



Exchanges

No 38 (Volume 11 No 3)

July 2006



CLIVAR is an international research programme dealing with climate variability and predictability on time-scales from months to centuries.

WCRP

CLIVAR is a component of the World Climate Research Programme (WCRP). WCRP is sponsored by the World Meteorological Organization, the International Council for Science and the Intergovernmental Oceanographic Commission of UNESCO.

Editorial

This edition of Exchanges is a general one affording the opportunity to provide a broader summary of activities than usual, including the meetings of CLIVAR's Indian Ocean and Pacific Panels, background to the the African Monsoon Multidisciplinary Analysis (AMMA), the development of a new US CLIVAR Working Group on the Madden-Julian Oscillation and outcomes of the 14th meeting of the CLIVAR SSG in Buenos Aires in April. In addition we feature some recently received papers on CLIVAR-relevant science in Australia, India and South America, a summary of the outputs of the European Commission's ENACT project and a sobering pointer to the decline in the system of Voluntary Observing Ships. In addition, we have a taste of the information available on North Atlantic climate in the ICES Report.

SSG-14 was the last for which we had the benefit of Tony Busalacchi as co-chair and the picture above shows him receiving some mementos of his time with CLIVAR at the SSG meeting. He will be much missed as co-chair of CLIVAR for his insight, enthusiasm and energy. His place will be ably taken up by Jim Hurrell in the New Year (more on which in a later edition).

Finally, it was sad to hear of the death of Kirill Kondratyev a little while ago. A tribute to him will be found on page 25.

Howard Cattle

Summary of CLIVAR SSG-14 – Development of a CLIVAR Road Map

Antonio J Busalacchi, Tim Palmer and Howard Cattle
Corresponding email hyc@noc.soton.ac.uk

Building on previous successes in meeting its near-term implementation objectives, reflected in the outcomes from the 1st International CLIVAR Science Conference (Baltimore, USA, 21-25 June 2004), CLIVAR is making significant contributions to advancing the implementation of WCRP's 2005-2015 strategic plan. CLIVAR Scientific Steering Group 13 (SSG-13, Baltimore, USA, 27-29 June 2004) and the CLIVAR assessment, led to a programmatic re-emphasis within CLIVAR on the four major themes of ENSO and other modes of tropical variability, monsoons, decadal variability & the thermohaline circulation, and anthropogenic climate change. These elements provided the focus for exploring the way ahead for CLIVAR during SSG-14 in terms of the development of a Road Map for CLIVAR for future research on exploring climate variability and change on a variety of timescales and how the interactions between the oceans and the atmosphere influence these.

CLIVAR SSG-14 was graciously hosted by Dr Carlos Ereno in Buenos Aires, Argentina from 19-22 April 2006 with financial support from the Argentine Ministry of Science, Technology and Productive Innovation. It concentrated its review of progress in CLIVAR against the four themes and the key role which observations and modelling play in meeting CLIVAR objectives. This was carried out through a series of mini-assessments that consisted of (a) overview papers by SSG members setting out the current status and science needs for each of the four topics followed by (b) round-table CLIVAR panel and working group contributions on how CLIVAR is addressing each theme and (c) discussions, led by "theme assessors", to develop the elements for a CLIVAR Science Road Map on the 2007, 2010 and 2013 timescales (2013 is the planned WCRP "sunset date" for CLIVAR). A similar approach was followed also for modelling and for CLIVAR ocean observation and synthesis activities, the latter under the general heading of "the role of the oceans in climate". Scene setting near the start of the meeting included introductions from sponsors and related programmes, projects and activities (WMO/WGNE, WCRP (including GEWEX), IOC, and IGBP. In addition the SSG was briefed on progress with national contributions to CLIVAR in the Netherlands and the US, and with MedCLIVAR and with IGBP IMBER. Science lectures on the GEF Project for the La Plata Basin (by V Barros and J Rucks) and on Regional Ocean Science Activities (by A Piola) were also presented.

Michelle Reinecker's review of ENSO and other tropical modes of variability revealed the still fundamental gaps there are in our knowledge, and hence our modelling, of the coupled atmosphere-land-ocean system responsible for the dominant modes of tropical variability. CLIVAR is already substantially engaged in this area through the activities of its Atlantic, Pacific and Indian Ocean basin panels and its Working Group on Seasonal to Interannual Prediction (WGSIP). Led by Michelle Reinecker and Axel Timmermann, key elements of a road map for this area were agreed to be (i) to implement, in the Indian Ocean, and to further develop and sustain, in the Pacific and Atlantic, the tropical ocean monitoring arrays; (ii) to seek to realise key planned field experiments (for example, the Tropical Atlantic Climate Experiment (an activity receiving CLIVAR endorsement at SSG-14) and Pacific and Indian Ocean process studies (see the separate reports of the Pacific and Indian Ocean Panel meetings on pages 4 and 6); (iii) through

increased understanding of intra-seasonal variability and predictability, to improve the representation of ENSO and other tropical modes of variability and their global teleconnections in coupled models in time for IPCC AR5; (iv) in parallel, to develop improved seasonal predictions of tropical variability, operational thermocline decadal anomaly predictions and experimental decadal predictions with comprehensive Earth System models and (v) to establish the sensitivity of ENSO to past climate change using paleoclimate proxies and coordinated coupled model experiments.

Because of their societal importance and role in the general circulation of the atmosphere, studies of monsoons form a key component of CLIVAR. Bin Wang reviewed present status from the perspective of the Asian-Australian (AA) Monsoon. A challenge within WCRP is to integrate the various modelling studies within GEWEX and CLIVAR and for the AA monsoon in particular. The SSG heard plans for a new GEWEX activity "Monsoon Asian Hydro-Atmospheric Scientific Research and prediction Initiative (MAHASRI) and for extension of the Coordinated Enhanced Observing Period activity (CEOP-II) which the JSC requested CLIVAR review. Duane Waliser led a small group to develop a CLIVAR monsoon road map emphasising the needs for better understanding and model representations across all monsoon sectors of the diurnal cycle, intra-seasonal variability and the tropical mean state (an issue also identified from an ENSO prediction perspective). Emphasis in the road map was placed on progressive transition from where we are now in terms of research/experimental status to operational systems with increased skill and relevance to applications. On the short to medium timescale there is a need to continue to analyse the outputs from the VAMOS and NAME field experiments and to continue to support and build on the successes of AMMA. An emerging activity, which arose out of a recommendation by the THORPEX/WCRP/ICTP Workshop on Organisation and Maintenance of Tropical Convection and the MJO, held in Trieste in March 2006, is development of the concept of a year of coordinated observing, modelling and forecasting of the topics to address the challenge of organised convection. Such an activity would be joint between THORPEX and other elements of WCRP and could form a WCRP contribution to the UN International Year of Planet Earth in 2008. The SSG were very supportive of this proposal which CLIVAR will seek to contribute to strongly. They asked Duane Waliser to take this forward.

Jochem Marotzke emphasised the crucial need for improving understanding of decadal variability and the meridional overturning circulation (MOC) to meet the key objectives of WCRP. There are considerable uncertainties regarding the mechanisms of decadal MOC variability and in our views of whether the MOC is changing/slowing. Key research needs emerging from Jochem's presentation and the road map exercise led by Wilco Hazeleger lie in terms of continued and sustained monitoring of, and the identification of proxies for, the MOC; establishment of the extent to which prediction is possible on decadal timescales; a move to initialisation-based approaches to decadal predictability studies and improved understanding of the mechanisms of decadal-interdecadal MOC variability.

Toshio Tokioka presented Bryant McAveney's paper on "Directions for Earth System Modelling" as a contribution to the

discussion on anthropogenic climate change (ACC). The paper stressed the critical need to develop ever more complex Earth system models. New understanding of aerosol effects, carbon cycle dynamics and cryosphere changes is pushing projected temperature increases towards the upper end of the previously published IPCC range. Key roles for CLIVAR will be to determine how important these amplifying effects are, to foster a more compete approach to studies of the role of feedbacks in the climate system and to develop convergence of the earth system approach with IGBP. In leading the discussion of ACC in the CLIVAR context, Tim Palmer focussed on the particular need to establish better the impacts of anthropogenic forcing on natural modes of variability. He proposed development of a pan-CLIVAR review paper based on AR4 integrations and atmosphere/ocean data analysis on the 2007/8 timescale with a similar activity towards the end of CLIVAR but based on IPCC AR5 Earth System Model integrations. Issues of WCRP modelling strategy (including the "seamless modelling" concept) and the optimal way of organising ACC research post CLIVAR would also need to be addressed. A key element of the timeline is of course that for IPCC AR5, which WGCM is already turning its thoughts to in terms of future scenario development.

Modelling and prediction lies at the heart of many CLIVAR activities. Presentations on the current status of coupled climate modelling, global ocean modelling and seasonal to interannual prediction were given by Jerry Meehl, Stephen Griffies and Ben Kirtman respectively. The way ahead in terms of a CLIVAR roadmap was developed from the perspective of complex Earth system models by Pedro Silva Dias with regard to (i) data assimilation for initial and boundary conditions; (ii) ensemble forecasting (iii) improved integration of regional and global modelling and (iv) theoretical studies on the non-linear coupling between the time and space scales of the various components of the Earth system. He saw (i) to (iii) above as being at the R&D stage at present. Transfer of techniques to operational prediction centres will provide a key metric for success. WGCM will provide the clear lead for WCRP's collaborative development of Earth system models with IGBP. Key medium term priorities for CLIVAR in terms of modelling include (a) finalisation of the WGSIP's Seasonal Model Intercomparison Project; (b) building on this, realisation of the major seasonal prediction experiment under the JSC Task Force for Seasonal Prediction, management of

which will pass to WGSIP in 2007, and (c) developing wider community involvement in Working Group on Ocean Model Development's Coordinated Ocean-ice Reference Experiments. The SSG continues to encourage CLIVAR's regional panels to coordinate activities to analyse these global runs and the outputs from the IPCC AR4 dataset.

Ed Harrison (chair, Ocean Observing Panel for Climate, OOPC) opened the session on the ocean's role in climate from the perspective of CLIVAR's role in the development of the global ocean observing system and products, including synthesis activities through ocean reanalysis. Detlef Stammer provided a review of Global Synthesis and Observation Panel (GSOP) activities in this area, including proposals for a global synthesis evaluation framework to determine the quality of analysis/synthesis products and assess their usefulness for climate research. David Legler led the road map activity from the ocean observation perspective. He emphasised the need for CLIVAR to (i) continue its close cooperation with OOPC through its ocean basin panels and GSOP; (ii) complete and validate multiple global reanalyses (especially in time for IPCC AR5) and (iii) stimulate international activity to evaluate the current state and development vector of the global ocean observation system. We should aim, by the end of CLIVAR, to have developed a global description of subsurface ocean variability and to have in place a permanent and truly global ocean observation system. Both of these would be key legacies of CLIVAR, a theme which Bob Weller subsequently picked up on. In particular it was suggested that a post-CLIVAR legacy would be the initiation of an "ocean data synthesis decade" built on the modelling and observational tools developed through the CLIVAR period. A key issue for CLIVAR is to firm up on its overall data legacy and to develop activities which bring this together.

Development of the Road Map for CLIVAR is continuing as a "post SSG-14 activity". It is being coordinated with the parallel development of an overall Road Map for WCRP. At the last JSC for WCRP (Pune, India, 6-11 March 2006) all WCRP projects and activities were asked to provide a set of metrics (to be kept under review) against which progress might be evaluated. The CLIVAR list, which formed the basis for that adopted by essentially all the other WCRP projects, is in the box below. Comments to the ICPO (icpo@noc.soton.ac.uk) on these and the CLIVAR Road Map activity from the community are welcome.

CLIVAR metrics

- New resources enabled by leveraging off of CLIVAR efforts, (e.g. \$15M GEF funding of LPB, ESF MedCLIVAR, Climate Process Teams, AR4 analyses)
- Improvements in:
 1. the spectral character (i.e. spectral power, frequency) and
 2. predictability of ISO, seasonal, interannual, and decadal variability in coupled models
- Number of global ocean observation deployments and transition of process study and research observations to operational status (e.g. TAO)
- Reduction of uncertainty in climate models, bias reduction, and the number of new parameterizations incorporated into operational models (e.g. CPT on marine stratus, VOCALS)
- Metric tracking capacity building within and incorporation of developing nations into CLIVAR activities (e.g. efforts within VAMOS, VACS, AAMP)
- Global and regional data products enabled by CLIVAR (e.g., global ocean data reanalyses, African Climate Atlas)

The International CLIVAR Pacific Panel Meeting

Axel Timmerman and the CLIVAR Pacific Panel

Corresponding author: axel@hawaii.edu

Surrounded by lush Hawaiian jungle, fighting mosquito bites and repelling fierce centipede attacks, the International CLIVAR Pacific Panel and a number of international guests met for three days (February 15-17th, 2006) in the beautiful Manoa Valley in Honolulu. The main objectives of this jungle retreat were to identify new scientific key thrusts and to discuss observational programs such as VOCALS, PUMP and SPICE (see below) which are presently in their planning stages.

The panel members are Magdalena Balmaseda (ECMWF, UK), Scott Power (BoM, Australia), Toshio Suga (Tohoku University, Japan), Dongxiao Wang (SCSIO, China), Rodney Martinez (CIIFEN, Ecuador), Bi Qiu (UH, USA), David Neelin (UCLA, USA), Bill Crawford (IOS, Canada), Alexandre Ganachaud (IRD, New Caledonia), Amy Clement (RSMAS, USA), Wenju Cai (CSIRO, Australia) and Dick Feely (PMEL, USA). The panel is chaired by Axel Timmermann (IPRC, Honolulu, USA)

A number of invited international guests gave presentations on ongoing theoretical and observational research activities in the Pacific (Fei-Fei Jin, Jay McCreary, Kelvin Richards), and Indian Ocean (Gary Meyers, Bin Wang). New panel members were also introduced to the international CLIVAR structure (Tony Busalacchi), and to the new structure of US CLIVAR (David Legler) and new NOAA initiatives within the Pacific Ocean (Mike McPhaden, Howard Diamond). Furthermore, the panel discussed the scientific justification of new field programs such as: the South Pacific Circulation and Climate Experiment (SPICE) (presented by Lionel Gordeau) focusing on the southern Pacific western boundary currents; the Pacific Upwelling and Mixing Physics Experiment (PUMP) (presented by Billy Kessler) – a process study on mixing in the eastern equatorial Pacific; and the VAMOS Ocean Cloud Atmosphere Land Study (VOCALS) (presented by Roberto Mechoso) focusing on the air-sea-land interactions in the south-eastern tropical Pacific. New directions for the next-generation of ocean models were presented by Stephen Griffies.

One of the focal points of the discussions and presentations was ENSO dynamics. The eastward propagating SST-westerly wind burst coupled instability, its role in triggering large El Niño events and its relevance for seasonal predictions was discussed thoroughly. In particular the effect of this type of instability in generating spread in ensemble forecasting was highlighted. Another key aspect of modulating ENSO activity is the annual cycle in the eastern equatorial Pacific which is mostly controlled by meridional, rather than by zonal SST gradients. Further theoretical and modeling work was recommended to elucidate the mechanisms which are responsible for controlling the amplitude of ENSO and its sensitivity to climate change. Fei-Fei Jin presented some theoretical work suggesting that at each point in parameter space ENSO is not just a single mode but rather consists of a combination of two modes: a biennial and a 4-year mode (in addition to the known SST modes). This new perspective may help to explain the diversity of ENSO behavior in the observed record. Furthermore, Fei-Fei Jin proposed a new semi-empirical ENSO instability index which can be directly estimated from observations as well as from coupled models. The panel recommended using this index as a standard index for CGCM evaluations.

Scott Power gave a presentation showing that ENSO can drive variability off the equator that is actually more predictable than ENSO itself. This arises because ocean thermodynamics and

dynamics in the region act as a low pass filter on the ENSO forcing. He used the same processes to explain why decadal ENSO-like patterns have a broader meridional structure than their interannual counterparts. Magdalena Balmaseda showed the current status of ENSO forecasting. Operational ENSO prediction with the multi-model approach now produces reliable seasonal forecasts, but it is usually at the expense of large ensemble spread. Increasing the forecast resolution can only be achieved by improving the quality of the individual forecasting systems. Crucial problems common to many forecasting systems are initialization shocks, weak MJO-ENSO interactions and errors in the simulated ENSO statistic. Some of these problems can be alleviated by short-term practical fixes such as flux correction or anomaly assimilation, but fundamental long-term solutions are still needed. Better coupled models and more balanced ocean-atmosphere initialization procedures are required. Ensemble strategies other than the multi-model, such as stochastic physics, should be explored. In recognition of our imperfect understanding of ENSO dynamics and in the light of the relatively slow progress in improving seasonal predictions, the panel proposed to organize an international ENSO meeting in Australia in late 2007.

Societal aspects of tropical climate variability were discussed by Rodney Martinez who presented an overview of how climate information percolates down to decision makers in South America. He mentioned the current applications on agriculture, health, climate disaster related management and other sectors. There are a lot of gaps between users and climate information producers. Considering the current societal needs is important to seasonal forecast development in Latin America, which combines dynamical and statistical methods. The impact of MJO and decadal variability in regional and local forecasting must be addressed to contribute more reliable products and applications to users. One of the main challenges in the Eastern Pacific which is directly related with social and economic impacts is to improve the understanding of coastal processes, mesoscale structures and convection mechanisms associated with global and regional circulation patterns. The presentation also raised the general question of who is most profiting from climate forecasts. Scott Power showed that the impact of ENSO is not always linear in all locations (e.g. in Australia and the SW U.S.), and this needs to be considered in the provision of climate services. These issues need to be further considered by the climate forecasting community, and will be addressed in the proposed 2007 ENSO meeting.

