Large and Rapid Climate Change

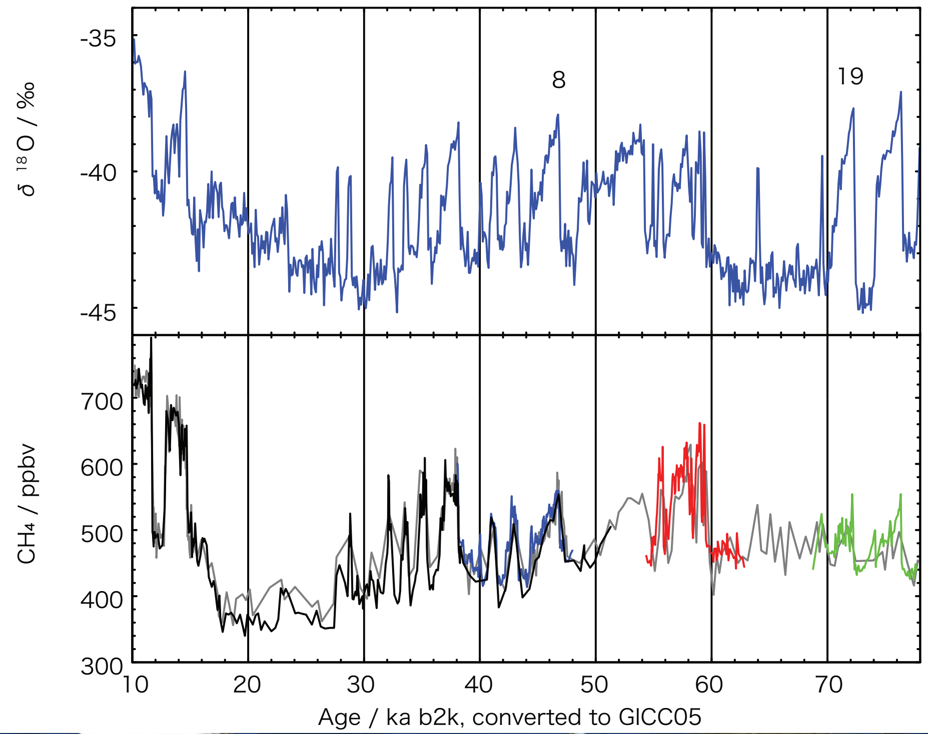
Large and rapid warming events have occurred many times in the past. Although their pattern and causes were quite different from contemporary climate change, they provide important information about biotic responses and biogeochemical feedbacks.

QUEST Activities

- A global dataset of climatic, ecosystem and fire indicators was compiled from natural archives for the past 75,000 years. They show multiple rapid warming events: up to and including the start of the present warm period (the past three decades, Figure 3, overleaf).
- Rapid changes in the concentration of the greenhouse gas methane were analysed, and found to closely track rapid climate events.
- The structure of multiple past warm periods were examined in relation to changes in the Earth's orbit, and were found to form a non-repeating pattern.
- The carbon cycle was modelled over a full glacial-interglacial cycle.
- The causes and consequences of the Palaeocene-Eocene Thermal Maximum (PETM) were modelled. This was an exceptionally warm period with high CO_2 concentrations that occurred 55 million years ago.
- A new synthesis of the consequences of climate change for biodiversity was developed, based on contemporary and palaeo observations, with major implications for conservation policy.

Figure 1: Methane (CH_4) across rapid climate changes of the last glacial period. The figure shows methane and Greenland $\delta^{18}O$ (a proxy for temperature). Dansgaard-Oeschger cycles 8 and 19 are shown.

Methane data are from the Greenland Ice Sheet Project 2, in grey (Blunier and Brook, 2001), Greenland Ice Core Project (GRIP) in black (Blunier and Brook, 2001, compiling data from earlier papers) and green (Flückiger et al., 2004), as well as NorthGRIP in blue (Flückiger et al., 2004) and red (Huber et al., 2006).



QUEST used a combination of data synthesis and modelling to account for the changes in the CO_2 concentration during the last full glacial-interglacial cycle. The QUEST project, DESIRE, a unique co-operation between QUEST and the Institut National des Sciences de l'Univers (INSU)—part of the French CNRS—compiled ice-core, marine and terrestrial data on the whole set of interglacials over the past 820,000 years. These projects were soon working together closely on the fundamental issues posed by the palaeorecord, considering both long-term and rapid changes. A further project, dPETM, took a multidisciplinary approach to reconstructing and modelling the extreme global warming of the PETM, its potential causes, and its consequences for the biosphere.

Later two Working Groups were formed that focused particularly on rapid changes. The Working Group on Abrupt Climate Changes (now continuing under an INQUA banner) assembled a crucial global data set of continuous records of past vegetation, the first to feature a globally unified taxonomy and data format. This was analysed to yield new insights about the rapidity of vegetation and atmospheric responses to millenial scale climate events and their near-global nature.

