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Abstract

We present top-down CO and NO_x emission estimates for a south-central Chilean fire from Sentinel-5P/TROPOMI observations. Applying the Cross-Sectional Flux method to CO and the Exponentially Modified Gaussian method to NO₂, with uncertainty propagated through 500-member Monte Carlo ensembles, we retrieve a median CO flux of 1,273 kg s⁻¹ (95% CI: 676–1,843 kg s⁻¹) and a median NO_x flux of 7,505 g s⁻¹ (95% CI: 3,620–9,655 g s⁻¹) on the peak fire day. Against the hourly Copernicus Atmosphere Monitoring Service Global Fire Assimilation System (GFAS) inventory, the top-down median CO flux is 21 times GFAS for the overpass hour and 4.1 times its local-day mean. The top-down NO_x flux is 2.4 times GFAS at the overpass hour but 52% below its local-day mean, and the retrieved CO:NO_x ratio is 8.5–8.7 times the GFAS ratio in both cases. GFAS sets its ratio with generic extratropical-forest and savanna emission factors; its forest NO_x emission factor is 2.5 times a TROPOMI-derived temperate-forest value. To map the region affected by the smoke, we drove a Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) forward dispersion simulation with the retrieved CO flux: the plume traveled more than 2,000 km north-northwestward within 96 hours, along the Chilean coast and over the subtropical southeast Pacific, where TROPOMI observed enhanced CO.

Keywords: emissions, NO_x, CO, TROPOMI, wildfire

1 Introduction

The Biobío region in central-south Chile holds approximately 632,000 ha of forest plantation, the largest plantation area of any Chilean region and about 28% of the national total of 2.28 million ha in December 2022.¹ These plantations consist primarily of *Pinus radiata* and *Eucalyptus globulus* and cover about a quarter of the region’s territory.² Fire activity in this belt is modulated by drought, the Southern Annular Mode, and El Niño–Southern Oscillation variability,^{3–5} producing episodic years of exceptional intensity, most notably January 2017 (>500,000 ha burned; Bowman et al.⁶, de la Barrera et al.⁷) and the January 2026 outbreak studied in this work (>45,000 ha burned; Brandenstein et al.²). These fuels differ chemically from the ecosystems that dominate emission factor (EF) compilations: the terpene-rich resin of *Pinus radiata* and the volatile terpenoid oils of *Eucalyptus globulus*⁸ influence combustion completeness and the flaming-to-smoldering ratio⁹, yet no published study has derived top-down emission estimates for Chilean plantation fires or for *Pinus radiata*–dominated fuel complexes specifically. Prior modeling work on Chilean fires has used chemistry transport simulations driven by Copernicus Atmosphere Monitoring Service (CAMS) Global Fire Assimilation System (GFAS) bottom-up emissions to evaluate the simulated columns against satellite observations,¹⁰ but the emission fluxes themselves have not been validated.

The Sentinel-5P Tropospheric Monitoring Instrument (TROPOMI)¹¹ provides daily near-global coverage with a nadir pixel of about 3.5 km × 5.5 km in the UV–visible bands since August 2019,¹² which makes it possible to detect fire smoke. Its aerosol index (AER_AI) maps the horizontal extent of UV-absorbing smoke,¹³ and its aerosol layer height product (AER_LH) gives the height of the aerosol layer.¹⁴ CO columns from TROPOMI have been used with cross-sectional flux (CSF) methods to estimate emission fluxes from fires,^{15,16} from cities,¹⁷ and from industrial parks,¹⁸ and as a cross-check for European integrated iron and steel plants.¹⁹ The NO₂ column has been used to estimate NO_x emissions using the Exponentially Modified Gaussian (EMG) method.^{20,21} The choice of method follows from the chemistry of each species. CO is removed slowly by reaction with OH, with a lifetime of days to more than a year,²² much longer than the time the plume needs to reach the transects. Its flux through each cross-section therefore stays close to the emission rate, which makes CO well suited to CSF.¹⁵ NO_x in fire plumes is converted within hours to nitric acid, peroxyacetyl nitrate, and organic nitrates,^{21,23} so its flux decreases downwind. The EMG model fits this decay and returns both the emission rate and the effective NO_x lifetime.^{20,21} Both methods are sensitive to the assumed plume injection height, source location, and retrieval geometry, and earlier studies have not propagated these three sources of uncertainty jointly into their emission estimates.

Top-down satellite constraints on fire emissions have been reported across the Southern Hemisphere, but they cluster on a few biomes and provide regional estimates rather than single-fire retrievals. Over African savannas (the largest Southern-Hemisphere fire source), CO has been quantified from geostationary Spinning Enhanced Visible and InfraRed Imager (SEVIRI) fire radiative power (FRP) and TROPOMI columns,²⁴ while NO_x emission coefficients have been derived from Ozone Monitoring Instrument (OMI) NO₂ and Moderate Resolution Imaging Spectroradiometer (MODIS) FRP²⁵ and, more recently, NO_x fluxes from TROPOMI NO₂ inversions.²⁶ Over South America, fire CO has been constrained by multi-year inversions of Measurements Of Pollution In The Troposphere (MOPITT) CO,^{27,28} and NO_x emission factors have been mapped from OMI NO₂.²⁹ The 2019–2020 Australian fire season was quantified through a Bayesian inversion of TROPOMI CO,³⁰ and TROPOMI CO and NO₂ combined with MODIS fire products have yielded Australian biome-averaged CO and NO_x emission factors.³¹ Global and multi-region surveys applying the CSF and related flux methods to TROPOMI CO^{15,16} and the EMG method to TROPOMI NO₂²¹ include Southern-Hemisphere fires; those that aggregate results classify fires by land-cover class and report emission coefficients or emission factors averaged over many events.^{15,21} However, two gaps remain in existing studies. First, no study has jointly retrieved CO and NO_x fluxes for an individual Southern-Hemisphere fire with uncertainty propagated jointly through the retrieval; the existing multi-fire surveys report fit-based errors or discrete sensitivity tests rather than joint uncertainty over injection height, source location, and retrieval geometry. Second, none of this work addresses temperate-plantation fuels. The South American applications target tropical deforestation and savanna, and the Australian and African studies target eucalypt woodland and savanna; the *Pinus radiata*–*Eucalyptus globulus* plantation complexes of south-central Chile remain uncharacterized.

Here we apply the CSF and EMG methods to a single TROPOMI overpass of the 18 January 2026 Biobío outbreak, which produced a fire cluster with a mean FRP of 954 MW at 37.55°S, 72.55°W. First, we retrieve the top-down NO_x and CO emission fluxes with uncertainties from a 500-member Monte Carlo ensemble that jointly samples injection height, source location, and retrieval-geometry choices. Second, we benchmark the top-down fluxes against the hourly CAMS GFAS inventory, for the hour of the satellite overpass and over the local day, integrated over an FRP-defined source region. Third, we characterize the downwind transport of the plume with a HYSPLIT forward dispersion simulation³² driven by the retrieved CO flux, tracing the transoceanic pathway the smoke follows. To the best of our knowledge, these are the first satellite top-down emission estimates for Chilean plantation fires. They extend the CSF¹⁵ and EMG²¹ frameworks to *Pinus radiata* and *Eucalyptus globulus*, two species not resolved as fuel classes in prior top-down retrievals and for which species-specific emission factors exist only from laboratory burns of dried wood.³³

2 Materials and Methods

2.1 TROPOMI Level-2 Products

We use four products from the Sentinel-5P TROPOMI Level-2 product at South American overpass (13:30 local solar time): (1) tropospheric NO₂ column, (2) total CO column, (3) UV Aerosol Index at 354/388 nm

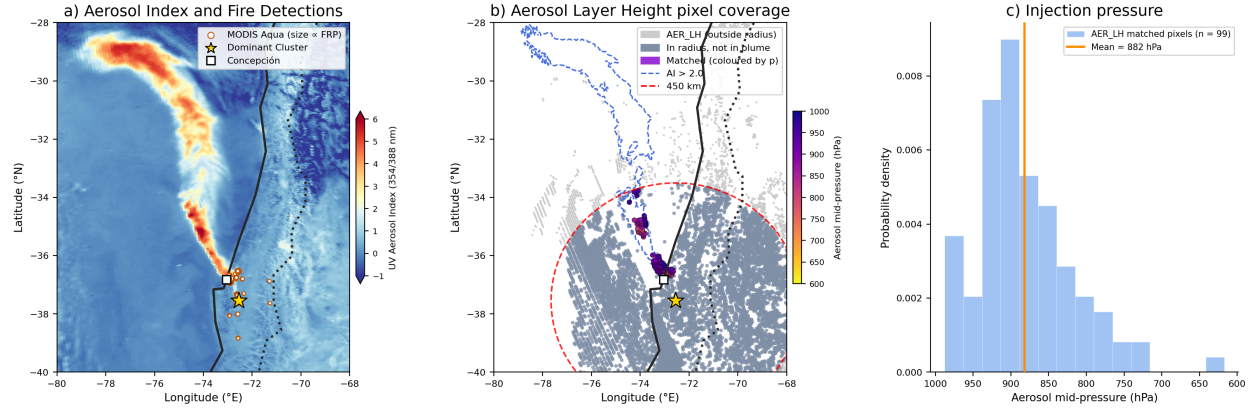


Figure 1: TROPOMI observations of the 18 January 2026 Biobío fire outbreak (13:30 local solar time). (a) UV Aerosol Index (AER_AI, 354/388 nm) over the source region and SE Pacific. Markers show MODIS Aqua active-fire detections; the dominant cluster (37.548°S, 72.554°W; mean FRP 954 MW) is highlighted, with Concepción, the coastline, and the national border marked. The smoke plume advects north-northwestward over the south-central Chilean coast. White gaps reflect the diagonal TROPOMI scan-line spacing. (b) Aerosol Layer Height (AER_LH) pixel coverage used to estimate the injection pressure. AER_LH pixels are classified as outside the 450 km extraction radius (grey), in-radius but not matched to the plume, or matched to the AER_AI plume (colored by aerosol mid-pressure). The blue dashed contour is the AER_AI > 2.0 plume boundary and the red dashed circle is the 450 km extraction radius; 99 of the in-radius AER_LH pixels match the plume. (c) Injection-pressure prior: histogram of the 99 matched AER_LH mid-pressures. The orange vertical line marks the mean (882 hPa; IQR 73 hPa), which sets the ERA5 wind-extraction level for the retrievals.

