

PAPER • OPEN ACCESS

Sudden Stratospheric Warming (SSW) climatic contribution to winter temperature in Belarus: case of SSW 2017/2018

To cite this article: T V Schlender *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **606** 012053

View the [article online](#) for updates and enhancements.

You may also like

- [The Temporal and Spatial Scales of Density Structures Released in the Slow Solar Wind During Solar Activity Maximum](#)
E. Sanchez-Diaz, A. P. Rouillard, J. A. Davies *et al.*
- [SONN: a spike-wave index quantification neural network with a pre-labeling algorithm for epileptiform activity identification and quantification in children](#)
Yifei Yu, Yehong Chen, Yuanxiang Li *et al.*
- [Boundary of the Slow Solar Wind](#)
Yuan-Kuen Ko, D. Aaron Roberts and Susan T. Lepri



The Electrochemical Society
Advancing solid state & electrochemical science & technology

243rd ECS Meeting with SOFC-XVIII

More than 50 symposia are available!

Present your research and accelerate science

Boston, MA • May 28 – June 2, 2023

[Learn more and submit!](#)

Sudden Stratospheric Warming (SSW) climatic contribution to winter temperature in Belarus: case of SSW 2017/2018.

T V Schlender, V V Zhuchkevich, A N Krasouski, S D Umreika

National Ozone Monitoring Research and Education Center, Belarusian State University, Minsk, Belarus, 220045

timajaya@mail.ru

Abstract. The influence of stratospheric processes on the troposphere is defined by a multifactorial mechanism containing various geophysical and photochemical processes. This interaction determines the weather and climate of a particular region of the Earth. The number of sudden stratospheric warmings (SSW) over Eurasia has doubled over the past 20 years if compared with the second half of the 20th century. As a result, one had an increase in dangerous weather phenomena associated with those stratospheric-tropospheric interactions. In this regard, there is a certain need for an early forecast of such dangerous weather phenomena and their study within the framework of the climate of a given region. The paper presents a possible mechanism of the interaction of the mesosphere, stratosphere and troposphere layers (the so-called "ozone mechanism"). Due to its orographical and geographical position, the northern region of the East European Plain is characterized by accumulation of total ozone (TO) over this territory and formation of sharp and severe colds during SSW. The conclusion is made about the key contribution of the "ozone mechanism" to the development of SSW in 2018, which has become the largest in the Northern Hemisphere over the past 20 years.

1. Introduction.

In January 1942, German troops were unable to attack the city of Moscow due to severe frosts. At this time, the surface temperature dropped to -35°C and, according to synoptic maps, an Arctic cyclone was observed in the Baltic Sea region moving from the northeast of the polar Urals to the southwest [1]. January of 1942 was featured not only by abnormal surface temperatures, but also by altitude anomalies. Thus, in December-January 1941-1942, at an altitude of 30 km at three ozone stations in Arosa (Switzerland), Tromsø and Dombas (Norway), one revealed TO values exceeding the norm by 50-100 DU [2]. By reconstructing the fields of geopotentials and temperatures of the upper troposphere and lower stratosphere, the authors of the article have found the warming of the upper layers of the atmosphere and lowering of geopotentials in the entire thickness of the troposphere over Northern Europe. As a result, the authors have concluded that SSW and a weakened polar vortex occurred in the atmosphere, and this was accompanied not only by an increase in the Aleutian minimum, cooling in Europe and warming in the Arctic and Alaska but also by a negative AO index and a positive NAO index.



