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ОРИГИНАЛЬНАЯ СТАТЬЯ ORIGINAL ARTICLE

Arctic polar vortex dynamics during winters 2014/2015 and 2020/2021

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Summary

The dynamic barrier of the polar vortex contributes to lowering the temperature inside the vortex in the lower stratosphere and prevents the penetration of air masses into the vortex. The presence of a dynamic barrier during winter is one of the criteria determining the possibility of ozone depletion from late winter to spring. We considered the dynamics of the Arctic polar vortex in the winters of 2014/2015 and 2020/2021 at the 50, 30 and 10 hPa levels by the vortex delineation method using the geopotential. In early January 2015 and 2021, sudden stratospheric warmings were recorded as a result of the splitting (4 January 2015) and the significant displacement (5 January 2021) of the polar vortex. In both cases, the weakening of the dynamic barrier of the polar vortex was observed. The polar vortex is characterized by the presence of a dynamic barrier, when the wind speed along the entire edge of the vortex is more than 20, 24 and 30 m/s at the 50, 30 and 10 hPa levels, respectively. A decrease in the average wind speed along the vortex edge below 30, 36 and 45 m/s, at the 50, 30 and 10 hPa levels, respectively, usually indicates a local decrease in the wind speed below 20, 24 and 30 m/s at these levels, i.e., indirectly indicates a weakening of the dynamic barrier.

Keywords: Arctic polar vortex, dynamic barrier, polar stratospheric clouds, vortex area, wind speed at the vortex edge.

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INTRODUCTION

Stratospheric polar vortices, which form in autumn in the winter hemisphere and collapse in spring, play a key role in polar ozone depletion from late winter to spring [1–3]. Ozone depletion is observed as a result of a cycle of heterogeneous and photochemical reactions inside the polar vortex [4–6]. Heterogeneous reactions occur on the surface and in the volume of polar stratospheric clouds (PSCs), which form and exist at extremely low temperatures (PSC type I at temperatures below –78 °C and PSC type II at temperatures below –85 °C) in the lower stratosphere inside the polar vortex [7]. Chlorine reservoirs (HCl and $ClONO_2$) condensing on PSC surfaces at low temperatures interact with the formation of photochemically active molecular chlorine, which participates in the catalytic cycle of ozone destruction with the appearance of solar radiation [8, 9]. The Antarctic polar vortex is much stronger and more stable than the Arctic one, especially in spring, which is reflected in the significant difference between the area and intensity of ozone depletion inside the vortices from late winter to spring [10, 11]. The Arctic polar vortex often undergoes a weakening of the dynamic barrier in winter (which has never been observed in Antarctica from 1979 to 2022). The dynamic barrier of the polar vortex contributes to a decrease in the temperature inside the vortex in the lower stratosphere and prevents the penetration of warm, ozone-rich air masses into the vortex (which manifests itself in a significant temperature gradient along the vortex edge) [12, 13]. The weakening of the dynamic barrier leads to an increase in the temperature inside the polar vortex in the lower stratosphere and subsequent melting of PSCs [14]. The chlorine compounds accumulated on PSCs evaporate together with PSCs, and then the process of accumulation of chlorine compounds on PSC surfaces begins again when the dynamic barrier is restored, the temperature decreases and the PSC is formed [15]. Ozone depletion is observed in cases where PSCs continuously existed for at least two months and accumulated a sufficient amount of chlorine compounds for large-scale ozone depletion to occur when solar radiation appears over the polar region [16]. Thus, the presence of a dynamic barrier during winter is one of the criteria determining the probability of ozone depletion from late winter to spring.

The weakening of the Arctic polar vortex often occurs under the influence of planetary waves and is sometimes accompanied by sudden stratospheric warmings (SSWs) [17–21]. SSW events are usually associated with the splitting of the polar vortex into two or its significant displacement [22, 23]. In the winters of 2015 and 2021, SSWs were recorded as a result of the polar vortex splitting on 4 January 2015 and a significant displacement of the polar vortex on 5 January 2021 [24–27]. In both cases, the dynamic barrier weakening was observed in early January. There are at least three methods for vortex delineation. The polar vortex edge can be determined from the maximum potential vorticity gradient [28], using the function M [29] and the geopotential values determined from the maximum temperature gradient [30]. Potential vorticity, being a ratio of the absolute vortex to the effective depth of the vortex, describes the dynamics of the vortex well. The function M, being a measure based on the length of Lagrangian fluid parcel trajectories, makes it possible to estimate the regional features of mass transfer and determine the area of the dynamic barrier along the vortex edge. The work considers the Arctic polar vortex dynamics in the winter-spring of 2014/2015 and 2020/2021 before and after the SSW events by the vortex delineation method using the geopotential.