(AER_AI), and (4) Aerosol Layer Height (AER_LH). All products are filtered with $qa_value \geq 0.5$. Typical pixel size at nadir is $5.5 \times 3.5 \text{ km}^2$ for the NO_2 , AER_AI and AER_LH products (UV-VIS-NIR), and $5.5 \times 7 \text{ km}^2$ for CO (SWIR band), following the 2019 resolution upgrade.

2.2 Fire Source Identification

The fire source was identified from MODIS Aqua Collection 6.1 active-fire detections (MCD14DL; Giglio et al.³⁴) over the 16–22 January 2026 window spanning the outbreak. Similar to Jin et al.²¹, who grouped daytime MODIS fire pixels within 20 km into one fire event with an FRP-weighted centre, we grouped daytime detections with confidence $\geq 75\%$ by complete-linkage hierarchical clustering with a 20 km distance threshold and assigned each cluster an FRP-weighted centroid. The dominant cluster was selected using the highest mean-FRP cluster whose centroid lies within 300 km of Concepción, the Biobío capital, and whose mean FRP exceeds 200 MW.

Detections peaked on 18 January (172 detections, the maximum of the 16–22 January window), which resolved into 24 clusters. The dominant 18 January cluster comprises 8 detections with a mean FRP of 954 MW; its FRP-weighted centroid is at 37.548°S, 72.554°W, 91 km southeast of Concepción (Figure 1a). Aqua’s $\sim 13:30$ local solar time overpass is approximately synchronous with the TROPOMI 13:30 local solar time overpass, minimizing temporal mismatch in source localization.

From the same detections we define an integration radius for the inventory comparison (Section 2.7): the radius enclosing 99% of the cumulative daytime MODIS FRP of the local complex, $R_{99} = 142 \text{ km}$ (centered on the dominant centroid).

We restrict the flux retrievals to 18 January. Three reasons drive this choice. First, 18 January has the highest mean FRP of the outbreak, giving the clearest single-fire signal; the next largest nearby cluster carries only about a quarter of the dominant cluster’s FRP. Second, CSF and EMG both assume one dominant source. On 19 January several clusters of comparable size sit within 150 km of the target fire, so a single-source retrieval would mix emissions from more than one fire. Third, on 20 and 21 January the target fire itself

has faded (FRP below 300 MW) and the AER_AI field shows only scattered elevated pixels rather than a coherent plume.

2.3 Aerosol Injection Height and Wind Extraction

Both the CSF and EMG retrievals require the wind vector at the altitude where the smoke mass is transported, so the smoke must be located in the vertical. We use two co-located TROPOMI products for this. The UV Aerosol Index (AER_AI, 354/388 nm) is most sensitive to UV-absorbing aerosol above the boundary layer,³⁵ and aerosol-index thresholds have been used to map the horizontal extent of Chilean smoke plumes.¹³ The Aerosol Layer Height product (AER_LH) retrieves the mid-pressure of a single, geometrically thin aerosol layer from the O₂ A-band,¹⁴ which we take as the vertical position of the smoke. We use AER_AI to identify which pixels belong to the plume and sample AER_LH only within that mask, rather than over the full scene.

All AER_LH pixels within 450 km of the fire centroid ($QA \geq 0.5$, finite mid-pressure) were matched to their nearest AER_AI pixel by a KD-tree nearest-neighbor search on the unit sphere; a pixel was retained if its nearest AER_AI neighbor lies inside the plume mask ($AER_AI > 2.0$). Of 8,034 in-radius AER_LH pixels, 99 matched the AER_AI plume (Figure 1b). The matched pressures have a mean of 882 hPa with an interquartile range of 73 hPa (Figure 1c).

The injection pressure sets the level at which the transport wind is extracted. ERA5 hourly pressure-level winds³⁶ (13 levels, 125–975 hPa) were log-pressure interpolated to the fire centroid at the overpass hour and evaluated at 882 hPa, giving a transport wind of $U = 8.72 \text{ m s}^{-1}$ from the south-southeast (147° ; $u = -4.78$, $v = +7.29 \text{ m s}^{-1}$). The wind vector enters both the CSF perpendicular-flux integration (Section 2.4) and the EMG wind-frame rotation and flux conversion (Section 2.5), and the injection-pressure distribution serves as the prior for the Monte Carlo ensemble (Section 2.6).

2.4 CO Emission Flux — CSF Method

Following Griffin et al. 2024,¹⁵ CO emission flux was estimated via the Cross-Sectional Flux (CSF) method. TROPOMI CO columns were gridded onto a regular grid with $4 \text{ km} \times 4 \text{ km}$ cells at the fire latitude, using the two-step oversampling of Adams et al.³⁷: every grid point inside a pixel footprint takes that pixel’s column, and each cell is the mean of these values weighted by the inverse of the pixel area, here within 7 km as in Griffin et al.¹⁵. The AER_AI field used for the plume mask is gridded in the same way. A background field was estimated as the median column in an upwind strip 200–300 km from the fire along the ERA5 10 m plume-mean wind, well away from the plume. Background-subtracted column enhancements ΔCO were then integrated across $N_t = 10$ transects of half-width $w = 100 \text{ km}$ placed uniformly along the downwind plume axis, each perpendicular to the ERA5 wind at the injection pressure (Section 2.3).

For each transect k the instantaneous CO flux is

$$F_k = U_{\perp,k} \int_{-w}^w \Delta\text{CO}(s; k) ds, \quad (1)$$

where s is arc length along the transect (m), w is the transect half-width, and $U_{\perp,k} = u_k \cos \theta_k + v_k \sin \theta_k$ (m s^{-1}) is the ERA5 wind component perpendicular to transect k , computed from the wind vector (u_k, v_k) ; in this work every transect uses the same ERA5 wind at the fire centroid and injection pressure (Section 2.3), so all transects are parallel. The approach follows the flux method of Griffin et al.¹⁵, which builds on Adams et al.³⁷ and integrates background-subtracted TROPOMI CO columns in a frame aligned with ERA5 winds at the plume height.

The 18 January scene has many missing CO pixels from cloud, low quality flag, and swath gaps. A transect crossing one of these gaps can show a low ΔCO reading simply because most of its pixels are absent, not because the plume is thin there. Samples along each transect are spaced 4 km apart. We keep a transect only if more than half of its samples have a finite ΔCO ; transects below this fraction are dropped. Because CO has a long atmospheric lifetime, its flux barely changes with downwind distance, so dropping a few transects still leaves most of the plume. The CO flux estimate is the mean of the remaining transect fluxes. Retrieval uncertainty is propagated through the Monte Carlo ensemble described in Section 2.6. Figure 2 shows the estimation end to end: the gridded column with the AER_AI plume mask and the transects overlaid (a), and the resulting per-transect fluxes (b).

2.5 NO_x Emission Flux — EMG Method

NO₂ line densities were computed by rotating all TROPOMI NO₂ pixels within 450 km (the extraction radius) of the fire centroid into a wind-aligned frame, mapping them onto a regular $0.05^\circ \times 0.05^\circ$ grid, and integrating the columns across the wind (± 100 km) in each downwind bin from -100 to 450 km, following Jin et al.²¹. The line density ρ (mol m⁻¹) was fit to the Exponentially Modified Gaussian (EMG) profile²⁰:

$$\rho(x) = \frac{a}{x_0} \exp\left(-\frac{x - \mu_x}{x_0} + \frac{\sigma_x^2}{2x_0^2}\right) \Phi\left(\frac{x - \mu_x}{\sigma_x} - \frac{\sigma_x}{x_0}\right) + B, \quad (2)$$

where x is the downwind distance from the fire centroid (km), Φ is the standard normal cumulative distribution function, a is a scale factor proportional to the total column-integrated NO₂ mass (mol m⁻¹ km), x_0 is the e-folding decay length (km), μ_x is the apparent source offset relative to the fire centroid (km), σ_x is the Gaussian smoothing length (km), and B is a background line density (mol m⁻¹).

