Insights into the Interannual Variability of Regional Pollution Using Two Decades of Tropospheric Ozone Observations Derived from the Empirically Corrected SBUV/TOMS Residual Method

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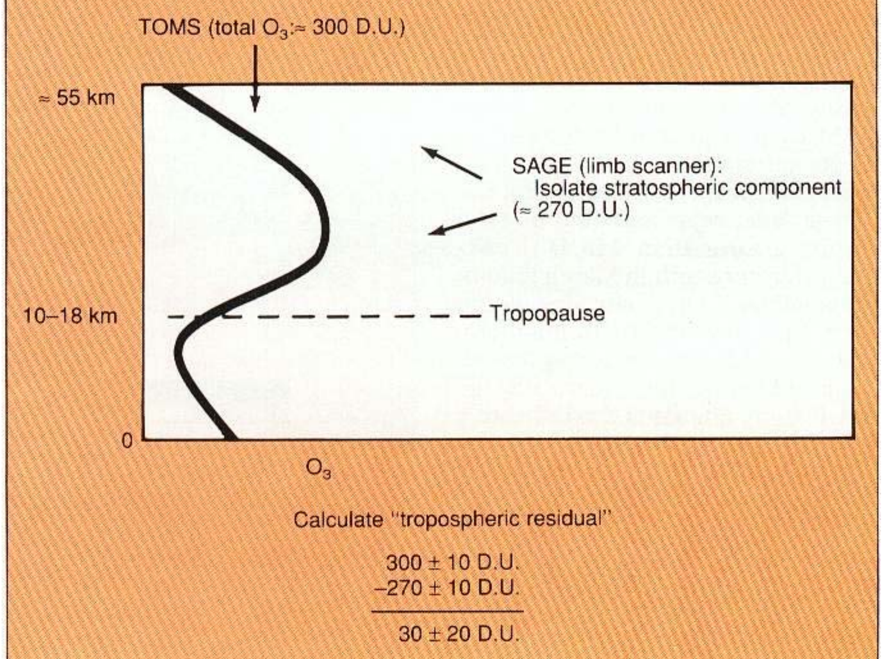
ROAD MAP

- EMPIRICALLY-CORRECTED TOR CLIMATOLOGY
- NORTH ATLANTIC TRANSPORT STUDY
- NORTHERN INDIA POLLUTION- POPULATION DENSITY STUDY

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



Fishman, 1991

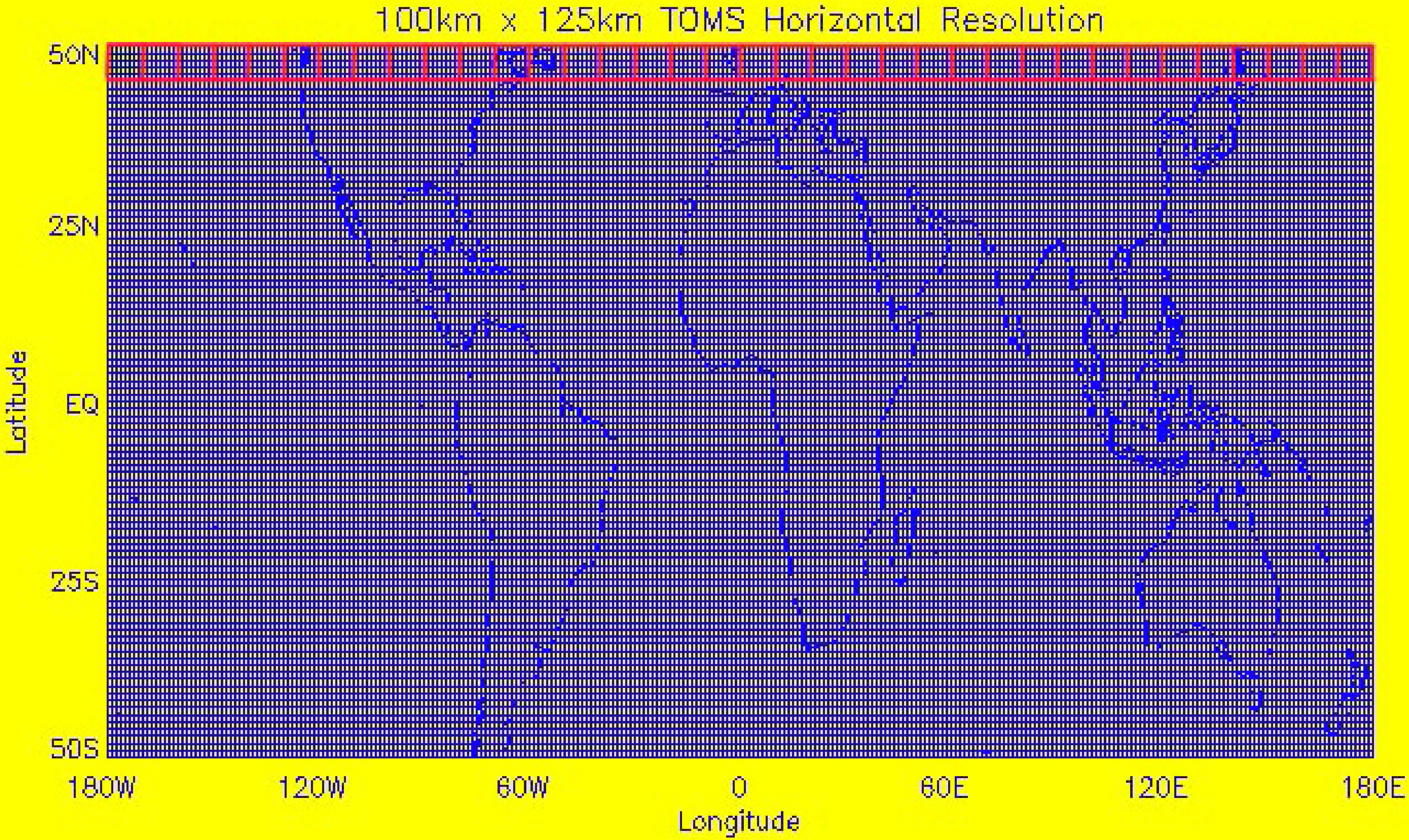
Other Data Sets Are Required To Separate Tropospheric Ozone From Total Ozone Measurements

- SAGE: Good Vertical Resolution; Poor Spatial Coverage
- HALOE: Good Vertical Resolution; Poor Spatial Coverage
- MLS: Vertical Resolution Only >68mb; Relatively Good Spatial Coverage
  Only One Archived Layer Below 100mb
- SBUV: Poor Vertical Resolution; Good Spatial Coverage
  Archived Layers: 1000-253mb; 253-126mb; 126-63mb
  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**: Uses Every TOMS Observations (up to 28,800 per day) [Fishman et al, 2003]
    ~ **1500 data points per 1° x 1.25°** grid box for seasonal climatology

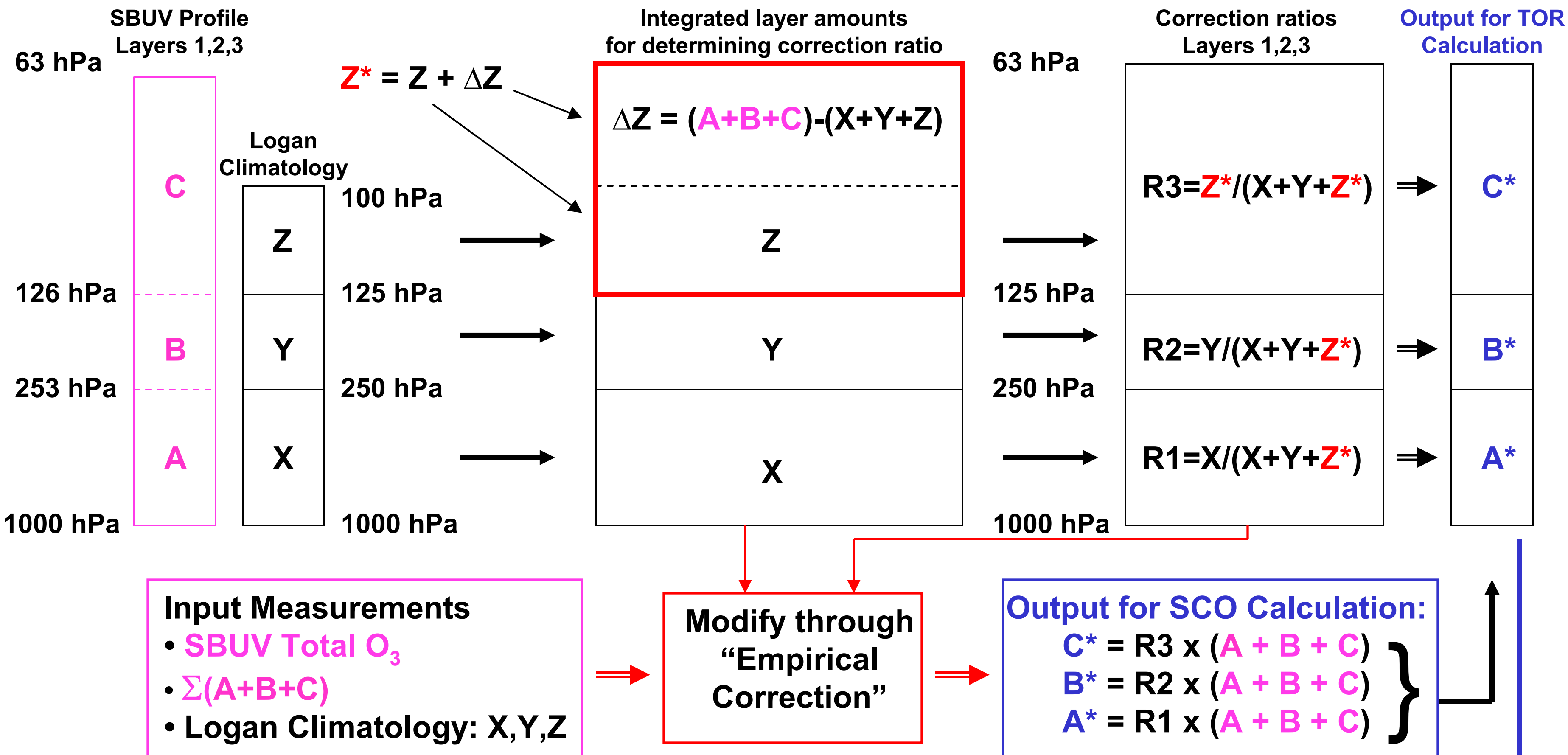
- Tropopause Heights: Archived Gridded Data Sets 2.5° x 2.5°

