80 лет

Исследование особенностей динамики стратосферы Арктики и их влияния на тропосферу в зимние сезоны 2019-20 и 2020-21 гг.

Investigation of Arctic stratosphere dynamics peculiarities and its tropospheric impacts in the winter 2019-20 and 2020-21

(+ some results on future changes of Arctic stratosphere in XX century)

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Paratunka, Kamchatka kray, 28 September 2021

Outlines:

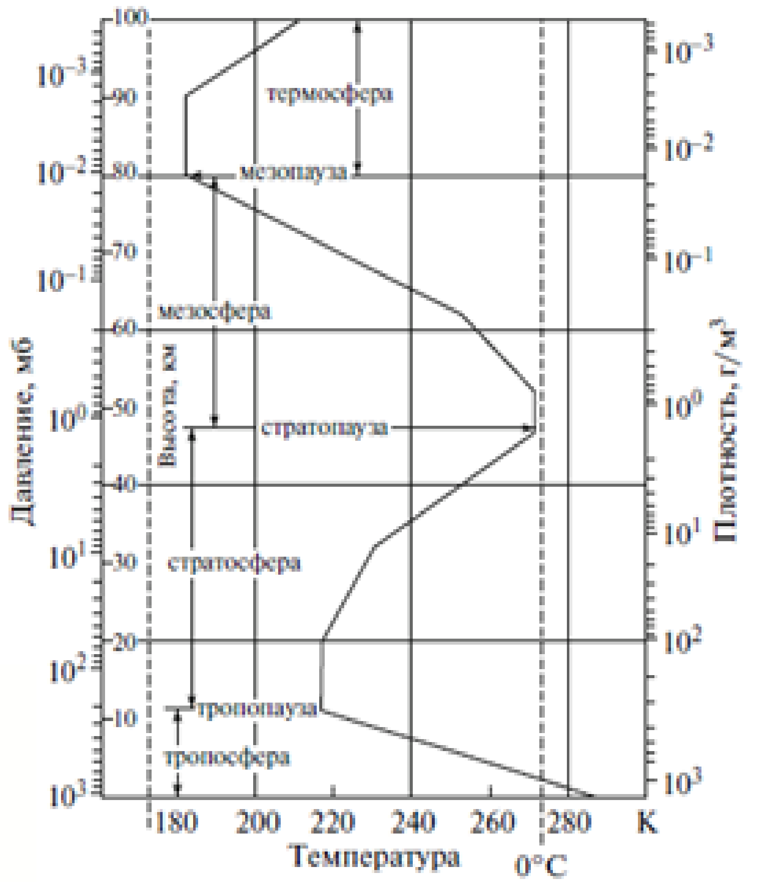
- Circulation of stratosphere, stratosphere-troposphere dynamical coupling
- Dynamical processes in Arctic stratosphere in the winter seasons (Dec-April) of 2019-2020 & 2020-2021
- Changes of Arctic stratosphere dynamics by the end of XXI century based on analysis of INM CM5 simulation data

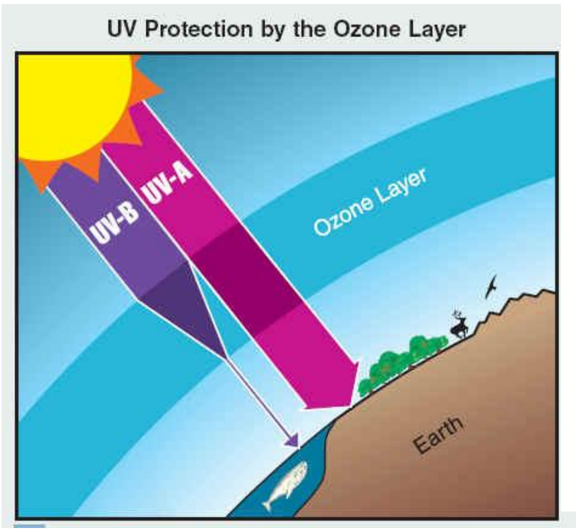
Publications

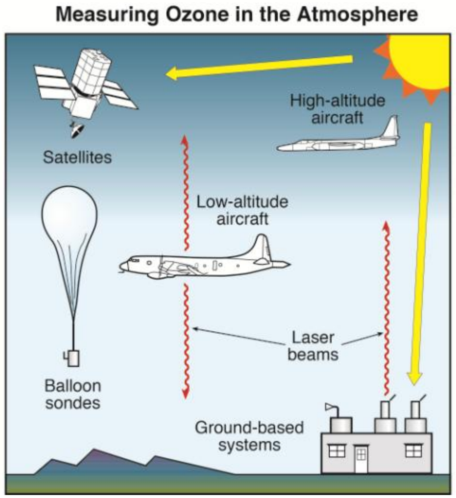
- *Варгин П.Н.* Динамическое взаимодействие стратосферы и тропосферы внетропических широт в период внезапного стратосферного потепления в Арктике в январе-феврале 2017 г. Метеорология и гидрология, 2018, № 5, с. 5-19
- *Варгин П.Н., Кирюшов Б.М*. Внезапное стратосферное потепление в Арктике в феврале 2018 г. и его влияние на тропосферу, мезосферу и озоновый слой. Метеорология и гидрология, 2019, № 2 с. 41-56.
- *Варгин П.Н., Лукьянов А.Н., Кирюшов Б.М*. Динамические процессы стратосферы Арктики зимой 2018-2019 г. Метеорология и гидрология, 2020, № 6, с. 5-18.
- *Варгин П.Н., Кострыкин С.В., Ракушина Е.В., Володин Е.М., Погорельцев А.И.* Исследование изменчивости дат весенних перестроек циркуляции стратосферы и объема полярных стратосферных облаков в Арктике по данным моделирования и реанализа. Известия РАН. Физика атмосферы и океана, 2020, т. 56, с. 1-13.
- *Варгин П.Н., Володин Е.М.* Исследование изменений динамики стратосферы Северного полушария в XXI веке по расчетам климатической модели ИВМ РАН. Экология. Экономика. Информатика. Серия: Системный анализ и моделирование экономических и экологических систем. 2020.
- *Smyshlyaev S.P., Vargin P. N., Lukyanov A. N., et al.* Dynamical and chemical processes contributing to ozone loss in exceptional Arctic stratosphere winter-spring of 2020. Atmos. Chem. Phys. Discus., 2021.
- *Варгин П.Н., Гурьянов В.В., Лукьянов А.Н., Вязанкин А.С.* Динамические процессы стратосферы Арктики зимой 2020-2021 г. Известия РАН. Физика атмосферы и океана. 2021, т. 57, № 6.
- *Цветкова Н.Д., Варгин П.Н., Лукьянов А.Н., и др.* Исследование химического разрушения озона и динамических процессов в стратосфере Арктики зимой 2019-20 г. Метеорология и гидрология, 2021, № 9.

