climate change

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Future climate variability and unpredictability in Scotland

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Enquirer: Climate Change Legislation Team

1. Introduction and Context

The Climate Change Legislation Team asked ClimateXChange to produce a brief report on the latest scientific evidence about how the variability and predictability of the future climate in Scotland will change as a result of climate change.

First, this brief addresses climate variability, which can be separated into two forms:

a) "Internal" natural variability, which occurs due to the huge number of complex interactions within and between the atmosphere and oceans; and

b) "external" variability, associated with the impact of external forces on the climate system, such as human-induced greenhouse gas emissions; changes in the sun's output; and volcanic eruptions.

Second, this review summarises our current understanding of the predictability of the future climate of Scotland.

2. Key Points

- The latest scientific evidence suggests that the "internal" natural variability of certain ocean climate systems may increase over the first half of this century, but there is significant uncertainty about our ability to predict the behaviour of the Atlantic climate system, which is highly relevant for Scotland. For the first half of the century, local "internal" natural variability could be more important in determining the behaviour of climate extremes than global climate change associated with human-induced emissions of greenhouse gases. In the second half of this century, human-induced climate change is likely to be the key determinant of shifts in many climate extremes.

- An increase in "internal" natural variability could reduce our overall ability to predict the climate of a particular year or series of years. However, our overall ability to predict the climate depends both on the manner in which internal variability changes through time and the extent of technical improvements in our models of the climate system.

- Human influences on climate associated with the emission of greenhouse gases will affect climate variability in more specific and, in some cases, much more predictable ways.

- As a result of human induced climate change:
    - Annual temperature ranges are likely to shrink in the East of Scotland[1], with temperatures of the coldest days and nights increasing faster than the temperatures of the warmest days.
    - Conversely, temperature ranges may expand in the North.
    - Rainfall is much less predictable, but may become more variable in terms of both amount and timing throughout Scotland (but particularly in the West).

- Because of these likely changes in temperature range, forecasts of temperature may become more reliable in the East of Scotland, but less reliable in the North.

- There is evidence to suggest that recent extreme events (heat-waves in particular) might become more typical ('normal') later in the century. If they become the new 'normal', it is harder to predict with any certainty the scale and severity of the new extremes.

3. Future Climate Variability

Internal natural variability

Internal natural variability in the climate system is difficult to assess due to a lack of climate data. The relevant natural cycles tend to operate over periods of between 2 and 20 years, and our observational record is simply not long enough to understand these kinds of variability fully (e.g., Russon et al., 2012)[2]. The North Atlantic Oscillation (NAO) is an index of the relative strength and position of atmospheric pressure differences in the North Atlantic, which are important drivers for Scottish climate, but its variability changes on relatively long time-scales. In climate system models that explore multi-decadal and historical patterns of climate, the variability of the NAO is generally over-estimated, even before taking current human induced forcing of the climate into account (Semenov et al., 2008). This suggests that recent changes in the NAO (including an upward trend between 1965 and 1995) which have been assumed to reflect human induced change may instead be natural, and that we are yet to see the full effects of greenhouse gas emissions. Over the next few decades, human induced drivers of climate change are expected to determine changes in average climate, but "internal" natural variability could be more important for determining the extremes of climate, when Atlantic circulation modifies human influenced climate further.

Internal climate variability in the Pacific and North Atlantic are linked (Lau and Nath, 2001), but as the strength of this link changes over time (Rodo and Comin, 2000), the implications for Scotland are unclear. More knowledge is needed on possible changes in the North Atlantic Oscillation before Scotland-specific results can be shown with confidence.

External variability

Changes in climate variability that are associated with natural external drivers (e.g. large changes in the sun's output and volcanic eruptions) are largely unforeseeable. It has been suggested that the Northern Atlantic Oscillation may move into a different phase within the next decade, which would rapidly lead to a drier Scottish climate (Sutton and Dong, 2012), and that large volcanic eruptions may lead to an increase in gales for eastern

[1] These results are drawn from the UKCP09 report. The administrative regions used by UKCP09 (and the UK Met Office) can be found here: http://bit.ly/12YHlrj

[2] Although the cyclical Pacific El Niño influences global-scale circulation, it has been suggested that hundreds or thousands of years of data would be required in order to understand long-term changes in its natural variability (Wittenberg, 2009).

