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A Joint Newsletter of the Past Global Changes Project (PAGES) and the Climate Variability and Predictability Project (CLIVAR)

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World Climate Research Programme
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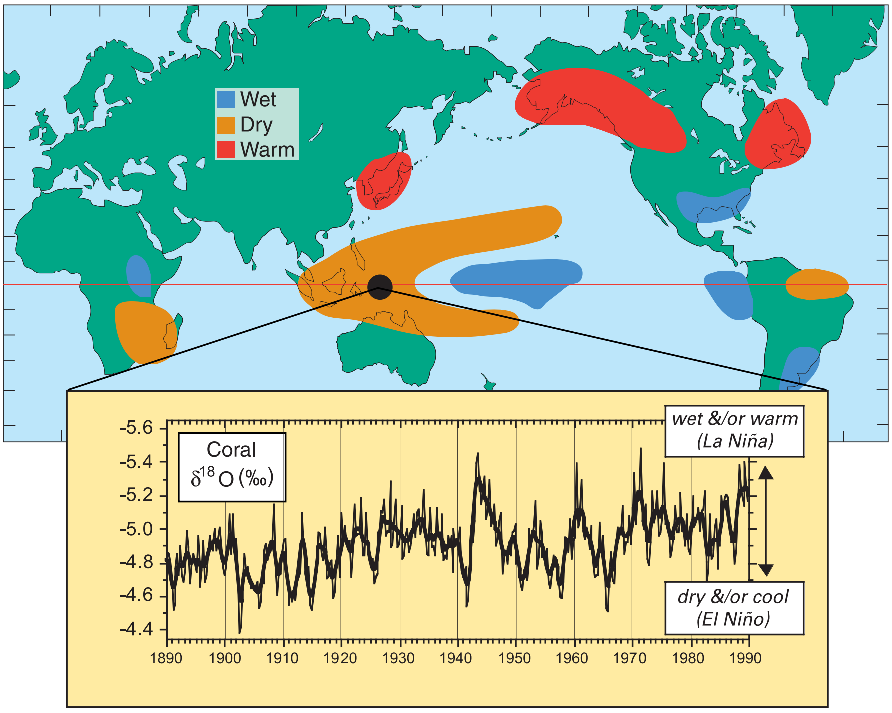
Exchanges



ENSO at the intersection of PAGES and CLIVAR

The oxygen isotope record from a modern coral located off the north coast of Papua New Guinea (see Cane et al., page 3). As visible in the underlying schematic of warm phase climate anomaly patterns during Northern Hemisphere winter, this region of the far western equatorial Pacific experiences relative drought and lowered sea surface temperatures (SSTs) during the El Niño phase of the Southern Oscillation. These climatic factors are recorded in the oxygen isotopic composition of the skeletons of corals growing in nearby reefs, with isotopically heavy skeleton (less negative δ^{18}O) deposited during the dry and cool El Niño events.

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Editorial

Interaction between IGBP-PAGES and WCRP-CLIVAR is driven by the overlapping interests of the past climate reconstruction and future climate prediction research communities. Paleoscientists rely on modern instrumental records in order to calibrate and validate their proxy climate reconstructions while climate prediction relies on the information about decadal and century scale variability which long, high resolution, multi-proxy paleorecords provide.

Following on from the initial success of the first PAGES / CLIVAR Intersection meeting (PAGES Report, 1996), and riding the momentum from the CLIVAR international meeting (WCRP Report 108), a series of PAGES / CLIVAR workshops, open meetings and short courses, with equal representation from the paleoclimate and climate dynamics communities, is underway. The most recent workshop, held in Venice, Italy from Nov. 8–12, 1999 concentrated on the theme "Climate of the Last Millennium." Many of the results and recommendations which grew out of this meeting are collected here in a special newsletter, produced as a joint effort and sent to the entire PAGES and CLIVAR communities.

In the first piece in this newsletter "Climate Paradigms for the Last Millennium" Ray Bradley provides a scientific editorial along the theme of the Venice workshop itself. This is followed by several scientific highlights authored primarily by participants in the Venice workshops on the topics of:

- ENSO Variability in the Pacific (Cane *et al.*)
- Abrupt Climate Change (Alverson and Oldfield)
- Regional Hydrological Change (Cook and Evans, Trenberth)
- North Atlantic Variability (Jansen and Koç, Sarachik and Alverson)

These same four themes are encapsulated in an series of PAGES / CLIVAR meetings and short courses, planned over the coming years, which will build on the recommendations agreed on at the Venice workshop, and highlighted in this newsletter. The entire series will provide continuity and momentum to this interdisciplinary effort, and culminate in an open synthesis meeting and publication.

- *Early 2001, TBA* : **ENSO and Monsoon Variability in the Pacific**
- **Nov. 10–15, 2001*, "Il Ciocco", Italy: **Abrupt Climate Change Dynamics**
- *2002, USA, TBA:* **Regional Hydrological Variability**
- **Oct. 11–16, 2003, Granada, Spain:* **North Atlantic Variability**
- *2004, Switzerland, TBA:* **PAGES/CLIVAR Synthesis Meeting**

* co-sponsored by EURESCO

The second and third part of this newsletter cover items related to PAGES and CLIVAR individually in order to provide the respective communities with information of their own programs. This newsletter concludes with a (joint) conference calendar covering the most important meetings in the near future. More comprehensive meeting information can be obtained through our websites.

Please note that the references in this issue are only avaible in an abbreviated form to save space.

K. Alverson and A. Villwock

Climate Paradigms for the Last Millennium

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Conventional wisdom has it that the climate of the last millennium followed a simple sequence – a "Medieval Warm Epoch" (MWE), a "Little Ice Age" (LIA) and then globally extensive warming. This view has its roots in the early work of H.H. Lamb (1963, 1965) but more recent research has reassessed this paradigm. Lamb defined the MWE as a period of unusual warmth in the 11th–13th centuries A.D., based almost exclusively on evidence from western Europe and the North Atlantic region. His studies pre-dated modern quantitative paleoclimatology so the values of temperature change that he attributed to this period are essentially anecdotal, and based largely on his own estimates and personal perspective. In revisiting the concept of a MWE, Hughes and Diaz (1996) reviewed a wide range of paleoclimatic data, much of it reported since Lamb's classic work (Lamb 1965). They concluded that "*it is impossible at present to conclude from the evidence gathered here that there is anything more significant than the fact that in some areas of the globe, for some part of the year, relatively warm conditions may have prevailed.*" Thus, they found no clear support for there having been a globally extensive warm epoch in the MWE or indeed within a longer interval stretching from the 9th to the early 15th century. Certainly, there is no evidence that global or hemispheric mean temperatures were higher during the MWE than in the 20th century (Crowley and Lowery, 2000) yet this notion has somehow become entrenched as common lore. This is unfortunate as it does not help our understanding of natural climate variability and its causes. Perhaps of greater significance is that there were significant precipitation anomalies during the period of the "MWE"; in particular, many areas experienced protracted drought episodes and these were far beyond the range of anything recorded within the period of instrumental records. For example, Stine (1994) describes compelling evidence that prolonged drought affected many parts of the western United States (especially eastern California and the western Great Basin) from (at least) A.D.910 to ~A.D.1110, and from (at least) A.D.1210 to ~A.D.1350. There is also strong evidence that prolonged drought affected Patagonia during the earlier of these episodes. This led Stine to argue that a better term for the overall period was the "Medieval Climatic Anomaly" (MCA) which removes the emphasis on temperature as its defining characteristic (Stine, 1998). The widespread nature of hydrological anomalies during the MCA suggests that changes in the frequency or persistence of circulation regimes may account for the unusual nature of the period, and naturally this may have led to anomalous warmth in some (but not all) regions.

Numerous studies provide strong evidence that cooler conditions characterized the ensuing few centuries, and the term "Little Ice Age" is commonly applied to this period. Since there were regional variations to this climatic deterioration, it is difficult to define a universally applicable date for the "onset" and "end" of this period, but commonly ~A.D.1550–1850 is used (Jones and Bradley, 1992). However, there is evidence that cold episodes were experienced earlier, by A.D. 1450 or even A.D. 1250 in some areas (Grove and Switsur, 1994; Luckman, 1994). This definitional problem is illustrated by the estimates of Northern Hemisphere mean annual temperature for the last 1000 years, reconstructed by Mann *et al.* (1999) which show a gradual decline in temperature over the first half of the last millennium, rather than a sudden "onset" of a "LIA". Furthermore, it is clear that within the period 1550–1850 there was a great deal of temperature variation both in time and space. Some areas were warm at times when others were cold and vice versa, and some seasons may have been relatively warm while other seasons in the same region were anomalously cold. No doubt the complexity, or structure that we see in the climate of the LIA is a reflection of the (relative) wealth of information that paleoclimate archives (tree rings, corals, varved sediments, ice cores, historical records etc.) have provided for this period. Having said that, when viewed over the long term this overall interval was undoubtedly one of the coldest in the entire Holocene. Such is the nature of perspective – there is the danger that on close examination one may not see the woods for the trees, yet a full explanation of the observed changes may require a fairly detailed understanding of the temporal and spatial details. If we had similar data for the last 1000 years, our somewhat simplistic concepts of Medieval climatic conditions would certainly be revised and strong efforts are needed to produced a comprehensive paleoclimatic perspective on this time period. Only with such data will we be able to explain the likely causes for climate variations over the last millennium. At present, it is difficult to unequivocally ascribe the changes to external forcing (solar, orbital, volcanic) or internal ocean-atmosphere interactions, or indeed to a combination of all of these, perhaps varying in importance over time (cf. Mann *et al.*, 1998, 1999; Crowley and Kim, 1999; Broecker *et al.*, 1999). Given that these forcing factors will play a role in future climate variations, getting a better appreciation for both the past record of climate and of forcing factors must be a top priority for both PAGES and CLIVAR.

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ENSO Through the Holocene, Depicted in Corals and a Model Simulation

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In the 1990s El Niño attained global name recognition just short of Michael Jordan's. (Perhaps not coincidentally, the economic impact of the two is estimated to have the same order of magnitude, US$ 10^{10}). ENSO (El Niño and the Southern Oscillation) has also received enormous attention from the scientific community. Both the popular and scientific attention came in recognition of the premier role ENSO plays in modern climate variability, variability with great consequence for human society. A special recent concern, both popular and scientific, is whether the apparently "unusual" ENSO behavior of the past two decades is due to anthropogenic changes in the climate system. Or is it consistent with natural variability? It is hard to say from the instrumental record of ENSO, which is only some 130 years long.

Putting recent ENSO variability in proper context requires the longer view afforded by proxy records. This longer view includes periods with mean conditions and orbital forcings very different from today, providing some idea of the sensitivity of the ENSO system to external forcing. A number of reports on ENSO in the mid-Holocene appeared in the latter half of the 1990s. (McGlone *et al.*, 1995; Shulmeister and Lees, 1995; Sandweiss *et al.*, 1996, 1997; Wells and Noller, 1997; Gagan *et al.*, 1998) culminating in that of Rodbell *et al.* (1999). The interpretations they offered for the paleoproxy evidence are often contradictory, and have been much debated.

Clement *et al.* (2000) suggest a picture of the mid-Holocene (5000–10000 BP) tropical Pacific consistent with all prior paleo-ENSO data. Their view is based on a model simulation in which the intermediate Zebiak and Cane (1987) ENSO model, a model still in use for ENSO prediction, is forced by variations in heating due to orbital variations in seasonal insolation. Some summary statistics from the model run are presented in Figure 1. We see that the model ENSO

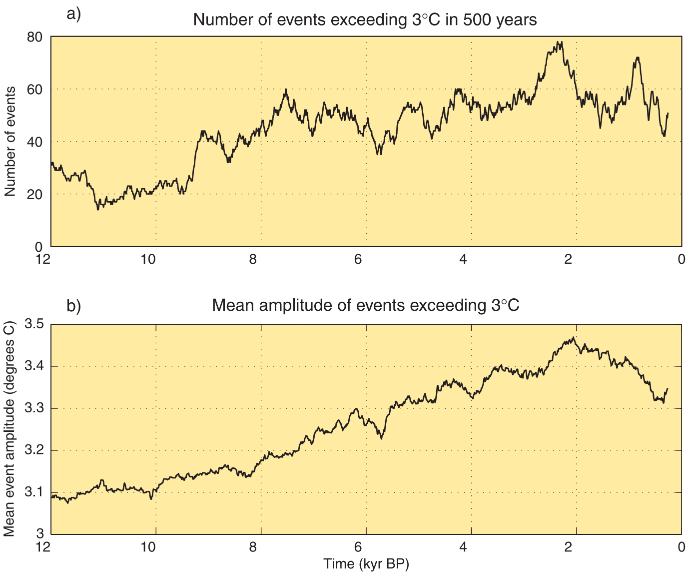

Figure 1: *Results of a run of the Zebiak and Cane model for ENSO forced by departures of solar heating due to orbital variations. (For details, see Clement et al.1999). (a) The number of occurrences of warm (El Niño) events in 500 year overlapping windows (overlapping every 10 years). A warm event is defined to occur when the mean Dec–Feb SST anomaly in the NINO3 region (90°W–150°W, 5°S–5°N – the eastern equatorial Pacific) exceeds 3°C. (b) The mean amplitude of the warm events in the same overlapping 500 year windows.*

variability does not vanish in the mid-Holocene (in contrast, for example, to the interpretation of Sandweiss *et al.* 1996), but is weaker than in the modern period. ENSO events continue to occur roughly every 4 years, but there are fewer strong events (>3°C), and the mean amplitude of strong events is less than in the modern era. The mean model state in the eastern equatorial Pacific was colder than in the modern era, but this is due to lower temperatures in the warmest season (April at present); the coldest season temperatures are unchanged.

