Sub-seasonal Forecasting of Sudden Stratospheric Warming Events and their Influence on the Troposphere in the NASA-GEOS-S2S Forecast System

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SSW Effects at the Surface

SSW associated with: enhanced Atlantic blocking, likelihood of extreme surface temperature and precipitation events, S2S forecast skill.

Average SLP anomaly in the month following an SSW

(a) Mean sea level pressure anomaly

JRA-55 anomalies 60-days following SSW

Seasonal Forecasts

[Kidston et al. 2015]

[Butler et al. 2017]

[Scnife et al. 2016]
Previous work suggests forecast systems show some skill in predicting SSW events at 10 days, but poor skill at longer range.

[Tripathi et al. 2015]
GEOS-S2S Version 2: in production since November 2017

Model

- AGCM: Post MERRA-2 generation, cubed sphere grid at ~0.5º, 72 hybrid sigma/pressure levels; GOCART interactive aerosol model, cloud indirect effect (2-moment cloud microphysics); MERRA-2 generation cryosphere;
- OGCM: MOM5, ~0.5º, 40 levels;
- Sea Ice: CICE-4.0.

Coupled Ocean Data Assimilation System

- atmosphere is “replayed” to “FPIT” (like MERRA-2); precipitation correction over land;
- NCEP-like LETKF code/system, set here to behave as Ensemble OI;
- Forecasts: initialized from ODAS, perturbations from analysis differences;
- Hindcasts: re-initialized from 5-day run of ODAS, perturbations from analysis differences

Observations

- nudging of SST and sea ice fraction from MERRA-2 boundary conditions;
- assimilation of in situ Tz and Sz including Argo, XBT, CTD, tropical moorings;
- assimilation of satellite along-track ADT (Jason, Saral, ERS, GEOSAT, HY-2A, CryoSat-2);
- sea ice concentration from the National Snow and Ice Data Center (NSIDC).

Molod et al. 2019 (submitted)
NASA S2S V2 Stratospheric Forecasts

Initial Analysis
3 Feb 2018 00UTC

10-Day Forecast
13 Feb 2018 00UTC

Verifying Analysis
13 Feb 2018 00UTC

EPV on the 850 K Potential Temperature Surface (~30 km)
February 2018 Warming Event Forecast
All 4 ensemble members are predicting a major SSW occurring in about 2 weeks.

The polar temperature rises in all 4 ensemble members.

The forecasted zonal winds and temperatures are consistent. How well did they do?
The polar vortex experienced strong disruption above 10 hPa and below 30 hPa, however, the SSW unexpectedly lagged at 10 hPa, 60°N.

Result: the forecasted wind reversal at 10 hPa was early by ~5-6 days.

The magnitude of the polar temperature rise was well captured in the S2S system.
# NASA’s GEOS Near Real-Time Sub/Seasonal Prediction Suite

<table>
<thead>
<tr>
<th></th>
<th>Subseasonal</th>
<th>Seasonal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length of Forecast</strong></td>
<td>45 days</td>
<td>9-12 months</td>
</tr>
<tr>
<td><strong>Frequency of forecasts</strong></td>
<td>Every 5 days</td>
<td>Every 5 days</td>
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<tr>
<td><strong>Number of Ensembles</strong></td>
<td>4 per start date</td>
<td>Total of 10 per month</td>
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<tr>
<td><strong>Frequency of submission</strong></td>
<td>Once per week</td>
<td>Once per month</td>
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<tr>
<td><strong>Initial Conditions from</strong></td>
<td>GEOS S2S-2_1 ODAS</td>
<td>GEOS S2S-2_1 ODAS</td>
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<tr>
<td><strong>Hindcasts</strong></td>
<td>1999-2016</td>
<td>1980-2016/7</td>
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## MERRA-2 SSW Events since 1999

