The International CLIVAR Climate of the 20th Century Project (C20C+)

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1. INTRODUCTION

The Climate of the Twentieth Century (C20C+ [*]) project was originally established by the Met Office Hadley Centre in the early 1990s, particularly to feed information about atmospheric model performance into the Climate Models – Evaluation chapter of the Second IPCC Scientific Assessment (Folland and Rowell 1995). The project was jointly re-established by the Met office Hadley Centre and the Center for Ocean-Land-Atmosphere Studies (COLA) in 1999 and became an official CLIVAR project in 2003. Over this period, the C20C+ project has brought together climate modelling and data analysis groups to study climate variations and changes over periods up to the last 150 years using observational data and general circulation models (GCMs). As in the original formulation of the project in the 1990s, there is some emphasis on atmospheric GCMs (AGCMs) forced with observed values of atmospheric composition (concentrations of greenhouse gases, aerosols, etc.) and surface conditions (sea surface temperature, sea ice extent, soil moisture and land surface vegetation, etc.) as well as on natural variations. However coupled models are playing steadily larger role in some key projects.

C20C+ is similar to, but differs from the Atmospheric Model Intercomparison Project (AMIP) in several ways. Firstly the length of the simulations is considerably greater. Some simulations are carried out beginning in the late 19th century, with a core period from 1950 to the present, which has better verifying data. The C20C+ project is much more about predictability, and related climate mechanisms, than is AMIP and includes decadal time scales, though aspects of model evaluation are included. Predictability studies benefit in a complementary way from different types of models and of course observed data, particularly reanalyses. Thus AGCMs, intermediate models with mixed layer oceans and CGCMs, and initial studies using observed data alone are used in C20C+ studies. One of the important goals of C20C+ is to determine the extent to which models are able to simulate the observed climate variations during the mid-19th to early-21st century period, for which sufficient observations are available to estimate means and variability, particularly of the surface climate. Of particular importance is the potential ability of ensembles of AGCM runs to simulate specific historical events such as regional floods and droughts, e.g. the Dust Bowl in North America, the persistent drought in the Sahel and other extreme seasons. As agreed at the fifth C20C+ Workshop in Beijing in 2010 (Kinter and Folland, 2011), the project has been extended to include a core research effort in collaboration with the International Detection and Attribution Group and the international Attribution of Climate-related Events activity studying the influence of anthropogenic forcing on climatic events, particularly extreme climate events. This is partly to support new research on quasi-operational attribution. This is a logical extension of C20C+ as in the longer-term quasi-operation attribution and seasonal forecasting in particular may increasingly merge to

[*] The project has used the acronym *C20C* until the sixth workshop in November 2013 when the group opted to recognize that the period of interest extends beyond just the 20th century and changed the acronym to *C20C+*.

provide an integrated service. At least in the medium term, AGCM runs forced with observed or modified SST and sea ice data are already a key component of this research.

The first workshop was held in late 1994 (Folland and Rowell, 1995) and its results were used in the Climate Models - Evaluation chapter of the Second Assessment Report of IPCC published in 1996 where the second author of this review was a Lead Author. In addition, a special C20C+ session was held at the First International AMIP Conference in 1995. Although this activity led to bilateral collaboration in 1999, the project was revitalized as a joint project of the Hadley Centre and the Center for Ocean-Land-Atmosphere Studies (COLA) with administrative support from COLA. A number of groups participated in the C20C+ project by running AGCM experiments forced with the then newly-released Hadley Centre HadISST sea surface temperature (SST) and sea-ice extent data set (Rayner et al., 2000, 2003).

A second workshop was held at COLA on 22-25 January 2002 to review progress and particularly to plan a more structured C20C+ project with (1) specified ensemble sizes, (2) fixed simulation durations, (3) standard diagnostics, (4) standard validation data sets (objective analyses and reanalyses) and (5) agreed protocols for sharing data. As a result of that workshop, more emphasis was placed on including other external forcings in addition to the surface boundary conditions, including

- Data from the Hadley Centre on changes in carbon dioxide since 1871.
- Volcanic stratospheric forcing (from 1950 only, as data before then are more uncertain).
- Changes in tropospheric and stratospheric ozone.

The C20C+ participating groups began creating links to the CLIVAR Working Group on Seasonal to Interannual Prediction (WGSIP), the JSC/CLIVAR Working Group on Coupled Modelling (WGCM) and the AMIP project.

2. A DECADE OF C20C+ ACHIEVEMENTS 2005 – 2014

The C20C+ project has made significant advancements over the past decade. These have included four workshops in 2005, 2008, 2010 and 2013 and several innovative coordinated experiments that have led to a substantial body of peer-reviewed publications (C20C+ related publications).

2.1 Workshops

2.1.1 2005 C20C+ Workshop

The Third C20C+ Workshop was held in Prague, Czech Republic, on 4-6 July 2005, hosted by the MAthematical Geophysics, Meteorology, and their Applications (MAGMA) project of the Charles University of Prague (est. 1348), which was funded under the European Union's Fifth Framework Programme for support to Newly Assisted States. The goal of the Prague workshop was to define, implement and analyze collaborative numerical experiments. The workshop explored:

- The efficacy of regionally coupled or "pacemaker" experiments where tropical Pacific SST is prescribed from observations, but coupled air-sea feedbacks are maintained in the other ocean basins (e.g. Lau and Nath, 2003)

- The possibility of simulating the response of the climate system to the changes in land cover and land use.

2.1.2 2007 C20C+ Workshop

The Fourth C20C+ Workshop was held on 13-15 March 2007 at the Hadley Centre for Climate Change of the Met Office, Exeter, UK. The workshop reviewed progress on coordinated climate simulations and analyses, including new results on 20th century climate variability, and developed plans for new integrated model experiments with various degrees of ocean-atmosphere-land coupling. New versions of the HadISST sea-surface temperature and sea-ice data set were discussed. There was also considerable discussion of how to coordinate C20C experiments with SPARC, the international project investigating Stratospheric Processes And their Role in Climate; http://www.atmosp.physics.utoronto.ca/SPARC/index.html), and the effects of land use and land cover change on the variability and predictability of climate. The workshop was well attended with 37 participants from 19 different institutions. Downloadable copies of the presentations and summaries of the three breakout group discussions are available from the workshop web site (http://www.iges.org/c20c/workshops/200703/home.html). This Workshop led to the publication in Climate Dynamics of the four most widely coordinated C20C+ papers so far, indicated with an asterisk in the bibliography (see section 2.3.3).

2.1.3 2010 C20C+ Workshop

The C20C+ project held its Fifth Workshop on 25-28 October 2010 at the Institute of Atmospheric Physics (IAP) of the Chinese Academy of Sciences, Beijing, China (Kinter and Folland 2011). The Fifth Workshop convened to review new results on forcing data sets, coordinated climate simulations and analyses, and to develop plans for new C20C projects. The 45 workshop participants from 16 institutions representing 10 countries were welcomed by Dr. Huijin Wang, Director of IAP. The workshop web site (http://www.lasg.ac.cn/c20c/) includes downloadable copies of the presentations and a fuller discussion of the Workshop. Summaries of the breakout discussions are available on the project web site (http://www.iges.org/c20c/).

Several new coordinated experiments (see Section 2.2) were discussed at this workshop, including:

- Detection and Attribution of Climate Change
- Evaluation of the Role of Weather Noise in Climate Predictability

Several new diagnostic sub-projects were also initiated at the Fifth Workshop:

- Summer North Atlantic Oscillation (Summer NAO)
- Precipitation over the 20th Century
- Predictability Diagnostics
- Statistical Properties of Mid-latitude Atmospheric Variability

2.1.4 2013 C20C+ Workshop

The Sixth Workshop of the C20C+ project was held on 5-8 November 2013 at the University of Melbourne, Australia. The goal of the Sixth Workshop was to review early progress in the new core activity of research into the detection and attribution of extremes, observational data sets that will support C20C activities, and other longer-standing key C20C projects. The 35 workshop participants from 18 institutions were welcomed by Prof. Janet Hergt, Dean of the Melbourne University Faculty of Science. A representative of the WCRP Working Group on Coupled Modelling, Dr Claudia Tebaldi, also attended. The workshop web site (http://www.iges.org/c20c/home.html) includes downloadable copies of most presentations and posters, and more detailed discussions of Workshop outcomes. A key decision was to rename the project C20C+ partly because of the new focus on research on operational attribution and because increasingly 21st century climate change is a crucial component of understanding variability and trend mechanisms.

