

Figure S1. Zonal mean altitude profiles of 545 North American pyroCb events (2013–2023). Data are aggregated into 1° latitude bins. The solid crimson line represents the mean maximum injection altitude for each bin, with the surrounding shaded region indicating ± 1 standard deviation. The dashed black line denotes the corresponding zonal mean tropopause height. Raw injection altitudes for all individual events are plotted as gray points in the background to illustrate the underlying data distribution and density.

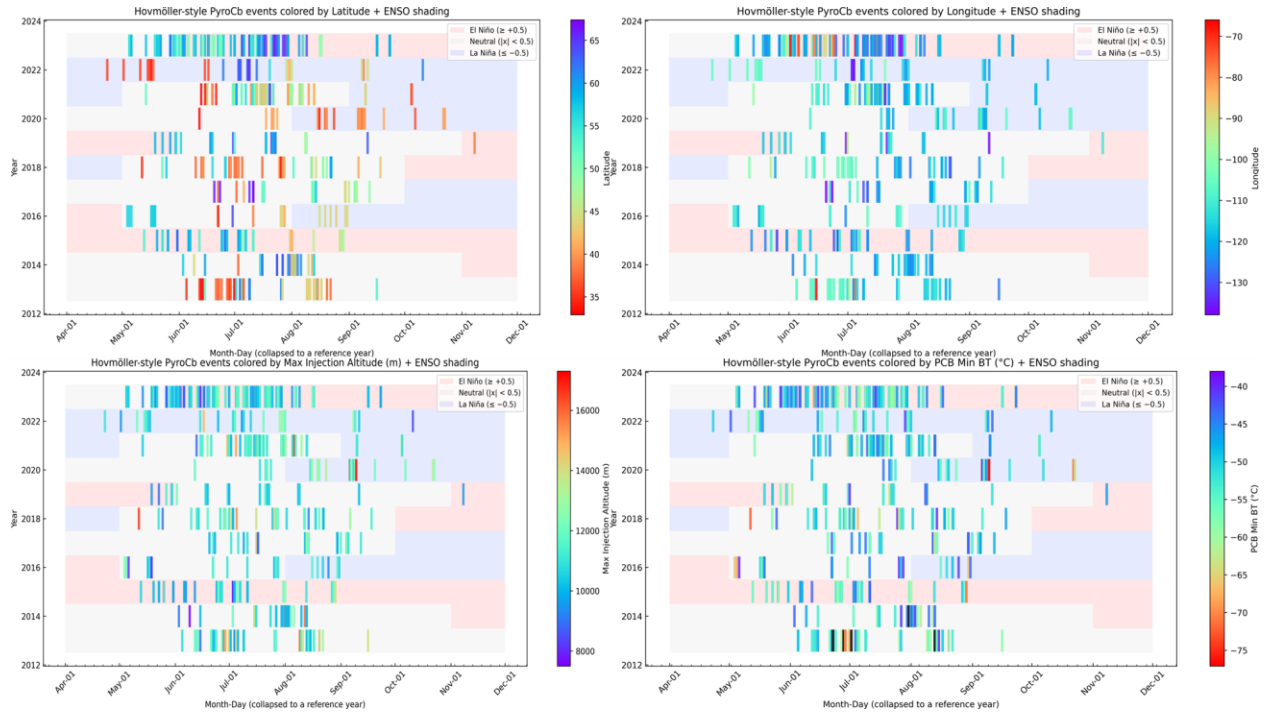
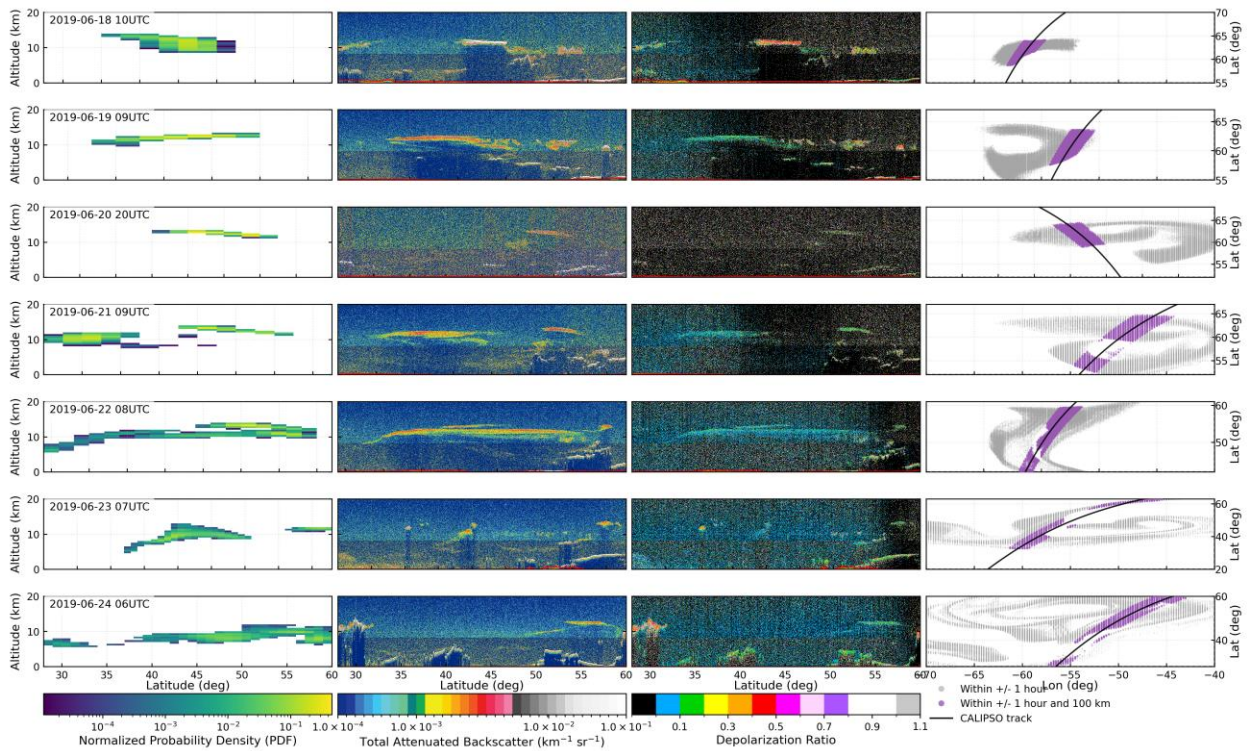
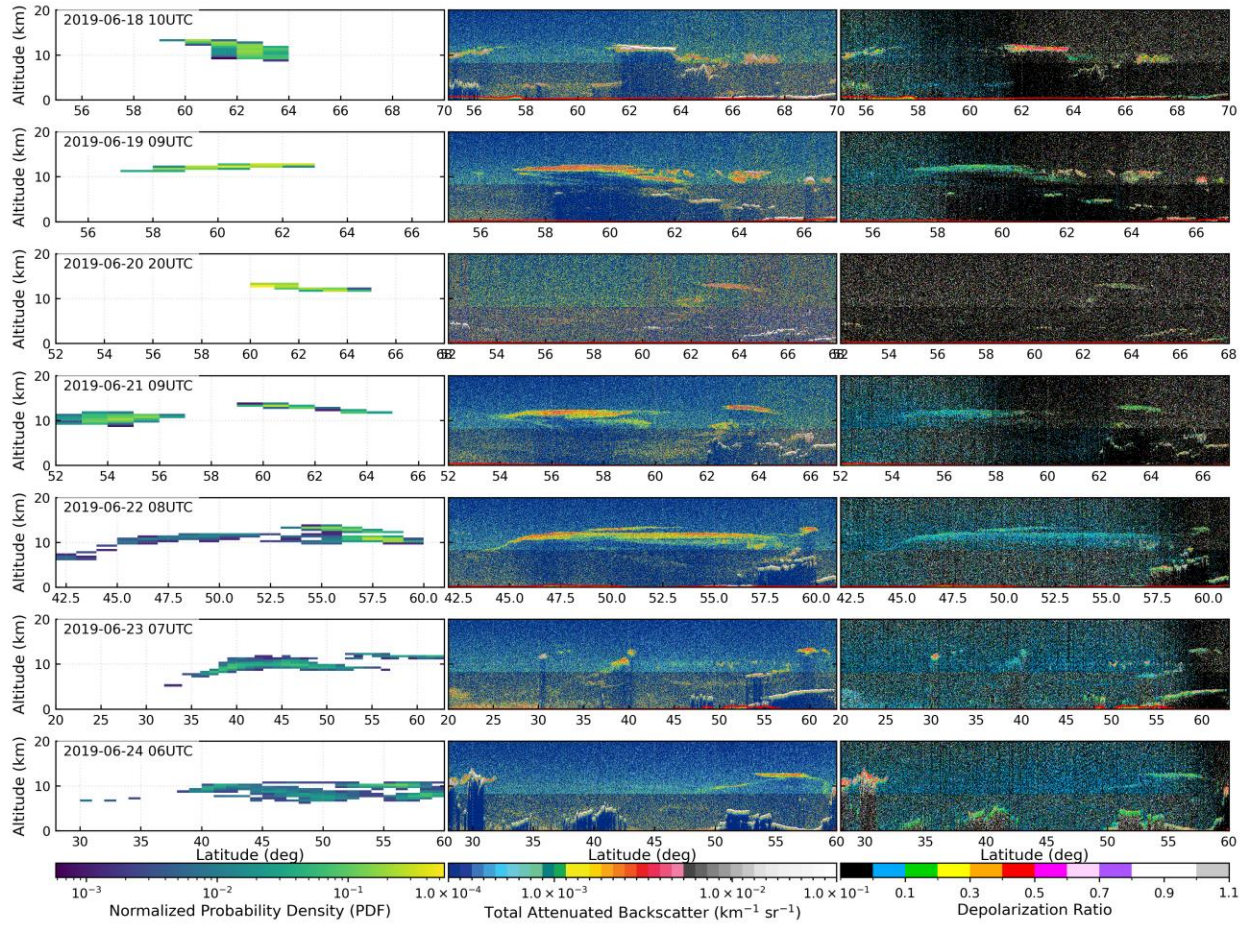
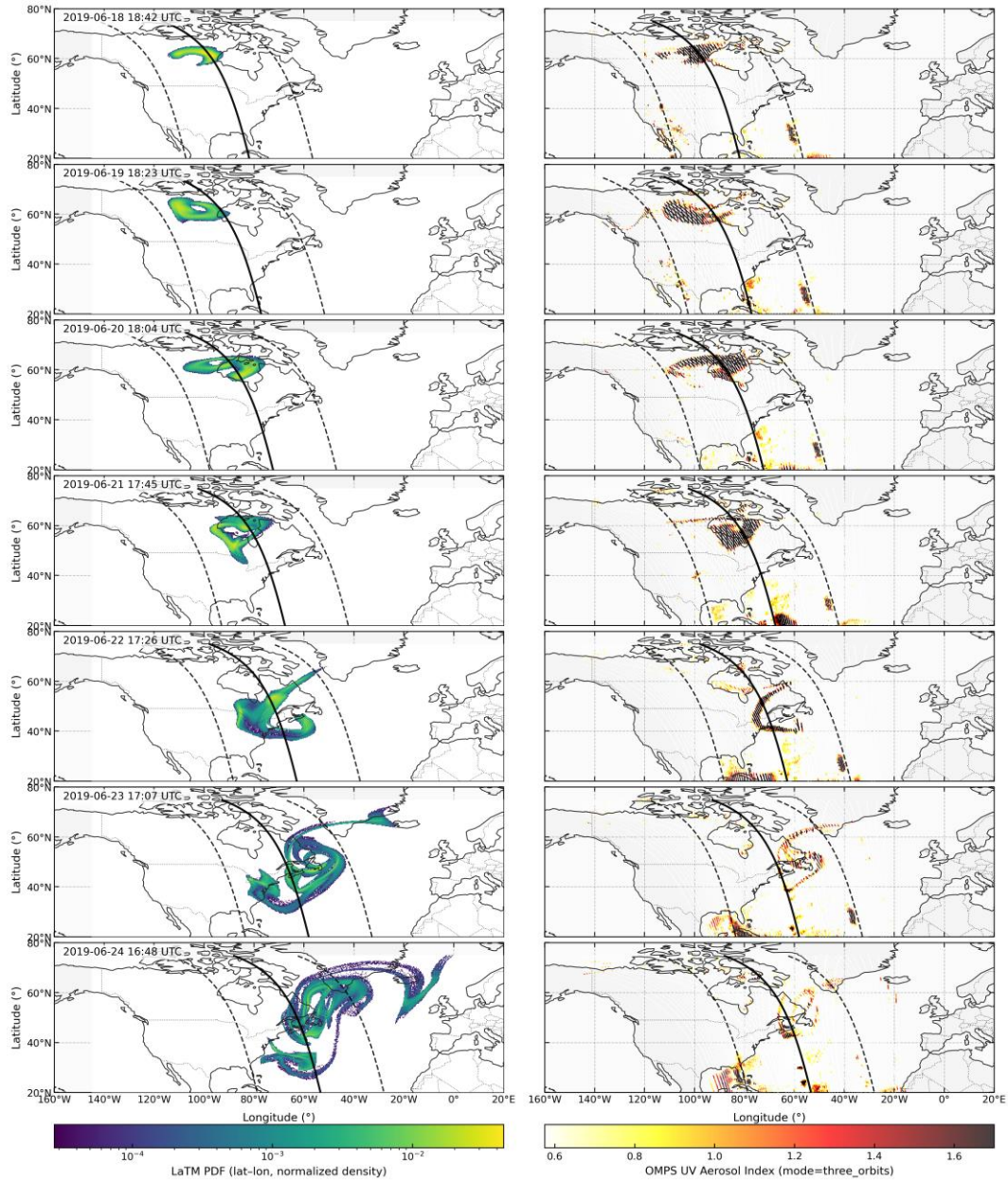
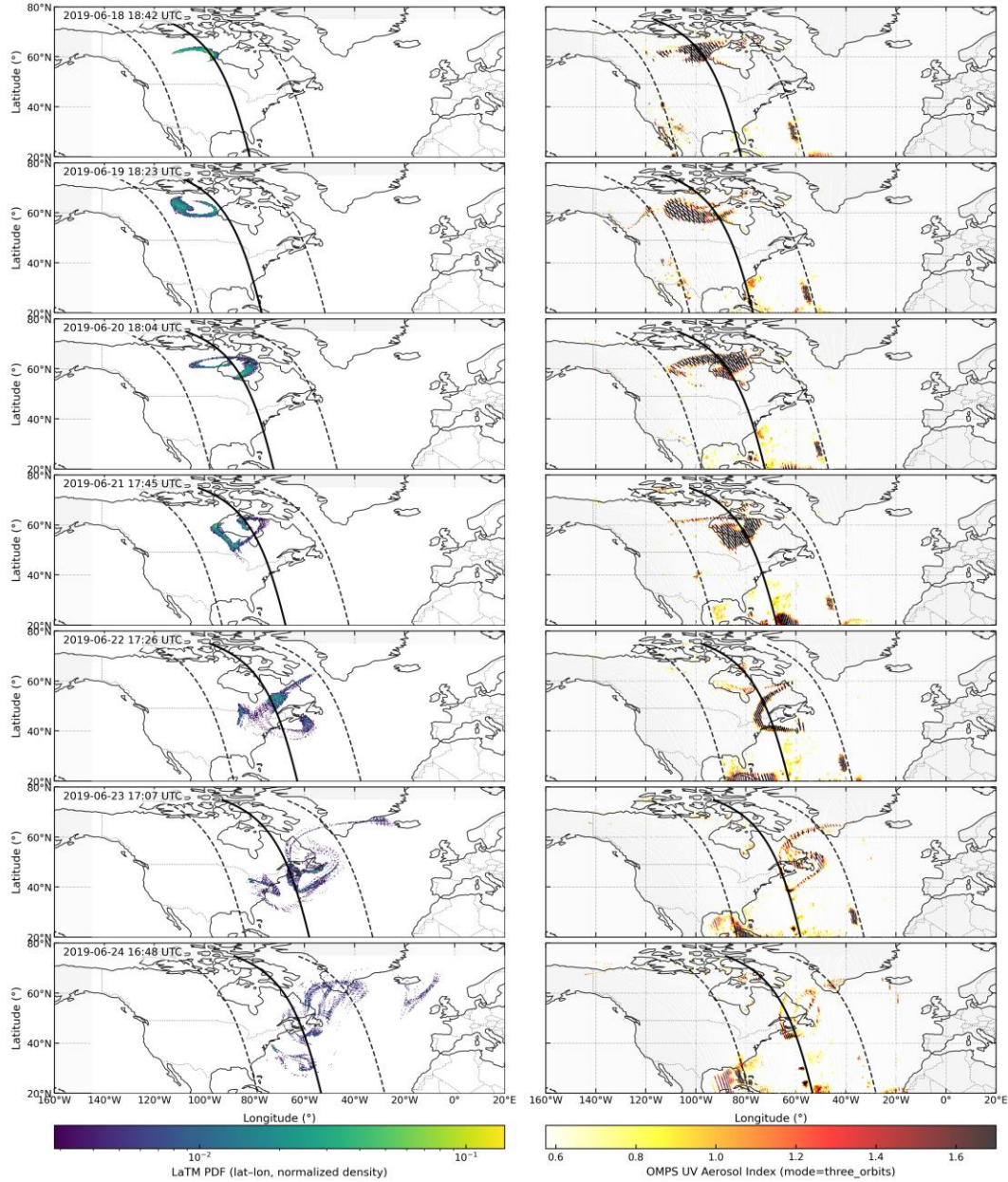


