Reply to Referee, Referee #2

We would like to thank Referee #2 for their constructive and useful suggestions. Many of them have been incorporated in the final version of the manuscript. Please find below our answers to general comments.

General Comments:

GC#1: The introduction has information that is not really relevant for the paper. All the volcanic eruption description (pag. 4095 Para. 15 and follow paragraphs until pag. 4096 Para. 5) does not contribute with the aim of the paper. Instead I recommend the author to make a better description of different methods used to get extended time series like the proposed by Lindfors A. et al 2013.

>> The authors think that the inclusion of the two most important volcanic events like El Chichón (1982) and Mt. Pinatubo (1991) it is relevant for this paper because it constitutes the proof of AOD series from MARK-I is able to properly detect the impacts of volcanic eruptions and is therefore a useful series for climate analysis.

The different methods used to extent time series are briefly described (from line 16 to 20, page 4095). However, we agree with the referee to improve the description of the different methods and it is done in the final manuscript.

GC#2: The method has to be rewritten. The method has to be supported by the mathematics and statistics used to end up with the AOD values you are presenting. It will help to better understand your results. There is not information about how you are treating the error propagation in your data, what is the uncertainty of your measurement? And how are you doing the cloud screening to your results? It is a really important part that has to be added in detail.

>> We like to state the inherent differences between the AOD retrieved my means of the Cimel AERONET and the GAW-PFR instruments. It is obvious that these instruments are reference instruments devoted to continuous aerosols monitoring. Many authors have been focused during years to the development of an accurate methodology, procedures and standardization to ensure the instrument long-term performance. However, we would like emphasize that Mark-I has been designed for astronomical purposes and thus has inevitably been subjected to continuous changes in hardware and software (mirrors changes, external mirrors cleaning, changes in photomultiplier…) during its long life by astronomical requirement. The obtaining of AOD from observations of the MARK-I is a secondary outcome and in no case is the ultimate purpose for which the instrument was designed. We have proposed the methodology to retrieve AOD information from solar observations with Mark-I but it is not possible for us to quantify the error propagation because some parts of the measurement process are quite complex and because all these reported changes in software and hardware. So, we cannot estimate the instrument precision in the same

way that is made for AERONET Cimel or GAW PFR. However, this handicap is counteracted thorough a comprehensive validation of AOD values using independent AOD observations (GAW-PFR and AERONET-Cimel) for many years (12 and 11 years, respectively), which is, in fact, the only objective way to assess the quality of the observations. We agree to include more information about cloud screening. Please, see response to Referee 1 GC#4.

GC#3: Pag 4102 Para. 15: You are saying: "The only exception for these thresholds was set during the period from1992 to 1993, when the Mt. Pinatubo eruption (June 1991) released huge amounts of volcanic aerosols into the stratosphere leading to an important decrease in solar radiation input as well as important positive anomalies in AOD. For this reason, the threshold in AOD for the Langley analysis was set in 0.3, an order of magnitude higher". From where did you come out with the 0.3?

>> This threshold was selected as a commitment solution to include enough V0's values to account for the variability in the calibration coefficient under such high AOD conditions. If the typical threshold of 0.04 was assumed, the number of Langleys would be 0 and 45 for 1992 and 1993, respectively. We considered that a threshold of 0.3, which led to 220 and 208 Langleys for 1992 and 1993, respectively, is enough to capture the variability of the instrument in this period.

GC#4: Pag 4102 Para. 25: Talking about V0 calculation you said: "The yearly V0 variation of Mark-I solar spectrometer determined from the Langley 25 analysis is shown in Fig. 3. A total of 24 402 V0 s have been obtained using this technique, being the rest of days without V0 information (about 16% of them) recovered by means of a cubic spline smoothing process. These values were subsequently reprocessed when a deficient calibration was observed, being the most important calibration problems associated to the existence of a fictitious diurnal cycle on AOD data. This problem in calibration procedure was identified by Cachorro et al. (2004, 2008)". Add one figure where you show how the data where looking before and after you apply the K-ciclo, it will help you to make a clear and better explanation of the problem and how it was solve.

>> In Fig. 1 one week of ~1-minute AOD values before (raw, in black) and after correction using the methodology proposed in this paper (in green) is presented. Raw data represents the AOD obtained using V0 from the smoothing spline curve (fig 3 of the manuscript), meanwhile corrected data represents the correction of this smoothed curve by means of the methodology developed by Cachorro et al. (2004, 2008). The calibration problem shown in this figure was caused by a change in the two mirrors of the coelostat performed on Jan 11th 1989.

