Modulation of El Niño Southern Oscillation and its impacts by the mean climate state

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The El Niño Southern Oscillation (ENSO) is the leading mode of interannual climate variability in the tropics and affects regional climates around the globe. By producing changes in atmospheric circulation, ENSO events can alter normal climate variability and lead to extreme impacts (such as flooding and forest fires) which represent an associated risk to populations and ecosystems. There are great uncertainties about how the intensity, frequency and global spatial patterns of ENSO events will evolve in the future. A better understanding of the physical mechanisms of ENSO will help to understand its teleconnections and future changes. This project will use state-of-the-art model simulations, including CMIP6 and very high-resolution global models, alongside observations to study ENSO impacts and their relation to changes in global large-scale circulation. The project will allow the candidate to work with scientists from the Institute of Climate and Atmospheric Science (ICAS) and the Priestley International Centre for Climate at the University of Leeds and from the Climate Prediction Group at the Barcelona Supercomputing Center (BSC-CNS). Regular visits to the CASE partner will be undertaken allowing the student to engage with scientists at a world leading climate modelling centre.

1. Introduction

The El Niño Southern Oscillation (ENSO) is known as the major driver of interannual climate variability in the tropics (Butler et al., 2014). Every two to seven years, natural ocean-atmosphere interactions in the equatorial Pacific lead to warm (El Niño) or cold (La Niña) sea surface temperature anomalies, which trigger a cascade of remote effects across the globe through changes to the atmospheric circulation in both northern and southern hemispheres (See Figure 1). ENSO impacts on interannual variability in global mean surface temperature and influences severe weather events across the globe (Christensen et al., 2013). Some examples of extreme events are extreme precipitation episodes during the rainy season especially in the southeast of South America that are associated with severe flooding (Grimm and Tedeschi, 2009), a significant increase in cyclone activity with more intense crossing central Europe during El Niño events (Fraedrich and Muller, 1992), and an intensification of drought episodes in some parts of the world (Janicot et al., 1996) that can lead to forest fires, particularly in Australia, Indonesia and California, devastating lives and ecosystems.

It has been suggested that the frequency, intensity and spatial variability of El Niño and La Niña events will become more dependent on external forcings such as anthropogenic driven increases in greenhouse gases (Kim and An, 2011). A warmer world with increased CO_2 concentration may lead to changes in the remote impacts of ENSO (especially rainfall). The long-term projected changes in response to increased greenhouse gases match the signature of the climate response to ENSO events; this subtlety, could either exaggerate or mask the climate response of ENSO in the future (Müller and Roeckner, 2008; Seneviratne et al., 2012).

The reliability of studies on ENSO dynamics and impacts using numerical climate models is determined by the model performance in simulating real world processes. Global coupled models have recently shown some improvement in climate simulations including higher horizontal resolution in the ocean and the atmosphere, allowing a better understanding of short-term changes in climate circulation.

