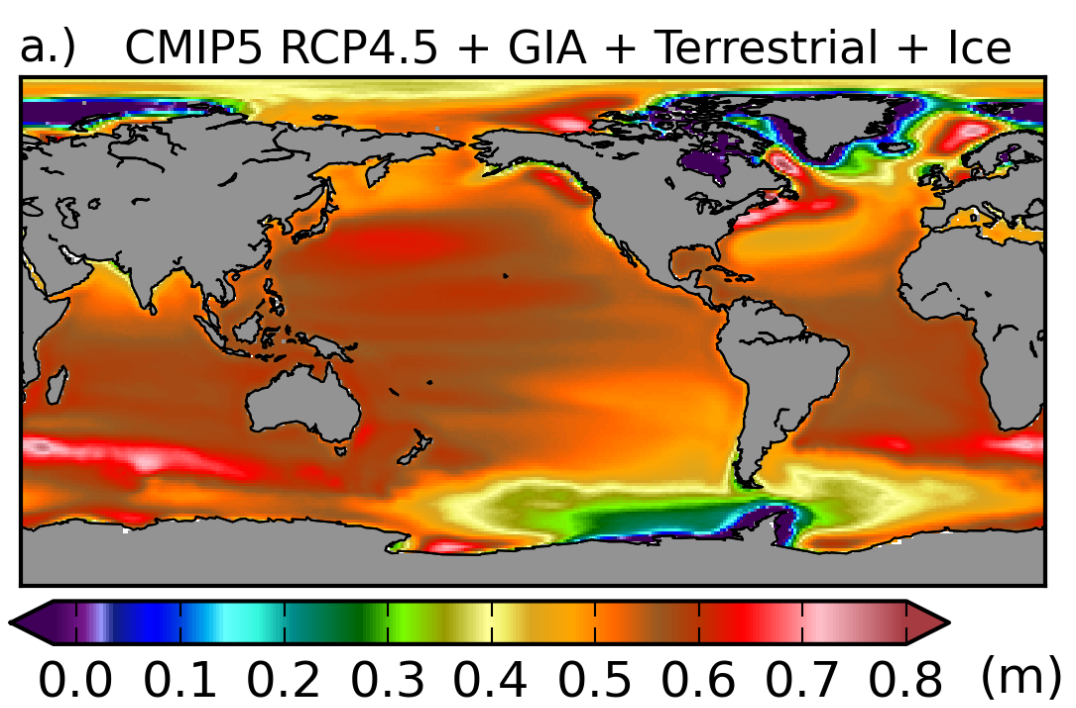
GC Regional Sea-Level Change and Coastal Impacts



Carson et al., 2015

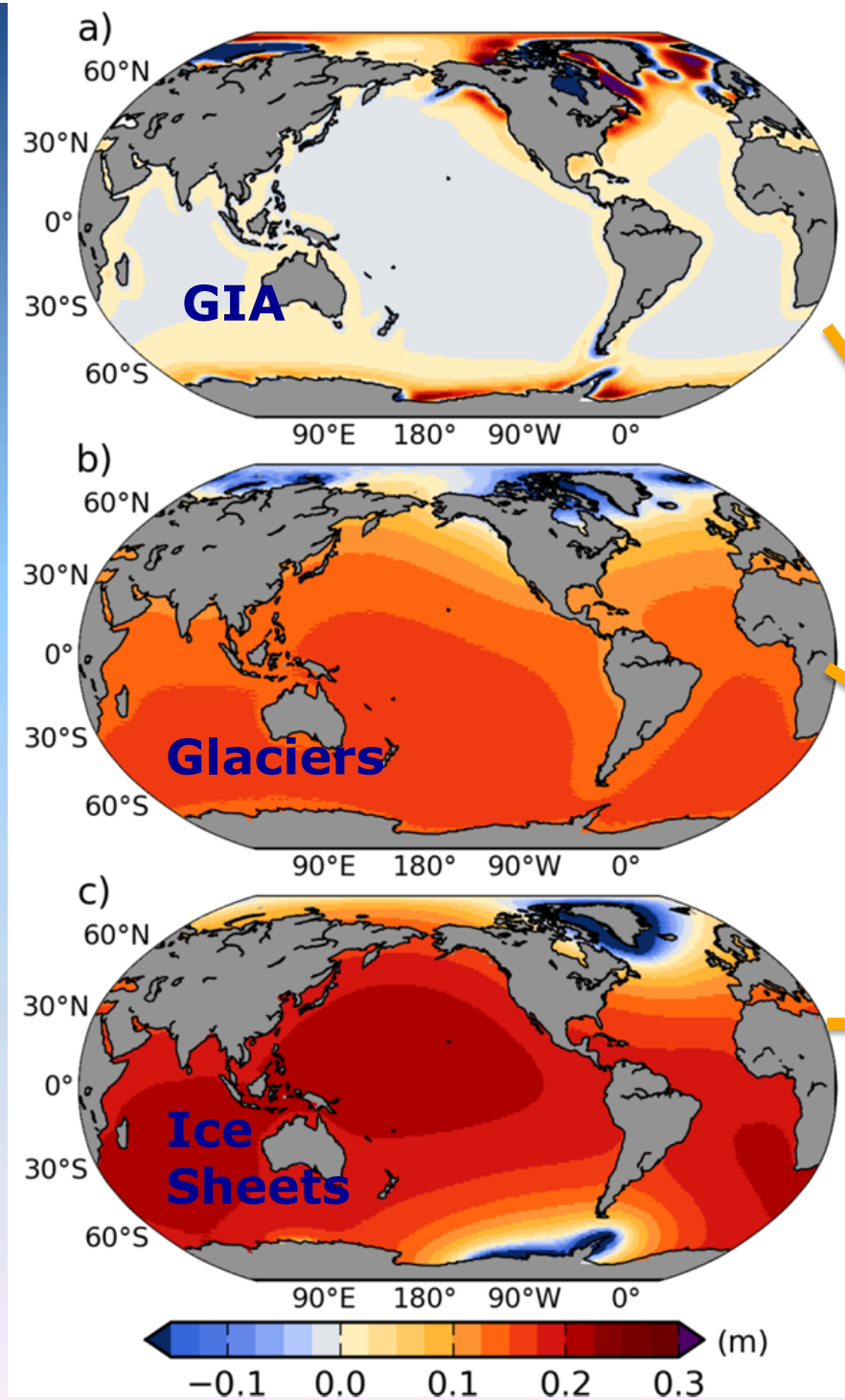
Robert Nicolls, Detlef Stammer, Roderik van de Wal.
The GC Sea Level Steering Team

