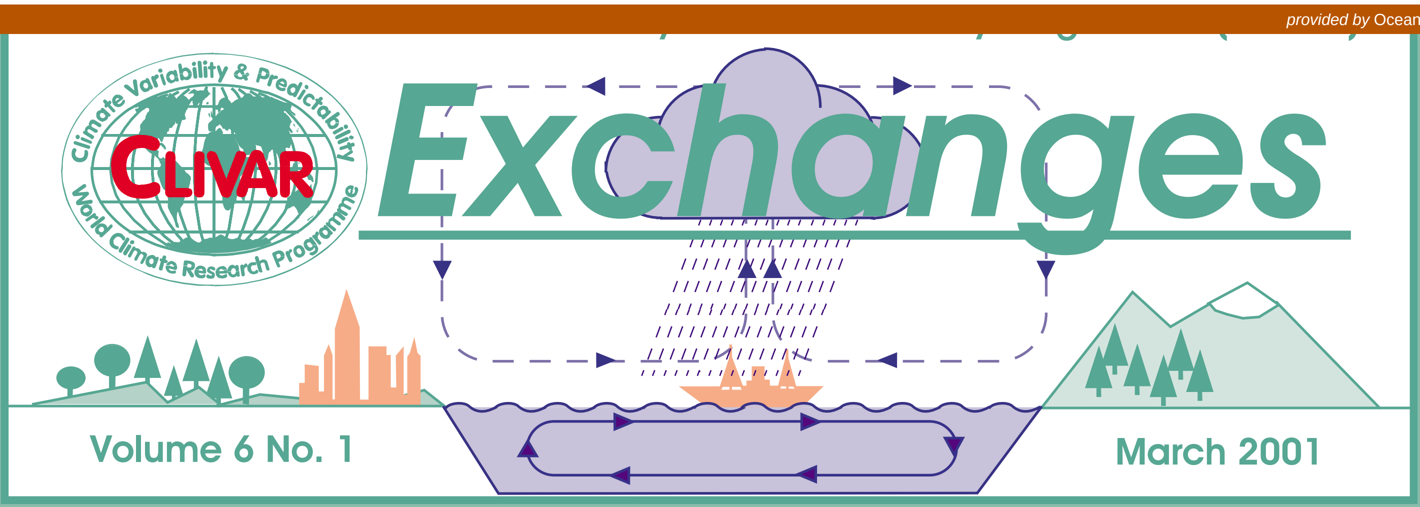

Exchanges

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Exchanges No. 19

Decadal Variability and Predictability Part 1: Global aspects and the Atlantic sector

Uncertainty in current climate forecasts on decadal timescales

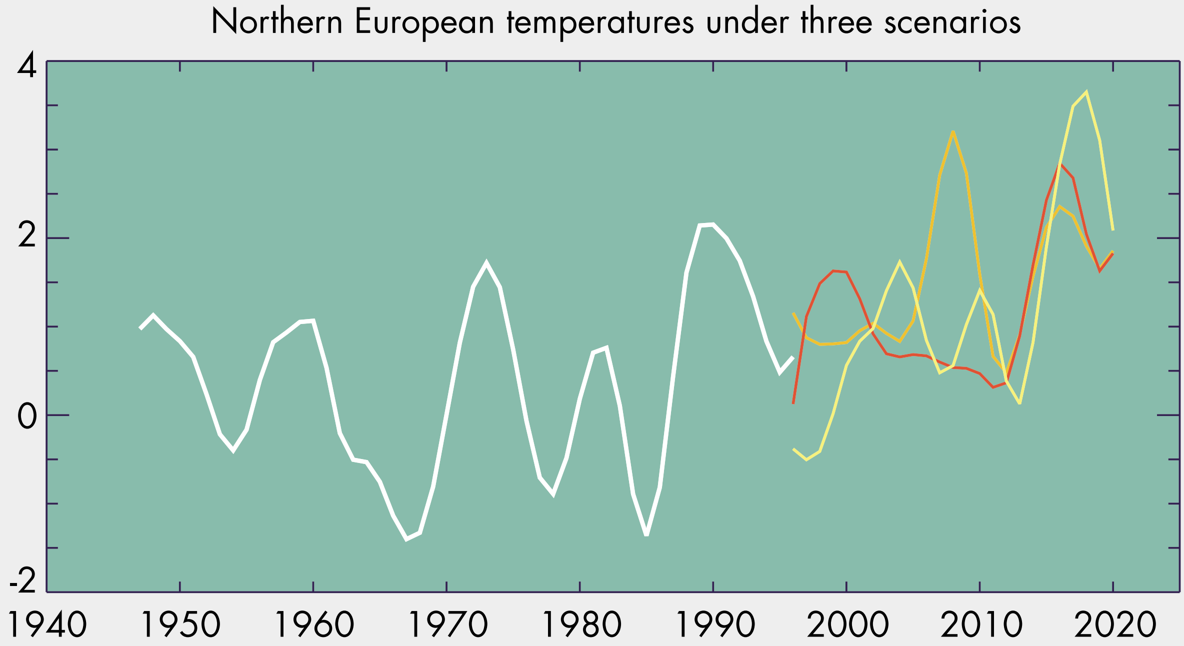

Figure 1 from paper: PREDICATE: Mechanisms and Predictability of Decadal Fluctuations in Atlantic-European Climate by Rowan Sutton:

Observations of Northern European temperature anomalies (white line) and three forecasts demonstrating the large uncertainty in climate scenarios for the next 20 years. Note that the forecasts are not continuous with the observations because no information about the current ocean (and atmosphere) state is currently employed. This is a key issue that PREDICATE is addressing.

The paper appears on page 11.

As a result of the series of scientific workshops this and the next issue of Exchanges highlight recent scientific work on the field of decdal variability and predictability, one of the main streams of CLIVAR.

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Editorial

Dear CLIVAR community,

One of the landmarks in climate research at the beginning of the 21st century is the progress that has been made in our understanding of decadal climate variability. 10 years ago, not much was known about the nature and the mechanisms of long-term climate variability. Improved modelling techniques, progress in data analysis and new historical and paleo data sets provide us with the basis to learn more about the long-term behaviour of our climate in the past and in future. Indeed, extending the climate record of paleo and instrumental data is one of CLIVAR's objectives.

We still have a long way to go. There are substantial gaps in our knowledge, there are conflicting theories about the mechanisms of decadal variability and it is still debateable to what extent reliable long-term climate predictions will be possible within the next decade. Thus, the understanding of decadal climate variability presents a big challenge and CLIVAR is addressing it as one of the three main streams of the programme.

In CLIVAR's Initial Implementation Plan the DecCen stream had five Principal Research Areas (PRA) dealing with the various aspects of decadal variability. Three concern phenomena in the Atlantic sector (North Atlantic Oscillation, Tropical Atlantic Variability and Thermohaline Circulation) and these are being co-ordinated through the new CLIVAR Atlantic Panel. The scientific questions relating to Pacific and Southern Ocean variability will be dealt with separately. CLIVAR panels for these two areas are currently being formed.

Underpinning this organizational structure, the scientific understanding of decadal variability has been documented through a series of workshops that took place through autumn and winter 2000/2001. We reported in the last issue about three meetings: The workshops on "Decadal Predictability" and "Shallow Tropical/Subtropical overturning cells and their interaction with the atmosphere" and the "Southern Ocean Implementation Workshop". The WOCE/CLIVAR workshop on the representativeness of the 1990s WOCE data set was reported on in the December 2000WOCE Newsletter (http://www.woce.org).

Since then, three more meetings have taken place: the "Chapman Conference on the North Atlantic Oscillation" undertook a comprehensive review of the progress in this area and workshops on Decadal Variability and on the implementation of CLIVAR in the Pacific were both held in Hawaii. Summaries from the NAO meeting and the Decadal Variability workshop can be found in this issue.

Our strategy with recent issues of CLIVAR Exchanges has been to go beyond the presentation of meeting summaries. We encouraged the submission of scientific results related to decadal variability and predictability and the response was very good. Thus, we were faced with either rejecting more than half of the submitted contributions or dedicating two issues of Exchanges to this topic. The quality of the papers and the importance of the topic means we have taken the latter option. For this issue we grouped all the papers related to the Atlantic together with some more general topics. The next issue will focus on monsoons and Pacific decadal variability.

As we mentioned above, the organizational structure of CLIVAR is expanding. Last year, the CLIVAR Atlantic panel and the VACS (Variability of the African System) panel were formed. The Southern Ocean Workshop and the Pacific Implementation meeting recommended the establishment of oversight panels. It is expected that by end of 2001 the organizational structure of CLIVAR will be fully developed with panels and working groups that cover all aspects of the programme.

In contrast to this build-up, the resources of the ICPO are currently rather reduced following Fred Semazzi's return to the USA. This means a very high workload on the remaining ICPO staff such that some tasks can not be covered adequately. For example we are currently not able to continue the development of the CLIVAR bibliography. This situation will improve very soon as we are in the process of hiring two new staff in addition to the recent recruitment of Carlos Ereño to cover VAMOS issues.

At the end of March the co-chairs of the CLIVAR SSG (Antonio Busalacchi and Juergen Willebrand) will present the annual summary of CLIVAR activities to the WCRP's Joint Scientific Committee (JSC) meeting in Boulder. The JSC will particularly look for areas in which interactions between WCRP projects could be fruitful. CLIVAR is already developing strong links with ACSYS/CliC in the Southern Ocean and northern North Atlantic and with GEWEX on monsoon systems. We will report on the JSC meeting in the next issue.

We hope that you all enjoy this and the next issue of Exchanges documenting the progress in the field of decadal climate variability.

J. Gould and A. Villwock

Decadal potential Predictability in Coupled Models

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Introduction

The analysis of decadal "potential predictability" in the coupled atmosphere-ocean system is, in essence, an analysis of long-timescale variability. Classical predictability measures the rate at which two initial close states of a system separate with time (and hence the rate of error growth in the system). Potential predictability, by contrast, is a measure of the variability of the system which attempts to quantify the fraction of long timescale variability that may be distinguished from the natural variability noise. This "signal", if it exists and is of appreciable magnitude, is deemed to arise from physical processes operating in the system which are, at lease potentially, predictable.

Potential Predictability

We analyse the potential predictability of surface air temperature (SAT). The statistical approach generally follows Rowel (1998), and Rowell and Zwiers (1999) and assumes SAT variation is of the form $T_{ab} = \mu + s_a e_{ab}$ with μ the climate mean, s_a the slow timescale "signal" component of the variability, and e_{ab} the remaining unpredictable climate noise. The ratio $r = s_s^2 / (s_s^2 + s_e^2)$ gives the fraction of the total variance associated with the "potentially predictable" component. The value is tested against the null hypothesis that $r = s_s^2 = 0$. Model drift is first removed by fitting low order orthogonal polynomials in time at each point.

The result for the potential predictability of decadal means is shown in Figure 1. The result does not depend on a single model or simulation in this case but is an ensemble estimate of the potential predictability of the coupled system based on the control simulations of eleven models participating in the Coupled Model Intercomparison Project (see for example Meehl et al., 1997 and Lambert and Boer, 2001). The high latitude oceans are the dominant regions exhibiting potential predictability although there is some indication also in the tropical Pacific.

Discussion

The decadal predictability of the coupled atmosphere / ocean / ice system is examined using a diagnostic "potential predictability" approach. Preliminary results indicate; (1) the models show a range of "drift" or "trend" in their control runs; (2) estimates of the "potentially predictable" fraction of decadal variance range from essentially zero to as much as 60% for various models and regions; (3) a multimodel ensemble estimate of potential predictability shows evidence of long timescale predictability at high latitudes over oceans and, to a lesser degree, in the tropical Pacific; (4) decadal predictability over land and sea-ice is generally low. The results direct attention to the high latitude oceans as the seat of mechanisms of potential importance to decadal predictability.

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Eleven model ensemble percentage of "potential predictability" for decadal means

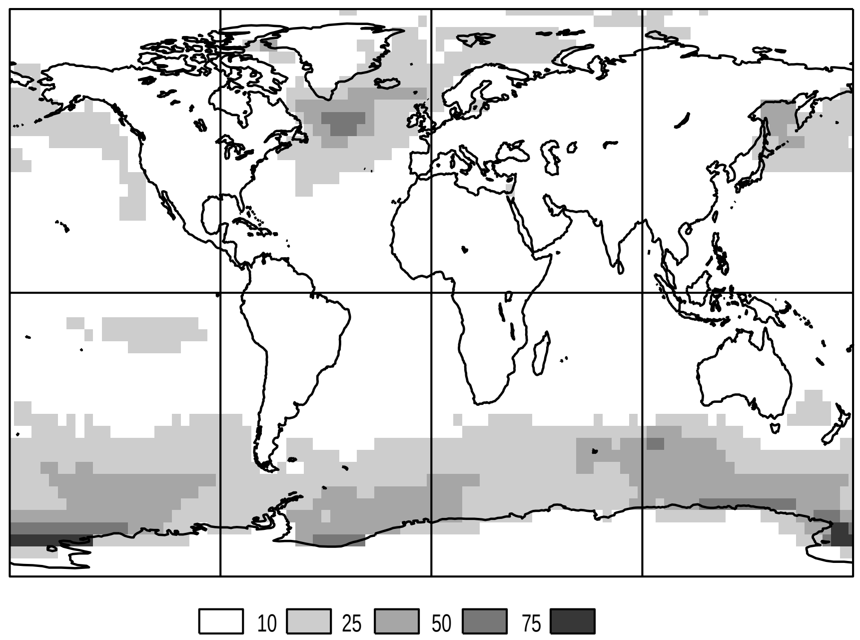

Fig. 1 (in colour on page 14): potential predictability for decadal means obtained from a model ensemble of 11 coupled models.

Improving Climate Predictability and Understanding Decadal Variability using Proxy Climate Data

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Regional climate predictions and climate reconstructions often both depend on the same underlying assumption - that climatic modes will be, or were, relatively unchanged outside the instrumental reference period. Usually, the instrumental period is too short to capture the full range of decadal scale variability for a given climate variable at a given location, and where longer proxy based records do exist they often indicate that this assumption of statistical stationarity is a tenuous one. Occasionally, one finds an apparent change in mode in a given climatic timeseries. The degree to which such a shift can be shown to be statistically significant, and thus be argued to reflect a fundamental change in the climate system, is directly proportional to the length of the timeseries. The longer the record, the more confident one can be that the changes on sees are not simply random fluctuations.

For these reasons, a full understanding of decadal variability, and its importance for climate prediction and detecting climate change, must employ extended climatic timeseries based on proxy data. Providing, and analysing, high resolution proxy based climatic timeseries is one of the important regions of intersection between CLIVAR and the PAGES (Past Global Changes) programme.

One example is ENSO. Although the basic coupled ocean-atmosphere dynamics involved in ENSO within the equatorial Pacific are fairly well (but not completely) understood, our knowledge of climatically important ENSO teleconnections outside this region are, with a few exceptions, primarily based on statistical analyses. Similarly, the role of decadal scale variability in modulating ENSO is primarily based on statistical studies. To first order, it seems clear that when decadal variability (such as the Pacific Decadal Oscillation) is acting to cause an overall background warming in the tropical Pacific, one might expect ‘enhanced’ ENSO warming, and vice versa. However, an understanding of the detailed dynamical nature of the interaction between ENSO and decadal variability, remains somewhat elusive.

