nationally determined contributions (INDCs)[4]. The INDCs represent an intermediate effort at global level between the two studied policy cases. It is not clear if the level of emission reductions and enforced energy policies implied by the pledges will be stringent enough in the case of a low-oil-price world. The implementation of the INDCs implies that an implicit national carbon price could compete with the global oil price, and that this balance will determine the accomplishment of the commitments.

As such, additional mitigation efforts may be necessary to reach the national targets if the oil price remains unexpectedly low. A safer approach may be to consider a low oil price in policy implementation, including a risk of higher policy cost. McCollum and colleagues do not provide any analysis about cost impacts from oil uncertainty, and did not model national emission and energy targets. This point is crucial and requires more investigation.

Following the trend in climate modelling, the joint uncertainty assessment of the energy system conducted by McCollum and colleagues is a practice that should be more systematic, especially when energy modelling embeds a large amount of predictive information on future technologies. This uncertainty analysis could bring a comprehensive overview of the interactions and substitutions within the energy system and help to understand the robustness of the emissions trajectories produced by these models. Going beyond the unique model approach demonstrated by McCollum and colleagues, a multi-model approach should be the standard for this type of assessment. ❐

Laurent Drouet is at the Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici, Corso Magenta 63, 20123 Milan, Italy, and at the Fondazione Eni Enrico Mattei, Corso Magenta 63, 20123 Milan, Italy.
e-mail: laurent.drouet@cmcc.it

References

1. Klevnäs, P., Stern, N. & Frejova, J. *Oil Prices and the New Climate Economy* (The Global Commission on the Economy and Climate, 2015); http://go.nature.com/1UtG2Jx
2. Tokarska, K. B., Gillett, N. P., Weaver, A. J., Arora, V. K. & Eby, M. *Nature Clim. Change* http://dx.doi.org/10.1038/nclimate3036 (2016).
3. McCollum, D. L. *et al. Nature Energy* **1**, 16077 (2016).
4. *Synthesis Report on the Aggregate Effect of the Intended Nationally Determined Contributions* FCCC/CP/2015/7 (UNFCCC, 2015).

OCEANOGRAPHY

Human influence on sea-level rise

Detection and attribution of sea-level rise is hampered by the lack of historical model estimates for the individual components. Now research bridges this gap and uncovers an accelerating anthropogenic contribution over recent decades.

Sönke Dangendorf

Over the past century, tide gauges have shown that the global mean sea level (GMSL) has risen steadily by 14–22 cm (ref. 1) (depending on the reconstruction technique); an increase very likely being unprecedented over any of the previous 27 centuries[2]. Despite having identified ocean thermal expansion and glacier mass loss as the two dominant contributors to GMSL rise over the twentieth century, debate has continued on how much of the observed GMSL change is related to natural or anthropogenic causes. The attribution to natural radiative forcings (such as solar and volcanic), natural internal climate variability and anthropogenic greenhouse gases or aerosols requires, besides observations, fully forced historical climate models containing individual forcings either in tandem or in isolation. Writing in *Nature Climate Change*, Aimée Slangen and colleagues[3] now uncover the anthropogenic contribution from the observed twentieth-century GMSL rise and provide evidence that it accelerated from less than 15% before 1950 to more than 70% in recent decades.

Changes in GMSL are a good climate indicator, as they reflect both thermal expansion/contraction in response to the warming/cooling of the ocean and changing mass input from ice sheets, glaciers or other terrestrial freshwater sources. Such changes occur on a wide range of timescales and it is generally hard to distinguish whether they stem from past or current natural climate variations, or from anthropogenic forcing. Although it has recently been demonstrated that the GMSL rise cannot be explained by natural variability alone[4], formal attribution studies have been limited to the individual components of thermal expansion[5,6] and glacier melting[7]. This is mainly due to a lack of observations spanning the entire century and/or sophisticated models of each individual component.

To address this issue, Slangen and colleagues[3] combined models of thermal expansion, glacier melting and mass change of the Greenland and Antarctic ice sheets, and forced them with results from historical runs of the Coupled Model Intercomparison Project Phase 5 (CMIP5). By summing up the different contributions when forced with both natural and anthropogenic factors, they are able to explain 74 ± 25% (±2σ) of the observed GMSL change (a mean of four of the most prominent reconstructions; see discussion below) since 1900. To separate natural from anthropogenic factors, the models were then forced with each factor in isolation.

The results suggest that the relative importance of natural and anthropogenic forcing has significantly changed over the twentieth century[3]. Before 1950 the observed increase was dominated by past climate variations and natural radiative forcing (67 ± 23%), but the anthropogenic contribution quickly increased to more than 70% in recent decades. Over the entire century, the authors estimate the anthropogenic contribution to be in an order of 38 ± 12%. The comparatively low value of 38% might be surprising, but it underlines the importance of natural climate variability, which was recently critically discussed with respect to the inertia of the ocean[8,9] and glaciers[7,8], and their combined impact on centennial GMSL variations[4]. In agreement with earlier studies[7], the authors find that much of the GMSL change before 1950 was indeed related to the delayed response to the end of the Little Ice Age, when large parts of the Northern Hemisphere were covered by ice.

© 2016 Macmillan Publishers Limited. All rights reserved.

