Tropical Ozone Variability & Trends in the Troposphere & Lowermost Stratosphere: Perspectives from SHADOZ Soundings (1998-2023)

Anne M. Thompson, NASA/Goddard
& Univ. of Md-Baltimore County; anne.m.thompson@nasa.gov

Ryan M. Stauffer (NASA/GSFC/614), Debra E. Kollonige* (Science Systems Applications Inc @NASA/GSFC/614), Bryan Johnson (National Oceanic and Atmospheric Administration/Global Monitoring Laboratory), Gary Morris (National Oceanic and Atmospheric Administration/Global Monitoring Laboratory) & Patrick Cullis (National Oceanic and Atmospheric Administration/Global Monitoring Laboratory)

AGU 2024, Wash, DC

*** Poster A13D-2072 Today, 9 Dec!**

Presentation Outline

- **Why/What/Who/Where is SHADOZ?**
  - Role of ozonesondes in "Protecting Ozone Layer"
  - Southern Hemisphere Additional Ozonesondes Project (1998-)

- **Ozonesonde Quality Assurance**
  - SHADOZ leads in raising sonde accuracy (*total* column O_3 to ± 2%)
  - Global sonde data can be used with confidence!

- **Lowermost Stratosphere & Troposphere Tropical Ozone Trends**
  - Lowermost stratospheric (LMS) update from Thompson et al, 2021
  - Troposphere: Changing convection & ozone trends over Eq. SE Asia

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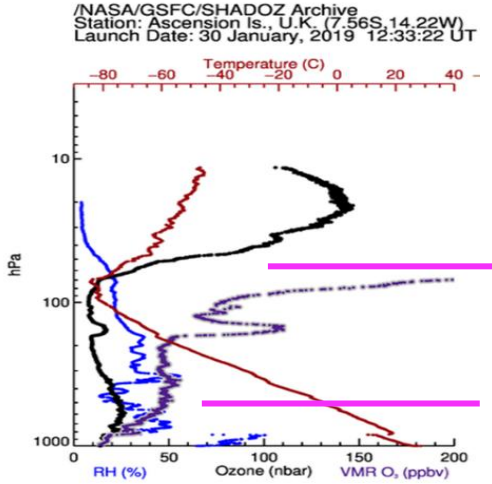
Importance of Sondes: Montreal Protocol

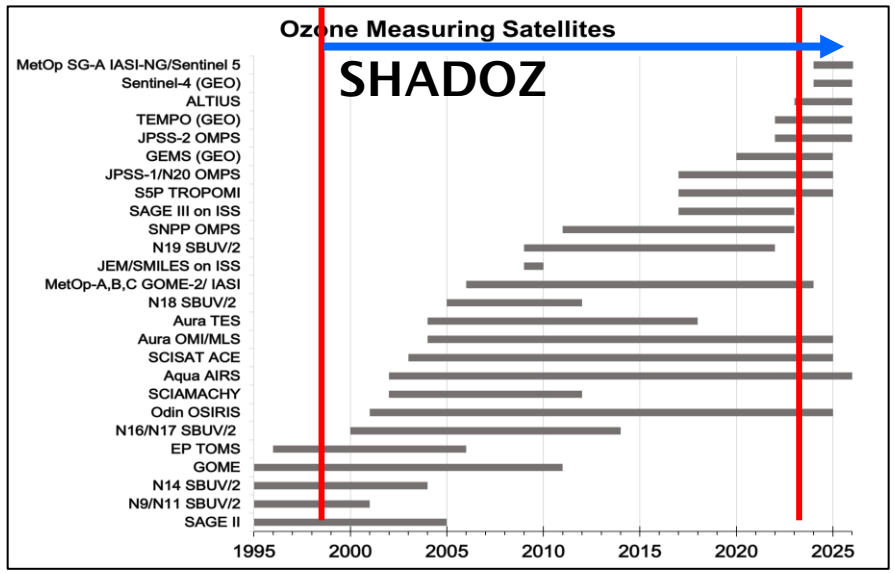
- Montreal Protocol (1987) signed by 193 nations to protect Ozone Layer requires every country to monitor their ozone
- Monitoring is done by satellite **cali-brated by ozonesondes** uniquely able to measure surface to ~10 hPa,



Upper-mid strat.

Lowermost strat. (LMS)
T'pause Transition Layer (TTL)

