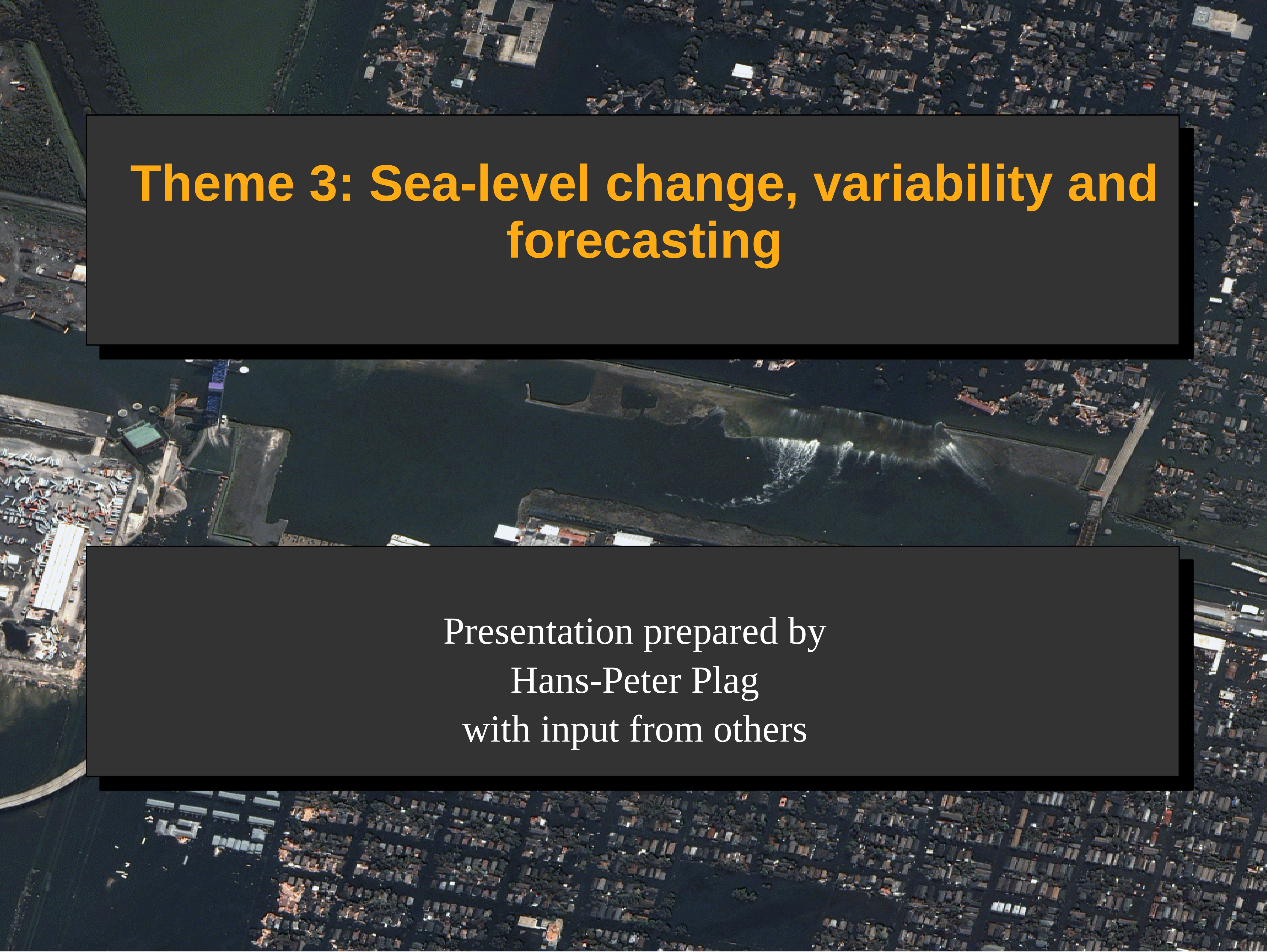
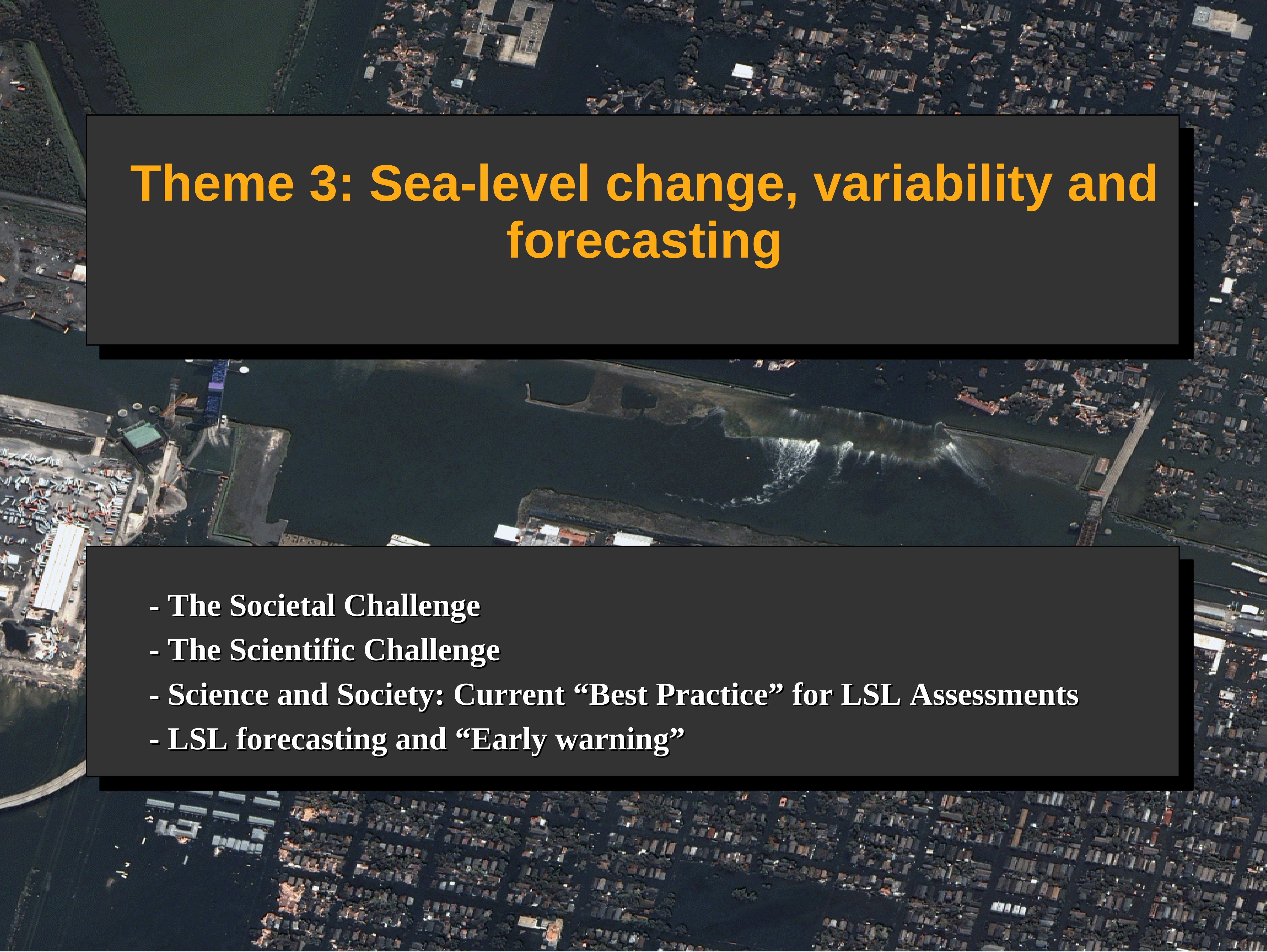


