On the Puzzle of Solar-Cycle/QBO Interaction in the Stratosphere

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References can be found at http://www.amath.washington.edu

Stratospheric solar cycle signal

- Tropical signal of 0.5-1 K understandable as from ozone absorption of solar UV radiation.
- Polar solar warming much larger ~10 K, but only occurs in late winter, and can be seen "only when stratified according to the phase of QBO" (LvL,88).
- Puzzling reports of reversal of the solar cycle warming during easterly phase of QBO (LvL,88) or the reversal of QBO warming by the solar max (Kodera, 93).
- Mechanism: sudden warming more frequent during solar max (LvL, 82). Is SSW the dynamical amplifier?
- Camp and Tung (2007) addresses these issues.

Reference: Camp, C.D., and K.K. Tung, 2007:The influence of solar cycle and QBO on the late winter stratospheric polar vortex, J. Atmos. Sci., 64, 1267-1283.

- Pioneering work: Labitzke (1982, 1987) first searched for the solar cycle influence in the stratospheric data in winter, and discovered an association between the 30-mb polar temperature and the Sunspot numbers only during the **westerly phase** of the equatorial QBO, with the phase defined by the equatorial 50-mb zonal wind.

- Reversal: Starting in Labitzke and van Loon (1988) the level at the equator used in defining the phase of QBO changed to the 45mb level. This change moved the winters of 1984 and 1987 from the westerly phase to the easterly phase category (Barnston and Livezey (1991)), and a surprising result was found: While the winter polar temperature at 30-mb varies *in phase* with the solar cycle during the **westerly** phase of the QBO, it varies *out of phase* with the solar cycle during the **easterly** phase.

- Theory: It is difficult to think of a dynamical mechanism for a solar cycle influence which reverses its effect on the atmosphere when the phase of the QBO changes (i.e. the solar cycle warms during westerly years but cools during easterly years)

- Statistics: Labizke and van Loon (1988) showed that their results are statistically significant using a Monte-Carlo test. Herein lies the dilemma.

New perspective: All warming should be viewed as relative to the unperturbed (or least perturbed) state

- Easterly QBO is a perturbation to the polar stratosphere (Holton and Tan, 1980). Warms
- Solar max is also a perturbation to the polar stratosphere (Labitzke, 1982). Warms.
- The least-perturbed state is w-QBO and SC min. Relative to this state all perturbation warms the polar stratosphere.

