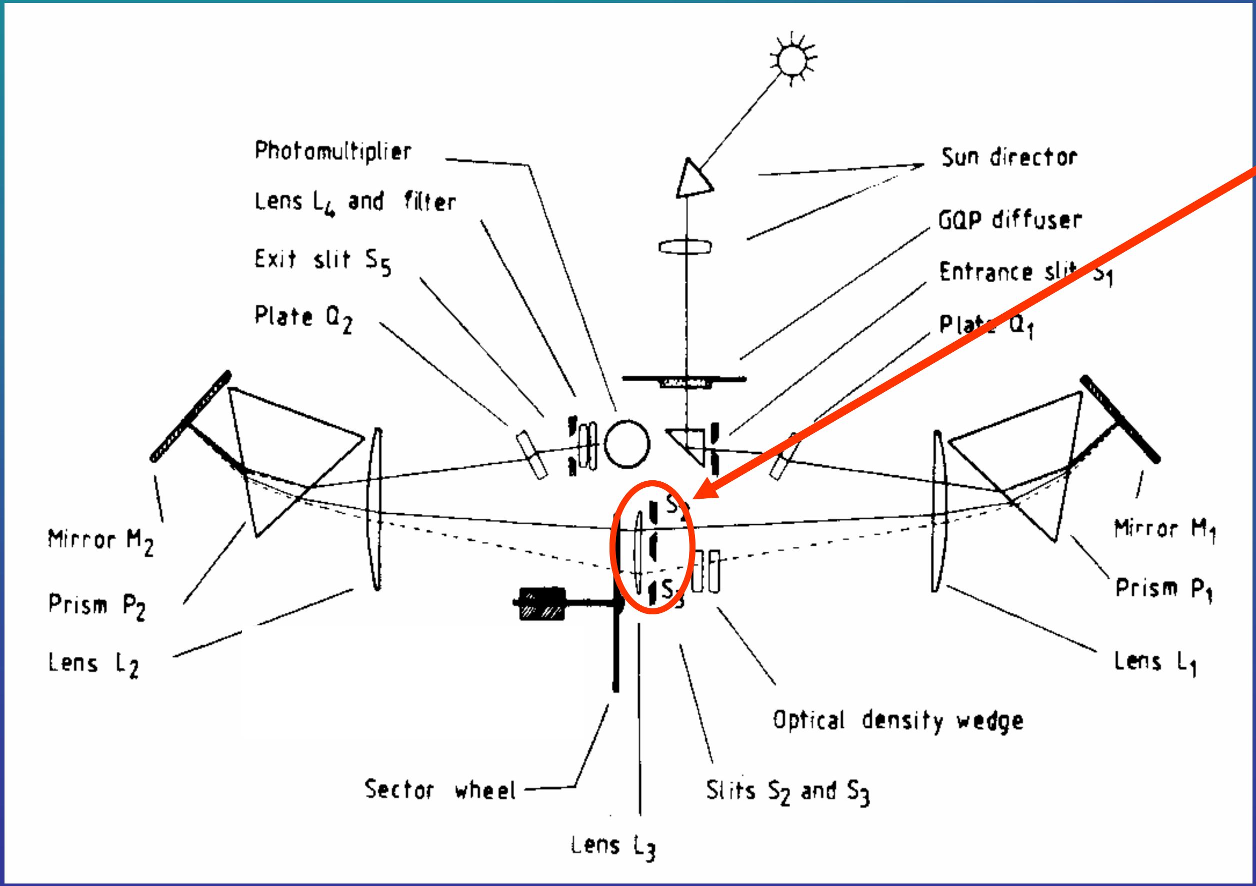
Dobson Ozone Spectrophotometer overview

Sir G.M.B. Dobson

The Dobson Ozone Spectrophotometer was developed in the 1920’s, originally for investigating atmospheric circulation by using stratospheric ozone as a tracer. It is the primary total ozone measuring instrument in the World Meteorological Organization’s Global Atmospheric Watch program.

The instrument measures the intensity difference between selected wavelength pairs (A, C and D)



The right side of instrument separates two wavelengths out of the 300-350NM range, one that is strongly attenuation by ozone (λ_1), the other is not (λ_2).

The left side puts the images of the slits back together in the PMT, and reduces off-band light.

