Ground-based total column ozone instrument calibration

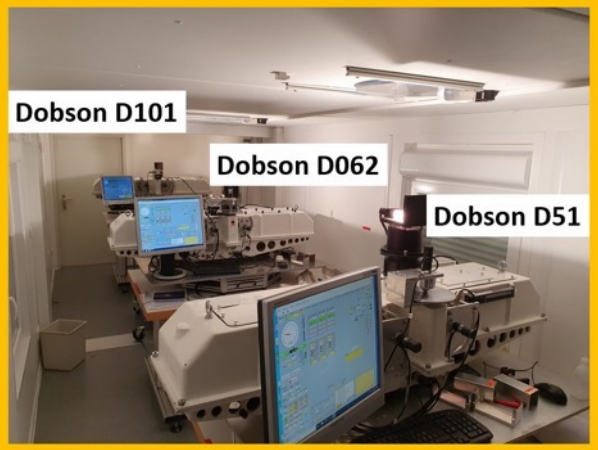
Luca Egli[1] *, Julian Gröbner*[1] *Herbert Schill*[1] *and Eliane Maillard Barras*[2]

[1] *Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center, Davos, Switzerland*

[2]*MeteoSwiss, Payerne, Switzerland*

pmod wrc

TCO Instrument park at PMOD/WRC



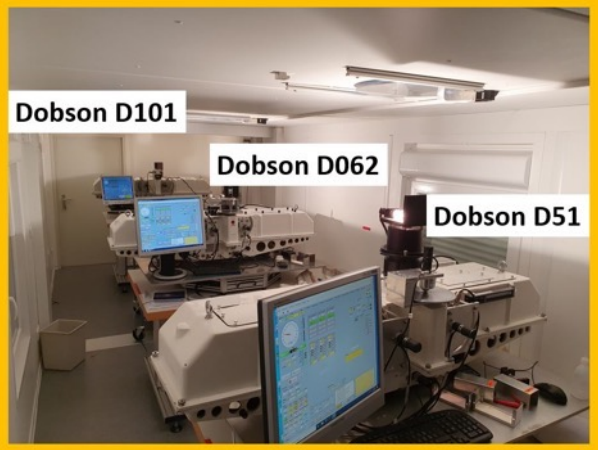
10 instruments:

- 3 Dobsons (automated) from MeteoSwiss
- 4 Brewers (3 MeteoSwiss and 1 PMOD/WRC)
- QASUME for traceable TCO measurements
- KOHERENT array spectroradiometer based instrument
- Pandora P120

Arosa/Davos timeseries started in 1926 (longest TCO timeseries)

pmod wrc

TCO Instrument park at PMOD/WRC



Our task for QA4EO:

Providing the best possible **calibration, traceability and validation** of the ground based TCO measurements in Davos.

Mainly four years of operation and data for QA4EO (some exceptions)

pmod wrc

Brewers

- **“50 years old instruments” –** maybe not manufactured anymore
- **Daily monitoring** of instrument parameters and validation of TCO data.
- **Immediate trouble shooting** if any inconsistencies occurred.
- **Regular technical** maintenance for prevention of data failure.
- **Calibration** of the extraterrestrial constant and ozone absorption coefficient on a two years schedule in **field campaigns.**
- **Traceable** to the regional/world Brewer reference **Brewer #185** from AEMET Izaña, Spain.

pmod wrc

Results General

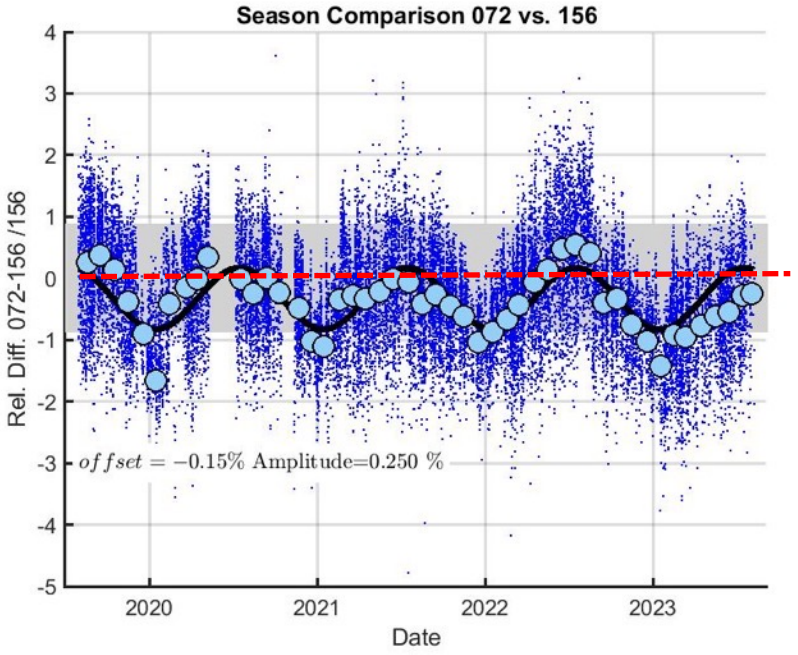
The instrument performance is here always compared with Brewer 156

