Nonlinear saturation of stationary planetary waves in the boreal stratosphere

Savenkova E.N (savenkova.en@mail.ru)

Russian State Hydrometeorological University

St.Petersburg

Russia

24-28 October 2011, Denver, Colorado, USA

Outline

Trends in the zonally averaged temperature, zonal mean flow, and amplitude of stationary planetary wave with zonal wave number 1 (SPW1) in the NCEP/NCAR data

Simulation of the Northern Hemisphere winter-time general circulation of the middle atmosphere with the Middle and Upper Atmosphere Model (MUAM) for 1960 and 2000 conditions

Climatic, Inter-annual (between ensemble members), and intra-seasonal variability of the SPW1 amplitude

Sensitivity of the stratospheric response to the lower boundary forcing of SPW

Previous results:

Kanukhina et al., Ann. Geophys., 2007, 26, 1233-1241

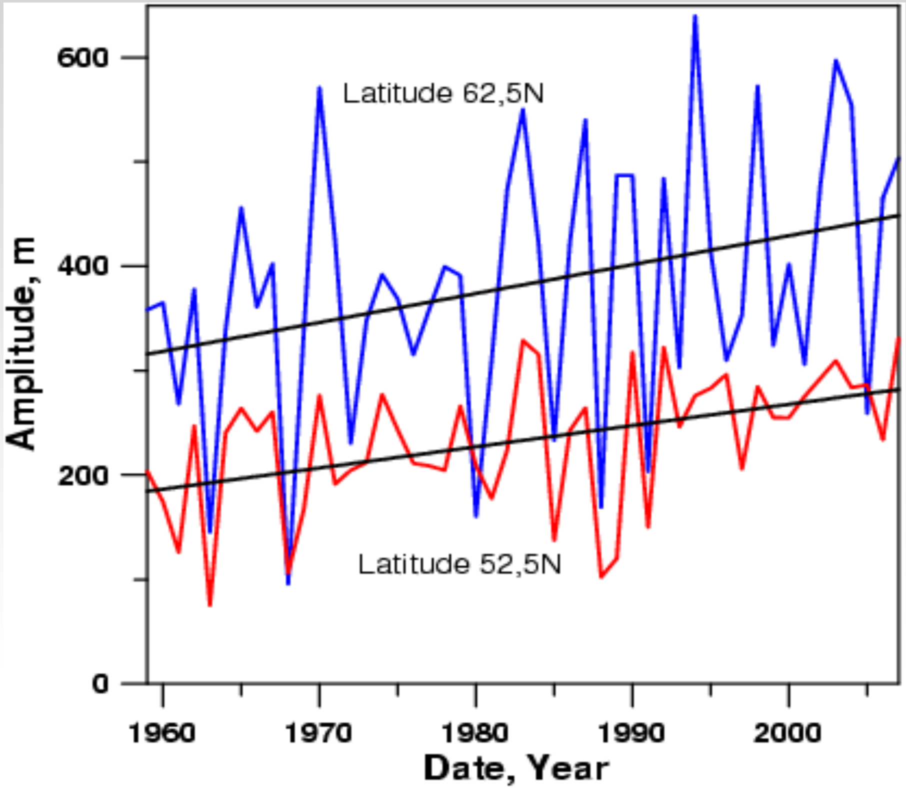
Noticeable climatic changes of the zonally averaged temperature in the lower atmosphere, which have different signs at low and high latitudes (increase in the latitudinal gradients)

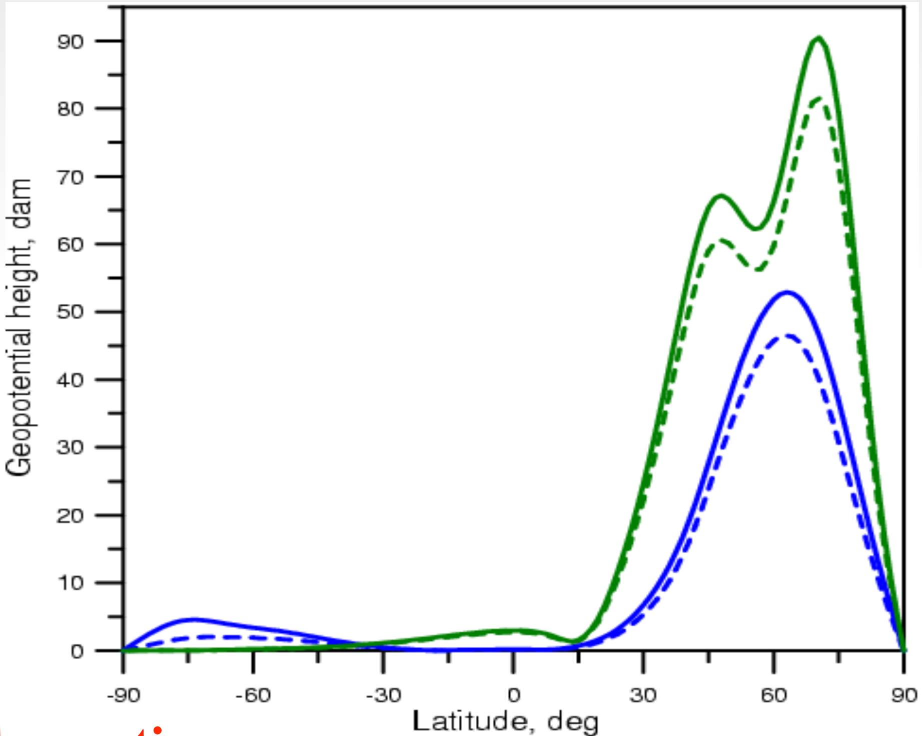
Changes of the positions and intensity of tropospheric jets are in a good agreement with the observed increase in the gradients of the zonally averaged temperature

Results of SPW1 simulation with the linearized model using the background wind typical for 1960 and 2000 show an increase in the SPW1 amplitude in the stratosphere and mesosphere

Analysis of the NCEP/NCAR data supports the results of the simulation and shows that SPW1 amplitude increases at higher-middle latitudes of the boreal stratosphere during the last decades

The amplitude of the SPW1 at 30 hPa level in the NCEP/NCAR data.





The calculated with a linearized model amplitude of the SPW1 at 25 km (blue lines) and 50 km (green lines) for 1960 and 2000 (dashed and solid lines, respectively).

Suggestion:

The observed increase in the SPW1 amplitude should be accompanied by the growth in the magnitude of the stratospheric vacillations.

Middle and Upper Atmosphere Model (MUAM)

Pogoreltsev, A.I., A.A. Vlasov. K. Fröhlich, and Ch. Jacobi, Solar-Terr. Phys., 2007, 69, 2083-2101

- **The MUAM is a 3D nonlinear mechanistic model of the atmospheric circulation extended from the 1000 hPa surface up to the heights of the ionospheric F2-layer. It is based on the Cologne Model of the Middle Atmosphere (COMMA).**

- **The MUAM is a grid-point model with horizontal (latitude/longitude) resolution of 5°*5.625°. It has up to 60 levels in the nondimensional log-pressure height x = - ln(p/1000) with a step-size of about 0.4. The model allows to use an arbitrary number of levels (ranging from 48 to 60) with the same vertical resolution. In the present study we use 48-level version with the upper boundary at x = 19, which corresponds to the geopotential height of about 150 km.**

- **To integrate the prognostic equations, the initial Cauchy problem was split into the set of simpler problems according to the physical processes considered. To solve these simpler problems, we use the Matsuno time-integration scheme.**

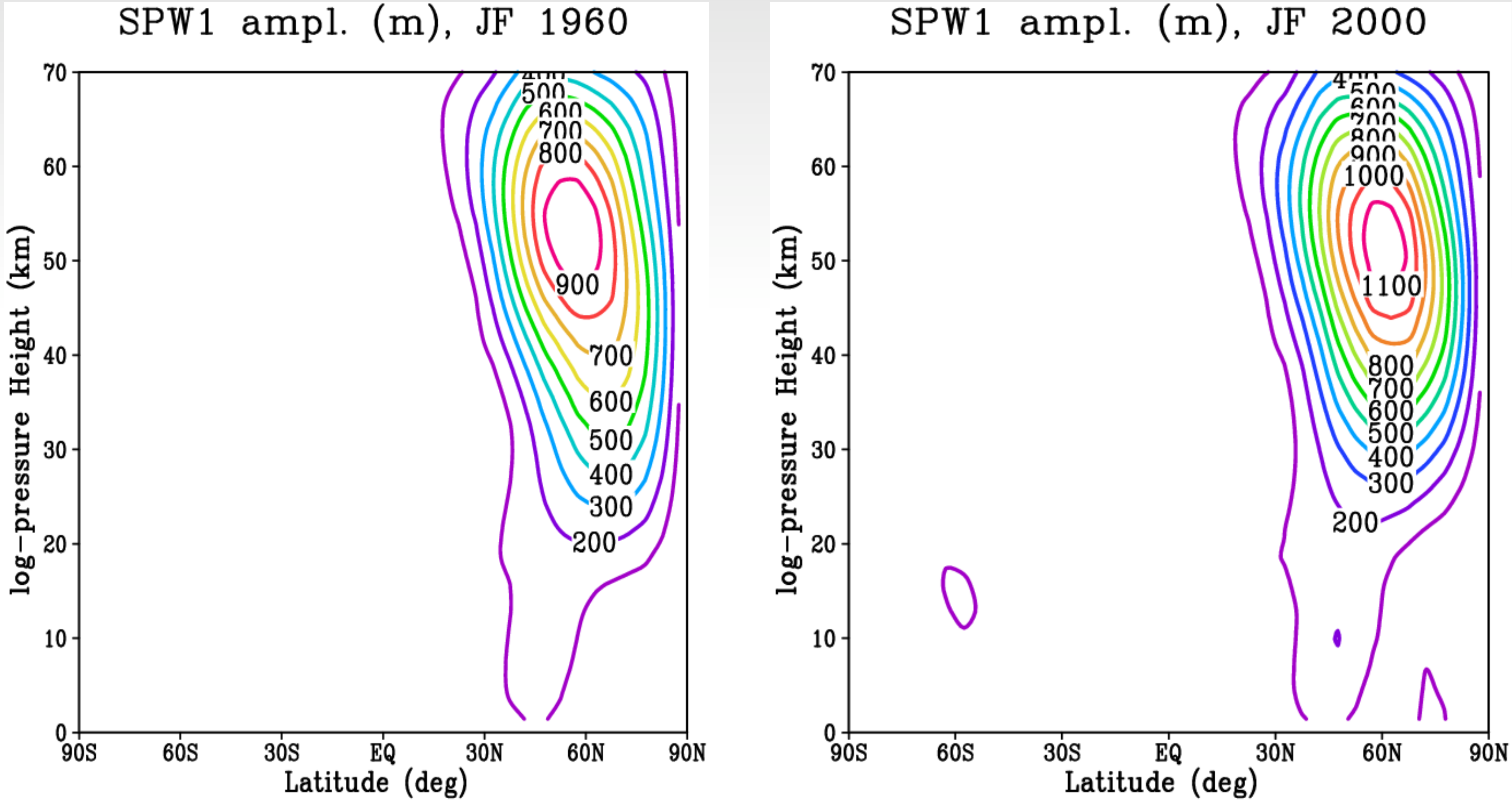
MUAM: outline of numerical experiments (2)

