July 10, 2000

EARLY SPRING IN EUROPE: A RESULT OF MORE DOMINANT NORTH-ATLANTIC SOUTHWESTERLIES ?

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Key Words: climate trends, advancement of spring in Europe, ocean-to-land advection, climatic feedbacks

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Abstract A 1999 study reports an advancement of spring in Europe by 0.2 days per year in the 30 years since 1960. Our analysis indicates that this trend results directly from a change in the late-winter surface winds over the eastern North Atlantic: the southwesterly direction became more dominant, and the speed of these southwesterlies increased slightly. Splitting the 52-year NCEP reanalysis dataset into the First Half, FH (1948-1973), and the Second Half, SH (1974-1999), we analyze the wind direction for the February mean at three sites at 45°N: site A at 30°W, site B at 20°W, and site C at 10°W. The incidence (number of years) of the southwesterlies in SH vs. (FH) at these sites respectively increased in SH as follows: 24(18), 19(12), 14(11); whereas the incidence of northeasterlies decreased: 0(2), 1(2), and 1(6). When the February mean wind is southwesterly, the monthly mean sensible heat flux from the ocean at these sites takes zero or slightly negative values, that is, the surface air is warmer than the ocean. Analyzing the scenario in the warm late winter 1990, we observe that the sensible heat flux from the ocean surface in February 1990 shows a "tongue" of negative values extending southwest from southern England to 37°N. This indicates that the source of the maritime air advected into Europe lies to the south of the "tongue." Streamline analysis suggests that the southwestern or southcentral North Atlantic is the source. For February 1990, we find strong ascending motions over Europe at 700 mb, up to -0.4 Pa s^{-1} as monthly averages. Associated with the unstable low-levels of the troposphere are positive rain and cloud anomalies. Thus, positive *in situ* feedback over land in late winter (when shortwave absorption is not significant) apparently further enhances the surface temperature through an increase in the greenhouse effect due to increased water vapor and cloudiness.

Introduction

From observations of phenological events in numerous European stations, Menzel and Fabian (1999) report an advancement of spring in Europe by 0.2 days per year in the 30 years of their study since 1960. The authors place this trend in the framework of the global warming. In the Balkan stations, however, the authors report a *decrease* in the growing season. Even though the global warming apparently does produce cooling in some regions (Russell and Rind, 1999, Russel et al., 2000, report a cooling in a region to the north of Scandinavia), this divergence of trends invites a closer examination. We pose the question: what is the *direct* forcing to this change in the length of the growing season? In our preliminary study, we suggest that a shift in the late-winter North Atlantic surface winds to more prevalent and stronger southwesterlies, by forcing low-level advection of warm and moist maritime air, produced an earlier snow-melt and an earlier onset of spring in Europe.

Our study is based primarily on the reanalysis dataset by the National Centers for Environmental Prediction (NCEP), described in detail by Kalnay et al. (1996), which extends from January 1948 essentially to the present. Improvements to the numerical weather prediction operational systems were introduced when satellite measurements become available (see Kalnay et al., 1996, for a documentation of the changes). The intent in processing was to produce a consistent dataset. Still, some discontinuity apparently was introduced starting with 1979, relative to the 1958-1978 period when no satellite observations were available (Pawson and Fiorino, 1999; Pielke et al., 1998a, 1998b). The analysis by Pielke et al. (2000; submitted for publication) did not show discontinuity in the wind fields at 200 mb, however.

We also examine relations between temperatures in Europe and the North Atlantic Oscillation (NAO). NAO represents fluctuations in opposite sense of the sea level pressure, occurring between the subtropical and subpolar regions of the Atlantic Ocean basin. It is defined in terms of the pressure field at two key centers of action, one over the Azores, where high pressure dominates climatologically, and the other over Iceland where mean low pressure prevails in all seasons (Rogers, 1984). In the positive mode of the NAO both pressure features are enhanced – that is, the Azores high is anomalously strong while the Icelandic low is unusually deep. In this mode the Atlantic westerlies are abnormally strong. Maritime airmasses advect then heat and moisture into Europe (Hurrell, 1996), while very cold return flow occurs over Greenland. The two pressure centers are both anomalously weak in the negative mode of the NAO. In this mode the weak Icelandic low is displaced to the southwest near Newfoundland and blocking high pressure cells frequently persist over the eastern Atlantic.

