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Exchanges

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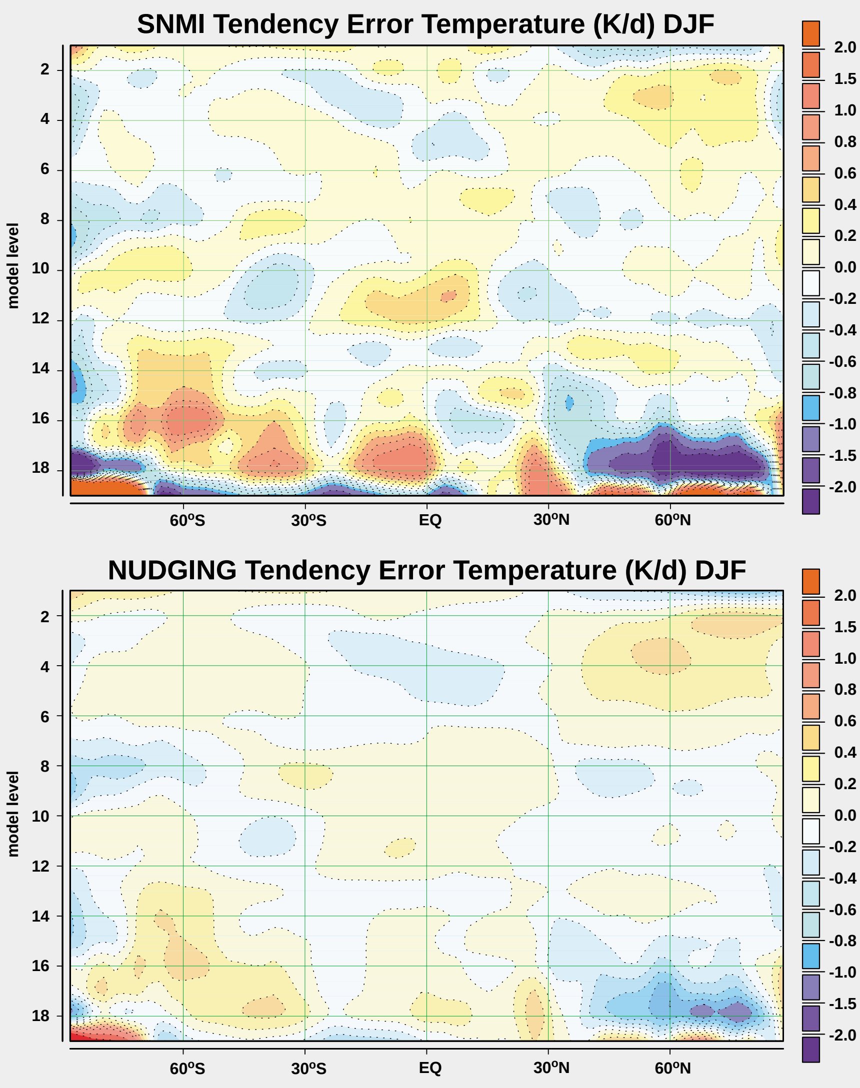
Exchanges No. 18

The challenge of climate research: linking observations and models
Part 2: Atmospheric and Paleoclimatic studies

Data assimilation techniques in atmospheric modelling



Zonal averaged winter season systematic initial tendency errors for temperature tendencies [K/s] based on eight years (1982-89) of ERA assimilations using the slow normal mode insertion (SNMI) technique (uper cross section) and using the simple nudging technique (lower cross section).

Figure 1 from the paper: Diagonsis of systematic initial tendency errors in an atmospheric AGCM using slow normal mode data assimilation of ECMWF reanalysis data.

The paper appears on page 9.

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Dear CLIVAR community,

The year 2000, that is now rapidly coming to its end, has been a very exciting year for CLIVAR, the ICPO and CLIVAR Exchanges.

CLIVAR is progressing and its implementation is getting more and more the main focus of the ICPO and the CLIVAR community. Throughout the year, we have seen progress on many parts of the programme. PAGES/CLIVAR has fostered its collaboration manifested in a very successful joint newsletter of PAGES and CLIVAR at the beginning of the year. This will be continued through the reconstituted PAGES/CLIVAR working group through a series of workshops starting in early summer next year with a CLIVAR/PAGES session on 'ENSO past and future' at the Global Change Open Science Conference in Amsterdam, jointly organised by IGBP and WCRP.

The next project that has shown considerable progress is CLIVAR Africa. Following up on the work of the initial CLIVAR Africa Study group an interim CLIVAR Africa Task Team was formed. These two groups paved the road for a successful CLIVAR Africa component by developing a Science and an Implementation Plan for CLIVAR research in the African region. These two important background documents are now the working basis for the new Variability of the African Climate System (VACS) panel that will meet for the first time in early 2001. In this context we should highlight the enormous effort that our ICPO staff member Fred Semazzi has put into the development of the CLIVAR Africa programme. His scientific expertise, engagement and last but not least his African roots were an invaluable help for this part of the project.

The other regional component of CLIVAR that has shown considerable progress throughout the Past year was CLIVAR VAMOS (Variability of the American Monsoon Systems). The project benefited very much from the positive spirit of the 6th Conference on Southern Meteorology and Oceanography that was held in Santiago in April. The VAMOS panel that met back to back to that conference defined a North American component of VAMOS, called NAME: the North American Monsoon Experiment as the counterpart of the Monsoon Experiment in South America (MESA). As a first pilot study a field experiment of the South American Low Level Jet will take place in about two years time. A special issue of CLIVAR Exchanges was dedicated to the VAMOS project, summarizing the planning efforts as well as the progress currently already being made on topics related to VAMOS. In fact the demand for this issue was so enormous that a reprint is being considered.

Other important news about VAMOS is the employment of a staff person in South America responsible for the oversight of the implementation of the VAMOS activities, especially in South America. Dr. Carlos Ereño from the University of Buenos Aires will aid in the implementation of CLIVAR research in South and Central America and help develop links between related research and applications efforts in the region, such as those supported through the IAI, IRI, World Bank, IADB, etc., and the wider CLIVAR programme. A short CV of Prof. Enero can be found on page 3.

The more ocean-related 'basin'-focused activities in the Atlantic, Pacific and Southern Oceans are in the process of developing their activities. For the Atlantic, a panel has been formed and their two meetings of this year have clearly shown substantial progress in developing research activities building on the successes of WOCE and TOGA but moving ahead to a more comprehensive understanding of the various modes of climate variability within the Atlantic area. In this context we would like to thank Allyn Clarke, who is stepping down as chairman of the panel for his efforts in setting up this group. Allyn will be replaced by Martin Visbeck from Lamont Doherty Earth Laboratory.

The Southern Ocean, known as a data sparse area, but of crucial importance for the understanding of the global ocean circulation and being the link between the polar regions and low latitude climates will hopefully explored in greater detail during the next decade. The CLIVAR Southern Ocean activity, that has recently been vitalised through a Workshop in Perth, Australia (see page 30) will try to contribute to fill the data gaps and the lack of understanding of climate processes and variability within that region.

In the Pacific sector, ENSO-related research has been traditionally strong since the start of TOGA. In recent years, successful ENSO predictions have shown considerable progress in our understanding of the ENSO mechanisms. Apart from that, modelling studies, observational and paleo data point us to interesting modes of decadal climate variability on different parts of the globe but in particular within the Pacific sector. Within two Principal Research Areas (PRA's) CLIVAR is addressing these scientific questions, ENSO and decadal variability in the Indo-Pacific regions. Now, CLIVAR is on its way to integrate these PRA's by forming another basin-type activity. An implementation workshop will be held in February 2001 in Hawaii.

Finally, the continuous work of the two modelling groups, Working Group on Seasonal-to-Interannual Predictions (WGSIP) and Working Group on Coupled Modelling (WGCM, with JSC) with their various intercomparison activities is an ongoing and vital tool to improve our understanding about model performance, detection and investigation of mechanisms of climate variability with the ultimate outreach to perform, successfully, reliable climate prediction for the future. Their activities have to be seen in the context of ongoing research on human impacts on climate that will be documented in the 3rd assessment report on climate change of IPCC that will be published next May. Although this is not a CLIVAR activity, the CLIVAR science community is heavily involved in preparation of this report and has established direct links through their Working Group on Climate Change Detection and WGCM.

Looking forward to 2001, we expect it be another very exciting year for climate research and for CLIVAR and we hope to see considerable steps forward in our understanding of the earth's climate system.

If we look at the ICPO, a number of changes will take place by the end of this year. After two years, our senior scientist Dr. Fred Semazzi will return to his faculty position at North Carolina State University. His enormous engagement for CLIVAR Africa has already been pointed out, but also through his very active participation in other part of CLIVAR, such as WGSIP, and of course through his friendly, open-minded cooperativeness he will leave a big gap in the ICPO.

Roberta Boscolo, who for many of you know as the WOCE newsletter editor, but who has also been taken care of the CLIVAR Atlantic activities, will leave Southampton for a new job in Vigo in northwest Spain. Nevetheless she will continue her ICPO work with the Atlantic Panel. This will be the same way in which Andreas Villwock has worked for the ICPO for the past 3 years while still remaining in Germany. At end of the year Andreas will relocate from Hamburg to Kiel continuing his CLIVAR work from the Institue fuer Meereskunde. We are also in the process of hiring new ICPO staff.

This issue of Exchanges is a continuation of the previous one under the overarching theme: "Challenges of climate research: Linking observations and models". The first one addressed the ocean part, is now followed by a more atmospheric view. We hope that you will enjoy it and we would like to express our satisfaction with successful calls for the different thematic issues we had since autumn 1999. We plan to continue the present format. A specific call for the next issue, that will address scientific issue related to decadal variability can be found on page 3.

Overall, we are looking back on a very busy but successful year for CLIVAR. We hope that you share our optimistic view on the progress of CLIVAR science in the past and for the future.

We wish you a Merry Christmas and smooth transition into the new millennium.

Andreas Villwock and John Gould.

We like to welcome Dr. Carlos Eñero, our new coordinator for the activities related to the VAMOS panel (Variability of the American Monsoon Systems). Dr. Eñero is Professor for Meteorology at the University of Buenos Aires. He received the Licenciado en Ciencias Meteorologicas from University of Buenos Aires in 1972 and completed the Master of Science in Meteorology, 1984 at the University of Wisconsin, Madison, USA. He was head of a number of meteorological departments and agencies, such as: Joint Antarctic Meteorological Office, Meteorological Office of the Argentine Navy and the Hydrographic Service of the Argentine Navy. His experience in teaching and education started in 1971 as Teaching Assistant of the Department of Meteorology at University of Buenos Aires and after a number of different affiliations with different departments with the University of Buenos Aires, he is Professor for Meteorology since 1990. In addition, Carlos Eñero is the Chair of the Executive Council of the Inter-American Institute for Global Change Research (IAI) and he has shown through his multiple membership and participation in international committees and organization his ability to coordinate international research efforts. In addition, he participated in several research activities and published about 30 papers.

Announcement
– Call for contributions –

Following up to the series of workshop of last autumn and winter we would like to present scientific highlights related to **"Decadal Variability and Predictability"** in the next issue of Exchanges that will apprear in March 2001. We would like to encourage scientists working in this field to submit short papers (max. 2 pages plus 1 figure) electronically by January 31st to:

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

The atmospheric energy budget and implications for surface fluxes

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Comprehensive diagnostic comparisons and evaluations have been carried out with the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) and European Centre for Medium Range Weather Forecasts (ECMWF) reanalyses of the vertically integrated atmospheric energy budgets. For 1979 to 1993 the focus is on the monthly means of the divergence of the atmospheric energy transports. For February 1985 to April 1989, when there are reliable top-of-the-atmosphere (TOA) radiation data from Earth Radiation Budget Experiment (ERBE), the implied monthly mean surface fluxes are derived and compared with those from the assimilating models and from the Comprehensive Ocean Atmosphere Data Set (COADS). Detailed methods are given in Trenberth (1997) and an earlier application to operational ECMWF analyses for one year is given in Trenberth and Solomon (1994).

Details of the processing and results are given in Trenberth et al. (2000). Full documentation of the many derived products is at **http://www.cgd.ucar.edu/cas/catalog/tn430/** from which it is possible to migrate to either the full listings of ECMWF or NCEP derived products, and all of these fields are available through ftp directories which are specified on the web pages for each dataset. The data can be downloaded either from the web browser or by standard anonymous ftp. The products are all global T42 single level vertically-integrated grids as individual monthly mean time series from 1979 through 1993, as well as monthly, seasonal and yearly averages (climatologies).

Comparisons of results show that while broadscale aspects of the surface flux climatological means are reproducible, especially the zonal means (not shown), differences are also readily apparent. Fig. 1 (page 5) presents the annualized net surface flux fields derived from the reanalyses atmospheric energy budgets for the oceans. Systematic differences are typically about 20 W m^{-2}. Land imbalances (not shown) indicate local errors in the divergence of the atmospheric energy transports for monthly means on scales of 500 km (T31) of 30 W m^{-2} in both reanalyses and about 50 W m^{-2} in areas of high topography and over Antarctica for NCEP/NCAR. Over the oceans in the extratropics, the monthly mean anomaly time series of the vertically integrated total energy divergence from the two reanalyses correspond reasonably well, with correlations exceeding 0.7. A common monthly mean climate signal of order 40 W m^{-2} is inferred along with local errors of 25 to 30 W m^{-2} in most extratropical regions. Except for large scales, there is no useful common signal in the tropics, and reproducibility is especially poor in regions of active convection and where stratocumulus prevails.

The climatological surface fluxes from the models used in the assimilations and COADS (da Silva et al. 1994) for the same period are given in Fig. 2 (page 6). The broad scale features of the atmospheric energy divergences and the surface fluxes are reproducible and credible. Net fluxes of energy into the ocean in the tropical eastern Pacific exceed 120 W m^{-2} in regions where the equatorial dry zone exists. The largest fluxes out of the ocean (> 150 W m^{-2}) are found off the east coasts of Asia and North America over the Kuroshio and Gulf Stream and patterns are quite similar. Large fluxes into the ocean in the tropical Indian Ocean and over parts of the southern ocean, North Pacific and tropical Atlantic are also reproducible. Consequently it is the details of the magnitudes and systematic biases that are of main concern. Although time series of monthly anomalies of surface bulk fluxes from the two models and COADS agree very well over the northern extratropical oceans, the total fields all contain large systematic biases which make them unsuitable for coupling to an ocean model. TOA biases in absorbed short-wave, outgoing long-wave and net radiation from both reanalysis models are substantial (>20 W m^{-2} in the tropics) and indicate that clouds are a primary source of problems in the model fluxes, both at the surface and the TOA. Time series of monthly COADS surface fluxes are found to be unreliable south of about 20^{o}N where there are fewer than 25 observations per 5^{o} square per month. Only the derived surface fluxes give reasonable implied meridional ocean heat transports.

[1] The National Center for Atmospheric Research is sponsored by the National Science Foundation.

