

Interactive comment on “Sulphur dioxide (SO₂) vertical column density measurements by Pandora spectrometer over the Canadian oil sands” by Vitali E. Fioletov et al.

Anonymous Referee #1

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The paper describes first measurements of vertical column density of sulfur dioxide (SO₂) in Canadian Oil sands region using ground-based PANDORA instrument in direct sun mode applying DOAS retrieval technique. The paper is particularly suitable for publication in AMT because it introduces new and practical method of measuring column amounts of important criteria pollutant SO₂ gas, which is precursor for sulfate aerosols. The paper is well written and discusses in sufficient details important aspects of the measurement technique, including the instruments, installation, operations, DOAS retrieval algorithm (comparison of different spectral fitting windows), modified calibration procedure for SO₂ (SCD reference), VCD conversion, data filtering and error estimates. References to the previous work are adequate and comprehensive.

The paper further discusses important relationship between SO₂ surface concentrations and columns as well as their dependence on wind direction relative to the SO₂ emission point sources. The paper further compares ground-based measurements with aircraft in-situ measurements (spirals) as well as with satellite OMI retrievals. The paper will be of great interest for a broad audience including DOAS community, atmospheric scientists, air quality decision makers and satellite retrieval community.

The paper can be accepted for publication with only minor suggestions:

We would like to thank the reviewer for the evaluation and comments that helped us improve the manuscript.

General comments:

I suggest changing spelling of “suphur” to “sulfur” throughout the paper to make it consistent with previous papers on SO₂ measurements.

It appears that “sulfur” is recommended spelling for AMT and ACP journals. We corrected the spelling to “sulfur” everywhere in the text.

Technical comments:

1, 17: I suggest removing sentence about spectral fitting uncertainty (0.05DU) from the abstract, because it is only part of the total error.

The sentence is removed.

1,30: with [the] oil sands operations

Corrected

2,9: remove, add: Many satellite . . . provide total column value[s] [once a day]

Corrected

2,10: Add: [Time resolved] ground-based measurements . . .

Corrected as suggested

2,31: add reference for MAX-DOAS SO₂ measurements: [Theys et al., JGR, 2015]

The reference is added

3,2 add comma: , which

Corrected

5,10 add parenthesis: (Fig.3c)

Corrected

7,30: explain how PANDORA measures ozone and how ozone absorption could interfere with the SO₂ retrieval?

We added the following text: "The spectral fitting algorithm includes ozone absorption spectrum as one of the main fitted functions. The ozone optical depth is about two orders of magnitude higher than the SO₂ optical depth (for 1DU of SO₂ and the 311-330 nm spectral window). Even a small imperfection in accounting for ozone absorption could cause a substantial error in retrieved SO₂."

8,6: colors

The AMT recommendations suggest that "colours" spelling is fine as long it is consistent.

9,17: suggest additional scenario for calculating aircraft in-situ integral linearly extrapolating aircraft measured mixing ratio below the lowest altitude. This scenario typically produce larger estimate of the

SO₂ column and would improve comparison with ground measurements on August 24 (Fig 11b) and Sep 3 (Fig.11d).

Thank you for the suggestion. We have added this scenario. It reduced the difference for the Sep 3 flight from 0.67 DU to 0.55 DU, but otherwise the changes were very small, about 0.1 DU. Figure 11 and Table 1 were modified and the text was adjusted accordingly.

9,31: the recent version [of the operational OMI SO₂ data] based . . .

Corrected

10,3: . . . and [this] is not surprising

Corrected

12,28: change to Netherlands Space Agency (NSO).

Corrected

19, Figure 1 caption, 1: Pandora instrument . . . the instrument's [optical] head . . .

Corrected

20, Figure 2 caption, 1: Explain how the measured slant column optical depths (red curves) for O₃, NO₂ and HCHO were obtained?

We added the following text: "The measured (red) lines for each gas were obtained from the measured irradiance logarithm by subtracting all other fitting functions except the absorption spectrum-based fit for that gas" to Figure 2 caption.

24, Figure 24 caption, 1: colors

The AMT recommendations suggest that "colours" spelling is fine as long it is consistent.

27, Figure 9: caption: Explain that azimuth 0 correspond to Northern wind direction, 180 – from the south, etc.

The explanation was added.

27, Figure 9 caption, 2: data show . . .

Corrected

27, Figure 9 caption, 5: based on simultaneous PANDORA and in situ measurements . . .

Corrected as suggested.

28, Figure 10 caption, 2: flight[s]

Corrected

28, Figure 10 caption, 5: are located and [to] the south-southeast . . .

Corrected

29, Figure 11 caption, 4: missing ratio -> mixing ratio

Corrected