Stratosphere-Troposphere Dynamical Coupling and Tropospheric Predictability

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Tropospheric Response to SSWs

**Stratospheric Sudden Warming**

Delayed, *persistent* shift of jet stream equatorward

*[Baldwin and Dunkerton, 2001]*
Tropospheric Response to SSWs

- response not “deterministic”
- mechanism not clear

[Figure 1: Composite of 30 Strong Vortex Events]

1998 - 1999 Northern Annular Mode

[Figure 2: Approximate boundary between the troposphere and the stratosphere.]

[Figure 3: Average sea-level pressure anomalies (hPa) for (A) the 1800 days during strong vortex regimes and (B) the 1080 days during weak vortex regimes.]

[Composite of 18 Weak Vortex Events]

[Composite of 30 Strong Vortex Events]

[Baldwin and Dunkerton, 2001]
Mechanisms

1. downward control [e.g. Hartley, Villarin, Black & Davis 1998; Thompson, Furtado & Shepherd 2006]
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2. stratospheric signal mediated by tropospheric eddies
   [e.g. *Kushner and Polvani* 2004; *Song and Robinson* 2004; *Chen and Held* 2007]
Mechanisms

1. downward control [e.g. Hartley, Villarin, Black & Davis 1998; Thompson, Furtado & Shepherd 2006]
2. stratospheric signal mediated by tropospheric eddies [e.g. Kushner and Polvani 2004; Song and Robinson 2004; Chen and Held 2007]
3. local wave-mean flow interaction (not driven by stratosphere) [e.g. Plumb and Semeniuk 2003]
Establish the role of the stratosphere in tropospheric response to SSWs

- Prior studies: perturb/modify the stratosphere above, observe the response below [e.g. Boville 1984; Norton 2003; Charlton, O’Neil, Lahoz & Massacand 2004]

- Here we perturb troposphere below to “erase” tropospheric memory following an SSW. Is the tropospheric response destroyed, or does the signal come from above?
Idealized Model Framework

- full GCM dynamics, simplified forcing
- captures SSWs, tropospheric response

NAM composite of o(100) events

[Polvani and Kushner, 2002; Gerber and Polvani, 2008]
Idealized Model Framework

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NAM composite of o(100) events

[Polvani and Kushner, 2002; Gerber and Polvani, 2008]
Ensemble Forecasting

- long control integration

polar vortex strength

major + minor warming events
Ensemble Forecasting

- long control integration
- determine warming events dates

polar vortex strength
Perturb Troposphere

- vorticity field perturbations
- confined to lower troposphere

![Graph showing perturbation horizontal and vertical structures with no perturbation in the stratosphere.](image)

**Note:** The graph illustrates the perturbation horizontal and vertical structures across various latitudes and longitudes. The color bar indicates the magnitude of the perturbation, with no perturbation observed in the stratosphere.
Ensemble Forecasting

- long control integration
- determine warming events dates
- launch perturbation integrations

Polar vortex strength

\[ \bar{u}_{60^\circ N, 10 \text{ hPa}} \text{(m/s)} \]
Ensemble Forecasting

- long control integration
- determine warming events dates
- launch perturbation integrations
- couple multiple realizations of the troposphere to one stratospheric event

polar vortex strength

\( \bar{u}_{60^0N, 10 \text{ hPa}} \) (m/s)
Stratospheric Predictability

- Stratospheric circulation more "predictable" after an SSW event: slow recovery

- polar vortex strength

\[ \bar{u}_{60^\circ N, 10 \text{ hPa}} \text{ (m/s)} \]
Stratospheric Predictability

- stratospheric circulation more “predictable” after an SSW event: slow recovery
- more limited predictability at other times

polar vortex strength
Stratospheric Predictability

black: control integration
colors: ensemble mean response

polar vortex strength

$\bar{u}_{60^\circ}N, 10$ hPa (m/s)

days

0
Stratospheric Predictability

black: control integration

colors: ensemble mean response

polar vortex strength

\( \bar{u} 60^\circ N, 10 \text{ hPa} \text{ (m/s)} \)
black: control integration

colors: ensemble mean response

Stratospheric Predictability

polar vortex strength

-20
-10
0
Stratospheric Predictability

black: control integration

colors: ensemble mean response

polar vortex strength

$\bar{u} 60^\circ N, 10 \text{ hPa (m/s)}$
Stratospheric Predictability

black: control integration
colors: ensemble mean response

polar vortex strength

$\bar{\mathbf{u}}$ $60^\circ$N, 10 hPa (m/s)

-100 0 150

days
Stratospheric Predictability

black: control integration

colors: ensemble mean response

SSW lost for leads >20 days
Tropospheric Predictability

SLP', day 0 (hPa)

SLP', day 50 (hPa)

run 1

run 2

run 3
Scrambling the Troposphere

ensemble spread of EKE at 250 hPa

ensemble spread of SLP

ensemble members completely randomized
Tropospheric Response to SSW

NAM index, control integration hPa
Tropospheric Response to SSW

NAM index, control integration

ensemble member, no response
Tropospheric Response to SSW

NAM index, control integration

ensemble member, no response

ensemble member, strong response
Robust Tropospheric Response

NAM index composite, 90 ensemble members

statistically significant response (>95%) in the troposphere
Summary and Conclusions

- ensemble forecasting framework for SSW events

![Graph showing polar vortex strength](image)
Summary and Conclusions

- ensemble forecasting framework for SSW events
- analyze stratospheric predictability

*How predictable are SSWs?*

*enhanced predictability after an SSW event*
Summary and Conclusions

perturbations erase tropospheric memory

\[ \downarrow \]

equatorward shift in tropospheric jet driven by stratosphere