Sudden Stratospheric Warmings and anomalous upward wave activity flux

Thomas Birner
John Albers* & Jeremiah Sjoberg**

Department of Atmospheric Science, Colorado State University
*CIRES, NOAA ESRL
**now at COSMIC, UCAR
Sudden stratospheric warmings
Abrupt Polar Stratospheric Circulation Changes
Sudden Stratospheric Warmings (SSWs)

- zonal mean zonal wind @ 10 hPa, 60 N falls below zero (westerly → easterly)
- see Butler et al. (BAMS, 2015) for details, comparisons with other definitions, discussion
- 26 events between 1979 – 2015
Abrupt Polar Stratospheric Circulation Changes

Deceleration Events

- Based on zonal mean zonal wind (U) at 10 hPa, averaged over 45–75 N
- **Deceleration Event** = 10-day change in U falls below –20 m/s (during November – March)
- 29 events between 1979 – 2015 (ERA-interim)
- similar to NAM-tendency index by Martineau & Son (2013)
Quasi-linear Theory – Matsuno (1971)

- Linear wave propagation on the sphere, combined with (non-linear) wave-mean flow interaction
- Switch-on wave forcing prescribed at lower boundary
- Initial value problem for non-linear transient wave-mean flow evolution

**Wave 2 Forcing**

![Wave 2 Forcing Graph](image)

Fig. 3. The amplitude of the waves forced at the lower boundary (solid line). The dashed line shows the observed amplitude of the $m=2$ wave at 300 mb in January–February 1963, (data from Dr. Hirota).
• Clark (1974): 'tuning' vortex geometry to support resonance
• Resonance mechanism hinges on positive feedback between waves and mean flow
• Tung & Lindzen (1979): waves in resonance with topographic forcing
• Scott & Polvani (2004, 2006): SSW-like events can arise due to internal stratospheric dynamics

→ is a burst of wave activity flux from the troposphere needed to trigger a SSW?

→ response to stratospheric zonal wind perturbation:

- Constant incoming wave forcing at lower boundary
- Imposed initial stratospheric deceleration → SSW
29 deceleration (SSD) events
wind tendency & upward wave activity flux

Colors: anomalous wind tendency (m/s/day)
Black Contours: anomalous wave 1+2 upward EP flux (Pa m/s²)
29 deceleration (SSD) events
wind tendency & upward wave activity flux

Colors: anomalous wind tendency
Black Contours: anomalous wave 1+2 upward EP flux
→ ~25% of wave 1 upward wave activity flux past 100 hPa (~10% for wave 2)
Example: January 1987 deceleration / SSW event
Standardized wind tendency & wave 1 upward EP-flux
Example: February 1979 deceleration / SSW event
Standardized wind tendency & wave 2 upward EP-flux
• Wave 2 dominates in lower troposphere in climatology

• But wave 1 dominates in forcing variability in the stratosphere!

→ significant enhancements of tropospheric wave 1 are not necessarily strongly anomalous w.r.t. wave 1+2 climatology
Upward Wave Activity Flux Events

• Based on upward EP flux of a given wave number and at a given level, as before averaged over 45–75 N

• Wave Event = 10-day averaged upward EP flux exceeds two standard deviations (during November – March, 1979 – 2015, ERA-interim)

• Here: lower tropospheric wave events (at ~700 hPa), 20 wave 1 events, 31 wave 2 events
Events in lower tropospheric upward wave activity flux

20 Wave 1 Events

wave 1 & deceleration event

Colors: wind tendency, normalized by std dev

Contours: upward wave activity flux (wave 1), normalized by std dev

(as before everything averaged 45-75 N and for Nov-Mar)
Events in lower tropospheric upward wave activity flux

20 Wave 1 Events

wave 1 & no deceleration event

Colors: wind tendency, normalized by std dev

Contours: upward wave activity flux (wave 1), normalized by std dev

(as before everything averaged 45-75 N and for Nov-Mar)
Events in lower tropospheric upward wave activity flux

20 Wave 1 Events

Colors: wind tendency, normalized by std dev

Contours: upward wave activity flux (wave 1), normalized by std dev

(as before everything averaged 45-75 N and for Nov-Mar)
Events in lower tropospheric upward wave activity flux

31 Wave 2 Events

Colors: wind tendency, normalized by std dev

Contours: upward wave activity flux (wave 1), normalized by std dev

(as before everything averaged 45-75 N and for Nov-Mar)
Conclusions

- Explosive growth of wave activity flux in stratosphere triggered by initial mean flow perturbation ("internal feedback")

- In some cases also burst of wave activity from the troposphere ("external feedback")

- Crucial dynamics appear to take place in the lowermost stratosphere (mostly between 300-200 hPa: "communication layer")

- Interpreting upward wave activity flux at 100 hPa as "input from the troposphere" is misleading