DEVELOPMENT OF AN AUTOMATED DOBSON CONTROL SYSTEM FOR UNATTENDED OPERATION

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ABSTRACT

Dobson and Brewer sun spectrophotometers are considered as the reference instruments for total ozone column measurements. If the fully automatic Brewer has replaced the manual Dobson in many countries, the primary reason is rather the lower operational costs than the data quality. Arosa is one of the few stations continuing to measure the total ozone column with multiple co-located Brewer and Dobson instruments. The analysis of these series show that there is still a systematic difference between these two instrument types which is presently not fully understood. Therefore, continuing parallel measurements at different stations still make sense until Dobson and Brewer data agree within their respective uncertainty. A new project has been initiated at MeteoSwiss to develop an automated Dobson in order to continue the measurements at optimized costs and possibly with a more homogeneous and at higher data sampling.

First results of the current development indicate a good agreement between the manually operated (D101) and the automatic (D062) Dobson units respectively, with a larger dispersion of the data for the manual instrument. Furthermore the automated Dobson demonstrates similar data dispersion with respect to collocated Brewer B040 (MKII, single monochromator) and Brewer B156 (MKIII, double monochromator).

INTRODUCTION

Dobson spectrophotometers have been developed at the beginning of the last century by G. M. B. Dobson to measure the ozone total column during sunny days. Figure 1 show the longest worldwide time series of the Arosa station. The long term ozone column has been fairly constant until about 1970 then it starts to decline due to the anthropogenic emission of CFC compounds. The Montreal protocol signed 25 years ago and the subsequent amendments have been successful enough to slow down this decline and stabilise the ozone layer above the mid-latitude. The ozone hole is still observed every year above the South Pole reminding that the problem is far from being solved and that the monitoring of the ozone layer is still required.

Brewer spectrophotometers are automated instruments developed in Canada in the eighties. Both Dobson and Brewer are measuring the absorption of the solar UV radiation in the 305 – 340 nm range. The Brewer are measuring ozone by combining the absolute intensities at four different wavelengths while the Dobson use relative intensities of three different wavelength pairs.

Figure 2 shows the distribution of the difference of the monthly means of pairs of collocated instruments. For a pair of Dobson (Fig 2a), respectively a pair of Brewer (Fig 2b), the centres of the density distribution (= systematic bias) are less than 0.5% and their width are within 1-2%. However, the pair comparison of a Dobson and a Brewer (fig 2c) shows a systematic bias of about 2% and variable widths of the distributions depending on the time periods considered. The distribution for the period 1990 - 1995 (fig 2c, green line) is quite different from the other periods and shows a -1% negative bias which illustrates problems linked to the calibration procedures of the Dobson and the Brewer networks which have evolved over the past 20 years.