Comparison of Pixel Size for Computing TOR



Calculation of TOMS/SBUV Tropospheric Ozone Residual

Part I: Calculate Stratospheric Column Ozone (SCO)



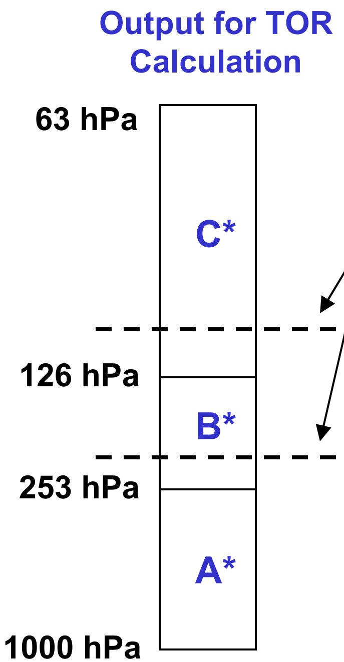
Part II: Calculate TOR from TOMS Total O_3 and SCO

(2a) **SCO = SBUV Total O_3 – γC* - βB* - A***

(2b) **TOR = TOMS Total O_3 - SCO**

Note: γ and β are values between 0 and 1 and are determined by NCEP/NCAR Reanalysis tropopause height

Define fractional coefficients (β and γ) for TOR calculation



Z_{trop} is tropopause height from NCEP/NCAR reanalysis

Z_{trop} in Layer C: β=1 and γ=fraction of Layer C in troposphere

Z_{trop} in Layer B: γ=0 and β= fraction of Layer B in troposphere

Part II: Calculate TOR from TOMS Total O_3 and SCO

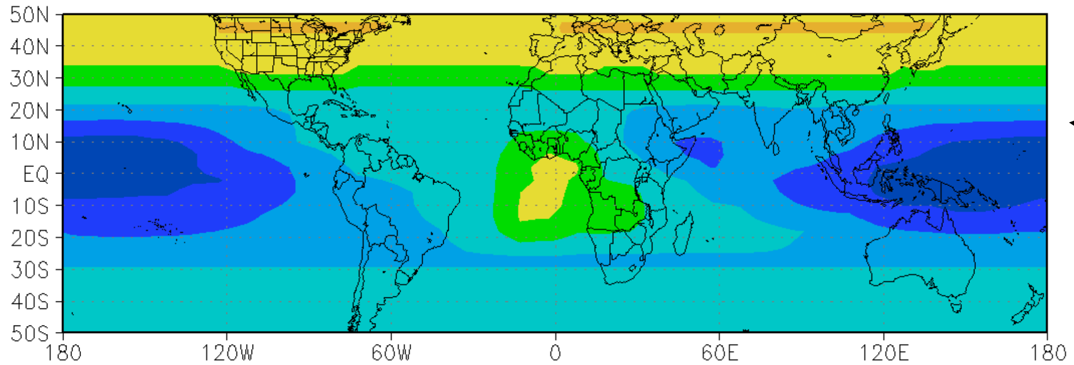
(2a) **SCO = SBUV Total O_3 – γC* - βB* - A***

(2b) **TOR = TOMS Total O_3 - SCO**

Note: γ and β are values between 0 and 1
if Z_{trop} is in Layer A, TOR is not calculated

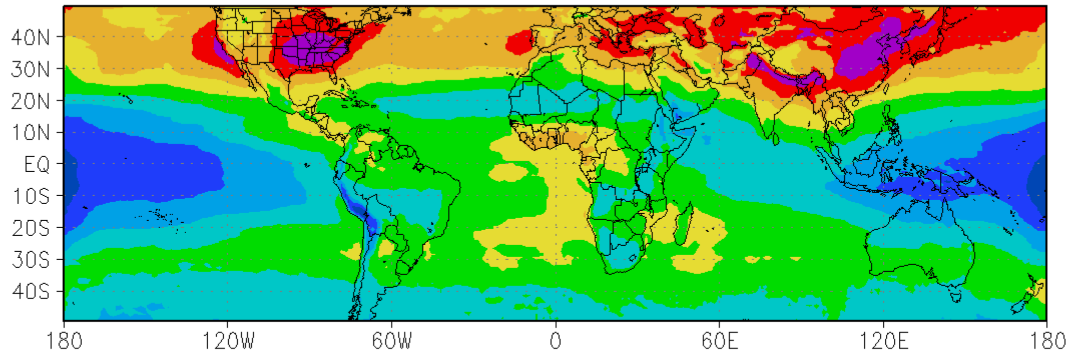
Comparison of Logan July Climatology and TOMS/SBUV TOR July Climatology

