

Mesosphere/Stratosphere Coupling during Major Sudden Warnings

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GOALS

- ❑ Examine the coupling between stratosphere-mesosphere-lower thermosphere (MLT) during SSWs

[Limpasuvan, Richter, Orsolini et al., JASTP 2012; Chandran et al., ASR 2013]

- ❑ Major SSW with Elevated Stratopause Events (ESE)

[Manney et al., JGR 2009; Orsolini et al, JGR 2010]

- ❑ Important for transport of trace species (e.g. NOx) into stratosphere, for ozone chemistry

[Kvissel, Orsolini et al., JASTP 2012; Tweedy, Limpasuvan, Orsolini et al, JGR 2013]

MODELLING TOOL

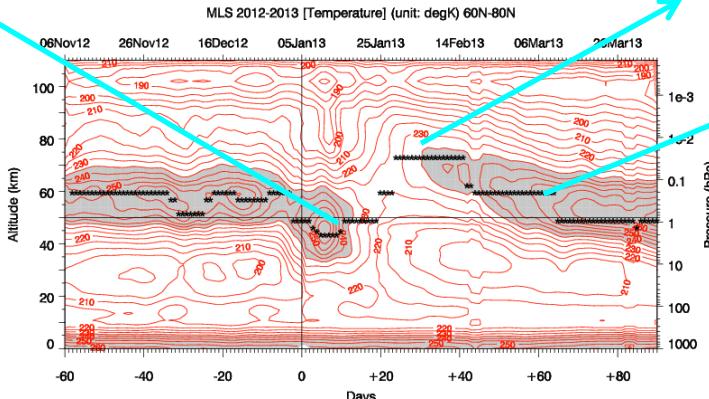
NCAR Whole Atmosphere CCM (V4) → WACCM

- 1.9° latitude X 2.5° longitude; up to ~130 km
- GW drag parameterization (convection, fronts, orography)
- WACCM-SD : Specified Dynamics (nudged) → up to about 50km, free running model above (incl. MLT region!)
- Simulation period: 1990-2013 (3-hourly output); Oct. 1 to Apr. 15

Observed Elevated Stratopause Event (ESE) in 2012/13

Aura MLS Satellite Observations

Plunging of polar stratopause down to 30km

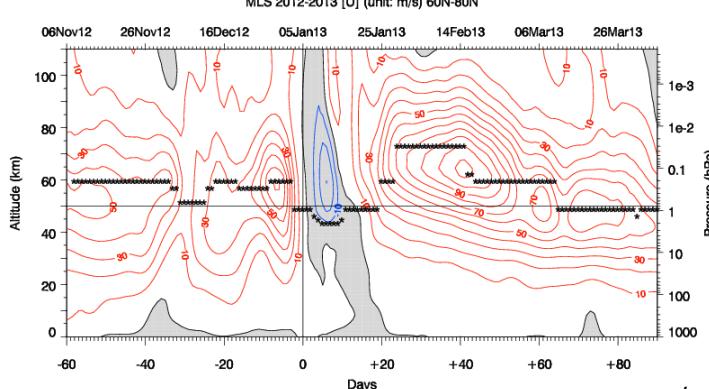


Re-formation of elevated stratopause near 75km – Strong descent

Strong descent

Temperature

SSW on 6 JAN 2013



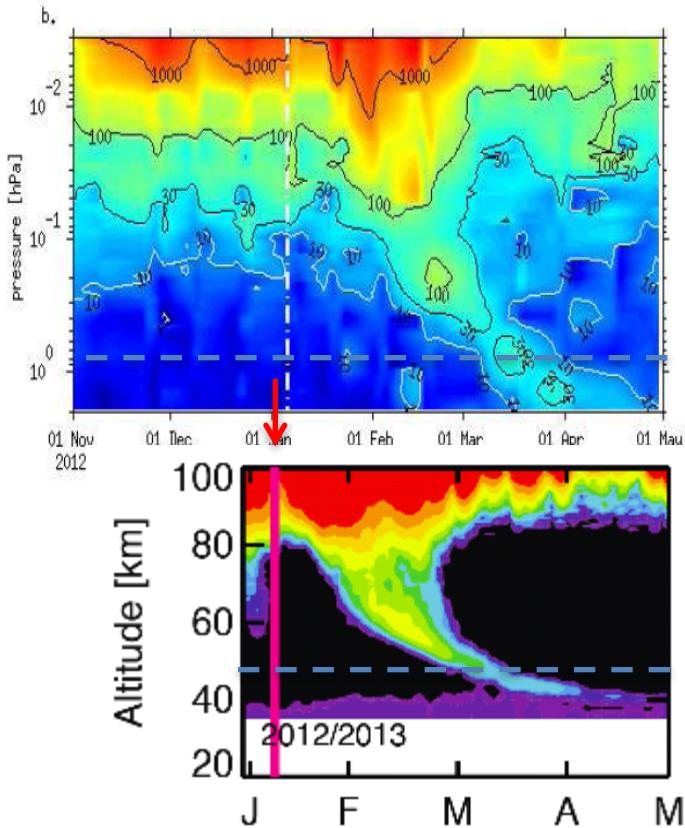
Geostrophic Zonal Wind

$t=0$: day of [U] reversal at 50km

Observed Elevated Stratopause Event (ESE) in 2012/13

Satellite Observations of Nitric Oxide (NO)