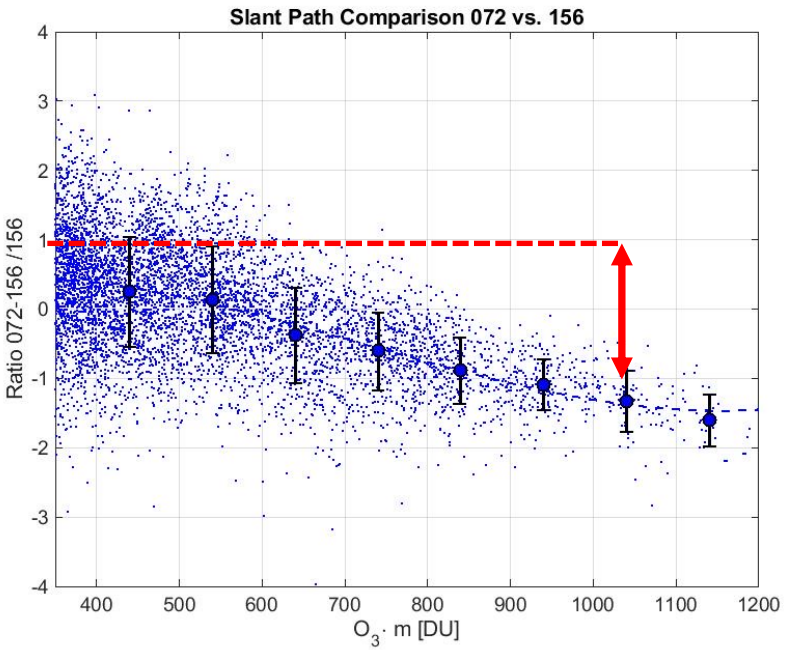
with new ozone cross section for best consistency (Redondas et al. 2018, Gröbner et al. 2021, Voglmair et al. 2024)

Parameters of validation/comparison:

- **Longterm offset** to Brewer 156.
- **Seasonal amplitude** to Brewer 156.
- **Slant path dependency** to Brewer 156 -> **air mass dependency.**

For Example Brewer 072





Results Brewers

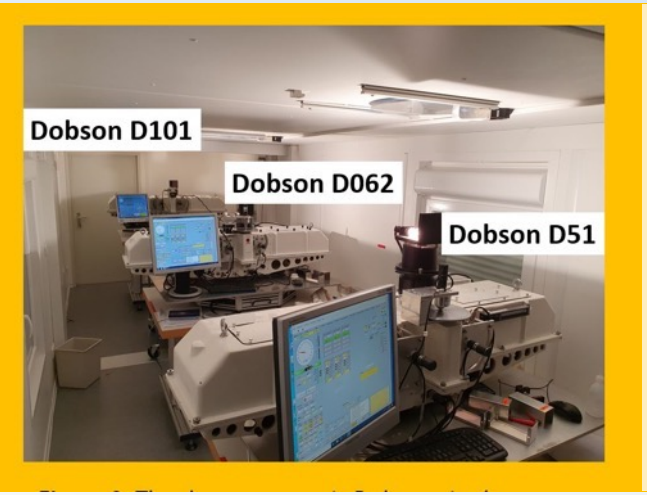
Instrument	Longterm Offset [%]	Seasonal Amplitude [%]	Slant Path (Min-Max) [%]
Brewer 040	-0.29	0.16	1.52
Brewer 072	-0.15	0.25	2.53
Brewer 163	0.21	0.02	0.35

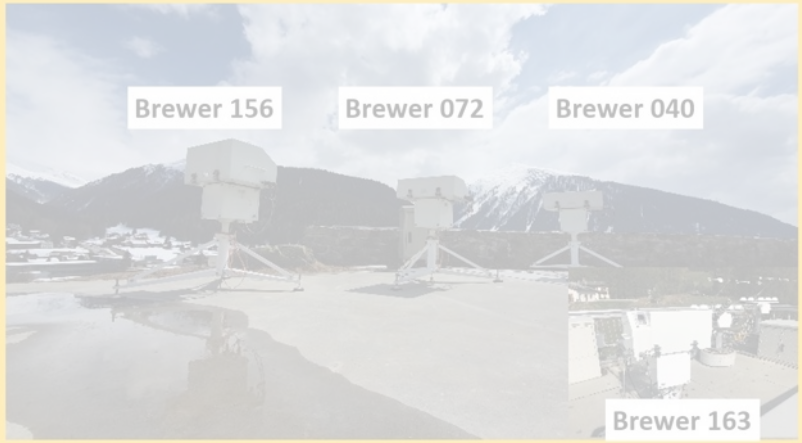
Conclusion:

- **Double monochromator Brewers** show **NO** slant path dependency
- **Single monochromator Brewer** show slant path dependency, **due to stray light**
- **Longterm offset close to zero.**

pmod wrc

Dobsons





- **“100 years old instruments” –** certainly not be manufactured anymore
- **Daily monitoring** of instrument parameters and validation of TCO data.
- Immediate trouble shooting if any inconsistencies occurred.
- Regular technical maintenance for prevention of data failure.
- **Calibration** of the extraterrestrial constant on a **five** years schedule in **field campaigns.**
- **Traceable** to the regional Dobson **reference Dobson #064** from DWD Hohenpeissenberg, Germany.

pmod wrc

Results Dobsons

Instrument	Longterm Offset [%]	Seasonal Amplitude [%]	Slant Path (Min-Max) [%]
Dobson 051	0.04	0.23	2.01
Dobson 062	0.24	1.23	3.89
Dobson 101	0.06	0.17	1.42

Conclusion:

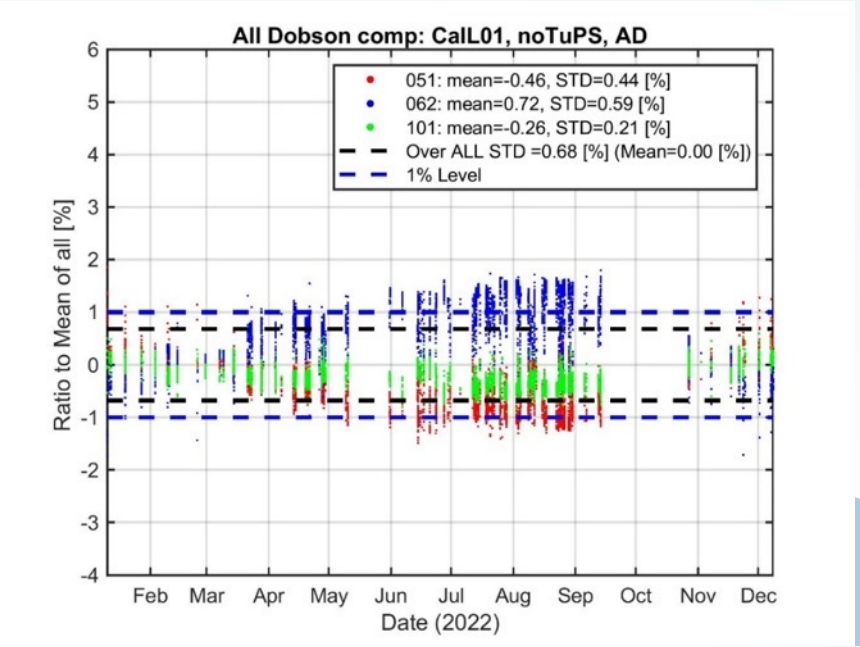
- **Longterm offset close to zero.**
- **Slant path dependency** similar as Brewer single double monochromator.
- Problem with D062

