

Reply to Referee #2

Dear Referee #2,

First of all, we would like to thank the referee for your helpful comments. We have studied your comments carefully and have made the necessary corrections according to the comments. In addition, wording of the original manuscript was revised by a native speaker. We feel that the revised manuscript is a great improvement on the original. We summarized points of revision below in reply to the comments.

(The referee's comments are indicated in red.)

Instrument: Instrument:

The radiometer is operated in double side band mode (line 11, p.1911). It would be interesting to know how the authors deal with the other sideband.

“We have confirmed there is no significant line to disturb the ClO spectrum from the other sideband by using the forward model calculation with molecular line parameters listed in JPL Submillimeter, Millimeter, and Microwave Spectral Line Catalog. Therefore, we ignore the line from the other sideband in retrieval process.”

Are there any significant lines in the other sideband? Is it perfectly DSB?

“Sideband suppression ratio was estimated to be about 0 dB (it means almost perfectly DSB) by observing the O₃ spectrum at 203.4 GHz. We adopted this value to the ClO measurements at 204.3 GHz because the frequency difference between the O₃ and ClO is small enough to assume the same value.”

The instrument is very narrow beam (line 26, p. 1910) what is excellent. On line 4, p. 1915 they say that the lowest elevation angle is 15° due to sidelobe effects. What is the sidelobe suppression and at what angle is the sidelobe showing up?

“As the referee mentioned, the original description about “side lobe” is not correct. This means that there is a mountain at the direction of observation, and therefore, when the observation angle is below 15 degree, the beam is suppressed by the mountain. We improve the manuscript as follows;”

The lower elevation limit was set to avoid the radiometer beam suppression by a mountain which is located at the direction of observation.

Observation method:

The given equations are difficult to read due to typesetting and they are erroneous.

Line 22, p. 1912: $e^{-\tau}$ is the transmissivity and not the absorption coefficient. I

recommend to modify the following equations with a better typesetting for better readability. Use $e^{-\tau}$ instead of $\exp(\tau)$. Replace the angles like EL_{ref} by α or similar. It would be even easier to replace $e^{-\tau}$ by t , the transmissivity.

As the referee mentioned, the original description that “the absorption coefficient is given by $\exp(-\tau)$ ” is not correct. Because τ is the optical depth, $\exp(-\tau)$ is the transmissivity. According to the comment, we have changed “absorption coefficient” to “transmissivity”. In addition, we have revised the type set pointed at the comment (eg., $\exp(-\tau)$, EL).

There is an error in equation (2) and (3). The very first term with T_{line} should not be divided by $\sin EL$. Equation (2) and (3) could be rewritten as:

$$T_{ref} = T_l t_{ref} t_{pl} + T_{trop} (1 - t_{ref}) t_{pl} + T_{pl} (1 - t_{pl}) + T_{rec}$$

where I used T_{rec} instead of T_{sys} as actually $T_{sys} = T_l + T_{rec}$

$$T_{obs} = T_l t_{obs} + T_{trop} (1 - t_{obs}) + T_{rec}$$

We believe that the equations (2) and (3) are correct. First of all, we assumed that the optical depth is uniformity in troposphere. Because the reference angle is not equal to the observation angle, the air mass toward the line of sight at the reference angle is different from that at observation angle. When the optical depth toward the zenith is defined “ τ ”, the optical depth toward the elevation direction of “ EL ” is expressed as $\tau/\sin(EL)$ (Parrish et al., 1988).

In a same manner, if we put T_{line} as the intensity of stratospheric ClO spectrum toward the zenith, the intensity of the ClO spectrum observed toward an elevation angle of EL should be divided by the air mass factor of “ $\sin(EL)$ ”. For these reasons, we divided τ and T_{line} by $\sin(EL)$.

Line 11, p. 1913.

T_{trop} is the equivalent temperature of the troposphere. Give details of how it is determined!

