Observed Decadal Midlatitude and Tropical Atlantic Climate Variability

Balaji Rajagopalan, Yochanan Kushnir, and Yves M. Tourre
Lamont-Doherty Earth Observatory of Columbia University, Palisades, New York

Abstract. Two common indicators of Atlantic climate variability, viz., the North Atlantic oscillation (NAO) and the cross-intertropical convergence zone (ITCZ) sea surface temperature (SST) gradient, are examined for their frequency characteristics and midlatitude-tropical links. SST anomalies north and south of the ITCZ are found to be uncorrelated on all time scales, while the sea level pressure (SLP) fluctuations associated with the NAO display a coherent seesaw between Iceland and the Azores. This out-of-phase relationship spans a broad range of time scales, but is particularly strong in the 5 - 10 year period band. Strong, broad-band coherence between the NAO and the tropical Atlantic cross-ITCZ SST difference is found in the 8-20 year period band, suggesting a significant midlatitude-tropical interaction. Moreover, tropical Atlantic SSTs on both sides of the ITCZ, separately, exhibit significant coherence with the NAO index and SLP variability over Iceland and the Azores. Based on these findings we hypothesize that the tropical Atlantic (TA) ocean-atmosphere interaction is affecting North Atlantic climate variability.

1. Introduction

Several recent studies reveal that the climate in the north Atlantic (NA) basin exhibits coherent variability at decadal and interdecadal time scales - in observations (Deser and Blackmon, 1993; Kushnir, 1994; Hurrell and van Loon, 1997; Mann and Park, 1994, 1996; Sutton and Allen, 1997, Tourre et al., 1998) and in coupled models (Zorita and Frankignoul, 1997; Weng and Neelin, 1997; Grötzner et al., 1998; Delworth and Mehta, 1998). Decadal variability was also reported in the South Atlantic (SA) by Venegas et al. (1998). The dominant pattern of atmospheric variability in the NA consists of a see-saw in the SLP with anomalies of opposite polarity situated around the centers of the Icelandic Low and the Azores High. A banded SST structure of alternate positive and negative anomalies is in spatial quadrature with the SLP anomalies (see e.g. Deser and Blackmon, 1993, Tourre et al., 1998). Xie and Tanimoto (1998) modeled that pattern and called it a "pan-Atlantic decadal oscillation", because it extends from the SA to the subpolar NA. This is corroborated in Tourre et al. (1998). The dominant periods associated with this pattern was found to be in the 10-12 year band by Deser and Blackmon (1993) and Tourre et al. (1998).

It is the goal of this paper is to further explore the relationship between the midlatitude and TA climate variability and its physical implications. We argue that the relationship between TA SST variability on both sides of the ITCZ, and the NAO provides for a possible new understanding of Atlantic decadal variability. In section 2 we briefly describe the data and methodology. Results are presented in Section 3 followed by discussion and conclusion in Section 4.

2. Data and Methods

The data used is from a "reduced space" optimal smoother algorithm applied to 136 years (1865-1991) of global monthly anomalies of SST obtained from the UK Hadley Center archives (Bottomley et al., 1990; Kaplan et al., 1997, and Kaplan et al., 1998), and a similar optimal interpolation of global monthly SLP anomalies from the NOAA Comprehensive Ocean Atmosphere Data Set (Woodruff et al., 1987, Kaplan, personal communication). TA SST anomalies display peak amplitudes in the zonal belt roughly 20° latitude wide (Servain, 1991; Houghton and Tourre, 1992; Chang et al., 1997; Tourre et al., 1998). Consequently we used the generally accepted definition of the north and south tropical regions to track SST variability there and form the following monthly indices for the 136 years :

1. TNA: Tropical North Atlantic SST index, normalized, area averaged SST anomaly in the region of 5°N-20°N, 20°W-40°W;
2. TSA: Tropical South Atlantic SST index, the normalized, area average SST in the region of 5°S-15°S, 15°W-5°E;
3. TNSD: TA north-south SST difference (across the ITCZ), the difference between TNA and TSA (which are defined above).