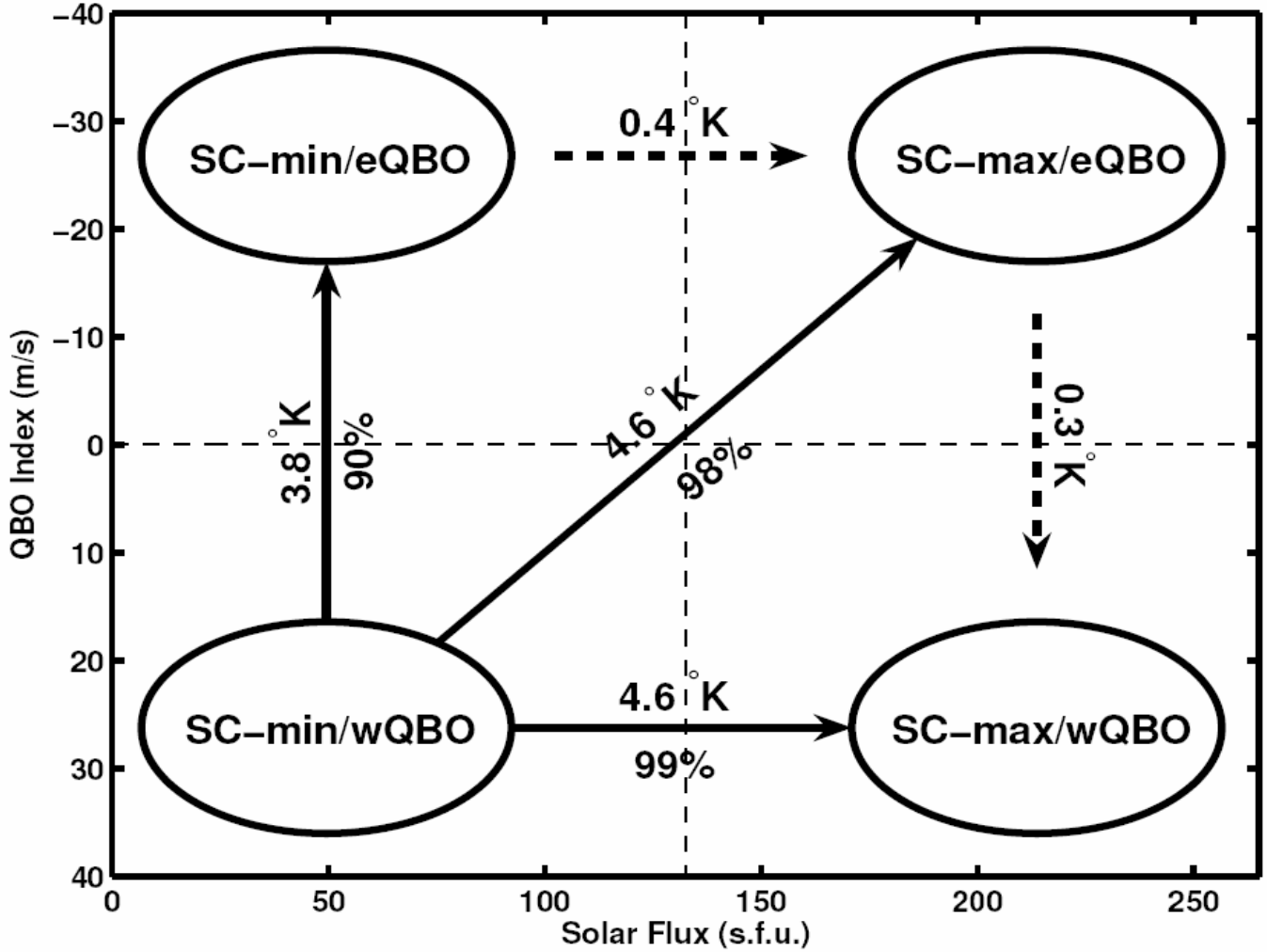


Figure 9: Summary schematic: The state of the SC-min/wQBO is the least-perturbed state. Solid arrows indicate the mean warming of the pole for the perturbed states relative to this state. Confidence levels for the associated LDA's are also shown. Dashed arrows indicate the small difference found between perturbed states, which are not statistically significant. All results are for the Feb.-Mar. average of 10-50 hPa layer mean temperature.

