Newsletter of the Climate Variability and Predictability Programme (CLIVAR)

Exchanges

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Natural Modes of Variability under Anthropogenic Climate Change

Background: a probabilistic analysis of the changing probability of seasonal-mean precipitation arising from anthropogenic climate change, based on IPCC AR4 integrations (Weisheimer and Palmer, 2005). Foreground: time series and attractor geometry for the standard Lorenz (1963) model (left hand panels) and for the Lorenz model under"climate change" forcing (right hand panels). Climate change in both simple and complex models is strongly influenced by the natural modes of variability pertaining to these models. See Introduction for more detail.

CLIVAR is an international research programme dealing with climate variability and predictability on time-scales from months to centuries. CLIVAR is a component of the World Climate Research Programme (WCRP). WCRP is sponsored by the World Meteorological Organization, the International Council for Science and the Intergovernmental Oceanographic Commission of UNESCO.

WCRP World Climate Research Programme

CALL FOR CONTRIBUTIONS

We would like to invite the CLIVAR community to submit CLIVAR related papers to CLIVAR Exchanges for the next issue. The deadline for submission is 31st August 2008

Guidelines for the submission of papers for CLIVAR Exchanges can be found under: http//www.clivar.org/publications/exchanges/guidel.php

Editorial

I was pleased indeed when Tim Palmer suggested the theme for this edition of Exchanges and agreed to write the introduction to it below (and provide the "harlequinesque" figure for the front cover) since the issue of how natural modes of variability will operate under climate change is a key issue for CLIVAR. As well as the papers addressing the main theme of the edition, we also include an article on the REMOL regional climate model, a summary of the CLIVAR Pacific Panel's very successful Workshop on the Western Tropical Pacific: Hatchery for ENSO and Global Teleconnections and a summary, from a CLIVAR perspective, of the discussions at the 29th meeting of the Joint Scientific Committee for WCRP. On a more sombre note, we were sad indeed to hear of the passing of Fritz Scott in Kiel on the 30 April last. Martin Visbeck provides a short tribute to Fritz on page 28 including a summary of Fritz's substantial involvement with WOCE and CLIVAR .

In the Project Office, we are looking forward to welcoming a new staff member, Dr. Kate Stansfield, starting on 4 August. Kate is an experienced oceanographer and amongst other tasks will manage CLIVAR's Southern Ocean Panel and aspects of CLIVAR data management and legacy. She also has experience of working in Africa and is keen to become involved with VACS activities.

Howard Cattle

Introduction

Tim Palmer
Co-Chair CLIVAR Scientific Steering Group, ECMWF, Reading, UK

Our climate is a chaotic system which exhibits certain preferred modes of variability; the Arctic Oscillation, El Niño, the Atlantic Multi-decadal Oscillation (AMO) are examples. From a dynamical systems perspective, these modes can be thought of as describing particular aspects of the geometry of the climate attractor, a fractal geometry embedded in some large dimensional state space of climate variables.

Does the chaotic nature of climate prevent us from making robust statements about the impact of increasing levels of greenhouse gases on climate? Certainly not. From a dynamical system's perspective, the problem of climate change can be phrased as follows: how is the geometry of the climate attractor affected by increasing greenhouse gas concentration? Although individual trajectories may be unpredictable in a chaotic system, changes in the geometry as a whole are perfectly predictable. A number of the articles in this edition of Exchanges address aspects of this question of how the geometry of the attractor is changing, from the perspective of these preferred modes of variability.

The figure on the front of this issue illustrates these particular issues. In the foreground are plots from the famous Lorenz (1963) model. The left hand plots show a timeseries of the X variable, and the attractor in X-Z space. The right hand plots show similar illustrations for a version of the model where a constant has been added to the right hand sides of the X and Y equations. This added forcing is a surrogate for "climate change" in the Lorenz world. The response of the model can be understood almost entirely in terms of a change in the preferred polarity of the key mode of variability of the Lorenz model associated with chaotic fluctuations between the two lobes of the butterfly attractor.

The background shows an analysis of changes in the probability of extreme seasonal-mean precipitation, based on the WCRP IPCC AR4 CMIP dataset. (cf Weisheimer and Palmer, 2005). Knowing how regional precipitation will be affected by increasing concentrations of greenhouse gases is central to defining meaningful strategies for societies to adapt to climate change. Since precipitation is so strongly linked with circulation patterns, then climate change for precipitation over Europe will depend on whether increased greenhouse-gas emissions lead to a change in the preferred polarity of modes of variability such as the North Atlantic Oscillation and the AMO. For example, if the frequency of occurrence of blocking anticyclones were to increase significantly, precipitation in the areas underneath these blocks would decrease. As such, the reliability of the AR4 predictions will depend on how well the AR4 models simulate these modes of variability. In this sense, the topic of natural modes of variability under anthropogenic climate change is really a key issue for regional climate prediction.

This issue of Exchanges, which arose from a special session of the Second International Conference on Earth System Modelling in 2007, provides some insights into this difficult topic.

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Mid-latitude Cyclones and Storms in an Ensemble of European AOGCMs under ACC

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1. Introduction

This study investigates the occurrence of mid-latitude cyclones and wind storms under anthropogenic climate change conditions from a multi-model perspective. It thus contributes to the work performed by the ENSEMBLES project (http://ensembles-eu.metoffice.com/index.html) which is supported by the European Commission's 6th Framework Programme. The main objective of ENSEMBLES is to "develop an ensemble prediction system for climate change based on the principal state-of-the-art, high resolution, global and regional Earth System models developed in Europe..". The ENSEMBLES approach is based on the assumption that "the prediction of both natural climate variability and the human impact on climate is inherently probabilistic, due to uncertainties in forecast initial conditions, representation of key processes within models, and climatic forcing factors. Hence, reliable estimates of climatic risk can only be made through ensemble integrations of Earth-System Models in which these uncertainties are explicitly incorporated." Thus, within this framework the present study aims at a robust diagnostic of the future occurrence of extreme cyclones under anthropogenic climate change (ACC) based on an ensemble of state-of-the-art global circulation models and at deducing measures of uncertainties of these ACC signals.

Mid-latitude cyclones are a vital part of the general circulation of the atmosphere. In the Northern Hemisphere, these extra-tropical cyclones mostly originate at the discontinuity zones in the atmosphere, the polar fronts of North Pacific and the North Atlantic, influenced by the characteristics of the Northern Hemisphere's long, planetary waves. Typically, surface cyclones travel along these zones of preferred growth conditions (e.g. Pinto et al., 2008) and are steered by the upper troposphere transient eddies of planetary (zonal) wave number 4-8. Some of the cyclones can develop to very intense systems with wind speeds of up to 250 km/h (70ms^{-1}) or more. Such developments depend on the environmental large-scale conditions, which are particularly favourable in the boreal winter half year from October to March. These winter storms are one of the most relevant meteorological-hydrological extreme events for central Europe (Cornford 2002, Ulbrich et al. 2003a, 2003b, Fink et al. 2004, Meehl & Tebaldi 2004) on which the focus of this study will be laid. Extreme meteorological conditions generate severe impacts on human facilities and infrastructure, and thus affect general socio-economic conditions (e.g. Leckebusch et al., 2007). Thus, it is necessary to increase understanding of climate change and its impact on society by generating concrete scientific information that can be used for impact studies, thus assisting a transfer of knowledge from the scientific community to decision-makers. In this context, it is of crucial importance to gain information on potential changes in central European storms and corresponding wind patterns under future climate conditions.

It is still uncertain whether the intensity or frequency of North Atlantic extra-tropical cyclones (ETC) has undergone a specific long-term trend in the recent past. There is some evidence from observational data that activity has increased since the 1960s, possibly associated with natural inter-decadal variability. (e.g. Lambert 1996, Serreze et al. 1997, Jones et al. 1999, McCabe et al. 2001, Paciorek et al. 2002, Geng & Sugi 2003). Additionally, different trends have been suggested in the Northern and Southern Hemispheres, the latter experiencing decreasing cyclone activity since the beginning of the 1990s (e.g. Simmonds & Keay 2000). It seems reasonable to investigate the potential future occurrence of ETCs, and their related wind fields, by means of global and regional climate modelling. While most authors have concentrated their studies on the diagnosis of ETCs for one specific model (e.g. Lunkeit et al. 1996, Carnell & Senior 1998, Kharin & Zwiers 2000, Knippertz et al. 2000, Leckebusch & Ulbrich 2004, Pinto et al., 2007), with partially different investigation methods, in this study a multi-model approach applying the same investigation method is performed. Multi-model ensemble studies investigating possible future trends in extreme cyclones were first published e.g. by Lambert and Fyfe (2006) and Leckebusch et al. (2006). A comprehensive overview of scientific results achieved so far can be found in Ulbrich et al. (2008). In order to quantify the confidence and uncertainties in future predictions, we investigated an ensemble of seven atmosphere-ocean coupled global climate

Model	No of runs	Resolution	20C	SRES A1B
MPI-ECHAM5	3	T63 (ca. 1.9°)	1961-2000	2071-2100
DMI-ECHAM5	1	T63 (ca. 1.9°)	1961-2000	2071-2100
IPSL-CM4	1	2.5 x 3.75°	1961-2000	2071-2100
FUB-EGMAM	1	T30 (ca. 4°)	1961-2000	2081-2100
CNRM-CM3 (ARPEGE Atm)	1	Available at 2.85°	1981-2000	2081-2100
BCCR-BCM2 (ARPEGE Atm.)	1	Available at 2.85°	1960-1999	2080-2099
HadGEM1	1	1.25 x 1.875°	1960-1999	2070-2099

Table 1: AOGCMs investigated in this study including the number of available model runs (second column), horizontal resolution, and time periods for the twentieth century (control climate) and future conditions (scenario climate).

models (AOGCMs). The climate change signal is identified based on the IPCC SRES A1B scenario (cf. Table 1).

2. Investigation Method and Results

Extra-tropical cyclones were assessed by applying an objective identification algorithm originally published by Murray & Simmonds (1991), which is organized in 2 steps. Firstly, cyclones are identified by an algorithm based on the search for the maximum of the Laplacian of the mean sea level pressure (ΔMSLP). Under quasi-geostrophic conditions, this is equivalent to the search for extremes of relative vorticity. Secondly, a tracking algorithm is applied, which takes into account the most probable propagation of the cyclone core under the given synoptic situations. ETCs were identified for the control and scenario period of each investigated GCM for the winter half-year (ONDJFM). In order to avoid artefacts, systems localized in areas with a terrain-height above 1500 m asl are excluded (due to underground extrapolation of the MSLP). Additionally, open and closed systems are differentiated: a cyclone is determined to be closed if a true minimum of MSLP is situated in the vicinity of a maximum of ΔMSLP. Furthermore, only systems with a Laplacian above the threshold of 0.1 (0.2) hPa deg.lat.$^{-2}$ for closed (open) systems are considered. If the Laplacian exceeds 0.6 hPa deg.lat.$^{-2}$, a system is classified as strong; otherwise it is classified as weak. Moreover, the only systems considered are at least closed and strong once in their lifetime. Details of the identification, established tracking algorithm, and current settings of the algorithm and its implications can be found in Murray & Simmonds (1991), Leckebusch & Ulbrich (2004), Pinto et al. (2005), Leckebusch et al. (2006). There is no single definition of what constitutes a wind storm event or an extreme wind speed. In accordance with previous studies we define the cyclone systems with a Laplacian of the MSLP above the long year 95th percentile (for the GCMs: of the control run) as extreme cyclones, or as severe winter storms.

The model's simulation of the recent climate is validated against ERA40-Re-analysis data (1961-2000). For all cyclone systems (Figure 1) as well as for the extreme cyclones (not shown) a very good agreement between the ensemble mean (Figure 1b) and ERA40-Re-analysis (Figure 1a) is found respecting cyclone track density. The two well pronounced centres of activity are correctly simulated in terms of position and intensity (number of tracks per winter). It should be noted that the model-to-model variability does not emerge in this ensemble mean perspective. For single models significant deviations from the re-analysis data could be observed. For each model the level of agreement with the ERA40-Re-analysis (which is taken here as an observational data set, though the assimilation is indeed a model simulation) is estimated and used to introduce different weightings for each model for the construction of the ensemble mean climate change signals. First, the weights are constructed via the spatial correlation coefficients between the GCM's and ERA40's cyclone track densities for all recognised cyclones: both the climatological mean track density and its interannual variability pattern are correlated between GCM and ERA40 and the product of both coefficients is taken as weight (w) for each model. In order to recognise more realistic models in the ensemble mean than unrealistic ones, this weighting factor was varied, from w to w^4. For these four different weighting factors the ensemble mean for the control period and the ACC signal were calculated. Consequently, the climate change signal is presented in terms of a weighted ensemble mean. In Figure 2, page 15, results for the weighting (w^4) are presented as an example.

For all identified and tracked cyclones a decrease in the hemispheric number of tracks is found (cf. Figure 2a), which is in accordance to other studies (e.g. Lambert and Fyfe, 2006). For the changes of extreme cyclones (Figure 2b) a different pattern arises: Indeed the hemispheric total number also decreases, but the horizontal distribution clearly identifies regions of increased frequency of extreme cyclones, and thus winter storms. Two regions show increased numbers of extreme cyclone tracks: the Northeast-Pacific and the Northeast-Atlantic. In both areas the increase is between 10% and 20% compared to the control period. The spatial distribution of the anthropogenic influence is more or less independent of the strength of weighting applied. The weighting leads more to changes of magnitude and statistical significance of the identified changes, e.g. over the Northeast-Atlantic. The more the influence of unrealistic models is decreased the more the statistical significance of the ACC signal is increased.

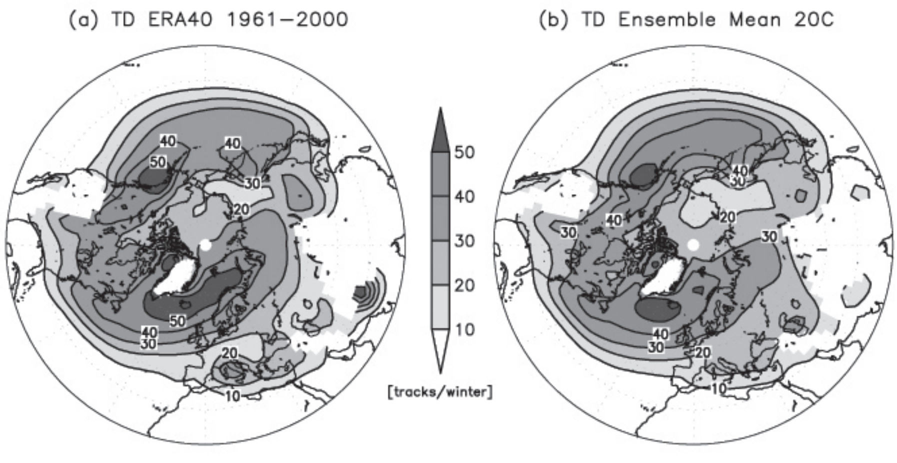

Figure 1: Cyclone track density for ERA40-Re-analysis (left) and the Ensemble Mean (right). Unit: tracks per winter (ONDJFM). Areas with an altitude above 1500 m are eliminated (without weighting).

3. Conclusion and Future Work

The results presented here reveal the importance of a regional perspective compared to an evaluation on hemispheric level. Although an overall decrease of the number of extreme cyclones is diagnosed, this holds not true for specific hot spots: the Northeast-Pacific and the Northeast-Atlantic affecting western Central Europe. These findings support results achieved with a simple one model-approach (e.g. Leckebusch and Ulbrich, 2004, Bengtsson et al., 2006, Pinto et al., 2007), as well as findings from multi-model studies (e.g. Leckebusch et al., 2006). It should be noted that the model-to-model variability is high, especially for the ACC signal for the extreme cyclones. The statistical significance of the ACC signal is thus reduced, if only one realisation of one model is incorporated. Nevertheless, the overall pattern with increasing number of extreme cyclones over the Northeast-Atlantic and the British Isles remains robust. Furthermore, from this multi-model perspective, it will be possible to deduce measures of uncertainties based on the model-to-model variability which is also assessed in this study but not presented here. Thus, it will be possible to advise the non-scientific community about the possible uncertainty of future climate developments as diagnosed from GCMs, based on the different setups of climate models. Future work will also concentrate on the identification of key reasons for the differing behaviour of "normal" vs. "extreme" cyclones. First results were published for one GCM (Pinto et al., 2008), giving hints for a broader baroclinic area during the intensification phase of extreme cyclones and a potentially increased influence of the equivalent-potential temperature on the storm development under ACC conditions.

