On the dynamics of stratosphere-troposphere planetary wave coupling

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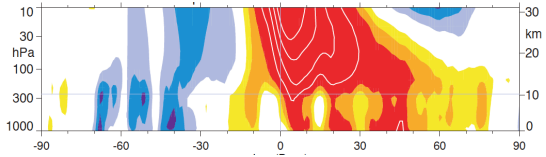
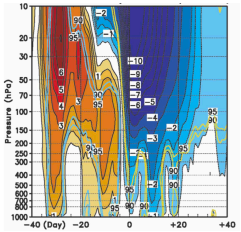
Community focusing on zonal-mean coupling between stratosphere & troposphere (*for good reasons*)

SSWs



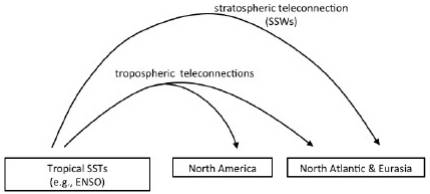
Baldwin & Dunkerton 2001

final warmings



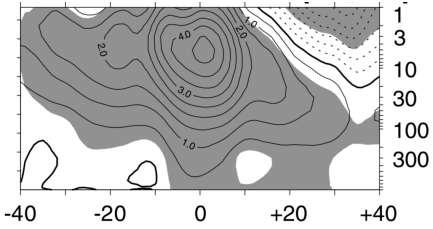
Black et al. 2006

ENSO teleconnections



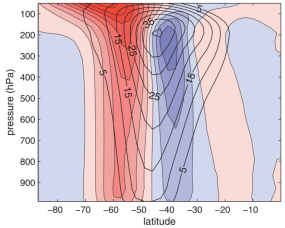
Butler et al. 2014

strong vortex events



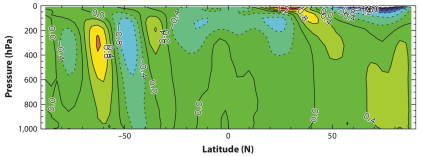
Limpasuvan et al. 2005

ozone depletion



Polvani et al. 2011

solar variability

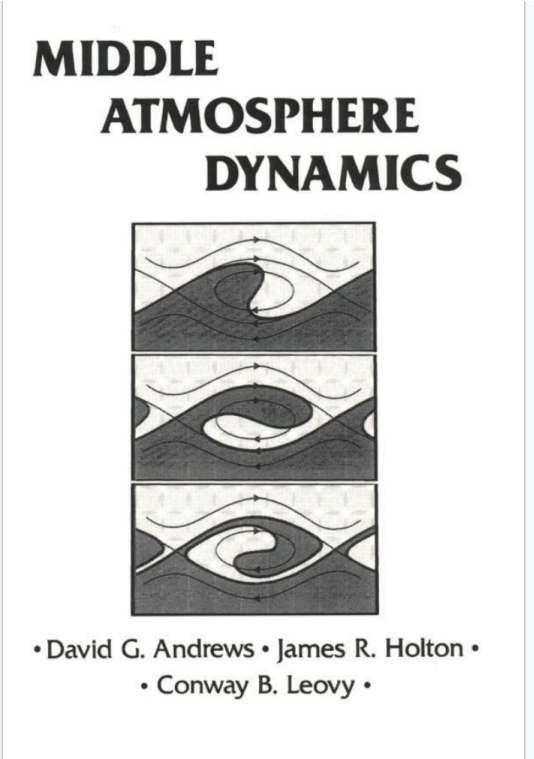


Solanki et al. 2013

However … early ideas focused on planetary-waves directly coupling both regions

Chapter 12:

”Only if wave reflection were to create a resonant amplification of tropospheric waves does it seem possible the wind changes in the stratosphere could influence the climate of the troposphere”



Early evidence of stratospheric impact on troposphere occurred via planetary waves

The Influence of the Polar Night Jet on the Tropospheric Circulation in a GCM

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(Manuscript received 8 June 1983, in final form 22 November 1983)

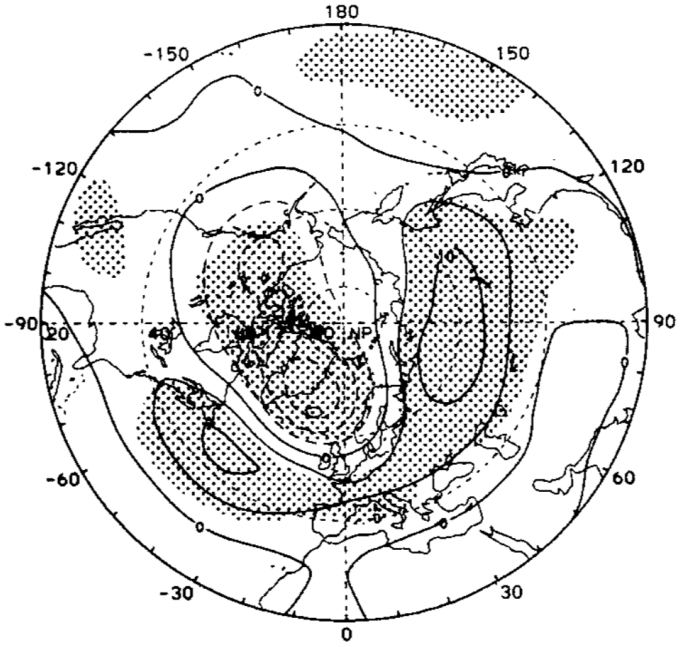
ABSTRACT

The influence of the polar night jet structure in determining the wave properties in the troposphere is examined using a general circulation model (GCM). It is shown that there are significant differences in the tropospheric simulation when the polar night jet is changed. Planetary wave theory leads us to expect that this will be the case for the stationary planetary waves; however, the changes found here extend to the transient eddies as well and to all scales in the model. The degree of trapping of the planetary waves in the troposphere is determined by the strength and structure of the polar night jet, resulting in the sensitivity of the troposphere to that structure.

The most significant changes in the height field occur at high latitudes, beneath the polar night jet, but significant changes in the heat and momentum fluxes take place at both middle and high latitudes.

The results indicate that inaccuracies in the stratospheric simulations of any general circulation model will produce serious errors in the planetary waves and therefore in the general eddy properties of the model.

