Atmos. Chem. Phys. Discuss., 7, S6305–S6318, 2007
www.atmos-chem-phys-discuss.net/7/S6305/2007/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Effects of total solar eclipse of 29 March 2006 on surface radiation" *by* S. Kazadzis et al.

S. Kazadzis et al.

Received and published: 24 October 2007

MS-NR: acpd-2007-0231 Version: 1 Received: 1 June 2007, 14:50 CET Title: Effects of total solar eclipse of 29 March 2006 on surface radiation Author(s): S. Kazadzis, A. Bais, M. Blumthaler, A. Webb, N. Kouremeti, R. Kift, B. Schallhart, and A. Kazantzidis

Authors response to the referees: We would like to thank the two anonymous referees and C. Emde and L. Millan-Valle for their comments and suggestions on the paper. We have tried to answer and include all referees suggestions in the new document.

General response There have been a lot of additions in all sections in the text in order to try to explain more the physics behind the presented phenomena. Results of earlier studies have been included after the referees suggestions. There has been an effort to improve the precision and accuracy of language in describing the experiments. We decided not to change the order of the results presented in the text. That is because the ozone is a by-product of the direct irradiance measurements but we decided to keep the ozone discussion in the beginning as the limb darkening effects and the diffuse light entering the field of view are introduced already in the ozone section. We also included sentences trying to connect parts of the text and tried to have a more connected text following the referees suggestions. Citation styles and spelling have been rechecked. The answers to all referees comments are presented point by point below.

The new text that was added is always in brackets [ ] in this response file. Also, since the on-line ACP system does not understand some symbols (e.g. the quotations marks and the apostrophe) in some cases grammar in this document is not correct (eg: authors response).

Anonymous Referee #1:

Comments: Abstract 1) In the abstract, page 1, line 10, add the word extraterrestrial before "ET". It was corrected as suggested

Campaign information, instruments and modeling tools 1) FWHM was clarified (Full Width at Half Maximum).

2) (end of subsection 2.2) it may be useful to provide the standard and random errors of the measurements. A paragraph was added in the end of section 2.2: [The uncertainty on the absolute level of the quantities of all instruments described above is less than 10%, while for the spectroradiometric measurements is less than 5%. Since most of the issues discussed in this paper are described using ratios of quantities measured by the same instrument or relative changes of GI, DI or AF, the uncertainty on the results shown is expected to be lower than the above percentages. .]

3) Description of STAR model A paragraph was added in the model description section as suggested by the reviewer: [Model calculations have been carried out for both eclipse and non-eclipse conditions to obtain the variation of various radiative quanti-

ties during the eclipse, under real atmospheric conditions but without the presence of clouds. The simulations of the radiative processes in the atmosphere have been performed by an improved version of the radiative transfer model STAR (Schwander et al., 2001). It is based on a one-dimensional radiative transfer algorithm (Nakajima and Tanaka, 1988) that considers absorption and scattering (including multiple scattering) of air molecules, aerosol particles and atmospheric trace gases.]

Total ozone column 1) Page 9241, lines 8-11. Please explain more clearly this difference between the two days. Two sentences were added to explain the ozone difference: This large (~30 D.U.) difference between the two days can be attributed to a stratospheric change of the total column ozone amount. Such large day-to-day changes are not rare for spring at the latitude that the measurements took place.

Spectral measurements of solar irradiance during the eclipse 1) Page 9241 discussion of figure 2. Relative changes for the Global irradiance are described in figure 3 while for direct irradiance in figure 6. The purpose of this graph here is to have a general overview of the eclipse parameters while in the whole manuscript it is with figure 5 the only figures showing the eclipse effect on radiation levels

2) Page 9241 (discussion of Figure 2) A paragraph was added in the text to describe the variability mentioned by the reviewer: [The variability that is observed around 10.20 U.T. and around 12 U.T. is due to clouds passing in front of the sun. The effect is more pronounced in the DI measurements, as the GI represents the sum of the (weighted with the cosine of the solar zenith angle) DI and the diffuse irradiance components.]

3) Page 9242, line 24: 90:30 was replaced with 09:30 as suggested

4) Page 9243 lines 19-21: Corrected as suggested

Extraterrestrial flux and solar effective temperature calculations 1) Page 9245, lines 15-18 The transmittance derived and assumed constant during the eclipse period is calculated without taking into account any cloud effects. So the main assumption was

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constant aerosol optical depth. The text was changed from: [The derived sky transmittance,…] to [The derived cloudless sky transmittance,..] Cloud transmittance was difficult to be modeled and used for the purposes of this paper. However, figure 7 shows spectra unaffected from clouds (measured at cloud free conditions) and figure 8 distinguishes points that are affected or unaffected from clouds.

