Unprecedented North American snowstorm and East Asian cold wave in January 2016: Critical role of the Arctic atmospheric circulation

Dong Si¹,2 | Dabang Jiang¹,³ | Xianmei Lang⁴ | Shenming Fu⁴

¹Climate Change Research Center, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China
²Collaborative Innovation Center on Forecast and Evaluation of Meteorological Disasters, Nanjing University of Information Science and Technology, Nanjing, China
³University of Chinese Academy of Sciences, Beijing, China
⁴International Center for Climate and Environment Sciences, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China

Abstract
During January 21–24, 2016, most land areas in the Northern Hemisphere experienced extreme low temperatures. In North America, a historic snowstorm hit the northern and eastern United States. In East Asia, an unprecedented cold wave occurred and led to record-breaking low temperatures in many regions. In this study, observational analyses revealed that both extreme events were triggered by a remarkable change in atmospheric circulation in the Arctic region in early January 2016, which switched from a concentric ring pattern to a dipole pattern. The dipole pattern resulted in two inverted Ω-shaped circulation patterns that dominated the North America and East Asia. The inverted Ω-shaped circulation patterns induced remarkable tropopause folding, which conveyed high-potential-vorticity cold air downwards from the lower stratosphere of Arctic to the middle and lower troposphere of North America, which increased cyclonic vorticity and negative height perturbations, and converged with moist air from the western North Atlantic and Gulf Stream, resulting in a severe snowstorm in the northern and eastern United States from 22 to 24 January. In East Asia, the tropopause folding transported high-potential-vorticity cold air downwards to the middle and lower troposphere of East Asia, resulting in the outbreak of a severe cold wave in East Asia from 21 to 24 January.

KEYWORDS
cold wave, inverted Ω-shaped circulation pattern, potential vorticity, snowstorm, tropopause folding

1 | INTRODUCTION

In the winter of 2015/2016, although the global surface air temperature (SAT) was the warmest on record, two unprecedented cold waves impacted many parts of the Northern Hemisphere from 21 to 24 January 2016, including North America and East Asia. In North America, a snowstorm named Jonas hit the northern and eastern United States from 22 to 24 January 2016, leading to total snow accumulations exceeding 500 mm extending from West Virginia to New York. Many sites in the New York area set all-time records for accumulation...
from a single storm, for example, 770 mm at John F. Kennedy Airport and 710 mm at Newark (WMO, 2017). According to the Northeast Snowfall Impact Scale (NESIS), which is presented to convey a measure of the impact of heavy snowstorms in the Northeast United States (Kocin and Uccellini, 2004), snowstorm Jonas was ranked the fourth most severe on the list of historic snowstorms to affect the Northeast United States (https://www.ncdc.noaa.gov/snow-and-ice/rsi/nesis). These record-setting blizzards and low temperatures caused widespread disruption to power infrastructure and transportation, closure of workplaces and public services, damage to agriculture and human casualties.

Moreover, a cold wave intruded most parts of East Asia and parts of Southeast Asia, leading to record-breaking low temperatures, widespread snow and human casualties (Ma and Zhu, 2019). Snow and sleet were even reported in Guangzhou in southern China for the first time since 1967 and Nanning for the first time since 1983, and the temperature at Hong Kong fell to 3.1°C, the coldest in 59 years (WMO, 2017).

The simultaneous occurrence of the two unprecedented cold events in both the Western and Eastern Hemispheres in late January 2016 naturally raises a scientific question about whether the two cold events were physically driven by the same atmospheric process. If so, what are the mechanisms involved in the North American snowstorm and the East Asian severe cold wave? This study aims to understand why both cold events occurred simultaneously and what mechanisms determined the physical linkages between them.

2 | DATA AND METHODS

We used atmospheric data from the European Centre for Medium-Range Weather Forecasts ERA-Interim reanalysis dataset (Dee et al., 2011) with a temporal resolution of 24 hr, and a horizontal resolution of 1.5 × 1.5°. The variables include the geopotential, temperature, zonal and meridional wind components, vertical p-velocity, 2-m air temperature and specific humidity. The Arctic Oscillation (AO) index, Quasi-Biennial Oscillation (QBO) index, Pacific–North America (PNA) teleconnection index and sea surface temperature (SST) index in the Niño3.4 region (5°S–5°N, 120°–170°W) datasets are obtained from the National Oceanic and Atmospheric Administration (NOAA).

