

Is Brewer-Dobson Circulation Accelerating? An Investigation using Measurements of Tropical Stratospheric Upwelling

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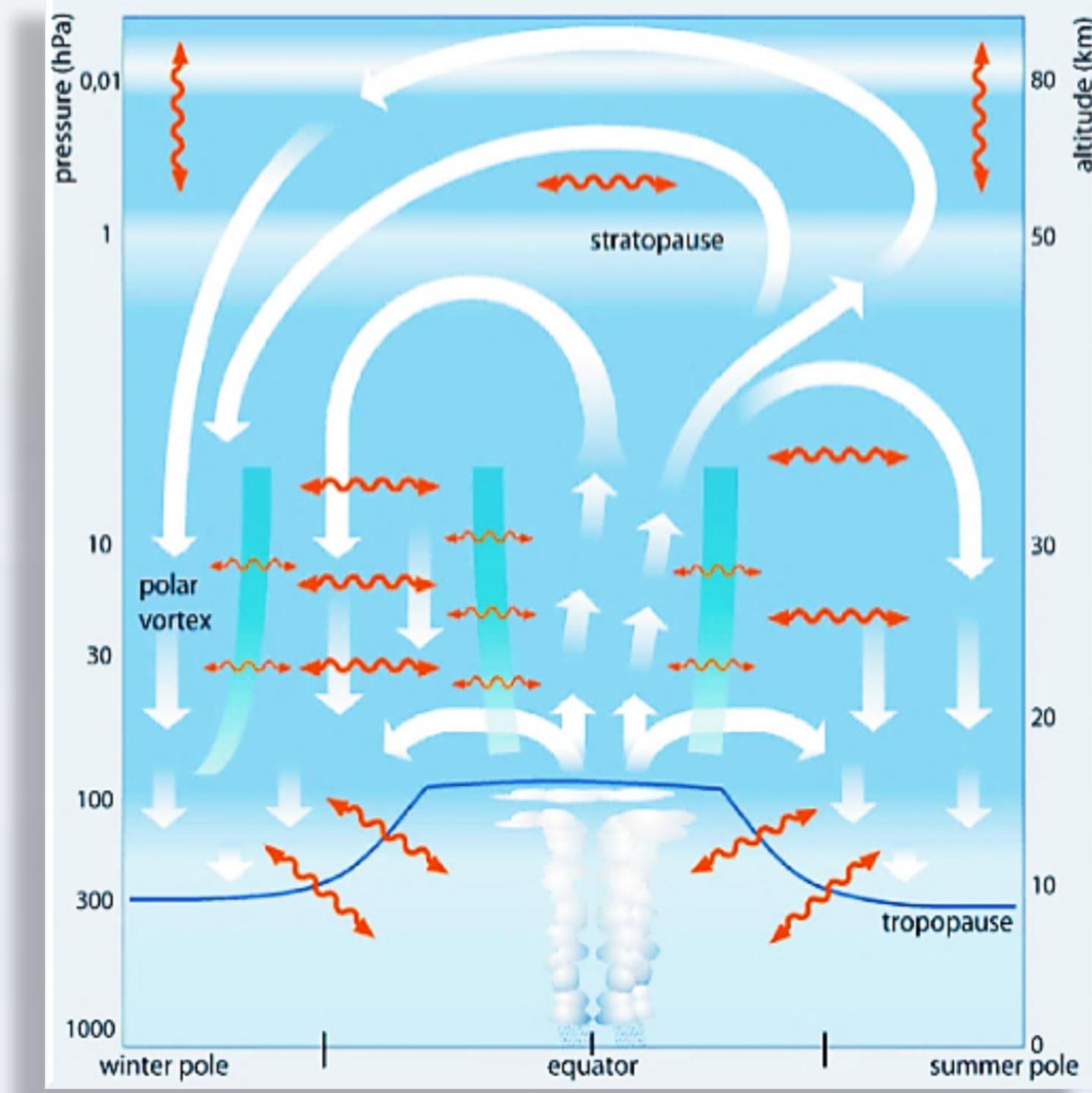
Abstract

There has been a debate on long-term variability of Brewer–Dobson circulation (BDC) using variety of metrics. Though a majority of the studies report an acceleration of BDC, the estimated rates differ largely. The discrepancies between climate models and observations were also reported. Investigation on long-term trend of BDC intensity using observations is the need of the hour for constraining climate models. Using stratospheric water vapour (H₂O) as a dynamically driven tracer of large-scale upwelling, the present Study investigates the intensity of the tropical branch of BDC. Apart from using the conventional metrics such as residual circulation, the rate of upwelling of tropical air in the lower stratosphere is estimated using H₂O profiles. The time evolution of H₂O at two pressure levels is employed to estimate the upwelling intensity using cross correlation analysis. The dynamical fields from the MERRA-2 reanalysis with H₂O measurements from the Microwave Limb Sounder (MLS) on-board AURA satellite are used for the study. A comprehensive analysis is carried out to evaluate the long-term evolution of BDC intensity from the measurements and the implications to the transport of trace gases in the stratosphere are discussed. The findings demonstrate the importance of direct measurements of BDC intensity in terms of upwelling in the lower stratosphere and estimating its long-term evolution.

Why Brewer Dobson Circulation is important?

