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Advection from the North Atlantic as the forcing of winter greenhouse effect over Europe

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Abstract. In winter, large interannual fluctuations in the surface temperature are observed over central Europe. Comparing warm February 1990 with cold February 1996, a satellite-retrieved surface (skin) temperature difference of 9.8K is observed for the region 50-60°N; 5-35°E. Previous studies show that advection from the North Atlantic constitutes the forcing to such fluctuations. The advection is quantified by Index I_{na}, the average of the ocean-surface wind speed over the eastern North Atlantic when the direction is from the southwest (when the wind is from another direction, it counts as a zero speed to the average). Average I_{na} for February 1990 was 10.6 m s^{-1}, but for February 1996 I_{na} was only 2.4 m s^{-1}. A large value of I_{na} means a strong southwesterly flow which brings warm and moist air into central Europe at low level, producing a steeper tropospheric lapse rate. Strong ascending motions at 700 mb are observed in association with the occurrence of enhanced warm, moist advection from the ocean in February 1990 producing clouds and precipitation. Total precipitable water and cloud-cover fraction have larger values in February 1990 than in 1996. The difference in the greenhouse effect between these two scenarios, this reduction in heat loss to space, can be translated into a virtual radiative heating of 2.6 W m^{-2} above the February 1990 surface/atmosphere system, which contributes to a warming of the surface on the order of 2.6 K. Accepting this estimate as quantitatively meaningful, we evaluate the direct effect, the rise in the surface temperature in Europe as a result of maritime-air inflow, as 7.2 K (9.8 K-2.6 K). Thus, fractional reinforcement by the greenhouse effect is 2.6/7.2, or 36%, a substantial positive feedback.

1. Introduction

Strong interannual variability characterizes winter surface temperature in mid-latitude Europe, 50-60°N;5-35°E. With the winter-sun low above the horizon and low absorptivity (high albedo) of the surface when snow-covered, advection from the oceans effectively controls the climate of the adjoining continent, as shown by Hurrell (1996). In winter, the surface of the North Atlantic is much warmer than that of mid-latitude Europe, whereas the Arctic can be colder, so that the temperatures on the European continent depend on the wind direction. Circulation patterns over the North Atlantic and Europe fluctuate with the North Atlantic Oscillation (NAO), the stage of which is quantified by an Index (Rogers, 1997). Recently, a new index, I_{na}, has been developed based on the strength of the ocean-surface southwesterlies over the eastern North Atlantic. I_{na} apparently is a more relevant measure than the NAO Index for quantifying the maritime-air advection as the forcing to higher winter temperatures in Europe (Otterman et al., 1999).

Our aim is to assess the dependence of the winter greenhouse effects over Europe on the value of I_{na}. In this season of low sun at these latitudes, the longwave radiative effects of clouds and water-vapor predominate and tend to increase the surface temperature. In other seasons, shortwave radiative effects predominate, because of the daytime reduction of insolation, and an opposite net effect is generally found (Otterman et al., 2000; Sun et al., 2000). In our preliminary analysis, we compare high-I_{na}, warm February 1990 with the opposite scenario in February 1996.

2. Datasets used in the study

From the Special Sensor Microwave/Imager, SSM/I, aboard the DMSP satellites, a large dataset of surface wind speeds over the global oceans has been derived. The Variational Analysis Method, VAM, was selected to derive wind-vector data (Atlas et al., 1996). In this method, the SSM/I retrievals of surface wind speed are combined with independent wind observations to produce consistent fields of wind speed and direction. The resulting global ocean-surface dataset is appropriate for climate analysis (Atlas et al., 1996).

The Pathfinder Path A dataset is compiled from measurements in numerous thermal and microwave bands basic to the TIROS Operational Vertical Sounder, TOVS, aboard polar-orbiting NOAA satellites. Temperatures, water vapor, cloudiness and radiative fluxes at various levels are inferred (Susskind et al., 1997). Monthly anomalies with respect to the 1979-2000 averages have been derived.

The ECMWF dataset is part of the Basic Level III-A analysis product within the ECMWF/WCRP Global Atmospheric Data Archive. In our study, we use ECMWF data for characterizing vertical motions at 700 mb.

Parts of our study are based on the NCEP/NCAR (National Centers for Environmental Prediction / National Center for Atmospheric Research) Reanalysis dataset, which extends from January 1948 essentially to the present. Improvements in the analysis were introduced when satellite measurements became available (Kalnay et al., 1996; Kistler et al., 2001). The years for which we extract the data fall in this latter period.