Z 500 bias

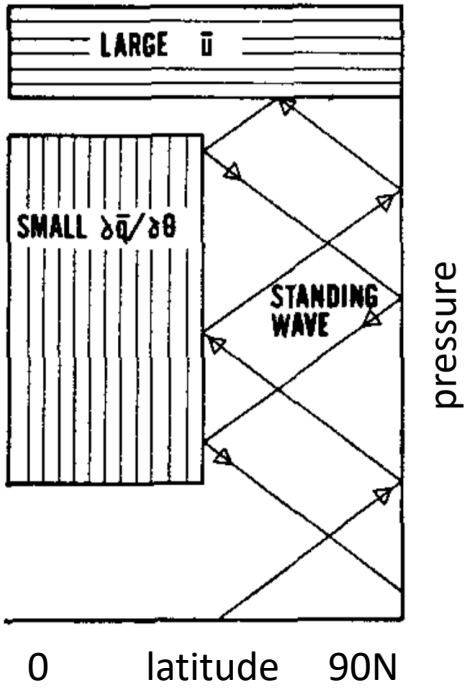


Stratospheric zonal-mean flow impacts planetary-wave coupling in three ways

1) Reflection $\overline{v'T'} < 0$

2) Refraction $\overline{v'T'} > 0$

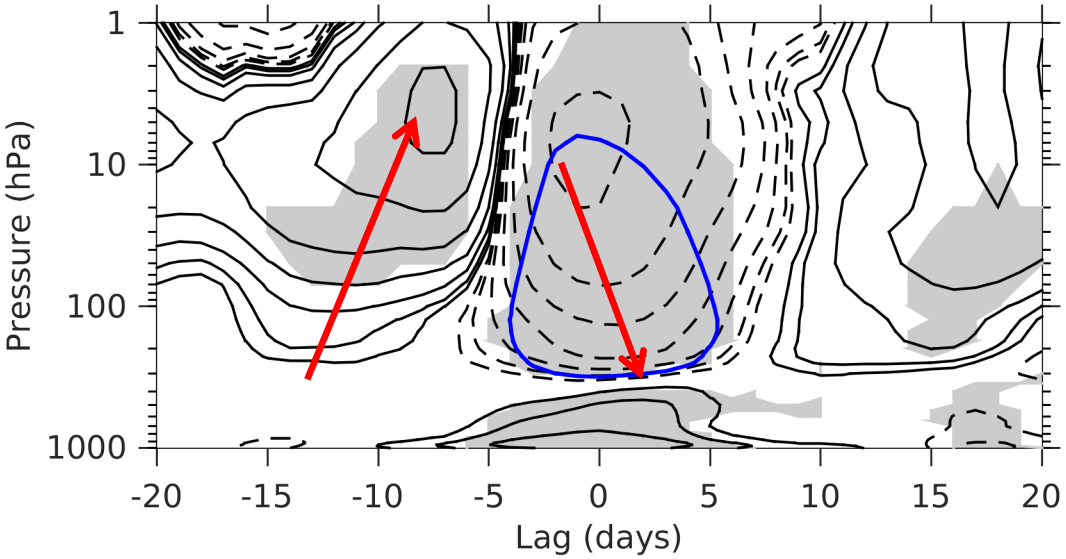
3) Resonance $\overline{v'T'} > 0$



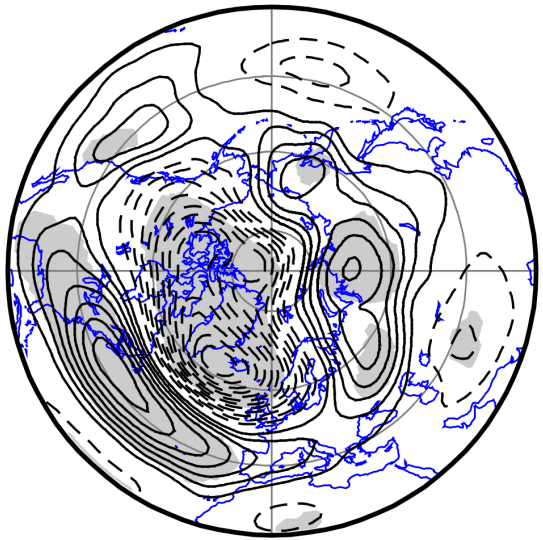
Matsuno 1970, Plumb 1981, Perlwitz & Harnik 2003, Shaw et al. 2010, Esler & Matthewman 2011

Planetary wave couples stratosphere & troposphere during extreme **negative** wave-1 heat flux events

$\overline{v'T'}_{k1}\ 6090N$



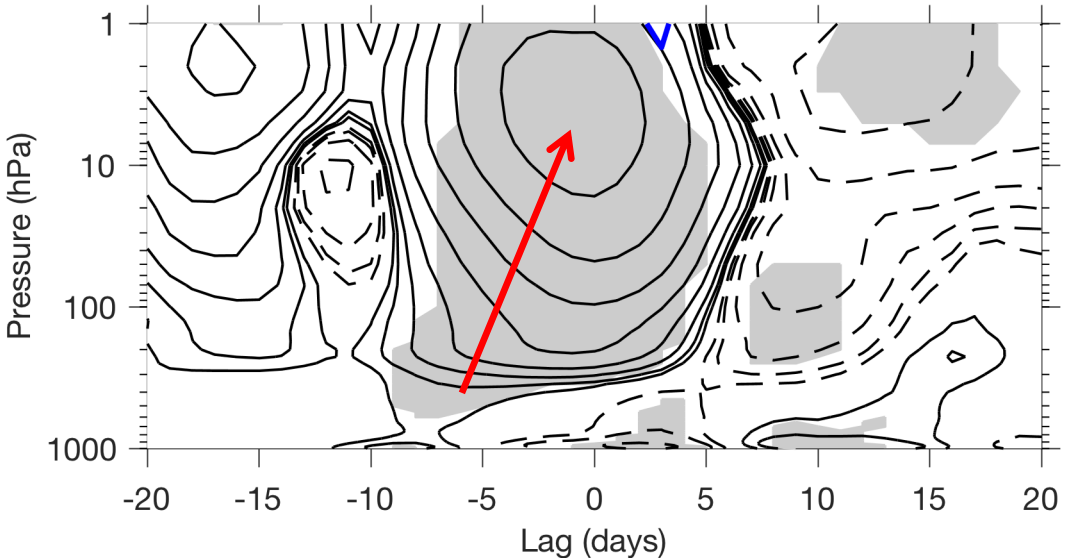
$Z\ 500hPa$



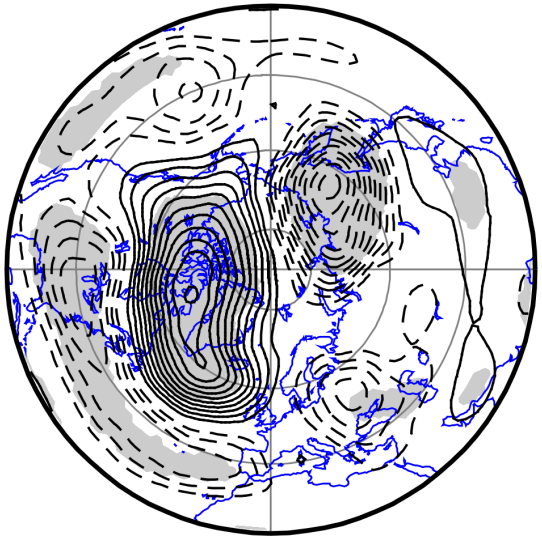
Shaw & Perlwitz 2013, Shaw et al. 2014, Dunn-Sigouin & Shaw 2015