Analysis

From the NCEP reanalysis, we extract first the February surface air temperature T_s at four European locations: Ireland 52.4°N; 9.4°W, Wales, 52.4°N; 3.8°W, northern France, 48.6°N; 1.9°E, and northern Russia, 60.0°N; 39.5°E. T_s is plotted as Fig. 1A vs. the year of analysis. We note pronounced variability, but a warming trend at these locations is observed, by 0.009, 0.006, 0.013, and 0.037°C/year, respectively. (see Table 1), which is consistent with findings by Menzel and Fabian (1999).

February averages of the North Atlantic surface wind at three locations, all at 45°N, A at 30°W, B at 20°W, and C at 10°W, are plotted as Fig. 1B. We present the wind strength S_f when the direction of the monthly average is southwesterly, and zero when the wind is from another direction. In the high S_f years 1950, 1966, 1977, and 1990, S_f was about 10 ms^{-1} at each of the sites. In Fig. 1C we present the NAO index N_{ao} (based on raw anomalies). In the four high S_f years cited above, N_{ao} was negative in two of them , 1966 and 1977. Those were "warm-Europe" Februaries, see Fig. 1A. The negative values of N_{ao} in these two years possibly indicate that strength of the southwesterlies possibly is more suitable than N_{ao} as quantifier of warm advection into Europe for the cases when these winds are very strong. The correlations of T_s at the four sites with S_f at site A (S_f at this site produced the highest correlation with each of the four locations; our expectation was that S_f at site C, 10°W, will produce highest correlation with T_s in France) and with N_{ao}, presented in Table 1, are only moderate, at about 0.50. Much higher correlations were found by Otterman et al. (1999) between February continental temperatures and specific Index of southwesterlies over the North Atlantic computed from the Special Sensor Microwave/Imager, SSM/I, data.

Splitting the 52-reanalysis years into the First Half (FH, 1948-1973) and the Second Half (SH, 1974-1999), we find that for February the incidence of southwesterlies is considerably larger in SH as compared with FH, while the incidence of northeasterlies is much smaller (see Table 2). N_{ao} for February was positive in 13 years in the (FH), and in 17 in the SH. In the last 12 years of the dataset N_{ao} was negative in only one year, 1994.

We compute the trend τ_{sf} in S_f, evaluating S_f as non-zero only in the years when the direction is from the southwest. Wind from other three quadrants is likely to produce cooling in

Europe, but the effect varies from one quadrant to another. We note that the surface air temperature T_s (Fig. 1A) tends to take a high value in the high-S_f years (see Fig. 1B). This further substantiates the viewpoint that advection from the ocean produces higher temperatures in Europe. The trends τ_{sim} are positive at 30 and 20°W (points A and B) and essentially zero at 10°W (data at this site may be non-representative because of land contamination).

In an attempt to identify the source-area of the maritime air masses advected at low-level into Europe, we examine ocean surface fluxes at sites A, B, C where we analyze the wind speed, Fig. 1B. Sensible heat and latent heat fluxes, F_s and F_l, are plotted in Figs. 1D and 1E, respectively. It is interesting to note that in the years of southwesterly wind, the sensible heat flux takes zero or slightly negative values (note the "dip" in F_s at 20 and 10°W in 1990), that is, the surface air is <u>warmer</u> than the ocean at these sites. The ocean does not warm the surface air then. Thus, the source of the warm airmasses advected at low level into Europe lies <u>upwind</u> of these three sites, that is, at latitudes lower than 45°N.

