Interannual Variability of Regional Enhancements of Tropospheric Ozone Determined from Two Decades of Satellite Observations

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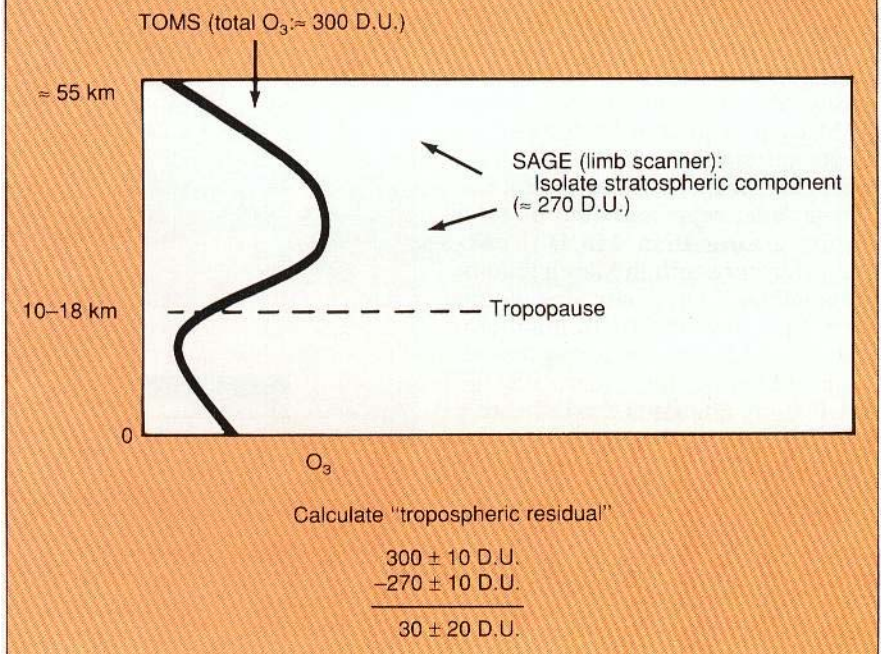
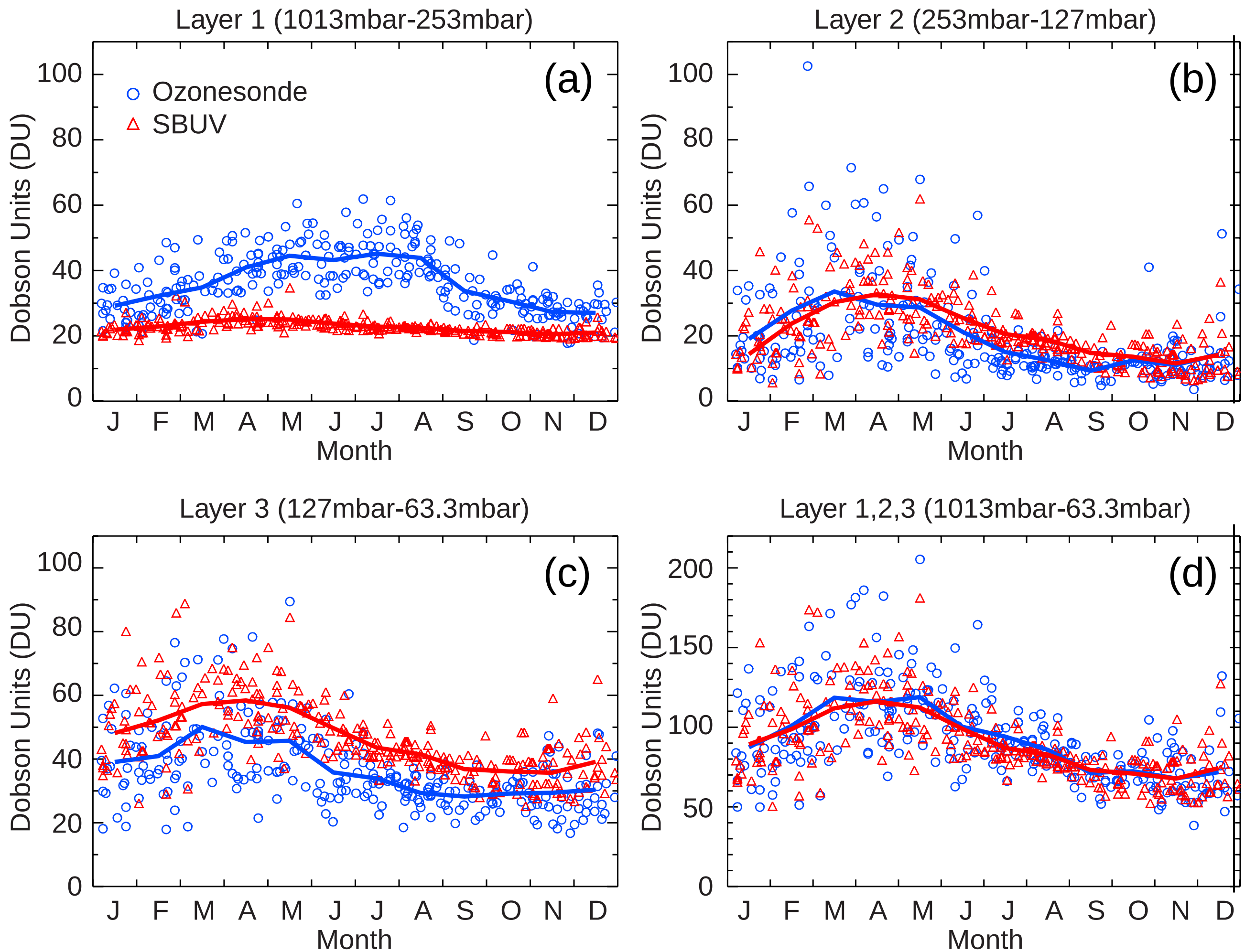
Separate Stratosphere from Troposphere to Compute Tropospheric Ozone Residual (TOR)

FIGURE 3
Schematic diagram showing how the tropospheric residual is calculated from coincident TOMS and SAGE measurements

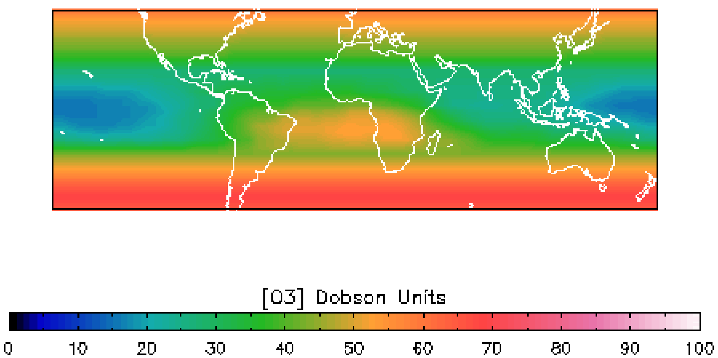


Climatological Comparison of Ozonesonde Data with SBUV Measurements at Wallops Island

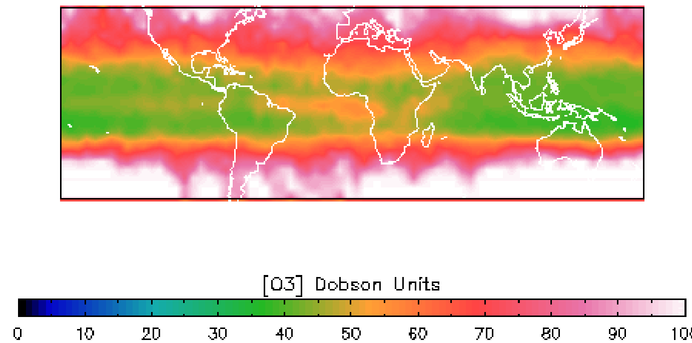


Information Contained in SBUV Measurements

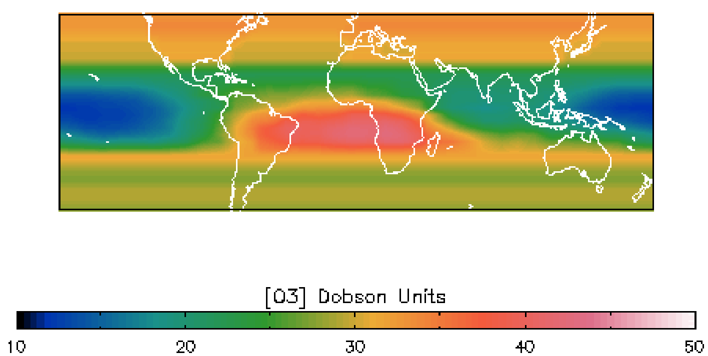
ozone.13.4x3.09
pressure level: 1000mb – 100mb



