Strong stratospheric impacts on surface ozone episodes over the western U.S. in spring: Not-so-rare events?

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AQ Outcomes: Contributions to the ozone ISA

The NEW GFDL AM3 model:

1) Cubed-sphere grid at ~50x50 km² (CalNex 2010) 
   48 vertical levels (surface → 86 km)
2) Nudged to NCEP GFS winds [Lin et al., 2012a; JGR]
   (weakening the nudging strength with decreasing pressure)
3) Fully coupled strat & trop chem [Donner et al., 2011]
   as opposed to using Linoz or Synoz tracers in prior CTMs
4) Stratospheric O₃ tracer (O₃S) defined relative to a 
   dynamically-varying tropopause [e90; Prather et al., 2011]

Maximum strat. impacts on surface O₃ in Apr-Jun 2010
(8-hour average; bias-corrected)
Thirteen intrusions in Apr-Jun 2010 enhanced daily max 8-hour ozone to 60-85 ppbv at WUS surface sites

<table>
<thead>
<tr>
<th>Events</th>
<th>Synoptic conditions in satellite imagery</th>
<th>Descent captured in ozonesondes, lidar, aircraft</th>
<th>Major surface impact regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apr. 6-7</td>
<td>AIRS /GFS PV</td>
<td>Not measured</td>
<td>Colorado, New Mexico, Wyoming</td>
</tr>
<tr>
<td>Apr. 9-10</td>
<td>AIRS/GFS PV</td>
<td>Not measured</td>
<td>Wyoming</td>
</tr>
<tr>
<td>Apr. 12-15</td>
<td>AIRS/GFS PV</td>
<td>Not measured</td>
<td>Arizona, Colorado, Utah</td>
</tr>
<tr>
<td>Apr. 21-23</td>
<td>AIRS/GFS PV</td>
<td>Not measured</td>
<td>Colorado, Nevada</td>
</tr>
<tr>
<td>Apr. 28-29</td>
<td>AIRS/GFS PV</td>
<td>Not measured</td>
<td>Colorado, Wyoming</td>
</tr>
<tr>
<td>May 11-13</td>
<td>AIRS/GOES-West</td>
<td>Sonde, P-3 aircraft</td>
<td>Arizona, New Mexico, W. Texas</td>
</tr>
<tr>
<td>May 17-20</td>
<td>AIRS/GOES-West</td>
<td>Sonde</td>
<td>California, Wyoming</td>
</tr>
<tr>
<td>May 22-24</td>
<td>AIRS/GOES-West</td>
<td>Sonde and lidar</td>
<td>New Mexico and Colorado</td>
</tr>
<tr>
<td>May 27-29</td>
<td>AIRS/GOES-West</td>
<td>Sonde and lidar</td>
<td>Arizona, California, Nevada</td>
</tr>
<tr>
<td>Jun. 7-8</td>
<td>AIRS/GOES-West</td>
<td>Sonde</td>
<td>Idaho, Utah, Wyoming</td>
</tr>
<tr>
<td>Jun. 10-15</td>
<td>AIRS/GOES-West</td>
<td>Sonde</td>
<td>Spread in Southwest</td>
</tr>
<tr>
<td>Jun. 16-17</td>
<td>AIRS/GOES-West</td>
<td>Sonde</td>
<td>Colorado</td>
</tr>
<tr>
<td>Jun. 22-23</td>
<td>AIRS/GFS PV</td>
<td>Not measured</td>
<td>Colorado</td>
</tr>
</tbody>
</table>

→ Five events directly led to exceedances of the NAAQS
→ In discussion with EPA R8 managers to flag events + quantify baseline
Stratospheric intrusions drive a substantial portion of the observed synoptic variability of surface ozone.

AM3 captures some high-O₃ events due to stratospheric influence, but limitations due to resolution of meso-scale meteorology.

Obs

Range ~200km

AM3

NA background (NA emis. off)

O₃-Strat

- AM3 captures some high-O₃ events due to stratospheric influence
- But limitations, due to resolution of meso-scale meteorology
Observing stratospheric intrusions from space: Consistent with AM3 lidar and (May 23, 2010)

NASA/Aqua AIRS
Ascending orbit (~1:30 pm)

A new storm arrived ~5 days later

Total column ozone (DU)

Contours (GFS PV at 300 hPa)

Southern California

Lidar

AM3

Ozone [ppb]
Subsidence of stratospheric O\textsubscript{3} to the lower trop of S. California (May 28, 2010)