In the upper panel of figure 1 (page 13) two climatic timeseries are presented. One is the Niño 3.4 equatorial Pacific sea surface temperature (SST) index as extended using proxy data (Kaplan et al., 1998). Note that the extension of the SST index back in time is based on proxy data from remote sites which are highly correlated with SST in the modern instrumental record. The validity of the extended SST record thus rests, to some degree, on the assumption that this correlation was not different in the earlier period. The second curve is a record of precipitation derived from an ice core taken from Mt. Logan in the Yukon, Canada, at approximately 60.5˚N (Moore et al., 2001). Both timeseries have been low pass filtered with a cut-off period of 15 years to show decadal scale variability and normalized by subtracting the mean and dividing by the standard deviation.

Concentrate first on the more recent, blue, section of the panel. During this period, from 1900 to the present, the two records show a strong positive correlation, statistically significant at the 99% level. This provides statistical evidence for an ENSO teleconnection influencing precipitation at this location. As is customary, the dynamical reason for this teleconnection is not fully understood, although it is clearly related to changes in the synoptic scale flow regime as seen in cross-correlation analysis of the Mount Logan timeseries with the annual 200 hPa geopotential field from the NCEP reanalysis 1948-1985, as shown in figure 2 (page 14) (Moore et al., 2001). Given the strong statistical correlation between these two records, and even some indication of the underlying causality, it would be fairly standard practice to, for example, extend the SST record back in time using the ice core data. Interestingly, in the older, yellow, portion of the panel the records are strongly anti-correlated, again at the 99% confidence level. Thus, our theoretical paleoreconstruction of SST based on this ice core data would produce variability of the incorrect sign. Climate predictions based on teleconnection patterns face exactly the same problem. A researcher with access to SST predictions in 1900, might confidently predict, based on the strength of correlation over the past 50 years, that precipitation at Mt. Logan would continue to be anticorrelated. Again, the prediction would be of the wrong sign.

It is unclear what caused the change in the sign of the ENSO-Mt.Logan teleconnection around 1900. The lower panel presents the opportunity to engage in tantalizing speculation. This panel shows, on the same timescale as that above, an evolutionary spectral SST analysis derived from an annually resolved coral from Maiana atoll in the equatorial Pacific (Urban et al., 2000). The analysis was performed on 40-year segments of data overlapped by four years, using multitaper methods with red noise background assumptions. Around 1900, indicated by the vertical black line, was a period of time when the variability expressed in the coral record was shifting from primarily decadal to power to higher frequencies. This shift appears to correlate with a shift in the phase of the correlation between the low frequency equatorial and extra-tropical response at Mt. Logan. Interestingly, tree-ring chronologies from high latitude sites in Alaska and Patagonia show a similar shift in coherence on the decadal time-scale around the same time (Villaba et al., 2001).

Leaving aside this rampant speculation, what can we conclude about decadal variability and climate prediction? Basically, the conclusion that this little story leads to is that understanding decadal variability of climate modes is difficult. Finding statistical significance in changes in interannual to decadal scale climate modes absolutely requires proxy based paleorecords that extend timeseries from the instrumental period. However, it is clear that no single proxy is sufficient. It is only with a wide geographical range of accurately dated, independent proxies including documentary evidence, tree rings, varved lake sediments, corals and ice cores that an understanding of decadal variability in climate teleconnections such as those associated with ENSO might evolve. And only then, will regional climate predictions based on these climate modes reliably transcend the assumption of statistical stationarity. Achieving such a thorough description and understanding of interannual to decadal climate variability is one of the primary goals of the CLIVAR / PAGES Intersection program. Interested readers are encouraged to become involved and to visit the CLIVAR (http: / / www.clivar.org) and PAGES (http: / / www.pages-igbp.org) websites for more information.

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On the Role of a quasiperiodic Forcing in the interannual and interdecadal Climate Variations

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After the seminal researches of Ed Lorenz the idea of the chaotic nature, i.e. instability and unpredictability, of the atmospheric variations of all scales won almost all of meteorologists. On the one hand, the practice of the present-day medium- and long-range weather forecasting corroborates this idea. Moreover, the power spectra of the higher-frequency atmospheric variations within the direct enstrophy and inverse energetic cascades (over the periods from one day up to one-two months) look to be continuous and without any sharp peaks. Such shape of the power spectra is an inherent property of the truly chaotic dynamics. On the other hand, the computations of the lower-frequency parts of the atmospheric spectra (over the periods more than one-two months) invariable reveal numerous peaks and bands of increased power energy (in addition to the trivial peaks of the annual period and its super harmonics) on a red-noise background. Of course, these peaks and bands are usually tested as statistically insignificant. But their observation in a huge number of atmospheric spectra is a proxy proof of their reality. The quasi-biennial oscillation (QBO) is the most often observed peak among these. First of all, QBO is clearly established in the temporal variations of the zonal winds within the equatorial lower stratosphere. But, the phenomenon is also observed in the variations of different atmospheric variables within extratropics. A quite satisfactory explanation what is the direct driver of the QBO of the equatorial winds was given by Lindzen and Holton (1968). But the general nature of QBO as a widespread phenomenon is unknown up to now.

In order to clear up the nature of QBO and other mentioned peaks and bands of increased power energy the notion of the so-called strange NONCHAOTIC attractor seems to be important. This notion was recently introduced by mathematicians to depict some aperiodic variations in the nonlinear dynamical systems forced by two or more periodic external forces at incommensurable frequencies. The variations excited by such a manner were found to be of the neutral stability, i.e. they are predictable without any limit even if their shapes are very complex. The phenomenon of the strange nonchaotic attractor turned out to be most evident if the ratios of the forcing frequencies ones to others are “worst” irrational numbers such as the root $X^*=1.8393\ldots$ of the cubic equation $X^3-X^2-X-1=0$. The power spectra of the strange nonchaotic variations consist of innumerable power-energy peaks with very different magnitudes. It was proven that the re-distribution of the peaks on the frequency axis forms a self-similar structure, i.e. a zoom of any part of a spectrum being considered reveals the peak re-distribution of the same character. But, in practical calculations, these spectra look like continuous ones, and their peaks seem to be statistically insignificant under the traditional tests. It is just the same that one can see in the lower-frequency atmospheric spectra.

Actually, the phenomenon of the strange nonchaotic attractor is well known in meteorology. An example is the oceanic and atmospheric tides. The tides are excited by the gravitation interactions between Earth, Sun, and Moon. These interactions are quasi-periodic, and the tides are known to be of neutral stability. But, our aim here is to indicate that the notion of the strange nonchaotic attractor may be also used to model and predict the interannual and interdecadal atmospheric variations.

Mention in this context the so-called Chandler wobble in the Earth's pole motion. The mean period of this wobble is about 14 months (1.2 year), and the ratio of its frequency to the frequency of the annual period seems to be similar to the "worst" irrational number Y=0.8393… derived from the above root of the cubic equation (Sidorenkov and Sonechkin, 1999). It is well known that the Chandler wobble excites a pole tide in the atmosphere. For certain, this pole tide forces the equatorial gravity and Kelvin waves that are known in the Lindzen – Holton theory to be the direct drivers of the QBO of the lower-stratospheric equatorial zonal winds. Although the magnitude of this pole tide is very small a nonlinear mechanism of its force enhancing like the so-called parametric resonance may be supposed. Some similar enhanced effects of the pole tide may also be supposed for the atmospheric variations within extratropics.

Thus the atmosphere turns out to be forced by a quasi-periodic manner. Therefore, the power spectra of the atmospheric variations must reveal some, possible subtle, peaks at both annual and Chandlerian frequencies and their combinational harmonics. In particular, a sequence of some peaks must exist at the difference frequency $Z=1-Y=0.1607\ldots$ (the oscillation of the about 6.5 years period), Z^2 (the oscillation of the about 40 year period) etc. as a consequence of the above-mentioned self-similarity of the power spectra of the strange nonchaotic attractor. This sequence can be also shifted along the frequency axis as a whole, so that all of the underlain periods are doubled, tripled, or quadrupled. For example, it is well known that the spectrum of the equatorial QBO reveals the main peak at the frequency of the doubled Chandlerian period (of the about 28 months, i.e. 2.4 years). The doubled period corresponding to Z (of the about 13-14 years) is also observed (Vlasova et al. 1987). Unfortunately, the length of the equatorial lower-stratospheric zonal wind record is too short to admit an accurate estimation of the energy of the wind oscillations at the frequency Z^2.

The ENSO spectra computed on the base of some essentially longer records reveal this peak clearly (Sonechkin and Wu Hongbao, 1999). It is interesting to mention that the ENSO records but the only ENSO spectra reveal a kind of self-similarity (Sonechkin et al. 1999). The well known maximal negative anomalies of the Southern Oscillation index near 1900s, 1941-42 and 1982-1983 coinciding with the greatest El Niños of the 20th century form the boundaries of the main constituents (of the about 40 year length) that form a self-similar structure of the temporal ENSO variations. Each of the constituents may be decomposed onto several parts the shapes of which turn out to be of the same character that is inherent to the main constituents. Moreover, the same self-similar structure is seen in the temporal variations of the hemispheric mean surface air temperatures and the European temperatures as well (Sonechkin et al., 1999). The 65-70 year long temperature oscillation recognized by Schlesinger and Ramankutty (1994) reveals itself as an envelope of the above main constituents. In other words, this oscillation is a result of the 40 years period doubling.

According to our estimation the contribution of all peaks considered and their innumerable harmonics into the general energy of the interannual and interdecadal atmospheric variations is about 25% of the general energy. Even if the rest of the energy is a product of some truly chaotic processes connected with slowly varying components of the global climate system we believe that a new approach to the prediction of these variations may be developed. The essence of this approach consists of the taking into consideration the depicted strange nonchaotic character of the quasi-periodic forced components of these. A certain robustness to the random distortions of the initial atmospheric data must be a prominent property of such prediction.

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Midlatitude Ocean-Atmosphere Interaction in an idealized Coupled Model

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1. Introduction

The midlatitude circulation in the upper ocean is forced by the atmospheric wind stress and advects sea surface temperature (SST) in the mixed layer, which, in addition, exchanges heat with the atmosphere. The heat flux anomalies due to SST changes may in turn affect the atmospheric flow. The objective of this study is to identify possible regimes of interannual-to-interdecadal timescale air-sea interaction in an idealized, nonlinear, quasigeostrophic ocean-atmosphere model that resolves baroclinic eddies in both the atmosphere and the ocean.

2. Model

The model (Dewar, 2000) consists of a single North Atlantic-size oceanic basin and a 2 x 10^4 km-long atmospheric channel. The coupling between the two-layer oceanic and atmospheric dynamical components occurs through a simple mixed layer parameterization. The SST is advected by the currents in the mixed layer and affects the atmospheric circulations through the associated air-sea heat fluxes.

3. Main conclusion

We find that the atmospheric behaviour on timescales longer than interannual depends little on oceanic dynamics. The dominance of the low frequencies in the power spectrum of the barotropic atmospheric field is shown to be due to internal atmospheric nonlinearities (cf. James and James, 1989). On the other hand, the oceanic low-frequency variability is primarily determined by the structure and time-dependence of the intrinsic atmospheric variability (cf. Saravanan et al., 2000).

4. Results

4.1 Model climatology

The atmospheric climatology is represented by a zonally-modulated climatological jet having a realistic amplitude. The relative locations of the jet maximum, storm track and maximum low-frequency barotropic activity are also realistic. The time mean oceanic circulation consists of subtropical and sub-polar gyres, which are separated by a midlatitude region of weak zonal current. This double midlatitude jet structure is similar to the Gulf Stream - Labrador current system.

4.2 Low-frequency variability in the model

Leading mode of variability

The leading pattern of atmospheric low frequency variability in the model involves intermittent equivalent barotropic highs and lows over the ocean (Fig. 1a). Associated with the low pressure anomalous atmospheric conditions is an SST anomaly, having positive values over most of the midlatitude and northern North Atlantic, with the exception of the region in between the model Gulf Stream and Labrador currents, where negative values are seen (Fig. 1b).

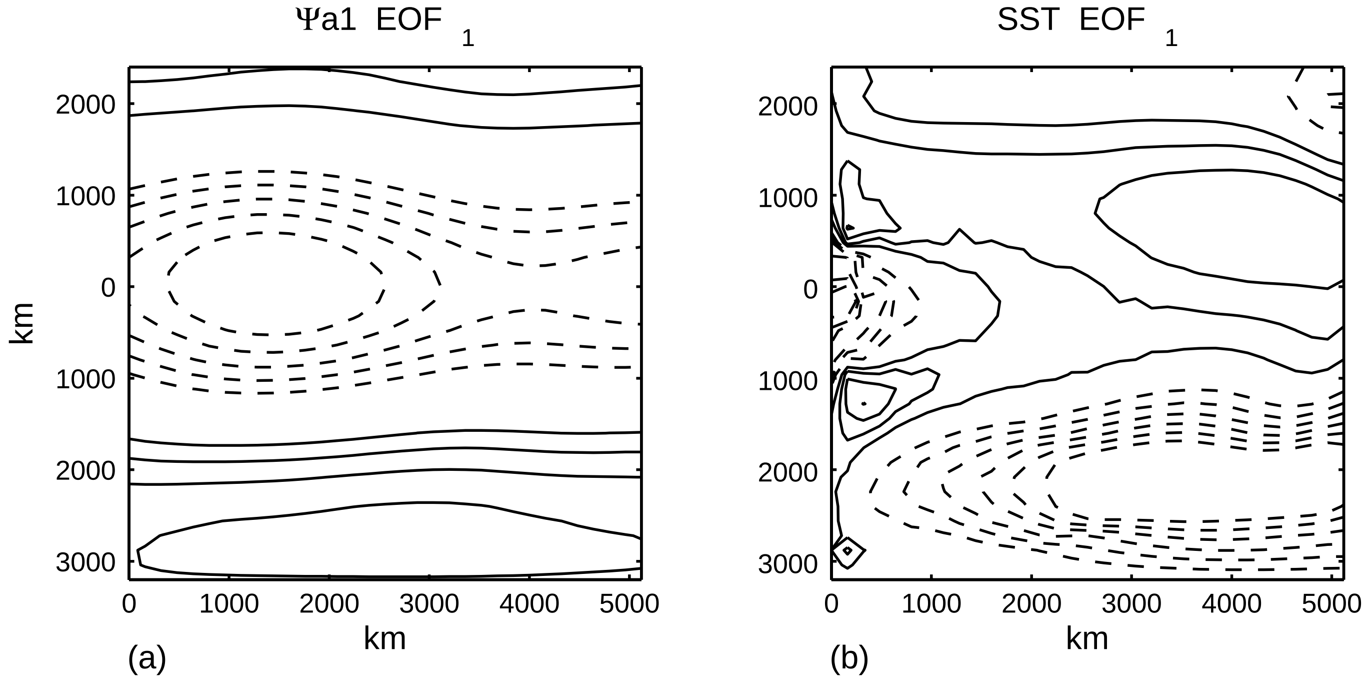

Figure 1: Leading EOFs of (a) lower atmospheric layer streamfunction (41% of variance), CI 0.5 x10^6m^{2}s^{-1}; (b) sea surface temperature (25% of variance), CI 0.1°C. Negative contours dashed, zero contours not plotted. The correlation between the corresponding 5 yr low pass-filtered PCs is about 0.7.

Negative SST anomalies also occur in the tropical ocean, but these are not expected to be realistic. This air-sea pattern is similar to that observed by Kushnir (1994) in his analysis of interdecadal climate behavior in the North Atlantic. This SST distribution is accompanied by intensified model Gulf Stream and weakened model Labrador current. A spatial structure of the SST anomaly shows that it cannot be locally forced by anomalous air-sea fluxes.

