Supporting Information for Stratosphere–Troposphere Exchange and Surface Ozone Pollution over Tropical Regions: A Case Study of Rossby Wave Breaking and Tropopause Folding

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*Supporting Information (Media files uploaded separately)

Introduction

This supplementary material provides additional context and visualisations supporting the analysis presented in the main manuscript, Stratosphere-Troposphere Exchange and Surface Ozone Pollution over Tropical Regions: A Case Study of Rossby Wave Breaking and Tropopause Folding. The figures presented here illustrate the synoptic processes driving stratosphere-to-troposphere transport (STE) and its effect on surface ozone over Mexico City during 12-13 March 2016.

Figure S1 shows the topography of the study region and the locations of observational stations considered in the analysis. Figures S2 and S3 present backward Lagrangian trajectories initialised over Mexico City, computed using LAGRANTO and ERA5 reanalysis fields. Figures S4 and S5 provide complementary analyses of ozone distribution, including ERA5 ozone mixing ratios, potential vorticity fields, and satellite-derived tropospheric and total ozone columns, demonstrating the spatial and temporal evolution of stratospheric intrusions and their contribution to surface ozone variability.

Additionally, an animation has been included to show wind streamlines at isentropic surfaces of 315 K, 330 K, and 340 K, further illustrating the dynamical evolution of the STE event.

Together, these supplementary figures provide a detailed view of the mechanisms underlying STE events and their regional influence on air quality in tropical urban environments.

Animation 1

File name: **Animation_1.mp4**

Animation 1. Wind streamlines at 315 K, 330 K, and 340 K potential temperature levels, illustrating quasi-conservative transport along isentropic surfaces. The red solid line marks the 2-PVU contour, indicating the dynamical tropopause. The animation spans 00 UTC 6 March to 00 UTC 14 March 2016 at hourly resolution, covering the domain latitude from 0° to 65°N and longitude between 135°W and 70°W.

References

Amante, C. (2009). ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis. NOAA Technical Memorandum NESDIS NGDC-24. *Marine Geology and Geophysics Division*, *19*.

Flynn, L., Vaishali, K., & Office, N. J. P. (2018). *NOAA JPSS Ozone Mapping and Profiler Suite (OMPS) Limb Profile Ozone Environmental Data Record (EDR).* NDE. NOAA National Centers for Environmental Information.

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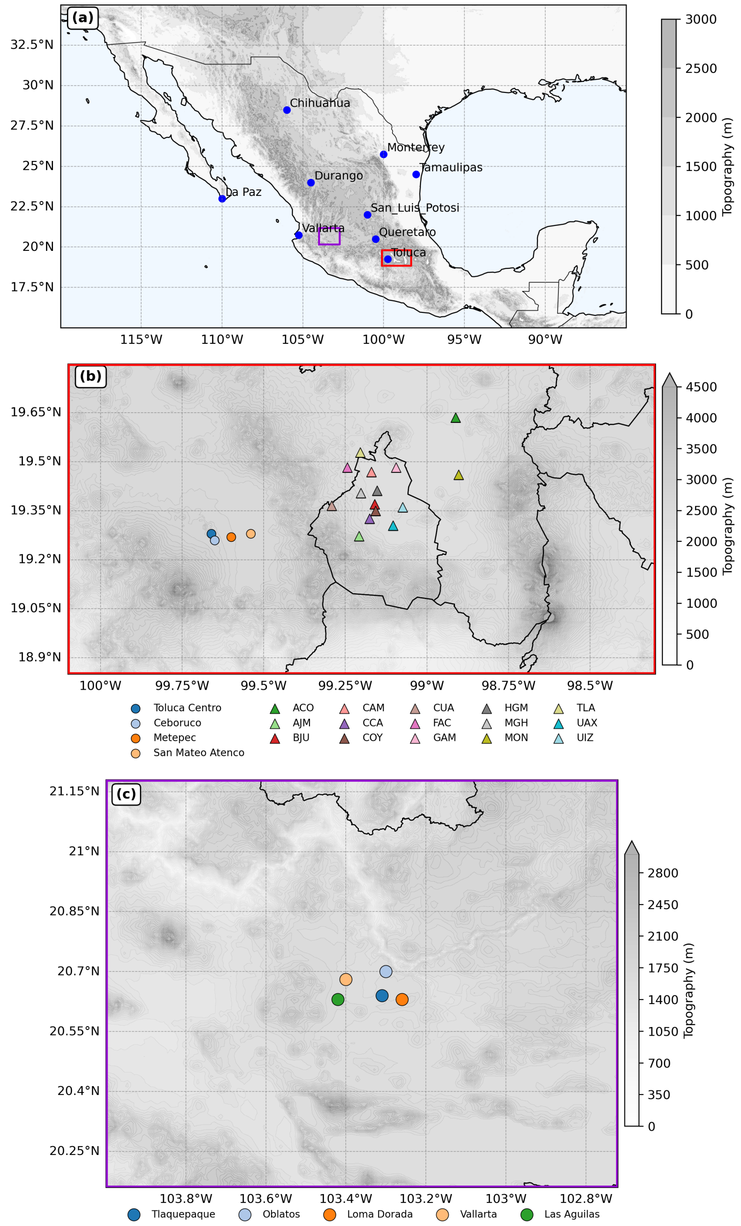