2) Page 9246 (discussion of figure 7) A possible explanation of the difference on the ET calculations is the measurement procedure of the two instruments mentioned in page 9246, lines 12-17. CCD measurement is almost instantaneous while Bentham measuring scanning time is ˜3 minutes. Changes in the radiation field for these 3 minutes can cause wavelength (due to the different timing of the irradiance measured at each wavelength) dependent changes in the calculated ETs.

Interactive comment from L. Millan-Valle

1) 9236, Line 15. Error corrected.

2) Global and direct irradiance and actinic flux explanation. The description of these radiation quantities was included in the introduction. A paragraph was modified / added: [In this study we investigate the effect of the solar eclipse on measurements of several radiation quantities during a two-day campaign at Kastelorizo. Such quantities are: global irradiance (GI), which is the irradiance measured on a horizontal surface, the direct irradiance (DI), which represents the direct sun irradiance component and actinic flux (AF), which represents the radiation measured by a spherical surface.]

3) A paragraph was added providing the references of the issue suggested by the referee: [Bojkov (1968) reported results from Dobson spectrophotometric observations during the solar eclipse of May 1966 and concluded that an increase of 14 Dobson units (DU) was observed at the maximum phase of the eclipse. In that paper a review of total ozone measurements during a solar eclipse was presented, and it was emphasized that similar results were also reported in other studies based on Dobson ozone observations [Svensson, 1958; Stranz, 1961].]

4) NILU (Norsk Intitutt for Luftforskning) instrument was defined as suggested

5) Two paragraphs were added to the text (ozone section) in order to clarify the ozone analysis provided in this work: (see also comments on the anonymous referee #2 – ozone section, below) [As mentioned in the introduction, the spectral dependence of the measured DI due to the limb darkening of the sun becomes relevant during measurements performed at an eclipse period. Due to this spectral dependent change of the ET, the wavelength pairs (ratios) that are used in the differential absorption method (Kerr, 2002) for calculating total column ozone, are also affected from the LD and result in an error on the calculated ozone.] and [Brewer DS measurements are performed with a finite field of view. Therefore there is inherently some fraction of the diffuse irradiance (aureole and Rayleigh components) entering the instrument measuring the direct irradiance (Arola and Koskela, 2004). The magnitude of this effect depends on the field of view and the wavelength but also on the air mass factor.]

6) Page 9241, line 10. A paragraph was added to comment on this day to day ozone change. [This large (˜30 D.U.) difference between the two days can be attributed to a stratospheric change of the total column ozone amount. Such large day-to-day changes are not rare for spring at the latitude that the measurements took place.]

7) Figure caption 1: Corrected as suggested.

Interactive comment of C. Emde:

The references you are suggesting have taken into account for the revised version of the paper.

Additions The results of Emde and Mayer (ACP Eclipse special issue) are now reported in this work. In the conclusions section it was added: [The comparison of model results and measurements showed that previous 1D model calculations underestimate this spectral limb darkening effect especially close to the totality of the solar eclipse. 3D model calculations performed by Emde and Mayer (2007) reported that 3D calculations

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show that the radiation decreases much more for shorter wavelengths than the 1D model would suggest due to limb darkening. They also quantified the uncertainty of the 1D approximation used for different times of the eclipse (eclipse phases). This result was confirmed by measurements from two different instruments presented in this study.]

Anonymous Referee #2:

Specific comments 1 Introduction

- The references suggested by C. Emde were added; also the Emde and Mayer paper was added.

- There have been considerable additions in the text and especially in the Total ozone section describing the reasons behind the effects seen. (See also comment responses a, c and d in the total ozone section of this manuscript)

- A paragraph was added providing the references as suggested by the referee: [Bojkov (1968) reported results from Dobson spectrophotometric observations during the solar eclipse of May 1966 and concluded that an increase of 14 Dobson units (DU) was observed at the maximum phase of the eclipse. In that paper a review of total ozone measurements during a solar eclipse was presented, and it was emphasized that similar results were also reported in other studies based on Dobson ozone observations [Svensson, 1958; Stranz, 1961].]