DATA AND METHODS

The daily mean data on zonal and meridional wind, the geopotential, air temperature and ozone mass mixing ratio in the region of 40–90° N with a horizontal resolution of 0.25 × 0.25° at the 50, 30 and 10 hPa levels for 1979–2021 were obtained from the ERA5 reanalysis data (https://doi.org/10.24381/cds.bd0915c6) [31]. The phases of the quasi-biennial oscillation are characterized by zonal winds in the equatorial region at the 30 hPa level (http://www.geo.fu-berlin.de/met/ag/strat/produkte/qbo/ qbo.dat) [32].

To analyze the dynamics of the Arctic polar vortex, we used the vortex delineation method using the geopotential [33]. A maximum temperature gradient and, as a rule, maximum wind speed values are observed along the edge of the polar vortex. Based on hourly data with a horizontal resolution of 0.25 × 0.25° for the 50, 30 and 10 hPa pressure levels for the period from 1979 to 2021, the following values were obtained: the temperature value at the point of a maximum gradient in the 40–90° latitude belt for each longitude value, the geopotential value at the points of the maximum temperature gradient, the maximum wind speed in the 40–90° latitude belt for each longitude value. On average for 1979–2021, the value of the geopotential Φ^* in the region of the maximum temperature gradient along the vortex edge equals $\Phi^* = (19.50 \pm 0.15) \cdot 10^4$ m^2/s^2 at the 50 hPa, $\Phi^* = (22.70 \pm 0.20) \cdot 10^4$ m^2/ s^2 at the 30 hPa and $\Phi^* = (29.50 \pm 0.30) \cdot 10^4$ m^2/ s^2 at the 10 hPa. The vortex area, mean and minimum wind speed along the vortex edge, mean temperature and mean ozone mass mixing ratio inside the vortex were calculated using the ERA5 reanalysis data, based on the fact that the Arctic polar vortex edge at the 50, 30 and 10 hPa levels is determined by geopotential values $19.5 \cdot 10^4$, $22.7 \cdot 10^4$ and $29.5 \cdot 10^4$ m^2/s^2, respectively. The dynamics of the characteristics studied in the winter-spring of 2014/2015 and 2020/2021 was considered in comparison with 30-year means and their standard deviations (SD, σ) obtained as a result of selecting 30 cases with the strongest vortex for 1979–2021 (during averaging, the data for the following years, when anomalous changes in the wind speed and vortex area exceeded 2 standard deviations, were removed (the period from July to June of the following year): 1983/1984, 1984/1985, 1986/1987, 1987/1988, 1998/1999, 2000/2001, 2001/2002, 2003/2004, 2005/2006, 2008/2009, 2011/2012, 2012/2013, 2018/2019). In obtaining climatological means for the Arctic polar vortex, which is characterized by significant variability, it is especially important to filter out cases with a weak polar vortex. Climatological means and their standard deviations were smoothed with the FFT filter (fast Fourier transform filter) over 15 points. Time series of the characteristics studied in 2014/2015 and 2020/2021 were smoothed with a 3-point FFT filter.

RESULTS AND DISCUSSION

Fig. 1 shows the dynamics of the main characteristics of the Arctic polar vortex from the December to March of 2014/2015 and 2020/2021 at the 50, 30 and 10 hPa levels, obtained by the vortex delineation method. Fig. 2 shows the geopotential, wind speed and temperature distributions from the December to March of 2014/2015 and 2020/2021 at the 30 hPa level. The main dynamic characteristics of the polar vortices (in addition to the presence of a dynamic barrier) are the vortex area of more than 10 million km^2 and the average wind speed along the vortex edge of more than 30, 36 and 45 m/s at the 50, 30 and 10 hPa levels, respectively [33]; marked with a blue dashed line in Fig. 1. The polar vortex is characterized by the presence of a dynamic barrier, when the wind speed along the entire edge of the vortex horizontally is more than 20, 24 and 30 m/s at the 50, 30 and 10 hPa levels, respectively [34]. The values of 22.7 · 104 m^2/s^2, describing the polar vortex edge, are connected by a line on the geopotential distributions in Fig. 2, and the values of 24 m/s, characterizing the dynamic barrier, are connected by a line on the wind speed distributions. The red dashed line in Fig. 1 marks the SSW events observed on 4 January 2015 and 5 January 2021 (marked on 4 January).