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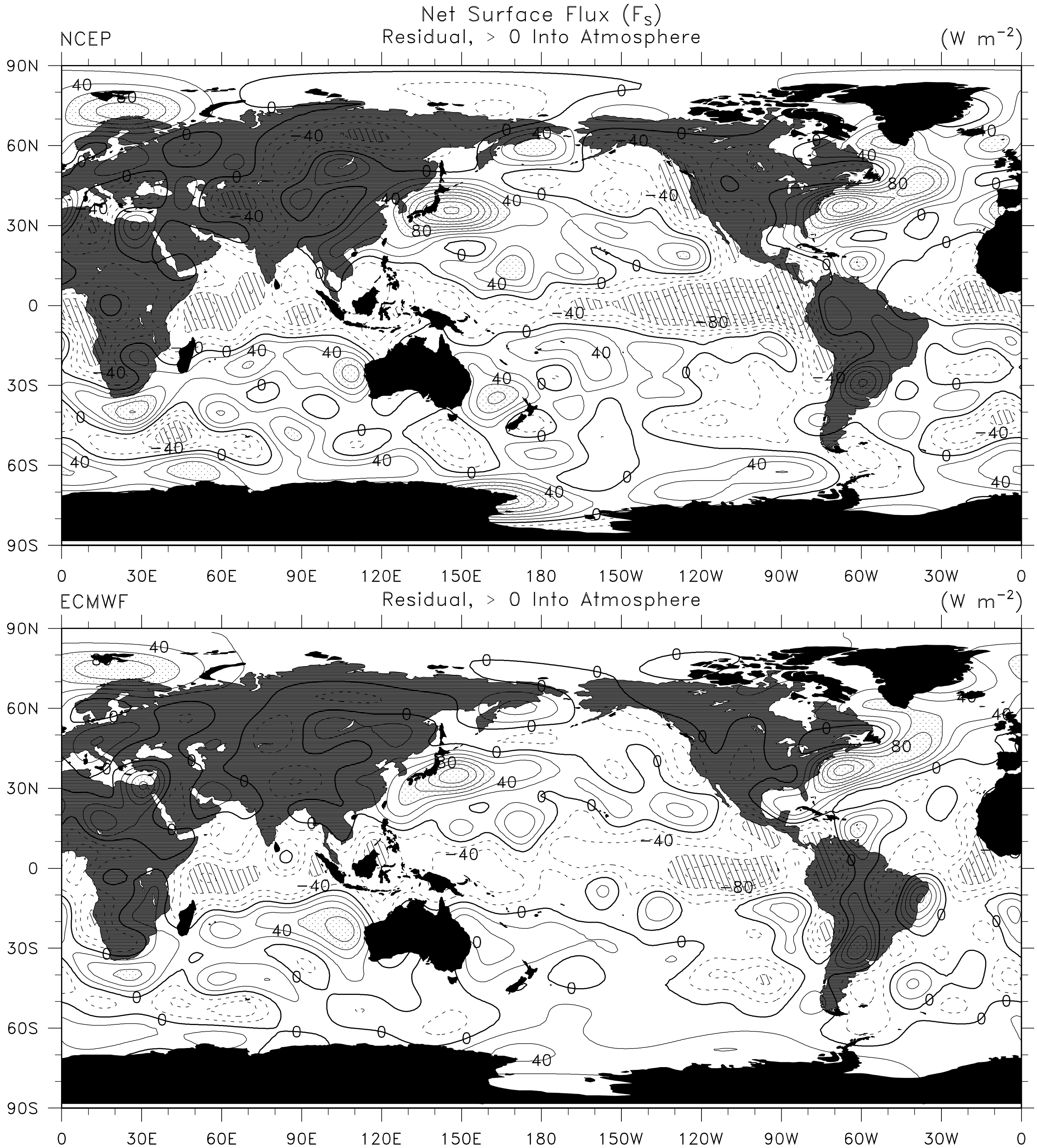

Above: Fig. 1: Net surface fluxes derived from the total atmospheric energy divergence and TOA radiation for February 1985 to April 1989 expressed as the annual mean in W m^{-2}. Positive values are upwards into the atmosphere. The contour interval is 20 W m^{-2} and values exceeding +60 W m^{-2} are stippled and values less than –60 W m^{-2} are hatched. Values are smoothed to T21 resolution.

Next page: Fig. 2: Annual mean surface fluxes based upon February 1985 to April 1989 from the models for NCEP (top), ECMWF (middle) and from COADS (bottom) in W m^{-2}. The contour interval is 20 W m^{-2} and values exceeding +60 W m^{-2} are stippled and values less than –60 W m^{-2} are hatched. Values are smoothed to T21 resolution.

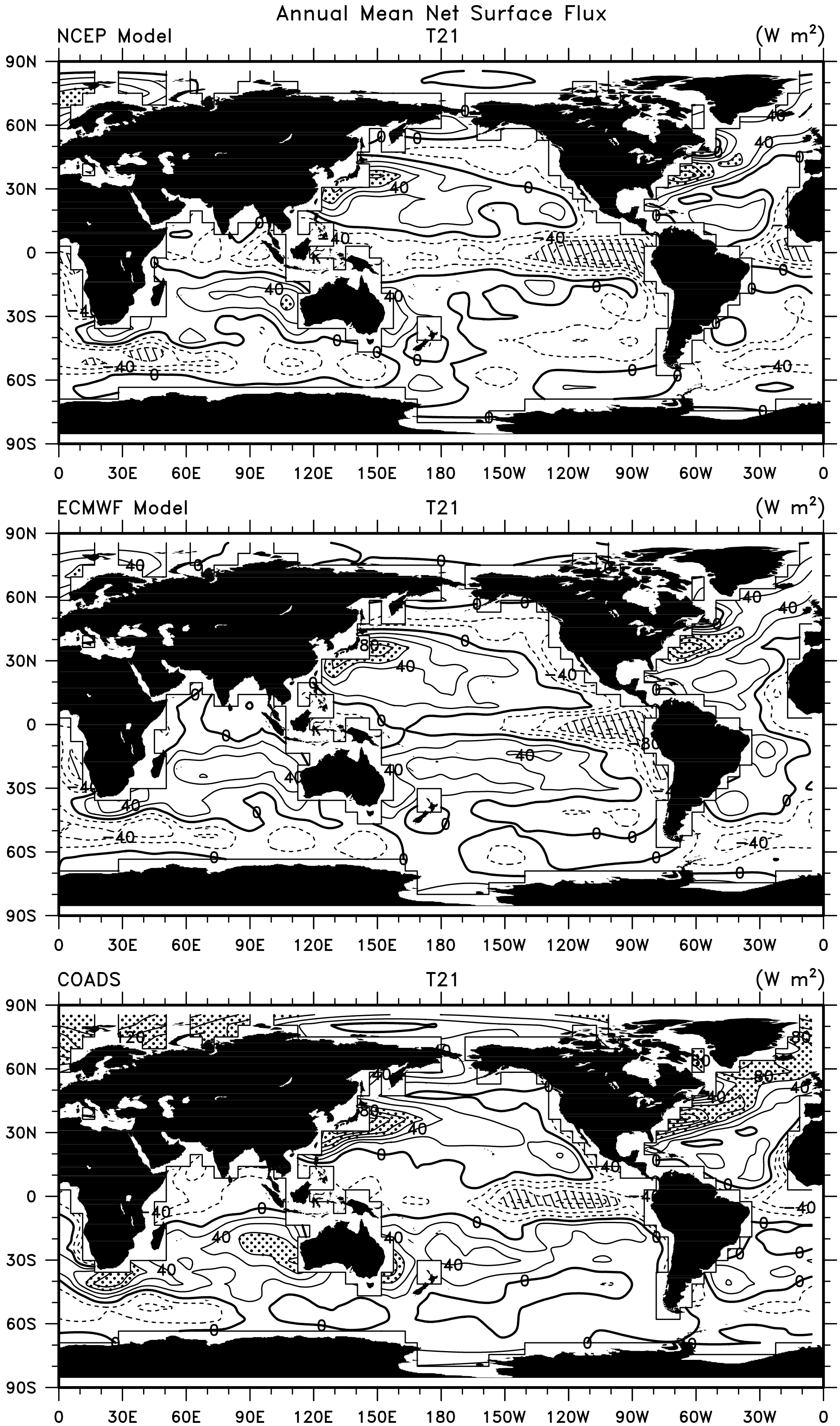

Fig 2.: caption see previous page

Tuning of a background constraint in a limited 3D-Var System

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In the past years, efforts were done to implement a 3D-VAR analysis system in the limited area model (LAM) Aladin, which is run operationally in many weather services with a horizontal resolution of about 10 km and coupling data provided by the global model Arpege. One particular feature of the LAM 3D-VAR is the use of a mesoscale Jb term, which acts as a band-pass filter in order not to reanalyze the large scales already analysed by the global model. Indeed, the refreshed large scale information is already provided by the coupling data (Sadiki *et al.*, 2000). The background error statistics are computed using the NMC method (National Meteorological Center, now NCEP), and here we investigate methods for reassessing the relative weight of the background and the observation cost functions. This problem is, in its simplest formulation, equivalent in tuning the ratio *r=Jo/Jb*.

For the calculation of the mesoscale statistics, the background error covariances are obtained from the differences between two forecasts of various durations, 36 hours and 12 hours, for the same validating time. The crucial point here is that both the 36h and the 12 h forecasts are run with the coupling data provided by the 36h sequence. It was noted that the effect of the Initialization by Digital Filters (DFI) and the integration of the model 24 hours later are enough to build the structure functions. We will call this method "lagged NMC". These statistics allow to reduce the energy in the large-scale spectrum, and to have more mesoscale representative analysis increments (as reported in Siroka, 2000). However, the "lagged NMC " method does not use the information of the analyses and the observations from the H+24 lead time. As a consequence, the information about the true level of the background error variances, compared to those of the observations, is missing.

The purpose of this study is to retrieve this information to control the analysis increments, by tuning the ratio *r=Jo/Jb*. Two diagnostics have been tried. An a posteriori calibration named "Jmin", used by Talagrand (1998) and Talagrand and Bouttier (1999), concerns the evaluation of the internal coherence of the background error statistics specified in entry of the assimilation system. According to this diagnostic, a variational system is called "coherent", if the statistical average of the cost function at its minimum is simply proportional to the number of observations "P". This result is valid as long as we assume to have a good estimation of the errors affecting the data to be assimilated. Consequently, a departure of the minimum from the theoretical value will indicate a bad specification of the error statistics.

We apply the diagnostic "Jmin" to the 3d-Var in Aladin, and study if we can use it to adjust the ratio "*r*" for the background error statistics from the "lagged NMC" method. The results show that the Aladin/Arpege system is rather "not coherent", in the sense of the error statistics: the values of the ratio E(Jmin)/P for both models (0.77 for Arpege and 0.72 for Aladin, on average over a month) are relatively strong and so different from the theoretical value "0.5" given by Talagrand. We tested the results for two different first guess data as input in the LAM 3D-VAR: the 6h Aladin forecast and the interpolated Arpege analysis. It is worth to notice that the use of the Arpege analysis as first guess (which is already relatively correlated to the observations) produces a ratio E(Jmin/P) that's worth 0.6 on average, thus closer to the theoretical value. In other words, the innovation vectors produced with the 6h Aladin forecast have larger error variances than those specified in the Jb matrice, while the innovation vectors obtained from the Arpege analysis are smaller and produce smaller Jo and Jmin values (Figure 1a).

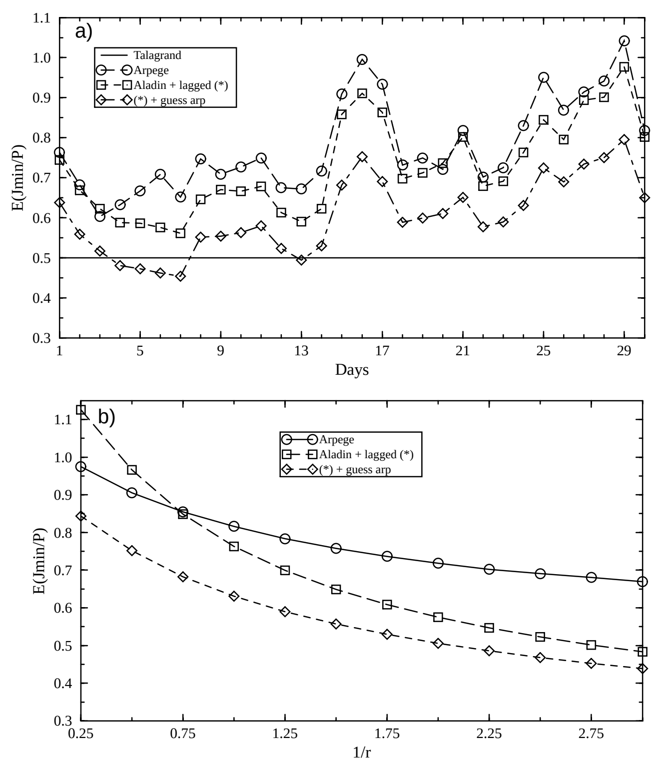

Fig. 1: Variation of the ration E(Jmin/P). a) during two weeks in March and May 2000 ("r"=1 for Aladin, "r"=0.9 for Arpege, b) as a function of 1/"r" for 08.05.2000 at 00 UTC.

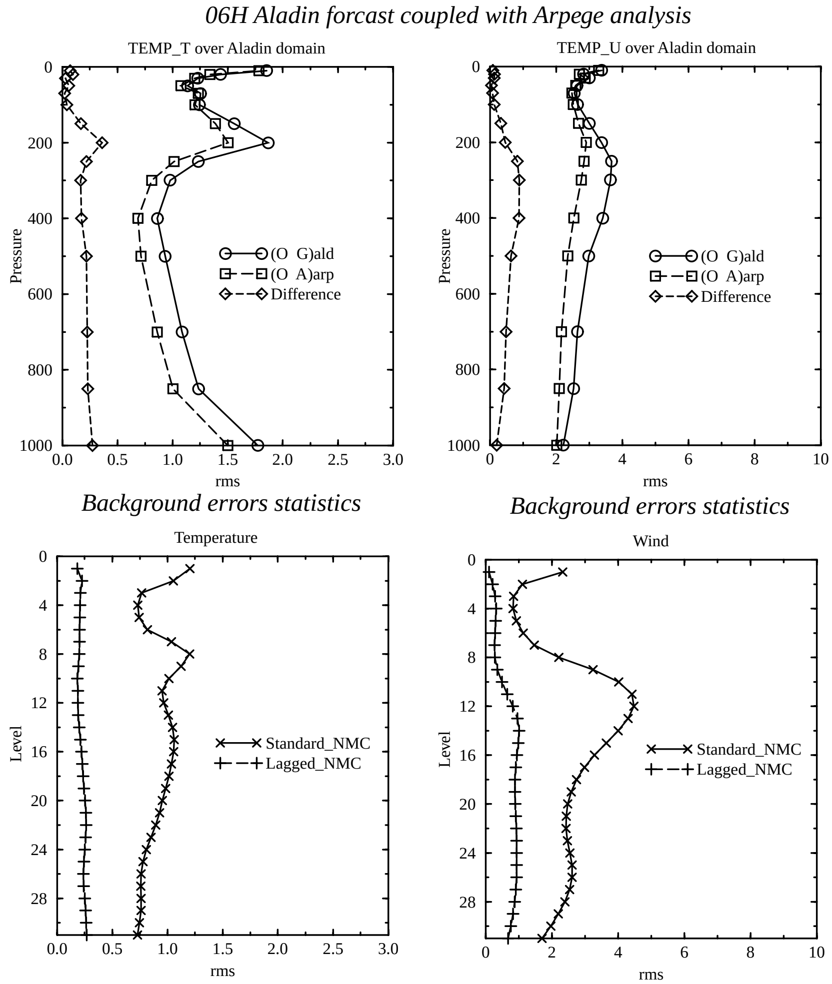

Fig. 2: Vertical Profiles of rms error for temperature (K) and wind (m/s). a) associated to the radiosonde observations, b) computed using the NMC mehtod (standard / lagged) as a function of model levels (31 levels).

Concerning the tuning of the ratio "*r*", we notice that the "Jmin" is sensitive to the changes in "1/*r*": the values of E(Jmin)/P according to "1/*r*"vary in Aladin, from 1.12 for "1/*r=0.25*" to 0.48 for "1/*r=3*". However, the two curves representing the variation of the ratio E(Jmin)/P in Aladin and in Arpege, with respect to "1/*r*", cross each other for the value "*1/r=0.75*". The corresponding E(Jmin)/P is worth 0.85 and thus quite bigger than the theoretical value (Figure 1b).

In the second method, scores with respect to the radiosonde observations are computed. They give an objective measure of the quality of the analysis. It consists in generating distances of background errors between radiosonde observations located in the Aladin domain, and forecast fields at 06 hour range. The extra difficulty, when compared to the usual computation of forecast scores, is to keep only the Aladin contributions in the small and medium scales. For this purpose, the LAM forecasts used for the score calculation are coupled with the global model analysis, so that a posteriori forecasts are performed by integrating the best available large-scale fields. Thus, we assume that the Aladin background errors over 6 hours, forced by the Arpege analysis, are constituted of two terms: the Arpege analysis error (O - A) and the Aladin background error (O - G). By subtracting the Arpege analysis RMS (Root Mean Square) error from the a posteriori forecast RMS error, we can estimate the Aladin error contribution and use it to calibrate the variances in the "lagged NMC" statistics. As a result, this method seems to indicate that the parameter "*r*" that we try to calibrate in Aladin must be close to 1 (Figure 2).