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Recent changes in the large-scale tropospheric circulation as viewed against climate change in Europe

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It is well-known that near-surface air temperatures have increased significantly during the last century on the global scale. However, this growth has been inhomogeneous, with two-phase warming, in the early 20th century and close to its end, with a period of weak changes (near-stable air temperatures) in the mid-20th century, between the two periods of warming. The most intensive warming has been registered in the lower troposphere during the past decades in the extratropical and polar regions of both Hemispheres, including those of Alaska, the Russian Arctic coast, North and Central Siberia, most of Europe and the Antarctic Peninsula; fresh estimates of rates of the recent warming can be found in the latest IPCC report. The warming is accompanied by changes in frequency and duration of extreme weather events. e.g., more frequent summer heat waves in the Southern Europe (Beniston, 2004); the latest event with fires in Greece, 2007 coincided with flooding events in the UK.

The atmospheric circulation is important as a driving mechanism for both the climate formation and regime of extremes; its natural modes have been studied in many respects, including variability of atmospheric circulation in a variety of time scales. Regional weather settings are traditionally determined and may be predicted by means of corresponding global or regional climatic indices such as those for NAO or ENSO (Hurrell et al, 2004, Turner, 2004). Important conclusions about the eastward shift of the NAO system was obtained by Jung et al., 2002; however it is not clear how weather patterns and corresponding weather settings are changed at the boundary of NAO influence, e.g. over the South East Europe or West Asia.

The main purpose of this study is to exhibit new opportunities for classification of the large-scale circulation on relatively few types, ranged by their probability, and to show how the circulation has been changed in the North Atlantic and European sector during the period of recent warming.

Data.
Daily mean sea level pressure (MSLP) data were taken from the ECMWF ERA-40 archive, on a 2.5X2.5º regular geographical grid. Although it is believed that the ERA-40 archive contains climatically reliable data from the late 1970s we concluded it can be used to analyze MSLP fields prior to the 1970s at least for Europe, by making regular comparisons with observational data and synoptic charts.

Predominant weather patterns in the lower troposphere
Method. Predominant (most probable) circulation patterns were distinguished on the basis of a statistical method developed by Prof. V. Martazinova (Martazinova, 2005). One of the most effective criteria that allow to geometrically distinguish MSLP fields is the similarity criterion calculated on the basis of the sign of the anomaly of MSLP fields (Bagrov, 1969):

$$\rho = \frac{n_+ - n_-}{K},$$

where n_+ is a number of points with coinciding anomalies in pressure fields, n- is a number of points with opposite anomalies, and K is the total number of gridpoints.

Mean squared distance η is another traditional measure of closeness of MSLP fields:

$$\eta = \sqrt{\frac{1}{K}\sum_{i=1}^{K}(x_{ij} - x_{im})^2}$$

where X_{ij}, X_{im} is the MSLP at the i^{th} -gridpoint of *j* and *m* MSLP fields.

The MSLP field having the highest degree of similarity (assessed by the maximum magnitude of the aggregated or mean ρ) with all other fields, provided ρ exceeds 0.30, and also having minimum η, is called the most probable field for the given period, or 'etalon'. It describes predominant circulation in a statistical sense. It is also possible to calculate weather patterns of intermediate probability, for the rest of theMSLP fields having $\rho < 0.30$ (Martazinova, 2005). The most rare class of MSLP fields is recognized when $\rho < 0$, and these are typically responsible for extreme weather events. In some cases MSLP fields show high similarity, especially in summer (no $\rho < 0$) and one can divide large-scale circulation patterns in general into 2 classes, of greater and smaller probability.

The most probable MSLP fields, for each decade from 1960s onwards, winter (DJF) are presented in Figure 1.

1960s: significant meridionality predominates in the North Atlantic, with a col between the Azores high and Greenland maximum and intensive cyclogenesis over the area of the UK, as well as north of Scandinavia. Eastern Europe lies close to the boundary between Atlantic and Siberian circulations. The Siberian high has greatest influence on Eastern Europe implying frequent cold intrusions and lower near-surface air temperatures in winter.

1970s: A trough is well-developed ove Europe; the main area of cyclogenesis is over the North Atlantic stretching north-east to reach the Kara Sea. Westerlies prevail over the most of Europe and adjacent Siberia. The Siberian high has become somewhat less intensive although is still responsible for cold spells in Southeast Europe, especially in the eastern regions of Ukraine.

1980s: The Iceland depression takes its typical place; intensive westerlies are directed towards North Europe with some shift northward in comparison to the 1970s. The curvature of the isobars acquires anticyclonic sign over most of Europe, mostly because of the northward expansion of the subtropical high; a weak trough is seen over Eastern Europe. The Siberian high continues to weaken; the frequency of cold spells is reduced, causing winter warming. This decade saw the start of the recent, most intensive air temperature growth over the most of Europe.

1990s: Intensive cyclogenesis east off Greenland is seen, with the most intensive westerlies at the latitude of the UK and weakening intensity of air flow over Eastern Europe. The subtropical high advances further north and prevails over southwest and south Europe. A well-developed wedge is

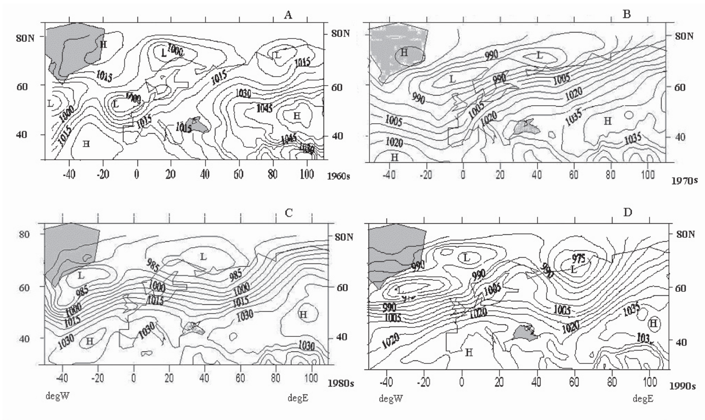

Fig. 1 The most probable MSLP fields for each decade during 1960-1990s, sector 50W-110E Northern Hemisphere, winter (DJF). Greenland and Black Sea are shaded and can be used as landmarks. Top left, 1960s; top right 1970s; bottom left 1980s;. bottom right 1990s..

seen over North European Russia (Kola Peninsula). The Siberian maximum occupies its smallest area in comparison with previous decades somewhat because of a deep cyclone on the Arctic coast centered near 60E. Intensive south-westerlies can be seen over the Central Siberia, being responsible for significant warming in this region.

In Summer, general MSLP gradients are less intensive than in winter, with greater influence of the Azores high on Europe (Figure 2). The most probable MSLP fields for the different decades are similar, specifically for the Atlantic-European area. Centers of lower pressure are located in the Norwegian Sea, close to Scandinavia in the 1960s and 1970s, with some displacement eastward in the 1980s. Strongest gradients are seen over the North Sea and UK; a weakly expressed MSLP field is seen over Eastern Europe, with Ukraine located close to the boundary between the regional low and high pressures. The Urals' high is close to the Ukraine in the 1960s and 1970s but weakened in he 1980s. Regional depressions and troughs are seen over the Mediterranean in all decades.

The most probable MSLP fields in the 1990s showed greater influence of the Azores high on Europe, with a separate center of high pressure over South-East Europe, close to the Black Sea, along with eastward displacement of the North Atlantic depression belt and strengthening of the pressure gradients over the UK and the Northern Sea. Another low pressure is positioned over the central Urals and the north-east region of Ukraine lies at the boundary between the two circulation systems. However general MSLP gradients are weak over Eastern Europe causing settled weather. Note also intensification of the low over North Africa and the adjacent Mediterranean close to longitudes of the Greenwich meridian.

As noted before, summer circulation is in general more homogenous than the winter one (no negative ρ).

Greater stability of atmospheric circulation in the 1990s can be explained mainly because of the greater temporal stability of high pressure over South and Central Europe during both winter and summer; this in turn causes favourable conditions for extreme weather events like heat waves and droughts to cover significant areas.

Discussion

Our research has confirmed the fact that each significant shift in climate is accompanied by changes in atmospheric circulation e.g. low tropospheric warming over Ukraine and most of Europe is attributed to the prevailing of high pressure and its significant temporal stability. In particular this can explain both winter warmth and summer heat waves. The predominant weather pattern is found to be associated with the background of the amplification of NAO (here not shown), along with NE displacement of North Atlantic cyclones and intensification of the subtropical high. Deepening of the West Asian low in winter resulted in the strengthening of warm air advection to Central Siberia suppressing the Siberian high.

This method of classification has also been successfully applied to the Southern Hemisphere extratropics, showing the atmospheric mechanism responsible for the recent climate warming in the region of the Antarctic Peninsula (Martazinova et al., 2007).

Conclusions

Atmospheric circulation patterns in the North-Atlantic-European sector during the recent warming episode significantly differed from those in decades right after the mid-20th century. Anticyclonic circulation has prevailed over most of Europe from the 1980s on, both in winter and

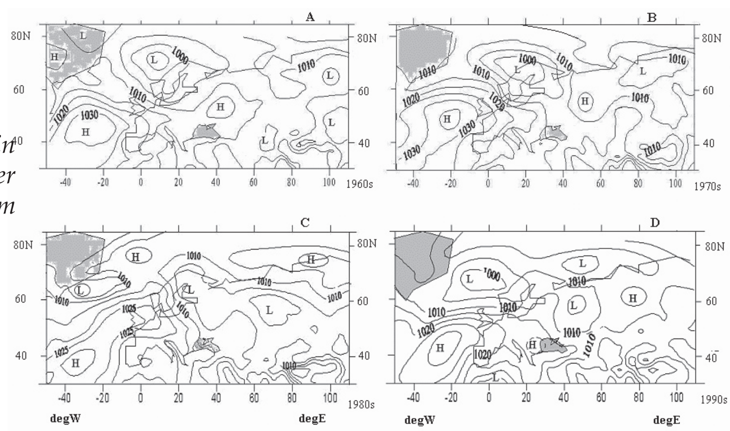

Fig. 2 The most probable MSLP fields for each decade within 1960-1990s, sector 50W-110E Northern Hemisphere, summer (JJA). Top left 1960s; top right 1970s; bottom left 1980s; bottom right 1990s.

summer causing conditions for warmer air mass formation or advection. Winter warming in Eastern Europe was enhanced by weakening of the Siberian maximum and a significantly smaller frequency of cold spells. Intensification and some eastward shift of the North Atlantic low has been accompanied by strengthening of the MSLP gradients in northern part of Europe.

Increased temporal stability of predominant weather patterns is detected throughout the year during the recent episode of warming. Persistence of the predominant weather pattern causes prolonged events of extreme weather such as summer heat waves and / or drought conditions, or long-lived warmth in winter.

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Relationship between the Atlantic Multidecadal Oscillation and the ice extent in Kara Sea

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Many climatologists consider that rapid reduction in the Arctic Ocean ice extent started in the 1980s as an early sign of the global climate warming. Meanwhile, surface air temperatures at Arctic meteorological stations do not exhibit any considerable positive linear trend during last half century, at least in winter seasons (Pokrovsky, 2007). On other hand, ocean heat capacity exceeds that of the atmosphere by many hundreds of times. Therefore, it is reasonable to assume that the contribution of incoming warm (ocean) waters in the Arctic to the ice melting process should be essential. It is known in particular that a considerable part of Atlantic warm waters enters the Arctic Ocean and plays an important role in the shaping of its circulation regime. Warm Atlantic waters enter the Arctic Ocean through the eastern Fram Strait and the Barents Sea and form an intermediate layer as they move below colder, fresher (less dense) Arctic surface waters. These inflows may promote ice melting and discourage ice growth.

The climate swings of the Atlantic Multidecadal Oscillation (AMO) most evident in and around the North Atlantic, take roughly 60 years to complete. The AMO is an ongoing series of long-duration changes in the sea surface temperature (SST) with cool and warm phases that may last for 20-40 years at a time and a difference of about 0.5°C between extremes. The AMO variability is pronounced: its range (0.49°C) is larger than either the range of interannual to decadal variability (0.46°C) or the integrated trend over the period 1870–1999 (0.38°C). The index shows persistent warm (pre-1900, 1930s –1950s) and cool (1900s–1920s, 1960s–1980s) phases typically lasting a few decades, as well as the onset of a warm phase in the 1990s.

Is the AMO a natural phenomenon, or is it related to global warming? Instruments have observed AMO cycles only for the last 150 years, not long enough to conclusively answer this question. However, studies of paleoclimate proxies, such as tree rings and ice cores, have shown that oscillations similar to those observed instrumentally have been occurring for at least the last millennium (Gray et al, 2004, Mann et al, 1995). This is clearly longer than modern man has been affecting climate, so the AMO is clearly a natural climate oscillation. In the 20th century, the climate swings of the AMO have alternately camouflaged and exaggerated the greenhouse warming, and made attribution of global warming more difficult to ascertain (Schlesinger, and Ramankutty, 1994).

The AMO index is correlated to air temperatures and rainfall over much of the Northern Hemisphere, in particular, North America and Europe (Sutton and Hodson, 2005). The AMO itself is associated with changes in the frequency of North American droughts and is reflected in the frequency of severe Atlantic hurricanes. It alternately obscures and exaggerates the global increase in temperatures due to human-induced global warming. Recent research suggests that the AMO is related to the past occurrence of major droughts in the Midwest and the Southwest in the USA (Sutton and Hodson, 2005). When the AMO is in its warm phase, these droughts tend to be more frequent or prolonged. The opposite occurs during the negative AMO (cool phase).

Knight et al (2005) have shown that the Hadley Centre model produces a rather realistic AMO with a period of 70 to 120 years. Moreover, the model AMO persists throughout the 1400-year run. Thus, the AMO is a genuine quasi-periodic cycle of internal climate variability persisting for many centuries, with its principal expression in the SST field and related to variability in the oceanic thermohaline circulation (THC). Judging by the 1400-year simulation, Knight et al predict that the conveyor will begin to slow within a decade or so. Subsequent slowing would offset - although only temporarily - a "fairly small fraction" of the greenhouse warming expected in the Northern Hemisphere in the next 30 years. Likewise, Sutton and Hodson (2005) predict more drought-prone summers in the central United States in the next few decades.

The aim of this paper is to investigate a linkage between the AMO and the Arctic ice extent during last century. Models

are not reliable enough to reproduce ice concentration in Arctic Ocean with appropriate accuracy. Therefore, our approach is to implement sophisticated methods for climate time series analysis. These are (Cleveland, 1979; Goupilland et al 1984; Tikhonov, 1963; Wahba, 1985):
1) a new smoothing algorithm based on Wahba's cross-validation, Cleveland's local polynomial approximation and Tikhonov's regularization;
2) Morlet's wavelet analysis.

In this study we used following datasets: (i) the AMO series for 1856-2007 prepared by the NOAA Atlantic Oceanographic and Meteorological Laboratory (see Enfield, et al, 2001) and (ii) ice extent in the Russian marginal seas for 1900-1999 prepared by the Arctic and Antarctic Research Institute (St. Petersburg) and used in the paper by Polyakov et al (2003). Systematic aircraft and ship observations of sea ice from the Kara Sea to the Chukchi Sea only began in 1932, when the Northern Sea Route was created. There were information gaps during World War II (1942–45). The missing data have been reconstructed using statistical regression models relating atmospheric processes (SLP gradients and SAT) to ice extent (Kovalev and Nikolaev, 1976). Aircraft ice-edge observations continued until 1979, when the satellite era began.

A smoothed AMO index (derived as the ten=year running mean of detrended Atlantic sea surface temperature anomalies north of the equator) for last 150 years was presented in Enfield, et al (2001). Our smoothing technique allows us to filter out the remainder of the high frequency components presented in Enfield's curve permitting us to reveal a 60-year AMO cycle in a more transparent mode. The AMO wavelet power spectrum (Figure 1, page 15, upper panel) demonstrates a very strong anomaly area corresponding to a cycle of about 60 years, confirming the result based on the AMO series smoothing. All other local maxima are much weaker. Moreover, an analysis of statistical significance showed the 60-year cycle to be a significant phenomenon at the 5% level. Similar wavelet analysis was carried out with the paleo AMO series. It permits us to come to the conclusion that the 60-year cycling has been an inherent AMO phenomenon at the 5% statistical significance level during the last 1400 years.

