9.4: Ozonesonde Quality Assurance: JOSIE-SHADOZ (2017) and SHALLOTS (2018)

- Anne M. Thompson, NASA GSFC
- H.G.J. Smit, Foschungzentrum Jülich GmbH
- Jacquelyn C. Witte, Science Systems and Applications, Inc.
- Ryan M. Stauffer, Universities Space Research Association, NASA Goddard Space Flight Center
- John T. Sullivan, NASA GSFC
- Katherine Wolff, Science Systems and Applications, Inc.
- George B. Brothers, CHEMAL Inc.
- Bryan Johnson, NOAA Boulder
- Ricardo K. Sakai, Howard University Beltsville
- Travis Knepp, Science Systems and Applications, Inc.

Ozonesonde data constitute a mainstay of satellite calibration and are used for climatologies and analysis of trends, especially in the lower stratosphere where satellites are most uncertain. The electrochemical-concentration cell (ECC) ozonesonde has been deployed at ~100 stations worldwide since the 1960s, with changes over time in manufacture and procedures, including details of the cell chemical solution and data processing. As a consequence, there are biases among different stations and discontinuities in profile time-series from individual site records. Since 1996 the Jülich [Germany] Ozone Sonde Intercomparison Experiment (JOSIE) has periodically tested ozonesondes in a simulation chamber designated the World Calibration Centre for Ozonesondes by WMO. In October-November 2017 a JOSIE campaign evaluated the sondes and procedures used in SHADOZ (Southern Hemisphere Additional Ozonesondes), a 14-station tropical and subtropical network. A distinctive feature of the 2017 JOSIE was that the tests were conducted by operators from eight SHADOZ stations; Nairobi, Natal, Irene, Costa Rica, Paramaribo, Reunion, Hanoi, Kuala Lumpur. Experimental protocols and preliminary results for the SHADOZ sonde configurations, which represent most of those in use today, are described. SHADOZ stations that follow WMO-recommended protocols record total ozone within 3% of the JOSIE reference instrument. Instrument biases noted in prior JOSIE and field tests like BESOS (2004) were noted in JOSIE-2017, with maximum effect in the stratosphere. In June 2018 we organized a series of dual launches during the OWLETS II campaign in the Maryland and Chesapeake Bay area (SHALLOTS = SHADOZ-OWLETS ParaLLel Ozonesonde Test Study). Instrument and solution types were varied as in JOSIE-2017 and three radiosonde-ozonesonde variants were tested. An example of a parallel sampling in SHALLOTS, from a Greenbelt EnSCI-iMet sonde combination flown with the Wallops SPC-LMS package, is illustrated in the Figure. The result was a range of biases but in general the instrument combination (EnSCI-iMet) deployed at 11 SHADOZ stations recorded ~5-10% less ozone in the stratosphere than the SPC ECC sonde flown with a Vaisala or LMS system. These 2017 and 2018 results and prior JOSIEs demonstrate that regular testing is essential to maintain best practices in ozonesonde operations and to ensure high-quality data for the ozone assessment communities.

OZONESONDE QUALITY ASSURANCE: JOSIE–SHADOZ (2017) AND SHALLOTS (2018)

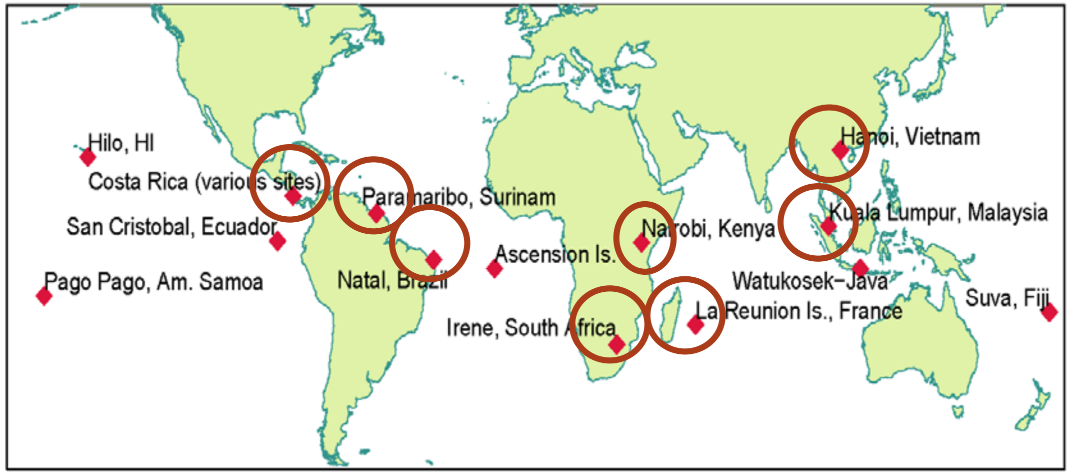
AMS MIDDLE ATMOS. CONFERENCE 2019, PHOENIX, 10 JAN. 2019

A. M. Thompson (NASA-GSFC), H. G. J. Smit (FZ-J), J. C. Witte (SSAI @NASA-GSFC), Ryan M. Stauffer (USRA@NASA-GSFC), J. Sullivan (NASA-GSFC), K. Wolff & G. Brothers (NASA/WFF), B. J. Johnson (NOAA), R. Sakai (Howard Univ), T. N. Knepp (SSAI@NASA-LaRC)

ROAD MAP

- **What/Why/Where is SHADOZ (So. Hemisphere Additional Ozonesondes)?** J. Witte Talk
- **What/Why/Where is JOSIE (Jülich Ozonesonde Intercomparison Experiment)?**
- **Why a JOSIE-SHADOZ?**
- **Results Part 1: JOSIE-SHADOZ, 9 Oct-3 Nov 2017 at World Calibration Centre for OzoneSondes (FZ-J)**
  - Two 2-week sessions, each with 4 SHADOZ groups plus coaches and referees. Total 20 organizations in Asia, North America, Africa & South America
  - What was tested in JOSIE-SHADOZ? 10 ozone profile simulations in each session
- **Specific Issues/Goals/Questions for a JOSIE-SHADOZ campaign:**
  - How do ECC ozonesondes prepared using both community-accepted and variant procedures compare to the ozone reference photometer in the FZ-J chamber?
- **Results Part 2: SHADOZ-OWLETS ParaLLel Ozonesonde Test Study (SHALLOTS)**
  - Field tests of dual/"parallel" ozonesonde launches in 2018: How do those results compare to the results obtained in JOSIE-SHADOZ?

What/Why/Where is SHADOZ?



- "Strategic" sonde network coordinates tropical/subtropical launches for stratospheric scientific studies, trends analysis and satellite algorithm and validation
- **Data and images available at: https://tropo.gsfc.nasa.gov/shadoz.**
- Operators from **8 circled Stations** took part in JOSIE-SHADOZ 2017 lab tests

What/Why/Where is JOSIE?

