THE STABILITY OF THE GLOBAL OZONESONDE NETWORK

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OUTLINE AND TAKE-HOME MESSAGES

- Introductory Material: (1) Ozonesonde instrument & profiles; (2) Global sonde network & Quality Assurance **(QA)** Needs; (3) ASOPOS Goals & Overview

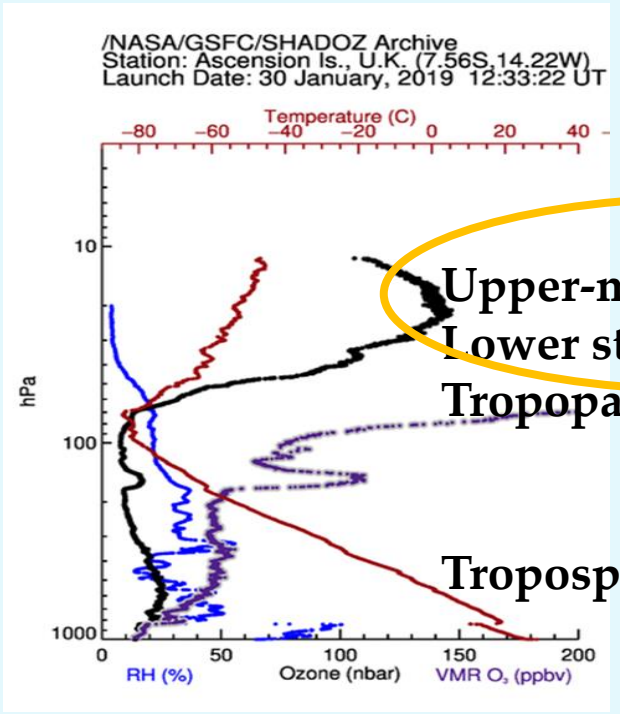
- ASOPOS 2.0 (**Assessment of Standard Operating Procedures [SOP] for OzoneSondes)** and WMO/GAW Report 268. Context for QA improvements

- Bonus – New finding! Stability of global ozonesonde data (Stauffer et al., *ESS*, 2022)

- **Take-home Messages and ASOPOS Impact**
  - ASOPOS 2.0 WMO/GAW Report & 11 related publications are a Game-Changer for sonde QA
  - New analysis of 60-station ozonesonde profiles shows +2% stability, 2005-2021
  - ASOPOS % and ozonesonde QA Going Forward: On-track to 3-5% data uncertainty. ***SAGE Users – use with confidence now. Data will get even better in the next 1-2 years***

OZONESONDE INSTRUMENT & OZONE PROFILE

- **Ozonesonde**: a small instrument attached to a radiosonde & flown on a weather balloon to measure O_3 concentration (black in Figure --- ->) from surface to 35 km with ~100-m resolution
- **Advantage of ozonesondes over spectral instruments –** high resolution, no cloud issues. Mid-stratosphere = main region of trend & satellite user interest



