Atmospheric Chemistry in the Tropics (I): Biomass Burning & Remote Sensing

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Introduction to Three Related Talks

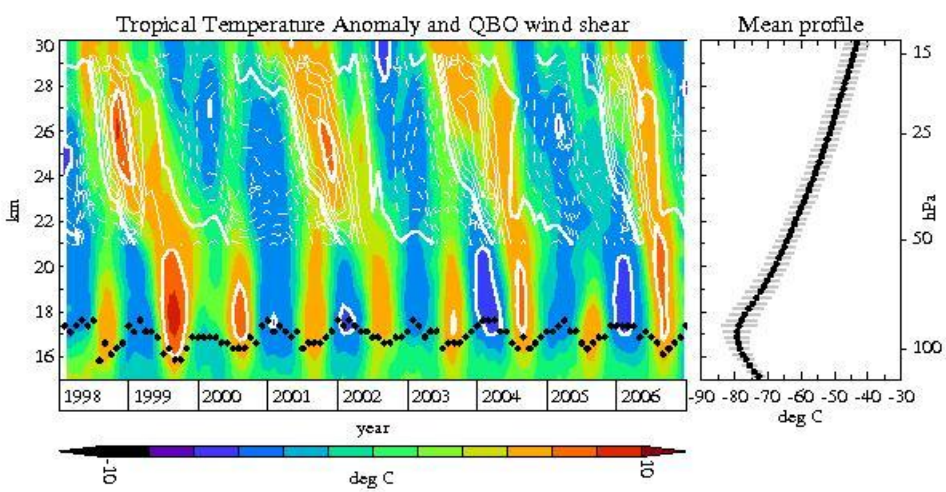
- SHADOZ & UT/LS Processes **Tuesday** √
  - Importance of Tropical UT/LS (TTL)
  - Regional differences in convection, extra-tropical influence, pollution (biomass burning, urban)
  - Climatological approach, Laminae (LID), SOMs
- Tropical Atmospheric Chemistry (I) **Wednesday** **Today**
  - Interannual variability (QBO, ENSO), trends (LS -yes, UT ?)
  - Remote sensing – SHADOZ motivation, progress, challenges
- Tropical Atmospheric Chemistry (II) **Thursday**
  - SHADOZ & related data collection – quantity and quality
  - African Fulbright research – "science & service"
  - Mega-city – Johannesburg, So Africa, trends or no?

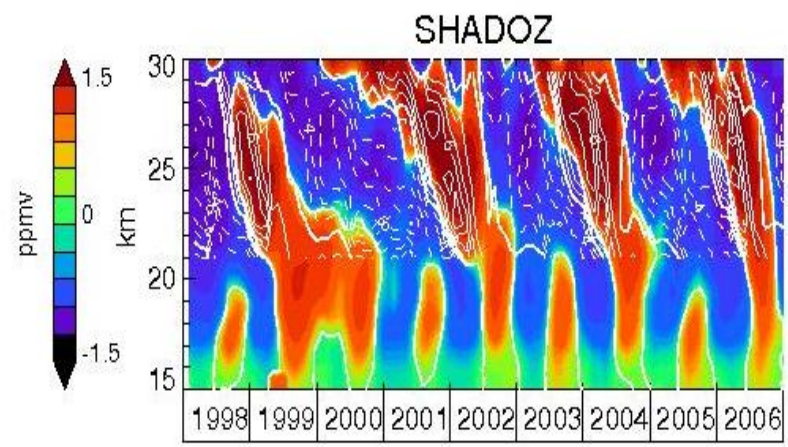
Road Map

- SHADOZ, Cont'd: Interannual Variability & Trends
  - QBO (Quasi-biennial Oscillation)
  - ENSO (El-Niňo-Southern Oscillation)
  - Lower stratospheric trends; tropospheric trends
- Biomass Burning & Remote Sensing
  - Fishman "classic" maps & TRACE-A/SAFARI-92
  - Soundings in TRACE-A
  - 1997-98 ENSO & Indonesian Fires
  - "Ozone Paradox" & SHADOZ
  - Aura Era
    - 'New Residual' Comparisons w/ SHADOZ
    - 2006 ENSO & TES

QBO Studies with SHADOZ Data

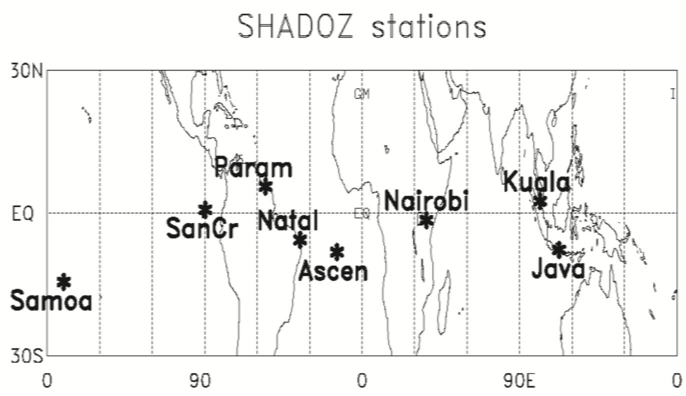
- Logan et al (JGR, 2003) – with SAGE
- Witte et al (ACP, 2008) Below, 9 yrs from 9-station means
- Lee et al (JGR, 2010)
- Randel & Thompson (JGR, 2011) ** With LS trends

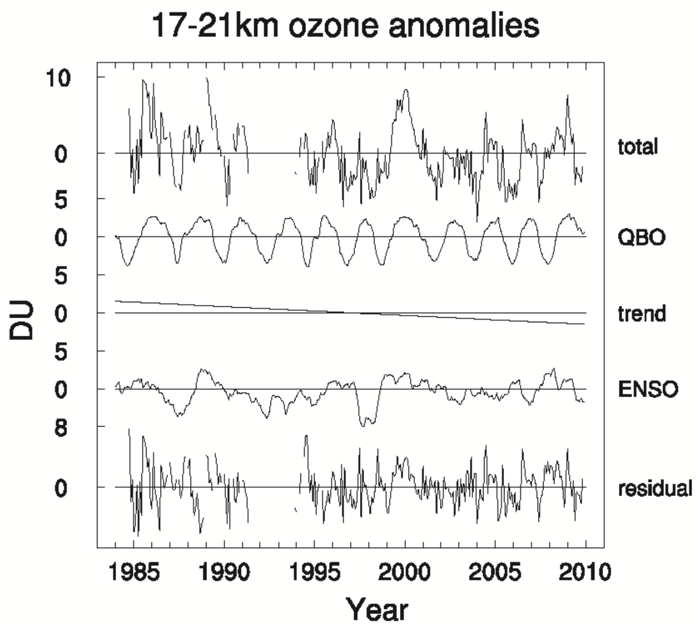




QBO, ENSO & LS Trends
(Randel & Thompson, JGR, 2011)

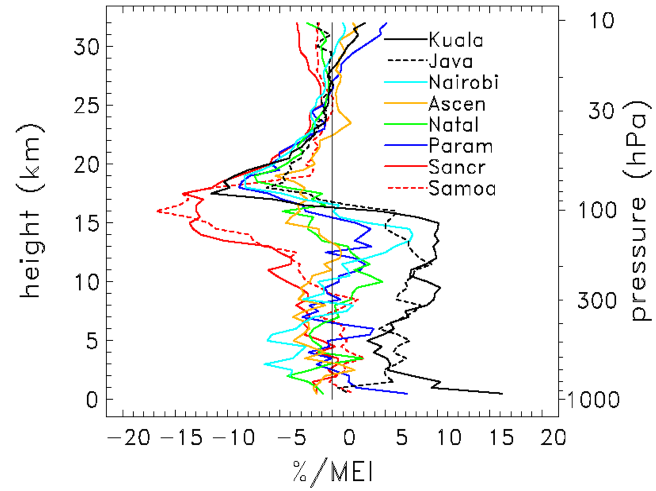
- Combined SAGE II (1984-2005) with SHADOZ (1998-2009) for 25-yr monthly mean ozone dataset
- Analyzed for LS (Lower stratosphere) trends with multi-variate regression model including solar cycle, QBO, ENSO terms