**Strong descent
of NO into
stratosphere**

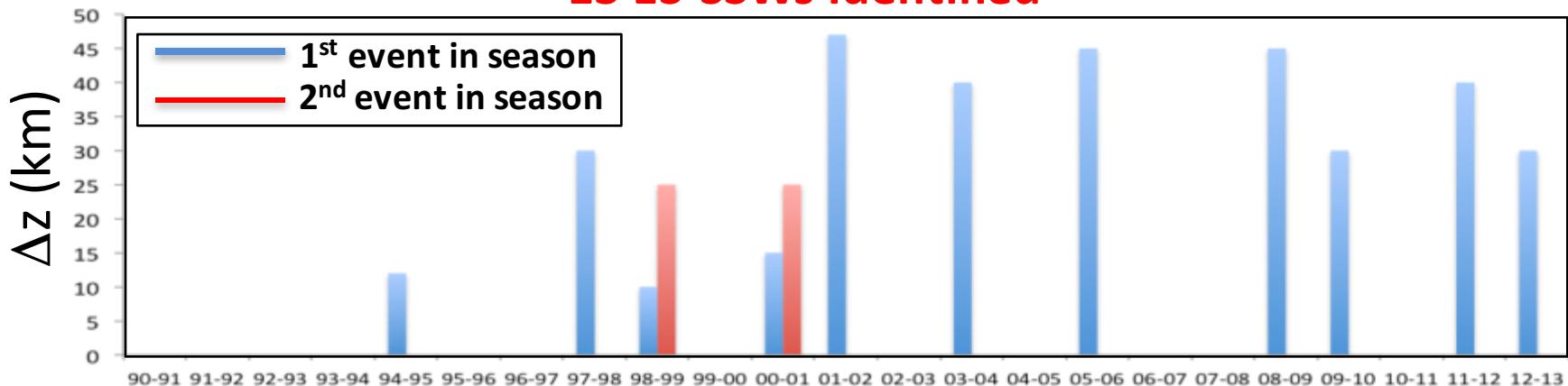


METHOD

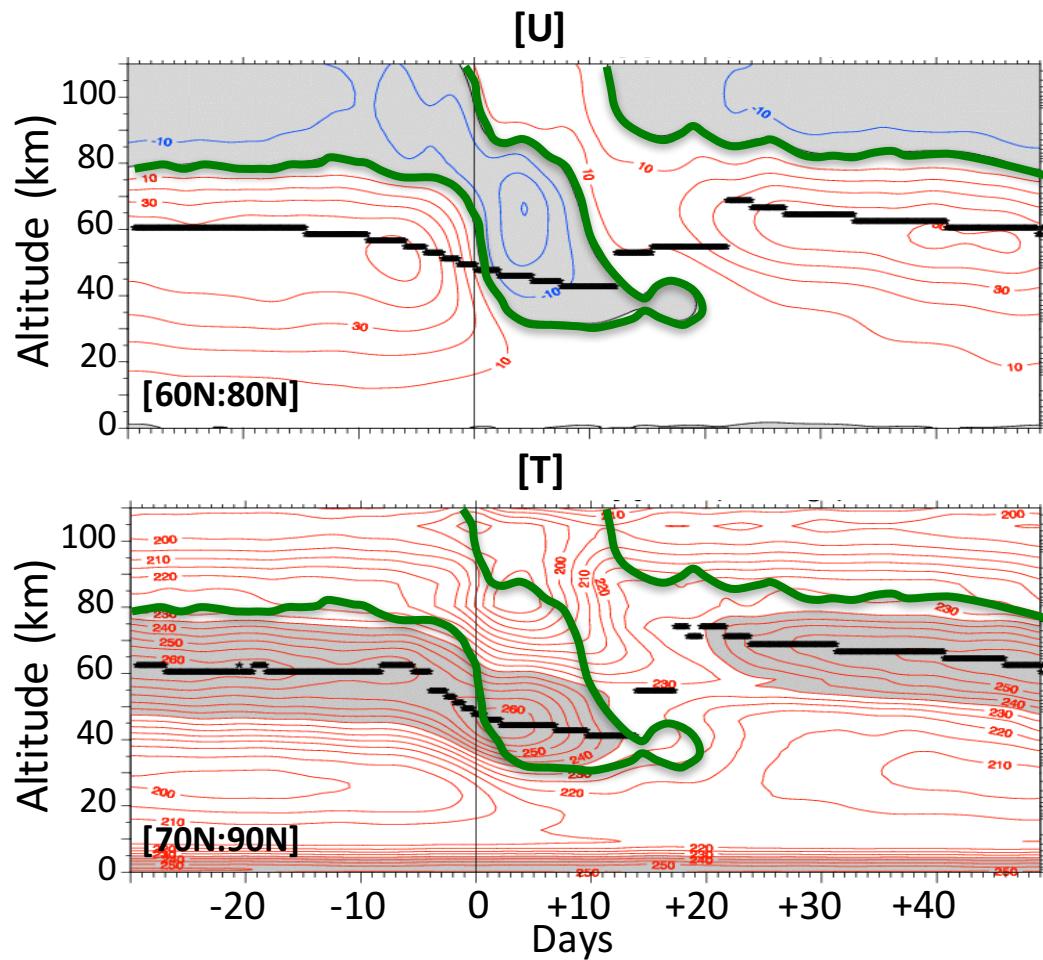
1. Select major SSWs with Elevated Stratopause (ES-SSWs)

- ✓ Stratopause “discontinuity” (Δz) ≥ 10 km
- ✓ [T] between 80-100 km < 190 K
- ✓ Persistent [U] reversal at 1 hPa > 5 days

13 ES-SSWs Identified



2. Composite with respect to Day 0 (onset @ 1 hPa)

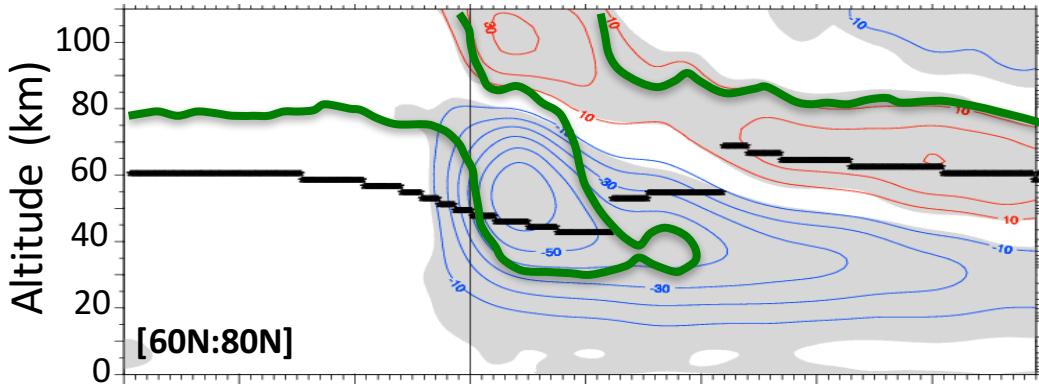


- Zonal-mean zonal wind **[U]** reversal
 - Associated zonal-mean temperature **[T]** change
- westward

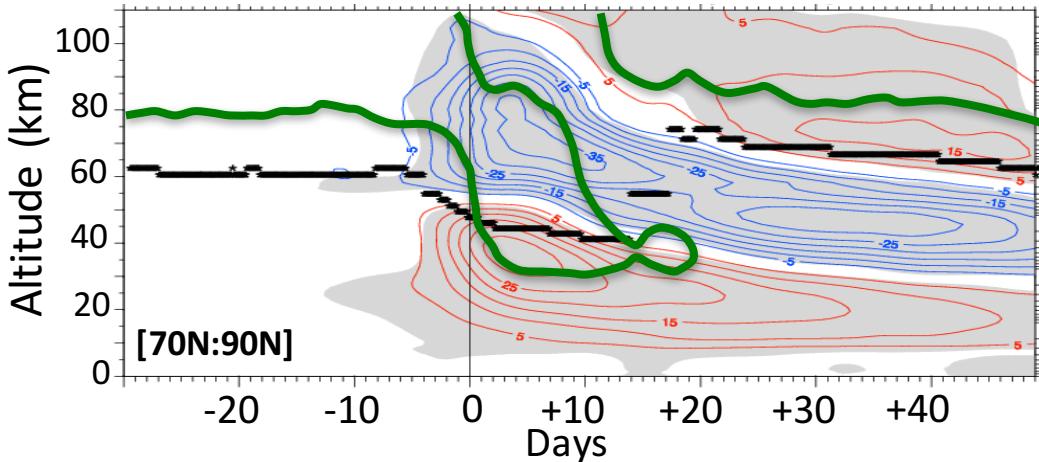
— eastward

— $[U] = 0$
- **stratopause**
- Elevated stratopause (at mesospheric heights) during vortex reformation