Upper-mid stratosphere
Lower stratosphere
Tropopause Transition Layer

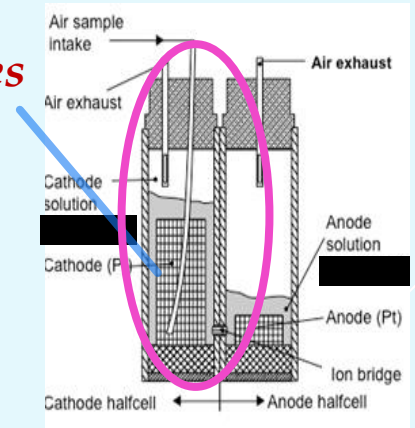
Tropospheric pollution

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

Air Intake

Pump Motor

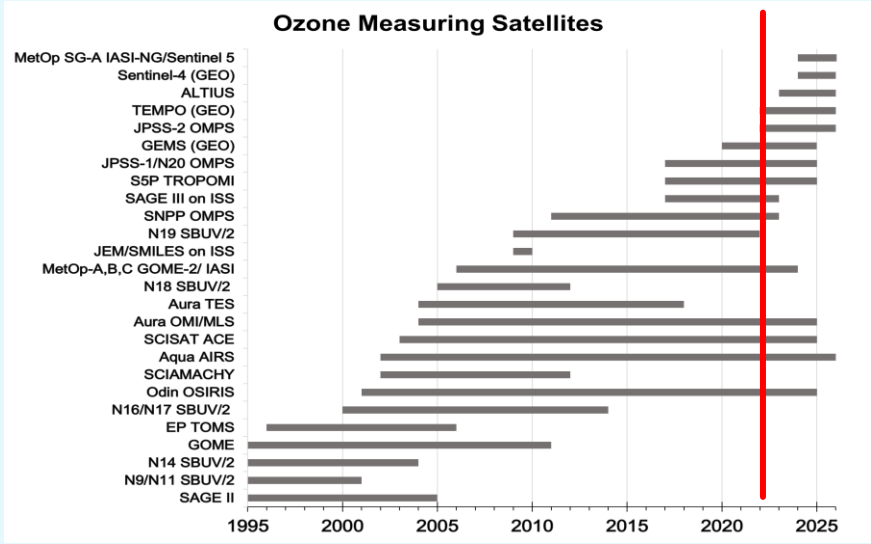
3 KI Sensing Solution Types SST

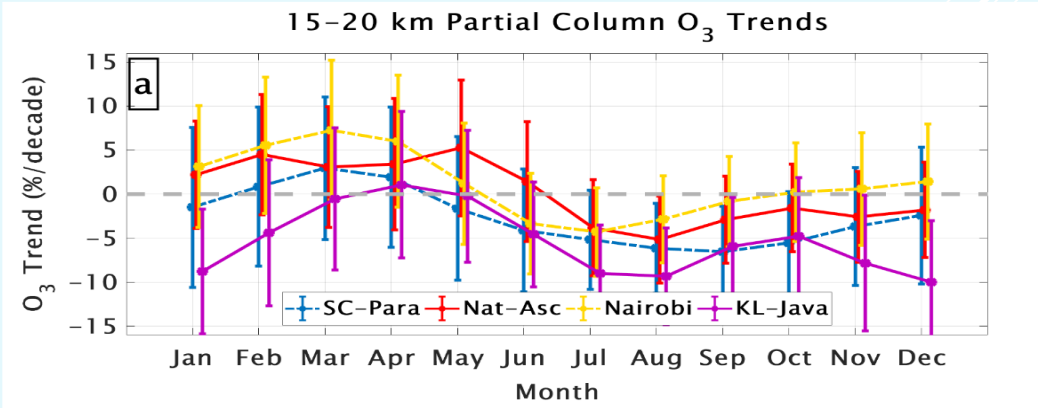


$$2\ KI + O_3 + H_2O \rightarrow I_2 + O_2 + 2\ KOH$$

SONDE QA REQUIREMENTS

- ECC sondes are launched 2/month – 3/week at ~60 sites.
- Since 2000, the sonde network has supported > 20 satellite instruments (WMO/GAW, 2021). **(-->)** Sonde profiles calibrate O_3 lidars, IAGOS aircraft data
- **Data user community now demands 5% or better accuracy and precision of sonde data because some satellites last longer than 10 years**
- **Trends users demand ≥5% metric which SHADOZ (-->) meets in TTL and LMS (Thompson et al., 2021; SAGE STM!)**



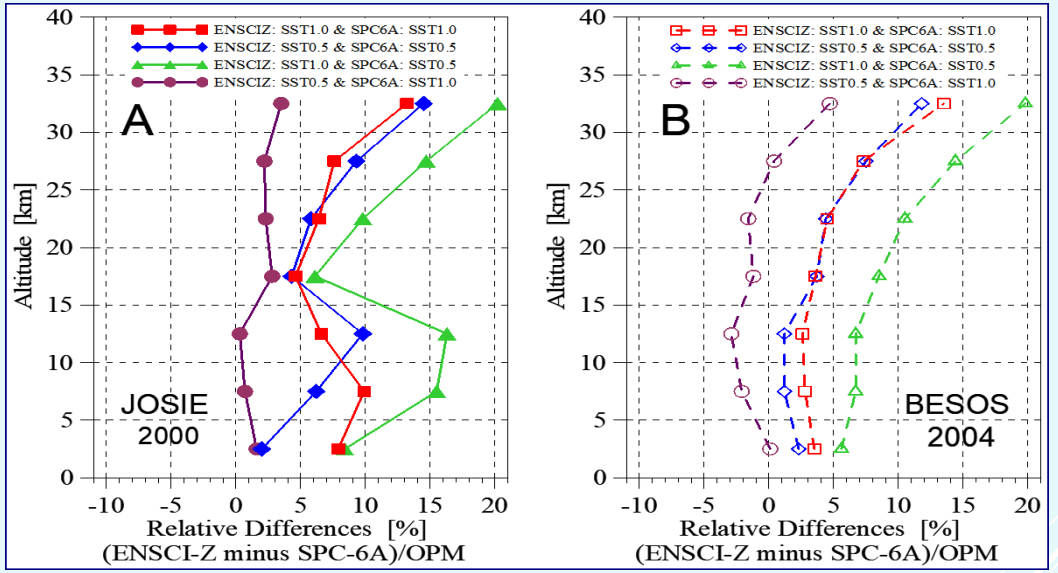


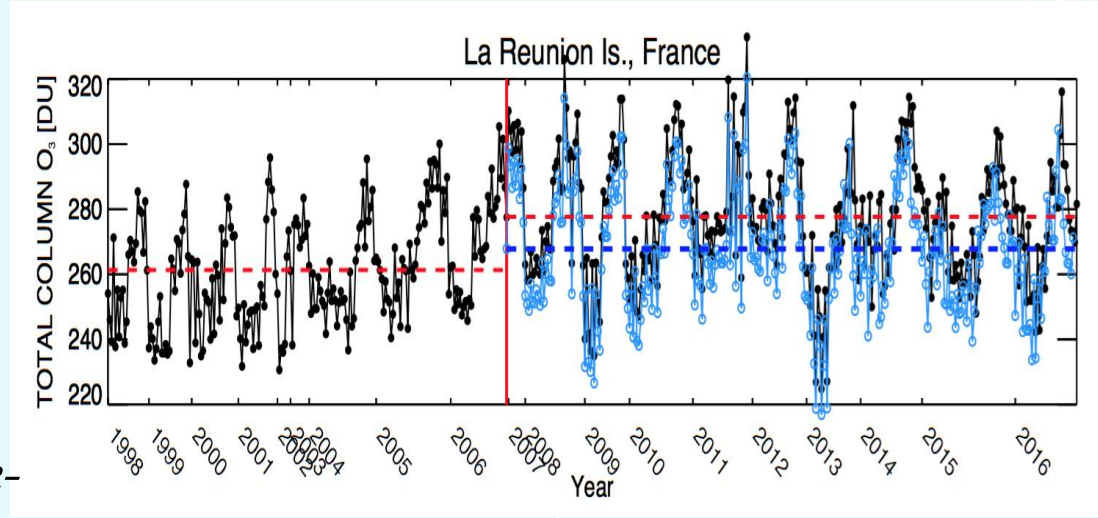
- **Challenge 1 of ozonesonde QA**: Each instrument is unique (launch-and-lose), prepared & calibrated in lab before launch
- **Challenge 2:** Two instruments (different manufacturer) & 3 KI "sensing solution" (SST) types are used. Sondes with varying instrument-SST combinations launched together in field or in a simulation chamber give systematically varying O_3 readings in various profile segments

WHAT DOES ASOPOS MEAN? HOW DOES IT WORK?

