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Climatic variations in the North Atlantic and the North Pacific in the 1990s: a comparative study

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The study is based on the results of the analysis of spatial and temporal features of winter sea surface temperature anomaly (SSTA) variations in the North Atlantic and the North Pacific during the past four decades. Several large-scale regions with coherent SSTA fluctuations within each region were defined in both oceans. SSTA variations in these regions are strongly related to the well-known atmospheric teleconnection patterns in the Northern Hemisphere. Four distinct decadal climatic regimes were identified in the North Atlantic during the period 1957–2000. The last regime, established in 1989, continued through the 1990s. In the North Pacific, the climatic regime established in the second half of the 1970s continued until 1998–1999. The 1990–1999 decade was the warmest in both oceans compared with the previous three decades. Climatic variations in the North Atlantic during the past 40 years were characterized by the second, interdecadal, mode of variability associated with a gradual northeastward warming of surface waters. In the North Pacific this mode was not so clear, though some signs of the northeastward spreading of warming were noted in the 1980s and 1990s.

Keywords: decadal changes, interdecadal changes, sea surface temperature anomaly (SSTA).

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Introduction

During the past decade, globally averaged air surface temperatures have been higher than in any decade since the mid-18th century (Jones *et al.*, 1999). However, there are significant regional differences in the extent and timing of warming. The main objective of this study was to compare the development of large-scale processes in the atmosphere and ocean in the North Atlantic and the North Pacific against a background of global warming.

Data

Data covering the period 1960 to 2000 were provided by the NOAA-CIRES Climate Diagnostics Center. They included mean winter (Dec–Feb) sea level pressure, geopotential heights on the 500 hPa surface, Northern Hemisphere teleconnection indices, and mean winter (Jan–Apr) Northern Hemisphere reconstructed Reynolds sea surface temperatures (SSTs). We used mean winter (Jan–Apr) SSTs at grid points of 5° latitude by 5° longitude in the North Atlantic and the North Pacific for the period 1957–2001, obtained from the Russian Hydrometeorological Center, to partition both the oceans into several large-scale subdomains with coherent SST anomaly fluctuations in each subdomain on the basis of the hierarchical clustering method known as Ward's method (Ward, 1963).

Results

Decadal variations

In each ocean we defined several large-scale subdomains with coherent SST anomaly (SSTA)

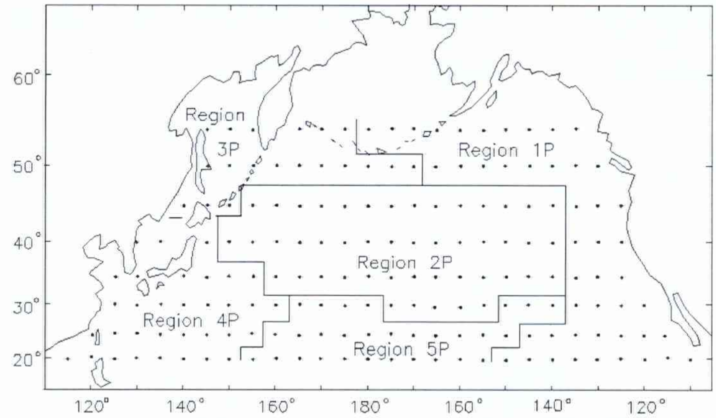

Figure 1. Results of cluster analysis for the SST anomaly field in the North Atlantic and the North Pacific. Dots show the position of the 5° latitude by 5° longitude grid for the SST data set.

Table 1. Loadings on the first 3 principal components from a principal component analysis of the 38 physical time-series in the Northern Hemisphere. The loadings are correlation coefficients between each time-series and each PC score (asterisks correspond to $|r| > 0.45$).

