SPBU & UHEL meeting on PEEX research collaboration

24 April 2020, Friday, 13:00-16:30 pm

Numerical simulations of the stratospheric warming events

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Sudden Stratospheric Warming (SSW):

1. Substantial temperature increases (up to 30 - 40 K) at high Northern latitudes in Winter or Spring at altitudes 30 - 50 km, and simultaneous decreases (or reversals) of the zonal-mean eastward wind accompanied by displacement or split of the stratospheric Polar Vortex.

2. SSW development depends on breaking of planetary waves (PWs), which propagate from the lower atmosphere.

3. SSW event has significant influence on the formation of the weather anomalous and climate changes in the troposphere.

4. SSW events can substantially affect the dynamics and energetics of different atmospheric layers, intensifying of the interactions between tropospheric and stratospheric layers.

=> It is important to reproduce correctly such types of events in the GCM models.

The GCM model “MUAM”

Middle and Upper Atmosphere Model “MUAM” is one of the most actively developing numerical models of atmospheric wave dynamics in Russia.

- 3-dimension nonlinear mechanistic model (Pogoreltsev et al., 2007), based on the finite-differences Cologne Model of the Middle Atmosphere-Leipzig Institute for Meteorology (COMMA-LIM; Fröhlich et al., 2003).
- The horizontal grid of the model has 36 steps along the latitudes and 64 steps along the longitudes.
- As the vertical coordinate the model uses the log-isobaric non-dimensional height with 48 - 60 vertical levels (depending on the version) covering altitude range from the ground up to 400 km.
- The MUAM model can reproduce atmospheric tides, SPWs, westward travelling atmospheric normal modes as well as eastward travelling Kelvin waves.
- The main equations and peculiarities of the model adjustment one can find here: (Pogoreltsev et al., 2007; Gavrilov et. al., 2018; Koval et al., 2018b)

The GCM model "MUAM"

- For a long time, there was a misconception that mechanistic general circulation models with a relatively low resolution cannot reproduce major SSWs. Pogoreltsev et al, (2014) showed that inclusion of normal atmospheric modes' parameterization can allow mechanistic models to simulate SSWs: MUAM is one of a mechanistic GCM able to reproduce major stratospheric warmings.
- The simulated in the MUAM parameters include geopotential, temperature, as well as zonal, meridional and vertical wind components.
- To improve statistical significance, ensembles containing 10-20 members of MUAM "runs" are usually observed.

Determination of SSW stages

The MUAM simulates all conventional types of SSW: major, minor, high, final.

“major”: “high”:

U: 62.5 North

dT:
82.5–87.5^{0} North

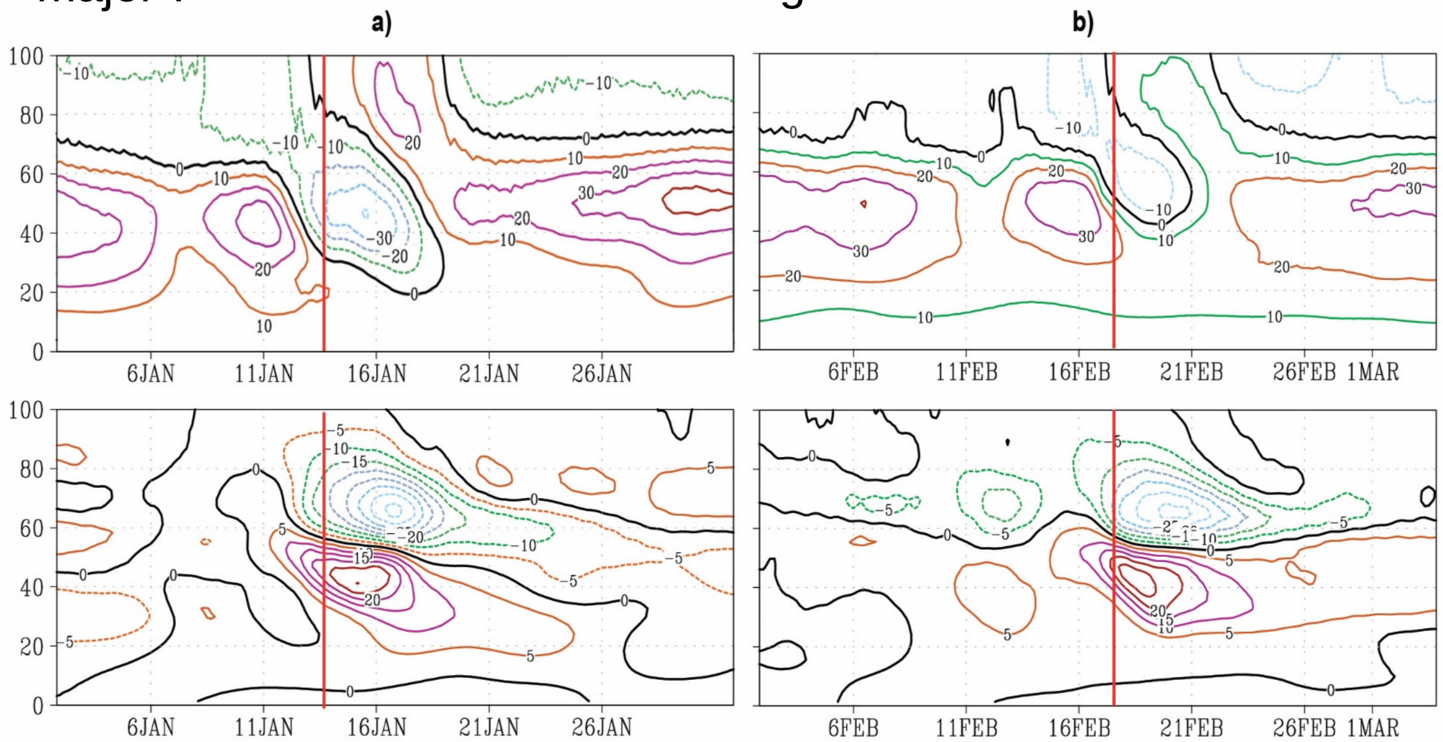


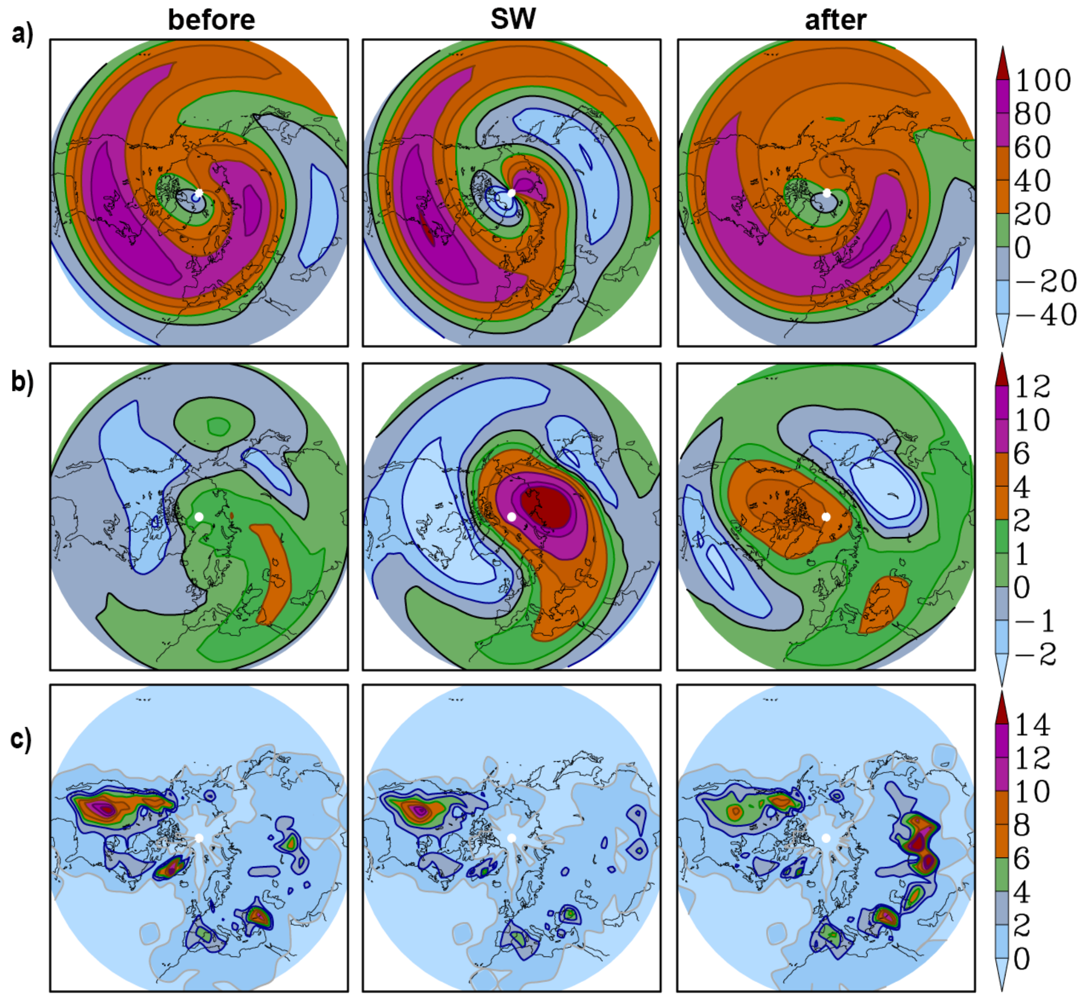
Figure 1. Examples of simulated evolutions of the zonal-mean zonal wind at 62.5°N (top) and deviation from the monthly-mean temperature at 82.5–87.5°N (bottom) for two different MUAM runs (a and b). Vertical lines show SSW starting dates. *(see Koval et al., 2019)*

Horizontal distributions of atmospheric parameters on the North Pole stereographic projection

Latitude-longitude distributions of zonal wind velocity for January at altitude 50 km in m/s (a), temperature at altitude 30 km in K (b) and OGW velocity amplitude at altitude 50 km in m/s (c) simulated with the MUAM and averaged over four 11-day time intervals before (left), during (middle) and after (right) the composite SW event.

Thick contours show zero values.

