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Type Classification of Sudden Stratospheric Warming Based on Pre- and Post-Warming Periods (JV04p-082)

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Abstract

In existing literature, sudden stratospheric warming (SSW) events have been typically defined as displacement or split types. Detailed reexamination of SSW evolution has revealed that an SSW event often alters its type before and after the central day of the warming event. On the basis of this observation, we objectively define three types of SSW using wave amplitude: displacement–displacement (DD) type, displacement–split (DS) type, and split–split (SS) type. The geopotential height (GPH) amplitude of planetary-scale waves averaged over 55°N–65°N at 10 hPa was used as a criterion for the classification. If the amplitude of zonal wavenumber 1 is larger (smaller) than that of wavenumber 2 before and after the central day of SSW, the event is regarded as a DD (SS) type.

If the amplitude of zonal wavenumber 1 is larger than that of wavenumber 2 before the central day but is smaller after that day, the event is regarded as a DS type. The above classification algorithm has been applied to both reanalysis data and model results. We observe that conventional split-type SSW events identified by previous studies can be categorized as either DS- or SS-type events, each type of which exhibits different evolution characteristics. In particular, they are distinctively different during the pre-warming period. In the SS type, the characteristics of the conventional split type are more obvious, and the features that differ from those of the DD type are the most robust. The model results generally resemble the reanalysis data, particularly in the DD cases.

Data and Model

➢ **Data**

- Daily MERRA (1 Jan. 1979-31 Dec. 2014)/ NCEP-NCAR (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 smoothed by a 31-day running mean are calculated based on 1 Jan. 1979-31 Dec. 2011 for MERRA and 1. Jan. 1981-31 Dec. 2010 for NCEP-NCAR Any anomaly fields are perturbations from these 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

1. Classification of SSW type

To classify the **major SSW events** in this study, we used a common definition based on the **zonal-mean zonal wind at 10 hPa and 60°N** during the boreal winter season (**1 October through 31 March**). A zonal wind reversal from westerly to easterly indicates a major SSW event; the first day of the wind reversal is defined as the **central day (day 0)** of the SSW.

Because zonal waves 1 and 2 develop during displacement-type and split-type SSW events, we began the classification based on the amplitude of planetary waves by using harmonic analysis. The process is described as follows.

a. For a individual SSW event, the **daily geopotential height (GPH) averaged over 55°N-65°N at 10 hPa** was decomposed by harmonic analysis to obtain the amplitudes for zonal wave number 1 and 2.

b. This analysis was conducted for a period of 21 days, from 10 days before the central day to 10 days afterward. **Throughout the 21 days of analysis, if the amplitude of wave 2 was larger than that of wave 1 on any day, the event was regarded as a wave-2 type; otherwise, it was regarded as a wave-1 type.** Although the names "wave 1" and "wave 2" were used temporarily for convenience, these two types are, in fact, very similar to the displacement and split types, respectively.

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

Datasets	Total SSWs	Wave-1 type	Wave-2 type
MERRA	25 (0.7)	13	12
NCEP-NCAR	37 (0.65)	20	17
WACCM	103 (0.52)	64	39

