

**Abstract.** The Po valley (Italy) is one of the most polluted regions in Europe. High NO<sub>2</sub> concentrations are often found due to industrial and urban activities and its particular geographical position. However, MAX-DOAS instruments, compliant to the Fiducial Reference Measurements for Ground-Based DOAS (FRM4DOAS) standards (<https://frm4doas.aeronomie.be>) were not present in the Po Valley. The purpose of the IDEAS-QA4EO "DOAS-BO: Towards a new FRM4DOAS site in the Po valley" WPs (contract funded by ESA-ESRIN n. 4000128960/19/I-NS) was to fill this measurement gap. To do this, we decided to exploit SkySpec-2D, an instrument fully compliant to the FRM4DOAS standards. In the first step, we performed a measurement campaign in BAQUININ (on the roof of La Sapienza University, Rome) to assess the SkySpec-2D performances against Pandora#117 and satellite (TROPOMI) data. The comparison was performed between the retrieved NO<sub>2</sub> Vertical Column Densities (VCDs). Then, during the 1<sup>st</sup> October 2021, we installed the SkySpec-2D at the "Giorgio Fea" observatory in San Pietro Capofiume, located in the middle of the Po Valley. From that day, the instrument has been continuously measuring zenith and off-axis diffuse solar spectra useful to retrieve trace gases information. Here, we show some results on the NO<sub>2</sub> VCDs, derived from zenith-sky spectra, and NO<sub>2</sub> vertical profiles retrieved by the Bremen Optimal estimation REtrieval for Aerosol and trace gases (BOREAS) algorithm (Bösch et al., 2018), developed at the IUP institute of the University of Bremen.

## Campaign at BAQUININ La Sapienza in Rome: SkySpec vs Pandora#117 (DOI: 10.5281/zenodo.5886950)

The campaign was performed between 6<sup>th</sup> and 21<sup>st</sup> September 2021. We compared the SkySpec-2D NO<sub>2</sub> VCDs from zenith-sky spectra with the ones retrieved from Pandora#117 and TROPOMI.



Fig 1: SkySpec-2D installed in BAQUININ on the roof of the La Sapienza University (Rome)

