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An Idealized-Model Experiment on the Remote Influence of Interannual Variations in the Tropics to the Winter Polar Vortex

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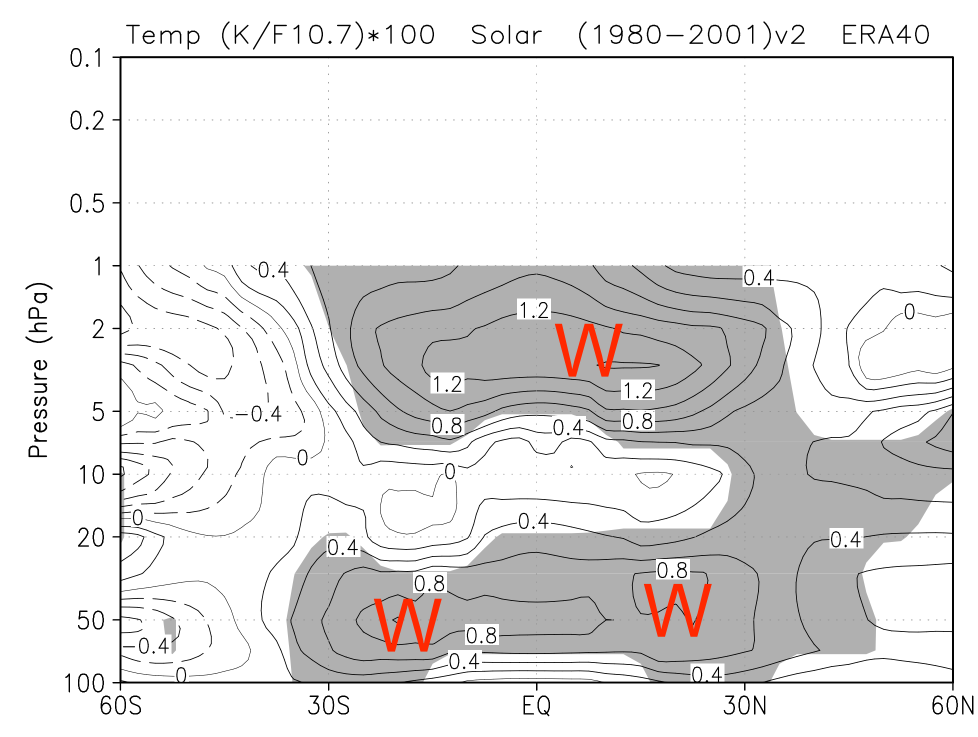
1. Introduction

❖ Kodera and Kuroda (2002)

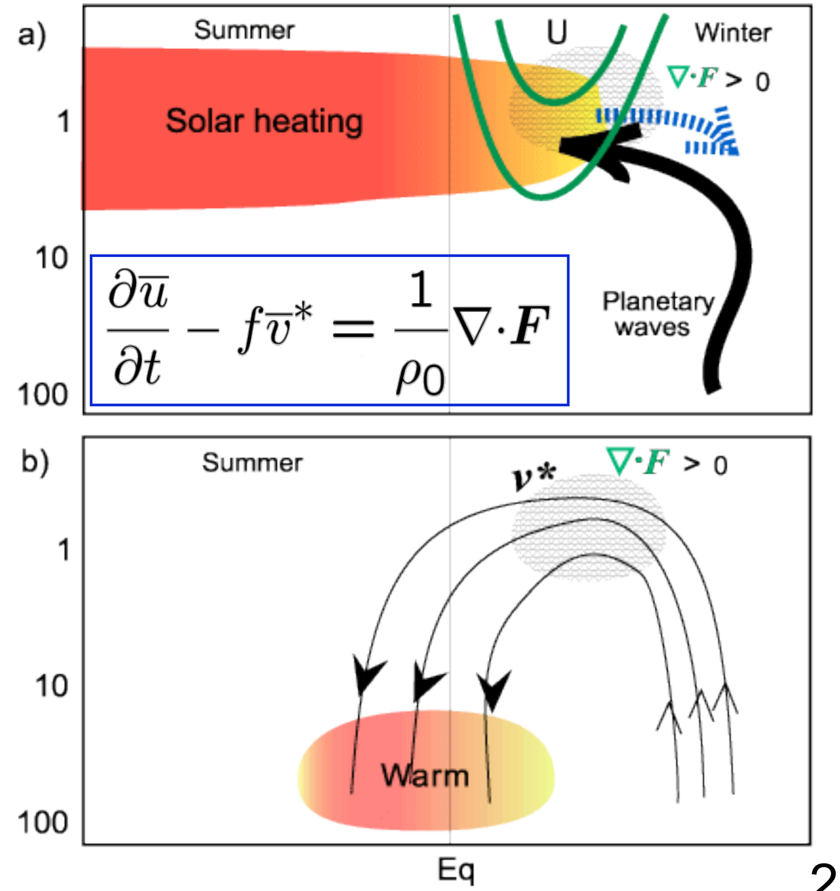
- Difference of time-mean zonal-mean temperature [*T*] in Dec. between Solar Max and Solar Min year