It is known that small variations in the initial conditions can have a substantial influence on the evolution of the modeled stratosphere in winter (Yoden, *J. Atmos. Sci*., 47, 1845-1853, 1990; Gray et al., *Q. J. Roy. Met. Soc*., 129, 925-945, 2003).

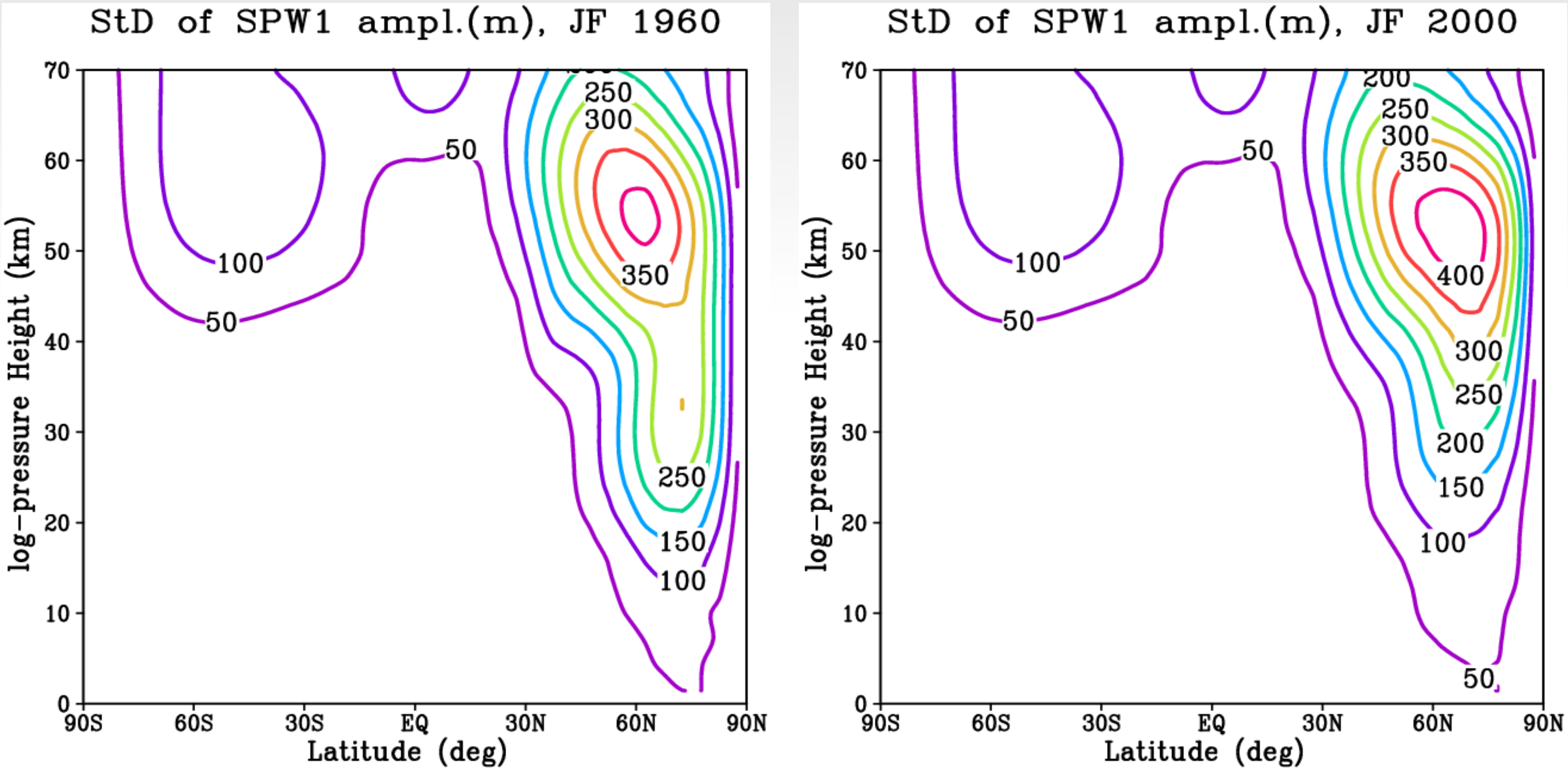
To reproduce the climatic changes of zonally averaged fields in the troposphere, the calculated zonally averaged temperature in the troposphere was adjusted to the observed temperature obtained for January-February 1960 and 2000.

In result, **2 sets of runs** (ensemble 1960 and 2000, respectively) were calculated to estimate a possible climatic change of the stratospheric dynamics. Each ensemble contains 10 members, obtained with different initial conditions.

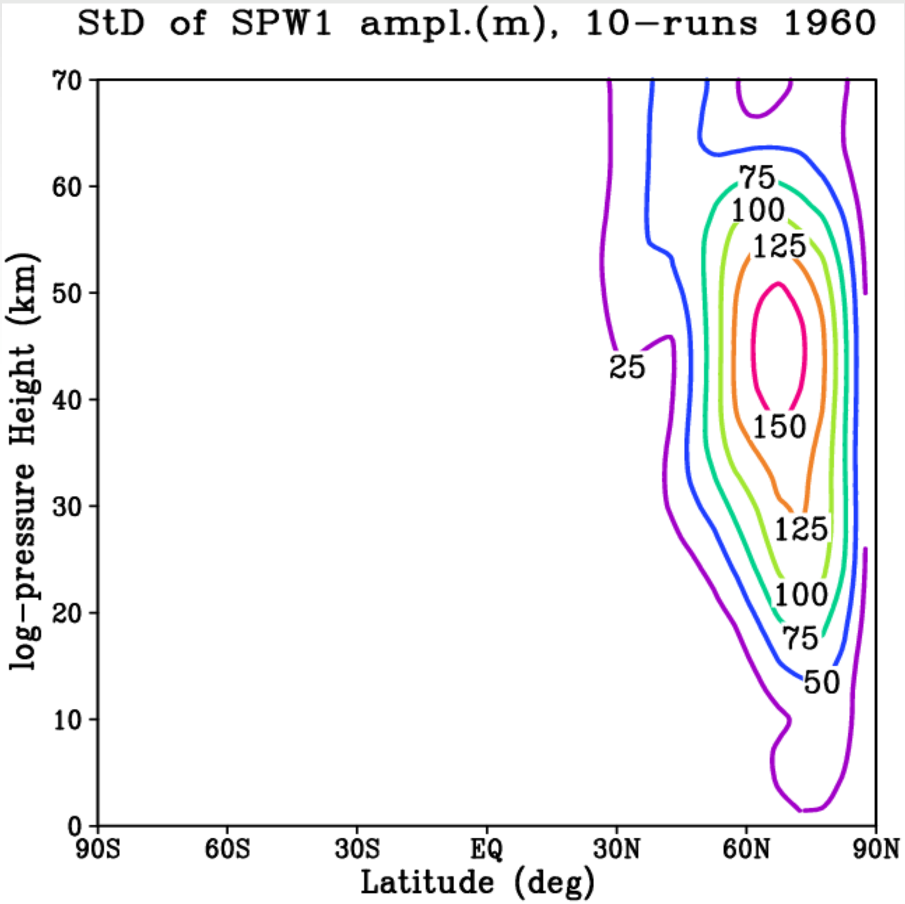
MUAM: **SPW1 amplitude in January-February calculated as averaged over 1960 and 2000 ensemble members (left and right panels, respectively).**