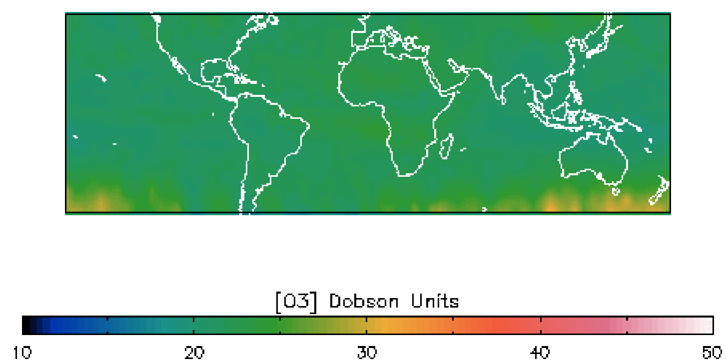
SBUV September 1992
pressure level: 1000mb – 63mb



ozone.13.4x5.09
pressure level: 1000mb – 250mb



SBUV September 1992
pressure level: 1013mb – 253mb



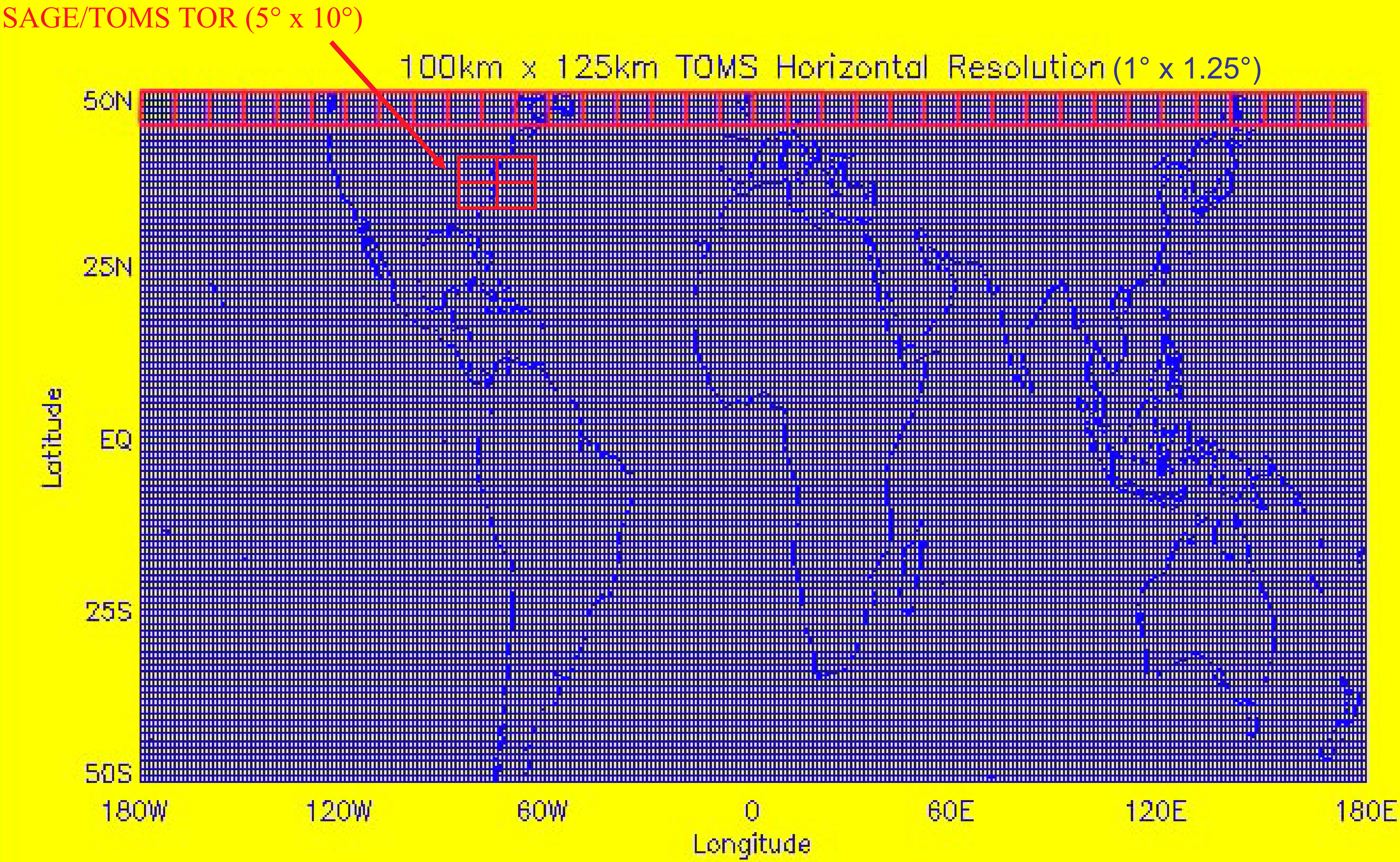
Other Data Sets Are Required To Separate Tropospheric Ozone from Total Ozone Measurements

- SAGE: Good Vertical Resolution; Poor Spatial Coverage
- HALOE: Good Vertical Resolution; Poor Spatial Coverage
- MLS: Vertical Resolution Only >68 mb; Relatively Good Spatial Coverage
- Only One Archived Layer below 100 mb
- SBUV: Poor Vertical Resolution; Good Spatial Coverage
  Archived Layers: 1000–253 mb; 253-126 mb; 126-63 mb
  Stratospheric Fields Generated from 5 Days of Data

  - **SAGE/TOMS TOR:** ~ 30,000 Coincident Observations 1979-1991 [Fishman & Brackett, 1997]
    ~ **10 data points per 5° x 10° grid box** for seasonal climatology
  - **SBUV/TOMS TOR:** Use Every TOMS Observation (up to 28,800 per day)
    ~ **1500 data points per 1° x 1.25° grid box** for seasonal climatology

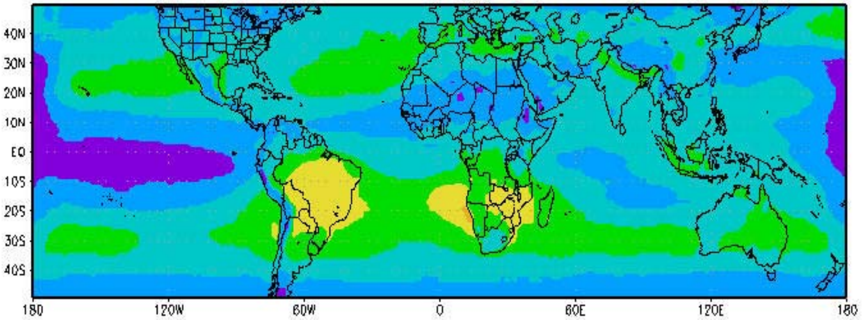
- Tropopause Heights: Archived Gridded Data Sets 2.5° x 2.5°

Comparison of Pixel Size for Computing TOR

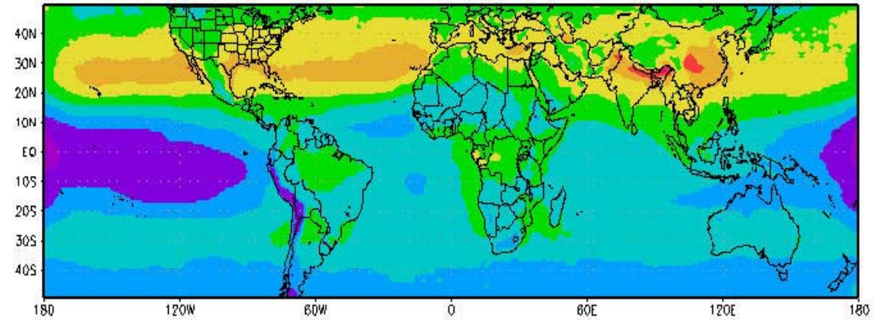


Seasonal Depictions of Climatological Tropospheric Ozone Residual (TOR) 1979-2000

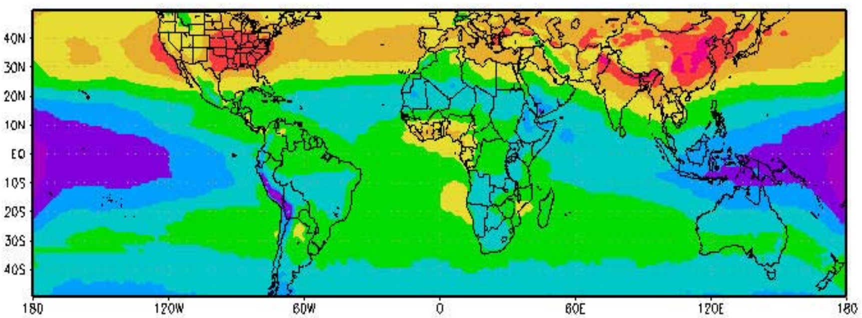
SBUV Tropospheric Ozone Residual (TOR) DJF 1979-2000



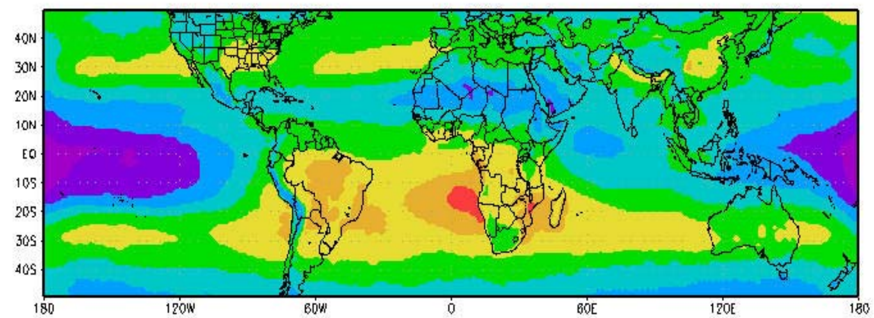
SBUV Tropospheric Ozone Residual (TOR) MAM 1979-2000