The Working Group on Biodiversity and Climate Change (hosted by the Royal Botanic Gardens, Kew) looked at *all* the evidence for how species and ecosystems react to rapid climate change. This group involved conservation practitioners and biologists as well as ecologists, population biologists and palaeo-ecologists. Its conclusions differ sharply from the current consensus in the scientifc literature. The conclusions emphasize the value of measures to promote natural migration and minimize non-climate threats. A key part of the underpinning evidence was the consistency between observed migrational responses of organisms to rapid climate change now, and rapid climate changes in the past.

Projects Involved

Quaternary QUEST; Dynamics of the Earth System Ice-Core Record (DESIRE); Dynamics of the Paleocene-Eocene Thermal Maximum (dPETM); Working Group on Abrupt Climate Change; Working Group on Biodiversity.

Publications

A full listing of QUEST research publications is constantly being updated by the QUEST synthesis team at the University of Bristol. Contact quest-info@bristol.ac.uk for more information.

Arneth A, 12 others (2010) Terrestrial biogeochemical feedbacks in the climate system. *Nature Geoscience* 3: 525–532.

Goodwin P, Williams RG, Ridgwell AJ, Follows MJ (2009) Climate sensitivity to the carbon cycle modulated by past and future changes in ocean chemistry. *Nature Geoscience*. 2: 145-150.

Harrison SP, Sanchez Goñi MF (2010) Global patterns of vegetation response to millennial-scale variability and rapid climate change during the last glacial period. *Quaternary Science Reviews* 29: 2957-2980.

Holden, PB, Edwards, NR, Wolff, EW, Lang, NJ, Singarayer, JS, Valdes, PJ and Stocker, TF (2010) Interhemispheric coupling and warm Antarctic interglacials. *Climate of the Past* 6, 431-443.

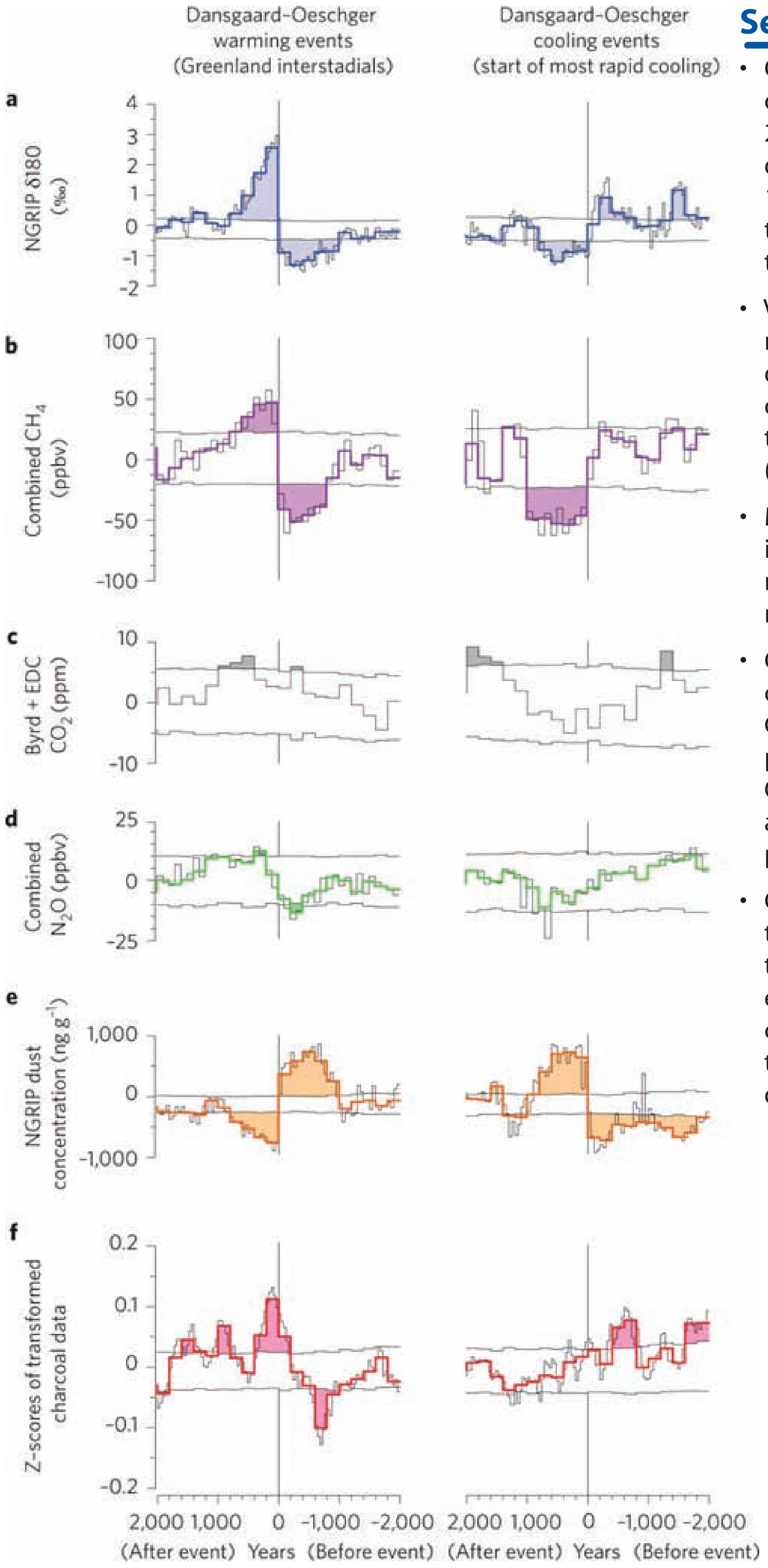
Lenton L, et al (2008) Tipping elements in the Earth's climate system. *Proceedings of the National Academy of Sciences* 105 (6) 1786-1793.