Logan Tropospheric Ozone Climatology (Surface-250mb) - JULY



Relatively Zonal Distribution

SBUV Tropospheric Ozone Residual (TOR) Climatology - JULY

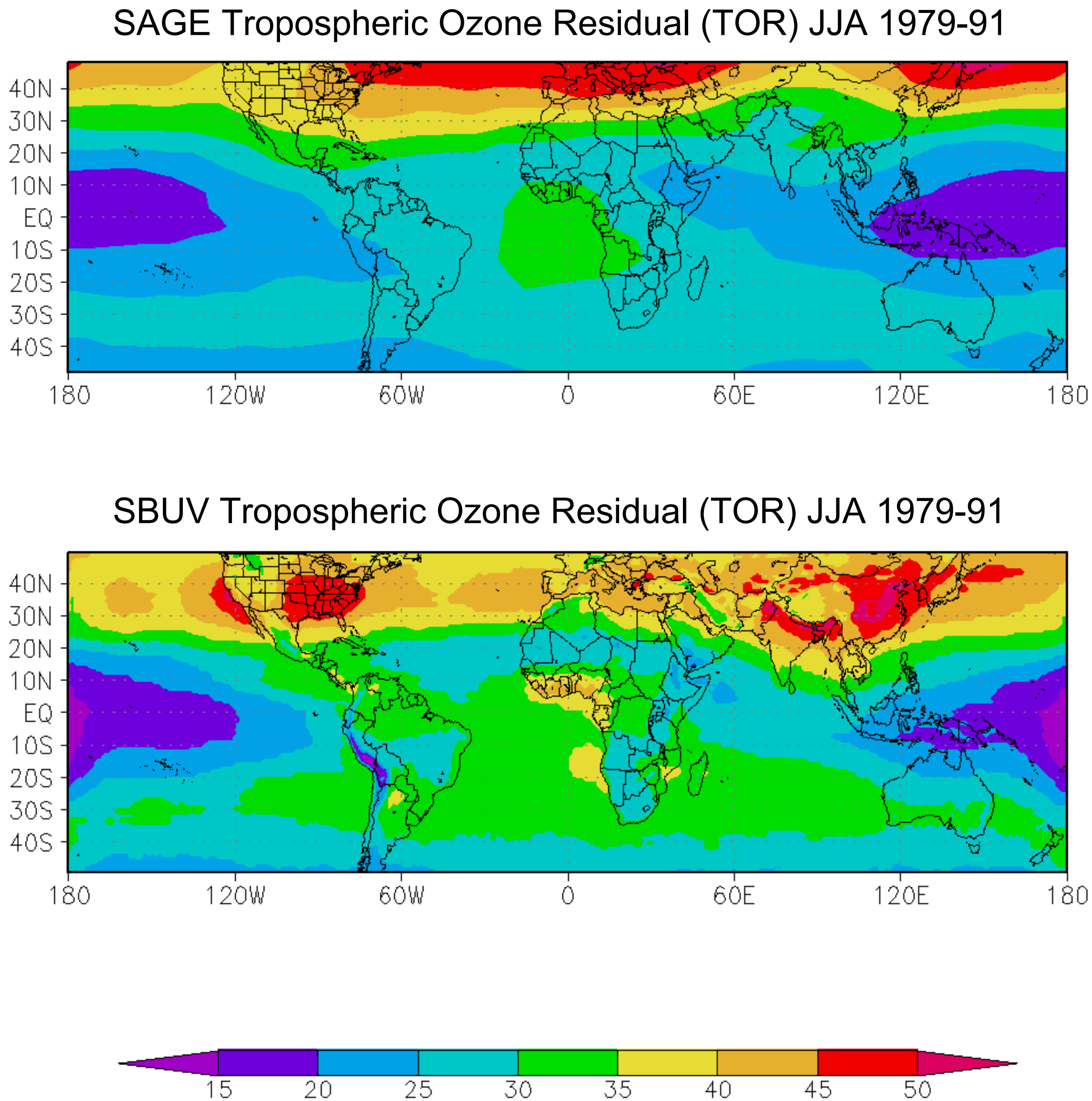


Much Greater Variability and a more Regional Focus

Comparison of TOMS/SAGE TOR with TOMS/SBUV TOR

SAGE

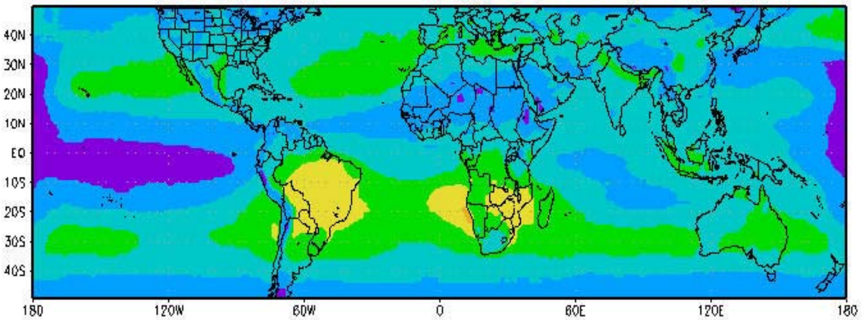
SBUV



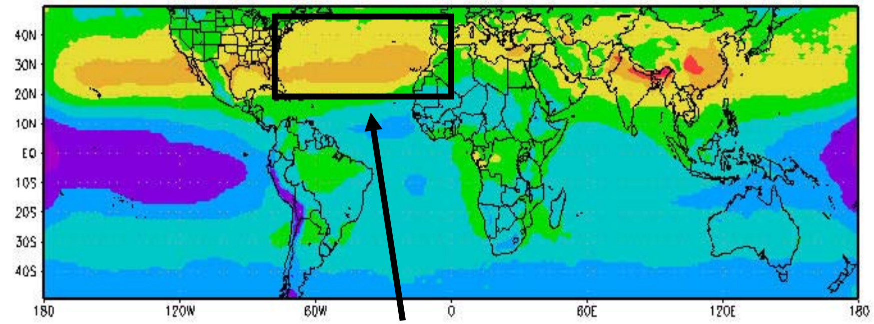
Fishman et al, 2003

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

SBUV Tropospheric Ozone Residual (TOR) DJF 1979-2000

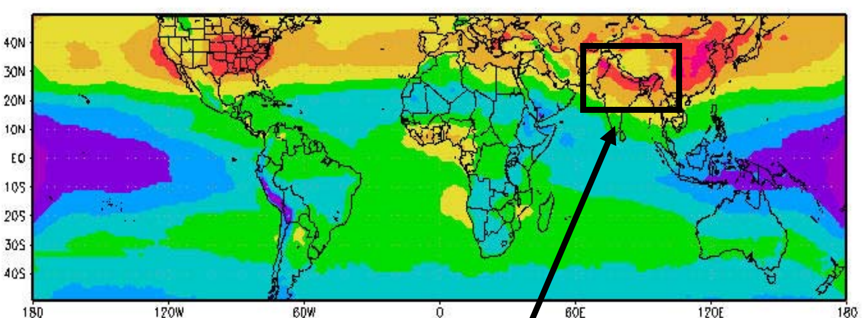


SBUV Tropospheric Ozone Residual (TOR) MAM 1979-2000



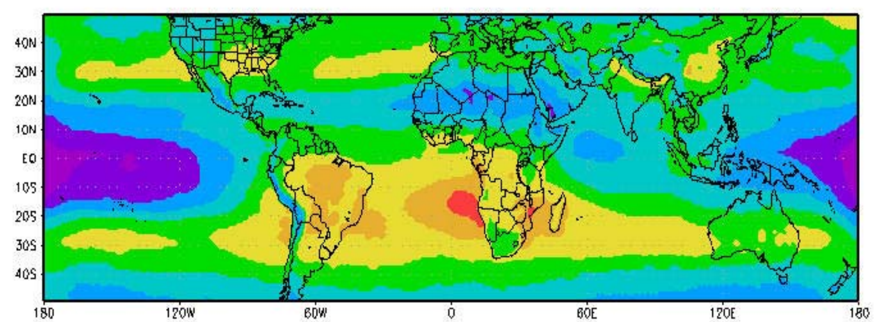
North Atlantic Transport Study

SBUV Tropospheric Ozone Residual (TOR) JJA 1979-2000



Northern India Pollution/Population Study

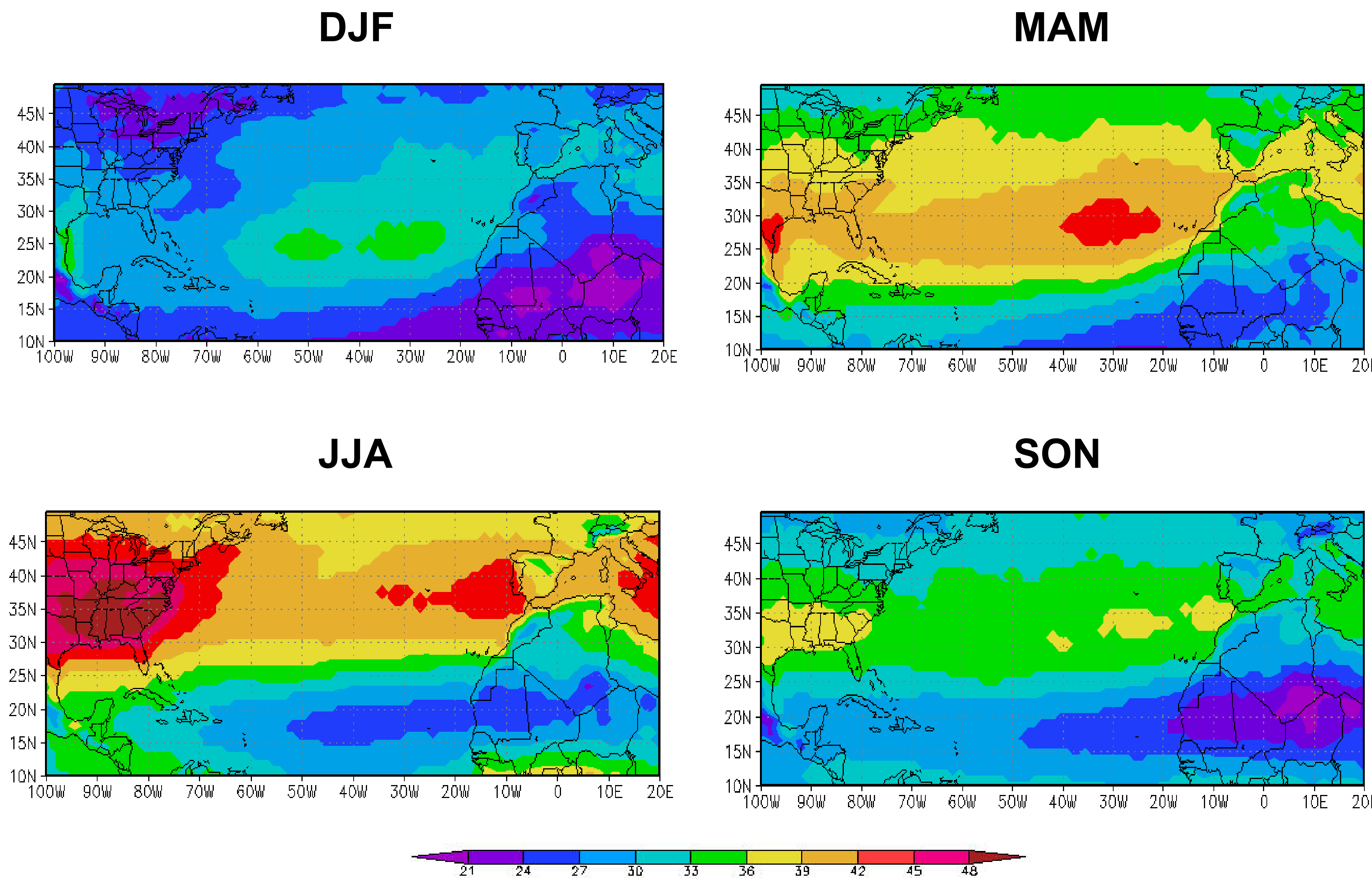
SBUV Tropospheric Ozone Residual (TOR) SON 1979-2000