In conclusion, the so-called "Jmin" diagnostic is a fast and effective tool to test various data types to be specified in entry of a 3d-Var system, whatever data are considered (forecast, analysis or any type of blend of the latter two). For the tuning of "*r*", according to this diagnostic the value of "*1/r*" must be around 3, so that the ratio E(Jmin)/P has the theoretical value fixed by Talagrand. However, such a value for "*1/r*" seems exaggerated in view of the other performed diagnostics. Furthermore, we saw that Arpege 3d-Var is not well adjusted either, under the conditions which we have defined. One possibility is to abandon the theoretical reference and to consider the average as reference observed in Arpege, consequently the value of "*1/r*" will be 0.75 agreeing more with the result obtained by the second diagnostic. In perspective, we propose to evaluate the previous results by testing other diagnostics like Generalized Cross Validation.

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Diagnosis of systematic initial tendency errors in the ECHAM AGCM using slow normal mode data assimilation of ECMWF reanalysis data

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Abstract

With the purpose of improving the performance of a state-of-the-art atmospheric global climate model (AGCM) a new technique to determine systematic initial tendency errors (SITEs) has been developed (Machenhauer and Kirchner, 2000). The AGCM in question is the latest versions of the ECHAM model (Roeckner et al., 1996a). When run in long simulations under present-day conditions typical systematic errors in the general circulation of the model atmosphere develops (Roeckner et al., 1996b, Fig. 3). It has been shown that these systematic errors cause significant errors in the simulated regional climate, precipitation and near surface temperatures, over Europe at least, both in course resolution ECHAM simulations and in simulations with a nested high resolution limited area model, HIRHAM. Similar large-scale errors which, however, differ on the regional scales are found in other state-of-the-art GCM/nested LAM systems (Machenhauer et al., 1996, 1998, Christensen et al., 1999). The presence of such errors leads to reduced confidence in the estimates of regional climate changes due to prescribed forcing scenarios (e.g. increasing greenhouse gas concentrations) which are being made with these climate models (Machenhauer et al., 1998, 2000). In order to obtain more reliable estimates of the regional climate changes, which may be expected from possible forcing scenarios, it is therefore necessary that the systematic model errors be substantially reduced. This has been our motivation for the development of an improved error detection technique to be introduced in the following.

The systematic errors in the fields of prognostic variables (e.g. temperature) which we want to eliminate must be caused by a misrepresentation of certain physical processes in the model. We want to isolate (and if possible correct) the dominant processes being misrepresented. Analysis of the systematic errors of the prognostic variables themselves are generally not helpful in this regard, because they show an integrated response to remote as well as local model errors. In themselves, such an analysis usually just tells us that something is wrong, not what and where. On the other hand systematic initial tendency errors (SITEs) are strictly local and therefore they can more easily be related to errors in specific physical processes (Klinker and Sardeshmukh, 1992). We have developed a new method designed specifically for estimates of SITEs in coarse mesh atmospheric climate models (AGCMs). In this method interpolated and truncated reanalysis data are assimilated in the AGCM using a relaxation (nudging) technique. In order to avoid as far as possible compensating balancing of the erroneous forcing which we want to detect we assimilate fully (insert) that part of the reanalysis data which project on the Slow Normal Modes (SNMs) of the AGCM (frequencies below a cut-off frequency equal to (2 pi)/(24 hours)). We call this assimilation: slow normal mode insertion (SNMI). The reanalysis data are available only every sixth hour at which times the SNMs are inserted fully (relaxation weight = 1) in the AGCM. Between these times the SNMs of the model are relaxed toward the time interpolated SNMs of the reanalysis data with a weight decreasing to zero midway between the reanalysis times. Thus, the model is used to interpolate the SNMs between the times when the reanalysis is available. The fast modes of the assimilating model develop freely and so do the soil variables and all prognostic variables of the hydrological cycle. Thereby, imbalances (due to the interpolation and truncation of the data) which project on the fast modes do not result in large spurious tendency errors. The assimilating model does not see them. As in a free run fast modes are forced by nonlinear interactions and parameterized physical processes and are being balanced dynamically. In this balance the field of vertical velocity will be consistent with the hydrological fields and a reason for the spin-up problem in the ERA analyses is eliminated. The SNMI method is tested on the ECHAM model and is compared with a method using a more simple nudging assimilation technique, which is not separating slow and fast modes. The superiority of the SNMI method has been demonstrated by validations of results from identical twin experiments as well as from long ECMWF reanalysis (ERA) data assimilation experiments. Here we shall present just one example of systematic initial tendency errors (SITEs), detected in a long SNMI ERA data assimilation run. The SITEs considered seems to be caused by certain model defects. We suggest changes in the parameterization, which are expected to reduce the corresponding systematic mean error.

In the attached figures are presented SITE estimates for the winter season (DJF) based on eight years of ERA assimilation (1982-89). Figure 1 (page 1) shows zonal averaged temperature tendency errors (TTEs) using the SNMI technique (upper cross section) and the simple nudging technique (lower cross section). Note that, due to less compensating balancing, generally the SNMI estimates are much stronger than the nudging estimates, and therefore more reliable. We concentrate on the cooling error seen at low levels and northern latitudes. In Figure 2 (page 16) the maps in the left column show TTEs at the lowest model levels. At the lowest one (level 19) the maximum excessive cooling is over the Greenland and Barents Seas. As seen in the map above the too strong cooling is spreading out to neighbouring longitudes in level 18. The excessive cooling will tend to create a thermal high pressure bias, a tendency which in fact is seen in the lower right map showing surface pressure SITEs. Taking into account a dominating eastward advection in long free ECHAM simulation this is consistent with the position over Kara Sea of a center of systematically too high pressure (see upper right map). We believe that a too large sea ice coverage and too thick sea ice in the model, in particular in the Greenland and Barents Seas, cause too little heating from the underlying ocean. Among the different processes influencing the temperature vertical diffusion is found to correlate the best (negatively) with the TTEs at the lowest levels, a fact which further supports this theory. To test this interpretation we have started an AMIP run in which more realistic thinner sea ice with less coverage is prescribed. From the evidence shown here it must be expected that this will eliminate or reduce the systematically too high pressure north of Europe and thus increase ECHAM's potential for regional climate simulations, at least over Europe and parts of the Arctic.

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Superensemble forecasts for weather and climate

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In 1999, we published a paper in Science entitled 'Improved Weather and Seasonal Climate Forecasts from Multimodel Superensemble'. That paper outlined a new procedure for weather and seasonal climate forecasts. This procedure partitions a time line into two parts. The part (prior to the initial state) comprises a training period when past forecasts from multimodels are regressed against a benchmark analysis field to obtain a library of bias errors for the multimodels. They are separately determined at all geographical locations (grid points), all vertical levels, all variables, and all multimodels. Given some 107 such statistical coefficients it is possible to perform very detailed bias corrections for the future forecasts for global weather (up to roughly a week) and for the seasonal climate. In two recent papers submitted to the Journal of Climate, we show several important results from the application of this procedure for weather and climate.

The training period for global weather comprises roughly of 120 forecast experiments for each of the multimodels. For seasonal climate, roughly 8 years of past climate forecasts by the multimodels are included. For hurricane forecasts some 60 past storms in each ocean basin were found to be minimally needed.

Roughly 7 to 8 multimodel forecasts were minimally needed to produce very effective superensemble forecasts. The effectiveness of weather and seasonal climate forecasts are assessed from measures of standard skill scores such as correlation against observed fields, root mean square errors, anomaly correlations and the so-called Briar skill scores for climate forecasts (assessing skills above those of climatology). The horizontal resolution of the superensemble is around 125 km (a common denominator of the multimodel resolutions).

Overall, the following types of results stand out in these computations:

- These superensemble forecasts have the highest skill compared to all multimodels as well as the straightforward ensemble mean. The ensemble mean assigns a weight of 1.0 to all models everywhere (and for all variables). That generally includes several poor models, assigning a weight of 1.0 to those poorer models uniformly degrading the skill of the ensemble mean.
- It is possible to remove the bias of models individually (again at all locations for all variables) and to perform

the ensemble mean of these bias removed models. That too performs poorly compared to the superensemble, which carries selective weights distributed in space, models, and variables. Removal of bias of a poorer model does not qualify it to have a uniform weight of 1.0 everywhere. A poorer model does not reach the level of the best model (to qualify for an equal weight) after its bias removal.

- The results of these applications have indeed provided detailed global superensemble forecasts for weather and seasonal weather that are generally much superior compared to the participating member models.
- Training is a major component of this forecast initiative. We have compared training with the best quality 'observed' past data sets versus training deliberately with poorer data sets. This has clearly shown that 'future' forecasts are much improved when higher quality training data sets are deployed for the evaluation of the multimodel bias statistics.
- In medium range real time global weather forecasts, the highest skills are seen for precipitation forecasts both regionally and globally. The overall skill of the superensemble is 40% to 120% higher than the precipitation forecast skills of the best global operational model. The rms errors was the skill parameter used here. The training database for precipitation came from the daily TESDIS operational files of TRMM microwave radiometer based rainfall estimates. These are augmented from the use of the US Air Force polar orbiting DMSP satellites that provided SSM/I data from a number of current satellites (F11, F13, F14, and F15). The greatest application of these precipitation forecasts were in the forecast guidance of heavy rains during recent episodes of floods over Mozambique.
- In real time global weather forecasts the superensemble has the highest skill compared to all participating member (operational) models for all variables. The striking improvements in skill are seen for the divergent part of the wind and the temperature distributions. Tropical latitudes show large improvements for the superensemble for daily weather forecasts. For almost all variables, we use the operational ECMWF analysis at 0.5° latitude/ longitude for the training phase.
- Real time hurricane forecasts are another major component of superensemble modelling at Florida State University. This approach of training followed by real time forecasts produces the best forecasts for tracks and intensity (up to 5 days) from the superensemble. Improvements in track forecasts are 25% to 35% better than all of the current operational forecast models; this has been noted over the Atlantic Ocean basin. The intensity forecasts for hurricanes are only marginally better than the best models. The recent real-time tests during 1999 showed marked skills in the forecasts of difficult storms such as Floyd and Lennie where the performance of the superensemble was considerably better than the best operational model forecasts.
- The area of seasonal climate forecasts has only been addressed thus far in the context of atmospheric climate models where the sea surface temperatures and sea ice were prescribed. In this context, given a training period of some 8 years and a training data base from the ECMWF the results were as impressive as those from the global NWP. Those were seasonal and multiseasonal forecasts of monthly mean precipitation, temperatures, winds, and sea level pressure distribution. The forecasts for the superensemble have higher skills compared to the member models, ensemble mean, bias removed ensemble mean and climatology. Further extension of this work is currently being pursued in the area of improved multimodel 'superensemble' based analysis and coupled climate models for seasonal forecasts.
- Some typical results of NWP forecasts for a multimodel superensemble are presented in Table 1(page 12) and Fig. 1 (page 17). The table shows the equitable threat scores on rainfall forecast skill for day 3 of forecast for August 2000. These show that the superensemble has higher rainfall skill compared to all 8 members models shown here. That skill is also much higher than that of the ensemble mean for several different regions of the globe. Also shown are the recent skill of the high resolution U. S. operational ETA model. It is apparent that the superensemble at the resolution T126 outperforms all rainfall forecasts by a reasonably big margin. These results can be seen at real time our web site:

http://estero.met.fsu.edu:5080/rtnwp

Fig. 1 (page 17) shows a Hovmöller diagram of a sequence of day 3 forecast rain from the best member model and the superensemble and are compared to the observed estimates of rain. These relate to floods over Mozambique in February 2000. That arose from two intense rainfall episodes. The superensemble captures the observed rainfall pattern extremely well compared to the best model.

Fig. 2 (page 17) illustrates an application of the superensemble forecasts for seasonal climate. Here the results of rms errors of monthly mean wind at 850 mb are shown. The errors of the multimodel are compared with the ensemble mean of bias removed individual models and with the superensemble. We note here that the errors of the superensemble are the least among these. Removing the bias of an individual model and assigning a weight of 1.0 to it does not make it equal to the best model hence bias removed ensemble mean does not work quite as well as the superensemble.

Fig. 3 (page 17) shows the typical seasonal track errors of all of the hurricanes of 1998 and 1999 over the Atlantic Ocean. Here again the smallest track errors are from the superensemble.

Table 1: Precipitation Equitable Threat Scores for August 2000

Pr mm	Member Models 1	2	3	4	5	6	7	8	Ens Mean	Super Ensemble	ETA Model
	Global (50°S - 50°N)										
0.2	0.313	0.295	0.343	0.302	0.296	0.268	0.276	0.273	0.386	0.568	
10	0.237	0.157	0.195	0.132	0.190	0.152	0.174	0.157	0.219	0.312	
25	0.215	0.117	0.153	0.089	0.165	0.114	0.136	0.119	0.148	0.257	
50	0.171	0.088	0.112	0.064	0.145	0.081	0.092	0.080	0.112	0.198	
75	0.073	0.057	0.012	0.000	0.037	0.044	0.055	0.044	0.011	0.272	
	North America (120°W-65°W, 20°N-50°N)										
0.2	0.202	0.256	0.200	0.171	0.180	0.222	0.232	0.215	0.305	0.641	0.308/1999
10	0.088	0.062	0.020	0.021	0.014	0.072	0.092	0.076	0.066	0.458	0.288/1995
25	0.054	0.045	0.000	0.012	0.000	0.038	0.066	0.049	0.006	0.425	0.221/1995
50	0.033	0.005	0.000	0.012	0.000	0.021	0.036	0.028	0.008	0.142	0.199/1995
75	0.013	0.000	0.000	0.012	0.000	0.000	0.020	0.014	0.000	0.039	0.131/1991
	South America (110°W-10°W, 50°S-15°N)										
0.2	0.340	0.261	0.309	0.325	0.266	0.240	0.248	0.247	0.369	0.594	
10	0.298	0.160	0.222	0.130	0.189	0.161	0.171	0.153	0.243	0.333	
25	0.251	0.118	0.153	0.083	0.148	0.119	0.135	0.114	0.133	0.276	
50	0.166	0.079	0.071	0.040	0.102	0.080	0.087	0.071	0.053	0.216	
75	0.115	0.052	0.026	0.012	0.057	0.048	0.053	0.041	0.018	0.151	
	Asia (50°E-120°E, 15°S-45°N)										
0.2	0.390	0.474	0.543	0.426	0.458	0.428	0.459	0.440	0.589	0.636	
10	0.306	0.172	0.270	0.197	0.236	0.165	0.200	0.177	0.246	0.352	
25	0.267	0.131	0.211	0.132	0.170	0.122	0.155	0.133	0.175	0.279	
50	0.198	0.092	0.160	0.045	0.122	0.088	0.112	0.072	0.132	0.198	
75	0.153	0.077	0.117	0.020	0.060	0.075	0.090	0.055	0.041	0.172	
	Africa (20°W-55°E, 35°S-40°N)										
0.2	0.411	0.462	0.457	0.416	0.396	0.431	0.447	0.439	0.569	0.692	
10	0.249	0.246	0.189	0.143	0.167	0.261	0.295	0.274	0.248	0.357	
25	0.217	0.167	0.137	0.105	0.131	0.190	0.216	0.204	0.151	0.286	
50	0.141	0.096	0.064	0.052	0.055	0.111	0.101	0.109	0.087	0.185	
75	0.097	0.065	0.052	0.017	0.036	0.085	0.075	0.078	0.025	0.145	
	Australia (110°E-160°E,40°S-0)										
0.2	0.363	0.341	0.368	0.380	0.340	0.292	0.324	0.322	0.364	0.425	
10	0.271	0.191	0.264	0.192	0.242	0.197	0.199	0.185	0.273	0.332	
25	0.218	0.146	0.219	0.114	0.194	0.156	0.165	0.141	0.193	0.285	
50	0.145	0.119	0.130	0.049	0.140	0.111	0.121	0.102	0.130	0.185	
75	0.094	0.116	0.085	0.029	0.111	0.088	0.089	0.076	0.073	0.155	

* "Pr mm" denotes precipitation class intervals for rainfall rates greater than the indicated amount in column 1.

