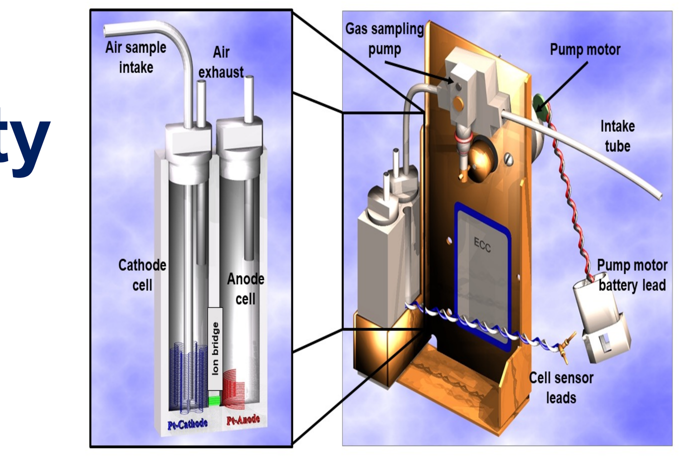
# Quality Assurance of the Global Ozonesonde Network: A Continuous Process of Reporting and Assessing the Sondes Measurement Quality on their Consistency and Uncertainties


Herman G.J. Smit[1], Anne M. Thompson[2], Roeland Van Malderen[3], Ryan M. Stauffer[2], David W. Tarasick[4], Bryan J. Johnson[5], Holger Vömel[6], Jonathan Davies[4], Gary Morris[5] and Debra Kollonige[2]

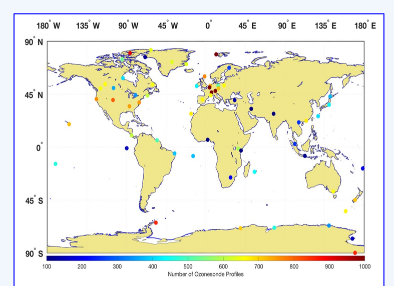
[1] Forschungszentrum Jülich, ICE-3, 52425-Jülich, Germany (Email: h.smit@fz-juelich.de); [2] NASA-Goddard Space Flight Center, USA; [3] Royal Meteorological Institute of Belgium; [4] Environment and Climate Change Canada; [5] NOAA-Global Monitoring Laboratory, USA; [6] NCAR, USA


## Global Ozonesonde Network: Detection Long Term Changes

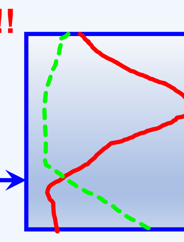
**Use balloon borne Ozonesondes**:

- Based on electrochemical principles
- 2 KI + $O_3$ + $H_2O$ → $I_2$ + $O_2$ + 2 KOH
- Formed $I_2$ is converted into electrical current
- Attached weather radiosonde transmits data to groundstation
- Unique instrument, launched & lost.
- Need standard preparation
- Mid 1990's most common O3S is the ECC Type at about 60 global stations:
  - Two manufacturers (SPC & En-Sci) &
  - Three different sensing solutions types (SST's)
  - Different O3S-SST pairings show systematic differences
  - **On-Going Quality Assurance is Essential !!!**




$$P_{O3} = 0.04307 \cdot \frac{1}{\eta_C} \cdot \frac{T_P}{\Phi_P} \cdot (I_M - I_B)$$

Ozone Pressure [mPa]; Pump Temperature [K]; Conversion Efficiency; Pump Flow [cm3/s]; Background Current [μA]; Measured Current [μA]



## The Three Pillars Of Quality Assurance

| Sonde Characterization & Calibration | Evaluation & Recommendation | Harmonisation of Sonde Records |
| --- | --- | --- |
|  |  |  |
| **JOSIE** Jülich Ozone Sonde Intercomparison Experiment | **ASOPOS** Assessment for Standard Operating Procedures for Ozone Sondes | **O3S-DQA** Ozone Sonde Data Quality Assessment |