← changes in E-P flux and Brewer-Dobson circulation associated with the solar effect near the stratopause



Shibata and Deushi
(2008, *Annales Geophysicae*)

Kodera's mechanism

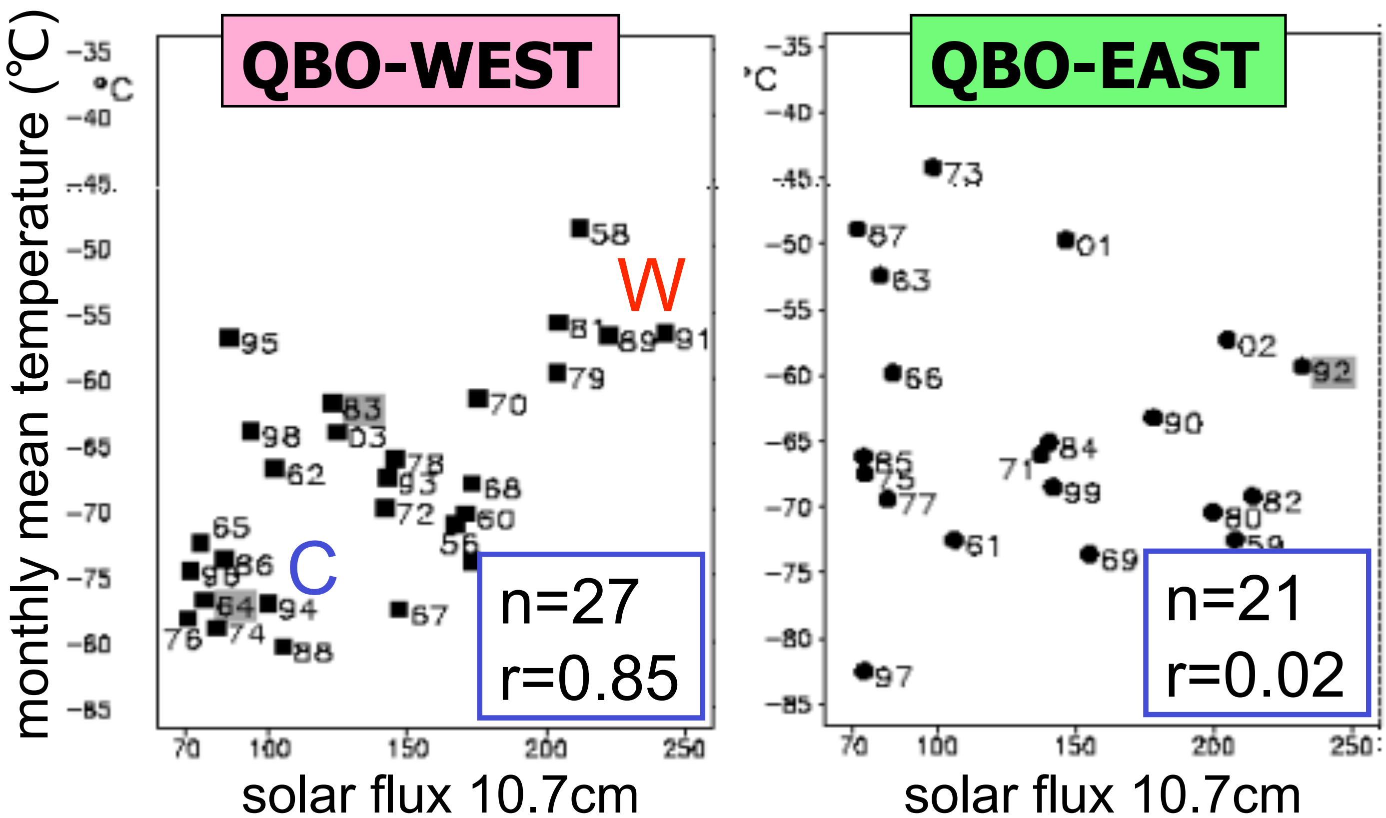


$$\frac{\partial \bar{u}}{\partial t} - f\bar{v}^* = \frac{1}{\rho_0}\nabla\cdot\boldsymbol{F}$$

❖ Labitzke (2005)

- ❍ Solar cycle (SC) effect on the North Pole is different, if the data are divided by the equatorial QBO phase

Correlation between solar activity and [T] (30-hPa, NP) in Feb.



