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)

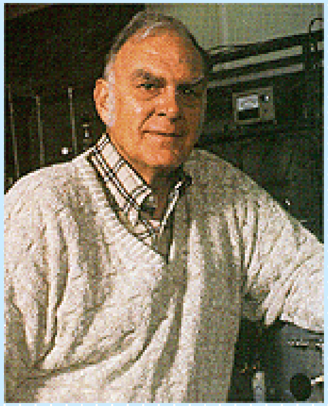
- Recent Studies Highlighting Use of Satellite Data:
    - Intercontinental Transport of Tropospheric Ozone (Creilson et al., 2003)
    - Interannual Variability of Tropospheric Ozone and its relationship with climate indices (ENSO, NAO, QBO) (in process)

- Future Direction: Use of Assimilated Satellite Data for Better Representation of Stratospheric Component

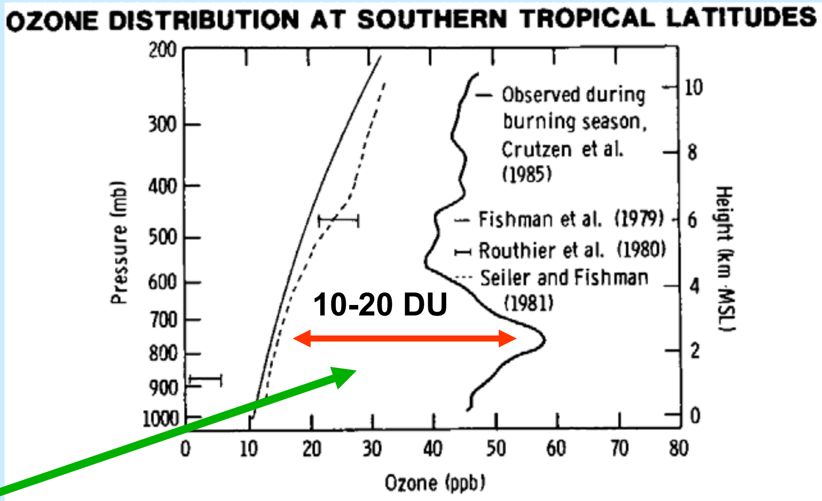
The Origin of Using Satellite Data to Study Tropospheric Ozone Can be Linked to Nobel-Prize Winning Research

from Nobel Prize press release:

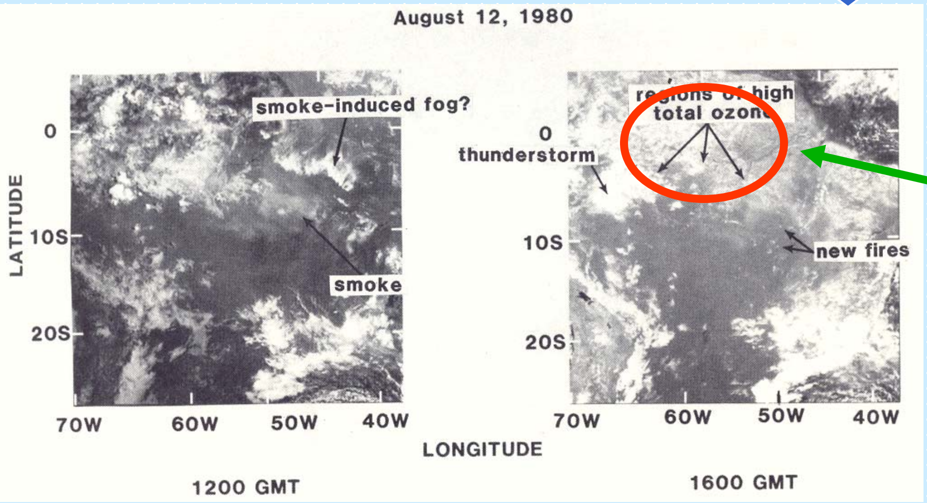
The Royal Swedish Academy of Sciences has decided to award the 1995 Nobel Prize in Chemistry to
Paul Crutzen, Mario Molina and **F. Sherwood Rowland**
for their work in atmospheric chemistry, particularly concerning **the formation** and decomposition **of ozone**.



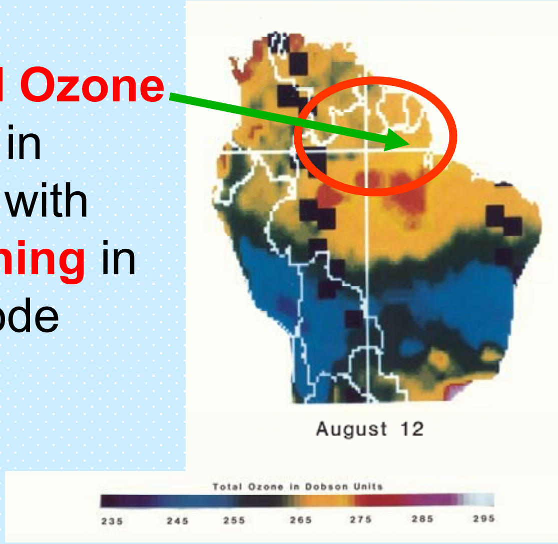
In the late 70's, Paul Crutzen led a team of NCAR scientists that made comprehensive measurements of trace gases where tropical biomass burning was occurring and found considerably higher concentrations than what had been published previously



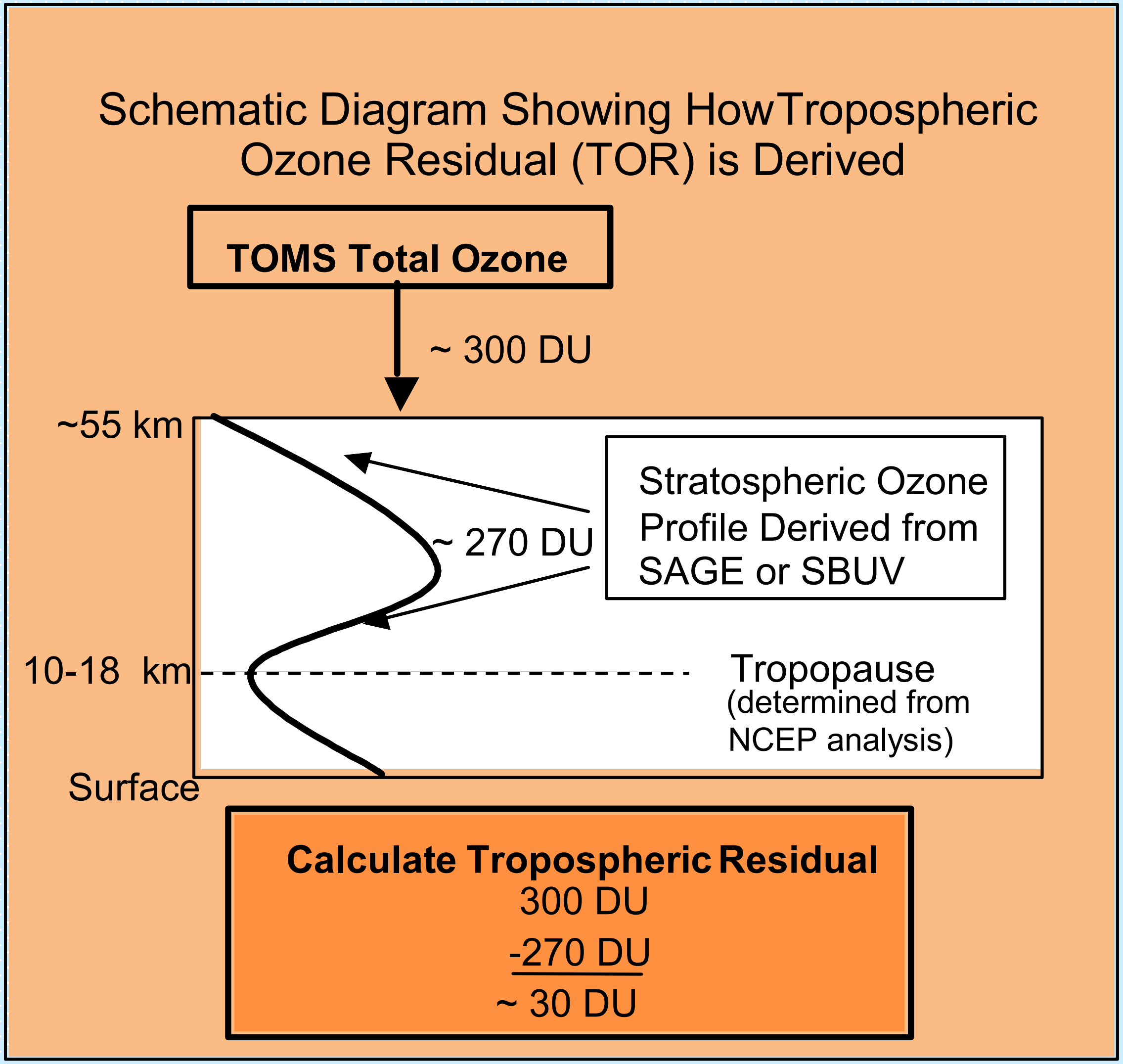
Can the 10-20 DU enhancement be identified with TOMS total ozone measurements?