Akio Kitoh gave a detailed description of the climate projection uncertainties in the Pacific as simulated by the multi-model ensemble of greenhouse warming simulations conducted for the Fourth Assessment Report of IPCC. The presentation showed that many of the state-of-the-art coupled general circulation models exhibit severe biases in the tropical mean state, the annual cycle and ENSO variability. One of the key systematic biases in the tropical eastern Pacific is the equatorial cold bias as well as the south-eastern tropical Pacific warm bias. Different hypotheses were discussed for the origin of these biases. While the cold bias might be due to a lack of resolved tropical instability waves in CGCMs or an unrealistic representation of light attenuation in the water column, warm biases in the south-eastern Pacific might be due to under-represented stratus cloud-SST feedbacks, lack of ocean eddies, or problems in

simulating the strength of oceanic Tsuchiya jets that upwell near the Peruvian coast. Roberto Mechoso's presentation of the new field program VOCALS which is strongly endorsed by the CLIVAR Pacific Panel, is aimed at targeting some of these questions. Also the new research program PUMP addresses some of these issues by focusing on the role of mixing in setting up the mean thermocline and its variability in the eastern equatorial Pacific. The CLIVAR Pacific panel recommended establishing closer ties between PUMP and VOCALS, since equatorial processes may influence the south-eastern Pacific via the atmosphere or changes in the heat divergence as well as the other way round, via eddy-heat transports and atmospheric circulation anomalies. Another key area for the global climate system is the western tropical Pacific warm pool which affects the strength of the Walker circulation and the position of the stationary wave patterns in the extratropics. In recent years, the general interest in temperature regulation in this area has decreased although fundamental questions on thermostats still remain unsolved. Owing to a delicate balance between radiative effects, latent cooling and ocean heat transport the average heat flux in the warm pool area for present-day conditions is close to zero. However, paleo data reveal that the warm pool area was about 4 K colder under glacial conditions than presently, suggesting that the delicate heat balance in this area is subject to long-term changes. Concern on the future temperature evolution in this area has been raised by the panel. Climate modeling uncertainties in this area are also large, thereby prohibiting an accurate assessment of the warm pool's role in global climate change. The panel recommended that more targeted field-programs have to be conducted to address these crucial questions and was strongly supportive of the ongoing and planned activities of the South China Sea Institute in launching extensive field campaigns in this area as presented by Dongxiao Wang.

Western boundary currents play an essential role in releasing heat originally coming from the tropical oceans to the atmosphere. They play a key role in modulating regional climates in Japan and Australia, as well as global climate. Wind-stress changes can lead to substantial changes in the position of the fronts accompanying these western boundary currents causing large temperature anomalies which may eventually influence also the atmospheric circulation. The very successful field program, the Kuroshio Extension System Study (KESS), has addressed some of these issues in the Kuroshio area and Bo Qiu's presentation on decadal changes in this region led to a discussion on the potential long-term predictability of thermocline anomalies in the western North Pacific. The panel decided to evaluate the hindcast/forecast skill of simple ocean prediction models driven by observed wind-stress anomalies as well their potential use for society. Toshio Suga discussed the role of eddy formation and mode waters in the climate of the North Pacific. Satellite data, as well as hydrographic data have helped jointly to disentangle some of the complex interactions between flow fields and temperature anomalies in the North Pacific as highlighted by Bill Crawford. The aim of the newly suggested field program SPICE is to understand the dynamics of the southwestern boundary currents as well as their influence on climate. Lionel Gordeau gave a convincing presentation on the scientific and technical challenges of such an endeavor. Physical aspects of subtropical-tropical connections in the South Pacific involving the western boundary currents were outlined by Kelvin Richards. Alexandre Ganachaud is actively involved in the planning stages of SPICE. The panel recommended establishing closer links to the KESS community to learn from their experience of an analogous experiment in the North Pacific. While SPICE is focusing mostly on the

subtropical gyres, a link should also be established to ongoing activities in China to monitor the low latitude western boundary currents (LLWBCs). Furthermore, the relevance of these boundary currents in the overall meridional oceanic heat transport needs to be re-assessed using ocean general circulation model simulations. Fritz Schott pointed out that the role of meridional heat transports associated with the LLWBCs is captured differently in different ocean assimilation products such as SODA-POP and ECCO. These results need to be reconciled soon using forced OGCM simulations.

Pan-oceanic connections were discussed by Wenju Cai and Axel Timmermann. Wenju Cai focussed on the supergyre in the southern hemisphere as well the oceanic connections between the Pacific and the Indian ocean via Godfrey's Island rule, Axel Timmermann presented results from the CMIP-2 waterhosing experiments which suggests that a weakening of the North Atlantic meridional overturning circulation leads to a southward shift of the ITCZ in the Atlantic and the Pacific with important consequences for the meridional SST gradient, the annual cycle and ENSO. These oceanic and atmospheric teleconnections between the ocean basins will be a major topic of the CLIVAR workshop on multidecadal to centennial climate variability which will be held in Honolulu from November 15-17th 2006.

Climate change issues in the Pacific were discussed by Amy Clement, Wenju Cai and Akio Kitoh. Amy Clement's presentation sketched how our understanding of paleo-climate can be used to assess future climate sensitivities. This linkage between PAGES and the CLIVAR Pacific panel will be consolidated in near future. The influence of the radiative forcing of aerosols has been estimated by Wenju Cai and colleagues. Most interestingly, the aerosol forcing can account for 0.6-0.8 K cooling in the central equatorial Pacific with the subpolar North Pacific subject to more than 1K cooling due to direct aerosol forcing. This may have compensated some of the greenhouse warming signal in the Pacific Ocean and its polar amplification. Akio Kitoh pointed out that climate modeling uncertainties for future climate change projections are still very large and exacerbate regional assessments of future climate change in the Pacific. An intense debate started on the question whether all CGCM greenhouse warming simulations should be treated equally by the IPCC or whether metrics can be introduced which lead to a weighting within the multi-model ensemble of CGCMs. Aristocratic and democratic viewpoints were put forward but no conclusion could be reached. Another important problem of climate change is that of the sources and sinks of carbon dioxide. Dick Feely presented results from the most recent field programs in the Pacific, illustrating that the interannual and interdecadal trends of surface water $p\text{CO}_2$ variability show significant large-scale spatial differences due to natural variability and anthropogenic impacts on atmosphere-ocean CO_2 fluxes.

The Pacific panel meeting concluded on Sunday with a hiking excursion to the Ko'olau Mountains. After some adjustment phase to the muddy trails and the little tropical winter drizzle, spirits were recharged with rewarding views into fern valleys, onto breathtaking mountain ridges and the deep blue Pacific Ocean.

The Third Session of the CLIVAR /GOOS Indian Ocean Panel

R. Boscolo and G. Meyers, CLIVAR/GOOS Indian Ocean Panel
Corresponding author: rbos@iim.csic.es

After a sudden change of venue in order to avoid the outbreak of Chikungunya fever in La Reunion, the Indian Ocean Panel ended up holding its third session in Honolulu, Hawaii USA, on 27 February – 2 March 2006.

The Indian Ocean Panel was established in 2004 and its primary goal was to prepare a regional implementation plan for sustained observations relevant to climate. The implementation plan was published just before the panel meeting (WCRP Informal Report No. 5/2006 and GOOS Report No. 152) and can be downloaded from <http://eprints.soton.ac.uk/19645/>

Some important scientific advances were presented during the meeting. There are a number of studies now that point toward the important (and often subtle) impacts of Indian Ocean Sea Surface Temperature (SST) on climate on a global scale. There are three places in the Indian Ocean where the thermocline is shallow enough to allow for significant dynamical feedback to SST. They are the upwelling regions off Somalia and Sumatra/Java and the ridge in the thermocline near 5-10°S. These places are important because slowly evolving features like Rossby and Kelvin waves and major currents can alter SST, interact with the atmosphere and affect Pacific SST and climate as far away as North America. Model results suggest that the development of ENSO can be influenced by Indian Ocean SST. The idea is that Indian Ocean SST does not cause ENSO but sometimes influences how it evolves.

Results of IOD-ENSO forecast experiments using the GFDL coupled model and SINTEX-F model show that past Indian Ocean Zonal Dipole Mode (IOD) events demonstrate a possible predictability with a lead time of about six months, although there is significant influence of the predictability barrier during winter and spring seasons. It seems that some but not all IOD events are predictable. The southwest tropical Indian Ocean is emerging as an important region for climate variability with potential predictability because of the thermocline ridge 10-15°S. Large ocean Rossby waves in response to ENSO and/or IOD propagate into the region and induce SST anomalies associated locally with precipitation and tropical cyclone activity. The transit time for these ocean waves across the basin is about one year, a delay that gives rise to enhanced predictability in the region.

The Indian Ocean ocean-atmosphere exhibits energetic intraseasonal SST variability. Intraseasonal variations are the building blocks of monsoons and understanding the heat budget of the upper ocean, particularly the mixed layer, at intraseasonal time scales is a critical area of research. There is no doubt the ocean responds to the atmosphere at this time-scale. For example, there is substantial sub-seasonal SST variability - O(1-2°C) - in the southwestern Indian Ocean thermocline ridge. Strong Ekman pumping raises the thermocline close to the surface and affects SST, as well as surface fluxes. Model experiments suggest 3-D oceanic processes and active ocean-atmosphere coupling occur during these events. But the role of ocean-to-atmosphere feedback at this time scale remains uncertain. Continuous time series are required for monitoring these events and one of the key reasons for establishing a basin-scale form mooring array with upper ocean temperature, salinity and current measurements.

All of the available MBT, XBT and hydrographic temperature profiles for the Indian Ocean during the 20th century are now assembled into a new, high quality, flagged data set called the

Indian Ocean Thermal Archive (IOTA). A preliminary analysis of the linear subsurface temperature trend using IOTA in the tropics from 1960 to 2000 shows warming of the surface layer and cooling in the depth range of the thermocline, i.e. increased stratification. Analysis of the subtropical and sub-antarctic region shows a warming trend extending to considerable depth, >500m.

A preliminary analysis of OA-flux - a newly developed surface heat flux dataset which integrates satellite observations with surface moorings, ship reports, and atmospheric model reanalyzed surface meteorology - and other products pre-dating the satellite period found that the amount of the net heat gain received by the tropical Indian Ocean has been reducing due to an increase in evaporation. Surprisingly, surface heat fluxes alone cannot explain the warming trend observed in much of the tropical Indian Ocean surface layer.

The panel reviewed the progress in implementing a basin scale mooring array and a multi-platform observing system in order to understand the role of the Indian Ocean circulation and structure in interactions between the IOD, ENSO and the monsoons. JAMSTEC (Japan) will maintain three TRITON moorings and an ADCP near the equator at 90-95°E. NOAA (USA) will maintain ATLAS moorings at 1.5°N, 0°, and 1.5°S along 80.5°E and at 0°, 90°E and an ADCP near 0°, 80°E. DoD (India) will maintain three moorings on the equator at 77°, 83° and 93°E. The meteorological measurements at the moorings will also be extremely valuable to weather forecasting, data assimilation issues and weather-reanalysis efforts. At present there are few such measurements in the Indian Ocean and this lack of information prevents accurate initial condition determination of weather forecasts and limits reanalysis efforts.

INCOIS (India) hosts the regional Argo data centre and coordinates float deployments and implementation activities. The Argo floats should eventually provide seasonal to interannual temperature and salinity fields. The mapping accuracy using the fully implemented Argo profile data was demonstrated by observing system simulations. Argo floats are needed to monitor the region south of 20°S. Advice on the regional implementation of Argo was passed to the International Argo Science Team.

The Panel identified the XBT lines that have highest priority for implementation. The Indian Ocean XBT network was enhanced to improve observation of oceanic structure related to Indonesian Throughflow and inflow to the western boundary cross equatorial currents.

The Panel reviewed the progress of the INSTANT experiment which aims at designing a monitoring array for mass, heat and salt transports in the Indonesian Throughflow. Data from the first 18 months have been collected and an additional 18 months are expected after the final recovery in December 2006. The data will be used to determine cost-effective proxy methods for long term monitoring.

The ability of a 5°x5° network of drifting buoys (drogued at 15m depth) to be maintained in the Indian Ocean given the divergent current systems existent in that region was explored using observing system simulation experiments. Even with targeted deployment, certain regions remained opaque to drifters: the upwelling regions off Somalia and Java during the Southwest monsoon. It is found that the divergence of drifters and the

oceanic eddies substantially impact the ability to reconstruct surface currents solely from drifter tracks. The 5°x5° sampling of drifters cannot resolve most of current and temperature variability except for large-scale meridional advection in the South Indian Ocean.

The Panel coordinated the planning of two research vessel based process studies on ocean-atmosphere interaction in intraseasonal variability—MISMO in the eastern Indian Ocean and VASCO/CIRENE in the western Indian Ocean. MISMO will be conducted in October - December 2006, focusing on the atmospheric evolutions in association with the intraseasonal disturbances known as the MJO (Madden-Julian Oscillation) and the ocean responses to the MJO events. Further information on MISMO can be found at <http://www.jamstec.go.jp/iorgc/mismo/>.

The VASCO-Cirene experiment will take place from the beginning of January until mid-February 2007. The ship campaign, within the western Indian Ocean will be synchronized with the meteorological measurements based on balloons launched from Seychelles. One ATLAS mooring

will be deployed at the beginning of the experiment at the flux reference site at 67°E, 8°S. The ship will then proceed to perform a ~25 day on station cruise in this region of strong intraseasonal perturbation with intensive physical oceanography, air-sea fluxes and atmospheric measurements.

Finally the Panel discussed the establishment of a virtual one-stop shop for integrated management of Indian Ocean climate data, to include data quality control as well as information about access to data. The rationale is to assist with product generation (maps, input to assimilation models, etc.), and to handle data types where Indian Ocean data are not easily aggregated from original data sites. The focus is on the ocean and atmospheric boundary layers with data from: Argo, drifters, moorings, XBT, sea level, ADCP, CTD and bottles. The project will utilise the existing capability at INCOIS and APDRC, as well as the Argo, Mooring and XBT facilities at other sites, and identify the gaps and challenges we face in establishing an integrated activity. More information on the activities of the CLIVAR/GOOS Indian Ocean Panel can be found at: <http://www.clivar.org/organization/indian/indian.php>

US CLIVAR Madden – Julian Oscillation Working Group (MJOWG)

D.E. Waliser¹ and K R Sperber²

¹Jet Propulsion Laboratory, Pasadena, U.S.A.

²Lawrence Livermore National Laboratory, Livermore, U.S.A.

Corresponding author: duane.waliser@jpl.nasa.gov

In spring 2006, US CLIVAR established the Madden-Julian Oscillation (MJO) Working Group (MJOWG). The formation of this 2-year limited lifetime WG was motivated by: 1) the wide range of weather and climate phenomena that the MJO interacts with and influences, 2) the fact that the MJO represents an important, and as yet unexploited, source of predictability at the subseasonal time scale, 3) the considerable shortcomings in our global climate and forecast models in representing the MJO, and 4) the need for coordinating the multiple threads of programmatic and investigator level research on the MJO. Near-term tasks involve the development of metrics for assessing model performance in both climate simulation

and extended-range/subseasonal forecast settings, as well as designing and coordinating multi-model experimentation and analysis to diagnose and improve model shortcomings and assess MJO predictability characteristics and present-day prediction skill. In addition, the WG will help to coordinate MJO-related activities across other programmatic bodies (e.g., GEWEX, International CLIVAR, Thorpex) and will explore the applications and potential user base for subseasonal predictions based on the MJO. Workshops that address these issues are being planned, with results being communicated in summary reports and peer-review articles. For additional details, see http://www.usclivar.org/Organization/MJO_WG.html.

AMMA and its first International Conference address the West African Monsoon

Jean-Luc Redelsperger¹, Chris Thorncroft², Arona Diedhiou³, Thierry Lebel³, Douglas Parker⁴, and Jan Polcher⁵

¹CNRM/GAME CNRS and Météo-France, ²SUNY at Albany, US, ³LTHE/IRD, Niger, ⁴University of Leeds, UK, ⁵LMD/CNRS, France

Corresponding author: chris@atmos.albany.edu

The West African monsoon (WAM) is a coupled land-ocean-atmosphere system characterized by summer rainfall over the continent and winter drought. Over the land the effects of the monsoon are most evident over an area stretching eastward from a line between Cameroon in the south and Niger in the north to the west coast of Africa. The annual cycle of rainfall in the West African region is characterized by a poleward migration of peak rainfall up to August followed by a more rapid retreat. It also includes an apparent “jump” in the location of peak rainfall at the end of June from the coastal region around 5°N to about 10°N. The precipitation is provided by the ubiquitous mesoscale convective systems and synoptic African easterly waves. Ultimately the nature of the surface conditions

over the land (e.g., soil moisture, vegetation) and over the ocean (sea surface temperatures) determine the nature and variability of the WAM on interannual and longer timescales. In addition, the Sahara, just north of the rainy zone, provides an abundant supply of dust which may interact with and impact the intensity of the WAM.

Over the past 50 years the change in West Africa from wet to much drier conditions is among the strongest interdecadal signals of the past century. This drying trend coupled with marked interannual variations has had devastating environmental and socio-economic consequences.

Fundamental gaps in our observation, understanding,

and modelling of this complex system have limited our prediction skills. To bridge these gaps, the African Monsoon Multidisciplinary Analysis (AMMA) Project, has adopted a multidisciplinary approach, involving substantial international collaboration that links observation, data analysis and modelling on a wide range of space and time scales.

The processes that couple the land, ocean and atmosphere take place in association with multiple interacting space and timescales. To address the multiple scales that characterize the WAM, AMMA is structured around four interacting spatial timescales (figure 1). AMMA is a multi-year project with three nested observation periods, LOP (2002–2010), EOP (2005–2007), and SOP (2006), which stand for the long-term, enhanced, and special observing periods, respectively.

The AMMA Project has three overarching aims: (1) improve our understanding of the WAM and its influence on the physical, chemical and biological environment, regionally and globally; (2) provide the underpinning science that relates variability of the WAM to issues of health, water resources, food security and demography for West African nations and defining and implementing relevant monitoring and prediction strategies; and (3) ensure that the multidisciplinary research carried out in AMMA is effectively integrated with prediction and decision-making activity.

Scientists from more than 30 countries, representing more than 130 institutes are involved in AMMA. AMMA receives funding from the European Union, France Action Programme Inter-organisme and the United Kingdom, as well as the United States and pan-African projects.

The CLIVAR Scientific Steering Group (SSG) endorsed AMMA as one of its key contributing projects in March 2003. AMMA was also approved by the GEWEX SSG as a Continental-Scale Experiment in February 2005. AMMA also has strong links to other international projects, including the International Geosphere-Biosphere Programme International Global Atmospheric Chemistry Project and international Land Ecosystem-Atmospheric Processes Study, and the Global Climate Observing System and Global Ocean Observing System. In collaboration with THE Observing System Research and Predictability Experiment (THORPEX), AMMA is addressing high impact weather prediction and predictability.