Ideally, the model should be compared to continuous records with annual resolution. Such a record, based on clastic layers in sediments from a lake in Ecuador, was provided by Rodbell *et al.* (1999). Clement *et al.*argue that since the clastic layers are caused by the heavy rains associated with strong El Niño events, the smaller number of these layers in the mid-Holocene is accounted for by the smaller number of strong El Niños. It is not necessary that the ENSO cycle cease entirely, only that it weakens. Sandweiss *et al.* (1996) proposed that the presence of tropical mollusks on the Peruvian coast indicates a permanent warm state. Clement *et al.* propose instead that the absence of strong cold (La Niña) events in this period keeps minimum temperatures warm enough for the mollusks to survive. An eastern Pacific with cooler maximum temperatures is consistent with the drier conditions on the coast of Peru indicated by Wells and others.

Because the Zebiak-Cane model is so simplified, certain physical interpretations of the results are immediate. The model includes only the tropical Pacific, so influences from the extratropics are excluded. Hence changes in its ENSO behavior can only be due to the *tropical* changes in the seasonal cycle of solar radiation. Orbital variations induce changes in the seasonal cycle of the coupled ocean-atmosphere system in the tropical Pacific. This changes the stability of the system, and since ENSO may be regarded as "just" an instability of this system (e.g. Tziperman *et al.*, 1994, 1997), ENSO behavior will change. Because the system is nonlinear, the changes in ENSO do not track the orbital variations in a straightforward way.

The simplified model is here being exercised in circumstances far from the modern setting for which it was constructed, so conclusions drawn from it must be tentative. Model aside, the scenario described above does appear consistent with the paleoproxy data, but this only underscores the fact that the data admits more than one interpretation. More definite conclusions require more data and more thorough model-data comparison.

The recent PAGES / CLIVAR Workshop on Climate of the Last Millennium (Venice, Nov 8–12, 1999) was an opportunity to begin comparing model results with coral records from the tropical Pacific. In many respects these corals provide the best ENSO proxy data we have. They come from the core ENSO region and their annual to subannual resolution captures ENSO's seasonal and interannual variability. Isotopic signals in these corals are known to be good proxies for sea surface temperature (SST), or, at the least, a combination of SST and rainfall. Even the combination is a rather direct measure of ENSO.

Figure 2 shows 3 oxygen isotope records from the north coast of Papua New Guinea: a modern record, a fossil coral dated at 2650 BP, and a fossil coral dated at 8400 BP (Tudhope *et al.*, manuscript in prep.) This region of the far western equatorial Pacific experiences relative drought and lowered sea surface temperatures (SSTs) during the El Niño phase of the Southern Oscillation. These climatic factors are recorded in the oxygen isotopic composition of the skeletons of corals growing in nearby reefs, with isotopically heavy skeleton (less negative $\delta^{18}O$) deposited during the dry and cool El Niño events. Consequently, isotopic analysis of the annually banded skeletons of large living and 'fossil' massive corals in the area can shed light on variations in the frequency and strength of ENSO.

Note the irregularity in all of these records. Strong and regular ENSO variability (~3–5 year periodicity) is evident from 1890 to 1925, and from the late 1960s until 1990, with a period of weak ENSO but large amplitude lower frequency variability in the intervening years (top panel). The 2,650 BP record (middle panel) shows modern-ENSO style variability (~3–5 year periodicity) in parts of the record, but much of the record is more like the weaker ENSO periods of the mid 20^{th} century, and nowhere does the record show as extreme a change as occurred in the early 1940s. Differences in the 8,400 BP record (Figure 2 bottom panel) are more clear-cut: there is variability in the typical 2–7 year ENSO band, but it is much weaker than in the other two records.

Figure 3 (data from Gagan *et al.*, manuscript in prep.) compares a modern coral from the Australian Great Barrier Reef with a fossil coral from the same environmental setting dated at 6200 BP (note that on this figure El Niño conditions are up, in contrast to Figure 2). These multi-proxy records reveal the sequence of environmental changes within the annual cycle that is diagnostic of El Niño in the western Pa-

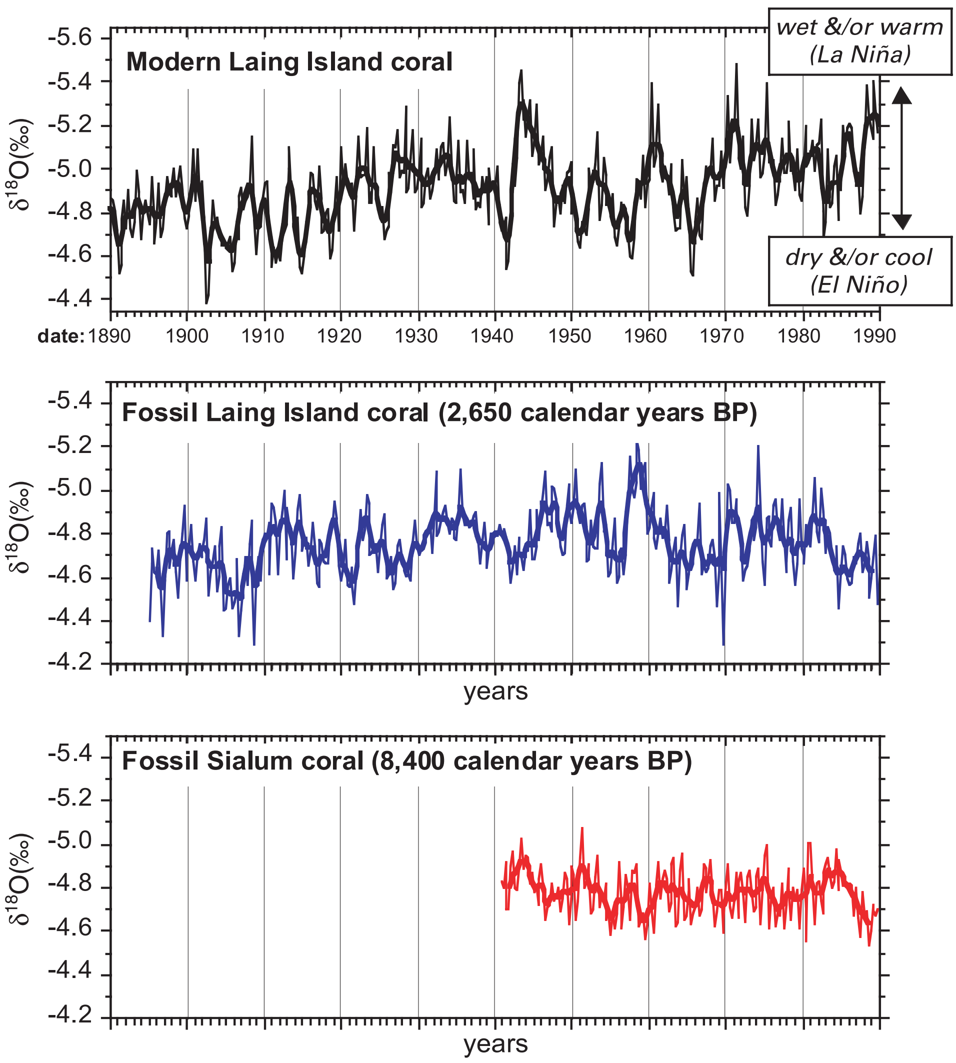

Figure 2:

Variability in ENSO in the Holocene revealed by a comparison of stable oxygen isotope records from living and Holocene Porites corals on the north coast of Papua New Guinea. Dating of fossil corals is by U-series alpha spectrometry. Data from: Tudhope et al, manuscript in prep.

Top Panel: One hundred year skeletal $\delta^{18}O$ record from a living coral at Laing Island (4°S, 146°E). Seasonal $\delta^{18}O$ data (thin line) has been smoothed with a 9pt binomial filter (thick line) to help reveal interannual variability. This coral data conforms with instrumental records of ENSO variations over this period.

Middle Panel: 95 year skeletal $\delta^{18}O$ record from a fossil coral at Laing Island dated to 2,650 calendar years BP.

Lower Panel: 50 year skeletal $\delta^{18}O$ record from a fossil, from Sialum (6°S, 148°E) coral dated to 8,400 calendar years BP. Modern corals from this Sialum site display similar amplitude ENSO variabilityto the Laing Island modern coral.

cific. Following the onset of El Niño, the 3-part sequence evident in the modern coral record includes: (i) relatively cool SSTs in the austral winter indicated by both the coral Sr/Ca and $\delta^{18}O$; (ii) reduced cloudiness in spring-summer indicated by the coral $\delta^{13}C$ values; and (iii) lower than average monsoon rainfall in summer shown by the $\delta^{18}O$. The strong El Niño events that are primarily confined to one annual cycle (1972/73, 1982/83, 1991/92) coincide with a strong 3-part signal in the coral record. At least 2 of the diagnostic indicators, usually cooler SSTs in winter followed by drought in summer, are observed during weak El Niños (1976/77, 1979/80, 1987/88).

Panel B in Figure 3 shows the same style of data for 6200 BP. In this 25 year long record, there is only one strong shift to El Niño. This event, in the middle of the record, clearly shows the 3 diagnostic features within the annual cycle that we know are associated with the development of an El Niño. The other 2 potential El Niños show winter SST cooling followed by drought, but the $\delta^{13}C$ signal is weak. Perhaps they are weak events. The record is short, but taken at face value it shows weaker and less frequent ENSO activity at 6200 BP than at present. Note too, that SSTs were ~1°C warmer and rainfall less variable than in the modern period, reminiscent of a more La Niña like state in the mean.

The model behavior shown in Figure 1 is in rough agreement with the coral records in showing weaker ENSO activity in the mid-Holocene (6250 BP and 8400 BP) than in the modern. The ENSO cycle does continue, but strong events are less frequent (longer periodicity). The model ENSO variability at 2650 is perhaps slightly stronger than in the modern era, while the coral record (Figure 2) is slightly weaker. Given the high degree of variability within each record, it is hard to say whether this discrepancy is more than an artifact of limited sampling.

Thus the coral records generally support the model based the scenario given above. The model results demonstrate the possibility that the weakening of ENSO in the mid-Holocene results solely from orbitally forced changes in the tropical Pacific. Impacts of the extratropics or remnants of the glacial era are not needed, and could be no more than second order influences.

The great variability within each of the sample records, coral or model, makes rigorous detailed comparison difficult. Even with constant forcing the model generates decadal and longer timescale variability. This model is known to be a chaotic dynamical system (Tziperman *et al.*, 1994). The same may well be true of the real system. Alternatively, the irregularity of the real ENSO may forced by atmospheric or oceanic noise. The record is too short to determine which is the

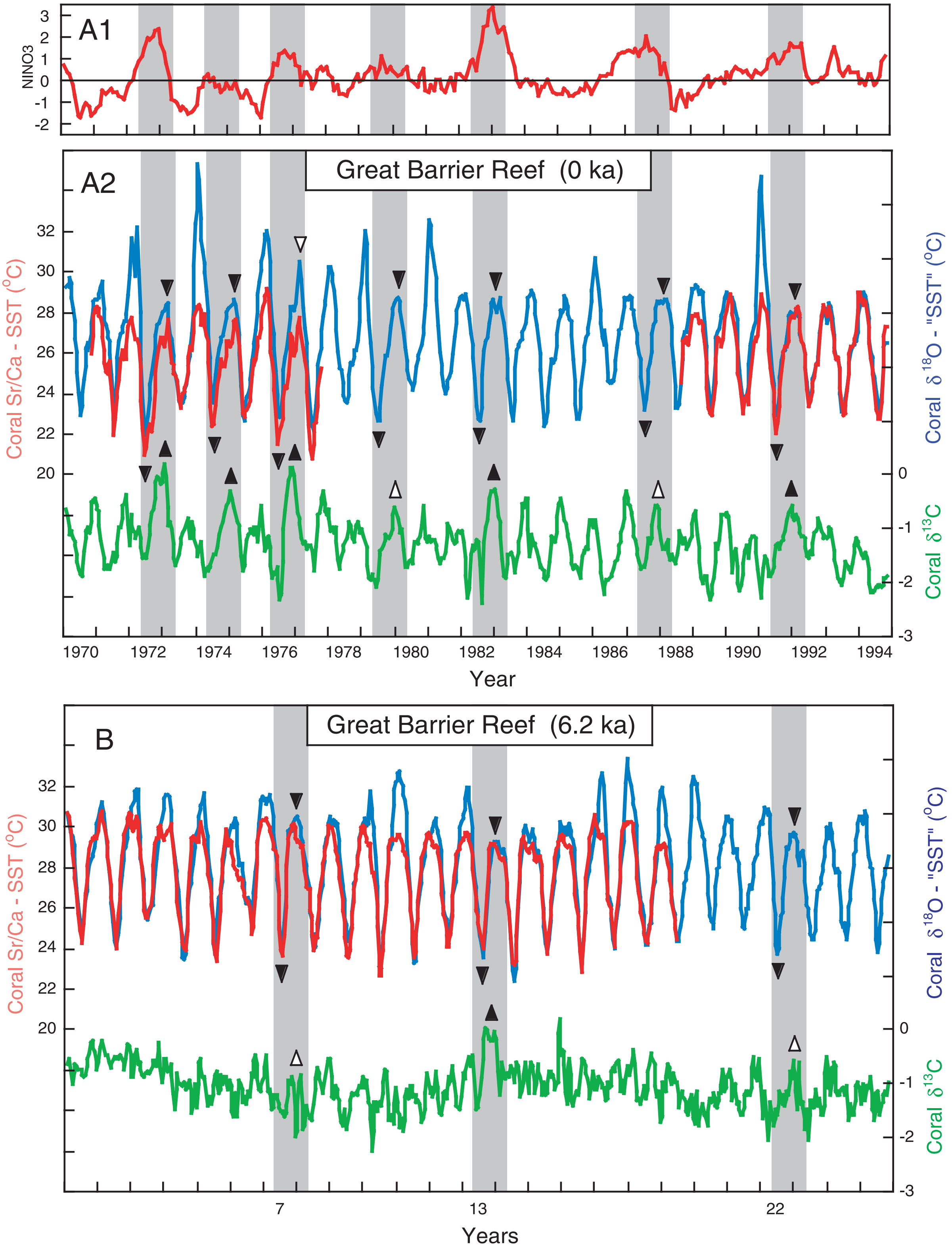

Figure 3:

A1: *SST anomalies for the eastern equatorial Pacific (5°N–5°S, 90°W–150°W) as an indicator of the timing and magnitude of El Niño events (stippled bars; from Kaplan et al., 1998).*

A2: *Seasonal changes in Orpheus Island, central Great Barrier Reef (18°45'S, 146°29'E) coral Sr/Ca, $\delta^{18}O$, and $\delta^{13}C$. Stippled bars mark years containing the 3-part sequence of environmental changes in the Great Barrier Reef that is diagnostic of El Niño: (1) cooler SSTs in the austral winter indicated by the coral Sr/Ca and $\delta^{18}O$; (2) reduced cloudiness in spring-summer indicated by higher coral $\delta^{13}C$ values; and (3) reduced monsoon rainfall in summer indicated by the coral $\delta^{18}O$. Black arrows indicate strong responses; weaker responses are indicated in white.*

B: *Sr/Ca, $\delta^{18}O$, and $\delta^{13}C$ results for a mid-Holocene coral (TIMS ^{230}Th age = 6,184 ± 34 yrs) from the same reef environment as the modern calibration coral. The coral Sr/Ca and $\delta^{18}O$ data were converted to temperature as defined by Gagan et al. (1998) and the $\delta^{18}O$ data for the mid-Holocene coral have been adjusted by –0.47 per mil (see Gagan et al., 1998).*

reason (Cane *et al.*, 1995). Regardless of the cause, the high degree of unforced variability makes it difficult to say with certainty that differences in the short coral records from different periods are not just due to sampling fluctuations. A modern example of the same problem arises from a coral record reported at the workshop by J. Cole, which shows lower frequency behavior in the mid–19th century than at present. The world was colder then; is there a causal relationship? The discrepancies noted above between the model and coral data at 2650 BP could be significant, or could just be due to limited sampling. By the same token, the agreement at earlier times could be fortuitous. More rigorous statistical analysis will sharpen the issue, and we plan to carry through such an analysis in the near future. However, it is most likely that this and similar issues can't be settled without more coral records. Finding the right fossil corals is in good measure a matter of luck. Moreover, fossil coral records tend to be rather short, exacerbating problems of interpretation. Another workshop talk, by C. Charles, illustrated a promising technique for overcoming this difficulty by joining series from different corals together, much as is done routinely for tree ring series. It appears realistic to believe that a coordinated program of modeling and fossil coral data acquisition could yield a reasonably complete picture of ENSO variations through the Holocene. Such a dataset would surely increase our understanding of ENSO dynamics, and our ability to tie ENSO variability to global changes through the Holocene.

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Abrupt Climate Change

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Any definition of 'abrupt' or 'rapid' climate changes is necessarily subjective, since it depends in large measure on the sample interval used in a particular study and on the pattern of longer term variation within which the sudden shift is embedded. Here, we avoid any attempt at a general definition but focus attention on different types of rapid transition found in the paleo-record in different time periods of the geologically recent past. Although distinctions between types are somewhat arbitrary, together they cover a wide range of shifts in dominant climate mode on timescales ranging from the last half million years to the last few centuries.

1. Over the past half million years, marine, polar ice core and terrestrial records all highlight the sudden and dramatic nature of glacial terminations, the shifts in global climate that occured as the world passed from dominantly glacial to interglacial conditions (e.g. Petit *et al.*, 1999). These climate transitions, although probably of relatively minor relevance to the prediction of potential future rapid climate change, do provide the most compelling evidence available in the historical record for the role of greenhouse gas, oceanic and biospheric feedbacks as nonlinear amplifiers in the climate system. It is such evidence for the dramatic effect of nonlinear feedbacks that, by very definition, supports the thesis that relatively minor changes in future climatic forcing may lead to dramatic, abrupt „surprises" in climatic response.

2. Within glacial periods, and especially well documented during the last one, spanning from around 110k to 11.6k years ago, there are dramatic climate oscillations, including high latitude temperature changes approaching the same magnitude as the glacial cycle itself, recorded in archives from the polar ice caps, high to middle latitude marine sediments, lake sediments and continental loess sections. These oscillations are usually referred to as Dansgaard-Oeschger Cycle and occur mostly on 1 to 2 kyr timescales (eg. Bender et al, 1999), although regional records of these transitions can show much more rapid change. The termination of the Younger Dryas cold event, for example, is manifested in ice core records from central Greenland as a near doubling of snow accumulation rate and a temperature shift of around 10°C occurring within a decade (Figure 1, Alley *et al.*, 1993). One hypothesis for explaining these climatic transitions is that the ocean thermohaline circulation flips between different stable modes, with warm intervals reflecting periods of strong deep water formation in the northern North Atlantic and vice versa (e.g. Stocker, 2000). It has been suggested that oscillation on this timescale is a persistent climatic feature which has continued throughout the Holocene, possibly including the Little Ice Age, albeit without the amplification associated with the presence of large Northern Hemisphere ice sheets (Bond *et al.*, 1999). Should this prove to be the case,

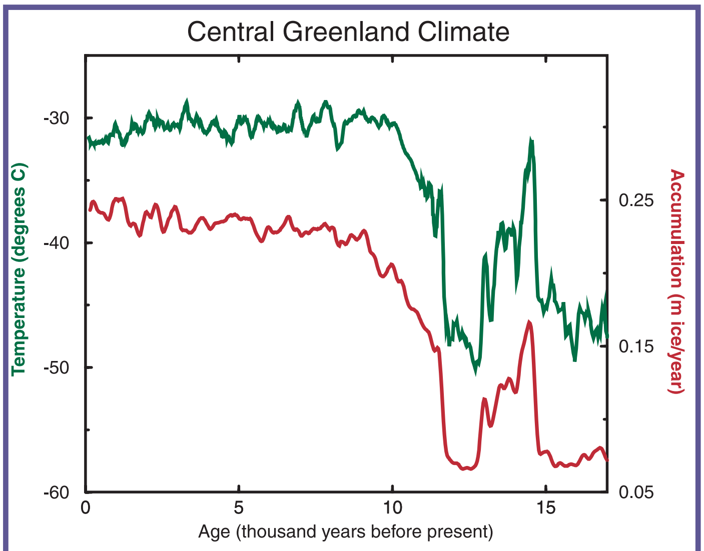

***Figure 1:** The termination of the Younger Dryas cold event some 11.6k years ago was an abrupt climatic shift. In this record, from Central Greenland, it is manifested as a warming of around 10°C, accompanied by a doubling in annual precipitation volume, occurring in about a decade. Shown here are accumulation and oxygen isotope (shown as inferred temperature) records from the GISP2 ice core. (Source: Alley et al., 1993)*

the cycle would necessarily modulate higher frequency climate modes such as the NAO, and prediction of future climate trends in the North Atlantic region would require accounting for these longer timescale processes.

3. During the first half of the Holocene, from 11.6k to around 6k years ago, evidence from lower latitudes especially points to rapid shifts in climate during the period when global ice volume, sea-level and vegetation were changing in the wake of the last glacial termination. Many of the changes taking place during the early Holocene, including melting of the polar ice caps, the rise of global sea level to something approaching its present height, the recolonization of extensive areas by vegetation adapted to new climatic conditions and the maturation of soils resulting from increasingly stable vegetation cover, took millennia to complete. Thus, although it is tempting to use evidence of climate variability during the first half of the Holocene as an indication of possible 'warm climate surprises', for all the reasons just noted, it is important to remember that the period was one of transition. This said, it is equally important to dispel the view that the Holocene as a whole was a period of relatively constant climate. This proposition, arising from the stable isotope record in Central Greenland ice cores, is highly misleading. Not only is there now clear evidence of higher levels of climate variability during the Holocene in Greenland itself, but at lower latitudes, evidence for Holocene climate variability is very strong.

One example of early Holocene rapid climate change is the '8200 BP' cooling event recorded in the North Atlantic region (e.g. von Grafenstein *et al.*, 1998). One possible explanation for this dramatic regional cooling is a shutdown in the formation of deep water in the northern North Atlantic due to fresh water input caused by catastrophic drainage of Laurentide lakes (Barber *et al.*, 1999). If this explanation proves to be correct it would lend support to the conjecture, based on numerical modeling experiments, that formation of deep water in the North Atlantic is highly sensitive to the fresh water forcing. This in turn would tend to reinforce the possibility of a rapid cooling 'surprise' in the North Atlantic region associated with potential future changes in the hydrological cycle.

The whole of the early to mid-Holocene is marked by dramatic shifts in lake level and wetland extent in Africa and Central America. It is often difficult to gauge the pace of change from such records since many lakes in the region are, in part, the surface expression of ground water table variations the response time of which is likely to be quite long. Nevertheless, in terms of the temporal resolution available and the expression of the hydrological changes in the archives studied, the major shifts appear to be rapid and of high amplitude. Numerous modeling studies suggest that the abruptness of the onset and termination of the early to mid-Holocene humid period across much of Africa north of the equator, depends on the presence of nonlinear feedbacks associated with both ocean circulation and changes in surface hydrology and vegetation (e.g. deMenocal *et al.*, 2000). Without including these feedbacks alongside gradual insolation forcing, it is impossible for existing models to come even close to simulating the rapidity or the magnitude of climatic change associated with the extension of wetlands and plant cover in the Sahara / Sahel region prior to the onset of desiccation around 5500 BP.

4. For the last 6k years there are many more well dated high resolution records from a wide range of archives such as corals, tree rings and laminated lake sediments. There is also greater confidence in quantitative calibration through comparison with instrumental records. Thus the concept of rapid change becomes something which can be better quantified though it is worth noting that our perception of particular changes will depend on the total time frame within which they can be set. Thus what appears as a sudden shift in mode of variability over a period of decades may be seen as a transient event or part of an oscillating system on century or millennial timescales. The clearest examples of significant rapid shifts in climate during this period are most confidently discernible at regional scale or with respect to spatially constrained modes of variability, for example, the major changes in frequency and strength of ENSO events noted by Cane et al, (this issue). When, as is the case with the changes associated with the so-called Little Ice Age (LIA) and Medieval Warm Period (MWP), claims are made for at least hemispheric, if not global coherence, confirming widescale synchroneity becomes problematical (see Bradley, this issue).

Many temporally well resolved proxy records show climate variability beyond the range revealed in modern instrumental records from the same region. These records also include sudden shifts in mode. For example, Figure 2 shows a lake record from the central US which indicates a shift in the mode of hydrological variability occurred around 1200 AD, with the earlier portion of the record experiencing much more protracted and severe droughts than the later (Laird *et al.*, 1996).

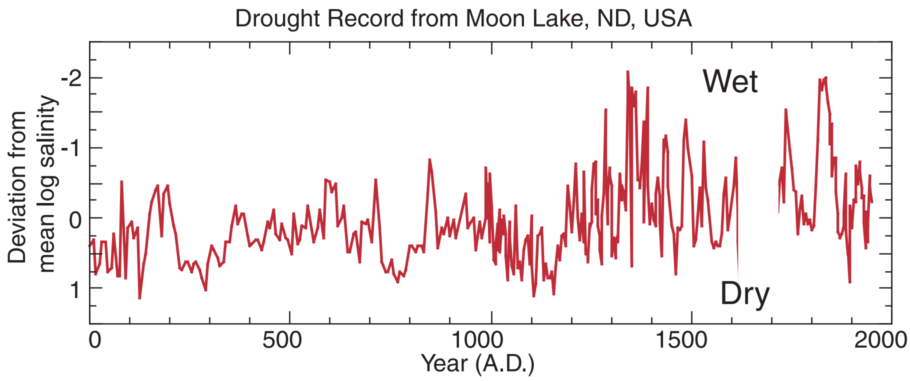

Figure 2: *Lake salinity record reconstructed for Moon Lake, North Dakota, illustrating regional drought variability over the last 2000 years. The severe droughts of the 1930's and 1890's (positive inferred salinity) are well reconstructed, but are eclipsed by more extensive droughts before the beginning of the instrumental period. There is an abrupt change in drought variability around AD 1200. Before that time, the high plains were characterized by much more regular and persistent (e.g., interdecadal) droughts. The mechanisms for major shifts in drought variability of the past are not well understood, and no processes model has successfully simulated these types of changes. Note that the gap in 17th century data coverage represents absence of data. (Source: Laird et al., 1996)*

Although a thorough review is well beyond the scope of this note, these examples serve to highlight a wealth of evidence which exists for rapid climate changes during the Late Holocene; not always demonstrably globally or even hemispherically synchronous, but regionally highly significant. These changes are expressions of natural variability, the ongoing pattern of which will interact with and modulate the expression of any anthropogenic climate change effects. The underlying causes of the rapid changes now well documented remain uncertain in many cases. Some short term, extreme transient events clearly reflect the impact of major volcanic eruptions (Briffa,1998). In other examples, abrupt changes have been linked to ^{14}C anomalies, a likely proxy for solar activity, as is the case with the widespread, major changes documented around 2650 BP by Van Geel *et al.* (1996) and the sequence of drought episodes reconstructed for Ethiopia by Verschuren *et al.* (2000) from lake sediment records covering the last 900 years (Figure 3).