The NO_x emission flux and atmospheric lifetime are

$$E = \frac{\gamma a U}{x_0}, \quad \tau = \frac{x_0}{U}, \quad (3)$$

where U is the ERA5 wind speed at the sampled injection level (Section 2.3) and $\gamma = 1.32$ is the NO_x:NO₂ molar ratio²¹. E is converted from a molar flux to mass with the molar mass of NO₂, so NO_x fluxes in this paper are given as NO₂ mass unless stated otherwise. Jin et al.²¹ and GFAS report NO_x as NO mass; when comparing with them we convert our fluxes to that basis. Parameters are estimated by nonlinear least squares, repeating the fit 50 times and reporting the median of the converged fits. The quality criteria are satisfied if fitting $R^2 > 0.5$ and $\sigma_x < x_0$. Retrieval uncertainty is propagated through the Monte Carlo ensemble described in Section 2.6. Figure 3 shows the corresponding NO_x flux estimation stages: the native NO₂ column (a), the wind-rotated binned line-density grid (b), and the downwind line density with the EMG fit (c).

2.6 Monte Carlo Uncertainty Propagation

We report two quantities for each species. The *point estimate* is the flux returned by a single retrieval in which every uncertain input is held at its best value: the mean injection pressure of the plume-matched AER_LH pixels (Section 2.3), the dominant-cluster centroid (Section 2.2), and the default retrieval geometry. It is one number and carries no uncertainty of its own. The Monte Carlo ensemble described below replaces those fixed inputs with distributions and repeats the retrieval; the resulting median and 95% credible interval are the headline fluxes we quote.

CO and NO_x flux retrievals depend on three uncertain inputs: the smoke injection height, the fire source location, and a set of retrieval-geometry and background choices made by the analyst. We propagate these jointly through an ensemble of $N = 500$ independent Monte Carlo members, each of which performs one complete CO (CSF) and one complete NO_x (EMG) retrieval. Within a member, a single injection pressure and a single fire centroid are drawn. The analyst-choice parameters are specific to each method and are drawn independently. We summarize each species as the median and 95% credible interval (2.5th–97.5th percentile) of the converged-member distribution.

Injection-pressure prior. The 99 AER_LH mid-pressures matched to the AER_AI plume (Section 2.3) were fitted with a Gaussian KDE (Scott’s bandwidth) to form the injection-pressure prior (Figure S1a). Each member draws a pressure from this KDE and retrieves the corresponding ERA5 wind vector by log-pressure interpolation to the sampled centroid.

Source-location prior. The fire-location prior is a two-dimensional FRP-weighted Gaussian KDE fitted to the 146 daytime MODIS Aqua detections (confidence $\geq 75\%$) within 200 km of the dominant centroid on 18 January (Figure S1b). Weighting by FRP lets the spread reflect the spatial distribution of fire intensity across the multi-pixel complex. The KDE is recentered on the canonical cluster centroid (Section 2.2) before sampling, so it represents source-location uncertainty without shifting the ensemble mean away from the best estimate. Each member draws an independent centroid from this distribution.

Plume-alignment gate. For each member we estimate the plume transport axis by an AER_AI-weighted principal-component analysis of plume pixels ($\text{AER_AI} > 2.0$) within 450 km of the sampled centroid; the first principal component is the axis of maximum spatial variance, which for a coherent plume aligns with the transport direction. A member whose sampled ERA5 wind direction deviates from this axis by more than 15° is rejected before retrieval as physically inconsistent with the observed transport.

Analyst-choice parameters. The retrieval-geometry and background parameters that represent analyst choices are sampled independently from the uniform ranges in Table S1. The CO retrieval samples the background window, transect half-width, and number of transects; the NO_x retrieval samples the downwind and cross-wind domain extents and the extraction radius. The two methods draw these parameters independently.

Convergence and reporting. Members rejected by the alignment gate, and members for which the retrieval does not converge, are logged as controlled failures; the run aborts if the total failure fraction exceeds 50%. To rank uncertainty drivers we fit a standardized linear regression of the output flux on all sampled inputs and report each predictor’s squared standardized coefficient as a share of their sum ($\hat{\beta}_i^2 / \sum_j \hat{\beta}_j^2$; tornado diagram, Figure 4c,d), with injection pressure and the two centroid coordinates entering as separate predictors. These weights rank the inputs by their linear influence on the flux.

2.7 Inventory Comparison

We benchmark the top-down fluxes against CAMS GFAS v1.4.2, which provides hourly fire emission rates. GFAS is a bottom-up inventory: it assimilates MODIS and VIIRS FRP observations, converts FRP to a dry-matter combustion rate with land-cover-specific conversion factors, and multiplies this rate by an emission factor for each species.³⁸ It does not use CO or NO_2 observations, so it is independent of the TROPOMI retrievals. Each hourly GFAS field is the mean emission-rate density ($\text{kg m}^{-2} \text{s}^{-1}$) over one UTC hour. We integrate the CO (`cofire`) and NO_x (`noxfire`) fields as an area-weighted sum over all grid cells within a physically defined source radius, the radius enclosing 99% of the cumulative daytime MODIS FRP of the fire complex ($R_{99} = 142 \text{ km}$; Section 2.2), centered on the dominant hotspot. The overpass time is taken from the TROPOMI NO_2 and CO files as the observation time of the valid pixel nearest the fire centroid. Because a single hour need not represent the fire day, we compare against two GFAS values: the UTC hour containing the overpass (18–19 UTC; the overpass-hour benchmark), and the mean over the local calendar day containing the overpass (UTC–3; 03 UTC 18 January to 03 UTC 19 January). The GFAS `noxfire` field expresses NO_x as NO,³⁹ whereas the top-down EMG fluxes are reported as NO_2 (Section 2.5). For the GFAS comparison, we place both on the NO mass basis. The FRP-defined radius removes the arbitrary choice of integration distance; we report a radius-sensitivity sweep (25–150 km) to show the dependence explicitly (Figure 5).

2.8 HYSPLIT Forward Dispersion model

To trace where the emitted smoke travels, we drive a forward dispersion simulation with the retrieved flux itself. We ran a HYSPLIT v5.1.0³² concentration simulation using the Monte Carlo median CO flux, emitting CO as a passive tracer (its multi-week lifetime makes chemistry negligible over the run, and no dry or wet deposition was applied) from a single source at the plume injection height ($\sim 950 \text{ m}$ above ground) at a constant rate over the 12 h fire-active window (10–22 UTC on 18 January). The run used GDAS1 1° ARL meteorology (weeks 3–4 of January 2026), 100,000 particles, and a source-centered 0.25° concentration grid, integrated over 120 h and sampled 3-hourly. Because GDAS1 is a different meteorological product from the ERA5 winds used in the flux retrievals (Section 2.3), transport errors in the simulation are largely independent of those in the retrieval. NO_x was not forward-modeled because its chemical lifetime is too short compared to the time scale of model simulation.

We define the modeled plume footprint as the grid cells where the modeled column exceeds $T = 6.0 \times 10^{16} \text{ molec cm}^{-2}$ and which lie more than 50 km from the source, the latter excluding the near-source emission-window maximum. The modeled column is placed on the 0.25° grid, and plume reach is the 99th-percentile source distance of the footprint. A comparison of modeled and observed column magnitudes within this footprint is reported in the Supporting Information (Section S3).

3 Results

The 18 January 2026 Biobío outbreak produced the highest single-day FRP total in the MODIS Aqua record of the outbreak window for south-central Chile. The dominant cluster (37.548°S , 72.554°W ; 954 MW) lies ~ 91 km southeast of Concepción, and the co-located TROPOMI aerosol index shows a dense plume reaching several hundred kilometers north-northwestward. We report the CO and NO_x fluxes and their propagated uncertainty, benchmark them against the GFAS inventory, and trace the downwind transport of the plume with a forward dispersion simulation driven by the estimated CO flux.