A smoothed ice extent curve for the Kara Sea September monthly data for 1900-2000 (Polyakov et al, 2003) demonstrates slow multi-decadal oscillations similar to AMO. We carried out similar study based on a more comprehensive smoothing technique, which permit us to reveal multidecadal oscillations in a more transparent mode. In fact, the monthly ice extent shows persistent low (pre-1910, 1940s –1950s) and high (1920s–1930s, 1960s–1970s) phases, typically lasting for more than a decade. There is good agreement with the AMO smoothed curve. Periods of high AMO index magnitudes correspond to low ice extent values and vice versa. Ice extent anomalies experience a few years delay in relation to the AMO fluctuations. We infer therefore that Atlantic water temperature's slow oscillations modulate corresponding Kara Sea ice extent fluctuations. The ice extent wavelet power spectrum (Figure 1, lower panel) and its comparison with the AMO wavelet spectrum (Figure 1, upper panel) confirm this important conclusion. Thus, it is the North Atlantic water temperature that is a major regulator of the ice extent in the Kara Sea. A similar result was obtained for the Barents Sea, but the ice extent values there were much lower and respective variability was in contrast higher.

Natural variability, such as that associated with the AMO and NAO, and other circulation patterns, has and will continue to have strong impacts on the Arctic sea-ice cover. Links between altered ocean heat transport and observed ice loss remain to be resolved, as does the attribution of these transport changes, but pulses such as those currently poised to enter the Arctic Ocean from the Atlantic could provide a trigger for a rapid transition. We are not yet capable of predicting exactly when the AMO will switch, in any deterministic sense. Computer models, such as those that predict El Niño, are far from being able to do this. What it is possible to do at present is to calculate the probability that a change in the AMO will occur within a given future time frame. Probabilistic projections of this kind may prove to be very useful for long-term planning in climate sensitive applications. In this respect the wavelet tools might be useful to trace the short-term climate fluctuations of various scales.

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Perspectives on the remote control of ENSO variability

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The Atlantic Multidecadal Oscillation (AMO) (Kerr 2000) has been shown to influence local climates in Europe (Pohlmann et al. 2006, Sutton and Hodson 2005), North America and the Sahel region (Lu and Delworth 2005, Zhang and Delworth 2006). Recent studies (Virmani and Weisberg 2006) suggest that the AMO may even play a role in modulating hurricane frequencies and intensities in the Gulf of Mexico.

Coupled general circulation model simulations (Delworth et al. 1993, Timmermann et al. 1998, Vellinga et al. 2001) have supported the notion that multidecadal changes of North Atlantic sea surface temperatures (SST) can be caused by variations of the Atlantic meridional overturning circulation (MOC). Internally generated multidecadal MOC variations simulated in state-of the art coupled general circulation models are relatively small (~10%). However if forced by massive meltwater pulses mimicking glacial ice sheet instabilities of the Laurentide ice sheet (so-called Heinrich events) or an abrupt disintegration of the Greenland ice-sheet, these models simulate a substantial reduction of the MOC. An associated decrease in meridional ocean heat transport is accompanied by severe cooling of the North Atlantic and massive reorganizations of atmospheric flow in the northern Hemisphere and the tropics. Southward shifts of the ITCZ are consistently simulated in state-of-the art CGCMs (Zhang and Delworth 2005, Stouffer et al. 2006, Timmermann et al. 2007) and have been reconstructed using different tropical climate archives, such as lake levels, sediments cores and pollen (see Menviel et al. 2008 for an overview). There is also strong modeling (Zhang and Delworth 2005, Timmermann et al. 2005, Timmermann et al. 2007b) and paleo-data evidence (Koutavas et al. 2004, Kienast et al. 2006, Pahnke et al. 2007) to suggest that large-scale reorganizations of the MOC have a discernable influence also on tropical Pacific climate.

Figure 1 page 15, shows an EOF analysis of several alkenone-derived SST reconstructions from the eastern equatorial Pacific. The analysis is based on data from 5ka-25ka B.P. The leading EOF mode describes a uniform warming of these cores that started around 16ka B.P., marking the beginning of the last glacial termination. The second EOF mode clearly captures millennial-scale variability in the eastern tropical Pacific associated with the Heinrich I (orange box in Figure 1) and Younger Dryas events and a rapid recovery from the Heinrich I event around 14.6 ka B.P (the Bølling Ållerød). The corresponding EOF pattern of SST is characterized by a meridional dipole structure, in accordance with four CGCM simulations that were subjected to massive anomalous freshwater forcing in the northern North Atlantic (Figure 1, right panel, contours). To explain this pattern Timmermann et al. (2007b) proposed the following mechanism: negative sea surface temperature (SST) anomalies in the tropical North Atlantic, associated e.g. with a weakening of the Atlantic meridional overturning circulation, generate a positive sea level pressure anomaly in the Caribbean and its surroundings (see Figure 2, page 16, right panel). Due to the associated trade wind-intensification in the north eastern tropical Pacific, a negative SST anomaly is generated there, which can spread significantly into the equatorial Pacific due to positive air-sea interactions (Wu et al. 2005, Xie et al. 2008). Coarser-resolution CGCMs tend to simulate also a trade-wind reduction south of the equator that can lead to net warming in the southeastern tropical Pacific. It should be noted here that this warming appears to be somewhat model dependent. A regional coupled model simulation (Xie et al. 2008) that was forced by tropical Atlantic cooling as well as the LBM-POP hybrid coupled model simulation (shown in Figure 2) forced by the tropical Atlantic SSTA pattern, that was derived from the CCSM2 waterhosing experiment, exhibit a more uniform intensification of the equatorial cold tongue, in particular during the boreal spring season.

The north eastern tropical Pacific cooling in turn leads to a weakening of the prevailing meridional cross-equatorial asymmetry in the tropical Pacific (Zhang and Delworth 2005) and hence, to a weakening of the equatorial annual cycle (Xie 1994). Due to the nonlinear interaction between the annual cycle and ENSO (Chang et al. 1994) these processes can trigger an intensification of ENSO variability. This is further demonstrated by a wavelet analysis of the averaged eastern equatorial Pacific Nino 3 SST for the CCSM2 waterhosing simulation in Figure 3, page 16.

These results also suggest that under present-day conditions one of the reasons for the existence of the eastern equatorial Pacific annual cycle is the presence of the MOC. The absence of a deep MOC e.g. under early Pliocene conditions would have led to an equatorward shift of the ITCZ in the Pacific, a collapse of the cold tongue and an enhancement of the semi-annual cycle regime in the east. These conditions would have also favored a strong response to the semi-precessional (~11 ka) orbital cycle. Using data from the Caribbean, Reuning et al. (2005) demonstrated that under early Pliocene conditions the semi-precessional tropical climate response was more dominant than the response to precessional forcing. This was interpreted as a manifestation of a collapsed meridional asymmetry in the eastern equatorial Pacific and the absence of an annual cycle mode.

Such massive changes of tropical Pacific climate variability through remote control via the MOC might have occurred under climate conditions that are very different from ours today. An important question to address is whether the much weaker natural variations of the MOC on multidecadal timescales might still influence tropical Pacific climate and its annual and interannual variability significantly. Dong et al. (2006) present modeling evidence demonstrating that even the relatively weak multidecadal variations of the MOC can modulate ENSO significantly. Furthermore, Timmermann et al. (2007b) illustrate that the strength of the annual cycle in the eastern equatorial Pacific in fact co-varies with the AMO. The short observational record however precludes any firm statistical conclusions. Paleo-proxy data as well as specially-designed hybrid coupled general circulation model experiments (Zhang and Delworth 2006) might shed some further light on the effects of the AMO on tropical Pacific climate.

Our results clearly demonstrate that an assessment of future changes of ENSO activity has to be based on a broader-scale perspective that takes into account remote effects from the Atlantic and Indian Ocean.

To predict ENSO's future response to greenhouse warming more reliably, key aspects of ENSO dynamics still need to be further improved in state-of-the-art CGCM simulations. Among them is the interaction between ENSO and the annual cycle. Clearly during El Nino events the meridional asymmetry that "nourishes" the annual cycle in the eastern equatorial Pacific is strongly reduced. On the other hand, a too strong annual cycle can lead to a substantial weakening of the simulated ENSO variability (Timmermann et al. 2007a) via the nonlinear frequency entrainment mechanism. Only few CGCMs today are capable of simulating both a realistic annual cycle and realistic ENSO variability. It is fair to say that our basic understanding of annual-cycle ENSO interactions in CGCMs and nature is still very much in its infancy.

Another key aspect of ENSO variability is its interplay with intraseasonal wind variations associated with westerly wind bursts in the western tropical Pacific and the Madden Julian Oscillation (Madden and Julian 1972, Zhang 2005). A number of studies have suggested that intraseasonal surface wind anomalies have significant impacts on ENSO variability and on the seasonal predictability of tropical Pacific SST anomalies (e.g., Kessler et al., 1995; Kleeman and Moore, 1997; Perigaud and Cassou, 2000; Yu et al., 2003; Lengaigne et al., 2004; Zavala-Garay et al., 2005). Moreover, not only is ENSO variability dependent on the equatorial intraseasonal variability, but the latter is also modulated by interannual SST anomalies, associated with ENSO (Keen, 1982; Luther et al., 1983; Kessler et al., 1995; Yu et al., 2003; Eisenman et al., 2005; Perez et al., 2005). An individual MJO/WWB (westerly Wind Burst) event can shift the warm pool front eastward, making it more likely for further MJO/WWB events to be generated. This eastward-propagating coupled instability can contribute considerably to the generation and amplification of large El Niño events (Keen 1982, Lukas 1988 and Lengaigne et al. 2004). Recent advances in ENSO theory (Lengaigne et al., 2004, Eisenman and Tziperman, 2005, Perez et al., 2005, Jin et al. 2007) have supported the notion that the nonlinear interaction between

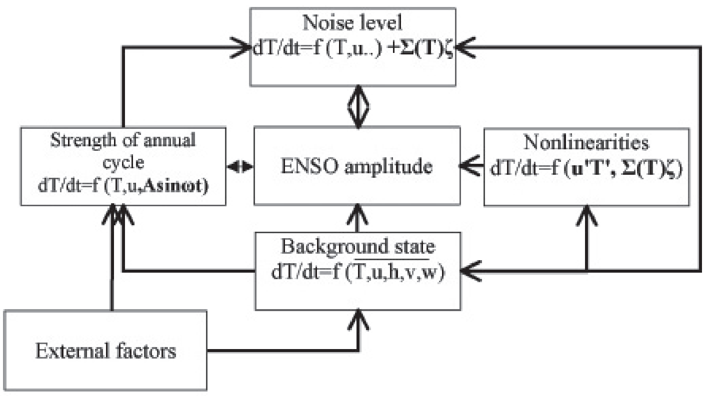

Figure 4: Schematics of processes that control ENSO variability.

tropical intraseasonal variability and the ENSO mode is a key element for the generation of tropical climate variability and provides an additional source for ENSO instability and skewness. A schematic of the processes affecting ENSO's amplitude is shown in Figure 4.

Promoting a deeper understanding of the depicted timescale interactions is a key element of the CLIVAR roadmap. Such an endeavor could strongly profit from a cross-fertilization with the PAGES community. Paleo ENSO data will eventually help to "calibrate" climate models to better represent ENSO's sensitivity to past and future climate changes.

Some of these important subjects and unresolved questions will be further explored during the upcoming CLIVAR-PAGES-WCRP-ARCNESS-IPRC summer school on "ENSO: dynamics and predictability" on the Big Island, Hawai'i.

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Extreme events associated to ENSO in control and scenario GCM simulations

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Introduction

On account of their potentially severe socio-economic impact, temperature extremes are a subject of great interest within the field of climate research. This is even more so when there appear to exist indications that global climate change might bring about an intensification of these extreme phenomena. The prediction of these changes, and of the probability of occurrence of extreme episodes themselves, would clearly benefit from a better understanding of how they are affected by relevant climatic signals such as El Niño-Southern Oscillation (ENSO). We are currently investigating these relationships in coupled model data from both control and scenario simulations, in an attempt to elucidate the impacts of ENSO on daily data statistics might be modified under global warming conditions. Some results for the GFDL coupled model are presented here.

Data and methodology

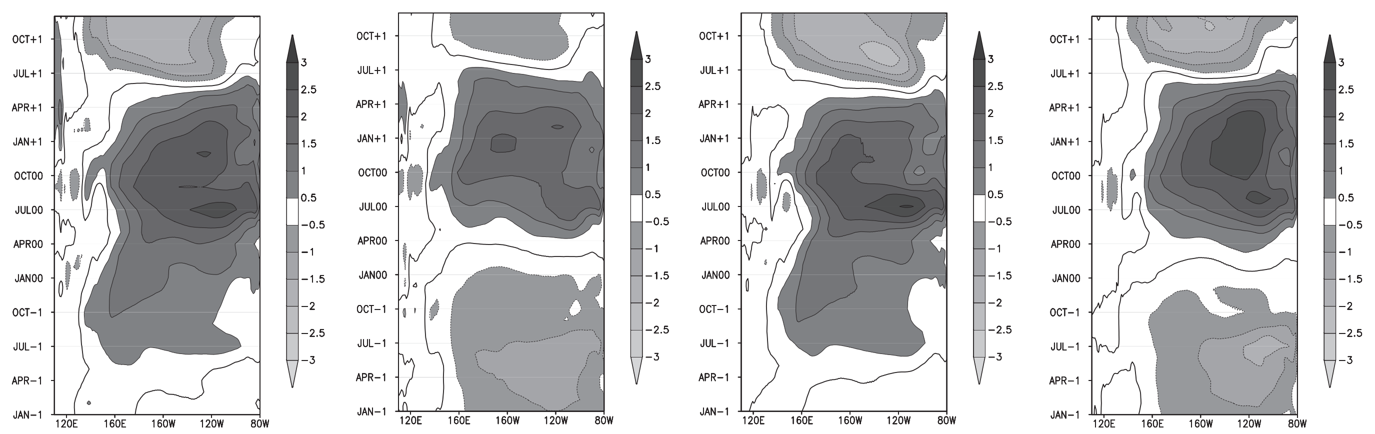
We analyze daily maximum and minimum surface temperature and monthly sea surface temperature (SST) data from different simulations with the Geophysical Fluid Dynamics Laboratory (GFDL) coupled model (Delworth et al., 2006). The atmospheric model has a horizontal resolution of 2°×2.5° in latitude and longitude, respectively, and 24 vertical levels. The ocean has a latitudinal resolution of 1°, increased to 1/3° in equatorial regions. The longitudinal resolution is 1°, and there are 50 vertical levels. The sea ice model has the same horizontal resolution as the ocean model. The model runs with a coupling frequency of 2 h., without any flux adjustment.

We examine a control run of 500 years with greenhouse gas (GHG) concentrations held fixed at conditions around 1860, and a climate change simulation of 240 years with concentrations varying as observed between 1861 and 2000, and then following the SRES A2 scenario during the 21st century.

The characteristics of ENSO in both simulations are addressed in the following way. Warm ENSO episodes are identified in the Niño3 Index (average SST anomaly over [150°W-90°W, 5°S-5°N]) when the one-standard-deviation threshold of the time series is crossed. In the case of the scenario simulation, the SST anomalies are previously detrended. The evolution of the tropical Pacific SST anomalies during different episodes is compared by means of a clustering technique that classifies events into groups showing common features; the classification procedure takes into account the spatial correlation between SST anomalies within 15°S and 15°N throughout the different episodes (Álvarez-García et al., 2006). Once the common sets of ENSO events have been selected, their impacts on the daily maximum and minimum temperature data are investigated. Two different stages are considered: the year of development of the episode (hereinafter, year 0) and the year of termination (hereinafter, year +1). We monitor the effects on the daily temperature distribution in terms of the fraction of days per year, for the collection of 'years 0' and 'years +1' associated with the different types of ENSO episodes, when the 90th percentile of the full daily record (computed locally and on a multi-year basis) is surpassed.