Planetary wave couples stratosphere & troposphere during extreme **positive** wave-1 heat flux events

$\overline{v'T'}_{k1}\ 6090N$



$Z\ 500hPa$



Shaw et al. 2014, Dunn-Sigouin & Shaw 2015

1) *Are extreme stratospheric heat flux events upward propagating or downward reflected waves ?*

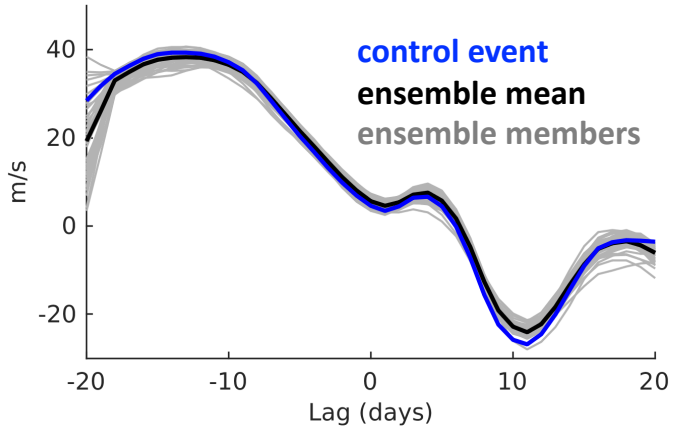
2) *Do extreme positive stratospheric heat flux and SSW events exhibit similar mechanisms ?*

Dunn-Sigouin & Shaw 2018 *JAS*
Dunn-Sigouin & Shaw 2019 under review in *JAS*

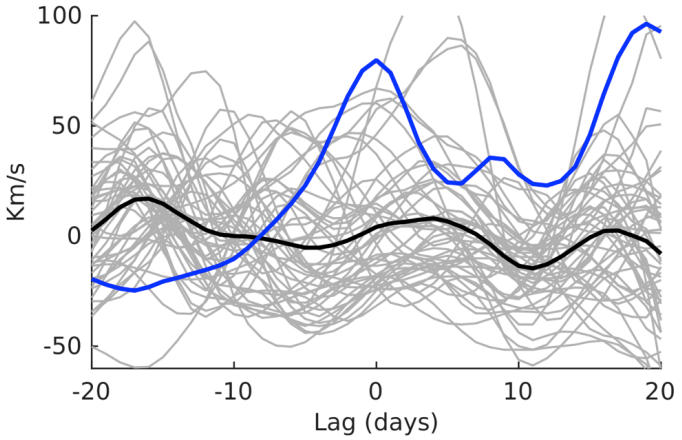
Ensemble spectral nudging in a dry-dynamical core

- Long control run with extreme heat flux & SSW events
- Nudge wavenumber to event evolution (e.g., zonal-mean)