GOAL: Provide QA assured data for trends & satellite validation consistent across 60 stations

- Through laboratory and field tests in which different instruments and SST are intercompared by referencing to an independent standard. **Right** – Offsets of various instrument-SST combinations
- WMO-sponsored ASOPOS refers to the process whereby a team of sonde 'experts' analyzes the test results to develop SOP, recommending instrument-SST combinations in WMO/GAW publications.
- ASOPOS also develops methods to "homogenize" data among stations with different sonde-SST
- **Lower** – Change in SST (2006) causes discontinuity in integrated total O_3 (Dobson Units, DU). *Corrected by re-processing the data, "trend" disappears.*





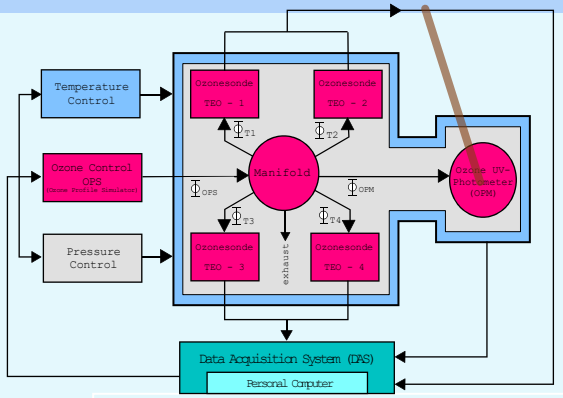
Witte et al., *JGR*, 2018

261 ± 17 DU

Old: 278 ± 19 DU
New: 268 ± 18 DU

ASOPOS 2.0 Initiated @ 2016 QOS (2016-2021)*

Chamber simulates T, P of O_3Sonde ascent. KEY=Standard Reference.



ASOPOS 2.0

9/19 – Outline
3/20 – First Draft
8-10/20 – Draft-> Review
5-7/21 – Final Edits -> WMO
8/21 – WMO/GAW 268 Published

JOSIE-SHADOZ-2017

8 SHADOZ Operators
20 Tropical Simulations
Capacity-Building

WCCOS -

World Calibration Center for OzoneSondes
JOSIE-Jülich Ozonesonde Intercomparison Expt.

Publications on O3S Performance:

- JOSIE 2017-SHADOZ: Thompson et al., BAMS, 2019
- Uncertainty Budget: Tarasick et al., ESS, 2021
- Resolving fast and slow time response: Vömel et al., AMT, 2020
- TCO-Drop : Stauffer et al., GRL, 2020

Publications on Homogenization:

- Tarasick et al., AMT, 2016
- Van Malderen et al., AMT, 2016
- Witte et al., JGR 2017, 2018, 2019
- Thompson et al., JGR, 2017
- Deshler et al., AMT, 2017
- Sterling et al., AMT, 2018

Ten peer-reviewed publications are foundation of ASOPOS 2.0 Report

*** See Smit et al., T4-101 Poster for Report Details**

ASOPOS 2.0 RESULTS: WMO/GAW REPORT 268 (2021)

"Ozonesonde Measurement Principles and Best Operational Practices"

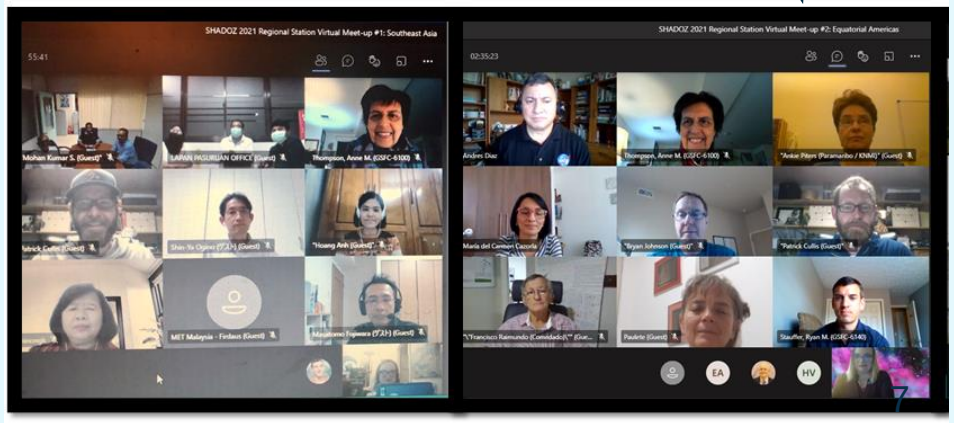
Editors: H. G. J. Smit (FZ-Jülich) & A. M. Thompson (NASA/Goddard Space Flight Center)

How ASOPOS Develops SOPs:

- ASOPOS Process is inclusive. Report Meetings (2021) endorsed by data providers, data users, manufacturers (SPC, EnSci, Vaisala). International Reviewers: 6 sonde experts from 6 continents.
- **CONSENSUS-BASED SOP.** Results of individual lab or field tests are considered. Each station adopts SOP, processing their data. NO "central" processing
- **SUMMARY of What is New in ASOPOS 2.0:** Four SOP on Data Processing & Uncertainties
- – Final data are traceable to a single reference standard: JOSIE OPM
  -- Metadata archived for each profile should be sufficient to allow re-processing
  -- SOP for specifying uncertainties in each archived profile
  -- SOP for continuous monitoring of overall sonde QA to detect unexpected changes