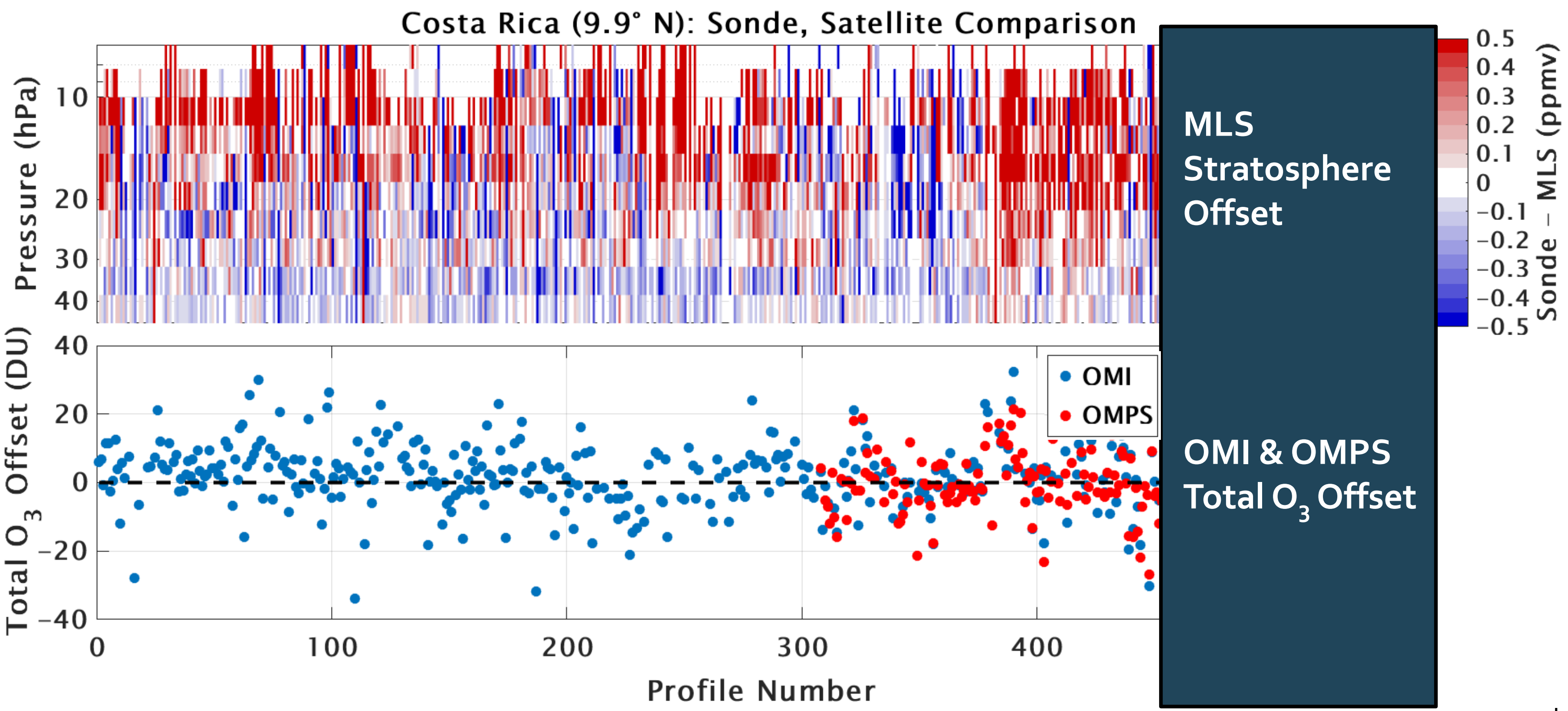
- Jülich World Ozone Calibration Centre chamber tests 4 sondes. "JOSIEs" since 1996 form basis of **WMO** Standard Operating Procedures (SOP)
- Chamber simulates O_3-P-T profiles for typical tropical/mid-latitude/polar conditions at balloon "ascent rate." Each sonde profile is compared to Reference O_3 Photometer or "OPM"
- Main variants in sonde are instrument (**batch, manufacturer**) & sensing solution type (**SST**)

Why JOSIE-SHADOZ? Example of Station Ozone Discontinuity

January 2016

Sonde O_3 comparisons with **Aura MLS** O_3 profiles (**top**), and total column O_3 from **Aura OMI** and **S-NPP OMPS** (**bottom**) at Costa Rica →

Around 2015-2016, a few **SHADOZ** sites began measuring lower O_3 compared to satellites & ground-based data (not shown; *Thompson et al., 2017; Sterling et al., 2018*)



Top: Sonde minus MLS O_3 mixing ratio at MLS pressure levels. Bottom: Sonde minus OMI & OMPS satellite Total Column O_3

JOSIE Testing of SHADOZ Instruments & SST

- What was tested in JOSIE-17?
  - "WMO-recommended" sonde/SST combos → (SPC 1.0% KI 1.0B, EN-SCI 0.5% KI 0.5B)
  - Some stations employ low-buffer "NOAA"-variant, 1% KI with 0.1 buffer with EN-SCI
  - "Batches" of older sondes to test for discontinuity issue (previous slide)

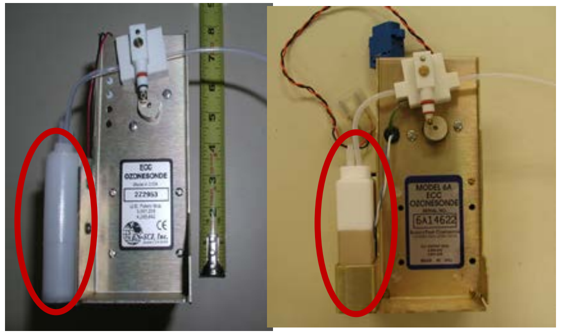
WMO/GAW Report #201

Session 1

- TESTING Protocol for each 2-Week Session with 4 SHADOZ groups:
  - Week 1:   5 tests with "SHADOZ" SOP*
    - *7 of 8 operators at JOSIE follow WMO/GAW

