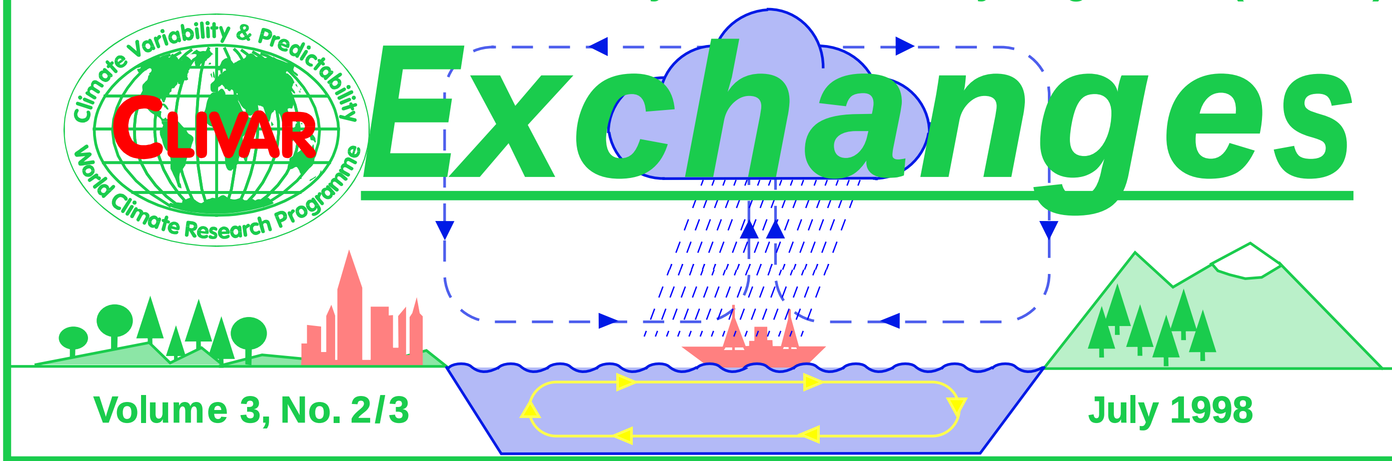
Newsletter of the Climate Variability and Predictability Programme (CLIVAR)

Exchanges



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From the Director ICPO

CLIVAR Initial Implementation Plan

As this issue of CLIVAR Exchanges goes to press, CLIVAR reaches another important milestone with the publication of its Initial Implementation Plan (IIP). Together with the 1995 Science Plan and the brochure “CLIVAR - A Research Programme on Climate Variability and Predictability for the 21st Century” published in August 1997, it spells out the scope of CLIVAR science. The term “Initial” implies that the plan reflects the present status of CLIVAR science and that this view will inevitably evolve as our understanding improves based on the results of TOGA, WOCE and CLIVAR itself.

The IIP is the culmination of 3 years of intensive discussions, workshops, writing assignments and editing and this has involved a great deal of hard work by many people. While it is impossible to thank everyone who has been involved, special mention needs to be made of the contributions from Andreas Villwock in the ICPO in Hamburg and from George Needler who played a major editorial role in the later stages.

The printed versions will be distributed from the ICPO in Hamburg and Southampton in July but it is already available in html format at
http://www.dkrz.de/clivar/vol2/contents_new.html
and on the US mirror site at
http://www.clivar.ucar.edu/vol2/contents_new.html
Additionally, you can preview, download and print
a camera-ready version of the plan in pdf-format from:
http://www.dkrz.de/clivar/vol2/contents_pdf.html
and its mirror site
http://www.clivar.ucar.edu/vol2/contents_pdf.html

CLIVAR Conference

The IIP will be an important preparatory document for the Intergovernmental CLIVAR Conference that will be held at UNESCO Headquarters in Paris Dec. 1-4,

1998. At that Conference we will be demonstrating the scope of CLIVAR science and its potential benefits and seeking expressions of interest and firm resource commitments from countries that wish to participate in the project.

Since CLIVAR is seeking commitments we expect that national delegations to the conference will consist primarily of senior representatives of funding agencies supported by key members of the scientific community. We do not now see this as a conference at which scientists will discuss amongst themselves the details of the IIP - those discussions will come later when the details of national commitments become clear. There has already been enormous interest in the Conference and in the IIP from individual scientists, research institutes, funding agencies and other institutions. These interests now need to be focused into the written submissions and presentations to be made by national delegations to the Conference.

The Conference Organizing Committee, now chaired by David Carson from the UK Meteorological Office, the CLIVAR SSG and the ICPO are preparing the Conference programme which will be distributed soon, together with information on what countries are asked to do in preparation. Updates on the current planning status will be put on our Conference websites: **http://www.dkrz.de/clivar/clivar_conf.html http://www.clivar.ucar.edu/clivar_conf.html**.

Other news

The spin-up of the relocated ICPO in Southampton is under way. A full time secretary (Mrs. Sandy Grapes) will be in post at the end of July and the process of recruiting a senior scientist to join the ICPO is progressing well. In the meantime the staff in the two office locations (Hamburg and Southampton) together with input from WCRP JPS in Geneva are supporting CLIVAR meetings, providing information on the project and preparing for the Conference.

This Newsletter

The 1997/98 ENSO event is of enormous importance both scientifically and as a wonderful opportunity to highlight the importance and relevance of CLIVAR science. I am therefore very pleased to see the stimulating ENSO review article by Kevin Trenberth. The remaining articles, while apparently reporting on meetings, contain much useful information relevant to CLIVAR implementation. The article by Neville Smith on the CLIVAR UOP meeting highlights a proposal (ARGO) for a global network of subsurface floats as part of the Global Climate Observing System (GCOS) and as a potential contribution to CLIVAR and GODAE. It would provide real-time data on upper ocean temperature and salinity distributions and have an enormous impact on both the global and regional implementation of CLIVAR. South America, SE Asia and Africa will be areas of intense interest in CLIVAR and all the meetings reported in this issue of Exchanges addressed aspects of implementation whether in these and other regions or more generally (WOCE Data Products Committee and the CLIVAR SSG). This is a bumper issue (Combining 1998 numbers 2 and 3). Number 4 will appear in the run-up to the December CLIVAR Conference.

CLIVAR Exchanges has the potential to be a means of rapidly spreading information on new scientific findings from CLIVAR-related research and I encourage you to submit any relevant articles to the ICPO for possible publication in future issues.

John Gould

CLIVAR Scientific Steering Group
- 7th Session -
Santiago de Chile, 27 April - 1 May 1998

The CLIVAR Scientific Steering Group (SSG) held its seventh session in Santiago, Chile, at the stately headquarters of the Chilean National Science Foundation. This was the first SSG meeting to be held south of the equator, and the site was selected to highlight the role of Latin American science and scientists in CLIVAR, and particularly VAMOS (the CLIVAR study of the Variability of the American Monsoon Systems). The local host was Dr. Fuenzalida of the University of Chile, the nominated CLIVAR liaison with the Inter American Institute for Global Change Research (IAI). Representatives from the local meteorological and hydrographic services also participated in the meeting. Scientific presentations were made by two local researchers, Drs Aceituno and Rutlland on climate predictions efforts in Chile and on a studies of regional climate dynamics.

The main focus of this SSG meeting was on implementation - i.e. working to ensure that what appears in the Plan (see introduction) becomes reality, and preparing for the upcoming CLIVAR Conference in Paris in December. There was considerable discussion of how best to oversee and coordinate a programme as ambitious and diverse as CLIVAR (sometimes referred to as “10 TOGAs”). The SSG preference was for minimizing the number of formal committees and using workshops and ad hoc working group meetings to develop and refine implementation of various aspects of the programme. The SSG was also looking to maximize the synergy with other related programmes, through shared resources and committees.

Some basic principles for CLIVAR implementation were agreed:

1. International coordination is the essence of CLIVAR implementation and is the primary responsibility of the International CLIVAR Project Office (ICPO).
2. The CLIVAR panels should focus primarily on implementation issues, based on what is in the Plan and on the outcomes of the December Conference, with the SSG providing overall scientific guidance and coordination amongst panels.
3. Implementation of CLIVAR reaches across timescales. In particular, many observing systems provide data essential for several principal research areas (PRAs) within GOALS, DecCen and ACC and modelling necessarily encompasses all timescales.
4. Many aspects of implementation are regional; therefore formation of regional oversight panels should be considered.
5. The SSG should encourage, and the ICPO should help coordinate, international and multi-national process studies. The SSG should regularly invite reports from these projects to enable effective coordination.
6. Background sustained observing systems should be recommended and encouraged by CLIVAR, but implemented through programmes such as GCOS and GOOS.

Three of the GOALS PRAs are already served by planning and oversight panels. Two of these - VAMOS and the Asian-Australian Monsoon, had just met. The SSG endorsed the staged approach to field programmes proposed by VAMOS (summary on page 21) and urged the ICPO to assist in implementing the first phase observing systems, particularly in the region of the low level jet in central South America.

The SSG discussed in depth how best to manage the five DecCen PRAs, each of which has a strong oceanographic component tied to regional and global atmospheric circulation issues and, in some cases, to sea ice and land surface processes, as well. The Group concluded that the three "Atlantic" PRAs would benefit from cross-fertilization and coordination under a single oversight Panel. This was consistent with the views expressed at the EuroCLIVAR Atlantic meeting which was held two weeks later in Florence. Draft terms of reference were drawn up and task groups established to recommend membership. Similar proposals were put forward for a Southern Ocean group and one for the Pacific. The Indian Ocean is being actively considered by the AA Monsoon Panel and the SSG felt that this Panel should currently remain the focal point for CLIVAR requirements in the area. The formation of all these groups is being coordinated with Ocean Observing Panel for Climate (OOPC) to avoid duplication of effort. In light of these developments, the terms of reference of the CLIVAR Upper Ocean Panel (UOP) would be reviewed at the end of 1999.

A second focus of the SSG meeting was a preliminary assessment of how well the 97/98 ENSO event, and its impacts around the globe, have been observed, modelled and predicted. Reports were heard from the various nations and institutions represented at the meeting as to their experiences and what lessons had been learned which might be applied to CLIVAR research. It was clear that the observing system in the Pacific had played a key role in the ability to predict the event, but also that most models failed to predict the intensity of the event until it was underway. Prediction of regional impacts saw a mixture of successes and failures; some of the latter may be attributable to anomalous conditions in the rest of the equatorial oceans and elsewhere. A comprehensive report will be compiled by K. Trenberth and submitted as a CLIVAR contribution to the United Nations 97/98 ENSO Retrospective which is being organized under the auspices of several UN agencies. A summary appears in this issue of Exchanges.

The organization of modelling efforts in support of CLIVAR research formed a central point of discussion at the meeting. It was recommended that the CLIVAR Numerical Experimentation Group (NEG1) increasingly focus on the seasonal to interannual prediction problem and interact more closely with the UOP, particularly in the specification of observations required for initializing models. The SSG will request that the Working Group on Coupled Modelling (WGCM) takes responsibility for those activities of NEG 1, such as the El Niño Simulation Intercomparison Project (ENSIP), that involve improving the ability of global coupled climate models to simulate seasonal to interannual climate variability as contained in the global models. The WGCM was urged to fully assess the ability of climate models to simulate modes of natural variability on all the timescale within the remit of CLIVAR, and to address in particular the impact of anthropogenic forcing on these modes. The

SSG also agreed to work with the WOCE SSG to ensure that issues related to the improvement of ocean models were adequately addressed within the WCRP modelling programme.