Causes of variability

We have shown that in our model the SST pattern described above is directly forced by the atmospheric time-dependent wind, whose structure is not sensitive to, and is independent of, the oceanic evolution. In the western part of the ocean the SST response is largely due to the advection of mean SST by anomalous baroclinic currents associated with the wind anomaly. In the east, heat fluxes associated with the anomalous Ekman currents and entrainment in the mixed layer dominate. There is a weak modulation of the SST structure by the heat flux, due to atmospheric temperature anomaly that accompanies the wind pattern.

Therefore, we propose an explanation of the long-term SST variability in the North Atlantic, which does not involve ocean-atmosphere feedbacks at all, nor the existence of self-sustained or damped oceanic eigenmodes. Instead, the atmospheric low-frequency pattern, which is internally generated by atmospheric nonlinearities and has a specific spatial structure, directly causes changes in the oceanic circulation, which determine the SST response.

Importance of the meridional position of the atmospheric variability

All the basin scale oceanic responses described above crucially depend on the meridional position of the atmospheric activity centre relative to the oceanic gyres. If the two positions are not in mutual adjustment, as they are in the coupled run, the details of the basin scale SST modes are altered. This occurs through changes in the relative amplitudes and spatial structure of different feedbacks in the mixed layer evolution. Thus, the spatial structure of atmospheric variability is crucial in determining the oceanic time dependence in the model.

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Mechanisms of extra-tropical Decadal Variability

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One of the fundamental questions in current research about the mechanisms of decadal variability in the extra-tropics is the interplay between the ocean and the atmosphere. Is the coupling between the ocean and the atmosphere crucial for the generation of decadal variability and if so what is the nature of this coupling? We have tried to answer this question within the context of a climate model of intermediate complexity ‘ECBilt’, developed in the predictability division of the Royal Netherlands Meteorological Institute (KNMI).

ECBilt was developed with the purpose of simulating qualitatively correctly the extra-tropical climate, with special focus on the simulation of the position and strength of the storm tracks and dominant modes of variability. The dynamical core of ECBilt is a quasi-geostrophic T21 model with 3 vertical levels. The diabatic processes are modelled using simple parameterisations. A full hydrological cycle is included. ECBilt is coupled to a coarse primitive equation ocean model with a horizontal resolution of 5.6 degrees and 12 vertical levels. Sea-ice growth is simulated with a zero layer thermodynamic model. A detailed description of ECBilt and its performance can be found in Opsteegh et al. (1998). The main advantage of ECBilt is that due to its relative simplicity and low computational cost carefully additional simulations can be performed to unravel cause and effect relationships of the phenomena simulated in ECBilt.

We have investigated decadal variability in the North Atlantic and in the Southern Ocean as examples of extra-tropical decadal variability.

North Atlantic

There is observational evidence for typical sea surface temperature (SST) variations in the North Atlantic on a time scale of 10 to 15 years (Deser and Blackmon, 1993). At the same time, a typical sea level pressure (SLP) variation is observed in the atmosphere, which resembles the North Atlantic Oscillation (NAO). A singular value decomposition (SVD) analysis of SST and 800 hPa geopotential height in a thousand year control integration of ECBilt, revealed a mode (Fig.1, page 9) with a dominant time scale of 16-18

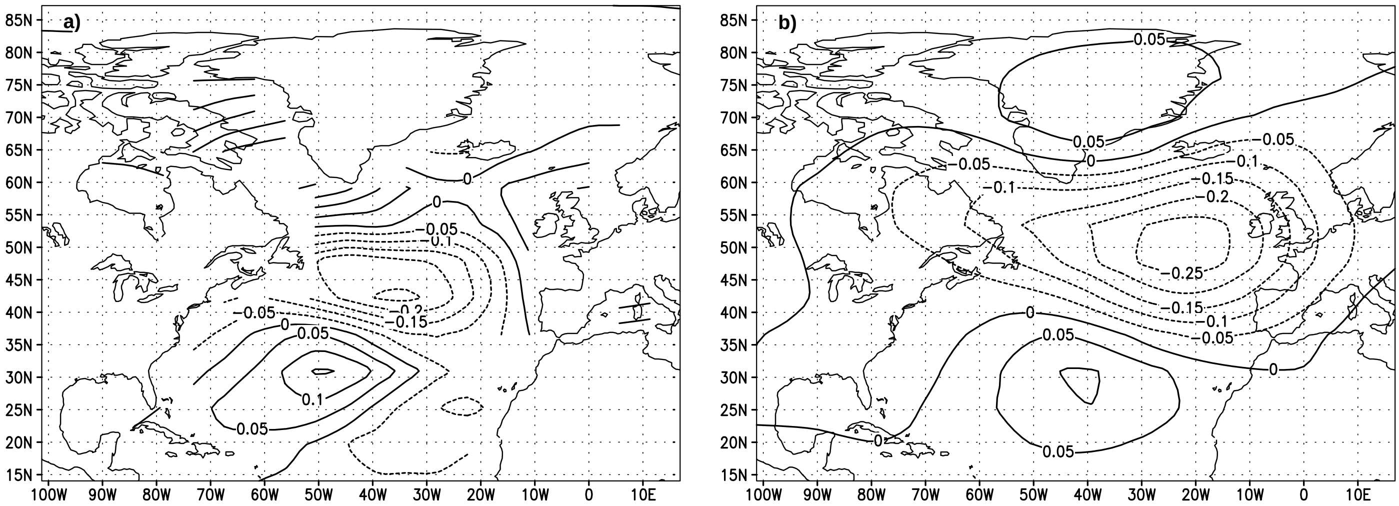

Figure 1: Covarying anomaly patterns of wintermean SST (a) and 800 hPa geopotential height (b). The amplitude variations of both are well correlated (0.7), with the atmospheric circulation anomaly forcing the SST anomaly.

yr in SST (Selten et al., 1999). This mode is similar to the first canonical correlation analysis (CCA) mode found by Grötzner et al. (1998) from observed SST and SLP. This observed mode peaks around a somewhat shorter time scale of about 12 yr. The 16-18 yr mode in SST in ECBILT is related to an oceanic subsurface oscillation which shows a clockwise propagation in the subtropical gyre (Fig.2, page 8). Additional experiments have revealed much of the underlying mechanism. In order to investigate the role of oceanic forcing on the atmospheric circulation for the decadal mode we performed the following experiment: We repeated the 1000-yr coupled integration but on an arbitrary year we decoupled the atmosphere from the ocean. From that year onward we used the daily SST values and sea-ice cover of that year as the lower boundary condition for the atmosphere. The ocean and the sea-ice are forced by the varying atmosphere. Thus the ocean is forced with fluxes that depend on the actual SST values, whereas the surface heat fluxes that the atmosphere receives depend on the prescribed SST. We will denoted this experiment as one-sided coupling. The SVD patterns of this one-sided coupled run are virtually the same as the SVD patterns of the coupled run. The spectra of the time series of these patterns are changed: They are less red and the dominant peak at 16-18 yr in SST has disappeared. In the subsurface of the ocean the oscillation with a time scale of 16-18 yr is however still present although significantly weaker. This demonstrates that the time scale of the 16-18 yr mode is set in the ocean

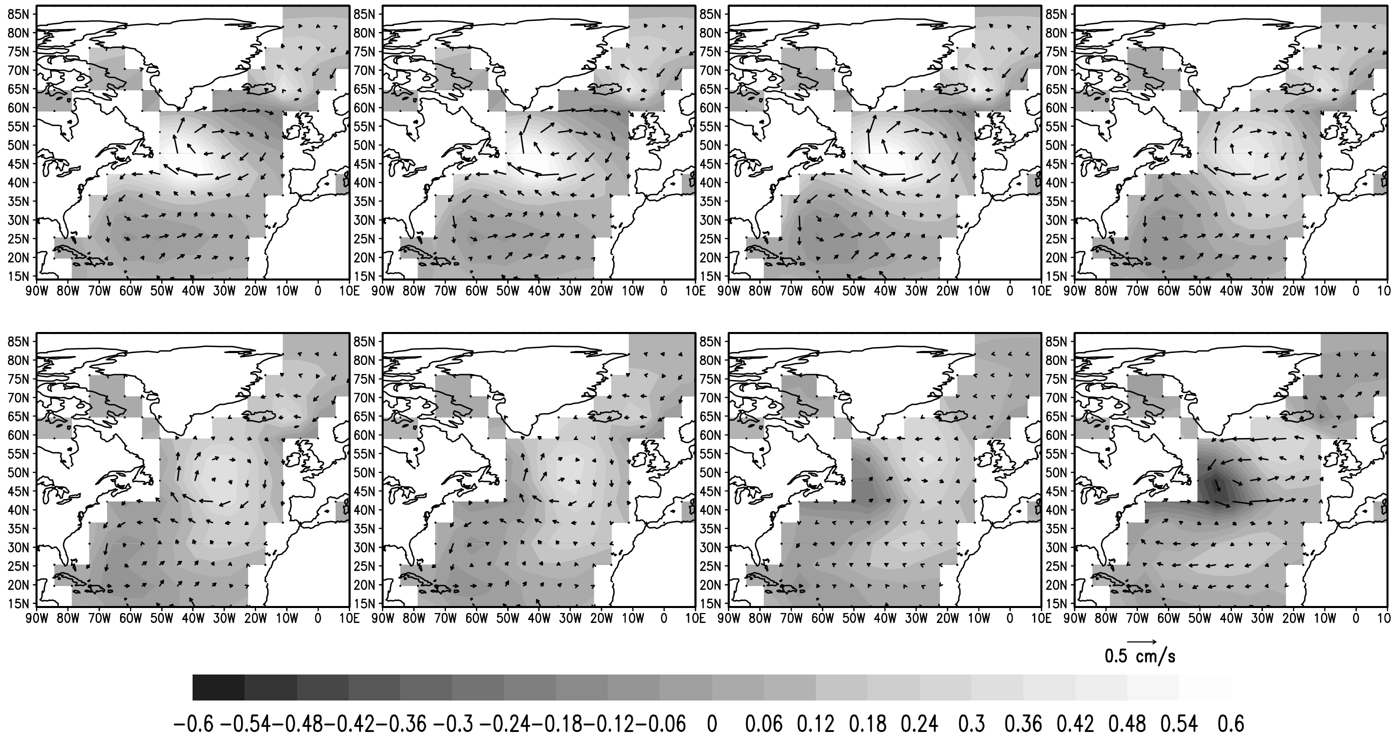

Figure 2: Time evolution of wintermean anomalies of subsurface (80-300 m) ocean temperatures [K] filtered to optimally show the 16-18 year oscillation. Arrows denote the filtered anomalous ocean sub-surface currents [cm/s]. First plot corresponds to year 395 of the 1000 year model simulation. Time step between two maps is one year.

and that a dynamic coupling between the ocean and the atmosphere is not necessary for the generation of this time scale. The less red spectrum and the disappearance of the peak in the SST are due the fact that in the one-sided coupling experiment the atmosphere is seen by the ocean as having an infinite heat capacity, because the overlying surface air temperature (SAT) does not adjust to the SST's, resulting in abnormally large surface fluxes and a rapid damping of the generated SST anomalies. The adjustment of SAT to the SST is thus crucial for the subsurface decadal time scale to be manifest at the surface. Additional sensitivity experiments have revealed that the dominant process for the generation of the 16-18 yr time scale are variations in the ocean salinity field. The subsurface temperature mode is accompanied by variations in the surface salinity. These salinity variations are responsible for the phase reversal in the subsurface mode by affecting convection off the coast of New Foundland. An additional experiment in which the windstress was prescribed revealed that the feedback of wind anomalies on the ocean gyre circulation is not essential for the generation of 16-18 yr mode. The windstress feedback enhances the amplitude of this mode through anomalous Ekman pumping, which is responsible for a deeper mixing of SST anomalies, resulting in subsurface anomalies with a larger thermal inertia.

Southern Ocean

In the same thousand year simulation of ECBilt, propagating SST variations are found in the Southern Oceans around the Antarctic continent at a typical timescale of 8 years. (Haarsma et al., 2000). These variations resemble the so-called Antarctic Circumpolar Wave (White and Peterson, 1996), characterized by alternating warm and cold SST anomalies propagating around the Antarctic continent in about 8 years. Additional experiments have shown that the mechanism for this 8 yr mode around Antarctica is very similar to mechanism for the 16-18 yr mode in the North Atlantic: The SST anomalies are generated by anomalies in the atmospheric circulation and are accompanied by a subsurface oscillation in the ocean, which propagates eastward around Antarctica (Fig. 3). The main difference is in the ocean dynamics setting the time scale. For the 8 yr mode around Antarctica the advective resonance mechanism of Saravanan and Mc Williams (1998), appears to be responsible for the dominant time scale. In the advective resonance mechanism the preferred time scale is set by the ratio of the horizontal scale of the dominant atmospheric forcing patterns and the advection velocity of the ocean currents. An experiment in which we doubled artificially the strength of the Antarctic circumpolar current (ACC) revealed that the time scale of the mode was halved from 8 yr to 4 yr. An additional simulation with climatological salinity values in the ocean density calculations revealed that the effect of salinity anomalies, which were crucial for the North Atlantic mode, are of minor importance for this mode.

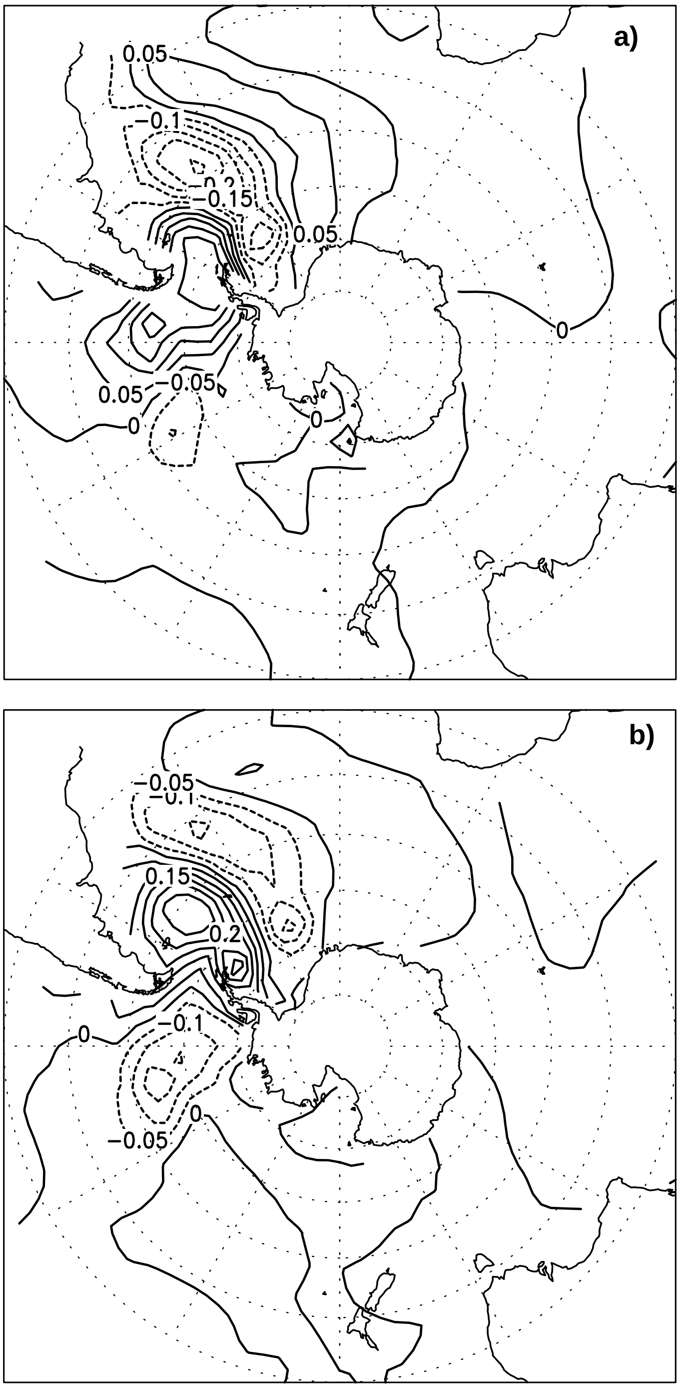

Figure 3: Subsurface temperature variations characterised by two patterns: (a) zero phase, (b) quarter phase which occurs 2 years later.