The First International AMMA Conference which was held in Dakar, Senegal, 28 November–2 December 2005, was very

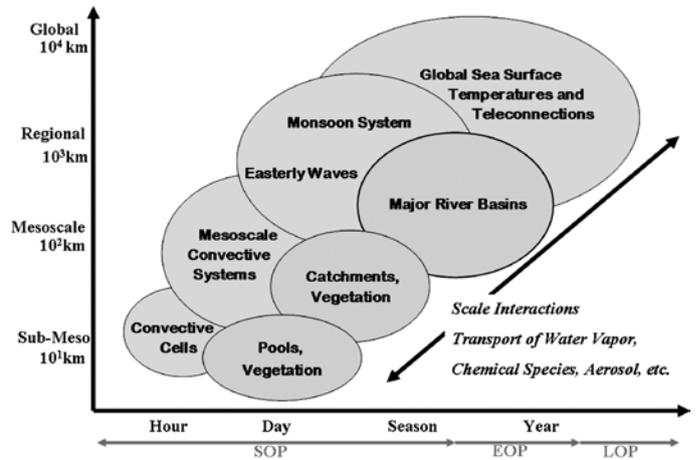


Figure 1: AMMA is structured around four interacting spatial timescales

successful with 255 participants from 23 countries and more than 300 abstracts submitted. The Conference brought together researchers from around the world working on the WAM and its impacts, to review ongoing research activities and to discuss future contributions and directions within the AMMA research program. It also provided the first real opportunity for establishing and coordinating collaborations at the international level, and in particular with African scientists.

The Conference program included a mixture of plenary sessions, poster sessions and parallel working sessions. The plenary sessions included invited and contributed oral presentations. The working sessions were designed to provide an opportunity to discuss future research directions in AMMA as well as to coordinate and promote international collaboration. A workshop dedicated to climate impacts took place immediately after the conference and a training workshop on monitoring and forecasting the African monsoon impacts on agriculture and vegetation was held the following week in Thiès.

More information about AMMA-International, including past and future meetings and the science international implementation plans is available at: <http://www.amma-international.org>.



Participants at the AMMA First International Conference, Dakar, Senegal, 28 November - 2 December 2005

The MJO and agricultural decision making in northern Australia.

Lexie Donald¹, Holger Meinke¹, Sarah Lennox¹, Matthew Wheeler², Fiona Lo², Aline de H N Maia³

¹Department of Primary Industries and Fisheries, Toowoomba Queensland, ²Bureau of Meteorology Research Centre Melbourne Victoria, ³Embrapa Meio Ambiente, Jaguariúna, Brazil.

Corresponding author: Alexis.Donald@dpi.qld.gov.au

In agriculture many decisions have to be made at sub-seasonal timescales, yet with lead times that go beyond the scope of weather forecasts. This, and the potential to forecast the chances of wet and dry spells that the Madden Julian Oscillation (MJO) offers, is behind the interest in the MJO shown by rural practitioners in Australia. This interest motivated us to conduct the research recently published in GRL (Donald et al 2006) where we investigated the near-global impact of the MJO on rainfall. Here we will provide an updated synopsis of the work reported in GRL, followed by an outline of a rural industry funded R&D project that commenced earlier this year.

Analysis of about 30 years of daily rainfall data reveals significant modulation of tropical and extra-tropical rainfall related to the equatorial passage of the MJO. We used the Real-time multivariate MJO (RMM) Index (Wheeler and Hendon 2004) to determine the location and amplitude of the MJO from June 1974 to May 2006, and linked the passage of MJO events with suppressed and enhanced rainfall in the Austral-Asian region and beyond (Figure 1 page 13). The aim was to develop a system with discriminatory ability that bridges weather-climate forecasting gap by providing a risk management tool for tactical decision-making in agriculture.

We calculate associated mean sea level pressure anomalies (MSLP) to determine synoptic scale features that might explain the observed rainfall anomalies (Figure 2 page 13). Standardised aggregated distributions of MSLP anomalies from stochastically generated MJO phases demonstrate the (low) probability of our results being random effect. The methodology follows that outlined in Donald et al (2006), but with up-to-date data. The results suggest that the west to east passage of the MJO across the tropics generates, via teleconnections, global atmospheric responses that enhance or suppress the prospect of precipitation across large parts of the Australasian region and beyond.

This information is now available on our experimental web site (www.apsru.gov.au/mjo). Amongst other users, this web site attracts many decision-makers from the grazing industry, largely because Australia's grazing lands are already threatened by climate variability and climate change. The beef industry is moving north in an attempt to escape ongoing drought and the possibility of further climate change induced rainfall reductions. However, such a shift north might not be sustainable given existing pressures, many of which are related to high climate variability. A repeat of past major degradation events must be prevented to avoid further irreversible damage and hardship. Better quantification and predictions of the onset, duration and termination of the northern Australian wet season would provide critically important information for better decision-making across the grazing industries, but would also have tangible benefits for other agricultural enterprises (grain, sugar, horticulture) and, in fact, other sectors (health, infrastructure development, tourism etc).

The "Enhancing the predictability of the northern Australian wet season" project aims to improve the predictability of onset, duration and termination of the Australian monsoon season by examining the influences of the MJO and ENSO. Knowledge of the tropical and extra-tropical MJO-associated weather states can significantly improve the tactical management of climate-

sensitive systems such as agriculture. Based on this research, an Australian R&D funder (Land & Water Australia via its 'Managing for Climate Variability' program) is providing resources to operationalise this research and make it an integral part of agricultural decision making. The project aims to offer improved probabilistic wet season predictions, initially targeted towards the specific needs of the Northern Australian grazing industry. However, the information generated will be sufficiently generic so that it can be adapted for use by other (agricultural) sectors and in other regions such as South and Southeast Asia and South America (www.apsru.gov.au/mjo; www.bom.gov.au/bmrc/clfor/cfstaff/matw/maproom/RMM/index.htm; www.bom.gov.au/climate/tropnote/tropnote.shtml).

Specifically the project will: 1) reduce climate related risk to agricultural industries (using the grazing industry as a case study) by providing improved quantification and predictions of the northern Australian wet season; and 2) create new technologies for better decision-making in climate sensitive systems of northern Australia. The specific industry driven objectives include probabilistic predictions of the entire wet season rainfall with lead times of 2 months or more. At leads of less than 2 months, the project will provide forecasts of active and break periods within the wet season.

A preliminary systems analysis determining the leverage points for climate information and forecasts has been conducted with grazing industry experts and representatives. This revealed that quantifying the length of the dry season is important information for decision making. It influences many logistical decisions such as staffing, stocking rates and stock movement. Profit margins shift during the dry season, and intraseasonal climate forecasts may help maximise returns and minimise risk. Forecasts about the wet season onset and duration will assist with determination of pasture growth, stocking rates for the subsequent dry season, and the growth rates of young stock.

Acknowledgement:

The project is funded by Land and Water Australia. Any queries to the Project Officer Alexis.Donald@dpi.qld.gov.au

References:

- Chang, C.-P in Chang, C.-P., Wang, B. and Lau, N.-C. G. (Eds) 2005. The Global Monsoon System: Research and Forecast. Report of the International Committee of the Third International Workshop on Monsoons (IWM-III) WMO/TD No.1266, TMRP Report No. 70
- Donald, A., Meinke, H., Power, B., Wheeler, M. C., Maia A de H. N., Stone, R. C., Ribbe J. and White N. 2006. Near-Global Impact of the Madden-Julian Oscillation on Rainfall, *Geophysical Research Letters*, **33**, L09704, doi:10.1029/2005GL025155
- Lorenz D.J. and Hartmann, D.L. 2006. The effect of the MJO on the North American Monsoon. *Journal of Climate*, **19**, 3, 333-343.
- Wheeler and Hendon 2004. An All-Season Real-time Multivariate MJO Index: Development of the index for monitoring and prediction in Australia. *Monthly Weather Review*, **132**, 1917-1932

On the variability of secondary heat sources over northwest India

U. V. Bhide, S. M. Bawiskar, V. R. Mujumdar, P. V. Puranik, S. P. Ghanekar, N. V. Panchwagh and M. D. Chipade
 Indian Institute of Tropical Meteorology, Homi Bhabha Road, Pashan, Pune, 411008, India
 Corresponding authors: bhide@tropmet.res.in, bawiskar@hotmail.com

Introduction

Kripalani et al (2005) have identified 'Speed-breakers' of All India Monsoon Rainfall (AIMR) and stated that Indian summer monsoon variability is partly due to the external surface boundary forcing and partly due to its internal dynamics. They have brought out that the dominance of 3-7 and 10-20 day modes in a monsoon season would favour monsoon activity over Indian region, while the 30-60 days mode would not. They have said that to forecast the behaviour of these intraseasonal modes is still a challenge for the researchers.

It is well known that many efforts have been made earlier to identify these modes through study of different circulation parameters over Indian region. Krishnamurti and Bhalmé (1976) have defined nine elements of the monsoon system over India and have shown that a quasi-bi-weekly oscillation existed in these parameters. They carried out a sequential ordering of these in terms of their respective phase angle and showed that in the stabilizing phase, soon after the realization of maximum dry and moist static instabilities, there occurred, in sequence, an intensification of the monsoon trough, satellite brightness, Mascarene high, Tibetan high and the tropical easterly jet, followed by a maximum in rainfall over central India which is primarily associated with monsoon depressions. Dominant modes are also found in the shorter time scales (<6 days) in their analysis. Gadgil (1988) has mentioned that the 5-7 day mode of rainfall variability over central India has been found to be linked to the synoptic scale monsoon disturbances while the 10-20 day mode is associated with the active-break cycle of monsoon rainfall.

While discussing the mechanisms of low frequency oscillation of monsoon system Goswami (1991 and references therein) has opined that the evolution of monsoon circulation from wet to dry conditions over India is associated with the destabilization and stabilization of the atmosphere due to latent heat released in the atmosphere. Also the interaction between the organised convection and the large scale dynamics is responsible for the low frequency oscillations of rainfall. A diagnostic study by Bhide et al (1997), hereafter referred as BR, has brought out the coincidence of the diabatic heat sources and the heavy rainfall zones over the monsoon trough region during the active monsoon phases of the southwest monsoon in 1979 using the data collection of FGGE MONEX-1979. The events of heavy rainfall were associated with transient synoptic scale disturbances in the monsoon trough area. The results have further shown that whenever an intense heat source developed over the western monsoon trough area in the later days of the active phases of monsoon 1979, a positive differential heating gradient developed from east to west. Das (1962) had observed a positive differential heating gradient from west to east for the month of July. Thus, in the later days of active phases, the heating gradient reversed during 1979 and such a reversal was observed due to the westward movement of disturbances from the Bay of Bengal. These disturbances also showed a typical path along more southerly latitudes compared to normal. These observations for 1979 have shown a relationship between the organized convection and the large scale dynamics of the monsoon system in relation to evolution of monsoon circulation from the active to break phases of monsoon 1979 as pointed out by Goswami (1991 and references therein).

In view of the above observations, an effort is made in the present paper to bring out the space-time variations of the secondary diabatic heat sources over the monsoon trough region for the southwest monsoon of 2002, a drought year for India. Kalsi et al (2004) have analysed many regional and planetary scale parameters related to the unusual behaviour of monsoon 2002. They observed a break-like situation in July 2002 when the monthly rainfall departure was as large as -49% from the long period normal. The rainfall deficiency of July was found to be the main cause of the drought in the year. It was unusual for the season that although ten low pressure areas formed over Bay of Bengal, none of them intensified into a depression or storm. Contrary to this during the normal monsoon year 1997, five depressions and a storm formed over the Bay of Bengal. This indicated that the circulation over India remained conducive for good rainfall activity during monsoon 1997. Hence, similar estimation of heat sources and moisture sinks is carried out for monsoon 1997 and the results compared with the drought year 2002.

Data and methodology

Daily NCEP/ NCAR reanalysis data (Kalney et al., 1996) of u, v, T and RH for standard levels between 1000 and 100 hPa for 1 June to 30 September 1997 and 2002, have been used to estimate the apparent heat source (Q_1) and the apparent moisture sink (Q_2) over India following Luo and Yanai (1984) and Bhide et al (1997). The information on synoptic features and rainfall activity for the two seasons is based on the Weather Reports for June to September 1997 and 2002 published by India Meteorological Department.

Results and discussion

The spatial and temporal variations of the heating rate (q_1) and drying rate (q_2), at 500 hPa along 22.5°N across the monsoon trough for 1997 and 2002 are discussed below through $x-t$ diagrams following BR. The latitudinal variation of the vertically integrated heat source $\langle Q_1 \rangle$ and moisture sink $\langle Q_2 \rangle$ have been studied through $y-t$ sections by averaging their values for the east (80°-90°E) and west (70°-80°E) regions.

Figures 1 and 2 show the $x-t$ diagrams of 3-day moving average of q_1 and q_2 along 22.5°N at 500 hPa for the period from 1 June to 30 September for the years 1997 and 2002 respectively. The low pressure systems which have formed over Bay of Bengal during these seasons are marked chronologically in the figures.

$x-t$ diagram of q_1 and q_2

The most prominent feature is the repeated occurrence of large positive values of q_1 and q_2 east of 80°E (Fig. 1) for monsoon 1997. These are generally in association with formation of synoptic scale disturbances like depressions and the cyclonic storm, which formed over the Bay of Bengal. The q_1 and q_2 values are mainly negative, occasionally noticed to be large negative to the west of 80°E. This indicates that the differential heating gradient is positive from west to east during the season along 22.5°N at 500 hPa. Das (1962) observed more diabatic heating over the northeastern part and radiational cooling over the northwestern part of the country for the month of July. Thus, the gradient during 1997 is similar to what was observed by Das (1962) for mean July. The gradient is very large, particularly in the presence of synoptic scale disturbances. For monsoon 2002, however, large positive values of q_1 and q_2 are predominant

to the west of 80°E (Fig. 2). This indicates a reversal of the normal heating gradient for the entire monsoon season over India. Peculiarly the reversed gradient is very strong around 26 June, 18 July and 25 August. In the period 21 to 28 June 2002 a well marked low pressure area moved from the Bay of Bengal towards northwest India, keeping a more southward track. Different subdivisions of India located around 20°-25°N and west of 80°E showed Weekly Rainfall Departures of as much as 300-400% in this period due to the movement of the well marked low (Weekly Weather Reports, IMD, 2002). Though this was only a well marked low pressure area daily rainfall amounts reported by some stations were observed to exceed 30 cm between 26 to 28 June in the western trough region. One station, Bhavanager, reported 42 cm of rain on 28 June. This shows that the diabatic heating is due to organized cumulus clouds in presence of a transient synoptic system. The second low pressure area which formed over the north Bay region on 15 July also moved across the monsoon trough but its life cycle was shorter compared to that of June. It is remarkable that during this period, even if the all India rainfall was deficient, ranging from 40 to 60 percent of the long term daily normal, the north west of India, its adjoining Arabian sea region and north peninsular India shows good cloudiness in the satellite images. During this period the x-t diagram also shows a marked reversal of heating gradient around 18 July (Fig. 2). Following these two events, a substantial decrease is observed in heating rates (q_1) on the western part (Fig. 2) for about ten days. In these epochs the q_2 values are observed to become negative practically for the entire longitudinal belt. The negative q_2 values are very large on the western and eastern ends of this belt. Such a change in the values of q_1 and q_2 indicates two epochs of suppressed convection over the monsoon trough region in July 2002. India experienced unprecedented below normal rainfall, -49% of the normal, for July 2002. The very large deficit in rainfall over

India for July 2002 has thus resulted from 2 epochs of break-like situations when circulation got disturbed. The monsoon did not revive even with the formation of a low pressure system over the Bay of Bengal on 15 July. The large positive q_1 and q_2 values between 15 and 20 July, observed west of 80°E, seem to be associated with the eastward moving cyclonic vortices. From the beginning of August, the heating and drying rates are observed to become positive and are also observed to spread over most of the belt covering 70° to 90°E. By 15 August the monsoon covered the entire country with a delay of about one month for the westernmost parts of India.

Monsoon 2002 showed a unique feature in the long historical records for India and that is the absence of monsoon depressions/storms over the entire season. The low positive or negative heating and drying rates for the eastern region of the monsoon trough over India for 2002 during July as well as August and September reflect this peculiar feature of the season (Fig. 2). During the season only five out of ten low pressure areas had a long life while others had a short life cycle. Contrary to this, presence of the large positive q_1 and q_2 values for the east region during monsoon 1997 (Fig.1) reflects frequent formation of monsoon depressions/storms in the season. Large q_1 and q_2 values have been observed in the presence of monsoon depressions and the storm for monsoon 1979 over the east region at the beginning of the two active phases of monsoon 1979 (BR).

y-t sections of $\langle Q_1 \rangle$ and $\langle Q_2 \rangle$

Figures 3 and 4 (page 14) show the y-t sections of daily vertically integrated heat source $\langle Q_1 \rangle$ and moisture sink $\langle Q_2 \rangle$ averaged over the east and west regions of India for monsoon 1997 and 2002 respectively. These figures show different persistent zones having positive values of $\langle Q_1 \rangle$ and $\langle Q_2 \rangle$. In these zones there are many occasions when the $\langle Q_1 \rangle$ and $\langle Q_2 \rangle$ values are simultaneously large positive. Development of a diabatic

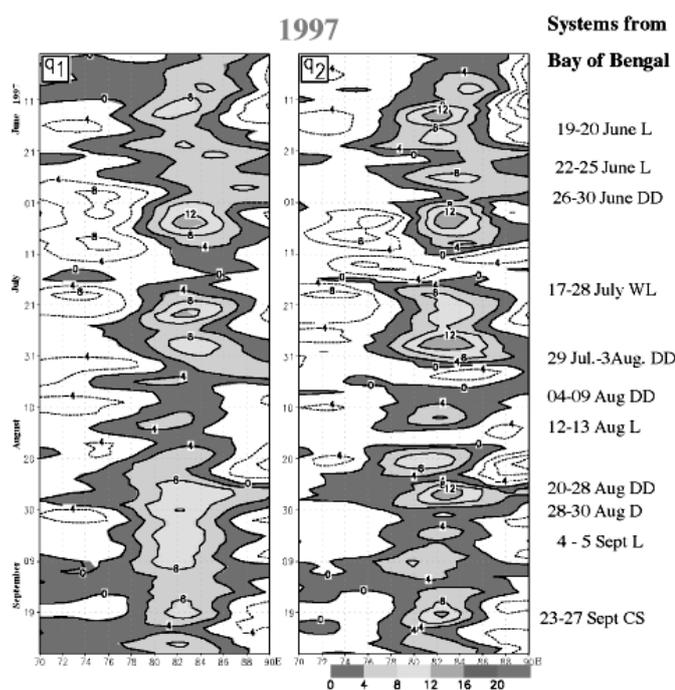


Figure 1 : x-t diagram of heating rate (q_1) and drying rate (q_2) at 500 hPa level along 22.5°N during June to 30 September 1997, between 70° to 90°E. The counter interval is at 4°C day-1. (L : low pressure area, WL : Well marked Low pressure area, D : Depression, DD : Deep Depression, CS : Cyclonic Storm)

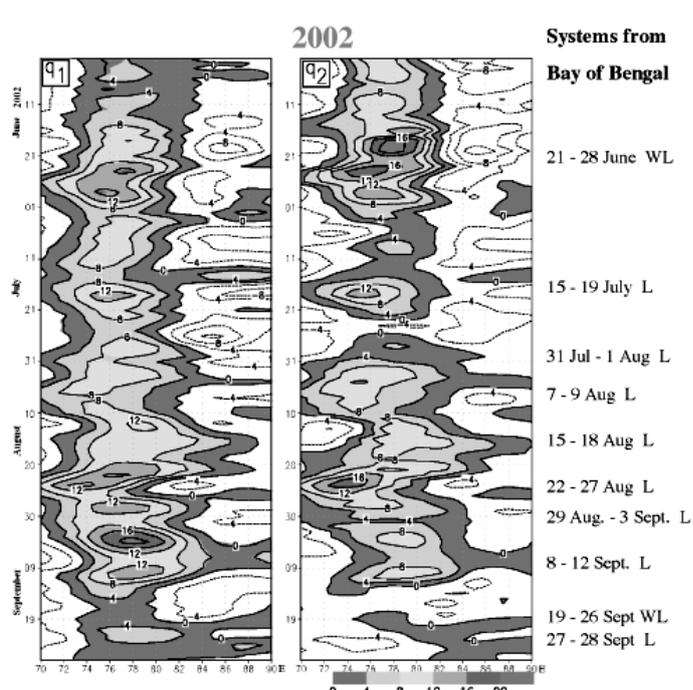


Figure 2 : Same as Fig. 1 except for 2002

heat source, due to cumulus clouds, is indicated by such a coincidence of large $\langle Q_1 \rangle$ and $\langle Q_2 \rangle$ values in these zones. Generally, cumulus clouds are organized in these events by synoptic scale disturbances. The latitudinal location of such a zone around 20°N is supposed to represent weather conditions of the monsoon zone (denoted by M) for both the east and the west regions of India. The latitudinal belt around 27.5°N on the east region is denoted by T to represent the convective activity over southern Himalayas or southern Tibetan region. The y-t sections for the west region show positive $\langle Q_1 \rangle$ and $\langle Q_2 \rangle$ values, north of 27.5°N which seem to be associated with presence of two types of systems, viz., eastward moving lows or cyclonic circulations induced due to eastward moving westerly waves in the mid-latitudes and west-northwestward moving monsoon systems from Bay of Bengal. This zone is hence denoted C. There is an intermediate zone of negative values of $\langle Q_1 \rangle$ and $\langle Q_2 \rangle$, denoted as $Q_1\text{NG}$ and $Q_2\text{NG}$ respectively.