Although previous works such as Parrish et al. (1988) reported that T_{trop} is estimated to be by ~ 7 K lower than the temperature near surface at microwave region, we assumed

that T_{trop} is equal to T_{hot} as following reasons. First, we put T_{hot} to a constant of 300 K, because the hot load puts in the room where the temperature was well controlled. Next, as the results of measurement of the temperature near surface at Atacama highland, the temperature near surface is estimated as by ~ 10 K in daytime and ~ 25 K in nighttime smaller the T_{hot} , respectively. Therefore, we inferred that the difference in temperature between T_{trop} and T_{hot} is typically within ~ 30 K, corresponding to the error in T_{trop} of $\sim 10\%$. For these reasons, we assumed $T_{trop} = T_{hot}$. In addition, we discussed in section 4.2.4 the retrieval error due to this difference of 30 K.

Line 11, p. 1914

It should read P_{obs} and P_{ref} . I believe that equation (8) is wrong. The factors with $1/\sin EL$ are not needed and should be deleted. The sign in front of T_{trop} is a minus and not a plus. There are however terms missing. Equation (8) can be written as

$$T_l = \frac{\left[\frac{P_{obs} - P_{ref}}{\alpha} - T_{trop} (1 - t_{obs} - t_{pl} + t_{ref} t_{pl}) \right]}{t_{obs} - t_{ref} t_{pl}}$$

We believe that equation (8) is correct.

For the reason as the reply about equation (2) and (3), the factors with $1/\sin EL$ are needed.

The sign in front of T_{trop} is correct at the equation is shown by the referee. However, the sign in front of T_{trop} at equation (8) is correct. This reason is that the sign in case arc is reverse at referee's equation and equation (8).

The derivation of the equation (8) is as follows.

From equation (1), $P_{obs} - P_{ref}$ is shown as follows.

$$P_{obs} - P_{ref} = \alpha [T_{obs} - T_{ref}] \quad (a)$$

The equation of parenthesis is expressed the residual between equations (2) and (3).

$$T_{obs} - T_{ref} = T_{line} A + T_{trop} B - T_{plate} \left[1 - \exp(-\tau_{plate}) \right] \quad (b)$$

where A and B is shown as follows, respectively.

$$A = \left[\frac{1}{\sin EL_{obs}} \exp\left(-\frac{\tau}{\sin EL_{obs}}\right) - \frac{1}{\sin EL_{ref}} \exp\left(-\frac{\tau}{\sin EL_{ref}} - \tau_{plate}\right) \right] \quad (c)$$

$$B = \left[1 - \exp\left(-\frac{\tau}{\sin EL_{obs}}\right) - \exp(-\tau_{plate}) + \exp\left(-\frac{\tau}{\sin EL_{ref}} - \tau_{plate}\right) \right] \quad (d)$$

For the reason as above, we assumed $T_{trop} = T_{hot}$. Because lossy plate is installed in our observation room, T_{plate} is assumed to be equal to T_{hot} . Therefore, we assumed that $T_{trop} = T_{plate}$.

Therefore, we rewrite the equation (b) as follows.

$$\begin{aligned} T_{obs} - T_{ref} &= T_{line} A + T_{trop} \left[B - 1 + \exp(-\tau_{plate}) \right] \\ &= T_{line} A - T_{trop} \left[-B + 1 - \exp(-\tau_{plate}) \right] = T_{line} A - T_{trop} B' \quad (e) \end{aligned}$$

where B' is as follows.

$$B' = \left[\exp\left(-\frac{\tau}{\sin EL_{obs}}\right) - \exp\left(-\frac{\tau}{\sin EL_{ref}} - \tau_{plate}\right) \right] \quad (f)$$

Finally, T_{line} is expressed as follows.

$$T_{line} = \frac{\frac{P_{obs} - P_{ref}}{A} + T_{trop} B'}{\alpha} \quad (g)$$

where α is expressed by equation (7).

Therefore, the sign in front of T_{trop} at equation (8) is plus.