Enhanced **Total Ozone** Observed in Conjunction with **Biomass Burning** in 1980 Episode

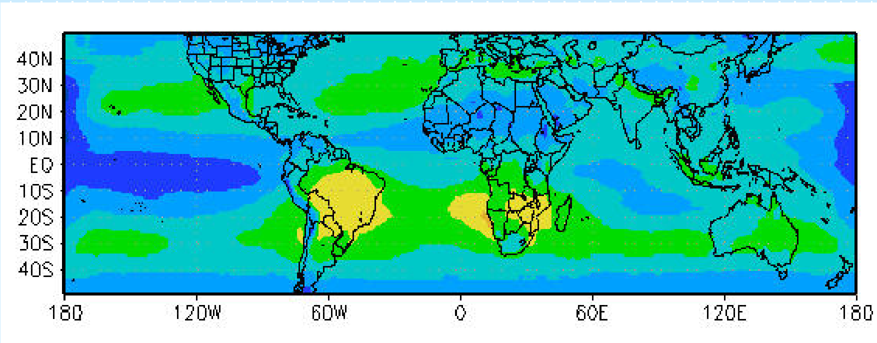


Separate Stratosphere from Troposphere to Compute Tropospheric Ozone Residual

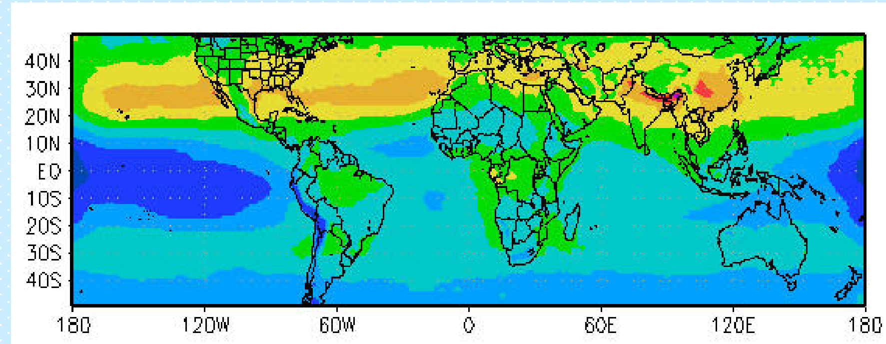


Seasonal Depictions of Climatological Tropospheric Ozone Residual (TOR) 1979-2000

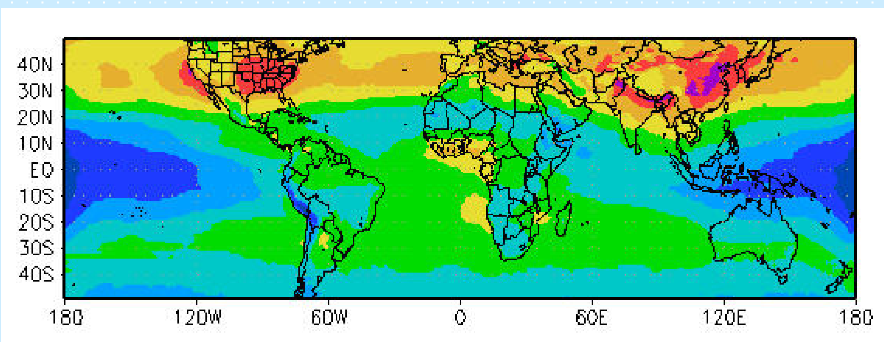
December - February



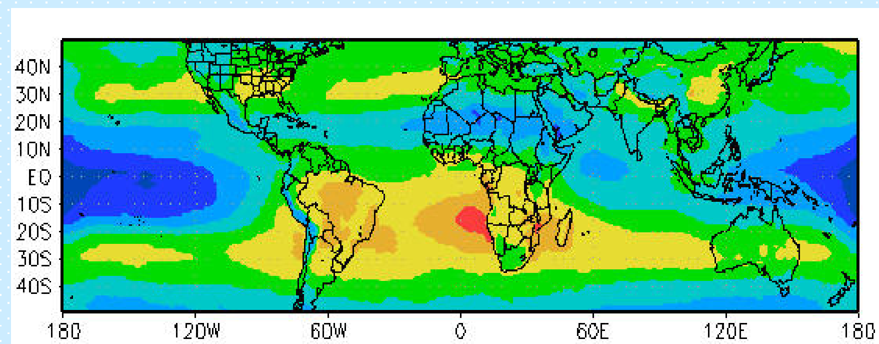
March - May

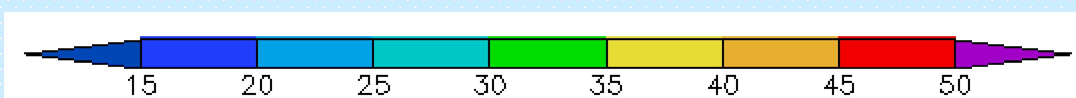


June - August



September - November





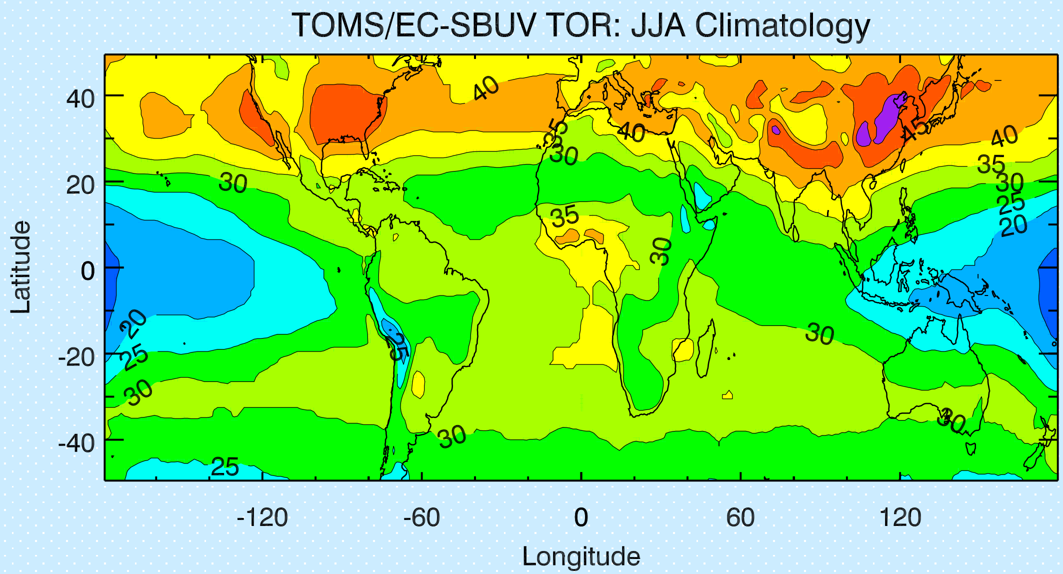
Dobson Units (DU)

from Fishman, Wozniak, Creilson, *Atmos. Chem. Phys.*, **3**, 2003

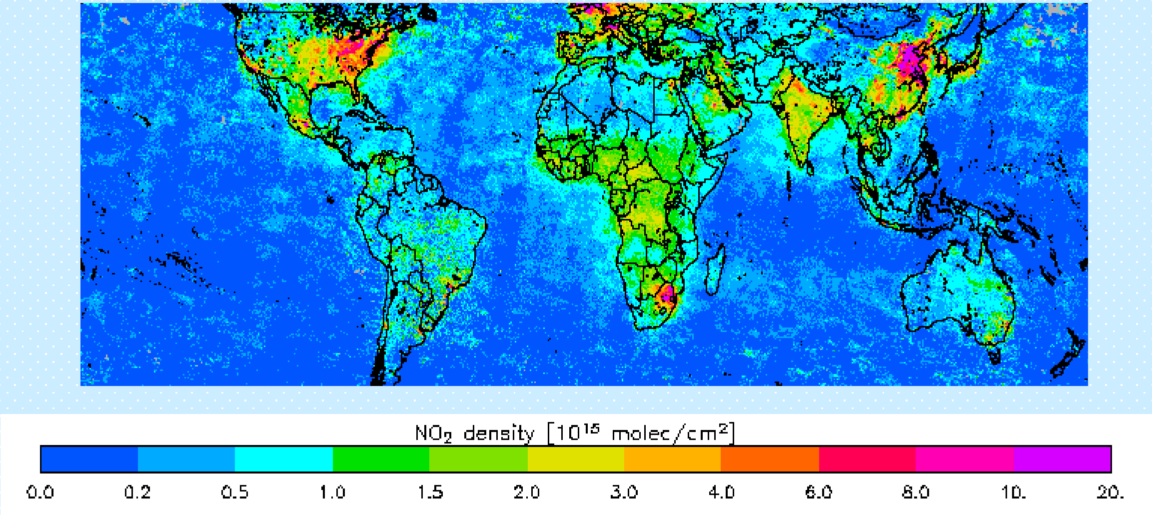
<u>How do we know what we are seeing is in the troposphere?</u>

Striking Similarity Between Global Distributions of TOR and Tropospheric NO_2

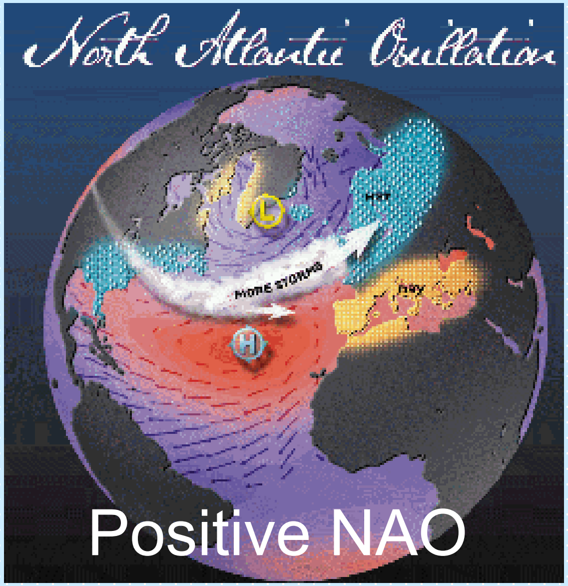
June-August Climatological TOR Distribution in Dobson Units (DU)



2003 Tropospheric NO_2 Distribution from SCIAMACHY (10^{15} molec. cm^{-2})



Previous Studies have shown Strong Relationship between TOR over Western Europe and the North Atlantic Oscillation