❖ In this study:

- We study remote influences of external forcings of QBO and solar cycle in the tropics to the winter polar vortex (Ito et al., 2008 submitted to.*GRL*)
- We use a 3-D global mechanistic circulation model (MCM) with an idealized setup, same as Naito, Taguchi, and Yoden (2003).
- A large sample method is used for long time series of 39,600 days to test the significance of differences in time averages between two runs in the combination of QBO and solar cycle.

		Solar	
		MIN	MAX
QBO	WEST	C	W
	EAST	--	--

Labitzke's relationship

- We perform parameter sweep experiments to study the sensitivity of responses to the details of external forcings.
- An EP-flux diagnosis is done to study the associated changes in the wave activity and propagation route of planetary waves.

2. Model and experimental setup

❖ Naito, Taguchi, and Yoden (2003; JAS, 60, 1380-)

- 3-D global Mechanistic Circulation Model (MCM)
  - GFD Dennou Club AGCM5 (1998)
  - Resolution: T21L42 (surface to the mesopause)
  - Simplified physical processes:
    - Newtonian heating/cooling under a perpetual-winter condition
    - Rayleigh friction at the surface
    - dry atmosphere
    - idealized surface topography of zonal wavenumber 1, *h*=1 km only in NH (winter)
  - Long time integrations
    - discarding initial spinup time
    - N = 39,600 days
    - time-constant external conditions

- "QBO-wind" forcing in the equatorial region
  - cf. Horinouchi and Yoden (1997)

$$du/dt = \cdots\cdots - \alpha_{QBO}(\phi, z)\{u - U_{QBO}(\phi, z)\}$$

$$\alpha_{QBO}(\phi, z) = (1/30)\,\gamma(\phi, z) \quad [1/day]$$

$$U_{QBO}(\phi, z) = 45\gamma(\phi, z)\cos\{2\pi(z - z_{ref})/z_{dep} + \theta\} \quad [m/s]$$

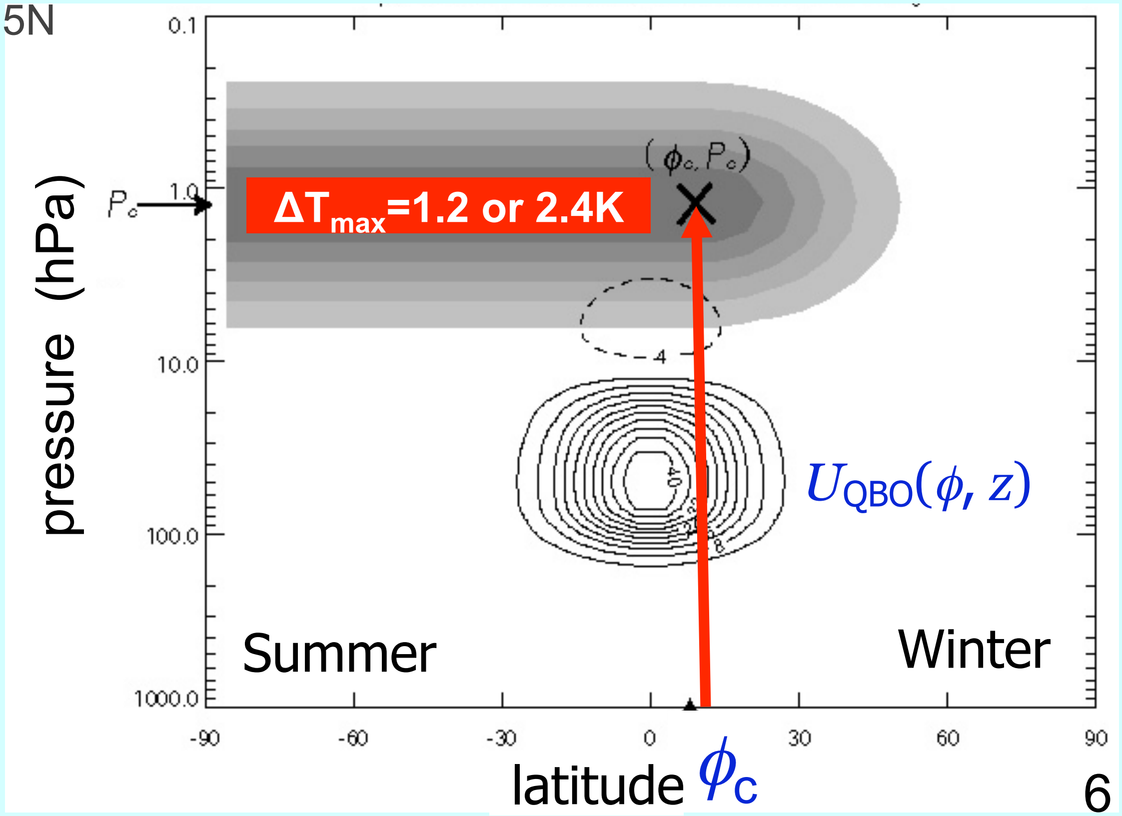
❖ SC modulation in radiative heating around the stratopause