Additional insight into the process of the ocean-to-land advection can be gained by examining the scenarios when the southwesterlies were especially strong. Such was the case with February 1990, when the wind speed was 10 ms^{-1} or slightly higher at <u>each</u> of the A, B, C sites (Fig. 1B). The value of the Index developed for quantifying the advection into Europe, based on the SSM/I dataset, was 8 ms^{-1} in that February (Otterman et al., 1999). The winter of 1989-1990 was representative of extreme strength of the North Atlantic westerlies, as measured by the NAO index. Sea level pressure gradients across 25°W longitude between latitudes 45-55°N were very strong, N_{ao} was 27 mb (Rogers, 1997). We show monthly-mean streamlines for February 1999 in Fig. 2A, marking ocean areas where the wind speed was above 10 m s^{-1}. Note the "streak" of high speed wind engulfing Ireland and England from the southwest. As Fig. 2B we present for the same region the sensible heat flux from the surface. In much of the area of the "streak" the flux is negative, that is, the near-surface air is warmer than the ocean. A "tongue" of negative values extends southwest from southern England to 37°N. Thus we infer that the source of this warm air is at latitudes lower than 37°N, that is, the southcentral or the southwestern North Atlantic, as indicated by the streamlines in Fig. 2A. In the down-wind regions, this low-level warm advection produced strong vertical motions, up to −0.4 Pa s^{-1} in cells around Europe in the February 1990 average, see Fig. 2C. The very strong North Atlantic southwesterlies on February 1, 1990, 00 Z, apparently contributed to cells of −1.2 Pa s^{-1} at 12 Z that day (not presented here).

Strong interannual variability of the ocean surface winds, and thus ocean-to-land advection, probably stems from (or at least is linked to) changes in the SST patterns. As Fig. 3 we present the differences in the monthly-mean SST, between the strong S_f, warm-Europe February 1990, and February of 1996 when opposite conditions prevailed. A string of negative-difference cells (up to −2.5°C) lies close to the shores of N. America, Greenland and Iceland. Note that the temperature gradient between 55°N; 40°W and 35°N; 50°W was larger in 1990 than 1996 by 4°C. We examined also the differences between high S_f February 1997 and an opposite-scenario February 1988. In this case strong anomalies also stretched in a "string" from Florida to the coast of Iceland, where cells of positive and negative differences alternated.

Discussion and Conclusions

Advancement of spring in Europe at latitudes 50-60°N over the recent decades can be regarded as an established trend, evidenced by the analysis of phenological events by Menzel and Fabian (1999), and other reports. Consistent with this trend are the rising surface-air February temperatures in 1948-1999 at four widely-separated European grid-points (our Table 1, NCEP reanalysis). We attribute this significant trend to changes in the North Atlantic surface winds.

Hurrell (1996) associated the warming in surface temperature over the Northern Hemisphere since the mid-1970's with changes in the Southern Oscillation, the North Atlantic Oscillation, and circulation over the North Pacific. Hurrell and Trenberth (1996) suggested that tropospheric depth averaged temperatures (specifically, the MSU-derived temperatures in their study) are primarily forced by advection. They point out that surface temperature variability is dominated by processes controlling surface fluxes and heat storage. Pertinent to our study is the remark by Plag and Tsimplis (1999): "Even small fluctuations of the global circulation pattern on interannual to decadal time scales may induce significant changes in range and form of the seasonal cycle in a region." Specifically relevant is the finding by Przybylak (2000) that the most important factor for the Arctic temperature is change in atmospheric circulation over the North Atlantic. Our study follows the concepts presented in the above references: since advection from the warm ocean surface constitutes apparently the control of the surface-air in Europe in late winter (Otterman et al., 1999), we suggest that the direct forcing to an early spring in Europe are more dominant southwesterlies over the eastern North Atlantic. The incidence of mean-monthly southwesterly flow for February is much higher in the period 1974-1999 than in 1948-1973, and the monthly-mean speed is also slightly higher (when the direction is southwesterly). The changes are quite pronounced. We do not compute their statistical significance, since the suspicion that the NCEP reanalysis is flawed by a discontinuity makes such evaluation not truly meaningful. Supporting evidence for our thesis is the increased incidence of positive N_{30} in Februaries of the SH, to 17 years from 13 in FH. Volcanic eruptions introduced discontinuities over the 52-year record that we analyze, which constitutes a complication when attributing decadal trends to a specific cause. Evaluation of these effects is highly challenging (see Rowntree, 1998, for instance), and beyond the scope of this short communication. Analysis of decadal trends by atmospheric GCM with prescribed SST appears as a worthwhile extension of our preliminary study, inasmuch as the SST record at least over the Atlantic is trustworthy (because of the ample ship data).