Results

A total number of 81 ENSO events are identified in the 500 years of data of the control simulation, while 42 episodes are detected in the 240 years of the climate change run. For both simulations, the clustering results in two classes of ENSO episodes, hereinafter Class I and Class II, that show similar features in each run. Most of the events are included in these groups, with only about 1/8 of the episodes remaining unclassified in both runs. Class I includes 40 events in the control simulation, and 20 in the climate change simulation. Figures 1a and 1c depict the evolution of SST anomalies averaged between 5°S and 5°N in the Class I composite event, which corresponds to a relatively long warming with traces of eastward propagation along the equator at some stage (see October, year 1 to January, year 0 between 160°E and 120°W in Figures 1a and 1c. Class II episodes,



a b c d

Figure 1: Time-longitude diagram of SST anomalies averaged between 5°S and 5°N: a) control run, class I; b) control run, class II; c) climate change run, class I; d) climate change run, class II.

of which there are 30 cases in the control run and 17 in the climate change run, are shorter and rather show slightly westward propagation of SST anomalies along the equator as illustrated in Figures 1b and 1d (see May, year 0 to August year - between 100°W and 160°E).

Figure 2 (page 17) depicts the changes in the fraction of days with maximum temperature above the 90th percentile of the full record, associated with each of the ENSO classes, under control and under climate change conditions. These changes are similar in the case of daily minimum temperature, so the corresponding figures are omitted.

The comparison of the control and climate change conditions reveals stronger modification in the impacts of Class II episodes than in the case of Class I events. Areas of cooling (where the fraction of days above the 90th percentile falls below 10%) extend considerably during both year 0 and year +1 of Class II episodes in the climate change simulation with respect to the control run, and warming in some locations, such as the north-eastern parts of the American continent in year +1, for instance, practically disappears.

In contrast to this, the impacts of the Class I events in the control and in the climate change runs are essentially similar, but for a reduced warming in the eastern equatorial Pacific and smaller extension of cool areas in the extratropical Pacific.

In summary, our study suggests the influence of ENSO on the distribution of daily temperatures thoughout the globe might be affected by climate change, in a mode-dependent way.

Acknowledgments
This work was supported by the project CGL2006-09268.

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CLIVAR CALENDAR

Dates	Venue	Title	Attendance	Contact
03-23 Aug	Ensenada B,C., Mexico	Satellite Oceanography 2008	Open	
04-14 Aug	Frascati, near Rome, Italy	4th ESA EO Summer School on "Earth System Monitoring & Modelling"	Open	
11-15 Aug	Trieste, Italy	Workshop on Multi-scale Predictions of the Asian and African Summer Monsoon	Open	Lisa Iannitti: iannitti@ictp.it
18-29 Aug	Utrecht, The Netherlands	Third Utrecht Summer School on Physics of the Climate system	Open	
31 Aug - 05 Sept	Monte Verità, Ticino, Switzerland	7th International NCCR Climate Summer School "Key challenges in climate variability and change"	Open	University of Bern, NCCR Climate Management Centre: nccr-climate@giub.unibe
08 -11 Sept	Bangor, Wales, United Kingdom	13th Bienniel Challenger Conference for Marine Science ,08	Open	Challenger2008@bangor.ac.uk
17-19 Sept	Halifax, Nova Scotia, Canada	The Seventh International Workshop on Unstructured Grid Modelling of Coastal,Shelf and Ocean Flows	Open	David Greenberg: GreenbergD@mar.dfo-mpo.gc.ca
17-27 Sept	Rhodes, Greece	1st ESF-MedCLIVAR summer school	Open	
18-19 Sept	WHOI Woods Hole, USA	9th session CLIVAR Atlantic Implementation Panel	Invitation	Roberta Boscolo: rbos@iim.csic.es,
22-26 Sept	Halifax, Canada	ICES 2008 Annual Science Conference	Open	Görel Kjeldsen: gorel@ices.dk
22- 24 Sept	Paris, France	WGCM Meeting	Invitation	Anna Pirani: anna.pirani@noc.soton.ac.uk
29 Sept - 01 Oct	Rhodes, Greece	3rd ESF-MedCLIVAR Workshop: Understanding the mechanisms responsible for the changes in the Mediterranean Sea circulation and sea-level trands	Open	Roberta Boscolo: rbos@iim.csic.es Mikis Tsimplis,: mnt@noc.soton.ac.uk Alexander Theocharis: alekos@ath.hcmr.gr
29 Sept - 03 Oct	Amsterdam, The Netherlands	8th Annual Meeting of the European Meteorological Society (EMS) and the 7th European Conference on Applied Climatology (ECAC)	Open	Copernicus Meetings: ems2008@copernicus.org

for the full calendar, see http://www.clivar.org/calendar/calendar_all.php

From Leckebusch et al. page 3: Mid-latitude cyclones and storms in an Ensemble of European AOGCMs under ACC

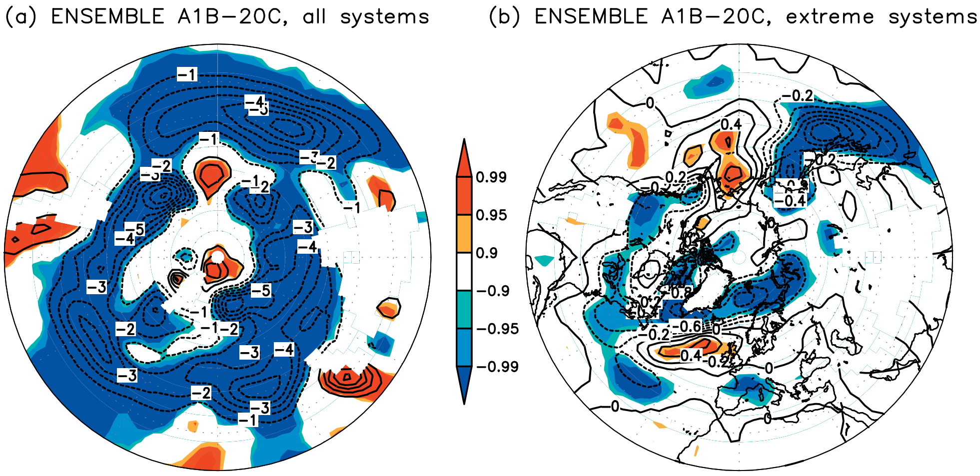

Figure 2: Ensemble mean climate change signal (IPCC SRES A1B) of the cyclone track density. Left a): All cyclones. Right b): Extreme cyclones. Units: systems per winter (ONDJFM). Areas with an altitude above 1500 m are eliminated. Coloured: Statistical significance above the 90/95/99% level according to a student t-test. The ACC ensemble mean signals are weighted by the quality of each model (for detail see text).

From Pokrovsky, page 8: Relationship between the Atlantic multidecadal oscillation and the ice extent in Kara Sea

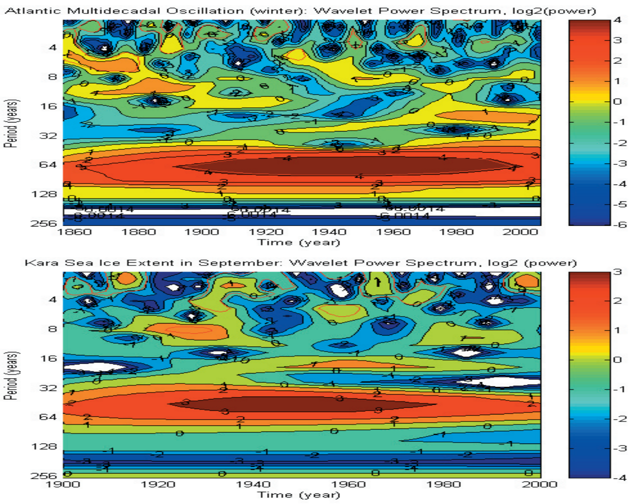

Figure 1. Coherency in wavelet power spectrum (log2 scale) for climate series of: AMO winter values for 1856-2000 (upper panel) and ice extent September values in Kara Sea (lower panel).

From Timmerman, page 10: Perspectives on the remote control of ENSO variability

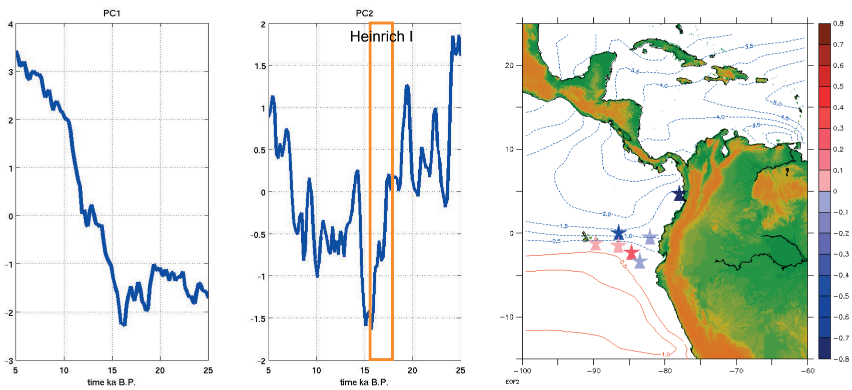

Figure 1: Left: Principal component of the first EOF of SST derived from Alkenone data from cores V19-27, ME24, V19-30, V21-30, RC11-238, V19-28, JPC32. All data were brought onto the same timescale using cubic spline interpolation. The first EOF mode represents the major deglaciation event. Its EOF (not shown) has the same sign for all core locations; Middle: Principal component of the second EOF of alkenone-derived SST data. This EOF captures the millennial scale events such as Heinrich I, the Bølling Ållerød and the Younger Dryas; Right: Loadings of the second EOF (multiplied by -1) of eastern equatorial Pacific Alkenone-derived SST data (stars) and simulated SSTA response [K] to a shutdown of the Atlantic Meridional Overturning Circulation in the GFDL-CM2.1 model A meridional dipole pattern results from an intensification of the Panama wind-jet due to the SST decrease in the Caribbean, and coupled air-sea feedbacks in the eastern equatorial Pacific involving the wind-evaporation SST feedback.

From Timmerman, page 10: Perspectives on the remote control of ENSO variability

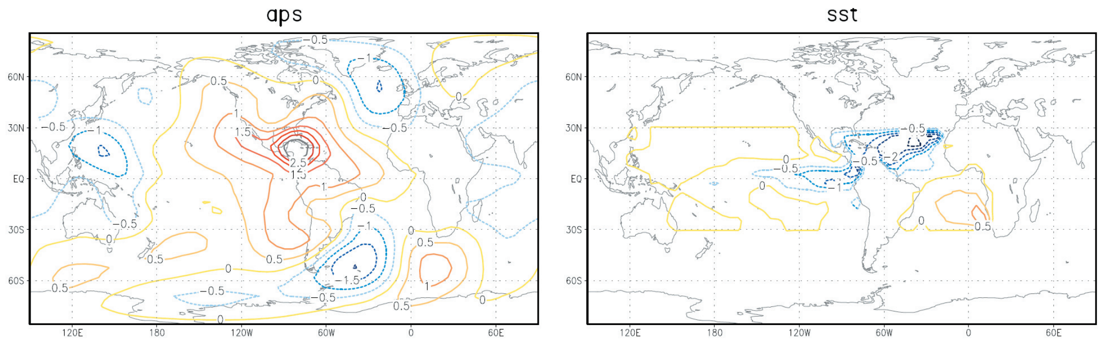

Figure 2: Results from the hybrid coupled model LBM-POP; Left: Global sea-level pressure response [hPa] simulated by the coupled model LBM-POP in response to the SSTA pattern in the right panel. Right: The Atlantic SSTA represents the initial forcing of the LBM-POP model, whereas the Pacific SSTA is simulated in response to this forcing and its atmospheric response. The LBM-POP model uses the linear baroclinic moist atmospheric model of Watanabe et al. (2002) in T21 resolution and the global ocean model POP in 1x1 degree resolution and 40 levels (Yeager et al. 2006). While the atmosphere and ocean are coupled in the tropical Pacific by using an anomaly coupling technique, the atmospheric SSTA forcing in the Atlantic is based on the tropical Atlantic SSTA pattern that corresponds to a collapsed MOC state in the CCSM2 1 Sv waterhosing simulation.

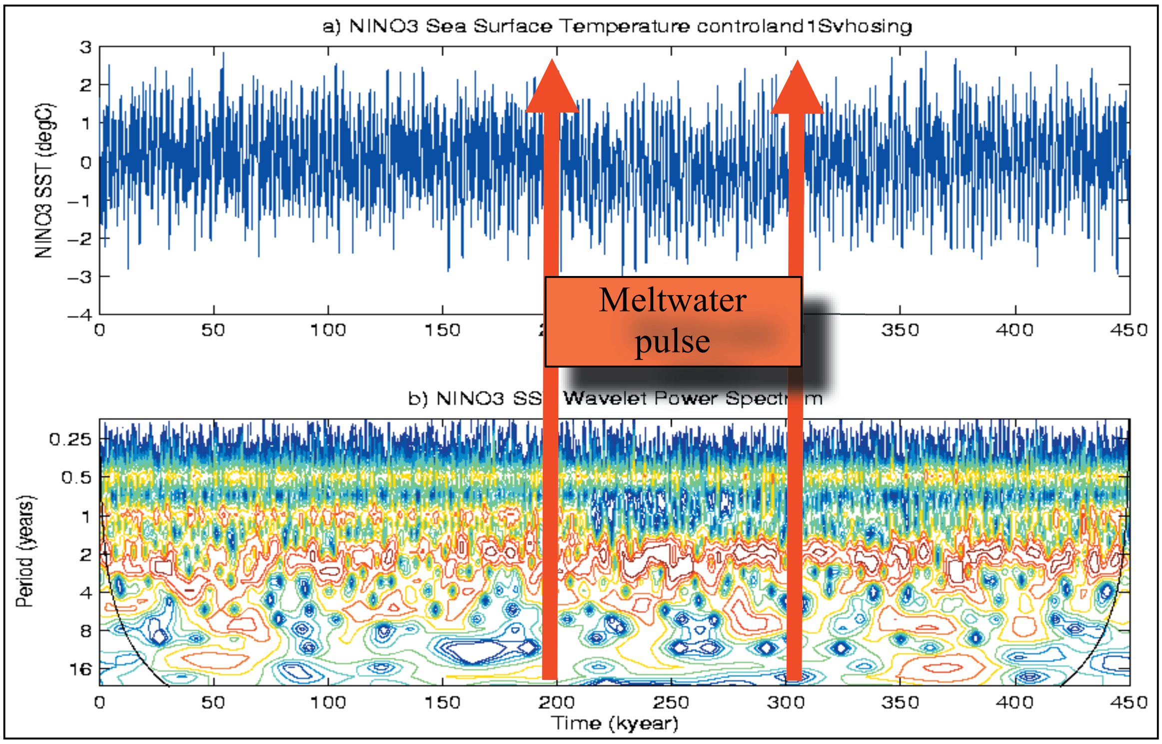

Figure 3 (a.) Simulated SST averaged over the eastern equatorial Pacific Nino3 ENSO index region (210°-270°E, 5°S-5°N). The first 200 years correspond to an unperturbed control simulation conducted with the CCSM2 CGCM. In year 201 a meltwater pulse of 1Sv is introduced into the northern North Atlantic. The resulting collapse of the MOC leads to a weak cooling of eastern tropical Pacific, the disappearance of the annual cycle and an intensification of ENSO activity, as demonstrated by the Morlet wavelet spectrum in (b.). A similar behavior is observed for the HADCM3, CCSM3, GFDL CM2.1 waterhosing simulations (Timmermann et al. 2007b).

