Indices of Pacific Walker Circulation strength: trends, correlations and uncertainty

Katarina Kosovelj, Žiga Zaplotnik, Nedjeljka Žagar

December 8, 2022

References

A. J. Clarke and A. Lebedev. Long-Term Changes in the Equatorial Pacific Trade Winds. *Journal of Climate*, 9(5):1020–1029, 1996.

D. G. Wright and K. R. Thompson. Time-Averaged Forms of the Nonlinear Stress Law. *Journal of Physical Oceanography*, 13(2):341 – 345, 1983. doi: 10.1175/1520-0485(1983)013⟨0341:TAFOTN⟩2.0.CO;2. URL https://journals.ametsoc.org/view/journals/phoc/13/2/1520-0485_1983_013_0341_tafotn_2_0_co_2.xml.

Table 1: Trends of normalized indices of annual-mean Pacific Walker circulation strength for different periods shown in Fig. 3 in the main text. The values in parentheses denote the standard error of the trend estimates. Stars denote statistical significance of the trend at 95% confidence using Mann-Kendall test. SST, V_e, L_τ and U_{ave} indices are multiplied by (-1) for easier comparison with other indices. Units in columns denote linear trend ($\pm$ 1 σ) in units yr^{-1}.

PWC index	1960-2020	1970-2020	1980-2020	1990-2020	2000-2020
χ_{max}	0.009 ($\pm$ 0.007)	0.013 ($\pm$ 0.010)*	0.041 ($\pm$ 0.012)*	0.050 ($\pm$ 0.019)*	-0.007($\pm$ 0.026)
SOI	0.003 ($\pm$ 0.007)	-0.005 ($\pm$ 0.009)	0.015 ($\pm$ 0.011)	0.023 ($\pm$ 0.017)	-0.003 ($\pm$ 0.031)
ΔSLP	-0.007 ($\pm$ 0.007)	-0.006 ($\pm$ 0.010)	0.014 ($\pm$ 0.013)	0.020 ($\pm$ 0.019)	-0.020 ($\pm$ 0.030)
ω_{500}	-0.003 ($\pm$ 0.008)	0.003 ($\pm$ 0.011)	0.027 ($\pm$ 0.014)*	0.045 ($\pm$ 0.022)*	-0.017 ($\pm$ 0.030)
ψ_{500}	-0.010 ($\pm$ 0.007)	-0.012 ($\pm$ 0.009)	0.007 ($\pm$ 0.012)	0.022 ($\pm$ 0.017)	-0.003 ($\pm$ 0.031)
-SST	0.006 ($\pm$ 0.007)	0.007 ($\pm$ 0.010)	0.019 ($\pm$ 0.014)	0.026 ($\pm$ 0.019)	-0.014 ($\pm$ 0.029)
-V_e	-0.015 ($\pm$ 0.007)	-0.013 ($\pm$ 0.010)	0.001 ($\pm$ 0.013)	0.013 ($\pm$ 0.020)	-0.016 ($\pm$ 0.032)
Q_{200}	-0.001 ($\pm$ 0.007)	-0.001 ($\pm$ 0.011)	0.024 ($\pm$ 0.015)	0.046 ($\pm$ 0.020)*	0.006 ($\pm$ 0.029)
-L_τ	-0.002($\pm$ 0.007)	0.002 ($\pm$ 0.010)	0.026 ($\pm$ 0.013)*	0.047 ($\pm$ 0.020)*	-0.012 ($\pm$ 0.031)
-U_{ave}	-0.007 ($\pm$ 0.007)	-0.005 ($\pm$ 0.010)	0.021 ($\pm$ 0.014)	0.041 ($\pm$ 0.021)*	-0.016 ($\pm$ 0.032)

