New classification showing the stratospheric memory concept: towards a better seasonal prediction

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Context

Every winter, in both hemispheres, a vortex forms in the stratosphere centered above poles, characterized by a cold temperature, low pressure, and strong zonal winds. During its winter life, the northern hemisphere polar vortex can be impacted by stratospheric warmings, the so-called sudden stratospheric warmings (SSWs), leading to the reversal of zonal winds and the breaking of the vortex in the most extreme cases. SSWs are caused by the interaction of propagating planetary waves (PWs) with the mean flow. At the end of the winter, the polar vortex disappears, with final stratospheric warming (FSW) occurring either early (dynamically-driven) or late (radiatively-driven) (Hauchecorne et al., 2022).

Since SSWs are studied, only the following classification of SSWs according to their magnitude and/or timing has remained widely used: Major, Minor, Final, and Canadian. However, there is still no clear definition for these four SSW categories, even though they are often based on a zonal wind criterion at the edge of the polar vortex (Butler et al., 2017). Here, we introduced the category of Important SSWs (ISSWs), including all events significantly affecting the polar vortex.

Figure 1 shows two typical polar vortex evolutions occurring during SSW events, i.e., the vortex is either displaced off (A) of the pole (wave-1 driven) or split (B) into two vortices (wave-2 driven). In addition, **these two geometric evolutions differently impact the weather at the surface** according to Mitchell et al. (2013).

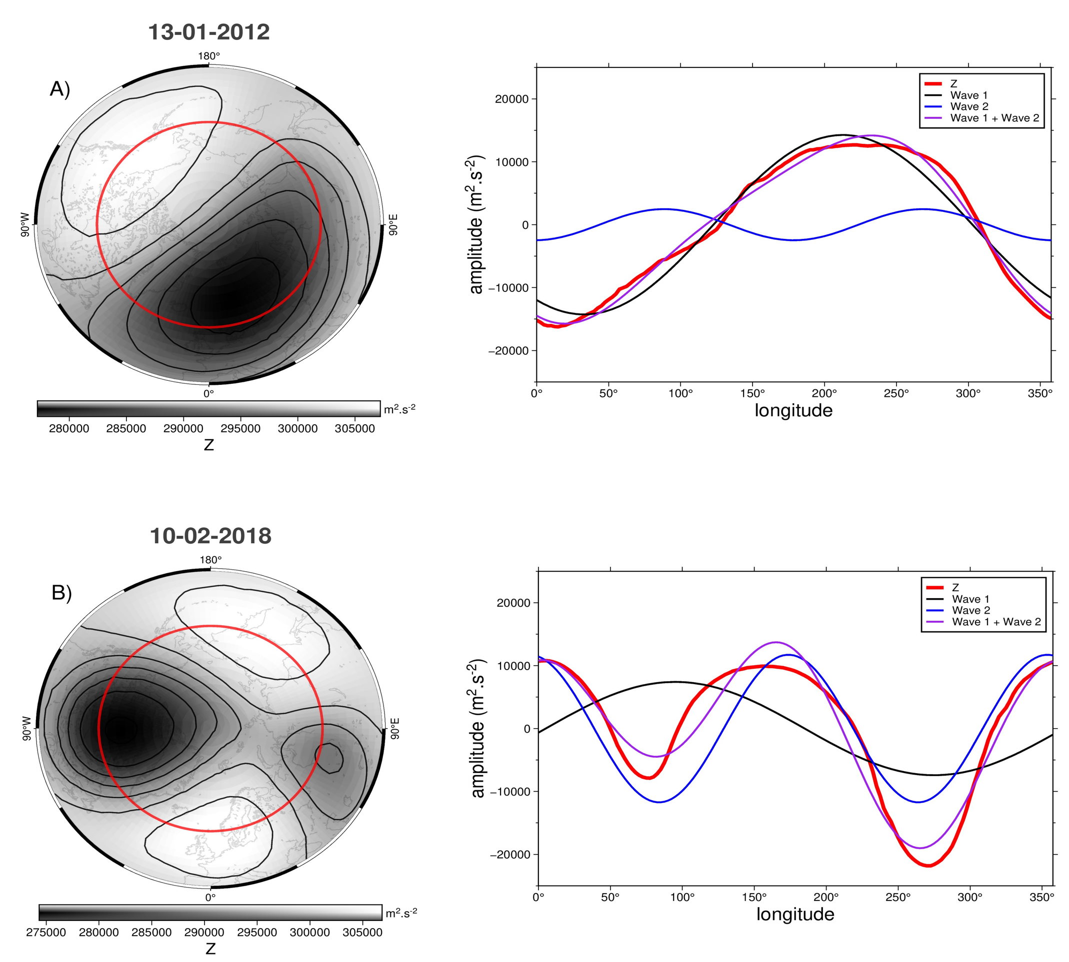
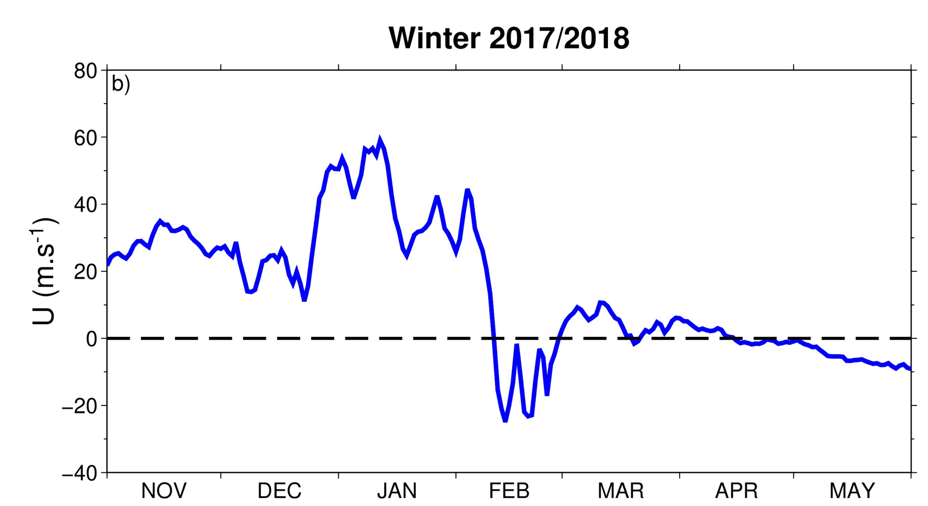