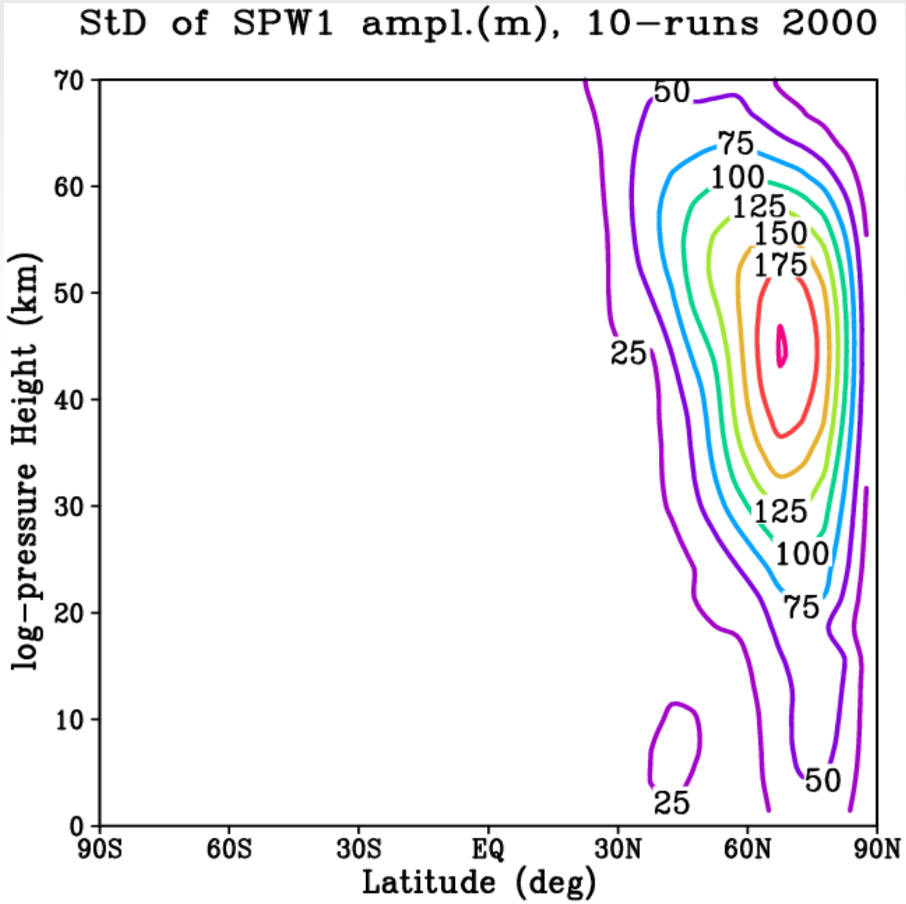


MUAM: **Intra-seasonal (during January-February) variability of the SPW1 amplitude for 1960 and 2000 – left and right panels, respectively.**



MUAM: **Inter-annual (between the ensemble members) variability of the SPW1 amplitude in January-February for 1960 and 2000, respectively.**





Conclusions

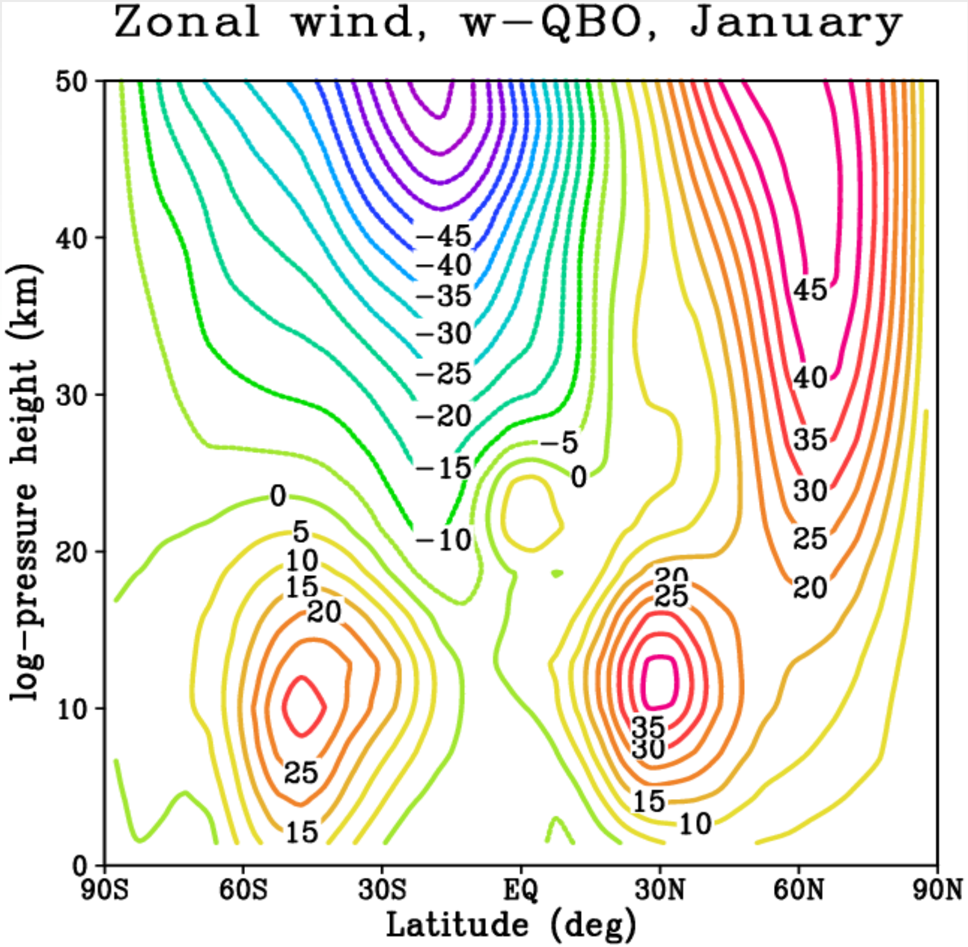
Pogoreltsev et al., JASTP, 2009, 71, 1529-1539.

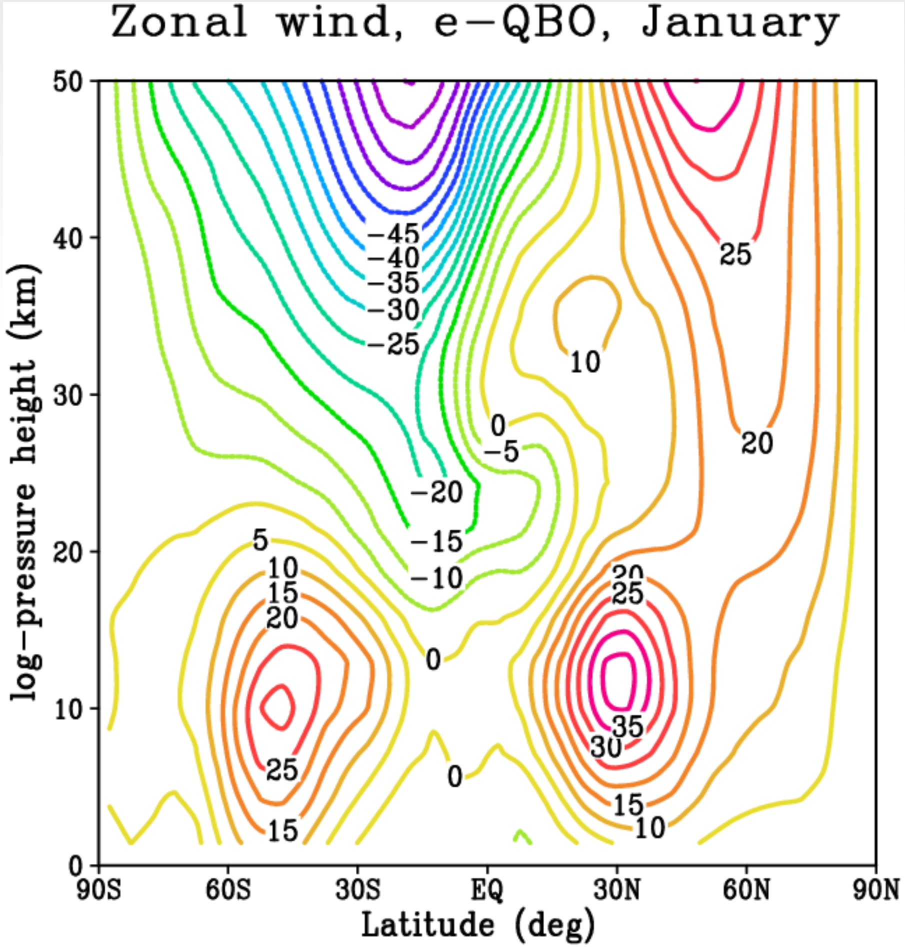
- The results of simulations with the MUAM show that in average SPW1 amplitude in January-February increases since 1960 to 2000. This result is in a good agreement with the behavior of SPW1 amplitude observed in the NCEP/NCAR data.

- Increase in the magnitude and the **intra-seasonal** and **inter-annual** variability of SPW1 during the last decades, which is noticeable in the boreal stratosphere during Northern Hemisphere winter, allows us to suggest that **stratospheric dynamics becomes more irregular and/or chaotic, and we can expect the corresponding changes in the troposphere and upper atmosphere.**

- Growth of the SPW1 variability can be interpreted as an amplification of the stratospheric vacillations, which are forced by the two-way nonlinear interaction between quasi-stationary PW and mean flow.

