the workshop included presentations on coupled modeling perspectives at different centers, coupling related issues (e.g. data assimilation and education), future software and hardware challenges and roundtable discussions.

The main conclusions of the workshop are the following.

- Current coupling technologies can roughly be split into two main categories. The "multiple executable" approach, in which component models remain independent executables, is less flexible and can be less efficient but is straightforward to implement requiring minimal modification to individual models. The "integrated" mono-executable approach requires the original codes to be split into initialization, running and finalization units and supposes some standardization of the resulting component interfaces; however, because components can be run sequentially or concurrently, this approach offers additional optimization opportunities.

- For maximum coupling flexibility and efficiency, climate component models should be re-factored into initialization, run and finalization units. However, this refactoring may be not straightforward to apply for some legacy models and it may be difficult to achieve an agreement on the standard component interfaces required for integrated coupling. To satisfy all cases, an "ideal" coupling technology should therefore offer both approaches. Current research in Generative Programming explores ways to build such an "ideal" technology.

- Existing coupling technologies have been developed with different priorities and constraints. In the short term, parallel development of a small number of coupling technologies should continue, each one with a significant amount of resources. However coupler developers should interact more closely and share basic utilities when possible (e.g. regridding libraries). The development teams should include computing scientists interacting closely with climate modeling scientists. Best practices in coupling should also be discussed, identified, and promoted.

- As we approach the exascale era, increased parallelism with more concurrent components seems essential. Moreover, it will be crucial to limit the load of the associated data communication e.g. by carefully distributing the coupled components over available processes, overlaying communication and calculation, performing redundant calculations, etc. Future hardware platforms will likely require significant changes in programming structures. If sweeping changes to ESM software are required, the geoscience modeling community should seriously consider combining as much as possible available development resources and evaluate where infrastructure convergence is possible.

For more details on the workshop including the proceedings, see https://verc.enes.org/models/software-tools/oasis/general-information/events

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The International CLIVAR Climate of the 20th Century Project: Report of the Fifth Workshop

Jim Kinter[1] and Chris Folland[2]

[1]COLA, IGES, Calverton, Maryland, USA
[2] Met Office Hadley Centre, Exeter, Devon, EX1 3PB, UK

1. Introduction

The International CLIVAR Climate of the 20th Century Project (C20C; Folland et al., 2002) held its Fifth Workshop on 25-28 October 2010 at the Institute of Atmospheric Physics (IAP) of the Chinese Academy of Sciences, Beijing, China. The C20C project brings together climate modeling groups to study climate variations and changes over the last 140 years or less using observational data and atmospheric general circulation models (AGCMs) typically forced with observed values of atmospheric composition (concentrations of greenhouse gases and aerosols) and surface conditions (SST, sea ice, land surface vegetation, etc.). Some work with coupled models is also part of the project. Several major C20C papers have been published since the last Workshop in Exeter, UK, in 2007, particularly in Climate Dynamics.

The goal of the Fifth Workshop was to review new results on coordinated climate simulations and analyses, and to develop plans for new C20C projects. As in all previous C20C meetings, the forcing data sets used in coordinated model experiments, including ongoing development of the Hadley Centre's SST and sea-ice analysis (HadISST) were discussed (see Section 2). There was also discussion of how to coordinate C20C experiments with related international research programs, in particular the Intergovernmental Panel on Climate Change Fifth Assessment (see Section 3) and the LUCID – Land Use and Climate, IDentification of robust impacts – project (see Section 6).

The 45 workshop participants from 16 institutions representing 10 countries were welcomed by Dr. Huijin Wang, Director of IAP, and enjoyed wonderful hospitality from the host institution. The workshop included 28 presentations on various C20C results and a series of breakout sessions, including new core foci for the project. 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/).

Both "standard" C20C simulations (in which the SST and sea ice are specified from HadISST) and alternative strategies (e.g., regionally-coupled or "pacemaker" simulations) were presented. The presentations summarized new findings on:

- the variability in the north Atlantic, including the role of atmospheric noise and more detailed evaluation of the summer North Atlantic Oscillation (SNAO)
- the attribution of changes in variability and trends
- variability and trends in precipitation
- the effects and impacts of land surface variability and change
- the effects of spatial resolution on the simulation of the mean climate and its variability, including extreme event
- the east Asian climate, including the summer and winter monsoons
- modes of variability in the atmospheric circulation
- new model developments by various groups

The proposed new core projects are now described.

2. HadISST

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. Key improvements of HadISST2 over HadISST1 are multiple realizations, better resolution in time, new bias corrections to SST right up to the present, inclusion of A(ATSR) satellite data and a considerably improved sea ice extent data set. HadISST2 will be fully available in summer 2011; a beta version is now available. Future versions will address the diurnal cycle through work planned 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. In the short term new analyses such as the single realization Met Office OSTIA analysis, but without full bias correction, easily achieve this – see http://ghrsst-pp.metoffice.com/pages/latest_analysis/ostia.html

It is planned to integrate HadISST and OSTIA over the next few years. In the meantime, a small number of the approximately 100 realisations of HadISST2 will be adapted for the C20C project.