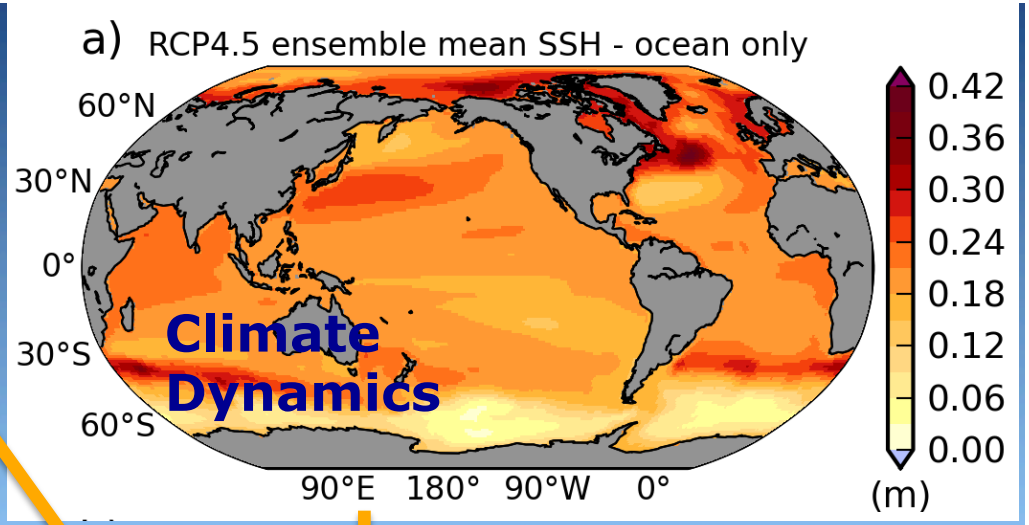
WCRP
World Climate Research Programme

Overarching Goal

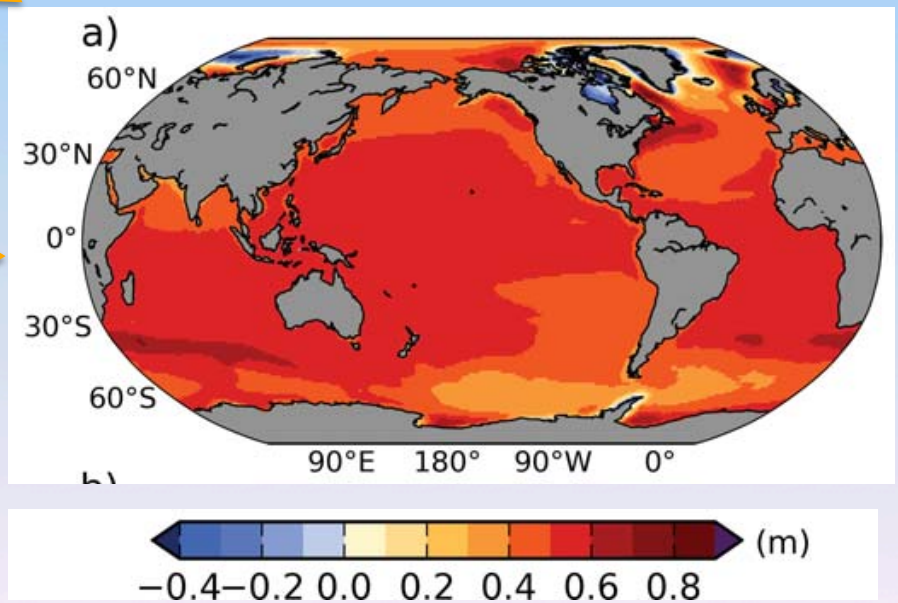
Integrated interdisciplinary program on SL research reaching from the global to the regional and local scales to:

- 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.





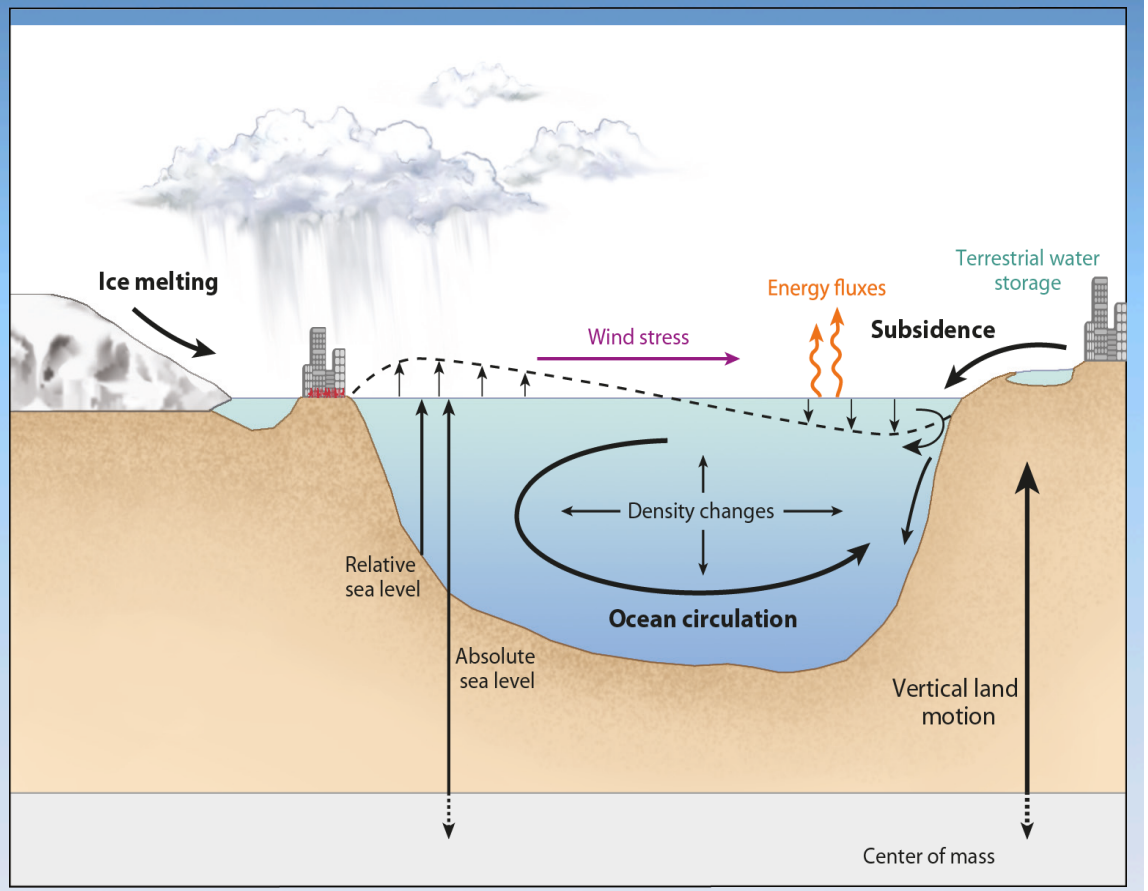
Net Sea Level Change
(plus a few other terms)