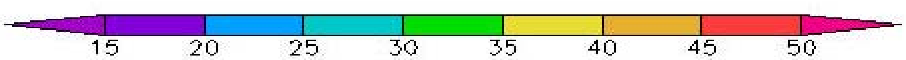


SBUV Tropospheric Ozone Residual (TOR) JJA 1979-2000

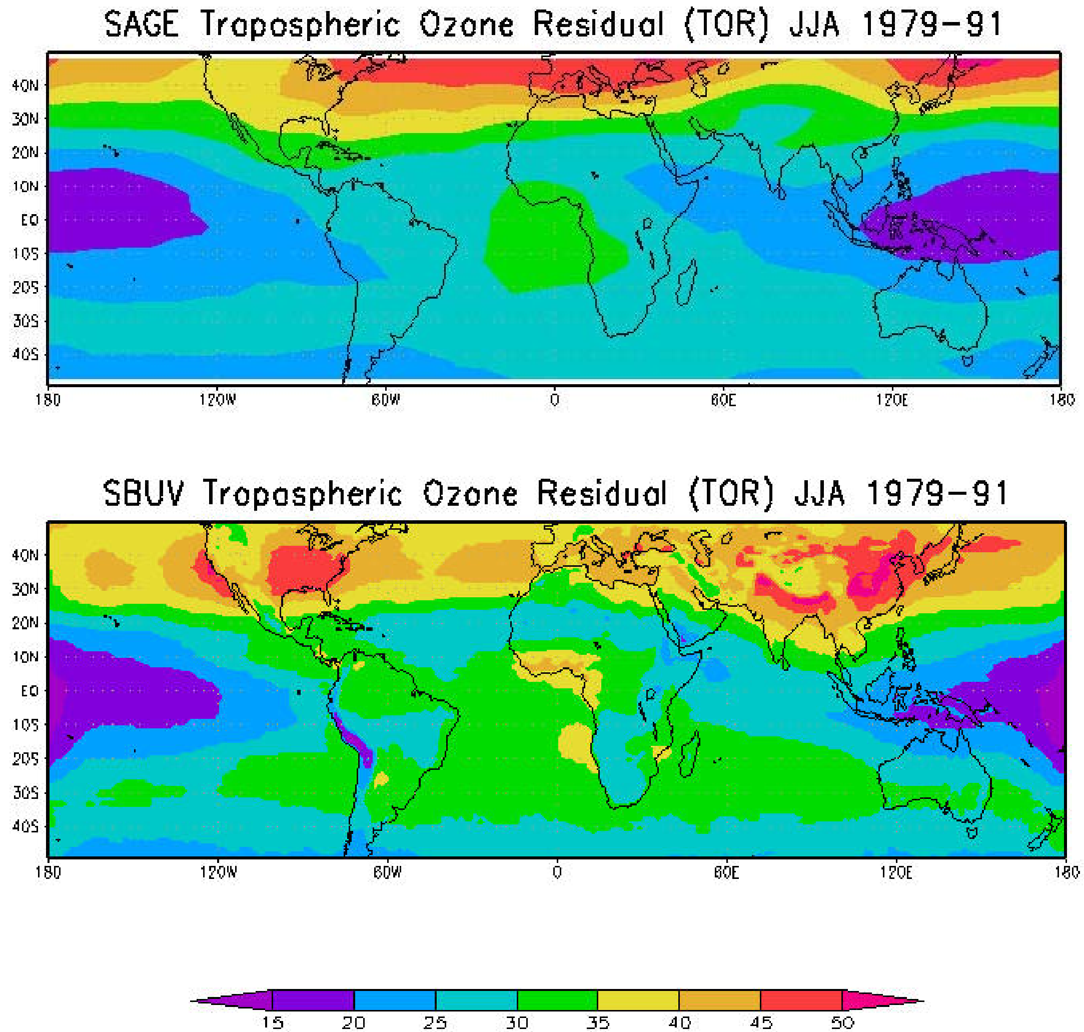


SBUV Tropospheric Ozone Residual (TOR) SON 1979-2000



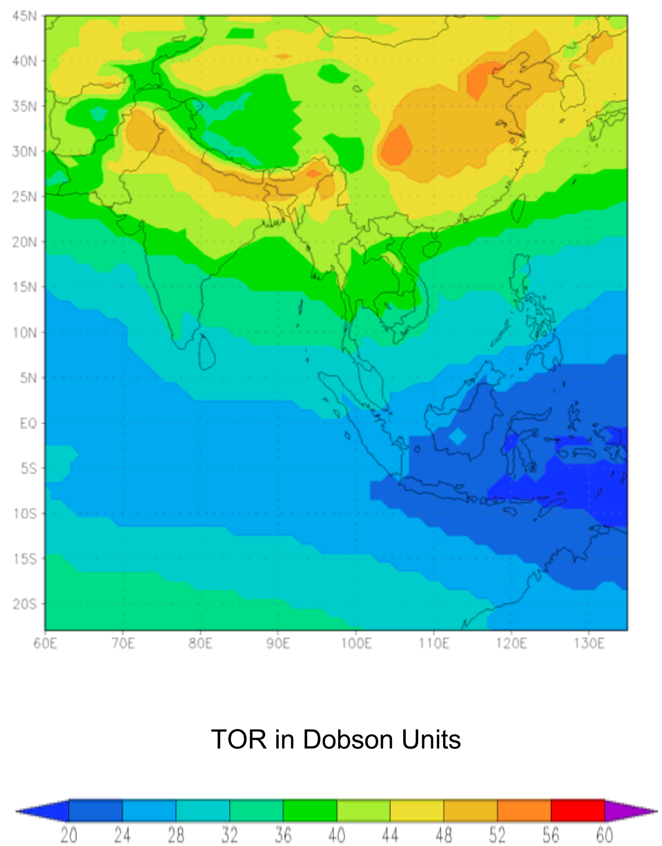


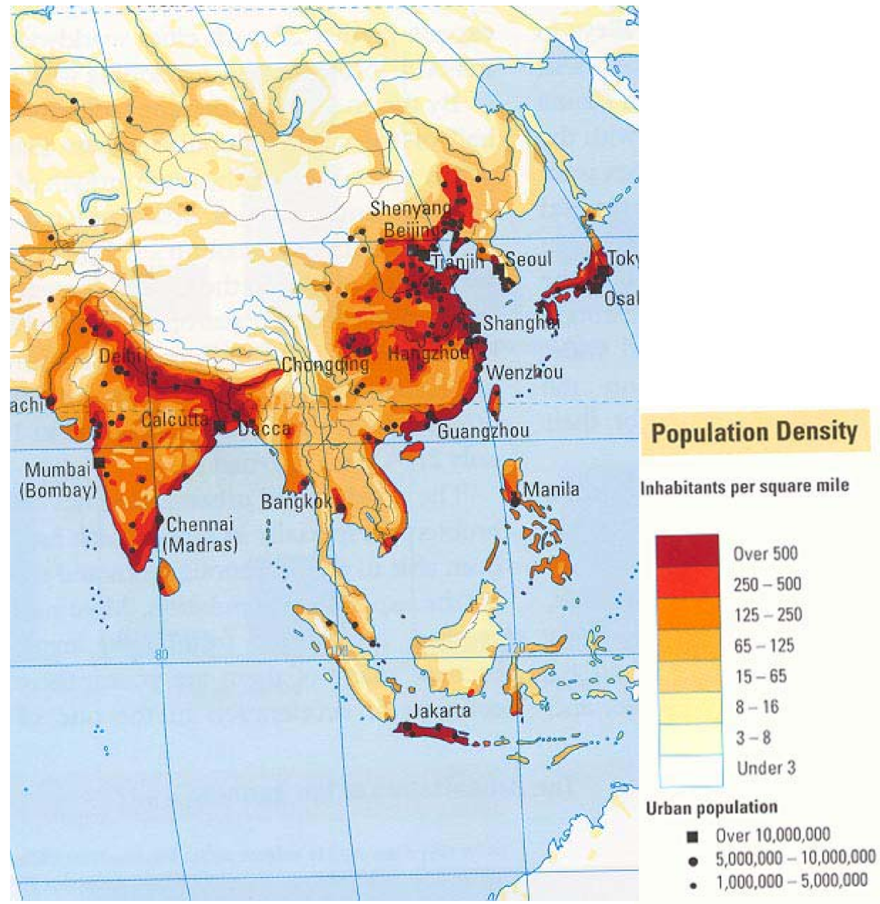
Comparison of TOMS/SAGE TOR with TOMS/SBUV TOR