Stratosphere

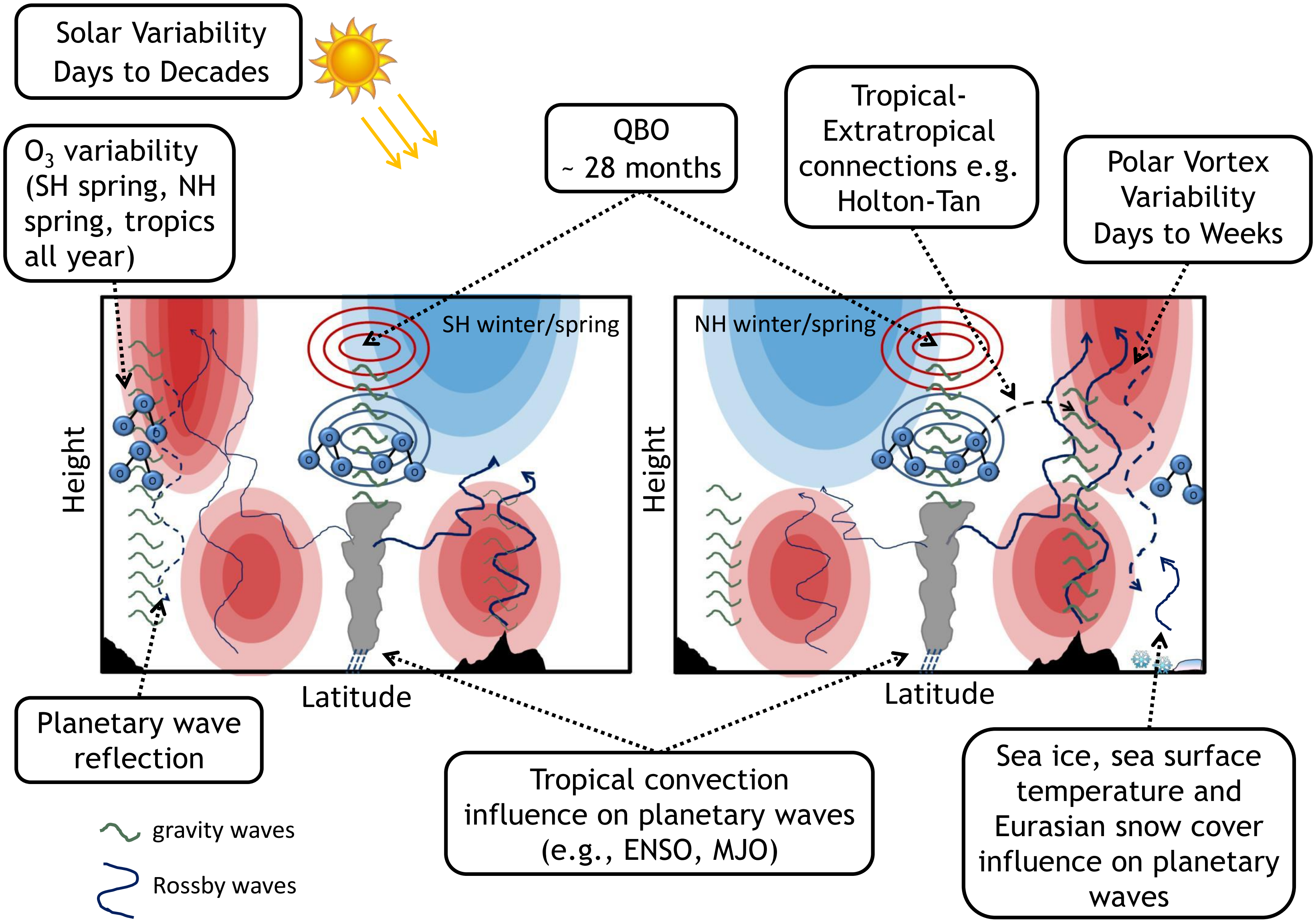
- Circulation of stratosphere is controlled by planetary waves (PW), propagated upward from troposphere.
- However stratosphere itself can influence a propagation of PW by its absorption, reflection toward low latitudes as well as into troposphere
- Ozone layer in stratosphere absorbs UV radiation (UV-B, 280-315 nm)







Circulation of Stratosphere

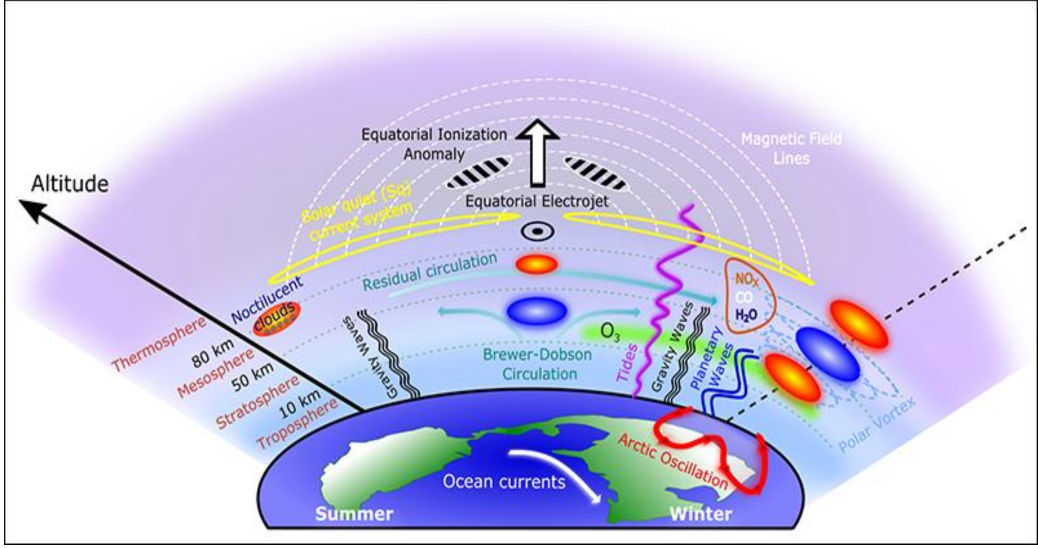


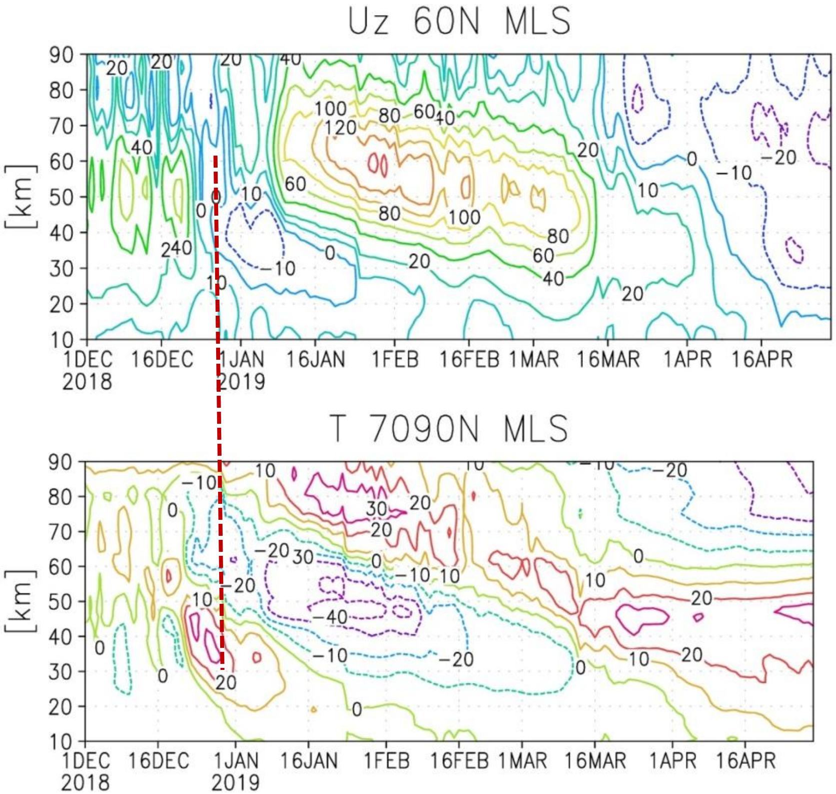
+ Sudden Stratospheric Warming (SSW) events define ozone destruction in Arctic and Antarctic lower stratosphere