Physical time-series	PC1	PC2	PC3
	19.8%	17.1%	9.2%
Western Atlantic teleconnection pattern (TP) index (500 hPa surface)	−0.67*	0.27	0.24
Eastern Atlantic TP index (500 hPa surface; Wallace and Gutzler, 1981)	−0.11	−0.03	−0.38
Eastern Atlantic TP index (500 hPa surface, Barnston and Livezey, 1987)	0.43	0.38	0.30
Eastern Atlantic-Jet TP index (500 hPa surface)	0.34	0.20	0.13
Western Pacific TP index (500 hPa surface)	0.31	0.41	0.46*
Eastern Pacific TP index (500 hPa surface)	0.00	−0.29	0.49*
North Pacific (NP) TP index (500 hPa surface)	0.17	0.05	−0.11
Pacific/North American TP index (500 hPa surface)	0.05	0.69*	−0.26
East Atlantic/West Russia TP index (500 hPa surface)	0.35	0.15	−0.36
Scandinavian TP index (500 hPa surface)	−0.23	0.06	0.22
Tropical/ Northern Hemisphere TP index (500 hPa surface)	0.07	−0.53*	−0.24
Polar/Eurasia TP index (500 hPa surface)	0.48*	0.09	−0.41
Pacific Transition TP index (500 hPa surface)	−0.02	−0.05	0.51*
Subtropical Zonal TP index (500 hPa surface)	0.02	0.04	0.34
Asia Summer TP index (500 hPa surface)	0.25	0.31	0.23
Winter (Dec–Mar) NAO index	0.90*	0.02	−0.12
Winter (Nov–Mar) North Pacific SLP index	0.02	−0.75*	0.18
Pacific Decadal Oscillation index	0.00	0.82*	−0.11
Sea level pressure (SLP) (Reykjavik)	−0.87*	0.14	−0.10
SLP (Gibraltar)	0.77*	0.06	−0.02
SLP (Darwin)	0.25	0.78*	0.02
SLP (Tahiti)	0.11	−0.76*	0.09
Southern Oscillation index (SOI)	−0.08	−0.86*	0.04
Arctic Oscillation index	0.86*	−0.18	−0.17
Azores High longitude	0.35	0.18	0.04
Aleutian Low longitude	0.04	0.75*	−0.12
Area-averaged mean winter SSTA in Region 1A	0.65*	−0.09	0.46*
Area-averaged mean winter SSTA in Region 2A	0.72*	−0.04	−0.02
Area-averaged mean winter SSTA in Region 3A	−0.52*	−0.03	0.48*
Area-averaged mean winter SSTA in Region 4A	−0.43*	0.48*	0.41
Area-averaged mean winter SSTA in Region 5A	0.30	0.42	0.53*
Area-averaged mean winter SSTA in Region 6A	0.26	−0.07	−0.18
Area-averaged mean winter SSTA in Region 1P	0.05	0.71*	−0.24
Area-averaged mean winter SSTA in Region 2P	0.30	−0.65*	0.10
Area-averaged mean winter SSTA in Region 3P	0.34	0.10	−0.47*
Area-averaged mean winter SSTA in Region 4P	0.48*	0.22	0.60*
Area-averaged mean winter SSTA in Region 5P	0.53*	−0.09	0.49*
Winter Tw anomalies (0–200 m) at Kola Section	0.61*	−0.07	−0.09

fluctuations. The results of cluster analysis for the North Atlantic and their discussion are given in the article by Krovnin and Moury (2003). The results of partitioning of the North Pacific are shown in Figure 1. The spatial structure of the SSTA fluctuations in the North Pacific is characterized by two independent patterns, one occurring in the eastern (region 1P) and central (region 2P) Pacific, and the second in its northwestern (region 3P) and southwestern (region 4P) parts. The changes in SSTA between regions 1P and 2P, as well as between regions 3P and 4P, are out of phase.

As in the North Atlantic, the SSTA variations in regions defined in the North Pacific are strongly related to the well-known teleconnection patterns at the 500 hPa surface in the Northern Hemisphere first described by Wallace and Gutzler (1981). The SSTA variations in the central (region 1P) and eastern (region 2P) North Pacific appear to be associated with the Pacific/North American (PNA) pattern, while those in two western regions seem associated with the Western Pacific (WP) pattern (maps not shown).

We used principal component analysis (PCA) to define the most important patterns of common variability in the 38 physical time-series in the North Atlantic and the North Pacific. They included time-series of indices of teleconnection patterns both in the sea level pressure (SLP) field (e.g. NAO index, North Pacific pressure index) and in the middle troposphere (at the 500 hPa surface, e.g., index of Eastern Atlantic teleconnection pattern), time-series of SLP at fixed points and area-averaged SSTA for regions defined in both the oceans. The first principal component (PC1) is associated with the NAO, and its time-series shows 4 distinct regimes between 1957 and 2000: 1957–1971; 1972–1976, 1977–1988, and 1989 through 2000, with the most abrupt transition in 1989 (Table 1; Figure 2a). PC2 is associated with the Southern Oscillation and Pacific Decadal Oscillation (PDO) pattern (Mantua *et al.*, 1997) and shows the rather prominent shift in 1977 with the predominance of negative values in the pre-1977 period and positive values since 1977. PC3 is related to the WP pattern. Its time-series shows the prominent shift from the predominant positive to negative values in the mid-1970s and the reverse shift in 1998.