For the east region, $Q_1\text{T}$ (Fig. 3a page 14) and $Q_2\text{T}$ (Fig. 3b) are narrow for monsoon 1997 while very broad for 2002 (Fig. 4a, page 14 and b). As far as the intensity of the vertically integrated heat source and moisture sinks, $\langle Q_1 \rangle$ and $\langle Q_2 \rangle$, is concerned a remarkable difference is observed between the two seasons. Many events of very large $\langle Q_1 \rangle$ and $\langle Q_2 \rangle$ values for monsoon 2002 are indicative of many events of heavy rainfall over southern Tibetan region. Normally heavy falls of rain occur in and near Himalayas during monsoon breaks under the influence of eastward moving troughs in westerlies further north (Rao, 1976). It is noteworthy that Kalsi et al (2004) observed the frequent passage of eastward moving cyclonic circulations throughout the monsoon season of 2002. During monsoon 1997, events of coincident heat source and moisture sink are less and their intensity is low compared to monsoon 2002 in the $Q_1\text{T}$ and $Q_2\text{T}$ zones for the east region (Fig. 3a and b). This indicates that the rainfall activity over Tibetan region was less during monsoon 1997 as compared to that for monsoon 2002.

The zones $Q_1\text{M}$ and $Q_2\text{M}$ show that for the east region during 1997 (Fig. 3a and b), the heat source and the moisture sink in the monsoon zone was frequently intense around 20°N . Also positive values of $\langle Q_1 \rangle$ and $\langle Q_2 \rangle$ are found to extend southward and northward from these zones. This indicates that the monsoon zone is quite broad during the events of intense convection. Due to this, the latitudinal extent of zones of heat source and moisture sink covers a very large portion of Indian region. Contrary to this, the $Q_1\text{M}$ and $Q_2\text{M}$ zones are narrow during monsoon 2002 (Fig. 4a and b).

For the west region, $Q_1\text{M}$ and $Q_2\text{M}$ zones show contrasting features for the two seasons with respect to intensity of heat source and moisture sink. During 1997, the heat source and moisture sink are weak and are found to be disorganized within the monsoon zones (Fig 3). While, during monsoon 2002, persistent zones of heat sources and moisture sinks are observed. Occasionally, in association with movement of synoptic systems, coming from the Bay of Bengal towards northwest India, the heat source and the moisture sink is very intense during the season (Fig 4). It is remarkable that during monsoon 2002, most of the westward moving low pressure systems took a more southward path than normal and decayed south of about 25°N . Contrary to this, monsoon depressions of July and August 1997 reached up to 30°N , over northwest India as weak systems. This variation in the tracks of the systems during the two seasons seems to be responsible for the difference in the pattern of $\langle Q_1 \rangle$ and $\langle Q_2 \rangle$ values over the west region. It can be noticed that as result of the absence of convective rainfall during July 2002, the $\langle Q_2 \rangle$ values are much smaller compared to $\langle Q_1 \rangle$ values.

Kalsi et al (2004) have noted the existence of a Tibetan Low/vortex, centered around 33°N and 85°E at 600 and 500 hPa levels in the monthly mean wind patterns for July 2002 and have linked this vortex to the frequent presence of eastward moving systems along the southern Himalayas during monsoon 2002. In the present study, the repeated occurrence of high values of the heat source and moisture sink in the zones $Q_1\text{T}$ and $Q_2\text{T}$ (Fig. 4) reflect such frequent passage of vortices. The absence of this feature during monsoon 1997 implies that the influence of mid-latitude westerly troughs was greater for monsoon 2002 over southern Tibet as compared to 1997. High positive $\langle Q_1 \rangle$ and $\langle Q_2 \rangle$ values for the east region in the Tibetan zone are associated with reduce convection in the monsoon zone in 2002. Intense negative values of the heat source and the moisture sink in $Q_1\text{NG}$ and $Q_2\text{NG}$ zones indicate more subsidence over the northern part of the monsoon trough region in association with the enhanced convection in the Tibetan zone.

Circulation changes over India during monsoon 1997 and 2002

The mean circulation pattern at 500 hPa showed very pronounced circulation changes from active to break phases of monsoon 1979 (BR) as compared to the other levels of the lower or upper troposphere over Indian region. Hence, the circulation changes are studied through y-t sections of daily average vector wind for 500 hPa for monsoon 1997 and 2002. Salient features of circulation changes observed for the two seasons are as follows.

y-t section of daily vector wind at 500hPa

Figures 5 and 6 (page 14) show the y-t sections of the vector wind for the east and west regions for 1997 and 2002 respectively. The scalar analysis of u (the zonal component of the wind) is superimposed. A comparison of these figures shows that during the peak monsoon months, July and August of 1997, there are many periods of strong monsoon westerlies (easterlies) to the south (north) of about 20°N for both the east and the west regions (Fig. 5). Monsoon depressions formed during these periods and many out of them intensified as deep depressions. Such a wind field indicates many long active phases of the monsoon over India during 1997, when the monsoon circulation remained undisturbed. Contrary to this, westerly flow is observed to cover the entire belt from 5° to 35°N during July 2002 except around 15 July (Fig. 6). Strong shears are observed around 25 June 2002 at 500 hPa indicating the presence of a cyclonic vortex in the east as well as the west region. A well marked low pressure system had traveled across the monsoon trough from the east to the west region after its formation over the Bay of Bengal on 21 June 2002. Such a vortex having a very strong circulation was found to be decay quickly over the western region by the end of June and subsequently, the entire Indian region came under the grip of westerly flow. Thus, the event of reversal of the heating gradient around 25 June as seen from figure 2, is found to be followed by significant circulation changes at 500 hPa (fig. 6). This sequence of events resembles the observations made by BR during monsoon 1979.

A weak vortex, noticed around 15 July (Fig.6), over east and west regions did not recover the monsoon activity since westerly/northwesterly flow is again seen to spread over the entire belt (5° to 35°N) in the subsequent period. This is the second time when the monsoon circulation became weak after reversal of the heating gradient this time (around 18 July) due to intense heating rates seen at 500 hPa on the western side of 80°E (Fig. 2). The break-like situation in July 2002 seems to have resulted due to these two periods when westerly winds dominated the entire Indian region, following two events of

continued on page17

From Donald et al (page 9): The MJO and agricultural decision making in Northern Australia

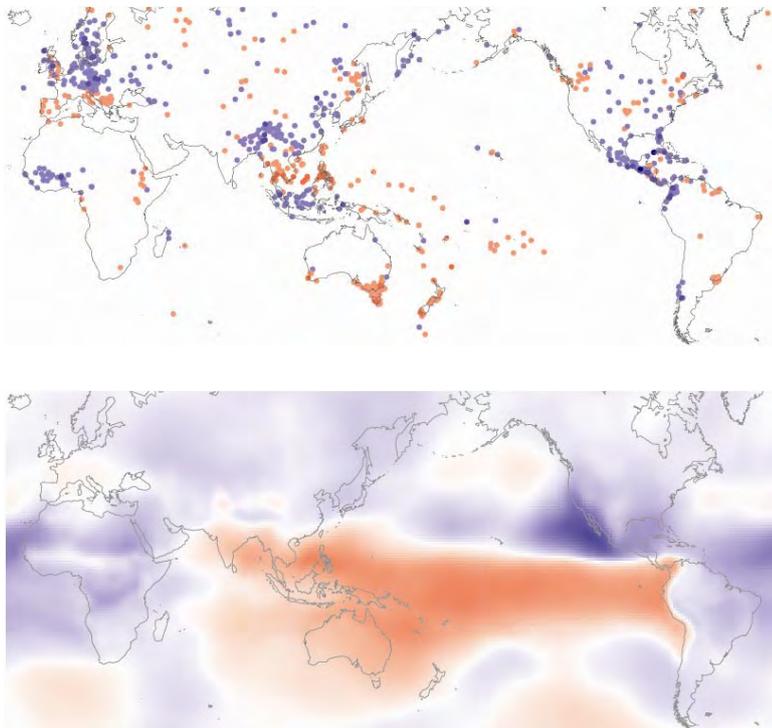
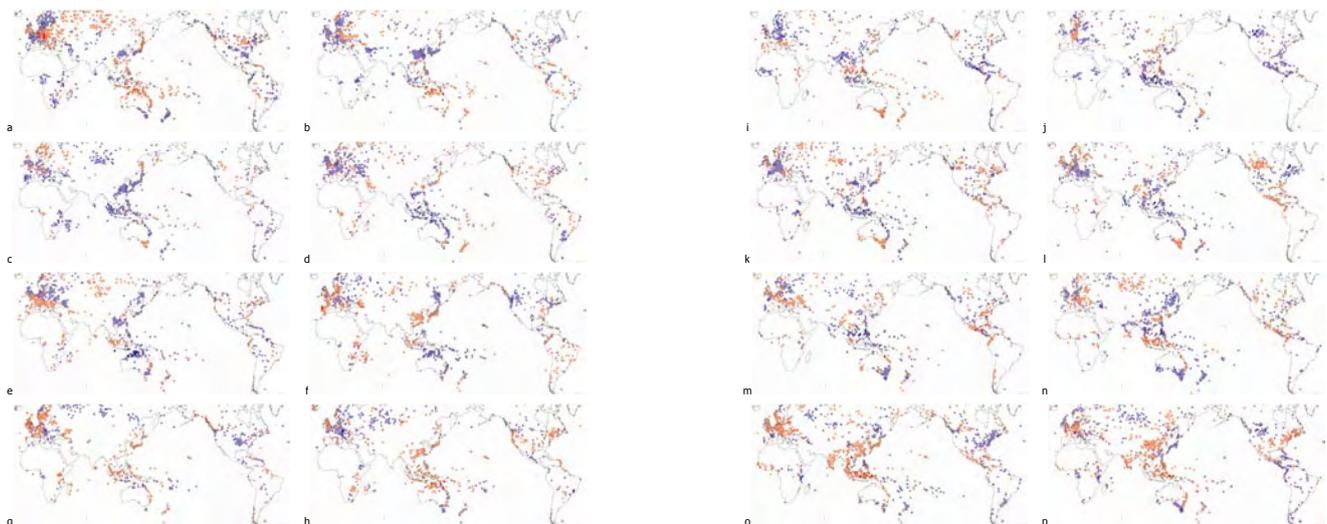


Figure 1: Austral Winter RMM Phase 1 Rainfall and MSLP anomalies. Rainfall anomalies (positive anomalies; enhanced rainfall; blue tones, negative anomalies; suppressed rainfall; red tones) correspond to MSLP anomalies (high pressure; positive anomalies; red tones, low pressure; negative anomalies; blue tones). A positive MSLP anomaly stretching from southern Asia, across the Maritime Continent and Australia to the western coast of South America is reflected by negative rainfall anomalies. Rainfall is suppressed throughout Asia and Australia in the region of the high pressure anomalies. Western Indonesia evidences rainfall enhancement, possibly maintained by local equatorial easterly anomalies (Chang et al, 2006). Negative MSLP anomalies (blue tones) correspond to enhanced rainfall effects in northwest Mexico and Arizona similar to those reported by Lorenz and Hartmann (2006).



2A

2B

Figure 2: Austral summer RMM Phases 1 – 8 (a-h) and winter RMM Phases 1- 8 (i- p) rainfall anomalies. Positive anomalies (enhanced rainfall) blue tones, negative anomalies (suppressed rainfall) red tones. See www.apsru.gov.au/mjo to see all corresponding MSLP anomaly maps, and standardised aggregated distributions.

from Bhide et al (page 10): On the variability of secondary heat sources over northwest India

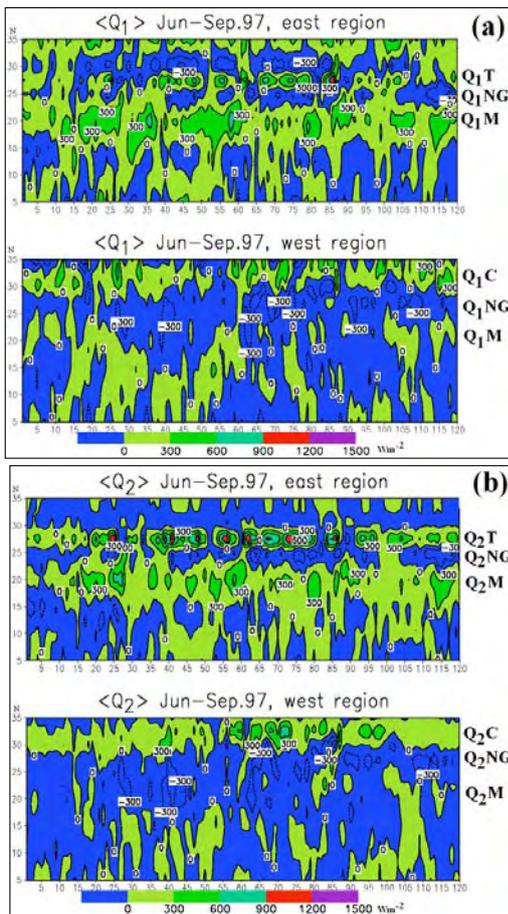


Figure 3 : y - t diagram of vertically integrated apparent a) heat source $\langle Q_1 \rangle$ and b) moisture sink $\langle Q_2 \rangle$, averaged over East (80°-90°E) and West (70°-80°E) regions of India in Wm^{-2} during monsoon 1997.

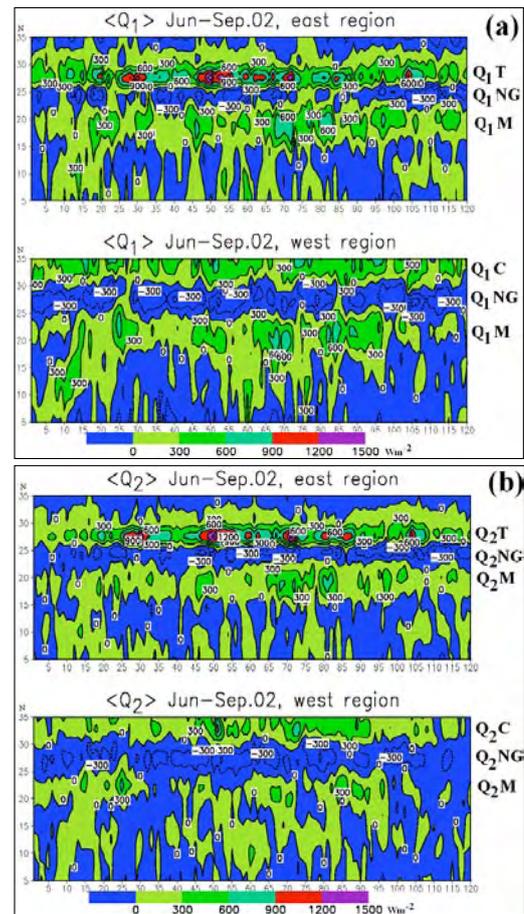


Figure 4 : Same as Figure 3 except for 2002

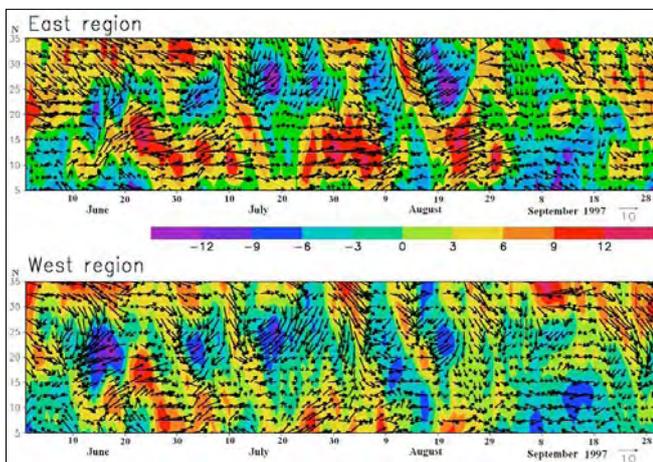


Figure 5 : y - t section of averaged vector wind (ms^{-1}) at 500 hPa level for (a) east region, (b) west region of India during the southwest monsoon 1997. Colour shading shows the zonal component (ms^{-1}) of the wind vector

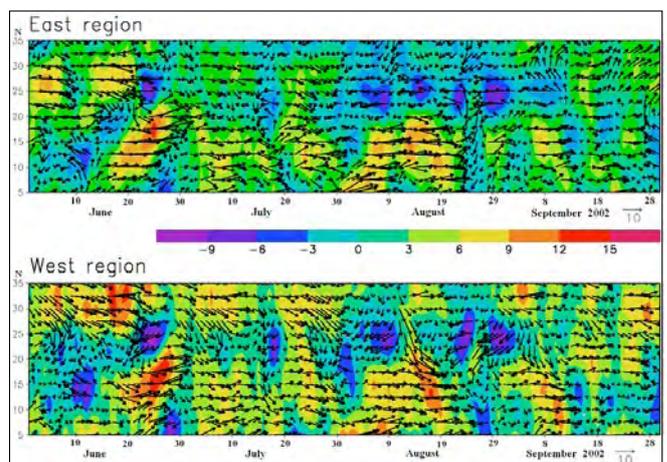


Figure 6 : Same as Figure 5 except for 2002

From Kent et al (page 20): *Voluntary Observing Ships: A vital marine observing system in decline*

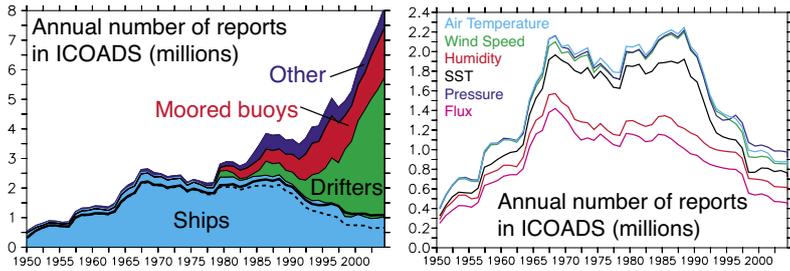


Figure 1: left: Shaded regions indicate annual number of reports from ICOADS for 1950 to 2004 by “platform type”. Solid line indicates number of reports made 6-hourly, the dashed line the subset of 6-hourly reports from VOS. The increasing report numbers are largely from sources reporting hourly or more frequently; right: Number of 6-hourly reports (as Figure 1a) containing: sea surface temperature (SST), air temperature, humidity, pressure and wind speed and all of these variables (“Flux”). Note the change of vertical scale.