The simulations with ECBilt support the following picture of decadal climate variations over the oceans and surrounding continents: Atmospheric circulation anomalies force typical patterns of SST anomalies, which are mixed to deeper layers due to Ekman pumping, in response to anomalous windstress. The ocean response to these anomalies gives rise to a preferred timescale which is imprinted back on the atmosphere primarily on the surface air temperature. The response of the atmospheric circulation to the SST anomalies is weak an not crucial for the preferred time scale. The thermodynamic adjustment of SAT to the SST anomalies enhances the persistence of SST anomalies and makes the subsurface signal manifest at the surface. In the North Atlantic salinity anomalies are essential for the generation of the preferred time scale, whereas in the Southern Ocean this time scale is set by the advective resonance mechanism of Saravanan and McWilliams.

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PREDICATE: Mechanisms and Predictability of Decadal Fluctuations in Atlantic-European Climate

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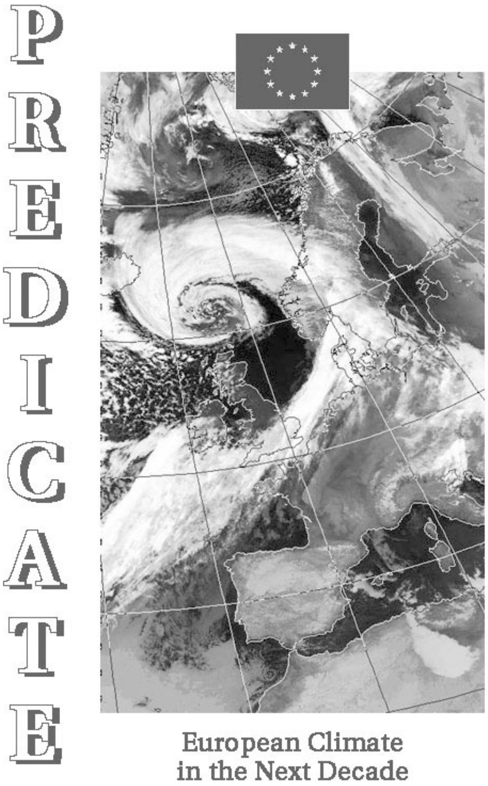
Understanding fluctuations of the climate system on time scales from decades to centuries is one of the major topics of the CLIVAR programme. Five Principal Research Areas (PRAs) within the Initial CLIVAR Implementation Plan (WCRP, 1998) focus on aspects of decadal climate variability. In the Atlantic Sector the key topics are the North Atlantic Oscillation, the Thermohaline Circulation and Tropical Atlantic Variability. The problem of understanding and forecasting these aspects of decadal climate variability presents a major challenge to the scientific community. An adequate response is beyond the resources of any single organisation, and thus coordination of activities is essential. PREDICATE is a 3-year research programme, funded by the European Union under Framework 5, in which eight of the leading climate centres in Europe have come together to provide a focused effort in this vital area.

The objectives of PREDICATE are:

1. To assess the predictability of decadal fluctuations in Atlantic-European climate.
2. To improve understanding and simulation of mechanisms via which ocean-atmosphere interactions cause decadal fluctuations in Atlantic-European climate.
3. To improve the European capability for forecasting decadal fluctuations in Atlantic- European climate by developing forecasting systems based on coupled ocean-atmosphere models.
4. To work with targeted user groups to assess the potential benefits from possible future decadal forecasts for selected sensitive industries.

As can be seen, PREDICATE targets the role of ocean-atmosphere interactions rather than the response to external forcings. These aims are to be achieved through a coordinated programme of numerical experimentation, evaluation against observations, and development of prediction systems. The project has four principal themes, as follows.



A) Mechanisms and Predictability of Decadal Fluctuations in the Atmosphere.

The potential predictability of the North Atlantic Oscillation (NAO) has been a subject of considerable recent debate. It has been shown that atmosphere models forced with observed SST can simulate NAO variability that is highly correlated with the observed record (Rodwell et al., 1999). Because of large sampling fluctuations there is need for caution in the interpretation of these results (Mehta et al., 1999, Bretherton and Battisti, 2000), but they have yet to be fully explained. In some models there appears to be no significant skill (L. Terray, personal communication), and in those where skill exists it is not clear whether consistent features of the SST variability are responsible.

A major contribution of PREDICATE to this topic is a rigorous quantitative comparison of four different atmosphere GCMs to assess their skill in simulating the climate variability that was observed over the last century, with a particular focus on the North Atlantic region. The comparison includes the powerful technique of signal-to-noise optimised Principal Component Analysis (Venzke et al., 1999). This approach enables determination of which features in the SST field exert most influence.

B) Mechanisms of Decadal Fluctuations in the Atlantic Ocean

Prominent amongst the observational results of recent years has been the identification of persistent, often propagating, surface and subsurface anomalies in the North Atlantic ocean (e.g. Dickson et al., 1988; Sutton and Allen, 1997; Curry and McCartney, 1998). A major current challenge is to understand the mechanisms through which these anomalies form, propagate, and decay, and to understand how their life-cycles are related to fluctuations in the atmosphere and in the oceanic gyre and thermohaline circulations.

In PREDICATE these issues are being addressed through a coordinated programme of experimentation with six different ocean GCMs. PREDICATE partners are investigating the skill with which the variability observed in the Atlantic during the second half of the twentieth century is simulated in models forced with observed winds and air-sea fluxes. The sensitivity of simulations to model resolution and the representation of the Arctic ocean is being explored.

C) Decadal Climate Prediction for the Atlantic European Region.

The problem of decadal climate forecasting presents considerable scientific and technical challenges. Predictability on these timescales arises from two influences: that of the ocean, and that of external forcings such as the rising trend of greenhouse gases. Current climate change forecasts make no use of information about the present state of the oceans (see Figure, page 1). This approach is very unlikely to be optimal for forecasts with time horizons of a few years or decades. Thus work to incorporate ocean state information into climate forecasts is essential.

Building on the understanding and evaluation of mechanisms achieved in other parts of the programme, a major part of PREDICATE is addressing the development of systems for decadal forecasting and the assessment of predictability on decadal timescales. The study of Griffies and Bryan (1997) was a pioneering step in this field. However, the coarse resolution of the model used brings into question the realism of the mechanisms it simulated. PREDICATE will take forward the work of Griffies and Bryan by performing experimental decadal predictions with four different coupled models, all of which have higher resolution than that used by Griffies and Bryan. The sensitivity of forecasts to initial conditions in both the ocean and the atmosphere will be investigated and a quantitative assessment of decadal predictability will be made for each of the models. The application to decadal forecasting of techniques (e.g. 'breeding') to generate initial perturbations for decadal forecasts will be investigated.

D) Interactions with Users and Dissemination of Results.

Decadal time horizons are of central concern for strategic planning in a wide range of industries. It is a high priority for PREDICATE that the needs of potential users are well understood and are taken into account throughout the programme. It is also essential that potential users begin to think seriously about how they could exploit future real-time decadal forecasts. To achieve these ends PREDICATE is promoting a dialogue between the climate prediction science community and business users in a wide range of sectors (for example, insurance, energy, water, construction). An example of the project activities is a workshop at The Royal Society London, 8-9 March 2002: 'Climate Risks to 2020: Business Needs and Scientific Capabilities'

The PREDICATE project began on 1 March 2000 and will end on 28 February 2003. The PREDICATE partners are:
CGAM: Centre for Global Atmospheric Modelling, University of Reading, UK, The Met Office, Bracknell, UK, MPI: Max Planck Institut für Meteorologie, Hamburg, Germany, LODYC: Laboratoire d'Oceanographie Dynamique et de Climatologie, Paris, France, NRSC: Nansen Environmental and Remote Sensing Research Centre, Bergen, Norway, ING: Istituto Nazionale di Geofisica, Bologna, Italy., DMI: Danmarks Meteorologiske Institut, Copenhagen, Denmark, CERFACS: The European Centre for Research and Advanced Training in Scientific Computation, Toulouse, France.

For further information see http://ugamp.nerc.ac.uk/predicate

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Alverson et al., page 4: Improving Climate Predictability and understanding Decadal Variability using Proxy Climate Data

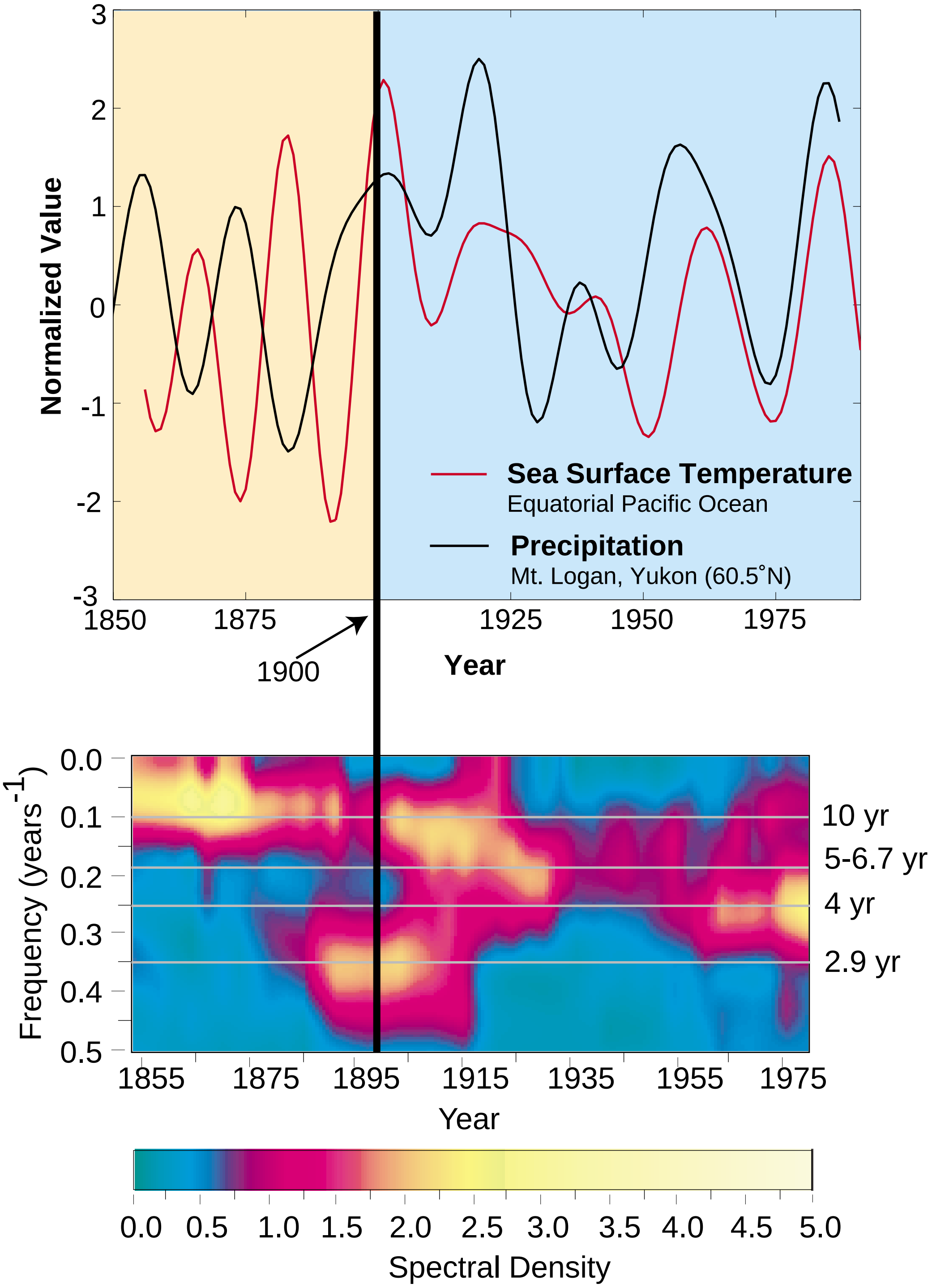

Figure 1: Upper panel: The Niño 3.4 equatorial Pacific sea surface temperature (SST) index as extended using proxy data (Kaplan et al., 1998) and the precipitation record from Mt. Logan (Moore et al., 2001), both low pass filtered with a cutoff of 15 years. Lower panel: An evolutionary spectral SST analysis derived from an annually resolved coral from Maiana atoll in the equatorial Pacific (Urban et al., 2000). Around 1900, indicated by the vertical black line connecting the two panels, was a period of time when the variability expressed in the coral record was shifting from primarily decadal to power to higher frequencies. This shift appears to correlate with a shift in the phase of the correlation between the low frequency equatorial variability and the extra-tropical response at Mt. Logan.

