Trans-Eurasian Transport of Ozone and its Precursors

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Abstract. We describe the impacts of European fossil fuel emissions on O_3 and CO over central and eastern Asia, and contrast these with the impacts of North American sources. Outflow of European pollution occurs principally in the boundary layer and thus transport and chemical processing differ significantly from North American or East Asian outflow which experience stronger lifting and occur largely over marine regions. We examine the implications of this for air quality over northeast Asia and find small but significant contributions to O_3 of about 2.5 ppbv in spring. We also note different impacts on OH from European sources and consider the implications for global climate.

Introduction

Transport of pollutants from major industrial regions across the Atlantic and Pacific Oceans has been investigated in aircraft measurement campaigns [e.g., *Fehsenfeld et al.*, 1996; *Jacob et al.*, 2003] and model studies [*Berntsen et al.*, 1999]. Transport of European pollutants over Eurasia has received less attention, principally because identification of the impacts over East Asia is more difficult due to additional sources over the continent and to different meteorological conditions governing transport. Low-altitude outflow, slower high-latitude chemistry, and surface deposition lead to substantial differences in the fate of European pollutants, and these differences are explored here.

Model Studies

This study uses the Frontier Research System for Global Change version of the University of California, Irvine global chemical transport model (FRSGC/UCI CTM) [*Wild and Prather*, 2000]. The model is driven with meteorological data for 1996 from the ECMWF Integrated Forecast System and is run here at T21 resolution (5.6°×5.6°) with 19 levels [*Sundet*, 1997]. An alternative meteorology at 4°×5° from the Goddard Institute for Space Studies (GISS) GCM version II′, used in earlier transport studies [*Wild and Akimoto*, 2001], is used to evaluate how robust these results are. European impacts are identified by removing fossil fuel emissions of NO_x, CO and NMHC over the region, and comparing the second year of a 2-year run with an unperturbed control run. Results with the ECMWF 1996 meteorology are presented unless otherwise specified.

European Outflow

The principal pathway for European outflow is east or northeastwards over Eurasia. Boundary layer O_3 production from European precursor sources is shown in Figure 1. In summer, regional production is large and there is net destruction downwind, as additional formation from exported precursors is less than destruction of exported O_3 except in northward outflow where chemical time scales are longer. In winter, when formation processes are slower, net destruction occurs north of 45°N over Europe, but in outflow regions to the south and southeast there is net production from exported precursors. In January, northward outflow of NO_x leads to continuing net destruction, and we find an O_3 deficit due to European sources extending into the Arctic.

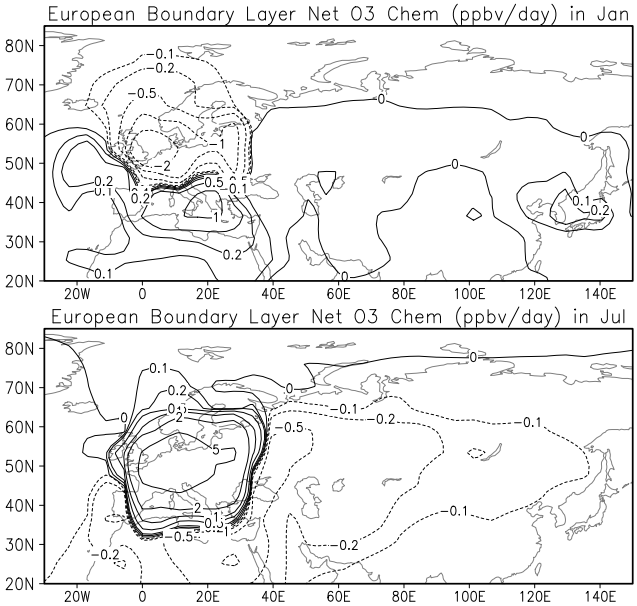

Figure 1. Monthly-mean net O_3 production (ppbv/day) in the boundary layer from fossil fuel sources in Europe in January (upper panel) and July (lower panel).

Impacts over Central Asia

The influence of European sources at Mondy, Siberia (52°N, 101°E) is shown in Figure 2. Impacts are greatest in spring, when transport is direct and lifetimes are still long, and smallest in summer, when lifetimes are short. Mean impacts are 10–30 ppbv for CO and 0.5–3.5 ppbv for O_3, and the impacts from North American and East Asian sources are generally somewhat smaller.

