

The Southern Hemisphere Subtropical Transport Barrier: Structure, Variability, and Long-Term Trends

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The tropical stratosphere is a key and sensitive atmospheric region, driving large-scale circulation and controlling the distribution of constituents such as ozone and aerosols. These compounds play crucial role, such as regulating the climate, structuring the atmosphere, or protecting against UV radiation.

It forms a reservoir bounded by subtropical transport barriers - STB (Fig. 1), characterized by sharp meridional gradients of potential vorticity (PV) and chemical species [1]. STBs limit meridional exchanges between the tropics and mid-latitudes. Tropical air masses thus remain partly isolated, with a composition distinct from that of mid-latitude air. Despite their important role, STBs remain insufficiently characterized [2].

This study analyzes the Southern Hemisphere STB over 1940–2024, using **daily PV fields** from the ERA5 reanalysis across seven isentropic levels (395–850 K).

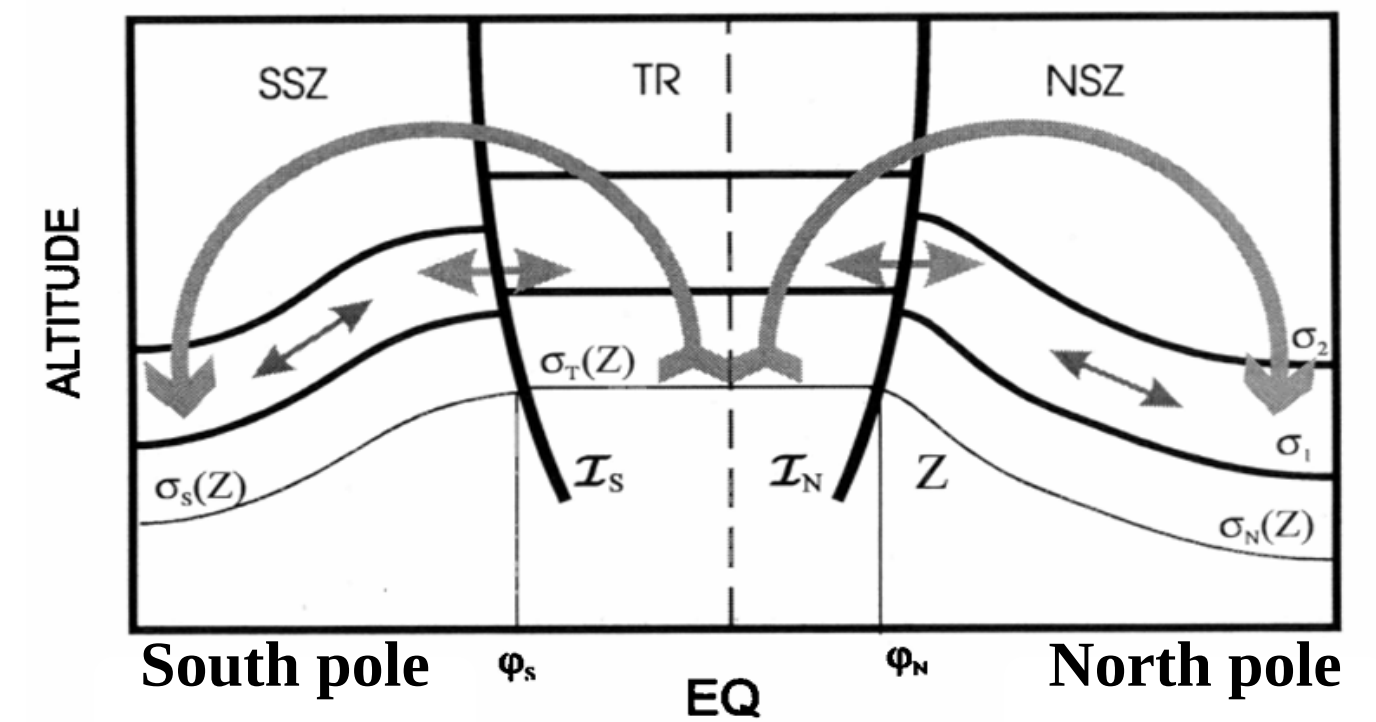


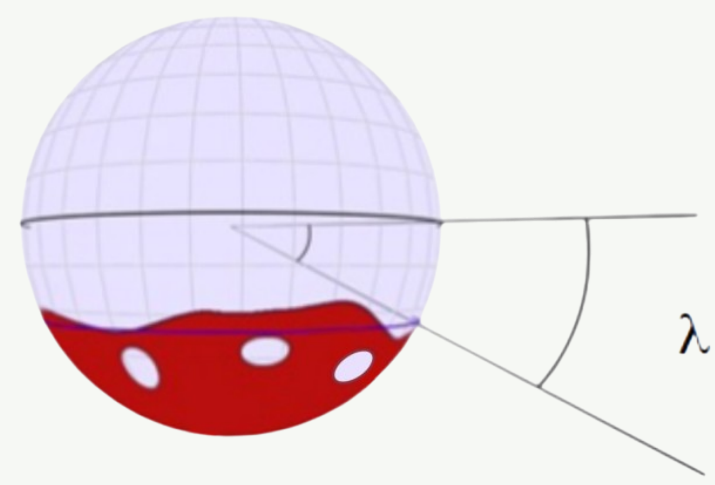
Fig. 1. The "leaky pipe" model, from Neu et Plumb, 1999 [3]

STB detection

STBs are identified as **maxima in the meridional gradient of isentropic PV (PVi)**, computed in area coordinates [4] (from ERA5) and using isentropic levels (i.e. potential temperature θ) as vertical coordinates [1].

$$PV_i = -g \cdot \frac{\partial \theta}{\partial p} \cdot (f + \xi \theta) \quad \text{Potential Temperature gradient in pressure coordinates}$$

Absolute vorticity (= relative vorticity $\xi \theta$ + Coriolis parameter f)



The **DyBaL algorithm** [1, 2] detects the maximum PV gradient from a PVi map at fixed θ , yielding the corresponding **equivalent latitude (λ)** and **PV threshold**. The **intensity** is estimated by the prominence of the peak.

Fig. 2. Area coordinates and equivalent latitude (λ). Source: [1]

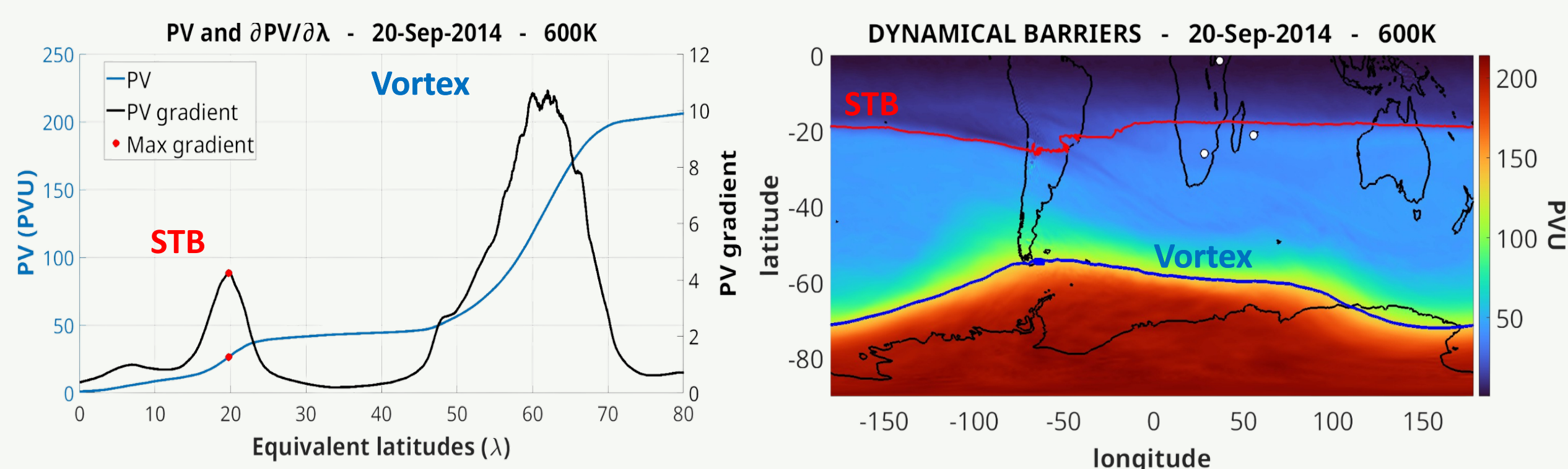


Fig. 3. Exp. of $|PV|$ and PV gradient curves as a function of equivalent latitude ($\delta PV/\delta \lambda$)

