THE 2021 ASOPOS (ASSESSMENT OF STANDARD OPERATING PROCEDURES [SOP] FOR OZONESONDES) 2.0 WMO/GAW 268 REPORT: GLOBAL OZONESONDE BEST PRACTICES

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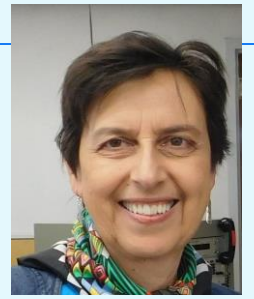


H G J Smit (FZ-Jülich), R M Stauffer, DE Kollonige (NASA/GSFC) & ASOPOS 2.0 Panel

WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observations – TECO-2022, Paris and Online,

Paper Topic 4, #095, 12 October 2022

WORLD METEOROLOGICAL ORGANIZATION
WEATHER CLIMATE WATER

WMO TECHNICAL CONFERENCE ON METEOROLOGICAL AND ENVIRONMENTAL INSTRUMENTS AND METHODS OF OBSERVATION (TECO-2022)

OUTLINE AND BOTTOM LINE: ASOPOS IMPACT

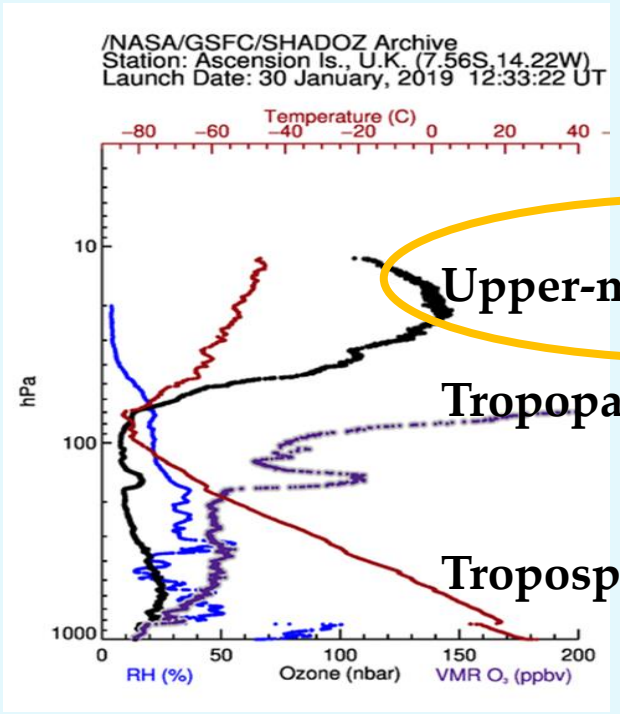
- Introductory Material: (1) Ozonesonde instrument & profiles; (2) Global sonde network & Quality Assurance **(QA)** Needs; (3) ASOPOS Goals & Overview

- ASOPOS 2.0 Report Activities (2015-2022) and WMO/GAW Report 268. Bonus – New paper on stability of global ozonesonde data (Stauffer et al., *ESS*, 2022)

- **Take-home Messages and ASOPOS Impact**
  - ASOPOS exemplifies the best of WMO's support for QA activities & support of World Calibration Centers, ie, FZ-Jülich, in the case of ozonesondes
  - ASOPOS 2.0 and 11 related publications since 2015 are a game-changer for sonde QA
  - ASOPOS continuity since 2000 and Looking Forward: Implementation of new SOP; capacity-building; on-track to reduce ozone profile data uncertainty to 3-5%

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

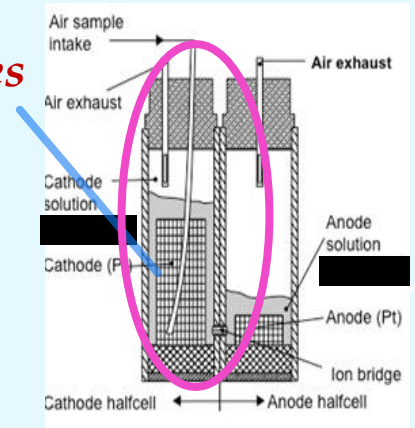


Electrochemical Concentration Cell (ECC) Ozonesonde – *Two manufacturers, SPC & En-Sci*