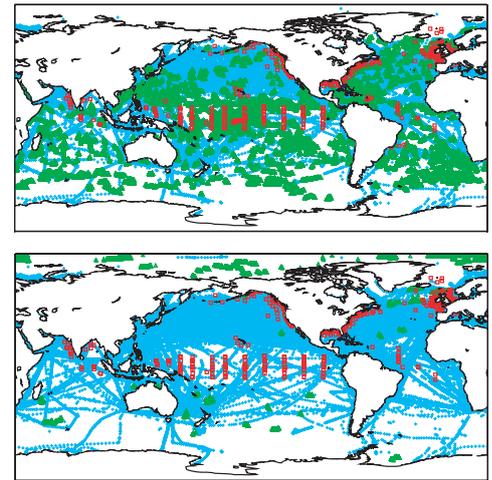


Figure 2: Distribution of SST (upper) and air temperature reports (lower) by platform type (VOS: light blue, drifters: green, moored buoys and platforms: red) in December 2004, the last available month of ICOADS.

Figure 3: Adequacy maps and uncertainty time-series for SST (left) and air temperature (right).

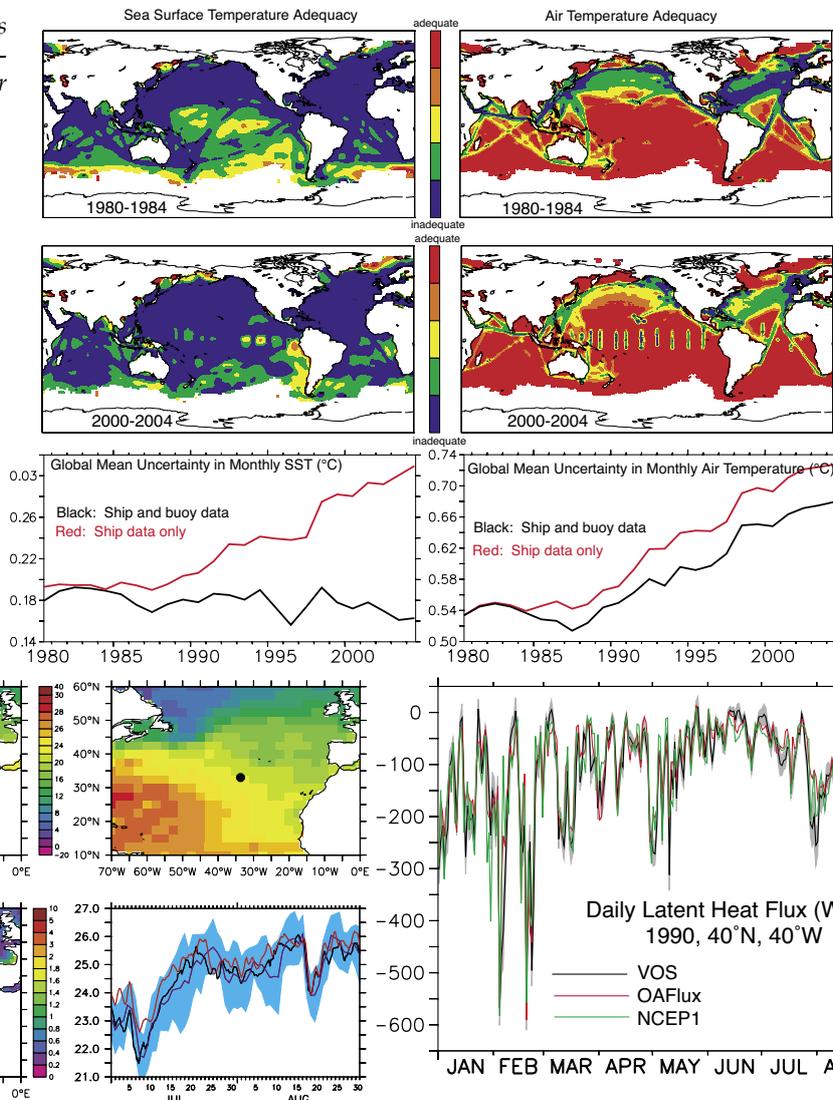


Figure 4: air temperature (°C) on 10th July 1992 from VOS observations (top left), and ERA 40 (top right) its uncertainty from VOS (lower left), and comparison with research-quality buoy data at 33 °N, 34 °W (black dot) in 1992 (Moyer and Weller, 1997) (black: buoy; blue: VOS; red: ERA40; all °C).

Figure 5: Comparison of daily latent heat flux estimates at 40 °N, 40 °W from VOS, OAFflux (Yu et al., 2004) and NCEP1 Reanalysis (Kistler et al. 2001).

From Muller et al (page 18): Rossby Wave propagation and its relationship with severe frosts over South America

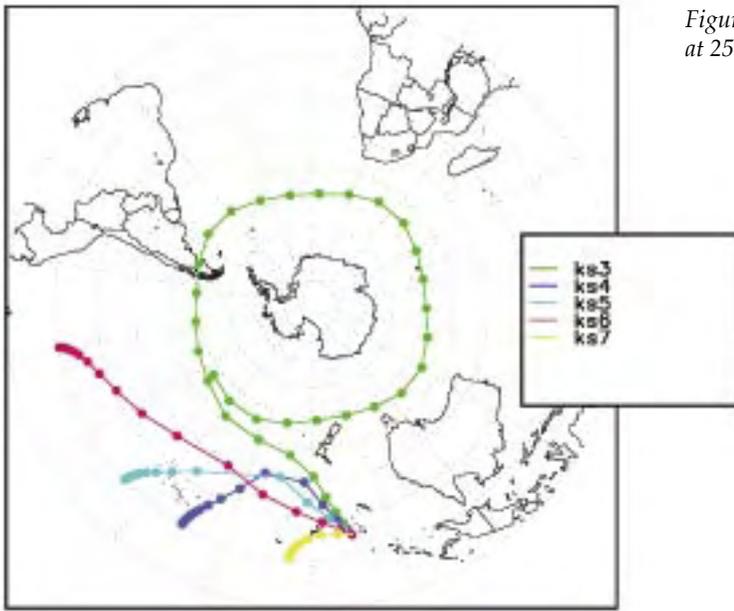


Figure 2: Trajectories of stationary Rossby wave energy propagation at 250 hPa

From ENACT partnership (page 22): Multi-model multi-method multi-decadal ocean analyses from the ENACT project

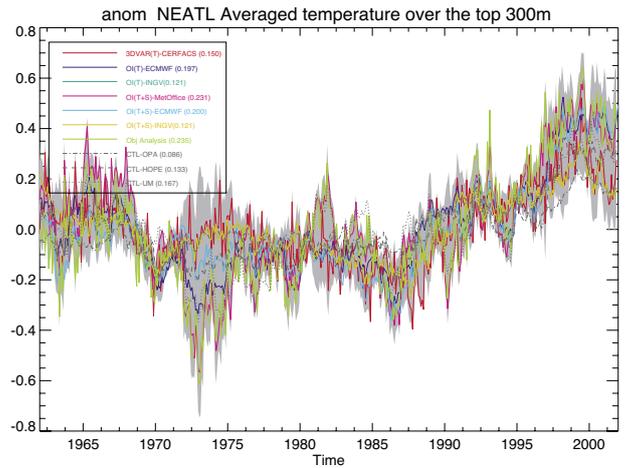
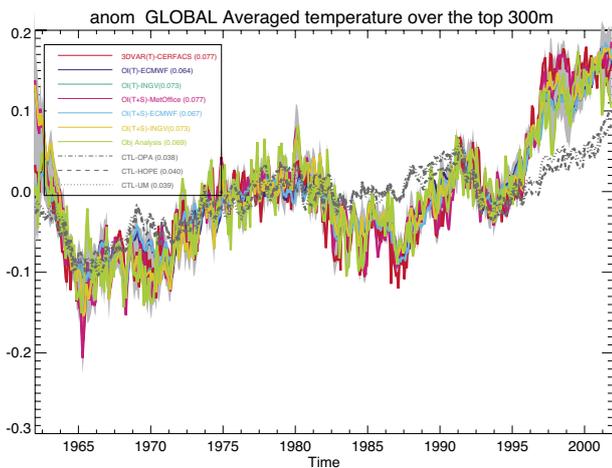


Figure 1: monthly anomalies of upper ocean (0-300m) globally-averaged temperature (0C) for 1962-2001. Numbers in the legend indicate temporal standard deviation values for the respective analyses. The shading indicates the plus/minus 2 standard deviation range of the ensemble of analyses for each month, excluding the controls (CTL) that did not use ocean subsurface observations.

Figure 2: As Fig. 1, but showing monthly anomalies for 0-300m temperature averaged over the north east Atlantic region (30N-60N, 40W-0E).

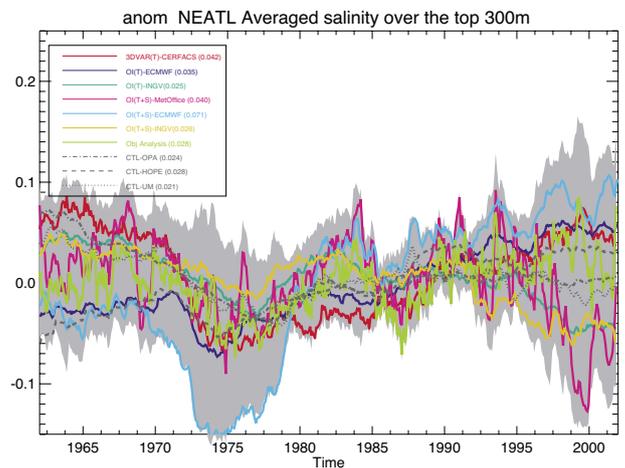


Figure 3: As Fig. 2, but showing monthly anomalies for upper ocean (0-300m) salinity (psu) averaged over the north east Atlantic region

continued from page 12

development of a secondary heat source over the western part of the monsoon trough. The persistence of strong monsoon circulation at 500 hPa in July and August 1997 is observed with the east-west heating gradient found to be undisturbed in the active phases of 1997. The contrast in the heating pattern and changes in the wind field at 500 hPa during month of July for the two seasons, emphasizes the role of secondary diabatic heat sources over northwest India in changing the monsoon circulation adversely in 2002.

Summary and conclusions

The space-time variations of the apparent heat source and the moisture sinks, for the two southwest monsoon seasons of 1997 and 2002, show a vast difference in the heating pattern due to latent heat released from cumulus convection over the Indian region. During monsoon 1997, intense diabatic heating is observed repeatedly over the eastern trough region in presence of five depressions and a storm. The monsoon circulation remained well developed in the season and India experienced normal monsoon rainfall. However during monsoon 2002, the east-west heating gradient over the monsoon trough region was disturbed repeatedly due to more diabatic heating over northwest India at a southerly latitude around 22.5°N. Such heating was found to be very intense around 25 June and 18 July 2002. In the following period the monsoon circulation became very weak in the peak monsoon month, July 2002. On most of the days in July the monsoon trough shifted to the foothills of the Himalayas and this resulted into a large deficit in All Indian rainfall for the month of July (-49% from the normal). The contrasting heating patterns and the associated circulation changes for the two monsoon seasons of 1997 and 2002 indicate that the organised convection over the western part of monsoon trough and subsequent stabilization of the atmosphere was responsible for the drastic change in the dynamics of monsoon trough region, over India from June to July 2002 leading to a drought situation. The study leads to the better understanding of the intraseasonal modes of variability in monsoon circulation and rainfall over India which is termed as the speed breakers of AIMR by Kripalani et.al (2005).

Acknowledgements

This work has been carried out under the project sponsored by the Department of Science and Technology (DST/ES/48/ICRP/009/2000), Government of India. Thanks are due to Director, Indian Institute of Tropical Meteorology, Pune for his valuable suggestions and providing the facilities. The authors are also thankful to DDGM (WF), Weather Central, IMD, Pune for making the weather charts available.

References :

- Bhide, U.V., V.R. Mujumdar, S.P. Ghanekar, D.K. Paul, T.C. Chen and G.V. Rao, 1997: A diagnostic study on heat sources and moisture sinks in the monsoon trough area during active-break phases of the Indian summer monsoon, 1979, *Tellus*, **49A**, 4, 455-473.
- Das P. K. 1962: Mean vertical motion and non-adiabatic heat sources over India during the monsoon, *Tellus* **14**, 212-220.
- Gadgil, S., 1988, "Recent advances in monsoon research with particular reference to the Indian monsoon", *Aust. Met. Mag.*, **6**, pp 193-204.
- Goswami, B. N., 1991: Mechanisms of low frequency monsoonal variations: An overview, WMO/TD No. 454, 157-181.
- Kalney, E., Kanamitsu, R. Kistler, W. Collins, W. Deaven, L. Gandin, M. Iredell, S. Saha, G White, J. Wollen, Y. Zhu, M Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K.C. Mo, C. Ropelewski, J. Wang, A. Leetma, R. Reynolds, Roy Jenne and dennis Joseph, 1996: The NCEP/NCAR 40-year Reanalysis Project, *Bull. Amer. Meteor. Soc.*, **77**, pp.437-471.

- Kalsi, S. R., H. R. Hatwar, N. Jayanthi, S. K. Subramanian, B. Shyamala, M. Rajeevan, and R. K. Jenamani, 2004: Various Aspects of Unusual Behaviour of Monsoon -2002, IMD Monograph: *Synoptic Meteorology No. 2/2004*.
- Kripalani, R. H., A. A. Kulkarni and S. S. Sabade, 2005: Are Intra-seasonal Oscillations 'Speed-breakers' to Seasonal Predictions?, *Clivar Exchanges*, **10**, 1, 27-29.
- Krishnamurti, T. N. and H. N. Bhalme, 1976: Oscillations of a Monsoon System. Part I. Observational Aspects, *J. Atmos. Sci.*, **33**, 1937-1954.
- Luo, H. and M. Yanai, 1984: The large scale circulation and heat sources over the Tibetan Plateau and surrounding areas during early summer of 1979. Part II: Heat and moisture budgets. *Mon. Wea. Rev.* **112**, 966-989.
- Rao, Y.P.O., 1976: "Southwest Monsoon". Meteorological Monograph, *Synoptic Meteorology No. 1*, India Meteorological Department. 186-200.

Rossby Wave Propagation And Its Relationship With Severe Frosts Over South America

Gabriela V. Müller and Tércio Ambrizzi

Department of Atmospheric Sciences, Institute of Astronomy, Geophysics and Atmospheric Sciences
University of São Paulo

Corresponding authors: gabriela@model.iag.usp.br and ambrizzi@model.iag.usp.br

Introduction

Although baroclinic wave activity is important in the process of generation of frost events, low frequency variability also plays an important role through the Rossby wave propagation patterns which in general are forced by heating sources. These waves can modify the structure of the upper level mean flow and modulate the characteristics of the anticyclone systems at low levels, which are responsible for the extreme temperature events mentioned above. Many studies have already analyzed the linear response of the relationship between anomalous heating forcing in the tropics and their impact on the circulation patterns in the extratropics (e.g., Hoskins and Karoly 1981; Coelho et al. 2002; Magaña and Ambrizzi 2005 and references therein).

The interaction between tropical convection and global circulation can occur through the dispersion of tropical – extratropical Rossby waves. The propagation of these waves is dependent of the basic state structure and the heat source (Ambrizzi et al. 1995). Considering a basic state formed by the composites of austral winters with maximum occurrence of Generalized Frosts (GF) over the Central-Northern Argentina, Müller (2005a) showed the tropical-extratropical interactions involved using a numerical model. A maximum frequency of occurrence of GF is considered when frosts are one standard deviation (σ) above the mean values during the austral winter (June-July-August) for the period 1961-1990 (GF + σ). The analysis of the atmospheric basic flow in the following section will be based on the composites of the GF + σ winters. Müller (2005) found that a source of heating over the tropical west Pacific just northeast of Australia can act as a Rossby wave source which propagates to the South-American continent and creates the right environment for the formation of GF events. These extreme events affect a large region over the Southeast of South America, called Wet Pampa (Argentina) as described by Müller (2006).

The main objective of this study is to determine the Rossby wave trajectories from the tropics to the South American extratropics using a GF + σ basic state. The composites of these events were obtained following the Müller et al. (2005) criteria. The wave trajectories were calculated using a ray tracing technique which will be briefly described in the next section.