The threat score for the respective member models over the indicated domain are displayed for the entire month of August 2000. The ETA models threat scores for August of several years (with the highest scores) are shown in the last column for the North American region. The 98 days training period ends with 1 August 2000.

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Project to Intercompare Regional Climate Simulations (PIRCS): Advancing the CLIVAR Agenda

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The CLIVAR Initial Implementation Plan recognizes the need to understand local and regional realization of global climate variability. During CLIVAR's life-span, global models will continue to improve but likely will not reach resolution sufficient to simulate regional (country-scale) behaviour accurately. For this reason, the Initial Implementation Plan promotes "evaluation of regional models driven by reanalysis data to determine the accuracy of the regional response when driven by perfect boundary conditions." The Project to Intercompare Regional Climate Simulations (PIRCS) is engaged in such evaluation through its mission to evaluate strengths and weaknesses of regional climate models and their component procedures by systematic, comparative simulations.

PIRCS has been a largely volunteer, community effort organized and implemented through a series of developmental meetings (Takle, 1994; Gutowski et al., 1998). The first PIRCS simulations are designed to complement the GEWEX Continental International Project (GCIP), and thus cover two hydrologic extremes in the central United States: 15 May – 14 July 1988 (drought, Exp. 1a) and 1 June – 31 July 1993 (flood, Exp. 1b). These simulations are relatively short for climate (2 months), a limitation imposed by computing resources available for a volunteer effort at the time the project began. Participating models simulate a domain covering the continental United States at approximately 0.5 degree resolution. Further details appear at the PIRCS web site, http://www.pircs.iastate.edu, and in Takle et al. (1999), which also gives initial results for the 1988 case.

A CLIVAR concern is modelling regional effects of global teleconnections. For PIRCS, this prompts two questions:

(1) How well do models ingest large-scale boundary conditions?

(2) How well do models develop regional climate in response to the boundary conditions?

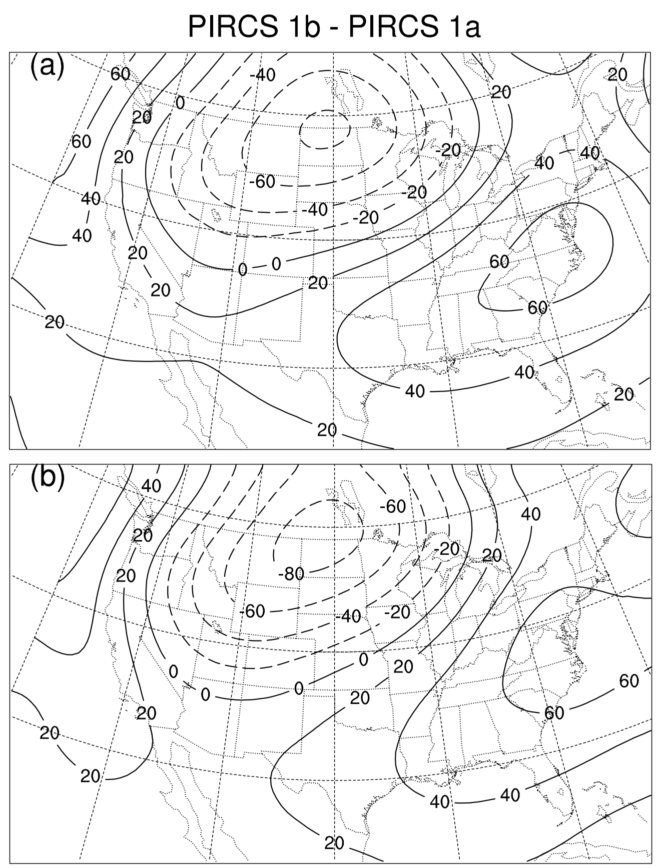

Fig. 1: 500 hPa geopotential difference, PIRCS 1b - PIRCS 1a, from (a) the NCEP/NCAR reanalysis and (b) ensemble average of PIRCS simulations. Contour interval: 20m.

The summers of 1988 and 1993 had very different large-scale environments (Trenberth and Guillemot, 1996). Anomalies of 300 hPa height over North America for the period May-June-July tended to be opposite in sign between the two years. Strong ridging occurred in the central U.S. in the summer of 1988, with coincident weak moisture flow from the Gulf of Mexico, a prime moisture source for the region. These features contributed to the dry conditions of the period. The summer of 1993 was marked by persistent stationary fronts in the central U.S. along which mesoscale convective systems propagated and strong atmospheric moisture flow from the Gulf of Mexico, features that helped produce widespread flooding.

Figure 1 (page 13) shows the change in 500 hPa height between the 1988 and 1993 periods given by the NCEP/NCAR reanalysis (Kalnay et al., 1996) and the ensemble average of seven models that have simulated both cases. The models simulate well the change in large-scale teleconnection patterns linking the region to remote sources of large-scale circulation driving. The ensemble average shown here is representative of the behaviour of individual models. In addition, for most models, daily root-mean-square differences between reanalysis and simulated 500 hPa heights across the U.S. tend to be about 10 – 20 m, i.e., about the accuracy of 500 hPa height estimates.

Although the models ingest teleconnection patterns well, they have difficulty simulating some of the regional outcomes of the patterns, such as precipitation extremes. Fig. 2 (page 15) shows ensemble average bias of simulated precipitation versus observed precipitation for the months of June 1988 and July 1993, using half-degree, gridded observed monthly precipitation from the VEMAP project (Kittel et al., 1997). As with 500 hPa heights, the ensemble average is representative of the behaviour of individual models. The models do show relatively large changes in precipitation between 1988 and 1993, but they are producing too much rain in the central U.S. during the drought and too little rain during the flood. The 1993 bias pattern also shows that models tend to shift the location of maximum precipitation to the northeast (essentially downstream) relative to the observed maximum. However, even accounting for this shift, there is still a shortfall of simulated precipitation versus the VEMAP data set.

The models thus can ingest large-scale teleconnection patterns faithfully for these cases and can produce local (but muted) responses in an important field, precipitation. Results indicate a need to explore further and improve the coupling of precipitation to large-scale circulation patterns (at both high and low extremes). Resolving this issue is important not only for regional model "downscaling", but also because global models may face the same problem when they eventually start running at the scale of contemporary regional models. The results also demonstrate the value of side-by-side model comparison in a common framework.

Model output from the 1988 simulations is now available to the general community. The PIRCS web site (http://www.pircs.iastate.edu) gives the data release policy. Requests for output and further information should be directed to pircs@iastate.edu.

Acknowledgements

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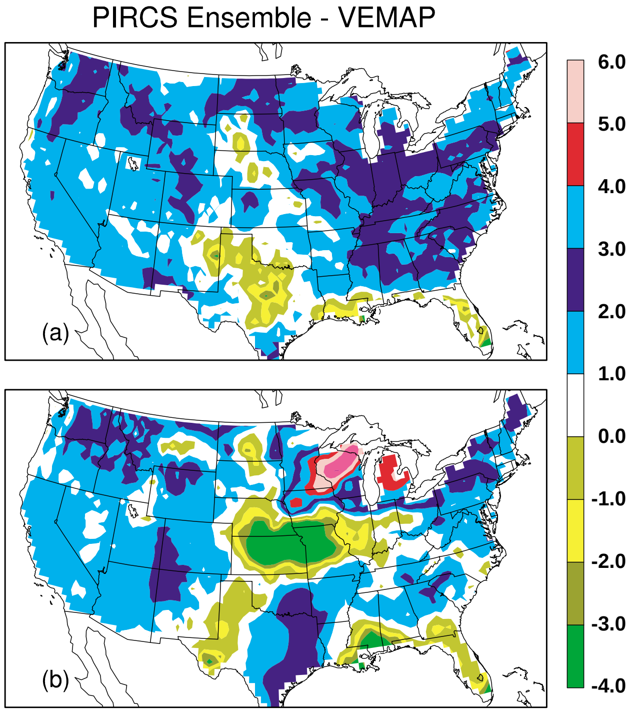

Fig. 2: PIRCS ensemble average minus VEMAP observed precipitation for (a) June 1988 and (b) July 1993. Contour interval: 1mm d^{-1}.

CLIVAR Working Group on Seasonal-to-Interannual Prediction (WGSIP) - 5th Session Buenos Aires, Argentina, 1-3 November 2000

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The fifth session of the CLIVAR Working Group on Seasonal-to-Interannual Prediction (WGSIP; previously known as CLIVAR NEG-1) was held in Buenos Aires, Argentina, 1 to 3 November 2000. Dr. Guillermo Berri from the University of Buenos Aires was the local host for the meeting. Dr. Steve Zebiak (Chairman of the WGSIP Panel) presided over the meeting.

During the three-day meeting there was extensive review of WGSIP research projects, discussions of plans for new initiatives, and other related international research activities. The CLIVAR Intercomparison of Niño-3 prediction and predictability project was recently completed. The purpose of this initiative was to assess skill of current "state-of-the-art" ENSO prediction systems that are used to make regular forecasts. The assessment is based on ensembles of forecasts initialized one month apart.

Key results are: (i) all the models produce skillfull forecasts of Niño-3 6 months in advance (ii) a simple consensus forecast (i.e. average of all the models) was the most skillful and (iii) much longer periods of retrospective forecasting are required in order to distinguish among the models. The final report is available at http://www.clivar.org/publications/wg_reports/wgsip/nino3/report.htm. A related study on the variability of the tropical oceans on seasonal and interannual time scales other than ENSO (STOIC) was also recently completed. Given the diversity in the contributing models, one of the significant outcome is the degree of commonality in many of the biases that have been detected. This suggests that there are some real improvements to be gained if we can understand the underlying causes. The shortfall in wind stress variability is one of the main features that needs correction. The final report has been published in the last issue of Exchanges (Sep 2000). The Seasonal Prediction Model Intercomparison Project (SMIP) which which begun in 1986 and involved 8 models was completed recently. SMIP was based on 4-month ensemble forecasts. The study involving data from seven models, focussed on the winters of 1982-83, 1986-87, 1987-88 and 1992-93, and the summers of 1987, 1988, 1993 and 1994. A key result is that skill and reliability differ largely among individual models. Skill of the multi-model ensemble is nearly the same as that of the best available model, except for the case when some members show very poor skill. It was found that the prediction skill of precipitation is low except for the region directly affected by ENSO.

WGSIP is in the process of launching several new major projects. One of these initiatives will focus on the development of a standard set of diagnostics and guidelines for facilitating model intercomparison and improvement, and for evaluating model performance in the context of regional forecast user requirements and CLIVAR science issues. Future model intercomparisons (MIPs) will be designed with emphasis on promoting and encouraging model improvement, and development of the interface with applications communities. A new project SMIP-2 has been approved by the Panel. SMIP-2 is an extension of the original SMIP that was done only for 4 selected summer and 4 winter cases. SMIP-2 will involve 15 cases (years) and will include a hindcast component based on persisted SST anomalies. As a follow-on activity for the Niño-3 forecast comparision project, WGSIP is experimenting with a prototype of real-time Niño-3 intercomparison study. Under this project the Panel will undertake collection (verification) and publication of ENSO forecasts statistics in quasi-real time. Routine intercomparisons will be published in the Experimental Long Lead Bulletin. On the issue of regional downscaling, WGSIP will draft a set of recommendations highlighting the relevant issues from the standpoint of seasonal forecasting, and will forward to the WGCM/WGNE ad hoc panel on regional modeling. A future project is being developed in the area of forecast product development, based on super-ensembles of model predictions (see article on page 10).

Regular section continues on page 19

Machenhauer and Kirchner, Diagonsis of systematic initial tendency errors in the ECHAM AGCM using slow normal mode data assimilation of ECMWF reanalysis data, page 9:

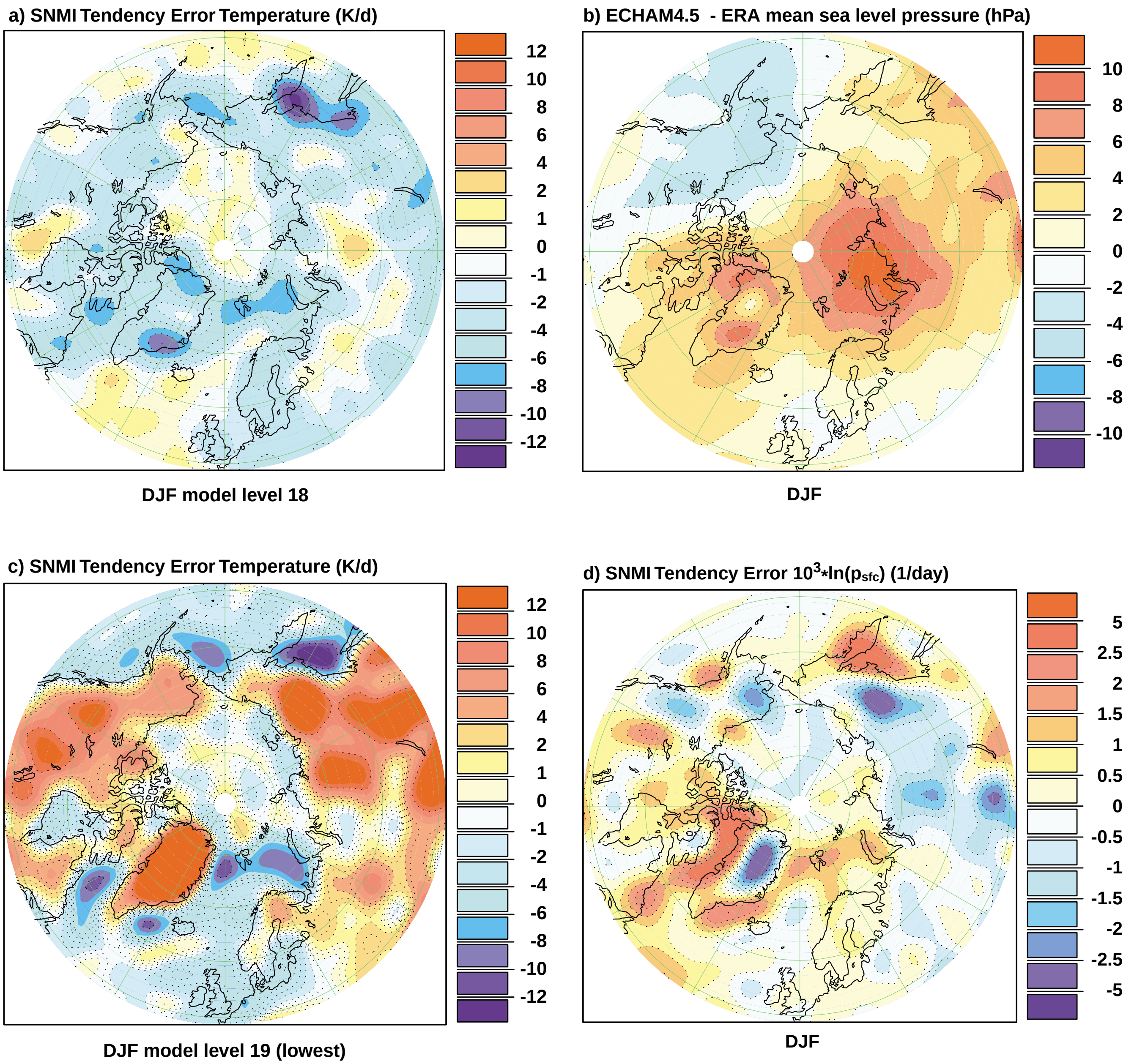


Fig. 2: Winter season SITEs and systematic error of mean sea level pressure

1. *Winter season SITEs based on eight years (1982-89) of ERA assimilations using the SNMI technique. Left column for temperature tendencies [K/s] at model level 18 (a) and level 19 (c). (d) for 1000*ln(p_{sfc}) tendencies [1/day] (~ surface pressure (p_{sfc}) tendencies [hPa/day]).*
2. *Winter season systematic errors of mean sea level pressure (MSLP) [hPa] based on 15 years of an ECHAM4.5 AMIP2 simulation and the corresponding 15 years of ERA data (b).*

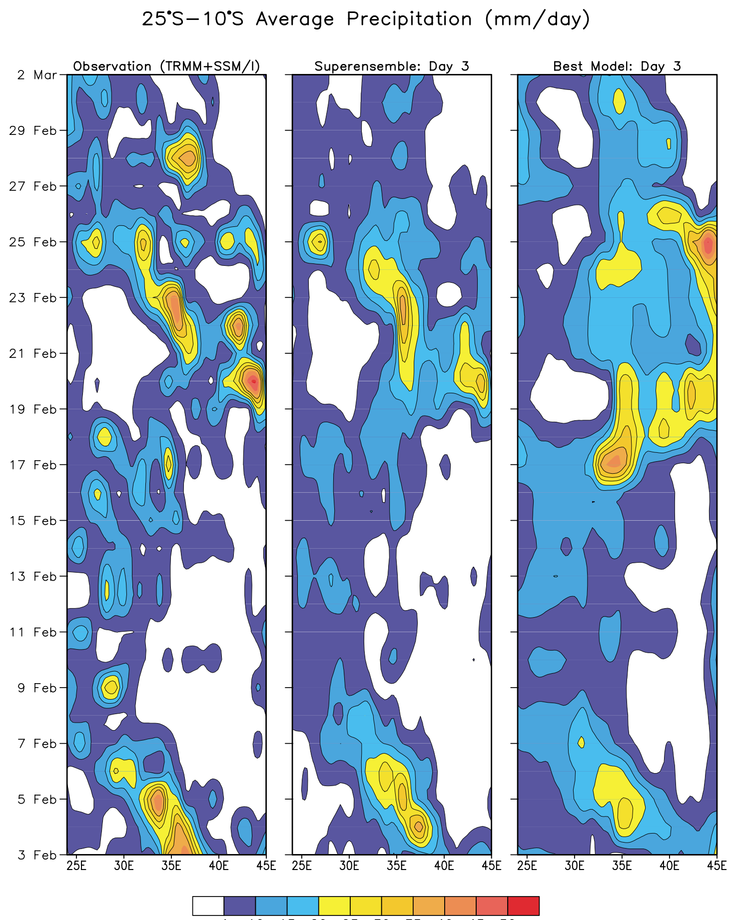


Fig. 1. Hovmöller diagram of a sequence of day 3 forecast rain from the best member model (right), the superensemble (middle) and are compared to the observed estimates of rain (left) forFebruary 2000 averaged from 25°S - 10°S. The time period relates to floods over Mozambique.