The reference: Stranz: D. Ozone measurements during solar eclipse. Tellus, 13. 276-279, 1961, was added to the reference list

2.2 Instrumentation

- Institute acronyms were added to the instrument description as suggested.

- There were no special corrections applied to the Bentham and Brewer data. Both instruments are using diffuser input optics with angular responses close to ideal so no

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cosine correction was applied. In addition no temperature or other corrections were applied for both instruments. The Brewer instrument is a double monochromator so no stray light correction was applied. The referenced campaign papers include information about technical issues of the two instruments. Here, nothing was added as no specific corrections were applied.

- [zenith radiance] was added as suggested.

2.3 Modeling of the ET…

- What is the modeled ET needed for this study ? A sentence was added: [For the specific study, the 1D modelled ET was used to compare its theoretical results of the LD effect on the ET, with the results derived from the measurements performed during the described campaign.]

- What kind of features are expected during the eclipse ? Answering this question/comment and in order to enrich the manuscript with more physics behind the phenomena described, we have added the paragraph below: [To determine solar radiation quantities reaching the Earths surface, the ET solar radiation is used, for which the scattering and absorption processes can be spectrally modeled. In general the ET solar irradiance at each wavelength is given as an average over the whole solar disc. During different eclipse periods, the moon covers different parts of the limb and the center of the sun. Thus the spectral dependence of the limb darkening of the sun becomes relevant.]

3 Total column ozone

- The wavelengths used in the Brewer algorithm are now mentioned as suggested: […at the standard Brewer Ozone wavelengths (306.3, 310.1, 313.5, 316.8 and 320.1 nm)]

-A paragraph was added to describe the effect of the limb darkening to the ET and to the total ozone calculation from the Brewer spectrophotometer: [As mentioned in the

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introduction, the spectral dependence of the measured DI due to the limb darkening of the sun becomes relevant during measurements performed at an eclipse period. Due to this spectral dependent change of the ET, the wavelength pairs (ratios) that are used in the differential absorption method (Kerr, 2002) for calculating total column ozone, are also affected from the LD and result in an error on the calculated ozone.] A reference was added to the reference list: Kerr, J. B., 2002: New methodology for deriving total ozone and other atmospheric variables from Brewer spectrophotometer direct Sun spectra. Journal of Geophysical Research, 107(D23), 4731, doi: 10.1029/2001JD001227.

- The reduction in DI measurements at 70% eclipse coverage corresponds to an air mass factor higher than 3, if measurements were performed under normal (non eclipse) conditions. These measurements are usually discarded in the standard Brewer total ozone measurements.

- A paragraph was added to explain more the phenomenon behind this [contamination] effect: [Brewer DS measurements are performed with a finite field of view. Therefore there is inherently some fraction of the diffuse irradiance (aureole and Rayleigh components) entering the instrument measuring the direct irradiance (Arola and Koskela, 2004). The magnitude of this effect depends on the field of view and the wavelength but also on the air mass factor.] A reference was added: [Arola, A. and T. Koskela, "On the sources of bias in aerosol optical depth retrieval in the UV range," J. Geophys. Res, 109, D08209, doi:10.1029/2003JD004375, 2004]

- in Figure 1: the percentage 70% was chosen as an indicative number to show the described effect.

4 Spectral measurements

- Title of the section was changed as suggested

- This figure was included only for the reader to have a picture of the eclipse effect and the solar zenith angle effect on the measurements. It is not used to quantify any of the eclipse effects and that is the reason that it is not in any of the subsections of section 4. Units are included in the Y – axis of figure 2 and also the Brewer instrument is mentioned in the figure caption.

- With the use of DI spectroradiometric data the spectral aerosol optical depth could be derived by using the Beer – Lamberts law and the methodology that is described in (Marenco et al., 1997). Marenco, F., Santacesaria V., Bais A. F., Balis D., Di Sarra A., Papayannis A.,and Zerefos C. S.: Optical properties of tropospheric aerosols determined by lidar and spectrophotometric measurements (PAUR campaign), Appl. Opt., 36, 6875– 6886, 1997. Was added to the references.

4.1 Global irradiance flux

- To clarify how the normalization was performed we have included the text below: [In more detail, first we have calculated the ratio A = [GI (,) / GI (,)] for the (cloudless) 28th of March (where is the wavelength, the solar zenith angle and the solar zenith angle at local noon) and afterwards we have multiplied GI (,) on the eclipse day with the factor A for every and .]