Butler et al., 2018

Upper Atmosphere
Sudden Stratospheric Warming (SSW) event impact

Pedatella et al., How sudden stratospheric warming affects the whole atmosphere, EOS, *2018*





Vargin et al., Dynamical processes of Arctic stratosphere in the winter season 2018-2019. Russ. Meteor. & Hydrol., 2019

- Increase of stratopause height
- Cooling of polar mesosphere
- Zonal wind direction change
- Main cause – changes of gravity wave propagation
- NOx increase, that is important for ozone chemistry in stratosphere (ex. Ageeva, Gruzdev et al., 2017)
- Residual circulation change: from downward to upward

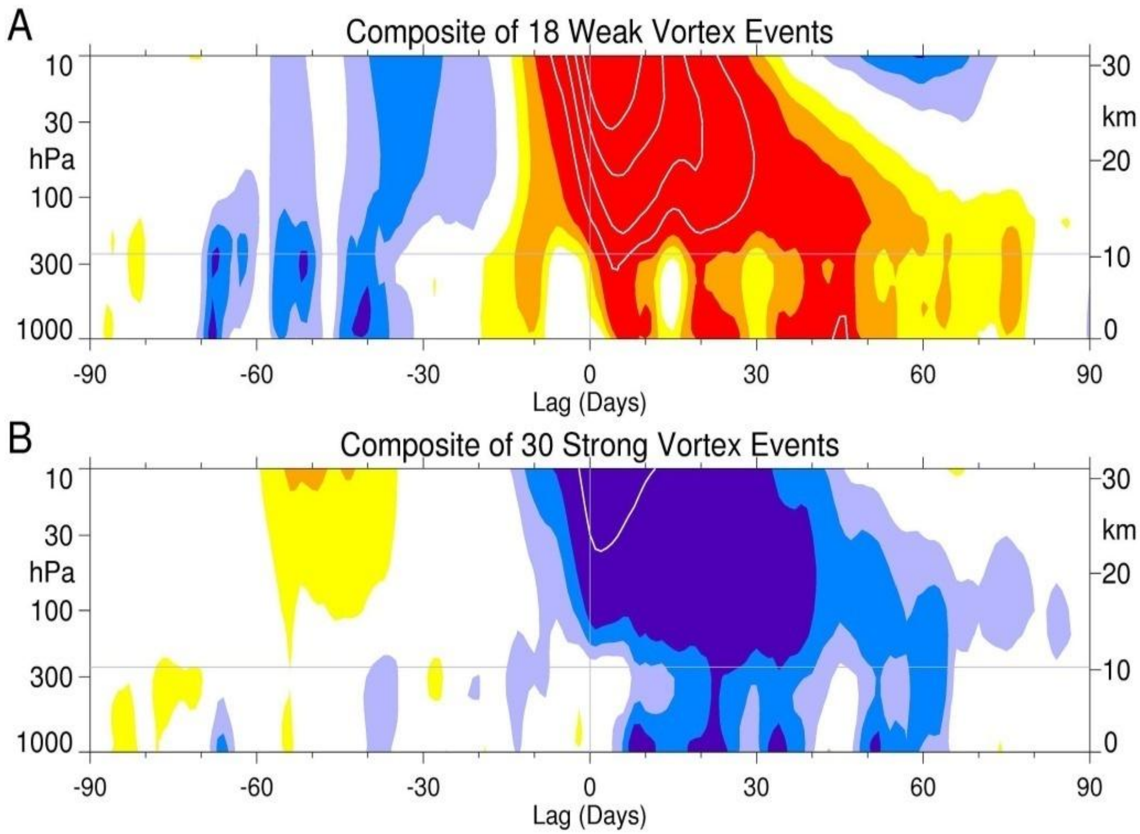
Baldwin et al., Sudden Stratospheric Warmings, 2020
Baldwin et al., 100 Years of Progress in Understanding the Stratosphere and Mesosphere, 2019

SSW events are accompanied by electron density changes in the region of geomagnetic equator - equatorial ionization anomaly [*Chau et al.,* 2012].

The amplitude of electron density changes during SSW events is comparable with ones caused by strong geomagnetic storm [*Goncharenko et al.,* 2010]

Stratosphere-Troposphere dynamical coupling

Связанные со слабым полярным вихрем возмущения динамики стратосферы сохраняются в тропосфере до 2-х месяцев (Baldwin, Dunkerton, Science, 2001 “Stratospheric harbingers of tropospheric weather regimes”)

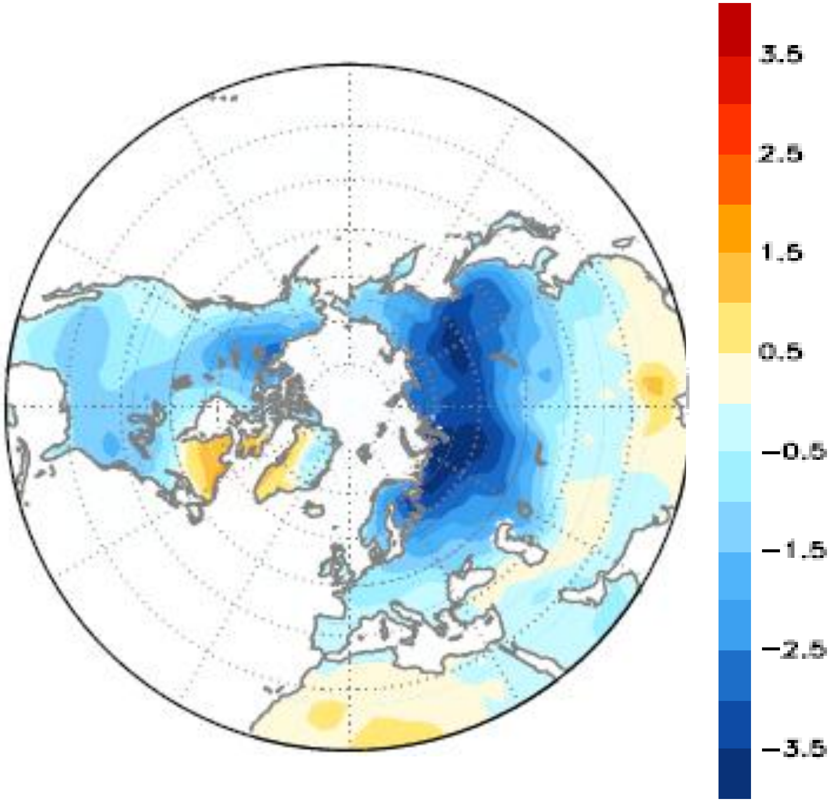


Composites – «strong» and «weak» Arctic stratospheric polar vortexes over past decades

-Propagation of stratospheric disturbances into troposphere
- Reflection of stratospheric planetary waves activity into troposphere

Although atmospheric reanalyses and climate model simulations clearly illustrate the downward propagation of the NAM anomalies, we do not yet fully understand the mechanism responsible for the stratospheric control of tropospheric weather patterns.