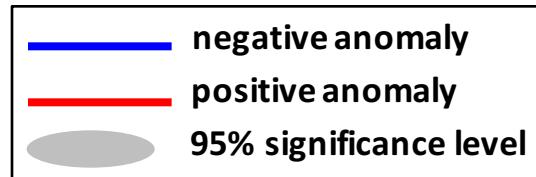
[U] Anomaly



[T] Anomaly

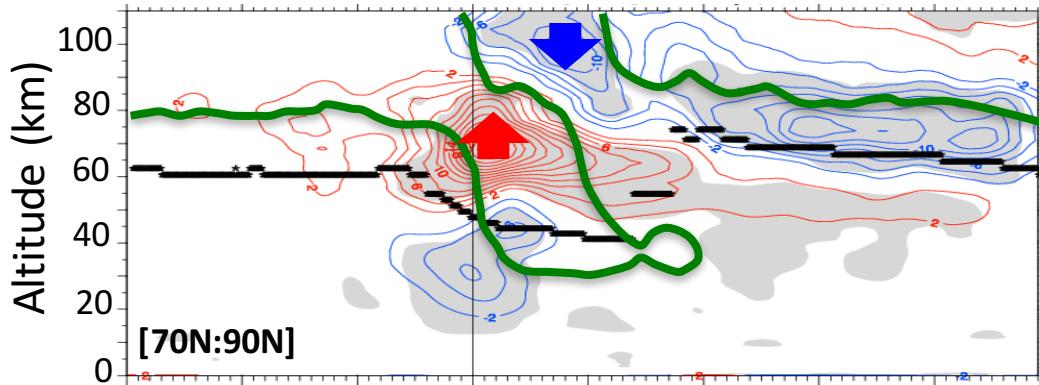


- Anomalies → departures from climatology of non-SSW years

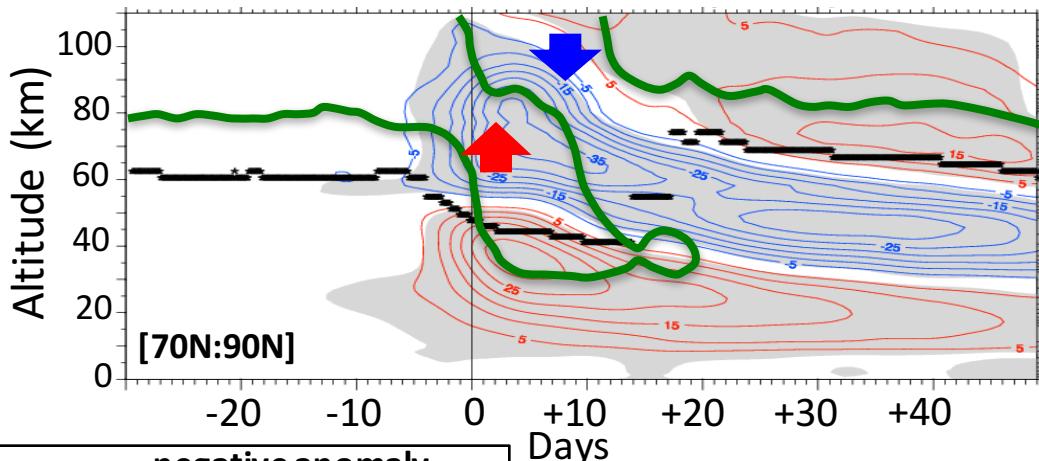


- Stratospheric warming/mesospheric cooling
- Gradual descent of anomalies toward lower altitude

w* Anomaly

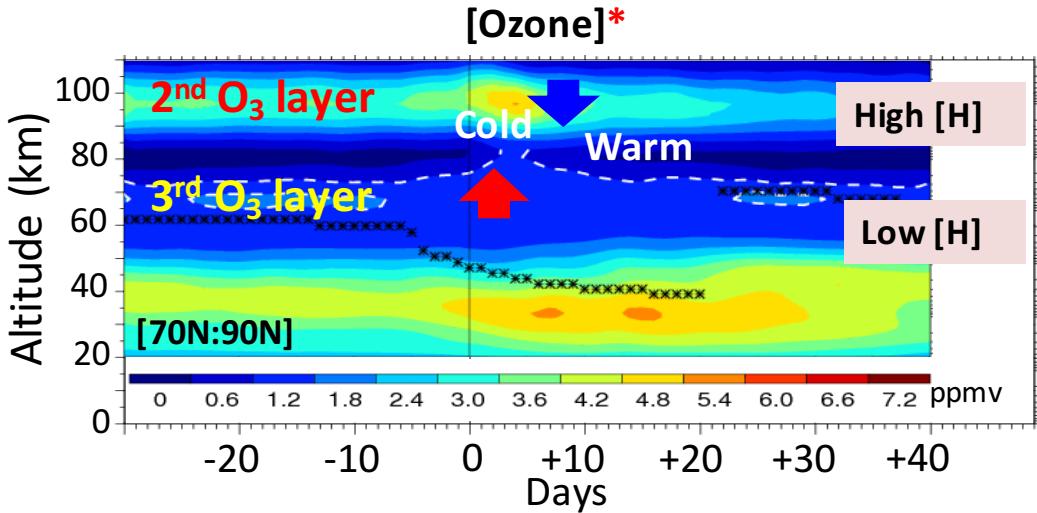
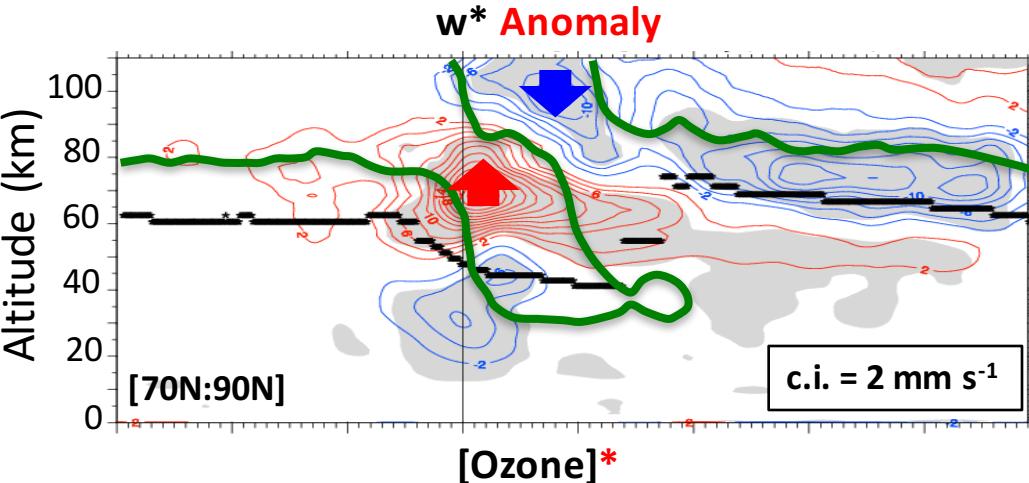