2. Scientific rationale

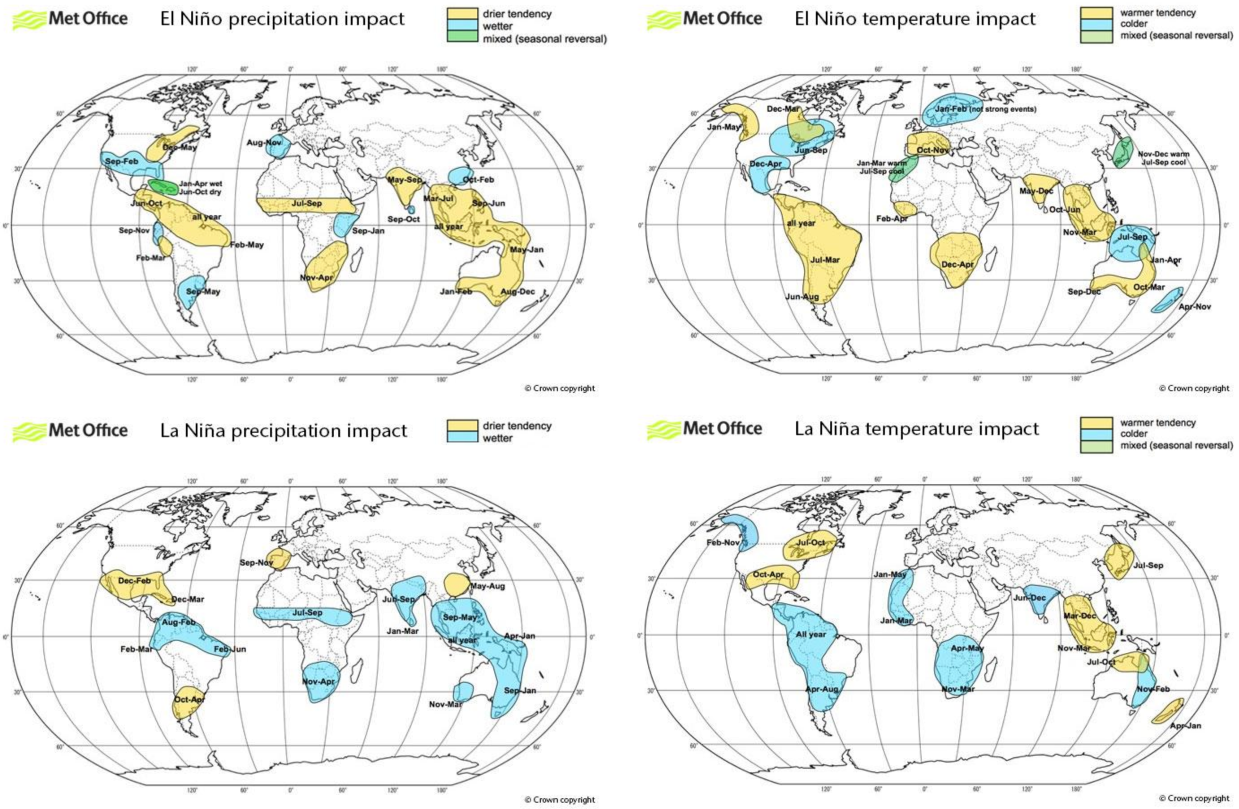

Figure 1 | Schematic representation of precipitation (left column) and temperature (right column) anomalies during El Niño (top row) and La Niña (bottom row) events. Orange colours show drier and warmer tendencies, wetter and colder conditions are shown in blue and mixed response marked by a strong seasonality is shown in green. The analyses for the temperature impact maps made use of monthly-average near-surface land temperature data from the National Centers for Environmental Prediction atmospheric re-analysis (1948-2011) and the CRUTEM4 gridded observational analysis (1850-2010). For the precipitation impact maps, the analyses made use of the University of East Anglia Climatic Research Unit 1900-1998 monthly precipitation dataset and the Global Precipitation Climatology Project 1979-2010 monthly gridded precipitation dataset (Met Office, 2016).

During ENSO events, changes to atmospheric circulation and precipitation patterns in response to perturbed sea surface temperature induce anomalous extratropical planetary Rossby waves originating from the tropics. These wave trains propagate poleward through the troposphere and the stratosphere leading to remote climate effects that vary regionally and by season. Internal modes of interannual climate variability such as the Pacific Decadal Oscillation (PDO) and the Atlantic Multidecadal Variability (AMV), along with anthropogenic sources of radiative forcing (eg. greenhouse gases emission and aerosol concentration) alter the global climate circulation on interannual and decadal timescales and therefore must be included in the study of ENSO impacts under future climate conditions.

Studies have assessed whether the dynamics of ENSO changes under global warming (Merryfield, 2006), but one study hints that changes to the remote effects of ENSO events may emerge before any evident changes to the behaviour of ENSO itself (Stevenson et al., 2012). While the effect of ENSO on mean climate has been studied in the present climate, there remain significant open questions regarding its effect on climate due to the relatively short observational record and the historically limited representation of ENSO in climate models.

Studies have shown that climate extremes are generally expected to increase in frequency and intensity under climate change in many parts of the globe, for instance, as shown in Figure 2.a, a warmer climate can result from fewer cold days, reducing the variance of temperatures, or more frequent hot days, expanding the variance. Climate change may affect both the frequency of climate extremes, increasing the variance, and the

