Tropospheric Response to Stratospheric Sudden Warmings in a Simple Global Circulation Model

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Importance of SSWs in S Variations

Frequency distributions of monthly-mean 30-hPa polar temperature

SSWs reflected in extreme temperatures
Importance of SSWs in T-S coupling

- SSWs may involve two-way T-S coupling.
  - Upward propagation of enhanced planetary waves
  - Downward propagation of S anomalies
  - S anomalies followed by anomalous T weather regimes

(Baldwin & Dunkerton 2001)
This study

- Use of mechanistic circulation models (MCMs) relative to obs. & GCMs
  - Obs. & GCMs
    Limited # of samples, coexisting various processes
  - MCMs
    Large # of samples, only dynamical processes

- This study
  Composite analysis of 132 SSWs in 10,000-day MCM run to understand nature of T-S coupling:
  - T circulation changes before & after SSWs
  - Interaction between planetary & synoptic waves
  - Relationship between SSWs & following T anomalies
  ⇒ Insights to T-S coupling in real SSWs
Model

- 3D primitive-equation model for globe
- Resolution: T21, L42
  \[\Rightarrow\] basic features of synoptic waves
- Simplified physical processes
  - Newtonian thermal relaxation to perpetual winter condition
  - Rayleigh friction at surface
  - Dry atmosphere
- Sinusoidal surface topography
  - Amplitude 1000 m
  - Zonal wavenumber 1
Model climatology (for 1000 days)

- [ ]: zonal mean
  - -: time mean

- Zonal mean temperature
- Zonal mean zonal wind
- Large S variability ~ SSWs
- Polar night jet
strarospheric Variability

SSW periods & key days ↓

⇒ Intermittent occurrence of SSWs

Define SSW events with the time series for composite analysis:
1. Search for periods when [T] is higher than time mean
2. Judge if maximum [T] in each period is higher than 270 K
⇒ 132 SSWs in whole 10,000 days

Results are robust, independent of subjective values
General Features of SSW Sequence

- Composites shown in anomalies normalized with $\sigma$
- Strong warming
- Upward propagation of enhanced PW
- SSW signals propagate downward for a month or longer
- Weaker-than-normal PW activity
- PNJ deceleration
General Features of $[U]'$ & $F'$ (QG EP flux) for WN1

Poleward & downward propagation of $[U]'$ incl. SSW signal

Enhancement of upward propagation of PW

Weakening of upward propagation

Normalized
Define pre- & post-SSW periods

T circulation is quite different before and after SSWs.

- **pre-SSW**: lag = $-7 \pm 5$ days
  - PW stronger than normal
- **post-SSW**: lag = $-20 \pm 5$ days
  - PW weaker than normal
Z*₁ (WN1) @ 254 hPa

(Composites shown in anomalies)

(a) CLIM.  (b) pre-SSW  (c) post-SSW

In-phase to climatology ⇒ amplification

Off-phase ⇒ Weakening + phase shift
Geostrophic wind relationship: $U^*$ reflect wave-1 $Z^*$

Zonal mean + all WNs

254 hPa

$Z^*_{1}$ (WN1)
254 hPa

\( \mathbf{U^*} \)
(zonal mean + all WNs)

Zonal wind regulates spatial distribution of SW activity

Variance of GPH of SWs (waves 4-10)
254 hPa

**U**
(zonal mean + all WNs)

**SWs act to maintain wave 1 zonal wind**

Zonal wind accel. by SWs:
Div. of 3D EP flux

Region $>20^\circ$ for $U^*$ (N>600) (Div. shifted by 5.6°)

$R=0.34$

$R=0.25$
Obtained SSW sequence

SSW

Wave 1

Stratosphere

Troposphere

Impose stronger damping

Upward PW propagation

Amplification

What happens?

Effect of SSWs?

Weakening

Lag = 0 day

Time
Procedures for Branch Runs

Lag = 0 day (SSW)

In branch runs, we can look at how T changes after we damp SSW signals for 10 days.
Thermal Relaxation Time for Branch Runs

Control

Branch

Identical in T
Choose one particular SSW event

Composites of 132 events

Broadly similar ⇔

(color bars different)
Control vs Branch Runs

SSW signals damped

Shorter relaxation time

PW signals in T change with damping of SSW signals

PW Weakening appears only following long-lasting SSW signals

CTL

BRN
Conclusion

Nature of dynamical T-S coupling associated with SSWs
Composite analysis of 132 SSWs in 10,000-day MCM run

- Basically Similar Features to obs. & GCM results
- Diagnosis of T Circulation before and after SSWs
  Interaction between PW & SWs
  ⇒ “positive feedback”
- PW Signal in T after SSWs
 Appears only following long-lasting SSW signals
  ⇒ tropospheric response to SSWs

To summarize T-S coupling in this model,
PW in T, interacting with SWs (and also mean flow),
responds to SSWs which the wave itself induces.