Climate Change and Sea Level Rise: A Challenge to Science and Society

Hans-Peter Plag

Nevada Bureau of Mines and Geology & Seismological Laboratory
University of Nevada, Reno, USA.

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Climate Change and Sea Level Rise: A Challenge to Science and Society

The Societal Challenge
The Scientific Challenge
The Science of Sea Level Changes:
- The Forcing Factors for Local Sea Level Changes
- The uncertainties
- Predictability
Science support for Adaptation and Mitigation

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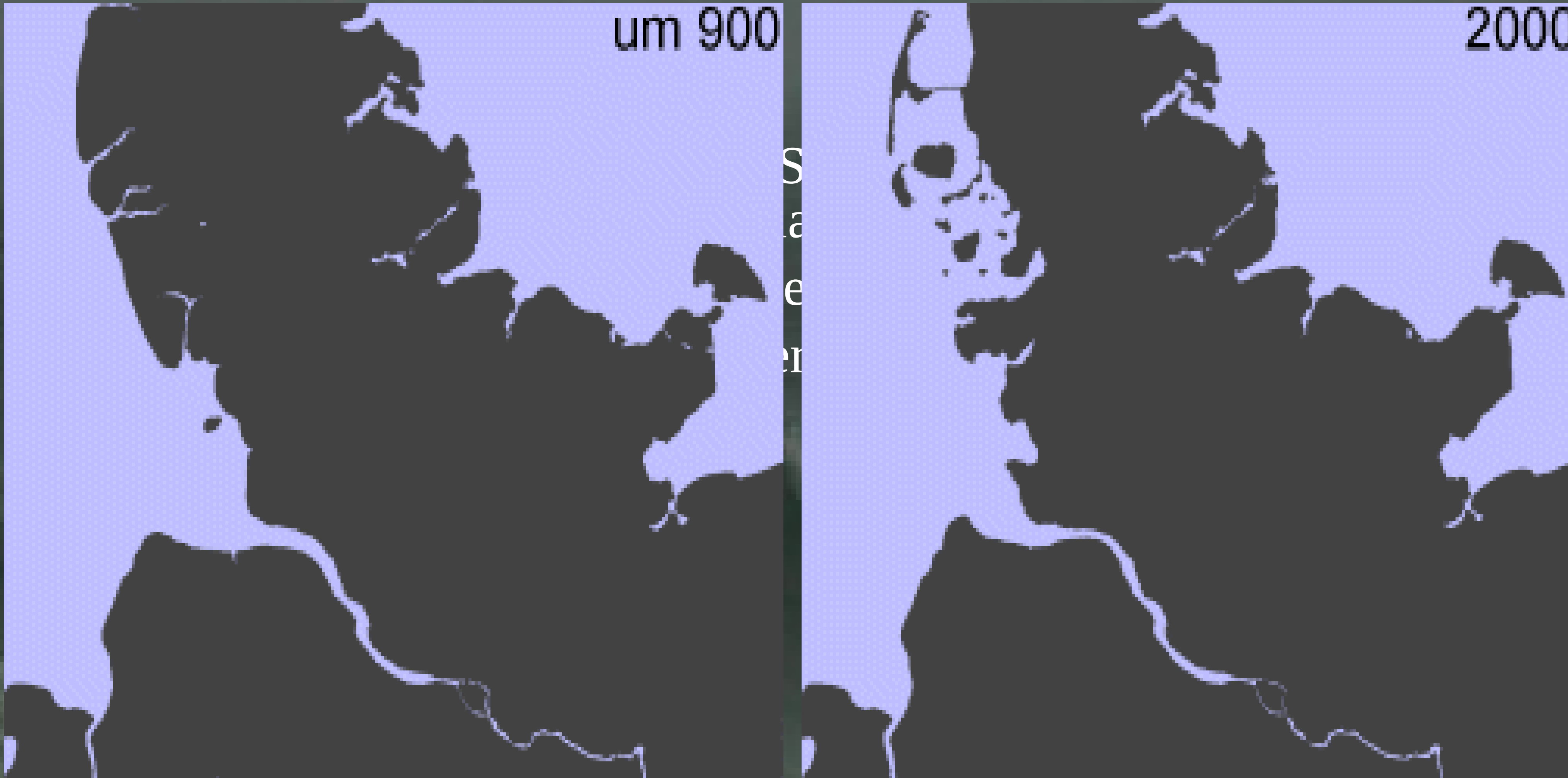


Even in times of relatively stable sea level, coast lines changed and human had to adopt and to move settlements ...

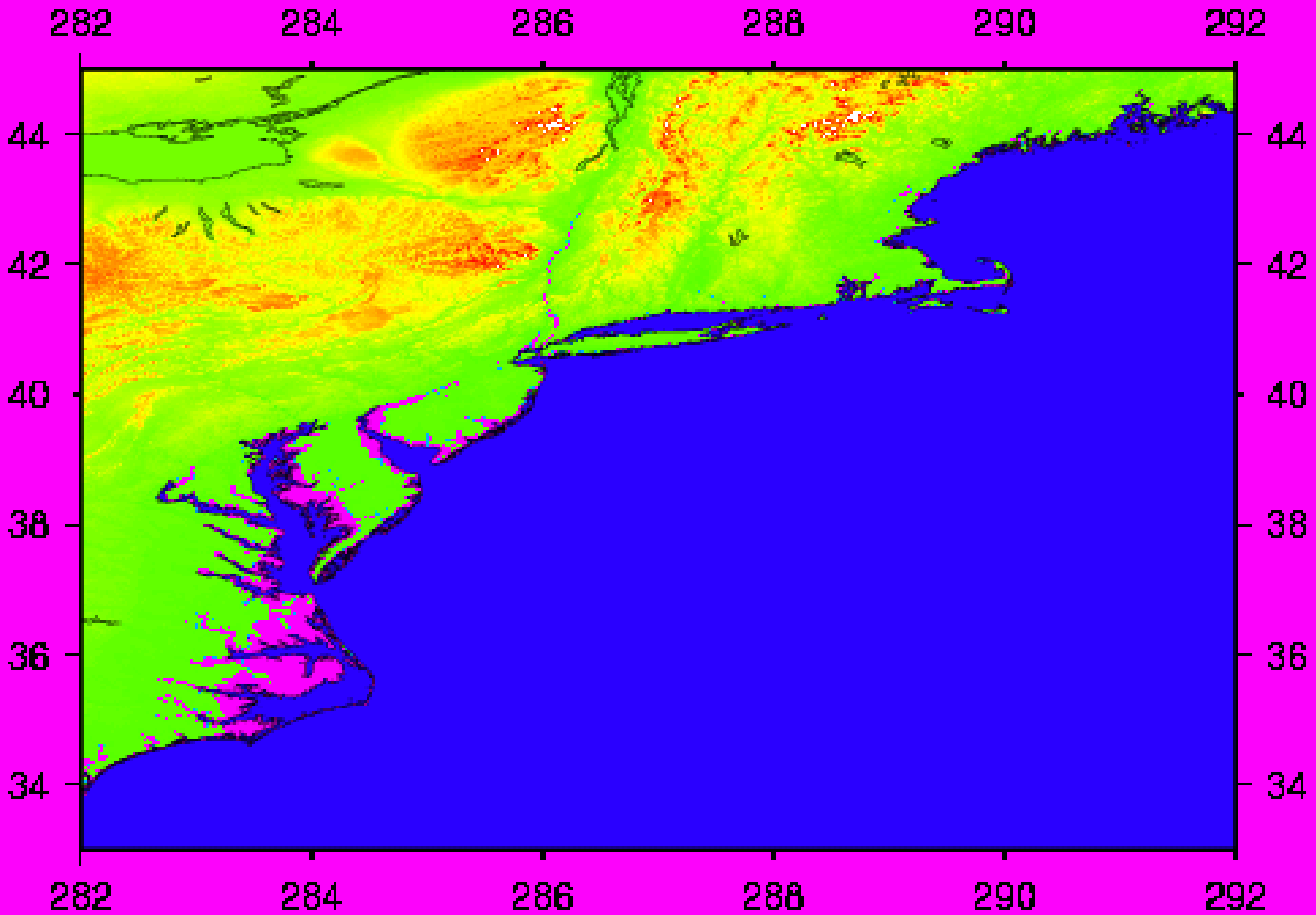
Over the last five decades, we have developed amazing engineering skills in coastal protection. We can maintain countries that are for a large part below current sea level.

