Warm climate, high seas.
How did sea level change in Europe during the Last Interglacial?

The big picture

Global sea-level rise is one of our greatest environmental challenges and is predicted to continue for hundreds of years, even if global greenhouse-gas emissions are stopped immediately (Clark et al., 2016). However, the range, rates and responses to sea-level rise beyond 2100 are poorly understood. Current models that project sea-level rise centuries into the future have large uncertainties, because the recent observations upon which they are based encompass too limited a range of climate variability. Therefore, it is crucial to turn to the geological record where there are large-scale changes in climate. Global temperatures during the Last Interglacial were ~1°C warmer than pre-industrial values and 3-5°C warmer at the poles (a pattern similar to that predicted in the coming centuries), and global sea level was 6-9 m higher (Dutton et al., 2015), far above that experienced in human memory.

The PhD project

This PhD project forms part of the €2 million European Research Council Starting Grant, "*Rates of Interglacial Sea-Level Change and Responses*" (RISeR) which aims to advance our understanding of the magnitude, rates and drivers of sea-level change during the Last Interglacial, to inform both global and regional sea-level projections beyond 2100.

European Research Council
Established by the European Commission

RISeR is focusing on developing a state-of-the-art Last Interglacial sea level record from northwest Europe. Relative sea-level changes in northwest Europe are a consequence of change in the volume and distribution of water in the global ocean, but also solid earth processes as a result of regional loading by ice sheets during glacial periods (termed glacial isostatic adjustment, GIA). This means the sea-level highstand during any interglacial period in northwest Europe differs in timing and magnitude from that recorded elsewhere (Hay et al., 2014; Lambeck et al., 2012). In particular, the Last Interglacial (~125 ka) sea-level highstand in northwest Europe is later than that experienced in the low-latitudes (Peeters et al., 2016). The pattern and rate of GIA in the current interglacial also differs from that during the Last Interglacial as the history of the ice sheets is different during each glacial phase, with the Eurasian ice sheet much bigger in the preceding (MIS 6) glacial than during the Last Glacial Maximum (Colleoni et al., 2016; Dendy et al., 2017; Rohling et al., 2017; Svendsen et al., 2004).

This PhD project will develop a regional GIA model to understand the solid earth response in northwest Europe during the Last Interglacial. The student will use a new generation of ice-sheet models within a global GIA model to compare to and interpret the new Last Interglacial relative sea-level reconstructions produced by the wider RISeR project. **This work will provide the first regional Last Interglacial glacial-isostatic adjustment model and a statistical assessment of the likelihood of different melt water sources to the Last Interglacial highstand and their contribution to relative sea-level change in northwest Europe.**

The methods

Research into Last Interglacial global datasets has shown the importance of the inputted ice sheet history (Düsterhus et al., 2016) with the need to better constrain its spatially variable distribution, rather than simply scaling for total ice-volume changes based upon the marine oxygen-isotope curve (Dendy et al., 2017; Rohling et al., 2017). Last Interglacial GIA research to-date has been on a global scale, which provides an excellent framework for PhD project to look at regional GIA in northwest Europe in detail. Regional case-studies have been a critical part of constraining post LGM and Holocene GIA models (e.g., Lambeck, 2002) and this PhD will contribute to the next-generation of Last

Interglacial GIA models, which have been identified as crucial to be able to better understand the rates and magnitudes of Last Interglacial sea-level change (Rohling et al., 2017). Understanding Last Interglacial solid earth processes, is also an important part of being able to use the Last Interglacial as an analogue for future coastal response to rates of RSL change under a warm climate, as the pattern of GIA during the Last Interglacial and the next centuries will differ.

The GIA modelling will conducted using a gravitationally self-consistent global sea-level model with Earth rotational feedbacks, migrating shorelines and deformation of a viscoelastic Earth with radially varying Earth structure, which has been used to answer a range of sea-level problems (Gomez et al., 2015a; Gomez et al., 2015b; Gomez et al., 2013; Hay et al., 2014). By subtracting the modelled GIA driven regional land-level changes from the reconstructed RSL curve, it will be possible derive an estimate of the contribution to the rates of change from ice loss during the interglacial period. This will be used to 'fingerprint' the sea-level signal for Last Interglacial ice loss (Greenland v Antarctica) (Figure 1).