Line 19, p.1914

Justify why it can be assumed $T_{trop} = T_{plate}$. This question is linked with the above one relative to T_{trop} .

For the reason shown above, we assumed $T_{trop} = T_{hot}$. Because lossy plate is installed in our observation room, T_{plate} is assumed to correspond to T_{hot} . Therefore, we assumed that $T_{trop} = T_{plate}$.

Data analysis:

Line 8, page 1915. Is local time identical to local solar time?

In this paper, “local time” was used as the local standard time express as “UT-4hrs”. On the other hand, “local solar time” was used as the time defined from the solar angle from

the meridian (Ricaud et al. 2000). There is a difference of 30 minutes between “local time” and “local solar time”. In order to focus on the data presentation and error estimation in this paper, we omit the section including the expression, “local solar time”.

Line 2, p. 1916.

The text enough difference... is twice. Delete.

We confirmed that this sentence is written twice. According the comment, we removed this sentence.

Line 14, p. 1916.

Why is S_R independent of altitude?

There are large variations of mixing ratio of stratospheric ClO (e.g., diurnal variation, seasonal variation, etc.). However, the accurate behavior of those variation and distribution is not clarified. Therefore, we gave the S_R which is the constant for altitude.

Line 20, p. 1916.

Give details about how the vertical resolution can be improved and how it relates to the width of the averaging kernels.

First of all, the correctly value of ε/ζ is 0.0016. “0.016” in manuscript is typographical error. We have revised the value of ε/ζ to 0.0016.

When ε/ζ is 0.016, the vertical resolution at 40 km is ~22 km. In addition, the peak of averaging kernel of 40 km lowers to 35 km. When ε/ζ is 0.00016, the vertical resolution at 40 km is ~16 km. However, the mixing ratio of ClO other than at 40 km is negative value.

Therefore, we set that the value of ε/ζ is 0.0016.

Results and discussion:

Line 20, p. 1917: It is said that spectra in Figure 3 have been averaged from 12:00 - 15:00. If I understand correctly actually it has been averaged over this time window but for ten days. The text is somewhat misleading. Please clarify.

Figure 3 showed the spectrum averaged 12:00 – 15:00 for twelve days.

We accept your comment. We revise this sentence as follows.

Figure 3 shows a typical averaged ClO spectrum, which was obtained between 12:00 and 15:00 local time (LT) averaged over 12 days over the Atacama highland;

Line 16, p. 1918: It is stated that the most reliable data are from 40 to 50 km altitude. Actually this would just correspond to one information as the altitude resolution is of the same order. Please be more specific regarding the information content of your measurement. For example determine the measurement response according Rodgers.

As the referee mentioned, the peak of averaging kernel between 40 km and 50 km is the same order. The averaging kernel shows that the information content of our measurement is very low. However, we analyzed the retrieval error (in section 4.2) and compared with the ClO profiles measured by NATAOS and AURA/MLS (in section 4.3). In this result, we showed that the mixing ratios of NATAOS measurements show the slightly positive bias to those AURA/MLS, which are ~13 % and ~18% at 40 km and 45 km, respectively but the AURA/MLS measurements agree with the NATAOS measurements within the error of NATAOS measurements.

In addition, we compare with the ClO profiles measured by NATAOS and JEM/SMILES. The ClO profile which is used by comparison is measured by JEM/SMILES at November 2009 and January 2010, because JEM/SMILE didn't observe the ClO line during the observational period of NATAOS. In this result, the mixing ratio at 50 km measured by NATAOS is larger than that measured by JEM/SMILES by ~8 %.

In the result of comparison with NATAOS and satellites measurements, it is stated that the most reliable data of NATAOS are from 40 km to 50 km.

According the comment, we have removed this sentence in section 4.1, and add the sentence at the end of section 4.3 as follows.