We built new settlements in areas prone to flooding, particularly if the protections fail.

Today, we are building magnificent barriers ...

But recent disasters have shown limitations of coastal protection:

- Hurricane Katrina exemplified the urban disaster.
- The 2004 Sumatra tsunami exemplified large-scale hazards.
- Venice exercises adaptation to a slowly developing disaster



The threats and challenges for humanity would be enormous.

What if sea level becomes unstable again?

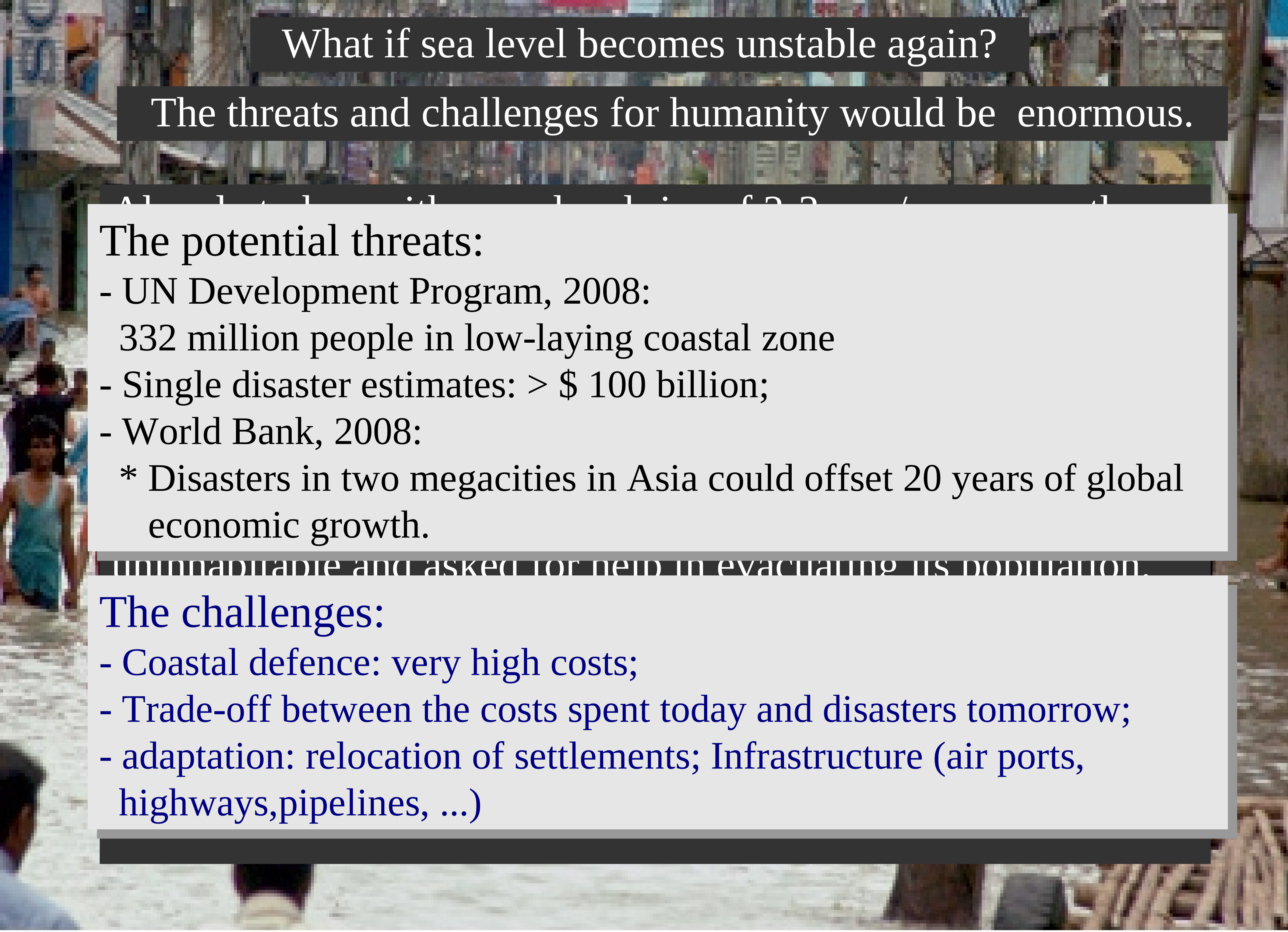
The threats and challenges for humanity would be enormous.

The potential threats:

- UN Development Program, 2008:
  332 million people in low-laying coastal zone
- Single disaster estimates: > $ 100 billion;
- World Bank, 2008:
  * Disasters in two megacities in Asia could offset 20 years of global economic growth.

The challenges:

- Coastal defence: very high costs;
- Trade-off between the costs spent today and disasters tomorrow;
- adaptation: relocation of settlements; Infrastructure (air ports, highways,pipelines, ...)



Shafiqul Islam/WPN

Science in Support of Policy Making

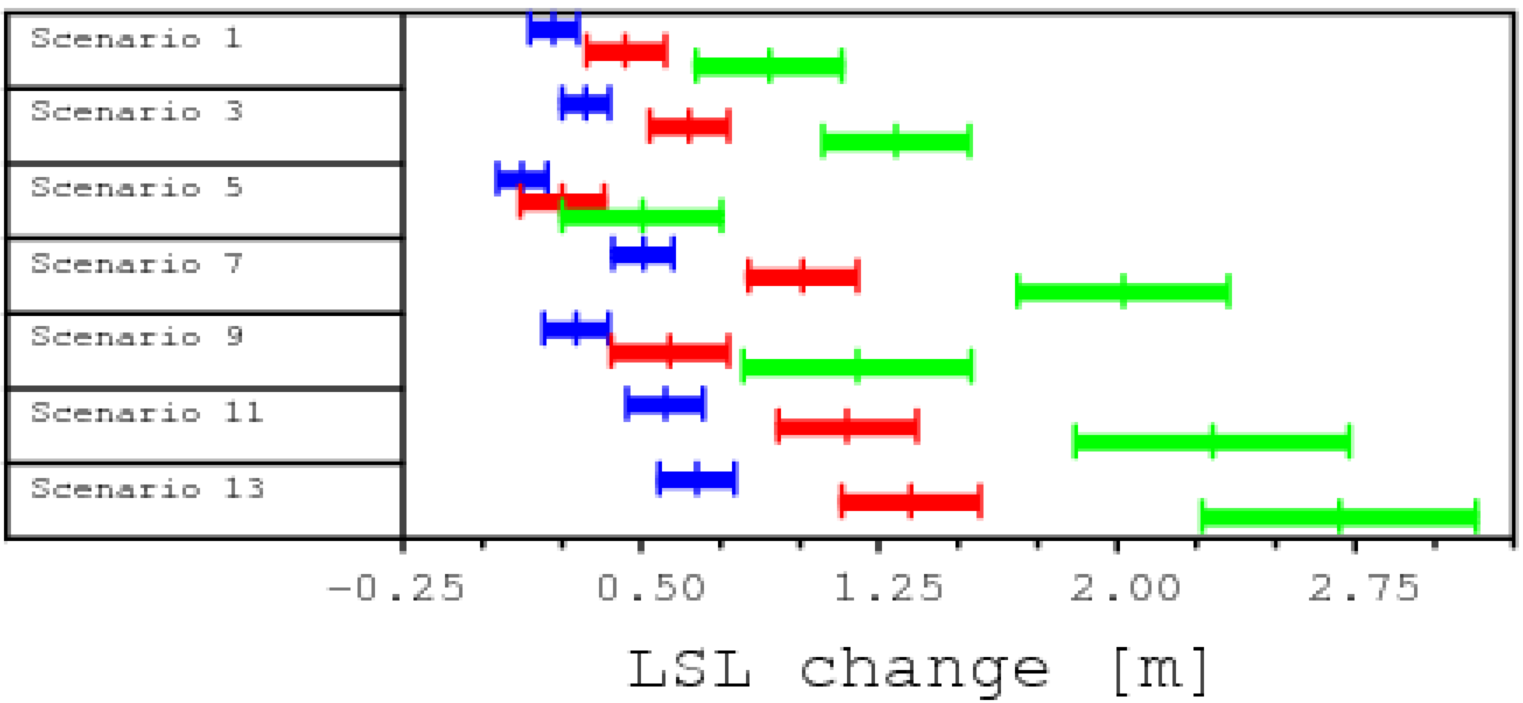
What do policy makers want?

