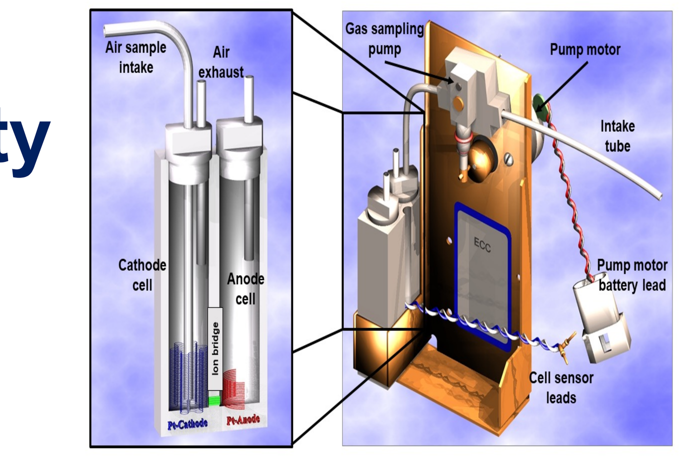
Quality Assurance of the Global Ozonesonde Network: A Continuous Process of Reporting and Assessing the Sondes Measurement Quality on their Consistency and Uncertainty Budget



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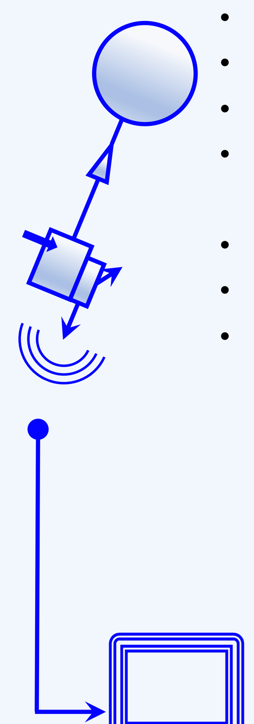
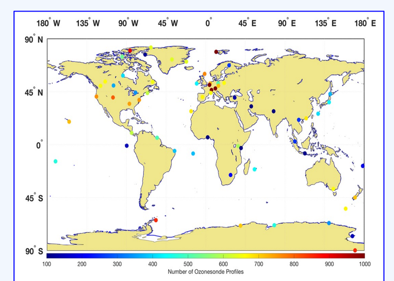
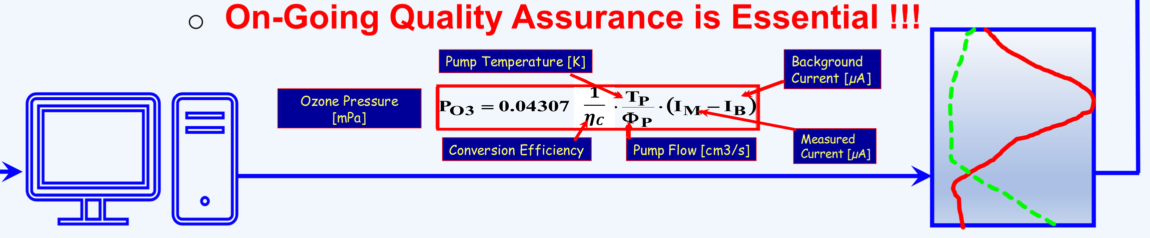
Global Ozonesonde Network: Detection Long Term Changes





Use balloon borne Ozonesondes:

- Based on electrochemical principles
- $2\,KI + O_3 + H_2O \rightarrow I_2 + O_2 + 2\,KOH$
- 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 !!!**



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

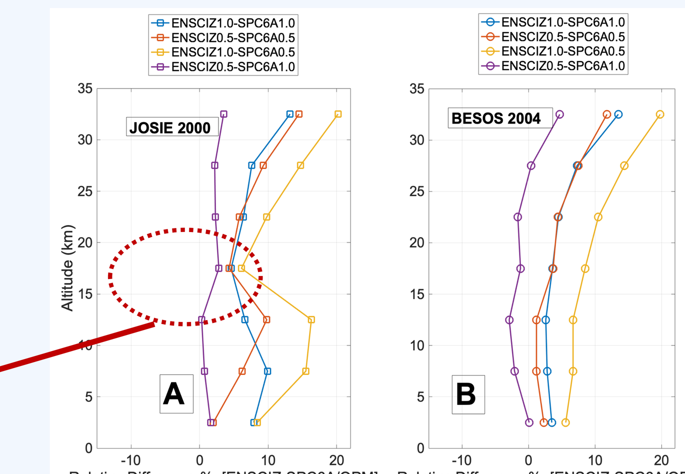
2 Different Manufacturers & **3** Different Sensing Solution Types

