Stratosphere-Troposphere Coupling: The Arctic Polar-night Jet Oscillation

Peter Hitchcock and Theodore G. Shepherd

Department of Physics, University of Toronto, Canada

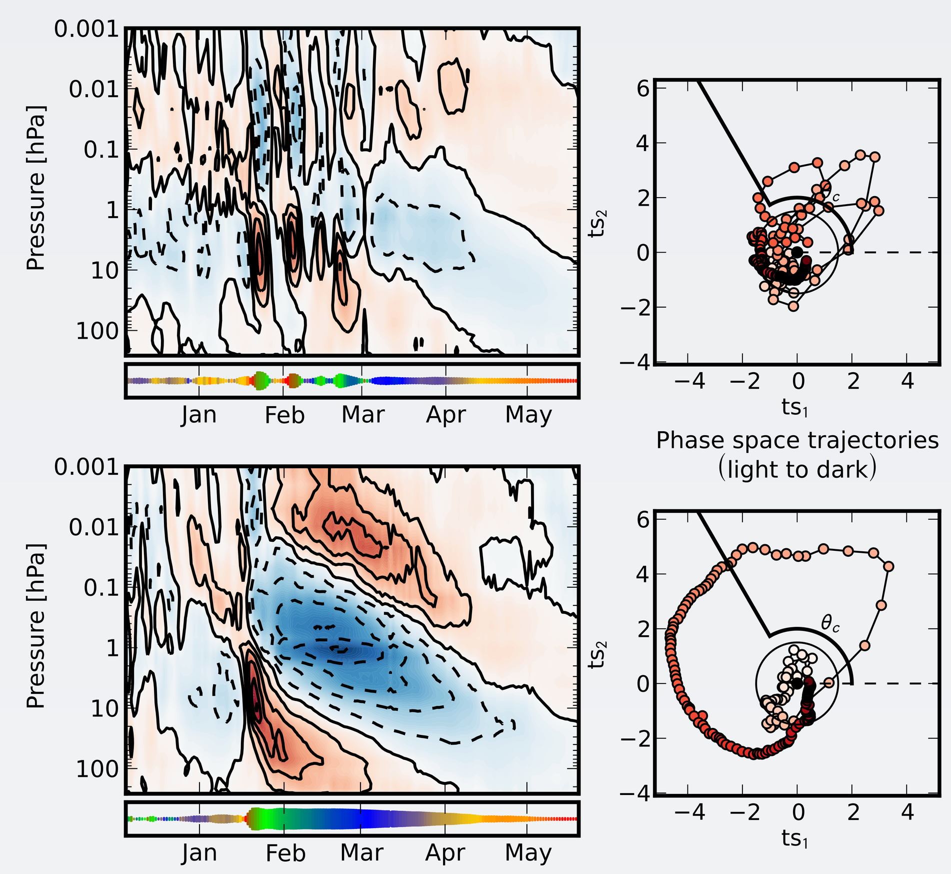
Introduction and Motivation

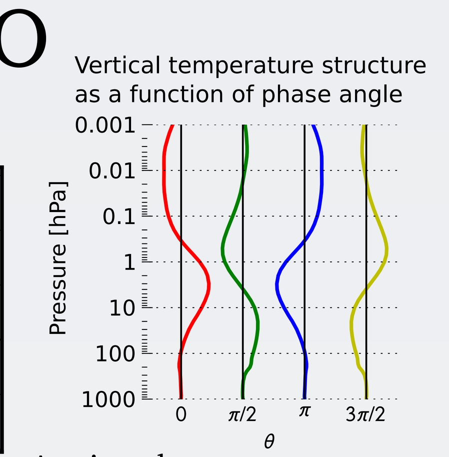
On seasonal time-scales, coupling between the Northern hemisphere stratosphere and troposphere is most pronounced following major sudden stratospheric warmings [1]. The extended dynamical timescales found in the lower stratosphere [2] are a potential source of skill in seasonal forecasts [3]. We show here, using a novel tool for the visualization of the variability of the polar-night jet, that the extended timescale recovery of the Arctic polar night jet is most pronounced following only a subset of major warmings. Following [4], we term these extended time-scale recoveries Polar-night Jet Oscillation (PJO) events. We make use of several reanalyses (ERA40, ERA Interim, MERRA), satellite observations (MLS) and the ensemble of three REF2 runs of the Canadian Middle Atmosphere Model (CMAM) from CCMVal1.