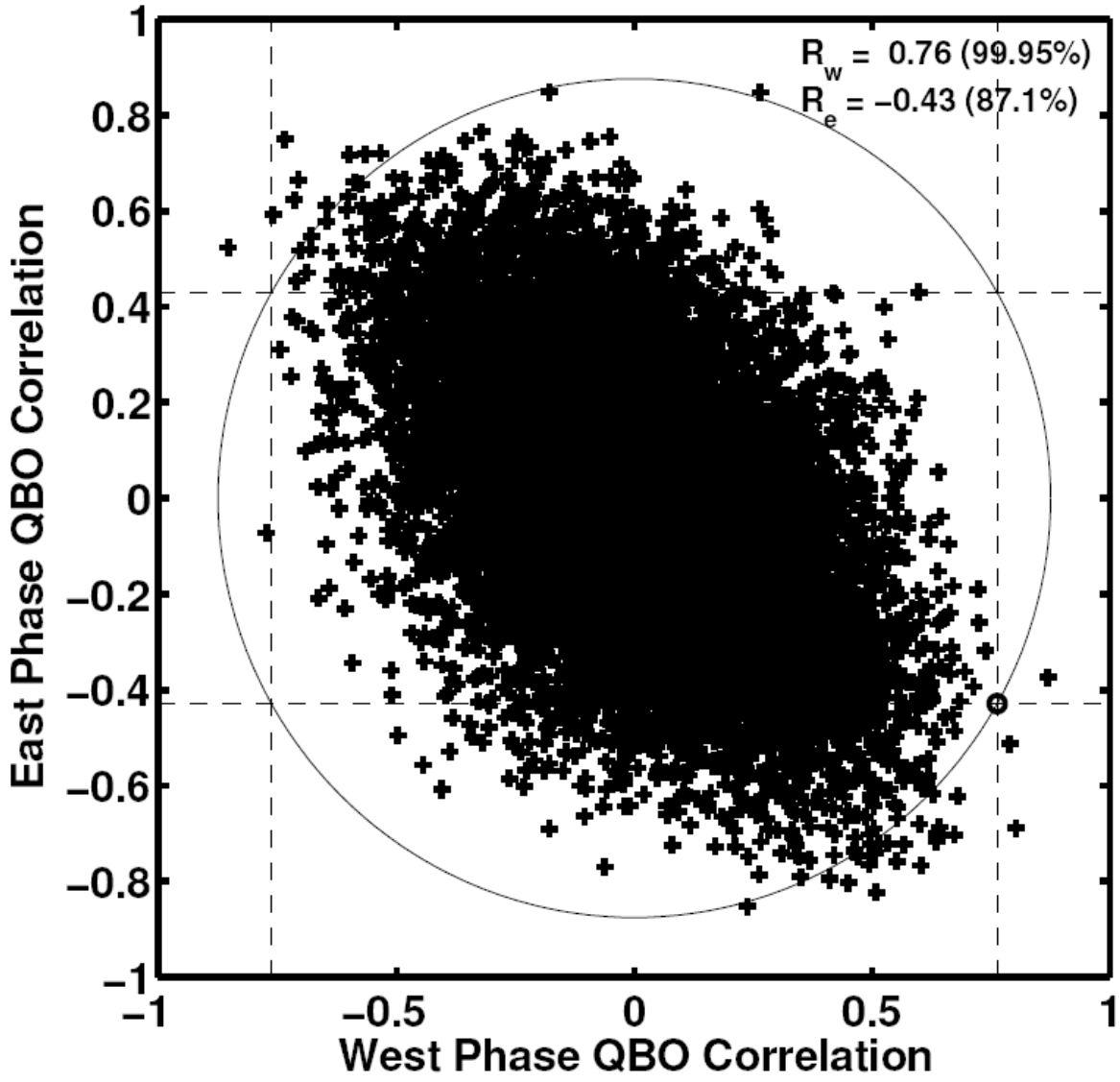


Figure 1: Reconstruction of LvL88 Figure 2. Paired correlations between the mean 30 hPa North Pole Temperature and the 10.7 cm Solar Flux when partitioned by the phase of the 45 hPa tropical QBO index. Mean values for Jan.-Feb. from 1956 to 1978 used. Statistical significances for the observed correlations determined by calculating the paired correlations from partitioning 10000 first-order autoregressive surrogate time series ($p_1 = -0.34$).