2.2 Coordinated Experiments

The C20C+ project is centered around a number of coordinated numerical experiments and diagnoses that can address the origins of the anomalies and trends in the climate of the recent past. The project has established a number of standards for the coordinated experiments, including a fixed set of external forcings, the specification of the HadISST SST and sea ice extent data set to be used in AGCM experiments and verification of simulations, and a minimum ensemble size of six integrations for the 1871-2002 period and 10 integrations for the 1949-2002 period. In this section, we describe the HadISST data set as well as several of the coordinated experiments.

2.2.0 HadISST

A mainstay of the project is the development and use of the HadISST SST and sea ice extent data set that has been maintained and updated by the Hadley Centre over the course of the C20C+ project. HadISST has been used far beyond C20C+, with several thousand citations. The Hadley Centre continues to develop improved analyses of global SST and sea ice concentration so as to include more observations and attain greater accuracy and resolution. The most recent version, HadISST2, includes multiple (100) realizations, better resolution in time, new bias corrections to SST up to the present, inclusion of AATSR satellite data and a considerably improved sea ice extent data set. The sea ice component is described in Titchner and Rayner (2014) Two further papers will soon be submitted: Kennedy et al (in prep.) describing the SST component and Rayner et al (in prep.) describing the combination of SST and sea ice. Future versions will address the diurnal cycle through work under the European Space Agency (ESA) Climate Change Initiative SST project (see http://www.esa-sst-cci.org/). It is highly desirable to have a 0.5°-resolution daily version of

HadISST, at least for the satellite era, such as has been experimentally created in the Met Office OSTIA analysis (single realization, without full bias correction), and it is planned to integrate HadISST and OSTIA over the next few years.

2.2.1 Pacemaker Simulations

As noted above and as discussed during the C20C+ Third Workshop, important elements of atmosphere-ocean-land co-variability (e.g., monsoons) cannot be reproduced when prescribing global SST. Energetically and dynamically consistent local air-sea feedbacks, created primarily through latent heat fluxes, are essential elements in simulating, and predicting the observed co-variability. The challenge is to design numerical experiments that reproduce the important aspects of this air-sea coupling while maintaining the flexibility to attempt to simulate the observed climate of the recent past. In order to address this problem, a number of research groups began numerical experimentation into regionally coupled or "pacemaker" experiments where tropical Pacific SST is prescribed from observations, but coupled air-sea feedbacks are maintained in the other ocean basins (e.g. Alexander et al. 2002; Lau and Nath, 2003). Pacemaker experiments were capable of reproducing the timing of the forced response to SST anomalies related to El Niño and the Southern Oscillation (ENSO), but also much of the co-variability that is missing when global SST is prescribed.

Pacemaker experiments can take a variety of forms in terms of what region is used for prescribing the SST, how air-sea feedbacks are incorporated in the interactive coupling region and how the coupled model is formulated (i.e., slab mixed layer, Q-flux-adjusted mixed layer, variable depth mixed layer, relaxation to observed SST, dynamical ocean etc.).

In the C20C+ project, Pacemaker experiments have been organized for two regions: (1) the deep tropical eastern Pacific where coupled ocean-atmosphere dynamics produces the ENSO interannual variability, and (2) the north Atlantic. In the case of the eastern Pacific, there is ample evidence that ENSO is a driver of seasonal to interannual variability throughout the tropics, which was exploited, e.g., by Cash et al. (2008a,b; 2009) with the C20C+ framework. A recent paper shows the efficacy of this approach in simulating the Indian monsoon (Shukla and Kinter 2014). In the north Atlantic, there is evidence that interhemispheric modes of variability in SST (or SST gradient), associated with what is often called the Atlantic Multidecadal Oscillation and, quite possibly, variations in thermohaline circulation (e.g. Knight et al., 2005), are important for variations of climate in Europe, North Africa and North and South America (e.g. Knight et al., 2006).

2.2.2 Land Use and Land Cover Change

Over the past 250 years, human settlement has made extensive changes to the landscape, primarily in the form of transforming forests into pastures and croplands. Given current trends, it is expected by 2100 that most of the natural vegetation will disappear in Africa and parts of Asia and that there will continue to be a reintroduction of forests in Europe and North America. Such massive changes in land cover produce large regional changes in the surface albedo. These in turn lead to changes in the global radiative forcing comparable to the change due to increasing greenhouse gas concentrations.

There is a general consensus from paleoclimate models that the LCC since the Holocene has resulted in a general cooling of the global mean surface temperature by 0.5°C, which can be compared with the perhaps 0.9°C increase estimated to have occurred in response to the change in greenhouse gas concentrations over the same period. By specifying the time-varying state of the global land surface vegetation, C20C+ experiments can determine the impact of changes in land cover. A new major international project called, Land Use and Climate, IDentification of robust impacts (LUCID; introduced in Newsletter 4, http://www.atm.helsinki.fi/ILEAPS/), which is being organized under the auspices of International Geosphere-Biosphere Program (IGBP) Integration Land Ecosystem – Atmosphere Processes Study (iLEAPS; http://www.atm.helsinki.fi/ILEAPS/) and the World Climate Research Program (WCRP) Global Water and Energy Experiment (GEWEX), is closely linking its numerical experimental plan with C20C.

Determining the response of the climate system to the changes in land cover and land use (LCC) is a critically important aspect of climate change. One difficulty with interpreting the range of available model results is that the model protocols are sufficiently varied to limit the robustness of their results. There have been shortcomings with the experimental design of previous attempts to explore the effect of LCC on the climate using global climate models such as shortness (< 20 years) of the simulations, single realizations, and spatial resolution tends to be quite coarse. Recent work in the context of coupled models is promising (Kumar et al. 2013).

The C20C+ project is running simulations in which the observed change in croplands and pasture, for which a global data set is available for 1871- 2002, is included. A scheme for inclusion of these data in models with various land surface treatments was developed. There are also simulations being made in which the soil moisture simulated in the control run is specified (without feedback) over the course of the integration. The effect of the soil moisture feedback will then be inferred from the difference of this experiment with the control integrations. Experiments with interactive vegetation are also being run as part of C20C+.

2.2.3 The Role of the Stratosphere in Climate

There has been increasing interest in the stratosphere community about the possibility of downward propagation of signals from the stratosphere to the troposphere and even to the surface. In the context of C20C, Scaife et al. (2005) showed this idea was important for understanding the climatic effects of the North Atlantic Oscillation on decadal time scales. The C20C+ project includes experiments, to be conducted in AGCM and CGCM simulations, testing the consequences of poor resolution of stratospheric dynamics in such models and to determine how the stratosphere might influence the coupled ocean-atmosphere system, both in terms of current climate variability and the potential role of the stratosphere in future climate change. These proposed experiments include identical model runs with and without a resolved stratosphere ("high-top" and "low-top" runs).

2.2.4 Detection and Attribution of Climate Change

The aims of the International Detection and Attribution Group are to characterize historical trends and variability in characteristics of damaging weather and short-term climate events as well as to determine the contribution of anthropogenic emissions to contemporary occurrence of these events. A key focus is on underlying uncertainties in these estimates. This will involve at least a dozen C20C+ groups around the world running atmospheric models in a semi-coordinated study of weather risk attribution. The experimental design can be summarized as:

- **All-Hist:** Simulations run under observed variations in radiative forcing and surface boundary conditions.
- **Nat-Hist:** Simulations run under variations that might have occurred in radiative forcing and surface boundary conditions had anthropogenic emissions never interfered with the climate system.