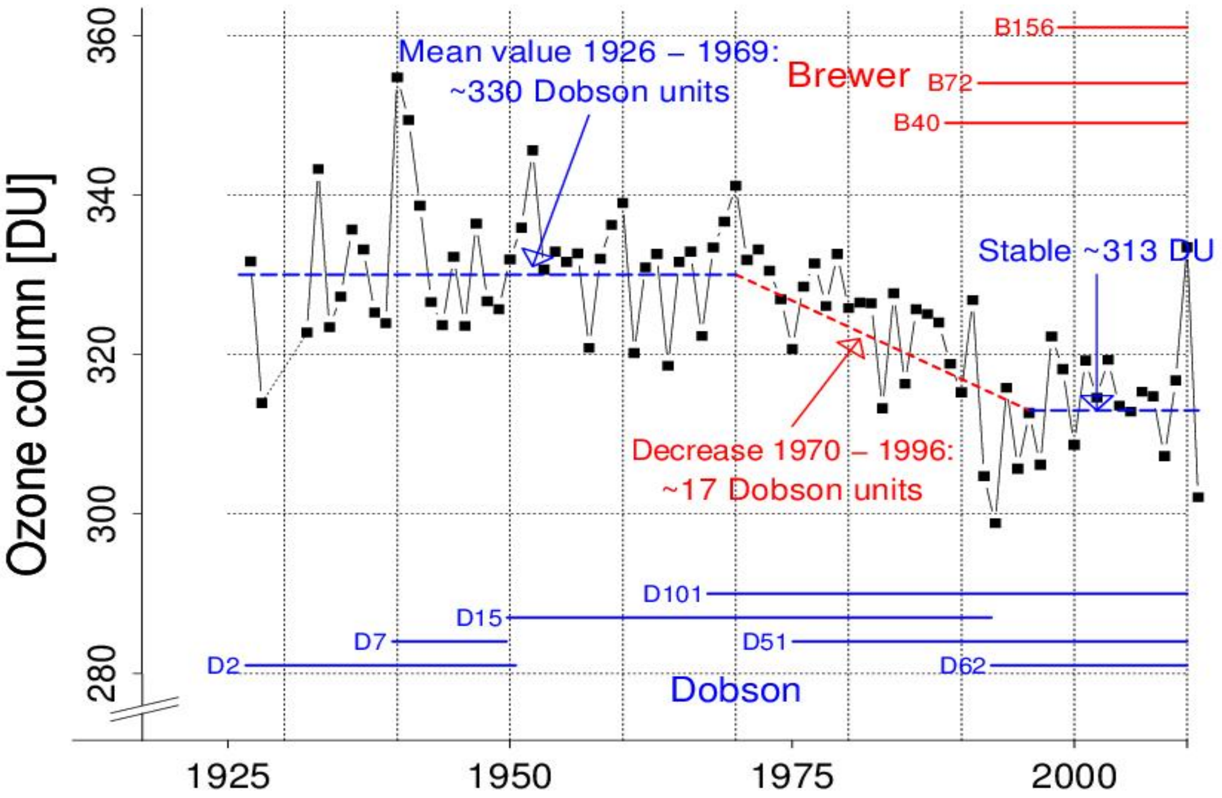

Figure 1: Arosa station total ozone time series of the annual means reconstructed from the data of three successive Dobson (D002 – D015 – D101).