Tropospheric pollution

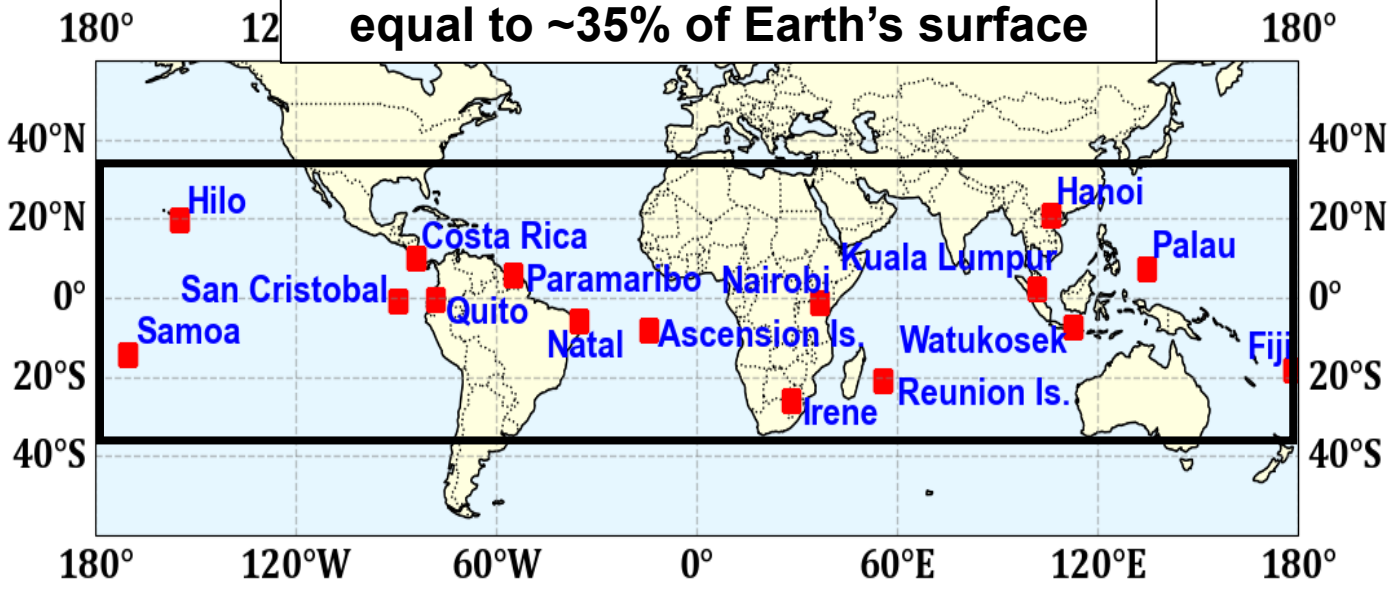


Every 4 years UNEP/WMO Scientific Panel issues "Ozone Assessment." 1989 – 1998; 2002-2022

SHADOZ Data Archive. Sustainability

- 14 stations with >10-year records. Launches 2-5/mo. w/ radiosonde, PTU
- 2024: **Palau** & **Quito** join SHADOZ. **>10,000 O_3-PTU** archived @ website
- SHADOZ v6 data DOI: https://doi.org/10.57721/SHADOZ-V06
- Key element of SHADOZ sustainability: > 20 sponsoring organizations

SHADOZ covers a latitudinal band equal to ~35% of Earth's surface



Webpage: https://tropo.gsfc.nasa.gov/shadoz

Thompson, AGU, 12/24

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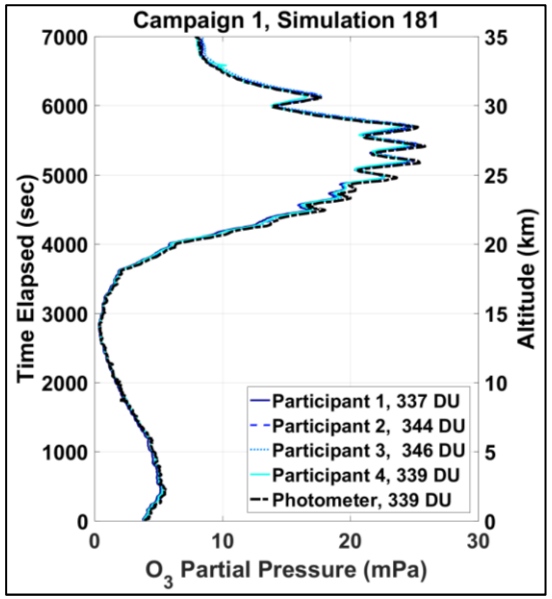
SHADOZ and Sonde Quality Assurance (QA) Challenge

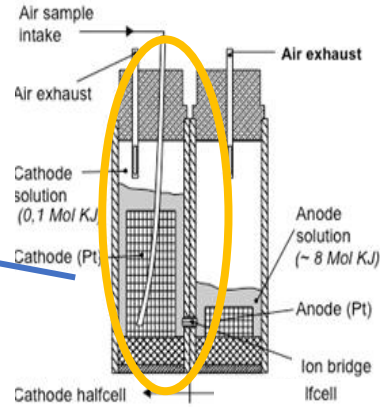
- **Ozonesonde QA Challenge: calibrate each instrument before launch**
  --2 instrument types & 3 sensing solutions create bias, discontinuities
  --Develop **SOP=Standard Operating Procedures** for preparation & data processing
- **WCCOS (World Calibration Center for Ozone-Sondes, Germany) & world reference with Assessment of SOP O3Sondes (ASOPOS) = > "homogenized" datasets**

SHADOZ WCCOS, tests 2017 →

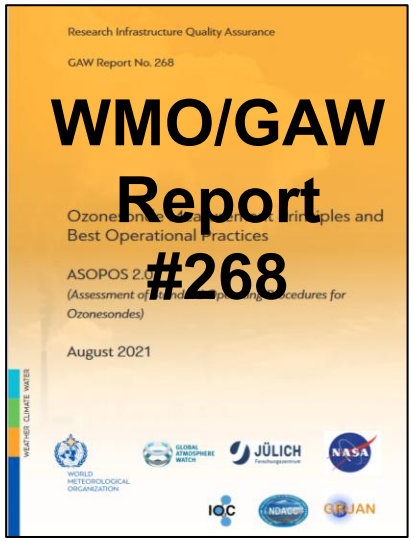


Electrochemical Concentration Cell (ECC) Ozonesonde – ***Two manufacturers, SPC & En-Sci***

