Institution: University of Southampton

Unit of Assessment: 07 Earth Systems and Environmental Sciences

Title of case study: 07-10 Raising awareness of the rapidity of past sea level change

1. Summary of the impact

Research at the University of Southampton has redefined understanding of the potential rapidity of sea level rise above the present, and of the relationship between climate change and sea level. It has informed the "worst-case scenario" for climate change flood risk assessment in the UK as well as key adaptation policy documents throughout Europe, North America and Australasia. Impact generation occurs mainly though active public engagement, which ensures widespread international media attention, and through direct interaction with the Environment Agency (EA) and UK Climate Impact Programme (UKCIP) which have now joined the research group in a £3.3 million consortium project to better define the "worst case scenario".

2. Underpinning research

Sea level rise is a key effect of climate change, putting coastal populations, infrastructure and world trade at risk. Around £150 billion of assets along the UK coastline are at risk from flooding, of which £75 billion are in London alone. Consequently, most nations have developed and implemented protection plans, using estimates of sea level rise based on global warming scenarios.

However, there is a lack of data on the extent to which past sea level rises exceeded present levels, prompting concerns that the world is underestimating the scale of future sea level rise. Since the mid-1990s, research by the University of Southampton at the National Oceanography Centre, Southampton (NOCS), led by Eelco Rohling, Professor of Ocean and Climate Change (1994-present), has developed with international collaborators a new method of reconstructing sea level change by measuring oxygen isotope ratios in fossils from the Red Sea. By studying how sea levels changed during warmer periods between ice ages, a view has been formed on how fast global ice volume/sea level can change, with implications for the future.

Prior to Rohling's methodology, first described in *Nature* in 1998 **[3.1]**, researchers focused on fossil reefs to reveal the magnitude of sea level peaks (highstands) of the past million years but could only measure sea level lowstands back to the Last Glacial Maximum, 20,000 years ago. The new method combined evidence of extreme high-salinity conditions in the glacial Red Sea with a simple hydraulic control model of water flow through the Strait of Bab-el-Mandab, which links the Red Sea to the Indian Ocean. This new approach has produced sea level lowstand estimates stretching back hundreds of thousands of years.

Supervised by Rohling and Dr David Smeed (NERC-NOCS), Mark Siddall (University of Southampton PhD student 2001-2004) furthered the methodology **[3.2]**. By combining oxygen isotope records from Red Sea sediments with a hydraulic model of water exchange at Bab-el-Mandab, the researchers could measure global sea level going back 470,000 years, to an accuracy of ±6 m compared with previous ranges of ±15 m.

With the input of Research Assistant Katharine Grant (University of Southampton 2005-present) the research matured to a complete record in 2008-2012 **[3.3-3.5]**. This included the first coherent estimate of rates of sea level rise above the present, at 1.6 ±1 metres per century **[3.3]**. This has helped the UK government define their worst-case planning scenario for future century-scale sea-level rises. Rohling's sea level record for the past 520,000 years also revealed a strong correlation on multi-millennial timescales between global sea level and Antarctic temperature **[3.4-3.5]**. Rohling estimated that the sea level around three million years ago – a period with near modern CO_2 levels – was 25 ±5m above the present. This indicates that future long-term sea level rise could far exceed existing projections **[3.4]**. This was supported by a major parallel effort led by Rohling, which established that climate sensitivity to radiative forcing at that time was similar to the present **[3.6]**.

3. References to the research (the best 3 illustrating quality of work are starred)

[3.1] Rohling, E.J., Fenton, M., Jorissen, F.J., Bertrand, P., Ganssen, G., and Caulet, J.P. Magnitudes of sea level lowstands of the past 500,000 years. *Nature, 394*, 162-165, 1998.

***[3.2]** Siddall, M., Rohling, E.J., Almogi-Labin, A., Hemleben, Ch., Meischner, D., Schmeltzer, I., and Smeed, D.A., Sea level fluctuations during the last glacial cycle, *Nature, 423*, 853-858, 2003.

***[3.3]** Rohling, E.J., Grant, K., Hemleben, Ch., Siddall, M., Hoogakker, B.A.A., Bolshaw, M., and Kucera, M., High rates of sea level rise during the last interglacial period. *Nature Geoscience, 1*, 38-42, 2008.

[3.4] Rohling, E.J., Grant, K., Bolshaw, M., Roberts, A.P., Siddall, M., Hemleben, Ch., and Kucera, M., Antarctic temperature and global sea level closely coupled over the past five glacial cycles. *Nature Geoscience, 2,* 500-504, 2009.

***[3.5]** Grant, K.M., Rohling, E.J., C., Bar-Matthews, M., Ayalon, A., Medina-Elizalde, M., Bronk Ramsey, C., Satow, C., and Roberts, A.P., Rapid coupling between ice volume and polar temperature over the past 150 kyr. *Nature, 491*, 744–747, 2012.