In addition we also use the NAO index as defined by the difference in normalized SLP anomalies between Ponta Delgada (Azores) and Reykjavik (Iceland).

Our study is based on the examination of the spectra and cross spectra of these indices. To that end we use the multi-taper spectral estimation (Mann and Lees, 1996) and spectral coherence estimation (Mann and Park, 1993) procedures which are designed to retain a high spectral resolution while reducing leakage and increasing statistical confidence in spectral features.

3. Results

Recent analyses by Mehta (1998) and Enfield (personal communication) show, that the correlation and coherence between TA SST anomalies north and south of the ITCZ are not statistically significant. Here we demonstrate and corroborate this in two ways. First, we obtain the product of TNA and TSA and smooth the resulting series by a 2 year filter, to remove high frequency fluctuations. This is shown in Fig. 1a (dotted line). The same is done with the product of Azores and Iceland SLP series and it is shown as a solid line in Fig. 1a. If SST anomalies north and south of the ITCZ are simultaneously out-of-phase, the value of the product will tend to be negative. Clearly this is not the case here where the product of TNA and TSA is centered roughly around zero. In addition we compute the squared coherency between TNA and TSA (Fig. 1b). Significant coherence at the 95% confidence level is limited to three narrow peaks, all at frequencies higher than 1/10 year^{-1}. In contrast the SLP anomalies comprising the NAO index describe a clear simultaneous seesaw fluctuations. This is evident in their product which is centered roughly around -0.5. The squared coherency between Iceland and Azores SLP anomalies (Fig. 1c) shows broad-band significant coherence (with a phase of $\pm\pi$) in the quasi-biennial to the quasi-decadal frequencies.

The spectra of TNA and TSA (Figs. 2a and 2b) display significant power in the 10-20 year period band at the 95% level. This broad-band power is also reflected in the spectrum of their difference, TNSD, (Fig. 2c), consistent with the results of Mehta (1998), Chang et al. (1997), and Xie and Tanimoto (1998). This frequency band partially overlaps the band over which the monthly NAO spectrum displays an increase in power, albeit only marginally significant (Fig. 2d). The decadal and interdecadal fluctuation in the NAO and tropical SST indices are strongly related. This is revealed in the cross spectral analysis between these indices, as shown in Fig. 3. Both TNA and TSA are significantly coherent above the 95% level with the NAO on decadal and interdecadal time scales (8-20 year period band, Figs. 3a and 3b). The coherence between NAO and TNA (Fig. 3a) extends over a wide range of periods from the quasi-biennial to the interdecadal (with a phase lag of $\pm\pi$). The coherence with the TSA index is however, prominent only in the decadal band (Fig. 3b, with no phase lag), with a limited coherence in the 3-year band. The TNSD also exhibits significant coherence with NAO in the 8-20 year period band (Fig. 3c, with a phase lag of $\pm\pi$). This strong association, spanning the quasi-decadal to interdecadal periods, suggests significant tropical-midlatitude interactions.

In order to determine the association of the two poles of the NAO (i.e. Azores and Iceland) with tropical SST we compute the spectral coherencies between the latter and the two SLP series, separately (Fig. 4, only frequencies lower than 0.2 cy/yr are shown). With TNA, the Azores SLP exhibits a strong coherenc in the 8-20 year period band, while Iceland SLP shows a weak coherence in this band (Fig. 4d and 4a respectively). This is somewhat expected, as the TNA region and Azores High overlap considerably. However, Iceland SLP displays a stronger coherence with TSA than with Azores SLP (Fig. 4b and 4e). Both Iceland and Azores SLP exhibit strong coherence in the 8-20 year period band with TNSD (Fig. 4c and 4f).