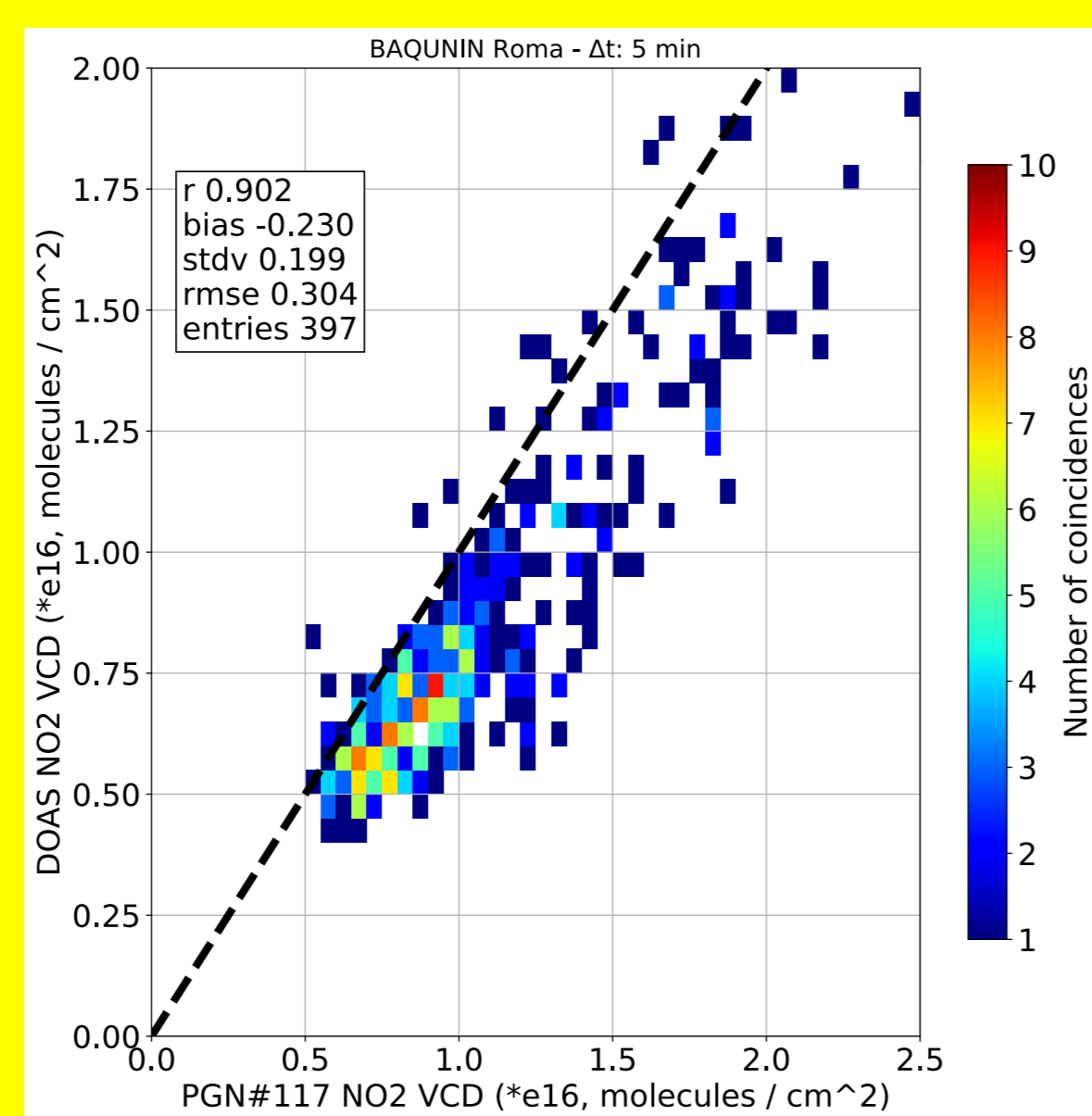


Fig 2: scatterplot of NO<sub>2</sub> VCDs retrieved from SkySpec-2D and Pandora#117 measurements and averaged in 5 minutes intervals.