Scotland (Dawson et al., 1997). However, due to the infrequency of these kinds of events, we have no reliable way to quantify how likely either of these outcomes actually are.

Although the predictability of natural (internal or external) variability decreases the further we look ahead, the impact of human induced climate change becomes less uncertain. This is because we expect the impact of human induced changes to the climate to exceed natural climate variability over time, and because global demographic and social trends (including energy and land use) do not tend to change quickly. Current projections of climate change are surprisingly insensitive to our scenarios of emissions over the next few decades (IPCC, 2007) but it is possible to make robust projections about broad changes in global climate likely to happen under a given global emissions scenario through to the end of the century (IPCC, 2007). Conversely, it is difficult to anticipate the changes that will happen at specific geographical locations through time, or to fully account for the role of specific drivers of the climate system, such as aerosol[3] emissions and land-use change[4] (Conway, 1998; Booth et al., 2012; Terray, 2012). Broad-stroke climate patterns can still be projected with some confidence, as detailed below.

Future variability in Scotland

Under a 'medium' scenario of greenhouse gas emissions we can expect annual average temperatures to increase for both northern Scotland and eastern Scotland. However, we can expect an increase in temperature range for Northern Scotland (meaning that there is likely to be a greater difference between the highest and lowest temperatures), and a decrease in the East (meaning that the difference between the highest and lowest temperatures in the East is likely to shrink).

Higher average temperatures will increase rainfall variability (IPCC, 2007), and we anticipate this more in the West of Scotland than in the East (UKCP09).

High extremes of temperature and rainfall (defined relative to the last 50 years) are set to increase across northern Europe (Klein Tank et al., 2003; Kiktev et al., 2004 ; Christidis et al., 2005). Conditions we regard as extreme now may be more common by the end of the century (Stott, 2004; Christidis et al., 2005; Beniston et al., 2007) but the full magnitude and frequency of future extremes remains uncertain. The occurrence of European heavy winter rainfall, frost days, and cold-snaps all depend upon the behaviour of North Atlantic atmospheric circulation, making these events difficult to predict with confidence into the future (Scaife et al., 2007).

4. Predictability

Predictability is closely linked to variability, and depends on the timescale being considered. Forecasts of internal natural variability driven by global circulation are available for several weeks (NOAA, 2009) and can be used by experts to assess sequences of events (like warm periods, or wet spells) with some accuracy, but the specific state of the atmosphere is essentially impossible to forecast over longer periods (Simmons and Hollingsworth, 2002). The probability (or likelihood) of internal natural variability can be predicted with some accuracy from one year to the next, including information on seasonal cycles. But it is often not possible to acquire a coherent picture of change or sequences of events beyond a few months (Palmer et al., 2004).

[3] Tiny particles of dust and smoke, including certain kinds of pollution.

[4] Which affects how the earth's surface reflects or absorbs heat, and can refer to ice or tree-cover loss, urban-expansion or even large-scale changes in farming practice.

North Atlantic conditions which are defined as “warm” seem to coincide with warmer, drier Scottish springs and wetter Scottish summers (Sutton and Dong, 2012). A stronger Atlantic circulation generally means wetter conditions in western Scotland (Stenseth et al., 2002), and warmer Pacific summer conditions generally relate to wet Scottish springs (Knippertz et al., 2003). However, these are generalisations that are only useful as conditions averaged over decades.

Using ocean conditions to predict the state of atmospheric circulation, and from there, surface climate over land (Collins & Sinha, 2003), has led to the development of multi-decadal prediction. This field of study is only now starting to show utility, as there are many uncertainties to be taken into account. The domain of the North Atlantic Oscillation and its impact on Western European climate show the most promise due to strong oceanic drivers (e.g. the Atlantic Multidecadal Oscillation) (Chikamoto et al., 2011). Technical improvements in our models may lead to increasingly useful multi-decadal prediction. If natural variability should change in a way that leads to a strengthened NAO circulation, the predictability that we can offer for Scotland is likely to increase, rather than decrease.