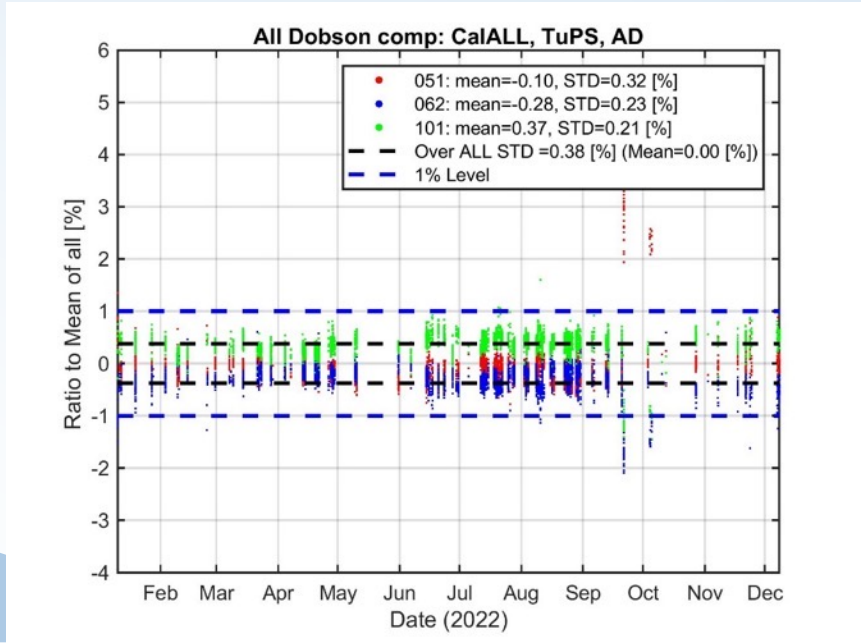
pmod wrc

Results Dobsons

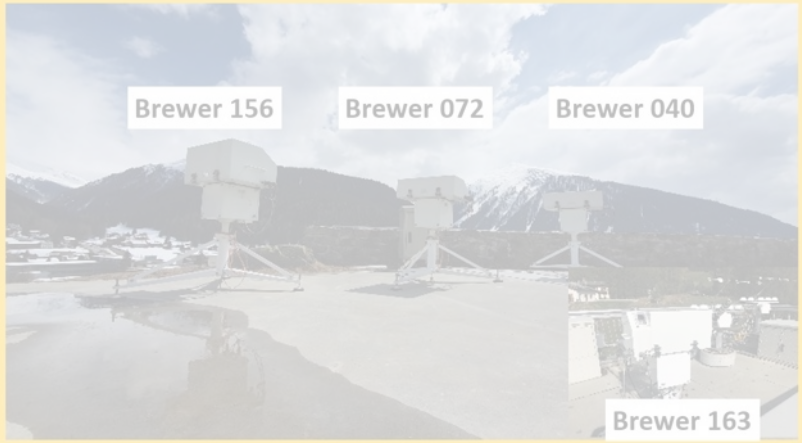
Instrument	Longterm Offset [%]	Seasonal Amplitude [%]	Slant Path (Min-Max) [%]
Dobson 051	0.04	0.23	2.01
Dobson 062	0.24	1.23	3.89
Dobson 101	0.06	0.17	1.42

New calibration constant determined at PMOD/WRC give better results:
Will be compared with official new constants at the Dobson campaign in August 2024





QASUME



- **„The unique instrument“**
- **High quality** direct UV spectra from the portable **world UV reference instrument QASUME** (Gröbner et al. 2005, Hülsen et al. 2016)
- Providing **traceable TCO** measurements directly from the laboratory.
- **No reference instrument** for calibration **needed** (Contrary to Dobson and Brewers).
- Full ozone uncertainty budget: **< 0.8 %**
- New standardized full spectrum TCO retrieval.
- Sporadic measurements at PMOD/WRC when QASUME was not on travel.
- Published in Egli et al. 2022 (AMT).

pmod wrc

QASUME TCO retrieval algorithms

LSF: Least square fit algorithm from direct solar spectra

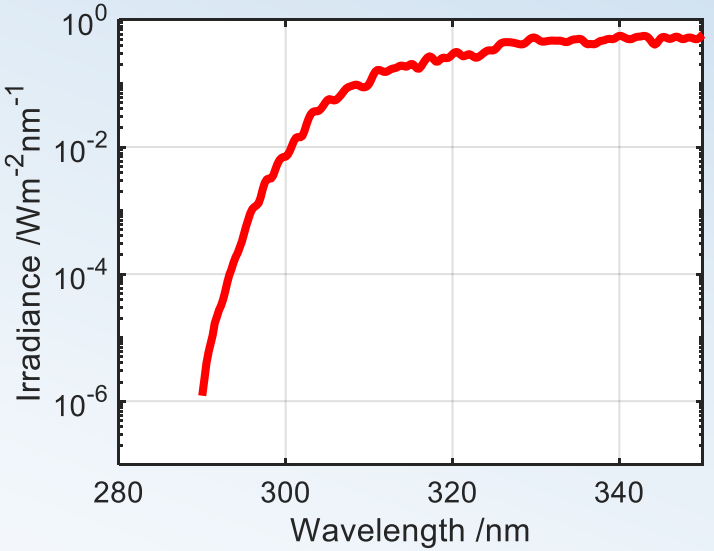
The procedure is based on the Beer-Lambert law

$$I_\lambda = I_\lambda^0 e^{-\tau_\lambda m}$$

We follow the method from **Huber et al., 1995**

Minimizing :

$$\sum_\lambda \left[\frac{I_m(\lambda) - I_c(\lambda, O_3, \tau_0)}{I_m(\lambda)} \right]^2 \Rightarrow \min$$

