Use of Satellite-Derived Air Pollution Observations to Provide Insight into the Relationship Between Population, Long-Range Transport, and Climate

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Road Map

- History Behind Use of Satellites to Study Tropospheric Air Pollution

- Tropospheric Ozone Residual (TOR) Methodology and Climatology (Fishman et al., 2003)

- **Recent Studies Highlighting Use of Satellite Data:**
  - Intercontinental Transport of Tropospheric Ozone (Creilson et al., 2003)
  - Interannual Variability of Tropospheric Ozone and its relationship with climate indices (ENSO, NAO, QBO) (in process)

- **Future Direction:** Use of Assimilated Satellite Data for Better Representation of Stratospheric Component
The Origin of Using Satellite Data to Study Tropospheric Ozone Can be Linked to Nobel-Prize Winning Research

*from Nobel Prize press release:*
The Royal Swedish Academy of Sciences has decided to award the 1995 Nobel Prize in Chemistry to **Paul Crutzen, Mario Molina** and **F. Sherwood Rowland** for their work in atmospheric chemistry, particularly concerning the formation and decomposition of ozone.
In the late 70’s, Paul Crutzen led a team of NCAR scientists that made comprehensive measurements of trace gases where tropical biomass burning was occurring and found considerably higher concentrations than what had been published previously.

Can the 10-20 DU enhancement be identified with TOMS total ozone measurements?

Enhanced Total Ozone Observed in Conjunction with Biomass Burning in 1980 Episode
Separate Stratosphere from Troposphere to Compute Tropospheric Ozone Residual

Schematic Diagram Showing How Tropospheric Ozone Residual (TOR) is Derived

- TOMS Total Ozone: ~300 DU
- Stratospheric Ozone Profile Derived from SAGE or SBUV: ~270 DU
- Tropopause (determined from NCEP analysis): 10-18 km
- Surface: ~55 km

Calculate Tropospheric Residual:
- 300 DU
- -270 DU
- ~30 DU
Seasonal Depictions of Climatological Tropospheric Ozone Residual (TOR) 1979-2000

- December - February
- March - May
- June - August
- September - November

Dobson Units (DU)

from Fishman, Wozniak, Creilson, Atmos. Chem. Phys., 3, 2003
How do we know what we are seeing is in the troposphere?

Striking Similarity Between Global Distributions of TOR and Tropospheric NO$_2$

June-August Climatological TOR Distribution in Dobson Units (DU)

2003 Tropospheric NO$_2$ Distribution from SCIAMACHY ($10^{15}$ molec. cm$^{-2}$)
Previous Studies have shown a Strong Relationship between TOR over Western Europe and the North Atlantic Oscillation.
Phase of the North Atlantic Oscillation Controls Transport Strength and Speed

Positive Phase of the NAO

Transport Processes Stronger during Positive Phase

Negative Phase of the NAO

from Creilson et al., 2003
Springtime TOR Variability Over North Atlantic Linked to Transport Patterns Modulated by the North Atlantic Oscillation (NAO)

Spring 1990 – Positive NAO

Spring 1980 – Negative NAO

Seasonal TOR Depictions

Seasonal Surface Pressure and 850mb Wind Depictions

(from Creilson et al., 2003)
Interannual Variability of Western Europe
Springtime TOR and Spring NAO Index

1986, 1990, 1992
Highest TOR Years

R=+0.61

(From Creilson et al., 2003)
Relationship between Arctic Oscillation and TOR even Stronger

R>6

R>7

Correlation Coefficient (R-Value)

Positive Phase of the Arctic Oscillation
**Comparison of Satellite TOR with Ozonesonde Measurements at two Mid-latitude Sites**

**How do we validate TOR measurements?**

TOR data are from 9° latitude by 11° longitude boxes (81 grid points) centered near the two sites.

Regression of Ozonesonde and TOR Monthly Difference

- Hohenpeissenberg TOR: $R = 0.96$
- Wallops Island TOR: $R = 0.98$

from Creilson et al., 2003
Studies have also discovered a relationship between Ozone Pollution over Northern India and both Population & Phase of ENSO
Population and Ozone Pollution Strongly Correlated in India and China

Summertime TOR Depiction
Asian Pollution Event Stronger than Historic 1988 Eastern United States Episode

Tor June 1982

TOR July 3-15 1988

Dobson Units (DU)

Episodic Depictions

TOR July 1988

TOR July 3-15 1988

Surface O₃ July 3-15 1988
U.S. Surface **Ozone** Levels
1982-2001
Interannual variability of TOR over Northern India strongly correlated with ENSO and strength of monsoonal flow.

June 1982 - Strong El Niño Year

June 1999 - Strong La Niña Year
Significant Interannual Variability is also Evident between North and South of the ITCZ in West Africa: Potential Linkage to Phase of the El Niño

Dobson Units

North-South TOR: June 1982

North-South TOR: June 1984

Strong El Niño

Strong La Niña
Strong Difference Seen in Outgoing Longwave Radiation Between June of 1982 (El Niño) and June of 1984 (La Niña)

Positive Versus Negative Anomaly over the Same Region
North-South (5N-5S) June TOR Differential Versus Nino Region 4 SSTA: Strong Correlation Evident

- Interannual variability of TOR is strongly correlated to ENSO cycle

$R = +0.78$
What can be said about the interannual variability of stratospheric ozone over this same region?
Stratospheric ozone over west Africa strongly correlated with quasi-biennial oscillation (QBO)

Distribution of TOR over same region highly correlated with El Niño/Southern Oscillation (ENSO)

Correlation of TOR with QBO is much less significant

Correlation of SCO with ENSO is NOT significant
The Next Challenge:

Coupling Satellite Measurements with Models for Air Quality Applications
RAQMS [Pierce et al., JGR, 2003] is a nested global- to regional-scale meteorological and chemical modeling system for assimilating and predicting the chemical state of the atmosphere (air quality).

*RAQMS includes online chemistry from the NASA LaRC unified (troposphere/stratosphere) chemical mechanism driven by the UW-Hybrid (global isentropic/sigma coordinates) and UWNMS (regional
SUMMARY

• Pioneering Research into Tropospheric Ozone Leads to Discovery of Tropospheric Signal in TOMS
  - 20 Years of Tropospheric Ozone (TOR) Data now available at http://asd-www.larc.nasa.gov/TOR/data.html

• Pollution Transport across North Atlantic Linked to NAO/AO

• Strong Correlation between Asian Pollution and Population
  - Asian pollution event stronger than historic U.S. episode
  - Interannual Variability over India Linked to Phase of ENSO

• Distinct Differences in West African Tropospheric versus Stratospheric Ozone-Climate Relationships:
  - Tropospheric-ENSO: Stratospheric-QBO

• Next Step: Coupling Satellite Measurements with Models for Air Quality Applications
GO SOX!!