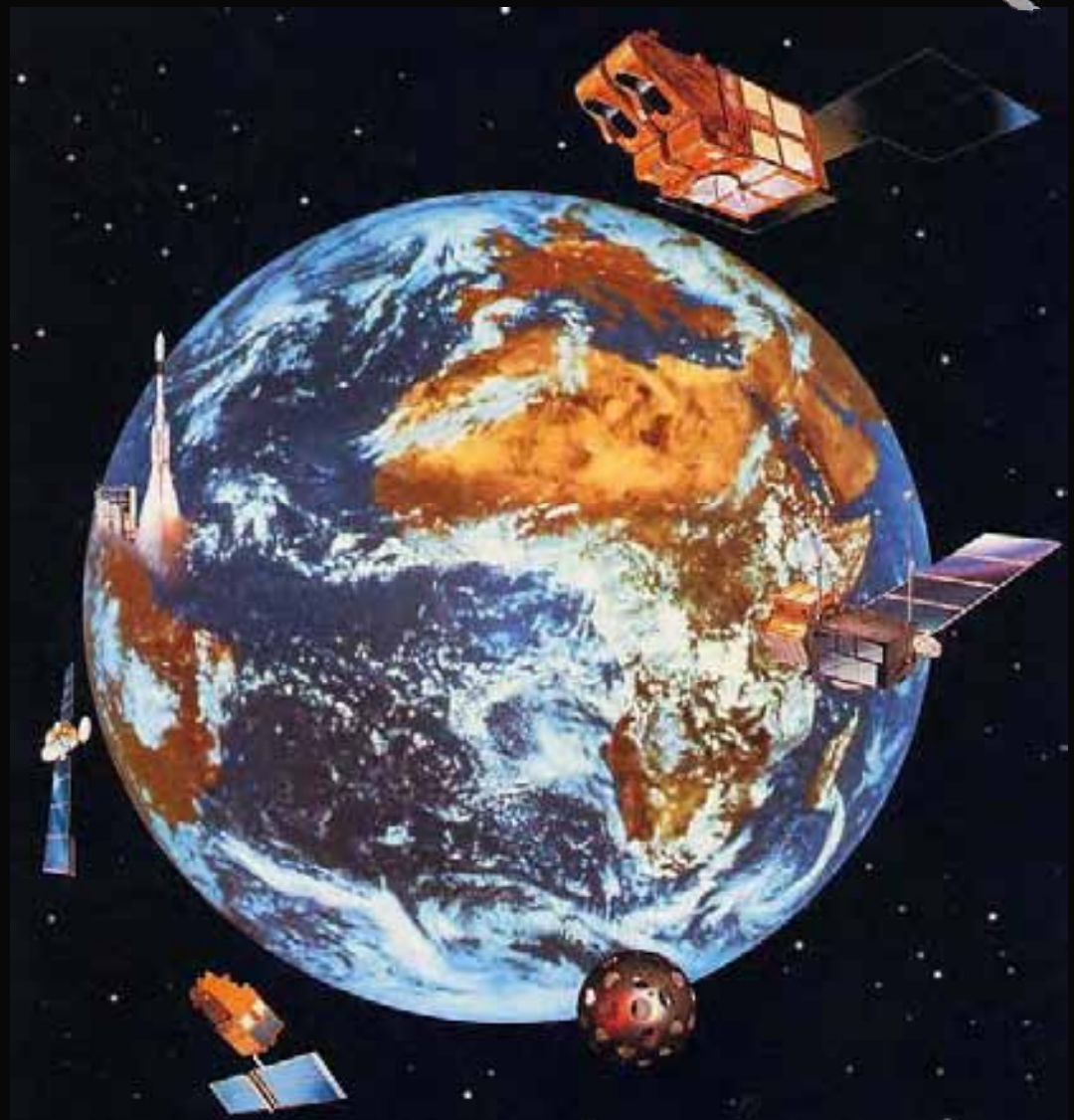
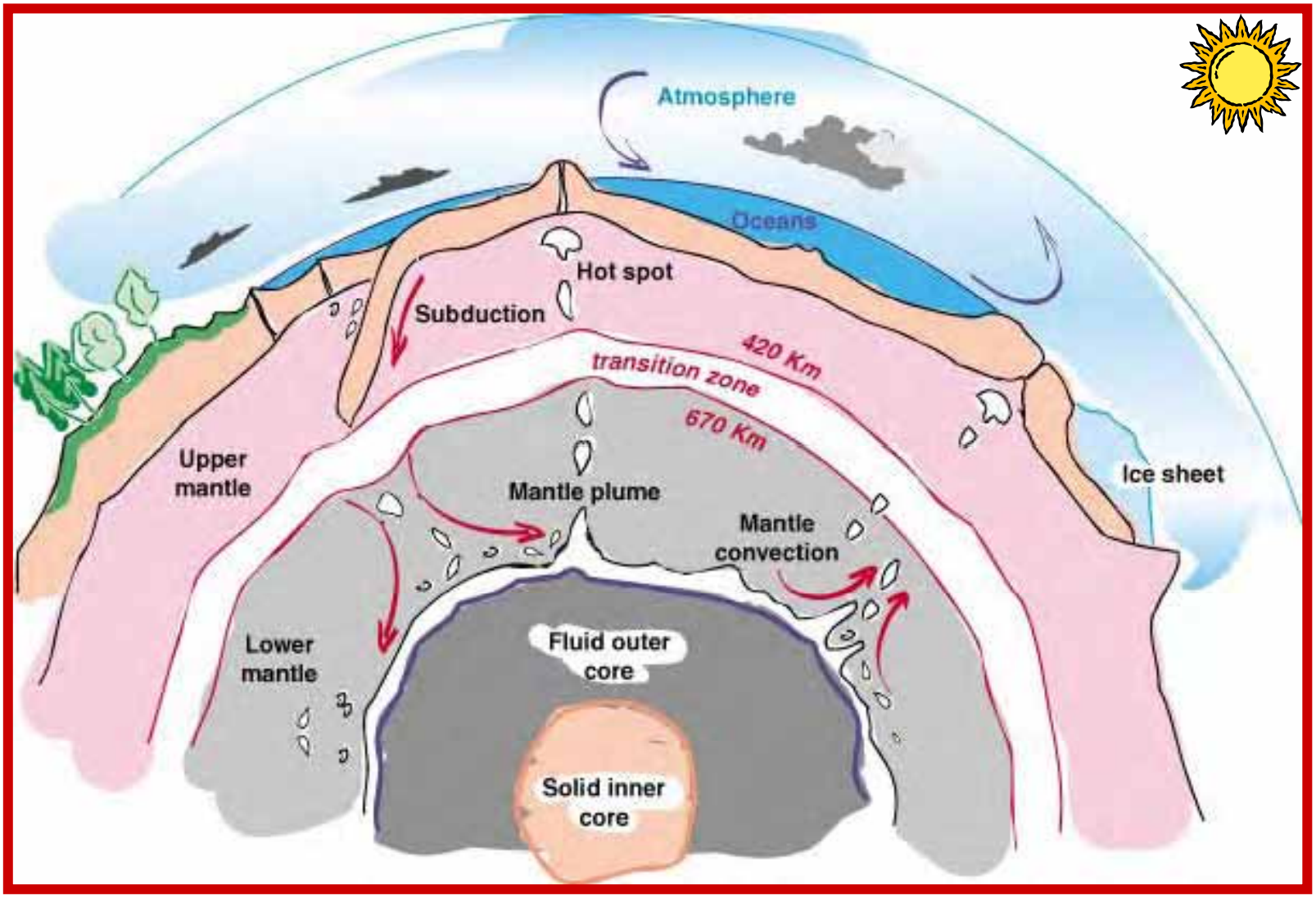
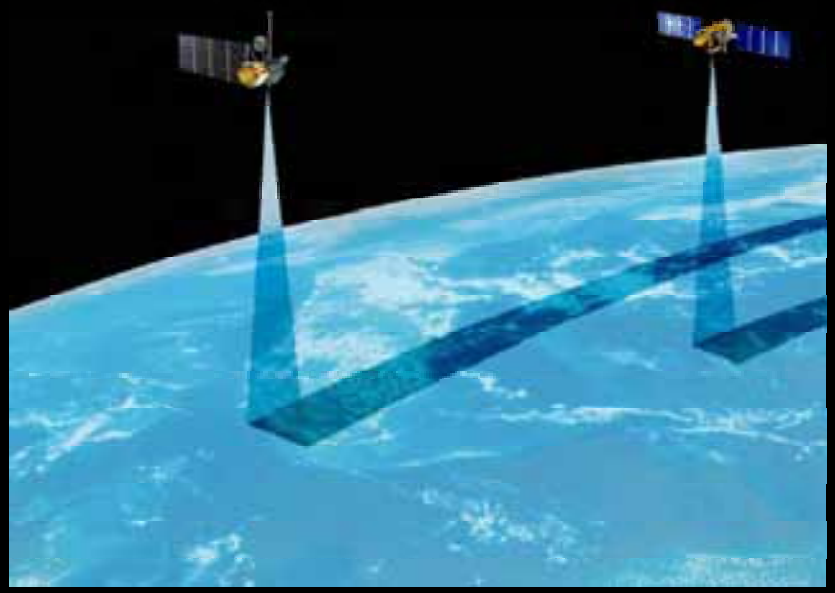
The Earth from Space



Anny Cazenave, LEGOS, Toulouse, France

The Earth System



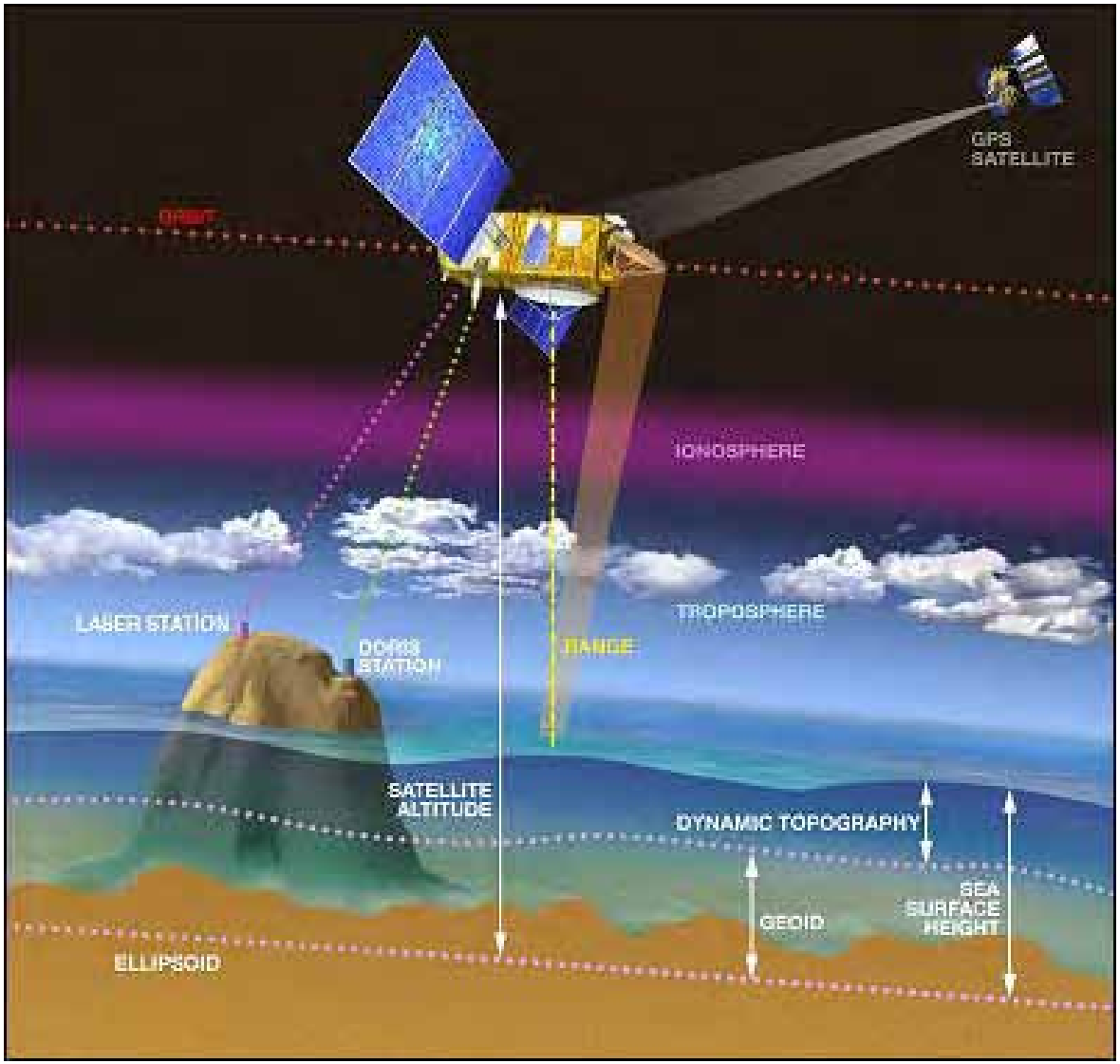


Satellite altimetry

Space gravimetry

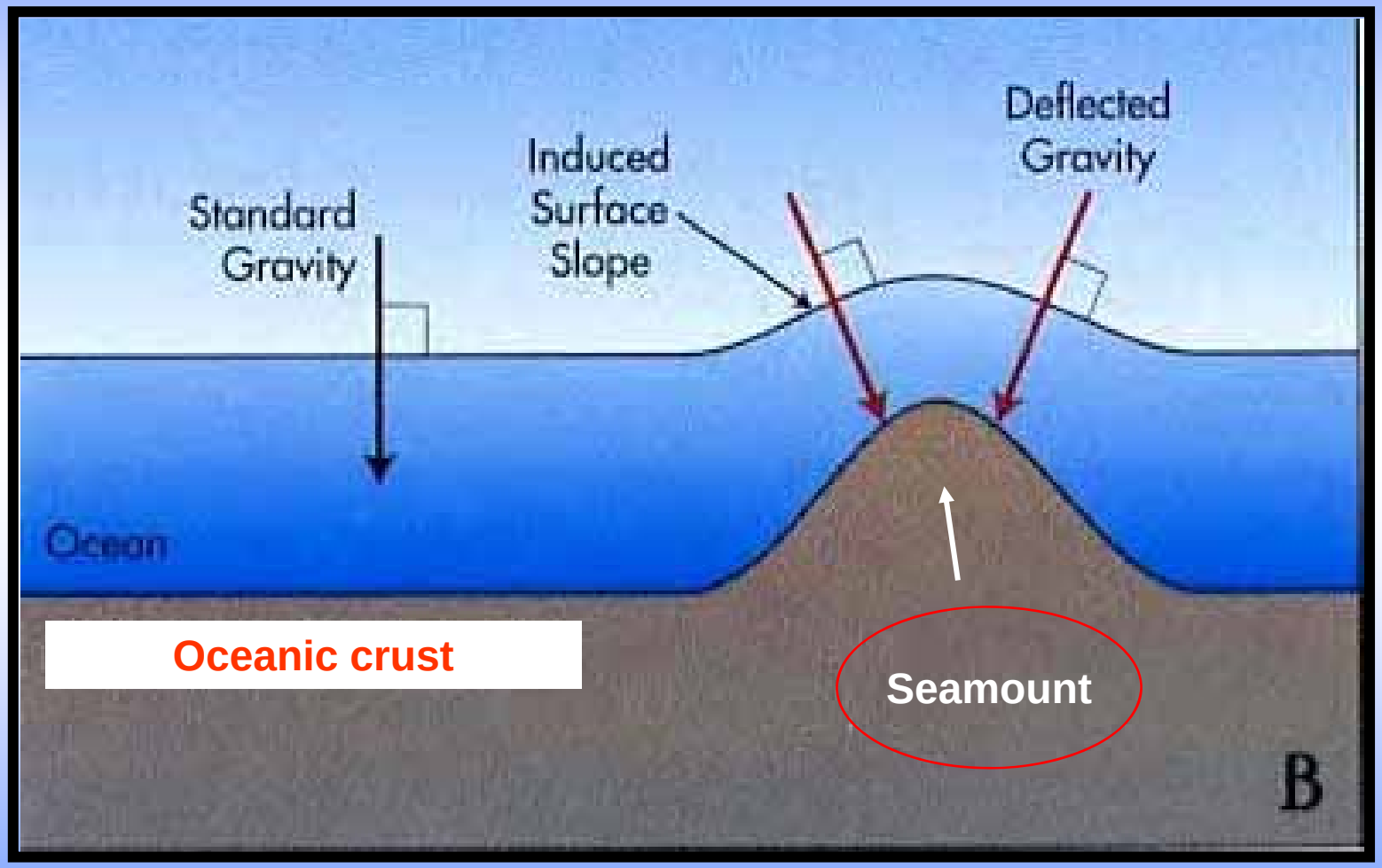
Satellite altimetry

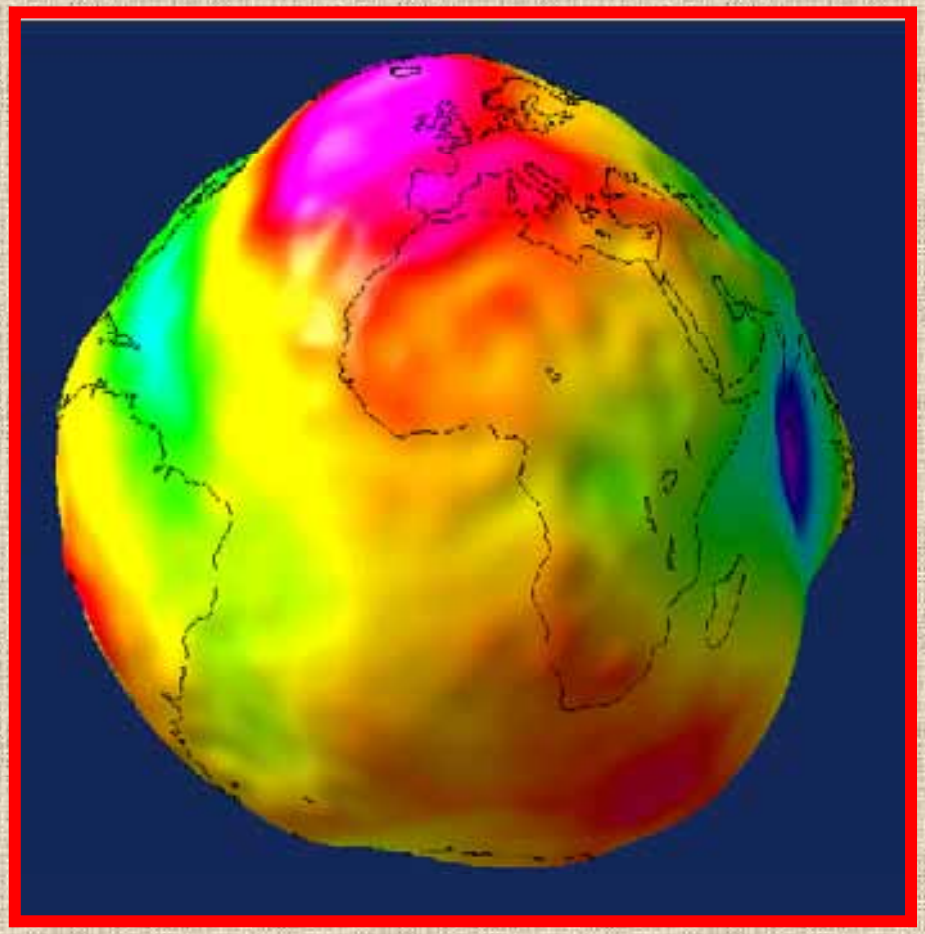
Satellite altimetry: how does it work?



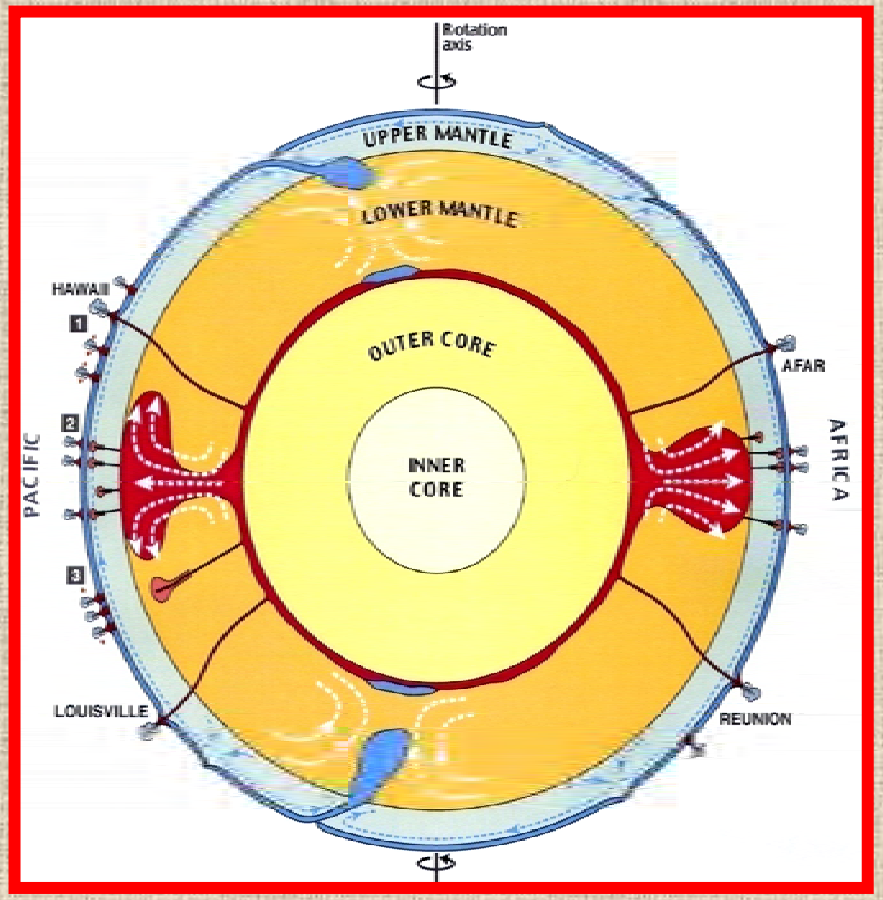
Global coverage of the Earth in 10 days

Permanent undulations of the sea surface



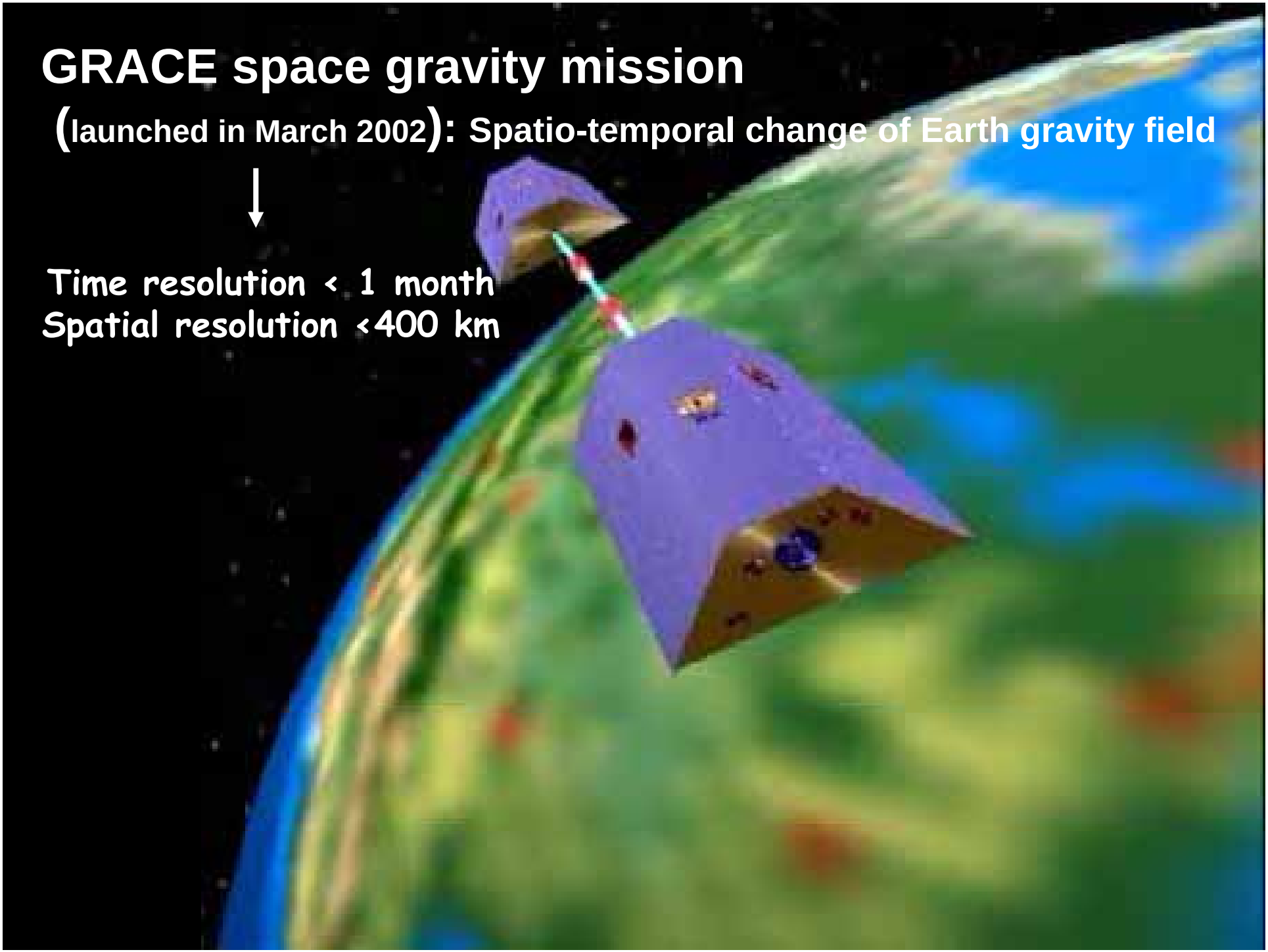


The geoid

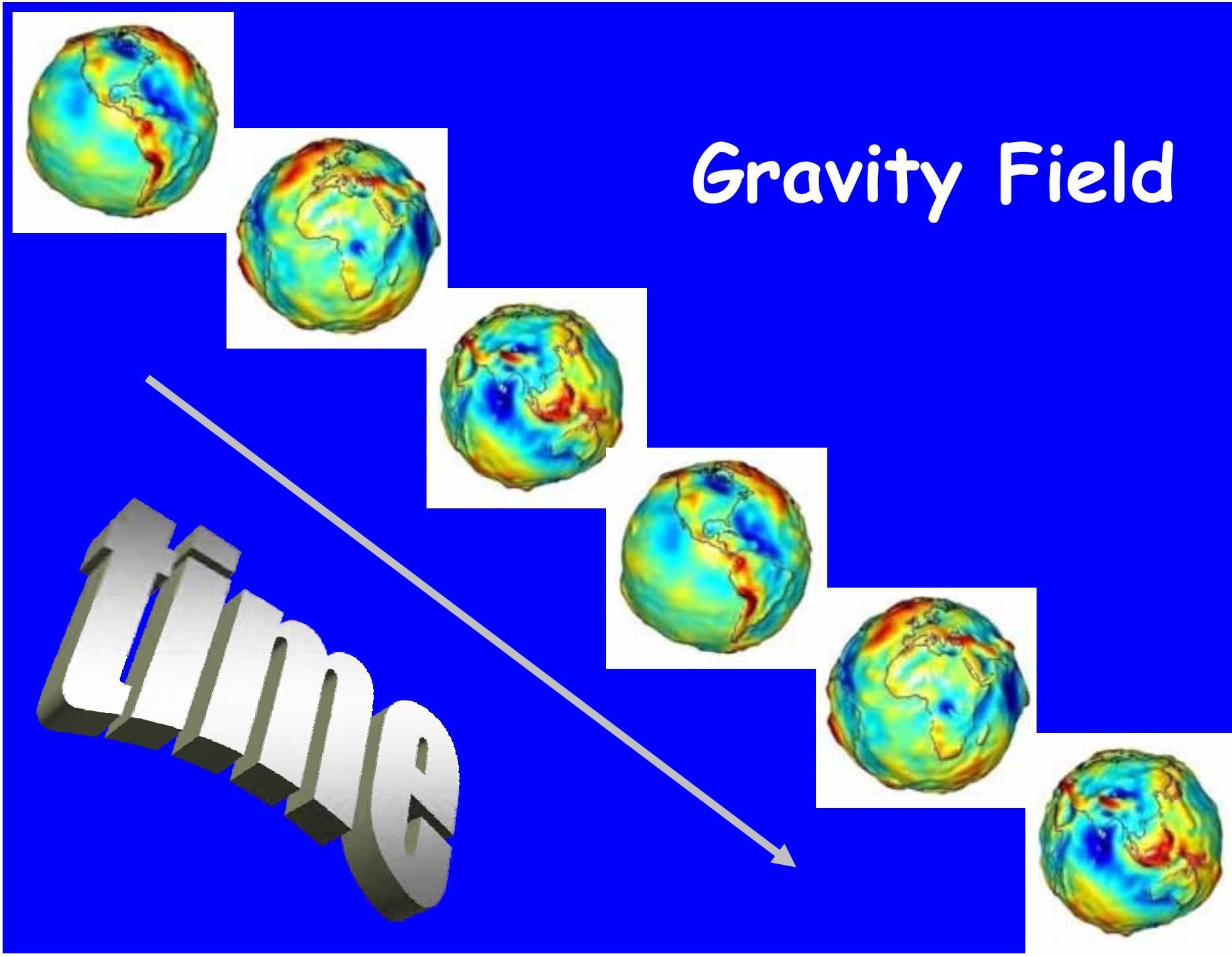


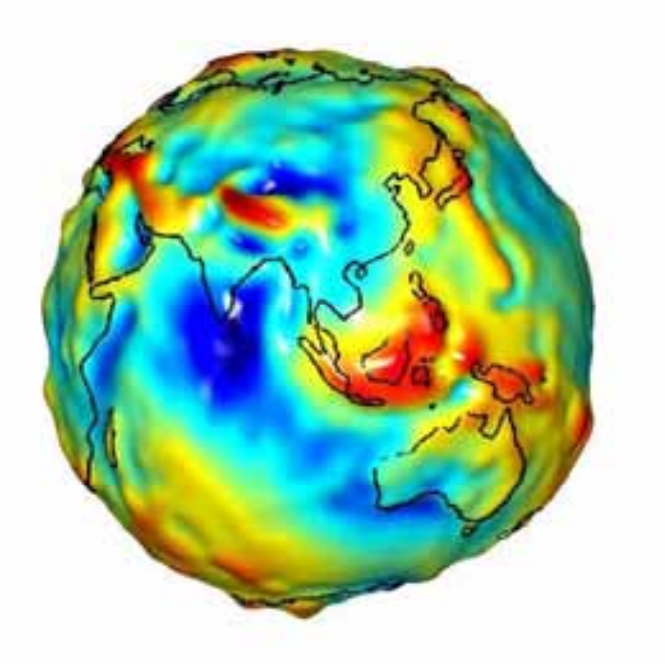
Earth's internal structure

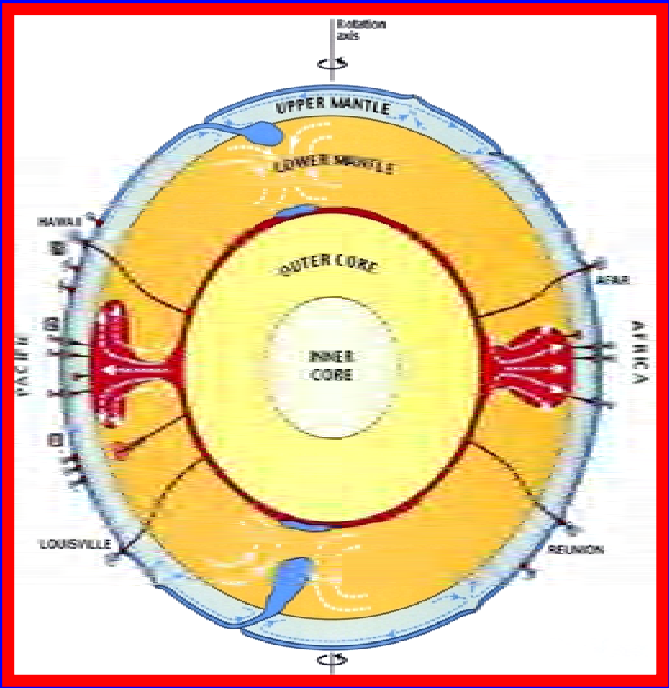
(from V. Courtillot)


