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Linkage of the lagged winter **stratospheric** circulation anomalies to leading **ENSO** forcing

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Outline

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C. Temporal lagged relationship

D. Possible mechanisms

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A. Motivation



1. Evidence of the ENSO's effect on the extratropical stratosphere

- During warm ENSO winters, the NH stratospheric vortex tends to be anomalously warmer and weaker due to the increased upward planetary waves

(van Loon et al. 1982; Labitzke and van Loon 1989; Camp and Tung 2007; Hamilton 1995; Sassi et al. 2004; Manzini et al. 2006; García-Herrera et al. 2006; Garfinkel and Hartmann 2007, 2008);

- The warm ENSO's effect is related to more occurrence of SSW events (Taguchi and Hartmann 2006) .

2. Possible delayed effect of ENSO

- Existing time lag of the polar warming from the upper to the lower stratosphere, following a warm ENSO phase (Manzini et al. 2006);
- The maximum warming response in the stratosphere lags the maximum Niño3.4 value for several months (García-Herrera et al. 2006);
- Maximum significant correlation between ENSO and the meridional EP flux divergence at 30hPa appears when ENSO leads the EP flux by about three seasons (Chen et al. 2003).

A. Motivation



3. The known delayed effect of ENSO in the troposphere

- The maximum correlation between the zonal-mean tropical temperature and the ENSO SST occurs **one to two seasons later than the ENSO peak** (Newell and Weare 1976; Angell 1981; Reid et al. 1989; Yulaeva and Wallace 1994) , because of the tropical oceans delayed response to ENSO (Kumar and Hoerling 2003) via the processes like “atmospheric bridge”, (Lau and Nath 2003; Klein et al. 1999) and PNA-like teleconnection pattern (Handoh et al. 2006) .

■ Questions

- 1) Does a significant lagged response in the extratropical stratosphere to ENSO exist?
- 2) What's the mechanism that links ENSO forcing to the stratospheric variability?
- 3) How to understand the relative importance between the concurrent response and the possible lagged response in the stratosphere?

B. Data



- **ENSO:** The monthly Niño3 anomaly index from 01/1950 to 12/2009 (<http://www.cpc.noaa.gov/data/indices/>);
The monthly SST fields from the NOAA-Extended-Reconstructed SST V3b dataset 01/1949 to 12/2009 (Reynolds et al. 2002) ;
- **Stratospheric polar vortex variability:** sign-reversed NAM index (<http://www.nwra.com/resumes/baldwin/nam.php>) denoted as NAM⁻ to easy reference to the lead/lag relationship.
(**positive NAM⁻**: warmer polar vortex; **negative NAM⁻**: colder polar vortex)
- The **monthly anomalies** are from the ERA40 reanalysis data fields at 18 standard pressure levels from 1000 to 10 hPa 09/1957 to 08/2002 (Uppala et al. 2005).
- The **isentropic mass anomaly** fields are derived from the isentropic data fields of ERA40.



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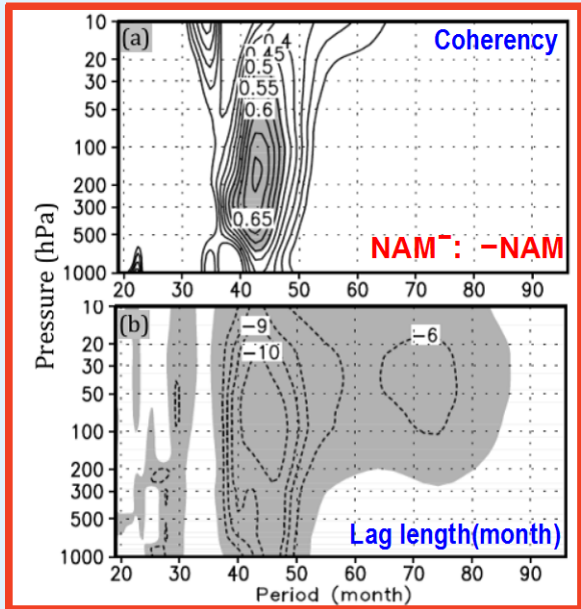
C. Temporal lagged relationship between ENSO and NAM⁻