$\overline{U}\ 10hPa\ 60N$

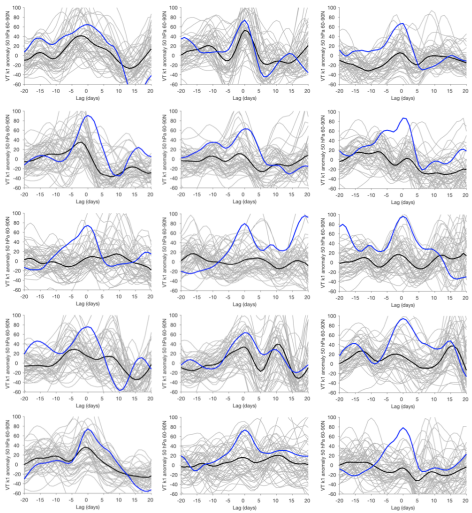


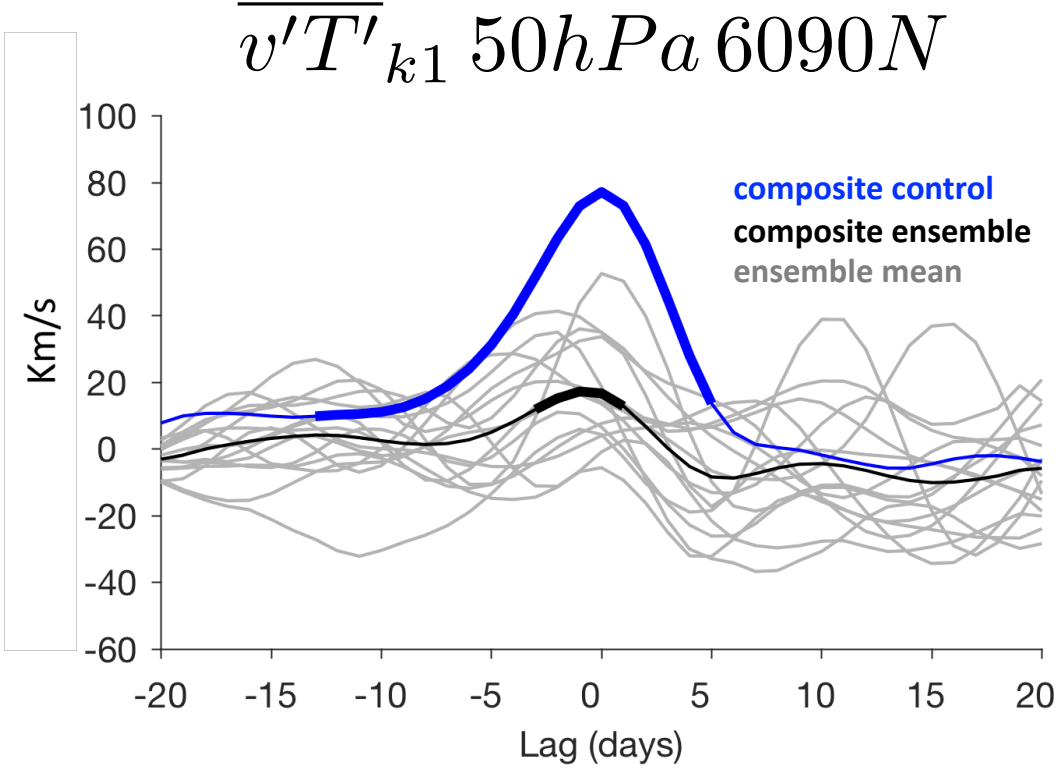
$\overline{v'T'}_{k1}\ 50hPa\ 6090N$



‘Meta’- ensemble simulation

15 ensembles



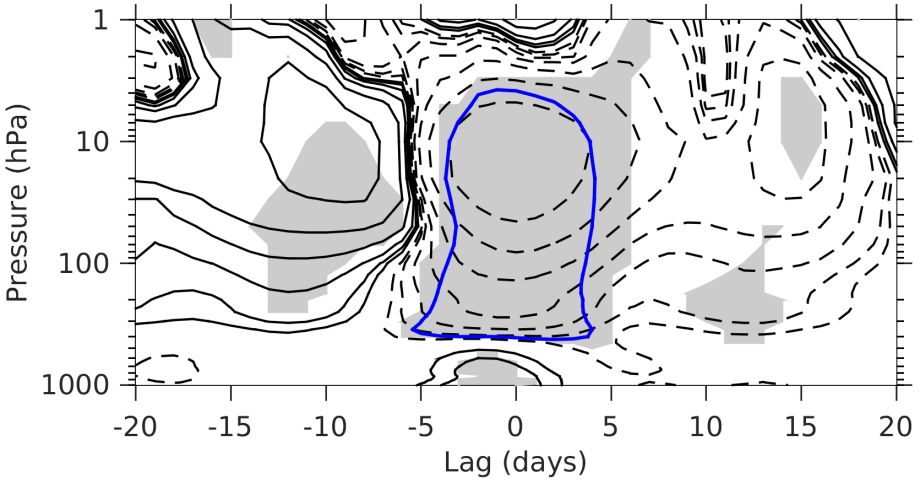


*1) Are extreme **negative** stratospheric heat flux events downward reflected waves ?*

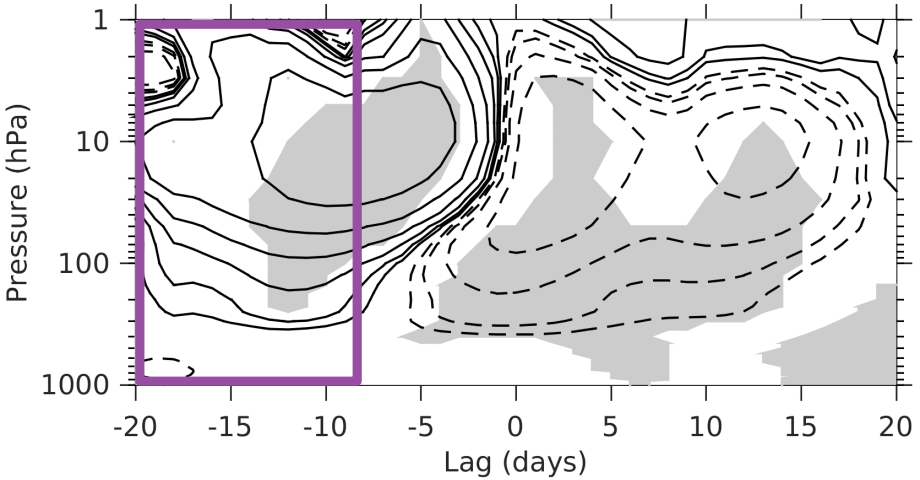
Wave-1 precursor does not reproduce negative heat flux events

$\overline{v'T'}_{k=1}$
60-90N

control



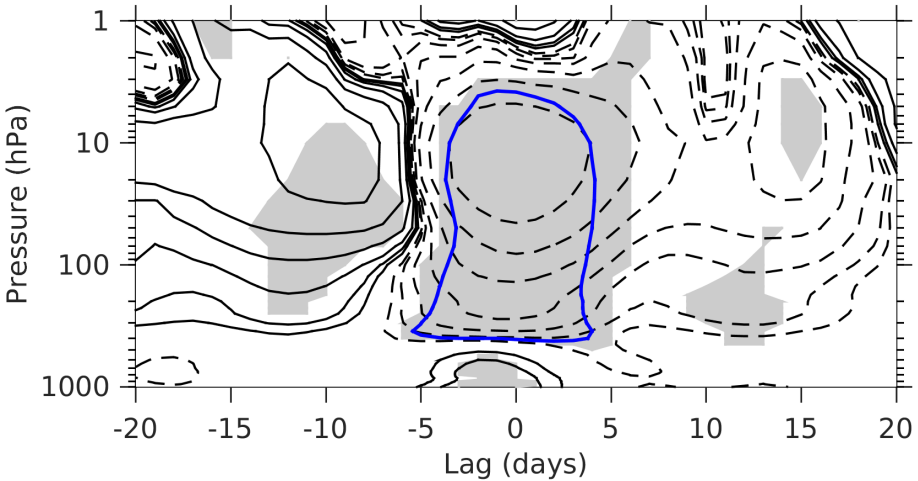
k1 (19%)



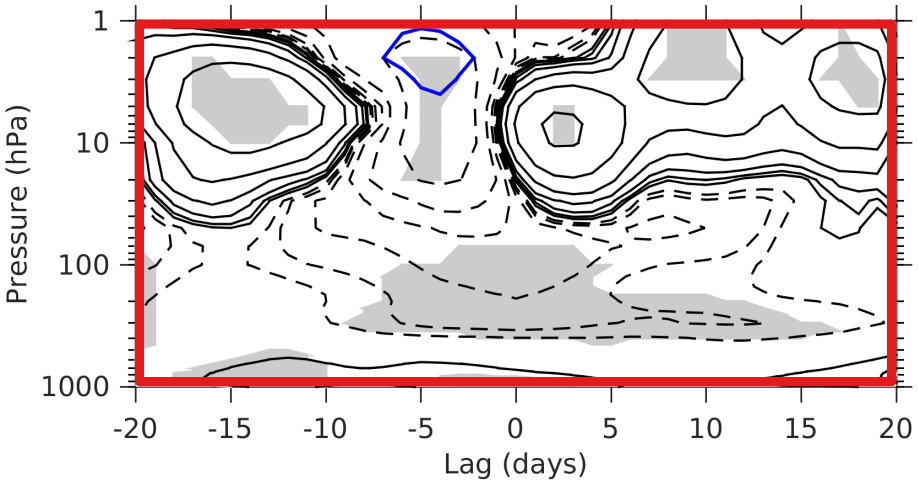
Zonal-mean flow does not reproduce negative heat flux events