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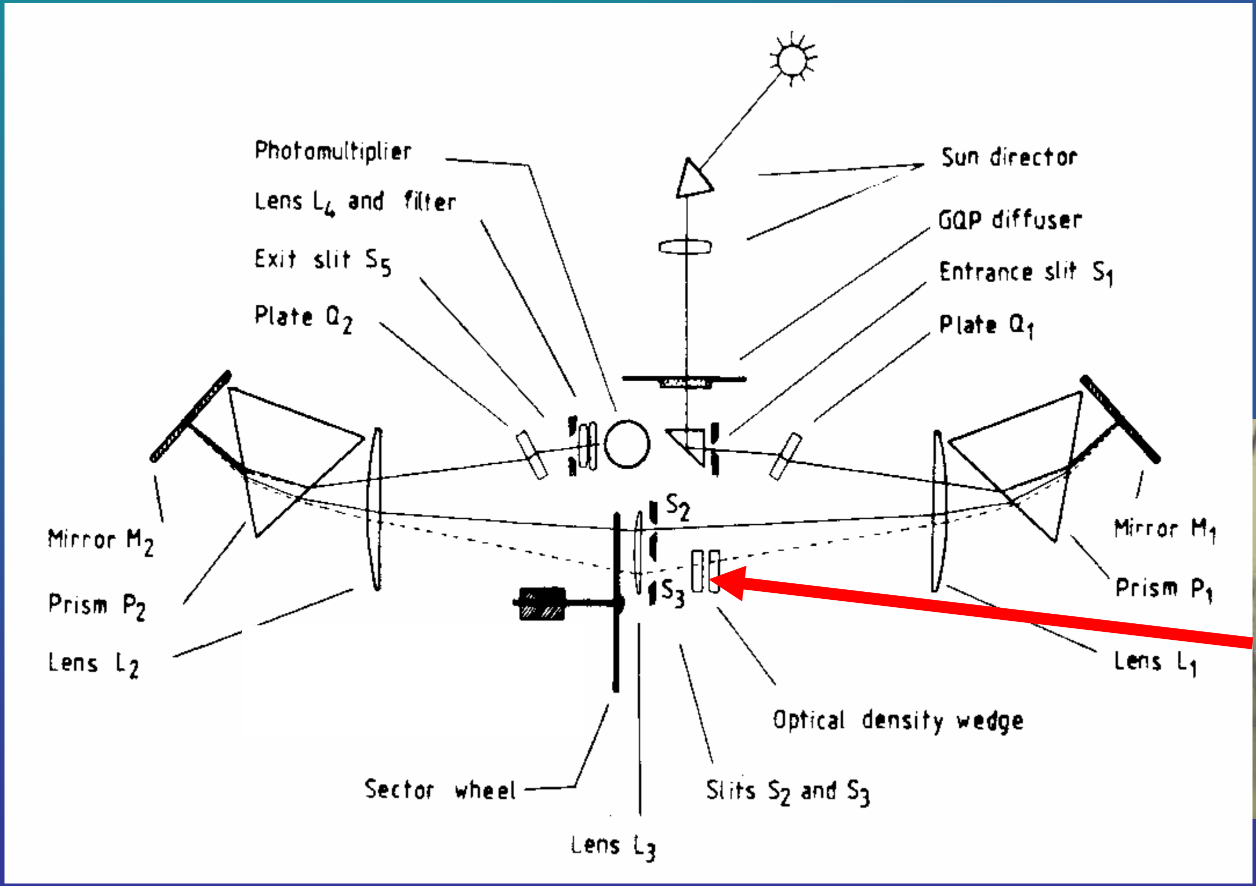
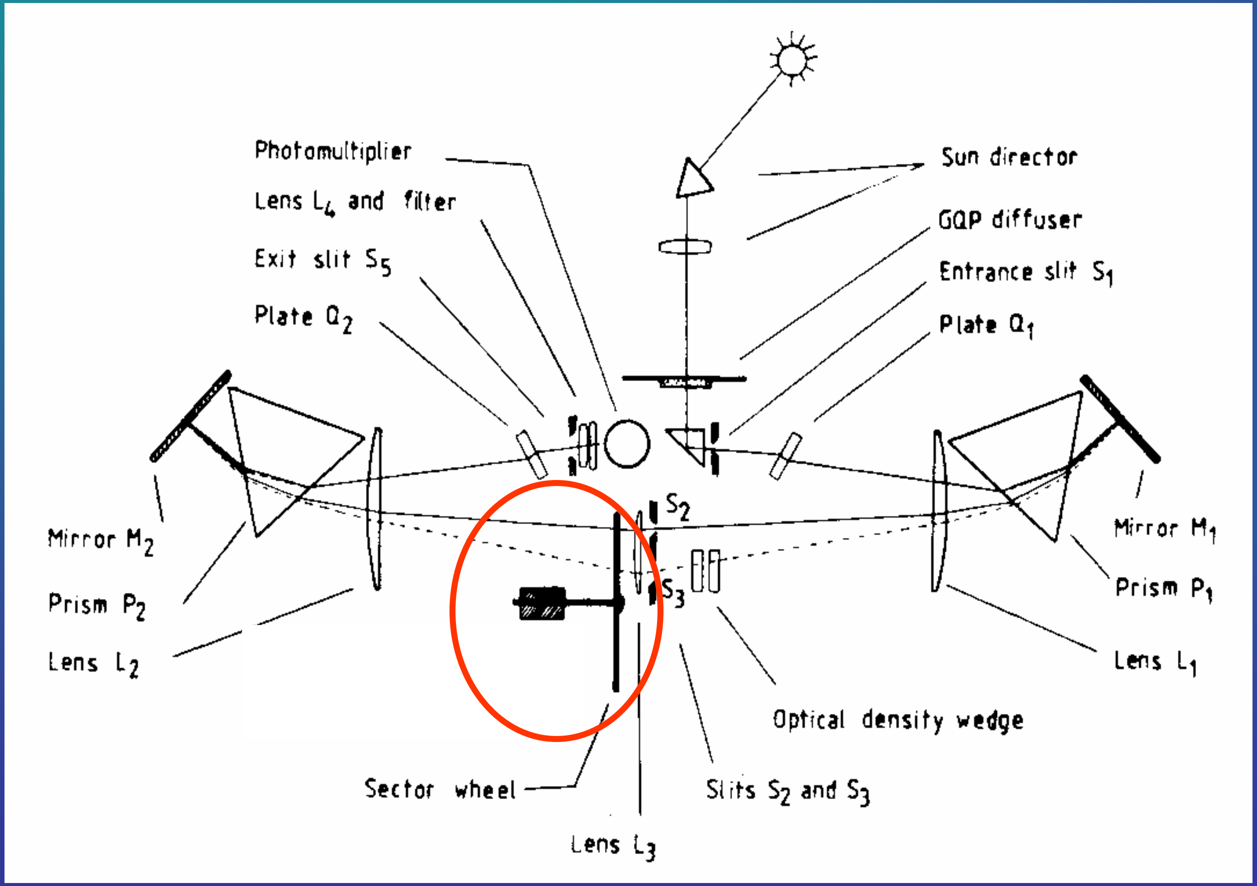


The variable neutral density filter (attenuator) is connected to the R-dial.

The instrument measures the intensity difference between selected wavelength pairs (A, C and D)



The instrument switches back and forth between λ_1 and λ_2 using the same spot in the phototube, and the same electrical amplifier. (The amplifier sense is reversed for λ_2).

Consider the instrument to be an optical bridge circuit

The output is summed in the external microammeter.

The optical attenuator is set so that the external microammeter reads zero.

The amount attenuated then represents the attenuation by ozone in the intensity of λ_1.

The position of the attenuator is used in the calculation of total ozone.

