Sentinel-5P TROPOMI Tropospheric Ozone in the Tropics: Improvements of the Cloud Based Techniques CCD and CSA

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Introduction

- The TROPOspheric Monitoring Instrument (**TROPOMI**) onboard the Sentinel-5 precursor (**S5p**) is part of the Copernicus space component programme. It was launched into a low Earth polar orbit in October 2017. TROPOMI provides information and services on air quality and climate.
- About 90% of the total ozone is located in the stratosphere, which makes tropospheric ozone difficult to measure from space. Different methods dealt with the problem: e.g. the Limb-Nadir matching technique [Eboije, 2013], the Convective Cloud Differential (**CCD**) method [Ziemke, 1998; Valks, 2014], and the cloud-slicing approach (**CSA**) [Ziemke, 2001]. We give you an update of the latest improvements to the IUP Bremen CCD and CSA retrievals.

S5p/TROPOMI data

- S5P level 2 OFFL/RPRO 01.01.07-02.02.01 (May 2018 – August 2021): CRB (clouds as reflecting boundaries) clouds data (CTP, CTH, CF) and GODFIT ozone data (total ozone, ghost column).
- **Fig.1**: OFFL Total ozone (CF<0.2) from 2021/02/01.

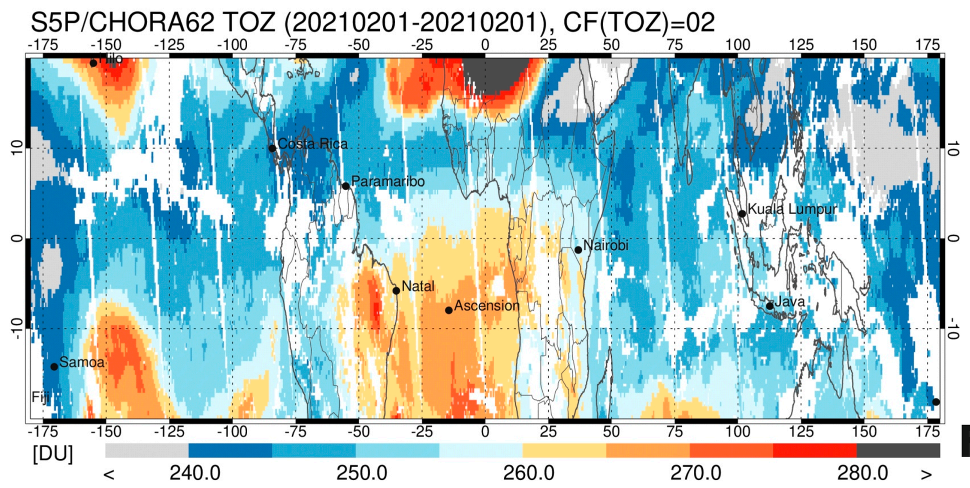


Fig.1

SHADOZ ozone profile

- We used NASA/GSFC SHADOZ V6.0 data from 9 sites: Ascension, Hilo, Costa Rica, Fiji, Kuala Lumpur, Nairobi, Natal, Paramaribo, Samoa.
- Data was taken: https://tropo.gsfc.nasa.gov/shadoz.
- A median VMR was calculated between 5 and 13 km for CHOVA/CSA and the profile was integrated to an ozone subcolumn up to 270 hPa for CHORA/CCD.
- **Fig.2**: SHADOZ ozone profile [0-18 km], measured over Costa Rica on 2020/12/18. The column up to 270 hPa is 15+/+3 DU (CCD), the median VMR between 5 and 12 km is 39+/-13 ppbv (CSA).