Alverson et al., page 4: Improving Climate Predictability and understanding Decadal Variability using Proxy Climate Data

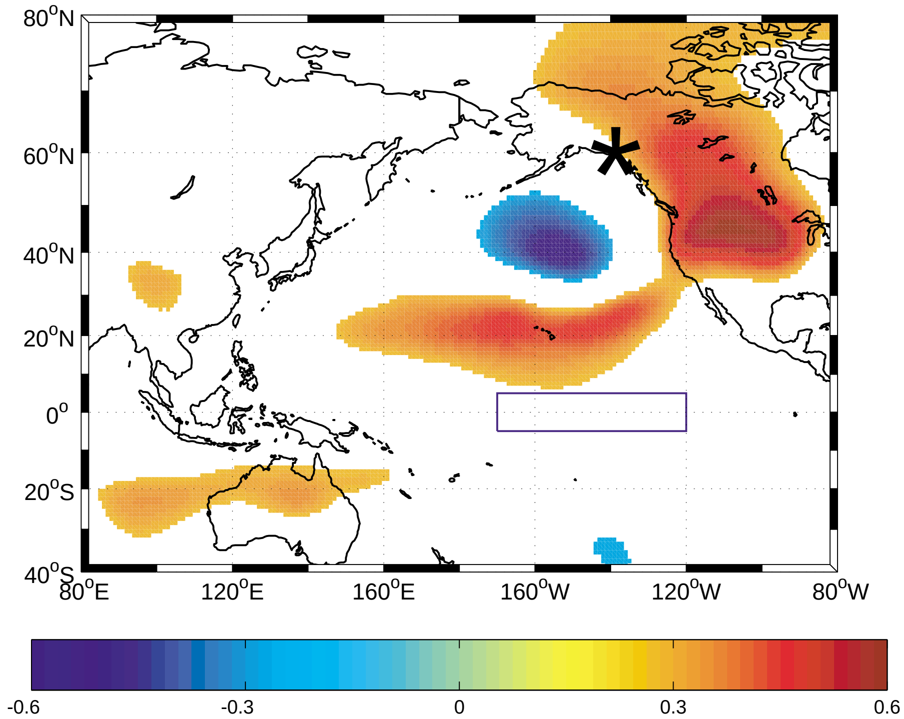

Figure 2: Cross-correlation of the Mount Logan annual snow accumulation timeseries with the annual 200 mb geopotential field from the NCEP reanalysis 1948-1985. The field is displayed at those points where the cross-correlation is significant at the 95% level. The location of Mount Logan is indicated by the ''. The Niño 3.4 region is bounded by the blue box.*

Boer, page 3: Decadal potential predictability in coupled models

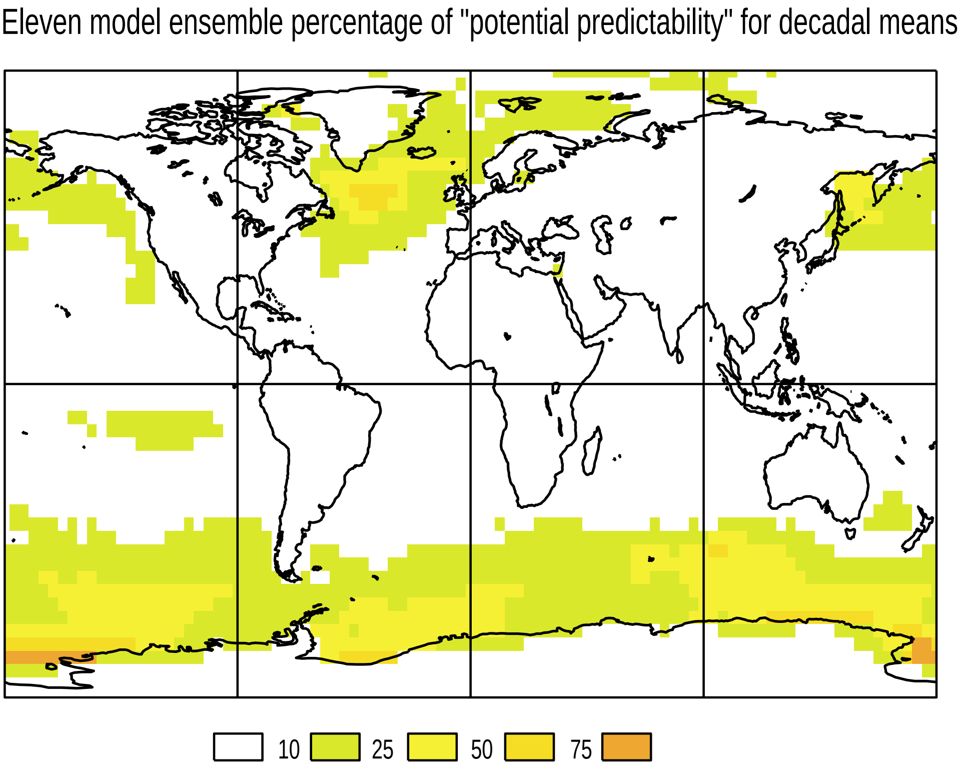

Fig. 1: potential predictability for decadal means obtained from a model ensemble of 11 coupled models.

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Role of Ocean Dynamics and Atmosphere – Ocean coupling in the observed North Atlantic Decadal Variability

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1. Introduction

To explore evidence and possible mechanisms of decadal variability and atmosphere-ocean coupling, we introduce and study a simple SST index, ΔT; from a long observational record (1856 - 1998); it measures the strength of the dipole of SST that straddles the Gulf Stream and was chosen because (i) it is a measure of low level baroclinicity to which cyclogenesis at the beginning of the Atlantic stormtrack may be sensitive (ii) it may contain a signature of anomalies in ocean heat transport associated with both wind driven gyres and thermohaline circulation. We show that pronounced decadal signals in ΔT are found which covary with the strength of sea level pressure (hereafter SLP) anomalies over the Greenland - Iceland Low and subtropical High regions. Using the simple coupled model developed in Marshall et al. (2000), we interpret features of the power spectrum of observed SST and SLP as the signature of coupled interactions between the atmospheric circulation and an anomalous wind driven ocean gyre and thermohaline circulation.

A much fuller discussion of the observational study summarized here, which builds on that of Deser and Blackmon (1993) - see also Grötzner et al. (1998) for a relevant modelling study - can be found in Czaja and Marshall (2001).

2. A cross Gulf Stream SST index

Figure 1 (upper panel) shows the time evolution of the SST index $\Delta T = T_N - T_S$ (difference of SST averaged over [60˚-40˚W; 40˚-55˚N] and [80˚-60˚W; 25˚-35˚N] in late winter – February through April), from Kaplan et al. (1997)[1]. Typical fluctuations of 1 K are found on interannual timescales (blue curve), and represent fluctuations of 10 - 20 % of the mean cross Gulf Stream SST gradient. As seen in Fig. 1 (page 16), they are reduced by about a factor of two on decadal timescales (green curve, 6- yr running mean). Using a composite analysis we investigate the typical evolution of the SST pattern captured by ΔT once it has been generated (Fig. 1, middle panel). Figure 1, middle panel, is obtained by compositing SST using high index years (red stars), using low index years (blue stars), and then subtracting low from high (to yield the High-Low plot); the same but using years shifted along by three relative to the stars (3 years later) and by six years (6 years later). High-Low reveals the tripole pattern (Fig. 1, middle panel, left plot) which evolves in time with damped oscillatory behaviour. No large scale signal is found three years after the tripole has been generated (Fig. 1, middle panel, middle plot), but it reappears 6 yrs later with opposite sign (Fig. 1, middle panel, right plot). When the analysis is made using longer lags, there is a hint of reappearance of the initial tripole after 12-14 yrs, but the statistical significance is lost (not shown). Based on a similar composite analysis with the long observational record of SLP by Kaplan et al. (1999), we find that atmospheric conditions which occur simultaneously with ΔT are reminiscent of the North Atlantic Oscillation (NAO) signature in SLP (not shown), although shifted slightly southwestward. They show opposite-signed anomalies over the Greenland - Iceland Low (hereafter GIL) and subtropical High (hereafter STH) regions, such that in years when SST are warmer north than south of the Gulf stream ($\Delta T > 0$), the surface atmospheric circulation is weakened.

3. Spectral analysis

Figure 1 (lower panel) shows the observed power spectra for ΔT (green), GIL (blue) and STH (red). In agreement with the damped oscillatory behaviour displayed by the SST tripole (Fig. 1, left panel), but sharply contrasting with the traditional red noise prediction of Frankignoul and Hasselmann (1977), the power spectrum of ΔT shows a broad peak in the decadal band, with no attening on longer timescales. Rather, the power in the ΔT index continues to decrease with increasing timescale. The power spectra of GIL and STH are similar up to timescales of about 25 yrs (blue and red curves respectively in Fig. 1, lower panel). This is consistent with a spectral coherence analysis, which indicates strong coherence and a robust out of phase relationship between GIL and STH up to 25 yrs (not shown), in agreement with the NAO paradigm. On longer

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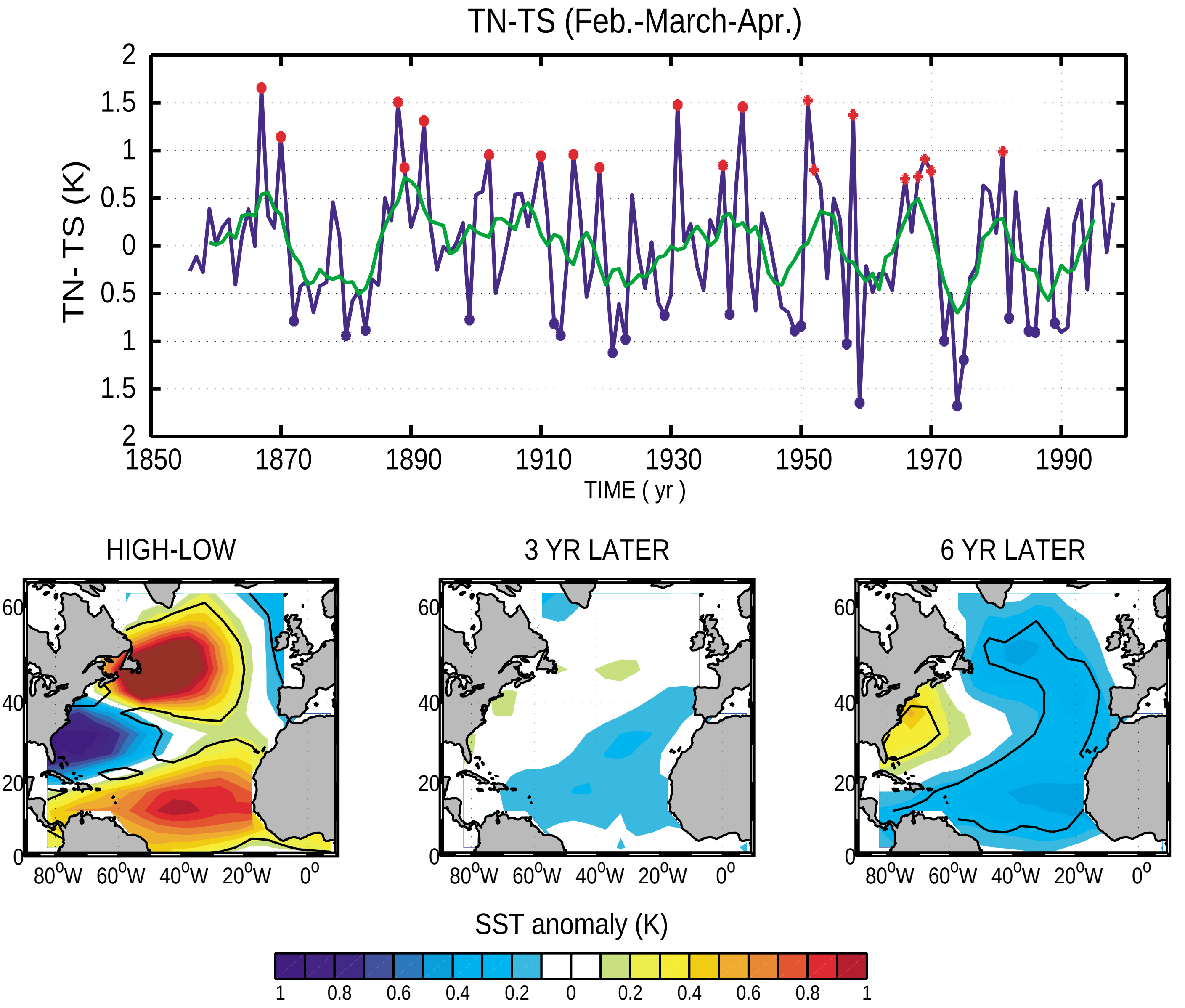
[1] *The ΔT index and related papers can be found at http://puddle.mit.edu/~czaja*



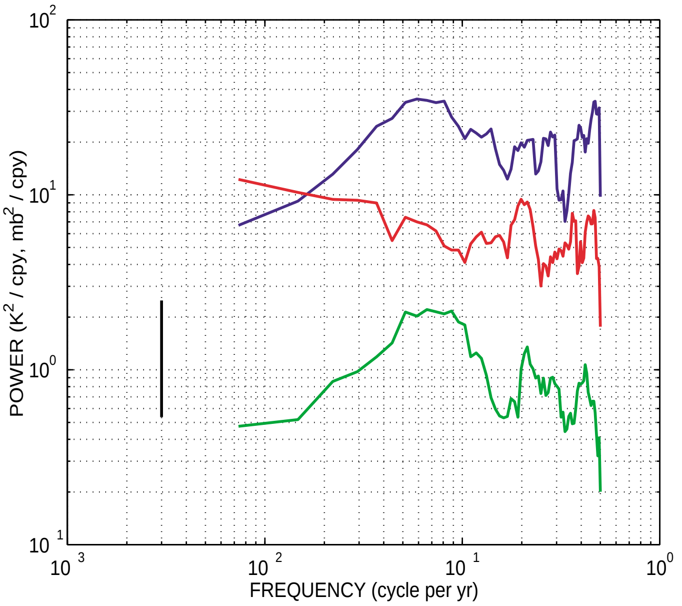


Figure 1.
Upper panel: Timeseries of the SST index $\Delta T = T_N$-T_S.

Middle panel: Composite maps for SST (in K). The black lines indicate the 95% confidence level.

Lower panel: Observed power spectra of SLP anomalies near Greenland - Iceland (GIL, blue) and near the subtropical High (STH, red). The power spectrum of the cross Gulf Stream SST index ΔT *is also plotted (green). The frequency is expressed in cycle per yr (cpy) and the power in* K^2 *=cpy for* ΔT *and* mb^2*/cpy for GIL and STH. The vertical bar indicates the 95% confidence level.*

timescales, however, the two spectra have different structures and the coherence between them is reduced (not shown). While the STH power spectrum keeps increasing with time scales, that of GIL decreases. The NAO index of Hurrell (1995), the normalized SLP difference between Iceland and Lisbon, has a power spectrum very similar to that of STH (not shown).

4. Discussion

Perhaps the most striking feature of the analysis present here is the decrease of power seen in both ΔT and GIL spectra at timescales longer than about 25 yrs. The latter can be captured by a simple coupled stochastic model (Marshall et al., 2000), and, in that model, arises essentially because the ocean circulation is assumed to play a role in advecting heat from the warm lobe to the cold lobe of the dipole (i.e. down gradient), but with some delay. Much further work is needed to fully determine what ocean dynamics might be responsible for the delay, and the role of Atmosphere - Ocean coupling in the decadal variability displayed by the SST tripole and GIL presented here. Our observational results suggest that a weak coupling is present through control of the strength of GIL by ocean circulation at low - frequency, presumably through its impact on SST and surface baroclinicity measured by ΔT. As discussed in detail in Czaja and Marshall (2000), predictive skill in the 10 to 20 year band is nevertheless expected to be low, owing to the small quality factor of the coupled oscillation.

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Are we seeing human-induced Warming of deep Layers in the north subtropical Atlantic?

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Ocean variability is most likely a crucial factor in regulating the interdecadal-to-multidecadal natural changes in the coupled ocean-atmosphere system and, hence, the low-frequency climate variability (Bjerknes, 1964; WCRP, 1998). At the same time, the Ocean damps the global warming through the changes of meridional heat transport and latent heat fluxes (Polonsky and Voskresenskaya, 1996; Voskresenskaya and Polonsky, 1994). So, the reliable detection of the low-frequency ocean variability is crucial factor to study the long-term (natural and human-induced) climate changes. Because of the limitations in the quantity and quality of oceanographic observations there is a problem of detection of the climatic signals in deep-ocean layers. The brief discussion of this problem is aim of present note with strong focus to the North subtropical Atlantic. More complete discussion will be published soon (Polonsky, 2001).

Deep-sea observations have been performed for more than a century. Before the 1970's, Nansen profiles were the main source of deep-sea data. Then the XBT and CTD soundings essentially replaced the Nansen measurements. However, the routine oceanographic observations are too sparse and noisy for the reliable detection of long-term changes of the oceanic fields in the deep ocean (below about upper 0.8-1 km layer). Even in the regions with the best coverage (such as North subtropical Atlantic), only small portion of the profiles reached the deep layers (especially before the WOCE programme) and observational activity was concentrated in recent decades (Fig. 1, page 18). This means that even there, only decadal-scale (not longer-term) variations in the upper (~1km) layer may be estimated with reasonable accuracy (signal-to-noise ratio ≥1). Regular XBT profiles have been collected during the recent 35 years and the maximum depth of XBT sounding is usually 800 m. In addition, there was an essential decrease of XBT activity after 1979. Therefore the XBT data cannot eliminate the lack of long-term deep-sea observations (see also, White, 1995). As a result there are at least two following problems: (a) the reliable detection of long-term variations of deep-ocean layers and (b) the separation of trend-like and low-frequency quasi-periodical signals. Unique observations permit different interpretations. I would like to demonstrate this point for the North Atlantic subtropical gyre using following remarkable example.