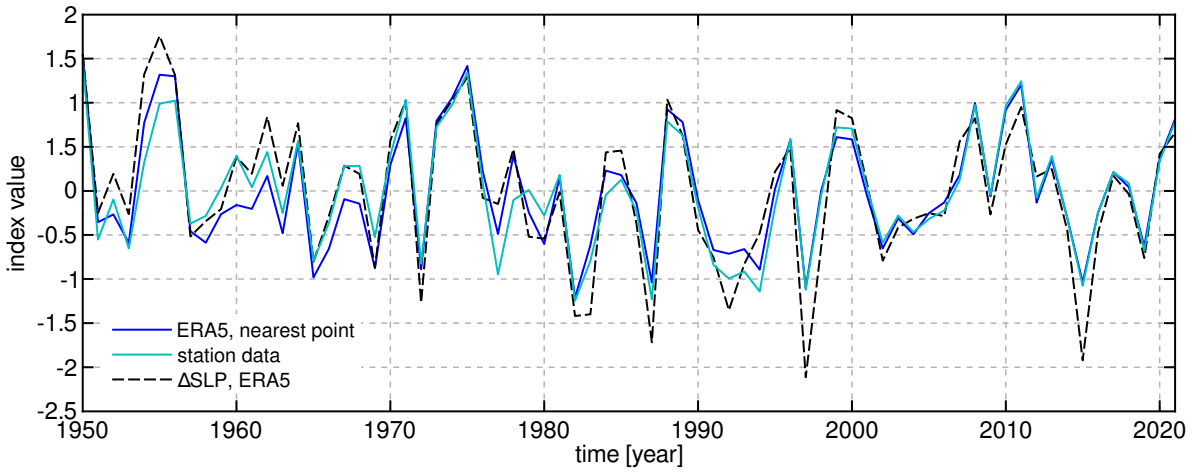

Figure S1: Time series of annual-mean Troup SOI (divided by 10), computed from ERA5 reanalysis using nearest gridpoints to Tahiti and Darwin stations, and NCAR Climate Data Guide station data time series. ΔSLP index computed from ERA5 data is added for comparison. Nearest point method produces almost identical values as bilinear interpolation of surface pressure data to station locations (not shown). The difference decrease significantly in the recent period, most likely due to the steady improvement of reanalysis accuracy when more observations are assimilated.

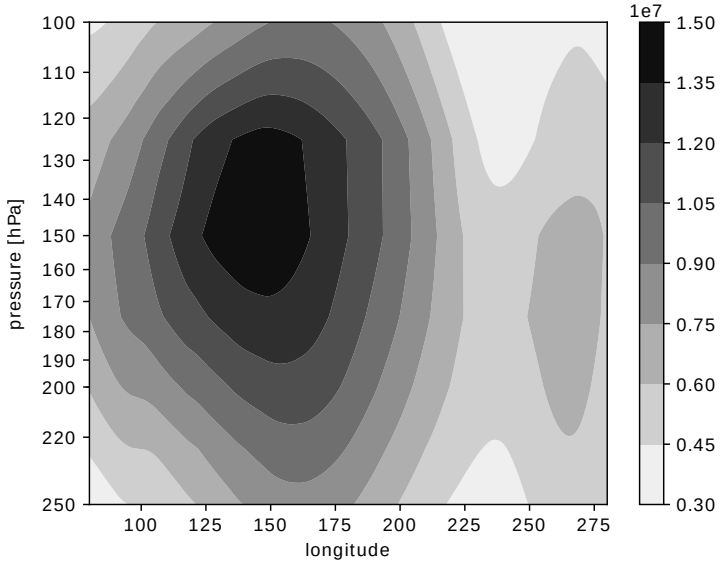

Figure S2: Maximal absolute value of χ (in s^{-1}) between 25°S and 25°N, in the upper troposphere over equatorial Pacific, averaged over 1951-2020.