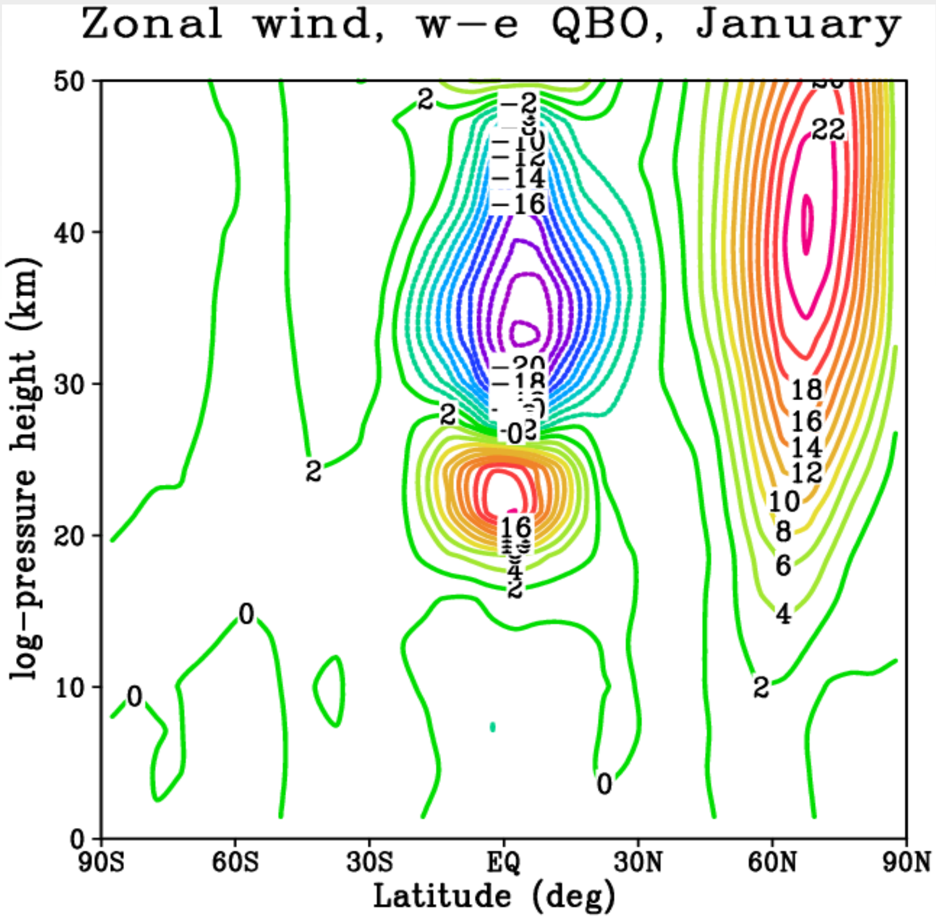
Zonal mean flow averaged over 7 years for westerly and easterly QBO conditions (UK Met Office data)



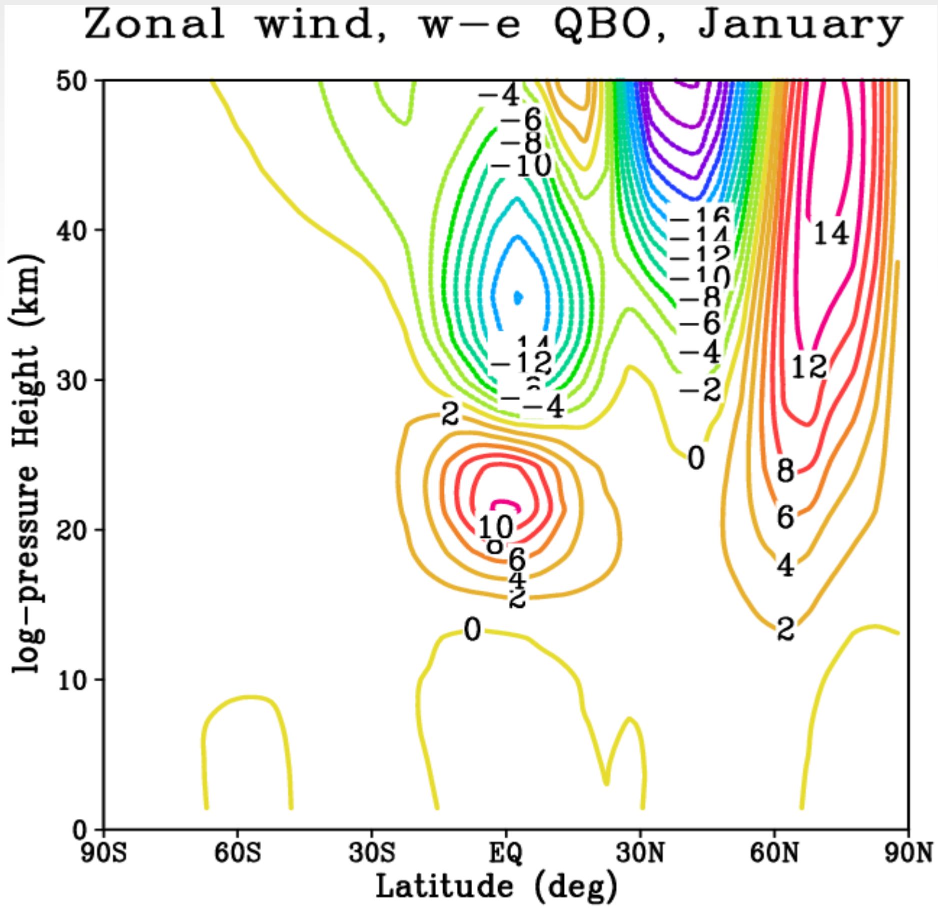


Difference in zonal mean flow during westerly and easterly QBO.