$\overline{v'T'}_{k=1}$
60-90N

control



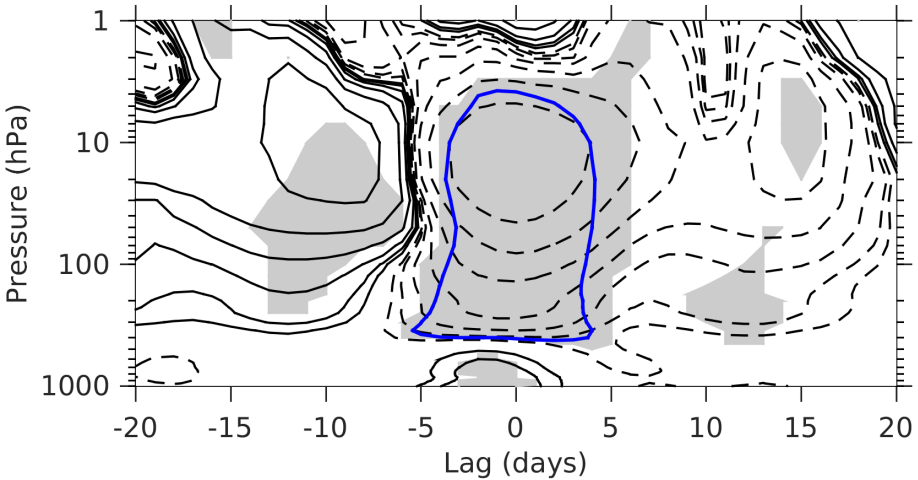
k0 (15%)



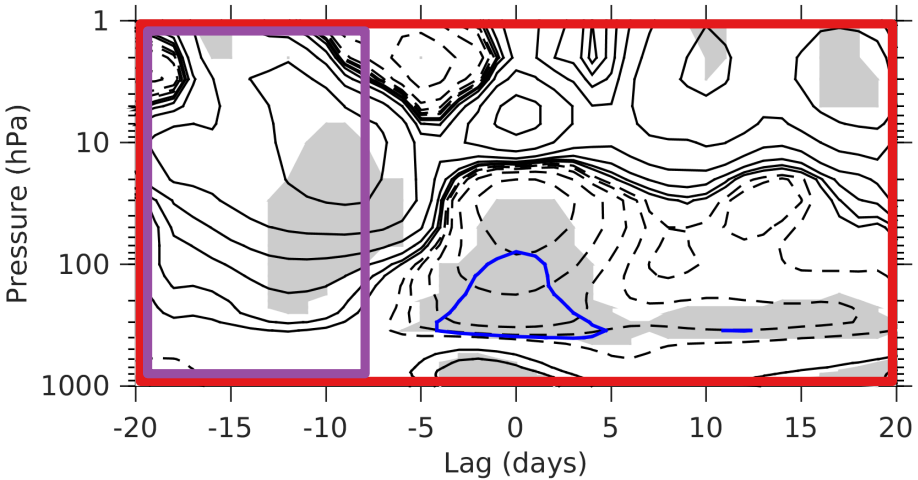
Wave-1 precursor & zonal-mean flow partially reproduce negative heat flux events

$\overline{v'T'}_{k=1}$
60-90N

control



k0 + k1 (37%)



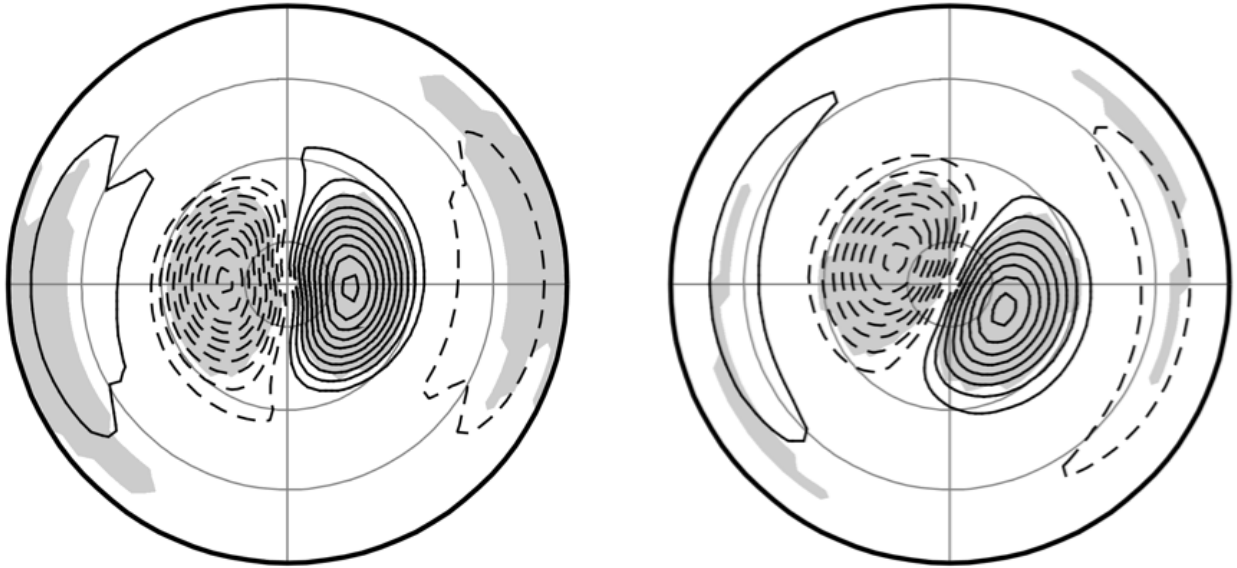
partially consistent with a reflected wave