Parrilla et al. (1994) found significant and quite uniform warming in deep Atlantic Ocean along 24˚N be-

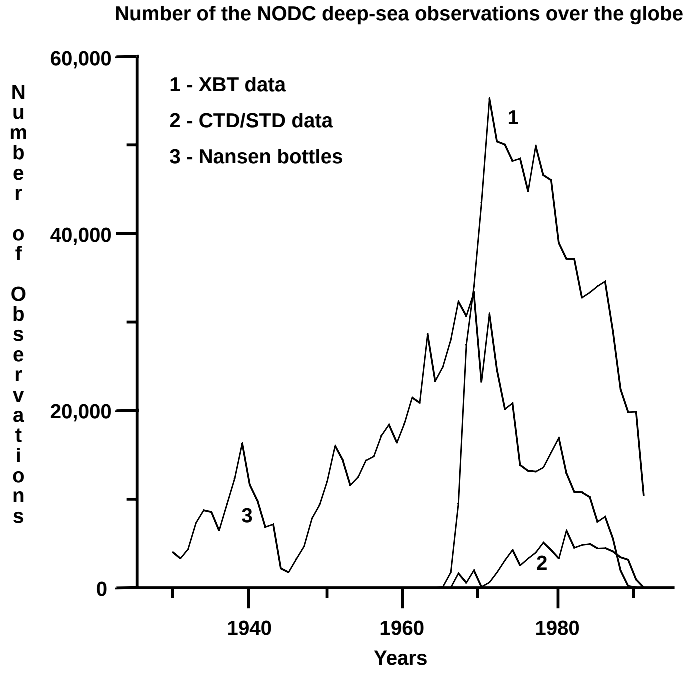

Fig.1: Number of NODC deep sea observations over the globe.

tween 1957 and 1992. It was at a maximum (>0.25˚C) between 1 and 2 km. “However, to what degree those observed changes represent large-scale volume changes or whether they occurred largely due to variations of the location of the gyre is not clear” (WCRP, 1998). Figure 2 shows that the latter assumption is very likely true. If subtropical gyre has shifted to the South by about 2˚ from 1957 to 1992 *even without any other changes*, it results in the deep-ocean temperature change along 24˚N resembling the warming described by Parrilla et al. (1994). In fact the intensification of the subtropical gyre occurred also in that time. Figure 3 demonstrates that the multidecadal quasi-periodical rise of the sea level pressure (SLP) in the Azores High and associated increasing of the Rossby (NAO) index from late 1950’s to early 1990’s have been accompanied by the displacement of the Azores High to the Southwest. This should be accompanied by the intensification and southward shift of the Subtropical gyre. Thus the warming observed by Parrilla et al. (1994) is likely the manifestation of multidecadal temperature variability due to changes of the location and intensity of the Atlantic Subtropical gyre as part of the coupled ocean-atmosphere system variability.

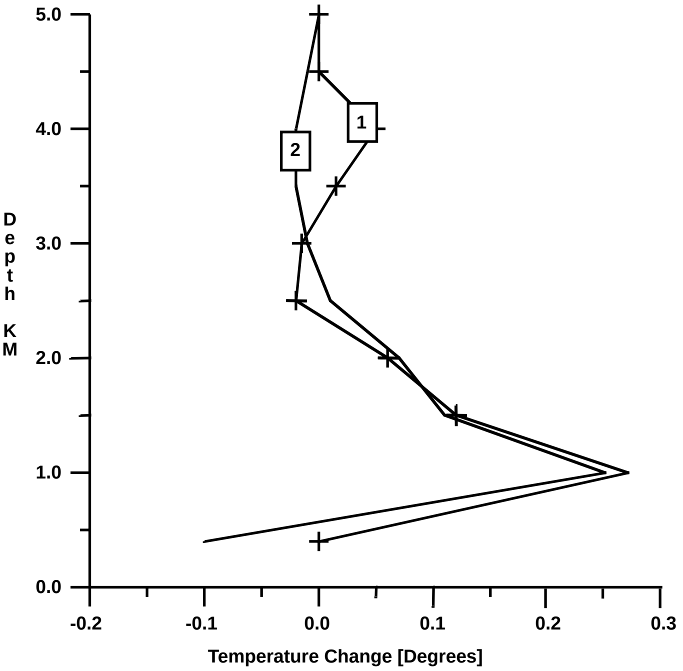

Fig. 2: Change of zonally averaged temperature in the North Atlantic Ocean as a function of depth: 1-difference of climate temperature at 25˚N and 23˚N calculated using NODC data; 2-observed by Parilla et al (1994) difference at 24˚N between 1992 and 1957.

Certainly, it is next to impossible to distinguish the natural multidecadal changes and human-induced warming of deep-ocean layers because the amount of available deep-ocean data is absolutely insufficient to separate the trend-like and low-frequency quasi-periodical signals in the extended ocean interior. Both of them look like long-term tendencies. Of course, the problem of separation of the human-induced warming and natural multidecadal changes is not so simple in principle even if one has the high-resolved long-term global observations (see e.g., discussion of this problem from the atmospheric point of view in *Nature* [Corti et al., 1999 and Hasselmann, 1999]). It is clear however, without such observations this is impossible at all. It concerns also the entire climate system including deep-ocean layers.

This should be noted, the long-term meteorological data provide some arguments for separation of the human-induced and natural multidecadal changes. For instance, the multidecadal and longer-term tendencies of subtropical SLP are opposite one another because the century trend-like Azores High deepening is accompanied by its shift to the North (Fig.3). There are also the essential differences between decadal-scale and multidecadal modes (Enfield and Mestas-Nunez, 1999; Polonsky et al., 1997). This is a result of differences between mechanisms those are responsible for the century-scale, multidecadal and decadal-scale changes in the ocean-atmosphere-land system. First of them is due likely to the human-induced processes, while the second and third ones are due mostly to the natural variability (changes of the global and basin-scale variability of the coupled system, respectively) (Polonsky, 2001). To clarify the relative importance of different mechanisms and their possible interaction it is a strategic task for the future. The ocean observational programme is an important element of this strategy.

Thus, what should we do during the next few decades for the development the study of the long-term climatic variability of the coupled ocean-atmosphere system on the globe, taking into account an uncertainty of climate ocean change due to lack of deep-ocean observations? It is clearly necessary to perform precise global *(including deep-ocean)* observations. However, a fast progress in the study of the long-term variability of climatic system using instrumental deep-ocean data is not likely. Duration of observa-

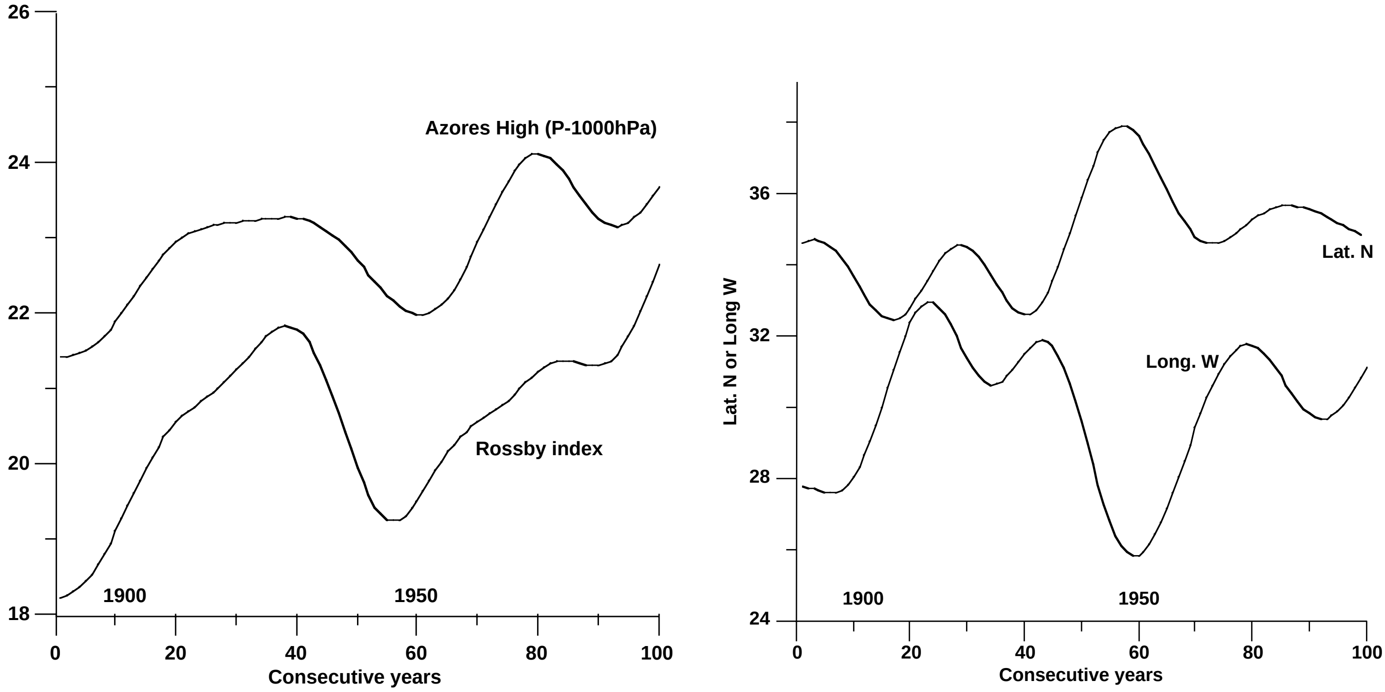

Fig. 3: Time series of (SLP-1000mb) in the Azores High (P), Rossby index (Ro,mb) (A) and latitude(˚N)/longitude(˚W) of the Azores High (Lat,/Long) (B). $Ro=SLP_{Az.High}-SLP_{Icel.Low}$ *is close to the non-normalized NAO index used by Hurrell (1995). Russian historical yearly data have been used (Polonsky et al.,1997). Series were filtered using low-passed (20 yr cut off) filter. The similar low-frequency variability of Azores High and Rossby index can be found in the time series published by Machel et al.(1998).*

tions should be at least of the same order as the typical time scale of processes to be studied. This means we should continue to support the global observational network at least during the next few decades and put attention to analysis of different kinds of observations. Precise long-term deep-ocean observations, such as WOCE soundings, are absolutely necessary for the study of low-frequency climatic change. Essential decreasing of the ocean observational activity as happened in the beginning of the satellite era (see Fig.1A) is inadmissible. This manifested among the others in the cessation of international subsurface observations at the Ocean Weather Stations. It is absolutely clear, the observations using new technology should continue the long-term time series and should not lead to their interruption.

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Decadal Variability in the South Atlantic Ocean

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Introduction

The South Atlantic Ocean plays a crucial role in the global Thermohaline Circulation as it transports large amounts of heat and salt towards and across the equator. Changes in the composition and thus the buoyancy of South Atlantic waters can affect the Atlantic Thermohaline Circulation (Weijer et al., 2001). It is therefore interesting to search for the origin of anomalies in South Atlantic water mass characteristics.

The South Atlantic Ocean receives large amounts of warm and salty water from the Indian Ocean via the so-called Agulhas leakage, the warm water path of Gordon's (1986) Global Conveyor Belt. This water than flows northward along the coast of Africa as the Benguela Current, crosses the Atlantic south of the equator and enters the Northern Hemisphere along the coast of Brazil. Cold water enters through Drake Passage (cold water path) and flows northward along the coast of South America as the Falkland or Malvinas Current. At about 45˚S , the Confluence region, it encounters the southward flowing Brazil Current and is deflected eastward. It finally reaches the area near the southern tip of Africa, where part of it branches directly into the Benguela Current (de Ruijter et al., 1999).

Method and Results

Both the warm and the cold water path thus come together near Cape Town. This is the key region to investigate origin and destination of water mass anomalies. To do so I define an index time series from the SST anomaly in this region (average over 10-18˚E and 26-34˚S) and correlate it backward and forward in time (i.e., at respectively negative and positive lags) with SST anomalies. This approach follows the one used by Sutton and Allen (1997) to track North Atlantic SST anomalies.

The SST product used is the one that entered the NCEP / NCAR reanalysis (Kalnay et al., 1996) as the lower boundary condition. It is available for the period 1949-2000. After removing the annual cycle and a linear trend, (austral) winter means (May-September) were calculated and smoothed by a five year running mean. This heavy filtering ensures that only decadal scale fluctuations remain. The resulting index time series is shown in Figure 1. It is characterized by large anomalies before approximately 1970, followed by a nearly constant period until about 1990, after which anomalies get larger again. This time series is significantly correlated with the time series of the third EOF of SST anomalies over the South Atlantic (70-0˚S, 70˚W-20˚E) . The EOF pattern resembles that of the correlation pattern at zero lag (see below). The third EOF explains nearly 16% of the variance.

The correlation of the index time series with SST for three different lags is shown in Figure 2 (lag positive if index time series leads). At lag 0 (middle panel) a large area of positive correlation following the path of the Benguela Current can be seen. At negative lags (upper panel) high correlations are found to the west of the index region and along the coast of East Africa. Inspecting a range of negative lags (not shown) reveals that the area of positive correlation in the South Atlantic starts to appear at approximately lag -5 (i.e., about five years before it peaks in the index region) in the Confluence region. Subsequently, it travels eastward and develops into the large area of positive correlation shown in the middle panel. At the same time the area of positive correlation in the Indian Ocean moves towards the tip of South Africa. It is, however, difficult to decide whether it really enters the South Atlantic or whether it is reflected into the Indian Ocean in the Agulhas

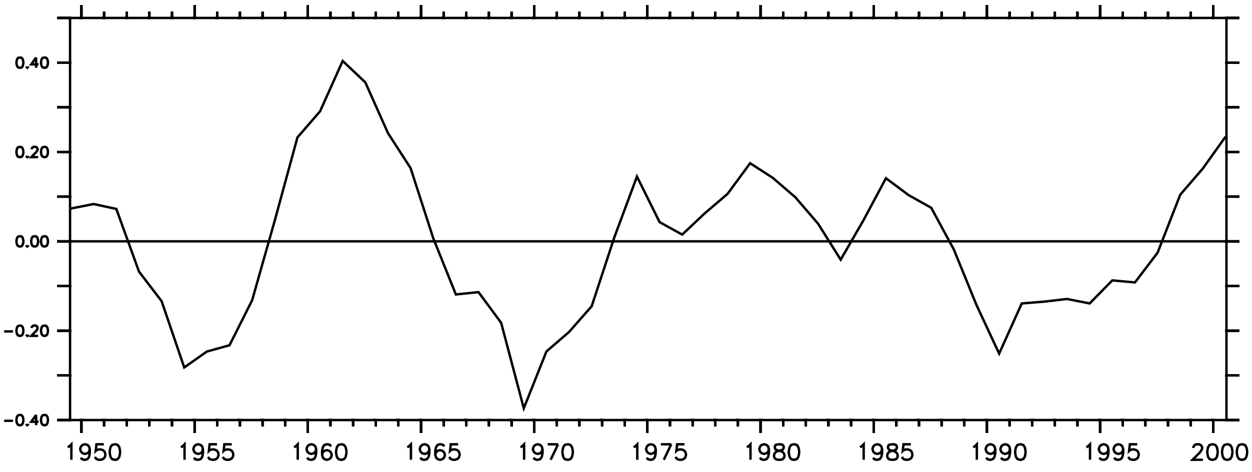

Figure 1: NCEP/NCAR SST anomalies averaged over 10-18^{o}E and 26-34^{o}S (1949-2000).

