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Atmospheric Chemistry and Physics Discussions

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Interactive Comment

Interactive comment on "Analysis of actinic flux profiles measured from an ozone sonde balloon" *by* P. Wang et al.

P. Wang et al.

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We would like to thank Referee # 1 for the detailed comments, useful suggestions and illustrative figures. The paper has been revised according to the referee's comments and suggestions. The revised texts are highlighted in the paper. One subsection about the wavelength dependence of actinic flux has been added in Section 3 with one new figure, Fig. 2. A picture of the instrument has been included as Fig. 1. Some references have been included. All the questions are in Italic font, the answers are in blue normal font.

Interactive comment on "Analysis of actinic flux profiles measured from an ozone sonde balloon" by P. Wang et al. Anonymous Referee #1 Received and published: 5 January

2015

The actinic flux drives the photochemistry of the atmosphere. As such its behaviour and understanding of the processes that affect it, is of great importance. Surprisingly there are very few measurements of this quantity under varying atmospheric conditions. The work presented in this paper describes a new instrument that have the potential to greatly improve this lack of measurements of this important quantity. It may be noted that an equally important radiative quantity, the net radiative heating/cooling rate that drives the atmospheric circulation, is on an even worse footing when it comes to atmospheric profile measurements.

Considering that the instrument is uncalibrated the authors are able to obtain a lot of useful insight by including ancillary satellite and ground-based information in their analysis. The main weakness of the paper is the assumptions used in the radiative transfer modelling. A single wavelength is used to represent the broad-band response of the diode detector. This may have implications for the model/measurement comparison as shown below for Fig. 11d. Also the use of a single layer cloud sometimes precludes a deeper understanding of the measurements, see remarks about Fig. 7d below. The authors are encouraged to redo the model simulations with the improvements suggested below before final publication of the manuscript.

A: The single layer cloud was chosen to limit the number of free parameters because there are no multi-layer cloud products from the SEVIRI CPP algorithm. We have added a subsection on the wavelength dependence of the actinic flux (Sect. 3.2). In Sect. 3.2 actinic fluxes have been simulated at 5 wavelengths from 450 to 650 nm. The question about Fig. 11d has been replied in the specific remarks.

Specific remarks Page 31171, line 4: It is stated that actinic flux profiles have been measured by tethered balloons and aircrafts. It might also be mentioned that actinic flux relevant radiation profiles have been measured by balloons in the stratosphere (Schiller et al, 1994) and the troposphere and stratosphere (Kylling et al., 2003). Furthermore, *accurate spectral actinic flux measurements were made by Hofzumahaus et al., 2002.*

A: The references have been included in the introduction.

Page 31171, lines 23-24: The Junkermann (1994) and Palancar et al. (2011) papers are mentioned, but the results they obtained are not summarised as is done for the other cited papers. For completeness please also do so for these two references.

A: The results from these two references are summarized and included in the introduction section.

Page 31172, lines 4-20: The wavelength dependence of the actinic flux should be further emphasized. The vertical profile of the actinic fluxes relevant for ozone and nitrogen dioxide are very different due to the processes that affect them. This should be discussed in connection to what the diode instrument measures.

A: Thank you for the suggestion. The text in the introduction has been revised. The simulation of actinic fluxes at different wavelengths has been added to Sect. 3.

Page 31172, lines 21-28: It might be mentioned that the CMF is wavelength dependent as demonstrated by Seckmeyer et al. (1996).

A: The wavelength dependence of CMF has been included in the text now.

Page 31172, line 24: It is stated that the CMF is the "ratio between UV radiation ...". Clearly the CMF is not restricted to UV radiation. Please remove "UV" from the sentence.

A: 'UV' has been removed.

Page 31173, line 5: A plot showing the spectral response of the diode should be included. This is important documentation of the instrument and makes it easier to understand what it is actually measuring. See also comments to Fig. 11d below.

