

Supplement of: Attributing stratosphere-troposphere mass exchange to tropopause folds: a 45-year trajectory-based climatology and trend analysis in ERA5

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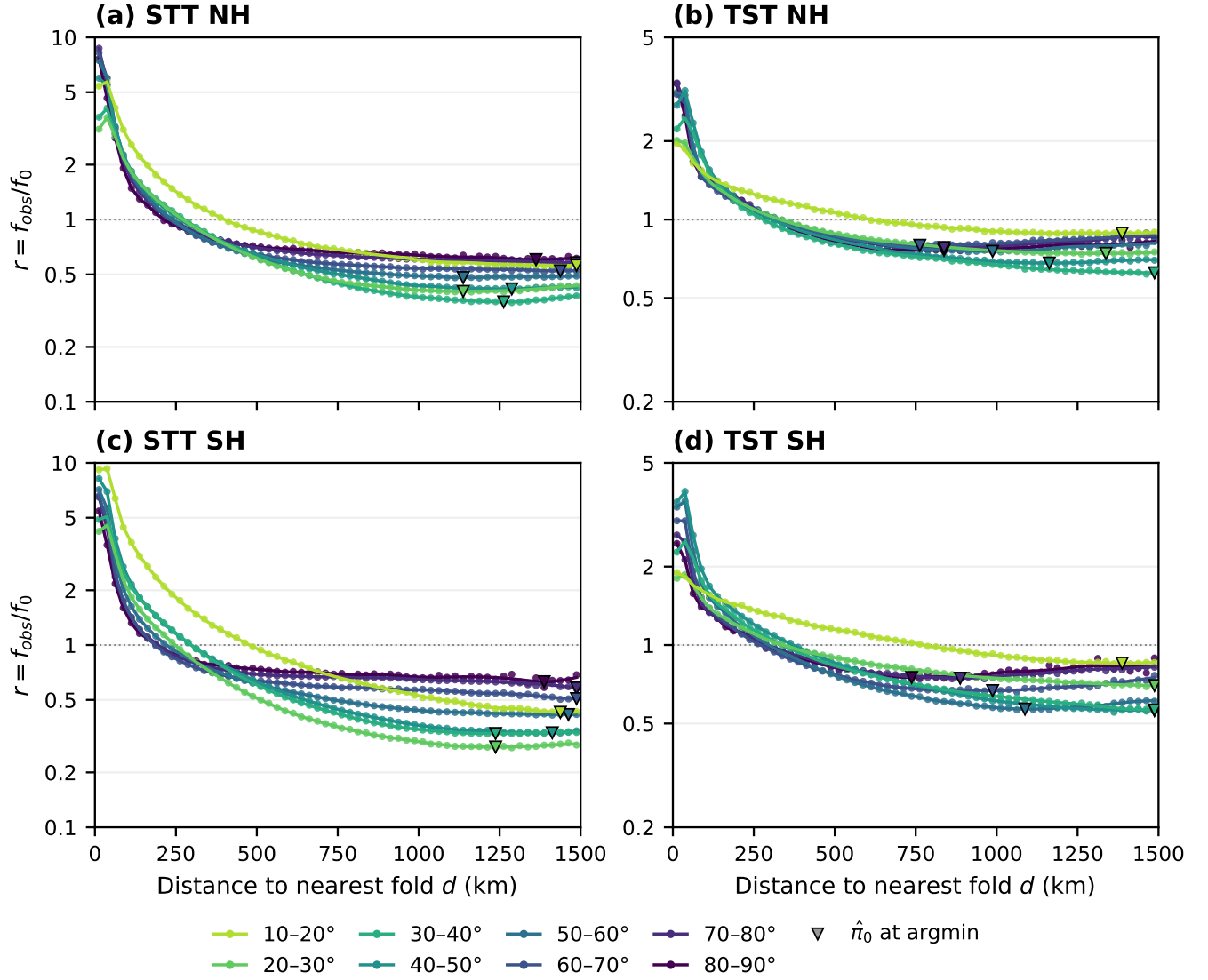