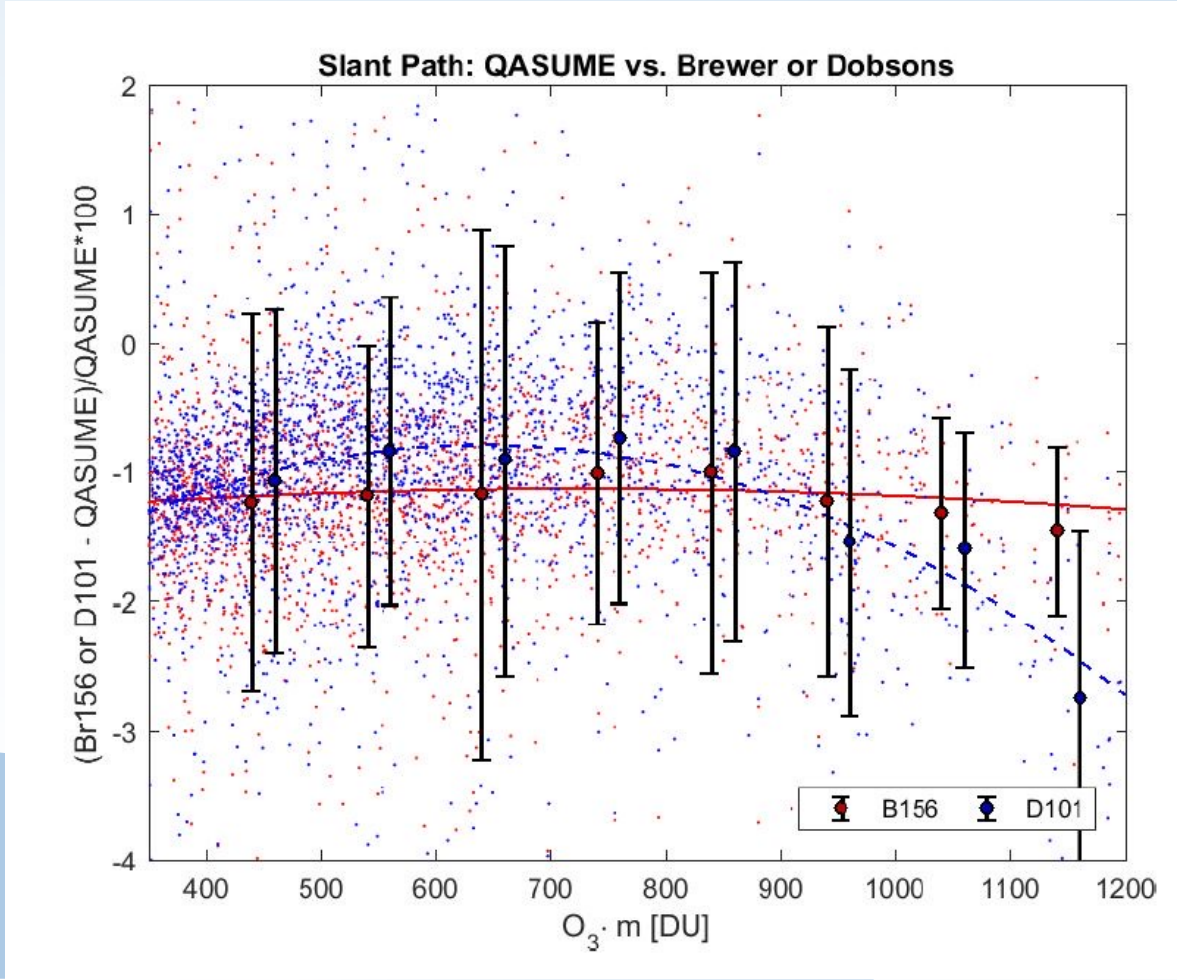


Huber, M., Blumthaler, M., Ambach, W., and Staehelin, J.: **Total atmospheric ozone determined from spectral measurements of direct solar UV irradiance**, Geophys. Res. Lett., 22, 53–56, https://doi.org/10.1029/94gl02836, 1995.

