Dedicated to the memory of Yves

Present-day sea level rise and climate change

Anny Cazenave (LEGOS-CNES)
+ many colleagues…

Special thanks to : B. Beckley, J. Benveniste, D. Chambers, J. Church, C. Domingues, M. Ishii, C.K. Shum, R. Sharroo, P. Woodworth

OSTST, Nice, Nov.2008

Why are sea level studies important?

↓

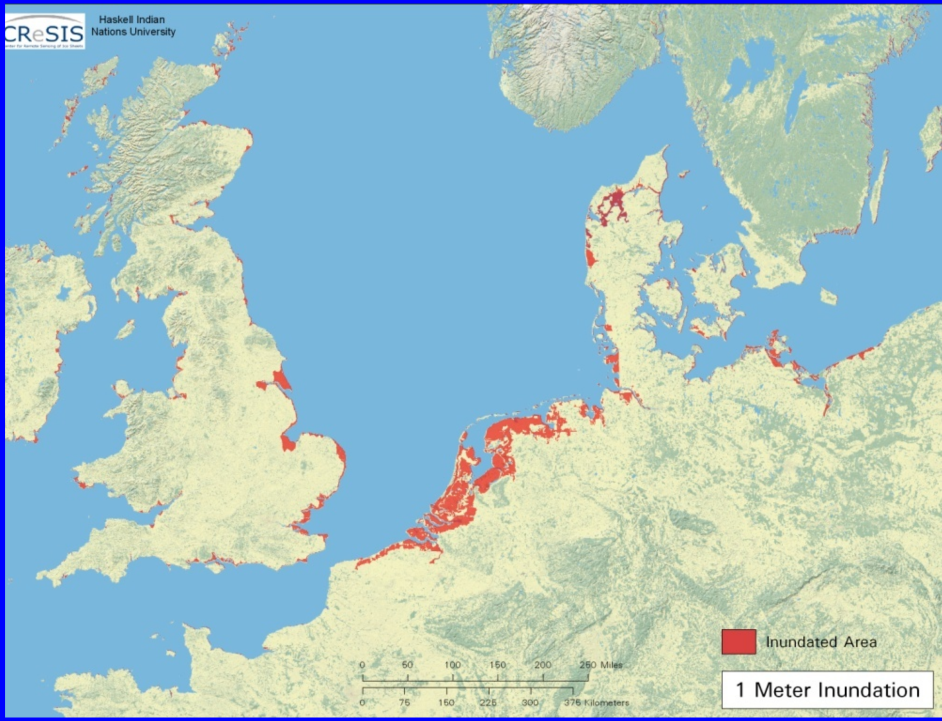
- Sea level rise : major consequence of global warming

- Sea level rise involves all components of the climate system (oceans, ice sheets, glaciers, land water reservoirs); even solid Earth is involved; complex response to global warming

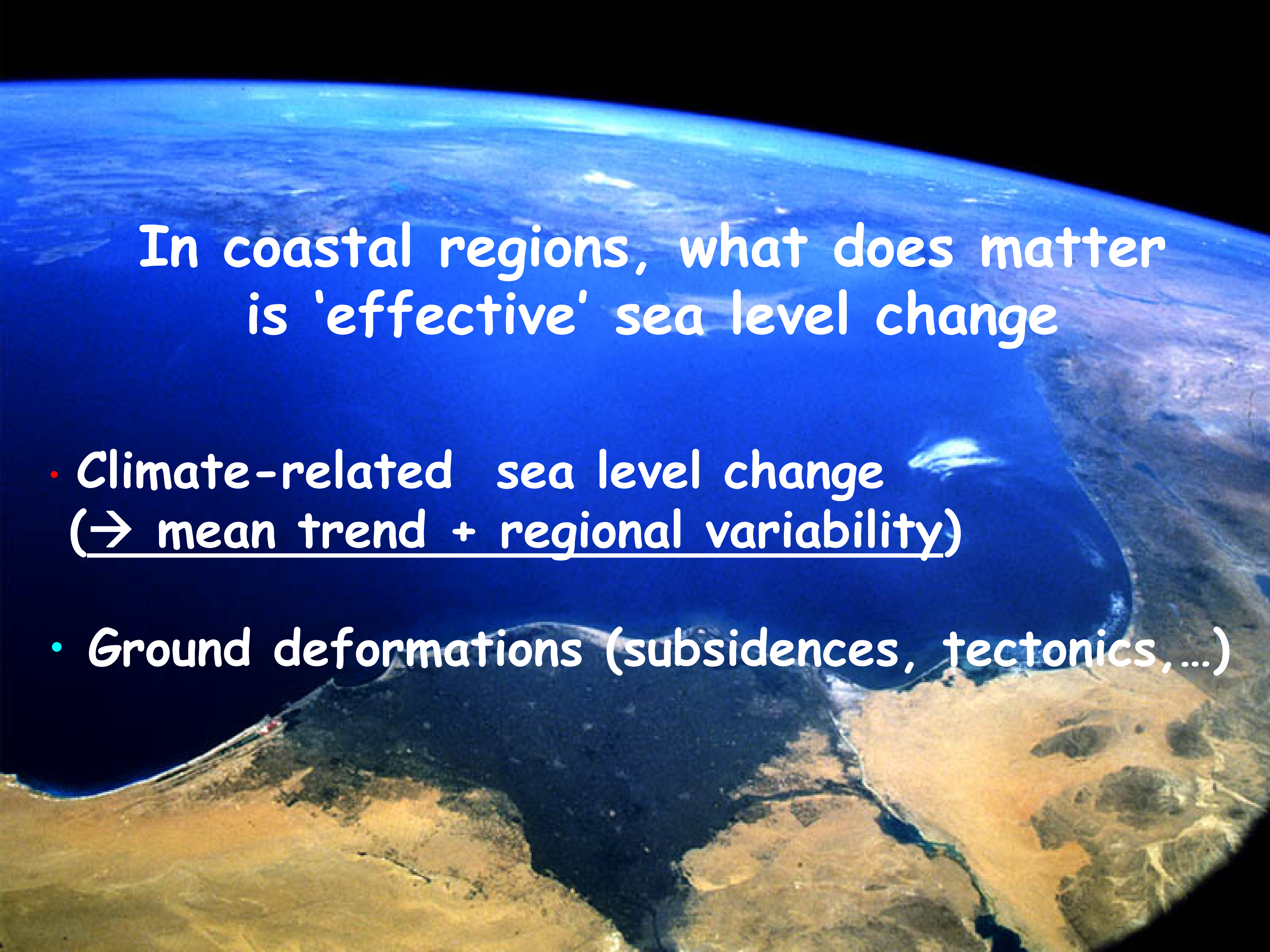
- Sea level modelling: very difficult; future projections very uncertain due to lack of knowledge of future ice sheets behaviour; future regional variability very poorly known

- Future sea level rise : major impact in low-lying, highly-populated coastal areas

Submersion of coastal land under 1 m sea level rise



Source: Tyndall Center for Climate Change Research



In coastal regions, what does matter is 'effective' sea level change

- Climate-related sea level change
  (→ <u>mean trend + regional variability</u>)

- Ground deformations (subsidences, tectonics,…)

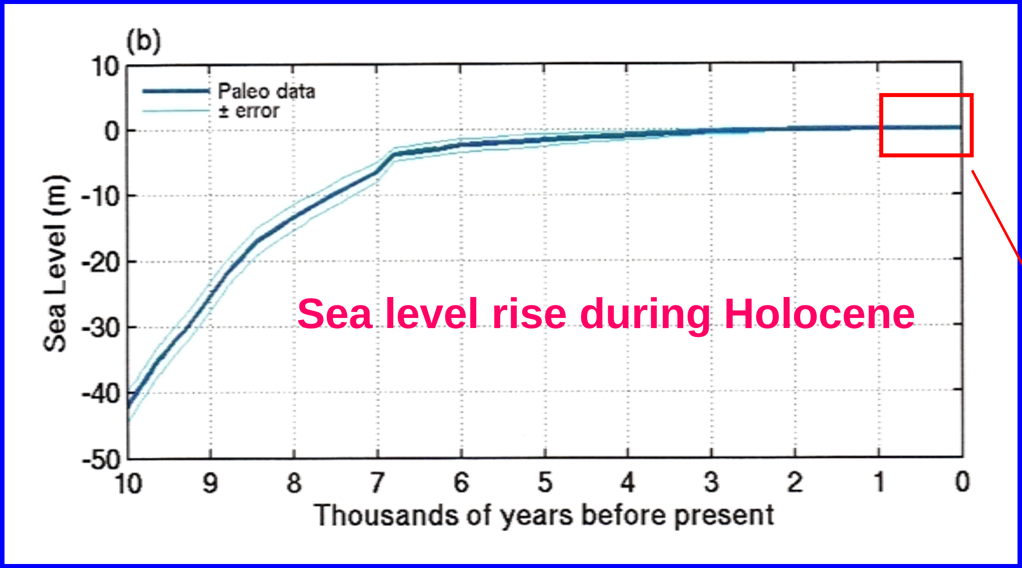
‘Effective ‘sea level rise in large river deltas under contemporary conditions (~ 2mm/yr sea level rise)

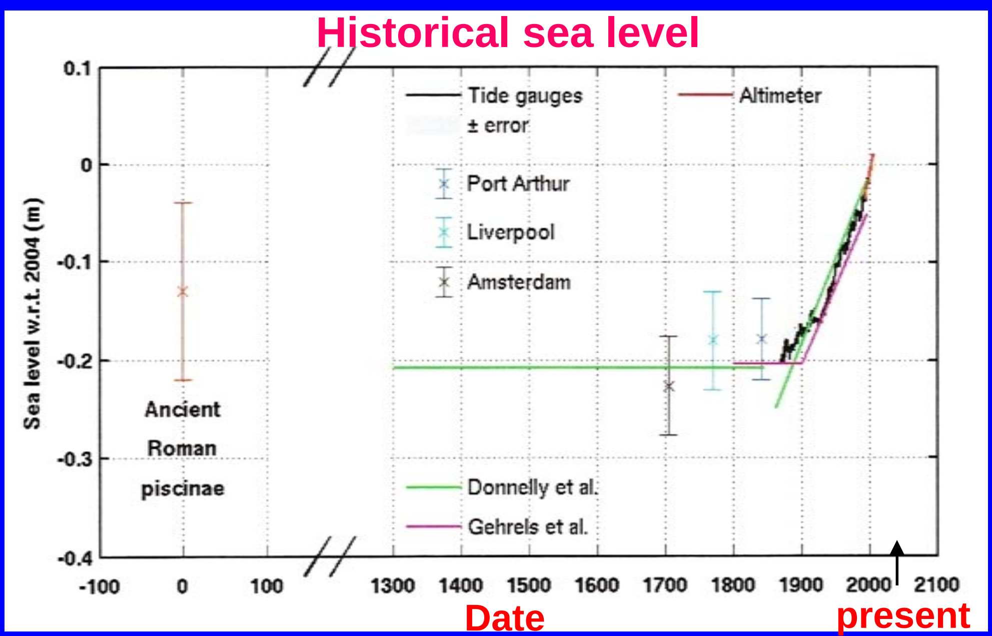
Fig. 5. Global distribution of ESLR under baseline conditions for each of the 40 deltas in this study. The upstream drainage basin for each delta is highlighted for presentation purposes. This figure represents contemporary conditions.

From Ericson et al., 2006

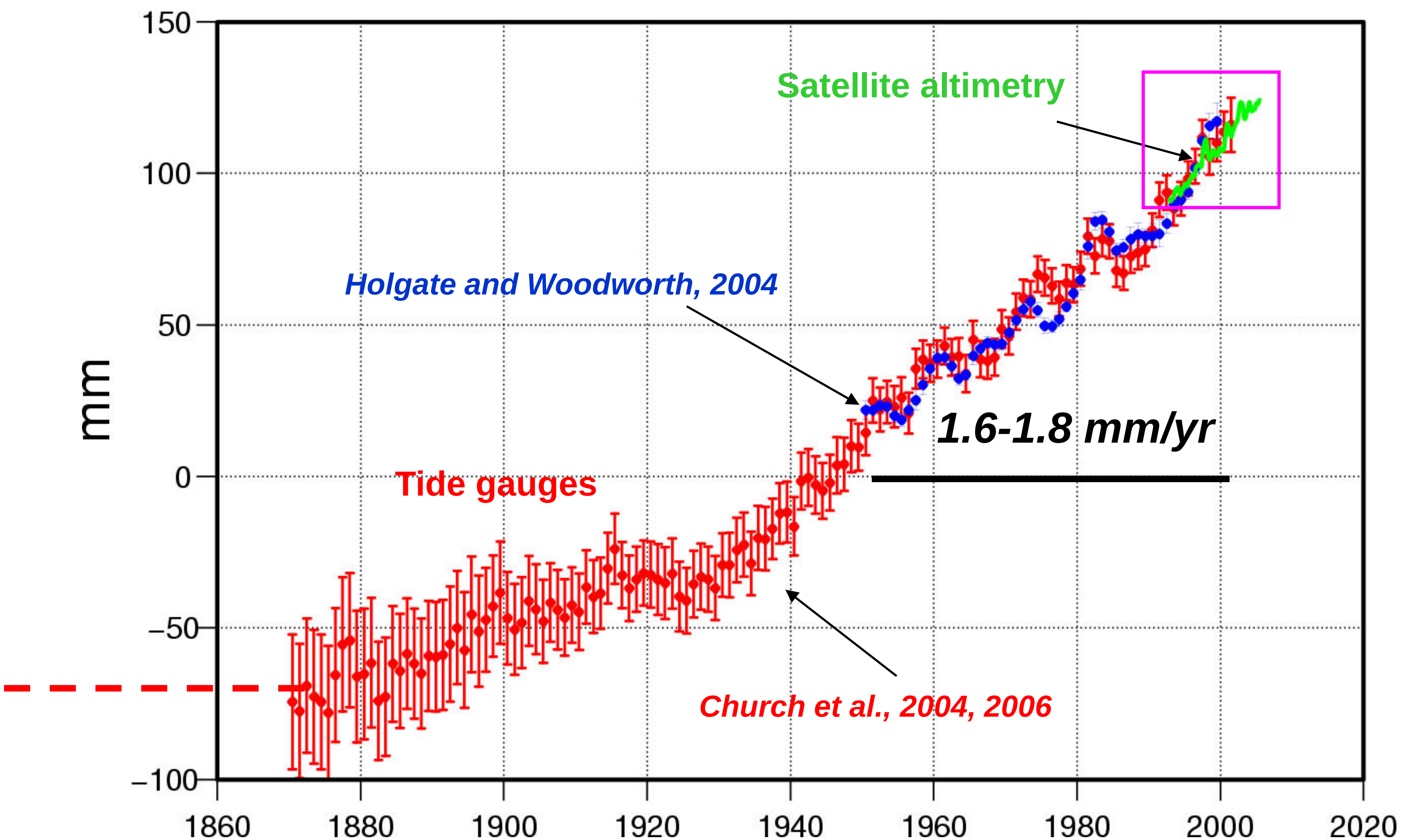
Paleo and historical sea level

(from Church et al., 2008)