Figure S1. The density ratio $r(d, \phi) = f_{obs}/f_0$ estimated at each distance bin (colored dots) and fitted function $r_{fit}(d, \phi)$ (colored solid line) as a function of the distance to the nearest fold d , shown separately for each 10-degree latitude band, for (a) NH STT, (b) NH TST, (c) SH STT, and (d) SH TST. The one-dimensional binomial P-spline, fitted to $\log r$ as a function of $\sqrt{d}$, was used to produce $r_{fit}(d, \phi)$. Triangles indicate the minimums of $r_{fit}(d, \phi)$, which is used to estimate the null fraction $\hat{\pi}_0$.

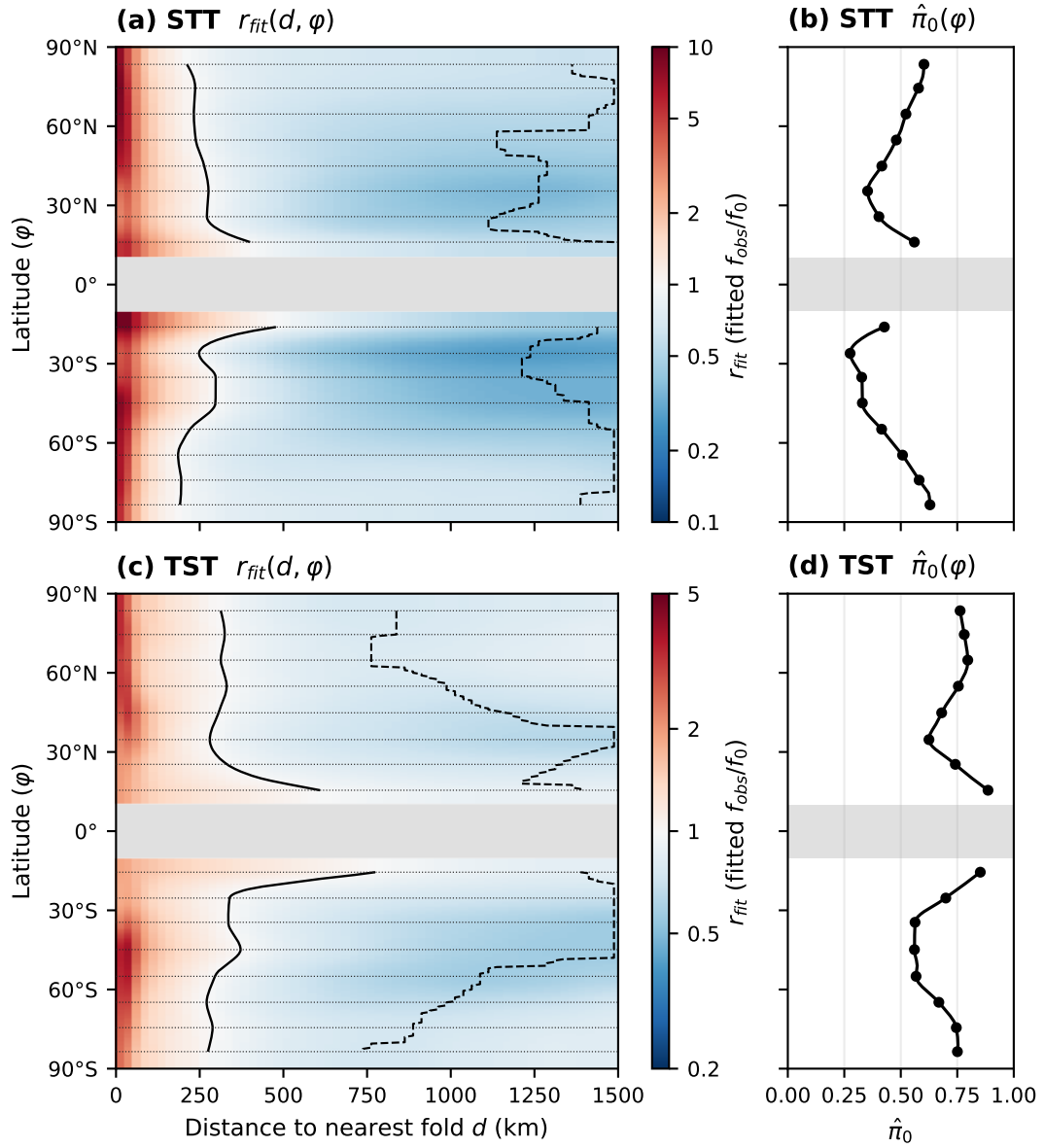


Figure S2. The smooth two-dimensional surface $r_{fit}(d, \phi)$ (shading), built by 1-D binomial P-spline fitting along d and PCHIP interpolation in latitude, for (a) STT and (c) TST. Dotted horizontal lines mark the crossing-count-weighted mean latitude of each 10-degree band, at which the band