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The Science-Policy Link: Stakeholder Reactions to the Uncertainties of Future Sea Level Rise?

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The Societal Challenge of Sea Level Rise

Policy makers and stakeholders in the coastal zone are equally challenged by the risk of an anticipated rise of coastal Local Sea Level (LSL) as a consequence of future global warming. More than 40% of the global population is living in or near the coastal zone and this fraction is steadily increasing. In many low-lying coastal areas with dense urban settlements, even a slow rise in LSL would increase the risk for coastal infrastructure and population dramatically, with potentially devastating consequences for the global economy, society, and environment. Policy makers are faced with a trade-off between imposing today the often very high costs of coastal protection and adaptation upon national economies and leaving the costs of potential major disasters to future generations. They need actionable information that provides guidance for the development of coastal zones resilient to sea level changes. Part of this actionable information comes from risk assessments, which require information on future LSL changes as input.

The Science Challenge of Sea Level Rise

The complexity of the Earth system and its inherent unpredictability make it difficult, if not impossible, to predict or usefully constrain the range of LSL changes on century time scales. Moreover, humans have re-engineered the planet and changed major features of the Earth surface and the atmosphere, thus ruling out model-based extrapolations of past and current changes into the future (as applied by IPCC, see Figure 1) as a reasonable approach. There is no scientific basis to exclude a rapid LSL rise, which introduces a low-probability but extremely high-risk option into the discussion of adaptation to LSL rise. The traditional reductionist approach may not work (Harrison & Stainforth, 2009). New scientific approaches to decision support need to be developed.

Science Support: The Deterministic Approach

In most cases, a deterministic approach has been used to provide predictions of the plausible range of future LSL trajectories as input for coastal risk assessments. However, deterministic predictions of Global Sea Level (GSL) rise and coastal LSL for the 21st century are not actionable: There is little consensus in the scientific community on how these trajectories should be determined, and what the boundaries of the plausible range are. Over the last few years, many publications in Science, Nature and other peer-reviewed scientific journals have revealed a wide range of plausible future GSL trajectories and significant epistemic uncertainties and gaps concerning LSL changes.

Stakeholder Reactions to the Deterministic Uncertainties

The uncertainties in the range of plausible future sea level trajectories are not communicated well. Based on the somewhat diffuse science input, policy and decision makers have made rather different choices for mitigation and adaptation in cases such as Venice, The Netherlands, New York City, and the San Francisco Bay area. In summary, decision makers do not get the support they need: '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"].

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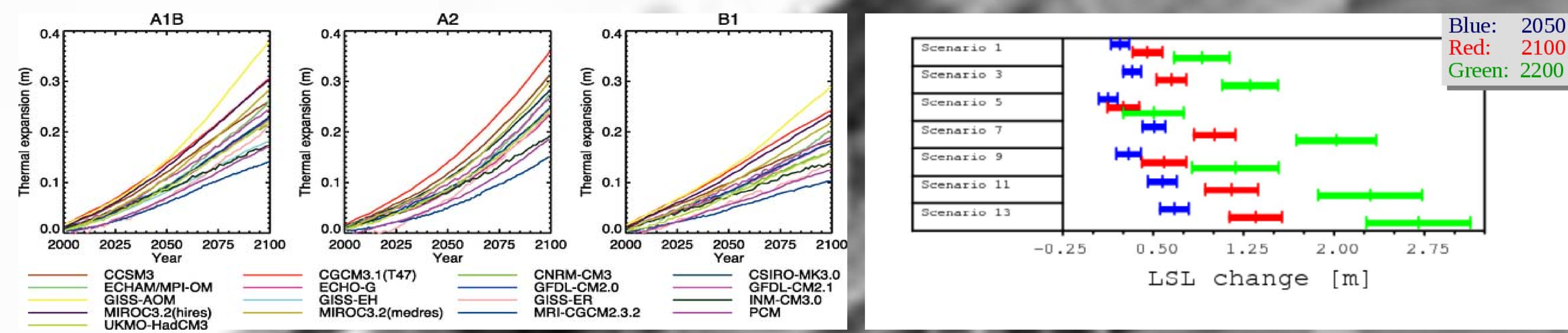

Figure 1: Left: IPCC Predictions for GSL rise over the 21st century. From Meehl et al. (2007). Right: Range of plausible LSL trajectories for the Netherlands assuming different ice melt scenarios.