❍ Solar Min runs

- ➢ QBO Westerly or Easterly forcing run, same as in Naito and Yoden (2006)
  ➔ W:min, E:min

❍ Solar Max runs

- ➢ setup of Solar Min runs (W or E) + anomaly of radiative equilibrium temperature
- ➢ swept parameters:
  max value of the anomary: ΔTmax (1.2 K or 2.4 K)
  latitudinal extent of the anomaly: ϕ_c (25S, 20S, 15S, ..., 20N, 25N)
  ➔ W:1.2K25S, ..., E:2.4K25N
  (2x2x11 = 44 runs)



Meridional profile of SC and QBO forcings

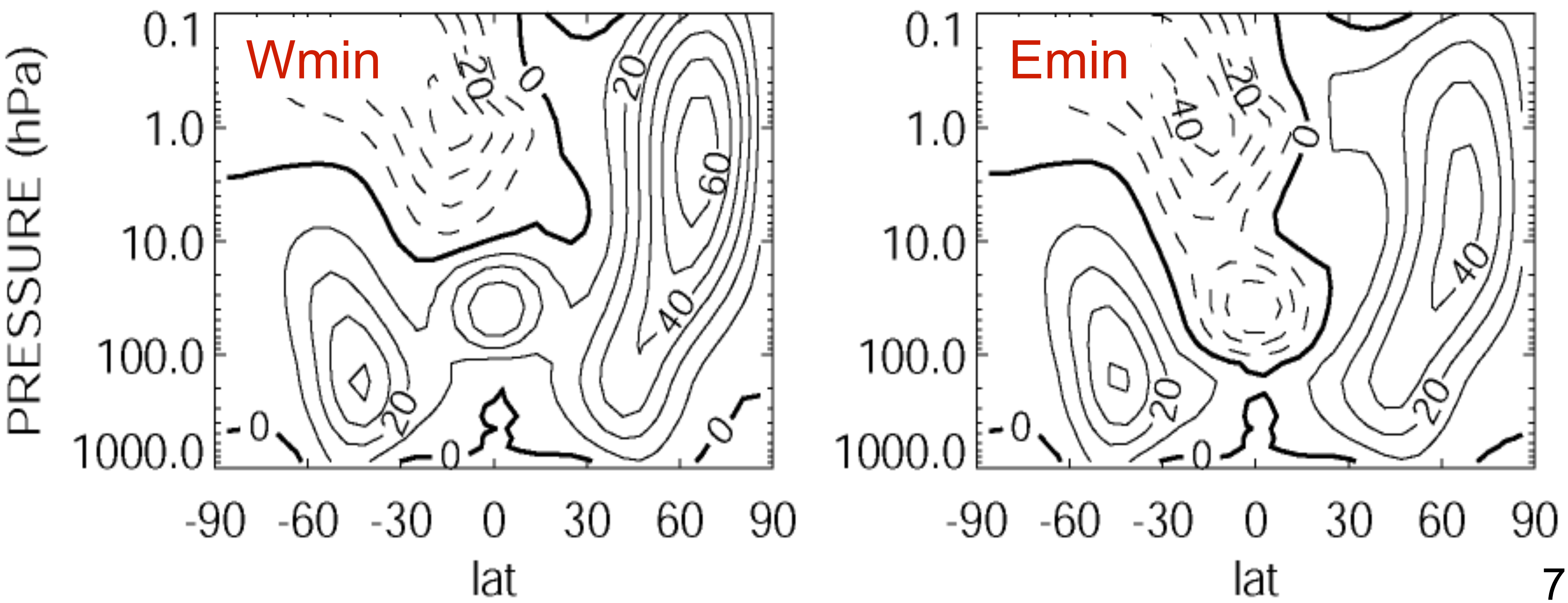
3. Results

❖ Solar Min runs

= Naito and Yoden (2006): reconfirmation of Holton-Tan (1980) relationship

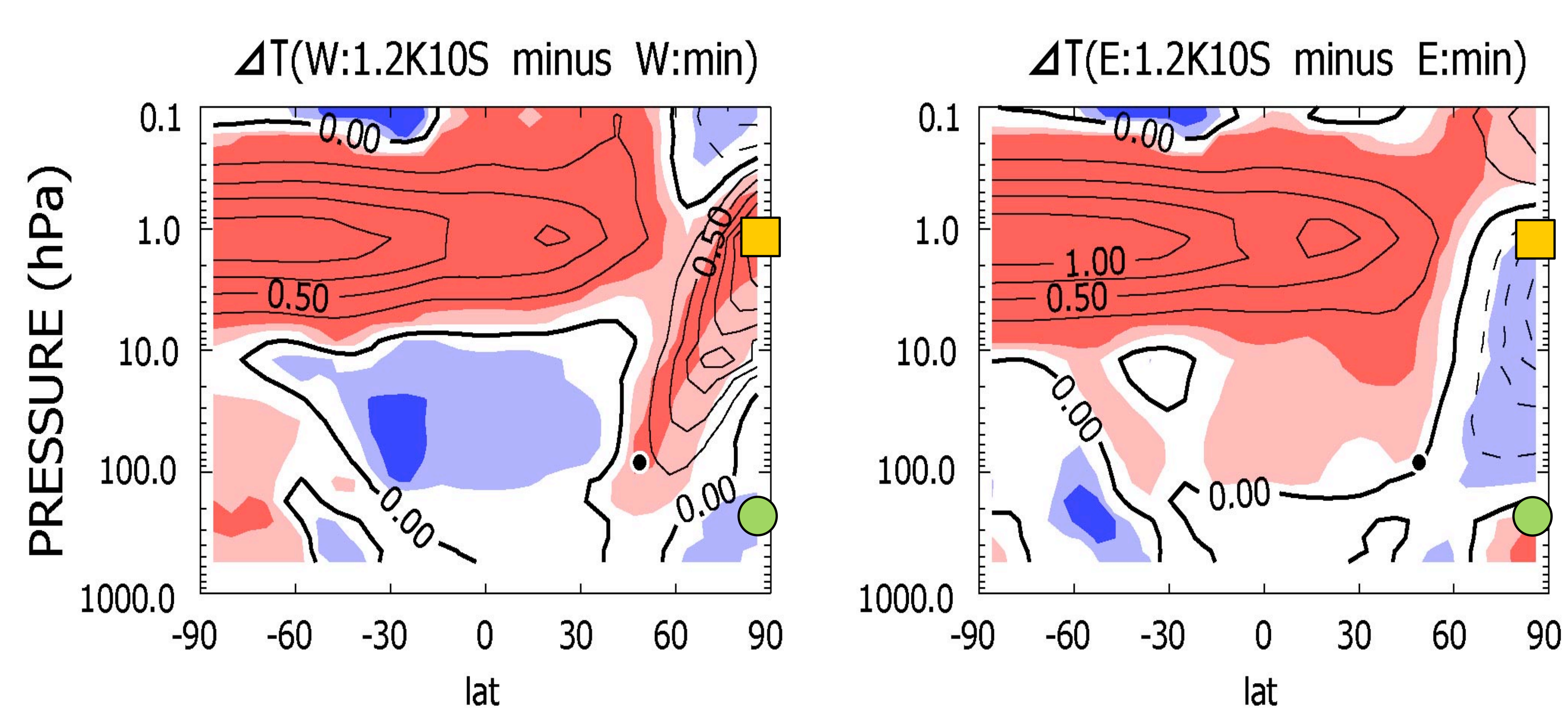
	QBO-WEST	QBO-EAST
Polar Vortex	Strong, Cold	Weak, Warm

