Predictability of Sudden Stratospheric Warmings in sub-seasonal forecast models

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Polar stratospheric vortex and its disruptions (SSWs)

Break downs of the vortex occur during Sudden Stratospheric Warmings (SSWs)

Polar vortex surrounded by westerly polar night jet is a normal state of the wintertime Arctic stratosphere.
Many SSWs are followed by anomalies in surface weather lasting for up to two months:

- Negative phase of the North Atlantic Oscillation
- Cold spells across northern Eurasia and eastern US
- Precipitation anomalies over Atlantic and western Europe

SSWs provide source of enhanced subseasonal predictability
Various studies suggest various predictability limits for various SSW events.

Table 1. Quantification of the predictability of SSW events obtained from a range of studies.

<table>
<thead>
<tr>
<th>Year</th>
<th>Model</th>
<th>Event (SSW)</th>
<th>Predictability</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>GFDL GCM</td>
<td>March 1965</td>
<td>2 days (captured only tendency)</td>
<td>Miyakoda et al. (1970)</td>
</tr>
<tr>
<td>1983</td>
<td>ECMWF</td>
<td>February 1979</td>
<td>10 days</td>
<td>Simmons and Strüting (1983)</td>
</tr>
<tr>
<td>1985</td>
<td>UCLA GCM</td>
<td>February 1979</td>
<td>5 days</td>
<td>Mechoso et al. (1985)</td>
</tr>
<tr>
<td>2005</td>
<td>ECMWF</td>
<td>September 2002 (Antarctic)</td>
<td>7 days</td>
<td>Simmons et al. (2005)</td>
</tr>
<tr>
<td>2005</td>
<td>JMA NWP</td>
<td>December 2001</td>
<td>14 days</td>
<td>Mukongwa et al. (2005)</td>
</tr>
<tr>
<td>2006</td>
<td>NOGAPS-ALPHA</td>
<td>September 2002 (Antarctic)</td>
<td>5 days</td>
<td>Allen et al. (2006)</td>
</tr>
<tr>
<td>2007</td>
<td>ECMWF</td>
<td>Various</td>
<td>10 days</td>
<td>Jung and Leutbecher (2007)</td>
</tr>
<tr>
<td>2007</td>
<td>JMA NWP</td>
<td>December 2003</td>
<td>9 days</td>
<td>Hirooka et al. (2007)</td>
</tr>
<tr>
<td>2009</td>
<td>NCEP SFSIE</td>
<td>Various</td>
<td>15 days</td>
<td>Stan and Straus (2009)</td>
</tr>
<tr>
<td>2010</td>
<td>NOGAPS</td>
<td>January 2009</td>
<td>5 days</td>
<td>Kim and Flatau (2010) and Kim et al. (2011)</td>
</tr>
<tr>
<td>2013</td>
<td>Met Office</td>
<td>January 2013</td>
<td>14 days</td>
<td>Scaife (2013)</td>
</tr>
<tr>
<td>2013</td>
<td>GEOS-5</td>
<td>January 2013</td>
<td>5 days</td>
<td>Lawrence Coy and Steven Pawson (<a href="http://gmao.gsfc.nasa.gov/research/highlights/SSW/">http://gmao.gsfc.nasa.gov/research/highlights/SSW/</a>)</td>
</tr>
</tbody>
</table>

*Tripathi et al. 2015, QJRMS*
SSW predictability in ECMWF system

- Ensemble mean forecast tells about SSW predictability in deterministic sense
- Ensemble spread tells about SSW predictability in probabilistic sense
Forecasting SSW probability

- Calculate probability of SSW for each day as a fraction of ensemble members predicting SSW, OR a fraction of pdf corresponding to SSW
- Focus on maximum predicted daily value of SSW probability in monthly forecast
SSW predictability in ECMWF system

- Day -22: 0.03
- Day -17: 0.44
- Day -12: 0.82
- Day -7: 1.0

Observed monthly probability ~0.13
SSW predictability in ECMWF system

How is this possible?

Enhanced predictability at long lead times

Not interesting case

Unpredictable?

Large errors already at first day of forecast?

Short predictability also in other forecast systems

Large errors already at first day of forecast?

SSW predictability in ECMWF system

Karpechko, 2018, MWR

Enhanced predictability at long lead times

15.12.98
26.02.99
20.03.00
11.02.01

6.01.03
05.01.04

11.01.06
24.02.07
22.02.08

24.01.09
09.02.10
07.01.13
SSW predictability in ECMWF system

SSW predictability averaged across 6 SSWs with strong tropospheric impacts

Karpechko, 2018, MWR

$p=0.5$

$p=0.9$

days 7-0: Deterministic limit

days 13-7: Fast increase in predictability

days 32-13: Slow increase in predictability
Sudden Stratospheric Warming 2018

60°N Zonal Mean Zonal Wind
10 hPa  MERRA2

1979-2018 mean

2017/2018

1978/1979-2017/2018

2017/2018

GEOS FP

P. Newman (NASA), E. Nash (SSAI), S. Pawson (NASA)

S2S predictions of SSW 2018

- SSW occurred on 12 February 2018
- Earliest deterministic forecasts by some models from 30-31 January (lead time 12-13 days)
  - Forecasts from 1 February (lead time 11 days): SSW probability of ~0.3 predicted by S2S models (151 members in total)
  - Forecasts from 8 February (lead time 4 days): SSW probability of 1.0 predicted by S2S models (151 members in total)
S2S predictions of SSW 2018

