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Polar vortex shape-transition during SSW depending on preceding NAO conditions

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Introduction and Motivation

Sudden stratospheric warming (SSW) characterized by a rapid increase in polar stratospheric temperature and an abrupt decrease in circumpolar westerly wind is accompanied by deformation in the shape of the polar vortex.

Major SSWs are defined when the zonal-mean zonal wind reverses from westerly to easterly at 10 hPa and 60°N during the boreal winter season (October–March).

Central day of the SSW (Day 0) is defined as the first day of wind reversal.

According to the classification devised by Choi et al. (2019), SSW events can be categorized according to vortex behavior: vortex displacement is classified as displacement–displacement (DD) type, while vortex split is classified as either displacement–split (DS) or split–split (SS) type based on the temporal evolution of the polar vortex before (days −10 to −1) and after (days 0 to +10) the occurrence of SSWs. The amplitudes of zonal wavenumbers 1 and 2 of geopotential height (GPH) averaged over 55°N–65°N at 10 hPa are used as the criteria for classification. In the type naming convention, the first and second letters indicate the shape of the polar vortex for waves 1 and 2, respectively, before and after the central day in the stratosphere. For example, for the DS type, D indicates vortex displacement for wave 1, while S indicates vortex split for wave 2.

Reference
Choi, H., Kim, B.M. and Choi, W. (2019) Type classification of sudden stratospheric warming based on pre- and postwarming periods. Journal of Climate, 32, 2349–2367. https://doi.org/10.1175/JCLI-D-18-0223.1.

Introduction and Motivation

Although there have been many studies on the classification of SSW types, the factors involved in determining the vortex breaking type remain unknown, especially for DS type.

SS type, which is characterized by the presence of two separate vortices before the central day, is distinguishable from DD and DS types and is not related to the North Atlantic Oscillation (NAO) phases before the onset.

Here, we show that existence of a polar vortex shape-transition during the course of the SSW life cycle can be attributable to the condition of NAO preceding before onset for DD-type and DS-type SSWs.

Data and Model

Data

- Two reanalysis datasets:
  Daily MERRA (1 Jan. 1979-31 Dec. 2014)/ NCEP-NCAR (1 Jan. 1957-31 Dec. 2014)
- Resolution:
  MERRA: 1000 hPa-0.1 hPa (42 pressure levels)/(lon. x lat.: 1.25° x1.25°)
  NCEP-NCAR: 1000 hPa-10hPa (17 pressure levels)/(lon. x lat.: 2.5° x 2.5°)
- The daily climatological values of each variable calculated based on periods of 1981–2010 for NCEP-NCAR and 1979–2011 for MERRA were smoothed by a 31-day running mean. In this study, all anomaly fields are defined by departure from these climatological means. **The results are insensitive to the dataset.**

Model

- Whole Atmosphere Community Climate Model version 4 (**WACCM4**)/(CESM1.0.6)
- Resolution: Vertical (1000 hPa-0.0001 hPa, 43 Pressure levels)/Horizontal (lon. x lat.: 2.5°x1.9°)
- **Climatological Boundary Condition**: Monthly Hadley Center Sea Ice and Sea Surface Temperature Climatology (1981-2010)
- The model was run for 361 years; **350 boreal winters** from the last 351 years are analyzed.
- We performed **student's two-sided t-test** to check statistical significance.

NAO index

To characterize the strength and phase of the NAO, **two daily NAO indices** are downloaded from two websites. One is NCEP/Climate Prediction Center (CPC). The other index is National Oceanic and Atmospheric Administration (NOAA)/Earth System Research Laboratory (ESRL)/Physical Sciences Division (PSD). Both NAO indices from **1 July 1957 to 30 June 2014** were used. **The modeled NAO index was calculated based on the ESRL/PSD method because of its relative simplicity**.