Time-mean zonal-mean zonal wind



❖ Influence of Solar Cycle modulation: a typical example

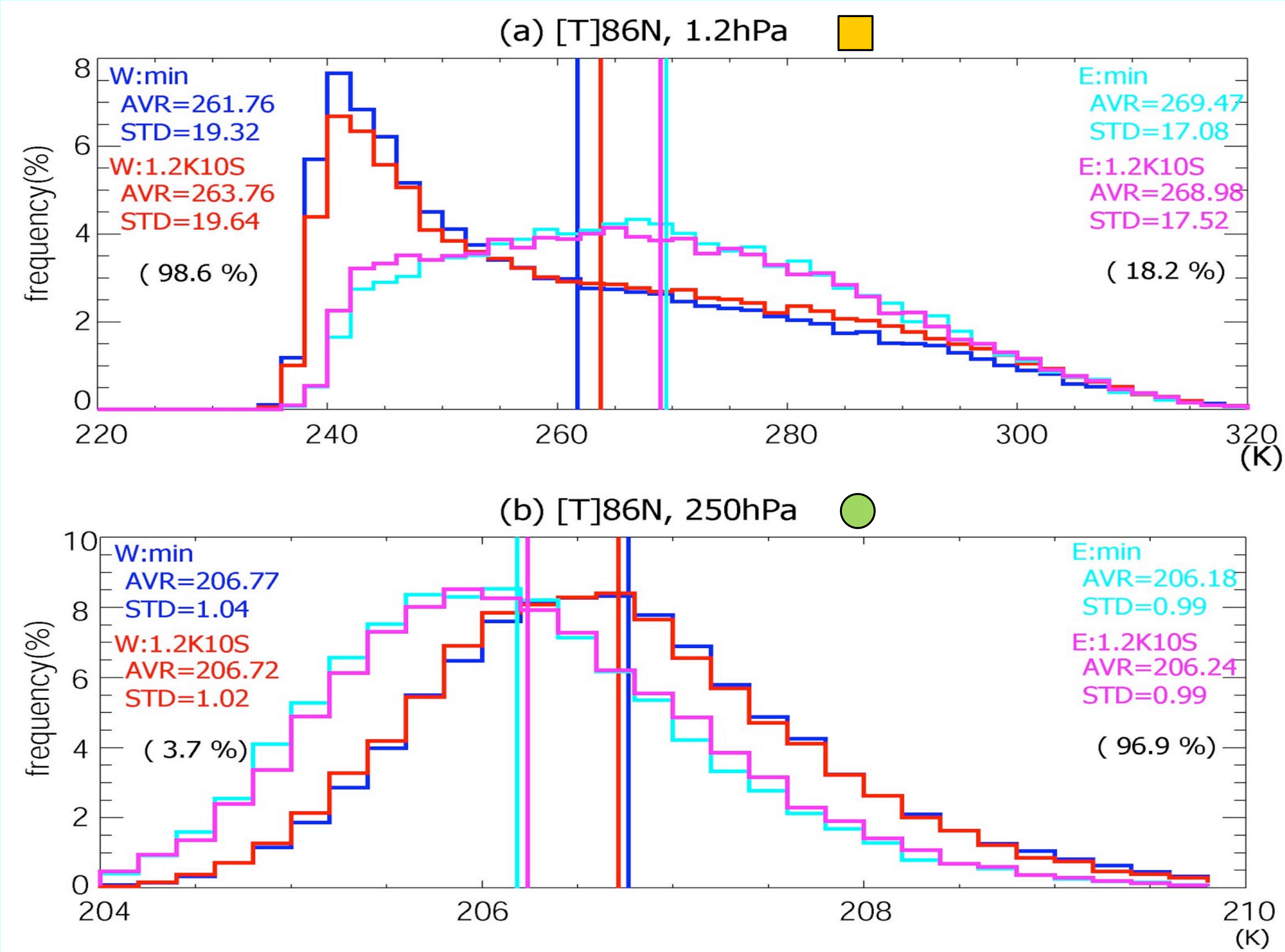
- ❍ Difference of time-mean zonal-mean temperature [*T*] in (K) between Solar Max run and Solar Min run for ϕ_c =10S