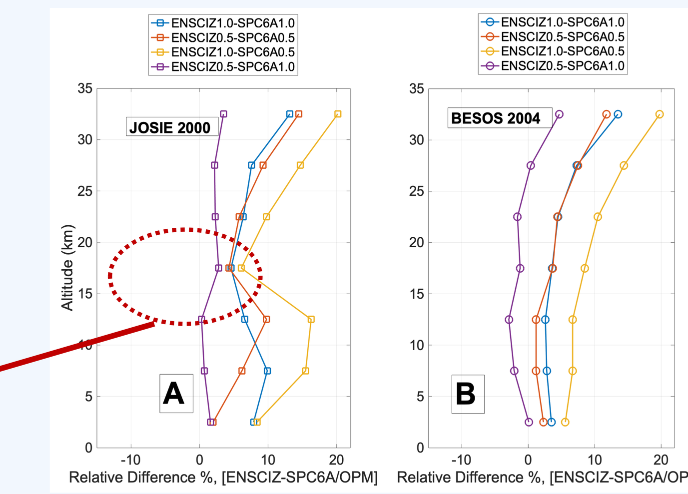
## 2 Different Manufacturers & 3 Different Sensing Solution Types

Comparisons during JOSIE (@WCCOS) and BESOS (Field Campaign):
SPC-6A & ENSCI-Z @ SST1.0 (1.0% & 1.0 Buffer) and @ SST0.5 (0.5% KI & 0.5 Buffer)

**Literature:**

- JOSIE 1996-1998-2000: *Smit et al, JGR, 2007*
- BESOS: *Deshler et al., JGR, 2008*
- JOSIE 2017-SHADOZ: *Thompson et al., BAMS, 2019*
- JOSIE 2009-2010: *Smit et al., AMT, 2024*

**Different Operating Procedures**

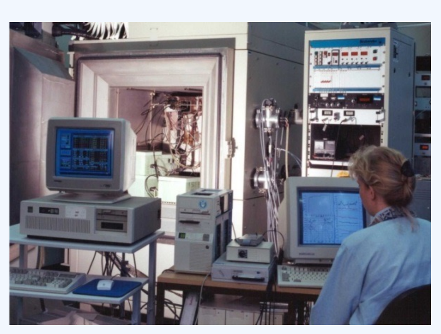


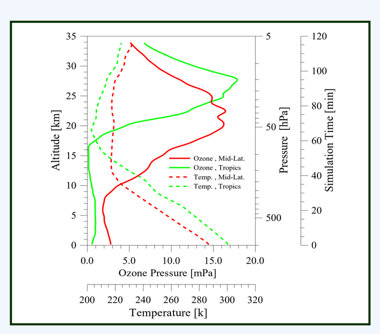

- **Consistent results over more than 25 years**: relative differences with reference (OPM) are varying minimal (< 1-3 %) for SPC-6A @ SST1.0 or ENSCI-Z @ SST0.5
- BESOS: **Precision of ECC-O3 sondes can be 3 % when strictly the same SOP's are used,** which is consistent over time as also observed in JOSIE 1998, 2000, 2009/2010
- JOSIE: When not same SOP's then a lower precision is the limiting factor in the troposphere only 5-10 % overall uncertainty can be achieved, particularly limited in UT in the tropics.

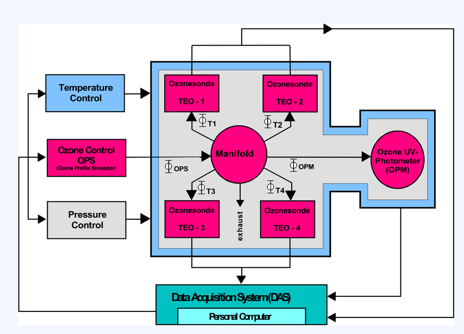
## WMO/GAW-WCCOS & JOSIE: Characterization & Calibration

**WCCOS** World Calibration Center for Ozone Sondes

**JOSIE** Jülich Ozone Sonde Intercomparion Experiment








- The facility enables control of pressure, temperature and ozone concentration and can simulate ozone soundings to Z=35 km with an ascent rate of 5 m/s.
- Different types of ozone-pressure-temperature profiles (e.g. polar, mid-latitude, tropical etc.).
- Enables downward and upward ozone step response tests.
- Four sondes can be "flown" in the simulation chamber simultaneously.
- Dual beam UV-photometer serves as a reference (uncertainty better than ± 3-5 %).