As seen in Fig. 1, no large-scale ozone depletion was observed in 2015 and 2021. A significant increase in the temperature inside the vortex was recorded in both years

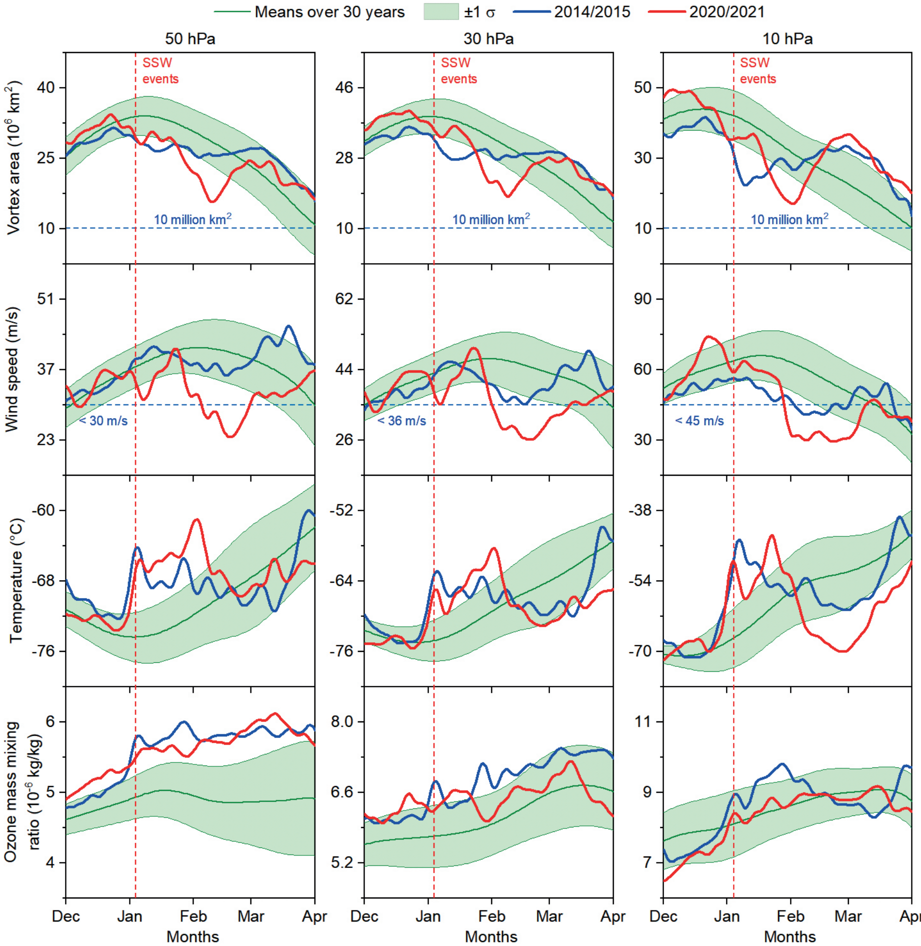

Fig. 1. Time series of the Arctic polar vortex area, mean wind speed along the vortex edge, mean temperature inside the vortex and mean ozone mass mixing ratio inside the vortex at the 50, 30 and 10 hPa pressure levels from December to March of 2014/2015 and 2020/2021 in comparison with the 30-year means with ±1 σ

Рис. 1. Временные изменения площади арктического полярного вихря, средней скорости ветра по границе вихря, средней температуры внутри вихря и среднего массового отношения смеси озона внутри вихря на уровнях 50, 30 и 10 гПа с декабря по март 2014/15 и 2020/21 гг. в сравнении с 30-летними средними значениями со среднеквадратичными отклонениями (СКО, σ)

shortly before the SSW, after which the average temperature inside the vortex remained high for at least a month, which eventually led to PSC melting and their absence for more than a month during the winter in both cases (and no ozone depletion in spring). As seen from Fig. 1, in 2015 and 2021, at the 50 and 30 hPa levels, where the vertical ozone gradient is positive, ozone values are above the climatological means, and at the 10 hPa level, above which the gradient becomes negative, ozone values are below the climatological means. Therefore, a possible cause may be a stronger settling of air masses in these winters. Unexpectedly, in 2015 no weakening of the dynamic barrier was