Equations

Beer's Law → $I_{measured}=I_o e^{-\alpha\Omega\mu}$

$$\log\ I_{measured}(\lambda) = \log I_o(\lambda) - \mu_h X \alpha(\lambda) - m\ \beta(\lambda) - \sec z\ \delta(\lambda)$$

(math happens with wavelength pairs and double combinations)

$$\boxed{N = L_0 - L = \log(I_0 / I'_0) - \log(I / I')}$$

$$X_{ad} = ((N_a - N_d) - m\ (\Delta\beta_a - \Delta\beta_d) - \sec z(\Delta\delta_a - \Delta\delta_d\ ))/\ ((\mu\ (\Delta\alpha_d - \Delta\alpha_d))$$

is simplified with the assumption that the aerosol term $(\Delta\delta_a - \Delta\delta_d)$ is zero and by working out the Rayleigh scattering to

$$X_{ad} = ((N_{ad})/(\alpha_{ad}\ \ \mu))\text{-}0.007p/p_o$$

Definitions

- X = total amount of ozone expressed in Dobson Units (1 DU = 10^{-5} m pure ozone at STP), or in atmo-cm;
- I_0 and $I_{0'}$ = intensities outside the atmosphere of solar radiation at the short and long wavelengths, respectively, of the wavelength pair;
- I and I' = measured intensities at the ground of solar radiation at the short and long wavelengths, respectively;
- β and β’ = Rayleigh scattering coefficients of air at the short and long wavelengths, respectively;
- m = ratio of the actual and vertical paths of solar radiation through the atmosphere, taking into account refraction and the earth's curvature: airmass;
- p = observed station pressure;
- p_0 = mean sea level pressure;
- δ and δ' = scattering coefficients of aerosol particles at the short and long wavelengths, respectively;
- SZA = solar zenith angle - angular zenith distance of the sun;
- ά and ά' = absorption coefficients of ozone at the short and long wavelengths, respectively;
- µ = ratio of the actual and vertical paths of solar radiation through the ozone layer, the mean height of the ozone layer being 22 km if not approximated by latitude of the station.

What is data?

- **The position of the attenuator.**
- **The time and place the reading was made.**
- **The calibration history of the instrument.**
- **The comments of the operator.**

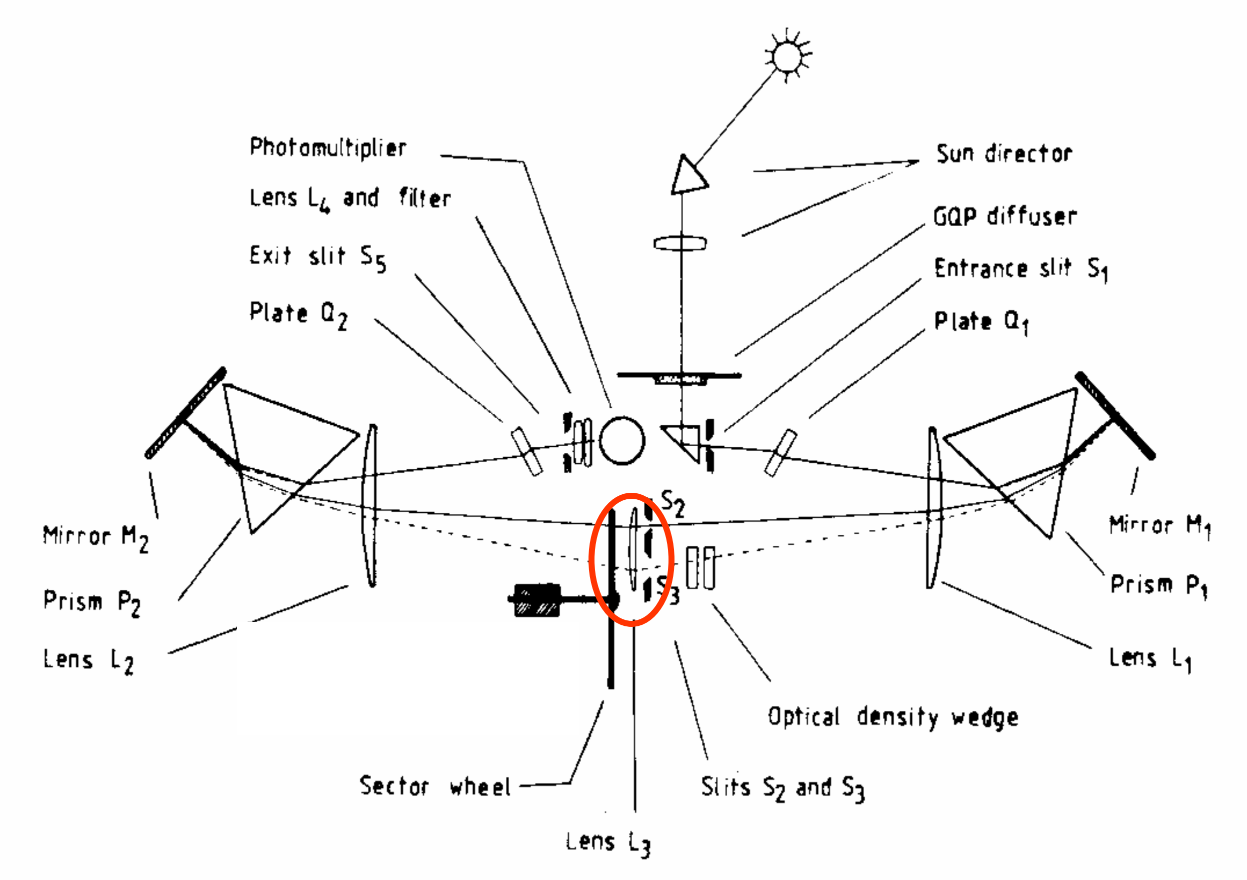
The "output" is a dial reading (R), the indication of the position of the optical attenuator. To analysis the reading and determine total ozone:

- Need calibration of the attenuator.
- Need the knowledge of the wavelengths selected, center and bandpass, so that the cross-section (absorption coefficients) can determined from Laboratory investigations.
- Need the instrumental extra-terrestrial reading (ETC)
- Need knowledge of the time and place of the measurement.
- Input by the operator, to evaluate the quality of the individual measurements.

Calibration of the attenuator.