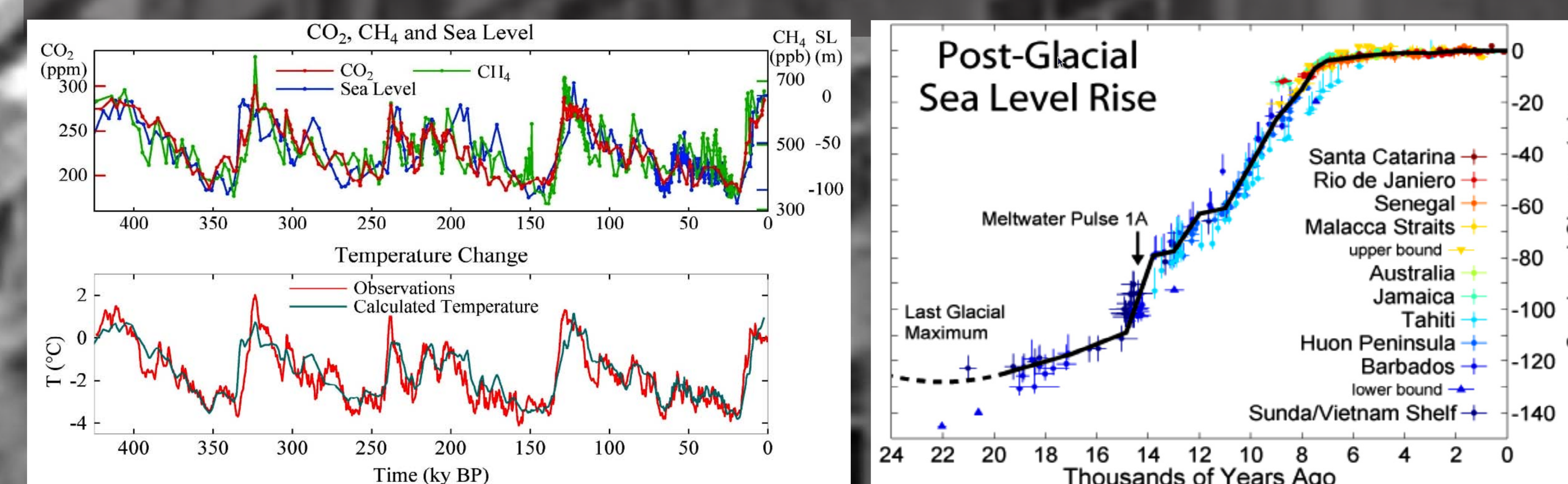

Figure 2: Paleo records of GSL and related parameters. Left: Global CO_2, CH_4, and GSL for the last 400 Ka. From Hansen et al., 2008. Right: GSL changes over the last 20 Ka. From http://en.wikipedia.org/wiki/File:Post-Glacial Sea Level.png.

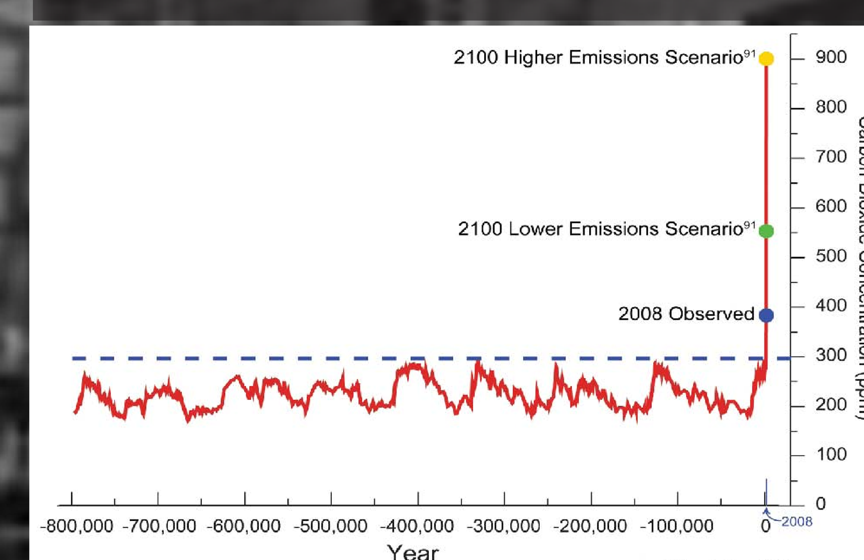

Figure 3: CO_2 changes over the last 800 Ka. From Karl et al. (2009).