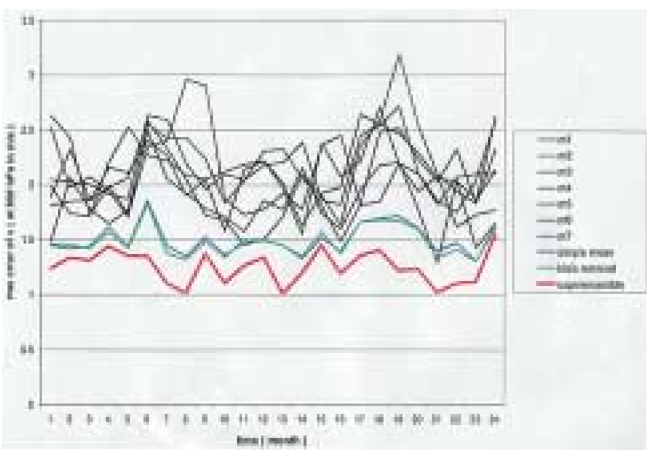


Fig. 2: Application of the superensemble forecasts for seasonal climate. The results show of rms errors of monthly mean wind at 850 mb for individual models(black curves), simple mean (blue), bias removal (green) and the superensemble (red).

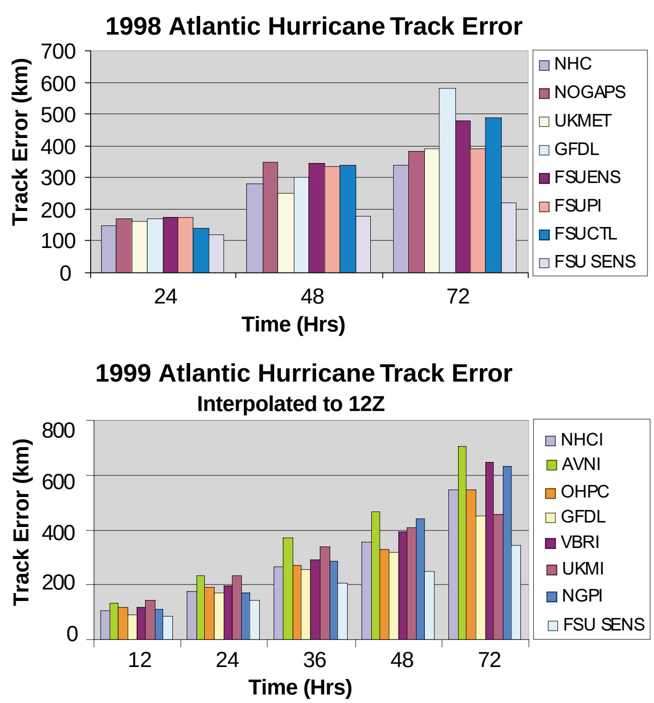
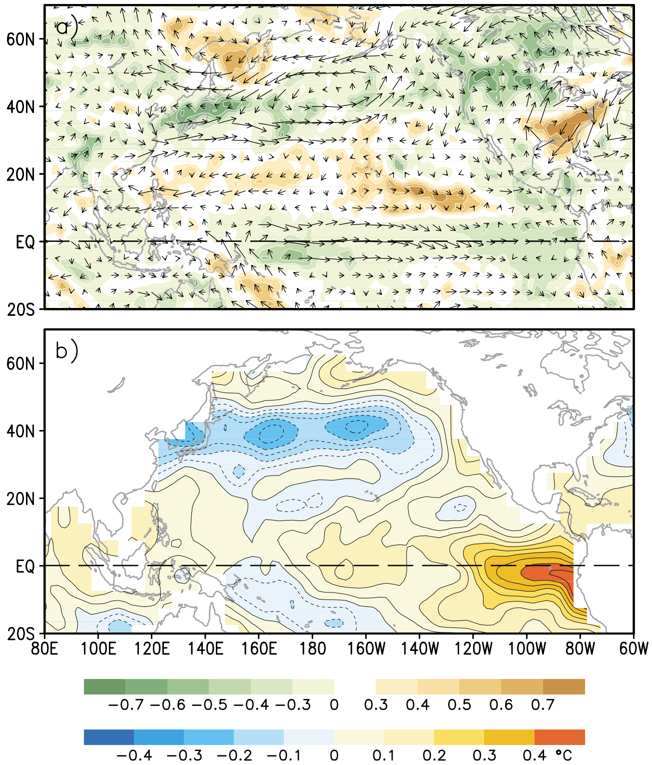
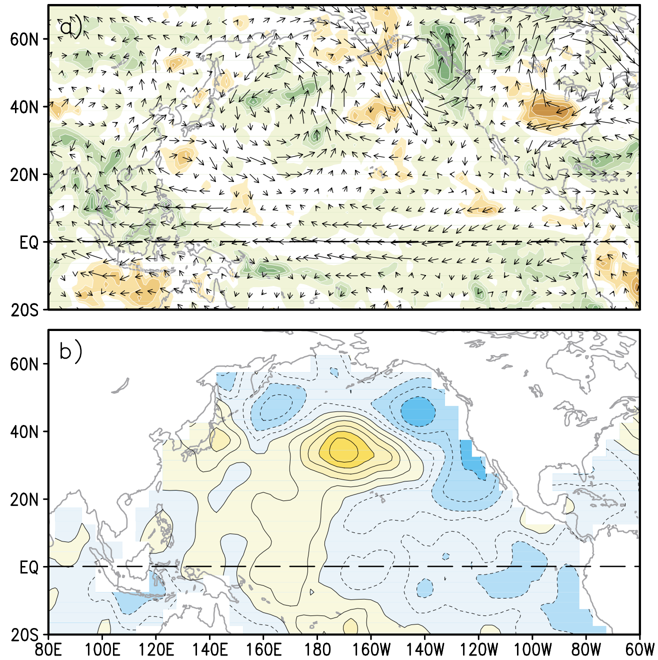


Fig. 3 (upper right): Superensemble track forecast errors (km) for 1998 Atlantic Hurricanes (the model members are arranged in their order from left to right, the last histogram being of the superensemble)
Fig. 3 (lower right): same as above for 1999.

Lau and Weng, Teleconnection linking Summertime Rainfall Variability over North America and East Asia, page 19:





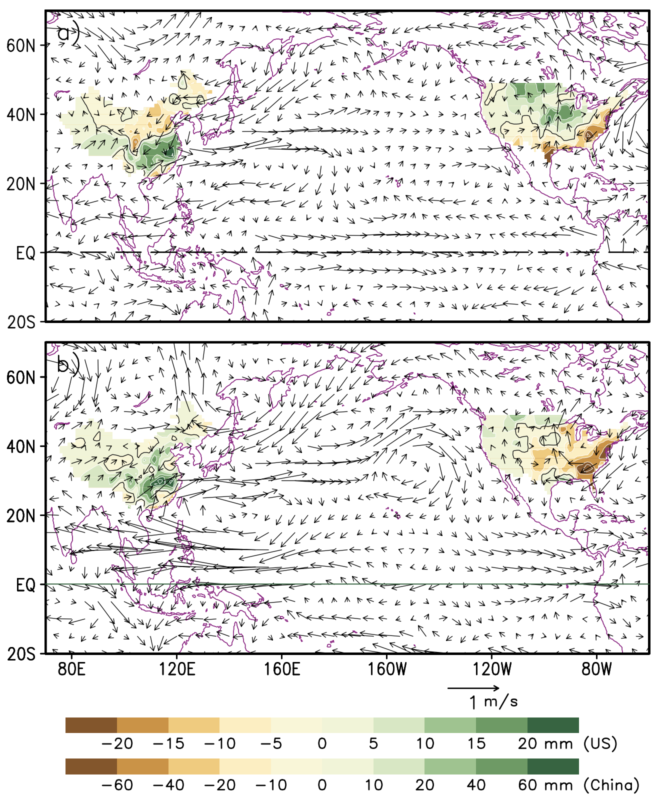


Fig. 1 (upper left): Spatial patterns of 850hPa horizontal wind, CMAP rainfall, and SST anomalies related to Mode-1.
a) Regressed wind anomaly for the period of 1955-98. Correlation between PC1r and CMAP rainfall anomaly for the period 1979-98 is shaded. (Green areas with negative correlations are above normal).
(b) Regressed SST anomaly for the period of 1955-98 (contour interval: 0.05°C).

Fig. 2 (above): As figure 1 for Mode-2.

Fig. 3 (left): Linear regression of (a) East Asian monsoon index (Lau et al., 2000) and (b) 850hPa monsoon index (Wang and Fang, 2000) against 850hPa wind and rainfall anomalies in the U.S. and China for the summers of 1955-98.

Teleconnection linking summertime rainfall variability over North America and East Asia

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1. Introduction

Summertime droughts and floods are among the most costly natural disasters affecting the United States. Yet, compared to wintertime severe weather, the mechanisms of summertime droughts and floods are much less known, and the prospect for long-term prediction is uncertain. Occurrences of summertime droughts/floods over the U. S. continent have been attributed to a large number of factors including the variations of tropical and extratropical sea surface temperature (SST), large-scale atmospheric circulation, soil moisture and land-atmosphere hydrology feedback. Some earlier studies (Palmer and Brankovic 1989, Trenberth et al., 1988; Trenberth and Guillemot, 1996) have suggested the possible influence of El Niño/La Niña. Others have pointed to the importance of remote forcings from transient or stationary waves (Livezey et al., 1997; Lau and Peng, 1992; Ting and Wang, 1997; Mo et al., 1997; Liu et al., 1998; Higgins et al., 1999). Since the Asian monsoon is the most energetic climate system during boreal summer, it is plausible that it provides a source of remote forcing for the summertime climate of North America. Alternatively, it is also possible that both the Asian monsoon and the North American climate are subject to the same global scale forcings from the tropics, e.g. El Niño, and the extratropics, e.g., the Pacific Decadal Oscillation or even the polar regions, e.g., the Arctic Oscillation. Hence understanding of the teleconnection between climate anomalies in Asia and in North America may shed new light on the mechanism and predictability of climate fluctuations for each continent. This article presents some preliminary evidence that there are intrinsic climatic modes linking summertime rainfall variability over North America to fluctuations of the Asian monsoon.

2. Data

In this study, we use monthly rainfall data from 102 divisions over the United States from the National Climate Data Center through Climate Prediction Center (CPC), monthly 500-hPa geopotential height and 850-hPa horizontal wind from NCEP/NCAR reanalysis, monthly sea surface temperature (SST) from the Hadley Centre for Climate Prediction and Research, U.K. Meteorological Office, and monthly global rainfall from CPC Merged Analyses of Precipitation (CMAP) (Xie and Arkin, 1997). The period for analysis is 1955-98. Anomalies are calculated as departures from the temporal mean over the 1961-90 base period, except for the CAMP rainfall which base period is 1979-90. To focus on interannual variability, the variability with time-scales longer than 8-years have been removed. Singular Value Decomposition (SVD) analysis was then applied to obtain the dominant modes of rainfall and large scale circulation patterns. The following discussion is focused on the teleconnection patterns associated with these modes and linkage between the Asian monsoon and US summer rainfall variability.

3. Intrinsic Climate Modes

Two intrinsic climate models linkg US summer precipitation to the large scale circulation and SST fields have been identified (see Lau and Weng 2000). Figure 1 (page 18) shows the patterns of 850-hPa wind, rainfall and SST associated with the most dominant mode (Mode-1) of US rainfall - 500 hPa geopotential variability (not shown). Mode-1 explains 32% of the co-variability between US rainfall and 500 hPA geopotential height and projects strongly on the disastrous flood over the midwest in 1993. It depicts a Pan-Pacific, zonally oriented rainfall/circulation pattern stretching from East Asia/Japan region to North America. Excessive rainfall is found over the northern and northwestern N. America and deficient rainfall over the eastern and southeastern U. S. The rainfall pattern is coupled to an anomalous low-level anticyclonic flow over the eastern US, which favours the transport of warm moist air from the Gulf coast to the midwest and dry air along the east coast. The band of excessive rainfall linking Canada and Japan coincides with regions of low-level cyclonic flow. Along the equator, there is a weaker signal indicating generally enhanced rainfall in a large fetch of enhanced westerlies in the central and eastern equatorial Pacific. The regressed SST anomaly pattern for Mode 1 (Fig. 1b) suggests possible El Niño influence, as evidence in the positive SST over the equatorial eastern and central Pacific. A prominent feature in the Fig. 1b is the presence of an extensive cold region in the extratropical Pacific (near 40ºN), coinciding with anomalous low-level westerlies and enhanced rainfall. These features suggest forcing of the extratropical ocean by atmospheric wind (Lau and Nath, 1996).

Mode-2 explains 30% of the co-variability between US rainfall and global geopotential height. The associated 850-hPa wind and CMAP rainfall patterns suggest that US summer time rainfall variability may be associated with deep convection (heavy monsoon rainfall) in the IndoChina and western Pacific region (Fig. 2a, page 18). The principal components (not show) of this mode shows a strong project on the 1988 drought over the US. Excessive rainfall is found over the west coast of Canada and below normal rainfall over the Great Plains and mid-west. The associated low-level flow indicates a large anticyclone over northeastern N. America coupled to a cyclone over the Gulf region. This anticyclone/cyclone couplet induces anomalous low-level easterlies in southern U.S., effectively cutting off moisture supply from the Gulf of Mexico, which will result in below rainfall condition in the mid-west. A well-developed cyclonic circulation over northwestern North America, with southerly flow that feeds moist oceanic air into the region may be responsible for the excessive rainfall along the west coast of Canada (Fig. 2a). The continental wave pattern over North America appears to be a part of a much larger and well-organized wavetrain emanating from the subtropical western Pacific, in an arc path across the north Pacific to North America. Regions of enhanced (reduced) rainfall appear to align along the direction of the wavetrain, coinciding with low-level cyclonic (anticyclonic) circulation that can be traced back to enhanced convection over Indo-China. The anticyclone over the subtropical western Pacific near the Philippine is of particular interest, because this circulation feature has been identified as one of the key features of the Asian summer monsoon variability affecting droughts and floods in China, Japan and Korea (Lau, et al., 2000). Mode-2 is associated with substantial changes in extratropical SST, with positive (negative) SST anomalies underlying the anticyclones (cyclones) (Fig. 2b), suggesting that the SST anomalies be forced by local atmospheric circulation. There is only a weak SST signal in the tropical eastern Pacific. Hence, this mode appears to be independent of El Niño/La Niña, arising from variability of the Asian/West Pacific monsoon convection.

