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Global Dynamics of Climate Variability and Change

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1. Introduction

On regional scales it is often the dynamics of regional climate rather than the thermodynamics of global warming that determines the impending risk of extremes or unprecedented events over the coming years. This is true across individual countries or even continental scales and it applies to the UK. Atmospheric dynamics governs summer and winter extremes ranging from storms and heavy rainfall and hence flooding, to temperature extremes such as heat waves. This is also the case in other parts of the world, where dynamical fluctuations, often arising from the remote influence of fluctuations in modes of atmospheric and oceanic variability such as El Niño or the Arctic Oscillation, change regional surface conditions. These changes can either greatly exacerbate or completely counter the background effects of a globally warming climate and can dominate extreme periods of UK climate, with impacts on key sectors such as energy (e.g. winter 2009/10 and 2010/11) and agriculture (e.g. Spring 2013).

This theme will provide much needed improvements in understanding and modelling of key dynamical aspects of regional climate. With a focus on Europe and the UK, it investigates the fidelity of coupled ocean-atmosphere climate models, the fundamental modes or drivers of climate variability and their global connections on timescales from months to decades. The Climate Dynamics Theme also considers the linear superposition and possible non-linear interaction between climate variability and forced climate change. It seeks to quantify the influence of dynamical fluctuations on past records and future climate predictions.

This theme feeds into underpinning work on model development and regional climate prediction. It is strongly geared with work carried out by Met Office Academic Partners. It is also closely aligned with the theme on Regional Climate Extremes and the Climate Prediction theme and it underpins our knowledge of atmospheric circulation required to improved estimates of temperature and wind for energy supply and demand. The Climate Dynamics theme allows us to interpret and understand the cause and reliability of results emerging from those activities and to thereby directly interpret and strengthen our regional climate predictions in Theme 5.

2. Topic 1: Modes of natural climate variability

Motivation: This topic will consider worldwide modes of natural variability and their effects on regional climate, with a focus on the European region. Examples include the El Niño Southern Oscillation, North Atlantic Oscillation, Pacific Decadal Oscillation and Madden Julian Oscillation. It will assess how well our latest climate models represent regional climate variability in general and will identify strengths and weaknesses of these models. It will consider the mechanisms that drive regional climate variability and quantify levels of predictability (e.g. Figure 1), so that we can be more confident of when and where climate predictions are likely to be trustworthy.

![Figure 1: Prediction skill of the winter North Atlantic Oscillation from the Met Office Global Seasonal Forecast System 5 (MacLachlan et al 2014). An update of these results will be provided, including extension to longer historical periods as requested by MOSAC/SRG last year. Figure from Scaife et al, 2014a.](image-url)
As well as identifying successful aspects of models, we will focus on model weaknesses. Errors in modes of variability in the ocean and atmosphere and their global teleconnections will be identified and targeted for analysis. As outlined in the draft deliverables below, a battery of dynamical diagnostics will be developed and used to identify the source of error in climate simulations, ranging from their source in the ocean or atmosphere, to their remote connections through the atmosphere (e.g. Figure 2), to local feedbacks from the ocean or land surface in their region of impact.

![Figure 2](image)

**Figure 2**: Observed (a) and predicted (b,c) connection between the tropical Quasi-Biennial Oscillation and extratropical winter sea level pressure. Observations show enhanced sea level pressure gradients in the Atlantic sector corresponding to a stronger Atlantic jet stream on average during the westerly phase of the QBO. Models have mixed success in reproducing this effect. Figure from Scaife et al, 2014b.

### 3. Topic 2: Interaction of natural variability and forced climate change

Motivation: this topic will examine the role of natural climate variability in modulating regional climate change. The occurrence of notable regional climate events is almost always linked to the combined effects of climate variability and systematic climate change. Similarly, regional variability can easily mask the effects of climate change for many years.

This topic will consider what can be gained if we consider the linear superposition of climate variability and climate change. It will test whether we can better understand the uncertainty in future regional climate in this way. It will also try to better quantify underlying climate change in the UK and northern Europe by first removing the effects of climate variability to reveal underlying trends (e.g. Figure 3). This topic will also consider the more complicated question of whether the modes of variability and their associated connections to UK climate are themselves being changed by anthropogenic influence. In addition to changes in the modes of variability themselves, it is likely that their regional impacts are altered due to spatial variations in the climate change signal.