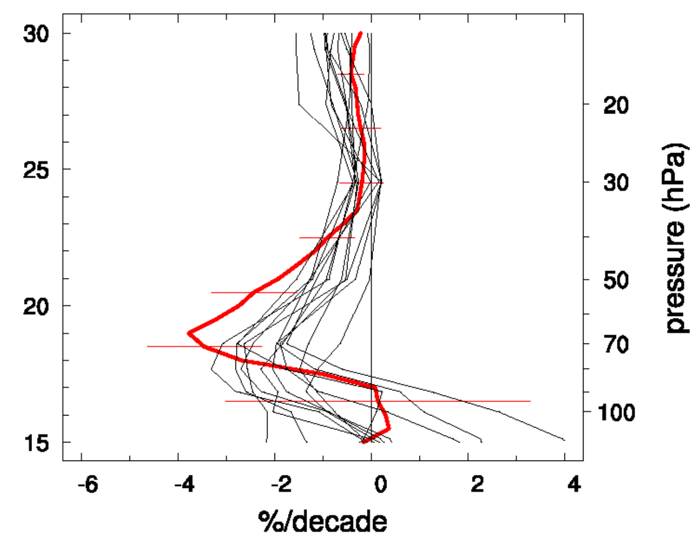




QBO, ENSO & LS Trends
(Randel & Thompson, JGR, 2011)

- ENSO signature in troposphere varies by site. Similar result by *Lee et* al. (JGR, 2010) with higher-frequency SHADOZ data, 1998-2005
- Robust lower stratosphere trend (%/decade) compared to a dozen models from CCMVal2 analysis





Tropospheric Trends

(Morioka, Fujiwara et al., 2011)

- Similar approach to R&T (2011) except (1) add IOD (Indian Ocean Dipole) oscillation; (2) 1993-2008 (KL, Watukosek) & 1998-2008 SHADOZ data; (3) 10 SHADOZ stations used
- Raw tropospheric column O_3 anomalies deseasonalized

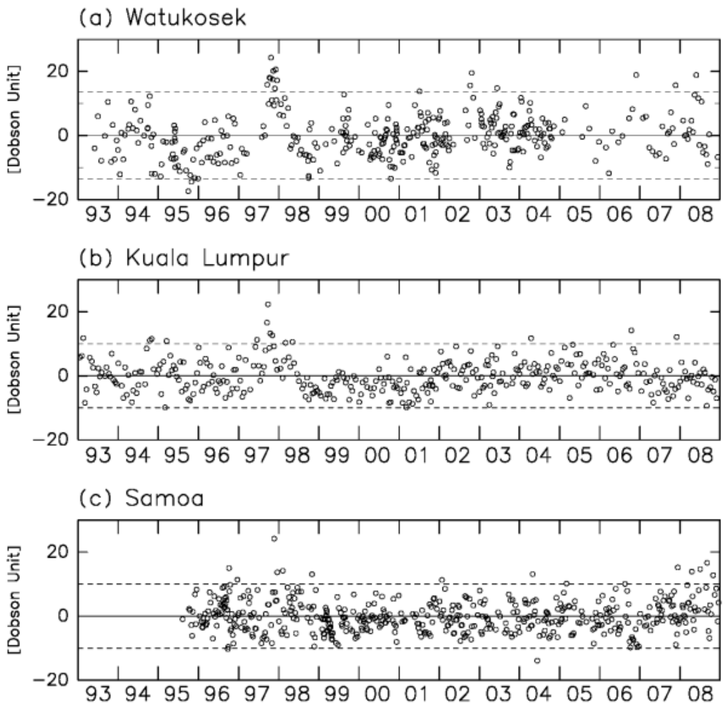
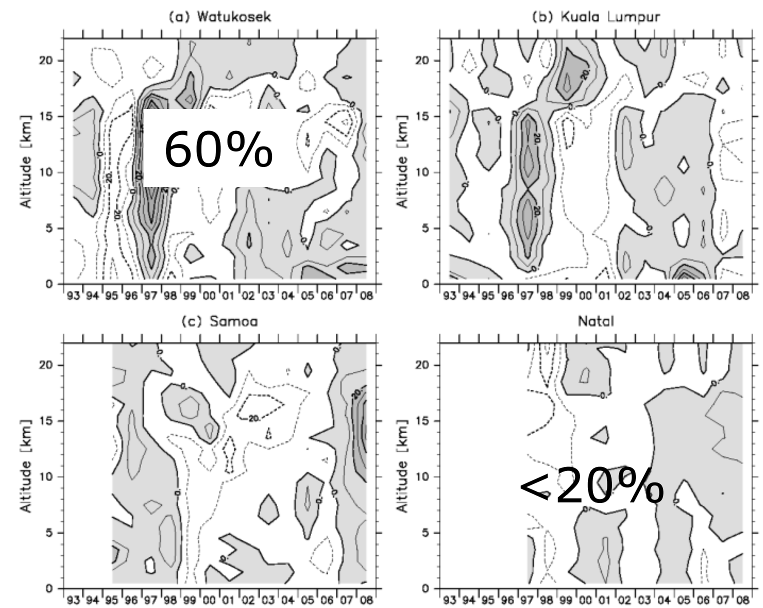


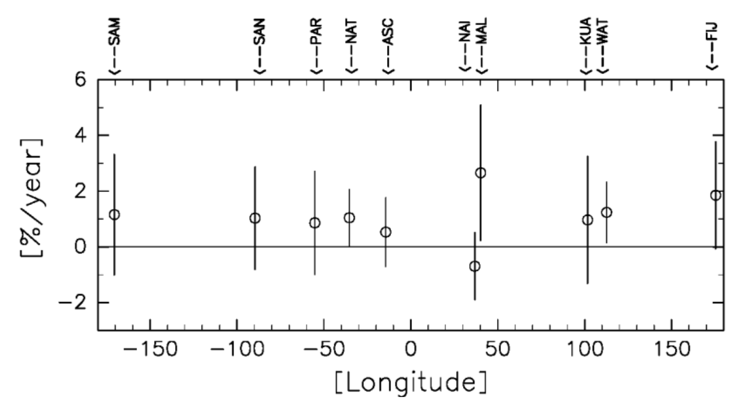
Figure 3: Time series of deseasonalized tropospheric column ozone anomaly.

Tropospheric Trends

(Morioka, Fujiwara et al., 2011)

- Vertical ozone anomaly time-series shows ENSO-IOD (1997-1998) dominance
- Trends of 1%/yr column increase would be important, but appear to be marginally significant





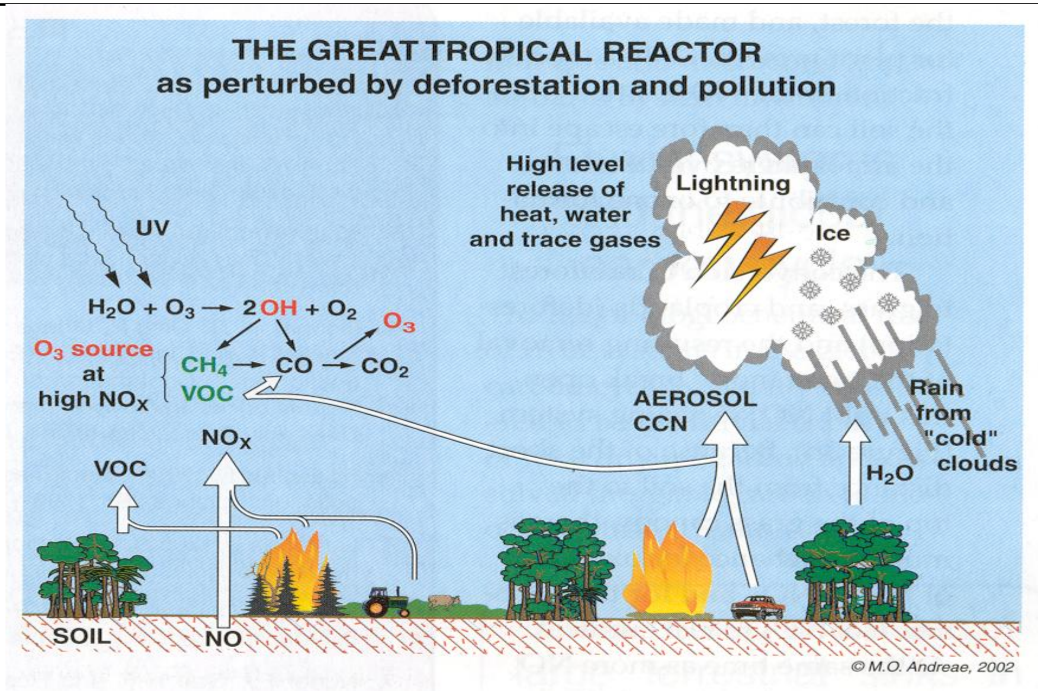
QBO, ENSO, Trends Summary

- Analysis of tropical ozone response to QBO greatly enhanced by temporal & vertical resolution of SHADOZ data. Complements SAGE (Logan et al, 2003) & HALOE (Witte et al, 2008)
- Ditto for ENSO – responses at individual stations vary (Lee et al, 2010; R&T, 2011). Constraint for model simulations
- SHADOZ & SAGE combined ozone record produces convincing 25-yr trend in LS, 1984-2009 (R&T, 2011)
- Tropospheric trends with SHADOZ problematic due to 1997 ENSO (Morioka et al, 2011)