4. Asian monsoon variability and rainfall anomalies over the United States

To reassure the physical link between Asian monsoon fluctuations and US rainfall variability, Fig. 3 (page 18) shows the pattern of JJA 850 hPa wind, and rainfall over the China (based on 160 stations) and the United States (based on divisional data) derived from regression with an index of the Asian monsoon for the period 1955-98. This index which is computed from the difference of the 200 hPa wind averaged over [40-50^{o} N, 110-150^{o} E] and [25-35^{o} N, 110-150^{o} E] as proposed by Lau et al. (2000). The rainfall pattern over China associated with this index shows above normal rainfall over southern China and below normal rainfall over northern and northeastern China. This pattern is nearly identical to the dominant mode of summertime rainfall variability over China (Lau and Weng 2000). Over the US, the associated circulation and rainfall patterns are quite similar to those associated with Mode 1, which is representative of the flood situation in 1993. (see Fig. 1a and Fig. 3). The pattern suggests an increase rainfall over southern China with reduced rainfall over northern China is associated with increase rainfall over the midwest and reduced rainfall over the east coast. A different monsoon index based on the west Pacific convection (Wang et al., 2000), yields a teleconnection pattern suggesting a combined contribution by both Mode 1 and Mode 2 (Fig. 3b). This patterns links overall above rainfall in all China to a wetter west coast and a drier east coast of the US. These results suggest that excitation of the aforementioned intrinsic climate modes, either singly or in combination, may lead to simultaneous shifts in large scale precipitation anomalies over the Asian and North America summertime monsoon climate system. This will have important implication on the fluctuations of the regional hydrologic cycles in both continents.

5. Conclusion

The results presented in this paper suggest that there may be a physical link between major summertime droughts and floods over North American and the Asian monsoon. In order to better understand the mechanisms of floods and droughts over North America, a more global view, taking into account the possible impact of the Asian monsoon has to be considered. It is likely that the teleconnection patterns described here may have evolved from preceding spring or winter seasons, as well as occurring on subseasonal time-scales. Identifying early season teleconnection pattern and subseasonal signals will be the key to improve summertime drought and flood forecasts over the U.S.

Acknowledgement

The authors are thankful to Drs. J. Arnott, Y. He, K.-M. Kim, D. Parker, and J. Zhou for providing data or data processing. This work was supported by the Global Modelling and Analysis Program and the Earth Observing System Interdisciplinary Investigation Program of the NASA/Earth Science Enterprise.

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Testing the 'natural' variability of a climate model: an example using tree-ring data

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Introduction

In studies of the detection, attribution and prediction of anthropogenic climate change, it is essential to have some estimate of natural fluctuations of climate in order to identify the significance of the human-induced climate change signal. The problem is one of separating the "signal" of climate change from the "noise" of natural variability, and often this involves making quantitative estimates of the confidence limits of the probability density function (PDF) of the natural variability (e.g. Tett et al., 1999).

Because of the multi-decadal to century time scales involved in the climate change problem, estimates of this PDF must be robust on such long time scales. The (global) observational record of climate is of little use because of its relatively short length (of a century or so) and because of its probable contamination with the anthropogenic climate change signal. Thus it is common in climate change studies to use an estimate of the natural variability taken from a long (i.e. multi-century) control experiment of a climate model, often a coupled ocean-atmosphere GCM. It is crucial then to validate the variability of such climate models on the multi-decadal to century time scales because of their weighting in the signal detection algorithms of the climate change problem. As the observed global record is inadequate in this respect, our only viable option is to use estimates of climate variability from palaeo records. The validation procedure must be quantitative (because we require quantitative estimates of the PDF of natural climate variability) but there are many problems associated with comparing palaeo estimates of climate variability with numerical models (e.g. Jones et al., 1998). For example, palaeo indicators (e.g. those derived from ice-cores) are often measurements of local climate, whereas climate models represent variables on the scale of their grid-boxes which can be many 100s of kilometres. Also palaeo indicators are often expressed in terms of variables which are not predicted by climate models (oxygen isotope ratios, tree-ring widths, etc).

Here we report briefly on a quantitative comparison of the decadal-century time scale variability of a coupled ocean-atmosphere climate model with palaeo-temperature estimates of the last 600 years derived from an extensive network of tree-ring densities. Collins et al. (2000) contains the full details of the study.

Data and Methods

The climate reconstructions used here are based on a network of 387 tree-ring density chronologies located over much of the northern hemisphere extra-tropics (Fig. 1). The chronologies range in length from 100 to more than 600 years, with each consisting of, on average, data from 25 tree cores from a site close to the present timber-line (i.e., at high elevation or high latitude) to maximise the tem-

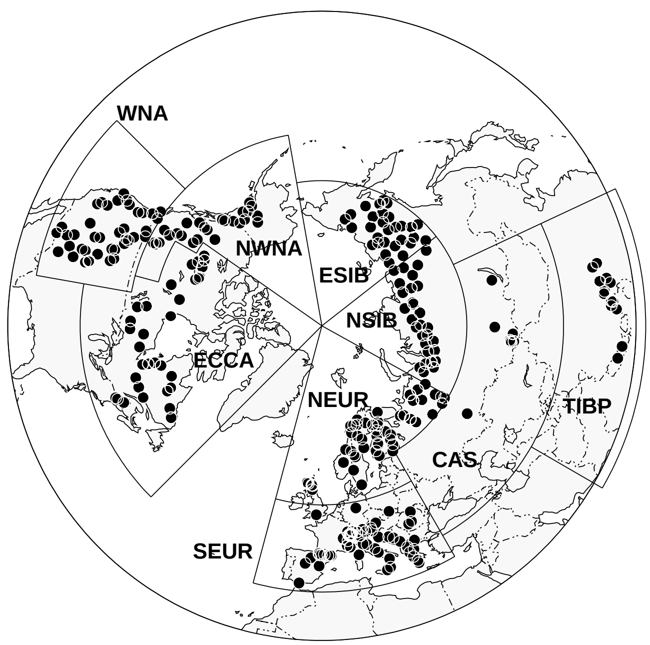

Figure 1: Locations of individual tree-ring density chronologies (dots) and the definition of the nine regional series used in the calibration against observed temperature. April-September temperatures were extracted from HadCM3 at land points in these regions.

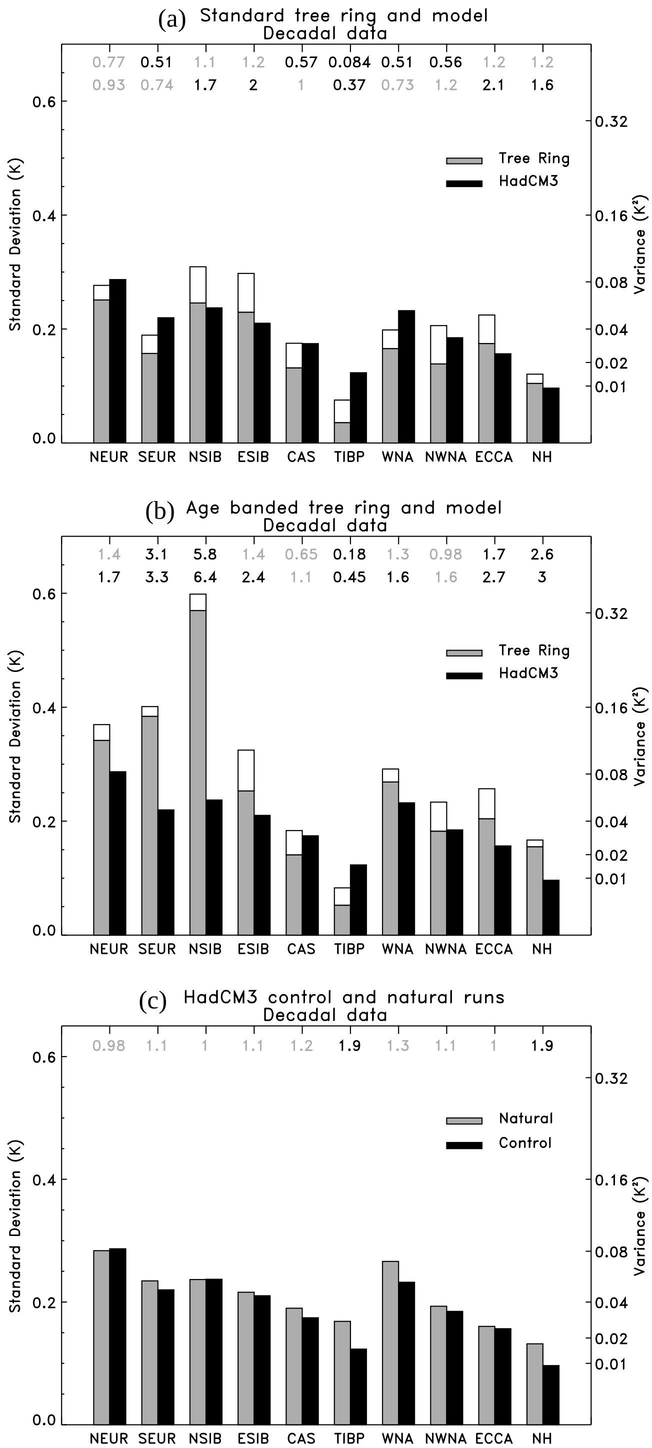

Figure 2: A comparison of the variance of temperature of HadCM3 and palaeo-estimates of temperature from tree-ring data. The black bars correspond to the model and the grey bars correspond to the tree-rings. The white bars show the residual variance from the calibration procedure which must be added to the tree-ring variances. The numbers above the bars are the ratios of tree-ring to model model variance without the residual variance (upper) and with the residual variance (lower). Bold numbers are statistically significant at the 95% level using an F-test. (a) is for the standard tree-ring data and (b) is for the ABD tree-ring data. (c) is a similar plot comparing the variance of the HadCM3 control and the HadCM3 simulations with natural forcings.

perature signal (Briffa et al., 2000b). The dominant climate signal in the data set as a whole is the growing season temperature, the timing of which varies with location, but the mean temperature from April to September provides the best overall correlations with tree-ring density. Briffa et al. (2000a, b) aggregate the local tree-ring series into regions (indicated on Fig. 1) and calibrate against observed temperatures over the period 1881-1960 using simple linear regression. They also form a Northern Hemisphere (NH) series as a weighted mean of these regional series. The linear regression leaves some unexplained variance and we take account of this in the comparison with the model (see Briffa et al., 2000b and Collins et al., 2000) for more details).

In addition to responding to growing-season temperature, the maximum latewood density of each tree-ring also depends upon the age of the ring (generally showing a downward trend with increasing tree age). Briffa et al. (2000a) contrast two approaches for removing this age effect. The “Standardisation” technique involves fitting and removing a generalised exponential function from each tree core and can result in a loss of multi-century variance, the extent of which is dependent on tree longevity. With the Age-Band Decomposition technique (ABD - Briffa et al., 2000a), the age effect is accounted for by only combining in absolute units the density from tree rings whose age falls in a restricted range (or band). There is no artificial loss of multi-century variability, but this is at the cost of greater uncertainty in the earlier part of the record for which there are fewer tree cores. Thus we contrast results obtained using the two methods for processing the tree-ring data which we denote “standard” and “ABD”.

We compare the tree-ring temperature estimates with a 1200 year control run of version three of the Hadley Centre Climate Model (HadCM3 - Gordon et al., 1999; Collins et al., 2001). HadCM3 has an atmosphere with a 3.75x2.5 degree longitude-latitude grid and 19 vertical levels, and an ocean with a 1.25x1.25 degree grid and 20 levels in the vertical. The model requires no flux adjustment term and has a stable climate in the global mean when initialised from an observed atmosphere-ocean state. The control simulation has constant concentrations of greenhouse gases and aerosols etc and hence only represents “internal” climate variability. Surface air temperatures (at a height of 1.5m) were extracted from land points in the regions indicated in fig. 1 and during the growing season of the trees (April-September).

Model-Data Comparison

A simple yet quantitative way of comparing the variability of HadCM3 with the tree-ring estimates is to compute the variance (or standard deviation) of temperature regionally and over the northern hemisphere as a whole (Fig 2a-b). We first average all time series into decades to focus on the decadal-century time scales and we take into account the residual variance from the calibration procedure. The reader is referred to Collins et al. (2000) for a comparison of other diagnostics such as power spectra and spatial patterns.

Comparing HadCM3 with the standard tree-ring reconstructions (Fig. 2a) the model captures the regional spatial pattern of variability well and there is no systematic under or overestimation of variability. For the hemispheric variability, the model underestimates the temperature variance, significantly so (by a factor of 1.6) when we include the residual variance from the calibration procedure. Comparing HadCM3 with the ABD tree-ring data (Fig. 2b) implies that the model on the whole underestimates regional variance with the maximum disparity between the model and the tree-ring reconstruction being for the Northern Siberian (NSIB) region where the tree-rings have over 6 times the variance of the model. For the Northern Hemisphere (NH) as a whole the model underestimates the variance by as much as a factor of 3.

Underestimation of the temperature variance by the model is serious as it could lead to false claims of the detection (and attribution) of climate change (e.g. Tett et al., 1999) and to underestimation of the uncertainties in future climate prediction. (Also, regional errors in variance can lead to errors in the relative weights used in the optimal detection algorithm thus making it less powerful.) Hence it is important to consider why the model may be underestimating the temperature variability.

The Role of Natural Forcings

The control simulation of HadCM3 only represents the "internal" variability of the climate system - that which is a consequence of non-linear interactions within (and between) the atmosphere and the ocean. Other "natural" factors such as variations in solar irradiance, volcanic eruptions, natural fluctuations in CO_2 etc. can affect climate and the tree-ring data might contain variance attributable to these natural forcings (over the period considered here, the last 600 years, orbital variations are of secondary importance). Hence we should include these factors in our simulation in order to make a correct comparison.

We have been unable to perform such a simulation, partly due to the lack of forcing histories and partly due to constraints on computer time. However, we do have 4 simulations with estimates of solar (Lean et al., 1995) and volcanic (Sato et al., 1993) forcing from 1860-1997. The variance of the regional and NH temperatures from these simulations are shown in Fig 2c. The forcings generally do not significantly increase the level of variance on the regional scale (apart from TIBP) but they do enhance the total NH variance by a factor of 1.9. Thus it is possible that the underestimation of variance by the model control simulation is due to the lack of natural climate factors such as solar variations and volcanoes. The conclusion is tentative because we have not run the model over the full 600 year tree-ring period with all the natural forcing factors, however it is consistent with the recent work of Crowley (2000).

Conclusions and Future Work

We have compared the temperature variability of a coupled climate model with palaeo-temperature estimates from a large network of tree-ring densities. On the hemispheric scale, the model appears to underestimate variance (by as much as a factor of 3) which is serious if the model is used as a surrogate for natural climate variability in studies of the detection, attribution and prediction of climate change. However, we have shown that this underestimation may be due to the lack of natural forcing factors such as solar variations and volcanoes. More detail can be found in Collins et al. (2000b).

Palaeo estimates of climate variability are the only way of validating climate models on time scales of many decades to centuries. This study has highlighted many areas where there needs to be more work. Firstly it is important to correctly interpret (e.g. Mann et al., 1998) and quantify the uncertainties in the palaeo data. Secondly it appears that models need to be forced with natural factors in order to make a like-with-like comparison. This in turn requires palaeo-estimates of these forcing factors (e.g. Crowley and Kim, 1999). Finally there is a need for a framework (such as the optimal detection framework (Tett et al., 1999) in which all the uncertainties in the model and in the palaeo data can be taken into consideration when making the comparison.

Acknowledgements

Tim Johns ran the HadCM3 control integration and Gareth Jones ran the ensemble of simulations with natural forcings. This work was supported by UK Department of the Environment, Transport and the Regions (PECD/7/12/37) and the Public Meteorological Service Research and Development Programme - MC and SFBT; the UK Natural Environmental Research Council (GR3/12107) and the European Union (ENV4-CT95-0127) - TJO, KRB, and FHS.