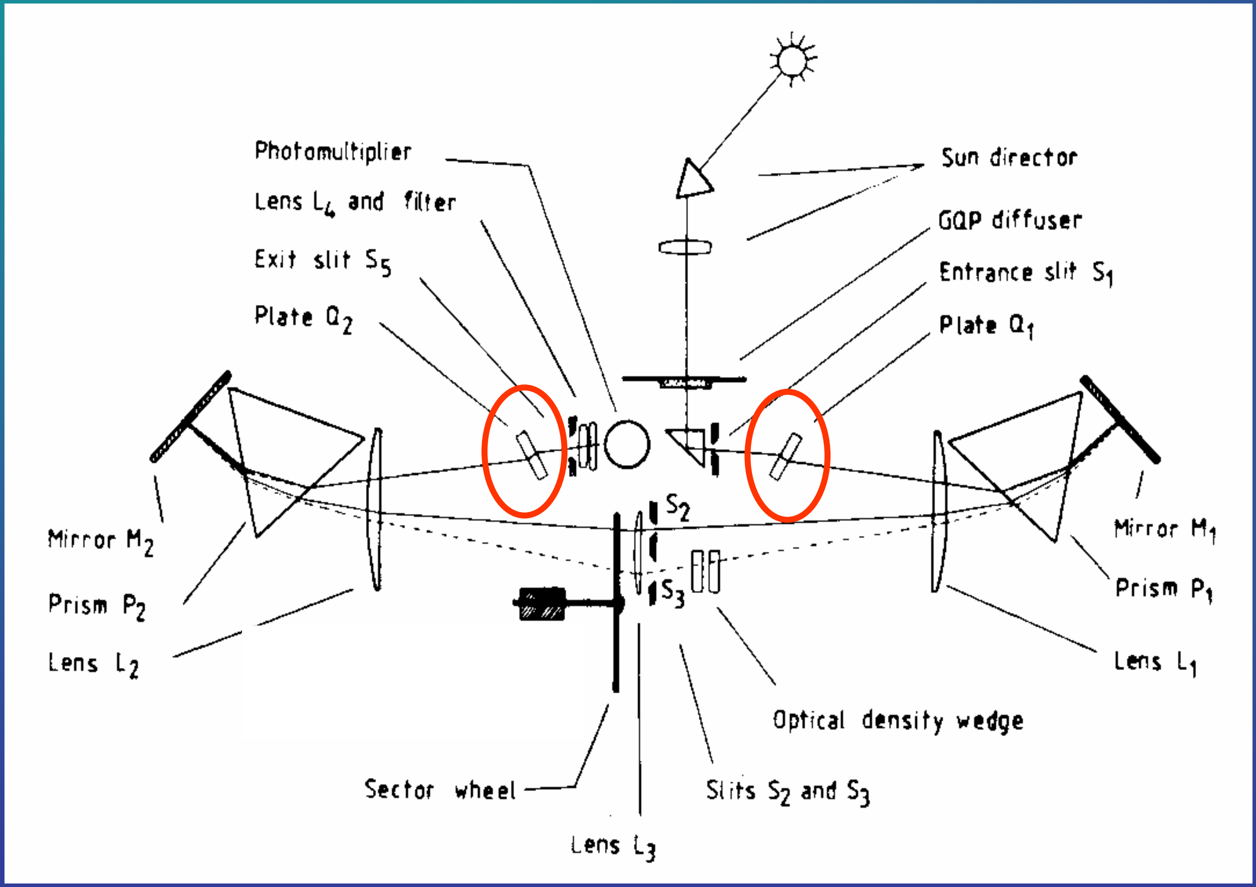
- This is part of the optical calibration of the instrument. The process is complicated and will not be described here.
- The attenuator calibration process has internal limits for acceptability of the data points that go into the calibration. These limits increase as the R-dial position increases, because repeatability of measurements becomes difficult as the attenuator range approaches 300. Based on simple models of the process, the acceptability limits imply a maximum of ±1.0 N uncertainty in the value at R=150.
- The change with time in the calibration of the attenuator has been minimized by the physical construction of this component.
- **The conversion of the R-dial indicator to intensity difference is by a table (gradient or "G" table). There are three tables, one for each wavelength pair.**

Wavelength selection



Two emission lines from a mercury discharge lamp are used to define the position of the spectrum projected on the slit board. The 312.96nm line defines the position of the short wavelength slit (S_2) and the 334.2nm line defines the position of the long wavelength slit (S_3).

