Impact on regional winter climate by CO_2 increases vs. by maritime-air advection

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[1] Fractional Outgoing Radiation, FOR (dimensionless), defined as the ratio of Outgoing Longwave Radiation, OLR (W/m^2), to upward Surface Longwave Emission, SLE (W/m^2), is a basic parameter for analyzing regional greenhouse effect. Here, FOR values are derived from a General Circulation Model by extracting OLR and SLE over areas in east-central Europe (at about 60°N) one hour after injecting appropriate CO_2 concentration (adjustments to the atmospheric profile are thus excluded) to the Feb. 1 midnight simulation. The reduction in FOR is 0.00051 when atmospheric CO_2 increases by 14 ppm, which is the currently expected per-decade increase. Fluctuations in the North-Atlantic surface winds produce fluctuations in FOR over central Europe: monthly-mean FOR in strong-wind February 1990 was 0.679, but 0.758 in weak-wind, lower cloud-fraction February 1996. Strong maritime-air advection in 1990 resulted thus in FOR reduced by 0.079, effect by two orders-of-magnitude stronger than the decrease effected by the per-decade increase in CO_2. *INDEX TERMS:* 3309 Meteorology and Atmospheric Dynamics: Climatology (1620); 3314 Meteorology and Atmospheric Dynamics: Convective processes; 3359 Meteorology and Atmospheric Dynamics: Radiative processes. **Citation:** Otterman, J., R. Atlas, G. L. Russell, and H. Saaroni, Impact on regional winter climate by CO_2 increases vs. by maritime-air advection, *Geophys. Res. Lett.*, *30*(15), 1822, doi:10.1029/2003GL017545, 2003.

1. Introduction

[2] Concentrations of CO_2 and other greenhouse gases increased markedly in the second half of the 20th century. Attributable to these increases, pronounced warming has been observed over the globe, characterized by regional and seasonal differences, with steepest warming in northern continents, 45–60°N [*Ross et al.*, 1996; *Angell*, 1999; *Hansen et al.*, 1999; *Otterman et al.*, 2002a]. In this last study, based on the NCEP/NCAR Reanalysis [*Kalnay et al.*, 1996], an increase in the central Europe surface temperatures by some 2.2°C was reported for the second half of February and first half of March in the period 1948–1999. Concurrently in this period, surface-winds at mid-northern latitudes, the westerlies, strengthened over the North Pacific and North Atlantic [*Graham and Diaz*, 2001; *Hoskins and Hodges*, 2002]. Stronger westerlies mean intensified maritime-air advection into the continents. Warmer winters over the continents (that is, regional effects) can produce hemispheric winter warming because high thermal inertia of the oceans will weaken the consequences of warm-air outflow.

[3] Specifically, the rise of surface temperatures in Europe has been linked to stronger advection from the North Atlantic [*Otterman et al.*, 2002a]. The advected air masses are moist as well as warm, enhancing cloud-cover and water-vapor over land. The mechanism is especially strong in the central European Plain, as there are no high mountains to impede the low-level flow into the continent. Sharp interannual fluctuations characterize the mechanism, since the ocean-surface winds fluctuate. The fluctuations allow us to assess the strength of the forcing to higher land temperatures and other climactic parameters by the ocean-surface winds. We compare this forcing to the primary forcing by CO_2 increases, which we analyze first.

2. Forcing FOR by CO_2 Increases

[4] The sensitivity of a GCM to a wide-range of radiative forcings, including CO_2 increases, was analyzed in a broad study by *Hansen et al.* [1997] focusing on the global mean temperature. The response was found to vary sharply depending on characteristics of the forcings, apart from its magnitude quantified by W/m^2. The principal mechanism involves alterations of lapse rate and increase/decrease of cloud cover. Our present study of primary change in the greenhouse effect (no change in the lapse rate or cloud-cover) by CO_2 increases could be regarded as a preliminary step in analyzing regional consequences of CO_2 changes.