Fishman et al, 2003
http://www.copernicus.org/EGU/acp/

NORTH ATLANTIC STUDY

SEASONAL DISTRIBUTION OF TOR ACROSS THE NORTH ATLANTIC



Creilson et al, 2003

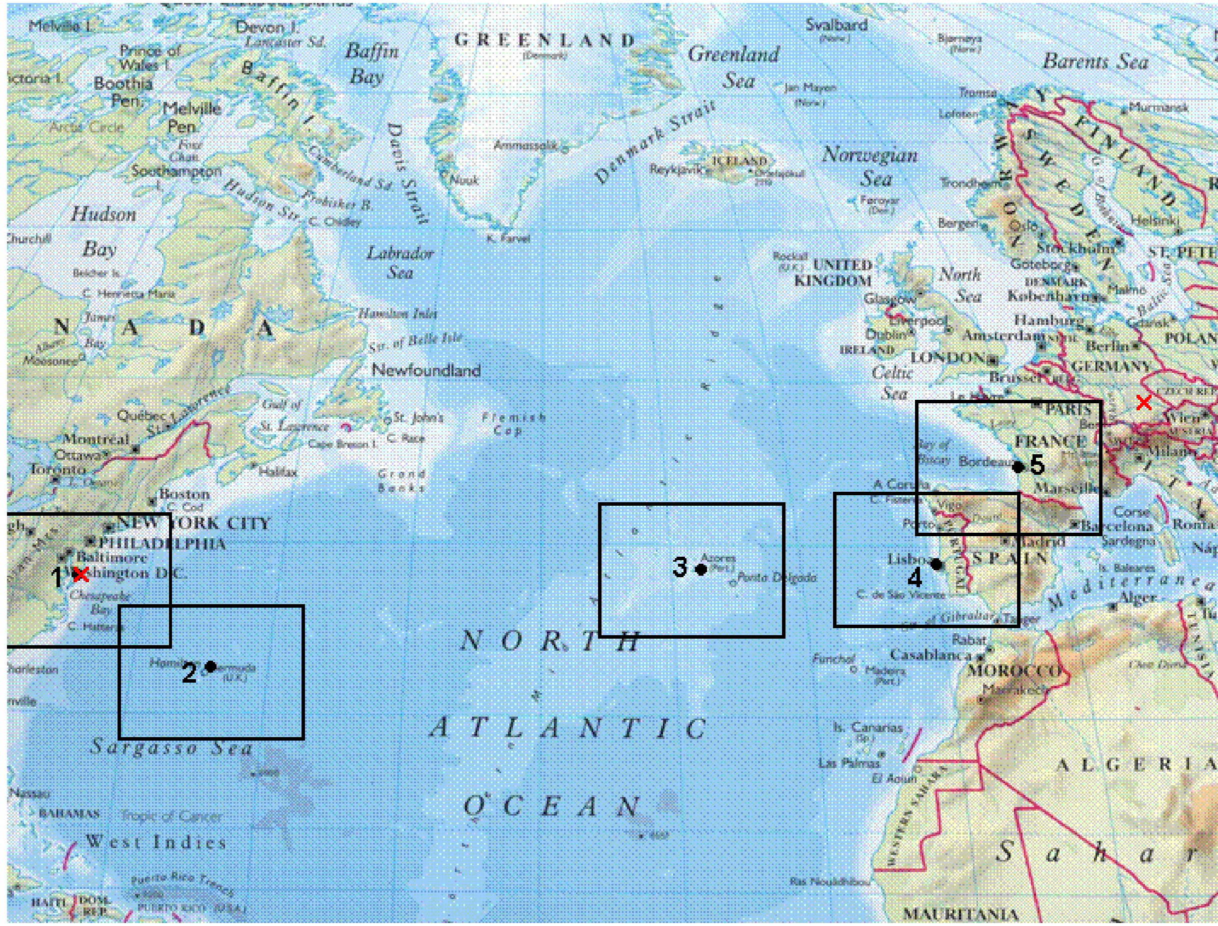
North Atlantic Study Area

<u>TOR Regions (**numbered**)</u>

1. Eastern U.S.
2. Bermuda
3. Azores
4. Lisbon
5. Western Europe

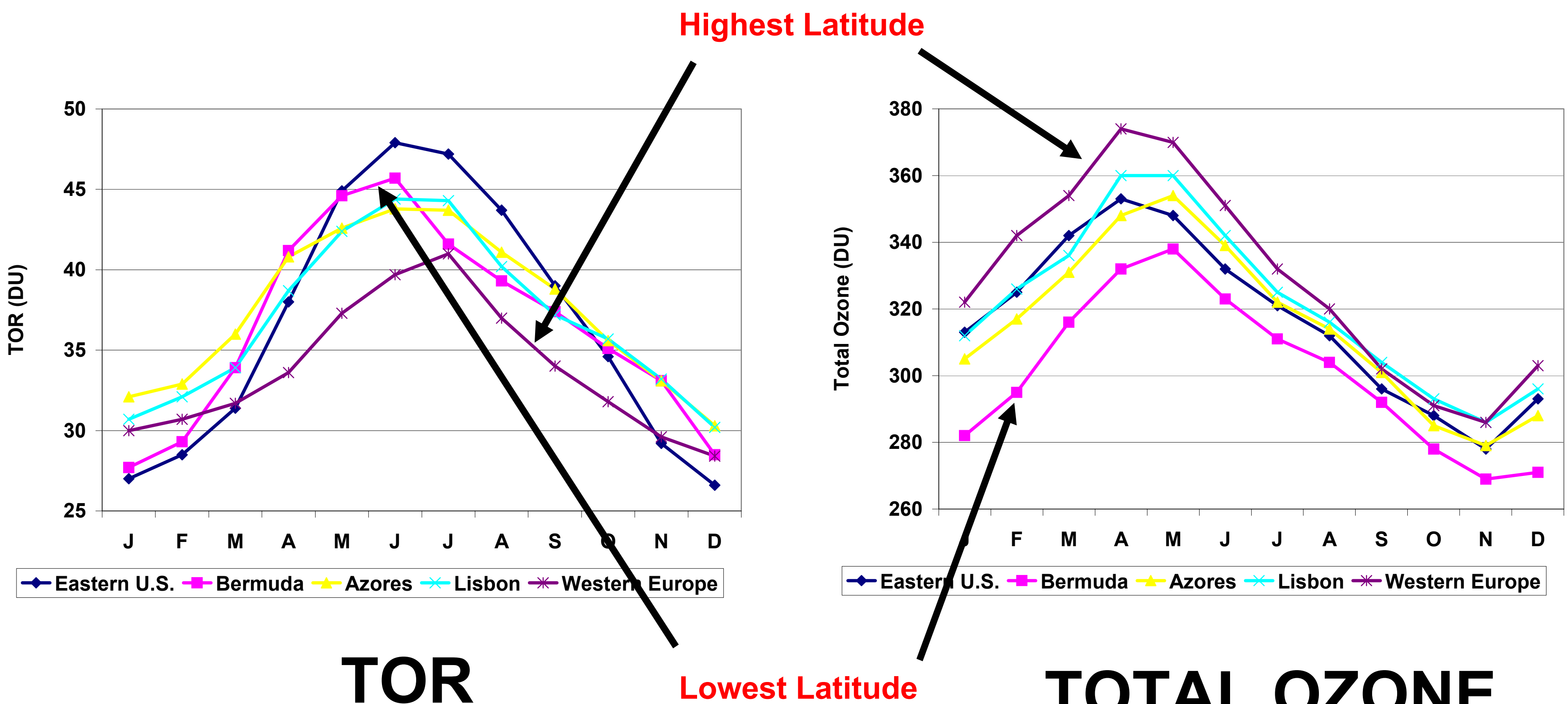
<u>Ozonesonde Locations (x)</u>

1. Wallops Island, USA
2. Hohenpeissenberg, Germany



Creilson et al, 2003

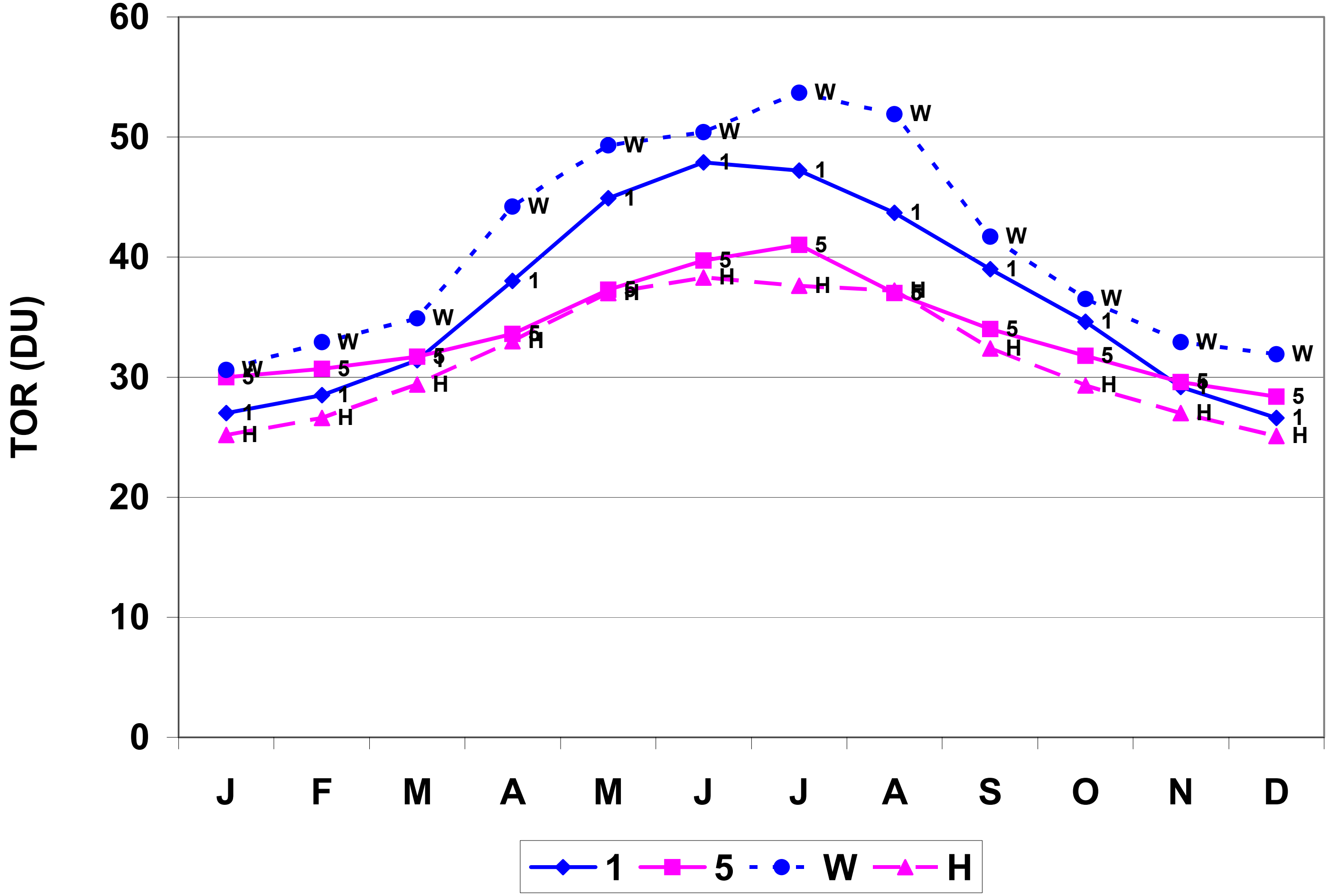
MONTHLY CLIMATOLOGY OF REGIONAL TOR AND TOMS TOTAL OZONE



TOR **TOTAL OZONE**

Creilson et al, 2003

Comparison between Region 1 TOR/Wallops Ozonesonde and Region 5 TOR/Hohenpeissenberg Ozonesonde



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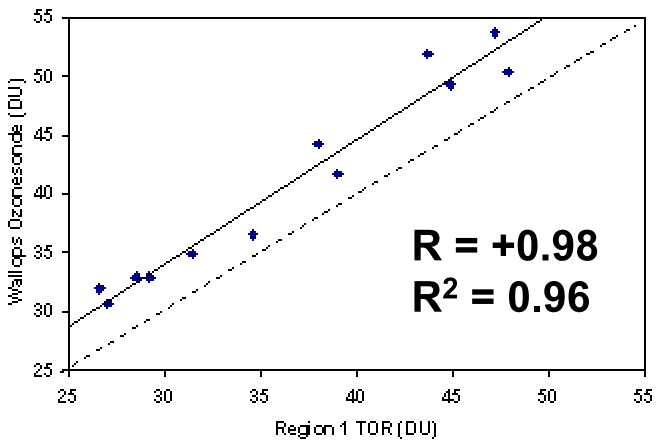
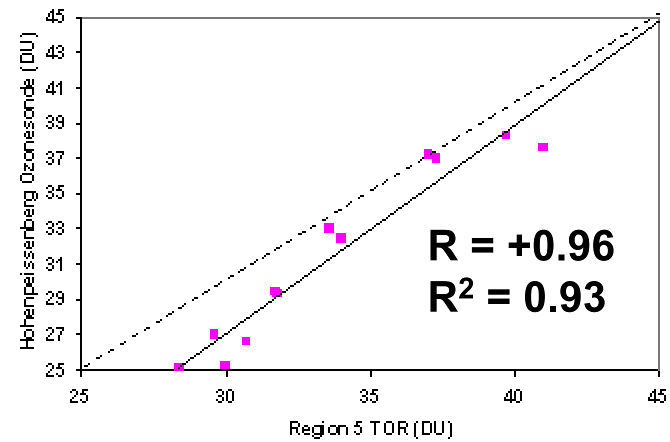
Scatter Plots between TOR over Eastern U.S. and Western Europe and between Ozonesonde Profiles at Wallops Island (USA) and Hohenpeissenberg (Germany)