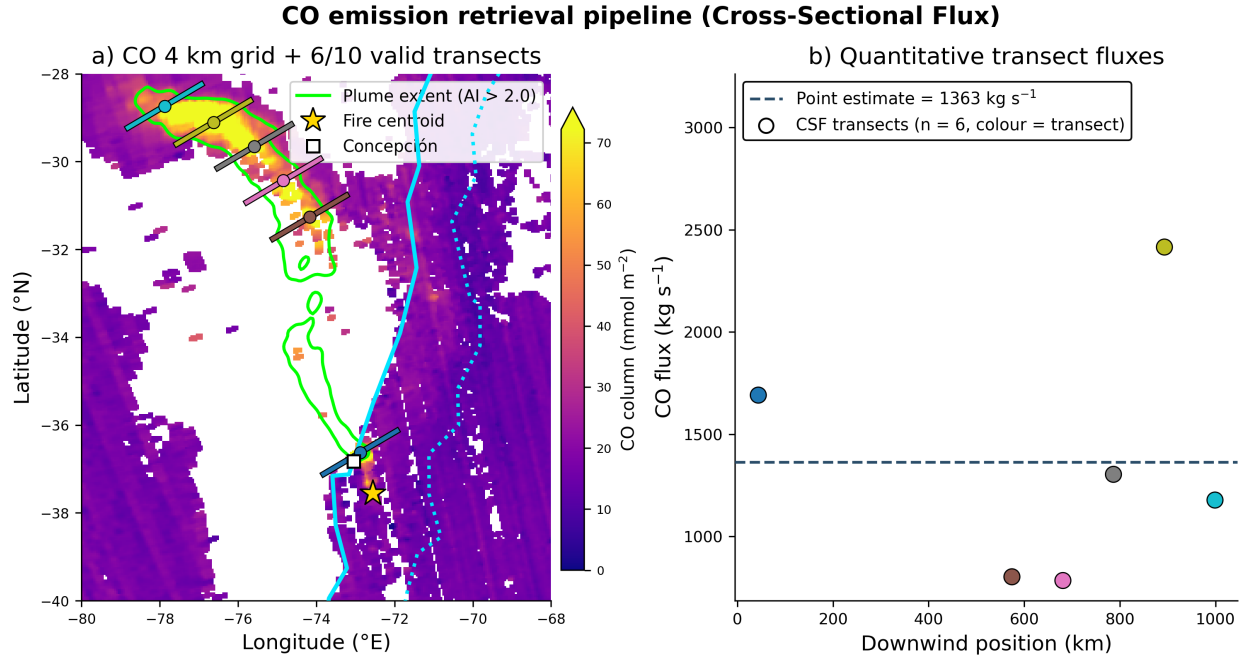


Figure 2: Calculated CO emission for the 18 January 2026 Biobío overpass. (a) CO column gridded to $4 \text{ km} \times 4 \text{ km}$ with the AER_AI plume extent ($\text{AI} > 2.0$) and the cross-sectional transects overlaid; each transect is perpendicular to the ERA5 wind at the AER_LH injection level, and colours identify individual transects. Transects with half or fewer of their ΔCO samples valid are rejected and not shown. (b) Per-transect CO flux versus downwind position (colours matching panel a); the dashed line is the mean over the six valid transects.

3.1 Top-down CO and NO_x emissions

The CO point estimate at the mean injection pressure is $1,363 \text{ kg s}^{-1}$. The 500-member Monte Carlo ensemble (Section 2.6) retains 287 members after the plume-alignment gate, with a median CO flux of **1,273** kg s^{-1} (95% CI: 676–1,843 kg s^{-1} ; $\pm 46\%$; Figure 4a). In the regression-based sensitivity ranking, injection pressure has the largest weight (57%), followed by transect half-width (24%) and fire-centroid longitude (12%); fire-centroid latitude (1%) and the remaining retrieval-geometry and background choices (6%) carry little weight (Figure 4c).

The EMG fit to the NO_2 line density reaches $R^2 = 0.846$ (Figure 3; Table S2). The source offset $\mu_x = 79.0$ km places the NO_2 peak downwind of the dominant-cluster centroid, where most of the fire complex was burning. The point-estimate NO_x flux is $8,415 \text{ g s}^{-1}$ with an effective lifetime $\tau = 0.75$ h. Propagating the same inputs leaves 285 converged members and a median NO_x flux of **7,505** g s^{-1} (as NO_2 ; 95% CI: 3,620–9,655 g s^{-1} ; $\pm 40\%$; Figure 4b). In the same ranking, fire-centroid latitude (60%) and longitude (27%) carry most of the weight, followed by injection pressure (7%) and downwind-domain extent (6%) (Figure 4d). The ensemble lifetime has a median of $\tau = 0.90$ h (95% CI: 0.70–1.86 h). Because the CO and NO_x retrievals use the same injection pressure and centroid within each member, their errors are shared by the two species

rather than independent.

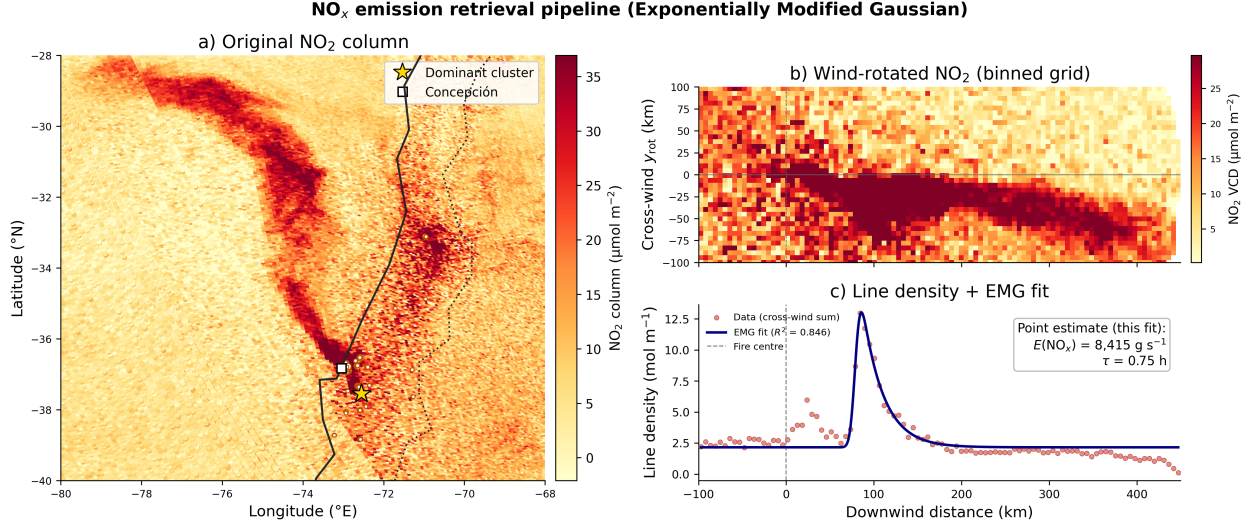


Figure 3: Calculated NO_x emission for the 18 January 2026 Biobío overpass. (a) Native TROPOMI NO₂ tropospheric column over the source region. (b) NO₂ column projected into the wind-aligned frame and binned to a regular downwind × cross-wind grid (0.05°). (c) Downwind line density with the least-squares EMG fit.

These emissions place the Biobío fire at the high end of single-fire top-down retrievals. On the NO mass basis our median NO_x flux is 4,895 g s⁻¹ (95% CI: 2,361–6,298 g s⁻¹), about 62% of the Australian fire that Jin et al.²¹ used to demonstrate the EMG method (7,870 g s⁻¹). The CO emission is of the same order as, and larger than, the CSF estimates for the highest-FRP fire in Goudar et al.¹⁶, which span 116–809 kg s⁻¹ depending on whether a constant injection height or a Lagrangian, downwind-varying plume height is assumed. The CO retrieval uncertainty (±46%) is close to the ~57% total uncertainty of the TROPOMI flux method of Griffin et al.¹⁵. The effective NO_x lifetime (median 0.90 h) is consistent with the lifetimes below 2 h that Jin et al.²¹ report for fires emitting more than 5,000 g s⁻¹.

3.2 Comparison with the CAMS GFAS inventory

Within R99, the hourly GFAS emissions vary strongly over the fire day (Supporting Information, Section S4 and Figure S3): over the local day, CO ranges from 12 to 469 kg s⁻¹ and NO_x from 392 to 15,366 g s⁻¹ (as NO), with the largest values between 08 and 13 UTC (05–10 Chile local time, UTC–3) and the overpass hour close to the daily minimum. For the hour containing the overpass (18–19 UTC), GFAS gives CO = 61 kg s⁻¹ and NO_x = 2,018 g s⁻¹; the local-day means are 309 kg s⁻¹ and 10,144 g s⁻¹. At the overpass hour the top-down median CO flux (1,273 kg s⁻¹) is 21 times GFAS (95% CI: 11–30), and GFAS lies below all 287 CO members. The top-down median NO_x flux (4,895 g s⁻¹ as NO) is 2.4 times GFAS (95% CI: 1.2–3.1), with GFAS at the 2nd percentile of the 285 members. Against the local-day mean, top-down CO is 4.1 times GFAS (2.2–6.0) and top-down NO_x is 0.48 times GFAS (0.23–0.62), with GFAS above all but one NO_x member (99.6th percentile). CO therefore exceeds GFAS in both comparisons, while the direction of the NO_x departure depends on which GFAS value is used. GFAS increases with the integration radius because it is a sum over grid cells: a larger circle includes more burning cells, until it encloses the whole fire complex (Figure 5). The top-down fluxes do not change with radius, because they are derived from the observed smoke plume.

The retrieved CO:NO_x mass ratio is ~260, whereas GFAS implies 30.0 at the overpass hour and 30.5 for the local-day mean. The GFAS ratio is set by its emission-factor tables rather than observed for this fire: the CO:NO_x ratio of each emitting GFAS grid cell within R99 is one of two fixed values (31.0 and 28.9), close to the ratios of the extratropical-forest and savanna fuel types tabulated for GFAS v1.0 by Kaiser et al.³⁸ (31.2 and 29.0). The extratropical-forest NO_x emission factor in that table (3.4 g kg⁻¹ DM) is 2.5 times the temperate-forest value derived from TROPOMI NO₂ by Jin et al.²¹ (1.36 g kg⁻¹ DM).

