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SHORT COMMUNICATION

ARE STRONGER NORTH-ATLANTIC SOUTHWESTERLIES THE FORCING TO THE LATE-WINTER WARMING IN EUROPE?

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ABSTRACT

We examine a possible mechanism leading to late-winter warming, and thus to an early spring in Europe. From the National Centers for Environmental Prediction reanalysis, we extract for the years 1948–99 ocean-surface winds over the eastern North Atlantic, and air temperatures at the surface T_s, and at the 500 hPa level T_{500} in late-winter and spring. T_s is extracted at six European locations, all at 50.5 °N, ranging in longitude from 1.9 °E (northeastern France) to 26.2 °E (Ukraine). To quantify the advection of maritime air into Europe, we evaluate for three-pentad groups the index I_{na} of the southwesterlies at 45 °N, 20 °W; I_{na} is the average wind speed at this point if the direction is from the quadrant 180–270° (when the direction is different, the contribution counts as zero). In late winter, correlations C_{it} between I_{na} and T_s are substantial, up to the 0.6 level in western Europe (but weaker correlations for Poland and Ukraine). C_{it} drops sharply by mid-March, occasionally taking negative values subsequently. This drop in C_{it} indicates that maritime air advection is no longer associated closely with the surface-air warming; the role of insolation becomes important, and thus the drop in C_{it} marks the arrival of spring. Correlations $C_{i\Delta}$ between I_{na} and our lapse-rate parameter Δ, the difference between T_s and T_{500}, indicate that the flow of warm maritime-air from the North Atlantic into this 'corridor' at 50.5 °N is predominantly at lower tropospheric level. By computing the best linear fit to I_{na} and T_s, the trends for the period 1948–99 are evaluated. The trends are appreciable in the second half of February and the first half of March: for I_{na}, the trends are 0.41 m s^{-1} and 0.15 m s^{-1} per decade in pentad groups 10–12 and 13–15 respectively (I_{na} increased from 1948 to 1999 by 2.10 m s^{-1} and 0.77 m s^{-1}); for T_s, the trends for western Germany are 0.36 °C and 0.43 °C per decade in these two respective pentad groups (T_s in this location increased from 1948 to 1999 by 1.86 °C and 2.19 °C). Such higher near-surface temperatures would markedly influence snow-melt, and thus absorption of insolation by the surface. Our three-pentad analysis points to the interval from mid-February to mid-March as the end of-winter period in which the southwesterlies over the eastern North Atlantic become stronger and the surface-air temperatures in Europe rise markedly, the lapse rate becomes steeper, and concurrently the longitudinal temperature gradient between the Somme (France) and the Oder (Germany–Poland border) (about −4 °C in 1948 for the 10° longitude distance) is reduced by 0.8 °C, i.e. by 20% of its 1948 value. Our thesis, that the observed late-winter warming and the concomitant advancement of spring in Europe results, at least in part, from stronger southwesterlies over the North Atlantic, merits further investigations.

KEY WORDS: climate trends; advancement of spring in Europe; ocean-to-land advection; Atlantic southwesterlies

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1. INTRODUCTION

A thesis is presented here that the late-winter warming and the concomitant advancement of spring observed toward the end of the 20th century in mid-latitude Europe (e.g. Menzel and Fabian, 1999; Jaagus and Ahas, 2000; Demareé *et al*., 2002) may be, at least in part, due to increasing southwesterlies over the eastern North Atlantic: more frequent direction from the southwest, and higher speeds when the ocean-surface winds are from that direction.

Substantial correlations were found between the speed of the surface southwesterlies over the eastern North Atlantic and the February surface-air temperatures in France and in longitudinal strips throughout Europe, all the way to the foothills of the Urals (Otterman *et al*., 1999). The correlations for March were much lower. In a subsequent short study, pentad-by-pentad analysis showed a precipitous drop in these correlations for pentad 16 and higher (i.e. Julian date 76, or 16 March), when the correlations occasionally took negative values (Otterman *et al*., 2000). This drop in the correlations was interpreted as the switch in the control of the surface-air temperature in Europe, from that of control in winter by the maritime-air advection, which raises surface-air temperatures when the ocean-surface winds are from the southwest, to that by the absorption of insolation in spring and summer. Indeed, it was suggested that the switch in the control can be regarded as most-relevantly defining the end of winter and the onset of spring.