The predominant meridional overturning circulation in the stratosphere is the Brewer–Dobson Circulation (BDC), which is distinguished by upwelling in the tropical lower stratosphere, and downwelling at middle and high latitudes, poleward transfer, and. The distribution, residence time, and chemical evolution of trace gases and aerosols in the stratosphere are all fundamentally regulated by BDC.

- **Stratospheric ozone distribution:** BDC regulates the movement of ozone and its precursors.
- **Trace-gas transport:** It links transport dynamics with stratospheric chemistry by controlling the meridional transport of long-lived molecules including N₂O, CH₄, and halogenated chemicals.
- **Climate coupling:** Changes in BDC have an impact on the stratosphere's thermal structure and radiative balance.
- **Age of Air (AoA):** BDC determines the average age of stratospheric air, a crucial indicator of mixing and transport efficiency.
- Stratosphere-Troposphere Exchange
- Model evaluation
- Reaction to climate forcing

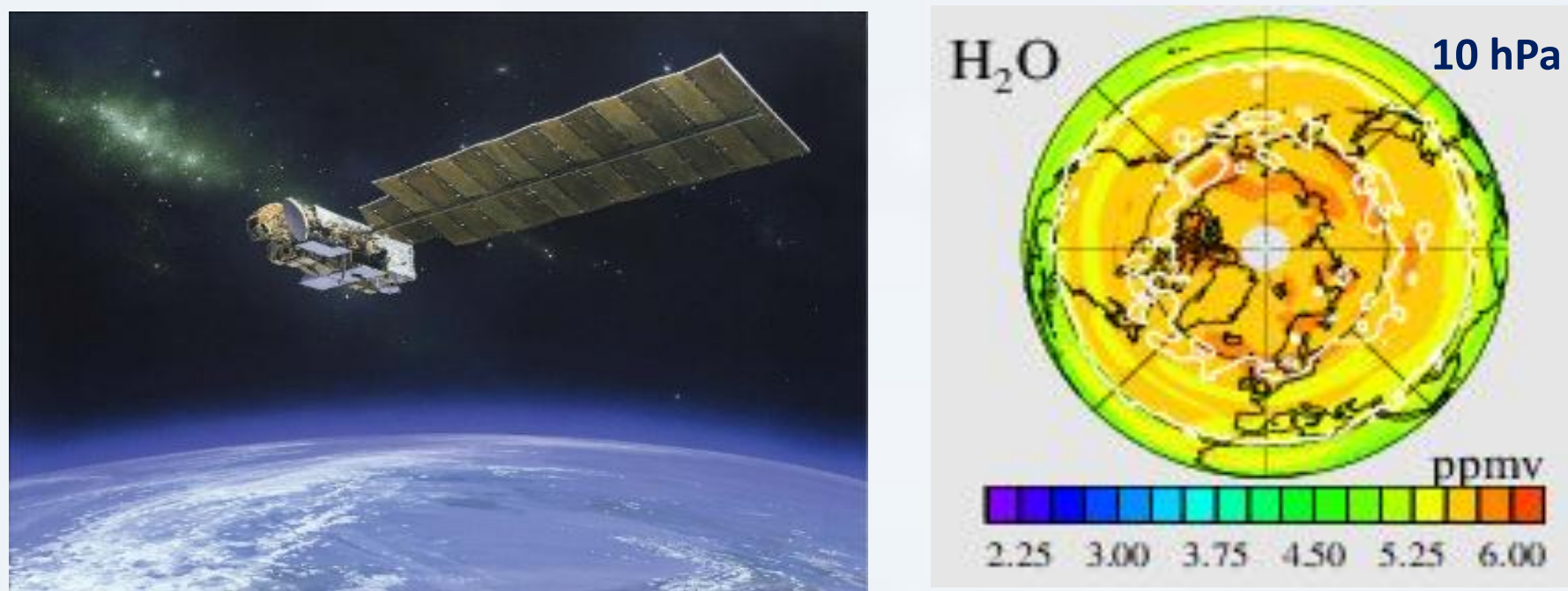


What do we already know?

Butchart 2014	Depending on the greenhouse gas scenario considered, model projections are reporting 2.0–3.2% per decade increase in the strength of the BDC especially the deep branch of the circulation.
Minschwaner et al 2016	A small decreasing linear trend (~6%/decade) in mean vertical velocity is observed from 2005 to 2014 but the authors concluded that the observational record was too short and ENSO-contaminated to establish a significant long-term trend.
Fu et al 2019	Provided observational evidence that the annual mean BDC accelerated for 1980–1999 but decelerated for 2000–2018, with the changes largely driven by the Southern Hemisphere (SH), which might be partly contributed by the effects of ozone depletion healing.
Ploeger et al 2021	ERA5 shows a significantly slower BDC than ERA-Interim, but its shallow and deep branches both accelerate, with the deep branch increasing by ~2.4% decade
Ray et al 2026	Revised in-situ observations show a significant decrease in Northern Hemisphere extratropical mean age since the 1990s, indicating BDC acceleration, with the observed acceleration stronger than model simulations, particularly in the upper stratosphere.

Data & Methodology

❖ Aura-MLS daily measurements of H₂O have been used for the time period 2005-2025.