[5] In our study we present and develop the Fractional Outgoing Radiation, FOR (dimensionless), defined as the ratio of Outgoing Longwave Radiation, OLR (W/m^2), to upward Surface Longwave Emission, SLE (W/m^2), as the basic parameter for analyzing greenhouse effects (notation OLR and SLE is consistent with that of *Otterman et al.* [2002b]). Here, FOR values are derived from a General Circulation Model [*Russell et al.*, 1995] by extracting OLR and SLE over areas in east-central Europe (at about 60°N) for the first hour after injecting a specified CO_2 concentration into a Feb. 1 midnight simulation. Thus, adjustments to the vertical atmospheric profile are excluded (evaluation of global warming is based on long-term integration). The reduction in FOR, ΔFOR, is 0.0034 ± 0.0004 when atmospheric CO_2 is increased from 315 ppm to 400 ppm (the reduction in FOR varies somewhat with cloud and aerosol conditions). Concentration 315 ppm prevailed in 1958, and 400 ppm is expected to apply in about 21 years from now, in 2024, inasmuch as the current (2003) concentration is about 370 ppm, and the per-decade increase in CO_2 is estimated as 14 ppm. There are 6.7 decades between 1958 and 2024 and thus, by dividing 0.0034 decrease in FOR from 1958 to

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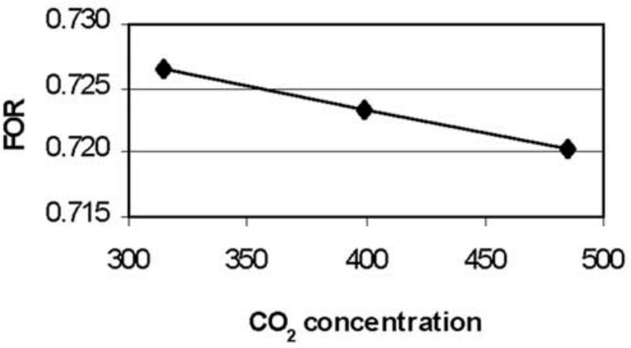

Figure 1. Fractional Outgoing Radiation, FOR, average of 5 areas in east-central Europe, vs CO_2 concentration. The decrease ΔFOR is 0.34 when CO_2 increase from 315 to 400 ppm, but somewhat smaller, 0.30, for a further increase by 85 ppm, to 485 ppm (due to increased saturation at land centers).

2024, the corresponding per-decade reduction in FOR is 0.00051. Dependence of FOR on the CO_2 concentrations are shown as Figure 1. We also analyze changes in the numerator (OLR) and the denominator (SLE) of FOR. When CO_2 increases from 315 ppm to 400 ppm, OLR decreases by 0.864 W/m^2 whereas SLE increases by only 0.013 W/m^2, a surface warming but of insignificant magnitude.

3. Forcing Changes in FOR by Airflow from North Atlantic

[6] Fluctuations in the North-Atlantic surface-winds produce fluctuations in the surface-air temperatures, first as the direct effect, the inflow of warm air masses into central Europe. That the inflow is at low-level is clearly indicated by the high correlation, 0.75, between the surface skin temperature T_s and the lapse rate parameter L_{pr} (difference between surface-air and the 500 mb temperature): See Figure 2, where March averages of both parameters are presented for the years 1989 to 2002 over Europe 48–60°N; 8–38°E. Greater lapse rate means an unstable atmosphere and since the advected air masses are moist as well as warm, cloud-cover increases. Monthly-mean FOR in strong-wind February 1990 was 0.679, but 0.758 in weak-winds, lower cloud-fraction February 1996 [*Otterman et al.*, 2002b]. Strong increase in maritime-air advection resulted thus in ΔFOR of 0.079, effect some 23 times stronger than the 0.0034 decrease by 27% increase in CO_2 under average cloud-cover/aerosol conditions.