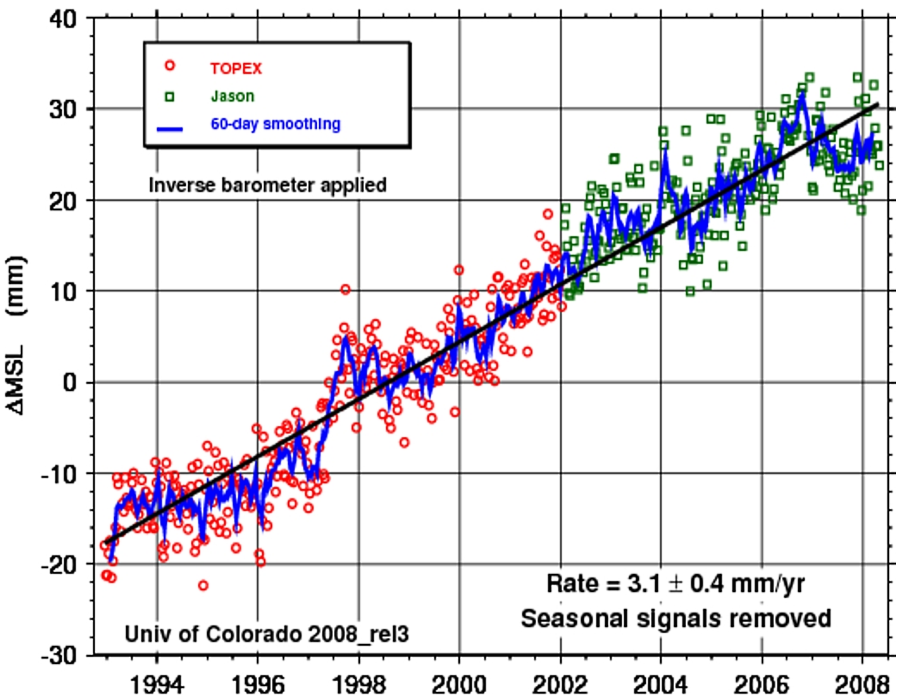
Global mean sea level rise during the 20th century



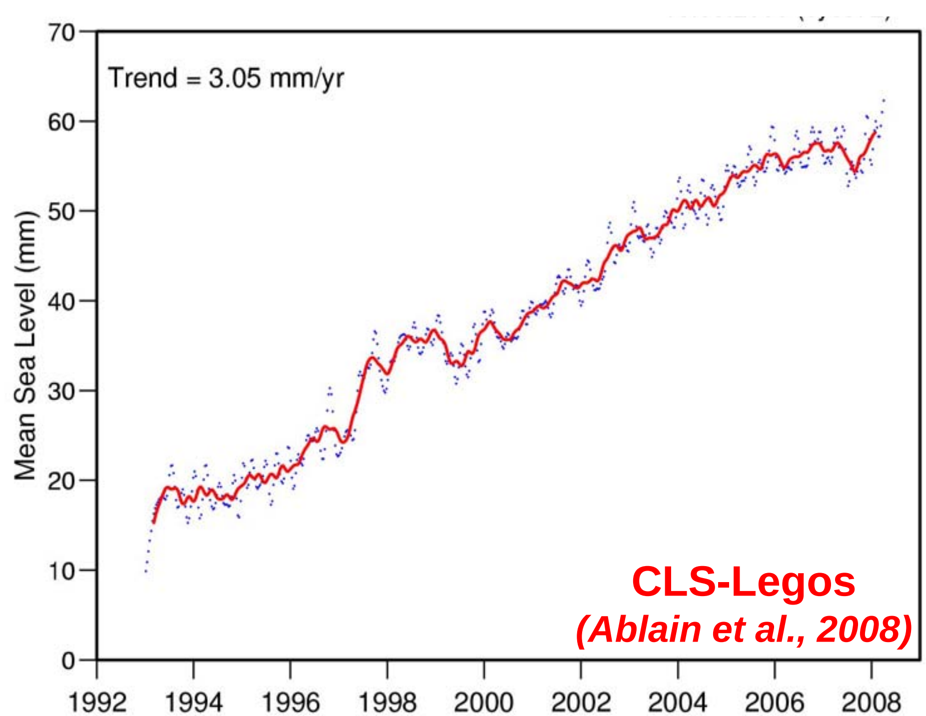
Global mean sea level evolution since 1993 from Topex/Poseidon and Jason-1 altimetry

Average rate of rise : 3.4 (+/- 0.4) mm/yr (1993-2008)

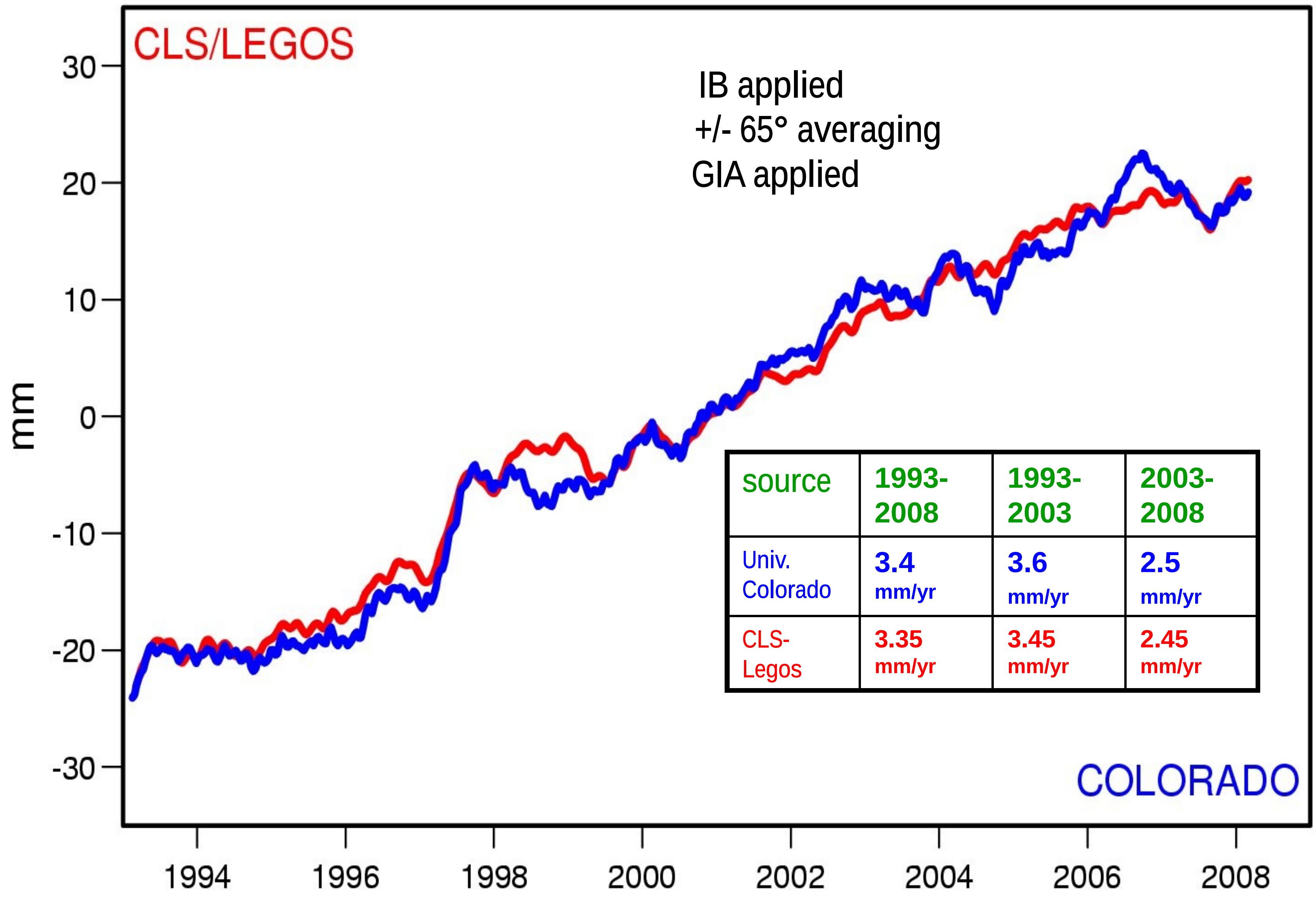
(GIA –Glacial Isostatic Adjustment- applied)



University of Colorado

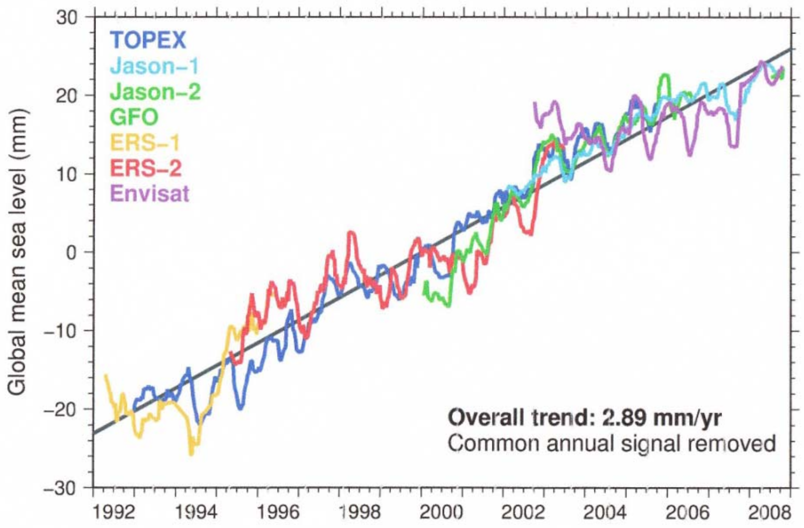


Topex+Jason global mean sea level curve (1993-2008)
→ Comparison between 2 groups

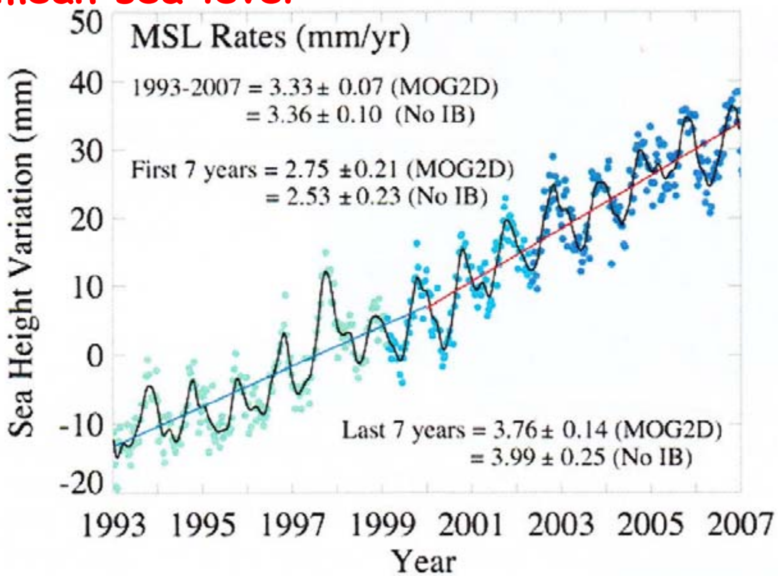


source	1993-2008	1993-2003	2003-2008
Univ. Colorado	**3.4** mm/yr	**3.6** mm/yr	**2.5** mm/yr
CLS-Legos	**3.35** mm/yr	**3.45** mm/yr	**2.45** mm/yr

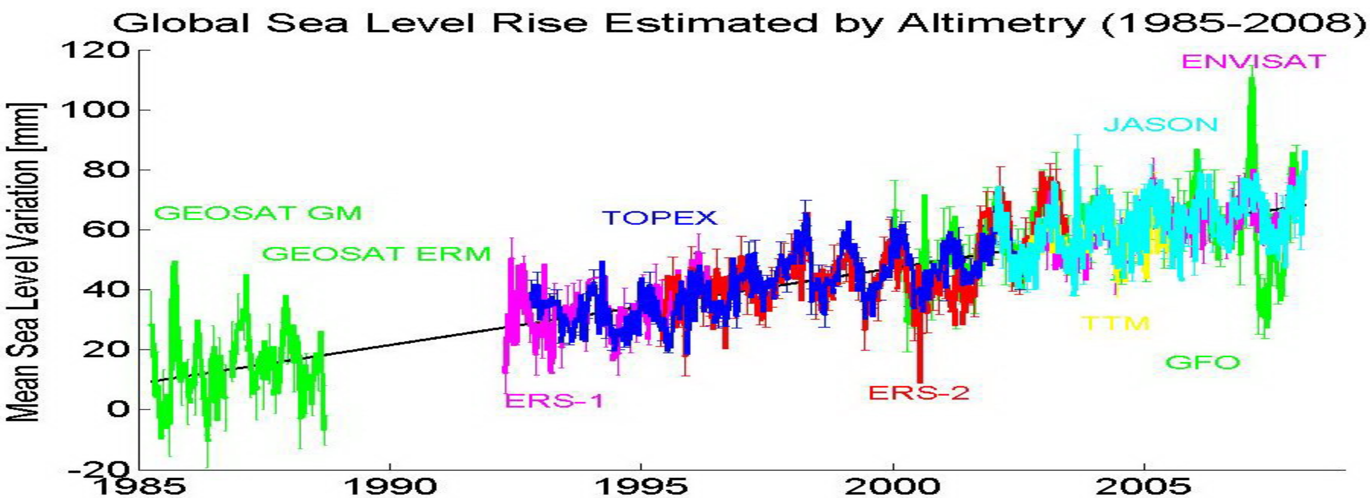
Altimetry-based global mean sea level



R. Sharroo (DUT)



Beckley et al.(2007)



C.K. Shum, Ohio State Univ.