❖ The time lag was determined using cross-correlation of the tape-recorder signals at different altitudes (one year time series with one day step), with the lag corresponding to the maximum correlation taken as the tracer propagation time.

$$\omega = \frac{\Delta z}{\tau_{max}}$$

❖ The mean residual vertical wind ($\bar{w}^*$) has been calculated using Transformed Eulerian Mean (TEM) framework:

$$\bar{w}^* = \bar{w} + \frac{1}{\rho_0} \frac{\partial}{\partial z} (\rho_0 \overline{v' \theta'}) / \frac{\partial \bar{\theta}}{\partial z}$$

References

1. Schoeberl et al. (2008): Schoeberl, M.R., Douglass, A.R., Stolarski, R.S., Pawson, S., Strahan, S.E. and Read, W., 2008. Comparison of lower stratospheric tropical mean vertical velocities. Journal of Geophysical Research: Atmospheres, 113(D24).
2. Flury et al. (2012): Flury, T., Wu, D.L. and Read, W.G., 2012. Correlation among cirrus ice content, water vapor and temperature in the TTL as observed by CALIPSO and Aura/MLS. Atmospheric Chemistry and Physics, 12(2), pp.683-691.
3. Flury et al. (2013): Flury, T., Wu, D.L. and Read, W.G., 2013. Variability in the speed of the Brewer–Dobson circulation as observed by Aura/MLS. Atmospheric Chemistry and Physics, 13(9), pp.4563-4575.

Results

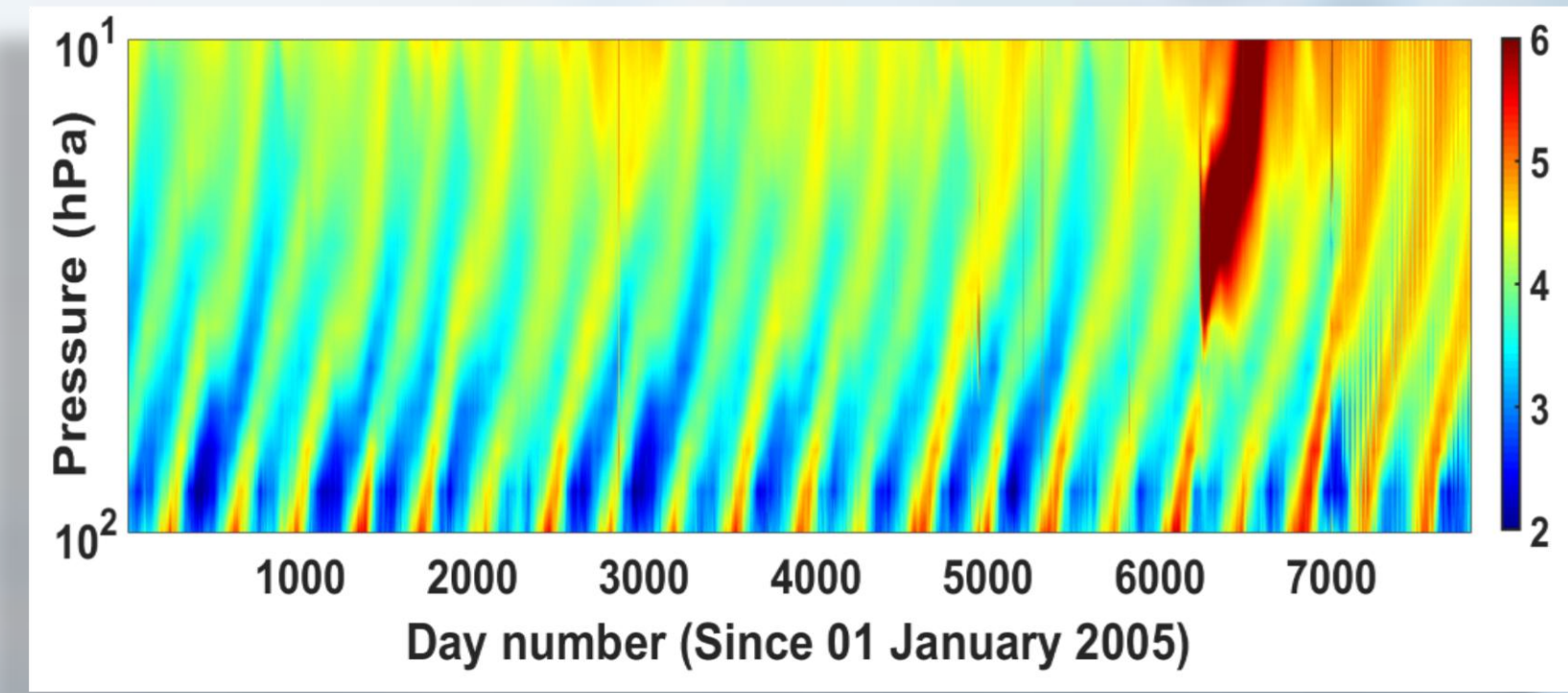


Figure 1. Time–pressure evolution of tropical stratospheric H₂O mixing ratio (ppmv), showing the upward propagation of the seasonal tape-recorder signal with time. The gradual movement of water vapour from lower stratosphere to higher altitude demonstrates the ascending branch of the BDC in the tropical stratosphere.

