Reexamination on the type classification of Stratospheric Sudden Warming

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Abstract

During stratospheric sudden warmings (SSW), stratospheric polar vortex is characterized by displaced off the pole toward low-latitude (displacement-type) or split into two vortexes (split-type) by undergoing the distortion and the division due to wave-mean interaction. We find that even though SSW events are identified as split-type, the evolutions can be distinctively different depending on the dominant wave disturbance prior to SSW in the middle stratosphere. Thereby, we classify the split-type SSW into displacement-split type (DS type) and split-type (SS type).

The frequencies of the both split types in the reanalysis data are almost similar and show distinct dynamical features during prewarming phase. In the SS type, the characteristics of the known split-type are more clearly seen. The DS type is rather similar to the displacement-type characteristics prior to the SSW. In the WACCM simulation with climatological surface boundary conditions, however, the number of split-type SSW is much less than that in reanalysis data and we found that this largely due to the inability of WACCM to simulate SS type. Most of the split-type are simulated as DS type, and the incidence rate of SS type to DS type is very low to 0.16 level.

Data and Model

➢ **Data**

- Daily MERRA (1 Jan. 1979-31 Dec. 2014)/ NCEP (1 Jan. 1958-31 Dec. 2014)
  Zonal wind (U), Meridional wind (V), Air temperature (T), Geopotential height (Z), Sea level pressure (SLP)
- 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°)

Climatological values are calculated base on 1 Jan. 1979-31 Dec. 2011 for MERRA and 1. Jan. 1981-31 Dec. 2010 for NCEP. Any anomaly fields are perturbations from their 31-day running-mean climatological values.

➢ **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 experiment is simulated for 211 years. For first 10 years, the output of the model is discarded and 200 boreal winters (October-March) are analyzed.

Results

➢ **Definition of SSW**

During the boreal winter season, the first day when the direction of zonal-mean zonal wind at 60°N and 10 hPa reversal from westerly to easterly is defined as the central date and we consider major SSW to have occurred. To exclude Stratospheric Final Warming (SFW), the central dates have to be appeared at last 10 days before the end of March and recover westerly before the end of March.

➢ **Classification of SSW type**

We determine the dominant shape of polar vortex using a simple Fourier analysis.

The following process conducted for daily between 5 days before and 10 days after the central date for individual SSW event.
1. The geopotential height averaged over 55°N-65°N at 10 hPa is decomposed using Fourier analysis to obtain the amplitudes for zonal wave number 1 and 2. The selected latitude belt is the place where polar jet is located mainly.
2. The number of the dates is counted when the ratio of zonal wave number 2 amplitude to zonal wave number 1 amplitude is more than 1.0
3. If the date is found at least one day, it is classified as split type (S type). Otherwise, it is regarded as displacement type (D type).

Table 1. Number of SSW events for different datasets and types. The numbers in parentheses give the SSW events per year.

Datasets	Total SSWs	D type	S type
MERRA	25 (0.7)	13	12
NCEP-NCAR	37 (0.65)	20	17
WACCM	103 (0.52)	66	37

Features

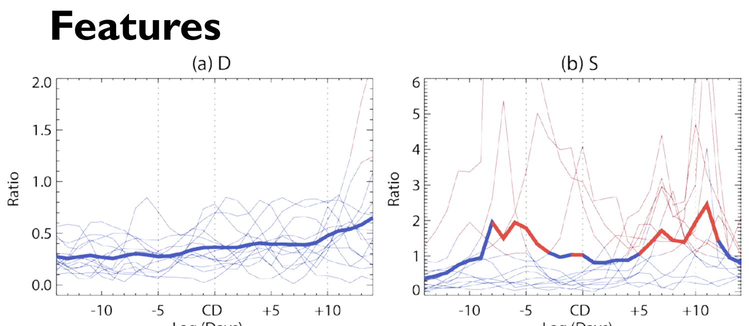

Fig. 1 Temporal evolution of the relative magnitude of wavenumber 2 amplitude for wavenumber 1 amplitude. Thin lines are for individual SSW event and a thick line is for their composite mean. Values of 1.0 or more is indicated in red, and values less than 1.0 is indicated in blue. (a) D type and (b) S type. CD is central date, 0 day. Note the range of the vertical axis is different.