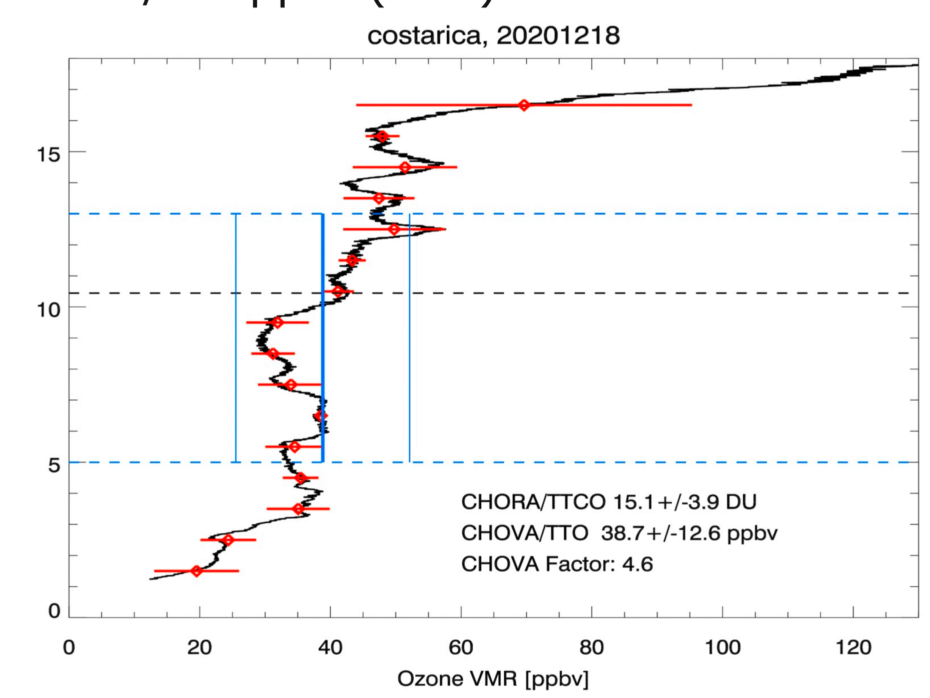


Fig.2

S5p CHOVA V6.4

- The CSA algorithm **CHOVA** (Cloud Height and Ozone Variation Analysis) retrieves volume mixing ratios of Tropical Tropospheric Ozone (**TTO**) [ppbv].
- *A*bove *C*loud *C*olumn *O*zone ($ACCO$, N_{vac}) [DU], derived from total ozone, is correlated to cloud top pressures (CTP, p_{ct}) [hPa]. Assuming a linear ensemble relationship of the two parameters, we calculate the mean ozone volume mixing ratio $<VMR>$ [ppbv] from cloud top pressure Δp_{ct} [hPa] and ozone differences ΔN_{vac} [DU] by Theil-Sen regression storing statistical parameters for quality flagging.
- Optically thick clouds at varying heights above 5.5 km (<550 hPa) and cloud fractions **CF>0.95** are needed with a minimum cloud pressure difference larger than 100 hPa. Sampling grid size is **2°x2°** lati-/longitude.
- **Fig.3** shows the TTO [ppbv], quality controlled, for most of mission life time from May 2018 to September 2021.