Fig. 4. $|PV|$ map with corresponding barriers

Variability & trends

The **Trend-Run algorithm** [5] is a multiple linear regression (MLR) model that decomposes a time series into a set of weighted explanatory variables (the **forcings**), a **linear trend**, and a **residual term**.

Forcings are selected **a priori**. Here, Trend-Run is applied to **monthly means** of the daily DyBaL-derived time series, over 1953–2021, a period constrained by forcing availability.

Equation used here:

$$Y(t) = \alpha_0 + \alpha_1 t + \alpha_2 AO(t) + \alpha_3 SAO(t) + \alpha_4 QBO_A(t) + \alpha_5 QBO_B(t) + \alpha_6 DMI(t) + \alpha_7 Ni\tilde{no}(t) + \alpha_8 SF(t) + \epsilon(t)$$

Y(t)	Geophysical signal, as a function of time
t	Time (months)
α_i	Weighting coefficients (α_0 : constant; α_1 : trend)
AO	Annual Oscillation
SAO	Semi-Annual Oscillation
$QBO_{A,B}$	Two components of the Quasi-Biennial Oscillation (from PCA)
DMI	Dipole Mode Index (Indian Ocean Dipole)
Niño	El Niño–Southern Oscillation
SF	Solar flux at 10.7 cm
ϵ	residual term