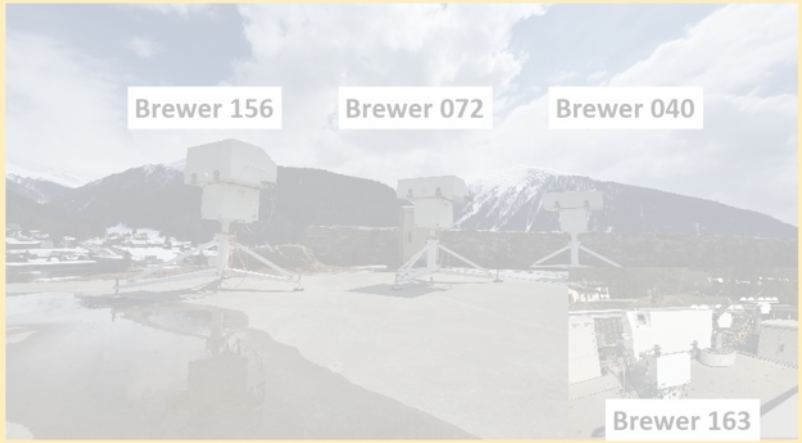
pmod wrc

Results QASUME

Instrument	Longterm Offset [%]	Seasonal Amplitude [%]	Slant Path (Min-Max) [%]
QASUME	1.13	0.22	0.45



Koherent (BTS)



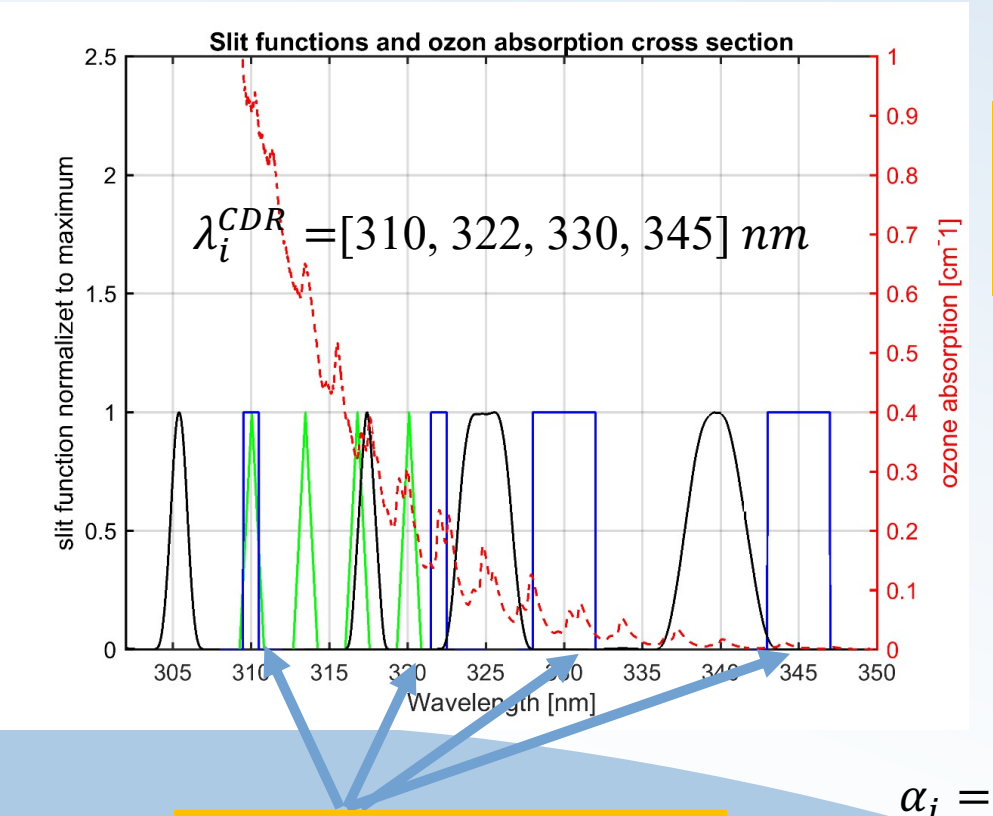
- **“The new player”** (best array spectroradiometer from technical perspective)
- Array Spectroradiometer **BTS2048-UV-S-F from** Gigahertz Optik.
- **Lens-based telescope** coupled with a fiber to the array spectroradiometer.
- **Small, cost effective, robust, low maintenance**, very stable for 5 years.
- Python software on an **embedded computer** for instrument control.
- UV wavelength range: **305 nm – 345 nm.**
- Published in Egli et al 2023 (AMT), Zuber et. al 2021 (AMT).
- Koherent **retrieval algorithm will be user-friendly** available and presented during the RBCC-E and RCDD-E campaign in Davos in August 2024.

pmod wrc

New TCO retrieval algorithm for Koherent

CDR: Custom Double Ratio Technique

In analogy to the **double ratio technique for Brewers** (or Dobsons)



CDR slit functions

Measurement Extraterrestial Solar Spec

$$TCO = \frac{F^{CDR} - F_0^{CDR} - \Delta\beta \cdot m^R}{\Delta\alpha \cdot m^{O3}}$$