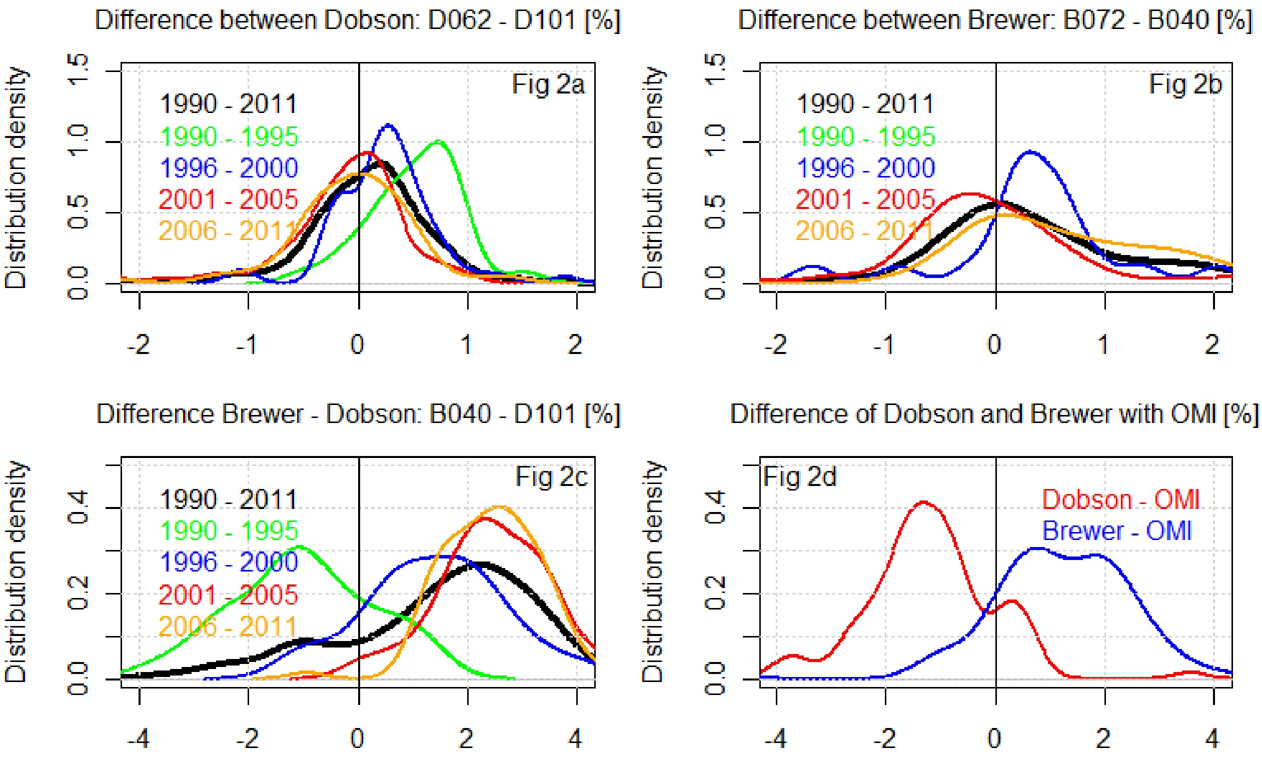

Figure 2: Density distribution of the difference [%] of monthly mean values between different instruments and for different time periods as mentioned in the legend: **2a)** D062 - D101, **2b)** B072 - B040, **2c)** B040 - D101 and **2d)** D101 - OMI (red line) respectively B040 - OMI (blue line).

Such long term change shows up as an artificial trend linked to instrumental effects which have to be corrected as far as possible. Figure 2d shows the results of the comparison of the overpass data from the OMI satellite instrument with Dobson (red line) and Brewer (blue line) measurements. This figure 2d) reveals a significant difference between the two distributions and the difficulty encountered to validate satellites data against ground based stations data as long as the two instrument types do not agree within their uncertainties.

AUTOMATED DOBSON CONTROL SYSTEM

Considering that manual operation of the Dobson instrument is nowadays not the optimal solution, a project has been initiated at MeteoSwiss to develop an automated version of this instrument. The goals of the project can be summarised as:

- Preserving and continuing the world longest total ozone and Umkehr time series
- Achieving measurements quality equivalent or better than the manual observation
- Increasing the frequency of Dobson observation
- Carrying out a systematic comparison between manual and automatic Dobson

The measurements principle of the Dobson spectrophotometer is illustrated in figure 3. The sun light beam entering through “slit S1” is dispersed by the prism P1 in the right side of the instrument. In the middle, the slits S2 and S3 select two wavelength λ_1 and λ_2 in the UV range 305 – 340 nm. The shorter wavelength λ_1 in the range 305-320 nm has been significantly attenuated in the atmosphere by the ozone molecules while the longer wavelength λ_2 around 340 nm has crossed the atmosphere without attenuation. The wedges before slit S3 act as a calibrated attenuator which allows to artificially decrease the intensity of λ_2 to match the intensity of λ_1. The wedges are driven externally by the so-called “R-dial” graduated disk.

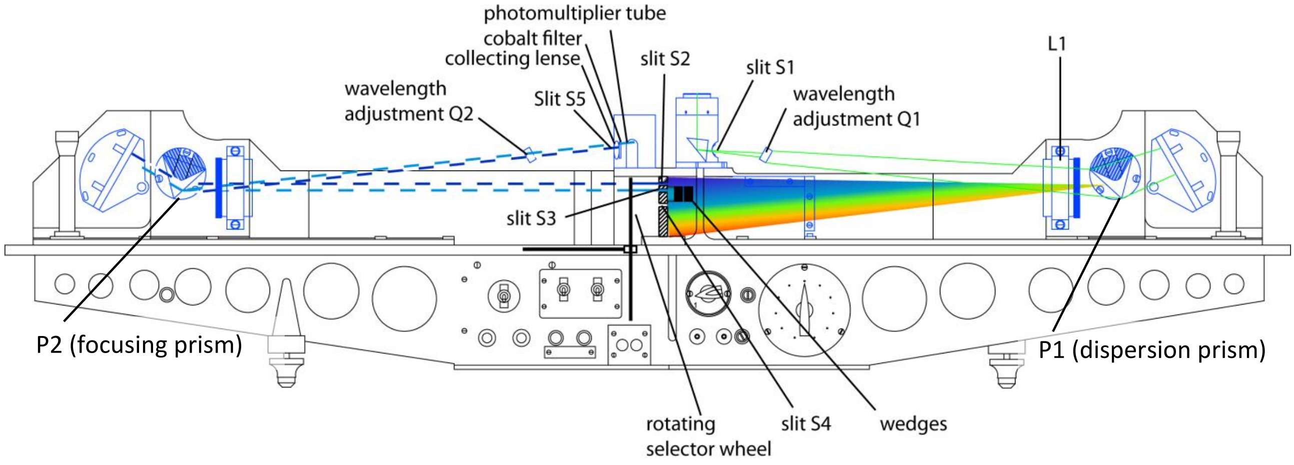

Figure 3: Illustration of the Dobson instruments light path and measurement principle.