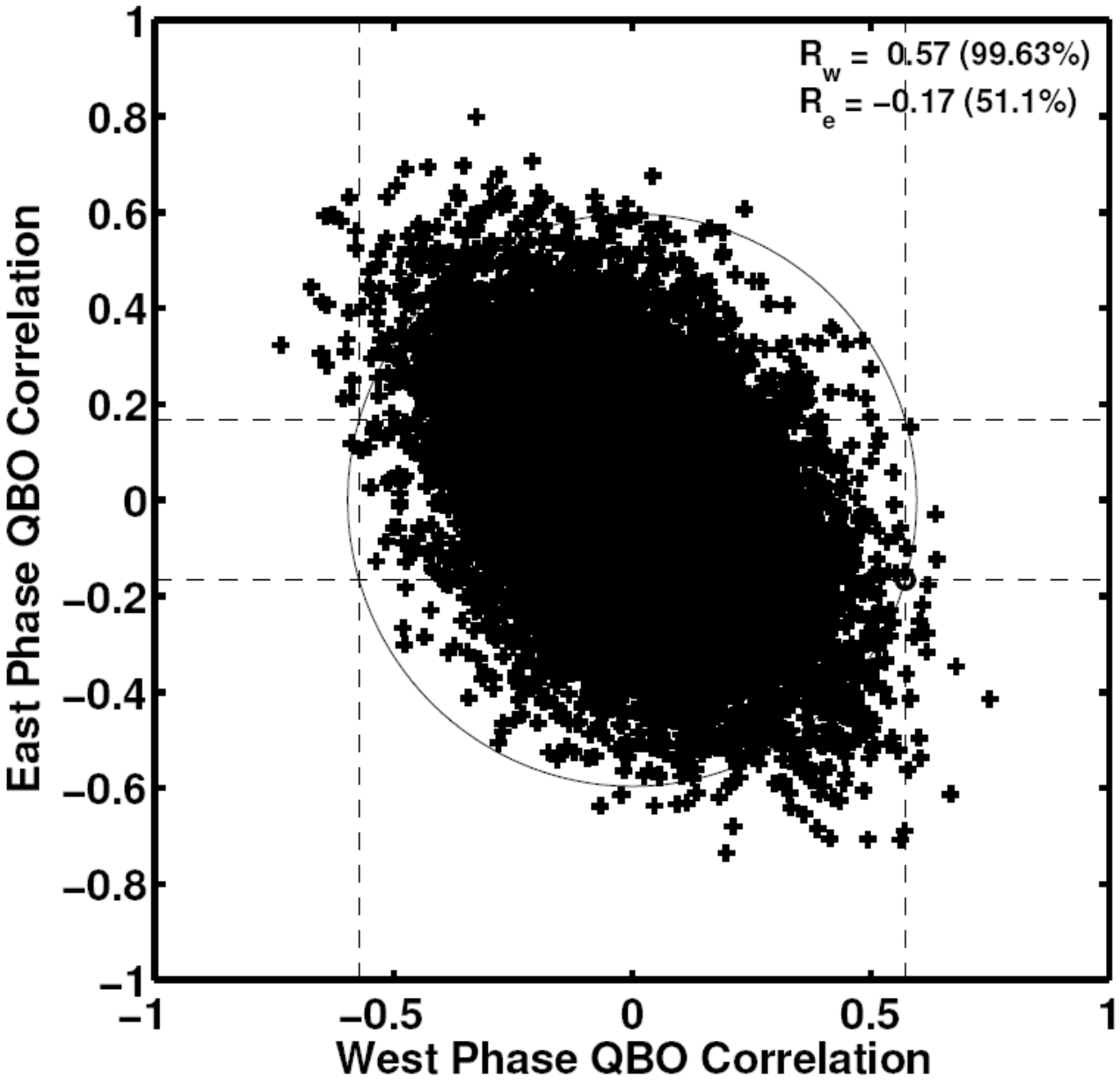


Figure 2: As Figure 1 for data from 1956 to 2001; ($p_1 = -0.33$.)