Rossby Wave Propagation Trajectories

Theoretical preliminaries

The remote atmospheric response to tropical forcing is analysed by considering the characteristics of the mean zonal flow and the forcing itself. Previous studies on atmospheric teleconnection patterns (e.g., Hoskins and Karoly 1981; Ambrizzi et al. 1995) have shown that linear wave theory can explain some of the observed low-frequency atmospheric variability. The climatological basic flows and the preferred trajectories followed by Rossby waves may be examined through the use of simple numerical models (Hoskins et al. 1977; Branstator 1983). To analyse Rossby wave dispersion, Hoskins and Ambrizzi (1993) derived the ray path radius of curvature which is dependent of the latitudinal variation of the stationary wavenumber [$K_s = (\beta^* / \bar{U})^{1/2}$] where β^* is the meridional gradient of absolute vorticity and \bar{U} the mean zonal wind. From a global distribution of K_s , it is possible to

identify the preferred propagation paths of Rossby waves for various mean flows. The agreement between ray paths and numerical solutions of a linearized barotropic model indicates that the rays retain the essential characteristics of Rossby wave propagation. This ray tracing is based on the integration with respect to time of the meridional and zonal wavenumbers. For further calculation details see, for instance, Yang and Hoskins (1996).

Stationary Rossby wave theory has successfully explained certain observed teleconnection patterns (Hsu and Lin 1992; Ambrizzi et al. 1995). However, as originally pointed out by Karoly (1983) and more recently by Yang and Hoskins (1996), there may be some differences with respect to low-frequency Rossby waves, particularly in its phase speed. A stationary Rossby wave ($c=0$) has been assumed in the present analysis, and the preferred trajectories followed by stationary Rossby waves have been determined using upper tropospheric (250 hPa) composites of GF + σ events.

Results

The trajectories of the Rossby wave propagation for different wavenumbers are calculated taking into account the observed convective anomalies in the composites of the GF + σ austral winter. The initial starting point was chosen based on the Outgoing Longwave Radiation (OLR) field composite of the same selected events which indicates a negative anomaly around 170°E and 15°S in the tropical west Pacific (Fig.1). As it is well known, such regions are generally associated with deep convective activity (Liebmann and Smith 1996) being responsible for the generation of Rossby waves. Fig.2 (page 16) shows the wave trajectories for different wavenumbers, ranging from 3 to 7 for a total period of 15 days integration. The results are plotted at each 6 hours. As mentioned before, the methodology to calculate the ray tracing is similar to that used by Yang and Hoskins (1996).

As seen from Fig.2, some rays propagate polewards from the source until they reach a latitude where $K_s = k$; they are then refracted back towards the tropics. Other rays propagate equatorwards from the wavemaker. They turn into a more meridional direction and slow down as they approach the critical latitude ($U=0$). The smaller wavenumber packets propagate rather slowly in a more meridional direction, while the larger wavenumber packets propagate more zonally and more rapidly, as we would expect from the theory. In particular, it is very interesting to see the behavior of wavenumber 3, which propagates from the tropics towards South America trapped inside the midlatitude waveguide around 50° S. A map of the K_s field during GF + σ calculated by Müller (2005) indicates the existence of this waveguide in the region. Numerical simulations performed by Müller (2005) considering the GF + σ basic state and a heating forcing positioned over the OLR negative anomaly in the west tropical Pacific show a Rossby wave train with wavenumber 3 reaching the continent in a similar manner as the ray tracing indicated. In fact, Fig.3 which shows the meridional wind anomaly at 250 hPa for the day 13 of integration from a baroclinic model (Ambrizzi and Hoskins 1997) exemplifies this propagation pattern. As one can see from this figure, the wave train propagates from the Pacific to the Atlantic Ocean following a great arc and passing through

southern South America. This pattern is usually called the Pacific South American in the literature (e.g., Cavalcanti and Kayano 1999).

On the other hand, when the wave trajectories for each wavenumber, i.e. from 3 to 7, were calculated using a basic state where the frequency of GF was minimum (GF $-\sigma$ following the criteria of Müller et al. 2005), the ray paths, and in particular wavenumber 3, did not reach South America (Figure not shown). This result suggests that in order to have a generalized frost over the Central-Northern Argentina the basic state has to be favorable for the propagation of Rossby waves through the continent.

Final Comments

The hypothesis that an anomalous heating in the occidental tropical Pacific can generate propagation of a Rossby wave towards South America favoring the occurrence of generalized frosts is tested using the ray tracing technique. The waves' starting point was based on the OLR austral winter negative anomaly composites during the maximum occurrence of GF $+\sigma$. The ray paths showed that the wavenumber 3 was the only one to reach South America. This result is in agreement with numerical simulations using the same basic state. In this case a clear Pacific South American pattern is observed. For the analysis using a GF $-\sigma$ flux, the ray path and propagation patterns were very different and any Rossby wave passed through the South American continent.

In summary, through ray tracing analysis and in agreement with some previous numerical and observational studies (e.g., Marengo et al. 2002; Müller 2005), anomalous convection over the tropical west Pacific can generate a Rossby wave pattern that will favor extreme generalized frosts over the Wet Pampa in Argentina. This work emphasizes how important is the atmospheric basic state variability to influence these events and indicates a specific analysis tool to study these patterns.

Acknowledgments

The authors would like to acknowledge CNPq and IAI - CRN055 for the financial support of this research.

References

Ambrizzi, T., B.J. Hoskins and H.-H. Hsu, 1995: Rossby wave propagation and teleconnection patterns in the austral winter. *J. Atmos. Sci.*, **52**, 3661-3672.

Ambrizzi, T. and B.J. Hoskins, 1997: Stationary Rossby wave propagation in a baroclinic atmosphere. *Q. J. Meteorol. Soc.*, **123**, 919-928.

Branstator, G., 1983: Horizontal energy propagation in a barotropic atmosphere with meridional and zonal structure. *J. Atmos. Sci.*, **40**, 1689-1708.

Cavalcanti, I. and Kayano M.T., 1999: High frequency patterns of the atmospheric circulation over the Southern Hemisphere

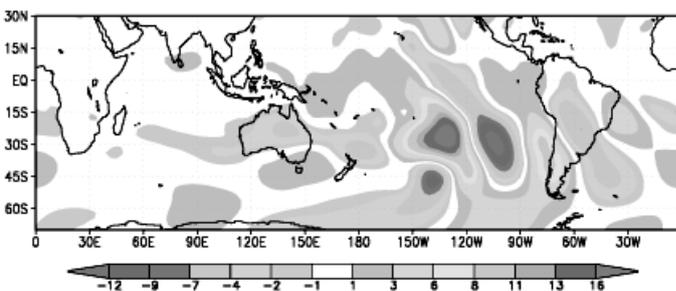


Figure 3: Meridional wind anomaly (m/s) at 250 hpa. Day 13 of simulation with tropical forcing at 170°E-15°S, and basic state of winter GF $+\sigma$

and South American. *Meteorology and Atmospheric Physics*, **69**, 179-193.

Coelho, C.A.S., Uvo, C. B., Ambrizzi, T., 2002: Exploring the impacts of the tropical Pacific SST on the precipitation patterns over South America during ENSO periods. *Theor. Appl. Climatol.*, **71**, 185-197.

Hoskins, B.J., A.J. Simmons and D.G. Andrews, 1977: Energy dispersion in a barotropic atmosphere. *Quart. J. Roy. Meteor. Soc.*, **103**, 553-567.

Hoskins, B.J. and D.J. Karoly, 1981: The steady linear responses of a spherical atmosphere to thermal and orographic forcing. *J. Atmos. Sci.*, **38**, 1179-1196.

Hoskins, B.J., and T. Ambrizzi, 1993: Rossby wave propagation on a realistic longitudinally varying flow. *J. Atmos. Sci.*, **50**, 1661-1671.

Hsu, H.H. and S.H. Lin, 1992: Global teleconnections in the 250 mb streamfunction field during the Northern Hemisphere winter. *Mon. Wea. Rev.*, **120**, 1169-1190.

Karoly, D.J., 1983: Rossby wave propagation in a barotropic atmosphere. *Dyn. Atmos. Oceans*, **7**, 111-125.

Liebmann, B. and C.A. Smith, 1996: Description of a complete (interpolated) outgoing longwave radiation dataset. *Bull. Am. Meteor. Soc.*, **77**, 1275-1277.

Magaña, V and T. Ambrizzi, 2005: Dynamics of subtropical vertical motions over the Americas during El Niño boreal winters. *Atmosfera*, **18** (4), 211-233.

Marengo, J.A., T. Ambrizzi, G. Kiladis and B. Liebmann, 2002: Upper-air wave trains over the Pacific Ocean and wintertime cold surges in tropical-subtropical South America leading to freezes in Southern and Southeastern Brazil. *Theor. Appl. Climatol.*, **74**, 243-247.

Müller, G.V., T. Ambrizzi and M.N. Nuñez, 2005: Mean Atmospheric Circulation Leading to Generalized Frosts in Central Southern South America. *Theoretical Applied Climatology*, **82**, Nro 1-2, 95-112.

Müller, G.V., 2005: Interannual Variability of the frequency of frost occurrence in Pampa Humeda and its relationship with the associated a atmospheric circulation. Doctoral Thesis, Department of Atmospheric and Oceanic Sciences. Pp 218, www.opac.bl.fcen.uba.ar.

Müller, G.V., 2006: Variabilidad Interanual de las Heladas en la Pampa Húmeda. *Brazilian Journal of Meteorology*, **21**, 135-141.

Yang, G.-Y and Hoskins B.J., 1996: Propagation of Rossby waves of nonzero frequency. *J. Atmos. Sci.*, **53**, 2365-2378.

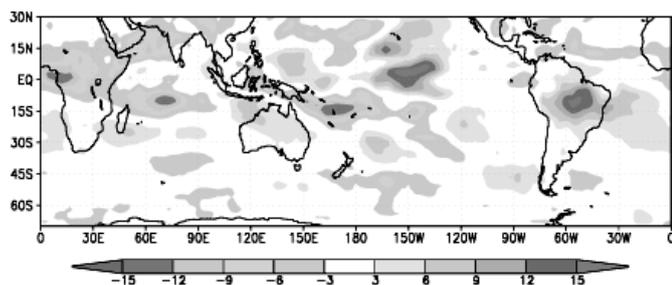


Figure 1: Composite of observed OLR anomalies (W/m^2), June to August 1970, 1976 and 1988 (GF $+\sigma$)

Figure 1: Composite of observed OLR anomalies (W/m^2), June to August 1970, 1976 and 1988 (GF $+\sigma$)

Voluntary Observing Ships: A Vital Marine Observing System in Decline

Elizabeth C. Kent¹, David I. Berry¹, Scott D. Woodruff² and Peter K. Taylor¹

¹ National Oceanography Centre, Southampton, UK; ² NOAA Earth System Research Laboratory, CO, USA.

Corresponding author: eck@noc.soton.ac.uk

Introduction

Shipboard marine meteorological observations extend back hundreds of years, and continue to form a critical component of the modern weather and climate observing system. Today, most of the participating ships are referred to as Voluntary Observing Ships (VOS), the VOS programme being managed by JCOMM¹. These observations benefit weather forecasters in real time and climate researchers in the longer term. VOS observations, along with meteorological information from buoys and a variety of other platforms are collated in the International Comprehensive Ocean-Atmosphere Data Set (ICOADS Worley et al. 2005, formerly COADS). ICOADS has been used in hundreds of published studies and remains the primary source for in situ surface marine meteorological information for climate research.

However Numerical Weather Prediction now relies more heavily on the information provided by satellites and drifting buoys. The sheer volume of information from these sources has played a part in recent improvements of weather forecasts, there are now ten times as many reports from buoys as from ships in ICOADS.

Recently several projects have significantly extended the availability of marine meteorological data going back as far as 1750, and improved the very data sparse periods due to the two World Wars. These include the Japan Meteorological Agency Kobe Collection Digitisation (Manabe 1999), tasks under the NOAA Climate Database Modernization Program (CDMP) and the European Union funded projects CLIWOC (García-Herrera 2005) and EMULATE (Ansell et al. 2006). However, it is important to note that significant resources are still required, but not currently identified, to incorporate these data into marine archives such as ICOADS (Woodruff et al. 2005).

Unfortunately the VOS observing system is now under threat: the number of reports has dropped dramatically over the last decade (Figure 1, page 15) while the observation count from other sources has risen.

VOS in the Multi-platform Record

Whilst buoys and other Ocean Data Acquisition Systems (ODAS) provide increasing numbers of reports, VOS (and their predecessors) form the longest in situ record and, over much of the ocean, are our main or only source of air temperature, humidity, and pressure data.

This is illustrated in Figure 2 (page 15). Although VOS coverage is not global, large areas are well sampled. While SST observations are supplemented by the drifting buoy and satellite network, away from the sparse and largely coastal, moored buoy network, only the VOS gives us the ability to estimate surface momentum, heat and freshwater air-sea exchange. Knowledge of these fluxes is vital to understanding the strengths and weaknesses of the atmospheric reanalyses (Kistler et al. 2001; Uppala et al. 2006; Sterl 2004) and satellite flux estimates (WGASF 2000).

Climate Research Requirements: Quality vs. Quantity

The quality of meteorological observations from VOS is often questioned. Indeed some ship reports are of poor quality,

and the use of observations ranging as far back as the 18th century raises important homogeneity questions. However many reports are made with care by experienced observers and contribute to an extremely valuable multi-century record of surface conditions over the ocean. VOS observations are actually better characterised than many other data sources, including reanalysis model output, many satellite products and ODAS (for which historical metadata are sparse and have not yet been carefully organized internationally). There is a long history of research quantifying bias and uncertainty in VOS data, examples for wind speed and SST are reviewed by Kent and Taylor (1997, 2006). Recently information on the methods of measurement and observation heights for VOS originally published by the WMO for operational use have been made available to the research community (Kent et al. 2006). These digital metadata, dating back to 1973, allow improved characterisation of marine meteorological reports and are already finding use in a wide range of applications. Further insight will come when a CDMP digitisation project extends this metadata record back to 1955.

Recent analysis has shown that VOS data have improved in quality over the last 30 years (Kent and Berry 2005). However our knowledge of meteorological variables over the ocean has actually declined with the number of reports. This is compounded by the increasing number of higher-resolution observations from shipboard Automatic Weather Systems, as well as ODAS. Gathering hourly observations is useful, for example to define the diurnal cycle, but successive observations are highly correlated and therefore give less information about the global climate than the same number of, say, six hourly observations.

Figure 3 (page 15) compares estimates of the uncertainty in SST and air temperature for the early 1980s and 2000s. The contouring has been designed to highlight regions of adequate (blue) and inadequate (red) data coverage based on a particular observational need - in this case the ability to estimate monthly mean, 5° area surface heat exchange to an accuracy of 10 Wm⁻² or better (WGASF 2000). Using this measure of adequacy, SST turns out to be generally well sampled and sampling has improved over time due to additional data from drifting buoys. In contrast, for air temperature there has been no such improvement in sampling and with the exception of the Tropical buoy arrays the marine air temperature is less well known than it was 20 years ago. The time series show the impact of moored and drifting buoy observations on the global accuracy of the in situ record and illustrate our reliance on ship observations for air temperature information (and by implication, for other variables such as humidity).

It should be remembered that every application has its own adequacy requirement. Our conclusion here, that sampling for SST is not a major problem, will not hold for other applications calling either for higher resolution SST fields or with a greater sensitivity to SST accuracy.

ICOADS Products and Applications

As the data themselves become better understood and characterised we can use more sophisticated methods of dataset construction, for example optimal interpolation (OI). Figure 4 (page 15) shows an example of one day's air temperature field for the North Atlantic calculated from VOS data only

¹Joint World Meteorological Organisation (WMO)/Intergovernmental Oceanographic Commission Technical Commission for Oceanography and Marine Meteorology

with a comparison to surface air temperature from the ERA40 reanalysis (Uppala et al. 2006). Much of the North Atlantic is relatively well sampled by the ships. It is clear that the in situ data show smaller scale detail than ERA40. Some of the small scale structure may be due to noise, but we expect further research to show that the ships, at least in some regions, can provide higher resolution data than the reanalyses. The accompanying uncertainty estimates mean that we can easily identify regions where we have confidence in the in situ estimates.

One of the strengths of the multi-variate ship record is that we can calculate estimates of air-sea exchange from the reports. Figure 5 (page 15) shows an example of the latent heat flux for 1990, again in the North Atlantic, calculated from ship data only (black with estimated uncertainty range in grey), the OAFlux product (red) and the NCEP1 reanalysis (green). There is qualitative agreement between these three estimates, and the periods of high and low evaporation are well captured by all. However closer inspection reveals significant differences between the estimates, falling well outside the uncertainty estimates (which are only available for the in situ data). This shows that in many ocean regions we can use the in situ flux estimates not only to validate model and satellite flux fields in the monthly mean, but also on the daily timescale.

Applications for ICOADS reports and derived products

Recent workshops have brought together scientists with diverse interests (e.g. Kent et al. 2006). ICOADS has a wide range of applications, including:

- International assessments of climate change (e.g., IPCC).
- Providing broad-scale context for process studies.
- To confront and understand atmospheric reanalyses.
- Multi-decadal analysis of air-sea interaction.
- Validation of the satellite and pre-instrumental proxy records.
- Data assimilation and model validation.
- Others applications such as fisheries, changes in coastal geological features, global anthropogenic emissions from ships (see Worley et al. 2005).

Outlook

As the number of ship reports declines, our ability to generate useful marine meteorological fields and surface fluxes diminishes.

Reversing the decline in the ship observations will require finding new resources, despite increasingly tight national and international budgets. In support of such efforts, it will be critical to review and define user requirements for a wide range of applications and to make adequacy assessments using those requirements. The support systems for the ships (for example the Port Meteorological Officer network) are also declining and will require bolstering if we are to maintain the quality of observations from VOS.

New observation sources such as automated systems on VOS and the integration of research vessels into the observing system through, for example, the Shipboard Automated Meteorological and Oceanographic System Initiative (SAMOS: <http://samos.coaps.fsu.edu/html/>) may prove part of the answer. But any transition must be well-planned and address the homogeneity requirements of climate assessments. It is clear that to characterise the marine atmosphere, to even the same standards as 20 years ago, requires the maintenance of a more distributed system than that which we now have. ODAS are not presently the answer as moored buoys cannot monitor the global ocean, and drifters do not meet our multi-variate accuracy requirements. The VOS have served us well and should be

recognised as making a valuable and ongoing contribution to the marine record. We must ensure that this contribution is maintained and enhanced until we are sure that any candidate systems to replace the VOS fulfil the Global Climate Observing System Monitoring Principles (GCOS, 2003).

