On the Role of Climate Variability on Tropospheric Ozone

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Drivers of trop. O$_3$ variability over the North Pacific and Western N. America in SPRING

PACIFIC SUBTROPICAL REGION:
- Sensitive to the subtropical jet location  
- Greater Asian than stratospheric influence on variability  
  [Lin et al., Nature Geosci, 2014a]

WESTERN U.S.:
- Sensitive to the eddy-driven jet
- Highly variable on synoptic time scales
- Prone to deep strat. Intrusions
  Langford et al. 2009; Lin et al. 2012ab
  Skerlak et al. [2014]

NEED PROCESS-LEVEL UNDERSTANDING ON DAILY TO MULTI-DECADAL TIME SCALES
Tropospheric ozone trends at Mauna Loa Observatory tied to decadal climate variability


Mauna Loa Observatory (3.4 km altitude)

The puzzle:
- Little change in spring
- Increase in fall

E. China NO\textsubscript{x} Emissions

almost tripled!

Tracer of East Asian Pollution

Spring

Fall

Normalized to 2000

1980 1990 2000 2010

Model

Satellites
Increasing ozone at Mauna Loa in FALL tied to a shift in circulation patterns since the mid-1990s

Mauna Loa Observatory (3.4 km altitude), Hawaii


OBS: 11% decade$^{-1}$ (p<0.05)
FIXEMIS (Nudged): 7% decade$^{-1}$ (p<0.05)
BASE (Nudged): 13% decade$^{-1}$ (p<0.05)

Must consider decadal climate variability as well as emission changes for attribution of pollutant trends

Decreasing ozone at Mauna Loa in **SPRING** tied to recent La-Niña-like decadal cooling + weakening airflow from Asia

LaNiña-like decadal cooling

[Chavez2003; Meehl2013; Kosaka2013]

**Ozone Anomaly, ppb**

(25th percentile)

**AMIP (fixed emissions)**

\[-1.4 \pm 1.0 \text{ ppb decade}^{-1}, \ P<0.01\]

\[r^2(\text{OBS, AM3})=0.39\]

Mean background

500 hPa, Apr-May

Decreasing ozone at Mauna Loa in **SPRING** tied to recent La-Niña-like decadal cooling + weakening airflow from Asia

![Graph showing ozone anomaly and El Niño/La Niña events](image)

**Key Points**
- Decreasing Rn (Bq/m³)
- Weakening airflow from Eurasia

**El Niño**
- Even higher?

**La Niña**
- Mean background 500 hPa, Apr-May

**Statistical Information**
- AMIP (fixed emissions)
  - \(-1.4 \pm 1.0\) ppb decade\(^{-1}\), \(P<0.01\)
  - \(r^2(OBS, AM3)=0.39\)

**References**
- Chavez2003
- Meehl2013
- Kosaka2013

Strong stratospheric influence on year-to-year variability of high-elevation Western U.S. surface \( \text{O}_3 \) during Apr-May

- In contrast, the influence of wildfire emissions and Asian pollution are minimal (see paper)
- Large IAV may complicate the attribution of observed \( \text{O}_3 \) trends in short records.
Following La Niña conditions, deep STT may occur with sufficient frequency as to confound NAAQS attainment.

- **1999 (La Niña)** →
  - Frequent deep STT events

- **1992 (Pinatubo)** →
  - Weaker events, lower mean values
The high tail of the observed daily surface O$_3$ distribution over Western U.S. increases during La Niña springs.

Neutral, $\mu = 56.5, \sigma = 7.5$

El Niño, $\mu = 56.9, \sigma = 7.3$

La Niña, $\mu = 58.5, \sigma = 7.9$

Pinatubo, $\mu = 54.3, \sigma = 6.5$

Changes in the high tail are statistically significant.

- Little change in WUS surface O$_3$ during El Niño despite increased UTLS O$_3$ burdens reported previously [e.g. Langford1998; Bronnimann2004; Neu2014].
Western US surface O₃ variability correlates poorly with O₃ burdens in the UTLS but strongly with that in the Free Trop.

Niño 3.4 Index

12-mon running mean UTLS O₃ anomaly (%) \( r^2(\text{UTLS}, \text{Surface}) = 0.07 \)

Apr-May mean FreeTrop & Surface O₃ anomaly (ppb) \( r^2(\text{FreeTrop}, \text{Surface}) = 0.74 \)
Late winter storm-track shifts towards U.S. Pacific Northwest during La Niña, facilitating deep tropopause folds

El Niño

La Niña

Anomalies in rms of 2-10-day bandpassed filtered 500mb heights

- Figure from Li & Lau (J. Climate, 2012); See also discussions in Trenberth et al, 1998; Seager2010
The enhanced storm-track activity over the central western U.S. persists in late spring for strong La Niña episodes.

**El Niño (NCEP1948-2013)**

- Winter
- Late Spring

**La Niña (NCEP1948-2013)**

- Winter
- Late Spring

Anomalies in rms of 2-10-day bandpassed filtered 500mb heights
Summarizing sources in daily to interannual variability of lower trop. ozone during spring related to ENSO

**El Niño**
- Low Pressure
- Persistent Extended Subtropical Jet Stream
- Increased mean background O₃ from Asian pollution

**La Niña**
- Meandering Polar Jet Stream
- Blocking High Pressure
- More frequent tropopause folds

Variance in daily O₃Strat at 500hPa

Take-Home Messages

La Niña Winter

More frequent deep STT events in the following spring over Western US;
*Potential for seasonal prediction*

El Niño Winter

Little influence on Western US surface O$_3$ despite increased UTLS O$_3$ burdens

Must consider climate variability when interpreting observed trends in tropospheric ozone levels.

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Additional slides for Q & A
GFDL model indicates influence from circulation shifts that modulate Asian pollution reaching Hawaii

**BASE**
- Varying emissions
- Nudged to “real winds”

**FIXEMIS**
- Constant emissions
- Nudged to “real winds”

Following El Niño conditions, stronger airflow from Asia towards Hawaii in SPRING.
Following La Niña conditions, deep STT may occur with sufficient frequency as to confound NAAQS attainment.

2011 (La Niña)

2007 (Neutral)
Role of dynamical variability on free tropospheric ozone over Western U.S. during spring

Western U.S. (32-50N, 128-104W, 3-8 km altitude)

- Observations as in Cooper et al. [2010; 2012].
- Sparse sampling and short records may complicate the unambiguous attribution of observed trends

Meiyun Lin et al., in prep