Wave-1 precursor & zonal-mean flow reproduce coupling with troposphere

$Z_{k1}500hPa$

control

k0 + k1

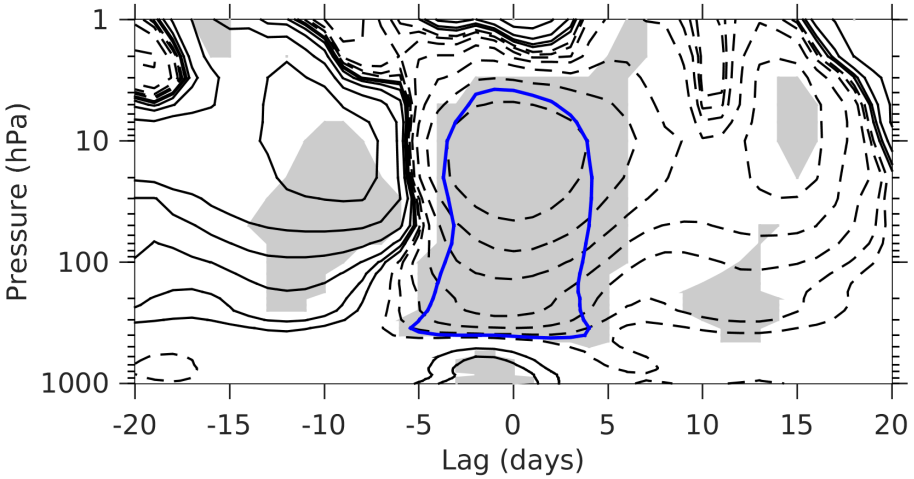


consistent with a reflected wave

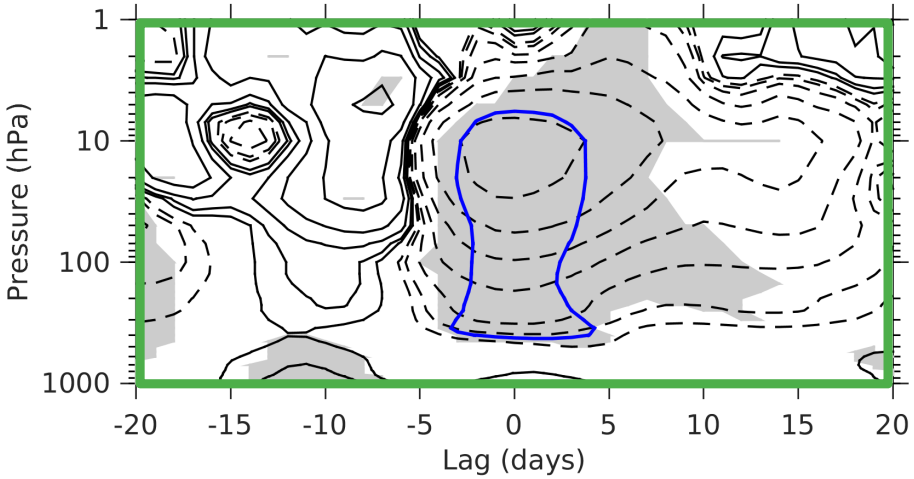
Wave-wave interaction plays key role in producing negative heat flux events

$\overline{v'T'}_{k=1}$
60-90N

control



k ≥ 2 (70%)



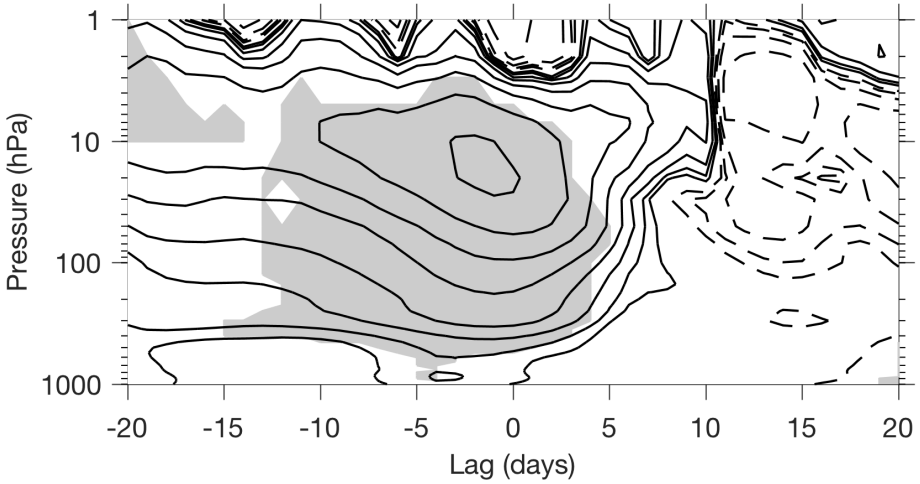
Consistent with previous work *(McIntyre 1982, Smith 1983)*

*1) Are extreme **positive** stratospheric heat flux events upward propagating waves ?*

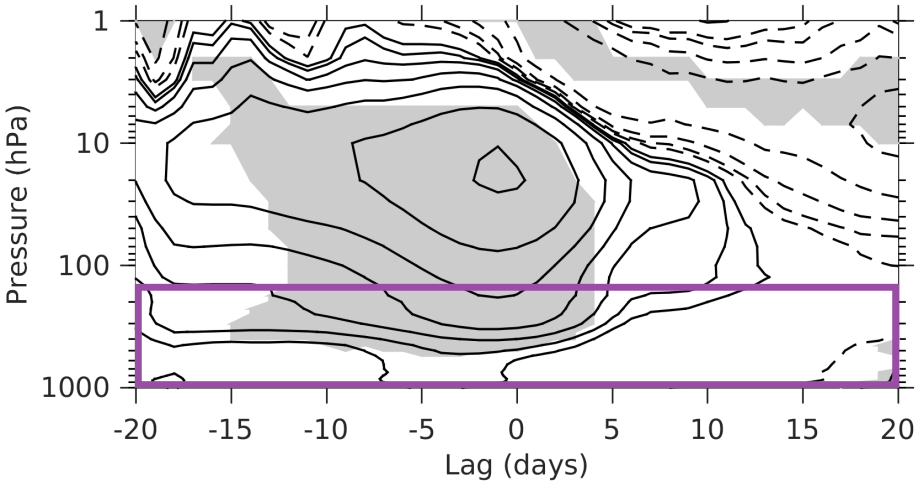
Tropospheric wave-1 reproduces majority of extreme positive eddy heat flux events

$\overline{v'T'}_{k=1}$
60-90N

control



k1 troposphere (60%)