Difference of surface temperature between 60-day periods with weakening and strengthening of Arctic stratosphere polar vortex



(Thomson, Baldwin, Wallace, J. Climate, 2002)

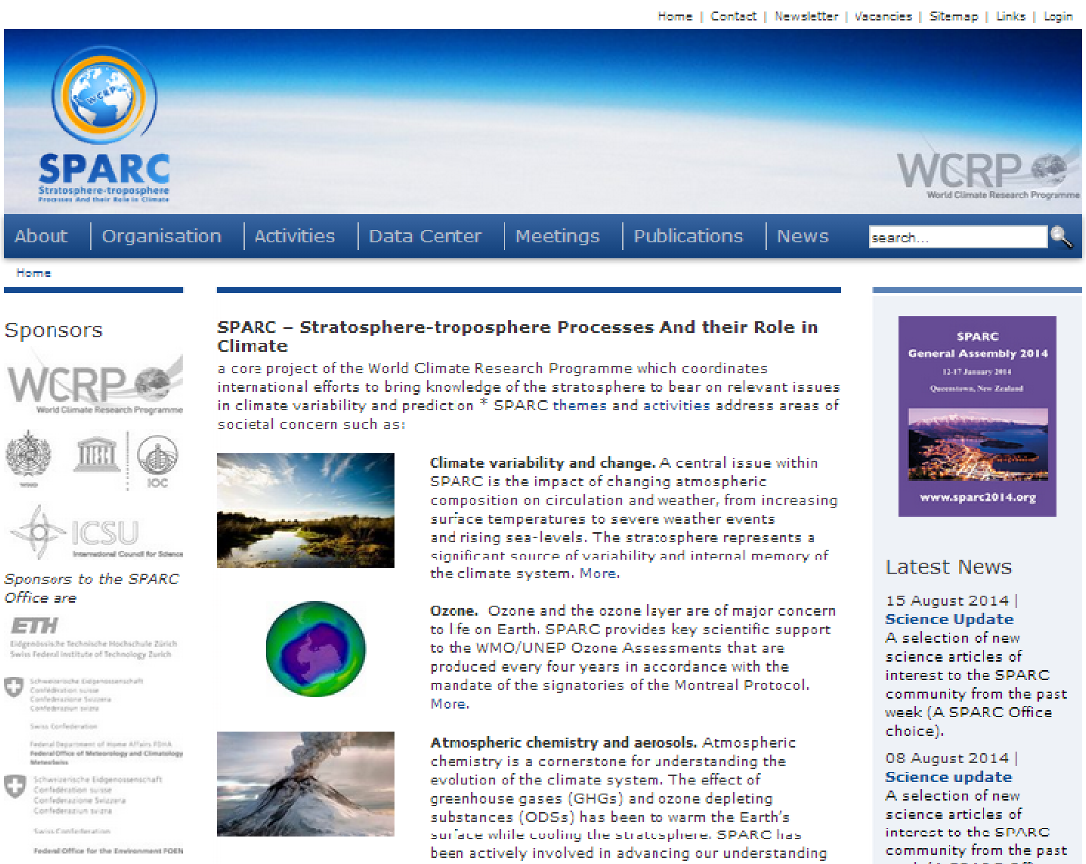
Observations show that:

– Strong weakening of stratospheric polar vortex is often preceded by negative anomalies of near surface temperature in high – middle latitudes. These events could be observed up to 2 months after stratospheric polar vortex weakening over high populated regions in Northern America, Northern Europe and North-Eastern Asia.

- Strengthening of stratospheric polar vortex is often accompanied by near surface positive temperature anomalies.

• About 40% of winter cold waves over Europe are related to weakening of stratospheric polar vortex (Tomassini et al., 2012)

Stratospheric processes and their Role in Climate (SPARC)

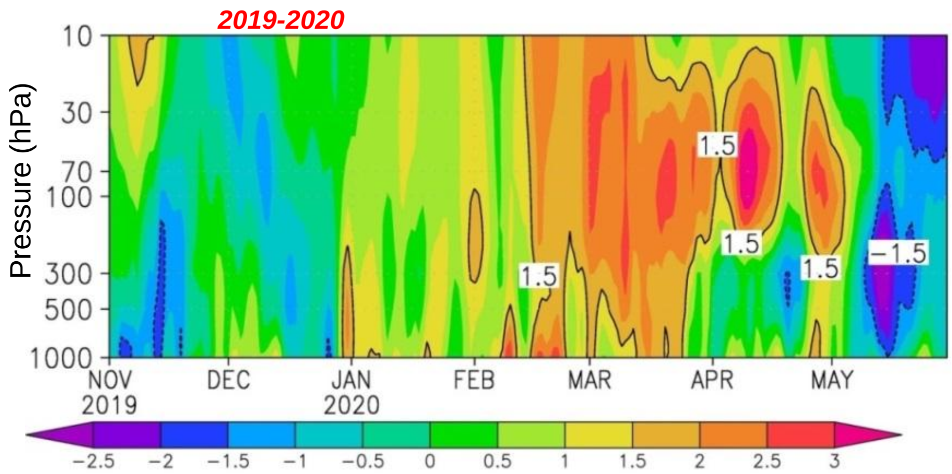


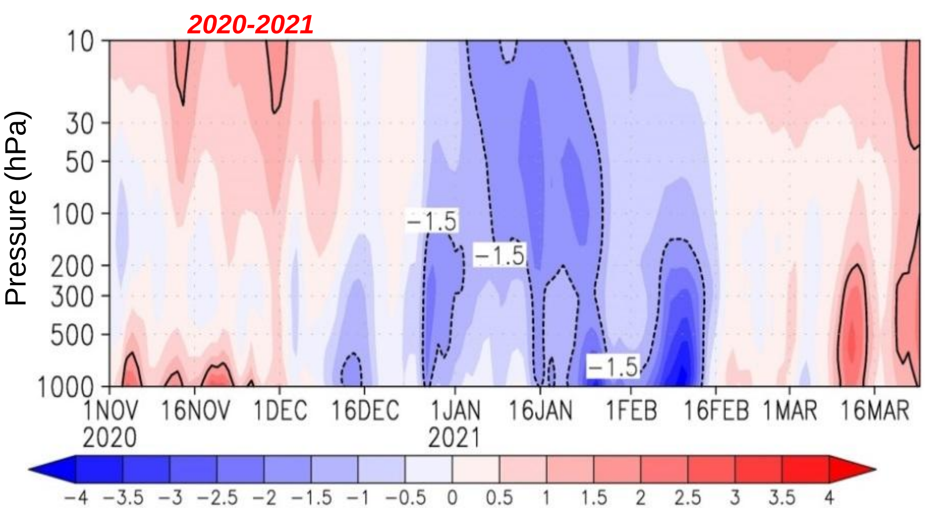
http://www.sparc-climate.org

Main objectives:

- Sudden Stratospheric Warmings events (SSW)
- Validation of dynamical processes in stratosphere - troposphere in climate models
- Stratospheric dynamical processes and development of seasonal weather forecasts.
- Aerosols and its climate impacts
- Stratospheric temperature trends (GHG, ozone, volcano)
- Changes of Stratosphere chemical composition and stratosphere-troposphere exchange

Stratosphere – troposphere dynamical coupling





North Annual Mode index (NAM) in November 2019 to May 2020 (a), in Nov. 2020 – March 2021 (b). Black solid / dashed lines correspond to area with absolute values more than 1.5 σ.