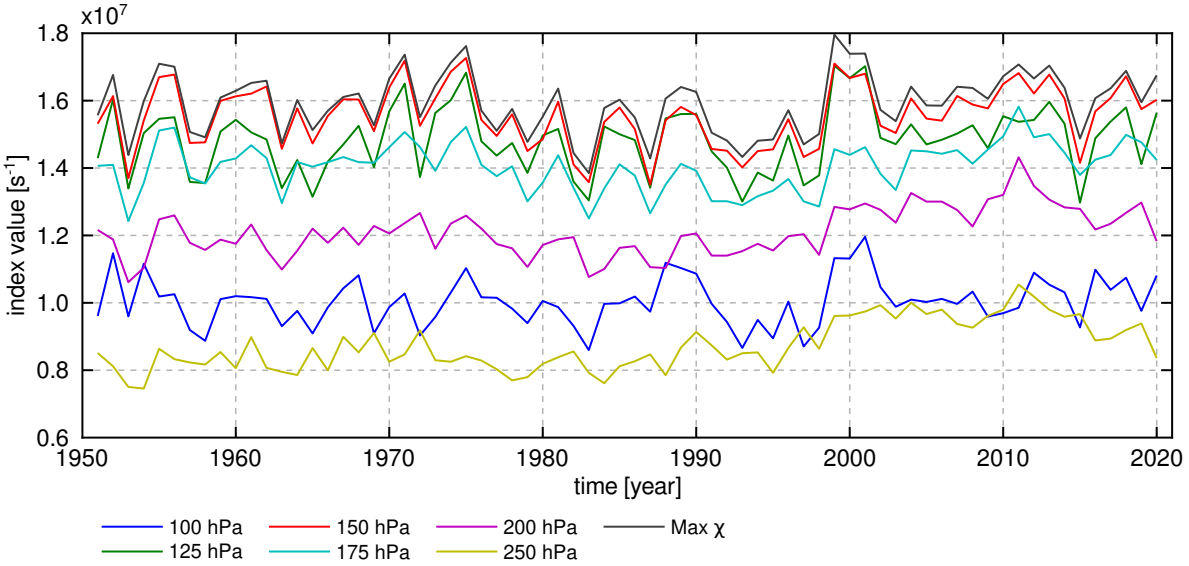

Figure S3: Time series of annual-mean values of χ index at different vertical levels. On average, 150 hPa level is the level closest to maximal divergent outflow in the upper-tropospheric branch of PWC, as χ at 150 hPa is almost perfectly correlated to the data-adaptive index of maximum velocity potential χ_{max} ($r = 0.98$). The latter is computed as a maximum of monthly-mean velocity potential (divergent outflow) at any pressure level in the troposphere.

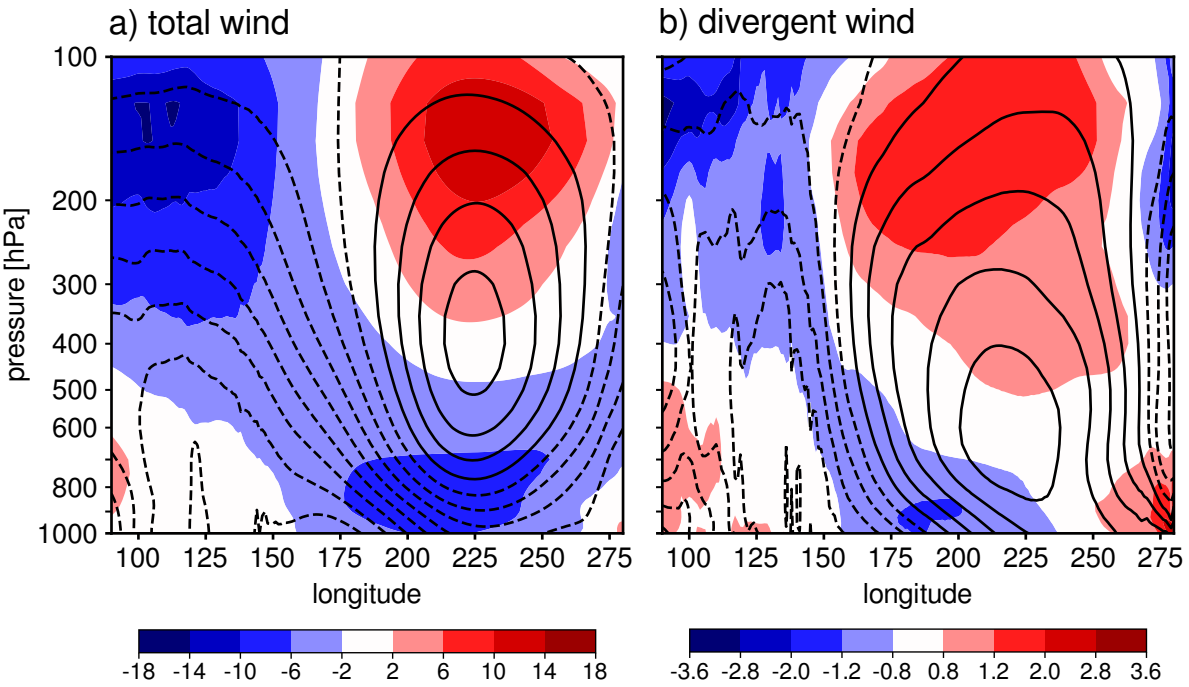

Figure S4: Vertical cross section of zonal wind (colors, in m/s) and mass stream function (contours), averaged over period 1950-2021 and from 5°S to 5°N. a) for total wind (contours every 2×10^{11} kg/s) and b) for divergent wind (contours every 0.4×10^{11} kg/s)