3. North-Atlantic winds as the control of the greenhouse effect in central Europe

We examine here the influence of the maritime-air advection on the greenhouse effects in Europe. The strength of the warm advection is quantified by a specific Index, I_{na}, of the ocean-surface southwesterlies over the eastern North Atlantic. From the SSM/I dataset (Atlas et al., 1996), we evaluate pentad (5-day) averages of the wind speed at 45° N; 20° W from all the observations reporting wind direction from the quadrant 180°-270°. When the direction is not southwesterly, the speed is counted as a zero in calculating the average. The Index I_{na} derived by this approach is plotted in Fig. 1 for the winters and early spring 1989/90 and 1995/96, that is, for the 24 pentads from Dec. 2-6 to March 27-31. The average I_{na} for February (averaging six pentads) 1990 is about 10.6 m s^{-1}, but only about 2.4 m s^{-1} for February 1996.

This large difference in I_{na} strongly affects the surface (skin) temperature T_s in central Europe, 50-60°N; 5-35°E. There are no high mountains between the Atlantic and the eastern edge of this strip, and thus it can be regarded as a "corridor" for low-level inflow to the continent. The maps of T_s (from Pathfinder Path A dataset) are shown in Fig. 2 for February 1990 (upper Figure) and February 1996 (middle Figure). The data have been normalized to what the observations would have been at 7:30 AM, to remove satellite orbit differences (Susskind et al., 1997). We observe area-average temperatures 272.9 K and 263.1 K, respectively for the two time periods (see Table 1). The difference, 9.8 K, is consistent with the sensitivity, slightly above 1.0 K/m s^{-1}, of the February surface-air temperature in Europe to an increase in I_{na}, analyzed by Otterman et al. (1999). We stress here that the high value of T_s in 1990 represents the combined consequences of the inflow of warm air (the direct effect), and of the enhanced greenhouse effect that this low-level inflow produces (which we regard as the feedback).

We present in Table 1 the Surface Longwave Emission, (SLE), calculated as:

$$SLE = \varepsilon\sigma T_S^4, \tag{1}$$

where ε is the surface emissivity (taken as 0.95) and σ is the Stefan-Boltzmann constant.

The air masses advected from the North Atlantic in the strong flow of February 1990 were certainly moist. The total precipitable water PW (g cm^{-2}) in central Europe was larger by more than 70% in February 1990 than in February 1996, as illustrated in Fig. 3, and given in Table 1 (from Pathfinder Path A). It is interesting to note that the weak winds in 1996 were effective in advecting moisture only to about 20° E; beyond this longitude the atmosphere was quite dry, with W values below 0.6 g cm^{-2}. In contrast, the strong winds of 1990 advected moisture all the way to the easternmost boundary of the region (PW of at least 1 g cm^{-2}).

Associated with the enhanced low-level warm moist advection, increased cloud cover is observed at middle and upper tropospheric levels, typically with a half-day delay. This enhanced cloudiness is likely derived from lifting associated with the same circulation feature responsible for the enhanced advection. A less stable lapse rate, resulting from the differential advection (warmest near the surface), is also a contributing factor. Cloud fraction was larger in 1990 than in 1996, as we report from the NCEP/NCAR Reanalysis (see Fig. 4 for high clouds). Differences between the two periods were greatest in the northern parts [15% for the medium-level clouds (between 678 and 350 mb, not shown here), 30% for high clouds (above 350 mb)], and also strong in the southwestern parts.

OLR tends to larger values when SLE is large, but is reduced by the cloud and water vapor effects. Separation of the opposing influences presents a challenge. The greenhouse factor was much stronger in Feb. 1990 than in Feb. 1996 (Figs. 3 and 4). OLR (W m^{-2}) for those two monthly means (from the Pathfinder Path A) is given in Table 1 and presented in Fig. 5. From Table 1, we compute that SLE in Feb. 1990 was larger than in Feb. 1996 by 15.8%, but that OLR was larger by only 3.7%. This disproportionately small increase stems from the more robust greenhouse effect by the more moist and cloudy 1990 atmosphere. The ratio OLR/SLE was only 0.679 in 1990, as compared to 0.758 in 1996. This comparison establishes the 1990 versus 1996 difference in the greenhouse effect as substantial.

