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The 1990s in the context of climatic changes in the North Atlantic region during the past 40 years

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The wintertime surface climate variations in the North Atlantic during the past 40 years were characterized by two modes of variability. The first mode is associated with decadal variations in atmospheric circulation and sea surface temperature (SST). The spatial structure of decadal SST anomaly (SSTA) variations is characterized by the existence of six large-scale regions with coherent SSTA fluctuations within each region. Four distinct decadal climatic regimes were identified during the 1957–2000 period: 1957–1971, 1972–1976, 1977–1988, and 1989–2000. The 1990–1999 decade was very warm in the North Atlantic. The second mode of variability in the North Atlantic during the past 40 years was associated with a gradual northeastward warming of surface waters, which is possibly driven by changes in the large-scale oceanic circulation.

Keywords: decadal variations, interdecadal changes, North Atlantic, sea surface temperature anomaly.

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Introduction

During the past decade, globally averaged surface temperatures have been higher than in any decade since the mid-18th century, and the seven warmest years of the global record have all occurred since 1990 (Jones *et al.*, 1999). However, significant regional differences in the extent and timing of warming exist. The main objective of this article is to consider the development of large-scale processes in the atmosphere and ocean in the North Atlantic region against a background of global warming.

Data

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

Results

1. Decadal variations

Results of cluster analysis show that the North Atlantic can be divided into six major regions with respect to the similarity in the SST anomaly (SSTA) variations (Figure 1). The SSTA fluctuation in the northeastern (1A) and southwestern (2A) regions are opposite to those in the northwestern (3A) and southeastern (4A) regions (maps not shown).

The SSTA variations in the defined regions are strongly related to the well-known teleconnection patterns in the northern hemisphere. Thus, SSTA

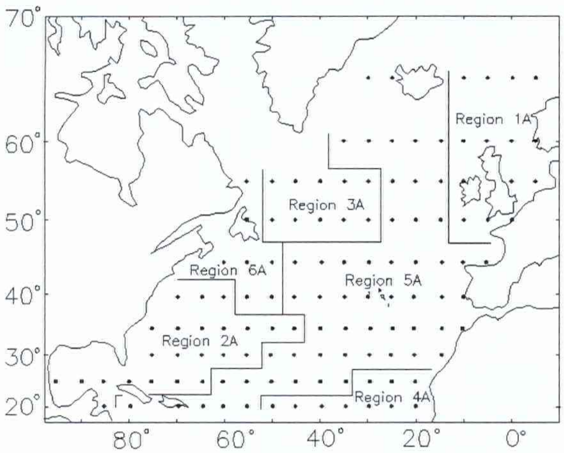

Figure 1. Results of cluster analysis for the SST anomaly field in the North Atlantic. Dots show the position of the 5° latitude by 5° longitude grid for the SST data set.

fluctuations in regions 1–3 may be forced by the Eastern Atlantic (Barnston and Livezey, 1987) and the Western Atlantic patterns (Wallace and Gutzler, 1981) (correspondent maps not shown). The SSTA changes in Region 4 are associated with both the Eastern Atlantic and Pacific/North American (PNA) patterns. Moreover, the SSTA fluctuations in the central North Atlantic appear to be connected with the PNA pattern, while there is no significant relationship with the North Atlantic teleconnection patterns.

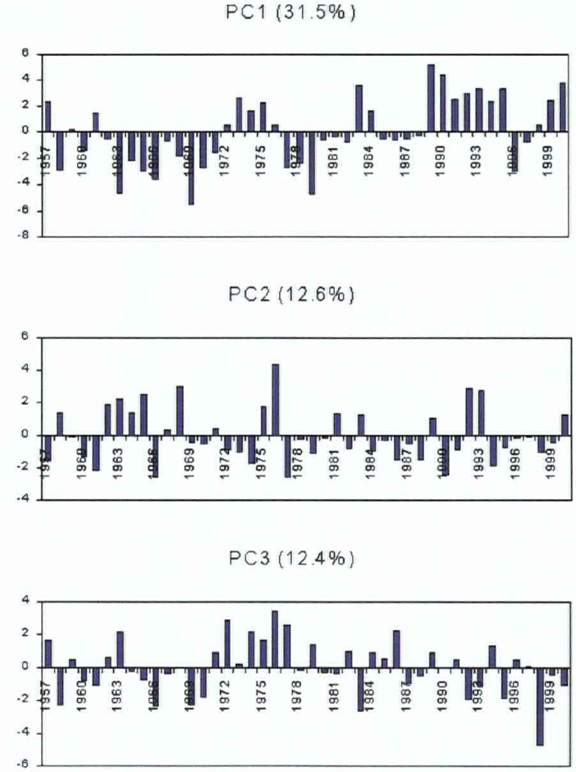

Figure 2. The first three principal component scores from a principal component analysis of the 22 physical time-series in the North Atlantic. The scores are normalized time-series.