Theme 3: Sea-level change, variability and forecasting

Presentation prepared by
Hans-Peter Plag
with input from others



Theme 3: Sea-level change, variability and forecasting

- The Societal Challenge
- The Scientific Challenge
- Science and Society: Current "Best Practice" for LSL Assessments
- LSL forecasting and "Early warning"

Consider the following scenario:

Several cities/regions are hit by major earthquakes (Magnitude >8) in the **SAME** year:

- Seattle/Vancouver,
- San Francisco
- Los Angeles
- Sumatra
- Jakarta
- Tokyo
- Istanbul
- Mexico City
- ...

Devastation would be enormous

Economic impact would be global

Response/rescue would be very limited

Recovery would be very difficult

Now consider this scenario:

Sea level becomes unstable and global sea level rises several meters (order 2 to 3 m) within a few decades:

The consequences would be enormous:

- several cities will be flooded; other would be hit by major storm surges within one to two years:
  - Rotterdam/Netherlands
  - Hamburg
  - New York
  - San Francisco
  - Shanghai
  - ...

Today, with a sea level rise of 2-3 mm/yr, we see the potential impact of sea level rise combined with extremes in many places ...

The UN Development Program, 2008:

332 million People live in low-lying coastal zones

Damage caused by a single disaster could exceed $100 billion

World Bank, 2008:

*** 1 m of sea level rise = 2% of GDP in East Asia**

*** ten megacities are threatened, one or two hit by a major hurricane could trigger global economic crisis**

The Societal Challenges:

- **Significant sea level rise would trigger extreme disasters;**
- **There is trade-off between the costs for adaptation today and disasters tomorrow;**
- **Coastal Defense is very expensive and there is a risk of overspending;**
- **Adaptation may require relocation of settlements and infrastructure (airports, highways, pipelines, ...)**

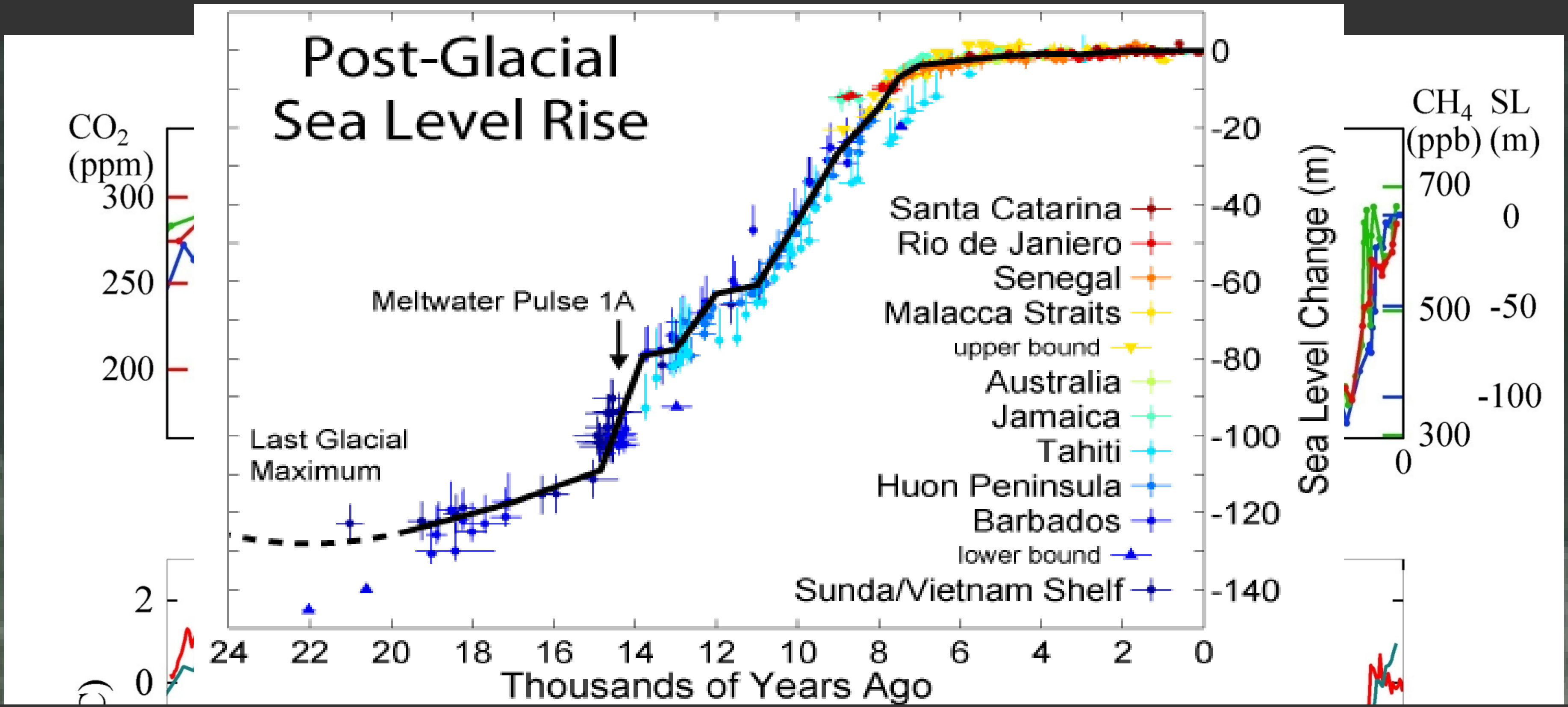
Is this scenario of ~2 m sea level rise within a few decades realistic?