3 KI Sensing Solution Types SST

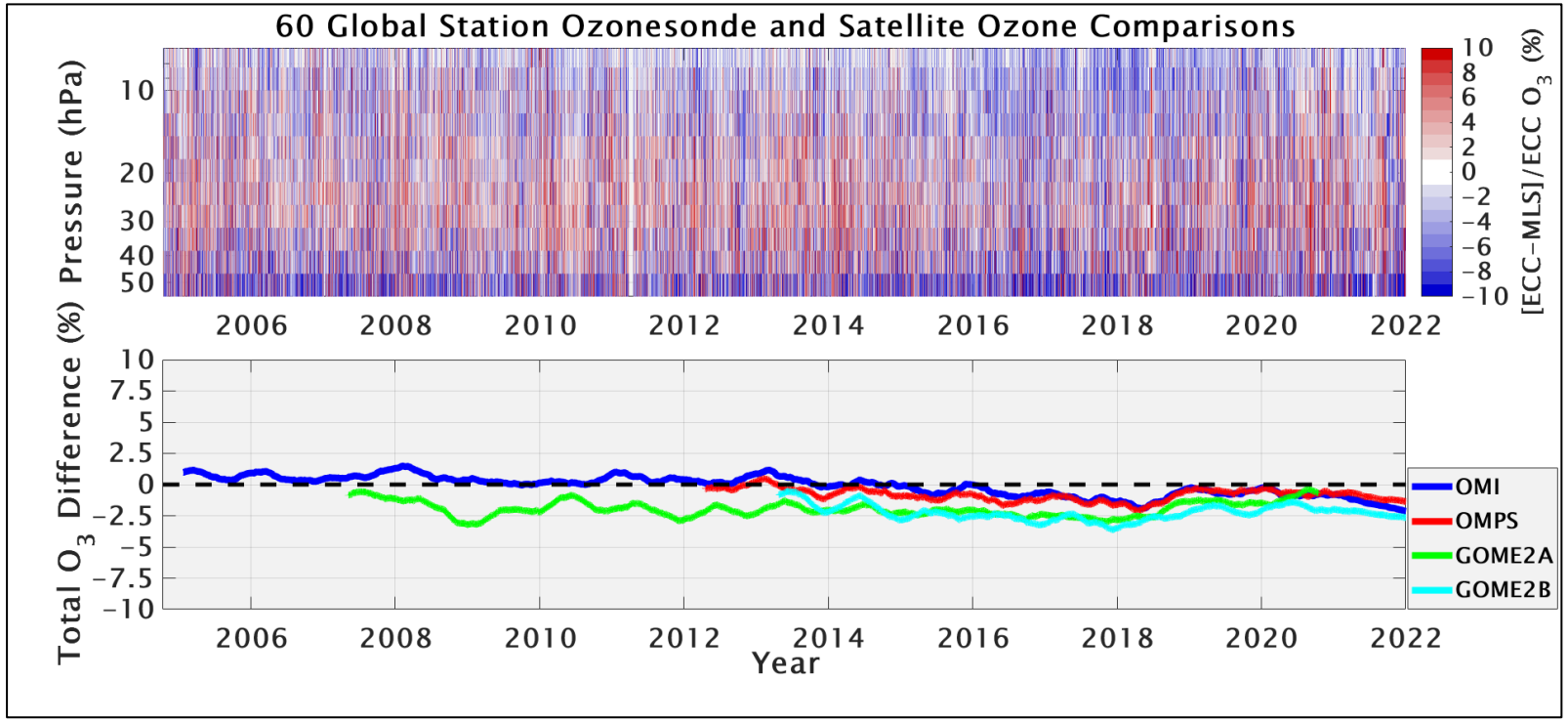


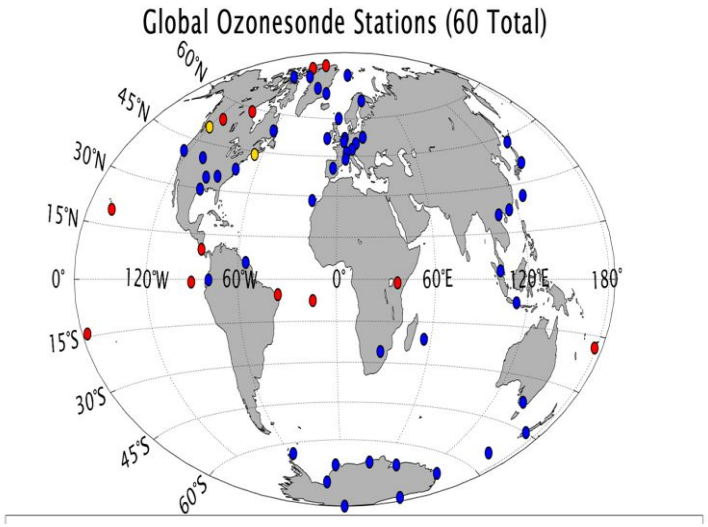
$$KI + O_3 + H_2O \rightarrow I_2 + O_2 + 2\,KOH$$



ASOPOS Outcome: ±2% Total O_3 Agreement!