References

- Ansell, T.J., and 38 others, 2006: Daily mean sea level pressure reconstructions for the European-North Atlantic region for the period 1850-2003, *J. Climate*, **19**, 2717-2742.
- García-Herrera, R., G.P. Können, D.A. Wheeler, M.R. Prieto, P.D. Jones, and F.B. Koek, 2005: CLIWOC: A Climatological Database for the World's Oceans 1750-1854. *Climatic Change*, **73**, 1-12.
- GCOS, 2003: Second Report on the Adequacy of the Global Observing Systems for Climate, GCOS-82/WMO TD-No. 1143, 74pp.
- Kent, E.C. and D.I. Berry, 2005: Quantifying Random Errors in Voluntary Observing Ships Meteorological Observations, *Intl. J. Climatology*, **25**, 843-856.
- Kent, E.C. and P.K. Taylor, 1997: Choice of a Beaufort Equivalent Scale. *J. Atmos. Oceanic Tech*, **14**, 228-242.
- Kent, E. C. and P.K. Taylor, 2006: Toward Estimating Climatic Trends in SST, Part 1: Methods of Measurement, *J. Atmos. Oceanic Tech.*, **23**, 464-475.
- Kent, E.C., S.D. Woodruff and D.I. Berry, 2006: WMO Publication No. 47 Metadata and an Assessment of VOS Observation Heights in ICOADS, *J. Atmos. Oceanic Tech.* (in press).
- Kent, E. C., S. D. Woodruff, N. A. Rayner, C. K. Folland, D. E. Parker, R. W. Reynolds and T. Yoshida, 2006: Report on the 2nd International Workshop on Advances in the Use of Historical Marine Climate Data, *CLIVAR Exchanges*, **36**, 29-30, January 2006.
- Kistler, R., E. Kalnay, W. Collins, S. Saha, G. White, J. Woollen, M. Chelliah, W. Ebisuzaki, M. Kanamitsu, V. Kousky, H. van den Dool, R. Jenne and M. Fiorino, 2001: The NCEP-NCAR 50-Year Reanalysis: Monthly means CD-ROM and documentation. *Bull. Amer. Meteor. Soc.*, **82**, 247-267.
- Manabe, T., 1999: The digitized Kobe Collection, phase I: historical surface marine meteorological observations in the archive of the Japan Meteorological Agency. *Bull. Amer. Meteor. Soc.*, **80**, 2703-2715.
- Moyer, K. A. and R. A. Weller, 1997: Observations of Surface Forcing from the Subduction Experiment: A Comparison with Global Model Products and Climatological Datasets, *J. Climate*, **10**, 2725 - 2742.
- Sterl, A., On the (in-)homogeneity of reanalysis products. *J. Climate*, 2004, **17**, 3866-3873.
- Uppala, S.M., and 44 others, 2006: The ERA-40 re-analysis, *Q. J. Royal Met. Soc.* **131**, 2961-3012.
- WGASF, 2000: Intercomparison and Validation of Ocean-Atmosphere Energy Flux Fields, Final Report of the Joint WCRP/SCOR Working Group on Air-Sea Fluxes, WCRP-112/WMO-TD-No 1036, 303pp.
- Worley, S.J., S.D. Woodruff, R.W. Reynolds, S.J. Lubker, and N. Lott, 2005: ICOADS Release 2.1 data and products. *Int. J. Climatol.*, **25**, 823-842.
- Woodruff, S.D., H.F. Diaz, S.J. Worley, R.W. Reynolds, and S.J. Lubker, 2005: Early ship observational data and ICOADS. *Climatic Change*, **73**, 169-194.
- Yu, L., R.A. Weller, & B. Sun, 2004: Improving latent and sensible heat flux estimates for the Atlantic Ocean (1988-1999) by a synthesis approach. *J. Climate*, **17**, 373-393.

Multi-model multi-method multi-decadal ocean analyses from the ENACT project

by the ENACT partnership*

* M. Davey, M. Huddleston, B. Ingleby (Met Office, UK), K. Haines (ESSC, Reading, UK); P.-Y. Le Traon (CLS, France), A. Weaver (CERFACS, France), J. Vialard (LODYC, France); D. Anderson, A. Troccoli, A. Vidard (ECMWF); G. Burgers. O. Leeuwenburgh (KNMI, Netherlands); A. Bellucci, S. Masina (INGV, Italy); L. Bertino (NERSC, Norway); P. Korn (MPG-IMET, Germany)

Corresponding author: mike.davey@metoffice.gov.uk

Overview:

The main objective of the European Union ENACT (ENhanced ocean data Assimilation and Climate predicTion) project was to improve the ocean analyses that provide the initial global ocean conditions for seasonal forecasts based on coupled general circulation models (GCMs). Advances were made with regard to the quality of forcing and assimilation data, and with several different data assimilation schemes that were implemented in various ocean GCMs. One major outcome was the production of an ensemble of ocean reanalyses for the period 1962 to 2001, as described in this article. Within the constraints of the experimental design, the ensemble provides estimates of the uncertainty in our knowledge of the ocean state through this period.

Description of the analysis design

The oceans hold much of the information required to predict climate variations at ranges of months to years ahead, so seasonal prediction systems based on coupled GCMs need to be able to make good use of available observations in the calculation of oceanic initial conditions for forecasts. The ENACT aims were to improve the required ocean analyses, and in so doing to generate ocean reanalyses for the past few decades. These reanalyses can be used for retrospective seasonal hindcasts as well as for evaluation to draw climatic inferences about the changing ocean state.

One way of obtaining initial ocean conditions is to force an OGCM with surface fluxes from atmospheric analyses over some period leading up to the time of forecast, usually also including some constraint to observed sea surface temperature (SST). For present purposes, we call this the 'control' method. The next step in complexity is to assimilate ocean observations with a computationally cheap scheme such as a form of optimal interpolation (OI), commonly used by current operational seasonal prediction systems, or a 3D-var variational scheme. With increases in computer power and improvements to algorithm efficiency, it is also becoming feasible to use more advanced assimilation schemes, such as ensemble Kalman filters (EnKF) and 4D-var, with the global coverage and resolution required for forecasting applications. Each of these methods has been applied in the ENACT project, each with substantial improvements made at the development and implementation stages.

Two main periods were defined for study in ENACT: Stream 1 (1987-2001) and Stream 2 (1962-2001). For Stream 1 ocean analyses were produced using all of the assimilation methods listed above: this was also the period selected for the production of sets of CGCM hindcasts with some of the ocean analyses used as initial conditions. Stream 2 corresponds to the ERA-40 atmospheric re-analysis period (1957-2001), with a 5 year adjustment phase before starting data assimilation in 1962. It was not possible to include the EnKF and 4D-var systems in Stream 2 due to their computational expense. A third stream (Stream A, 1993-2001) corresponding to the period for which satellite altimeter data are continuously available was also defined.

The various ocean analyses produced in ENACT are summarised

in Table 1 (page 24). The result is a unique multi-model multi-method collection of multi-decadal ocean analysis datasets. Subsets of the data have been archived on a common grid (see appendix), and these are being made available for use by the scientific research community via an OPenDAP/DODS server.

An important feature of ENACT is the use of a common experimental design, with each system using the same observational datasets prepared as part of the project. Daily surface fluxes were obtained from the ERA-40 atmospheric analysis, with a correction to the freshwater flux made to allow for systematic biases. (Comparisons with precipitation observations showed a considerable improvement of the corrected ERA-40 precipitation fields: Troccoli and Källberg, 2004). In situ temperature (T) and salinity (S) datasets were created, using a new quality control system, with data from the World Ocean Database 2001 (WOD01; Conkright et al, 2001). For the period after 1990 additional data were used from; the World Ocean Circulation Experiment (WOCE), Australia (XBT data from 1997), Pacific Marine Environmental Laboratory (Pacific CTD data, Johnson et al. 2002) and GTSP (used from Jan 2000 onwards as WOD01 coverage tails off). (See Ingleby and Huddleston 2005 for details). The latest version of the in situ dataset is available at http://hadobs.metoffice.com/enact_qc/. An additional by-product of this in situ QC work is a model independent gridded objective analysis, which is denoted ObjA in Table 1.

Another important data source is sea level derived from satellite altimeter measurements. An ENACT partner (CLS) provided improved gridded and along-track sea level anomaly data for the period 1992-2004. Additionally, a mean dynamic topography for 1993-1999 was produced, to provide an absolute reference sea level, and sea level anomaly data were provided for 1986-1989 based on reprocessed GeoSat data.

One problem that was addressed in the design of the ENACT analyses was that of ocean model drift. Without some form of constraint the ocean states in OGCMs tend to drift away from reasonable values. Only where large amounts of ocean data are available can the assimilation be sure to control this problem. The best-observed oceanic field is SST, and we decided to use a strong constraint to observed SST in the form of a relaxation term with a coefficient of $200 \text{ Wm}^{-2}\text{C}^{-1}$. Even with SST information and assimilation of other data, the sparseness of observed data (particularly S) means that substantial drift still occurs if some form of limitation is not used: moreover, such drift can cause data rejection and degradation of the assimilation process. On the other hand, overly-strong limitations to avoid drift would unrealistically suppress variability on interannual and decadal timescales. After some experimentation, we decided to use a relaxation of subsurface T and S to climatological values (using a running 3-month average climatology derived from the Levitus 1998 gridded dataset), with a 3 year e-folding timescale. This relaxation also effectively sets an upper limit to the memory of the model for the data being assimilated. (For OGCM stability reasons, some minor variations to this strategy were needed in some systems: details are in the full

report.) These surface and sub-surface constraints were applied to all the ENACT dynamical analyses, with and without data assimilation. Further work is underway post-ENACT to try to reduce artificial relaxation to a minimum so as to recover more long-timescale variability in the ocean analyses.

Example results for 1962-2001

The ocean analysis datasets are being investigated, both individually and collectively: various results are in the final report and in publications by the partners. To aid assessment we defined a set of 23 oceanic subregions. This article presents a few illustrative collective examples, which provide information regarding the consistency of the analyses, and the accompanying uncertainties.

Fig. 1, page 16, shows 40-year timeseries of upper ocean globally-averaged T anomalies from the longer Stream 2 analyses (hence not all analyses are represented). The anomalies are calculated from monthly-average T fields. The monthly climatology is subtracted in each dataset here to emphasise the interannual behaviour, and averages are taken over the upper 300m. The figure contains three basically different types of analysis. Those labelled 'CTL' (control) in the legend are analyses from three different OGCMs with no use of subsurface data assimilation: the interannual variability in these datasets is determined entirely by the surface forcing and the SST relaxation. The one labelled 'Obj Analysis' is the objective analysis calculated from the in situ data alone, with no use made of an OGCM or surface forcing or SST information. Note that apart from some light use of the Levitus 1998 subsurface climatology in each case, the 'CTL' group is independent of the 'Obj Analysis' results. The other timeseries in Fig. 1 are analyses from 6 combinations of OGCMs and assimilation schemes: we shall refer to this as the ASSIM group. (Note: the two contributions from INGV have very similar temperature, but differing salinity.)

Although the analyses in the ASSIM group (that all used in situ ocean T observations) differ in a noisy fashion from month to month, they are quite consistent with each other on interannual timescales, with decadal variability being the dominant feature. (This decadal variability is consistent with that described elsewhere: e.g. Levitus et al. 2005.)

The temporal standard deviations of each of these analyses (indicated in the legend) are quite similar. The ObjA timeseries is very similar to this group. This indicates that the observational data are sufficient to define the broad characteristics of this global-average quantity as reproduced by the assimilation models, and that there are no gross inconsistencies between the model-generated analyses and the data.

The spread each month of the ASSIM and ObjA data is indicated in Fig. 1 by the shading with ± 2 standard deviation limits. This spread is one measure of the uncertainty of monthly-average global-upper-ocean T, with values typically between 0.05 and 0.1C: substantially less than the range of decadal variability. Note: these values are likely to be an underestimate of the true uncertainty, because all analyses used the same forcing. (Note also the relatively large spread in the first few months, as assimilation 'spins up' in each model.)

The three CTL timeseries also show a high degree of consistency with each other, but there are some notable differences between the CTL group and the other global-average analyses. The CTL group is slightly warmer in 1969-71 and (more noticeably) in 1984-90, and clearly cooler from 1996 onward, with a distinctly weaker warming trend. At other times the CTL and ASSIM behaviour is quite similar. The differences have important implications, suggesting that the ocean GCMs may have deficiencies in the processes that propagate surface conditions (which are well controlled by SST relaxation) to the upper ocean.

(The recent warming differences in Fig. 1 between CTL and ASSIM groups are partly due to the double-correction of the fall rate of some XBT data from 1995 onwards in the in situ dataset: see below.) The regional results for upper ocean temperature similarly show overall high consistency between the various analyses, and episodic differences. (Some episodes of larger-than-usual regional spread are: South Pacific in 1965-66; North West Subtropical Pacific after 1998; North East Atlantic 1972-74; North West Atlantic 1998-2000). Spreads are largest in the southern oceans, where data are sparse and trends are not obvious or well defined. Note: the various regions have a wide variety of behaviour, with interannual variability substantially larger than the global average: in recent years some regions are cooling rather than warming, as described in e.g. Willis et al. 2003, Levitus et al. 2005. An example is provided in Fig. 2, page 16, for the NE Atlantic region (30N-60N, 40W-0E) for Stream 2: note the larger temperature scale relative to Fig. 1.

With regard to upper ocean salinity, there is typically a large spread in the monthly analysis values: often larger than the temporal interannual variability of anomalies. This spread reflects the very sparse nature of salinity observations and also the differing representations of hydrological processes and sources in the analysis systems. Note that unlike T there was no constraint to surface S observations – the uncertainty in S emphasises the need for satellite-derived surface salinity observations. Again, the true uncertainty is likely to be even larger than that of our ensemble: all our models used the same surface fluxes, which undoubtedly also have substantial uncertainties.

The example in Fig. 3, page 16, shows timeseries of upper ocean (0-300m) monthly salinity anomalies averaged over the NE Atlantic region for Stream 2. (Note that 3 of the 6 ASSIM analyses shown assimilated S observations as well as T, as denoted by T+S in the legend.) The analyses have widely varying behaviour: the only common feature is the dip in salinity in the 1970s associated with the 'Great Salinity Anomaly' (Dickson et al. 1988), which is evident in the CTL group as well as the ASSIM and ObjA results, but especially in the ECMWF T+S ASSIM. (The ECMWF T+S analysis made use of a new algorithm treating salinity assimilation differently to temperature: Haines et al. 2006.) It would be difficult to deduce any reliable decadal trends from this evidence if all the results are equally trusted. With the advent of improved observational salinity data coverage from the Argo network after 2001 this uncertainty should decrease substantially. The S analyses in some other regions have better defined collective interannual variability than this example, notably in the tropics where substantial interannual vertical displacements can provide consistent S signals in ASSIM, CTL and ObjA.

As well as the anomaly behaviour, the climatological mean values (not shown here) are of interest. In particular, the CTL analyses contain differing systematic model-dependent biases that the assimilation of observations should correct. For globally-averaged upper ocean T, averaged over the Stream 2 period, the mean CTL values are up to two tenths of a degree warmer than their ASSIM counterparts: regional differences can be larger. In some areas assimilation reduces the spread in mean temperature values, but increases the spread in mean salinity values. Model error, data sparseness and the variety of assimilation methods all contribute to the spread in the mean salinity values.

Effect of XBT fall rate correction from 1995 on

As noted above, there is an error involving double correction of some XBT fall rates from 1995 onwards in the in situ dataset developed and used in ENACT. The error means that temperatures are biased higher. Regionally the effect is clearly

evident in the subtropical Pacific and Indian regions, but is small (compared to interannual variability) in other areas: e.g. the bias is less than 0.05C averaged monthly over the NE Atlantic region. The dataset has since been corrected. The error is quantified in Fig. 4, which shows the globally averaged upper 300m T timeseries (with monthly mean climatology removed, but annual mean climatology retained) for 1984-2005 for the objective analysis from the ENACT dataset, and for the objective analysis from the revised dataset (i.e. the ENSEMBLES dataset described in Ingleby and Huddleston 2005). (Similar regional timeseries are available at the Met Office website cited above.) From Fig. 4 it is clear that the error resulted in higher analysed global upper ocean T values from 1995 on, with the error decreasing after 2001 as increasing amounts of Argo data become available. The global upper ocean temperature rise in Fig. 1 in the ASSIM and ObjA timeseries after 1995 is increased by this effect.

Summary

Using a mix of models and assimilation schemes, a number of global ocean analyses have been produced in a common framework as a major part of the ENACT project. The result is a unique dataset that is being made available for investigations of ocean climate, variability, uncertainty and processes. The monthly average data (see appendix) are being provided on an OPenDAP/DODS server: see http://www.ecmwf.int/research/EU_projects/ENACT/index.html for details. Some data are also available on a Live Access server with a graphical interface at <http://www.nerc-essc.ac.uk/godiva/>. Full details of the ENACT project can be found in the final report, available at the Met Office and ECMWF websites listed.

The advances in ocean analysis made in ENACT are being continued with further development and application to long-range forecasting in the EU ENSEMBLES project (<http://www.ensembles-eu.org/>), and it is planned to update and extend the current sets of analyses.

No single combination of OGCM and assimilation method is clearly 'the best': each has various advantages and disadvantages. In the context of seasonal forecasting,

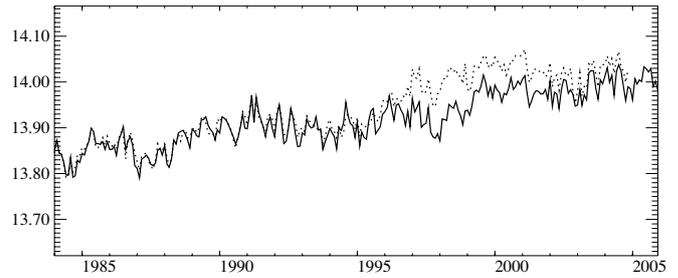


Figure 4: Time series of globally-averaged upper ocean (0-300m) temperature, with the monthly mean annual cycle removed, for 1984-2005, from the ENACT objective analysis (dashed) and from the objective analysis derived from the corrected in situ dataset (solid)

the advantages of a 'multi-model' approach were clearly demonstrated in the EU DEMETER project (<http://www.ecmwf.int/research/demeter>). The developments in ENACT both serve such forecast multi-models and form the first steps in multi-model ocean analysis and monitoring.

Acknowledgements:

The ENACT project was supported by the European Commission under contract no. EVK2-CT2001-00117. Particular thanks to Arthur Vidard for producing the collective figures.