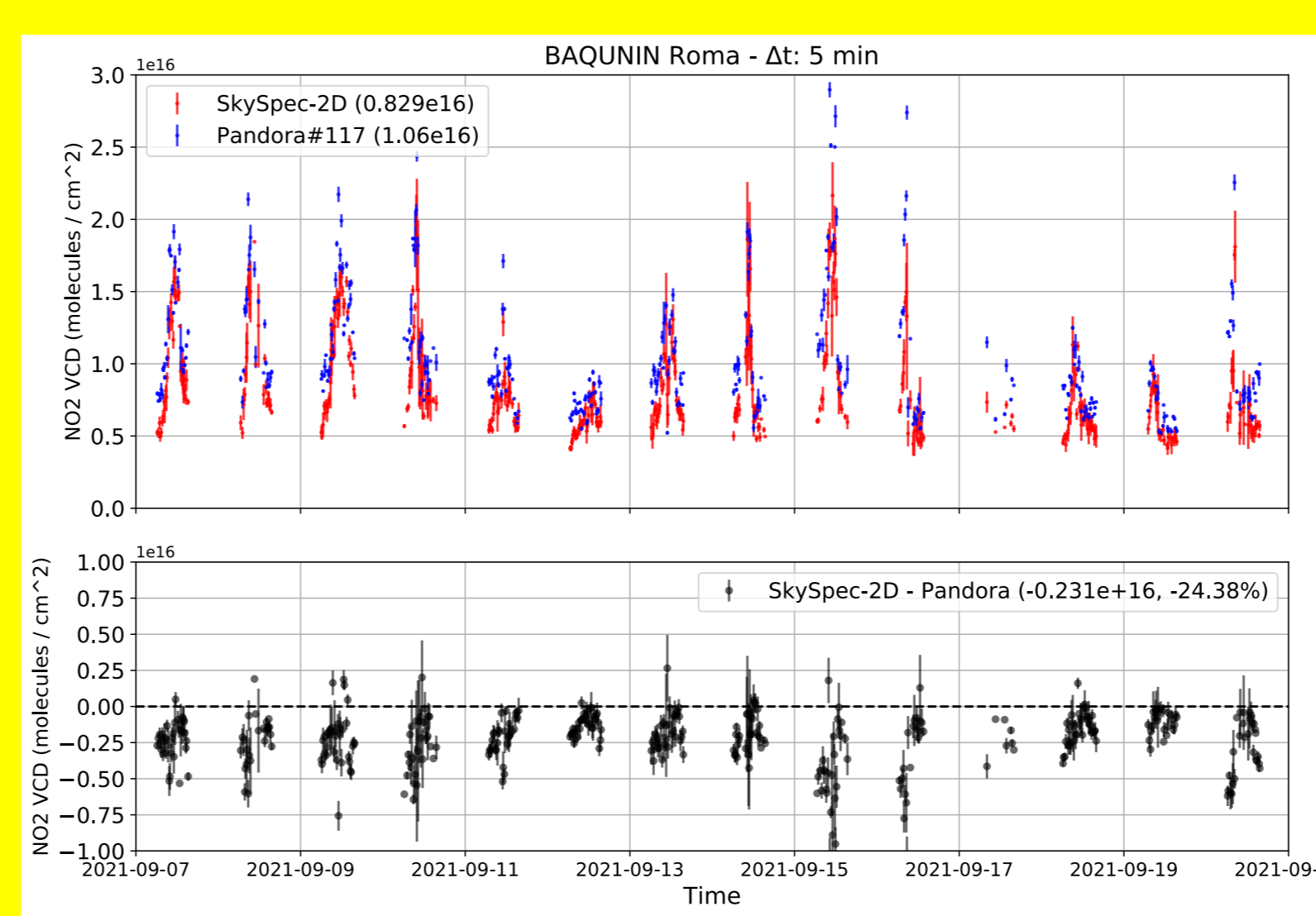


Fig 3: timeseries of NO<sub>2</sub> VCDs retrieved from SkySpec-2D and Pandora#117 measurements and averaged in 5 minutes intervals.