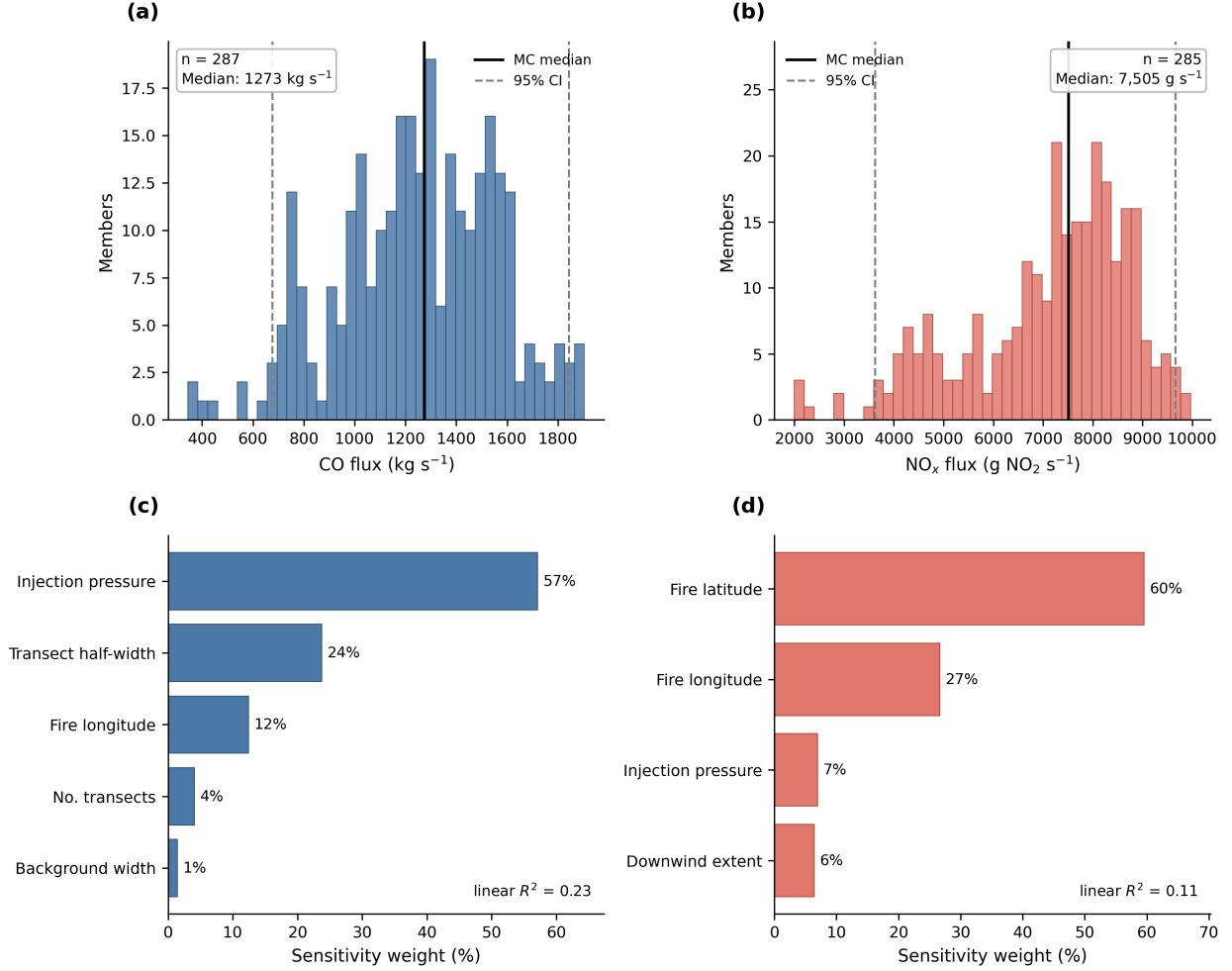


Figure 4: Monte Carlo retrieval-uncertainty distributions. (a) CO flux histogram ($N_{\text{conv}} = 287$) and (b) NO_x flux histogram ($N_{\text{conv}} = 285$) for the converged 500-member ensembles; black lines mark the MC medians, grey dashed lines the 95% credible intervals. (c, d) Regression-based sensitivity of the output flux to each sampled input for CO and NO_x; the linear model explains 23% (CO) and 11% (NO_x) of the ensemble variance.

Table S3 in the Supporting Information places these ratios among published satellite-based estimates. For seasonal or regional totals, top-down CO and NO_x emissions differ from GFAS and other inventories by factors of about 0.4 to 2.3, with a sign that depends on species, region, and inventory^{15,24,26,28,40}. Our overpass-hour (2.4) and local-day (0.48) NO_x ratios fall within this range, and the local-day CO ratio (4.1) lies just above it. The overpass-hour CO ratio (21) lies far outside it, mainly because GFAS places its daily minimum close to the overpass for this fire (Supporting Information, Section S4). The CO:NO_x ratio does not depend on the GFAS hour and is the more robust comparison. Our value (~ 260 , NO_x as NO) is about seven times the temperate-forest values of the emission-factor compilations (35–38) and above their boreal and extratropical-forest values (103 and 109)^{23,41}, the TROPOMI-derived ratio for southeastern Australian temperate forest 90;³¹ and the satellite ratio for the 2016 Horse River wildfire 100;³⁷. For the Horse River fire, as here, the satellite ratio exceeded the GFAS ratio (30). Part of our excess may come from the NO₂ retrieval: Jin et al.²¹ found that fire NO_x emission coefficients derived from the standard TROPOMI NO₂ product, which we use, are on average 46% lower than with an updated a priori NO₂ profile. A correction of that size would bring our ratio to about 140, between the boreal compilation values and the laboratory values for these fuels (67–120; Cereceda-Balic et al.³³).

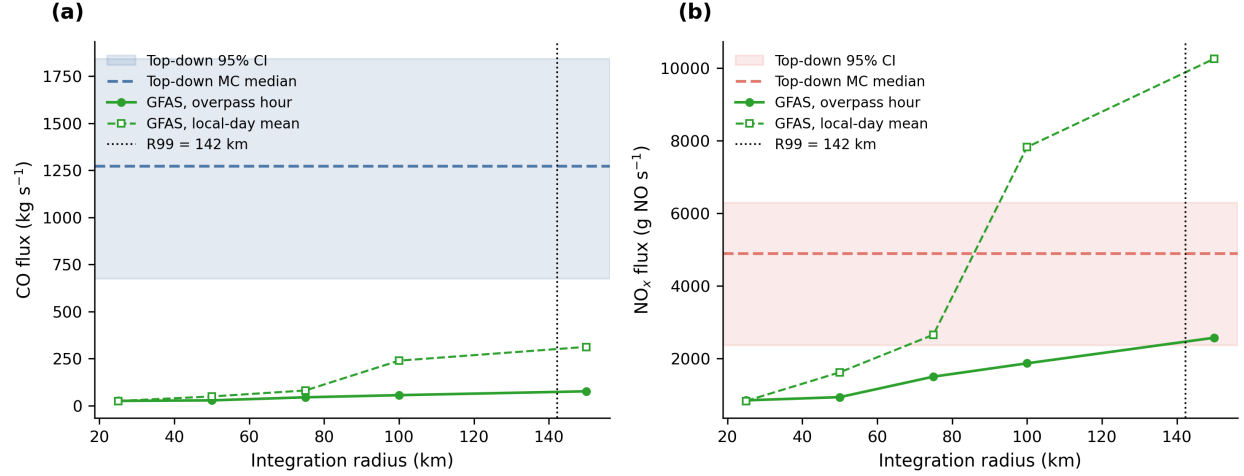


Figure 5: Integration-radius sensitivity of the comparison with CAMS GFAS. (a) CO and (b) NO_x GFAS emission integrated within each radius, for the UTC hour containing the TROPOMI overpass (solid green) and the local-day mean (UTC-3; dashed green), compared with the top-down Monte Carlo posterior (dashed line, MC median; shaded band, 95% credible interval), which does not depend on the integration radius because the retrievals sample the whole plume downwind of the complex. NO_x is on the NO mass basis. The vertical dotted line marks R99 = 142 km, used for the comparison.

3.3 Transport characterization

The modeled plume footprint extends from 1,080 km at the +1 d overpass to 2,220 km at the +4 d overpass (99th-percentile source distance). The spatial overlay (Figure 6) shows the plume advecting north-northwestward, following the Chilean coast before turning offshore onto the subtropical southeast Pacific, with elevated observed TROPOMI CO along the same corridor. A quantitative comparison of the modeled and observed column magnitudes is reported in the Supporting Information (Section S3).

