

Ecole d'Eté 2014

Altimétrie spatiale

Sea level variations at climatic time scales: observations & causes

Benoit Meyssignac

Ccnes

IGN

robservatoire CIIS

🕼 Observatoire 🍓 🛲 业 le cnam 🗐

Ecole d'Eté 2014, Saint-Pierre d'Oléron, 1-5 septembre 2014



Physical processes which generate variability in sea level

Time scale



Physical processes which generate variability in sea level

Time scale



Physical processes which generate variability in sea level

Time scale

Outline

- What do we mean by « sea level » (What is in the sea level signal?)
- **Observed sea level variations over the last 20 000yr** (Is sea level rise accelarating? Is the current sea level rise unusual?)
- Causes of the sea level variations at climatic time scales (can we explain the present sea level rise and close the sea level budget?)

•Future sea level rise

(What will be the future sea level in 2100?, what is the associated uncertainty?)

Outline

- What do we mean by « sea level » (What is in the sea level signal?)
- **Observed sea level variations over the last 20 000yr** (Is sea level rise accelarating? Is the current sea level rise unusual?)
- Causes of the sea level variations at climatic time scales (can we explain the present sea level rise and close the sea level budget?)

•Future sea level rise

(What will be the future sea level in 2100?, what is the associated uncertainty?)

What do we mean by sea level?

absolute sea level and relative sea level



relative SSH = absolute SSH - absolute LSH

International Terrestrial Reference System:



International Terrestrial Reference Frame uncertainty:



Sea level trend generated by an uncertainty in the ITRF geocenter of (-1.5,-2.2,-2.1) mm/yr between 2000 and 2006 (ITRF2000 – IGS ppp). 0.4 mm/yr in GMSL

What is in the sea level signal? SSH = geoid+MDT+SLA



What is in the sea level signal: SSH-geoid = MDT+SLA



01/1993

Sea level anomaly from satellite altimetry over 1993-2010



Outline

- What do we mean by « sea level » (What is in the sea level signal?)
- **Observed sea level variations over the last 20 000yr** (Is sea level rise accelarating? Is the current sea level rise unusual?)
- Causes of the sea level variations at climatic time scales (can we explain the present sea level rise and close the level budget?)

•Future sea level rise

(What will be the future sea level in 2100?, what is the associated uncertainty?)

Global mean sea level rise since the Last Glacial Maximum (- 20 000 years)





Sea level evolution during the past 6000 years

From Lambeck et al., 2010

Evolution of the mean sea level over the last 2000 years



Kemp et al. (2011)

Instrumental era (since mid/late-19th century)



Global mean sea level (20th century) from tide gauge records



Rate of sea level rise (20th century) : 1.8 +/- 0.3 mm/yr

Sea level change now measured by satellites



Global coverage of the Earth in a few days





Topex-Poseidon(1992-2006) GFO (1998-2008) Jason-1 (2001-2013) Jason-2 (2008) ERS-1/2 (1991-2000/1995-2011) Envisat (2002-2012) Cryosat(2010) HY2A(2011) Saral-Altika(2013)

Current sea surface height accuracy : 1cm-2 cm for a single measurement

High-precision satellite altimetry

Global Mean Sea Level Rise measured by altimeter satellites since 1993



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	0.44
Tide gauge calibration (Micthum and Nerem; Beckley et al.; Ablain et al.)	0.4

Regional sea level: Sea level does not rise uniformly!

Sea level trend patterns from satellite altimetry (1993-2012)



Summary of the Global mean sea level evolution



Outline

- What do we mean by « sea level » (What is in the sea level signal?)
- **Observed sea level variations over the last 20 000yr** (Is sea level rise accelarating? Is the current sea level rise unusual?)
- Causes of the sea level variations at climatic time scales (can we explain the present sea level rise and close the level budget?)

•Future sea level rise

(What will be the future sea level in 2100?, what is the associated uncertainty?)

Can we explain the observed sea level rise?

Climatic contributions to the global mean sea level (1993-2012)



Ocean temperature measurements (XBT, CTD, Argo)



Past few decades: coverage mainly along commercial roads







Upper ocean thermal expansion (0-700 m) 1950-2009



Deep ocean warming \rightarrow contribution poorly known but estimated to ~ 20%



***: including the deep ocean contribution

Can we explain the observed sea level rise?

Climatic contributions to the global mean sea level (1993-2012)



Contribution of glacier melting to sea level rise

Image SPOT 5 du massif du Mont Blanc









Contribution of glacier melting to sea level rise



Annual Ice mass loss by glacier melting (Gt/year)

Glacier contribution to sea level rise: (1993-2010): 1. +/- 0.2 mm/yr (2005-2010) : 1. +/- 0.15 mm/yr

Can we explain the observed sea level rise?

Climatic contributions to the global mean sea level (1993-2012)



Ice sheet mass balance measured by remote sensing over the last 2 decades



Contribution of ice sheets to sea level rise

Annual ice mass loss (Gt/yr) over 1993-2010



Greenland + Antarctica contributions: (1993-2010) → 0.6 +/- 0.2 mm/yr (2005-2010) → 1. +/- 0.15 mm/yr


Global Mean Sea Level Rise measured by altimeter satellites since 1993



Global Mean Sea Level Rise measured by altimeter satellites since 1993



Regional sea level: Sea level does not rise uniformly! Sea level trend patterns from satellite altimetry (1993-2012)



Regional variability of the rates of sea level change over 1993-2012 (global mean rise removed)



Observed sea level by satellite altimetry

Observed thermal expansion + salinity changes Another source of regional variability in sea level rise →large-scale water mass redistribution due to land ice melt deforms ocean basins because the Earth mantle is viscous and the crust is elastic