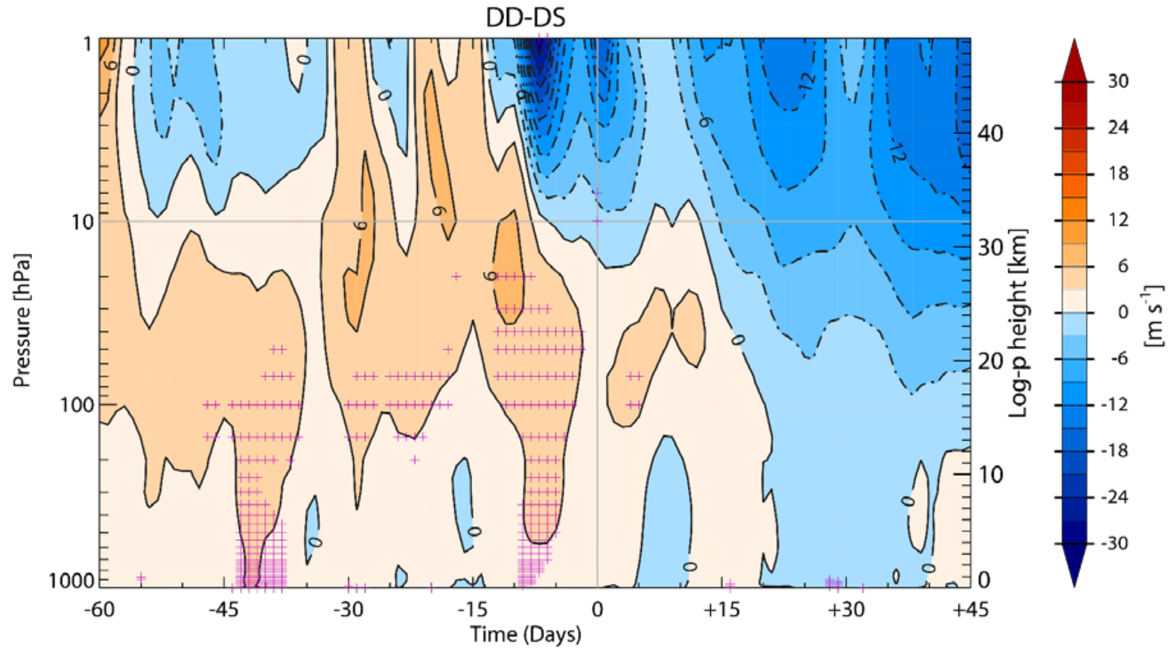
Number of Cases Used for a Composite Analysis

Datasets	DD	DS
MERRA (1979-2014)	13	7
NCEP-NCAR (1957-2014)	20	10
WACCM	123	55

Difference in MERRA Zonal Mean Zonal Wind

50ºN-70ºN (DD minus DS)

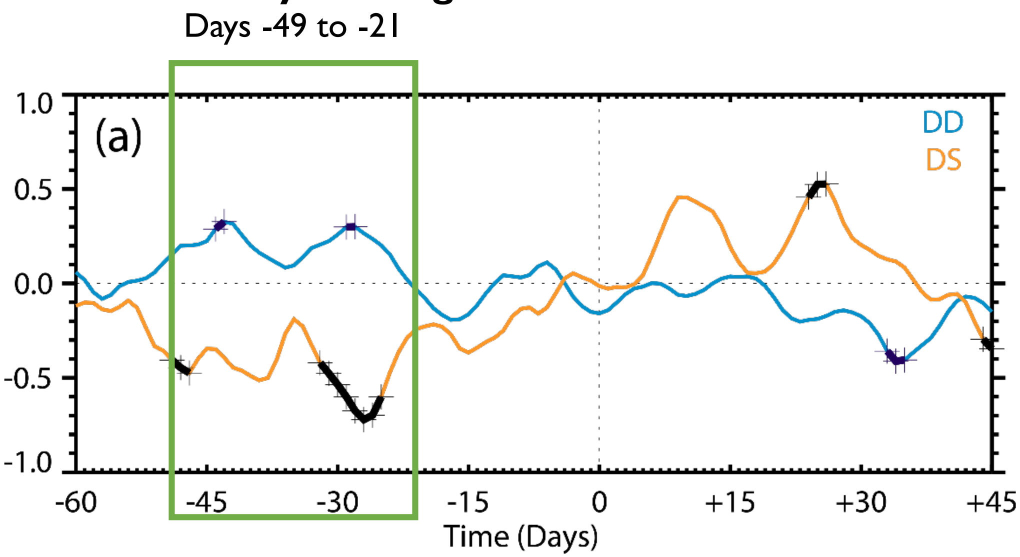
Zonal wind in the high-latitude lower stratosphere between 100 hPa and 80 hPa is significantly **stronger for DD type than for DS type** beginning from a month and a half before the occurrence of the SSW.



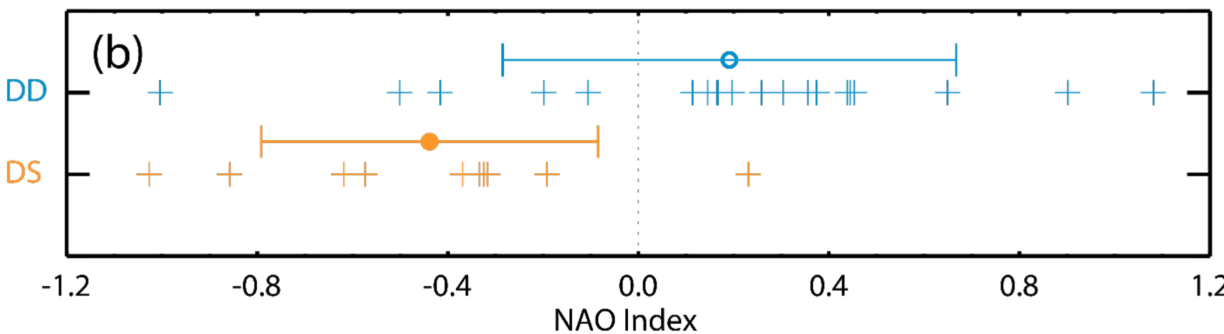
Solid (Dashed-dotted) Contour: Positive (Negative) value
Contour Interval: 3 m s^{-1}
Crosses: 95% Sig.