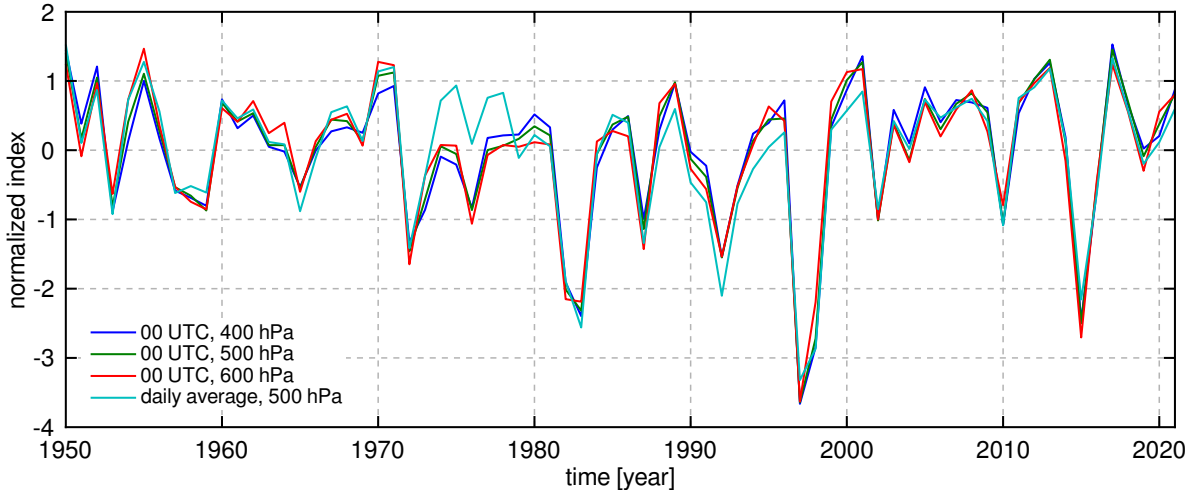

Figure S5: Time series of ω-indices of Pacific Walker circulation strength in ERA5 reanalysis between 1950 and 2021. Different ω-indices, computed from hourly data at 00 UTC or daily mean data at different pressure levels (400, 500, 600 hPa) are compared. Time series are normalized by their standard deviation. The indices are largely insensitive to the vertical level or to the data used (daily-mean data or 00 UTC) with their correlations higher than 0.95 for any pair of presented indices.

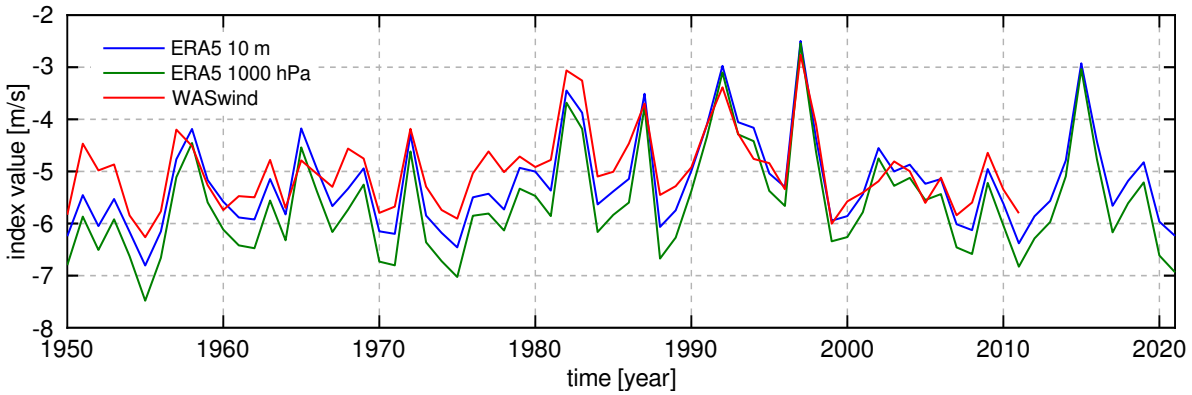

Figure S6: Time series of annual-mean U_{ave} index from ERA5 (at 10 m and at 1000 hPa) and from raw WASwind data.