Our intention now is to evaluate the contribution of the reduced losses to space into an impact on T_S. For this, we require information about the partitioning of OLR between the emission effectively from the surface (which is dominant in the 11μm band) and that effectively from the atmosphere (which is dominant at wavelengths 15-20 μm). In this preliminary study, we resort to a simplified approach, assuming that an 1 K increase in T_s produces OLR larger by 1 W m^{-2} (Wu and Susskind, 1990). Thus, T_s of 272.9 K (an increase by 9.8 K over the reported 1996 T_s) should produce OLR of 205.4 W m^{-2} in Feb. 1990 (adding 9.8 W m^{-2} to the observed 1996 OLR of 195.6 W m^{-2}). This is 2.6 W m^{-2} larger than what was actually observed. Relating this enhancement of the greenhouse effect by the 1990 atmosphere (that is, this reduction in the heat loss to space) to the surface temperature effect, we evaluate the consequence for T_s as an increase by 2.6 K. Thus, the regional greenhouse-effect feedback constitutes some 26.5% of the combined (the direct inflow-effect, and the feedback) difference in T_s of 9.8 K, and 36% of the direct (combined less the feedback) 7.2 K effect.

4. Discussion and conclusions

The aim of this preliminary study is to analyze the relationship in winter between the ocean-to-land advection and the greenhouse-factor parameters over the central European plain, 50-60 °N; 5-35 °E, which we regard as a "corridor" for the near-surface flow. It was advantageous in the study to have four different datasets choosing the appropriate dataset for each parameter. Still, it is not a definitive analysis, considering that we only compare two monthly scenarios and do not perform detailed radiative transfer calculations.

The SSM/I dataset of ocean surface winds is a reliable information source, especially accurate in regions such as the eastern North Atlantic, where comparisons with the surface measurement are ample. Ocean-surface winds are highly variable on time scales of a pentad (5 days) and shorter. The effects over the continent lag (depending on the distance from the ocean and the wind speed) the ocean wind observations. It was quite fortuitous, however, that our pentad-by-pentad analysis for the two selected Februarys showed I_{na} (m s^{-1}) fluctuating in a relatively narrow range around 10.6 m s^{-1} in 1990, 2.4 m s^{-1} in 1996 (see Fig. 1), so we could analyze monthly averages in the other datasets (rather than be forced to conduct pentad-by-pentad analysis).

Pathfinder Path A dataset is quite reliable for large-region assessment, but incomplete coverage of small regions where gaps in satellite observations introduce greater inaccuracies into the averages. Data from two satellites were averaged for Feb.

1990, and another two for Feb. 1996, which might have introduced small discrepancies because of differences in the inter-satellite calibrations. A drawback of this dataset is that clouds below high clouds tend to be underestimated, and for that reason we resorted to the NCEP/NCAR Reanalysis for middle and high clouds.

The mechanism underlying the enhancement of the greenhouse effect involves the vertical motions at 700 mb. The ECMWF dataset, most useful for this evaluation, shows strong ascending motions for Feb. 1990 but not for Feb. 1996. Specifically, 12 hours after especially strong southwesterlies over the eastern North Atlantic (SSM/I data), cells of strong upward motion are arranged in a semicircle around western Europe, from Scandinavia to the Mediterranean at 12 UTC on Feb. 1, 1990 (Otterman et. al., 2001). The increased cloudiness can be attributed to this lifting and the available moisture.

The difference G between the surface emission SLE and OLR specifies the greenhouse effect (W m^{-2}) in a given scenario. G in 1990 was much greater than in 1996 because the effectiveness of the 1990 atmosphere in reducing heat-loss to space was far greater in 1990, <u>and</u> because SLE was also much larger in 1990. To compare two different atmosphere/surface scenarios, we must assess the greenhouse effect relative to SLE. We assume that a 1K increase in T_s produces an 1 W m^{-2} increase in OLR (Wu and Susskind, 1990). The feedback effect calculated on this basis is likely to be on the order of 2.6 K, a substantial fraction of the total (direct and feedback) difference of 9.8 K in the surface temperature. Based on this value of the feedback, the direct effect is estimated as 7.2 K (9.8 K-2.6 K), and its reinforcement by the feedback stands at 36%. This analysis establishes the enhancement of the greenhouse effect, i.e., the increased downward longwave flux primarily associated with greater cloudiness, as a substantial positive feedback to the direct effect, which is the southwesterly inflow of warm air to the low troposphere over Europe.

Trends for warmer winters in Europe have been observed (Ross et al., 1996; Demarée et al., 2002). Several studies reported the trend to stronger winds over the North Atlantic for the recent decades (Bacon and Carter, 1991; Kushnir et al., 1997; Gulev and Hasse, 1999). Is the trend in the temperature in Europe related to the increasing strength of the North Atlantic surface winds? The strengthening advection might have contributed to increased cloudiness over land, which was observed by Keevallik and Russak (2001), and by Sun et al. (2000), for instance. Further studies of these important ocean-to-land advection effects, including simulation with General Circulation Models, are warranted.