Tab. 1. Equation terms and selected forcings

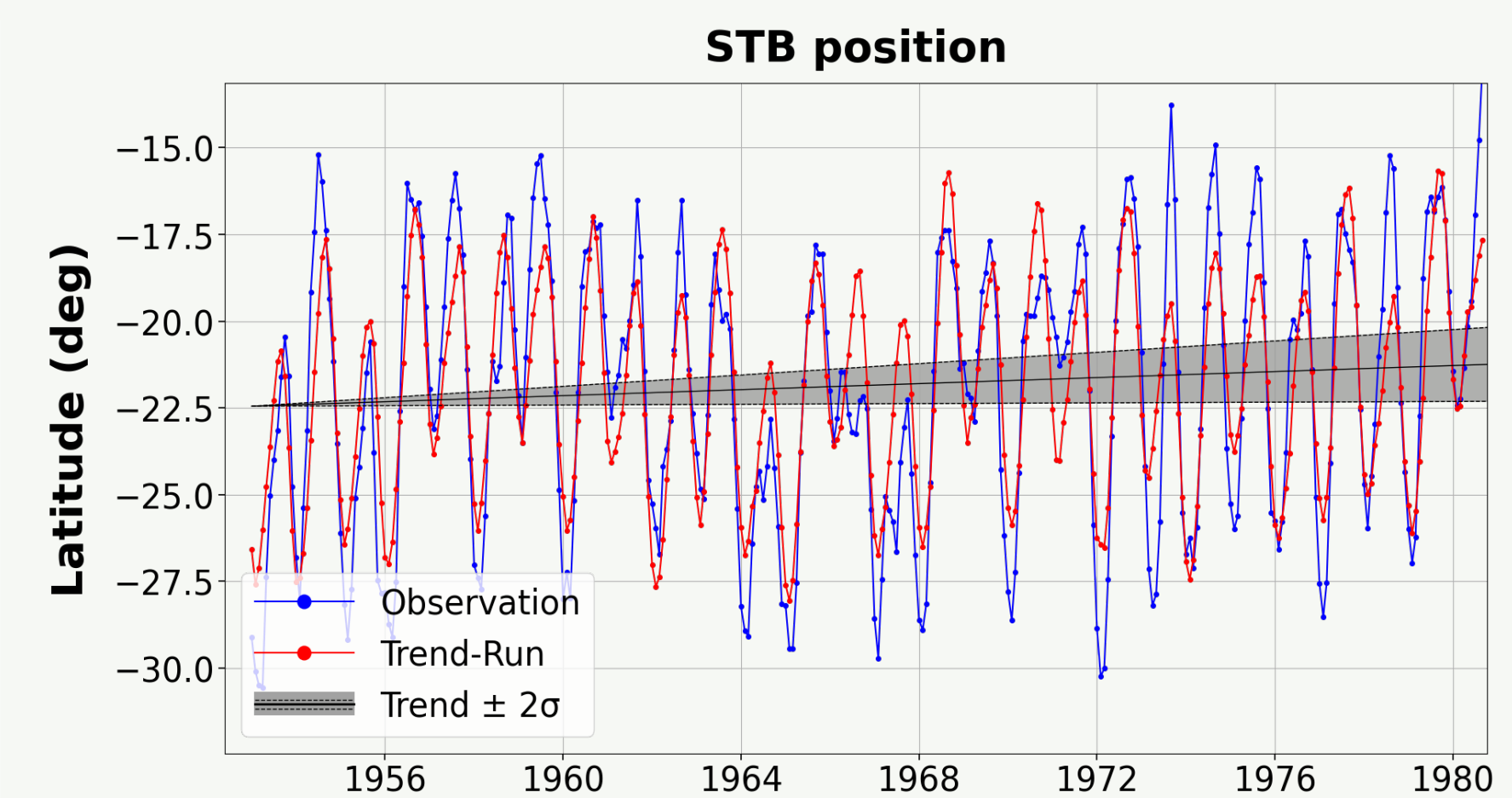


Fig. 5. Example of Trend-Run regression applied to the STB position at 475 K, over 1953–2021 (zoomed on the first decades). $R^2 = 66\%$, trend = $0.43^\circ \pm 0.38^\circ$ per decade, 2σ .

Seven isentropic levels studied: 395, 430, 475, 530, 600, 700 and 850 K (~17.5–31 km in the subtropics)

Results: **forcing contributions** (seasonal cycle and QBO dominate) $\rightarrow$ **seasonal analysis** $\rightarrow$ **QBO-phase analysis** $\rightarrow$ **trend analysis**. Focus on the **600 K level** (~24 km), considered representative.

Isentropic level	STB position							R^2
	850 K	700 K	600 K	530 K	475 K	430 K	395 K	
850 K	6.2	31.7	-3.9	4.0	-3.2	1.5	1.2	52%
700 K	4.6	29.3	-7.4	3.3	-1.7	5.7	0.5	53%
600 K	2.4	39.0	-11.9	-4.7	-1.7	5.7	1.4	67%
530 K	1.3	41.8	-4.5	-12.9	1.7	5.4	1.0	69%
475 K	3.8	37.6	4.2	-10.8	1.5	3.8	4.2	66%
430 K	7.7	20.4	5.5	-6.2	-1.8	2.3	2.1	46%
395 K	6.1	5.3	2.5	-1.4	-1.7	0.6	-1.8	20%
Isentropic level	STB intensity							R^2
	850 K	700 K	600 K	530 K	475 K	430 K	395 K	
850 K	9.5	22.2	-8.9	13.5	-0.8	-0.8	1.9	58%
700 K	7.6	25.5	-23.4	-4.2	-5.1	2.1	2.4	70%
600 K	4.5	18.3	-19.6	-22.5	-3.2	1.1	2.3	71%
530 K	2.3	7.8	-7.3	-53.3	-0.7	-1.6	-0.1	73%
475 K	4.9	0.7	15.2	-36.1	0.2	-1.3	-3.4	62%
430 K	6.3	5.4	13.9	-7.9	1.6	-3.3	-3.6	42%
395 K	11.5	28.1	4.0	-3.4	4.4	0.0	-3.8	55%

SAO AO QBO A QBO B DMI Niño SF

Contribution (%)

Fig. 6. Relative contribution (%) of each forcing to the regression of STB position (top) and intensity (bottom), over 1953–2021 (bold: significant at 2σ). The AO and the QBO contribute most: the AO dominates the STB position, whereas the QBO dominates its intensity.