C. Temporal lagged relationship



Cross Spectrum (Niño3 & NAM⁻)



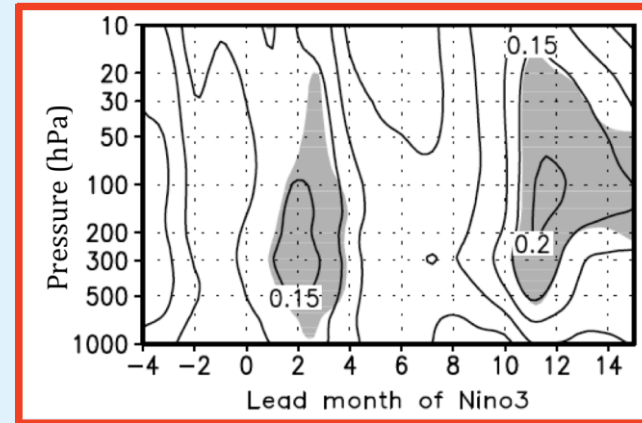
Negative: Niño3 lead

Lagged correlation

ENSO and the stratospheric NAM are significantly correlated at the timescale of about 3-5 year;

A weaker/stronger polar vortex is related to a warm/cold ENSO leading by about 10-11 months.

Lead/Lag Regression of NAM⁻



(Shading: 5% sig. level.)

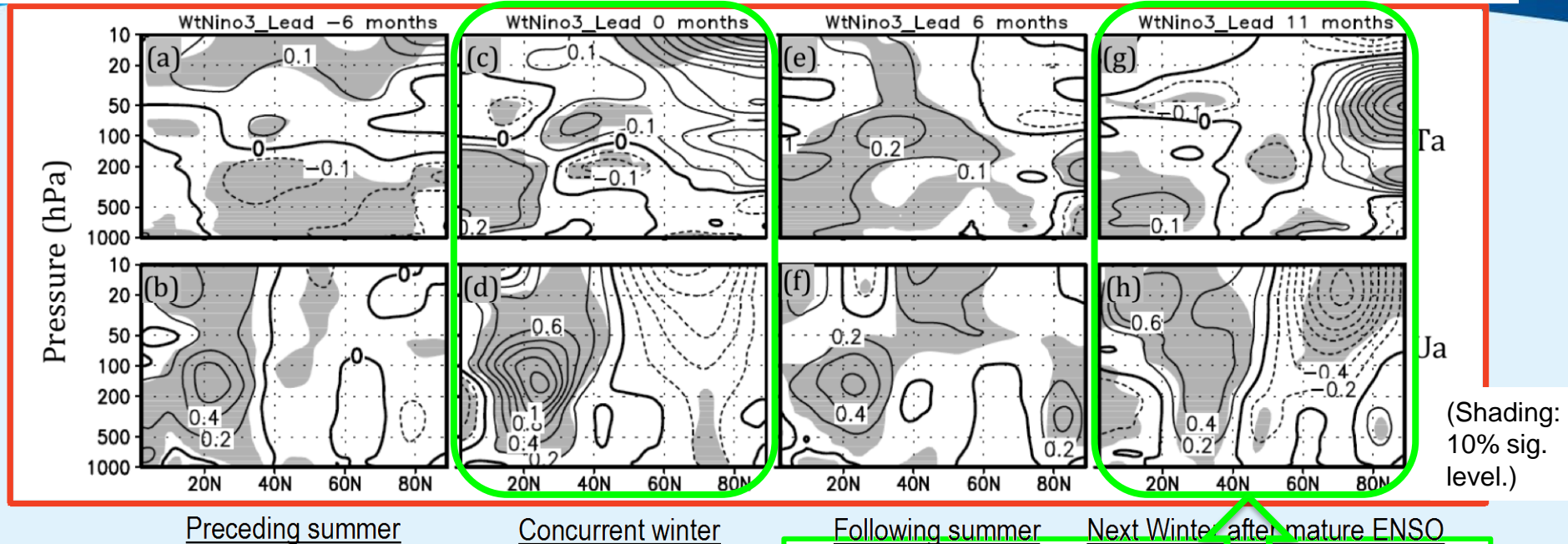
Delayed response

The maximum response of NAM in winter stratosphere to ENSO appears, rather than concurrently, but in the next winter season after the peak phase of ENSO.