Figure S1. Topography from ETOPO 2022 (30 arc-second resolution; Amante, 2009) is shown in grey shading. Blue dots in panel (a) mark the locations used for the analysis in Fig. S4. The red rectangle highlights the Mexico City–Toluca region displayed in panel (b), while the purple rectangle outlines the Guadalajara area in panel (c). Ground-based air quality data were obtained from monitoring networks: (b) Mexico City (coloured triangles) and Toluca (coloured circles), and (c) Guadalajara, Jalisco.

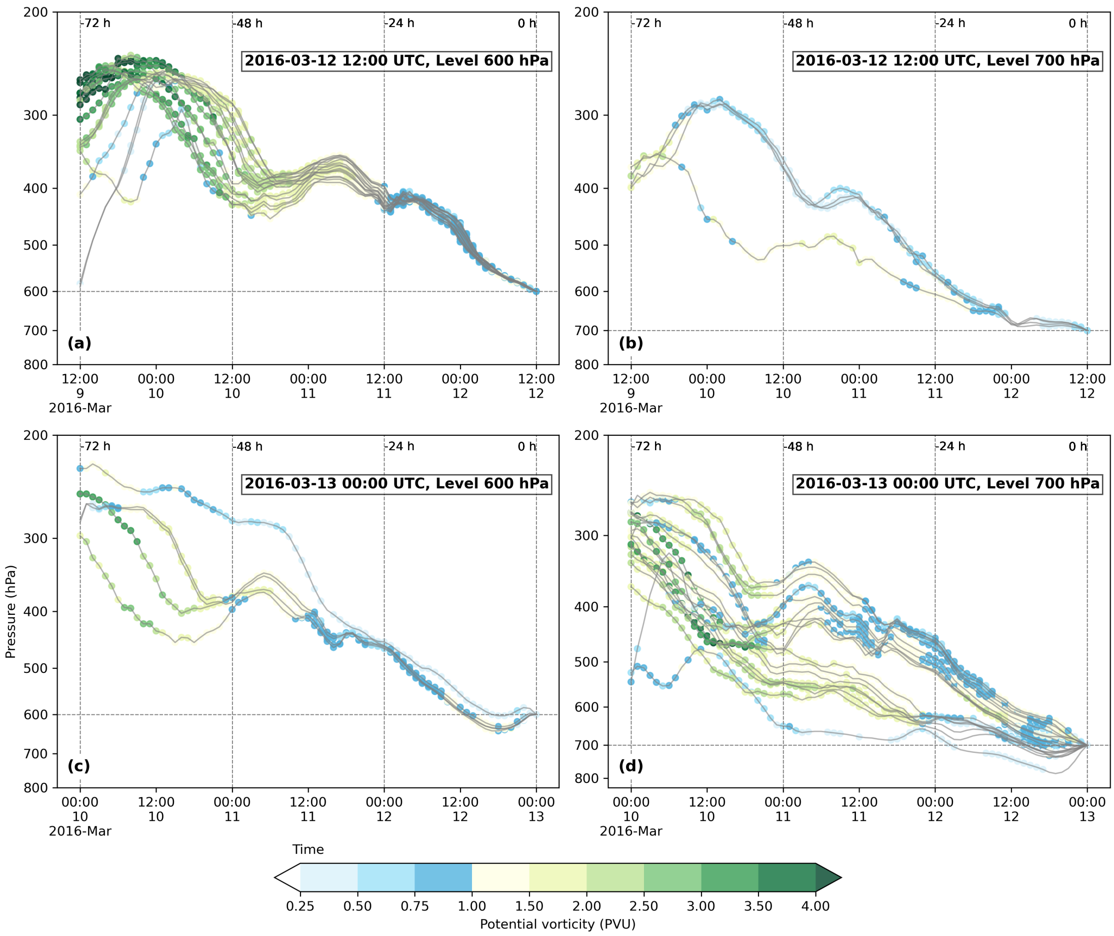

Figure S2. Backward trajectories initialized over Mexico City and its metropolitan area during 12–13 March 2016, computed with LAGRANTO using ERA5 fields. Panels (a–b) show trajectories arriving at 600 hPa and 700 hPa at 12 UTC 12 March, while panels (c–d) illustrate the evolution at 00 UTC 13 March at the same levels. Potential vorticity (PVU) is shown as shading along the trajectories. Only trajectories with $\Delta P > 200$ hPa and $PV > 2$ PVU at upper levels were retained. Most parcels originated in the stratosphere above 250 hPa within the tropopause fold region, confirming stratosphere-to-troposphere transport.