[T] Anomaly



—	negative anomaly
—	positive anomaly
●	95% significance level

- Reversal (or weakening) of polar motion in MLT
- Upwelling in upper mesosphere: cooling
- Downwelling first in lower thermosphere, followed by mesospheric descent
- Important for trace species transport



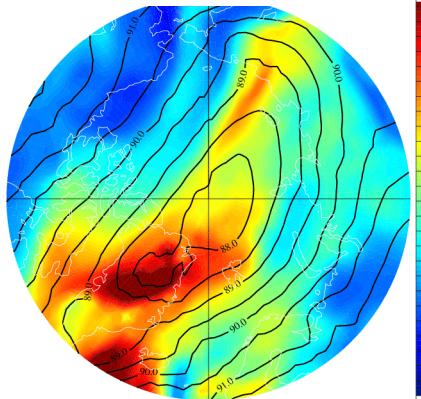
Impact on mesospheric ozone

- **2nd O₃ layer:** nighttime O₃ chemical equilibrium [Smith *et al.*, 2009]
 - Sources: [O] & [O₂]
 - Sinks: [O] & [H]
- Anti-correlated with temperature

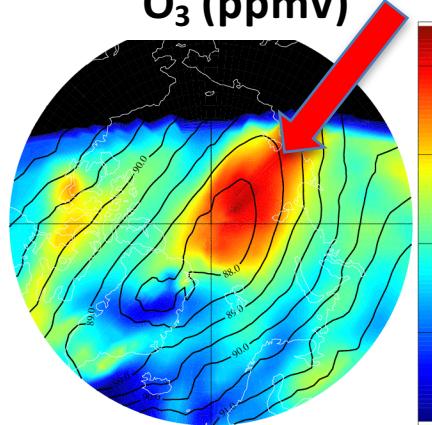
*Tweedy, O., V. Limpasuvan, Y. Orsolini, A. Smith, R. Garcia, D. Kinnison, C. Randall, O.-K. Kvissel, F. Stordal, V. Harvey, A. Chandran, 2013: Nighttime secondary ozone layer during major stratospheric sudden warmings in specified-dynamics WACCM, *J. Geophysical Research*, doi:10.1002/jgrd.50651.

Modelled ESE in 2012/13 : origin of peak in mesospheric O₃

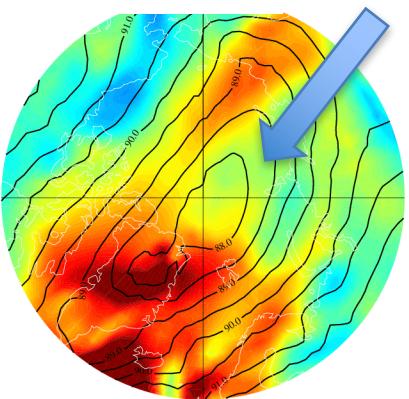
O (/1E3 ppmv)



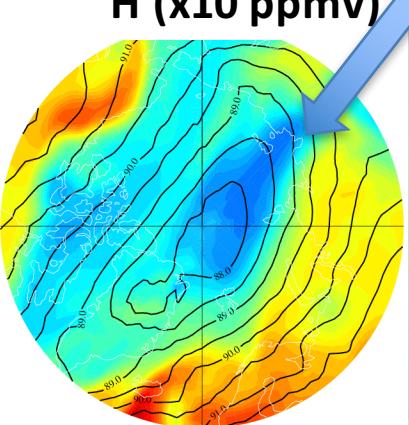
O₃ (ppmv)



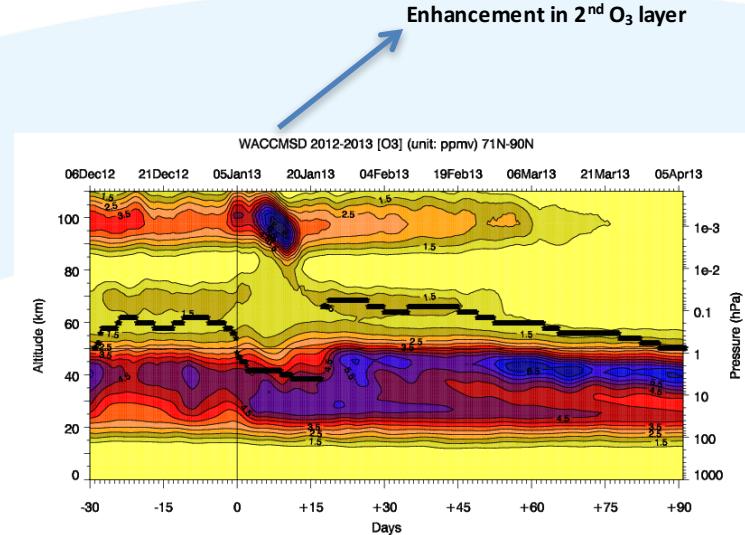
T (K)



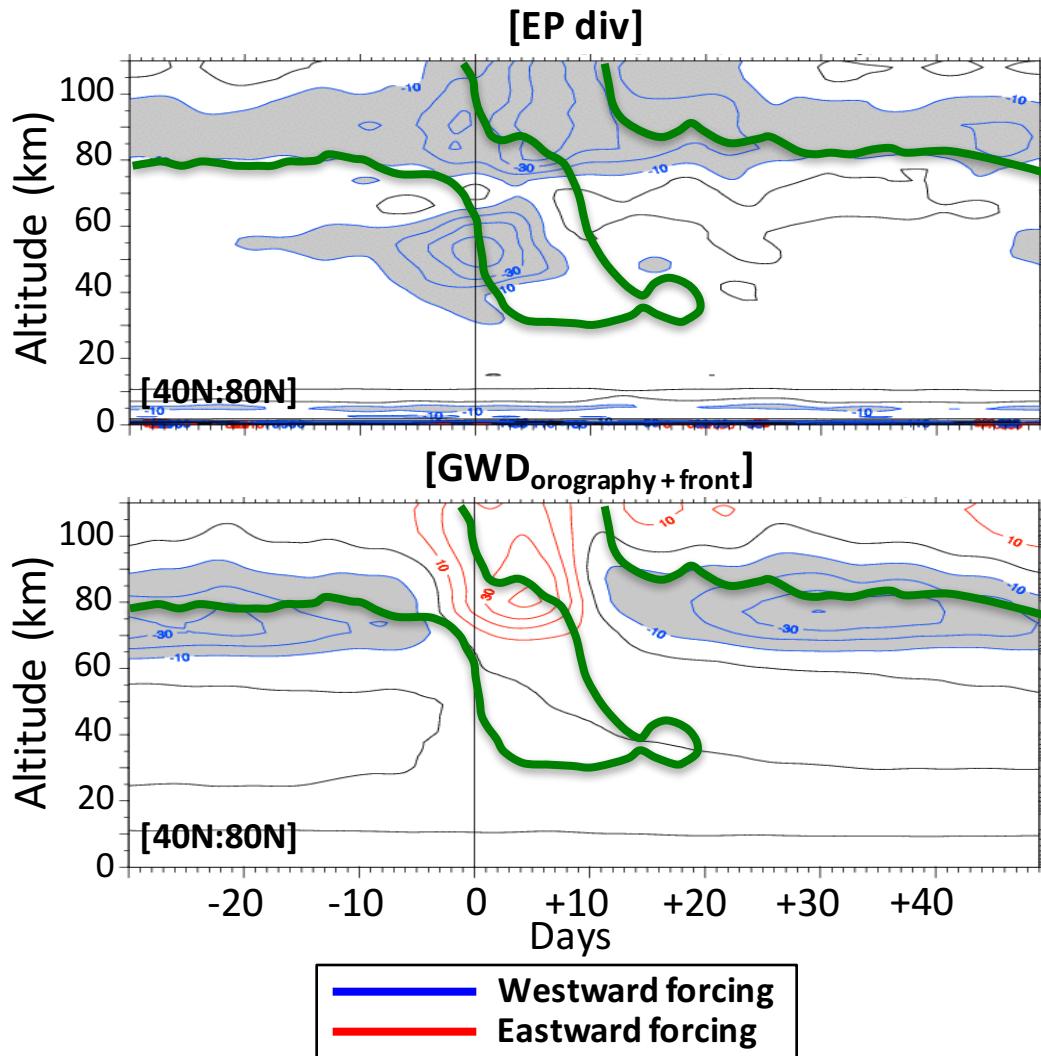
H (x10 ppmv)