4. Discussion and Conclusion

The NAO directly modulates surface fluxes of latent heat over the northern tropical and midlatitude Atlantic region (Cayan, 1992). Thus it is not surprising to see the coherence between TNA and the NAO. As for TSA the absence of the short time-scale coherence (aside from a single "peak" at a ~2.2 year period) is suggestive of a more complex link with the NAO. If both TNA and TSA were forced from the NA, it is hard to explain the lack of coherence between these two ocean regions in particular at the decadal time scales. How then can we explain the observed characteristics of the time series we examined above? One tantalizing possibility is that the NA, and at very low frequencies the Azores High and Icelandic Low separately, are responding to TA SST variability, because the latter is associated with changes in tropical heating. As discussed in Tourre et al. (1998) the apparent coherence between the north and south tropical Atlantic in their study is perhaps, due to the use of orthogonal analysis (see also Houghton and Tourre, 1992) and also the fact that both these regions are independently coherent with the NAO. Changes in TA heating (e.g. deep convection in the ITCZ and the Amazon) may affect the northern hemisphere atmospheric circulation in much the same way tropical Pacific heating anomalies does. There is some evidence to that from modeling studies (Nigam et al., 1986, 1988; Hoskins and Sardeshmukh, 1987; Robertson, personal communication). Despite the lack of coherence between TNA and

TSA, their difference - TNSD, also the cross-ITCZ SST gradient, is a good indicator for the state of the tropical system and the links to the NA.

A clear decadal "preference" of tropical Atlantic SST variability is evident in this and previous studies. Several mechanisms have been offered to explain this "preference" (Chang et al., 1997; Xie and Tanimoto, 1998) related to the ocean-atmosphere interaction in the TA, independent of external midlatitude variability. If so, then the decadal fluctuations of the NAO could have be forced from within the TA.

Decadal predictions of SSTs in the TA from dynamical (Chang et al., 1997) and statistical (Penland and Matrosova, 1998) models may provide more skill than persistence. Our results suggest that the predictability of the NA atmospheric circulation can also be enhanced on decadal timescales. The basin wide teleconnections at low frequencies as seen from modeling studies and the results in this paper thus, indicate strong potential for long-lead predictability of the Atlantic ocean-atmospheric climate variability.

Acknowledgments. The authors would like to thank Mark Cane and Steve Zebiak for fruitful discussions. The authors also thank Mike Mann, and an anonymous reviewer for helpful comments and suggestions which improved the interpretation of the results. BR and YMT were supported in this study by CSD10-10775411D/NA47GPO188. YK was supported by NOAA Grant NA56GP0161. This LDEO contribution number 5854.

References

Bottomley, M., C. K. Folland, J. Hsiung, N. R. E., and D. E. Parker, 1990: *Global Ocean Surface Temperature Atlas*. Meteorological Office Bracknell UK and Dept. of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, 20 pp., 313 plates.

Cayan, D., 1992: Latent and sensible heat flux anomalies over the northern oceans: The connection to monthly atmospheric circulation. *J. Climate,* **5**, 354-369.

Chang, P., L. Ji and H. Li, 1997: A decadal climate variation in the tropical Atlantic Ocean from thermodynamic air-sea interaction. *Nature*, **385**, 516-518.

Delworth, T. L., and V. M. Mehta, 1998: Simulated interannual to decadal variability in the tropical and sub-tropical North Atlantic. *Geophys. Res. Lett.*, **25**, 2825-2828.

Deser, C., and M. L. Blackmon, 1993: Surface climate variations over the North Atlantic Ocean during winter: 1900-1989. *J. Climate*, **6**, 1743-1753.

Grötzner, A., M. Latif, and T. P. Barnett, 1998: A decadal climate cycle in the north Atlantic ocean as simulated by the ECHO coupled GCM,. *J. Climate,* **11**, 831-846.

Hoskins B., J. and P. D. Sardeshmukh, 1987: A diagnostic study of the dynamics of northern hemisphere winter of 1985-86, *Quart. J. Roy. Meteor. Soc.,* **113**, 759-778.