    = "SHADOZ" SOP on following slide
  - Week 2:   5 tests with "NOAA/JOSIE" SOP

EN-SCI   SPC

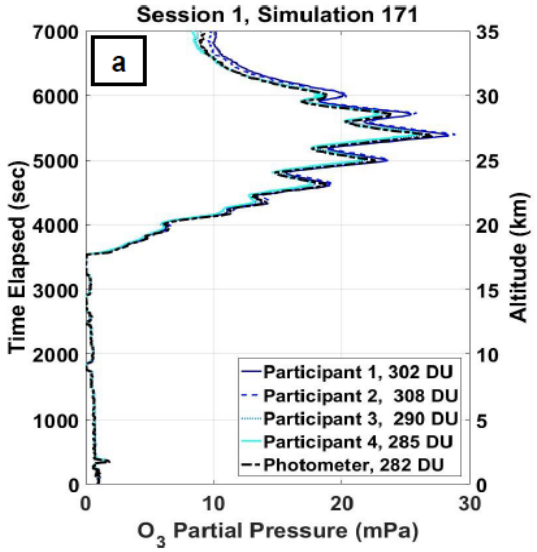


Cells with Sensing Sol'n

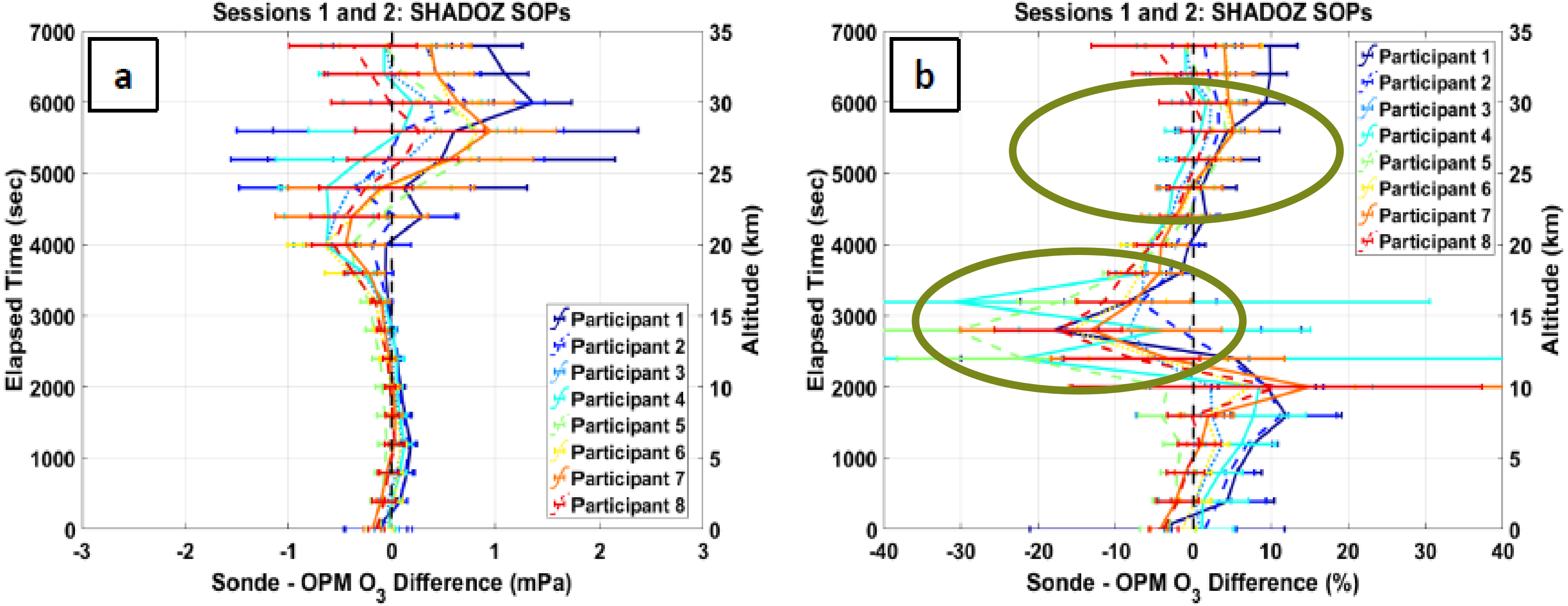
Session 2

PHOTOS – Upper: **Session 1** Coaches, 4 SHADOZ operators
Bottom: **Session 2** Coaches, 4 SHADOZ operators, FZ-J staff

Compare "SHADOZ" Station Profiles to JOSIE Reference Profile



Summary statistics for "SHADOZ"/WMO recommended procedures



Top – Sample Test, Raw Data

\- -

Center – Means of all 10 Tests by 8 groups relative to JOSIE Ref (absolute units)

Right – Mean of 10 Tests (% difference with JOSIE Ref)

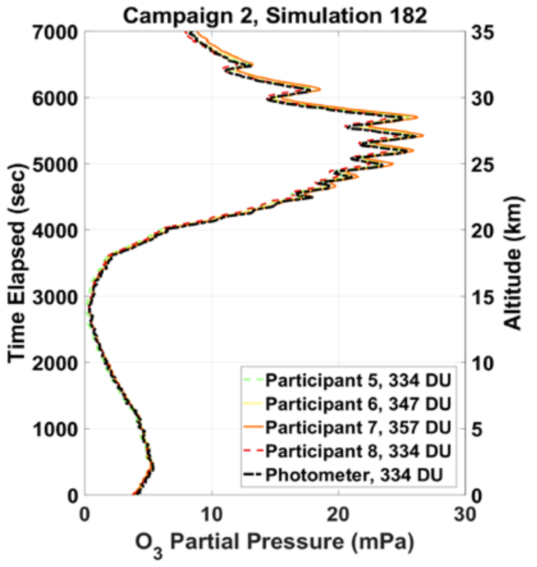
Regions of Interest (circles on **Right**):

Mid-stratosphere – O_3 maximum – agreement good, small bias

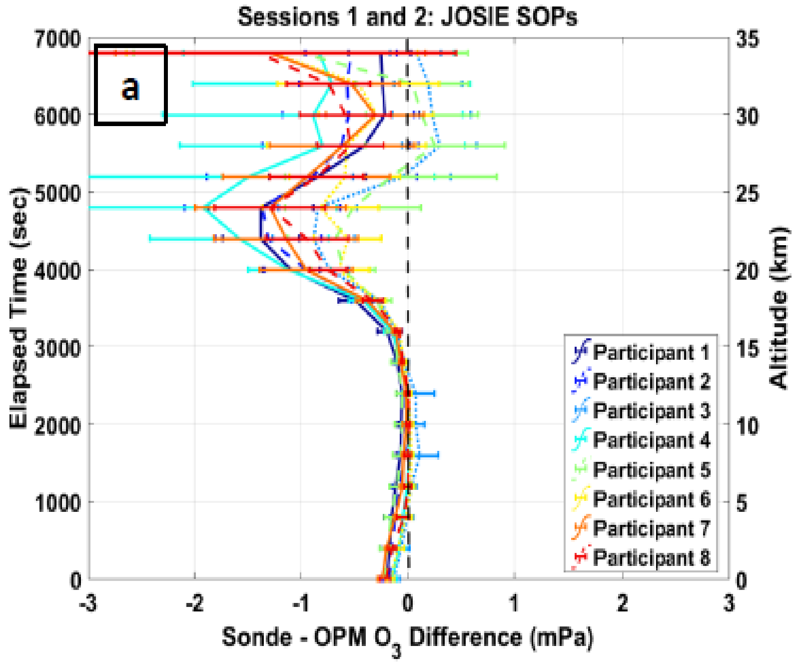
TTL (tropopause transition layer) – maximum uncertainty in profile. WMO SST prone to higher uncertainty than "JOSIE" SST

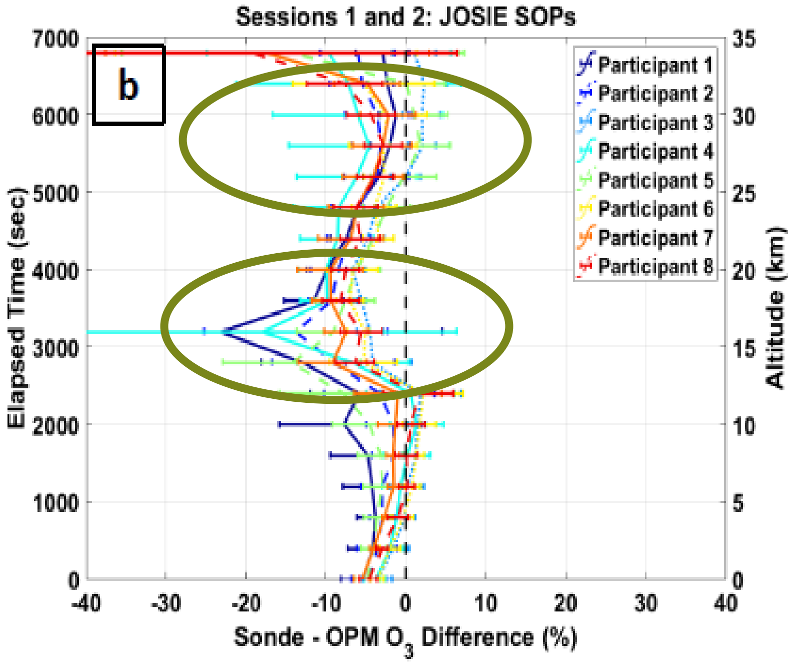
Thompson et al., *BAMS*, Jan. 2019 issue.