GRACE space gravity mission
(launched in March 2002): Spatio-temporal change of Earth gravity field
Time resolution < 1 month
Spatial resolution <400 km

Gravity Field







Permanent component

99% of the observed geoid;

Related to solid Earth' structure

+

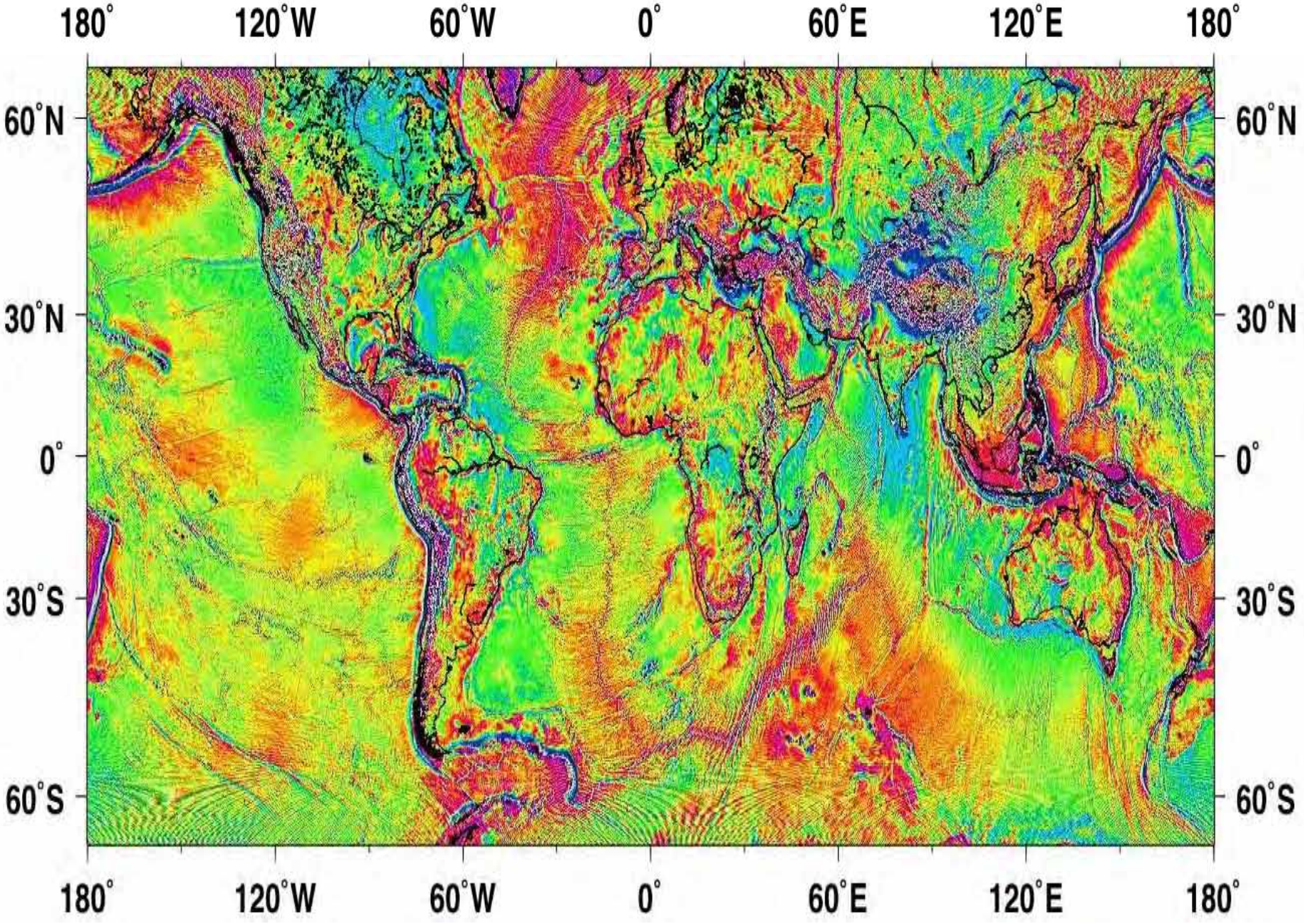
Temporal variations

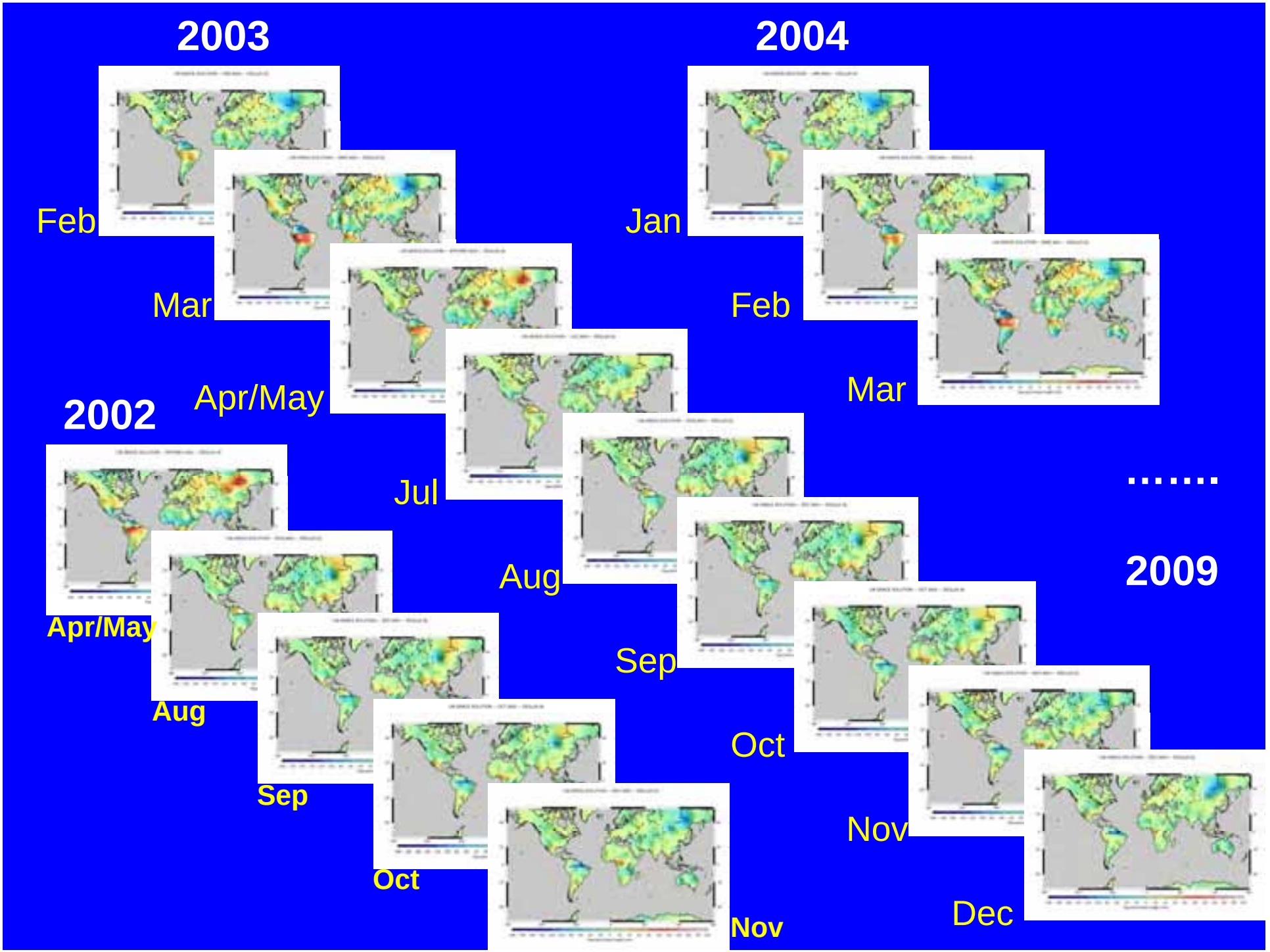
- **surface mass redistributions :**

atmosphere, oceans, land waters, ice sheets

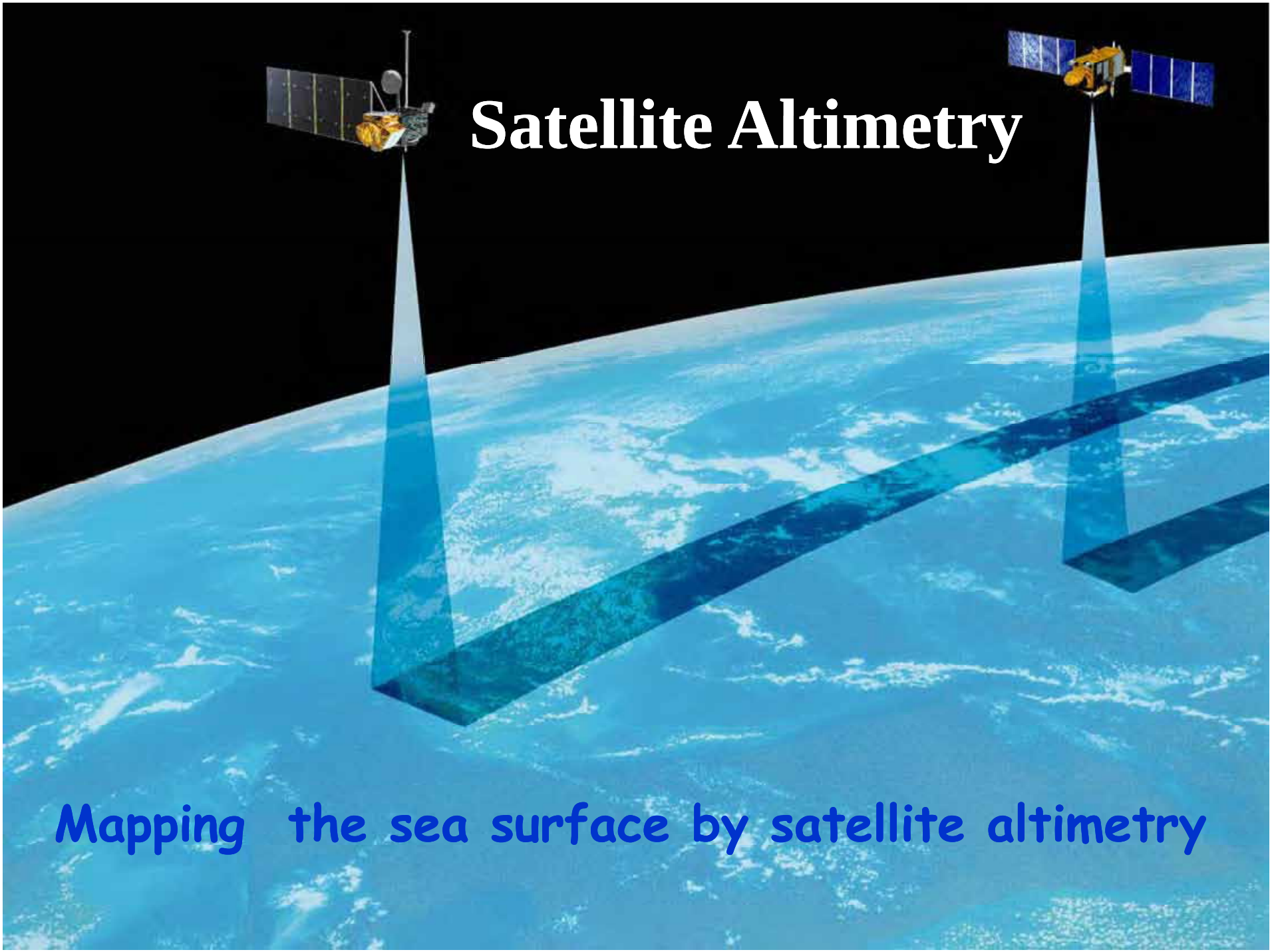
- **Post-Glacial Rebound**

High-resolution Earth's gravity

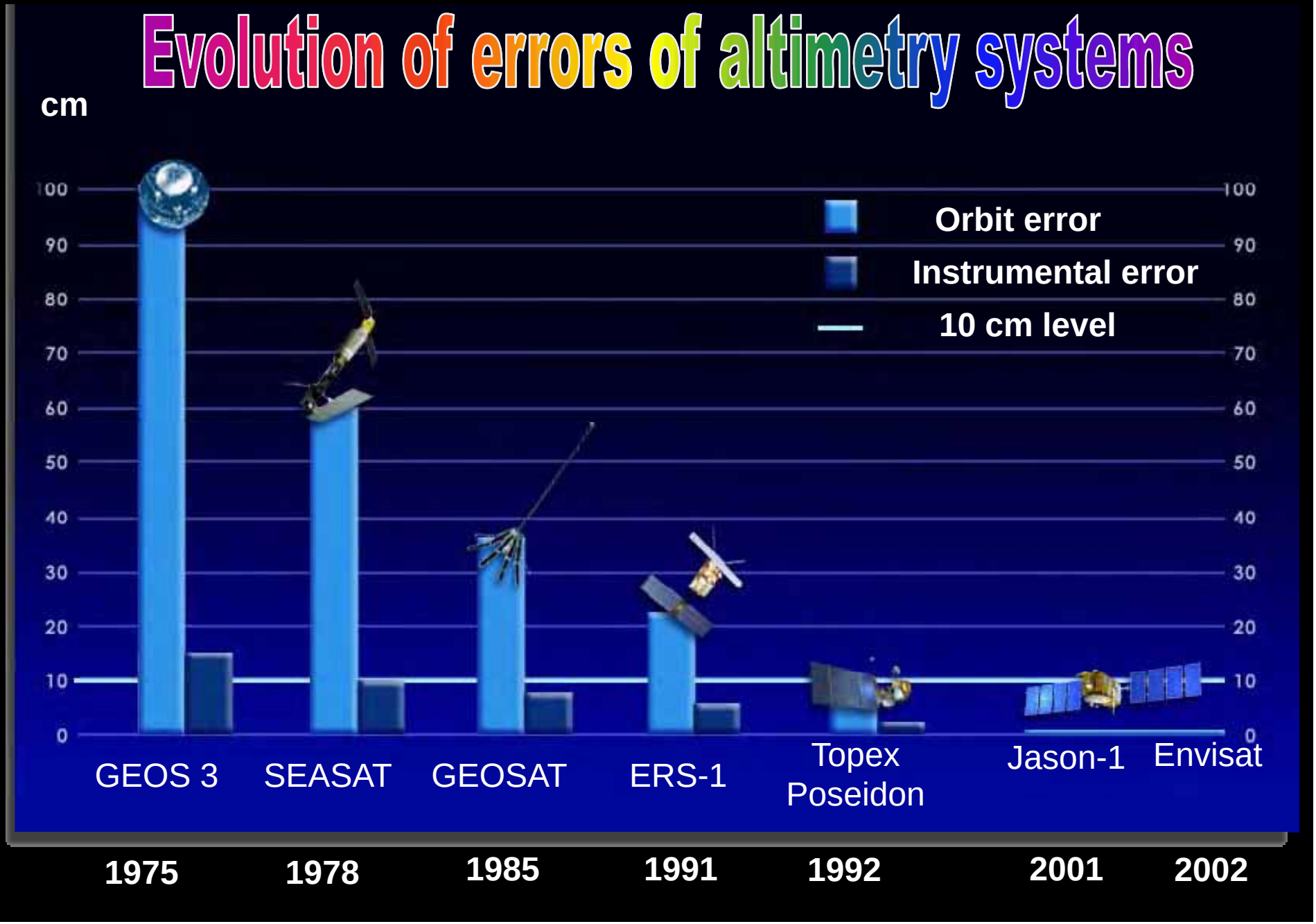



2003
Feb
Mar
Apr/May
Jul
Aug
Sep
Oct
Nov
2004
Jan
Feb
Mar
.....
2009
2002
Apr/May
Aug
Sep
Oct
Nov
Dec

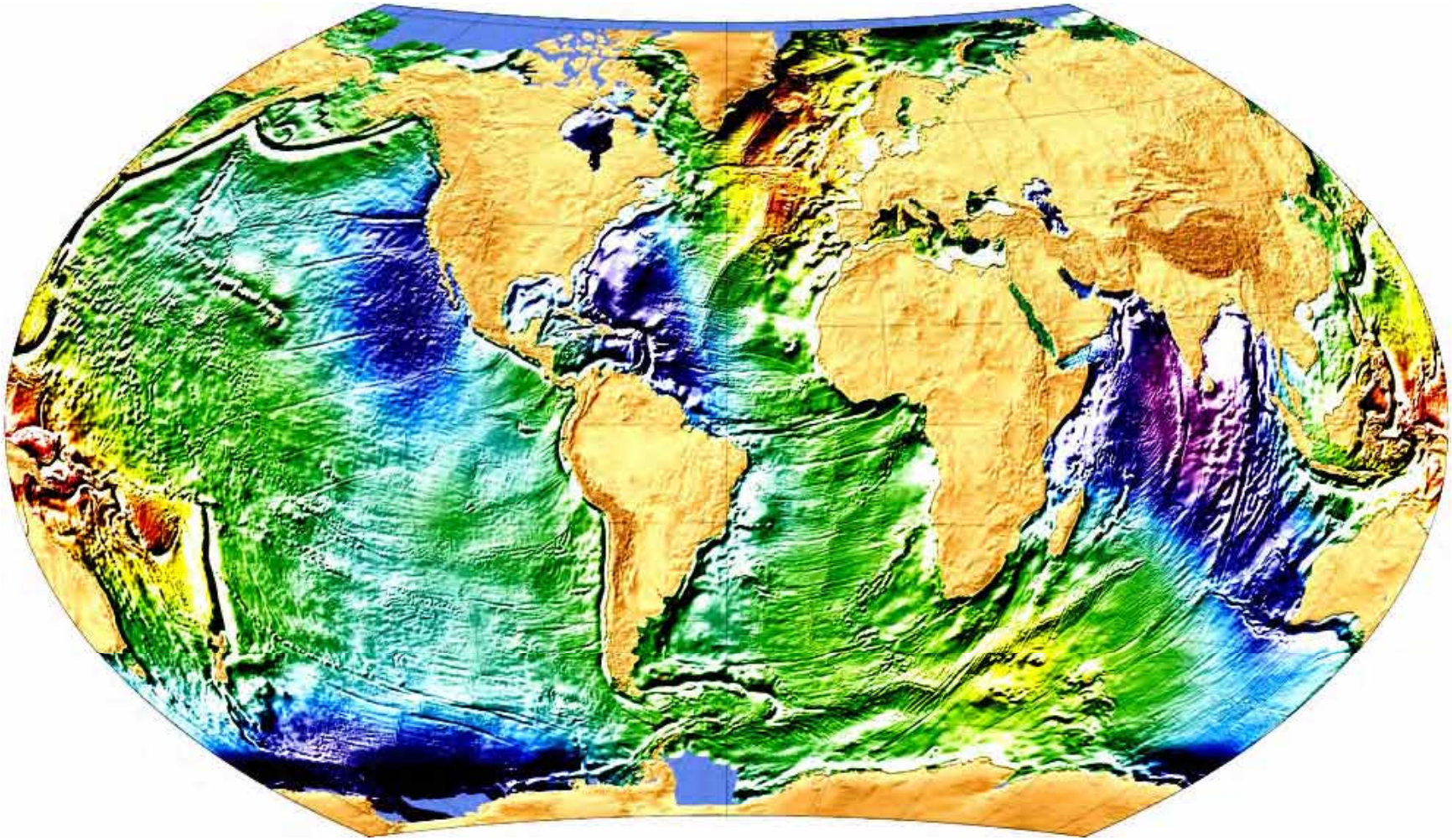

A few examples of scientific applications


Satellite Altimetry
Mapping the sea surface by satellite altimetry

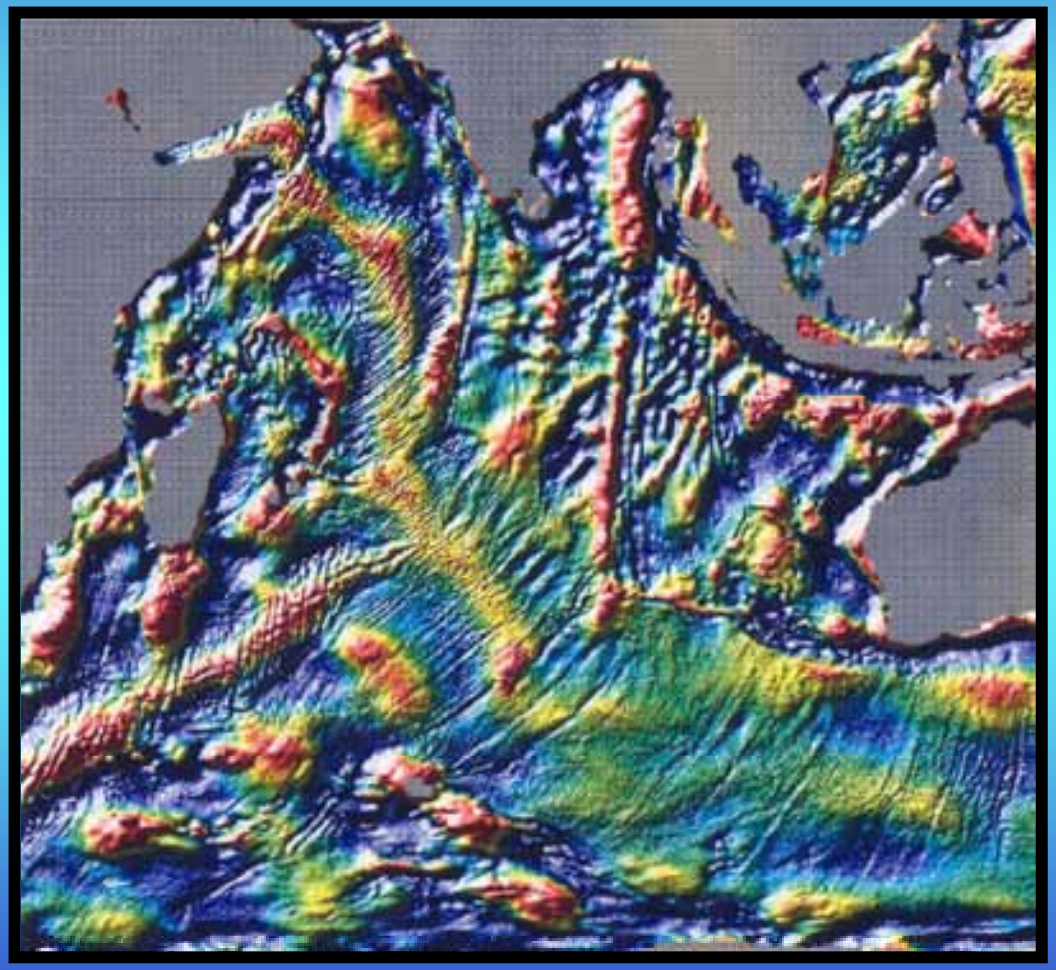
Evolution of errors of altimetry systems

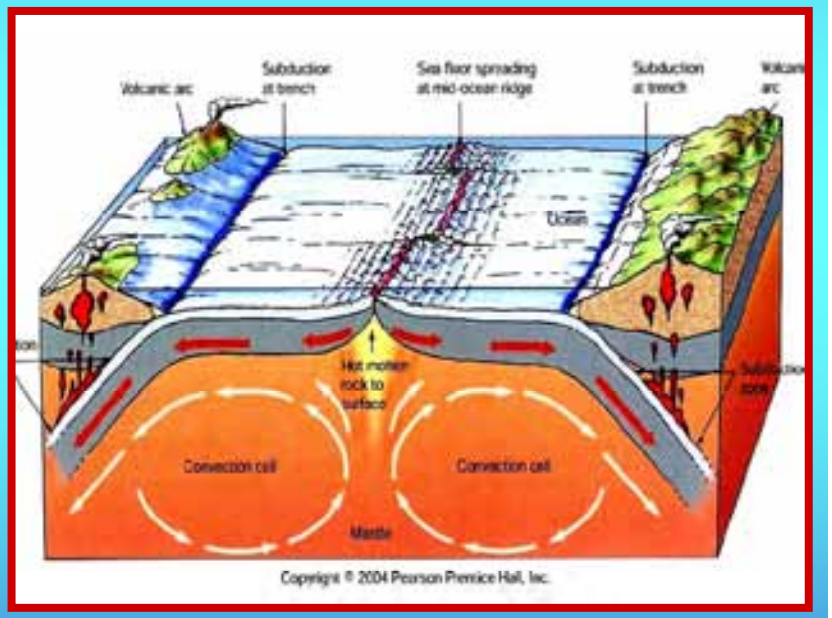


The marine geoid mapped by satellite altimetry

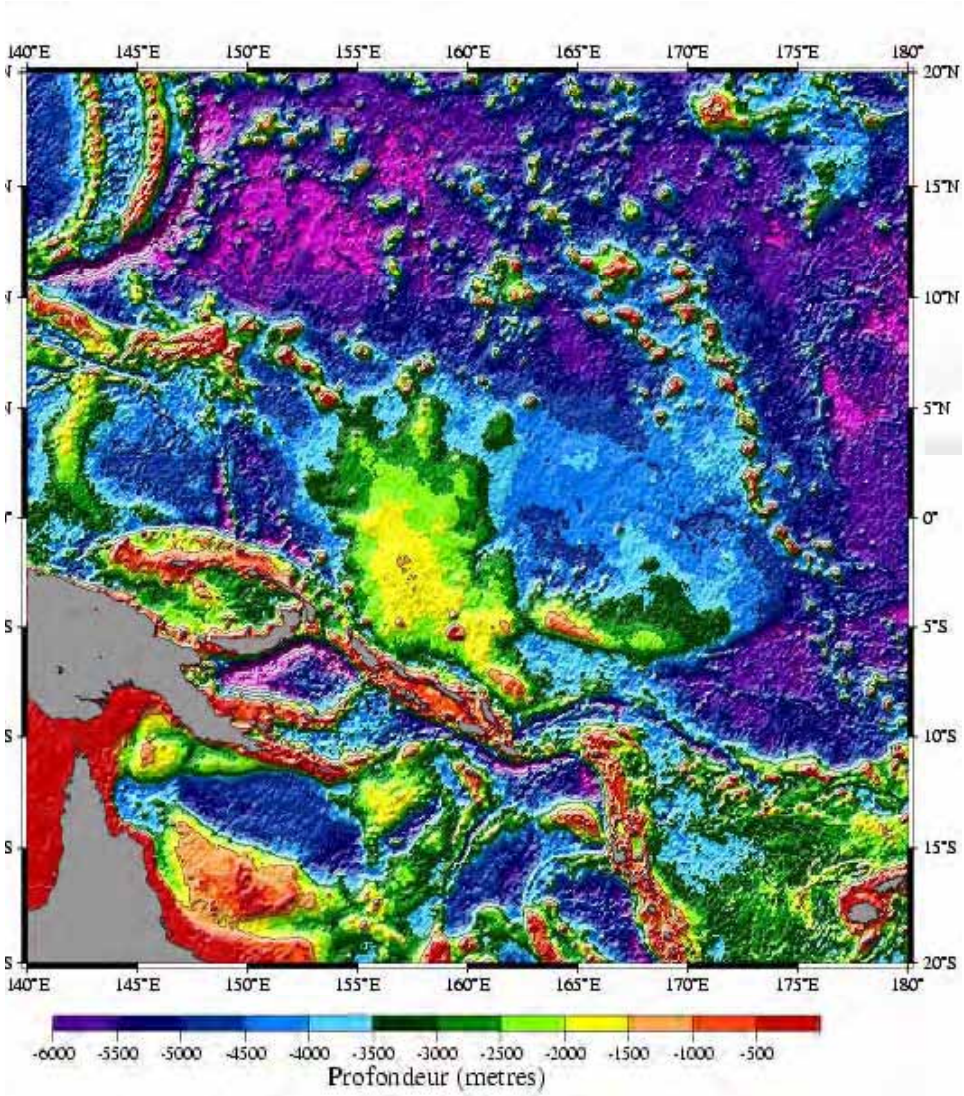


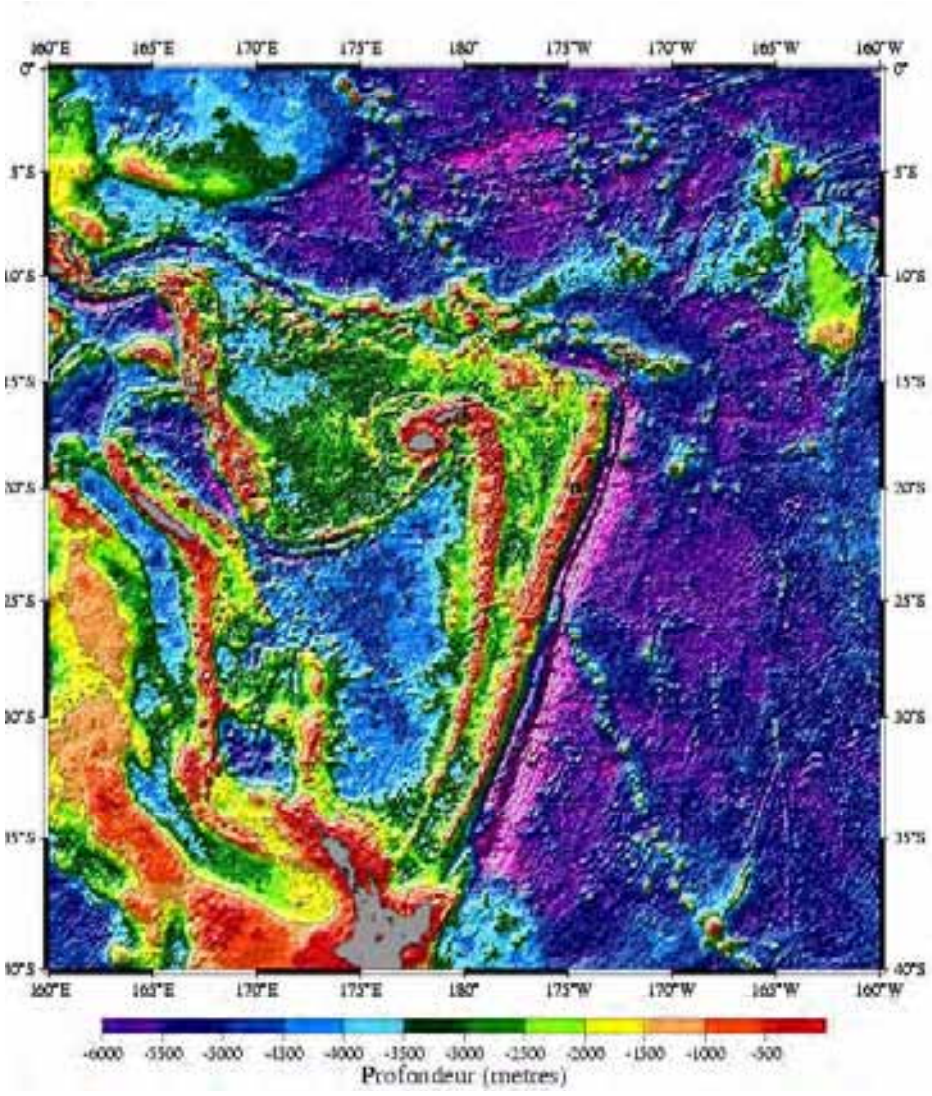
Marine geoid – Indian Ocean





Seafloor topography (South West Pacific)