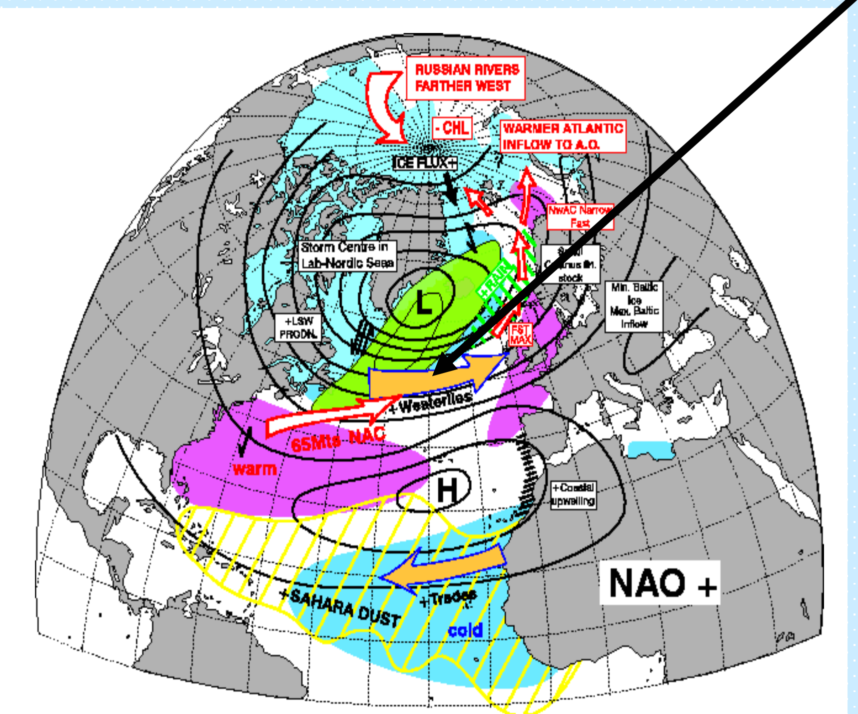
Positive NAO

Negative NAO

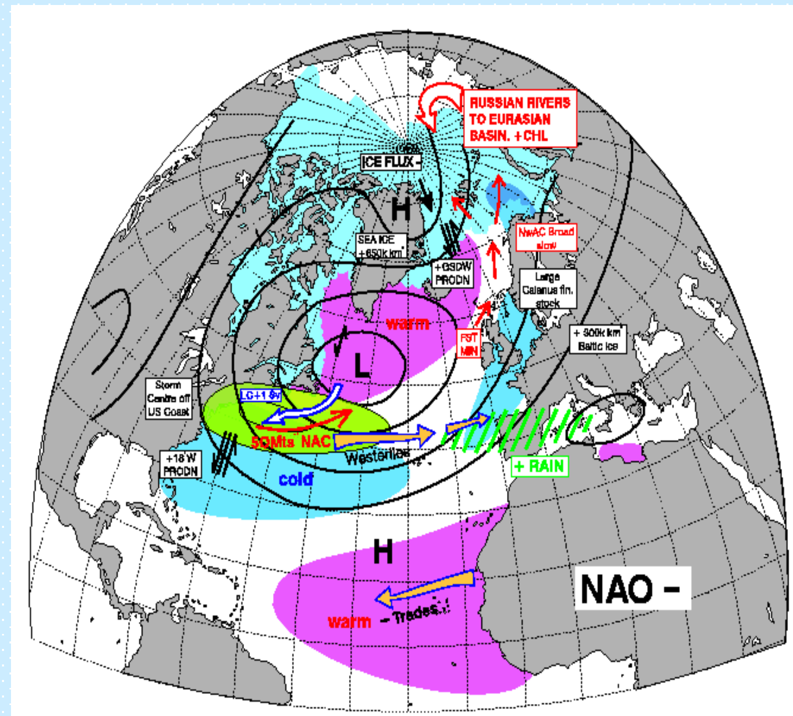
from Creilson et al., 2003

Phase of the North Atlantic Oscillation Controls Transport Strength and Speed

Transport Processes **Stronger** during Positive Phase



Positive Phase of the NAO

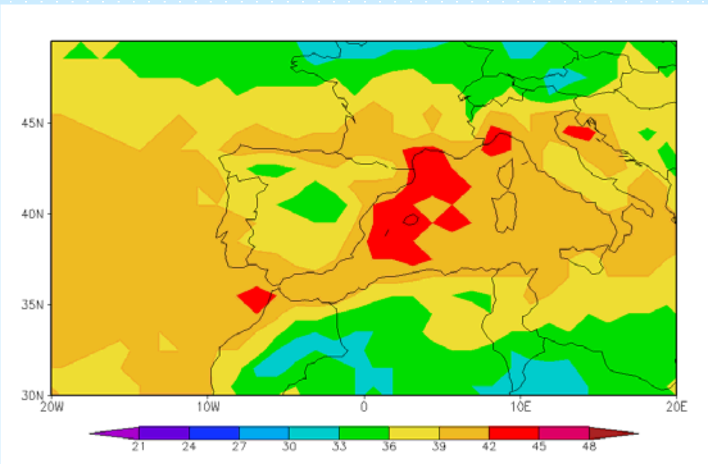


Negative Phase of the NAO

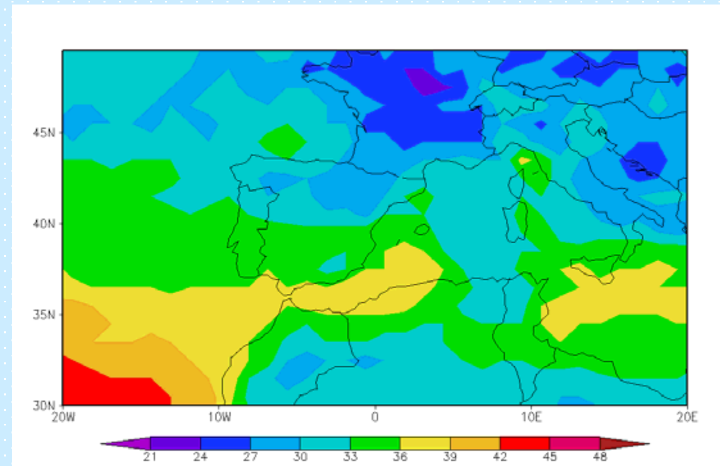
from Creilson et al., 2003

Springtime TOR Variability Over North Atlantic Linked to Transport Patterns Modulated by the North Atlantic Oscillation (NAO)