Acknowledgements

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Period (month)	I_{na} ($m\ s^{-1}$)	T_s (K)	SLE ($W\ m^{-2}$)	PW ($g\ cm^{-2}$)	OLR ($W\ m^{-2}$)	G ($W\ m^{-2}$)	OLR/SLE
Feb. 90	10.6	272.9	298.76	10.3	202.8	95.96	0.679
Feb. 96	2.4	263.1	258.06	5.9	195.6	62.46	0.758

Table 1. Index I_{na} and the greenhouse-effect parameters: comparison of February 1990 with February 1996.

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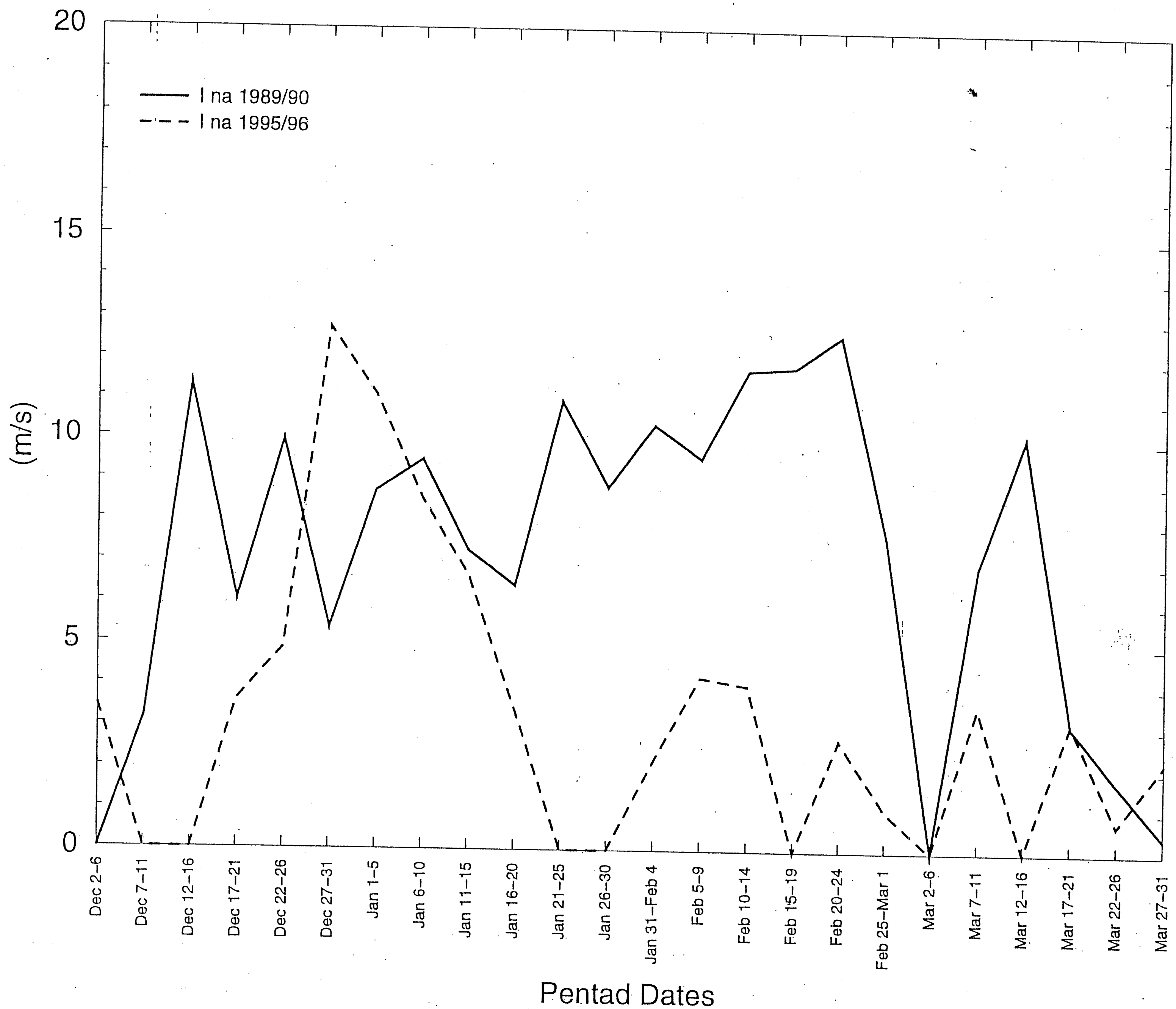
List of Figures