Comparable to the impact of a large meteorite: unlikely but can not be excluded?

“Sea-level hazard” is one of many hazards challenging society:

- includes waves/currents/tides, storm surges, tsunamis, saltification;

- is modified by (slow) changes of mean Local Sea Level (LSL).



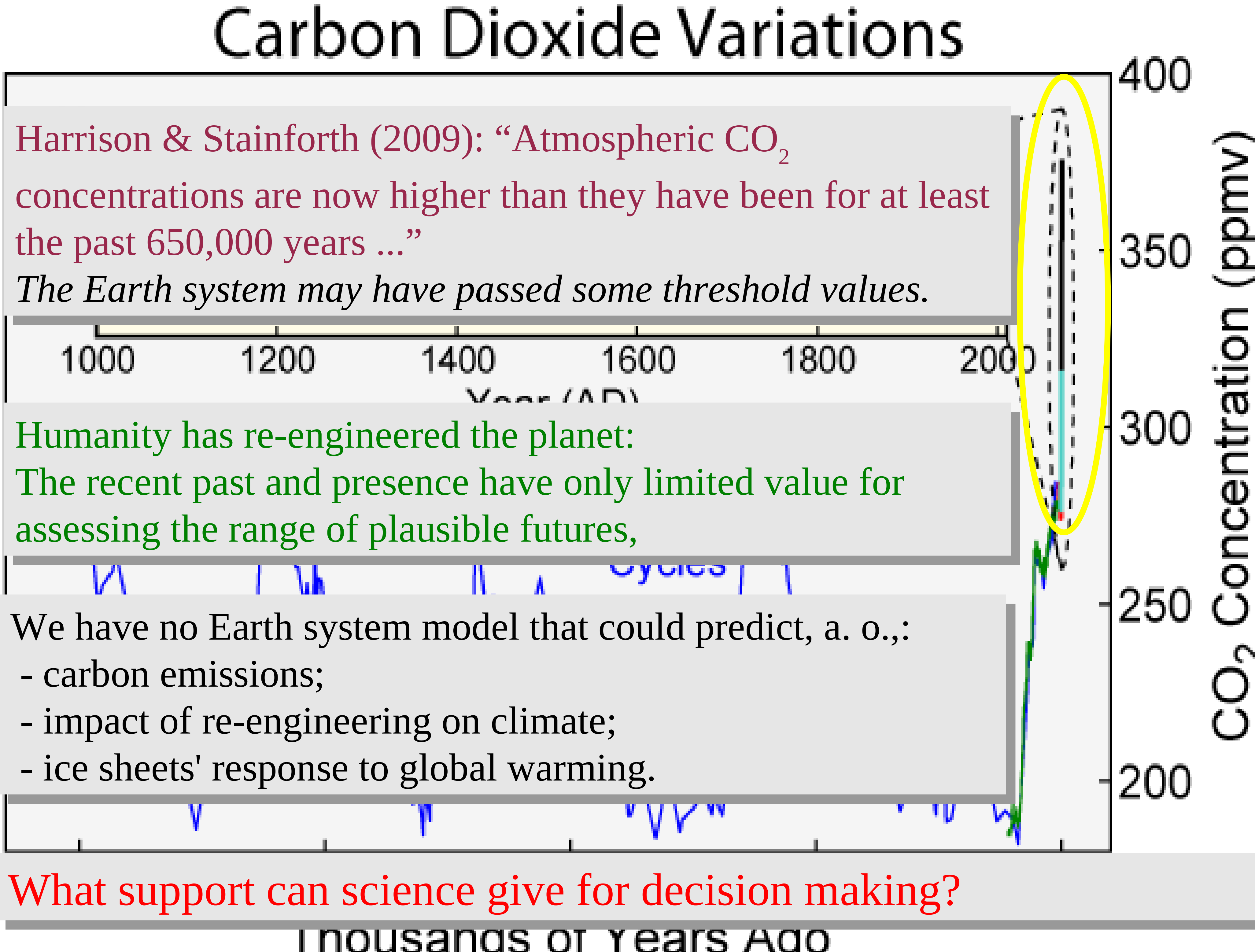
Paleo-records of global sea level

- demonstrate large changes: roughly 2 m/century during warming and peak rates of 4-5 m/century;
- about 8,000 years ago, sea level became very stable;
- humans could settle in the coastal zone and benefit from the many advantages of this location;
- this stable phase made us believe that ‘sea level doesn’t change very much.’

Traditional science has modeled the world based on the assumption that change is incremental and predictable (Walker and Salt, 2006).

In resilience thinking, the concept of threshold values makes room for the system to rapidly move to a new state, if a threshold is exceeded.

Based on the paleo-record of sea level changes, we cannot exclude that sea level becomes unstable if a (unknown) threshold is exceeded.



Harrison & Stainforth (2009): “Atmospheric CO_2 concentrations are now higher than they have been for at least the past 650,000 years ...”

The Earth system may have passed some threshold values.

Humanity has re-engineered the planet:
The recent past and presence have only limited value for assessing the range of plausible futures,

We have no Earth system model that could predict, a. o.,:

- carbon emissions;
- impact of re-engineering on climate;
- ice sheets' response to global warming.