\textbf{Sonde O\textsubscript{3} [ppbv]}

\begin{itemize}
\item \textbf{Point Reyes}
\item \textbf{Joshua Tree}
\item O\textsubscript{3}-strat contributes \textasciitilde75\% to enhanced O\textsubscript{3}>100 ppbv at 2-5 km a.s.l.
\item Consistent with observed low humidity; NA emissions contribute little
\end{itemize}
Transport of stratospheric O$_3$ to the surface (e.g. May 29, 2010)

- High O$_3$-strat coincides with regions experiencing peak surface O$_3$ levels (+ sharp decreases in humidity and dew point temperature)
- Stratospheric intrusions elevate baseline levels (~15 ppbv) and can contribute 35-55 ppbv to MDA8 O$_3$ during events, up to 2-3 times higher than previously reported!
Summarizing results for Apr-Jun 2010

15 high-elevation (>1.4 km) western U.S. sites

- Background O$_3$ can reach 60-75 ppbv for ~25% of observed high-O$_3$ >=70 ppbv
- A major role for strat. intrusions in driving high-O$_3$ events (spring; west)
  → Enhanced knowledge needed to forecast and identify events

NA background (PRB)
O$_3$-Strat
Bias-corrected

Current NAAQS
Future?
New IP: Can NASA satellite provide an advanced warning of potential $O_3$ action days due to a stratospheric intrusion?

Enhanced observed $O_3$ and model $O_3S$ in surface air southeast of the intrusion as seen by AIRS (consistent with ozonesondes)
Key Points:
- Stratospheric intrusions can episodically contribute 50-60% to surface $O_3$
- Regularly influence the high-elevation WUS in late spring
- NASA near real-time ozone products may provide an advanced warning

For further discussions, please contact Meiyun.Lin@noaa.gov
Additional slides for Q&A
The new GFDL CM3/AM3 chemistry-climate model

Donner et al., Golaz et al., Griffies et al., J. Climate, 2011

GFDL-AM3

Forcing
- Solar Radiation
- Well-mixed Greenhouse Gas Concentrations
- Volcanic Emissions

Ozone-Depleting Substances (ODS)

Pollutant Emissions
- (anthropogenic, ships, biomass burning, natural, & aircraft)

Atmospheric Dynamics & Physics
- Radiation, Convection (includes wet deposition of tropospheric species), Clouds, Vertical diffusion, and Gravity wave

Atmospheric Chemistry
- Chemistry of $\text{O}_3$, $\text{HO}_x$, $\text{NO}_x$, Cl, Br, and Polar Stratospheric Cloud (PSC)
- Chemistry of gaseous species ($\text{O}_3$, $\text{CO}$, $\text{NO}_x$, hydrocarbons) and aerosols (sulfate, carbonaceous, mineral dust, sea salt, secondary organic)

Aerosol-Cloud Interactions
- Dry Deposition

Land Model version 3
- (soil physics, canopy physics, vegetation dynamics, disturbance and land use)

Naik et al., in prep

SSTs/SIC from observations or CM3 CMIP5 Simulations

AM3 option to nudge to “reanalysis winds”

48 vertical levels
Surface → 86 km
AM3 cubed sphere grid
→ C48 (~200x200 km$^2$)
→ C180 (~50x50 km$^2$)

M. Lin, et al., JGR, 2012

Modular Ocean Model version 4 (MOM4)
& Sea Ice Model

SSTs/SIC from observations or CM3 CMIP5 Simulations

Ozone–Depleting Substances (ODS)

Forcing
- Solar Radiation
- Well-mixed Greenhouse Gas Concentrations
- Volcanic Emissions

Pollutant Emissions
- (anthropogenic, ships, biomass burning, natural, & aircraft)
AM3 O$_3$S

Observed

May 29, 2010
Case #3: Stratospheric intrusions drive a substantial portion of the observed synoptic variability of surface $O_3$. 

AQS/CASTNet

GFDL AM3

Stratospheric

June 10

0610

June 12

0612

June 15

0615

Daily max 8-hour $O_3$ in surface air
Stratospheric impacts on the Four Corners region

May 24

April 13

Background O₃-Strat

NAAQS

NAAQS

Observed MDA8 O₃

Model MDA8 O₃

Model MDA8 O₃

[c] May 23-26

[d] Apr 12-16

25 35 45 55 65 75
Distinguish *stratospheric* vs. *tropospheric* air using the e90 tropopause tracer proposed by *Prather et al. [2010]*; allowing double tropopause

Set $O_3S$ equal to $O_3$ in stratospheric ($e90<85$ ppb) air masses; subject to chemical and depositional loss in tropospheric ($e90>85$ ppb) air masses

Transport of $O_3S$ and e90 both driven by meteorology

*Lin, et al., 2012, submitted to JGR*