Remote Sensing and Biomass Burning – A 20-Year Perspective

- Fishman “classic” maps & TRACE-A/SAFARI-92
- Soundings in TRACE-A
- 1997-98 ENSO & Indonesian Fires
- “Ozone Paradox” & early SHADOZ
- Aura Era
    - ‘New Residual’ Comparisons w/ SHADOZ
    - 2006 ENSO & TES

Tropical Tropospheric Chemistry



- Surface O_3 = “smog;” free tropo. O_3 = greenhouse gas
- Tropics - greatest “natural” sources of ozone precursors – lightning, soil NO, vegetative VOC
- Strong human impact: biomass burning, development

South Atlantic Ozone Maximum (Fishman et al, 1991; 1996)

- As early as 1986, Fishman

Developed the **tropospheric ozone “residual” concept** (*Science*, 1991) → Hypothesis – SON maximum when so. Hemisphere fires maximize causes ozone maximum in south tropical Atlantic

Design aircraft mission with ~15 instruments: CO, NOx, NO_y, hydrocarbons, DIAL aerosols , ozone, HNO_3, H_2O, etc

Stage US → Brazil → So Africa → Ascension Island , 20 Sept-22 Oct 1992

Complement aircraft sampling with ozonesondes over 3 African locations (Brazzaville, Okakuejo, Pretoria/Irene); Ascension Island; Natal, Brazil

Multi-aircraft, ground-based sampling in southern Africa = “SAFARI-92”
Special JGR Issue, 30 Oct 1996

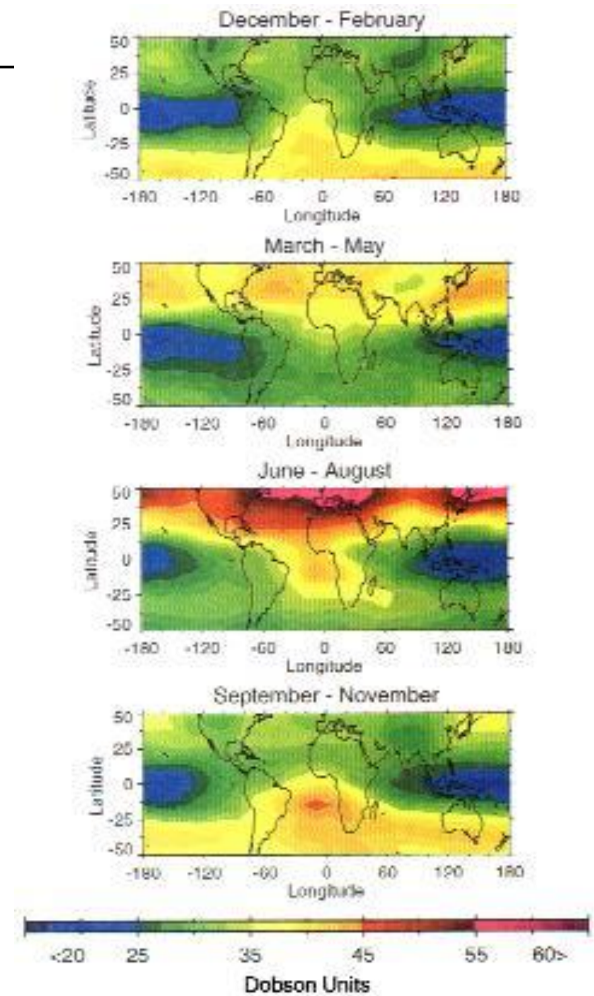
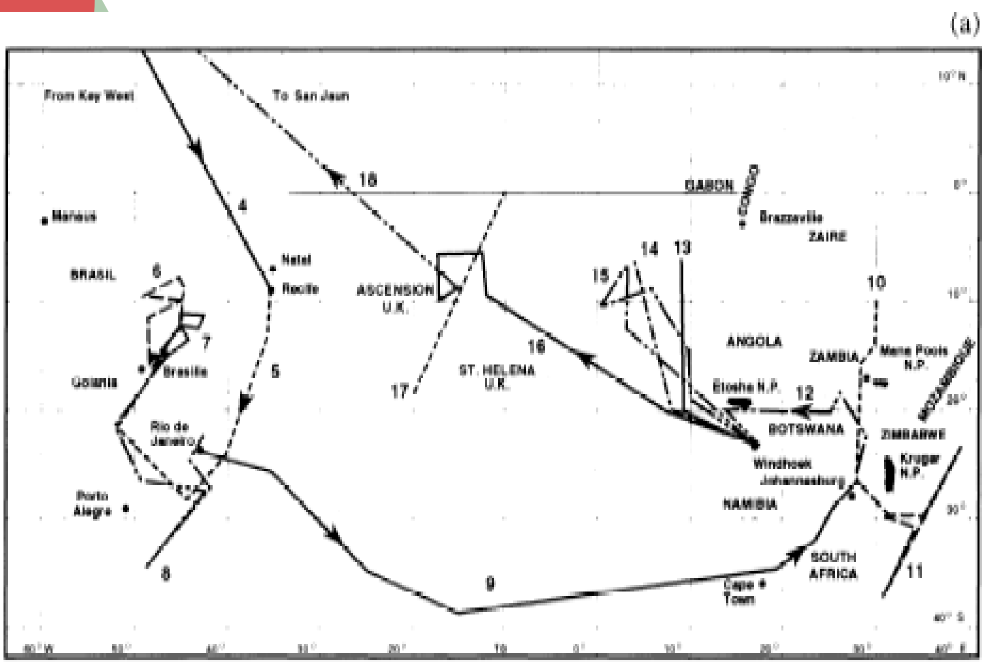


Plate 1. Depiction of climatological satellite data during four seasons. Note the September-November panel showing plume of high-tropospheric ozone in South Atlantic.

Fishman et al (96) – Left, Map; Thompson et al (96) – Right, Sounding Stations & Africa Closeup



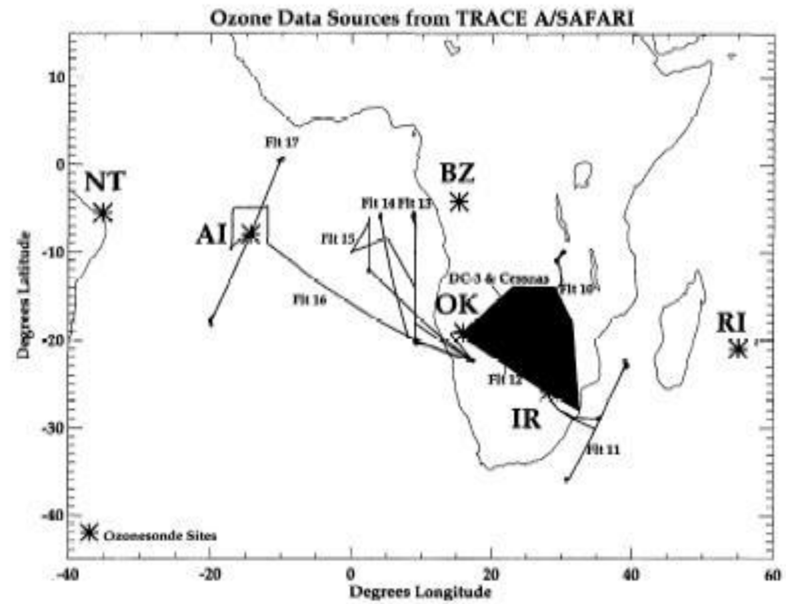
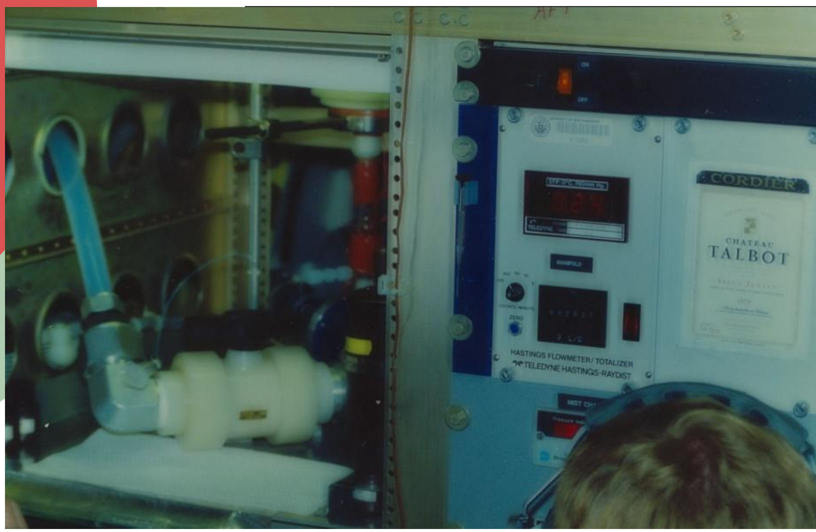