Wavelength selection

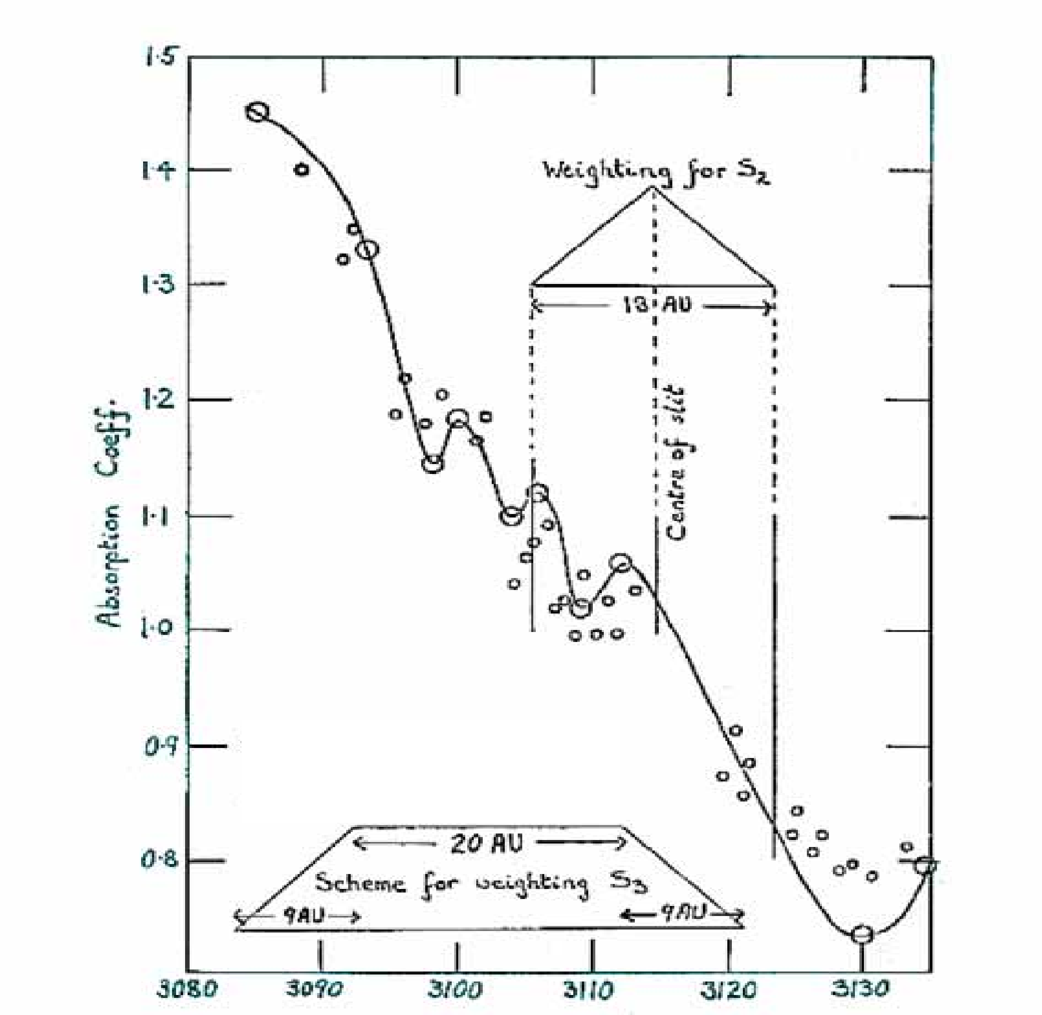


The mechanism for moving the spectrum across the slits and selecting the wavelength pairs is calibrated using a series of discharge lamps.
Temperature dependence of wavelength setting is measured with a number of mercury discharge lamp tests over a wide range of temperature.

Wavelength selection errors

- Temperature dependence of wavelength setting is measured with a number of mercury discharge lamp tests over a wide range of temperature.
- The slit width is set by measurement after the slit separation is defined by the mercury lines – with a microscope.
- The wavelength setting accuracy is checked, usually monthly, using the 312.96nm mercury line. The tolerance of these checks implies an uncertainty of ±0.08nm in the short wavelengths.
- The tolerances in the measurement, defining the dispersion (S2-S3 separation), plus the tolerances in the monthly checks map to ±0.20nm in the short C wavelength determination.

Band-pass



The published slit width for S_2 and S_3 are 0.9nm and 2.9nm respectively (width at half maximum).

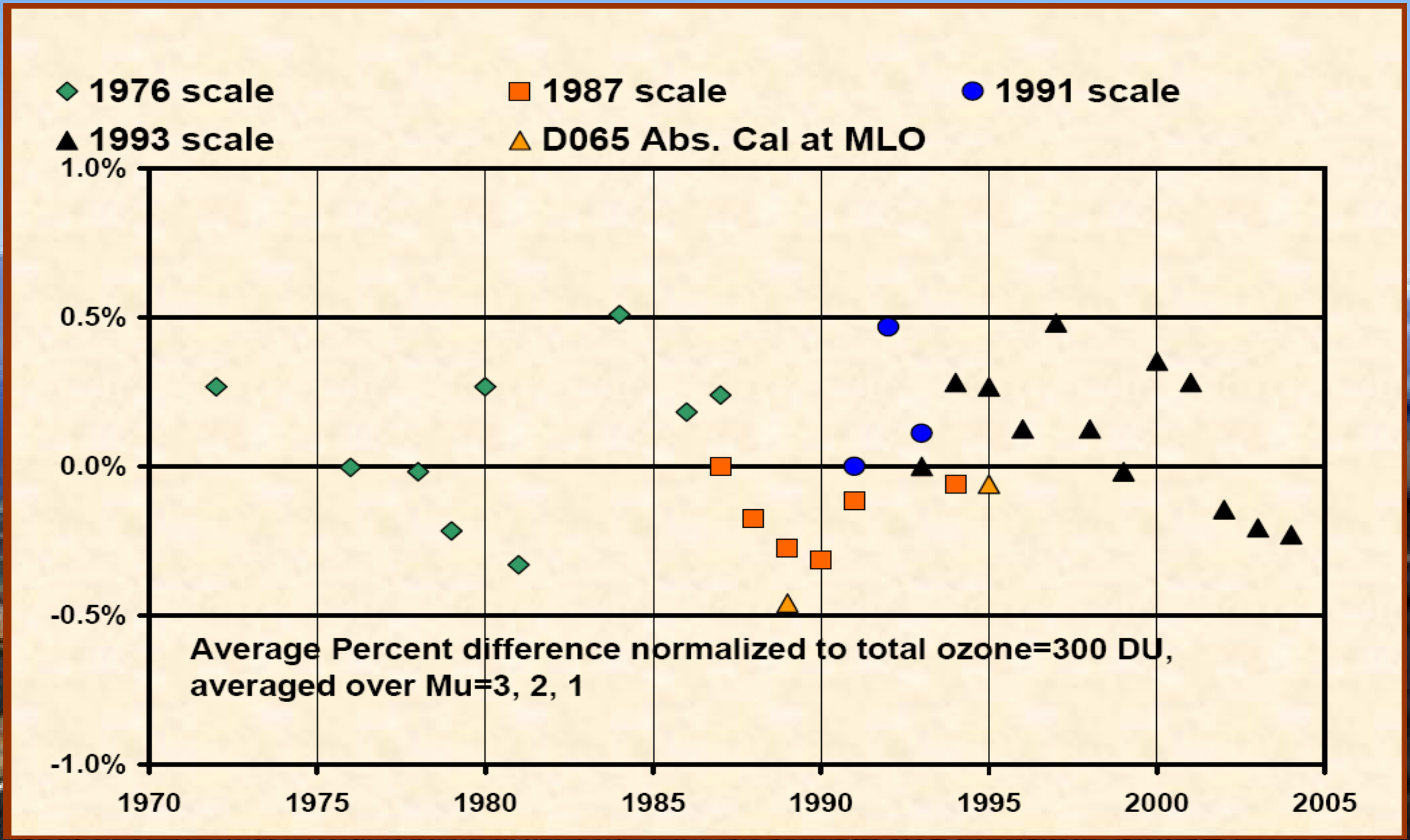
The tolerances allowed in the setting of the widths, by measurement, map to 0.9nm ±0.02 and 2.9nm ±0.05 for S_2 and S_3.

Band-pass errors

- The actual slit function has only been measured completely for the world standard instrument. The optical alignment process for the other instruments attempts to mechanically match the standard.
    - Alignment problems such as focus errors can affect the slit function.
    - There are optical components whose position in the instrument is not well defined. Some components in the instruments are glued in place – and after 50+ years may have slowly moved.
    - Some instruments have been damaged by rain, or exposure to high humidity and temperature.