Slangen et al.(2014)

Regional Sea Level

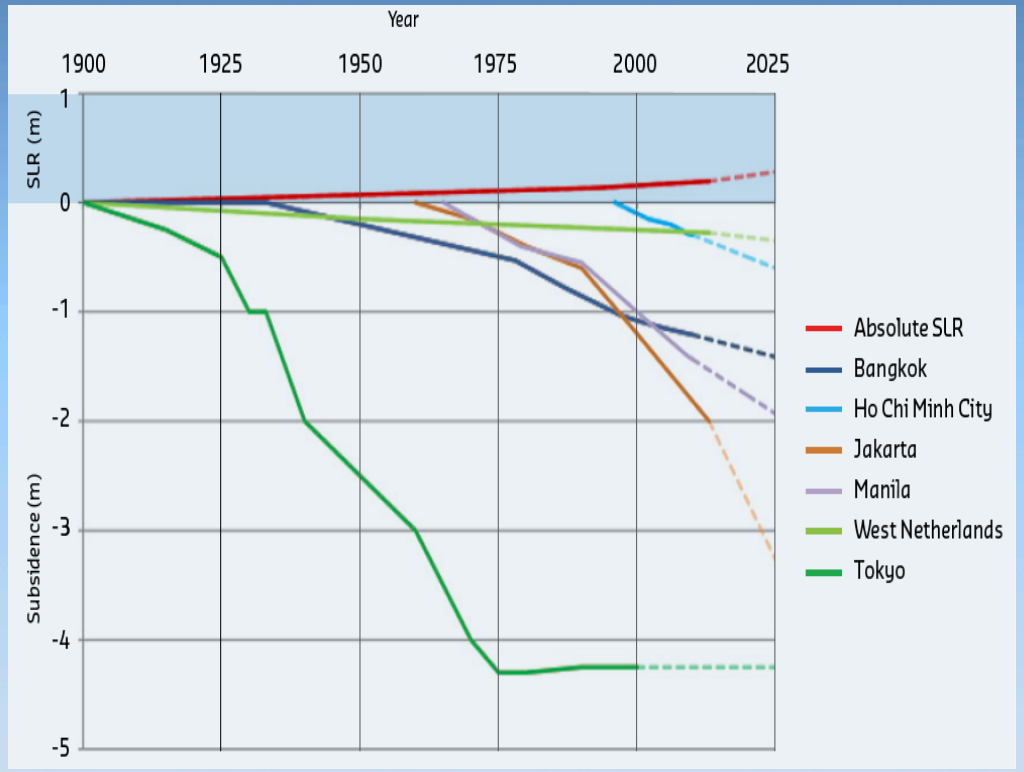
- Climate parameter with immediate societal relevance
- Affected by all climate components: its changes are an integral measure of climate change
- Strong contributions not related to climate (not covered by WCRP)



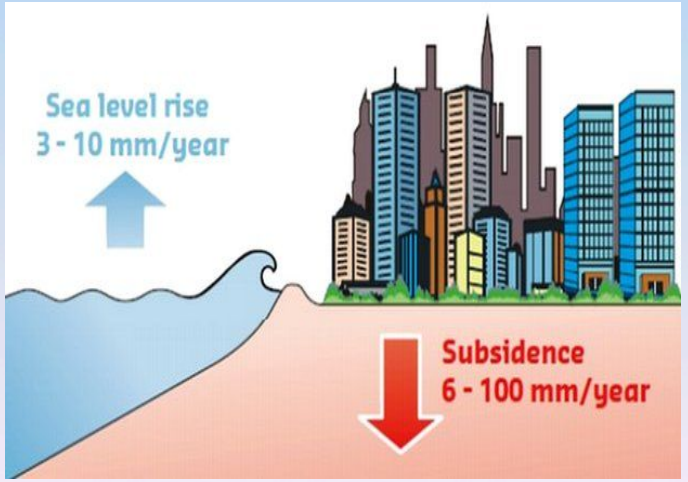
(Stammer et al., 2013)

Dealing with sea level requires interaction with many communities within and outside WCRP.

WHAT WE LEARNED FROM THE PAST



Land subsidence can contribute to RSLR much more than SLR



Coordinated Ocean Storm Surge Climate Project (COSSCLIP)

Storm surges are a coastal problem and manifest on the continental shelf.

