



Aspen Global Change Institute Energy Project

September 2015 Quarterly Science Supplement

ANALOGS OF OUR FUTURE: SEA LEVEL RISE OF ~6 METERS

Dutton A., A. E. Carlson, A. J. Long, G. A. Milne, P. U. Clark, R. DeConto, B. P. Horton, S. Rahmstorf, M. E. Raymo. 2015. Sea-level rise due to polar ice-sheet mass loss during past warm periods. *Science* (349) 6244.

Hansen J., M. Sato, P. Hearty, R. Ruedy, M. Kelley, V. Masson-Delmotte, G. Russell, G. Tselioudis, J. Cao, E. Rignot, Velicogna, E. Kandiano, K. von Schuckmann, P. Kharecha, A. N. Legrande, M. Bauer, and K.-W. Lo. 2015. Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2 (deg) C global warming is highly dangerous. *Atmos. Chem. Phys. Discuss* (15) 20059–20179.

A discussion paper by Jim Hansen and colleagues (2015) and a review paper by Andrea Dutton and colleagues (2015) consider past sea level rise when the Earth was as little as 1-2 C° warmer than preindustrial global average temperature. These conditions existed during two of the past interglacials about 120,000 and 400,000 years ago¹. During these interglacials sea level is estimated to have been about 6 meters higher than it is today.

Interglacials, while imperfect analogs to the present, serve as a way to better understand how much sea level rise to expect from conditions that are slightly warmer than the present. In addition to paleoclimate studies, modern observations and climate models are also helping scientists put together a more complete picture of the magnitude, rate, and mechanisms underlying global mean sea level rise.

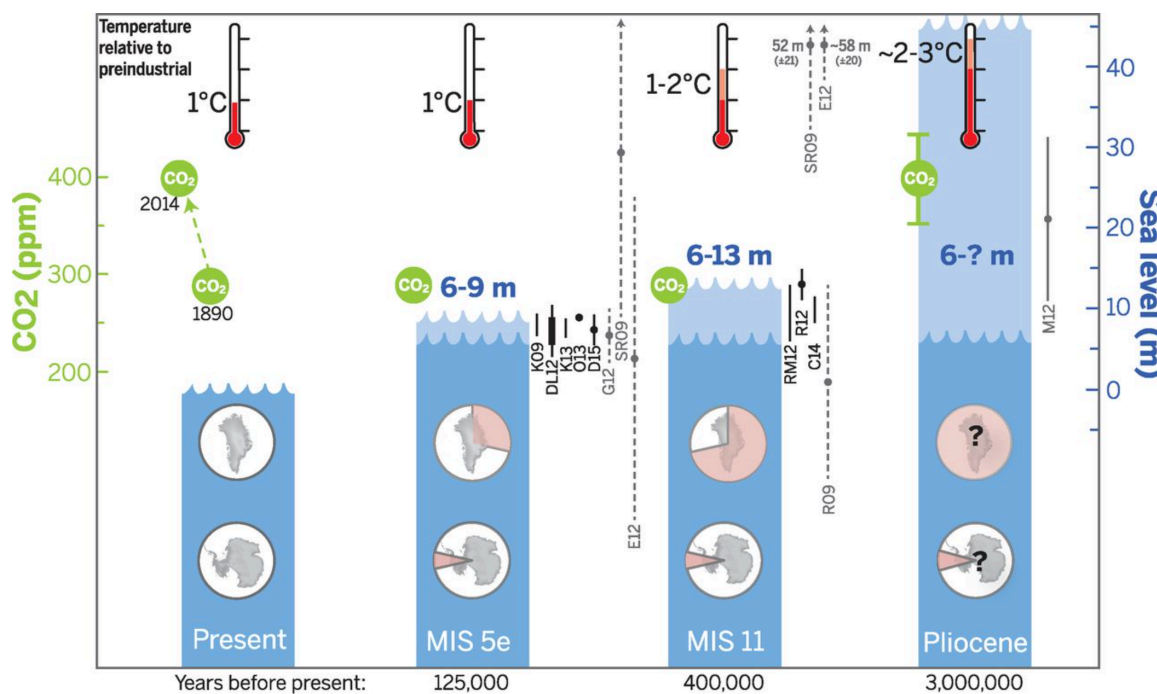
Reconstructing past sea levels and what can be derived from these estimates in relation to future conditions is a rapidly advancing field of study. The extent and rate of sea level change requires adding up the sources of rise, which include thermal expansion (i.e., ocean water expanding due to warmer temperatures), mountain glacial melt, and other more complex mechanisms that lead to ocean discharge from changes in ice sheet dynamics on Greenland and Antarctica.