Figure 1. Maps showing staging sites for SAFARI/TRACE A aircraft and major fixed experimental locations: AI, Ascension; BZ, Brazzaville; NT, Natal, Brazil; OK, Okaukuejo; IR, Irene (Pretoria); RI, Réunion Island. SAFARI aircraft sampling region (shaded) applies from September 16 to October 6. TRACE A flights (numbered) took place from October 6 to 22, 1992.

Experimental – NASA DC-8 A/c Closeup; Brazilian, African Fires



- Talbot HNO_3 – above
- Brazilian fire (middle); African fires with denser smoke

Fires Observed During TRACE-A

Intense smoke near
11° S, 30° E (Northern Zambia)
October 6, 1992

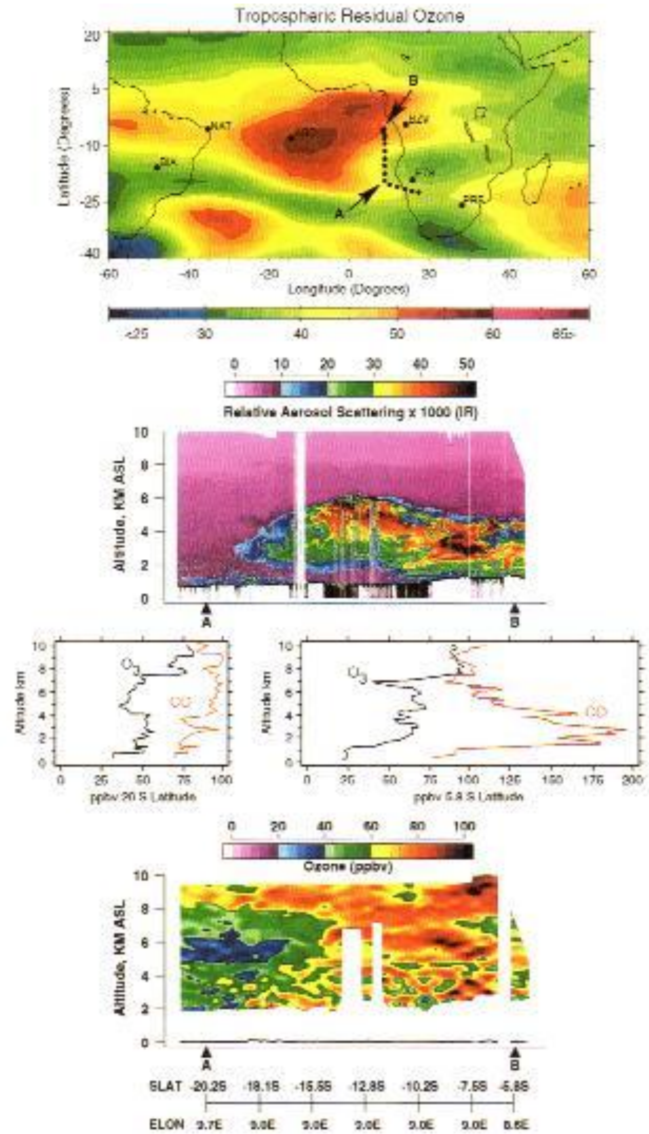
Typical Brazilian fire
near 9° S, 48° W
September 27, 1992

Fire scar area near
11° S, 30° E
October 6, 1992

Plate 3. Photographs from DC 8 showing burning in Africa and Brazil.

Ozone Detail (Satellite) & DIAL Ozone, Aerosols on 14 Oct 1992, SW African Coast

- Primary GOAL – Validation of "residual"
- Fishman et al, 1996
- Evidence of fires, with chemistry downwind, meaning Mid-troposphere winds easterly carrying pollutants from Africa toward Atlantic



Brazilian O_3 Increase in two Sept 92 Soundings (Pickering et al., 1996); Trajectories: Natal Ozone is Combination of Brazilian *and* African Pollution (Thompson et al., 1996)

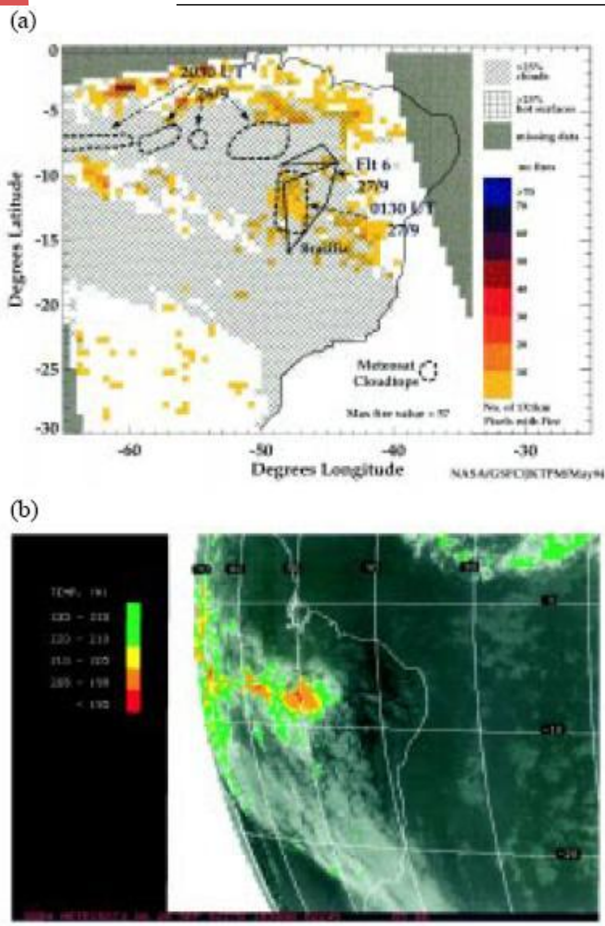


FIG. 5. (a) Sampling location on TRACE-A flight 6 (27 September 1992), cloud locations from Meteosat imagery of 26–27 September, superimposed on AVHRR-derived fire counts for 26 September 1992. (Fire counts from J. Kendall and C. Justice, NASA/GSFC.) (b) Satellite imagery shows cloud top heights reached up to 16 km. *Meteosat-4* imagery, 1830 UTC 26 September 1992.