Sea Level Steering Team

Expertise	Name	Country	Partner Organization
Geodesy/ Geophysics	Natalya Gomez	Harvard, USA	
	Mark Tamisiea	NOC, UK	
Glaciology/ Ice sheets	Roderik van de Wal	U. Utrecht, The Netherlands	Co-Chair
	Tony Payne	U. Bristol, UK	CliC
	Bette Otto-Bliesner	NCAR, USA	PAGES
Regional processes, Reconstrcutions Climate modes Climate modeling	David Holland	Courant, USA	CliC
	Rui Ponte	AER, USA	
	Detlef Stammer	CEN, Germany	CLIVAR, Co-Chair
	Catia Domingues	U. Tasmania, Australia	CLIVAR
	Benoit Meyssignac	LEGOS, France	
	Jianjun Yin	U. Arizona, USA	
	Jonathan Gregory	U. Reading, UK	
Global balances	Anny Cazenave	ISSI	WCRP JSC
Subsidence, Extremes, storm surges, waves and coastal impacts and adaptation.	A.S. Unnikrishnan	NIO, India	
	Gonéri Le Cozannet	BRGM, France	
	Kathy McInnes	CSIRO, AU	
	Kevin Horsburgh	NOC	IOC/WMO JCOMM
	R. Nicholls	U. Southampton, UK	Co-Chair
	Pietro Teatini	U. Padova, Italy	

Work Programm

Five parallel, but interconnected, working groups:

1. **An integrated approach to paleo time scale sea level estimates**
2. **Quantifying the contribution of land ice to near-future sea level rise**
3. **Causes for contemporary regional sea level variability and change**
4. **Predictability of regional sea level**
5. **Sea level science for coastal zone management**
6. **Global sea level change (NEW)**

- The GC group 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.
- The GC team will write **summaries on data and modeling issues**, bringing together information and recommendations from all working groups.

GC Sea Level Science Plan

Availble at: http://www.clivar.org/research-foci/sea-level

Will get updated continuously.

Established:

1) International teams for each WP
2) New: WP 6 (Anny Cazenave)
3) Contain several CMIP6 MIPS (ISMIP, FAFMIP, ...)

How the GC works

- Steering team meets once a years; coordinates and steers overall effort.
- Each WP lead by several steering team members; has its own team; is self funded and raises support for meetings and activities.
- Results are reported back to steering team to identify gaps and next steps.

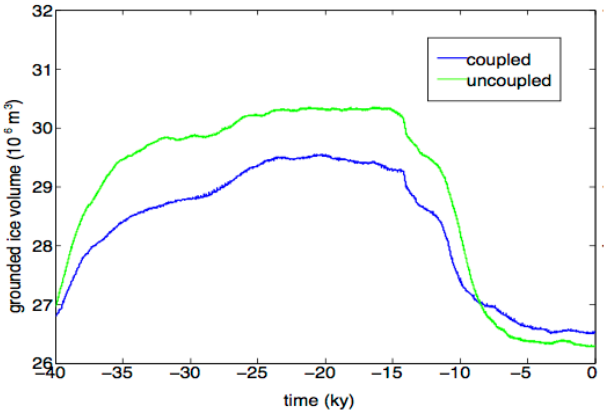
WP 1: An integrated approach to paleo time scale sea level estimates

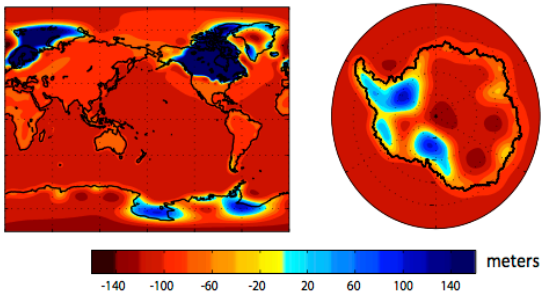
Leads: Natalya Gomez, Roderik van de Wal, Mark Tamisiea, Bette Otto-Bliesner

- Generate a **consistent sea level budget** for different time periods:
  - Last glacial max, – far-field indicators consistent with total ice volume
  - The Eemian interglacial, 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 models of ice, land, ocean, 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 paleo data set** of sea level change

Coupled ice sheet – sea level modeling

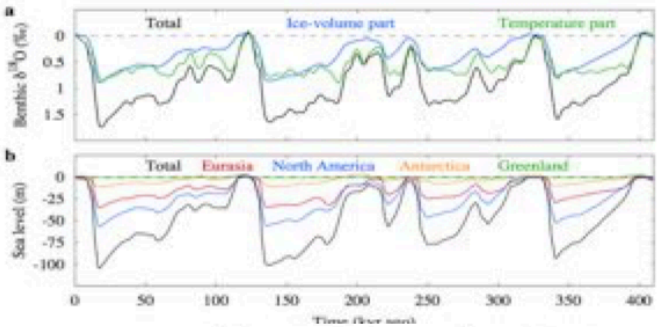
Antarctic ice sheet growth and retreat over the last 40ky dampened by sea-level coupling



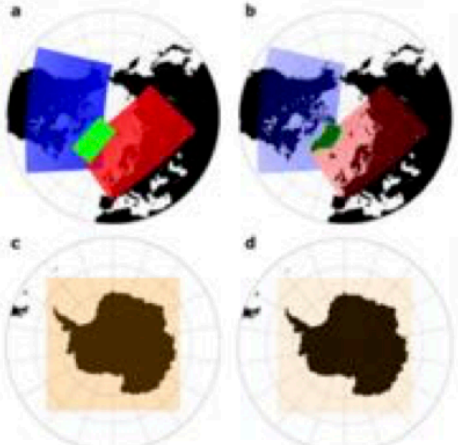


Gomez et al. (2013)

Global dynamic ice cover changes coupled to a global sea level model



Others: Konrad, Berends, Bradley…



De Boer et al. (2014)

WP 2: Quantifying the contribution of land ice to near-future sea level rise

Leads: Tony Payne, David Holland, Roderik van de Wal, Ayako Abe-Ouchi

- Improving understanding of **key processes**, such as iceberg calving and ice-ocean interactions around Antarctica.
- Improve global **glacier and ice cap modeling**, and establish coordinated approaches to making future projections of global glacier mass balance.
- Test the numerical basis of the new generation of ice sheet models in a range of idealized test cases, in particular related to processes affecting the Marine Ice Sheet Instability.
- Validate **CMIP climate simulations** of atmospheric and oceanic climate above and around the ice sheets of Greenland and Antarctica.
- Conduct a range of **model inter-comparison exercises** for the both the Greenland and Antarctic ice sheets.
- Characterize the high-magnitude, low-probability end of future sea-level's probability density function.
- Stimulate the **inclusion of ice sheets in global coupled climate models.**
- **Tipping points** for Greenland and western Antarctica ice sheets (CliC)