The SSG recognized that a successful CLIVAR required active coordination with other WCRP programmes. Based on the reports from VAMOS and the modelling groups, it was agreed that cooperation with GEWEX should be increased in the following areas: (1) the study of stratus clouds, particularly VAMOS with GEWEX Cloud System Study (GCSS), (2) land processes (VAMOS with LBA, AA Monsoon with GAME), and (3) the work of WGCM, NEG 1, and the radiation and cloud panels of GEWEX.

The second major goal of WOCE is to determine the representativeness of the specific WOCE data sets for the long-term behaviour of the ocean, and to find methods for determining long-term changes in ocean circulation. Meeting this objective is of paramount importance to CLIVAR, and the CLIVAR SSG volunteered to work with the WOCE SSG to develop plans for a workshop on the representativeness of WOCE data sets.

The CLIVAR Conference to be held in Paris 1-4 December 1998 will provide an opportunity to advertise CLIVAR to programme managers and decision makers interested in climate science. It should also allow nations to publicize their plans for participation in CLIVAR activities, and to make some preliminary steps towards coordination with the activities of other nations. The SSG will take stock of what constitutes CLIVAR after the December meeting and will direct the programme accordingly, working to fill gaps and modifying projects as necessary.

The SSG developed some guidelines concerning the formulation of the Conference programme. In particular it stressed that the audience should take home the message that CLIVAR is in tune with user requirements and interested in improving the application of CLIVAR research for the socio-economic benefit. The SSG restructured the Conference Organizing Committee in order to get stronger advice from nations on how this Conference would best serve their needs as well as CLIVAR’s. The SSG is looking to the Organizing Committee (now chaired by D. Carson of the Hadley Centre, UK), with the assistance of the ICPO, to develop in the very near future an appropriate agenda and selection of speakers.

Valery Detemmerman

Development and Forecasts of the 1997/98 El Niño: CLIVAR Scientific Issues[1]

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Abstract

A brief description is given of the developments in the tropical Pacific during the 1997-98 El Niño event and how well they were predicted by objective means (dynamical models and statistical methods) and how these were translated into forecasts to the community and public. The failure of a previously successful model inhibited early recognition of the event, although alerts were given in a very timely fashion, and the forecasts for the second half of 1997 were excellent. The description highlights research issues for both the physical scientists and social scientists. For the former, there is a call for more detailed description and diagnosis of what went on and the processes involved, and for studies, including numerical experimentation, to sort out the role of sea surface temperatures in different oceans and the prominent intraseasonal oscillations that existed through the buildup phase of the event, implications for the observing system, the role of global climate change, and attribution of weather and climate anomalies to the El Niño. Further attribution questions arise in linking the climate anomalies to impacts and, because the event was forecast ahead of time, it is suggested that the successes and failures in mitigation of effects may provide useful analogs for societal response to global warming. Substantial issues arise on communication, use and utility of information, and the user needs.

Introduction

The development of the 1997-98 El Niño event into, by some measures, the biggest on record in over a century has given the CLIVAR community a wonderful opportunity to exploit an experiment mounted for us by nature. This event is the best observed ever and the worth of the TAO moored buoy system straddling the equatorial Pacific has been clearly demon-

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[1] Based in part on presentations made at the Seventh session of the CLIVAR SSG in Santiago, Chile (April 1998).

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

strated by its ability to provide data that firstly showed the evolution of subsurface temperature anomalies and secondly was very useful for initializing models for successful prediction of the future evolution. “El Niño” is in the public vernacular. All kinds of things have been blamed on El Niño when sometimes there is at best a tenuous link. A new aspect of this event is that it was predicted by CLIVAR scientists well in advance, and forecasts were widely disseminated. But how good were the forecasts? Were the expressions of uncertainty appropriate? Were the forecasts used? And were they misused? How can the links to El Niño be established and impacts attributed? Clearly, this event demands a careful, in-depth analysis of its many aspects and has lessons for CLIVAR. It is expected that several workshops and conferences will touch on aspects important for a full retrospective examination of the 1997-98 event. There are a huge number of possible subtopics, with many of direct concern to CLIVAR. In this note, the main focus is on the forecasts of the developing stage of the event and possible lessons to be learned.

The Development of the 1997-98 El Niño

Several figures are presented to show the evolution of the 1997-98 El Niño. The startling change in SST anomalies is revealed by the fields for December 1996 and 1997 (Fig. 1). Weak positive SST anomalies in the western tropical Pacific and SSTs that were more than 1°C below normal in the eastern Pacific gave no hint of the explosive warming that peaked in December 1997 with anomalies over 5°C above normal. However, by December 1996 there were clear signs of the developing event below the surface of the ocean (Fig. 2). The evolution of the main relevant fields in the tropical Pacific can be seen as longitude-time sections of anomalies of zonal winds, SSTs, and the depth of the 20°C isotherm (Fig. 3). Note that the latter is in the middle of the thermocline (Fig. 2) and thus reveals the upper ocean heat content and thermocline evolution.

The subsurface ocean observations come from the TAO array and are especially revealing when examined week by week and month by month. The latter show a wonderful series of the evolution of observations of the subsurface temperature and temperature anomaly (Figs. 2 and 3). TOPEX/Poseidon altimeter

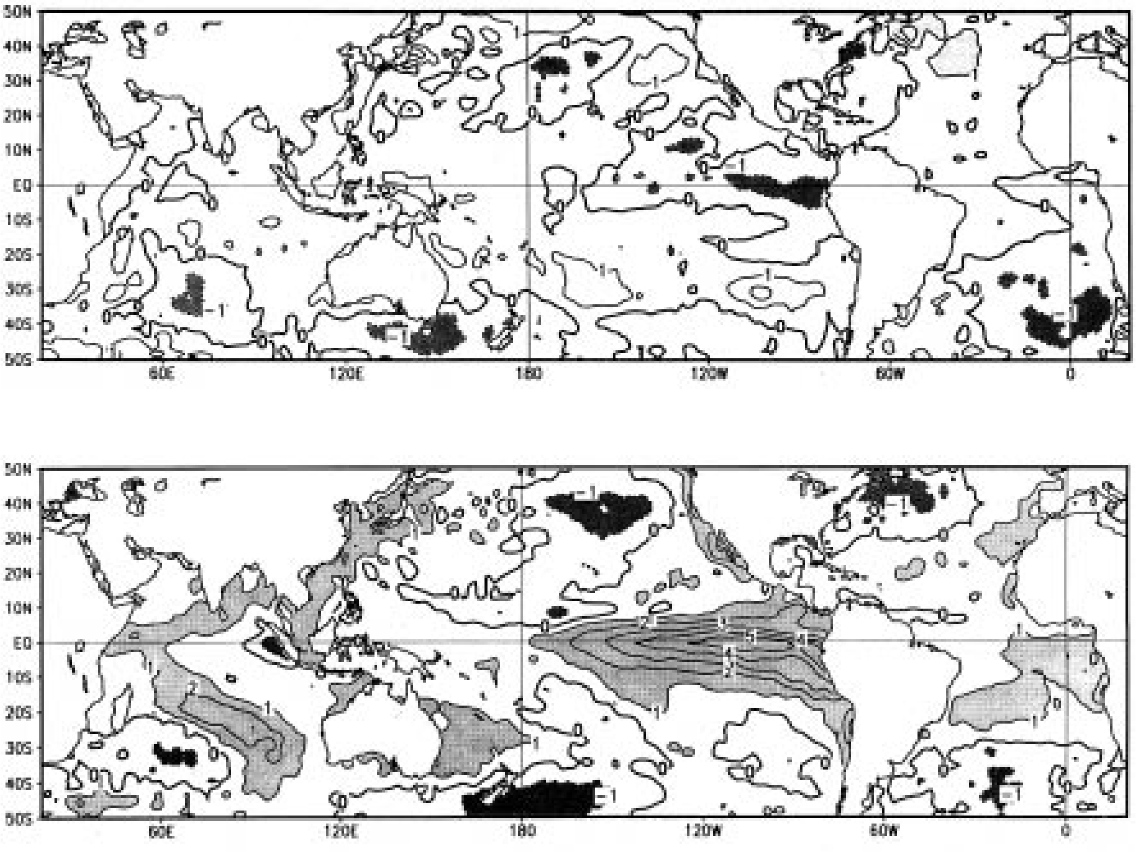

Figure 1: Anomalous sea surface temperature for Dec. 1996 (upper panel) and Dec. 1997 (lower panel). Contour interval is 1^{o}C. Dashed contours indicate negative anomalies. The SST analysis is the OI analysis, while anomalies are departures from the adjusted OI climatology (Reynolds and Smith, 1995, *J. Climate*, **8**, 1571-1583) (from Climate Diagnostics Bulletin, Dec. 1996, resp., Dec. 1997).

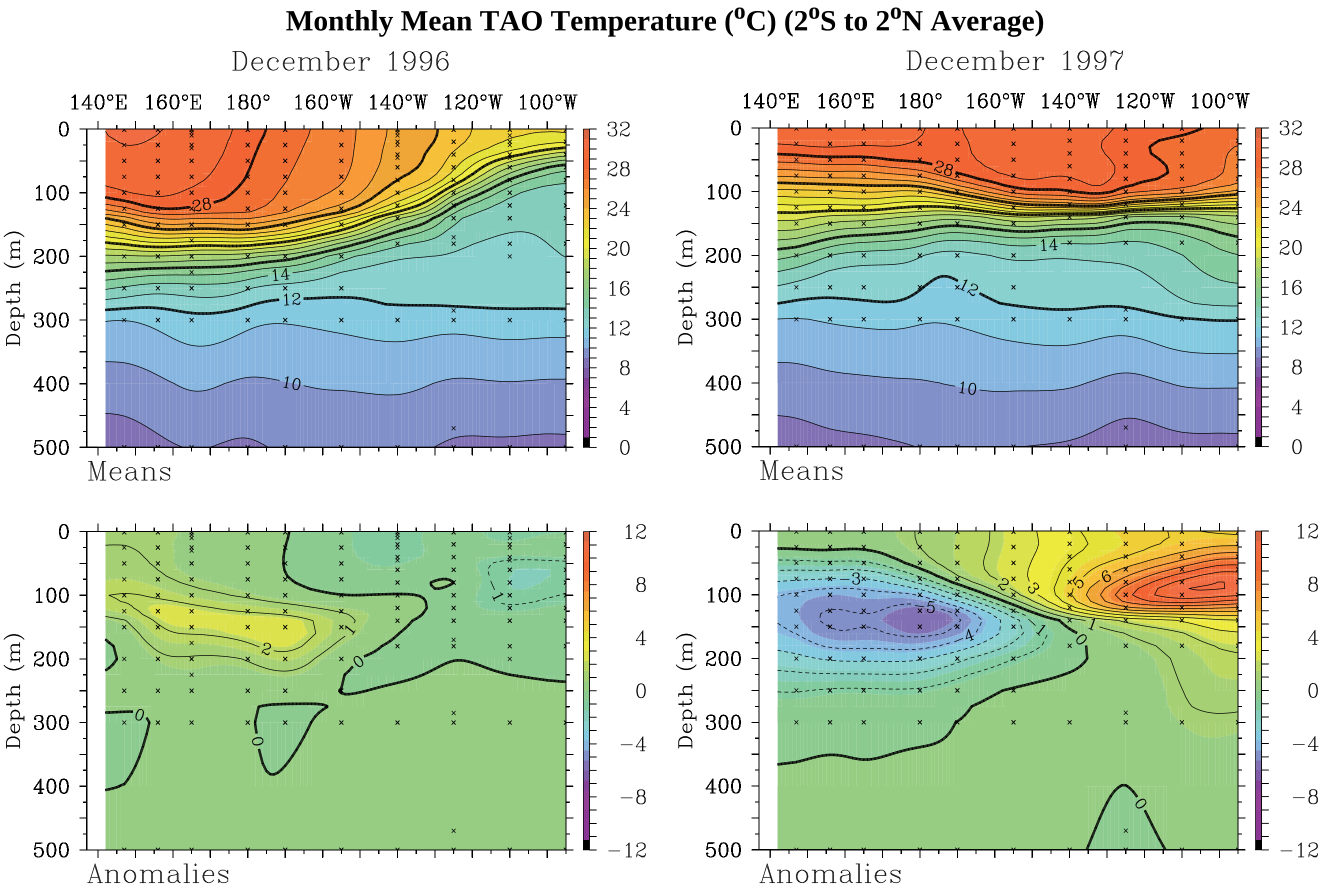

Fig. 2: Longitude-depth cross-sections of mean TAO array temperatures from 2°S to 2°N in the equatorial Pacific Ocean for the months of December 1996 and December 1997. Contours every 1°C. Top panels: total field; bottom panels: corresponding anomalies (courtesy of NOAA/PMEL).