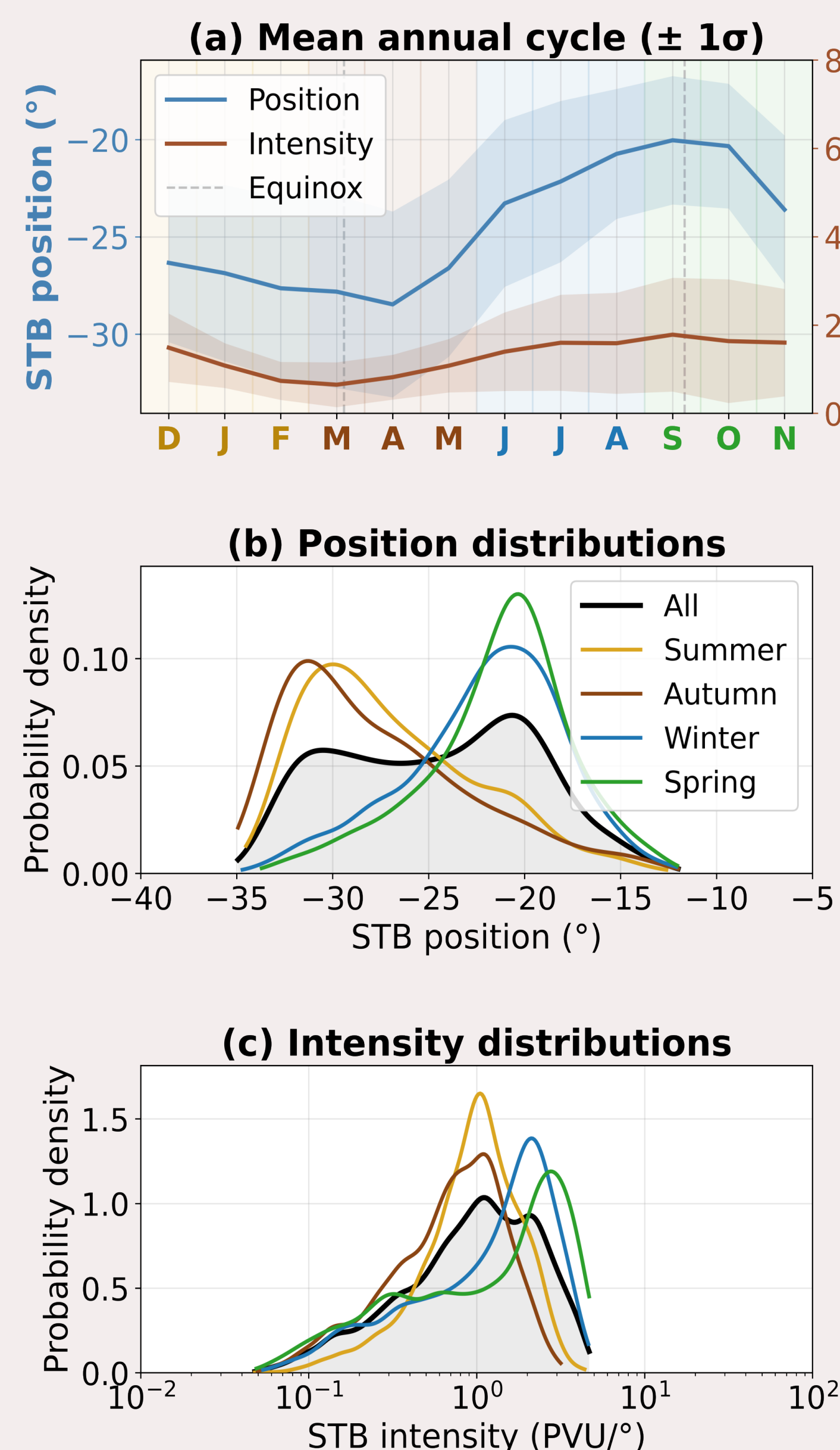


Fig. 7. Seasonal variability of the STB at 600 K (1940–2024): (a) mean annual cycle ($\pm 1\sigma$); (b, c) daily distributions of STB position and intensity by austral season. The STB lies preferentially poleward in austral summer–autumn and equatorward in winter–spring, when it is also stronger.