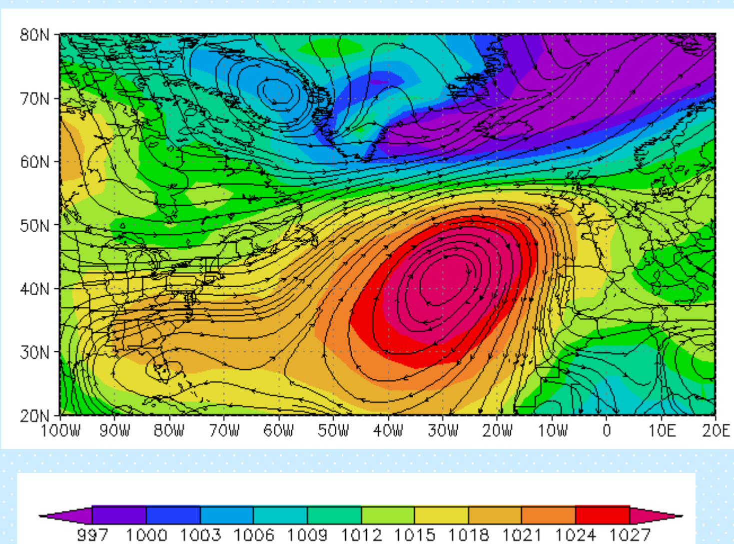
Spring 1990 – Positive NAO

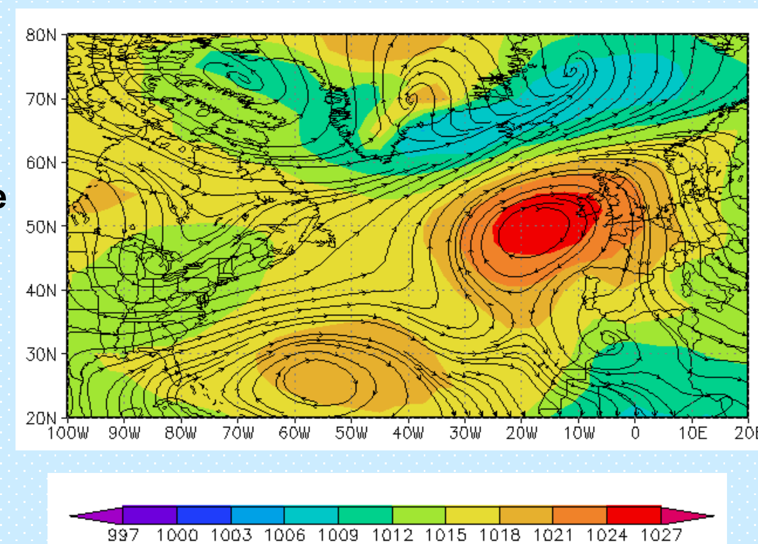


Spring 1980 – Negative NAO



Seasonal TOR Depictions

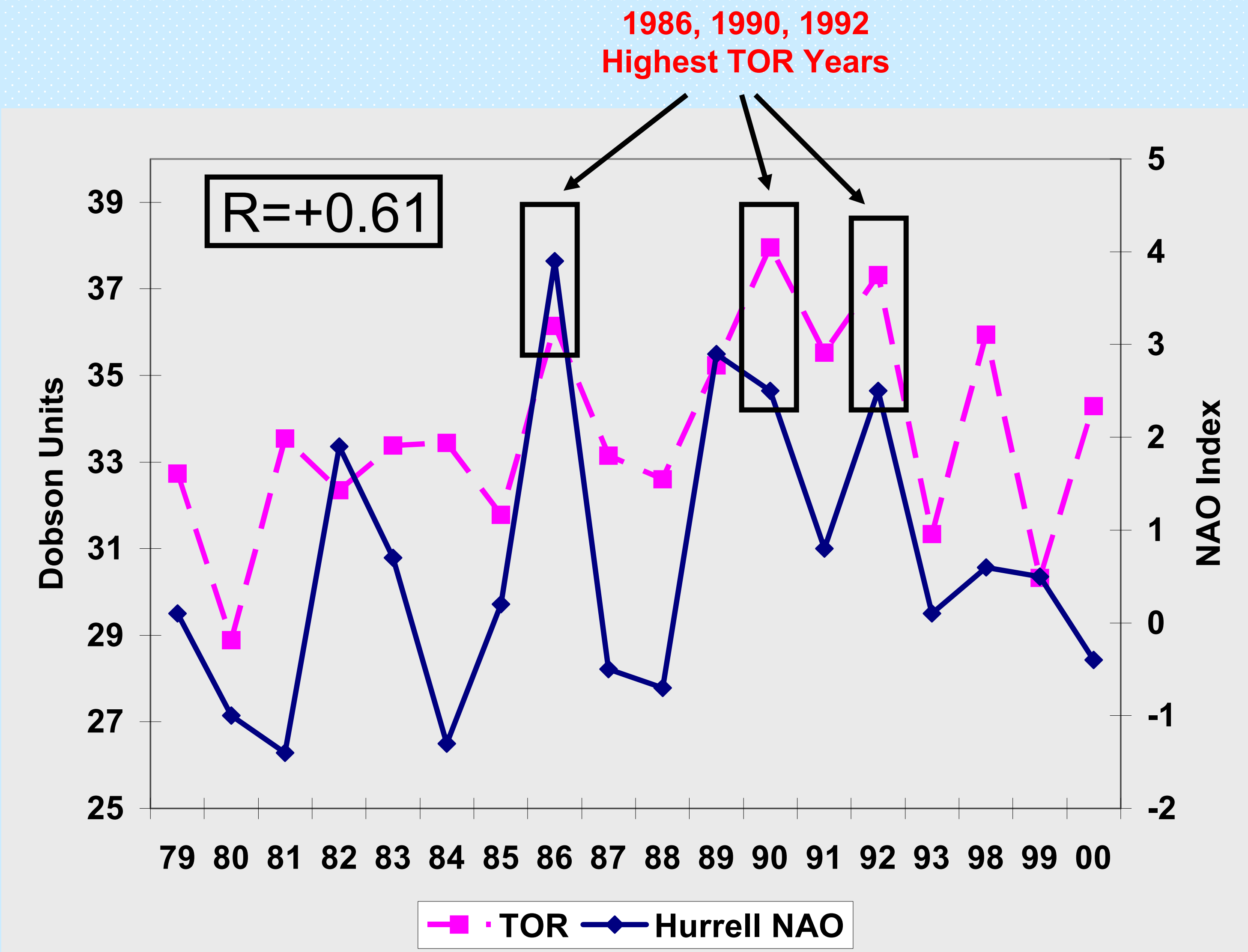




Seasonal Surface Pressure and 850mb Wind Depictions

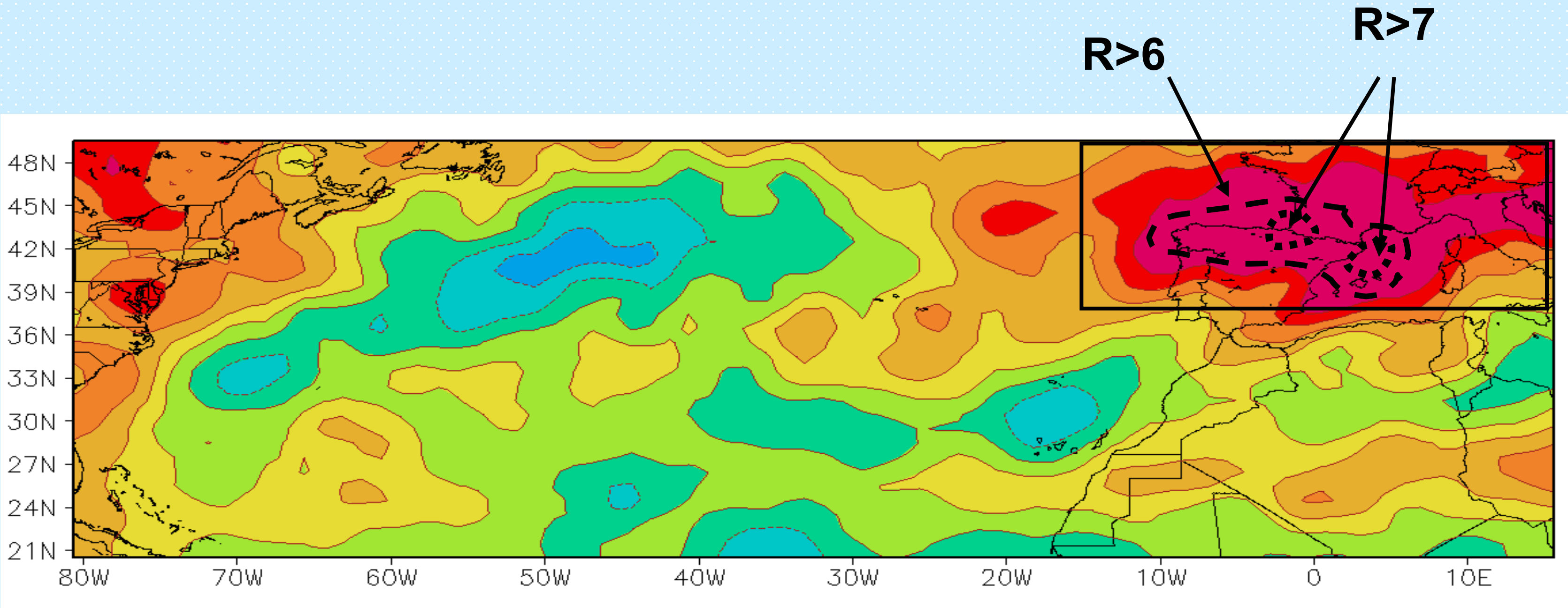
from Creilson et al., 2003

Interannual Variability of Western Europe Springtime TOR and Spring NAO Index

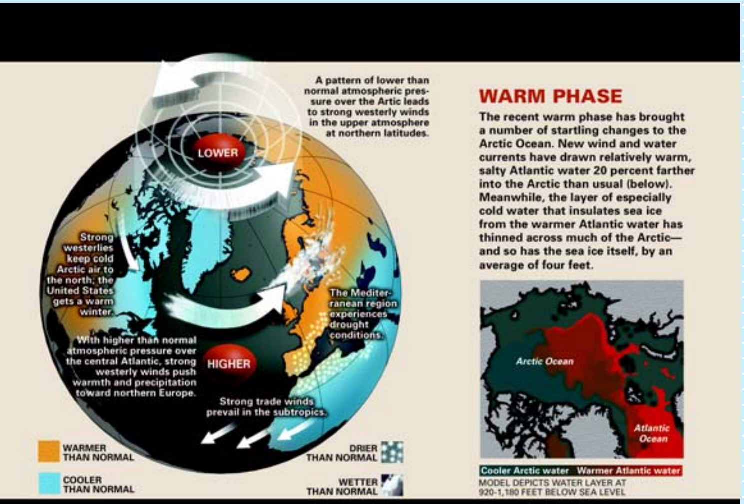


from Creilson et al., 2003

Relationship between Arctic Oscillation and TOR even Stronger

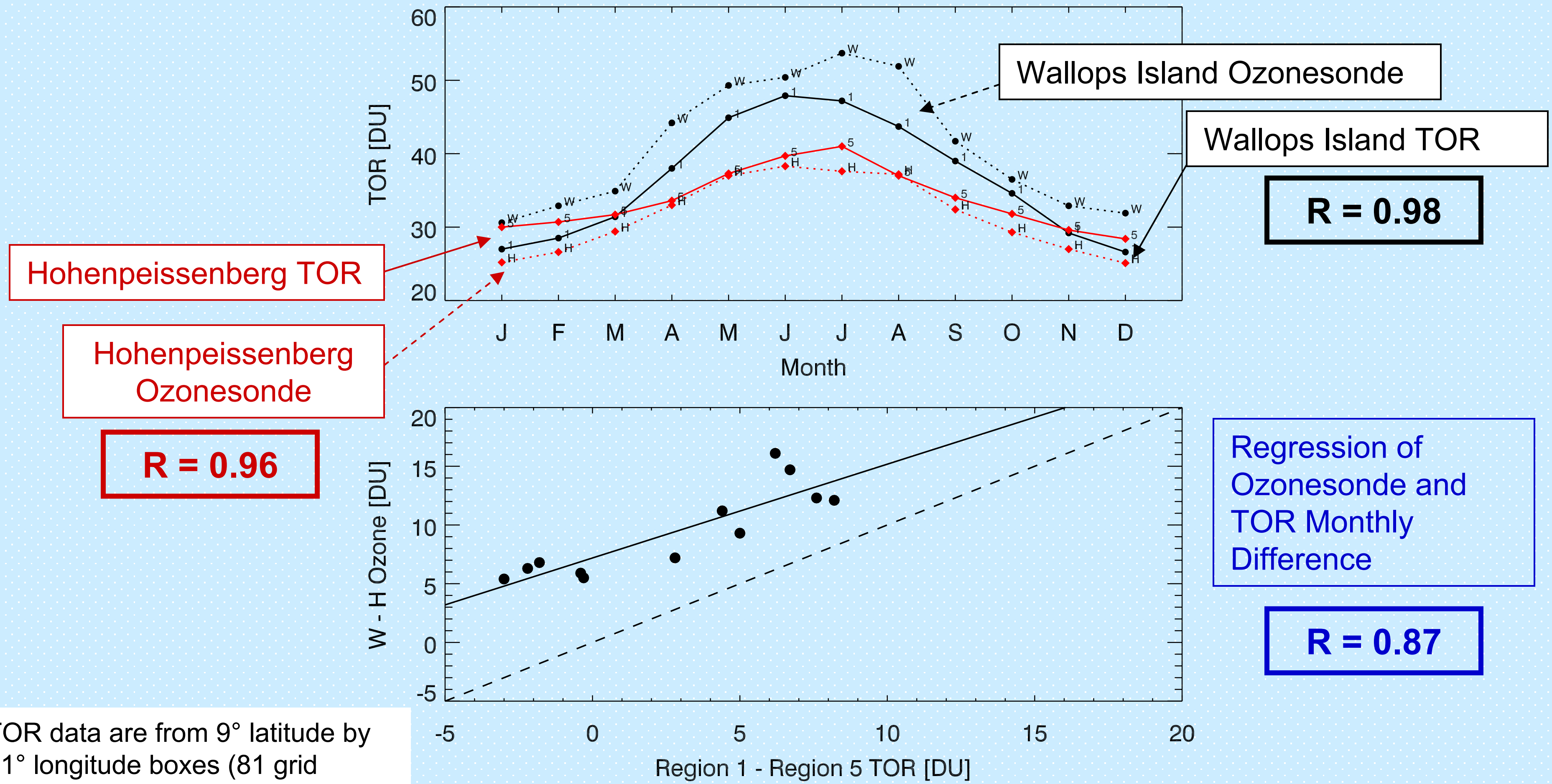


Correlation Coefficient (R-Value)



← Positive Phase of the Arctic Oscillation

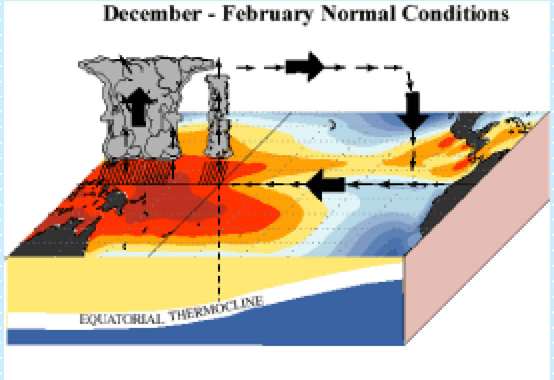
Comparison of Satellite TOR with Ozonesonde Measurements at two Mid-latitude Sites