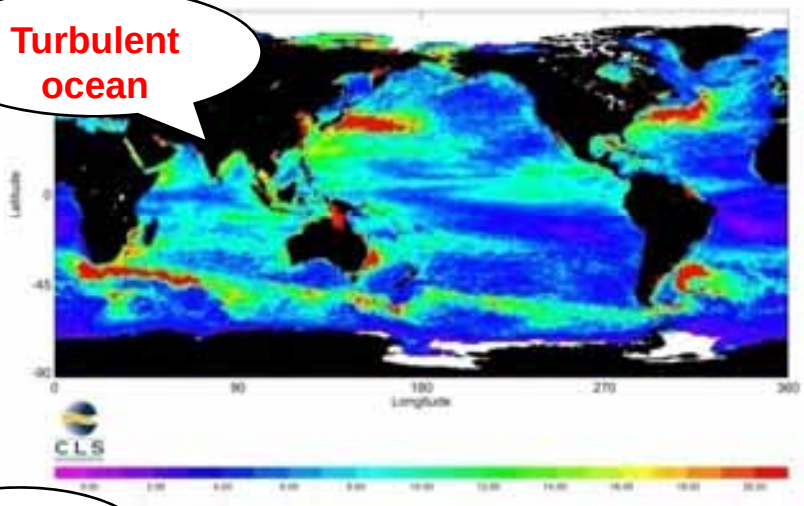
High-precision altimetry

Topex/Poseidon
(1992-2006)

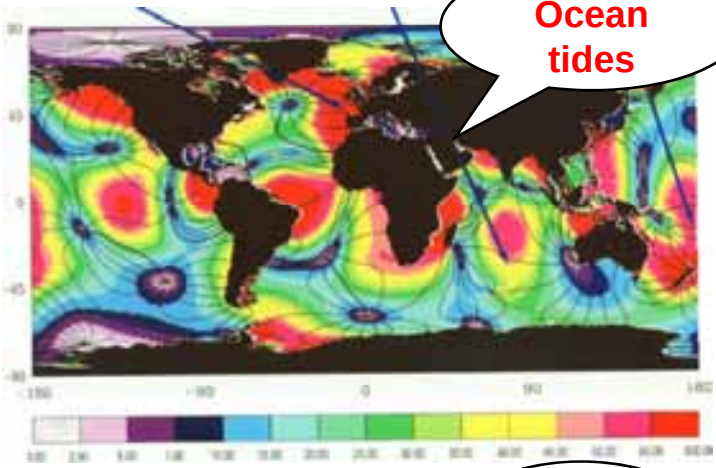
JASON-1 (2001-)
JASON-2 (2008-)

Important achievements in oceanography with high-precision satellite altimetry

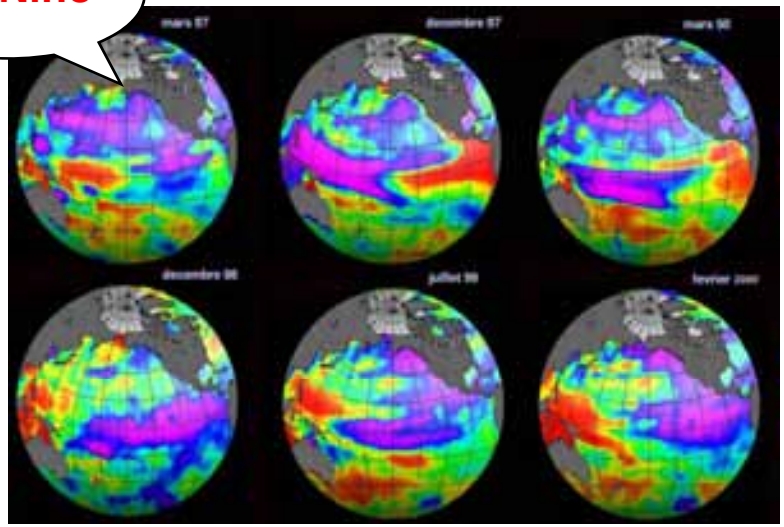
Turbulent ocean



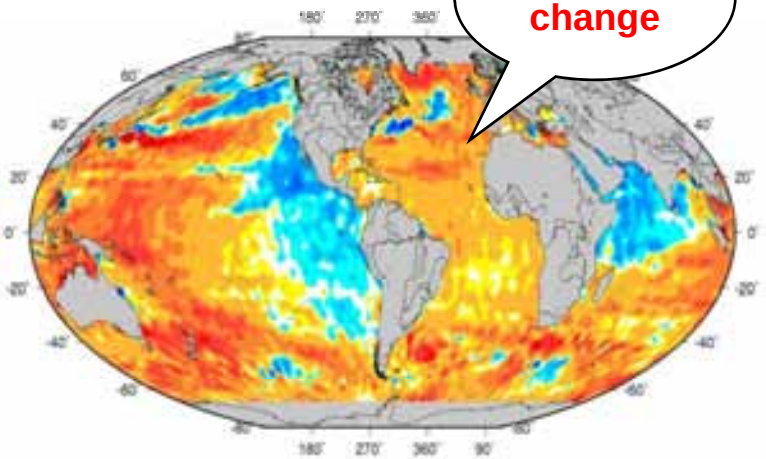
Ocean tides



El Nino



Sea level change

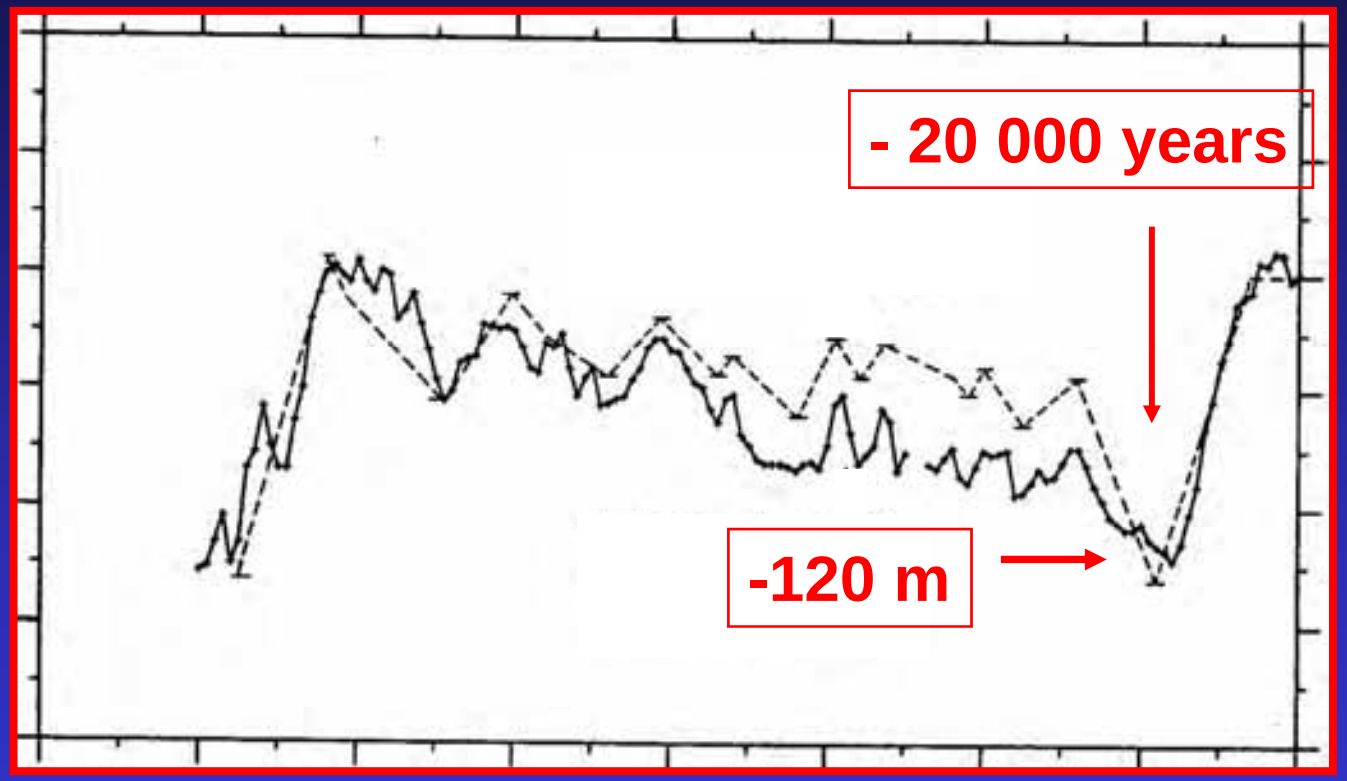


20 000 years ago….

Today

Sea level variations over the last 140 000 years

Last glacial cycle

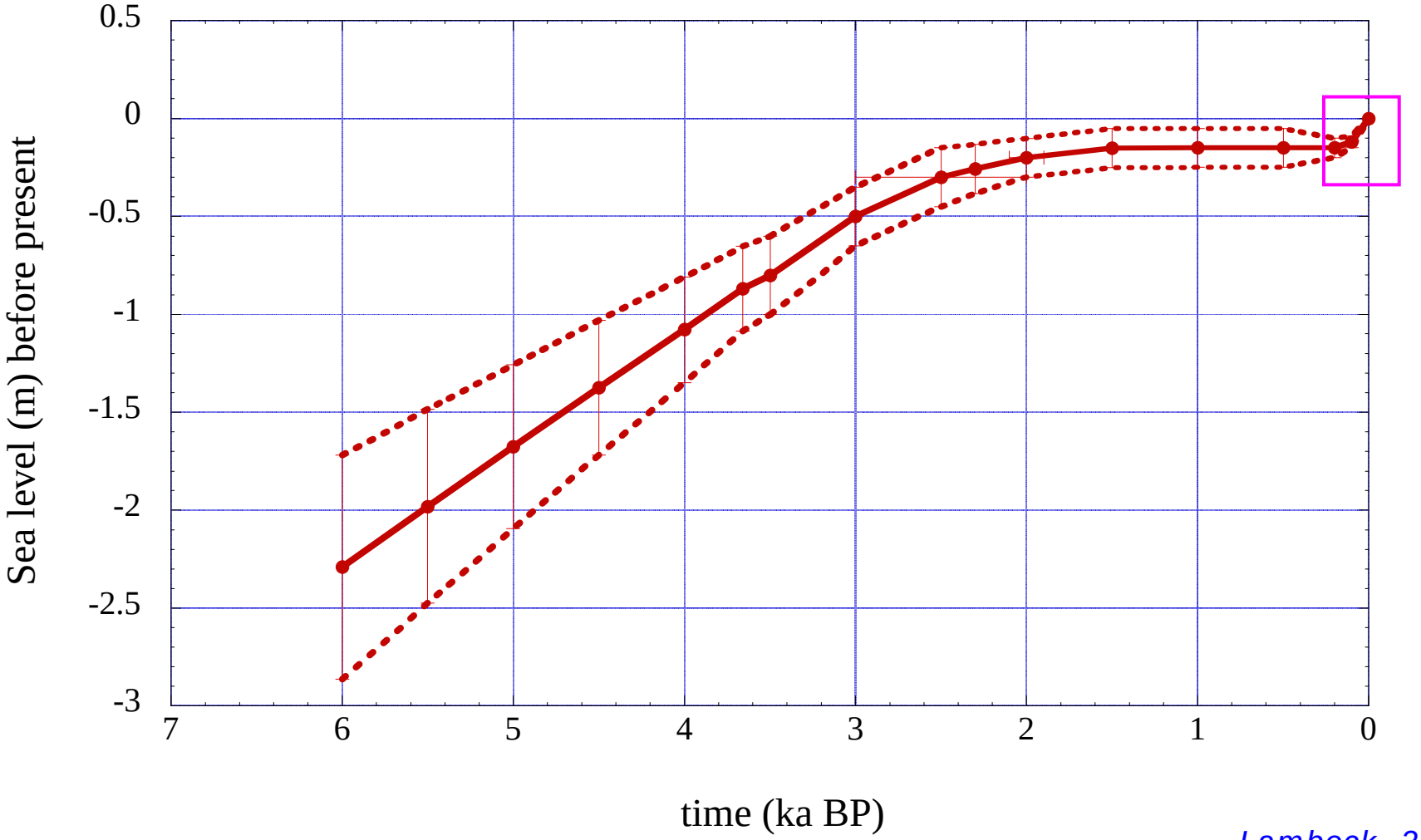


Present-day

-140 000 years → present

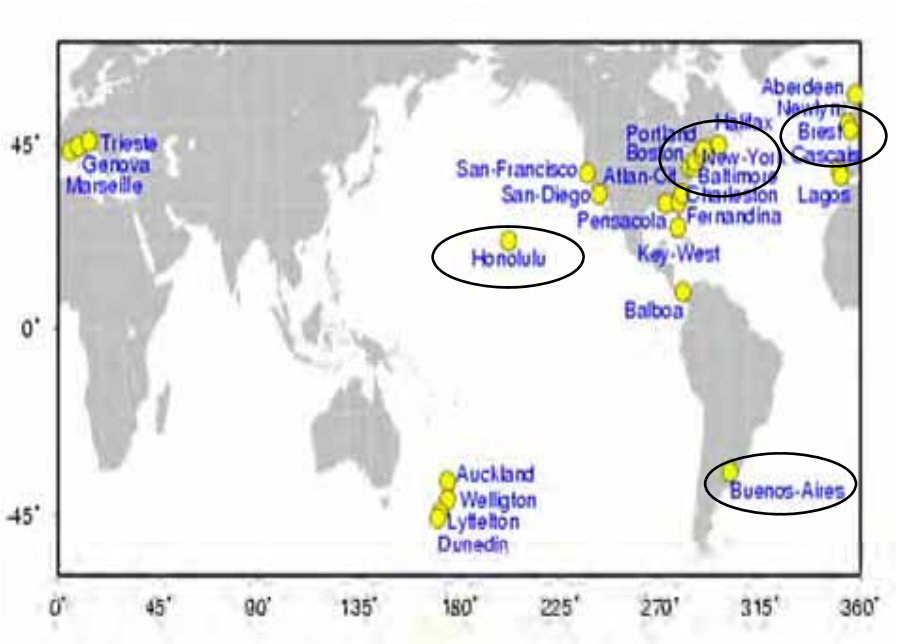
After Shackelton, 2002.

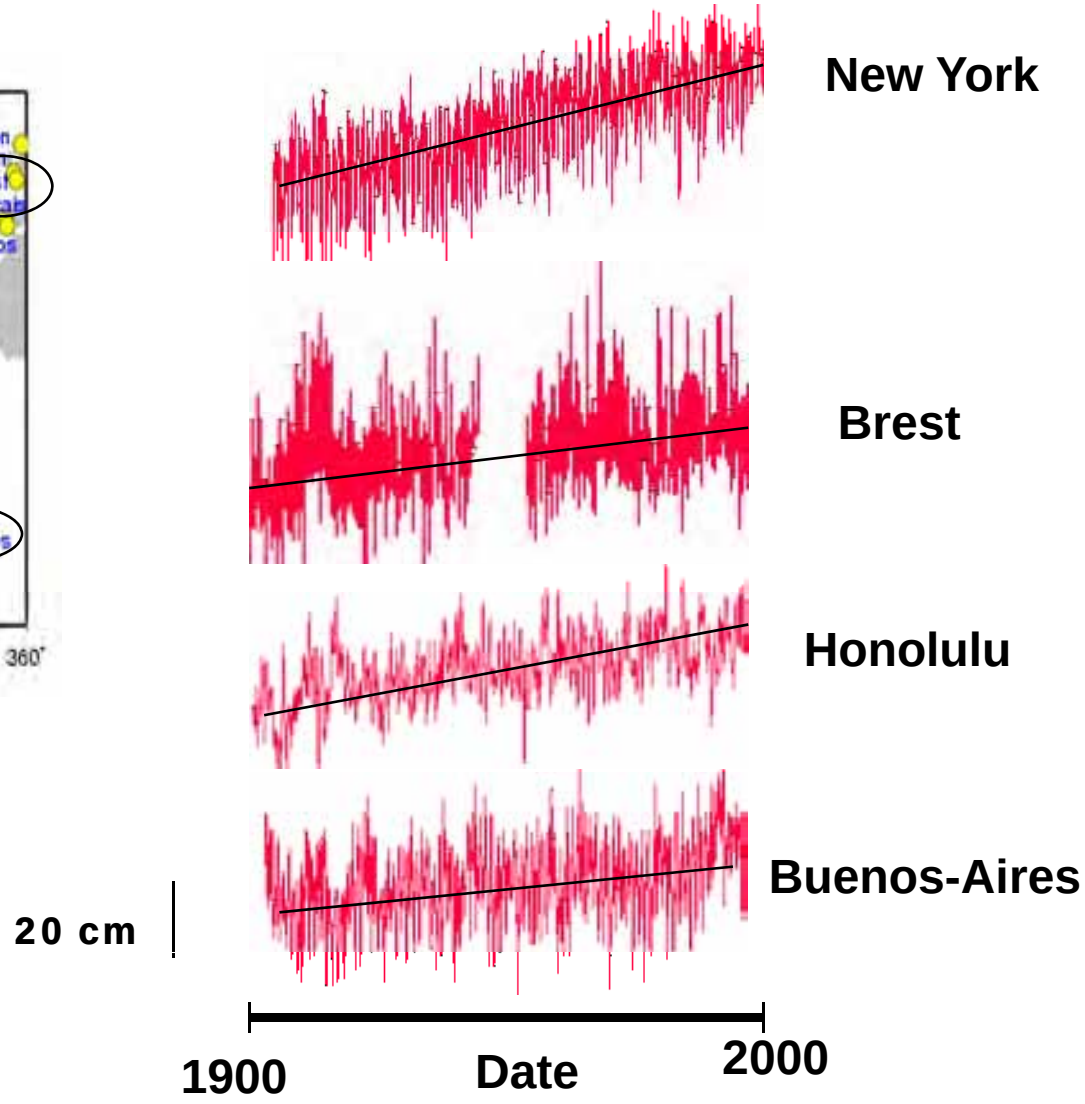
Mean sea level variation during the past 6000 years



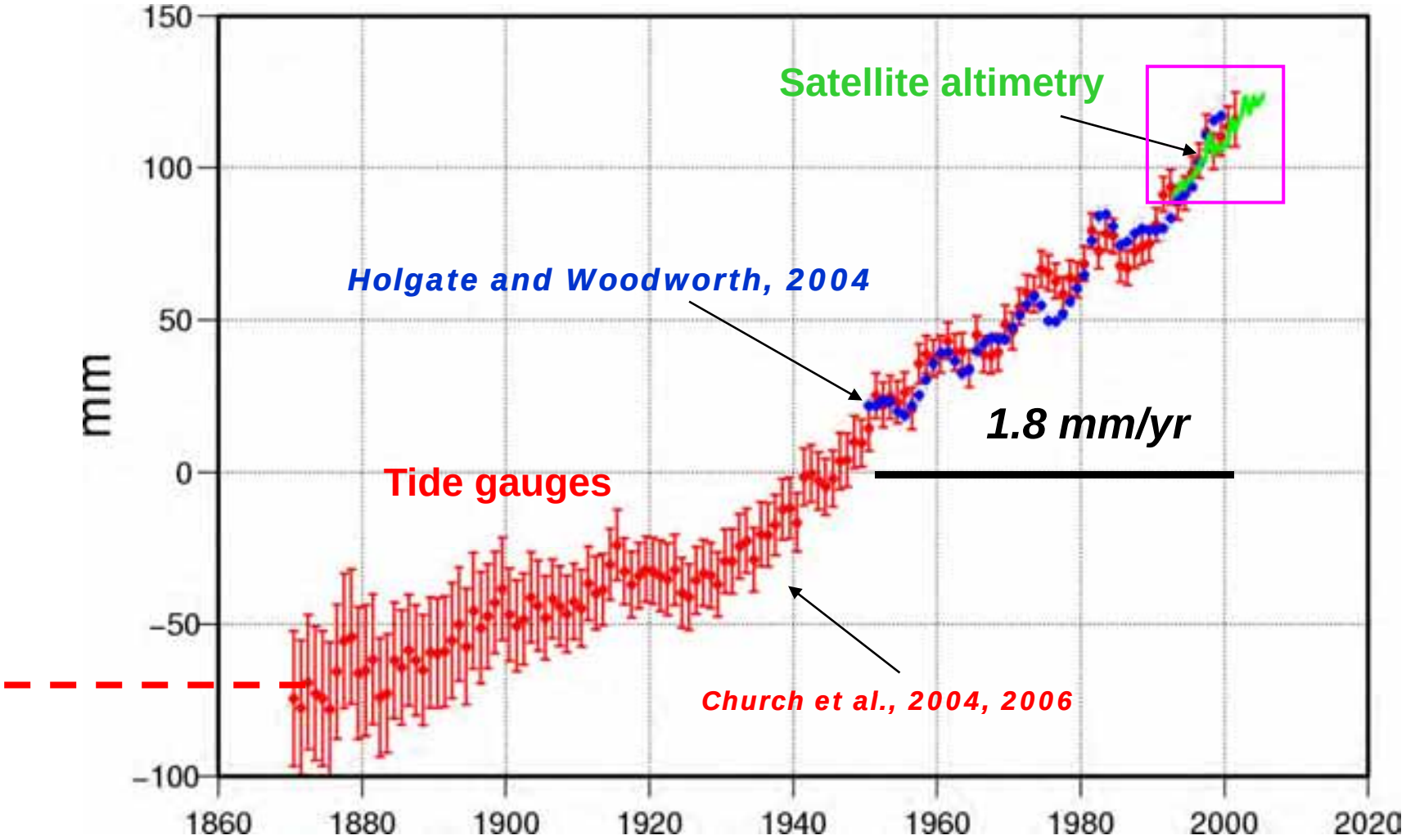
Lambeck, 2006

Historical tide gauge records of sea level

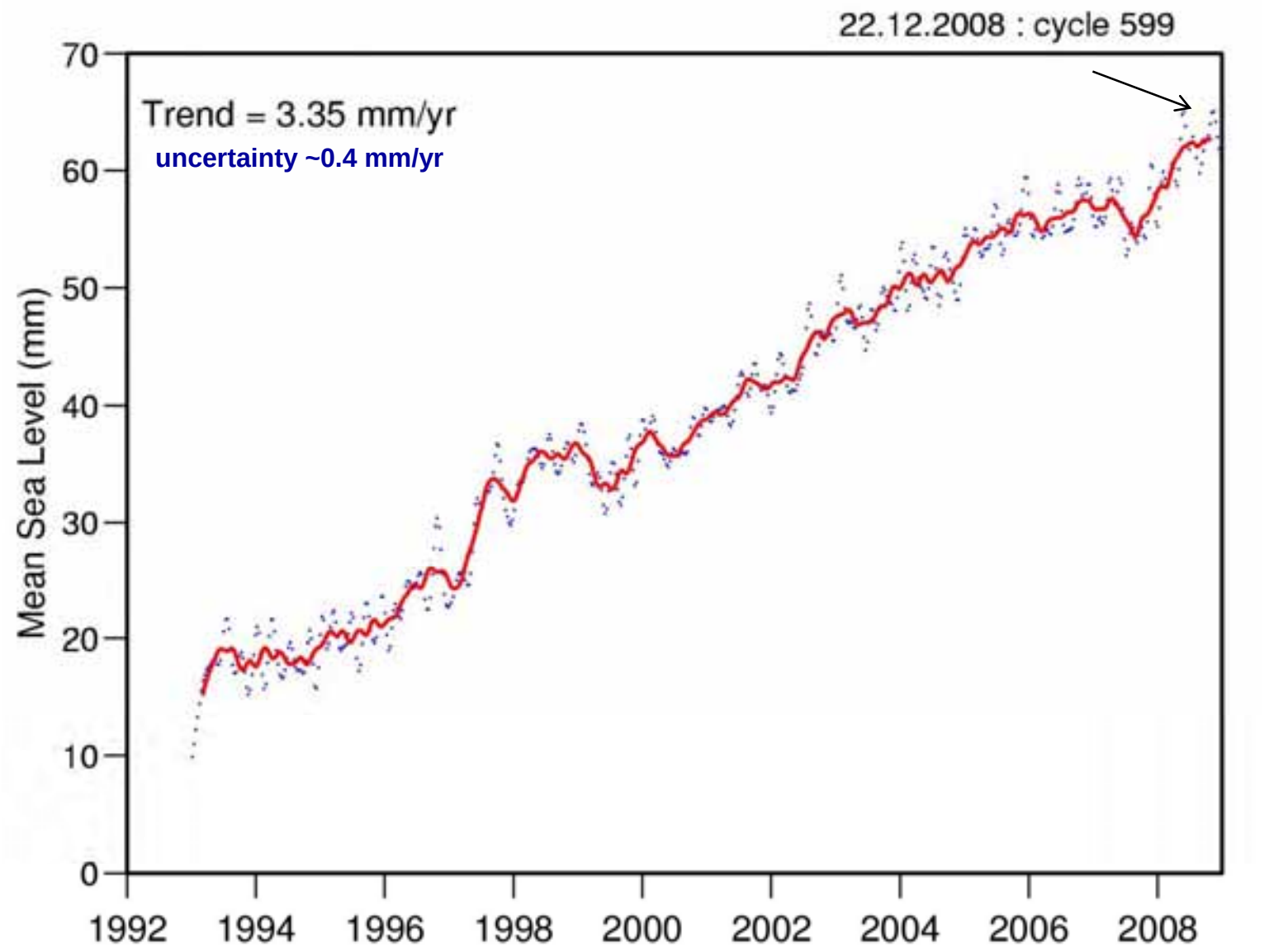




Global mean sea level rise during the 20th century



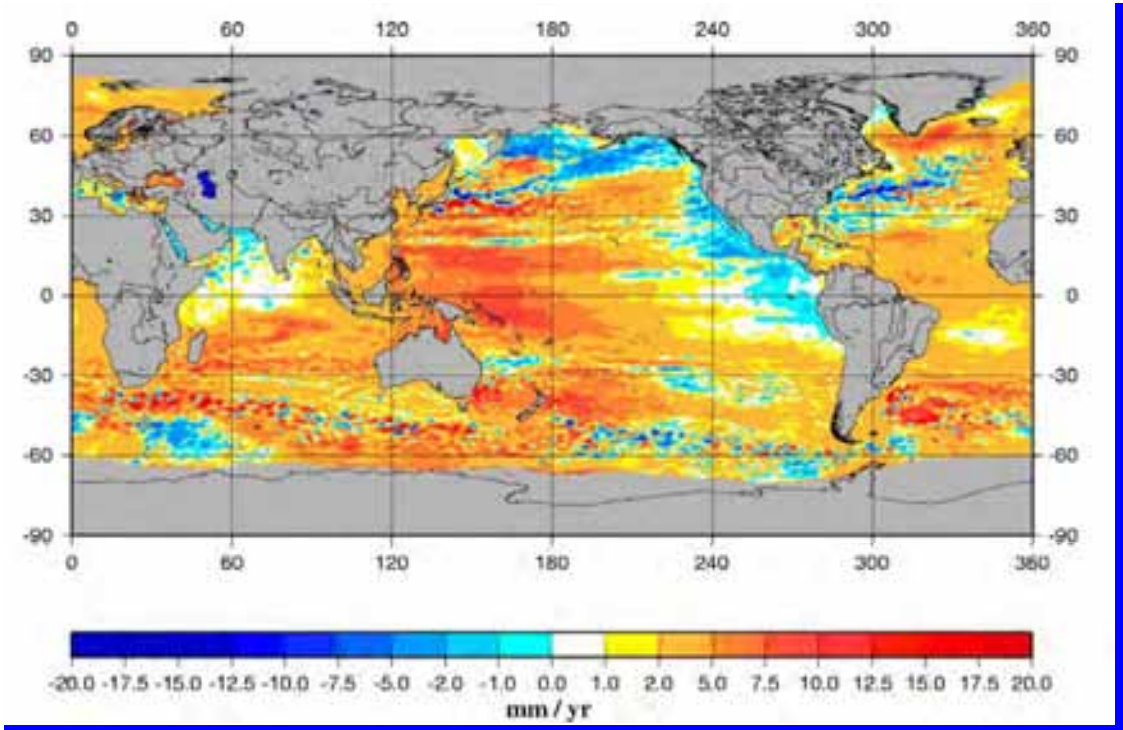
Global mean sea level between 1993 and 2008 (Topex/Poseidon and Jason-1 satellites)

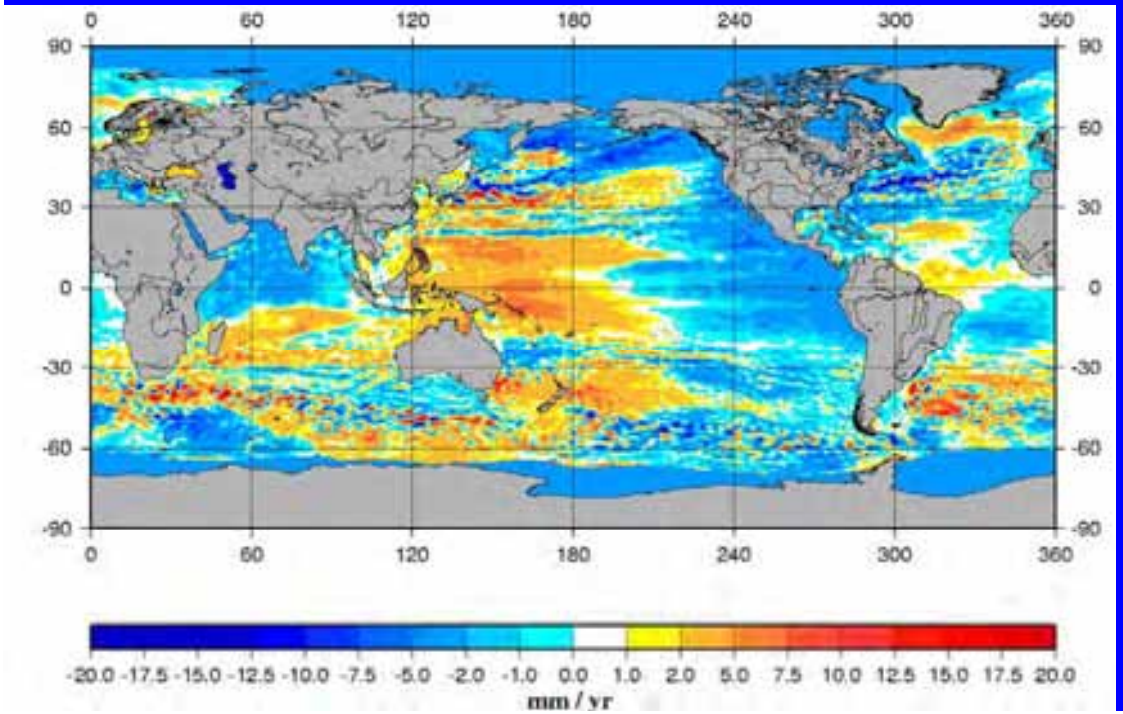


Present-day Sea Level Rise:

1950-2000: 1.7-1.8 mm/yr
1993-2008: 3.0-3.5 mm/yr

Acceleration?
Decadal fluctuation?