Effects of Greenland and Antarctica mass loss on present-day sea level measurements



from Tamisiea and Mitrovica 2011

Regional variability of the rates of sea level change over 1993-2012 (global mean rise removed)



Observed sea level by satellite altimetry

Observed thermal expansion + salinity changes

Regional variability of the rates of sea level change (global mean rise removed)



Observed sea level by satellite altimetry

Reconstructed sea level With Tide gauges, satellite altimetry and OGCMs Summary on sea level rise over the last 20 years

•Present sea level rise is due to thermal expansion of the ocean + land ice melt

•The interannual variability in sea level is essentially due to land water storage in response to the main climate modes of variability

• The regional variability in sea level rise is essentially due to the redistribution of heat and salt in the ocean by the circulation Key questions about global sea level rise

•Is present sea level rise linked to anthropogenic green-house gazes emissions?

<complex-block>



Terre



Canonical Climate Forcing +2% S₀ or $2xCO_2$ Case 1. Black Body \rightarrow + 1.2°C

Case 2. Fast Feedbacks \rightarrow + 3°C H₂O, Sea Ice, Clouds, Aerosols

Case 3. Fast Feedbacks + Slow Surface Changes → + 6°C Ice Sheets, Vegetation



Energy Budget of the Earth from data



Energy Budget of the Earth

Thermal expansion of the ocean



Energy Budget of the Earth

Glaciers ice melt



Ice sheet mass balance =

surface mass balance (accumulation/ablation) + ice loss through calving of icebergs (dynamical change)



Summary on global sea level rise

•Sea level is rising fast compared to previous 3000yr

•Similar or higher rates already occurs in the past (14000 yrs ago) but for different reasons

•Present sea level rise is due to thermal expansion of the ocean + land ice melt

• The ocean warming and glaciers ice melt are linked to the anthropogenic GHG emissions

Outline

- What do we mean by « sea level » (What is in the sea level signal?)
- **Observed sea level variations over the last 20 000yr** (Is sea level rise accelarating? Is the current sea level rise unusual?)
- Causes of the sea level variations at climatic time scales (can we explain the present sea level rise and close the level budget?)
- •Future sea level rise
- (What will be the future sea level in 2100?, what is the associated uncertainty?)

Greenhouse Gas Emissions



→ Representative Concentration Pathways (RCPs)

 \rightarrow 4 RCP scenarios defined by their total radiative forcing by 2100:

RCP2.6 (2.6 Wm⁻²) RCP4.5 (4.5 Wm⁻²) RCP6.0 (6.0 Wm⁻²) RCP8.5 (8.5 Wm⁻²)

Radiative forcing : an energy imbalance imposed on the climate system either externally or by human activities; ususally reported as a change in energy flux at the top of the atmosphere and expressed in units of watts per square meters (Wm⁻²) 4 scenarios for future greenhouse gas emissions considered by IPCC AR5 for the 21st century



Earth surface mean temperature projections



From IPCC AR5,2013

Projections in future sea level rise:

•Will sea level continue to rise in the future?

•Can we estimate the future global and regional? sea level rise?

Depends on many still poorly known processes, e.g.:

-Deep ocean heat uptake

-Future land water changes due to human activities (e.g., ground water pumping)

-Future dynamical behaviour of the ice sheets

Global mean sea level projections



Global mean sea level evolution



Key question: Can we predict the future total 'relative' sea level rise at any location?

i.e., the global mean sea level rise?

the climate-related regional variability (due to ocean warming and freshening of sea waters)?

÷,

÷

regional variations caused by deformation of ocean
basins in response to ice mass redistribution
(due to Last Deglaciation & future land ice melt)?

Local vertical motions of the ground (subsidence or uplift)?

Regional variability in relative sea level in 2080-2100 (*RCP 4.5***)**





From IPCC AR5,2013

Regional variability in relative sea level and uncertainty (rcp 4.5)



Regional variability in relative sea level in 2080-2100



From IPCC AR5,2013

Long-term climate change

Many aspects of climate change will persist for many centuries even if emissions of greenhouse gases are stopped!

- 20% of emitted CO₂ will remain in the atmosphere more than 1000 years
- Sea level will continue to rise for mainy centuries in response to deep ocean warming and associated thermal expansion
 - Ice sheet mass loss may become irreversible (Greenland)
 → sustained warming above a certain threshold (1°C-4°C) may lead to near-complete loss of the Greenland ice sheet over a time scale of 1000 years (→ 7 m of sea level rise)

Conclusions

- Current global mean sea level rise is likely accelerating
- The sea level budget (altimetry era) almost closed
- Global mean sea level rise: very likely a consequence of anthropogenic global warming
- Regional variability (spatial trend patterns) :due to heat redistribution still dominated by natural (internal) modes of climate variability
- The global mean sea level will continue to rise during the 21st century in response to global warming (values by 2100 in the range 50 cm-1 m NOT unlikely)
- The regional variability will amplify the global mean rise by 30%-40% in the tropics
- Even if GHG emissions stop tomorrow, sea level will continue to rise during several centuries

Great challenges for the coming years

- Insure continuity of in situ and space-based observations of all components of the climate system
- Improve sea level estimates and projections from climate models at regional & local scales, integrating climate change processes & non climatic factors (e.g., solid Earth processes, human-related changes in hydrology)
- Evaluate coastal vulnerability and adapt according to LOCAL PROJECTIONS of future sea level rise

Thanks for your attention


Extra slides





Post Glacial Rebound







Vertical crustal motions can amplify the climate-related sea level rise (if the ground is subsiding)



What counts is the TOTAL 'relative' sea level !!!