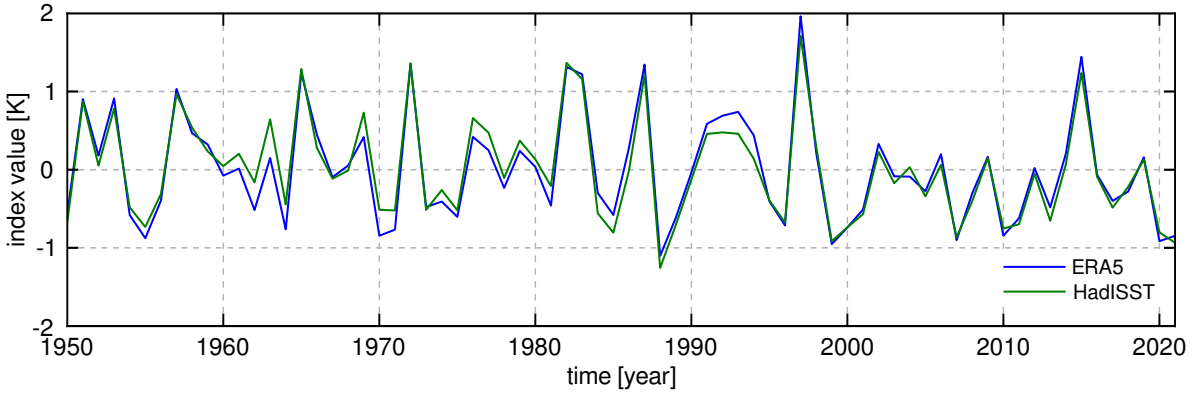

Figure S7: Time series of annual-mean SST index from ERA5 and from raw HadISST data.

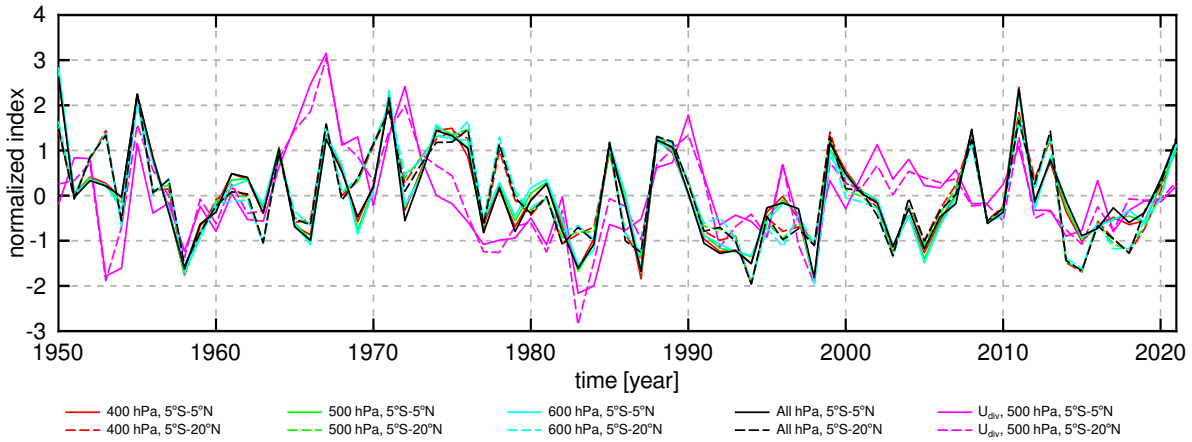

Figure S8: Time series of different variations of normalized ψ index from total zonal wind (annual means), at different vertical levels and for different meridional extent of areas over which wind was averaged. Vertical pressure level stands for indices computed as maximal mass stream function at particular level, "All hPa" denotes index, computed as maximal stream function in the zonal-vertical cross section, and "U_{div}" denotes index, computed from divergent component of zonal wind.