15 JAN 2013

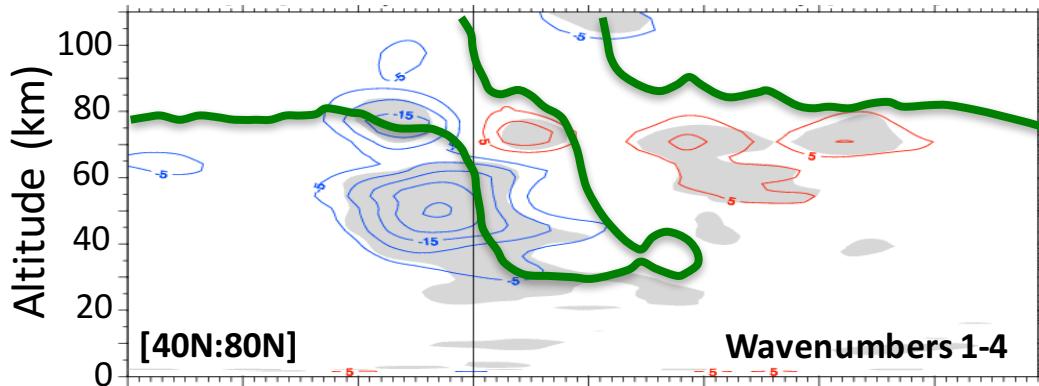


Forcing by planetary and gravity waves

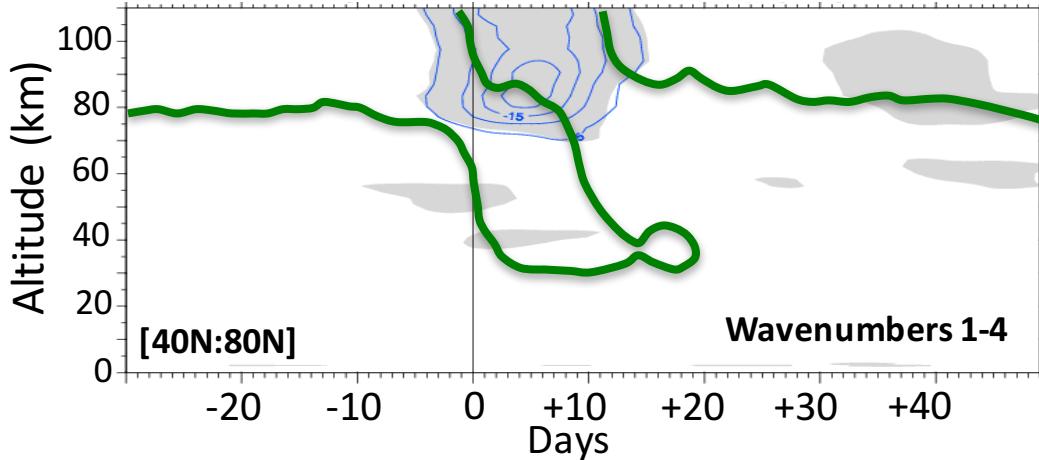


- Drastic changes in wave forcing driving the mean meridional circulation
- Strong PW westward forcing
 - First Peak near 50km
 - Amplification of PWs above 70km
- Reversal of total GW drag in MLT
[Siskind *et al.*, 2005]

[EP div] PW Quasi-Stationary Anomaly ($P > 20$ days)



[EP div] PW Westward Anomaly ($1 < P < 20$ days)



Quasi-stationary and propagating planetary waves

- Stationary wave forcing below 70 km
- Westward forcing in LT → instability?
- Confirmed by observations*

Observed Planetary waves in MLT during ESEs – satellite and ground-based SuperDarn radar data –

SABER Temperature
(2012–2013)

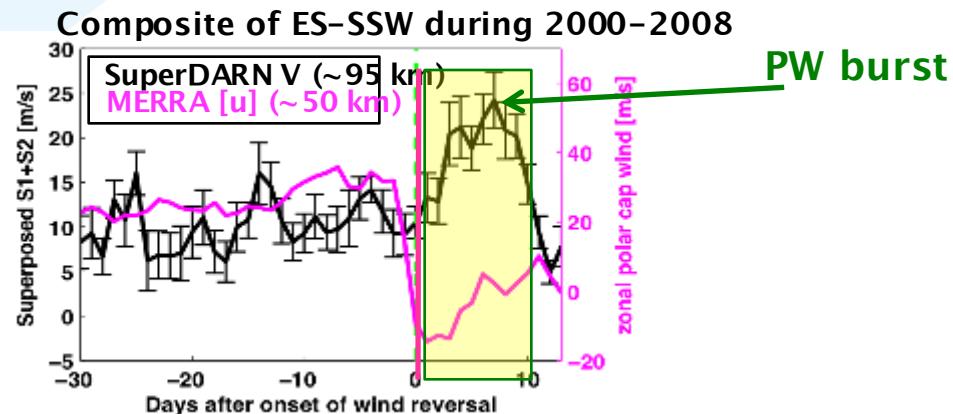
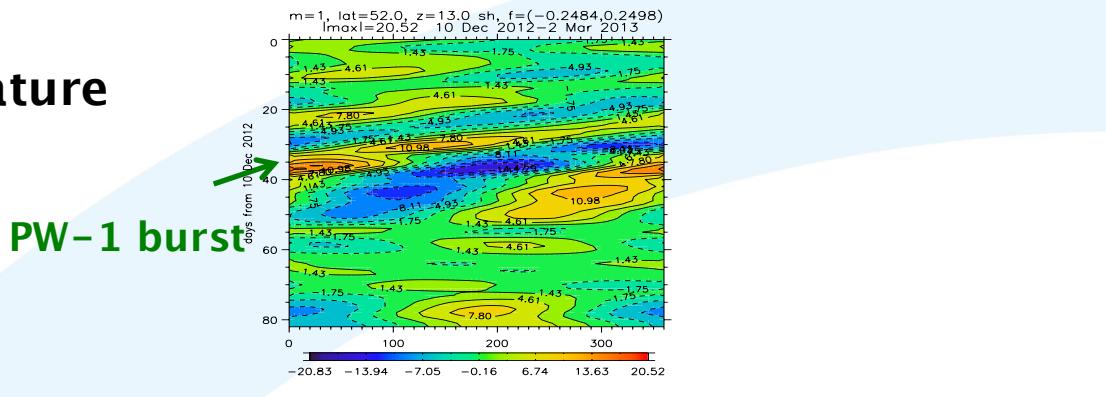
near 91 km