We envisage warm low-level advection dominating the surface-air temperature (anyway, in a layer below 700 mb), which induces strong upwelling motion at 700 mb level. The *in situ* (over land) positive feedback resulting from these ascending motions can appreciably enhance the near-surface temperature: increased water vapor and clouds at cooler levels (above 700 mb) reduce the longwave losses (while the reduction in the shortwave absorption is not significant, because of the low mean solar elevation, and the high albedo of the snow-covered surface in late winter).

We attribute this increased dominance of the southwesterlies in SH(1974-1999) to changes in SST. We do not establish the reason for this trend, but the increased melting of the

Greenland ice sheet (Abdalati and Steffen, 1996) and the higher frequency of icebergs breaking off the Greenland shores (NOAA, 1999), by cooling the waters of the northwestern North Atlantic [the region of eastern Canada/northwestern North Atlantic was the only region at these latitudes for which cooling was reported (Ross et al. 1996; Hansen et al., 1999)], might have affected the pattern of the currents and produced this SST trend. Deser et al. (2000) report a response in atmospheric circulation to the changing sea-ice cover east of Greenland, with cyclone frequency increasing appreciably.

The change in the NAO index and in the pattern of surface winds over the North Atlantic is likely to be related to the change in the Arctic Oscillation (AO). AO is associated with fluctuations in the location of major ridge and trough regions at high latitudes in the Northern Hemisphere (Thompson and Wallace, 1998; Thompson et al., 2000). For the recent three decades (1968-1997), pronounced trends in winter and springtime surface air temperature and sea-level pressure were reported: parts of Eurasia have warmed by as much as 4°C, sea level pressure over parts of the Arctic has fallen by 4 hPa, and the lower stratospheric polar vortex has cooled by several degrees. Chase et al. (1996; 2000a; 2000b) analyzed by GCM model Northern Hemisphere circulation patterns and possible reasons for such changes. As discussed by Przybylak (2000) and by Deser et al. (2000), the connection between weather patterns in the Arctic and the midlatitudes is strongest in the Atlantic region. Does the change in the Arctic result from the change over the North Atlantic, or vice versa? Do these changes stem from a common cause? Is this common cause a trend in the SST?

Acknowledgments. Comments by P. Morel, NASA Headquarters, and J. Angell, NOAA, significantly improved the presentation of our ideas.

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	Ireland 52.4°N; 9.4°W	**Wales** 52°4N; 3.8°W	**France** 48.6°N; 1.9°E	**Russia** 60.0°N; 39.5°E
Trends in T_s °C y^{-1}	0.009	0.006	0.013	0.037
Correlation T_s with S_f	0.47	0.49	0.54	0.30
Correlation T_s with N_{ao}	0.57	0.55	0.40	0.57

Table 1. Trends in the February surface air temperature, T_s; the correlation of T_s with the North Atlantic southwesterlies for February with S_f at site A (where the highest correlation among the sites A, B, C is observed); and the correlation with the N_{ao} index.

	A 30°W	**B** 20°W	**C** 10°W
Southwesterlies SH(FH)	24(18)	19(12)	14(11)
Average Value of Southwesterlies S_f ms^{-1} SH(FH)	7.1 (6.0)	6.6 (6.3)	5.3 (5.6)
Trend τ_{stm} in the Southwesterlies m s^{-1} y^{-1}	0.033	0.027	-0.0017
Northwesterlies SH (FH)	0(2)	4(7)	8(4)
Northeasterlies SH(FH)	0(2)	1(2)	1(6)

Table 2. Statistics of the February average monthly surface winds at three eastern North Atlantic sites, each at 45°N.

Figure Captions

Figure 1. February mean surface air temperature in Ireland, Wales, Germany, and northern Russia, in Fig. 1A; February mean wind speed S_{fm} if the direction is from southwest (otherwise zero) at three sites in eastern North Atlantic; in Fig. 1B; NAO index N_{ao} in Fig. 1C; at the same sites sensible heat flux, in Fig. 1D; latent heat flux in Fig. 1E; all vs. year of analysis.