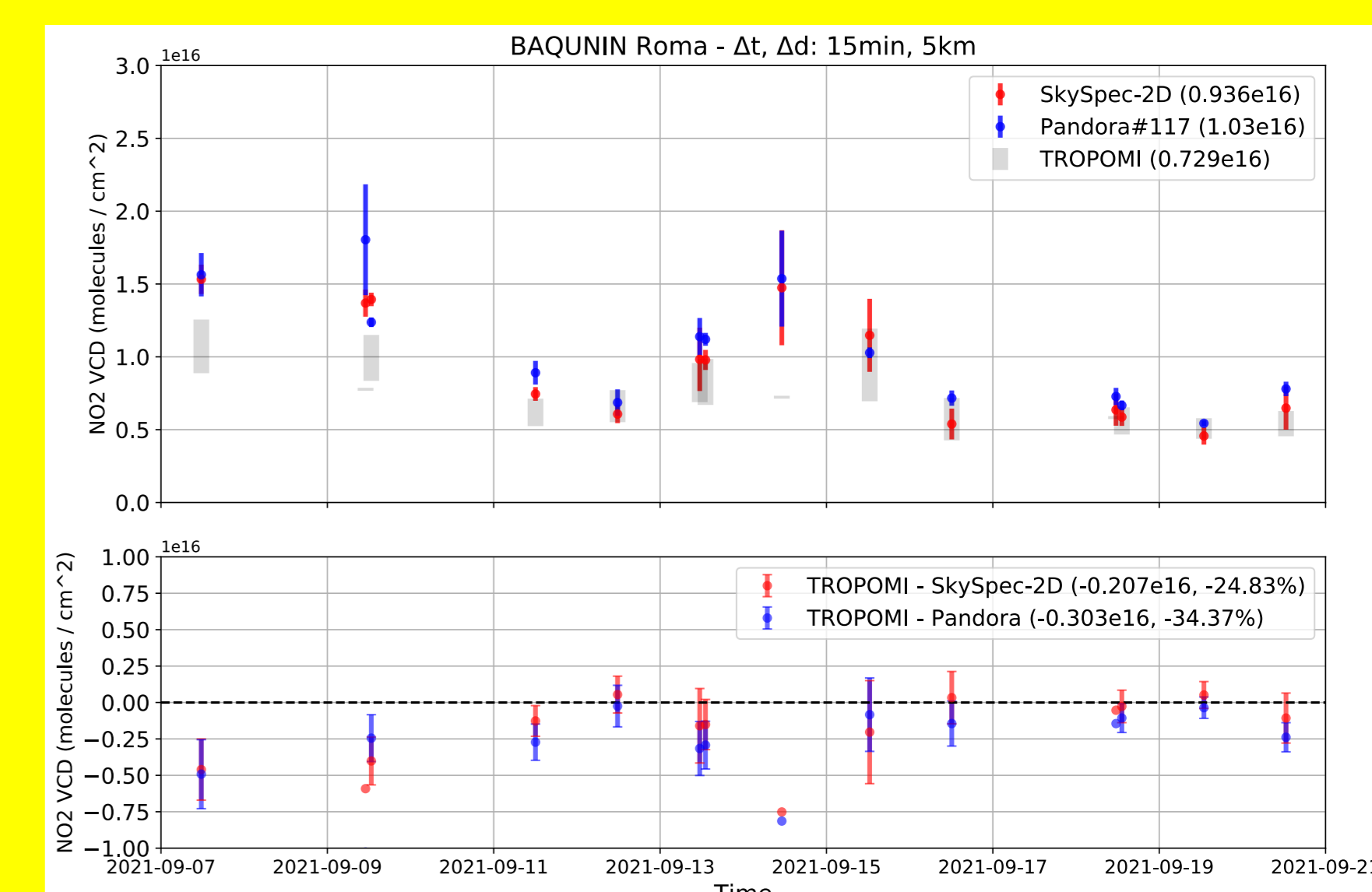


Fig 4: NO<sub>2</sub> VCDs from SkySpec-2D (red) and Pandora#117 (blue) averaged over 15 minutes and TROPOMI (grey shadow) averaged in a region of 5 km radius..

## SkySpec-2D routine measurements in SPC

SkySpec-2D has been measuring zenith and off-axis diffuse solar spectra in San Pietro Capofiume since 1<sup>st</sup> October 2021. Here are some results of NO<sub>2</sub> VCDs and vertical profiles retrieved from its spectra.

Measurement strategy	
AZIMUTH ANGLES	135°, 250°, 315°
ELEVATION ANGLES	1°, 2°, 3°, 5°, 10°, 30°, 90°
SPECTRAL RANGE	VIS(410-550 nm) and UV(300-400 nm)



Fig 5: image of the Po Valley.



Fig 6: permanent position of SkySpec-2D at Giorgio Fea observatory in San Pietro Capofiume