5. The past 200 years span the period of major human environmental perturbation. Over this period greenhouse gas concentrations have risen extremely rapidly to levels that are unprecedented in at least the past 400,000 years (e.g. Raynaud, 2000). The magnitude and rate of measured global temperature rise during the past 200 years, on the other hand, does not appear to be unusual within the context of the Holocene. During the same 200 year period, the rate of land cover change has probably also been unprecedented in the Holocene. The apparent ENSO phase shifts during the 1970's seems unique over this time period, and may thus represent a real climate shift (e.g. Trenberth and Hoar, 1997), although the available time series is probalby too short to unequivocally prove that the shift is significant (Wunsch, 1999). The inability to resolve questions of this kind from short instrumental time series provides one of the strongest arguments for extending the instrumental record of climate variability with well dated, temporally finely resolved and rigorously calibrated proxy data.

6. Implications for the future. Growing attention has been paid to the possibility of anthropogenic climate change leading to 'surprises' – shifts well beyond the range of variability upon which planning and construction schemes are based and even outside the envelope of projections generated by climate models. The paleorecord does not preclude such possibilities.

One such potential 'surprise' that has been the target of several recent modeling studies is a shut down of North Atlantic Deep Water production occurring as an indirect result of increasing greenhouse gas levels (Manabe and Stouffer, 1993) and possibly even in a manner sensitive to the *rate* of CO_2 increase (Stocker and Schmittner, 1997). Regional climate changes linked to such an event would certainly constitute a 'surprise' and, for many parts of the world, possibly even a catastrophe.

Another example is the possibility of greenhouse gas driven warming leading to a change in the frequency of ENSO events. Modeling studies indicate that a strong enhancement of ENSO conditions is not inconceivable (Timmerman *et al.*, 1999). Such a drastic shift in ENSO frequency would have enormous consequences for both the biosphere and humans. Paradoxically, one possible consequence might be a sufficient increase in E-P forcing over the subtropical Atlantic to stabilize the thermohaline circulation (Schmittner *et al.*, in press)

The messages from the paleorecord for the future are not limited to these examples. Nor is belief in anthropogenic greenhouse gas warming an essential prerequisite for heed-

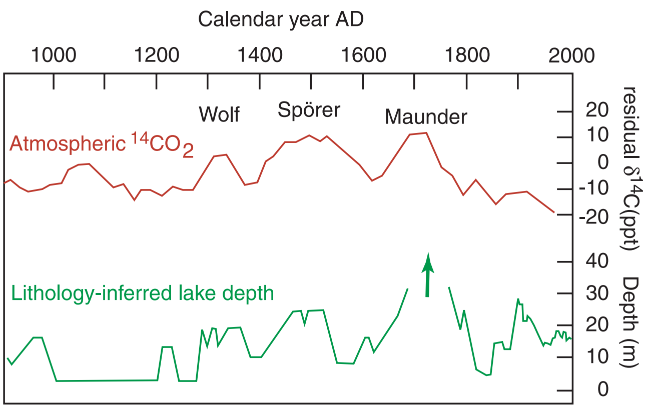

Figure 3: *A comparison between inferred water depth in the Crescent Island Crater Lake, Ethiopia as an indicator of prolonged drought incidence, and the decadal record of atmospheric δ^{14}C production, a likely proxy for solar activity (Adapted from Verschuren et al., 2000).*

ing these messages. Extending the record of climate variability back through time reveals changes, often sudden and sometimes persistent on decadal to century timescales that lie outside the range of instrumental records. The concepts of future sustainability, water supply and food security may be dangerously short sighted if they fail to accommodate the evidence from the longer term record. This is especially the case in relation to changes in the magnitude and frequency of extreme events (e.g. Knox, 2000) and to shifts in hydrological regime (e.g. Hodell *et al.*, 1995; Messerli *et al.*, 2000). The growing consensus however, is that future climate change will reflect not only natural variability but anthropogenic forcing as well. It is interesting to compare even the most modest predictions of greenhouse warming with natural variability recorded in the recent past. Even though the last six centuries appear to have recorded both the coldest and warmest decades to have occurred in the late Holocene (e.g. Bradley, 2000), the amplitude of variation in Northern Hemisphere mean annual temperature between these extremes is less than the lowest projected temperature increases for the next century.

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Improving Estimates of Drought Variability and Extremes from Centuries-Long Tree-Ring Chronologies: A PAGES/CLIVAR Example

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The impact of severe drought on agriculture, water supply, and the overall environment is an increasing global concern as the demand for water outstrips supplies in many areas of the world. Reliable long-range forecasting methods need to be developed to allow agricultural and water resource planners and administrators to reduce the impact of future droughts. In addition, longer climate records are needed for improving regional drought risk assessments, especially those dealing with the rare, extreme events. For both purposes, the instrumental climate database is likely to be inadequate, even in the well monitored U.S. It is very difficult to know if the instrumental records are long enough to include the full range of drought variability likely to happen in any given region in the future. This issue was specifically addressed in a recent workshop convened by NOAA and NASA: “Assessing the Full Range of Central North America Droughts and Associated Landcover Change”, Boulder, Colorado, June 2–4, 1999. One conclusion drawn from this workshop was that instrumental climate data over the U.S. are inadequate for capturing the “full range” of drought. Consequently, there is an urgent need to develop long records of past drought from a variety of proxy records. Among those available, precisely dated annual tree-ring chronologies from centuries-old trees growing on drought-stress sites are ideally suited for this pupose.

A recent paper by Woodhouse and Overpeck (1998) has likewise highlighted the limitations of instrumental climate data by examining the paleoclimate record of drought in the western U.S. They find evidence of past “megadroughts” of unusual severity and duration in the paleoclimatic record, ones that appear to have exceeded even the Midwestern “Dustbowl” drought of the 1930s. The analysis of Woodhouse and Overpeck (1998) illustrates the tremendous value of paleoclimate data in studying past drought. However, it also shows the current limitations of the available proxy records. Among the data they use is the 154 grid point network of well-calibrated and verified summer drought reconstructions from annual tree-ring chronologies produced by Cook *et al.* (1999) for the coterminous U.S. This network, based on the Palmer Drought Severity Index (PDSI; Palmer, 1965), provides a highly detailed record of drought and wetness over the U.S. in both space and time. Unfortunately, these reconstructions only extend back to 1700 at the present time. Yet, Woodhouse and Overpeck (1998) clearly show in a sparser collection of much longer individual drought reconstructions that some notable megadroughts occurred in the western US, mostly prior to AD 1600. Therefore, there is a great need to produce a substantially longer, high-density network of drought reconstructions for the U.S. that extends 600–800 years back into the past. Such a network would provide the means to carefully map the occurrence of drought during these megadrought periods. In so doing, it may be possible to analyze the spatial patterns and evolutive trajectories of these megadroughts and infer their causes.

To illustrate the importance of extending the drought reconstructions further back in time, we have applied optimal interpolation (OI; Kaplan *et al.*, 2000) to the U.S. PDSI reconstruction grid (Cook *et al.*, 1999) after it had been augmented with a number of much longer tree-ring estimates in certain parts of the network. This has enabled us to use OI to extend the PDSI reconstructions over the entire U.S. from 1200 to 1994. Figure 1 shows the first varimax rotated EOF of reconstructed PDSI and its scores using the extended OI PDSI data. This factor emphasizes the southwestern US and is probably the highest quality region produced by the OI analysis. The OI scores have a correlation of 0.77 with instrumental PDSI from the Southwest on an annual basis and 0.86 on a smoothed, inter-decadal basis over the period 1895–1994. They also have a correlation of 0.93 with the varimax factor scores for the same region based on non-interpolated PDSI reconstructions over the common period 1469–1978.

The factor scores clearly illustrate the importance of extending the drought reconstructions as far back in time as possible. Prior to 1600, there is evidence for three megadroughts in the 1280s, 1340s, and 1580s. The 1280s "Great Drought" has been associated with the disappearance of the Anasazi indian culture in the Southwest (Douglass 1929); and the 1580s drought is coincidental (perhaps linked) with the drought associated with the disappearance of the colonists on Roanoke Island (Stahle *et al.* 1998). Woodhouse and Overpeck (1998) also document the occurrence of the 1280s and 1580s droughts in the western US, but do not describe the 1340s event indicated here. Besides having three of the worst droughts of the past 800 years, the AD 1200–1600 interval is also characterized by enhanced inter-decadal variability that is associated with more prolonged episodes of drought and wetness. This is clearly illustrated in the following table, which lists the five driest 5, 10, and 20-year periods in this southwestern US drought record.

	5-Year Period		10-Year Period		20-Year Period	
Rank	Dates	Mean	Dates	Mean	Dates	Mean
1	1581–1585	–1.717	1576–1585	–1.442	1573–1592	–1.008
2	1666–1670	–1.584	1338–1347	–1.237	1336–1355	–0.730
3	1338–1342	–1.479	1664–1673	–1.010	1273–1292	–0.709
4	1399–1403	–1.343	1728–1737	–0.987	1945–1964	–0.629
5	1421–1425	–1.289	1280–1289	–0.910	1445–1464	–0.609

Table 1. *List of the five driest 5, 10, and 20-year periods in the PDSI factor scores shown in Fig. 1. The units are in standard normal deviates. Note the prevalence of megadroughts in the AD 1200–1600 period that would be totally missed if the PDSI reconstructions only extend back to, say, 1600.*

Note that for both the 5-year and 20-year intervals, 4 of the 5 driest periods were in the AD 1200–1600 epoch. Also, the late–16th century drought examined by Stahle *et al.* (2000) appears to be *the* megadrought of the past 800 years in the southwestern US. Thus, it is clear that PDSI reconstructions covering only the past 300–400 years are not sufficient to capture the full range of drought / wetness variability across the coterminous US. In fact, the recent few centuries could be interpreted as being conspicuously *deficient* of megadroughts, due perhaps to climate associated with the "Little Ice Age" (see Bradley, this issue). Why this is so is a mystery that needs to be solved and modeled. Any return to the modes of climate variability characteristic of the pre–16th century period in the US Southwest would be diasterous. If we truly want precisely dated, annual estimates of past drought for improving our understanding of drought variability and extremes, and for testing hypothesized forcings of drought and wetness (e.g. Cole and Cook, 1998; Cook *et al.*, 1997), the only recourse is to use centuries-long tree-ring chronologies and novel statistical estimation procedures to reconstruct the past.

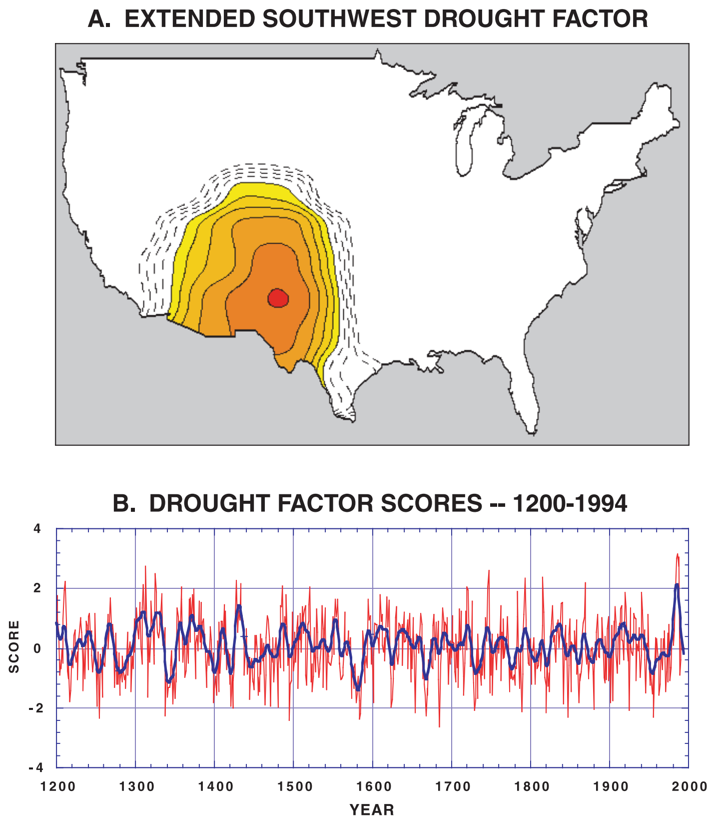

Figure 1:

(A) The first varimax rotated Empirical Orthogonal Function (EOF) of a Palmer Drought Severity Index (PDSI) grid derived from optimally interpolated tree ring chronologies. This factor emphasizes the southwestern US and is probably the highest quality region produced by the analysis.

(B) The scores for this EOF for the period 1200–1994. This timeseries has a correlation of 0.77 with instrumental PDSI from the Southwest on an annual basis and 0.86 on a smoothed, inter-decadal basis over the period 1895–1994.

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Conceptual Framework for Changes of Rainfall and Extremes of the Hydrological Cycle with Climate Change

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A physically based conceptual framework is put forward that explains why an increase in heavy precipitation events should be a primary manifestation of the climate change that accompanies increases in greenhouse gases in the atmosphere. The same arguments apply generally for all kinds of climate change. This paper summarizes Trenberth (1998, 1999) and a full set of references is given in those works.

The term "global warming" is often taken to refer to global increases in temperature accompanying the increases in greenhouse gases in the atmosphere. In fact it should refer to the additional global heating (sometimes referred to as radiative forcing, e.g., by the IPCC (1996)) arising from the increased concentrations of greenhouse gases, such as carbon dioxide, in the atmosphere. Increases in greenhouse gases in the atmosphere produce global warming through an increase in downwelling infrared radiation, and thus not only increase surface temperatures but also enhance the hydrological cycle, as much of the heating at the surface goes into evaporating surface moisture. This occurs in all climate models regardless of feedbacks, although the magnitude varies substantially.