- 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);

What do we (scientists) give them?

- Projections give a wide range of LSL trajectories.
- no reliable PDFs.

Blue: 2050
Red: 2100
Green: 2200



Recent examples: U.K., Venice, Dutch Coast, Southern Coasts of U.S.

Science in Support of Policy Making

What do policy makers want?

- 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);

Some (unpleasant) questions:

- Do we have the knowledge to provide the requested advice?
- How large are the uncertainties and how do we communicate these?

Large public interest in climate change impact and particularly sea level rise:

- In 2008-2009 at least 15 articles in New York Times alone that addressed sea level and adaptation;
- Reference to a number of *Nature*, *Science*, *GRL*, etc. articles;
- Message of scientists is mixed, and partly contradicting, particularly with respect to the contribution of the ice sheets;
- No consensus about the upper limit for the next century or two.

Lester R. Brown (2007): If I could monitor only one environmental parameter, it would be atmospheric Carbon.

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

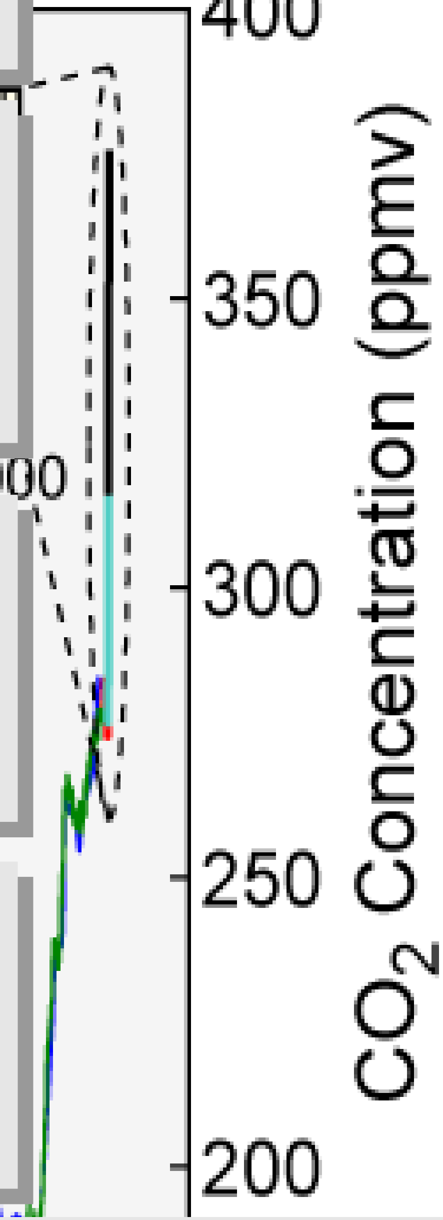
The Earth system may have passed some threshold values.

Humanity has reengineered the planet:

The past and presents have only limited value for assessing the range of plausible futures, including Global and Local Sea Level trajectories.

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

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

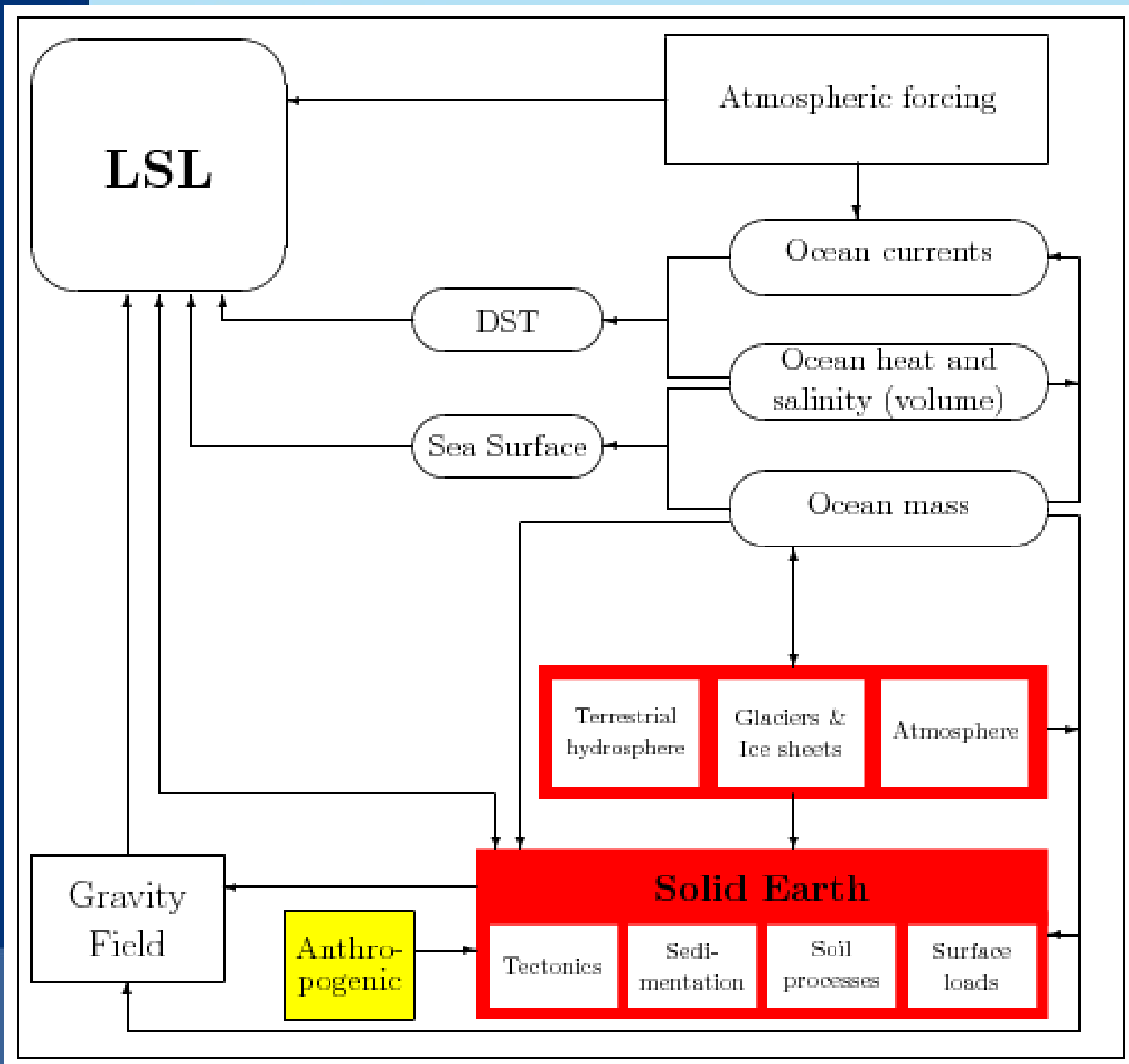


We have to ask:

How realistic is the range of plausible Local Sea Level trajectories?