Ridgwell A, Schmidt DN (2010) Past constraints on the vulnerability of marine calcifiers to massive carbon dioxide release. *Nature Geoscience* 3: 196-200.

Sanchez Goñi MF, Harrison SP (eds) (2010) Vegetation Response to Millennial-scale Variability during the Last Glacial. *Special issue: Quaternary Science Reviews* 29: 2823-2980.

QUEST Quantifying and Understanding the Earth System

NATURAL ENVIRONMENT RESEARCH COUNCIL



Selected Highlights

- Climate changes (Dansgaard-Oeschger cycles) of comparable rate and magnitude to projected 21st century warming occurred many times during the last (and previous) ice ages (Figure 1). These events were near-global although the tropics saw mainly water balance changes, and the south saw smaller changes than the north.
- Vegetation, fire regimes and atmospheric methane concentrations responded with no discernible lag over D-O cycles. CO_2 and nitrous oxide responded more slowly, consistent with their longer lifetimes in the atmosphere (Figures 2 and 3).
- Modelling favours rapid, climate-driven changes in natural (i.e. wetland and fire) sources of methane, rather than sinks, as the main cause of natural variations in atmospheric methane.
- Climate simulations across rapid climate change events provide a new way to evaluate Global Climate Models of "IPCC class" by comparison with data syntheses like those done by QUEST. "Benchmarking" of model simulations against known past climate changes will provide a new dimension for evaluating models.
- Climate models underestimate how easily a thermohaline circulation collapse can be triggered, as illustrated by the Younger Dryas event. This could benchmark an aspect of climate model "sensitivity" to ocean circulation that cannot be gauged from contemporary data alone.