Air Intake

Pump Motor

3 KI Sensing Solution Types SST

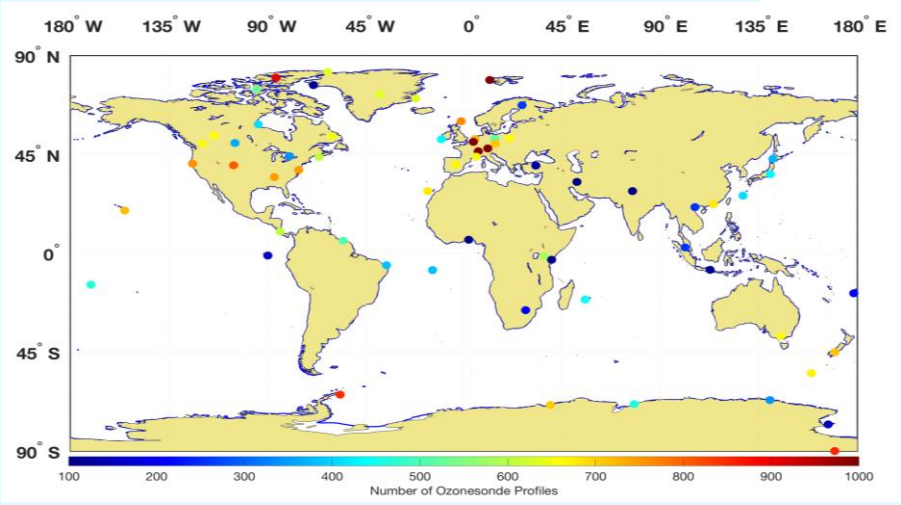


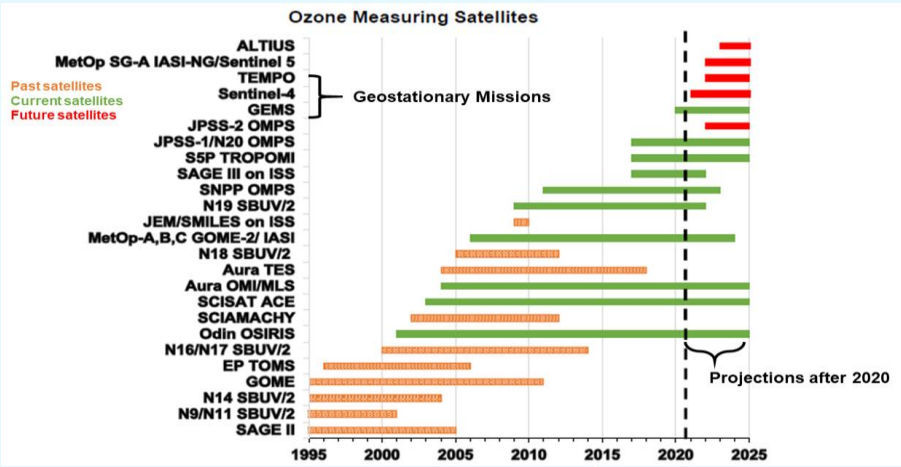
$$2\ KI + O_3 + H_2O \rightarrow I_2 + O_2 + 2\ KOH$$

Thompson, T4-095-TECO-22

GLOBAL SONDE NETWORK & QA REQUIREMENTS

- ECC sondes are launched 2/month – 3/week at ~60 sites. Map shows profile numbers since 2005 **(Upper) ->**
- Since 2000, the sonde network has supported > 20 satellite instruments (WMO/GAW, 2021). **(Lower) ->** Sonde profiles calibrate O_3 lidars, IAGOS aircraft data and are used in near-real-time (NRT)Air Quality models
- **Data user community now demands 5% or better accuracy and precision of sonde data because some satellites last longer than 10 years**