The rotating selector wheel after the slits S2 / S3 alternatively let the beam λ_1 or λ_2 pass to the left side of the instrument as illustrated by the dashed blue lines and alternatively illuminates the photomultiplier tube (PM) after passing the “focusing prism”. The PM output is an AC signal at the frequency generated by the rotating wheel which reads zero when the intensities of λ_1 and λ_2 are equal. The wavelengths selection is made by the rotation of the quartz plates Q1 (right side) and Q2 (left side) externally controlled by the so-called Q-levers. In the usual measurement mode, three such pairs of wavelengths “λ_1 -λ_2“ are measured within ~2-3 minutes. The combination of these three pairs of wavelengths allows improving the final estimate of the atmospheric ozone column measured in Dobson unit [DU].

The first step toward the automation consists in a detailed analysis of the manual operation that has been partially unconsciously developed by the observers. In the second step, the strategy for the implementation of the automatic procedures is defined and the hardware assembly redesigned. The third step is the work at the mechanical workshop and it is a clear milestone in the project since it requires high precision machining and simultaneously avoiding any new friction in the control of the different precision movements (in particular Q-levers and R-dial). In figure 4 below, the details of the realized “motor / encoder” assemblies are illustrated in the left panel for the R-dial control and in the right panel for the Q-levers wavelength selectors.

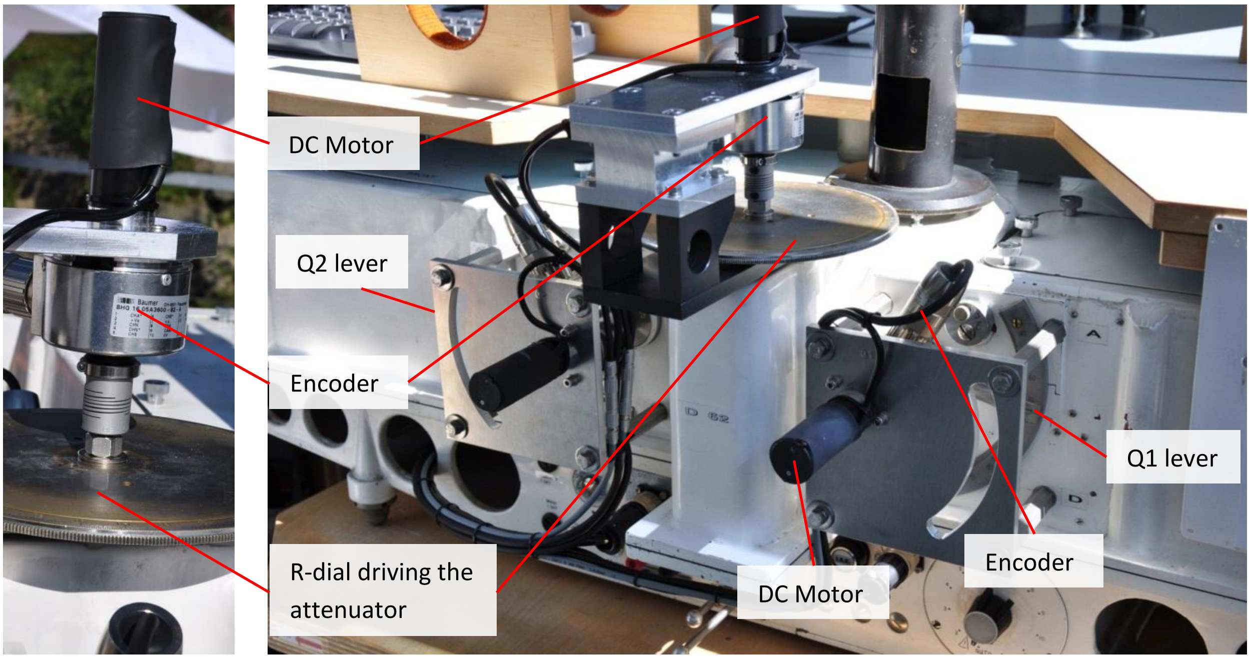

Figure 4: Left panel shows details of the R-dial automatic control: the DC motor at the top drives the axis which goes through the encoder. Right panel: illustration of R-dial, Q1- and Q2-levers assemblies.