Fig. 1: Geopotential contour at 10hPa during two SSW events in the NH and the contribution of waves 1 and 2 at 60°N.

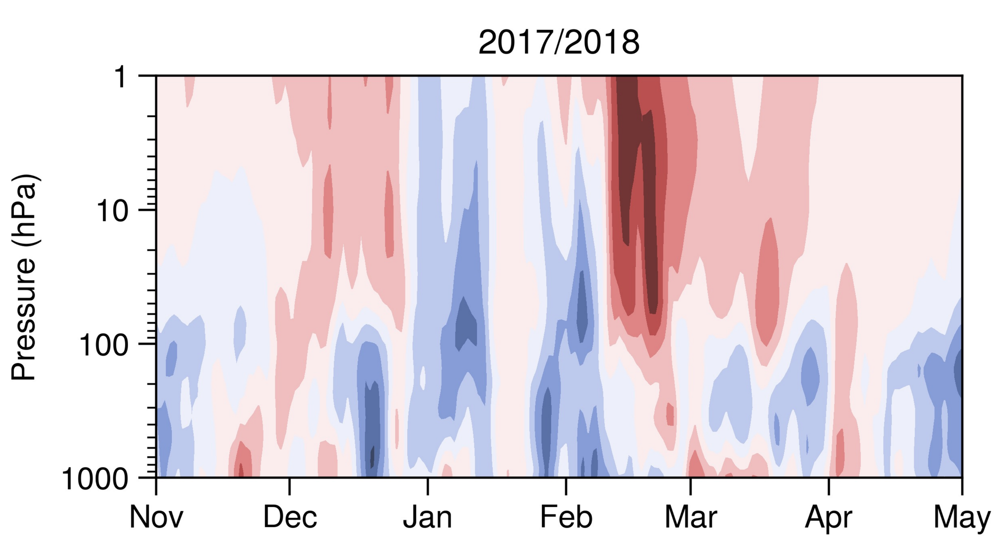
Data and method

In this study, we extracted zonal winds data at 10hPa and 60°N for the **70 winters** between 1950 and 2020 from the last generation of reanalyses, ERA-5, produced by the ECMWF. The following Figure illustrates the zonal mean zonal wind at 10hPa-60°N evolution for winter 2017/2018 during which a Major SSW occurred.



Here, a new method of classification based on the empirical orthogonal functions **(EOFs)** analysis of stratospheric zonal mean zonal wind anomalies in the northern hemisphere has revealed that the winter stratosphere **follows four different evolutions.**