[3.6] PALAEOSENS Project Members (Rohling, E.J. et al), Making sense of palaeoclimate sensitivity. *Nature, 491*, 683–691, 2012.

Research Funding

(i) NERC project NE/C003152/1 (£ 217 k) *A centennial-scale sea level record for the last 450,000 years* (1 Oct 2005 - 30 Sep 2010)

(ii) successor project NE/H004424/1 (£ 406 k) *Centennial-scale relationship of sea level variability with global temperature and CO2 concentrations* (1 Feb 2010 - 31 Jan 2014) (both awarded to Prof. Rohling),

(iii) NERC consortium project NE/I009906/1 (entire consortium £ 3.3 M; Southampton component £ 626 k) *Using inter-glacials to assess future sea level scenarios (iGlass)* (1 Jul 2011 - 30 Jun 2015) (Prof. Rohling was consortium coordinator and is PI of the Southampton component).

4. Details of the impact

The 2008 finding, by a group led by Rohling, that global sea level could rise 1.6 ±1 metres per century helped reshape the worst case scenarios considered in planning documents worldwide. It provided the first real-life estimates and in the UK helped to bring estimates down from very high initial assumptions (UK Climate Projections UKCP09, **[5.1]**; Environment Agency (EA) Thames Estuary (TE) 2100 Plan **[5.2]**). Assimilation of the work into planning arose from a combination of scientific publications (which led to widespread international media coverage across more than 400 news outlets) and active engagement at expert workshops and conferences.

The UK's latest climate change projections present a "*sensible maximum value*" for planning and flood risk assessments **[5.1]**, amongst others taken up by the EA **[5.2]**. The UKCP09's H++ scenario warns of sea level rise between 0.93 and 1.9m by 2100; the upper estimate directly relates to Rohling's estimates **[5.1]**. The EA uses values of the H++ scenario in its flood risk management strategy for the Thames Estuary, ensuring that its plans could cope with a sea level rise of 2 to 2.7 m; this "*reduction in worst case scenario for this century means that a (*proposed*) tide-excluding estuary barrage will not be necessary to manage flood risk this century and can be dropped from our final options*" (TE2100 Plan **[5.2]**).

Rohling's research also informed the scientific underpinning of The Netherlands' Delta Committee Report *Working together with water: A living land builds for its future* **[5.3]**, which presents an integrated vision for the long term protection of the Dutch coast and its hinterland extending to 2100 and beyond. The recommendations were completed in 2008, presented to the Dutch Cabinet in 2010, ratified in November 2011, and have been implemented since January 2012**.**

In New Zealand Rohling's work informed the 2008 report *Climate Change: Impacts on Dunedin*, which recommended the adoption of a new upper limit to sea level rise. These estimates, contained in Dunedin City Council's *Climate Change Predictions Policy* (2011) are reflected in council policies, for example increased minimum floor levels for new buildings **[5.4]**.

In Canada the British Columbia Ministry of Environment *Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use* (2012) make extensive use of Rohling's work (via the associated 2011 *Draft Policy Discussion Paper*). Another contributor to this report Golder Associates have used the new guidelines in their Harbourside development in Vancouver and "*proposed a shoreline concept adapted for sea level rise*". They also comment that *"Anticipating climate change is now paramount for most land use and design projects"* **[5.5]**. Rohling's work is also used in Vancouver municipal authority's 2008 report *Vulnerability of Vancouver sewerage area infrastructure to climate change* and the City of Vancouver *Climate Change Adaptation Strategy (2012)*.

Other examples of a wide variety of uses include, Australia's Climate Change White Paper (2008), the World Wildlife Fund's Arctic Programme Report *A closing window of opportunity - global greenhouse reality* (2008) and in the November 2012 World Bank report *Turn down the Heat*: *Why a 4 degree centigrade warmer world must be avoided*.

Sustained public engagement has helped ensure that future sea level rise remains at the forefront of public debate on climate change. Worldwide media coverage (for example the BBC, Reuters, Chinapost.com) **[5.6]** followed the online publication of **[3.3]** in December 2007 and **[3.4]** in June 2009, resulting in continuing interactions with global broadcast and print media, and email exchanges with the public. In December 2011 at the American Geophysical Union Fall meeting (the world's largest geophysical sciences conference), together with James Hansen and Ken Caldeira, Rohling gave an hour-long press conference in which his palaeoclimate research was covered **[5.7]**. This led to a USA Today feature article **[5.7]** (referenced on its front page; 3.2 million readers daily), which attracted 200+ reader comments/likes/recommends/tweets. The article was reproduced on ABC News with 300+ audience comments/likes/recommends/tweets, and led to a nine-minute interview for Scientific American **[5.8]** (3.88 million unique users per month).