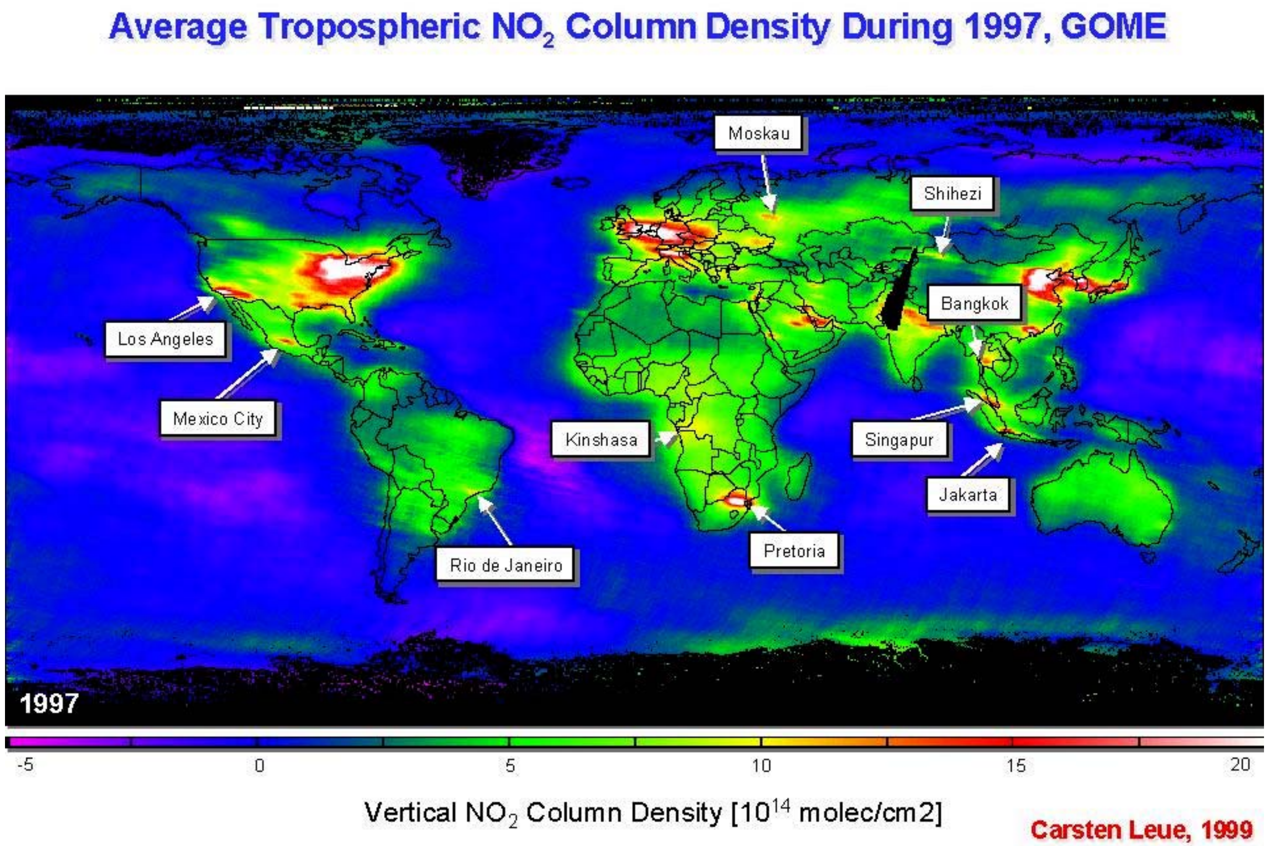
Population and Ozone Pollution Strongly Correlated in India and China

Summer Climatological Distribution

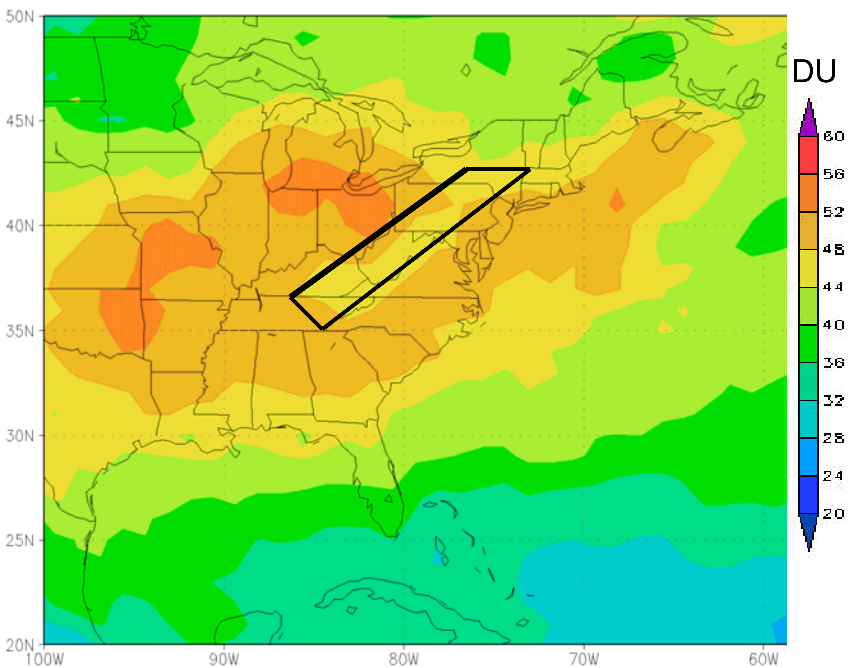




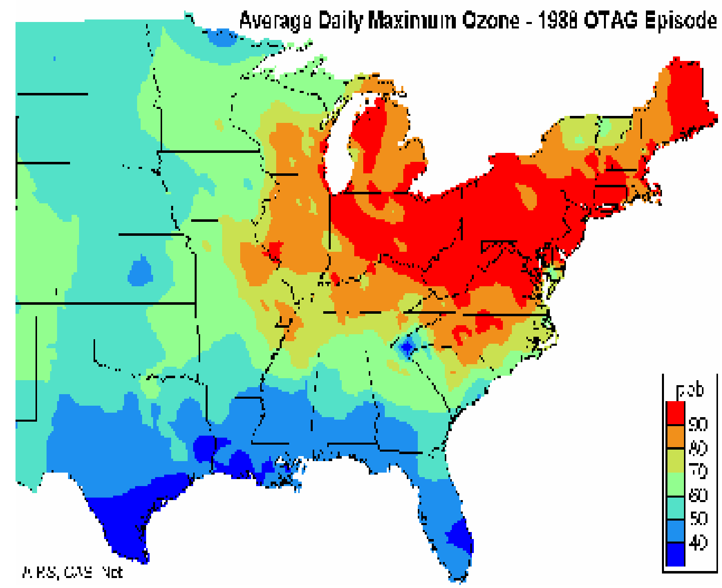
GOME NO_2 Measurements Also See Enhancements over India and China



July 1988 Monthly TOR Captures High Ozone During Major Pollution Episode



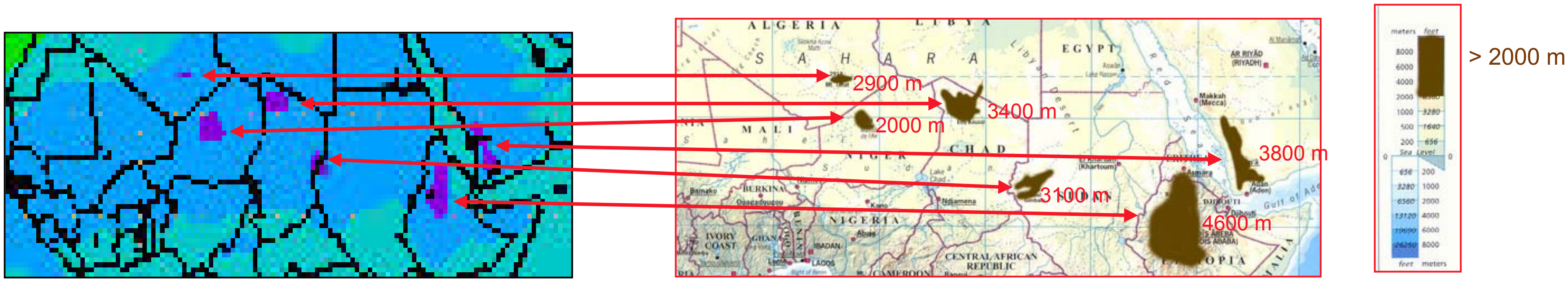
July 1988 TOR



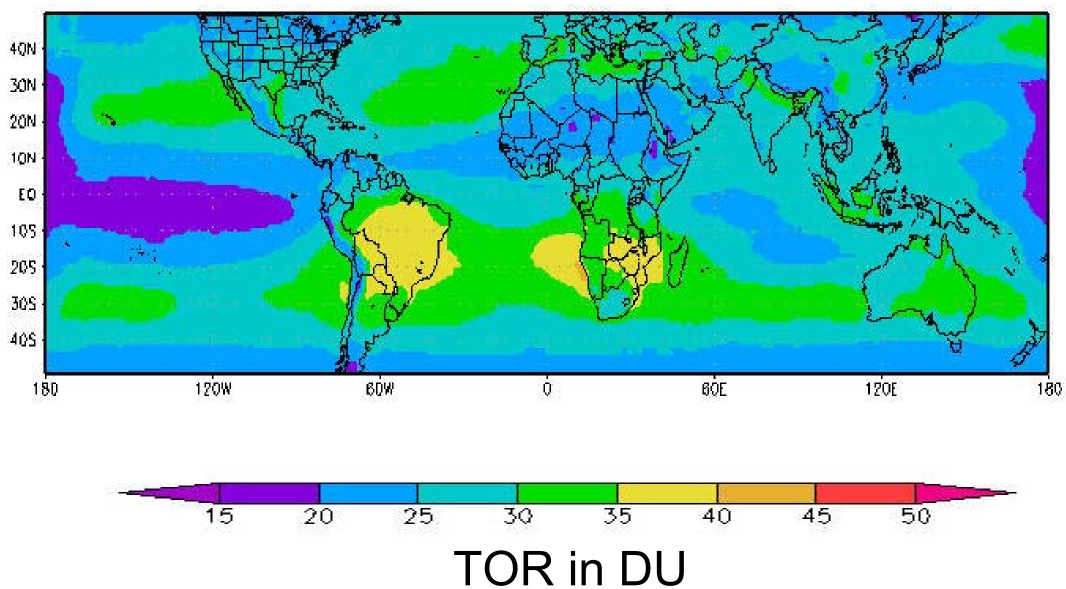
July 3-15 Average Daily Max. O_3
(from Schichtel and Husar, 1998)