Figure S2. Hovmöller-style plots illustrating the variability, frequency, seasonality, and spatial distribution of 545 PyroCb events over North America. The top two panels use color to represent event latitude and longitude, respectively, while the bottom two panels depict maximum injection altitude and brightness temperature as color scales. ENSO phases are indicated by background shading based on the Oceanic Niño Index (ONI): El Niño (SST > 0.5°C), La Niña (SST < -0.5°C), and Neutral conditions (all other values).









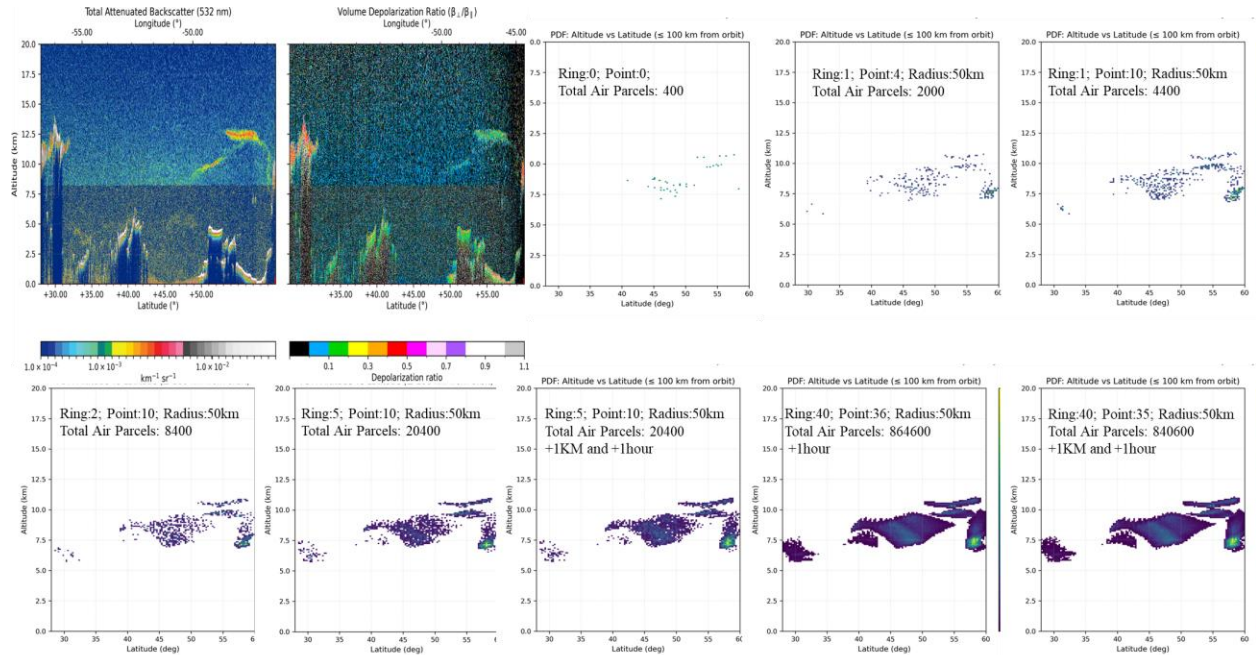


Figure S4. Comparison of total attenuated backscatter, depolarization ratio, and LaTM sensitivity results for the Chuckegg Creek Fire case study, all shown at day 7 post-injection. The panels demonstrate that the spatial, vertical, and temporal distributions of the smoke plume are consistently captured across datasets, including the identification of two distinct layers at approximately 10 km (centered near 50°N) and 12.5 km (centered near 55°N). These results highlight the robust capability of LaTM to simulate PyroCb smoke transport.