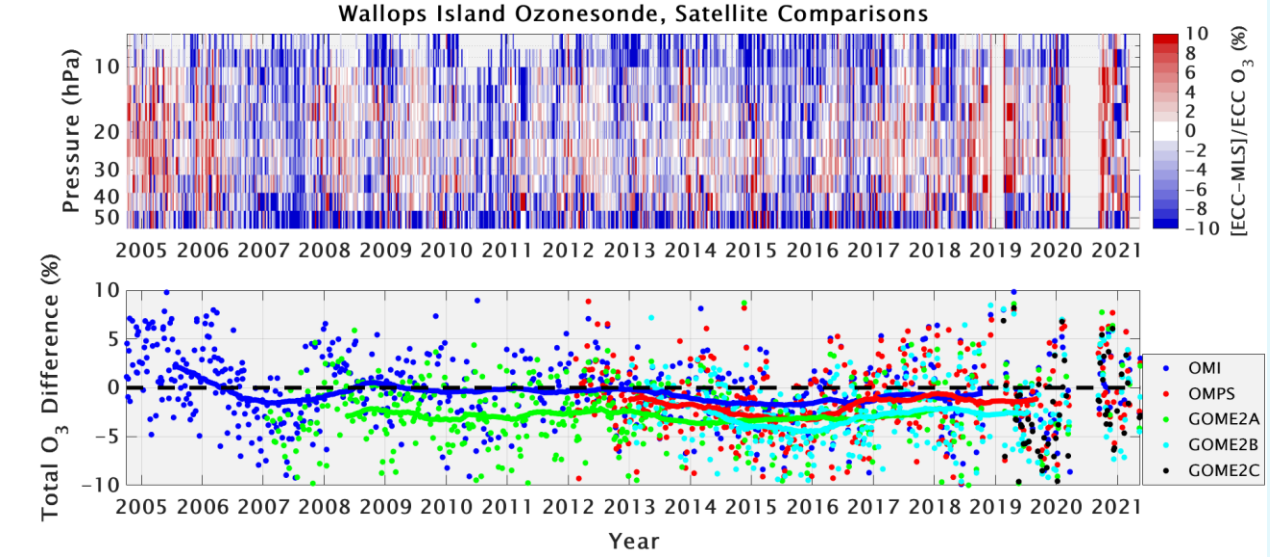
NEW!!

- **ASOPOS has an Implementation Plan**
  -- Webinars for each WMO/GAW 268 Chapter are being recorded for open Web distribution by Jan. 2023
  -- 2023: Regional Online Meetings offered to ALL stations. Model is SHADOZ 2021 & 2022 meetings (**Photos**) to enhance communications & **build capacity** even in COVID!

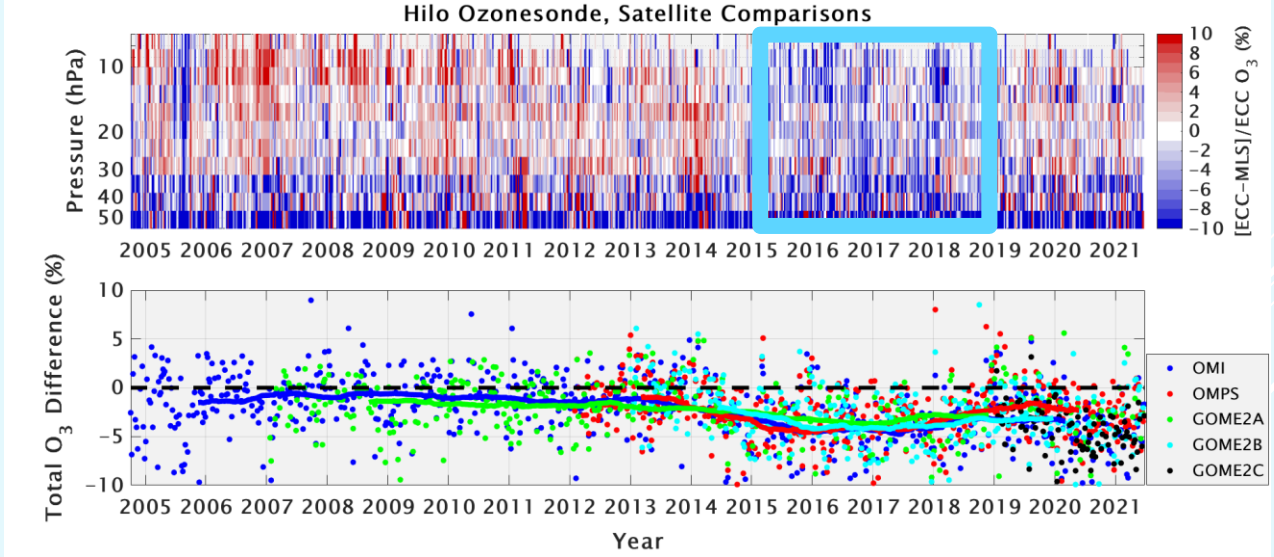


NEW RECOMMENDATION: CONTINUOUS COMPARISON OF TOTAL COLUMN (TCO) & STRATOSPHERIC PROFILES, POST-2005, WITH SATELLITE, GROUND-BASED DATA => EARLY DETECTION OF QA CHANGE

Mid-latitude Station



Sub-tropical station



LEFT: Excellent, stable ozone measurements in stratospheric layers with Aura/MLS (upper) *and* 5 Polar-orbiting uv-vis TCO satellites (lower)

*Updated from Stauffer et al., *GRL*, 2020

RIGHT: Post-2013 stratospheric "dropoff" in ozone **(Upper, box). Lower:** up to 5% less TCO relative to 5 Polar-orbiting uv-vis TCO satellites