Estimates of altimetry-based sea level rise

Source	Rate of sea level rise *(GIA/-0.3 mm/yr and IB applied)* unit: mm/yr	Time span
Beckley et al. (2007)	3.6 +/- 0.4 (T/P + Jason)	1993-2007
S. Nerem (Univ. Colorado)	3.4 +/- 0.4 (T/P + Jason)	1993-2008
CLS-LEGOS	3.4 +/- 0.4 (T/P + Jason)	1993-2008
C.K. Shum (Ohio St. Univ.)	2.9 +/- 0.4 (T/P + Jason) 3.0 +/- 0.4 (multi sat)	1993-2008
R. Sharroo (TU Delft)	3.2 +/- 0.4 (multi sat)	1993-2008

Global mean sea level trend: error budget

Source	Trend error (mm/yr)
Orbit (Beckley et al., Ablain et al.)	0.25
Wet atmos. (TMR/JMR drift) (Ablain et al.)	0.3
Topex A-Topex B (Ablain et al.)	0.25
Dry atmos. (pressure fields) (Ablain et al.)	0.1
Sea state bias (Ablain et al.)	0.1
Quadratic sum	***0.45***
Tide gauge calibration (Micthum and Nerem; Beckley et al.; Ablain et al.)	0.4

Recommendation 1:

- Keep tight control on altimetric system performance (→ long term stability)

- Investigate the causes of differences in sea level trend estimates

- Implement a dedicated network of tide gauges equipped with GPS at <1 km distance

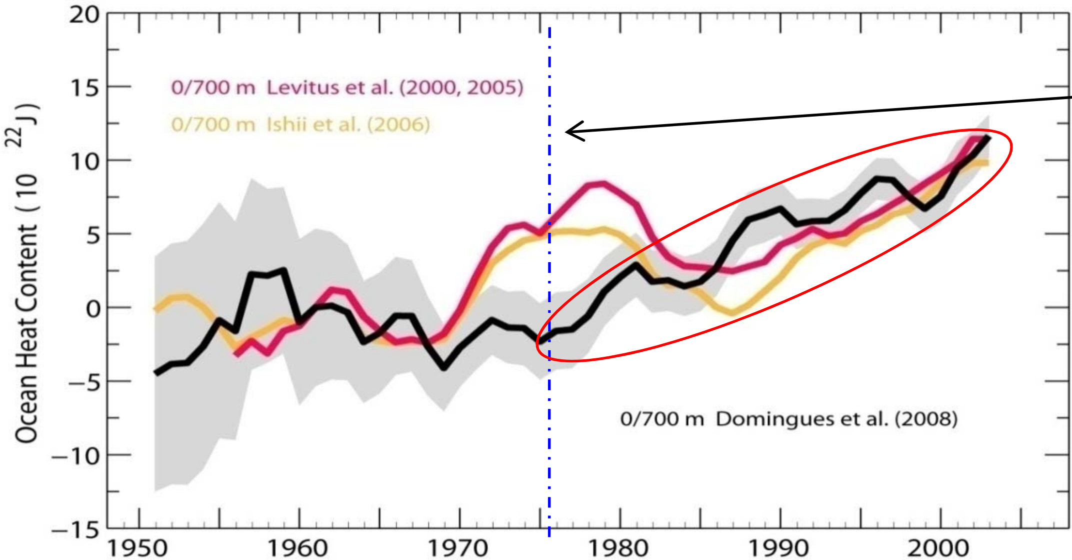
- Perform sea level budget studies (→ constraints on observed sea level rise)

Sea Level budget:

Comparison between observed sea level change and sum of climate contributions (thermal expansion, land ice, land waters)

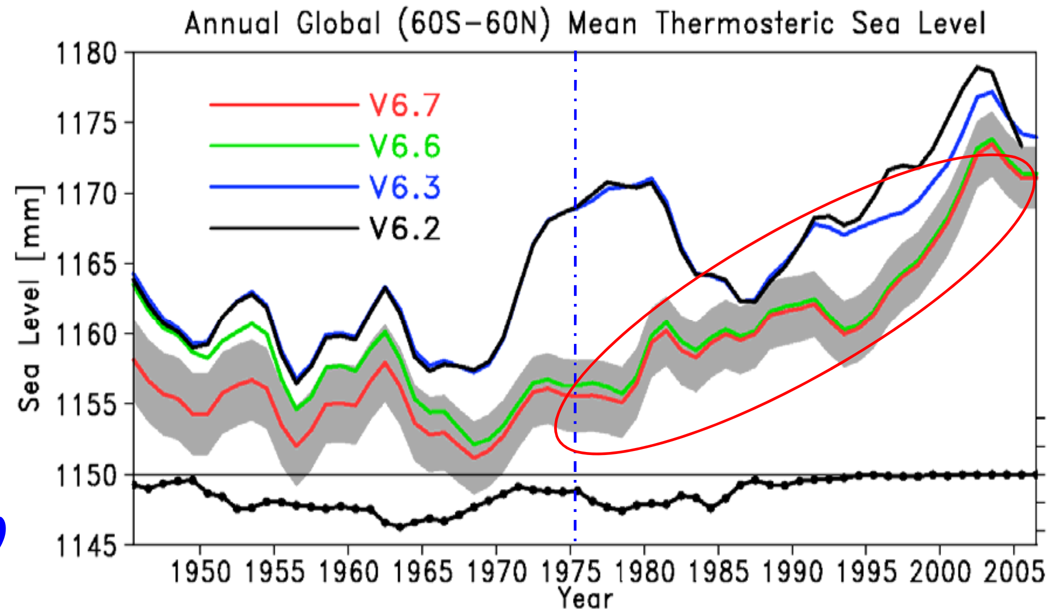
- **1950-2000**
- **1993-2003**
- **2003-2008**

Change in Ocean Heat Content -past 50 years-



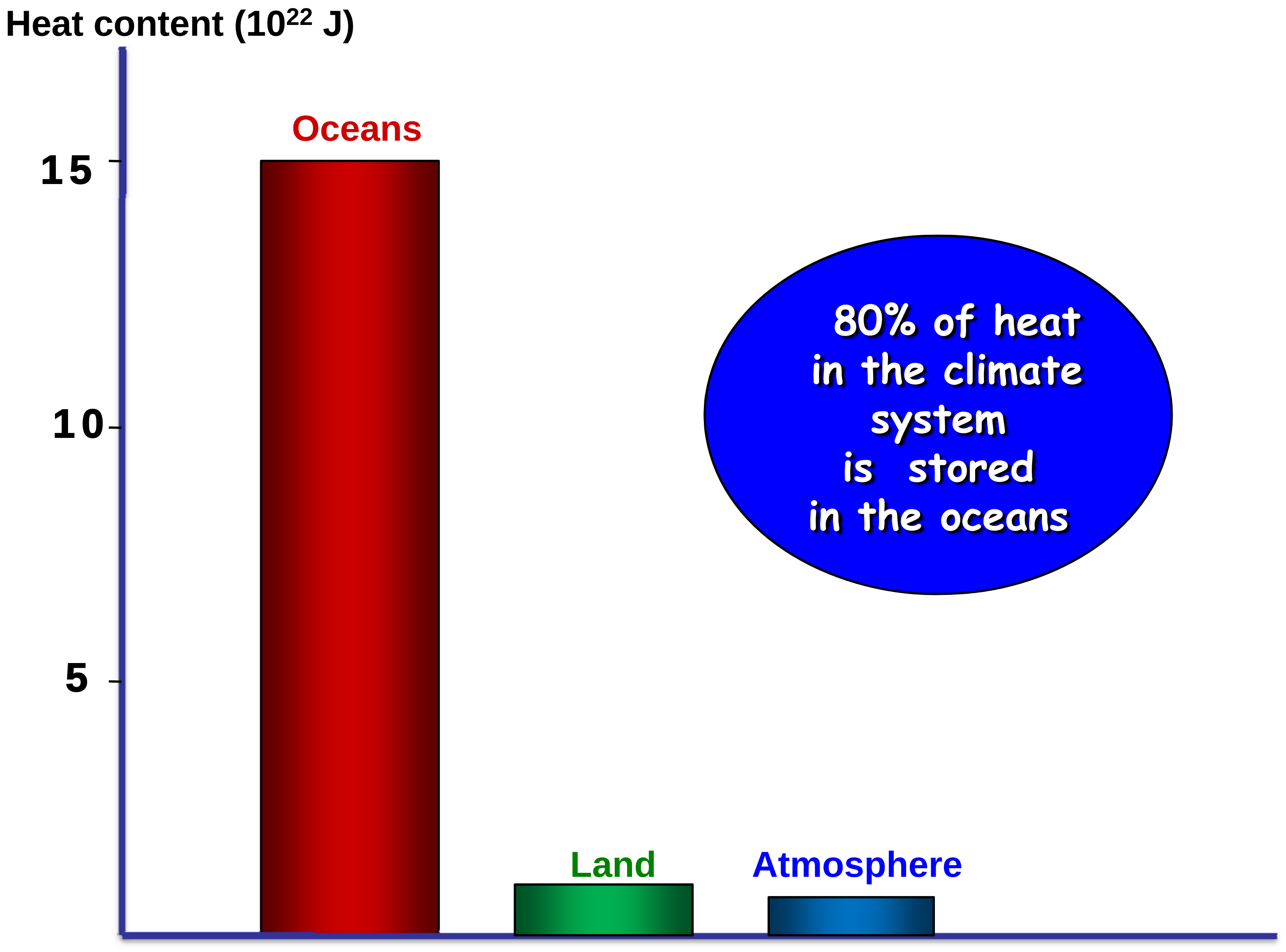
1976 Climate regime change

Domingues et al. (2008)



Ishii & Kimoto (2008)

Thermal budget of the climate system (last 50 years)



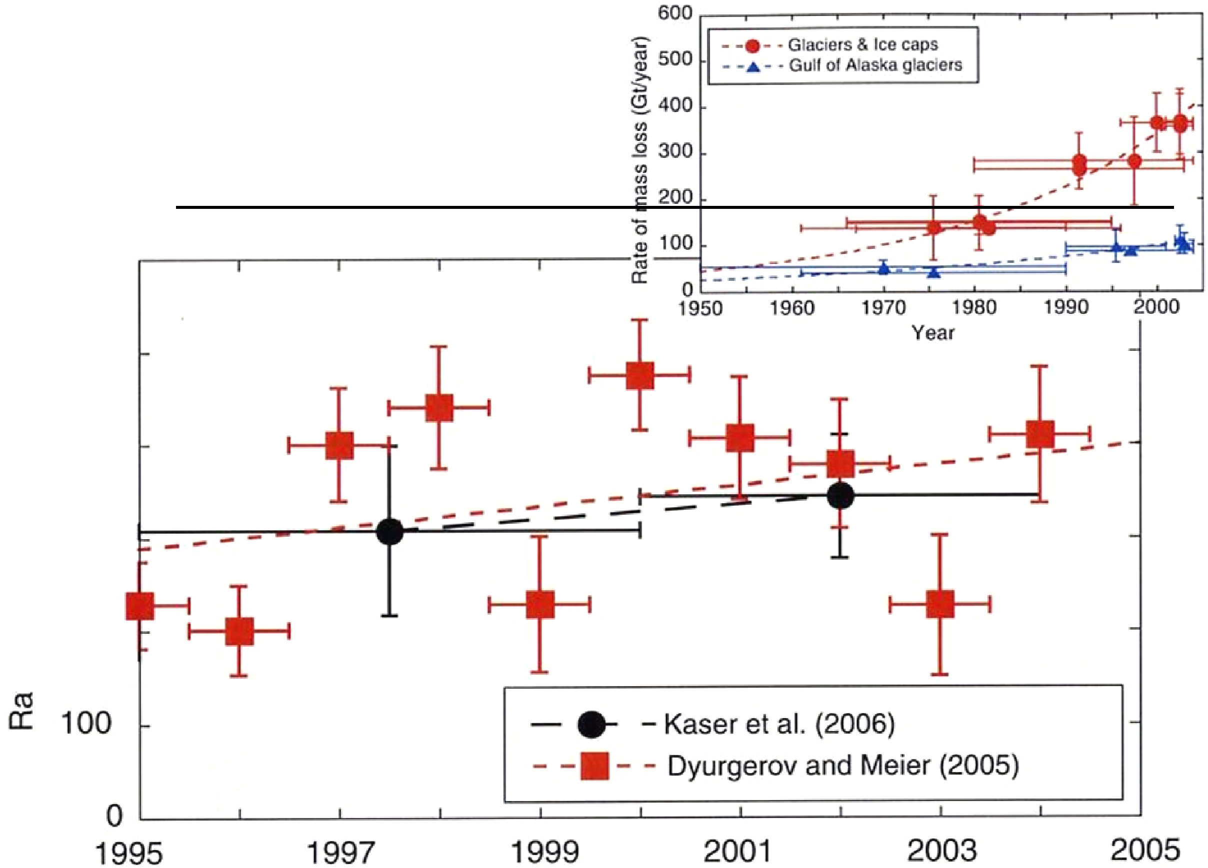
After Levitus et al., 2005

Contribution of thermal expansion

Source	1961-2003 mm/yr	1993-2003 mm/yr
IPCC AR4 0-700m	0.35 +/- 0.06	1.6 +/- 0.25
Ishii & Kimoto (2008) version 6.7 0-700 m	0.3 +/- 0.06 *(1950-2005)*	1.23 +/- 0.3 *(1993-2005)*
Domingues et al. (2008) 0-700 m	0.6 +/- 0.1	1.6 +/- 0.2

Land Ice contribution

Contribution of glacier melting to sea level rise

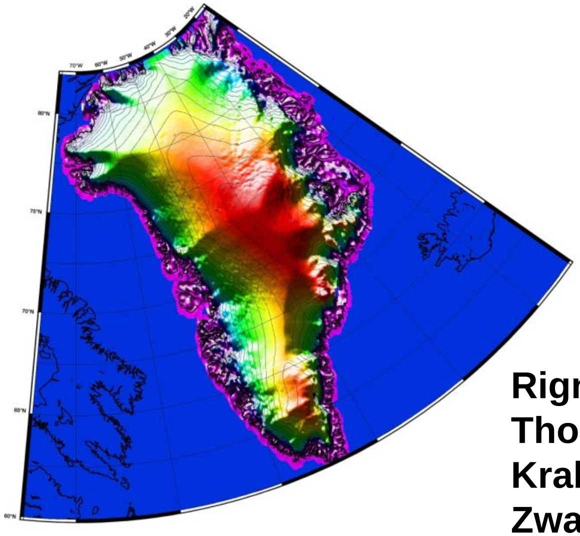


Rate of ice mass loss by glacier melting (Gt/year)

Contribution to sea level :
1961-2003: 0.5 +/- 0.18 mm/yr
1993-2003 :0.8 +/- 0.2 mm/yr)
IPCC, 2007

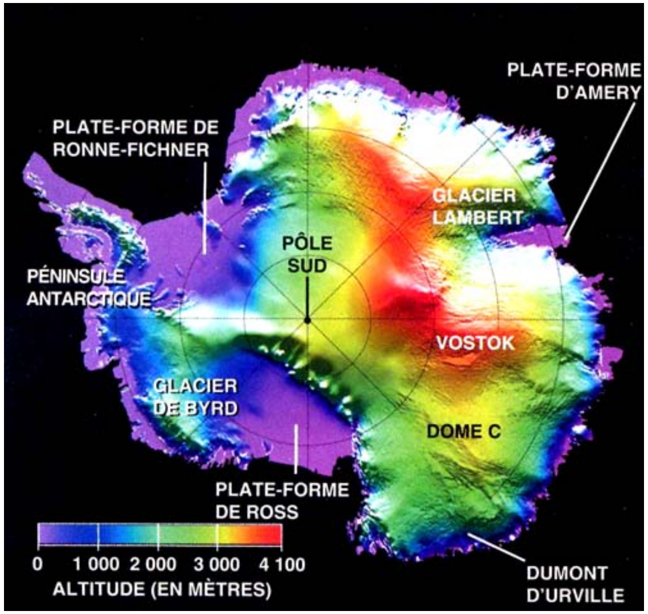
Meier et al.(2007)