Regional distribution of sea level trends 1993-2008

Observed by satellite altimetry

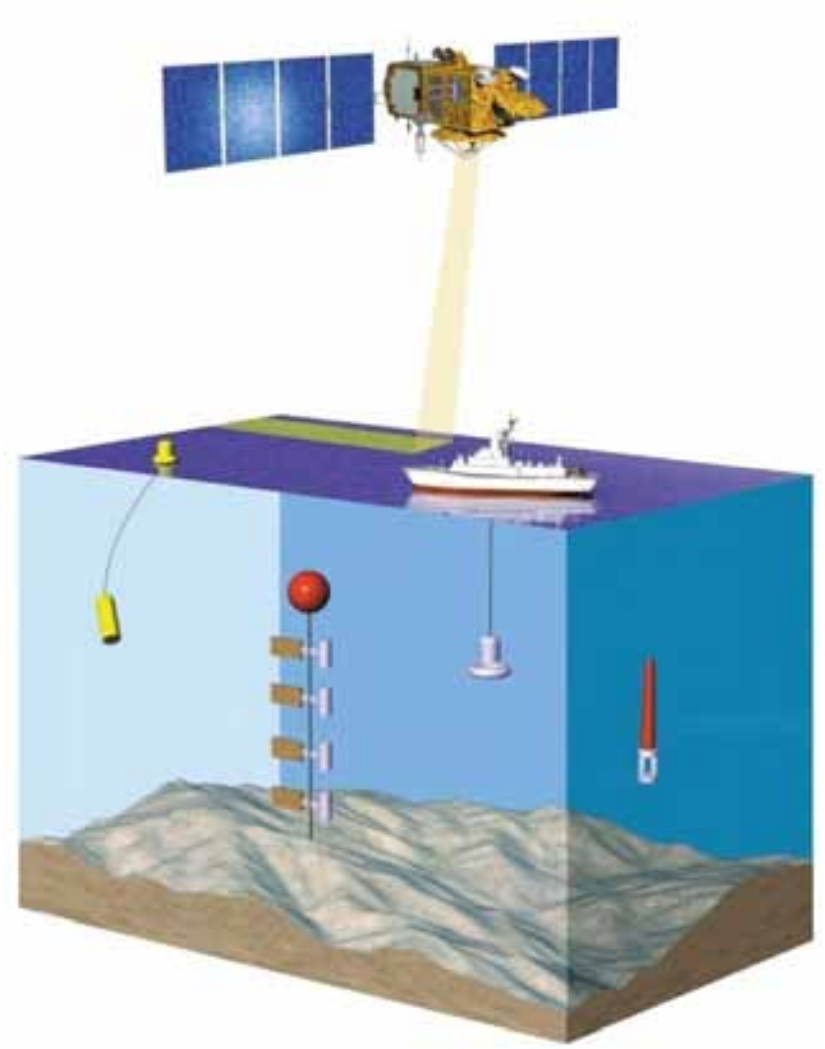
Uniform trend (of 3.3 mm/yr) removed

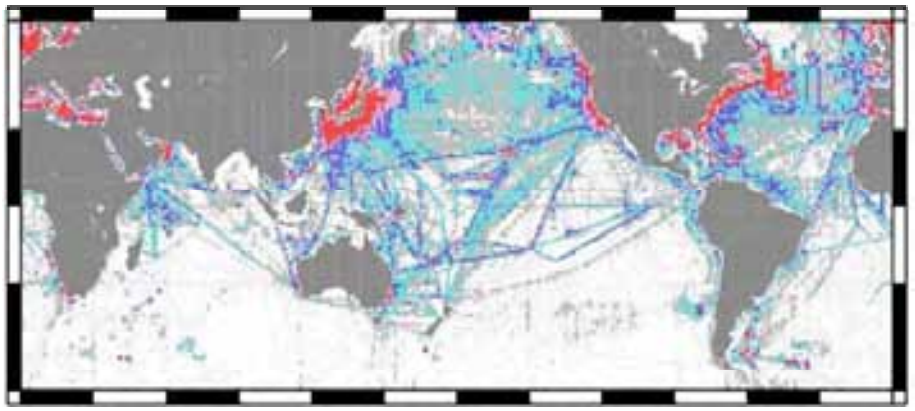
Causes of sea level rise….

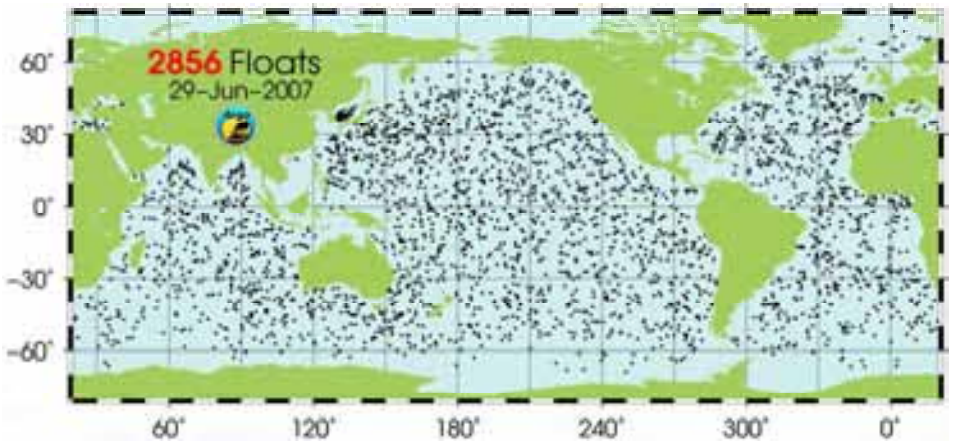
- Thermal expansion of sea water due to ocean warming

- Ocean mass increase due to water addition from land ice melt and terrestrial waters stores

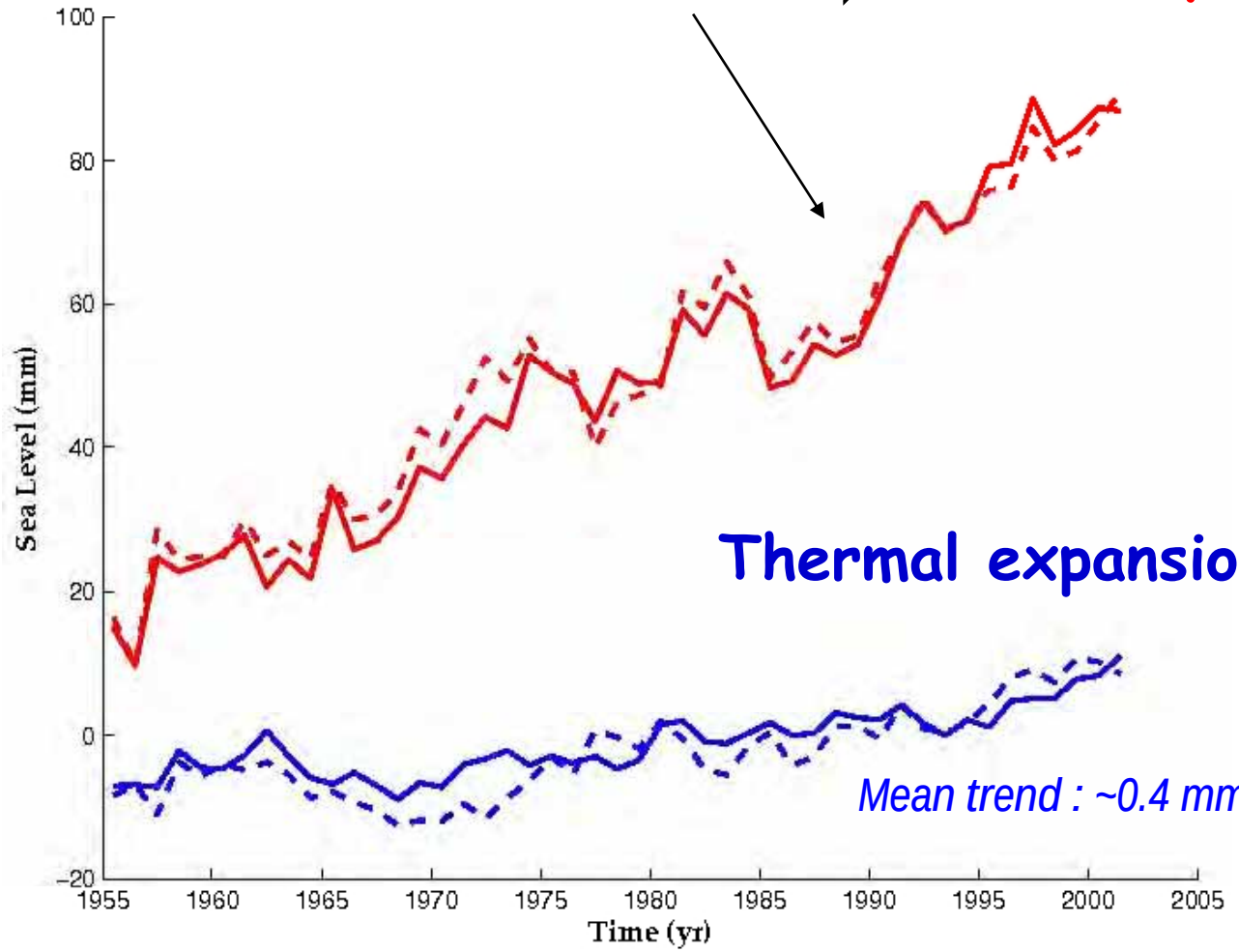
Ocean temperature data collected during the past 50 years



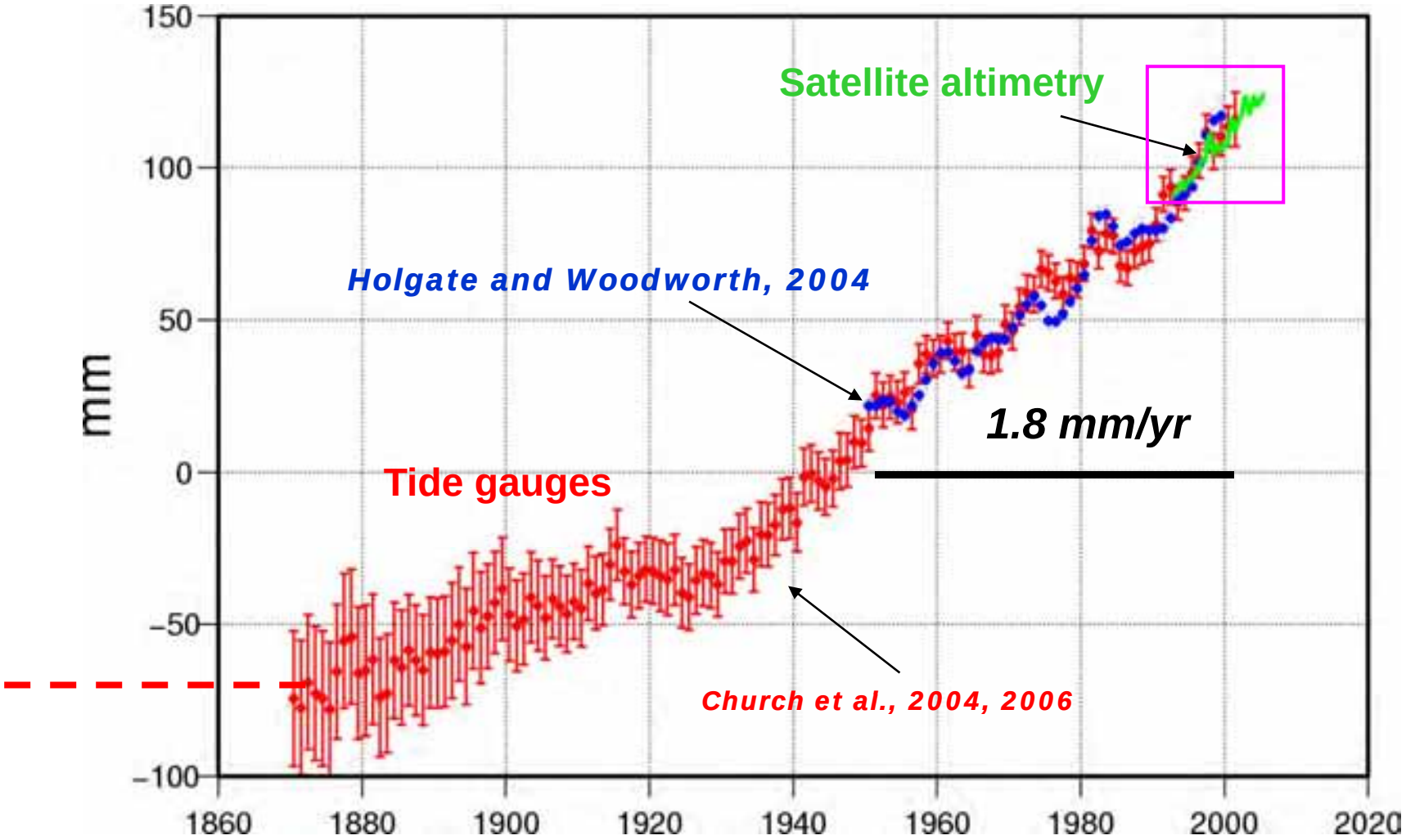




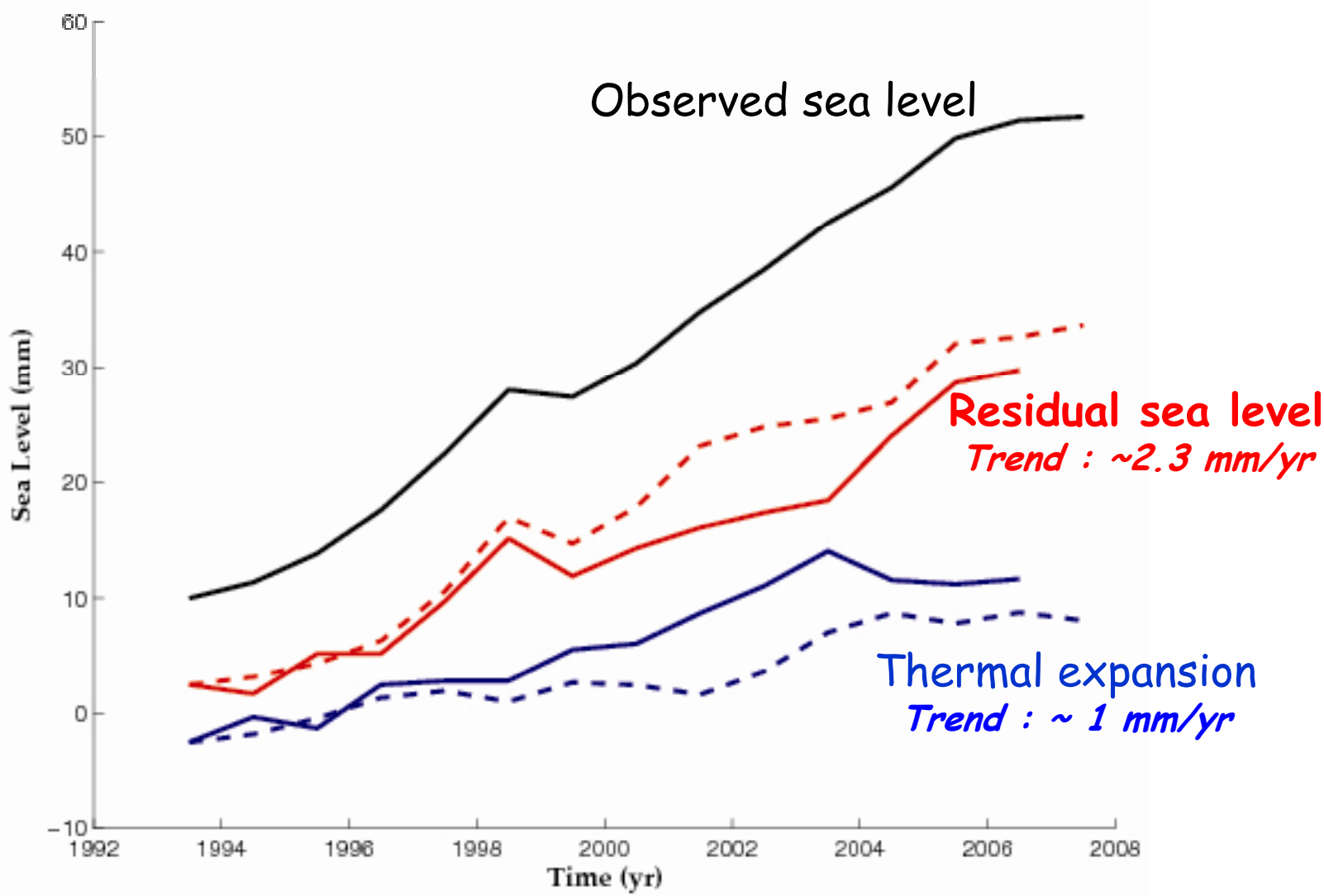
Observed sea level minus thermal expansion
(= ocean mass) ➡ 1.4 mm/yr



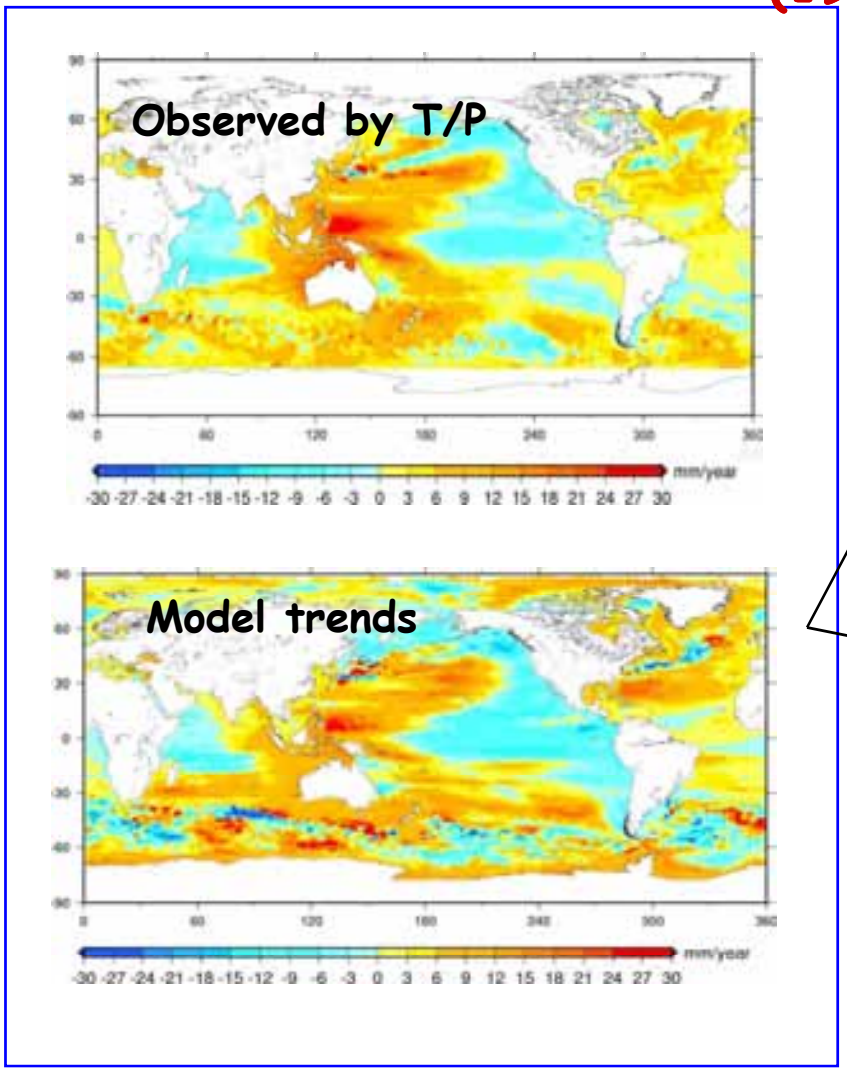
Global mean sea level rise during the 20th century

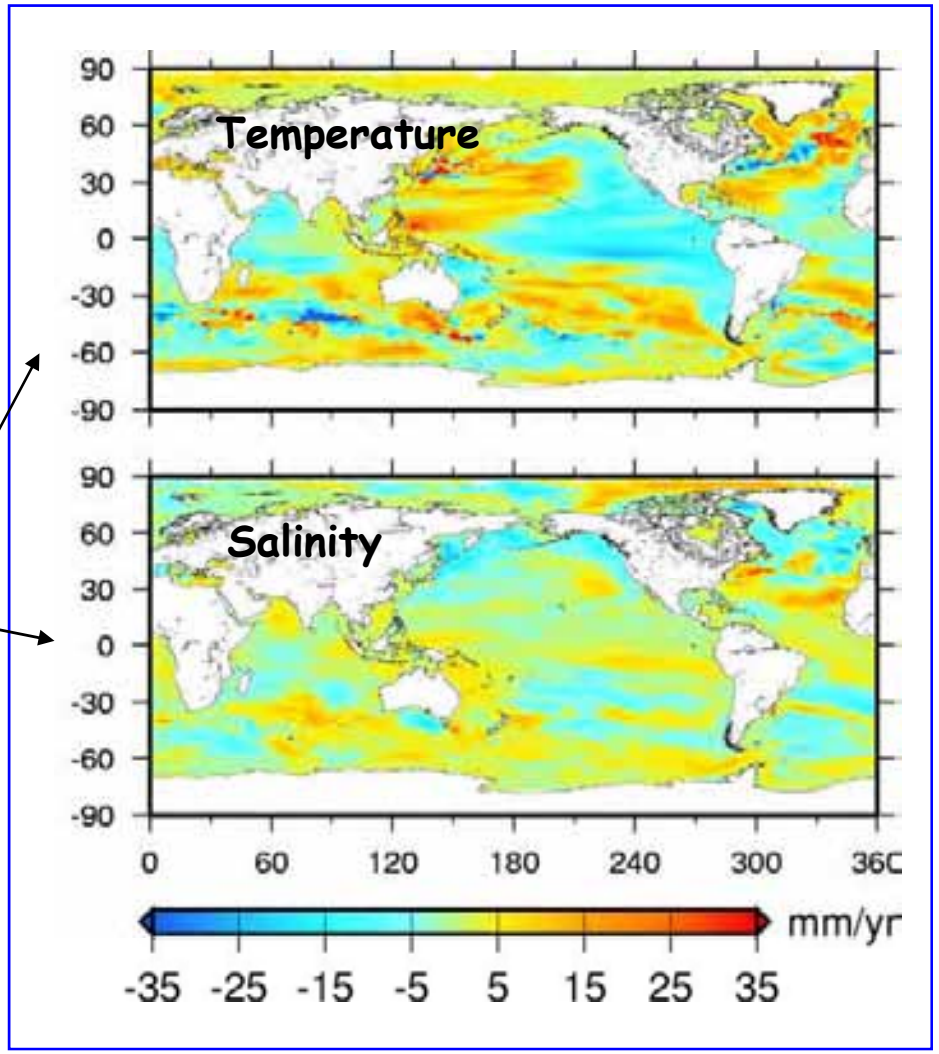


Observed sea level and thermal expansion since 1993



Comparison between spatial patterns in sea level trends observed by satellite altimetry and estimated by the ORCA025 ocean circulation model (no assimilation) (1993-2001)



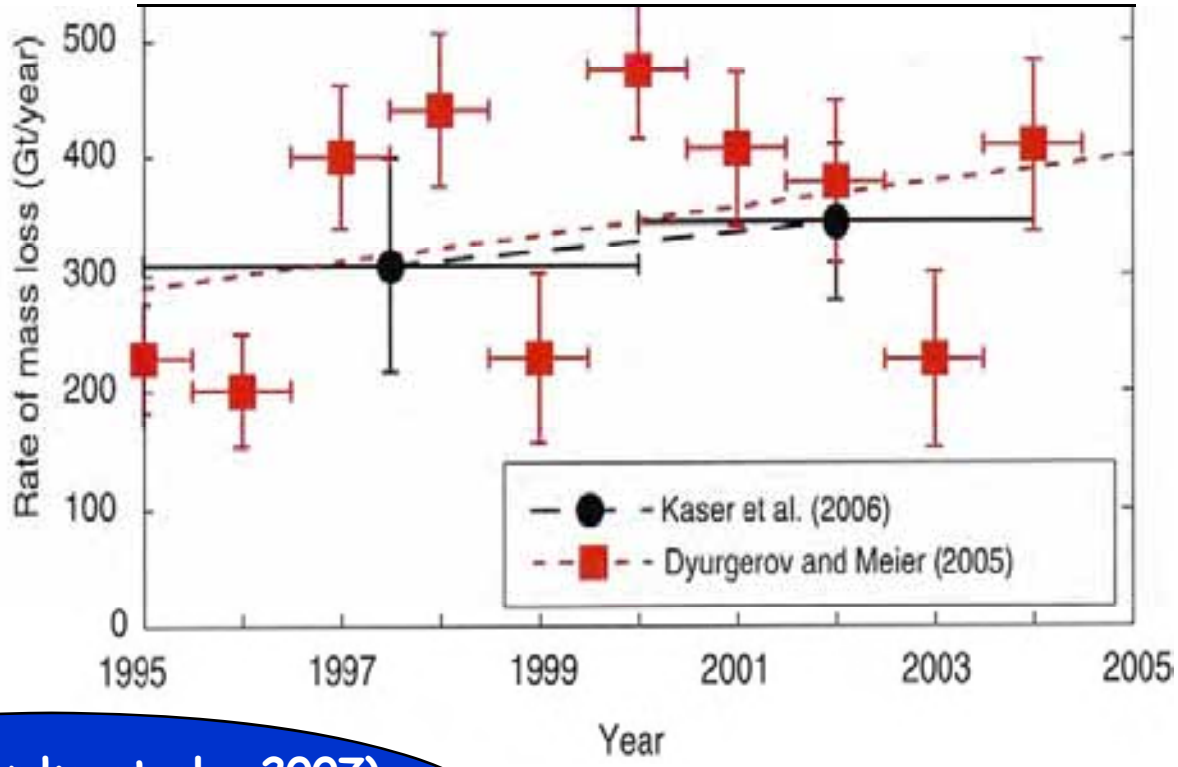


Lombard et al. (2007)

Land ice

Contribution of glacier melting to sea level rise

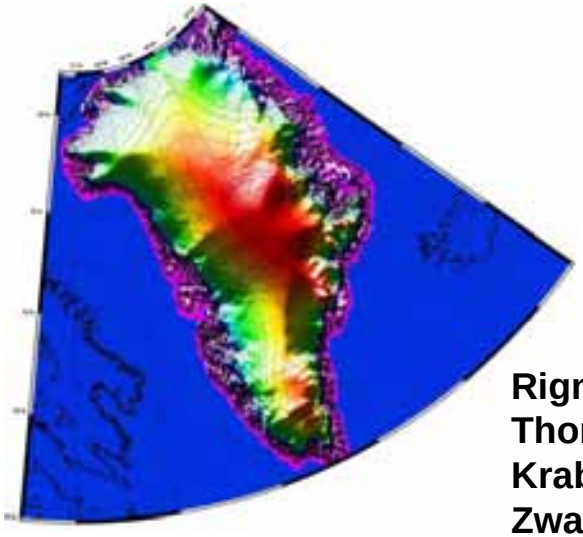
Ice mass loss by glacier melting (Gt/year)



IPCC AR4 (Lemke et al., 2007)
Contribution to sea level :
0.77 +/- 0.1 mm/yr (1993-2003)