- Global survey of 60 stations in ***Stauffer et al., (2022)*** showed total column ozone stability with satellites of ±2%. Agreement with Aura MLS profiles is ±5%
- **<u>Data reprocessing</u> has been highly successful! Uncertainties reduced from *~20% in the 1990s to near 5% today***





- Global ozonesonde data are accurate enough to detect a drift in **OMI** v8.5 total column ozone (see above), which has since been corrected
- ***<u>Ozonesonde profile trends are computed with added confidence!</u>***

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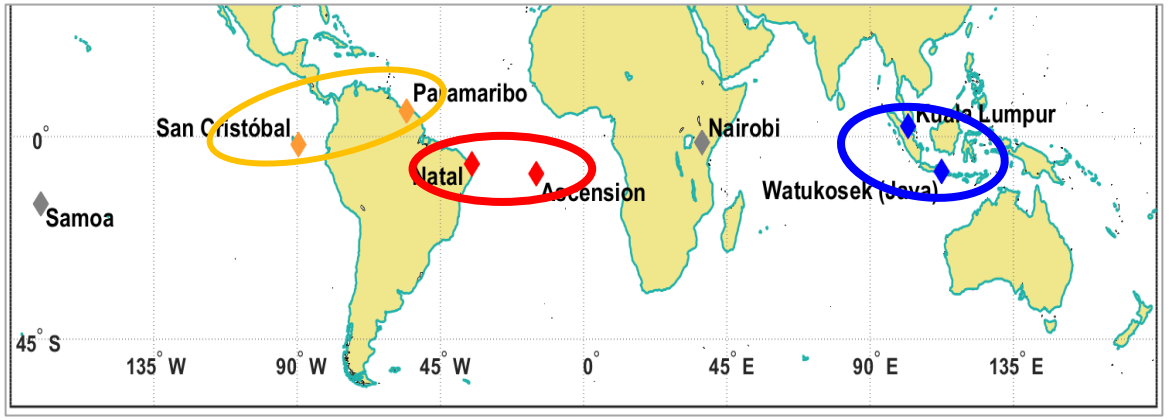
SHADOZ Ozone Trends: Seasonal & Regional Variability

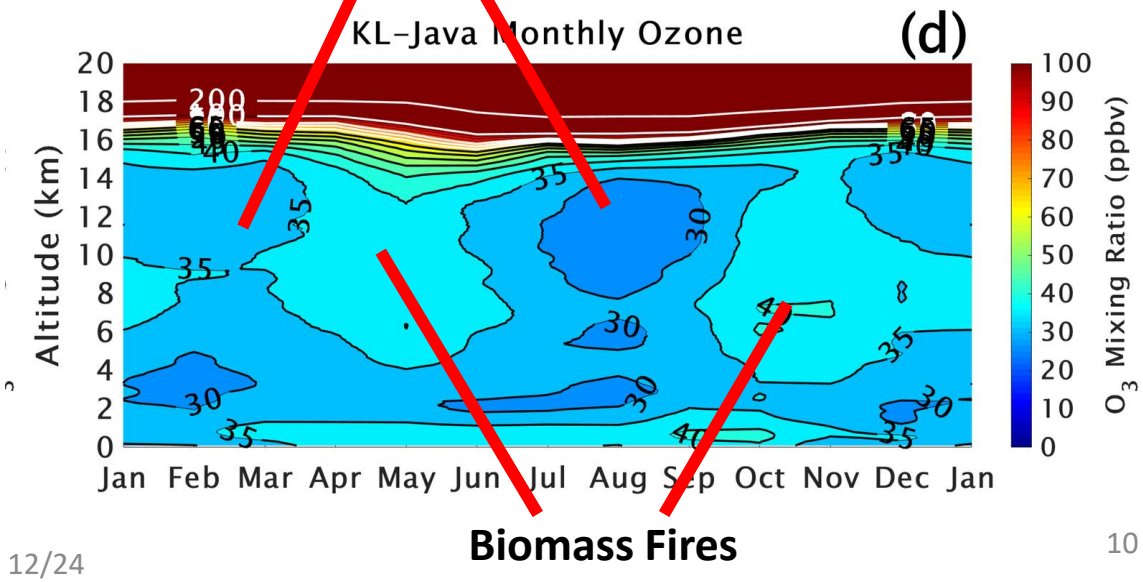
- **Satellite O_3 Trend Challenge:** Below 50 hPa (20 km) satellite O_3 data is most uncertain
- **Use SHADOZ data (1998-2019/2023)** to compute trends in O_3. **Sonde advantages**
  - (1) 100-150-m resolution at fixed sites *and* FT and LMS trends in 1 dataset
  - (2) Regional sondes avoid zonal means
  - (3) Radiosondes give tropopause height **(TH)**



SC-Para Nat-Asc KL-Java

- **Data used from 5 "sites," 3 combo** for better statistics; > 5500 total profiles **(Upper)**
- **Seasonal O_3 (Below) TH annual cycle, white**
- "Seasonal" FT O_3 transitions show changes in dynamic influences, ie convection vs fire pollution (**Thompson et al., *JGR*, 2012; *JGR*, 2021 = "T21;" *ACPD, submitted, 2024***)