Stauffer et al., *ESS*, 2022

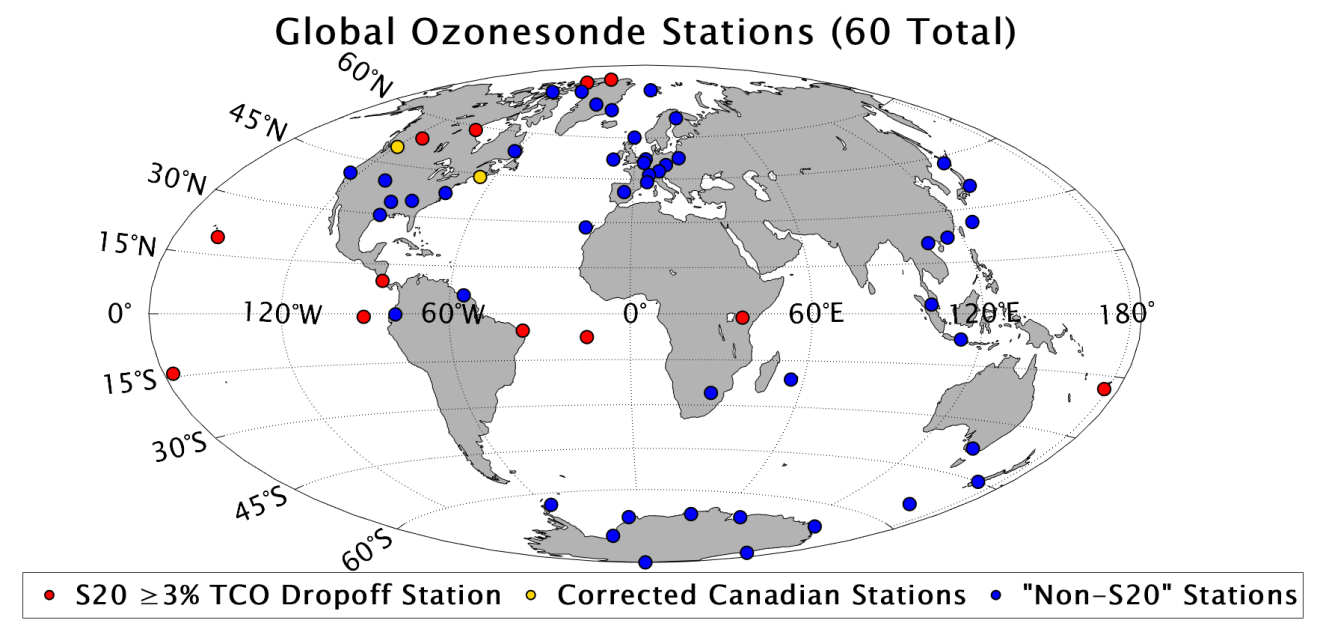
EN-SCI TCO "DROPOFF" UPDATE AND PATH FORWARD

Original 2020 (Stauffer et al., 2020; GRL; "S20") paper with 37 stations now expanded to 60 global stations in Stauffer et al., (2022; ESS) →

Dropoff station defined as having a 3% TCO drop relative to OMI

Kelowna and Yarmouth Canadian station data were missing a correction for non-standard ozonesonde sensing solution. Canada looks better!

>30,000 OMI and ozonesonde TCO comparisons to evaluate, in addition to other independent data



New analysis of 60 stations shows that less than 20% of network affected by a 3% TCO drop