Table 1. Loadings on the first three principal components (PC) from a principal component analysis of the 21 physical time-series in the North Atlantic. The loadings are correlation coefficients between each time-series and each PC score. (Asterisks indicate |r| > 0.45).

Physical time-series	PC1	PC2	PC3
	31.5%	12.6%	12.4%
Western Atlantic (WA) pattern	−0.72*	0.27	−0.43
Eastern Atlantic (EA) pattern (WG)[1]	−0.10	0.92*	−0.01
Eastern Atlantic (EA) pattern (BL)[2]	0.38	−0.70*	−0.34
East Atlantic Jet pattern (EA-Jet)	0.29	−0.25	−0.30
East Atlantic/West Russia pattern (EA/WR)	0.35	0.44	−0.05
Scandinavian pattern (SCA)	−0.23	−0.63*	0.08
Tropical/Northern Hemisphere pattern (TNH)	0.16	−0.17	0.72*
Polar/Eurasian pattern (POL)	0.48*	0.43	−0.05
Winter NAO index	0.92*	−0.03	−0.04
SLP (Reykjavik)	−0.88*	0.16	0.07
SLP (Gibraltar)	0.79*	0.15	−0.27
Southern Oscillation Index (SOI)	0.00	0.03	0.63*
Arctic Oscillation Index	0.86*	0.31	0.03
Azores High Longitude	0.32	0.10	−0.38
SSTA (Jan–Apr) in Region 1	0.60*	−0.18	−0.28
SSTA (Jan–Apr) in Region 2	0.72*	−0.27	0.16
SSTA (Jan–Apr) in Region 3	−0.58*	0.17	−0.35
SSTA (Jan–Apr) in Region 4	−0.54*	−0.13	−0.62*
SSTA (Jan–Apr) in Region 5	0.18	−0.12	−0.74*
SSTA (Jan–Apr) in Region 6	0.30	0.35	−0.05
Winter T_w anomalies (0–200 m) at Kola Section	0.62*	0.22	−0.12

[1] WG = Wallace and Gutzler (1981). [2] BL = Barnston and Livezey (1987).