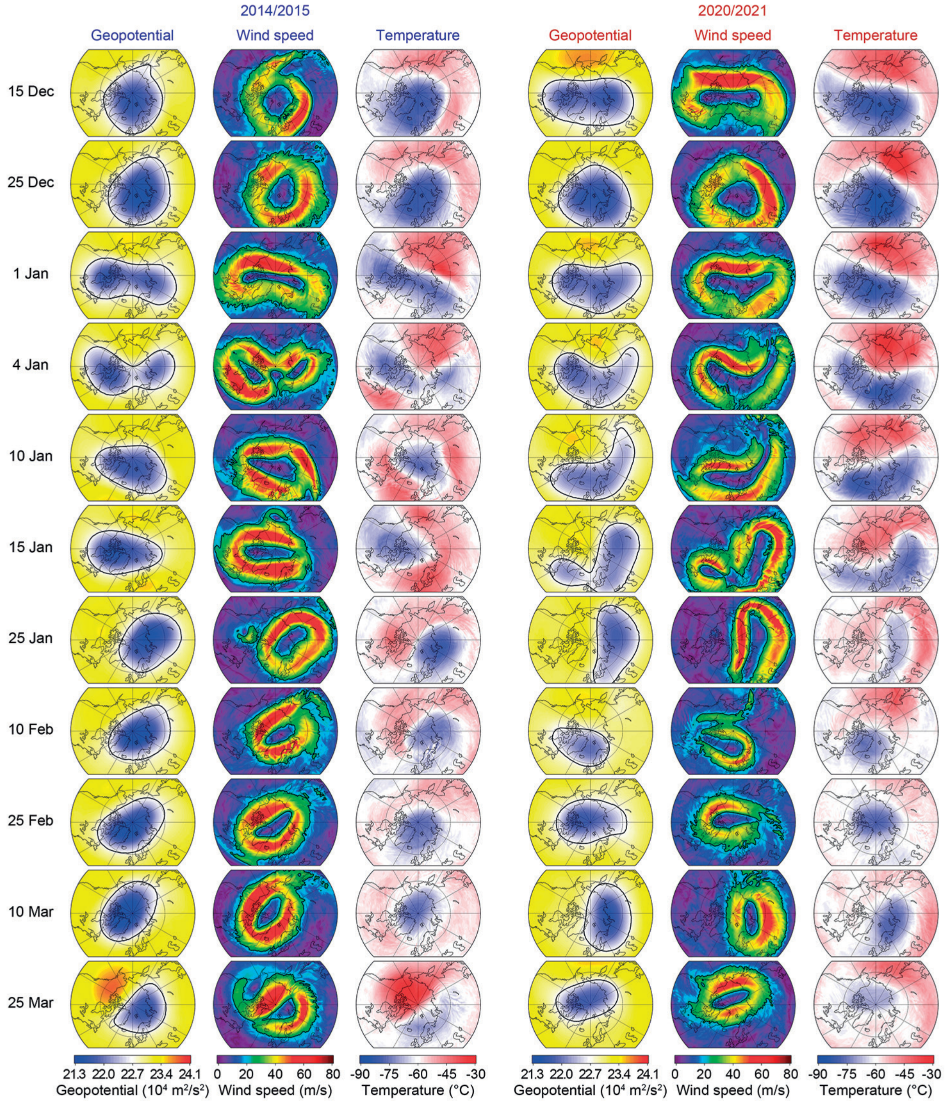

Fig. 2. Geopotential, wind speed and temperature distributions at the 30 hPa pressure level over the Arctic from 15 December to 25 March of 2014/2015 and 2020/2021

Рис. 2. Поля геопотенциала, скорости ветра и температуры на уровне 30 гПа над Арктикой с 15 декабря по 25 марта за 2014/15 и 2020/21 гг.

observed after the splitting of the polar vortex at the 50 and 30 hPa levels, but it was observed at the 10 hPa level. In contrast, in 2021 the weakening of the dynamic barrier of the polar vortex at all the three levels considered was recorded throughout most of the winter, especially after the SSW event. As noted above, the dynamic barrier weakening is observed with a local decrease in the wind speed along the vortex edge below 20, 24 and 30 m/s, at the 50, 30 and 10 hPa levels, respectively, which often occurs when the average wind speed along the vortex edge decreases below 30, 36 and 45 m/s at these levels. As seen from Fig. 1, in 2021, the average wind speed was below the marked values almost throughout February, while in 2015 it was observed only at the 10 hPa level. It should be noted that while a decrease in the average wind speed along the vortex edge below 30, 36 and 45 m/s, at the 50, 30 and 10 hPa levels, respectively, usually indicates a weakening of the dynamic barrier, the values of the average speed above the values noted do not indicate the presence of the dynamic barrier, because local weakening of the dynamic barrier can be observed at high average wind speeds (as was observed in January 2021, in particular, on 10 January, Fig. 1, 2).

As seen from Fig. 2, in general, in the winter-spring of 2014/2015, the polar vortex was stronger and more stable than in 2020/2021. In early January, in both cases, the vortex became elongated, after which, the vortex splitting was observed in 2015 and the strong displacement of the vortex occurred in 2021. In 2015, a few days after the splitting, the gradual recovery and strengthening of the polar vortex was observed until mid-March (Fig. 2). In contrast, in 2021, after the vortex displacement in early January, its gradual slow weakening was observed until breakdown in April (Fig. 1, 2). The vortex area in both years was more than 10 million km^2 until April (Fig. 1).