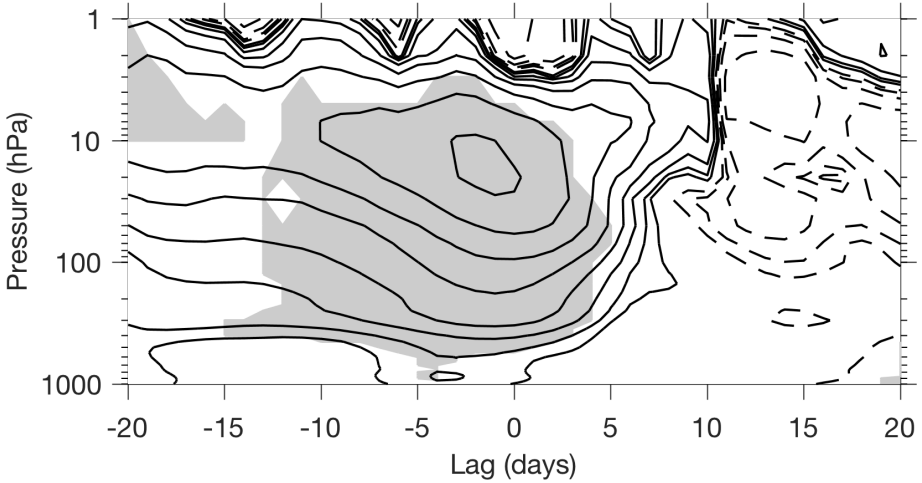


consistent with upward propagating wave

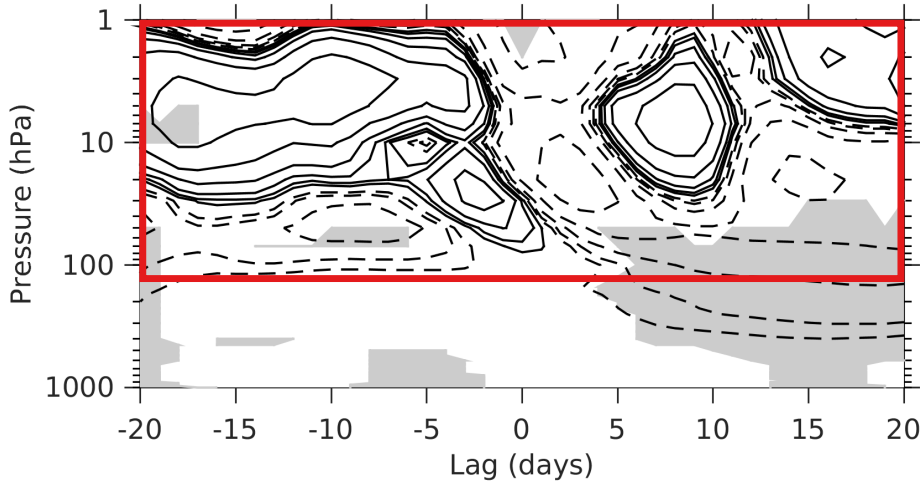
Stratospheric zonal-mean flow does not reproduce extreme positive eddy heat flux events

$\overline{v'T'}_{k=1}$
60-90N

control



k0 stratosphere (0%)

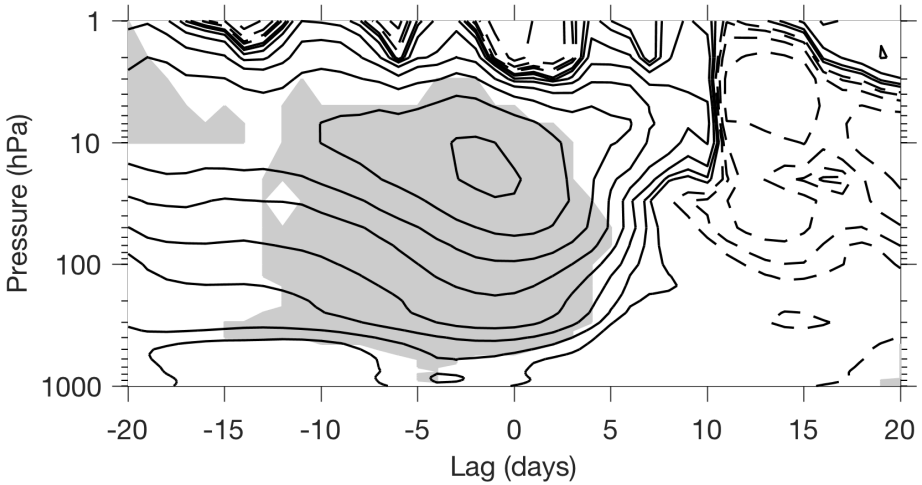


not consistent with resonance

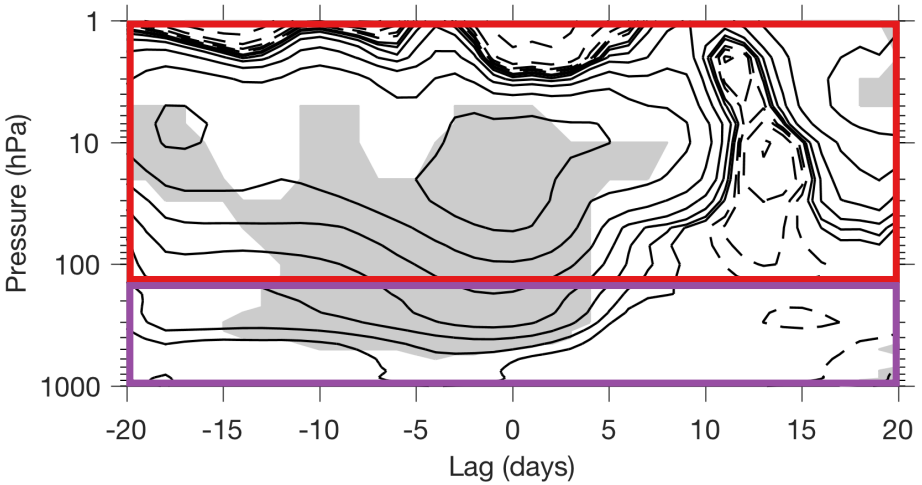
Tropospheric wave-1 and stratospheric zonal-mean flow reproduces extreme positive heat flux events