The use of AGCMs to detect and attribute trends, variations and extremes in the climate record of the past 140 years is a high priority for the C20C project and the Intergovernmental Panel on Climate Change Fifth Assessment. An international working group on detection and attribution has recommended a core project within C20C. Its primary purposes would be:

- to characterize historical trends and variability in the probabilities of damaging weather events, including the differences across climate models;
- to estimate the fraction of the historical, present, and future probabilities of damaging weather events that is attributable to anthropogenic emissions, and to characterize underlying uncertainties in these estimates.

This project is to a large extent an extension to the multimodel ensembles of Pall et al. (2011). It will comprise ensembles of simulations run under different scenarios of external radiative forcing, land use, SST and sea ice. Along with the base scenario of past observed changes in the boundary conditions, other scenarios will examine the effect of omitting changes in selected boundary conditions.

The main project will involve generating a standard C20C ensemble of historical simulations for 1950-2020 using HadISST2 (before 2011) and DePreSys (Smith et al., 2007; after 2010) for SST, and forced with historical changes in greenhouse gases, tropospheric aerosols, land surface conditions, volcanic aerosols, and solar luminosity. This ensemble will provide a basis for estimating changes in the probabilities of damaging events. A parallel ensemble will be generated in which anthropogenic contributions to the forcings are altered to pre-industrial conditions and the SST is altered accordingly. Comparison of these two ensembles will indicate the degree to which anthropogenic emissions have contributed to changes in the probability of selected weather events. The altered SST will be estimated using optimal fingerprinting regression analysis, a standard tool in detection and attribution studies.

Using the adjustment factors and linear combinations of the climate model response patterns, a spatio-temporal anthropogenic signal in SST will be estimated that will then be subtracted from HadISST2. Various methods for treating sea ice are being examined, with an option for no-change.

4. 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 will compare the properties of actual atmospheric weather noise implied by the various models. The weather noise would be computed by subtracting ensemble and monthly mean simulated fields from observational analyses. The potential uses for this product include:

- 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?).
- 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.

5. 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 will focus on the pattern and impacts of SNAO simulated by C20C models. Initial tests with coupled models show that models tend to produce different SNAO patterns, or sometimes not show a reasonable SNAO pattern. Thus, we need to separate 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.

6. Links between LUCID and C20C

The LUCID project aims are to identify and quantify the robust biogeophysical impacts of land-use induced land-cover changes (LULCC) on the historical climate. To that end, a first set of snapshot ensemble simulations were carried out by 7 international modeling groups. The models were forced with 30 years (+ 1 year of spin-up) of observed SST and sea ice (1870-1900) for the pre-industrial era and for the present-day (1972-2002). Results show that the impacts of LULCC can be very large regionally, as large as (sometimes larger than) the impacts of the combined changes in atmospheric CO_2 , SST and sea ice (Pitman et al. 2009). LULCC should be accounted for whenever regional interpretations of past and future changes, and/or detection and attribution studies are carried out (see Section 3 above).

An interesting feature of LUCID results is that the dispersion among the models' responses to LULCC is substantially larger than that of their response to changes in SST and sea ice. This results from the different strategies applied to individual models to incorporate LULCC into their land-cover maps, and because land-surface parameterizations differ from one model to another. Thus it is very challenging to include LULCC in an identical way in model simulations. Two groups of experiments are proposed:

- Using observed SST and sea ice since 1870 as in standard longer C20C simulations;
- Using fully coupled atmosphere-ocean models, building on the CMIP5 experimental protocol.

The first set of C20C-style simulations will be ensembles done in two ways:

- constant land-cover throughout the period, prescribed to its pre-industrial state
- varying land-cover from year to year.

7. Precipitation over 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 spatial resolutions of the datasets are 2.5° latitude/longitude (GPCP and CMAP) and 5° (reconstruction); all offer monthly temporal resolution.

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.

Since existing models and observations are relatively limited in skill and accuracy, the effort will focus on large spatial and long time scales. Existing C20C model runs are adequate to create initial results. A critical challenge will be developing a standard set of metrics and protocols.

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.

Precipitation anomaly simulations from C20C runs will be compared against reconstructed precipitation anomalies over the full period from 1900-2000 or later. GPCP and CMAP will be used for more detailed examination of the mean annual cycle on a regional basis and for greater spatial detail.

8. 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). The proposed project aims to apply this methodology in AGCM and coupled models to:

- Validate a climate model's simulation of the variability of tropical SST. Principal component analysis will be applied to the observed SST and simulated SST respectively. The derived EOFs will be compared each other. If they are similar, the corresponding principal components will be further compared each other.

- Validate the general circulation simulated by climate models. Here the seasonal mean is decomposed into components that arise from radiative forcing, from low frequency oscillations of the ocean and atmosphere, and from intraseasonal variability. Although each component cannot be separated a priori, their covariance matrices can be estimated (e.g. Zheng et al. 2009). Singular value decomposition of the covariance matrices of the simulated and observed component fields can be used to assess the validity of the simulation.

- Validate simulated temperature and precipitation. The above decomposition methodology can be applied to the cross-covariance matrices between temperature (or precipitation) and circulation. Then temperature (or precipitation) changes can be associated with the relevant component of the general circulation. Finally, partial least squares regression can be used to study associations between the daily variability of temperature and precipitation and the variability of the dominant circulation patterns of a given component.

9. 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.

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