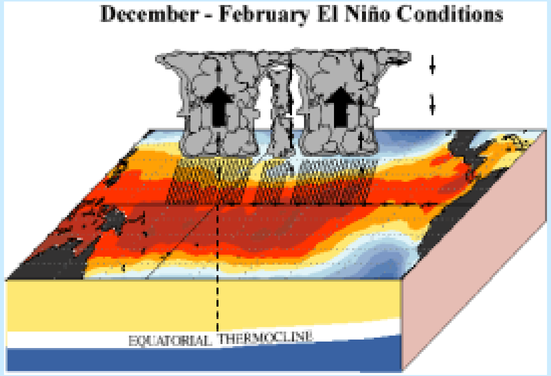
TOR data are from 9° latitude by 11° longitude boxes (81 grid points) centered near the two sites

from Creilson et al., 2003

Studies have also discovered a relationship between Ozone Pollution over Northern India and both Population & Phase of ENSO



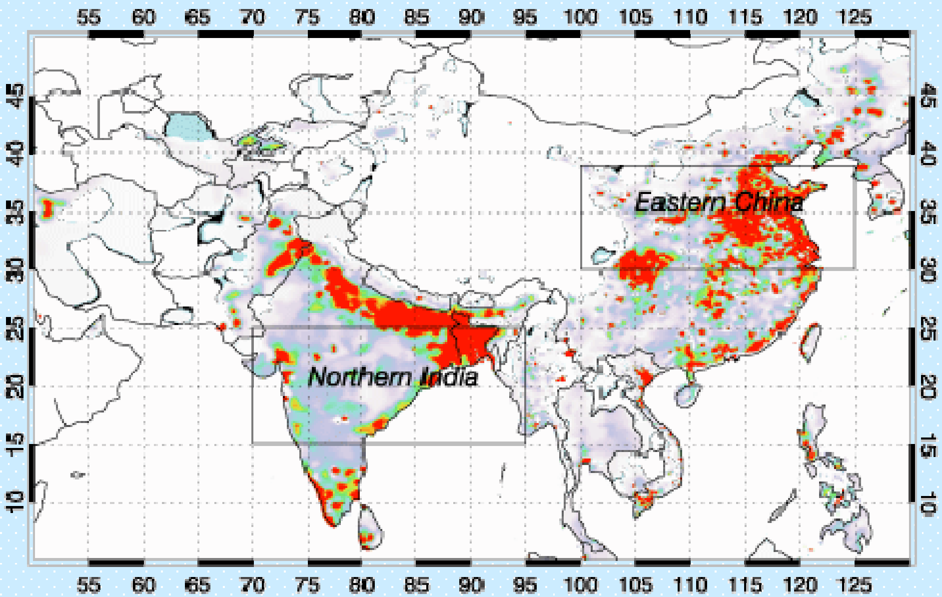
Normal Conditions



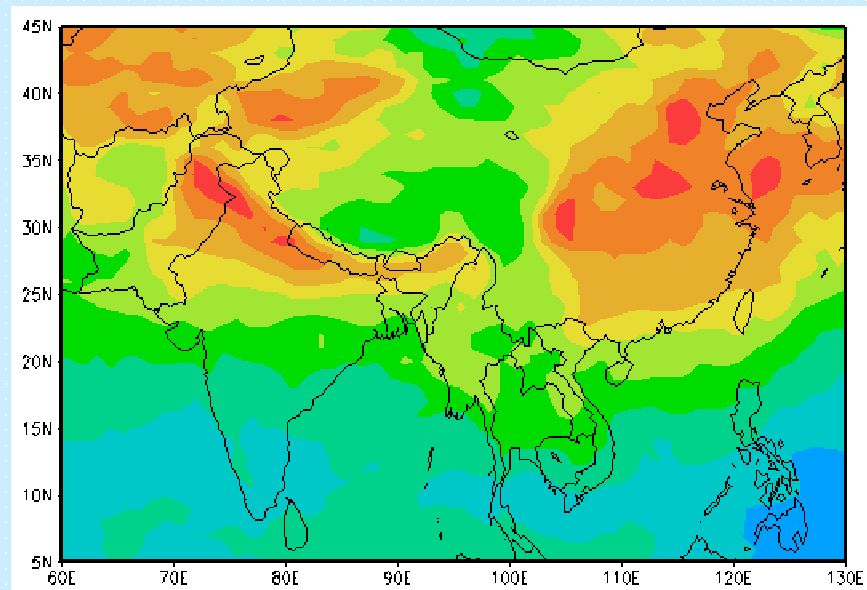
Typical El Niño

Population and Ozone Pollution Strongly Correlated in India and China

Population Density

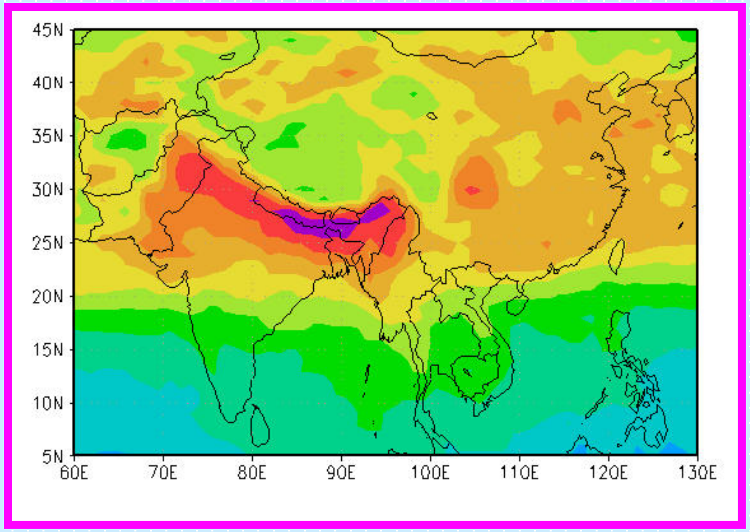


Summertime TOR Depiction

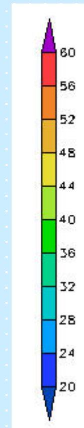


Asian Pollution Event Stronger than Historic 1988 Eastern United States Episode

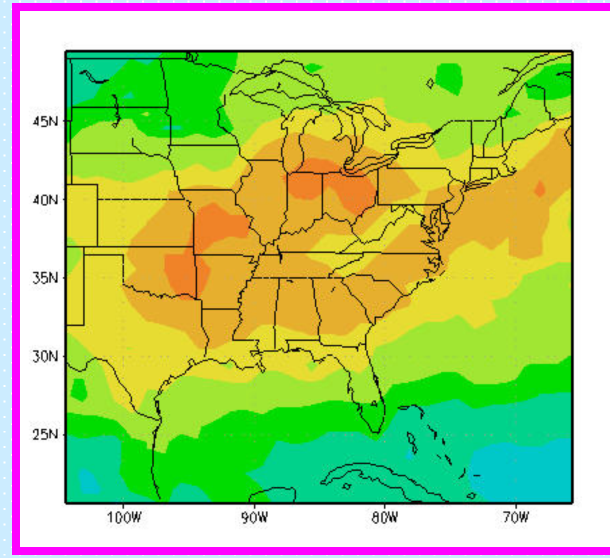
Monthly Depictions



TOR June 1982

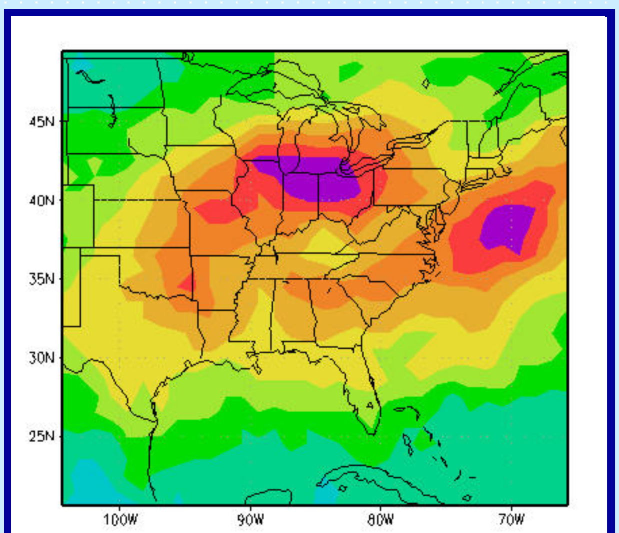


Dobson Units (DU)