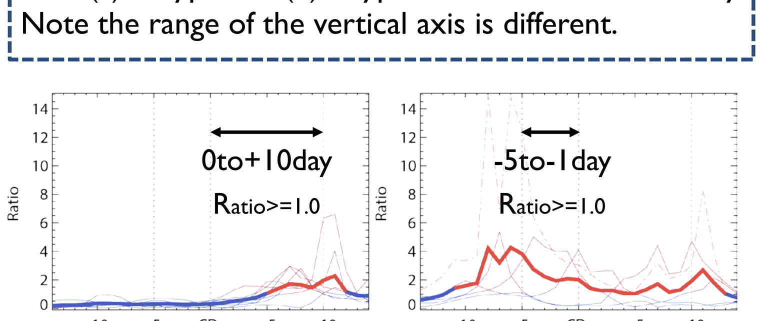

Fig. 2 Same as Fig. 1 but for (a) DS type and (b) SS type. 7 events for DS type and 5 events for SS type. Dashed dotted profile in (b) corresponds to the 24 January 2009 warming event.

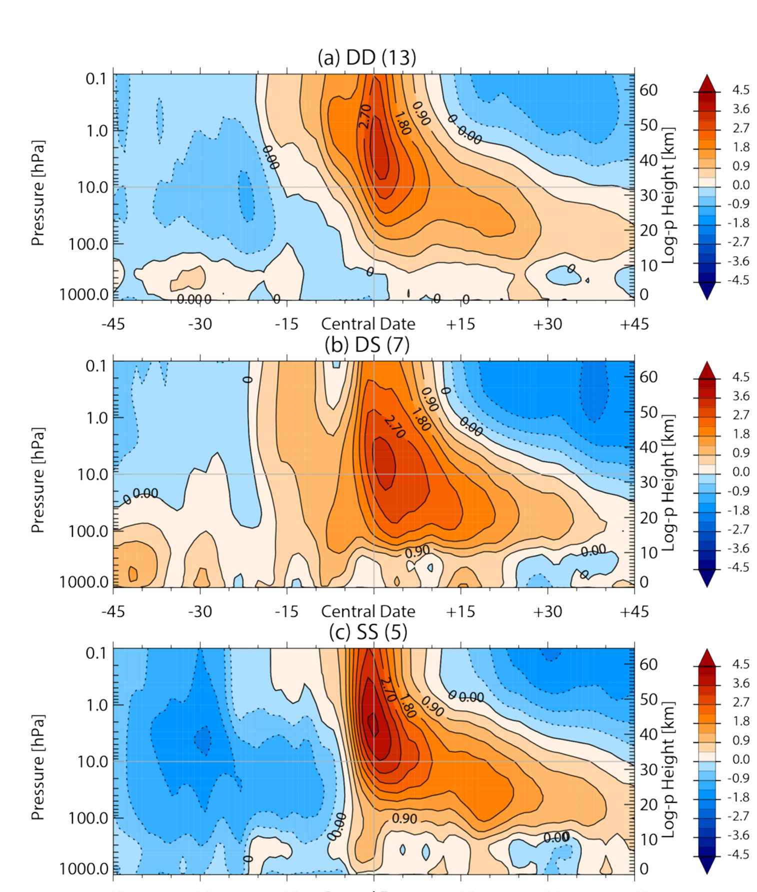

Fig. 3 Composite polar cap height (PCH) anomaly calculated using MERRA geopotential height anomaly averaged over 65°N-90°N. (a) DD type, (b) DS type, and (c) SS type.