Ice sheets Contribution (recent years)

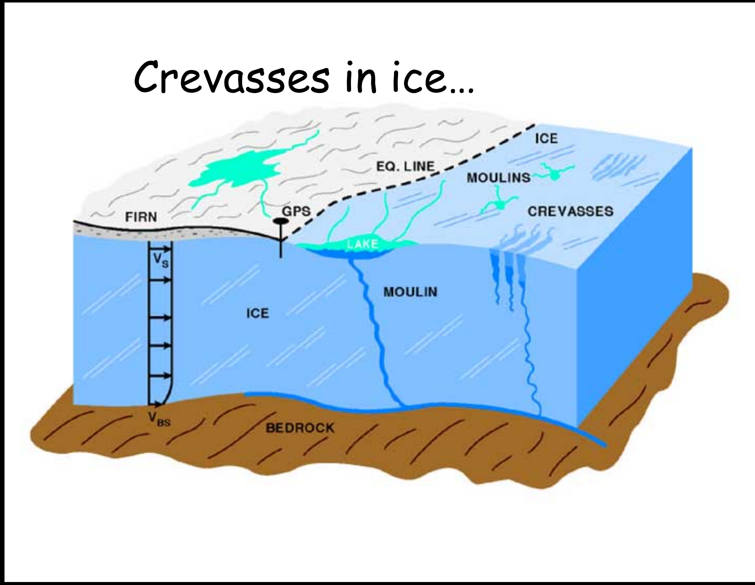


Greenland

Rignot & Thomas, 2002
Thomas et al., 2004
Krabill et al., 2004
Zwally et al., 2005
Johanessen et al., 2005
Davis et al., 2005
Rignot & Kanagaratnam, 2006
Rignot et al., 2006
Velicogna & Wahr (2005, 2006)
Ramillien et al. (2006)
Chen et al. (2006)
Lutchke et al. (2006)
Rignot et al. (2008)
Cazenave et al. (2008)
Wouters et al. (2008)
……….

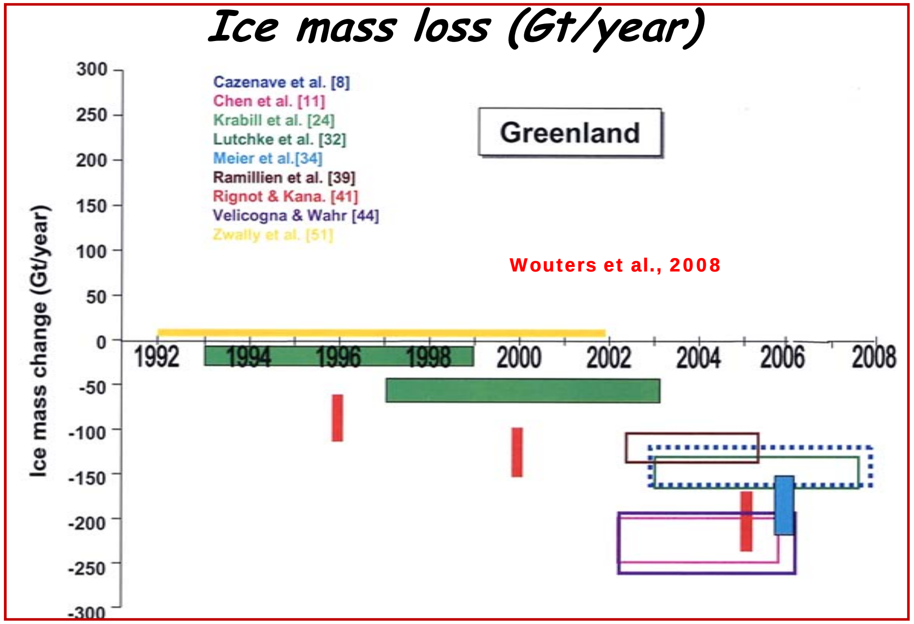


Antarctica

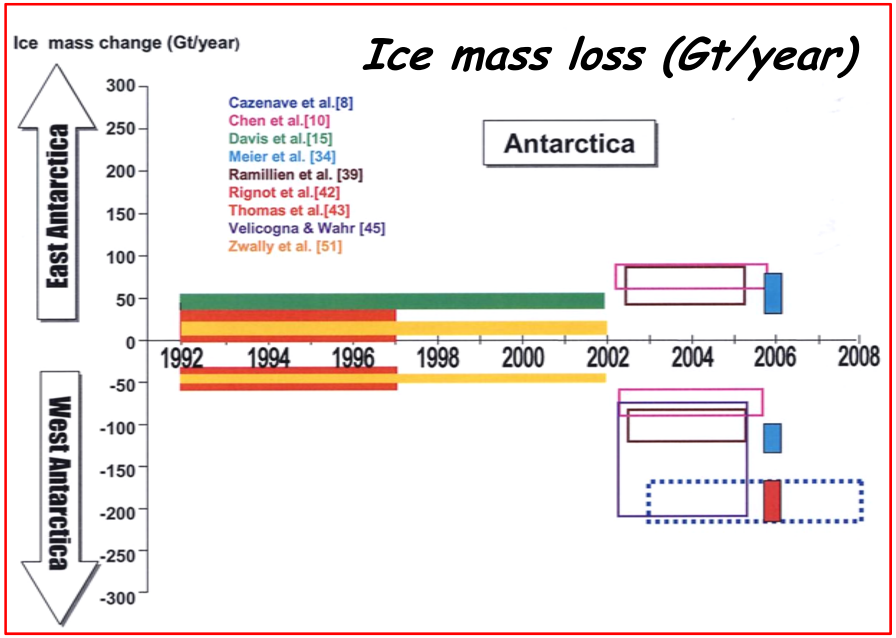


Greenland ice sheet

Greenland and Antarctica mass balance



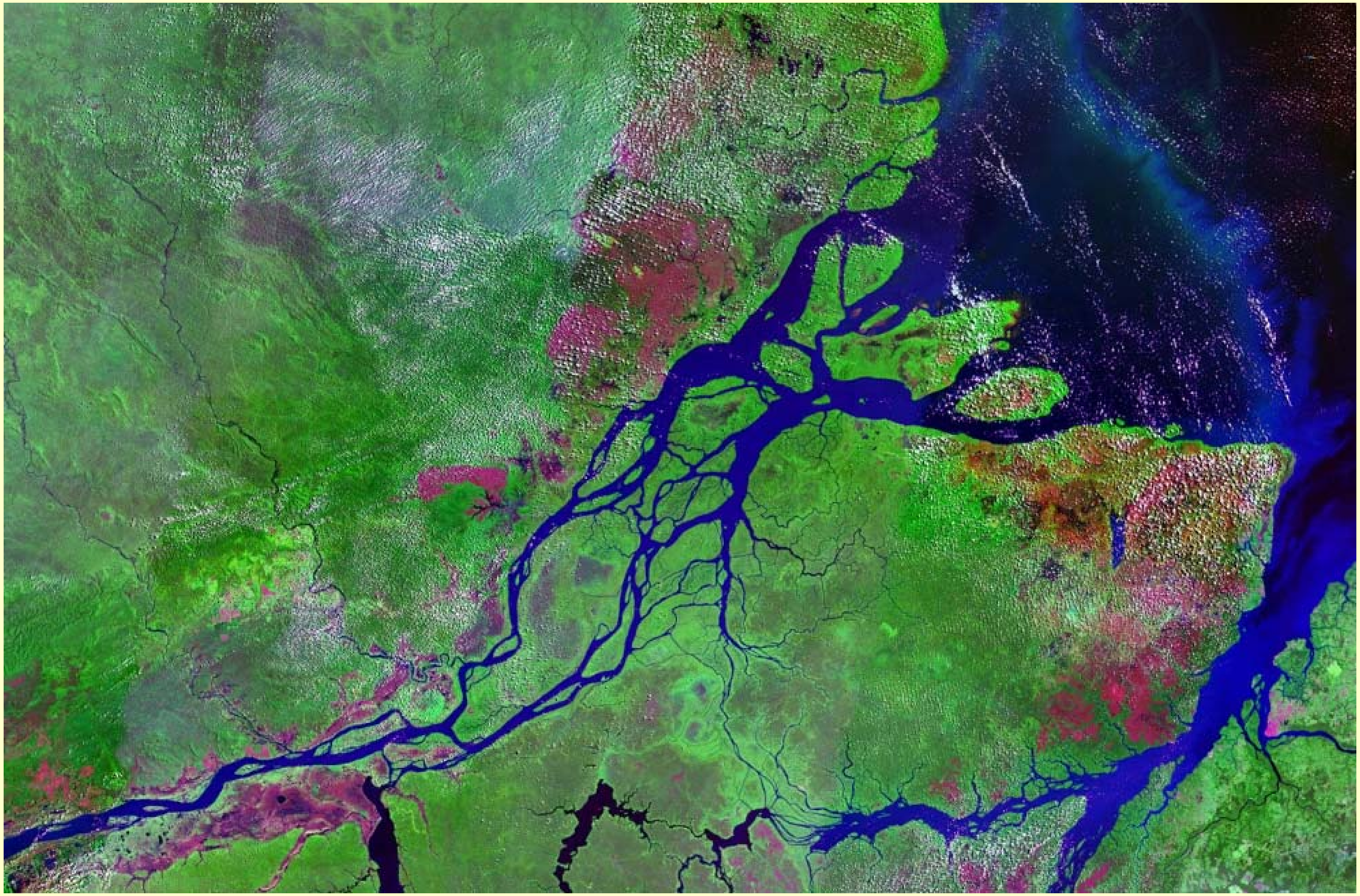
Greenland contribution to sea level rise (1993-2003) : 0.21 +/-0.04 mm/yr (IPCC AR4)

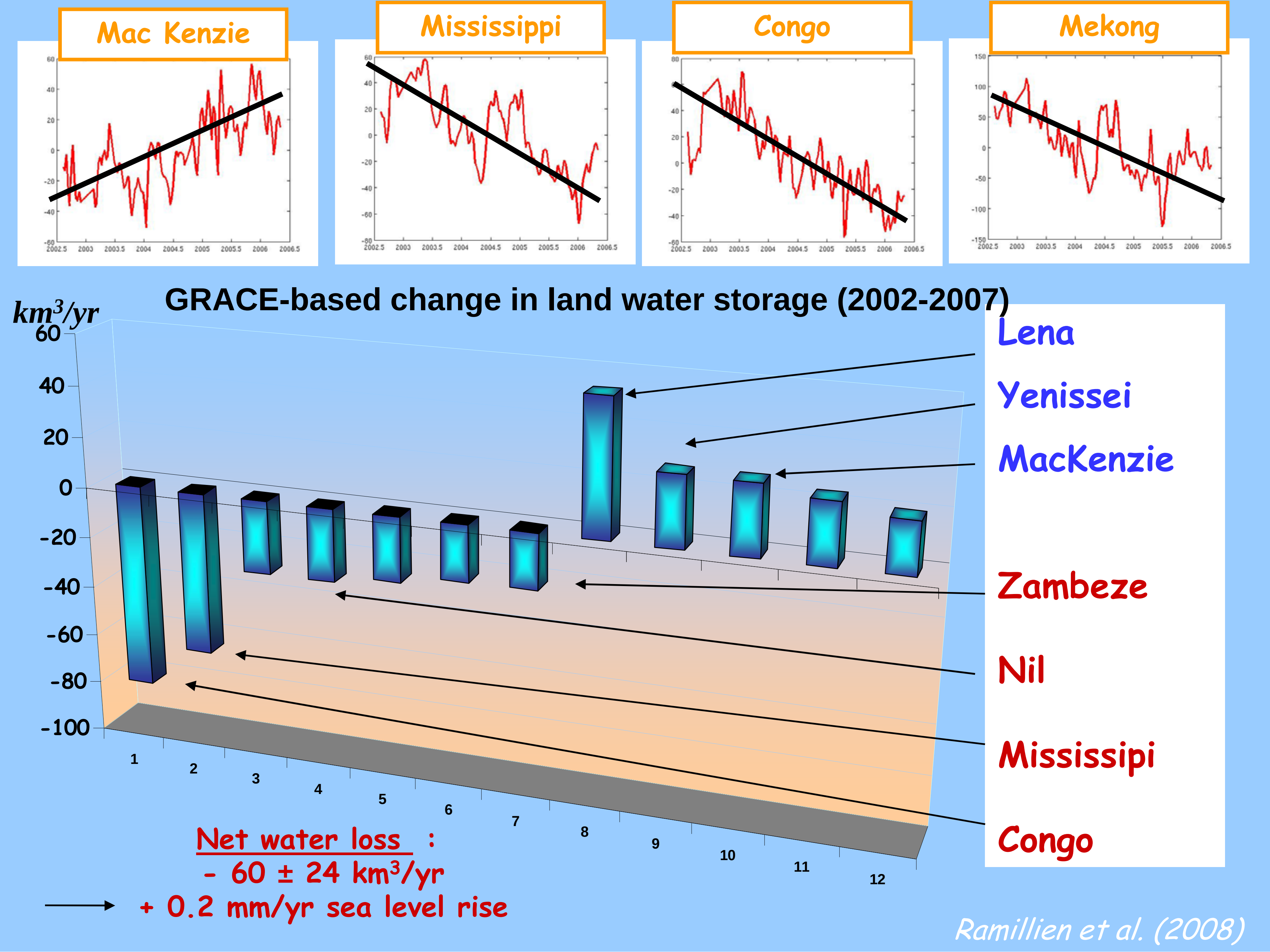


Antarctica contribution to sea level rise (1993-2003) : 0.21 +/-0.18 mm/yr (IPCC AR4)

