ence of declining summer insolation by the orbital factors. Both the MWP and a two-phased LIA are detectable in the data set, as well as rapid cooling and warming intervals, happening over a decade: Note cold-warm-cold phase in the period 1300–1450 AD according to the time scale of the core. Possible century scale cycles may be identified in the data set, but await improved chronological control.

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

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

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

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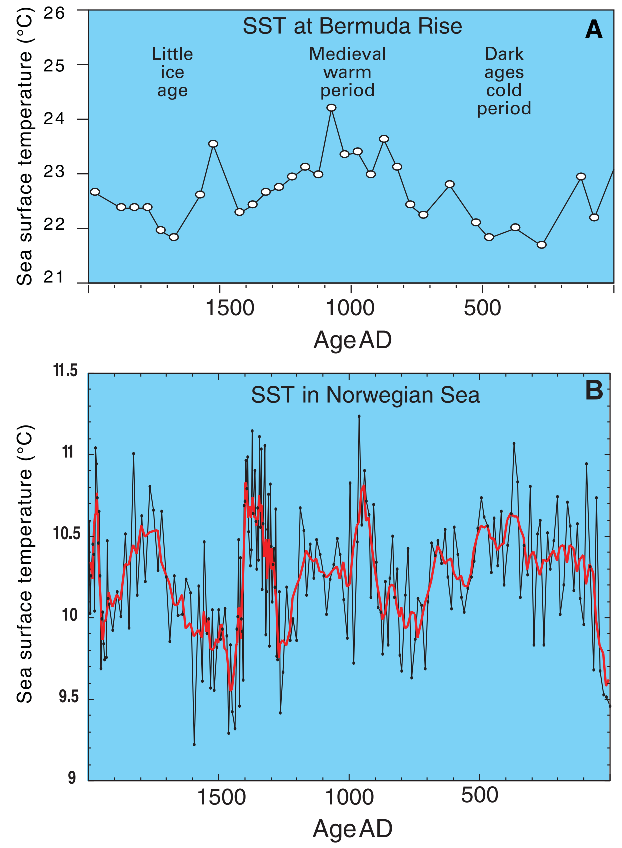

Figure 1: *(A) SST-summer estimates for the last 2000 years at Bermuda Rise. From [Keigwin and Pickart, 1999]. (B) New SST- summer estimates for the last 2000 years at Vøring Plateau, Eastern Norwegian Sea based on diatom transfer functions. The red line is a 5pt running mean.*

Opportunities for CLIVAR/PAGES NAO Studies

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

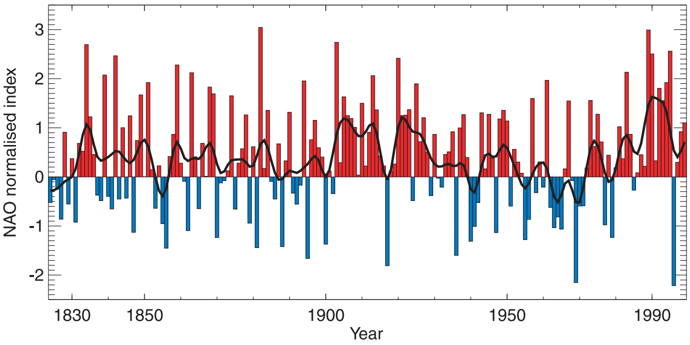

Figure 1: *Updated winter NAO index based on instrumental data. Courtesy of P.D. Jones to T. Osborn (http://www.cru.uea.ac.uk/~timo/projpages/nao_update.htm)*