<table>
<thead>
<tr>
<th>Event</th>
<th>SSW Date</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>26 Feb 1999</td>
</tr>
<tr>
<td>2</td>
<td>20 Mar 2000</td>
</tr>
<tr>
<td>3</td>
<td>11 Feb 2001</td>
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<td>4</td>
<td>30 Dec 2001</td>
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<td>5</td>
<td>17 Feb 2002</td>
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<td>18 Jan 2003</td>
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<td>21 Jan 2006</td>
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<td>10</td>
<td>22 Feb 2008</td>
</tr>
<tr>
<td>11</td>
<td>24 Jan 2009</td>
</tr>
<tr>
<td>12</td>
<td>9 Feb 2010</td>
</tr>
<tr>
<td>13</td>
<td>24 Mar 2010</td>
</tr>
<tr>
<td>14</td>
<td>6 Jan 2013</td>
</tr>
<tr>
<td>15</td>
<td>12 Feb 2018</td>
</tr>
<tr>
<td>16</td>
<td>1 Jan 2019</td>
</tr>
</tbody>
</table>

Evaluating forecast skill using the ensembles for the 14 events in the retrospective forecast set.
Monthly Sea Level Pressure Anomalies following SSW Events 1999-2015

MERRA-2 Observations
Mean Sea Level Pressure Anomaly 30 days following SSW events

Retrospective Forecasts
Mean Sea Level Pressure Anomaly days 10-40 following SSW events
SSW Forecast Lead Time

(a) Temperature

Temperature vs. Days Relative to SSW

(b) Zonal Wind

Zonal Wind vs. Days Relative to SSW
SSW Forecast Lead Time

**Temperature**

- Days Relative to SSW
- K (Temperature)
- (90°N, 10 hPa)
- MERRA-2 Composite

**Heat Flux**

- Days Relative to SSW
- K ms⁻¹
- (45°N-75°N, 100 hPa)
S2S vs MERRA2 Stratospheric Zonal Wind Skill

60°N 10 hPa

5 Day Forecast

15 Day Forecast

25 Day Forecast

30 Day Forecast

35 Day Forecast

Dec-Jan-Feb

Correlation

Forecast Days
Mean Sea Level Pressure 10-40 day Forecast Skill
Skill in forecasts initialized +/-5 days from onset of major SSW

Improvements in skill particularly in the Atlantic sector following SSW
Ongoing Work: Reducing Bias with Gravity Wave Drag

NASA’s high-resolution (12km), short range (10-day) forecasts

- Tuning orographic gravity wave drag can reduce forecast bias and improve prediction skill?

Stronger orographic gravity wave drag:
- reduced mean forecast bias
- improved forecast variability
- accurate 10-d forecast of a very early final warming
Ongoing Work: Reducing Bias with Gravity Wave Drag
Observational Constraints: Moving beyond adhoc tuning
Mountain Waves in AIRS Observations and Forecasts at varying resolutions
Mountain Waves in AIRS Observations and Forecasts at varying resolutions

Studying gravity wave drag in local events & globally
- Scalability
- Settings for optimal simulation
- Evaluation of new parameterizations
➢ The Antarctic stratosphere is poised to undergo a minor (wavenumber 1) warming in the next few days

➢ Exemplified by the PV animation, a forecast from Friday August 30 to Monday September, 2019

➢ GEOS-S2S forecasts are consistently projecting a very warm Antarctic stratosphere over the next weeks.
GEOS S2S V2 system was consistently forecasting the minor warming and its persistence for weeks.
GEOS S2S V2 system was consistently forecasting the minor warming and its persistence for weeks. The system forecast these anomalous conditions about 2 weeks in advance.
Summary: The GEOS S2S V2 system ...

- 45-day forecasts show characteristic anomalous surface patterns in the months following major SSW
- shows skill in forecasting the onset of anomalous stratospheric conditions at 10-15 days
- shows improvement in SLP skill in the N Atlantic at 10-40d following SSW

Ongoing development of the system ...
- higher resolution in both atmosphere and ocean components
- advanced ocean/sea ice analysis and satellite observations
- modernizing parameterized orographic and non-orographic gravity wave schemes to further reduce stratospheric biases