

**Responses to referee comments on manuscript no. acp-2013-773, titled:  
Diurnal Variations of Stratospheric Ozone Measured by Ground-based Microwave Remote Sensing  
at the Mauna Loa NDACC site: Measurement Validation and GEOSCCM model comparison**

**Anonymous Referee #1** - (Interactive comment on Atmos. Chem. Phys. Discuss., 13, 31855, 2013.)  
Received and published: 13 January 2014

Comment: The authors could think about a few adds in order to make the article more understandable for non-experts, e.g., they could explain why ground-based microwave radiometry seems to be the only measurement technique which can measure the diurnal ozone variation.

Response: Passive microwave instruments can observe spectral lines of ozone (and other species) in emission, as the energy levels of the rotational transitions at millimeter wavelengths are so closely spaced that they are excited by intermolecular collisions at stratospheric temperatures, and are in local thermodynamic equilibrium. Because microwave emission observations have no dependence on solar illumination, they can be made at all hours of the day or night. These points were made, in different language, on page 5 in the paragraph beginning on line 7. The issues involved in making microwave and infrared ozone emission measurements from satellite platforms were also discussed in this paragraph. As a clarification, we added the sentence "These lines are excited by intermolecular collisions, so no external source of illumination is required for observations and they can be made either during the day or at night." after "...wavelengths" on line 9.

Comment:

In the introduction and later, I am missing a reference to a related new study: "A climatology of the diurnal variations of stratospheric and mesospheric ozone over Bern, Switzerland S. Studer, K. Hocke, A. Schanz, H. Schmidt, and N. Kämpfer Atmos. Chem. Phys. Discuss., 13, 22445-22485, 2013". For example, Parrish et al. wonder that the night-morning differences are larger in the model world than in the observations. I think, Studer et al. experienced the same.

Response:

We have added references and discussion beginning at line 24 on page 4 and in the discussion beginning at line 24 on page 20.

Comment:

In the introduction, it could be emphasized that observational results of the tiny diurnal variation in stratospheric ozone were quite uncertain until now. I don't believe much in the TIMED/SABER results on the diurnal ozone variation at stratospheric altitudes. They look quite shaky and seem to be not consistent. Actually the present Parrish et al. study is most convincing since their radiometer measures the complete daily cycle at an high-altitude station. The observational results of Haeferle et al. and Studer et al. (2013) are also good and in agreement with Parrish et al. but a rest risk remains in the data retrieval of Haeferle and Studer because of the high tropospheric opacity at a low altitude station such as Bern or Payerne. Thus the main point seems to be that Parrish et al. give for the first time a really clear observational evidence of the daily cycle of stratospheric ozone. I would suggest that the authors communicate this crucial point in a clear manner in the revised version.

Response:

We made this point in an added paragraph beginning at line 11 on page 7.

Comment: p.31858, line 6, the equation for photolysis of O<sub>2</sub> is missing.

Response: We added this reaction at line 26 on page 2.

Comment, p.31878, last sentence: "The good agreement between MWR, Aura-MLS, UARS-MLS, and SMILES suggests that the last three, together with the model, can be used to estimate such adjustments over a wider range of latitudes. "I disagree with this statement. The authors did not make a model

validation at polar latitudes where model simulations of ozone photochemistry, polar vortex variations and tides are much more difficult than at mid-latitudes.

**Response:** We deleted this statement.

**Comment:** Acknowledgments: I am missing an acknowledgment to the ISSI ozone team where most of the authors participated.

**Response:** We added this acknowledgement at line 24 on page 24.

### **Anonymous Referee #3**

Received and published: 20 December 2013

**Comment:**

This paper presents an intercomparison of ozone datasets with the aim to tease out small diurnal variations in stratospheric ozone. The comparisons are thorough, convincing and certainly merit publication. While this is a potentially very good paper, I did feel, however, that they didn't go quite far enough. As the authors do note, there is a rich literature on this from Huang et al and also Haefele and yet the authors do not adequately place their results in context with these earlier studies. Do they agree? For example for Day 85, Huang et al (2010) (their Figure 5) show a decrease in the afternoon at 30 hPa which they believe to be real. It appears, based upon the comments at the very end of Section 4, that the present authors disagree. If so, they should say so.

**Response:**

We added material beginning at line 24 on page 20 to better place our work in context with previously published studies. We note that it is difficult to know how meaningful direct comparisons between measurements made at different latitudes will be. We give an example of this on line 25 on page 20.

**Comment:**

The final comparison of the present paper is limited to March. One wonders if another figure for a solstice case would be any different. For example, Huang et al [2010] show both day 85 and day 180 analyses and Haefele et al have a section on seasonal variations. Perhaps at the relatively low latitudes of Hawaii, seasonal variations are less important. But this would be good to clarify. I do not think the above comments would require much work to address; however, I certainly would suggest adding another figure, for a different season, to complement Figure 8 and another couple of paragraphs of discussion where they put their results in context.

**Response:** We replaced Figure 8 with Figures 8a and 8b on pages 37 and 38. These show measurement and model outputs for winter and summer. The associated revised discussion begins at line 14 on page 19.

**Comment:**

Since the existence of the afternoon stratospheric ozone enhancement is not a new result, their results are more of a confirmation (albeit the most comprehensive that has been presented) rather than a discovery and this should be explicitly stated.

**Response:** We replaced the sentence "However, ground-based microwave measurements by Haefele..." with "Haefele et al. (2008) also reported the afternoon enhancement based on their ground-based microwave measurements and attributed it to continuing ozone formation during the day through reaction (3) and the relatively high density and consequent low O/O<sub>3</sub> ratio." at line 24 on page 4.

