GEOPHYSICAL RESEARCH LETTERS, VOL. 28, NO. 15, 2959-2962, August, 2001.

Arctic Oscillation signature in a Red Sea coral

Norel Rimbu, Gerrit Lohmann, Thomas Felis, and Jürgen Pätzold

Department of Geoscience, University of Bremen, Germany

Abstract. We show that the winter time series of the Ras Umm Sidd coral oxygen isotope record from the northern Red Sea (approximately 28°N) is linked to the Arctic Oscillation phenomenon, the Northern Hemisphere's dominant mode of atmospheric variability. Until now, the detection of this mode, which is most prominent in winter, in proxy climate records was difficult due to the lack of a clear seasonality in most paleoclimatic archives. The results suggest that northern Red Sea corals can provide information about the low-frequency variability of the Northern Hemisphere winter circulation during the pre-instrumental period.

1. Introduction

Compared to other paleoclimatic archives, annually-banded massive corals from the surface oceans provide a clear seasonal resolution. However, the development of coral reefs is restricted to warmer water temperatures: Most reef-building corals are located in regions where mean annual water temperatures are around 24°C and/or mean winter minimum temperatures are not below 18°C. Therefore, recent coral-based paleoclimatic research has focused mainly on the tropics [e.g., Cole et al., 1993; Charles et al. 1997; Urban et al., 2000]. Here we show that a subtropical coral from the northern Red Sea has the potential to archive past mid- and high-latitude climate variability.

Coral oxygen isotope records have been successfully used for reconstruction purposes of sea surface temperature (SST) and hydrologic balance in the pre-instrumental period [e.g., Cole et al., 1993; Charles et al. 1997; Urban et al., 2000]. The ratio of the isotopic species of oxygen ($^{18}O/^{16}O$) incorporated into coral skeletons during growth, reported as $\delta^{18}O$, is influenced by both temperature and $\delta^{18}O$ of the ambient seawater during skeleton precipitation. Variations in coral $\delta^{18}O$ are therefore related to climate conditions and ocean circulation.

Recently, a bimonthly-resolution oxygen isotope record was generated from a coral growing at approximately 28°N in the northern Red Sea [Felis et al., 2000]. The coral record from Ras Umm Sidd, near the southern tip of the Sinai Peninsula (27°50.9'N, 34°18.6'E), located at the northern rim of the African-Asian arid belt, was shown [Felis et al., 2000] to be correlated with regional SST, air temperature, precipitation and sea level pressure (SLP) variability and revealed the important role of Atlantic and Pacific teleconnections on Middle East climate variability during the past nearly 250 years.

Here, we analyze the winter time series of the Ras Umm Sidd coral $\delta^{18}O$ record showing large decadal variations over the last centuries. Historical and reanalysis data sets are used to find the associated atmospheric circulation and sea surface temperature pattern. One objective of our study is to understand the teleconnections that control the low frequency variations in the coral record. We provide evidence that the Arctic Oscillation phenomenon, the leading mode in the Northern Hemisphere wintertime circulation pattern, is well documented in the winter time series of this coral record from the northern Red Sea.

2. Data

The January-February values of each year were taken from the bimonthly-resolution Ras Umm Sidd coral $\delta^{18}O$ record [Felis et al., 2000] to generate a winter time series for the period 1750-1995. The winter time series was low-pass filtered (3-year running mean), linear detrended and normalized by its standard deviation.

For the Northern Hemisphere atmospheric circulation we used a historical SLP data set (5°x5° grid box resolution) covering the period 1899-1995 [Trenberth and Paolino, 1980]. SST and evaporation data were extracted from UWM/COADS (1°x1°) covering the period 1945-1993 [da Silva et al., 1994]. SST (1°x1°) and surface wind (2.5°x2.5°) data were extracted from GISST2.3b [Rayner et al., 1996] and NCEP/NCAR reanalysis [Kalnay et al., 1996] data sets respectively, covering the period 1948-1995. All fields were processed in the same way. Monthly means of January and February were calculated, averaged, detrended, and smoothed (3-year running mean) in order to obtain the low-frequency components of the fields.