Distinctive Features in NAO Index Between DD and DS Types

3-day running-mean CPC NAO index



Bold black solid part of each line with crosses: 95% Significant periods



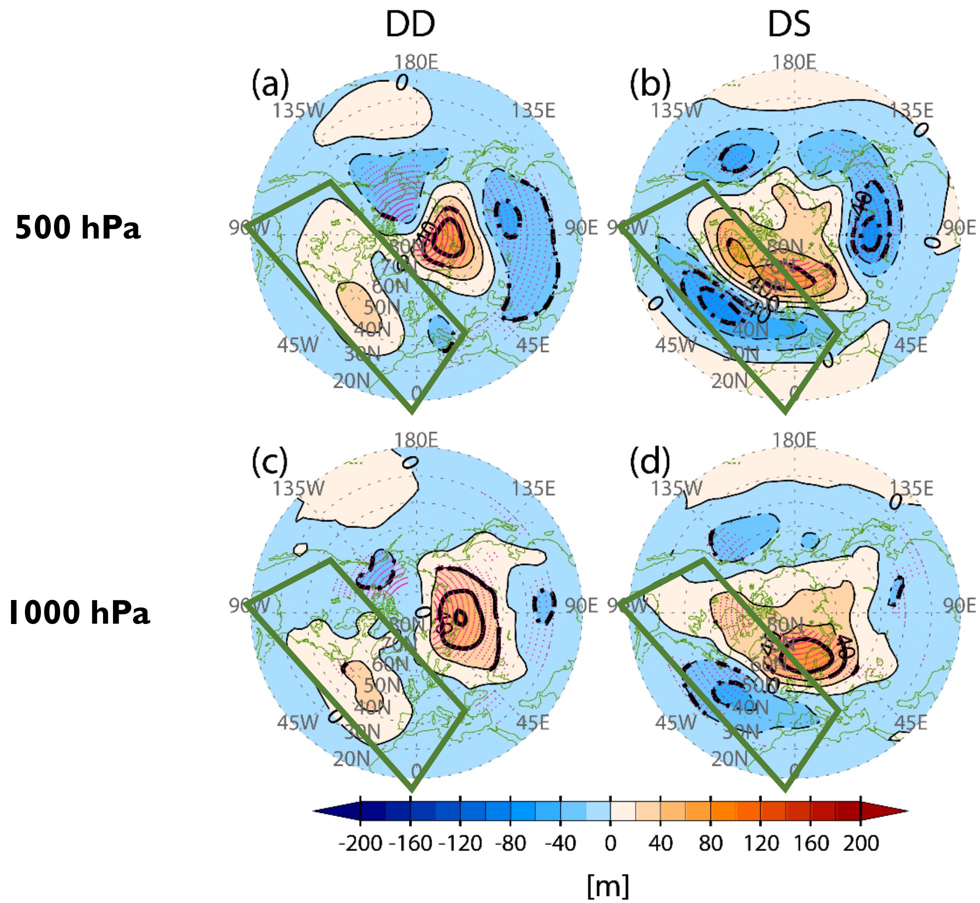
Averaged over days -49 to -21
Closed circle: Mean NAO index
Filled Circle: 95% Significant periods
Error bar: One standard deviation

A **positive NAO phase** preceded **15 DD-type** events out of 20, while a **negative NAO phase** preceded **9 DS-type** events out of 10.

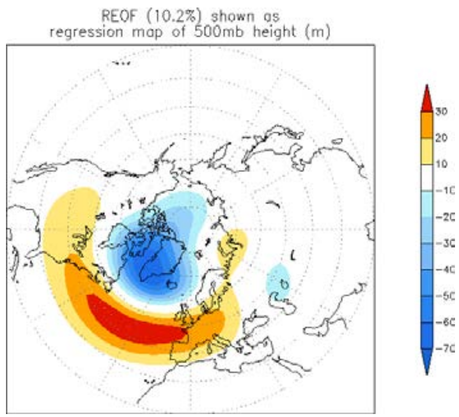
	- NAO	**+ NAO**
DD type	5	15
DS type	9	1

