Influence of ENSO on Stratospheric Variability, and the Descent of Stratospheric Perturbations into the Lower Troposphere

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Introduction

ENSO → strength of the stratospheric polar vortex

e.g., van Loon and Labitzke 1987; Hamilton 1993; Garcia-Herrera et al. 2006; Garfinkel and Hartmann 2008

Anomalous stratospheric polar vortex → North Atlantic-European (NAE) climate

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Hypothesis: ENSO/NAO linkage through stratospheric pathway

- **Li, Y.** and N.-C. Lau,: Influences of ENSO on stratospheric variability, and descent of stratospheric perturbations into the lower troposphere. *J. Climate*, in press.
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Data and Diagnostic tool

Data

- GFDL CM3
    - 800-yr pre-industrial control integration
    - atmosphere: 48 layers; model top 0.01 hPa
- ERA-40 Reanalysis (Sep. 1957 Aug. 2002)

Diagnostic tool

- Stationary wave field: $\overline{Z}^* = \overline{Z} - [\overline{Z}]$
- EP flux and its divergence:

$$F_\phi = -\rho_0 a \cos\phi [v^* u^*], \qquad D_F \equiv \frac{1}{\rho_0 a \cos\varphi} \nabla \cdot \mathbf{F},$$

$$F_z = f \rho_0 a \cos\phi \frac{[v^* \theta^*]}{[\theta]_z}. \qquad \nabla \cdot \mathbf{F} = \frac{1}{a \cos\phi} \frac{\partial}{\partial \phi} (F_\phi \cos\phi) + \frac{\partial}{\partial z} (F_z).$$

- Mass streamfunction: $\Psi_M = \frac{2\pi a \cos\phi}{g} \int_0^p [v] dp$

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Relationship between ENSO and stratospheric vortex anomalies

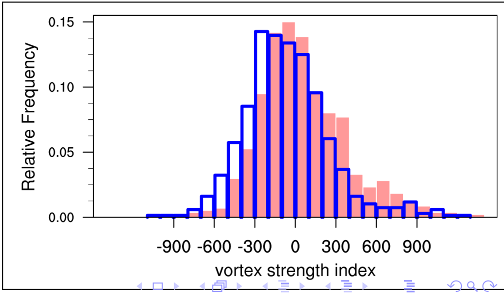
Identification of anomalous stratospheric polar vortex months

- Definition of Vortex Strength Index (VSI)
  monthly mean (from Nov to Mar), Z [70°–90°N, 3–30hPa]
- Months of weak (strong) stratospheric vortex:
  monthly mean VSI $>$ 90th percentile ($<$ 10th percentile) for the cold season (NDJFM)

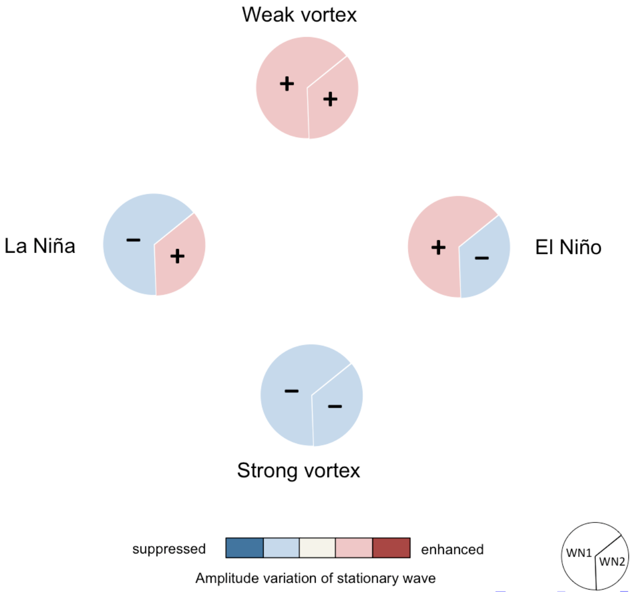
number of weak/strong vortex mo.