Compare "NOAA/JOSIE" Profiles to JOSIE Reference Profile



Summary statistics for "NOAA/JOSIE" recommended procedures





Top – Sample Test, Raw Data

- -

Center – Means of all 10 Tests by 8 groups relative to JOSIE Ref (absolute units)

Right – Mean of 10 Tests (% difference with JOSIE Ref)

Regions of Interest (circles on **Right**):

Mid-stratosphere – O_3 maximum – lower than Ref, SST is less sensitive; bias low

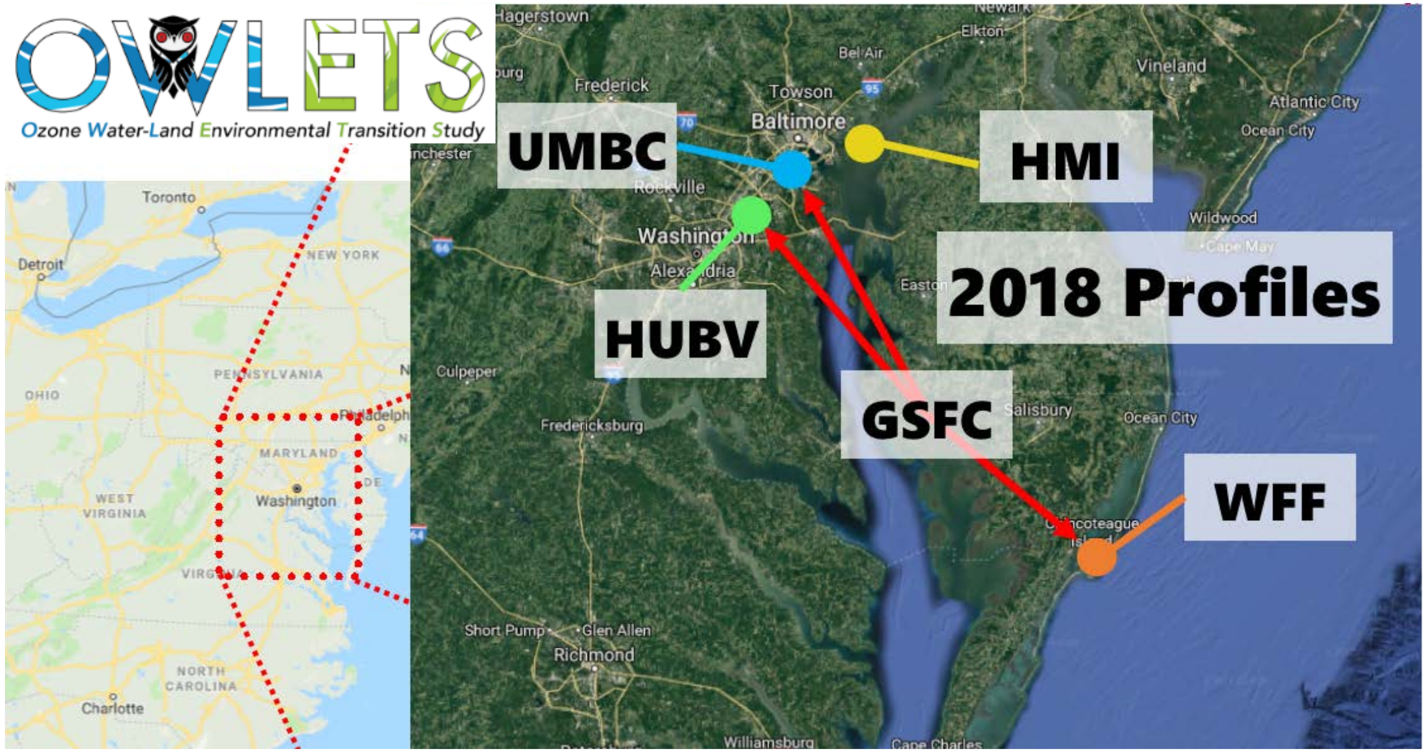
TTL – This SST is more responsive, closer to JOSIE Reference

Mean: NOAA SOPs record 5-6% less total O_3 than WMO/GAW

How do Field Tests Compare to JOSIE Results?

SHADOZ-OWLETS ParaLLel Ozonesonde Test Study (SHALLOTS)

- Post-JOSIE **field tests** of ozonesondes:
  1) "Batches" (2012 vs. 2017)
  2) WMO and "NOAA" SSTs
- **June-July 2018**, 10 "parallel" ozonesonde flights at three host locations (NASA/WFF, UMBC, HUBV)



Preparation of "parallel" ozonesonde (two radiosondes, two ozonesondes) at NASA/WFF in June 2018

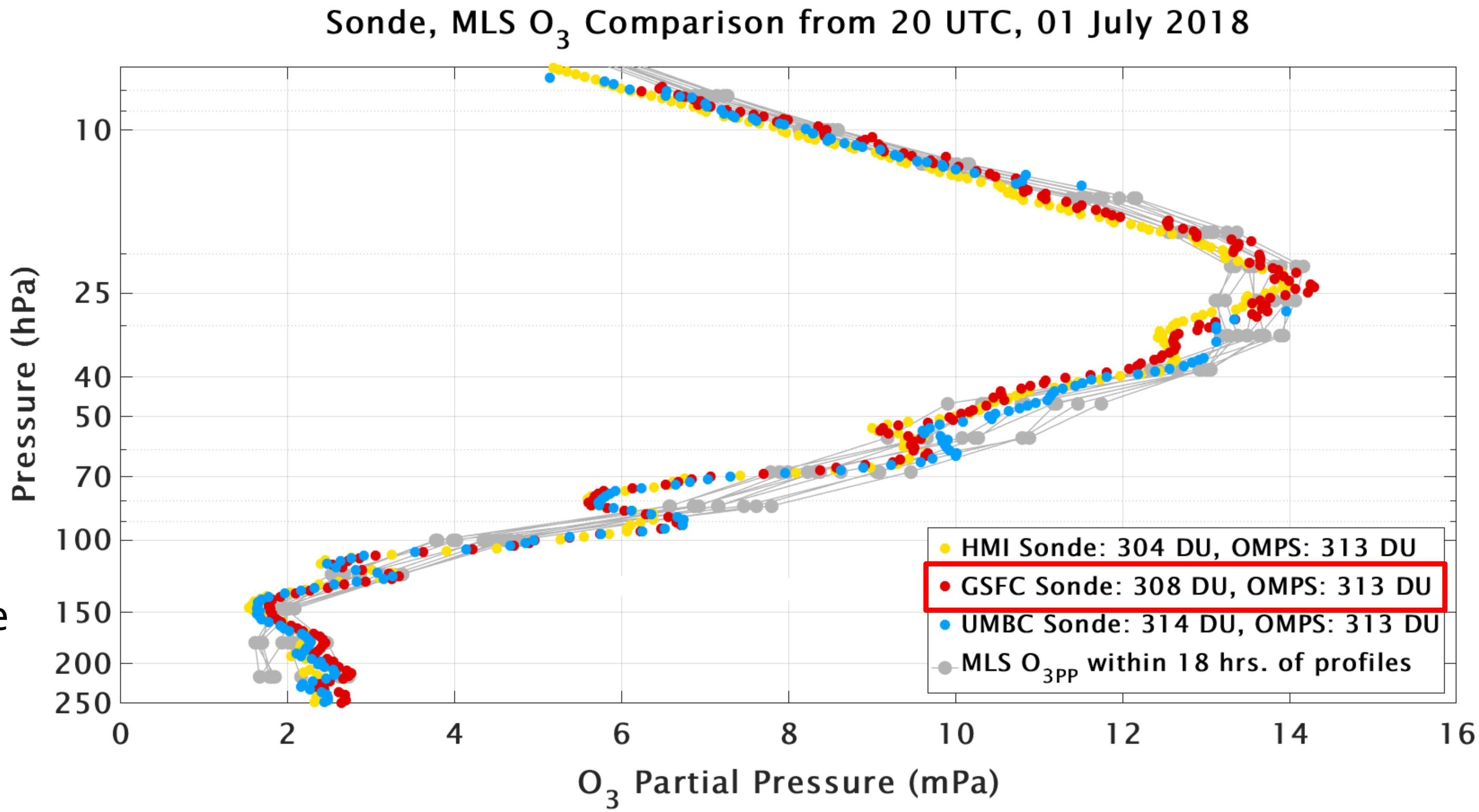
- Analysis includes dozens of profiles from **OWLETS-2 (2018)** Mid-Atlantic US air quality study