In these studies from the Special Sensor Microwave Imager (SSM/I) and the European Centre for Medium-Range Weather Forecasts (ECMWF) datasets, the analysis extended for the 11 year period 1988–98. In the present study we extract information about the surface winds over the eastern North Atlantic (45 °N, 20 °W) and the air temperatures at six European locations from the National Centers for Environmental Prediction (NCEP) reanalysis (Kalnay *et al*., 1996), available now for the years 1948–2000. This much longer period of the available data allows us to assess trends. The correlation analysis for this period of 52 years presented here for several three-pentad groups indicates further that ocean-surface winds from the southwest constitute to a significant degree the control of these temperatures in late winter.

2. THE NCEP REANALYSIS

Our study is based on the NCEP reanalysis dataset, 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 became available — see Kalnay *et al*. (1996), for a documentation of the changes. The intention of processing was to produce a consistent dataset. Still, some discontinuity at high atmospheric levels was apparently introduced starting with 1979, relative to the earlier (1948–78) period when no satellite observations were available (Pielke *et al*., 1998a,b; Pawson and Fiorino, 1999). This uncertainty, crucially important to the evaluation of trends, is addressed in a recent report on the reanalysis project (Kistler *et al*., 2001). We discuss this question in Section 5.

3. THE EXTRACTED DATA AND COMPUTATION OF THE CORRELATIONS

From the NCEP reanalysis we extract the ocean-surface winds at 45 °N, 20 °W (this location was chosen for computing I_{na} since it provided higher correlation than five other locations, to the east, west, and south of 45 °N, 20 °W) for all available data points (four data points per day), and compute for the pentad-group (three pentads) average the index I_{na} of southwesterlies: wind speed is counted toward the average only if the direction is from azimuth 180 to 270° (if the direction is different, the point counts toward the average as a zero speed). I_{na} is plotted versus the year of the reanalysis, 1948–99, for the pentad group 10–12 in Figure 1 (solid black line). We note strong interannual variability: I_{na} has a zero value in the years 1965, 1969, 1988, and 1993, peaking at about 11 m s^{-1} in 1990 and 1997. (Index computed in a 'box' in the eastern North Atlantic for February of these two years was about 8 m s^{-1}, see Otterman *et al*. (1999).)

We likewise extract from the NCEP reanalysis the 2 m temperature T_s (and also the 500 hPa level temperature T_{500}, see below, where we compute our lapse-rate parameter) at six European locations, all at 50.5 °N: (1) northeastern France, 1.9 °E; (2) western Germany, 7.5 °E; (3) eastern Germany, 11.2 °E; (4) western Poland, 16.9 °E; (5) eastern Poland, 22.5 °E; and (6) Ukraine, 26.2 °E. Our motivation is to analyse how the influence of maritime air advection on the temperatures T_s (established for longitudinal strips through Europe by Otterman *et al*. (1999)) changes with the distance from the North Atlantic. The six temperatures T_s are plotted for the pentad group 10–12 alongside I_{na} in Figure 1. We note strong interannual variations, which generally tend to follow the variations in I_{na} presented there. For instance, we observe record or near-record temperatures T_s in all six locations in the high-index year 1990, and low T_s in the zero-index years 1965 and (except for France) 1988. (However, T_s took very low values in 1963, when I_{na} was 5 m s^{-1}.) The best fit to T_s for eastern Germany, showing a substantial positive trend in the pentad group 10–12 for this 52 year period (dotted line Figure 1), is discussed later.

To point out how effective is the influence of the North-Atlantic southwesterlies in late winter in determining the onset of spring in Europe, we compare the final snow dates (FSDs) in the high I_{na} years versus the average FSD in southern Estonia. For the two southernmost stations, Vöru and Valga, FSDs were respectively 19 March and 21 March in 1950 (I_{na} of 8 m s^{-1}), and 16 March and March 15 in 1990 (I_{na} of about 11 m s^{-1}), compared with the 2 April mean FSD: an advancement by about 2 weeks (personal communication from J. Jaagus, University of Tartu).