PJO events are characterized by large amplitude temperature anomalies in the Arctic middle-atmosphere. Their long timescales are a result of both the long radiative timescales in the lower stratosphere, and the suppression of further dynamical perturbations from upwelling planetary waves. The persistent lower-stratospheric temperature anomaly leads to a more persistent, stronger tropospheric response during PJO events as opposed to non-PJO warmings. In the upper stratosphere following the initial warming, the jet overshoots its climatological state, leading to a high, strong jet. This changes the filtering of gravity waves, leading to a high and descending stratopause. Finally, we point out that the large amplitudes and long timescales of PJO events can easily mislead standard statistical tests for significance.

[1] M. P. Baldwin and T. J. Dunkerton (2001) *Science*, **294**:581--584.
[2] M. P. Baldwin et al. (2003) *Science*, **301**:636--640.
[3] H. Mukougawa et al. (2009) *Geophys. Res. Lett.*, **36**:L08814.
[4] Y. Kuroda and K. Kodera (2001) *J. Geophys. Res.*, **106**:20703--20713.
[5] A. J. Charlton and L. M. Polvani (2007) *J. Clim.*, **20**:449--469.
[6] J. Perlwitz and N. Harnik (2004) *J. Clim.*, **17**:4902--4909.
[7] M. Rex et al. (2006) *Geophys. Res. Lett.*, **33**:L23808.
[8] P. Haynes et al. (1991) *J. Atmos. Sci.*, **48**:651--678.
[9] P. Hitchcock et al. (2010) *J. Atmos. Sci.*, **67**:2070--2085.
[10] SPARC CCMVal (2010) SPARC Report No. 5, WCRP-132, WMO/TD-No. 1526