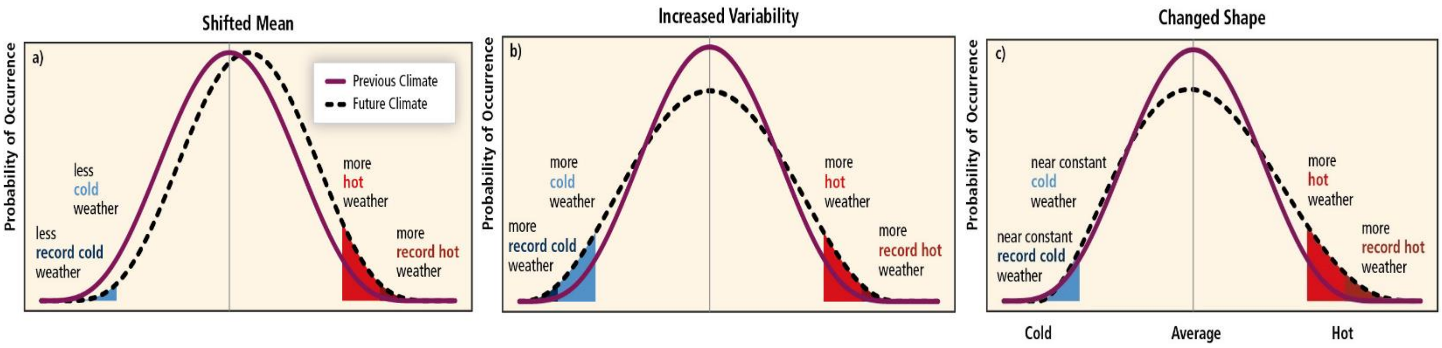

Figure 2 | The effect of changes in temperature distribution on extremes. Different changes in temperature distributions between present and future climate and their effects on extreme values of the distributions: a) effects of a simple shift of the entire distribution toward a warmer climate; b) effects of an increased temperature variability with no shift of the mean; and c) effects of an altered shape of the distribution, in this example an increased asymmetry toward the hotter part of the distribution (Lavell et al., 2012).

mean, changing the shape of the distribution of a certain variable in the future (Lavell et al., 2012). In a warmer climate, the increase in atmospheric moisture may intensify the variability in precipitation associated with ENSO (Christensen et al., 2013). However, generally few attempts have been made to examine the specific contribution of ENSO to changing extremes. This project will examine, how the effects of a given ENSO event on climate extremes depend on changes to the background climate state and global warming.

A especial focus of the project will be on evaluating the influence of the North Atlantic mean state on ENSO and its climate impacts. This will be addressed by contrasting ENSO impacts between simulations in which the North Atlantic SST will be constraint to warm or cold conditions. Recent literature suggests that Atlantic multidecadal variability (AMV) can modify the tropical Pacific mean state (McGregor et al., 2014, Li et al., 2016, Ruprich-Robert et al., 2017). However, it is still not clear how those changes in the Pacific mean state translate into changes of ENSO behaviours (e.g. Wang et al., 2017). In addition, recent studies suggested that the AMV can also influence ENSO teleconnections even without changing ENSO itself (Lopez-Parages et al., 2015). A better understanding of the AMV influences on ENSO and its teleconnections will increase the level of confidence of extreme impacts assessments and seasonal forecasts.

The IPCC Fifth Assessment Report (2013) concluded there was low confidence in projected changes to climate extremes in many parts of the globe. Understanding how internal drivers of climate variability will respond to external forcings in the near future has been defined as a “Grand Challenge” by the World Climate Research Programme. A better understanding of the physical mechanisms of the different ENSO teleconnections will help to improve the resilience of society to climate change and climate impacts (Dunstone et al., 2016).

The latest climate model simulations encompassed in the Climate Model Intercomparison Model Phase 6 (CMIP6) will represent significant improvements in the representation of ENSO (Collins et al., 2014) in terms of model resolution and a more realistic representation of internal modes of climate variability (Haarsma et al., 2016), enabling the following important scientific questions to be addressed in this project:

- Are the global climate effects of different magnitude El Niño (warm phase) and La Niña (cold phase) events just opposite in model simulations?
- How does model resolution modify the simulation of ENSO and its teleconnections? In particular, does increased model resolution allow a better representation of ENSO impacts over continents and their associated modulation of weather extremes such as drought and heat waves?
- How do ENSO impacts depend on the mean climate background state? How will ENSO impacts evolve under future climate conditions?

3. Objectives

The main aim of this project is to establish the effects of ENSO in the present and future climate by using state-of-the-art coupled climate models. This will be achieved through the following research objectives:

1. Investigate ENSO and its impacts from different model resolutions. In particular, contrasting these in low and high resolution simulations, including those performed within the High Resolution Model Intercomparison project (HighResMIP) and other very high resolution simulations performed by BSC.
2. Evaluate the influence of different mean states on ENSO and its impacts (including precipitation and temperature extremes) by comparing simulated ENSO impacts from present day with end of 21th century simulations.
3. Assess ENSO impacts with different North Atlantic background conditions using the Decadal Climate Prediction Project (DCPP) Component C experiments of CMIP6.
4. Determine relationships between ENSO and different anthropogenic forcing levels from step change perturbation experiments.
5. Determine the most vulnerable regions to future ENSO events and make an impact assessment of extremes.

Objectives 1 and 3 will consist in developing a better understanding of the physical mechanisms associated with global ENSO teleconnections at regional scale. Objectives 2,4 and 5 will build on this new understanding to examine the role of ENSO in future climate variability and associated impacts.