What support can science give for decision making?

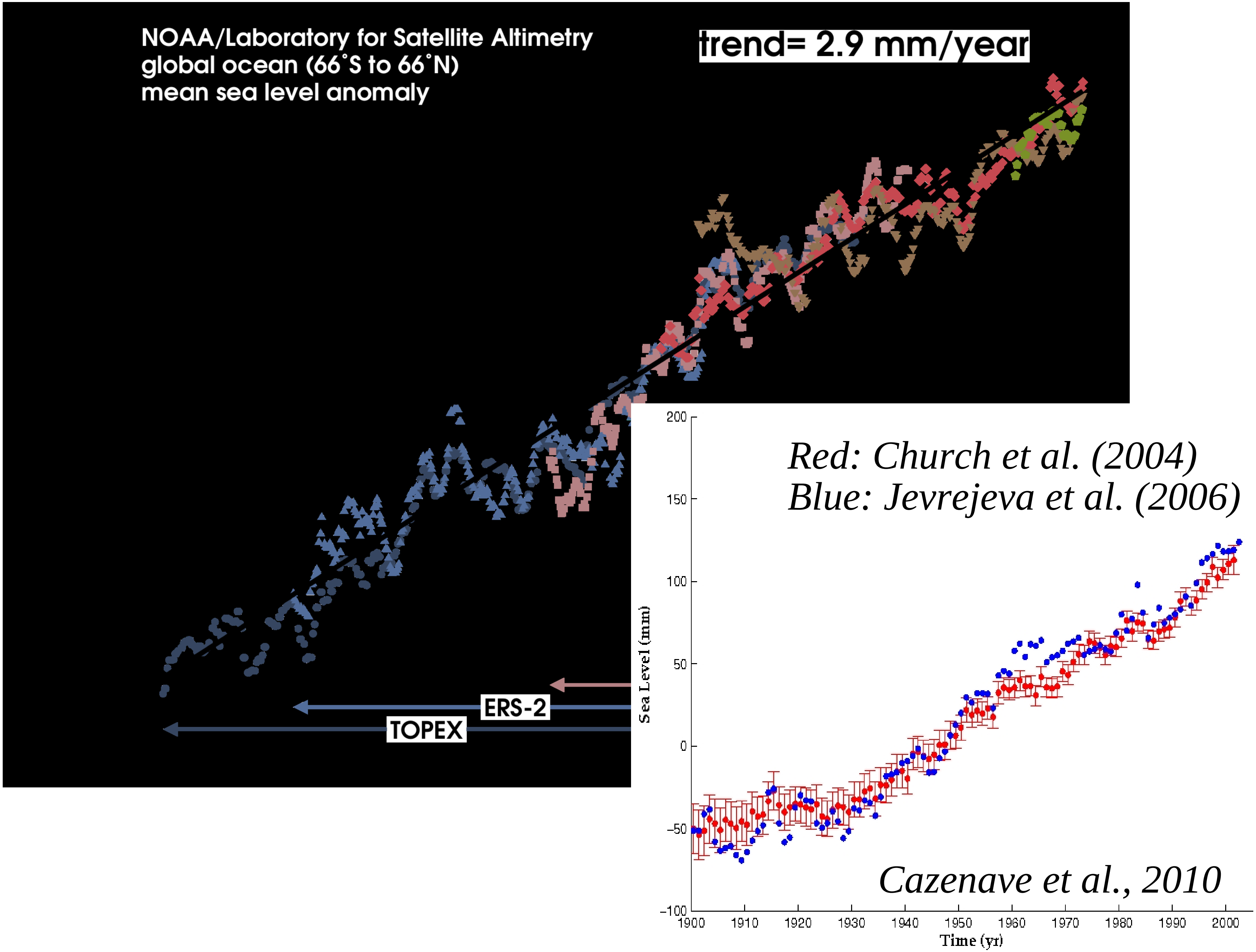
What do policy and decision makers ask science for?

- Local sea level (LSL) rise projections for the next 100 to 200 years, particularly high end;
- reliable uncertainties;
- full range of “plausible LSL trajectories” with probability density function (PDF);

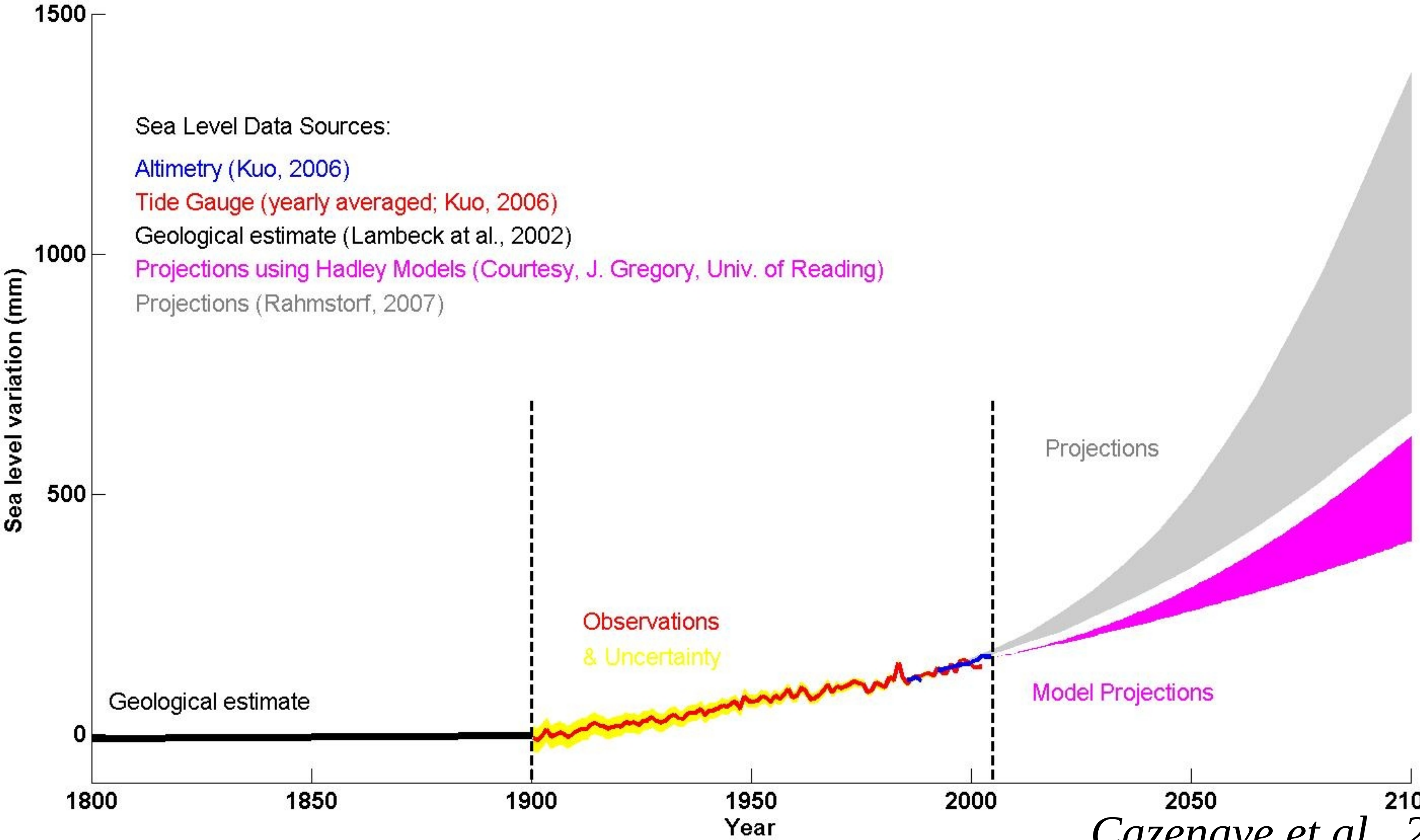
Global sea level:

- of interest for science
- of interest for climate change and water cycle studies
- less important for practical applications and adaptation, due to large spatial variations in LSL

Global Sea Level Projections



Global Sea Level Projections



Cazenave et al., 2010

Local Sea Level (LSL): vertical distance between sea surface and land surface.

LSL = high-frequency part + low-frequency part

High-frequency LSL variations are the <u>result of local and regional processes, including waves, tides, storm surges, seiches, tsunamis, earthquakes, ...</u>

Local Sea Level (LSL): vertical distance between sea surface and land surface.

LSL = high-frequency part + low-frequency part

Low-frequency LSL variations are the result of local, regional, and global processes including temperature and salinity changes, circulation in ocean and atmosphere, past and present mass exchange with cryosphere and terrestrial water storage, geodynamics, ...

All **mass movements on the Earth surface**:
- change the geoid (gravity field);
- displace the ocean bottom and land surface vertically;
- redistribute water mass in the oceans.

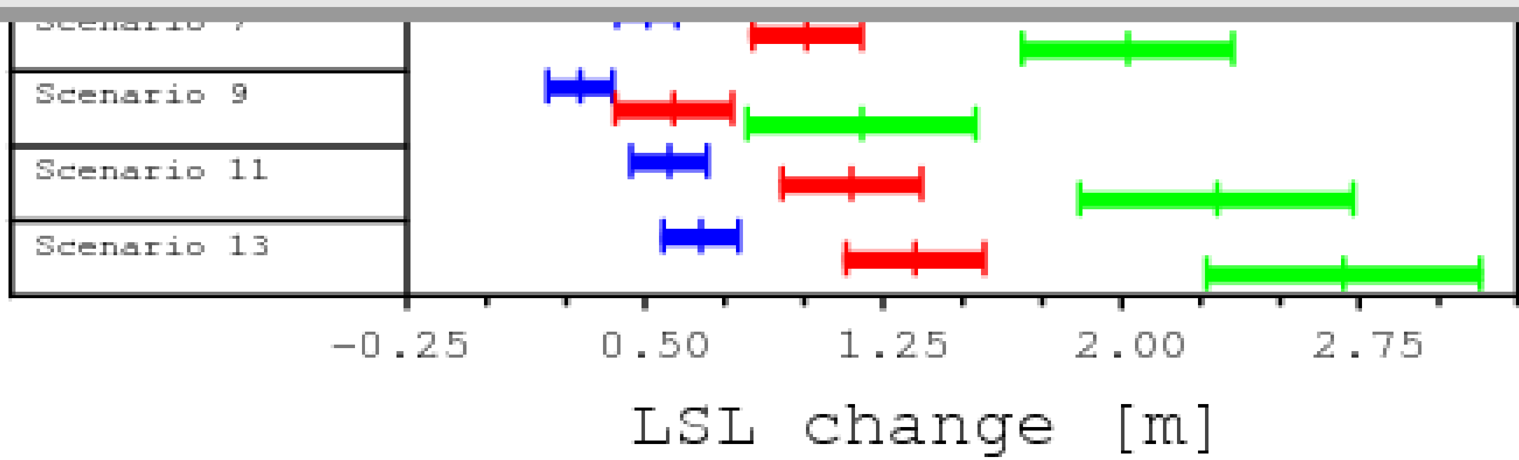
We understand the forcing processes but we have no Earth system model to predict LSL variations (both past and future LSL).