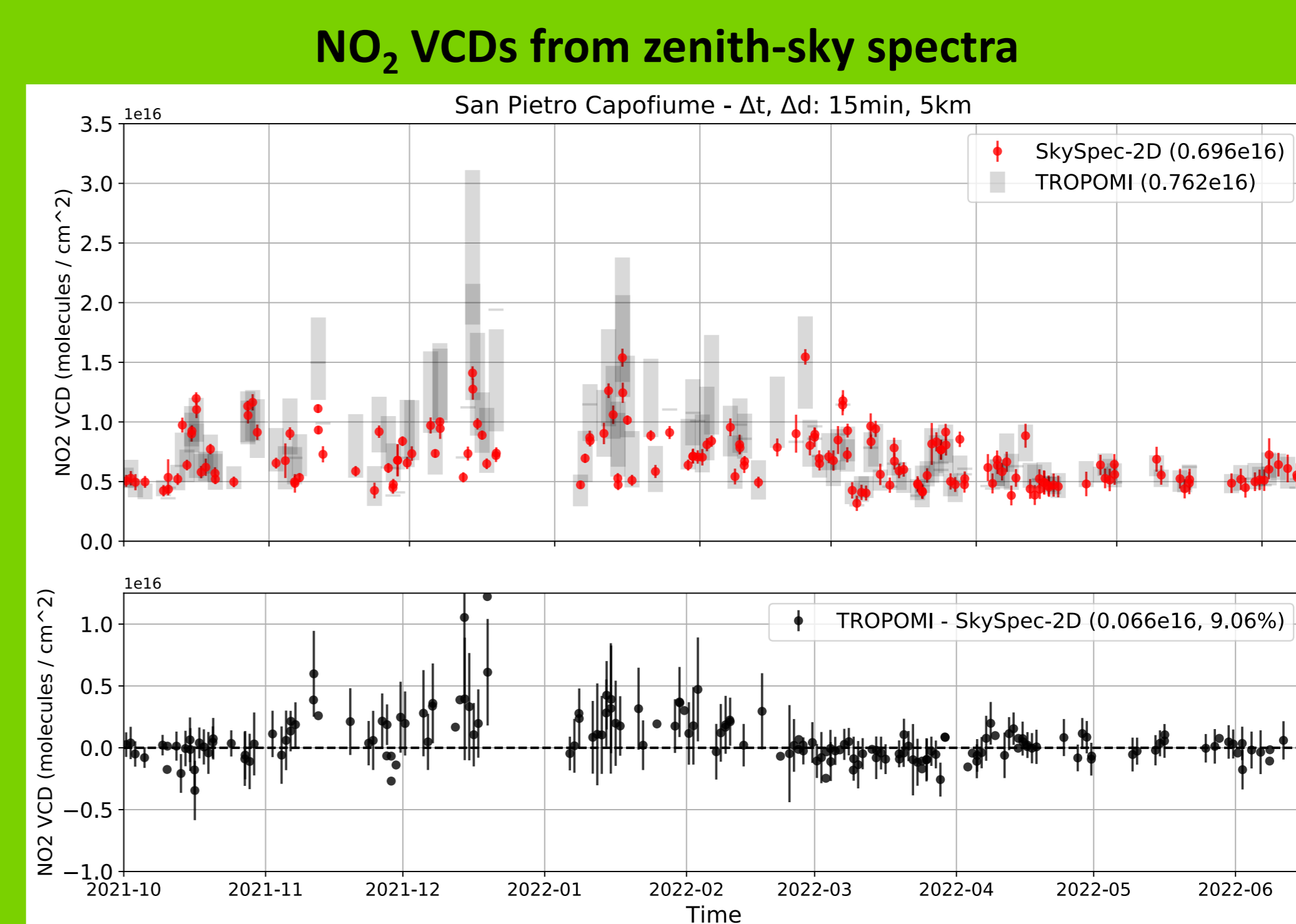


Fig 7: NO<sub>2</sub> VCDs retrieved from SkySpec-2D zenith-sky spectra (red) and TROPOMI (grey shadow) in SPC. Here, we consider TROPOMI data in a region of 5 km radius around the Giorgio Fea observatory and SkySpec-2D data in 15 minutes around the satellite overpass time.