Science of Sea Level Changes

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



LSL is the result of local, regional, and global Earth system processes.

We have no Earth system model to predict LSL variations (both past and future).

We have models for some of the processes.

Best practice:

- Local approach: sum of contributions from various processes

Science of Sea Level Changes

Local Sea Level (LSL) = high-frequency part + low-frequency part

Separation at periods of about 2 months

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

Science of Sea Level Changes

Low-frequency LSL Variations are the <u>result of local, regional and global processes</u> including:

- Changes in ocean temperature, salinity (density of sea water, including melting of sea ice);
- Changes in ocean circulation;
- Changes in atmospheric circulation;
- Concurrent mass exchange with ice sheets, glaciers, and land water storage/mass redistribution in the water cycle;
- Past mass redistribution (postglacial rebound)
- Vertical land motion and geoid changes
- Changes in the shape and extent of the ocean basins

The processes involving mass redistribution in the water cycle need a special comment ...

Science of Sea Level Changes

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.

LSL changes caused by redistribution of mass in the global water cycle are the difference between the local changes in geoid and ocean bottom height plus an offset for the mass change in the ocean.

We can compute these LSL changes using the integral equation that links the mass redistribution over the whole surface of the Earth (including the oceans) to LSL changes.

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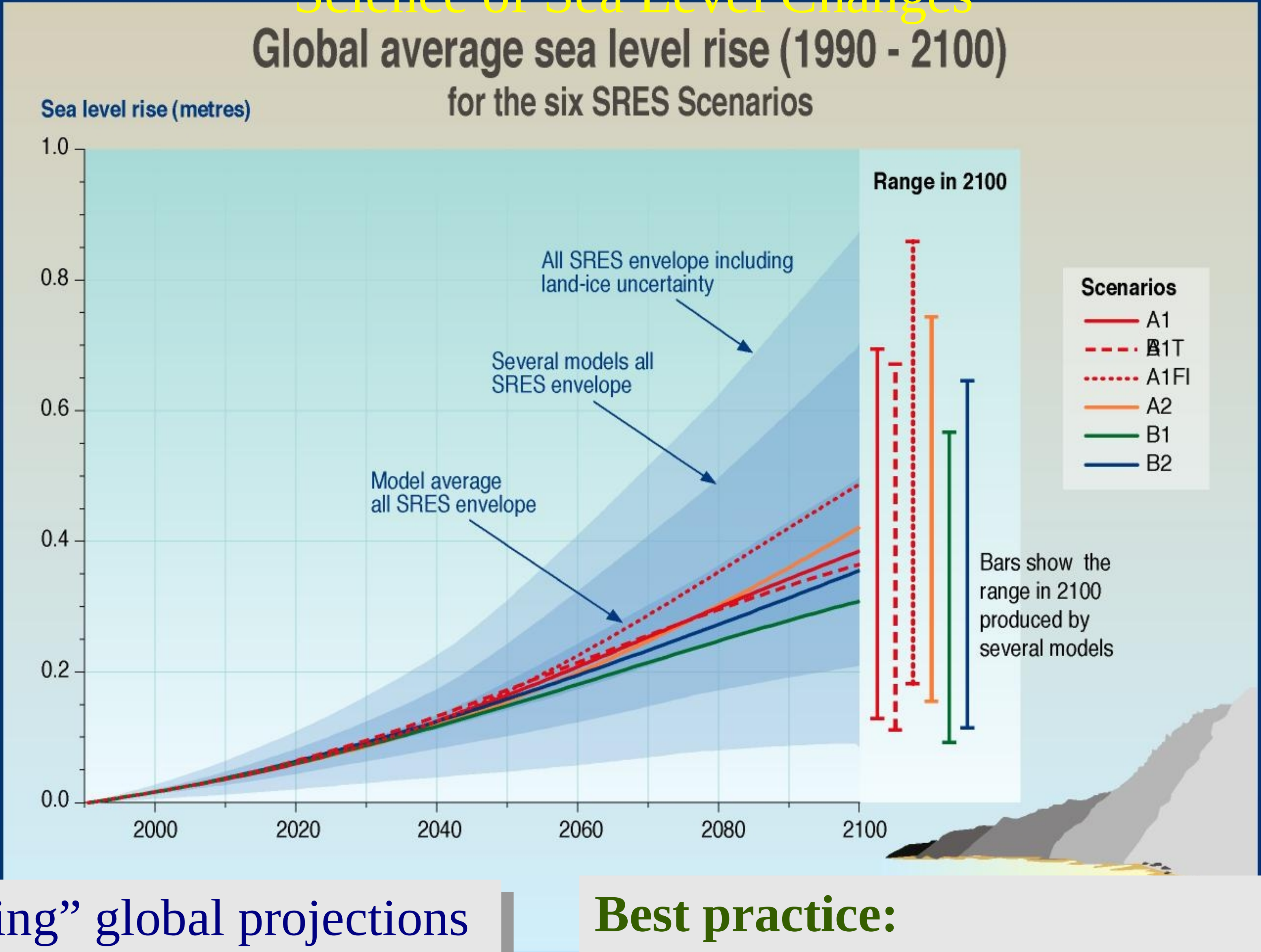
Science of Sea Level Changes



"Localizing" global projections

Best practice:

- Local approach: sum of contributions from various processes

What are the Uncertainties? Some examples ...

Uncertainties

Recent assessments: Sum of projections for each term in the LSL equation; combination of individual PDFs.

Problem: Different types of uncertainties (Manning and Petit, 2003):

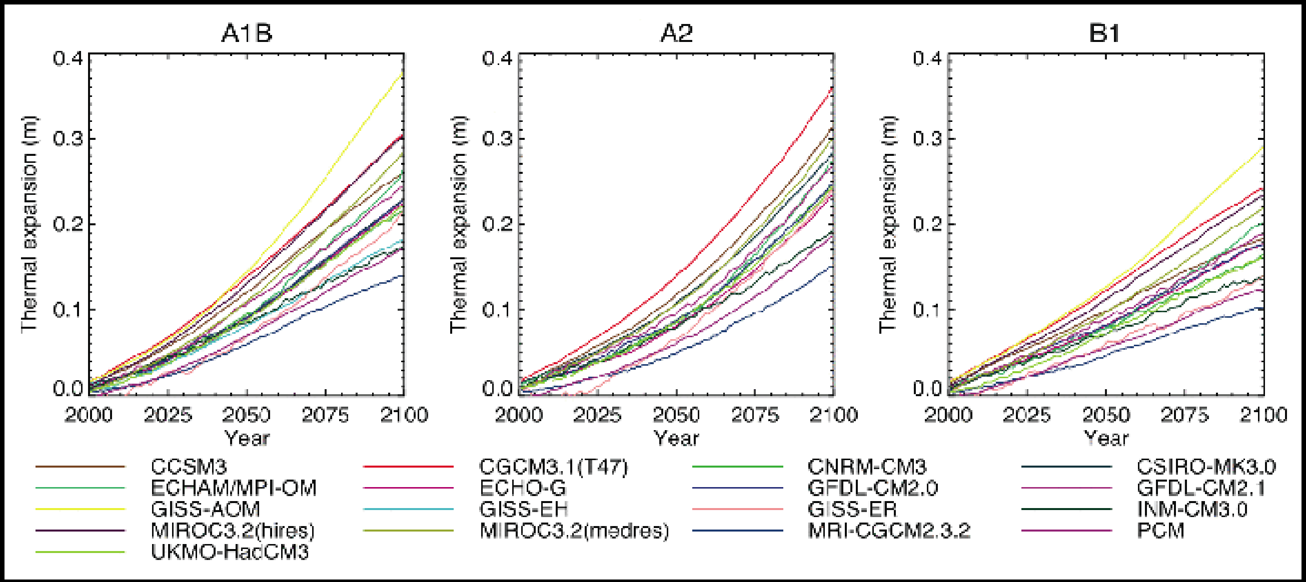
Uncertainty	Class	LSL forcing process

Treatment of uncertainties in the mapping of plausible LSL trajectories:

- Aleatory (statistical): values and PDF estimates from past observations;

- Epistemic (systemic): research; scenario approach: realistic assumptions concerning forcing; Ensemble studies (chaos, lack of predictability)

Uncertainties

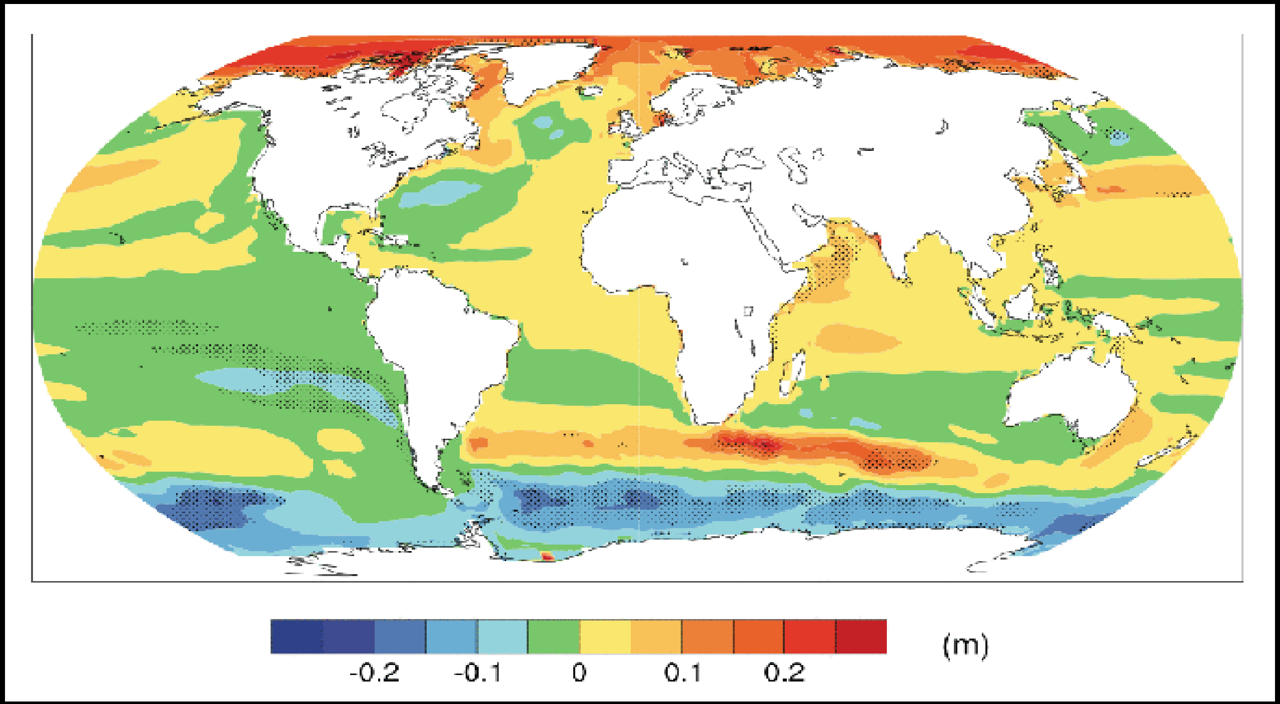


Thermal expansion

Method:

IPCC Emission Scenarios and Ensemble studies:

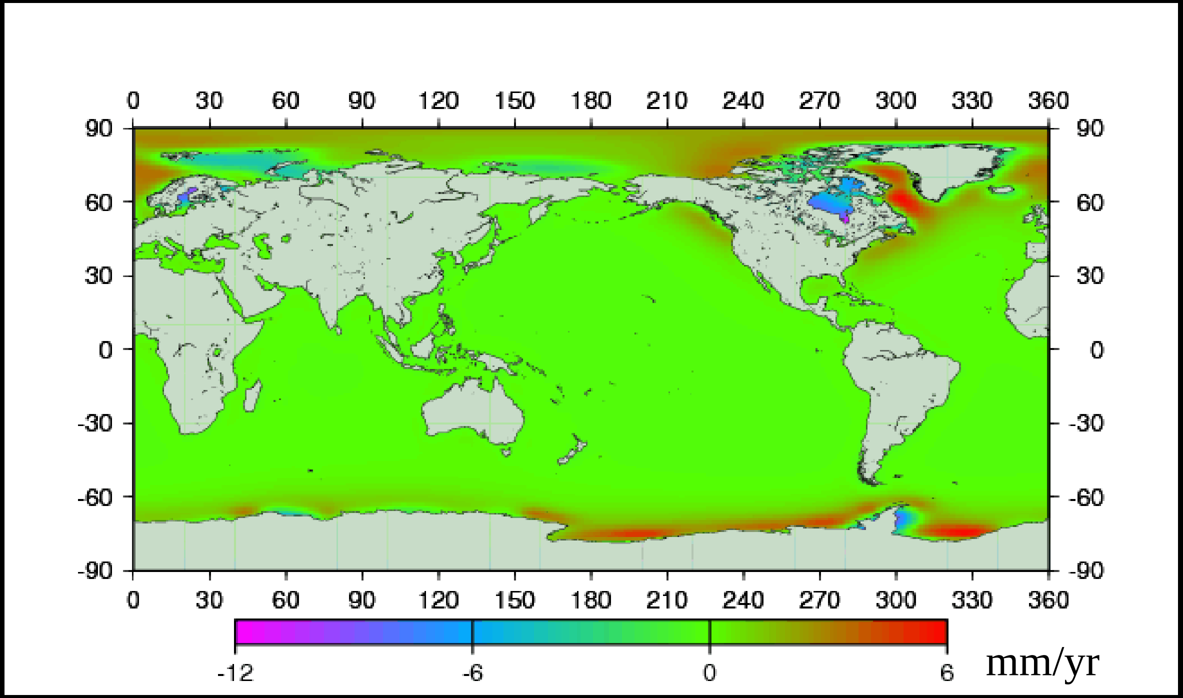
- GSL rise due to steric effect : 1.0 – 3.5 mm/yr