Ice mass loss measured by remote sensing techniques

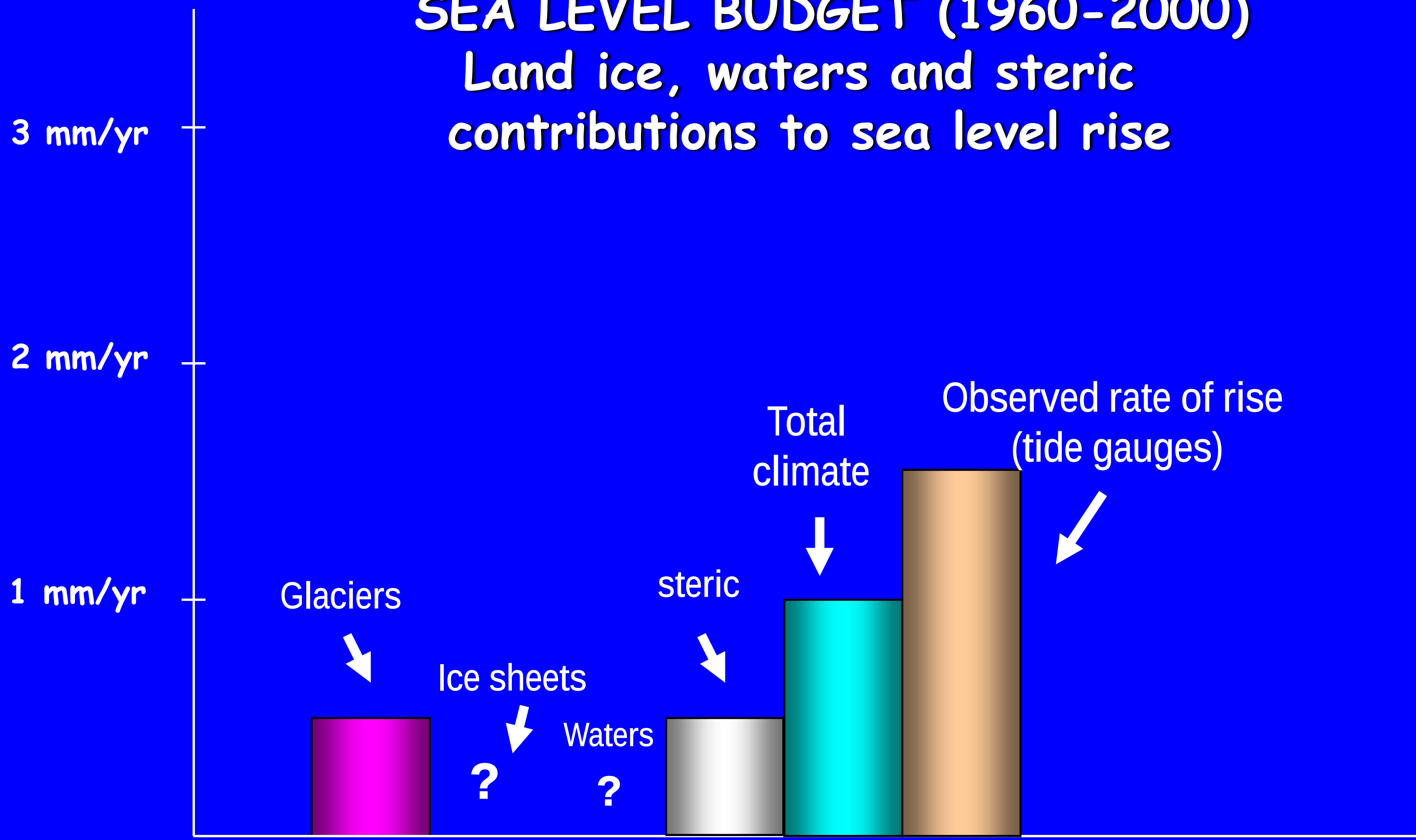
Land waters contribution



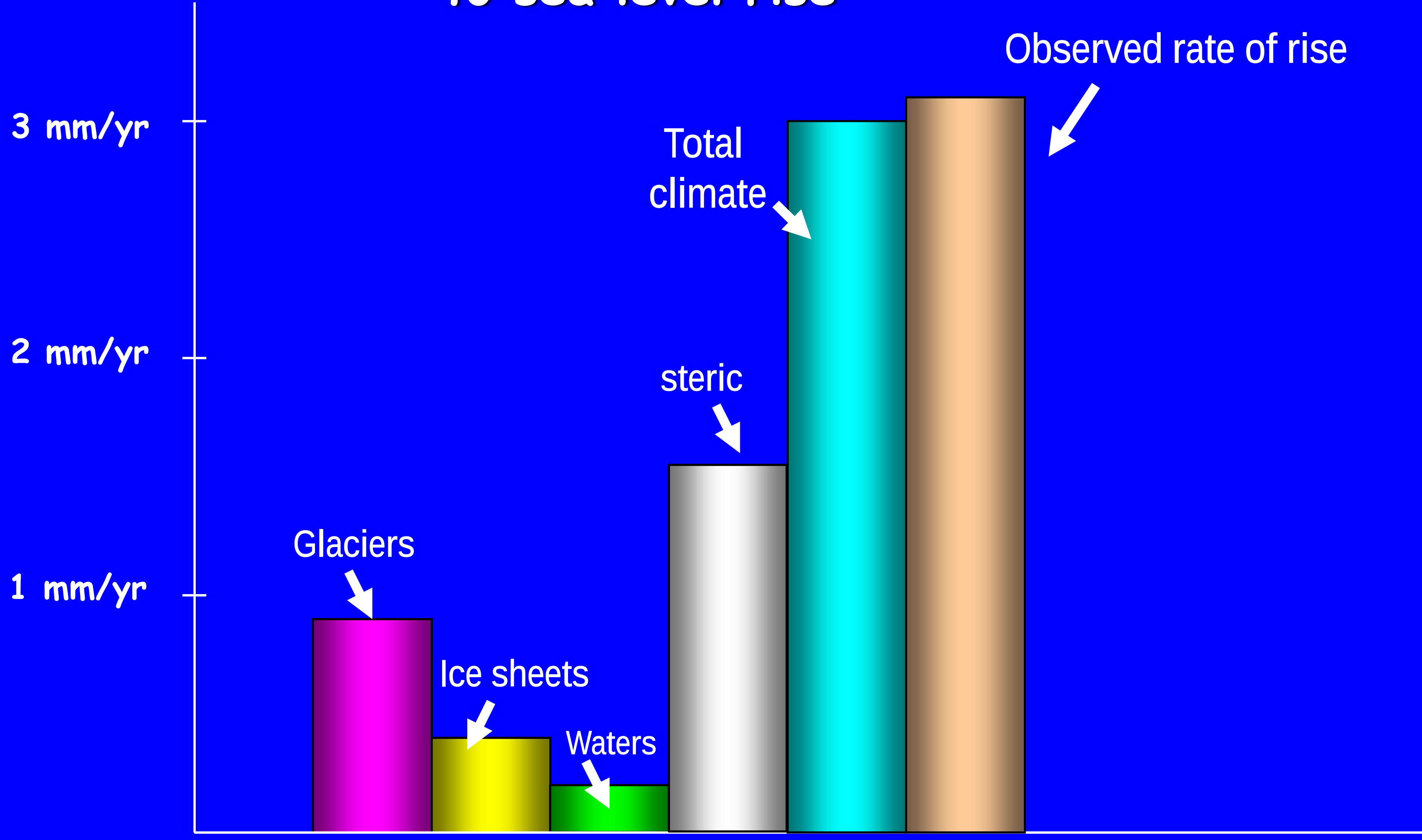


Mac Kenzie
Mississippi
Congo
Mekong
GRACE-based change in land water storage (2002-2007)
km³/yr
60
40
20
0
-20
-40
-60
-80
-100
1
2
3
4
5
6
7
8
9
10
11
12
Lena
Yenissei
MacKenzie
Zambeze
Nil
Mississipi
Congo
Net water loss :
- 60 ± 24 km³/yr
+ 0.2 mm/yr sea level rise
Ramillien et al. (2008)

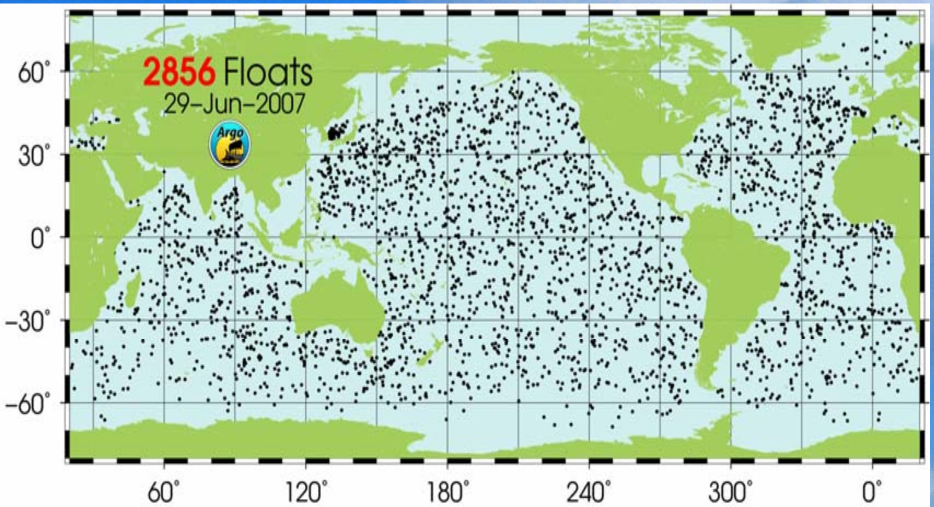
SEA LEVEL BUDGET (1960-2000)
Land ice, waters and steric contributions to sea level rise



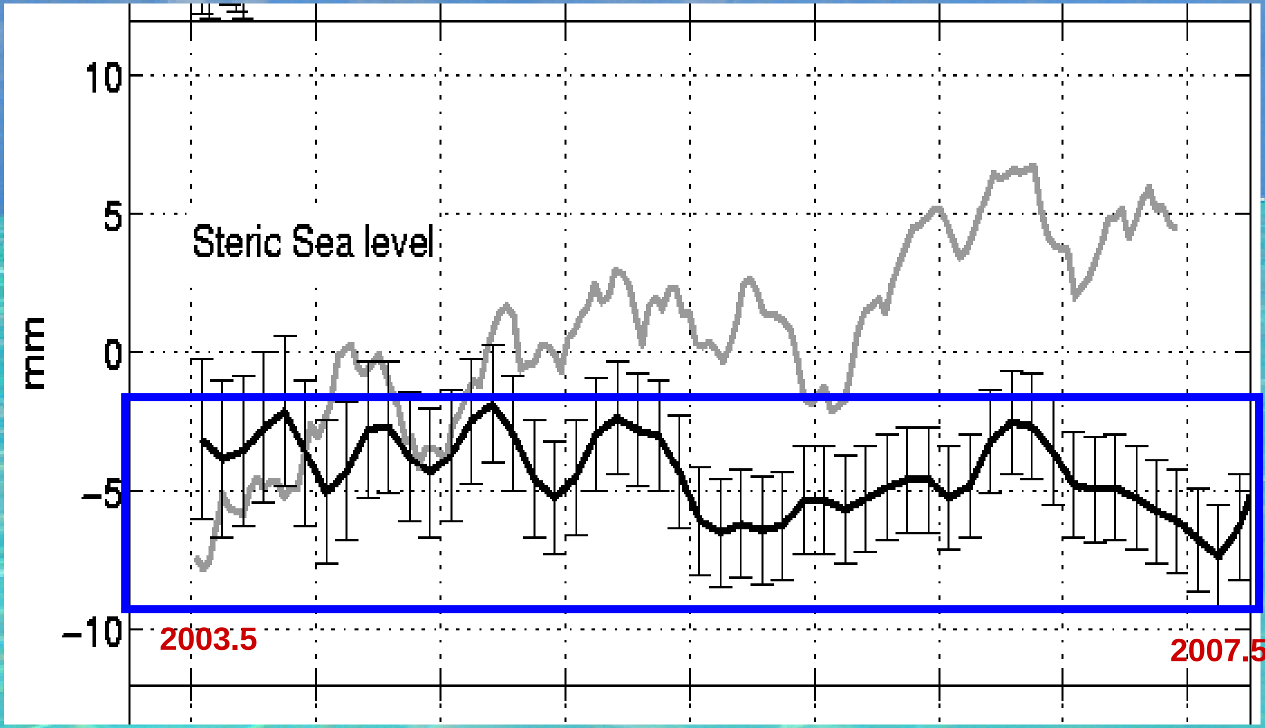
Sea Legel Budget *1993-2003*
Land ice, waters and steric contributions to sea level rise