4. Discussion and Conclusions

[7] The studies cited in the Introduction report the strongest trends of continental temperatures at latitudes 45–60°N in winter/spring. The temperature differences between ocean and land are strongest then, and this can be taken as suggesting a major role for maritime-air advection. The trends at the tropospheric levels are of the same sign as at the surface, but of lower magnitude, which is consistent with low-level advection. Our analysis, summarized below, strengthens the case of ocean-to-land flow as the dominant mechanism of the observed winter/early-spring warming of the northern continents.

[8] We present here the changes in FOR (dimensionless), the fractional outgoing longwave radiation, as the measure of forcing a change in regional climactic conditions. Change in

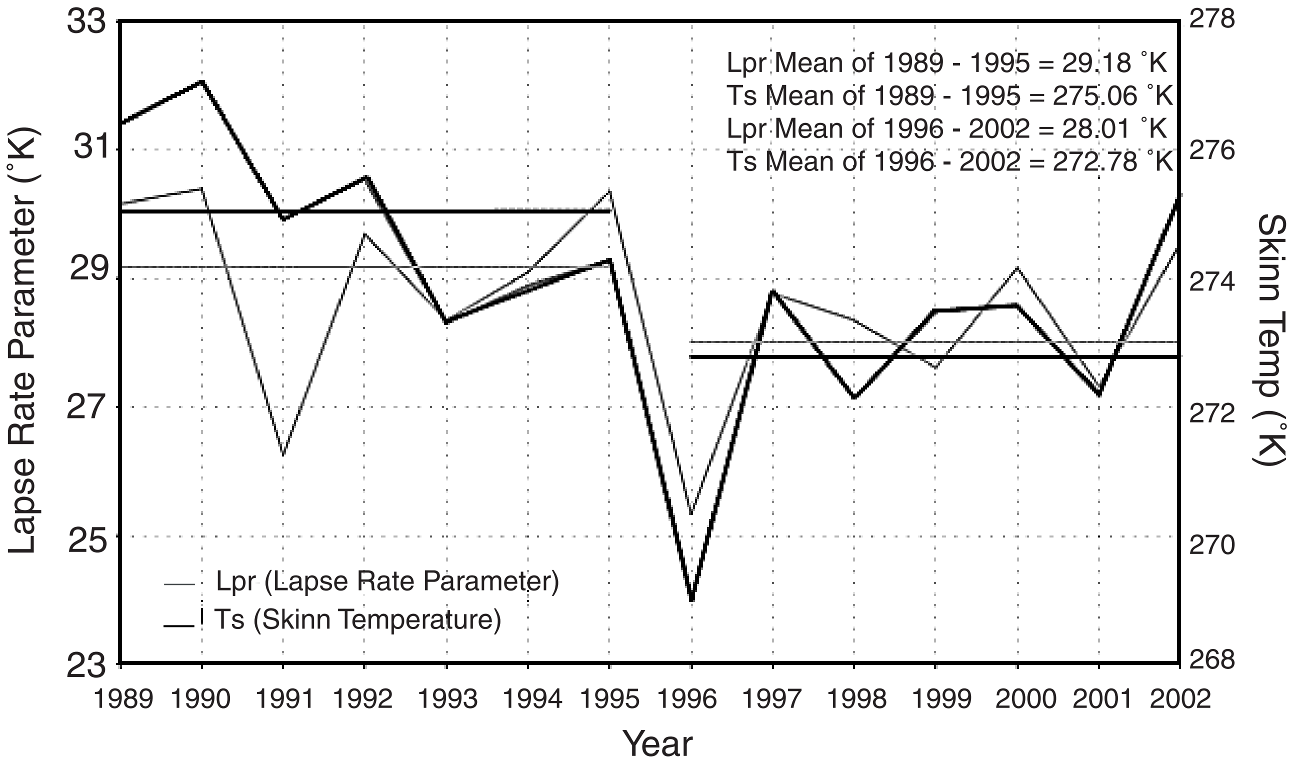

Figure 2. Surface Skin Temperature T_s and lapse rate parameter L_{pr} over Europe 48–60°N; 8–38°E for March 1989 to 2002; averages for first 7 years and subsequent 7 years.

primary FOR (without adjustments in the atmospheric profile) by 27% increase in the CO_2 concentration from the 1958 concentration level, 315 ppm to 400 ppm expected in about 21 years from now, stands as 0.0034 ± 0.0004(depending on the cloud/aerosol conditions) for winter in Europe (simulation applying GCM of *Russell et al.* [1995]). The corresponding per-decade decrease in FOR stands as 0.00051.

