# SHADOZ (Southern Hemisphere Additional Ozonesondes): Status Report to GRUAN

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**12 March 14, 6th GRUAN ICM, Greenbelt**

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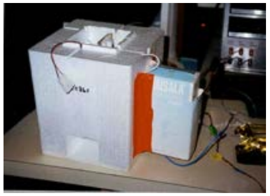
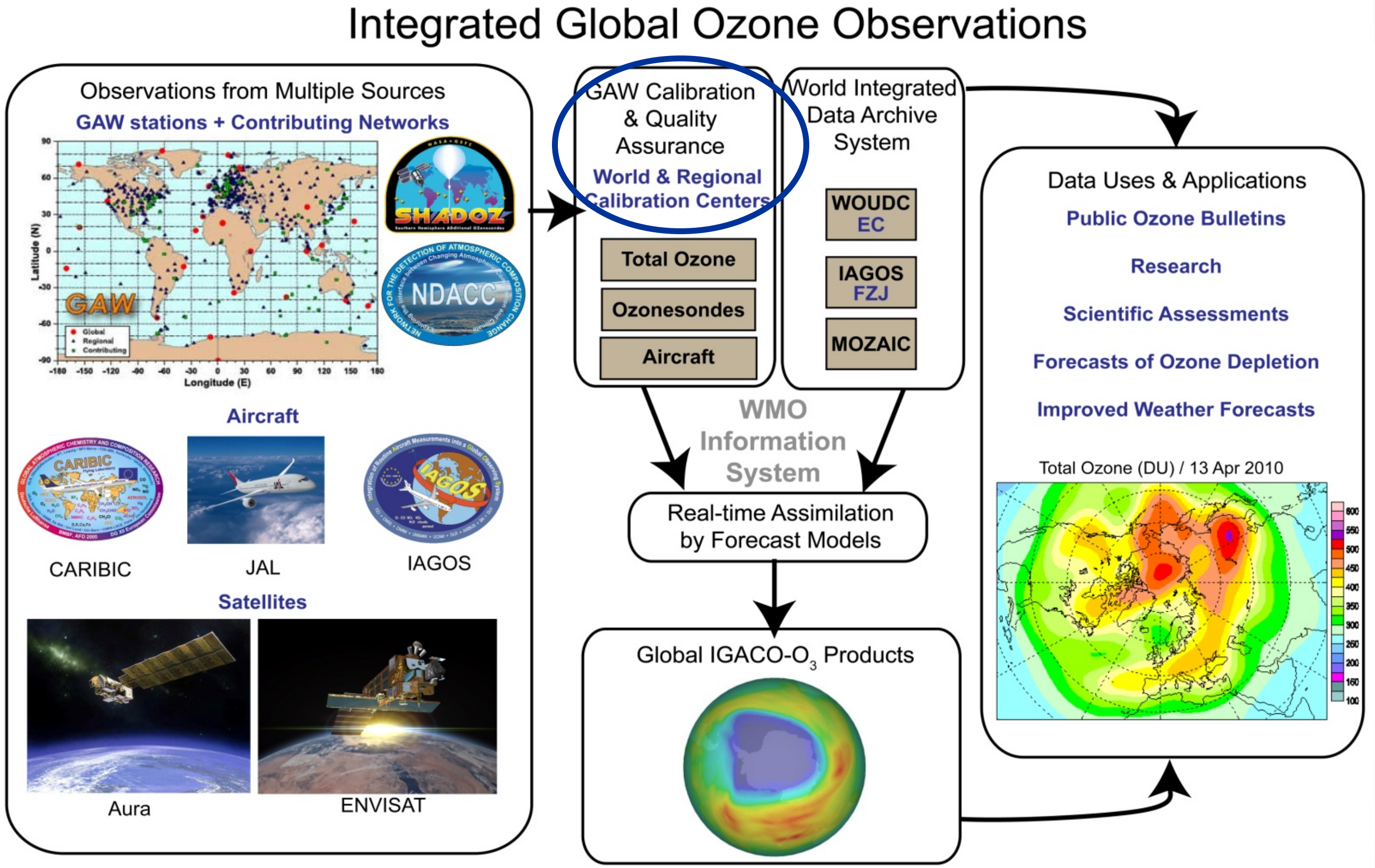
http://croc.gsfc.nasa.gov

# Outline of Presentation

- **What, Why, Where, Who of SHADOZ**
- **New SHADOZ Science: Examples from Trend Studies**
- **Archive Updates**
  - Reactivation of Stations
  - Data Re-processing by WMO/NDACC Ozonesonde Guidelines. Focus on 3 variables (Sensing Solution Type [SST], Instrument type, Pump Correction Factor [PCF]).
- **Other Ozone/Radiosonde Issue with SHADOZ Impact**
  - Background Current (Voemel & Diaz, 2009; Stuebi & Levrat, 2009). Implication for SHADOZ at certain sites
  - Radiosondes (RS80-> RS92->Imet). "Pressure Offsets" - new AMT paper (Stauffer et al, 2014) includes SHADOZ data
  - Third (new) instrument type. SPC stable, ENSCI-> DMT ??
- **Summary** – SHADOZ at Year 16. Instrument changes will require periodic re-processing & lab testing

# Integrated Earth Observing for Ozone






Measure

Model

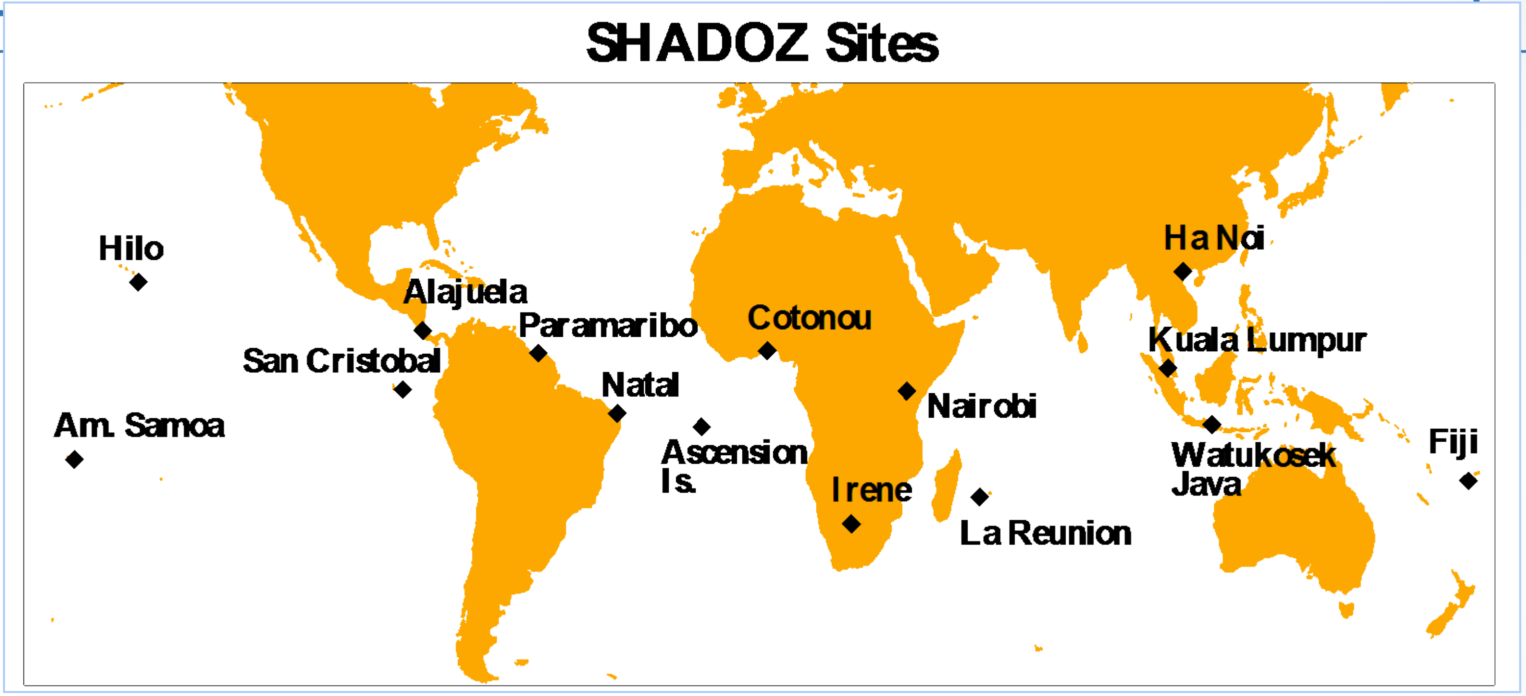
Predict

- Satellites with ground-based (eg Dobson) instruments for total column
- Profile validation - partial columns (lidar, aircraft); only sondes measure surface to 5-10 hPa (35 km) with 50-100 m vertical resolution

# Why & How: SHADOZ Initiative in 1998

- “Strategic” ozonesonde network coordinates launches in space & time for specific scientific purposes
- Validate ozone profilers & new tropospheric products from TOMS/UARS/SBUV. Also SCIAMACHY, Aura, NPP
- Wave-one in total ozone – in stratosphere or troposphere? => *Requires zonal coverage of stations*
- What is role of dynamics (convection, QBO, ENSO, etc) in ozone variability? => *Requires 2-5 launches/month*
- ADD IN PRACTICAL CONSTRAINTS
  - Operational – host supplies ground stations, launch gas, personnel
  - NASA, NOAA supply *some* sondes – ALL data archived @ GSFC
  - Data distribution: open, timely, user-friendly format
  - Leveraging resources key to sustaining network

# Where, When, Who: SHADOZ Stations & Data Archive




- **WHERE & WHEN** are the data?
  - Fifteen stations operated 2005-2009 [Thompson et al, JGR, 2012]
  - http://croc.gsfc.nasa.gov/shadoz . Annual -> WOUDC, with links to NDACC, AVDC. In 2014 > 6K P-T-U & $O_3$ profile sets
- **WHO:** Anne Thompson, PI; Jacquie Witte, Archiver & International Team from ~15 host countries and sponsors (Europe, US, Japan, Africa, So Am.)