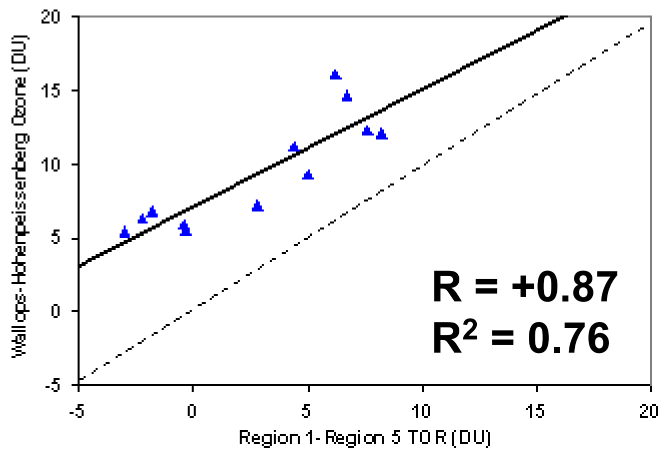
EASTERN U.S. TOR VERSUS WALLOPS OZONESONDE



WESTERN EUROPE TOR VERSUS HOHENPEISSENBERG OZONESONDE



EASTERN U.S.-WESTERN EUROPE TOR VERSUS WALLOPS-HOHENPEISSENBERG OZONESONDE



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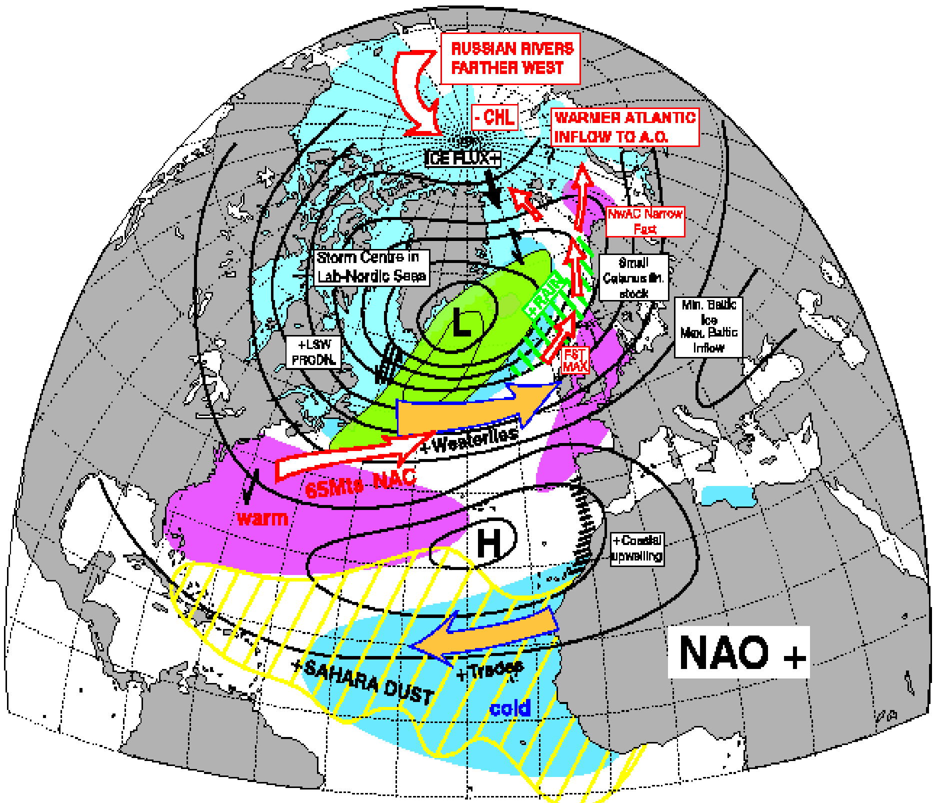
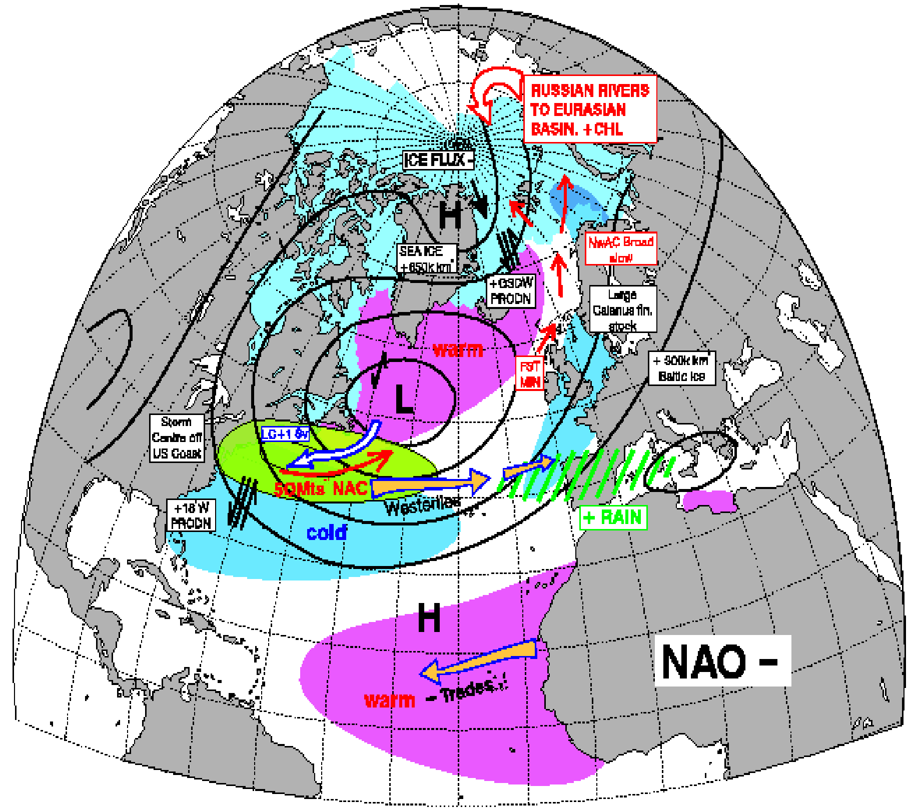
PHASES OF THE NORTH ATLANTIC OSCILLATION (NAO)



Positive NAO



Negative NAO

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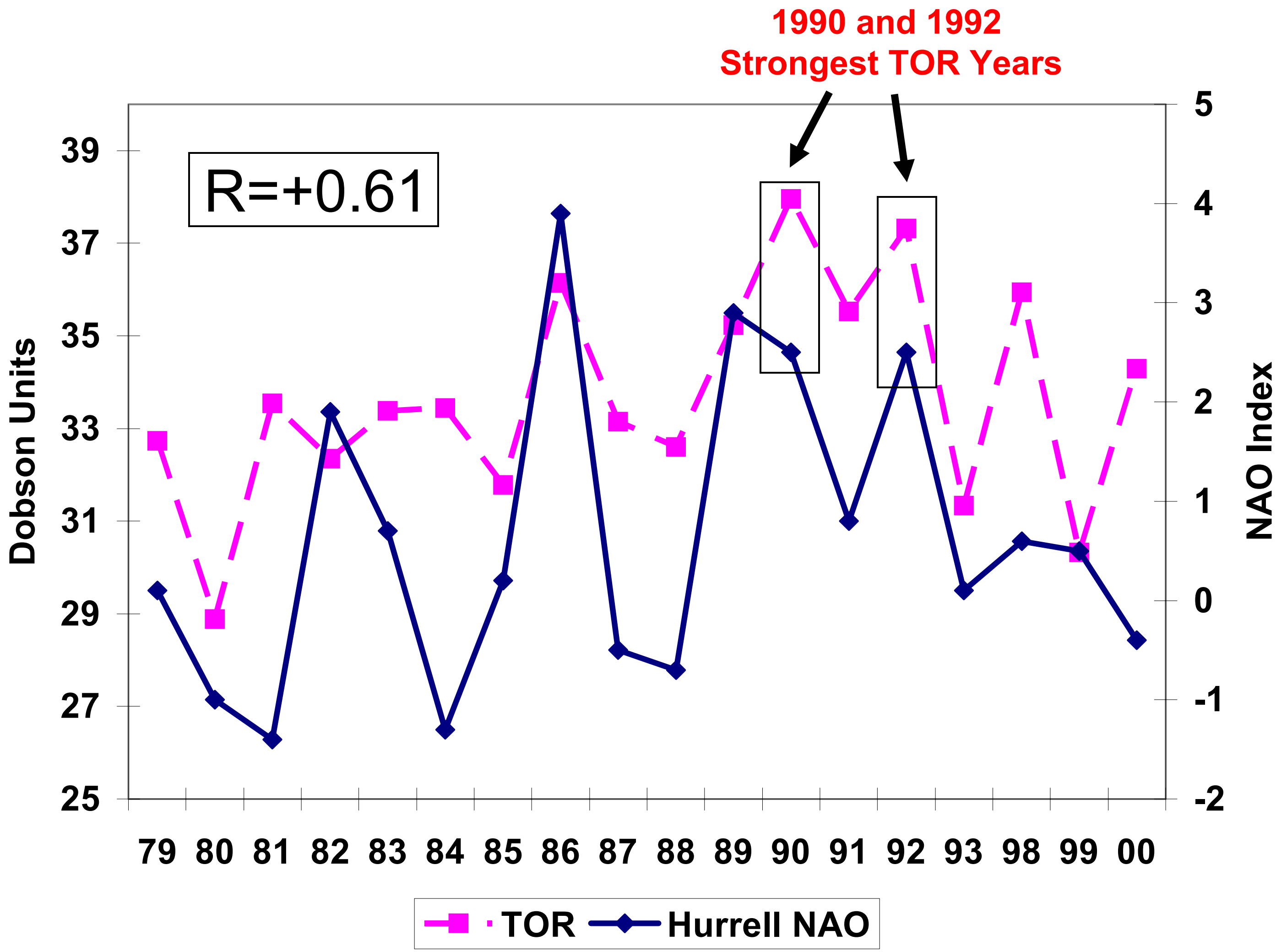
INTERANNUAL VARIABILITY OF REGION 5 SPRINGTIME TOR AND SPRING NAO INDEX