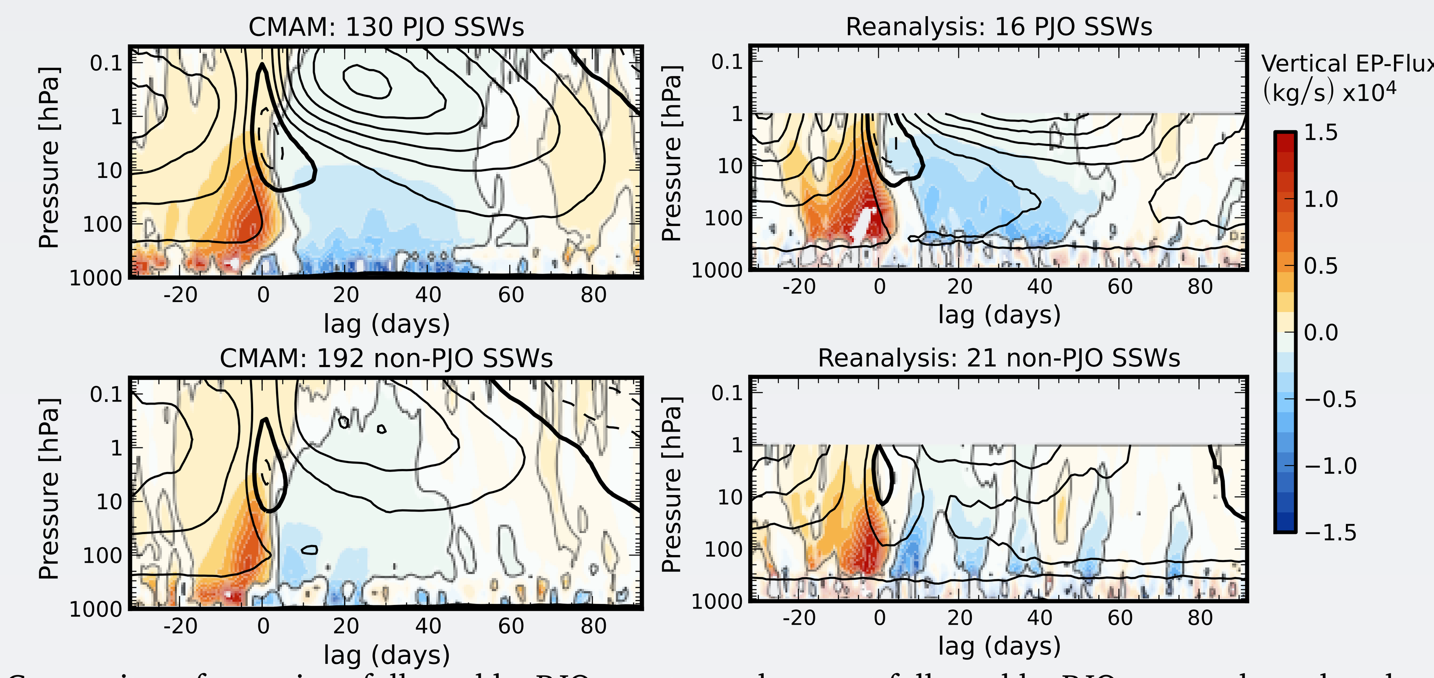
Abacus plots and the PJO





Arctic polar-cap temperature anomalies are well-described by their first two EOFs. The corresponding PC time series define a trajectory in 2D phase space, which can be used to visualize the variability in a compact manner. The 2008 and 2009 major warmings are shown here as examples; the latter was followed by an archetypical PJO event.