- Lower TOR within box due to terrain artifact
- Use terrain information for global validation

Lower TOR over North African Desert Regions Coincident with Higher Elevations



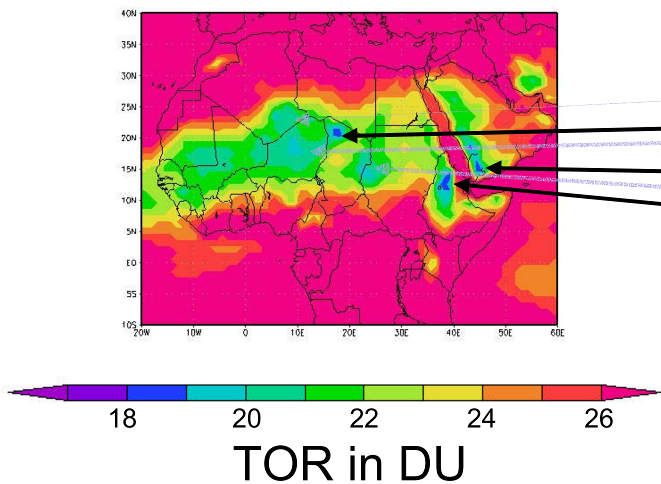
December-February TOR

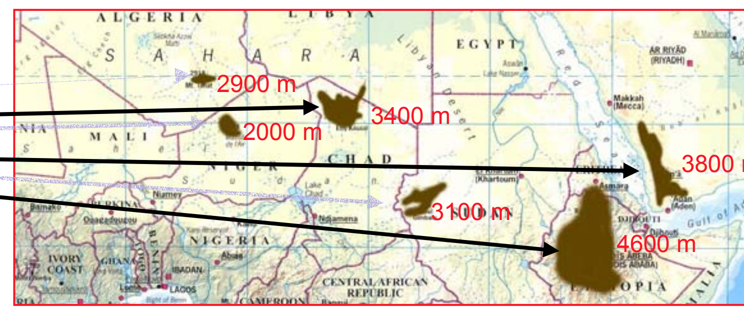


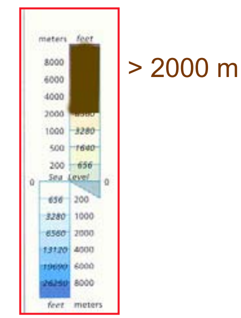
<u>Implications</u>:

- TOMS Capable of Isolating Small (Regional) Scale Features
- ~3 DU for $\int^{2km} dz \Rightarrow$ ~20 ppb in pbl
- Information can be used to validate O_3 backscatter sensitivity in boundary layer over cloudless unpolluted area

Higher Elevation Differences (3-4 km) Coincident with Greater O_3 Deficits (5-7 DU)





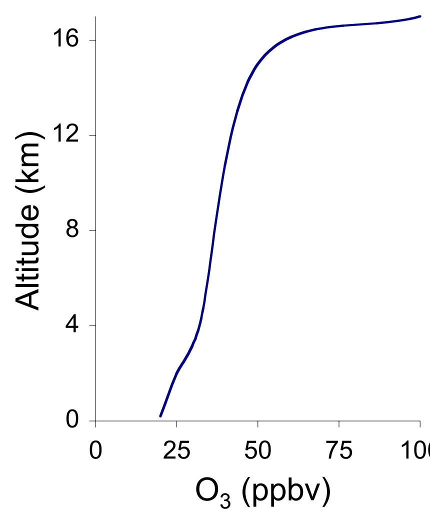


- Inferred Ozone Profile over North Africa Desert Region:

$$\int^{\mathbf{2}\ \mathrm{km}} [O_3]\, dz = \sim 3\ \mathrm{DU}$$

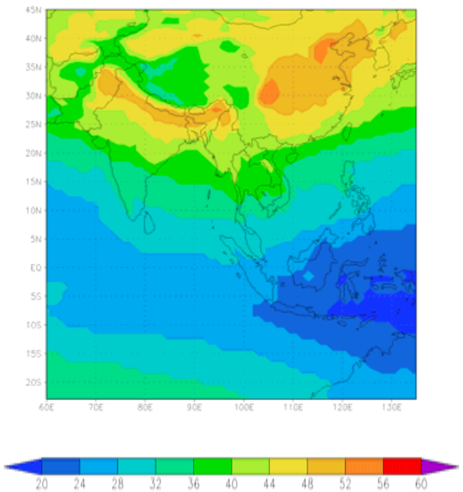
$$\int^{\mathbf{4}\ \mathrm{km}} [O_3]\, dz = \sim 6\ \mathrm{DU}$$

$$\int^{\mathrm{Trop.}\ (\sim 17\ \mathrm{km})} [O_3]\, dz = \sim 25\ \mathrm{DU}$$

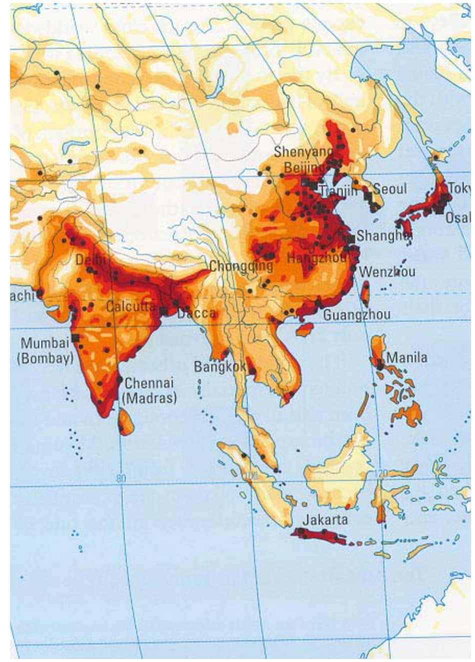


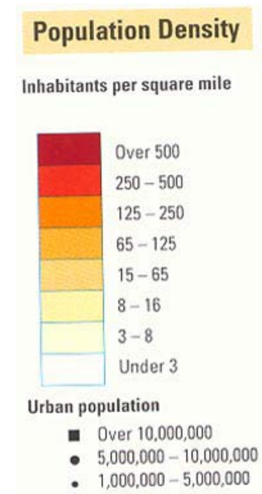
Ozone Enhancement over India

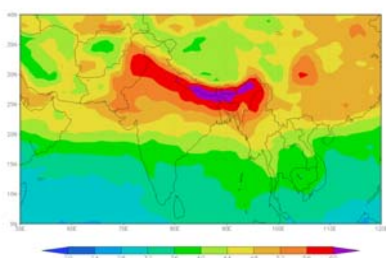
Summer Climatological Distribution



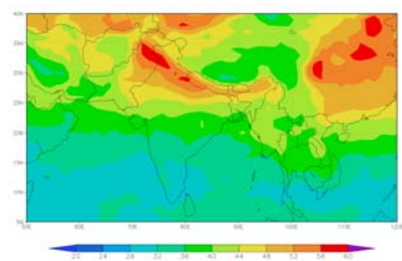
TOR in Dobson Units







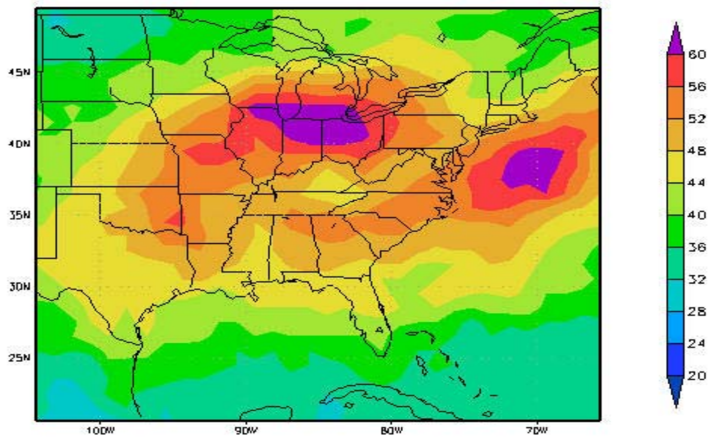
June 1982 – El Niño

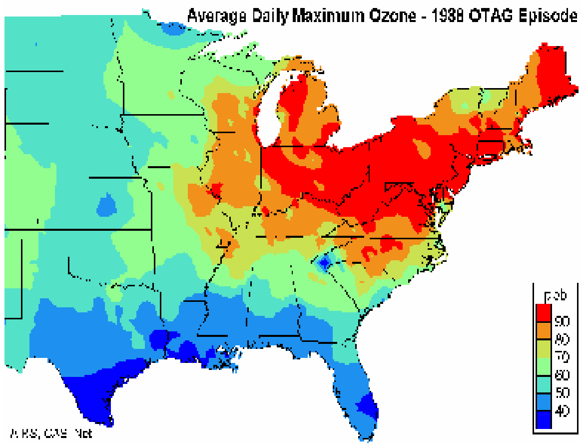


June 1999 – La Niña

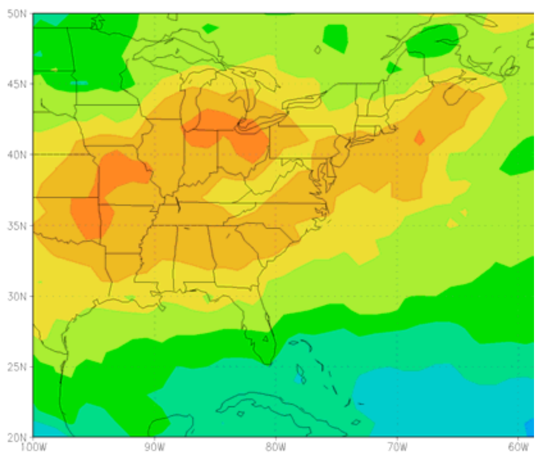
How does the Amount of Ozone over India Compare with the Amount Observed over the Eastern United States?