NCEP-NCAR GPH Anomaly

Averaged over Days -49 to -21



+ NAO

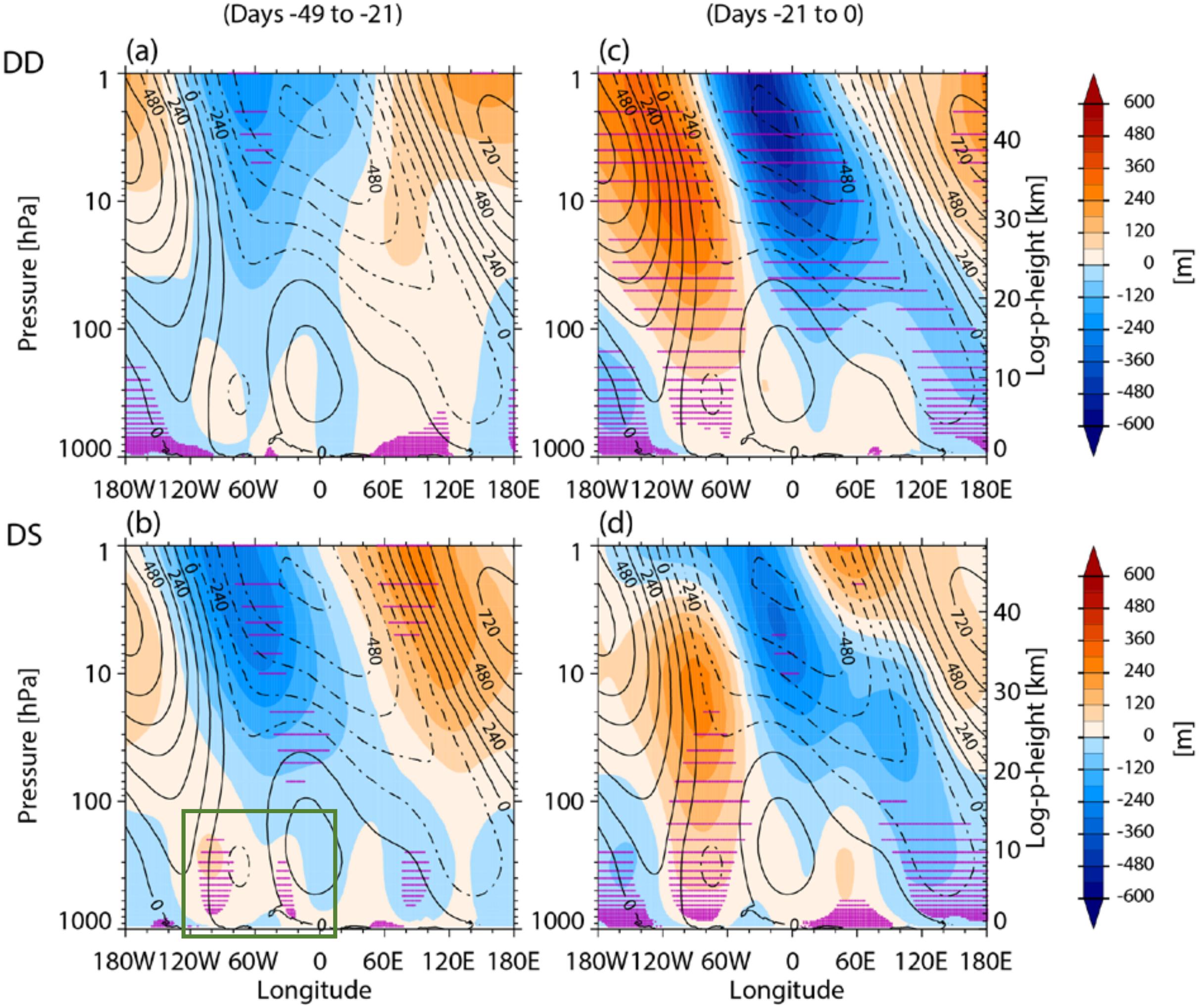


http://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/nao_loading.html

Contour Interval: 20 m
Dashed-dotted Contour: Negative value
Bold contour and Pink dots: 95% Sig.