NAM – daily hgt 60-90° N anomalies from climate means, normalized on standard deviation (σ) and multiplied by -1.

Winter 2019-2020

- Strong and Cold stratospheric polar vortex till the middle of March

- Record Values of PSC volume

-Weakening planetary waves propagation from troposphere

- Record destruction of ozone layer which reached up to 90% over some observational station in March.

- Positive Arctic oscillation and dominated positive temperature anomalies in middle and high latitudes.

- Winter mean chemistry ozone loss in Arctic over winter season 2019-2020 reached 157 +/- 22 Dobson Units.

-Tsvetkova N.D., et al. Investigation of chemistry ozone loss and dynamical processes in the Arctic stratosphere winter 2019-2020. Russ. Meteorol. & Hydrol, 2021, # 9.

Winter 2020-2021

- Major and long-lasting Sudden Stratospheric Warming (SSW) in early January led to large decrease of PSC volume and to minimal ozone destruction.

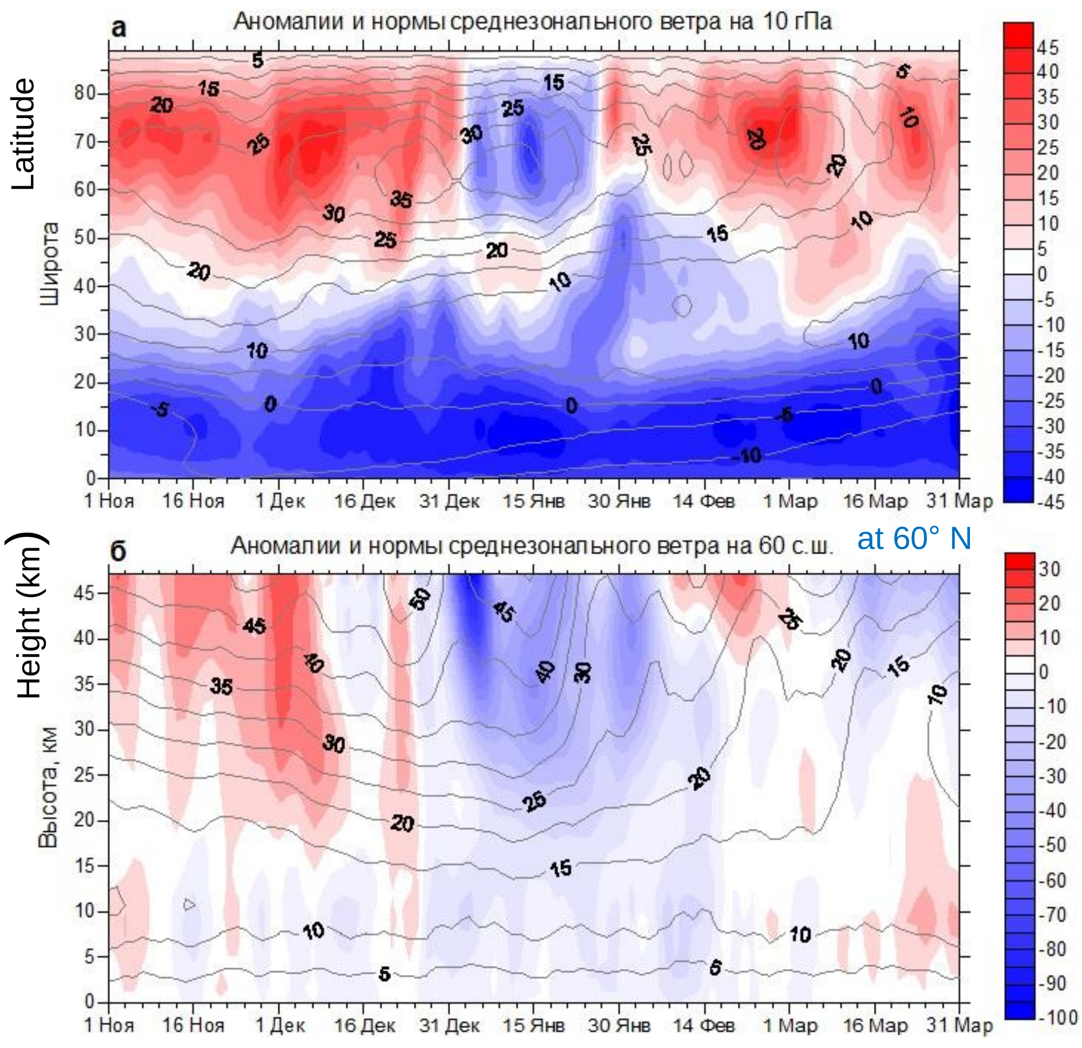
- Negative Arctic Oscillation in December, January and first part of February is accompanied by negative near surface temperature anomalies.

- Strong and long-lasting cold wave in Canada, north, middle and south of the US in February 2021 related to refraction of planetary waves

Vargin et al. Arctic stratosphere dynamical processes in the winter 2020-21. Izvestya. Atmospheric & Oceanic Physics. 2021, V. 57, No 6.

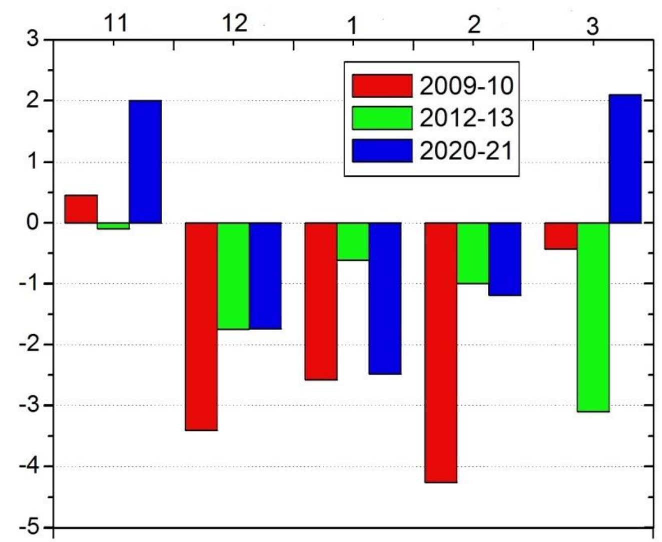
Winter 2020-2021 with major SSW in early January

Zonal mean zonal wind anomalies and climate means at 10 hPa (~30 km)



November - March

Arctic oscillation index



November - March

Vargin et al., Dynamical processes in Arctic stratosphere winter 2020-2021. Izvestya RAS. Physics of Atmosphere and Ocean. 2021, V. 57, # 6.