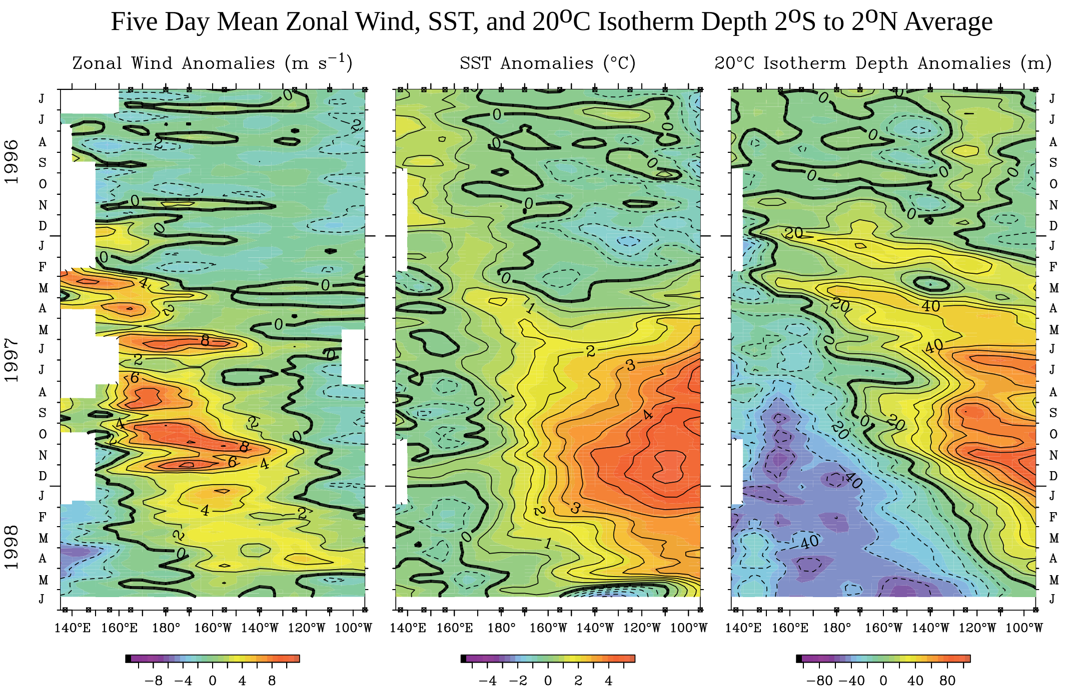

Fig. 3: Time / longitude sections of anomalies in the surface zonal winds (in m s^{-1}), SST (in ^{0}C) and 20^{0}C isotherm depth (in m) for the past 24 months. Analysis is based on 5-day averages between 2^{0}N-2^{0}S of moored time series from the TAO array. Anomalies are relative to monthly climatologies cubic spline fitted to 5-day intervals (COADS winds, Reynolds SST, CTD/XBT 20^{0}C depths).

Positive winds are westerly. Squares on the abscissas indicate longitudes where data where available at the start of the time series (top) and at the end of the time series (bottom). The TAO array is presently supported by the US (NOAA Office of Global Programs), Japan (JAMSTEC), Taiwan (NSC), Korea (STA) and France (ORSTOM). Further information is available from Dr. M.J. McPhaden (NOAA/PMEL) (courtesy of NOAA/PMEL).

data (published in the NOAA Climate Diagnostics Bulletin) also reveal aspects of the evolution through the sea surface topography. Several other space-based sensors were also available to provide sea surface temperatures, surface winds, ocean colour and precipitation and these should lead to a better description of the event than has ever been possible before.

The TAO data reveal that the subsurface anomalies which eventually developed into the El Niño were traceable at least from about September 1996 on the equator in the far western Pacific. However, positive subsurface temperature anomalies in the upper one to two hundred meters in the far western Pacific exceeded 1°C for all of the months of 1996, and so this was not a sufficient predictor. In addition, because sea level anomalies are determined by salinity as well as temperature anomalies, and the salinity is especially prone to change in the west Pacific Warm Pool when eastward shifts occur in heavy rainfall during El Niño, the TAO information is not sufficient for initializing models.

The contrast between the state of the subsurface in December 1996 versus December 1997 at the peak in SST anomalies (Fig. 1), is shown in Fig. 2. By December 1996 subsurface temperature anomalies in the vicinity of the equator had grown to exceed 2.5°C at about 150 m depth and the warm anomaly extended from at least 140°E (the westernmost buoy) to 140°W. However, conditions were still below normal in the eastern Pacific. By December 1997, the subsurface warm anomaly had progressed eastward and amplified to produce positive anomalies exceeding 11°C at about 100 m depth, accompanying the surface SST anomalies exceeding 5°C. Also note, however, in December 1997 the subsequent cold anomaly of over 5.5°C in the western equatorial Pacific near 150 m depth, as the warm pool had been displaced into the central Pacific from 130 to 170°W.

In early 1997, positive anomalies in subsurface temperatures prevailed when integrated across the entire Pacific in the equatorial region. By the end of 1997, the heat content was clearly being depleted as negative anomalies appeared to dominate, and this trend has continued through May 1998 where the heat content is clearly anomalously below normal. This indicates the effect of the El Niño on effectively removing heat from the tropical Pacific during its course as has been found for the 1986-87 event (Sun and Trenberth 1998). No doubt the heat losses after the peak in the event contributed to the exceptional warmth evident in surface temperatures globally during the first five months of 1998.

Another key feature of this event was the presence of intraseasonal oscillations which may have helped to initiate the event. A prevailing theory of ENSO is that it behaves as a delayed oscillator in which Rossby waves travel westwards off the equator to the western side of the Pacific where they are reflected and manifested as Kelvin waves along the equator and cause a reversal of the previous conditions. Evidence for such a sequence is not readily apparent in the onset of this event. Instead, the intraseasonal oscillations (40-50 day Madden-Julian Oscillation, (MJO)) were very prominent in the westerly wind anomalies in the far western Pacific, with westerly bursts in December 1996, February, May, August, October, and November 1997, and each one is traceable as a down-welling Kelvin wave propagating rapidly eastwards (across the Pacific in about 3 months) in the thermocline, as seen in the 20°C isotherm anomalies, see Fig. 3. Thus within the overall envelope of the eastward developing subsurface temperature anomalies, there is important structure associated with the MJOs. The first warming at the surface in March 1997 coincided with the arrival of the downwelling Kelvin wave generated in December 1996 (Fig. 3). The role of MJOs in the development and intensification of the 1997-98 ENSO is a key scientific question (e.g., see Li and Zhou 1994, Li and Liao 1998).

Forecasts of the Onset of the 1997-98 El Niño

Onset of some warming was predicted by several dynamical models beginning about November 1996. These included the Scripps, NCEP, COLA, UKMO and ECMWF dynamical model predictions. There were also some notable failures (LDEO/Cane-Zebiak). Of forecasts available operationally (which did not include those from ECMWF), none captured the strength of the warming during the first part of 1997 (NCEP seems to come closest to observed). However, ECMWF did very well in forecasting observed tropical Pacific SST increases for May 1997 from December 1996, but this forecast was only available later (see Stockdale et al., 1998). Several aspects of the predictions of the event are discussed by Anderson and Davey (1998).

A preliminary assessment of some forecasts of the event, but only from about February-March 1997, is given by Barnston (1997). Barnston includes both empirical methods of all kinds and dynamical model-based forecasts in his evaluation. Despite some claims of success, the statistical/inverse models did not seem to show skill of value. The statistical Canonical Correlation Anomaly (CCA) method of Barnston and Ropelewski (1992) predicted a warming of 1.5 standard deviations for Niño 3.4 (170°W to 120°W, 5°N to 5°S) SSTs for JJA 1997 in September through November 1996 but by February 1997 this method was not predicting as much or as rapid warming. Some intermediate low order coupled models, which are typically spun up with observed winds, were able to forecast the future evolution of the event once it had begun and the winds had changed, an example is the prediction by the BMRC intermediate model of Kleeman (1993), although the latter does assimilate subsurface information as well.

In digesting these predictions in real time, it was not possible to make a forecast of the coming El Niño until April 1997 when SST warming first became clearly evident in the eastern tropical Pacific and the El Niño can be said to have begun. Expectations at the end of 1996 from forecast models based on past performance had led to considerable confidence being placed in intermediate models such as the Cane-Zebiak model, which had successfully forecast the 1986-87 event (Cane et al. 1986, Zebiak and Cane 1987, Cane 1991). Hence, the failure of the Cane-Zebiak model to forecast warming in 1997 was a substantial inhibition on issuing a forecast for El Niño until it became clear that results from that model were unreliable and should not be considered. In January 1997, the NOAA Climate Prediction Center (CPC) issued an ENSO Advisory about the current cold phase of ENSO and indicated that conditions in the tropical Pacific "will gradually return to near normal by mid-1997, and become slightly above normal by the end of the year." On April 9, 1997, a new ENSO Advisory was issued by the CPC in which they noted that warming in the tropical Pacific was progressing to the point where SST anomalies exceeded +1°C in the extreme eastern Pacific and near the date line by the end of March. The advisory noted that there were forecasts for warming later in the year and that conditions should be closely monitored. A subsequent advisory in May noted that a warm event had begun and the outlook was now for continued warming throughout the year. In Australia, the Australian Bureau of Meteorology, in its regular Seasonal Climate Outlook in May 1997 noted the likely development of an El Niño event and gave the implications for Australia of the likelihood for drier conditions across eastern Australia. In Japan, regular one month, three month and Warm/Cold season forecasts are issued based on dynamical ensembles for one month and empirical methods for longer ranges. On May 20, 1997 the Japanese Meteorological Agency (JMA) released a forecast for a cold summer for Japan with 50% probability based on El Niño. While observed conditions were below normal in Nansei Islands, they were above normal over most of Honshu