20
15
10
5
0
(m/s)
I na 1989/90
I na 1995/96
Dec 2–6
Dec 7–11
Dec 12–16
Dec 17–21
Dec 22–26
Dec 27–31
Jan 1–5
Jan 6–10
Jan 11–15
Jan 16–20
Jan 21–25
Jan 26–30
Jan 31–Feb 4
Feb 5–9
Feb 10–14
Feb 15–19
Feb 20–24
Feb 25–Mar 1
Mar 2–6
Mar 7–11
Mar 12–16
Mar 17–21
Mar 22–26
Mar 27–31
Pentad Dates

Fig. 1

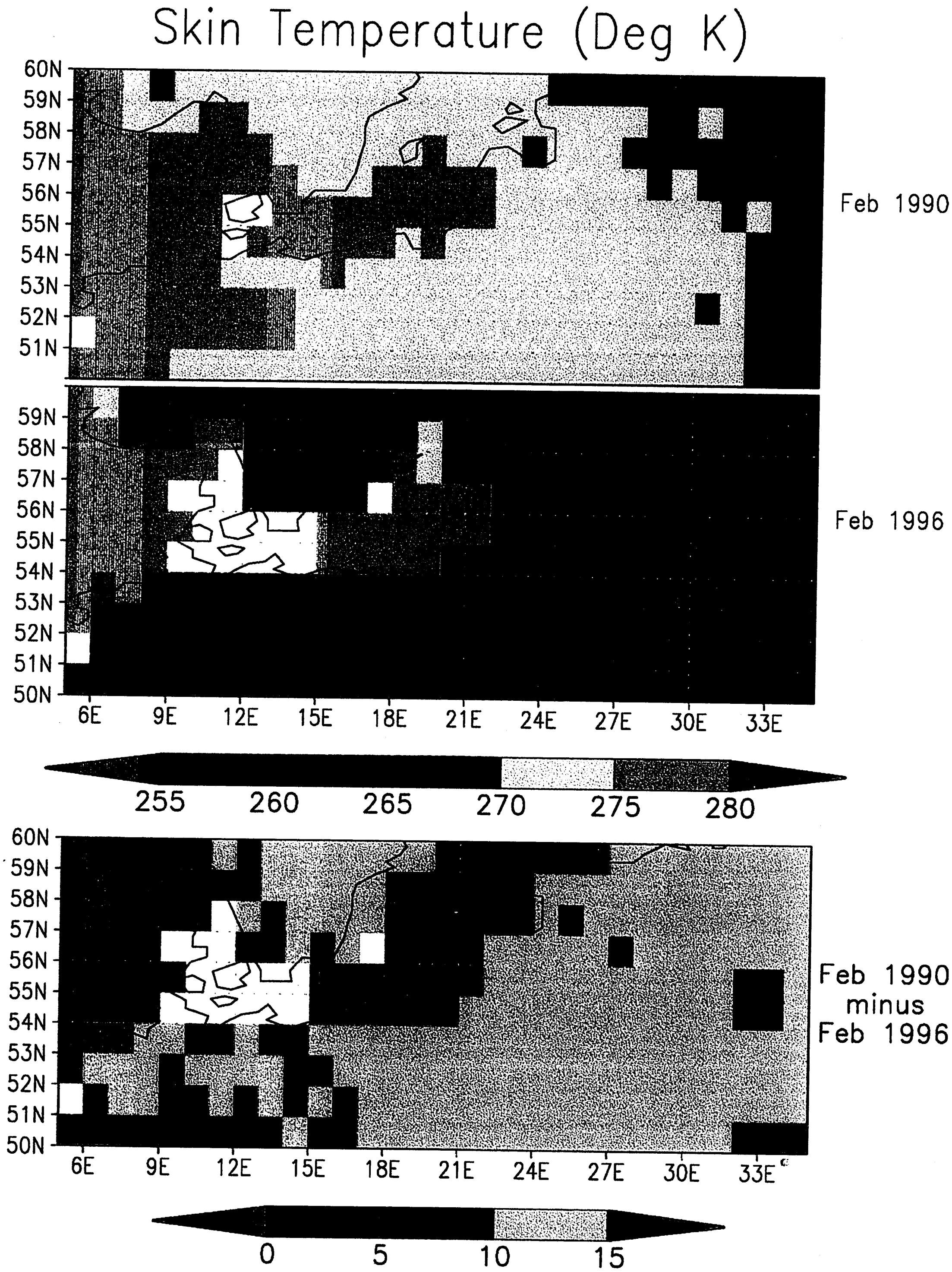

Skin Temperature (Deg K)
60N
59N
58N
57N
56N
55N
54N
53N
52N
51N
50N
6E
9E
12E
15E
18E
21E
24E
27E
30E
33E
Feb 1990
Feb 1996
255
260
265
270
275
280
Feb 1990
minus
Feb 1996
0
5
10
15