3. Connection to Northern Hemisphere circulation

In order to identify atmospheric circulation patterns associated with low-frequency variations of the winter coral time series, we determine the spatial distribution of the correlation coefficients between sea level pressure

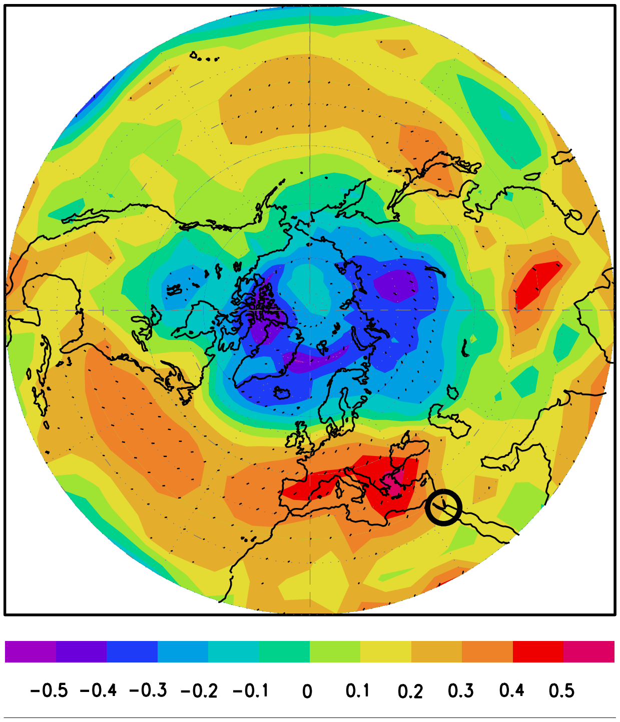

Figure 1: One-year-lag correlation of sea level pressure [Trenberth and Paolino, 1980] with coral δ^{18}O for January-February. The areas with correlations significant at the 95% level are hatched. The coral location is indicated by the circle.

[Trenberth and Paolino, 1980] and coral δ^{18}O for the period 1899-1995. The correlation map (Fig. 1) shows a Northern Hemisphere pattern with significant correlations over the Arctic region and with opposite sign over mid-latitudes.

This correlation pattern is strikingly similar to the Arctic Oscillation (AO) sea level pressure pattern [Thompson and Wallace, 1998]. The variability of the projection on this spatial pattern is strongly coupled to the strength of the stratospheric polar vortex [Baldwin and Dunkerton, 1999; Thompson and Wallace, 2000] and has attracted considerable interest recently, both in terms of understanding its observed behavior [Perlwitz and Graf, 1995] and its role in masking the global warming trend [Fyfe et al., 1999].

We notice only slight differences between the pattern of the AO and Fig. 1: a westward displaced high pressure center in the Pacific, and a high pressure center over southern Asia relative to the AO. To better asses and confirm the relation between the pattern represented in Fig. 1 and the AO, we compare the winter coral δ^{18}O time series directly with the AO index (Fig. 2). The AO index is highly correlated with the winter coral time series when AO leads by one to two years the δ^{18}O variations. The highest correlation is over the last 50 years (r=0.75). The AO index for 1899-1957 is based on data described in Trenberth and Paolino [1980] and for 1958-1995 on NCEP/NCAR reanalysis data [Kalnay et al., 1996].

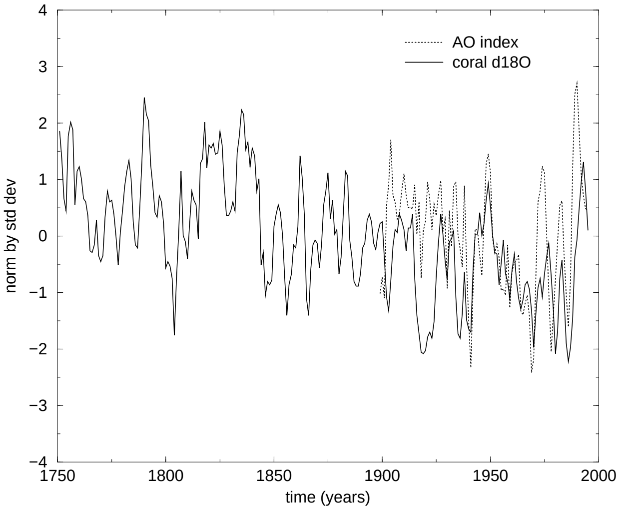

Figure 2: Normalized coral δ^{18}O (solid line) and AO index (dotted line) time series for January-February.