Ice Sheet Model Intercomparison Project for CMIP6

S. Nowicki (USA), T. Payne (UK), E. Larour (USA)

A. Abe Ouchi (JP), H. Goelzer (Uetr. U.), J. Gregory (UK)

W. Lipscomb (USA), H. Seroussi (USA), A. Shepherd (UK).

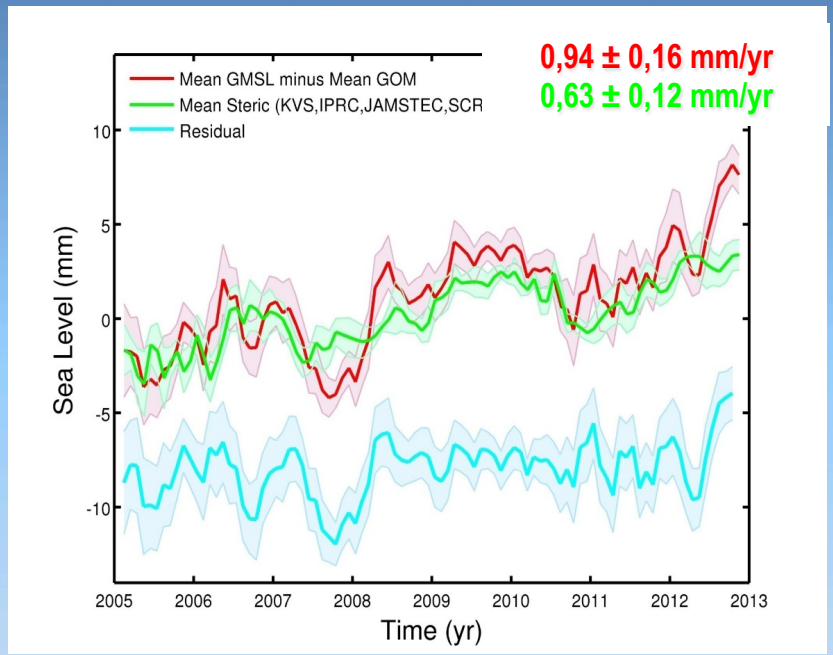
CliC Climate and Cryosphere

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

Leads: Rui Ponte, Catia Domingues, Benoit Meyssignac, D. Stammer

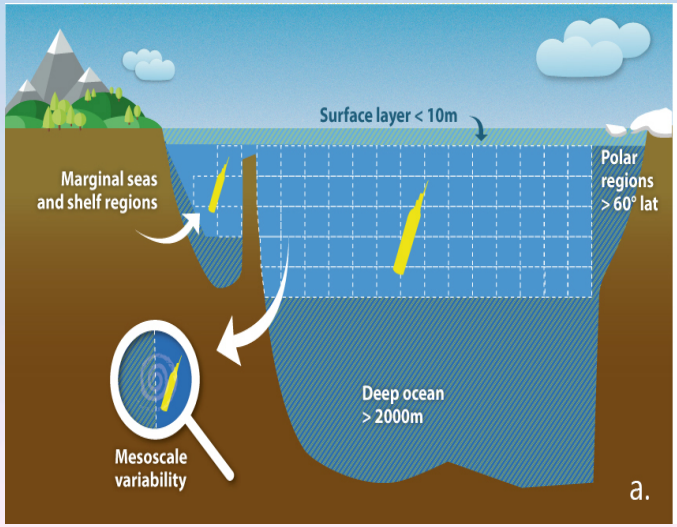
- Understand and reduce **uncertainties in mass and steric contributions** to contemporary sea level budgets at global, regional and local spatial scales.
- Determining the **role of climate modes** (e.g., ENSO, IOD, PDO, SAM, NAO, AMO) and internal variability in general on sea level.
- Understanding the role of **coastal and ocean interior processes** (e.g., shelf sea dynamics, ocean mixing, freshwater input, etc) on local sea level.
- **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 ground-based) **sea level observing system**.

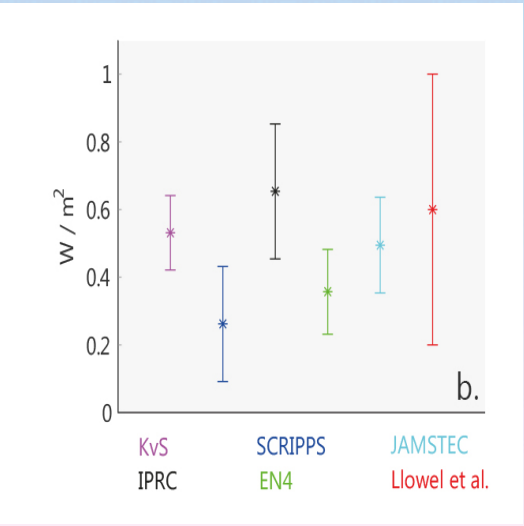
Sea level budget: data errors and missing contributions



- Sea level budget residual = Deep ocean (>1500m) contribution + errors : ~ 0.3 ± 0.4 mm/yr
- Constraint on the Earth energy imbalance ~ 0.6 ± 0.4 W/m^2

Dieng et al. (2015,Survey of Geophysics)
von Schuckmann et al. (2016, Nat CC)
Slangen et al. (2016 Nat CC)





Llovel et al. and Dieng et al.