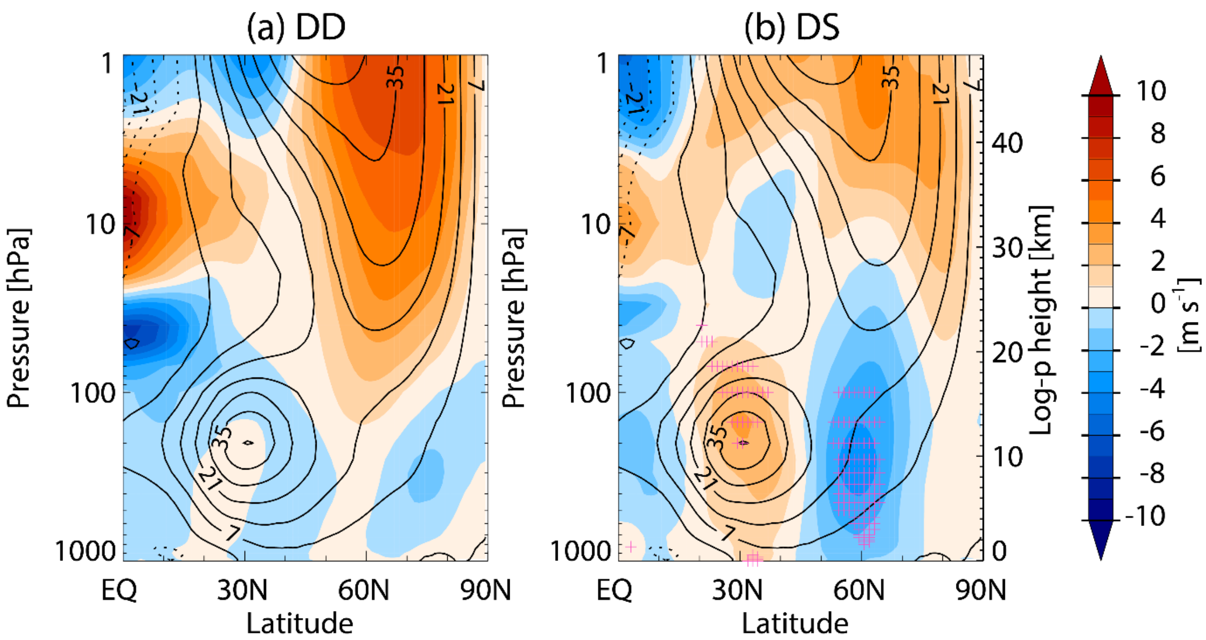
Vertical Structure of Waves

MERRA Zonal-perturbation GPH Anomaly (45ºN-75ºN)



Contour: DJF-mean Climatology Waves (Interval: 120 m)
Dashed-dotted Contour: Negative value
Bold contour and Pink dots: 95% Sig.

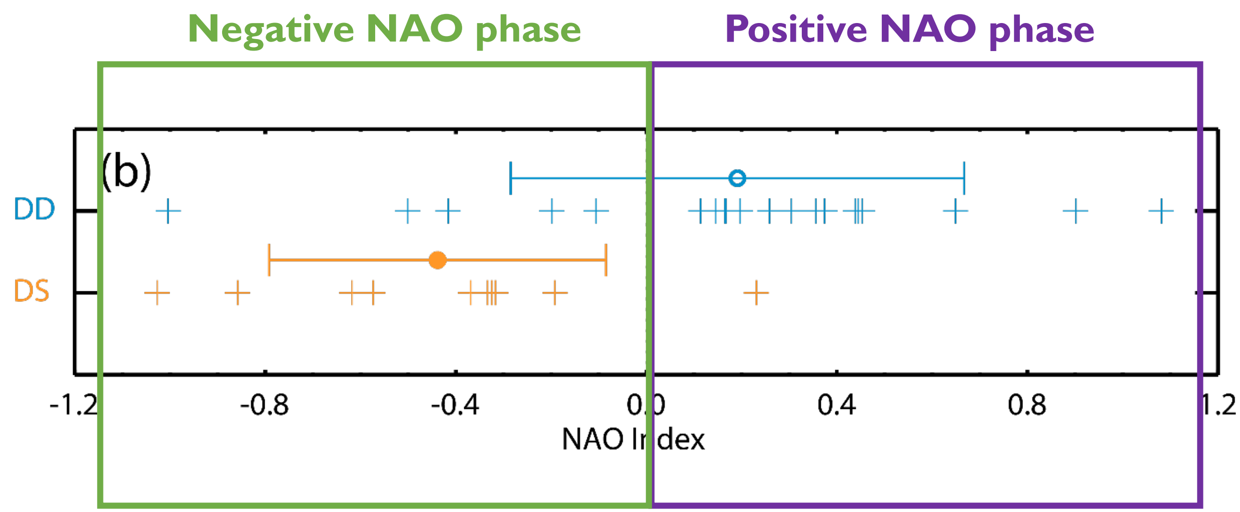
MERRA Zonal-Mean Zonal Wind Anomaly



Zonal-mean zonal wind anomalies (shading) averaged over days -49 to -21 for (a) DD and (b) DS types and climatological DJF mean value (contour) based on MERRA data. Contour interval is 7 m s^{-1}. Crosses indicate the statistically significant region at 95% confidence level.

For DS type, polar vortex weakens significantly from troposphere to the lower stratosphere between days -49 to -21 .

CPC NAO Index Averaged Over Days -49 to -21



Number of each SSW type that occurred during two NAO phases.

	- NAO	+ NAO
DD type	5	15
DS type	9	1

- **Most DD-type SSW** events are preceded by **positive NAO phase** without the type transition.
- SSW events following the **negative NAO phase** have a **strong tendency** to **change their type**.