	weak	strong
El Niño	87	37
La Niña	47	103

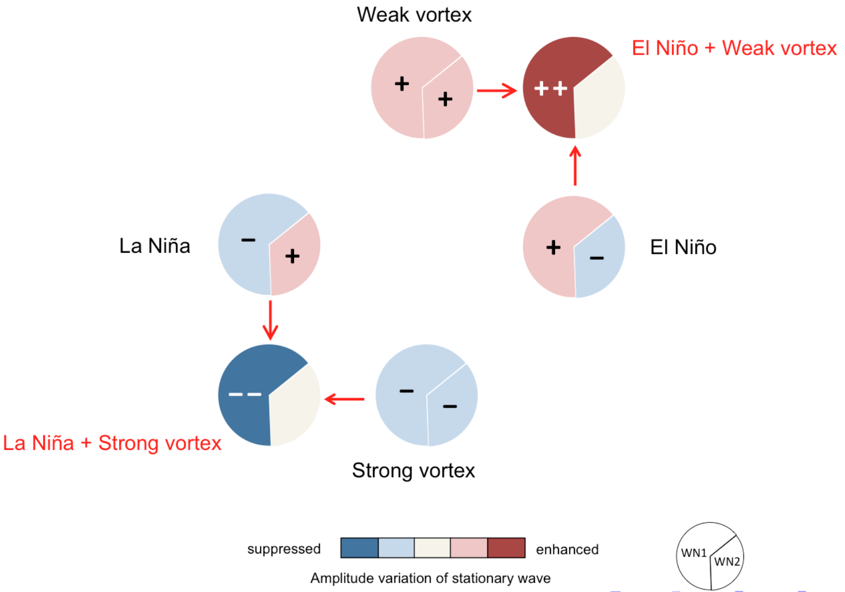
Relationship between ENSO and freq. of occurrence of weak/strong vortex



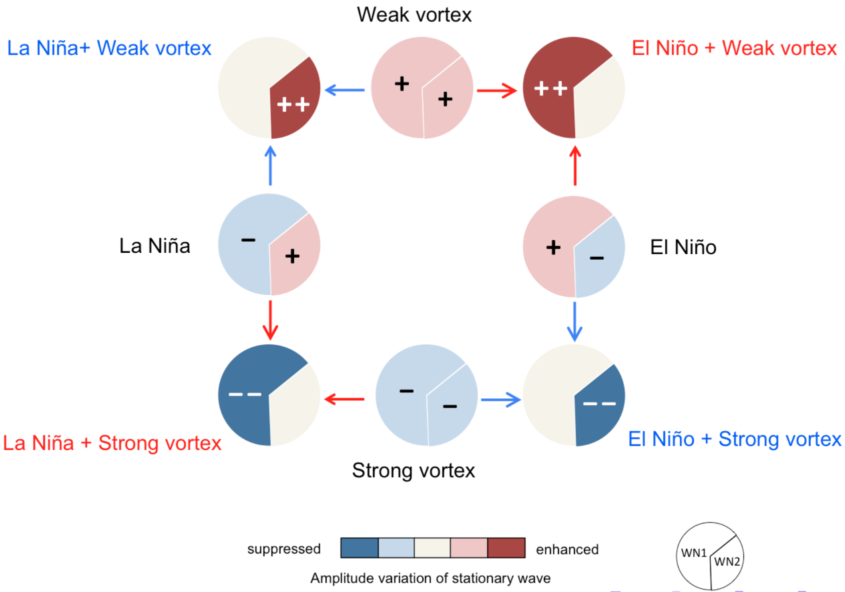
Combinations of the ENSO responses and precursors to polar vortex anomalies

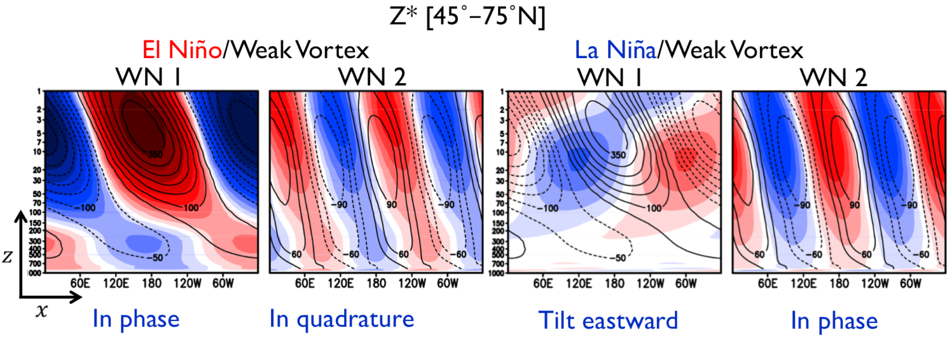


Combinations of the ENSO responses and precursors to polar vortex anomalies ("Wavenumber-1" combination)