## ASOPOS 2.0: Evaluation Best Practices (2016-2021)

**Base for ASOPOS 2.0:**

- ❑ Results JOSIE 2009/2010
- ❑ Results Homogenisation ( O3S-DQA )
- ❑ Results JOSIE 2017-SHADOZ

**All based on peer reviewed literature:**

**A.) on Homogenisation:**

- Tarasick et al., *AMT, 2016*
- Van Malderen et al., *AMT, 2016*
- Witte et al., *JGR 2017, 2018-A &-B, 2019*
- Thompson et al., *JGR, 2017*
- Deshler et al., *AMT, 2017*
- Sterling et al., *AMT, 2018*
- Ancellet et al., *AMT, 2022*
- ……….and still ongoing……….

**B.) on O3S Performance:**

- JOSIE 2017-SHADOZ: *Thompson et al., BAMS, 2019*
- Uncertainty Budget: *Tarasick et al., ESS, 2021*
- Correction fast & slow time response: *Voemel et al., AMT, 2020, Smit et al., AMT, 2024.*
- TCO-Drop : *Stauffer et al., GRL, 2020; ESS, 2023.*
- Pump efficiency: *Nakano and Morofuji, AMT, 2023*


**ASOPOS 2.0** Assessment for Standard Operating Procedures for Ozone Sondes

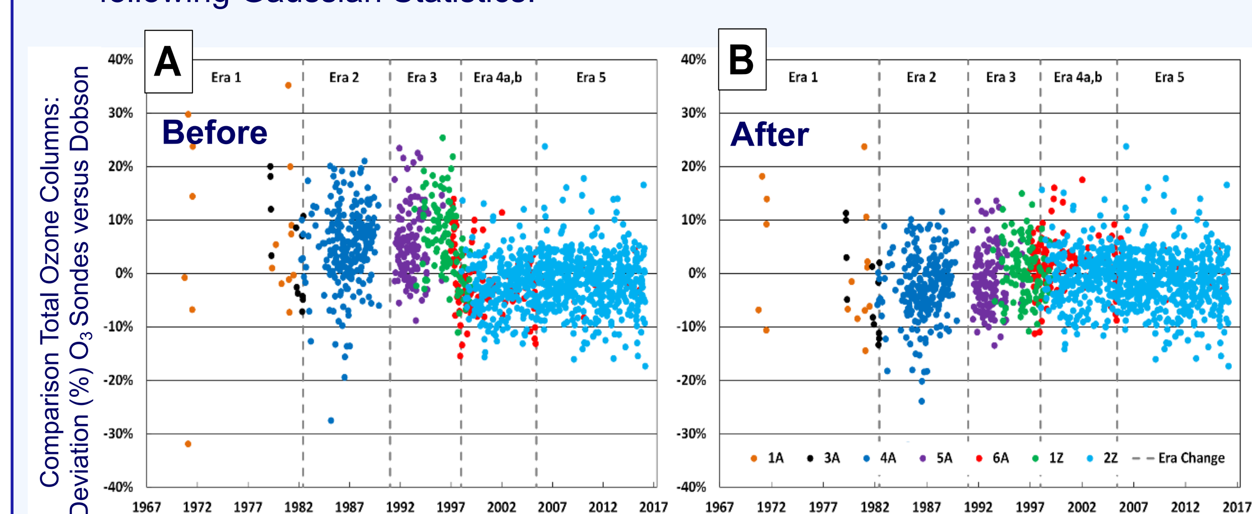
**Editors: Herman Smit (FZJ,Germany ) & Anne Thompson (NASA, USA)**

**Lead Authors**: Herman Smit, Anne Thompson, Bryan Johnson (NOAA, USA),Debra Kollonige (NASA, USA), Gary Morris (St.Edwards Univ., USA), Ryan Stauffer (NASA, USA), David Tarasick (ECCC, Canada), Peter von der Gathen (AWI, USA), Roeland Van Malderen (RMI, Belgium), Holger Voemel, NCAR, USA), Jacquelin Witte (NCAR, USA), Richard Querel (NIWA, New Zealand), Jonathan Davies (ECCC, USA), Patrick Cullis (NOAA, USA)