Fig. 2

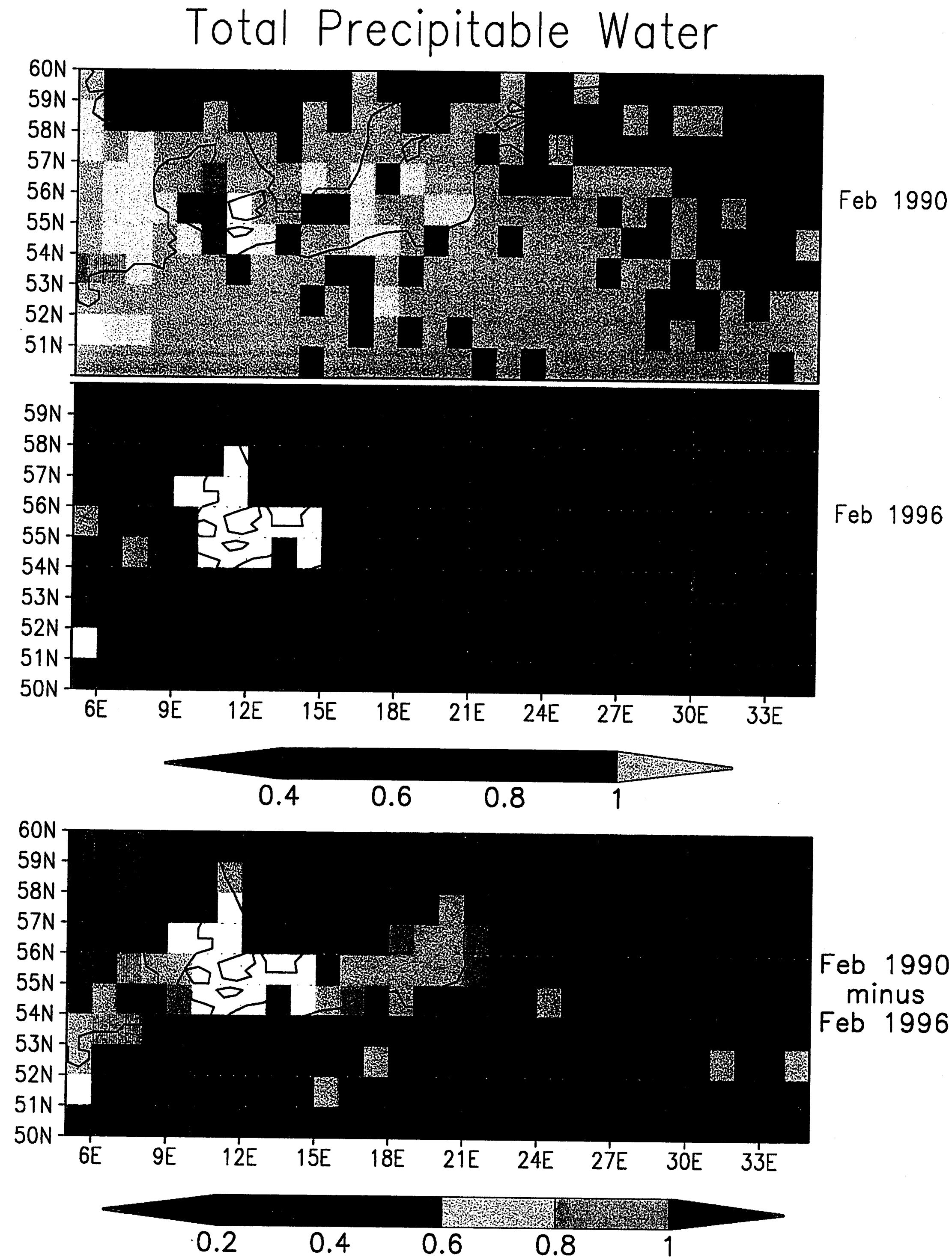

Total Precipitable Water
60N
59N
58N
57N
56N
55N
54N
53N
52N
51N
50N
6E
9E
12E
15E
18E
21E
24E
27E
30E
33E
Feb 1990
Feb 1996
0.4
0.6
0.8
1
Feb 1990 minus Feb 1996
0.2
0.4
0.6
0.8
1

Fig. 4

High cloud cover (percent)