In winter, there are sharp temperature increases and wind changes to the opposite direction in the stratosphere of the polar latitudes. This phenomenon is called the “sudden stratospheric warming” (SSW). According to the WMO definition [3], SSW is characterized by a sharp gain in temperature (40-60 K) for several days in the polar (60° latitude and higher) stratosphere (10 mb and below) and slowing down or changing the direction of the zonal wind flow. These warmings were first discovered by the German meteorologist Richard Sherhag in 1952 [4]. The formation of SSW is believed to occur due to the penetration of waves from the troposphere into the stratosphere up to 30–45 km. T. Matsumo suggested that the formation of SSW could be caused by the interaction of planetary waves (zonal wave numbers $m = 1, 2$) with the average flux [5], which may ultimately lead to the circulation restructuring. According to [6], an increase in temperature begins in the upper stratosphere and lower mesosphere. In the mesosphere, on the contrary, air cooling above the warming zone in the stratosphere is observed [7]. The influence of stratospheric processes on the troposphere is defined by a multifactorial mechanism containing various geophysical and photochemical processes. This interaction determines the weather and climate of a particular region of the Earth [8]. Baldwin and Dunkerton [9] first showed the relationship between SSW and extreme and anomaly weather events in the Northern Hemisphere. The number of SSW over Eurasia has doubled over the past 20 years, if compared with the second half of the 20th century. The authors have revealed that large SSWs are observed in the eastern phase of QBO and on the peak of solar activity, and low SSWs are observed in the western phase of QBO and on the decline in solar activity [10]. This follows by an increase in dangerous weather phenomena associated with stratospheric-tropospheric interactions. In this regard, there is a need for an early forecast of such phenomena and their study. Here, we present a possible mechanism for the relationship between the TO anomalies and extreme negative surface temperatures in the winter for the territory of Belarus.

2. Data

The TO data were taken from the Aura satellite (OMI/OMPS instruments) (<https://exp-studies.tor.ec.gc.ca>) and from reanalysis of the MERRA-2 Reanalysis (<https://acd-ext.gsfc.nasa.gov>). The average and minimum surface temperature data were obtained at Belarusian Hydrometeorological Center (www.pogoda.by) and from reanalysis of the MERRA-2 Reanalysis (<https://disc.gsfc.nasa.gov>). Data on the tropopause level and geopotential height for 300 hPa (polar front), air temperature at a height of 10 hPa, and zonal wind at a height of 10 hPa were obtained from reanalysis of the MERRA-2 Reanalysis (<https://disc.gsfc.nasa.gov>). To construct maps and graphs, the Giovanni visualization tool (<https://giovanni.gsfc.nasa.gov>), ArcGIS, and Origin Pro were employed. One also studied the data of the QBO phase [<http://www.geo.fu-berlin.de>], the level of solar activity [<http://omniweb.gsfc.nasa.gov>], and the geomagnetic polar index [<http://pcindex.org>].

3. Ozone mechanism

The ozone mechanism [8, 11] may be viewed as an example of solar-terrestrial connections through the influence of solar energy on various layers of the atmosphere and its small components (in particular, the mesosphere, ionosphere, stratosphere, and troposphere). In general, the ozone mechanism can be described in lower atmosphere as follows:

- a set of stratospheric mechanisms determines the spatial distribution of TO in the stratosphere, which, in turn, forms the shape and height of the tropopause above the circulating tropospheric cells;
- a change in the position of the tropopause changes the speed of circulation processes in the troposphere thereby affecting the position of stationary fronts and stream flows;
- stationary fronts, which are the boundaries between the global circulation cells, define the trajectories of the pressure formations in the troposphere; The degree of influence of tropospheric and stratospheric mechanisms depends on the region and season. In the tropics, thermodynamic processes (convection) prevail throughout the year in the unstable troposphere, while the stratospheric ozone mechanism is typical for the polar latitudes. In the middle latitude zone, where Belarus is located, troposphere processes have a significant influence in the summer, and the ozone mechanism mainly

acts during transition to the winter period, which was confirmed statistically by the correlation between the deviations of TO and the deviations of surface temperatures for the territory of Belarus in this article [12].

4. Results

In Table 1, the data of all large SSW from 1980 to 2019 can be found. Considerable negative minimum surface temperatures and deviations from the average daily and monthly surface air temperatures during SSWs are analyzed for Minsk, Belarus. Over a period of 40 years, as to large SSWs, in 11 cases of 18 there were observed monthly average negative temperature deviations (from -0.5 to -8 °C) and significant minimum diurnal temperatures (from -7 to -25 °C). A large SSW during the month can hold from 3 to 14 days, and its contribution to the average monthly temperature will be slightly smoothed. But if we take decade-long average values, then a significant decrease in temperature will be revealed. Until 1988, the contribution of SSW to a lowering of surface temperatures was significant, in particular, in January 1987, the average monthly temperatures deviated by -8 °C from the norm, and the minimum surface temperature reached 25.6 °C. In the period from 1988 to 2001, the contribution of large SSWs to a decrease in monthly, decade (every ten days of the month), or daily average surface temperatures was not detected. On the contrary, one observed excess of the norm. In the period of 2004-2019, there is an alternation of negative deviations of the monthly average surface temperature every two SSWs. The largest deviation of the average monthly surface temperature was revealed in February 2006 and amounted to -3.9 °C from the norm, while the minimum surface temperature reached -28.6 °C.