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Monthly TOR Values Over Western Europe (Region 5) 1979-2000

Jan 30.1		Feb 30.8		Mar 31.8		Apr 33.7		May 37.4		Jun 39.8		Jul 41.0		Aug 37.1		Sep 34.2		Oct 31.7		Nov 29.7		Dec 28.5	
1989	35.0	1992	36.7	1981	35.4	1992	41.3	1990	42.7	1979	48.4	1990	44.4	1983	41.1	1989	41.2	1992	39.1	1991	34.6	1990	30.6
1990	33.0	1998	34.8	1992	34.7	1990	38.3	1986	41.4	1999	45.6	1985	44.4	1988	40.7	1981	35.7	1991	34.0	1980	34.6	1979	30.4
1979	32.9	1986	34.4	1990	34.4	1989	38.1	1998	41.3	1992	42.1	1998	43.7	1999	40.2	1992	35.4	1979	33.7	2000	34.6	1986	30.3
1992	31.8	2000	33.1	1983	34.3	1987	37.0	2000	40.3	1981	40.8	1999	43.2	1982	40.0	1991	35.3	1982	32.5	1992	31.8	1992	30.2
1982	31.5	1987	32.4	1998	34.2	1984	35.5	1984	40.0	1984	40.6	1987	43.0	1998	38.6	1988	35.1	2000	32.2	1999	30.5	1989	29.8
1983	31.4	1983	31.7	1986	34.1	1999	35.4	1982	39.1	1988	40.5	1979	42.4	1984	38.5	1982	34.7	1981	32.1	1989	30.2	2000	29.3
1985	30.8	1990	31.0	1985	33.3	1988	34.8	1989	38.9	1982	40.4	1992	42.4	1986	38.3	1990	34.5	1980	31.8	1990	30.1	1988	29.0
1991	30.4	1985	31.0	2000	33.3	1998	34.8	1992	38.7	1987	39.9	1988	41.3	1990	37.6	1986	34.3	1990	31.7	1985	29.7	1980	29.0
1984	30.3	1989	30.3	1987	32.6	1983	33.6	1991	38.4	1985	39.5	1991	40.9	1979	37.5	1997	34.0	1984	31.7	1986	29.4	1999	28.9
1987	29.9	1988	30.2	1989	32.4	1979	33.6	1988	37.4	2000	39.3	2000	40.6	1981	37.5	1985	33.8	1998	31.5	1979	28.5	1987	28.7
2000	29.8	1993	29.9	1993	31.0	1981	32.3	1985	36.4	1990	38.4	1980	40.2	1992	36.7	1979	33.8	1989	31.1	1988	28.1	1991	28.5
1988	29.3	1979	29.9	1979	30.1	1991	31.4	1979	35.7	1989	37.7	1981	39.3	1980	36.4	1983	33.5	1986	31.0	1981	28.1	1997	28.1
1986	28.2	1984	29.7	1984	29.0	1986	31.4	1981	35.5	1983	37.6	1986	39.2	1997	35.6	1984	33.3	1985	30.9	1987	27.8	1985	27.9
1999	28.2	1999	29.6	1982	28.9	1980	30.8	1983	34.8	1986	37.4	1984	38.3	1989	34.6	1987	33.3	1983	30.7	1984	27.3	1983	27.4
1993	27.6	1980	28.7	1980	27.8	1993	30.4	1980	32.2	1998	36.7	1983	38.2	1987	34.5	1998	33.3	1997	30.3	1983	26.9	1982	26.8
1998	27.6	1991	28.6	1988	27.4	1982	29.7	1987	32.1	1991	36.7	1982	37.9	2000	34.0	1999	32.9	1999	30.0	1982	26.5	1984	25.4
1980	27.1	1981	26.7	1999	27.0	1985	29.4	1999	31.3	1980	34.7	1989	37.8	1985	33.3	1980	31.2	1988	29.0	1997	25.7	1981	24.1
1981	26.6	1982	25.4	1991		2000	28.9	1993		1993		1993		1991	32.6	2000	30.3	1987	28.1	1993		1993	

Monthly Averages for Each Year are Rank-Ordered:

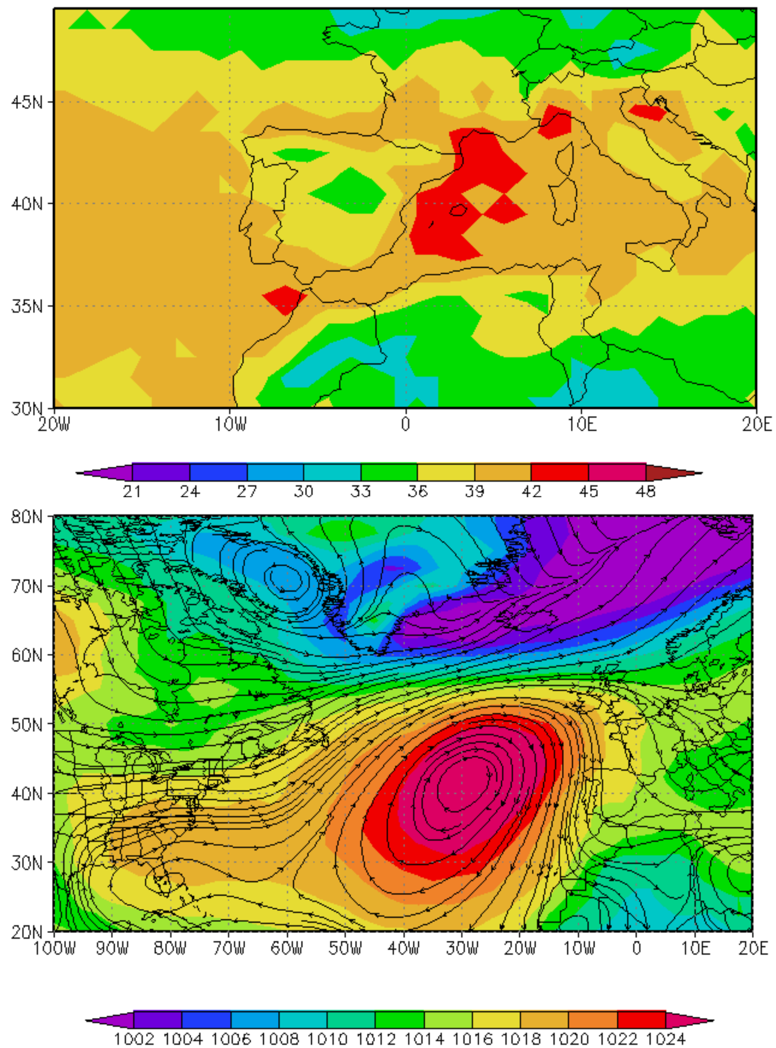
1990 Highlighted in Magenta
1980 Highlighted in Blue

Creilson et al, 2003

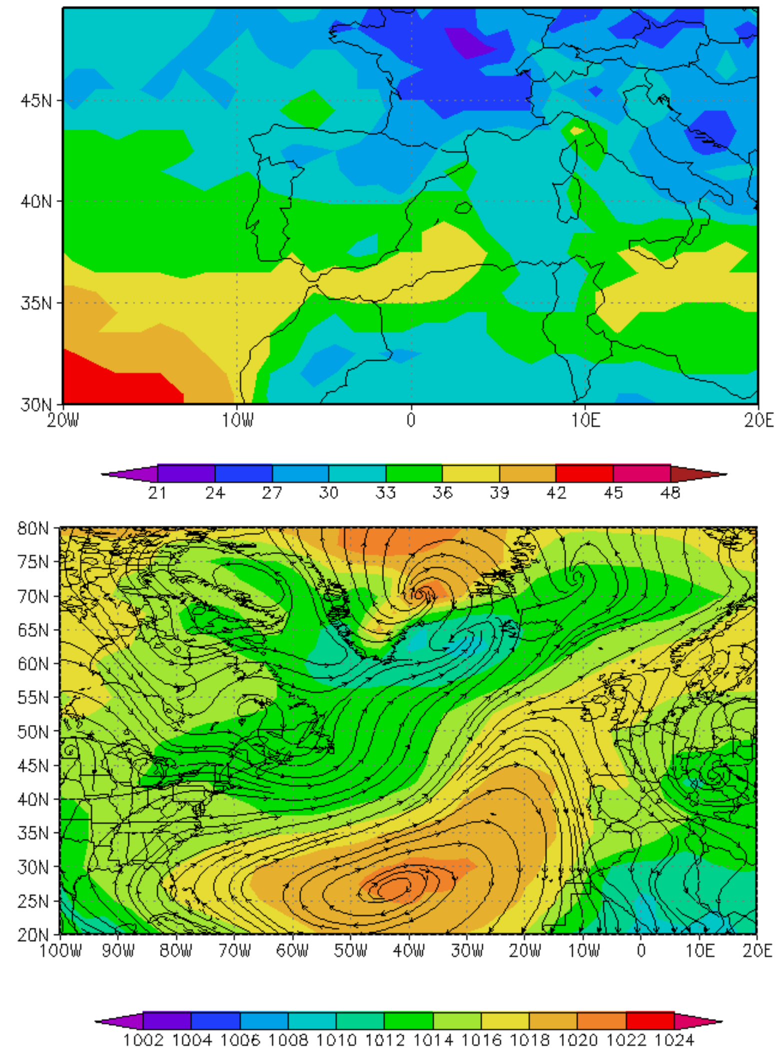
Springtime TOR Variability Over North Atlantic Mid-Latitudes