[9] Change in FOR was also assessed comparing two scenarios of late-winter conditions over an area 46 to 62°N in Europe. Monthly means of cloud-cover and total precipitable water were pronounced for February 1990, when the North-Atlantic surface southwesterlies were 10.6 m/sec, but substantially weaker for February 1996 when the wind average was only 2.4 m/sec. FOR was derived as 0.679 for the strong-advection 1990 case, and 0.759 for the weak-advection 1996 case [*Otterman et al.*, 2002b]. The difference, ΔFOR of 0.079, is by factor of 23 stronger forcing than that evaluated above for the 27% increase in CO_2, the increase projected from 1958 to 2024.

[10] We conclude that, if the increase in the ocean-surface winds over the North Atlantic, forced by the North Atlantic Oscillation, NAO, was linked to the Increases in the Greenhouse Gases, IGG, this link [*Shindell et al.*, 1999] constitutes a very powerful local feedback to IGG. Winter and spring temperatures in Europe were rising markedly If the rise in NAO index and other circulation indices are not linked to IGG but oscillate independently, downturns in the indices will produce periods of substantially cooler winters in northern latitude lands. Cool conditions indeed prevailed in central Europe in 1996–2002 (which continued into February/March 2003) as can be seen in Figure 2. It is also worth noting that cool conditions prevailed over the globe in the first half of 1999 [*Hansen et al.*, 1999]. It may be appropriate to quote here in a broader sense (as pertaining to regional and even hemispheric temperature trends) a statement made in conjunction with a slight cooling observed over the years 1950–1999 in the eastern United States and the neighboring North Atlantic: "The spatial and temporal patterns of the temperature change suggest that more than one mechanism was involved..." [*Hansen et al.*, 1999].

[11] Northwestern North Atlantic is indeed a good example of a region where several mechanisms can affect a climate change. Enhanced melting of the Greenland icecap (due to warmer conditions or stronger winds) increases the cold-water flow into and from the Labrador Sea, cooling the ocean more to the south. In this area the cold flow starts to encounter the warm outer fringes of the Gulf Stream. Stronger gradients of the sea surface temperature favor increased low clouds (or fog), which would reduce absorption of insolation, producing cooler summer conditions. The specific processes in this region merit in-depth examination.

[12] Continued global warming, due to increasing concentration of anthropogenic greenhouse gases and adjustment of the ocean temperatures to warmer climate, is discussed in numerous studies and WMO reports. To this generally established forecast, we contribute analysis of two kinds of forcing changes in the greenhouse effects. First, our analysis suggests that the primary (that is, without feedbacks) forcing to the global warming by increased CO_2 will be rather modest. Second, interannual fluctuations in the winter/early-spring greenhouse effects over the northern continents (which are caused by fluctuations in the low-level maritime-air advection) are by two orders of magnitude stronger than the increases in the greenhouse effects (decreases in FOR) from the expected per-decade increases in CO_2.

[13] Currently, neither NCEP/NCAR Reanalysis [*Kalnay et al.*, 1996] nor Pathfinder Path A retrievals (J. Susskind, NASA/GSFC, personal communication) incorporate changes due to the increases in CO_2. Our study provides guidelines to accounting for these changes. Continued simulation studies and accurate measurements of the ocean-surface winds are warranted.

[14] **Acknowledgments.** Comments by J. Susskind, NASA/GSFC, and a GRL reviewer, resulted in a much improved presentation of our material.

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