A: We did not measure the spectral response of the diode, because we do not have the

ACPD
14, C12619–C12632, 2015

equipment to do this. The LED used in this paper is similar to the Radio Shack green LED, which spectral response is shown in Fig. 2 of Brooks and Mims (2001). The spectral response covers the range from 450 nm to 580 nm and is asymmetric. The peak of the response function is at about 560 nm whereas the middle of the response function is close to 525 nm. This has been discussed in the revised paper. Brooks, D. R., and F. M. Mims III (2001), Development of an inexpensive handheld LED-based Sun photometer for the GLOBE program, J. Geophys. Res., 106(D5), 4733–4740, doi:10.1029/2000JD900545.

Page 31173, lines 5-27: Please include following information:
– If you measured the angular response of the instrument, please include plot.
– A picture showing the instrument would be helpful.
– What is the temporal sampling frequency?
– Where in the balloon payload is the instrument located? Please discuss possible effects of shadow from the balloon and/or the payload.

A: A picture of the instrument has been added as Fig. 1. The temporal sampling is 1 second, but the data are averaged over 10 seconds. The ozone sonde is attached to the balloon using a line of 15-20 meters long and the light sensor is located at 2 m below the ozone sonde.

Since the ozone sonde is connected to the balloon using a long line of 15-20 meters, we do not expect that the shadow of the balloon affects the light sensor measurements. Furthermore, the solar zenith angle (SZA) is usually larger than 30 deg during the measurements, so the shadow of the balloon would not be directly below the balloon. However, in case SZA < 30 deg, at high altitudes (30 km) the light sensor went sometimes into the shadow of the balloon for a few seconds, because of the rotation (swing) of the light sensor below the balloon. These data points have been identified and removed already. This information has been added to the text in Sect.2.

The angular response of the instrument has been checked before launch and was

ACPD
14, C12619–C12632, 2015

adjusted to within 2%. The small scale variations of the measurements above cloud top and clear-sky cases are smaller than 2%. This suggests that the angular response of the instrument is <2% during the measurements.

Page 31174, lines 12-25: Which ozone cross section and Rayleigh scattering cross section were used?

A: ozone cross section is taken from Johnston (1997). H.S. Johnston, personal communication (1997) to E.-P. Röth, R. Ruhnke, G. Moortgat, R. Meller, and W. Schneider, Berichte des Forschungszentums Jülich, jül-3340, 1997.
(http://satellite.mpic.de/spectral_atlas/cross_sections/Ozone/O3_Johnston(1997)_298K_408-599nm.txt)

Rayleigh scattering cross section is from Bodhaine et al., 1999. Bodhaine, B.A., N.B. Wood, E.G. Dutton, and J.R. Slusser, On Rayleigh Optical Depth Calculations, J. Atmospheric and Oceanic Technology, vol. 16, 1854-1861, 1999.

The references have been included in the paper and the text has been included in Sect. 3.

Page 31174, line 21: What is the justification for using a single wavelength in the radiative transfer modelling and not doing it correctly by calculating a spectrum and convolving the spectrum with the spectral response of the diode? See also comments to Fig. 11d below.

A: The reason for the approximation of using a single wavelength is that the scattering by clouds has hardly any wavelength dependence in the visible wavelength range. Furthermore, the wavelength dependence of Rayleigh scattering has less influence in the visible range than in the UV range. Another reason is that we do not have to simulate the absolute value of the actinic fluxes. The approximation of using a single wavelength is mostly valid for simulations at small solar zenith angles, say SZA < 45 deg. At large solar zenith angles (SZA > 60 deg), indeed a spectrum has to be simulated and

ACPD
14, C12619–C12632, 2015

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convolved with the spectral response of the LED. Simulations of actinic flux profiles at different wavelengths have been included in Sect. 3 in the revised paper.

Page 31175, line 9: is the 3 km x 6 km SEVIRI resolution latitude longitude or vice versa?

A: Longitude x latitude. The sentence has been revised.