C. Temporal lagged relationship

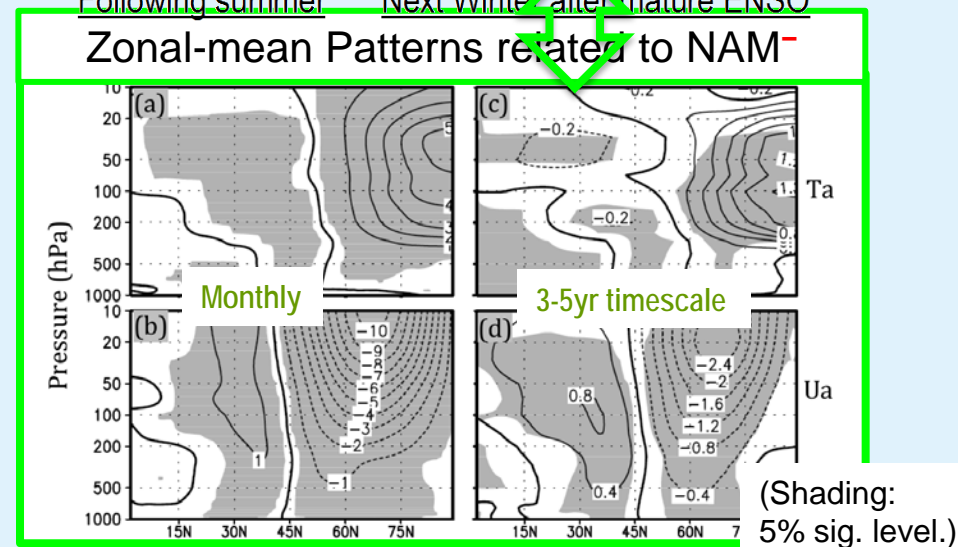


Lead/Lag Regression of Zonal-mean Ta and Ua against the winter Niño3 in 3-5 year timescale



NAM-related zonal-mean patterns:

Other than that in the concurrent winter, the ENSO-related zonal-mean patterns in the next winter after ENSO peak, is the strongest and exhibit a typical zonal-mean patterns of NAM-variability (or SSW event).



C. Temporal lagged relationship



Concurrent regression pattern of SSTa against Nino3

(a)

Leading regression of SSTa against the stratospheric NAM- at 11-months lag

(b)

ENSO-related SSTa patterns:

Part of the tropical ENSO SST variability is connected to the interannual variability of the winter stratospheric polar vortex in the next winter.

Mature warm/cold ENSO pattern tends to appear in the previous winter of a weaker/stronger stratospheric polar vortex.

