Institution: University of Derby
Unit of Assessment: Earth Systems and Environmental Sciences (07)
Title of case study: Impact of research into Pliocene climate

1. Summary of the impact (indicative maximum 100 words)

1) Influence on research figuring in the present Assessment Report (AR5) of the IPCC

2) Influence on public understanding of climate change

2. Underpinning research (indicative maximum 500 words)

There is strong international scientific interest in the climate of the mid-Pliocene (*c.* 3 million years ago) because this is the most recent interval in Earth history when global mean surface temperature was significantly higher (by 2-3 ºC) than at present. Studies of regional mid-Pliocene climate can therefore potentially provide accurate insights into future climate of the areas concerned in circumstances of similarly elevated global temperature, as predicted for the end of the present century. The main finding of the UoA, derived from stable-isotope and microgrowth-increment studies of bivalve molluscs, is that over at least significant parts of the mid-Pliocene interval winter temperatures in the North Sea area were little different from now. This does not agree with outputs from numerical climate models for the mid-Pliocene North Sea and therefore calls into question the accuracy of regional temperature predictions for the end of the present century made using the same models.

Doctoral research at Derby from 1994-1997 by Jonathan Hickson, under the supervision of Andrew Johnson, established that modern examples of the marine bivalve *Aequipecten opercularis* faithfully record a signal of ambient water temperature in the oxygen stable-isotopic composition of their shells. Serial sampling through the shell was shown to provide an accurate profile of seasonal temperature variation through the lifetime of the organism (ref. 1 below). Subsequent investigations by Johnson and Hickson, whilst the latter was employed in a temporary lecturing capacity at Derby, yielded cool winter temperatures (similar to now) from mid-Pliocene examples of *A. opercularis* collected in eastern England (ref. 2), contrary to other estimates (mostly much warmer) for the area based on other proxies (mainly the composition of biotic assemblages) and on numerical modelling. Initially, it was suspected that the low temperatures were erroneous: a possible reflection of chemical alteration of the shells. However, work conducted in 2008 by Johnson in collaboration with a research assistant, Annemarie Bird (now Valentine), and adding study of microgrowth increments to stable-isotope investigations, showed that the shells were unaltered and the temperature results valid (ref. 3). As well as confirming cool winter temperatures the study indicated that summer surface temperatures were elevated above present. An isotopic investigation of another bivalve species (*Arctica islandica*) from the mid-Pliocene of eastern England, conducted in collaboration with Prof. Bernd Schöne (University of Mainz) in 2005, provided results similar to those from *A. opercularis* (ref. 3). As a doctoral student supervised by Johnson, Valentine has obtained isotopic evidence of similar winter temperatures to now, and elevated summer surface temperatures, from bivalves of the Belgian and Dutch mid-Pliocene, confirming the generality of such conditions in the North Sea area (ref. 4). Bivalve-based isotopic (and growth-increment) work on mid-Pliocene climate has also been carried out by the UoA in collaboration with colleagues at the University of Leicester (material from Antarctica; ref. 5), United States Geological Survey (material from the US Atlantic Coastal Plain) and, in almost all the above cases, the NERC Isotope Geosciences Laboratory. An important result from work conducted in collaboration with the USGS is that isotopically determined winter temperatures from a Pliocene unit in Virginia and North Carolina, equivalent in age to that studied in England, are no warmer than those recorded on the US eastern seaboard now. This probably reflects reduced Gulf Stream heat transport and therefore affords an explanation for the similar winter temperatures to now in the North Sea region (an area influenced by Atlantic heat supply), alongside warmer summer conditions.

3. References to the research (indicative maximum of six references)

1. Hickson J A, **Johnson A L A**, Heaton, T H E and Balson P S (1999) The shell of the Queen *Scallop Aequipecten opercularis* (L.) as a promising tool for palaeoenvironmental reconstruction: evidence and reasons for equilibrium stable-isotope incorporation. *Palaeogeography, Palaeoclimatology, Palaeoecology* **154**, 325-337.

2. **Johnson A L A**, Hickson J A, Swan J, Brown M R, Heaton T H E, Balson P S and Chenery S (2000) The Queen Scallop *Aequipecten opercularis*: a new source of information on late Cenozoic marine environments in Europe. Pp 425-439 in E M Harper, J D Taylor & J A Crame (eds) *The evolutionary biology of the Bivalvia*; Geological Society, Special Publications 177.

3. **Johnson A L A,** Hickson J A, Bird A, Schöne B R, Balson P S, Heaton T H E and Williams M (2009) Comparative sclerochronology of modern and mid-Pliocene (c. 3.5 Ma) *Aequipecten opercularis* (Mollusca, Bivalvia): an insight into past and future climate change in the north-east Atlantic region. *Palaeogeography, Palaeoclimatology, Palaeoecology* 284, 164-179.

4. Valentine A, **Johnson A L A**, Leng M J, Sloane H J and Balson PS (2011) Isotopic evidence of cool winter conditions in the mid-Piacenzian (Pliocene) of the southern North Sea Basin. *Palaeogeography, Palaeoclimatology, Palaeoecology* 309, 9-16.