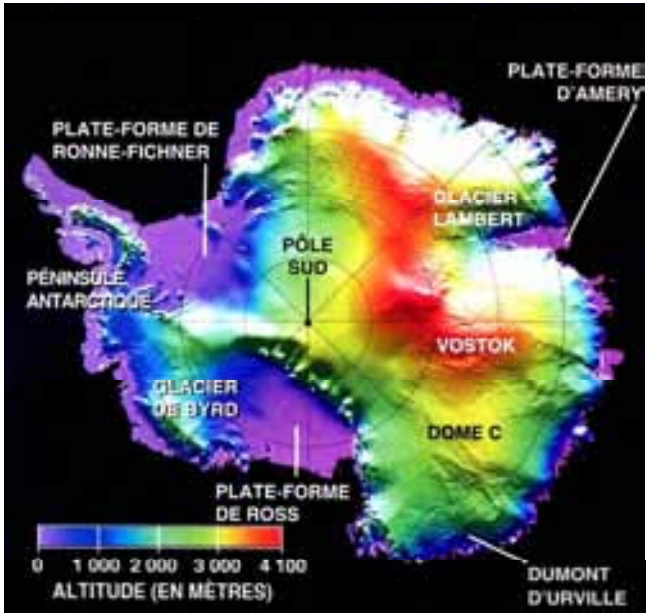
Meier et al.(2007)

Ice sheets Contribution (recent years)



Greenland

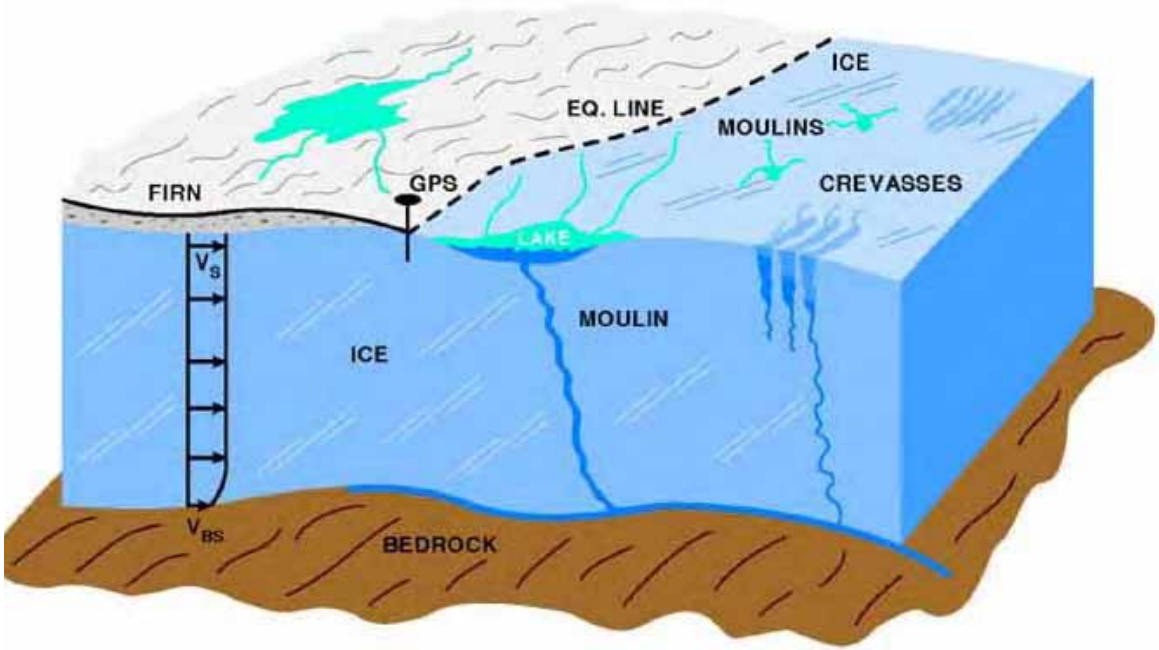
Rignot & Thomas, 2002
Thomas et al., 2004
Krabill et al., 2004
Zwally et al., 2005
Johanessen et al., 2005
Davis et al., 2005
Rignot & Kanagaratnam, 2006
Rignot et al., 2006
Velicogna & Wahr (2005, 2006)
Ramillien et al. (2006)
Chen et al. (2006)
Lutchke et al. (2006)
Rignot et al. (2008)
Cazenave et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



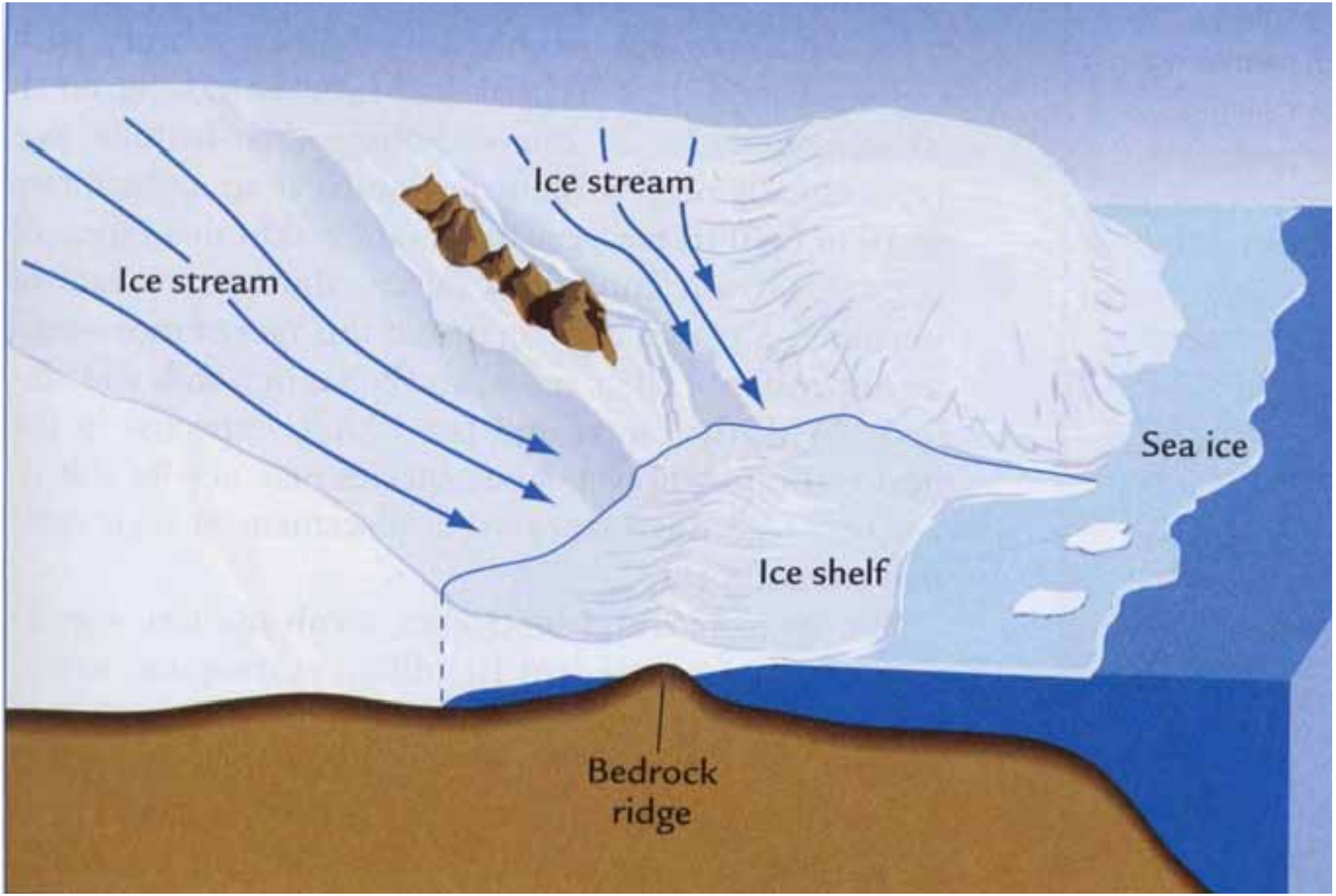
Antarctica

Greenland ice sheet

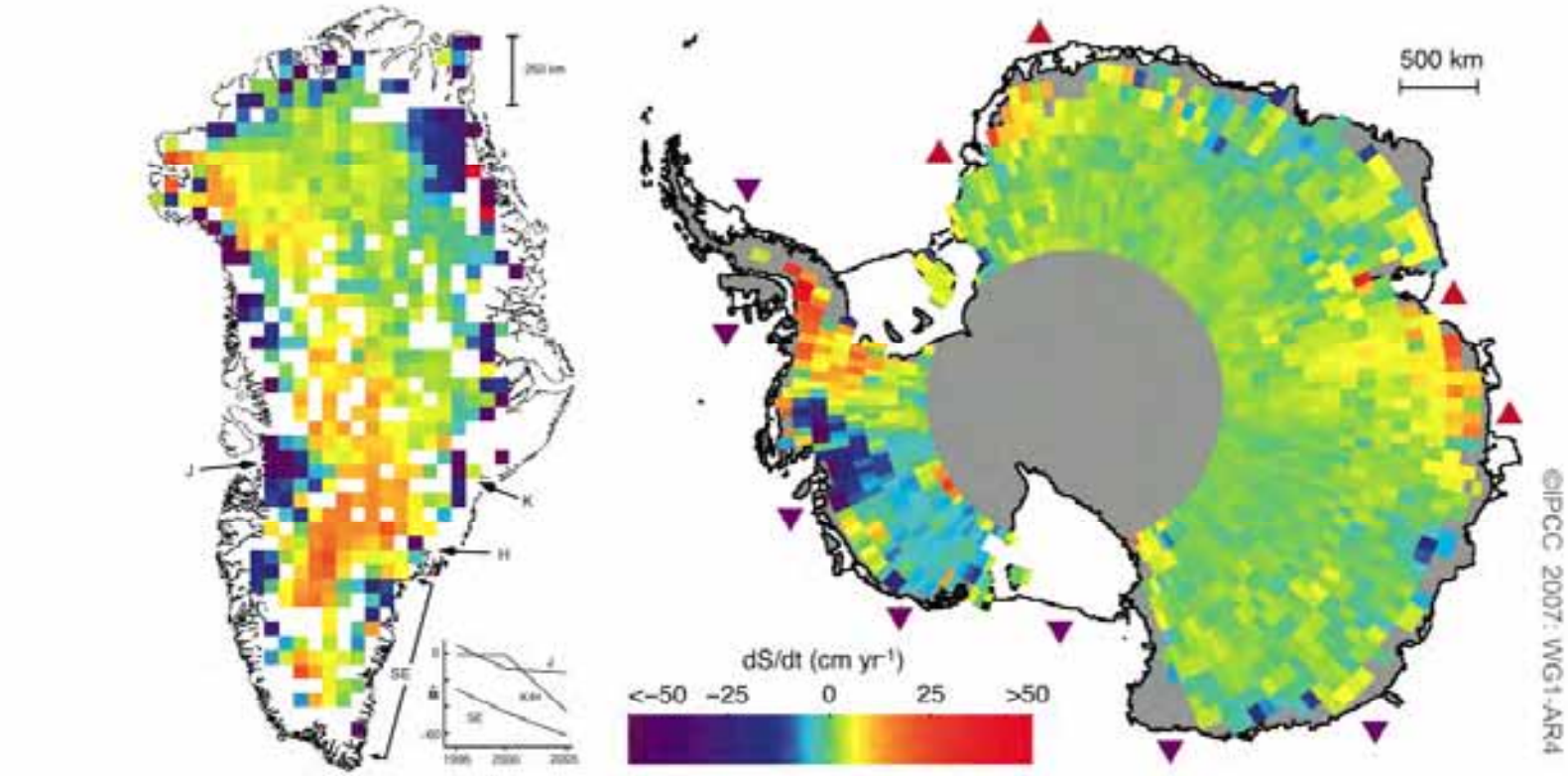
Crevasses in ice…



Role of ice shelves



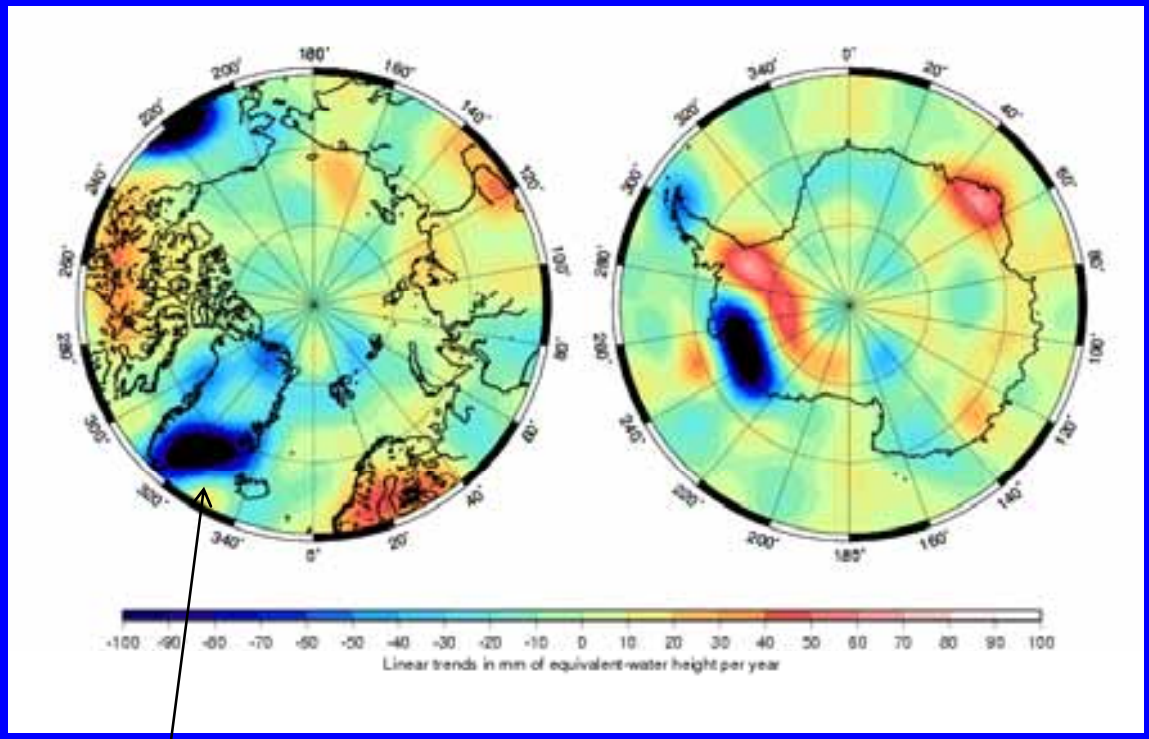
Change in ice thickness measured by laser and radar altimetry

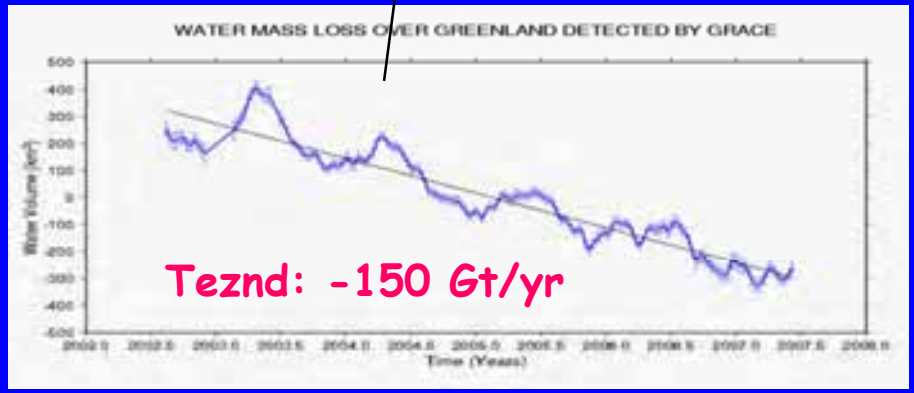


IPCC, 2007

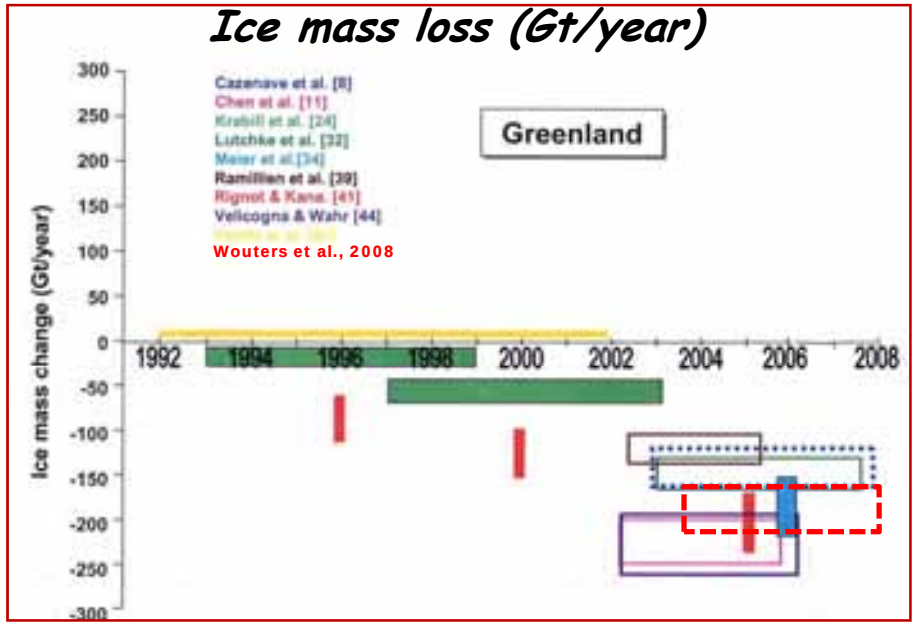
Space gravimetry : GRACE mission (2002-)

→ Ice mass change



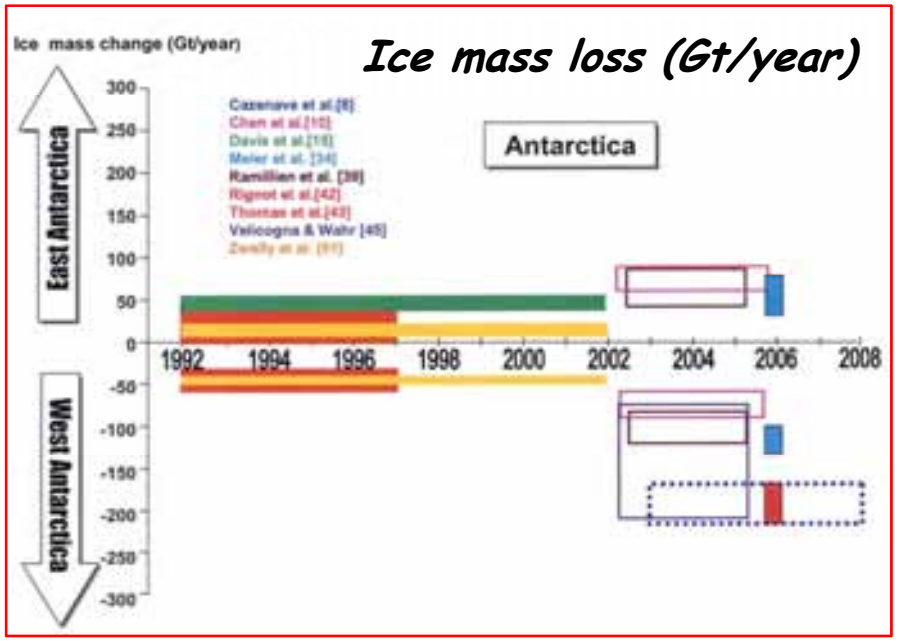


Greenland and Antarctica mass balance



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

Sea Level Budget

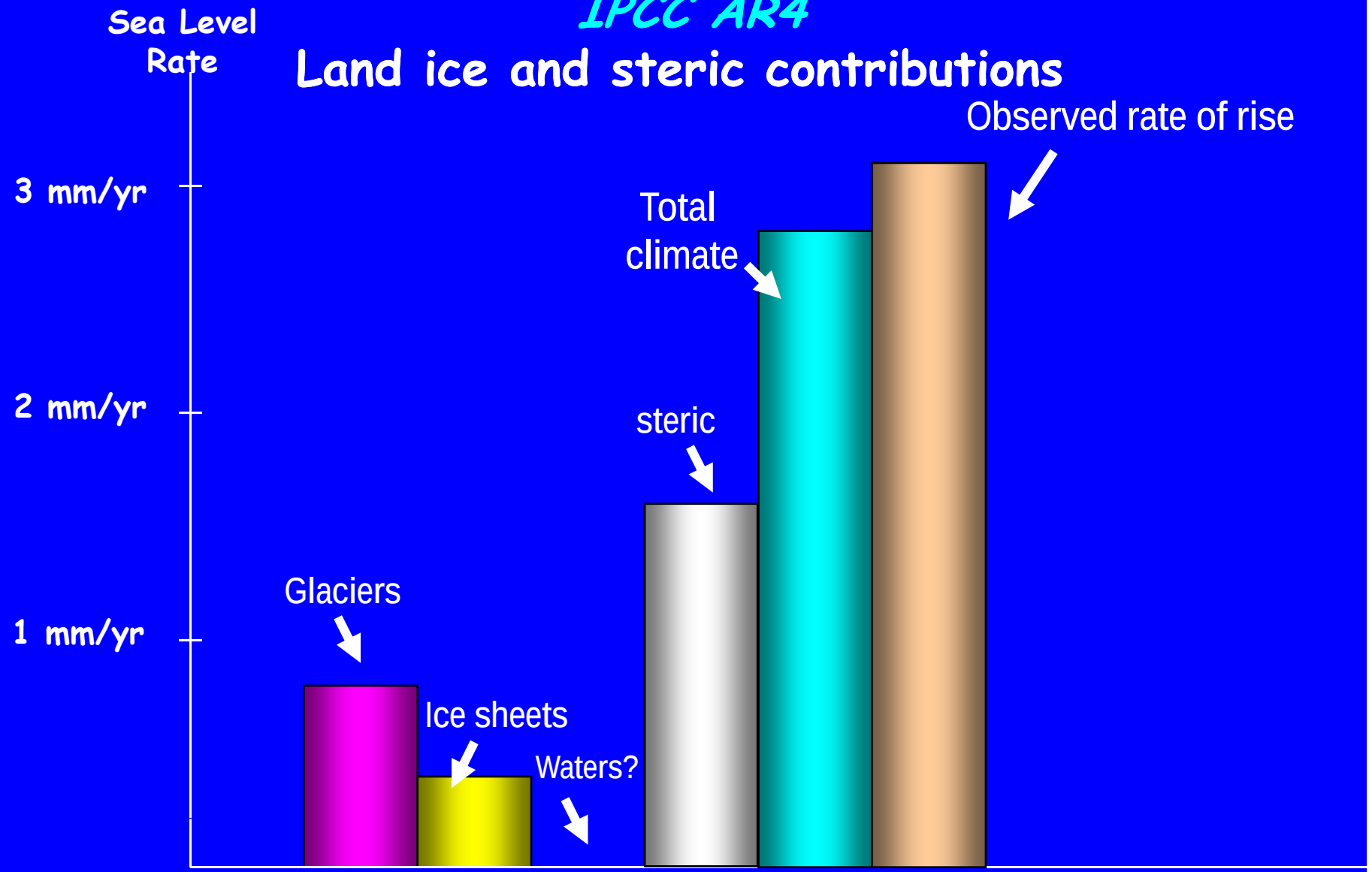
1993-2003

(IPCC AR4)

Sea Legel Budget 1993-2003

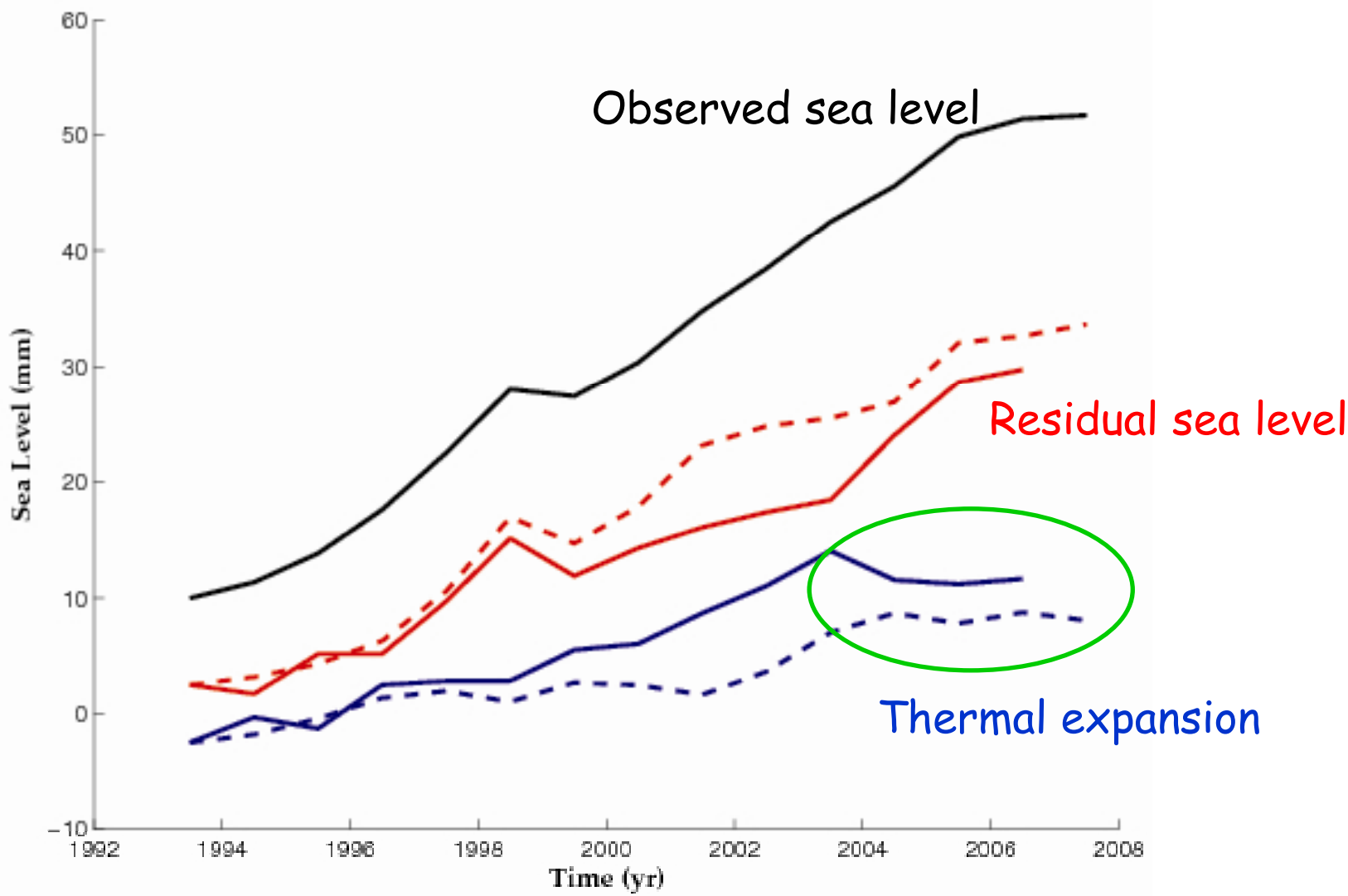
IPCC AR4

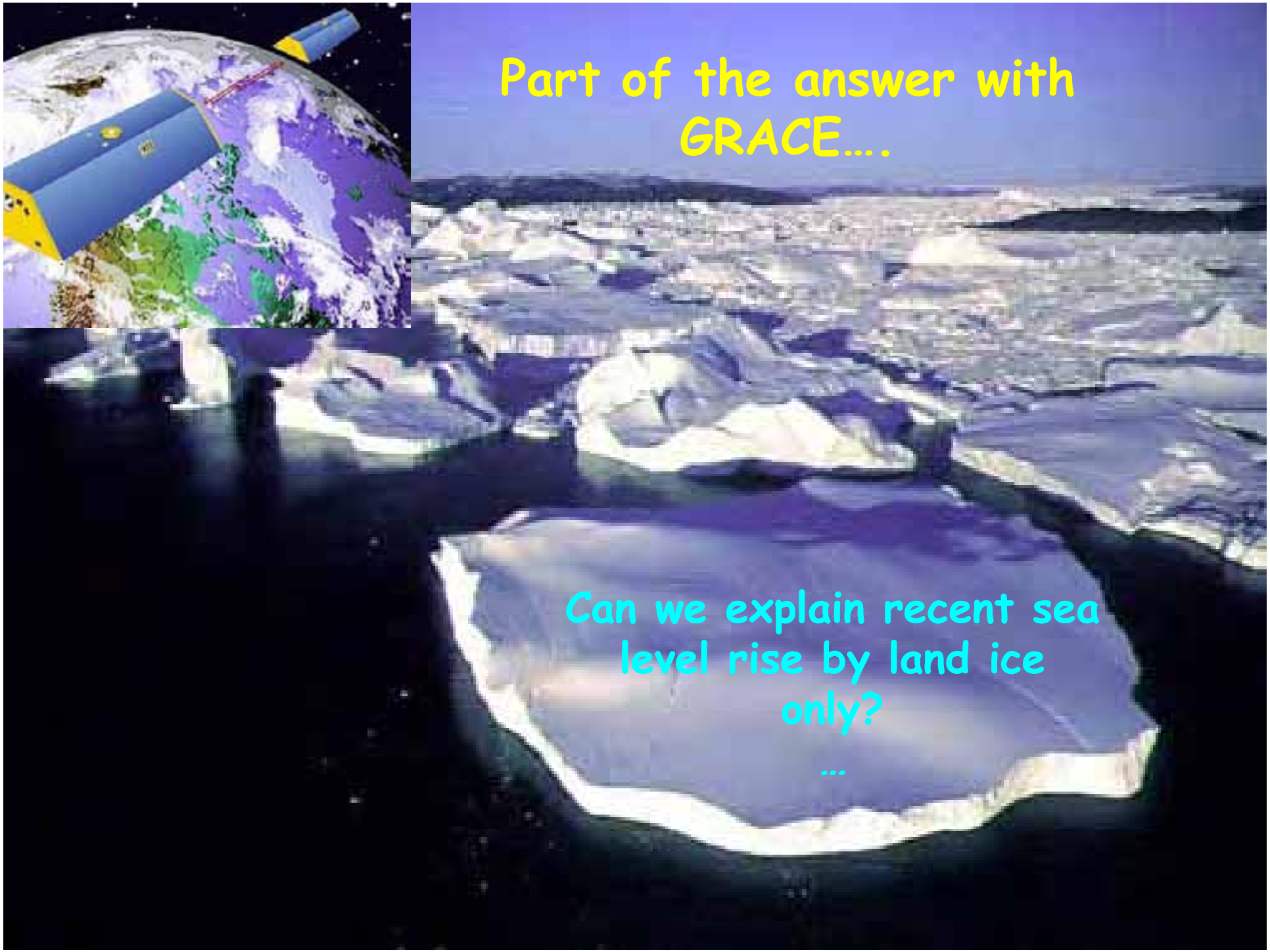
Land ice and steric contributions



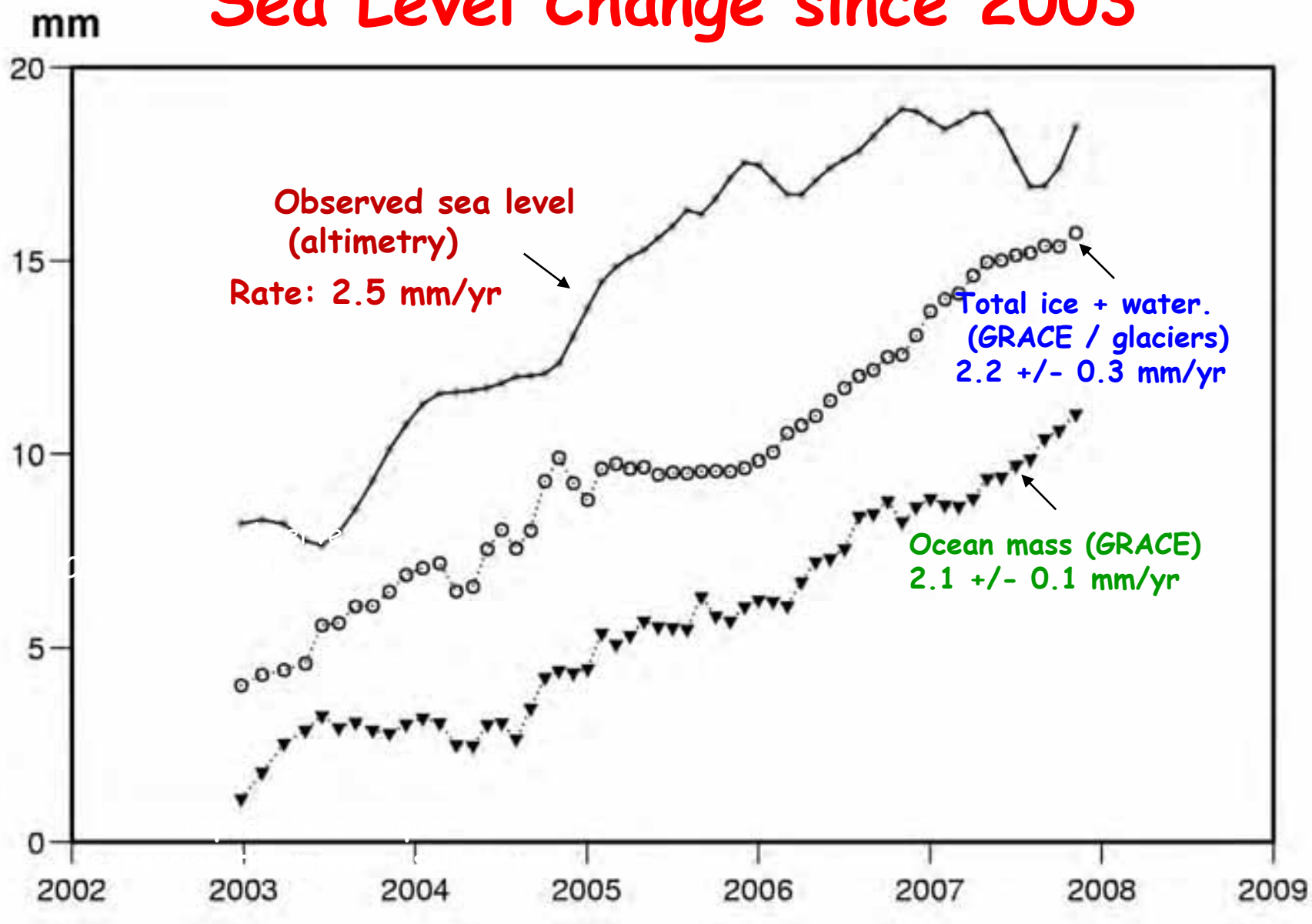

Sea Level Rise
since 2003
Surprises!...