Correlations C_{it} between I_{na} and the temperatures T_s, for pentad-groups from 7–9 to 28–30, are plotted in Figure 2. We note close grouping of the three western locations (France, and two locations in Germany), and separately the three eastern locations (two locations in Poland, and one in Ukraine). For the three western stations C_{it} is in the 0.4 to 0.6 range in February and first half of March, dropping sharply for pentad group 16–18, i.e. the second half of March. Such a drop in the pentad-by-pentad correlation analysis was interpreted

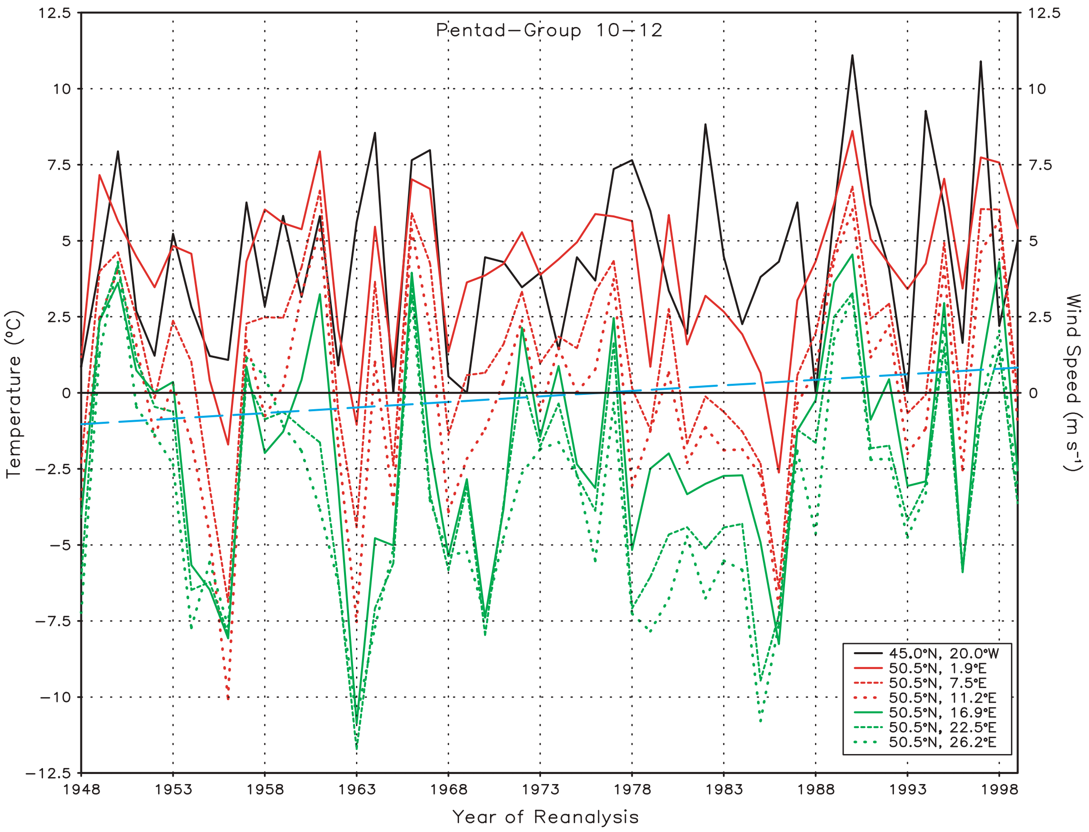

Figure 1. Surface-air temperature T_s at six European locations, and the index I_{na} of the southwesterlies at 45 °N, 20 °W, versus the year of the reanalysis, for pentad group 10–12; trend (linear best fit) is indicated by dotted lines for eastern Germany, 11.2 °E, only

as marking the onset of spring in Europe (see Otterman *et al.*, 2000): as the sun rises higher above the horizon and the snow-melt reduces the surface albedo, insolation replaces advection as the dominant control of the temperatures.

C_{it} for the three eastern locations take lower values in late winter than those for the three western locations. We attribute this difference in the climate characterization by C_{it} to the Sudeten Mountains, and possibly to the higher North Carpathian Mountains, and to the longer distance involved in the maritime-air advection. The drop in C_{it} into spring for these eastern locations is more gradual.