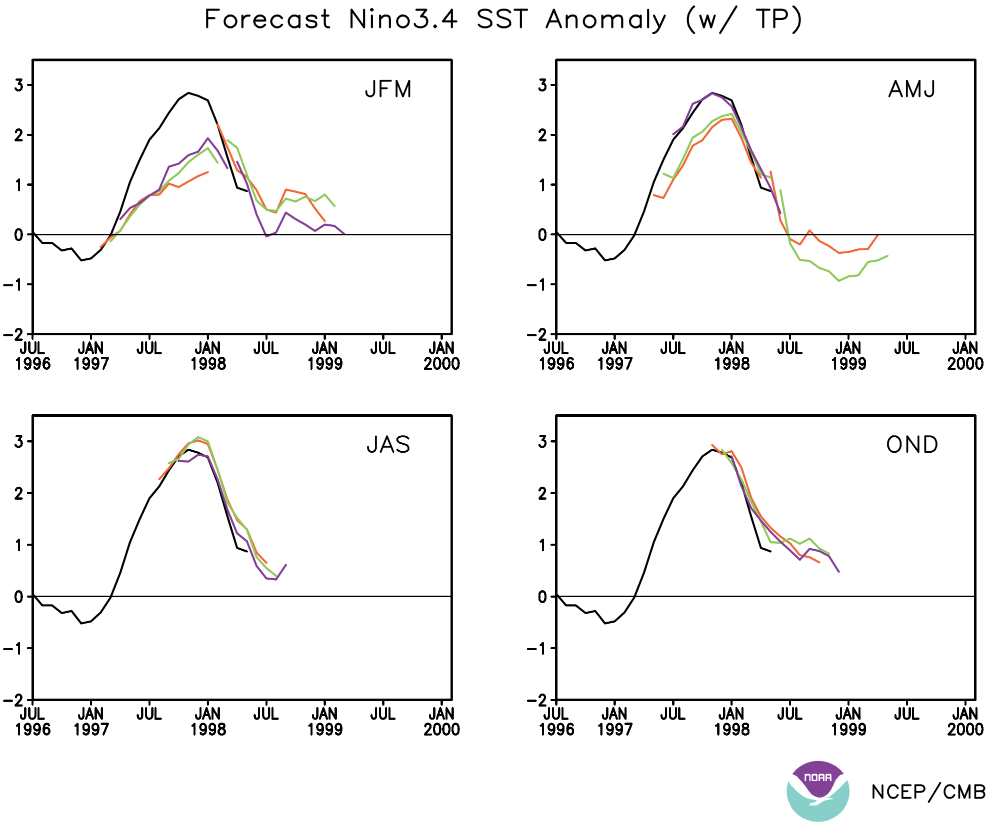

Figure 4: Plume diagrams of the evolution of forecasts of SST anomalies in the tropical Pacific from NCEP for the Niño 3.4 region. The continuous line is the observed and forecasts issued from the months given at upper right in each panel for a year ahead (courtesy Vernon E. Kousky, NOAA).

(the main Japanese Island) in summer 1997.

Information on the forecasts, advisories or warnings available in other countries is not readily available, although considerable information was exchanged on the world wide web (www) and through the NOAA Experimental Long Lead Forecast Bulletins which publish, in near real-time, forecasts from many groups every quarter (see also Barnston 1997). In retrospect, given the historical performance of models, the CPC and agencies in other countries picked up on this El Niño very quickly and alerted the community through their advisories.

The Subsequent Predictions of the Event in 1997

As noted earlier, this event was one in which the full climate models were the most successful for the first time (see also Kerr 1998). These models consist of a full atmospheric general circulation model (GCM) coupled to a dynamical ocean GCM, at least for the tropical Pacific, and thus contain much of the full complexity of the real world. One key advantage of this is that observations are of direct relevance to the atmospheric and oceanic state depicted by the models through data assimilation, whereas this is often not the case for simple or intermediate models whose internal modes of variability generally differ from those in the real world. However, these models are not perfect and require corrections of various kinds, in some cases with flux adjustments to the models themselves, or in other cases by allowing for the biases and systematic drifts in evaluating the results. The strategy for doing this varies from group to group and is a developing art. In addition, the results are not deterministic because of the fundamentally chaotic nature of climate dynamics. Consequently, small changes in initial conditions can give rather different outcomes. Nevertheless, the tropical Pacific appears to be predictable for a year or so in advance.

One way to depict the predictability, for example, of the SST anomalies in the tropical Pacific, is to

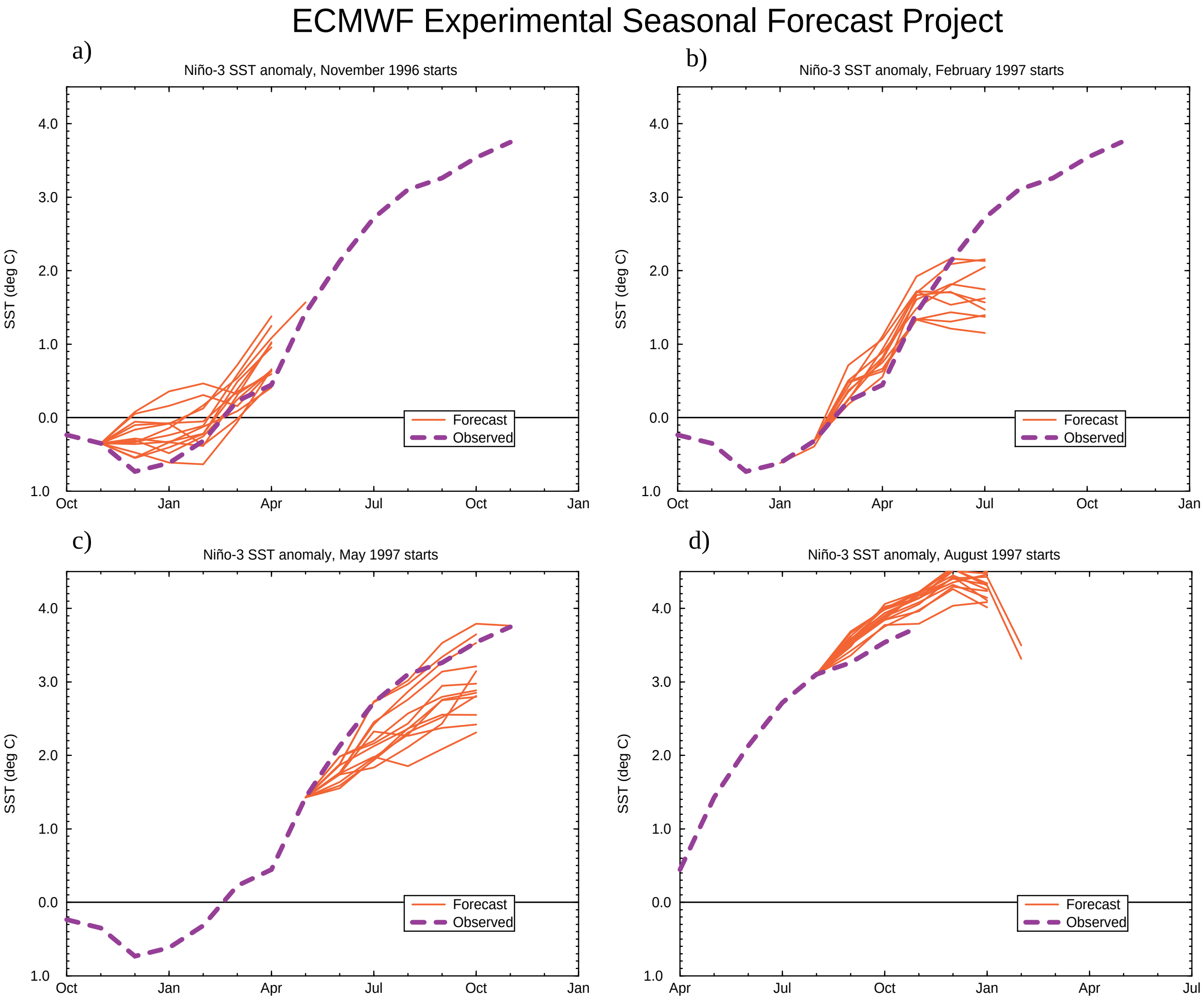

Figure 5: Plume of monthly mean SST anomalies predicted for the Niño 3 region for forecasts initiated in a) November 96, b) February 97, c) May 97 and d) August 97. Three forecasts are initiated weekly and run for six months. The heavy line shows the observed values. From the ECMWF Seasonal Forecast Project page.

show how the different predictions from ensembles of model runs evolve. These are referred to as “plume” diagrams, and examples are shown in Fig. 4 for the Niño 3.4 (170°W to 120°W, 5°N to 5°S) region for NCEP (A. Leetmaa, personal communication), and one result is shown for each month for 11 months in advance. Other examples are given in Fig. 5 for Niño 3 for ECMWF (from ECMWF 1997) showing 13 ensemble members as 6 month forecasts (although not available in real time) and Fig. 6 for the UKMO (courtesy M. Davey). For the UKMO, initialization uses winds only and the model cold bias led to a displacement in the initial value of the anomaly in Niño 3 SSTs. In this case, the change is the quantity of interest.

Warming was predicted by the NCEP model from November 1996 although the magnitude was underestimated by at least a factor of 2 prior to April 1998. Forecasts after that time, at least until May 1998, were excellent. In November 1996, ECMWF 6 month forecasts picked up on the modest warming, but in February 1997, the model prediction indicated a levelling off of the warming in May, whereas the observations showed it continuing. By August, the ECMWF forecasts were overpredicting the warming, although they correctly indicated the drop off in anomalies in January and February 1998, as did the forecasts from NCEP beginning as early as June 1997. Similar plume forecasts of ensembles from the UKMO show reasonable warming being forecast from December 1996, warming in most but not all ensemble members in February 1997 although with substantially underpredicted magnitude by 4 months, pronounced realistic warming in most forecasts in May 1997 but with cooling being predicted prematurely in August 1997. Forecasts from other centres demonstrated skill as well, but the ones shown are representative of the state of the art.

Conditions in the tropics are generally regarded as being fairly predictable, given large SST anomalies. However, there were exceptions in the 1997-98 event. In Australia, winter (JJA) 1997 rainfall was below average over most of eastern Australia but the departures were much less than in other major El Niños, such as 1982-83. In India, summer (JJA) 1997 rainfall was only slightly below normal. One factor contributing to the latter, in particular, seemed to be the intraseasonal oscillations which were strong enough to overcome the larger-scale tendency for dry conditions and brought rain events through the region. The MJOs no doubt had significant influences in other parts of the globe and vice versa (Slingo 1998).

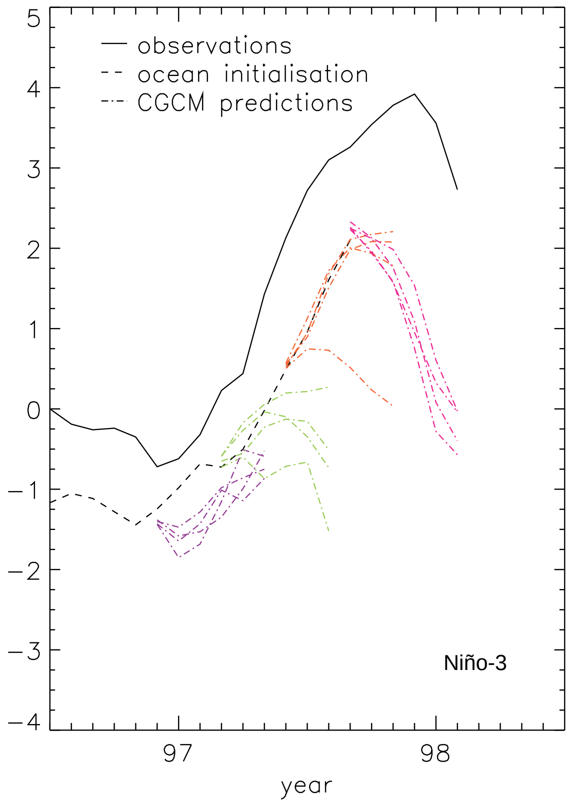

Figure 6: Plume diagrams of the evolution of forecasts of SST anomalies in the Tropical Pacific from the UKMO for Niño 3 (courtesy S. Ineson). The solid line is the observed, the dashed is the initial ocean state (tropical Pacific OGCM forced by FSU wind anomalies with no assimilation of ocean observations so the model ocean is biased colder than observed in 96/97). The other lines are 4 member ensemble members starting on successive days as 6-month predictions using the tropical Pacific OGCM + Hadley Centre ACGM; monthly values are plotted with the first point for each trajectory as the prediction for month 1, so displaced from the initial state.