In addition to the influence of planetary waves, the dynamics of the Arctic polar vortex in the winter-spring of 2014/2015 and 2020/2021 can be affected by quasi-biennial oscillation (QBO). As is known, during the western phase of the QBO, polar vortex strengthening is observed, and during the eastern phase, it weakens, which manifests itself in the Arctic throughout the entire winter-spring period, while in the Antarctic it occurs only in spring [35–40]. The eastern and western phases of the QBO were observed in the winter-spring of 2014/2015 and 2020/202,1 respectively, (during the entire period of the existence of the polar vortex). It is assumed that in 2015 the eastern phase of the QBO contributed to the weakening of the initially strong polar vortex, while in 2021 the relatively weak polar vortex, due to the western phase, lasted an unusually long time, taking into account the frequency of weakening of the dynamic barrier.

CONCLUSION

In this work, we considered the dynamics of the Arctic polar vortex in the winters of 2014/2015 and 2020/2021 at the 50, 30, and 10 hPa levels by the vortex delineation method using the geopotential. In the early January of 2015 and 2021, SSW events were recorded as a result of splitting (4 January 2015) and a significant displacement (5 January 2021) of the polar vortex. In both cases, a weakening of the dynamic barrier of the polar vortex was observed. The polar vortex is characterized by the presence of a dynamic barrier, when the wind speed along the entire edge of the vortex horizontally is more than 20, 24 and 30 m/s at the 50, 30 and 10 hPa levels, respectively. At the same time, a decrease in the average wind speed along the vortex edge below 30, 36 and 45 m/s, at the 50, 30 and 10 hPa levels, respectively, usually indicates a local decrease in the wind speed below 20, 24 and 30 m/s at these levels, i. e. indirectly indicates a weakening of the dynamic barrier.

In 2015, after the splitting, the polar vortex quickly recovered in the lower stratosphere, and subsequent weakening of the dynamic barrier was observed only at the 10 hPa level. It is assumed that the temperature increase and PSC melting inside the vortex in the lower stratosphere were observed due to the weakening of the dynamic barrier at the 10 hPa level and the presence of vertical motions inside the polar vortex. In contrast, in 2021, the weakening of the dynamic barrier after the SSW event was periodically observed at all heights. In 2015, after the splitting of the polar vortex, its gradual recovery and strengthening was observed until mid-March, while in 2021, after the displacement of the vortex in early January, its gradual slow weakening and destruction was observed in April. It is assumed that in 2015 the eastern phase of the QBO contributed to the weakening of the initially strong polar vortex, while in 2021 the initially weak polar vortex had an unusually long duration of existence due to the western phase.

Competing interests. The authors have no competing interests.

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REFERENCES

1. *Waugh D.W., Randel W.J.* Climatology of Arctic and Antarctic polar vortices using elliptical diagnostics. J. Atmos. Sci. 1999, 56 (11): 1594–1613. doi: 10.1175/1520-0469(1999)056<1594:COAAAP>2.0.CO;2.

2. *Waugh D.W., Randel W.J., Pawson S., Newman P.A., Nash E.R.* Persistence of the lower stratospheric polar vortices. J. Geophys. Res. 1999, 104 (22): 27191–27201. doi: 10.1029/1999JD900795.

3. *Waugh D.W., Sobel A.H., Polvani L.M.* What is the polar vortex and how does it influence weather? Bull. Amer. Meteor. Soc. 2017, 98 (1): 37–44. doi: 10.1175/BAMS-D-15-00212.1.

4. *Solomon S.* Stratospheric ozone depletion: a review of concepts and history. Rev. Geophys. 1999, 37 (3): 275–316. doi: 10.1029/1999RG900008.

5. *Manney G.L., Santee M.L., Rex M., Livesey N.J., Pitts M.C., Veefkind P., Nash E.R., Wohltmann I., Lehmann R., Froidevaux L., Poole L.R., Schoeberl M.R., Haffner D.P., Davies J., Dorokhov V., Gernandt H., Johnson B., Kivi R., Kyro E., Larsen N., Levelt P.F., Makshtas A., McElroy C.T., Nakajima H., Parrondo M.C., Tarasick D.W., von der Gathen P., Walker K.A., Zinoviev N.S.* Unprecedented Arctic ozone loss in 2011. Nature. 2011, 478 (7370): 469–475. doi: 10.1038/nature10556.

6. *Solomon S., Kinnison D., Bandoro J., Garcia R.* Simulation of polar ozone depletion: An update. J. Geophys. Res. 2015, 120 (15): 7958–7974. doi: 10.1002/2015JD023365.

7. *Finlayson-Pitts B.J., Pitts J.N.* Chemistry of the Upper and Lower Atmosphere: Theory, Experiments, and Applications. California: Academic Press, 2000: 969 p.