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In the results of comparison with NATAOS and satellites, the most reliable mixing ratio values in this study were those between 40 km and 50 km. The altitude range of reliable values in this study covered the altitude range included the altitude of where the stratospheric ClO mixing ratio peaked. In the next section, we will report the measurement of the diurnal variation of ClO focused the mixing ratios from 40 to 50 km.

Line 24, p. 1920. The effective temperature is assumed to be equal to the hot load temperature. What do you mean by effective temperature. Is it T_{trop} used before? If yes,

this would not be correct.

As referee mentioned, “effective temperature” is mean the equivalent temperature of the atmosphere below the stratosphere (T_{trop}). For the reason as above, we assumed $T_{\text{hot}} = T_{\text{trop}}$.

According to the comment, we have improved the description as follows.

T_{trop} is assumed to be equal to be hot load temperature.

The whole error analysis could be presented in a more compact way. All the figures dealing with the error could be summarized in one single figure. Please use a grid in the figures to facilitate reading of the values.

According the comment, we have revised the figures of error analysis to figure A. In addition, we have revised the section of error analysis as more compact.

Figure 4: Please explain why the error gets smaller the further away you are in altitude from the region of 40-50km where you get reliable data. Probably the information content is vanishing an the retrieved profile is approaching the a-priori one. But please specify otherwise this is misleading.

As the referee mentioned, the error bar became smaller as it got away from 40 km. This reason is that the content information of measurement is smaller as it got away from 40 km. Therefore, the retrieved profile of ClO draws near the a priori profile.

According to the comment, we have added the following sentence at end of the total error section.

In addition, the error bar at Fig 4 is shown the total of the random error. Because the information content is vanished the retrieved profile and the retrieved profile is approached to the a priori profile, the error bars get smaller the further away from the altitude region which is from 40 to 50 km.

Figure 11 right: Is the relative error relative to MLS or relative to NATAOS?

Figure 11 right is shown the relative error to AURA/MLS.

According the comment, we have revised Figure 11 to Figure B.

Figure 12: I see no arrows.

As the referee mentioned, there is no right-left arrows in Figure 12.

We have drawn the right-left arrows over Dcember 5 – 16 2009 in figure 11.

Technical Comments

At the beginning of the paper you should tell the reader that the instrument is called NATAOS.

Line 11, p.1908: ... spectral data at 204.3 GHz

Line 24, p. 1909: What is difficulty of spectroscopy?

Line 12, p. 1913: ... of atmosphere below the stratosphere. This is the troposphere ;-)

Line 2, p.1916: ...enough difference... this sentence is printed twice.

Line 8, p.1931: Geneva and not Genova. Genova is in Italy.

According to the technical comment, we have revised the manuscript.

In addition, we have revised the sentence line 24, p. 1909 as follows.

Because it is difficult that the stratospheric ClO line which is very weak intensity is observed by spectroscopy,