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Workshop and Meeting Reports

Workshop on Decadal Climate Predictability Scripps Institution of Oceanography, La Jolla, CA, USA, 4-6 October 2000

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The joint WGCM/WGSIP Workshop on Decadal Climate Predictability took place at the Scripps Institution of Oceanography, La Jolla, CA, USA, from 4-6 October 2000. There were over 30 participants from 18 different scientific institutions, groups and organizations. The objective of the workshop was to form an overall sense of the "state of the art" in decadal predictability. Since this area of study is in its infancy, the intent was a true "workshop" which would explore observed and simulated decadal variability, decadal predictability, and such practical attempts to produce decadal forecasts as were available. The Workshop was organized into a series of presentations in these broad areas followed, on the final morning, by three break-out working groups. The groups summarised the status of observations and observed variability, simulations and simulated variability, and prediction/predictability and made recommendations and suggestions.

Most presentations on observations and simulations focused on interdecadal variability in the Pacific and North Atlantic. Several talks highlighted the multi-decadal variability in the Atlantic Ocean. This type of variability has typical time scales of 60-80 years, and it can be described from direct temperature observations and from indirect data for the last millennium. The multi-decadal variability involves an interhemispheric dipole in the Atlantic sea surface temperature, and there is some evidence that it may be predictable several years in advance, based on a perfect-model predictability study made with a coupled ocean-atmosphere general circulation model. Other regions of relatively high "potential" decadal predictability, identified in the control runs of 11 coupled models in the CMIP1 database, are the North Pacific, the tropical Pacific and the Southern Ocean. Decadal predictability of surface temperature over land appears to be very modest in these results.

In sum, the workshop considered long time-scale phenomena in the coupled system and the evidence for decadal predictability. There was some indication of predictability, mainly at higher latitudes and associated with long timescales in the ocean, obtained from prognostic perfect model and diagnostic potential predictability studies. The utility and practical achievement of decadal forecasts, nevertheless remains an open question which requires directed attention and active research.

Observations and simulations of decadal variability

Considerable attention was paid to the North Atlantic Oscillation, although no clear consensus emerged as to its preferred time-scale. To first order, it appears that the atmosphere forces the sea surface temperature via heat fluxes and Ekman currents. A secondary effect is due to changes in the Atlantic gyre or thermohaline circulations responsible for anomalies. As well as uncertainties in the underlying mechanism for the North Atlantic Oscillation, simulations of response/feedback to the associated sea surface temperature anomalies differed among models.
The understanding of the North Pacific Oscillation (or Interdecadal Pacific Oscillation), is also comparatively rudimentary, although there has recently been progress in modelling decadal changes in the North Pacific. In the tropical Pacific, coupling to mid-latitudes does not appear to explain much of the variance (temperature/salinity anomalies may be the key, but these anomalies are small). The role of the Southern Hemisphere oceans, if any, is unknown. Decadal variability could also not be clearly separated from global warming which might itself be responsible for some decadal variability. How global warming might interact with "natural" decadal variability is not yet clear.

As a basis for further progress, much longer time series of data and model runs were seen as essential (i.e. from reanalyses, paleoclimatic data, and extended coupled model integrations). The requirement was also expressed for a multi-decadal ocean and/or coupled ocean/atmosphere reanalysis for hypothesis testing, for initialising simulations and decadal forecasts.

Predictability and prediction

Some predictability at decadal timescales of the ocean circulation at higher latitudes (particularly the thermohaline circulation) was inferred from potential predictability studies and perfect model experiments. Associated variations over land might be predictable also, but only explain a small fraction of the total variance. In the tropical Pacific, some weak evidence of decadal predictability was noted. The question of how decadal and interannual variability interact is unanswered. There are large areas where there is yet no firm understanding, namely those concerning the tropical Atlantic dipole, the Interdecadal Pacific Oscillation, and the North Atlantic and the predictability of the North Atlantic Oscillation.

There was some consensus that the thermohaline circulation may be predictable at decadal time scales provided that initial oceanic conditions could be satisfactorily specified. However, the impact of the North Atlantic Oscillation on the export of freshwater from the Arctic remained to be clarified. Improved simulations of overflows and deep (ocean) convection which affect temperature/salinity locally were also needed. The interaction between ENSO variability on decadal timescales and the thermohaline circulation was not well understood. A pioneering attempt at practical decadal forecasting (by the Hadley Centre) is underway but has achieved only modest results to date.

Future directions

It was considered that a vital step in making progress from the current rather elementary position was work on understanding the mechanisms that might underlie predictability (including the study of particular modes). The understanding of the dynamics involved in these mechanisms is limited. Time-scale interactions (e.g. the Interdecadal Pacific Oscillation with ENSO) also needs study.

The possibility of a "Historical Decadal Forecast Project" was raised, which would include efforts toward an improved understanding of mechanisms, use of initial conditions from atmospheric and oceanic reanalyses (based on data from merging all available observations and model simulations), model development (in particular sub-grid scale ocean features such as overflow, convection), and ensemble approaches (forecasts from sequential analyses and from different models, estimates of skill, statistical treatments, probabilistic forecasts). Other areas where work was needed was better international co-ordination of ocean analysis as a basis for initializing decadal forecasts (including quality control of data, obtaining more salinity observations), and the study of the relative roles of sea surface temperature, sea-ice, vegetation cover, and external effects. Another useful step would be to begin to document the potential societal impact of decadal predictions.

Working Group on Coupled Modelling - 4th Session - Scripps Institution of Oceanography, La Jolla, CA, USA 9-11 October 2000

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The fourth session of the JSC/CLIVAR Working Group on Coupled Modelling (WGCM) also took place at the Scripps Institution of Oceanography, La Jolla, CA, USA, 9-11 October 2000, following the Workshop on Decadal Climate Predictability. The paragraphs below summarise some of the main items discussed.

In its review of the outcome of the Workshop on Decadal Climate Predictability, WGCM particularly stressed the need for work and numerical experimentation to explore mechanisms which might underline decadal predictability (noting that the principal foci of the workshop had been statistical analysis and model simulation of certain specific modes). WGCM suggested that a diagnostic project using the extended CMIP data base (see below) could be useful in this respect and in understanding timescale interactions. WGCM, in the light of its own experience, was very aware of the difficulty of initializing coupled models (as needed for a decadal prediction) and thus did not consider the time yet ripe to take up the "Historical Decadal Forecast Project" suggested by the workshop. Nevertheless, WGCM strongly encouraged work to investigate the many outstanding questions. The importance of developing data assimilation of coupled ocean-atmosphere systems (which would also help in specifying the observational system needed) was particularly stressed. WGCM asked Mojib Latif to maintain an overview of this area on its behalf and to report in the following year on progress that had been made.

One of the key projects overseen by WGCM is the Coupled Model Intercomparison Project (CMIP). So far CMIP has comprised two components - CMIP1 to collect and document features of global coupled model simulations of present-day climate (control runs); CMIP2 to document features of climate sensitivity experiments with CO_2 increasing at 1% per year. The sets of simulations established at PCMDI have formed the basis for a wide variety of diagnostic projects (including activities undertaken by WGSIP such as ENSIP and STOIC) and which have also been extensively drawn on in the IPCC Third Assessment Report. At its present session, WGCM agreed formally on a "CMIP2+" in which a much greater range of data from control runs and transient integrations would be collected (i.e. more parameters, at daily resolution, or even higher temporal resolution for certain periods). This would enable a much more detailed study of characteristics of coupled models (of the same type that have been performed in AMIP). The data sets to be compiled will be finalized by the CMIP panel, data assembly initiated (already partly underway), and an announcement made to the research community.

WGCM further agreed to undertake "CMIP3", which will collect (locally) standardized runs for the twentieth century. Runs (from coupled atmosphere-ocean general circulation models only) from 1850 (if possible from 1700) to the present should be undertaken. At least three runs per forcing (to permit an ensemble approach in evaluation) should be prepared. For initialization, existing control runs should be employed. The issue of mixing present day temperatures with 1700 radiative forcing conditions needed to be considered. One common greenhouse gas forcing only should be performed, but other integrations including other (non-standardized) forcings (e.g. solar, aerosol, volcanism, changes in land-cover use) would also be welcome. An essential factor was that the radiative forcing must be documented, and the forcing data sets be in the public domain (or made public). The CMIP panel will work out the details and invite modelling groups to submit integrations. (The criteria set for the IPCC Data Distribution Centres for "SRES" integrations will essentially be followed).

Other points discussed included:

1. Increased co-operation with the GEWEX Radiation Panel in studying cloud-climate forcing and feedback, with more interaction between observationalists and modellers (joint AMIP and CMIP projects to study the relationship between the large-scale / meso-scale circulations and cloud properties / forcings);
2. Developments in ocean climate modelling (based on the review prepared by the WOCE/WGCM Working Group on Ocean Model Development): it was recognized that more institutional support to ocean modelling is required;
3. Organization jointly with IGRP/GAIM of a series of experiments with CO_2 as a prognostic variable. The basic approach is co-ordinated transient model runs using fully coupled atmosphere-land-ocean-carbon models with specified (fossil fuel) CO_2 emissions (other forcing could also be included in terms of equivalent CO_2) for a contemporary period (1800-2000) and for the period 2000-2001 using various emission scenarios. The atmospheric carbon dioxide concentration would evolve freely (depending on the model representation of carbon processes and absorption into/exchanges with ocean/land-surface). This is in contrast to the type of experimentation fostered by WGCM so far where the actual atmospheric carbon dioxide concentration has been specified. A (joint WGCM/GAIM) planning group has been set up to define the experimental protocol in detail. PCMDI will act as a clearing house for collecting simulations.

CLIVAR Workshop on Shallow Tropical-subtropical overturning Cells (STCs) and their Interaction with the Atmosphere, Venice, Italy 9-13 October 2000

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The Meridional Overturning Circulations (MOCs), in particular the Atlantic Ocean MOC, have been the object of numerous investigations during the last decade. Much less attention has been given to observational and modelling studies of the shallow subtropical/tropical overturning cells (STCs) that can act as a mechanism for transferring mass, heat, salt and tracers between the subtropical and equatorial gyres. Through their effect on the Sea Surface Temperature (SST), the STCs have been proposed as the oceanic component of coupled modes of air-sea variability that influence atmospheric climate on multiple time scales, from the seasonal to the interannual, decadal and multi-decadal. Hence a workshop was convened in Venice, October 9-13, 2000, under the CLIVAR banner, to bring together observationalists and modellers to assess our present understanding of the structure of these cells and of their influence on the atmosphere. This assessment will be used to develop strategies for future observational and modelling studies, here proposed as recommendations to the CLIVAR Implementation Panels for the three oceans.

Overall Objective of the workshop was:

- to assess the present understanding of the structure and dynamic of the STCs and their interaction with the atmosphere and to develop strategies for future observational and modelling studies.

Specific objectives are to compare model results and observations of the mean and time-dependent STCs to address the following issues:

- What are the sources for and what determines the rate of subduction of subtropical waters that contribute to the shallow cells?
- What are the pathways and time scales from the subtropics to tropical upwelling areas (e.g. western boundary currents and/or interior ventilation)?
- What processes determine the intensity of equatorial upwelling (e.g. local winds versus remote forcing)?
- What are the pathways for the return upwelled waters to the subtropical subduction region?
- What is the role of the global thermohaline circulation in influencing the STC structure and intensity?
- What processes control the effect on the atmosphere of SST variability induced by the STCs?

Based on the understanding of the above issues, propose a strategy for:

- an air-sea network to observe the STCs and their effect on the atmosphere
- numerical modelling activities to increase the understanding of the STCs

The workshop addresed these objectives through scientific sessions with invited overview presentations and poster sessions for the three oceans basins (Atlantic, Pacific, Indian Ocean) focussing on a) observations; b) ocean models; c) coupled systems/models. Thereafter, three Working Groups (WGs) met to address specific scientific priorities for the three oceans such as:

- **Q1:** Do STCs play a role in seasonal to centennial climate variability, and, if so, how?
- **Q2:** What are the sources and pathways of STCs, including other features such as the Tsuchiya jets, the Meridional Overturning Circulation (MOC) for the Atlantic Ocean, and the Indonesian Throughflow for the Pacific and Indian Oceans?
- **Q3:** How do surface fluxes affect subduction properties and the three-dimensional ocean circulation within the STCs?
- **Q4:** What are the relative mean and time-variable contribution of northern and southern hemisphere STCs to the equatorial circulation?
- **Q5:** How do the STCs affect the mean and time-variable ocean-atmosphere tropical heat budget?

To address the above scientific issues, improved definition and understanding are necessary of the long-term mean and seasonal-to-centennial time-scales variations of:

- Water mass properties in the thermocline of the tropical and subtropical oceans.
- The rates and water mass properties of waters subducted in the subtropics, and the regions where subduction occurs.
- Western boundary currents mass and heat transports
- Equatorial and coastal upwelling rates and source waters
- Indonesian Throughflow, and its relation to western boundary and interior ocean current transports (Pacific and Indian Oceans).
- Meridional Overturning Circulation (MOC) and how the upper warm return pathways affect the STCs (Atlantic Ocean).
- Eastern boundary termination of major zonal currents such as the Equatorial Undercurrent (EUC), the Tsuchiya Jets, and other thermocline flows.
- The pathways by which upwelled waters return to subtropical subduction zones.
- Surface fluxes of momentum, heat and fresh water
- Surface and subsurface salinity

The paramount importance of satellite measurements and atmospheric observations cannot be overemphasized for the understanding of the above seasonal-to-centennial variabilities, and consequently properly address the five major scientific objectives of the workshop. General recommendations for the three oceans are:

- The workshop endorsed the development of satellite missions for remote sensing of the global surface salinity field. The European Space Agency has approved one mission (SMOS) and another is under consideration by NASA. The NASA mission is planned for a repeat ground track every 14 days, 70-100 Km. Spatial resolution, and an accuracy of O(0.1 psu). These missions have the potential to contribute significantly to studies of the STCs in all ocean basins (Q2 and Q4).
- Continuity of key satellite measurements is essential for climate studies related to the STCs. These measurements include SST, scatterometer winds, sea level, rainfall, insolation and ocean color from which penetrative radiation can be inferred (Q1-4)
- The need is emphasized for improved meteorological packages on vessels of opportunity and increased meteorological observations from moored buoys.

The detailed observational and modeling strategies recommended for the three oceans are summarized in the working group reports that are part of the forthcoming CLIVAR report of the workshop.

Meetings Around the World

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Meetings of CLIVAR scientists seem to have a pronounced semi-annual periodicity with peaks in Spring and Autumn. The Autumn peak has just passed and I have attended a number of these meetings. The following is a mixture of personal accounts and reports from the meeting convenors. More complete reports will be available in due course via the CLIVAR Web pages.

The WOCE/CLIVAR Workshop on Representativeness and Variability Fukuoka, Japan, 17-20 October 2000

Between 1990 and 1998 WOCE conducted the most comprehensive survey ever undertaken of the ocean circulation using satellite and in situ data with the aim of using these data to validate and improve ocean models for use in climate research. The WOCE data set can be used as a baseline against which past data may be compared in order to document changes occurring on time-scales up to several decades. The satellite (and to a lesser extent the in-situ) data contain information on seasonal and interannual time-scales and during the WOCE observations we experienced the 1997/8 El Niño event.

The Fukuoka workshop addressed these issues in a series of plenary talks, poster sessions and discussion groups. The meeting was co-sponsored by WOCE and CLIVAR since the assessment of the variability encountered in WOCE can provide guidance for how CLIVAR should best design its observational strategy particularly in the extra-tropical regions and for decadal time-scales.

The meeting was attended by approximately 80 scientists from 12 countries. Its venue in Japan was in recognition of the enormous contribution that Japanese scientists have made, and continue to make, to our understanding of ocean variability. Generous financial support was given by Japanese agencies and for this we are very grateful.

The meeting themes were as follows:

Global views of WOCE Variability: data and models

The plenary speakers were Sergei Gulev (air sea fluxes) and Dudley Chelton (satellite altimetry). The Session presented a global perspective on surface fluxes, satellite observations, ocean observations, ocean models, coupled models and ocean state estimation.