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*

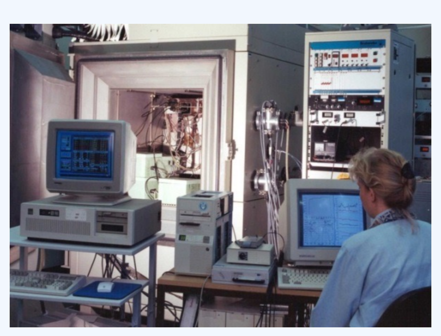
Different Operating Procedures

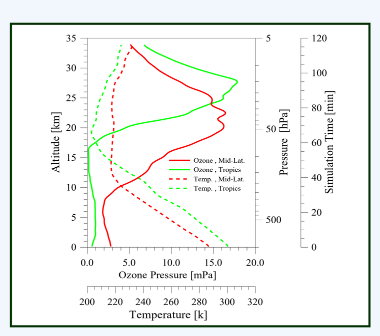


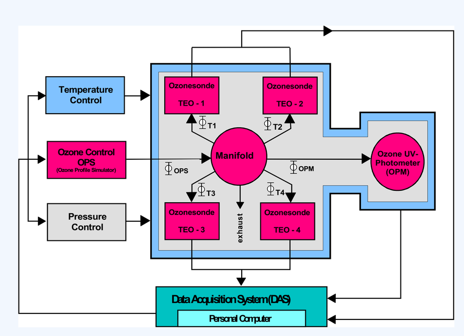
- ➢ **Consistent results over more than 25 years**: relative differences with reference (OPM) are varying minimal (< 1-3 %) for SPC-6A @ SST1.0 or ENSCI-Z @ SST0.5
- ➢ BESOS: **Precision of ECC-O3 sondes can be 3 % when strictly the same SOP's are used,** which is consistent over time as also observed 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	JOSIE
World Calibration Center for Ozone Sondes	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)

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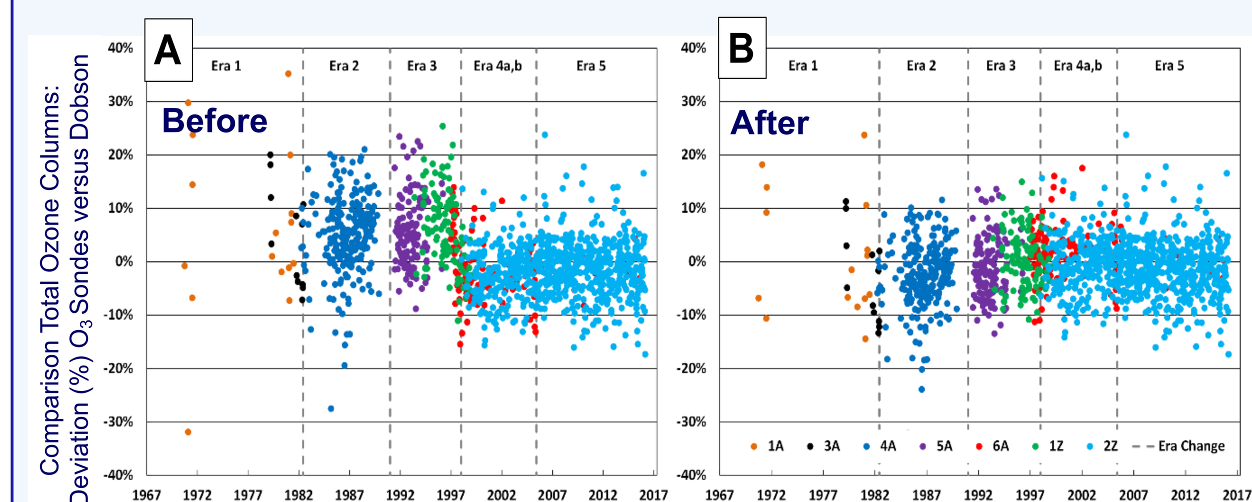
O3S-DQA:Homogenisation of O3S Records