Retroflection Zone, as the regions of positive correlation in both ocean basins are always separated by a small area of near zero correlation. At positive lags (lower panel), i.e., after the peak in the index region, the area of positive correlation fades away in the Benguela Current.

Discussion and Conclusions

From this analysis the following picture emerges. SST anomalies originate in the Confluence region from where they spread eastward until they span the whole basin. In the region near South Africa (our index region) they may or may not be amplified by anomalies entering the South Atlantic from the Indian Ocean. The Benguela Current subsequently transports the anomalies northwestward into the tropical Atlantic. In this picture the cold water path plays an important role, at least for the spreading of SST anomalies.

The index time series (Figure 1) displays some oscillatory behaviour, at least during its first half. It is therefore not surprising that the positive correlations discussed above are preceded and followed by negative correlations at lags around ±10. However, the length of the time series (51 years) is too short to confidentially identify oscillations with such a long period.

To overcome this problem I tried to reproduce the results using the Kaplan (1998) reconstruction, which covers a much longer period. Although the corresponding index time series (Figure 3, page 22) clearly oscillates with a period of approximately 12 years, the correlation plots (not shown) do not display any significant negative correlations. Furthermore, the spreading path identified above from the NCEP / NCAR data is not reproduced. Instead, a clear connection with the Indian Ocean is found. However, the Kaplan dataset has a resolution of only 5˚lat / lon, compared to 1.875˚ for the NCEP / NCAR data set, so that the narrow currents around South Africa are not adequately resolved. This resolution problem may also cause the spreading path across the South Atlantic not to show up.

It may be clear from the foregoing discussion that the robustness of the results presented needs further investigation. Investigations should also address the subsurface ocean where large amounts of anomalous waters may be transported while being masked by SSTs that have locally been generated by air-sea exchange.

Acknowledgement:

I want to thank Wilco Hazeleger for valuable discussions. The data were obtained from the ingenious Ingrid site at LDEO (http: / / ingrid.ldeo.columbia.edu / SOURCES), and the plotting was done with Ferret.

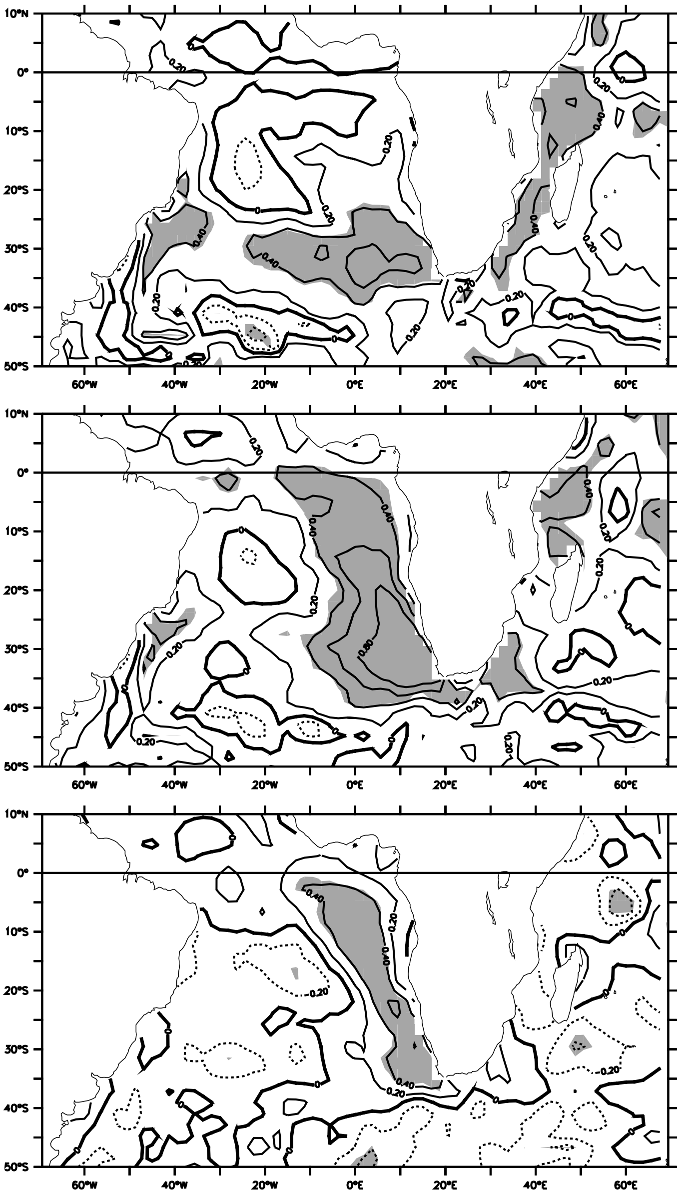

Figure 2: Correlation between index time series (Figure 1) and SST anomalies at lag -2 (upper panel), 0 (middle), and +2 (lower). Lag is positive when index time series leads. Shaded areas indicate significance exceeding 99%.

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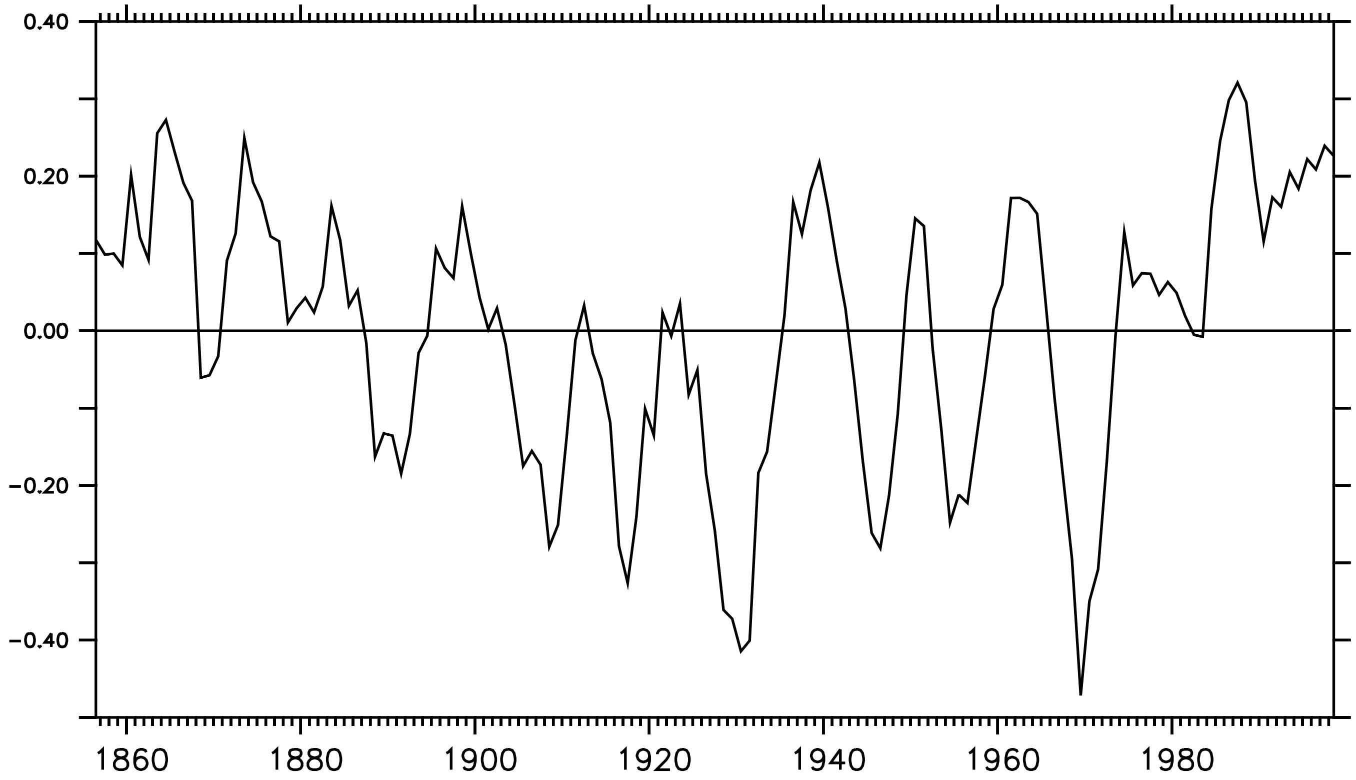

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Report from Variability of the African Climate System (VACS) Panel

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The first meeting of the VACS panel was held at the Drought Monitoring Centre (DMC) in Nairobi between 29-31 January 2001. After initial welcome greetings from the host and co-chair Laban Ogallo, the meeting was officially opened by Dr. Mukabana, Director of the Kenya Meteorological Department and Permanent Representative (PR) of Kenya to WMO. Dr Mukabana reminded the panel of the often very severe impacts of African climate variability on society and encouraged the panel to promote research which would help us improve our understanding of the climate variability and its impacts. The participants of the meeting included VACS panel members, Mike Harrison from the WMO CLIPS office, Daniel Olago from PAGES/ START, Fred Semazzi from North Carolina State University, and local scientists from the DMC.

The meeting was arranged around 9 sessions. Most time was devoted to the four projects identified in the CLIVAR Africa Implementation Plan (IP): Annual Cycle, Interannual Variability, Intraseasonal Variability and Decadal Variability. Sessions were also included on current related activity taking place in other CLIVAR panels, Observational Issues, Users and Applications, Awareness and Funding Issues and Capacity Building. There were also presentations from Laban Ogallo on DMC activities and Daniel Olago on PAGES activities. A detailed summary of the different sessions is included in a report which can be found on the VACS webpages. The most important points of interest regarding the four projects are included in this brief summary.

Annual Cycle

As noted in the IP, it is fundamentally important that we are able to document and understand the annual cycle over Africa and its role in the global climate system. Evidence exists already that highlights severe problems that current GCMs have in reproducing even basic aspects of the annual cycle of rainfall. We would be naive to assume that this does not have impacts on the global and regional climate in models used for seasonal and climate change prediction. The nature and magnitude of these impacts is something which needs to be investigated.

With this background in mind, and following the IP, the initial activity to be promoted during the first year of VACS will be the production of an atlas. The atlas will include key variables and diagnostics to document the an-

The paricipants of the first meeting of the VACS panel, Nairobi, Kenya

nual cycle of the African climate and the two-way interactions with the global climate. This atlas will be in electronic format with downloadable gridded data which can be used for research and for evaluating dynamical models. It was agreed that it would be useful to consider two scales during this activity: (a) a global scale concerned with the whole continent, surrounding oceans and the interactions with the rest of the world and (b) a regional scale where more local aspects may be considered. It was recognised that the regional centres in Niamey, Nairobi and Harari should play an important role in this activity, especially on the regional scale. Details of the key variables and diagnostics to be included in the atlas will be agreed by panel members during the next 6 months. After this, the activity will be coordinated internationally in order to start production of the atlas.

Interannual Variability

It was agreed that there would be benefit to include some key variables and diagnostics in the atlas described above which are relevant to interannual variability of African climate. Again, exactly what should be included will be discussed over the next 6 months.

A second activity which will be promoted during the first year of VACS is the case-study of the 1997/ 98 East African / Southern Africa rainfall event introduced in the IP. Following discussion at the meeting it was decided to extend the time period of the case-study to include 1999 through to early 2001 in order to allow consideration of the Mozambique floods and drought followed by extreme rainfall events in east Africa. The area will also be extended to include West Africa and the Atlantic. This framework was viewed a good one to consider key processes thought to be important in the generation of climate anomalies in Africa. These include consideration of the impacts of ENSO, the interaction of ENSO circulations with regional ocean basin forcing, feedbacks of African climate anomalies in remote circulations and regional oceans, and evaluation of land surface processes in the anomalous evolution of the annual cycle in these years. It was agreed that during the first year of VACS the large-scale SST- FORCED perspective for the case-study will be examined. This will be coordinated by e-mail amongst groups able to contribute results and analysis, including regional African climate centres.

Some regional modelling activity will contribute to the case study and a subgroup of the panel is considering how to plan this.

Intraseasonal Variability

It was recognised that this topic has strong links with the previous two and also with applications. Initial activity will be focused on the analysis of rainfall, satellite and reanalysis data to diagnose the nature of intraseasonal variability and associated regional circulations. This will be coordinated with the production of the atlas described above and again with the regional African centres.

There was also some discussion on the possibility of promoting a new sub-project on the variability of tropical cyclones in the Atlantic and Indian Oceans. Since this will link strongly with the VAMOS and Asia-Australian monsoon panels it was decided that these ideas should be discussed with these panels during the next year. The issue of Atlantic tropical cyclone activity could also be discussed at the planned tropical Atlantic workshop in Paris later this year.

Decadal variability

It was agreed by the panel that this project has lower priority than the previous three projects. The only activity promoted at this stage is to document observed decadal rainfall variability in the 20th Century and the extent to which this is captured in multi-decadal atmospheric GCM simulations forced with observed SSTs. More details about these plans and the other sessions of the meeting are included in the report which can be found on the VACS web page.

Finally, it should be noted that many of the VACS panel members visited the DMC the day after the meeting and interacted with African scientists currently attending a course on seasonal prediction. It was agreed that this type of activity should be encouraged at all future VACS meetings.

First International Conference on the North Atlantic Oscillation (NAO): Lessons and Challenges for CLIVAR

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The North Atlantic Oscillation (NAO) is characterized by an oscillation of atmospheric mass between the Arctic and the subtropical Atlantic. It is usually defined through changes in surface pressure, although it is evident in meteorological data into the stratosphere. When the NAO is in its "positive" phase, the wintertime meridional pressure gradient over the North Atlantic is large because the Icelandic low-pressure centre and the high-pressure center at the Azores are both enhanced. Both centres are weakened during its "negative" phase (see Fig. 1).

The changes in pressure gradient from one phase to another produce large changes in the mean wind speed and direction over the North Atlantic. Heat and moisture transport between the Atlantic and the surrounding continents also vary markedly, as do the intensity and number of winter storms, their paths, and the weather associated with them. Consequently, the NAO dictates climate variability from the eastern seaboard of the United States to Siberia and from the Arctic to the subtropical Atlantic, especially during winter. Agricultural yields, water management, energy supply and demand, and fish inventories, among many other things, are directly affected by the NAO. Yet, in spite of this pronounced influence, scientists remain puzzled about the basic climate processes that govern NAO variability, how the phenomenon has varied in the past or will in the future, and whether or not it is at all predictable.

Such issues were at the heart of a recent American Geophysical Union Chapman Conference in Ourense, Spain[1]. For the first time, atmospheric scientists, oceanographers, paleoclimatologists, biologists and those interested in the socio-economic impacts of climate variability came together to focus exclusively on the NAO and assess current understanding of it. About 180 scientists and students, from throughout Europe, North America and Japan, attended the meeting.