SuperDARN radar
wind
(Composite of ESEs
during 2000–2008)

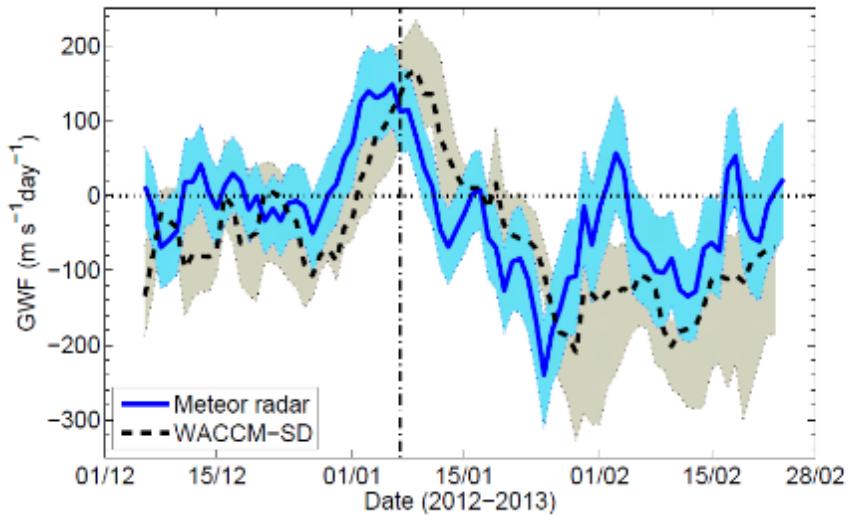
near 97km



Stray, N., Y. Orsolini, P. Espy, V. Limpasuvan, and R. Hibbins, 2015: Observations of Planetary Waves in the Mesosphere-Lower Thermosphere during Stratospheric Warming Events, *Atmospheric Chemistry & Physics*, doi:10.5194/acp-15-4997-2015.



Gravity wave forcing in 2012/2013 : comparison with radar observations above Trondheim (Norway)

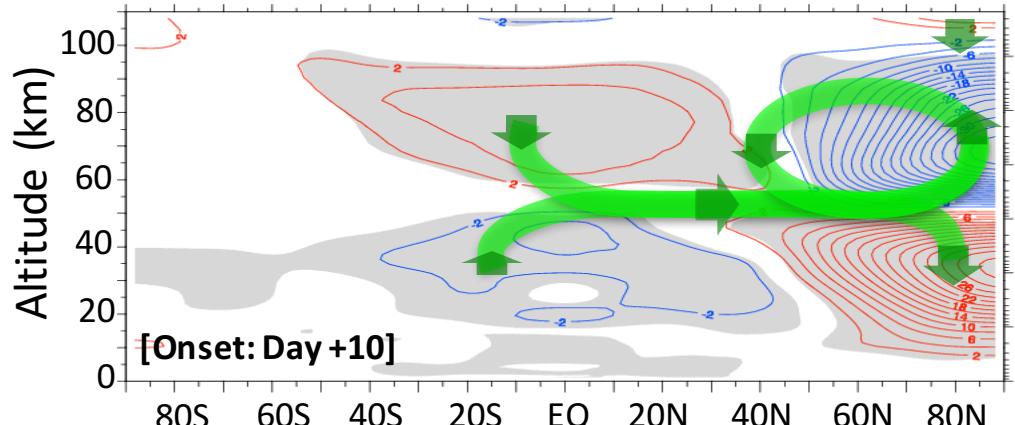


(Parameterized)
local GWF in
WACCM_SD
compares well with
radar observations
(80–100 km)

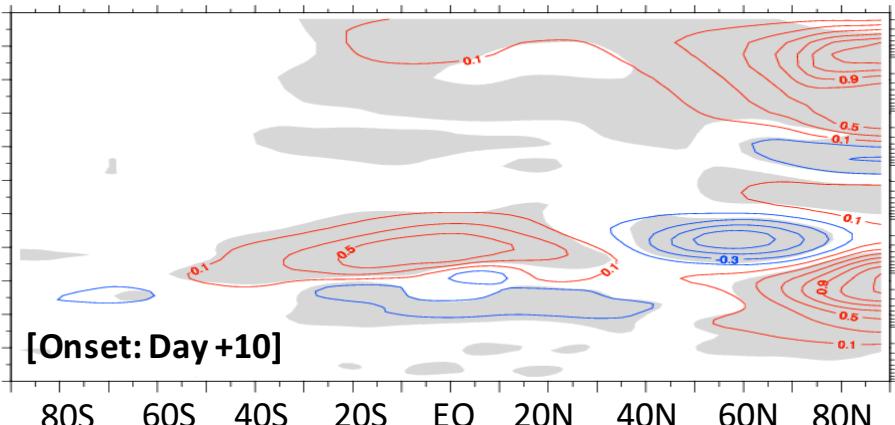
→ Peak eastward
forcing around
reversal time of
ESE

See: De Wit, R. J., R. E. Hibbins, P. J. Espy, Y. J. Orsolini, V. Limpasuvan, and D. Kinnison, 2014: Observations of gravity wave forcing of the mesopause region during the January 2013 major Sudden Stratospheric Warming, *Geophysical Research Letters*, **41**, doi:10.1002/2014GL060501.