| Topic of Study | Station* | Co-I/Sponsor** | SHADOZ start year | Site start year | Network affiliation ** | Ancillary data/UACO variables | Expected sonde freq./year |
|---|---|---|---|---|---|---|---|
| **Long-term Validation / Trends** <br><br> **(Data available prior to 1995)** | **Kuala Lumpur** | Maznorizan bt Mohamad, & YY Toh, Malaysian Met., S. Yonemura, Japan | 1998 | 1992 | | | 26 |
| | **Watukosek** | Ninong Komala, LAPAN & Masatomo Fujiwara, Hokkaido Univ. | 1998 | 1998 | SOWER | CFH-water vapor profiles | 26 |
| | **Am. Samoa** | Bryan Johnson & Samuel J. Oltmans, NOAA | 1998 | 1986 | NDACC / GAW | Dobson / surface CO2, CH4, CO, CFCs, O3 | 52 |
| | **Natal** | Francis J. Schmidlin, NASA/Wallops & Neusa Paes Leme, INPE | 1998 | 1979 | NDACC | Brewer | 52 |
| | **Hilo** | B. Johnson , D. Hurst & S. J. Oltmans, NOAA | 1998 | 1982 | NDACC / GAW | MLO – Dobson, FTIR, O3 Lidar, CFH-water vapor / surface CO2, CH4, CO, CFCs, O3 | 52 |
| | **Irene** | G.J.R. Coetzee, S. African Weather Serv. | 1999 | 1990 | | Dobson | 26 |
| | **La Reunion** | Françoise Posny, Université de La Réunion | 1998 | 1998 | NDACC | SAOZ, O3 Lidar | 26 |
| **Processes in the FT, TTL, and LS** | **Fiji** | B. Johnson & S. J. Oltmans, NOAA | 1998 | 1997 | | | 26 |
| | **San Jose*** ** | Rennie Selkirk, NASA/GSFC & Holger Vömel, GRUAN Lead Center | 2006 | 2006 | GRUAN | SO2 sondes, CFH-water vapor profiles | 52 |
| | **San Cristobal** | B. Johnson (NOAA) & H. Voemel | 1999 | 1998 | GRUAN / SOWER | CFH-water vapor profiles | 52 |
| | **Paramaribo** | Rinus Scheele, KNMI | 1999 | 1999 | NDACC | Brewer | 52 |
| | **Ascension Is.** | Francis J. Schmidlin, NASA/Wallops | 1998 | 1990 | TCCON / GAW | Carbon columns / surface CO2, CH4, CO, CFCs | 26 |
| | **Nairobi** | Bertrand Calpini, MeteoSwiss & John Nguyo, KMD | 1999 | 1996 | | Dobson, surface O3 | 52 |
| | **Ha Noi** | H. Gia Hiep, AMO, S. Ogino, JAMSTEC, M. Fujiwara, Hokkaido Univ., & M. Shiotani, RISH | 2005 | 2004 | SOWER | CFH-water vapor profiles | 26 |

* Colors for stations indicate geographic region: blue-Western Pacific, red-Atlantic/Africa, white-Subtropics, & green-Equatorial Americas
** See Acronyms in Appendix
*** Station formerly referred to as Alajuela / Heredia

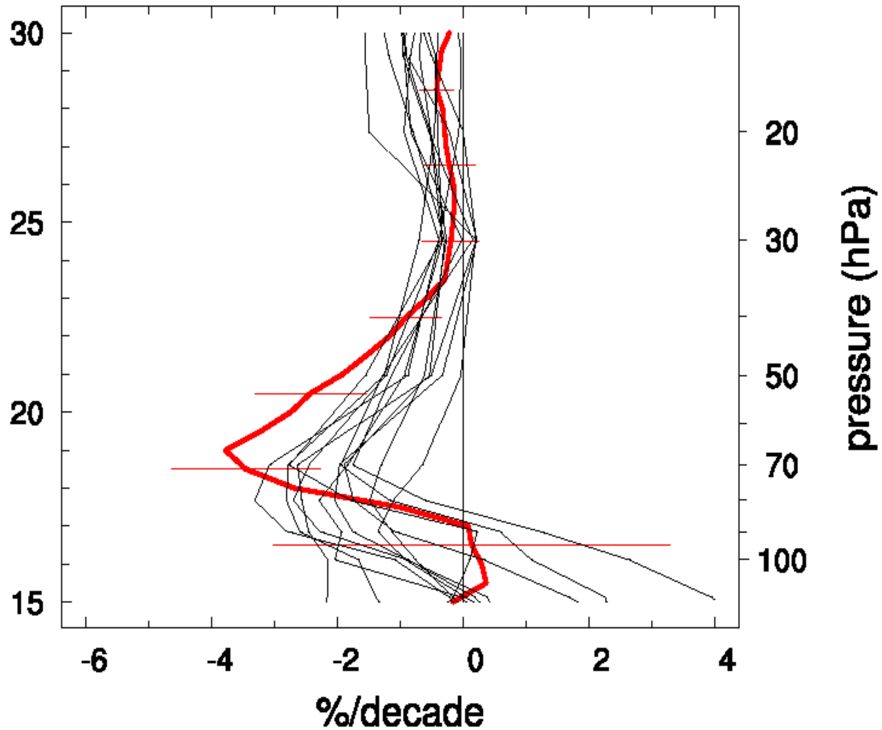
# SHADOZ Archive Status, March 2014

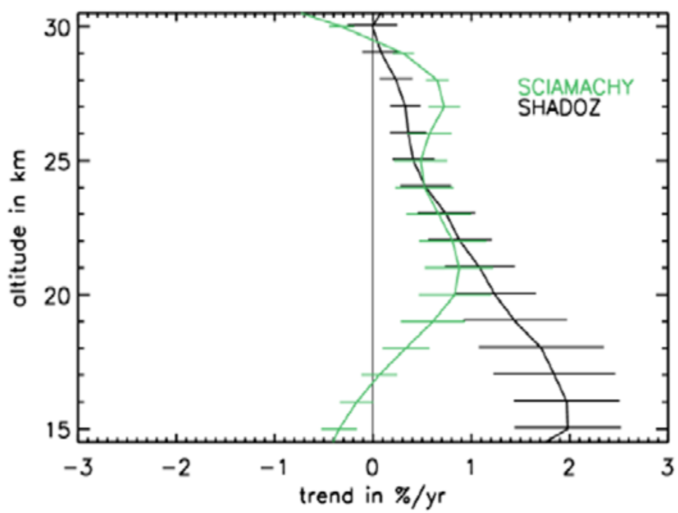
- Data gaps at 5 stations have been resolved (thanks to NOAA & partners, GSFC/WFF, INPE, SAWS)
  - Gaps began 2008 at Fiji, San Cristobal (Galapagos, Ecuador), Irene (So. Africa). <u>All are operational as of 2014. Irene since 2012.</u>
  - Ascension & Natal gaps started in 2010. <u>Natal operational, 10/13</u>
- Data Link to SHADOZ at NDACC. WOUDC data delivery from SHADOZ complete for 2012, partial for 2013.
- Re-processing underway at all stations.
  - NOAA – Station data delivered to SHADOZ 3/14: Fiji, Samoa, Hilo. San Cristobal & Costa Rica pending.
  - Underway: Nairobi, Paramaribo, Réunion, Watukosek.
  - More complex: Kuala Lumpur, Hanoi, Natal

# New "Science" from SHADOZ

- Fifteen-year record (late 80s/early 90s at 5 sites) invites trends analysis.
- Example (1): Combined with SAGE II, 1984-2009 (Randel & Thompson, 2011) is "standard" for evaluating Chem-Climate Models (CCM). Lower strat (LS) ozone <u>declining.</u>
- Example (2): Combine selected SHADOZ stations, compare to SCIAMACHY, MLS, OSIRIS, 2002-2010. Data sets not in agreement, but mostly show LS ozone <u>increasing!</u> Gebhardt et al, *ACP,* 2013 ➔ Increase in Brewer-Dobson circulation has "paused"
- Example (3): Large free tropospheric ozone increases over SHADOZ Irene and Réunion, 1990-2008 (Thompson et al. 2014) suggest rapidly growing SH pollution transport!

**Trends (1): Well-resolved LS from SAGE-SHADOZ = 25-year Record (Red, Left)**
**Trends (2): Gebhardt et al, ACP, 2014. Diverse Results with SCIAMACHY, SHADOZ for 2002-2011. (Right)**



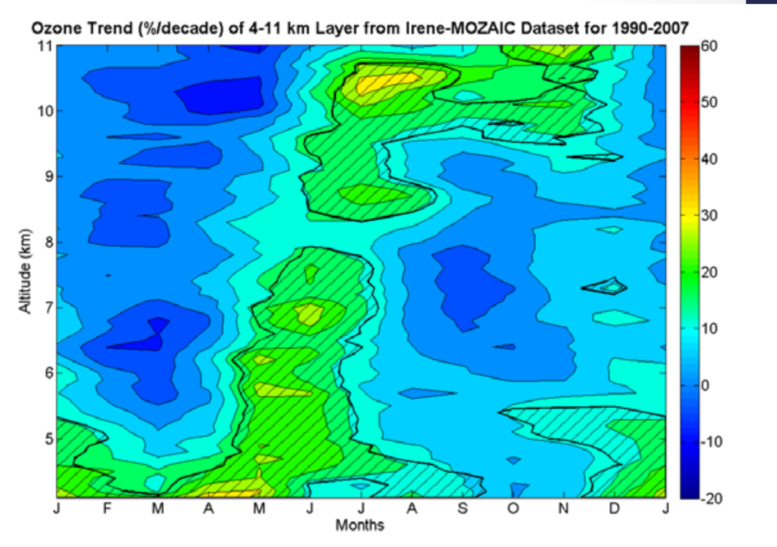



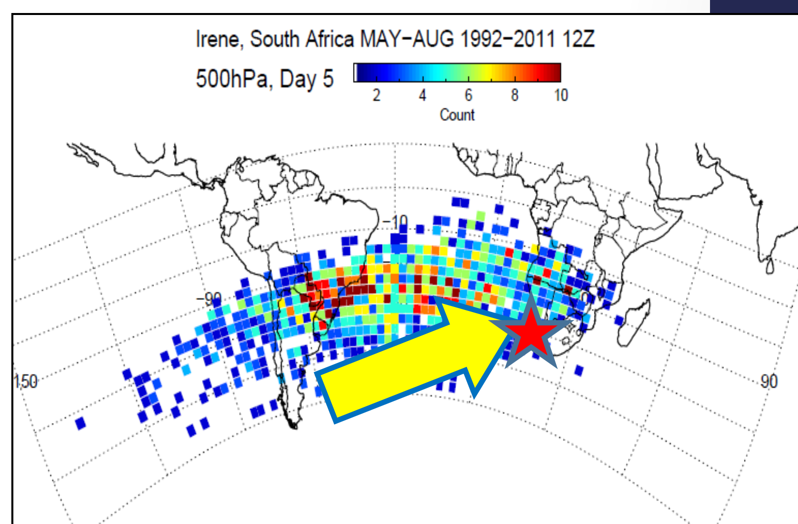

Ozone Decline, 17-21 km, 1984-2009

Ozone increase (?), 2002-2011

# Free Tropospheric Ozone Trend from Irene (Pretoria) SHADOZ Station, 1990-2007

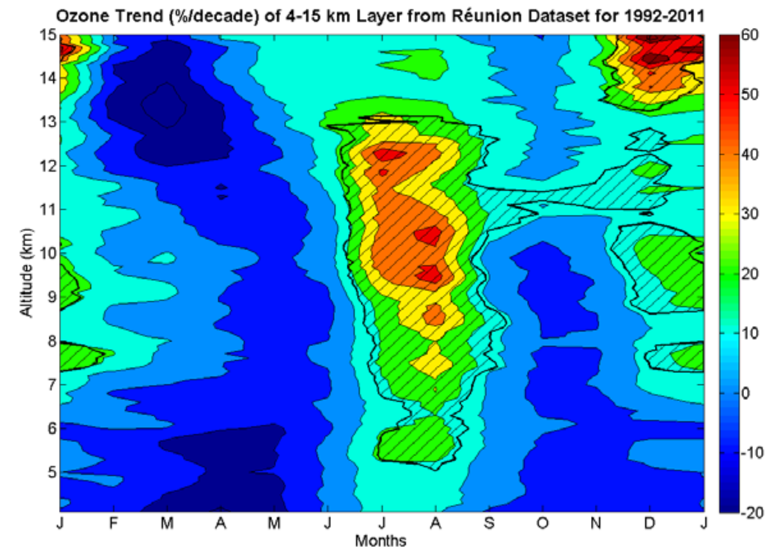
- At 4-5 km in April to June (upper) there may be a near-surface ozone pollution trend
- In 5-11 km layer +25-decade ozone increase, in <u>winter</u>!
- Back-trajectories (lower) reveal much of the ozone origins from South America where mega-cities growing in emissions 20%/decade or more
- (Thompson et al, *ACP*, submitted, 2014)