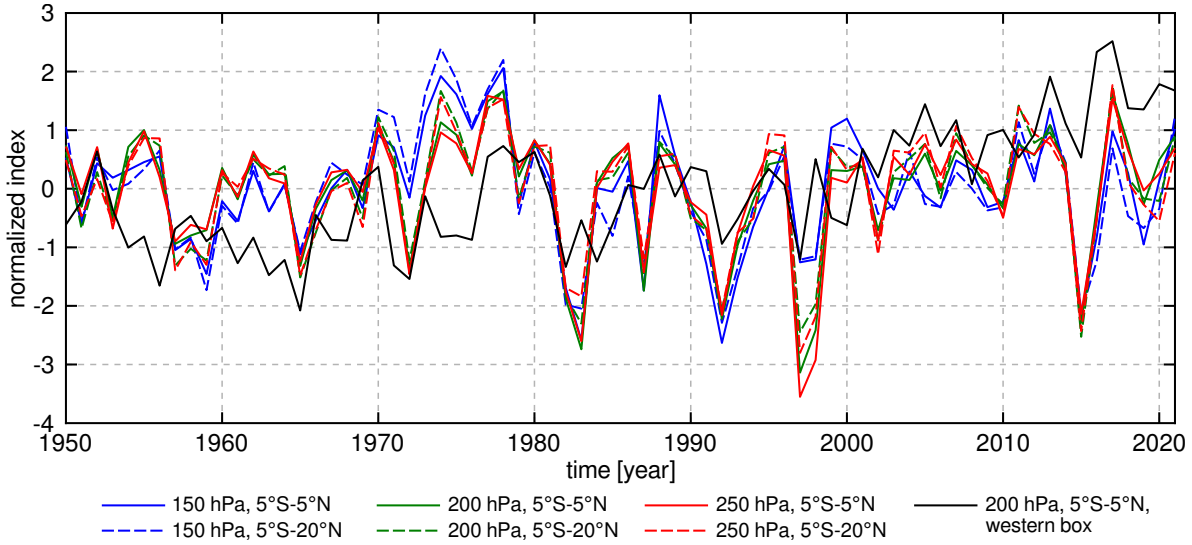

Figure S9: Time series of normalized annual mean values of Q index, calculated at different pressure levels, averaged over areas with different meridional extent. The index is largely insensitive to the change of meridional extent ($r > 0.94$ for any pair of indices). The same applies in the case of change in vertical level from 200 to 250 hPa ($r > 0.98$), whereas differences are larger in the case of change to 150 hPa ($r = 0.8$). Black line represent Q index computed from the western Pacific box only, without subtraction of values from the eastern Pacific box. The index does not distinguish circulation signal from the climate-change induced thermodynamic signal.

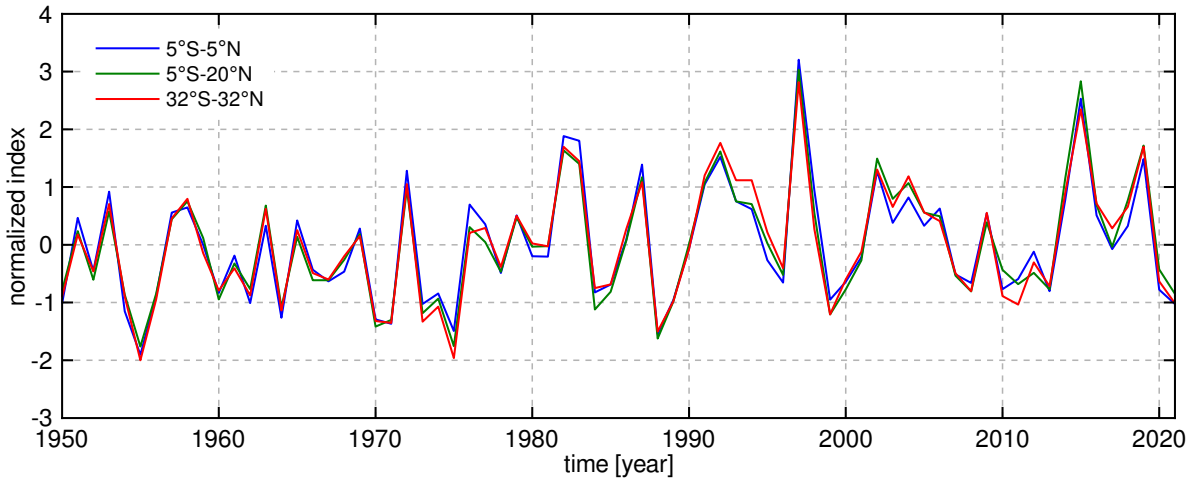

Figure S10: Time series of normalized annual means of V_e index computed for different meridional extent of horizontal areas: narrow tropical belt (5°S to 5°N) as in the main text; belt around ITCZ (5°S to 20°N), whole tropical belt (32°S to 32°N). Normalized V_e index show little sensitivity to change in meridional extent of area for computation of the index ($r > 0.97$).