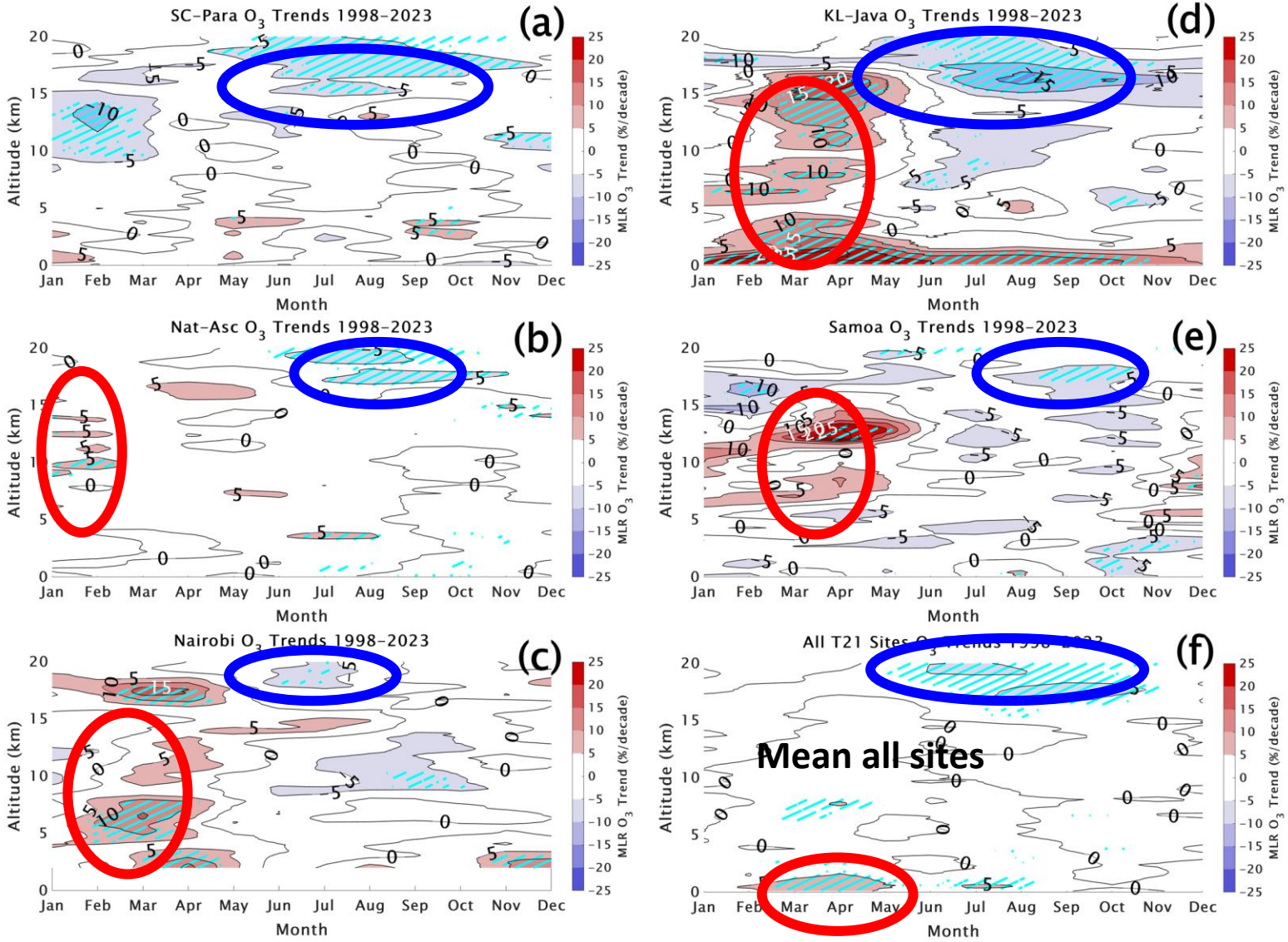
Convective seasons – KL-Java/Eq. SE Asia



Biomass Fires

What Do Trends Look Like? Mostly Similar for 5 Sites

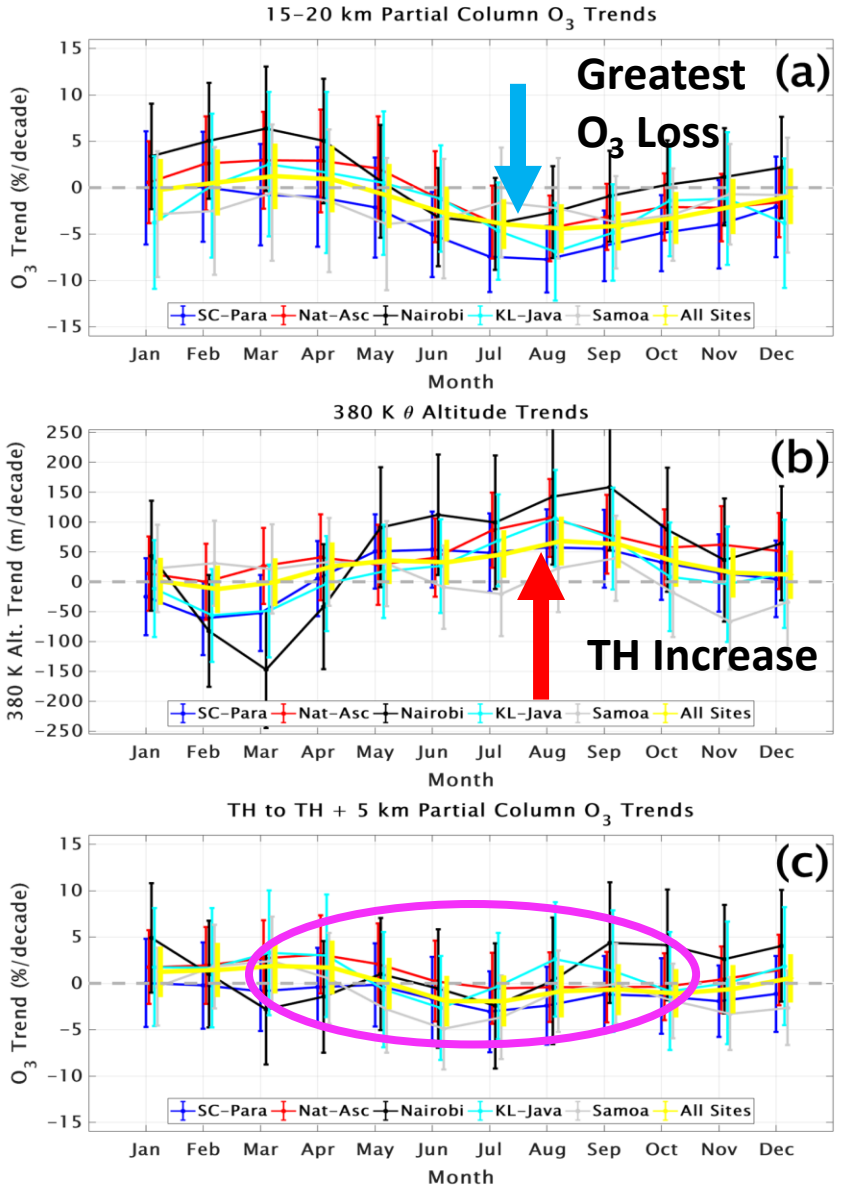
- Trends in monthly mean O_3 & TH (alt. of 380K θ) computed by Goddard Multiple Linear Regression (MLR) model with QBO, ENSO as MEI, IOD terms, seasonal, annual cycles. 100-m resolution. Trends: **Reds = ozone increase. Blues = ozone loss. Cyan significant at 95% CI**
- **LMS** ozone losses greatest after June, >5%/dec over KL-Java
- Early year **FT** ozone increases greatest over Nairobi, KL-Java (20%/dec), Samoa.
- **Mean (*lower right*) LMS loss; tropospheric increases < 3 km**
- **What mechanisms are at work?**