Temperature increases signify that the water-holding capacity of the atmosphere increases and, together with enhanced evaporation, the actual atmospheric moisture should increase, as is observed to be happening in many places. Of course, enhanced evaporation depends upon the availability of sufficient surface moisture and over land, this depends on the existing climate. However, it follows that naturally-occurring droughts are likely to be exacerbated by enhanced potential evapotranspiration. Further, globally there must be an increase in precipitation to balance the enhanced evaporation but the processes by which precipitation is altered locally are not well understood.

Precipitating systems of all kinds feed mostly on the moisture already in the atmosphere at the time the system develops, and precipitation occurs through convergence of available moisture on the scale of the system. Hence, the atmospheric moisture content directly affects rainfall and snowfall rates, but not so clearly the precipitation frequency and thus total precipitation, at least locally. Thus, it is argued that global warming leads to increased moisture content of the atmosphere which in turn favours stronger rainfall events, as is observed to be happening in many parts of the world, thus increasing risk of flooding. It is further argued that one reason why increases in rainfall should be spotty is because of mismatches in the rates of rainfall versus evaporation.

The arguments on how climate change can influence moisture content of the atmosphere, and its sources and sinks are assembled in the schematic in Fig.1. The sequence given is simplified by omitting some of the feedbacks that can interfere. For example, an increase in atmospheric moisture may lead to increased relative humidity and increased clouds, which could cut down on solar radiation (enhance short-wave cloud forcing) and reduce the energy available at the surface for evaporation. Those feedbacks are included in the climate models and alter the magnitude of the surface heat available for evaporation in different models but not its sign. Figure 1 provides the rationale for why rainfall rates and frequencies as well as accumulations are important in understanding what is going on with precipitation locally. The accumulations depend greatly on the frequency, size and duration of individual storms, as well as the rate and these depend on static stability and other factors as well. In particular, the need to vertically transport heat absorbed at the surface is a factor in convection and baroclinic instability both of which act to stabilize the atmosphere. Increased greenhouse gases also stabilize the atmosphere. Those are additional considerations in interpreting model responses to increased greenhouse gas simulations.

However, because of constraints in the surface energy budget, there are also implications for the frequency and / or efficiency of precipitation. The global increase in evaporation is determined by the increase in surface heating and this controls the global increase in precipitation. But precipitation rates are apt to increase more rapidly, implying that the frequency of precipitation must decrease, raising the possibility of fewer but more intense events.

It has been argued that increased moisture content of the atmosphere favours stronger rainfall and snowfall events, thus increasing risk of flooding. Although there is a pattern of heavier rainfalls observed in many parts of the world where the analysis has been done, flooding records are confounded by changes in land use, construction of culverts, dams and so forth designed to control flooding, and increasing settlement of flood plains which changes vulnerability to flooding.

The above arguments suggest that there is not such a clear expectation on how local total precipitation amounts should change, except as an overall global average. With higher average temperatures in winter expected, more precipitation is likely to fall in the form of rain rather than snow, which will increase both soil moisture and run off, as noted by the IPCC (1996) and found in many models. In addition, faster snow melt in spring is likely to aggravate springtime flooding. In other places, dipole-like structures of precipitation change should occur in places where storm tracks shift meridionally. Beyond this, it is suggested that examining moisture content, rainfall rates and frequency of precipitation and how they change with climate change may be more important and fruitful than just examining precipitation amounts in understanding what is happening in model projections. To be compatible with life times of significant rain

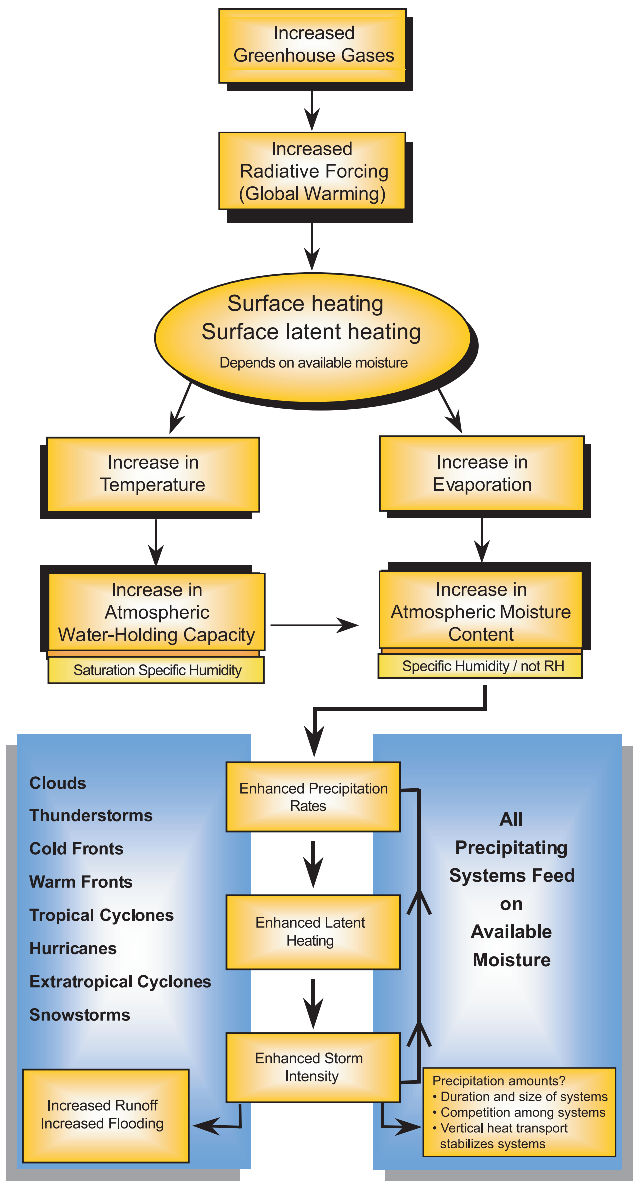

Figure 1: *Schematic outline of the sequence of processes involved in climate change and how they alter moisture content of the atmosphere, evaporation, and precipitation rates. All precipitating systems feed on the available moisture leading to increases in precipitation rates and feedbacks. (Trenberth, 1998)*

events, yet still deal with whole storms rather than individual rain cells, hourly precipitation data are recommended. Such data are also retrievable from climate models.

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Century to Decadal Scale Records of Norwegian Sea Surface Temperature Variations of the past 2 Millennia

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Recent focus on rapid climate change and millennial scale climate variability in paleoceanography has led to a marked improvement in the temporal resolution of paleoceanographic climate records. Recent studies have indicated a possible existence of pervasive cycles of oceanic variability at approximately 1500 years, both in surface waters and in the strength of North Atlantic deep water flows (Bond *et al.*, 1997; Bianchi and McCave, 1999). These cycles appear to continue into the Holocene (postglacial phase – i.e. the last 11,000 years). The last such event may have been the warm-cold alteration normally associated with the Medieval Warm Period (MWP) centred at approximately 1000 AD, and the Little Ice Age (LIA) between 1400 and 1800 AD in Europe. This increased potential for detailed paleoclimatic records from rapidly accumulating sediments, as documented by these and other results, has spurred much interest in the community. The focus has been on obtaining ultra high temporal resolution from sediment cores retrieved from areas where sediment focusing expands the sections and enables detailed sampling. It is also a prerequisite that it is possible to utilise the normal methods of paleoclimatic estimation. This would require open ocean settings and a temporal resolution approaching decadal scale in the best cases. In some very restricted areas annually laminated sediments may be found, which may provide annually resolved paleoclimate records. Outside of these areas, one would need to obtain cores from rapidly deposited sediments in areas of high sediment focusing. Annual resolution is not feasible here.

Using this approach, a pilot study was conducted in high accumulation rate sediments from the Vøring Plateau in the Eastern Norwegian Sea at 67°N (IMAGES core MD95–2011). The study documents SST-variations during the last millennia at hitherto unprecedented resolution (Fig. 1b) from this kind of research. This indicates that careful selection of cores will enable quantitative estimates of ocean proxies approaching decadal scale (see below). The core is dated by ^{210}Pb and AMS-^{14}C (6 dates for the past 2000 years). We estimate the accuracy of the time scale to be about 50 years, which may be somewhat improved in the future by more detailed AMS ^{14}C-chronology. The summer SST is estimated using diatom transfer functions. Parallel work using other SST-estimation techniques are underway.

As can be noticed in the figure, SST during the past 2000 years varied around a mean with amplitude of variations of 1–2 degrees. Compared to the thermal optimum of the Early Holocene (data not shown here) the mean SSTs are a few degrees colder, probably due to the long term influence of declining summer insolation by the orbital factors. Both the MWP and a two-phased LIA are detectable in the data set, as well as rapid cooling and warming intervals, happening over a decade: Note cold-warm-cold phase in the period 1300–1450 AD according to the time scale of the core. Possible century scale cycles may be identified in the data set, but await improved chronological control.

In the figure we have compared this record with the SST record from Bermuda Rise over the same time period recently published (Keigwin, 1996; Keigwin and Pickart, 1999) (Fig. 1A). The lower temporal resolution of the sediment section and possibly a higher degree of bioturbation at this site, has probably worked as a low pass filter on the variability over Bermuda Rise. Hence, only the main multi-centennial scale variations may be compared at this stage. SST changes associated with the MWP and LIA at Bermuda Rise were of the same order of magnitude as in the Norwegian Sea. The timing of the warm and cold phases are not identical. This may be due to the bioturbation filtering, time scale problems, or time scale inaccuracies. Hence, improved temporal resolution and chronologies are required to further compare the spatial SST variability in the North Atlantic. An important path to follow by further investigations is the intriguing proposition of Keigwin and Pickart (1999). They suggest that opposite SST anomalies between the Western North Atlantic and the Labrador Sea region were developed during the LIA in a similar way as the anomaly pattern known from the NAO phases (see Sarachik, this issue).

This work is now underway. Under the auspices of the PAGES marine program, IMAGES, a large community based coring expedition was conducted in the summer of 1999, using the unique large coring system of the French *RV Marion Dufresne*. A large number of sites dedicated for ultra-high resolution studies of this type were cored in the Circum Atlantic and the Nordic Seas. A new era of very high-resolution paleoceanographic reconstructions has been initiated by this cruise, and a wealth of new high quality data can be expected in the next years. This holds good promise for future interaction between the paleoceanogrphy community of PAGES and CLIVAR.

Acknowledgements: We acknowledge support from the EU-Environment and Climate Programme, the Norwegian Research Council and the French CNRS / IFRTP for supporting the IMAGES coring expeditions.

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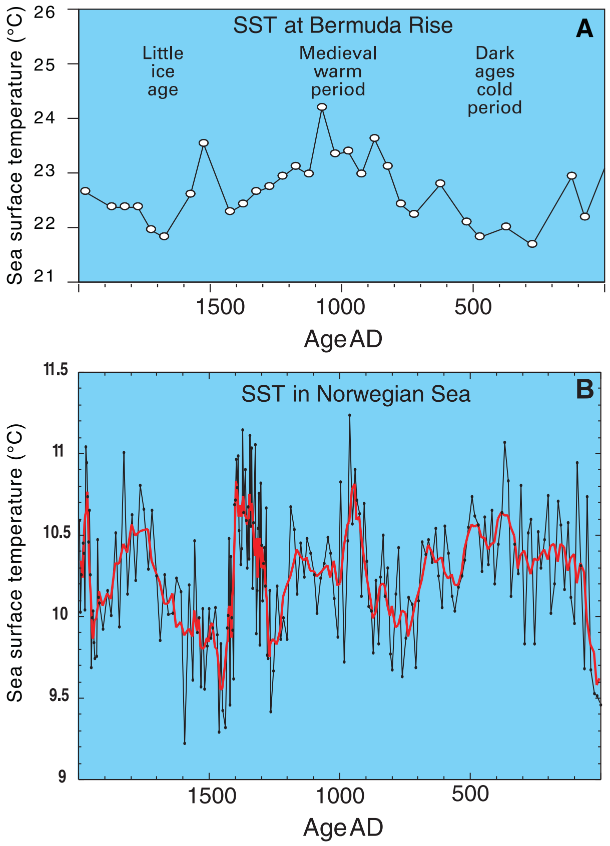

Figure 1: *(A) SST-summer estimates for the last 2000 years at Bermuda Rise. From [Keigwin and Pickart, 1999]. (B) New SST- summer estimates for the last 2000 years at Vøring Plateau, Eastern Norwegian Sea based on diatom transfer functions. The red line is a 5pt running mean.*

Opportunities for CLIVAR/PAGES NAO Studies

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The normal atmospheric situation over the North Atlantic Ocean has surface westerlies blowing across the ocean at about 40°N between the surface expression of the Icelandic low and the Azores high, with the most intense westerlies existing during the winter season. On times scales ranging from monthly to interdecadally, there is an oscillation of the strength of these pressure features which can be conveniently measured by the difference in surface pressure between the Azores (or some nearby station) and Iceland. The state of this North Atlantic Oscillation (NAO) is positive when the Azores high is strong and the Icelandic low is deep and negative when reversed. A time series of this normalized winter index is given in Fig. 1.

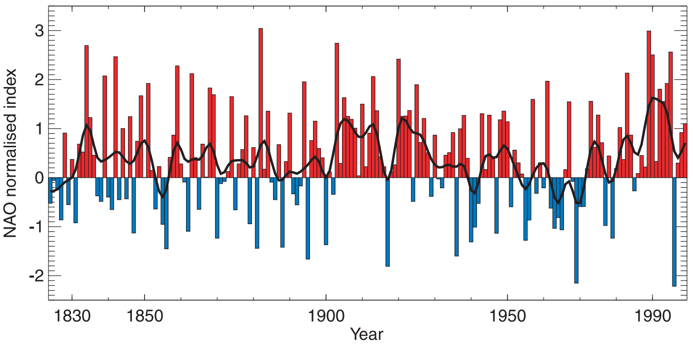

***Figure 1:** Updated winter NAO index based on instrumental data. Courtesy of P.D. Jones to T. Osborn (http://www.cru.uea.ac.uk/~timo/projpages/nao_update.htm)*

The extraordinary climatic interest in the NAO arises from two observations: the unusual locking of the NAO in its positive phase almost continuously since 1976 and the concomitant collection of climatic phenomenon which can be associated with its positive and negative phases. These two phases are given by the two parts of Figure 2.