The composite map of SST and surface wind for winter (Fig. 3) emphasizes a regional circulation pattern for the Middle East region compatible with the correlation pattern represented in Fig. 1. When high coral δ^{18}O winter values are realized, enhanced advection of cold air from southern Europe over the eastern Mediterranean and the northern Red Sea is observed. This circulation pattern results in lower SSTs in the Black Sea, the eastern Mediterranean Sea, and the Red Sea as well as higher SSTs in the western Mediterranean Sea. Along with the strong continental influence during positive AO, the Red Sea area receives cold and dry air from the north. Based on the high correlation of the AO index and coral δ^{18}O, the winter circulation during a phase of positive AO is very similar to that shown in Fig. 3. The remote effect on Middle Eastern climate is consistent with a North Atlantic influence on Middle Eastern rainfall described in earlier studies [e.g., Hurrell 1995, Eshel and Farrell, 2000; Cullen and deMenocal, 2000].

4. Red Sea basin scale analysis

In the Red Sea, the excess evaporation over precipitation drives the thermohaline circulation causing a northward surface inflow from the Indian Ocean [Cember, 1988]. Intermediate and deep waters are formed at the northern end of the basin giving rise to southward flowing currents at depth. The upper layer of the Red Sea is renewed on a timescale of a few years [Eshel and Naik, 1997].

The large scale AO atmospheric forcing induces basin scale perturbation with strongest variability in the central Red Sea. The corresponding leading empirical orthogonal functions (EOFs) for winter SST and evapo-

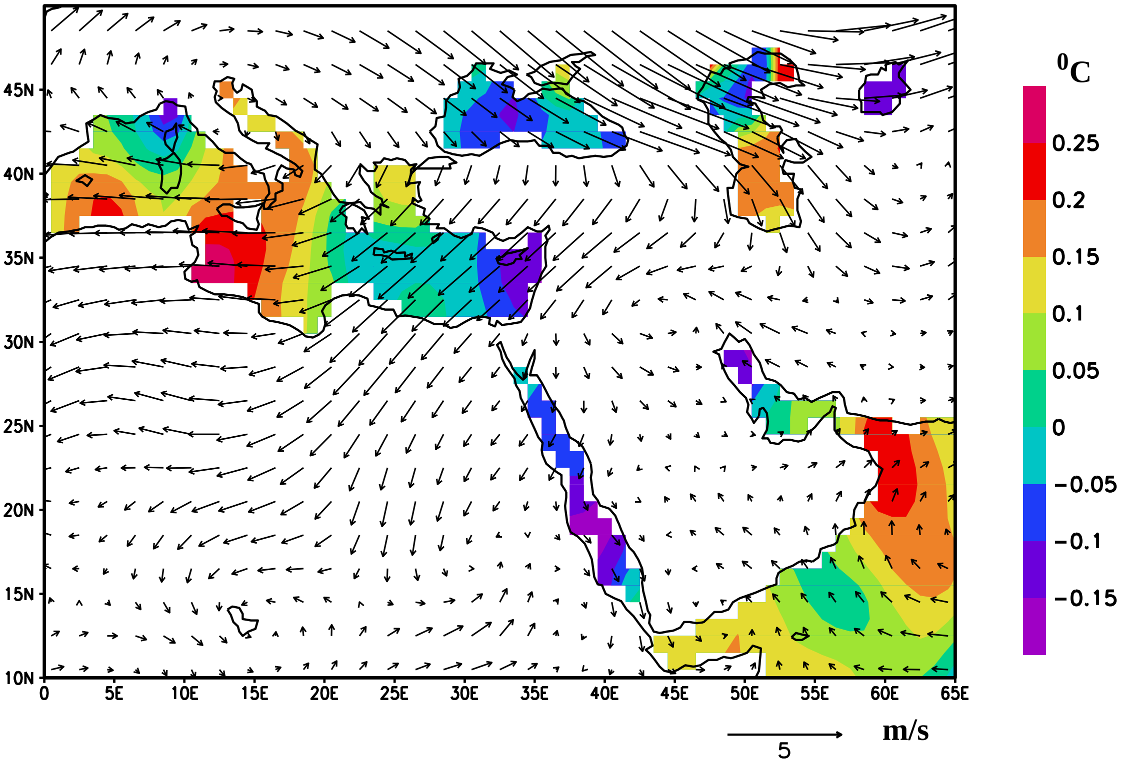

Figure 3: Composite maps (difference between averaged maps for which winter coral δ^{18}O was higher/lower than one standard deviation) for SST (color) [Rayner et al., 1996] and 925 mb wind (vector) [Kalnay et al., 1996] for the period 1948-1995, January-February. Units are °C and m/s, respectively.