Page 31176, line 15: The albedo used in 1D radiative transfer models is an effective albedo. As the altitude of the instrument increases the effective albedo 'seen' by the instrument will change as the instrument 'sees' a larger and larger area including the ocean to the west. While the effect is probably minor due to the low surface albedo, it might be worthwhile to mention.

A: The text has been revised.

Page 31177, line 24: How was it determined that the sky was clear? Are contrails allowed in clear-sky profiles?

A: The clear-sky was checked from the MODIS images and Total Sky Imager data at Cabauw. Contrails may be exist.

Page 31177, line 24, Fig. 2a and Fig. 3: The clear-sky actinic flux profiles have some periodic small scale variability. This may be caused by rotation of the balloon and hence the payload. It might be interesting to calculate the frequency of this variability in the actinic flux and see if it is consistent with the expected period for rotation of the payload. The periodic variability in the actinic flux should be larger when the instrument is exposed to the direct sun and less or absent when the instrument is inside a cloud. This is so because imperfections in the angular response are more evident in an inhomogeneous light field. Evidence for this behaviour is seen in Figs. 3a-e where little or no small-scale variability is seen inside and below the cloud and then it appears ones the instrument is above the cloud and exposed to the direct sun.

A: There are two possible rotations in our sonde system. One is the swinging of the

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14, C12619–C12632, 2015

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sonde below the balloon. This is considered to be a good thing, because it will keep the sensors out of the wake of the balloon, and so the potential of interference of the balloon on the temperature, humidity and ozone measurements is reduced. As the balloon is obscuring different parts of the sky, an effect on the radiation field is likely. The period of this swing is estimated to be between 10 and 20 seconds.

The other rotation of the system - including the light sensor - is spinning along a vertical axis. In 2006 and 2007 we used a line made of a twisted natural fiber. Untwisting of the line during the flight is quite likely, although we have never seen it happen. We hope and think this spinning does not affect any of our sensors.

We estimated the small scale variations using the data between 15 and 30 km in the ascending profiles. Of the 63 profile measurements, 59 have variations smaller than 2%. Based on the uniform response test before launch, the angular dependence of the instrument is as expected. The text in Sect. 4.2 has been revised accordingly.

Page 31177, lines 11-12: May also sub-visible cirrus and far away clouds contribute here?

A: Indeed there could be a contribution from sub-visible cirrus and small scale clouds. Text has been revised according.

Page 31177, lines 21-22: It is stated that the 'altitude dependence of the internal radiation field in a scattering atmosphere depends mainly on the optical depth'. It is not defined what is meant by 'internal radiation'. Also, depending on the wavelength, altitude distribution of the optical thickness and the magnitude of the optical depth, the amount of overlying atmosphere and its properties, possible pollution in the cloud (single scattering albedo smaller than 1.0) and surface albedo may play a role. The phase function may also be of importance depending on the phase of the cloud. Thus, this sentence appears to oversimplify as it stands. Finally, the expression within the parenthesis may be omitted. It is trivial that " = 0 at TOA.." etc.

ACPD

14, C12619–C12632, 2015

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A: Thanks for these suggestions. The text has been revised.

Page 31180, line 25: Please state what the magnitude of the SEVIRI COT negative bias is.

A: The COT retrieval error is about 15% according to the MSG CPP product description. We do not know the magnitude of the SEVIRI COT negative bias because of the small number of data used in the paper.

Page 31183, lines 6-8: It is stated that "COT values in the maps are averaged over 0.1 degree grids, while the COT values are given for single pixels". But in the caption of Fig. 7c the single pixel values are from 0.1 x 0.1 pixels. Are there two types of 0.1 degree pixel values? What are they and what are the differences? Please clarify.

A: The grid is always 0.1x0.1 degree. Within the grid box, there are about 5 SEVIRI pixels. Two types of COT values are used here: one is the mean of the 5 COT in the 0.1x0.1 degree grid box, which is used for the images. the other is the COT value of every SEVIRI pixel in the grid box, not averaged, which is used in the simulations. It has been clarified in the revised paper.