There was a clear demonstration that except for the N. Atlantic, the uncertainties in integrating the surface heat fluxes from VOS measurements to give implied ocean heat transports are too large for the calculation to be of real use. For the North Atlantic with its better sampling the implied divergence are be useful in constraining direct estimates from ocean sections.

Combining scatterometer winds and microwave SSTs reveals enhanced wind stress and curl associated with oceanic fronts, with implications to frontal dynamics and biological production. NSCAT and QuikSCAT data have allowed the accuracy of the wind field analyses from ECMWF and NCEP to be assessed. The results show a significant improvement in ECMWF between the Oct'96-June'97 NSCAT period and the QuikSCAT period since Aug'99. The greatest improvement has been in the tropics, but the is significant improvement in the operational analyses of 10m winds at middle and high latitudes. The spatial resolution of the operational analyses are still limited to scales greater than 500-700 km and therefore ECMWF and NCEP considerably underestimate the intensities of the derivative wind fields (divergence and curl).

In the session's posters the 8-year TOPEX-POSEIDON altimeter record has detected energetic variability on time scales from monthly to interannual and space scales from 100 km to global. On seasonal, interannual and even decadal time scales the variability matches that observed in the atmosphere. Of particular importance here are the repeat XBT lines. Ocean models, both hindcasts and coupled to an atmosphere, are being used to extend this ocean variability in time and space, and to investigate mechanisms for its generation and propagation.

Principal Mechanisms for Variability

The speakers were Jim Hurrell and Kimio Hanawa. Hurrell spoke about the state of the atmosphere during WOCE. There was anomalously low atmospheric pressure at high latitudes driving higher than average westerly winds over the subpolar and northern subtropical oceanic gyres. In the N. Pacific, this is reflected in a low North Pacific Index (NPI). Hanawa presented evidence that fluctuations in the NPI and the Kuroshio properties were 90^{o} out of phase and suggested that this was indirect evidence of a coupled oceanic/atmospheric process involving the two phenomena.

Bill Dewar's poster examined an analytic/QG model of an NAO-like mid-latitude phenomenon and again suggested that this may be part of a coupled ocean-atmosphere. This issue was revisited in the focus group discussion.

Other topics discussed were: the effects of oceanic shear on the propagation of variability (Killworth): the importance of Ekman pumping on rapid barotropic variability (Webb): the role of Kelvin and Rossby waves in connecting Pacific and Indian Ocean variability in the Indonesian Passages (Yang): the use of WOCE hydrography in the study of the changes in the thermohaline flows in the Atlantic to the NAO (Dobroliubov: the importance of eddy fluxes in the structure of the meridional overturning circulation in the tropics (Danabasoglu).

Model/data comparisons: where are we?

Detlef Stammer presented results on model and data comparison at high frequencies and at the mesoscale. He showed that models can be used to help the data interpretation. First data assimilation results at low resolution are encouraging. The optimization is working and, in particular, heat flux errors appear to be corrected in the right way to reduce the misfit between data and models. The current work deals with the comparison of the outputs of the assimilation system with WOCE data. Future (GODAE) plan is to improve the model resolution and physics.

One of the main conclusions of this session (and from posters in other sessions) is that unconstrained models do show skill in reproducing some variability signals. They can thus be used to explore these signals. Many illustrations of this joint use of data and models were presented in the workshop. The next and complementary step will be to merge the data and models through data assimilation.

There followed presentations on Pacific/Indian (Dean Roemmich), Southern Ocean (Nathan Bindoff), Arctic (Andrei Proshutinsky) and Atlantic (John Gould - standing in for Bob Dickson) variability.

Focus group discussion were held on Seasonal/Interannual Variability: Decadal Variability: Variability Hypotheses: Model/data Comparisons and Assimilation: and on Future Observations.

From Fukuoka I travelled (slowly) to Perth where CLIVAR was involved in a series of meetings held there as part of Australia's Indian Ocean Climate Initiative 2000.

Sustained Observations for Climate in the Indian Ocean (SOCIO), 13-15 November 2000

This meeting was organised by Gary Meyers and held under the auspices of the Intergovernmental Oceanographic Commission (IOC) who have recently established a regional office in Perth covering the Indian Ocean. While not specifically sponsored by CLIVAR the meeting covered a number of issues in which CLIVAR (and particularly the CLIVAR Ocean Observations Panel - formerly the Upper Ocean Panel has an interest). In the over 60 attendees there was excellent representation of nations bordering the Indian Ocean and of other countries with a strong research interest in the area.

Plenary talks covered Intraseasonal variability (Peter Webster and Peter Hacker), Indonesian Throughflow (Janet Sprintall), Ocean prediction and marine applications (Neville Smith), Climate Prediction and Applications (Mark Jury), Monsoon Ocean Coupling and Marine Applications (Sulochana Gadgil), Satellite and In-situ measurements (Ian Barton and Greg Holland). These gave an excellent summary of the physical processes through which the Indian Ocean affects climate and of the potential applications of such knowledge.

Naturally, the discussions focused on the contributions that could be made by the various types of observations and the level of commitment that could be made to them. A central plank of ocean observations will be the ARGO array of profiling floats. Commitments made prior to and at the meeting suggest that, by 2004 the Indian Ocean north of 30S could be covered at the global 3 deg global target level. A substantial amount of profile data is already available from floats deployed during WOCE. An issue still to be resolved is the depth at which the floats should best be parked - deep to allow them to move slowly and hence maintain the spatial distribution of shallow to reveal the circulation but then liable to be entrained into boundary currents. This is an issue for the COOP and the Argo science team to resolve.

Among the other topics discussed at length was the extension of a TAO/TRITON-like moored equatorial array into the Indian Ocean to supplement buoys already in place around India. A proposal for a West Indian Marine Applications Project incorporating a 9 buoy array was presented by Mark Jury. (See TAO report below).

A recurring theme was the uncertainty of air-sea flux estimates throughout the Indian Ocean region. A moored array will make a substantial contribution to solving this issue.

Position papers prepared for the meeting can be found at
http://www.marine.csiro.au/conf/socio/socio.html

A conference summary is in preparation and links to it will be given from the CLIVAR web site.

There followed two meetings held in parallel. The following report is a précis by Mike McPhaden of the TAO Implementation panel that I did not attend.

TAO Implementation Panel (TIP-9) 16-17 November 2000

The TIP reviewed the status of the TAO/TRITON array addressing technical and logistic issues related to its maintenance and provided a forum for discussion of enhancements and expansions of the array. The Panel also addressed the design and development of a moored buoy program for the Indian Ocean building on the results of SOCIO.

Ming Ji gave a presentation on the uses of TAO/TRITON data in operational analysis and forecasting. Seasonal-to-interannual salinity variations are pronounced in the western equatorial Pacific. Although there are few real-time salinity observations, NCEP has techniques to use TAO/TRITON subsurface temperature data and satellite altimetry data to derive pseudo-salinity and assimilate temperature and salinity into the ocean model for improved ocean analyses. The new system is capable of assimilating both temperature and salinity from TAO/TRITON and from future ARGO floats.

The Pacific (TAO/TRITON) and Atlantic (PIRATA) arrays were reviewed and noted that:

From 1 January 2000, the Pacific array became the TAO/TRITON array following JAMSTEC's responsibility for TRITON sites in the western Pacific. Wind, SST, air temperature, relative humidity, and subsurface temperature from ATLAS and TRITON buoys are on the GTS merged into a data set available at (http://www.pmel.noaa.gov/tao/) and (http://www.jamstec.go.jp/jamstec/TRITON) Real-time daily averaged data return for ATLAS moorings between 95ºW and 165ºE was 89% for the 12 month period from October 1999.

Vandalism continues to plague the TAO/TRITON and PIRATA arrays. Data return is lower in regions of high tuna catch in the eastern and western Pacific, and the eastern Atlantic. In addition, over the past three years, 17 of 220 ATLAS moorings between 95ºW and 137ºE broke free and drifted away. 9 systems disappeared while 8 partial systems were recovered. Evidence from recovered systems suggests vandalism is a major contributor. Of 10 TRITON moorings between 138ºE and 156ºE, 9 showed signs of vandalism, though none were completely lost. Efforts to combat vandalism continue. As a consequence sites along 130ºE, 138ºE, and 147ºE will be occupied at a slower pace than originally planned in 2001 because of vandalism. In addition, the planned TRITON deployments of TRITON buoys in the Indian Ocean at 0º, 90ºE and 5ºS, 95ºE in have been delayed to November 2001.

NOAA's Eastern Pacific Investigation of Climate (EPIC) has enhanced and extended the TAO/TRITON array along 95ºW for the 4-year period 1999-2003. This will provide a set of oceanic and meteorological data to support descriptive, diagnostic, and modelling studies of ocean-atmosphere interactions in the ITCZ, cold tongue and stratus deck regions and provide the context for process-oriented field studies in August-September 2001.

Additional ATLAS moorings were added to the 95ºW line at 3.5ºN, 10ºN, and 12ºN in the past year. All these moorings measure shortwave and longwave radiation, barometric pressure, and rainfall in addition to the usual suite of meteorological instrumentation. They also include salinity at 7 depths in the upper 120 m and current at 1 to 2 depths in the upper 40 m. Most daily average measurements are available in real-time.

A specially designed land-based intercomparison on IMET, ATLAS and TRITON instrumentation was conducted by Woods Hole Oceanographic Institute in May-June, 2000. Preliminary results can be viewed on the web at http://www.pmel.noaa.gov/tao/epic/whoitests.shtml

The new TAO web pages provide easier access to TAO/TRITON (and PIRATA) data sets, and updated technical information. (http://www.pmel.noaa.gov/tao/).

PIRATA, (jointly sponsored by France, Brazil, and the US), will move to a 5-year "consolidation" phase until 2006. This will permit demonstration of the utility of PIRATA data in climate forecasting and applications. Success could lead to consideration of PIRATA as a permanent feature of GOOS and GCOS. The consolidation phase will eliminate two ATLAS sites (2ºN and 2ºS, 10ºW) where there is intense fishing vandalism. These two sites are not considered critical for achieving the basic objectives of the field programme, but their elimination should improve data return from the 69% for 3 year period from October 1997. NOAA has funded a northwest extension of PIRATA with a Woods Hole flux mooring to be deployed in April 2001 at 16ºN, 51ºW. Northeast, southeast, and southwest extensions are under discussion for the tropical Atlantic, with support from countries bordering these regions.

An international conference in May-June 2001 in Paris will consider implementation of an integrated satellite and in-situ climate observing system in the tropical Atlantic Ocean in support of CLIVAR, GOOS, and GCOS. PIRATA will be a key element of that observing system.

The TAO Panel recommended that priority be given to the design and implementation of an Indian Ocean moored buoy array within the context of CLIVAR, GOOS, and GCOS and recommended that an ad hoc working group should develop a science and implementation plan. The panel strongly endorsed the mooring component of the Western Indian Marine Applications Program (WIMAP) and the JAMSTEC plan for TRITON buoys at 0º, 90ºE and 5ºS, 95ºE.

The TAO Panel finally made recommendations for its future work and organisation and these will be discussed by the SSG.

The focus of the Perth meetings then moved to the Southern Ocean. The following is a shortened version of a summary by John Church and Steve Rintoul.

The CLIVAR Southern Ocean Workshop 16-18 November 2000

The Southern Ocean is a central element of the global ocean circulation and the global climate system. The workshop sought to identify the main issues of regional and global relevance and the appropriate ways of addressing them. The workshop was co-sponsored by CLIVAR and by CLIC (the WCRP's Climate and Cryosphere project). The workshop was attended by over 35 scientists and received input from a number of others unable to attend. Virtually all nations active in Southern Ocean research were represented.

The workshop reviewed the considerable progress in understanding the Southern Ocean over the last decade. We are now in a strong position to make significant progress on the role of the Southern Ocean in global and regional climate variability. The workshop recommended that a Southern Ocean Panel be formed to carry forward planning and implementation of a coordinated observation and modelling program for the Southern Ocean region.

Research Areas

The workshop identified four research areas of importance to society. For each of these areas, significant progress can be expected over the next ten years if an internationally coordinated Southern Ocean Project is undertaken. The research areas are:

- Variability of the coupled climate system: The Antarctic Circumpolar Wave, teleconnections and low frequency variability,
- Subantarctic Mode Water and Antarctic Intermediate Water: Formation, sensitivity to change and exchange with lower latitudes,
- Variability of the Antarctic Circumpolar Current system and interbasin exchange, and
- Antarctic Bottom Water formation and the stability of the overturning circulation.

Requirements

Progress in each of these areas requires observational (*in situ* and satellite) and modelling activities. There is considerable overlap between the requirements of the four research areas thus allowing a cost-effective program to be conducted. The main sustained *in situ* observational requirements are:

- a global ARGO programme, including under the extensive areas of winter sea-ice in the Southern Ocean,
- repeat sections conducted from research ships, merchant vessels and Antarctic resupply vessels,
- moored arrays to measure the outflow of deep and bottom water,
- in situ observations to allow improved estimates from satellites and atmospheric models of air/sea fluxes of momentum, heat and freshwater, and
- improved estimates of freshwater input and sea-ice volume.

While the primary justification for these measurements is a need to understand the physical processes driving climate variability and change, a Southern Ocean observing system will also provide improved estimates of the exchange of carbon between the ocean and atmosphere, insights into controls on biological productivity and its variability, and underpin more effective management of the Southern Ocean region. The proposed Southern Ocean Panel will coordinate continuing efforts to define and implement a cost-effective observational programme.

The national submissions made to the workshop can be found on the CLIVAR web site (http://www.clivar.org)

Shortly after my return to the UK I attended the second meeting of the CLIVAR Atlantic Panel in Orense, Spain, November 31- December 1 (immediately following the AGU Chapman Conference on the NAO). For reasons of space a report on the meeting will appear in the next issue of CLIVAR Exchanges. However the panel made substantial progress in defining the key observational and modelling activities that will be used to refine the appropriate sections of the CLIVAR Initial Implementation Plan.

I should note that Martin Visbeck has now assumed the chairmanship of the panel, replacing Allyn Clarke who despite a very heavy workload has brought the panel to the present position from which it can move forward to address the many climate issues and uncertainties relating to the Atlantic sector. Thank you Allyn.

Two themes emerge when I look back on all these meetings

1) The crucial need for a substantial improvement in our estimation of air sea fluxes. This is an issue not just for CLIVAR but for all of WCRP.

2) The central role that CLIVAR plays in all areas of climate research and the direct relevance of this CLIVAR research to people's lives

It was an interesting round the world trip and a salutory return to the wettest UK autumn on record.

CLIVAR Calendar

2000/2001	Meeting	Location	Attendance
January 8-12	NASA/IPRC Workshop on Decadal Climate Variability	Honolulu, USA	Invitation
January 14-19	American Meteorological Society, 81th Annual Meeting	Albuquerque, USA	Open
January 29-31	Variability of the African Climate System (VACS) Panel Meeting - 1st Session	Nairobi, Kenya	Invitation
February 5-8	CLIVAR Pacific Implementation Workshop	Honolulu, USA	Invitation
March 5-6	WG on Ocean Model Development	Santa Fe, USA	Invitation
March 12-16	International Meeting of Statistical Climatology	Lüneburg, Germany	Open
March 19-23	Joint Scientific Committee of the WCRP - 22nd Session -	Boulder, USA	Invitation
March 19-20	Asian-Australian Monsoon Panel, 4th Session	New Dehli, India	Invitation
March 21-22	International Colloquium: Forecasting the Monsoon from Days to Decades	New Dehli, India	Open
March 23-28	International Workshop on Monsoons	New Dehli, India	Open
March 26-30	CLIVAR VAMOS Panel, 4th Session	Montevideo, Uruguay	Invitation
March 27-30	CLIVAR Ocean Observations Panel	Hobart, Australia	Invitation
May 14-18	CLIVAR Scientific Steering Group, 10th Session	Toulouse, France	Invitation
May 21-25	WCRP/SCOR Workshop on Intercomparison and Validation of Ocean-Atmosphere Flux Fields	Washington DC, USA	Open

Check out our Calendar under: ***http://clivar-search.cms.udel.edu/calendar/default.htm*** *for additional information*

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