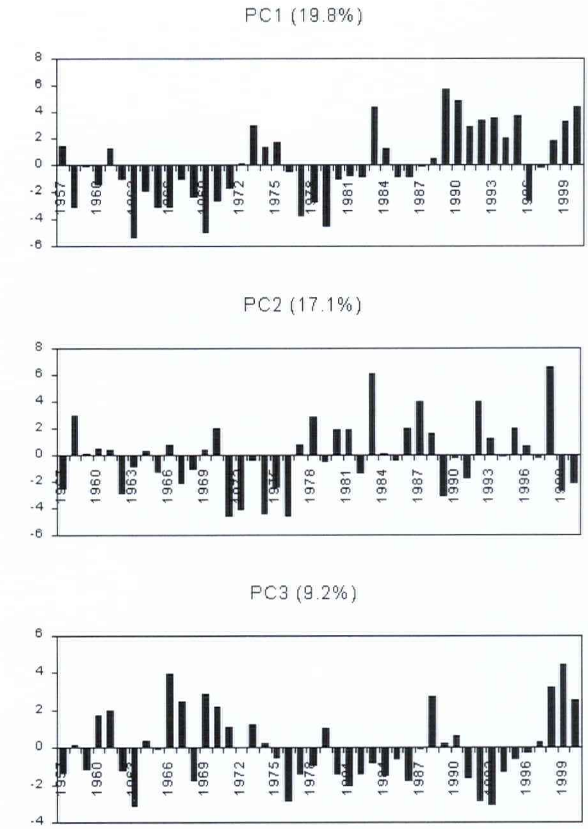

Figure 2. The first 3 principal component scores from a principal component analysis of the 38 physical time-series in the North Atlantic and the North Pacific. The scores are normalized time-series.

Interdecadal variations

Figure 3 (left panel) shows SLP changes between two consecutive decades over the North Pacific–North Atlantic sector. It demonstrates an intensification and eastward shift of low- and high-pressure anomaly cells south of 50°N and general strengthening of zonal flow over the North Atlantic north of 50°N from the 1970s to 1990s. Figure 3 (right panel) shows a gradual northeastward spreading of warming in the North Atlantic in accordance with the shift of the high pressure anomaly cell, but north of 50°N SST changes were not correspondent to changes in local winds. In the North Pacific, SST changes in the 1970s–1980s were, in general, consistent with the changes in atmospheric circulation. At the same time, the signs of the northeastward propagating warming appeared in the 1980s and in the 1990s the warming was observed over most of the North Pacific.

Conclusion

Using data for 1890–1940, Bjerknes (1964) concluded that the long warming trend during the first quarter of the last century in the North Atlantic was linked to a basin-scale interaction in which the Gulf Stream and the North Atlantic Current responded to the intensifying circulation in the subtropical

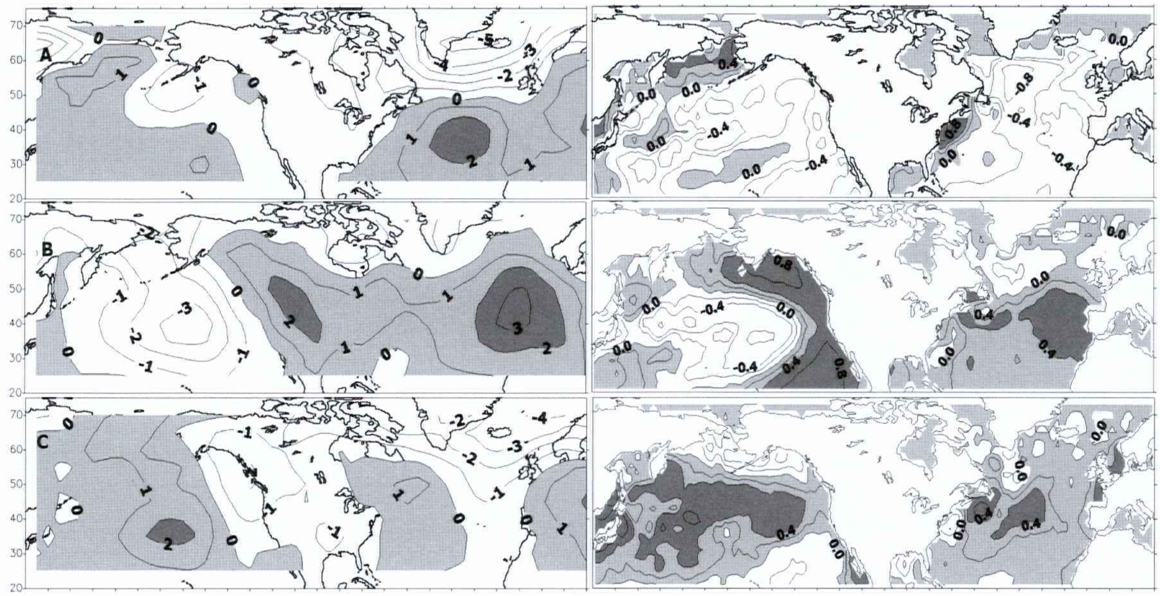

Figure 3. Difference maps for SLP (left panel) and SST (right panel) anomalies in the North Pacific–North Atlantic Region between: 1970–1979 and 1960–1969, 1980–1989 and 1970–1979, and 1990–1999 and 1980–1989. Positive values are shaded.

anticyclone. The interdecadal changes in the North Atlantic characterized by the warming trend during the 1970s–1990s resembled in many aspects the warming of the 1920s–1930s described by Bjerknes. In particular, there were inconsistent changes in SSTA and local winds north of 50°N. In the North Pacific the heat exchange at the sea surface contributes to SSTA changes on an interdecadal time scale to a larger extent than in the North Atlantic. Thus, unlike the North Atlantic, the effect of oceanic circulation in the North Pacific on the interdecadal SSTA changes is seen only in the periods of general lessening of atmospheric circulation.

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