Page 31183, line 17: It is straightforward with a radiative transfer model to include several cloud layers and this should be done to better reproduce the measurements. In Fig. 1 (this review) single cloud layer (red) and two cloud layers (green) simulations are included. The total optical depth was 25 in both cases and the solar zenith angle as in Fig. 7d. The wavelength is 550 nm, the surface albedo 0.15 and no aerosols were included. Clearly the two layers simulation better resembles the measurements in Fig. 7d. The really intriguing feature with the measurements shown in Fig. 7d is the decrease in radiation as the altitude increase from about 0.5 to 2.0 km, that is between the two cloud layers. Below a sufficiently thick cloud little of no vertical variation is expected as shown by the model results in Fig. 1 (this review), green line. The behaviour of the measurements in this altitude range is unexpected. Aerosols may play a role, but it is not at all clear to this referee what the reason is for this behaviour.

ACPD

14, C12619–C12632, 2015

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A: We have also done simulations using two cloud layers for this case but did not show them. The result is very similar to figure 1 in this comment: we cannot simulate the decrease in the radiation when the balloon rises from 0.5 to 2.0 km altitude. It could be due to the assumed horizontal homogeneity of the two cloud layers in the simulation. It is possible that the balloon went through one cloud layer first, with no second cloud layer above, then moved into the second cloud layer after a horizontal drift below the second cloud layer.

Page 31184, line 18: Should it be 0.1-degree box instead of 1-degree?

A: It should be 0.1-degree.

Page 31184, lines 21-22: It is stated the balloon passed through the cloud top resulting in a sharp peak in the actinic flux at 3 km. In the next sentence it is stated that the "COT increased again at about 4 km". But then the balloon was above the cloud? Or was there another cloud? Or was the ballon flying at 4 km and the COT of the underlying cloud increased? Please clarify.

A: It was the balloon flying at 4 km and the COT of the underlying cloud increased. This has been clarified in the revised paper.

Page 31184, line 24: The measured and simulated profiles are said to follow each other "very well". May you please quantify "very well" by providing rms differences or similar?

A: We have revised the text. The rms difference is difficult to quantify.

Page 31184, lines 25-26: Please prove your conclusion by varying the extinction coefficient with altitude and thus make the simulated actinic flux agree with the measurements.

A: The text has been revised. We did not do extra simulations for this comment.

Page 31185, line 5: What is meant by "properly simulated"?

ACPD
14, C12619–C12632, 2015

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A: The sentence has been revised.

Page 31185, lines 6-23: For large solar zenith angles a difference between the measured and simulated actinic flux is seen below about 10 km in Fig. 11d. It is speculated that full spherical geometry is needed to explain this discrepancy. However, the DAK simulations are made for the single wavelength of 550 nm under the assumption that this single wavelength best describes the broad band response of the diode. This assumption may hold for small solar zenith angles, but not necessarily for large solar zenith angles. The clear-sky actinic flux varies with wavelength (Rayleigh scattering). To investigate this effect the actinic flux was calculated as a function of altitude for wavelengths of 450, 550 and 650 nm for a solar zenith angle of 75 degree. A water cloud with optical thickness of 30 evenly distributed between 0.1 and 1.0 km, was included in the simulations. Pseudo-spherical geometry was assumed. In Fig. 2 (this review) the actinic flux normalised to its value at 30 km is shown for the three wavelenghts. It is seen that the actinic flux varies considerably with wavelength below about 15 km and that a wavelength of 650 nm resonably well resembles the measurement presented in Fig. 11d. Thus the choice of 550 nm in the DAK simulations is not representative for large solar zenith angles. This example very clearly demonstrates the danger involved when using a single wavelength to simulate an instrument with a broad spectral response. Rather then using a single wavelength, the DAK simulations should be made for all wavelengths covered by the diode and the resulting spectrum convolved with the spectral response of the diode. Finally note the difference between the black and green lines in Fig. 2 (this review). For the green (black) line the cloud optical depth was evenly distributed between 0.1 (0.8) and 1.0 km. The black line best reproduces the red line in Fig. 11d of the manuscript, but it is not clear from the text how the vertical distribution of the optical depth was for the calculation presented in the manuscript.