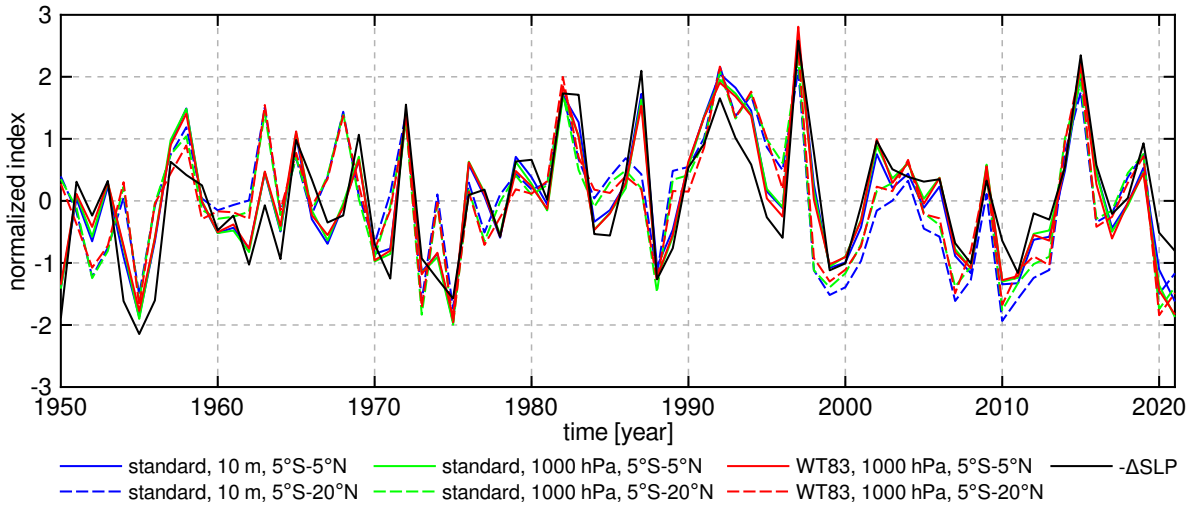

Figure S11: Time series of normalized annual mean values of L_τ index, computed from "standard" formula (Clarke and Lebedev, 1996) at 10 m and 1000 hPa, and following Wright and Thompson (1983) at 1000 hPa. For comparison, ΔSLP index multiplied by (-1) is added to the plot for comparison. Wind stress index is more sensitive to the change in meridional extent of horizontal area used for calculation of index than to the change in calculation of τ_x

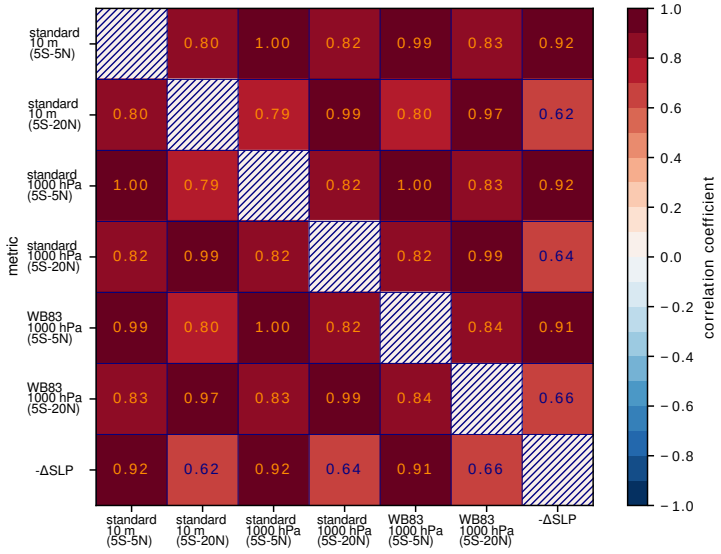

Figure S12: Correlation coefficients between different variations of L_τ index, and between different variations of L_τ index and ΔSLP index. High correlations with ΔSLP confirm the findings of Clarke and Lebedev (1996) that the wind-stress index and surface pressure index may be used interchangeably when studying multidecadal variability.