¹Marine Isotope Stage 5e and MIS 11 respectively

Reducing uncertainty in the eventual magnitude of change is important, but from the standpoint of people that live in coastal areas, knowing how the rate of change is shifting – now at a seemingly innocuous 3mm per year – is fundamental to understand the fate of coastal settlements on decadal to century timescales.

Magnitude of sea level change in the past

The paper by Dutton's team on the most recent interglacial period (MIS 5e, or ~129,000 to 116,000 years ago) estimates a total sea level rise of 6-9 meters, +/- 3m. The largest source of rise was about 4m from the Antarctic Ice Sheet (AIS), 2m from the Greenland Ice Sheet (GrIS), and about 1m from thermal expansion and mountain glacial melt. This interglacial had an estimated global average temperature of approximately 1 C° above preindustrial temperatures. Since the 1800s the global average temperature has already increased by 0.8 C° or nearly the 1 degree that was previously enough to significantly alter eventual sea level.



This figure from Dutton shows present conditions in the left bar graph where CO₂ is already higher than during MIS 5e and MIS 11 and comparable to 3 million years ago when the Earth was 2 to 3 C° greater than preindustrial global average temperatures. The bar graph on the far right depicts conditions during the Pliocene (~3 million years ago) when sea level may have been significantly greater than 6m. The authors point out the estimates going back as far as the Pliocene are more uncertain due to difficulties in determining geologic changes in topography. The circles within the bar graphs indicate the approximate extent of ice sheet loss from Greenland on top and Antarctica below shaded in pink. The small green circles represent the estimated concentration of CO₂ in the atmosphere for each period.

Possible mechanisms of rapid sea level change

The rate of sea level change is key to envisioning the future: how long will it take for the processes described in Dutton's paper to unfold? The Hansen et al. paper explores the

magnitude of sea level rise, as did Dutton, but it also offers additional ideas on the rate of change and possible mechanisms.

The Hansen paper contends that the rate of future sea level rise may be more rapid than previously thought. One possible mechanism is the way ice sheets that are in contact with a warming ocean may be susceptible to rapid disintegration. In this paper, Hansen assembles lines of evidence from the paleoclimate record, climate models, and observations to support the idea of discontinuous jumps in contributions to sea level from the major ice sheets. The paper considers many aspects of the atmosphere, ocean, snow, and ice systems, piecing together evidence about the last interglacial and gaining insight into possible superstorms that were part of the last interglacial. The paper concludes that it is possible to have rates of sea level change as much as 2m (6.5 feet) in 50-200 years.

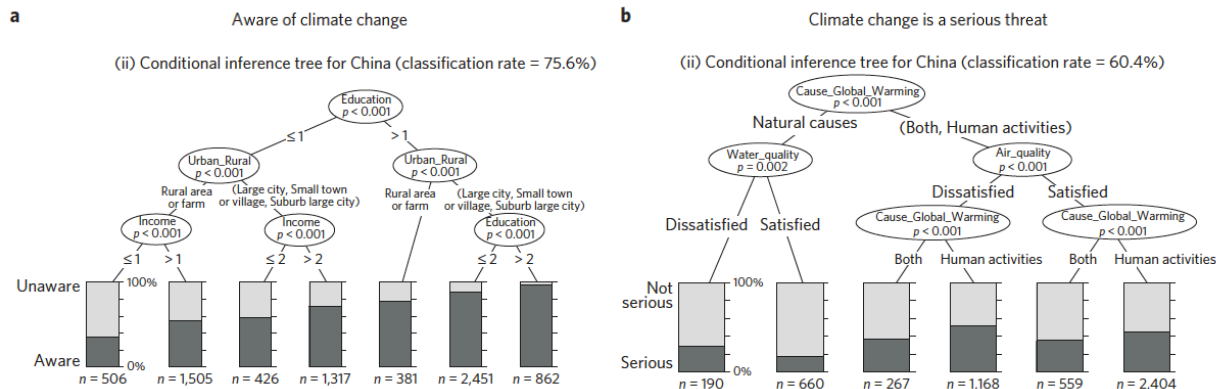
The international goal to not exceed 2 C° above preindustrial global average temperature may allow for a situation more dangerous than previously thought given the exposure of coastal settlements around the world to sea level change and associated storm surge, salt water intrusion, and direct inundation of the built environment. From Hansen's abstract came a clear warning: *We conclude that 2 C° global warming above the preindustrial level, which would spur more ice shelf melt, is highly dangerous.*