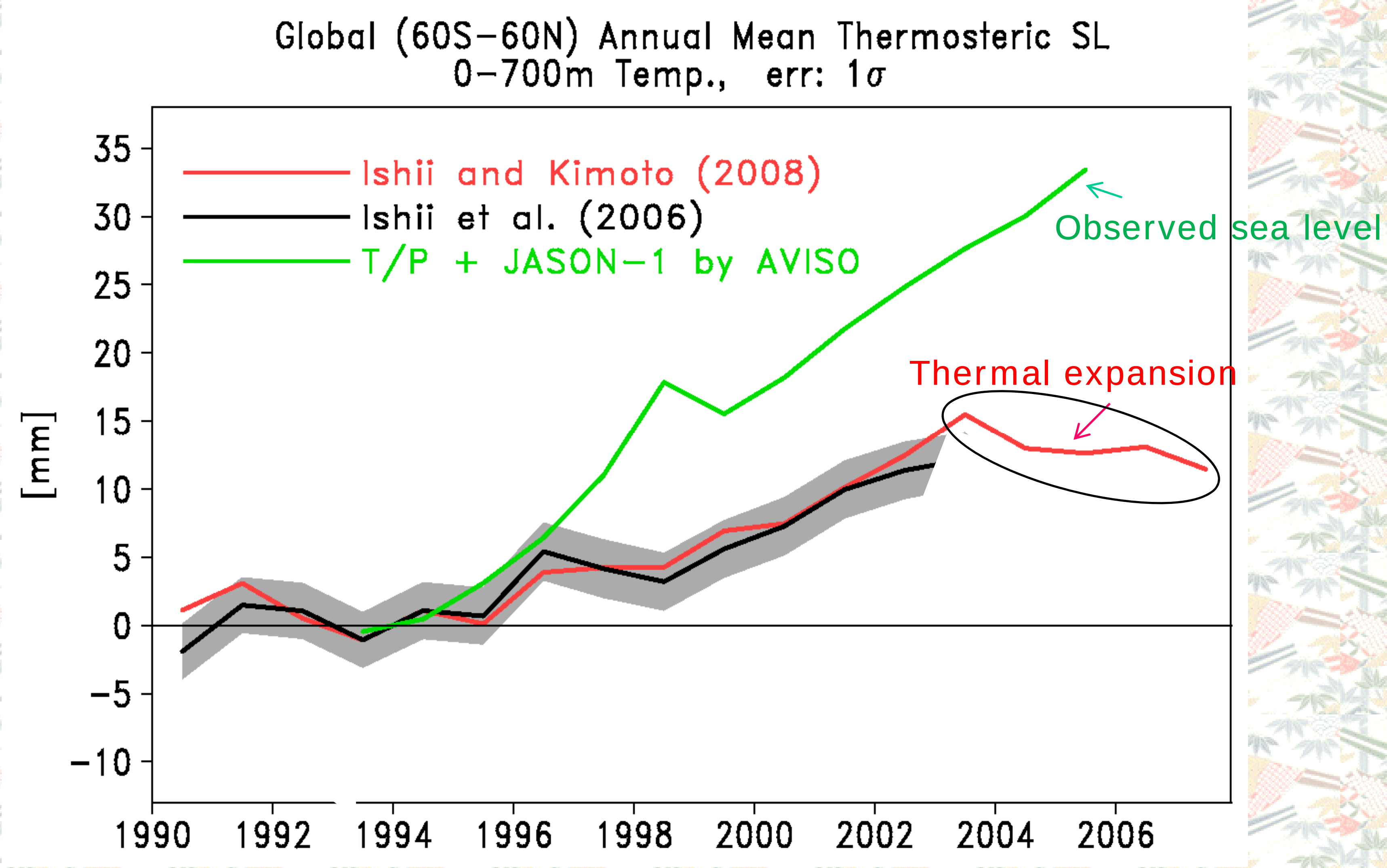

Sea Level Rise
since 2003
New questions…



Steric sea level from ARGO

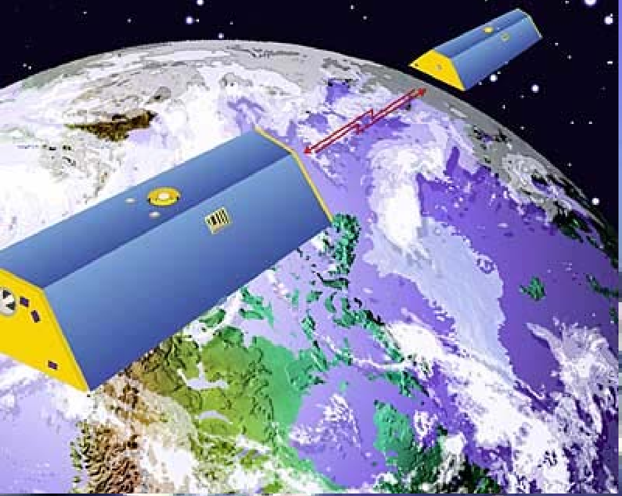


From Willis et al., 2008



Recent thermosteric sea level changes (Ishii and Kimoto, 2008)

Courtesy M. Ishii



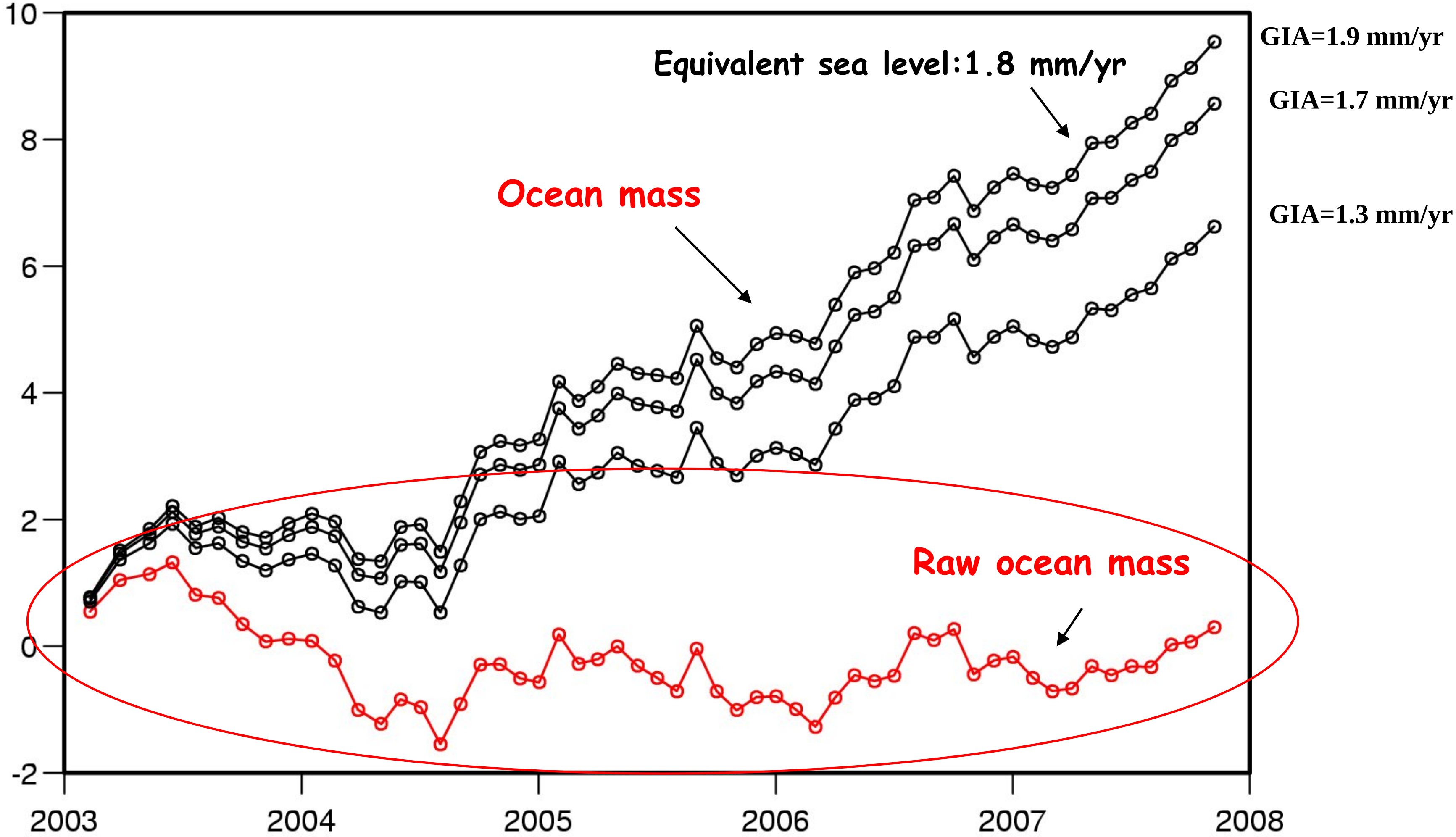
the answer from GRACE….

Can we explain recent sea level rise by land ice only?

…

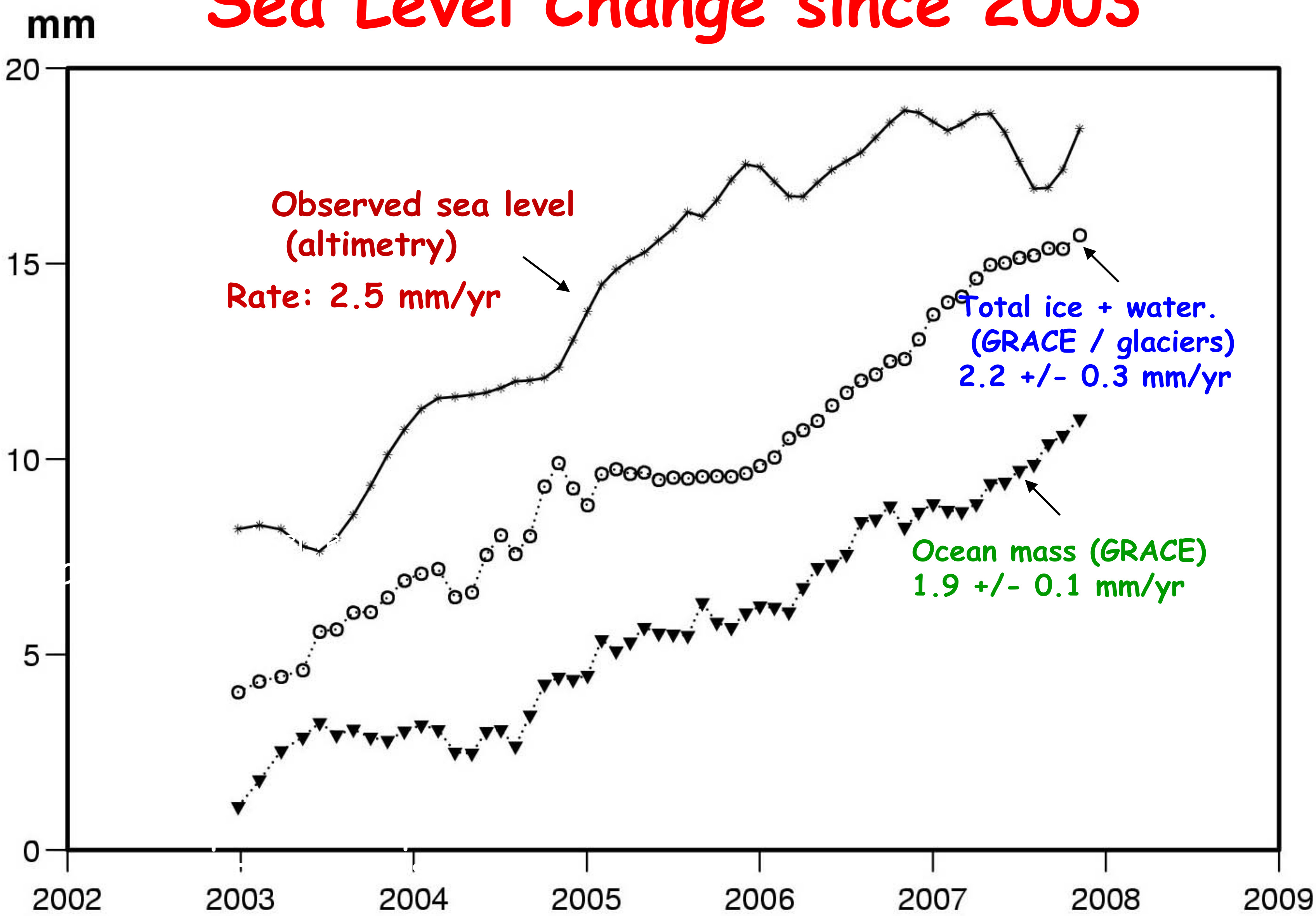
Ocean Mass Change from GRACE

GIA/ocean mass →Peltier, 2008: 1.9-2 mm/yr
when rotational effects are accounted for



Source LEGOS

Sea Level Change since 2003



Contribution of glacier melting to sea level rise (recent years)

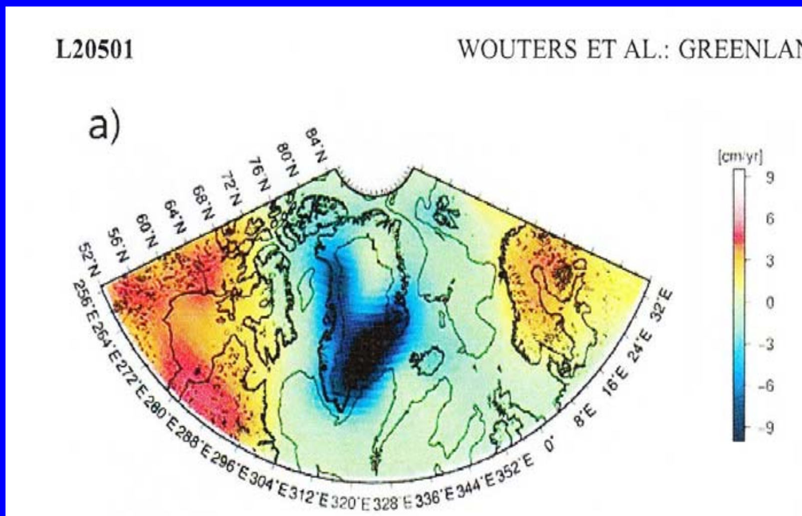
-Glaciers (2001-2004): 1.0 +/- 0.19 mm/yr

Kaser et al. (2006)

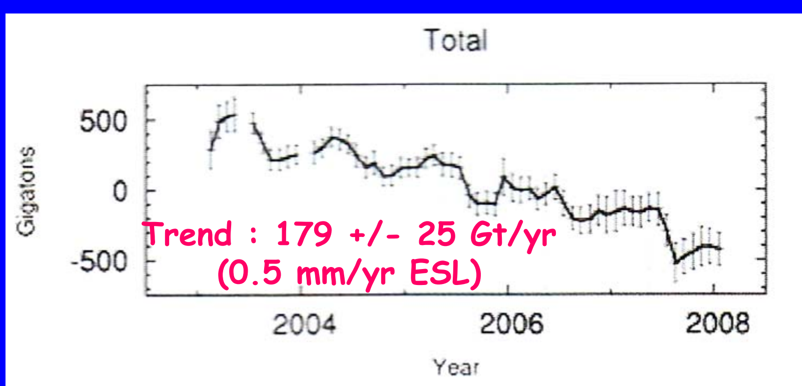
-Glaciers (2006): 1.1 +/- 0.24 mm/yr

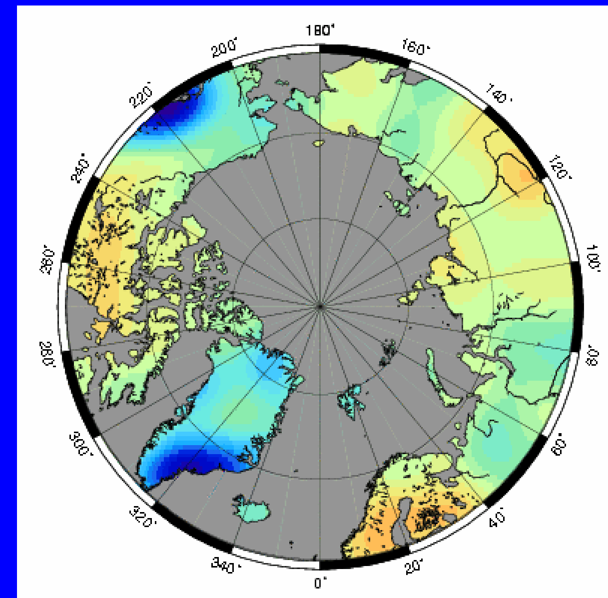
Meier et al. (2007)

Space gravity mission GRACE (2002-)
→ temporal gravity variations → surface mass changes

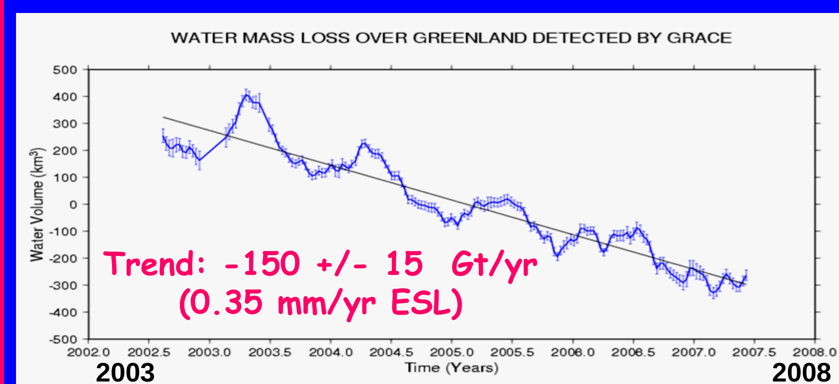


Wouters , Chambers, Schrama (2008)