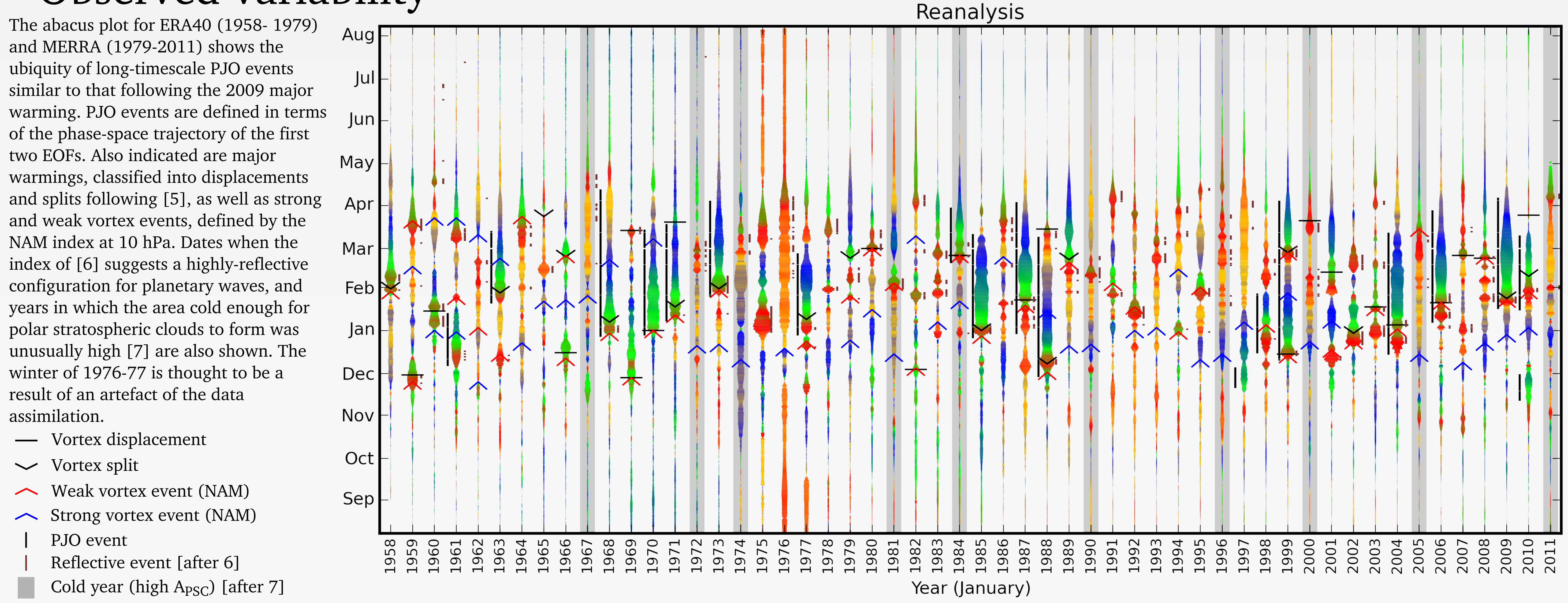
Planetary wave suppression



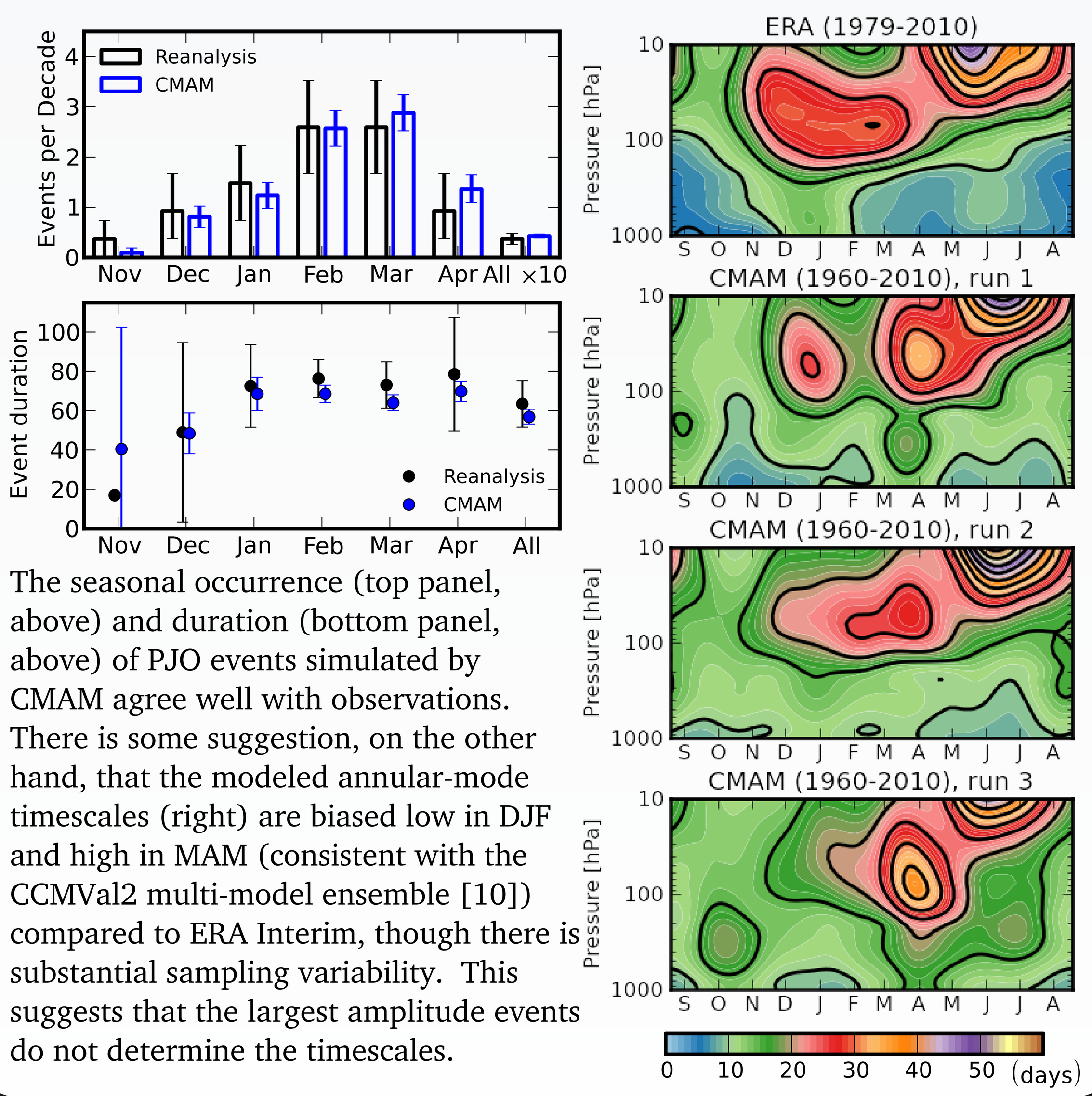
Composites of warmings followed by PJO events vs. those not followed by PJO events show that the upward Eliassen-Palm flux (shading) into the vortex (50-70N) is strongly suppressed for 60 days following the warming. The model results suggest that this suppression extends down to the surface. This coincides with the period of weak westerly zonal winds (contours) in the lower stratosphere.