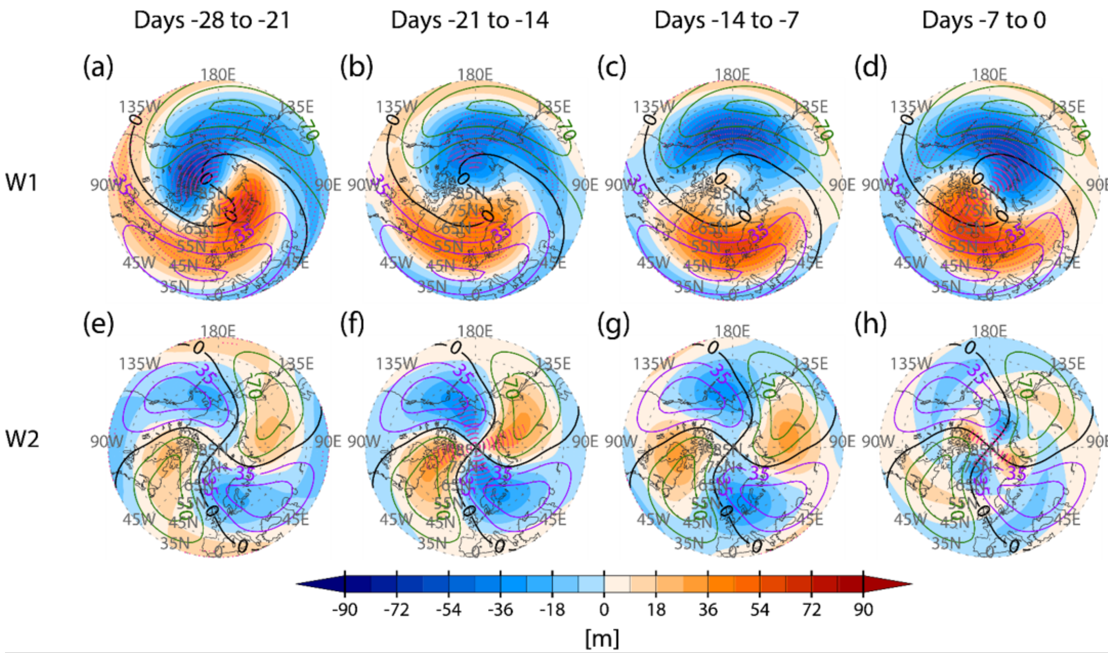
Dependence of SSW Type-Transition on Preceding NAO Conditions

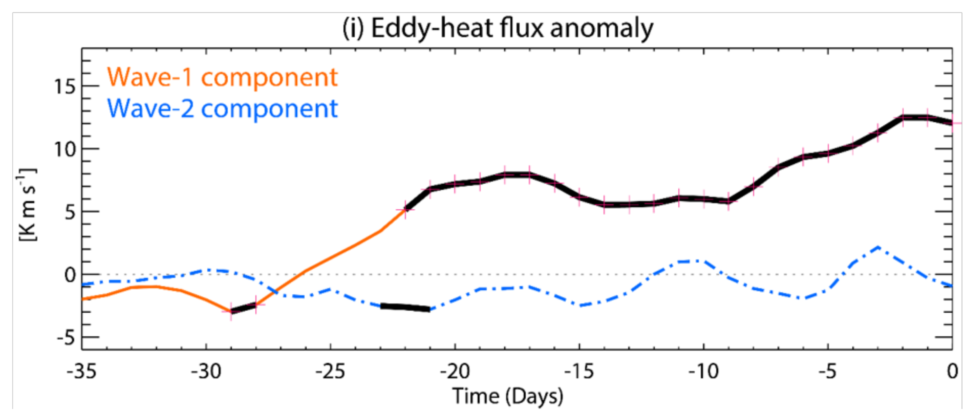
Positive NAO Condition (Based on NAO Index averaged over Days -49 to -21)

15 DD type + 1 DS type

(a)-(h): **GPH anomalies at 500 hPa** averaged over 7 days from days -28 to 0 for DD and DS types following **positive NAO Phase**
Shading: Anomaly (Color interval: 9 m)
Contour: DJF-mean climatological value (Contour interval: 35 m)
Purple and Green Contour: Positive and Negative values
Thick Solid Contour: 0 m
Pink dots: 95% Sig.

(i) Meridional eddy heat flux averaged over 45°N-75°N at 100 hPa for DD and DS types following the **positive NAO phase**
Pink Crosses (Thick solid part): 95% (90%) Sig.





The wave-1 component in the heat flux anomaly begins to increase by approximately day -21 before the central day. However, **the role of the wave-2 component in the heat flux anomaly is marginal throughout the period (i)**.