References:

Conkright, M.E., J.I. Antonov, O. Baranova, T. P. Boyer, H.E. Garcia, R. Gelfeld, D. Johnson, R.A. Locarnini, P.P. Murphy, T.D. O'Brien, I. Smolyar, C. Stephens, 2002: World Ocean Database 2001, Volume 1: Introduction. Ed: Sydney Levitus, NOAA Atlas NESDIS 42, U.S. Government Printing Office, Washington, D.C., 167 pp.

Dickson, R.R., J. Meincke, S.-A. Malmberg, A.J. Lee, 1988. *Prog. Oceanog.*, **20**, 103-151.

Haines, K. and J. Blower, J.-P. Drecourt, C. Liu, A. Vidard, I. Astin and X. Zhou, 2006. Salinity assimilation using S(T): Covariance relationships. *Mon. Weath. Rev.*, **134**, 759-771.

Ingleby, B and M. Huddleston, 2006. Quality control of ocean

centre	stream	Data	scheme	OGCM
CERFACS	S1	T, TS	3D-Var, 4D-Var	OPA
	S2	T, TS	3D-Var	
LODYC	Sa	A	4D-Var	OPA
INGV	S1	T	OI	OPA
	S2	T, TS	"	
	Sa	A	"	
NERSC	Sa	A	EnKF	OPA
ECMWF	S1	T, TS	OI	HOPE-E
	S2	T, TS	"	
	Sa	TSA	"	
KNMI	S1	TSA	EnKF	MPI-OM
MPIM	Sa	A	3D-Var	MPI-OM
Met Office	S1	TS	OI	GloSea (UM)
	S2	TS	"	
	Sa	TSA	"	
	1956-2001	TS		ObjA

Table 1: ocean analyses produced in ENACT.

S1 indicates stream1 (1987-2001); S2 is stream 2 (1962-2001); Sa is the satellite stream (1993-2001). T denotes assimilation of in situ temperature data, S salinity, A sea level anomalies from altimeter data. OI denotes use of a type of optimal interpolation assimilation scheme, EnKF denotes an ensemble Kalman filter scheme, ObjA denotes an objective analysis.

For each model there is also a control analysis for which no ocean in situ or sea level data were assimilated. For OPA a control analysis with a higher resolution OGCM version was also produced for comparison.

- temperature and salinity profiles – historical and real-time data. *J. Mar. Sys.*, in press.
- Johnson, G.C., B.M. Sloyan, W.S. Kessler, K.E. McTaggart, 2002. Direct measurements of upper ocean currents and water properties across the tropical Pacific during the 1990s. *Prog. Oceanog.*, 52, 31-61.
- Levitus, S., J. Antonov, T. Boyer, 2005. Warming of the world ocean, 1955-2003. *Geophys. Res. Lett.*, L02604, doi:10.1029/2004GL021592
- Troccoli A. and P. Kallberg, 2004: Precipitation correction in the ERA-40 reanalysis, ERA-40 Project Report Series, 13.
- Willis, J.K., D. Roemmich and B. Cornuelle, 2004. Interannual variability in upper ocean heat content, temperature, and thermosteric expansion on global scales. *J. Geophys. Res.*, 109, C12036, doi:10.1029/2003JC002600

Appendix: common data

Common output grid and data:

A common grid similar to the 'Levitus' grid was designated for the post-processed output of select data fields listed below. The grid has one degree horizontal resolution with longitude gridpoints from 0 to 359 and latitude gridpoints from -89

to +89. (There is thus a 0.5 degree latitude shift with respect to the original Levitus grids, to retain points at the equator and at the precise TAO mooring locations). The vertical resolution is as Levitus, with 31 levels at the following depths:

0, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500, 1750, 2000, 2500, 3000, 3500, 4000, 4500, 5000, 5500 metres.

Monthly average output data (3D fields)

Potential temperature referenced to the surface (degC); salinity (psu); zonal and meridional velocity components (m/sec), vertical velocity (m/day).

Daily average output data (2D fields):

Sea level (m), SST (degC), surface solar and non-solar heat flux applied as forcing (W/m^2), surface net heat flux (including the SST relaxation term, W/m^2), surface freshwater flux forcing (mm/day), surface net freshwater flux (mm/day), zonal and meridional wind stress (N/m^2), depth of the 20C isotherm (m).

Obituary: Kirill Kondratyev

On 2 May, the ICPO was informed in an email from Tatyana Rotanova, forwarded by Lennart Bengtsson, that Kirill Kondratyev had passed away on 1 May. I have fond memories of meeting and having lunch with Kirill and his wife during the period of the 25 session of the Joint Scientific Committee for WCRP in March 2004. Below, we print the full text of Tatyana's email in tribute to Kirill Kondratyev.

Howard Cattle

Hereby we grievously inform you about the premature decease of Kirill Kondratyev that occurred on the 1st of May, 2006. Our friend and colleague, Kirill Kondratyev was a famous scientist, full Academician of the Russian Academy of Sciences, an acknowledged expert in the area of climate and environment. He is the author of more than one thousand papers in the most prestigious journals as well as of more than hundred monographs and textbooks published in the former USSR, Russia and abroad.

The area of scientific interests of Kirill Kondratyev was extremely broad encompassing the theory of transfer of thermal radiation through the atmosphere, green-house effect, natural and man-induced catastrophes, remote sensing of environment and global climate change.

Kirill Kondratyev was the honorary member of the American Meteorological Society, Royal Meteorological Society of the Great Britain, Academy of Natural Sciences "Leopoldina" (Germany), foreign member of the American Academy of Arts and Sciences, member of the International Astronautic Academy, honorary Doctor of Sciences of the Universities of Lille (France), Budapest (Hungary) and Athens (Greece). During many years he was editor-in-chief of the Russian Journal (Earth Observations and Remote Sensing", he also was member of the editorial board of such journals as "Optics of the atmosphere and ocean", "Proceedings of the Russian Geographical Society", "Meteorology and Atmospheric Physics" (Austria), "Idojaras" (Hungary), "Il Nuovo Cimento C" (Italy), "Atmosfera" (México), "Energy and Environment" (Great Britain).

For his salient scientific attainments Kirill Kondratyev was awarded with the State Award of the USSR, and decorated with a gold medal by the World Meteorological Organization, the Simons gold medal by the Royal Meteorological Society of the Great Britain.

During first 30 years of his scientific career, Kirill Kondratyev was insolubly related to the State University of Leningrad, where he made a way from a professor assistant to the rector of the university. An important part of his activities was also related to the A.I. Boeykov Main Geophysical Observatory.

The next 30 years were tied up with his work at the Institute of Limnology and the Center for Ecological Safety, Russian Academy of Sciences. The latter was the last affiliation of Kirill Kondratyev, where he held the position of the Counsellor of the Russian Academy of Sciences.

Kirill Kondratyev was one of the founders of the Nansen International Environmental and Remote Sensing Centre (NIERSC) in St. Petersburg. For many years he was a co-chairman of NIERSC.

Kirill Kondratyev was participant of Second World War. He was decorated with the honorary sign as a defender of Leningrad, the Order of Lenin, two orders of the Labor Red Banner, order of the Patriotic War and many others.

The ICES Report on Ocean Climate 2005

Sarah L. Hughes, N. Penny Holliday and the ICES Working Group on Oceanic Hydrography

The ICES Report on Ocean Climate (IROC 2005) has recently been published (www.ices.dk/marineworld/oceanclimate.asp). The report provides a synthesised view of environmental conditions in the North Atlantic in 2005 by summarising results from long-term observations at standard sections and stations. The IROC (formerly known as the ICES Annual Ocean Climate Status Summary) is an annual publication by the ICES Working Group on Oceanic Hydrography (www.noc.soton.ac.uk/JRD/ICES_WGOH). Some of the overview figures are given here. The time-series selected for the report have been extracted from larger datasets as indicators of the conditions in a particular area. The key parameters described are seawater temperature and salinity, and less frequently, air temperature. The data

presented have usually been collected as part of a standard oceanographic section, repeated annually or more frequently. Observations in 2005 are compared to the average conditions and to long-term trends in each dataset.

Highlights of the North Atlantic Ocean in 2005 as identified by the IROC 2005 are:

- * The upper layers of the North Atlantic and Nordic Seas were warmer and more saline than the long-term average.
- * The warm surface anomaly located between UK and Iceland in 2004 moved into the Norwegian and Barents Sea.
- * The trend in the last decade (1995-2005) has been of warming and increasing salinity in the upper ocean.

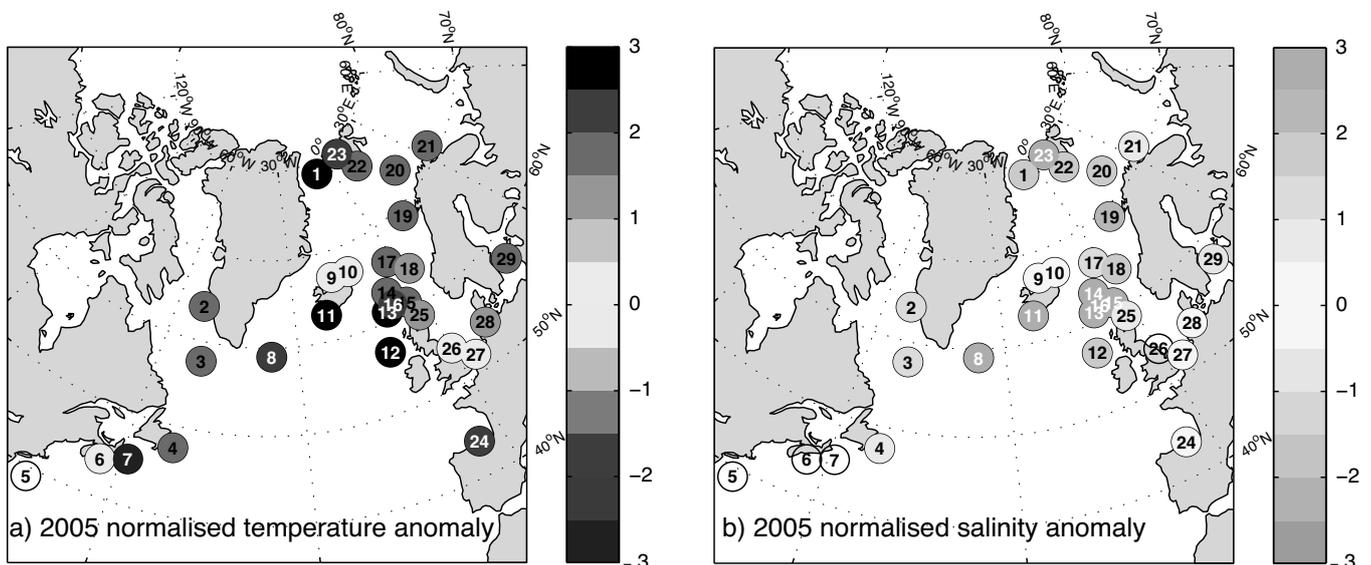


Figure 1. 2005 normalised upper ocean temperature anomalies (left) and salinity anomalies (right). Although the scale is presented as greyscale here, only locations 5, 7, 10, and 24 have negative temperature anomalies, and only location 29 has a negative salinity anomaly. Full colour figures are available in the IROC 2005.

The International Council for the Exploration of the Seas (ICES) coordinates and promotes marine research in the North Atlantic.

The Working Group on Oceanic Hydrography (WGOH) is one of many expert groups which cover all aspects of the marine ecosystem. It is co-chaired by Sheldon Bacon and Penny Holliday.

The IROC 2005 can be downloaded in pdf format from

www.ices.dk/marineworld/oceanclimate.asp.

Alternatively, hardcopies may be ordered from www.ices.dk/products/mailord.htm.

The ICES Data Centre contains physical, biological and chemical oceanographic data from the North Atlantic region dating back as far as the 1870s.

Data and metadata can be searched and downloaded from www.ices.dk/datacentre/data_intro.asp.

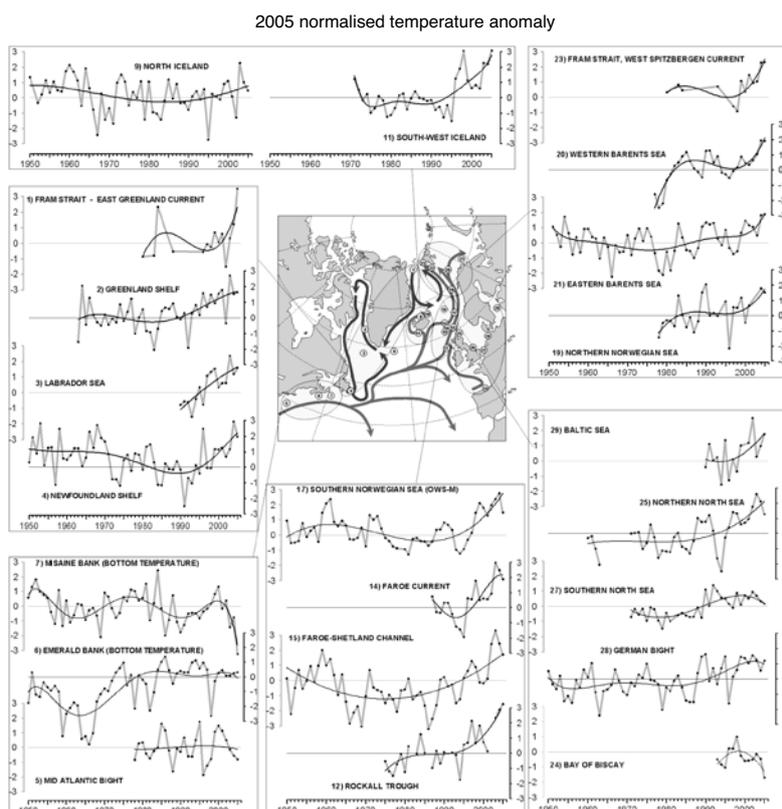


Figure 2. Overview of upper ocean temperature anomalies across the North Atlantic. Temperature data are presented as anomalies from the long-term mean (1971-2000); for consistency anomalies are normalised with respect to the standard deviation, e.g., a value of +2 indicates two standard deviations above normal.

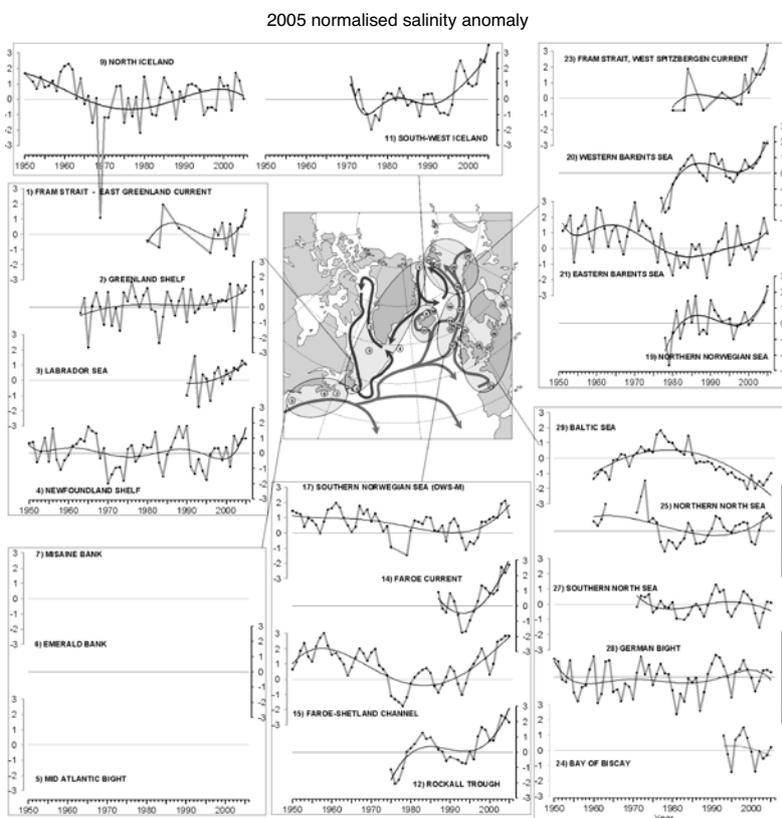


Figure 3. Overview of upper ocean salinity anomalies across the North Atlantic. Data are presented as normalised anomalies as for Figure 2

Contents

Editorial	1
SSG	2
The International CLIVAR Pacific Panel Meeting	4
The Third Session of the CLIVAR/GOOS Indian Ocean Panel	6
US CLIVAR Madeen-Julian Oscillation Working Group (MJOWG)	7
AMMA and its first International Conference address the West African Monsoon	7
The MJO and agricultural decision making in northern Australia	9
On the variability of secondary heat sources over northwest India	10
Rossby Wave propagation and its relationship with severe frosts over South America	18
Voluntary Observing Ships: A vital marine observing system in decline	20
Multi-model multi-method multi-decadal ocean analyses from the ENACT project	22
Obituary: Kirill Kondratyev	25
The ICES Report on Ocean Climate 2005	26

Argo brochure

Mailed with this copy of CLIVAR Exchanges is a brochure produced for the Second Argo Science Workshop in March 2006 and describing the international Argo profiling float project.

Argo is sponsored by CLIVAR and provides an unprecedented ability to monitor upper ocean temperature and salinity and to provide new insights into global scale heat storage. Argo is approaching its 3000 float target (2500 operating in mid-July). All Argo data are freely available.

More information on Argo can be found at <http://www.argo.ucsd.edu>

Flux News

Also mailed with this copy of CLIVAR Exchanges is FLUX News - a newsletter of the WCRP Working Group on Surface Fluxes (WGSF).

WGSF deals with air-sea energy and mass exchanges and aims to address all the requirements of research, observations, analysis and modelling of surface fluxes across WCRP. WGSF activities are closely coordinated with those of CLIVAR.

The CLIVAR Newsletter Exchanges is published by the International CLIVAR Project Office
ISSN No: 1026 - 0471

Editors: Howard Cattle
Layout: Sandy Grapes
Printing: Technart Ltd., Southampton, United Kingdom

CLIVAR Exchanges is distributed free of charge upon request (icpo@noc.soton.ac.uk)

Note on Copyright

Permission to use any scientific material (text as well as figures) published in CLIVAR Exchanges should be obtained from the authors. The reference should appear as follows: Authors, Year, Title. CLIVAR Exchanges, No. pp. (Unpublished manuscript).

If undelivered please return to:
International CLIVAR Project Office
National Oceanography Centre Southampton
University of Southampton Waterfront Campus
Southampton, SO14 3ZH, United Kingdom



Please recycle this newsletter by passing on to a colleague or library or disposing in a recognised recycle point