Observed sea level and thermal expansion since 1993

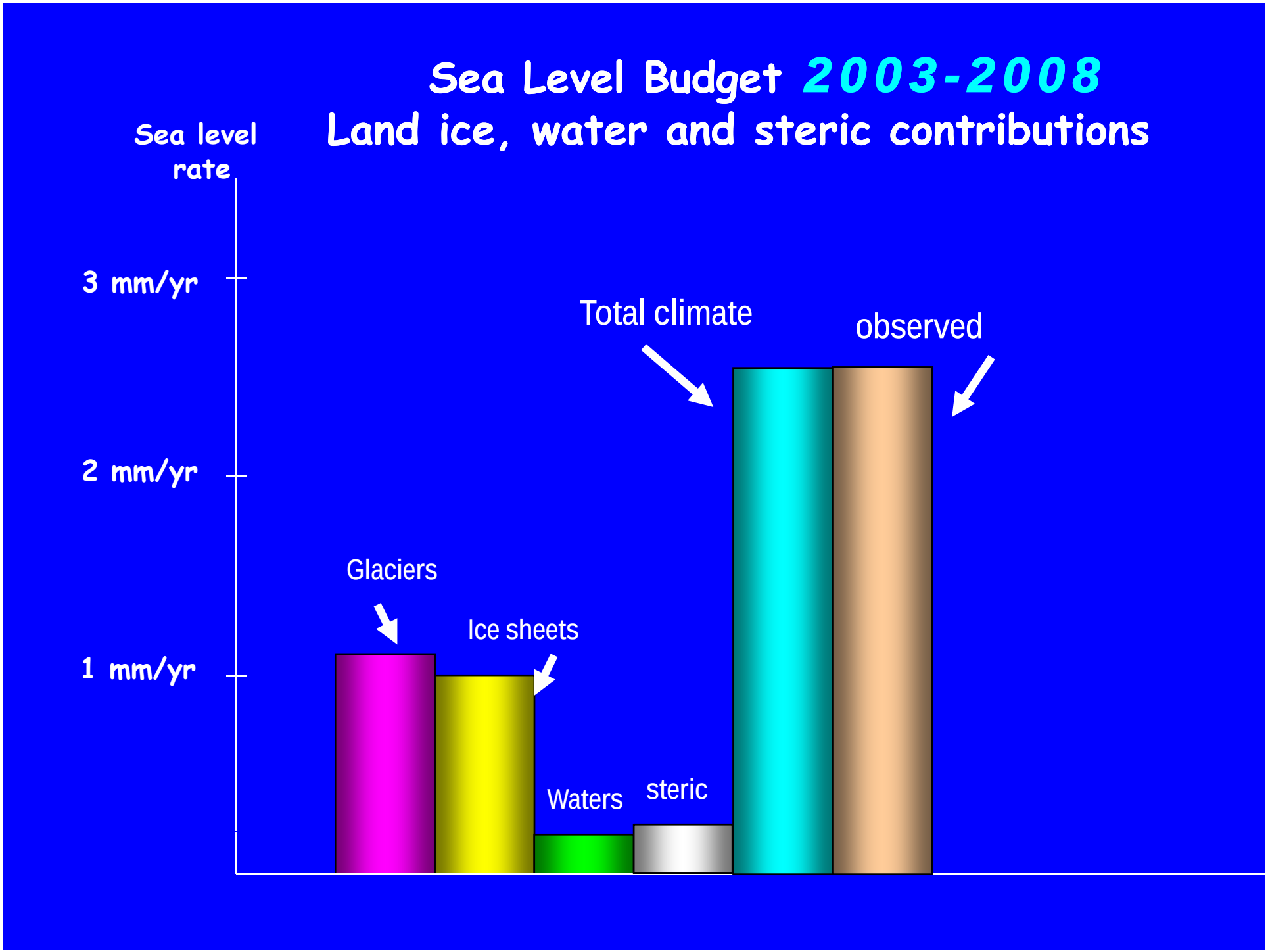



Part of the answer with GRACE….
Can we explain recent sea level rise by land ice only?
…

Sea Level Change since 2003

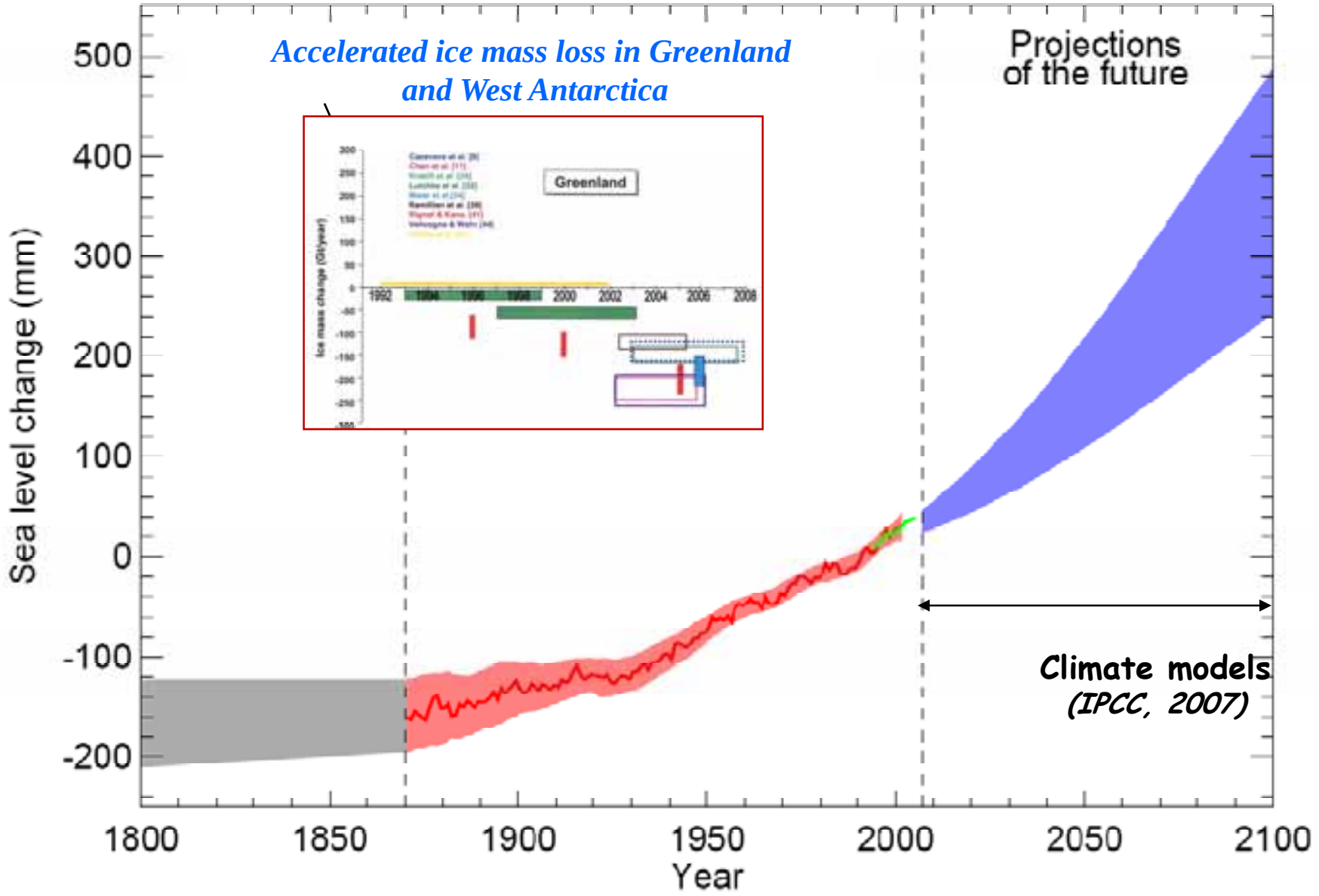


Sea Level Budget 2003-2008
Land ice, water and steric contributions



Future sea level rise

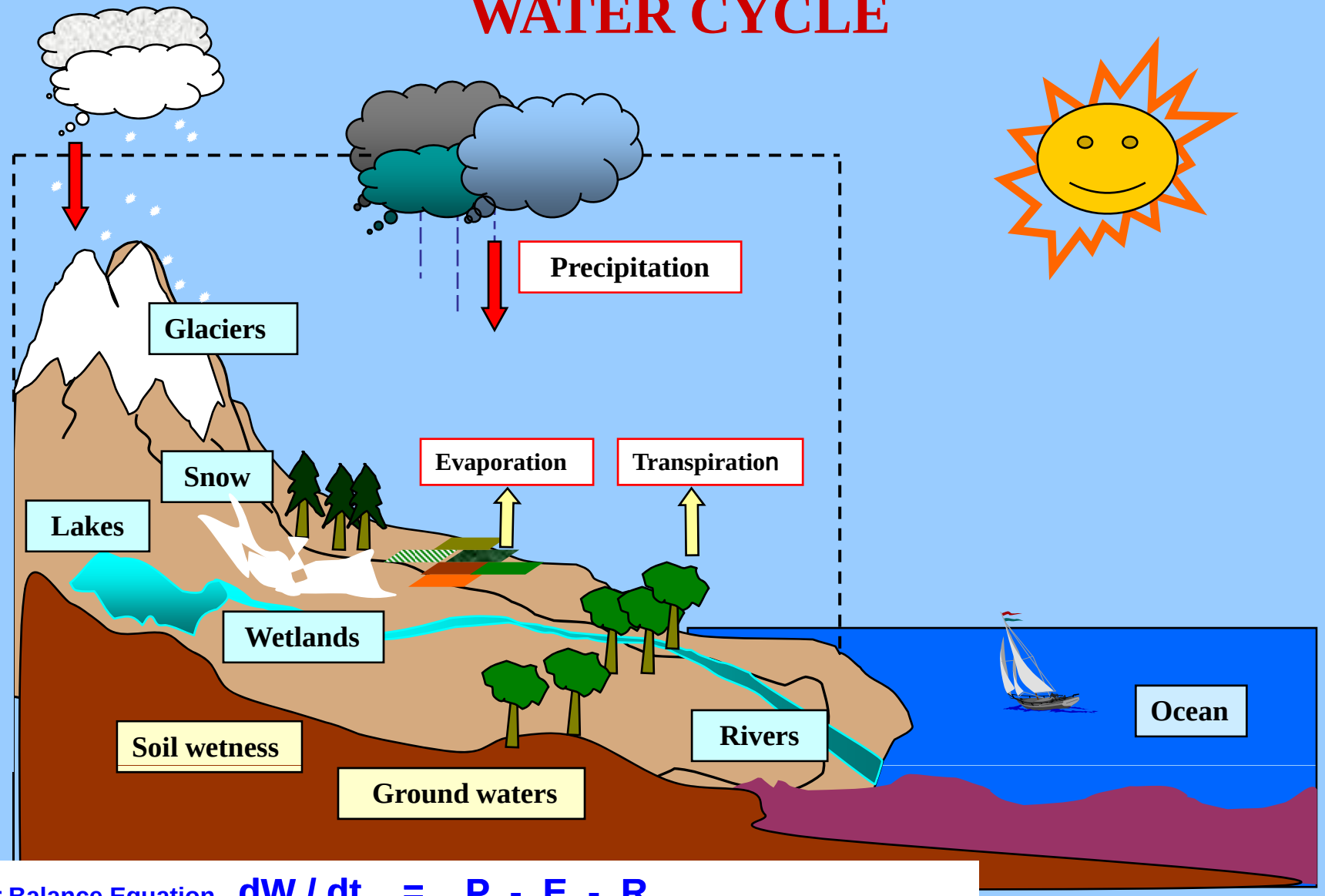
Global mean sea level from 1800 to 2100



IPCC AR4, 2007


Monitoring
terrestrial waters
by satellite
© CNES 2000

WATER CYCLE



Water Balance Equation $dW / dt = P - E - R$

Total land water storage — *Precipitation* — *Evapotranspiration* — *Runoff*

Causes of spatio-temporal change of the continental water cycle

- Climate variability (natural and anthropogenic)

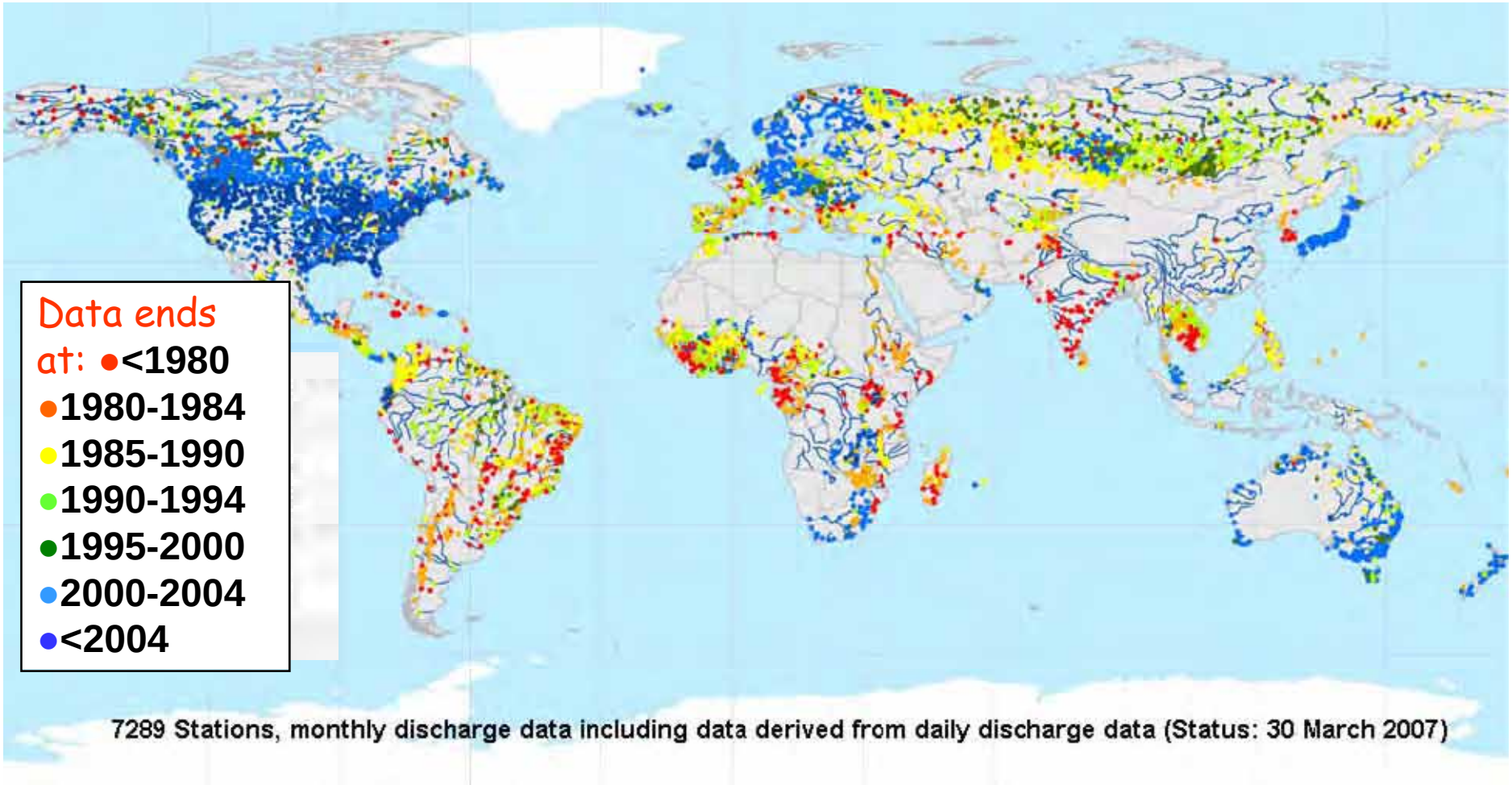
- Direct human effects:

  - groundwater mining
  - irrigation
  - dam building
  - urbanization
  - deforestation
  - change in land use

Applications

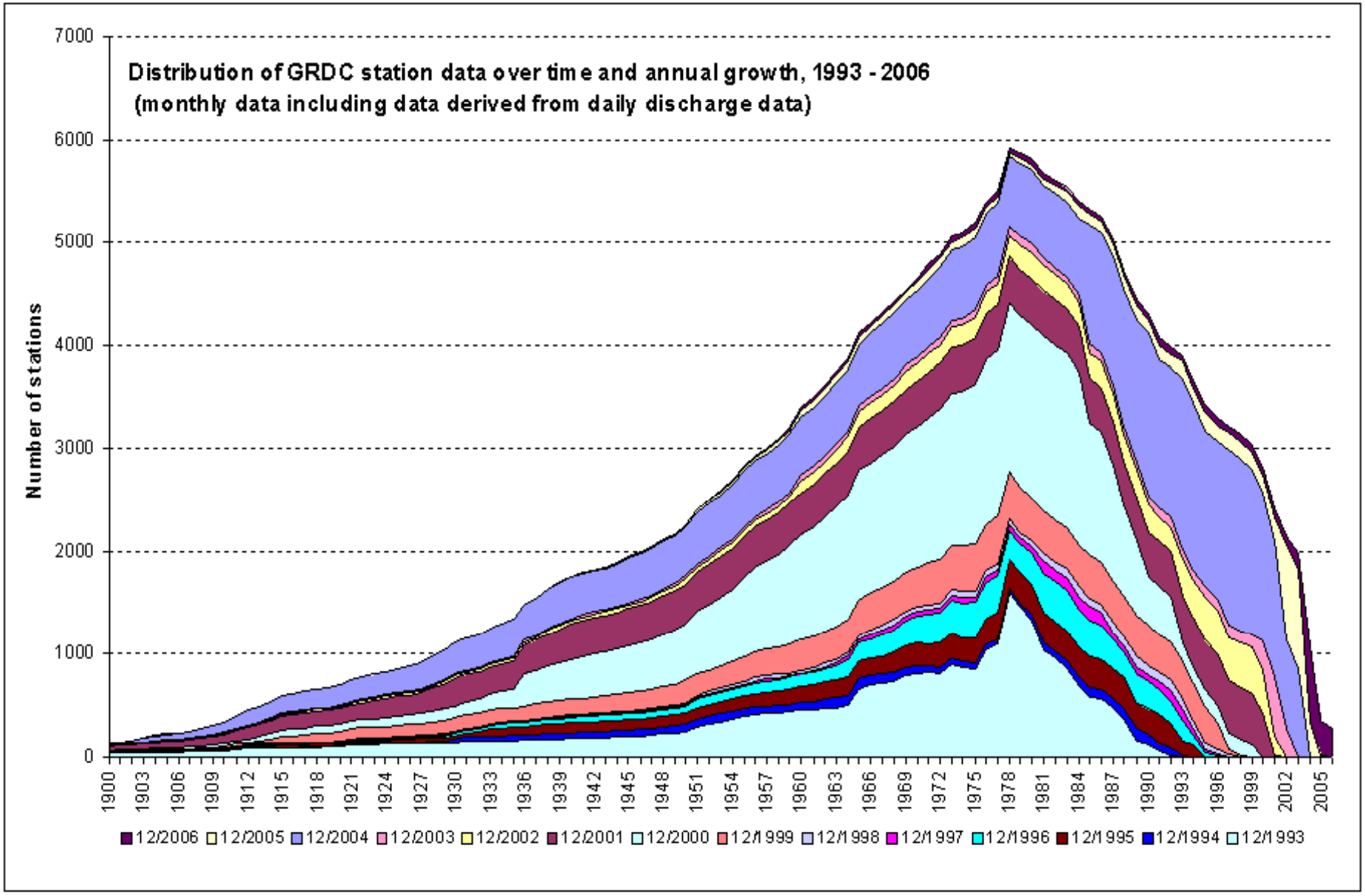
- Weather forecast
- Climate modelling
- Water resources management
- Natural Hazards:
  - floods, droughts
- Agriculture (irrigation)
- Hydro-electric energy production
- Fluvial navigation
- Land use and management
- Carbon cycle
- Sediment transport
- Sea level change
- Etc.

Status (in March 2007) of monthly discharge and stage data in the Global Runoff Data Center (GRDC)



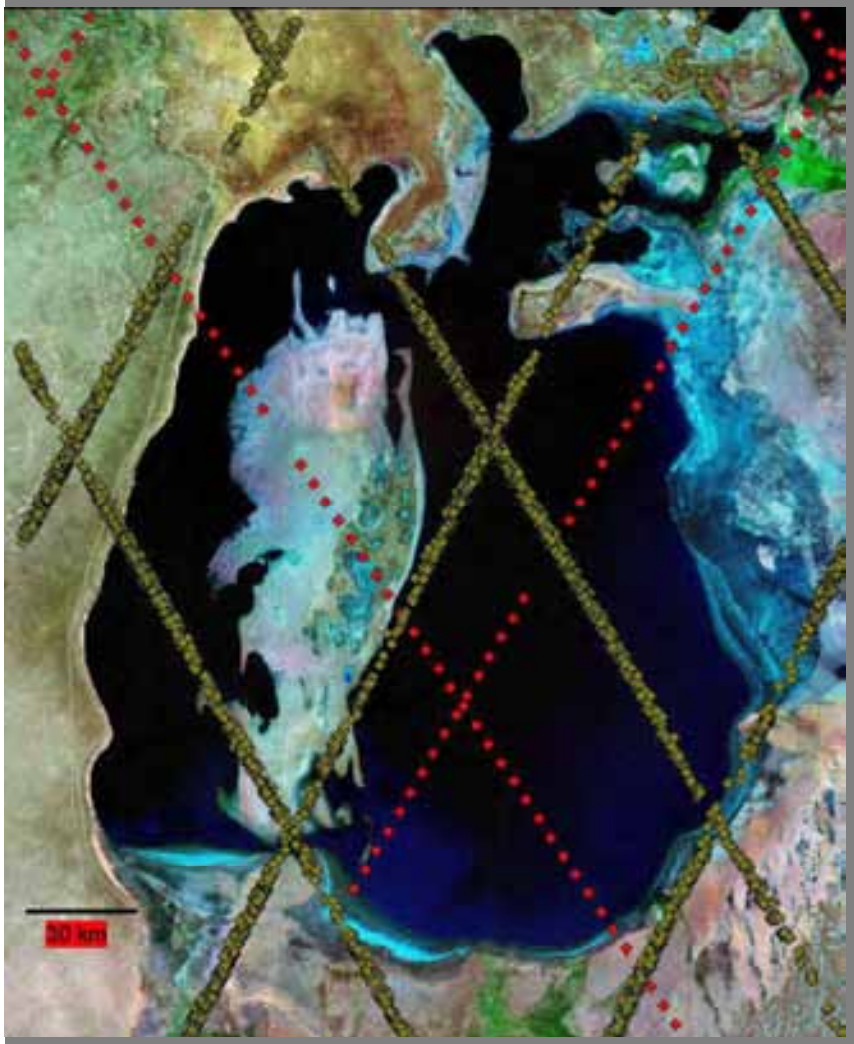
Global Runoff Data Center

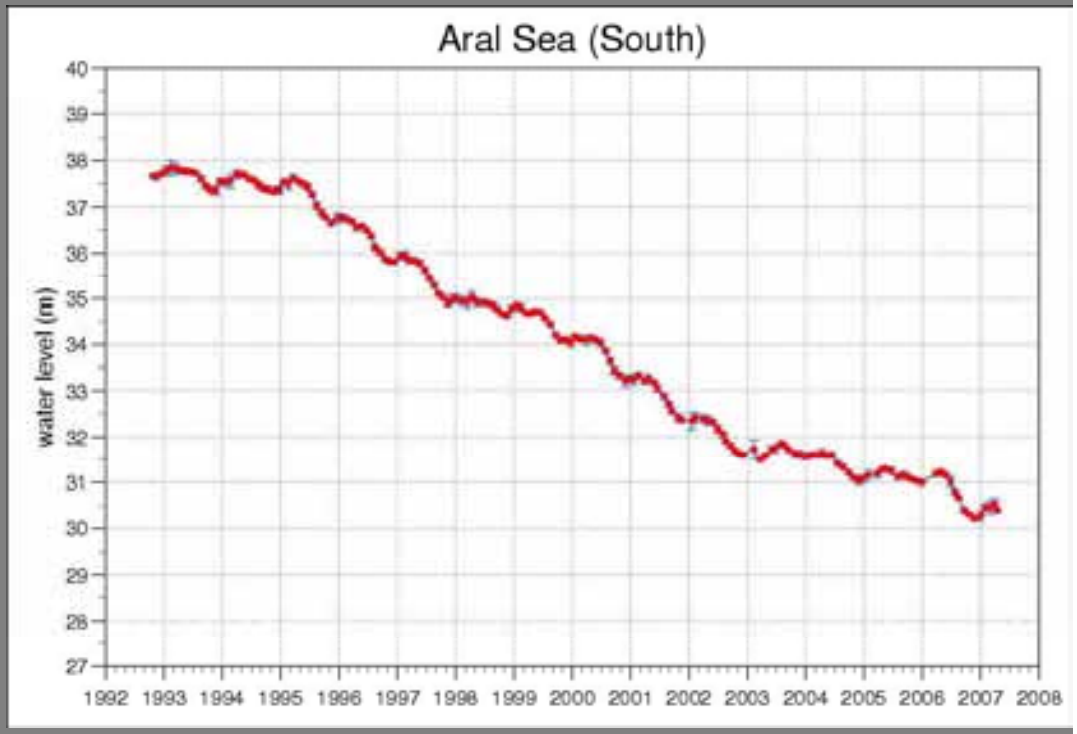
Distribution of GRDC station data over time (1900-2007)



Remote sensing technique	Soil moisture	Ground waters	Snow pack	Surface waters (extent, level, volume, discharge)
Visible Imagery	Extent		Extent	Extent
Active microwaves (Radar imagery)	Extent Volume		Extent	Extent
Passive microwaves (Radiometry)	Extent Volume		Extent Thickness	Extent
Altimetry				■Level ■Discharge (indirect) ■Volume (if combined with imagery)
Space gravimetry	Mass	Mass	Mass	Mass

ARAL Sea


30 km


Aral Sea (South)
water level (m)
40
39
38
37
36
35
34
33
32
31
30
29
28
27
1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008

Lake Sarykamish (Asie)