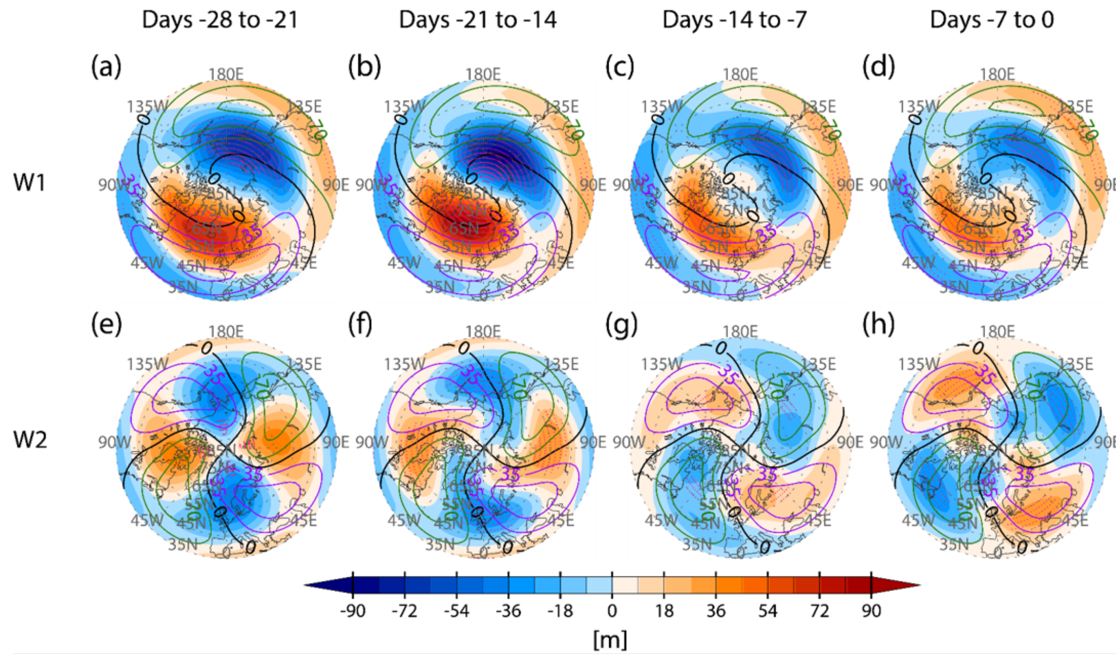
Dependence of SSW Type-Transition on Preceding NAO Conditions

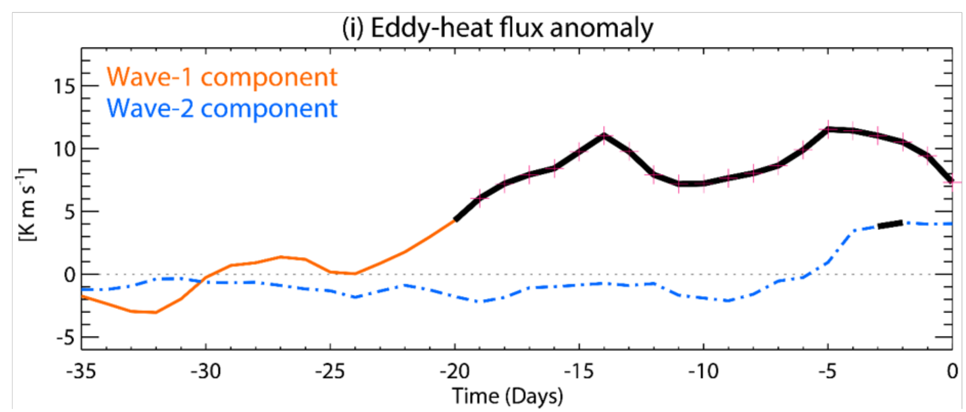
Negative NAO Condition (Based on NAO Index averaged over Days -49 to -21)

5 DD type + 9 DS type

(a)-(h): **GPH anomalies at 500 hPa** averaged over 7 days from days -28 to 0 for DD and DS types following **negatvie NAO Phase**
Shading: Anomaly (Color interval: 9m)
Contour: DJF-mean climatological value (Contour interval: 35 m)
Purple and Green Contour: Positive and Negative values
Thick Solid Contour: 0 m
Pink dots: 95% Sig.

(i) Meridional eddy heat flux averaged over 45oN-75oN at 100 hPa for DD and DS types following the **Negative NAO phase**
Pink Crosses (Thick solid part): 95% (90%) Sig.