## NO<sub>2</sub> vertical profiles retrieved by BOREAS

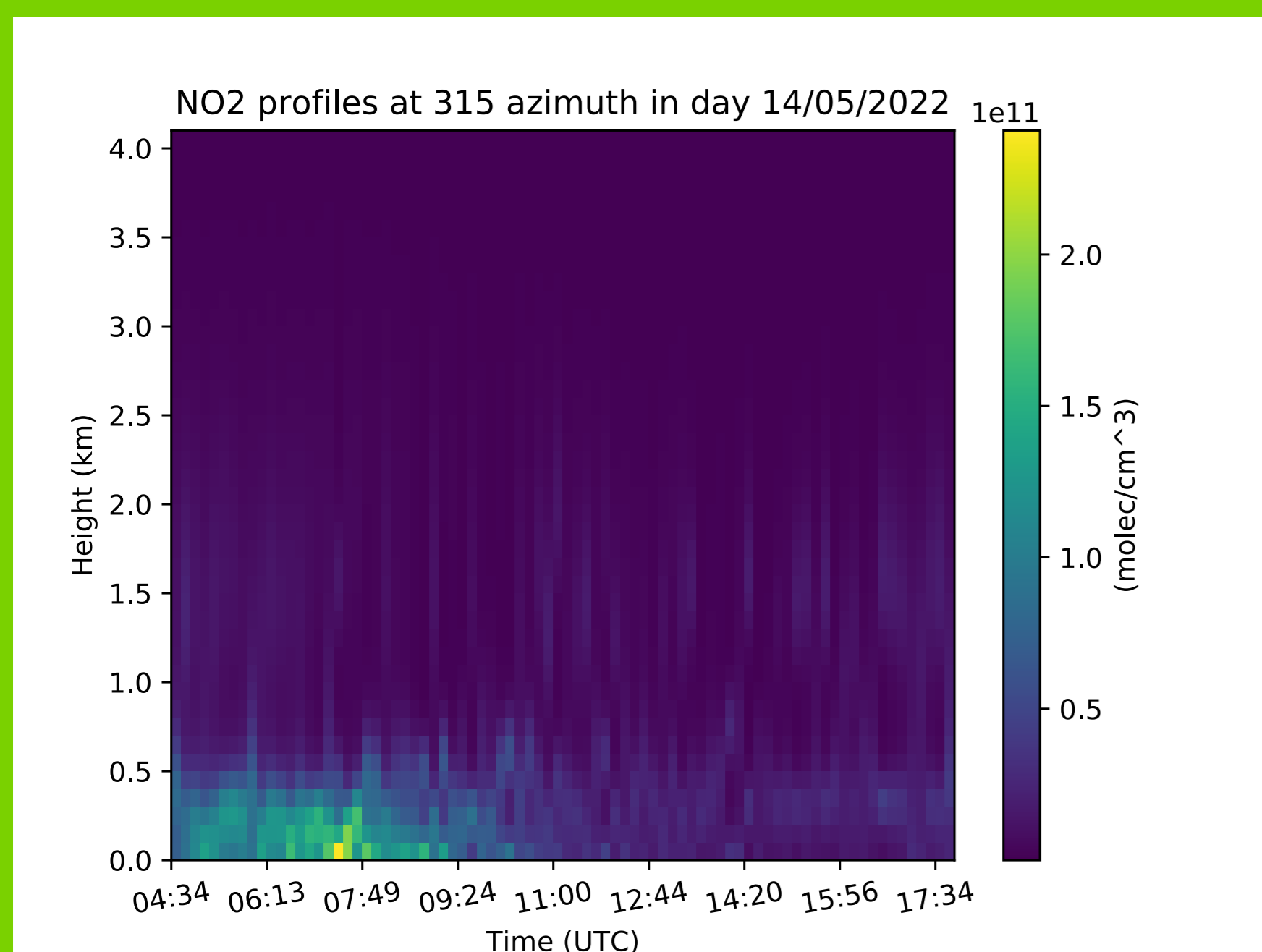


Fig 8: example of NO<sub>2</sub> vertical profiles retrieved by BOREAS using the spectra acquired at 315° azimuth during 14/05/2022.

