Predictability of the Stratospheric Polar Vortex Breakdown

An Ensemble Reforecast Experiment for the Splitting Event in January 2009

Shunsuke Noguchi1#, Hitoshi Mukougawa2
Yuhji Kuroda1, Ryo Mizuta1, Shoukichi Yabu3, Hiromasa Yoshimura1

1) Meteorological Research Institute, Japan
2) Kyoto University, Japan
3) Japan Meteorological Agency, Japan

From Noguchi et al. (2016, JGR) #: noguchi@mri-jma.go.jp
Outline

• Ensemble forecast experiment for a **split-type SSW** (Stratospheric Sudden Warming) **occurred in January 2009**

• **Sudden change of forecast skills** during this event

• **Composite analysis** to reveal what process contributes to such rapid time variation of the predictability

• **Summary**

Three dimensional evolution of vertically weighted potential vorticity (as in Matthewman et al. 2009) during the period from 5 Jan to Feb 5 2009 (↑)
SSW occurred in January 2009

- One of the most dramatic SSWs
  - The strongest & most prolonged on record
  - Rapid & clear breakdown

- Clear features of this event attract many attentions:
  - Details of the onset process, Influence on the upper layers
  - Forecast skills

---

**Temperature @ NP 10hPa [K]**

- ~ 70 K
- ~ 5 days

**Zonal–mean zonal wind @ 60N 10hPa [m s⁻¹]**

- Central Date: 24 Jan
Purpose, Strategy and Situation

• Clarify the predictable period of the vortex splitting
• Reveal what process determines the predictability

To fully examine the time variation of predictability related to the rapid vortex-splitting evolution, we conduct densely initialized ensemble forecasts by using AGCM with almost operational settings.

• Previous forecast studies on the splitting-type SSW gave only a “rough sketch” of the flow dependent predictability using sparsely initialized hindcast data (e.g. initialized only 3 times in one month)
Experimental Setup

• **Model:** MRI-AGCM  
  - Global spectral model whose fundamental part is common to the JMA operational NWP model

<table>
<thead>
<tr>
<th>Resolution</th>
<th>TL159 ($\Delta \sim 110$ km)</th>
<th>L60 (Top: 0.1 hPa, Hybrid coordinate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SST</td>
<td>Initial anomaly + Climatology</td>
<td></td>
</tr>
<tr>
<td>Ozone</td>
<td>Zonal-mean climatology</td>
<td></td>
</tr>
</tbody>
</table>

• **Ensemble Forecast System:** MRI-EPS  
  - Port (\& Ext) ver. of the JMA operational 1-m forecast system

<table>
<thead>
<tr>
<th>Perturb. Method</th>
<th>Breeding of Growing Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Condition (25 members)</td>
<td>1 Control run (from ERA-Interim) 24 Perturbed runs (ERA-I ± ptb {#1-12})</td>
</tr>
</tbody>
</table>
Experimental Setup (Cont.)

- **Initialization date**: Everyday
  
  - 60-day ensemble predictions are initialized Everyday (12UTC) from 1 to 30 January 2009
Overview of the Forecast Results

- **Ensemble mean** of forecasts initialized after **Day-6** reproduces the wind reversal.
- **Ensemble spread** of forecasts initialized just before **Day-6** shows large value after the wind reversal date.

![Diagram showing wind reversal over time](image)
Overview of the Forecast Results

- **Ensemble mean** of forecasts initialized after **Day-6** reproduces the wind reversal
- **Ensemble spread** of forecasts initialized just before **Day-6** shows large value after the wind reversal date
Composite Analysis

- Focus on forecasts initialized at **Day -8 & -7** (16 & 17 Jan)
- Make composite groups:
  - Classify ens. members into **major/minor SSW groups** if predicted U (10 hPa) value during a peak period of easterly (29-31 Jan) is **smaller/larger** than average of these forecasts ± one standard deviation.
Composite Analysis

- Focus on forecasts initialized at **Day -8 & -7** (16 & 17 Jan)

- Make composite groups:
  - Classify ens. members into **major/minor SSW** groups if predicted U (10 hPa) value during a peak period of easterly (29-31 Jan) is **smaller/larger** than average of these forecasts ± one standard deviation.