Field Test: 2012 vs. 2017 Batches of Ozonesondes

Three ozonesondes launched at the same time (GSFC and UMBC parallel) on 1 July 2018

Comparisons with **MLS** O_3 profiles shown in **grey**

New ozonesonde performance is identical to the older ozonesonde (GSFC). All sonde measurements within a few percent of MLS and **within 3%** of satellite total O_3 from **OMPS**



Ozonesonde O_3 partial pressure profiles compared to coincident MLS O_3 partial pressure profiles

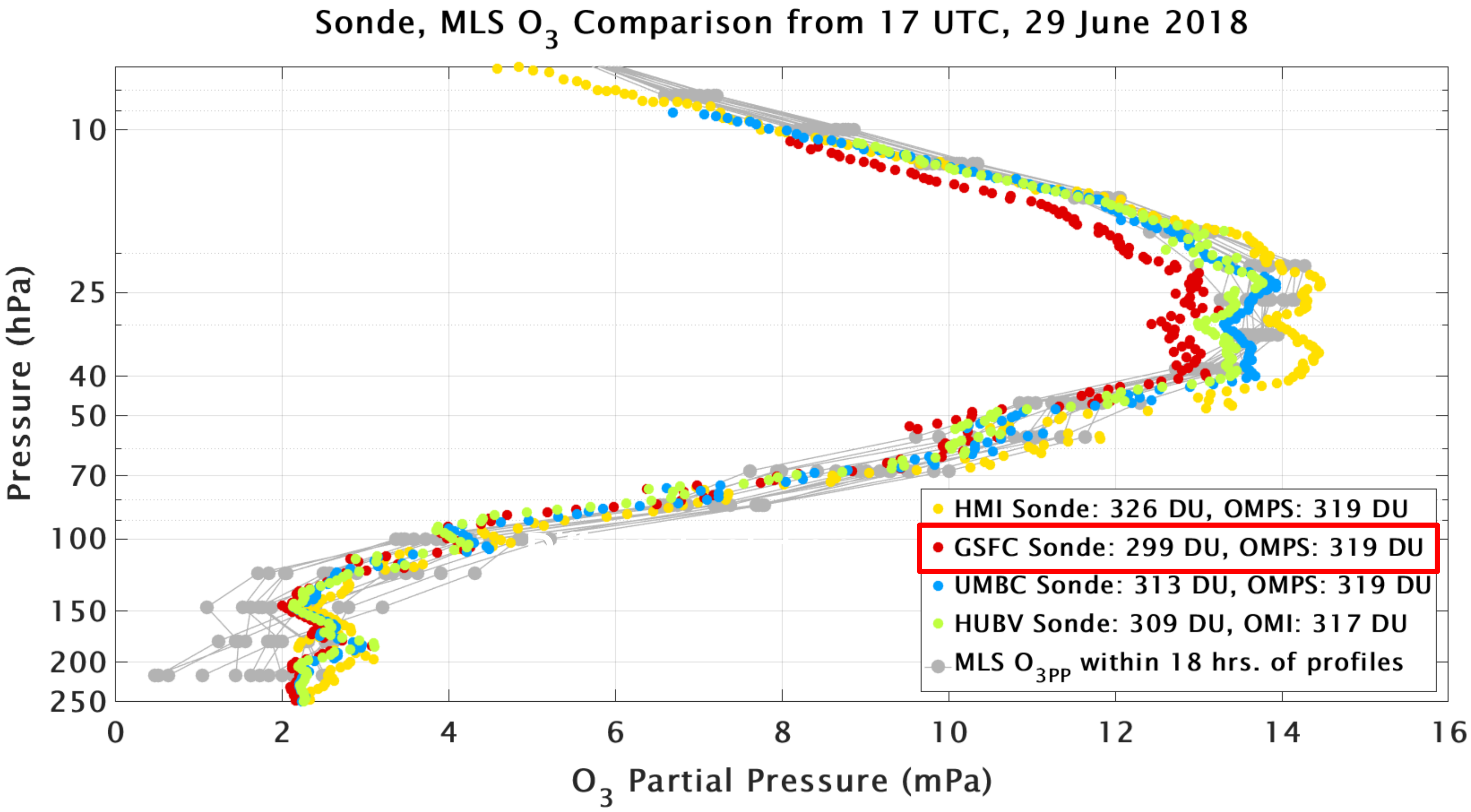
Field Test: WMO and NOAA O_3 Sensing Solutions

Four ozonesondes launched at the same time (GSFC and UMBC parallel) on 29 June 2018. All new ozonesondes.

The GSFC sonde with the "NOAA" SST is lower than the other sondes that use the "standard" sensing solution

Other tests, e.g., Hilo SHADOZ launch (4/18) have shown the opposite!

Bottom Line: Need more statistics from field tests of differing O_3 sensing solutions



Ozonesonde O_3 partial pressure profiles compared to coincident MLS O_3 partial pressure profiles

SUMMARY AND CONCLUSIONS

- **Current SHADOZ practices, w/ WMO/GAW or NOAA SST, give excellent results vs JOSIE Reference.**
  - JOSIE-SHADOZ confirms that SHADOZ user community goal of ≥5% accuracy, minimum station bias has been met
  - WMO/GAW (3% higher than Reference) & NOAA low-buffer (3% lower) offsets resemble JOSIE-2000, BESOS field tests
  - Partnering and capacity building in JOSIE and SHADOZ ➔ have sustained long-term sonde records of high quality

- **SHALLOTS 2018 results confirm JOSIE-SHADOZ findings on offset of WMO vs NOAA SST and instrument type.**
  - However, results not always consistent.
  - More Lab and Field tests needed for statistics, transfer fcns.

- Activities like **JOSIE-SHADOZ and SHALLOTS are essential aspects of a "global ozonesonde community"** that creates protocols and "Standard Operating Procedures" based on joint experiments & consensus!