fits are placed for the interpolation in latitude, the solid black contour is $r_{fit} = 1$, and the dashed black line marks the distance at which r_{fit} is minimized at each latitude. The gray band denotes $|\phi| < 10^\circ$, which is excluded from the analysis. Panels (b) and (d) show the resulting estimated null fraction $\hat{\pi}_0(\phi)$ for STT and TST, respectively.

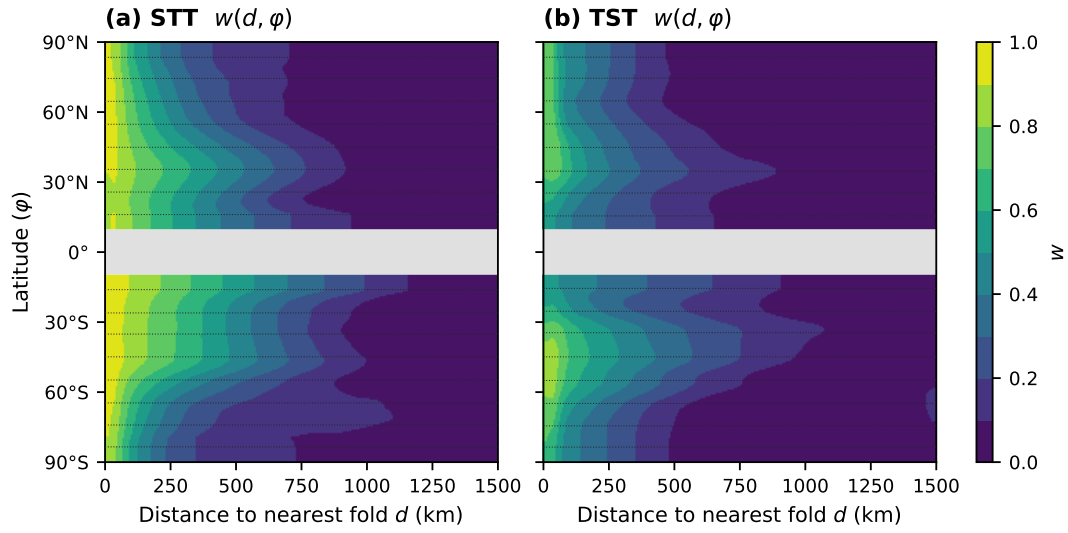


Figure S3. The weight $w(d, \phi) = 1 - \text{lfd}r(d, \phi)$, i.e. the estimated probability that a crossing event at distance d from the nearest fold and latitude ϕ belongs to the nonnull (fold-associated) population, for (a) STT and (b) TST. The weight is derived from the smooth surface $r_{fit}(d, \phi)$ of Fig. S2 and is the quantity applied to each trajectory's mass flux to obtain the fold-associated transport. Crossings with no fold within 1500 km are assigned $w = 0$.