Potential calibration constants

$$F^{CDR} = \sum_{i=1}^{4} w_i \cdot log\ I^{CDR}(\lambda_i^{CDR})$$

$$w_i^{CDR} = [+1\ -1\ -1\ +1]$$

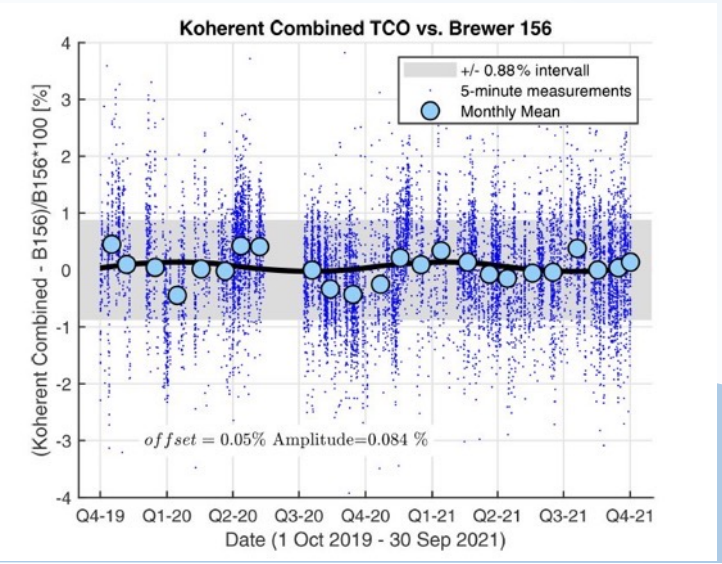
$$\alpha_i = \frac{\int SG14(\lambda, T) \cdot s(\lambda)\ d\lambda}{\int s(\lambda)\ d\lambda}$$

$$\Delta\alpha = 0.751$$

pmod wrc

Results Koherent

Instrument	Longterm Offset [%]	Seasonal Amplitude [%]	Slant Path (Min-Max) [%]
Koherent: LSF 305 nm - 345 nm	0.26	1.17	4.42
Koherent: LSF 310 nm - 345 nm	0.02	0.86	2.18
Koherent: LSF Stray Light Corrected	0.67	0.30	0.46
Koherent: CDR	0.02	0.17	2.13
Koherent: CDR ETC Adjusted	-0.59	0.34	2.12
Koherent: CDR & LSF combined	0.05	0.08	1.62

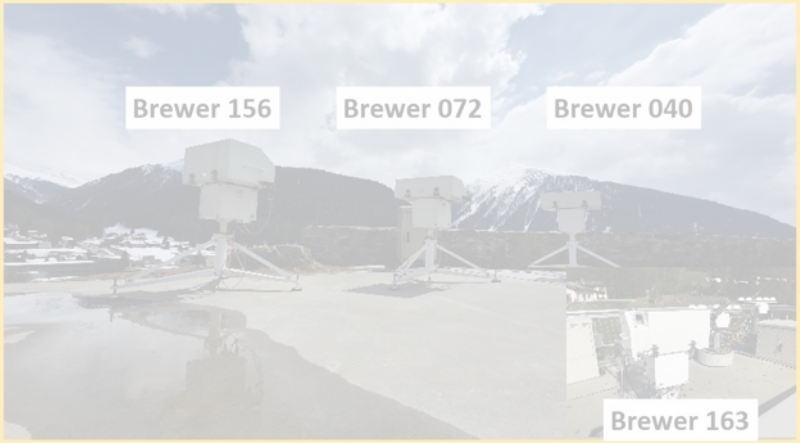


Conclusion:

- **Longterm offset close to zero.**
- **Slant path dependency** similar as Brewer single monochromator (CDR).