Bull. Am. Meteor. Soc., 10.1175/BAMS-D-2017-311-0. January 2019 Issue

OZONESONDE QUALITY ASSURANCE

The JOSIE–SHADOZ (2017) Experience

Anne M. Thompson, Herman G. J. Smit, Jacquelyn C Witte, Ryan M. Stauffer, Bryan J. Johnson, Gary Morris, Peter von der Gathen, Roeland Van Malderen, Jonathan Davies, Ankie Piters, Marc Allaart, Françoise Posny, Rigel Kivi, Patrick Cullis, Nguyen Thi Hoang Anh, Ernesto Corrales, Tshidi Machinini, Francisco R. da Silva, George Paiman, Kennedy Thiong'o, Zamuna Zainal, George B. Brothers, Katherine R. Wolff, Tatsumi Nakano, Rene Stübi, Gonzague Romanens, Gert J. R. Coetzee, Jorge A. Diaz, Sukarni Mitro, Maznorizan Mohamad, and Shin-Ya Ogino

As a backbone for satellite algorithms and monitoring stratospheric ozone recovery, ozonesondes require regular evaluation, here performed by operators of the tropical SHADOZ network.

The periodic ozone assessments sponsored by Albritton et al. (1991, 1995), Ajavon et al. (2011, 2015), and related studies have long recognized the role of ozonesondes in the suite of global observations because sondes are the only technique practical for in situ monitoring of profiles. The sonde instrument is easy to deploy in remote locations and is relatively inexpensive. Sondes operate in both the troposphere and stratosphere (see sidebar "Ozone in the Earth's atmosphere") and in clouds, precipitation, and periods of darkness. Most important, as they ascend, ozonesondes measure ozone with an effective resolution of 100–150 m, far better than satellites. Indeed, sondes, like the ground-based networks of lidar, Dobson, and other spectrometers, constitute an essential component of satellite calibration and cross calibration (Fishman et al. 2008; Hubert et al. 2016; Steinbrecht et al. 2017; Tarasick et al. 2018, manuscript submitted to *Elementa*). The vertical structure of ozone as measured at a typical tropical station appears in the "Ozone in the Earth's atmosphere" sidebar, along with background on ozone in the atmosphere. Although dozens of stations began launching ozonesondes in the 1970s and 1980s, the concepts of standardizing and testing instruments in a coordinated network did not evolve until the 1990s (Mohnen 1996; Melamed et al. 2015). This was the period when both JOSIE and SHADOZ began (see the appendix for a list of key acronyms used in this article).

Over 50 years of ozonesonde data taking, there have been several instrument designs. Furthermore, as instruments have changed and preparation and data-processing techniques have evolved over time, time series of data from individual stations often display discontinuities and gaps that lead to inhomogeneous data records. Thus, the reliability of ozonesonde trends was questioned in some of the earlier ozone assessments (Albritton et al. 1991, 1995; Harris et al. 1998).

THANK YOU FOR YOUR ATTENTION!

Acknowledgments & References

- **Support from NASA Upper Atmos Res. Program & Aura (K. Jucks), NOAA. JOSIE & O_3-DQA sponsored by WMO UNEP for Vienna Convention Trust Fund for JOSIE-SHADOZ.**
- **ALL SHADOZ Co-Is, STATION OPERATORS. FZ-J WCCOS Chamber Staff.**

Special thanks to:

GLOBAL ATMOSPHERE WATCH

UNEP

- Smit, H. G. J. and the Panel for ASOPOS (2014), Quality assurance and quality control for ozonesonde measurements in GAW, World Meteorological Organization, GAW Report #201, available at: http://www.wmo.int/pages/prog/arep/gaw/documents/ FINAL_GAW_201_Oct_2014.pdf.
- Smit, H. G. J., et al., Assessment of the performance of ECC-ozonesondes under quasi-flight conditions in the environmental simulation chamber….. (JOSIE), *JGR*, 112. D19306, doi: 10.1029/ 2006JD007308, 2007.
- Sterling, C. W., B. Johnson, et al., Homogenizing and estimating the uncertainty in NOAA's long-term vertical ozone profile records measured with the electrochemical concentration cell ozonesonde, *Atmos. Meas. Tech.*, amt-2017-397, 2018.
- Sullivan, J. T., et al., Bull. Am. Meteor. Society, doi.org/10.1175/BAMS-D-18-0025, 2018.
- Thompson, A. M., et al., First reprocessing of Southern Hemisphere ADditional OZonesondes (SHADOZ) profile records (1998-2016) 2: Comparisons with satellites and ground-based instruments, *JGR*, 122, doi: 10.1002/2016JD027406, 2017.
- Thompson, A. M., H. G. J. Smit et al., *Bull. Am. Meteor. Soc., doi:/ BAMS-D-* 2017-311-0, 2018.
- Witte, J. C., et al., First reprocessing of Southern Hemisphere ADditional OZonesondes (SHADOZ) profile records (1998-2015) 1: Methodology and evaluation, *JGR*, 122, doi: 10.1002/2016JD026403, 2017.
- Witte, J. C., et al., First reprocessing of Southern Hemisphere ADditional OZonesondes (SHADOZ) profile records. 3. Uncertainty in ozone profile and total column, *JGR*, 123, doi: 10.1002/ 2017JD027791, 2018.

Why a JOSIE-SHADOZ? Impacts of Sonde Variations

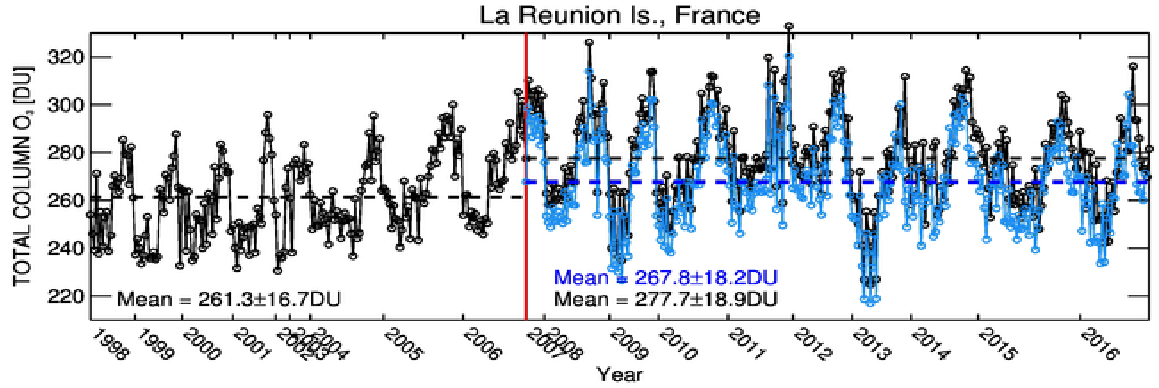
Reprocessed SHADOZ data, designed to "homogenize" 7500+ records to account for instrument and SST <u>motivate</u> JOSIE-2017:

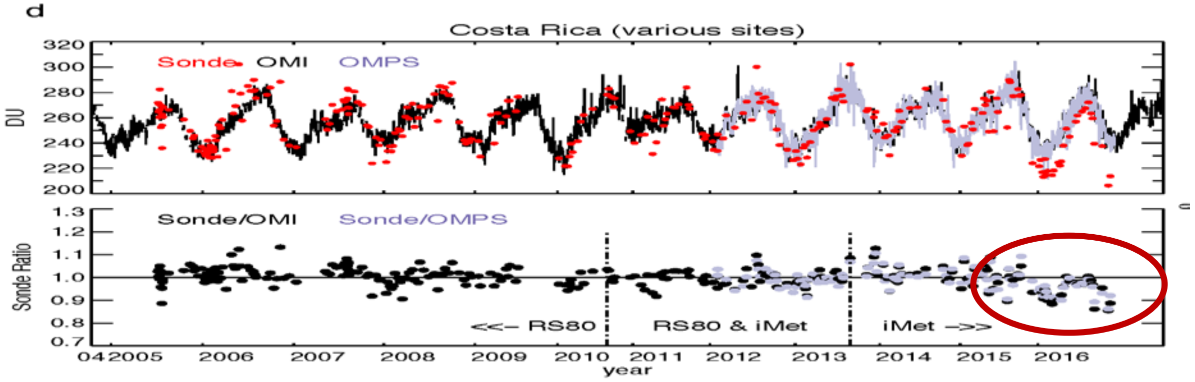
1. Discontinuity associated with **<u>SST change</u>** (**Upper**) is "corrected" post-2006 in reprocessing

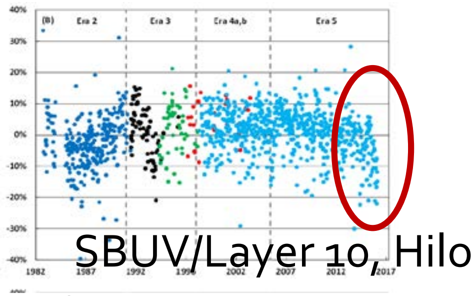
2. Post-2015 total O_3 decline at several stations. Does it originate in EN-SCI **<u>instrument changes?</u>** Costa Rica (**Middle**), Hilo, HI (**Lower**)

➔ JOSIE-SHADOZ evaluated all current instruments and SST used in SHADOZ

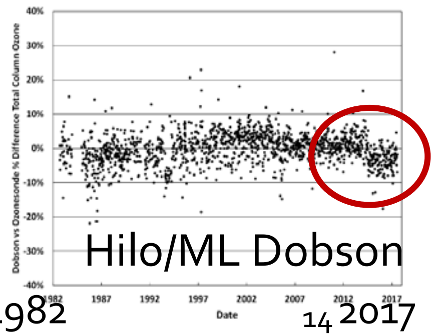
Refs: 1: Witte et al. (2018). 2: Thompson et al. (2017); Sterling et al. (2018).







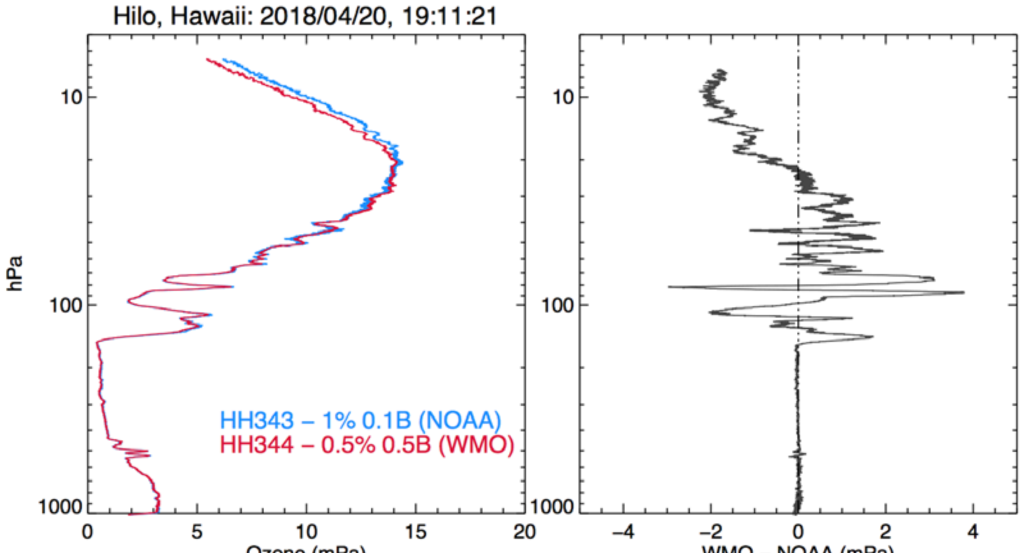
1982 2017

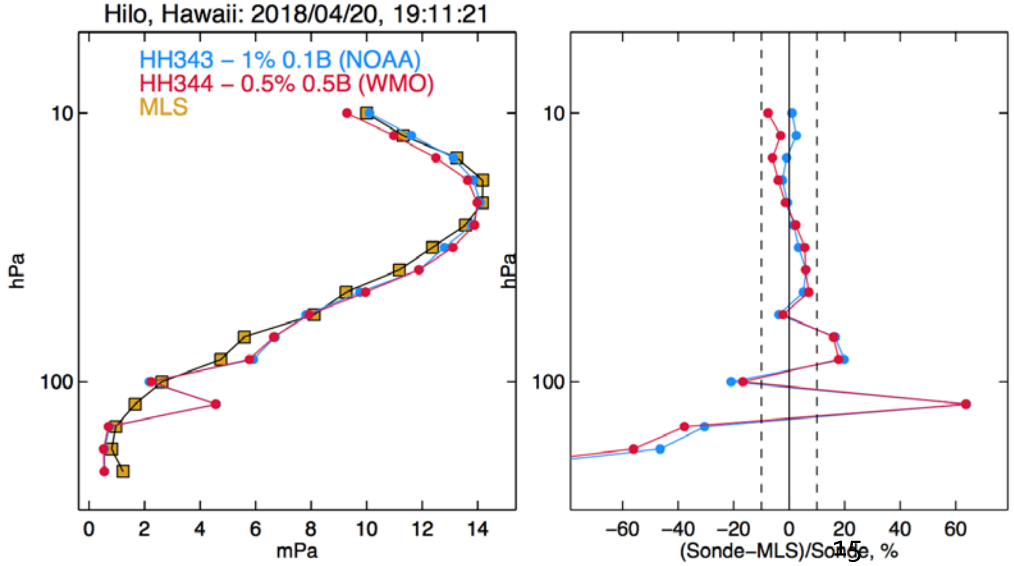


1982 2017

First Post-JOSIE-SHADOZ Field Test (Hilo, HI; April 2018)

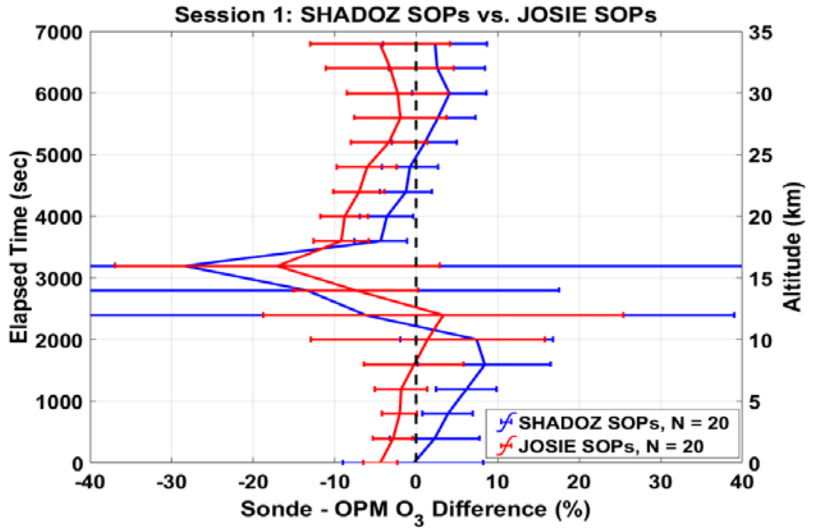
- Solutions prepared by NOAA, same EN-SCI batch
  - Sonde prep, WMO/GAW SST by Anne Thompson, NASA
  - Sonde prep, "NOAA" SST by Bryan Johnson, NOAA
- Opposite result to JOSIE-SHADOZ (2018&)
  - In stratosphere, NOAA (HH343) is slightly higher than NASA (HH344). Offsets shown in Upper panels
  - Similar offsets when compared to MLS, Lower
  - But NASA/WMO O_3 total column agrees better with OMPS satellite than NOAA (within 1 DU vs 4 DU)