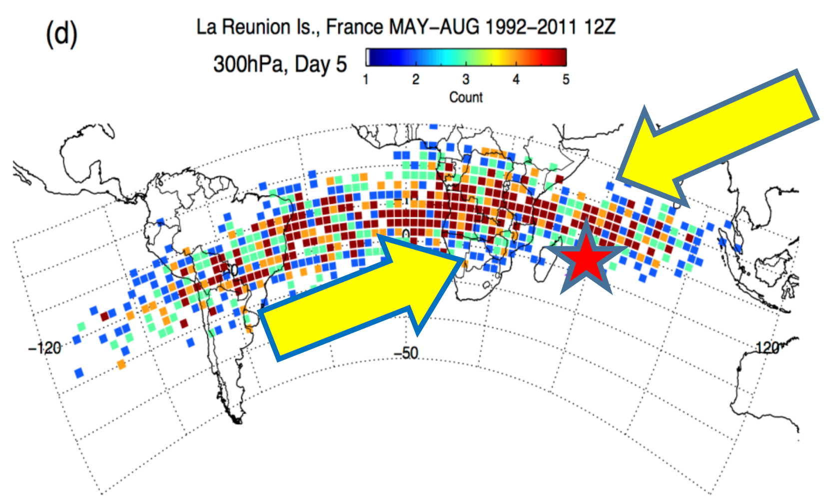


# Free Tropospheric Ozone Trend from Réunion SHADOZ Station, 1992-2011

- Magnitude at Réunion much greater than at Irene (but 2 yr longer record)
- Trajectories imply Asian as well as African, So American pollution transport in winter
- Irene and Reunion have Launch Time shift from early to later in day that artificially introduces more $O_3$ into BL, so trends only above 4 km!
- (Thompson et al, *ACP*, submitted, 2014)



# Chronology of SHADOZ QA Issues

- 1998-2005
  - Biases apparent in early SHADOZ data when total ozone column amounts compared to Dobson, TOMS satellite
  - Discrepancies in stratosphere rationalized by comparisons of vertical structure because strat. COLUMN amount does not vary
  - JOSIE-2000 Lab tests with WMO seem to explain some biases

- **2005-2009 (in Thompson et al, 2012, JGR)**
  - After JOSIE-2000 and 2004 field tests, some stations changed solutions, instrumentation. Introduced "noise" in record
  - One station 're-processed' data so OMI agreement excellent but how is unknown

- **2012-2014 Community "Homogenization" of Ozone data underway**

# Variables Affecting Ozone Measurement. Some Affect Entire Profile, Others More Important in Stratosphere, Troposphere or TTL

- Every sonde launched is a new instrument; $I_{bg}$ measured in lab

- $P_{O3} = 4.31 \times 10^{-2}$ (I- **$I_{background}$** ) x $T_{pump}$ x **PCF** (1/F)

- Calibrated through exposure to low, high ozone amounts.
- Important variables
  - **SST = sonde solution type.** KI strength, buffering, eg 0.5%, buffered; 1% buffered, 2% unbuffered, etc
  - Response time, $I_{background}$ **($I_{bg}$)** determined in pre-launch calibration
  - Pump efficiency correction, **PCF,** important above 25 km
  - Instrument manufacturer **(two "types")*,** materials
    - * 3rd manufacturer since 2010
- Mixing ratio = [Partial pressure of ozone = PO3]/P(total $_{Atm}$)

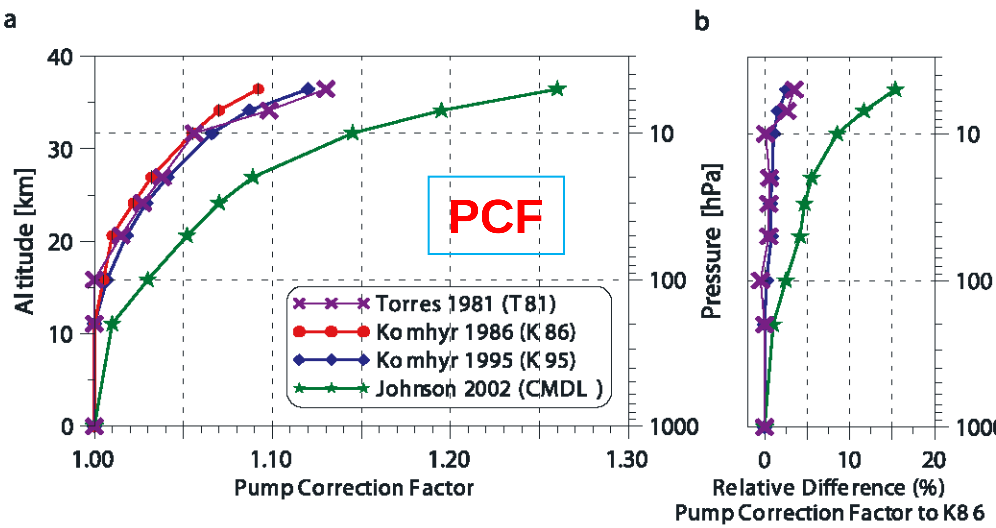
$O_3$-sonde Radiosonde

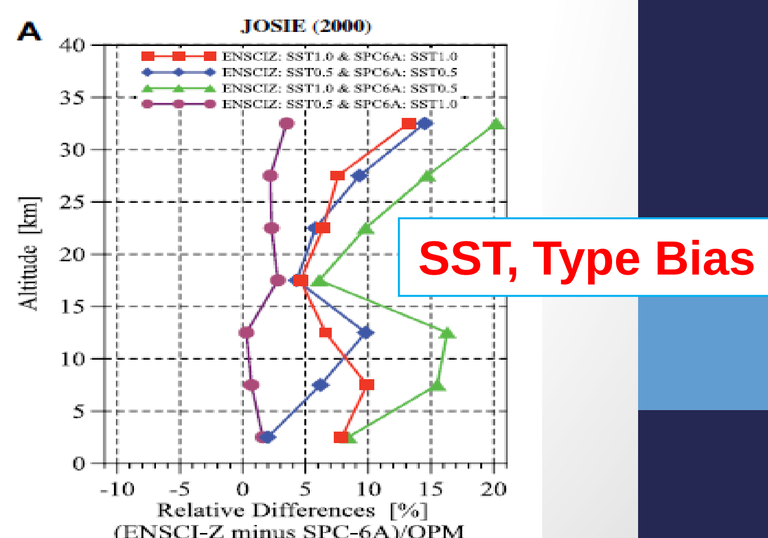
# Status for SHADOZ, 2005 (in *Smit et al.*, 2007; *Thompson et al.*, 2007).

**Table 1.** SHADOZ Sites and Method, With Parameters During JOSIE-2000 Tests

| SHADOZ Sites | Latitude, deg | Longitude, deg | Station Method, PCF | Station Instrument | JOSIE Method[a] | JOSIE Instrument |
|---|---|---|---|---|---|---|
| Suva, Fiji | −18.13 | 178.4 | 2% KI, N[b] | SPC | 2% KI | SPC |
| Pago Pago, American Samoa | −14.23 | −170.6 | 2% KI, N | SPC | 2% KI | SPC |
| Papeete, Tahiti | −18 | −149 | 2% KI, N | SPC | 2% KI | SPC |
| San Cristóbal, Galapagos | −0.92 | −89.6 | 2% KI, N | SPC | 2% KI | SPC |
| Paramaribo, Surinam | 5.81 | −55.2 | 1% KI, K[b] | SPC | . . . | . . . |
| Natal, Brazil | −5.42 | −35.38 | 1% KI, W[b] | SPC,[c] ENSCI | 1% KI | SPC |
| Ascension Island | −7.98 | −14.42 | 1% KI, W | SPC,[c] ENSCI | 1% KI | SPC |
| Cotonou, Benin (started 2005) | 6.21 | 2.23 | 1% KI, K | SPC | . . . | . . . |
| Irene, South Africa | −25.25 | 28.22 | 1% KI, K | SPC | . . . | . . . |
| Nairobi, Kenya | −1.27 | 36.8 | 1% KI, K | ENSCI | 1% KI | ENSCI |
| Malindi, Kenya | −2.99 | 40.19 | 1% KI, K | SPC | . . . | . . . |
| Kuala Lumpur, Malaysia | 2.73 | 101.7 | 1% KI, K | SPC | . . . | . . . |
| La Réunion | −21.06 | 55.48 | 0.5, 1% KI | SPC,[c] ENSCI | .5, 2% KI | ENSCI |
| Watukosek, Indonesia | −7.57 | 112.7 | 2% KI, N | ENSCI | . . . | . . . |
| Kaashidhoo, Maldives[d] | 5 | 73.5 | 2% KI, N | ENSCI | . . . | . . . |
| Aerosols99 Cruise[d] | . . . | . . . | 2% KI,N | ENSCI | . . . | . . . |

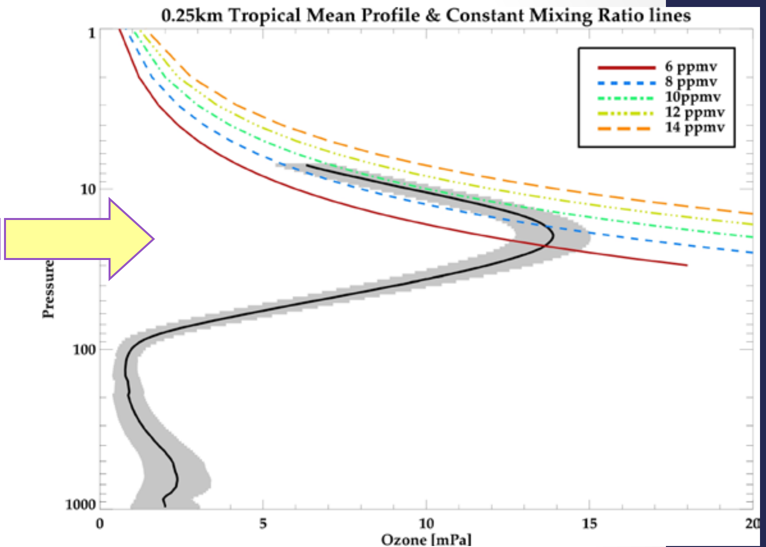
[a]Responsible Co-I JOSIE participant: NOAA/CMDL for Fiji, Samoa, San Cristobal, and Tahiti; NASA Wallops Flight Facility (WFF) for Natal and Ascension; Méteosuisse for Nairobi; Univ. Réunion for La Réunion. FZ-Jülich JOSIE participant test method used at Irene, Paramaribo.
[b]PCF key: N, NOAA/CMDL [*Johnson et al.*, 2002]; K, *Komhyr* [1986] and *Komhyr et al.* [1995]; W, Wallops laboratory test [*Torres*, 1981].
[c]Mixture of solution strengths, instruments used; see details given by *Thompson et al.* [2003a].