CLIVAR and the community at large are interested in the NAO primarily for three reasons:

First, the NAO strongly affects the Atlantic and Arctic Ocean by inducing substantial changes in surface wind patterns, thereby altering the heat, freshwater and momentum exchange at the ocean surface. These changes in turn affect the strength and character of the Atlantic's wind driven and thermohaline circulation (THC), the strength of the Arctic gyre and the amount of ice exported into the Atlantic. Some models suggest that a recent, prolonged upward trend in the NAO could temporarily reverse the expected slowing of the Atlantic THC in response to an-

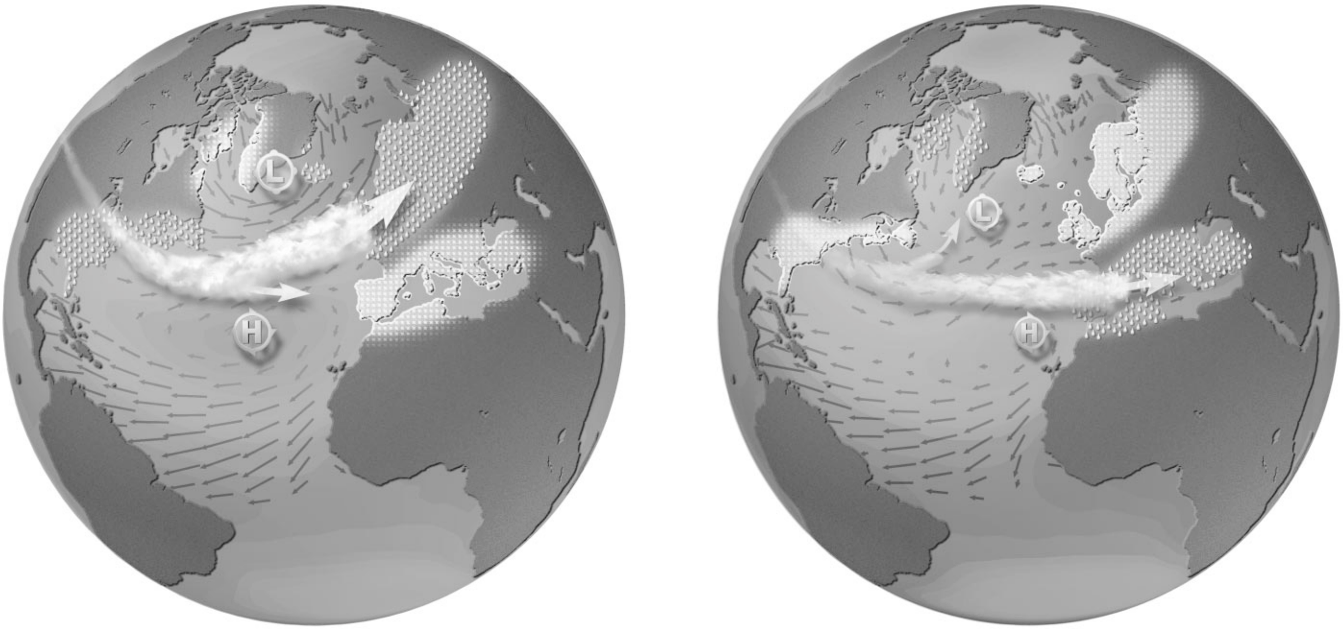

Fig. 1: The two phases of the NAO and some impacts on Europe and the eastern US. (left: positive phase, right negative phase)

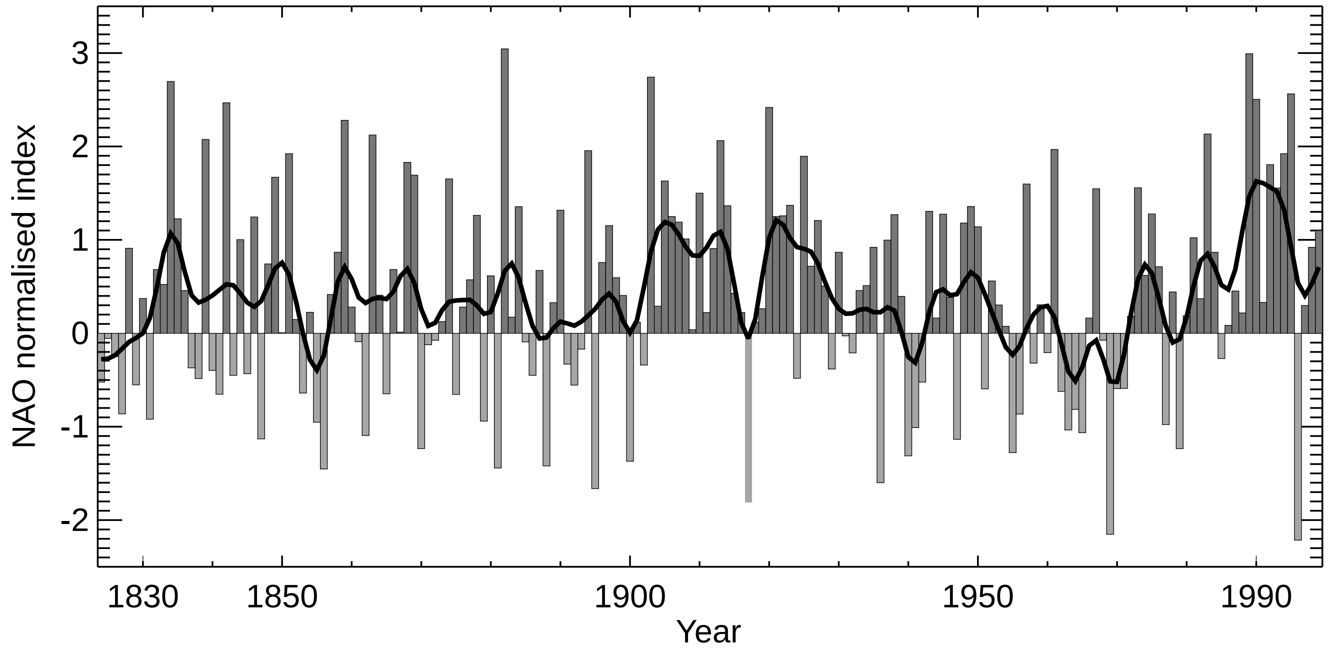

Fig. 2: Timeseries of the NAO from 1830 to present. (Courtesy T. Osborn, Climate Research Unit, University of East Anglia, UK.

thropogenic climate change. How will the NAO modulate the ability of the ocean to sequester CO_2?

Second, changes in the NAO have a wide range of effects on marine and terrestrial ecosystems, including the large-scale distribution and population of fish and shellfish, the production of zooplankton, the flowering dates of plants, and the growth, reproduction, and demography of many land animals. This strong projection on the environment and society makes even limited levels of NAO predictability "useful".

Third, low frequency changes in the NAO seem to contradict the notion that only chaotic atmospheric processes are at work over the North Atlantic. If the NAO is responding in a more or less systematic way to slower changing parts of the climate system, which parts are responsible and might they be the key to NAO predictability?

Recent research presented at the Chapman conference suggests that some stratospheric control of the troposphere may be occurring. The trend toward the positive phase of the NAO in recent decades may, therefore, be linked to processes affecting the stratospheric circulation on long time scales. Reductions in stratospheric ozone and increases in greenhouse gas concentrations, which radiatively cool the lower and middle stratosphere during the polar night, are obvious candidates.

The ocean may also have an appreciable influence on the atmosphere. Evidence presented at the conference indicated that the tendency of the ocean to preserve its thermal state from one winter to the next might impress some persistence on the atmosphere. A new statistical analysis revealed patterns in Atlantic sea surface temperatures (SSTs) that precede specific phases of the NAO by up to 6 months.

Moreover, it has recently been shown that atmospheric general circulation models, forced with the known global evolution of SST and sea ice cover, reproduce observed low frequency NAO variations. This indicates that low-frequency North Atlantic climate variability is not merely stochastic atmospheric noise but rather contains a response to changes in ocean surface temperatures and/or sea ice. Some of the latest results link the recent NAO trend to a progressive warming of tropical SSTs, in particular, the observed warming of the tropical Indian and Pacific Ocean waters.

The relevance of the NAO for CLIVAR is that it is an integrating theme. For instance, tropical variability may force remote atmospheric responses that affect the amplitude and time scales of NAO variability, while the NAO acts as an important extratropical forcing to excite changes in at least the tropical Atlantic. The NAO also orchestrates changes in the water properties of the North Atlantic and Arctic Oceans, including the distribution and intensity of the sinking branches of the THC. Clearly, then, the NAO needs to be studied with a global, rather than a regional, context.

Reference:

(1) The North Atlantic Oscillation, Ourense, Spain, 28 November-1 December 2000. Abstracts and other information are available over the web at: http://www.ldeo.columbia.edu/NAO/conference/chapman_conf.html

Summary of the Proceedings of the NASA-IPRC-CLIVAR Workshop on Decadal Climate Variability

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Introduction

The NASA-IPRC-CLIVAR Workshop on Decadal Climate Variability was convened in the East-West Center at the University of Hawaii in Manoa, Hawaii from 8 to 12 January 2001. The Organizing Committee consisted of Vikram Mehta, Jay McCreary, David Battisti, Tony Busalacchi, Tom Delworth, Chet Koblinsky, Bill Lau, Eric Lindstrom, Mike Mann, Doug Martinson, Jerry Meehl, Eric Smith, Martin Visbeck, and Toshio Yamagata. The Workshop was sponsored by NASA's Oceanography Program, the University of Hawaii's International Pacific Research Center (IPRC), and CLIVAR. IPRC was the local host. The Workshop was organized

- to bring together researchers active in various aspects of Decadal Climate Variability,
- to provide inputs to NASA's Earth Science program from this community, and
- to continue to develop an integrated framework of research in the observation, description, physics, prediction, and societal impacts of Decadal Climate Variability and its interaction with seasonal-to-interannual and anthropogenic climate phenomena.

The Workshop was divided in sessions on Decadal-multidecadal climate variability seen via paleoclimate data, Observations of decadal-multidecadal climate variability, Interaction between natural decadal-multidecadal climate variability and anthropogenic climate change, Modelling and predictability of decadal-multidecadal climate variability, High-latitude ocean-ice-atmosphere processes that lead to decadal-multidecadal climate variability, Interaction between natural decadal-multidecadal and interannual climate variabilities, and Observing and data assimilation systems for decadal-multidecadal climate variability. There were approximately 100 participants in this Workshop, 78 of whom made oral presentations on various aspects of decadal climate variability. In addition to the oral presentations, there were discussion sessions on Paleoclimate data, Instrument-measured data, Role of ocean circulations, Role of sea ice, Multiyear-to-decadal climate predictability, and Observing and data assimilation systems. The participants included program managers and other representatives from NASA, NOAA, NSF, CLIVAR, and US-CLIVAR. Preliminary conclusions and recommendations are summarized below.

Workshop conclusions

1. It is important to study decadal climate variability and predictability because of its societal impacts and because there are mechanisms in the climate system that have inherent decadal time scales. Decadal climate variability should not be viewed, however, in isolation but as an important component of multi-time scale climate interactions.
2. There are growing needs to co-ordinate individual research efforts and to identify key targets for predictability and prediction studies.
3. It is becoming increasingly important to identify true decadal-multidecadal oscillations and reduce the number of "important" spatial patterns. It is also vitally important for understanding and predictability to rigorously test observed and model data to see if decadal-multidecadal spectral peaks rise above background noise.
4. There is an increasing recognition that the influence of the oceans may not be manifest in decadal-multidecadal climate variability solely via sea surface temperatures.
5. Paleoclimate data are vital for further progress and may have much more to offer than hitherto recognized.

Workshop recommendations

1. A strategy to provide decade(s)-long, space-based, geophysical data products should be developed by space agencies. This encompasses the need to work carefully to maintain calibration and validation for long periods despite changes in technology, agency responsibility, and evolving science requirements. Long, global, well-maintained, instrumental time series are critical to climate studies.
2. In support of this space-based observing program, there should be an in-situ measurement / calibration program using buoy- and float-mounted instruments. In view of the observations and model results showing a likely association between the subtropical gyres, and decadal SST and upper-ocean heat content anomalies, extensions of the TAO and PIRATA arrays to the equatorward sides of the subtropical gyres is worth considering. To observe gyre circulations and potential subduction processes, globally deployed PALACE floats in the Atlantic and the Pacific are required that would reside along a particular subsurface density surface and profile to the surface intermittently. The assimilation of these in-situ observations in global ocean-atmosphere models should be an integral part of this program.
3. The decadal climate community should develop closer links with the paleoclimate community. Modelling efforts should be organized to simulate paleoclimate proxy data to develop an understanding of the interactions between paleoclimate "observers" such as trees, ice cores, and corals; and the environments in which

these "observers" evolve. Such an understanding would facilitate a better interpretation of the existing and future paleoclimate proxy data.

4. U.S. scientists and their international collaborators need increased support for development of global instrumental and proxy databases through special projects, including data archaeology and rescue projects. A hierarchy of quality-controlled ocean, atmosphere, and land data sets ranging from the basic data sets containing original measurements to various levels of derived data sets should be established. The databases, developed as a result of such projects, will support efforts in climate system modelling and remote sensing.
5. There should be a programme to rigorously analyse these historical (instrument-measured and proxy) data sets to quantify characteristics of decadal climate variability, decadal variability of ENSO and its teleconnections, and to conduct empirical predictability studies.
6. Real, interactive links should be developed between the decadal climate community and the climate impacts and applications communities so that societal impacts assessment information can guide multiyear to decadal climate predictability and prediction efforts.
7. A Web-based, virtual Center should be developed to co-ordinate decadal climate variability and predictability efforts.

Conference announcement

The Joint Assembly of the International Association for the Physical Sciences of the Oceans (IAPSO) and the International Association for Biological Oceanography (IABO), will be held in Mar del Plata, Argentina, on 21 - 28 October 2001, with a number of CLIVAR and WOCE related Joint Symposia. For CLIVAR the most interesting sessions are:

1. Role of Ocean on Climate Variability over South America (Convenor C.R. Mechoso)
2. Decadal Variability and Predictability (Convenor: T. Busalacchi)

and sessions as: 'South Pacific Circulation and Links with the Indian and Southern Oceans', 'South Atlantic Links with the Indian and Pacific Oceans' and 'Interhemispheric Water Exchange in theAtlantic Ocean'.

Abstracts must be submitted electronically, and must be in the format given on the Joint Assembly Web page at http://www.criba.edu.ar/2001_ocean
The abstract deadline is 6 April 2001.

CLIVAR Calendar

2001	Meeting	Location	Attendance
March 19-23	Joint Scientific Committee of the WCRP - 22nd Session -	Boulder, USA	Invitation
March 21-22	International Colloquium: Forecasting the Monsoon from Days to Decades	New Dehli, India	Invitation
March 23-28	International Workshop on Monsoons	New Dehli, India	Open
March 25-30	European Geophysical Society XXVI General Assembly	Nice, France	Open
March 26-30	CLIVAR VAMOS Panel, 4th Session	Montevideo, Uruguay	Inviation
March 27-30	CLIVAR Ocean Observations Panel, 1st Session	Hobart, Australia	Invitation
May 14-18	CLIVAR Scientific Steering Group, 10th Session	Toulouse, France	Invitation
May 21-25	WCRP/SCOR Workshop on Intercomparison and Validation of Ocean-Atmosphere Flux Fields	Washington, USA	Open
June 6-8	Climate Change and Variability in Northern Europe - Proxy Data, Instrumental Records, Climate Models and Interactions	Turku, Finland	Open
June 12-14	CLIVAR Atlantic Panel , 3rd Session	Boulder, USA	Invitation
July 10-13	IGBP/WCRP Open Science Conference	Amsterdam, The Netherlands	Open
July 14	PAGES/CLIVAR Working Group	Amsterdam, The Netherlands	Invitation
July 10-18	IAMAS General Assembly	Innsbruck, Austria	Open
September 3-7	CLIVAR Tropical Atlantic Workshop	Paris, France	Open
September 10-14	4th International GEWEX Conference	Paris, France	Open

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

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