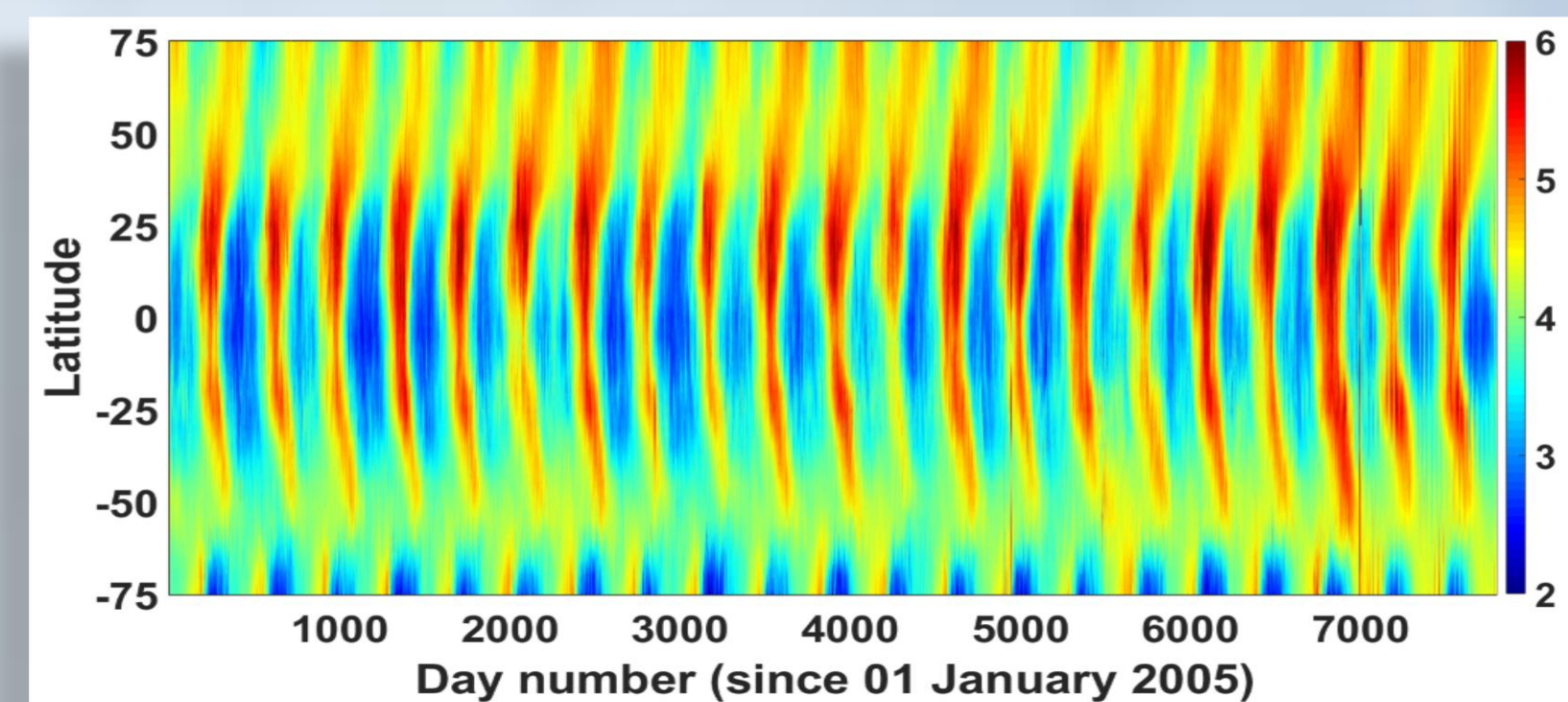


Figure 2. Time–latitude evolution of H₂O mixing ratio (ppmv) at 100 hPa, illustrating the seasonal and latitudinal variability of stratospheric water vapour. The H₂O distribution at 100 hPa shows a clear seasonal cycle with strong latitudinal variation. The tracer signal is strongest in the tropics and propagates toward higher latitudes, indicating transport from the tropical tropopause region toward the extratropics.