From Alvarez et al, page 13: Extreme events associated to ENSO in control and scenario GCM simulations

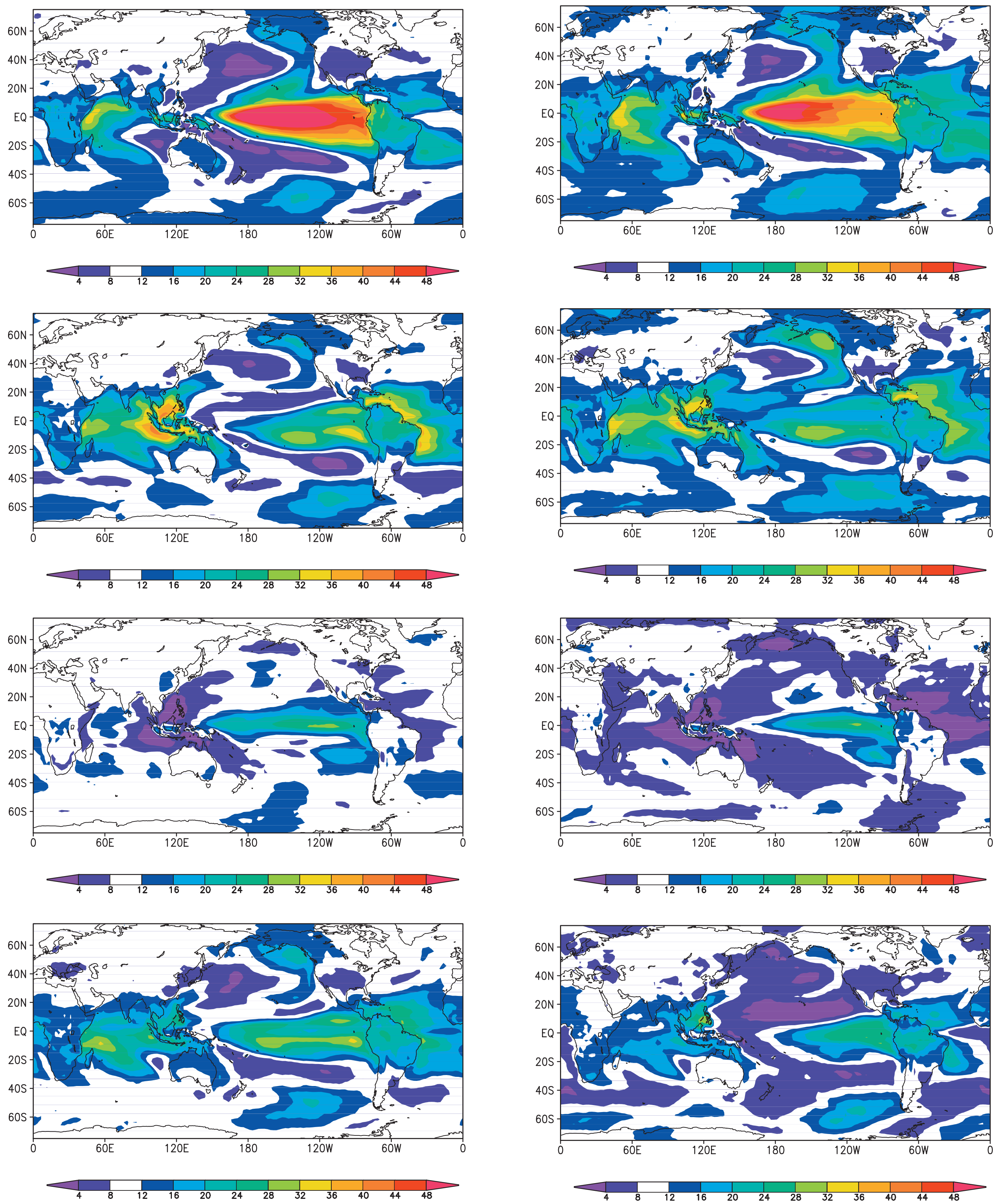

Figure 2: Fraction of days (%) with daily maximum temperature above reference 90th percentile starting top left, then top right and so on down: a) control run, Class I-year 0; b) scenario run, Class I-year 0; c) control run, Class I-year +1; d) scenario run, Class I-year +1; e) control run, Class II-year 0; f) scenario run, Class II-year 0; g) control run, Class II-year +1; h) scenario run, Class II-year +1.

From Kulkarni et al, page 21: Warming over India under Anthropogenic Climate Change

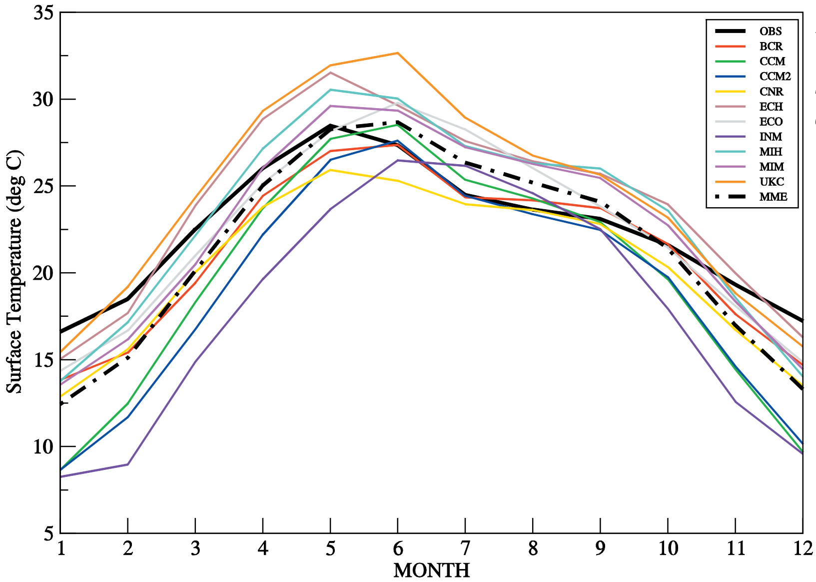

Fig 1 : Annual cycles of the surface temperatures over the Indian region simulated by ten selected models. The solid black line is the observed from the CEP Reanalysis and the dash-dot line the ensemble mean.

From Szépszó, Page 24: First results with the REMO regional climate model at the Hungarian meteorological Service

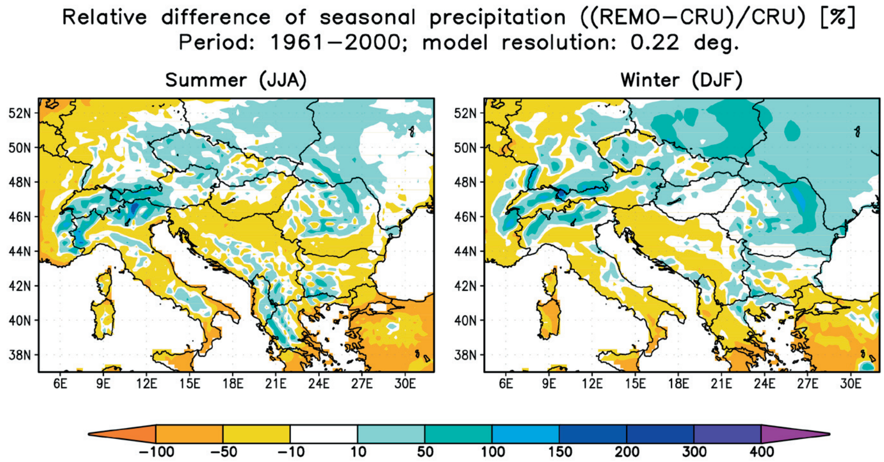

Figure 1 Relative difference (in percentage) of the seasonal (left: summer, right: winter) precipitation amount between the model results and the 10-minute resolution CRU dataset, related to the CRU dataset for the period of 1961–2000. The intercomparisons were carried out on the 0,22 degree resolution re-rotated model grid.

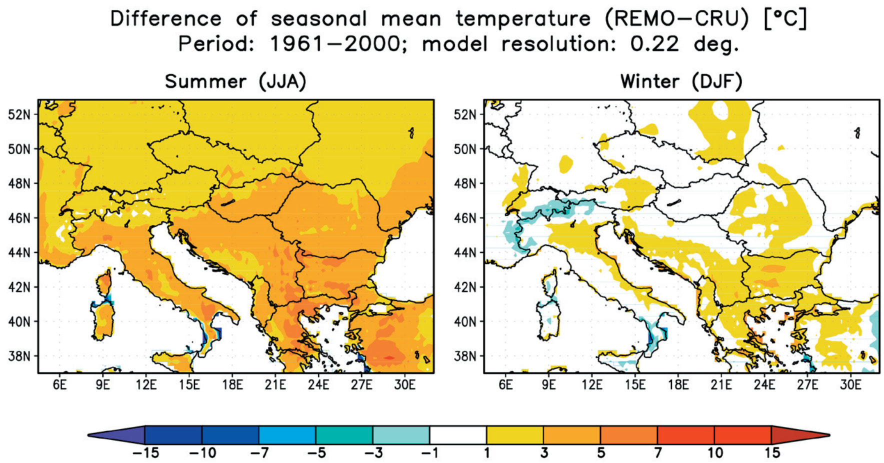

Figure 2 Difference (in Celsius degree) of the seasonal (left: summer, right: winter) mean temperature between the model results and the 10-minute resolution CRU dataset for the period of 1961–2000. The intercomparisons were carried out on the 0,22 degree resolution re-rotated model grid.

Summertime Temperature Variability In South America Between 1948 – 2007

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Introduction

Climate change has been studied over South America (SA; 60°S-10°N; 90°W-20°W) mainly in the context of deforestation in the Amazon (Nobre et al. 1991 and others). There have been few studies about climate change which consider the whole of SA and which focus on temperature. In this work we investigate how the air temperature at 2 meters above the Earth's surface in SA varies in the NCEP/NCAR reanalysis dataset (Kalnay et al. 1996). It is important to emphasize that El Niño Southern Oscillation (ENSO) is the most important coupled ocean-atmosphere phenomenon to produce climate variability over SA on an interannual timescale. In this paper we also consider therefore if ENSO significantly affects temperature variability over SA.

Methodology

The temperature variability at 2 meters above the Earth's surface in the NCEP/NCAR reanalysis is investigated in SA between 1948 and 2007. Hereafter, air temperature at 2 meters above the surface will be referred to only as "temperature". The means and the standard deviations of the temperature in December-January-February (DJF) during 1948-1975 and 1976-2007 are calculated for each month and the results presented in this paper are the average of the DJF for the years considered. This division into these periods is based on the work of Obregon and Nobre (2003) who verify the occurrence of climate change in the mid 1970's from station precipitation data in SA. To evaluate the temperature variability in the second period only (1976-2007), this period is further subdivided into 1976-1991 and 1992-2007 and a similar analysis is conducted. We also consider the temperature of the last seven years (2001-2007). The period between 2000-2006 is considered as the globally warmest of the last 100 years (IPCC AR4 2007). The year 2007 was the least warmest of the past seven years for the majority of SA and the global value for 2007 is the 5th warmest in the 128-year period of record (Lawrimore 2008). To evaluate the influence of natural variability and/or an anthropogenic influence in the results, we also perform an analysis involving the four strongest El Niño and the three strongest La Niña events observed between 1976 and 2007 for the DJF season. We consider the La Niña events: 1975-1976, 1988-1989, 1998-2000 and the El Niño events: 1982-1983, 1986-1987, 1991-1992, 1997-1998.

Results

The spatial patterns of the summertime temperature in SA are nearly similar in both periods, 1948-1975 and 1976-2007 (Figure 1a, 1b). However, there are some notable differences. Over the majority of SA, the mean temperature is between 21°C and 24°C in the period 1948-1975. In this period, we observe temperatures between 18°C and 21°C over the mountain regions of Rio Grande Sul (Serra Gaúcha) and over the "Serra da Mantiqueira". Temperatures above 24°C are observed in the northern part of the Amazon region, east and north of Northeast Brazil (NEB) and east of the Andes Cordillera. In the period 1976-2007, we observe a change in the temperature pattern in SA, with southward (in tropical South America (TSA) and subtropical south America (SSA)), and eastward displacement of the 24°C isotherm (Figure 1b). Thus, in this period the temperature over most of the continent is above 24°C and the area with temperatures below 24°C decreased in size. In the "Serra Gaúcha" and "Serra da Mantiqueira" the temperature is above 21°C. Over most of the continent and the west part of the South Atlantic Ocean the temperature is warmer in this second period. The temperature difference between 1948-1975 and 1976-2007 is significant particularly over Brazil, Argentina and part of Chile, with temperature differences above 0.6°C and 1.2°C respectively (Figure 1c). The last value is higher than the increase in the total global temperatures (0.76°C increase) from 1850-1899 to 2001-2005 estimated by the IPCC AR4 (2007). We also observe a warming above 0.6°C over the South Atlantic Ocean, with a pattern that resembles the SACZ (Chaves and Nobre 2004; Chaves and Ambrizzi 2005).

The spatial patterns of the temperature are similar in the periods 1976-1991 and 1992-2007 (Figure not shown). However, in the period 1976-1991 the 27°C isotherm is located in the north of Argentina , while it is found along the SA north coast between 1992-2007 . Thus, we observe cooling in SSA and warming in TSA in the period 1992-2007 when compared with 1976-1991. Considering a similar number of ENSO events between the periods 1976-1991 and 1992-2007, the results above suggest a non-ENSO influence and may be indicative of a human influence on the South American climate.

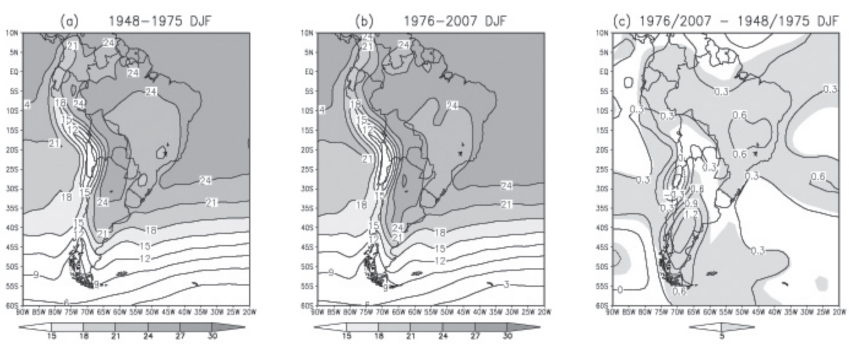

Figure 1 - Mean air temperatures at 2 meters above the Earth's surface (°C) in DJF during (a) 1948-1975, and (b) 1976-2007 and (c) the difference of the mean temperature between these two periods In Figure 1c shaded areas represent statistical significance at the 5% level.

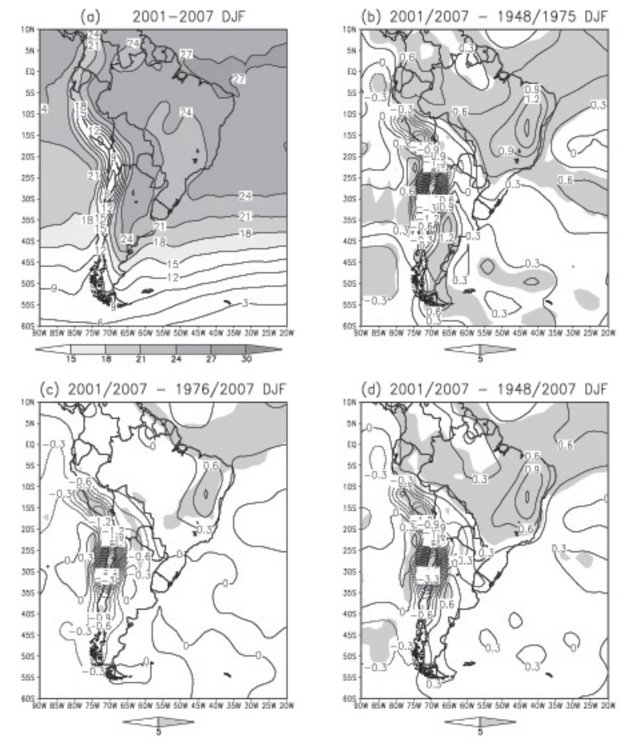

Figure 2 - (a) Mean air temperature at 2 meters above the Earth's surface (°C) in DJF for 2001-2007, (b)the difference of the mean temperatures (°C) between 2001-2007 and 1948-1975, (c) the difference of the mean temperatures (°C) between 2001-2007 and 1976-2007, (d) the difference of the mean temperatures (°C) between 2001-2007 and 1948-2007. For (b), (c) and (d) the shaded areas represent statistical significance at the 5% level.

The mean temperature for DJF for the period 2001-2007 is shown in Figure 2a. In this period a warming over almost the whole of SA is evident (compare Figure 2a with Figure 1a, 1b) with an increase of the area with temperatures above 24°C over the continent. We also observe an increase of the area with temperatures above 27°C in the North Atlantic Ocean near the northern coastline of SA. However, over the central Andes Cordillera the area with lower temperatures gets cooler, with temperatures below 6°C for the period 2001-2007.