The Positive phase of the NAO is mostly easily characterized during the winter and has the following effects:

- Stronger Westerlies across the Atlantic extending further north towards the British Isles and pointing toward northern Europe;
- A more intense storm track roughly steered by the displaced westerlies;
- Stronger upwelling off the coast of Portugal and Northwestern Africa due to the southerlies accompanying the intensified Azores high;
- Stronger (easterly) trades off the coast of Africa into the subtropical Atlantic;
- Wet anomalies over the eastern US coast extending across the Atlantic into Scandinavia and northern Siberia;
- Dry anomalies over the Labrador sea and over Southern Europe and the Mediterranean region;
- Wet anomalies over northern Africa extending eastward into the Arabian Sea;
- Warm anomalies over major parts of the US (as far west as Alaska), northern Europe and extending eastward all the way across Siberia;
- Cold anomalies over the Labrador Sea and simultaneous warm anomalies over the GIN seas;
- Increased ice flux out of the Artic Ocean from the Fram Straits.

There are also direct effects of NAO variability on the ocean, both in terms of direct driving of fluxes by the NAO (Cayan, 1992) and in convective responses to NAO changes in heat and freshwater inputs (Dickson *et al.*, 1996).

We may note that the Pacific manifestations of the NAO are consistent with the idea that the NAO itself is part of a more annular (circumpolar) mode of variability that has expression in both the North Atlantic and Pacific (Thompson and Wallace, 1998). For the purposes here, we will not distinguish between the NAO and the so-called Arctic Oscillation (AO). We might also note that the above mentioned positive phase of NAO since 1976 is coincident with (and may be related to), the rapid global surface warming, especially at high latitudes, evident in the record.

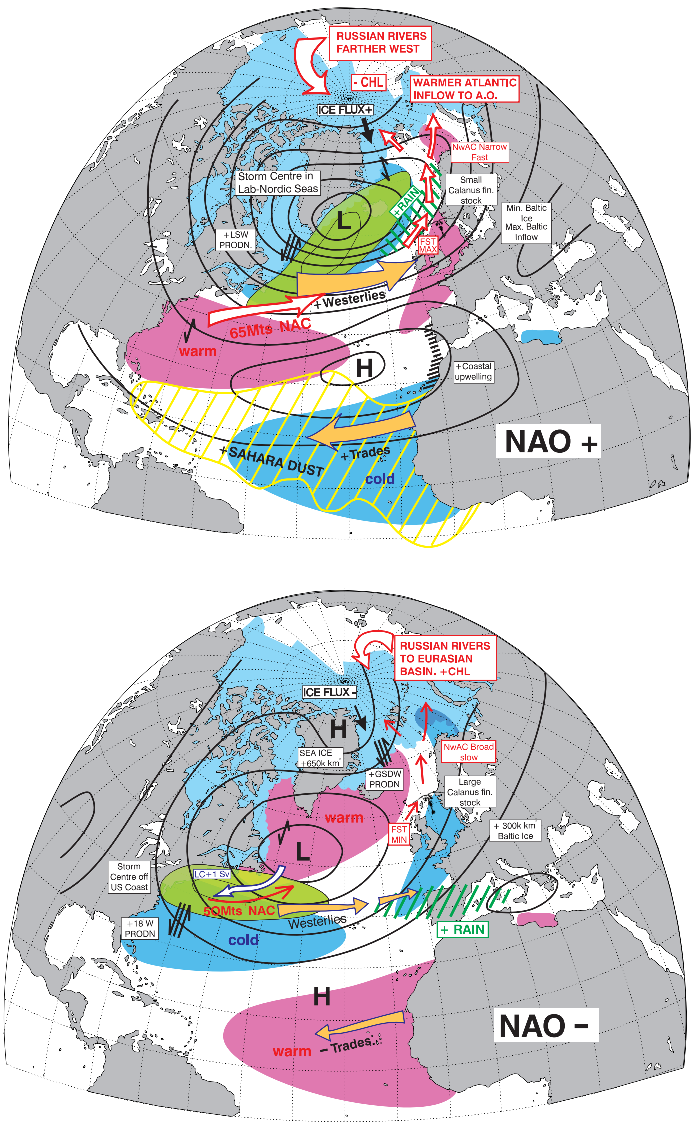

***Figure 2:** Schematic representations of the (a) positive and (b) negative phases of the North Atlantic Oscillation. (courtesy of B. Dickson, CEFAS).*

Paleoclimatic Opportunities:

The instrumental record of the NAO index extends back to about 1850 since long surface pressure records have been available at the antipodes of the NAO. As pointed out by Wunsch (1999) there are numerous difficulties involved in determining if features seen in this extant, relatively short, instrumental record of the NAO are statistically significant, let alone understanding any underlying dynamical mechanisms which may exist. For example, the instrumental record is not nearly long enough to decide if the locking in the positive phase since 1976 is truly unusual, or, if in a short record dominated by decadal signals, it has appeared many times

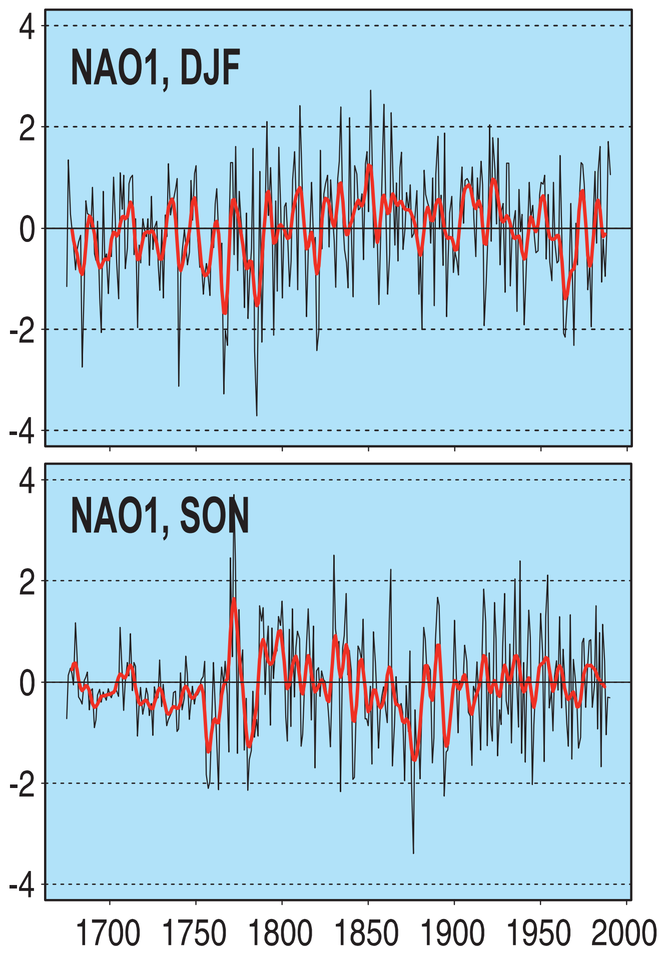

Figure 3: *Normalized time series of the reconstructed mean winter (DJF) and autumn (SON) indices from 1675 to 1990. Red lines are 7 point low-pass filtered time series. (Source: Luterbacher et al., 1999)*

before. Therefore, in order to better interpret the instrumental record of NAO variability it is imperative that a longer record be obtained.

Several paleoclimatic proxies have the potential to record aspects of North Atlantic climatic variability, and thereby the NAO index, with annual or higher resolution to well before the year 1700. Recent paleo-proxy NAO reconstructions with annual or better resolution include, for example, those from tree rings (Cook *et al.*, 1998), ice cores (Appenzeller *et al.*, 1998), stalagmites (Proctor *et al.*, in press) as well as combined tree ring and ice core data (Stockton and Glueck, 1999). Regional synthesis of paleo-proxy indicators with subdecadal resolution can provide information regarding historical impacts of the NAO on regional moisture balance. One example is the multiproxy regional synthesis of historical records, tree-rings, laminated lake sediments, speleothems, geomorphological and other sources in the Mediterranean region currently being undertaken as part of the PAGES PEP III synthesis (detailed information on this program will be published in the upcoming PAGES Newsletter Vol.8, N°2). Multiple proxies in the Scandinavian region, including annually laminated lake sediments, tree rings, glaciers and speleothems provide another fruitful area for future paleoclimatic synthesis of NAO variability and regional expression in the past.

Luterbacher *et al.* (1999) have published a multiproxy derived NAO index with monthly resolution from 1675 to the present. Their reconstruction is shown in figure 3. In addition to the reconstruction, Luterbacher *et al.*show that the correlations between the many individual paleo reconstructions that are now available are not high enough to regard any one of them as definitive. An approach which includes multiple, independent, paleoclimatic archives and proxies is clearly required in order to provide an extended record of NAO variability. Such studies are underway (e.g. Cullen *et al.*, submitted) and will lead, in the next few years, to both an improved record of NAO variability as well as better understand the underlying dynamics associated with this important mode of climatic variability.

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PAGES
PAST GLOBAL CHANGES

PAGES Section

Reconstructing Climatic Variability from Historical Sources and Other Proxy Records

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An international conference titled, "Reconstructing Climatic Variability from Historical Sources and Other Proxy Records" was held in Manzanillo, Mexico, on 1–3 December, 1999. The meeting attracted 21 participants from 9 countries. The goal of the conference was to highlight historical research directed at reconstructing climatic variations prior to the modern era of instrumental records. A special focus was on historical climate research in the Americas, although a number of papers also focused on new results from other parts of the globe. In addition, some papers specifically addressed this topic from the perspective of epidemiological history and the possible role that climatic variations may have had in initiating and / or exacerbating communicable diseases, especially vector borne illnesses.

Papers were presented covering three major themes: 1) Reconstructing major drought and flood episodes, primarily in the region of the Americas for the past four centuries; 2) Documenting multiscale teleconnections and their association with El Niño / Southern Oscillation (ENSO) events and other decadal climate variability, such as the North Atlantic Oscillation (NAO); and 3) Emerging studies on the connections between climate and human health. A central goal of the meeting was to advance the study of historical analysis for the purposes of emphasizing those times where significant historical events and periods may have been affected by major climatic events—prolonged cold episodes or extended drought, perhaps associated with the occurrence of extreme events such as ENSO, or large volcanic eruptions. Another goal of the conference was to promote the exchange of views and information among the participants, and to foster new ideas for collaborative research.

The papers presented at the conference underscore the wide depth and breadth of ongoing research, and illustrate the potential of this type of analysis within the study of long term climate change. There exists in the Americas, as well as in many other parts of the world, rich sources of archived information that can be used to infer climatic changes in the past, on annual, interannual, and decadal timescales. Below, a few of the more promising studies and their possible use in climatic reconstruction are highlighted.

In the United States, large amounts of weather and climate information were recorded, mostly in diaries during the 19th century by pioneers moving west across the continent, primarily from the 1840s onward. In the earlier-settled eastern United States, useful climate information can be extracted from diaries and other such documentary records back to the start of the 19th century, and earlier in a few in-

Exterior and interior (next page) views of the historical archive in Seville, Spain in which records of voyage duration of the Manila Galleons, dating as far back as the late 1500's, are stored.

stances. The beginnings of organized weather and climate services in other parts of the Americas generally parallel those in the U.S. and Europe, because many of the major figures that played important roles in that development were from Europe or the U.S.A. High-resolution climate proxies can be extracted in places where the daily state of the weather was important for commercial reasons. For instance, high mountain passes in the Andes of South America, which were an important transportation artery between major settlements, recorded daily snow conditions for much of the year. Normalized time series of snowfall quantity have been developed from the mid–1700s for an area in the central Andes along the Argentinean–Chilean border.

Other presentations focused on continuing efforts to improve and refine the chronology of El Niño events prior to the modern instrumental records, which go back to about the mid–1800s. These efforts include the mining of information about weather phenomena usually associated with ENSO events from a variety of sources, as well as the use of coral records from the tropical Pacific. New information useful for the analysis of long term variations in the NAO has been developed from the Canary Islands, using agricultural time series as proxies for precipitation. Another interesting set of proxy records is the voyage durations of the Manila Galleons, whose yearly trips from Acapulco, Mexico to Manila, The Phillippines, starting in the late 1500s, and continuing for more than two centuries, may be able to provide a record of decadal scale variability in the strength of the North Pacific trade winds. The utility of comparative analysis among different proxy records was illustrated by the fact that a period of apparently weaker trades in the western tropical Pacific, inferred from the presence of significantly longer voyage durations of the Manila Galleons from about 1630–1680, coincides with a large increase in the incidence of typhoon landfalls in southeastern China during the same period. The typhoon landfall data for southeastern China was compiled from documentary historical sources in China. Additional research to establish the validity of these decadal

climate changes and their context within large-scale circulation patterns during that time appears warranted.

Innovative new research is being carried out to utilize tree-ring proxy records together with historical information to infer the occurrence of a major drought episode in the late 1500s, that affected areas stretching from northern Mexico to the eastern United States. Early indications are that this drought equals or exceeds any drought episode in the 20th century, but its spatial extent and duration – twenty years or more in some areas – appears to be unprecendented in the context of the last half-millennium.