Observed variability

The abacus plot for ERA40 (1958- 1979) and MERRA (1979-2011) shows the ubiquity of long-timescale PJO events similar to that following the 2009 major warming. PJO events are defined in terms of the phase-space trajectory of the first two EOFs. Also indicated are major warmings, classified into displacements and splits following [5], as well as strong and weak vortex events, defined by the NAM index at 10 hPa. Dates when the index of [6] suggests a highly-reflective configuration for planetary waves, and years in which the area cold enough for polar stratospheric clouds to form was unusually high [7] are also shown. The winter of 1976-77 is thought to be a result of an artefact of the data assimilation.

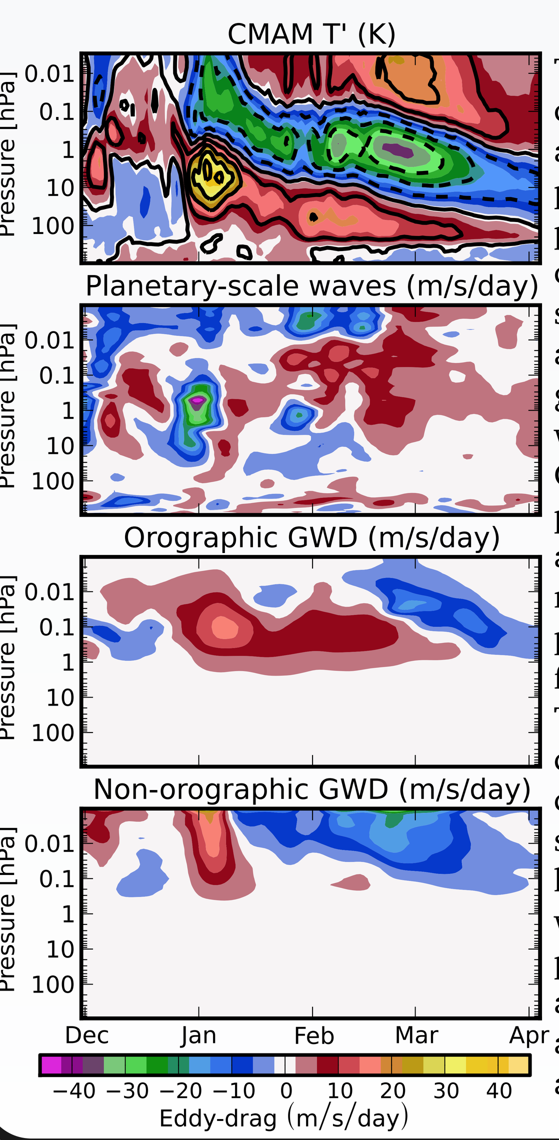


Annular-mode timescales

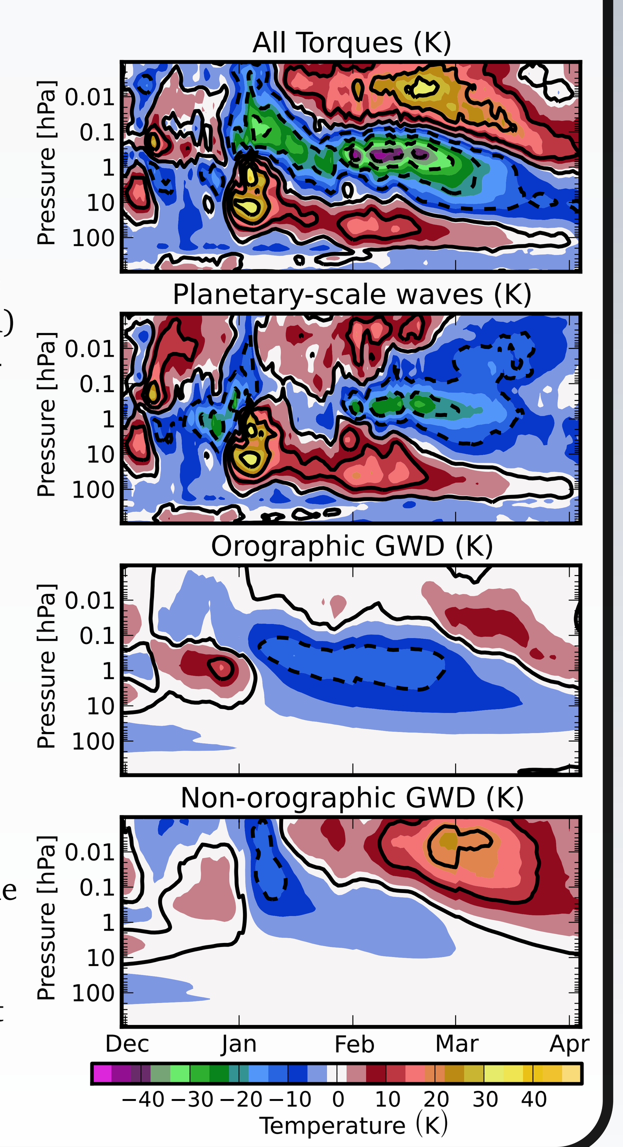


The seasonal occurrence (top panel, above) and duration (bottom panel, above) of PJO events simulated by CMAM agree well with observations. There is some suggestion, on the other hand, that the modeled annular-mode timescales (right) are biased low in DJF and high in MAM (consistent with the CCMVal2 multi-model ensemble [10]) compared to ERA Interim, though there is substantial sampling variability. This suggests that the largest amplitude events do not determine the timescales.