In addition, it is planned that some coupled global models, regional models and selected impacts models will be used. Observations and models will also supply key climate indices. Output from the main simulations is being published on the Earth System Grid Federation (ESGF, http://esg.nersc.gov) under the project name "c20c". The data will also be used by other C20C+ projects.

2.2.5 Weather Noise

Based on earlier work by Hasselmann, Schneider and Fan (2007) showed that some features of low frequency variability may result from stochastic variations in the atmosphere, sometimes called weather noise. Analyses of the output from existing C20C+ ensemble simulations compare the properties of actual atmospheric weather noise implied by the various models. The weather noise is computed by subtracting ensemble and monthly mean simulated fields from observational analyses. Quite extensive studies have now been published (e.g. Chen et al., 2013 and Chen and Schneider, 2014). The potential uses for this product include:

a. *Model verification*: By determining whether the weather noise inferred from a model satisfies the causality principle that the weather noise is unpredictable, the model's realism can be assessed. The predictable part of the weather noise should be included in the ensemble means of the simulations; hence, the residual should be unpredictable if the model is realistic. Predictability can be determined from simple lag regression analyses (e.g. does the North Atlantic tripole index predict future weather noise surface fluxes?).
b. *Studies of low frequency coupled climate variability*: The weather noise surface fluxes could be used to force simplified coupled models (such as versions of the Interactive Ensemble CGCM – Kirtman and Shukla, 2002) to analyze properties and mechanisms of the low frequency SST variability forced by weather noise.
c. *Identifying the strengths and limitations of AGCMs for studying climate variability and predictability:* The general conclusion so far is that AGCMs are a valuable tool except perhaps for quantitative simulations of oceanic tropical rainfall.

2.3 Diagnostic Sub-Projects

Another hallmark of the C20C+ project is the coordination of diagnoses of both long-term climate data sets (objective analyses and reanalyses) and climate model simulations of the recent climate. Here we describe several of the diagnostics that are representative of the C20C+ analysis.

2.3.1 Summer NAO

The Summer North Atlantic Oscillation (SNAO) can be defined as the first EOF of July-August or June-August extratropical North Atlantic pressure at mean sea level. It exerts a strong influence on European climate, e.g. rainfall, temperature and cloudiness, but is also associated with climate variability elsewhere, e.g. eastern North America, the Sahel region in Africa and eastern Asia (e.g. Folland et al. 2009) Moreover, modeling and observational results indicate that SNAO variations are partly related to the Atlantic Multidecadal Oscillation (AMO) on interdecadal time scales.

This project focuses on the pattern and impacts of SNAO simulated by C20C+ models together with palaeoclimatic studies of the long term variability and influence of the SNAO. Initial tests with coupled models show that models tend to produce different SNAO patterns, or sometimes not show a reasonable SNAO pattern. The diagnosis separates those models that produce an SNAO pattern from those that don't. Composites of SNAO with surface air temperature, precipitation, and storm tracks from the different AGCMs and coupled models will be used to evaluate the impacts of SNAO on different regions (including East Asia). SST influences and the emerging issue of Arctic sea ice influences will also be investigated. Recent research describes physical mechanisms showing how a given SNAO phase affects the summer East Asian monsoon a week or two later (Linderholm et al, 2011). Further research discusses the influence of the SNAO on East Asian climate on decadal and longer time scales using tree rings (Linderholm et al, 2013). A surprising new development is the discovery of an influence of the QBO on summer European and Arctic climate including the SNAO, as well winter Antarctic climate, seen both in observations and the HadGEM3 coupled model.

2.3.2 Precipitation in the 20th Century

A number of reconstructions of global precipitation for the past century or more have been developed. Most have focused on the satellite era, but some have inferred precipitation back to the beginning of the 20th century. Datasets to be used in the C20C+ project include modern global precipitation analyses such as the well-known Global Precipitation Climatology Project (GPCP) data set and the Climate Prediction Center Merged Analysis of Precipitation (CMAP) data set, together with the new 20th Century reconstruction of precipitation (Smith et al. 2010).

The project will focus on:

- Validation of precipitation simulations in C20C models;
- Improvement of observational datasets; and
- Enhanced understanding of climate variability and change during the 20th century.

Particular diagnostics of interest will include:

- the simulated global mean and the long-term mean annual cycle of precipitation over large domains (global, hemispheric, land/ocean, continental) and changes over the century;
- the simulation of precipitation features associated with large-scale modes of climate variability such as ENSO, the NAO, the Pacific Decadal Oscillation/Interdecadal Pacific Oscillation and the AMO;
- the relationship of the features to be evaluated to observed atmospheric and SST variations.

2.3.3 Predictability Diagnostics

A novel mathematical diagnostic method to measure predictability that separates different spatial modes of variability, including a separation of the influence of external forcing from internal variability was developed by Zheng et al. (2008). It was first applied to C20C+ simulations by Zheng et al. (2009). It is the basis of a major coordinated C20C+ study of the predictability of southern hemisphere climate modes in Grainger et al (2011) using the AGCM data described at section 2.2. Ongoing work applies this methodology in AGCM and coupled models to:

- validate simulations of the variability of tropical SST using principal component analysis
- validate the general circulation simulated by climate models using singular value decomposition of the covariance matrices of the simulated and observed component fields
- validate simulated temperature and precipitation using cross-covariance matrices between temperature (or precipitation) and circulation.

Scaife et al (2009), in a second major coordinated C20C+ analysis using the same AGCM data introduced a new conceptual way of analyzing the predictability skill shown by models when compared to observations. They also showed that AGCMs that under-respond to ENSO are likely to underestimate global warming. Zhou et al. (2009), in a third major coordinated study using this

AGCM data, investigated the predictability of the East Asian and Australian monsoons and several ,associated indices. Finally Kucharski et al (2009), using the same AGCM data, studied decadal forcing of the Indian monsoon over 1950-2000 and showed that AMO forcing was a contributor.

2.3.4. Statistical Properties of Mid-latitude Atmospheric Variability

Theoretical and observational arguments suggest that the two main features of mid-latitude northern hemispheric winter variability can be almost unambiguously separated. First, synoptic phenomena can be associated with the release of available energy driven by conventional baroclinic conversion. Secondly, at lower frequencies (10-40 days), the planetary scale variability is related to non-linear orographic resonance processes. Moreover, non-linear wave self-interaction theories predict the existence of multiple equilibria of the mid-latitude planetary wave amplitude including switches from unimodal to multimodal regimes of the atmospheric circulation.

Focusing on December-February in the latitudinal belt where the bulk of the baroclinic and low frequency planetary waves are observed, daily averages of 500hPa height provide a one-dimensional longitudinal field representative of atmospheric variability in the mid-latitudes. Its variability can be described using a space-time Fourier decomposition introduced by Hayashi (1979). By computing the cross-spectra and the coherence of the signal, the eastward and westward wave propagating components can be discerned from the standing component.

3. C20C+ FUTURE PLANS

Future C20C+ simulations will address questions raised in previous rounds to help better understand mechanistic questions relating to seasonal and decadal predictability and forecasting, and to prepare contributions to the Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC). Experimental designs are in place for more detailed pacemaker simulations and land use change experiments. There are already strong ties in place to the Working Group on Seasonal-to-Interannual Prediction (WGSIP) of the WCRP and now to the LUCID project.

3.1 Detection and Attribution of Climate Change

This is expected to become the new single largest project within C20C+ by the time of the next workshop. C20C+ project outputs produced to address the questions of detection and attribution will support the *Bulletin of the American Meteorological Society's* annual State of the Climate attribution supplement (Peterson et al., 2013). Before the next C20C+ Workshop, it is hoped to organize a journal special issue providing an overview of the first results from the detection and attribution subproject. More details can be found on the C20C+ web site http://grads.iges.org/c20c/home.html and at the subproject web site http://portal.nersc.gov/c20c/. Ideas for possible future experiments were discussed at the workshop, including a focus on the effects of specific forcings, a focus on projections for some future period, and a focus on geo-engineering problems.