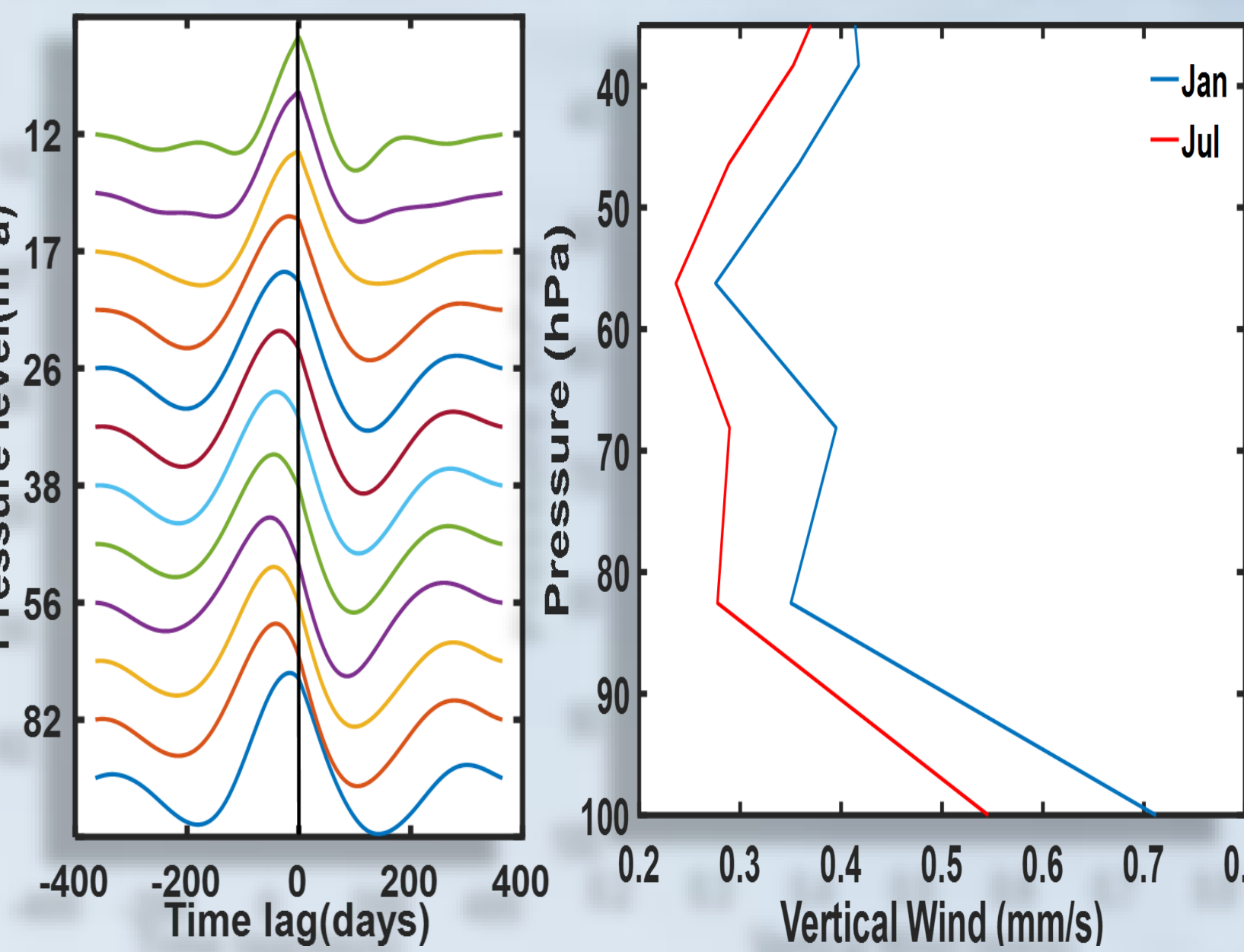


Figure 3. (left panel) Cross-correlation of water vapor time series at two adjacent pressure levels & (right panel) mean profile of Vertical Wind derived from MLS measured Water Vapor as tracer for the month of January and July.