To exemplify the effect of SSW on the surface weather and regional climate in Belarus, we studied all cases of the formation and development of SSWs for the period of 1980-2019 considering the ozone mechanism. As a result, they all have a common transformation scheme over Europe. Therefore, in the given article, only the case of SSW in February 2018 will be considered, which is presented in figure 1. This was one of the strongest warmings in recent years for the Northern Hemisphere. Warming began on February 9th with a slowdown in the wind speed and a positive increase in temperature deviations at an altitude of 10 hPa, and on February 12th, the sign of the wind speed changed completely. The phenomenon continued until March 1st. Furthermore, one observed a minimum of the 11 year cycle of solar activity and the eastern phase of QBO at this time. The geomagnetic index throughout the whole February had frequent jumps over its limit value.

February was the coldest month of the calendar winter of 2017-2018. The peak of frosty weather fell this year on the last days of February. In these days the temperature fell below normal by 7 degrees in the Central region of the Russian Federation. In Moscow and the Moscow region, the night of February 23rd turned out to be the coldest in the season with the temperature having dropped to -30 °C. (<https://meteoinfo.ru/novosti/14769-fevral-vnosit-kholodnyj-vklad-v-itogi-zimy>). The most part of Europe also suffered heavy snowfalls and frosts in late February - early March. As a result of such a nature cataclysm, more than 60 people died and many suffered hard (<https://www.theguardian.com/uk-news/gallery/2018/feb/27/siberian-blast-blankets-europe-snow-in-pictures>).

Table 1. Minimum surface temperatures, deviations of the monthly average and daily average surface air temperatures for the city of Minsk during the existence of SSWs.

Data/years	1980	1984	1987	1987	1989	1998	1999	2001	2001
Date SSW	29/02- 26/03	24/02- 04/04	23/01- 20/02	08/12- 16/12	21/02- 21/03	15/12- 20/12	26/02- 18/03	11/02- 24/02	30/12- 03/01
Anomaly surface T (°C) mean month from norm	-3,9 MAR	-1,3 FEB	-8,4 JAN	0,3 DEC	7,3 FEB	-1,3 DEC	1,2 FEB	0,3 FEB	-5 DEC
Absolute MIN T (°C) for days of SSW	-19,7	-16,3	-25,2	-10,2	-2,5	-7,1	-11,7	-16	-21,6
Anomaly T (°C) for day of Absolute MIN T	-11,5	-7,9	-13,6	-4,8	5,1	-1,5	-2,6	-10	-9,5
Data/years	2004	2006	2008	2009	2010	2013	2016	2018	2019
Date SSW	05/01- 15/01	21/01- 16/02	22/02- 28/02	24/01- 22/02	09/02- 23/02	06/01- 27/01	05/03- 31/03	12/02- 28/02	02/01- 21/01
Anomaly surface T (°C) mean month from norm	-1,9 JAN	-3,2 JAN	5,0 FEB	1,1 JAN 0,4 FEB	-0,3 FEB	-2,8 JAN	1,5 MAR	-1,6 FEB	-0,6 JAN
Absolute MIN T (°C) for days of SSW	-17,1	-28,6	-1,9	-18,9	-17,0	-18,5	-8,2	-19,8	-22,1
Anomaly T (°C) for day of Absolute MIN T	-10,1	-21,1	2,2	-10,2	-8,4	-9,4	-5,2	-12,3	-11,6