3.2 Atmospheric Circulation, Rainfall and Atmospheric Noise

At the Sixth C20C+ Workshop, an Atmospheric Circulation and Rainfall Working Group was formed. Following several recent published papers, some listed below, the atmospheric noise project will look at long time-scales of climate variability. These may be forced (partly at least) by atmospheric noise due to coupled atmosphere-ocean processes or ocean internal variability. With the help of AAGCM-only ensembles to estimate weather noise, the noise component of key drivers of decadal variability in CGCM control experiments and decadal prediction experiments will be studied using diagnostic models.

There is increasing evidence that state of the art models represent processes affecting European climate considerably better than in the past (e.g. Scaife et al , 2014). The role of C20C+ will be particularly in studying European climate forcing mechanisms in the summer and for winter half-year UK and European droughts (e.g. Folland et al., in preparation). The former project is studying the mechanisms of European summer climate variability following a number of recent papers on the summer North Atlantic Oscillation (SNAO). Particular emphases are tropical rainfall forcing, SST forcing including the AMO, the effect of the recent decline in Arctic sea ice and the newly discovered influence of the QBO. The project is also reconstructing the SNAO over the last millennium (Linderholm et al., 2013) and using CMIP5 models to try to simulate SNAO variations over this long period. Reanalyses are important to this project; SNAO modes essentially involve changes in the tropospheric jet stream and the reanalysis project is expected to provide further advice on suitable reanalyses. There is considerable further potential to uncover the relative variance of potentially predictable modes and internal variability in both hemispheres using the Grainger et al. (2011) statistical method.

In the context of forcing factors for atmospheric circulation modes and for studies of rainfall data in their own right, there is a considerable need for a review of, and advice on, rainfall data sets to support C20C+ activities. Many such global or quasi-global data sets now exist. It is expected that using the core C20C+ model data, a much more extensive analysis will be done on trends and variations in global precipitation; this activity will also cast light the strengths and weaknesses of the many observed data sets. Further investigation of monsoon rainfall mechanisms will be done using coupled simulations being produced with the IFS system having 16km atmospheric grid spacing and 1^{o} ocean resolution. A 50-member ensemble of seasonal predictions is available for 1980-2010.

Finally as a background to these activities, it was agreed to add to the C20C+ project an ongoing study of the time-varying causes of the current slowdown in global warming, and how this might end. It was also agreed that the next workshop would be in 2016 or 2017 at the Center for Ocean-Land-Atmosphere Studies, George Mason University, Fairfax, Virginia, USA.

REFERENCES

Hayashi, Y., 1971: A generalized method for resolving disturbances into progressive and retrogressive waves by space Fourier and time cross-spectral analysis. J. *Meteor. Soc. Japan*, **49**, 125-128.

Hayashi ,Y., 1979: A generalized method for resolving transient disturbances into standing and travelling waves by space-time spectral analysis. *J. Atmos. Sci.*, **36**, 1017-1029.

Kirtman, B. P. and J. Shukla, 2002: Interactive coupled ensemble: A new coupling strategy for CGCMs, *Geophys. Res. Lett.*, **29**, 1367, doi:10.1029/2002GL014834.

Pall, P., A. Tolu, D.A. Stone, P.A. Stott, T. Nozawa, A.G.J. Hilberts, D. Lohmann and M.R. Allen, 2011: Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000. *Nature,* **470,** 382–385, doi:10.1038/nature09762.

Pitman, A. J., N. de Noblet-Ducoudré, et al., 2009: 'Uncertainties in climate responses to past land cover change: First results from the LUCID intercomparison study*. Geophys. Res. Lett.,* **36**, doi:10.1029/2009GL039076*.*

C20C+ RELATED PUBLICATIONS

Adler, R. F., and Coauthors, 2003: The version-2 Global Precipitation Climatology Project (GPCP) monthly precipitation analysis (1979–present). *J. Hydrometeor.*, **4**, 1147–1167.

Alexander, M. A., I. Blade, M. Newman, J. R. Lanzante, N.-C. Lau, and J. D. Scott ,2002: The atmospheric bridge: The influence of ENSO teleconnections on air-sea interaction over the global oceans, *J. Climate*, **15**, 2205 – 2231.

Allan, R., and T. Ansell, 2006: a new globally complete monthly historical gridded mean sea level pressure dataset (HadSLP2): 1850–2004. *J. Climate*, **19**, 5816–5842.

Allan, R. and C.K. Folland, 2012: Atmospheric circulation. 1. Sea level Pressure. In: State of the Climate 2011. *Bull. Amer. Met. Soc.*, **93 (7)**, S36-37.

Ansell, T.J., P.D. Jones, R.J. Allan, D. Lister, D.E. Parker, M. Brunet, A. Moberg, J. Jacobeit, P. Brohan, N.A. Rayner, E. Aguilar, H. Alexandersson, M. Barriendos, T. Brandsma, N.J. Cox, P.M. Della-Marta, A. Drebs, D. Founda, F. Gerstengarbe, K. Hickey, T. Jónsson, J. Luterbacher, O. Nordli, H. Oesterle, M. Petrakis, A. Philipp, M.J. Rodwell, O. Saladie, J. Sigro, V. Slonosky, L. Srnec, V. Swail, A.M. García-Suárez, H. Tuomenvirta, X. Wang, H. Wanner, P. Werner, D. Wheeler, and E. Xoplaki, 2006: Daily Mean Sea Level Pressure Reconstructions for the European–North Atlantic Region for the Period 1850–2003. *J. Climate*, **19**, 2717–2742.

Baines, P. and C.K. Folland**,** 2007: Evidence for a rapid global climate shift across the late 1960s. *J. Climate,* **12,** 2721-2744. *Also News Focus item in Science 10 Aug 2007 (Kerr)*

Barnston, A.G. and Livezey, R.E. 1987. Classification, seasonality, and persistence of low-frequency atmosphere circulation patterns. *Mon. Wea. Rev.*, **115**, 1083–1123.

Basnett, T.A., and D.E. Parker, 1997: Development of the global mean sea level pressure data set GMSLP2. Hadley Centre Climate Research Technical Note **79**, Met. Office, Bracknell, UK.

Benzi, R., P. Malguzzi, A. Speranza and A. Sutera, 1986: The statistical properties of general atmospheric circulation: observational evidence and a minimal theory of bimodality. *Quart. J. Roy. Meteor. Soc.*, **112**, 661-674.

Bladé, I., Fortuny, D., van Oldenborgh, G. J. and Liebmann, B. (2012). The summer North Atlantic Oscillation in CMIP3 models and related uncertainties in projected summer drying in Europe. *J. Geophys. Res.*, **117**, D16104. DOI: 10.1029/2012JD017816 (25-08-2012)

Bladé, I., Liebmann, B., Fortuny, D., and Oldenborgh, G. J. (2011). Observed and simulated impacts of the summer NAO in Europe: implications for projected drying in the Mediterranean region. *Climate Dyn.*, **39**, 3-4. DOI:10.1007/s00382-011-1195-x (01-08-2012)

Bosilovitch, M., S. Schubert and G. Walker 2005: Global changes of the water cycle intensity. *J. Climate*, **18**, 1591-1608.

Bracco, A., F. Kucharski, R. Kallummal and F. Molteni 2004: Internal variability, external forcing and climate trends in multi-decadal AGCM ensembles. *Climate Dyn.*, **23**, 659-678.

Brohan, P., Kennedy, J., Harris, I., Tett, S.F.B., and Jones, P.D. 2006: Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850. *J. Geophys. Res.*, **111**, D12106, doi:10.1029/2005JD006548.

Buzzi, A., A. Trevisan, A. Speranza, 1984: Instabilities of a baroclinic flow related to topographic forcing. *J. Atmos. Sci.*, **41**, 637-650.

