

1 **Validation of six years of TES tropospheric ozone retrievals**
2 **with ozonesonde measurements: implications for spatial**
3 **patterns and temporal stability in the TES bias**

4 **W. W. Verstraeten^{1,2}, K. F. Boersma^{1,2}, J. Zörner^{2,*}, M. A. F. Allaart¹, K. W.**
5 **Bowman³, and J. R. Worden³**

6 [1]{Royal Netherlands Meteorological Institute, Climate Observations, De Bilt, the
7 Netherlands}

8 [2]{Eindhoven University of Technology, Fluid Dynamics, Eindhoven, the Netherlands }

9 [3]{Jet Propulsion Laboratory (CalTech), Pasadena, California, USA }

10 [*]{now at: Max-Planck-Institute for Chemistry, Mainz, Germany }

11 Correspondence to: W. W. Verstraeten (w.w.verstraeten@tue.nl)

12
13
14
15 **Reply to referee 1**

16
17 Specific comments:

18 1) Sect.2: I suggest the authors add a paragraph or a few sentences in this section describing
19 improvements of the TES retrieval algorithm for this version (V004) relative to previous
20 versions of ozone retrievals. This will be useful for readers to understand why the TES biases
21 in the ozone measurements have remained nearly the same.

22 *Reply: Thank you for this comment. In the revised manuscript we have added a small*
23 *paragraph indicating the improvements of the V04 data compared with version 2.:*
24 *“Improvements to the temperature and water retrievals resulted in slightly improved*
25 *agreement between calculated and actual uncertainties of the vertical ozone profile (Boxe et*
26 *al., 2010). However its not clear that this changed any bias characteristics of the TES data.”*

1 2) Page 1251, Line 11-13: TES biases are higher at northern mid-latitudes than those in the
2 Tropics. It is explained as weaker vertical sensitivity or higher stratospheric influences. Can
3 you find some evidence to support the statement? For example, a positive correlation between
4 TES biases and averaging kernel values in the stratosphere?

5 *Reply: Lower sensitivity will affect the bias because the effect of the bias on the estimate will*
6 *depend on the sensitivity (see Worden et al., 2011). However, biases from not completely*
7 *resolving variability in temperature and H₂O vertical profiles will affect the TES ozone*
8 *because these effects cannot be completely reduced through averaging.*

9 *Worden, J., Noone, D., Galewsky, J., Bailey, A., Bowman K., Brown, D., Hurley, J., Kulawik, S., Lee, J. and*
10 *Strong, M. Estimate of bias in Aura TES HDO/H₂O profiles from comparison of TES and in situ HDO/H₂O*
11 *measurements at the Mauna Loa observatory. Atmos. Chem. Phys., 11, 4491-4503, 2011.*

12

13 3) Page 1253, Line 21-24: ‘The p-values show that none of the slopes are significant . . .’. But
14 in Table 1 the p-value for the Northern mid-latitudes is small (0.00). Is it a typo? Or reflecting
15 a robust trend for the seasonal averages?

16 *Reply: The p-values larger than 0.05 are not considered significant. We have added this in*
17 *the revised manuscript. The p-values in Table 1 refers to the statistical test on the intercepts.*
18 *This was not mentioned in the caption of Table 1 of the earlier version of the manuscript. In*
19 *order to avoid any confusion we have added this to the caption in the revised manuscript.*

20

21 Technical corrections:

22 Page 1247, Line 23: ‘Boxe and Worden (2010)’ should be ‘Boxe et al. (2010)’

23 *Reply: Thank you for noticing it. It is corrected in the revised manuscript.*

24

25 Page 1248, Line 21: Suggest change ‘TES O₃ measurements profiles’ to ‘TES ozone
26 profiles’.

27 *Reply: We have changed this in the revised manuscript as suggested.*

28

1 Page 1264, Fig. 3: In the caption, please describe the latitude bin for the right panel. Please
2 also state the values of the dashed latitudinal lines.