8. *Solomon S., Garcia R.R., Rowland F.S., Wuebbles D.J.* On the depletion of Antarctic ozone. Nature. 1986, 321: 755–758. doi: 10.1038/321755a0.

9. *Solomon S., Portmann R.W., Sasaki T., Hofmann D.J., Thompson D.W.J.* Four decades of ozonesonde measurements over Antarctica. J. Geophys. Res. 2005, 110 (21): D21311. doi: 10.1029/2005JD005917.

10. *Solomon S., Portmann R.W., Thompson D.W.J.* Contrasts between Antarctic and Arctic ozone depletion. Proc. Natl. Acad. Sci. USA. 2007, 104 (2): 445–449. doi: 10.1073/pnas.0604895104.

11. *Solomon S., Haskins J., Ivy D.J., Min F.* Fundamental differences between Arctic and Antarctic ozone depletion. Proc. Natl. Acad. Sci. USA. 2014, 111 (17): 6220–6225. doi: 10.1073/pnas.1319307111.

12. *Manney G.L., Zurek R.W., O'Neill A., Swinbank R.* On the motion of air through the stratospheric polar vortex. J. Atmos. Sci. 1994, 51 (20): 2973–2994. doi: 10.1175/1520-0469(1994)051<2973:OTMOAT>2.0.CO;2.

13. *Sobel A.H., Plumb R.A., Waugh D.W.* Methods of calculating transport across the polar vortex edge. J. Atmos. Sci. 1997, 54 (18): 2241–2260. doi: 10.1175/1520-0469(1997)054<2241:MOCTAT>2.0.CO;2.

14. *Newman P.A., Nash E.R., Rosenfield J.E.* What controls the temperature of the Arctic stratosphere during the spring? J. Geophys. Res. 2001, 106 (17): 19999–20010. doi: 10.1029/2000JD000061.

15. *Zuev V.V., Savelieva E.* Arctic polar vortex dynamics during winter 2006/2007. Polar Sci. 2020, 25: 100532. doi: 10.1016/j.polar.2020.100532.

16. *Zuev V.V., Savelieva E.* The role of the polar vortex strength during winter in Arctic ozone depletion from late winter to spring. Polar Sci. 2019, 22: 100469. doi: 10.1016/j.polar.2019.06.001.

17. *Limpasuvan V., Thompson D.W.J., Hartmann D.L.* The life cycle of the Northern Hemisphere sudden stratospheric warmings. J. Climate. 2004, 17 (13): 2584–2596. doi: 10.1175/1520-0442(2004)017<2584:TLCOTN>2.0.CO;2.

18. *Charlton A.J., Polvani L.M.* A new look at stratospheric sudden warmings. Part I: Climatology and modeling benchmarks. J. Climate. 2007, 20 (3): 449–469. doi: 10.1175/JCLI3996.1.

19. *Charlton A.J., Polvani L.M., Perlwitz J., Sassi F., Manzini E., Shibata K., Pawson S., Nielsen J.E., Rind D.* A new look at stratospheric sudden warmings. Part II: Evaluation of numerical model simulations. J. Climate. 2007, 20 (3): 470–488. doi: 10.1175/JCLI3994.1.

20. *Matthewman N.J., Esler J.G., Charlton-Perez A.J., Polvani L.M.* A new look at stratospheric sudden warmings. Part III: Polar vortex evolution and vertical structure. J. Climate. 2009, 22 (6): 1566–1585. doi: 10.1175/2008JCLI2365.1.

21. *Kuttippurath J., Nikulin G.* A comparative study of the major sudden stratospheric warmings in the Arctic winters 2003/2004–2009/2010. Atmos. Chem. Phys. 2012, 12 (17): 8115–8129. doi: 10.5194/acp-12-8115-2012.

22. *Butler A.H., Seidel D.J., Hardiman S.C., Butchart N., Birner T., Match A.* Defining Sudden Stratospheric Warmings. Bull. Amer. Meteor. Soc. 2015, 96 (11): 1913–1928. doi: 10.1175/BAMS-D-13-00173.1.

23. *Ayarzagüena B., Polvani L.M., Langematz U., Akiyoshi H., Bekki S., Butchart N., Dameris M., Deushi M., Hardiman S.C., Jöckel P., Klekociuk A., Marchand M., Michou M., Morgenstern O., O'Connor F.M., Oman L.D., Plummer D.A., Revell L., Rozanov E., Saint-Martin D., Scinocca J., Stenke A., Stone K., Yamashita Y., Yoshida K., Zeng G.* No robust evidence of future changes in major stratospheric sudden warmings: a multi-model assessment from CCMI. Atmos. Chem. Phys. 2018, 18 (15): 11277–11287. doi: 10.5194/acp-18-11277-2018.