Then, the stratosphere-troposphere coupling is evaluated with the northern annular mode (NAM) which represents the leading mode of wintertime variability in the Northern Hemisphere circulation. The NAM indices are computed by following the method described in Baldwin and Thompson (2009) based on the EOFs of daily zonally-averaged geopotential. The Figure (on the right) shows the time-height evolution of NAM indices for the winter 2017/2018. Blue corresponds to a strong polar vortex and red to a weak polar vortex. The anomaly generated by the SSW in February in the stratosphere propagates downward into the troposphere.



Results of the new classification:

61 winters classified !

Three perturbed scenarios:

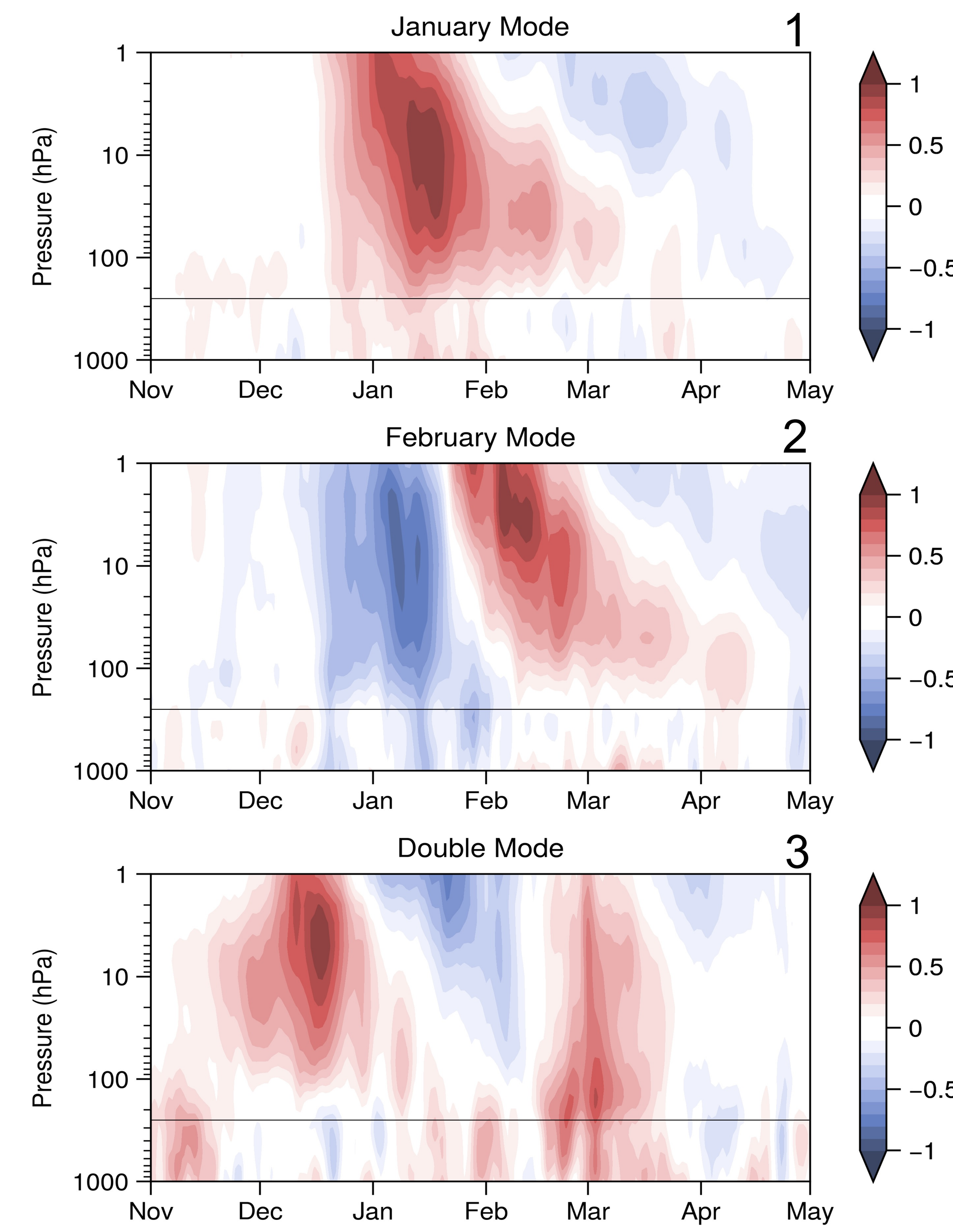
- 17 winters associated with the EOF-1 (**January mode**)
- 17 winters associated with the EOF-2 (**February mode**)
- 7 winters associated with the EOF-3 (**Double mode**)