**Very minor comment:** For Figure 3, I was a bit confused (line 15 of text) Which of the

colored curves is the best? Is it the black curve? Is this what is used to create the bottom panel?

**Response:** We revised the caption on page 32 for clarity.

Referee 2:

**Comment:**

Analyzing the magnitude of the diurnal variation of stratospheric and mesospheric ozone is nothing really new. In the introduction I would have expected to see a more comprehensive summary of previous work (historical and recent) on the subject. Whilst most of the early work focussed on the mesosphere, some of these studies contain also results for the mid to upper stratosphere and at different latitudes. In order to place the new work in an appropriate (historical) context, I suggest that the authors amend this part and refer the interested reader to relevant earlier work addressing ozone diurnal variation.

**Response:**

We added material beginning at line 27 on page 4 and several paragraphs beginning at line 4 on page 21 to respond to this comment.

**Comment:**

Results obtained in this study on the magnitude of the ozone diurnal variation in the stratosphere (Sections 3 and 4) should then also be compared with results from previous studies by different authors. What is consistent with earlier work and what is new in this study?

**Response:**

The several paragraphs beginning at line 4 on page 21 address this comment.

**Comment:**

Finally, in an ACP paper one would also expect a bit more discussion of the reasons for the diurnal variation in the stratosphere (in Section 4, GEOSCCM model comparison). Concerning the abstract, the observed magnitude and characteristics of the observed diurnal variation should be described before validation and model comparison results are summarized.

**Response:**

We have added new material beginning at line 17 on page 19 to address this comment.

**Comment:**

Some references:

Wilson and Schwartz, Diurnal variation of mesospheric ozone using millimeter wave measurements, JGR 86, 7385-7388, 1981

Vaughn G., Diurnal variation of mesospheric ozone, Nature 296, 1982

Zommerfelds et al., Diurnal variations of mesospheric ozone obtained by ground-based microwave radiometry, JGR 94, 12819-12832, 1989

Ricaud et al., Diurnal and seasonal variations of stratomesospheric ozone: Analysis of ground-based microwave measurements in Bordeaux, France, JGR, 96, D10, 18617-18629, 1991  
Connor et al. 1994, Ground-based observations of ozone in the upper stratosphere and mesosphere, JGR 99, 16,757-16,770, 1994

Schneider et al., Seasonal and diurnal ozone variations: Observations and modelling, J. Atmos. Chem., 50, 1, 25-47, 2005

Haefele et al. Diurnal changes in middle atmospheric H<sub>2</sub>O and O<sub>3</sub>: Observations in the Alpine region and climate models, J. Geophys. Res., 113, 2008

Studer et al., A climatology of the diurnal variations of stratospheric and mesospheric ozone over Bern, Switzerland, Atmos. Chem. Phys. Discuss, 13, 22445-22485, 2013

**Response:**

We have added references and discussion beginning at line 24 on page 4 and in the discussion beginning at line 24 on page 20. We mostly used recent references in which the measurement and analysis techniques are more highly developed.

**Technical comments:**

31859, 7

"Further refinement of ozone records will reduce the time required to make the detection ..." I would argue that it is even more important to continue monitoring of O<sub>3</sub>.

An extension of existing ozone data records will considerably lower the error of trend estimates.

**Response:** We agree with your argument. And every effort is being made to continue the NDACC microwave observations at MLO and at its companion station at Lauder, New Zealand. We did this work because it would contribute to the problem of joining time series of measurements between instruments, and we limited the scope of this paper to this subject. We don't see how the manuscript can be read to suggest that this work is more important than continuing the long term record. We would certainly be willing to modify specific language that suggests the contrary.

**Comment:**

When it comes to correcting the effect of ozone diurnal variation in satellite ozone timeseries, the caveat is that ground-based microwave observations have only a relatively rough vertical resolution and cannot be used too obtain the magnitude of the ozone diurnal variation at a given altitude. Therefore, validation of atmospheric models with potentially high vertical resolution is essential.

**Response:**

Higher resolution is always better but less important in this work than one might think. To make this point, we now show the original model output (which is produced on a grid with a ~1 km vertical spacing) in Figure 8 in addition to the model output after it has been convolved with the MWR averaging kernels. As discussed beginning at line 8 on page 19, the differences are negligible except at a few levels.

**Comment:**

31868 9-11: Simplify / reformulate this sentence. Are you referring to MLS daytime and nighttime profiles?

**Response:**

The revised sentence appears at line 17 on page 12.

**Comment:**

13 Suggest to move "plotted in black" to the Figure caption

**Response:**

The phrase "plotted in black is" indeed unnecessary here as it is already described in the figure caption. We deleted it.

Comment:  
31869, 13 "the" amplitude

Response:  
Thanks for noticing this omission, which has been fixed.

Comment:  
31870, 6 Reference JAXA 2012. Please check whether this is the correct reference. I couldn't find the information on hydrostatic pressure and temperature retrieval in the document.

There are two recent validation studies on SMILES ozone products which might be more relevant?

Response:  
We found that this information also in Imai et al. (2013) and replaced the JAXA reference with it.

Comment:  
Figures 1 and 7 could be slightly larger. Should have the same size as Figures 2,5,6.

Response:  
These all now are the same size.

Comment:  
The multi-panel Figures 4 and 8 should be enlarged.

Response:  
We enlarged Figure 4 somewhat. Figure 8 is constrained by the panel arrangement.

Comment:  
Caption Fig 2: "desscribed" -> "described"

Response:  
Thanks for noticing this typo, which has been fixed.