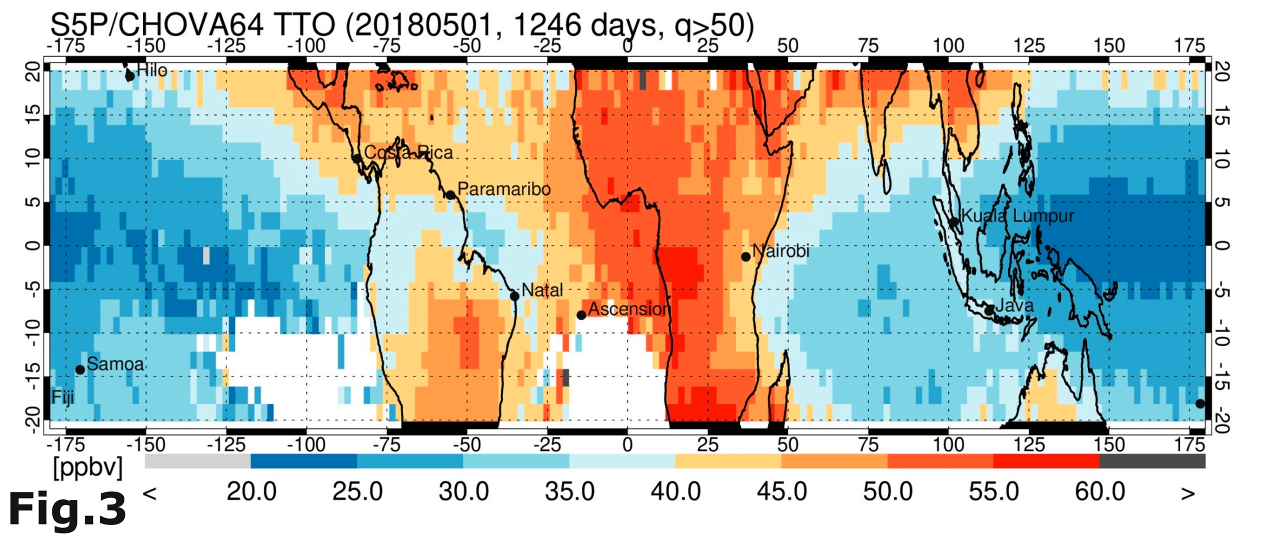


Fig.3

S5p CHORA V6.3

- The CCD algorithm **CHORA-PS** (Cloud Height and Ozone Reference Analysis, Pacific Sector) retrieves Tropical Tropospheric Column Ozone (**TTCO**) [DU] for subcolumns above 270 hPa.
- Measurements of ozone above clouds in the Pacific sector are used to calculate the ACCO daily field for cloud top pressures below 350 hPa.
- Each ACCO(p_{ct}) is height corrected to 270 hPa using the CHOVA VMR climatology.
- TTCO is calculated by subtracting ACCO from daily total ozone measurements under nearly cloud free conditions (**CF<0.2**). Sampling grid size is **0.5°x0.25°** lati-/longitude.
- **Fig.4** shows the high resolution TTCO [DU], centered over the Pacific, for most of mission life time from May 2018 to September 2021. Low columns can be found over Mountain regions (Andes) and the region east of Indonesia.