Comparison of Indian and U.S. Air Pollution Episodes

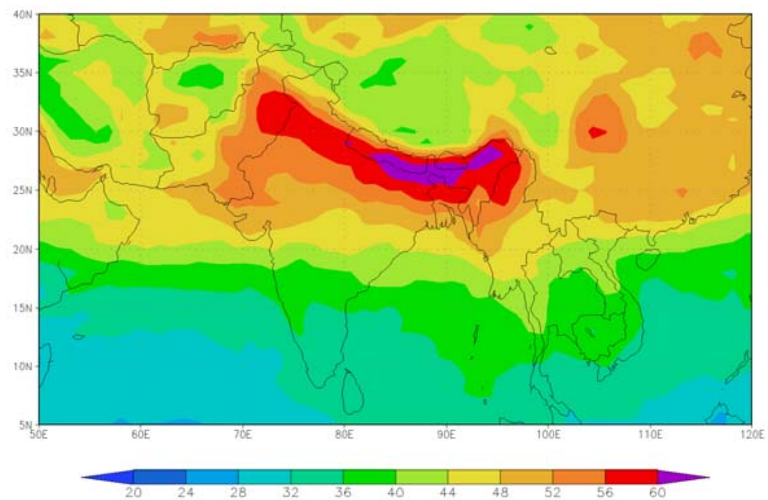




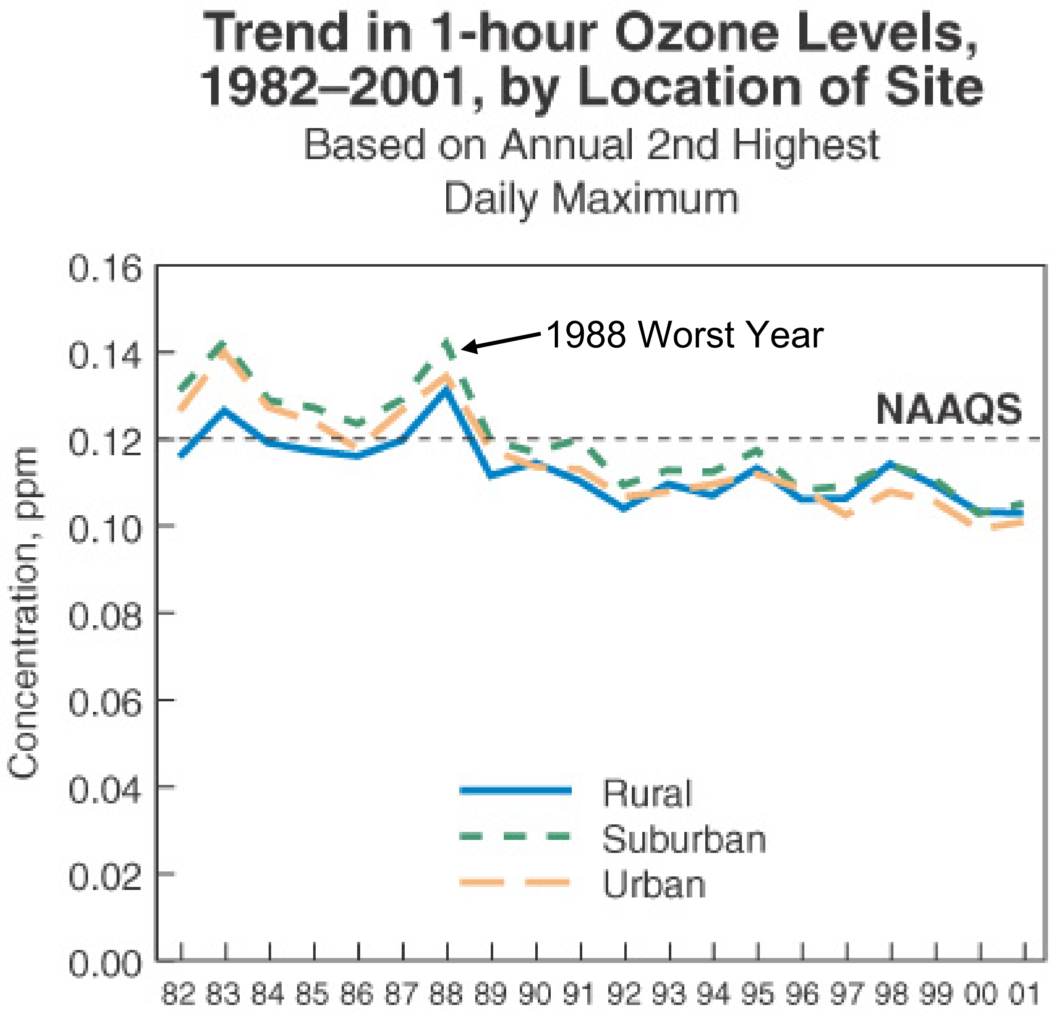
TOR and Surface O_3 Depiction During July 3-15 Pollution Episode



July 1988

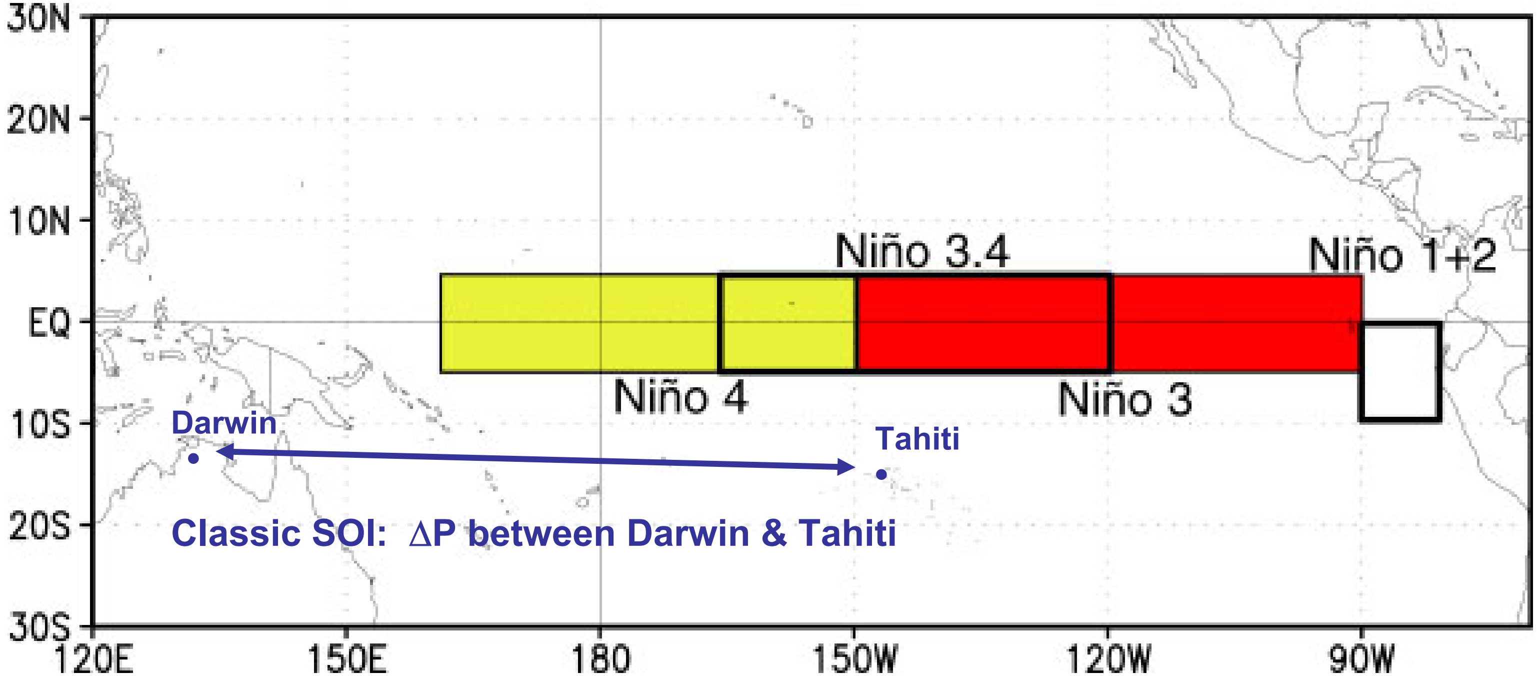


June 1982



Trend in 1-hour Ozone Levels,
1982–2001, by Location of Site
Based on Annual 2nd Highest
Daily Maximum
1988 Worst Year
NAAQS
Concentration, ppm
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01
Rural
Suburban
Urban