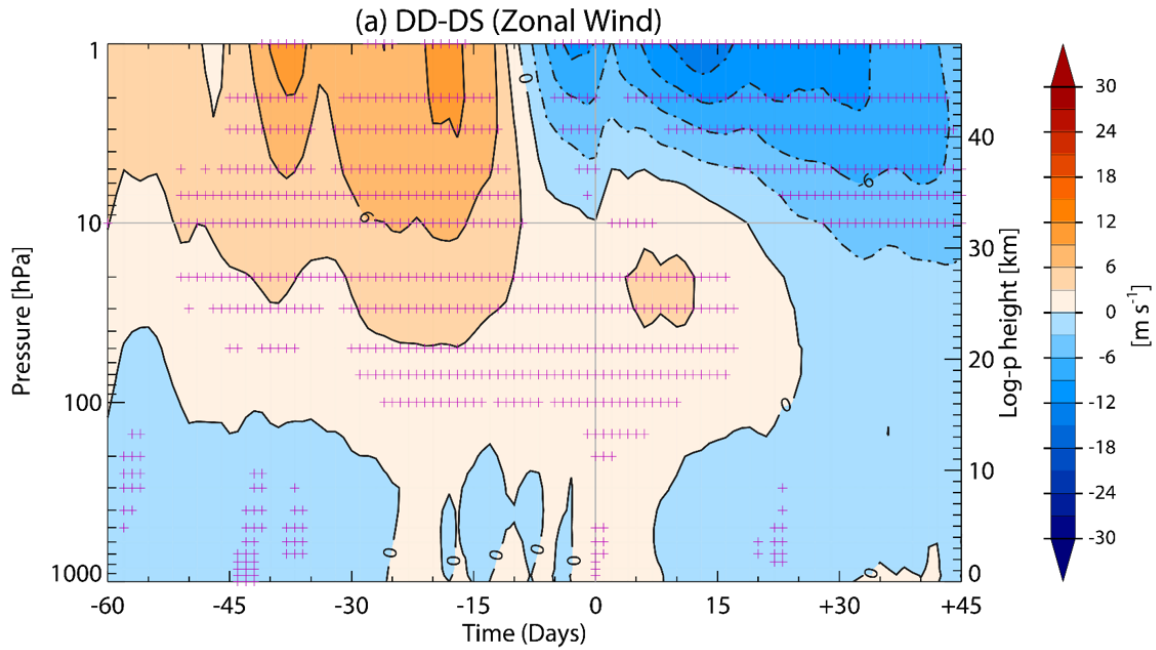


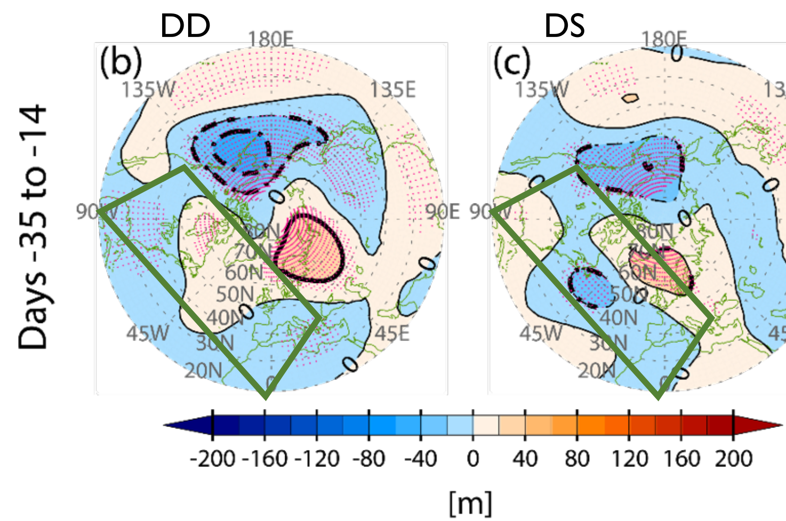
The **wave-2 anomaly is in phase with the climatological wave-2 height**, a few days before the central day **(h)**. This pattern can help **enhance wave-2 height and contribute to increase in the vertical wave flux**, responsible for splitting of stratospheric polar vortex **(i)**.

Model Results

Number of each SSW type that occurred during two NAO phases. NAO index is averaged over days **-35 to -14.**

	DD type	DS type
+NAO	63	19
-NAO	60	36





(a): **WACCM Zonal mean zonal Wind (50°N-70°N)**
Dashed-dotted Contour: Negative value
Contour Interval: 3 m s^{-1}
Crosses: 95% Sig.

(b) and (c):
WACCM GPH Anomaly at 500 hPa
Dashed-dotted Contour: Negative value
Bold contour and Pink dots: 95% Sig.

Summary

SSW type can be distinguished depending on the vortex shape. SSW events preceded by a displacement in polar vortex center are characterized by whether they retain their displaced form (DD type) or split into two vortices (DS type) after onset.

We focus on examining the role of NAO as a precursor for DD- and DS-type SSWs, which account for approximately 80% of total SSW events.

We show that existence of a transition during the course of the SSW life cycle can be attributable to the condition of NAO preceding before onset: Positive NAO favors SSW of DD type with no transition while negative NAO favors the DS type. We show that, in positive NAO precondition, vertical flux of wave activity immediately before onset is mostly contributed only by wavenumber 1 component, which contrasts with the relatively stronger contribution of wavenumber 2 in negative NAO pre-condition.

This study provides probability that the North Atlantic anomaly can induce a favorable condition for the development of small scale waves and lead to the occurrence of SSW type-transition although the mechanism remains uncertain.

Whole Atmosphere Community Climate Model (WACCM) simulation results reproduce well the observational findings.

NAO can be regarded as a useful precursor for determining the type of forthcoming SSW events.

Choi H, Choi W, Kim S-J, Kim B-M. Dependence of sudden stratospheric warming type-transition on preceding North Atlantic Oscillation conditions. Atmos Sci Lett. 2020;e953. https://doi.org/10.1002/asl.953