Figure 2. Wind streamlines, wind strength (below and above 10 ms^{-1}) in Fig. 2A; sensible heat flux from the surface in Fig. 2B; ascent rates at 700 mb in Fig. 2C (from ECMWF); all for February 1990.

Figure 3. Difference in the monthly-mean SST over the North Atlantic: February 1990 minus February 1996.

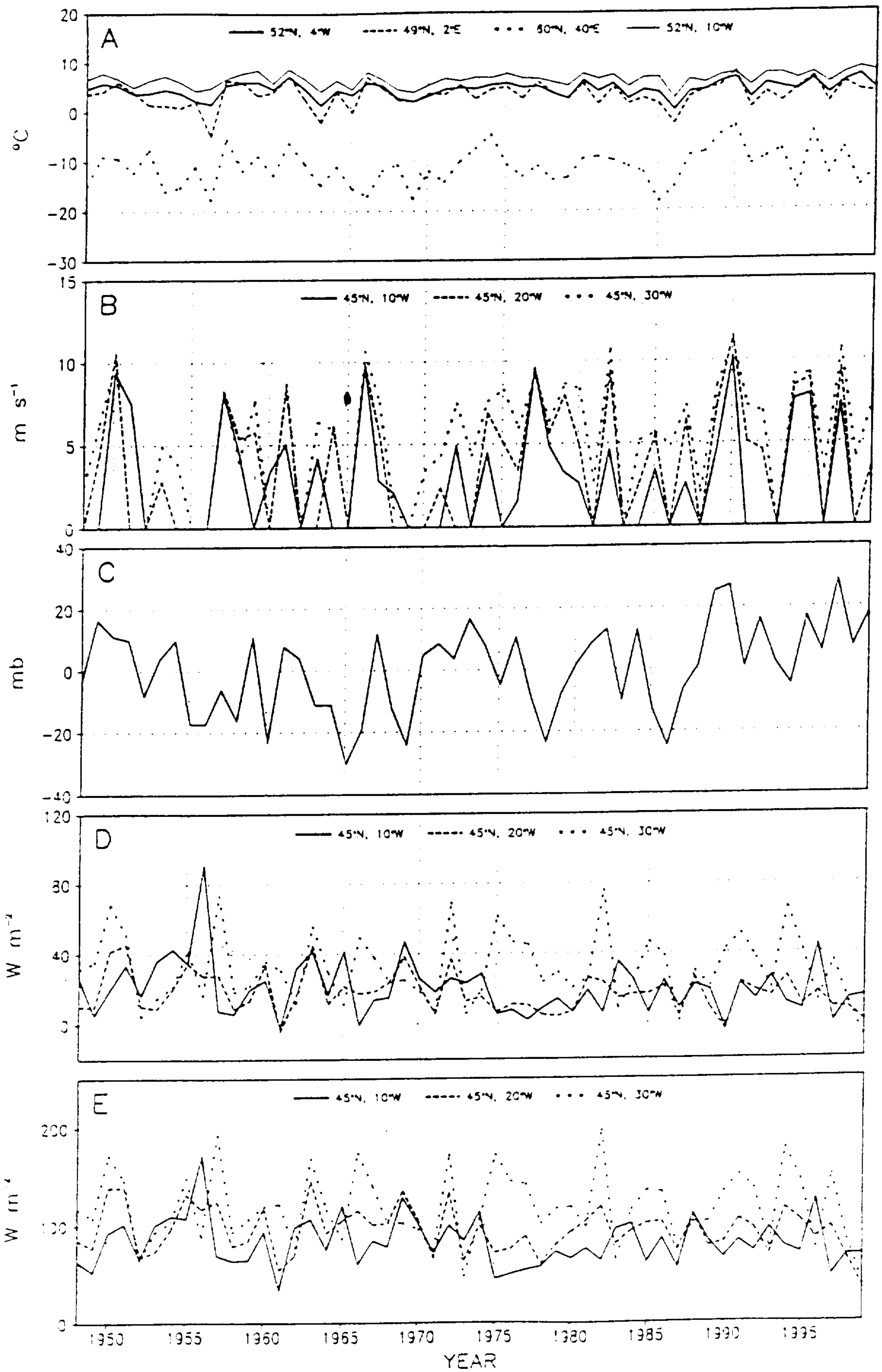