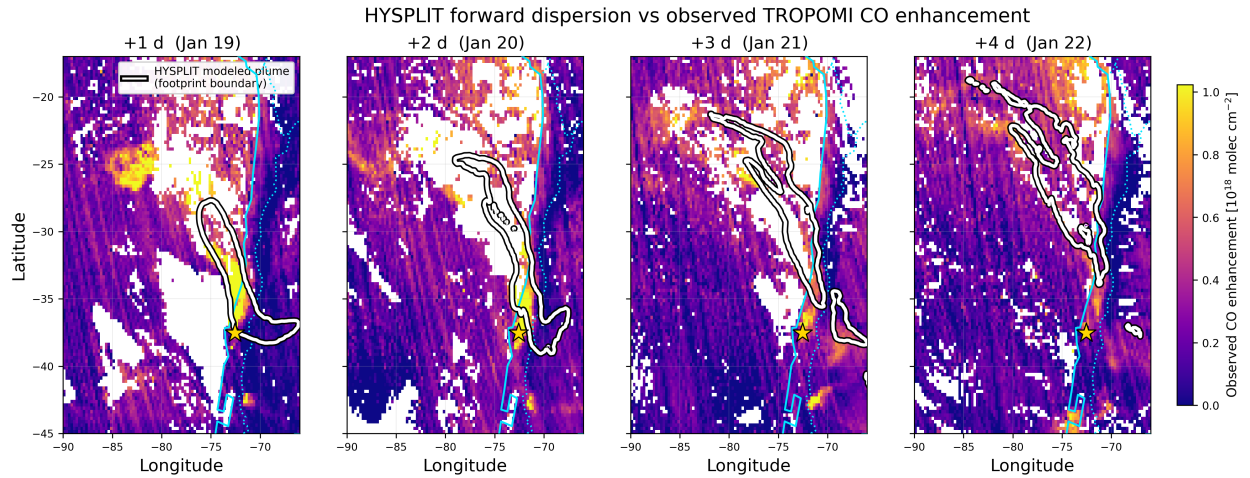


Figure 6: Spatial transport characterization of the 18 January 2026 Biobío plume at the four downwind overpasses (+1 to +4 d). Shading: observed TROPOMI CO column enhancement (QA ≥ 0.5; column minus the same-day 10th-percentile off-plume background) on the 0.25° analysis grid. White contour: HYSPLIT modeled plume footprint boundary, driven by the MC-median flux of 1,273 kg s⁻¹.

4 Discussion

The flux estimation constrains a single wildfire rather than a biome average, and carries injection height, source location, and retrieval geometry jointly into the reported credible intervals. In the sensitivity ranking, the two observation-informed inputs carry the largest weights for both species, but in opposite order: injection pressure for CO, source location for NO_x. Fixing either at its best estimate would understate the interval and would hide that the two species are limited by different measurements. The multi-fire surveys that include Southern-Hemisphere fires^{15,16,21} quantify uncertainty from regression statistics, transect spread, synthetic tests, or sensitivity tests that vary one input at a time, often summarized over many events, which cannot resolve this distinction for an individual fire.

Although the analysis covers one fire on one day, the estimates rest on a dense set of independent observations of that event: 146 MODIS detections define the source-location prior, 99 plume-matched AER_LH pixels the injection-pressure prior, six valid transects spread over about 1,000 km of plume give the CO flux, and about 21,800 TROPOMI pixels within 450 km of the fire build the NO₂ line density. Several independent checks agree. Both point estimates lie inside their Monte Carlo intervals; the 50 EMG fits with perturbed initial guesses agree to within 0.01%; the effective NO_x lifetime matches the values reported for fires of similar intensity²¹; and a forward simulation driven by the retrieved CO flux under independent meteorology follows the CO corridor that TROPOMI observed over the following four days. The method is not specific to this event. It derives its priors from co-located TROPOMI aerosol products, rejects ensemble members whose winds disagree with the observed plume, and retrieves CO and NO_x from the same overpass, so it can be applied to other large fires with a coherent plume.

GFAS derives every species from the same FRP-based dry-matter combustion rate, multiplied by a species-specific emission factor.³⁸ The GFAS value chosen therefore scales CO and NO_x together: the GFAS CO:NO_x mass ratio is 30.0 at the overpass hour and 30.5 for the local-day mean, while the size of each departure, and for NO_x its sign, changes between the two. The ratio of the two departures barely changes: top-down CO/GFAS exceeds top-down NO_x/GFAS by a factor of 8.7 at the overpass hour and 8.5 for the local-day mean, the same factor that separates the top-down CO:NO_x ratio (~ 260) from the GFAS ratio (~ 30). Neither the timing of the GFAS emission nor its fire-intensity term can remove this factor. It points to the CO:NO_x emission ratio that GFAS assigns to this fuel, or to a species-specific bias in one of the retrievals. Laboratory measurements for these fuels point the same way. Burning oven-dried stem-wood shavings in a combustion chamber, Cereceda-Balic et al.³³ obtained NO_x emission factors of 0.41 g kg⁻¹ DM for *P. radiata* and 0.58 g kg⁻¹ DM for *E. globulus*, which give CO:NO_x mass ratios of about 120 and 67, two to four times the GFAS ratio for this fire. Their burns were dominated by flaming (a modified combustion efficiency near 0.96 follows from their CO and CO₂ emission factors), and they do not state the mass basis of NO_x, so their ratios cannot be compared directly with the open-fire ratio retrieved here. On either mass basis, however, they exceed the GFAS ratio. A correction that applies to NO_x alone, such as an air-mass-factor correction for NO₂ shielded by dense smoke^{21,42}, would raise the top-down NO_x flux and reduce the factor, but closing it would require an increase of about 8.5 times.

The forward simulation places the retrieved emission in its meteorological context. It is driven by GDAS1 winds, a different product from the ERA5 winds used in the retrieval, and traces the plume more than 2,000 km north-northwestward over four days. The simulation is a model result, not an observation; the observations are the TROPOMI CO fields in Figure 6, which show enhanced CO along the same corridor. We do not read the correspondence as a validation of the flux magnitude, for the reasons set out in the Supporting Information (Section S3). Long-range export of this kind is documented for Northern-Hemisphere fires such as the 2023 Canadian wildfires, whose smoke reached Europe and raised PM_{2.5} exposure there.⁴³ Lapere et al.¹⁰ simulated a plume extending more than 2,000 km for the 2017 central-Chile mega-fires, a distance similar to the one we find for 2026, which suggests that long-range export of smoke from south-central Chilean fires recurs.

The comparison cannot say which estimate is closer to the truth, but it shows what satellite observations add. GFAS converts FRP to emissions through land-cover conversion factors, tabulated emission factors, and a diurnal cycle, none of which uses observations of the gases emitted by the fire being estimated. The TROPOMI retrieval measures CO and NO_x in the plume itself, for fuels that have no open-fire emission factors, and constrains the CO:NO_x ratio independently of the inventory hour. With daily global coverage, the same retrieval can be applied to every large fire with a coherent plume, so inventory emission factors

can be tested fire by fire rather than only through biome averages. For this fire, the top-down median CO exceeds GFAS for every GFAS hour, the direction of the NO_x comparison depends on the hour chosen, and the CO:NO_x ratio differs by a factor of about 8.5 whatever the hour.

5 Conclusions

We calculated CO and NO_x emission fluxes for a single south-central Chilean plantation fire from one TROPOMI overpass, with injection height, source location, and retrieval geometry propagated jointly through a 500-member Monte Carlo ensemble. These are, to the best of our knowledge, the first top-down emission estimates for a *Pinus radiata*–*Eucalyptus globulus* plantation fire, a fuel not resolved as a fuel class in earlier top-down work and for which species-specific emission factors exist only from laboratory burns of dried wood.³³ The top-down median CO exceeds the hourly GFAS inventory for every hour of the fire day, the direction of the NO_x comparison depends on the GFAS hour, and the retrieved CO:NO_x ratio is about 8.5 times the ratio GFAS assigns to this fire; a forward simulation driven by the retrieved flux traces the plume more than 2,000 km onto the subtropical southeast Pacific under independent meteorology. Settling the inventory disagreement will require open-fire emission measurements for these fuels, which to our knowledge have not been made, and applying the same uncertainty-propagated retrieval to further Chilean fires would show whether the disagreement is systematic for this fuel or specific to this event.

Data Availability Statement

TROPOMI Level-2 products are available from the Copernicus Open Access Hub (<https://dataspace.copernicus.eu>). MODIS MCD14DL active fire data are distributed by NASA FIRMS. ERA5 reanalysis is available from the Copernicus Climate Data Store. CAMS GFAS fire emissions are available from the Copernicus Atmosphere Data Store. GDAS1 meteorology is from the NOAA ARL archive. Analysis code (retrievals, HYSPLIT forward run, and inventory comparison) will be archived in a public repository upon acceptance.

Conflict of Interest

The authors declare no competing financial interest.

Supporting Information

The Supporting Information is included at the end of this preprint: Monte Carlo parameter priors and ranges (Section S1, Figure S1, Table S1); EMG fit parameters of the point-estimate NO_x flux (Section S2, Table S2); comparison of the HYSPLIT modeled and observed CO columns (Section S3, Figure S2); hourly GFAS emissions within R99 (Section S4, Figure S3); comparison with published satellite-based estimates and emission-factor compilations (Section S5, Table S3).

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Supporting Information

Number of figures: 3 (Figures S1–S3). Number of tables: 3 (Tables S1–S3).

Contents: S1, Monte Carlo parameter priors and ranges; S2, NO_x fitting parameters; S3, forward-simulation comparison with observed CO columns; S4, GFAS hourly emissions; S5, comparison with published satellite-based estimates.

S1 Monte Carlo Parameter Priors and Ranges

The Monte Carlo ensemble (Section 2.6 of the main text) samples two observation-informed priors and a set of analyst-choice parameters. The two priors are shown in Figure S1 and the analyst-choice ranges are listed in Table S1.