A: Indeed the simulation at 650 nm fits the measurements better. However, we doubt that the green LED has much sensitivity at 650 nm, looking at the spectral data from Brooks and Mims (2001). We agree that the wavelength dependence of the AF simulation is important. Some simulations have now been included in Sect. 3 to show the wavelength dependence of AF. We agree that the wavelength dependence of the actinic flux may be the main reason for the difference between the measured and simulated actinic fluxes for this case. The simulation may not have significant improvement if a full spherical model is used. The text has been changed accordingly in the revised paper.

Fig. 2 in revised paper, Simulated actinic flux profiles at wavelengths: 450, 500, 550, 600, 650 nm at SZA = 30 and 75 degree. The cloud top is at 1.3 km, cloud base is at 0.8 km, cloud optical thickness is 30. The aerosol optical thickness is 0.18 at 550 nm and surface albedo is 0.15. The normalized actinic fluxes are shifted 1 km up in the y-axis.

Page 31187, line 5: After the simulations have been redone accounting for the spectral response of the diode instrument, the shapes of measured and simulated actinic fluxes will most likely agree for SZA > 75 degree and the conclusions may be changed accordingly.

A: We agree that at SZA > 75 deg the AF wavelength dependence is more important than at smaller SZA. Because we do not have actual spectral response measurements of our LED we are not sure whether the simulation at 650 nm would be suitable for our instrument. We have added a remark on this point.

Page 31194, Fig. 4a-b: Have you tried to use log-scale on both the x- and y-axes in Fig. 4a? And have you tried to use log-scale on the x-axis of Fig. 4B?

A: A log-scale for the x-axis is now used in Fig. 4b. In Fig. 4a the y-axis has been changed to Actinic flux ratio of cloud base and top.

Page 31195, Fig. 5a-b: Please mark the launch site in Fig. 5a or even better include a square marking the region shown in Fig. 5b. Fig. 5a looks like a MODIS image obtained directly from the MODIS web site. A little more work is warranted to make the

ACPD

14, C12619–C12632, 2015

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presentation clearer.

A: Fig. 5 has now been remade using MODIS data at 0.15x0.3 degree grid with the flight track on top of it. The white area indicates missing AOD data, this could be due to clouds.

Page 31195, Fig. 5c: It is not marked which lines correspond to the measurement and the model. Also, it would be interesting to include a model/measurement ratio or difference plot.

A: The legend has been added to the figure.

Technical remarks Page 31172, line 12: The sentence "the photodissociation of nitrogen ...." is unclear, please rewrite. Page 31175, lines 12-18: The sentences in this part are hard to read; please rewrite.

A: The sentences have been rewritten.

Page 31186, line 15: Replace "an large" with "a large".

A: Corrected

Interactive comment on Atmos. Chem. Phys. Discuss., 14, 31169, 2014.