Instrument ETC

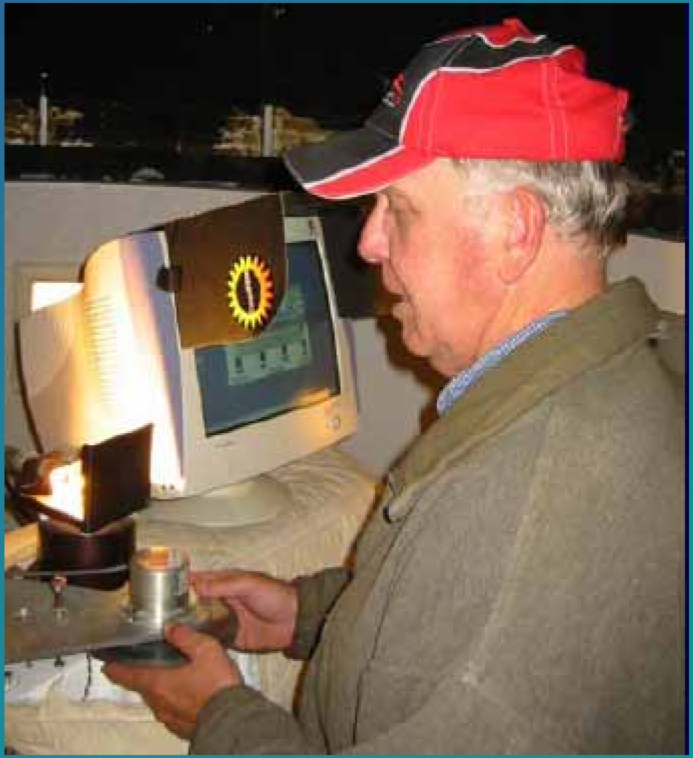
The ETC for the World Standard Dobson was determined by the Langley plot method, and is now verified by approximately yearly campaigns at Mauna Loa Observatory.



- The Standard's ETC calibration is applied to the network of Dobson instruments though a set of secondary, regional and national standards.
- The process is a side-by-side comparison of simultaneous measurements on the three wavelength pairs.
- The G-tables for the "test" instrument are each adjusted by a single number so that the test instrument readings are the same as the standard.
- The adjusted G-tables are then called N-tables. The calculated total ozone value is not considered in the transfer of the ETC value, except in the following evaluation.
  - The precision of the instrument is considered to be +/-1%. The corresponding difference in the value Nad that produces a 1% difference in calculated total ozone, for a value of 300DU, averaged over one-half day is 0.7. If the calculated Nad difference between the test and standard instrument is less that 0.7, the calibration of the test instrument is left unchanged. If the difference is equal to or greater than 0.7, the calibration is changed.

Tracking calibration levels.

- The intercomparison schedule is once every 4 years for station instruments, and once every 2-3 for regional standards.
- The “drift” in the ETC level is tracked with reference lamps, These checks are normally done monthly, and the results are applied to the N-values used in the calculation of total ozone.



Optical Alignment is also monitored.

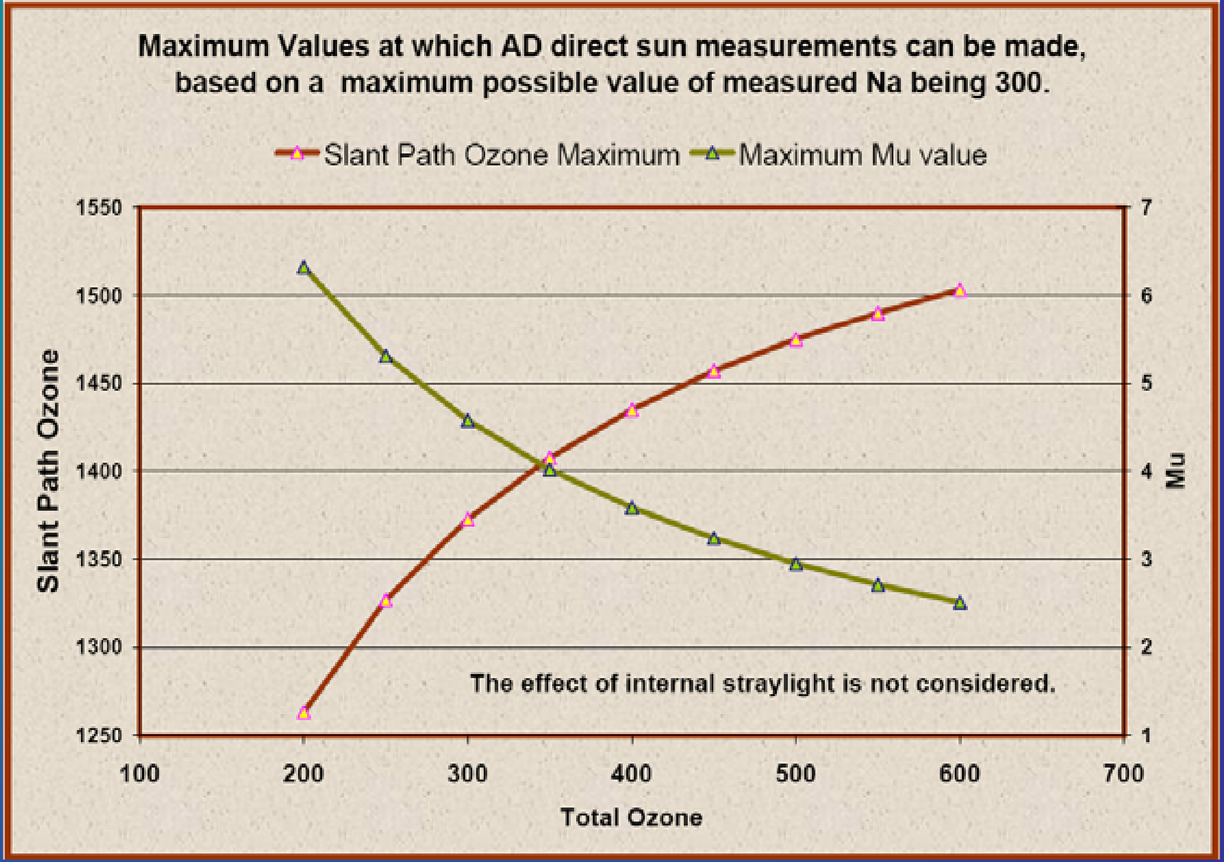
- Monthly checks using a mercury discharge lamp and the 312.96NM line to verify the wavelength setting.
- Tests are made at temperatures similar to the normal operating temperature during measurements.