The injection-pressure prior (Figure S1a) is a Gaussian KDE (Scott’s bandwidth) fitted to the 99 AER_LH aerosol mid-pressures matched to the AER_AI plume within 450 km of the fire centroid (Section 2.3 of the main text). The distribution is centered at a mean of 882 hPa with an interquartile range of 73 hPa; each ensemble member draws one pressure from this KDE and retrieves the corresponding ERA5 wind. The source-location prior (Figure S1b) is an FRP-weighted two-dimensional Gaussian KDE fitted to the 146 daytime MODIS Aqua detections (confidence $\geq 75\%$) within 200 km of the dominant centroid, recentered on the canonical centroid (Section 2.2 of the main text) before sampling so that it represents source-location uncertainty without shifting the ensemble mean. Each member draws one centroid from this distribution, shared between the CO and NO_x retrievals.

The retrieval-geometry and background parameters that represent analyst choices are sampled independently from the uniform ranges in Table S1; the CO and NO_x retrievals draw their method-specific parameters independently.

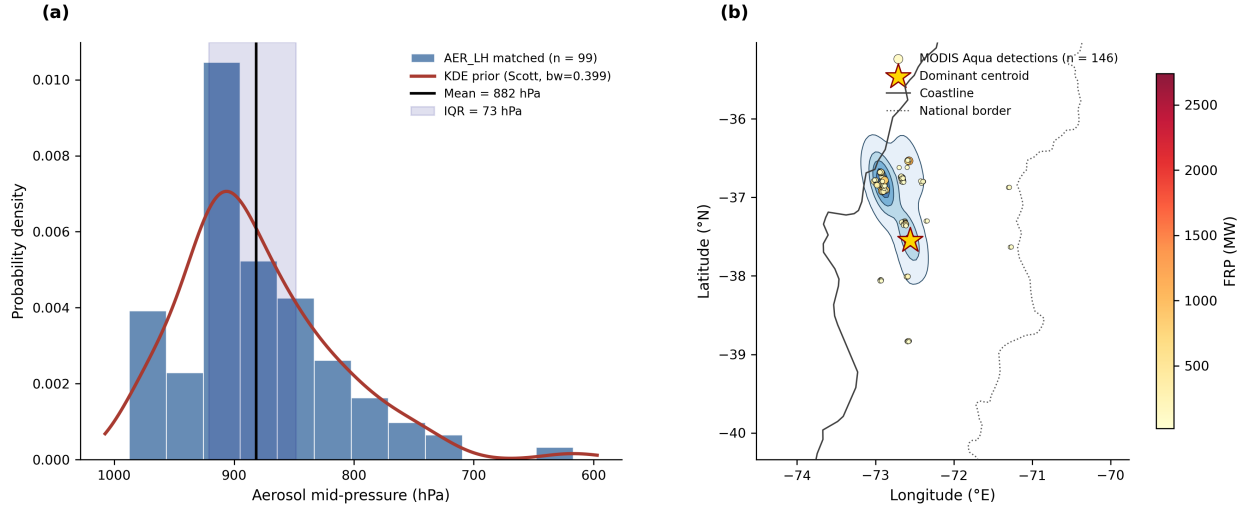


Figure S1: Observation-informed priors sampled by the Monte Carlo ensemble (Section 2.6 of the main text). (a) Injection-pressure prior: histogram of the 99 AER_LH mid-pressures matched to the AER_AI plume within 450 km of the fire centroid, with the fitted Gaussian KDE (Scott’s bandwidth) used as the sampling prior. The vertical line marks the mean (882 hPa) and the shaded band the interquartile range (73 hPa); the pressure axis is inverted so that higher altitude is to the right. (b) Source-location prior: FRP-weighted two-dimensional Gaussian KDE of the 146 daytime MODIS Aqua detections (confidence $\geq 75\%$) within 200 km of the dominant centroid (gold star), recentered on the canonical centroid before sampling. Detections are colored by FRP. Each Monte Carlo member draws one injection pressure and one centroid, shared between the CO and NO_x retrievals.

Parameter	Symbol	Prior / Range	Retrieval
<i>Shared (observation-informed priors)</i>			
Injection pressure	p	1-D KDE (mean 882 hPa, IQR 73 hPa)	CO, NO _x
Fire centroid latitude	ϕ_f	2-D FRP-weighted KDE ($n = 146$ detections)	CO, NO _x
Fire centroid longitude	λ_f	(same KDE)	CO, NO _x
<i>CO analyst-choice parameters (uniform)</i>			
Background window start	x_{bg}	$\mathcal{U}(-350, -250)$ km	CO
Background window width	Δx_{bg}	$\mathcal{U}(80, 120)$ km	CO
Transect half-width	w	$\mathcal{U}(75, 150)$ km	CO
Number of transects	N_t	$\mathcal{U}\{8, 9, \dots, 14\}$ (discrete)	CO
<i>NO_x analyst-choice parameters (uniform)</i>			
Downwind domain extent	x_{max}	$\mathcal{U}(400, 500)$ km	NO _x
Cross-wind domain extent	y_{max}	$\mathcal{U}(80, 120)$ km	NO _x
Extraction radius	r_{ext}	$\mathcal{U}(400, 500)$ km	NO _x

Table S1: Sampled parameters for the Monte Carlo retrieval-uncertainty ensemble ($N = 500$ draws). All uniform ranges are sampled independently per member. Parameters shared between the CO and NO_x retrievals use the same draw (injection pressure, fire centroid); analyst-choice parameters are drawn independently.

S2 NO_x Fitting Parameters

Table S2 lists the parameters of the EMG fit that gives the point-estimate NO_x flux (Section 2.5 of the main text), and the Monte Carlo flux and lifetime. The fit has its origin at the dominant-cluster centroid and uses the ERA5 wind at the mean injection pressure (882 hPa; $U = 8.72 \text{ m s}^{-1}$). The 21,792 TROPOMI NO₂ pixels within 450 km of the centroid were binned onto $0.05^\circ \times 0.05^\circ$ cells in the wind-aligned frame: 100 cells downwind, from -100 to 450 km, and 37 cells across the wind.

The five parameters were fitted by bounded nonlinear least squares. To test the effect of the initial guess, we repeated the fit 50 times, and we report the median of each parameter over the converged fits. All 50 fits converged, and the coefficient of variation of E across them is 2×10^{-6} . The lower bound of x_0 is the grid spacing (about 5.5 km), because the line density does not resolve a shorter decay length. The point estimate fit meets both quality criteria of Section 2.5 of the main text: $R^2 = 0.846$, and $\sigma_x = 4.7$ km is smaller than $x_0 = 23.6$ km. With the median parameters, the flux and lifetime relations of Section 2.5 give $E = 8,415 \text{ g s}^{-1}$ (as NO₂) and $\tau = 0.75$ h.

The Monte Carlo values in Table S2 are medians and 95% credible intervals over the 285 converged members (Section 2.6 of the main text). The point estimate lies at the 77th percentile of the member fluxes.

<i>EMG fit geometry</i>		
Integrated line density a	374.5 kmol	
Decay length x_0	23.6 km	
Source offset μ_x	79.0 km	
Gaussian width σ_x	4.7 km	
Background B	2.15 mol m ⁻¹	
Goodness of fit R^2	0.846	
<i>Monte Carlo flux results</i>		
NO _x emission flux E	7,505 g s⁻¹	[3,620–9,655] g s ⁻¹
NO _x lifetime τ	0.90 h	[0.70–1.86 h]

Table S2: EMG fit diagnostics and Monte Carlo flux results for the 18 January 2026 Biobío overpass. Fit parameters are from the nonlinear least-squares fit at the mean injection pressure; emission flux and lifetime are reported as Monte Carlo medians with 95% credible intervals (2.5th–97.5th percentile, $N_{\text{conv}} = 285$ members).

S3 Forward-Simulation Comparison with Observed CO Columns

This section reports the quantitative comparison between the HYSPLIT modeled CO column and the observed TROPOMI CO enhancement, and sets out why we treat it as a secondary analysis rather than a test of the retrieved flux.

Within the modeled plume footprint (Section 2.8 of the main text) we compare the median modeled column with the median observed enhancement (TROPOMI CO minus the same-day 10th-percentile off-plume background) over the cells where TROPOMI has a valid pixel. The modeled footprint-median column rises to $\sim 9.3 \times 10^{17}$ molec cm $^{-2}$ within the 12-h emission window and dilutes to $\sim 1.4 \times 10^{17}$ molec cm $^{-2}$ by +48 h (Figure S2). At the four downwind overpasses the observed median exceeds the modeled median by factors of 2.3–4.0 (5.4×10^{17} vs 2.3×10^{17} molec cm $^{-2}$ at +1 d).

Two effects keep this ratio from constraining the retrieved flux. First, the simulation carries only the 18 January emission, while the observed column at each subsequent overpass integrates the emissions of the intervening days; the fire remained active, at reduced intensity, through 21 January (Section 2.2 of the main text). The observed median is therefore expected to exceed the modeled median whether or not the retrieved flux is accurate, and a single-day simulation cannot separate that excess from a retrieval error. Second, TROPOMI CO coverage within the footprint is incomplete and varies between scenes, from 53% of footprint cells at +2 d to 81% at +1 d. The missing cells are not a random sample, since CO retrievals fail preferentially over cloud, so the surviving cells need not represent the plume as a whole.

We therefore use the simulation for the spatial characterization reported in Section 3.3 of the main text and do not read the magnitude ratio as evidence for or against the retrieved flux.