2. Objective definition of the displacement-split type

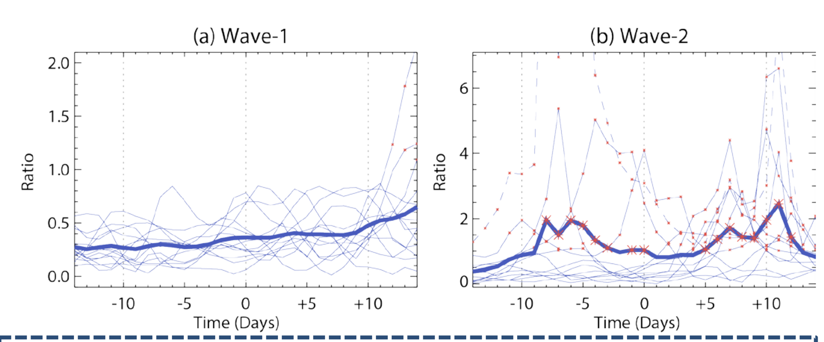

Fig. 1. Temporal evolution of the amplitude ratio of wave 2 to wave 1. Thin lines represent individual SSW events, and the thick line shows their composite mean. Ratios larger than 1.0 are shown with a red asterisk. (a) 13 wave-1 type SSW events; (b) 12 wave-2 type SSW events. The dashed line in (b) corresponds to an SSW event occurring on 24 January 2009 with maximum ratios of 14.9 on day –8 and 8.3 on day +11. It should be noted that the range of the vertical axis is different.

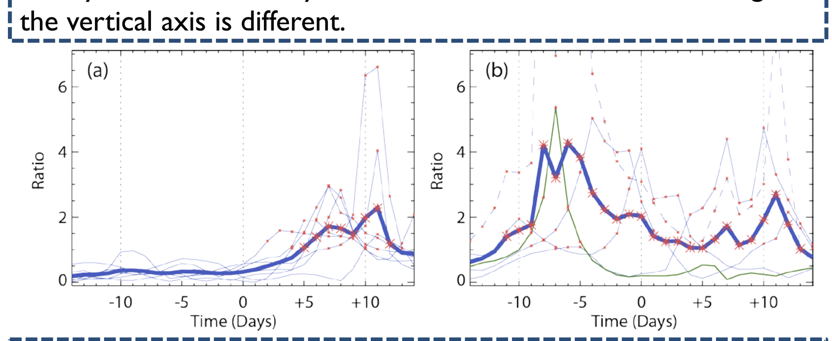

Fig. 2. Same as in Fig. 1 but for (a) 7 DS types and (b) 5 SS types. The dashed line and the green line in (b) correspond to SSW events occurring on 24 January 2009 and on 24 February 2007, respectively.

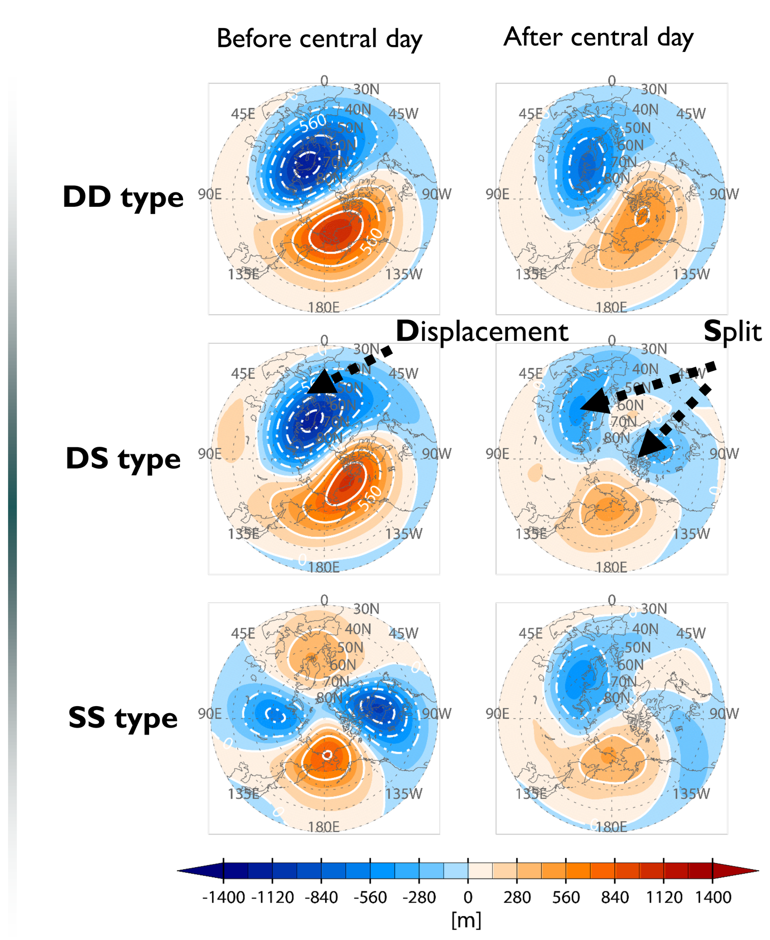

Fig. 3. MERRA Zonal perturbation GPH at 10 hPa on (left) day -5 and (right) day +5. Contour interval is 280 m.