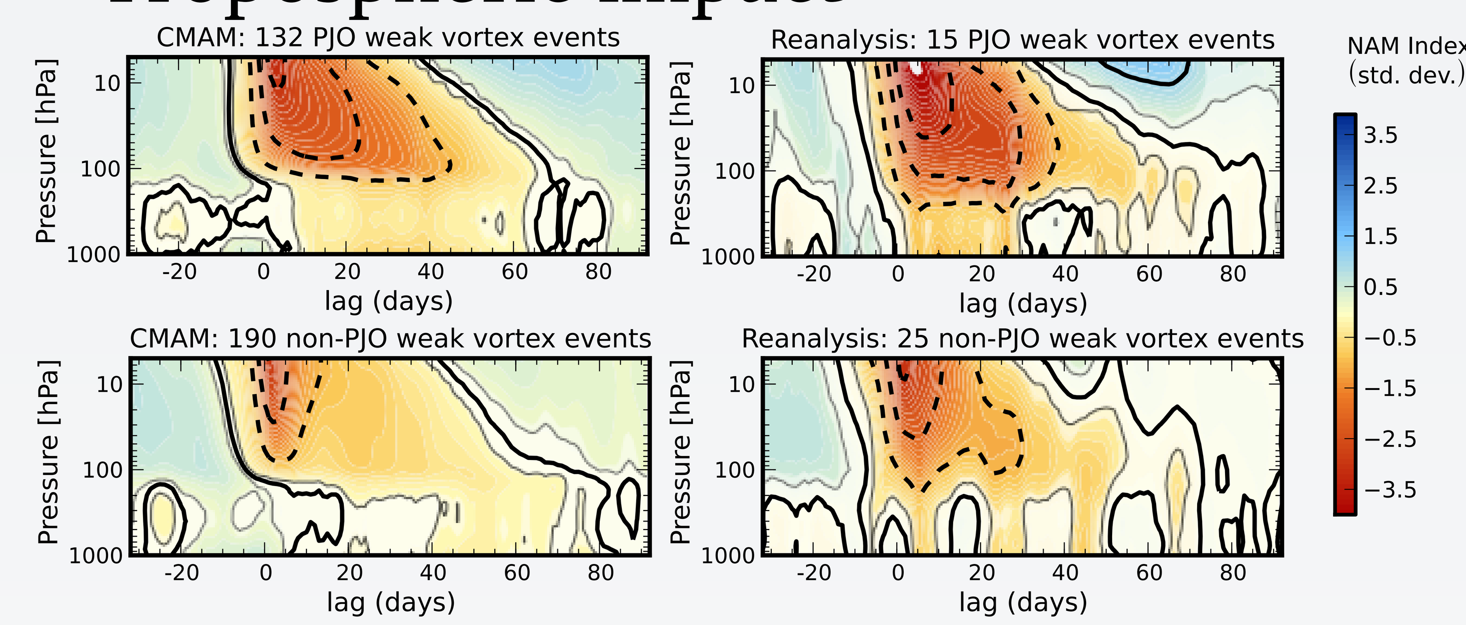
Zonal-mean dynamics



The dynamics of the zonal-mean circulation are essentially that of Eliassen adjustment to the torques generated by planetary-scale Rossby waves and parameterized gravity waves. The polar cap temperature anomalies from one case study simulated by CMAM (left, top panel) are well described by a zonal-mean quasi-geostrophic model on the sphere [8] in which the eddy-forcings generated by CMAM are imposed (left, bottom three panels). The diabatic heating is well-approximated by Newtonian cooling [9], resulting in a fully linear model. This permits the transient response to each forcing to be computed (right panels). The lower stratospheric anomaly persists due to long lower-stratospheric radiative damping timescales, and (in this case) a secondary pulse of planetary waves. The high, descending stratopause following the warming is a result of strongly filtered parameterized gravity waves. The cold anomaly in the mid stratosphere is almost as much a result of filtered gravity waves as it is of reduced planetary wave drag.