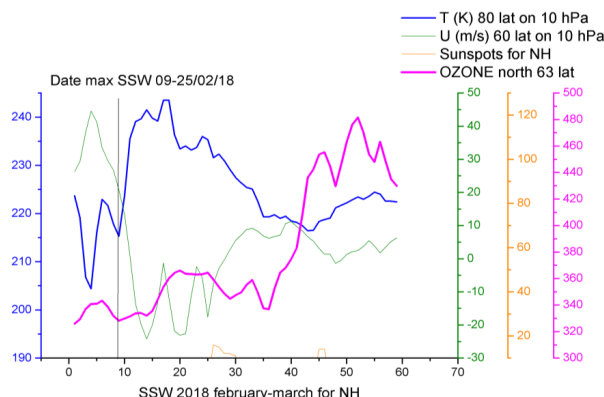


Figure 1. Graph of SSW in February, 2018. Those indicated are air temperature (at 80° latitude of the northern hemisphere), zonal wind (at 60° latitude of the northern hemisphere) at 10 hPa, the average TO in the polar region (north of 63° for the northern hemisphere), and the number of sunspots per day. The beginning of SSW is marked by a vertical solid black line in the graph.

Stemmed from the ozone mechanism, such an abnormal cold is explained by the fact that the anomalously high TO for this region and season contributed to a decrease in the height of the tropopause to 470 hPa (5.5 km), compared with 195 hPa (12 km) in the North Atlantic. Thus, the altitude difference was 175 hPa or 7.5 km, which is shown in figure 2. Normally, in polar conditions, Arctic air has a low tropopause height, in a range of 7-8 km. In this case, due to an increase in TO in the stratosphere, a decrease in the tropopause reached a mark of 5-6 km allowing the cold air to move quickly and penetrate deep into the mainland. Also, a characteristic feature of the terrain of this area contributed to a certain trajectory of the Arctic air. The Scandinavian and Ural mountains bounded cold air, both in space and in height, creating a kind of “tunnel”, where Arctic air accumulated and moved along a given trajectory. In the surface pressure, in the region, bounded by high TO, low tropopause, and the southern shift of the polar front line, the cyclonic nature of the weather was evident.

Due to the significant amount of TO, the line of the polar stationary front acquired a wave character. One part, where the cold air was located, shifted to the Black and Mediterranean Seas, and the other, with the warm air, shifted to the Barents Sea and Spitsbergen Island. Strong winds and jet flows were observed in zones of large tropopause TO gradient, height and temperature.

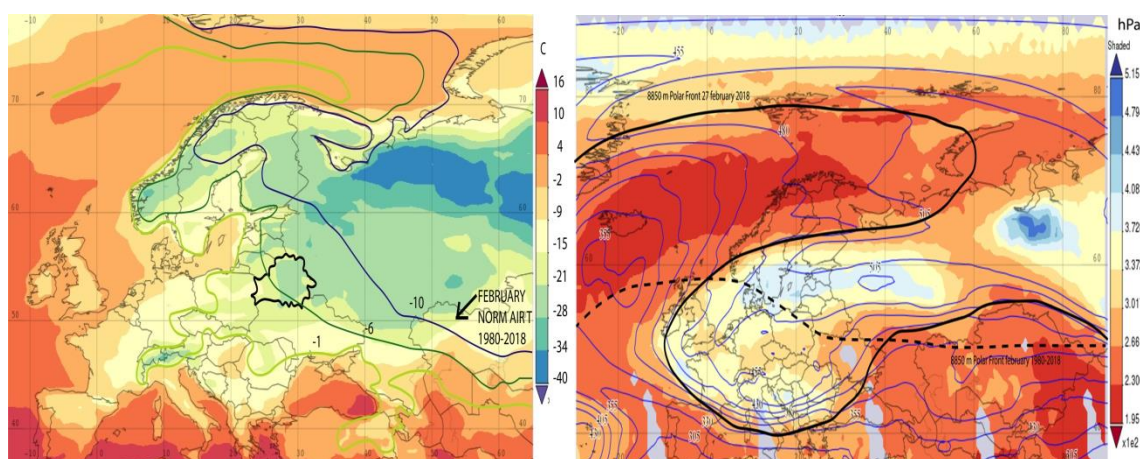


Figure 2. Right: tropopause - color fill (in hPa), TO - blue lines (in DU), polar front - line (black solid) of geopotential (m) at 300 hPa 02/20/2018 and line (dotted black) of the polar front for February 1980-2010 (from MERRA-2). Left: the minimum daily air temperature (MERRA-2) on 02/27/2018 and the contour of the average air temperature for February covering 1980-2018 years. In Europe, the minimum air temperature during the SSW period has a strong anomaly with approximately 15-20 °C below the norm of surface air temperature in February.