We observe in the maps of the surface winds that when I_{na} takes a high value a southwesterly flow from the North Atlantic is evident, with the direction often rotating anticlockwise by some 20° over the continent. Except for the mountains mentioned above which apparently constitute to some extent a barrier to the near-surface flow (see the reduction in C_{it} for the three locations to the east), the advection of the warm maritime air in the 'corridor' from the North Atlantic into Ukraine at 50.5 °N takes place at lower tropospheric levels. Thus the primary effect is that air temperatures T_s at the 2 m level are raised, and the lapse rate is enhanced by this advection. This low-level flow is indicated by the positive correlations $C_{i\Delta}$ between I_{na} and the lapse-rate parameter Δ, which is the difference $T_s - T_{500}$. Correlations $C_{i\Delta}$ (not presented here) are smaller than C_{it} when taking in the pentad groups 7–9 and 10–12, with values up to 0.3 for the three western (France and Germany) locations and up to 0.2 for the eastern (Poland and Ukraine) locations. Again (as in Figure 2), fairly close grouping of $C_{i\Delta}$ characterizes the three western locations, and *separately* the three eastern locations. These groupings point to our correlations (C_{it} and $C_{i\Delta}$) as being of value in delineating homogeneous climatic regions.

We selected three-pentad groups as the time units for our analysis after finding that this approach consistently produced higher correlations compared with the one-pentad analysis. This can be well understood, since the maritime air masses take quite a few days (note in Figure 1 the variability of the wind speed) to arrive at the six European locations, which are distant from the North Atlantic point 20 °W (where we compute I_{na}) by up to 46° in longitude (in the case of Ukraine). Longer time-units are counterindicated, since periods of differing teleconnections, different seasons or subseasons, would be combined in one time frame. A study based on division of the year into four seasons, customary in climate studies (e.g. Ross *et al.*, 1996), or even into eight seasons (such as in a study by Jaagus and Ahas (2000)), would have failed to quantify appropriately (or even detect) the trends reported here.

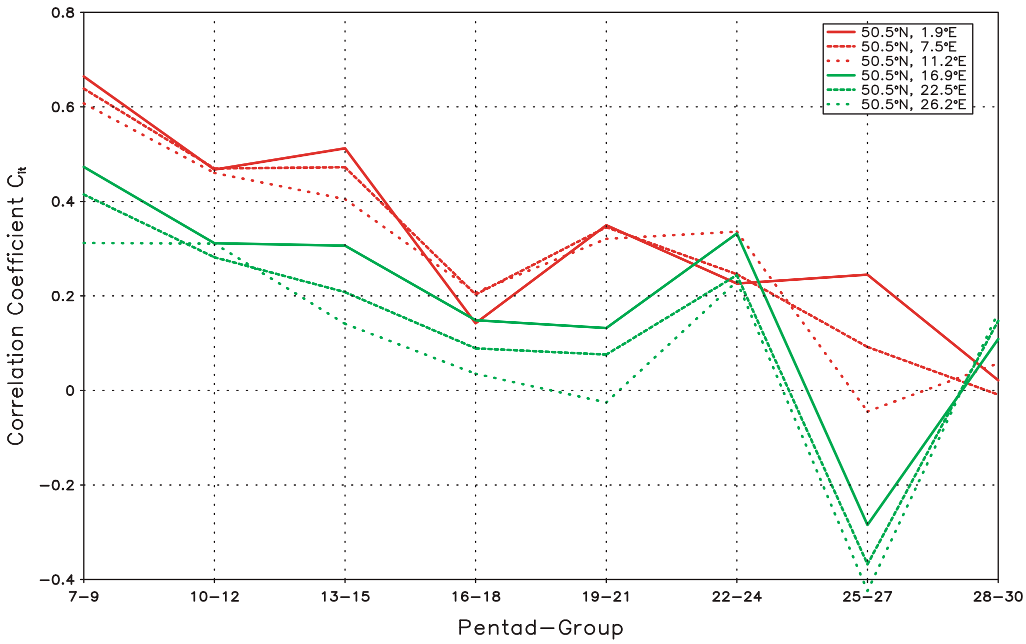

Figure 2. Correlations C_{it} between I_{na} and the temperature T_s at six European locations for eight pentad-groups, from 7–9 to 28–30