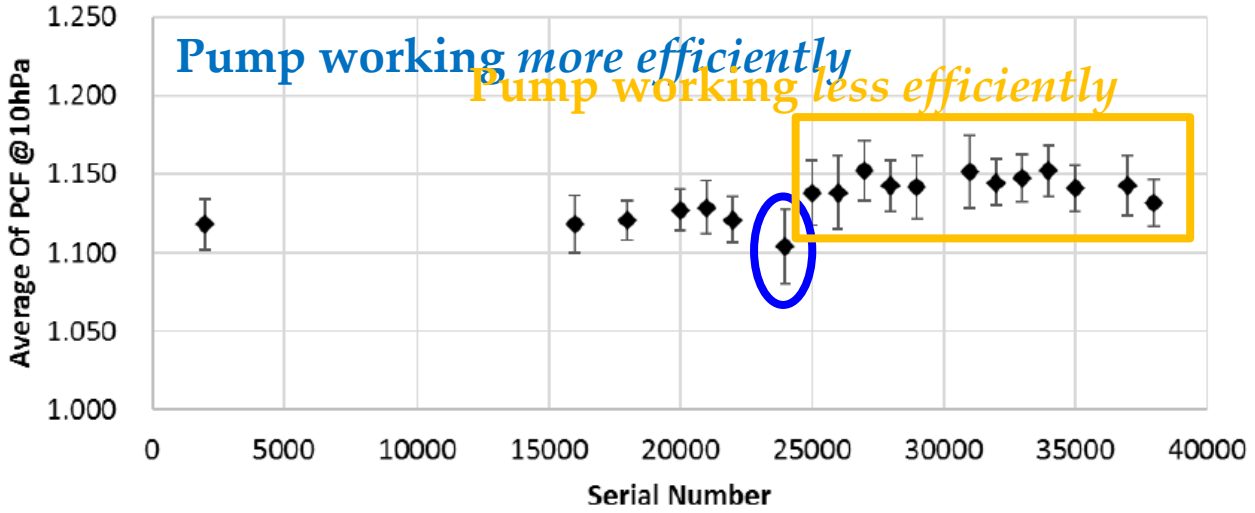
CHANGING EN-SCI PUMP EFFICIENCY COINCIDES WITH TCO DROPOFF

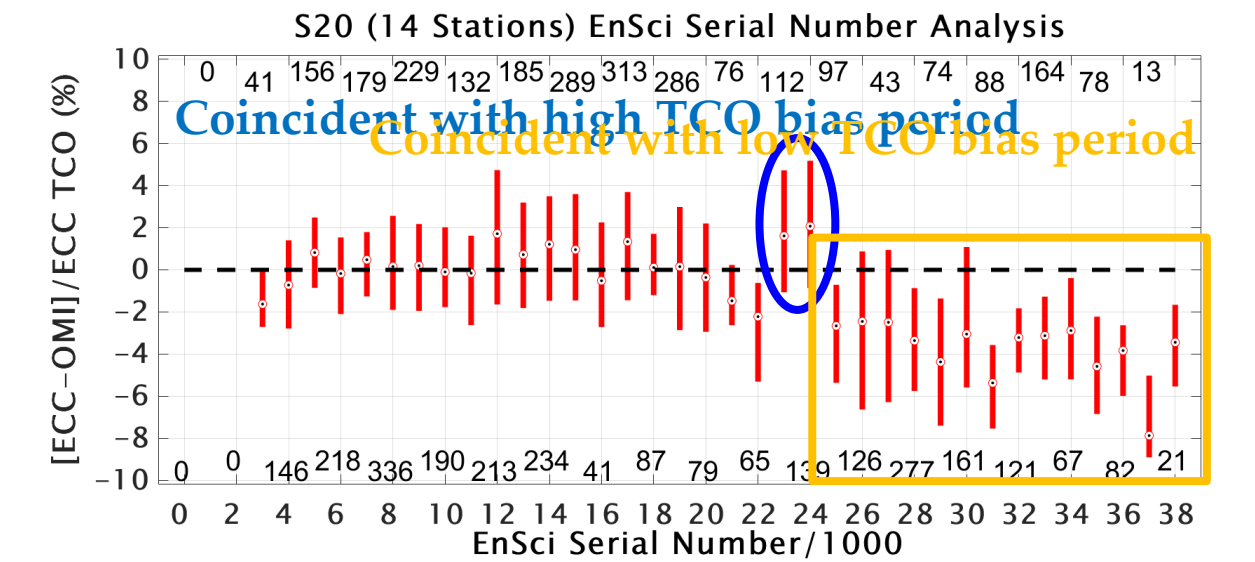
Ozonesonde data are processed using average values to account for the decrease of pump efficiency at stratospheric pressures

A new paper, Nakano and Morofuji (2022; AMTD) shows that there have been changes to the En-Sci ozonesonde pump efficiencies, and that average values are not sufficient. ***These changes are coincident with the En-Sci TCO Drop* En-Sci Serial Numbers →**

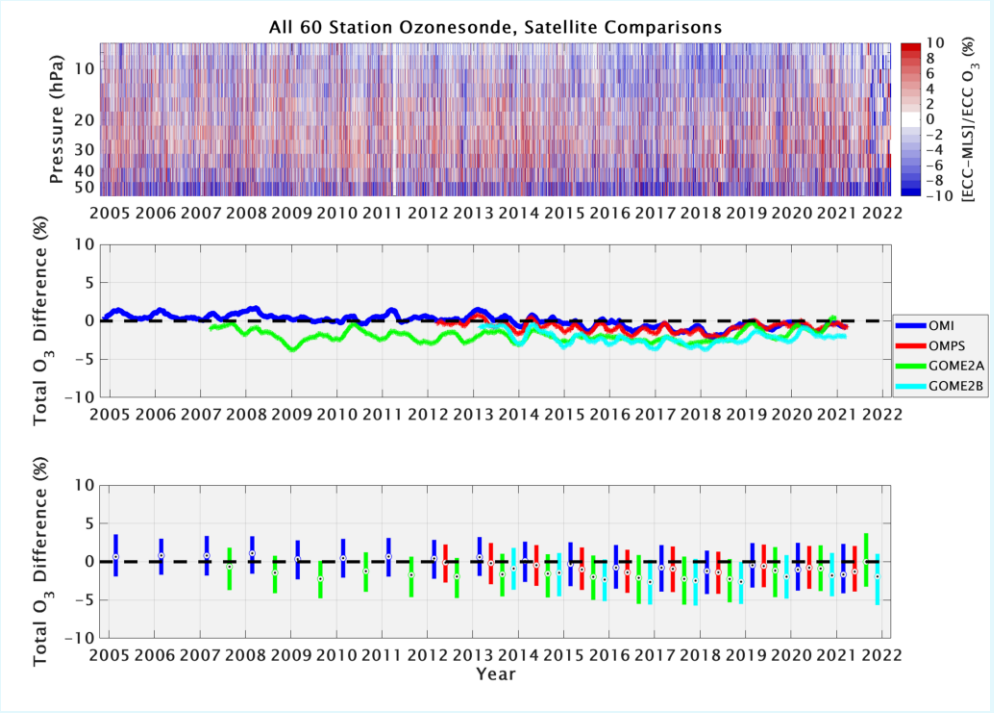
Reprocessing ozonesonde data using new pump efficiencies will resolve some of the magnitude of the TCO drop