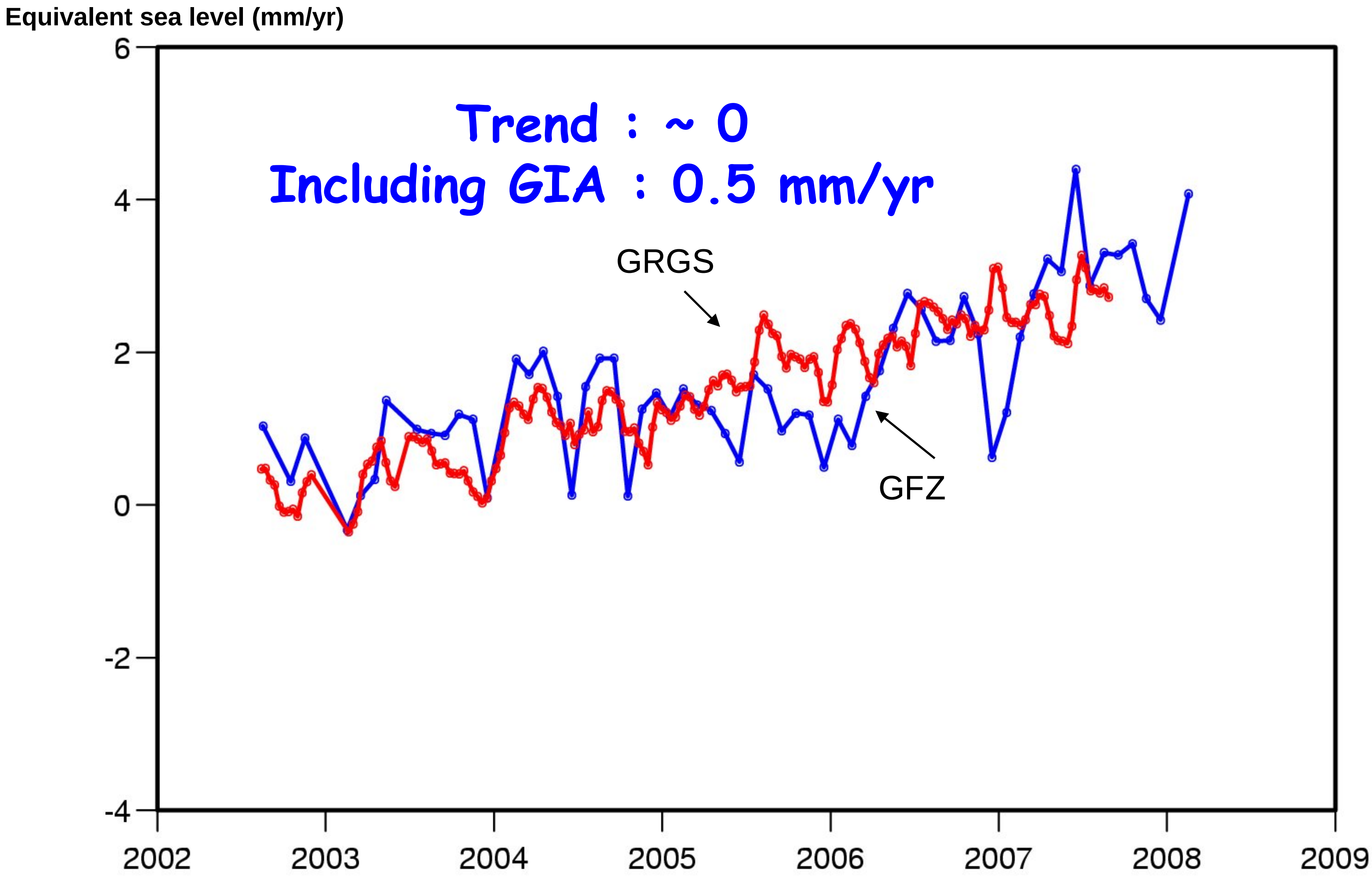


Ramillien et al. (2008)



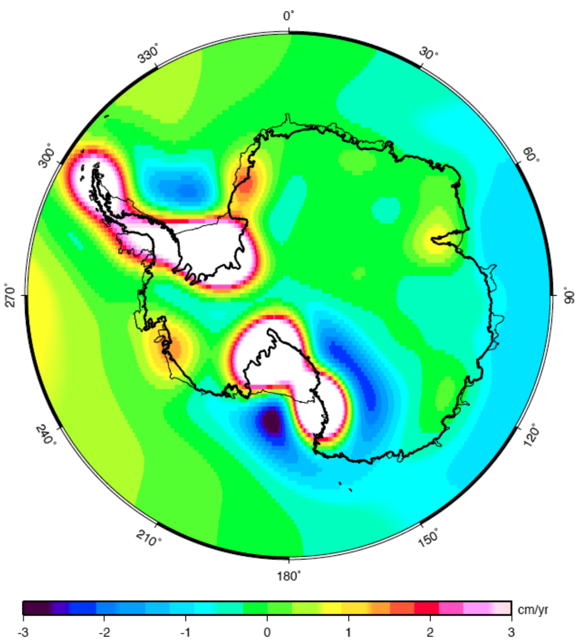
Greenland ice mass loss from GRACE

Antarctica contribution to sea level (GRACE)

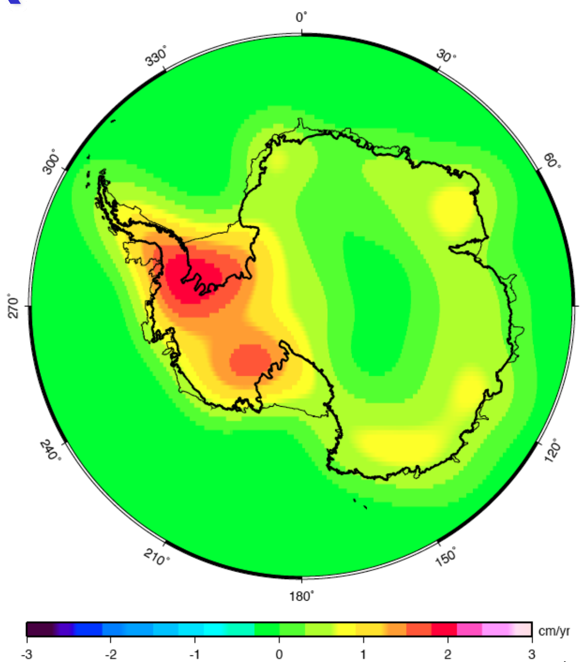


Source: LEGOS

GIA Models (Water Thickness Change)

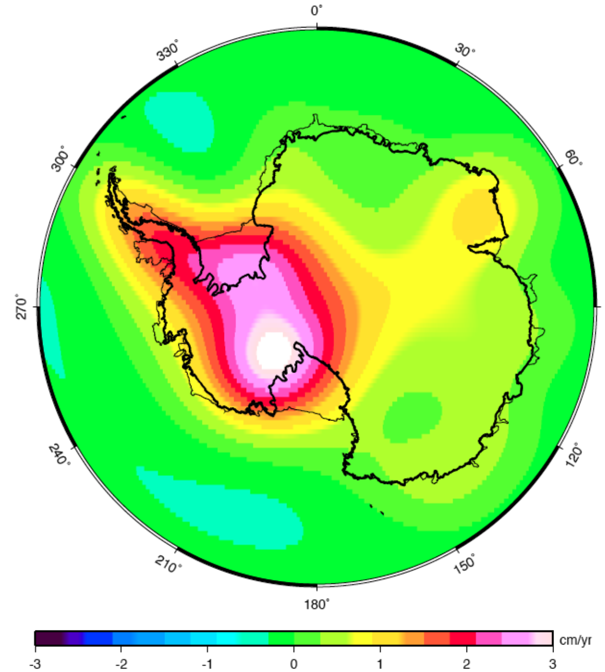


ICE 5G (VM4); Peltier

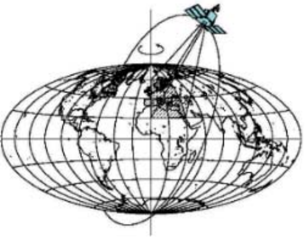


-3 +3 cm/yr

Ivins-James

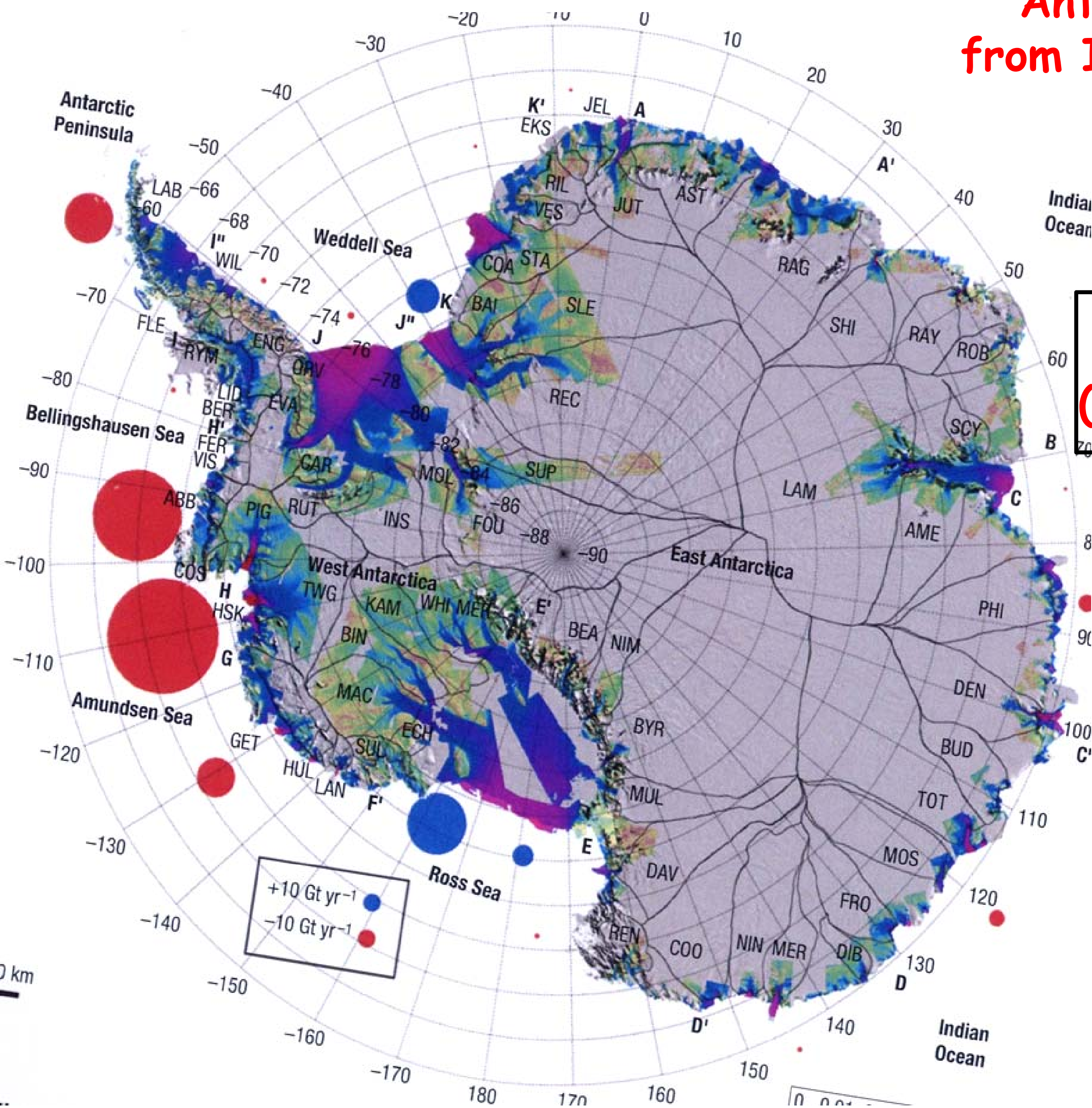


Wu RF3S20



Courtesy : C.K. Shum

Antarctica mass balance from INSAR (remote sensing)

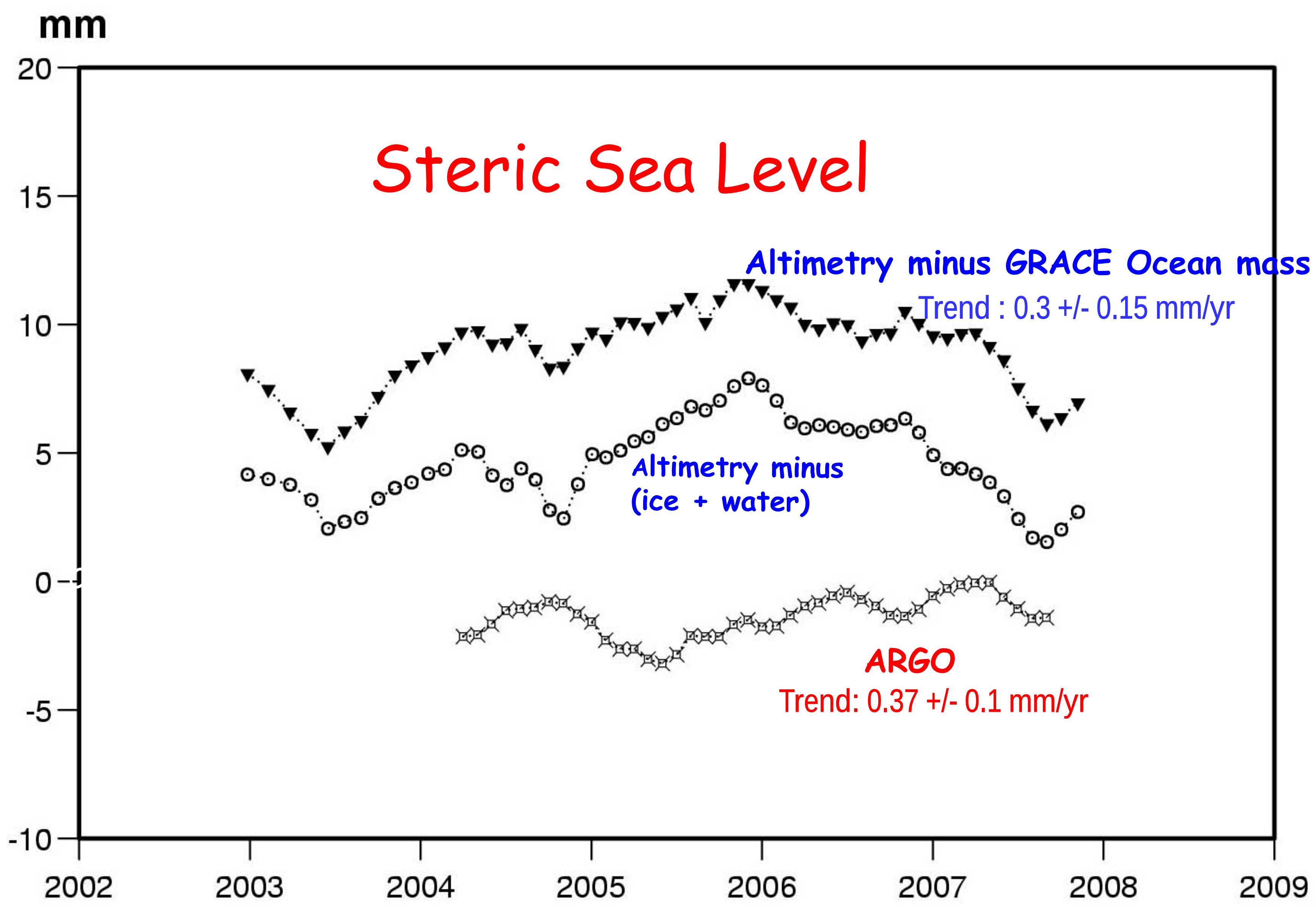


2006 : 0.5 mm/yr (equivalent sea level)