WP 4: Predictability of regional sea level

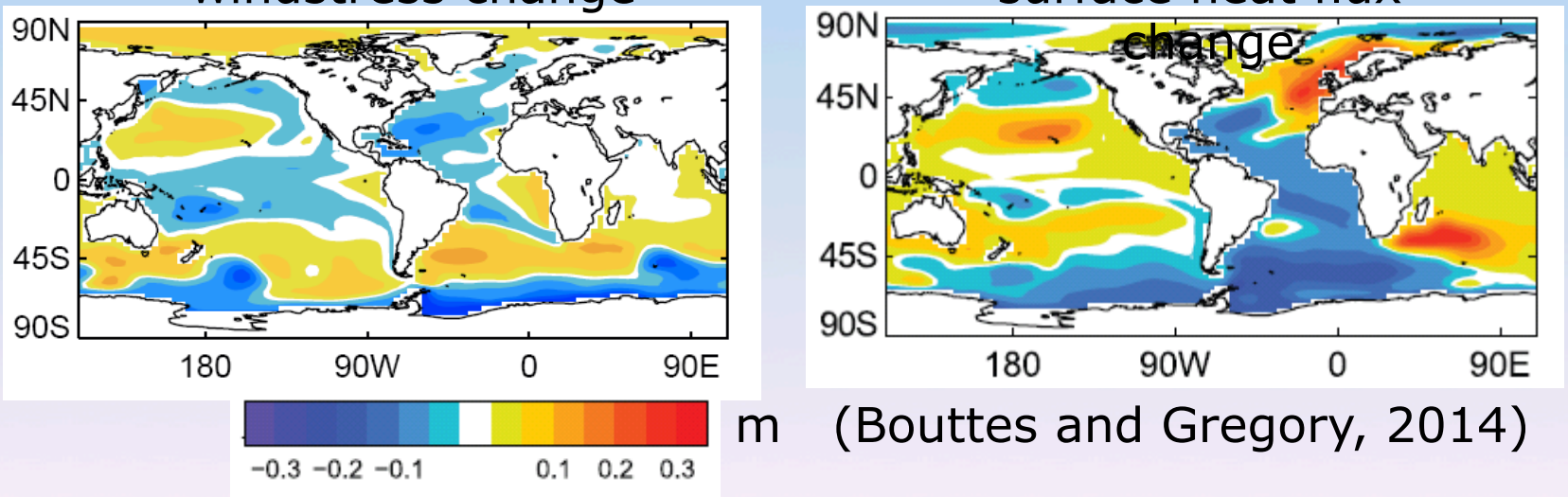
Leads: Jonathan Gregory, Jianjun Yin, Tony Payne, Detlef Stammer

- 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 regional sea level change in AOGCMs**, especially glaciers, ice-sheets. Including ice-sheets will place a focus on a better representation of polar regions in climate models.
- Provide reliable estimates of **terrestrial hydrology**.

FAFMIP (flux-anomaly-forced models)

- **Scientific motivations:**
  - Patterns of sea level change – how much depends on model rather than flux
  - Efficiency of ocean heat uptake from experiment (2), $\partial T/\partial t$ diags requested
  - Sensitivity of AMOC to buoyancy forcing from experiments (2) and (3)
- In foregoing work, one model was forced with anomalous fluxes from each of many models.

Sea level change (wrt global mean) in FAMOUS AOGCM forced by windstress change CMIP5 surface heat flux change



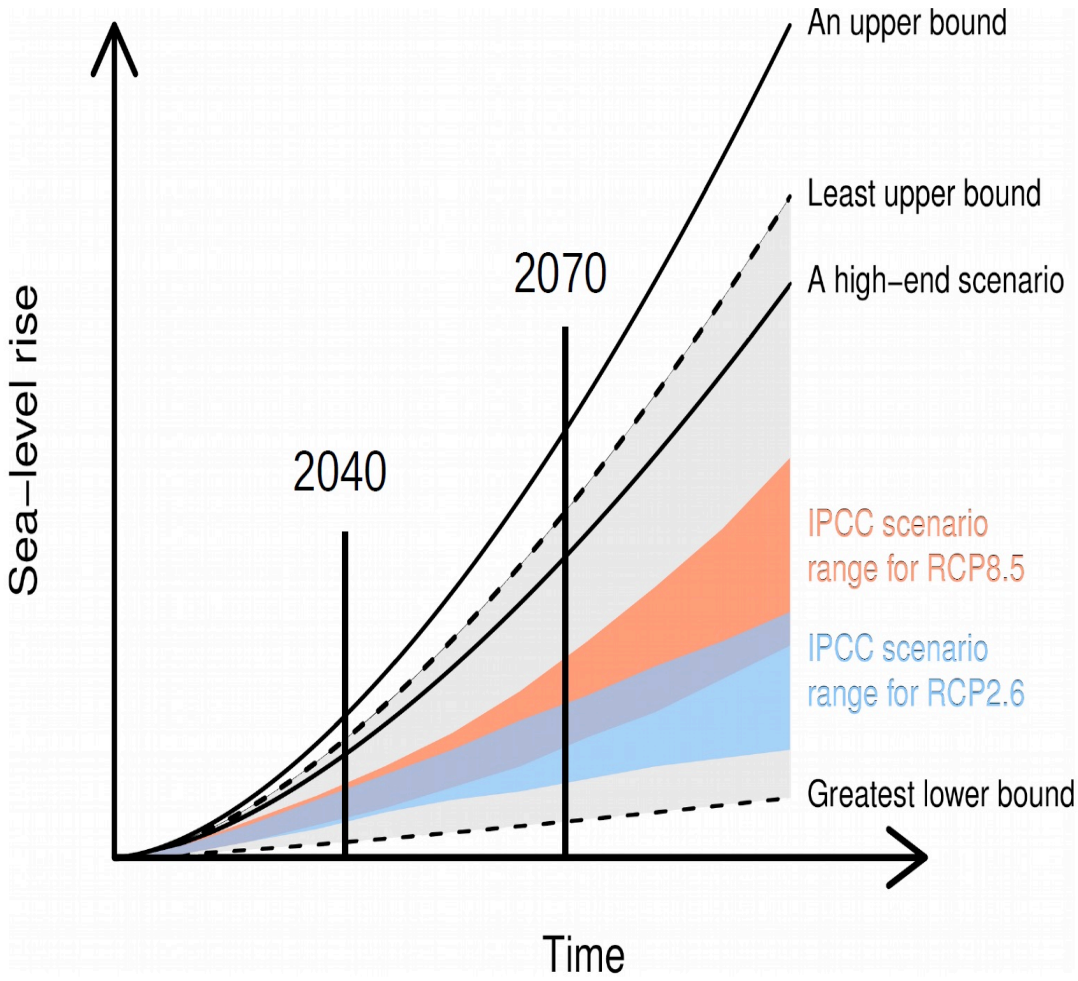
(Bouttes and Gregory, 2014)

WP 5: Sea level science for coastal zone management

Leads: Robert Nicholls, Goneri Le Cozannet, S. Unnikrishnan, Kathy McInnes, Kevin Horsburgh, Pietro Teatini, Jochen Hinkel

- **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.