- Wind forecasts from 1 February strongly correlate with eddy heat flux forecasts across ensemble members ($r=0.94$) which is underestimated by most members (see also Taguchi 2016).
- Forecasts from 8 February correctly predicted the magnitude of the heat flux. Consequently, SSW was also well predicted.
Tropospheric forcing of SSW 2018

- SLP anomaly averaged over 1-11 February in reanalysis and forecast from 1 February show several anomalous anticyclones

- Anticyclones, in particular over northern Europe, are often associated with SSW forcing (e.g. Martius et al. 2009; Woollings et al. 2010)

- For the SSW 2018, errors in the forecasted location of the high over Ural turned out to be strongly correlated with the errors in stratospheric winds

see also Tripathi et al. 2016
Subgroup of ensemble members with best forecasts of the Ural high predicts stronger eddy heat flux to the stratosphere and eventually predicts an SSW to occur one day after the observed event.

Karpechko et al. in prep.
There is large variability in predictability of SSW event (defined as a reversal of zonal mean zonal winds in mid-winter)

Individual events are predicted with significant ($p>0.5$) probability 3-17 days in advance

Weak, short-lived events have shortest predictability limits

SSWs events with significant tropospheric impacts are predicted in probabilistic sense 8-13 days in advance – consistent with most previous estimates – although “deterministic“ predictability is limited to $\sim$7 days

The 2018 SSW was predicted at lead times 12-13 days by some models.

The predictability of the 2018 SSW was limited by errors in the forecasted location of weather system and underestimated magnitude of the stratospheric wave forcing
ADDITIONAL SLIDES
SSW predictability in S2S models
Stratospheric forecast skill
Reliability of SSW probability diagnostic

- In general SSW probability is a reliable diagnostic
- Underconfidence at medium probabilities may be due to small positive bias in forecast zonal winds
- Also reliable when only days 15-32 are considered!
ECMWF forecast system

- Forecasts for 32 days (currently for 46 days)
- Version with 91 levels since November 2013
- Hindcasts for four winters (2013/14-2016/17)
- Altogether 2120 hindcasts during 1993-2016 initialized between November and March
- Ensemble of 5 members (11 members for winters 2015/16-16/17)
- Cover 13 major SSWs from 1998 to 2013
Downward propagation

(b) Northern Annular Mode index
# SSW predictability

<table>
<thead>
<tr>
<th>Central date</th>
<th>dSSW / nSSW</th>
<th>Split / Displacement</th>
<th>Predictability (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>( p=0.5 )</td>
</tr>
<tr>
<td>15.12.98</td>
<td>nSSW</td>
<td>D</td>
<td>14</td>
</tr>
<tr>
<td>26.02.99</td>
<td>dSSW</td>
<td>S</td>
<td>11</td>
</tr>
<tr>
<td>20.03.00</td>
<td>nSSW</td>
<td>D</td>
<td>8</td>
</tr>
<tr>
<td>11.02.01</td>
<td>dSSW</td>
<td>S</td>
<td>12</td>
</tr>
<tr>
<td>30.12.01</td>
<td>nSSW</td>
<td>D</td>
<td>5</td>
</tr>
<tr>
<td>18.01.03</td>
<td>nSSW</td>
<td>S</td>
<td>3</td>
</tr>
<tr>
<td>05.01.04</td>
<td>dSSW</td>
<td>D</td>
<td>12</td>
</tr>
<tr>
<td>21.01.06</td>
<td>dSSW</td>
<td>D</td>
<td>10</td>
</tr>
<tr>
<td>24.02.07</td>
<td>nSSW</td>
<td>D</td>
<td>5</td>
</tr>
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<td>22.02.08</td>
<td>nSSW</td>
<td>D</td>
<td>17</td>
</tr>
<tr>
<td>24.01.09</td>
<td>dSSW</td>
<td>S</td>
<td>8</td>
</tr>
<tr>
<td>09.02.10</td>
<td>dSSW</td>
<td>S</td>
<td>5</td>
</tr>
<tr>
<td>07.01.13</td>
<td>dSSW</td>
<td>S</td>
<td>13</td>
</tr>
</tbody>
</table>

- Most SSWs are predicted (in probabilistic sense) at lead time 8-13 days
- The range is between 3 and 17 days
- Displacements are predicted slightly better, but not significantly better, than splits