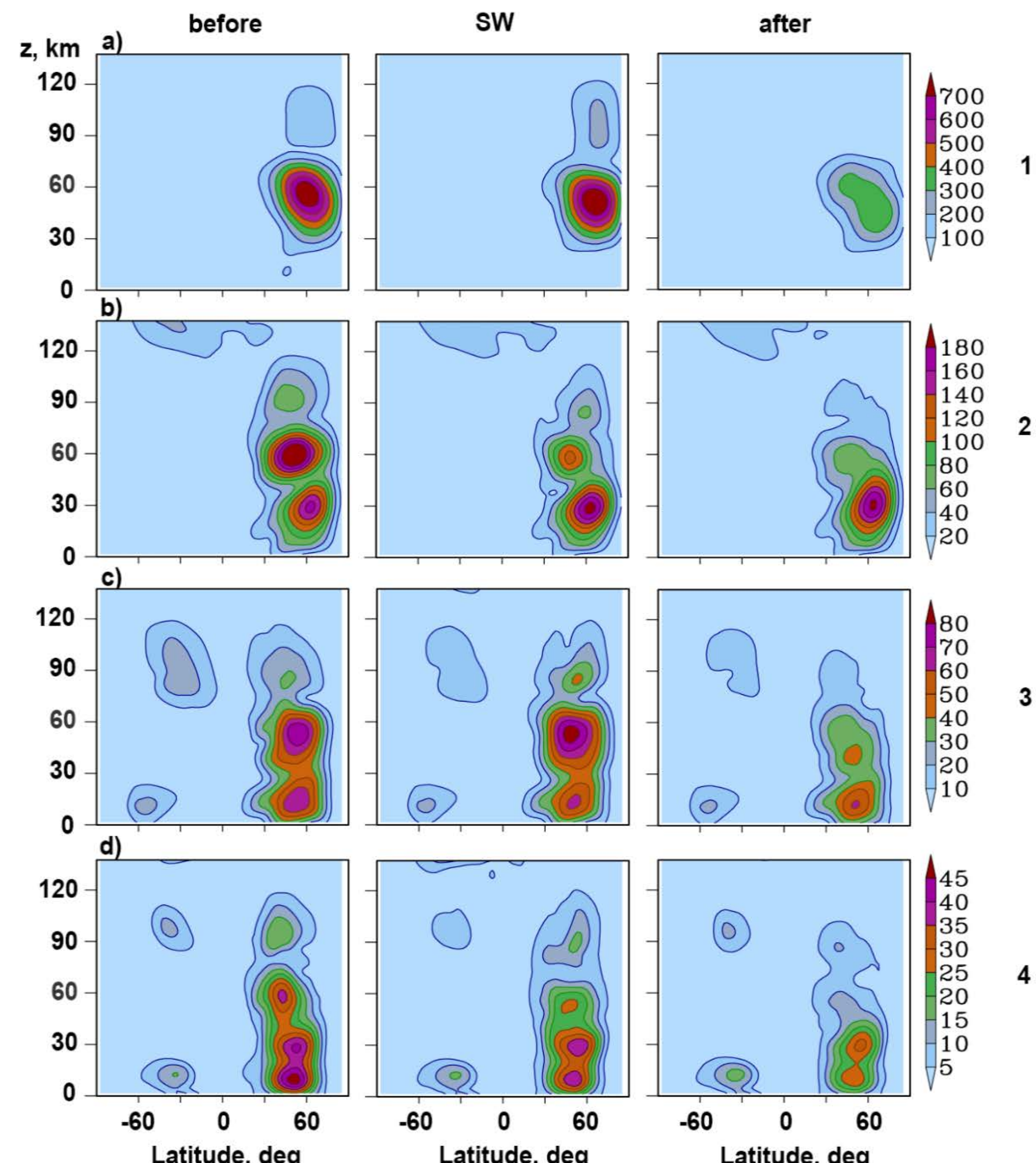
(see Gavrilov et al., 2018)



Amplitudes of geopotential height variations caused by SPWs

Average amplitudes of geopotential height (in gpm) variations caused by stationary planetary waves having zonal wave numbers m = 1, 2, 3, 4 (a, b, c, d), before (left), during (middle) and after (right) simulated composite SSW event.

(see Gavrilov et al., 2018)



Amplitudes of geopotential height variations caused by the westward atmospheric NMs

Average amplitudes of geopotential height (in gpm) variations caused by westward travelling normal modes having periods and zonal wave numbers:

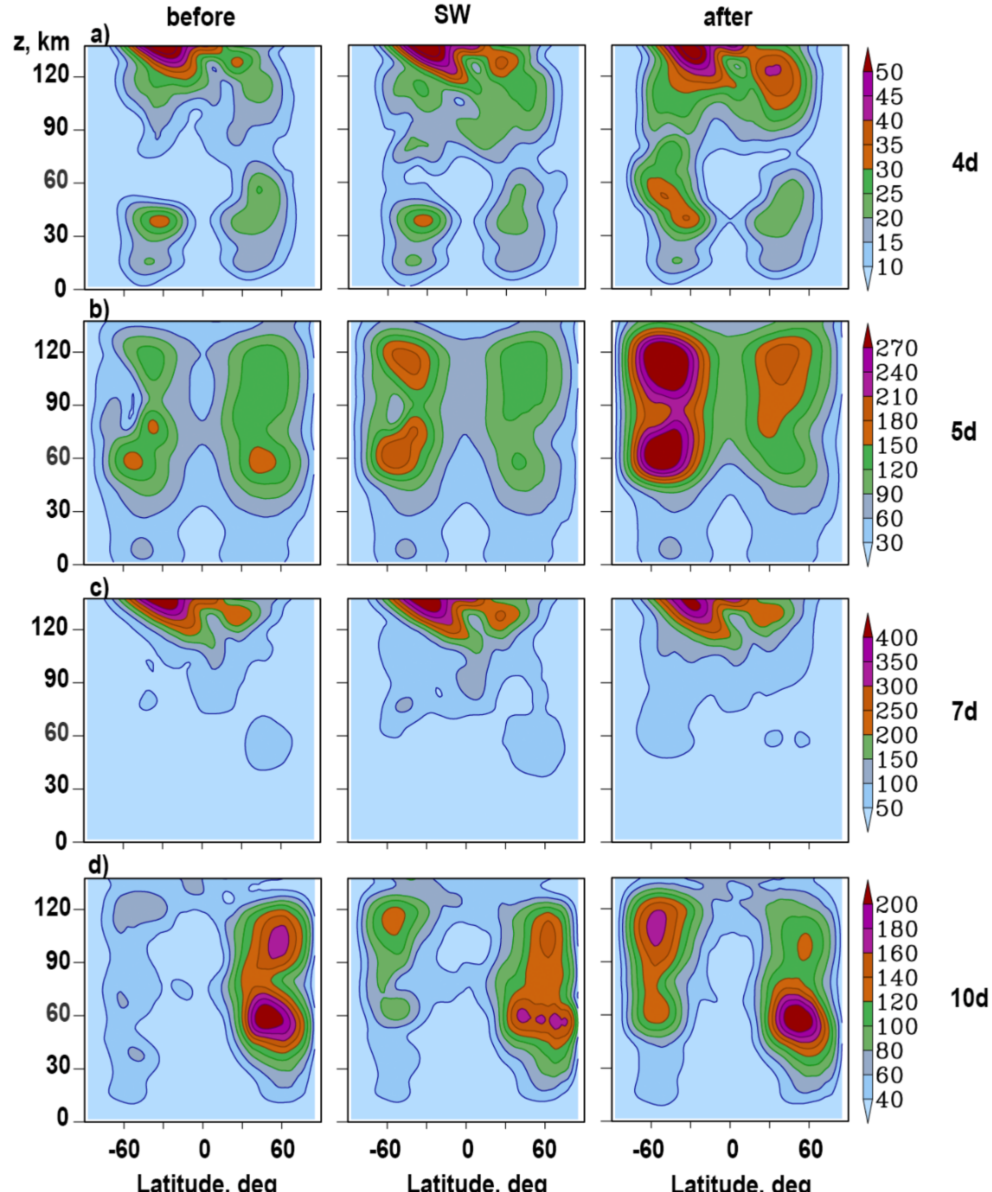
s = 4 days, m = 2 (a);

s = 5 d, m = 1 (b);

s = 7 d, m = 2 (c);

s = 10 d, m = 1 (d).

(see Gavrilov et al., 2018)