24. *Manney G.L., Lawrence Z.D., Santee M.L., Read W.G., Livesey N.J., Lambert A., Froidevaux L., Pumphrey H.C., Schwartz M.J.* A minor sudden stratospheric warming with a major impact: Transport and polar processing in the 2014/2015 Arctic winter. Geophys. Res. Lett. 2015, 42 (18): 7808–7816. doi: 10.1002/2015GL065864.

25. *Vargin P.N., Guryanov V.V., Lukyanov A.N., Vyzankin A.S.* Dynamic Processes of the Arctic Stratosphere in the 2020–2021 Winter. Izv. Atmos. Ocean. Phys. 2021, 57: 568–580. doi: 10.1134/S0001433821060098.

26. *Lee S.H.* The January 2021 sudden stratospheric warming. Weather. 2021, 76 (4): 135–136. doi: 10.1002/wea.3966.

27. *Zhang C., Grytsai A., Evtushevsky O., Milinevsky G., Andrienko Y., Shulga V., Klekociuk A., Rapoport Y., Han W.* Rossby waves in total ozone over the Arctic in 2000–2021. Remote Sens. 2022, 14 (9): 2192. doi: 10.3390/rs14092192.

28. *Lawrence Z.D., Manney G.L., Wargan K.* Reanalysis intercomparisons of stratospheric polar processing diagnostics. Atmos. Chem. Phys. 2018, 18 (18): 13547–13579. doi: 10.5194/acp-18-13547-2018.

29. *Smith M.L., McDonald A.J.* A quantitative measure of polar vortex strength using the function M. J. Geophys. Res. 2014, 119 (10): 5966–5985. doi: 10.1002/2013JD020572.

30. *Zuev V.V., Savelieva E.* Stratospheric polar vortex dynamics according to the vortex delineation method. J. Earth Syst. Sci. 2023, 132 (1): 39. doi: 10.1007/s12040-023-02060-x.

31. *Hersbach H., Bell B., Berrisford P., Hirahara S., Horányi A., Muñoz-Sabater J., Nicolas J., Peubey C., Radu R., Schepers D., Simmons A., Soci C., Abdalla S., Abellan X., Balsamo G.,*

Bechtold P., Biavati G., Bidlot J., Bonavita M., de Chiara G., Dahlgren P., Dee D., Diamantakis M., Dragani R., Flemming J., Forbes R., Fuentes M., Geer A., Haimberger L., Healy S., Hogan R.J., Hólm E., Janisková M., Keeley S., Laloyaux P., Lopez P., Lupu C., Radnoti G., de Rosnay P., Rozum I., Vamborg F., Villaume S., Thépaut J.-N. The ERA5 global reanalysis. Q. J. Roy. Meteor. Soc. 2020, 146 (729): 1–51. doi: 10.1002/qj.3803.

32. *Baldwin M.P., Gray L.J., Dunkerton T.J., Hamilton K., Haynes P.H., Randel W.J., Holton J.R., Alexander M.J., Hirota I., Horinouchi T., Jones D.B.A., Kinnersley J.S., Marquardt C., Sato K., Takahashi M.* The quasi-biennial oscillation. Rev. Geophys. 2001, 39 (2): 179–229. doi: 10.1029/1999RG000073.

33. *Zuev V.V., Savelieva E.* Antarctic polar vortex dynamics during spring 2002. J. Earth Syst. Sci. 2022, 131 (2): 119. doi: 10.1007/s12040-022-01879-0.

34. *Zuev V.V., Savelieva E.* Antarctic polar vortex dynamics depending on wind speed along the vortex edge. Pure Appl. Geophys. 2022, 179 (6–7): 2609–2616. doi: 10.1007/s00024-022-03054-4.

35. *Niwano M., Takahashi M.* The influence of the equatorial QBO on the Northern Hemisphere winter circulation of a GCM. J. Meteor. Soc. Jpn. 1998, 76 (3): 453–461. doi: 10.2151/JMSJ1965.76.3_453.

36. *Hampson J., Haynes P.* Influence of the equatorial QBO on the extratropical stratosphere. J. Atmos. Sci. 2006, 63 (3): 936–951. doi: 10.1175/JAS3657.1.

37. *Camp C.D., Tung K.-K.* The influence of the solar cycle and QBO on the late-winter stratospheric polar vortex. J. Atmos. Sci. 2007, 64 (4): 1267–1283. doi: 10.1175/JAS3883.1.

38. *Garfinkel C.I., Hartmann D.L.* Effects of the El Niño–Southern Oscillation and the Quasi-Biennial Oscillation on polar temperatures in the stratosphere. J. Geophys. Res. 2007, 112 (19): D19112. doi: 10.1029/2007JD008481.