One unperturbed scenario:

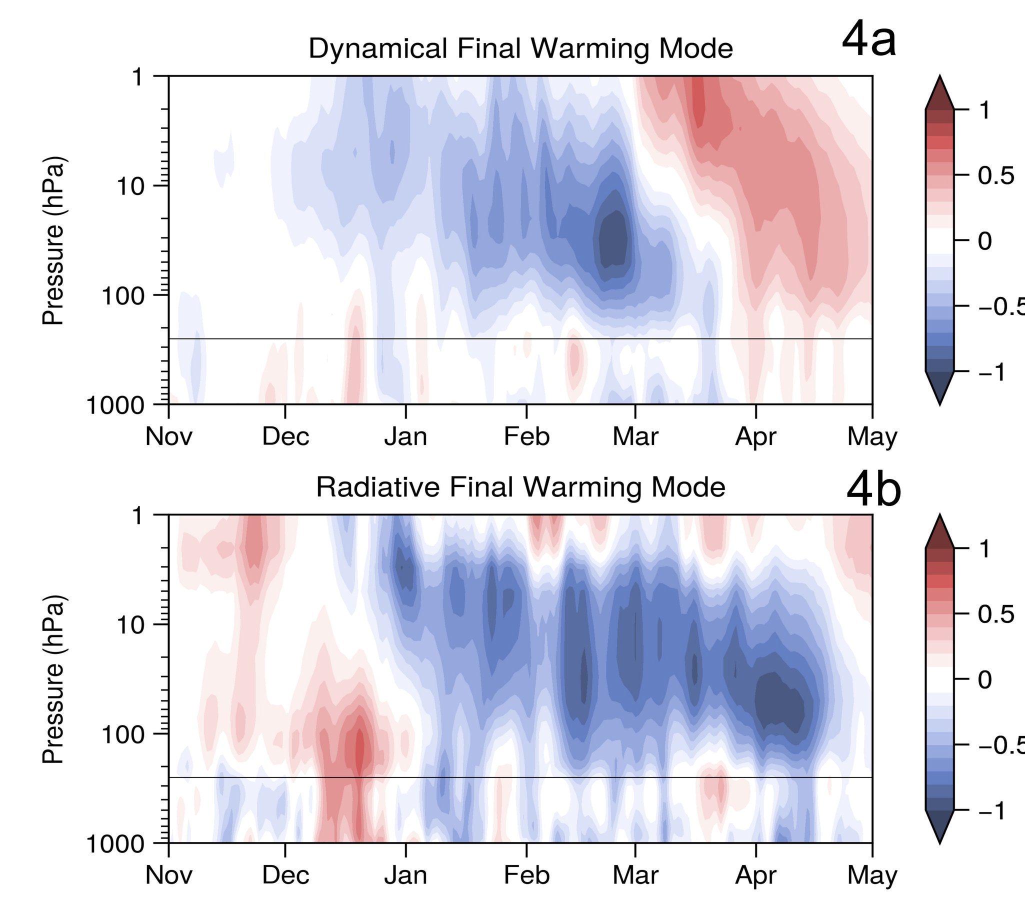
- 15 winters associated with the **Dynamical Final Warming mode**
- 5 winters associated with the **Radiative Final Warming mode**