In the extratropics, conditions are not as predictable. There, established teleconnections and statistically reliable relationships are often used to identify effects of El Niño. This again was an example where full GCM model results provided useful guidance that would not have otherwise been possible. Stockdale et al. (1998) provide an example of an ECMWF forecast of highly statistically significant wet conditions over Europe during the summer (June-August) 1997 which largely verified but would not have been expected from past experience. In places where a pronounced signal often occurs, such as over India and Australia, the model forecasts indicated no clear signal and the result was indeed not a classical signal of much drier than normal conditions. However, the ECMWF forecast for JJA did not pick up on the heavy rains in Chile which eventuated. Above, we further noted that the statistical expectation for Japan for their summer was mostly incorrect. These examples show the limits to statistical analyses which do not have a large enough data base on which to discriminate between different “flavours” of El Niño, and the potential power of models which can predict the unique aspects associated with a particular event. Models can, in principle, also factor in other different factors such as the changing climate and global warming effects.

A superficial assessment indicates that some effects fit the classical model (as given by previous events), but many did not. Another area where highly anomalous conditions were experienced was Kenya and the horn of Africa region where heavy rains were surely linked to very high SSTs in equatorial Indian Ocean (above 95th percentile, above 29°C) after about September 1997. The rains in northeastern Kenya and southern Somalia were apparently the heaviest since 1961. They began in October 1997 and continued through January 1998 leading to a major outbreak of Rift Valley fever – not only in livestock but also with tens of thousands of cases in humans (P. Epstein, personal communication). Major convection in this area clearly had an impact on the divergent atmospheric circulation and there is good reason to believe it altered teleconnections. These aspects need to be established more firmly. It is likely that these changes had impacts on Australia, India, Southern Asia, – all regions where conditions were not as dry as expected from past events – and elsewhere, but again these need to be confirmed.

Forecasts of the northern winter were made well ahead of time and were widely publicized and, fortunately, were generally excellent. In the United States, patterns of temperature and precipitation anomalies were forecast based in part on model output but in large part on statistical relationships developed in the Climate Prediction Center of NOAA, and matched the observed remarkably well. These aspects will not be pursued here.

Research Questions Arising from the El Niño Event

1. *Role of MJOs*

Given the presence of strong MJOs throughout the developing phase of this event,

- Were these waves a key in triggering and amplifying the event?
- Or was their role minimal, as El Niño occurs in intermediate models that do not have MJOs? i.e., are they merely “embroidery”? This is the prevailing hypothesis because no GCMs simulate MJO waves very well, yet several made skilful predictions. However, some MJO effects are in the initial conditions for forecasts, especially in the surface winds. If MJOs are important, it has implications for predictability and highlights the need to improve models.
- Was their continual presence a reason for the large magnitude of this event?
- If they are important, why is that the case? Presumably it must relate to positive feedback effects arising from changes in SSTs and subsequent changes in winds.

The role of MJOs in the 1997-98 ENSO is a key question that can and should be explored with diagnostic and numerical experimentation studies. For instance, as well as diagnostic studies of observations, the initial conditions in an atmospheric model can be altered to remove the MJO and thus alter its influence on the ocean.

2. *Forecast verification and accuracy*

As well as the onset of the event, dynamical model-based forecasts of the evolution of tropical SSTs continued to be made throughout the event and appeared to show considerable skill for several months in advance, including the timing of the peak in SST anomalies in December 1997.

We need to answer how well the event was forecast throughout, both for SST forecasts and the weather regimes around the world (coastal erosion, precipitation, temperature, storminess, flooding, drought, fires, etc.).

In addition, an important research question is to be sure why some models did well and other models did not do well, in spite of strong similarities in several of the models. Unravelling the role of initial conditions for each model, the ocean physics, the atmospheric physics, and the coupling is a challenging task.

3. *SSTs in other regions*

As noted above, a superficial assessment indicates that some effects fit the classical model (as given by previous events), but many did not. It was noted that the SSTs were exceptionally high in the tropical Indian Ocean after September 1997. SSTs also became abnormally high in the tropical Atlantic. One consequence of the high SSTs throughout the tropical oceans may have been a tendency for a more zonal (less wavy) response so that the drought in the western tropical Pacific was more confined to Indonesia and nearby areas, including Papua-New Guinea and the

Philippines, and did not spread as much to Australia and parts of Southeast Asia.

SST anomalies also developed in the extratropical Pacific of both hemispheres, as is expected (notably cold anomalies about 40°N and 40°S just east of the dateline).

There is a strong need for numerical experimentation to test effects of high SSTs in other tropical oceans: Indian and Atlantic, to sort out what might be attributed to the tropical Pacific SSTs, and whether the extratropical SST anomalies played a role. This is readily done by specifying SST patterns in different oceans and running atmospheric GCMs.

Of course, warming in the tropical Indian Ocean usually accompanies El Niño events, so these other SST anomalies also may not be independent of those in the Pacific. A possible interesting experiment was discussed at the April 1998 CLIVAR SSG meeting (by Trenberth and Palmer). It would be to run an atmospheric model with the observed Pacific SSTs only (for 1997). Use the winds and heat fluxes from this experiment to drive an Indian Ocean model. The scientific question - was the big SST anomaly in the Indian Ocean forced by El Niño, via an atmospheric teleconnection, or was it independent of El Niño?

4. *Global warming factors*

The above mentioned warmth of all the tropical oceans, along with mild conditions elsewhere late in the 1997, led to 1997 being the warmest on record. This warmth has continued into the first five months of 1998 where February 1998 appears to have been by far the warmest month on record in terms of its anomaly which was 1.6°C above the 1961-90 normal for land areas (as reported in the Climate Diagnostics Bulletin); previous anomalies have not exceeded 1.0°C except for January 1998. Part of this warmth may have arisen from the release of heat from the tropical Pacific into the atmosphere, cooling the ocean, as was noted above. Over the United States the winter (December-February) 1997-98 was second warmest on record since 1895.

Another major question concerns whether global warming itself is contributing to the prevalence and size of the El Niño. Trenberth and Hoar (1996, 1997) have noted the unusual behaviour of El Niños in the past 20 years as the tendency toward more El Niños and fewer La Niñas has become more apparent. The magnitude of the 1997-98 El Niño has reinforced this evidence.

This also highlights the need for more comprehensive models, ones that deal not just with El Niño and SSTs but also changes in atmospheric composition including both increases in greenhouse gases and aerosols from human activities and debris from volcanic eruptions. The role of the El Chichon eruption in April 1982 at the time of onset of the 1982-83 El Niño has yet to be deciphered. How much did this eruption contribute to differences between that event and the 1997-98 event? All these climate forcings need to be included in forecast models and it must be recognized that interannual variations occur in the setting of the decadal and longer-term variations.

In any case, short-term climate anomalies provide many useful analogs for longer-term climate change studies about impacts and societal response. Analogs include

- Sea level rise along the coast of California, which combined with storms to produce excessive coastal erosion. Sea level is expected to rise in general with global warming.
- The substantially above normal temperatures over land mirror the kinds of changes projected with global warming. It is also noteworthy that the largest warming occurred in areas of below normal rainfall while excessive rainfall and associated cloud accompanied cooler conditions.
- Precipitation patterns change, leading to flooding in some areas such as Chile, Peru, California, the Southeast U.S, and drought in other places (Indonesia, Central America) leading to out-of-control fires often arising from slash and burn agriculture, in spite of ample warnings.
- With the fires came respiratory problems in adjacent areas 1000 km distant. Disease outbreaks, such as Rift Valley fever in Kenya, cholera in Peru, and malaria in Africa occurred and could have been and were anticipated to some extent.
- Because predictions were made, individuals and institutions could respond. Some chose not to; some were unable to.

All of these and many more provide examples of how successful mitigation may be.

5. *The 1997-98 El Niño impacts*

How can a weather event be attributed to El Niño? It usually can not in an absolute sense, as weird weather can happen almost any time. Instead El Niño changes the odds of certain kinds of weather occurring. To determine what these odds are we would like to have the complete probability distribution function for each variable at each location on Earth for the given conditions external to the atmosphere under this situation, which in this case is dominated by the SST anomalies. The only way this can be approximated is with models run as multiple ensembles with different initial states in the atmosphere to generate the appropriate statistics and compare these with normal conditions. In this way a rigorous probabilistic statement can be made about the likelihood that a given anomalous weather event was made more likely by the El Niño. Some studies at the NOAA Climate Diagnostics Center are making ensemble forecasts with and without anomalous SSTs to determine the influence on the evolution of the forecast; the other factor is the anomalous initial state of each forecast. In the 1997-98 El Niño, a general characteristic of the dynamical model forecasts which follows from the magnitude of the anomalies, is that the forecasts tended to be more consistent than usual, more skilful than usual, and the anomaly patterns are large-scale and coherent, all of which helps with the attribution question.

Attributing other things such as outbreaks of disease or pests is even more difficult as these require a chain of events linking the El Niño to a particular weather phenomenon which in turn favours outbreaks of some kind that lead to the impact in question. Examples include warmer and wetter conditions which favour more malaria-carrying mosquitoes, or absence of a freeze that would kill off or reduce a pest or fungus and thus which subsequently causes problems with fauna.

Many questions arise here.

- What was caused by El Niño, what can be attributed to it?
- What were clearly linked to El Niño and what were only tenuously linked?
- What impacts were positive?
    - 1997 Atlantic hurricane suppression.
    - Warm conditions over North America in 1997-98 winter, less heating, less coal, oil and natural gas use, and lower heating bills for consumers.
- What impacts were negative?
    - Layoffs in natural gas industry.
    - Coastal damage, flooding, drought, fires, etc.
    - Tornadoes in Florida, ice storms in Canada and New England.

No attempt is made here to compile a list. Instead, it is clear that lists do need to be compiled and the task will not be easy. It is apparent that for many positive impacts, there were negative impacts elsewhere. For instance, while it may be possible to attribute the tornadoes in Florida to the active and southward-displaced storm track, thereby favouring the conditions that led to the outbreak in that location, it is possible that tornadoes may have simply occurred elsewhere, such as in Georgia. Similarly, other examples above are the benefits of warm conditions on consumers but not on the heating companies, and the shift in hurricane activity from one ocean basin to another. These highlight the need to separate the positive and negative effects or else one might conclude that the effects of El Niño economically were zero because of cancellation between huge positive and huge negative impacts.

There is a need for data base development of various kinds and careful analysis.

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Some Lessons from the 1997-98 El Niño Event

The 1997-98 El Niño – Possible activities

The following lists some initial suggestions for activities, it is not intended to be comprehensive.