Hoskins et al. (1985) and many other researchers have advocated the construction of isentropic potential vorticity (IPV) analyses to describe dynamical processes within the atmosphere, such as explosive cyclones and fronts (e.g., Davis and Emanuel, 1991; Davies and Rossa, 1998; Deng et al., 2017). This method allows for a quantitative diagnosis of cold air and cold surges, which are generated by adiabatic cooling alone. Assuming frictionless adiabatic motion, cold air masses move with IPV as a conserved variable. Here, we investigate the origin and formation of the North American snowstorm and East Asian cold wave in January 2016 through IPV analysis.

The vertical component of the IPV is computed as follows:

\[ IPV = (\zeta_\theta + f) \left( -\frac{g \partial \theta}{\partial p} \right) \]  

where \( \zeta_\theta \) is the vertical component of the relative vorticity evaluated along isentropic surfaces, \( f \) is the planetary vorticity, \( g \) is the gravitational constant, and \( -\frac{\partial \theta}{\partial p} \) is the static stability. We first interpolated the wind, temperature and humidity to the isentropic surfaces and then computed the IPV according to Equation (1).

3 | RESULTS

The global SAT set a record high in December 2015 among Decembers from 1850 to 2015, and the SAT was above the 1981–2010 average over most of the world’s land areas, especially in the middle and high latitudes of the Eurasian continent and central and eastern North America (Figure 1a). The latitudes at 30°–60°N were 2°C above the 1981–2010 average, but the temperatures in the Arctic were relatively mild. In January 2016, severe cold waves affected the mid-latitudes and subtropical regions of the Northern Hemisphere and resulted in extremely low temperatures and snowfall in North America and East Asia (Figure 1b). The temperature at 30°–60°N dropped to at least 3°C below the 1981–2010 average in January 2016, which in turn caused a sharp warm to cold shift over North America and East Asia between December 2015 and January 2016. As seen in Figure 1c, the SAT over North America fluctuated between anomalously warm and cold from late December 2015 to mid-January 2016, and decreased to 6–11°C below the normal when the snowstorm occurred. Over East Asia, the SAT decreased successively from late December 2015 to mid-January 2016, and decreased to 6–8°C below the normal when the cold wave occurred.

We examined the large-scale atmospheric circulation in the extratropical regions in December 2015 and January 2016. In December 2015, the northern extratropical pattern was characterized by a strong circum-polar high-pressure zone, confining the polar vortex to the North Pole (Figure 2a) and resembling the positive phase of the AO (Figure 2d). These features do not favour
outbreaks of cold air and cold surges over the northern mid-latitudes (Cheung et al., 2012). In January 2016, the polar vortex split into two centres: one centre shifted to East Asia, and the other moved to the Barents–Kara Sea and Greenland. At the same time, ridging was enhanced over Central Asia and western North America (Figure 2b, c). Thus, the northern extratropical circulation underwent a shift from a concentric ring pattern in December 2015 to a dipole pattern in the early and middle January 2016, and maintained throughout the extreme cold period of January 21–24, 2016 (Figure 2b,c). The AO changed from a positive phase in December 2015 to a strongly negative phase in January 2016 (Figure 2d).