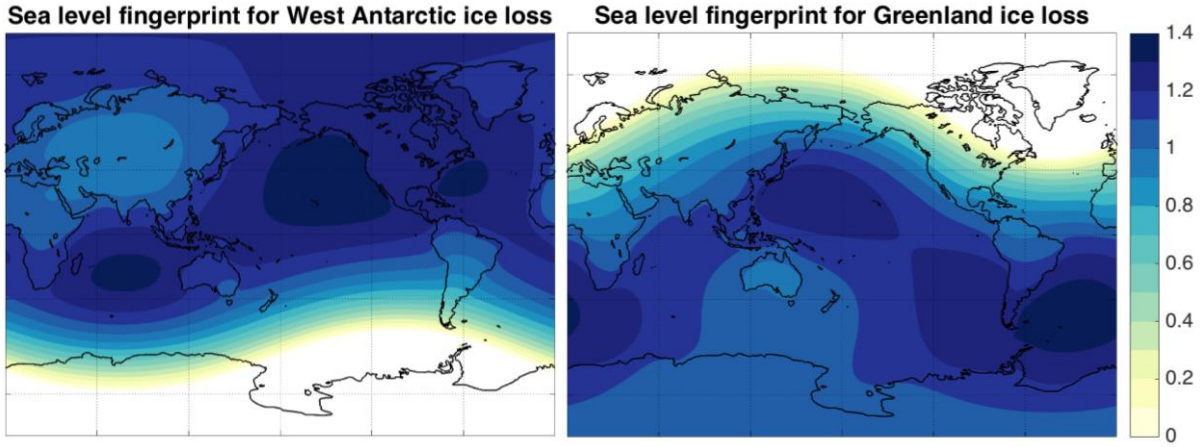

Figure 1 – Illustration of the spatial fingerprint of sea-level change (m) caused by example melting scenarios of the West Antarctic and Greenland ice sheets. Image credit: Dr Natalya Gomez.

Training and support

This fully-funded PhD is a key component of the wider RISeR project, and the student will work closely with research fellows and the international research team, as well as being an active part of the research programme. You will benefit from a wider research network at the University of Leeds including Leeds Quaternary, the Institutes of Applied Geoscience, Earth System Science and Climate and Atmospheric Science, Priestley International Centre for Climate, and an outstanding computing infrastructure. The project will be supervised by Dr Natasha Barlow, Dr Lauren Gregoire (Leeds) and Dr Natalya Gomez (McGill, Canada) with the potential for a research visit to Canada. You will be able to access the excellent centralised training provided by the University of Leeds and specific training will be given in:

- Significant research themes in the discipline of Quaternary environmental change
- Operating the sea level model on high performance computing facilities
- Designing methods for quantifying uncertainty in projections
- Programming in Fortran and python
- Visualising and analysing data and ice sheet and sea level model output

There will be opportunities to present at national and international conferences and join part of a wider sea level research community in the UK.

Student profile

This is a **fully-funded** project open to UK/EU citizens who have a background in Geosciences, mathematics, physics or a related discipline, ideally with a minimum of a BSc at 2i, or a related Masters degree. Some experience in computer modelling would be a benefit. A keen interest in environmental change is desirable, in particular in climate and sea-level change. A willingness to contribute to the wider research programme and work within a larger team is essential.

The expected start date is October 2019. Funding is available for 3.5 years, subject to satisfactory progression, including tuition fees (£4,400 for 2018/19), a tax-free stipend (£14,777 for 2018/19) and a research training and support grant.

How to apply

The position will remain open until it is filled, but we encourage interested applicants to apply by 26th April 2019. Please submit a copy of your CV, and a 400 word statement of motivation explaining why you have applied for this project and the skills you will bring to RISeR.

Formal applications for research degree study should be made online through the University of Leeds website. Please state clearly in the research information section that the PhD you wish to be considered for is the 'Warm climate, high seas. How did sea level change in Europe during the Last Interglacial?' as well as Dr Natasha Barlow as your proposed supervisor.