World Meteorological organization press-release

Extreme weather hits USA, Europe (21/02/2021)

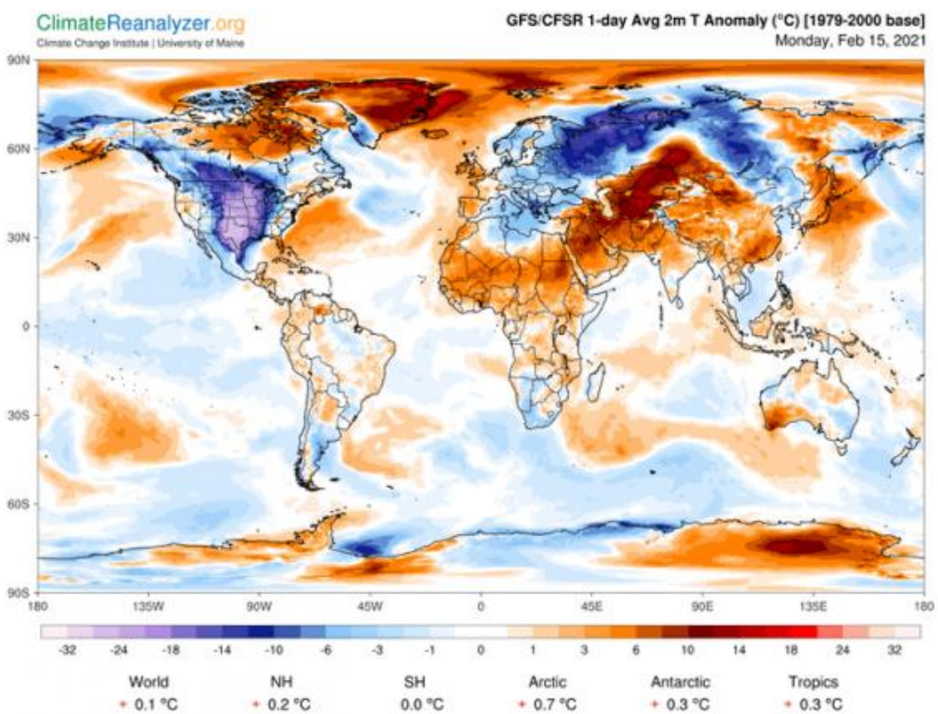
https://public.wmo.int/en/media/news/extreme-weather-hits-usa-europe

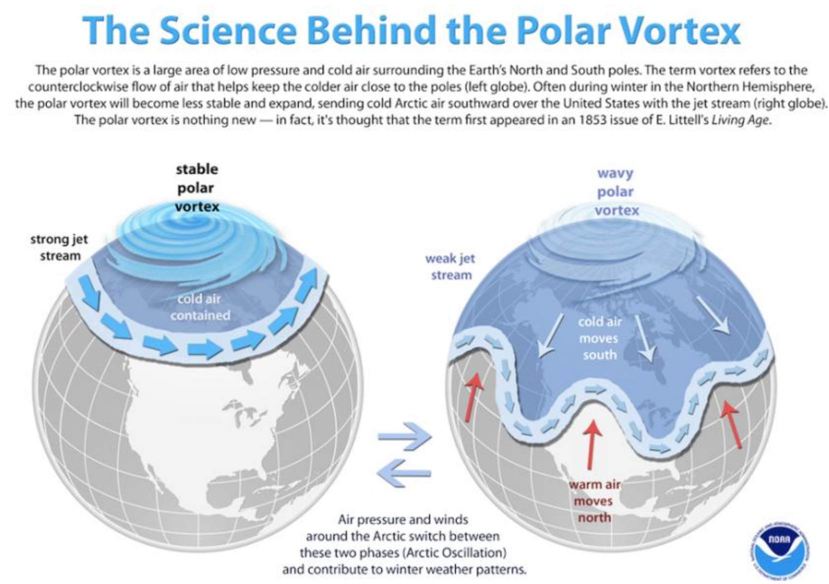
February’s extreme weather was triggered by large scale and interconnected atmospheric circulation patterns and a recent meteorological event called a Sudden Stratospheric Warming (SSW) event high up in the Stratosphere, about 30 km over the North Pole.

SSW events lead to polar vortex weakening in troposphere – region with low pressure, surrounded by strong zonal winds.

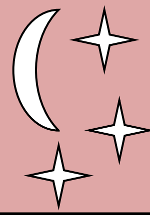
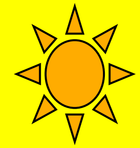
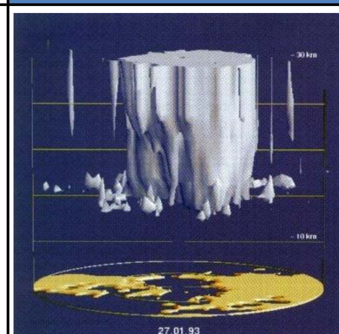
Usually these winds are strong and limit propagation of cold air masses from Arctic.

Weakening of these winds allow cold air masses penetrate in middle latitudes, whereas warm air masses penetrate in polar latitudes.



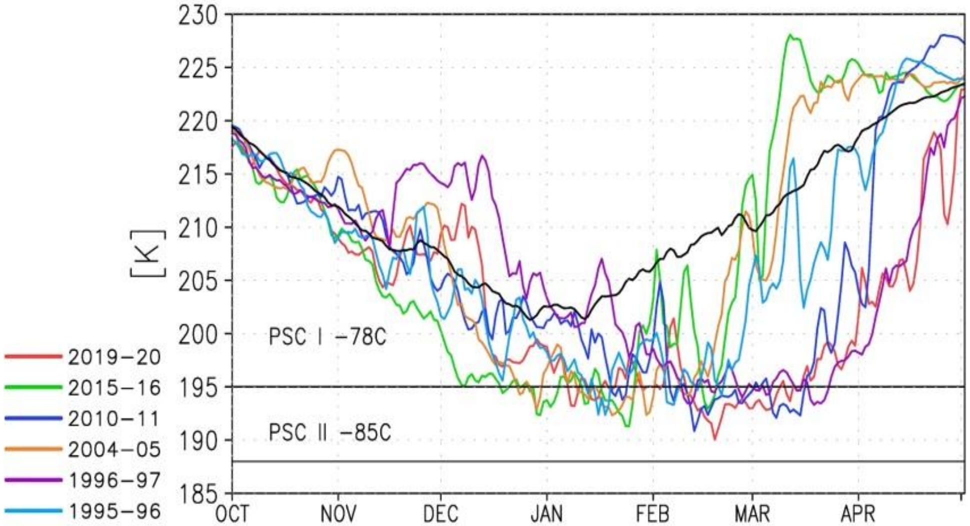


Ozone layer destruction in polar stratosphere

Winter polar night 		**Spring -Solar irradiance reaches polar stratosphere** 
1. Polar Stratospheric Cloud (PSC) formation (T < -78C) **HNO_3** **===> PSC** **H_2O** 	**Cold, stable & well isolated stratospheric polar vortex with temperature inside less than менее -80°C (195K)**	**3. ClO formation** **Cl_2 + UV radiation => 2 Cl** **HOCl + UV radiation => OH + Cl** **Cl + O_3 => ClO+O_2**
2. Ozone depleting substances activation on PSCs **$ClONO_2$** **HOCl = > PSO = > Cl_2 & HOCl** **N_2O_5** **HCl**		**4. Destruction of stratospheric ozone (up to 80 %)** **ClO+ClO = > Cl_2O_2** **Cl_2O_2 + UV radiation => Cl+O_2** **Cl+O_3=>ClO+O_2**