The control hardware is built around the National Instrument PXI series ™ and consists in:

- a chassis PXI-1036
- a windows PC controller PXI-8101
- a data acquisition board M-series PXI-6221
- a 4-axis Stepper/Servo Motion Controller PXI-7344

The control software is written in Labview ™ language and the PM output signal measurement is done with a Digital Lock-in Amplifier (DLA). The measurements sequence consists in:

- pointing the instruments to the sun (azimuth and elevation)
- setting the chosen wavelength pair (Q1 and Q2 levers)
- selecting a position of the R-dial (attenuator) close to the “zero” signal
- performing a set of three fixed positions around the zero to interpolate the “zero” position
- getting to this position and having a PID controller tracking this “zero” position.
- recording the R-dial position for typically 20 second.

FIRST RESULTS

An example of the R-dial position time series recently measured by the automated Dobson is illustrated in figure 5 for the three wavelength pairs called C, D and A. The first part of the record until 15h50 is a direct sun total ozone column observation followed at 15h55 by a zenith sky Umkehr observation until the sunset. The rupture of the R-dial position around 15h50 reflects the change of the light intensity when passing from a direct sun (high intensity) to a zenith observation (low diffuse intensity) which is compensated by a significant increase of the PM high voltage. One “C-D-A” cycle is recorded every 2 minutes, half of that time is devoted to the change of the positions of Q1, Q2 and R. The open symbols (right axis of figure 5) are the standard deviations of the R-dial positions measured during the 20 seconds averaging time. The values are of the order of 0.1°deg and increase to 0.2°deg at the end of the Umkehr measurements. This illustrated the very good overall stability of the control system even at low light intensity and high PM voltage.

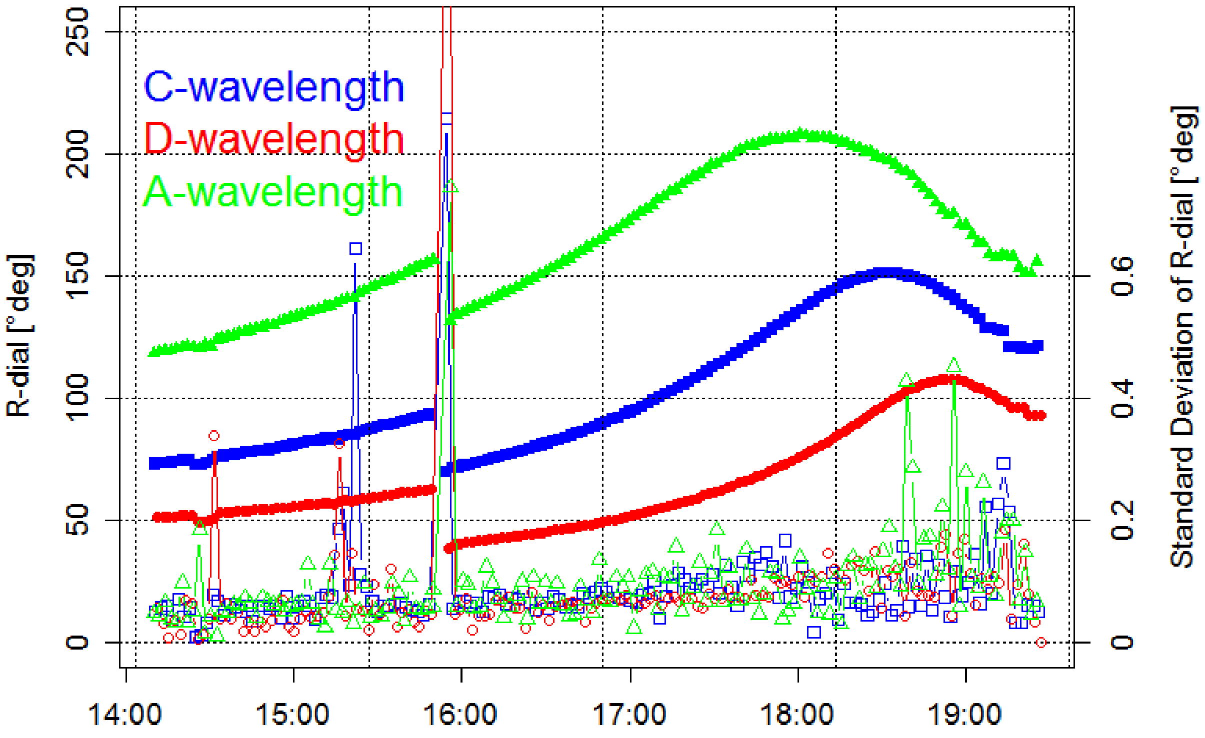

Figure 5: Time series of the raw data for “direct sun” total ozone column measurements (14h00 - 15h50) followed by “zenith sky Umkehr” measurements (~15:55-19:30). The open symbols with the corresponding right axis are the standard deviation of the R-dial positions over the 20 seconds averaging period.