- For wave-1 type shown in Fig. 1a, the ratio is less than one, which implies that the amplitude of wave 2 was relatively small.
- For wave-2 type shown in Fig. 1b, two peaks occurred in the composited ratio. These double peaks imply that some of the SSW events had a large wave 2 either before or after the central day or both.

- The wave-2 types were separated into two groups, as shown in Fig. 2. **Fig. 2a** shows the cases in which a ratio larger than the threshold value of 1 was observed between **day 0 and day +10**, i.e., only after the central day. **Fig. 2b** shows that SSW events had a ratio larger than the threshold value of 1 before the central day (**from –10 to –1**). Based on the temporal evolution of the ratio during the pre-warming and post-warming phases given in Fig. 2, we classified **the SSW events in Fig. 2a as displacement–split (DS) type** and **those in Fig. 2b as split–split (SS) type.** In the name of each type, the first and second characters represent both the dominant wavenumber and the shape of the polar vortex before and after the central day. **D represents wave 1 and vortex displacement, and S denotes the wave 2 and vortex split.** As shown in **Fig. 1a**, wave 1 persisted both before and after the central day and was classified as **displacement–displacement (DD) type** by applying the same naming scheme.

- Fig. 3 can be confirmed that the number of the wave between the dominant planetary waves 1 and 2 is consistent with the shape of the polar vortex.