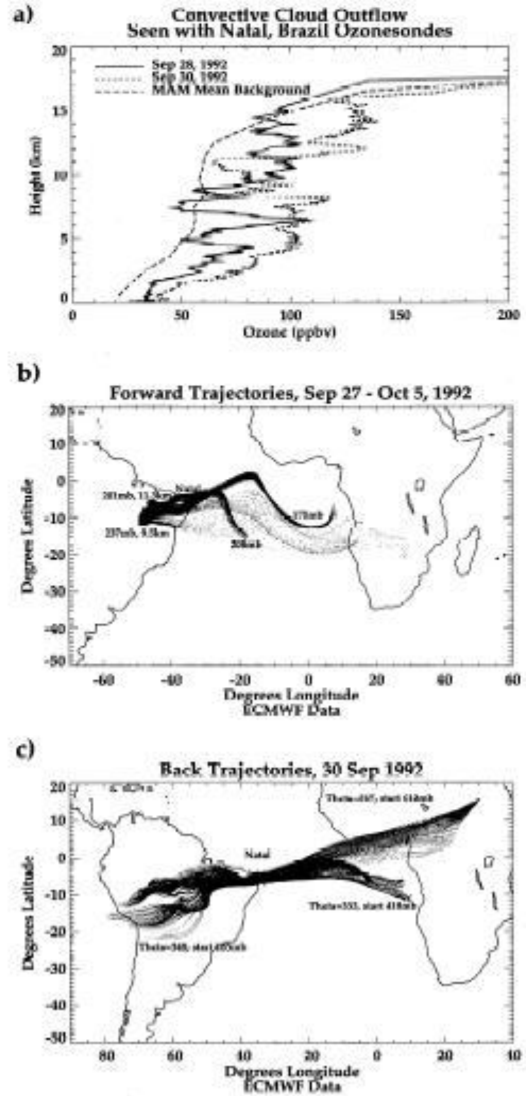
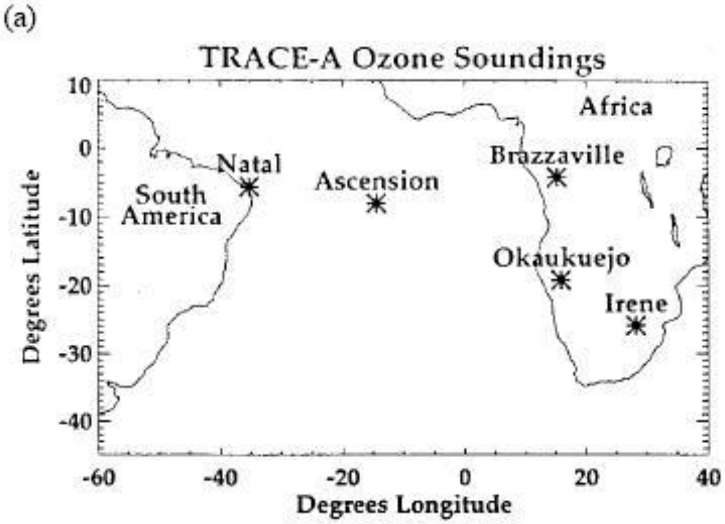
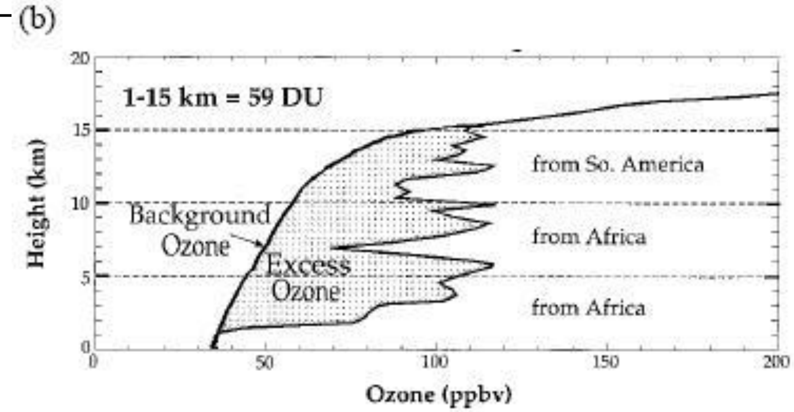


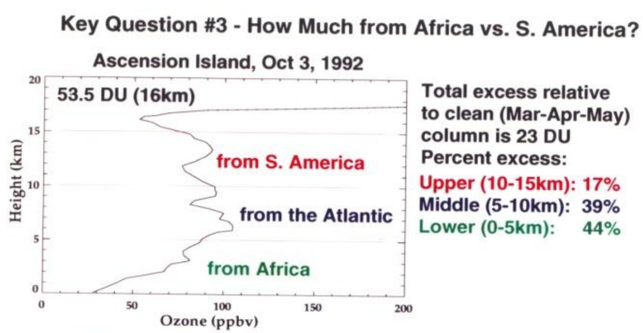
Figure 10. (a) Ozone profiles from Natal, Brazil, soundings

- Refer to Pickering et al & Thompson et al for calculations of ozone formation rates *and* to see NO increase from lightning!

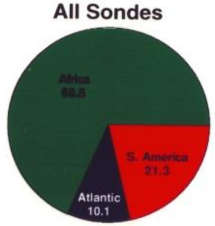
Summary of TRACE-A Ozone Formation & Transport over So Atlantic Ocean – Sonde-Trajectory Apportionment



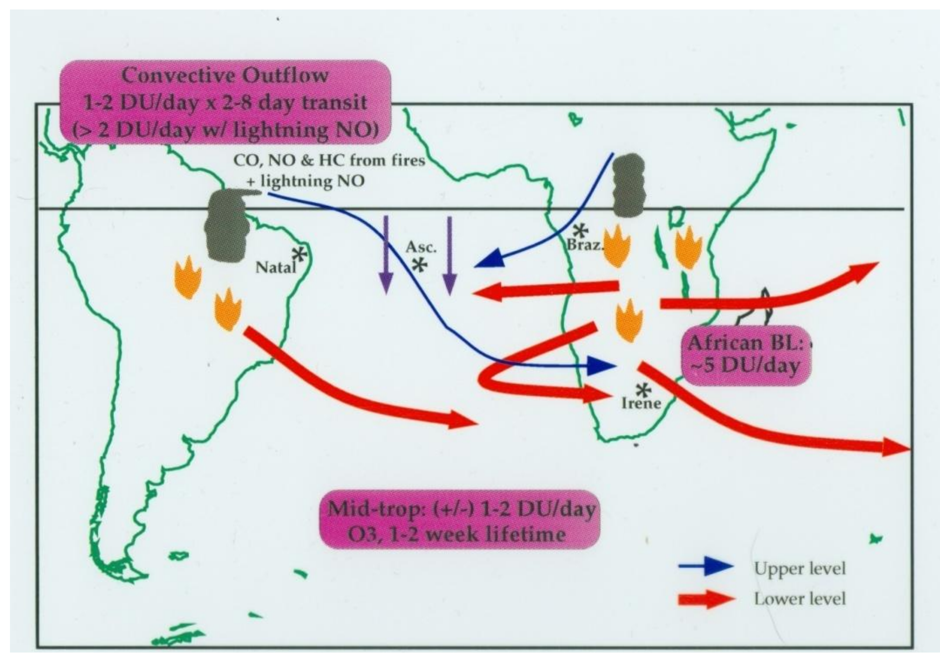




All Sondes



- 1992 Burning Season
- Sonde sites:
  Natal, Brazil
  Ascension Island
  Brazzaville, Congo
  Okaukuejo, Namibia
  Irene (Pretoria), S. Africa



Origins of SHADOZ

- After TRACE-A African, Ascension soundings ceased
- PEM-Tropics-A (1996), NASA DC-8 over Pacific. NOAA-NASA sounding partnership at Tahiti, Samoa, Fiji. Soundings ceased after experiment
- SHADOZ initiated 1998 restart of 3 Pacific stations, Ascension, added Reunion & Nairobi. Re-activated South Africa, incorporated Waukosek w/ Japanese support.
- First SHADOZ add-on campaign – Aerosols99 cruise. North and South Atlantic contrast "Ozone Paradox" is stimulus for adding northern hemisphere stations

What-Where-When-How SHADOZ?
(So. Hemisphere Additional Ozonesondes)