- ❍ significance test

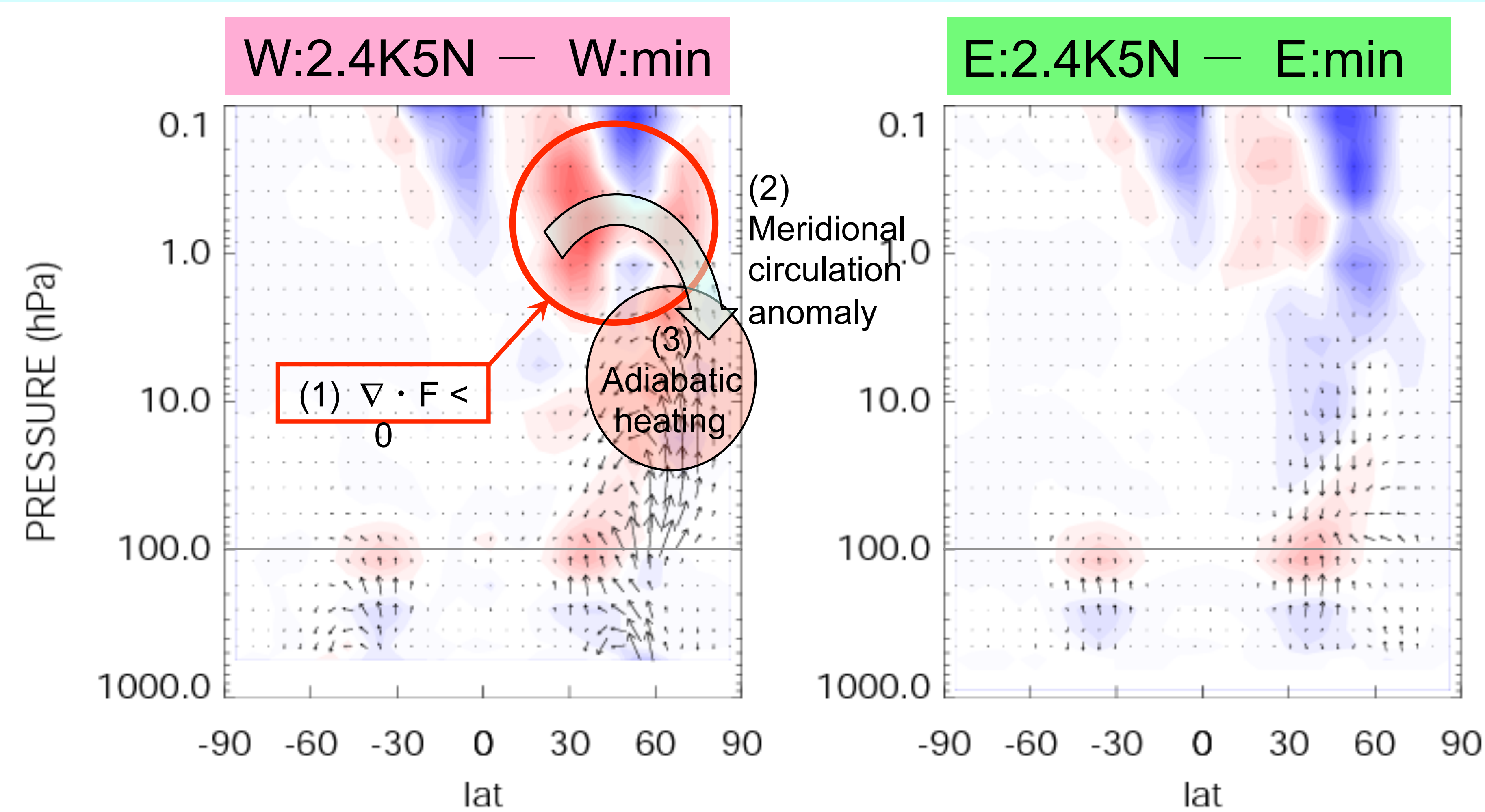
Warm		>95%		>80%
Cold		>95%		>80%

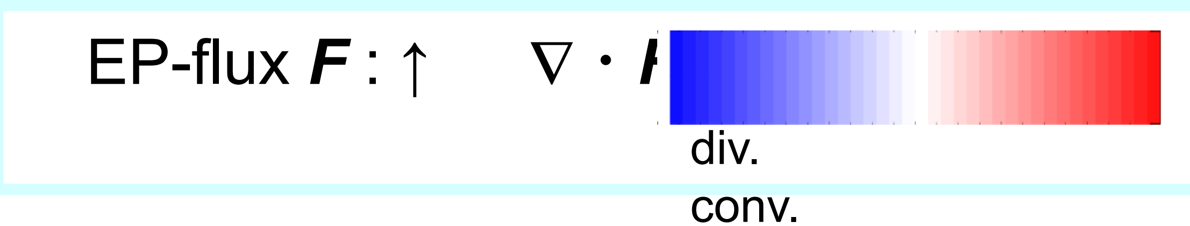
- Frequency distribution of time-mean zonal-mean temperature for Solar Max runs and Solar Min runs in W or E phase of QBO