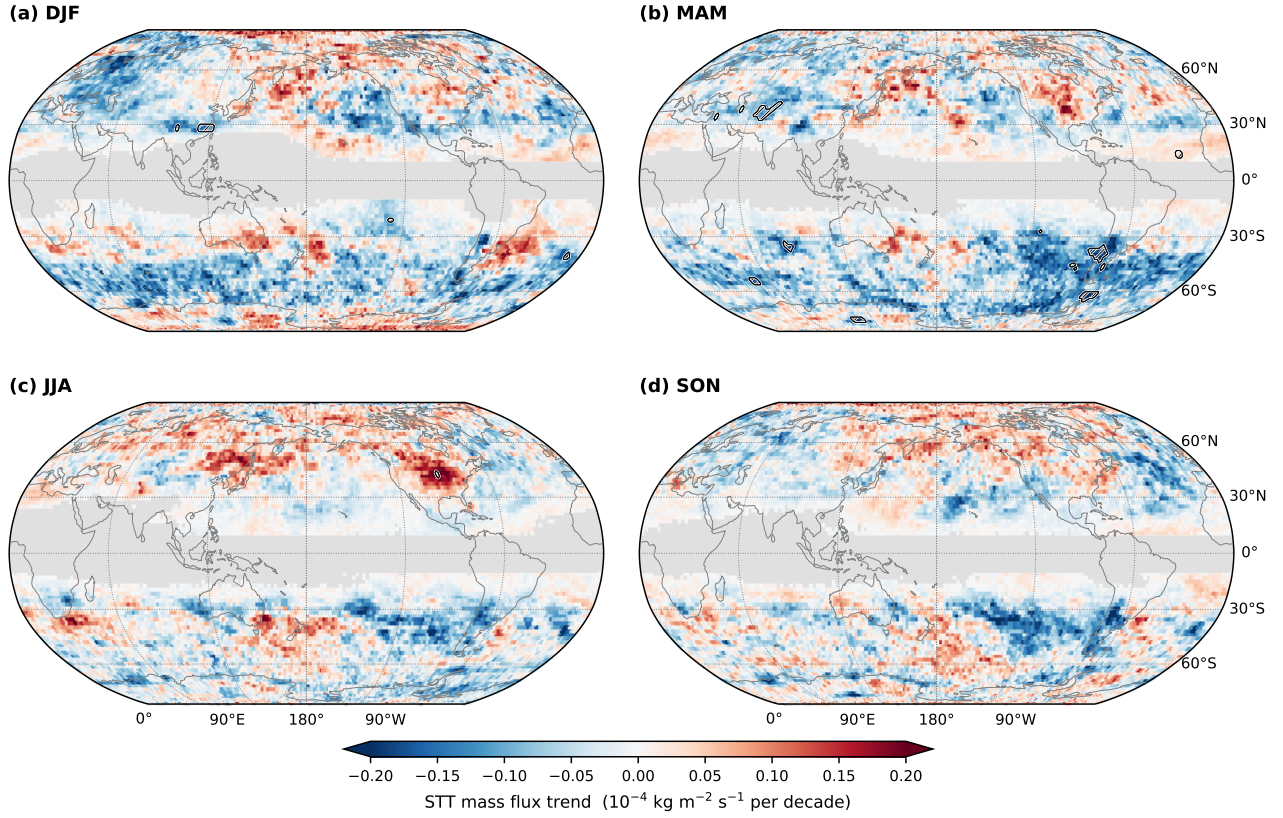


Figure S4. Trends of the seasonal mean STT mass flux over 1981–2024 (colors, in $10^{-4} \text{ kg m}^{-2} \text{ s}^{-1}$ per decade) for (a) DJF, (b) MAM, (c) JJA, and (d) SON, on the 2° grid of the main-text flux maps; grid boxes with non-zero flux in fewer than 40 of the 44 years are excluded. Hatched regions pass the Benjamini–Hochberg FDR criterion at $\alpha_{\text{FDR}} = 0.10$, defined as in the main text.