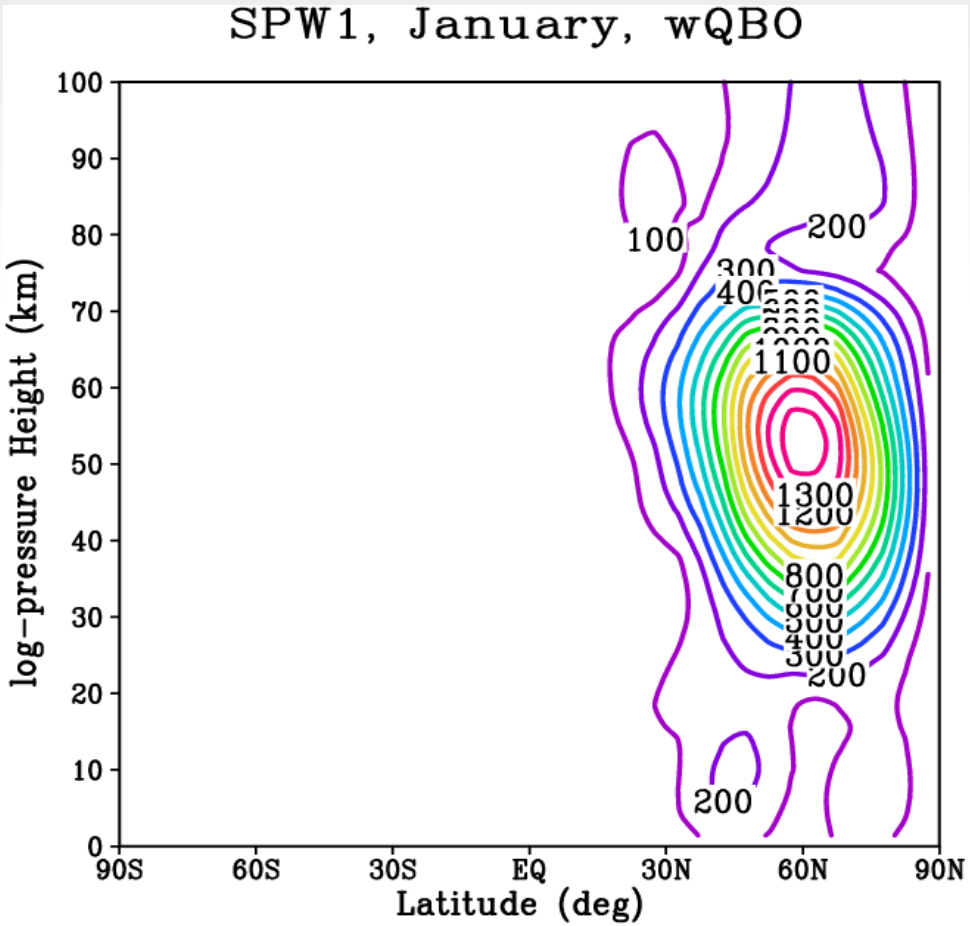
UK Met Office data

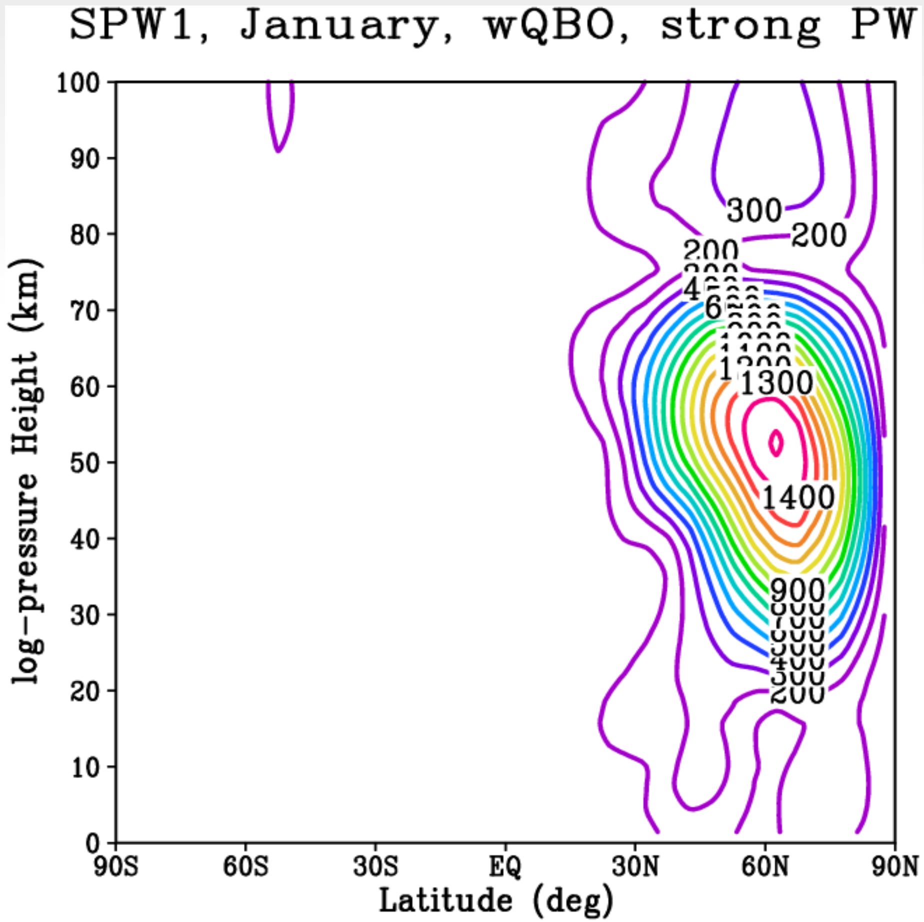


simulated with MUAM

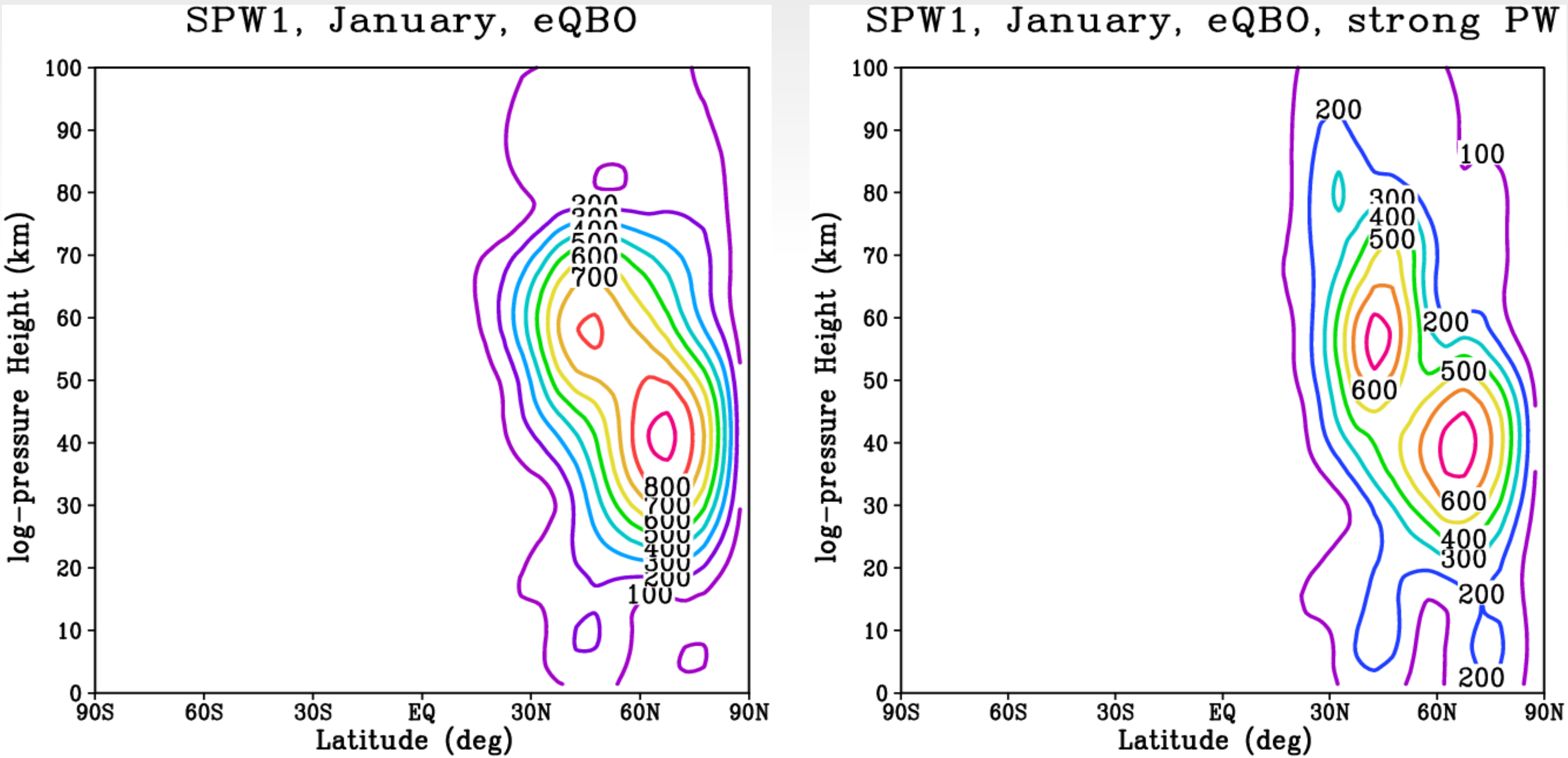


Simulated with the MUAM amplitudes of SPW1 in the geopotential height for the westerly QBO.
Strong lower boundary forcing = SPW*1.2, right).

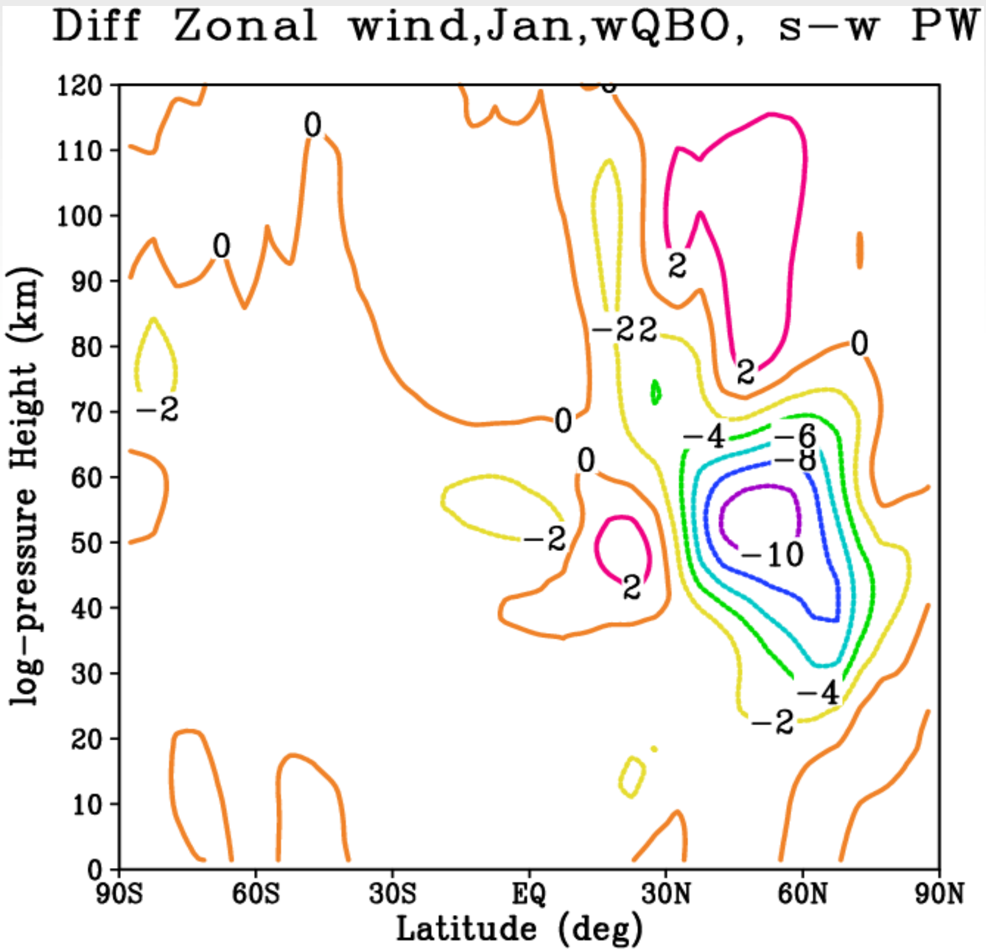


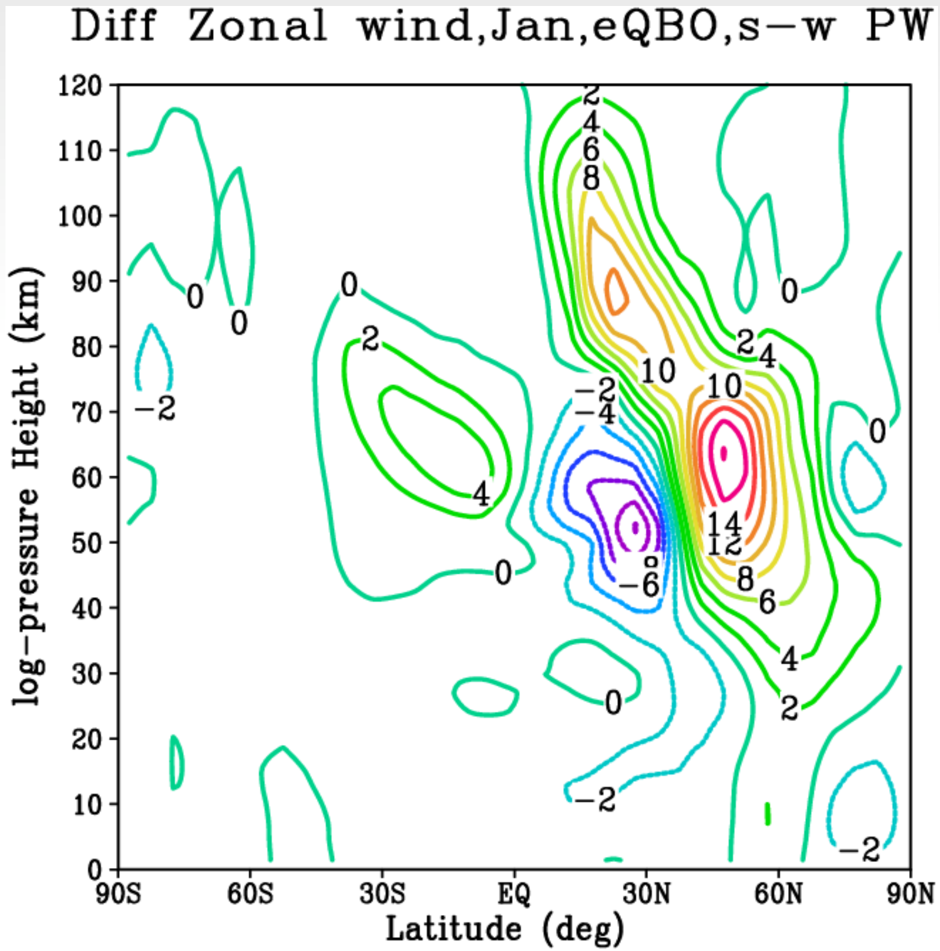


Simulated with the MUAM amplitudes of SPW1 in the geopotential height for the easterly QBO. Strong lower boundary forcing = SPW*1.2, right).