Instrument limitations to the Measurement

- There is a physical limit to the range of attenuation (movement) in the variable neutral density filter.
- There are internal stray light problems.
  - The optical path has a large number of surfaces for reflections.
  - Quality of the optics (impurities in the quartz).
- The field of view is large enough that forward scattered light in the atmosphere can effect the readings at low sun.
  - ➢ The limitations of the short wavelength pair in a double pair measurement are the limiting factors for that measurement.
- ❑ **The skill and dedication of the operator and the program manager directly effect the quality of the results.**

Instrument Limitations to Dobson Measurements – A-pair

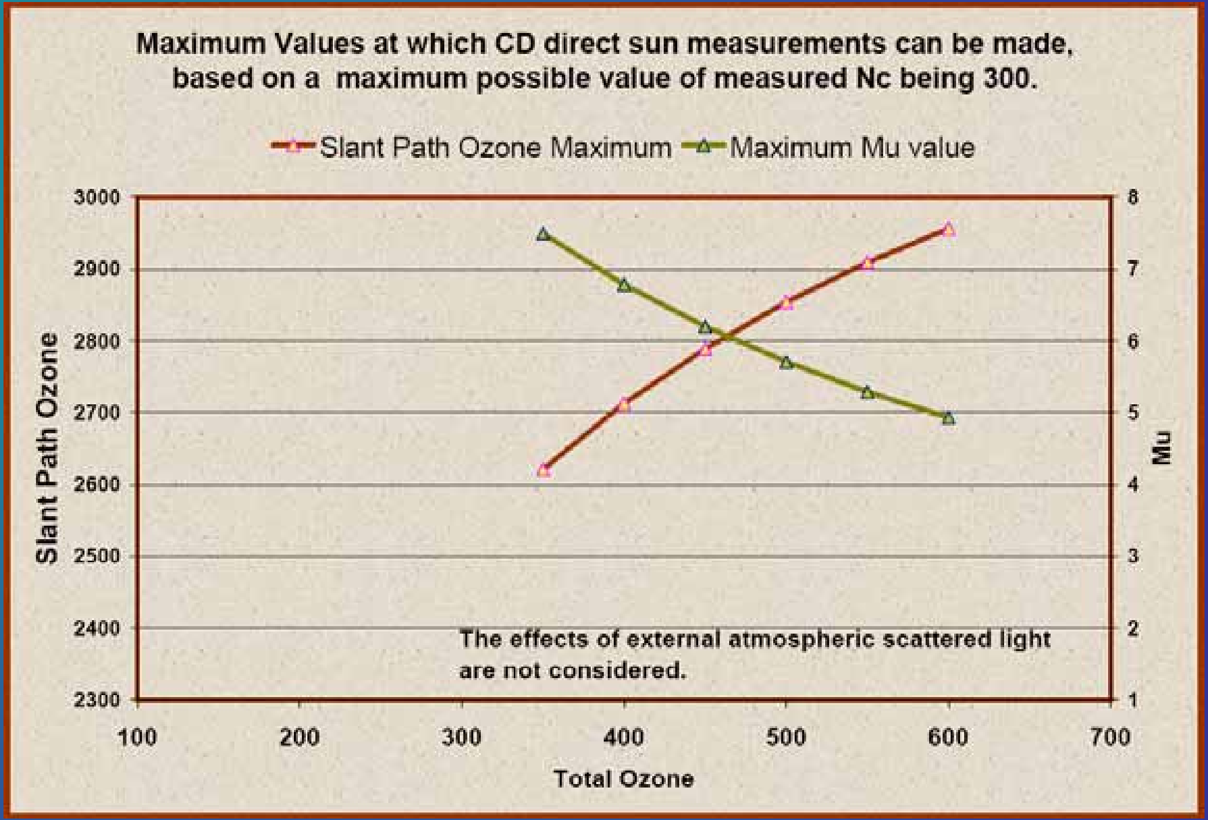
The upper measurement limit for N is approximately 300. This upper value is instrument-dependent. This limits the A pair to a µX value of 1435 (to a µ value of 3.6) at total ozone of 400 DU, for the upper limit of 300.



Internal stray light affects the A-pair readings also, further limiting the higher mu range. Estimation of the stray light by Reid Basher in the 1980's was at the best possible conditions, stray light is at 10^{-5}. At this time, stray light in specific instruments is not measured, but only estimated from performance at large µX values.

Instrument Limitations to Dobson Measurements – C-pair

The upper measurement limit for N is again approximately 300, This limits the C pair to a µX value of 2700 (to a µ value of 6.8) at total ozone of 400 DU, for the upper limit of 300.


Maximum Values at which CD direct sun measurements can be made, based on a maximum possible value of measured Nc being 300.

The effects of external atmospheric scattered light are not considered.

As the mu value increases, the effect (reduced measured Nc value) of forward scattered light in the atmosphere increases. A change in the operation of the instrument to focused image observations does help reduce this effect by reducing the field of view, but the observations are more difficult. The total effect (error) is difficult to estimate due to dependence on the clarity of the sky around the sun's image.

Limitations in the reduction to ozone values

- Absorption coefficients are defined for mid-latitude ”standard” atmosphere.
  - effective temperature of the ozone layer assumed to be -46.3°C
- Absorption coefficients are defined for Dobson instruments as a group – there are not individual values for each instrument. (Alignment of the instrument attempts to force the individual instrument to have the correct value).
- There are uncertainties in the transfer of the ETC.
- There are uncertainties in the derivations of the absorption coefficients.

The “Official” Wavelengths and absorption coefficients (alpha’s) for all Dobson instruments.

The alphas were determined from the 1985 Bass and Paur laboratory measurements, Dr. Carl Mateer’s calculations, and modified by Komhyr and Hudson, 1992

	Center Wavelength (nm)	ά (atm-cm)$^{-1}$	β (atm)$^{-1}$	(β)/(ά) (atm-cm/atm)
A-short	305.5		0.489	
A-long	325.0		0.375	
A-pair		1.806	0.114	0.063
C-short	311.5		0.450	
C-long	332.4		0.341	
C-pair		0.833	0.109	0.131
D-short	317.5		0.414	
D-long	339.9		0.310	
D-pair		0.374	0.104	0.278
AD		**1.432**	**0.010**	**0.007**
CD		**0.459**	**0.005**	**0.011**

Cross-Section History

Researchers had determined there were problems with total ozone determined from Dobson measurements. Several schemes using the 1953 and 1967 Vigroux laboratory absorption spectra were tried to solve this problem. During the mid 1980's, several research groups re-determined ozone absorption coefficients in the region used by the Dobson instrument. (Bass and Paur).