NAM indices for each scenario

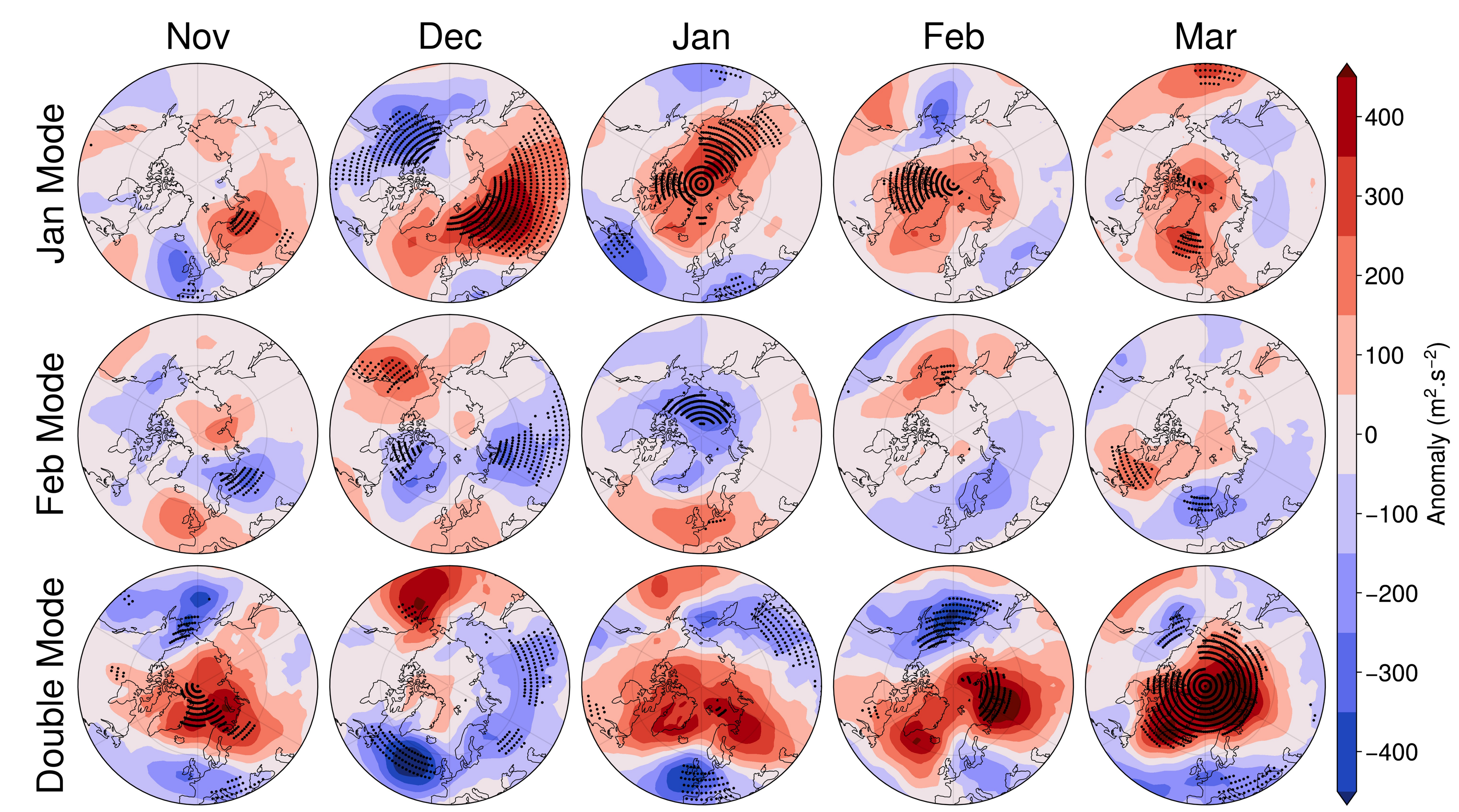
1. The Three Perturbed Scenarios



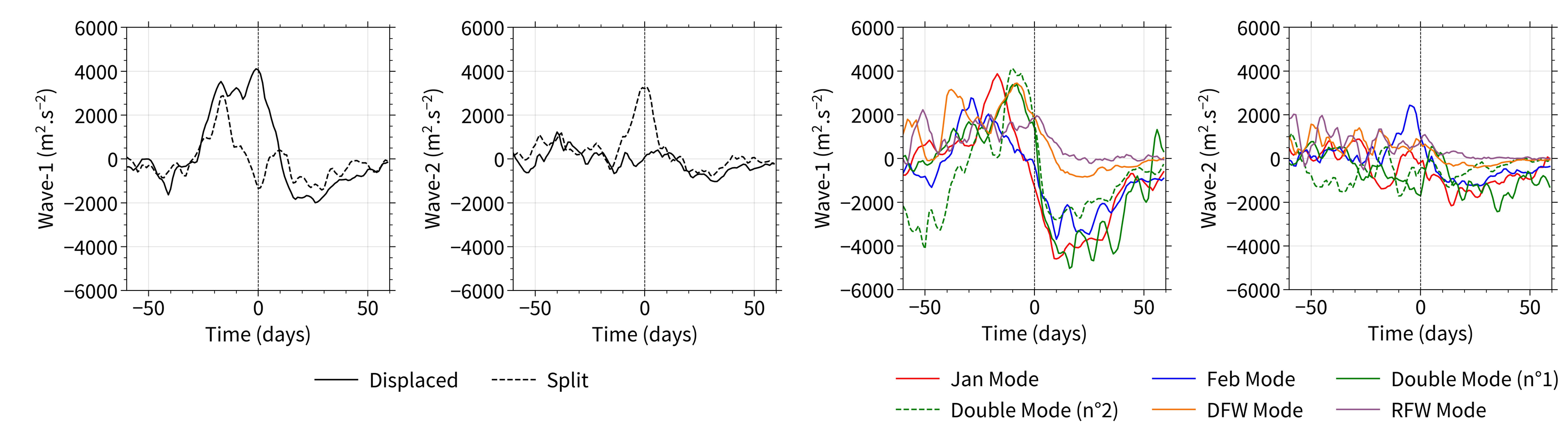
2. The Unperturbed Scenario (with two sub-modes)



Geopotential anomaly at 1000 hPa



Comparison with classification done in Mitchell et al. (2013)



Conclusions

- The wintertime stratosphere in the northern hemisphere tends to follow four scenarios modulated by the timings of SSWs and FSWs. There are three perturbed scenarios with SSW occurring in mid-winter and one unperturbed scenario for which only the FSW type differs, either dynamical or radiative.
- In December, opposite harbinger signals at the surface are found between the January and February modes.
- While the anomaly patterns at ground seem similar between the January and Double modes before and after the SSW's occurrence but with a shift of one month.
- Following the SSW's occurrence, the February mode signal at the ground is less significant than those for January and Double modes.
- Surface harbingers are present in November for the Double mode.
- The February mode is the only mode with increased wave-2 activity before SSW's onsets as found for splitting events, while other modes are more wave-1 driven as displaced events are.

References

1. Mitchell, D. M., Gray, L. J., Anstey, J., Baldwin, M. P., & Charlton-Perez, A. J. (2013). The influence of stratospheric vortex displacements and splits on surface climate. *Journal of climate*, *26*(8), 2668-2682.

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Abstract **EGU23-1376**

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