Figure 2e shows the height–time cross section of geopotential and zonal wind anomalies averaged over the polar cap. In December, there were distinct negative geopotential anomalies and positive zonal wind anomalies in the stratosphere, indicating a strong stratospheric polar vortex and positive Northern Annular Mode (NAM). Note that the strong anomalous signals propagated downwards from stratosphere to troposphere, which resulted in strong positive AO in the middle and late December. The reason for the positive NAM and strong stratospheric polar vortex in December was attributed to the westerly QBO in preceding autumn. According to the Holton–Tan relationship, the westerly phase of QBO favours southwards propagating of planetary waves from extratropics to equator, which results in a strong stratospheric polar vortex and positive NAM (Holton and Tan, 1980; 1982). Moreover, this relationship is well established in northern autumn (Inoue et al., 2011). Recent study revealed a significant correlation between westerly QBO in autumn and the NAM in early winter, and this correlation reaches the strongest when the QBO leads the NAM by approximate 4 months, and substantially weakens during mid-winter and late winter (Cheung et al., 2016). The QBO index was in the easterly phase from the winter to spring 2015 and changed to westerly phase in the summer 2015 and reached the highest in autumn (Figure 2f). Thus, the westerly phase of QBO in the autumn 2015 favoured the positive NAM and positive phase of AO in the early winter 2015/2016. However, contrary to the downwards propagation of stratospheric signals in December 2015, there was an upwards propagation of signals characterized by negative zonal wind anomalies and positive geopotential anomalies from the lower troposphere in January 2016 (Figure 2e). This upwards propagation of the
tropospheric signals corresponded with upwards Eliassen–Palm wave flux assembling in the upper troposphere, which resulted in an abrupt transition of the AO to the negative phase in January 2016 (Figure 2d). This result is consistent with Cheung et al. (2016), who argued that the stratosphere–troposphere interactions led to the phase transition of AO in late December 2015. Moreover, it can be seen in Figure 2c that the strong negative phase of AO was also associated with the distinct dipole pattern and the splitting polar vortex, which attributed to the rapid establishment of blocking high over the Aleutian and Ural regions in January. Cheung et al. (2016) found that the December–January–February (DJF) El Niño–Southern Oscillation (ENSO) events have a significant time-lagged relationship with the January–February–March NAM, and this relationship is enhanced when the QBO is in the westerly phase. When El Niño event occurs in DJF, the NAM tends to be in the negative phase in the middle and late winter, which contributes to negative phase of AO. The record global high temperature in 2016 was largely attributed to the strong El Niño event in 2015/2016, which matured in DJF 2015/2016. The January SST in Niño3.4 region reached its maximum in 2016 (Figure 3a). The enhanced heating associated
with the El Niño event generated a northeastwards propagation of wave train with two anomalous high pressures over the tropical Pacific and North America–Aleutian regions, and one low pressure in extratropical Pacific in the middle and upper troposphere (Figure 3b), which resembled the Pacific–North America (PNA) pattern. This suggests that the El Niño event can enhance the blocking high over Aleutian–western North America regions through the PNA pattern. The PNA index was slightly negative during the middle and late December 2015 partly due to the downwards propagation of stratospheric signals, while it rapidly increased and changed to positive from the late December (Figure 3c) under the forcing of the El Niño event. The positive PNA pattern substantially reinforced the Aleutian blocking high, which contributed to the occurrence of the dipole pattern and the splitting of tropospheric polar vortex.

Accompanying the occurrence of the dipole pattern, two inverted Ω-shaped circulation patterns moved southwards and dominated the eastern North America–North Atlantic sector and East Asia–North Pacific sector. High-IPV cold air formed within the inverted Ω-shaped circulation pattern, whereas low-IPV air formed outside the inverted Ω-shaped circulation pattern (Figure 4). The inverted Ω-shaped pattern conveyed the high-IPV cold air southwestwards to eastern North America, while a tongue of low-IPV air built over western North America and extended northeastwards to central North America. This feature is referred to an anticyclonic Rossby wave breaking (RWB) event (Thorncroft et al., 1993). According to Equation (1), the IPV can be treated as a combined variable of the absolute vorticity and static stability on an isentropic surface. The static stability is higher in the stratosphere than in the troposphere; thus, the vorticity of the air mass increases when moving from the lower stratosphere to the troposphere. Therefore, when the long tongue of high IPV air moved southwards from the lower stratosphere to the North America in the troposphere, the vorticity increased and the pressure decreased rapidly. On January 22–24, 2016, a wedge-shaped high-IPV cold air mass intruded over the central and eastern United States, which favoured pressure lowering and cyclonic-wind enhancement in the lower troposphere (Figure 4). This led to the occurrence of snowstorm Jonas. Another anticyclonic RWB event can also be seen in the Eastern Hemisphere. The inverted Ω-shaped pattern conveyed the high-IPV cold air southwards to East Asia, which resulted in the East Asian cold wave in January 2016. While a tongue of low-IPV air built rapidly over the Urals and extended northeastwards to Lake Baikal.