❍ Changes in the time-mean EP-flux and its divergence

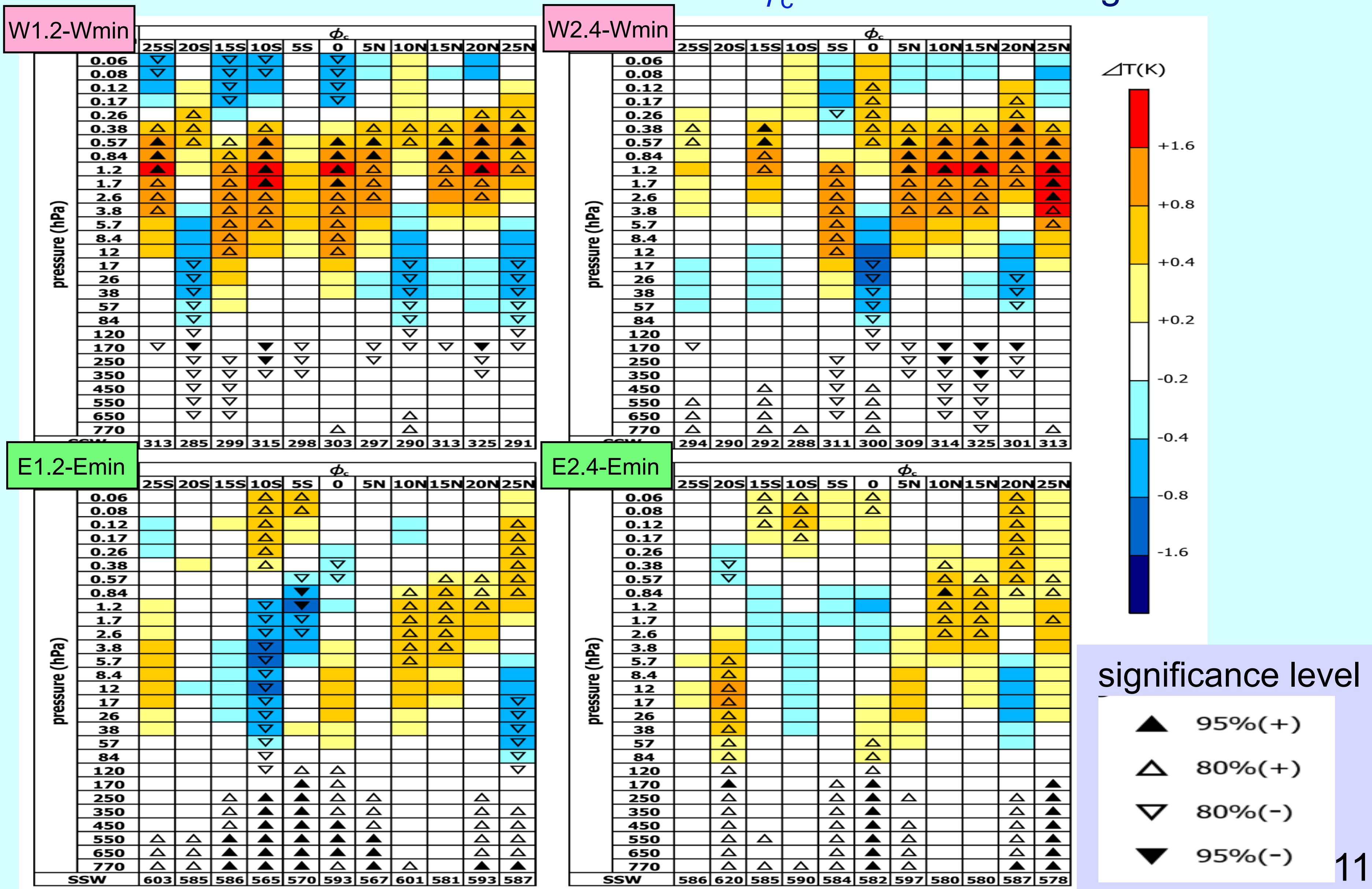
➢ consistent with the changes time-mean zonal-mean temperature at winter NP





❖ Parameter sweep experiments

❍ [T] anomaly at the winter pole between Solar Max and Solar Min runs for 11 values of the latitudinal extent ϕ_c of the solar forcing



4. Concluding remarks

- [*T*] changes in the winter pole caused by solar heating anomaly around the stratopause are consistent with Labitzke relationship in the presence of QBO:

		Solar	
		MIN	MAX
QBO	WEST	C	W
	EAST	– –	– –

Labitzke's relationship

- However, the difference is much smaller than that caused by the "QBO" with heavy overlapping of the PDFs.
- Frequent occurrence of stratospheric sudden warming (SSW) and large EP-flux convergence in Solar Max experiments are consistent with the higher [*T*] in winter pole in the stratosphere.
- We need to check…
  - effect of various wavenumber components
  - sensitivity to the altitudes of solar and QBO forcings
  - effect of seasonal march, compared with the present perpetual runs