On the physical climate side:

- description of event: gathering requisite datasets
- diagnosis of processes, empirical studies
- verification of numerical predictions, forecasts
- development of forecast verification techniques, especially using ensembles
- implications of the event for the observing system
- implications for model development
- numerical experimentation
- the role of global warming
- attribution of local and regional climate anomalies to the event,
- any process studies that should follow?

On human dimensions and applications side:

- proliferation of “information” (e.g. on the www) of mixed quality
- attribution of impacts to El Niño
- impacts of El Niño
- costs/damage and benefits of El Niño
- actions taken because of forecasts (whether useful or not)
- impacts of actions not taken
- impacts of busted forecasts where actions were taken
- assessment of information available
- utility of information
- effectiveness of communication and dissemination of information
- benefits of forecasts (mitigating losses etc.)
- assessment of user needs and how well they were met.

The CLIVAR plans in this area are developing. They fit within a United Nations framework on El Niño that has occurred independently of the CLIVAR initiative. The UN General Assembly passed a resolution in December 1997 on International Cooperation to Reduce the Impact of the El Niño Phenomenon. The resolution, which was coordinated under the framework of the International Decade for Natural Disaster Reduction (IDNDR), has led to the establishment of an El Niño “Task Force” encompassing several UN agencies and programmes. The WMO, for example, has been asked to take the lead in coordinating the provision of scientific and technical advice on El Niño, other agencies will coordinate the socioeconomic impacts and response aspects.

CLIVAR needs to take the lead on the physical aspects perhaps by sponsoring workshops and conferences, and activating panels and working groups to promote such things as numerical experimentation, forecast evaluations, assessment of associated weather events and attribution, and so on. Many of these will happen whether CLIVAR helps or not. However, CLIVAR wishes to be kept informed of pertinent activities.

CLIVAR Upper Ocean Panel 3rd Session

Toulouse, France, 27-29 April 1998

The third meeting of the CLIVAR Upper Ocean Panel focused mainly on the development of a basic observing system for sea level, S(z) and T(z) for the purposes of CLIVAR research.

For almost all Principal Research Areas of CLIVAR (e.g. G1 (Salinity important for ENSO forecasting), G2 (E-P), D5 (Thermohaline circulation), A1/2 (long term trends), etc.) a regular systematic sampling of temperature and salinity of the upper ocean is necessary to achieve the goals of CLIVAR. This will be especially true for the understanding decadal variability and processes in areas where deep convection is important.

Based on the proposals for an Array for Real-time Geostrophic Oceanography (ARGO) and for Global Ocean Salinity Monitoring (GOSAMOR) focusing on a global observations for T(z) and S(z), the UOP came to the following conclusions:

During the last two years there has been significantly progress made in the technical development of the salinity sensors and float equipments that enable a global coverage (about 3000 floats) with these instruments at feasible costs (about $12M). Additionally, salinity measurements from merchant ships, moorings, drifting buoys and stations are becoming more common in the near future. Hence the UOP recommended that CLIVAR implements a global programme of routine sampling of T(z) and S(z) using a bunch of techniques.

Although the systematic errors of the different observational methods could be reduced substantially (e.g. altimetry, XBT, XCTD), there is a need for a combination of the different methods to reduce the errors to a level that allows the detection of decadal and long term climate variability in the upper ocean.

Therefore the UOP will work towards an integrated global observing system for CLIVAR to detect natural climate variability on different timescales (seasonal to decadal)

- to monitor long term climate trends (naturally or anthropogenically caused)
- to deliver products needed to calibrate and validate satellite measurements
- to provide observational data for validation of models resp. assimilation into these models (e.g. for purposes of climate forecasting).

Additionally to the proposed global float array, special attention is needed along the boundaries / in narrow channels. Furthermore this proposed measurement system will provide measurements up to a depth of about 2000 meters at present time. Deep ocean measurements (e.g. needed for the monitoring of long term trends) cannot be covered by this network.

For the implementation of the proposed global array as a multinational effort, the UOP recommended to organize a workshop within 6 months. This would enable CLIVAR to present a detailed plan for the main basic upper ocean observational network in time for the CLIVAR conference in December. It was proposed to hold the meeting in conjunction with the first GODAE steering group meeting beginning of July in Tokyo.

Other UOP business:

The UOP discussed in depth the future of the panel. It was felt that the UOP will be needed in future to act as an scientific advisory and oversight committee for CLIVAR and the OOPC. In contrast the OOPC is mostly concerned with the implementation aspects of an operational ocean observing system. Therefore is was felt that a dissolving or a merging of the UOP with the OOPC would not be the right way. The implementation of the proposed monitoring array during the next year will be one of the main tasks of the panel. Additional efforts are required to work towards an integrated observing system for the purposes of CLIVAR.

The UOP has now been in existence for three years and it was felt that the panel should start to rotate membership. The current chair Dr. Ants Leetmaa would like to step down from his chairmanship by end of this year. He would like to stay on the panel for another year and rotate off thereafter. Dr. Chet Koblinsky has been proposed as his successor.

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Prospectus for ARGO
A global profiling float array

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1. Background

The 1998 Year of the Oceans has focused international attention on the ocean and problems such as ocean prediction, the open ocean environment, environmental sustainability in the coastal zone and climate change and prediction. In each case there is a fundamental dependence on ocean data and our inability to adequately observe the ocean, both historically and now, effectively limiting progress. Technical and logistical constraints restrict the rate of data flow and our ability to observe globally at a resolution that is useful.

The ocean community is presently determining implementation strategies for two major endeavours, CLIVAR (the Climate Variability and Predictability Programme of the World Climate Research Programme) and GODAE (the Global Ocean Data Assimilation Experiment). Both have a strong, and understood, need for direct observations of the ocean (complemented by remote sensing and modelling) but, to this point, the prospects for satisfying these requirements have been limited.

This paper proposes a strategy for meeting the global requirement. The strategy is based on the development of a truly global ocean *in situ* observing system, using existing and trusted methods such as the Tropical Ocean-Atmosphere array and Volunteer Observing Ships as the foundation, and **a major deployment of profiling ocean floats** to complete the global sampling. The project has been christened *ARGO*[1] since it is seen as an essential complement to the satellite altimetry mission *JASON* and its successor missions.

2. The Scientific Case: GODAE and CLIVAR

GODAE is in essence an experiment in global ocean estimation, with applications ranging from the provision of boundary conditions to coastal prediction systems, to initialization of climate models. Its overall aim is to demonstrate the viability, feasibility and practicality of operational oceanography and a truly global, integrated ocean observing system. At its first meeting, the GODAE Scientific Steering Team concluded that a significant enhancement of the global direct ocean observing network was necessary for the successful execution of the experiment in 2003-2005 and recommended a major float deployment to meet this requirement. The enhancements were needed to fill gaps in global coverage, to provide more frequent, real-time samples of the ocean and to complement other components of the GODAE system. The GODAE strategy emphasises the complementary role of the direct and remote observing networks and the role of models and data assimilation in integrating incoming information and producing useful and practical outputs.

The focus of CLIVAR is improved understanding of climate variability and predictability and the development of models useful for prediction. The time scales range from the intraseasonal scales of the monsoon systems, through interannual scales of phenomena like the El Niño, to decadal and longer variations and trends. CLIVAR has concluded that a global sustained network of temperature and salinity observations is critical for most of its Principal Research Areas (PRAs) but particularly for understanding decadal variability and processes in areas where deep convection is important. CLIVAR noted that the paucity of global subsurface salinity data constituted a major weakness, in effect limiting scientific progress in climate studies.

Based on these considerations, CLIVAR has recommended the implementation of a global network of profiling floats, integrated with other elements of the climate observing system, to detect natural climate variability on different timescales (seasonal to decadal), to monitor long term climate trends (naturally or anthropogenically caused), to deliver products needed for calibration and validation of satellite measurements, and to provide data for validation of models and for assimilation and climate forecasting.

GODAE and CLIVAR provide a strong scientific rationale for immediate action. Without the enhancements proposed herein GODAE cannot meet its main objectives and CLIVAR research will be limited to an extent that is not sustainable long-term. Both argue for an integrated approach whereby the recommended enhancements are seen as complementary and value-adding for the (operational/sustained) global ocean observing system. Without such an enhancement, it is argued, the existing and planned investment in remote sensing and modelling will not realise its true potential. The proposal is consistent with the recommendations of the Ocean Observing System Development Panel and its successor, the Ocean Observations Panel for Climate with respect to the establishment of a long-term global ocean climate observing system.

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[1] The present paper has been developed from two previous discussion papers, one of which was titled *A proposal for Global Ocean Observations for Climate: the Array for Real-time Geostrophic Oceanography (ARGO)*, by D. Roemmich. At around the same time a second paper was prepared, with the same observational basis but focused on salinity, and titled *GOSAMOR* (for Global Ocean Salinity Monitoring, by R. Schmitt). This paper combines these ideas within the context of scientific discussions which have taken place within GODAE and CLIVAR, retaining *ARGO* as the reference name.

3. The Proposal

Existing observational methods for the upper ocean, such as the Ship-of-Opportunity Programme of XBTs and the Tropical Atmosphere-Ocean array in the Pacific have been extremely successful and provided important data for TOGA and WOCE. However the sampling of the former is biased by the merchant shipping routes while the latter is most effective in the near-equatorial regions. Both are limited in terms of depth-range (typically less than 750 m) and salinity sampling.

Neither GODAE nor CLIVAR can be sustained with a fragmented, regional set of observations since both are inherently global and, in the case of CLIVAR, have obvious needs for deeper measurements and for salinity as well as temperature. This paper proposes that recently developed profiling float technology provides a cost-effective, feasible solution to this problem.

The profiling float is based on technology developed within WOCE by R. Davis to track currents at mid-depth using an autonomous freely-drifting device called ALACE (Autonomous Lagrangian Circulation Explorer) which has the ability to periodically cycle to the surface, transmit data and have its position fixed, then sink once more to its drifting depth. In the latter phase of the WOCE observational programme these devices were fitted with thermistors so that temperature profiles could be obtained as it surfaced (referred to as PALACE floats, though variants of such devices exist elsewhere, e.g. MARVOR). Recently stable, medium-cost salinity sensors have also been added, paving the way for a new approach to temperature and salinity sampling. Trials in the North Atlantic have shown that the technology works, including real-time transmission. The big challenge is to find a way to apply this technology globally, with a sampling that is effective for both CLIVAR and GODAE, and with a view to satisfying the long-term needs of GCOS/GOOS.

It is not possible to be truly objective in the prescription of desired global sampling since both GODAE and CLIVAR are aiming for complicated, model-based processing streams with multiple-parameter input streams. The community has little experience combining *in situ* and satellite data for ocean estimation, and there is essentially no historical counterpart to the proposed data stream upon which estimates of required climate sampling might be based. In the absence of such basic knowledge, both GODAE and CLIVAR are relying on subjective, consensus estimates by scientists familiar with ocean data and those involved with satellite data and modelling. The best-guess at present is:

- a global array of around 3000 profiling floats, measuring both temperature and salinity, giving an effective spatial sampling of 250-300 km;
- a cycle time for each float of 10-14 days, yielding around 80,000 profiles per year; and
- a park depth at around 1500 m (determined by the need for subsurface drift data) and a profile depth of 1500-2000 m.

To first order, this would double the number of profiles presently available per year through the combined efforts of the Ship-of-Opportunity Programme and TAO, but with enhanced vertical extent and salinity (close to a factor of 4 increase in the available information). Moreover, the sampling would preferentially target the data sparse regions, increasing its value in the context of determining the global ocean circulation.