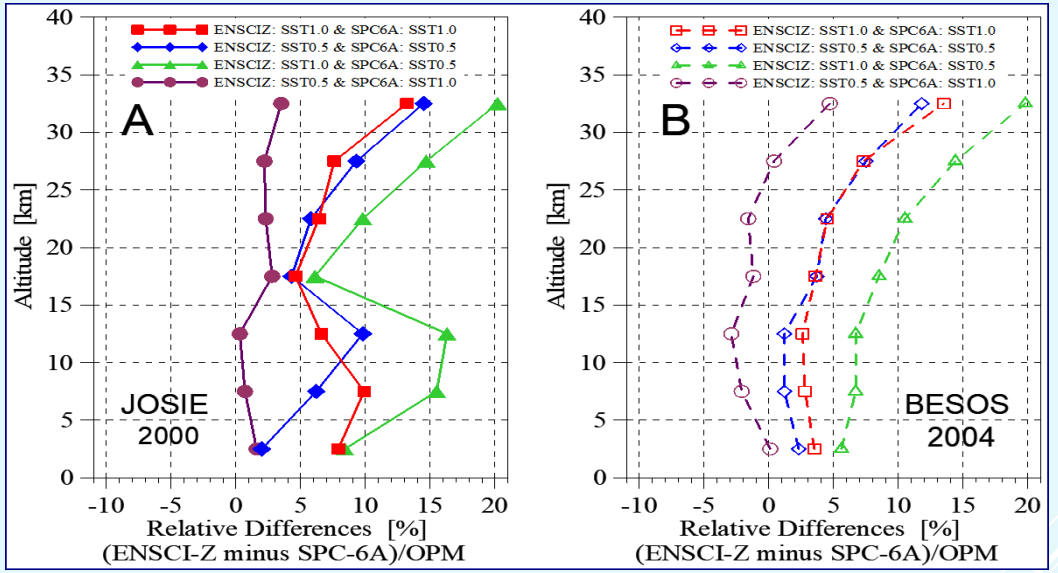
Challenge 1 of ozonesonde QA: Each instrument is unique (launch-and-lose), prepared & calibrated in lab before launch

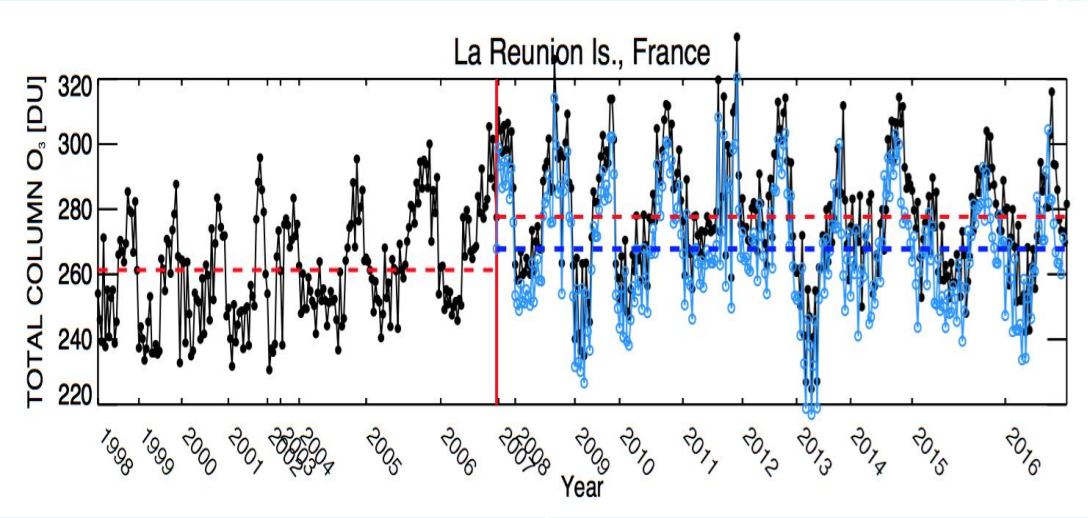
Challenge 2: Two instruments (different manufacturer) & 3 KI "sensing solution" (SST) types are used. Sondes with varying instrument-SST combinations launched together in field or in a simulation chamber give systematically varying O_3 readings in various profile segments

WHAT IS ASOPOS? 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. **See H. Smit Poster T4-101 for details!**
- ASOPOS also develops methods to "homogenize" data across time-series at a single station or 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.*