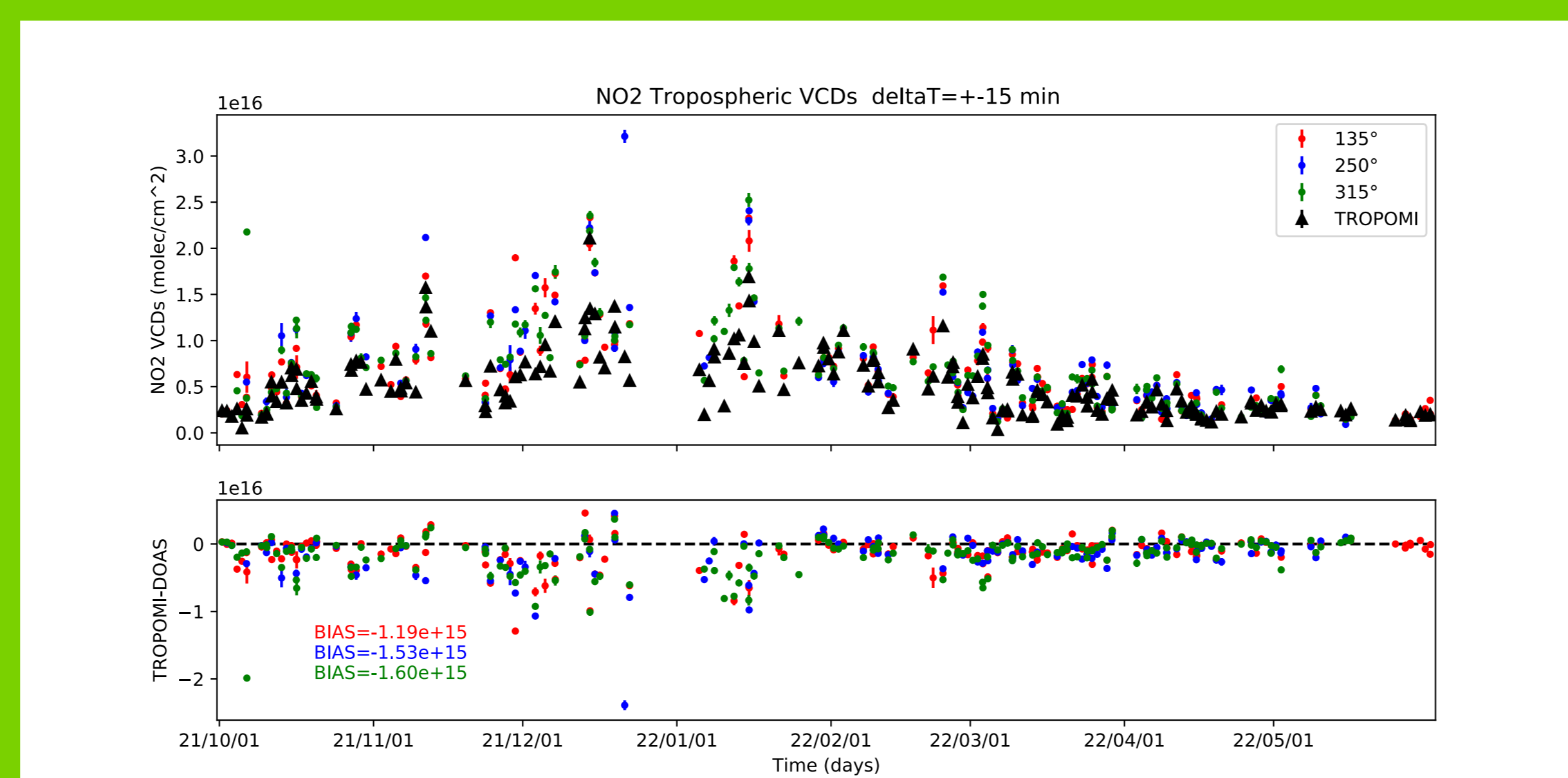


Fig 9: comparison between NO<sub>2</sub> tropospheric VCDs derived from MAX-DOAS vertical profiles (in the three azimuth directions) and TROPOMI.