3. Characteristic feature of the three SSW types

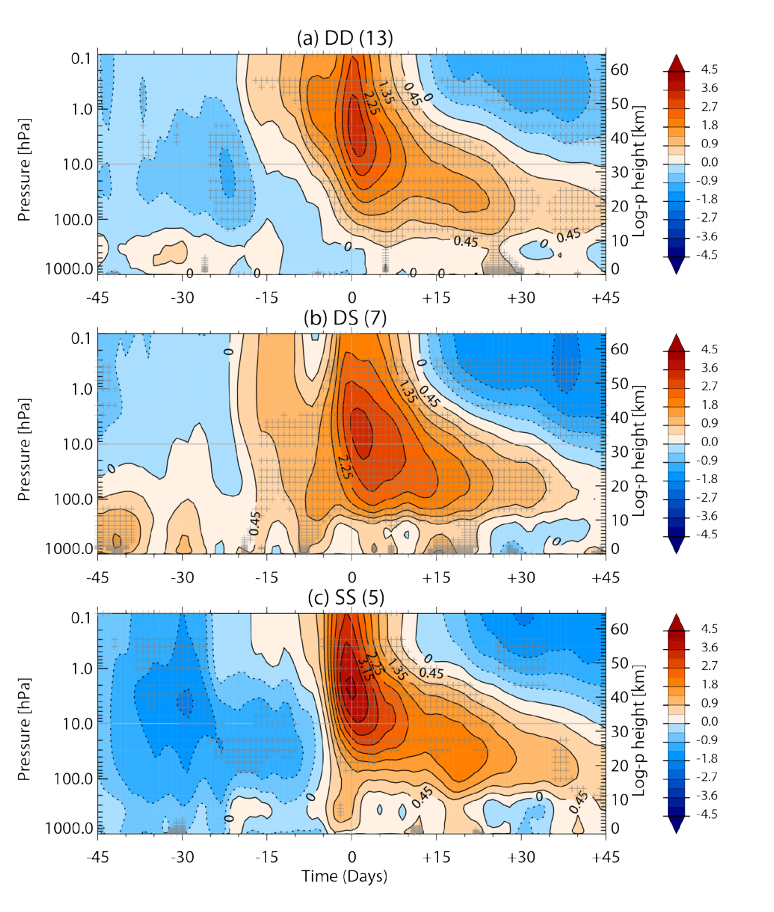

Fig. 4. Polar cap height (PCH) anomaly based on the MERRA GPH anomaly averaged over 65°N–90°N for (a) 13 DD events, (b) 7 DS events, and (c) 5 SS events of SSW. Crosses indicate statistically significant regions at the 90% confidence level.

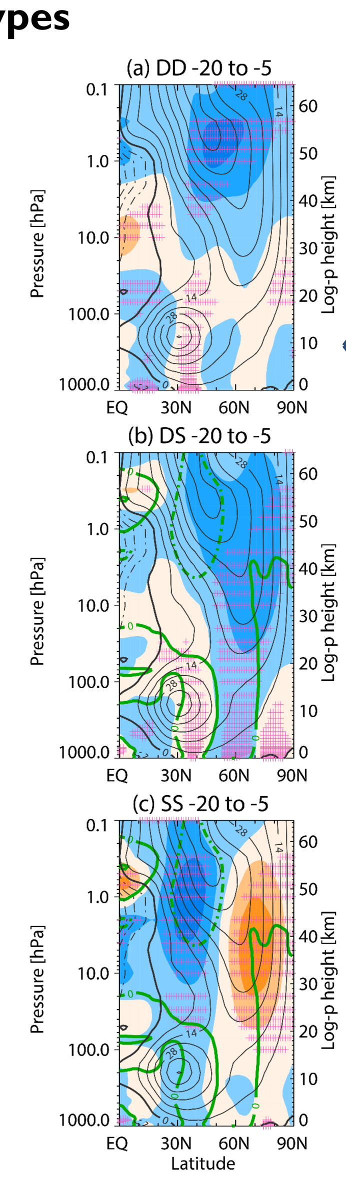

Fig. 5. Zonal-mean zonal wind anomaly (shading) and climatological December–February (DJF) mean and zonal-mean zonal wind (contours) based on MERRA data. The results from top to bottom are shown for DD, DS, and SS types, respectively, averaged over days -20 to -5, The bold solid and dashed–dotted contours denote zero and negative wind speeds. The contour and shading intervals are 7 m s^{-1}. Crosses indicate the statistically significant region at the 90% confidence level. The green contour in Figs. 5b and 5c shows the wind anomaly using the combined DS+SS type.

- Conventional split type which is a combination of DS and SS type (green contour) does not share similarities with either DS or SS anomalies. Thus the separation of the conventional split types into DS and SS types has been validated.

- We also evaluated the different characteristics in upward-propagating wave activity and a tropospheric height field (not shown) prior to the central day of the SSW. The DS and SS types exhibited similar wave-2 behavior only close to the central day. Previous studies describing the split type appear to preferentially represent the feature of the SS type.

- Although the DD and DS types appear to be similar the mechanism of the wave 1 change to wave 2 for the DS type remains unknown and will be examined in future research.

