
  - The Eemian interglacial and other warm periods (e.g. Mid-Pliocene) in the past, when temperatures were only slightly higher than today but sea levels were much higher
  - The 20th century and recent budgets considered in WP 3.
- Self-consistent interaction between the models of ice, land, ocean, and atmosphere
- Understanding ice and sea level histories over Holocene
- Assessing the effects of a lateral variations in earth structure and non-Maxwell rheologies
- Supplementing geologic sea level indicators with geodetic data, while accounting for other contributors to these observations
- Identifying weaknesses in the observational data set of paleo sea level change

Fields involved: geodesists, glaciologists, geophysicists, geologists and geomorphologists.

WP 2: Process understanding of fast ice sheet dynamics (contemporary) (**CliC**)

Potential lead: Tony Payne, David Holland, Fiamma Straneo

Challenges:

- Process understanding of ocean ice interaction
- Downscaling sea level information along ice-ocean interface.
- Mass transfer form ice sheets to ocean
- Regional coupled ocean/glacier intercomparison; Later entire coupled ice sheet/ocean intercomparison study

Fields involved: ocean, glaciologists, atmospheric sciences

WP 3: Causes for contemporary regional sea level variability and change

Potential lead: Rui Ponte, Catia Domingues, Benoit Meyssignac

Challenges:

- Understanding and reducing uncertainties in individual contributions to contemporary sea level budgets at global, regional and local spatial scales.
- Role of climate (ocean coupled) modes of variability (e.g., ENSO, IOD, PDO, SAM, NAO, AMO).
- Role of coastal and ocean interior processes (e.g., shelf sea dynamics, ocean mixing, freshwater input, etc).
- Attribution of regional sea level change to natural (e.g., solar, volcanic) and anthropogenic (e.g., tropospheric aerosols, greenhouse gases) radiative forcing agents.
- Requirements for an optimal and integrated (satellite and groundbased) sea level observing system.

Fields involved: oceanography, terrestrial hydrology, glaciology, geodesy, atmospheric science

WP 4: Predictability of regional sea level

Potential lead: Jonathan Gregory, Jianjun Yin, Tony Payne

Challenges:

- Determining limits of predictability of sea level as function of space and time scale and the role of changing climate modes for sea level predictions.
- Understanding and reducing regional inter-model sea level spread in predicted sea level due to change in ocean properties (temperature, salinity, circulation, mass distribution).
- Provide reliable uncertainties for sea level predictions and projections, including those for ice sheets and glacier projections.
- Incorporate processes relevant for sea level change in AOGCMs, especially glaciers, ice-sheets and terrestrial hydrology . Including ice-sheets will place a focus on a better representation of polar regions in climate models.
- Tipping points for Greenland and western Antarctica ice sheets (CliC).

Fields involved: ocean, terrestrial hydrology, glaciology, geodesy, atmosphere, climate

WP 5: Sea level science for coastal zone management

Potential lead: Goneri Le Cozannet, S.Unnikrishnan, Kathy McInnes, Kevin Horsburgh

Challenges:

- Sea level information potentially useful for coastal community
- Transitioning sea level variability and uncertainties from regional to local coastal scale,
- Probabilistic information and return-period from combined effects of sea level rise and changes in extremes (e.g., storm surges).
- Pilot studies for mega city, delta, island state, etc. using accurate sea level products from working groups 1-4.

Fields involved: geodesy, geophysics, geologist, geomorphologists, coastal oceanography, social, environments and economic sciences, coastal engineers, atmospheric scientists

Potential GC Sea Level Team

Expertise	Name	Country	Partner Organization
Geodesy/ Geophysics	Natalya Gomez	Harvard, USA	IAG
	Mark Tamisiea	NOC, UK	IAG
Glaciology/ Ice sheets	Roderik van de Wal	U. Utrecht, The Netherlands	IPCC
	Tony Payne	U. Bristol, UK	CliC
	Fiamma Straneo		CliC
Regional processes, Reconstrcutions Climate modes Climate modeling	David Holland	Courant, USA	CliC
	Rui Ponte	AER, USA	
	Detlef Stammer	CEN, Germany	CLIVAR
	Catia Domingues	U. Tasmania, Australia	CLIVAR
	Benoit Meyssignac	LEGOS, France	
	Jianjun Yin	U. Arizona, USA	
	Jonathan Gregory	U. Reading, UK	IPCC
Extremes, storm surges, waves and coastal impacts	A.S. Unnikrishnan	NIO, India	IPCC
	Gonéri Le Cozannet	BRGM, France	
	Kathy McInnes	CSIRO, AU	
	Kevin Horsburgh	NOC	IOC/WMO JCOMM
	R. Nicholls	NOC	

Time Line

1) Presentation of draft science plan at JSC

2) Discussion of draft science plan at pan-CLIVAR meeting in The Hague (July 2014)

3) Consultation with communities outside WCRP

4) Revision of science plan jointly with CliC and GEWEX (?)

5) Presentation to CLIVAR SSG, Nov. 2014

6) Start of work before end of 2014