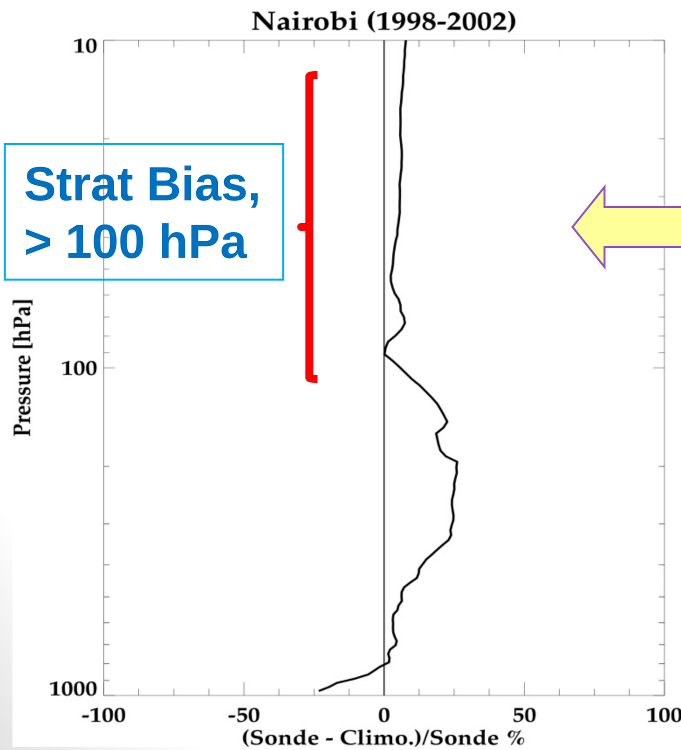



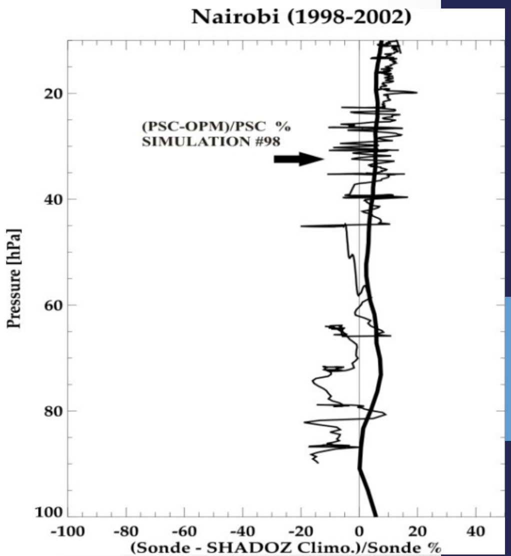
# SHADOZ Tropical Climatology Illustrates Bias at Individual Stations – Thompson et al., *JGR*, 2007

- Individual stations show bias in *stratospheric* profile compared to SHADOZ tropical mean.
- Nairobi relatively high.  Interpret in terms of JOSIE-2000 lab tests?



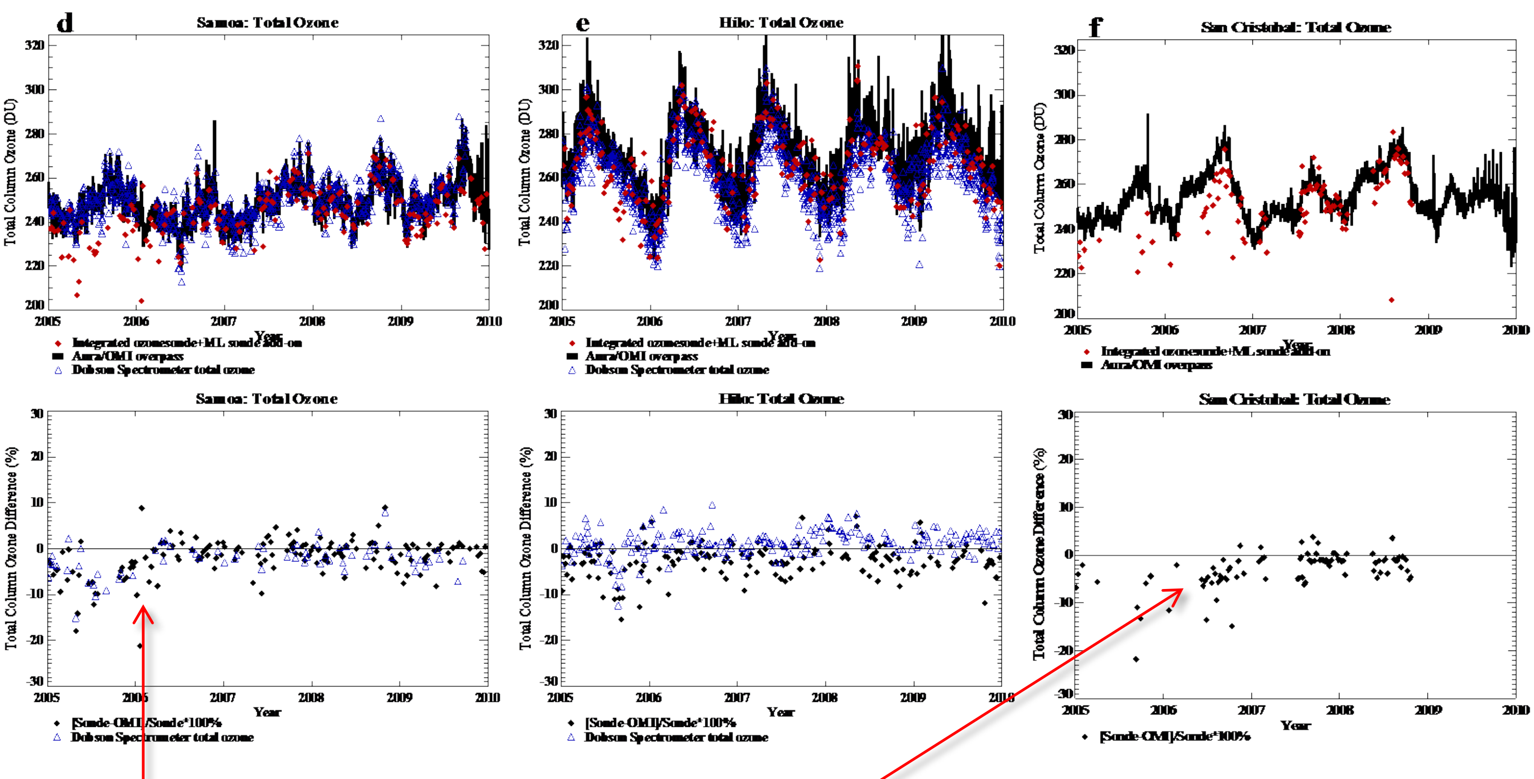

**Strat Bias, > 100 hPa**



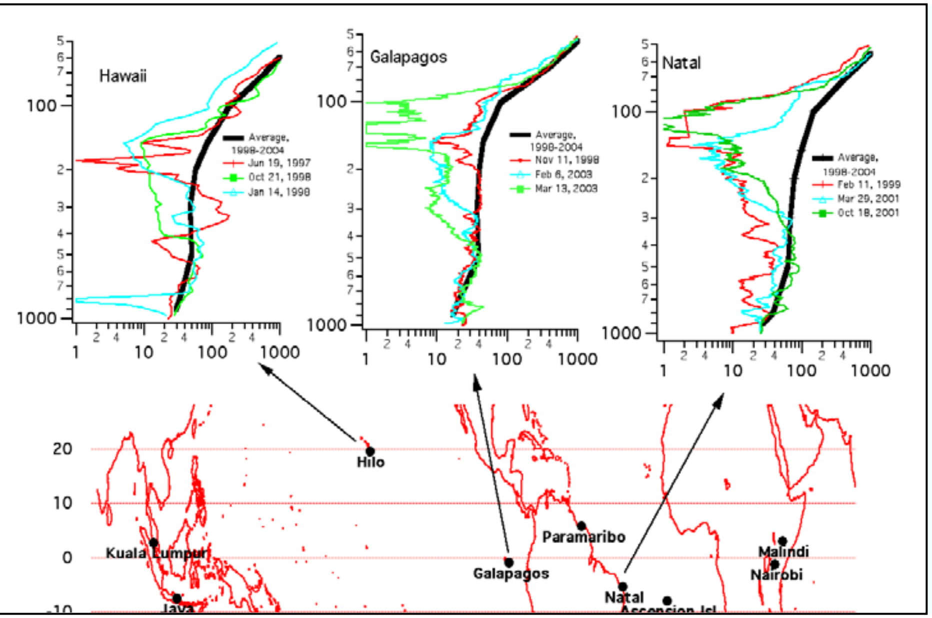
# UPDATES. How to Address SHADOZ Data Set, from 1998-2013?

