Elevated stratopause and mesospheric intrusion following a stratospheric sudden warming in WACCM

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Behavior of the stratopause during SSWs

✓ descent of the polar stratopause during SSW
(e.g. Labitzke et al., 1972; Von Zahn et al., 1998)

✓ mesospheric coolings associated to SSWs, forced by eastward GWs
(e.g. Holton, 1993; Liu and Roble, 2002; Siskind et al., 2005; Hoffman et al., 2007; Ren et al., 2008; Yamashita et al., 2010)

Nevertheless, recent satellite observations have revigorated the study of the behavior of the polar stratopause during and after SSWs:

→ occurrences of abrupt stratopause ”jumps”: re-formation of an elevated stratopause at standard mesospheric altitudes

→ followed by strong mesospheric descent as the stratopause returns to its climatological altitude
Stratopause “jump” in MLS T observations 2009

Manney et al. [2009] using MLS (top) and GEOS-5 assimilation (bottom)
During these 3 SSWs:

high-altitude stratopause re-formation followed by descent (here seen in H2O)

MESOSPHERIC T and H₂O from Odin/SMR elevated polar stratopause

20-21 JAN 2004

7-8 FEB 2006

22-23 FEB 2009

75km

85km

50km
Key issue that we address here:

the respective roles of planetary and gravity waves in

- forcing the displacements of the stratopause
- driving the anomalous mean meridional circulation during these SSWs events
The Whole Atmosphere Community Climate Model (WACCM3.5) from NCAR

- New gravity wave parameterization to account for several sources of GWs: not only orographic, but also convective and frontal waves
- New turbulent mountain stress parameterization to account for effect of unresolved orography

As shown by Richter et al. (J. Atmos. Sci., 67, 136, 2010; Garcia R., Chapman conference AGU 2011), these WACCM 3.5 simulations show

- a more realistic (higher) frequency of occurrence for SSWs
- Numerous SSW events with stratopause "jumps"
The Whole Atmosphere Community Climate Model (WACCM) from NCAR

- look in detail at one SSW event identified in the WACCM CCMVAL run over 1954-2005: model year (1979-80)

- we performed a 6-month branching run with more complete output (3-hourly chemistry+dynamics)

- Horizontal resolution of 1.9° latitude by 2.5° longitude
- 66 vertical levels (ground to ~140 km)
- CCMVAL run covering the period
SSW 1979/80 in WACCM

Zonal Wind

Temperature

Total Wave Forcing

$w^* (\text{mm/s})$

$\uparrow$ Mesospheric coolings
Roles of PWs and GWs

Total Wave Forcing

Resolved Wave (~PW)
(blue: westward)

Frontal
(red: eastward)

Parametrized GWD

Orography
(shutdown during SSW)
Roles of PWs and GWs

1) Prior and after the SSW: GWs drive the poleward and downward ("normal") circulation, responding to a westward forcing.

2) Eastward gravity waves play a role in initially re-establishing the vortex: they drive an equatorward and upward circulation (mesospheric coolings), responding to eastward forcing.

3) Planetary waves in upper mesosphere force the initial downward motion of the stratopause, before westward GWs are allowed to propagate again.

(Note: this is an upper-mesospheric wave-1 not the stratospheric wave-2 responsible for the warming.)
To look in detail at one SSW event identified in the WACCM CCMVAL run: model year (1979-80):

- mesospheric ozone
- descent of CO into the stratosphere
Plunging stratopause prior to the high-altitude re-formation: use of CO as "mesospheric tracer"

- CO winter descent interrupted by SSW: "Hook"-pattern
- Stronger mixing aloft at time of jump leads to a cut-off CO intrusion "blob"
- CO-rich air of mesospheric origin isolated in the mid-stratosphere at 60N
Conclusions related to dynamics
(based on a detailed study of a stratopause jump event in WACCM)

• GWs of frontal origin plays key role in such events: contribute to mesospheric coolings, to initial lower mesospheric vortex recovery and stratopause descent, and to ascent in lower thermosphere

(see also Chandran et al., GRL, 2011)

• Nevertheless, PWs first drive the mesospheric descent of the elevated stratopause, followed by the GW contribution

  • Nature of the PW-1 in upper mesosphere still unclear: could arise from the interaction of GWs and PWs (Smith A., 1996), or from in-situ instabilities

• PWs also drive the plunge of the polar stratopause down to mid-stratosphere

Conclusions related to transport of minor species
(based on a detailed study of a stratopause jump event in WACCM)

• strong decrease in amplitude of O\textsubscript{3} secondary maximum at time of the stratopause jump

• fluctuations in altitude of O\textsubscript{3} tertiary maximum
  (GW-induced feature linked to w*)

• "Cut-off" intrusion of high CO into the mid-latitude stratosphere