The temperature differences in DJF between 2001-2007 and 1948-1975, 1976-2007 and 1948-2007 (Figure 2b, c, d) show in each case, warming in TSA mainly in NEB and over the equatorial North Atlantic Ocean. These temperature differences are greater when 2001-007 is compared with the 1948-1975 period, with values above 1.4°C in North East Brazil (NEB) (Figure 2b). In part of the SSA region the warming is observed with values above 1.2ºC and 0.6ºC compared with the periods 1948-1975 and 1948-2007 respectively. We observe cooling over part of the SSA region, mainly over the Andes Cordillera, in the period 2001-2007 when compared with the periods 1976-2007 and 1948-2007 (Figure 2c, 2d).

Figure 3 shows the mean temperature difference between the strongest La Niña and El Niño events in the period 1976-2007. We observe warming in SSA, mainly over the central part of Argentina, with values above 0.6°C, and cooling in TSA, with values around -0.6°C. This difference has statistical significance at better than the 10% level. Comparing the values of mean temperature difference between ENSO extremes with the values of the mean temperature difference between the periods above (Figure 1c, 2b, 2c, 2d and 3), we see that the values are slightly greater between the periods than those associated with the difference between extreme ENSO events. As ENSO events are associated with the hypothesis of natural climate change; the values of the difference between positive and negative phases of these events should be higher and also with greater statistical significance when compared with the two long periods considered. Thus, this result indicates that this phenomenon cannot be largely responsible for these temperature differences between the different periods.

4. Conclusions

This work shows how the air temperature at 2 meters above the Earth's surface in SA varies in the NCEP/NCAR reanalysis dataset between 1948 and 2007. In DJF during 1948-1975, over the majority of SA, the mean temperature is between 21°C and 24°C. However, in the period 1976-2007, the mean temperature over most of SA is above 24°C, with warming in the TSA and SSA regions. Thus, even considering the occurrence of a greater number of El-Niño events in the period 1976-2007, the warming observed in this period could not be associated to this phenomenon. The analysis also shows cooling in the SSA latitudes and warming in the TSA latitudes in the period 1992-2007 compared with the period 1976-1991. The results presented here indicate that the climate change over SA may not only be due to the natural variability of the climate but it may be a result of human activity. Indeed, there has been more land use change and greater carbon dioxide release in the most recent period. It is possible that changes in the observational networks could influence the results, however to verify this hypothesis it would be necessary to examine dataset from meteorology stations over a long period of time. Even with undetermined causes, the most important finding in this

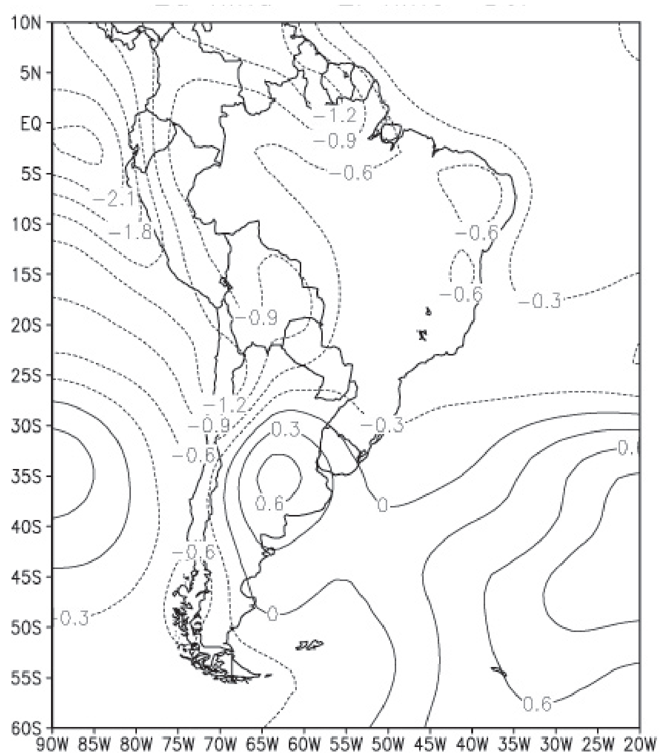

Figure 3: Temperature differences (°C) between the strongest La Niña and El Niño events observed between 1976 and 2007

work is the demonstration that a change in the temperature patterns of SA occurred between 1948-2007.

Acknowledgments:
R. Chaves is grateful to the FAPERJ (APQ1171.225/2006 and APQ170.339/2006), CNPq (PQ-301591/2005 and EU-472832/2006-9), TECNORTE and FINEP (CICLONES and PREVRIO) for financial support and to the USF Department of Geography for support through the use of facilities during the preparation of this paper. A full version this paper is under review at the Journal of Climate. We thank Howard Cattle for important suggestions in this article.

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Warming over India under Anthropogenic Climate Change

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Introduction

The monitoring and analysis of atmospheric temperatures on global and regional scales has acquired special importance in the last few decades owing to the clear indications of global warming in the post-industrial era. It has been concluded in the Intergovernmental Panel on Climate Change (IPCC) reports (IPCC, 2001 and also the 4th Assessment Report 2007), that the global mean surface air temperature has increased by 0.3°C-0.6°C during the 20th century, with many warmest years occurring in the last decade or so. In particular, the variability of surface temperature on regional and global scales is considered as of much importance as the monitoring of precipitation. The significant increase in the mean annual global surface air temperature during the past century is predominantly over the Northern Hemisphere (NH).

The South Asian sub-continent (5-35°N, 65-95°E) which is a major part of the NH is highly vulnerable to climate variability/change due to its dense human population. It lies in the torrid zone and hence has a very hot climate throughout the year. Also its economy and agriculture mainly depends on monsoon rainfall. Kripalani et al (2007a) have extensively analyzed the outputs of 22 models from the WCRP Coupled Model Inter-comparison Project 3 (CMIP3) dataset for the twentieth century simulations to study the ability of models to simulate present climate over south Asian region. Ten out of 22 models could simulate the monsoon rainfall over South Asian domain reasonably well. These are bccr_bcm2_0 (bcr), ccma_cgcm3_1(ccm), cccma_cgcm3_1_t63(ccm2), cnrm_cm3(cnr), mpi_echam5(ech), miub_eco_g(eco), inmcm3_0(inm), miroc3_2_hires(mih), miroc3_2_medres(mim), ukmo_hadcm3(ukc). (for details of the model- resolutions, data period etc please refer to Kripalani et al 2007a). Kripalani et al (2007b) have also examined these models for simulation of East Asian monsoon. The projections of South Asian monsoon precipitation in transient climate change experiments of 1% increase per year in CO_2 till doubling have been discussed by Kripalani et al (2005, 2007a). As the surface temperature plays a major role in monsoon circulation, the ability of the same ten models to simulate surface temperature has been examined in this study. The future projections by these 10 models over the Indian land region (land region in the area 5-35° N, 65-95°E) are examined for three twenty-first century climate change scenarios from 2000 to 2100

(i) SRES B1 (low forcing ie. CO_2 concentration about 550 ppm by 2100) ;

(ii) SRES A1B (medium forcing ie. CO_2 concentration of about 700 ppm by 2100) and

(iii) SRES A2 (high forcing ie. CO_2 concentration about 820 ppm by 2100) in two time slices 2031-2050 and 2081-2100.

Scenario A2 has a rapid increase of CO_2. A1B exhibits a much slower increase in CO_2 as compared to A2.

In order to study the projections we apply the techniques of multi-model ensembles (MMEs), taking the average of simulation results from multiple models. This averaging will help to reduce the individual model biases (and can also reduce the uncertainties arising due to different initial conditions).

Data

(i) The monthly surface temperature data for 10 models under present century '20c3m' experiments available for simulation times of one and half centuries (1860s -2000) and climate change experiments under SRES B1, A1B and A2 for the next century (2001-2100).

(ii) Surface temperature data from NCEP / NCAR Reanalysis data set used as observed data to validate the simulated model outputs.

Simulated surface temperature climatology

The economy and agriculture of the Indian land mass mainly depends on the summer monsoon precipitation received during the period of four months June through September. Also temperature is the major factor in various stages of the growth of crops. Hence it is interesting to study the surface-temperature variability over Indian region. Global coupled climate models provide a useful tool to study the future projections of climate. If the models are able to simulate the observed characteristic features then they can be used to estimate the future projections.

Annual Cycle

Figure 1 (page 18) compares the annual cycle of surface

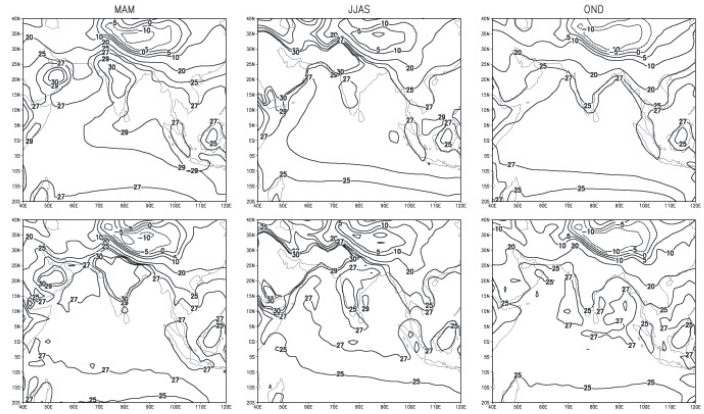

Figure 2 : MME average of simulated (top) and observed (NCEP Reanalysis-bottom) surface temperature (deg C). Left MAM; centre JJAS; right OND

temperature over the Indian land mass simulated by the MME average of the individual models , with that observed through NCEP Reanalysis data. The outputs are based on the last 20 years of simulation, 1981-2000. The observed curve (solid black line) shows that the surface temperature starts rising rapidly from the month of March when the sun crosses the equator from south to north. It attains a maximum in the month of May-June and then gradually decreases up to September. In September the sun crosses the equator again, moving south, hence the temperature over Indian landmass decreases quite rapidly until December. In general all these models simulate the shape of the annual cycle reasonably well. The models exhibit large variability among themselves in simulating temperatures in January to May; however the discrepancy between models is comparatively less from June to December. All the models underestimate the temperature in December and January.The dash-dot line shows the MME of the 10 simulations. Interestingly the MME has a positive bias in temperature in the monsoon months (June to September) and a negative bias in the pre and post monsoon season.

Seasonal Spatial Patterns

The ability of models to simulate the spatial characteristics of surface temperature over the Indian landmass and adjacent oceans is also examined. Figure 2 shows the MME simulations of seasonal surface temperature (top panels) and the observed patterns (bottom panels). In the pre-monsoon season March-April-May (MAM) the temperature over both the Indian landmass and west Asia are very well simulated.

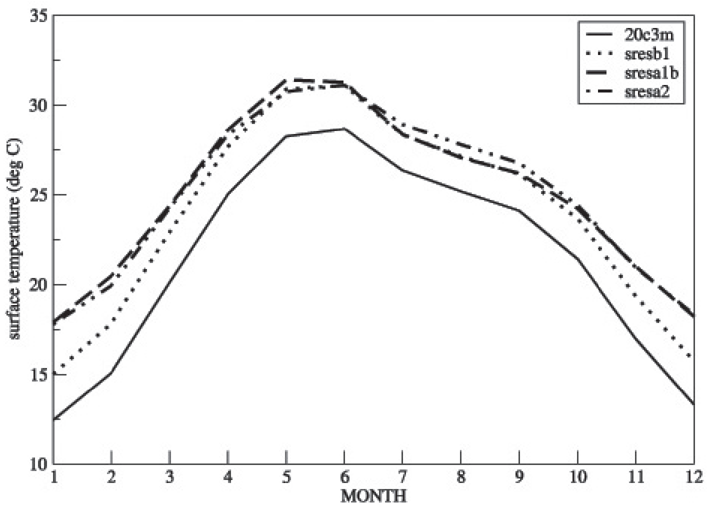

Fig 3 : MME average of simulated (20c3m) and projected (SRES B1, A1B and A2) annual cycle of surface temperature over India

However the models show a positive bias of around 2° C over the equatorial Indian ocean along 70-100° E. In the summer monsoon season June through September (JJAS) the simulations are reasonably good (middle panels). The land regions are slightly warmer than observed. In the post monsoon season October-November-December (OND) the land temperatures show a cold bias as compared to observed but the ocean temperatures are well simulated.

Projections

Since the MME of these ten models simulates observed patterns reasonably well, we study the projected annual cycle and the spatial distribution of seasonal precipitation in climate change experiments under SRES B1, A1B and A2. As mentioned earlier these three experiments have different concentrations of the anthopogenic gases, especially CO_2, hence the projected changes in surface temperatures under these scenarios can be contributed to the anthopogenic effect.

Projected annual cycle

Figure 3 depicts the MME simulated and projected annual cycle of surface temperature over the Indian land mass in the three climate change experiments SRES B1, A1B and A2. The projections are based on the data for the end of the next century, 2081-2100. Interestingly the shape of the annual cycle does not change in the next century. Experiment B1 has the lowest concentration of CO_2. This scenario projects warming of approximately 2°C in all the months. A1B and A2 show similar rises in temperature, of the order of 4° C as compared to present century in the early and late parts of the year. Though A2 has rapid growth of anthropogenic gas concentrations as compared to A1B, it also specifies somewhat greater sulphate aerosol concentrations which are supposed to have cooling effect on surface temperature. Hence the projections under A1B and A2 are not much different though CO_2 concentrations are substantially different. During period May-September all the scenarios project similar increases in temperature over the Indian land mass. The projections under different scenarios differ more in the January-April and October-December periods.

Projected Spatial Patterns

Figure 4 shows the MME projected changes in surface temperatures for MAM (top panel) and JJAS (bottom panel). The changes are computed as differences based on 2081-2100 period of each scenario and the 1981-2000 period of the 20c3m experiments. Since heating in pre-monsoon months plays a vital role in deciding the strength of the subsequent monsoon over India, surface temperature projections of

MAM are of prime importance. In each case, the maximum warming is observed over the Tibetan region along 35°N, 80-100°E. In MAM scenario A1B shows more warming as compared to B1. A2 is the experiment with maximum concentration of CO_2 and shows the greatest warming over the Tibetan Plateau. However the temperature increases over the Indian subcontinent are suppressed compared with A1B possibly due to the cooling effect of sulphate aerosols in A2. These two factors lead to large temperature gradients between the two regions.

In JJAS, in all climate change experiments, substantial warming of 2-4°C is projected over Pakistan region, which strengthens the Pakistan heat low. This situation is conducive to good monsoon conditions over India. Also a the warming of 1-3°C over the equatorial Indian Ocean will act to strengthen the cross equatorial monsoon flow and bring more rainfall to the Indian landmass. Though there is little difference in the averaged temperatures over the Indian subcontinent between A2 and A1B (Figure 3), there are notable differences in the intensity of patterns of warming with again a much larger contrast between the warming over the Tibetan Plateau and the Indian subcontinent in A2. The land-ocean temperature difference is pronounced in A2, hence A2 shows very strong increasing trend in monsoon precipitation over India (Sabade et al., 2008).

Summary

The present study documents the performance of 10 selected coupled climate models from the WCRP CMIP3 data set in simulating the seasonal surface temperature over the Indian land mass and their projected changes as simulated by these 10 models under three anthropogenic climate change scenarios SRES B1, A1B and A2. Among these scenarios B1 has the slowest growth of anthropogenic greenhouse forcings while A2 projects the fastest growth. The multi-model ensemble temperature simulations of these 10 models has been compared with observed surface temperature from the NCEP/NCAR reanalysis data. The models are able to simulate the pattern of the annual cycle reasonably well. In the pre-monsoon (MAM) and monsoon (JJAS) season the land temperatures are overestimated while in the post-monsoon season there is a cold bias over the Indian land mass. However the temperatures over adjacent oceans are reasonably simulated. The temperature over Indian land mass is projected to increase by around 2°C in all the months for scenario B1. The maximum increase is projected in scenario A2 though this is ameliorated by the effects of greater sulphate aersols compared to the other scenarios. In MAM the maximum warming is projected over the Tibetan region. In the monsoon season relatively greater warming of the land region over Pakistan is projected, also the land-ocean heat contrast increases in the A2 experiments which suggest increased monsoon precipitation over India.