Meridional mean circulation changing during SSW

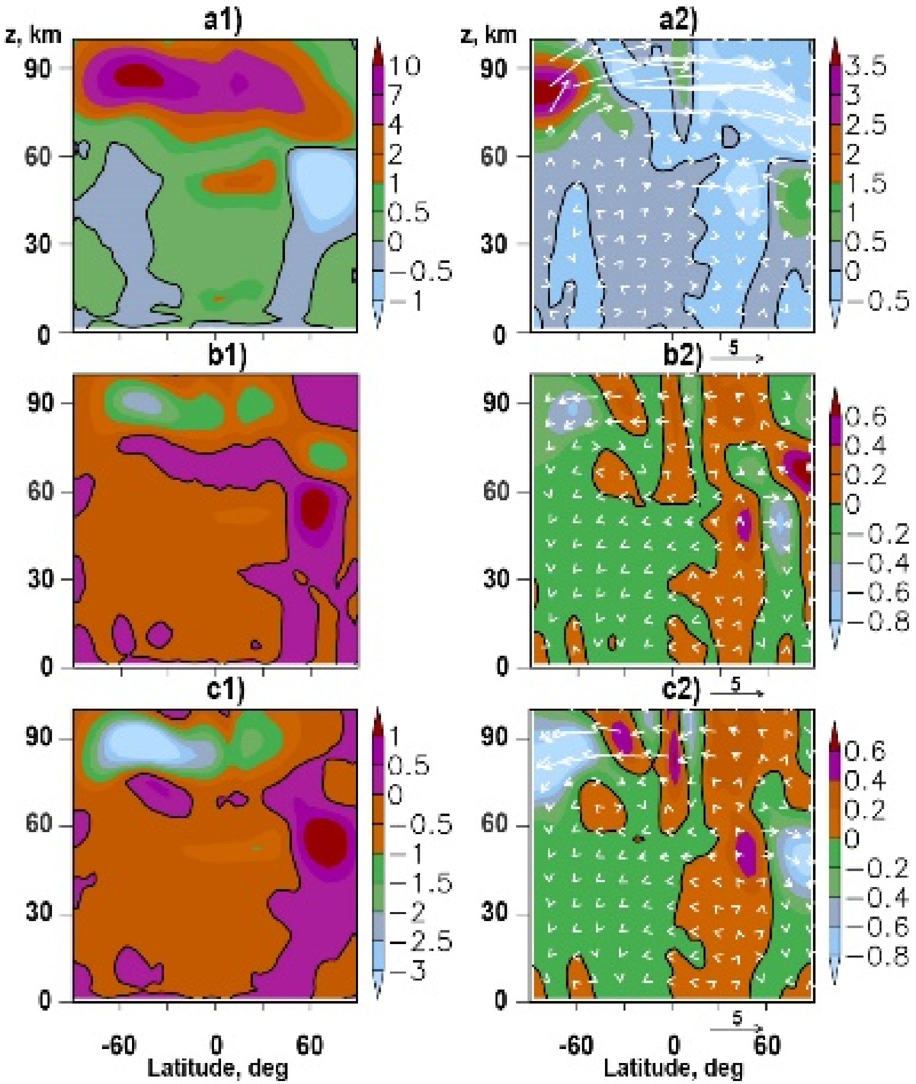
Zonal-mean meridional velocity in m/s (a1) and vertical velocity in cm/s (a2) simulated with the MUAM and averaged over 12 model runs for 11-day intervals before SSW (a1).

Arrows show velocity vectors in the meridional plane in m/s (vertical component is multiplied by 100 for the sake of illustration);

(b) and (c) show corresponding differences between the time intervals during and before (b), also after and before (c) simulated SSWs.