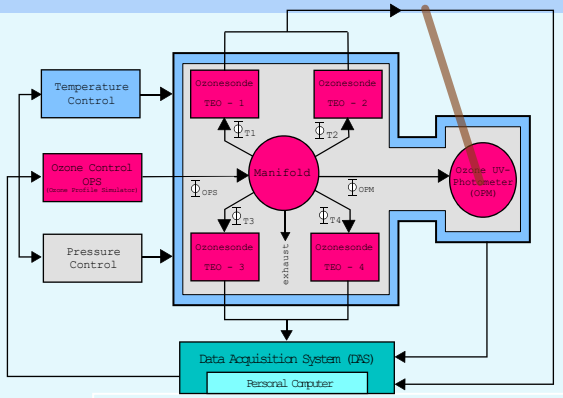
Witte et al., *JGR*, 2018

261 ± 17 DU

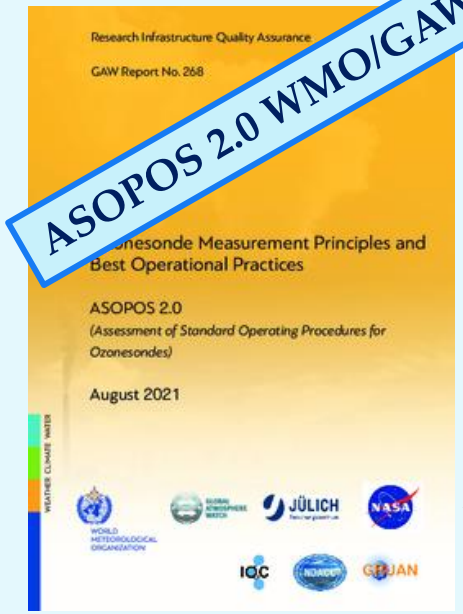
Old: 278 ± 19 DU
New: 268 ± 18 DU

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

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



ASOPOS 2.0 WMO/GAW 268



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)

Report Co-sponsored by IO3C, NDACC, GRUAN

Important ASOPOS 2.0 Features:

- Same Reference Ozone Photometer used in JOSIE-2000 and BESOS (2004), ie one standard
- 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 for NDACC, SHADOZ, WOUDC, NOAA. NO "central" processing

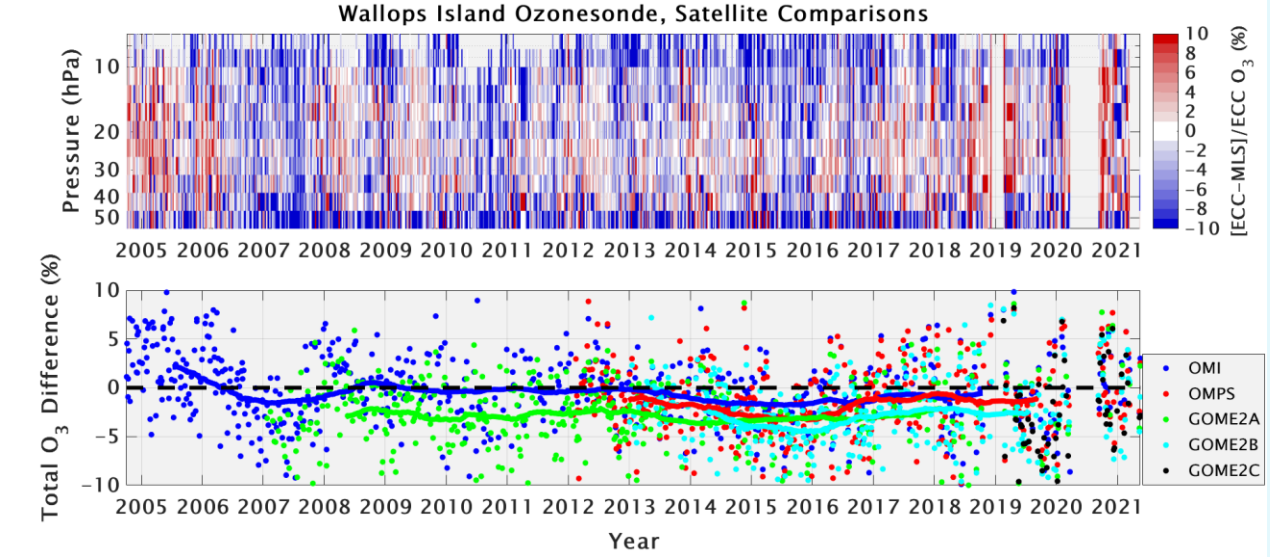
Contents: Five Chapters on Instrumentation, Operations, Data Archiving similar to WMO/GAW 201
Five Annexes include detailed Steps, Guidelines for Uncertainties and Updated Data Homogenization

OVERALL SUMMARY:

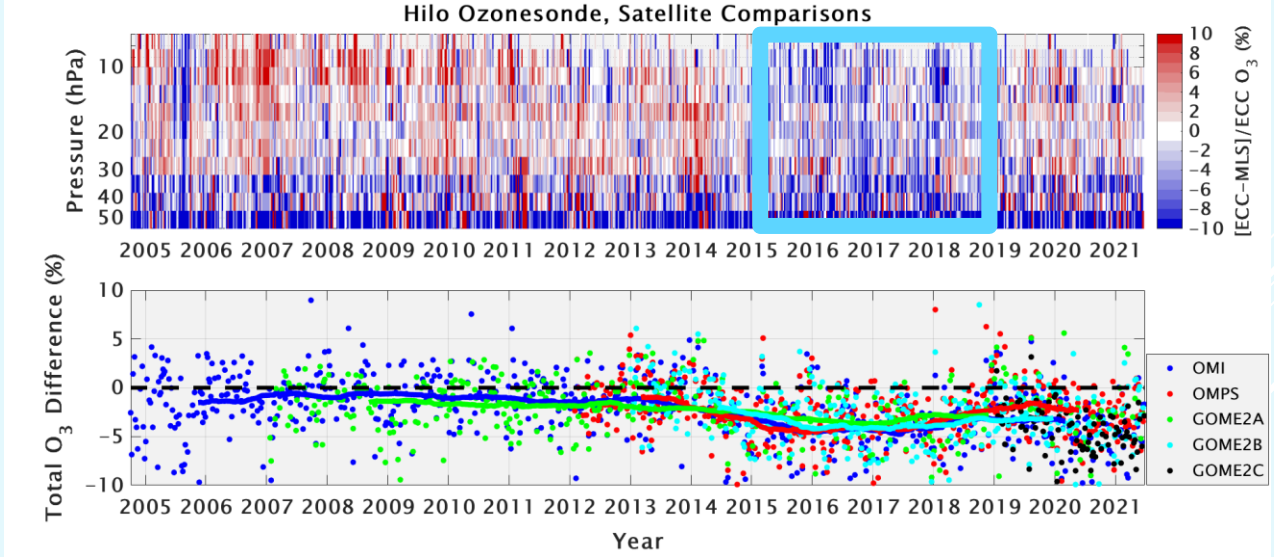
- *Similar to ASOPOS 1.0:* Hardware-SST combinations and Pre-launch preparation
- ***New in ASOPOS 2.0:*** Four SOP that address Data Processing & Archiving uncertainties:
  - Final data are traceable to a single reference standard: JOSIE OPM
  -- Metadata archived for each profile should be sufficient 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 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



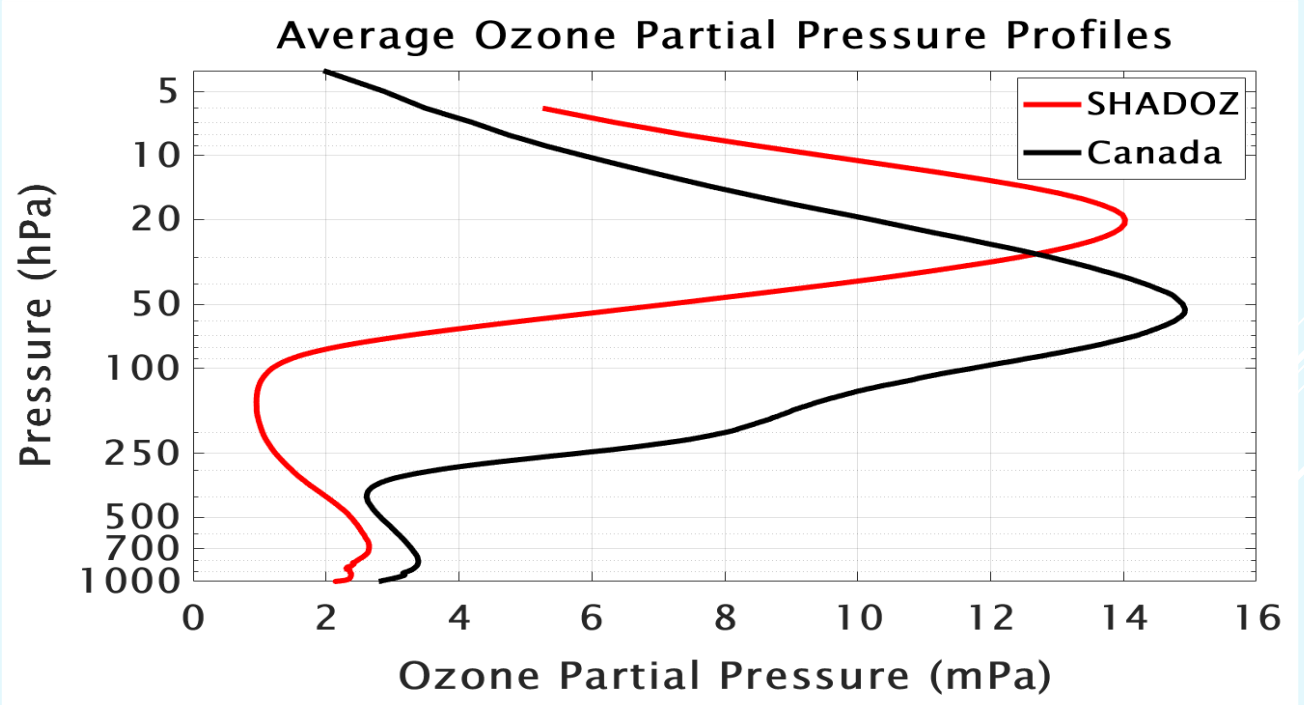
LEFT: Excellent, stable ozone measurements in stratospheric layers with Aura/MLS (upper) *and* 5 Polar-orbiting uv-vis TCO satellites (lower)