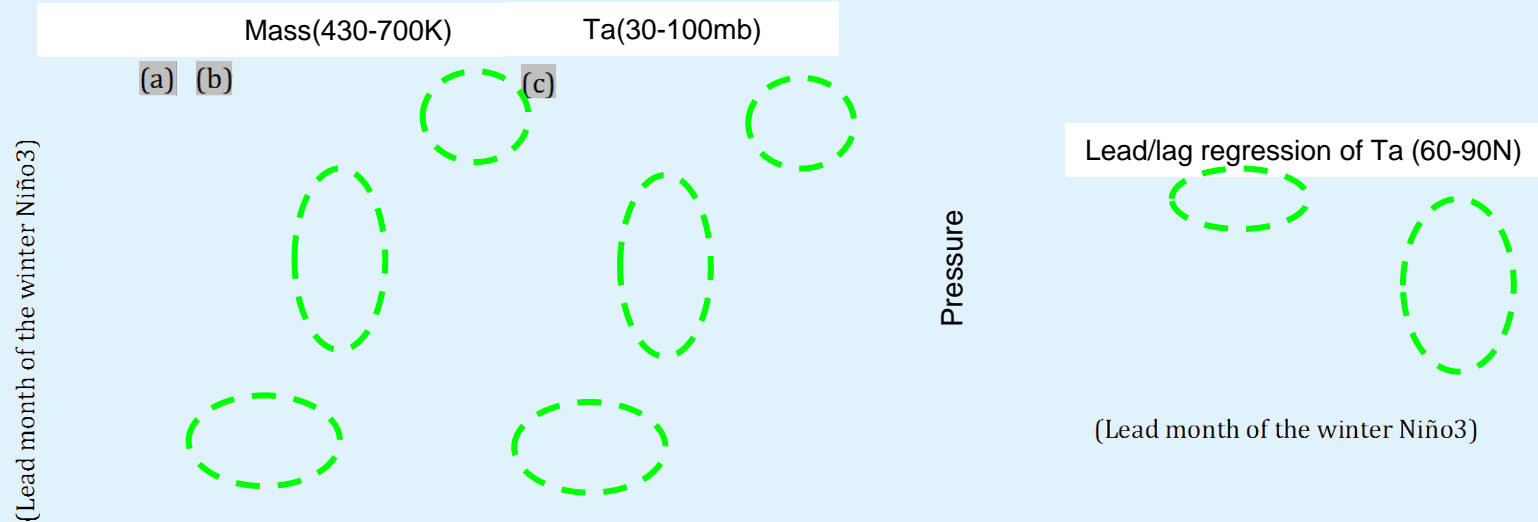


D. Possible mechanisms responsible for the lagged linkage



D. Mechanisms for the lagged linkage

ENSO-induced inter-annual variability of the NH global mass circulation

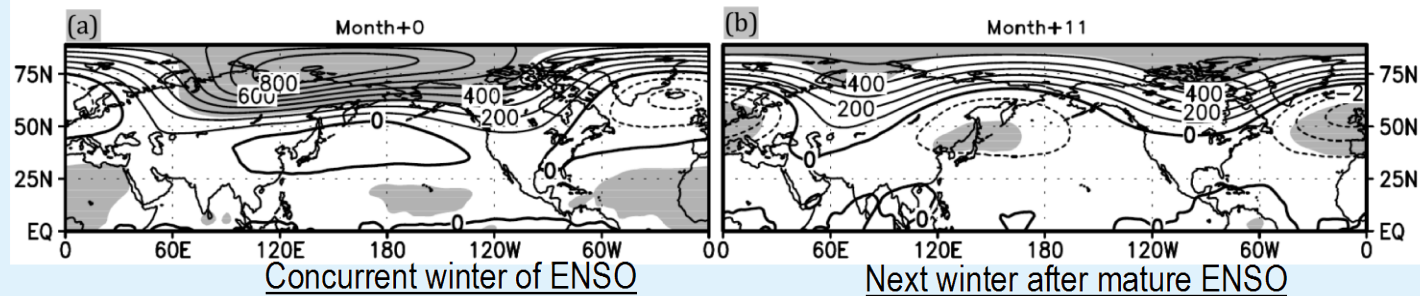


- Warm ENSO is related to poleward propagation of positive mass and temperature anomalies **from the tropics to the polar area** and from **the initiating stage** (previous winter) to **the ending stage** (next winter) of a warm ENSO, manifesting a strengthening of the poleward mass circulation in the stratosphere.
- The polar warming in the next winter is much stronger and with deeper vertical structure.