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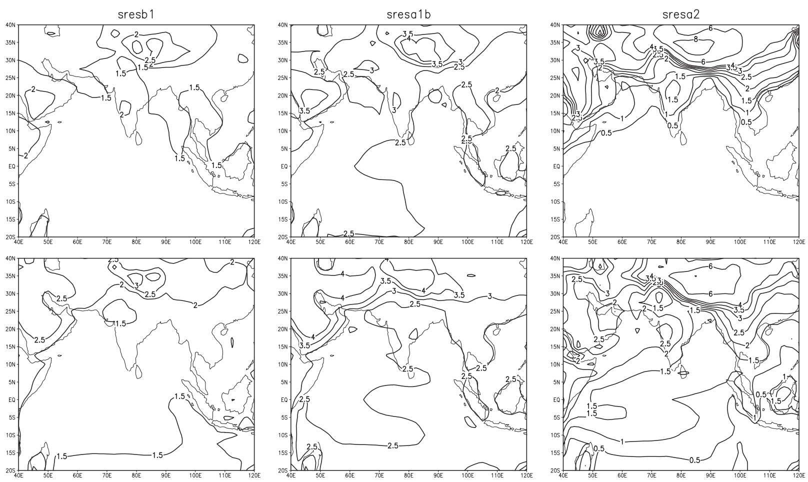

Fig 4 : MME average of projected changes in surface temperature (2081-2100)-(1981-2000) for MAM (top) and JJAS (bottom). Left SRES B1; centre SRES A1B and right SRES A2

First results with the REMO regional climate model at the Hungarian Meteorological Service

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Introduction

Nowadays the global climate models developed and exploited by the world climate centres are rather reliable for providing realistic projections for the synoptic scale characteristics of the climate. However they are insufficient for detailed regional scale estimations. A couple of years ago two regional climate models were adapted at the Hungarian Meteorological Service: the ALADIN/Climate model developed by Météo France on the basis of the internationally developed ALADIN modelling system and the REMO model developed by the Max Planck Institute for Meteorology (MPI-M) in Hamburg. It is anticipated in Hungary that these models will be able to give realistic regional climate estimations for the next few decades particularly for the area of the Carpathian Basin. This area of interest is especially important considering the fact that one of the largest climate projection uncertainties can be found over the Carpathian Basin as was already identified by large international climate projects (PRUDENCE for instance – Prediction of Regional scenarios and Uncertainties for Defining European Climate change risks and Effects). Various versions of the REMO model had already been tested all over the world for different geographical domains and for different past periods, however recently further validations and tests had been started also at the Hungarian Meteorological Service (HMS). This article briefly summarises the first validation experiments of the REMO model in Budapest.

Description of the model

More than ten years ago the REMO regional climate model was developed on the basis of the “Europa Model” (the former numerical weather prediction model of the German Weather Service) together with the inclusion of the global atmospheric general circulation model ECHAM4’s physical parameterization package.

REMO (Jacob and Podzun, 1997) is a gridpoint model for which the primitive equations are written in advective form in a rotated spherical coordinate system. The phase-errors caused by horizontal discretization are reduced by a staggered Arakawa grid (C-type) (Mesinger and Arakawa, 1976). The prognostic variables of the model are the temperature, the horizontal wind-components, the water-vapour content and the cloud-water content on the model levels and the surface pressure. In the vertical a hybrid coordinate-system is defined (Simmons and Burridge, 1981). The maximum number of vertical levels in the model is 49 (presently 20 levels are used). At the moment only the hydrostatic model version is available (the non-hydrostatic version is under development), therefore the highest possible, plausible resolution of the model is about 10 km. Due to the Eulerian treatment of advection the longest possible time-step, used at the highest resolution, is 45 seconds. For the appropriate treatment of the lateral boundary conditions the model uses the classical Davies’ scheme (Davies, 1976).

In the REMO version adapted in Budapest (REMO 5.0) the description of the thermal and hydrological processes in the soil follows the ECHAM4’s schemes (Roeckner et al., 1996): the temporal evolution of the soil temperature is predicted by solving the diffusion equation using a five-layer model (Warrilow et al., 1986); the vertical diffusion and surface turbulent fluxes are calculated based on the Monin–Obukhov similarity theory (Monin and Obukhov, 1954); the runoff scheme is based on catchment considerations including sub-grid scale variations of field capacity over inhomogeneous terrain (Dümenil and Todini, 1992). The parameterization of radiation processes is called every hour during the model integration: the description of short-wave radiation follows the method developed by Fouquart and Bonnell (1980) in two spectral intervals; for the longwave the model uses the narrow-band model after Morcrette et al. (1986) with several modifications for additional greenhouse gases and various types of aerosols. The parameterization of the moist convection is based on a mass flux scheme (Tiedtke, 1989), but the version described by Nordeng (1994) is also available, which contains also several further improvements.

The summer-drying problem

The summer drying problem over the Danube catchment area is a relatively known problem of regional climate models. In the framework of the RAACS project (Regionalization of Anthropogenic Climate Change Simulations; Machenhauer et al., 1998) it was already recognised that many regional climate models (including also REMO) simulate too dry and too warm summer climate over Central and Eastern Europe for the second half of the 20th century. Later on, in the MERCURE (Modelling European Regional Climate, Understanding and Reducing Errors) project an important task was to understand and reduce (possibly fully eliminate) this model bias. The main conclusion from this project was that for most of the participating models the systematic errors in the dynamics appear to be an important cause for the summer drying (Hagemannet al., 2004) concluded, that the errors are mainly induced by problems in the simulated general circulation, where too little moisture is advected into the region). On the other hand in the case of some models deficiencies in the land surface parameterisations contributed significantly to the excessively dry model climate (the models simulated too weak a diurnal temperature cycle).

Despite the efforts and results mentioned above the exact cause of the summer drying problem was not identified, therefore the elimination of the bias was not yet possible. The investigations in the PRUDENCE project focused on the period of 1961–1990 with the simulations of ten regional models (using a horizontal resolution of about 50 km). Compared to CRU data, the results have shown that the summer warm bias still exists in the majority of the participating RCMs; therefore no model developments seem to have improved the situation substantially (Hagemann and Jacob, 2007).

Experiments on the summer drying problem carried out at

MPI-M using an increased number of vertical levels (Göttel et al., 2004) also provided negative results: more vertical levels didn't lead to improved simulations. It was decided at HMS that a similar study be performed just looking at increase of the horizontal resolution. Due to the fact that the finest possible REMO model resolution is 1/10 degree, this maximal resolution was tested with respect to a "reference" of coarser resolution (Árvay, 2007). The finest resolution tests did not bring any improvements – the summer drying problem was even more dramatic than it is the case for the coarser resolution experiments. The reasons for these results are still unknown and require further experimentation and understanding.

Simulation with REMO for the ERA40-period

As indicated above the summer drying problem is still an open and acute issue strongly influencing the uncertainty of climate change projections in Central and Eastern Europe. This issue as well as other factors determining the uncertainty in climate change projections will therefore be addressed within the CLAVIER (Climate Change and Variability: Impact on Central and Eastern EuRope) project (http://www.clavier-eu.org) supported by the European Commission. In this project REMO 5.0 has been used for the area of interest of the Hungarian Meteorological Service, applying 25 km horizontal resolution. An approximately 40-year simulation was achieved for the period of 1957–2000, which was driven by ECMWF ERA40 re-analysis data. The main motivation for this long REMO experiment was on the one hand to explore the possible weaknesses and strengths of the model for a longer past period (and check the existence of the summer drying problem) and on the other hand to prepare a high-resolution dataset for further hydrological investigations in the CLAVIER project.

The model results were compared to various observational datasets: the 10-minute (approximately 20 km) version of the CRU-database (New et al., 2002) and the gridded (0,1-degree resolution) Hungarian observational dataset. The validation mostly concentrated on the period 1961–2000 for two parameters: the mean temperature and the precipitation amount. These parameters were investigated at monthly, seasonal and annual scale both for the entire period and for the single decades. Investigating the annual precipitation amounts (not shown) the main orographic characteristics can be immediately noticed: around the two highest orographic features in Europe (the Swiss, Italian and Austrian ranges of the Alps and the ridge of the Carpathian Mountains) the model overestimates the precipitation – which is pronounced not in the peaks (where underestimation is typical), but over the slopes. The error of overestimation exceeds sometimes even 150% (compared to the observed precipitation) in the Alpine region. At the same time opposite tendencies can be detected in other elevated parts of Europe – like the Adriatic side of the Alps, the Dinarian Mountains or the Apennines. Over Hungary a separation line can be noticed which isolates the too wet and too dry regions of the model: North from the Carpathians REMO overestimates the amount of precipitation, while over large part of the Basin and for the Southern part of Europe it provides too dry a past climate (this fact might reflect the difficulties in providing reliable precipitation estimates for the Hungarian territory). Otherwise the simulation for Hungary is fairly realistic: the departures from the observations generally don't exceed 10% (only at the Southwest regions). Regarding the seasonal results it can be concluded, that the summer mean precipitation (Figure 1, page 18, left panel) for the forty years has a similar distribution to the annual case: the too wet and too dry regions predicted by the model are nearly the same, there are some differences only in the (generally larger) degree of misestimation. In winter (Figure 1, right panel) the relative amount of wet areas increases. This tendency is further maintained in spring, where the dry regions are focused only on a small region over the Adriatic Sea. Contrary to that, in autumn underestimation is dominant almost on the entire study area, and its magnitude grows seriously at the Adriatic coast exceeding even 50%.

The departure fields of mean temperature do not show such large temporal and spatial variance. In the case of annual results the model overestimates the observed values by 1-3 degrees everywhere (both for the single decades and for the entire period), however over Bulgaria the overestimate is even higher. The same is typical also in spring, but in summer (Figure 2, page 18, left panel) the overheating grows to 3-5 degrees over the southern regions (Italy, Balkan Peninsula, Southern Hungary). Then the overestimation is rather moderate in autumn and in winter (Figure 2, right panel), when the model is quite perfect.

Summary

In this article a short overview was given about the various validations of the REMO regional climate model. The summer drying problem (SDP) was diagnosed also based on the Hungarian data. Studying the impact of the finer horizontal resolution for the SDP it can be concluded, that (either horizontal or vertical) resolution increase doesn't improve the model predictions. Finally the experiment for the ERA40 period (which was verified against a detailed Hungarian observational dataset, too) confirms the significant errors in temperature and especially in precipitation over the Carpathian Basin in the summer and autumn months. According to the results one can say as a general conclusion, that the model is far from being perfect requiring further improvements and tests in the future. However it has to be remarked that these conclusions are not yet final, because a small error was found over some isolated sea points in the interpolation of global data to the regional grid, which can slightly affect the results.

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Workshop on the Western Tropical Pacific: Hatchery for ENSO and Global Teleconnections

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The western tropical Pacific warm pool is one of the key regions of our climate system. Small temperature anomalies, driven by either radiative forcing or ocean dynamical changes can easily lead to large diabatic forcing anomalies that affect the atmospheric circulation worldwide. Furthermore, the western Pacific warm pool plays a crucial role in the El Nino-Southern Oscillation. Recharging (discharging) of equatorial heat prior to (after) an El Nino event is partly accomplished by the low-latitude western boundary current dynamics. Leakage of planetary waves through the Indonesian Seaways can affect climate in the Indian Ocean, thereby affecting rainfall patterns in Indonesia and Australia. While it is widely accepted that the western tropical Pacific warm pool plays a major role in our climate system, very little is in fact known about its response to increasing CO_2 concentrations and about the detailed dynamical processes that e.g. establish the meridional transport of heat and mass during El Nino events. This lack of in-depth understanding inspired the CLIVAR Pacific panel to organize an international workshop on this subject in Guangzhou, China.

From November 26-28th, 2007 the workshop Western Tropical Pacific: Hatchery for ENSO and Global Teleconnections attracted about 80 scientists from 11 countries. It was generously funded by the Chinese Academy of Sciences, the National Natural Science Foundation of China, the Guangzhou Association for Science and Technology, the First Institute of Oceanography (SOA, China), WCRP and US CLIVAR. The Guangzhou-based South China Sea Institute of Oceanology (CAS) hosted the workshop and participants applauded the warm hospitality that also helped to establish new international collaborations. On the first day, the workshop focused on the effects of the South China Sea on regional and large-scale climate. While the effects of South China Sea sea surface temperature anomalies on regional climate and weather patterns are well documented, their influence on global-scale wind and precipitation patterns was subject to an intense debate. During the afternoon session Dunxin Hu from the Chinese Academy of Sciences gave an overview on the Chinese oceanographic activities that are related to charting the dynamics of the northwestern tropical Pacific boundary currents. The new Chinese field program NPOCE (North Pacific Ocean Circulation Experiment) will provide a detailed view of cross-equatorial flow, regional-scale ocean circulation and the northern branch of the ENSO discharging process. Focusing on the South Pacific, the international program SPICE (Southwest Pacific Ocean Circulation and Climate Experiment, spear-headed by Alex Ganachaud) is expected to provide information on the southern hemispheric western boundary current. The idea to develop a comprehensive view of low latitude boundary currents in both hemispheres and the Indonesian Throughflow as well as their roles in the climate system was further discussed in the CLIVAR Pacific Panel meeting that followed the workshop. The first day of the workshop concluded with a dinner party and spontaneous outbursts of musical talent.

The second day of the workshop continued with a review of ongoing observational activities in the eastern equatorial Pacific (VOCALS, Roberto Mechoso) and the North Pacific W-PASS (Western Pacific Air-Sea interaction Study) and SUPRFISH (StUdy on PRediction and application of FISH species alternation) programs that were presented by Toshio Suga. The afternoon session was devoted to the interaction between the Madden-Julian Oscillation (MJO), westerly wind bursts (WWBs), and ENSO. A consensus emerged during the discussions that this interaction is a key element of the ENSO cycle that needs to be represented properly by state-of-the art coupled general circulation models. Suggestions for improving coupled model performance in the tropical Pacific were discussed. Whether state-dependent intraseasonal tropical noise is sensitive to greenhouse warming is still an open question. A recent analysis of CMIP-3 model simulations presented by Fei-Fii Jin suggested that tropical instraseasonal variability in the warm pool region can be intensified by up to 30% in response to a doubling of atmospheric CO_2 concentrations.

The last day of the workshop focused on longterm ENSO changes, predictability of ENSO and the issue of how ENSO predictions are actually used by societies. While in general ENSO forecasting systems have been quite successful, many improvements need to be made in future, including: the reduction of coupling shocks, the improved representation of MJO-ENSO interactions, ENSO nonlinearity and the reduction of tropical biases. ENSO's longterm characteristics are still uncertain. Although the CMIP3 greenhouse warming projections agree that the mean equatorial easterlies will likely weaken, simulated changes in ENSO variance seem to be highly model-dependent. New multi-parameter ensemble experiments conducted at the Hadley Center (Mat Collins) have shed some light on the potential structural instability of ENSO in state-of-the art CGCMs.

Important recommendations that were derived from this workshop include:
- the role of South China Sea SST anomalies on the atmospheric circulation needs to be studied using higher resolution coupled general circulation models and well-designed coupled and hybrid coupled modeling experiments
- improving the representation of MJO-WWB-ENSO interactions in coupled general circulation models is an important step towards increasing ENSO forecast skill
- scientific coordination of VOCALS and SPICE might prove useful to elucidate some key aspects of the dynamics of the South Pacific Convergence Zone
- coordination of NPOCE, SPICE and PACSWIN (PAcific Source Water INvestigation) will help to elucidate the fundamental role of low latitude western boundary currents for the ENSO re- and discharging process.

Further information on the workshop and most of the presentations can be found on http://www.clivar.org/organization/pacific/meetings/pacific_workshop.php

The workshop received wide media attention in China. Guangzhou Daily, China Ocean News, Science Times and Southern Television covered the workshop and interviewed Dongxiao Wang, Yihui Ding, Guoxiong Wu and Axel Timmermann.

Through stimulating scientific discussions, entertaining social events and thanks to a terrific organization, this workshop has helped to establish new partnerships between the Chinese climate and oceanographic community and CLIVAR.