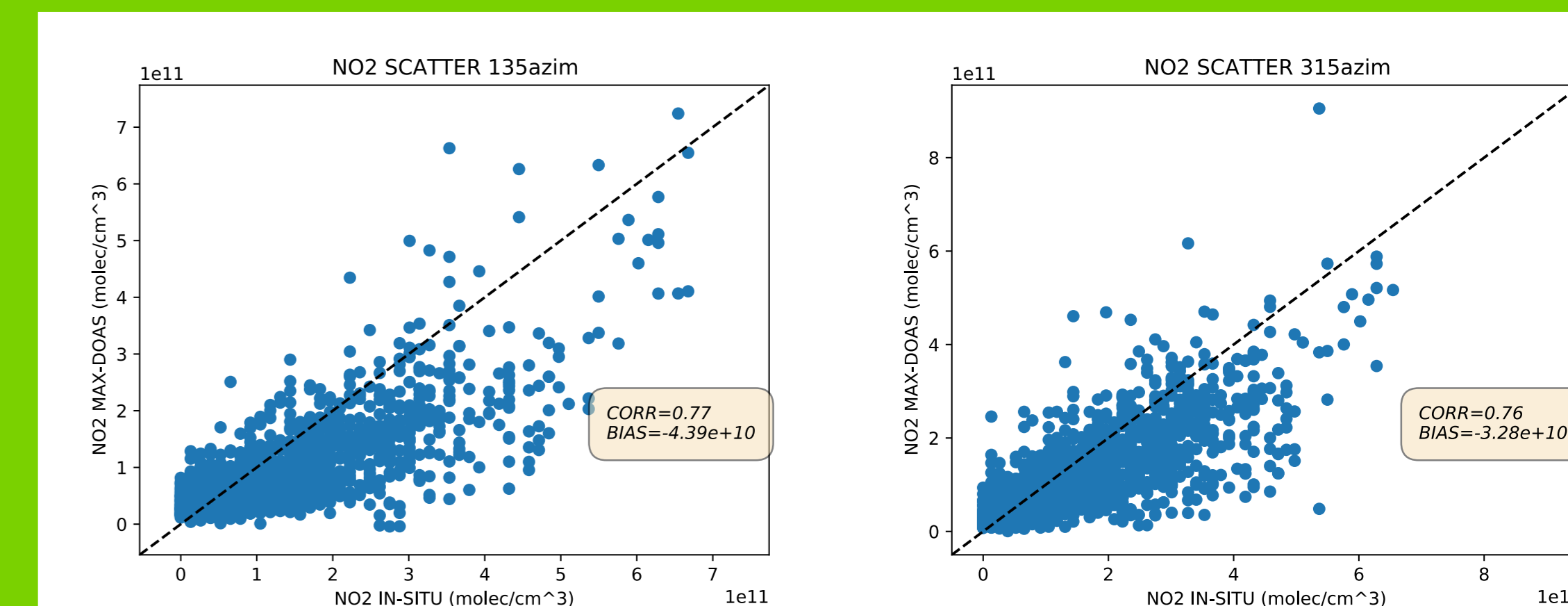


Fig 10: comparison between the lowest point of the NO<sub>2</sub> vertical profiles derived from MAX-DOAS measurements in two azimuth directions (135° and 315°) and NO<sub>2</sub> in-situ data acquired by ARPA-E (<https://www.arpae.it/it>). In-situ data are acquired few meters far from the SkySpec-2D. Data from the 1<sup>st</sup> October 2021 to the end of May 2022 are used.

## Conclusions

- 1) Good performances of SkySpec-2D compared to Pandora#117 and TROPOMI (see Fig. 2, 3 and 4). Its NO<sub>2</sub> VCDs are lower than the Pandora#117 ones (bias of  $-0.23 \times 10^{16}$  molec/cm<sup>2</sup>), but highly correlated (0.9), and higher than the TROPOMI ones ( $0.21 \times 10^{16}$  molec/cm<sup>2</sup>, corresponding to 25%).
- 2) SkySpec-2D is continuously measuring in the middle of the Po Valley and its spectra are routinely provided to the FRM4DOAS community for their central processing.
- 3) We automatically process its zenith-sky spectra to retrieve NO<sub>2</sub> VCDs. Good agreement with TROPOMI data (see Fig. 7).
- 4) An example of NO<sub>2</sub> vertical profiles retrieved by BOREAS is given in Fig. 8. The tropospheric NO<sub>2</sub> VCDs computed from the retrieved profiles are in good agreement with TROPOMI products (see Fig. 9). Good consistency is also present between the lowest points of the vertical profiles and NO<sub>2</sub> in-situ data (Fig. 10). However, the NO<sub>2</sub> concentrations at ground level retrieved from MAX-DOAS measurements are systematically underestimated, due to the vertical resolution of the retrieval.