LMS Ozone Trends – Artifact of Higher Tropopause?

- **SHADOZ ozonesonde profile trends updated from T21. 1998-2023 trends calculated with MLR model at five stations (8 total individual sites *and* all sites combined in yellow)**
- **In the 15-20 km layer, negative trends of -5 to -7 %/decade occur ~July-September (upper). This coincides with positive trends in tropopause height (TH) (middle). *Are SHADOZ LMS trends an artifact of tropopause height changes?***
- **Referencing ozonesonde profiles to the TH, re-calculating shows trends "disappear"! (bottom). A "climate signal in TH" causes negative LMS ozone**

- **Trends output from *Thompson et al., (2021; JGR)* at: https://tropo.gsfc.nasa.gov/shadoz/SHADOZ_PubsList.html - Constraint for model comparisons**

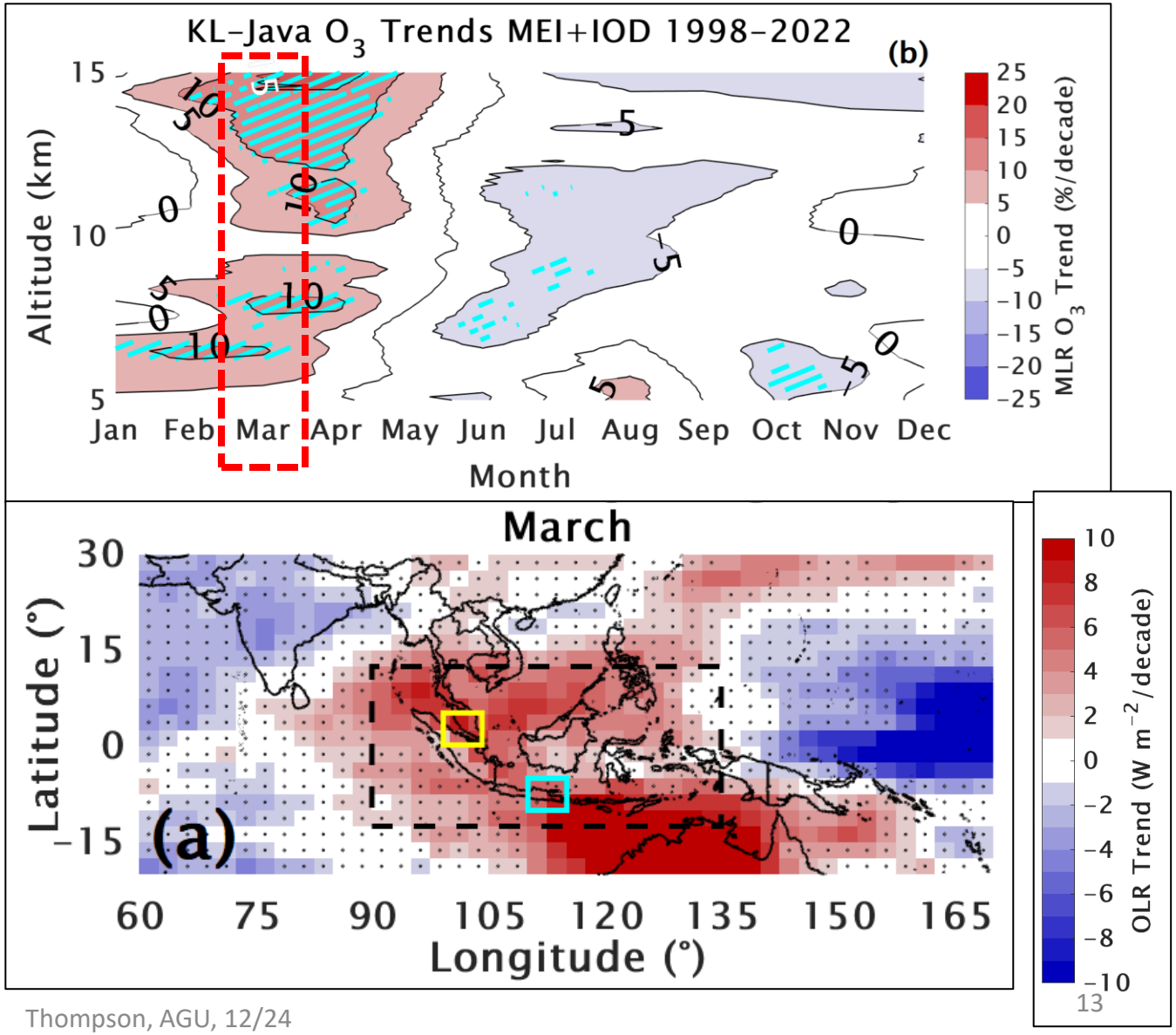


T21 update in Thompson et al. (2024)

FT Ozone Trends & Convection Links?