Strategic Design Addresses Questions – 1998->

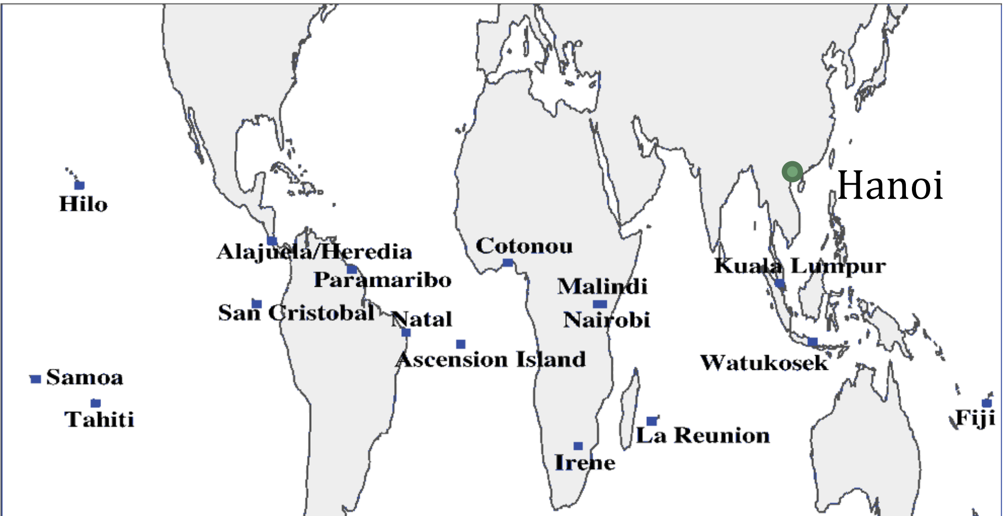
1> Satellite/model validation & optimization

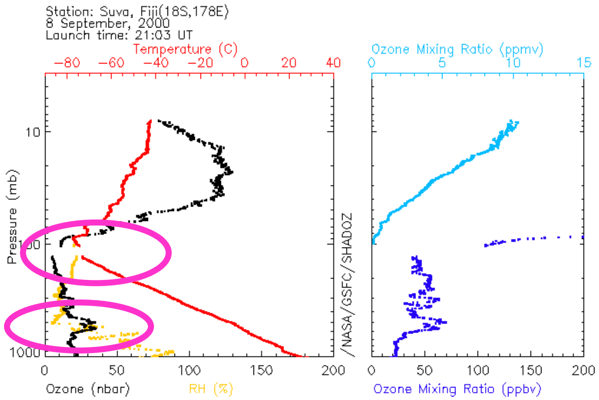
2> **Nature of zonal wave-one**

3> **Ozone variability on multiple time, space scales**

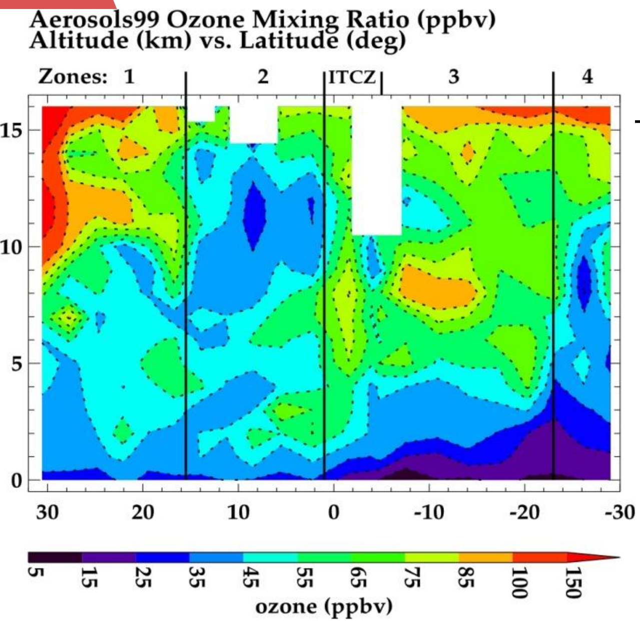
- Resolution in *stratosphere, troposphere* requires sounding
- Full zonal coverage – 9 sites in 1998, now 13; weekly soundings
- Complements campaigns & archives data (SAFARI-2000, TC4)
- **2011 - > 5000 profiles** at http://croc.gsfc.nasa.gov/shadoz

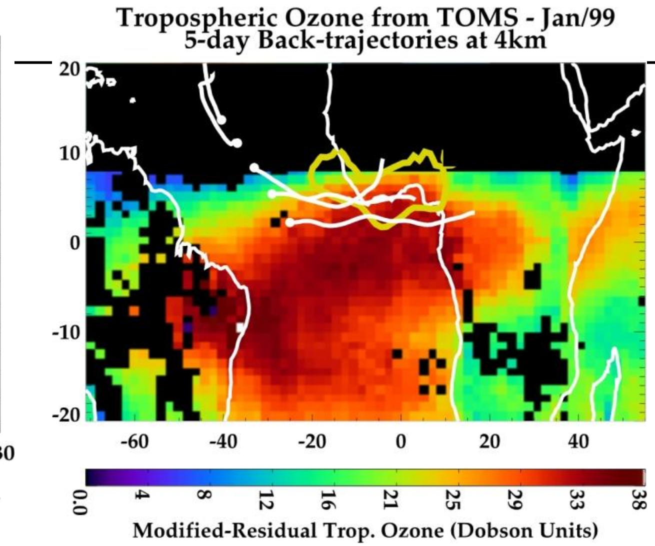
SHADOZ Locations

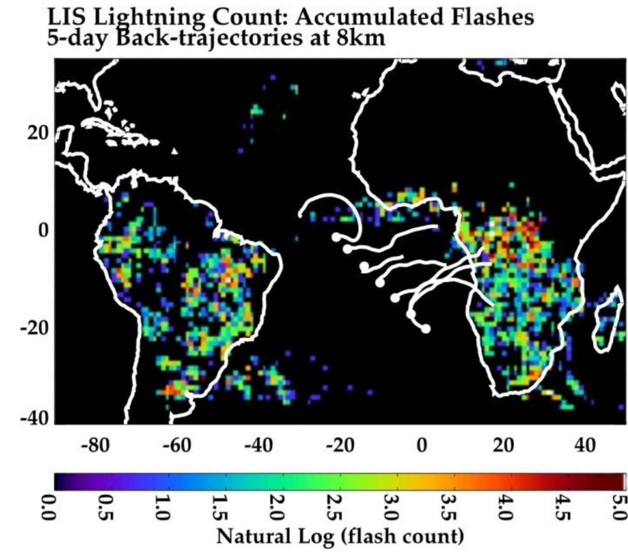




Atlantic "Ozone Paradox"