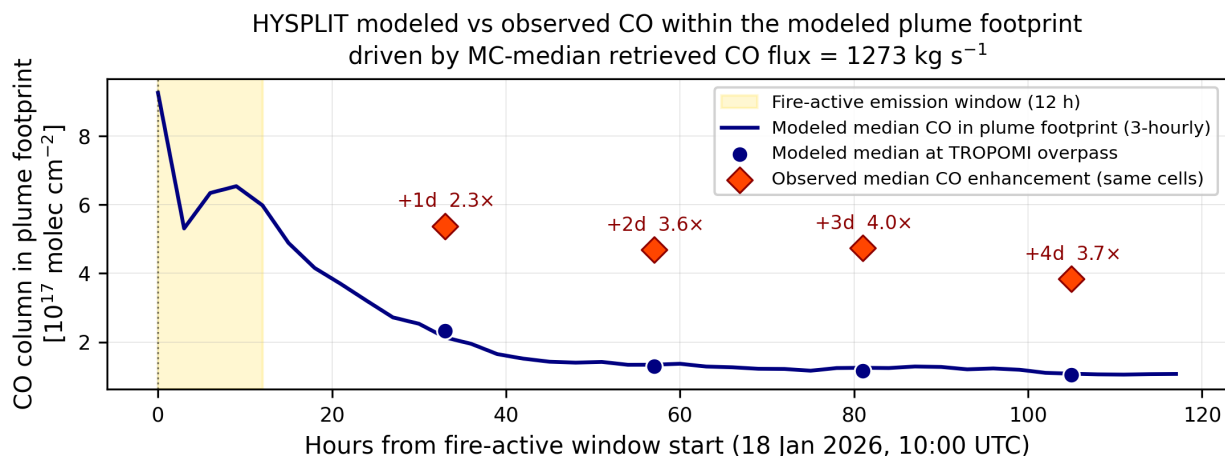


Figure S2: HYSPLIT modeled CO column within the modeled plume footprint (navy line: footprint-median column at the native 3-hourly sampling), driven by the MC-median CO flux (1,273 kg s $^{-1}$). Navy circles mark the modeled median at each of the four following TROPOMI overpasses; orange diamonds the observed median CO enhancement over the same footprint cells, annotated with the observed/modelled ratio.

S4 GFAS Hourly Emissions

Figure S3 shows the hourly GFAS v1.4.2 emissions integrated within R99 from 17 to 19 January 2026, the series from which the benchmarks of Section 3.2 of the main text are taken. The GFAS values stay constant over several consecutive hours and change in steps, and the largest values on 18 January fall between 08 and 13 UTC (05–10 Chile local time, UTC–3), before the overpass.

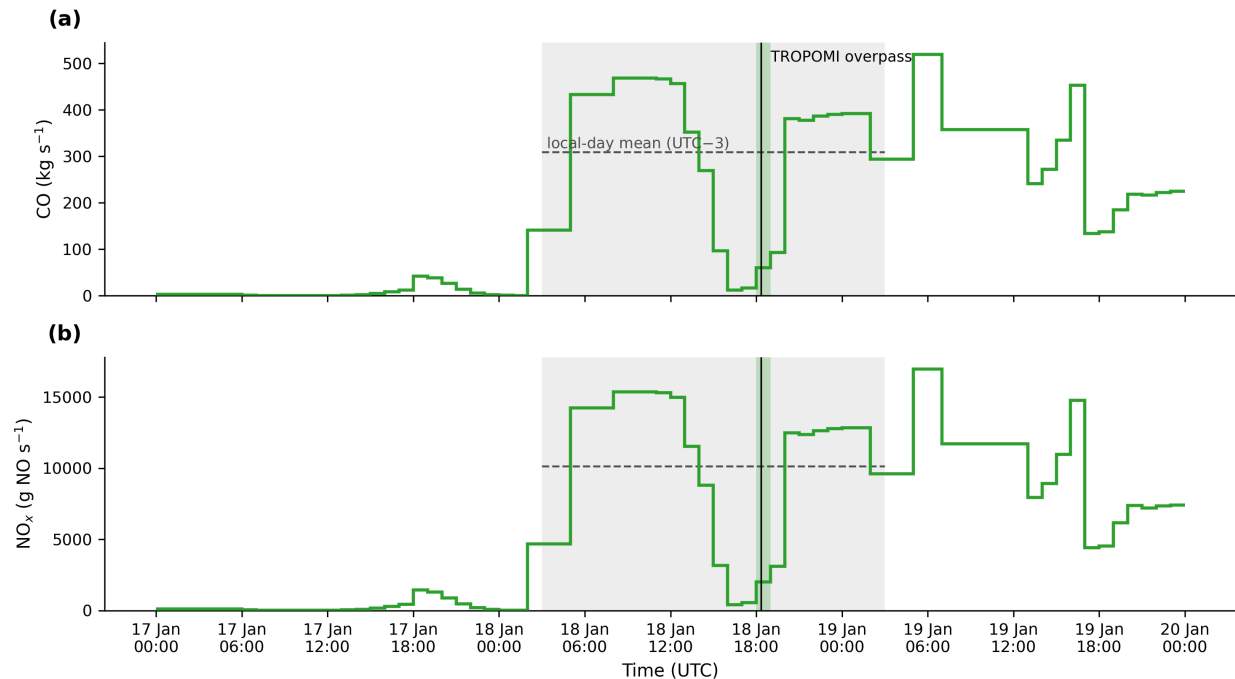


Figure S3: Hourly CAMS GFAS v1.4.2 emissions of (a) CO and (b) NO_x (as NO) within $R99 = 142$ km of the fire centroid, 17–19 January 2026. Each step is the mean over one UTC hour. Grey shading: the local day containing the overpass (UTC–3), with its mean (dashed line); green band: the UTC hour containing the TROPOMI overpass (vertical line, 18:21 UTC).

S5 Comparison with Published Satellite-Based Estimates

Table S3 places the top-down estimates of this study among published satellite-based fire emission estimates (panel a) and emission-factor compilations (panel b). Values marked with an asterisk are ratios that we computed from the two totals reported in the cited study; all other values in panel (a) are as reported. In panel (b), ratios are computed from the reported CO and NO_x emission factors, except for Adams et al.³⁷, where they are the inverse of the reported NO_x/CO emission ratios. GFAS reports NO_x as NO mass (main text, Section 2.7).

<i>(a) Top-down / inventory emissions</i>				
Study	Fire or region (period)	Satellite data and method	Inventory	Ratio
This study	Biobío, Chile (18 Jan 2026)	TROPOMI CO (cross-sectional flux) and NO ₂ (EMG)	GFAS v1.4.2	CO 21 (overpass hour), 4.1 (local-day mean); NO _x 2.4, 0.48
Griffin et al. ¹⁵	Global (2019)	TROPOMI-derived CO emission coefficients × GFAS fire radiative energy	GFAS; GFED v4.1; FINN v2.5	CO 0.80*; 0.71*; 0.50*
Naus et al. ²⁸	Amazon (2003–2018 mean)	MOPITT CO, TM5-4D-Var inversion	GFAS v1.2; FINN v1.5	CO 1.5 (2.3 in 2015); 1.2
Nguyen et al. ²⁴	Northern / southern Hemisphere Africa (2004–2019 mean)	SEVIRI FRP × TROPOMI-derived CO emission coefficients	GFED4.1s	CO 1.25* / 0.97*
van der Velde et al. ³⁰	Southeast Australia (Nov 2019–Jan 2020)	Satellite CO, Bayesian inversion	Five fire inventories	CO ₂ >2
Byrne et al. ⁴⁰	Canada (May–Sep 2023)	TROPOMI CO inversions	Mean of GFED4.1s, GFAS v1.2, QFED v2.6r1	Carbon (CO ₂ + CO) 1.4*
Marais et al. ²⁶	Subtropical southern Africa (Jun–Oct 2019)	TROPOMI NO ₂ , GEOS-Chem mass-balance inversion	GFAS v1.2; GFED v4s and FINN v2.5	NO _x 1.3*; 0.40–0.43*
<i>(b) CO:NO_x emission mass ratio</i>				
Source	Fuel or fire	Basis	CO:NO _x	
This study	Plantation fire, Biobío, Chile	TROPOMI, top-down	260 (170 with NO _x as NO ₂)	
Kaiser et al. ³⁸	Extratropical forest; savanna	Emission factors used by GFAS	31; 29	
Andreae ⁴¹	Temperate forest; boreal forest; savanna and grassland	Emission-factor compilation	38; 103; 28	
Akagi et al. ²³	Temperate forest; extratropical forest; savanna	Emission-factor compilation	35; 109; 16	
Wan et al. ³¹	Temperate forest, southeastern Australia	TROPOMI CO and NO ₂	90 (NO _x basis not stated)	
Adams et al. ³⁷	Horse River wildfire, Canada (May 2016)	IASI CO and OMI NO ₂	100 (GFAS v1.2: 30)	
Cereceda-Balic et al. ³³	<i>P. radiata</i> ; <i>E. globulus</i> wood shavings	Laboratory combustion chamber	120; 67 (NO _x basis not stated)	

Table S3: Satellite-based fire emission estimates compared with bottom-up inventories, and CO:NO_x emission mass ratios. (a) Ratio of top-down to inventory emissions. (b) CO:NO_x emission mass ratio, with NO_x as NO mass unless noted.