Stratospheric Intrusion Catalog: A 10-year Compilation of Events Identified by using TRACK with NASA’s MERRA-2 Reanalysis

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Introduction to Upper-level flow

Upper-level wave trains exist, with troughs often forming as the flow is disturbed by mountains.
• Converging air accumulates and subsides
• Diverging air draws air upwards from the surface
• As air enters the trough, wind speeds increase resulting in a jet maximum at the trough base.
• upper-level trough supports development of a mid-latitude cyclone

• **Descent** behind cold front
Tropopause Fold (Stratospheric Intrusions: SI)

SIs are associated with:
- High O$_3$, PV
- Low CO, moisture ("dry intrusion")

Background | Question | Results | Conclusion
$O_3$ is a regulated air pollutant

- SIs can lead to concentrations of ground-level $O_3$ exceeding the national ambient air quality standard (NAAQS) set by the EPA, especially at high elevations
- In October 2015, the EPA revised the U.S. NAAQS for daily maximum 8 h average (MDA8) $O_3$ from 75 parts per billion by volume (ppbv) to 70 ppbv
SIs misrepresented in models….until now!

- SIs are fine-scale features, resolution needs to be high enough to capture the filaments
- Simulating and predicting such events remains challenging
- Need horizontal resolution of 50 km or less
NASA’s MERRA-2 Reanalysis

- High resolution data set
  - 0.5° latitude x 0.625° longitude, 72 vertical levels up to 0.01 hPa
- Satellite era
  - 1 January 1980 to within a couple weeks of real time
- Product of GEOS-5 data assimilation system v 5.12.4
- Assimilates conventional meteorological observations, aerosols and ozone
  - Since October 2004, high resolution stratospheric O₃ profiles from the MLS and total column ozone from OMI.
Atmospheric dynamics

- Tropopause descends to ~600 hPa
- Wrapped around jet core

- Tropopause folds are associated with:
  - High O₃, PV
  - Low RH, CO

Knowland et al., 2017, GRL
• Tropopause folds are associated with:
  • High O₃, PV
  • Low RH, CO

Knowland et al., 2017, GRL
Since assimilated O\textsubscript{3} is mainly stratospheric, MERRA-2 O\textsubscript{3} captures SIs, however biased elsewhere in the troposphere.

Knowland et al., 2017, GRL
Questions

• Can we objectively capture SI events in MERRA-2 in order to assist the identification of stratospheric intrusion influenced ozone exceedence events?

• Are there regional differences in the western and eastern USA?
1. Construct storm tracks

- Using the objective feature tracking algorithm, TRACK (Hodges 1995, 1999) identify cyclones in reanalysis dataset by maxima in 850-hPa relative vorticity ($\zeta_{850}$ hPa).
  - Smaller scale systems are more easily identified.
  - Not strongly influenced by the large scale background field.
  - Less extrapolation below orography.
MERRA-2 $\xi_{850 \text{ hPa}}$ MAM 2012 tracks

- Background
- Question
- Method
- Results
- Conclusion
MAM 2012
Upper-level (300 hPa) ζ_{300 hPa} tracks

ζ_{850 hPa} storm tracks
2. SI Filtering

In order to select tracks which are likely associated with SIs, the tracks for 2005-2014 were filtered by:

1. 300 hPa winds for COLs during track life time (similar to Pineiro et al., 2016).
2. Anomalies of EPV > 2PVU, RH < 10 %, H < 0 dam and three thresholds for O$_3$ > 25 ppbv, > 50 ppbv, > 100 ppbv (7° search radius)
3. Maximum $\omega_{500 \text{ hPa}}$ and $\omega_{700 \text{ hPa}}$
(a) March 27, 2012 0UTC  (b) May 27, 2012 9UTC

Knowland et al., 2017, GRL
### Stratospheric Intrusions in MERRA-2 (2005-2014)

<table>
<thead>
<tr>
<th></th>
<th>DJF</th>
<th>MAM</th>
<th>JJA</th>
<th>SON</th>
</tr>
</thead>
<tbody>
<tr>
<td>WUSA</td>
<td>ω₅₀₀ hPa</td>
<td>ω₇₀₀ hPa</td>
<td>ω₅₀₀ hPa</td>
<td>ω₇₀₀ hPa</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>100</td>
<td>185</td>
<td>173</td>
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<tr>
<td>EUSA</td>
<td>55</td>
<td>30</td>
<td>94</td>
<td>57</td>
</tr>
</tbody>
</table>

Compared to other seasons,

- More MAM filt-ζ₃₀₀hPa tracks over the WUSA with the potential to impact lower tropospheric O₃ concentrations
- The impact of the filt-ζ₃₀₀hPa tracks in the EUSA and in the other seasons must be considered

Knowland et al., in prep.
Pacific North American (PNA) pattern

(a) PNA +

(b) PNA -
PNA weighting

Cyclone tracks are weighted by the NOAA Climate Prediction Center’s monthly EOF-based PNA index, using the method described in Bengtsson et al. (2006) and Hodges (2008).

Gives a weight close to 1 for PNA index values ≥ 1σ

No hard cut-off in data near the threshold value

More data is included during the 10-year data period (2005-2014)
Background | Question | Method | Results | Conclusion
**Background**

- **Question**: Research focus on upper level features and storm track variability.

**Method**

- **PNA Difference**
  - DJF
  - MAM
  - JJA
  - SON

**Results**

- **Upper level features**
  - Storm track

- **Mean Intensity difference**
  - $\xi_{300\text{ hPa}}$

- **Track Density difference**
  - $\xi_{850\text{ hPa}}$

**Conclusion**

- Red $\rightarrow$ PNA +
- Blue $\rightarrow$ PNA -
PNA- is associated with $\xi_{300 \text{ hPa}}$ tracks with high EPV, low RH, and high O$_3$ over Western USA
**Track density** (# per month) for filt-$\zeta_{300\text{hPa}}$ tracks with $O_3$ anomaly > 25 ppbv where the max $\omega$ at 500 and 700 hPa in the WUSA for MAM 2005-2014 weighted by the PNA index

- **PNA+** → more filt-$\zeta_{300\text{hPa}}$ tracks at 35°N impacting $O_3$ at 500 hPa
- **PNA-** → more filt-$\zeta_{300\text{hPa}}$ tracks at 40°N with anomalously high $O_3$ at 700 hPa
Summary

• MERRA-2 reanalysis is a high-resolution global reanalysis which can be used in scientific studies to identify and track SIs by both atmospheric dynamics and $\text{O}_3$.
• Location of SIs over the W. USA can be linked with teleconnection patterns, such as the PNA.
• In particular, it may be the intensity or location of the upper-level trough, and not the frequency, that is the main driver in deep SI events.