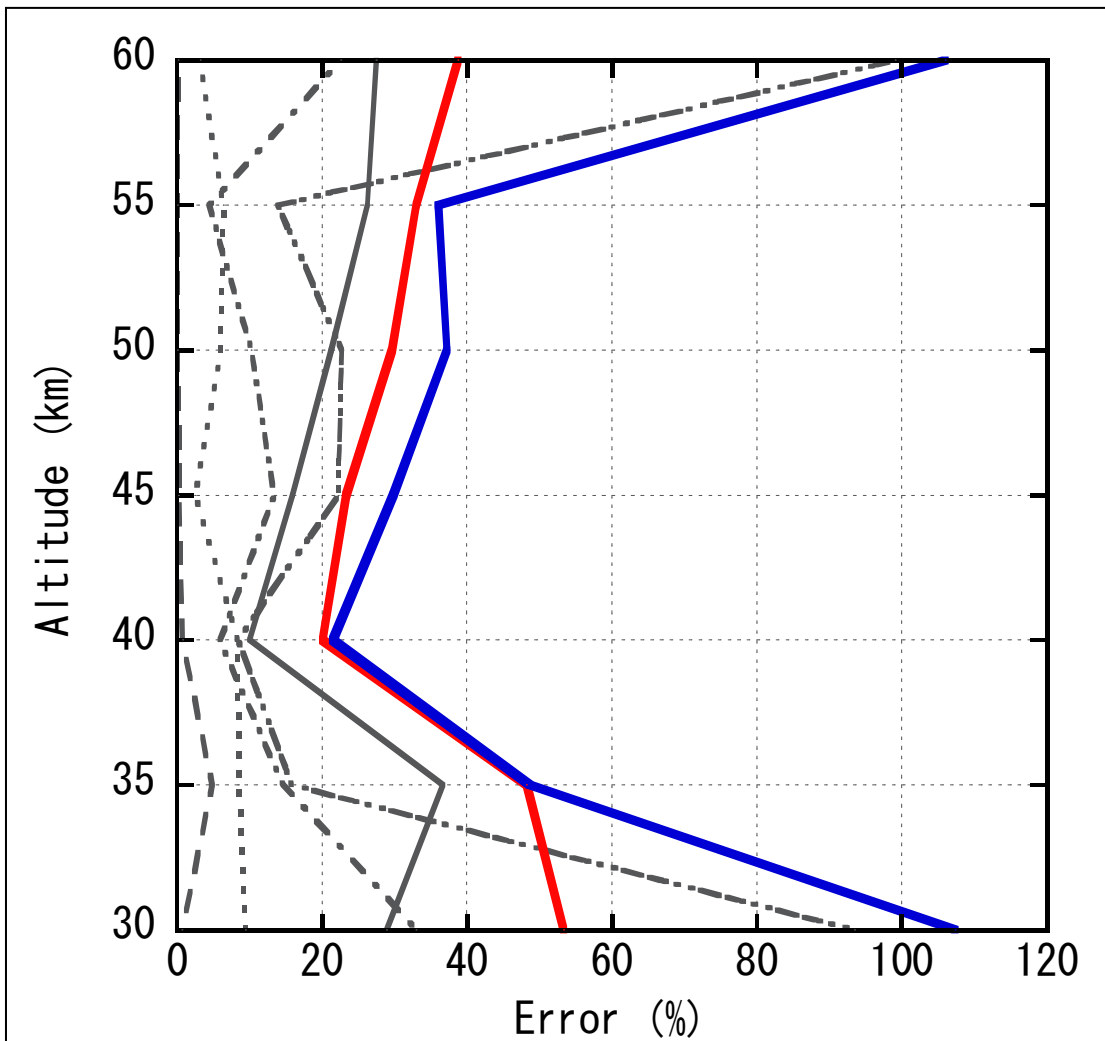
Reference list

Pickett et al (1992), Submillimeter, millimeter, and microwave spectral line catalog, Tech. Rep., 80-23, Rev. 3, Jet Propulsion Lab.

Nagahama et al (1999), Ground-based millimeter-wave observations of ozone in the upper stratosphere and mesosphere over Tsukuba, Earth Planets Space, 51, 1287-1296,1999

Conner et al (1995), Error analysis for the ground-based microwave ozone measurements during STOIC, JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 100, NO. D5, PP. 9283-9291, 1995

Ricaud et al (2000), Temporal evolution of chlorine monoxide in the middle stratosphere, J. Geophys. Res., 105, 4459-4469,2000.



FigA. Random error due to temperature profile (dash), a priori profile (day: dash-dot, night: dash-dot-dot), random noise on the spectrum (solid), and atmospheric correction (dot) and total of random errors (day: red-solid, night blue-solid).