Mass loss

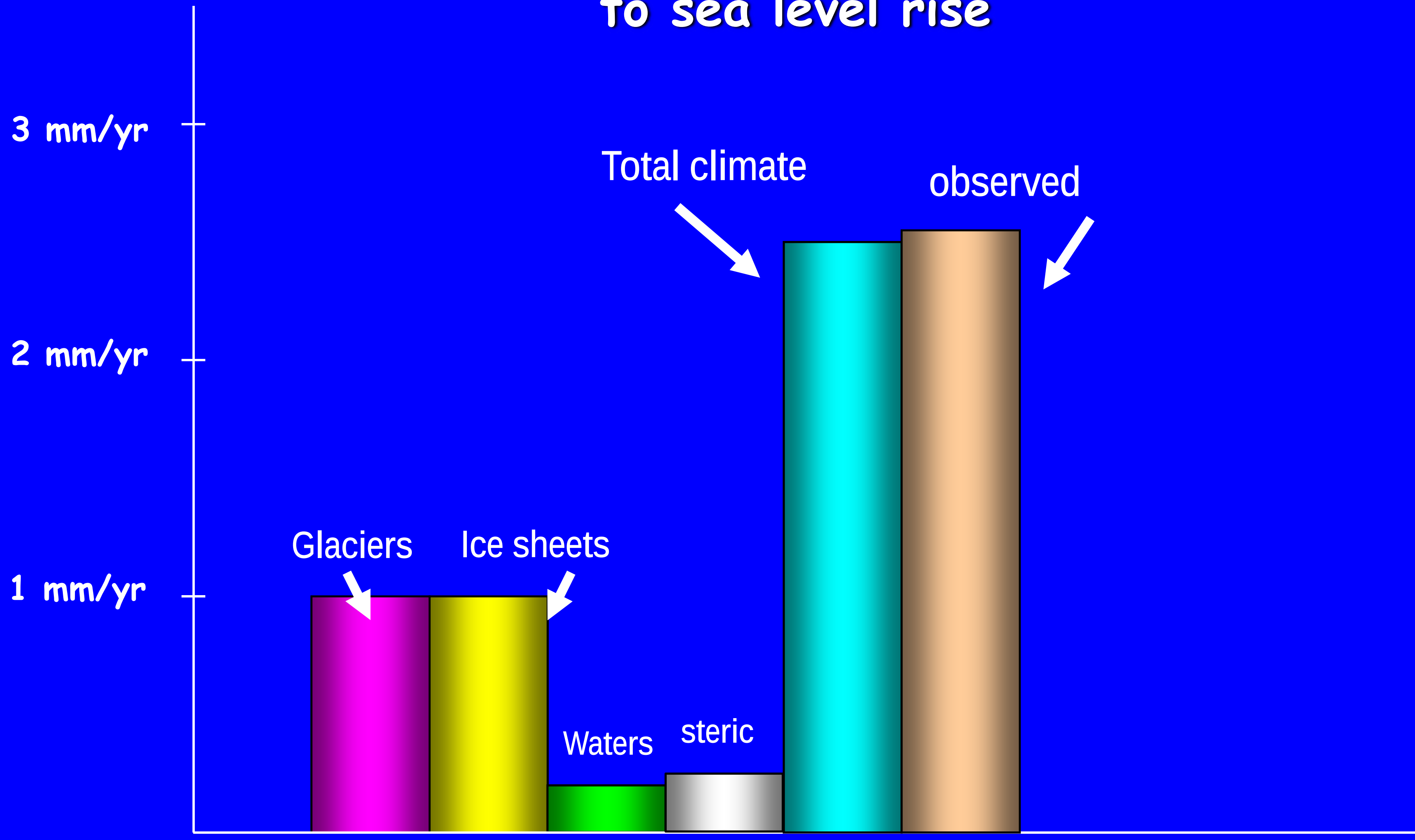
Mass gain

Rignot et al., 2008



mm
Steric Sea Level
Altimetry minus GRACE Ocean mass
Trend : 0.3 +/- 0.15 mm/yr
Altimetry minus
(ice + water)
ARGO
Trend: 0.37 +/- 0.1 mm/yr
20
15
10
5
0
-5
-10
2002
2003
2004
2005
2006
2007
2008
2009

Sea Level Budget 2003-2008
Land ice, waters and steric contributions to sea level rise



Recommendation 2:

- Improve GRACE products (ocean mass change, ice sheet mass balance)
- Improve GIA corrections (Grace-based ocean mass & ice sheets)

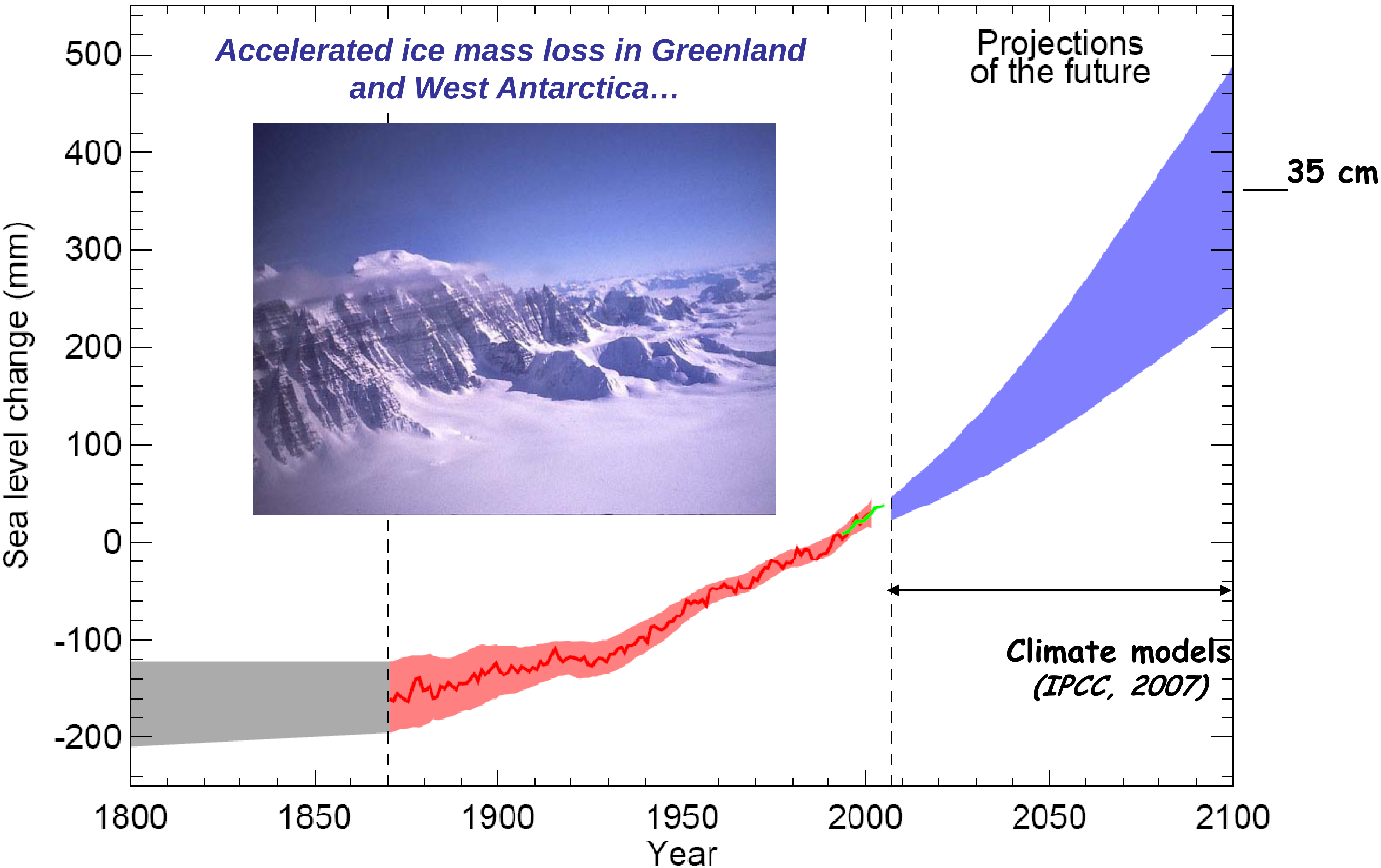
⬇

Data base of GRACE products (of interest for sea level studies) and associated GIA corrections based on expert group consensus (with regular updates)

???


Future Sea Level Rise…

Global mean sea level from 1800 to 2100



IPCC, 2007

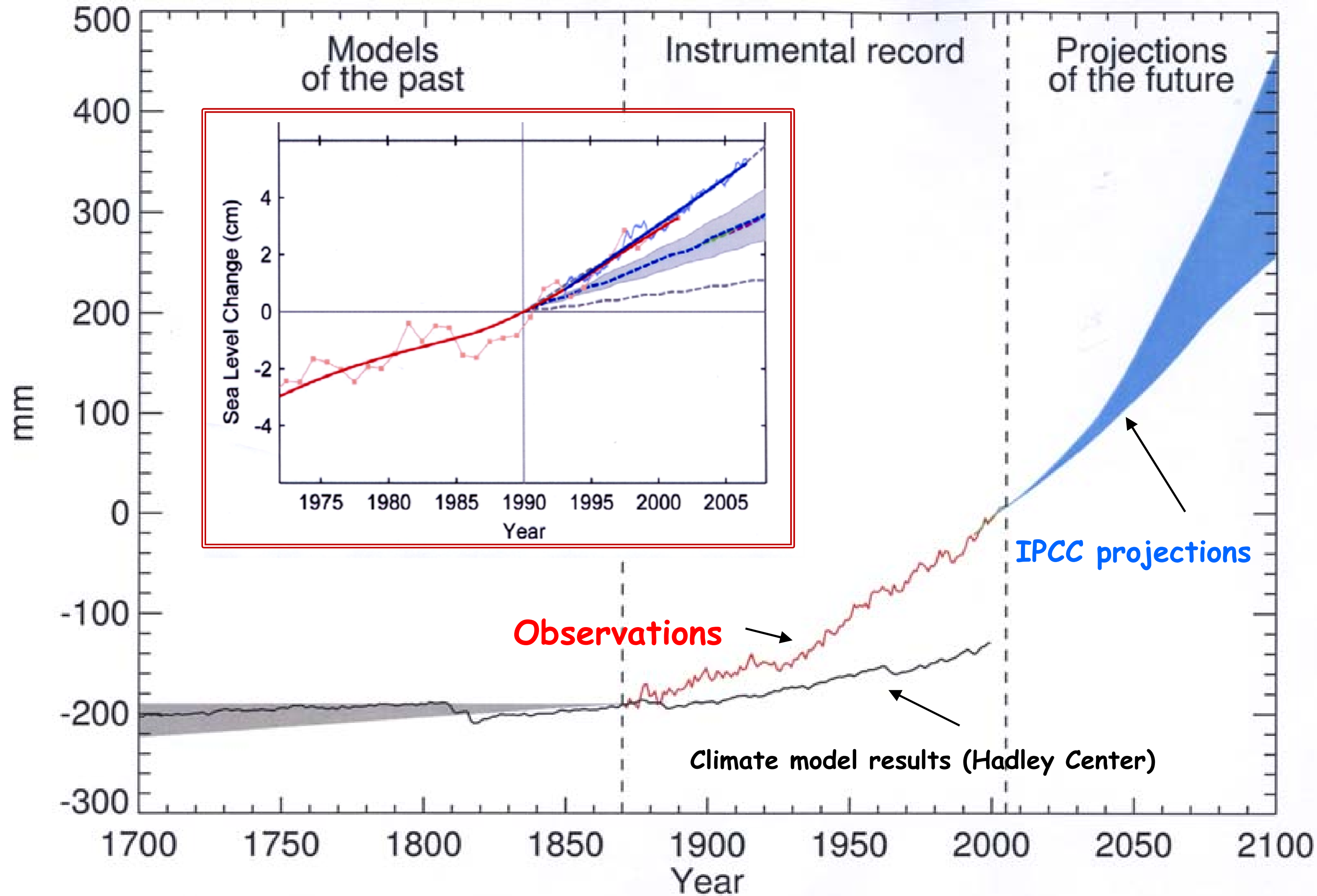
Potential dynamical contribution of the ice sheets (ice dynamics) in 2100

↓

1-2 m!

Pfeffer et al, Science, Sept. 2008

Sea level change (1700 – 2100)



Recommendation 3:

Improve climate model predictions of future sea level at global and regional scales

- Long time series of space – JASON-3 - and in situ observations (sea level + climate contributions) of crucial importance!

-Sea level budget studies

-Past sea level reconstructions
(→constraints on past regional variability)

Recommendation 4:

- Develop multidisciplinary impact studies in selected coastal regions using realistic regional sea level projections plus precise estimates of vertical crustal motions (subsidences, etc.), sediment supply from rivers, etc.

Future scientific Challenges

1. Detect any acceleration in the rate of sea level rise

2. Close the sea level budget

3. Understand the regional variability

4. Constrain (and improve) climate models

5. Study coastal impacts of sea level rise in selected coastal regions using realistic regional sea level projections plus precise estimates of vertical crustal motions (subsidences, etc.), sediment supply from rivers, etc.


End
CRDS
SRI
RSPR
OLIC RELIEF SERVICES