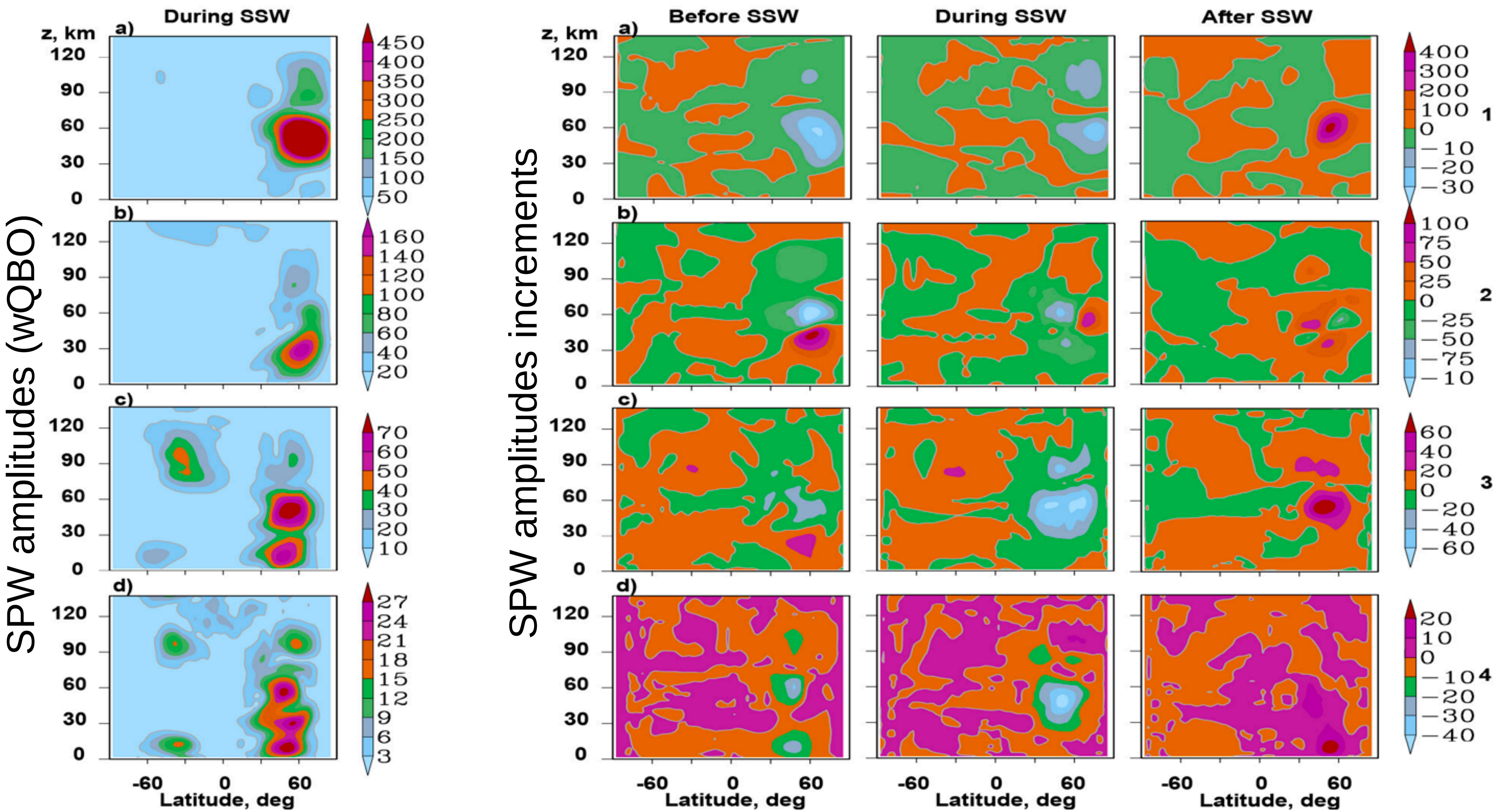
Solid contours correspond to zero levels.

(see Koval et al., 2019)



SPW amplitudes under different QBO phases

Differences wQBO – eQBO in geopotential height amplitudes for SPWs having zonal wave numbers m = 1, 2, 3, 4, at different stages of the SSW.



There are generally smaller SPW amplitudes (up to 30 – 50%) in the westerly QBO during SSW above heights 20 – 40 km at middle and high northern latitudes. After SSW differences in SPW amplitudes are generally positive in the northern hemisphere. *(see Koval et al., 2018a)*

Conclusions

- ✓ We performed some successful numerical experiments concerning the ability to simulate SSW events in the MUAM model. The results achieved were compared to the reanalysis datasets (UKMO; MERRA-2; JRA-55) as well as with observational data.
- ✓ We focused on the changes of the mean zonal and meridional circulation in the middle atmosphere during different stages of the simulated composite SSW events.
- ✓ Also we studied the changes in planetary waves amplitudes during different stages of SSW as well as during SSW for different quasi-biennial oscillation (QBO) phases. The main results published are listed below.

- ✓ Many questions are still unresolved (especially relevant for the middle and lower atmosphere), e.g.:

  - identification of features of the onset and development of SSW depending on the intensity and structure of residual mean circulation (RMC);
  - estimation of the thermal RMC effect on the high-latitude stratosphere during SSW;
  - features of SSW development at different solar and geomagnetic activity levels;
  - many more….

References

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