Tropopause folding is characterized by the descent of a tongue of stratospheric air into the troposphere and forms a “fold” in the tropopause. Reed (1955) proposed the idea that tropopause folding often contributed to the upper-level frontal zones. Tropopause folding conveys stratospheric cold and high-potential-vorticity air mass downwards to the troposphere (Danielsen, 1968). Previous studies revealed that tropopause folding plays a crucial role in the extratropical cyclones, fronts (Reed, 1955; Uccellini et al., 1985; Fu et al., 2014; 2018) and snowstorm (Richard and Clark, 2003). As seen in Figure 5e–h, the high-IPV air moved southwards from the Arctic region to East Asia and descended towards the middle and lower troposphere, resulting in a pronounced tropopause folding above East Asia. The tropopause folding associated with the inverted Ω-shaped pattern transported the high-IPV cold air downwards to East Asia in

---

**Figure 3** (a) Variation of SST index in Niño3.4 region in January during 1950–2016. (b) The regression of the 500 hPa geopotential (units: 10^2 m^2 s^-2) on the SST index in Niño3.4 region in January during 1981–2010. Values exceeding the 90% confidence level are stippled. (c) The daily PNA index from December 2015 to January 2016.
the troposphere, which resulted in the East Asian cold wave in January 2016. Additional analyses concerning the impact of downstream development process on this cold wave were performed by a recent study (Si et al., 2021). The tropopause folding reached its maximum strength on 23 January; the contour of 1 potential vorticity unit (PVU) approached 700 hPa.

Furthermore, tropopause folding was also observed in North America as a result of the occurrence of the inverted Ω-shaped pattern, which conveyed the
high-IPV air downwards to North America in the middle and lower troposphere (Figure 5a–d). The high-IPV air descended towards the middle and lower troposphere, caused the horizontal contraction of the high-IPV column and increased its cyclonic wind field. The increased cyclonic wind field and negative height perturbations (Davis et al., 1996; Fu et al., 2014; 2018) eventually reinforced snowstorm Jonas. In
addition, the inverted Ω-shaped pattern can distinctly modulate the meridional circulation along eastern North America. Accompanying the tropopause folding above eastern North America, the geopotential height decreased above Southeast United States (between 20°–40°N), while it increased to the north of the folding region (north of 40°N). These features can be clearly seen in Figure 5a–c, which show that the geopotential height and low-IPV increased over Northeast United States and eastern Canada. Consequently, a meridional circulation cell formed, with an ascending branch over Southeast United States and a descending branch over the Northeast United States–eastern Canada sector. This clockwise meridional atmospheric cell conveyed the cold air southwards; moreover, a counterclockwise cell to its south conveyed abundant moisture from the western North Atlantic and Gulf Stream northwards (Figure 6). The cold air and warm moisture converged in the northern and eastern United States, resulting in blizzards over there.

Similarly, a clockwise meridional atmospheric cell also emerged in the East Asia–Siberia sector (Figure 5e–g). The cell increased geopotential height and descending motion over the Siberian region and enormously enhanced the Siberian High, which also contributed to the outbreak of the cold wave (Si et al., 2021). Many previous studies revealed that the enhanced Siberian High favours the occurrence of cold waves (Hao and He, 2017; Ding et al., 2020). However, this meridional circulation cell weakened after 23 January.

4 | CONCLUSIONS

In December 2015, the global SAT set a record-breaking high, with maximum high values over the North American and Eurasian continents. However, an unprecedented snowstorm and cold wave impacted North America and East Asia from 21 to 24 January 2016, resulting in a sharp warm–cold reversal in the Northern Hemisphere. Based on the ERA-Interim reanalysis dataset, this study analysed the causes of the snowstorm in North America and cold wave in East Asia in January 2016. The analysis revealed that both events were closely related to a remarkable change in the atmospheric circulation in the Arctic region. From December 2015 to January 2016, the northern extratropical circulation experienced a distinct change from a concentric ring pattern to a dipole pattern. The AO changed from a positive phase in December 2015 to a strongly negative phase in January 2016.

After the dipole pattern emerged, two inverted Ω-shaped circulation patterns dominated the eastern North America–North Atlantic sector and East Asia–North Pacific sector and caused remarkable tropopause
folding above North America and East Asia. In North America, the tropopause folding associated with the inverted $\Omega$-shaped pattern transported the high-IPV air to North America in the middle and lower troposphere, which converged with the moisture from the western North Atlantic and Gulf Stream and led to the occurrence of snowstorm Jonas. In East Asia, tropopause folding not only conveyed high-IPV cold air masses from the Arctic region downwards to East Asia but also remarkably intensified the Siberian High by exciting a meridional circulation cell, ultimately resulting in the occurrence of a cold wave over East Asia. Our results show robust support for Arctic circulation simultaneously driving extreme snowstorms and cold events in North America and East Asia.