- T21 showed evidence for reduced convection only at Feb-April period leading to ***hypothesis: is declining convection aiding ozone increase?***
- *Stauffer et al.,* (2024; ACP TOAR-II SI) shows **Feb-Apr large positive ozone trends** over Southeast Asia (**top;** KL and Java SHADOZ stations) are associated with significant convection loss in region, OLR is convective proxy (**bottom**) **1998-2022. Yellow = KL, Cyan = Java**
- Decrease in convection reduces lofting and redistribution of near-surface ozone; FT ozone accumulates.

- **Convective proxy trends (4) observed only February-April (next slide)**



Convection Proxy Monthly Trends & AIRS CO (500 hPa)
(1) KL (yellow); (2) Watukosek (cyan) (3) SE Asia Region (black)

➔ **Early-Year FT Ozone Increase in SE Asia coincides with waning convection and a small CO pollution decline.**

Similar results at other SHADOZ sites, some less pronounced

Unique Power of Sondes. (1) High-resolution *monthly* trends differentiate Regions & Seasons (2) Dynamic information points to observable mechanistic changes!

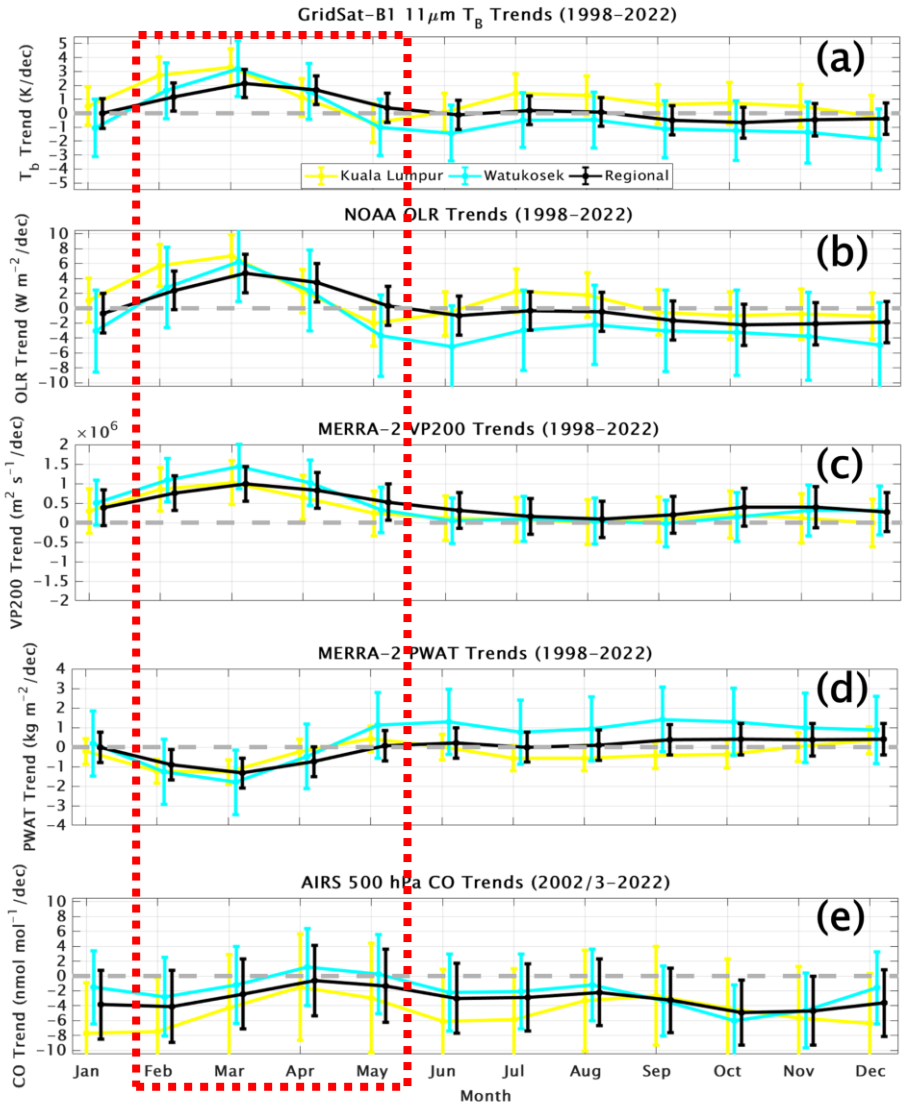
Cloud-top Brightness T

OLR

Merra2-VP-200

Merra2-PWAT

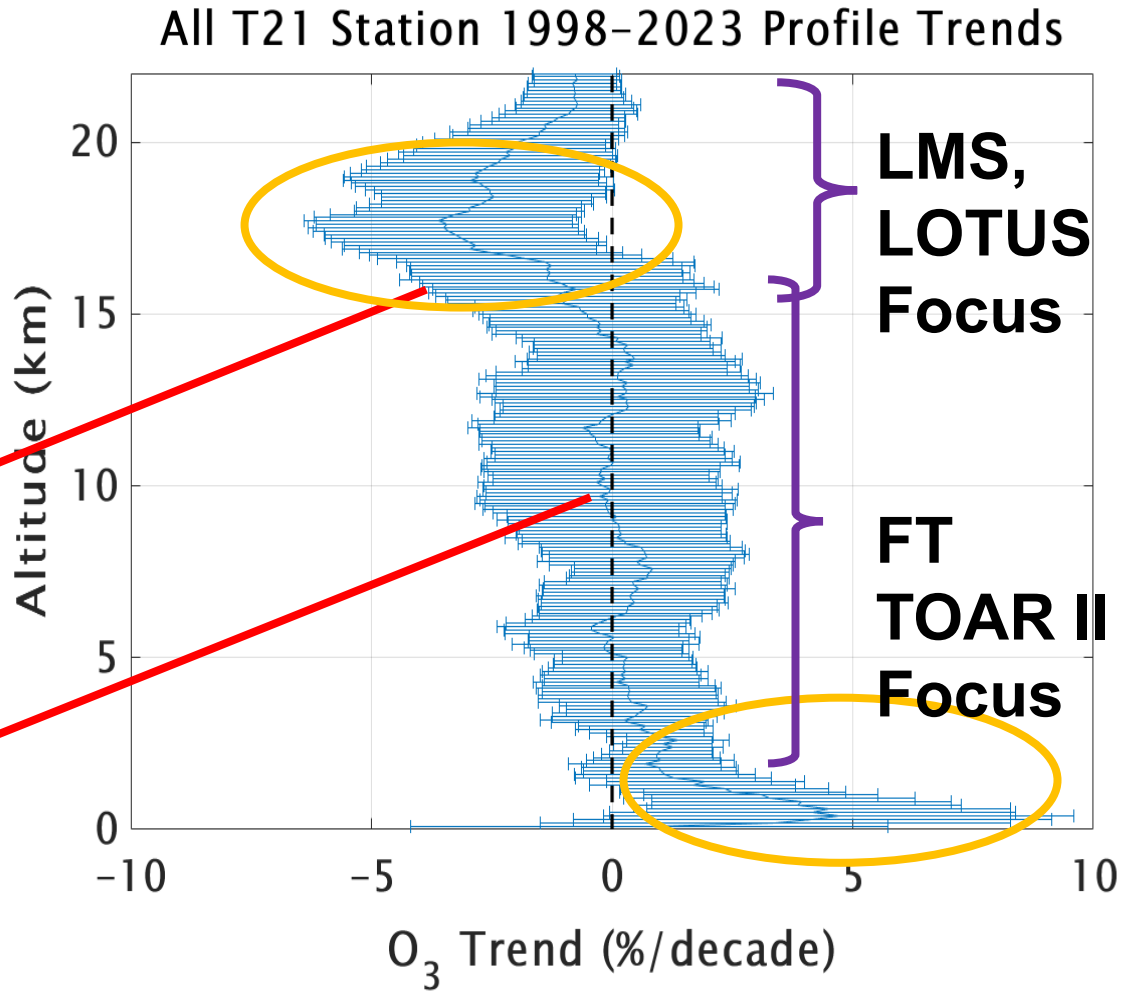
AIRS CO



Stauffer et al., ACP, 2024

Summary – SHADOZ at 25+ Years

- SHADOZ (1998-) put ozonesondes "on the map" as essential for monitoring, trends & process studies
- SHADOZ & JOSIE "rewrote" Ozonesonde SOP: ASOPOS 2.0
- SHADOZ trends in LMS & FT ozone "Set the Bar" for satellite data *and* models to reproduce
  - LMS O_3 *negative* trends, July-September, negligible when TH changes accounted for