DIVERSITY IN DRIVERS OF INTERNATIONAL CLIMATE CHANGE AWARENESS & RISK PERCEPTION

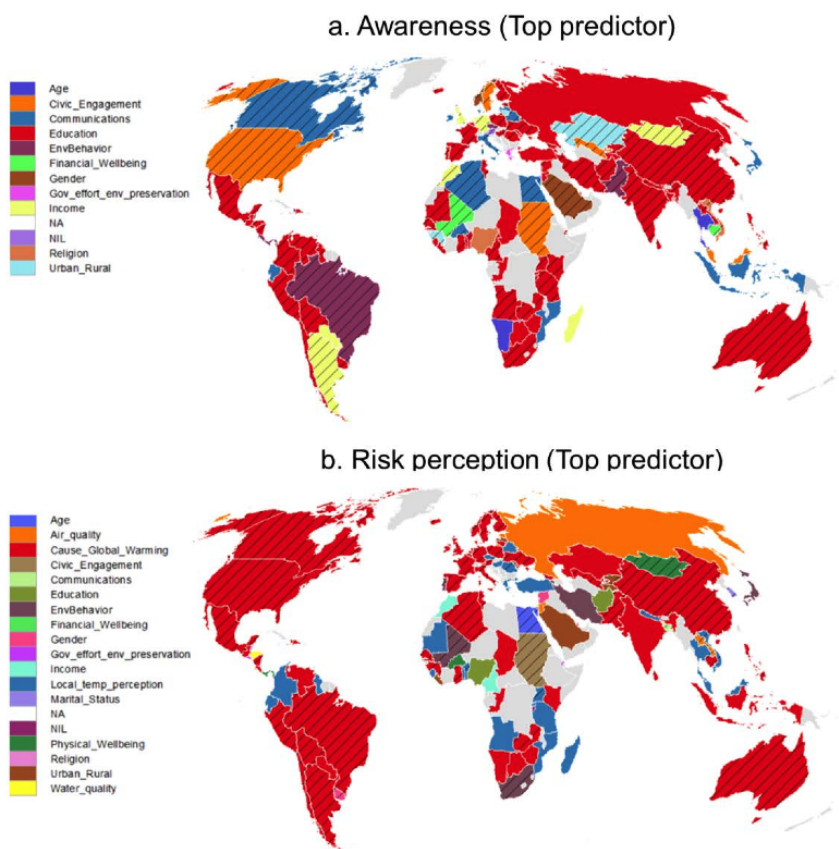
Lee, T.M. E.M. Markowitz, P.D. Howe, C.Y. Ko, & A.A. Leiserowitz. 2015. Predictors of public climate change awareness and risk perception around the world. *Nature Climate Change*. 2015/07/27 Advance Online Publication.

There is extreme variation around the world in public demand for and support of climate change policy. This has been attributed to varying levels of understanding around climate change causes and risks, based on findings of public opinion research done largely in the United States, Europe, and Australia where data is readily available.

In this groundbreaking report, Tien Ming Lee and colleagues identify individual predictors of climate change awareness and perceptions of risk in 119 countries – the largest comparative international analysis of climate change perceptions ever conducted. The authors used Gallup World Poll data and conditional inference trees (illustrated in the figure below) to overcome variations in data availability, ultimately identifying significant predictors of climate change perceptions, as well as the interactions between top predictors on a per country basis.



This analysis carries great potential not only in identifying the basic state of understanding around climate change, its causes, and associated risks, but also in pinpointing underlying drivers in those understandings. Variables analyzed included socio-demographics, physical and financial well-being, beliefs about climate change, communication/media access, civic engagement, satisfaction with air and water quality, satisfaction with governmental measures to preserve the surrounding environment, perceptions of warming vs. cooling, urban vs. rural residence, religion and education level, among others. Worldwide, top predictors of climate change awareness and risk perception were education level (62% of countries) and beliefs about the cause of climate change (48%).



The key finding of this analysis, however, is that there is no single common underlying predictor of climate change awareness globally (as is evidenced in the diversity of top predictors illustrated in the figure to the right). Improving primary and secondary education, climate literacy, and access to communication/media are in many cases sound strategies for bolstering public awareness of climate change and risk, but they are not a panacea. Furthermore, even regional comparisons about

predictors of awareness and risk are not significant in determining awareness and perception on an individual level. While certain regions (south Asia, Latin America) have common predictors, many nations have distinctive sets of predictors that are unlike their neighbors. Likewise, GDP and Human Development Index (HDI) proved insignificant in correlating with predictor trends.

Citizen engagement must therefore be tailored to country-specific correlates. The supplementary indices of this research provide hundreds of pages detailing interactions between top predictors of climate change awareness and perceptions of risk for each of the 119 countries analyzed, providing a resource of unique value and depth for researchers and climate science communicators working around the world.

