Mixing between a stratospheric intrusion and a biomass burning plume


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Ozone, carbon monoxide, aerosol extinction coefficient, acetone, nitric acid and relative humidity measured from the NOAA P3 aircraft during the TexAQS/GoMACCS 2006 experiment, indicate mixing between a biomass burning plume and a stratospheric intrusion in the free troposphere above eastern Texas. Lagrangian-based transport analysis and satellite imagery are used to investigate the transport mechanisms that bring together the tropopause fold and the biomass burning plume originating in southern California, which may affect the chemical budget of tropospheric trace gases.

Measurements & modelling

NOAA P3 measurements of aerosol extinction coefficient ($\omega_a$) and acetone concentration can be used as biomass burning tracers. Positive correlations between $\omega_a$ and acetone indicate the biomass burning origin of CO enhancements. HNO$_3$ can be used as a stratospheric tracer. Positive correlations between HNO$_3$ and ozone indicate a stratospheric origin of ozone enhancements.

To identify the origin of the polluted plume and simulate air pollution transport over North America, we use the FLEXPART Lagrangian particle dispersion model (version 6.2). We conducted forward simulations of long-range and mesoscale transport of anthropogenic pollution tracers from North America and emissions from BB to assess their impact on observed CO concentrations over Texas and the Gulf of Mexico (See http://flextart.ieo.csic.es/products/flextart/ for further details).

FLEXPART was driven by model-level data from ECMWF, with 15 vertical levels, 1200 km resolution of 1°x1° with nested wind at 91 vertical levels. We use the MODIS fire detection data and link it to land cover types to calculate emission factors (Andrea and Merlet, 2001). Area burned to anthropogenic CO emissions is reported from forest fires, injection heights between 0 and 5 km. Stratospheric ozone tracer is initialized within the model (Pv/Pv$_0$) and continually released at the model boundaries (180° W, 5° S, 18° N, 61° N) with a linear (reflection) boundary condition. The tropopause or stratospheric boundary is only used to transport the stratospheric ozone tracer below.

The enhancement of CO (from 30 to 80 ppbv) is positively correlated with the with nitric acid (from 50 to 150 pptv) and negatively correlated with relative humidity. The HNO$_3$ to ozone slope is: $\text{HNO}_3=0.0022*\text{O}_3-0.055$, and is consistent with previous measurements obtained in the lower stratosphere where the typical HNO$_3$ mixing ratio at the tropopause is 300 pptv (Neuman et al., 2001).

Figure 1: NOAA P3 time series of CO (black line, ppbv), ozone (blue line, ppbv), VOC (green line, pptv/2), and relative humidity (green solid line, %, right vertical axis) on September 25 16:25 UTC, colored by (top) the modeled biomass burning CO tracer and (bottom) the tropospheric ozone tracer. The grey background represents the distribution of MOZAIK ozone and CO measurements in top 5 km troposphere (plotted by 300 km horizontal boxcar filter and 30 km vertical boxcar filter). Figure 2: NOAA P3 CO and ozone mixing ratios on September 25, 16:00-21:00 UTC, colored by the models biomass burning CO tracer and (bottom) the tropospheric ozone tracer. The grey background represents the distribution of MOZAIK ozone and CO measurements in top 5 km troposphere (plotted by 300 km horizontal boxcar filter and 30 km vertical boxcar filter) (left) and the satellite imagery (right)

Figure 1 (Top) presents the visible channel of the GOES East satellite at 13:15 UTC, September 25, 3 hours before the aircraft sampled the BB plume. A narrow plume is visible north of the aircraft position at 16:10 UTC (red cross), and extends from eastern Texas to the Great Lakes region. The tropopause fold is located below the BB plume, as the sun is low in the sky and the underlying surface is not bright.

FLEXPART back trajectories were used to locate the source region of the BB CO that contributed to the two P3 flights. Figure 4 presents the percentage of surface contribution to the BB CO mixing ratios, scaled according to the maximum surface contribution encountered in the domain output (red pixel). It shows that the main source is located north of Los Angeles.

Figure 5 (Left) presents a meridional vertical cross section of the FLEXPART stratospheric ozone tracer (green) and the biomass burning tracer (blue) at 1500 UTC on 25 September 2006. The black line indicates the tropopause and the red line indicates stratospheric background. Figure 5 (Right) presents a meridional vertical cross section of the BB tracer at 16:10 UTC (black circle in Fig 3, Right). A potential mixing region (red pixels) is identified between 3 and 5 km altitude. The BB plume lies next to the tropopause fold from Texas to the Great Lakes region. The narrow BB plume seen in the GOES image (Fig. 3, top) is well simulated by FLEXPART. The NASA Earth Observatory reports that this fire began on September 4 and burned with varying intensity until the end of September.

Figure 5. Left: Vertical and right: horizontal cross sections of the FLEXPART stratospheric ozone tracer (green) and the biomass burning tracer (blue) at 1500 UTC on September 25, 2006. The black line indicates the tropopause and the red line indicates stratospheric background. Figure 5 (Right) presents a meridional vertical cross section of the BB tracer at 16:10 UTC (black circle in Fig 3, Right). A potential mixing region (red pixels) is identified between 3 and 5 km, using a threshold of 10 ppbv for the BB CO tracer and 13 ppbv for the stratospheric ozone tracer, in the vicinity of the NOAA P3 aircraft (black circle). This Lagrangian-based study confirms that mixing does occur between biomass burning plumes and stratospheric intrusions in the free troposphere. To assess the frequency of these events, we performed a statistical analysis using the FLEXPART forward simulations from August 1 to October 1, 2006 above the Texas and Gulf of Mexico region. During the same period, FLEXPART simulations for stratospheric intrusions and biomass burning, assuming an area binned of 180 km per fire detection (Stohl et al., 2007). When a stratospheric intrusion (ozone tracer>30 ppbv) was present in this region, some portion of it was mixed with the aircraft position at 16:10 UTC (black circle in Fig 3, Right). A potential mixing region (red pixels) is identified between 3 and 5 km altitude. The BB plume lies next to the tropopause fold from Texas to the Great Lakes region. The narrow BB plume seen in the GOES image (Fig. 3, top) is well simulated by FLEXPART. The NASA Earth Observatory reports that this fire began on September 4 and burned with varying intensity until the end of September.

Figure 5 (Right) presents a horizontal cross section of the FLEXPART stratospheric ozone tracer at 4 km altitude and the mean BB CO tracer between 3 and 5 km altitude. The BB plume lies next to the tropopause fold from Texas to the Great Lakes region. The narrow BB plume seen in the GOES image (Fig. 3, top) is well simulated by FLEXPART. Figure 5 (Left) presents a meridional vertical cross section at the longitude of the aircraft position at 16:10 UTC (black circle in Fig 3, Left). A potential mixing region (red pixels) is identified between 3 and 5 km, using a threshold of 10 ppbv for the BB CO tracer and 13 ppbv for the stratospheric ozone tracer, in the vicinity of the NOAA P3 aircraft (black circle). These results imply that mixing between stratospheric intrusions and biomass burning plumes can influence tropospheric chemistry and may have implications for surface air quality.

Conclusion