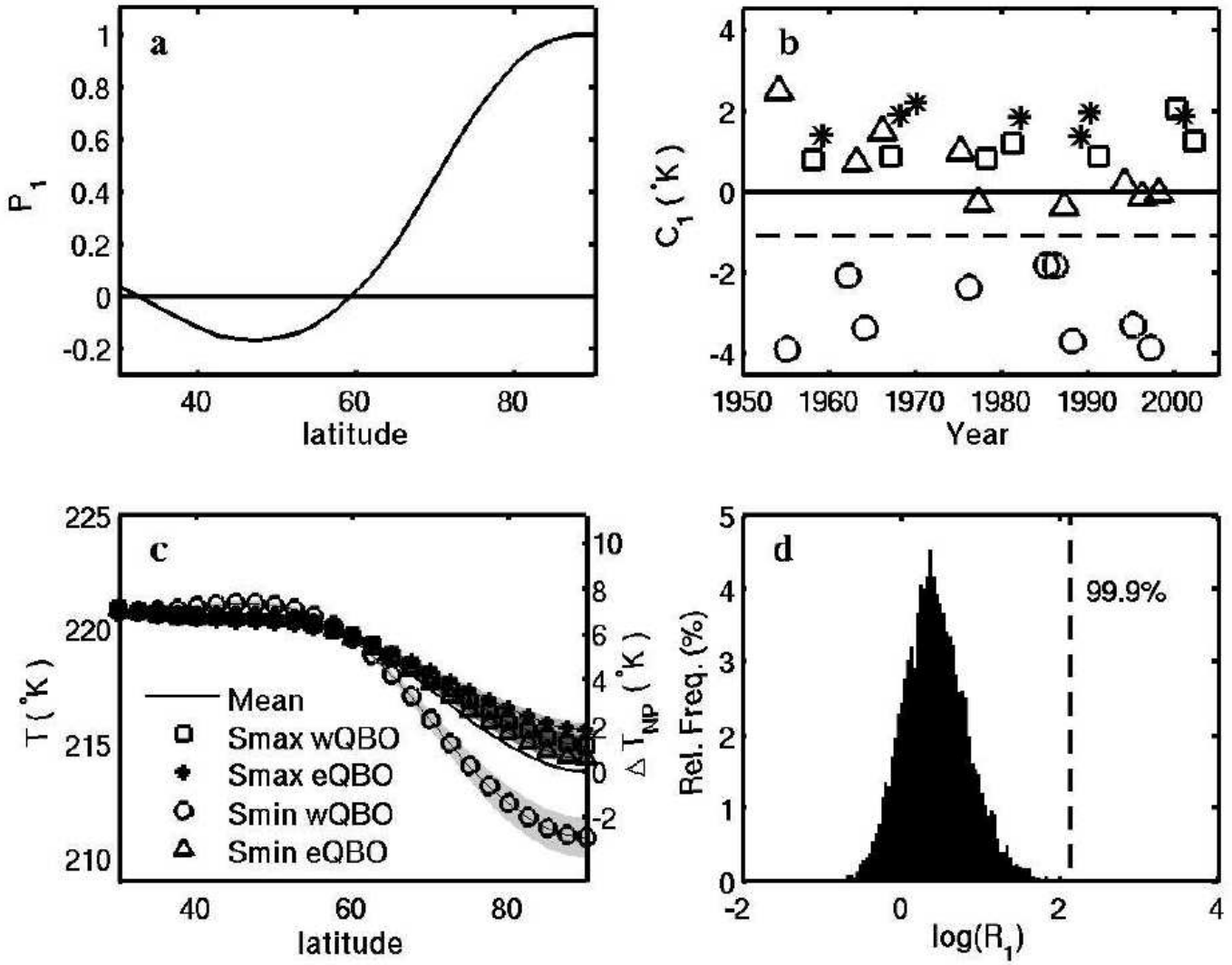


Figure 5: Results of a 4-group LDA for the Feb.-Mar. average of the zonally averaged difference between 10-50 hPa geopotential surfaces for 1954 to 2005. Grouping based on both the solar cycle and 30 hPa equatorial QBO indices. (a) 1^{st} discriminant pattern, $P_1(\mathrm{x})$, (b) 1^{st} time series index: $C_1(t)$, (c) Mean state (unmarked line) plus group-mean projections onto $P_1(\mathrm{x})$ for all 4 groups, Shaded regions show 1σ projections for all groups. (d) Monte Carlo distribution of variance ratios showing percentile of observed variance ratio, $\mathcal{R}_1$, for the first discriminant.

Conclusion from this slide

- Three of the perturbed states are not distinguishable separated from each other
- But the three perturbed states are clearly separated from the least-perturbed state of w-QBO/SC min
- Perturbation (warming) takes the form of a sudden warming near the pole and compensating cooling at mid-latitudes.
- Thus it appears that the SC max warms the pole in the same way as e-QBO, through preconditioning for sudden warming to occur in late winter.