*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

NEW EVALUATION OF 60 GLOBAL STATIONS DEMONSTRATES 2% STEADY AGREEMENT OF SATELLITE-SONDE TCO RECORDS AT 80% OF SITES. EXCEPTION AT 7 TROPICAL SHADOZ SITES WHERE REDUCED STRATO-SPHERIC PUMP EFFICIENCY HAS RELATIVELY GREATER LOW-O_3 IMPACT



LEFT: Very stable ozone measurements in both stratospheric layers with Aura/MLS *and* 4 operating Polar-orbiting uv-vis TCO satellites. **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.

Figures from *S*tauffer et al., *ESS*, 2022

SUMMARY. SIGNIFICANCE OF ASOPOS 2.0 ACCOMPLISHMENTS

- After reviewing the value of the ozonesonde and its unique QA challenges, we showed how the WMO-sponsored ASOPOS process of test data collection, analysis & development of a consensus-based SOP successfully built on ASOPOS 1 (WMO/GAW, 2014) to create a powerful ASOPOS 2.0

- **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 data quality monitoring by satellite & ground-based comparisons
  - Success of the ASOPOS SOP for reprocessing and QA monitoring (Stauffer et al., 2022): ozone column accuracy agrees to ±2% with satellite & ground-based TCO at > 80% of stations!
  - Implementation Plan (**next slide**) emphasizes empowerment of individual stations through capacity-building and more consistent, frequent communication

- **Research continues on**: (1) Empirical correction for decreasing pump efficiency at altitude; (2) options for incorporating 2-reaction impacts on data processing; (3) the causes and SOP for correcting data with the "dropoff" problem

LOOKING AHEAD. IMPLEMENTATION OF ASOPOS 2.0 SOP

- **Good News.** Sounding stations continue to re-process time-series. ~2/3 of 60 stations are complete
- ASOPOS Panel has created an ASOPOS 2.0 **Implementation Plan –** H. Smit and R. van Malderen, Co-Chairs
  - Draft Webinars by Lead Authors of each WMO/GAW 268 Chapters have been reviewed and will be recorded for open Web distribution by Jan. 2023
  - Early 2023: Regional Online Meetings for meeting operators and data providers will be organized by the ASOPOS Panel for Questions and Answers and additional training. Follow model that SHADOZ used in 2021 and 2022 (**Photos**) to enhance communications about operational issues, strengthen engagement in ASOPOS process, **build capacity!**

- **ASOPOS GOES ON WITH EVOLVING COMMUNITY!**
  - Changes in manufacture will continue, deliberate or not
  - Following ongoing QA tests and analyses, expect SOP to be updated again. Iterations of ASOPOS tests & SOP will continue
  - Keep building capacity, empowering stations to maintain QA
  - World Calibration Center Standard Reference & test chamber are essential to the highest quality ozonesonde data!

ACKNOWLEDGMENTS. SONDE QA REFERENCES

1. The ozonesonde community, in particular the ASOPOS Panel, is grateful to WMO for sponsorship of its activities, especially for support of the World Calibration Center for OzoneSondes, essential to monitor instrument changes, update SOP and to provide Reference Standard for every archived profile
2. ASOPOS 2.0 was sponsored by WMO and carried out collaboratively with NDACC, IO3C and GRUAN

Smit, H. & A. M. Thompson, Editors, ASOPOS 2.0 Report, WMO/GAW 268, 2021
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