Upper bounds



Source: Hinkel et al. Nature Climate Change (2015)

The 100th Thames Barrier Closure

Source: Environment Agency

In Preparation

- Terminology paper
- White paper on status of sea level research
- Paper on sea level uncertainties at coastlines

Regional Sea-level Changes and Coastal Impacts

July 10 – 15, 2017

Earth Institute, CU, NY

A joint GC SeaLevel/WCRP– IOC Conference

Conference Objectives

WCRP, jointly with the Intergovernmental Oceanographic Commission of UNESCO (IOC), is organizing an international **conference on sea level research** that will address the existing challenges in describing and predicting regional sea level changes, and in **quantifying the intrinsic uncertainties**.

It follows 11 years after the first WCRP sea level conference (Paris, 2006), and three years after the last Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).

It will provide a comprehensive summary of the state of worldwide climate-related large scale sea level research.

Conference Outcome

In detail the conference will:

I. Identify the key factors contributing to past, present and future regional sea level rise and variability.

II. Organize a systematic attack on the error budget of these factors.

III. Identify stakeholder needs for sea-level information for coastal planning and management purposes.

IV. Define the requirements for new and augmented research, technical development and observations consistent with the above.

Participation

- **Open conference**. We expect participation from **up to 400** people from natural sciences , social sciences and the coastal management community.
- 356 abstracts submitted.
- 37% of the abstracts is by female first authors, about 100 ECS and 75 students.
- The new approach is to **include the coastal zone management** community to enhance interaction and networking as well as knowledge transfer in both directions.

Sea Level Conference 2017

	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5
Date	**Monday, 10-Jul**	**Tuesday, 11-Jul**	**Wednesday, 12-Jul**	**Thursday, 13-Jul**	**Friday, 14-Jul**
Venue	Columbia University	Columbia University	Columbia University	Columbia University	Columbia University
AM	**8:00-9:00 Registration**				
	9:00-10:30 Opening session	**9:00-10:30 Oral session 3: Contemporary contributions from ice sheets and glaciers**	**9:00-10:30 Oral session 5: Coastal Zone**	**9:00-10:30 Oral session 8: Contemporary sea level change**	**9:00-11:00 Oral session 10: Projections**
	10:30-11:00 Coffee/Tea	**10:30-11:00 Coffee/Tea**	**10:30-11:00 Coffee/Tea**	**10:30-11:00 Coffee/Tea**	**11:00-11:30 Coffee/Tea**
	11:00-12:30 Opening session	**11:00-12:30 Poster session 1: Paleo sea level ice sheet interactions**	**11:00-12:30 Poster session 3: Coastal Zone**	**11:00-12:30 Poster session 4: Contemporary sea level change**	**11:30-12:30 Closing session**
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	15:30-16:00 Coffee/tea	**15:30-16:00 Coffee/tea**	**15:30-16:00 Coffee/tea**	**15:30-16:00 Coffee/tea**	
	16:00-17:30 Oral session 2: Millennial-scale ice sheet and sea level interactions	**16:00-17:30 Oral session 4: Contemporary sea level change**	**16:00-17:30 Oral session 7: Coastal Zone, Panel Discussion**	**16:00-17:30 Poster session 5: Projections**	
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Thank you

Sea Level and Mass Budgets

Sea Level Budget

Observed Global Mean Sea Level

=

Ocean Thermal Expansion + Ocean Mass

$$\Delta M_{ocean} = -\Delta M_{LI} - \Delta M_{LW} - \Delta M_{WV} - \Delta M_{Snow} - \ldots\ldots$$

Ocean mass | *Land ice* | *Land waters* | *Atmospheric water vapor* | *Snow*

Δ = Time variation
M = Mass components
LI = Land Ice (glaciers + ice sheets)
LW = Land Waters
WV = Water Vapour

Mass Budget

WCRP Grand Challenge
« Regional Sea Level and Coastal Impacts »

WP 6: Global Sea Level Budget (Sea level as 'global climate indicator'; Focus on altimetry era & observations)

Leads: Anny Cazenave and Benoit Meyssignac

Tentative supporting team (*alphabetic order*): M. Ablain, J. Bamber, J. Benveniste, T. Boyer, D. Chambers, B. Chao, J. Chen, J. Church, C. Domingues, J. Famiglietti, R. Forsberg, A. Gardner, A. Groh, M. Horwatt, M. Ishii, J. Kusche, K. Lambeck, F. Landerer, P. Leclercq, B. Legresy, E. Leuliette, W. Llovel, D. Masters, M. Marcos,B. Marzeion, C. Merchant, S. Nerem, F. Paul, R. Ponte, J.T. Reager, R. Rietbroek, R. Riva, D. Stammer, K. von Schuckmann, S. Seneviratne, G. Spada, M. Tamisiea, I. Velicogna, Y. Wada, R. van de Wal, C. Watson, S. Wjiffels, B. Wouters + *all colleagues interested to join*

Scientific objective: **ASSESS** products used in the sea level budget (sea level and components) provided by different groups worldwide and on-going international projects (e.g. the ESA Climate Change Initiative/CCI Sea Level Budget Closure Project -SLBC_cci-, NOAA annual sea level budget, IMBIE2, ….).