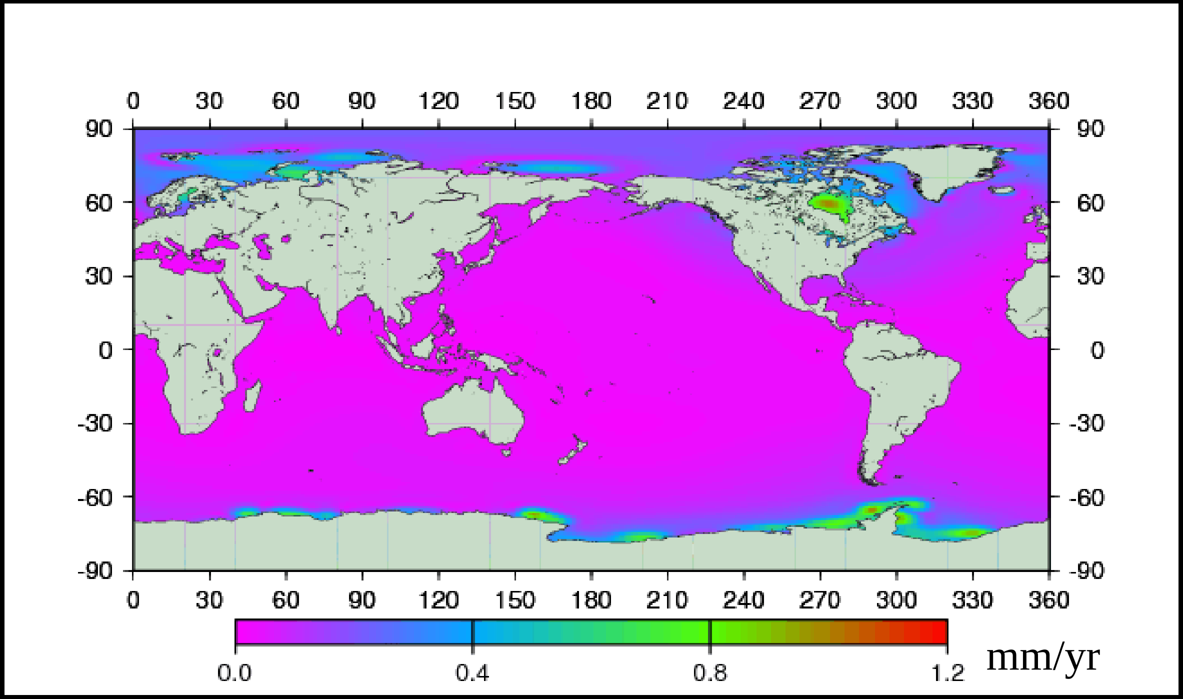


Regional variations:

- IPCC: ±2.0 mm/yr
- Some regional studies: ±4.0 mm/yr

Uncertainties





Postglacial rebound:

Method:
Extrapolation of predicted present-day signal in sea level;

Mean of many predictions
Example: 14 different predictions
Signal: -10 to 5 mm/yr

Uncertainty from standard deviation:
Max. ± 1.2 mm/yr, relative: ~15%

Uncertainties

Present-day mass exchange:

- Ice sheets
- Glaciers
- Land water storage

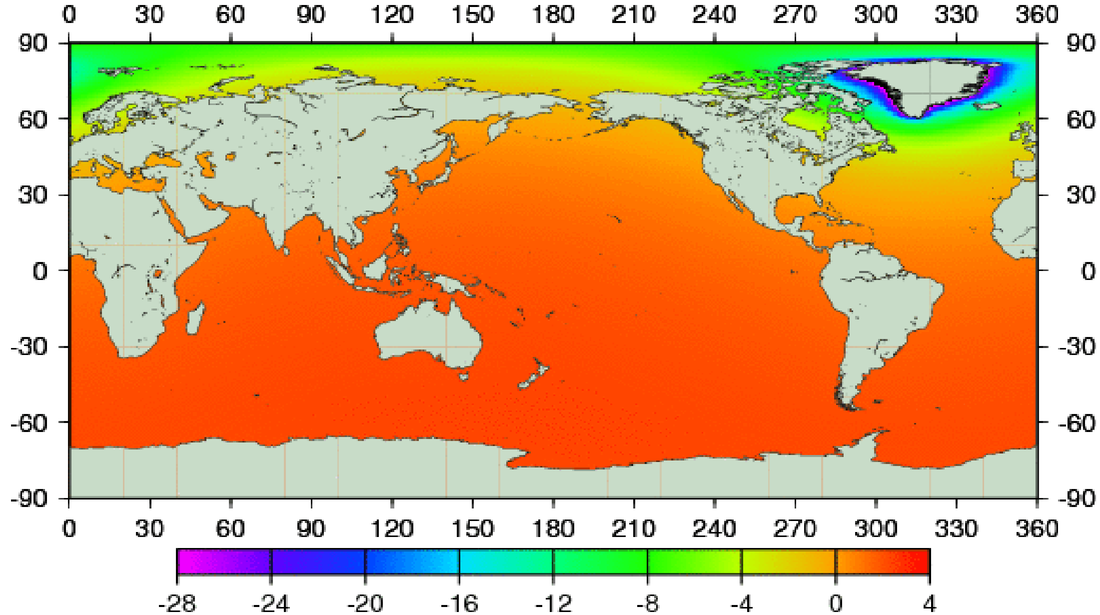
For known mass changes: Solution of the static sea level equation

Simplifications:
- spherically symmetric Earth model
- elastic (up to century time scales)

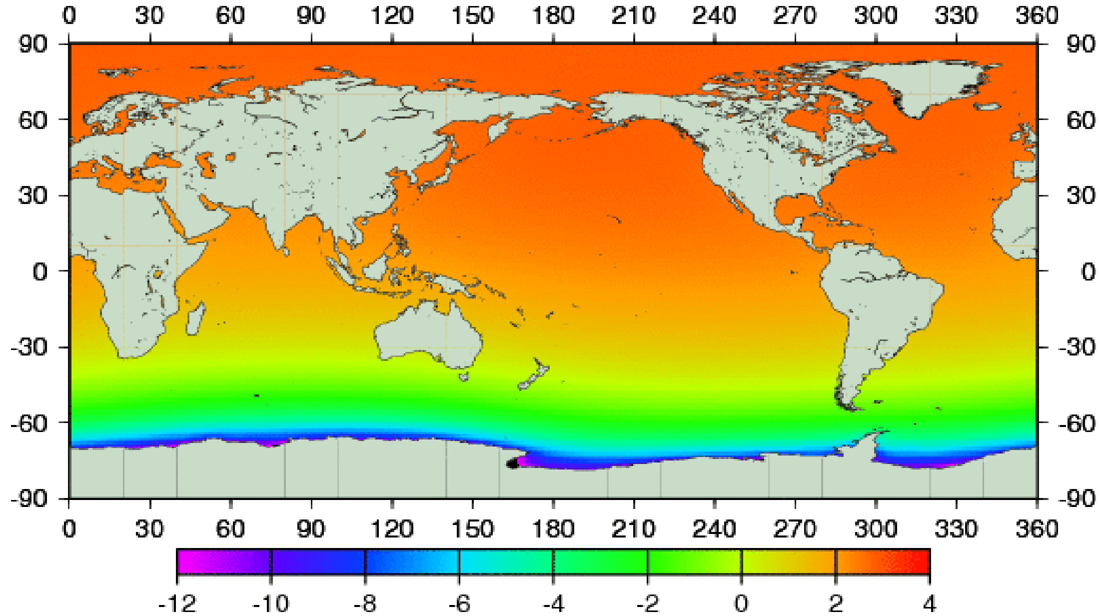
Fingerprint admittance functions: *describe the effect of a unit ice mass change in a given area on sea level.*

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

Greenland



Antarctica



Uncertainties

Ice Sheet Contribution highly uncertain:

- Zwally et al., 2002: dynamic response due to meltwater intrusion;
- van de Wals et al., 2008: feedback through sea water; Greenland is slowing down;
- Pfeffer et al., 2008: Contribution might be as large as 2 m by 2100;
- Bambers et al., 2009: Total contribution of West Antarctic ice sheet smaller than previously predicted;
- McPhee et al., 2009: Greenland meltwater might increase sea level at the Northern Coasts of North America.

Lipscomb et al. (2009): "Recent observations show that ice sheets can respond to climate change on annual to decadal timescales and that the Greenland and West Antarctic ice sheet are **losing mass at an increasing rate.** The current generation of ice sheet **models cannot provide credible predictions of ice sheet retreat** , ... The IPCC provided neither a best estimate nor an upper bound for 21st-century sea level rise because of uncertainties in the dynamic response of ice sheets."