Molina M., Rowland F. Stratospheric sink for chlorouoromethanes: chlorine atom-catalysed destruction of ozone. – Nature, 1974

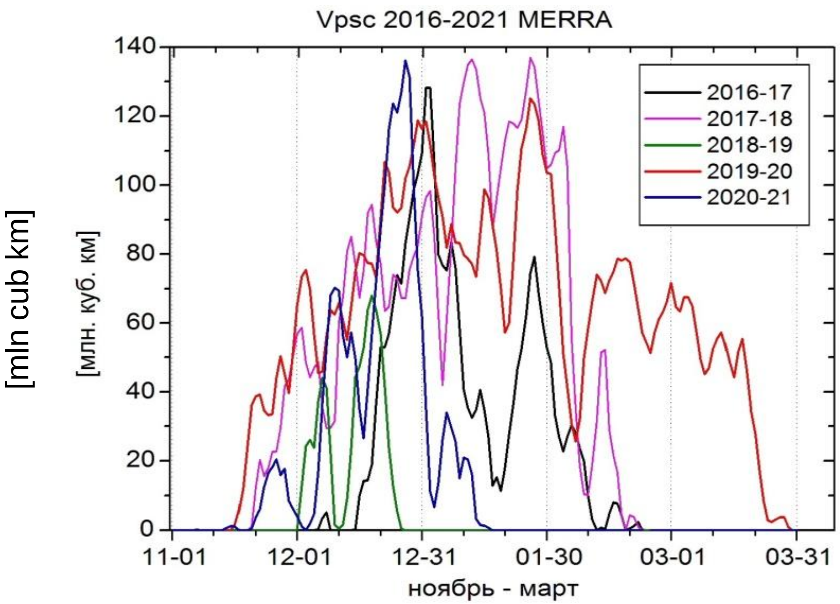
Interannual variability of the Arctic lower stratosphere temperature



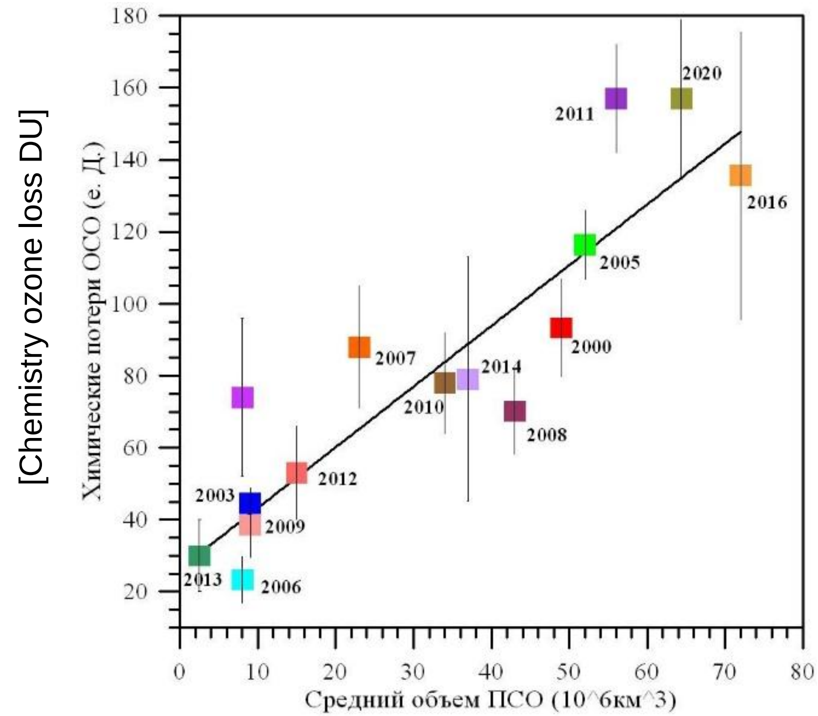
Minimal temperature averaged over 70°- 90° N at 70 hPa (~18 км) in October - April 1995-1996, 1996-1997, 2004-2005, 2010-2011, 2015-2016, and 2019-2020.

Black curve – mean values over 1981 - 2010.

Horizontal lines correspond to threshold for PSC type I and type II formation temperature.



Variability of PSC volume over November –March 2009-2010, 2012-2013, 2019-2020, 2020-2021 and mean values over 1979-2020



Chemical ozone loss vs winter mean PSC volume in Arctic stratosphere from 2000 to 2020

Coupled climate model of Marchuk Institute of Numerical Mathematics (INM CM5)

INM CM5: atmosphere + ocean (Volodin et al., 2017)

- **Atmosphere:** resolution 1.25° × 1° longitude -latitude, 73 vertical levels from surface up to ~60 km (0.2 hPa)

- **Ocean**: 0.5°×0.25° and 40 vertical levels. Ocean block includes block of sea ice calculation

- Two model experiments from 2015 to 2100 performed in the framework of international project CMIP6 are analyzed.

1st experiment (intermediate scenario / ssp2-4.5) radiation forcing will increase by the end of XXI century on 4.5 W /m^2 in comparison with pre-industrial climate (before 1750) and CO_2 up to ~600 ppm^{-1},

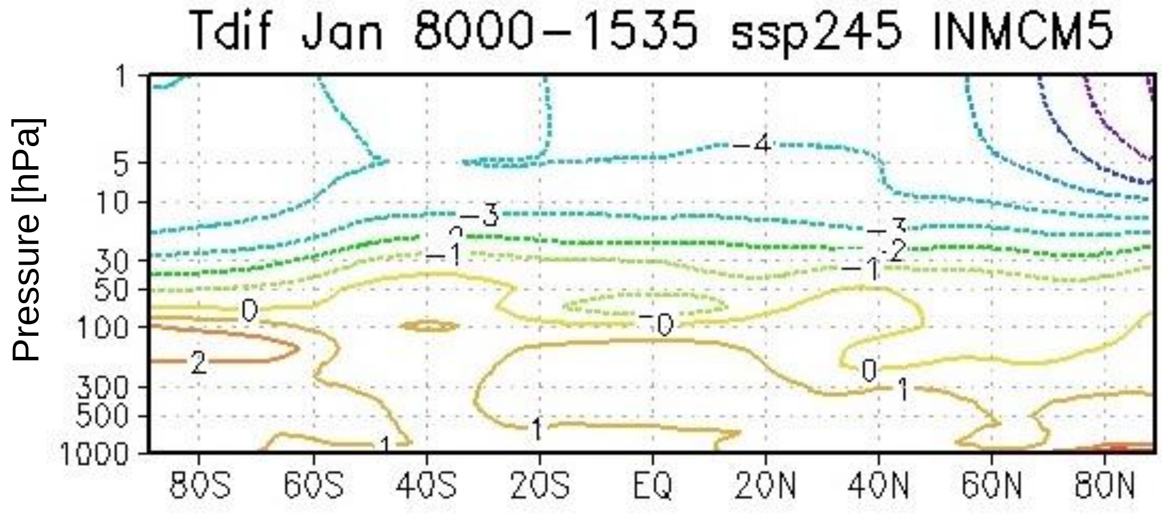
2nd experiment (hard scenario / ssp5-8.5): radiation forcing will increase on 8.5 W /m^2 and CO_2 in ~4 times up to 1135 ppm^{-1}.