Tidal excitation [T] Anomaly

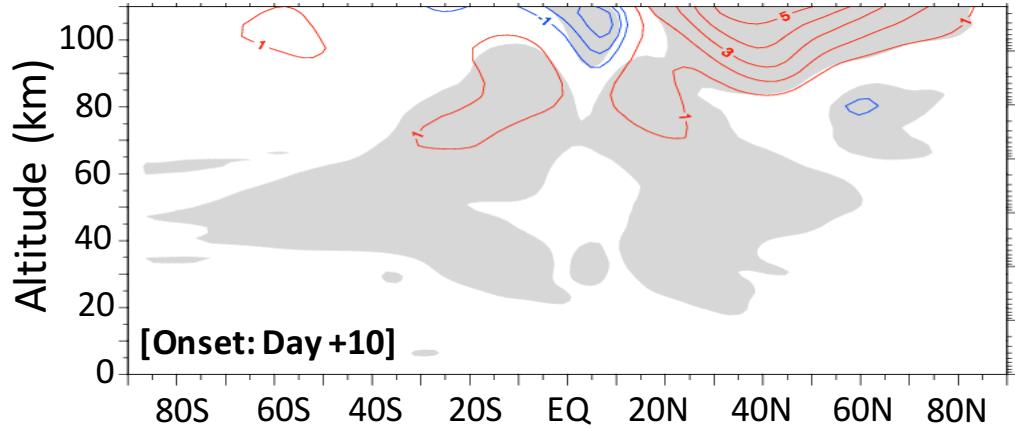


[Ozone] Anomaly



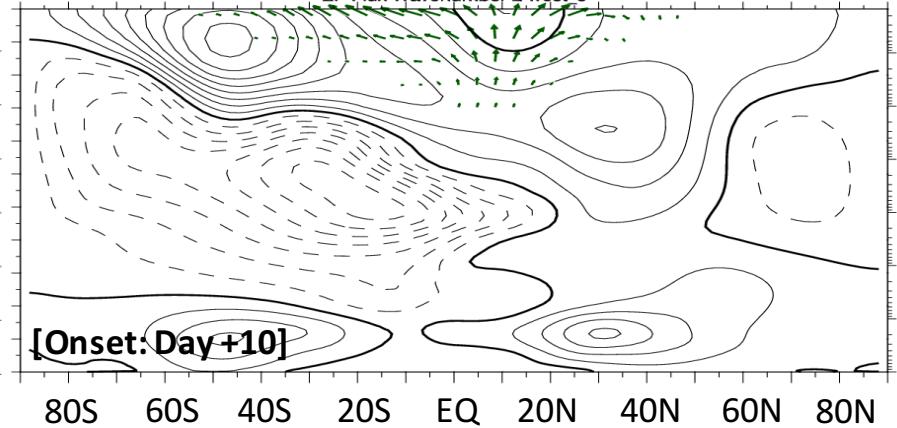
Semidiurnal Migrating Tide

V SW2 RMS Amplitude Anomaly

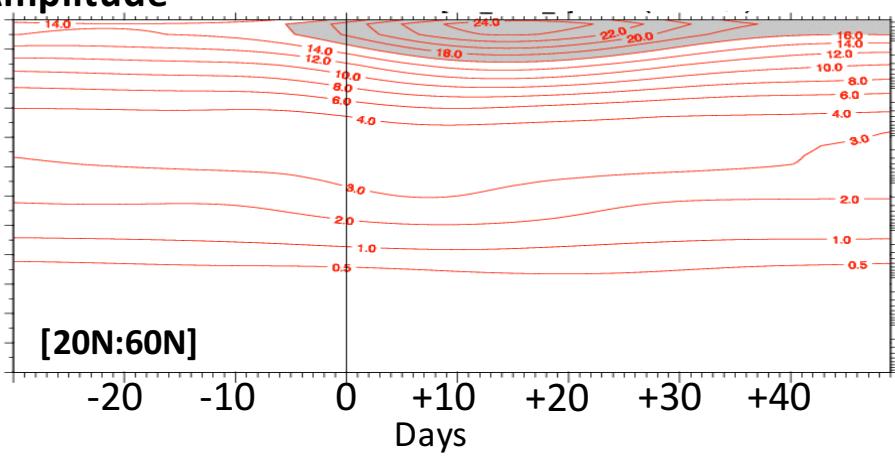
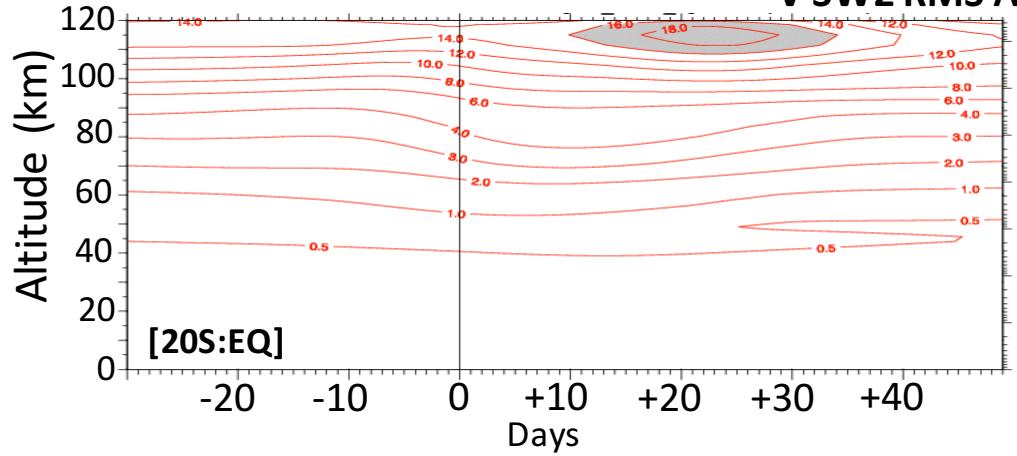


SW2 EP Flux

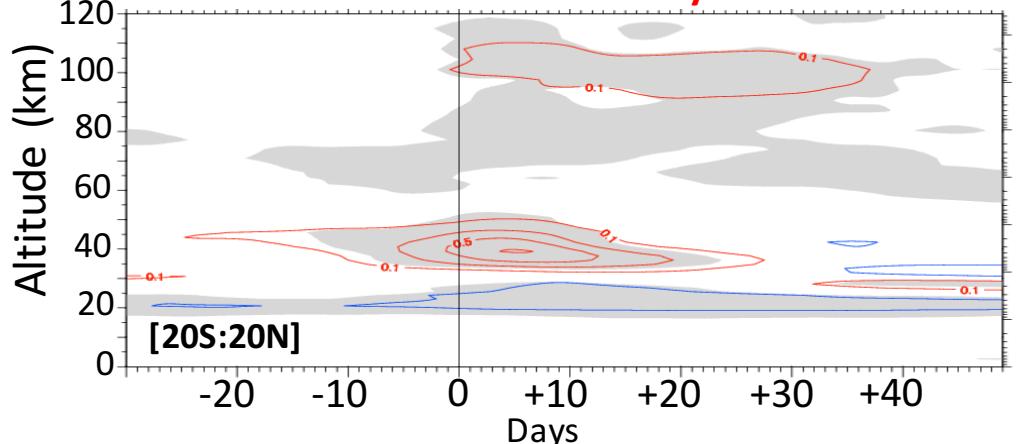
EP Flux Wavenumber 2 west s



V SW2 RMS Amplitude



Ozone Anomaly



- Amplified tides (SW2)
- Tropical ozone enhancement between 30-60 km [*Goncharenko et. al., 2012**]