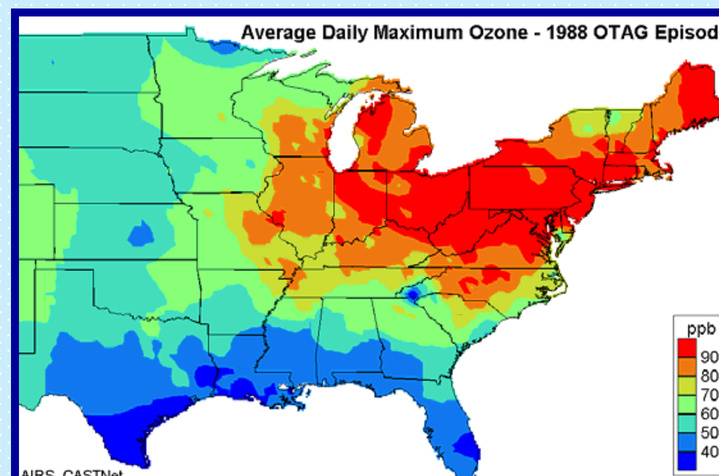


TOR July 1988

Episodic Depictions

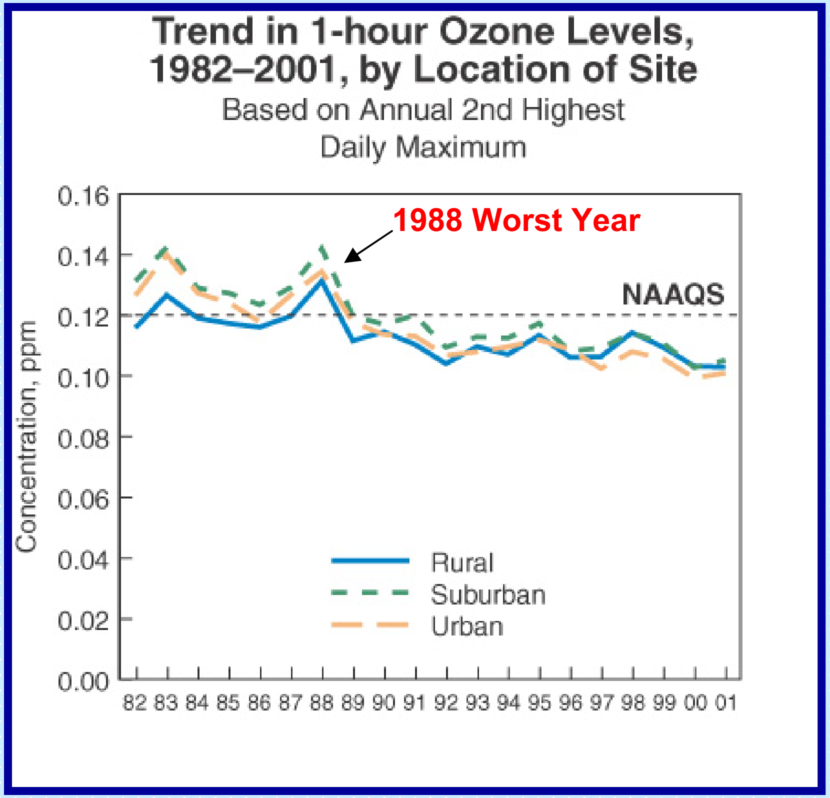


TOR July 3-15 1988

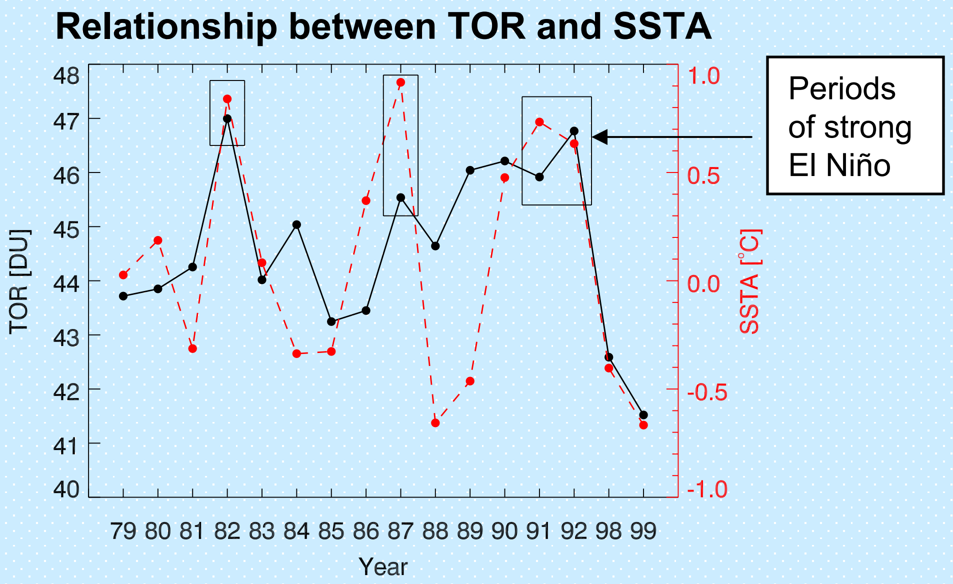


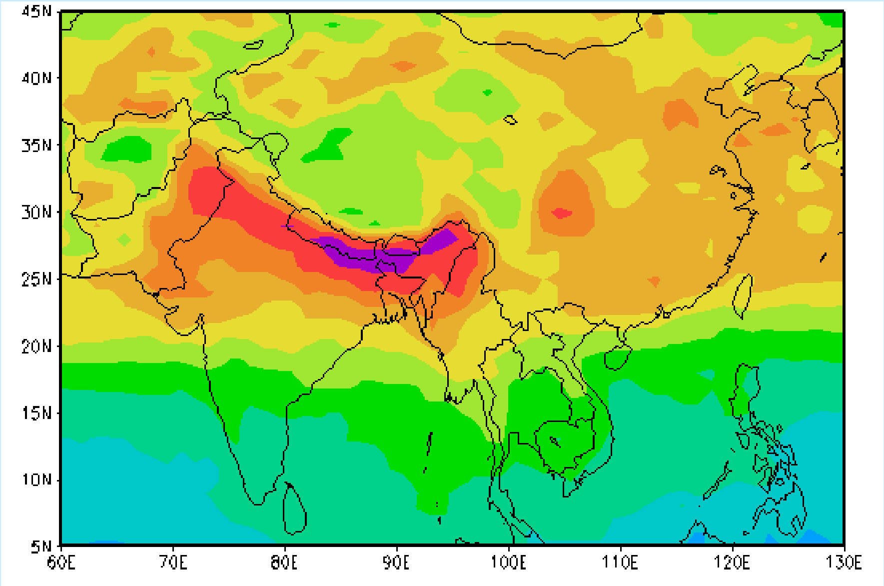
Surface O_3 July 3-15 1988

U.S. Surface Ozone Levels 1982-2001

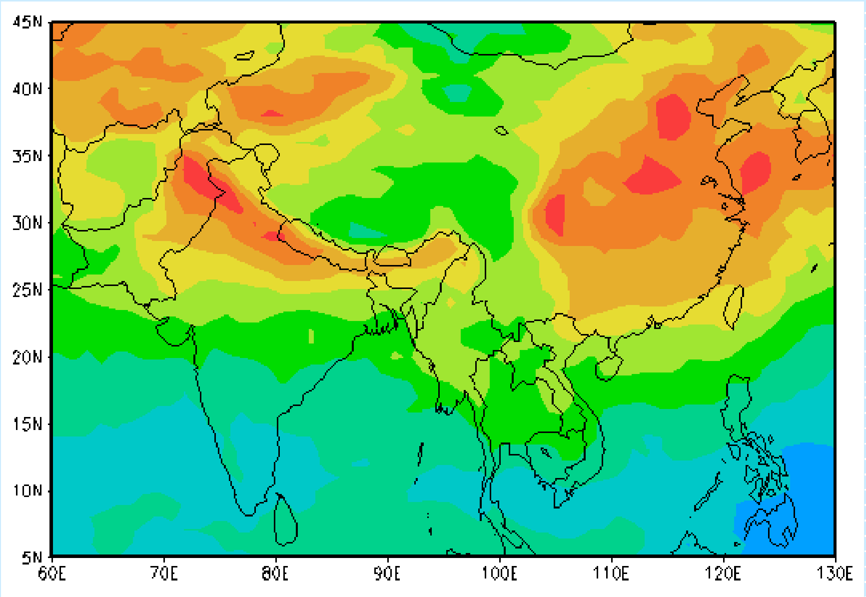


Interannual variability of TOR over Northern India strongly correlated with ENSO and strength of monsoonal flow





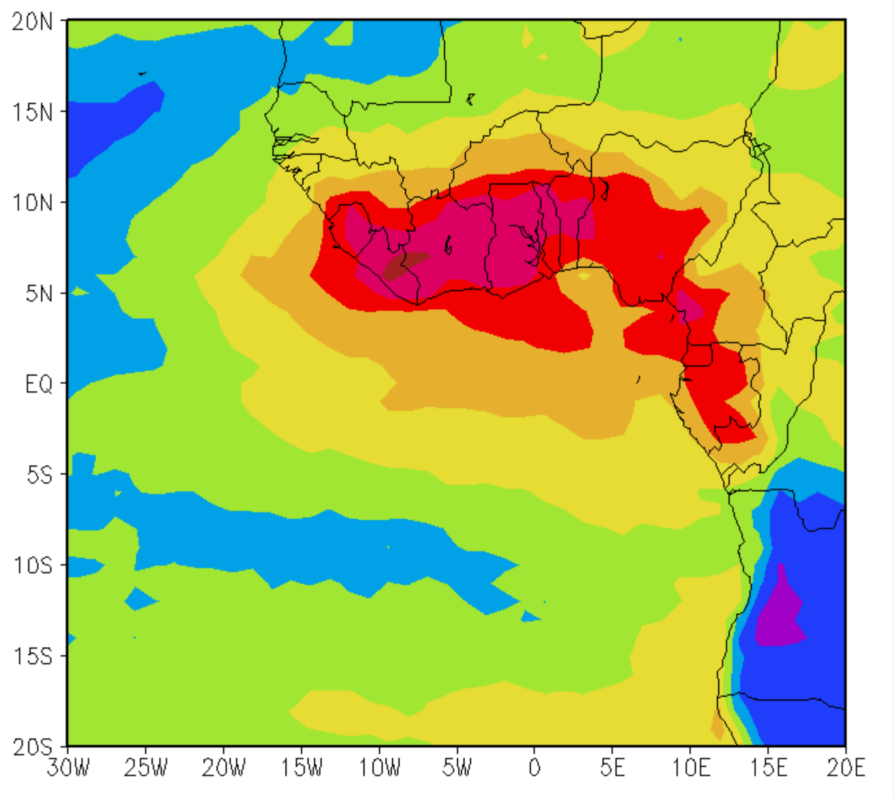
June 1982 - Strong El Niño Year

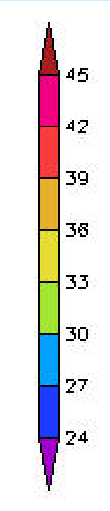


June 1999 - Strong La Niña Year

Significant Interannual Variability is also Evident between North and South of the ITCZ in West Africa: Potential Linkage to Phase of the El Niño