5. Summary of the Predictability of Climate Variability

There are statistical limits on our ability to forecast the most important drivers of climate variability. Our assumptions of climate system stability may not hold true through time. There is a 'blind spot' between our understanding of the climate variability of the next few years and the next few decades, where both forecasts and our models of probability are currently unsuccessful (Hanlon, 2012). However, if the climate system continues in a familiar or foreseeable state, without reaching so called 'tipping points' (loss of Arctic sea ice, substantial changes in circulation, etc.) our models offer the following: short-term forecasts of variability (from week to week); short-medium term predictions of probable variability (from season to season); and long-term scenarios of future variability. As the climate system changes, the first and second of these may become less reliable, but decade-to-decade prediction is likely to improve. For Scotland, the behaviour of the North Atlantic Oscillation is of key importance to future climate variability, but we currently lack the data to assess its capacity for change with any certainty.

6. References

Beniston, M, D. B. Stephenson, O. B. Christensen, C.A.T. Ferro, C. Frei, S. Goyette, K. Halsnaes et al., (2007): Future extreme events in European climate: an exploration of regional climate model projections. Climatic Change 81: 71-95.

Booth, B. B. B., N. J. Dunstone, P. R. Halloran, T. Andrews, and N. Bellouin, (2012): Aerosols implicated as a prime driver of twentieth-century North Atlantic climate variability (vol 484, pg 228, 2012). Nature, 485, 534-534.

Chikamoto, Y., Kimoto, M., Ishii, M., Mochizuki, T., Sakamoto, T. T., Tatebe, H., & Imada, Y., (2012). An overview of decadal climate predictability in a multi-model ensemble by climate model MIROC. Climate Dynamics, 1-22.

Christidis, N., Stott, P. A., Brown, S., Hegerl, G. C., & Caesar, J. (2005). Detection of changes in temperature extremes during the second half of the 20th century. Geophysical Research Letters, 32(20), L20716.

Coles, S., & Pericchi, L. (2003). Anticipating catastrophes through extreme value modelling. Journal of the Royal Statistical Society: Series C (Applied Statistics), 52(4), 405-416.

Collins, Matthew, and Bablu Sinha (2003). Predictability of decadal variations in the thermohaline circulation and climate. Geophysical Research Letters, 30(6) 1306

Conway, D. (1998). Recent climate variability and future climate change scenarios for Great Britain. Progress in Physical Geography, 22(3), 350-374.

Dawson, A. G., Hickey, K., McKenna, J., & Foster, D. L. (1997). A 200-year record of gale frequency, Edinburgh, Scotland: possible link with high-magnitude volcanic eruptions. The Holocene, 7(3), 337-341.

Frei, C., Schöll, R., Fukutome, S., Schmidli, J., & Vidale, P. L. (2006). Future change of precipitation extremes in Europe: Intercomparison of scenarios from regional climate models. Journal of Geophysical Research, 111(D6), D06105.

Hanlon, H., G. Hegerl, S. Tett, and D. Smith (2012). Can a decadal forecasting system predict temperature extreme indices?. J. Climate. doi:http://dx.doi.org/10.1175/JCLI-D-12-00512.1

IPCC (2007). Climate Change 2007: The Physical Science Basis.

Kiktev, D., Sexton, D. M., Alexander, L., & Folland, C. K. (2003). Comparison of modelled and observed trends in indices of daily climate extremes. Journal of Climate, 16(22), 3560-3571.

Klein Tank, A. M. G., & Können, G. P. (2003). Trends in indices of daily temperature and precipitation extremes in Europe, 1946-99. Journal of Climate, 16(22), 3665-3680.

Knippertz, P., Ulbrich, U., Marques, F., & Corte-Real, J. (2003). Decadal changes in the link between El Niño and springtime North Atlantic Oscillation and European? North African rainfall. International journal of climatology, 23(11), 1293-1311.