Additional information

Last Interglacial sea level was 6-9 m higher (short YouTube video)
Understanding past sea-level change on Climatica
Find out more about the RISeR project
You can find the supervisors on Twitter @DrTashaBarlow, @LaurenGregoire, @NatalyaGomezEPS

References

- Clark, P.U., Shakun, J.D., Marcott, S.A., Mix, A.C., Eby, M., Kulp, S., Levermann, A., Milne, G.A., Pfister, P.L., Santer, B.D., Schrag, D.P., Solomon, S., Stocker, T.F., Strauss, B.H., Weaver, A.J., Winkelmann, R., Archer, D., Bard, E., Goldner, A., Lambeck, K., Pierrehumbert, R.T., Plattner, G.-K., 2016. Consequences of twenty-first-century policy for multi-millennial climate and sea-level change. Nature Clim. Change 6, 360-369.
- Colleoni, F., Wekerle, C., Näslund, J.-O., Brandefelt, J., Masina, S., 2016. Constraint on the penultimate glacial maximum Northern Hemisphere ice topography (≈140 kyrs BP). Quaternary Science Reviews 137, 97-112.
- Dendy, S., Austermann, J., Creveling, J.R., Mitrovica, J.X., 2017. Sensitivity of Last Interglacial sea-level high stands to ice sheet configuration during Marine Isotope Stage 6. Quaternary Science Reviews 171, 234-244.
- Düsterhus, A., Tamisiea, M.E., Jevrejeva, S., 2016. Estimating the sea level highstand during the last interglacial: a probabilistic massive ensemble approach. Geophysical Journal International 206, 900-920.
- Dutton, A., Carlson, A.E., Long, A.J., Milne, G.A., Clark, P.U., DeConto, R., Horton, B.P., Rahmstorf, S., Raymo, M.E., 2015. Sea-level rise due to polar ice-sheet mass loss during past warm periods. Science 349.
- Gomez, N., Gregoire, L.J., Mitrovica, J.X., Payne, A.J., 2015a. Laurentide-Cordilleran Ice Sheet saddle collapse as a contribution to meltwater pulse 1A. Geophysical Research Letters 42, 3954-3962.

- Gomez, N., Pollard, D., Holland, D., 2015b. Sea-level feedback lowers projections of future Antarctic Ice-Sheet mass loss. 6, 8798.
- Gomez, N., Pollard, D., Mitrovica, J.X., 2013. A 3-D coupled ice sheet – sea level model applied to Antarctica through the last 40 ky. Earth and Planetary Science Letters 384, 88-99.
- Hay, C., Mitrovica, J.X., Gomez, N., Creveling, J.R., Austermann, J., E. Kopp, R., 2014. The sea-level fingerprints of ice-sheet collapse during interglacial periods. Quaternary Science Reviews 87, 60-69.
- Lambeck, K., 2002. Sea Level Change from Mid Holocene to Recent Time: An Australian Example with Global Implications, in: Mitrovica, J.X., Vermeersen, B. (Eds.), Ice Sheets, Sea Level and the Dynamic Earth. AGU Geodynamics Series 29, Washington, DC, pp. 33-50.
- Lambeck, K., Purcell, A., Dutton, A., 2012. The anatomy of interglacial sea levels: The relationship between sea levels and ice volumes during the Last Interglacial. Earth and Planetary Science Letters 315, 4-11.
- Peeters, J., Busschers, F.S., Stouthamer, E., Bosch, J.H.A., Van den Berg, M.W., Wallinga, J., Versendaal, A.J., Bunnik, F.P.M., Middelkoop, H., 2016. Sedimentary architecture and chronostratigraphy of a late Quaternary incised-valley fill: A case study of the late Middle and Late Pleistocene Rhine system in the Netherlands. Quaternary Science Reviews 131, 211-236.
- Rohling, E.J., Hibbert, F.D., Williams, F.H., Grant, K.M., Marino, G., Foster, G.L., Hennekam, R., de Lange, G.J., Roberts, A.P., Yu, J., Webster, J.M., Yokoyama, Y., 2017. Differences between the last two glacial maxima and implications for ice-sheet, δ18O, and sea-level reconstructions. Quaternary Science Reviews 176, 1-28.
- Svendsen, J.I., Alexanderson, H., Astakhov, V.I., Demidov, I., Dowdeswell, J.A., Funder, S., Gataullin, V., Henriksen, M., Hjort, C., Houmark-Nielsen, M., 2004. Late Quaternary ice sheet history of northern Eurasia. Quaternary Science Reviews 23, 1229-1271.