Houghton, R.W., and Y. Tourre, 1992: Characteristics of low-frequency sea surface temperature fluctuations in the tropical Atlantic,. *J. Climate,* **5**, 765-771.

Hurrell, J. W. and H. van Loon, 1997: Decadal Variations in Climate associated with the North Atlantic Oscillations. *Climatic Change*, **36**, 301-326..

Kaplan, A., Y. Kushnir, M. Cane, and B. Blumenthal, 1997: Reduced space optimal analysis for historical datasets: 136 years of Atlantic sea surface temperatures. *J. Geophys. Res.*, **102**, 27,835-27,860.

Kaplan, A., M. A. Cane, Y. Kushnir, A. C. Clement, M. B. Blumenthal, and B. Rajagopalan, 1998: Analyses of Global Sea Surface Temperature 1856-1991. *J. Geophys. Res.*,, **103**, 18567-18589.

Kushnir, Y., 1994: Interdecadal variations in North Atlantic sea surface temperature and associated atmospheric conditions. *J. Climate*, **7**, 141-157.

Mann, M. E., and J. Lees, 1996: Robust estimation of background noise and signal detection in climatic time series. *Climatic Change,* **33**, 409-445.

Mann, M. E., and J. Park, 1993: Spatial correlations of interdecadal variation in global surface temperatures. *Geophys. Res. Let.*, **20**, 1055-1058.

Mann, M. E., and J. Park, 1994: Global scale modes of surface temperature variability on interannual to century time scales. *J. Geophys. Res.*, **99**, 25819-25833.

Mann, M. E., and J. Park, 1996: Joint spatiotemporal modes of surface temperature and sea level pressure variability in the Northern Hemisphere during last century. *J. Climate*, **9**, 2137-2162.

Mehta, V. M, 1998: Variability of the tropical ocean surface temperatures at decadal-multidecadal time scales, Part I: The Atlantic Ocean. *J. Climate,* in press.

Nigam, S., I. M. Held and S. W. Lyons, 1986: Linear simulation of the stationary eddies in a general circulation model, Part I: The no-mountain model. *J. Atmos. Sci.*, **43**, 2944-2961.

Nigam, S., I. M. Held and S. W. Lyons, 1988: Linear simulation of the stationary eddies in a general circulation model, Part II: The "mountain" model. *J. Atmos. Sci.*, **45**, 1434-1452.

Penland, C., and L. Matrosova, 1998: Prediction of tropical Atlantic sea surface temperatures using linear inverse modeling. ,*J. Climate,* **11**, 483-496.

Servain, J., 1991: Simple climatic indices for the tropical Atlantic Ocean and some applications. *J. Geophys. Res.*, **96**, 15,137-15,146.

Sutton, R. T., and M. R. Allen, 1997: Decadal predictability in North Atlantic sea surface temperature and climate. *Nature*, **388**, 563-567.

Tourre, Y. M., B. Rajagopalan, and Y. Kushnir, 1998: Dominant patterns of climate variability in the Atlantic Ocean region during the last 136 years. *J. Climate*, (in press).

Venegas, S. A., L. A. Mysak, and D. N. Straub, 1998: An interdecadal climate cycle in the South Atlantic and its links to other ocean basins. *J. Climate,* (in press).

Weng, W., and J. D. Neelin, 1997: On the role of ocean-atmosphere interaction in midlatitude interdecadal varibilty. *Geophys. Res. Lett.,* **25**, 167-170.

Woodruff, S. D., R. J. Slutz, R. L. Jenne, and P. M. Steurer, 1987: A comprehensive ocean-atmosphere data set. *Bull. Amer. Meteor. Soc.*, **68**, 1239-1250.

Xie, S., and Y. Tanimoto, 1998: A pan-Atlantic decadal climate oscillation. *Geophys. Res. Lett.,* **25**, 2185-2188.

Zorita, E., and C. Frankignoul, 1997: Modes of North Atlantic decadal variability in the ECHAM1/LSG coupled ocean-atmosphere general circulation model. *J. Climate*, **10**, 183-200..