Cash, B. A., X. Rodó and J. L. Kinter III, 2009: Links between tropical Pacific SST and the regional climate of Bangladesh: Role of the eastern and central tropical Pacific. *J. Climate*, **21**, 4647-4663.

Cash, B. A., X. Rodó, J. L. Kinter III, 2008a: Links between tropical Pacific SST and the regional climate of Bangladesh: Role of the western tropical and central extratropial Pacific. *COLA Technical Report,* **243**, 25 pp., Center for Ocean-Land-Atmosphere Studies, Calverton, Maryland.

Cash, B. A., X. Rodó, J. L. Kinter III, 2008b: Non-ENSO variability and the regional climate of Bangladesh: Implications for cholera risk. *COLA Technical Report*, **260,** 39 pp., Center for Ocean-Land-Atmosphere Studies, Calverton, Maryland.

Cash, B. A., X. Rodó, J. L. Kinter III, 2009: Links between tropical Pacific SST and the regional climate of Bangladesh: Role of the western tropical and central extratropical Pacific. *J. Climate,* **22**, 1641-1660*.*

Cash, B. A., X. Rodó, J. L. Kinter III, Md. Yunus, 2010: Disentangling the impact of ENSO and Indian Ocean variability on the regional climate of Bangladesh: Implications for cholera risk. *J. Climate,* **23**, 2817-2831*.*

Caminade C. and L. Terray, 2006: Influence of increased greenhouse gases and sulphate aerosols concentration upon diurnal temperature range over Africa at the end of the 20th century. *Geophys. Res. Lett.*, **33**, L15703, doi:10.1029/2006GL026381.

Charney, J. G., J. G. DeVore, 1979: Multiple flow equilibria in the atmosphere and blocking. *J. Atmos. Sci*., **36**, 1205-1216.

Chen, H., E. K. Schneider, B. P. Kirtman, and I. Colfescu, 2013: Comparison of a coupled model and an SST forced atmospheric model. *J. Climate*, **26**, 3766-3784

Chen, H., E. K. Schneider, B. P. Kirtman, I. Colfescu, 2013: Evaluation of Weather Noise and Its Role in Climate Model Simulations. *J. Climate*, **26**, 3766–3784.

Chen, H., and E. K. Schneider, 2014: Comparison of the SST Forced Responses Between Coupled and Uncoupled Climate Simulations. *J. Climate*, **27**, 740-756.

Christidis, N., et al., 2013: An attribution study of the heavy rainfall over eastern Australia in March 2012. In "Explaining Extreme Events of 2012 from a Climate Perspective". *Bull. Amer. Meteor. Soc.*, **94**, S58-S61.

Chylek, P. Folland C.K., Lesins G., Dubey M., and M. Wang, 2009: Arctic air temperature change amplification and the Atlantic Multidecadal Oscillation. *Geophys Res. Lett.,* **36**, L14801, doi:10.1029/2009GL038777

Chylek, P., C K. Folland, G. Lesins and M K. Dubey, 2010: The 20th Century bipolar seesaw of the Arctic and Antarctic surface air temperatures. *Geophys. Res. Lett.* **37,** L08703, doi:10.1029/2010GL042793.

Chylek, P., C.K. Folland**,** H. Dijkstra, G. Lesins and M. K. Dubey, 2011: Ice-core data evidence for a prominent near 20 year time-scale of the Atlantic Multidecadal Oscillation. *Geophys. Res. Lett***.,** **38,** L13704, doi:10.1029/2011GL047501

Chylek, P., C. K. Folland, L. Frankcombe, H Dijkstra, G. Lesins, and M. Dubey, 2012: Greenland ice core evidence for spatial and temporal variability of the Atlantic Multidecadal Oscillation. *Geophys. Res. Lett.,* **39,** L09705, doi./10.1029/2012GL051241

Colfescu, I*.,* E. K. Schneider*, and* H. Chen *(*2013*),* Consistency of 20th century sea level pressure trends as simulated by a coupled and uncoupled GCM*, Geophys. Res. Lett.*, **40***,* 3276–3280*,*

Dell'Aquila, A., V. Lucarini, P. M. Ruti and S. Calmanti, 2005: Hayashi spectra of the northern hemisphere mid-latitude atmospheric variability in the NCEP–NCAR and ECMWF reanalyses *Climate Dyn*., **25**, 639-652 doi:10.1007/s00382-005-0048-x.

Dell'Aquila, A., P. M. Ruti, S. Calmanti, V. Lucarini, 2006: Southern Hemisphere midlatitude atmospheric variability of the NCEP-NCAR and ECMWF reanalyses *J. Geophys. Res*. **112**, doi:10.1029/2006JD007376.

Donlon, C., et al, 2007: The Global Ocean Data Assimilation Experiment High-resolution Sea Surface Temperature Pilot Project, 2007: *Bull. Amer. Meteor. Soc*., **88**, 1197-1213.

Druyan, L.M., J. Feng, K.H. Cook, Y. Xue, M. Fulakeza, S.M. Hagos, A. Konare, W. Moufouma-Okia, D.P. Rowell, and E.K. Vizy, Seidou Sanda Ibrah, 2010: The WAMME regional model intercomparison study. In Special Issue "*West African Monsoon and its Modeling*", *Climate Dynamics*. **35**, 175-192. DOI 10.1007/s00382-009-0676-7.

Dunn, J.R.H., K. M. Willett, P. W. Thorne, E. V. Woolley, I. Durre, A. Dai, D. E. Parker, and R. S. Vose 2012: HadISD: a quality controlled global synoptic report database for selected variables at long term stations from 1973-2010.*Climate of the Past*, **8**, 1649-1679.

Folland, C.K**.**, 2005: Assessing bias corrections in historical sea surface temperature using a climate model. *Int. J. Climatol.*. (Special issue, CLIMAR II Conference), **25**, 895 - 911.

Folland, C.K., Bloomfield, J., Hannaford, J., Kendon, M., M.J. Prior and E. Wallace, 2014: Multiannual droughts in the UK and climatic driving factors. *To be submitted to Hydrology and Earth System Sciences.*

Folland, C.K**.**, Colman, A., Rowell, D.P., and M.K. Davey, 2001: Predictability of North East Brazil rainfall and real-time forecast skill, 1987-1998 *J. Climate,* **14,** 1937-1958*.*

Folland, C. and J. L. Kinter III, 2002: The Climate of the Twentieth Century Project. *CLIVAR Exchanges*, **7(2)**, 37-39.

Folland, C.K., Knight, J., Linderholm, H.W., Fereday, D., Ineson, S. and Hurrell, J.W. 2009: The Summer North Atlantic Oscillation: past, present and future. *J. Climate*, **22**, 1082- 1103.

Folland, C.K., J.A. Renwick, M.J. Salinger and A.B. Mullan, 2002: Relative influences of the Interdecadal Pacific Oscillation and ENSO on the South Pacific Convergence Zone. *Geophys. Res. Lett.*, **29** (13): 10.1029/2001GL014201.

Folland, C.K., and D.P. Rowell (eds.), 1995: Workshop on simulations of the Climate of the Twentieth Century using GISST. Hadley Centre Climate Research Technical Note 56, Met. Office, Bracknell, UK.

Folland, C.K, Scaife, A.A., Lindesay, J. and D.B. Stevenson, 2012: How potentially predictable is northern European winter climate a season ahead? *Int. J. Climatol.,* **32,** 801–818. DOI: 10.1002/joc.2314

Folland, C.K., Shukla J., Kinter J., and M. J. Rodwell, 2002: C20C: The Climate of the Twentieth Century Project. CLIVAR Exchanges, 7, 37-39. (Available from International CLIVAR Project Office, Southampton Oceanography Centre, Empress Dock, Southampton, SO14 3ZH, UK; http://www.clivar.org/publications/exchanges/ex24/ex24.pdf)

Frederiksen, C.S. X. Zheng, 2004: Variability of seasonal-mean fields arising from intraseasonal variability, Part 2, application to NH winter circulations. *Climate Dyn*., **23**, 193-206, doi:10.1007/ s00382-004-0429-6.