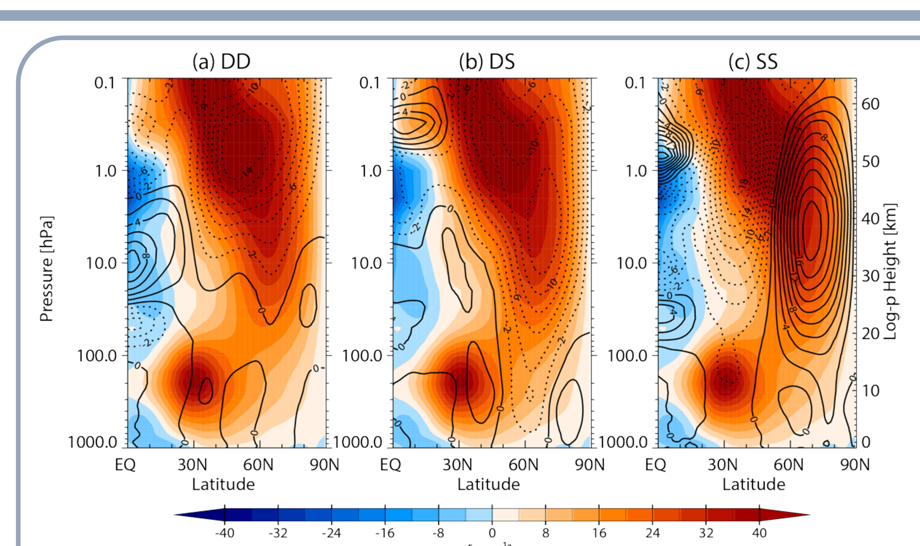

Fig. 4 MERRA time mean zonal mean zonal wind anomaly averaged over -20 to -5 days (contour) and MERRA climatological DJF-mean and zonal-mean zonal wind (shading). (a) DD type, (b) DS type, and (c) SS type. Contour interval is 2 m s^{-1}.

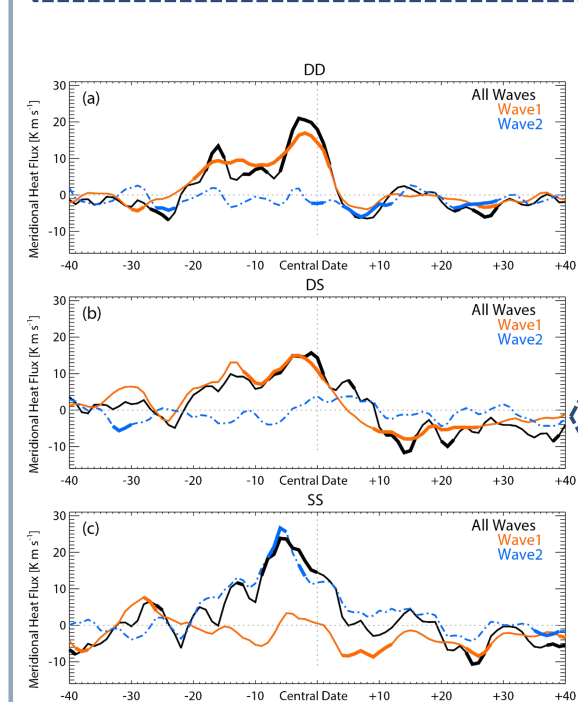

Fig. 5 MERRA composite meridional heat flux anomaly averaged over 45°N-75°N at 100 hPa. Black lines show total anomalous meridional heat flux, orange (blue) lines show anomalous meridional heat flux due to zonal wave number 1 (2). Solid portions of each line show that the anomalous heat flux is significant different from zero at the 0.1 confidence level. (a) DD type, (b) DS type, and (c) SS type.