4. Model

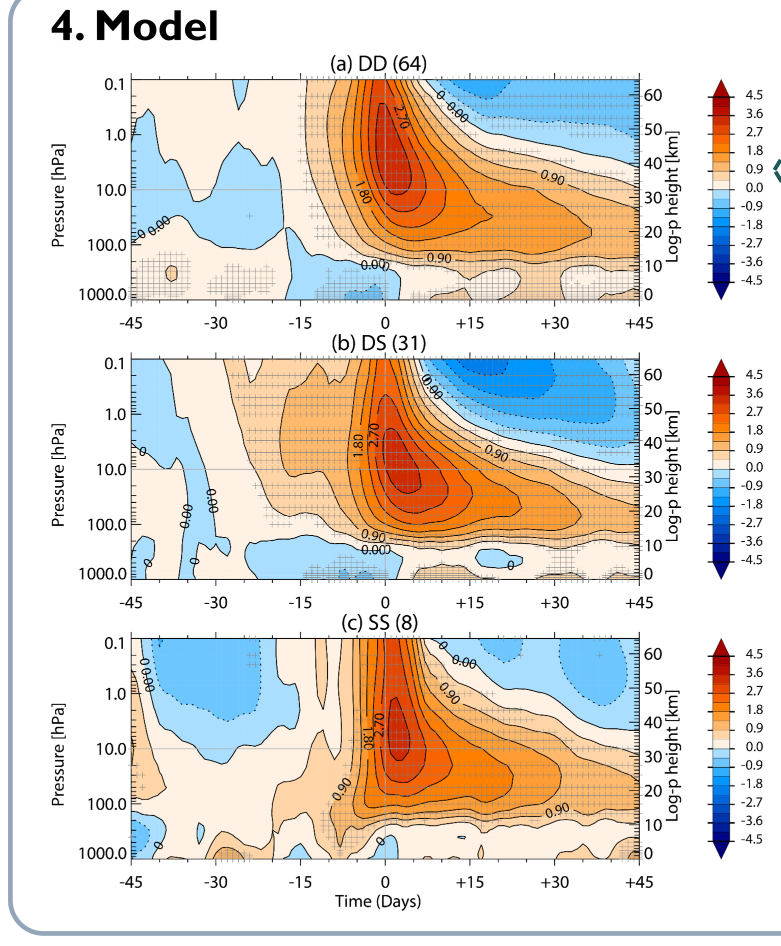

Fig. 6. Same as Fig. 4 but for the PCH anomaly calculated by using the WACCM results for (a) 64 DD types, (b) 31 DS types, and (c) 8 SS types.

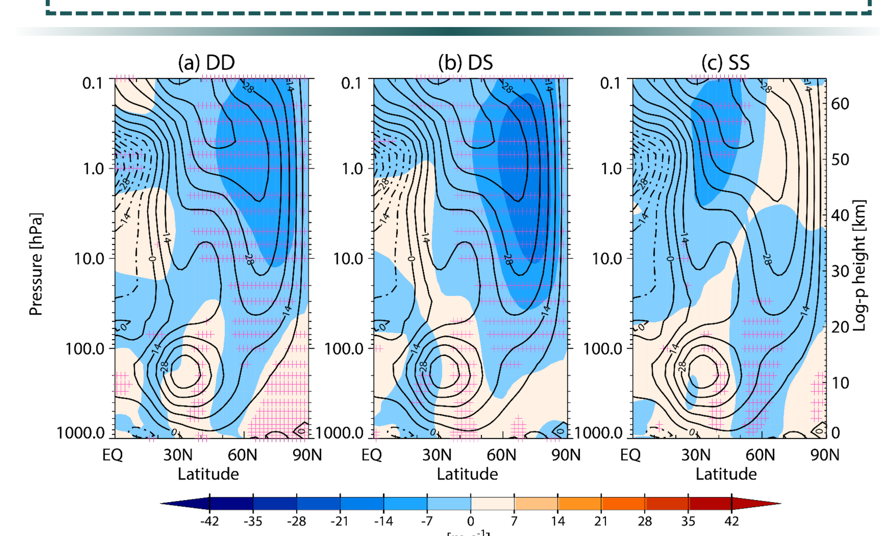

Fig. 7. Same as Figs. 5 but for WACCM data.

4. Model (*Continued*)

- The split type in the WACCM occurred less frequently than the displacement type. Because the split type is simulated mostly in the form of the DS type in the model, the lower frequency of the split type can be attributed to the lack of SS-type simulations.
- The characteristic features reproduced by the model for DD and DS types were similar to those shown in the reanalysis data, whereas the observed and simulated SS types shared fewer similarities.