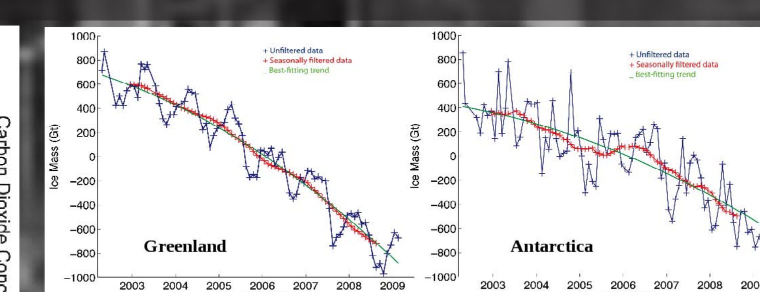

Figure 4: Acceleration of ice mass loss for the Greenland and Antarctic ice sheet as determined by GRACE. From Velicogna (2009).

Science Support: The Statistical Approach

Replacing the deterministic, prediction-based approach with a statistical one that fully accounts for the uncertainties and epistemic gaps provides a different kind of science input to policy makers and stakeholders. Like in many other insurance problems, where deterministic predictions are not possible, the statistical approach to coastal resilience requires stakeholders to base decisions on probabilities instead of predictions. The science input for informed decisions on adaptation consists of probability density functions of decadal to century-scale sea level changes derived from paleo records, including the probabilities for large and rapid rises.

What Do Paleo Records Tell Us?

The extrapolations of current knowledge used for the IPCC assessments seem to indicate that the 21^{st} century GSL rise will not exceed 1 m (Figure 1). Other recent assessments limit the upper end for the 21^{st} century GSL rise to about 2 m (e.g., Pfeffer et al., 2008). However, paleo-records show that the Earth system has the capability to produce larger century GSL rises (Figure 2). During the last several 100 Ka (Ka=1,000 years), the mean GSL rise was on the order of 1.5 m/Ha (Ha = 100 years) while maximum rates may have exceeded 3 m/Ha, and LSL changes of up to 4.5 m/Ha appear possible.

The Challenge of a Re-Engineered Planet

Humanity has re-engineered the Earth at an exceptional speed and created states not encountered over the past few million years. The CO_2 concentration of 385 ppm observed in 2008 exceeds the previously occurring maximum of 300 ppm observed during the last 800 Ka by 65% of the total Glacial-Interglacial Range (GIR) of 130 ppm during this time, CO_2 values in excess of 400% of the GIR are predicted by the end of the 21^{st} century (Figure 3), exceeding all changes recorded over the last million years (Karl et al., 2009). The speed of change is unparalleled, too: while during the last million years, maximum changes in CO_2 on the order of 100 ppm took place over thousands of years, humanity accomplished this in less than three centuries. Likewise, ocean acidity, land cover, and many other system parameters have been changed to values not encountered in the most recent several million years. Under the unparalleled conditions created by humans, the response of the climate system may also exceed all rapid responses documented in the paleo-records. Rapid LSL changes exceeding those recorded in the paleo-records cannot be excluded.

Is There a "Black Swan" Waiting for Us?

The current wide-spread science approach to GSL and LSL changes lays the ground for a 'Black Swan' event. A Black Swan is an event

(1) that is an outlier, as it lies outside the realm of regular expectations;
(2) that carries an extreme impact;
(3) can be explained after the fact (Taleb, 2010).

The current wide-spread science approach to GSL and LSL changes lays the ground for a Black Swan event. The extremely stable GSL experienced by humans during the last 7,000 years has led many to think that mean GSL and LSL change slowly. Nothing occurring during the time of human civilizations indicates that a rapid GSL rise could happen. Even as scientists we tend to ignore the paleo-record. Many scientists consider a 21st century GSL rise of more than 1 m as highly unlikely and more than 2 m as impossible. A 21st century GSL rise of more than 2 m would carry an extreme impact: in all previous times when such rapid GSL changes redrew the global coast lines, large-scale built environment was absent and humans could easily adopt to shifting coast lines. Today, with wide-spread built environment and potentially polluting infrastructure in coastal zones, rapid changes in coast lines and inundations during storm surges would be devastating both economically and environmentally if they meet us unprepared.

The Need for Sea Level Forcasting

Similar to other problems where the occurrence of a hazard is associated with a high risk (like a fire in a house), a monitoring and warning system (a "smoke detector") capable of detecting any onset of a rapid GSL or LSL rise is needed. There is a growing societal need for actionable forecasts of LSL changes on decadal time scales (comparable to the ongoing sky-watch for near-Earth objects, which addresses another low-probability/high-risk event). Key elements of a LSL Forecasting Service (LSL-FS) are a Global Cryosphere Watch (GCW) and models capable of assimilating GCW and other observations. A LSL-FS could facilitate adaptation where and when necessary.

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