Participants at the Workshop on Western Tropical Pacific: hatchery for ENSO and Global Teleconnections

Obituary – Professor Fritz Schott

It is with great sadness that we learned of the passing of Fritz Schott on April 30, 2008 in Kiel. Fritz had been fighting leukemia for about a year, during which he maintained a positive attitude, keeping in touch with several of his friends around the world, writing scientific papers and essential chapters for a new text book in Physical Oceanography.

Fritz was awarded a PhD in Oceanography from the Institut für Meereskunde at the University of Kiel in 1964 under the guidance of Professor Günter Dietrich, where he returned in 1968 to pursue a very successful academic career in the department of Regional Oceanography. In 1978 he moved to RSMAS, where he was Chairman of the Division of Meteorology and Physical Oceanography from 1979-1984. Fritz returned to Kiel in 1987 and became Professor for Physical Oceanography at the Institut für Meereskunde (now Leibniz-Institut für Meereswissenschaften, IFM-GEOMAR), becoming Professor Emeritus in October 2004.

The ocean circulation and its central significance for global climate lay at the heart of Fritz Schott's research. In the context of hard-won data from his more than 30 research cruises to key regions of the Atlantic and Indian Oceans, he made fundamental contributions to our understanding of the ocean circulation.

Fritz was an extraordinarily talented physical oceanographer with an ability to synthesize field data and model results into a compelling vision of how the oceans behave and interact in the climate system. He focused on the 'big' problems and derived significant results and insight on the dynamics and properties of the oceans. Many prestigious awards recognized his contributions to science:

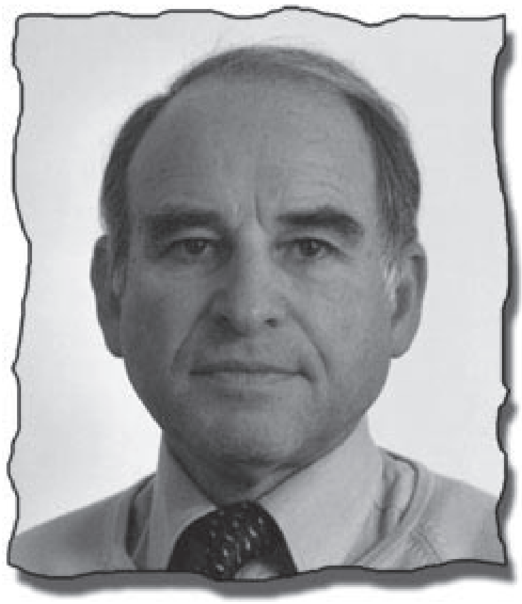
- The Fridjof-Nansen Medal of the European Geophysical Society in 1997
- Fellowship of the American Geophysical Union in 1997
- Fellowship of the American Meteorological Society in 2004
- The Henry Stommel Research Award of the American Meteorological Society in 2004
- The Prince Albert I Medal, International Association for the Physical Sciences of the Ocean in 2005.

Friedrich Schott's scientific portfolio comprises more than 100 major publications in international, peer-reviewed journals. Leading national and international scientific organizations recognized his exceptional research and service. WCRP benefitted from his insights in numerous significant ways:

He was very active during the World Ocean Circulation Experiment (WOCE) and became a member of the Implementation Panel (CP1) from 1985-1994. Between 1998 and 2001 he served as a member of the Global Ocean Observing System (GOOS) Steering Committee.

Right from the beginning of CLIVAR Fritz provided leadership and guidance to set CLIVAR off to a great start. His official contributions to CLIVAR included:

- Member, Science Steering Group, 1993-1997
- Co-author, CLIVAR Science Plan (1995) and CLIVAR Initial Implementation Plan (1997)



- Co-Chairman, CLIVAR/DecCen Implementation Conference, Villefranche 1996
- Member, CLIVAR Atlantic Implementation Panel, 2000-2003
- CLIVAR Tropical Atlantic Workshops organized (with R. Molinari): Kiel 2002, Miami 2003
- Lead author White paper "Tropical Atlantic Climate Experiment (TACE)" for CLIVAR Atl. Panel, 2003.
- Member, CLIVAR Indian Ocean Implementation Panel, 2004 – 2008.
- CLIVAR Conference: Reviewer of DecCen Program for CLIVAR Self Assessment, Baltimore, June 2004
- Invited speaker, CLIVAR Workshop "North Atlantic Thermohaline Circulation Variability", September 2004
- Member, GCOS-GOOS-WCRP Ocean Observations Panel for Climate (OOPC), 2005 - 2008

While many see retirement as an opportunity to relax, Fritz continued to devote himself to his research, and his publications continued unabated. The CLIVAR community will sorely miss Fritz, his wise counsel, intellect, frank comments and humor.

I am sure I speak for all of us in CLIVAR when I extend sincere condolences to Inge, their three sons and four grandchildren.

Martin Visbeck

Report from 29th Meeting of the WCRP Joint Scientific Committee (JSC)

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The 29th meeting of the Joint Scientific Committee for WCRP was held in Arcachon, France from 31 March to 4 April 2008. All three of us attended. Overall we felt that this meeting of the JSC was extremely helpful is seeking to move WCRP forward. The atmosphere was relaxed but businesslike, helped by the presence of the new Director of WCRP, Ghassem Asrar. This was John Church's last JSC and during the meeting it was agreed that he would be succeeded as JSC Chair by Tony Busalacchi.

Overarching agenda items and the approximate length of time intended for each were as follows:

1. Welcome, introduction
2. Review of WCRP cross cutting activities with special session on climate extremes (1 + 1/2 days)
3. Review of WCRP core projects (3/4 day)
4. Review of WCRP WGs and Panels (WGCM, WGNE, WOAP ...) (0.4 day)
5. Review of other projects and activities (ESSP, START, THORPEX...) (1/4 day)
6. Discussion of WCRP post 2013 (3/4 day)
7. Executive sessions etc including budgets (1 day)
8. Science lectures (1/4 day)

The meeting report is currently being finalized and will be made available to all as soon as we have it. In the meantime, the notes below are intended to give a flavour of the meeting from a CLIVAR perspective. Copies of CLIVAR-co-authored documents for the JSC meeting and the CLIVAR presentations on seasonal and decadal prediction and the CLIVAR report to the JSC can be downloaded from http://www.clivar.org/organization/ssg/JSC29/JSC29.php. We are grateful to all the members of the CLIVAR community who fed into the reports and presentations, either directly or indirectly

As will be seen from the outline agenda above, the JSC gave considerable time to reviewing the WCRP cross cutting topics, reiterating both the importance of these to the overall WCRP 10-year strategy set out in the "COPES" document published in 2005 and the role of the projects in providing both science input to and management of them. These cross cuts encompass:

- Atmospheric Chemistry and Climate, AC&C, managed by SPARC (Roberto Mechoso is CLIVAR's nominated representative to this)
- Anthropogenic Climate Change, ACC, managed from the WCRP Paris Office.
- Seasonal Prediction, for which the upcoming pan-WCRP Climate system Historical Forecast Project (CHFP) is managed by CLIVAR through WGSIP.
- Decadal Prediction, managed by CLIVAR with the planned pan-WCRP decadal prediction experiment being designed jointly between WGCM and WGSIP.
- Monsoons, managed jointly between CLIVAR and GEWEX with GEWEX taking the lead in making the presentation to the JSC this year.
- Climate Extremes, managed jointly between CLIVAR and GEWEX A special half day session was devoted to this topic during the meeting
- IPY, managed by CliC; CLIVAR contributes through SO Panel activities
- Sea Level Rise, managed by CliC

It was recognised by the JSC that the cross cuts should focus on a limited number of high priority "bite sized" problems but also integrate across WCRP. From this perspective, the need for greater project involvement in the ACC cross cut was agreed. At the same time, CLIVAR, along with the other projects, are asked to review the outcomes of the "Learning from IPCC" Workshop Report (WCRP, 2007), to see how its recommendations are, or can be, accommodated into activities (see the paragraph below on Jim Hurrell's CLIVAR presentation also).

Tim Palmer gave the Seasonal Prediction cross cut presentationon behalf of Ben Kirtman, He outlined the outcomes of the CLIVAR-organised WCRP Seasonal Prediction Workshop in Barcelona (for details, see http://www.clivar.org/organization/wgsip/spw/spw_main.php). A position paper arising from the workshop describing the current state of the art in seasonal forecast skill has now appeared as a WCRP report, at: http://wcrp.wmo.int/documents/WCRP_SeasonalPrediction_PositionPaper_Feb2008.pdf

A particular message from Tim's presentation was that over the last decade, seasonal forecasting using ensembles of global coupled models has made the transition from research to operations. However, whilst great progress and significant levels of skill have been achieved, one of the key conclusions of the Barcelona meeting was that there is currently untapped predictability. This predictability will not be realised until some of the key biases in global climate models have been significantly reduced. Evidence was shown that increasing resolution in the middle atmosphere could help reduce biases in the troposphere. Further, because of existing biases in simulations over the tropical Atlantic, it is unlikely that the full potential of either Pirata or Argo data are currently realised. Indeed, in relation to the Pacific, only now can the impact of the TOGA TAO data be clearly seen in terms of impact on seasonal forecast skill.

Tim also gave the JSC a presentation on progress in the Coupled Historical Forecast Project, an outcome of the JSC Task Force on Seasonal Prediction, now being managed by WGSIP. A number of key groups around the world are involved in this project, which will give new state of the art assessments of seasonal predictability. A workshop is planned in 2009.

Jochem Marotske's presentation on the decadal cross cut outlined plans being developed by WGCM and WGSIP for "near term" (out to 2030) decadal timescale prediction experiments and the contributions to our understanding of the role of the MOC on decadal variability being developed through the CLIVAR Atlantic Panel. The JSC are keen to see wider contributions to the scientific basis for decadal prediction across all of the CLIVAR basin panels; they also identified a need for a WCRP-wide effort focussing on the development of the science of data assimilation for all components of the coupled climate system for initialization of decadal forecasts.

GEWEX led on the monsoon cross cut presentation summarizing the work of both GEWEX and CLIVAR in this area and including development of the Science Plan for the "Asian Monsoon Years 2007-11 as a contribution to the JSC's concept of an "International Monsoon Study" (IMS) to integrate across WCRP's efforts on monsoons. As yet the IMS concept is still being worked out but the JSC recognised the need for improved communication amongst the various WCRP and related WMO monsoon activities. To facilitate this, it recommended the formation of a WCRP/World Weather Research Programme (WWRP) monsoon and tropical meteorology coordinating panel. The panel will work by email with one focus the creation of a monsoon cross cut web site hosted by the GEWEX IPO. It also agreed that a 2nd Pan-WCRP workshop be held in conjunction with the WMO monsoon conference in Beijing in October 2008 to develop IMS planning .

The climate extremes cross cut was the subject of a special half day session. Presentations covered stakeholder needs, including those of reinsurance, the work of the CCl/CLIVAR/JCOMM ETCCDI (Expert Team on Climate Change Detection and Indices), other WCRP research priorities vis a vis extremes (including presentations on drought and modelling by Jim Hurrell and Tim Palmer), a summary of progress with the cross cut to date (Howard Cattle) and a wide-ranging panel and JSC discussion on how to progress research on climate extremes. Outcomes from the JSC included agreement to form a wide-ranging Task Force to determine focus and deliverables for this cross cut and a recommendation for a broadening of the participation in ETCCDI by other WCRP projects.

Jim Hurrell presented an update on the CLIVAR programme, highlighting the major activities and achievements of the global observational and modelling panels, as well as the regional implementation panels. Jim's presentation was centred around CLIVAR contributions to the WCRP cross cuts, the leading role of CLIVAR science and scientists in the Fourth Assessment Report of IPCC, and how CLIVAR activities are addressing components of the scientific issues highlighted in the Sydney Workshop and Survey Report "Future Climate Change Research and Observations: GCOS, WCRP and IGBP Learning from the IPCC Fourth Assessment Report". Jim also presented the major future plans of all of the CLIVAR panels, an outline of the activities and accomplishments of the ICPO, and major outcomes and discussion points of CLIVAR SSG-15 (September, 2008). The latter included a number of issues for JSC consideration. Jim's presentation can be downloaded from http://www.clivar.org/organization/ssg/JSC29/JSC29.php

In the course of the subsequent discussion, the JSC expressed a keen interest in the success of the forthcoming OceanObs'09 Conference, not least because it will highlight the crucial role of ocean observations for understanding

Delegates at JSC-29. Ghassem Asrar, the new Director of WCRP, is second from the right at the front. Tim Palmer is diagonally two across from him whilst Jim Hurrell and Howard Cattle feature near the back.

and predicting climate and identify new opportunities and promote partnerships to sustain and advance development of the system into the 21st century. A one-year task force was proposed to solicit input from various groups and bodies, e.g. IMBER, PAGES, CLIVAR (all its membership), CliC, SOLAS, and those involved in research on surface fluxes, etc.

Following the presentations from the other projects (GEWEX, CliC and SPARC), the JSC also received reports from other WCRP Panels and Working Groups, including WGCM. During the SPARC report the issue of WCRP views on geo-engineering was raised. After discussion the JSC agreed to invite authoritative speakers on this topic to its next session and to set up a small group to review the subject. There was extensive discussion of the preparations for the upcoming Modelling Summit under the WCRP Modelling Panel (the Summit was held at ECMWF from 6-8 May 2008) and how to achieve greater integration amongst the various WCRP modelling activities, a topic to be revisited following the Summit. A White Paper on Revolution in Weather, Climate and Earth System Prediction was also extensively discussed as was the issue of regional climate downscaling. A JSC Task Group is being set up to help coordinate WCRP's downscaling efforts.

The wider activities of WCRP and it's partners (ESSP, START, WWRP, THORPEX...) were reviewed and there was extensive discussion of the preparations for World Climate Conference-3 (WCC-3, Geneva 31 August-4 September 2009), the "theme" of which is "climate services" Martin Visbeck and Dr Ramaswamy (JSC member) both sit on the International Organising Committee and Martin Visbeck also chairs the Programme Committee for WCC-3. The JSC will also provide independent input to the programme committee and will seek to do that through the WCC-3 secretariat. In particular, it was agreed that a JSC-led group will work on a WCRP Statement to WCC-3. The Statement will present a strategic vision of WCRP development based on the results of deliberations at the Modelling Summit, the White Paper on Revolution in Weather, Climate and Earth System Prediction, and WCRP-wide discussion of its future (see below)

An important topic for this JSC was the start of discussions on WCRP strategy and development before and beyond 2013 (the "transition date" for most of the Projects, including CLIVAR).

For the near-term perspective, the general consensus among the JSC was that the strategy outlined in the so called COPES (Coordinated Observations and Prediction of the Earth System) document, is the desirable way forward. WCRP will continue to build activities of its projects and use their potential to implement the objectives of the cross cutting initiatives that either require contributions from more than one project or serve the goals (deliverables), appropriate for the whole of WCRP rather than its individual projects (i.e. GEWEX, CLIVAR, CliC and SPARC). Delivering on the cross cutting activities will serve the needs of society and therefore all aspects of WCRP need to be assessed against the COPES goals. Work on several of the cross cuts has started (as reflected above) and it was noted that CLIVAR panels have already significantly contributed to several of these. A document will be prepared summarising the achievements of WCRP in implementing the COPES strategy.

As an introduction to the strategy discussion on post 2013 scenarios, Jim Hurrell presented the new structure achieved by US CLIVAR a couple of years or so ago. The earlier IGBP restructuring process was also discussed. At the end of the day, it was recognised that WCRP needs a full understanding of requirements, capabilities and wishes of the community to progress the strategy. As a result, projects, including CLIVAR, are requested to generate a timetable, by which they can define our respective legacies, consider which functions need to be retained beyond 2013 and which science questions will need to be addressed in the future. The JSC were also asked to review the COPES document and propose three main functions or capabilities for the future WCRP and a structure with no more than five elements that would serve its functions.

Finally, during it's session, the JSC heard two scientific lectures. One was by Dr S. Planton, co-authored by M. Déqué, S. Somot, and H. Douville, was entitled "Regional climate modelling over Europe: some recent results on key uncertainties". It focussed on causes of uncertainties in the regional climate projections and the impact of coupling of atmosphere with the ocean at the regional scale. The other was by Dr. S. Bony entitled "Clouds in the climate system: New prospects for an old problem".

Reference

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