- A text was added in this section to answer and clarify the percentages given for the wavelength ratios described in figure 3. [The changes of these wavelength ratios are describing how the limb darkening is affecting GI measurements at the earths surface. This effect leads to a faster decrease of the GI at lower wavelengths than the GI at higher ones. The above given percentages indicate that for 99% sun coverage GI at 312nm is decreasing 20%, 10% and 5% more than the GI at 380, 340 and 320 nm respectively.]

- 11:15 was changed to 11:00 UT as suggested

- The reason for the more pronounced eclipse effect on GI than the AF was discussed based on the Kopke paper as suggested. A paragraph was added: [As the eclipse

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progresses the ratio in the eclipse day becomes lower compared to the previous day, suggesting that GI is affected more by the eclipse than the AF. The reason is the faster decrease in the direct irradiance compared to the diffuse irradiance during the eclipse which will have a more pronounced effect on GI than on AF. Due to the missing cosine weighting in the AF, the diffuse radiation far from the zenith contributes more strongly to the signal. Therefore the relative contribution of the direct component in the AF is systematically lower than in the GI (Koepke et al., 2001).]

- Additional information about the model used in the mentioned section described using the following paragraph: [GI and AF values were calculated from the libRadtran model (Mayer, B., and A. Kylling, 2005). The radiative transfer equation was solved with the discrete ordinates algorithm, using six streams and pseudospherical correction. The Air Force Geophysical Laboratory (AFGL) U.S. standard atmosphere profiles were used for ozone, temperature and air pressure. The type of landscape suggests a relatively small surface albedo, thus the spectrally constant values of 0.03 was used for the while UV region.] A reference as added to the reference list: Mayer, B. and Kylling, A. Technical note: The libRadtrans oftware package for radiative transfer calculations -description and examples of use. Atm. Chem. and Phys., 5: 1855-1877, 2005.

- The introduction to the photolysis rates has been changed so to indicate the motivation of describing these parameters. The new text is: [As it was shown, the LD effect has an impact on the GI and AF measured at the ground. The impact can be seen during the eclipse, by the faster decrease of the GI and AF at shorter wavelengths than the one at higher ones. As it is known, JO1D and JNO2 photolysis rates can be retrieved from the AF measurements. Furthermore, they are sensitive to the AF at different wavelength bands (JO1D around 307 nm and JNO2 around 380 nm). Thus, the LD effect can be clearly seen also when measuring these two photolysis rates. The results in figure 5 show that the LD effect on the calculated photolysis rates leads to a faster decrease of the JO1D photolysis rate than the one of JNO2, as it was expected to be. Both rates and their ratio are shown in figure 5.]

- The sentence was changed to: [The calculated photolysis rates are sensitive to the actinic flux at different wavelength bands (JO1D around 307 nm and JNO2 around 380 nm).] [Depending on the solar zenith angle] was eliminated. The old sentence has the purpose to indicate that the main contributing wavelengths of 307nm and 380nm that were mentioned are changing depending on the solar angle. That is because for higher solar angles eg: JO1D is [sensitive] to the actinic flux from higher wavelengths. In any case the solar zenith angle dependency on the wavelengths of the actinic flux is not adding something new to this work so it was not included in the new version.

4.2 Direct irradiance

- First two sentences of this section were changed to: [The measured DI was corrected for the changing solar zenith angle according to Beers law of extinction and as we are interested in relative changes, the above ratios were normalized to their values at around 10:00 UT.]

- It was the STAR model calculations and the sentence was changed to: [A similar pattern is seen also in the ratios 675 / 340 nm and 675 / 500 nm which were derived from the STAR model calculations.]

- The Arola paper and the problem of the diffuse irradiance entering the field of view have been included in the text (see similar comment on ozone section). Trying to have a more quantitive idea about the phenomenon we have calculated the diffuse irradiance entering the field of view of the Brewer instrument and its ration divided by the direct irradiance measured at various solar angles. For the aerosol optical depth measured at Kastelorizo, cloudless sky conditions and for air mass equal with 3 we have calculated a 0.5% and 2% for 360 and 305 nm respectively. But during the eclipse the radiation field is altered as Emde and Mayer, 2007 are describing due to the Limb darkening effect which could be an additional component to the above mentioned percentages.