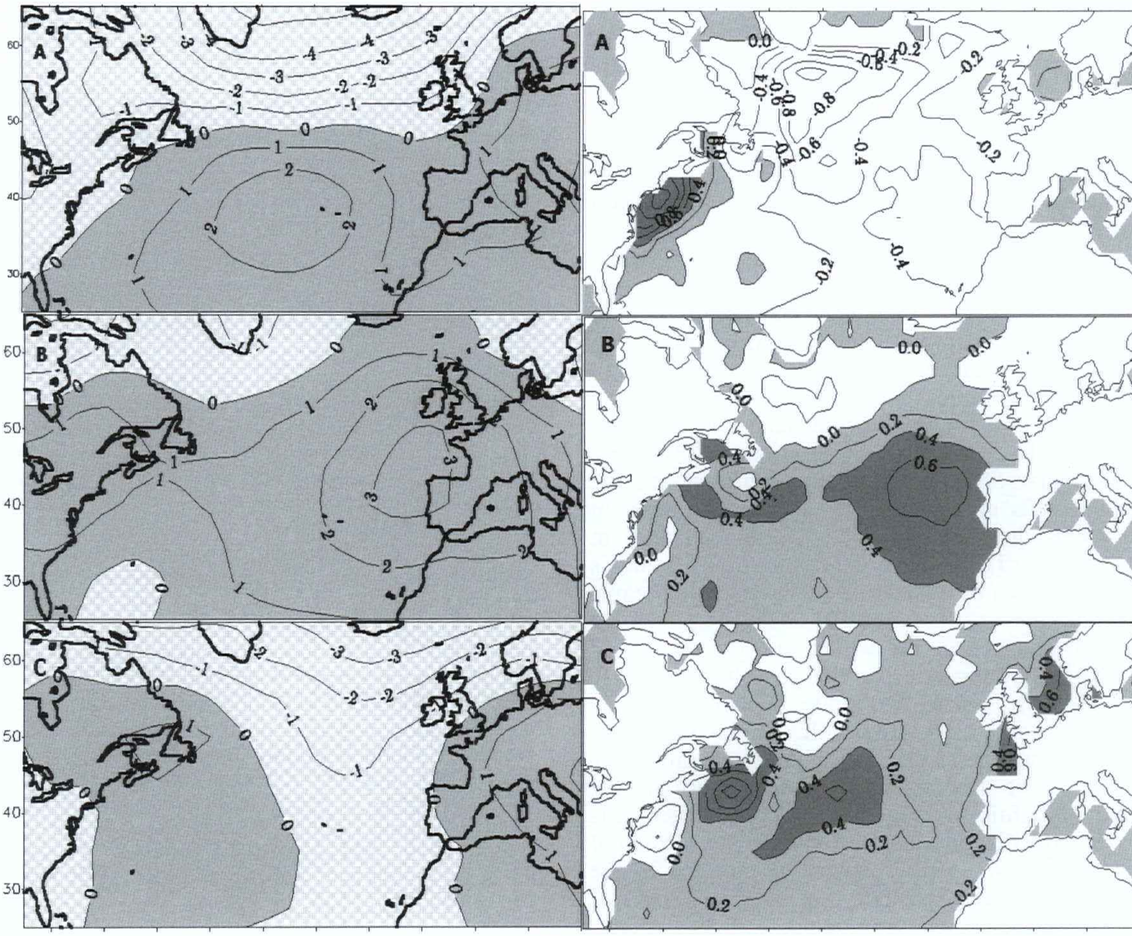

Figure 3. Difference maps for SLP (left panel) and SST (right panel) change in the North Atlantic between 1970–1979 and 1960–1969, 1980–1989 and 1970–1979, and 1990–1999 and 1980–1989. Positive values are shaded.

We used principal component analysis (PCA) to define objectively the most important patterns of common variability in the 21 physical time-series in the North Atlantic. The time-series of the first principal component (PC1), associated with the North Atlantic Oscillation, shows four 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 2). The second PC, related to the Eastern Atlantic teleconnection patterns shows the prominent shift in 1969 with the predominance of positive values in the pre-1969 period and negative values since 1969. PC3 is related to the Tropical-Northern Hemisphere (TNH) teleconnection pattern, which in turn is associated with the Southern Oscillation (Barnston and Livezey, 1987). Note the high inverse correlation of SSTA variations in the central and southeastern parts of the ocean (Regions 4–5) with PC3.

2. Interdecadal variations

Figure 3 (left panel) shows SLP changes between two consecutive decades (i.e. 1970–1979 minus 1960–1969, etc.) over the North Atlantic region. There was a general increase in SLP, a clear eastward shift of a high pressure anomaly cell south of 50°N and a gradual decrease in SLP to the north of this latitude from the 1970s to the 1990s. This indicated the strengthening of zonal atmospheric flow north of 50°N. Figure 4 (right panel) demonstrates a gradual northeastward warming of the North Atlantic in accordance with the interdecadal shift of the high pressure anomaly cell.

Discussion

Using data for 1890–1940, Bjerknes (1964) provided evidence that interannual fluctuations in SST are governed by wind-induced changes in latent and sensible heat fluxes at the sea surface. Deser and Blackmon (1993) showed that the surface climate over the North Atlantic exhibited coherent decadal variations that resembled the fluctuations on an interannual time scale. However, as it was concluded by Bjerknes that the long warming trend in the first quarter of the last century 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 anticyclone. A similar idea was used to explain the cooling trend in the North Atlantic that occurred during the 1950s and 1960s (Greatbach *et al.*, 1991; Kushnir, 1992). The warming trend in the North Atlantic during the 1970s–1990s resembles in many aspects the warming of the 1920s–1930s described by Bjerknes. In particular, SST changes in the Northeast Atlantic in the 1980s and southwest of Newfoundland in the 1990s did not correspond to the changes in local winds. Thus, the observed warming trend is possibly driven by changes in the large-scale oceanic circulation.

Thus, changes in the winter surface climate of the North Atlantic during the past 40 years have been characterized by two modes of variability. The first mode was associated with decadal variations in the atmospheric circulation and resulting SST changes. The second mode of variability in the North Atlantic during the past 40 years was associated with a gradual northeastward warming of surface waters, possibly driven by changes in the large-scale oceanic circulation.

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