4. EVALUATION OF TRENDS AND THE 1948–99 CHANGES

We evaluate trends in the extracted data, I_{na} and T_s, by regression analysis of these seven variables for four time periods. The best fit to T_s in northeastern Germany, 11.2 °E, for the pentad group 10–12 is shown in Figure 1, where we easily note that the magnitude of the slope (the trend) is small compared with that of interannual variations. The trends for pentad groups 7–9 to 16–18, presented in Table I, are consistent (positive) and appreciable for I_{na} and all locations in Europe for only two pentad-groups: 10–12 (second half of February) and 13–15 (first half of March). The resulting changes for the 52 year period are fairly appreciable for these two pentad-groups: from 1948 to 1999 the index increased by 2.10 m s^{-1} and 0.77 m s^{-1} respectively, while the corresponding increases of T_s in western Germany were 1.9 °C and 2.2 °C respectively. In other locations the temperature increases are likewise reported for this 30-day period important for the timing of final snow-melt in Europe, but they are smaller. All these 1948–99 changes are smaller than the standard deviations from the best-fit lines (Table I), indicating that our method is not based on robust statistics. In the three-pentad group preceding the mid-February to mid-March period, as well as in the subsequent group (which we regard as already spring), we report small negative trends in T_s (with one exception); the trends in I_{na} are also small.

In view of the correlations between I_{na} and the lapse-rate parameter Δ, the increases in I_{na} in the mid-February to mid-March period must have produced a steeper lapse rate, appreciably so in the three western locations, and only weakly in the east. T_s in eastern Germany increased by 0.8 °C more than in northeastern France (Table I). Thus, the longitudinal temperature gradient between the Somme and the Oder (about −4 °C in 1948 for the 10° longitude distance) is reduced by 0.8 °C, i.e. by 20% of its 1948 value.

5. DISCUSSION AND CONCLUSIONS

Late-winter warming over the recent decades and the concomitant advancement of spring in Europe at latitudes 54–60 °N can be regarded as established trends, evident in the surface-air temperature analysis in Belgium

Table I. Index I_{na} and 2 m temperatures T_s: 1948–99 trends (per decade), standard deviation (SD) of interannual fluctuations, 1948 and 1999 values, and their differences

Pentad group		I_{na} (m s^{-1}) 45 °N, 20 °W	T_s (°C) 50.5 °N, 1.9 °E	50.5 °N, 7.5 °E	50.5 °N, 11.2 °E	50.5 °N, 16.9 °E	50.5 °N, 22.5 °E	50.5 °N, 26.2 °E
7–9	Trend	0.12	−0.10	−0.16	−0.03	−0.38	−0.27	−0.01
	SD	3.16	2.58	3.41	3.67	3.90	3.72	3.69
	1948/1999	4.65/5.25	4.31/3.79	1.31/0.52	−0.77/−0.93	−2.51/−4.46	−4.25/−5.62	−5.61/−5.66
	Diff.	0.60	−0.52	−0.79	−0.17	−1.95	−1.38	−0.05
10–12	Trend	0.41	0.21	0.17	0.36	0.21	0.01	0.04
	SD	2.80	2.47	3.10	3.35	3.53	3.58	3.60
	1948/1999	3.31/5.41	3.58/4.64	0.86/1.72	−1.03/0.83	−2.33/−1.25	−2.91/−2.84	−3.60/−3.39
	Diff.	2.10	1.07	0.85	1.86	1.09	0.07	0.21
13–15	Trend	0.15	0.27	0.34	0.43	0.29	0.28	0.28
	SD	2.56	2.30	2.94	3.14	3.40	3.12	2.97
	1948/1999	3.60/4.37	5.21/6.58	2.75/4.47	1.37/3.55	−0.46/1.03	−1.61/−0.17	−1.86/−0.41
	Diff.	0.77	1.37	1.72	2.19	1.49	1.44	1.44
16–18	Trend	−0.10	0.08	−0.11	−0.08	−0.06	−0.09	0.06
	SD	1.99	1.54	1.80	2.15	2.51	2.88	2.97
	1948/1999	4.06/3.58	7.23/7.62	6.06/5.52	5.21/4.83	3.66/3.36	2.53/2.10	1.93/2.22
	Diff.	−0.49	0.39	−0.54	−0.39	−0.30	−0.43	0.29

by Demareé *et al*. (2002), and by an analysis of phenological events for most of Europe by Menzel and Fabian (1999) and for Estonia by Jaagus and Ahas (2000). This trend is consistent with the rising late-winter temperatures in the 1948–99 period in the six locations at 50.5 °N, from France to Ukraine, reported here from the NCEP reanalysis.

Menzel and Fabian (1999) put the warming trend that they report (averaged for Europe) within the framework of global warming, even though a cooling in the Balkans is reported. Indeed, regional cooling has been reported in simulations of global warming (Russell and Rind, 1999). Nevertheless, the Balkans' cooling trend suggests that causes specific to the warming in mid-latitude Europe should be examined.