Frederiksen, C.S., X. Zheng and S. Grainger 2013: Teleconnections and predictive characteristics of Australian seasonal rainfall. *Climate Dyn.* doi: 10.1007/s00382-013-1952-0.

*Grainger, S., C. S. Frederiksen, X. Zheng, D. Fereday, C. K. Folland, E. K. Jin, J. L. Kinter III, J. R. Knight, S. Schubert, J. Syktus, 2011: Modes of variability of Southern Hemisphere atmospheric circulation estimated by AGCMs. *Clim. Dyn.* **36***,* 473-490 doi: 10.1007/s00382-009-0720-7.

Kang, I.-S., E. K. Jin, K.-H. An, 2006: Secular increase of seasonal predictability for the 20th century. *Geophys. Res. Lett*., **33**, doi 10.1029/2005GL024499.

Kennedy J. J., N.A. Rayner, S.C. Millington, M. Saunby, 2014: The Met Office Hadley Centre Sea Ice and Sea-Surface Temperature data set, version 2, part 2: sea-surface temperature analysis (In prep.)

Kiktev, D., Sexton D., Alexander, L. and C.K. Folland, 2003: Comparison of modelled and observed trends in indicators of daily climate extremes. *J. Climate,* **16**, 3560-3571.

King, M. P. and F. Kucharski 2006: Observed decadal connections between the tropical oceans and the North Atlantic Oscillation in the 20th century. *J. Climate*, **19**, 1032-1041.

King, M. P., Kucharski, F. and Molteni, F., 2010: The roles of external forcings and internal variabilities in the Northern Hemisphere atmospheric circulation change from the 1960s to the 1990s. *J. Climate*, **23**, 6200–6220, doi: 10.1175/2010JCLI3239.1.

Kinter III, J. L., M. J. Fennessy, V. Krishnamurthy and L. Marx, 2004: An evaluation of the apparent interdecadal shift in tropical divergent circulation in the NCEP-NCAR reanalysis. *J. Climate*, **17**, 349-361.

Kinter III, J. L. and C. Folland. 2011: The international CLIVAR Climate of the 20th Century Project: Report of the Fifth Workshop. *CLIVAR Exchanges*, **57**, 39-42.

Knight, J., Allan R.J., Folland, C.K., Vellinga, M. and M.E. Mann, 2005: Natural variations in the thermohaline circulation and future surface temperature. *Geophys. Res. Lett.,* **32,** L20708, doi: 1029/2005GL024233.

Knight, J.R., Folland, C.K. and A.A. Scaife, 2006: Climatic impacts of the Atlantic Multidecadal Oscillation. *Geophys.Res. Lett.,* **33,** L17706. doi: 10.1029/2006GL026242.

Kucharski F., Bracco, A., Barimalala, R. and Yoo, J. H., 2010: Contribution of the east-west thermal heating contrast to the South Asian Monsoon and consequences for its variability. *Climate Dyn*., **37**, 721-735, doi 10.1007/s00382-010-0858-3.

Kucharski, F., Bracco, A. , Yoo, J. H., Molteni, F., 2007: Low-frequency variability of the Indian Monsoon-ENSO relation and the Tropical Atlantic: The 'weakening' of the '80s and 90s. *J. Climate*, **20**, 4255-4266, doi: 10.1175/JCLI4254.1.

Kucharski, F., Bracco, A. , Yoo, J. H., Molteni, F., 2008: Atlantic forced component of the Indian monsoon interannual variability. *Geophys. Res. Lett*., **35**, doi:10.1029/2007GL033037.

Kucharski F., F. Molteni and A. Bracco 2006: Decadal interactions between the western tropical Pacific and the North Atlantic Oscillation. *Climate Dyn*., **26**, 79-91, doi: 10.1007/s00382-005-0085-5.

Kucharski F., F. Molteni, and J. H. Yoo, 2006: SST forcing of decadal Indian monsoon rainfall variability'. *Geophys. Res. Lett*., **33**, L03709, doi: 10.10029/2005GL025371.

* Kucharski, F., A. A. Scaife, J. H. Yoo, C. K. Folland, J. L. Kinter III, J. Knight, D. Fereday, A. M. Fischer, E. K. Jin, J. Kroger, N.-C. Lau, T. Nakaegawa, M. J. Nath, P. Pegion, E. Rozanov, S. Schubert, P. V. Sporyshev, J. Syktus, A. Voldoire, J. H. Yoon, N. Zeng, & T. Zhou, 2009: The CLIVAR C20C Project. Skill of simulating Indian monsoon rainfall on interannual to decadal timescales. Does GHG forcing play a role? *Climate Dyn*., **33,** 615-627,doi :10.1007/s00382-008-0462-y.

S. Kumar, P. A. Dirmeyer, V. Merwade, T. DelSole, J. M. Adams, and D. Niyogi, 2013. Land use/cover change impacts in CMIP5 climate simulations– A new methodology and 21st century challenges. *J. Geophys. Res. Atmos*., **118**, 6337–6353.

Kusunoki, S., K. Matsumaru, T. Nakaegawa, I. Yagai and O. Arakawa, 2004: East Asian monsoon in climate simulation with the AGCM "MJ98". *Gross Wetter*, **42**, 38-56. (in Japanese)

Kusunoki, S., T. Nakaegawa and O. Arakawa, 2005: Reproducibility of the East Asian summer monsoon by an AGCM. In "Cool Summer of 2003 in Japan", *Kisho-Kenkyu Note*, **210**, 171-180. (in Japanese)

Kusunoki, S., T. Nakaegawa, O. Arakawa, and I. Yagai, 2009: Simulations of land-surface air temperature and land precipitation in the twentieth century by the MJ98 AGCM. *J. Meteor. Soc. Japan*, **87**, 473-495. http://www.jstage.jst.go.jp/article/jmsj/87/3/87_473/_article

Lau, N.-C. and M. J. Nath, 2003: Atmosphere-ocean variations in the Indo-Pacific sector during ENSO episodes. *J. Climate*, **16**, 3-20.

Linderholm, H.W., Folland, C.K. and Walther, A. 2009: A multicentury perspective on the summer North Atlantic Oscillation (SNAO) and drought in the eastern Atlantic Region. *J. Quaternary Sci.*, **24**, 415-425.

Linderholm, H.W., Ou, T., Jeong, J-H., Folland, C.K., Gong, D., Liu, H., Liu, Y. and Chen, D., 2011: Teleconnections between the Summer North Atlantic Oscillation and summer climate in China. *J. Geophys. Res.,* **116**: D13107, doi:10.1029/2010JD015235.

Linderholm, H.W., et al., 2013: Exploring teleconnections between the summer NAO (SNAO) and climate over East Asia over the last four centuries – a tree-ring perspective. *Dendrochronologia*, **31**, 297– 310. 10.1016/j.dendro.2012.08.004.

Lucarini, V., S. Calmanti, A. Dell'Aquila, P. M. Ruti, A. Speranza, 2007: Intercomparison of the northern hemisphere winter mid-latitude atmospheric variability of the IPCC models. *Climate Dyn*. doi:10.1007/s00382-006-0213-x.

Lucarini, V., S. Calmanti, A. Dell'Aquila, P. M. Ruti, and A. Speranza, 2007: Intercomparison of the northern hemisphere winter mid-latitude atmospheric variability of the IPCC models. *Climate Dyn.,* doi:10.1007/s00382-006-0213-x.

Ma, H., H. Xiao, C. Mechoso, and Y. Xue, 2012: Sensitivity of global tropical climate to land surface processes: Mean state and interannual variability. *J. Climate*. doi:10.1175/JCLI-D-12-00142.1,

Martens, H. and T. Naes, 1989: *Multivariate Calibration*. Chichester etc. Wiley.