$\overline{v'T'}_{k=1}$
60-90N

control



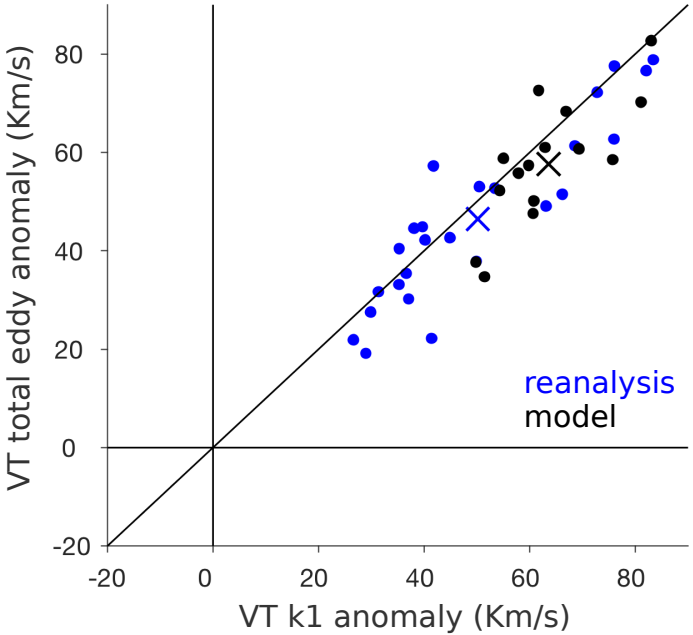
k0 stratosphere +
k1 troposphere (89%)



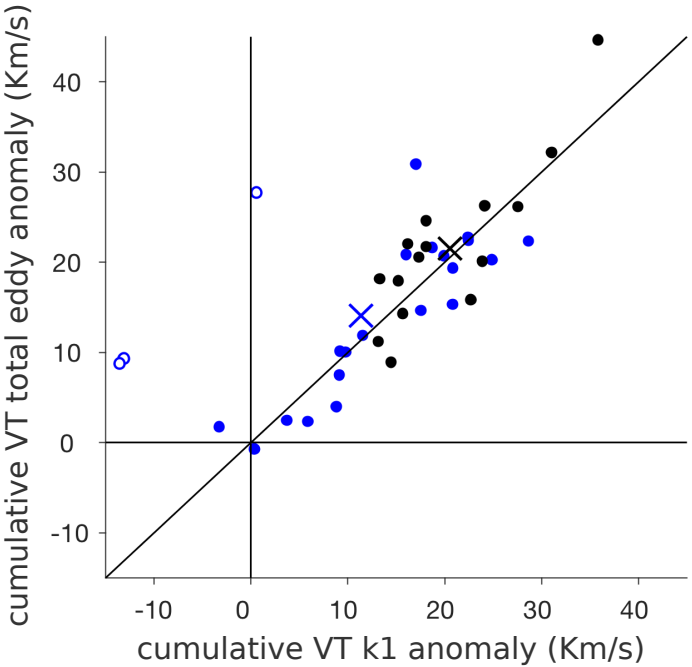
consistent with refraction

*2) Do extreme **positive stratospheric heat flux** and **SSW** events exhibit similar mechanisms?*

eddy heat flux events



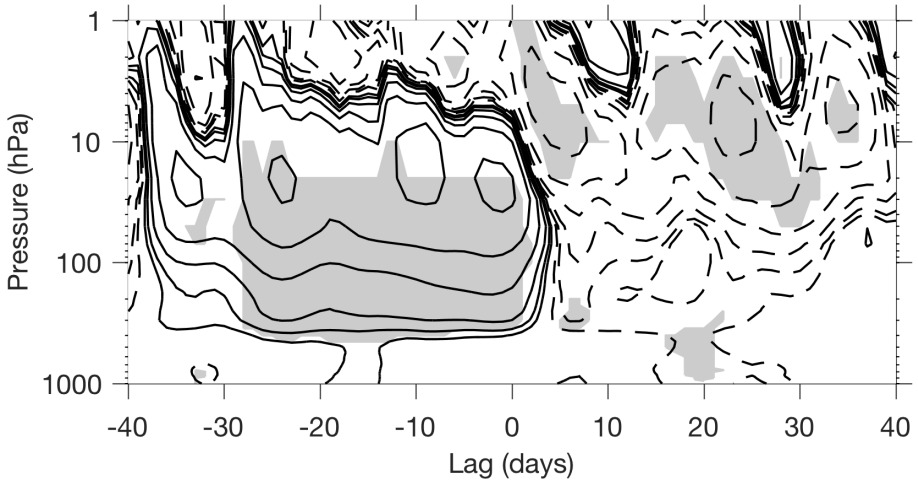
SSW events



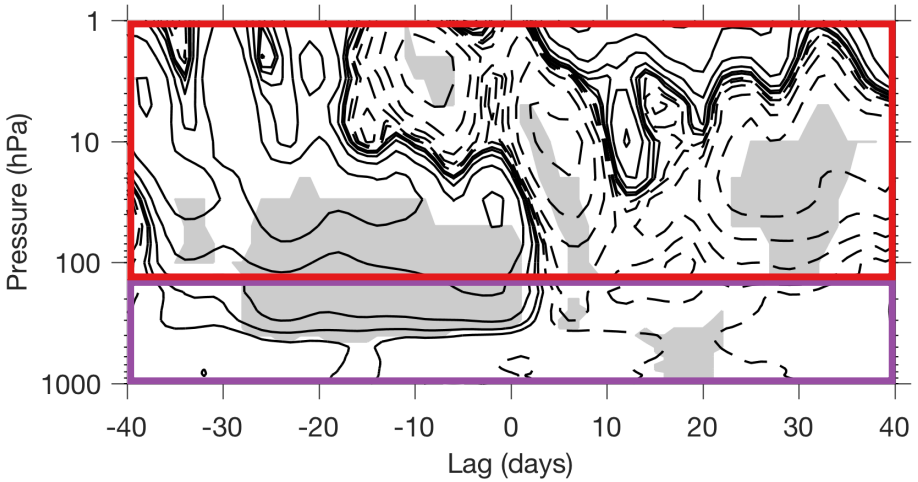
Extreme heat flux and SSW events exhibit similar mechanisms

$\overline{v'T'}_{k=1}$
60-90N

control



k0 stratosphere +
k1 troposphere (72%)



k0 stratosphere alone (-55%), k1 troposphere alone (94%)

Conclusions

1) *Are extreme stratospheric heat flux events upward propagating or downward reflected waves ?*
   - Overall yes
   - non-linearities can play an important role

2) *Do extreme positive stratospheric heat flux and SSW events exhibit similar mechanisms?*
   - Overall yes