Combinations of the ENSO responses and precursors to polar vortex anomalies ("Wavenumber-2" combination)





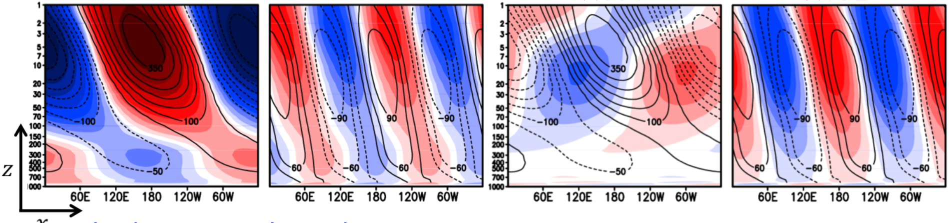
El Niño/Weak Vortex	preceded by enhancement	WN1
La Niña/Weak Vortex	of climatological stationary	WN2

Geopotential height anomaly precursors (Lag = −1 month)

Z^* [45°–75°N]

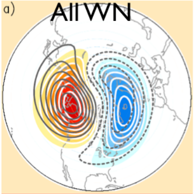
El Niño/Weak Vortex — WN 1, WN 2

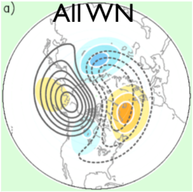
La Niña/Weak Vortex — WN 1, WN 2



In phase | In quadrature | Tilt eastward | In phase

Z^* 10hPa





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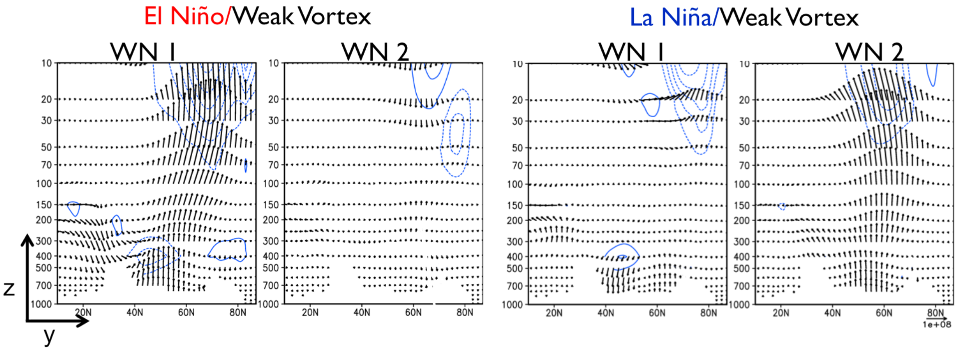
EP-flux Pattern (Lag = 0 month)

arrow: *EP* flux; contour: D_F



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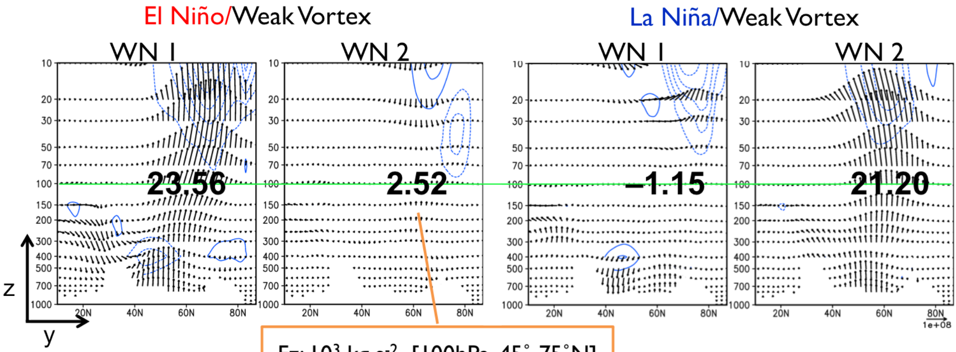


Fz: 10^3 kg s^{-2} [100hPa, 45°-75°N]