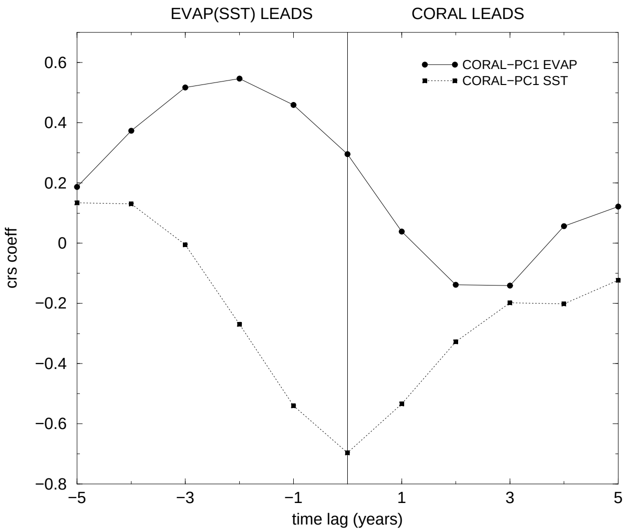

Figure 4: Cross-correlation functions for January-February coral δ^{18}O and time series of the expansion coefficients for the leading EOFs of evaporation (solid line) and SST (dashed line). Cold and saline conditions in the water are related to high coral δ^{18}O values.

ration in the period 1948-1995 [da Silva et al., 1994] explain 81% and 75% of the low-frequency variance, respectively. The time series of the expansion coefficient for the evaporation EOF is maximal correlated when leading the winter coral δ^{18}O values (Fig. 4). Note that the AO index is best correlated with the coral time series when leading it by about one year, consistent with the characteristic Red Sea ocean circulation timescales estimated by Eshel et al. [2000]. An ocean circulation model study [Eshel and Naik, 1997] further attributed this time scale to salinity anomalies south of the deep-water formation region, which precondition the northern Red Sea water column to winter deep mixing. It is conceivable that salinity anomalies are generated by strong evaporation in the central Red Sea during a phase of strong AO. The zero lag for SST (Fig. 4) is consistent with a necessary condition for winter convection related to episodic atmospheric cold air advection which is suppressed in the climatological ocean forcing [Eshel and Naik, 1997].

Analyzing the seasonal cycle of the coral δ^{18}O record, we further find, that summer coral δ^{18}O values are highly correlated with the previous winter evaporation forcing (not shown), supporting a propagation mechanism. A detailed analysis of this mechanisms will need further investigations using a model of the Red Sea and is beyond the scope of the present study.

5. Discussion and Conclusions

We have shown that the Arctic Oscillation phenomenon, the leading mode in the Northern Hemisphere wintertime circulation pattern, is well documented in the winter time series of the Ras Umm Sidd coral δ^{18}O record from the northern Red Sea [Felis et al., 2000]. The results suggest that northern Red Sea corals can be used both to obtain information related to the low-frequency variability of the Northern Hemisphere winter circulation during the pre-instrumental period and to bring climate shifts, as i.e. indicated by the AO index in the 1970's, into a long-term context.

Do we expect to detect the AO in all corals at subtropical latitudes? The relatively narrow Red Sea is constantly supplied with continental air. Therefore, climate variations with strong continental influence such as the AO can be monitored by corals in this marginal sea.

Acknowledgments NR would like to acknowledge the hospitality at Bremen University during his visit in the Department of Geosciences. We received funding from the German Federal Ministry for Education and Research through KIHZ project. Profs. G. Wefer and K. Herterich are greatfully acknowledged for their support. The manuscript benefited from comments of Gidon Eschel, Walter Hale, and an anonymous reviewer.