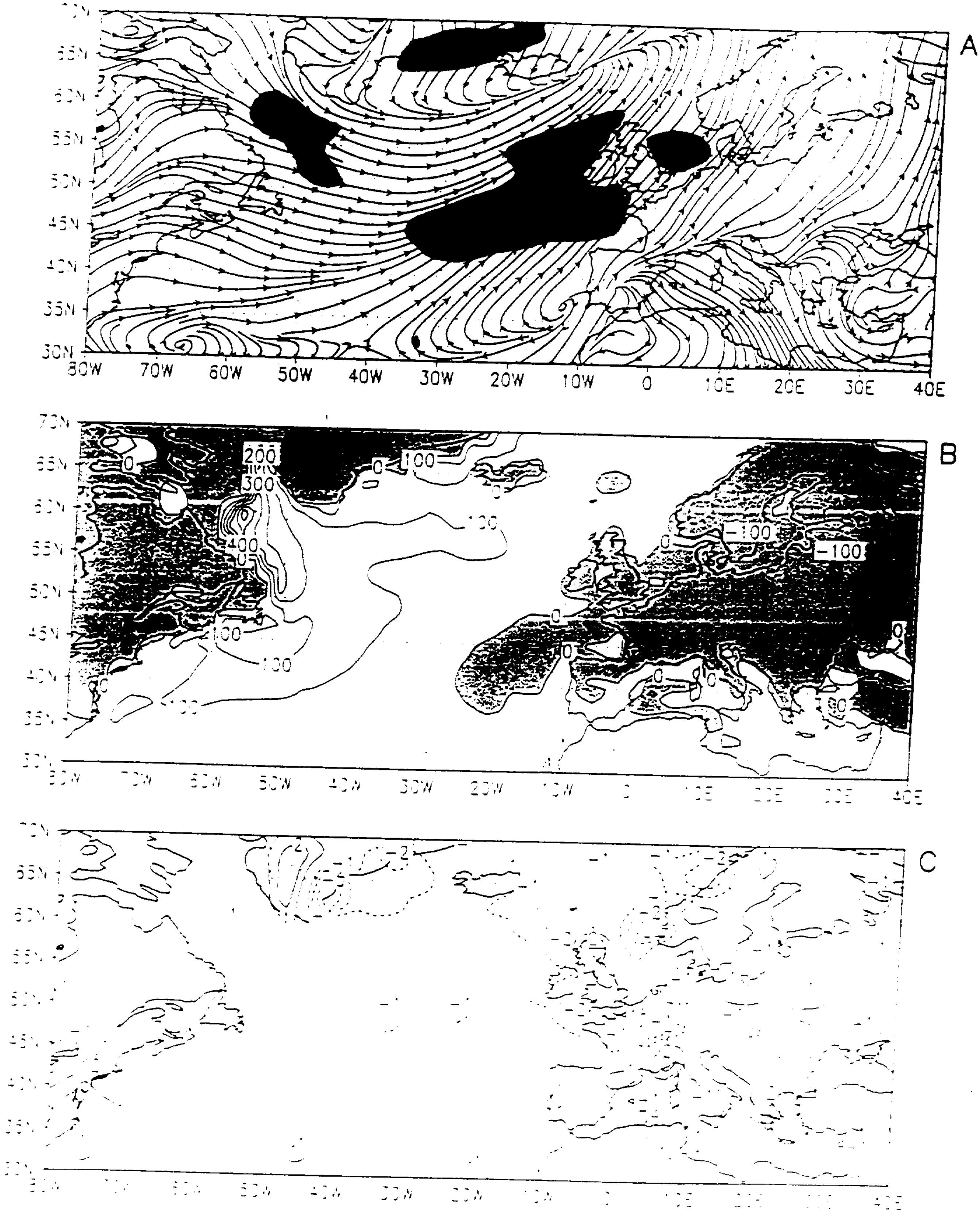


Fig. 1 /J. Otterman — J. Terry terry@dao.gsfc.nasa.gov


A
30N
35N
40N
45N
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60N
65N
80W
70W
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30W
20W
10W
0
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B
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C
-2