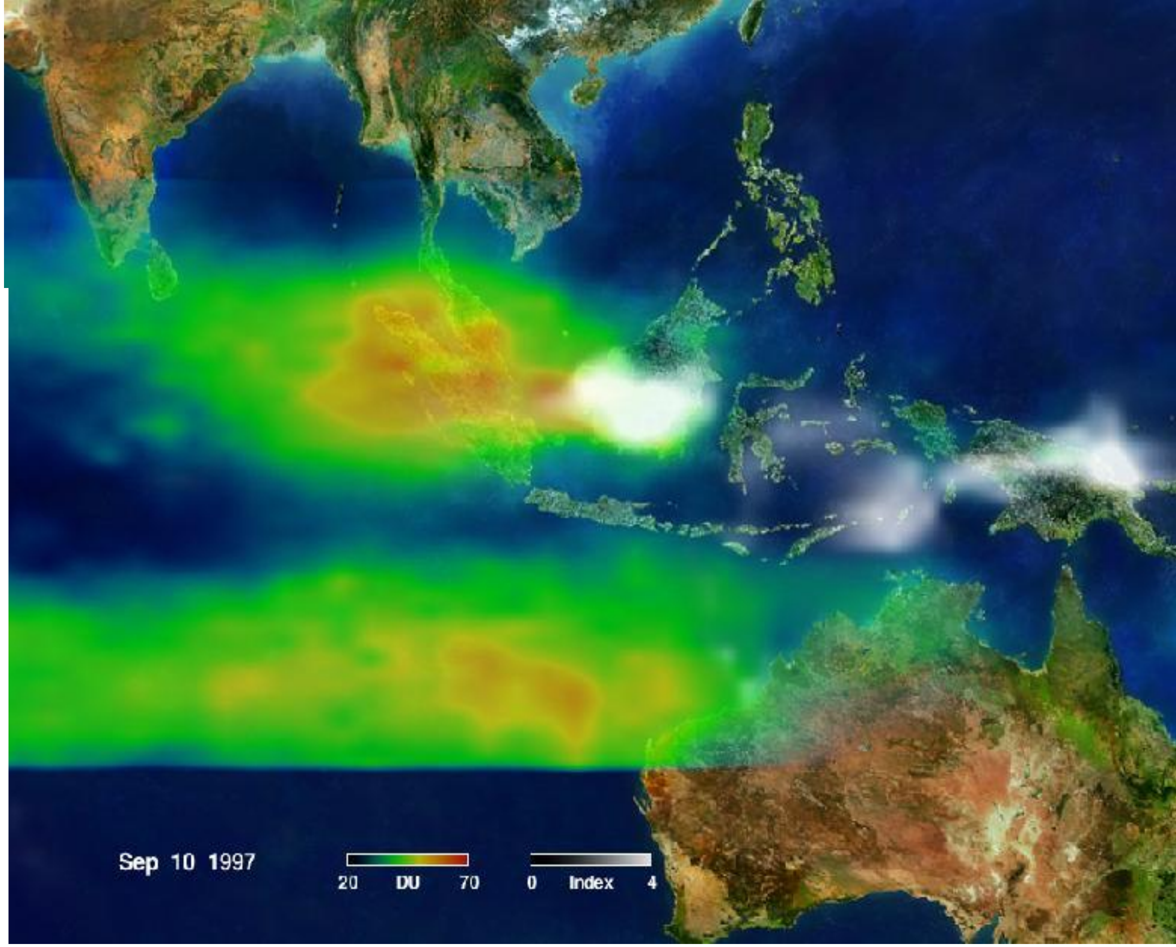




- "Paradox" - more DJF ozone over southern hemisphere when north tropics burning! Thompson et al. (GRL, 2000)
- Mechanisms: Interhemispheric transport, subsidence of ozone over So. Atlantic, lightning. Left = soundings; Center = TOMS tropo ozone; Right = TRMM/LIS lightning
- ***How much of each process?*** Edwards et al. 2003; Jenkins et al. 2003

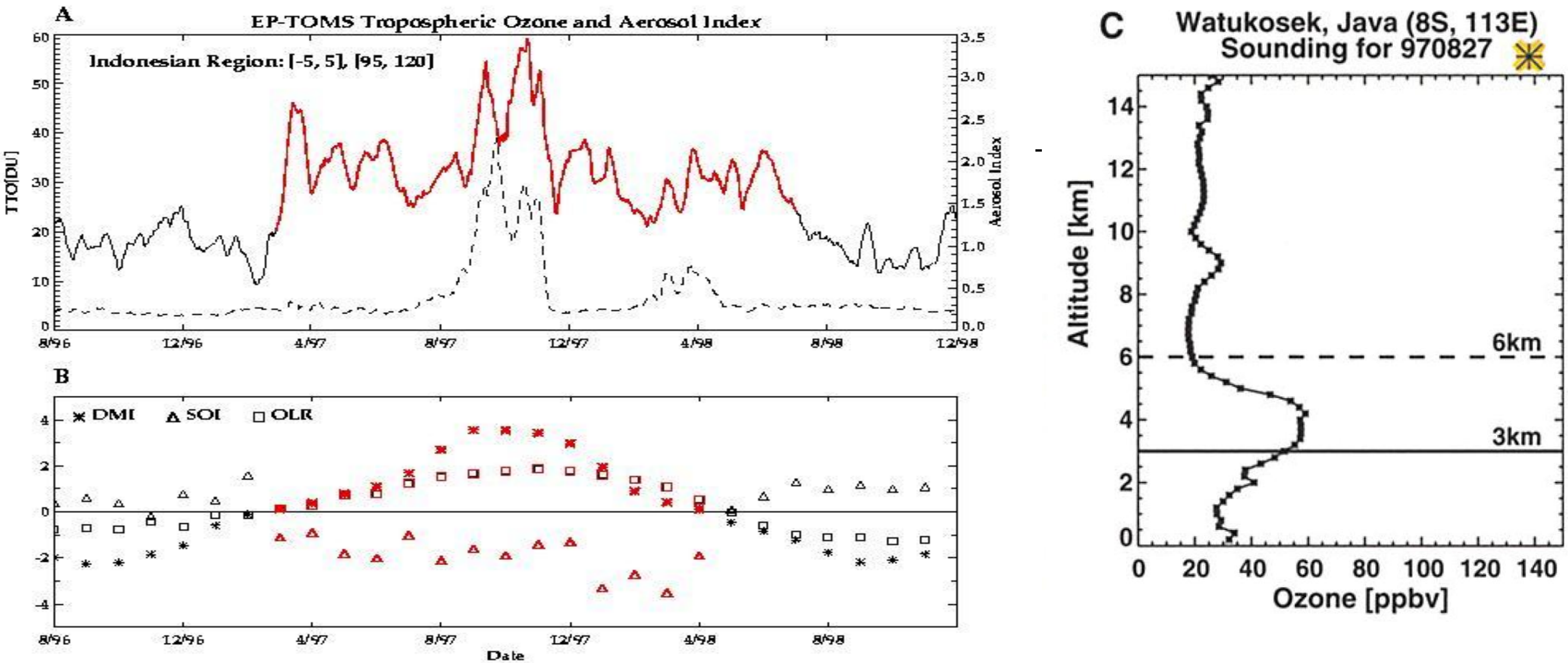
Indonesian Fires from 1997 El-Nino (Aug.-Nov.)

- TOMS image, 10 Sept., resolves smoke from fires (gray), ozone (colors)
- Upper plume from Indonesia, unusual ENSO event; lower plume annual from Africa



No EOS- Pre-MODIS, MISR, etc

- Time-series shows (1) smoke, ozone transport can diverge (traveling in different layers); (2) two plumes merge in late October 1997



- TOMS time-series: Indo. ozone (red solid) increase at ENSO onset (indices, lower) four months prior to onset of fires ➔ regional subsidence
- Late August 97 sounding (not shown, very dry above 6 km) From Thompson et al., Science, 2001

Adding Satellite Data to ENSO Observations

- Multi-year records with TOMS/OMI-derived trop ozone by Ziemke/Chandra et al. Clear ENSO signals
- Ready for trends? Cf SHADOZ and enhanced OMI/MLS tropospheric column: *Schoeberl et al, 2007*

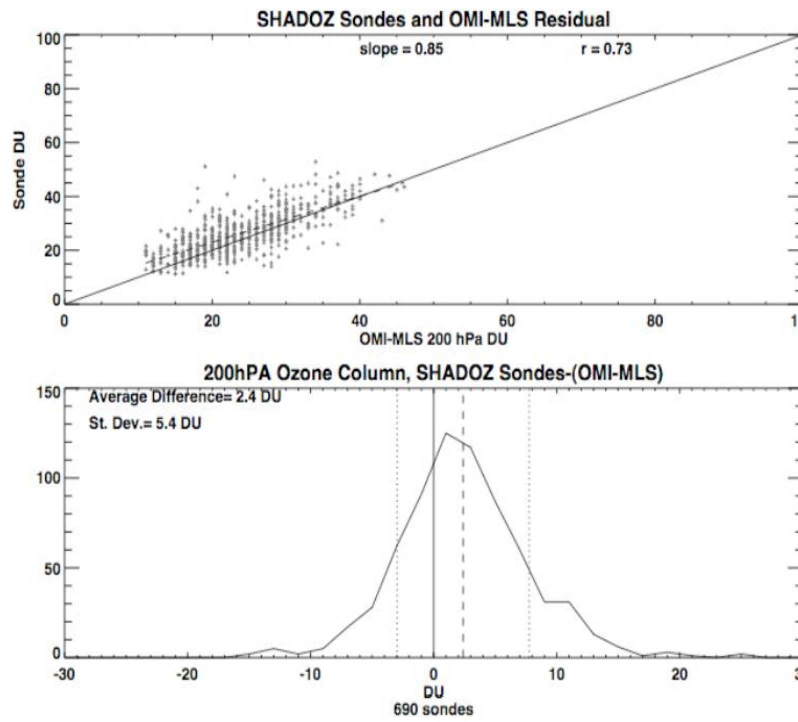


Figure 3. Comparison of ozonesondes 200TSC and the our 200TSC estimate. Upper figure shows the data poi the slope of the data (dashed line) and the correlation coefficient (r). The one-to-one line is the solid line. The lower figure shows a PDF of the difference between the sonde 200TSC with the mean and standard deviation (dashed and dotted, respectively).