Minobe, S. et a.l, 2008: Influence of the Gulf Stream on the troposphere. *Nature*, **452**, 206-210, doi/10.1038/nature06690

Molteni F., King, M.P., Kucharski F. and Straus, D. M., 2010: Planetary-scale variability in the northern winter and the impact of land-sea thermal contrast. *Climate Dyn*., doi 10.1007/s00382-010-0906-z.

Nakaegawa, T. and M. Hosaka, 2006: A study of potential predictability of seasonal prediction of river discharge in tropical Asian monsoon based on a dynamical ensemble method. *Ann. J. Hydraul. Eng*., **50**, 523-528. (in Japanese with English abstract).

Nakaegawa, T. and M. Hosaka, 2006: Potential predictability of seasonal mean river discharge in dynamical ensemble prediction using MRI/JMA GCM. *SOLA*, **2**, 112-115.

Nakaegawa, T., M. Sugi and K. Matsumaru, 2003: A Long-term numerical study of the potential predictability of seasonal mean fields of water resource variables using MRI/JMA-AGCM. *J. Meteor. Soc. Japan*, **81**, 1041-1056.

Parker, D.E**.,** Folland C.K., A.A. Scaife, A. Colman, J. Knight, D. Fereday, P. Baines and D. Smith, 2007: Decadal to interdecadal climate variability and predictability and the background of climate change. Special Issue of *J. Geophys. Res. (Atmos),* **112**,.D18115 doi 10.1029/2007JD008411.

Peterson, T.C. et al, 2013. Explaining Extreme Events of 2012 from a Climate Perspective, Special Supplement*, Bull. Amer. Meteor. Soc*., **94**, S1-S74.

Pitman, A. J., de Noblet-Ducoudré N., et al., 2009: 'Uncertainties in climate responses to past land cover change: First results from the LUCID intercomparison study*. Geophys. Res. Lett.,* **36**, doi:10.1029/2009GL039076*.*

Power, S., Casey, T., Folland, C.K., Colman, A and V. Mehta, 1999: Inter-decadal modulation of the impact of ENSO on Australia. *Climate Dynamics***, 15**, 319-323

Rayner, N.A., J.J. Kennedy, R.O. Smith and H.A. Titchner, 2014: The Met Office Hadley Centre Sea Ice and Sea-Surface Temperature data set, version 2, part 3: the combined analysis (In prep.)

Rayner, N.A., Parker, D.E., Horton, E.B., Folland, C.K., Alexander, L.V., Rowell, D.P., Kent, E.C., and A. Kaplan, 2003: Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. *J. Geophys. Res*., **108**, D14, 4407, doi: 10.1209/2002JD002670. (29pp + 8 supplementary colour pages). (THIS IS THE HADISST PAPER)

Rayner, N.A., D.E. Parker, P. Frich, E.B. Horton, C.K. Folland, and L.V. Alexander, 2000: SST and sea-ice fields for ERA40. In: *Proc. 2nd WCRP International Conference on Reanalyses*. WCRP-**109**, WMO/TD-No. **985**, World Climate Research Programme, Geneva, Switzerland, 18- 21*.*

Rodwell, M.J., Rowell, D.P. and C.K. Folland, 1999: Oceanic forcing of the wintertime North Atlantic Oscillation and European climate. *Nature*, **398**, 320-323.

Rodwell, M.J. and C.K. Folland**,** 2002: Atlantic air-sea interaction and seasonal predictability. *Q. J. Roy. Met. Soc.,* **128**, 1413-1443.

Rodwell, M.J. and C.K. Folland, 2003: Atlantic air-sea interaction and model validation. *Annals of Geophysics. Special Issue for results of EU SINTEX project,* **46**, 47-56.

Ruti, P. M., V. Lucarini, A. Dell'Aquila, S. Calmanti, A. Speranza, 2006: Does the sub-tropical jet catalyze the atmospheric regimes? *Geophys. Res. Lett*., **33**, doi:10.1029/2005GL024620.

Sajani, S., T. Nakazawa, A. Kitoh and K. Rajendran, 2006: Ensemble simulation of Indian summer monsoon rainfall by an atmospheric general circulation model. *J. Meteor. Soc. Japan*, **85**, 213-231.

Saravanan, R., 1998: Atmospheric low-frequency variability and its relationship to midlatitude SST variability: Studies using the NCAR Climate System Model. *J. Climate*, **11**, 1386-1404.

Scaife, A.A., A. Arribas, E. Blockley, A. Brookshaw, R.T. Clark, N. Dunstone, R. Eade, D. Fereday, C.K. Folland, M. Gordon, L. Hermanson, J.R. Knight, D.J. Lea, C. MacLachlan, A. Maidens, M. Martin, A.K. Peterson, D. Smith, M. Vellinga, E. Wallace, J. Waters and A. Williams. Skilful Long Range Prediction of European and North American Winters. *Geophys. Res. Lett.,* **41**, DOI: 10.1002/2014GL059637.

Scaife, A.A., C.K. Folland, L.V. Alexander, A. Moberg, and J.R. Knight, 2008: European climate extremes and the North Atlantic Oscillation. *J. Climate*, **21**, 72–83.

Scaife, A., J. Knight, G. Vallis and C.K. Folland**,** 2005**:** A stratospheric influence on the winter NAO and North Atlantic surface climate. *Geophys. Res. Lett.* **32**, L18715, doi: 10.1029/2005GL023226.

* Scaife, A., F. Kucharski, C. Folland, J. Kinter III, D. Fereday, A. Fischer, S. Grainger, E. Jin, I. Kang, J. Knight, S. Kusunoki, N. Lau, M. Nath, T. Nakaegawa, P. Pegion, S. Schubert, P. Sporyshev, J. Syktus, J. Yoon, N. Zeng, & T. Zhou, 2009: The CLIVAR C20C Project: Selected 20th century climate events. *Climate Dyn*., , **33**, 603-614 doi:10.1007/s00382-008-0451-1.

Schneider, E. K., 2006: Stochastic forcing of surface climate. *COLA Tech. Rep*., **224**, 43 pp.

Schneider, E. K., L. Bengtsson, and Z.-Z. Hu, 2003: Forcing of Northern Hemisphere climate trends. *J. Atmos. Sci*., **60**, 1504-1521.

Schneider, E. K., M. Fan, 2007: Weather Noise Forcing of Surface Climate Variability. *J. Atmos. Sci.*, **64**, 3265–3280.

Shukla, R. P. and J. L. Kinter III, 2014: Simulations of the Asian Monsoon Using a Regionally Coupled-Global Model. *Climate Dyn*. (in press) doi: 10.1007/s00382-014-2188-3

Smith, D. M., S. Cusack, A. W. Colman, C. K. Folland, G. R. Harris and J. M. Murphy, 2007: Improved surface temperature prediction for the coming decade from a global climate model, *Science*, **317**, 796-799, doi:10.1126/science.1139540.

Smith, T. M., P. A. Arkin, M. R. P. Sapiano, and C.-Y. Chang, 2010: Merged statistical analyses of historical monthly precipitation anomalies beginning 1900. *J. Climate*, **23**, 5755-5770.

Schubert, S. D. M. J. Suarez, P.J. Pegion, R. D. Koster, and J.T. Bacmeister, 2004: Causes of long-term drought in the U.S. Great Plains. *J. Climate*, **17**, 485-503.

Schubert, S. D., M. J. Suarez, P. J. Pegion, R. D. Koster, and J. T. Bacmeister, 2004: On the cause of the 1930s Dust Bowl. *Science*, **33**, 1855-1859.

Schubert, S.D., M.J. Suarez, P.J. Pegion, R.D. Koster, and J.T. Bacmeister, 2008: Potential predictability of long-term drought and pluvial conditions in the U.S. Great Plains. *J. Climate*, **21**, 802–816.