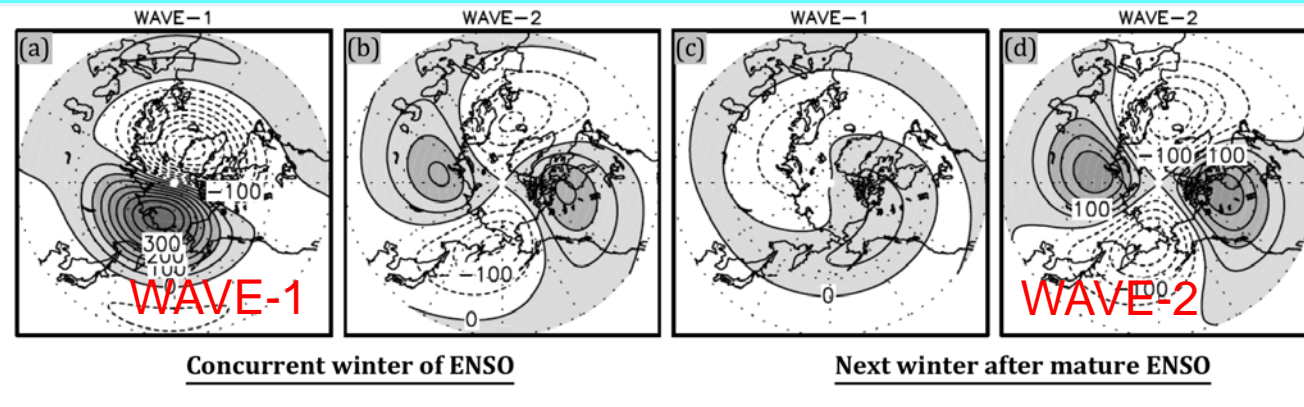
D. Mechanisms for the lagged linkage

Planetary waves in the concurrent and the next winter following warm ENSO

Regression of the winter Geo.potential height anomalies at 10hPa

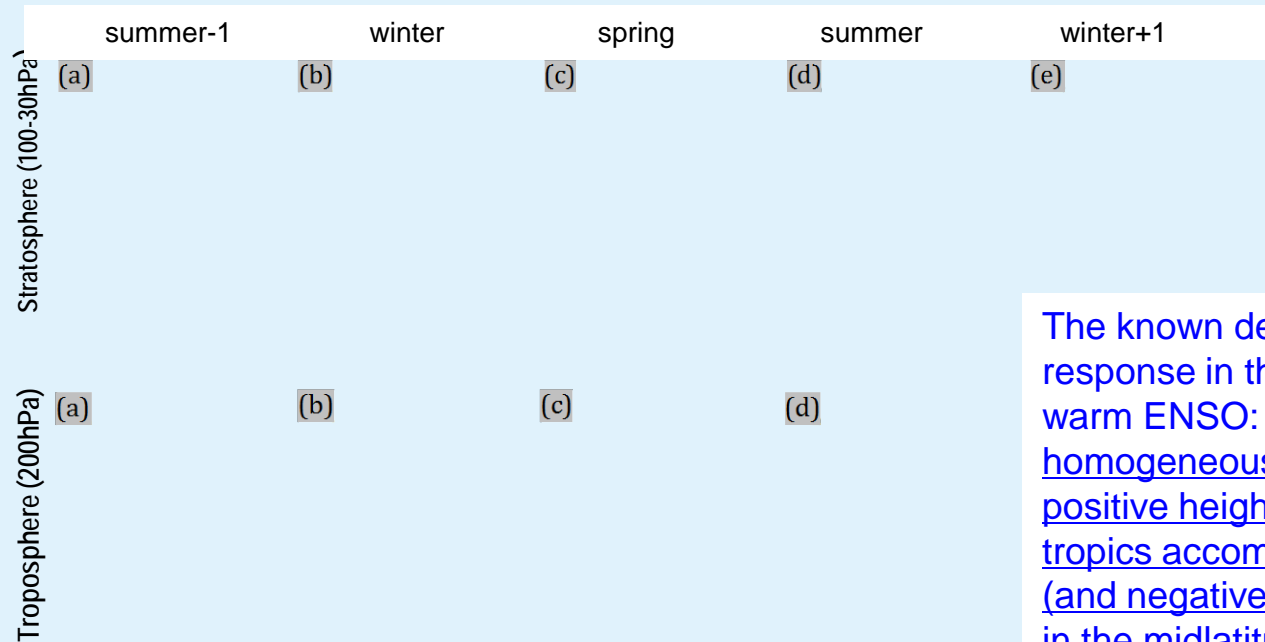


The polar stratosphere is dominated with **positive height anomalies** in both winters. An anomalous **Aleutian high** is induced in the **concurrent winter**, which increases the **wavenumber-1** of the anomalous planetary wave; **While in the next winter** after the ENSO peak, the winter stratosphere is dominated by an anomalous **wavenumber-2**.