Finally, more information is becoming available relating the outbreak of vector-borne diseases, such as malaria and yellow fever, and outbreaks of cholera in past centuries to the occurrence of major climatic events, such as major El Niño episodes. It was the goal of this conference to explore connections among information extracted from historical documentary records and proxy climate records of various sorts. The goal was also to try to use the inferred climatic events in order to provide some degree of context to understand and to develop hypotheses about the impacts of these salient climatic events on human society. We will have succeeded in our goals to the extent that new ideas, scientific partnerships, and renewed interest in pursuing these endeavors come to fruition as a result of this conference.

Acknowledgments

The conference on “Reconstructing Climatic Variability from Historical Sources and Other Proxy Records” was supported by the Earth System History Program of the U.S. National Science Foundation and the Paleoclimatology Program of the Office of Global Programs of the U.S. National Oceanic and Atmospheric Administration. Local support was provided by the University of Colima, Colima, Mexico, and the Museo Universitario de Arqueología de Manzanillo, Mexico. The organizers gratefully acknowledge their support.

Modelling Extreme Climates of the Past : What we have learned from PMIP and related Experiments

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The Paleoclimate Modeling Intercomparison Project (PMIP), endorsed by both CLIVAR and PAGES, was established in 1991 for the purpose of improving our understanding of past climatic changes and assessing how well models can simulate such changes. If climate models can demonstrate skill in simulating conditions much different from today, this will build confidence in their predictions of future climate changes.

The initial PMIP experiments focused on two periods of the relatively recent past: the last glacial maximum, 21,000 years before present (BP), and the mid-Holocene climate, 6000 year BP (Joussaume and Taylor, 1995). These periods were selected in part because of the relatively plentiful data available for comparison with model output. In addition, the last glacial maximum was a period of relatively extreme cold, and this provides a challenge to climate models, forcing them to simulate a state much different from the present one, which they are to some extent “tuned” to reproduce. The mid-Holocene, on the other hand, provides an opportunity to test whether models can realistically respond to a significant change in the seasonal insolation pattern forced by well-known small perturbations in Earth’s orbital configuration (i.e., Milankovitch forcing).

The third PMIP Workshop was held in Québec (Canada), 4–8 October 1999, hosted by the Canadian Climate System History and Dynamics (CSHD) Research Network and funded by CSHD, UQAM, and PAGES. The purpose of the workshop was to report on PMIP results and PMIP related work and to reach some agreement about the future of PMIP, based on a synthesis of the results. Here we summarize results of PMIP and its future direction as discussed at the workshop. A full report on the PMIP Workshop will be published soon by the WCRP.

Simulations for the mid-Holocene with eighteen different climate models all simulate an increase in the summer monsoon over Africa and Asia as a result of increased summer insolation, but, when compared quantitatively to biome reconstructions over Africa (Jolly *et al.*, 1998), all the models underestimate the northward displacement of the desert-steppe transition (Joussaume *et al.*, 1999; Harrison *et al.*, 1998]. Comparisons with proxy data over Europe (Masson *et al.*, 1999; Guiot *et al.*, 2000) and high northern latitudes (Harrison *et al.*, 1998) also show an underestimation of the model response. It should be noted, however, that the PMIP simulations were purposefully simplified in order to isolate differences in the atmospheric component of climate models. In particular, both ocean and land surface feedbacks were suppressed in these experiments, which obviously strongly constrains the models and hampers evaluation against paleodata. The quantitative discrepancy between PMIP model results and paleodata has led to several sensitivity experiments and new experiments with more comprehensive models designed to evaluate the importance of positive feedbacks by vegetation and land surface changes (Kutzbach *et al.*, 1996; Brostrom *et al.*, 1998; Claussen and Gayler, 1997; de Noblet *et al.*, 2000; Texier *et al.*, 1997 and 1999; Coe and Bonan, 1997) as well as by ocean processes (Kutzbach and Liu, 1997; Hewitt and Mitchell, 1998; Braconnot *et al.*, 2000a). Land surface or ocean feedbacks individually, however, do not seem sufficiently strong to explain the observed biome shifts over the Sahara. Recent experiments with a coupled atmosphere-ocean-vegetation model exhibit a synergy between the two feedbacks that produces a stronger northward migration of monsoon rains (Braconnot *et al.*, 2000b). Overall, results from PMIP and related Holocene experiments suggest that vegetation feedbacks and atmosphere-ocean interactions, which are not commonly included in state of the art simulations of future climate change, can substantially alter climate response to small perturbations.

In the other PMIP experiment, designed to further understanding of the last glacial maximum, one focus has been the apparent inconsistencies between the magnitude of tropical cooling over land and oceans inferred from paleodata and simulated by models. Thanks to a new terrestrial data synthesis (Farrera *et al.*, 1999), PMIP confirms earlier studies that model simulations with SST's prescribed according to CLIMAP, with relatively warm oceans, produce cooling over land that is generally weaker than that inferred from paleodata. Models that include a slab ocean to calculate sea surface temperatures show a range of terrestrial cooling that is closely tied to the magnitude of tropical ocean cooling (Pinot *et al.*, 1999). Some models produce a strong terrestrial cooling, but this is associated with maritime cooling that is too large to be consistent with recent alkenone data. One model, however, gives reasonable results over both land and oceans, which suggests that both types of data may in fact be reconcilable after all.

Over Eurasia, models reproduce the reconstructed LGM temperature and precipitation changes reasonably well except over western Europe in winter (Kageyama *et al.*, 2000). This apparent discrepancy may arise in part because of the simplifications inherent in the PMIP experiments. In the prescribed SST experiment, there are uncertainties in the SSTs reconstructed from proxy-data, and in the computed SST experiment, a simplifying assumption has been made that the ocean heat transport remains fixed. In the coming years, better SST estimates should become available from the EPILOG project, and coupled atmosphere-ocean models will begin to be developed for the LGM. Vegetation feedbacks may have also played an important role (Crowley and Baum, 1997; Kubatzki and Claussen, 1998; Levis *et al.*, 2000). Until then, modeling groups participating in PMIP plan to share results from exploratory studies that may cast some light on the limitations of the initial PMIP simulations.

At the workshop, various options for the future of PMIP were discussed, including the possibility of terminating the project. The strong interest expressed in extending PMIP activities, notably with respect to coupled model simulations and to new time intervals, suggested that PMIP could continue to serve the community through coordinating some of this research. It was decided that as a first step, working groups would be established to focus on a few priority themes briefly outlined below. The mid-Holocene and Last Glacial Maximum periods will remain central to a portion of both the modeling and data synthesis components of PMIP. Based on recent exploratory work by several groups, the following decisions were reached:

- The model-model and model-data comparisons for the mid-Holocene will be extended to coupled atmosphere-ocean model simulations, which are now available. The design of a common coupled ocean-atmosphere-vegetation experiment will be defined for future investigation.
- For the LGM, it is premature to consider carrying out a common coupled model experiment, but work will continue less formally through the sharing of results from individual experiments. PMIP remains strongly interested in the EPILOG project and strongly encourages the effort of the paleooceanographic community to revise estimates of SSTs at the LGM. Reliable estimates of sea-surface conditions (along with error bars or other indications of accuracy) will be essential for future simulations and for validation of the ocean models being used in coupled model simulations of the LGM.
- Two other periods (the early Holocene and the end of the last interglacial) appear to be of interest to many PMIP participants. Working groups have therefore been formed to analyze the possibility of defining new common experiments and to foster further discussion of these time periods.
- Of particular interest to the groups involved in PMIP is the early Holocene, when insolation forcing was stronger, but (unlike the mid-Holocene) ice sheets were still present. An effort will be initiated to design a new PMIP experiment for this time period.
- An experiment focusing on inception of ice growth at the end of the last interglacial (~115 ka BP) was considered premature. Several groups, however, have already begun exploratory work on this period, so it was agreed that a special session would be dedicated to this subject during the next PMIP workshop, in two years from now.

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Addenda to PAGES Newsletter 99–3

Two articles in the last issue of PAGES News appeared without full authorship and reference information.

The article entitled “A 300,000 Year Record from the Lac du Bouchet, France” (p. 8) failed to include a list of co-workers whose results were used (Andrieu V., Beaulieu J.L., Coulon C., Creer K.M., Féraud G., Reille M., Roger S., Williams T.) and made no reference to the publications from which the pollen analytical data were taken: Reille *et al.*: Quaternary Science Reviews 17, 1107–1123 (1998); Reille & de Beaulieu: Review of Palaeobotany and Palynology, 54, 233–248 (1988), Palaeogeography, Palaeoclimatology, Palaeoecology, 80, 35 – 48 (1990) and Quaternary Research, 44, 205–215 (1995), and de Beaulieu & Reille: Mededelingen Rijks Geologische Dienst, 52, 59–70 (1995). Full references are available on the PAGES website.

The article entitled “Southern Ocean Core MD 94–101” (p. 9) was co-authored by Monique Labracherie and Jean-Louis Turon, Département de Géologie et Océanographie (DGO), CNRS URA 197, Université de Bordeaux I, France (labracherie@geocean.u-bordeaux.fr and turon@ geocean.u-bordeaux.fr) and Laurent Labeyrie CNRS-CEA, France (labeyrie@cfn.cnrs-gif.fr)

Announcement – call for contributions

In the next issue of PAGES News, due to appear in May 2000 we plan to highlight the PAGES-PANASH (Paleoclimates of the Northern and Southern Hemispheres) program, the associated PEP (Pole-Equator-Pole) transects, and inter-PEP connections. We encourage scientists with material relevant to the PEP transects to submit short research highlights (max 2 pages, 2 figures), program news (max 500 words), or workshop reports electronically by March 31 to: alverson@pages.unibe.ch. Detailed guidelines for publication in the PAGES Newsletter are available from our website *www.pages.unibe.ch/publications/newsletters.html.*

Past Global Changes and their Significance for the Future

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The most recent issue of Quaternary Science Reviews (Vol. 19, No. 1–5, pp. 1–480) is a special issue arising from the PAGES Open Science Meeting, held in 1998. This collection of papers is on the one hand, a comprehensive review of the state of the art in paleoenvironmental reconstruction. Moving beyond review and reconstruction however, the volume seeks to bring a wealth of paleoclimate information to the forefront of deliberations about modern environmental change and, indeed, future climate predictions.

The volume, which is also available as a hardbound book from Elsevier press, is guest edited by K. Alverson, F. Oldfield and R. Bradley and consists of 27 papers divided into five sections. The first section highlights a range of examples, given quantitative calibration and robust chronology, for local, regional and global paleoenvironmental reconstruction from individual proxy archives. The fact that climate change has shown both global coherence as well as highly differentiated regional expression, implies that individual proxy records must be placed within a robust spatial framework. Thus, the second section of the volume presents recent results from the coordinated PAGES Pole-Equator-Pole (PEP) transects based on multiple sites and multiple proxies. In the third section of the volume, the spatial mosaic provided by the PEP transects is complemented by a detailed look at the temporal evolution of the climate system associated with stadial/interstadial transitions which, together with the glacial cycle itself, comprise some of the most dramatic events to have occurred in the last half a million years. The fourth section of the volume concentrates on paleoclimate modeling, and comparison of models with paleoclimate data syntheses, an important test for models currently being used for climate prediction purposes.

Finally, in light of the fact that recent past climatic and environmental change, and indeed future change, are intricately interwoven with human society, the volume closes with a set of papers which give an overview of the late Holocene. The papers in this final section demonstrate that the climate of the last few millennia has fluctuated far beyond the range of variability captured by recent instrumental records. The potential human consequences of such natural variability are staggering. Indeed, the final paper hints at a concept of ‘vulnerability trajectories’, specific to given regions and societies, but each reflecting the interplay between climate variability and human development. Creating a deeper understanding of this interplay on the basis of evidence from the past comprises a further challenge for PAGES.

For more information on this publication, including the full table of contents and ordering information, see http://www.pages.unibe.ch/publications/reports00.html.

CLIVAR Section

Changes in the CLIVAR SSG
Thanks Kevin, welcome Tony !

On behalf of the CLIVAR SSG, the ICPO, and in my capacity as incoming SSG Co-Chair with Jürgen Willebrand, I would like to take this opportunity to thank Kevin Trenberth for his past 4 years of service as the SSG Co-Chair. His background and experience in TOGA, IPCC, decadal variability from an atmosphere-ocean perspective, together with observational and empirical climate studies have been an immense benefit and resource to CLIVAR. During his tenure, Kevin has provided invaluable leadership, drive, and guidance to the development of CLIVAR. Together with Allyn Clarke, Kevin lead the plan to launch and implement CLIVAR on the international stage. As part of these efforts he was involved in selecting John Gould as the Director of the ICPO, producing the CLIVAR Implementation Plan, and the staging of the CLIVAR Conference held December, 1998 in Paris. In addition, Kevin has been a tireless source of energy in promoting CLIVAR in various fora around the world. While not always received with unanimity, Kevin has served as a catalyst for engendering much needed debate on such issues ranging from CLIVAR priorities to a CLIVAR retrospective of the 1997–1998 El Niño. While stepping down as Co-Chair, an orderly transition has been achieved with Kevin remaining a member of the SSG for another year while also serving on the JSC of the WCRP. Once again, we are extremely appreciative for Kevin's years of service on behalf of CLIVAR and look forward to continued interactions as CLIVAR proceeds.