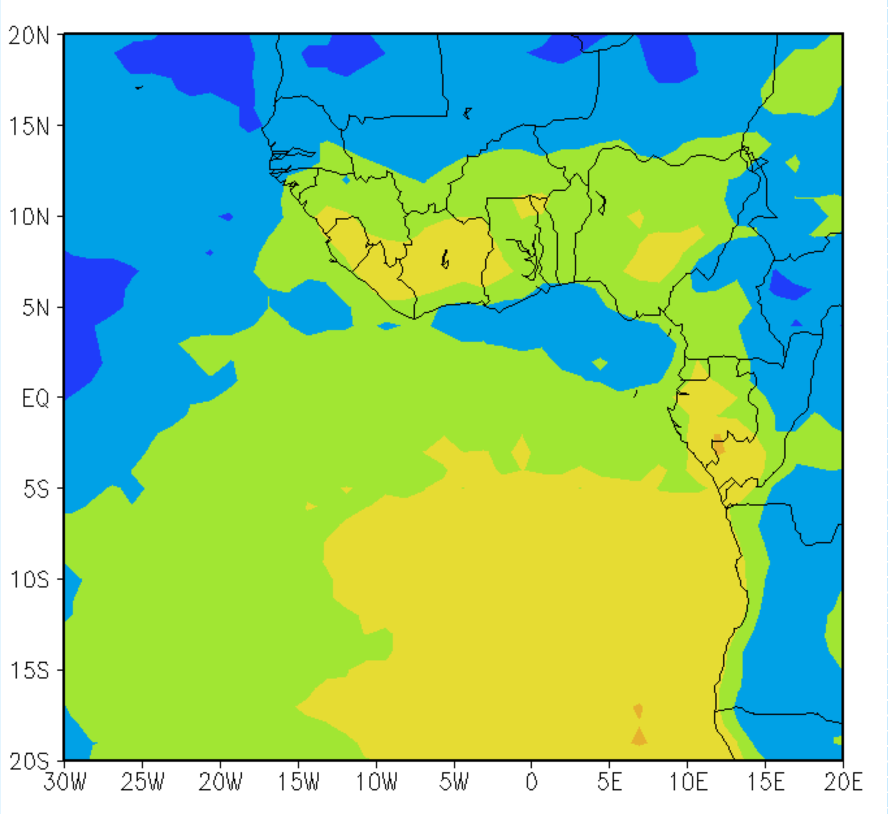
North-South TOR: June 1982





Dobson Units

North-South TOR: June 1984

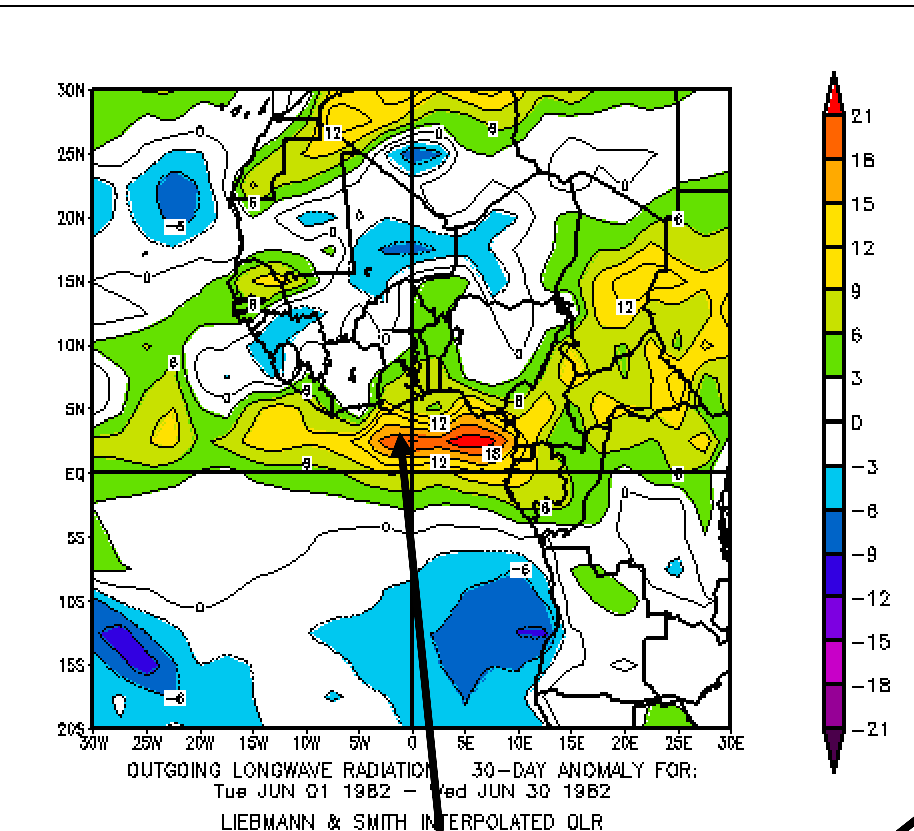


Strong El Niño

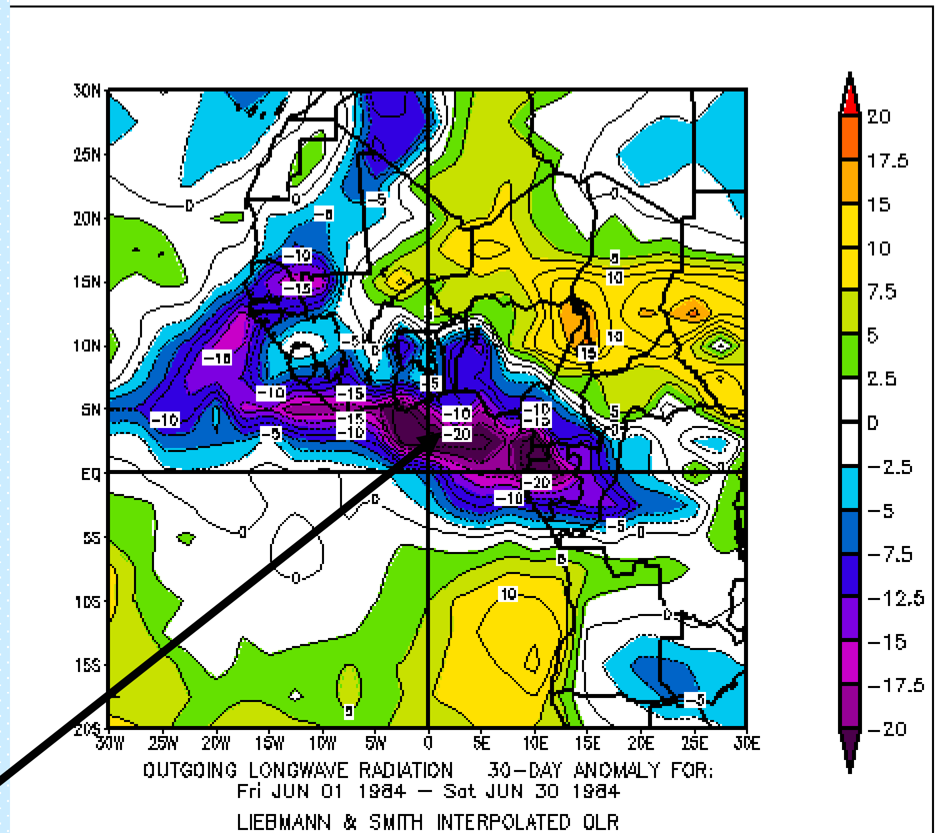
Strong La Niña

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

OLR – June 1982

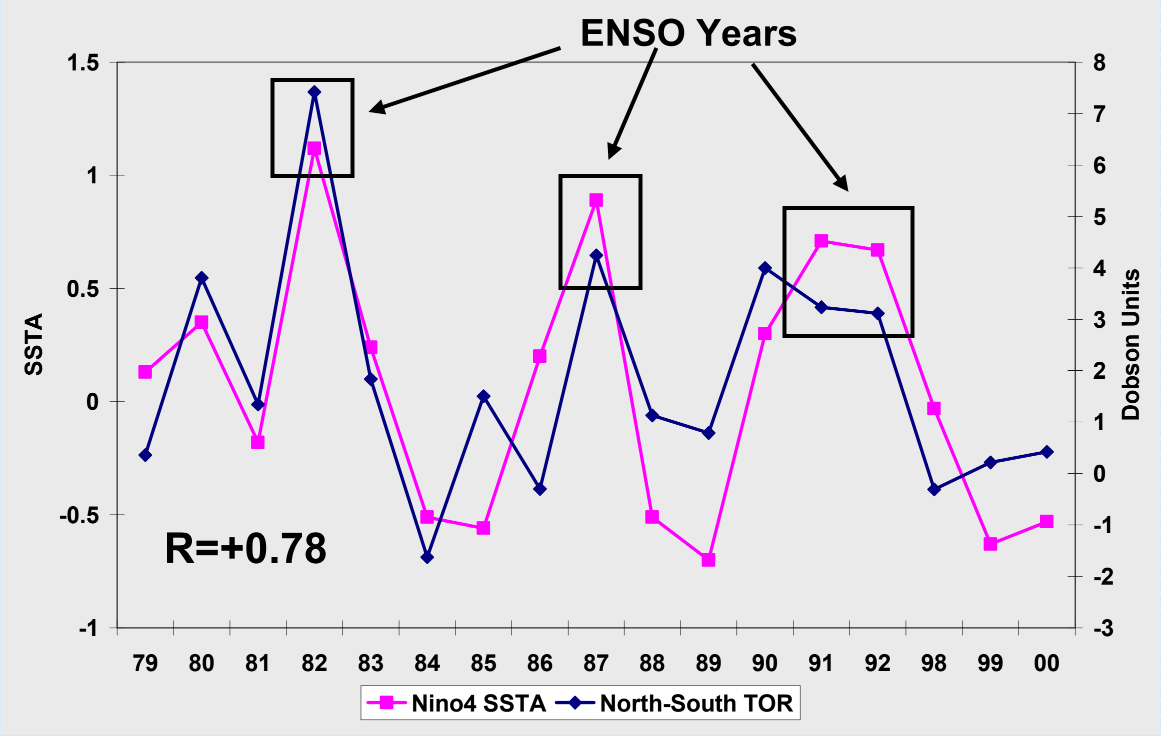


OLR – June 1984

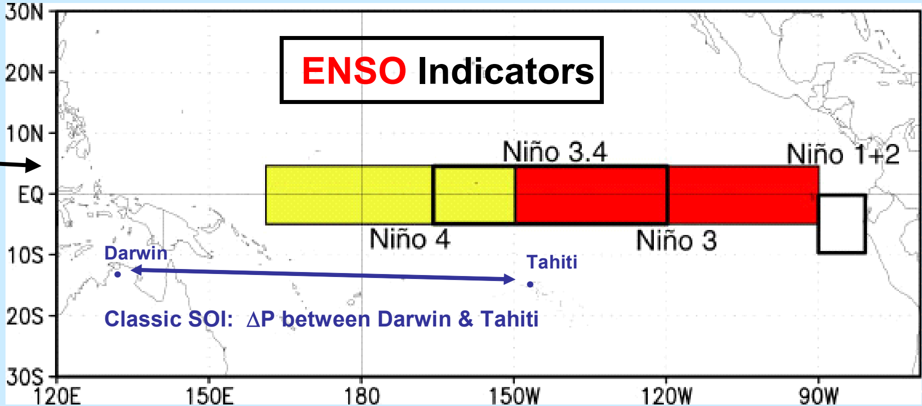


Positive Versus Negative Anomaly over the Same Region

North-South (5N-5S) June TOR Differential Versus Nino Region 4 SSTA: Strong Correlation Evident