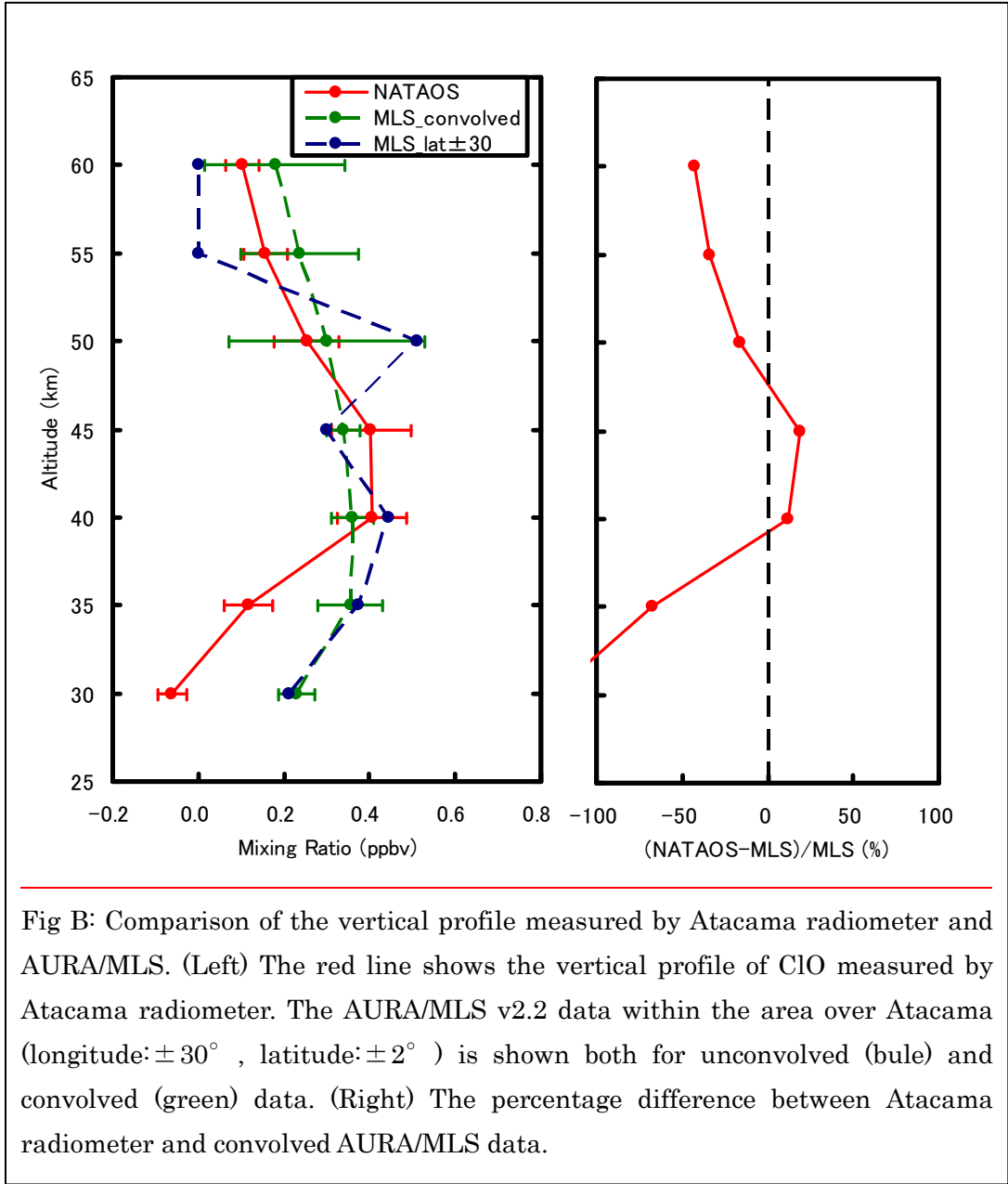


Fig B: Comparison of the vertical profile measured by Atacama radiometer and AURA/MLS. (Left) The red line shows the vertical profile of ClO measured by Atacama radiometer. The AURA/MLS v2.2 data within the area over Atacama (longitude: $\pm 30^\circ$, latitude: $\pm 2^\circ$) is shown both for unconvolved (blue) and convolved (green) data. (Right) The percentage difference between Atacama radiometer and convolved AURA/MLS data.