Tony Busalacchi, co-chair CLIVAR SSG

Announcement
– Call for contributions –

In the next issue of Exchanges that will apprear in June 2000 we would like to present scientific highlights related to the variability of the monsoon systems, in particular reasearch related to VAMOS (Variability of the American Monsoon Systems).We would like to encourage scientists working in this field to submit short papers (max. 2 pages plus 1 figure) electronically by April 30th to:

andreas.villwock@clivar.dkrz.de

Our new SSG – co-chair: Antonio J. Busalacchi

Antonio J. Busalacchi received his Ph.D. in oceanography from Florida State University in 1982. He has studied tropical ocean circulation and its role in the coupled climate system. His interests include the development and application of numerical models combined with in situ and space-based ocean observations to study the tropical ocean circulation and response to surface fluxes of momentum and heat. His research in these areas has supported a range of international and national research programs dealing with global change and climate, particularly as affected by the oceans. Most notably, he has helped to define and plan the Tropical Ocean Global Atmosphere (TOGA) Program within the US. From 1989–1996 he served on the National Academy of Sciences / National Research Council (NAS / NRC) TOGA Advisory Panel and for 1991–1993 he was a member of the NAS / NRC Panel on Ocean Atmosphere Observations Supporting Short-Term Climate Predictions. More recently, he has served on the International Science Steering Groups for CLIVAR, PIRATA, and VAMOS. From 1985–1999 he served as Associate Editor of JGR Oceans and from 1997–1999 he was an Editor of the Journal of Climate.

Since 1982 he has been an oceanographer at the NASA / Goddard Space Flight Center in Greenbelt, Maryland. In 1991, he was appointed to the Senior Executive Service in the U.S. Government as the Chief of the NASA / Goddard Laboratory for Hydrospheric Processes. In this capacity he furnishes scientific direction to a broad, many-faceted program in Earth system science. NASA's Laboratory for Hydrospheric Processes is responsible for an extensive range of programs dealing with theoretical and experimental research in the oceanic, cryospheric, and hydrologic sciences. The expertise within the laboratory constitutes an end-to-end capability involving instrument, algorithm, and numerical model development; the validation and analysis of remotely sensed data from a wide variety of sensors with in situ hydrological data, and ultimately, the application of these data to geophysical process studies and global change investigations. One example of which is the SeaWiFS ocean color project within the laboratory which provides space-based daily estimates of chlorophyll concentration for the world's oceans. Satellite missions being studied in his laboratory of relevance to CLIVAR include remotely sensed approaches to monitor global sea surface salinity and soil moisture. Dr. Busalacchi has received numerous awards internal and external to NASA. Among these, in 1991, he was the recipient of the Arthur S. Flemming Award, as one of five outstanding young scientists in the US Federal Government. In 1995 he was selected as Alumnus of the Year at Florida State University, in 1997 he was the H. Burr Steinbach Visiting Scholar at the Woods Hole Oceanographic Institution, and in 1999 he was recognized by President Clinton in receiving the Presidential Rank Meritorious Executive Award.

The First International Conference on the Ocean Observing System for Climate:

A new era for ocean observation

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Oceanography is at a critical stage. A new era may be on the horizon with observations implemented globally and fully integrated to serve a broad range of requirements from the extensive research demands of CLIVAR to more immediate operational applications. In order to attain this vision, the ocean community must resolve to act with common and agreed purpose and work strategically over the coming decades.

The first International Conference on the Ocean Observing System for Climate held in Saint Raphael, France 18–22 October, sought the consensus needed to initiate this step, addressing the collective needs of both research and operational oceanography. The Conference was bold in its vision and goals, successfully developing a broadly based and sound scientific rationale for the establishment of a sustained system. CLIVAR research themes, practical El Niño forecasts, climate change detection, and ocean and marine forecasts were prominent rationale.

The Conference was purposefully structured with 40 solicited presentations and 5 round table discussions to encourage consideration of, and agreement on, the value of a multi-purpose, integrated system. This value was evident in many of the 160 contributed papers presented in the poster sessions, for example, the wide application of altimeter and wind vector measurements and in the many considerations of complementary data streams. The conference agenda, all of the solicited papers, the conference statement, and a section for community feedback, which is ongoing, can be found at the website: http://www.bom.gov.au/OceanObs99/. We welcome your comments.

The Conference explicitly considered issues of cost and returns on investment. Highest priority was attached to those elements that were perceived to be reliable, efficient and sustainable, from the perspective of delivering both short and long-term value for the investment. Proven methodologies were preferred to emerging or potential techniques. However, presentations on emerging technologies highlighted the need for agility in long term planning to accommodate advanced technologies, a broader measurement suite, observation efficiency, and improved economy in the future.

Remote sensing has become a mature technology for collecting regular, global observations. Sea surface temperature, surface wind vectors, surface wave height and surface topography can all be measured with reliability from space. The Conference agreed that for a global system such capacity is fundamental. Continuity was seen as a major issue in order to meet the CLIVAR research requirements for multi-decadal data, as well as sustained operational requirements. A plenary round-table discussion highlighted the need to develop effective strategies for the transition of proven experimental techniques into a sustainable, operational mode.

Somewhat surprisingly, sea surface temperature emerged as an important future issue. In order to meet requirements, a more effective integration of available data must be achieved. It was less surprising that strategies to improve the currently available salinity measurements came up in many presentations.

A multi-faceted, robust in situ network must also be implemented, in part as a complement to, and validation for, remotely sensed data, but also for its own intrinsic value in various applications. The primary contributions include

- The tropical Pacific ENSO Observing System and its mooring array;
- The global array of profiling floats, Argo, returning around 100,000 profiles of temperature and salinity annually;
- A global surface drifter array and surface and subsurface networks operated from voluntary observing vessels;
- Surface and subsurface reference sites, such as provided by sea level stations and fixed-point deep measurements;
- Hydrographic measurements targeting the carbon cycle and the deep ocean circulation; and
- Acoustic tomography in selected high latitude regions.

These contributions would be supported by a program of dedicated enhancements in areas of high priority, for example PIRATA in the tropical Atlantic. Strategies for under-observed regions, such as the Indian Ocean, are anticipated outcomes from CLIVAR.

The development of a new paradigm for oceanography was one of the major achievements of the Conference. Free and wide availability of all data and products need to become the norm, not the exception. Significant challenges remain for many aspects of data and information management but none are regarded as insurmountable obstacles to progress.

While the focus of the Conference was on measurement networks, all participants recognized the fundamental importance of models and data assimilation to the progress, prosperity and evolution of the observing system.

The new paradigm is fashioned around the use of models to interpret and exploit data and to develop products that encourage wide adoption and value-adding.

The degree of unanimity achieved by the Conference exceeded expectations, yet there is clearly much work remaining, both in terms of detail and in terms of enacting the recommendations. However the ocean community can look forward with some confidence to an era of great prospect and opportunity, and also one of enhanced responsibility. For oceanography and climate at least, the integrated global observing strategy is now being realized.

Science Highlights from the Monsoon Symposium and CLIVAR Monsoon Panel Meeting

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The CLIVAR Asian-Australian (AA) Monsoon Panel held its second official meeting on December 8–10, 1999 at the East-West Center, Honolulu, Hawaii. The panel meeting was preceded by a 2-day (Dec. 6–8) Monsoon Symposium to celebrate the careers of Profs. T. Murakami, and M. Yanai who are now both retired. The first day of the panel meeting was devoted to a Model Intercomparison Workshop, sponsored by the CLIVAR AA-Monsoon Panel in response to the CLIVAR SSG's call for focused efforts to improve our understanding of the causes and consequences of the massive ENSO disturbances of 1997–1998. Results were presented showing Atmospheric General Circulation Model (AGCM) performance in simulating monsoon circulation, for given Sea Surface Temperatures (SSTs). Further presentations examined the performance of Oceanic General Circulation Models (OGCMs) in simulating the observed SST anomalies (SSTAs), given observed or estimated surface fluxes. A summary of scientific highlights presented at the meetings are as follow:

- The monsoon is a coupled ocean-atmosphere-land phenomenon. Modelling and prediction of the monsoon and its variability requires the inclusion of all three components. In particular, the annual cycle of heat balance and oceanic transports in the Indian Ocean play a significant role in the annual cycle of the monsoon.
- Variability of the monsoon is influenced by, and probably influences, the ENSO phenomenon. However, the relationships are spasmodic and vary on interdecadal time scales.
- Intrinsic coupled monsoon rainfall-SST modes have been identified in the western Pacific and the Indian Ocean that contribute significantly to variability of monsoon intensity. Understanding of the physical make-up of these modes is crucial in unravelling fundamental mechanisms of monsoon-ENSO relationships.
- Regarding the existence of a strong biennial variability of the monsoon, a number of theories have been proposed invoking feedbacks between the land, ocean and atmosphere of the monsoon regime extending from the western Pacific Ocean, the Asian land mass and the Indian Ocean. However, like the ENSO-monsoon relationship, there appears to be interdecadal variability of the biennial signal.
- There are new findings suggesting that the Indian Ocean possesses coupled ocean-atmosphere modes that may be independent of ENSO. One of these modes occurs in the form of an oscillating east-west dipole in SST and precipitation. Whereas the relationship to monsoon variability is unclear, it is strongly correlated with the East African fall monsoon rains.
- New evidence suggests that regional components of the monsoon, i.e. the South Asian and the East Asian monsoons oscillate between active and break phases, which are related to intraseasonal oscillations on 40–60 day time scales. These fluctuations are associated with the "Madden-Julian oscillation" (MJO) but are modified by the strong north-south pressure gradient and basin-scale SST fluctuations that exist during the established monsoon. While the ISO may limit interannual monsoon predictability, it offers great promise for short-term (~weeks) monsoon forecasts.
- Interesting and significant results are coming out from recent field experiments e.g., SCSMEX, JASMINE and BOBMEX. For example, preliminary results from JASMINE indicates that the ocean-atmosphere heat flux during the established monsoon in the southern Bay of Bengal region is similar to the mean heat flux in the tropical Pacific warm pool. The variability of surface fluxes on intraseasonal time scales in the eastern Indian Ocean is very large, suggesting strong local air-sea interaction.

Deliberations at the Hawaii Panel Meeting provided a number of recommendations for action in the areas of modelling, process studies and long-term monitoring. These recommendations form the basis of a CLIVAR Monsoon Implementation Plan, which is being developed. For a preliminary draft of the Implementation Plan, please check the website http://climate.gsfc.nasa.gov/~kmkim/clivar/

CLIVAR — Climate Variability & Predictability — World Climate Research Programme
PAGES PAST GLOBAL CHANGES

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News from the TAO Implementation Panel

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The most significant development with regard to the TAO Panel is that the TAO array became the TAO/TRITON array as of 1 January 2000. ATLAS moorings were phased out of the western Pacific along 137°E, 147°E and 156°E in 1999, and were replaced with JAMSTEC TRITON moorings. During 1998 and 1999 data from several multi-month side-by-side deployments of TRITON and ATLAS buoys were compared for various locations in the western Pacific to ensure interchangeability of the mooring measurements. Real-time and delayed mode TAO/TRITON data are being made available via the GTS and the World Wide Web as a seamless data stream. The combined data sets can be viewed at: http://www.pmel.noaa.gov/toga-tao/realtime.html.

Fishing vandalism is an ongoing problem in for both the TAO/TRITON array in the far western and eastern Pacific as well as for PIRATA in Atlantic. Efforts have been made to to reduce the vandalism by supplying information for the international Fish Aggregation Device (FAD) conference. In addition the distribution of brochures to fisheries agencies, fishing associations, and fishermen about the TAO, TRITON, and PIRATA programs have been continued.

PIRATA was virtually completed with the deployment of ATLAS moorings at two sites along 10W in early November 1999. The full array now consists of 12 moorings and will be in place until the end of 2000. Planning for a 5-year continuation of PIRATA beyond its initial pilot phase is also underway. Real-time data from the array can be viewed at: http://www.pmel.noaa.gov/pirata/

The TAO Panel endorsed the recommendation of the CLIVAR Upper Ocean Panel to expand its purview to include the global tropics. The expectation is that this expanded purview can facilitate development of moored buoy programs in the Indian Ocean, and facilitate the continued operation of PIRATA in the Atlantic.

CLIVAR Calendar

2000	Meeting	Location	Attendance
March 13 – 17	Joint Scientific Committee of WCRP, 22nd Session	Tokyo, Japan	Invitation
April 3 – 7	6th International Conference on Southern Hemisphere Meteorology and Oceanography	Santiago, Chile	Open
April 5 – 7	WOCE/CLIVAR Data Products Committee	College Station, USA	Invitation
April 8 – 10	CLIVAR VAMOS Panel 3rd Session	Santiago, Chile	Invitation
April 13 – 14	CLIVAR Atlantic Panel, 1st Session	Natal, Brazil	Invitation
April 25 – 29	European Geophysical Society, XXV Assembly	Nice, France	Open
May 1 – 5	CLIVAR SSG – 9th Session	Honolulu Hawaii	Invitation
May 30 – June 3	AGU Spring Meeting	Washington , USA	Open
July 10 – 14	Meteorology at the Millennium	Cambridge, UK	Open
October 4 – 6	WGCM Workshop on Decadal Predictability	La Jolla, USA	Limited
October 9 – 11	JSC/CLIVAR WGCM – 3rd Session	La Jolla, USA	Invitation

For more information, please contact the ICPO or check out our web-page: **http://www.dkrz.de/clivar/latest.html**

PAGES CALENDAR (for full version please check *www.pages.unibe.ch/calendar/calendar.html*)

(* indicates open meetings – all interested scientists are invited to attend)

- ***2–7 April, 2000 "International Conference on Dendrochronology for the Third Millennium". Mendoza, Argentina**
  International Conference, Laboratorio de Dendrocronología, IANIGLA - CRICYT, CC 330 (5500) Mendoza, Argentina
  dendrocon@lab.cricyt.edu.arInternet:
  www.cricyt.edu.ar/congresos/dendro/index.html

- ***6–11 May, 2000 "The Ecological Setting of Europe – From the Past to the Future: European Agriculture on its Way from the Past to the Future". Scania, Sweden**
  www.esf.org/euresco/00/c_cal00.htm

- ***1–3 June, 2000 "Paleograssland Research 2000: A conference on the reconstruction and modelling of grass-dominated biomes". Westbrook, CT, USA**
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