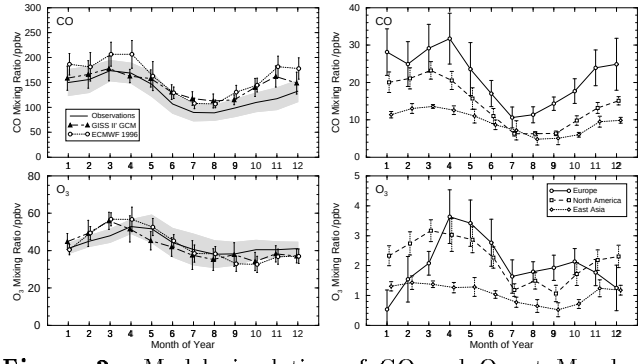

Figure 2. Model simulation of CO and O_3 at Mondy, Siberia (left panels) and the contributions from fossil fuel sources over Europe, North American and East Asia (right panels). 1-σ error bars or shading show 3-hourly variability.

Impacts over Northeast Asia

Further transport southeastwards over northern Asia brings European influence to Japan. Figure 3 shows the impacts of European sources at Mt. Happo, Japan (37°N, 138°E), where mean impacts are 2–25 ppbv for CO and 0.2–2.5 ppbv for O_3. Although these contributions are relatively modest, springtime O_3 is sufficiently high that this makes a significant contribution to exceedance of air quality standards, currently set at 60 ppbv over one hour in Japan.

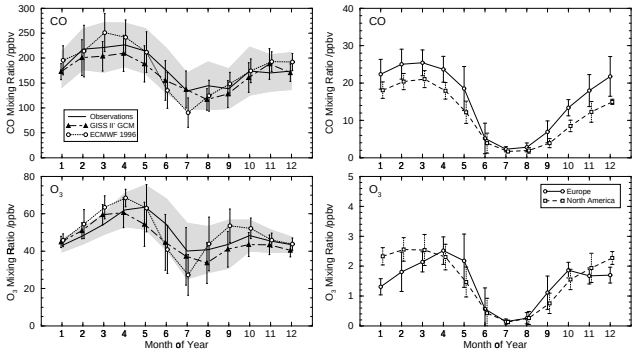

Figure 3. Model simulation of CO and O_3 at Happo, Japan (left panels) and the contributions from fossil fuel sources over Europe and North American (right panels).

North American impacts are only slightly smaller than European impacts at the surface, and exceed them in the mid-troposphere, as found in previous studies [*Liu et al.*, 2002]. To examine the reasons for this, we run one-day pulses of emissions from North American and European sources in March and April and follow the evolution of O_3 production and the pathways for transport each day. 60–70% of gross production occurs in the regional boundary layer, but convection and frontal lifting over the western Atlantic raise a significant fraction of North American outflow, so that maximum enhancements after a week typically occur at 400–500 hPa (5–6 km). Lifting of European outflow is weaker, and maximum enhancements generally remain below 600 hPa (4 km). Trans-Atlantic transport from North America is particularly effective when O_3 build-up in the polluted boundary layer is followed by cyclonic lifting of a number of days' oxidants together, and transport at 5–8 km altitude brings it to Japan in about 2 weeks. In contrast, the lower altitude of European outflow leads to slower transport and shorter lifetimes than from North American sources, and peak O_3 enhancements are typically smaller and take a similar time to arrive over Japan, 12–14 days [*Wild et al.*, 2004].

Global impacts

Two-thirds of gross O_3 production from European sources occurs in the boundary layer, slightly more than from North American and East Asian sources (about 60% each), and less occurs in the upper troposphere (5% above 280 hPa compared with 8–10%). The lower altitude of outflow leads to more rapid destruction and the chemical lifetime of the O_3 formed is thus shorter, see Table 1. However, the slower chemical time scales at high latitudes also lead to reduced loss of CO, which has a longer lifetime from European sources.

The dominance of continental boundary layer outflow suggests that deposition may be a more important loss route for O_3 from European sources than from North American or East Asian sources, where outflow occurs over the oceans. However, we find only marginally greater deposition, 17% of the gross annual O_3 production versus 14–15% from these other regions. Outflow to the Arctic, Mediterranean and North Africa, where deposition over ice, water or desert surfaces is slow, together with control of surface O_3 by subsidence from the free troposphere at longer time scales may account for this.

Table 1. Annual Mean Tropospheric Chemical Lifetimes

Source Region	CO	O_3
Europe	83 days	18 days
North America	61 days	19 days
East Asia	62 days	21 days
South Asia	56 days	25 days
Tropospheric mean	55 days	30 days

European sources have a smaller impact on O_3 due to slower production and faster loss. However, the climate impacts of regional emissions are also driven by changes in longer-lived greenhouse gases such as CH_4 due to changes in OH. For North American and East Asian sources, climate forcing from additional O_3 is partially offset by reduction in CH_4 due to higher OH. In contrast, we find that European emissions cause a decrease in OH, as destruction by additional CO and NMHC outweighs formation from additional O_3. Recent reductions in European emissions of NO_x and CO may thus benefit climate through reductions in both O_3 and other longer-lived greenhouse gases. However, further studies are required to quantify these long-term climate effects more thoroughly.

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