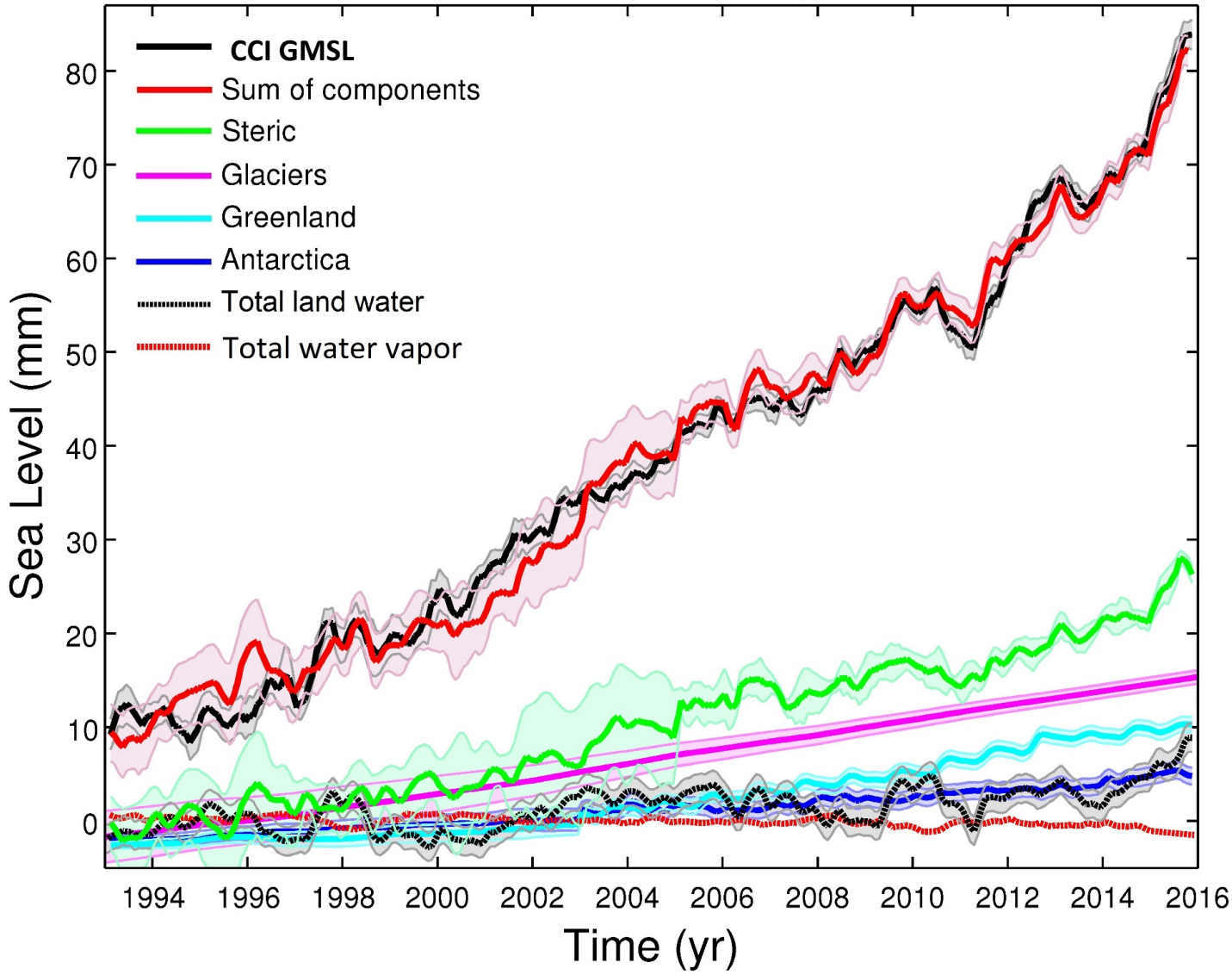
- Describe data sets used for the sea level budget
- Characterize uncertainties
- Examine (non) closure of the sea level and mass budgets

Schedule: 1st assessment exercise ready late 2017 and a 'team' article (authored e.g. as 'the WCRP GSLB') submitted to the Earth System Science Data journal early 2018; following assessments on a yearly basis

Organisation

Components of the sea level budget (estimate, validation & uncertainty)	**Section leads** *(2 names)*	**Participants**
Altimetry-based global mean sea level		**M. Ablain, J. Benveniste, A. Cazenave, D. Chambers, J. Church, B. Legresy, E. Leuliette, W. Llovel, M. Marcos, B. Meyssignac, S. Nerem, C. Watson**
Steric sea level	**K. von Schuckmann, ….**	**T. Boyer, D. Chambers, C. Domingues, M. Ishii, G. Johnson, M. Marcos, C. Merchant, W. Llovel, R. Ponte, K. von Schuckmann, D. Stammer, S. Wjiffels**
Glaciers		**E. Berthier, G. Cogley, U. Falk, A. Gardner, B. Marzeion, P. Leclercq, F. Paul, B. Wouters**
Greenland		**J. Bamber, J. Chen, J. , R. Forsberg, A. Hogg, M. Horwatt, I. Velicogna, R. van de Wal, B. Wouters**
Antarctica		**J. Bamber, J. Chen, R. Forsberg, A. Hogg, M. Horwatt, A. Shepherd, I. Velicogna, R. van de Wal, B. Wouters**
Land Waters	**J. Reager, Y. Wada**	**B. Chao, J. Chen, P. Döll, J. Famiglietti, J. Kusche, J. Reager, S. Seneviratne, Y. Wada,**
Atmospheric water vapor; snow & permafrost		**P. Döll, …..**
Ocean mass from GRACE		**A. Blazquez, J. Chen, D. Chambers, A. Groh,, M. Horwatt, F. Landerer**
GIA	**G. Spada, R. Riva**	**R. Riva, G. Spada, M. Tamisiea**
Mass budget (GRACE-based ocean mass versus sum of mass components)		**J. Bamber, D. Chambers, A. Groh, M. Horwatt, J. Kusche, F. Landerer, R. Rietbroek, R. Riva, D. Stammer, B. Wouters**
Sea level budget (altimetry-based sea level versus sum of steric and mass components)		**A. Cazenave, D. Chambers, J. Church, J. Kusche, F. Landerer, E. Leuliette, B. Meyssignac, S. Nerem, R. Rietbroek**

Exemple of Sea Level Budget 1993-2015



Steric Sea Level