Hurrell (1996) associated the surface warming over the Northern Hemisphere since the mid-1970s 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 temperature (specifically, the Microwave Sounding Unit 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. Highly pertinent to our thesis 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." Rogers (1997) associated climate variability of north Europe with the storm track variations over the North Atlantic. Our study follows the concepts presented in the above references. Advection from the warm ocean surface apparently constitutes the control of the surface air in Europe in late winter (Otterman *et al*., 1999), as we further analyse for the three-pentad groups here. A thesis is presented that this trend to earlier onset of spring may be, at least in part, due to more dominant southwesterlies over the eastern North Atlantic. Our three-pentad analysis points to the interval from mid-February to mid-March as the end-of-winter period, in which the surface-air temperatures in Europe rise appreciably, and concurrently the southwesterlies over the eastern North Atlantic become considerably stronger. We envisage warm (and moist) low-level advection directly increasing the surface-air temperature (anyway, in a layer below 700 hPa), and at the same time enhancing the lapse rate. This flow induces strong upward vertical motion at the 700 hPa level, which we observe subsequent to days with strong southwesterlies (speeds above 20 m s^{-1}). In these vertical motions water vapour moves to higher (cooler) levels, and clouds form, which reduces the loss of heat to space (it is immaterial in this respect whether precipitation is produced or not).

We compared surface-air temperature measured in Brussels (average of daily maximum and minimum temperatures) with the reanalysis data in northeastern France. These two locations are not very far from each other, and thus the temperature differences are rather small. Root-mean square differences are 1.48 °C and 1.91 °C for pentad groups 10–12 and 13–15 respectively for the years 1948–73 (first half of the reanalysis), and 0.90 °C and 0.93 °C for the 1974–99 period, between which a discontinuity might have been introduced. The difference between the two periods, of ∼0.5 °C, in these France-to-Belgium differences is likely to be the result of stronger winds in the 1974–99 period, which reduced the temperature gradients. This calculation suggests that if the NCEP reanalysis does have a discontinuity, it is not very large in the case of the near-surface data: most of the 1948–99 temperature differences in these two pentad-groups (Table I) are larger than 0.5 °C.

The very strong interannual variability in I_{na} and T_s can be considered as noise in our study trends. Thus, the pronounced increases in the 2 m temperatures from 1948 to 1999 for a fraction of the hemisphere and for the short-time period of 30 days (mid-February to mid-March) are not established by high-significance statistics. The possibility that in the NCEP reanalysis a discontinuity was introduced when satellite-derived information was incorporated raises an uncertainty, as discussed in the summary report on the project (Kistler *et al*., 2001): "during the earliest decade (1948–1957, there were fewer upper air data observations and they were made 3 hours later than the current main synoptic times, ... so the reanalysis is less reliable than for the later 40 years." It is unlikely that this caveat applies forcefully in the case of the ocean-surface winds, for which ample information was available for the entire period 1948–99 (from the ship reports over the North Atlantic). The caveat does apply to the temperatures T_s and T_{500}, which were not utilized in producing the reanalysis.

The increase in I_{na} derived here from the NCEP reanalysis is consistent with several previous studies, which reported an increase in the wave height over the North Atlantic, resulting from the trend to stronger winds

(Carter and Draper, 1988; Bacon and Carter, 1991; Kushnir *et al.*, 1997; Gulev and Hasse, 1999). Trends in the southwesterlies specifically have not been analysed. Pressure gradients are the underlying mechanism (Bacon and Carter, 1993), which are affected by sea-surface temperature (SST). The enhancement of the North-Atlantic southwesterlies may stem from changes in SST, such as the increasing temperature gradients between 45 °N, 20 °W and 35 °N, 35 °W that we observe (but do not discuss here). 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, might have affected the pattern of the ocean currents and produced this SST trend.

The thesis presented here closely parallels the report that the winter warming in the Czech Republic is due in part to changes in the circulation patterns in *this* country (Huth, 2001). We envisage that changes in the circulation over the European continent are forced by changes in the surface winds over the North Atlantic, which are quantified by the specific index I_{na}. These large-scale circulation patterns are in a large measure influenced by the North Atlantic oscillation. However, I_{na} apparently is a more directly relevant parameter for characterizing maritime-air advection into Europe in winter (see Otterman *et al.* (1999) for detailed discussion). Because of its importance, our concept merits further examination.

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