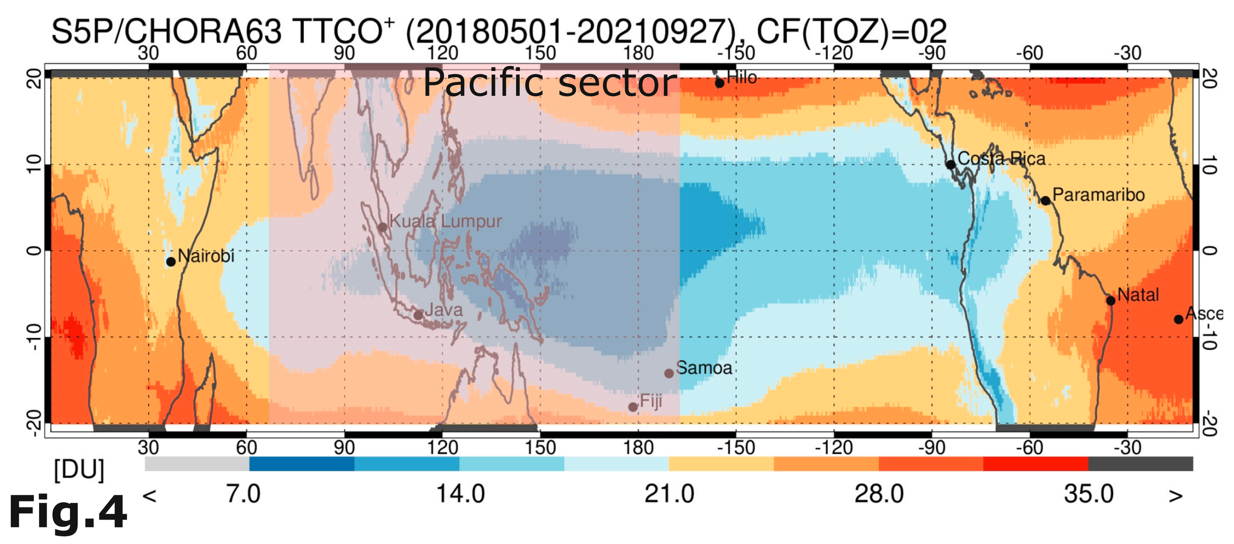


Fig.4

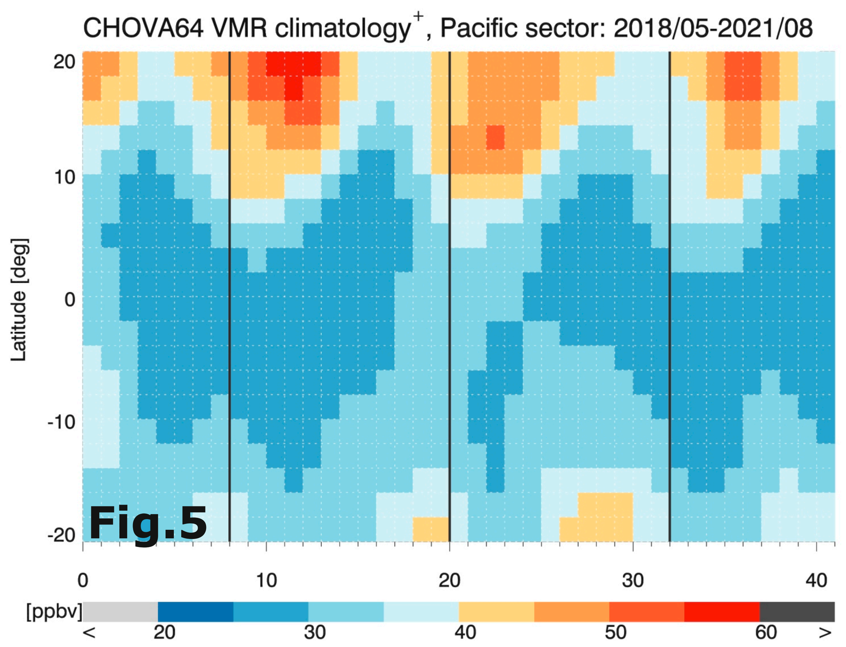


Fig.5

CHORA Improvements

- **Fig.5**: CHOVA/CSA TTO zonal monthly mean climatology of the Pacific sector [70E-190E] on a 2° latitude grid for the period May 2018 – September 2021.
- This is used for the pressure level ACCO adjustment to 270 hPa, calculated for CHORA/CCD in the Pacific sector.
- **Fig.6**:The ACCO matrix (daily, 0.5° lat) is gap filled and 2d smoothed (right).