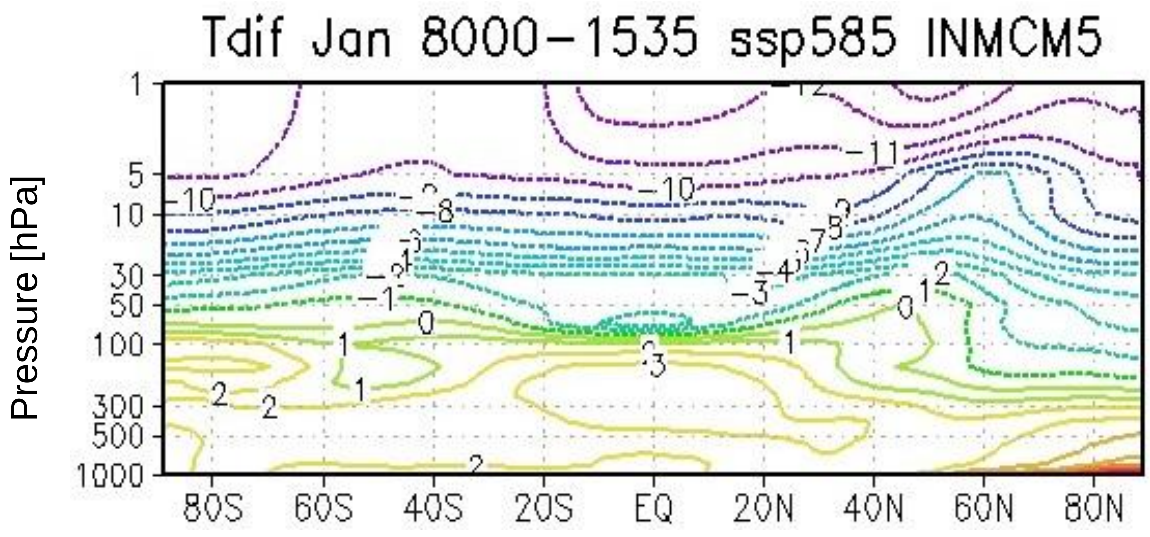
Volodin E.M. et al., Simulation of modern climate by new version of climate model INM RAS. // Izvestya. Atmospheric and Oceanic Physics, 2017.

Stratospheric temperature decrease

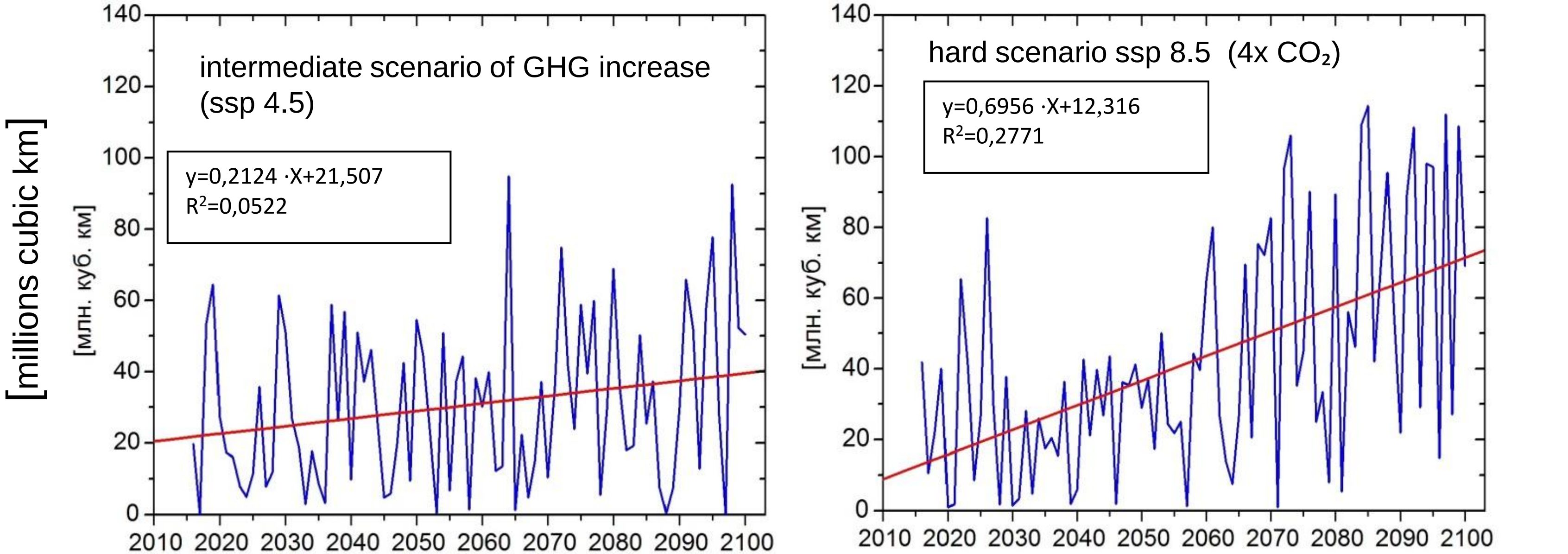
(2080-2100)
-
(2015-2035)

~50 км





Arctic Polar Stratosphere Clouds volume increase in the XXI century



Will be submitted to Atmosphere

PSC volume averaged over December – March from 2016 to 2100. Red line – linear trend. Both trends are significant.

Increase of PSC volume by the end of XXI century, strongest one under hard scenario. Increase of PSC volume is observed for January, February and March monthly means.
Strengthening of interanual variability of PSC volume as well as an increase of maximum values.

Obtained estimates are in the agreement with results of CMIP6 climate models including some chemistry climate models [Gathen et al., 2021].

Gathen P., et al., Climate change favours large seasonal loss of Arctic ozone // Nature Communications. 2021.

Summary

Investigation of interannual and long term variability variability of Arctic stratosphere is actual due its influence on troposphere, weather conditions, ozone layer, upper atmosphere and also due to interaction of expected ozone layer recovery and climate change and related changes of stratospheric circulation.

Recent winter seasons in Arctic stratosphere are characterized by high interanuual variability and its influence on troposphere, weather conditions and ozone layer.

Analysis of INM CM5 simulations shows possible increase of Polar Stratospheric Clouds Volume in Arctic stratosphere during XXI century under intermediate and especially hard scenario of GHG increase. Therefore favorable conditions for large ozone layer destruction (even stronger than observed in the spring of 2011 and 2020) are possible in some winters.


СПАСИБО ЗА ВНИМАНИЕ
Thank you very much for your attention