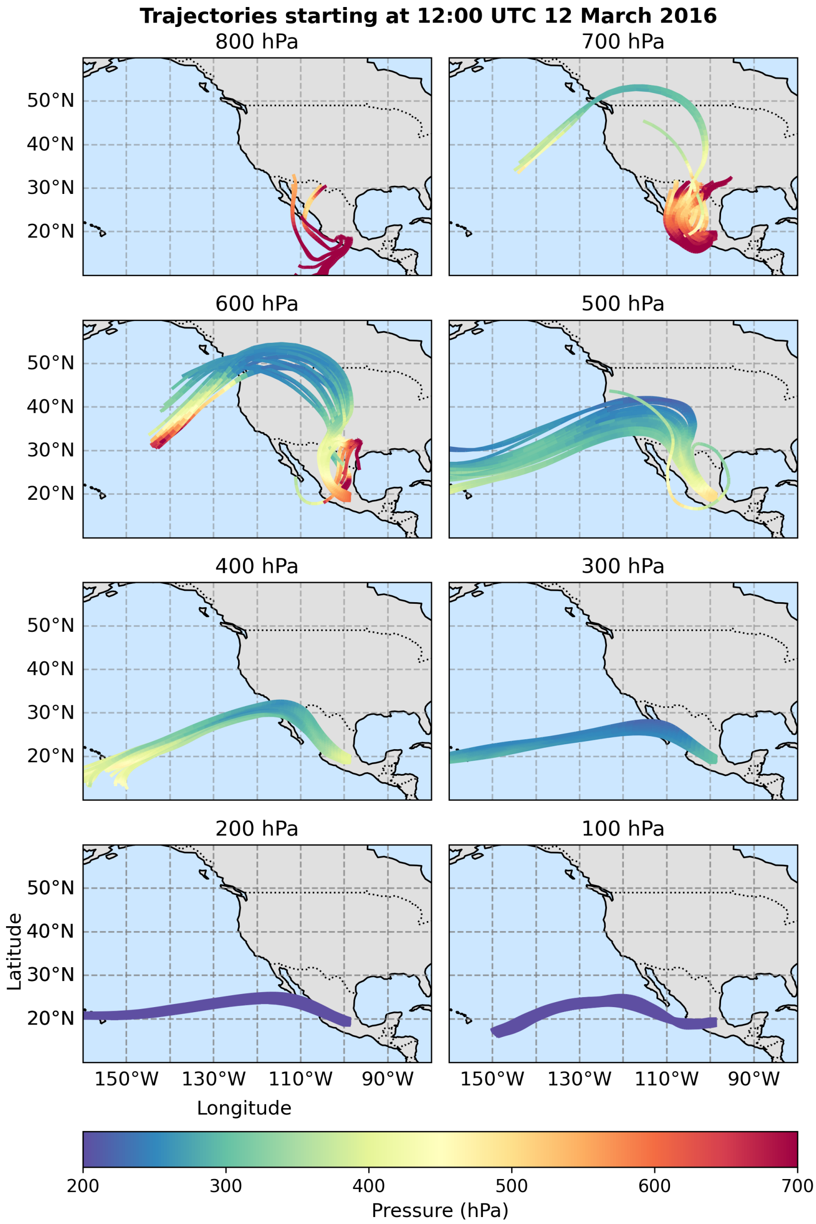

Figure S3. Lagrangian 72-hour backward trajectories over Mexico City during the STE event in March 2016, dynamically linked to Rossby wave breaking and the cut-off low (Fig. 5). Backward trajectories starting at 12:00 UTC on 12 March 2016 and 00:00 UTC on 13 March 2016. Trajectories were calculated with LAGRANTO using ERA5 reanalysis fields and initialized over the Mexico City region (Longitude: 100°W to 98°W, Latitude: 18.5°N to 20°N) at levels between 700 hPa and 100 hPa (700 hPa accounts for Mexico City's 2,300 m meters above mean sea level). At the initial time, the horizontal distance between parcels is 50 km at each level. Trajectories illustrate downward intrusion along the sloping tropopause fold into 300–700 hPa.