Linked to Differences in Prevailing Transport Patterns

Spring 1990 – Positive NAO



Spring 1980 – Negative NAO

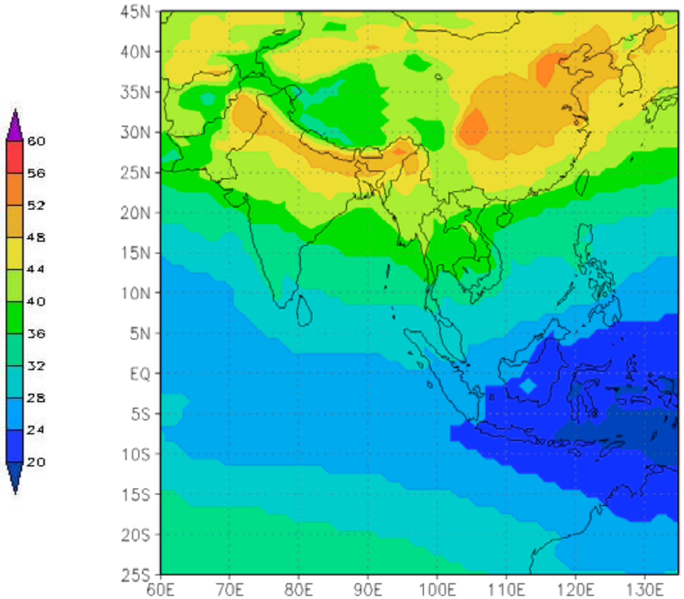


Creilson et al, 2003

NORTHERN INDIA POLLUTION STUDY

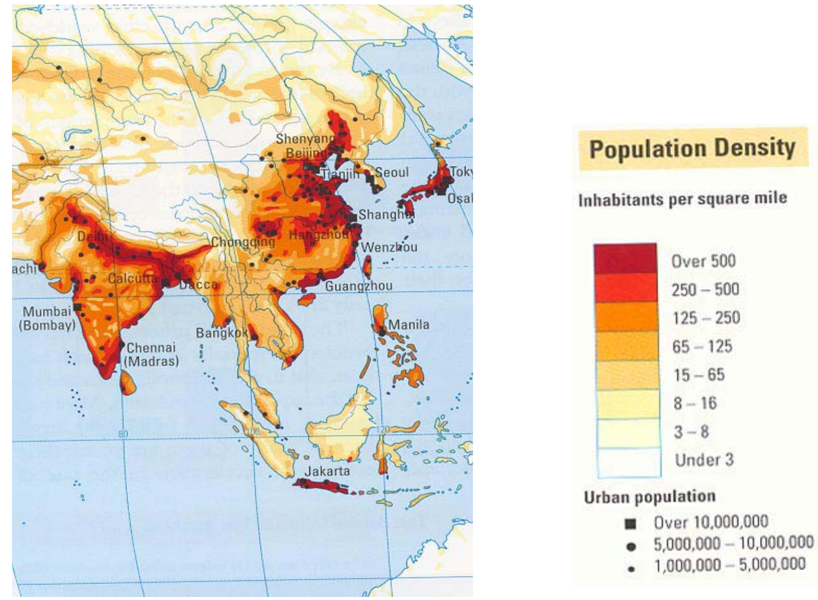
Ozone Enhancement over India

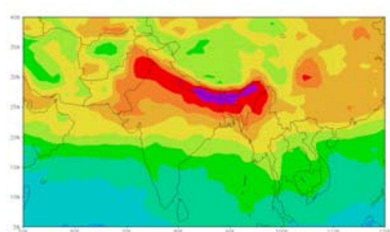
Summer Climatological Distribution



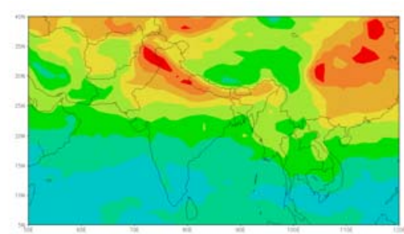
TOR in Dobson Units

Population Density





June 1982 – El Niño

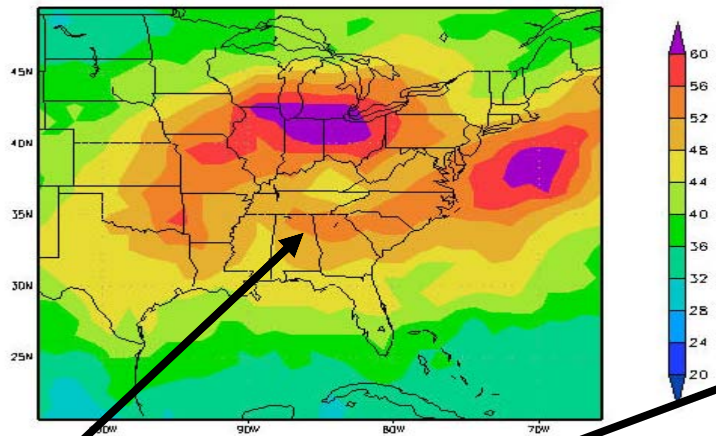


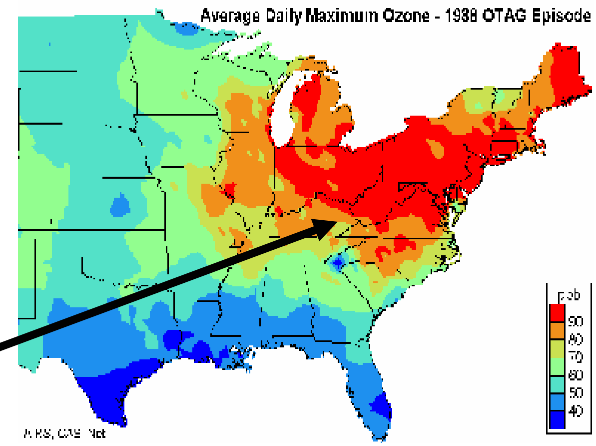
June 1999 – La Niña

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

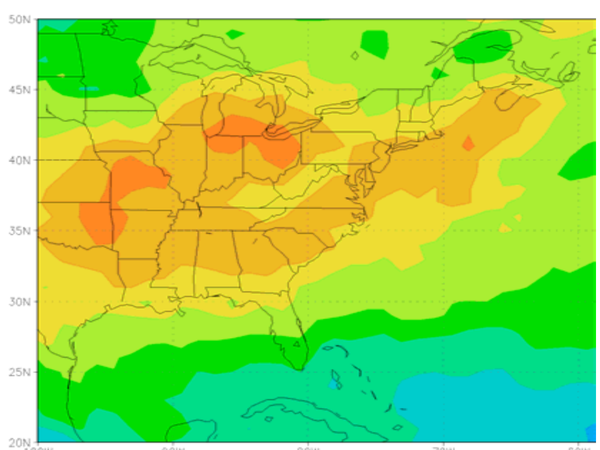
Fishman et al, 2003

Comparison of Indian and U.S. Air Pollution Episodes

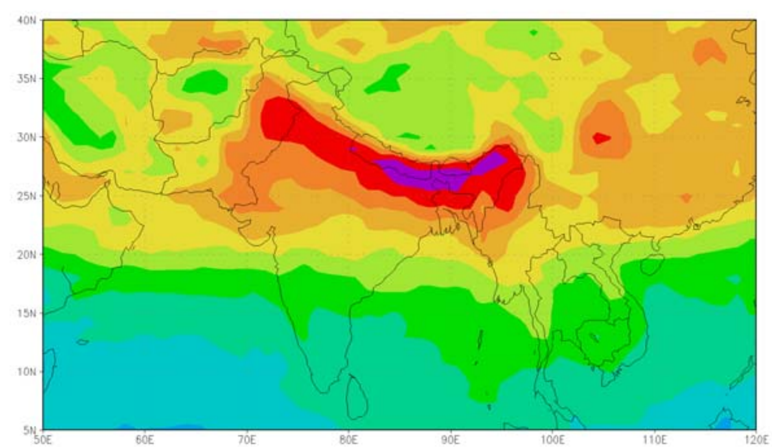




TOR and Surface O_3 Depiction during July 3-15 1988 Pollution Episode



July 1988



June 1982

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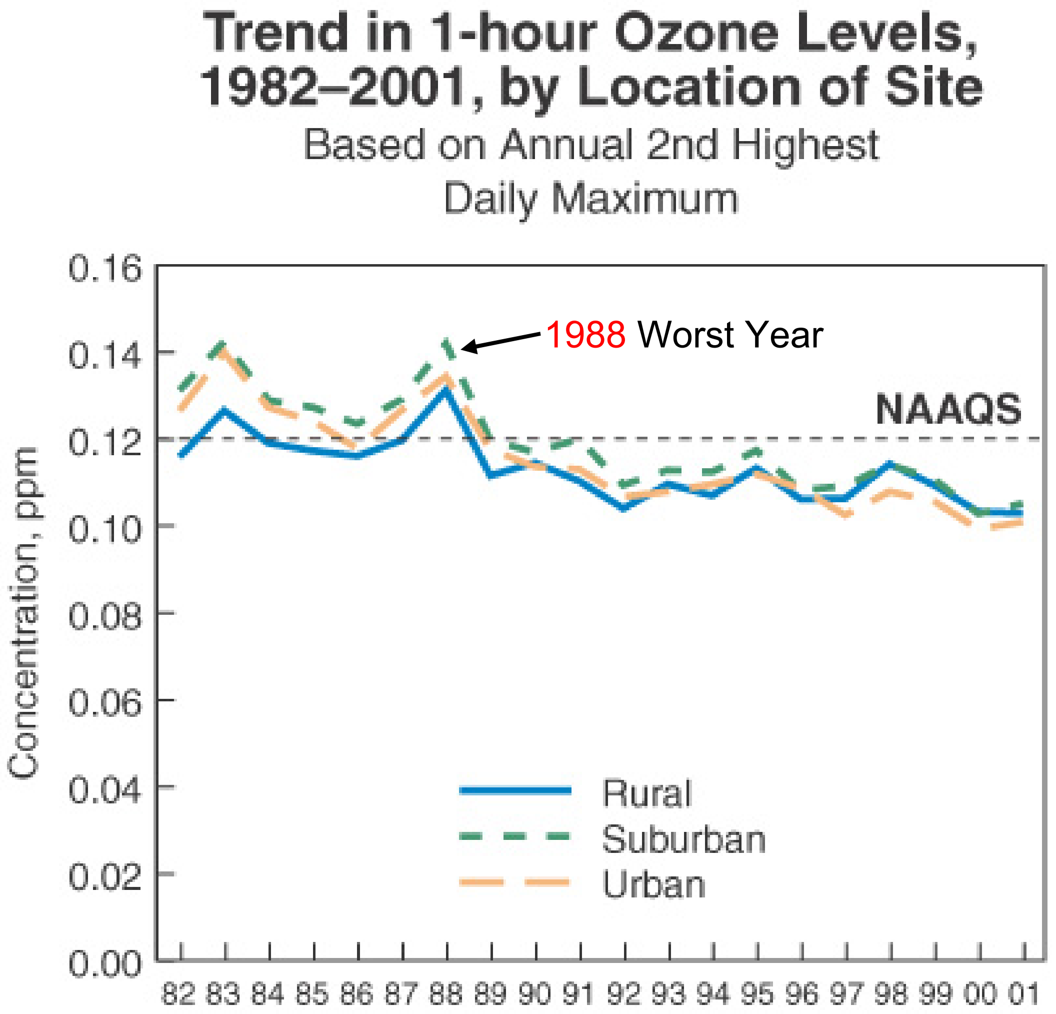
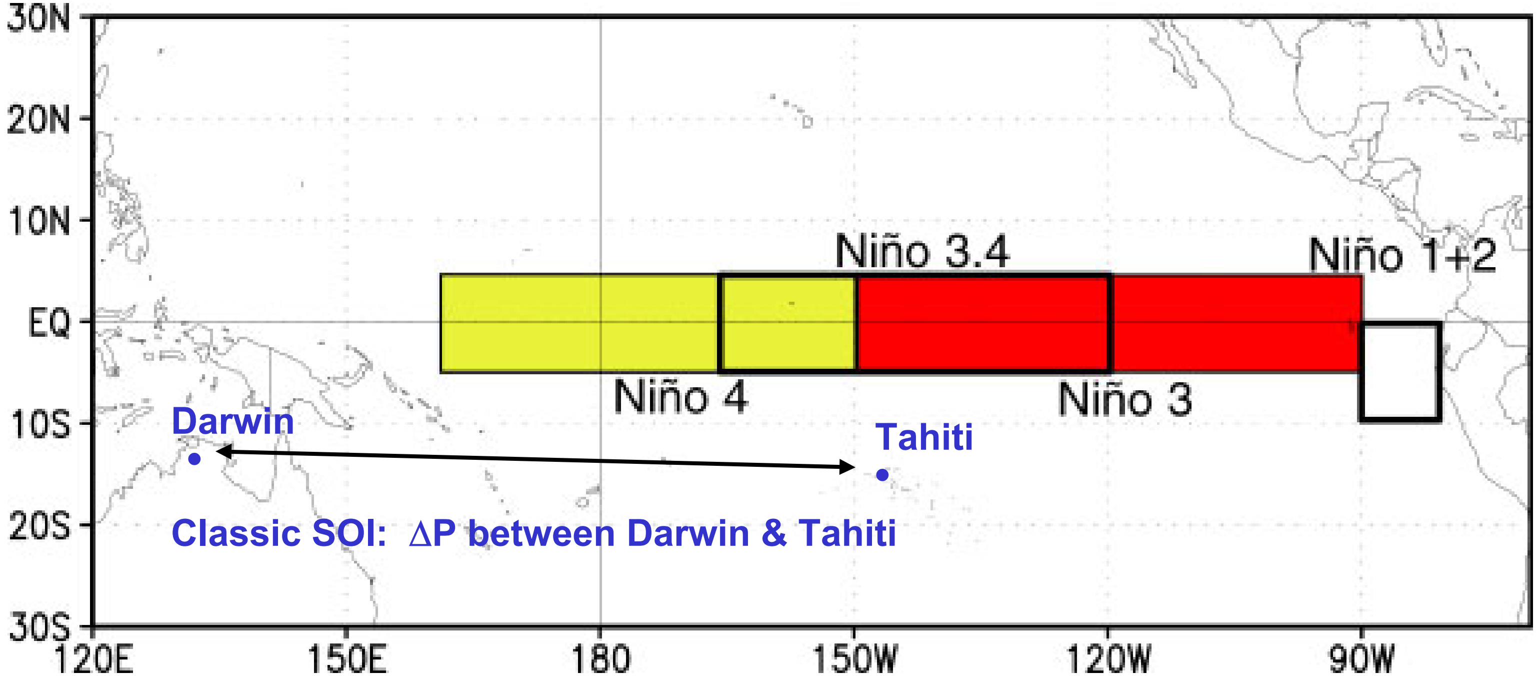

Trend in 1-hour Ozone Levels, 1982–2001, by Location of Site
Based on Annual 2nd Highest Daily Maximum
1988 Worst Year
NAAQS
Concentration, ppm
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01
Rural
Suburban
Urban

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