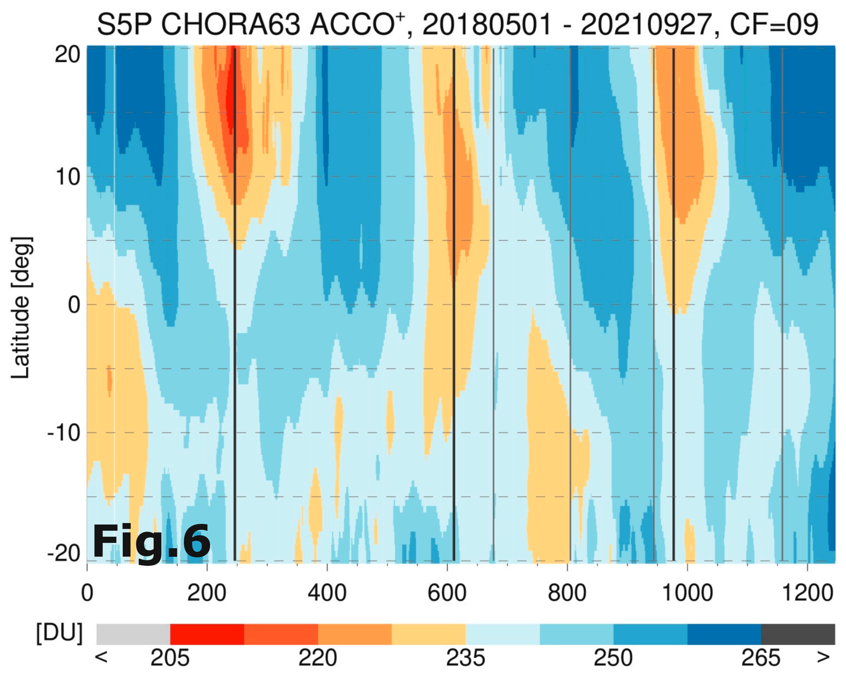


Fig.6

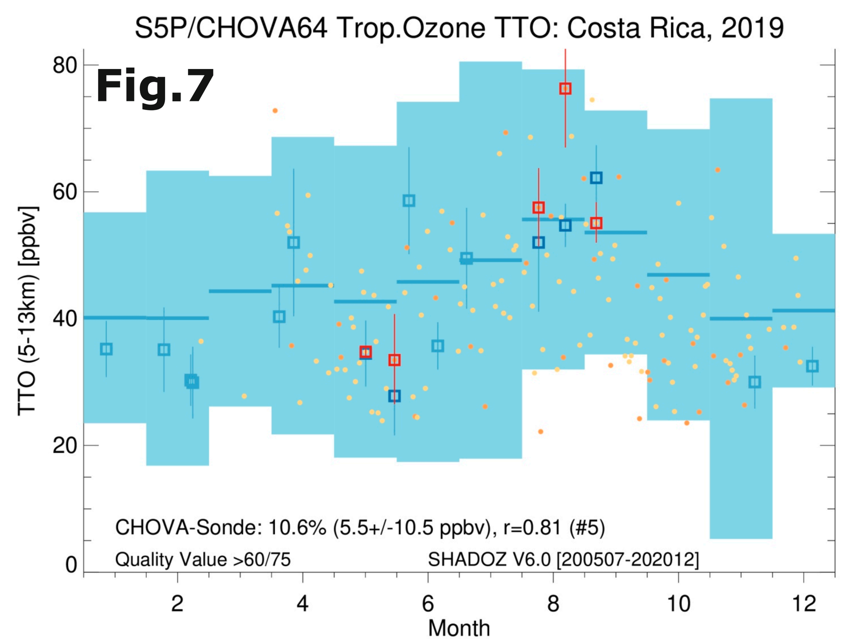


Fig.7

SHADOZ validation

- S5p daily TTO/*TTCO* (red/orange) are compared with SHADOZ ozone sonde data (blue) from Costa Rica for 2019.
- **Fig.7**: Only few daily CHOVA collocations can be found (Fig.X) with high correlation (r=0.8). The measurements mostly lie in the range of historical values and follow the annual cycle. The bias is 10% with a scatter of 10 ppbv.
- **Fig.8**: More CHORA collocations are observed (r=0.7) with a bias of -10% and a dispersion of 4 DU (Fig.XX). Also here an annual cycle is detected.