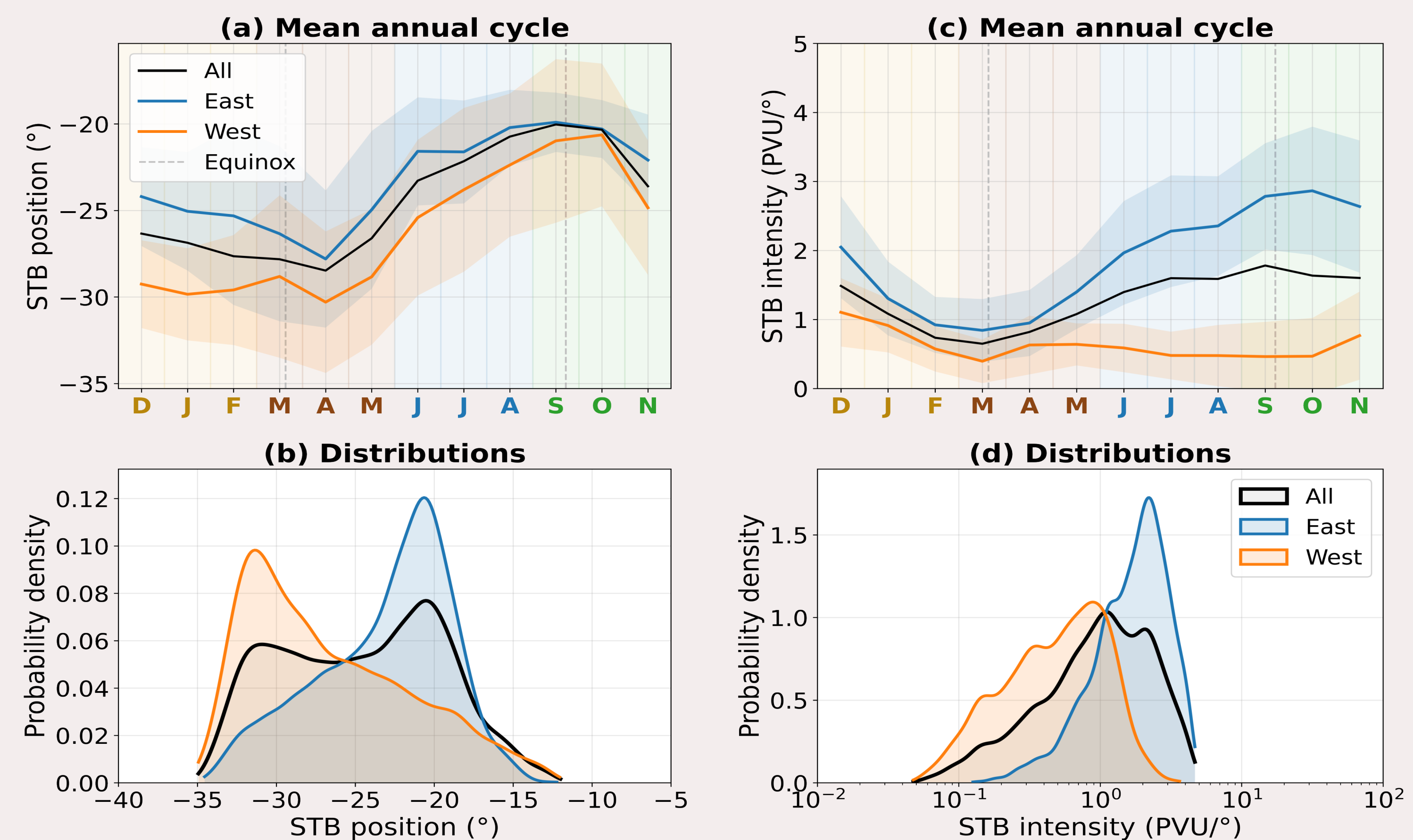


Fig. 8. STB position and intensity at 600 K by QBO phase at 30 hPa. Period: 1953–2021. (a, c): mean annual cycles ($\pm 1\sigma$). (b, d): corresponding daily distributions. The QBO leaves a strong imprint on the STB intensity, and also contributes to the bimodal distribution of its position.