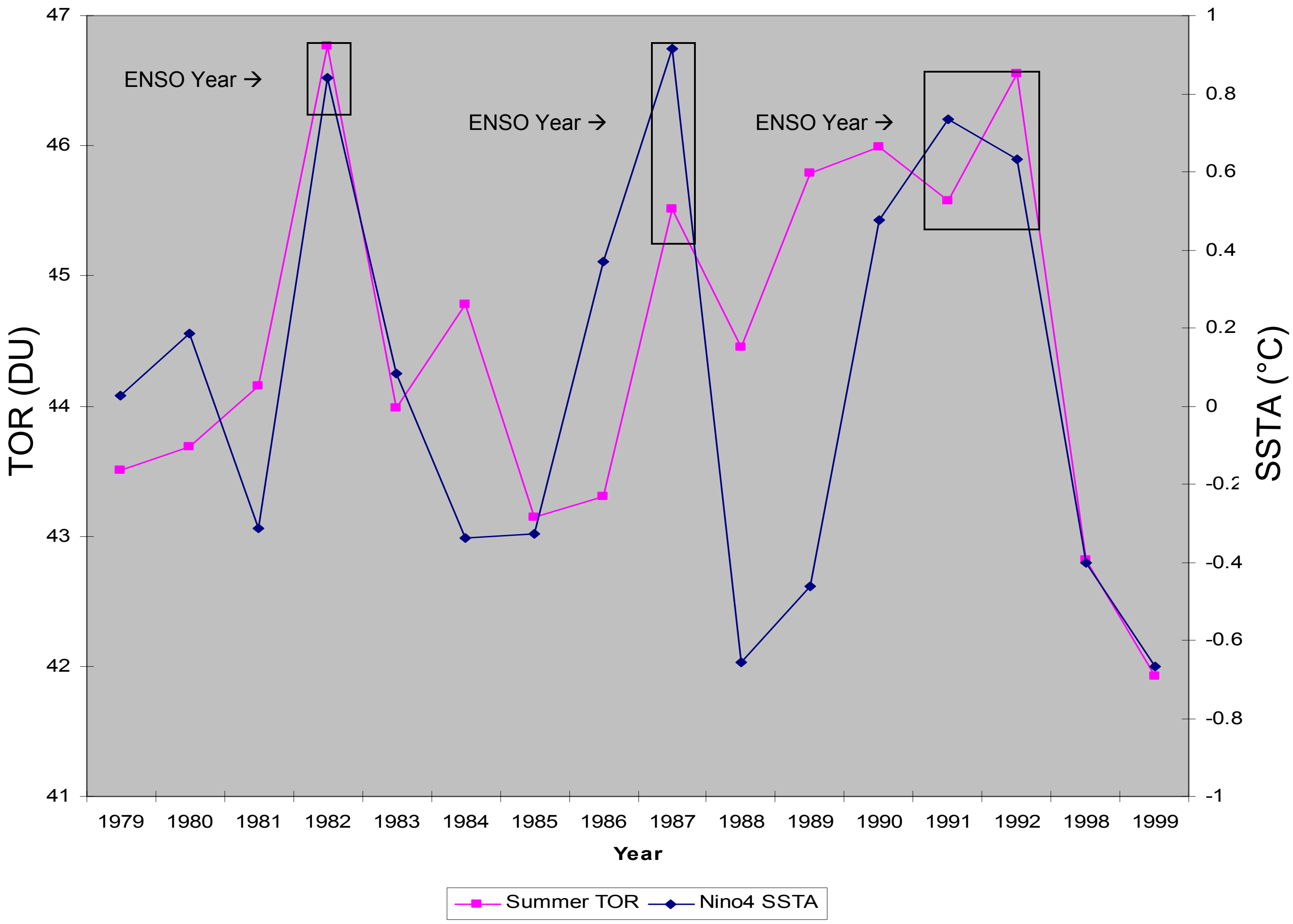
Definitions of ENSO Indicators



Other definitions include Sea Surface Temperature Anomalies (SSTA) in various regions of the Pacific:

Niño 1+2: Off coast of Ecuador; Niño 3: Eastern Pacific; Niño 4: Western Pacific; Niño 3.4: Central Pacific

Summer India TOR and SSTA-Niño 4 from 1979-1999



Correlation Coefficients Between Northern India Monthly TOR Values and Monthly/Seasonal ENSO Indicators (1979-1999)

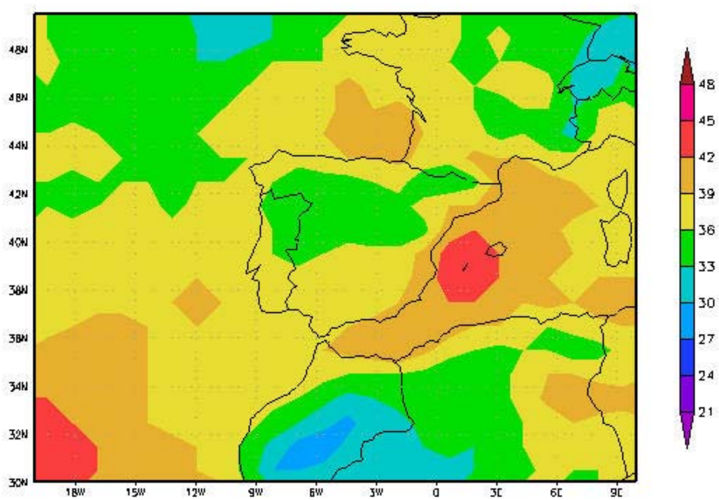
Month	Mean TOR	Range		SOI		ENSO SST Region			
		High	Low	Mon	Seas	1&2	3	3.4	4
January	29.8	31.5 (1991)	25.7 (1980)	.04	-.01	.07	-.04	-.06	-.01
February	29.9	33.3 (1992)	25.1 (1991)	-.33	**-.45**	.11	.27	.33	.21
March	34.6	40.5 (1989)	26.7 (1999)	.02	.02	-.15	-.14	-.06	.15
April	44.0	47.2 (1982)	40.5 (1985)	-.21	-.23	-.05	.13	.19	.31
May	47.3	52.9 (1982)	42.4 (1998)	.21	.23	-.17	.11	.15	.31
June	48.2	52.1 (1982)	45.4 (1999)	**-.45**	**-.56**	-.09	.28	.41	**.44**
July	46.4	48.3 (1982)	44.0 (1999)	**-.53**	**-.60**	.09	**.43**	**.62**	**.70**
August	42.0	43.7 (1992)	40.4 (1999)	**-.44**	**-.53**	.15	**.46**	**.54**	**.61**
September	36.8	40.1 (1990)	35.2 (1979)	.09	.16	-.26	-.25	-.22	.06
October	32.7	35.0 (1999)	30.6 (1987)	**.55**	**.45**	-.36	-.42	**-.46**	**-.52**
November	30.5	33.2 (1981)	28.6 (1984)	.27	.08	.11	.04	.00	-.12
December	27.9	30.0 (1997)	25.8 (1984)	**.43**	.21	.14	.02	-.07	-.13

Note: Monthly Average for each year comprised of >7500 TOR measurements (252 points x ~30 days)

- Shaded Values Statistically Significant (>.9 confidence level)
- Most Significant Relationship between Summer TOR and Seasonal ENSO Indicators

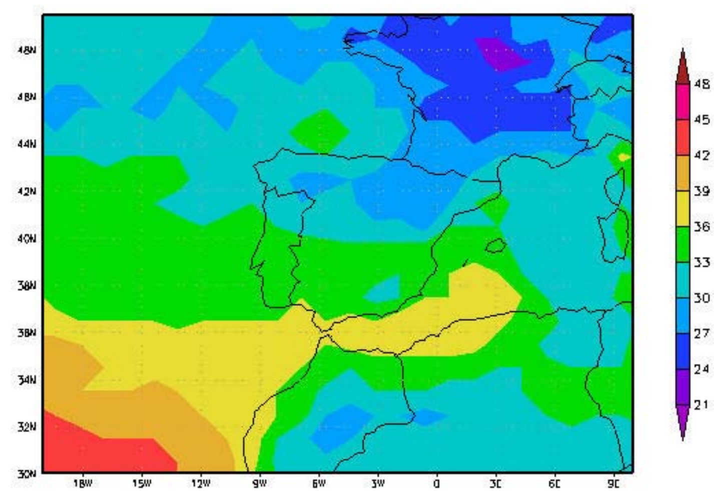
Springtime TOR Variability Over Atlantic Mid-Latitudes Linked to Differences in Prevailing Transport Patterns