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

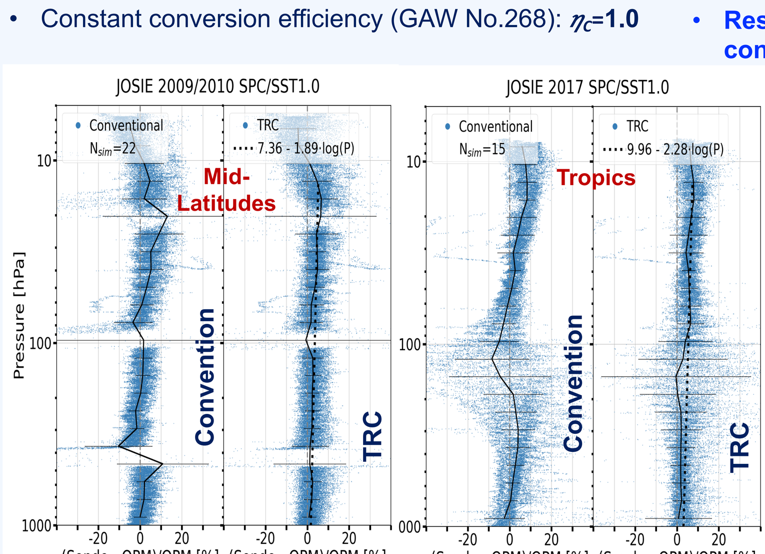
Tarasick et al., ESS, 2021; Voemel et al., AMT, 2020; Smit et al., AMT, 2024

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): η_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 nume rical 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 η_C.**
- ➢ Bias is independent of ozone profile: **Introduction of Calibration Functions.**

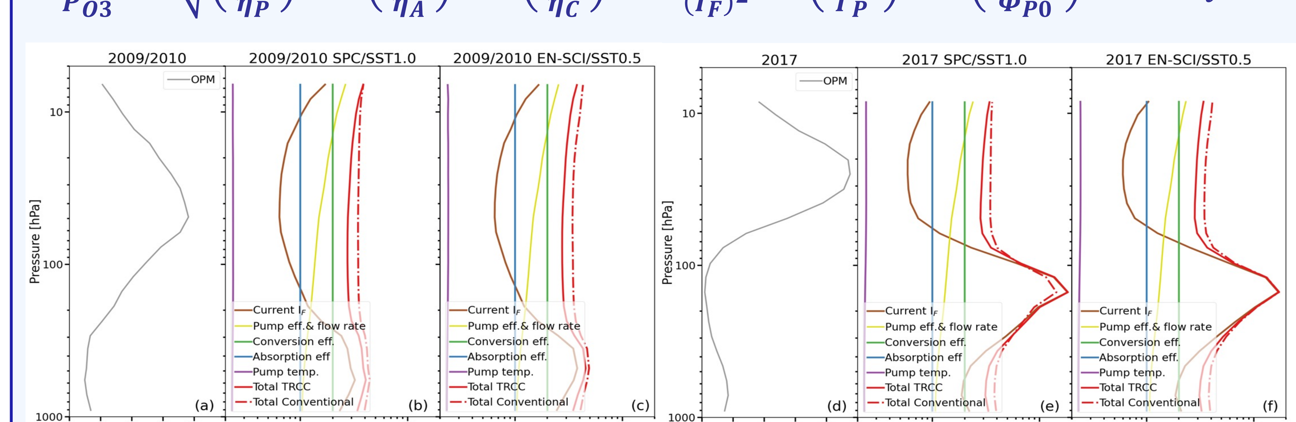
Uncertainty Budget

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

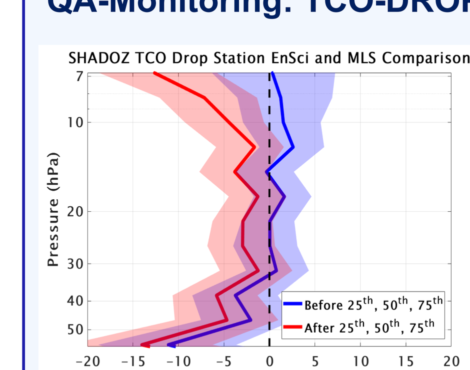
QA/QC Is An On-Going Process

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**