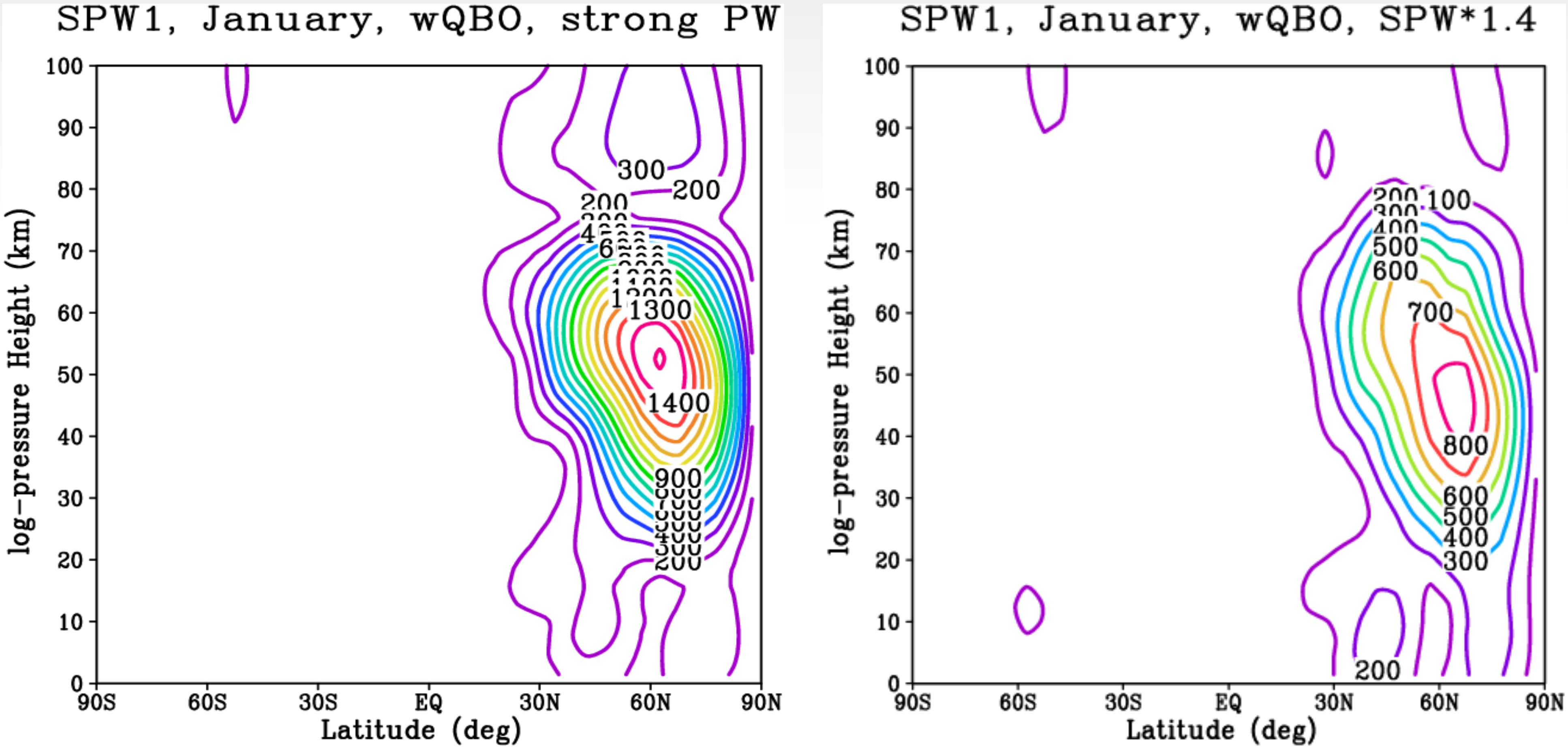


Difference in zonal mean flow with strong and weak PW at the lower boundary during westerly and easterly QBO.

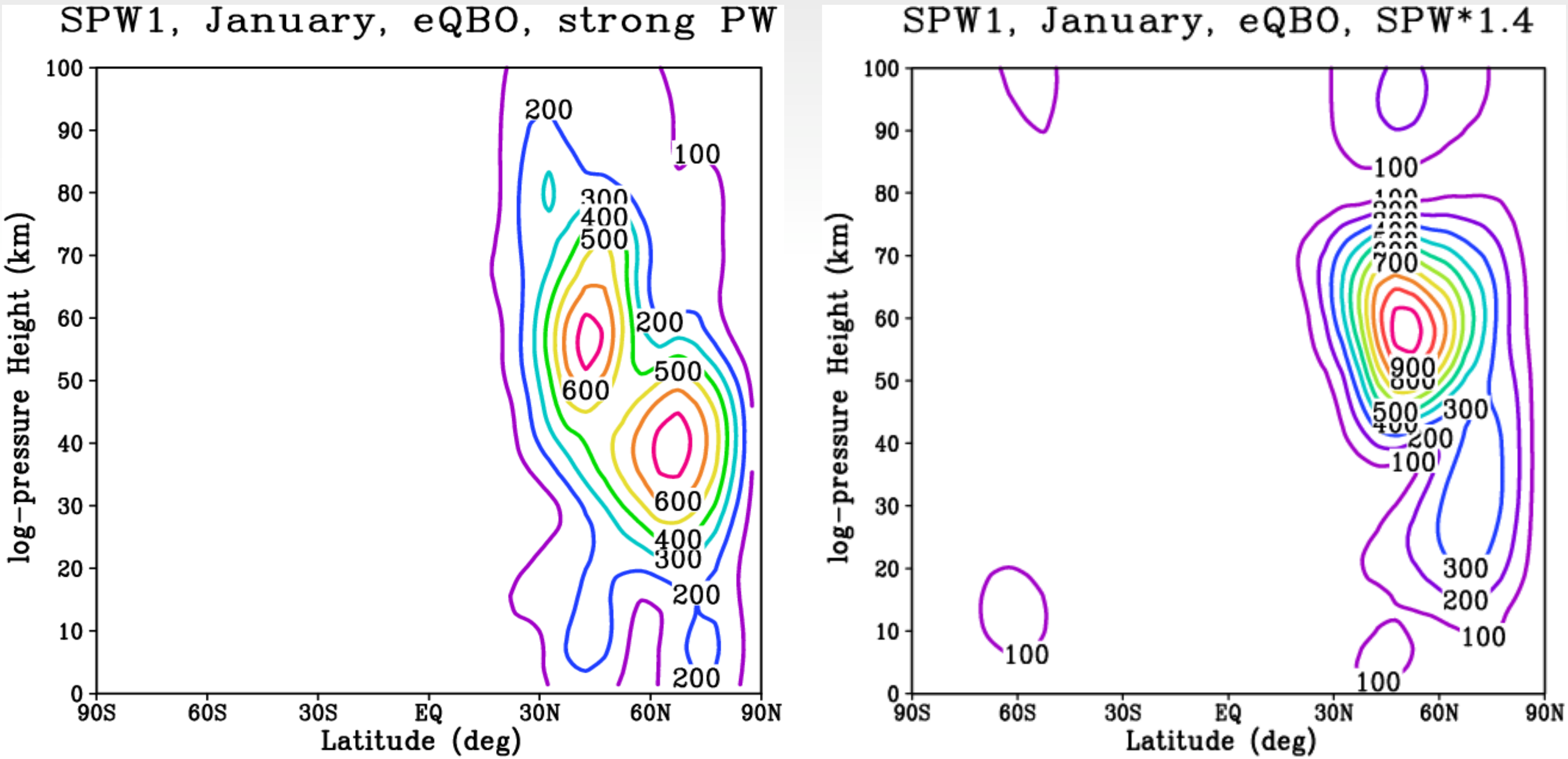




Simulated with the MUAM amplitudes of SPW1 in the geopotential height for the westerly QBO.
Lower boundary forcing SPW*1.2 and SPW*1.4



Simulated with the MUAM amplitudes of SPW1 in the geopotential height for the easterly QBO.
Lower boundary forcing SPW*1.2 and SPW*1.4