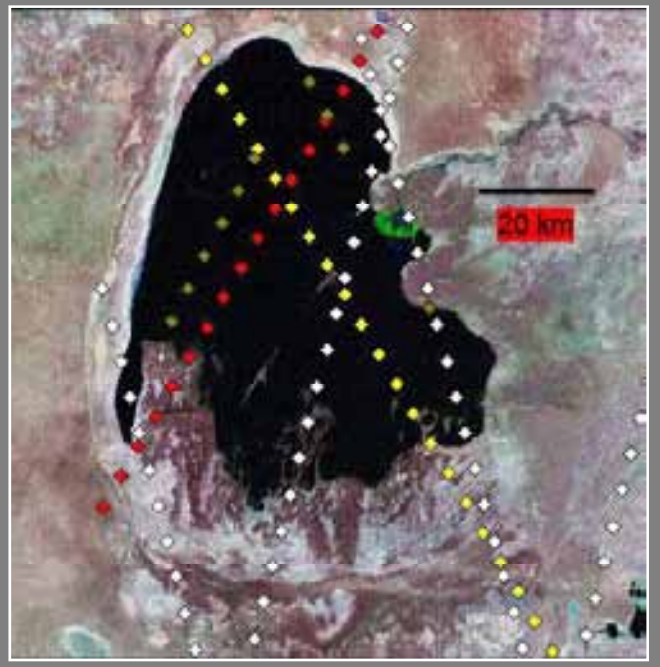
+8

Water level (m)

0

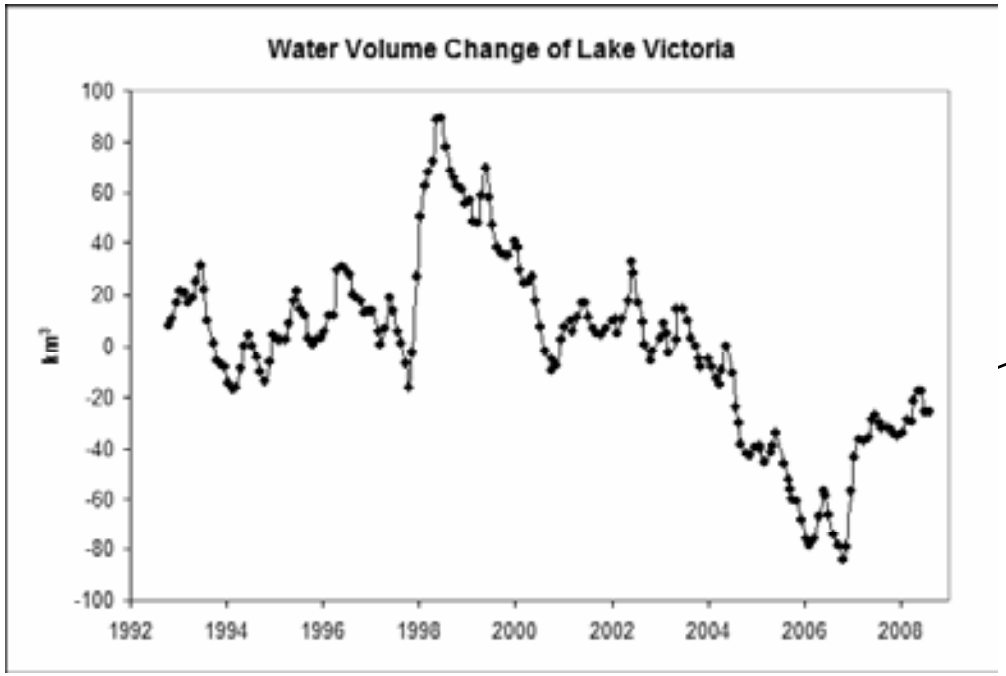
1992

2008



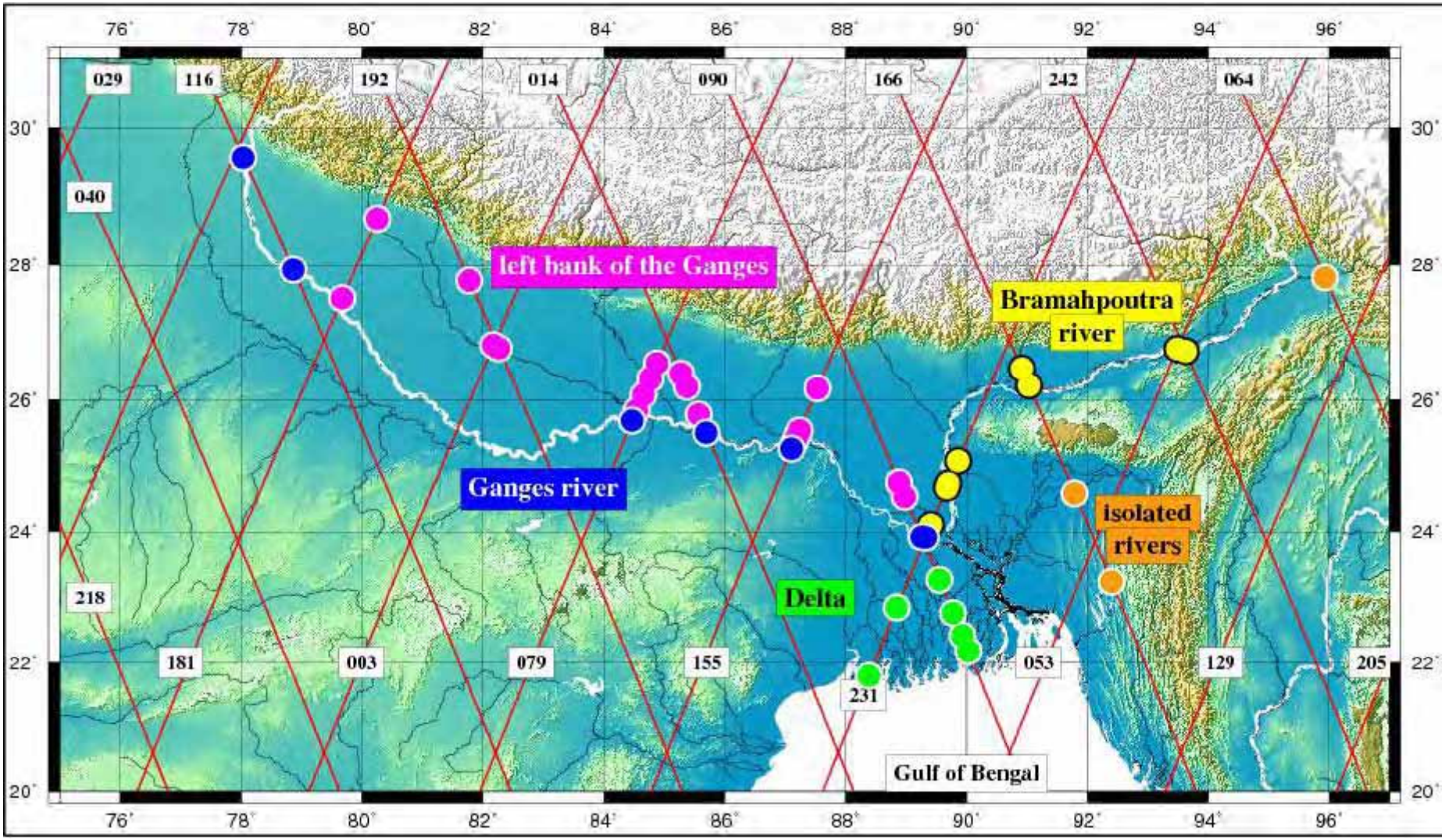
Lacs d'Afrique de l'Est

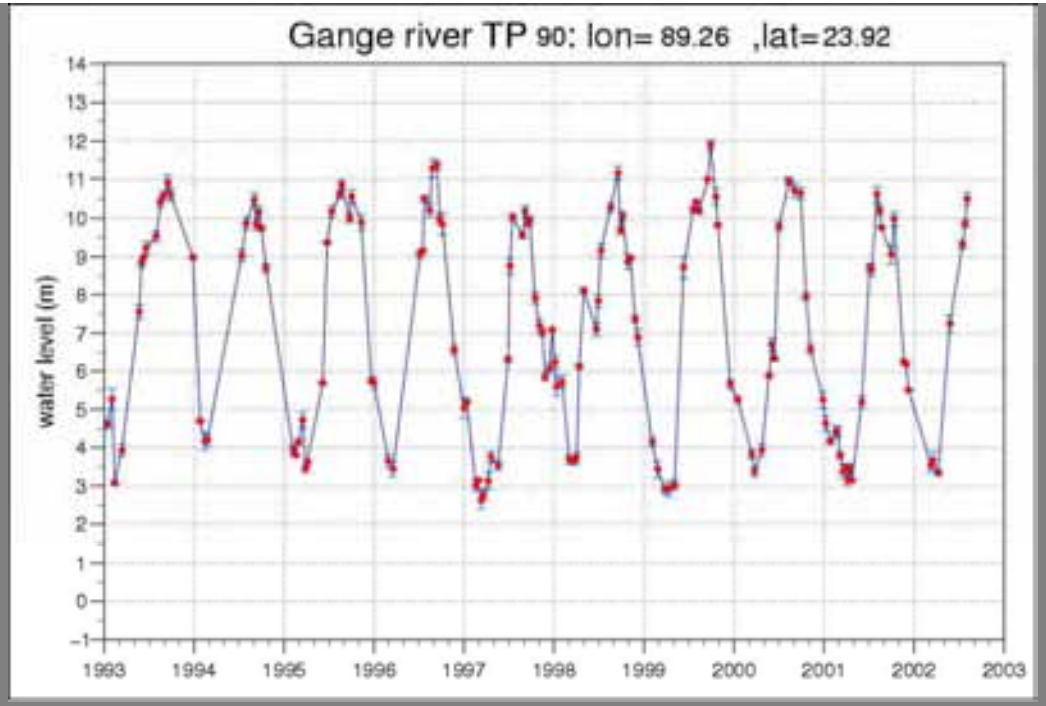
Lac Victoria

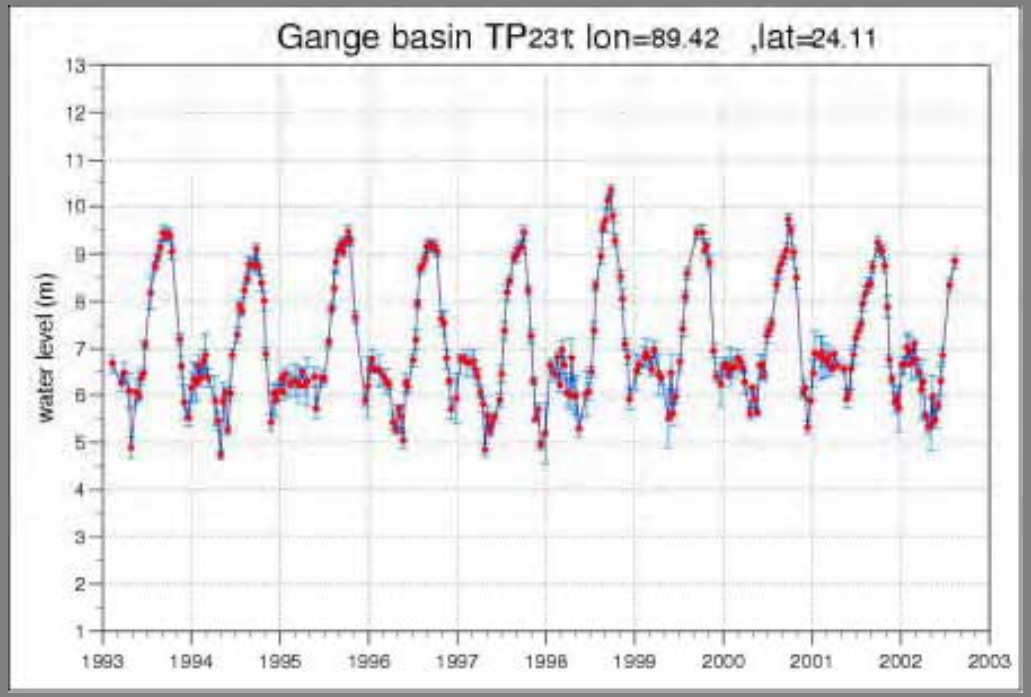


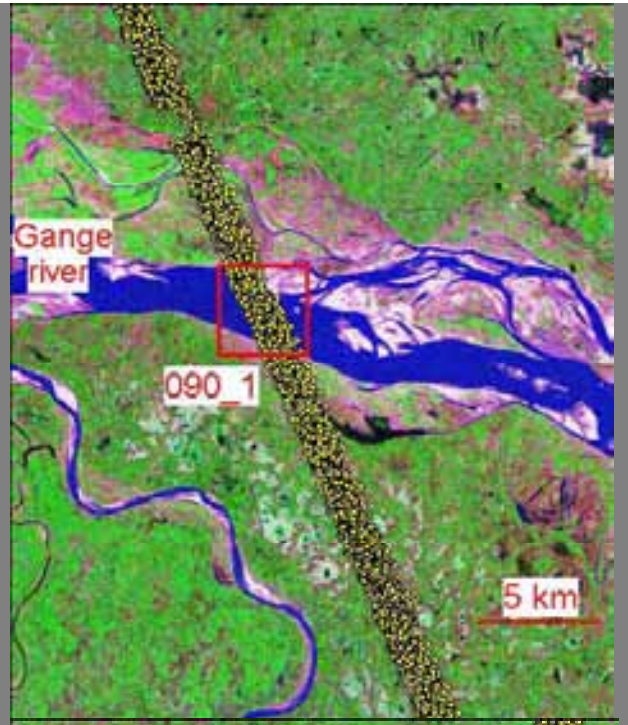
1992 2008

Example of altimetric coverage over rivers




Gange river TP 90: lon= 89.26 ,lat=23.92
water level (m)
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003

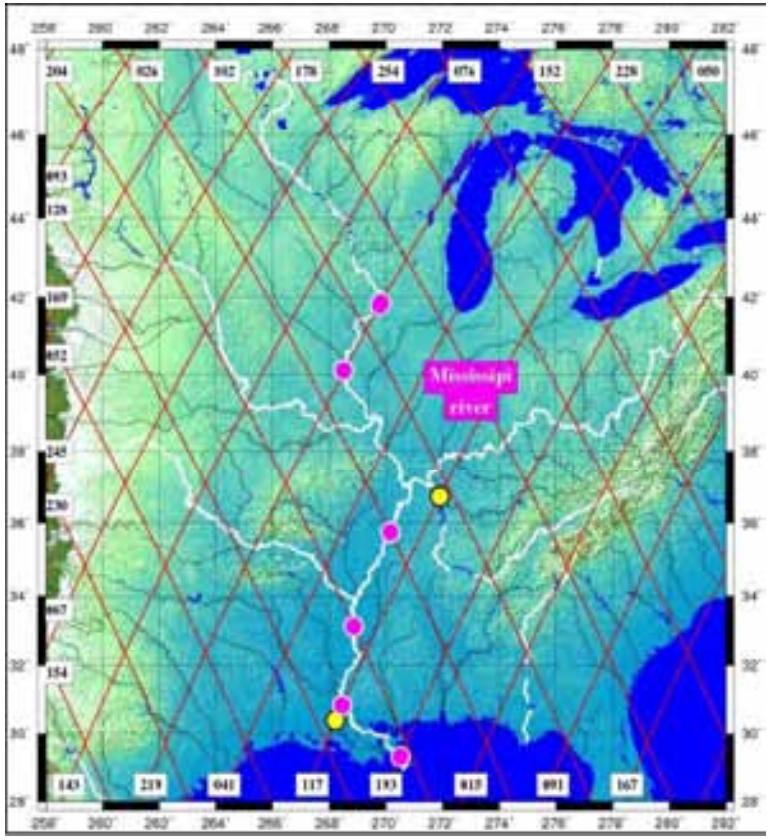

Gange basin TP231: lon=89.42 ,lat=24.11
water level (m)
13
12
11
10
9
8
7
6
5
4
3
2
1
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003


Gange river
090_1
5 km

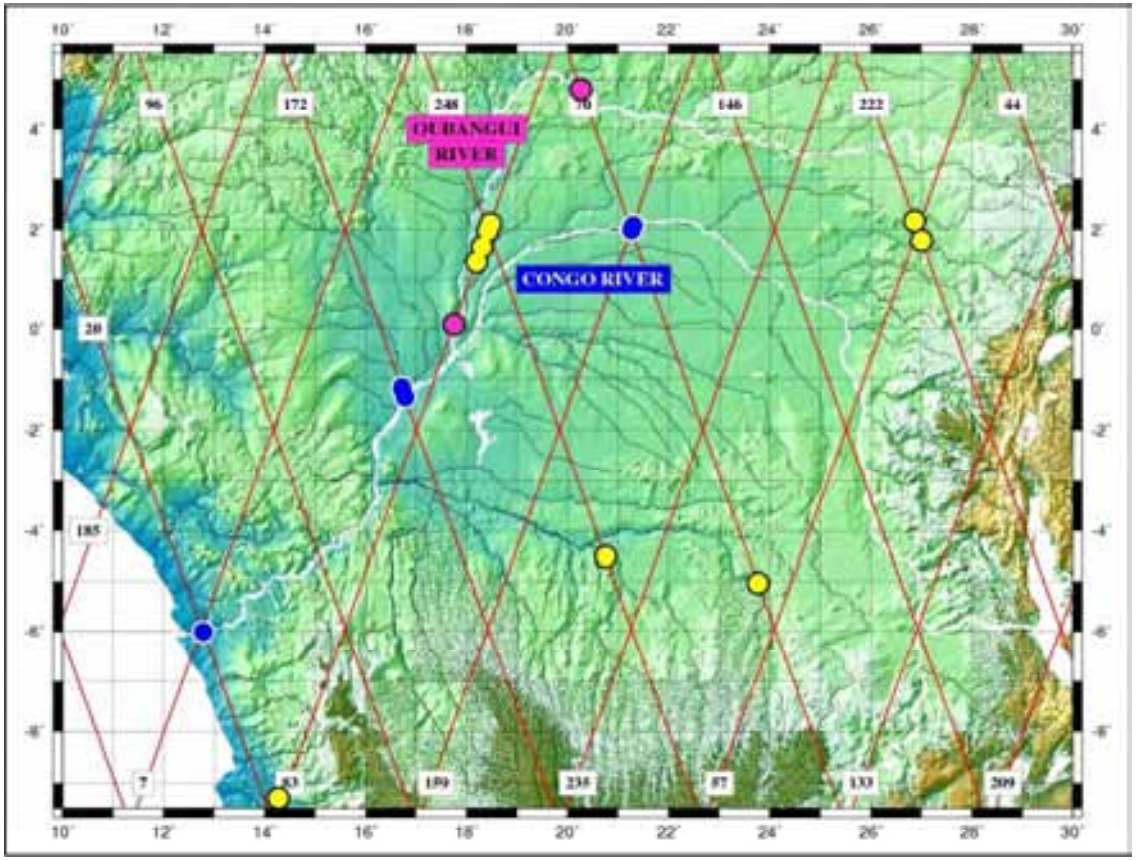

Gange river
231_1
5 km


Problems....
© CNES 2000

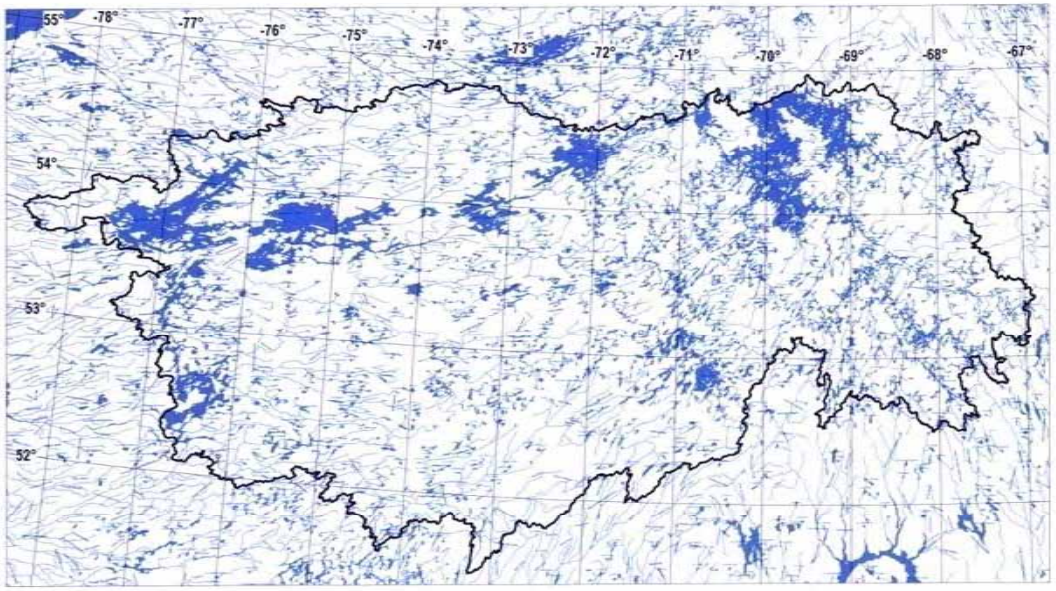
Satellite Altimetry Coverage



Mississipi

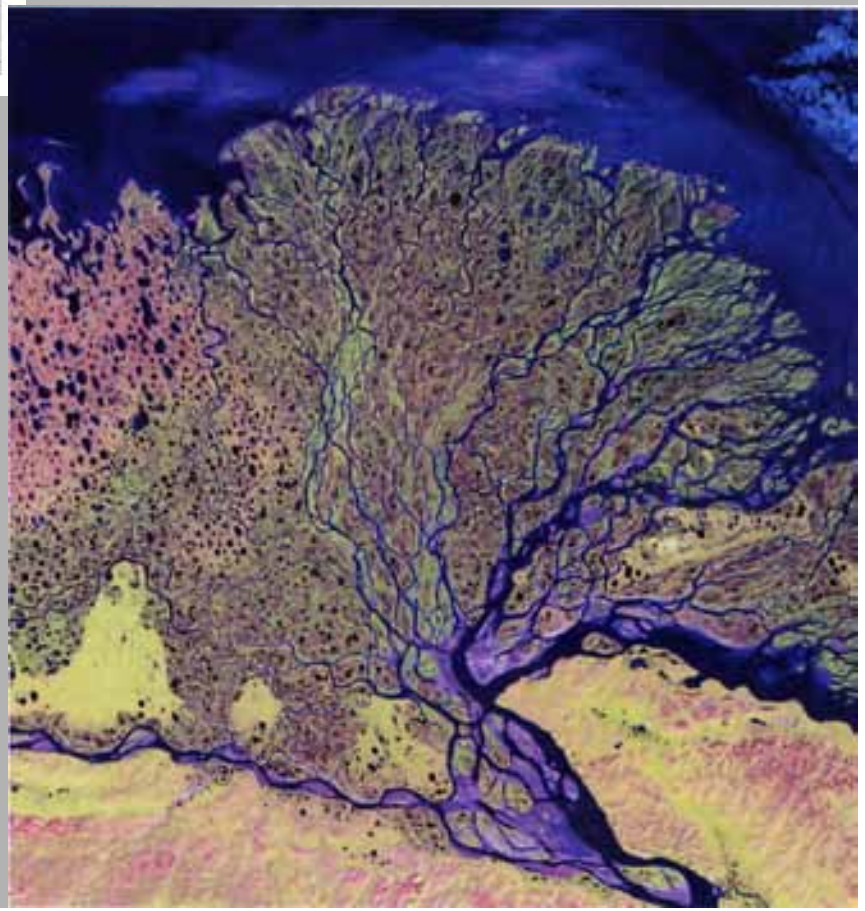


Congo



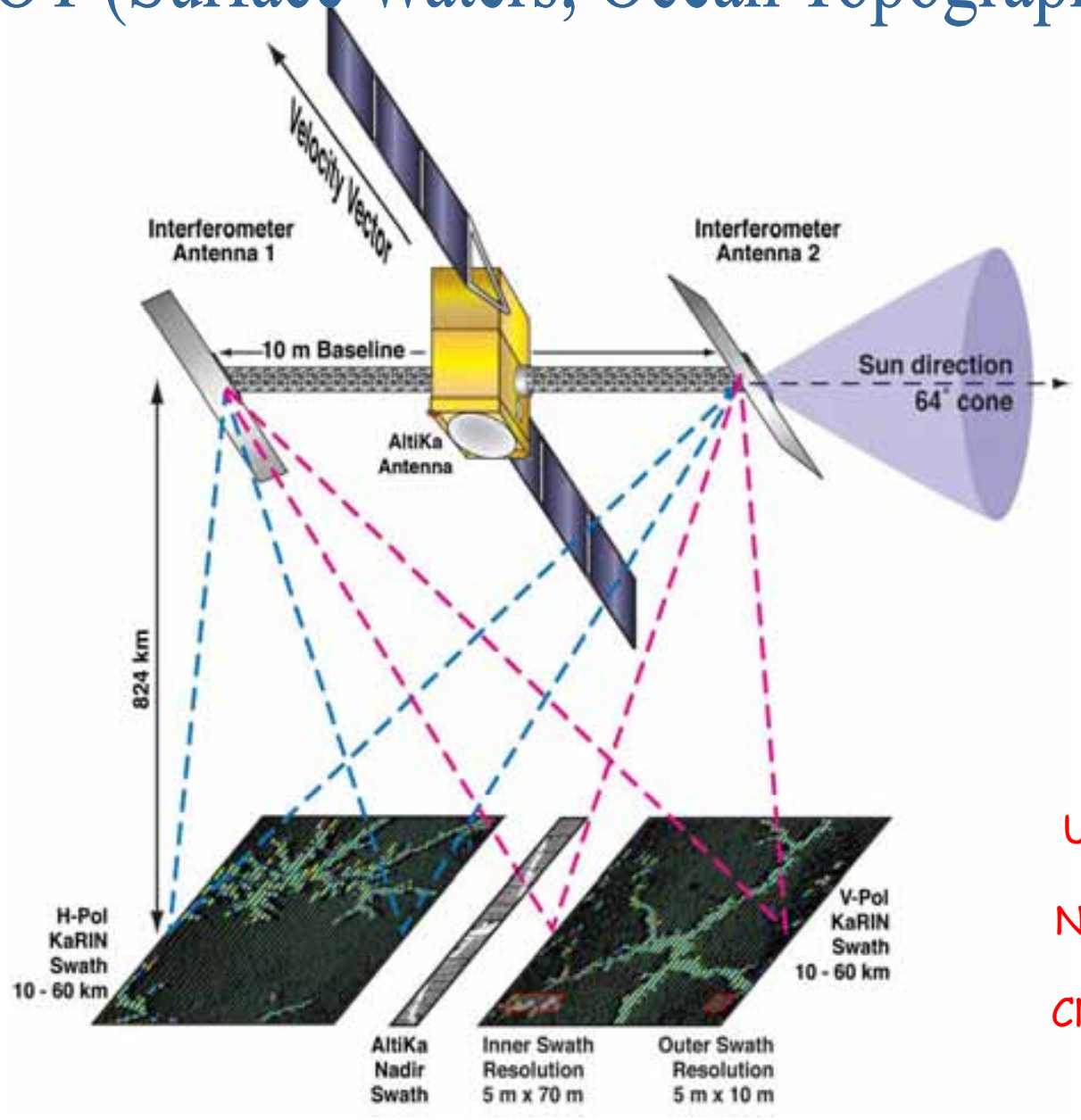
Wetlands in Quebec (Canada) ←

(Hydroelectric energy production)

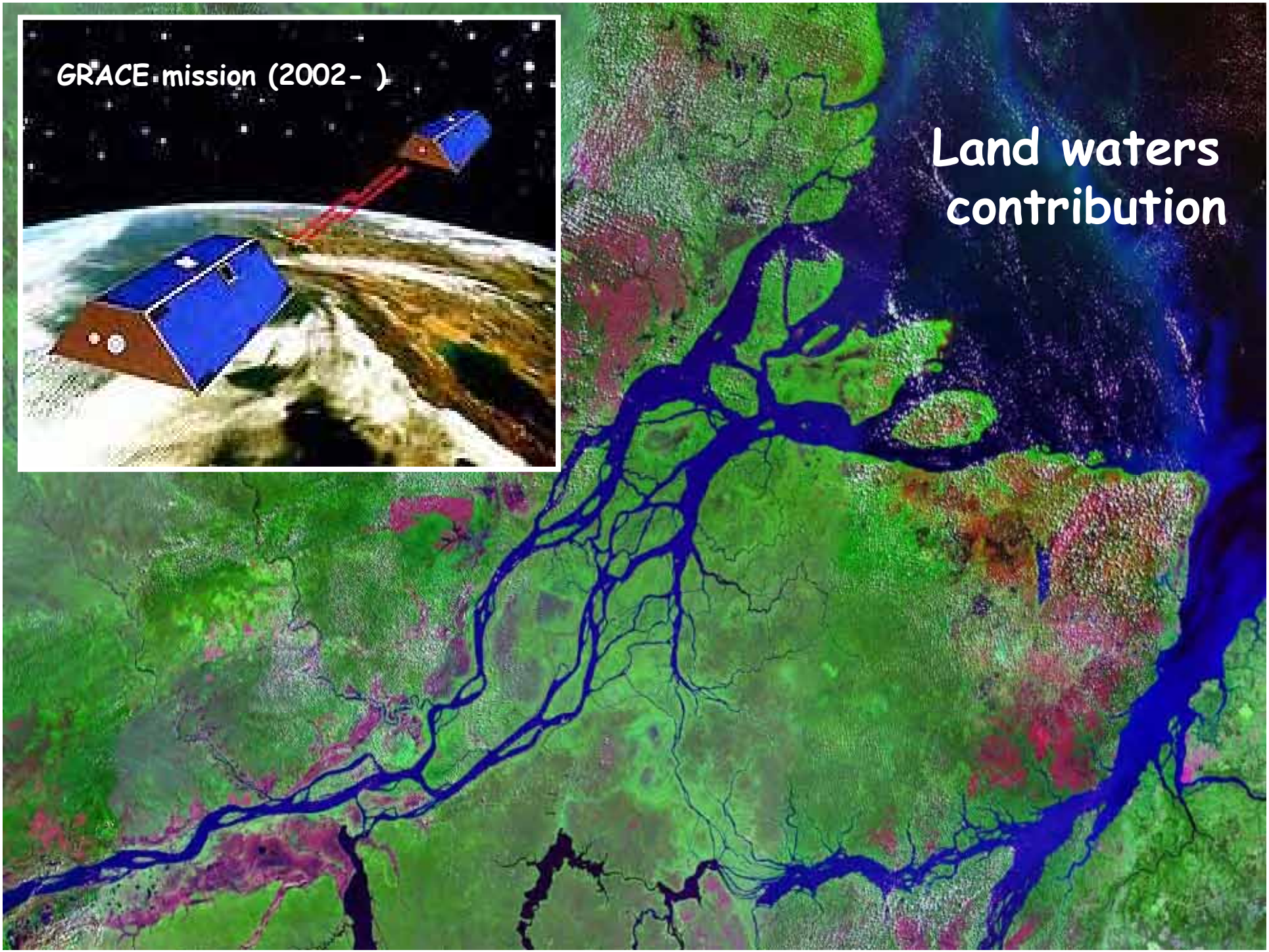


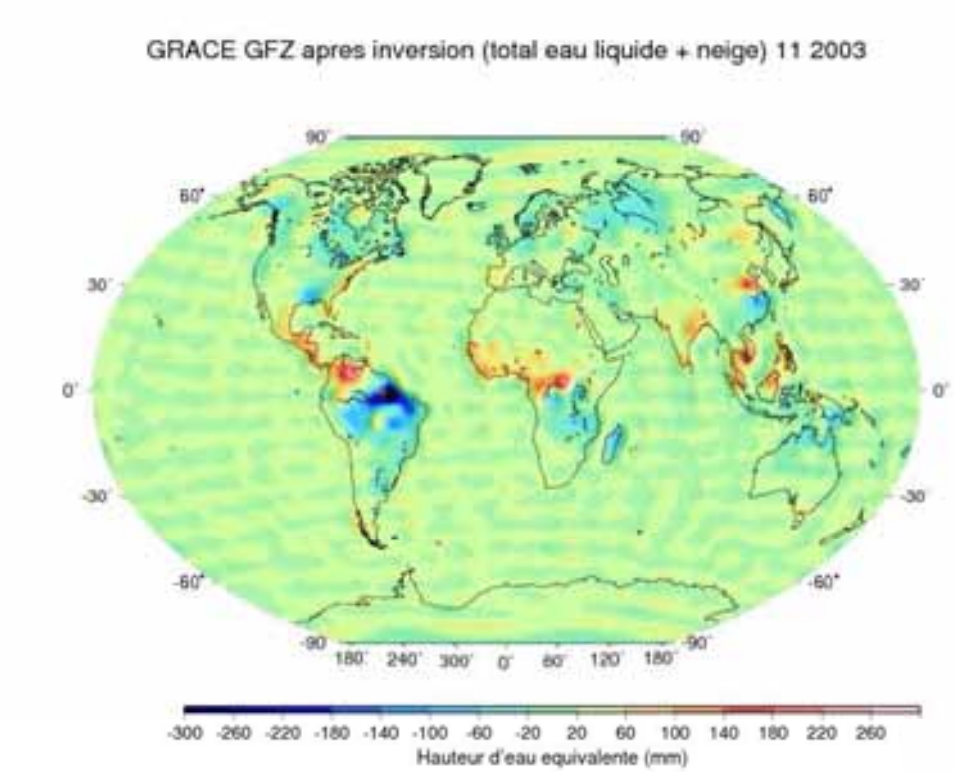
Delta of Lena River (Siberia) →

New space mission for land hydrology
SWOT (Surface Waters; Ocean Topography)