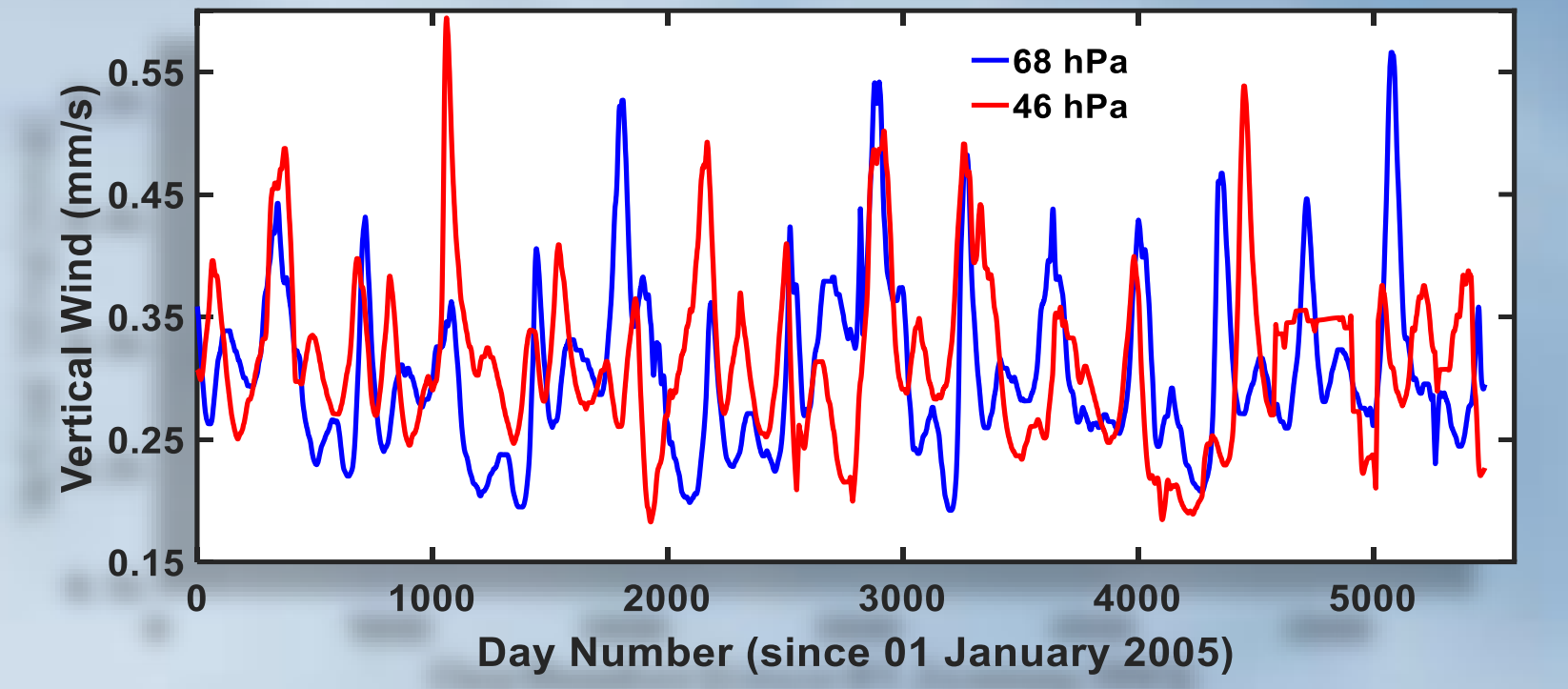


Figure 4. Time series of Vertical Wind derived from MLS measured Water Vapor as tracer at 68 and 46 hPa.