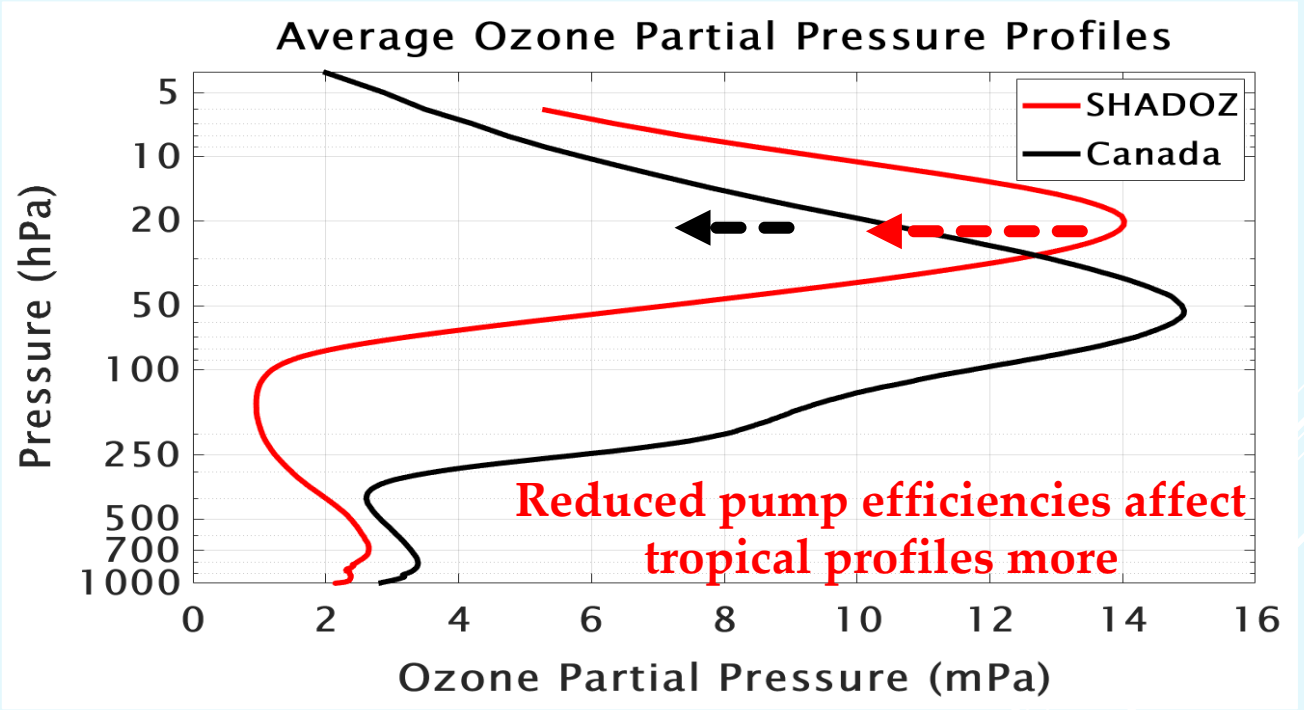
Stauffer et al., *ESS*, 2022 →





DESPITE DROPOFF AND PUMP EFFICIENCY ISSUES, OVERALL NETWORK DATA QUALITY IS EXCELLENT. TROPICAL STATIONS AFFECTED MORE





LEFT: Very stable ozone measurements in both stratospheric layers with Aura/MLS *and* 4 operating Polar-orbiting uv-vis TCO satellites (±2% TCO). **Mid:** 500-sonde Running means. **Lower:** annually averaged mean ranges

RIGHT: Much of high-latitude station ozone lies below 50 hPa where stratospheric pump underestimates are absent - less influence on total column. New study (Nakano & Fujimora, *AMT*, in review) finds Ensci pump effects worsened after 2013, ie, contributed to tropical "dropoff." Other sonde factors are also under study.

Thompson, SAGE STM, 10/22 Figures from Stauffer et al., *ESS*, 2022

SUMMARY & LOOKING AHEAD

ASOPOS 2.0 & WMO/GAW 268 is a game-changer!

- Significant advances in ozonesonde QA with the first guidelines for uncertainties, traceability to a global standard, continuous QA monitoring by satellite comparisons
- Success of the ASOPOS SOP for reprocessing & QA monitoring (*Stauffer et al.*, ESS 2022): ozone column accuracy agrees to ±2% with satellite & ground-based TCO at > 80% of stations!
- Research continues on: (1) Corrections for decreasing pump efficiency at altitude; (2)ways to treat 2-reaction impacts on final data; (3) causes of & SOP for correcting "dropoff" data

- ☞ ***For SAGE III: Re-processed sonde data (2/3 of 60 sites) – use with confidence!***

ASOPOS is Evolving in Community of Data Providers, Users, Sonde Makers

- Changes in manufacture will continue, deliberate or not
- Following ongoing QA tests & analyses, expect SOP and profiles to change again, again!
- Keep building capacity, empowering stations to maintain QA
- World Calibration Center with Global Reference is essential to highest QA sonde profiles

ACKNOWLEDGMENTS. SONDE QA REFERENCES

1. The ozonesonde community is grateful to WMO for sponsorship of ASOPOS, especially for support of the World Calibration Center for OzoneSondes & Global Standard, essential to monitor instrument changes
2. As SHADOZ PIs and SAGE STM members we thank Richard Eckman and Ken Jucks for support. ASOPOS 2.0 was carried out collaboratively with NDACC, IO3C and GRUAN