Under study
at
NASA (USA)
and
CNES (France)

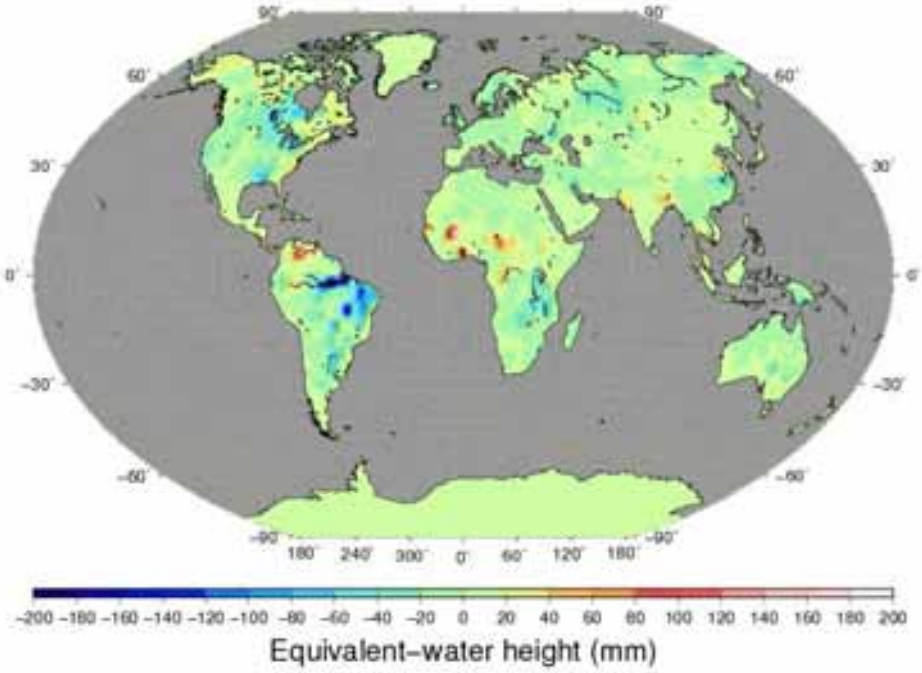

GRACE mission (2002-)
Land waters contribution



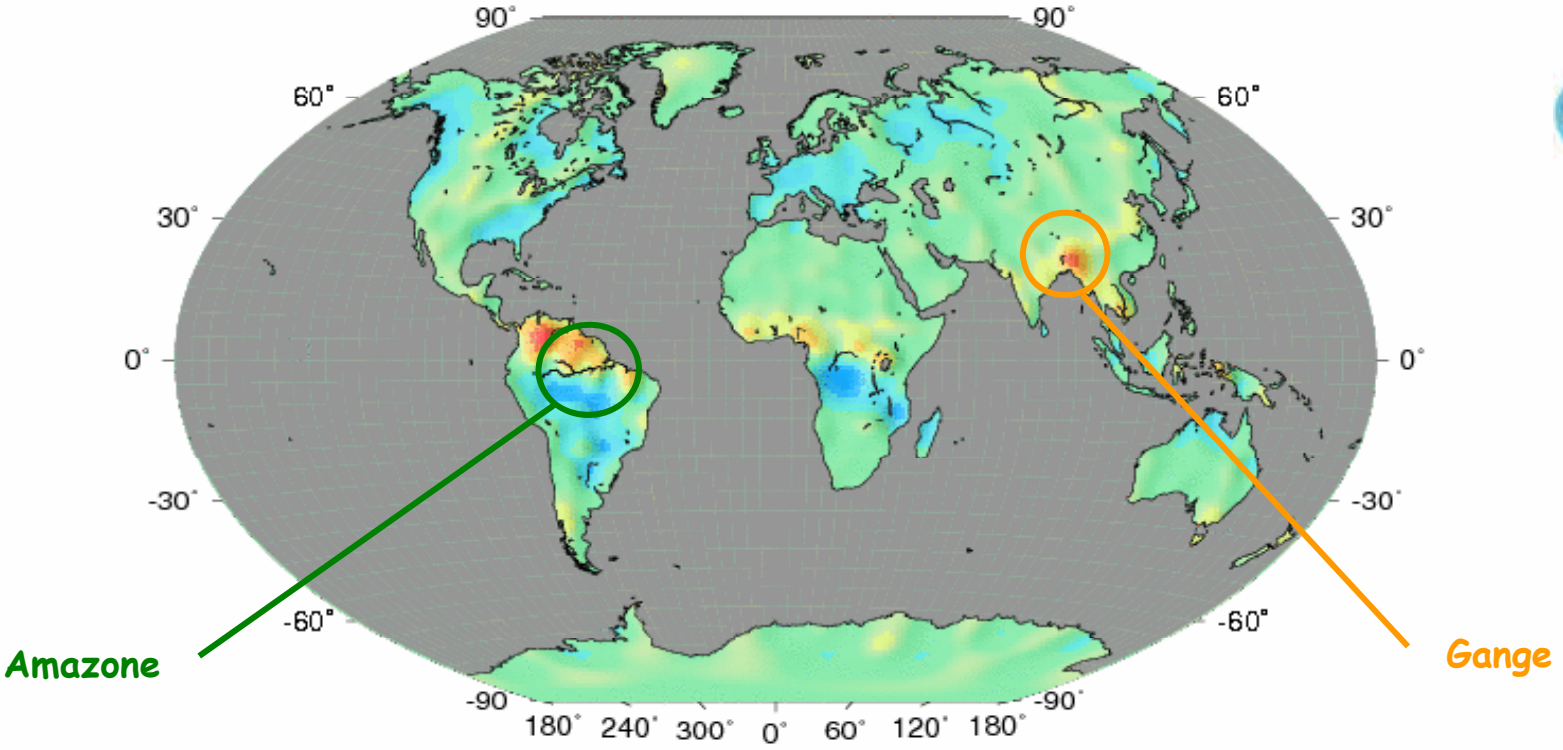
GRACE

Total land water storage
November 2003

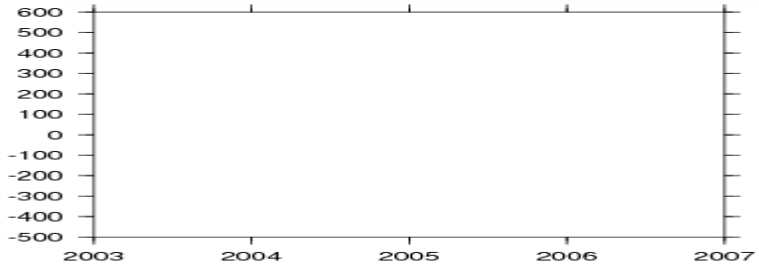
Water Gap Hydrological Model



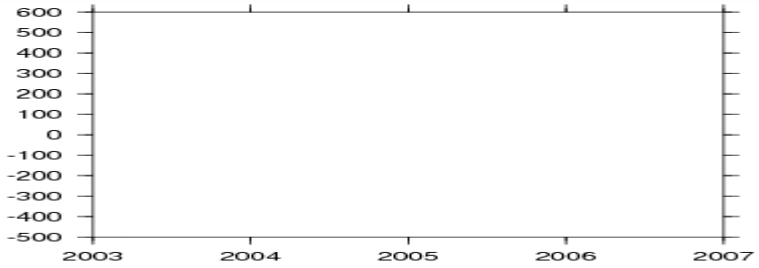
Change with time of land water storage from GRACE



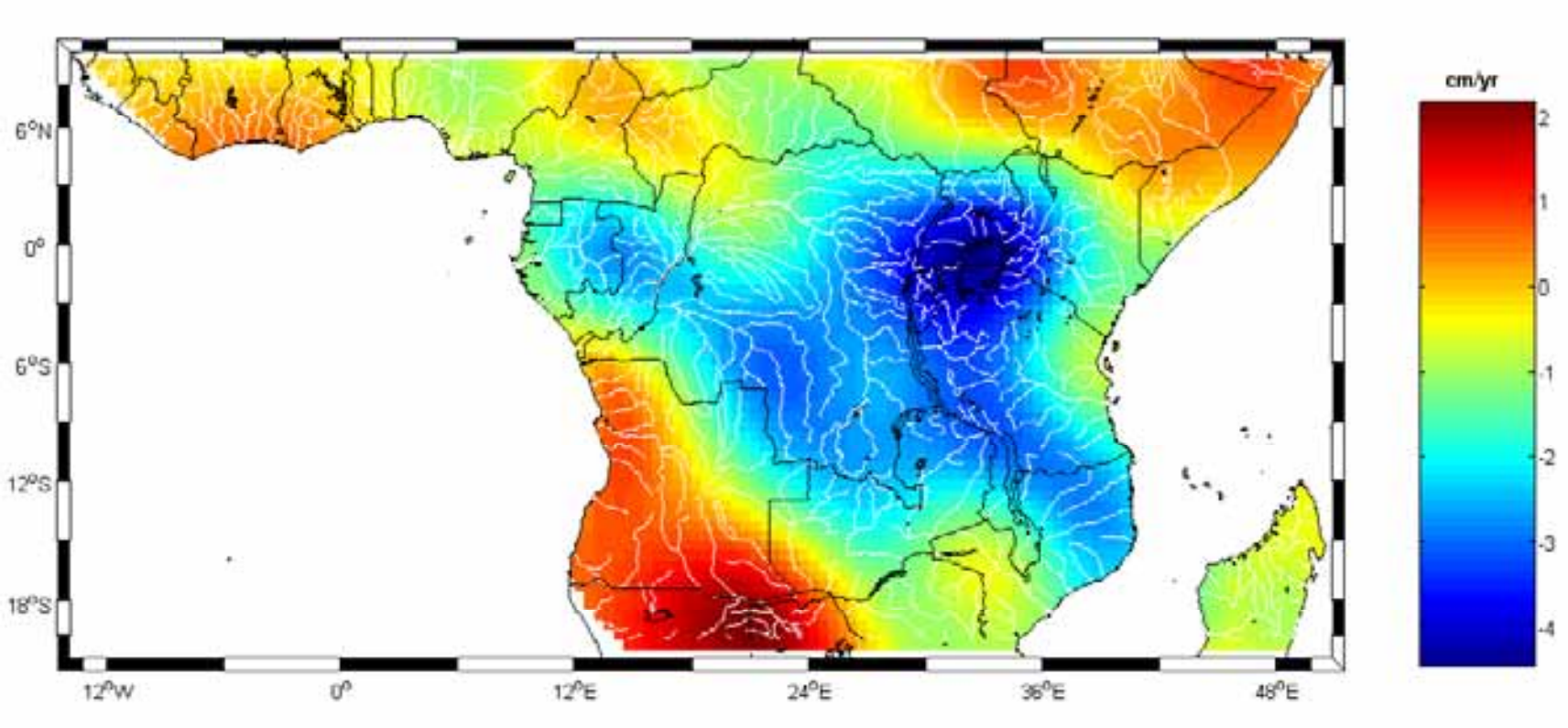
Volume d'eau total du bassin de l'Amazone (km³)



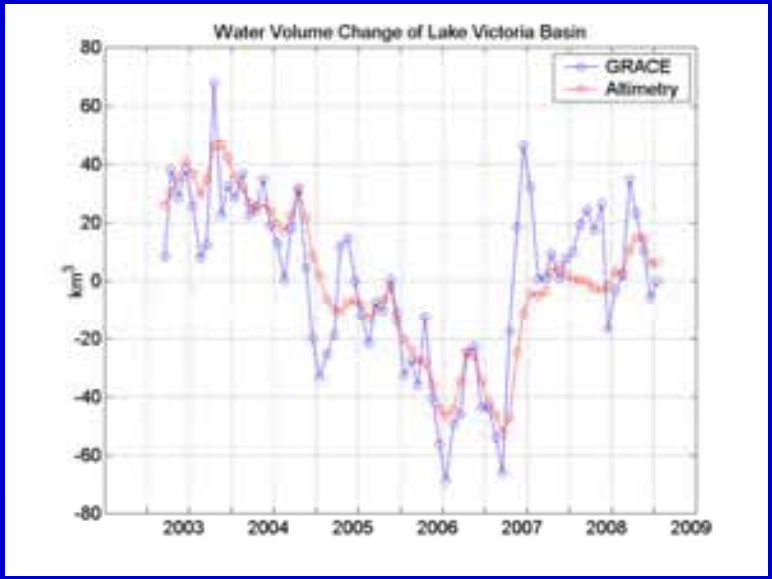
Volume d'eau total du bassin du Gange (km³)

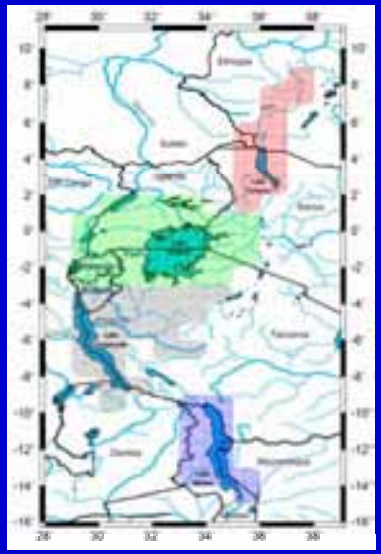


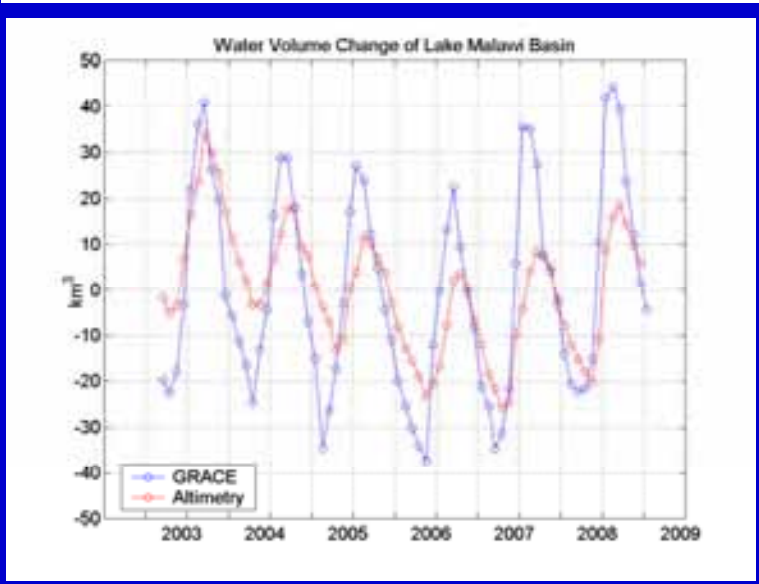
Land water storage change (trend map) from GRACE 2002-2008

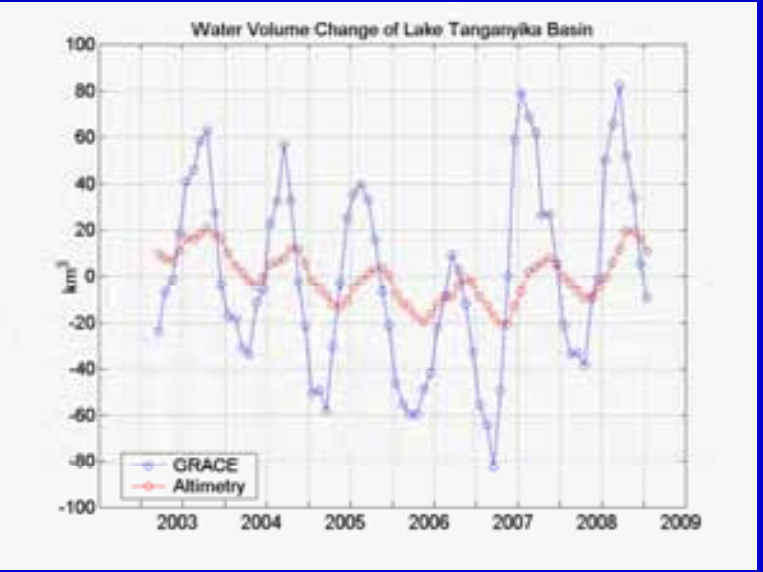


Vertically-integrated water volume change from GRACE

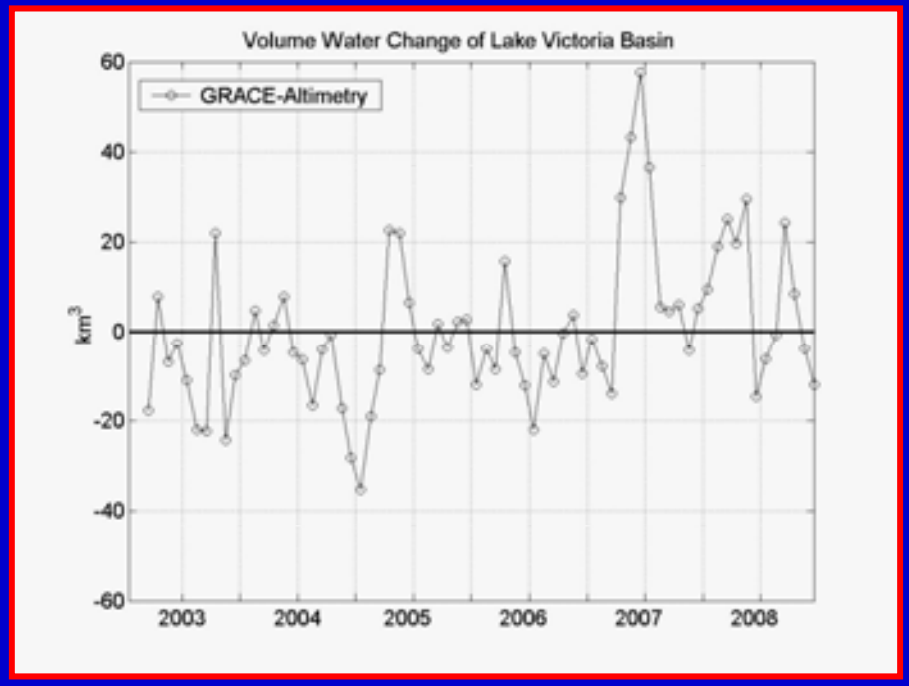


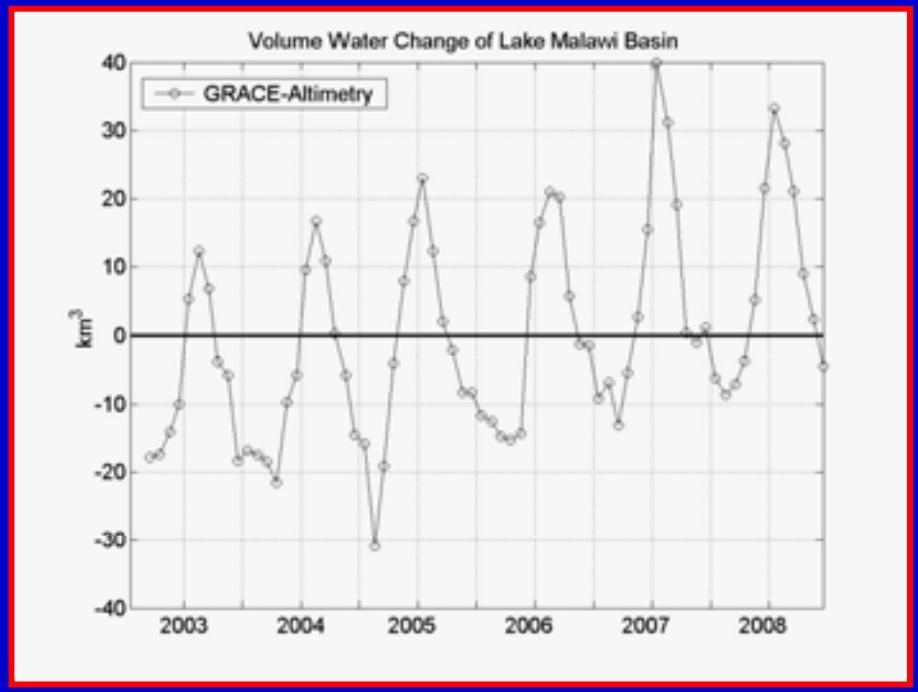




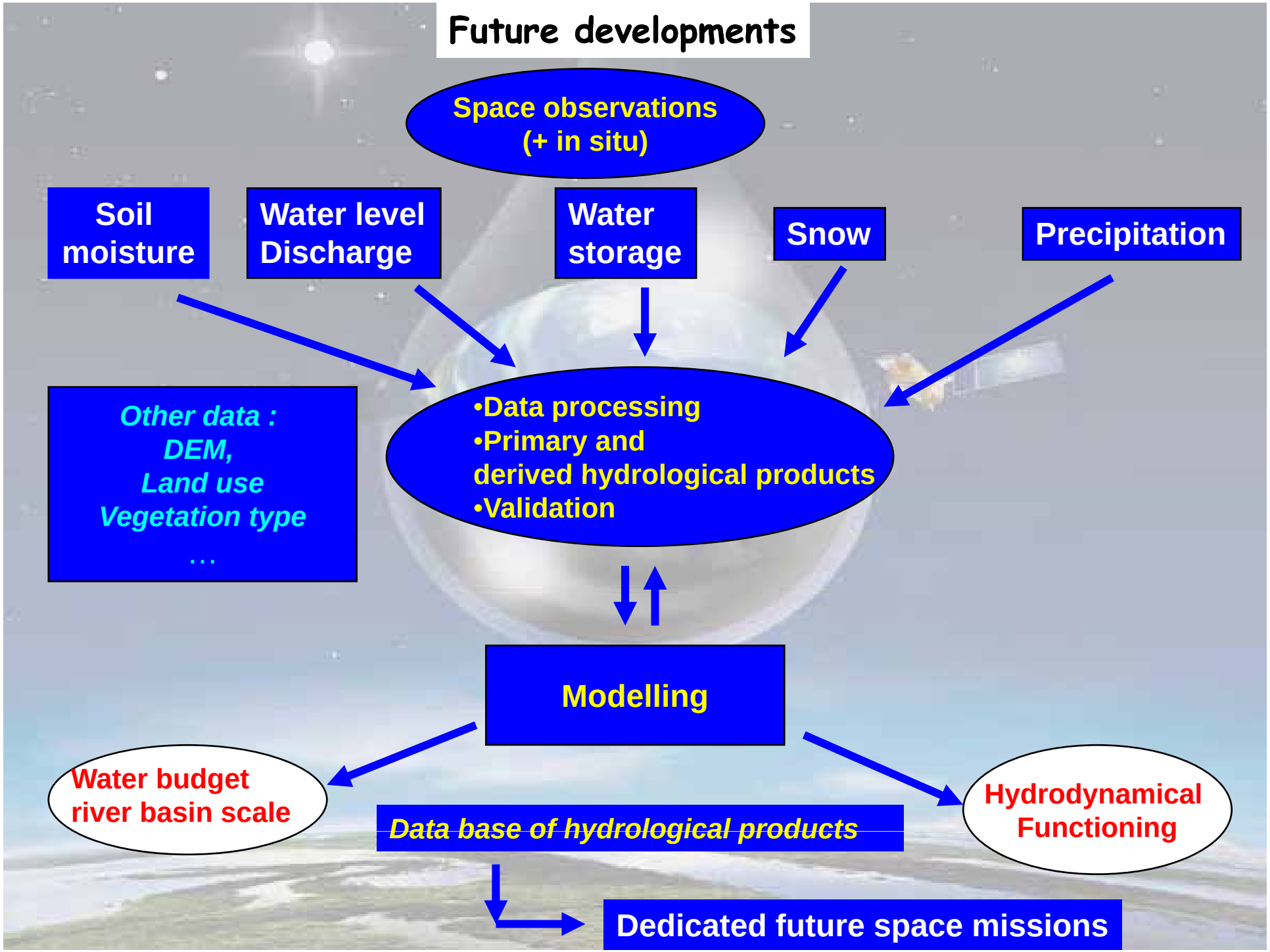


Ground waters (GRACE minus surface water volume)

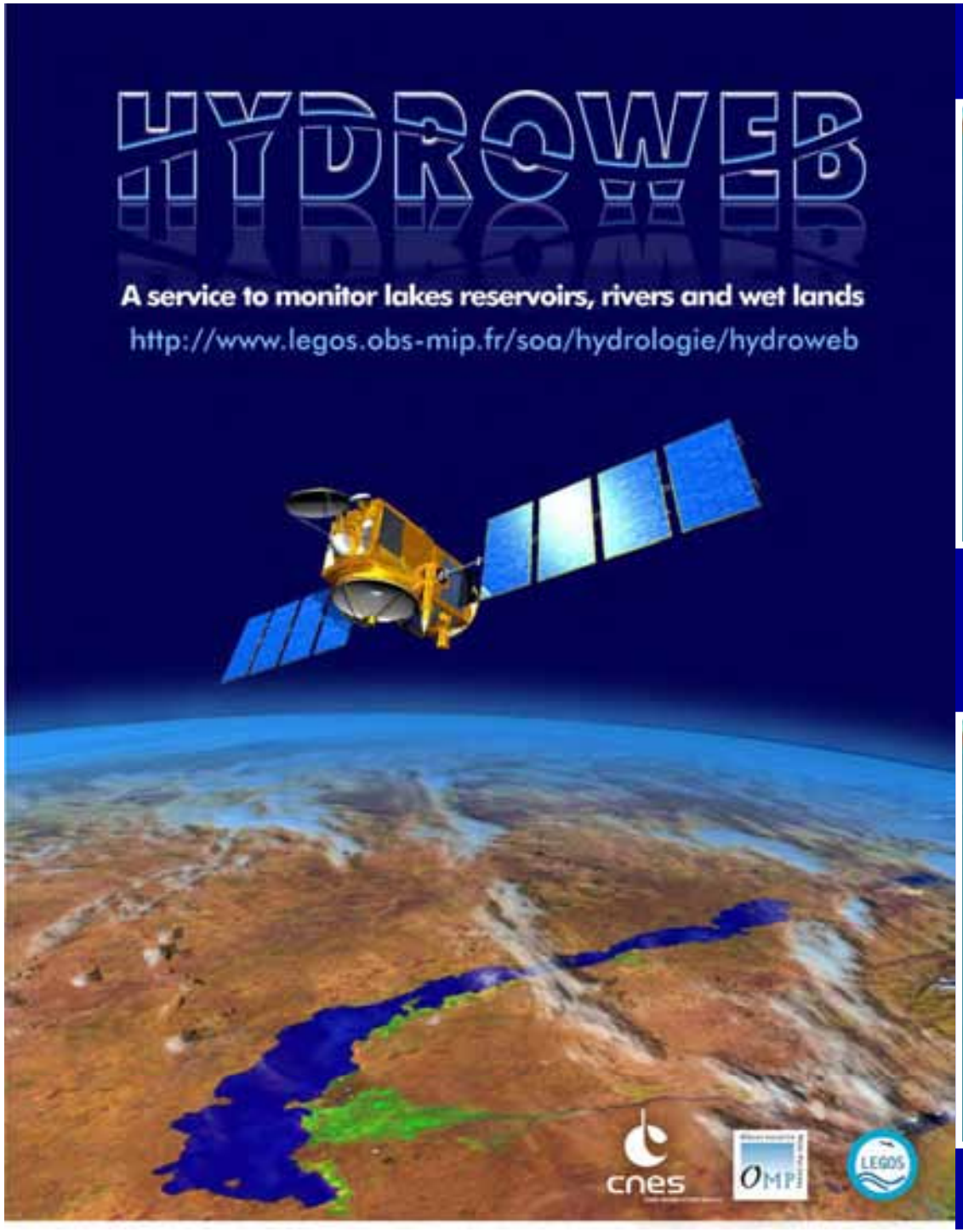




Future developments




End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