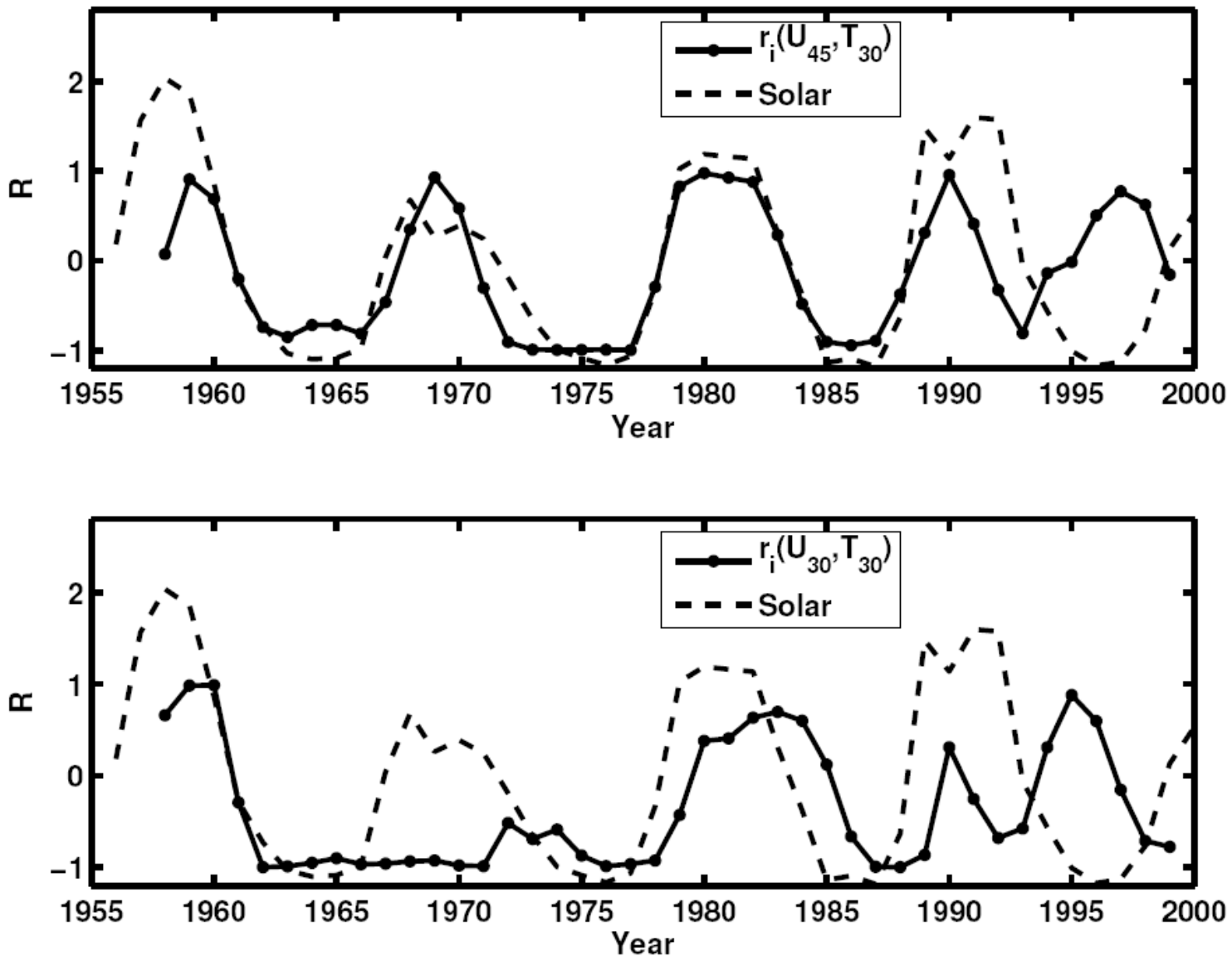


Figure 3: (a) 3-yr running correlation between the 45 hPa equatorial zonal wind in Jan. and the Jan.-Feb. average of the 30 hPa North Pole temperature. Dashed line is the normalized 10.7cm solar flux, Dec.-Jan.-Feb. average. (b) as (a) using the 30 hPa equatorial zonal wind.

Conclusion from this slide

- Kodera (1993) result does not hold if the correlation between the polar temperature is correlated with the QBO index at the same level.
- At 45 hPa or 50 hPa over the equator, westerly QBO often stalls even if the phase of the QBO changes at 30 hPa. This accounts for the decadal variation in the correlation coefficient.