  - FT trends: zero on average; early-year increase ➔ declining convection
  - Only below 5 km is tropospheric O_3 increasing, mostly over SE Asia



Thank You for Attention!

PI (1998-2021)

PI (2021-)

Archiver, Webmaster (2019-)

Dr. Anne M. Thompson Dr. Ryan M. Stauffer Dr. Debra E. Kollonige

Funding: NASA HQ (UACO, K. Jucks; SAGE III, R. Eckman). Relevant References (TOAR II in Bold)

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Witte, J. C., et al., *J. Geophys. Res.,* 122, 6611-6636, doi: 10.1002/2016JD026403, 2017 (SHADOZ Reprocessing)

Quality Assurance from SHADOZ & Other Sondes

Ozonesonde Instrument & Its Quality Assurance (QA) Challenge: each instrument, flown with a radiosonde, is unique & must be calibrated before launch

With 2 instrument types & 3 sensing solutions (SST) in use, profile biases can affect station-station comparisons or compromise time-series with a change in procedure

- ***Correct for This!*** **SOP=Standard Operating Procedures specify how to obtain accurate & consistent profiles from each station. SOP also provide guidelines for reprocessing data**
- **Key to SOP is WCCOS (World Calibration Center for OzoneSondes; Jülich, Germany) with standard reference! Adoption of SOP from (WMO/GAW 268, published 2021) => more accurate & precise global data**

SOPs – Reprocess Data

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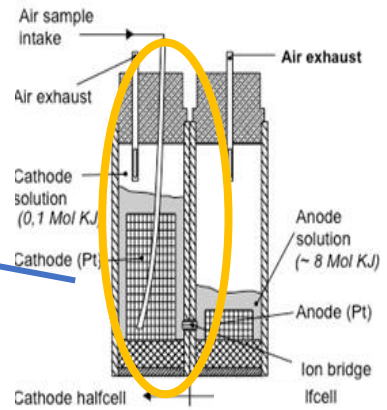
3 KI Sensing Solution Types SST



Air Intake

Pump Motor

$$KI + O_3 + H_2O \rightarrow I_2 + O_2 + 2\,KOH$$