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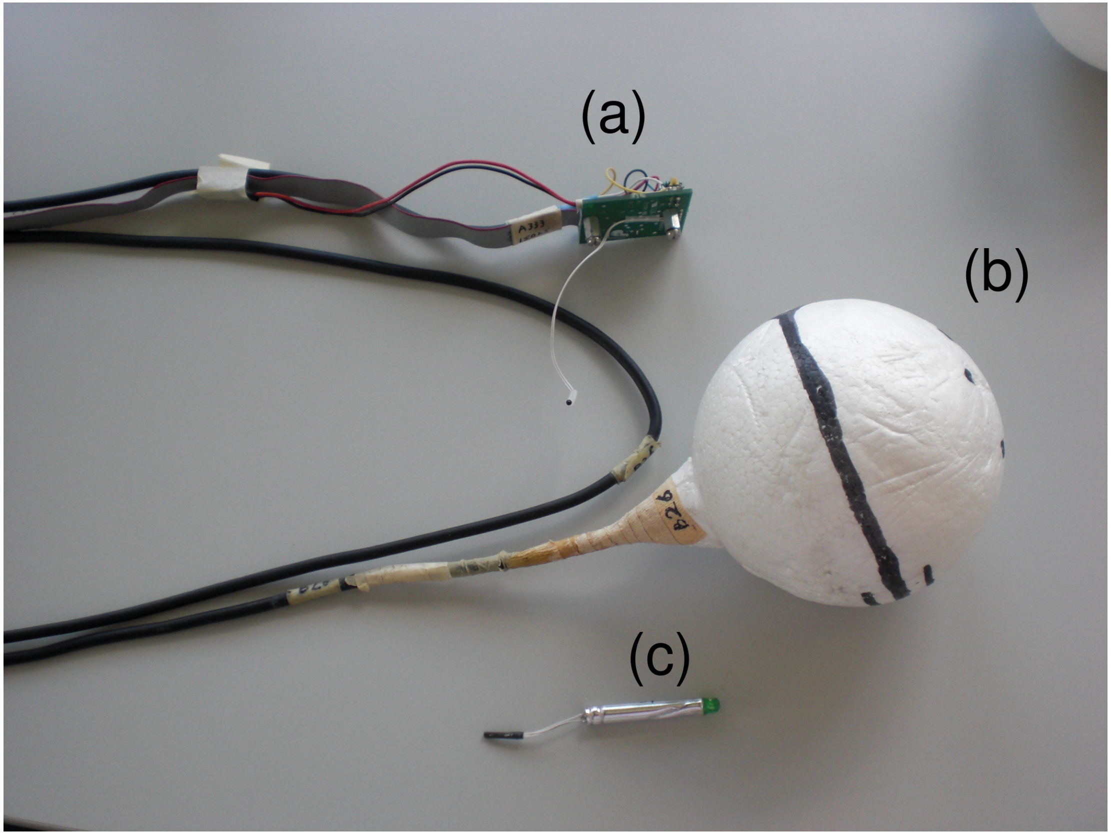

Fig. 1. Photo of the light sensor: (a) data transmitter (b) sphere, (c) green LED.

ACPD
14, C12619–C12632, 2015

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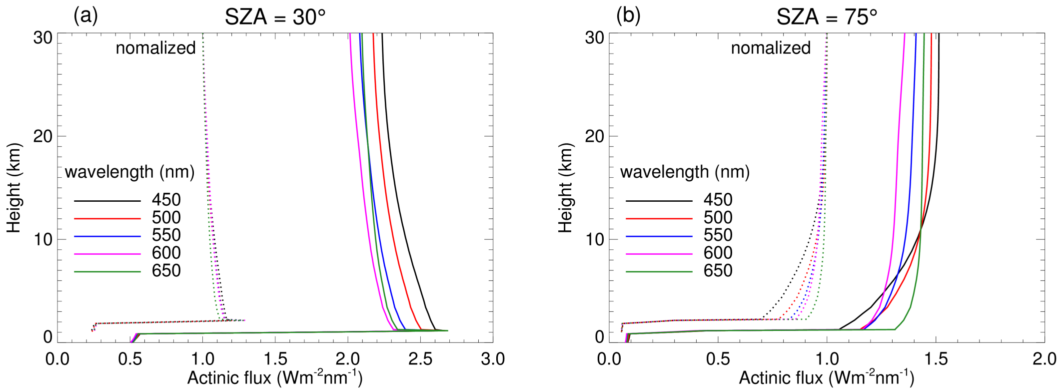

Fig. 2. Simulated actinic flux profiles at 5 wavelengths.

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