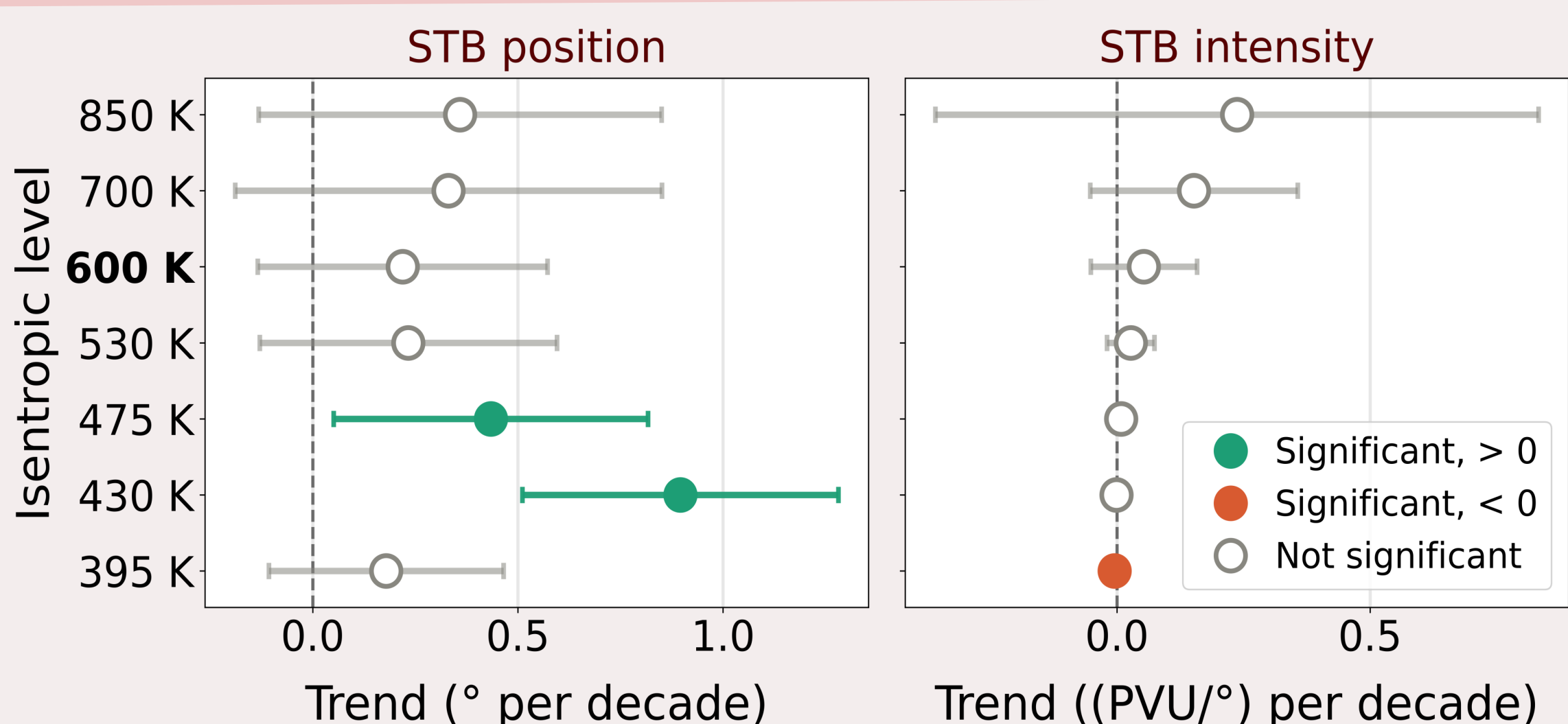


Fig. 9. Absolute decadal trends ($\pm 2\sigma$) in STB position (left) and intensity (right), over 1953–2021. The STB shifts equatorward at all levels (significantly at 430–475 K), with a slight intensification (not significant at 2σ).

Main points

- A long-term (85 years) analysis of STB characteristics and trends.
- The annual cycle and the QBO are the dominant forcings of STB variability.
- Long-term linear trends: an equatorward shift (significant at 430–475 K) and a slight, non-significant intensification.

Ongoing/Outlook

- Seasonal and QBO-phase-dependent trends, and non-linear trend analysis.
- Extension to the polar vortex.
- Investigation of the mechanisms driving STB variability and trends, and their implications for the transport of ozone and aerosols.

Acknowledgements

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