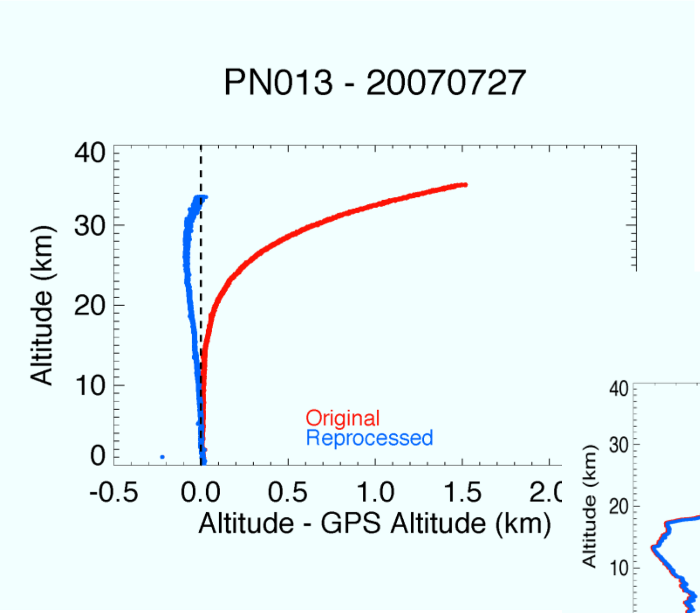
- Challenge shown below (from T12). SST change, 2005-2009?
- Recommended “transfer function” developed by O3-DQA (WMO/JOSIE) will be used to “homogenize” data
- Individual PIs process data, add meta-data to archive files

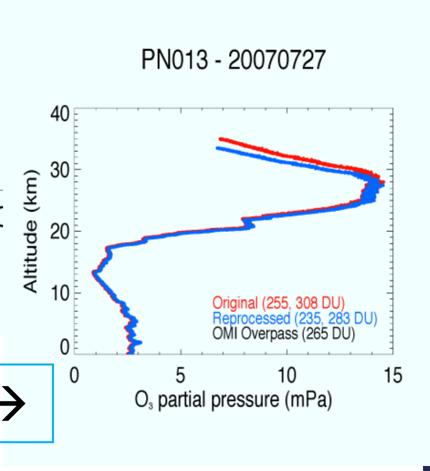


# New Technical Issues include Radiosonde

- **Background Current** (Voemel & Diaz, 2009; Stuebi & Levrat, 2009). Implication for SHADOZ at certain sites. *Solomon et al.* 2005, **Left***
- **New Radiosondes** (RS80-> RS92->Imet). Pressure offsets! **Right**
- **Third instrument type.** SPC stable, ENSCI-> DMT change displays operational problems – impact on long-term record TBDl!




* < 1% of soundings near-zero in TTL

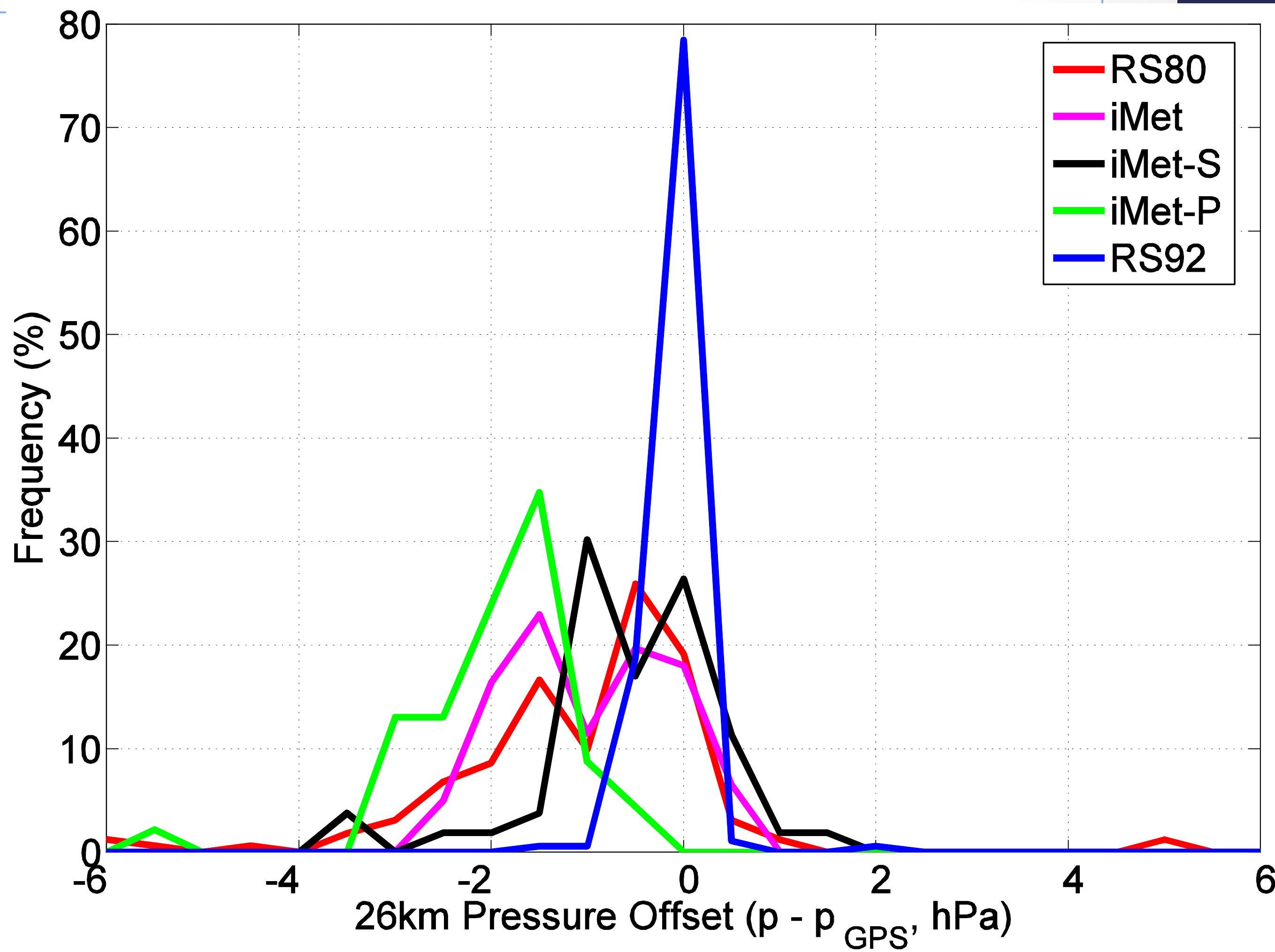
7-8% correction →

# Radiosonde Pressure Offsets at 26km

Radiosonde pressure measurements compared to GPS-derived pressure

Pressure errors propagate to ozone measurements, only a few to 10%. Total column little affected

Performance of RS92 in the stratosphere is superior to other radiosonde types




*Stauffer et al., AMT-doi:10.5194/amt-7-65-2014.*

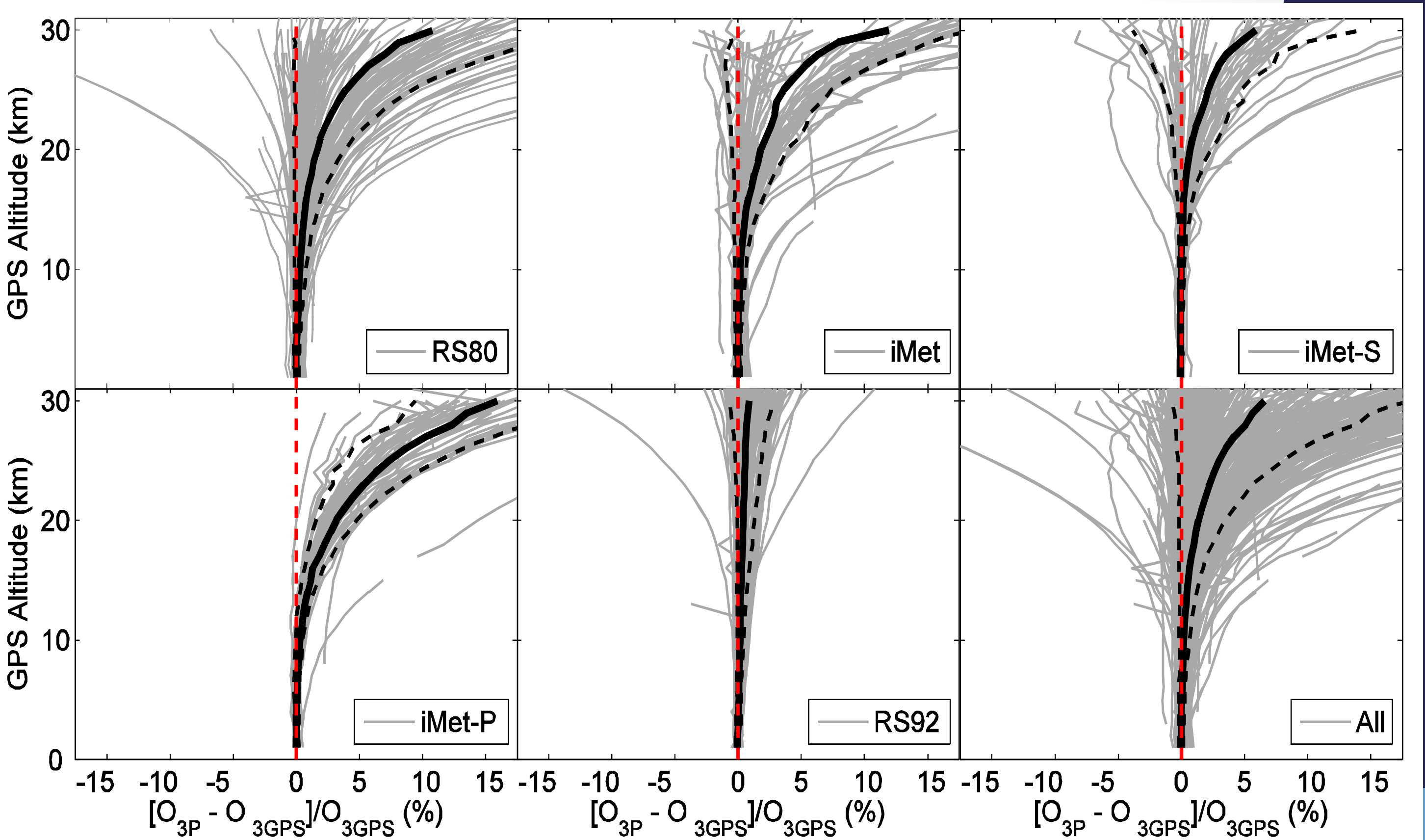
# $O_3$ Mixing Ratio Errors from Pressure Offset