(Received July 15, 1998; revised September 10, 1998; accepted September15, 1998)

Balaji Rajagopalan, Yochanan Kushnir and Yves Tourre, Lamont-Doherty Earth Observatory of Columbia University, PO Box 1000, Rt. 9W, Palisades, NY 10964-8000. (e-mail: rbala@rosie.ldgo.columbia.edu; kushnir@rosie.ldgo.columbia.edu; tourre@iri.ldgo.columbia.edu)

Figure 1: (a) The relationship between north and south TA SST anomalies (TNA and TSA, respectively) as depicted by the product of the two monthly time series, shown as the dotted line (smoothed version is shown to emphasize fluctuations with a period of 2 years and longer); the solid line represents the same, but for the normalized SLP anomalies from Azores and Iceland; (b) The squared coherency between TSA and TNA; (c) Same as in (b) but between SLP anomaly series at Azores and Iceland. The abscissa in (b) and (c) is the frequency in 'cycles/year', the lower and upper solid horizontal lines depict the 95% and 99% confidence intervals based on an F-test (Mann and Park, 1993), the dotted lines are the phase.

Figure 2: Power spectra of (a) TNA SST index, (b) TSA SST index, (c) TNSD, and (d) NAO index. The abscissa in these figures is the frequency in 'cycles/year' and, the dashed lines from the bottom, show the median, 90%, 95 and 99% confidence levels respectively. The confidence levels are based on the robust estimation of red noise level (Mann and Lees, 1996).

Figure 3: Squared coherence between the NAO index and (a) TNA SST index (b) TSA SST index and (c) TNSD. The axes are same as in Fig. 1(b) or (c), the solid horizontal lines are the confidence levels and dotted lines the phase.

Figure 4: Squared coherence between the SLP anomaly series from Iceland and (a) TNA SST index (b) TSA SST index and (c) TNSD. The same with the SLP series from the Azores in (d), (e) and (f) respectively. The axes are same as in Fig. 1 (b) or (c), the solid horizontal lines are the confidence levels and dotted lines the phase.

Figure 1: (a) The relationship between north and south TA SST anomalies (TNA and TSA, respectively) as depicted by the product of the two monthly time series, shown as the dotted line (smoothed version is shown to emphasize fluctuations with a period of 2 years and longer); the solid line represents the same, but for the SLP anomaly series from, Azores and Iceland; (b) The squared coherency between TSA and TNA; (c) Same as in (b) but between SLP anomaly series at Azores and Iceland. The abscissa in (b) and (c) is the frequency in 'cycles/year', the lower and upper solid horizontal lines depict the 95% and 99% confidence intervals based on an F-test (Mann and Park, 1993) the dotted lines are the phase.

Figure 2: Power spectra of (a) TNA SST index, (b) TSA SST index, (c) TNSD, and (d) NAO index. The abscissa in these figures is the frequency in 'cycles/year' and, the dashed lines from the bottom, show the median, 90%, 95 and 99% confidence levels respectively. The confidence levels are based on the robust estimation of red noise level (Mann and Lees, 1996).

Figure 3: Squared coherence between the NAO index and (a) TNA SST index (b) TSA SST index and (c) TNSD. The axes are same as in Fig. 1(b) or (c), the solid horizontal lines are the confidence levels and dotted lines the phase.

Figure 4: Squared coherence between the SLP anomaly series from Iceland and (a) TNA SST index (b) TSA SST index and (c) TNSD. The same with the SLP series from the Azores in (d), (e) and (f) respectively. The axes are same as in Fig. 1(b) or (c), the solid horizontal lines are the confidence levels and dotted lines the phase..

RAJAGOPALAN ET AL.: MIDLATITUDE-TROPICAL ATLANTIC CLIMATE VARIABILITY

RAJAGOPALAN ET AL.: MIDLATITUDE-TROPICAL ATLANTIC CLIMATE VARIABILITY