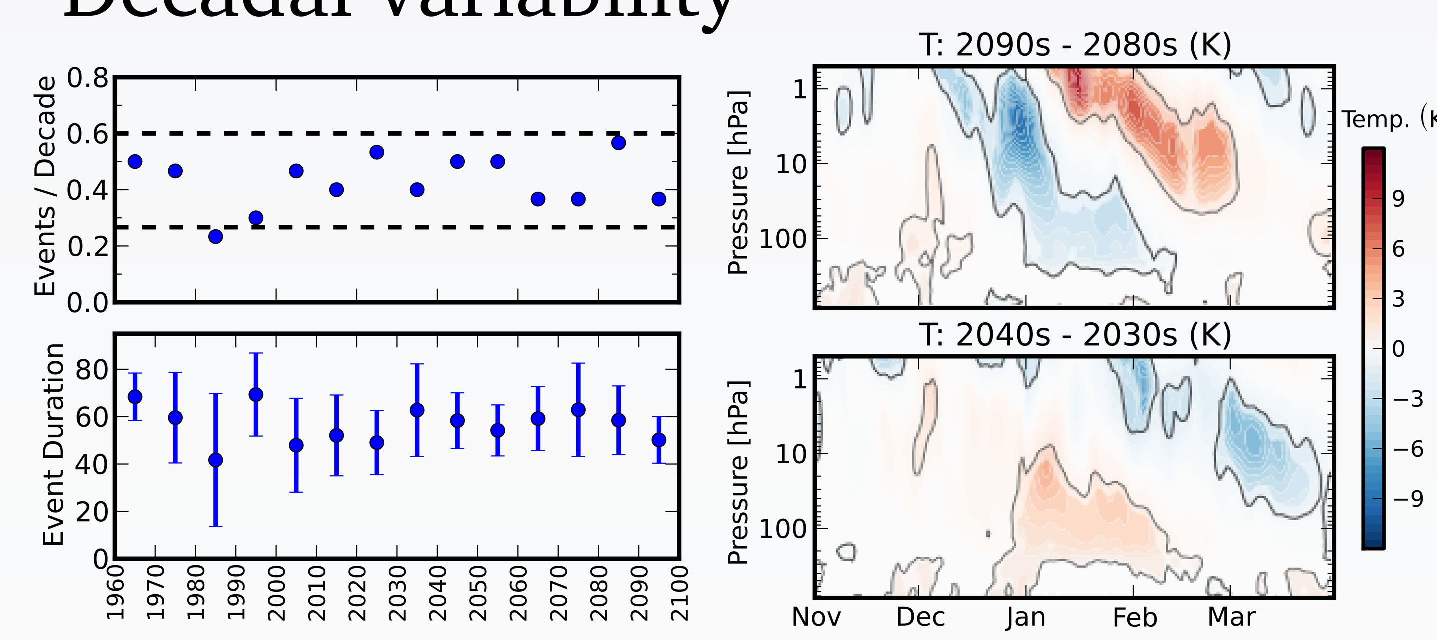


Tropospheric impact



Composites of the northern annular mode indices during weak-vortex events followed by PJO events vs. those not followed by PJO events show that the more persistent, larger amplitude events in the stratosphere also have a stronger and more persistent impact on the troposphere. PJO events are best predicted by the depth to which the warming descends in the stratosphere. They are more likely following the largest amplitude weak-vortex events, but they cannot be defined by a particular threshold.

Decadal variability



The occurrence of PJO events in the ensemble of three CCMVal 1 REF2 integrations of CMAM are well described, statistically, by assuming that one will occur each winter with probability $p = 43\%$. The ensemble-averaged frequency of events shows no evidence of a trend; nor does their mean duration. Nonetheless, their large amplitude and serial correlation can easily lead to highly structured polar-cap temperature anomalies of up to 10 K between 30-year climatologies, which appear highly (but erroneously) significant by standard statistical tests (coloured shading).

Conclusions

We show here that highly coherent, large amplitude, and long-timescale recoveries occur following roughly half of all major stratospheric sudden warmings. These PJO events are well simulated by the CMAM. We have also presented a novel tool for the visualization of the variability of the Arctic polar night-jet, which is useful for understanding the relationship between these events and other commonly used indices of Arctic variability. The robustness of the circulation anomalies during PJO events and the dominance of radiative processes during the recovery phase suggests that they are highly predictable, and their impact on the troposphere suggests this may in turn be a source of skill in seasonal forecasting. Their large amplitude and strong serial correlations, however, present challenges for the detection and attribution of externally-forced changes in the Arctic stratosphere.