An example of the total ozone time series measured by four different spectrophotometers collocated in Arosa is illustrated in figure 6. The automated Dobson (black symbols) are compared to the manual operated Dobson (red symbols) and to the automatic Brewer instruments (blue and green symbols). The systematic difference of 3-8 DU between Dobson and Brewer instruments is well known as already illustrated in figure 2c. The precision of the automated Dobson is comparable to that of B040 instrument (green) and is a little better to the precision of B156 (blue) for that particular day. Figure 6 also clearly shows the good agreement between the two Dobson with a larger dispersion of the data for the manually operated instrument.

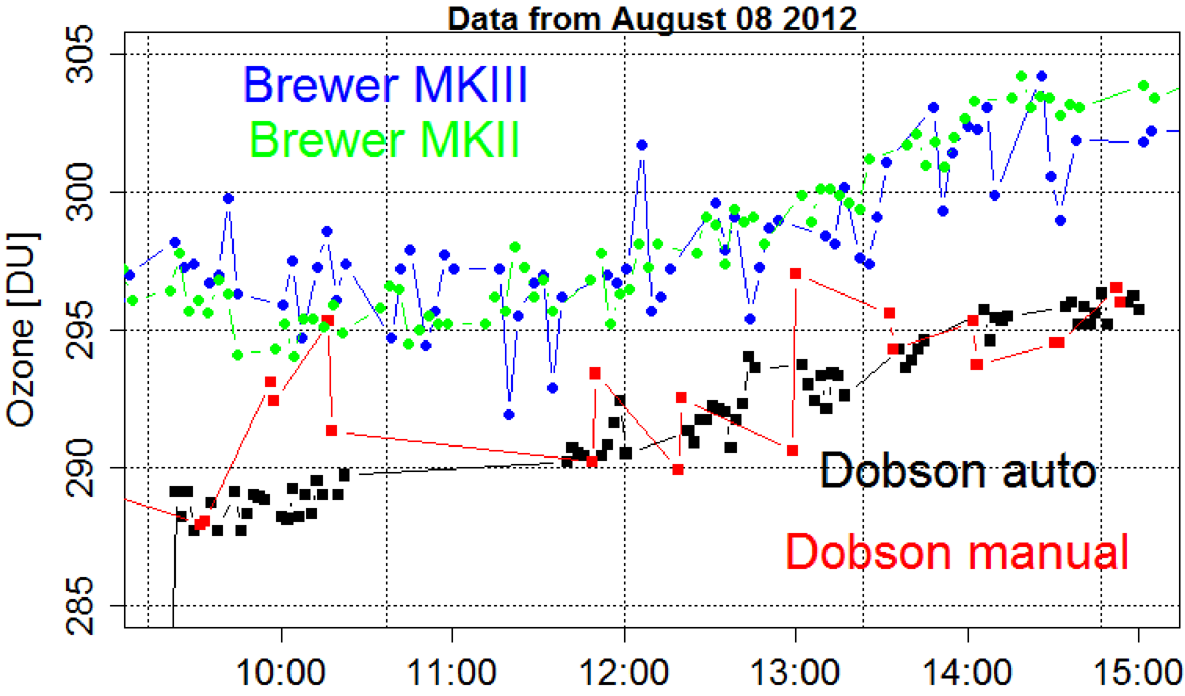

Figure 6: Time series of the total ozone column measured by 4 different instruments collocated at Arosa station, Switzerland.

Presently, the automated data acquisition is operational and a systematic comparison with the manual measurements has started under the control of the operator. The next step will be the development of a new shelter and the automatic instruments orientation.

CONCLUSION

Recent developments towards an automated version of the Dobson sun spectrophotometer have been presented. The first results of the comparison with a manually operated Dobson as well as with collocated Brewer instruments show that the data are in good agreement. The precision of the automated Dobson is as good as the manual one and it is also comparable to the Brewer instruments. The frequency of the data acquisition for the automated Dobson is comparable to the one of the Brewer. This first stage of the project gives very promising results and the development will be continued towards a 100 % automatic version of the Dobson. In parallel, systematic series of comparison will be started to assure the equivalence of the manual and automated versions of the Dobson.