D. Mechanisms responsible for the lagged relationship

The delayed warming response in the midlatitude stratosphere to warm ENSO

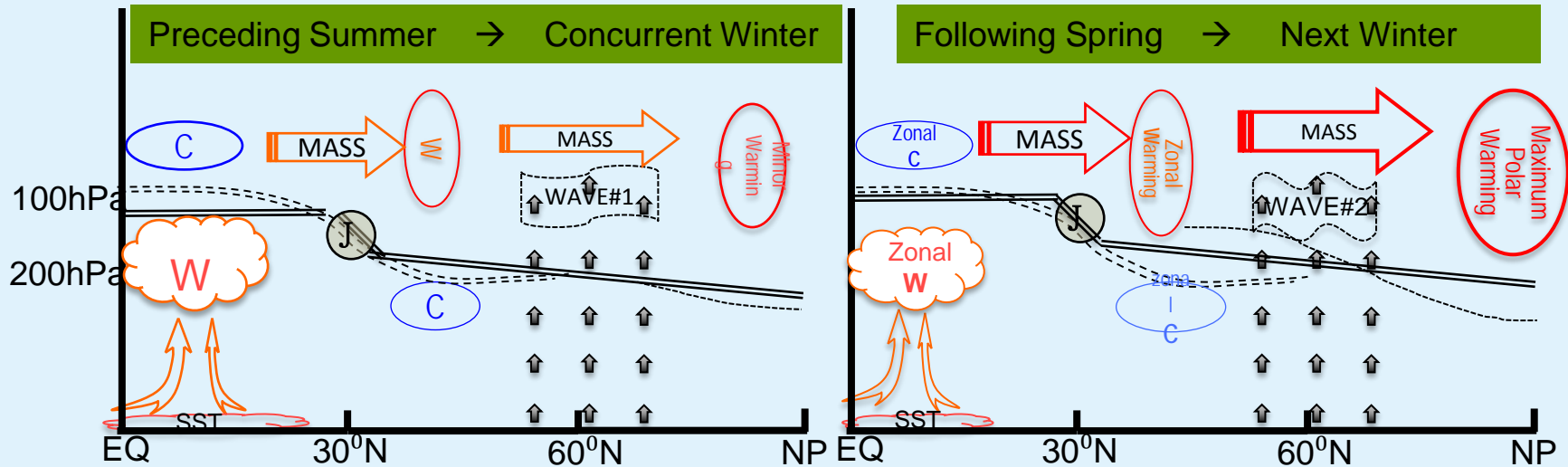


The known delayed atmospheric response in the troposphere to a warm ENSO: zonally homogeneous warming (and positive height) anomalies in the tropics accompanied with cooling (and negative height) anomalies in the midlatitudes (Kumar and Hoerling 2003; Lau et al. 2005).

Associated with the strengthened mass circulation, there is **zonally homogeneous warm anomalies persisting in the midlatitude stratosphere** from the preceding to the **following summer**, which is coupled with the cooling anomalies just below in the upper troposphere.

D. Mechanisms responsible for the lagged relationship

Schematics for the connection between ENSO and the stratospheric variability



Lead/lag regression of the zonal-mean wave-driven poleward heat flux at 60° N

Pressure (hPa)

(Lead month of the winter Niño3)



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E. Summary

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- ❑ **Significant lagged relationship** between ENSO and the stratospheric variability exists in timescale of about 3-5 year; **the stratospheric response to ENSO is stronger in the next winter** after a mature ENSO, than that in the concurrent winter;
- ❑ Following a warm ENSO, the extratropical stratospheric response in the concurrent winter is related to an **anomalous Aleutian high** (wavenumber-1) and the minor weakening of the polar vortex; While in the next winter, an **anomalous wavenumber-2** dominates the winter stratosphere and results in a maximum weakening of the polar vortex;
- ❑ Warm ENSO is associated with a **strengthening of the poleward mass circulation in the stratosphere**, represented by a **poleward propagation** of positive mass and temperature anomalies from the tropics to the polar area and from the initiating stage to the ending stage of a warm ENSO;
- ❑ There is **warm and positive mass anomalies persisting in the midlatitude stratosphere** from the preceding to the following summer relative to a warm ENSO peak, which contributes to the stronger poleward mass transport, and thus the maximum weakening of the polar vortex in the next winter.

Thanks

LASG , Institute of Atmos. Phys., C.A.S., China

Ren, et al, 2011, Observational evidence of the delayed response of stratospheric polar vortex variability to ENSO SST anomalies. ***Climate Dyn.***
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