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

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

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

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

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

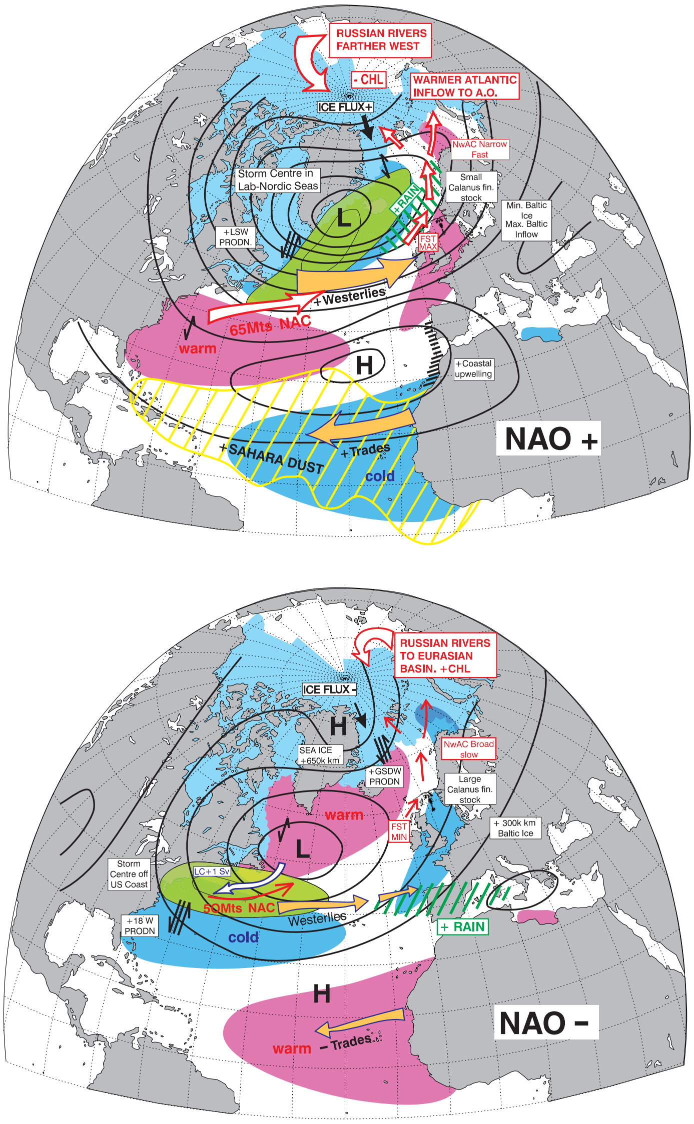

Figure 2: *Schematic representations of the (a) positive and (b) negative phases of the North Atlantic Oscillation. (courtesy of B. Dickson, CEFAS).*

Paleoclimatic Opportunities:

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

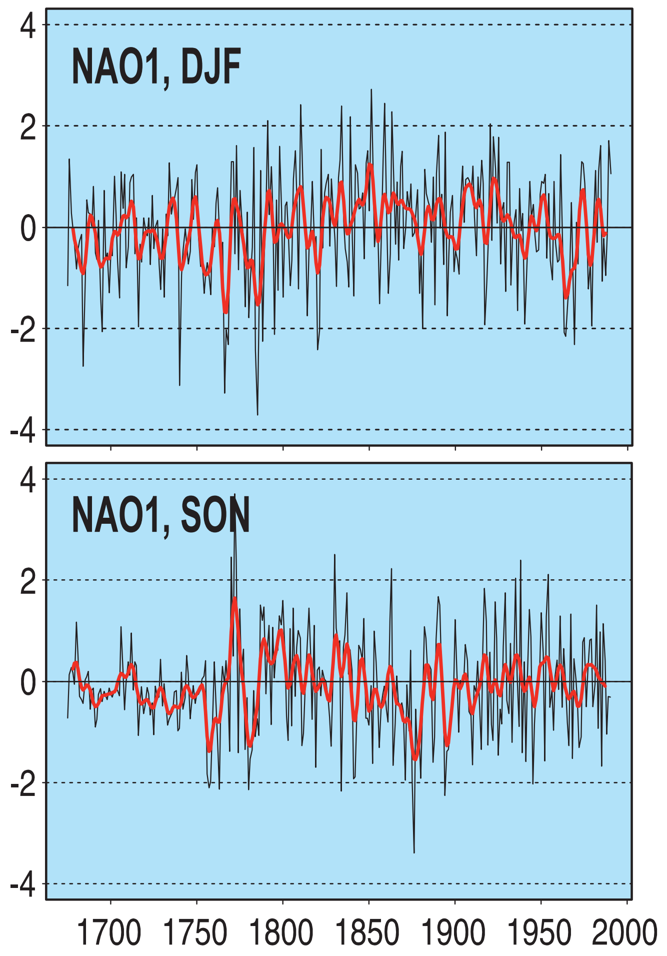

Figure 3: *Normalized time series of the reconstructed mean winter (DJF) and autumn (SON) indices from 1675 to 1990. Red lines are 7 point low-pass filtered time series. (Source: Luterbacher et al., 1999)*

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

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

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

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