The distribution of TO over the territory of Belarus on February 20, 2018 can be observed in figure 3. Within the western and eastern borders of the country (the distance is about 500 km), the gap in TO was about 50-60 DU. Such large values of TO, about 400 DU, and higher, are characteristic of arctic air masses. Normally, TO accumulates in the Far East and, with the course of time, transfers further eastwards, since the stratosphere has a stable atmosphere. But in late February and early March 2018, stratospheric ozone changed its direction to the west and began to shift meridionally to the south, creating abnormal weather conditions in the lower troposphere. The minimum surface temperatures over the territory of Belarus reached -20°C , which indicated a deviation from the daily average

norm over 10 °C. In February, decade average daily deviations of the surface average air temperature for the city of Minsk from the daily average norm amounted to 1.36 °C, 1 °C and - 8.6 °C. Against the background of the deviation of the average monthly temperature in February 2018, which was -1.6 °C from the norm for 1980-2010, a significant contribution of the SSW is mainly revealed in the analysis of decade deviations of the surface air temperature.

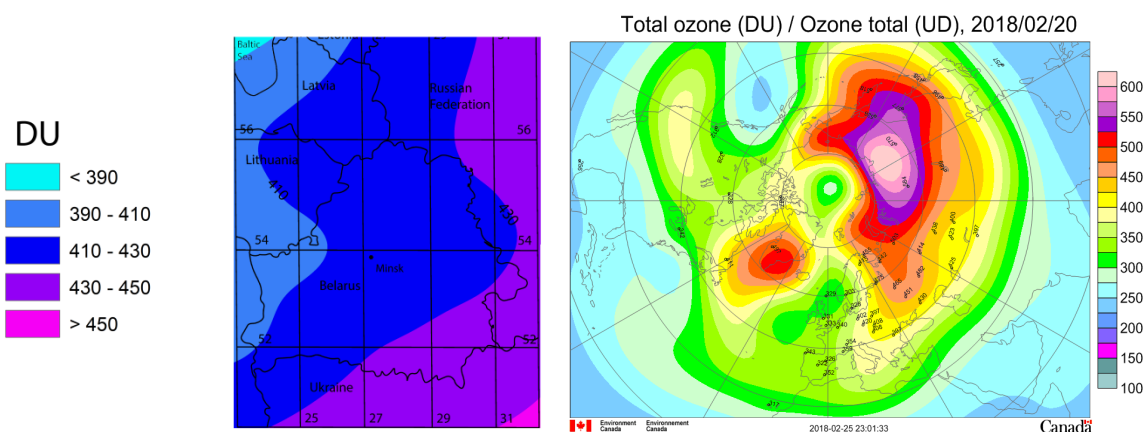


Figure 3. Distribution of TO in DU over the Republic of Belarus on February 20, 2018 (left) and for the Northern Hemisphere (right) according to OMI / TOMS satellites instruments.

5. Conclusion

As a result, the relationship between TO and atmospheric dynamics parameters was identified and analyzed using the example of SSW and negative temperatures in winter for the territory of Belarus. The last 20 years, the influence of SSW on the winter temperatures of Belarus occurs every 2-3 years. The most significant contribution of stratospheric warming occurs in the decade-long values of the month when it is observed, where a positive TO anomaly occurs in Belarus. The obtained result confirms the numerical experiments of SSW 2017-2018 in this work [12]. A possible mechanism for the formation and development of such weather anomalies in Eastern Europe is proposed. The essence of the theory lies in the idea that TO field is formed by the competition of two mechanisms, one of which, that can be called "radiative", is responsible for the formation of TO in the upper stratosphere and lowers the height of the tropopause, while the other, traditional, or "thermodynamic", acts in the troposphere, creating conditions for increasing the height of the tropopause, which leads to a decrease in the total amount of TO. The main feature of this mechanism is that it work not directly, instead, it changes the position of the global circulation cells (with their characteristic elements - stationary fronts, stream flows, and tropopause height level) [14, 15]. Undoubtedly, the formation of SSW affects all layers of the atmosphere [16, 17], and has recently been the subject of intensive research.