**Reviewers**: Maria del Carmen Cazorla (Univ.San Frisco de Quito, Ecuador), Gert Coetzee (SAWA, South Africa), Masatomo Fujiwara (Hokkaido Univ., Japan), Samuel Oltmans (NOAA, USA), Wolfgang Steinbrecht (DWD, Germany) Matthew Tully (BOM, Australia)

## O3S-DQA:Homogenisation of O3S Records

1. Homogenisation of long-term ozonesonde records in the global network
2. Correction of all known bias-effects (e.g. changes of SST, location $T_{pump}$)
3. Determination of uncertainty budget for each ozonesonde measurement following Gaussian Statistics.




**NOAA/Boulder:** ***Sterling et al., AMT, 2018***

Overall uncertainty of long term O3S records improved from 10-20% down to 5-10%

## ECC-Current: Resolving Fast & Slow Component

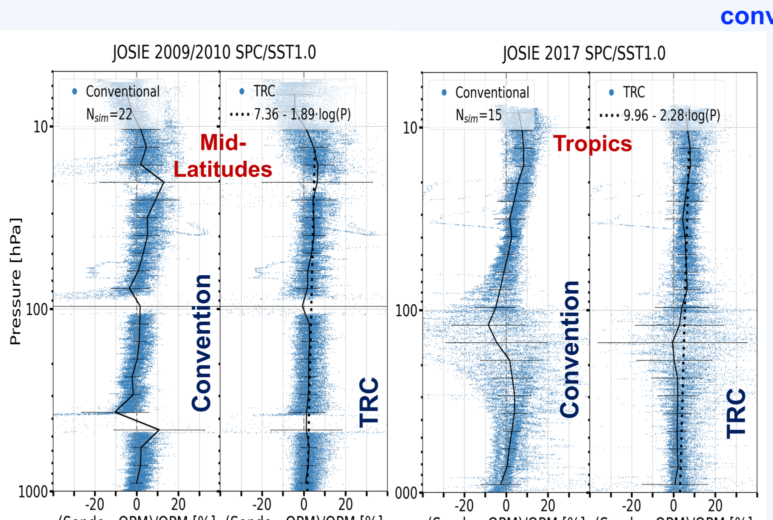
*Tarasick et al., ESS, 2021; Voemel et al., AMT, 2020; Smit et al., AMT, 2024*

**Conventional**

- Measured cell current $I_M(t) = I_{O3}(t) + I_{B1}$
- $I_{O3}(t) = I_M(t) - I_{B1}$
- Improper Komhyr pump efficiency (K86/K95)
- Constant background current $I_{B1}$ correction
- Constant conversion efficiency (GAW No.268): $\eta_C$=1.0

**Time Responses Correction (TRC)**

- $I_M(t) = I_{Fast}(t) + I_{Slow}(t) + I_{B0}$
- $I_{O3}(t) = I_{Fast}(t) = I_M(t) - I_{Slow}(t) - I_{B0}$
- Correct pump efficiency (Nakano et al., 2023)
- Constant background current $I_{B0}$ correction
- Resolving $I_{slow}(t)$ and $I_{Fast}(t)$ with a numerical convolution and deconvolution scheme resp.




**TRC Compared to Conventional:**

- Large reduction of relative differences around response time intervals.
- **Independent of past ozone exposure.**
- Slightly linearly increasing bias with decreasing $Log_{10}$(pressure) (dotted line) = **Conversion Efficiency $\eta_C$.**
- Bias is independent of ozone profile: **Introduction of Calibration Functions.**