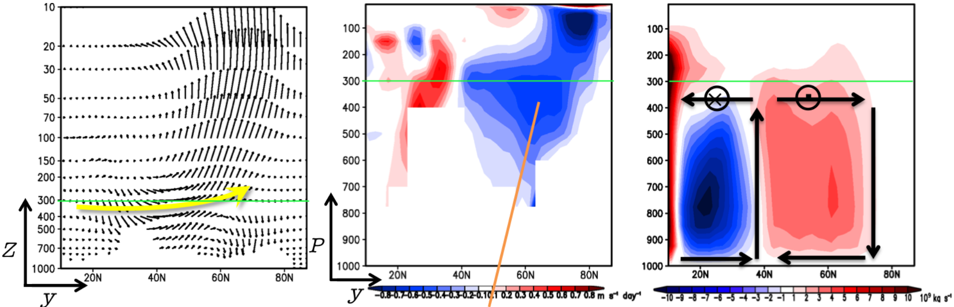
El Niño/Weak Vortex	driven by increased upward propagation of tropospheric stationary	WN1
La Niña/Weak Vortex		WN2

Relationship between wave propagation and zonal-mean meridional circulation (El Niño/Weak Vortex)

$F = (F_\phi, F_z)$
Lag $=$ 0 mo

$\frac{\partial}{\partial y}(F_\phi) \propto -\frac{\partial}{\partial y}(v^* u^*)$
Lag $=$ 0–1 mo

$\Psi_M = \frac{2\pi a \cos\phi}{g} \int_0^p [v] dp$
Lag $=$ 0–1 mo



Eddy mtm flux div. → easterly wind anm.

- F_ϕ bends strongly poleward
- dipolar pattern of eddy momentum flux convergence
- two-cell tropospheric overturning circulation

Relationship between wave propagation and zonal-mean meridional circulation (La Niña/Weak Vortex)

$F = (F_\phi, F_z)$ Lag $=$ 0 mo

$\frac{\partial}{\partial y}(F_\phi) \propto -\frac{\partial}{\partial y}(v^* u^*)$ Lag $=$ 0–1 mo

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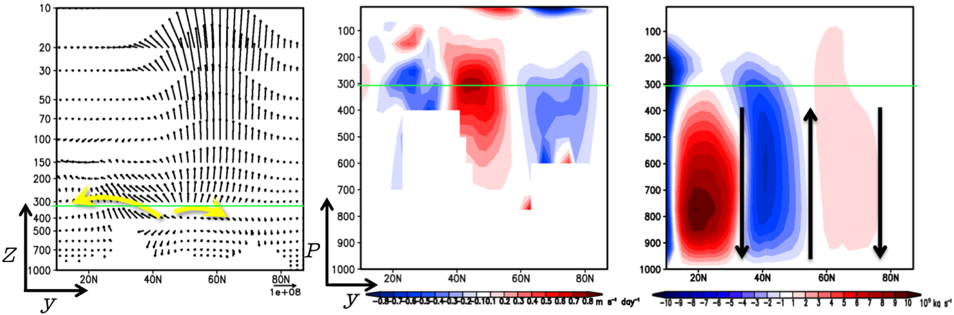
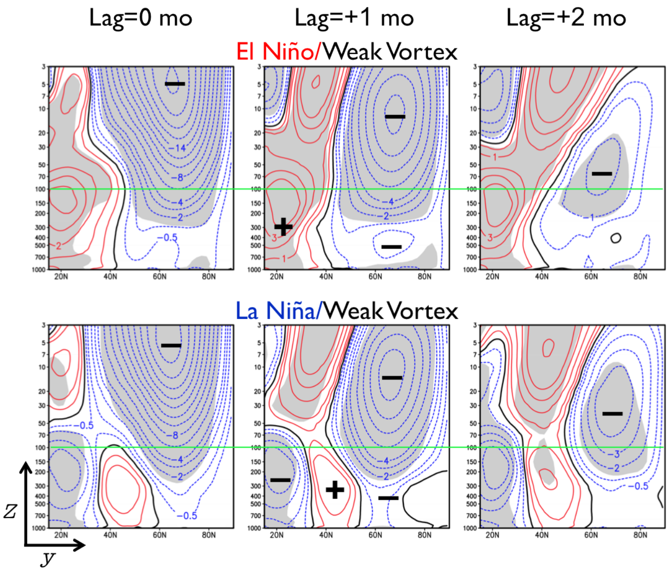


- F_ϕ refracts away from midlatitude towards both low- and high-latitudes
- tripolar pattern of eddy momentum flux convergence
- three-cell tropospheric overturning circulation