4. Technical and Resource details

Like the sampling strategy, there are many technical and resources uncertainties, concerning the development and cost of the float itself, concerning telemetry, and related to deployment. It would be unwise and irresponsible to paint an over-optimistic picture, but equally it would be a poor strategy that did not take account of likely improvements and attempt to build a realistic assessment. In the following we try to give cost and capability estimates for the present, near-future (Year 2000) and five years hence when presently developing technology should be ready for implementation and GODAE is beginning its intensive, "experiment" phase.

Cost and Capability
Present

Parameter	Unit Cost	Lifetime	# Samples	z resolution	accuracy
UAVERAGE	$8K	2-3 yrs.	50-60	at 1200m	5%?
+ T	+$2K	2-3 yrs.	50-60	80 pts, 1200m	0.02°C
+ S	+$5K	1 yr.	~ 25	80 pts, 1200m	0.02

Years 2000-2002

Parameter	Unit Cost	Lifetime	# Samples	z resolution	accuracy
$U_{AVERAGE}$	$6K	3-4 yrs.	~ 100	at 1200m	5%?
+ T	+$2K	3-4 yrs.	~ 100	80 pts, 1200m	$0.02^{o}C$
+ S	+$4K	2 yrs.	~ 50	80 pts, 1200m	0.01

Years 2003-2005

Parameter	Unit Cost	Lifetime	# Samples	z resolution	accuracy
$U_{AVERAGE}$	$5.5K	4 yrs.	100-120	at 1500 m	5%?
+ T	+$1.5K	4 yrs.	100-120	800 pts, 2000m	$0.01^{o}C$
+ S	+$3K	3-4 yrs.	~ 100	800 pts, 2000m	0.001

Several factors impinge upon the cost per unit of information from a float programme including

- Assume *ARGO* has a phased implementation, allowing for necessary R&D, reaching full implementation around 2003;
- Cost of the unit, and cost of the T and S sensors (instrument builders are estimating costs *lower* than those quoted above, ~ $7500, not including possible savings from “mass” production);
- Power available, presently split 50-50 between profiling and communications: power expended per unit of information transferred is the key parameter. A factor of 2 improvement is assumed;
- Capability to profile deeper than the drift level (available now);
- The number of cycles is directly determined by available power, so it is critical they are attuned to the signal of interest;
- Stability of sensors; S is presently stable for 1 year; projected 4-fold improvement by 2003;
- Band-width available from platform to base (Argos projects x 4 improvement);
- Availability of 2-way communications (permits order of magnitude improvement in use of power, and thus order of magnitude improvement in bandwidth). The tables assume that by 2003 full resolution and accuracy can be communicated in real-time.

GODAE would place highest premium on the spatial and temporal sampling, while CLIVAR places a high premium on accuracy, vertical resolution and the availability of stable and long-life salinity sensors.

5. Schedule and Investment

Many of the details of the *ARGO* implementation are yet to be debated, and the projected total cost has several uncertainties. However we can make a reasonable estimate based on the tables above and expected add-ons and processing costs. Assume

- Telemetry at 10% of hardware costs. Presently ARGOS would cost around $10 per profile; future enhancements would more likely be used to improve the information content of the telemetered message rather than reduce cost.
- Deployment costs at around 15% of the hardware costs. The GOSAMOR proposal estimates were considerably larger than this but there is no reason to expect that *ARGO* will be significantly different from the present surface drifter deployment costs, which are minimal. In any event, we could safely assume significant levels of in-kind support from the international community.
- It is critical that realistic levels of scientific and processing support are included in the budget. WOCE and TAO experience suggests up-front investment is most effective (i.e., allow for scientific QC and data and information management as close to the source of the data as possible).
- All data transmitted in real-time but allow for at least dual processing streams; one to effect circulation of data to operational centres (e.g., via ARGOS), another to apply necessary scientific QC for the climate (final) data sets (TAO is probably a good model).

In the following table we assume 25 cycles per year and an incremental improvement in the life-time of the float sensors as indicated (T and S for temperature and salinity respectively). The seeding rate is assumed to apply for the whole period. The cost per profile is calculated from the unit cost divided by the total number of expected cycles times the total percentage overhead (estimated to be 50% for 2003-2005).

	Present T~2yr, S~1yr	**2000-2002** T~3.2yr, S~2yr	**2003-2005** T~4yr, S~3yr
Investment in H/W	~ $3M	~ $5M	~$8M
Add-on costs	$0.75M	$1.25M	$2M
Processing	($1M?)	$1M	$2M
Total Investment/yr.	$4M	$7.25M	$12M
Seeding rate/yr.	250 (75 with S)	500 (250)	800 (800)
Total # profiles/yr.	12,500 (1,875)	40,000 (12,500)	80,000 (60,000)
Cost/drift+T	~ $265	~ $150	~ $105
incremental cost for S	~ $265	~ $120	~ $60

In summary, we are expecting *ARGO* to have an annual budget of around US$12M for the period 2003 and beyond. If experience in meteorology is used as a guide, we might expect many efficiencies but these are likely to be offset by greater demand (denser and more frequent sampling and/or deeper profiles and/or more sophisticated instrumentation). The total budget is probably of the same order as that presently invested in TAO and SOOP combined but, it can be argued, is at least, if not more efficient in terms of the information returned. It is also of the same order as that projected for Jason 2 (~70%) if that mission reaches its targeted efficiencies.

6. Implementation

There are of course many uncertainties, perhaps the greatest being the capacity of the community to undertake the necessary scientific and technical development on the above schedule. The needed investment is also significant but it must be cast in the light of expected international investment in ocean observations. If TOGA and WOCE are used as a guide, then we might have expected at least such an investment in oceanographic research observations in the normal course of research programmes over the next decade (indeed, cast in this light, the return from *ARGO* is in fact both efficient and extremely high). The fact that GODAE (and GCOS/GOOS) are targeting operational activities opens up the opportunity of obtaining significant investment from outside the research community, just as operational agencies now provide significant resources for the surface float programme.

The above allows for a modest R&D schedule, with perhaps the improvement in the salinity sensor being the most difficult target. The costs have been based on experience with PALACE floats, but other platforms (SOLO, Marvor, ..) are available. For climate applications, improvements in telemetry are essential; these might come from expected enhancements to ARGOS or via other developing communications.

The development of the global system is likely to be done both regionally and globally, using existing and developing projects as the basis. A possible phased approach is

- 1998-1999 ACCE and its continuity; 1st deployments in N. Pacific units: 400
- 2000-2001 Implement N. Pacific, maintain and expand Atlantic array 1000
- 2001-2002 1st Southern Ocean and Indian Ocean deployments 2000
- 2003 Focus on targeted global coverage 2500
- 2004+ ARGO implemented 3000

7. Planning

A GODAE/CLIVAR ARGO Workshop

This paper is intended as background for a Workshop on the *ARGO* proposal, to be held with the second meeting of the GODAE Scientific Steering Team 6-10 July, Tokyo. The Agenda for the Workshop will include

(a) Review of the scientific rationale for *ARGO* (formerly ARGO and GOSAMOR);
(b) Review of the main technical issues;
(c) Review of the draft resource outlook, emphasising that the outlook must be realistic and practical;
(d) Review the draft sampling strategies, including spatial density, frequency of cycles, depth range, drift depth, need for T and S, needed accuracy, etc.
(e) Decide minimal and ideal strategies, the former being a cut-off at which *ARGO* is abandoned as a project;
(f) Draft an outline of a phased implementation, noting critical dependencies and links; and
(g) Decide on a work plan, including needed technical and scientific meetings/workshops, means of organisational support, links to GODAE, CLIVAR, satellite agencies, etc.

The Programmes: GODAE, CLIVAR and GOOS/GCOS

The responsibility for the scientific and technical development and oversight of implementation of *ARGO* will be shared by GODAE (Scientific Steering Team) and CLIVAR (Upper Ocean Panel). In concept at least, the thermal component of *ARGO* can in part be regarded as a response to the recommendations of GCOS/GOOS and will thus be part of the Initial Observing System of the Ocean Climate Observing System. The Ocean Observations Panel for Climate, who initiated GODAE, have responsibility for the oversight of this system and, in particular, for the operational parts of the ocean observing system (e.g., SOOP). In parallel with the development of *ARGO*, it has been proposed that a new Implementation Plan for Subsurface observations (SOOP, TAO, etc.) be redrafted which will take account, as far as possible, of emerging float capabilities. OOPC will take the lead for this activity.

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VAMOS/PACS Workshop of Field Programmes - 1st Session of the CLIVAR VAMOS Panel

IOUSP, São Paulo, Brazil, 30 March - 2 April 1998

A joint VAMOS/PACS Workshop of Field Programmes and the first Session of the CLIVAR VAMOS Panel were held at the Instituto Oceanográfico of the University of São Paulo. The chairman of the CLIVAR VAMOS Panel, Prof. C. R. Mechoso and the co-chairs of the organizing committee, Drs. C. Nobre and R. Weller, and the local host, Dr. E. Campos, welcomed about 60 participants. The major goals of this workshop were

1. to identify the scientific problems for a study of the American monsoon systems,
2. to review the existing and already planned field programmes and process studies,
3. to identify opportunities for and encourage collaboration among monsoon-related programmes in the Americas, and
4. to initiate the planning of field programmes and process studies under VAMOS.

After a review of the VAMOS objectives, the workshop started with a series of talks that reiterated the science issues and objectives of the programme from various perspectives. Three overview presentations about the American Monsoon Systems were given. For the North American monsoon system (NAMS) the following basic questions were reviewed:

1. What data are required to study the physical mechanisms for the life cycle of the NAMS, and to what extent is this life cycle captured in global and regional models?
2. What are the relative roles of internal atmospheric dynamics, remote boundary forcing, and local and regional land surface forcing in determining the interannual and intraseasonal variability of the NAMS?
3. What are the dominant factors responsible for determining the interannual variability of the monsoon onset?

The Central American monsoon system is less well-defined in terms of calendar dates and distinct transitions, though the seasonal variations are quite distinct on the Pacific side of Central America. A basic question related to the mechanism of rainfall variability is whether the SST variations in the eastern Pacific warm pool exert a fundamental control on the fluctuations in ITCZ precipitation over the region. The available observational datasets are not suitable to address these issues.

The South American monsoon system (SAMS) develops over a land mass characterized by a large area at the equator, very high mountains to the west that effectively block air transport, and surface cover that varies from tropical forests over Amazonia to high altitude deserts over the Bolivian altiplano. Plentiful moisture supply from the Atlantic maintains a precipitation maxima over central Brazil. The combination of this heat source and the orography results in seasonal evolution of convection latitude systems in the organization of tropical precipitation. Many important questions remain on the relative roles of orography, the Bolivian altiplano, the Brazilian planalto, the Andes mountains and tropical heat sources on regulating circulation features over South America. Modelling and theoretical studies have given partial answers to these questions, but validation of these results require observational confirmation with more complete data sets.

These talks were followed by a number of presentations about the role and importance of different processes (e.g., in atmosphere, ocean, land).

Thereafter, the relevant field work relevant to VAMOS was reviewed which enabled the participants to establish focal points for VAMOS field programmes. Thereafter the workshop splitted into two working groups, one focusing on the specific problems of the North and Central American Monsoon System and the other on the aspects of the South American Monsoon followed by a plenary discussion of the monsoon systems.