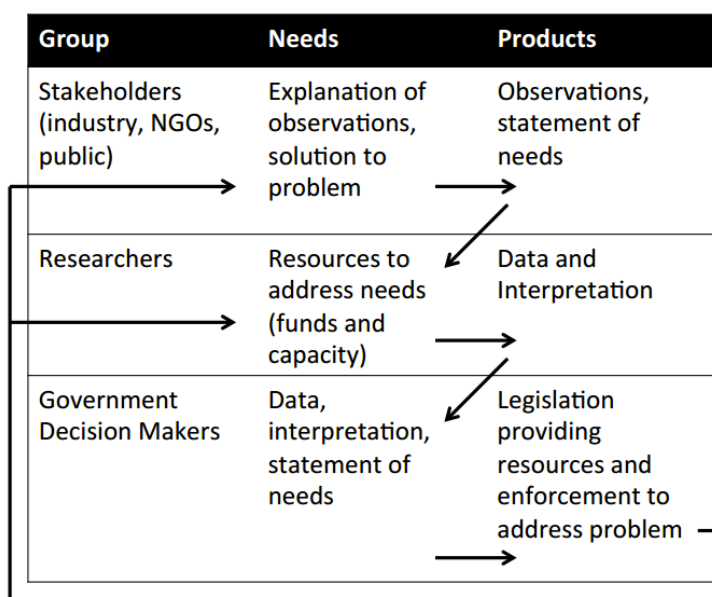
SUCCESSSES AND CHALLENGES OF OCEAN ACIDIFICATION LEGISLATION

Cooley, S.R., E.B. Jewett, J. Reichert, L. Robbins, G. Shrestha, D. Wieczorek and S.B. Weisberg. 2015. Getting ocean acidification on decision makers' to-do lists: Dissecting the process through case studies. *Oceanography* 28(2):198-211.

The effects of ocean acidification operate on massive spatial and temporal scales. The world's oceans are currently a main sink for atmospheric CO₂, which is already resulting in significant changes to the pH balance of ocean water and has compromised the ability of shellfish to reproduce and build healthy shells. But as Sarah Cooley and colleagues discuss, getting ocean acidification onto the agendas of decision-makers is often dependent on the convergence of readily synthesized data, legislative framework availability, decision-maker need, and bottom-up cross-cultural support.

Through a series of case studies on local, state, national, and international scales, the authors of this paper identify success and complexities associated with making headway on addressing ocean acidification. Successful

frameworks in Oregon, Washington, and Maine resulted from bottom-up approaches where industry needs, scientific findings, and decision-maker support resulted in task forces that successfully put forth legislation mitigating local non-CO₂ sources that contribute to ocean acidification (such as pollution from farms and septic systems). The task forces were most successful when issues raised by decision-makers and industry



(often in the face of crises) had straightforward scientific explanations. Conversely, when interactions of various causes for ocean acidification were presented (e.g., identifying multiple drivers including CO₂), responses by decision-makers were significantly slower and less successful.

State and national authority in the U.S. to address CO₂ as a driver of ocean acidification is currently lacking. The authors identify the limitations of the Clean Water Act (CWA) as a potential framework through which to address ocean acidification. The CWA was established before ocean acidification was a consideration and therefore lacks regulatory authority for states to address atmospheric (e.g. CO₂) and land-based non-point sources of pollution (e.g. nutrient runoff from activities such as agriculture). Due to lack of legislative authority, state and national efforts to address ocean acidification are often confined to filling gaps in scientific research on the subject.

International coalitions of scientists, governmental agencies, philanthropic foundations, and non-governmental organizations have also formed task forces and councils, but again lack a legislative framework. These organizations often work to generate distilled messages, which the public and decision-makers rely on to understand the origins, impacts and challenges of ocean acidification. The UN Framework Convention on Climate Change, meeting for the 21st time this December, may provide the most promising avenue for international mitigation of CO₂ as a means of addressing ocean acidification. Success in this venue will require scientists to clearly define ramifications of inaction – a challenging task given the inherent complexities and uncertainties within ocean acidification research.

Looking forward, this paper identifies the clear need for cross-cultural, interdisciplinary collaborations to yield successful results in addressing the underlying causes of ocean acidification. Filling gaps in research has and will prove imperative to addressing specific decision-maker questions and demands when they arise – as these times have proven the most opportune for pushing forward ocean acidification legislation. Developing legislative frameworks on various political scales is also necessary if decision-makers hope to mitigate ocean acidification as an increasingly glaring consequence of anthropogenic manipulation of the carbon cycle.