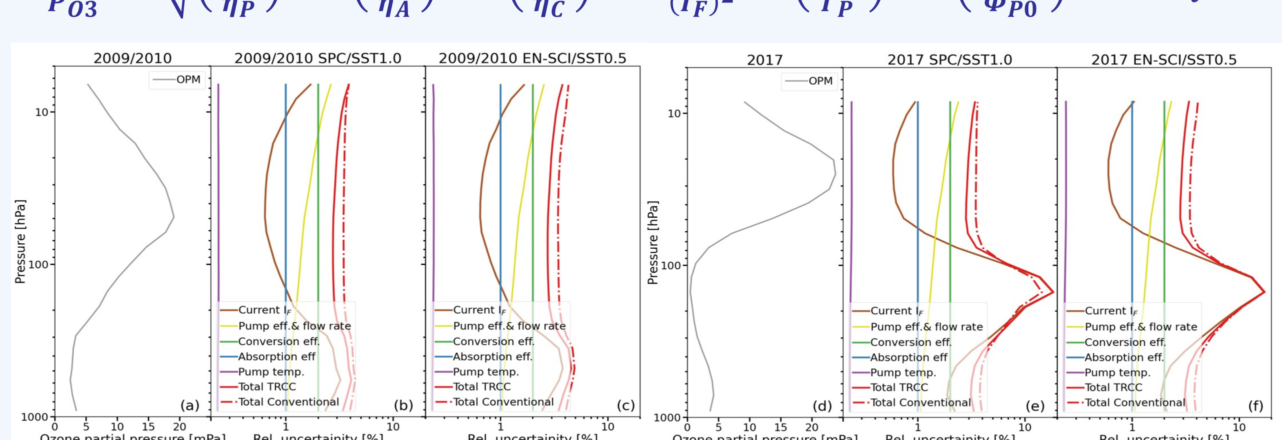
## Uncertainty Budget

**Basic ECC Formula:**

$$I_F(t) = I_M(t) - I_S(t) - I_{B0} \qquad P_{O3} = 0.043085 * \frac{T_P}{(\eta_P * \eta_A * \eta_C * \Phi_{P0})} * I_F$$

**Gaussian Error Propagation:**

$$\frac{\Delta P_{O3}}{P_{O3}} = \sqrt{\left(\frac{\Delta\eta_P}{\eta_P}\right)^2 + \left(\frac{\Delta\eta_A}{\eta_A}\right)^2 + \left(\frac{\Delta\eta_C}{\eta_C}\right)^2 + \frac{(\Delta I_F)^2}{(I_F)^2} + \left(\frac{\Delta T_P}{T_P}\right)^2 + \left(\frac{\Delta\Phi_{P0}}{\Phi_{P0}}\right)^2 + \sum \varepsilon_i^2}$$




- Background current ($I_{B0} + I_{Slow}(t)$) in the troposphere and conversion efficiency in the stratosphere are the dominant uncertainty sources

## QA/QC Is An On-Going Process

**New ozonesonde data format (GEOMS-HDF format) for all O3S data archives:**

Leading principle of the new ozonesonde data format is that ***each stored $P_{O3}$-measurement*** of the ozonesonde data is traceable and consists of:

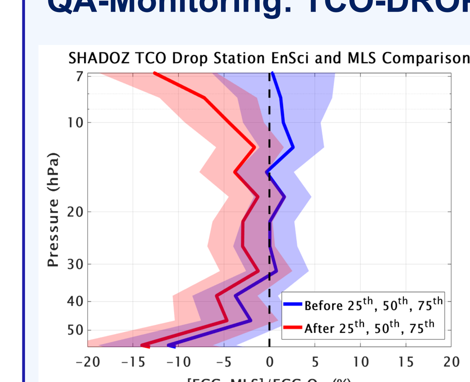
***A. Measured value*** as obtained following the SOPs of the ozonesonde

***B. Uncertainties*** in same physical quantity as measured value.

***C. Flag Code Scheme:*** state of processing/validation/reliability (NRT, L1, L2..)

***D. Meta Data: essential and required for reprocessing***

**QA-Monitoring: TCO-DROP: O3S Stations EN-Sci versus MLS**




*Stauffer et al.( GRL, 2020 & ESS, 2022)*

- Reprocessing (resolving artifacts) have reduced the number of stations suffering the TCO Drop
- However, continuous QA monitoring is essential to alert for outliers in the network in-time.
- NRT Data provision essential for the future
- **QA-Manufacturer, QA-SOP's, QA-Capacity building, QA-Data storage are essential to guarantee the high quality and reliability of long term ozonesonde data**