Fishman et al, 2003

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

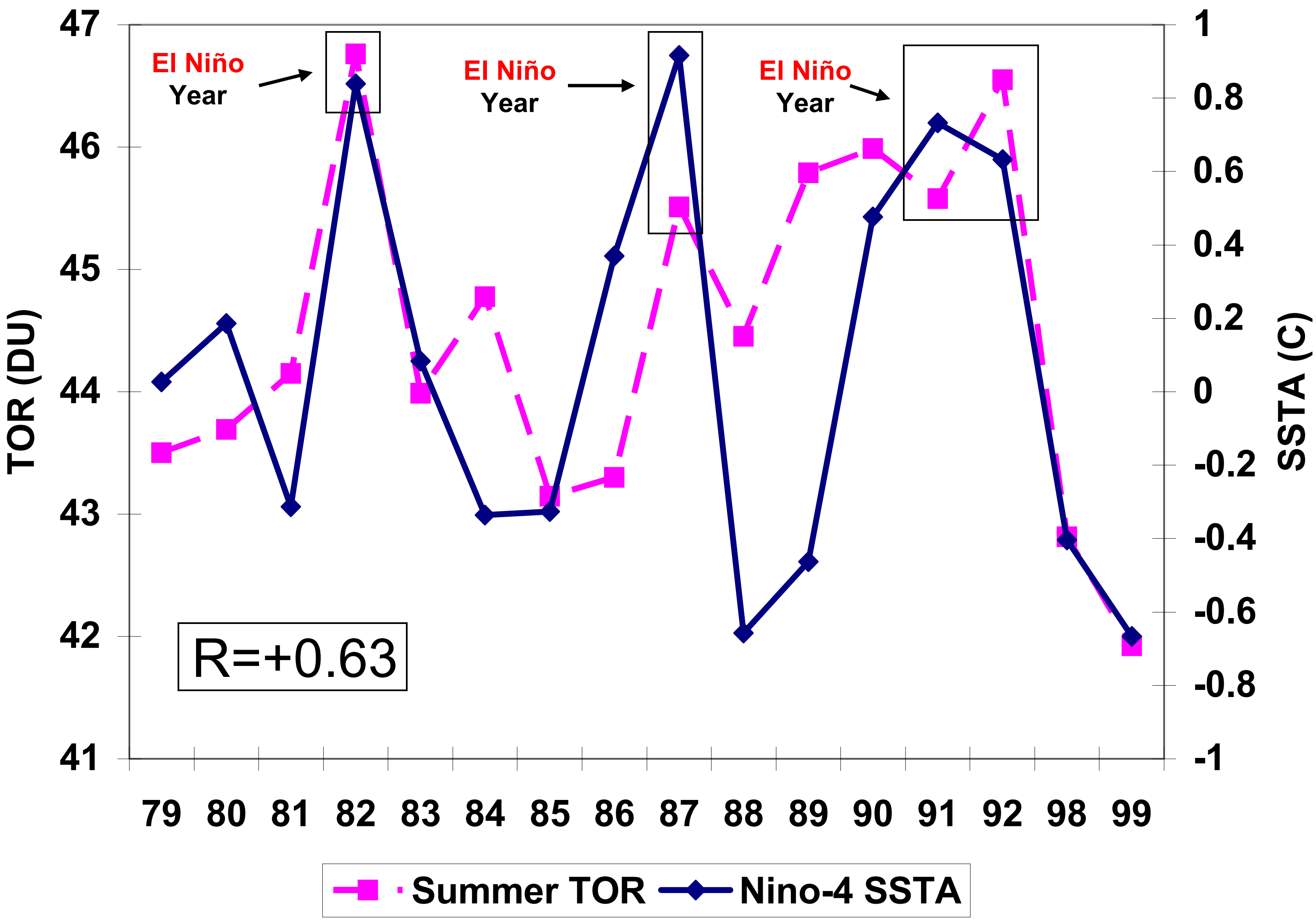
Month	Mean TOR	Range		SOI		ENSO SST Region			
		High	Low	Mon	Seas	1&2	3	3.4	4
January	29.8	31.5 (1991)	25.7 (1980)	.04	-.01	.07	-.04	-.06	-.01
February	29.9	33.3 (1992)	25.1 (1991)	-.33	**-.45**	.11	.27	.33	.21
March	34.6	40.5 (1989)	26.7 (1999)	.02	.02	-.15	-.14	-.06	.15
April	44.0	47.2 (1982)	40.5 (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

Fishman et al, 2003

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



Fishman et al, 2003

Summary

- 2-Decade Record of TOR Now Available
  - **http://asd-www.larc.nasa.gov/TOR/data.html**

- Two-Part TOR Calculation Schematic Highlights TOMS/SBUV Focus and Use of Logan Climatology for Correction Ratios

- Transport of Pollution across North Atlantic Linked to NAO
  - Increase in Springtime TOR over Western Europe Correlated to Positive Phase of the North Atlantic Oscillation for 1979-2000 Time Period

- Strong Correlation between Population and Pollution
  - Interannual Variability over Northern India Linked to ENSO

- Can ENSO or Other Indicators be Used as Predictors?

- New Satellite Instruments (OMI, HIRDLS) Promise Much Better Tropospheric Measurement Capability within Next Few Years