3 *Reply: We have added this in the captions of Fig. 3 in the revised manuscript.*

4

1 **Reply to referee 2**

2

3 General comments

4 The validation study is centered on the discussion of the biases. The authors should consider
5 to discuss also the expected error on the retrieval that is given by the RMS of the comparison
6 between the retrieval and the ozonesondes.

7 *Reply: In the revised manuscript an additional table (a new Table 1) is included (as also*
8 *suggested in one of your further comments). We will also add some remarks in the revised*
9 *manuscript. The RMS mainly reflects the variability of the residuals. Large RMS in the UT is*
10 *likely attributable to the high variability in upper tropospheric and lower stratospheric ozone*
11 *(e.g. Logan, 1999). But also the low tropopause heights in the northern mid-latitude winter*
12 *may play a role since it reduces the degrees of freedom for signal in the troposphere.*
13 *Atmospheric variability may account for a significant portion of variability in the TES-sonde*
14 *differences thus reducing the potential contribution from the errors in the TES*
15 *measurements(Nassar et al, 2008).*

16 *Logan, J. A. (1999), An analysis of ozonesonde data for the troposphere: Recommendations for testing 3-D models and*
17 *development of a gridded climatology for tropospheric ozone, J. Geophys. Res., 104(D13), 16,115–16,149,*
18 *doi:10.1029/1998JD100096.*

19

20 Moreover it would be very valuable to discuss how the TES retrieval is able to capture the
21 natural variability observed by the sondes. It is very important if one wants to use this data to
22 study variability and trend of tropospheric ozone.

23 *Reply: There is clearly a linear relationship between TES and sonde measurements for the*
24 *different latitudes for both the upper and lower troposphere (see also section 5, paragraph 3).*
25 *For the northern mid latitude and the Arctics this is less pronounced for the LT. This linearity*
26 *gives confidence to users of TES data that relative variations as observed on a global map are*
27 *significant, even though biased. As such TES datasets have the capability to study variability*
28 *and trends in tropospheric ozone. In the revised manuscript, an additional table is provided*
29 *that summarizes the linear regression statistics for TES vs. sonde observations of ozone in LT*
30 *and UT mentioned in section 5, paragraph 3.*

31

1 Specific comments

2 Abstract: the authors should consider the providing also the relative biases in percent.

3 *Reply: We included the relative biases in percentage in the revised version.*

4

5 Section 2: If the TES data used for this study are publicly available, the authors should
6 mention it and provide the way to access the data.

7 *Reply: The data are freely available at the TES website: <http://tes.jpl.nasa.gov/data/>. We have
8 added this in the revised manuscript.*

9

10 P1246, 18: Is the interpolation performed in logarithmic scale?

11 *Reply: Yes indeed, as indicated at page 1246 lines 4-5: “The estimate, \hat{X}_{TES} , as well as the
12 true state and prior are in units of log (VMR).”*

13

14 P1248, 113: in which unit is the RMS given?

15 *Reply: The rms is unitless. The rms (root mean square) of the difference between observed
16 and fit radiance normalized by the Noise Equivalent Spectral Radiance (NESR)
17 ($nW/cm^2/sr/cm^{-1} / nW/cm^2 /sr/cm^{-1}$).*

18

19 P1249, 120-end : It could be helpful for the reader if all the number were summarized in a
20 Table or a Figure.

21 *Reply: We have incorporated an additional table (new table 1) in the revised version
22 summarizing the statistics for the TES-sonde comparisons in the lower and upper
23 troposphere.*

24

25 P1250 – discussion on the UT bias: the authors should mention that the bias in the UT is also
26 observed for other IR sounders like IASI for example (see e.g. Dufour et al., AMT, 2012)

27 *Reply: We have added an extra sentence mentioning that bias in the UT is also observed for
28 other IR sounders like IASI for example (see e.g. Dufour et al., AMT, 2012).*

1

2 Technical corrections:

3 P1247,l22: Boxe and Worden (2010) should be replace by Boxe et al. (2010).

4 *Reply: Thank you for noticing it. It is corrected in the revised manuscript.*

5

6 Fig. 2: change lunched to launched

7 *Reply: Thank you for noticing this. We have corrected this in the revised manuscript.*

8