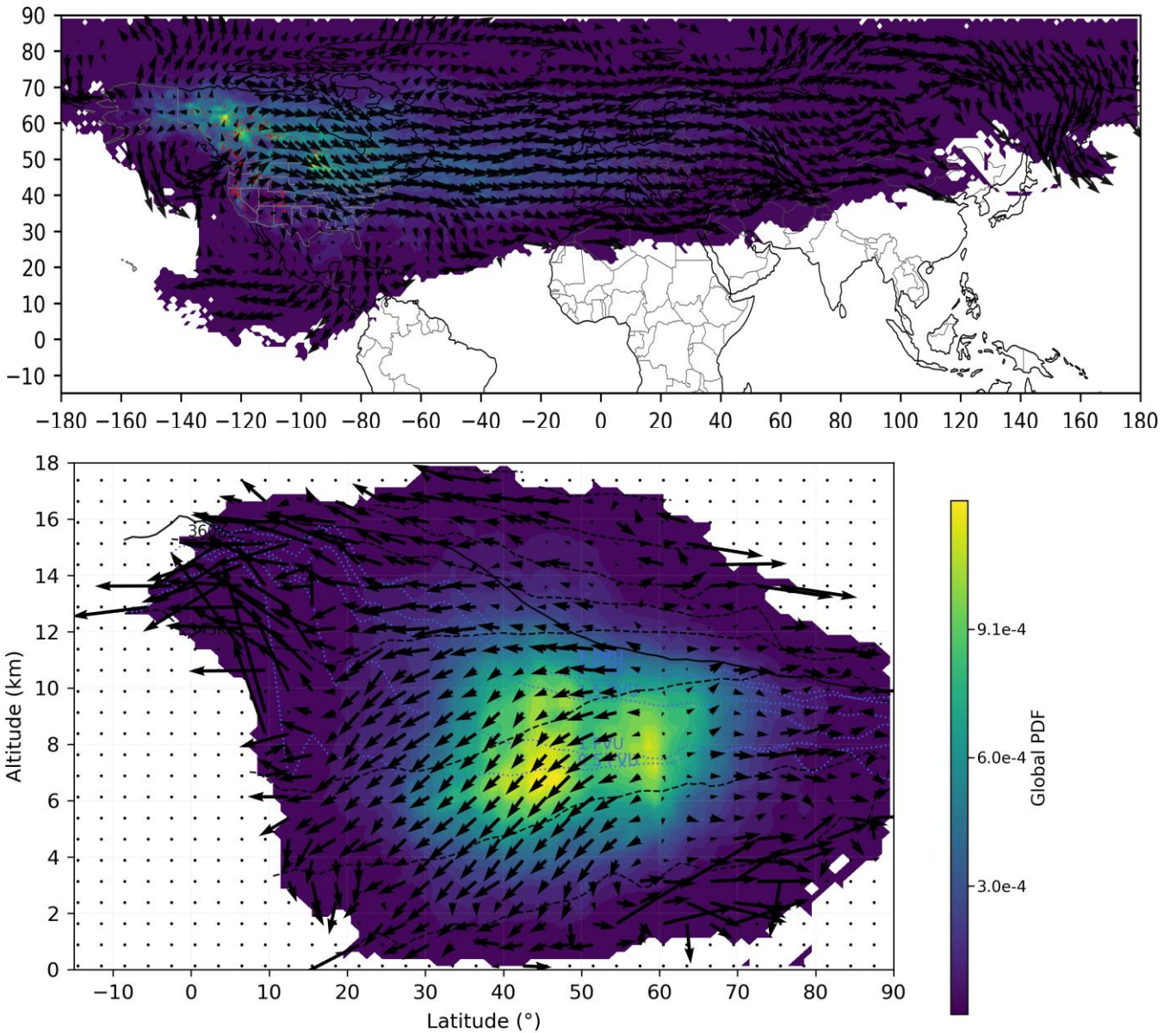


Figure S5. Visualization of PyroCb smoke transport using quiver plots, contextualized within broader atmospheric circulation and dynamics. Wind fields were derived from trajectory statistics (latitude, longitude, altitude, and time). The top panel displays quiver plots of wind vectors near the tropopause (UTLS region), with red dots marking PyroCb event locations in the global latitude–longitude distribution. The bottom panel presents quiver plots in altitude versus latitude space, illustrating vertical and meridional transport. Blue dashed lines indicate approximate potential vorticity (PV) contour lines, black dashed lines represent isentropic (potential temperature) levels, and solid black lines denote the average tropopause height.

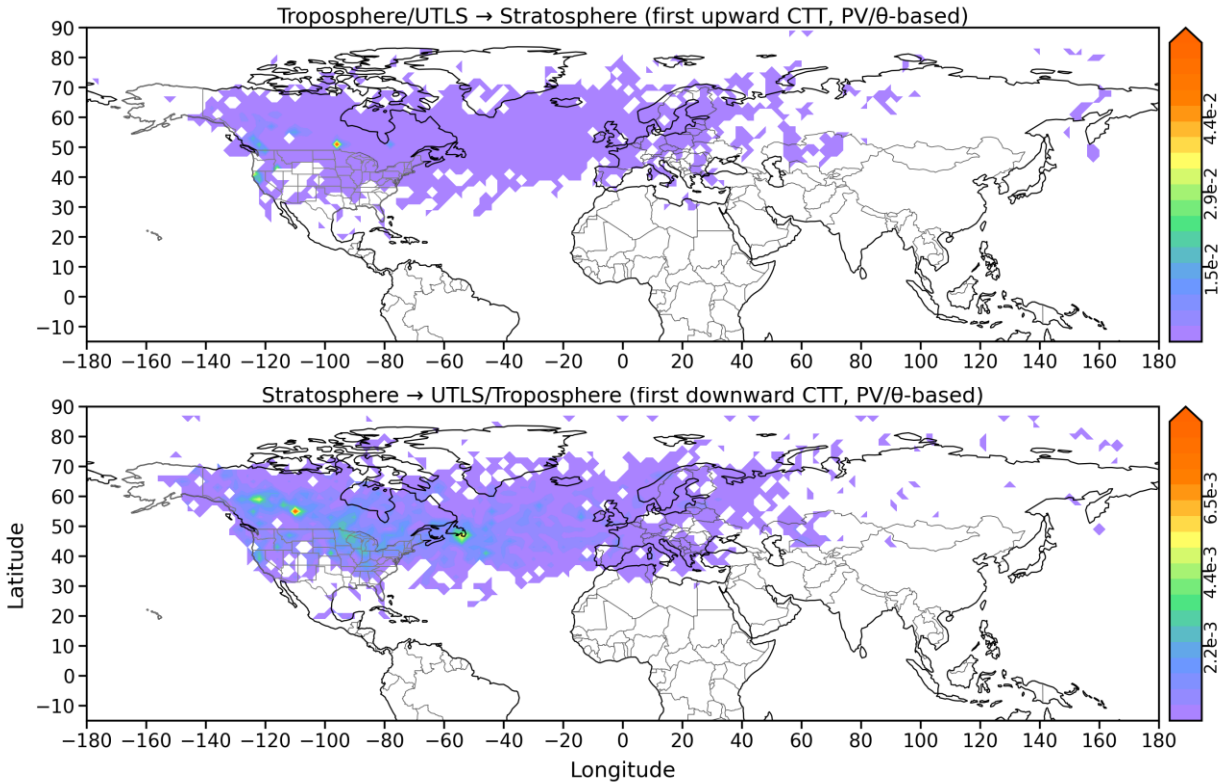


Figure S6. Geographical distribution of cross-tropopause transport (CTT) events diagnosed from LaTM trajectories using a combined potential vorticity (PV) and potential temperature (θ)–based tropopause definition. The top panel shows the locations of the first upward crossings from the troposphere or UTLS into the stratosphere, while the bottom panel displays the first downward crossings from the stratosphere into the UTLS or troposphere. Colors represent the normalized occurrence frequency (probability density) of crossing locations on a $2^\circ \times 2^\circ$ longitude–latitude grid. In the extratropics ($|\varphi| \geq 20^\circ$), the tropopause is defined at 3.5 PVU, with the UTLS spanning 2.5–4.5 PVU and troposphere/stratosphere below/above these thresholds. In the tropics ($|\varphi| < 20^\circ$), the classification is based on a $\theta = 370$ K tropopause, with the UTLS defined as 360–380 K. For each trajectory, only the first crossing in each direction is included in the analysis.