$O_3$ mixing ratio percent errors of each radiosonde type- mean= black

RS-80s mainly from Houston, TX

iMet, -S and -P from Idabel, OK, Houston, MD & CA NASA DISCOVER-AQ locations

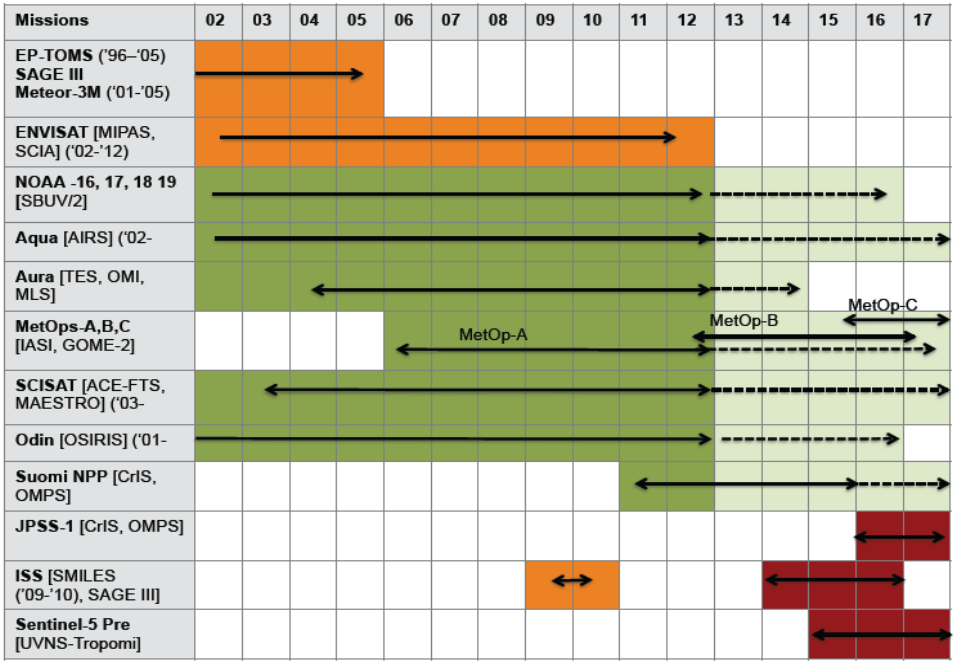
RS92s from <u>Beltsville,</u> *Ronald H. Brown* and Irene, SA SHADOZ




*Stauffer et al., AMT, doi:10.5194/amt-7-65-2014.*

# Summary: SHADOZ Re-processing – Iterative over Next 2-3 Years, Consultative with WMO O3-DQA

- WMO O3-DQA, Data Quality Assurance activity, 2010-2012, is "homogenizing" $O_3$ data given known biases in instrument type, SST
- SHADOZ stations re-processing in 2013-2014. Will re-evaluate biases, ground-ozone/OMI comparisons
- Results - Guidelines for a follow-on JOSIE (2015?). Anticipate evaluation of radiosonde change impacts. Below: Satellites supported by SHADOZ, 2002-



# THANK YOU FOR YOUR ATTENTION!

# Acknowledgments & References


- **Support from NASA, NOAA, with JOSIE and O3-DQA sponsored by WMO.**



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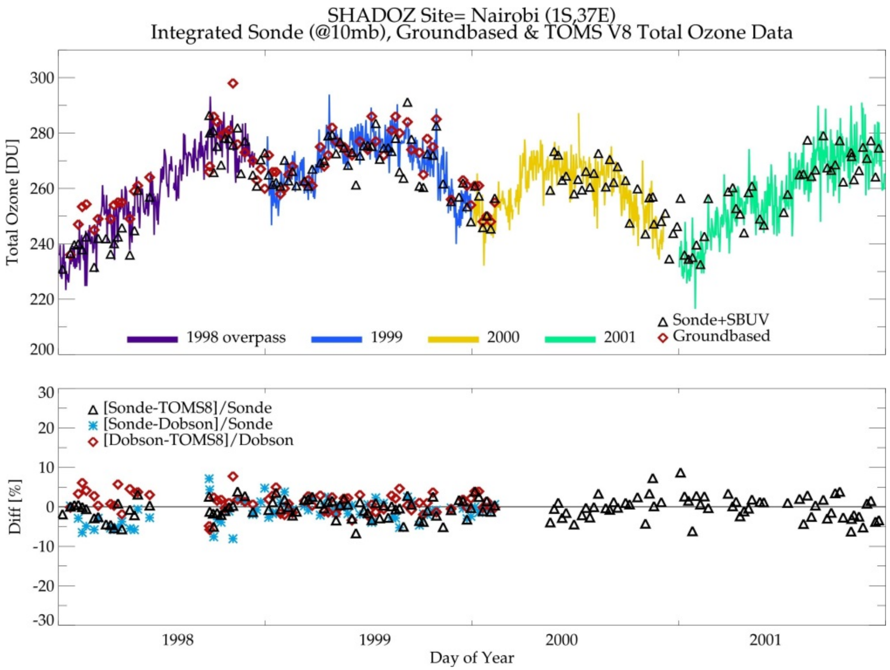
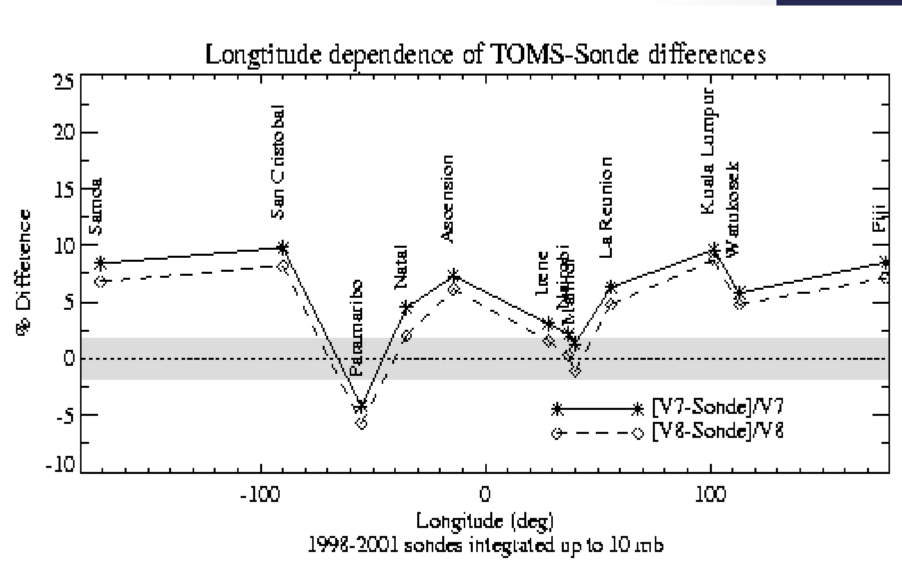
# extras

# SHADOZ Re-Processing Schedule & Deliverables

| Timeline | SHADOZ PI, Collaborator/Partner Activities for O3S-DQA & SI2N | Deliverables, Reporting & Publications |
|---|---|---|
| April 2012 | Sonde Technical Issues in O3S-DQA, Greenbelt Workshop, attended by PI, NASA, NOAA collaborators and Members of the WMO Ozone SAG | - Processing with first set of Transfer Functions by SHADOZ volunteers.<br>- O3S-DQA Report to SI2N Workshop, Columbia, MD. |
| June – Dec. 2012 | Preliminary data re-processing at changes. Optimize background current correction. (First scheduled: Fiji, Samoa, San Cristóbal) | AGU Special Session on O3S-DQA and related sonde technical results: Dec. 2012, San Francisco |
| Jan. – June 2013 | Workshop, O3S-DQA Report, Publication preparations for SI2N and UNEP/WMO 2014 Assessment deadline. | - SHADOZ Deliverable: O3S-DQA Report(s).<br>- SHADOZ PI, Collaborators submit 1 or more journal articles for publication. |
| June – Dec. 2013 | Workshop: (1) evaluate Transfer Function and other re-processing changes on SHADOZ dataset; (2) Assess needs and protocol for Tropical-JOSIE to be conducted in 2014-2015. | Re-process all SHADOZ datasets (V06) for self-consistency within given station. Apply Transfer Function as needed. |
| Jan. 2014 – Dec. 2015 | Review Results at WMO-sponsored Workshop. | Conduct Tropical-JOSIE at WCCOS, Jülich. |
| Jan. – Dec. 2016 | Report at Quadrennial Ozone Symposium. | - Reprocess & homogenize the 1998-2015 SHADOZ Data.<br>- Prepare publication(s) for 2018 UNEP/WMO Ozone Assessment. |
| Timeline | SHADOZ Statistical Analyses, Classifications with LID & SOM, Interannual Variability & Trends | Deliverables, Reporting & Publications |
| 2013 – 2014 | - Classified profiles on SHADOZ website or link<br>- Comparisons of LID & SOM for Ascension, Natal, Irene | Prepare journal article, 2014 |
| | SHADOZ comparisons with TES | Prepare journal article, 2015 |
| 2014 - 2015 | Classified profiles for KL, Hilo, Nairobi, Samoa | |
| | Analyze reprocessed, homogenized data for climate signals, trends | Prepare journal article, 2016 |

# Comparison of SHADOZ, Late EP/TOMS, Dobson (Left). Comparisons of Stations (Right)



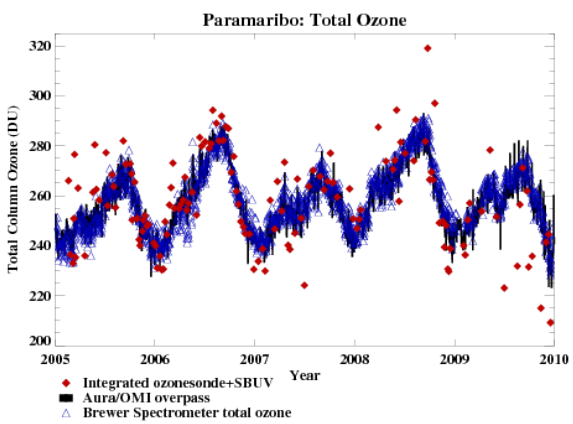

Nairobi site comparison - Excellent TOMS-Sonde-Dobson agreement.

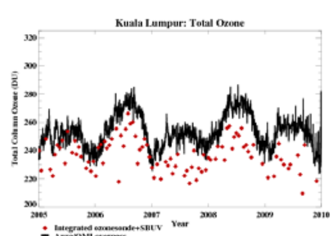
Summary of Station Agreement With TOMS (1998-2005 Data)

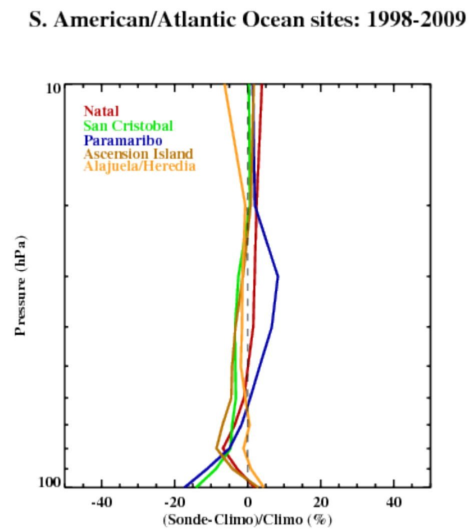
Thompson et al, JGR, 2007= “T07”

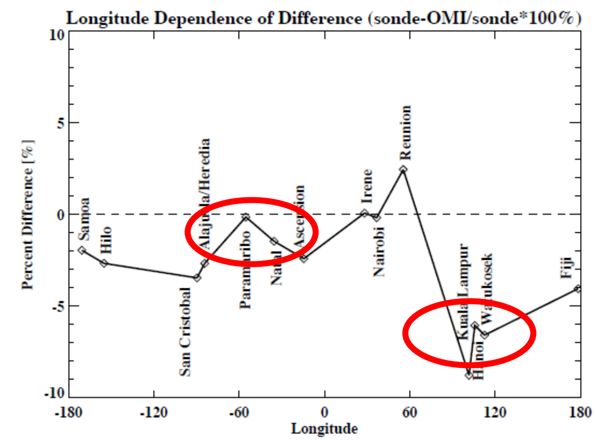
# Current Status. SHADOZ Biases due to Solution, Instrument Type, PCF Characterized.