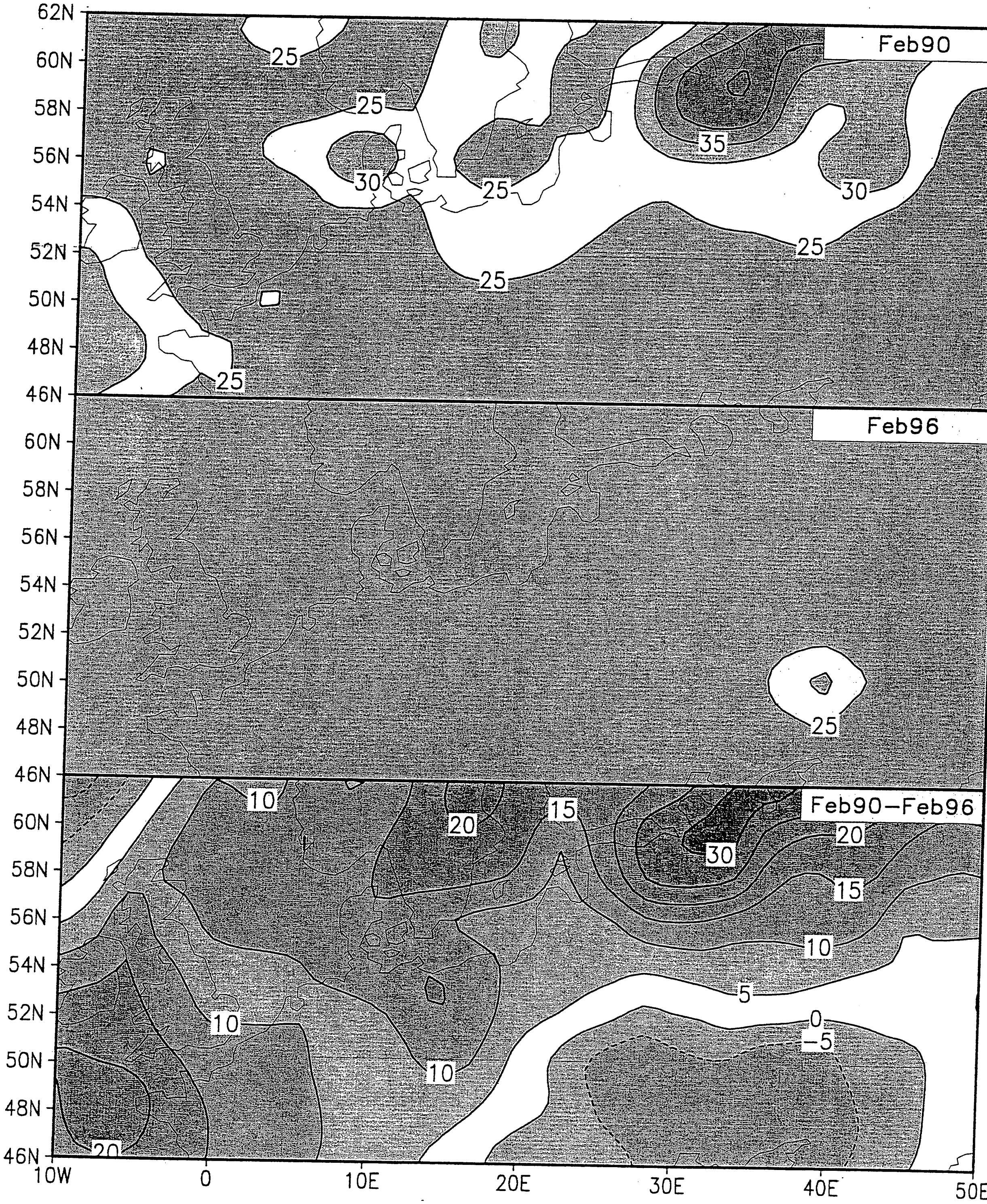


Fig 6

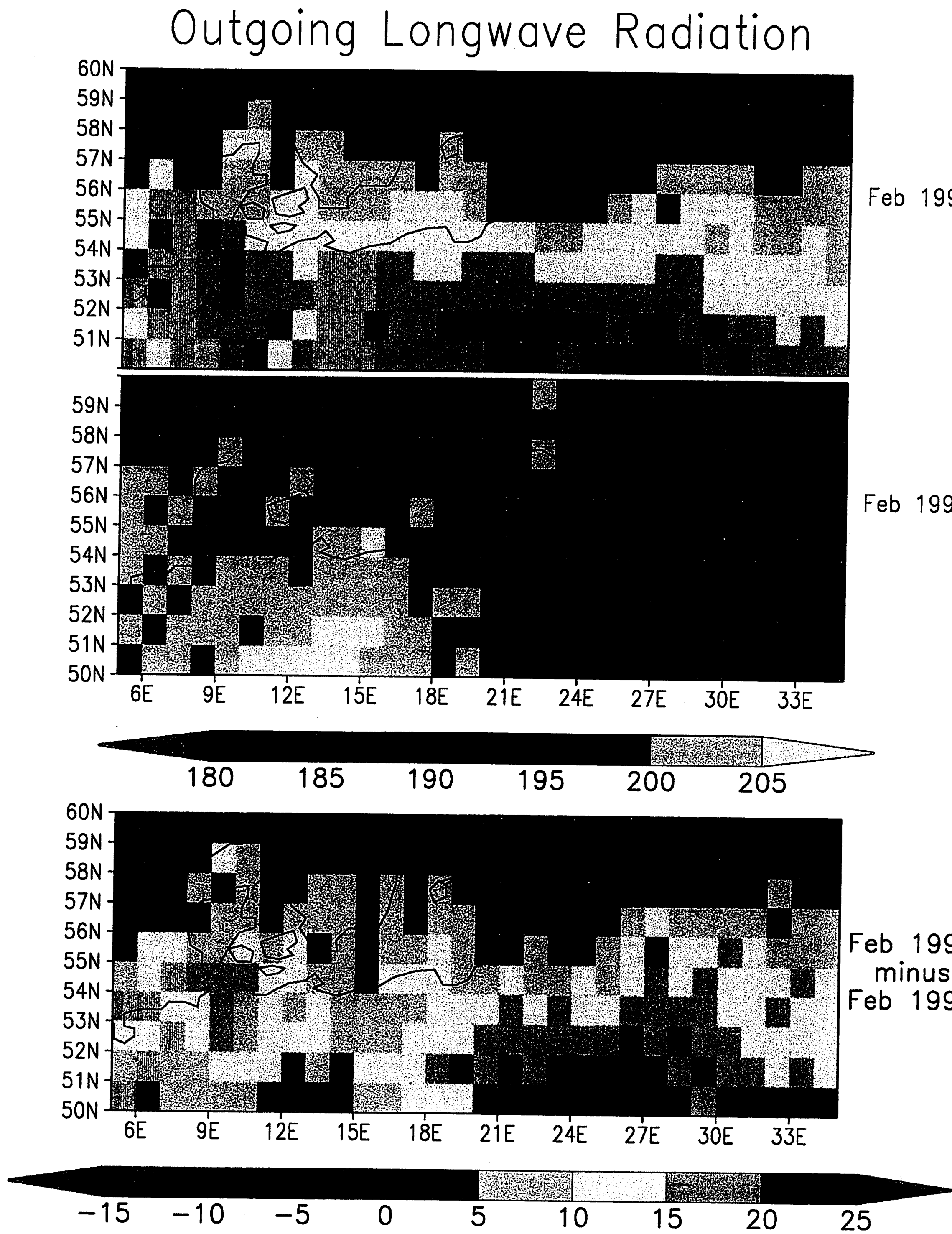

Outgoing Longwave Radiation
60N
59N
58N
57N
56N
55N
54N
53N
52N
51N
50N
Feb 1990
Feb 1996
6E
9E
12E
15E
18E
21E
24E
27E
30E
33E
180
185
190
195
200
205
Feb 1990
minus
Feb 1996
−15
−10
−5
0
5
10
15
20
25

Fig. 7

POPULAR SUMMARY

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In winter, large interannual fluctuations in the surface temperature are observed over central Europe. Comparing a warm February (1990) with a cold February (1996), a satellite-retrieved surface (skin) temperature difference of 9.8°C is found for the region 50-60°N; 5-35°E. Previous studies show that interannual differences are attributable to significant interannual differences in the dominance and strength of southwesterly flow over the eastern North Atlantic, derived from satellite measurements. Strong southwesterly flow results in advection of relatively warm, moist maritime air into the European continent. Strong ascending motions are also observed in the lower troposphere (700 mb) in association with the occurrence of enhanced warm, moist advection from the ocean and produce enhanced clouds and precipitation. The greater atmospheric water vapor and cloud-cover fraction lead to a further enhancement of the advection warming through a greenhouse effect. For February 1990, it is estimated that 2.6°C of the observed 9.8°C warming relative to February 1996 is due to the greenhouse enhancement reduction in heat loss to space). This amounts to 36% of the actual warming, a substantial positive feedback with significant consequences for central Europe.

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