Conclusion

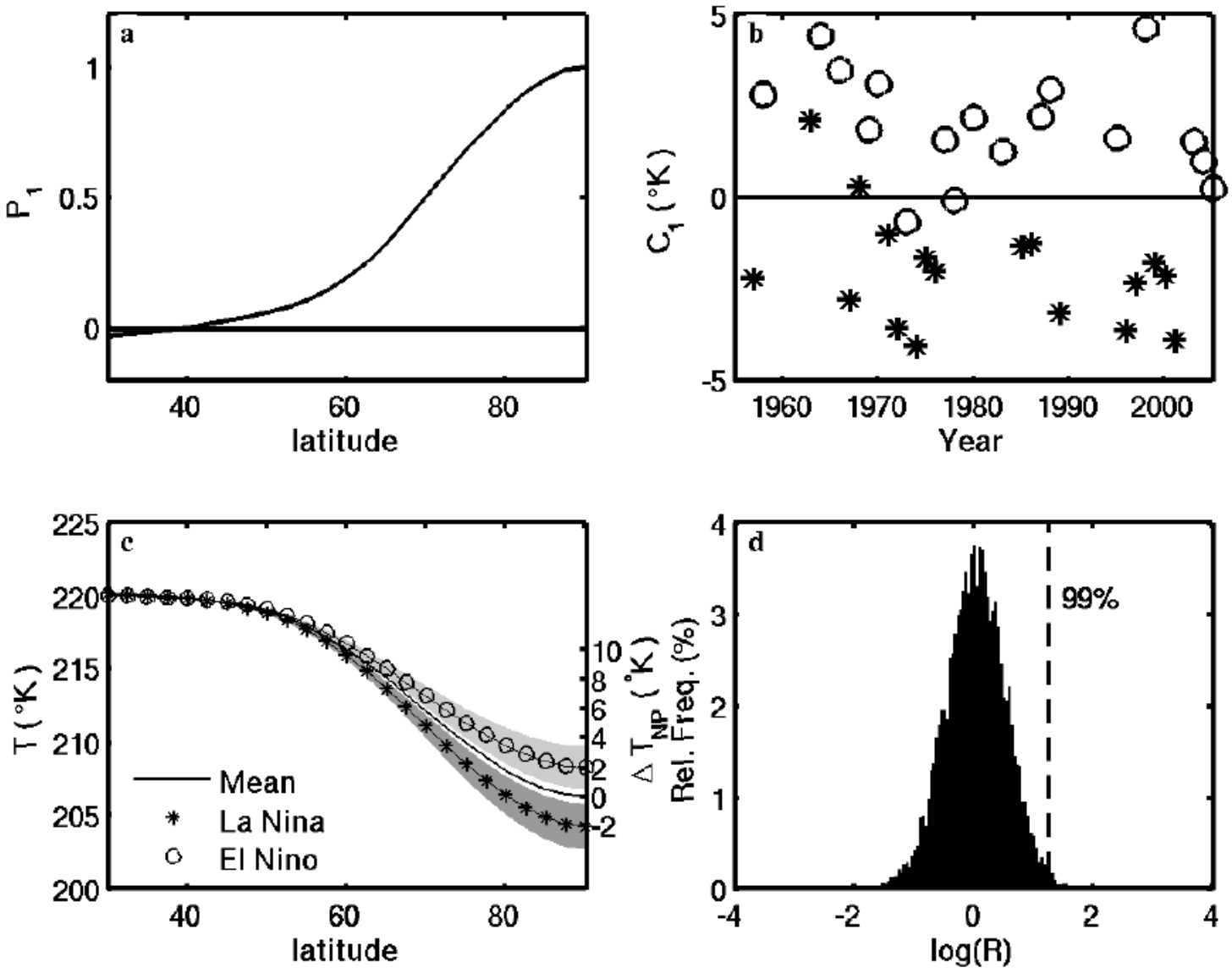
- Stratosphere polar signal easier to understand if relative to the least-perturbed state: no reversal; solar max warms, eQBO warms, both through SSW.

- Additional negative results on QBO/Solar Cycle Interaction: Fischer and Tung (2008) JGR: No evidence in the longest QBO record that the equatorial QBO period is lengthened during solar min (e.g. Salby and Callaghan, 2000).

Three “external” perturbations to polar vortex in winter

- QBO: easterly QBO warms.
- Solar cycle: solar max warms
- ENSO: warm ENSO warms

All can be shown to be statistically significant, all yield about the same perturbation ~4 °K. More frequent occurrences of SSW.



Reference: Camp, C. D. and K. K. Tung, 2006: Stratospheric polar warming by ENSO in winter, a statistical study, Geophys. Res. Lett., submitted.