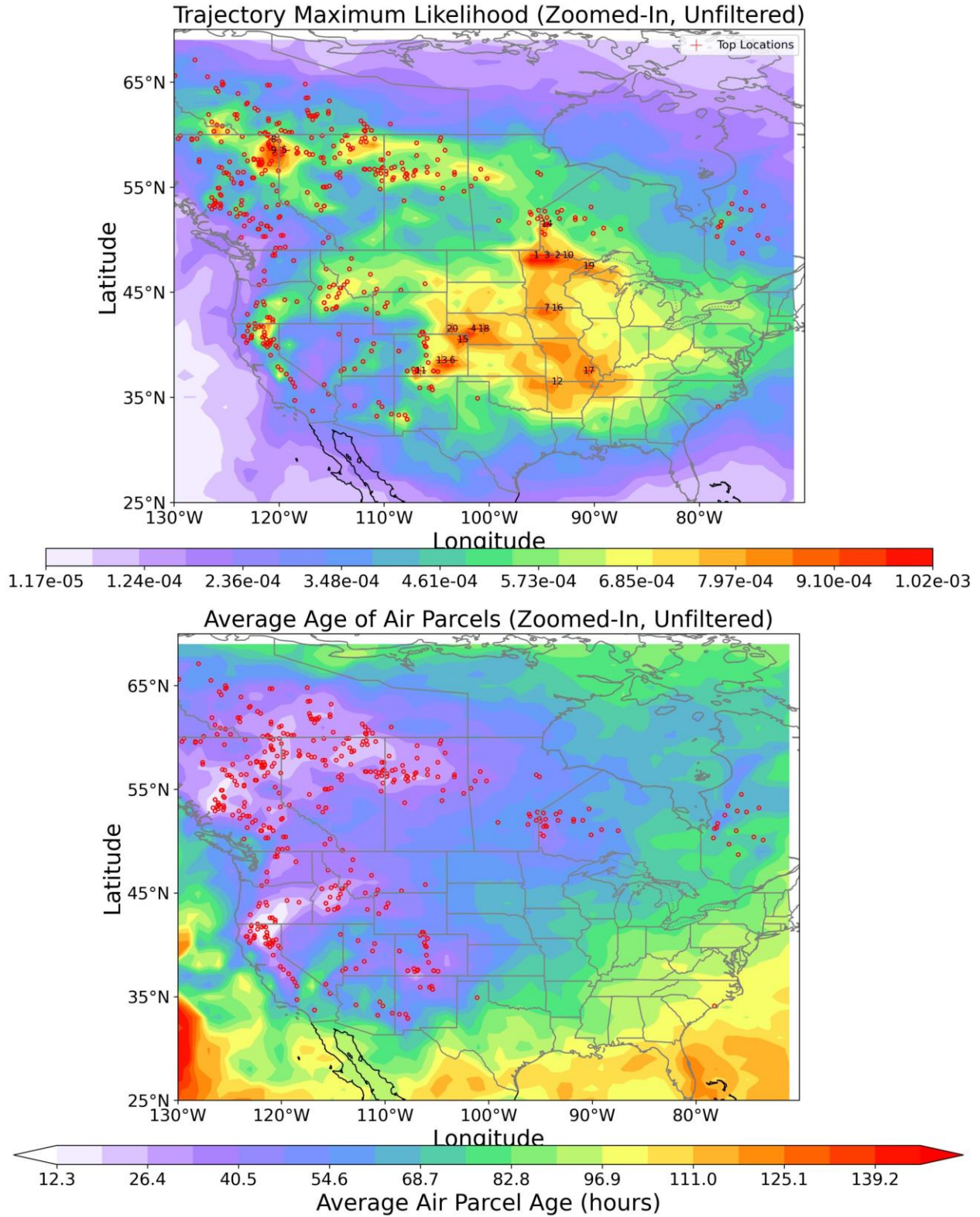


Figure S7. Maximum likelihood locations of PyroCb smoke air parcels over North America. The top panel displays the probability density function (PDF) of air parcel occurrence, while the bottom panel shows the corresponding average age of the smoke. Numbered markers indicate ranked locations with the highest likelihood of air parcel presence.