39. *Chen W., Wei K.* Interannual variability of the winter stratospheric polar vortex in the Northern Hemisphere and their relations to QBO and ENSO. Adv. Atmos. Sci. 2009, 26 (5): 855–863. doi: 10.1007/s00376-009-8168-6.

40. *Naoe H., Shibata K.* Equatorial quasi-biennial oscillation influence on northern winter extratropical circulation. J. Geophys. Res. 2010, 115 (19): D19102. doi: 10.1029/2009JD012952.

Динамика арктического полярного вихря зимой 2014/15 и 2020/21 гг.

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Резюме

Динамический барьер полярного вихря способствует сохранению низкой температуры внутри вихря в нижней стратосфере и препятствует проникновению воздушных масс внутрь вихря. Наличие динамического барьера на протяжении зимы является одним из критериев, определяющих возможность формирования озоновой аномалии в период с конца зимы по весну. В работе рассмотрена динамика арктического полярного вихря зимой 2014/15 и 2020/21 гг. на уровнях 50, 30 и 10 гПа с использованием метода оконтуривания вихрей с помощью геопотенциала. В начале января 2015 и 2021 гг. регистрировались внезапные стратосферные потепления в результате расщепления (4 января 2015 г.) и значительного смещения (5 января 2021 г.) полярного вихря. В обоих случаях наблюдалось ослабление динамического барьера полярного вихря. Полярный вихрь характеризуется наличием динамического барьера, когда скорость ветра на протяжении всей границы вихря по горизонтали составляет более 20, 24 и 30 м/с на уровнях 50, 30 и 10 гПа, соответственно. При этом снижение средней скорости ветра по границе вихря ниже 30, 36 и 45 м/с соответственно на уровнях 50, 30 и 10 гПа, как правило, свидетельствует о локальном уменьшении скорости ветра ниже 20, 24 и 30 м/с на этих уровнях, т. е. косвенно свидетельствует об ослаблении динамического барьера.

Ключевые слова: арктический полярный вихрь, динамический барьер, площадь вихря, полярные стратосферные облака, скорость ветра по границе вихря.

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ДИНАМИКА АРКТИЧЕСКОГО ПОЛЯРНОГО ВИХРЯ ЗИМОЙ 2014/15 И 2020/21 ГГ. (РАСШИРЕННЫЙ РЕФЕРАТ)

Динамический барьер полярного вихря способствует сохранению низкой температуры внутри вихря в нижней стратосфере и препятствует проникновению воздушных масс внутрь вихря. Наличие динамического барьера на протяжении зимы является одним из критериев, определяющих возможность формирования озоновой аномалии в период с конца зимы по весну. В работе рассмотрена динамика арктического полярного вихря зимой 2014/15 и 2020/21 гг. на уровнях 50, 30 и 10 гПа с использованием метода оконтуривания вихрей с помощью геопотенциала. В начале января 2015 и 2021 гг. регистрировались большое и малое внезапные стратосферные потепления в результате расщепления (4 января 2015 г.) и значительного смещения (5 января 2021 г.) полярного вихря. В обоих случаях наблюдалось ослабление динамического барьера полярного вихря. Полярный вихрь характеризуется наличием динамического барьера, когда скорость ветра на протяжении всей границы вихря по горизонтали составляет более 20, 24 и 30 м/с на уровнях 50, 30 и 10 гПа соответственно. При этом снижение средней скорости ветра по границе вихря ниже 30, 36 и 45 м/с соответственно на уровнях 50, 30 и 10 гПа, как правило, свидетельствует о локальном уменьшении скорости ветра ниже 20, 24 и 30 м/с на этих уровнях, т. е. косвенно свидетельствует об ослаблении динамического барьера.

В 2015 г. после расщепления полярный вихрь достаточно быстро восстановился в нижней стратосфере, и последующие ослабления динамического барьера наблюдались только на уровне 10 гПа. Предполагается, что повышение температуры и разрушение частиц ПСО в нижней стратосфере наблюдались вследствие ослабления динамического барьера на уровне 10 гПа и наличия вертикальных движений внутри вихря. В свою очередь, в 2021 г. ослабление динамического барьера после события ВСП периодически прослеживалось на всех рассматриваемых уровнях. В 2015 г. после расщепления полярного вихря наблюдалось его постепенное восстановление и усиление вплоть до середины марта, в то время как в 2021 г. после смещения вихря в начале января наблюдалось его постепенное медленное ослабление и разрушение в апреле. Предполагается, что в 2015 г. восточная фаза КДЦ способствовала ослаблению изначально сильного полярного вихря, в то время как в 2021 г. изначально слабый полярный вихрь благодаря западной фазе имел необычно длительную продолжительность существования.