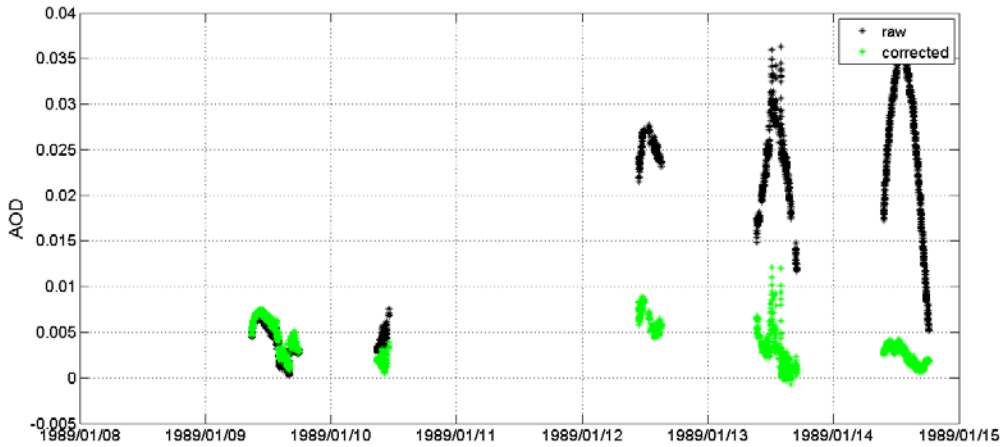

Figure 1: AOD in Izaña in the period January 8th to 14th extracted after Langley calibration (raw, displayed in black), and after the correction (in green) proposed by Cachorro et al. (2004, 2008).

GC#5: Add the scatter plots between AERONET and GAW AOD results with Mark-I AOD it will help again to clarify the results.

>> Done. Scatter plots against PFR and Cimel for every year have been included. See Referee 1 GC#1 and Referee 1 figure 8.

GC#6: In the conclusion you are mention: "However, our results indicated that calibration errors are not dependent on the aerosol load and therefore, V0 can be calculated using this technique in those days with relatively high turbidity (AOD up to 0.3), provided aerosol concentration remains constant" I do not agree with this affirmation taking in to account all the consideration and restriction you are doing to your time series. You are applying K-ciclo to your data because of calibration issues. This part has to be better analyzed and explain.

>> What we have found is that Langley calibration can be performed under AOD conditions of relatively high aerosol loads (AOD<0.3) provided AOD remains constant through the day. We agree that, in general, the stability is easier to assess in cases of very low AOD conditions (AOD<0.05). However, and according to our experience at Izaña, this stability in AOD is also reachable under relatively high aerosols (mineral dust) content. On the other hand, there are some cases in which this methodology fails under AOD apparently constant. This is the case of several events in which the Langley technique does not provide satisfactory results and the K-ciclo correction is then applied. These problems are not restricted to Mark-I, they are common in sun-photometry in general, and we have detected similar problems with the GAW-PFR and the AERONET-Cimel. As an example we present in Figure 2 a calibration problem affecting PFR data (quality assured data) showing a fictitious diurnal cycle.

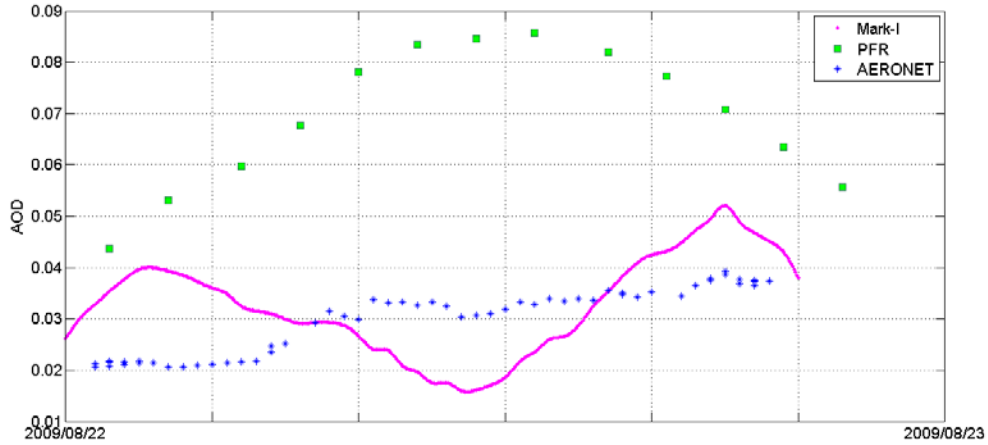

Figure 2: AOD evolution at Izaña on August 22th, 2009.

Of course, these calibration problems tend to be amplified under low AOD conditions, but, in any case, they can be corrected using the methodology proposed by Cachorro et al (see the fig. 1).