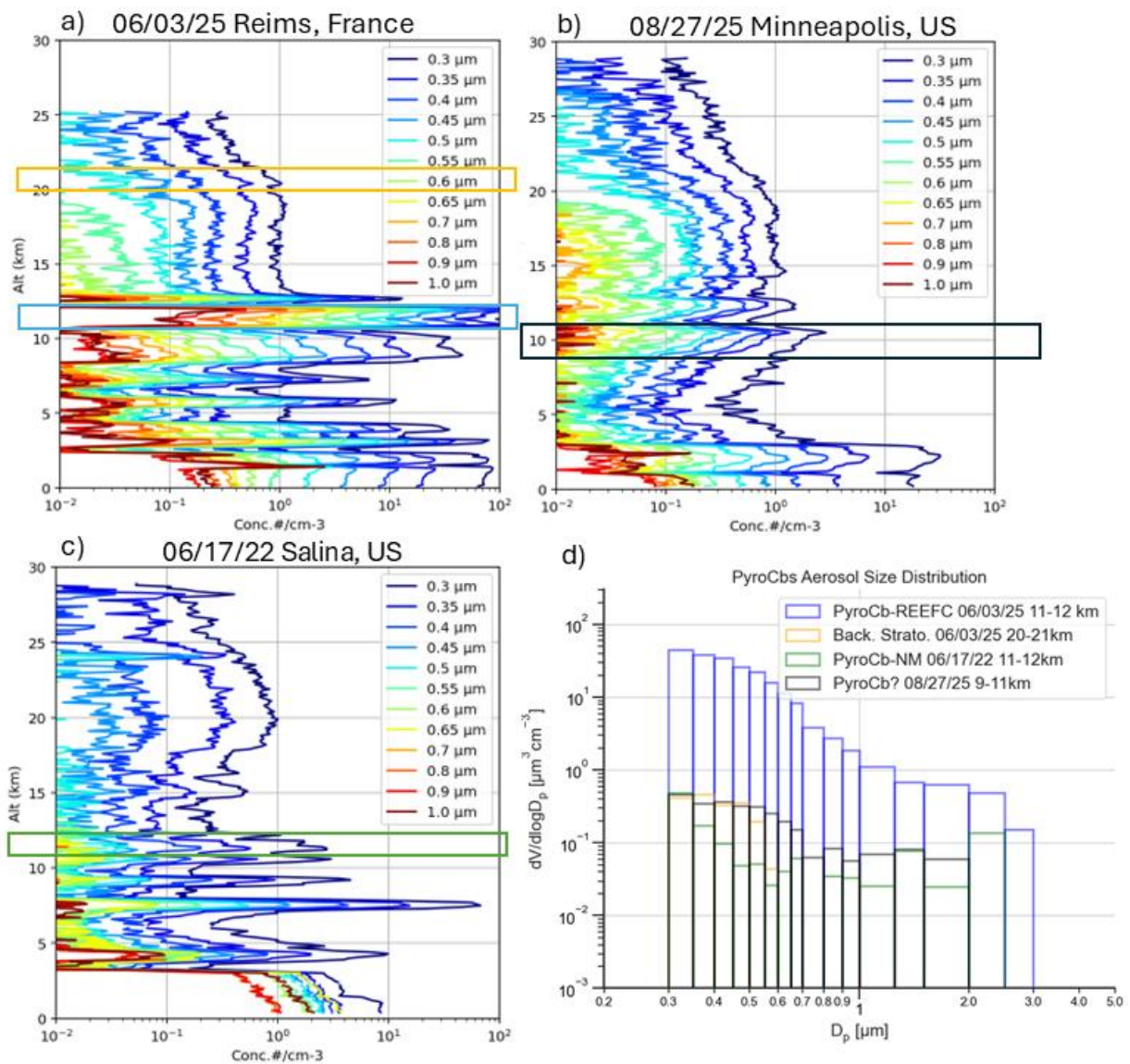


Figure S8. (a, b, c) differential concentration profiles for the first 12 channels of the Profiling Optical Particle Counter on 06/03/25 from Reims/France, 08/27/25 from Minneapolis/US, and 06/17/22 from Salina/US. (d) The volumetric aerosol size distribution from several layers suspected to have originated from several pyroCbs.

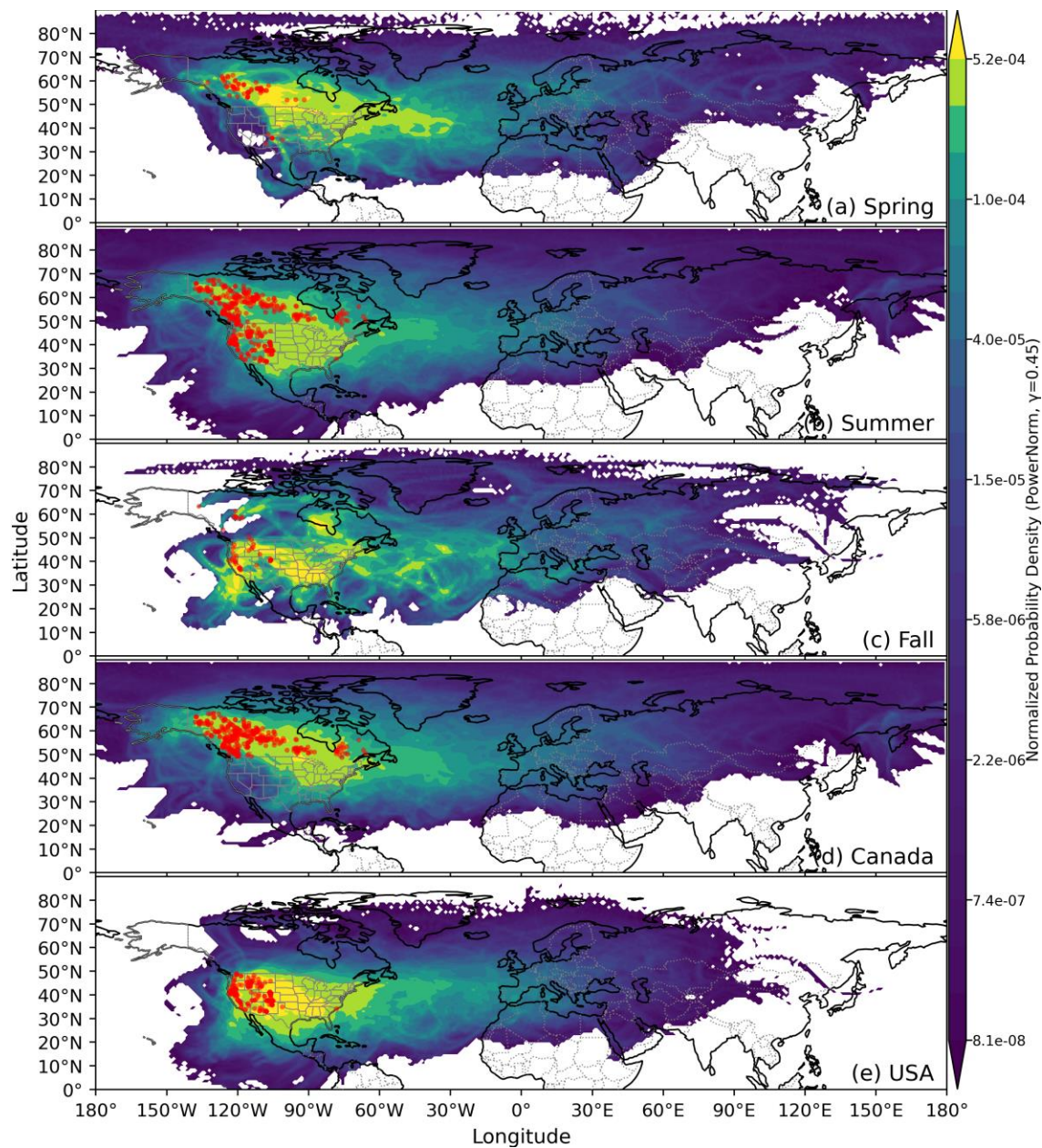


Figure S9. Five-panel maps of normalized trajectory density (PDF) for spring, summer, fall, Canada, and CONUS/USA, with pyroCb locations overlaid (red markers). A PowerNorm scaling is used to enhance visibility of low-density, long-range transport pathways within the 7-day trajectory window.