Reducing the Uncertainties

Uncertainties:

- steric contribution (thermal expansion):
  * separation of mass and steric contribution (gravity, sea surface).
- mass exchange:
  * ice sheets: improved observational constraints (ice and land surfaces, gravity);
  * glaciers: more observations of LSL, land surface and mass balance for coastal glaciers;
  * land hydrology: improved observational constraints (land surface and gravity).
- validation of admittance functions:
  * improved observations close to large, rapidly changing ice loads (LSL, land surface, gravity).
- vertical land motion:
  * improved tie between reference frame origin and center of mass;
  * observations in high risk areas (in particular, coastal mega cities).

Science Support for Adaptation and Mitigation

If we can reduce uncertainties successfully, what will we get?

Improved retrofit: Yes

Reduced range of plausible LSL trajectories: Hardly

Problem: Policy making, mitigation, and adaptation in the face of large, and **mostly unreducable uncertainties**

Science Support for Adaptation and Mitigation

Two articles in EOS:

Dessai et al., 2009: *Do we need better Predictions to adapt to changing climate?*
Harrison and Stainforth, 2009: *Predicting Climate Change: Lessons from Reductionism, Emergence, and the Past*

Reductionism:
- Basic assumption: system can be described by a set of equations, and, if initial conditions are known, predicted.
- We first predict, then react/adapt

Reductionism does not work for climate impacts:
- Complex, continuously changing system, potentially unpredictable;
- Presence is different from the last 650,000 years (and future will be);
- Past has limited value for exploration of the future;
- System with unpredicted, emerging characteristics: <u>surprises</u>.

Emergence:

Monitoring and understand the trajectory of the system through well-observed, emerging properties.

Science Support for Adaptation and Mitigation

Problem: Policy making, mitigation, and adaptation in the face of large, and mostly unreducable uncertainties

Contribution of the Scientist:

- understand and respect the uncertainties (type, quantity, predictability)
- map the range of plausible futures,
  * use reductionism where appropriate;
  * use ensemble and scenario approach where necessary;
- monitor emerging characteristics and components that are not predictable;
- develop assimilation models with limited (in time) predictive capabilities to support rapid response to new developments (forecasting)

Towards Forecasting of Local Sea Level Changes:

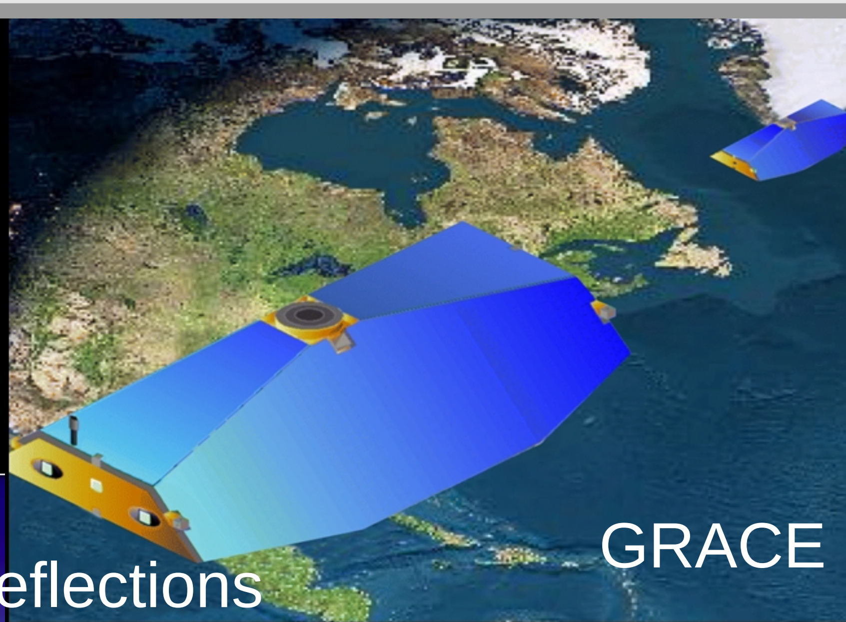
- Monitor the main reservoirs in the global water cycle;
- Develop models that can predict reservoirs on decadal time scales;
- Develop models that can relate reservoir changes to LSL;
- aim for five to ten years and more. ...

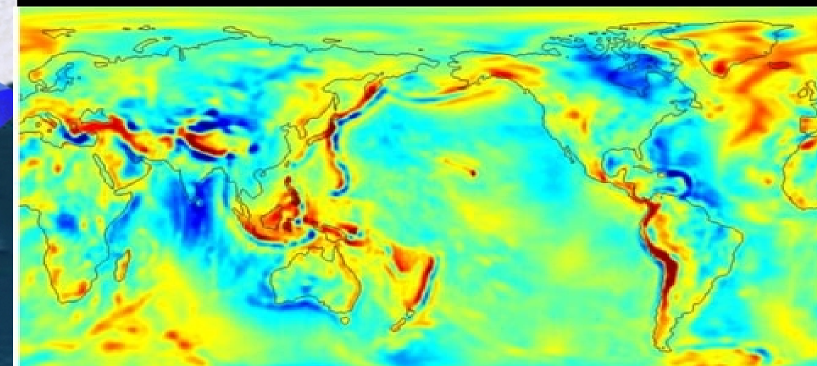
Towards a Local Sea Level Forecasting Service

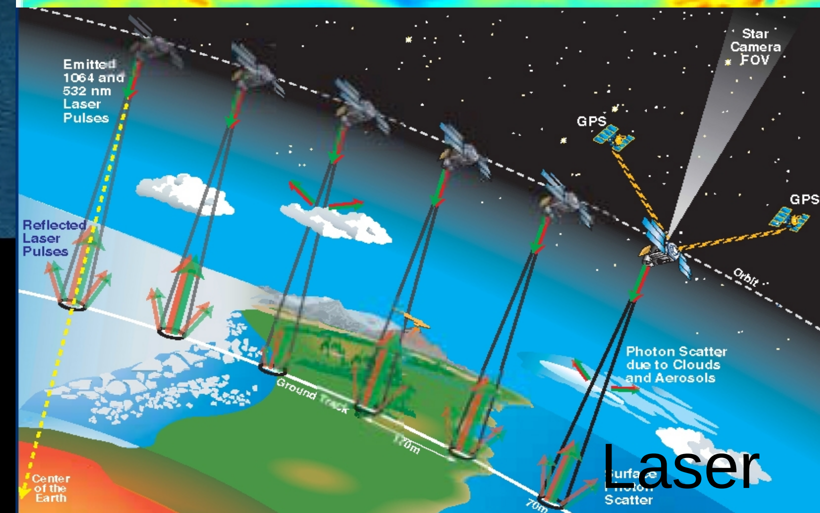
Wilkens Ice Sheet:

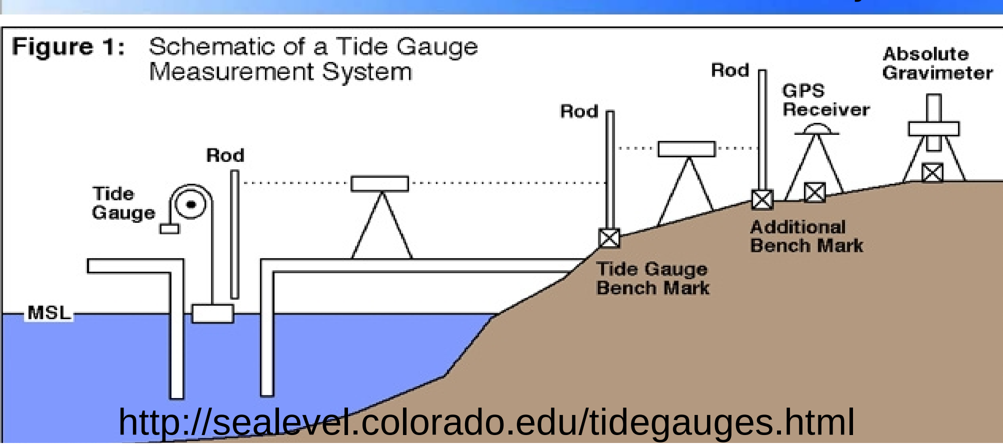
Reuter, January 22, 2009 (quoting David Vaughan): Loss of ice shelves does not raise sea levels significantly because the ice is floating and already mostly submerged by the ocean. But the **big worry is that their loss will allow ice sheets on land to move faster**, adding extra water to the seas.