Lau, N. C., & Nath, M. J. (2001). Impact of ENSO on SST variability in the North Pacific and North Atlantic: Seasonal dependence and role of extratropical sea-air coupling. Journal of Climate, 14(13), 2846-2866.

Mann, M. E., Zhang, Z., Rutherford, S., Bradley, R. S., Hughes, M. K., Shindell, D., ... & Ni, F. (2009). Global signatures and dynamical origins of the Little Ice Age and Medieval Climate Anomaly. Science, 326(5957), 1256-1260.

NOAA, 2009: North Atlantic Oscillation (NOA). Accessed November 15th, 2012. Available at: http://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/nao.shtml

Palmer, T., Andersen, U., Cantelaube, P., Davey, M., Deque, M., Doblas-Reyes, F. J., ... & Thomsen, M. C. (2004). Development of a European multi-model ensemble system for seasonal to inter-annual prediction (DEMETER).Bulletin of the American Meteorological Society, 85(6), 853-872.

Rodó, X., & Comin, F. A. (2001). Links between large-scale anomalies, rainfall and wine quality in the Iberian Peninsula during the last three decades. Global Change Biology, 6(3), 267-273.

Russon, T, S. Tudhope, G. Hegerl, 2012: 'Understanding the variability of the El-Niño Southern Oscillation phenomenon'. Science Brief for ClimateXChange

Scaife, A. A., Folland, C. K., Alexander, L. V., Moberg, A., & Knight, J. R. (2008). European climate extremes and the North Atlantic Oscillation. Journal of Climate, 21(1), 72-83.

Scaife, A. A., Kucharski, F., Folland, C. K., Kinter, J., Brönnimann, S., Fereday, D., ... & Zhou, T. (2009). The CLIVAR C20C project: selected twentieth century climate events. Climate Dynamics, 33(5), 603-614.

Semenov, V. A., Latif, M., Jungclaus, J. H., & Park, W. (2008). Is the observed NAO variability during the instrumental record unusual?. Geophysical Research Letters, 35(11), L11701.

Simmons, A. J., & Hollingsworth, A. (2002). Some aspects of the improvement in skill of numerical weather prediction. Quarterly Journal of the Royal Meteorological Society, 128(580), 647-677.

Stenseth, N. C., Mysterud, A., Ottersen, G., Hurrell, J. W., Chan, K. S., & Lima, M. (2002). Ecological effects of climate fluctuations. Science, 297(5585), 1292-1296.

Stott, P. A., Stone, D. A., & Allen, M. R. (2004). Human contribution to the European heatwave of 2003. Nature, 432(7017), 610-614.

Sutton, R. and Dong, B. (2012) Atlantic Ocean influence on a shift in European climate in the 1990s. Nature Geoscience, 5. pp. 788-792. ISSN 1752-0908 doi: 10.1038/ngeo1595

Terray, L., L. Corre, S. Cravatte, T. Delcroix, G. Reverdin, and A. Ribes (2012). Near-Surface Salinity as Nature's Rain Gauge to Detect Human Influence on the Tropical Water Cycle. J Climate, 25, 958-977.

UKCP09: Murphy, J. M., Sexton, D. M. H., Jenkins, G. J., Booth, B. B. B., Brown, C. C., Clark, R. T., Collins, M., Harris, G. R., Kendon, E. J., Betts, R. A., Brown, S. J., Humphrey, K. A., McCarthy, M. P., McDonald, R. E., Stephens, A., Wallace, C., Warren, R., Wilby, R. & Wood, R. A. (2009). UK Climate Projections science report: Climate change projections. Met Office Hadley Centre, Exeter, UK.

Watanabe, M., Kug, J. S., Jin, F. F., Collins, M., Ohba, M., & Wittenberg, A. T. (2012). Uncertainty in the ENSO amplitude change from the past to the future. Geophysical Research Letters, 39(20), L20703.

Wittenberg, A. T. (2009). Are historical records sufficient to constrain ENSO simulations? Geophysical Research Letters, 36(12), L12702.