Summary of JOSIE-SHADOZ Ozone Results

- Mean "SHADOZ" Total Col. ozone = 3% *Higher than* Ref. Mean "JOSIE/ NOAA" Total Col = 3% *Lower than* Ref. TTL improvement with "JOSIE/NOAA" reduced buffer is offset by reduced response at strat. O_3 maximum (**Upper**)
- How does this compare to JOSIE-2000? Similar! NOAA low-buffer recipe in JOSIE-2000 recorded ~5% less O_3 than WMO/GAW SST (Johnson et al., 2002; Smit et al., 2007; Thompson et al., 2007)
- How do instrument biases with same SST, EN-SCI vs SPC, in JOSIE-SHADOZ compare to JOSIE-2000?
  - For same SST, EN-SCI readings in JOSIE-2000 were ~5% higher than SPC
  - Result confirmed in JOSIE-SHADOZ-2017 (**Lower**)



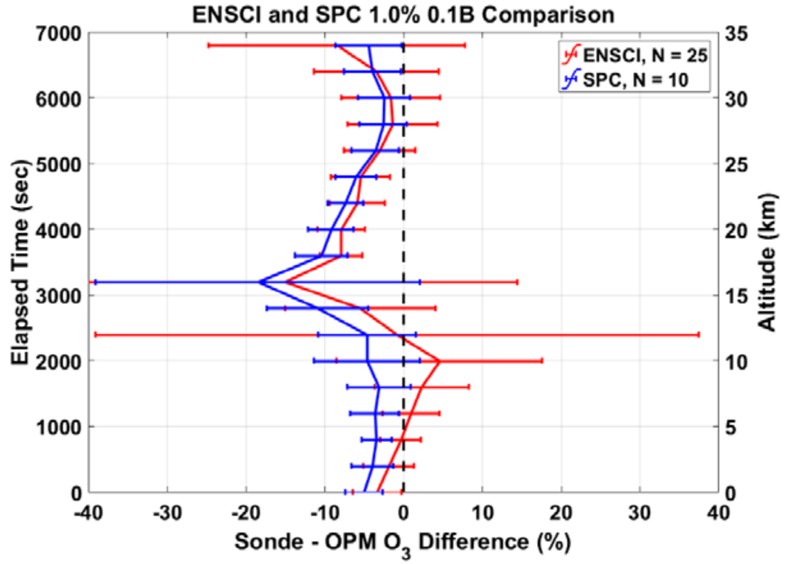


Table 2: SHADOZ stations operating at least 10 years between 1998 and 2017

*Operated Meisei RS II-KC79D radiosonde-ozonesonde system 1992-1999; Vaisala RS80 1998-2013.

Station	Latitude, Longitude	Current ECC Sensor	Current Radiosonde
Pago Pago, Am. Samoa	14.23S, 170.56W	ENSCI	iMet-1
Hilo, Hawaii	19.40N, 155.00W	ENSCI	iMet-1
San Cristobal, Galapagos, Ecuador	0.92S, 89.60W	ENSCI	Vaisala RS92
San Pedro, Costa Rica	9.94N, 84.04W	ENSCI	iMet-1
Paramaribo, Surinam	5.81N, 55.21W	SPC	Vaisala RS92
Ascension Is., U.K	7.98S, 14.42W	ENSCI	iMet-1
Natal, Brazil	5.42S, 35.38W	SPC	Lockheed-Martin-Sippican LMS6
Irene, S. Africa	25.90S, 28.22E	SPC	Vaisala RS92
Nairobi, Kenya	1.27S, 36.80E	ENSCI	Vaisala RS92
La Réunion, France	21.10S, 55.48E	ENSCI	Modem M10
Kuala Lumpur, Malaysia	2.73N, 101.70E	ENSCI	GRAW DFM-09
Hanoi, Vietnam	21.02N, 105.80E	ENSCI	Vaisala RS92
Watukosek-Java, Indonesia	7.57S, 112.65E	ENSCI	---*
Suva, Fiji	18.10S, 178.40E	ENSCI	iMet-1

Participant Number	SST	Operator	Affiliation	Station
		Session 1		
1	1.0% Full Buffer	Tshidi Machinini	South African Weather Service	Irene, South Africa
2	1.0% Full Buffer	Francisco R. da Silva	Brazilian Space Agency	Natal, Brazil
3	0.5% Half Buffer	Kennedy Thiong'o	Kenyan Meteorological Department	Nairobi, Kenya
4	0.5% Half Buffer	Ernesto Corrales	University of Costa Rica	San Pedro, Costa Rica
		Session 2		
5	1.0% Full Buffer	George Paiman	Meteorological Service of Suriname	Paramaribo, Surinam
6	0.5% Half Buffer	Zamuna Zainal	Malaysian Meteorological Department	Kuala Lumpur, Malaysia
7	0.5% Half Buffer	Françoise Posny	Université La Réunion, Météo-France, CNRS	La Réunion Is., France
8	0.5% Half Buffer	Nguyen Thi Hoang Anh	Vietnam Meteorological and Hydrological Administration	Hanoi, Vietnam

Other Operator Participants		
Name	Affiliation	Country
George Brothers	NASA/Wallops Flight Facility	USA
Katherine Wolff	NASA/Wallops Flight Facility	USA
Ryan Stauffer	NASA/Goddard Space Flight Center	USA
Coaches		
Name	Affiliation	Country
Marc Allaart	Royal Netherlands Meteorological Institute	Netherlands
Patrick Cullis	NOAA/Global Monitoring Division	USA
Rigel Kivi	Finnish Meteorological Institute	Finland
Bryan Johnson	NOAA/Global Monitoring Division	USA
Gary Morris	St. Edward's University	USA
Anne Thompson	NASA/Goddard Space Flight Center	USA
Referees		
Name	Affiliation	Country
Jonathan Davies	Environment and Climate Change Canada	Canada
Peter van der Gathen	Alfred Wegener Institute	Germany
Roeland van Malderen	Royal Meteorological Institute of Belgium	Belgium
Other Participants		
Name	Affiliation	Country
Réné Stübi	Federal Office of Meteorology and Climatology MeteoSwiss	Switzerland
Gilbert Levrat		
Gonzague Romanens		
Greg Kok	ENSCI	USA
Nakano Tatsumi	Japan Meteorological Agency	Japan
Jacquelyn Witte	NASA/Goddard Space Flight Center	USA

All Tables from Thompson, Smit et al, *Bulletin of Am. Meteor. Soc.*, ***doi:/ BAMS-D-* 2017-311-0, in press, 2018. Jan. 2019 issue.**