- This corresponds to whether the vortex is **splitting** or not:

  - Period (i): 18–20 Jan
  - Period (ii): 21–23 Jan
  - Period (iii): 24–26 Jan
  - Period (iv): 27–29 Jan

Spaghetti diagrams of the vortex edge (isolines of PV at 850 K) for 3-day-mean fields...
Meridional cross section of each composite:

Major (Splitting)

- Wind-deceleration region moves poleward & downward

**Wind-deceleration region moves poleward & downward**

(i) 18–20 Jan  
(ii) 21–23 Jan  
(iii) 24–26 Jan  
(iv) 27–29 Jan

Minor (Reflection)

- Wind-acceleration region appears in high latitude
- Wave activities propagate downward

(i) 18–20 Jan  
(ii) 21–23 Jan  
(iii) 24–26 Jan  
(iv) 27–29 Jan
• Longitude-height cross section of each composite:

**Major (Splitting)**

- (a) 18–20 Jan

→ Strong upward prop. from BH over Alaska (with westward phase-tilt with height)

**Minor (Reflection)**

- (d) 18–20 Jan

→ 2nd upward prop. over Eurasia → New ridge at WP & eastward phase-tilt

- (iii)

→ Westward shift of the lower part of Pacific ridge $\cong \text{ EPFz }$↓

**Z eddy (60N-70N)**

- Plumb’s Fx & Fz (60N-70N)

- $[m^2 s^{-2} Pa^{-0.5}]$

- Z & Z eddy @ 500hPa
Significant difference before the westward shift:
- Wind deceleration over Europe (**weaker** in the minor group)

(ii) Difference (Major-Minor) of Zonal wind (50N-70N)
(b) 21–23 Jan (diff)

Zonal wind (50N-70N) of Major and Minor composite
(b) 21–23 Jan (major & minor)

This affects local wave propagation properties
- Wave packets (absorbed there in the major SSW group) is reflected or refracted in the minor SSW group
- Local downward prop. of wave packets over Siberia contributes to shift the pre-existing ridge (B) further westward as shown in Kodera et al. (2008, 2013)
• Significant difference at period (i) (just after the initialization):
  - Upward prop. in the downstream of the blocking over Alaska (slightly **weaker** in the minor SSW group)
  - This in turn produces weaker deceleration of upper stratospheric zonal wind over Europe during the subsequent period

Although the predicted difference of zonal wind in the upper stratosphere would be attributed to the difference in the firstly incoming wave activity from the troposphere, the induced difference in zonal wind in the upper stratosphere just before the splitting decisively controls the propagating property subsequently incoming wave activity...

**Stratospheric condition plays an important role for the successful prediction of SSW!**
Schematic illustration of the possible interpretation: Error growth process via prop. of wave-packets

(i) Major (Splitting)

(ii) (ii-major) 21 Jan -

(iii) (iii-major) 24 Jan -

(iii-minor) 24 Jan -

(Atlantic-Europe) (Siberia-Pacific)

(Atlantic-Europe) (Siberia-Pacific)
Summary

• Sudden change of the predictability during a typical vortex-splitting event in January 2009 is observed about one week before the wind reversal.

• Stratospheric planetary waves are reflected back into the troposphere for failed forecasts, whereas they are absorbed within the stratosphere for succeeded forecasts.

• Stratospheric flow condition would be another important control factor for the prediction of SSW, besides the anomalous upward propagation of planetary waves from the troposphere.
Backups
• Predicted vortex shape at **Day 0** (24 January 2009): 

Spaghetti diagrams of the vortex edge [isolines of PV at 850 K (~ 10 hPa)]

—: ERA-Interim  —: Ensemble runs  

Cf. Matthewman et al. (2009)
• Time-height cross section of each composite:

**Major (Splitting)**
- 2\textsuperscript{nd} peak of upward wave-activity fluxes
  (Consistent with Harada et al. 2010)
- Deceleration lasts, easterly region propagates downward

**Minor (Reflection)**
- No 2\textsuperscript{nd} positive peak, rather negative peak
- Deceleration stops at the upper stratosphere

![Composite of 10 major runs](image1)

![Composite of 10 minor runs](image2)

Period: (i) (ii) (iii)

• How does such a contrasting phenomenon occur?