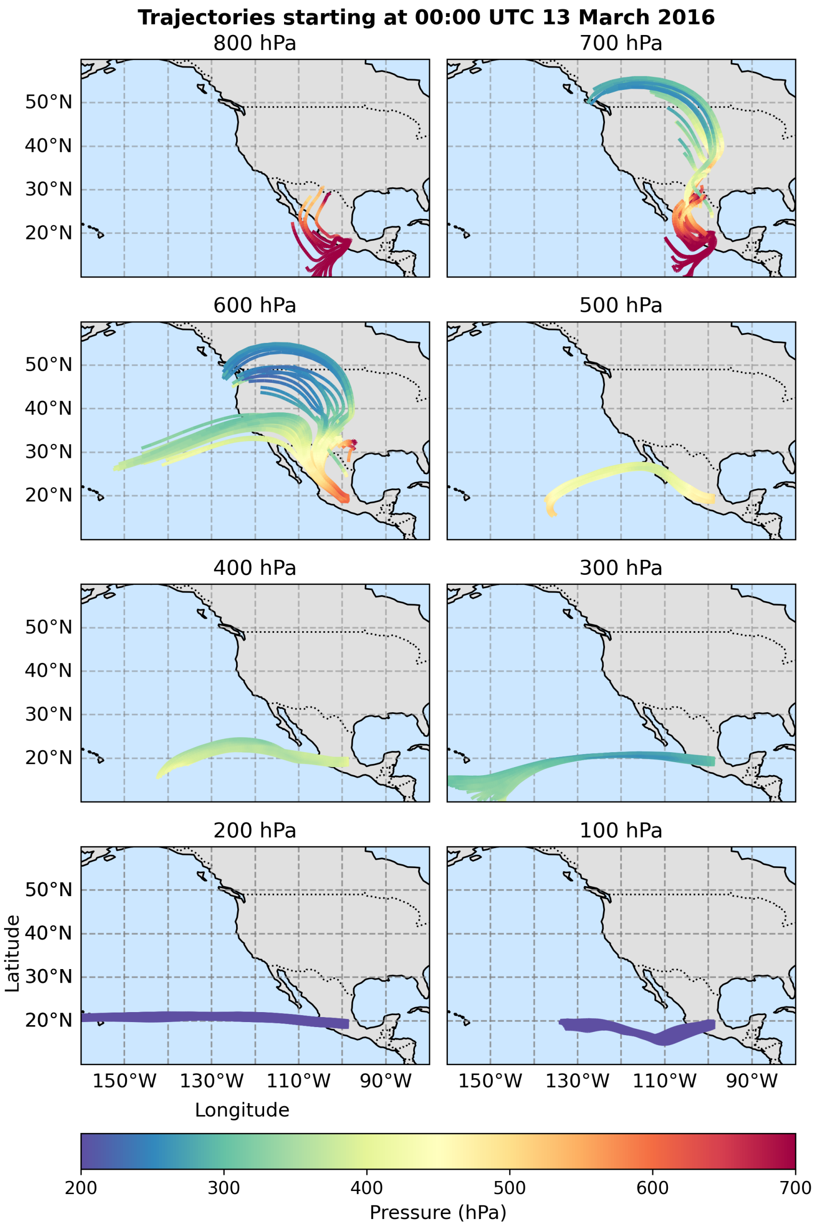

Figure S3 (continued from the previous page). Backward trajectories starting at 00:00 UTC on 13 March 2016.

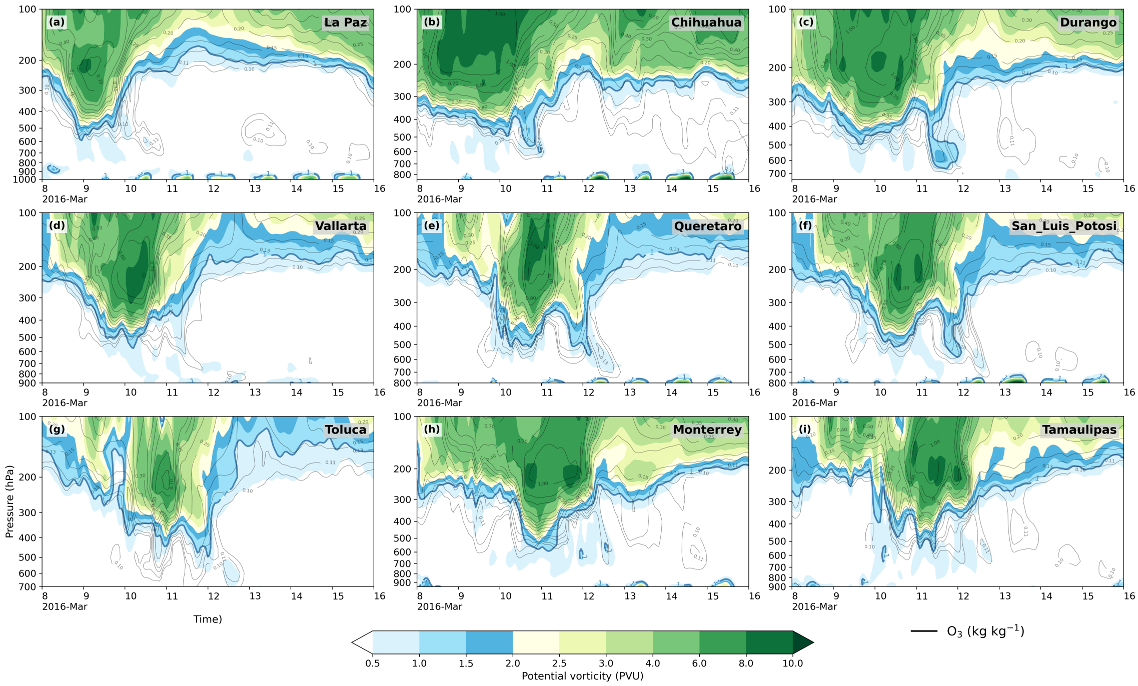

Figure S4. Stratosphere–troposphere exchange over Mexico City, 8–16 March 2016. ERA5 ozone mixing ratio ($\times 10^{-8}$ kg kg^{-1}) is shown in black contours, and potential vorticity (PV, PVU) in shading. Ozone mixing ratio and PV are averaged over different locations in Mexico (locations shown as blue dots in Fig. S1a): (a) La Paz, (b) Chihuahua, (c) Durango, (d) Puerto Vallarta, (e) Querétaro, (f) San Luis Potosí, (g) Toluca, (h) Monterrey, and Tamaulipas.