ACKNOWLEDGEMENTS

The authors would like to thank Editor and two anonymous reviewers, whose critical and constructive comments significantly improved this paper. This research is supported by the National Natural Science Foundation of China (41991284 and 41875104) and the National Key Research and Development Program of China (2016YFA0600704).

CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

AUTHOR CONTRIBUTIONS

Dong Si: Conceptualization; formal analysis; methodology; writing-original draft; writing-review & editing.
Dabang Jiang: Conceptualization; formal analysis; methodology; writing-original draft; writing-review & editing.
Xianmei Lang: Formal analysis; writing-original draft; writing-review & editing.
Shenming Fu: Formal analysis; writing-original draft; writing-review & editing.

ORCID

Dong Si https://orcid.org/0000-0001-5541-3759

REFERENCES

Cheung, H.N., Zhou, W., Leung, Y.T., Shun, C.M., Lee, S.M. and Tong, H.W. (2016) A strong phase reversal of the Arctic Oscillation in midwinter 2015/2016: role of the stratospheric polar vortex and tropospheric blocking. *Journal of Geophysical Research: Atmospheres*, 121(22), 13443–13457. https://doi.org/10.1002/2016JD025288.

Cheung, H.N., Zhou, W., Mok, H.Y. and Wu, M.C. (2012) Relationship between Ural–Siberian Blocking and the East Asian winter monsoon in relation to the Arctic Oscillation and the El Niño–Southern Oscillation. *Journal of Climate*, 25(12), 4242–4257. https://doi.org/10.1175/JCLI-D-11-00225.1.

Danielsen, E.F. (1968) Stratospheric–tropospheric exchange based on radioactivity, ozone, and potential vorticity. *Journal of the Atmospheric Sciences*, 25(3), 502–518. https://doi.org/10.1175/1520-0469(1968)025<0502:STEBOR>2.0.CO;2.

Davies, H.C. and Rossa, A.M. (1998) PV frontogenesis and upper-tropospheric fronts. *Monthly Weather Review*, 126(6), 1528–1539. https://doi.org/10.1175/1520-0493(1998)126<1528:PF>2.0.CO;2.

Davis, C.A. and Emanuel, K.A. (1991) Potential vorticity diagnostics of cyclogenesis. *Monthly Weather Review*, 119(8), 1929–1953. https://doi.org/10.1175/1520-0493(1991)119<1929:PVDOC>2.0.CO;2.

Davis, C.A., Grell, E.D. and Shapiro, M.A. (1996) The balanced dynamical nature of a rapidly intensifying oceanic cyclone. *Monthly Weather Review*, 124(1), 3–26. https://doi.org/10.1175/1520-0493(1996)124<0003:TBDNOA>2.0.CO;2.

Dee, D.P., Uppala, S.M., Simmons, A.J., Berrisford, P., Poli, P., Kobayashi, S., Andrae, U., Balsanida, M.A., Balsamo, G., Bauer, P., Bechtold, P., Beljaars, A.C.M., van de Berg, L., Bidlot, J., Bormann, N., Delsol, C., Dragani, R., Fuentes, M., Geer, A.J., Haimberger, L., Healy, S.B., Hersbach, H., Hólm, E.V., Isaksen, L., Kållberg, P., Köhler, M., Matricardi, M., McNally, A.P., Monge-Sanz, B.M., Morcrette, J.-J., Park, B.-K., Peubey, C., de Rosnay, P., Tavolato, C., Thépaut, J.-N. and Vitart, F. (2011) The ERA-Interim reanalysis: configuration and performance of the data assimilation system. *Quarterly Journal of the Royal Meteorological Society*, 137(656), 553–597. https://doi.org/10.1002/qj.828.

Deng, D., Davidson, N.E., Hu, L., Forry, K.J., Hankinson, M.C.N. and Gao, S. (2017) Potential vorticity perspective of vortex structure changes of tropical cyclone Bilis (2006) during a heavy rain event following landfall. *Monthly Weather Review*, 145(5), 1875–1895. https://doi.org/10.1175/MWR-D-16-0276.1.

Ding, T., Gao, H. and Yuan, Y. (2020) The dominant invading paths of extreme cold surges and the invasion probabilities in China. *Atmospheric Science Letters*, 21(9), e982. https://doi.org/10.1002/asl.982.

Fu, S., Sun, J., Li, W. and Zhang, Y. (2018) Investigating the mechanisms associated with the evolutions of twin extratropical cyclones over the Northwest Pacific Ocean in mid-January 2011. *Journal of Geophysical Research: Atmospheres*, 123(8), 4088–4109. https://doi.org/10.1002/2017JD027852.