![Figure 3](image)

**Figure 3**: Winter England and Wales residual precipitation obtained by subtracting precipitation estimated from the typical historical values observed in various circulation types from the actual precipitation. The aim is to subtract the influence of year-to-year variations in the seasonal mean circulation from underlying changes in the precipitation. The trend is 0.20 mm/year for 1900-2013 (significant at the 5% level, based on randomly reordering the residuals and recalculating trends). The upward trend is suggestive of a long-term wetting of winter climate. Figure courtesy of David Fereday.
4. Potential Deliverables

The following list gives the set of topics being considered as foci for future HCCP work in this Theme. The final list will be narrower than this initial broad range:

**Global warming pause**: internal variability or external forcing? Is it ending? What regional mechanisms govern the predictability of ocean heat, fresh water content and sea level and how do they influence surface temperature variability such as the warming pause?

**Europe and the UK**: how well are circulation patterns such as the NAO modelled? Are influences on surface temperature, precipitation, winds and other quantities realistic? How important are tropical connections to Europe? Are they well modelled? What other factors drive European climate e.g. volcanic eruptions? What causes weak signal to noise ratios in our climate predictions (see e.g. Figure 4) and what, if any, are the implications for long term projections and attribution studies? (with Theme 4 on regional extremes)

![Figure 4: The ratio of correlation coefficient to signal to noise ratio for seasonal hindcasts of December-January-February (DJF) means (left) and decadal hindcasts of 4 year annual means for years 2–5 (right). Mean sea level pressure forecasts are used. The expected ratio is 1 and regions stippled in red show areas where correlations significantly exceed the expected value, from Eade et al. (2014).](image)

**Global variability and climate modes**: monsoons, ENSO, IOD, PDO, AMO, MJO etc. Are these modes and their global connections well represented in models? Is it the source or the background state that creates errors? Can we use initialised predictions to understand model error? Does increased model resolution reduce errors? Which mechanisms are responsible for ENSO and its global climate impacts? Do models distinguish the different types of ENSO event? How dependent is this on model resolution?

**Improved suites of dynamical tools** in the UM and other software:
- Rossby wave sources and wave activity diagnostics
- refractive index and ray tracing
- teleconnection metrics for modes of variability
- nudging and relaxation methods
- simple models (with NERC researchers)

**The Atlantic Ocean**: the tropical Atlantic as a notorious area for model simulation, mechanisms of variability and interactions with surface climate in models. Is extratropical variability coupled to the extratropical ocean? Change in the Meridional Overturning circulation - what are the impacts and what controls long term stability? Development of observationally-based constraints to distinguish between different mechanisms using new instrumental datasets (e.g. Argo, RAPID, JASON), ocean reanalyses, and high resolution palaeo-proxies in collaboration with the NERC. Can we make real time climate predictions (see Figure 5 for an experimental example) to warn of impending MOC change?
Climate change and regional dynamics: can we extract dynamical variability from observational climate records (e.g. Figure 3) to reveal more robust estimates of underlying climate change? Similarly, for future regional climate change uncertainty – how much arises from dynamics? Are there non-linear interactions between climate variability and climate change? Will regional climate variability become more volatile in future? (with Theme 4 on extremes)

What governs the position and strength of jet streams? internal variability vs remote drivers, Gulf Stream influence, weather regimes and predictability. What mechanism governs what will happen to the extratropical jet streams in future? Rossby wave trapping, resonance and mid latitude extremes: do these ideas work? Are they key to future extreme events? What will happen to the regional Hadley Circulation and the subtropical jets in future? How fast do we expect the desert regions to expand? What is the mechanism and do models correctly capture it? What about the Walker Circulation, will it speed up as a tropical thermostat or slow down as projected? (with NERC, link with Theme 4)

5. Resource Requirements and Collaborators

This is a new Theme within the HCCP but is crucial for improving regional climate predictions on timescales from months to decades ahead. It also aligns with the WMO – World Climate research Programme’s grand challenges for climate science. Some expertise exists in the Hadley Centre, but this will develop over the project. Collaborations with NERC and international climate scientists will be important for successful delivery and pull through into improved predictions and attribution for Europe and UK climate. A number of key collaborators at Met Office academic partner universities are already identified. This work also requires interaction with other Themes such as Theme 4 on regional extremes and ongoing efforts on model development.

6. References