- In T07 (not shown) mean total ozone offset relative to *TOMS* - 10 stations ~7% low, range 1-11% low
- In T12 (left, center), “re-processing” eliminated Paramaribo offset; 13-site mean offset < 5% relative to *OMI*. Hanoi, KL, Watukosek largest (low sonde) offset (right). Unknown cause.



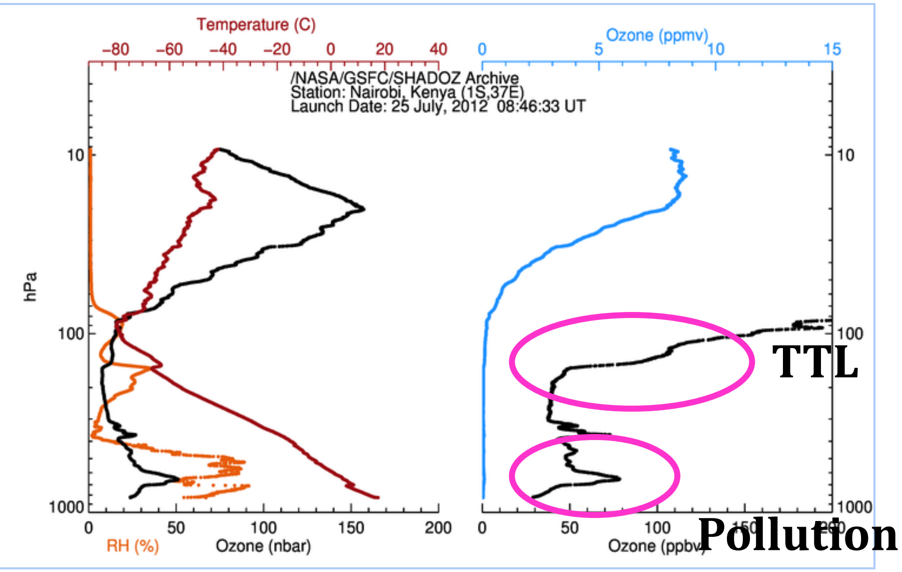



# Good & “Bad” Ozone

**UNITS: Partial Pressure, Mixing Ratio, Dobson**

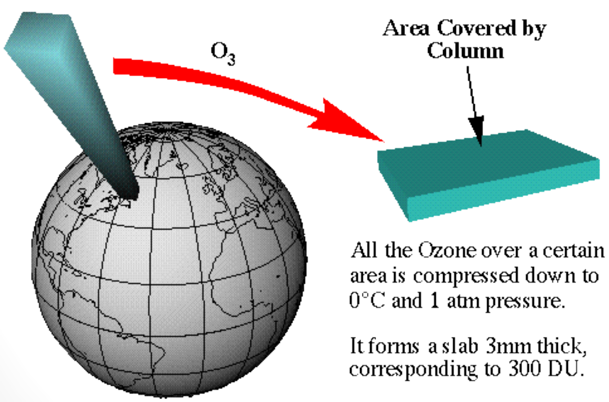
**Left – Mid-latitude; Lower – Dobson; Right – “Hole”**



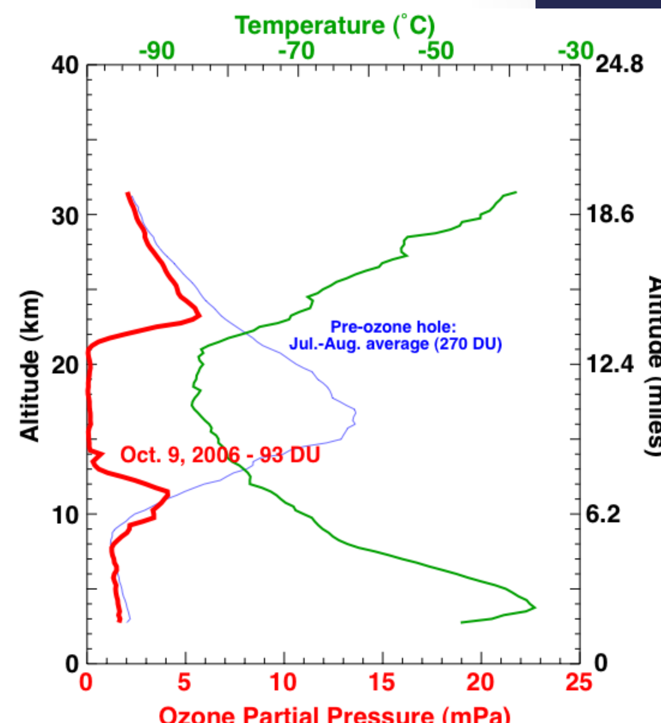

← Good ozone in ppmv

Dynamics/climate interest in UT/LS or “TTL”

Pollution > 30 ppbv (tropics), 80 ppbv

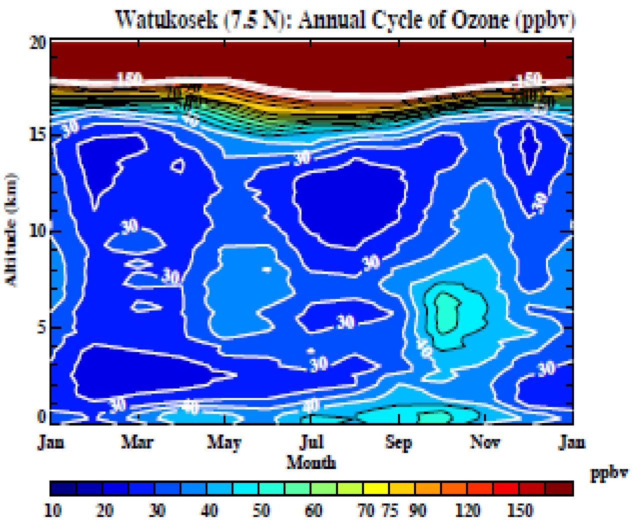


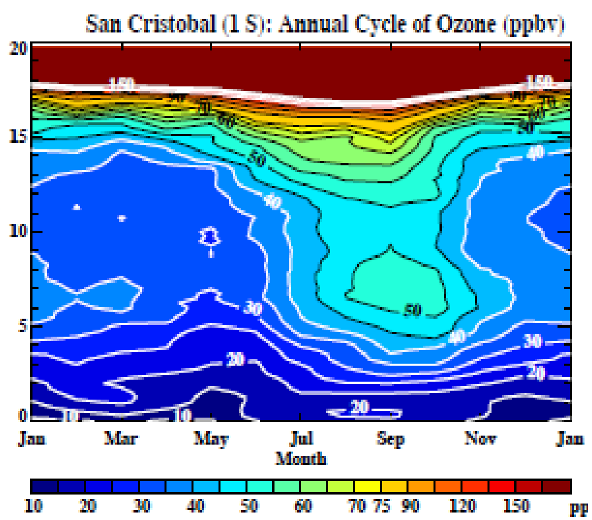

Antarctic “$O_3$ Hole”
270 DU to 93 DU
9 Oct 2006
“Bite” at coldest T,
Particle-Cl reaction

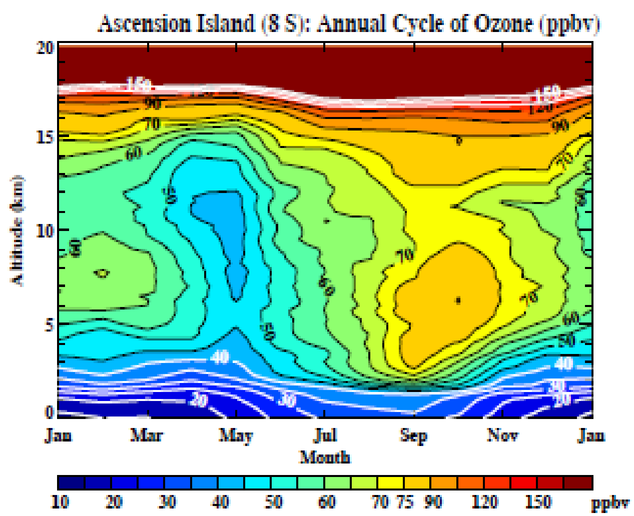



NOAA’s B Johnson & D Hoffman ->

# Processe & Validation. Three Distinct Regions:
# W Pacific, 'Equatorial Americas', Atlantic
# GWI = Convective Proxy, Declines West to East.
# Pollution Increases West to East