5. Williams M, Nelson A E, Smellie J L, Leng M J, **Johnson A L A**, Jarram D R, Haywood A M, Peck V L, Zalasiewicz J, Bennett C and Schöne B R (2010) Sea ice extent and seasonality for the Early Pliocene northern Weddell Sea determined from fossil *Austrochlamys* bivalves. *Palaeogeography, Palaeoclimatology, Palaeoecology* 292, 306-318.

6. Dowsett H J, Robinson M M, Stoll D K, Foley K M, Riesselman C R, **Johnson A L A** and Williams M (2013) The PRISM (Pliocene palaeoclimate) reconstruction: time for a paradigm shift. *Philosophical Transactions of the Royal Society A 371*: 20120524.

Awards (notifications of awards available on request)

Studentships:

1) NERC studentship GT4/94/322 (J.A. Hickson): c. £19,500 (including fieldwork costs) over three years (1994-1997)
2) BGS studentship BUFI S157 with UoD supplement (A. Valentine): *c.* £55,000 (including fieldwork costs) over three years (2008-2011)

Fellowship

3) Resumption of Fellowship from Alexander von Humboldt Foundation (A.L.A. Johnson): Jan.-Mar. 2009, €4,400

Stable isotope analytical facilities, NERC Isotope Geoscience Laboratory

4) IP/417/0994: notional value £7,500
5) IP/573/0998: notional value £15,000
6) IP/1108/0509: notional value £6,500
7) IP/1155/1109: notional value £11,285
8) IP/1351/1112: notional value £10,000

4. Details of the impact (indicative maximum 750 words)

The work with the USGS described above is ongoing and contributing to the Pliocene Data Intercomparison Project, a recently established theme (complementing a Model Intercomparison Project) within the Pliocene Research, Interpretation and Synoptic Mapping (PRISM) project, centred in the USGS. For the last 20+ years PRISM scientists have been engaged in compiling successive generations of a worldwide proxy database of Pliocene environmental conditions, particularly surface temperature. This has been used in both the construction and testing of numerical climate models for the Pliocene, and is featured in Assessment Report 5 (draft, 2013) of the Inter-Governmental Panel on Climate Change because of its relevance to prediction of future climate. PRISM work cited in AR5 (e.g. Dowsett *et al.* 2012, *Nature Climate Change* 2, 365-371) makes reference to the mollusc-based technique developed under Johnson's direction at Derby. The high-resolution data obtained through it have contributed to a 'paradigm shift' in the PRISM approach to climate reconstruction (ref. 6 above), whereby attention will be given to fluctuations in climate (at various timescales) within the context of the generally warm Pliocene world. This will enable refinement and more rigorous testing of models,

ultimately leading to increased accuracy in predictions of future climate. The leader of the PRISM group, Dr H.J. Dowsett, has supplied a letter (submitted alongside this) confirming the contribution of Johnson and his team to PRISM research featured in AR5 and to planned work for AR6.

As well as feeding into international research and policy development, the work at Derby described above has had more general impact in that it has figured in TV and radio broadcasts, YouTube videos, lectures and an exhibit dealing with climate change in general. In these the emphasis has been on demonstrating to a lay audience the existence of past climate change and scope for accurate documentation of it. Initial interest was in many cases created by the 'green' methods of travel used by Johnson for research. Two lengthy research visits (summer 2007 and summer 2011) to the USA exclusively involved travel by container ship, train and bicycle in order to avoid the large carbon-footprint associated with conventional plane and car travel. The first of these led to invitations to appear on BBC Radio Derby (03/04/2008) and BBC TV East Midlands (27/05/2008), the creation of two YouTube videos (Container ship – 60 Seconds of Science and Green travel: 1339 and 758 'hits', respectively, by 06/11/2013) and invitations to speak to the Geographical Association - North Staffordshire (05/03/2008) and Derby Cycle Touring Club (11/03/2008). More recently Johnson has spoken on climate change to the UK Alexander von Humboldt Association (15/10/2010) and collaborated with colleagues Jones and Pope in an exhibit on the climate of Derby over the last 350 million years for the University's Fun Day (05/05/2013; see http://www.flickr.com/photos/derbyunipress/sets/72157633431829397). In this, opportunities were provided for members of the public to drill samples from ancient carbonates (Carboniferous brachiopod and Quaternary speleothem) and have them isotopically analysed (winners of a raffle). Visitors to the display were asked to complete a questionnaire on climate change. Of the 49 respondents (see returns supplied alongside this), 32 stated that they had initially thought only crude estimates could be made of past climate but now understood that precise estimates could be made using the chemical approaches explained in the exhibit. Changes of view were also evidenced by responses to the three other questions asked, amounting *in toto* to significant impact.

5. Sources to corroborate the impact (indicative maximum of 10 references)

Letter from Dr Harry Dowsett (United States Geological Survey)

Fun Day questionnaire returns

Website showing Fun Day activities:
http://www.flickr.com/photos/derbyunipress/sets/72157633431829397 (the second [IMG_4275] and third [IMG_4273] images show the climate change exhibit and associated activity)

Individuals who could be contacted:

Prof. Harry Dowsett, United States Geological Survey (e-mail: hdowsett@usgs.gov)

Brady Haran, BBC TV reporter (e-mail: bradyharan@hotmail.com)