“Best Practice” for LSL Assessments:

- Local approach: sum of contributions from “most relevant” processes
- Individual treatment of terms, depending on predictability and pdf: extrapolation, model predictions, scenarios

Current Situation:

- Many assessments in the last 10 years;
- Large range of plausible trajectories of future LSL;
- Large uncertainties particularly for ice sheet contribution;
- Due to new observations/knowledge out-dated within a few years;

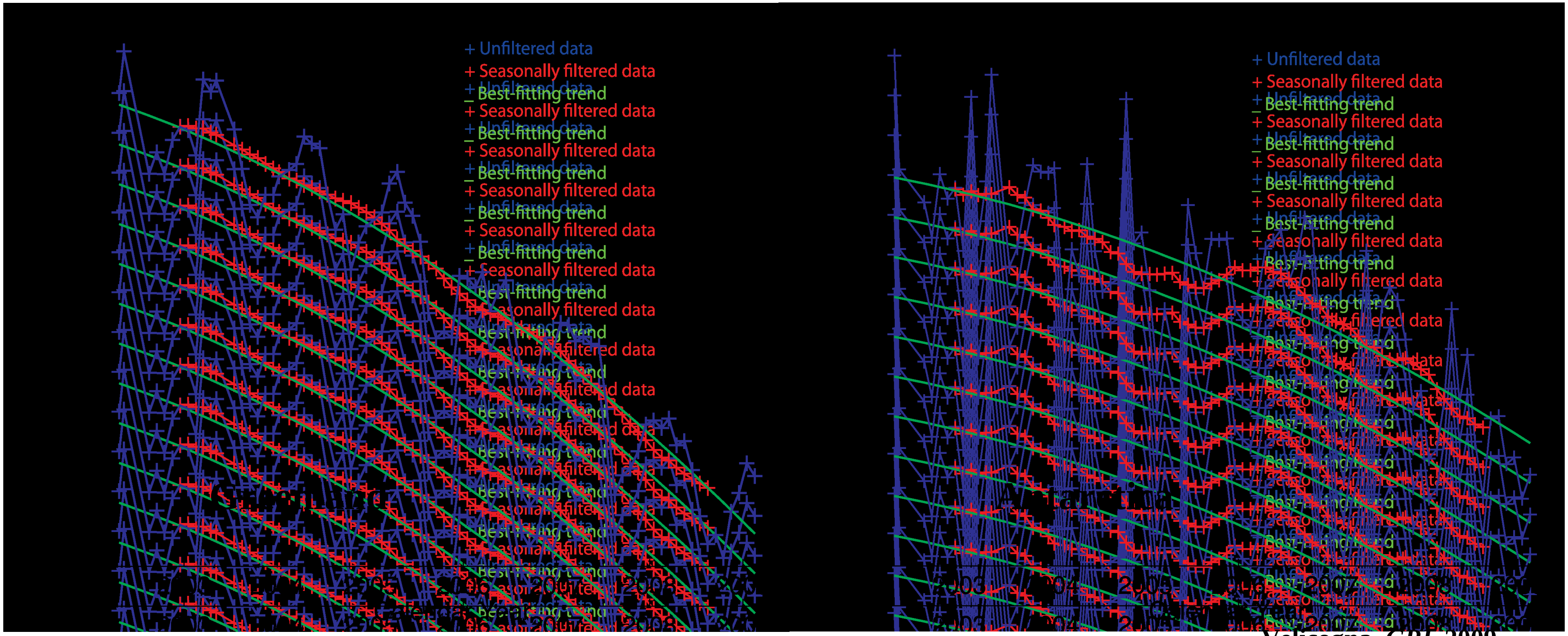


GRACE Detects Accelerated Ice Mass Loss in Greenland and Antarctica

During the period of April 2002 to February 2009 the mass loss of the polar ice sheets was not constant but increased with time, implying that the ice sheets' contribution to sea level rise was increasing.

Greenland:
- mass loss increased from 137 Gt/yr in 2002–2003 to 286 Gt/yr in 2007–2009
- acceleration of -30 ± 11 Gt/yr^2 in 2002–2009.

Antarctica:
- mass loss increased from 104 Gt/yr in 2002–2006 to 246 Gt/yr in 2006–2009
- acceleration of -26 ± 14 Gt/yr^2 in 2002–2009.



Velicogna, *GRL*,2009

We understand the forcing processes but we have no Earth system model to predict LSL variations (both past and future LSL).

"Best Practice" for LSL Assessments:

- Local approach: sum of contributions from "most relevant" processes
- Individual treatment of terms, depending on predictability and pdf: extrapolation, model predictions, scenarios

Current Situation:

- Many assessments in the last 10 years;
- Large range of plausible trajectories of future LSL;
- Large uncertainties particularly for ice sheet contribution;
- Due to new observations/knowledge out-dated within a few years;
- Message of scientists is mixed, and partly contradicting, particularly with respect to current and potential contribution of the ice sheets;
- No consensus about the upper limit for the next century or two.

Reaction of Decision Makers:

"'*We can't make multi-billon dollar decisions based on the hypothetical'* says Rohit Aggarwala, the city's director of long-term planning and sustainability." Wall Street Journal, September 11, 2009, "New York City Braces for Risk of Higher Seas"

“Best Practice” for LSL Assessments

Range of “plausible LSL Trajectories” too large to act on.

Can we reduce the uncertainties and the range of what is plausible?

An Alternative Approach

LSL rise is an “insurance problem”:

- What is the LSL rise hazard?
  * We need a global map of LSL rise hazards based on pdfs for each contributing process (location-dependent pdf of LSL rise);
  * Pdfs for contributions based on long-term paleo-record, not just model studies.

Response: How much do we want to spend on hazard monitoring, mitigation of risks and reduction of vulnerability?

- reduction of vulnerability in high risk areas (building codes, retreat) and increase of resilience (similar to e.g. seismic hazards).

Preparation for less likely, extreme LSL rise:

- Extreme LSL rise (> 1 m/century) can not be excluded;
- comparable to meteorite impact: Very unlikely but disastrous if it happens
- “Early warning” when an extreme LSL rise is likely to occur.

“Early Warning” and LSL Forecasting

Towards Forecasting of Local Sea Level Changes:
- Monitor the main reservoirs in the global water cycle;
- Develop models that can predict reservoirs on decadal time scales;
- Develop models that can relate reservoir changes to LSL;

...

Sea Level Equation

Large differences in spatial variability of different model predictions.

Elastic solution of sea level equation has not been validated!