Sexton, D. M. H., H. Grubb, K. P. Shine, C. K. Folland, 2003: Design and Analysis of Climate Model Experiments for the Efficient Estimation of Anthropogenic Signals. *J. Climate*, **16**, 1320–1336.
Shukla, R. P. and J. L. Kinter III, 2014: Simulations of the Asian Monsoon Using a Regionally Coupled-Global Model. *Climate Dyn*. (in press) doi: 10.1007/s00382-014-2188-3
Smith, T.M., Arkin, P.A., Sapiano, M.R.P., and C.-Y. Chang, 2010: Merged statistical analyses of historical monthly precipitation anomalies beginning 1900. *J. Climate*, **23**, 5755-5770.

Sporyshev P. V., V. P. Meleshko, T. V. Pavlova, V. A. Govorkova, V. A. Matyugin, 2003: The water cycle over the Caspian Sea drainage basin in observations and in simulations of atmospheric general circulation models. In: *Hydrological and Meteorological Problems of the Caspian Sea and its Drainage Basin*. I. A. Shiklomanov and A. S. Vasil'ev (ed.), "Gidrometeoizdat", St. Petersburg, 6-23 (in Russian).

Sporyshev P.V., V.M. Kattsov, V.A. Matyugin, 2012: A Correspondence between the Model Ensemble Simulations and Observations of Temperature Changes on the Territory of Russia. *Rus. Meteor. Hydrol*., **37**, 1–11.

Stott, P. A., et al, 2013: Attribution of weather- and climate-related events. In: *Climate Science for Serving Society: Research, Modelling and Prediction Priorities,* Eds: G. R. Asrar and J. W. Hurrell. Springer, 307-337.

Sugi, M., and J. Yoshimura, 2012: Decreasing trend of tropical cyclone frequency in 228-year high-resolution AGCM simulations, *Geophys. Res. Lett.*, **39**, L19805, doi:10.1029/2012GL053360.

Titchner, H.A. and N. A. Rayner, 2014: The Met Office Hadley Centre Sea Ice and Sea-Surface Temperature data set, version 2, part 1: Sea ice concentrations. *J. Geophys. Res. (Atmos.)*, in press.

Toniazzo, T., A. A. Scaife, 2006: The influence of ENSO on winter North Atlantic climate. *Geophys. Res. Lett.* **33**, doi:10.1029/2006GL027881.

Tory, K.J., S. S. Chand, J. L. McBride, H. Ye, R. A. Dare, 2013: Projected changes in late 21st century tropical cyclone frequency in thirteen coupled climate models from the Coupled Model Intercomparison Project Phase 5. *J. Climate*, **26**, 9946-9959.

Vitolo, R., P. M. Ruti, A. Dell'Aquila, M. Felici, V Lucarini, A Speranza, 2009: Accessing extremes of mid-latitudinal wave activity: methodology and application Tellus, **61A**, 35-49 doi:10.1111/j.1600-0870.2008.00375.x.

White, W. B., Allan, R. J. and Ansell, T. J., 2006: The interdecadal Antarctic circumpolar wave: teleconnections with the interdecadal oscillation. *J. Geophys. Res. - Oceans* (submitted).

Wu, R., J. L. Kinter III and B. P. Kirtman, 2005: Discrepancy of interdecadal changes in the Asian region between the NCEP-NCAR reanalysis and observations**.** *J. Climate,* **18,** 3048-3067.

Xie, P., and P. A. Arkin, 1997: Global precipitation: A 17-year monthly analysis based on gauge observations, satellite estimates, and numerical model outputs. *Bull. Amer. Meteor. Soc.*, **78**, 2539–2558.

Xue, Y., F. De Sales, K-M W. Lau, A. Boone, J. Feng, P. Dirmeyer, Z. Guo, K.-M. Kim, A. Kitoh, V. Kumar, I. Poccard-Leclercq, N. Mahowald, W. Moufouma-Okia, P. Pegion, D. Rowell, S. D. Schubert, A. Sealy, W. M. Thiaw, A. Vintzileos, S. Williams, M.-L C. Wu, 2010: Intercomparison and analyses of the climatology of the West African Monsoon in the West African Monsoon Modeling and Evaluation Project (WAMME) First Model Intercomparison Experiment. In Special Issue "*West African Monsoon and its Modeling*", *Climate Dyn.,* **35**, 3-27. doi: 10.1007/s00382-010-0778-2.

Xue, Y., F. De Sales, R. Vasic, C. R. Mechoso, S. D. Prince, A. Arakawa, 2010: Global and temporal characteristics of seasonal climate/vegetation biophysical process (VBP) interactions. *J. Climate*, **23**, 1411–1433.

Yadav, R. K., Yoo, J. H., Kucharski, F., Abid, M.A., 2010: Why is ENSO influencing Northwest India winter precipitation in recent decades? *J. Climate*, **23**, 1979-1993, doi:10.1175/2009JCLI3202.1.

Zeng, N., 2003: Drought in the Sahel. *Science*, **15**, 3474-3487.

Zeng, N., K. Hales, and J. D. Neelin, 2002: Nonlinear dynamics in a coupled vegetation-atmosphere system and implications for desert-forest gradient. *J. Climate*, **15**, 3474-3487.

Zeng, N., A. Mariotti, and P. Wetzel, 2005: Terrestrial mechanisms of interannual CO_2 variability, *Global Biogeochem. Cycles*, **19**, GB1016, doi:10.1029/2004GB002273.

Zeng, N., J. D. Neelin, 2000: The role of vegetation-climate interaction and interannual variability in shaping the African savanna. *J. Climate*, **13**, 2665-2670.

Zeng, N., J. D. Neelin, K.-M. Lau, and C. J. Tucker, 1999: Enhancement of interdecadal climate variability in the Sahel by vegetation interaction. *Science*, **286**, 1537-1540.

Zeng, N., H. Qian, C. Roedenbeck, and M. Heimann, 2005: Impact of 1998-2002 midlatitude drought and warming on terrestrial ecosystem and the global carbon cycle. *Geophys. Res. Lett.*, **32**, L22709, doi:10.1029/2005GL024607.

Zeng, N., J. Yoon, J. Marengo, A. Subramaniam, C. Nobre, A. Mariotti, J. D. Neelin, 2008: Causes and impacts of the 2005 Amazon drought. *Environ. Res. Lett.*, **3**, doi:10.1088/1748-9326/3/1/014002.

Zheng, X., D. Straus, and C. S. Frederiksen, 2008: A variance decomposition approach to the prediction of the seasonal mean circulation: comparison with dynamical ensemble prediction using NCEP's CFS. *Quart. J. Roy. Meteor. Soc.*, **134**, 1997-2009.

Zheng, X., D. Straus, C. S. Frederiksen and S. Grainger, 2009: Potentially predictable patterns of seasonal mean geopotential heights in an Ensemble of Climate Simulations with COLA AGCM. *Quart. J. Roy. Meteor. Soc.*, **135**, 1816-1829.
Zhao, M., A. J. Pitman, T. N. Chase, 2001: The impact of land cover change on the atmospheric circulation. Clim. Dyn. **17**, 467-477.
Zhou, T. and R. Yu, 2006: 20th century surface air temperature over China and the globe simulated by coupled climate models. *J. Climate*, **19**, 5843-5858.
Zhou, T., L. Zhang, and H. Li, 2008: Changes in global land monsoon area and total rainfall accumulation over the last half century. *Geophys. Res. Lett.*, **35**, doi:10.1029/2008GL034881.
* Zhou, T., B. Wu, A. A. Scaife, S. Bronnimann, A. Cherchi, C. Deser, A. M. Fischer, C. K. Folland, K. E. Jin, J. Kinter III, F. Kucharsk, S. Kusunoki, N.-C. Lau, Lijuan Li, M. J. Nath, T. Nakaegawa, P. Pegion, E. Rozanov, S. Schubert, P. Sporyshev, A. Voldoire, & J.H. Yoon, 2009: The CLIVAR C20C Project: Which components of the Asian-Australian Monsoon variability are forced and reproducible? *Climate Dyn*., **33**, 1051-1068,doi :10.1007/s00382-008-0501-8.