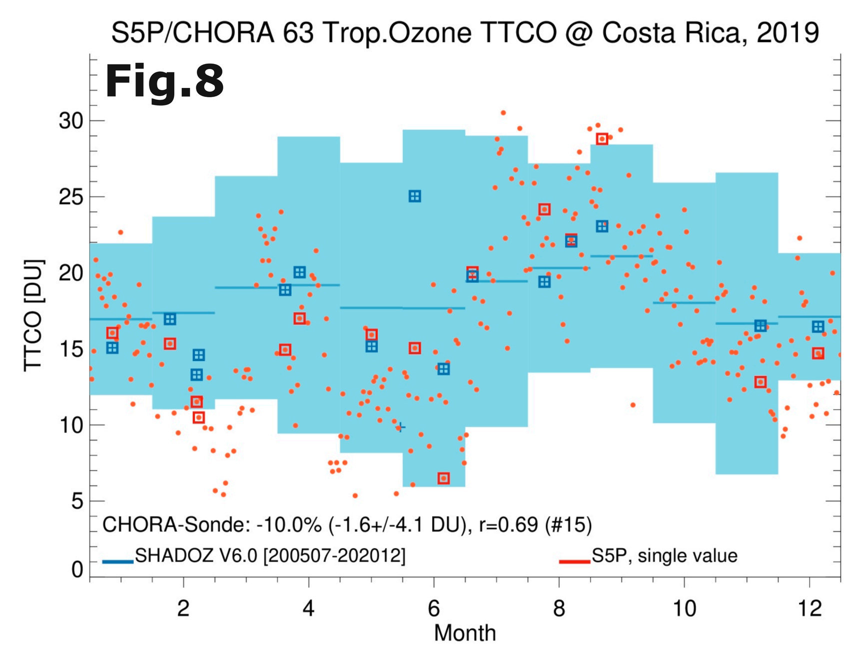


Fig.8

	TTO [ppbv]		TTCO [DU]	
SAT-SONDE	Bias-Median	IP68/2	Bias-Median	IP68/2
Diff.	1	12	1.1	5
Rel.Diff. [%]	**3**	**28**	**5**	**25**
Low VMR RD [%]	12	35	7	27
High VMR RD [%]	-6	26	4	23

Overall

- The CHOVA/CSA bias in comparison to 6 SHADOZ sonde stations is quite low (3%) but the dispersion is high (12 ppbv). This is based on daily collocations with 159 measurement pairs and a medium correlation of 0.53.
- The CHORA/CCD bias has been much improved (5%) while the dispersion (5 DU) remains at that level after the optimizations.

CHORA-LRS

- While **CHORA-PS** uses „stratospheric" columns in the Pacific sector to subtract from global TOZ, this approach is not suitable if the method is extended beyond the tropics, because of a more dynamic stratosphere.
- The now under development **CHORA-LRS** (LRS: Local reference sector) retrieves TTCO by subtracting more local ACCO from TOZ. For each grid pixel, the algorithm automatically searches for cloud fields in the vincinity and calculates mean ACCO for smallest ACCO grid box possible.
- The ACCO grid size starts from +/-5° up to 50°around the grid point (**Fig.9**). Sampling TOZ grid size is **1°x1°** lati-/longitude.