2006 ENSO – Three Species from TES

L03816 LOGAN ET AL.: EFFECTS OF THE 2006 EL NIÑO SEEN BY TES L03816

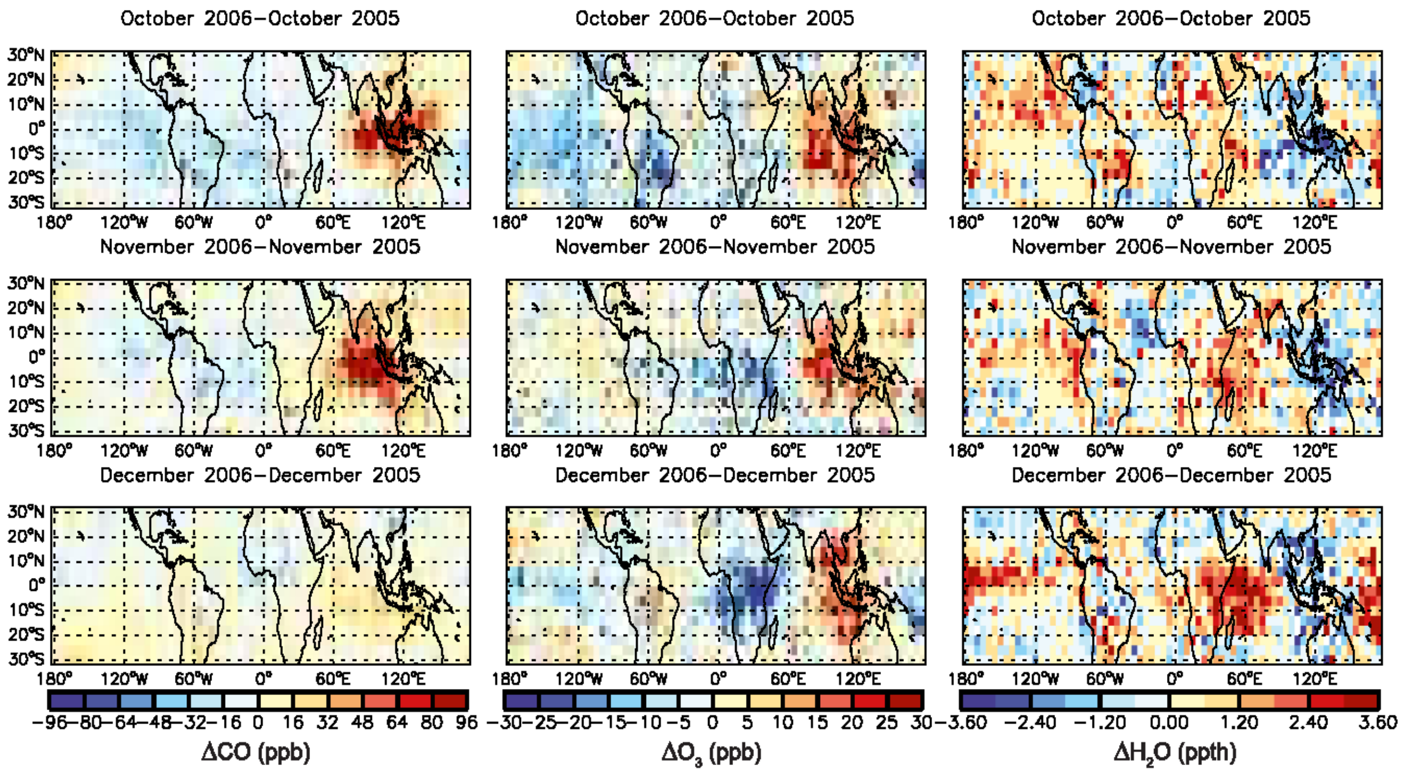
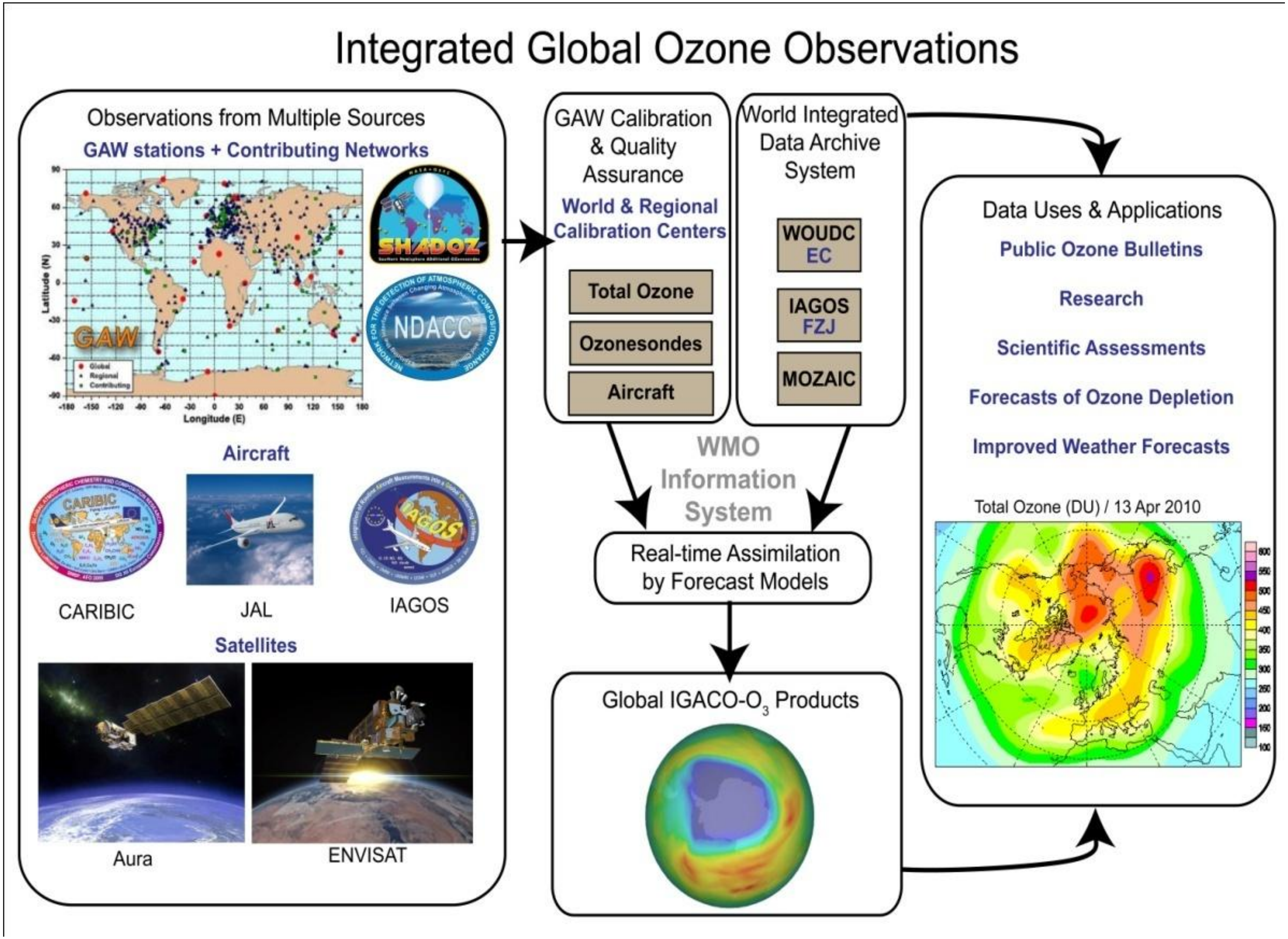


Figure 2. The difference between 2006 and 2005 for (left) CO, (middle) O_3, and (right) H_2O for October to December at the 511 hPa retrieval level; CO and O_3 are in ppb, H_2O in ppth.

Logan et al., *GRL*, 2008



Integrated Global Ozone Observations
Observations from Multiple Sources
GAW stations + Contributing Networks
GAW
Global
Regional
Contributing
Latitude (N)
Longitude (E)
SHADOZ
NDACC
Aircraft
CARIBIC
JAL
IAGOS
Satellites
Aura
ENVISAT
GAW Calibration & Quality Assurance
World & Regional Calibration Centers
Total Ozone
Ozonesondes
Aircraft
World Integrated Data Archive System
WOUDC EC
IAGOS FZJ
MOZAIC
WMO Information System
Real-time Assimilation by Forecast Models
Global IGACO-O3 Products
Data Uses & Applications
Public Ozone Bulletins
Research
Scientific Assessments
Forecasts of Ozone Depletion
Improved Weather Forecasts
Total Ozone (DU) / 13 Apr 2010