ECMWF Skin Temperature, Feb 1990–1996

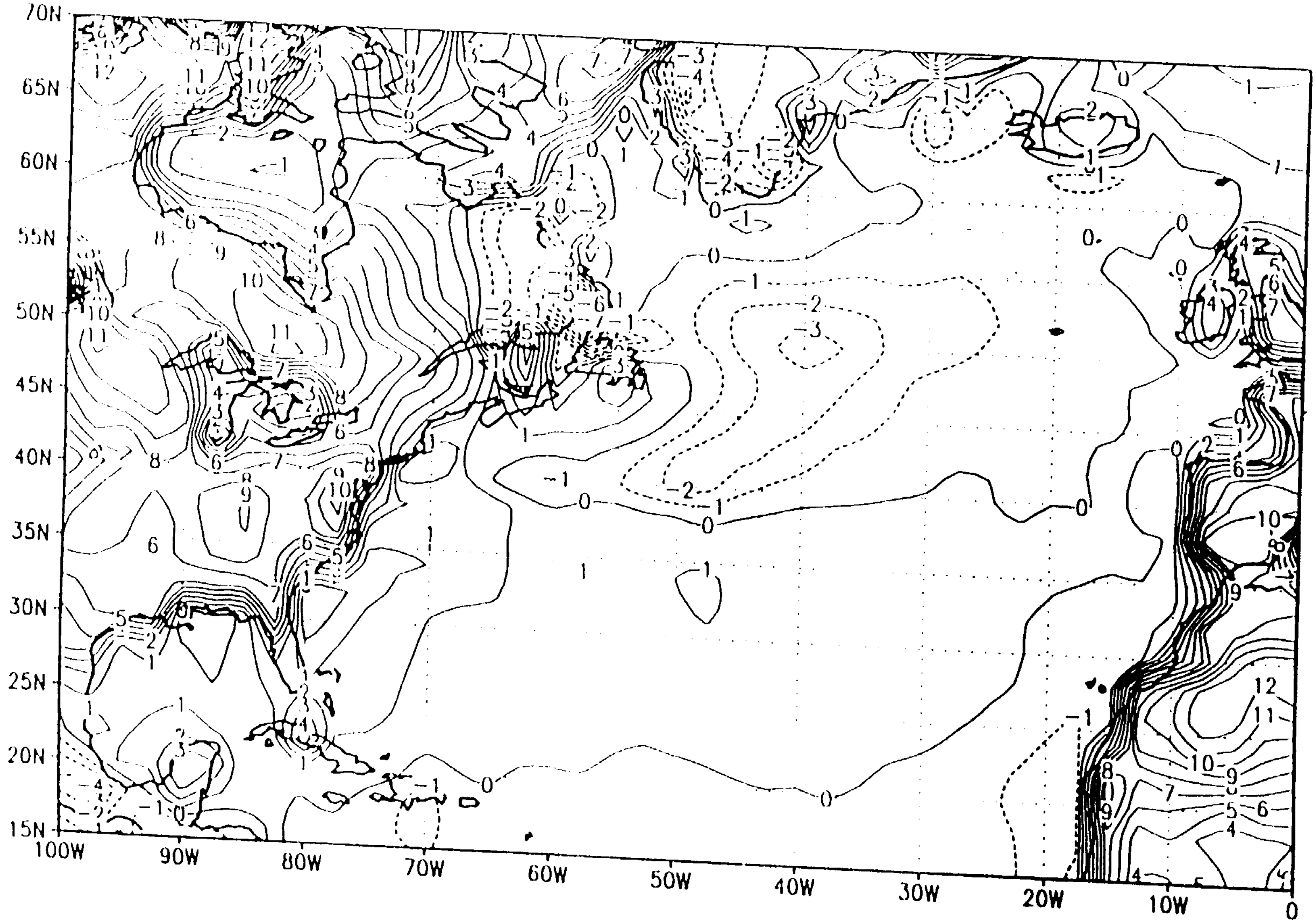

Fig. 3 /J. Otterman -- J. Terry terry@dao.gsfc.nasa.gov