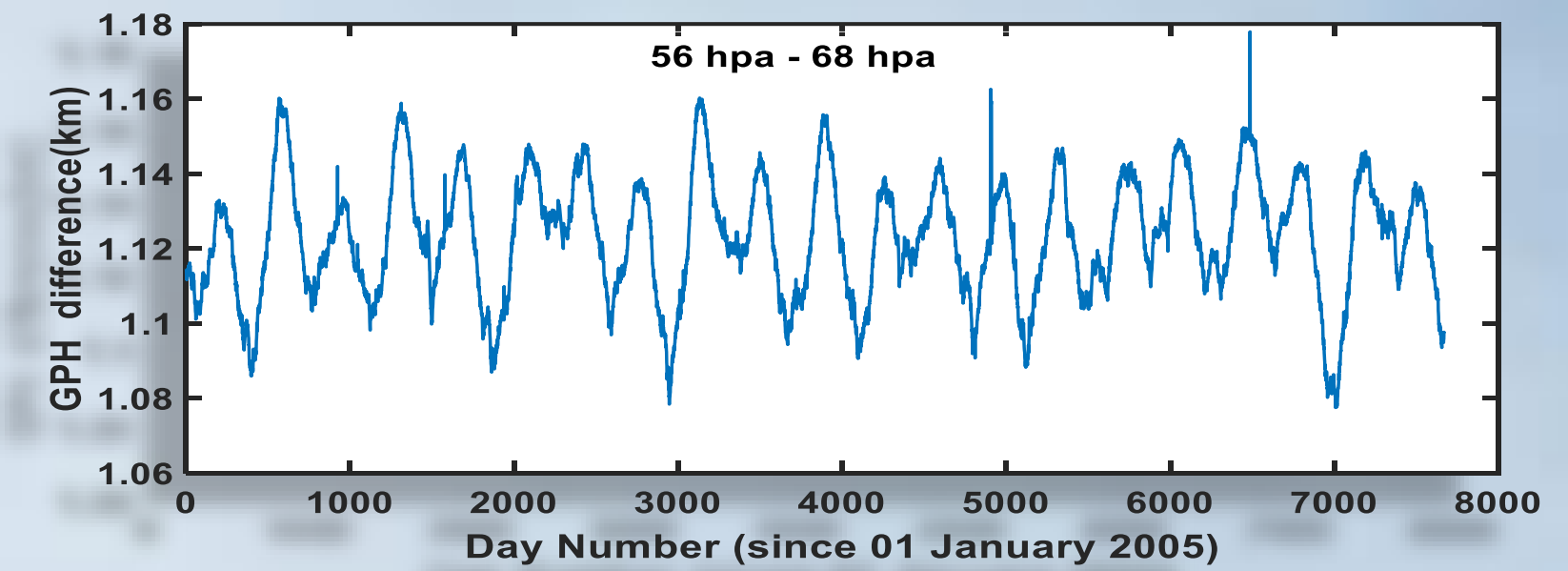


Figure 5. Geopotential Height difference showing no trend

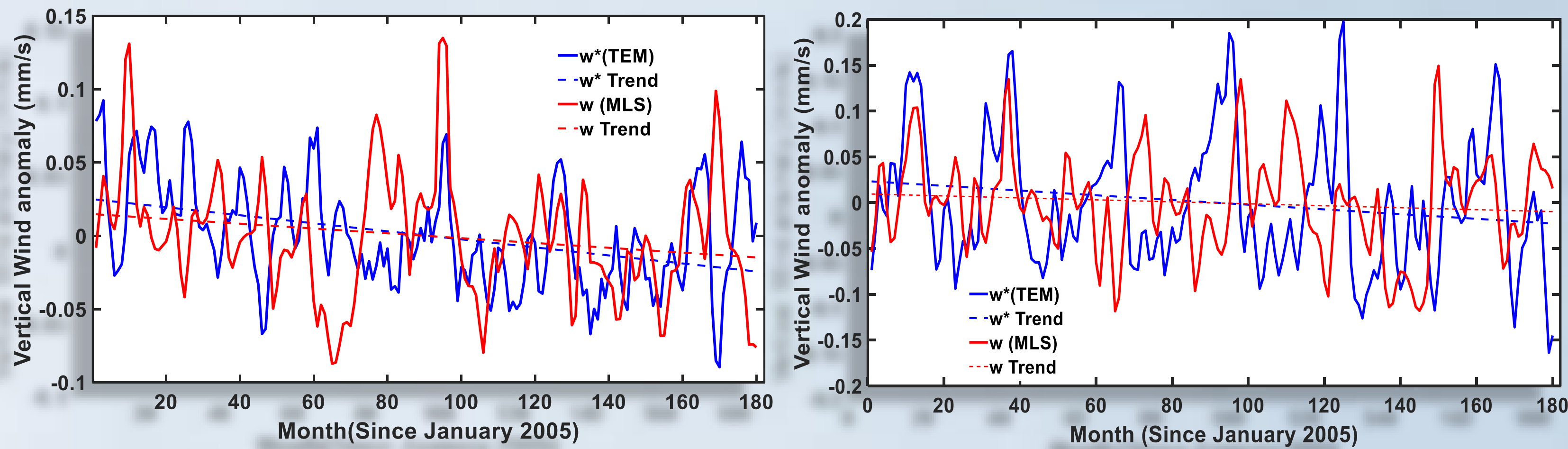


Figure 6. Long term trends in deseasonalized residual vertical winds derived from MERRA-2 reanalysis using TEM framework at 40 hPa and vertical wind speed estimated from MLS water vapor measurements at 82 hPa (left panel; w* Trend: -0.032 mm/s/decade, P value : 0.00 and w_MLS Trend: -0.02 mm/s/decade, P value:0.002) & 46hPa (right panel; w* Trend: -0.033 mm/s/decade, P value : 0.004 and w_MLS Trend: -0.0135 mm/s/decade, P value:0.11).