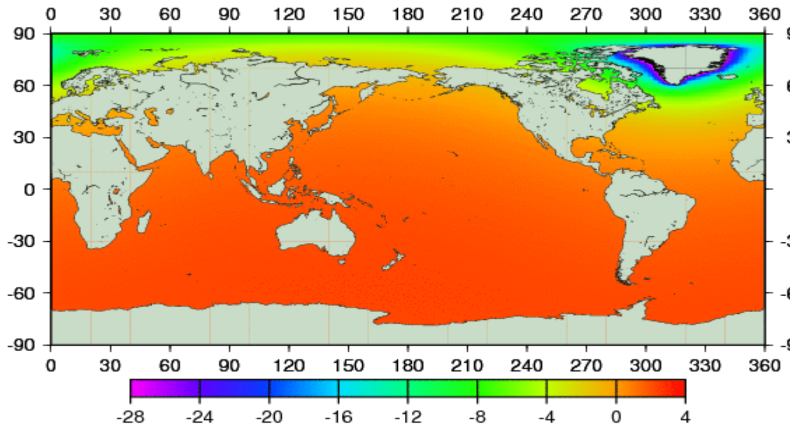
Large concurrent mass changes needed.

Kierulf et al., 2009:
- Admittance function for Svalbard on the order of 45 to 80

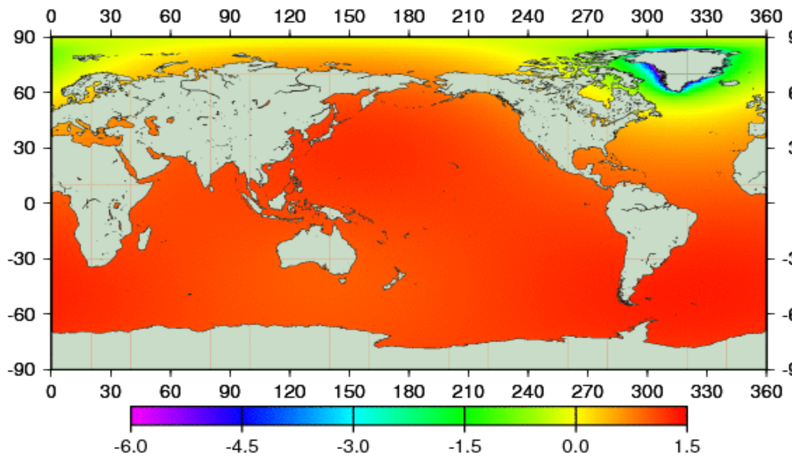
Unpublished Greenland:
- Admittance function greater 20.

Uncertainties:
- in mass change predictions;
  * total amount;
  * spatial distribution
- in admittance functions.

Plag & Juettner, 2001 Greenland



Vermeersen et al., 2008 Greenland

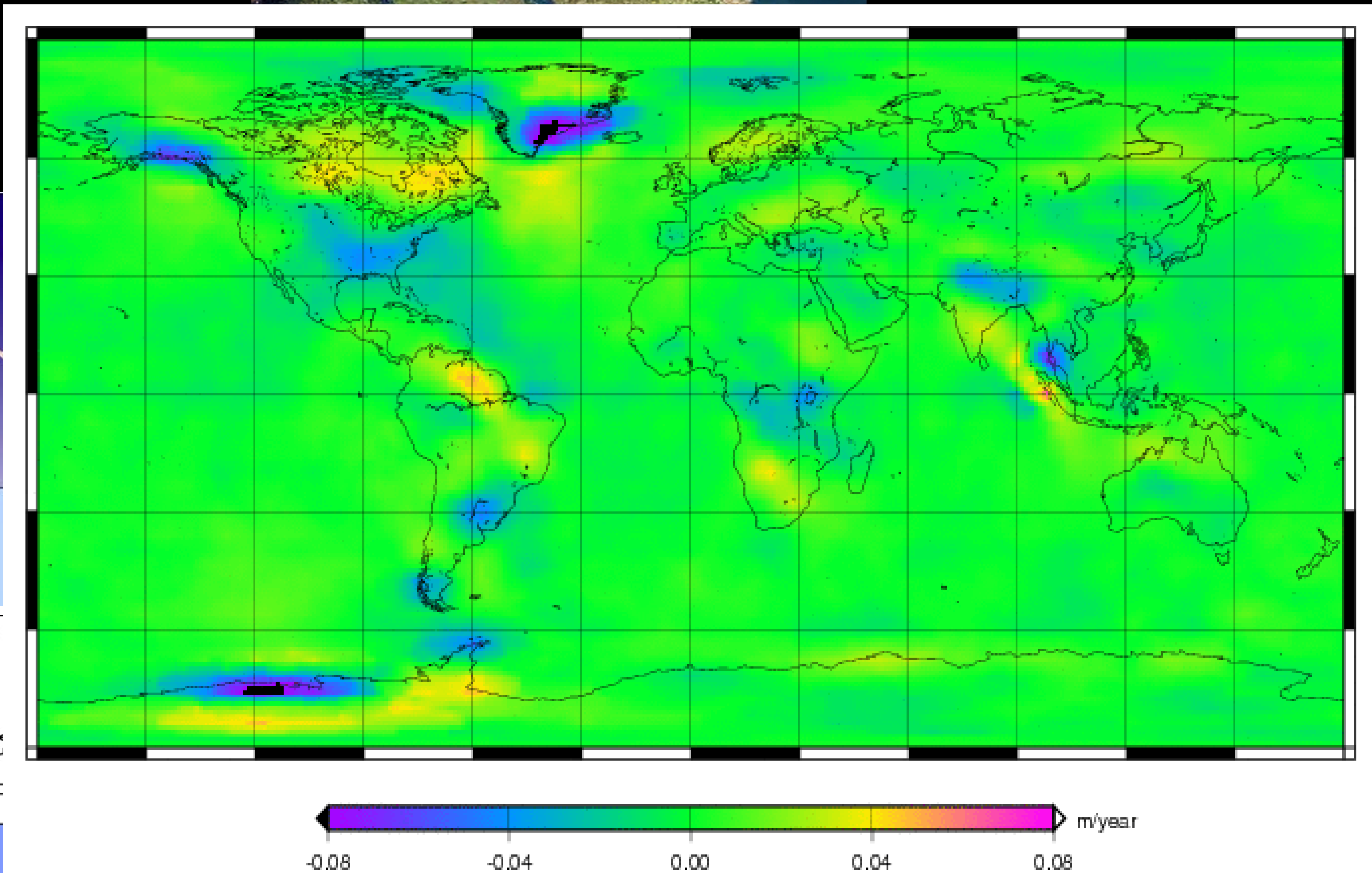


“Early Warning” and LSL Forecasting

Towards Forecasting of Local Sea Level Changes:

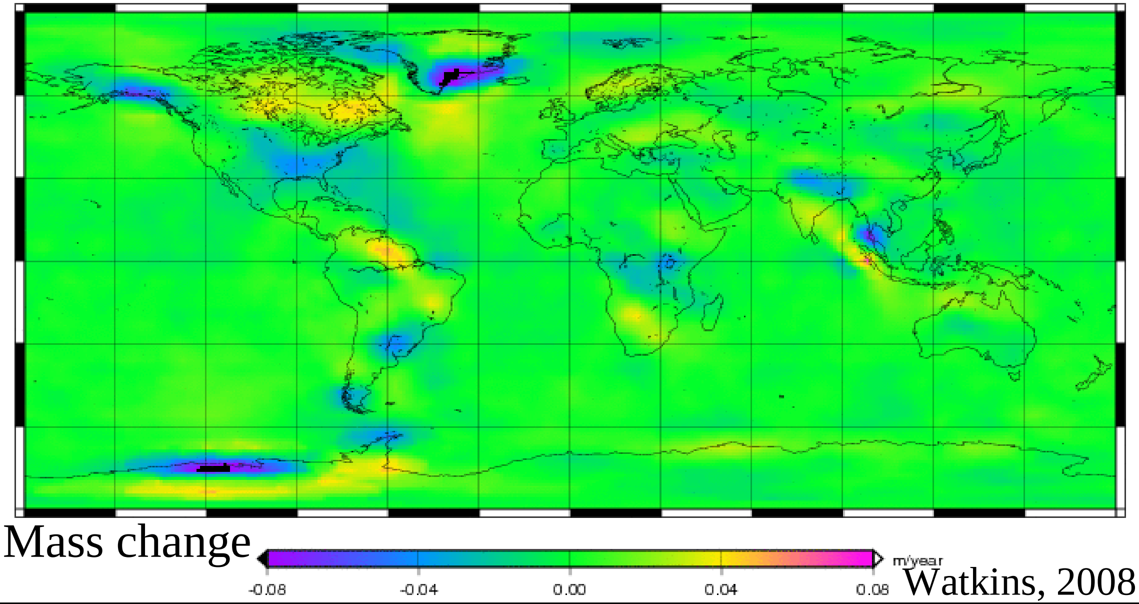
- Monitor the main reservoirs in the global water cycle;
- Develop models that can predict reservoirs on decadal time scales;
- Develop models that can relate reservoir changes to LSL;
- Aim for five to ten years and more. ...

"Early Warning" and LSL Forecasting



http://sealevel.colorado.edu/tidegauges.html

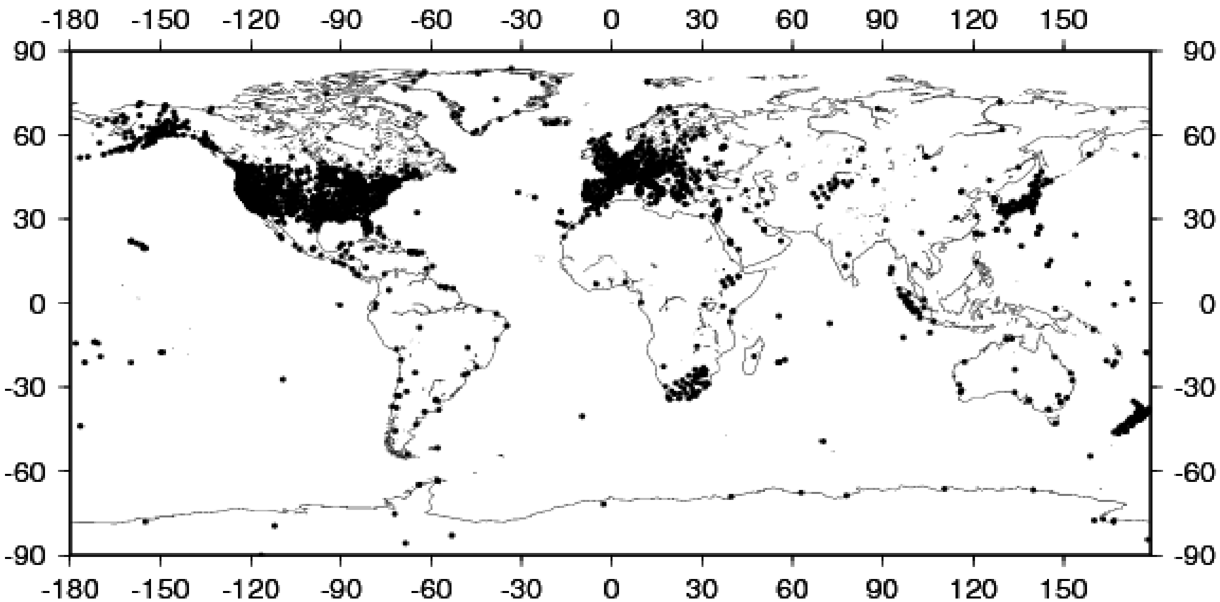
"Early Warning" and LSL Forecasting



Watkins, 2008

Spatial gaps hamper integration of gravity and displacements

GPS site locations, ~4,000 sites



Blewitt and Kreemer, 2008

"Early Warning" and LSL Forecasting

Towards Forecasting of Local Sea Level Changes:

- Monitor the main reservoirs in the global water cycle;
- Develop models that can predict reservoirs on decadal time scales;
- Develop models that can relate reservoir changes to LSL;
- aim for five to ten years and more. ...

What is needed:

- Maintain/improve the monitoring system (comparable to "Near-Earth Object Watch");
- Community effort to develop the models needed for decadal predictions (in particular, mass changes in ice sheets, ocean and atmospheric circulation, loading);
- Start forecasting as soon as possible to get a basis for the assessment of the forecasting capabilities;

What can GGOS contribute?

- Monitoring of mass redistribution and products related to changes in the water cycle.
- Support of local measurements (infrastructure, data processing, capacity building).
- Observations for validation of models.