In the following the ocean-atmosphere and land-atmosphere interactions were discussed in depth. In these sessions attempts were made to step back from the specifics of individual experiments and to address linkages e.g., among regions, programmes, and between the land, atmosphere, and ocean. For example, an effort was made to diagrammatically summarize the large scale moisture transports in the Americas and the adjacent oceans. This was a particularly fruitful discussion, as it laid the groundwork for developing hypotheses that could be tested by VAMOS field programmes. One example drawn from the session is the discussion of why the warm waters of the Gulf of Mexico and the Caribbean do not act more like a traditional warm pool and the hypothesis that the amazonian convection dominated the region. Further discussion of this topic raised questions about the contrast between the influence of the warm water found on the west coast of Central America and that found in the Gulf of Mexico and about the moisture fluxes into North America from these two regions. A second example is the discussion of the stratus clouds found off Peru and Chile and the possibilities that the convection over the altiplano in South America contributes to the atmospheric subsidence in the stratus deck region and that there is some transport through the Andes between the altiplano and the eastern Pacific. Because of links between ENSO variability and climate in South America, there may thus be a possible feedback to the equatorial eastern Pacific by the Altiplano's influence on the stratus region, which in turn influences the cold tongue - warm pool region.

In the last session a number of action items were identified to keep the momentum up and the development of VAMOS field programmes moving forward. In the near term, completion of a workshop report and communication of the results of the workshop was flagged as important. Groups to facilitate writing a workshop report were identified. While the science thrusts of and plans for work on the North American monsoon and on the eastern tropical Pacific are maturing as the Pan American Climate Study (PACS) and the Eastern Pacific Investigation of Climate processes in the coupled ocean-atmosphere system (EPIC), the discussion identified the need to encourage further developments associated with the South American monsoon system and the stratus. After a review of planned and proposed process studies issues of data sets and enhanced monitoring relevant to VAMOS were discussed. For the further planning of the VAMOS programme, the workshop recommended to establish five small working groups with a primary task to collect, assess and integrate the information about a) process studies, b) data sets, c) sustained measurements, d) stratus, and d) the South American Monsoon System. With the exception of the SAMS Working Group, these groups have a limited lifetime to prepare the workshop report. The SAMS Working Group was tasked to organize a workshop about the specific aspects of the South American monsoon later in 1998 or early 1999.

The VAMOS Panel met for its first session after the workshop. There was general agreement on a planning approach based on phases, each of which will address the problems of capacity building in data-void regions of the Americas. The Panel reviewed the results of the workshop and made the following recommendations:

- to endorse EPIC as a VAMOS programme;
- to endorse a field programme on the South America low-level jet;
- to encourage PIRATA planners to extend their programme to match the EPIC period;
- to encourage the planification of a field programme on the Altiplano heat source;
- to encourage exchanges between VAMOS and to other CLIVAR panel focusing on the Pacific and Atlantic Oceans.

Furthermore, the VAMOS Panel expressed the opinion that a programme on the Southern Atlantic can contribute significant to VAMOS. It was also decided to invite an IAI Application Scientist to the next panel meeting, which was tentatively fixed in Costa Rica for March 1999.

C.R. Mechoso and R. Weller

CLIVAR African Study Group meeting

Abidjan Ivory Coast, 7-9 May 1998

The uptake of long-range predictions by user groups vulnerable to climatic impacts is increasing worldwide. CLIVAR can fill an important role in Africa by enhancing the knowledge base upon which reliable forecasts of seasonal rainfall and temperature depend. In this context, the CLIVAR African Study Group was tasked by the WCRP, through the CLIVAR SSG, with reviewing the state of research on African climate variability. From these foundations, the CLIVAR Africa group's aim was to develop key questions and recommendations for scientific research to improve our understanding and prediction of interannual fluctuations of climate.

The inaugural meeting of CLIVAR Africa was held 7-9 May 1998, between the West African Climate Prediction Forum in the Ivory Coast and the Southern African Climate Outlook Forum in South Africa. The meeting was convened by M. Jury, Univ. Zululand. Participants include: O. Baddour - ACMAD/Morocco, M. Harrison - UKMO, E. Klopper representing E. Poolman, South African Weather Bur., P. Lamb - Univ. Oklahoma, H. Mulenga - Zambia Met. Serv., S. Nicholson - FSU, USA, L. Ogallo - Univ. Nairobi/CLIPS, F. Semazzi - NC State Univ., J. Servain - ORSTOM France, W. Thiaw - NCEP/UCAR, Y. Tourre - IRI, L. Unganai - Zimbabwe / DMC, N. Ward - Univ. Oklahoma, plus observers.

A number of scientific papers were presented by group members on day one, followed by informal brain-storming workshops on day two and three, with observers providing useful inputs. The overview topics included the observed climate and teleconnections, the role of El Niño in African climate variability, the global role of the African climate system, and a review of predictability estimates. These presentations revealed the complexity of the African climate system and its many links to the surrounding oceans and the global atmospheric circulation. It was evident that much remained to be learned about the climate dynamics of the continent. The participants recognised three themes: global teleconnections, continental scale processes and predictability. A common question was: how does the global circulation modulate seasonal rainfall across Africa? Geographical groupings were identified for process studies: North/West, Central/East and Southern/Mascarene.

Recommendations emerged for modelling, empirical and diagnostic studies, observing systems, data archaeology, process studies, and capacity building. The recommendations will be prioritized based on immediate needs, likelihood of success, and socio-economic benefits. The group felt that enhanced monitoring efforts in the tropical east Atlantic and western Indian Oceans would significantly advance understanding and prediction of African climate. Some of these monitoring efforts would serve other aspects of CLIVAR. The strong requirement for capacity building was stressed. A major aim would be to involve local researchers in international research projects and to give researchers from Africa the tools and experience necessary to develop climate research in their home countries, including making data and literature more accessible. The African Study Group recognized the need for links between climate researchers and the user - applications community. Groundwork was being laid by the climate outlook fora where climate researchers, operational meteorologists, forecast users and decision makers met together to build consensus outlooks. It is anticipated that an African CLIVAR initiative would lead to improved climate forecasts and thereby increase their utility for strategic planning.

A full report of the meeting is in preparation. Thematic science contributions will be led by Yves Tourre, Neil Ward and Wassila Thiaw. Mark Jury has been tasked to integrate the ideas of panel members and the rest of the community into a document which would serve as an implementation plan for CLIVAR-Africa, and which could be used to gain international support for additional observations, analysis and modelling work required to better predict the climate of Africa. The report will be circulated internally within the coming months, and it is intended that a final draft be submitted for external review early in 1999. The African Study Group will seek endorsement of their plans and recommendations at the next meeting of the CLIVAR SSG scheduled for May 1999.

V. Detemmerman

WOCE Data Products Committee
-11th Session-
Honolulu, Hawaii, 5-9 January 1998

At the eleventh meeting of the WOCE Data Products Committee (DPC) the main topic under discussion was the production of Version 1.0 of the WOCE Global Data on CD-ROMs. The WOCE Data Assembly Centre (DACs) and Special Analysis Centres (SACs) have constructed CD-ROMs of their data holdings and products under the guidance of the DPC, and the meeting had been timed to coincide with the final stages of preparation so the content and format of the CD-ROMs could be reviewed. The committee also heard about the recent activities of the DACs and SACs, discussed the development of the WOCE data resource through the Analysis, Interpretation, Modelling and Synthesis (AIMS) phase and beyond 2002, and considered some issues pertinent to a CLIVAR data system.

The meeting began with a series of scientific seminars on a variety of subjects designed to stimulate discussion on the requirements (with respect to data sets and products) of the AIMS period. The talks highlighted the intercomparison of Topex/POSEIDON altimeter data and WOCE One-Time hydrographic sections, implications for WOCE data sets of some current issues in climate and oceanic modelling, a new strategy for the assimilation of WOCE tracer data into an ocean circulation model, intercomparison of various high resolution models with available WOCE data, large-scale decadal water mass changes in the Pacific by comparing WOCE sections with historical data, availability and synthesis of accurate surface wind fields required for ocean model forcing and the value of the use of data from different sensors and platforms.

Much of the meeting was spent reviewing the final draft versions of the individual CD-ROMs produced by each DAC and SAC.The CD-ROM sets (WOCE Global Data Version 1.0, WOCE Report 158/98) were distributed at the WOCE Conference in Halifax in May 1998 and were enthusiastically received by the participants. Their production is an exciting achievement for WOCE and an important step in the effort to make WOCE data available to the community. A further two versions of the Global Data are planned. Version 2.0 (available in early 2000) will include additional data submitted to the DACs and will also be a step towards the concept of a single WOCE data resource. Version 3.0 will include all WOCE data and a variety of products.

The WOCE Archive is at the US-National Oceanographic Data Center (NODC) and the DPC reviewed the progress made in implementing it. All WOCE data and documentation will be catalogued, archived, distributed to World Data Centres, and made available on-line and by request. NODC are developing a search and retrieve facility which will allow users to access data from several databases in one action; so making more progress towards the single WOCE data resource.

An important issue for the WOCE data system is how to transfer the benefits and experience of the existing system to CLIVAR, and how to improve, adapt and expand to meet the requirements of CLIVAR. The DPC discussed an ICPO issue paper outlining potential CLIVAR data requirements and recommended that a full Data Products Transition document be written by the DPC chairmen, IPO and ICPO for consideration by the CLIVAR community. In addition it was suggested that a joint WOCE/CLIVAR DPC be formed to tackle transition and other issues. A joint DPC would need to cover a wider range of issues than presently covered by the WOCE DPC (an increased number of data types and more emphasis on real-time delivery of data are two obvious examples) but there are also many common interests.

Finally, the DPC expressed its gratitude to the outgoing chairman Eric Lindstrom, for all the dedication and drive he has given to the DPC and previously the Data Management Committee. He is ably replaced by joint chairmen, Nathan Bindoff and David Legler, and the next meeting of the DPC will be in April 1999 at the Sea Level DAC in Bidston, UK.

N. P. Holliday, WOCE International Project Office

CLIVAR Calendar

1998	Meeting	Location	Attendance
August 10 - 13	WOCE/CLIVAR Workshop on Ocean Modelling for Climate Studies	Boulder, CO, USA	Limited
August 17 - 21	International Conference on Satellites, Oceanography and Society (Expo'98)	Lisbon, Portugal	Open
August 23 - 28	6th International Conference on Paleooceanography	Lisbon, Portugal	Open
September 14 - 16	Euroclivar Workshop on Climatic Impact of Scale Interactions for the tropical Ocean-Atmosphere System	Paris, France	Invitation
September 22 - 25	WOCE Indian Ocean Workshop	New Orleans, USA	Limited
September 22 - 25	NASA Workshop on Decadal Climate Variability	Williamsburg, VA, USA	Invitation
September 22 - 26	International Conference on the Variability and Predictability of the Asian Monsoon (ICAM)	Xi'an, China	Open
October 5 - 7	Euroclivar Workshop on Ocean Data Assimilation	Bologna, Italy	Invitation
October 12 - 16	WOCE Scientific Steering Group, 25th Session	Brest, France	Invitation
October 16 - 19	JSC/CLIVAR Working Group on Coupled Modelling, 2ndSession	Melbourne, Australia	Invitation
October 29 - 30	Euroclivar 5th, Session	UK	Invitation
November 9 - 13	CLIVAR - NEG-1, 3rd Session	Palisades, NY, USA	Invitation
November 9 - 13	CLIVAR/GCOS TAO Implementation Panel, 7th Session, PIRATA, 5th Session	Abidjan, Ivory Coast	Invitation
December 1 - 4	International CLIVAR Conference	Paris, France	Limited

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