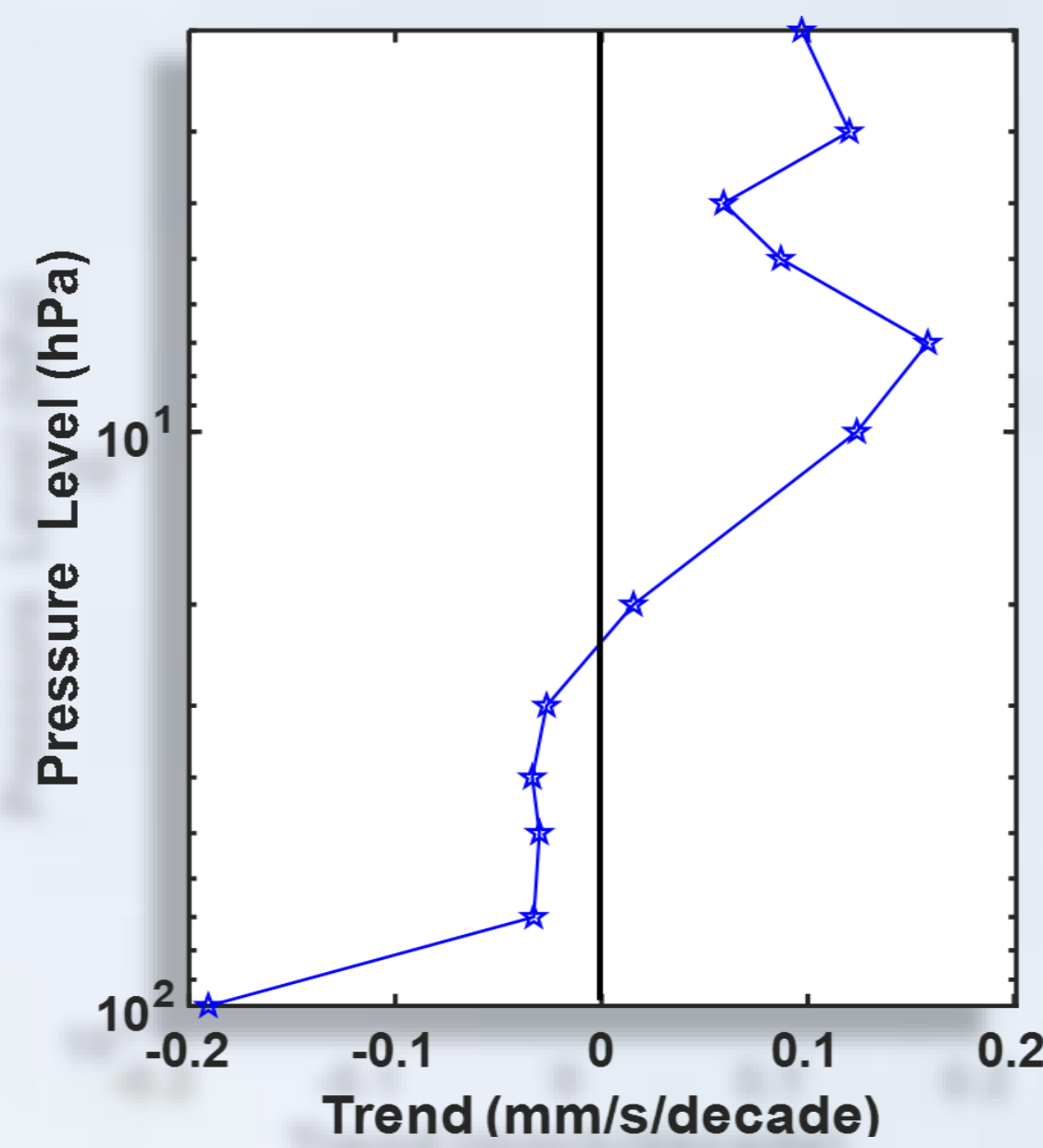
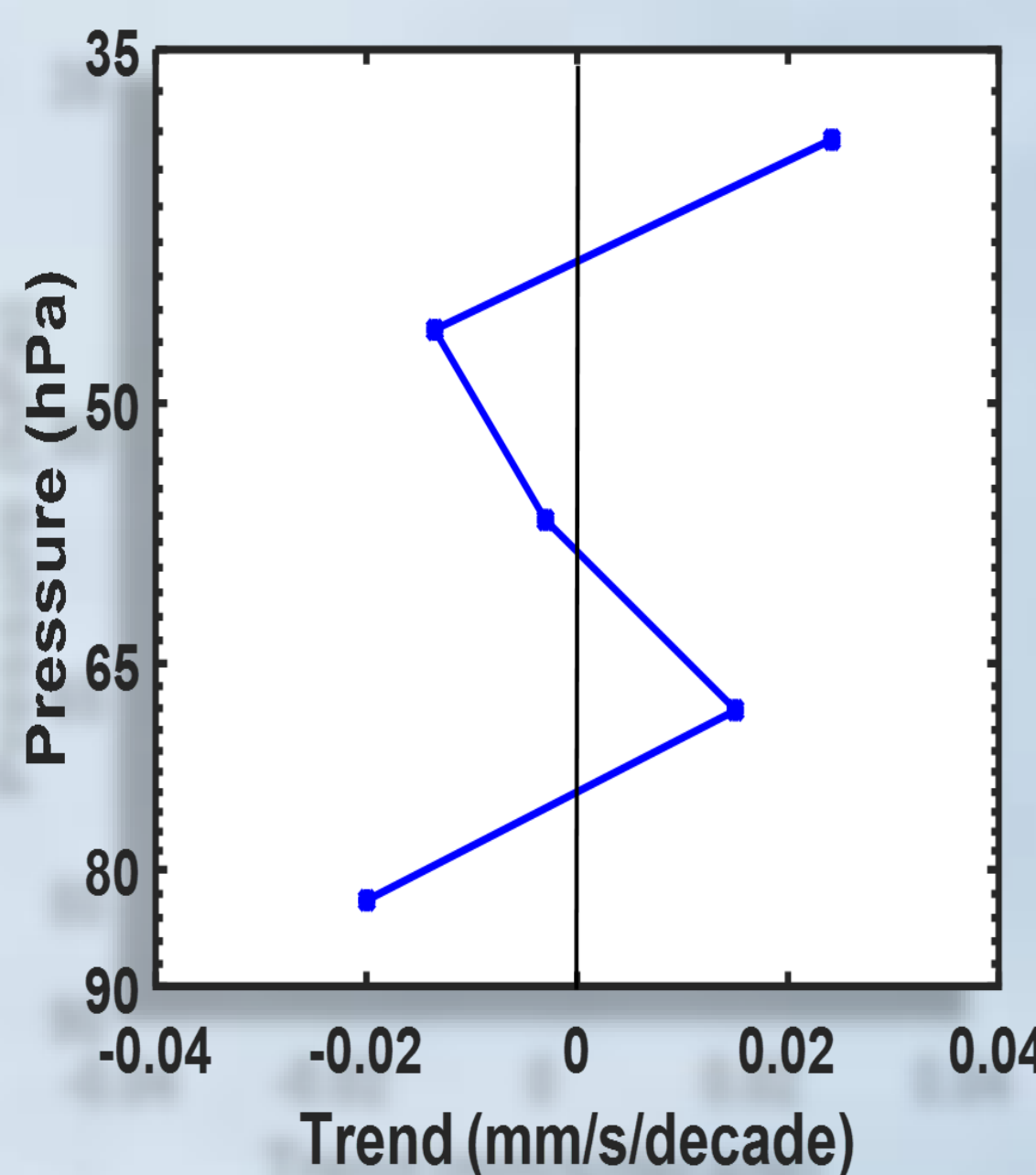


Figure 7. Height Profile of Trend of w* (TEM). The profile show Deceleration below 30 hPa (Shallow Branch) and acceleration above this level (Deep Branch)

Figure 8. Height Profile of Trend of w_MLS water vapor. The profile show Deceleration below 35 hPa (Shallow Branch) and acceleration above this level (Deep Branch) similar like TEM



Findings

- The time series of tropical upwelling generated for the period 2005-2019 in the lower stratosphere using MLS water vapour measurements exhibits substantial variability with pronounced seasonality and inter annual variability
- The deseasonalized anomalies in the upwelling derived from TEM residual vertical velocity using MERRA-2 reanalysis agrees reasonably well with that derived from MLS water vapour measurements. The MLS derived upwelling indicates deceleration of BDC in the lower stratosphere with significant decreasing trends at 82 and 48 hPa levels.
- Interestingly, the residual vertical winds derived from MERRA-2 also show decreasing trends in the lower stratosphere (below 30 hPa) agreeing with the direct observations from MLS. However, there are differences in the estimated magnitudes of trends. The long term trends in residual vertical winds show deceleration of BDC below 30 hPa and acceleration above this pressure level.
- The findings thus demonstrate the importance of direct measurements of BDC intensity in terms of upwelling in the lower stratosphere, estimating its long-term evolution and validating the reanalysis datasets.