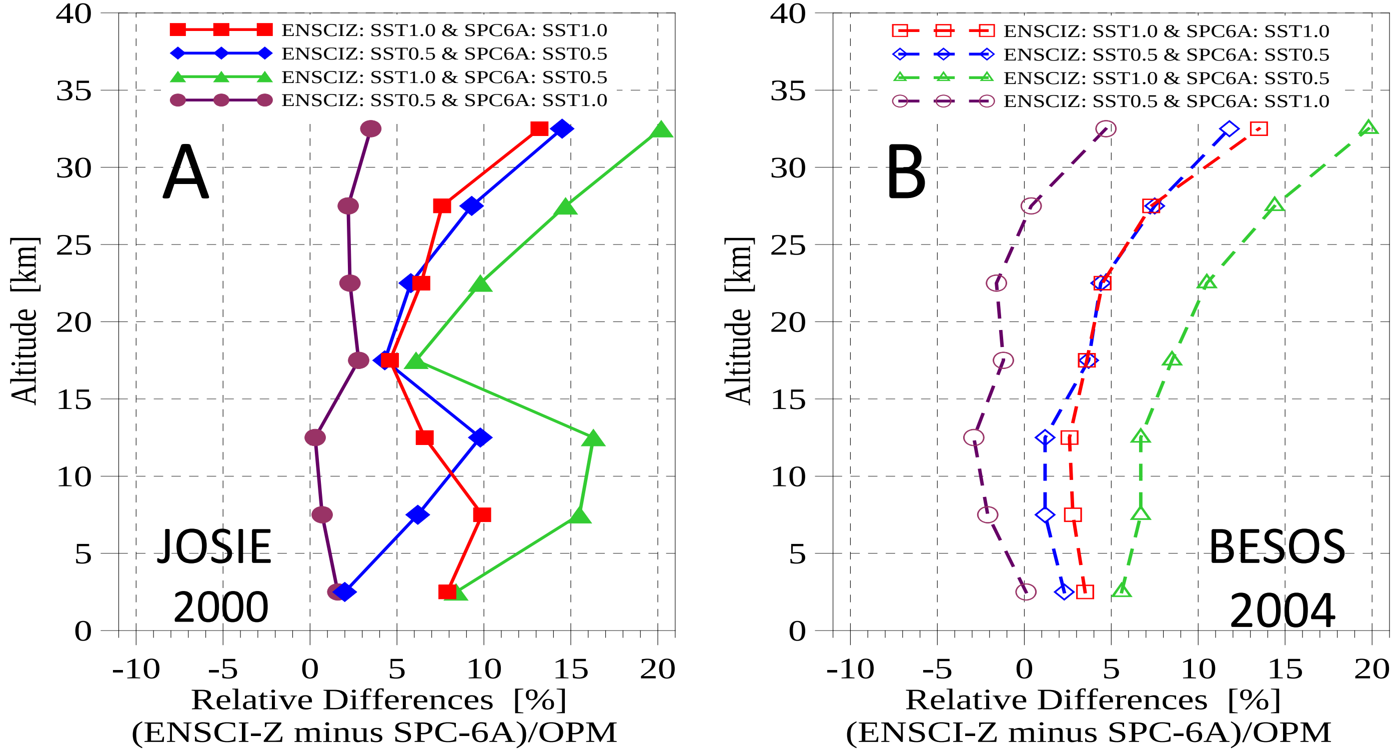



| Property | Watuk. | San Cris. | Ascen. |
|---|---|---|---|
| T'pause Altitude | 16.6 km | 16.6 km | 16.0 km |
| 5-15 km Mean Mixing Ratio | 33 ppbv | 48 ppbv | 64 ppbv |
| Mean GWI [arbitrary unit] | 18.5 | 12.6 | 8.35 |

**Comparisons of 4 SSTs (KI strength) & Manufacturer in Chamber/JOSIE (left) & on Field Test (BESOS) (right), relative to standard uv photometer. (From H. Smit, in *Thompson et al.*, 2010).**




**OPM = UV Photometer "Standard" used in JOSIE chamber & on BESOS Balloon:**

1) **Precision and accuracy both 5-10% vs 15% pre-SHADOZ**
2) **WMO/GAW (World Meteorological Organization/Global Atmospheric Watch) adopted new standards as a result**

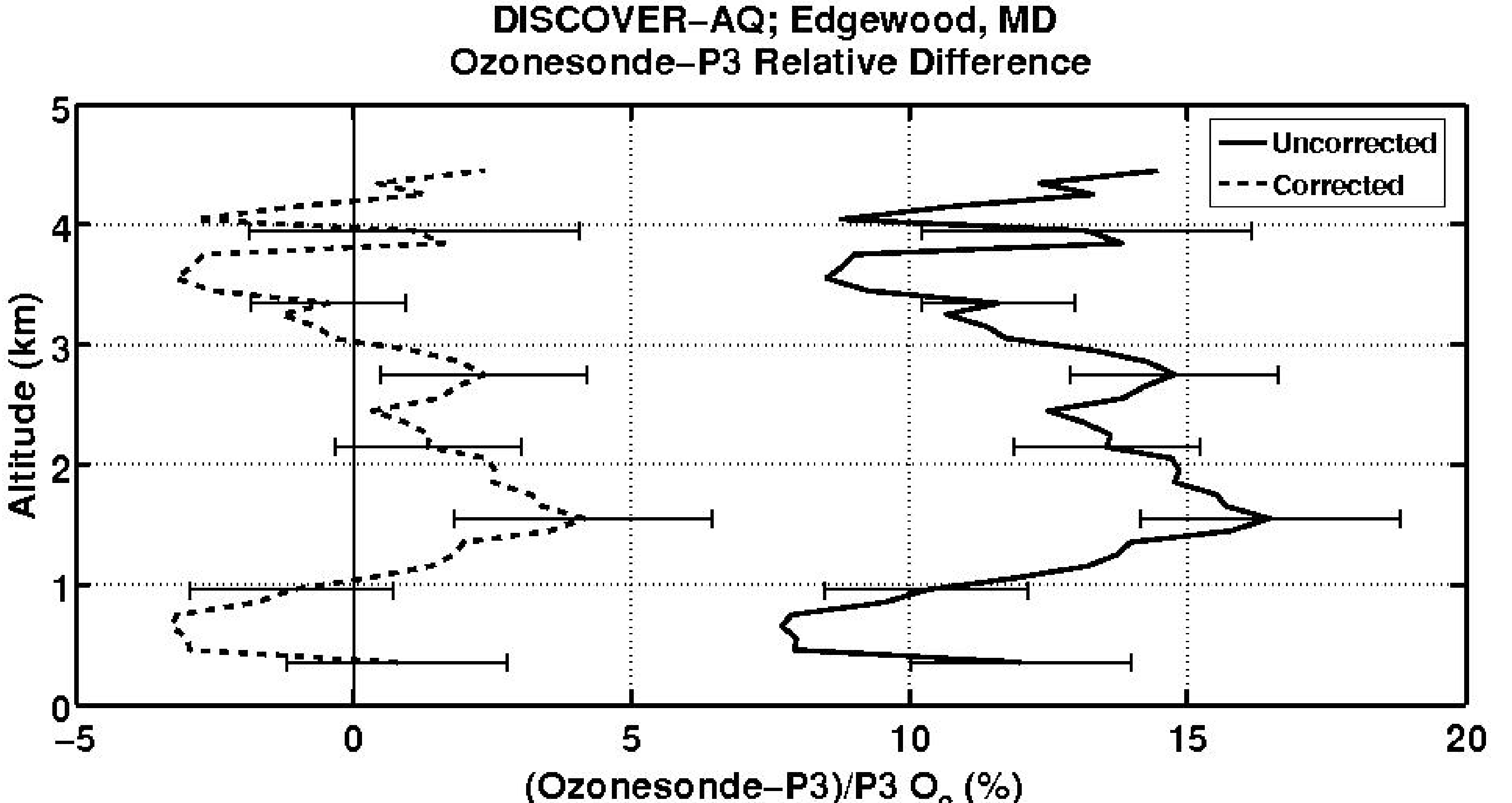
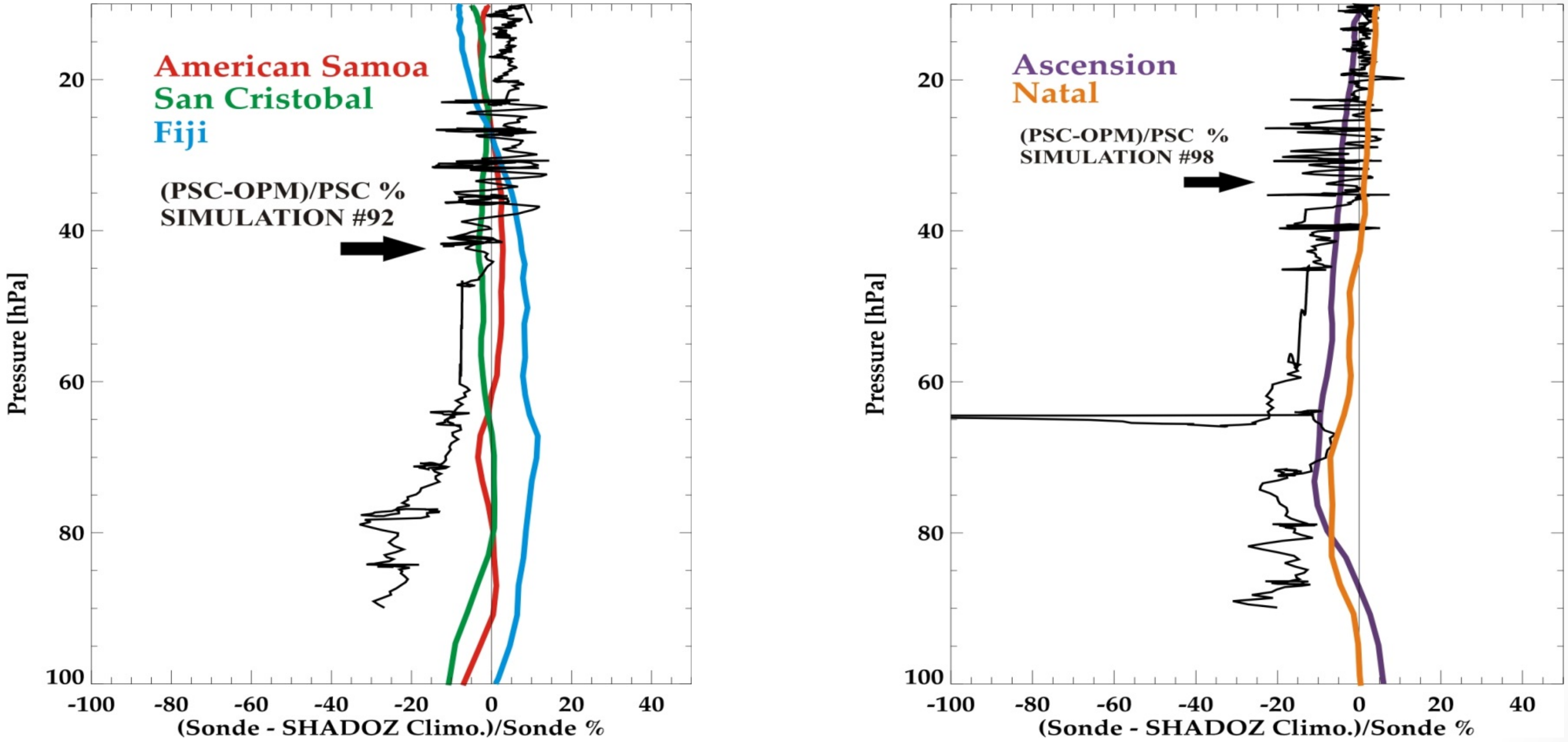



Figure: Uncorrected versus corrected ozonesonde data percent error compared to the P3-B in situ chemiluminescence measurement of ozone. Correction is from the application of the controlled simulations of JOSIE-1998 (*Smit et al., 2007*)

| Statistic | Uncorrected | Corrected |
|---|---|---|
| Normalized Mean Bias (%) | 13.3 | 0.1 |
| $RMSE_{cv}$ (%) | 13.6 | 8.3 |

# Other SHADOZ-JOSIE-2000 Comparisons




- **JOSIE sonde behavior relative to UV ozone standard follows SHADOZ fairly well [Thompson et al., 2007].**
- **Homepage <*http://www.fz-juelich.de/icg/icg-ii/josie*>**