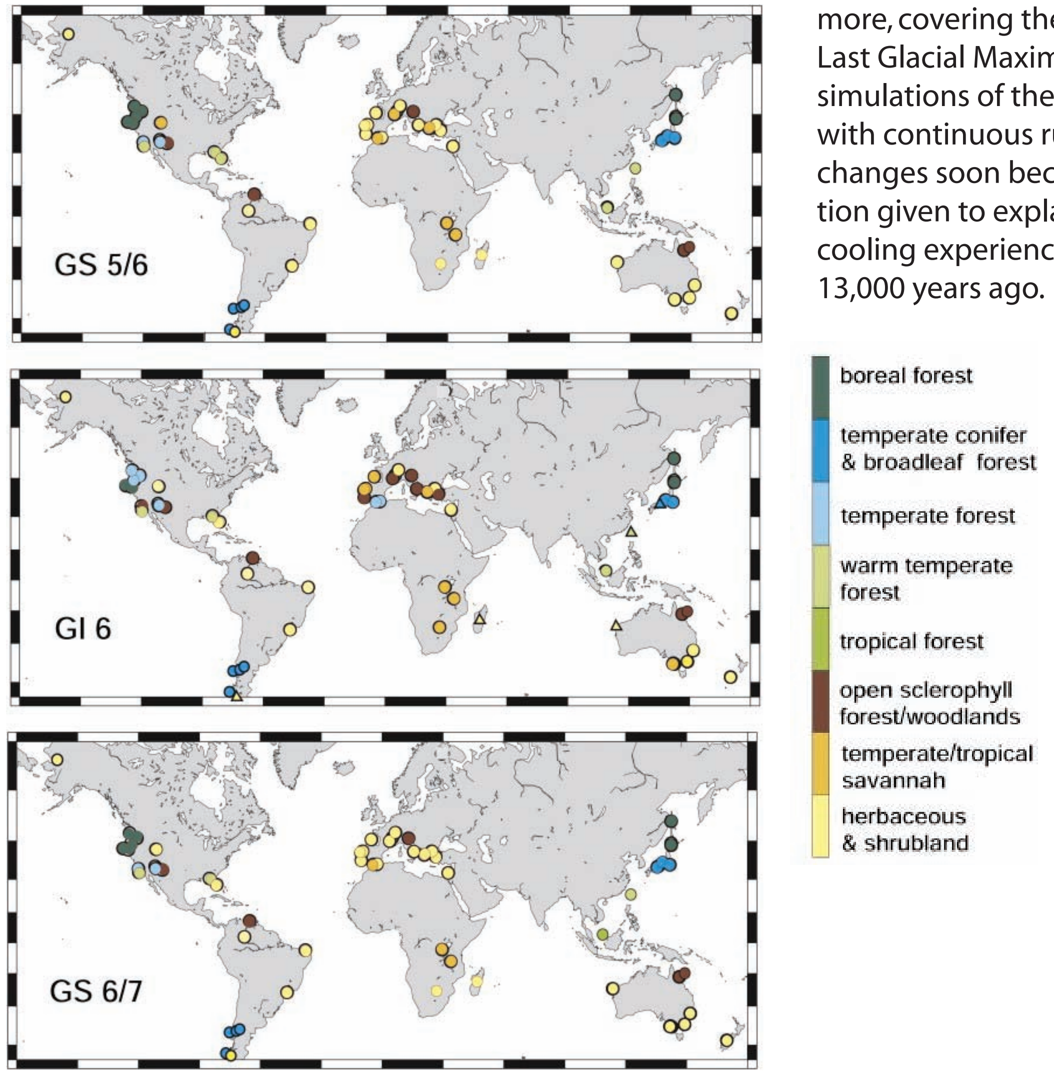
Figure 2: Response of a time series of ice-core and biomass burning records over the interval 80,000-10,000 years ago to the the Dansgaard–Oeschger cycles. The repeated occurrence of abrupt warming and cooling events define these D-O cycles, which occurred during the last glacial period. Shading indicates significant patterns in the response of the time series to the events of abrupt warming and rapid cooling.

a) The Greenland oxygen-isotope record, an index of regional temperature, shows the characteristic saw-tooth pattern of an individual D-O cycle.

b–f) Distinctive responses associated with the abrupt warming or cooling.

Byrd: Byrd station, Antarctica; EDC: EPICA Dome C; NGRIP: North Greenland Ice Core Project. From Arneth et al (2009).

- The idea that projected warming is "unprecedented" (in magnitude and rate) for biodiversity can no longer be supported. The palaeorecord provides clear evidence for species moving in response to large and rapid climate changes. As a result, predicted mass extinctions from climate change alone are not inevitable. These findings suggest a policy goal to facilitate natural migration rather than try to preserve species *in situ*.
- Palaeo evidence and population biology agree that large mammals are more at risk of extinction than plants, small mammals or insects.
- Analysis of the PETM has confirmed the severe consequences for marine biology of a large and rapid increase of atmospheric CO_2.
- Previous assumptions stated that methane released from submarine hydrates was partly responsible for rapid climate changes in the past but recent QUEST research now indicates that this mechanism is unlikely.



QUEST research

The Earth system science perspective reveals how multidisciplinary observations from geologically recent periods can provide vital information for contemporary climate science. When QUEST began, the principle focus was on documenting and modelling "snapshots" of past time and large and rapid climate changes were the "elephant in the room". Thanks to ice-core research and subsequent high-resolution terrestrial and marine analyses we knew they had occurred but computational limitations restricted our ability to undertake palaeoclimate simulations of these events using general circulation models (GCMs). In addition, the effort required to build unified, continuous palaeodata sets appeared daunting.

QUEST has been at the forefront of changing these perspectives. One project has assembled data on fires, wetlands, vegetation, stable isotopes and more, covering the past 21,000 years following the Last Glacial Maximum (LGM), and carried out simulations of the glacial-interglacial transition with continuous runs of a GCM. Rapid climate changes soon became a focus, with special attention given to explaining a short period of dramatic cooling experienced during the Younger Dryas, 13,000 years ago.

Figure 3: Vegetation changes associated with Dansgaard-Oeschger (D-O) cycle 6. The maps show the vegetation type recorded at individual sites during Greenland Stadial (GS) 6/7 (a colder period) through Greenland Interstadial 6 (a warmer period) and into GS 5/6.

Triangles indicate where vegetation change was not extensive enough to result in a change of biome (i.e. the vegetation types described in the key to the left), despite large changes in temperature. An upward triangle indicates an increase in forest elements, while a downward triangle indicates a decrease in forest elements.

(Harrison and Goñi 2010).