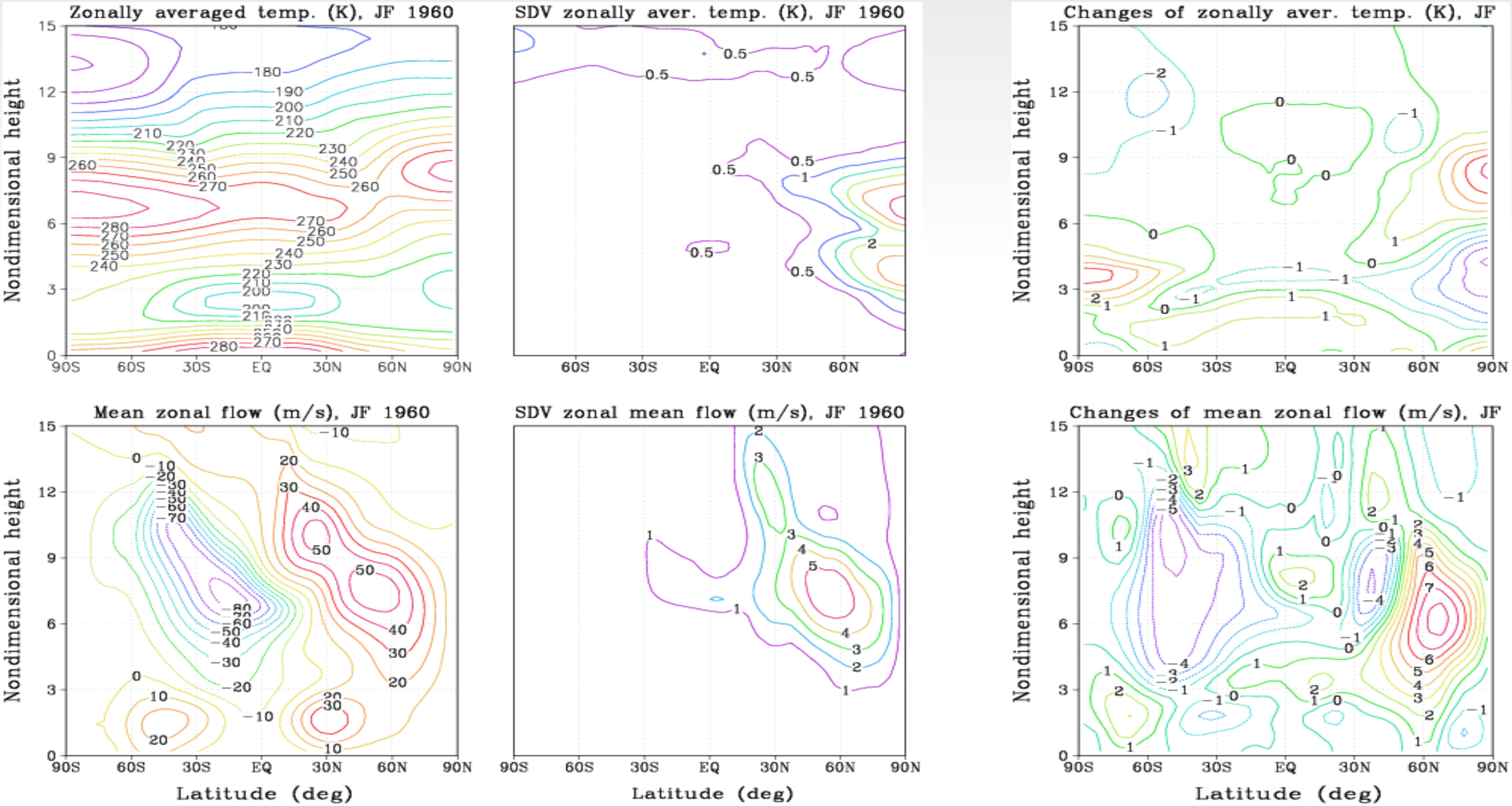
Conclusion

- Results of numerical simulation with the MUAM show that response of the stratosphere to the lower boundary forcing is substantially nonlinear – an increase of the SPW1 amplitude at the lower boundary leads to the changes of the mean flow at the middle and higher-middle latitudes in the lower stratosphere. These changes are crucial for the SPW1 propagation and the changes of the SPW1 amplitude in the stratosphere are weak or even negative. These effects are stronger during the e-QBO.

- The results obtained can be interpreted as the **nonlinear saturation** of the SPW1 in the stratosphere (*Giannitsis C. and R.S. Lindzen, 2009. Nonlinear saturation of vertically propagating Rossby waves, J. Atmos. Sci., 66, 915-934*).

Thank you for attention!

MUAM: January-February zonally averaged temperature (upper panel) and zonal mean flow (lower panel) calculated as averaged over ensemble 1960 and changes from 1960 to 2000 (right panel).



MUAM: the lower boundary conditions

- At the lower boundary of MUAM (1000 hPa pressure level) the monthly mean climatological geopotential height and temperature fields including the zonal mean state and stationary planetary waves with zonal wave numbers m=1, 2, and 3 are specified. These fields were obtained by averaging over 11 years (1992-2002) of NCEP/NCAR reanalysis data.

- To reproduce more correctly the zonally averaged field in the troposphere, up to the lower stratosphere heights the zonally mean temperature is relaxed to the climatological NCEP/NCAR temperature by inserting a nudging term into prognostic equation for temperature.

- The prognostic equation for the geopotential height perturbation (deviation from the steady-state climatological value) at the lower boundary has been used to simulate the global resonant properties of the atmosphere.

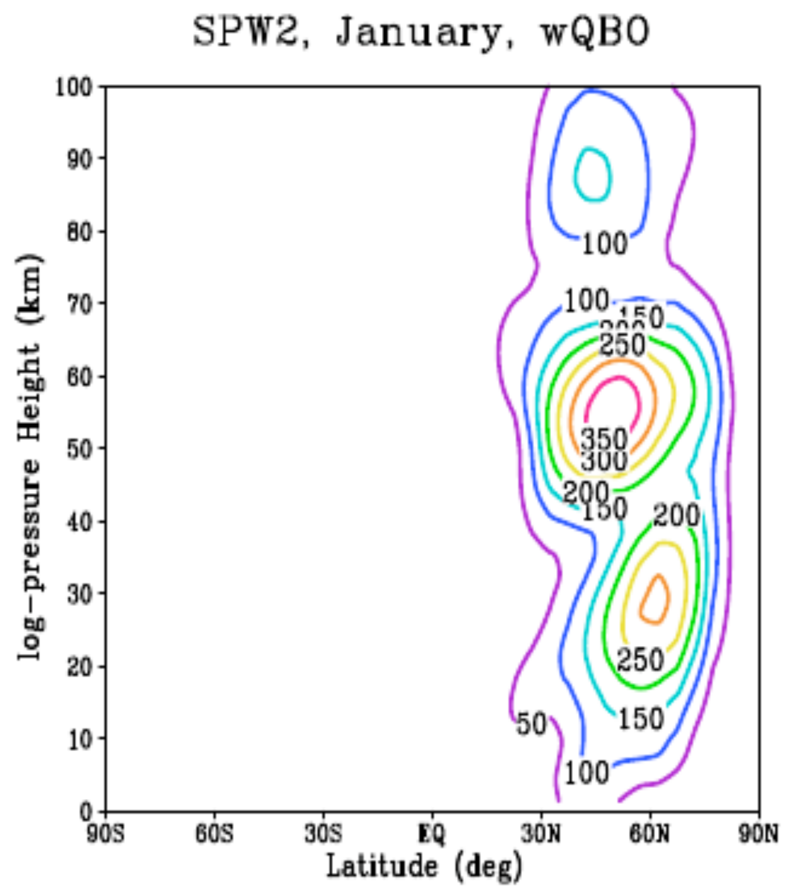
MUAM: outline of numerical experiments (1)

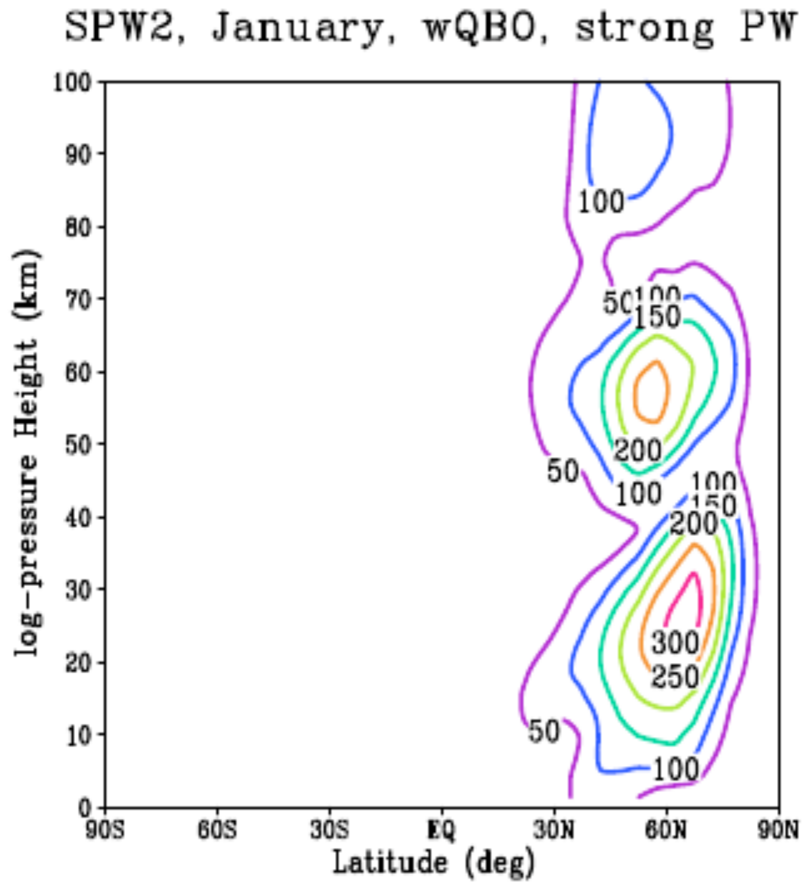
- To reach a steady-state solution, the model was integrated for 120 days starting from an initial windless atmosphere and using daily averaged heating for perpetual January 1st conditions. At this stage the prognostic equation for geopotential height perturbation at the lower boundary was not included, and stationary PW were introduced after 30 days of running.

- Then the model was integrated for the next 210 days again under perpetual January 1st conditions, but with account of prognostic equation for geopotential height perturbation at the lower boundary and the diurnal variability of solar heating.