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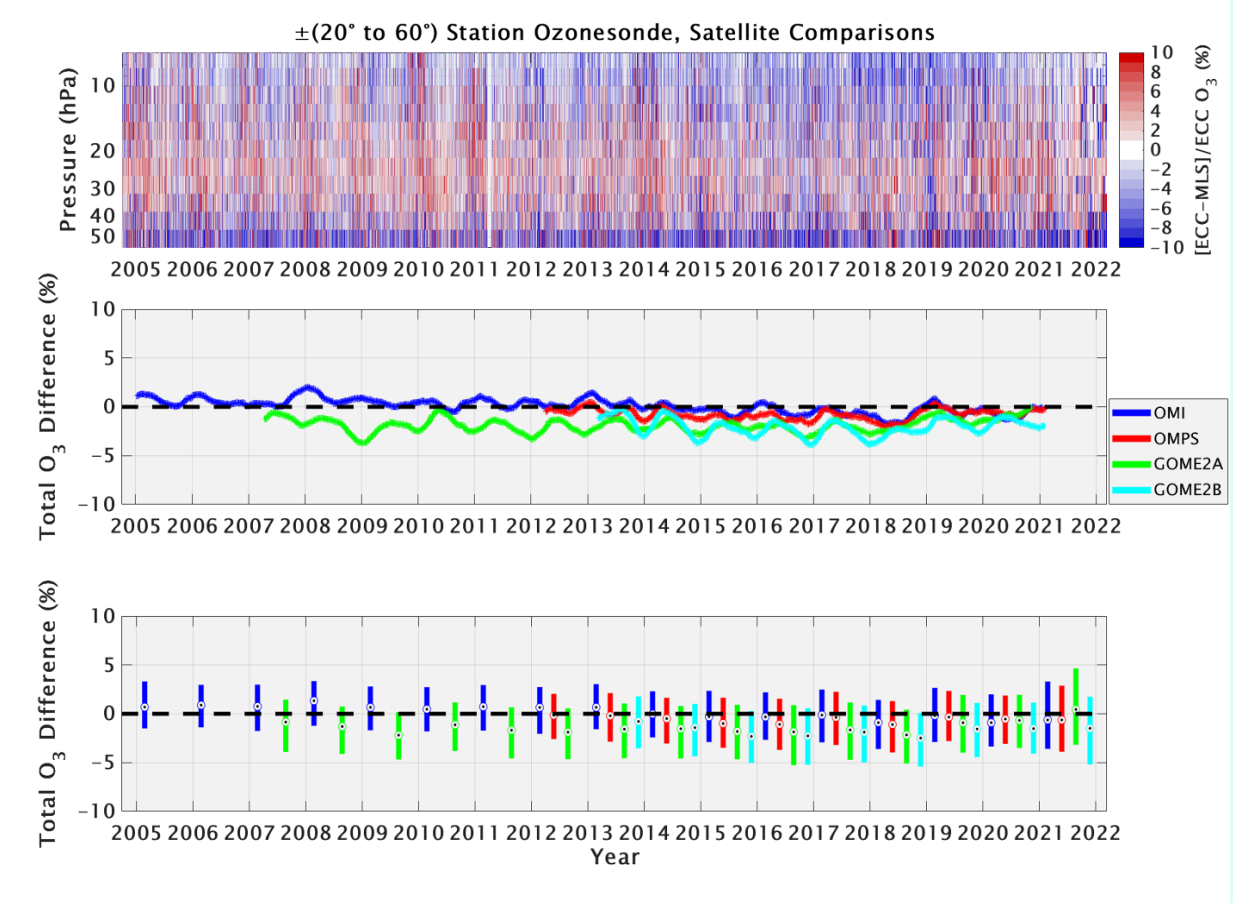
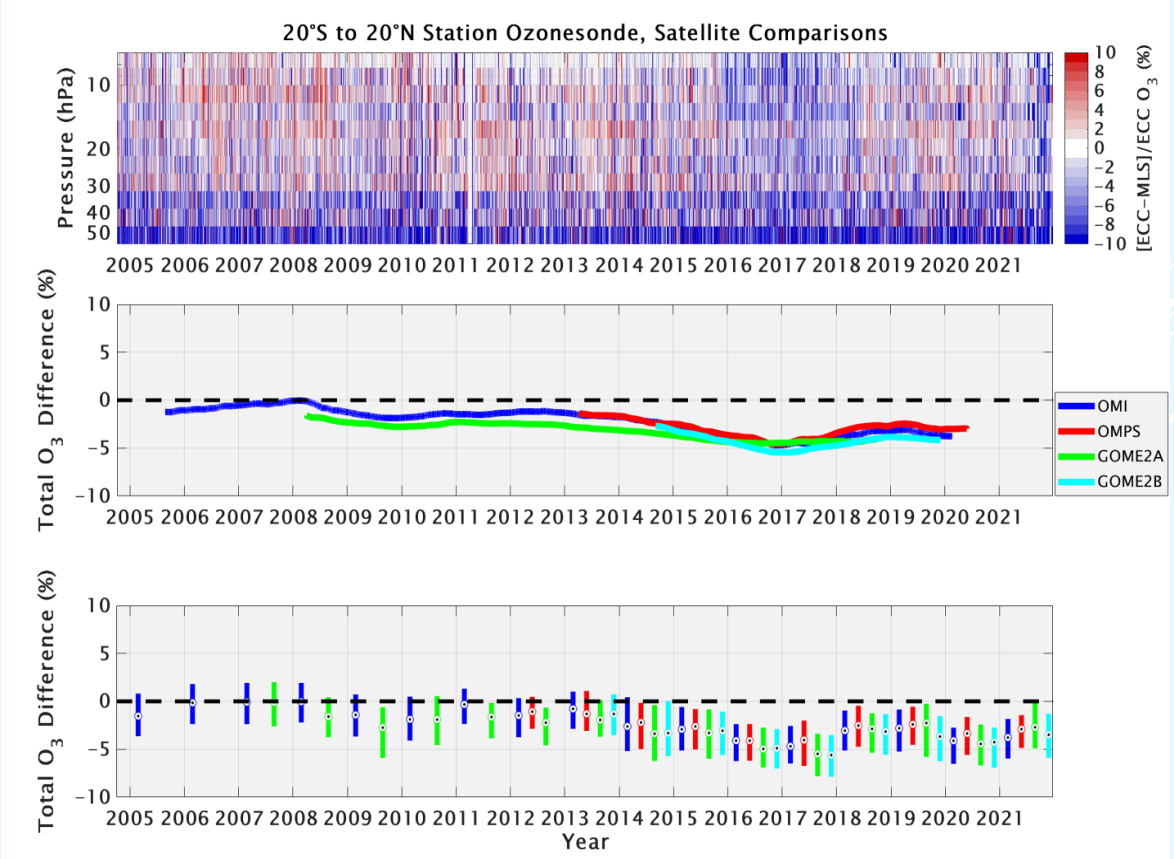
NEW!! REGIONAL DIFFERENCES IN OVERALL QUALITY – MID-LATITUDE VS TROPICAL SONDES IN GSFC-ASOPOS 60-STATION UPDATE (*STAUFFER ET AL.*, 2022)

Mid-latitude Stations



Tropical/Sub-tropical stations



Thompson, SAGE STM, 10/22 Figures from *Stauffer et al., ESS*, 2022