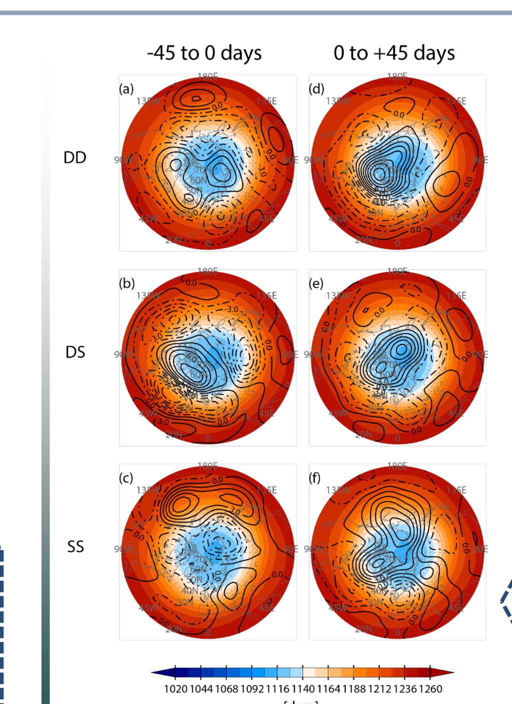

Fig. 6 NCEP composite geopotential height anomaly at 200 hPa (contour) and DJF-mean climatological values of the geopotential height field (shading). Left panels shows features averaged -45 to 0 days prior to events and right panels shows features averaged over 0 to +45 days following events. From top to bottom, DD type, DS type, and SS type. Solid contour indicates positive anomaly and dashed doted contour shows negative anomaly, respectively. Contour interval is 1.5 decameter (dam).

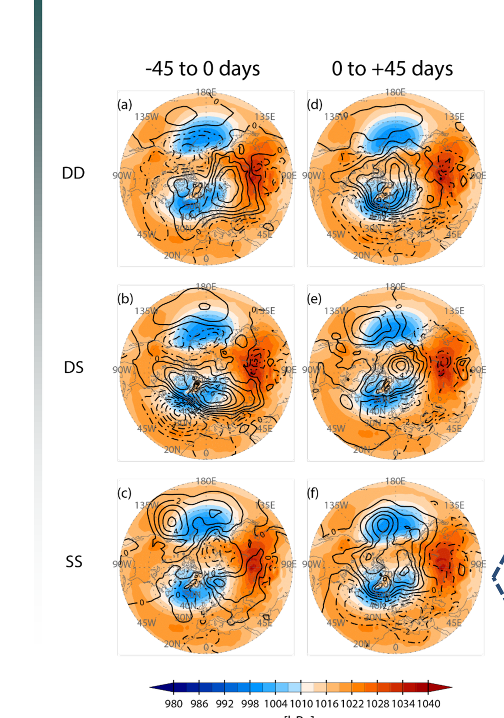

Fig. 7 Same as Fig. 6 but for NCEP sea level pressure (SLP) anomaly. Contour interval is 1.0 hPa.