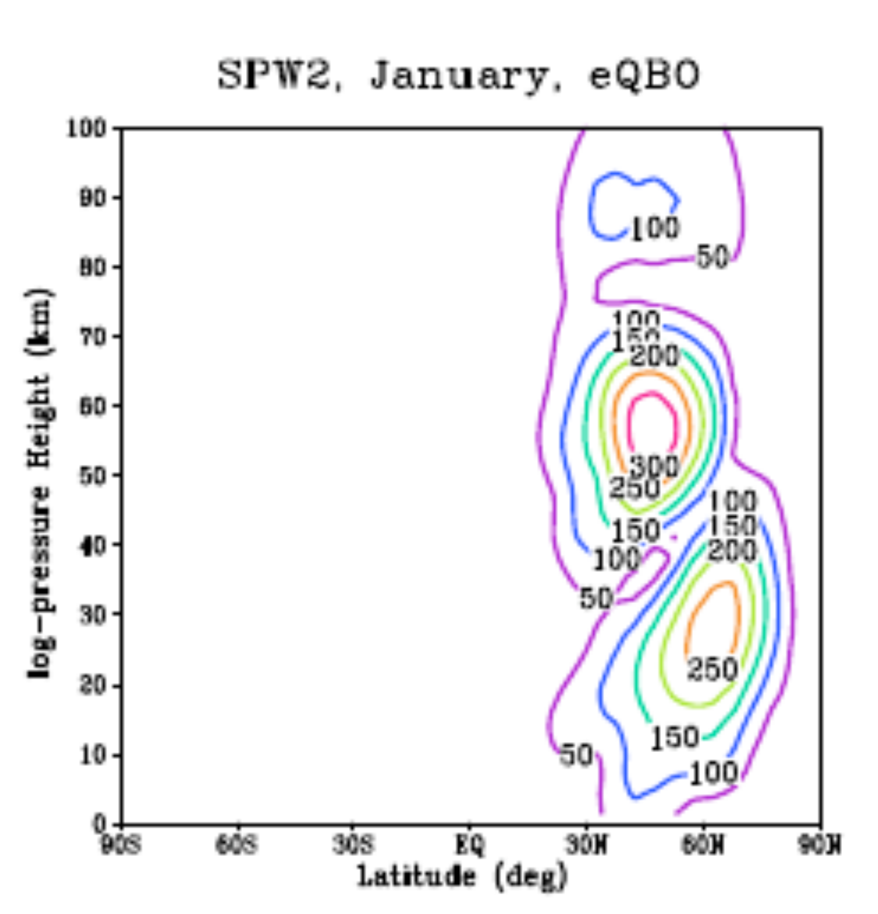
- Finally, we started the seasonal change of solar zenith angle and the model was integrated for additional 60 days. Therefore, the time interval from 331 until 390 days of running corresponds to the January-February conditions.

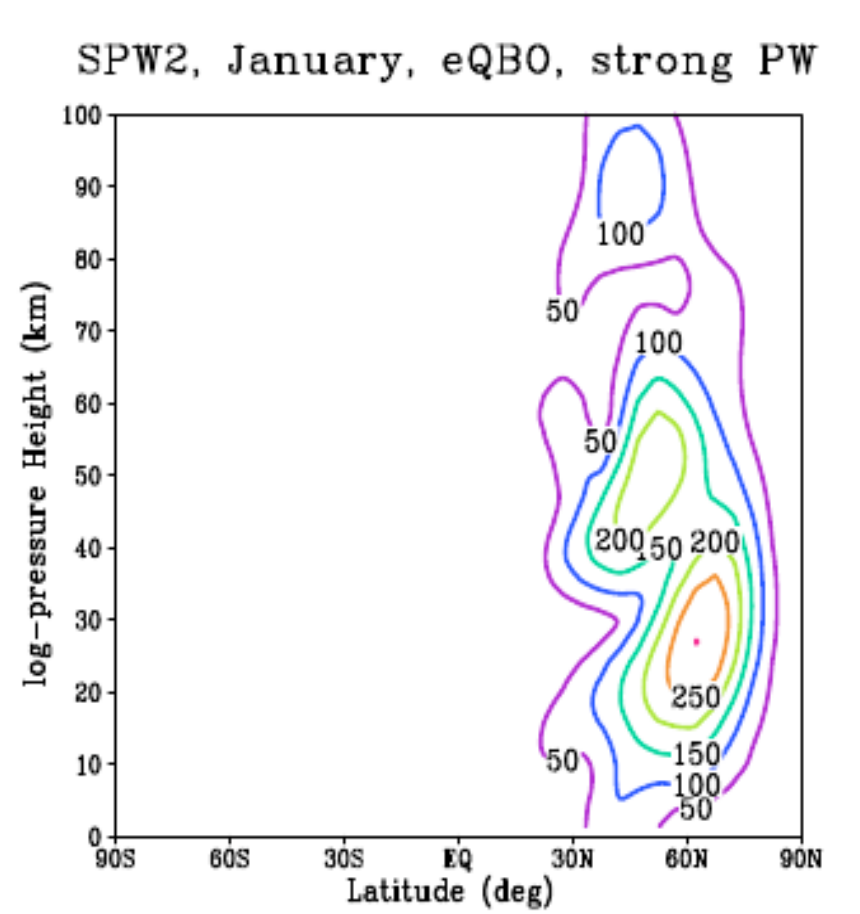
Simulated with the MUAM amplitudes of SPW2 in the geopotential height for the westerly QBO.
Strong lower boundary forcing = SPW*1.2, right).



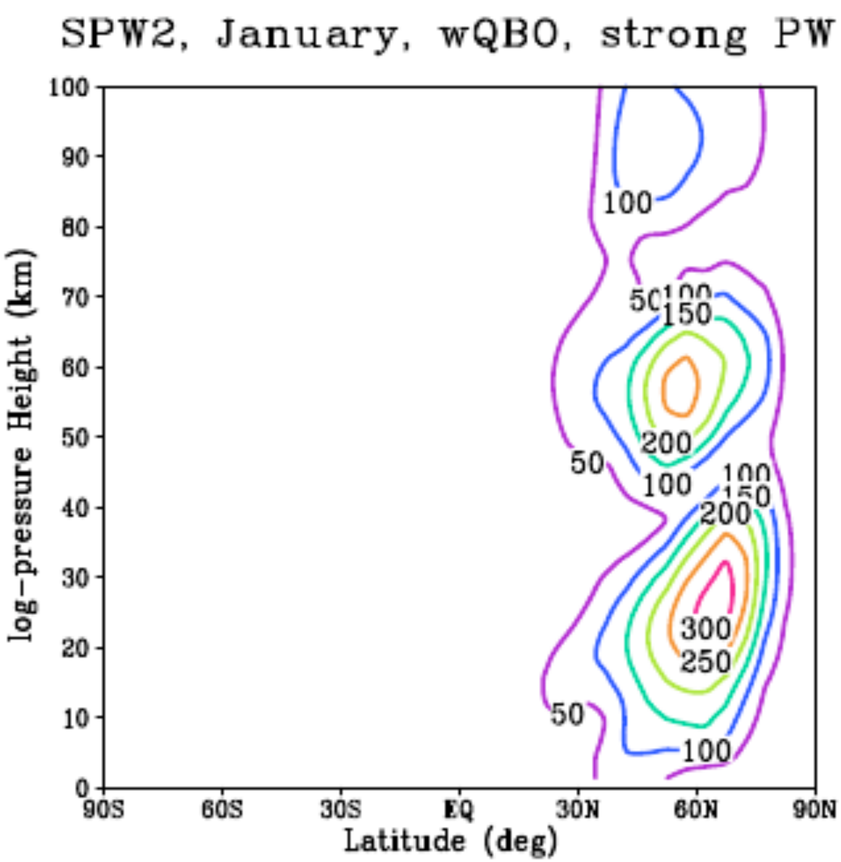


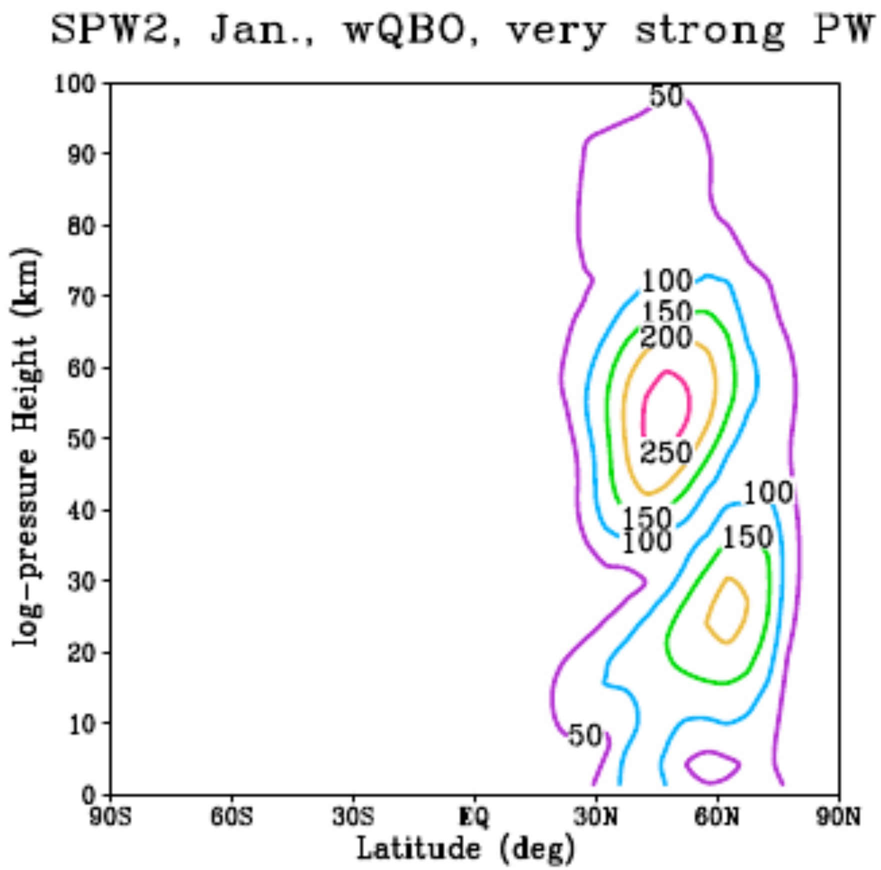
Simulated with the MUAM amplitudes of SPW2 in the geopotential height for the easterly QBO. Strong lower boundary forcing = SPW*1.2, right).





Simulated with the MUAM amplitudes of SPW2 in the geopotential height for the westerly QBO.
Lower boundary forcing SPW*1.2 and SPW*1.4





Simulated with the MUAM amplitudes of SPW2 in the geopotential height for the easterly QBO.
Lower boundary forcing SPW*1.2 and SPW*1.4