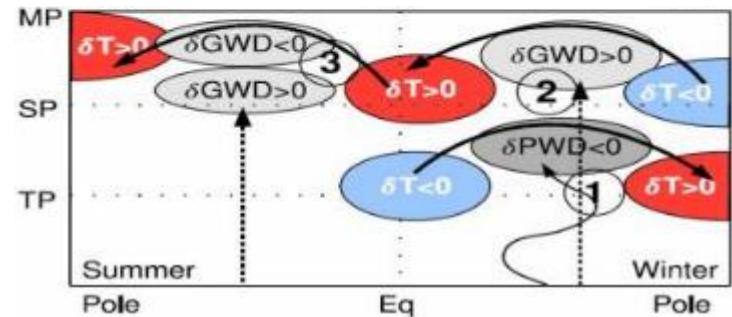
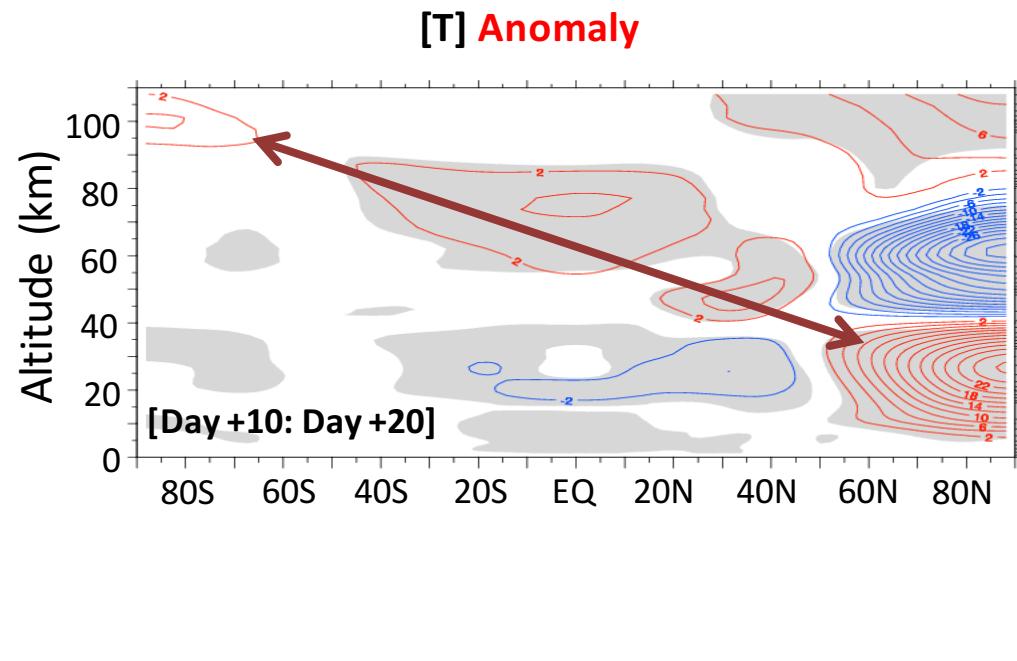
*Goncharenko, L., A. Coster, R. Plumb, and D. Domeisen, 2012: The potential role of stratospheric ozone in the stratosphere-ionosphere coupling during stratospheric warmings, *Geophysical Research Letters*, doi:10.1029/2012GL051261.

Evidence for inter-hemispheric coupling (IHC)

- Teleconnection between winter polar stratosphere → summer polar upper mesosphere

- Role of GW drag in summer hemisphere (?)

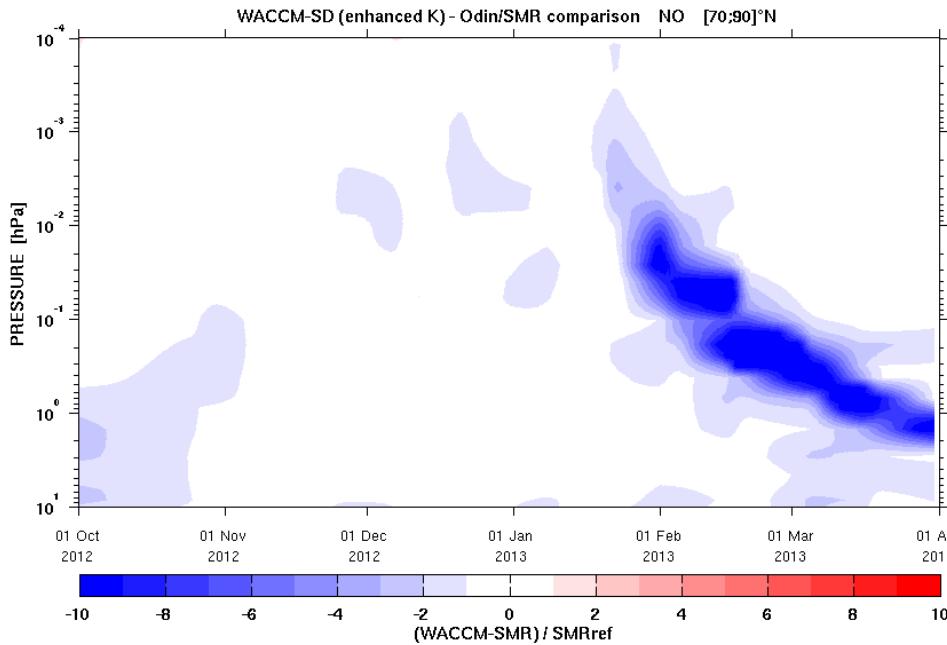
IHC [Körnich & Becker, 2010 ; Karlsson et al., 2012]
 In WACCM: [Tan et al., 2013 ; Limpasuvan et al., 2012]



WACCM_SD / Odin-SMR comparison of NO during ESE of 2012/13

18

- ✓ WACCM_SD minus SMR
- ✓ scaled to remove background z-gradient
- ✓ Collocated (WACCM_SD sampled as SMR)



- Model deficit in NO : clearly related to abrupt onset of mesospheric descent
- Not merely related to a too small background eddy diffusion
- Role of PWs and GWs in driving anomalous meridional circulation (w^*) ?

CONCLUSIONS

- Robust vertical coupling → tracers (ozone & NO_x)
- Interplay between PW and GW momentum forcing (supported by observations)
 - Amplification of mesospheric PW after onset
 - Filtering of GW, drag reversal by altered [U]
- Amplification of semidiurnal migrating tide after SSW onset
- Hints of inter-hemispheric coupling [*Körnich & Becker, 2010*]

“On the Composite Response of the MLT to Major Sudden Stratospheric Warming Events with Elevated Stratopause”,

By Varavut Limpasuvan, Yvan J. Orsolini, Amal Chandran, Rolando R. Garcia, Anne K. Smith, Doug E. Kinnison, to be submitted to JGR