Model

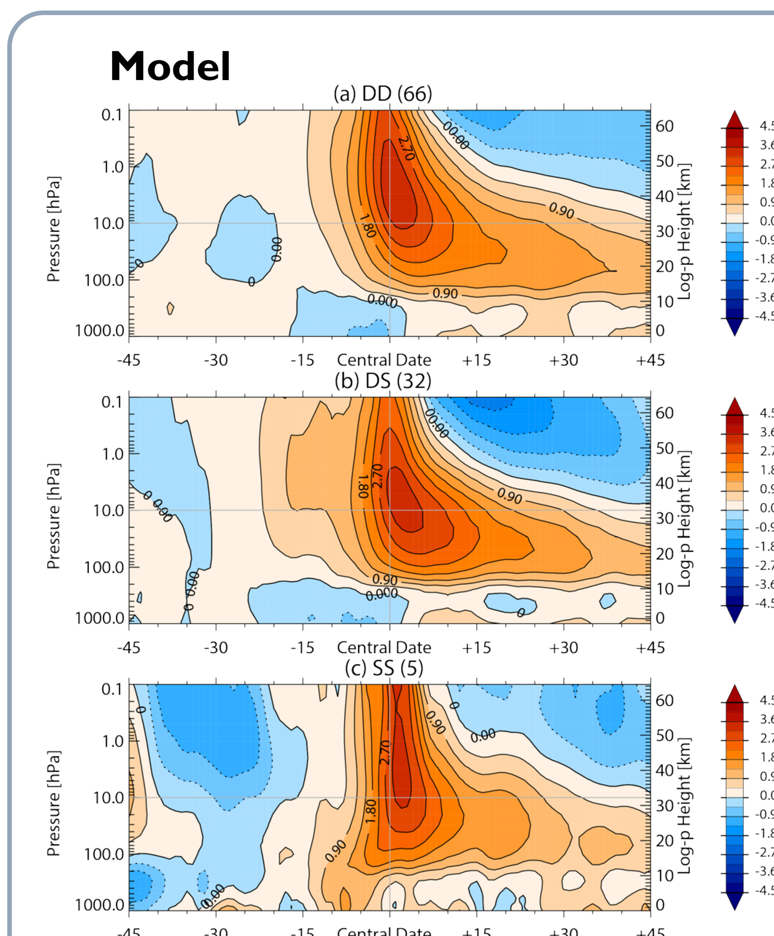

Fig. 8 Same as Fig. 3 but for polar cap height anomaly calculated using WACCM geopotential height anomaly.

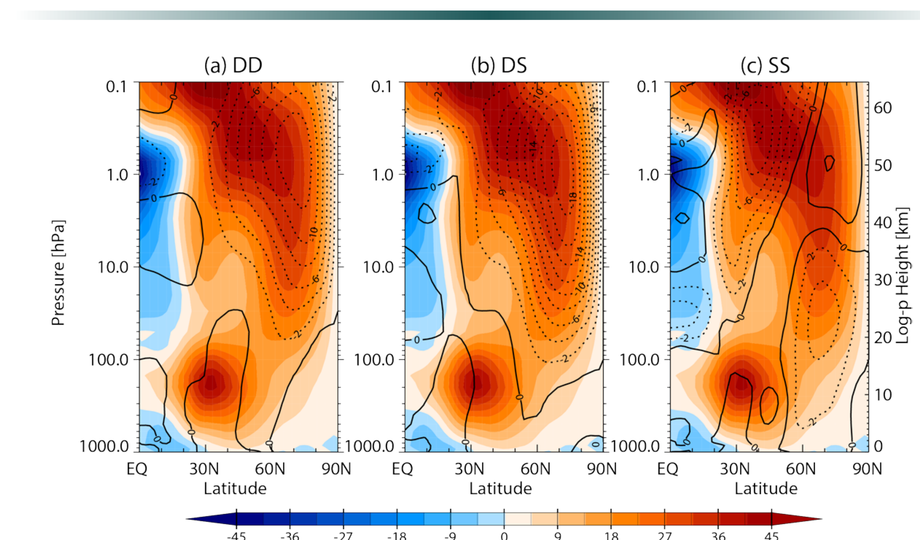

Fig. 9 Same as Fig. 4 but for WACCM zonal-mean zonal wind anomaly.

Summary

- To classify the type of the major SSW events, the dominant shape of polar vortex is identified using Fourier analysis.
- The evolutions in events identified as S type are distinctively different depending on the dominant wave disturbance in the middle stratosphere prior to SSW. Based on these differences, we subclassify the S type into DS type and SS type.
- In the reanalysis data, the incidence of DS type and SS type is almost comparable. DS and SS type show different characteristics in PCH anomaly, zonal wind anomaly, meridional heat flux anomaly, and sea level pressure anomaly before the SSW.
- The results using reanalysis data shows that the characteristics of the previously confirmed S type are more clearly shown in SS type separately. The characteristics of the DS type are generally similar to those of the DD type before the central date.
- We also investigate how model simulate the characteristics depending on the SSW types.
- S type in model only occurs in almost half of DD type. The S type events are mostly simulated in the form of a DS type, and the SS type events are rare.
- The circulation features identified from model for DD and DS type are similar to those seen in reanalysis. The simulated SS types also show some of the characteristics identified in the reanalysis data, but are relatively less clear.