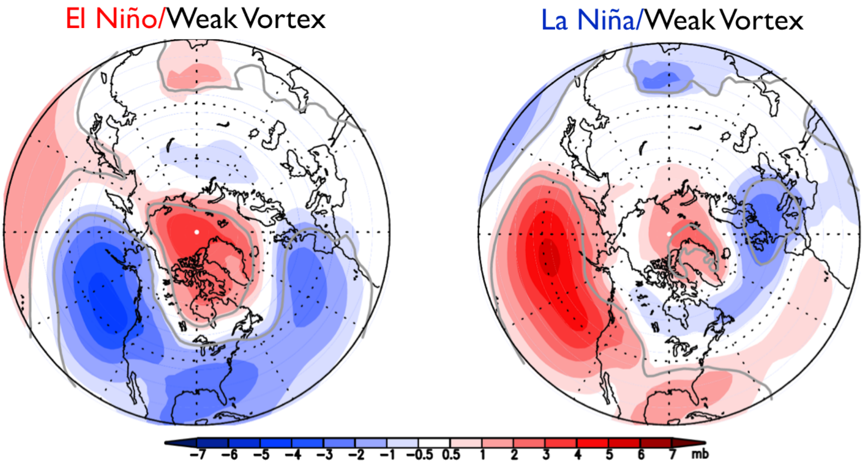
Responses of the zonal-mean zonal wind $[U]$



Similar descending of $[U]'$ in the stratosphere

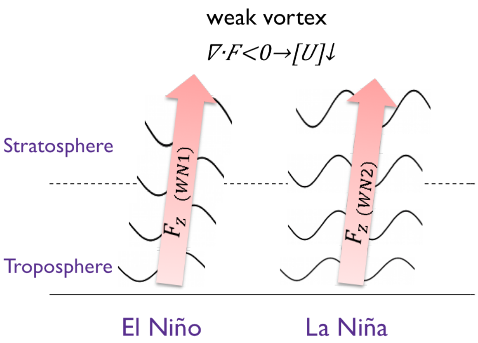
Different patterns of $[U]'$ (di-/tri-polar) in the troposphere

Responses of the SLP (Lag=0–2mo)



- Similar poleward part of the positive SLP anomaly is in phase with the weakened strength of the polar vortex
- different pattern of SLP anomaly (dipolar/tripolar) over N. Atl

Summary



- El Niño/Weak vortex month > La Niña/Weak vortex month
- The weak vortex during El Niño (La Niña) are driven by the increased upward propagation of the tropospheric stationary WN-1 (WN-2)
- North of ~60°N: $\nabla \cdot \mathbf{F} < 0 \rightarrow U \downarrow$ descend to the lower stratosphere
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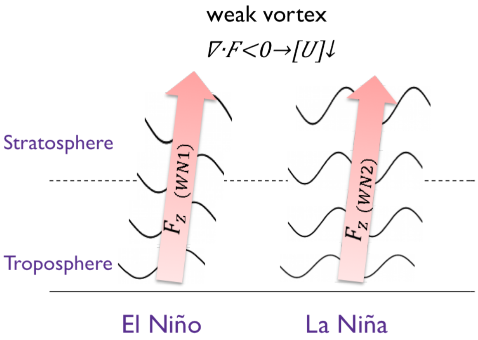

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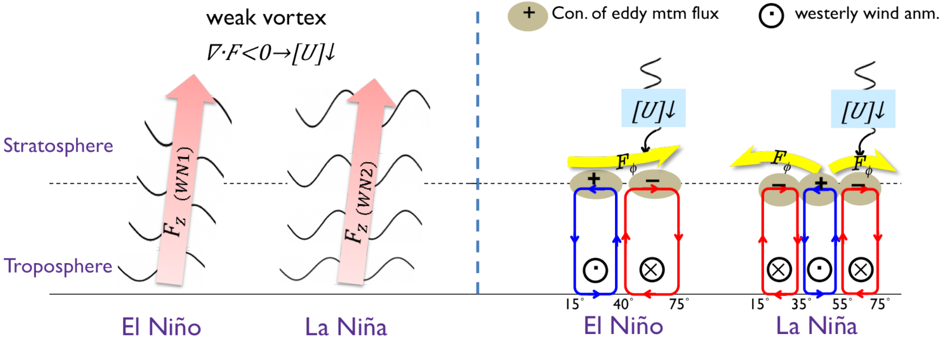

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