4. Methodology

The project will make use of new state-of-the-art climate model experiments encompassed in the PRIMAVERA project, with a special focus on HighResMIP. PRIMAVERA is a Horizon 2020 project funded by European Commission that aims to develop high-resolution global climate models to simulate regional climate impacts. The student will have the opportunity to undertake visits to the Barcelona Supercomputing Center and make use of the Earth System Model at the high performance MareNostrum system. This approach will allow to make progress in dynamical global modelling, study the role of ENSO in global climate variability and reduce uncertainties in ENSO impacts and mechanisms. Also, the multi-model comparison will contrast low, high and very high resolution simulations, including the BSC Very high resolution simulation (15 km) with atmosphere-ocean configurations.

The use of multiple models and ensemble members from CMIP6 piControl and historical simulations will allow robust statistics on climate extremes to be isolated. The project will also use future climate projections from CMIP6 for different Shared Socioeconomic Pathways (SSP) that explore a range of scenarios for the future greenhouse gas and aerosol emissions. These will allow to isolate the impacts of ENSO for different levels of background warming. The investigation of the transient CMIP6 simulations will be complemented by analyses of simulations from Precipitation Driver and Response Model Intercomparison Project (PDRMIP), which include experiments with idealised step-changes in different forcing agents (CO_2, methane, aerosols, solar forcing). Also, the experiments will be design to study independently different magnitude ENSO events to identify changes according to different characteristics of the event such as intensity and geographic location of SST anomalies.

Some of the experiments of CMIP6 that this project will use are the Scenario Model Intercomparison Project (ScenarioMIP), that provides multi-model climate projections based on different scenarios of emission and land use change, the High Resolution Model Intercomparison Project (HighResMIP) that represent a great advantage in terms of high-resolution runs that will allow to assess small-scale impacts. Finally, experiments from the DCPP component A will investigate the ability of climate extremes to be predicted based on hindcasts and DCPP-C will be the base of idealized AMV experiments.

Annual research visits will be undertaken to BSC to facilitate access to latest model simulations and data and to ensure a strong collaboration with scientists in the Climate Prediction group.

5. Expected outcomes

This is a proposed PhD by published work with different parts that will lead to individual but not independent publications on scientific journals. Publication ideas will be developed from a comprehensive literature review and in discussion with supervisors and the PhD advisory panel. They will aim to have a potential impact on the global community, the following scientific publications are initially suggested:

- ✓ Different resolution multi-model CMIP6 simulations of ENSO impacts.
- ✓ Climate impacts of different ENSO flavours in the present and future.
- ✓ Impacts of North Atlantic decadal variability on ENSO
- ✓ Very High resolution simulations of ENSO- driven climate extremes.

By the end of the project, the results obtained will broaden the global knowledge of the global climate response to ENSO. A new understanding of the mechanisms of the different ENSO teleconnections across the globe will reduce uncertainties in the global climate response to ENSO and the likelihood of extreme events.

6. Training

The School of Earth and Environment (SEE) was ranked 2nd in the UK for Research Power in “Earth and Environmental Sciences” in the 2014 UK Research Excellence Framework (REF) Assessment. The student will be based within the Physical Climate Change research group in the Institute for Climate and Atmospheric Science (ICAS) in SEE, which consists of 7 academic staff and 14 PhDs and postdoctoral researchers who meet regularly providing a supportive forum to discuss research and receive feedback on your work.

Specific skills that will be developed during the project include:
(1) Techniques to handle the large data sets produced by models.
(2) Application of statistical analysis methods to climate model experiments.
(3) Understanding of sources of uncertainty in predictions.
(4) Use of observational datasets to evaluate model simulations.
(5) Working with people from a range of backgrounds.
(6) Effective communication through presentations at conferences, informal talks at project meetings, and writing peer-reviewed journal articles.

The student will be expected to undertake annual visits to the CASE supervisor to ensure effective collaboration and interactions. The student will receive assistance from the CASE supervisor and other scientists at the Barcelona Supercomputing Center in learning how to analyse model experiments performed on high performance computing facilities.

There will be numerous opportunities present your research at national and international conferences and meetings, as well as to attend summer schools and other training workshops. In addition, an active internal and external seminar series within ICAS will provide a broad background in research topics across atmospheric and climate science.

Leeds hosts a NERC Doctoral Training Partnership (DTP), which recruits a total of 28 students per year across 6 departments. This fosters a strong research student cohort in which students feel part of a strong and lively community and take advantage of the many research, training and social opportunities that are available. The University of Leeds also offers a tailored programme of dedicated training and development courses for postgraduate researchers, see: http://www.emeskillstraining.leeds.ac.uk/.

The University of Leeds is a member of the Met Office Academic Partnership, which gives students access to Met Office models, datasets and seminar series. The Priestley International Centre for Climate has been established at the University of Leeds to promote interdisciplinary research in Climate Science across several Departments and offers graduate-level lectures on topics in climate science, modelling working groups and training in communication to policy makers and the public.

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