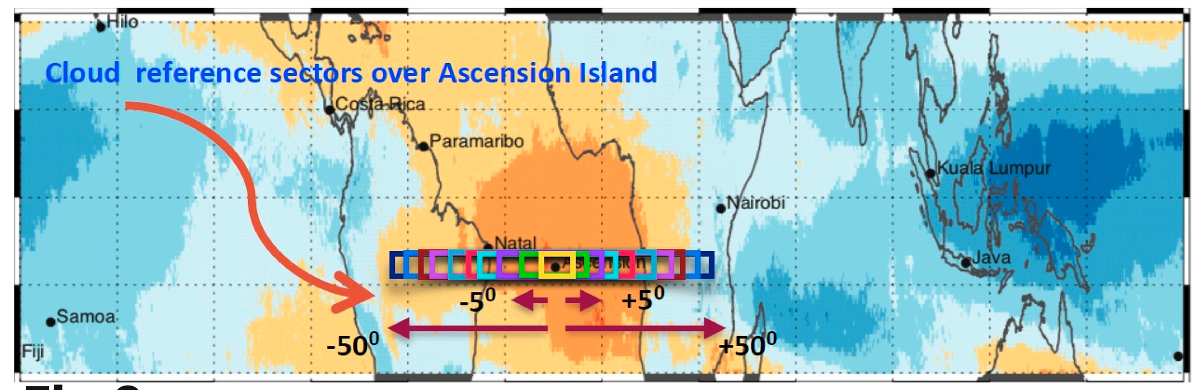
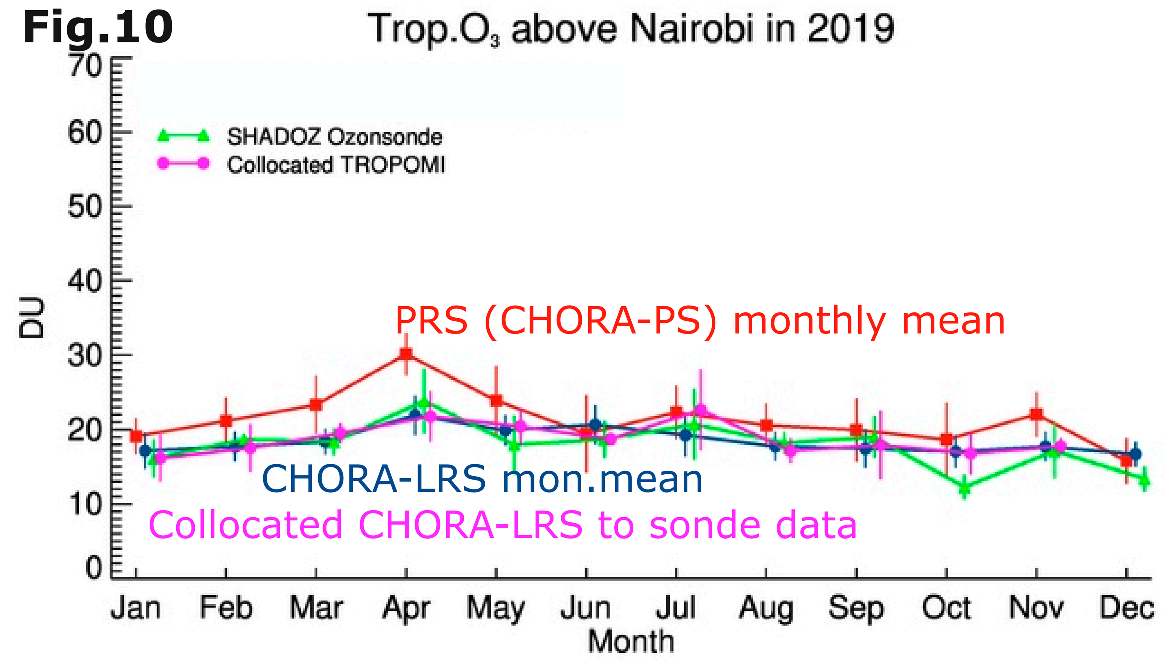


Fig.9

Fig.10



- **Fig.10:** Comparison of monthly mean TTO from CHORA-PS and -LRS with ozone sonde for Nairobi in 2019.
- The new LRS algorithm gives better results wrt to sondes. Thus local cloud ACCOs are better suited to reduce bias at some locations and to improve the dispersion.

Conclusions

- Both the CHORA and CHOVA programs have been upgraded. The retrievals now provide output based on daily measurements. More than 3 years of TROPOMI retrieval results are currently available.
- While the overall biases in comparison to ozone sondes are low (<5%), the dispersion is rather high. This is partly due to the natural variability of single ozone profiles in comparison to satellite area means.
- The CHORA/CCD algorithm can be further optimized when calculating the ACCO more locally to the measurement pixel instead of in the Pacific sector.
- The local approach will be extended to the extra-tropics to use data from geo-stationary instruments (ESA Sentinel 4, NIER GEMS, and NASA TEMPO.

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- Ziemke, J. R. et al.: Cloud slicing: A new technique to derive upper tropospheric ozone from satellite measurements, J.Geophys.Res., 2001.
- Valks, P. et al.: Tropical tropospheric ozone column retrieval for GOME-2, Atmos.Meas.Tech., 2014.
- Sterling, C. W. 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., 2017 (and references to SHADOZ therein!).

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