Spring 1992



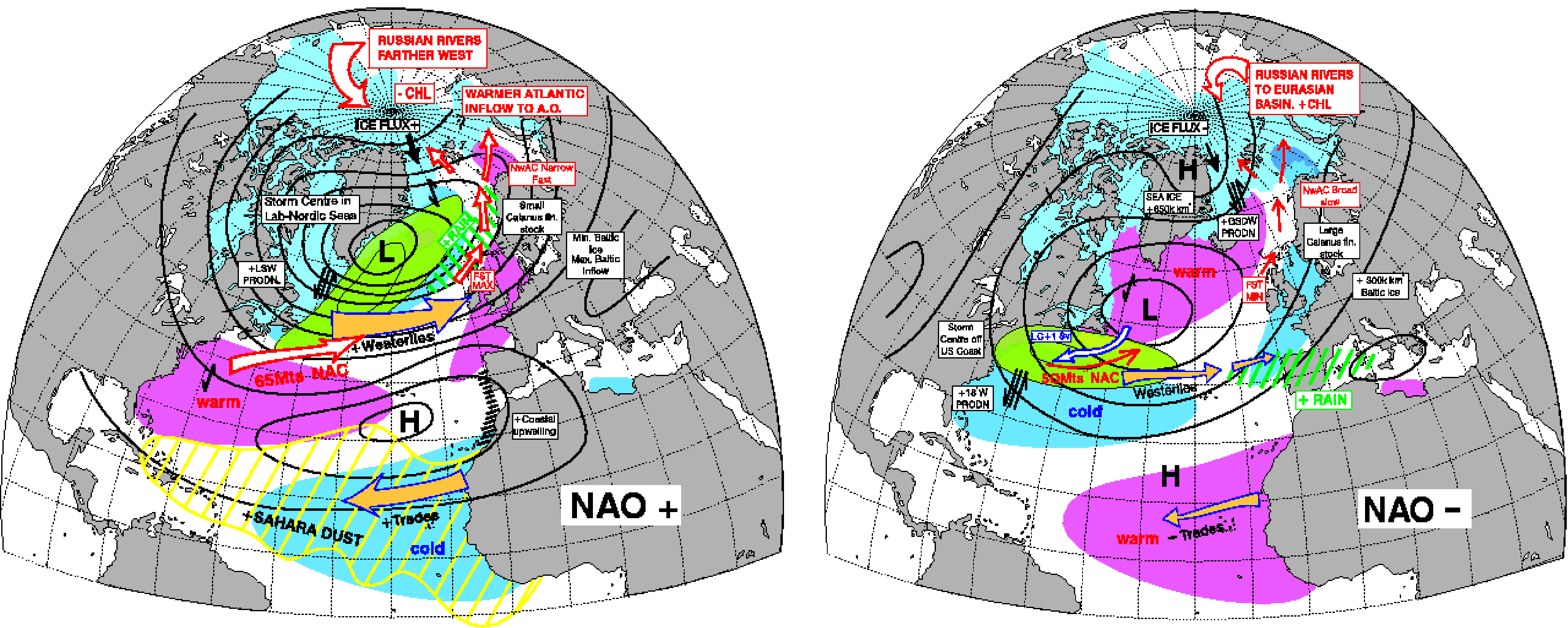
Positive NAO

Spring 1980

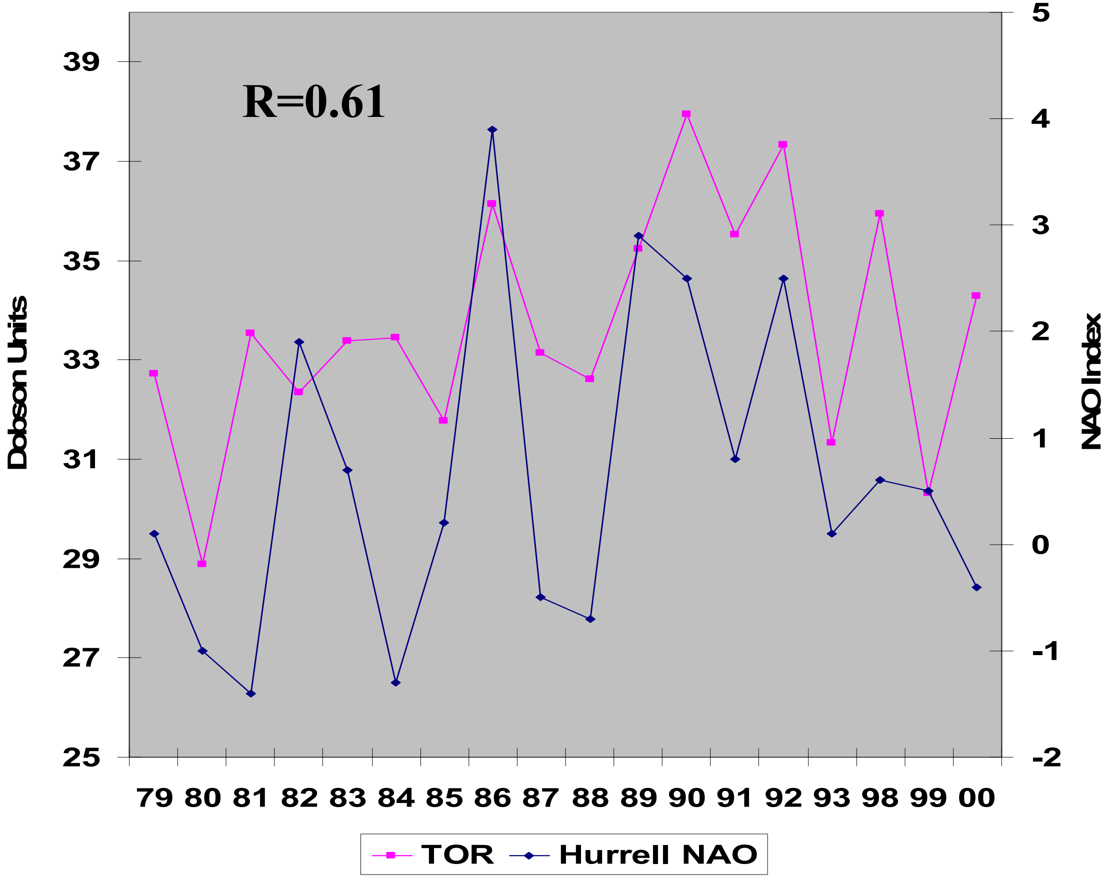


Negative NAO

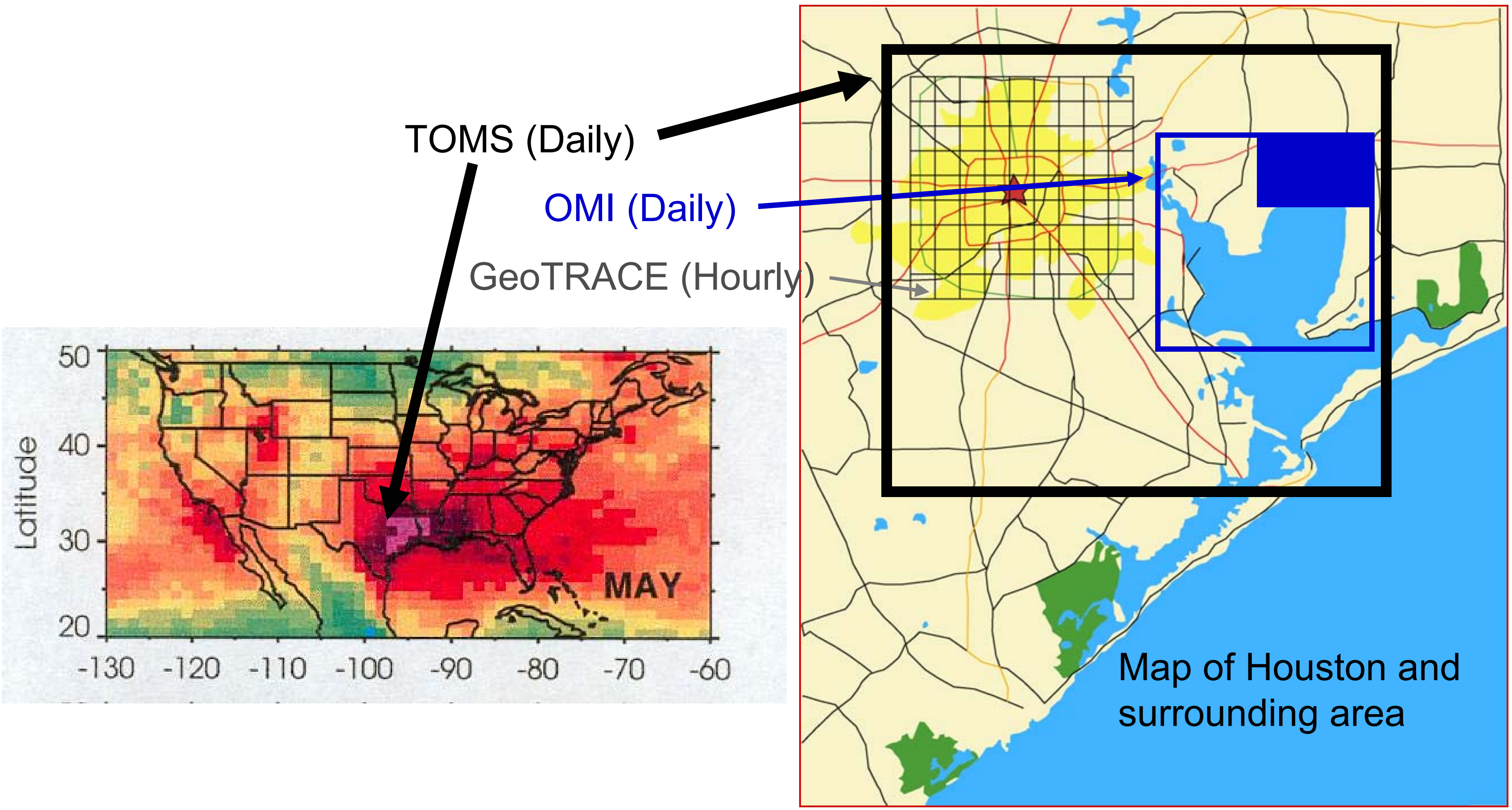
North Atlantic Oscillation Determines Intensity of Transport Across Atlantic



Strong Correlation between TOR and NAO Index



Geostationary Observations Will Provide Hourly Observations with 5-km Resolution



Summary of 20 Years of SBUV/TOMS TOR Measurements

Data located at:

http://asd-www.larc.nasa.gov/TOR/data.html

- Strong Correlations Apparent:
  - Pollution and Population Distributions
  - N.E. India and ENSO
  - Atlantic and NAO
- High Resolution Data Delineate Elevated Terrain
  - Possible Use for Validation
- Can ENSO or Other Indicators be Used as Predictors?
- Best Way to Study Tropospheric Chemistry is from Geostationary Platform