pmod wrc

Pandora

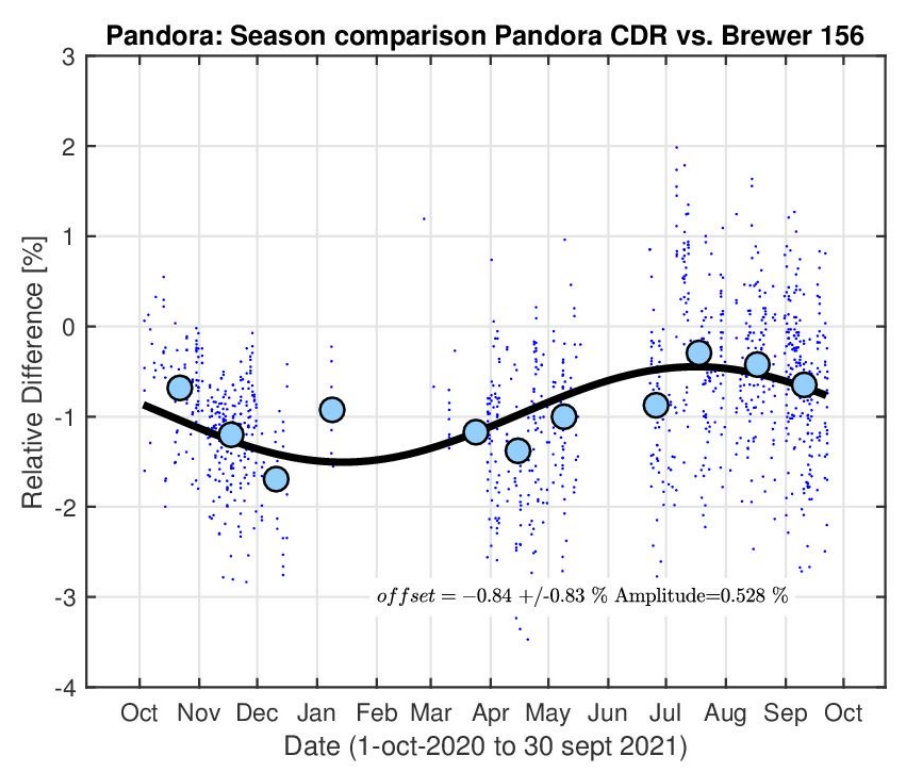


- **“The established array spectroradiometer”**
- P120 from SERCO, Italy.
- Data post processing and TCO delivered by the **Pandonia global network** (www.pandonia-global-network.org)
- “out0” = old TCO output, “out2”= new TCO output.
- Some technical failure at PMOD/WRC.
- Koherent CDR algorithm applied to Pandora spectra.
- CDR algorithm for Pandora with PMOD/WRC calibration.

pmod wrc

Results Pandora

Instrument	Longterm Offset [%]	Seasonal Amplitude [%]	Slant Path (Min-Max) [%]
Pandora “out0”	-0.61	2.5	0.83
Pandora “out2”	-3.87	0.18	0.05
Pandora CDR	-0.84	0.53	2.32
Pandora CDRcal	1.66	0.26	1.46



Conclusion:

- **Slant path dependency** almost **perfect** as a Brewer double monochromator or QASUME.
- Problem with longterm offset.

pmod wrc

Results Summary

Instrument	Longterm	Seasonal	Slant Path
Brewer 040	-0.29	0.16	1.52
Brewer 072	-0.15	0.25	2.53
Brewer 163	0.21	0.02	0.35
Dobson 051	0.04	0.23	2.01
Dobson 062	0.24	1.23	3.89
Dobson 101	0.06	0.17	1.42
QASUME	1.13	0.22	0.45
Koherent: LSF	0.02	0.86	2.18
Koherent: LSF Stray Light	0.67	0.30	0.46
Koherent: CDR	0.02	0.17	2.13
Koherent: CDR ETC Adjusted	-0.59	0.34	2.12
Koherent: CDR & LSF combined	0.05	0.08	1.62
Pandora “out0”	-0.61	2.5	0.83
Pandora “out2”	-3.87	0.18	0.05
Pandora CDR	-0.84	0.53	2.32
Pandora CDRcal	1.66	0.26	1.46
MEAN of ALL (exept grey)	**0.11** (+/- 0.65)	**0.22** (+/- 0.12)	**1.43** (+/- 0.81)

wrc

Conclusion & Outlook

General benchmark for TCO performance with different instruments

For validation of other TCO observation techniques (pragmatic view):

- Longterm offset : < **1%**
- Seasonal Amplitude : < **0.25 %**
- Slant path dependency : < **1.5 %**

pmod wrc

Conclusion & Outlook

General benchmark for TCO performance with different instruments

For validation of other TCO observation techniques (pragmatic view):

- Longterm offset : < **1%**
- Seasonal Amplitude : < **0.25 %**
- Slant path dependency : < **1.5 %**

If your satellite TCO estimation meets these benchmarks you are good.

pmod wrc

Conclusion & Outlook

General benchmark for TCO performance with different instruments

For validation of other TCO observation techniques (pragmatic view):

- Longterm offset : < **1%**
- Seasonal Amplitude : < **0.25 %**
- Slant path dependency : < **1.5 %**

If your satellite TCO estimation meets these benchmarks you are good.

„Not beeing holier than the pope“

pmod wrc

Conclusion & Outlook

Unique dataset

We now have an **unique longterm dataset** measured at Davos to evaluate the performance, traceability and calibration of the **most important ground based TCO instruments**

Outlook:

- Re-calibration of Brewer, Dobsons and Koherent at the regional Brewer and Dobson intercomparison 19 – 28 August 2024 in Davos.

- Re-processing of the data for four years.

- Delivering dataset and final report for QA4EO.

pmod wrc