Other dissemination efforts at focused workshops have included the Challenger Society meeting on sea level change (Royal Society, Nov. 2010), and a workshop at UNESCO's Venice office in 2010, which led to a UNESCO report **[5.9]** looking at the future of Venice under climate change.

Rohling considers continued outreach directly to the wider public to be important, because only education can change attitudes. In November 2011, Rohling gave a keynote speech at a public engagement event on climate change organised in Amsterdam by the Dutch media. It was attended by 300 members of the public and journalists. The debate was given extensive coverage in the national daily newspaper NRC **[5.10]** (840,000 readers) and NRC.next (350,000 readers), as well as the climate blog of Paul Luttikhuis, which has 20 million page views per month. He also gave talks and workshops to a variety of smaller meeting audiences, including marine engineers, Royal Navy officers, Wessex public heath specialty registrars, and charities, and he contributed to fact-finding and script-definition for climate change documentaries by NHK Japan, Picture Films for National Geographic, and Wildfire TV.

Rohling set up NERC consortium project iGlass, which includes direct involvement of seven UK research institutes, two overseas academic partners and – importantly – three key stakeholders: UKCIP (formerly UK Climate Impact Programme), EA, and global re-insurance specialist Willis Ltd. The stakeholders are directly involved in project development, results synthesis and in defining strategies to ensure that results are developed and presented from the outset in optimized form for planning purposes (e.g., to assist the insurance industry in improving their understanding of likely rates of future sea level change). The EA considers this research "*with its key outcome to place sound limits on the likely ice-volume contribution to maximum sea level rise estimates for the near future, vital if we are to prepare adequately for the full range of potential impacts*" **[5.11]**.

5. Sources to corroborate the impact

[5.1] UK Climate Projections (UKCP09) are funded by Defra on behalf of the UK Government and the Devolved Administration to meet the needs of people who need to assess potential impacts of projected future climate. UKCP09 Science report: Marine and coastal projections (2009). http://ukclimateprojections.defra.gov.uk/media.jsp?mediaid=87850&filetype=pdf (pages 31-33).

[5.2] Environment Agency plan (TE2100) "Managing flood risk through London and the Thames estuary" (2012) https://brand.environment-agency.gov.uk/mb/CtyxlR, with summaries of underpinning findings at http://www.environment-agency.gov.uk/homeandleisure/floods/125063.aspx and http://www.environment-agency.gov.uk/research/137601.aspx

[5.3] Working together with water: A living land builds for its future – Findings of the Deltacommissie (2008) http://www.deltacommissie.com/doc/deltareport_full.pdf (pages 114-5)

[5.4] Climate Change: Impacts on Dunedin http://www.sustainabledunedincity.org.nz/?p=426 Climate Change Predictions Policy http://www.dunedin.govt.nz/your-council/council-documents/policies/climate-change-predictions-policy Change in guidance http://www.dunedin.govt.nz/your-council/latest-news/november-2012/minimum-floor-levels-in-some-coastal-areas-to-rise-to-counter-climate-change

[5.5] Guidelines and Discussion policy http://www.env.gov.bc.ca/wsd/public_safety/flood/fhm-2012/draw_report.html (3a and c), new guidelines http://www.globe-net.com/articles/2011/may/7/bc-releases-new-sea__level-rise-report.aspx and Golder article http://www.golder.com/as/modules.php?name=Newsletters&op=viewarticle&sp_id=183&page_id=1100&article_id=612

[5.6] Selection of online articles following publication of 2007 and 2009 papers demonstrating the worldwide coverage achieved.

[5.7] AGU Press conference (December 2011): Paleoclimate record points toward potential rapid climate changes. http://www.youtube.com/watch?v=KTTlAAiwgwM&feature=youtu.be and follow up article in USA Today (December 2011): http://www.usatoday.com/tech/science/environment/story/2011-12-06/global-warming-raises-sea level/51684646/1

[5.8] Scientific American interview (December 2011): Out of our depth: Sea level on the rise. http://www.scientificamerican.com/podcast/episode.cfm?id=out-of-our-depth-sea level-on-the-r-11-12-08

[5.9] UNESCO report from Venice workshop held in November 2010: From global to regional: Local sea level rise scenarios- Focus on the Mediterranean Sea and the Adriatic Sea. http://www.unesco.org/new/fileadmin/MULTIMEDIA/FIELD/Venice/pdf/rapporto1_very%20high%20res.pdf

[5.10] NRC debate (November 2011): http://www.nrc.nl/klimaat/2011/11/03/een-historische-relativering-maar-dan-omgedraaid/ and http://kennisvoorklimaat.klimaatonderzoeknederland.nl/nrcklimaatdebatten

[5.11] iGlass partners: Regional Climate Change Manager - Thames Region, Environment Agency.