- The paragraph was changed to: [The higher DI rations that can be seen after the totality compared with the ones before (left panel of figure 6), might indicate the effect of cirrus clouds appearing just after the total eclipse. These results for the spectral variation of the DI are very well confirmed by analyses of DI measurements with the CCD spectrometer, which show exactly the same behavior (see right panel of Figure 6).]

5 ET flux

- According to the referees comment the sentence was changed to: [Being a mixture of black body spectra of different temperatures the calculated spectrum at the top of the atmosphere, during the different phases of the eclipse, can be corresponded to a different effective temperature for each eclipse time (sun coverage percentage).]

- The word direct was used in the text as suggested.

- The comment has been taken in account and sentence was corrected to: [The dashed lines represent the STAR model calculations for different fractions of sun coverage..]

- In the same section it is mentioned that: [Spectra of DI were measured by means of the scanning spectroradiometer (Bentham DTM 300), and the CCD spectrometer, while measurements at single wavelengths were provided also by the 2 handheld Microtops sun-photometers. Zerefos et al., (2001) calculated using the same methodology the pre-eclipse ET spectrum and the ET at the eclipse maximum (88%) at Thessaloniki, Greece for the eclipse of 11 August 1999].

Probably this methodology it could be described with more. Main point is that the calculated from measurement ETs were normalized – divided by the percentage of the geometrical sun coverage at each eclipse point. For example for the 50% eclipse percentage the ET was divided by 0.5. So the remaining difference is due to the Limb darkening effect. This paragraph was changed to:

[It has to been mentioned that we compared the ET at no eclipse conditions with the measured (from DI) ETs at certain times (sun coverage percentages) during the eclipse. The latter was corrected (normalized) dividing it with the percentage of geo-

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metrical sun coverage at each point. For example the 50% eclipse ET (shown in the upper plot of figure 7) was first calculated from the DI measurements, then divided with a factor of 0.5 and finally compared with the non eclipse ET. The difference of the two is due to the limb darkening effect. If this effect was not existed all ET ratios would be equal to one and all temperature differences would be equal to zero for all wavelengths. We have calculated these ratios and temperature differences for various points (times) during the eclipse (shown in figure 8) while Zerefos et al., 2001 have calculated the same feature only for the maximum (88% sun coverage) of the eclipse.]

- We think that the explanation given above and the alteration to the text answer the comment about the increase of the ET at 10% sun coverage. The calculated ET (from DI measurements) is of course decreasing compared to the ET at non eclipse conditions for all points. But normalizing with the geometrical percentage of sun coverage someone can see more clearly the limb darkening effect. In the case of the 10% sun coverage in reality the calculated ET is of course decreasing due to the sun blocking from the moon. The non normalized ratio of: ETnon-eclipse / ETcalculated is equal with 0.945. That means that despite the 10% geometrical sun coverage and due to the Limb darkening effect and the reasons explained in the text, the ETcalculated has decreased only by 5.5%. Using the normalization that was described above we end up to this raise in the ET ratios as described in the text. The use of this normalization was included in order to see the LD effect at all points of the eclipse in order not having to present coverage percentages and ETcalculated decreases at each point (time) of the eclipse.

- The referees suggestion was added to the end of this section: [In general, modeled ETs and ETs inferred from measurements during times not disturbed by clouds show mostly good agreement [

6 Conclusions

- Solar radiation was used as suggested.

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- The paragraph was changed as suggested to: [The results were compared with changes in the extraterrestrial solar flux predicted according to the technique explained in (Köpke et al., 2001).]

- According to the referees suggestion the text was changed to: [It is suggested that this decrease in total ozone is an artifact due to the increasing contribution of diffuse radiation against the decreasing direct irradiance (that is used for the total ozone column retrieval) caused by the eclipse.]

- Response to the comment related with the [artificial] change of the ET: The word [artificial] was used because the parameter [ET] is not really changing (The ET calculates from the sun emission is of course not changing) but if it is calculated with the help of measurements at the earths surface we see a change that is due to the effect of the Limb darkening as explained in the text. - Remote Sensing techniques are referred here as the acquisition of information about the suns physical property from a distance. The sentence was changed to: [The limb darkening effect induces changes in the ET spectrum measured with the help of remote sensing techniques.] TECHNICAL

All technical suggestions have been taken into account and included in the text.

Interactive comment on Atmos. Chem. Phys. Discuss., 7, 9235, 2007.