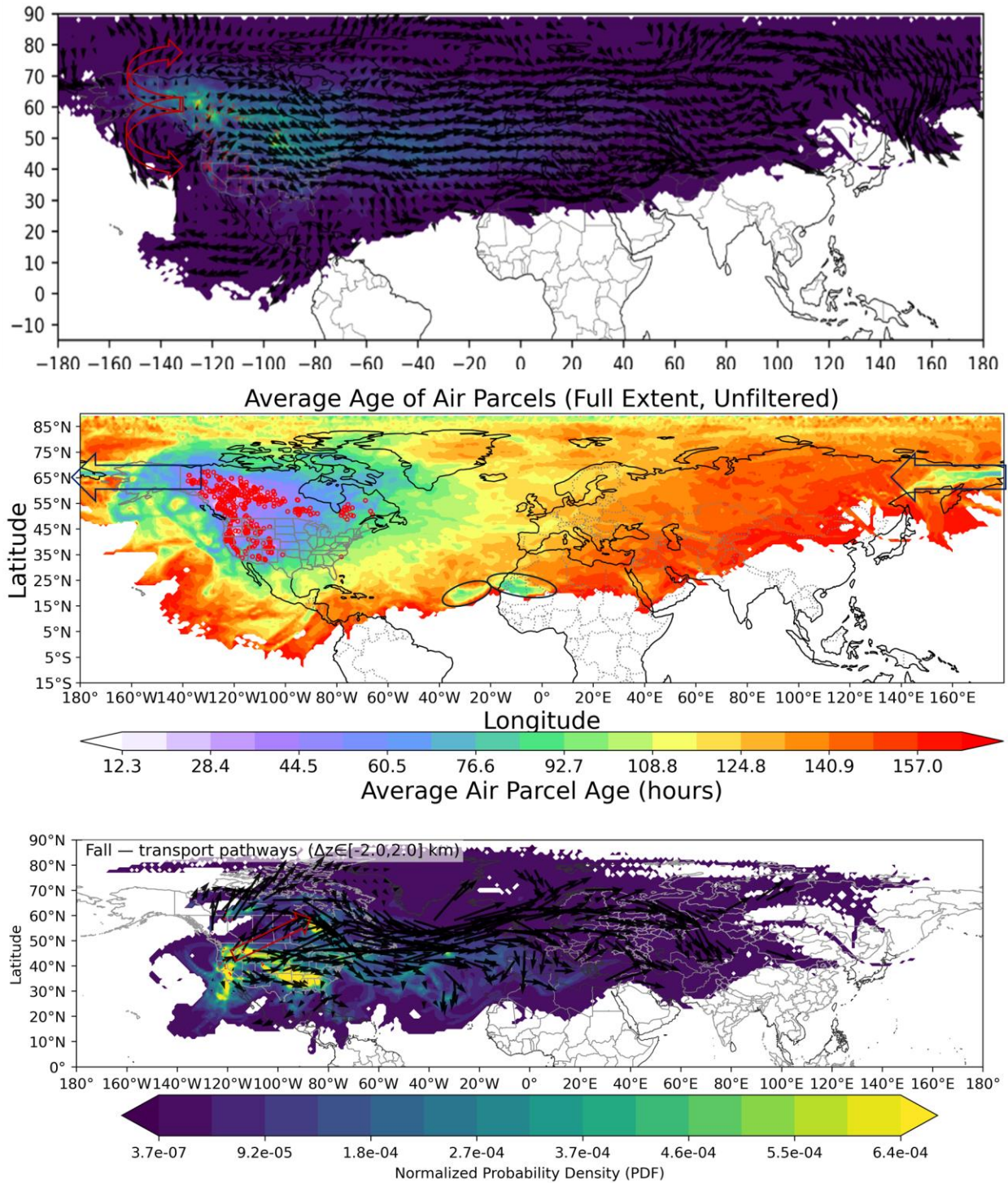


Figure S10. Synoptic blocking and resultant non-zonal transport pathways. (Top) The establishment of a Yukon Omega block, highlighted by wind vector anomalies (arrows). (middle) The anomalous upper-level retrograde flow driven by the western flank of the blocking anticyclone. (bottom) Time-averaged autumn trajectories demonstrating the subsequent transport of aerosols toward the semi-permanent low-pressure region over Hudson Bay. The two oval markers (15°N–25°N, 5°E–35°W) indicate localized pockets of younger air parcels embedded within an older background air mass, suggesting rapid advection of smoke layers caught within the fast-moving subtropical jet.

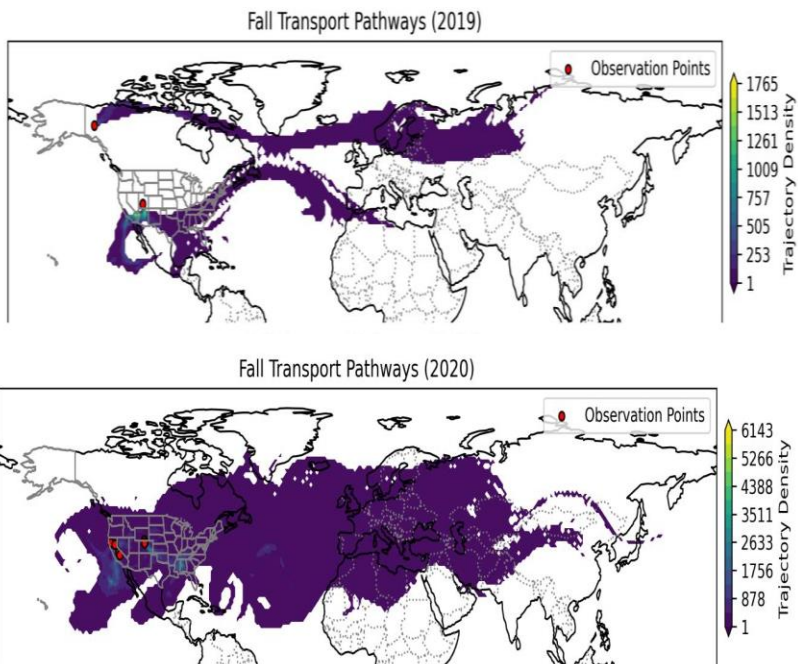


Figure S11: Episodic fall transport anomalies for the 2020 and 2019 pyroCb events. The panels show trajectory probability-density fields for the fall-season events in each year, highlighting the anomalous southwestward transport into the eastern subtropical Pacific that contributes to the fall composite feature. The PDFs shown here are not normalized, so the values should be interpreted as event-specific trajectory-density patterns rather than directly comparable normalized probabilities.