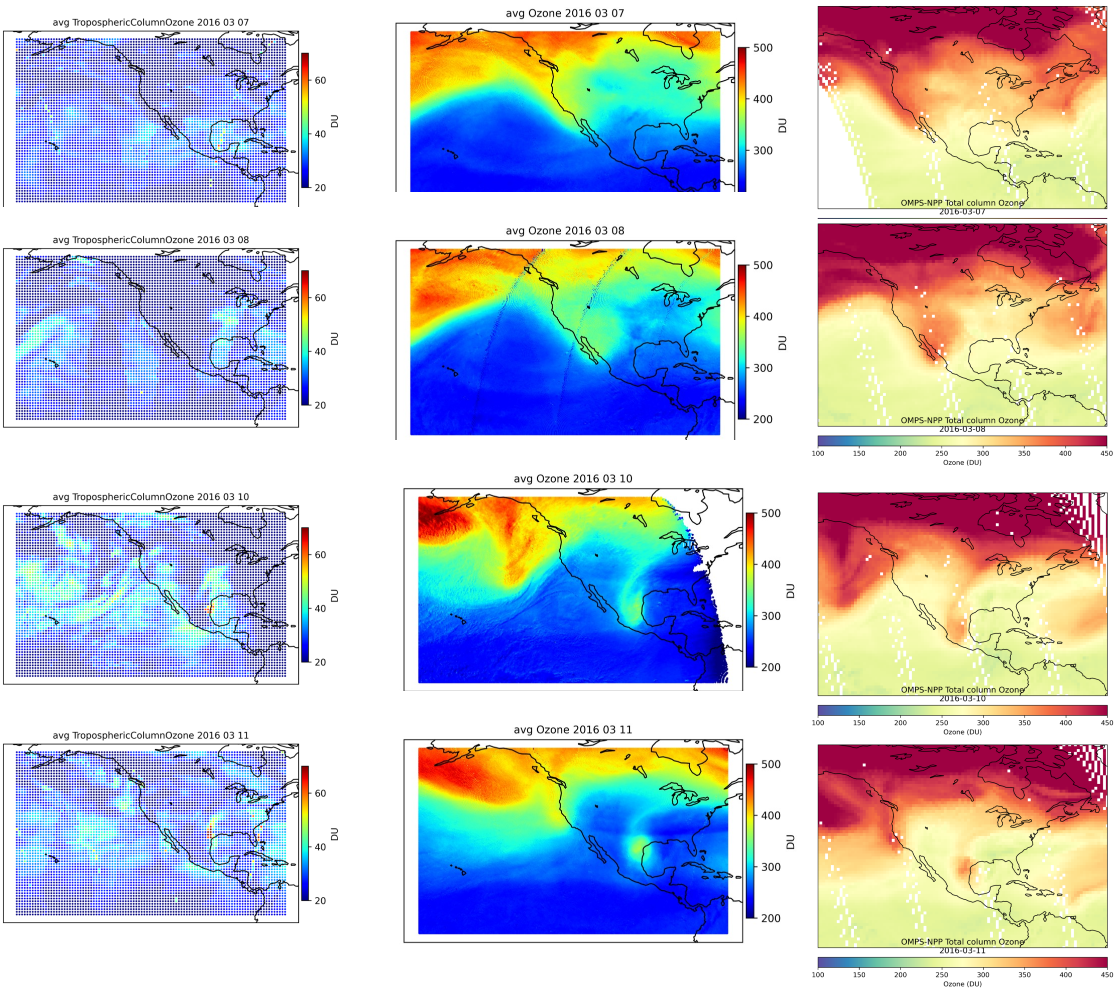

Figure S5. Daily averaged tropospheric ozone column (first column) and total ozone column (second column) from DSCOVR EPIC (Kramarova et al., 2021; Marshak et al., 2018) and total ozone column OMPS-NPP (Flynn et al., 2018) (third column) between 7 and 11 March 2016.