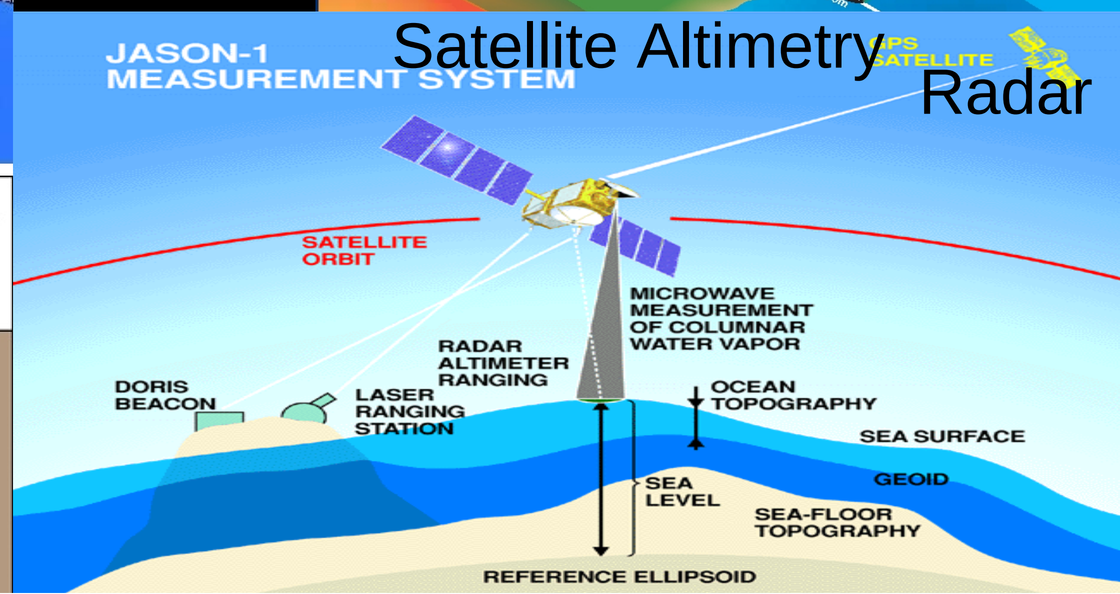
Towards Local Sea Level Forecasting Service



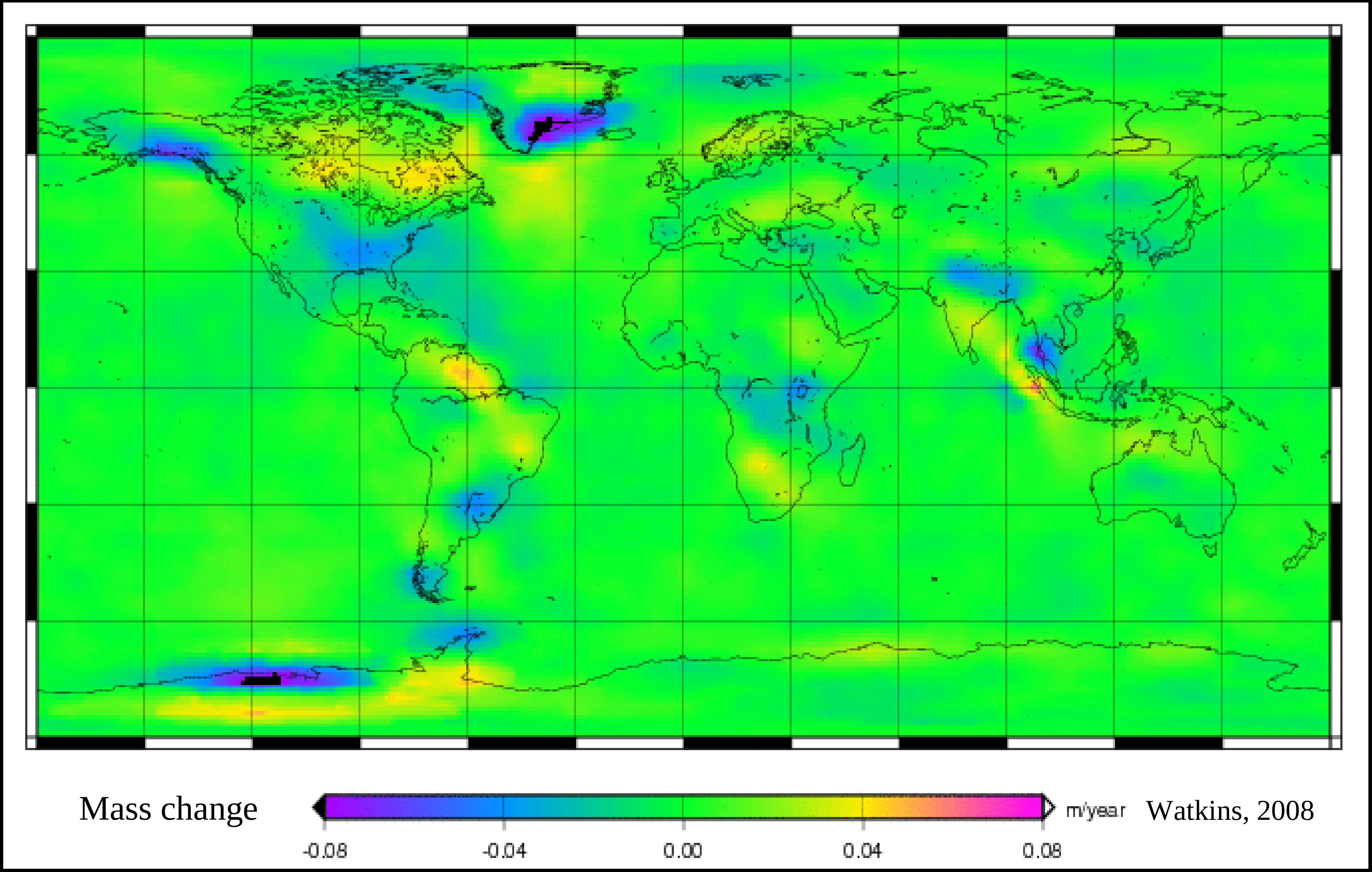








Towards a Local Sea Level Forecasting Service



Science Support for Adaptation and Mitigation

Problem: Policy making, mitigation, and adaptation in the face of large, and **mostly unreducable uncertainties**

Contribution of decision/policymakers:

- Respect the uncertainties (and scientific limitations);
- Coastal zones have always changed and will continue to change;
- We have off-set coastal changes with protections and engineering;
- We might not be able to continue to off-set future (larger) changes;
- Foster monitoring of the Earth: be informed about pending changes
- Frequent reassessments of the development;
- Plan and prepare for changes (including big surprises) and thus:
  * **REDUCE VULNERABILITY,**
  * **INCREASE RESILENCE;**

Thank you for your attention!