Based on the example of such a phenomenon as SSW, the ozone mechanism has explained hazardous weather phenomena, such as the anomaly cold in Europe. However, further studies are needed to fully confirm this theory. This example contributes to our understanding of the evolution of atmospheric processes. In particular, a change in the height of the tropopause (or TO) under a certain orographical situation can alter the tropospheric circulation in winter in Eastern and Central Europe.

Thus, it has been statistically and experimentally determined that both TO and stratospheric-tropospheric processes can affect the troposphere, weather and regional climate and contribute to the occurrence of dangerous meteorological phenomena, such as anomaly cold, in winter period. Observation of the ozone layer can help predict the emergence of various climate hazards.

References

- [1] Lejenäs H 1989 The Severe Winter in Europe 1941–42: The Large-Scale Circulation, Cut-off Lows, and Blocking *Bulletin of the American Meteorological Society* **70** **3** 271–81
- [2] Brönnimann S Luterbacher J Staehelin J and Svendby T 2004 An extreme anomaly in stratospheric ozone over Europe in 1940-1942. *Geophys. Res. Lett.* **31** **(8)**
- [3] Butler A Seidel D Hardiman S Butchart N Biner T and Match A 2015 Defining sudden stratospheric warmings *Bull. Am. Meteorol. Soc.* **96** 1913–28
- [4] Scherhag R 1951–52 Die explosionsartige Stratosphärenerwärmung des Spaitwinters R. *Scherhag Ber. Deut. Wetterdieustes.* **6** 51–63
- [5] Matsumo T 1971 Dynamical model of the Stratosphere sudden warming *J. Atmos. Sci.* **28** 1479–94
- [6] Schoeberl M 1978 Stratospheric warmings: Observations and theory *Rev. Geophys. Space Phys.* **16** **(4)** 521–38
- [7] Labitzke K 1972 Temperature changes in the mesosphere and stratosphere connected with circulation changes in winter *J. Atmos. Sci.* **29** 756–66
- [8] Shalamianski A 2013 Conception of atmospheric ozon and North hemisphere air mass interaction *Trudy GGO* **568** 173-94
- [9] Baldwin M, Dunkerton T 2001 Stratospheric harbingers of anomalous weather regimes *Science* **294** 581 - 4
- [10] Ageyeva V, Gruzdev A, Elokhov A, Mokhov I and Zueva N 2017 Sudden Stratospheric Warmings: Statistical Characteristics and Influence on NO₂ and O₃ Total Contents *Izv. Akad. Nauk, Fiz. Atmos. Okeana* **53****(5)** 545-55
- [11] Krasovski A, Turyshv L, Svetashev A, Zhuchkevich V, Borodko S 2016 Ozone mechanism for managing regional climate and weather *Science and innovation* **9** 17-20
- [12] Shlender T, Zhuchkevich V, Umreika S and Krasovski A 2018 Revealing a Role of Stratospheric Processes in the Development of Weather of the Republic of Belarus Employing Monitoring Data *J. Climatol. Weather Forecasting* **6** **(1)** 1-8
- [13] King A, Butler A, Jucker M, Earl N, Rudeva I 2019 Observed relationships between sudden stratospheric warmings and European climate extremes *J. Geoph. Res. Atmosph.* **124** 13943-61
- [14] Son S-W and et al, 2010 Impact of stratospheric ozone on Southern Hemisphere circulation change: A multimodel assessment *J. Geophys. Res.* **115** **19**
- [15] Thompson D W J, Solomon S 2002 Interpretation of recent Southern Hemisphere climate change *Science* **296** 895-9
- [16] Manney G, et al. 2009 Satellite observations and modelling of transport in the upper troposphere through the lower mesosphere during the 2006 major stratospheric sudden warming *Atmos. Chem. Phys. Discuss.* **9** 9693 – 745
- [17] Vargin P, Kiryushov B 2019 Major Sudden Stratospheric Warming in the Arctic in February 2018 and Its Impacts on the Troposphere, Mesosphere, and Ozone Layer *Russian Meteorology and Hydrology* **44** 112-23