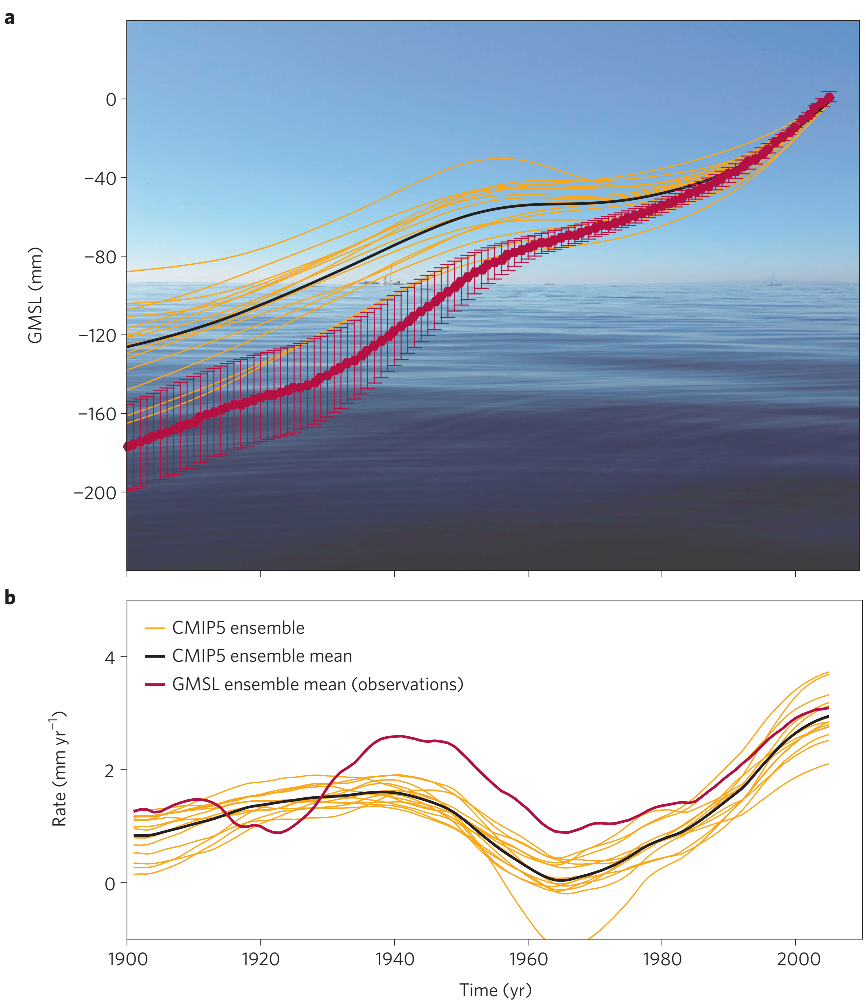

Figure 1 | Twentieth-century sea-level rise. **a**, GMSL rise from an ensemble mean of observations and as modelled with CMIP5 historical forcing by Slangen *et al.*[3]. **b**, The corresponding rates of rise.

The work of Slangen and colleagues[3] is the first attribution assessment integrating all individual contributions to GMSL and thus represents a major step forward. However, the work also signifies some important issues related to the closure of the twentieth-century GMSL budget. Despite some striking multi-decadal similarities in the GMSL rates, the CMIP5 ensemble of individual (modelled) components is only able to explain 74 ± 25 % of the observed total GMSL change (Fig. 1). These differences may result from poor model performance or uncertainties in the available GMSL reconstructions from the sparse tide gauge network[10]. Although the authors demonstrate that their conclusions about the anthropogenic contribution are insensitive to the choice of the GMSL reconstruction, the obtained differences should stimulate further research not only towards better model parameterizations but also to enhance our understanding of the differences in individual GMSL reconstructions.

Overall, the paper by Slangen and colleagues[3] provides important insights into the role of natural and anthropogenic contributions to the observed GMSL change. Although sea-level changes have become symbolic for anthropogenic climate change, it has also become very clear that the atmosphere–cryosphere–ocean system takes decades (or even centuries) to adjust to climatic changes. This implies, in turn, that not only anthropogenic factors were at play over the twentieth century — this has important implications for the future. First of all, it underpins that current changes in the climate system will have serious impacts on many future generations. Second, it emphasizes the role of natural variations in future climate projections. Natural sea-level variability can significantly mask or amplify anthropogenic long-term changes with serious impacts on our coasts. Hence, coastal safety management and planning, which usually occurs over timescales of a few decades, must also take natural variations — in addition to the accelerating anthropogenic contribution — into account. ❐

Sönke Dangendorf is at the Research Institute for Water and Environment, University of Siegen, Paul-Bonatz-Str. 9–11, 57076 Siegen, Germany.
e-mail: soenke.dangendorf@uni-siegen.de

References

1. Church, J. *et al.* in *Climate Change 2013: The Physical Science Basis* (eds Jouzel, J., van de Wal, R., Woodworth, P. L. & Xiao, C.) Ch. 13 (IPCC, Cambridge Univ. Press, 2013).
2. Kopp, B. *et al. Proc. Natl Acad. Sci. USA* http://dx.doi.org/10.1073/pnas.1517056113 (2016).
3. Slangen, A. B. A. *et al. Nature Clim. Change* **6,** 701–705 (2016).
4. Dangendorf, S. *et al. Nature Commun.* **6,** 7849 (2015).
5. Marcos, M. & Amores, A. *Geophys. Res. Lett.* **41,** 2502–2507 (2014).
6. Slangen, A. B. A. *et al. Geophys. Res. Lett.* **41,** 5951–5959 (2014).
7. Marzeion, B. *et al. Science* **345,** 919–921 (2014).
8. Dangendorf, S. *et al. Geophys. Res. Lett.* **41,** 5564–5571 (2014).
9. Wunsch, C. *Ann. Rev. Mar. Sci.* **8,** 1–33 (2016).
10. Hamlington, B. & Thompson, P. *Geophys. Res. Lett.* **42,** 4102–4109 (2015).

Published online: 11 April 2016

© 2016 Macmillan Publishers Limited. All rights reserved.