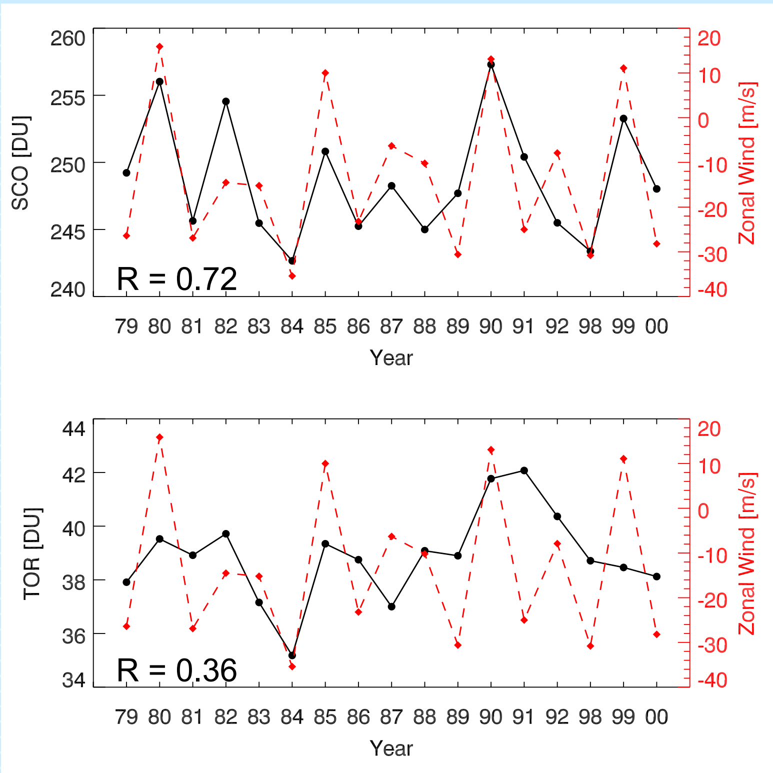


• Interannual variability of TOR is strongly correlated to ENSO cycle



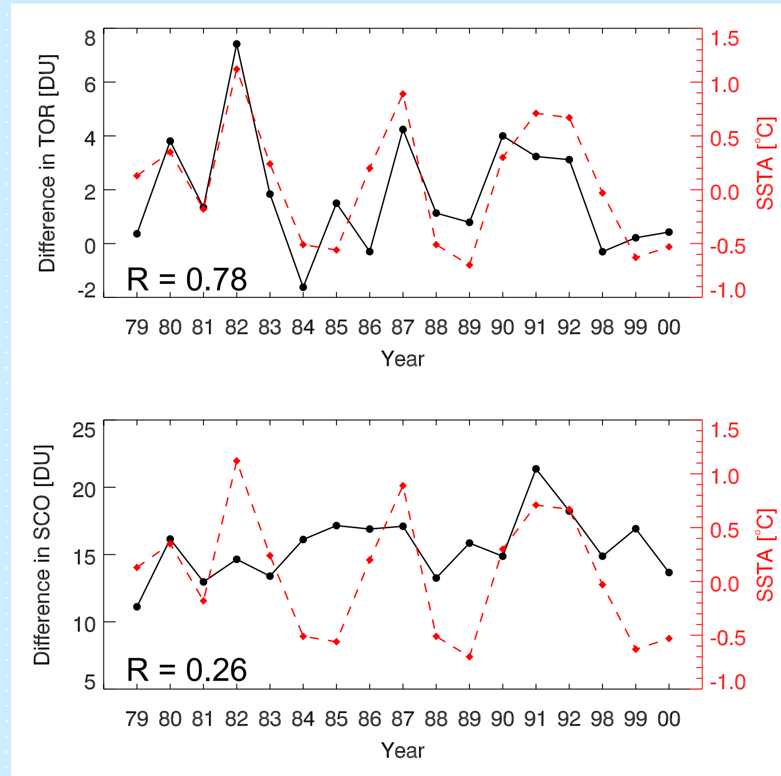
What can be said about the interannual variability of stratospheric ozone over this same region?

Stratospheric ozone over west Africa strongly correlated with quasi-biennial oscillation (QBO)



Correlation of TOR with QBO is much less significant

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



Correlation of SCO with ENSO is NOT significant

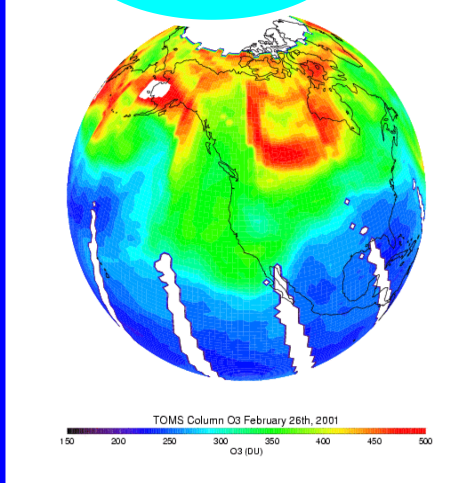
The Next Challenge:

Coupling Satellite Measurements with Models for Air Quality Applications

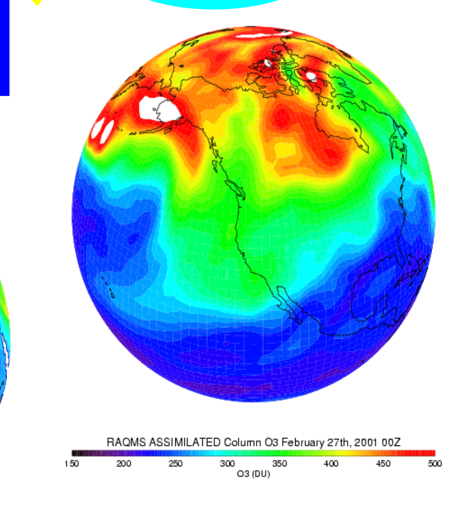
Regional Air Quality Modeling System (RAQMS)
A NASA Langley/UW-Madison Cooperative Research Effort*

RAQMS Ozone Prediction
February 27, 2001

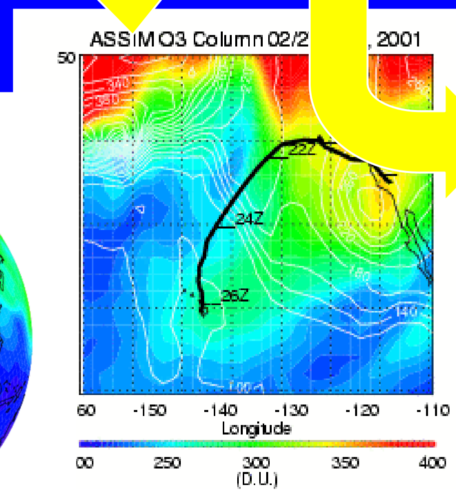
Satellite Data Products



Global Assimilation

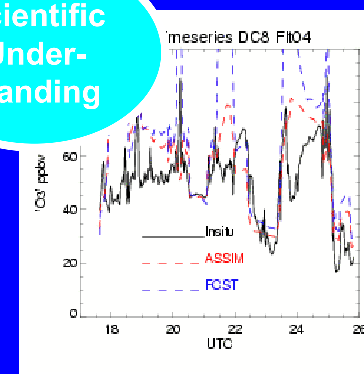


Regional Prediction



Public Impact

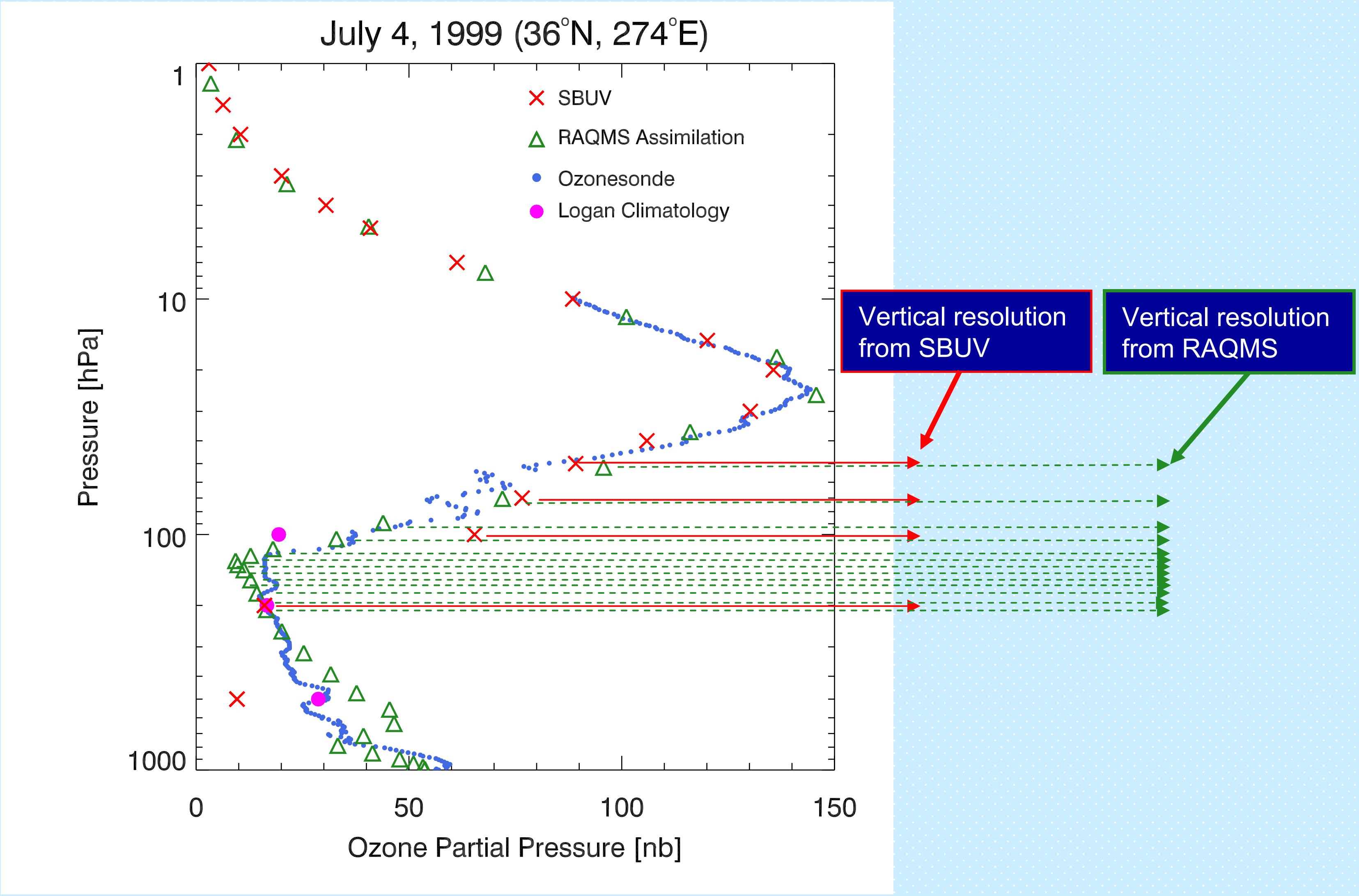
Scientific Under-standing



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

Assimilated Data Provide Much Better Information in Upper Troposphere and Lower Stratosphere Compared to Nadir-viewing Satellites: Critical for Residual Techniques



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!!