References

Baldwin, M. P., and T. J. Dunkerton, Propagation of the Arctic Oscillation from stratosphere to troposphere, *J. Geophys. Res., 104,* 30937-30946, 1999.

Cember, R. P., On the sources, formation, and circulation of Red Sea deep water, *J. Geophys. Res., 93 (C7),* 8175-8191, 1988.

Charles, C. D., D. E. Hunter, and R. G. Fairbanks, Interaction between the ENSO and the Asian monsoon in a coral record of tropical climate, *Science, 277,* 925-928, 1997.

Cole, J. E., R. G. Fairbanks, and G. T. Shen, Recent variability in the Southern Oscillation: Isotopic results from a Tarawa Atoll coral, *Science, 260,* 1790-1793, 1993.

Cullen, H. M., and P. B. deMenocal, North Atlantic influence on Tigris-Euphrates streamflow, *Int. J. Clim., 20,* 853-863, 2000.

da Silva, A., A. C. Young, and S. Levitus, Atlas of surface marine data, Vol. 1: Algorithms and procedures, *NOAA Atlas NESDIS 6,* U.S. Department of Commerce, Washington, D.C., 1994.

Eshel, G., D. P. Schrag, and B. F. Farrell, Troposphere-planetary boundary layer interactions and the evolution of ocean surface density: lessons from Red Sea corals, *J. Clim., 13,* 339-351, 2000.

Eshel, G., and B. F. Farrell, Mechanims of eastern Mediterranean rainfall variability, *J. Atmos. Sci., 57,* 3219-3232, 2000.

Eshel, G., and N. H. Naik, Climatological coastal jet collision, intermediate water formation, and the general circulation of the Red Sea, *J. Phys. Oceanogr., 27,* 1233-1257, 1997.

Felis, T., J. Pätzold, Y. Loya, M. Fine, A. H. Nawar, and G. Wefer, A coral oxygen isotope record from the northern Red Sea documenting NAO, ENSO, and North Pacific teleconnections on Middle East climate variability since the year 1750, *Paleoceanography, 15,* 679-694, 2000.

Fyfe, J. C., G. J. Boer, and G. Flato, The Arctic and Antarctic Oscillations and their projected changes under global warming, *Geophys. Res. Lett., 26,* 11, 1601-1604, 1999.

Hurrell J. W., Decadal trends in the North Atlantic Oscillation: Regional temperatures and precipitation, *Science 269,* 676-679, 1995.

Kalnay, E. M. and co-authors, The NCEP/NCAR 40-year reanalysis project, *Bull. Amer. Meteor. Soc., 77,* 437-471, 1996.

Perlwitz, J., and H.-F. Graf, The statistical connection between tropospheric and stratospheric circulation of the Northern Hemisphere in winter. *J. Clim., 8,* 2281-2295, 1995.

Rayner, N. A., E. B. Horton, D. E. Parker, C. K. Folland, and R. B. Hackett, Version 2.2 of the Global sea-Ice and Sea Surface Temperature data set, 1903-1994, *Clim. Res. Tech. Note. 74,* Hadley Centre, U.K. Meteorol. Off., Bracknell, England, 1996.

Thompson, D. W. J., and J. W. Wallace, The Arctic Oscillation signature in the wintertime geopotential height and temperature fields, *Geophys. Res. Lett., 25,* 1297-1300, 1998.

Thompson, D. W. J., and J. W. Wallace, Annular modes in the extratropical circulation. Part I: month-to-month variability, *J. Atmos. Sci., 13,* 1000-1016, 2000.

Trenberth, K. E., and D. A. Paolino, The northern hemisphere sea level pressure data set: Trends, errors and discontinuities, *Mon. Wea. Rev., 108,* 855-872, 1980.

Urban, F. E., J. E. Cole, and J. T. Overpeck, Influence of mean climate change on climate variability from 155-year tropical Pacific coral record, *Nature, 407,* 989-993, 2000.

N. Rimbu, G. Lohmann, T. Felis, and J. Pätzold.
Bremen University, Department of Geosciences,
Klagenfurter Str., 28359 Bremen, Germany.
e-mail: gerrit@palmod.uni-bremen.de

Received February 26, 2001
accepted April 24, 2001