Fu, S., Sun, J. and Sun, J. (2014) Accelerating two-stage explosive development of an extratropical cyclone over the northwestern Pacific Ocean: a piecewise potential vorticity diagnosis. *Tellus A*, 66(1), 23210. https://doi.org/10.3402/tellusa.v66.23210.

Hao, X. and He, S. (2017) Combined effect of ENSO-like and Atlantic Multidecadal Oscillation SSTAs on the interannual variability of the East Asian winter monsoon. *Journal of Climate*, 30(7), 2697–2716. https://doi.org/10.1175/JCLI-D-16-0118.1.

Holton, J.R. and Tan, H.-C. (1980) The influence of the equatorial quasi-biennial oscillation on the global circulation at 50 mb. *Journal of the Atmospheric Sciences*, 37(10), 2200–2208. https://doi.org/10.1175/1520-0469(1980)037<2200:EQBO>2.0.CO;2.

Holton, J.R. and Tan, H.-C. (1982) The quasi-biennial oscillation in the Northern Hemisphere lower stratosphere. *Journal of the Meteorological Society of Japan*, 60(1), 140–148. https://doi.org/10.2151/jmsj1965.60.1_140.
Hoskins, B.J., McIntyre, M.E. and Robertson, A.W. (1985) On the use and significance of isentropic potential vorticity maps. *Quarterly Journal of the Royal Meteorological Society*, 111(470), 877–946. https://doi.org/10.1002/qj.49711147002.

Inoue, M., Takahashi, M. and Naoe, H. (2011) Relationship between the stratospheric quasi-biennial oscillation and tropospheric circulation in northern autumn. *Journal Geophysical Research: Atmospheres*, 116(D24), D24115. https://doi.org/10.1029/2011JD016040.

Kocin, P.J. and Uccellini, L.W. (2004) A snowfall impact scale derived from northeast storm snowfall distributions. *Bulletin of the American Meteorological Society*, 85(2), 177–194. https://doi.org/10.1175/BAMS-85-2-177.

Ma, S. and Zhu, C. (2019) Extreme cold wave over East Asia in January 2016: a possible response to the larger internal atmospheric variability induced by Arctic warming. *Journal of Climate*, 32(4), 1203–1216. https://doi.org/10.1175/JCLI-D-18-0234.1.

Reed, R.J. (1955) A study of a characteristic type of upper-level frontogenesis. *Journal of Meteorology*, 12(3), 226–237. https://doi.org/10.1175/1520-0469(1955)012<226:ASOACT>2.0.CO;2.

Richard, P.J. and Clark, J.H.E. (2003) The diagnosis of vertical motion within dry intrusions. *Weather and Forecasting*, 18(5), 825–835. https://doi.org/10.1175/1520-0434(2003)018<0825:TDOVMW>2.0.CO;2.

Si, D., Ding, Y. and Jiang, D. (2021) A low-frequency downstream development process leading to the outbreak of a mega-cold wave event in East Asia. *Journal of the Meteorological Society of Japan*, 99(5). https://doi.org/10.2151/jmsj.2021-058.

Thorncroft, C.D., Hoskins, B.J. and McIntyre, M.E. (1993) Two paradigms of baroclinic-wave life-cycle behaviour. *Quarterly Journal of the Royal Meteorological Society*, 119(509), 17–55. https://doi.org/10.1002/qj.49711950903.

Uccellini, L.W., Keyser, D., Brill, K.F. and Wash, C.H. (1985) The Presidents’ Day cyclone of 18–19 February 1979: influence of upstream trough amplification and associated tropopause folding on rapid cyclogenesis. *Monthly Weather Review*, 113(6), 962–988. https://doi.org/10.1175/1520-0493(1985)113<0962:TPDCOF>2.0.CO;2.

WMO. (2017) WMO statement on the state of the global climate in 2016. Geneva: World Meteorological Organization. WMO-No: 1189, 28 pp. Available at: https://library.wmo.int/doc_num.php?explnum_id=3414.

**How to cite this article:** Si, D., Jiang, D., Lang, X., & Fu, S. (2021). Unprecedented North American snowstorm and East Asian cold wave in January 2016: Critical role of the Arctic atmospheric circulation. *Atmospheric Science Letters*, 22(11), e1056. https://doi.org/10.1002/asl.1056