Cross-Section History

Dr. Carl Mateer determined values from the 1985 Laboratory results of Bass and Paur.

- These values produced inconsistent values when station data set were recalculated.
- Walter Komhyr produced an “adjusted set” that produced better matching for the ozone calculated for the three wavelength pairs, and the two double pair observations for the World Standard (D083) data set from MLO.
- These values were accepted by the IOC for all reporting instruments.

(Komhyr, W.D., Mateer, C.L. and R.D. Hudson, Effective Bass-Paur 1985 ozone absorption coefficients for use with Dobson ozone spectrophotometers. J. Geophys. Res., 98(D11), 20451-20465, 1993.)

New Work

- During investigations into differences in calculated ozone from various instruments at the South Pole, Dr. Germar Bernhard re-calculated the cross-sections, using the same data set as Dr. Mateer. His results were different than Dr. Mateer's, but similar to the official 1992 values.

  (Bernhard, G., R. D. Evans, G. J. Labow, and S. J. Oltmans (2005), Bias in Dobson total ozone measurements at high latitudes due to approximations in calculations of ozone absorption coefficients and air mass, J. Geophys. Res., 10, D10305.)

  – Using these coefficients would result in total ozone values being higher by about 0.3% from the Dobson direct sun observations.

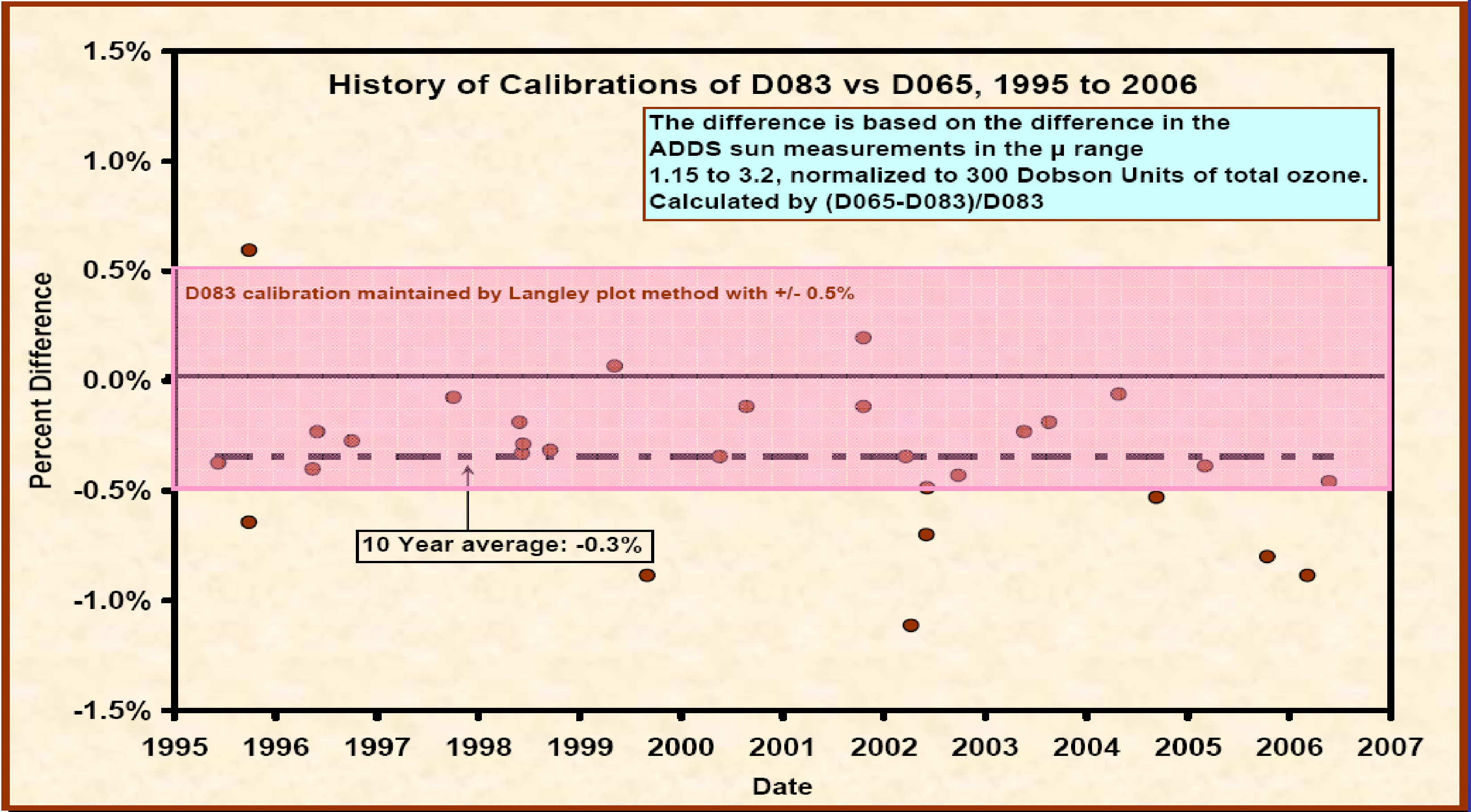
- Other investigations into the cross-sections for the Dobson instrument have produced similar results to the Bernhard 2005 values (G. Labow and others, 2006, Personal Communications)

Operations

- Manually operated. Twelve+ instruments are automated, some others are semi-automated with devices to record the attenuator position electronically
- Two to five observation sets per day.
- Multiple observations made during calibrations, and Umkehr effect observations.
- Sheltered, and normally operated at instrument temperatures above 10 degrees C
- Instrument is stored in stable temperatures, near the operating temperature.
- **Observations for total ozone are made as combinations of sets of measurements on two pairs of wavelengths to minimize effects of aerosols.**

Calibration considerations for the two Dobson Instruments at FMI-ARC

D065 is the secondary standard, with a calibration date of June 1994. The instrument is compared against the primary standard D083 at least twice a year. The instrument is semi-automated in that the R-position is recorded by a computer – encoder arrangement during observations.



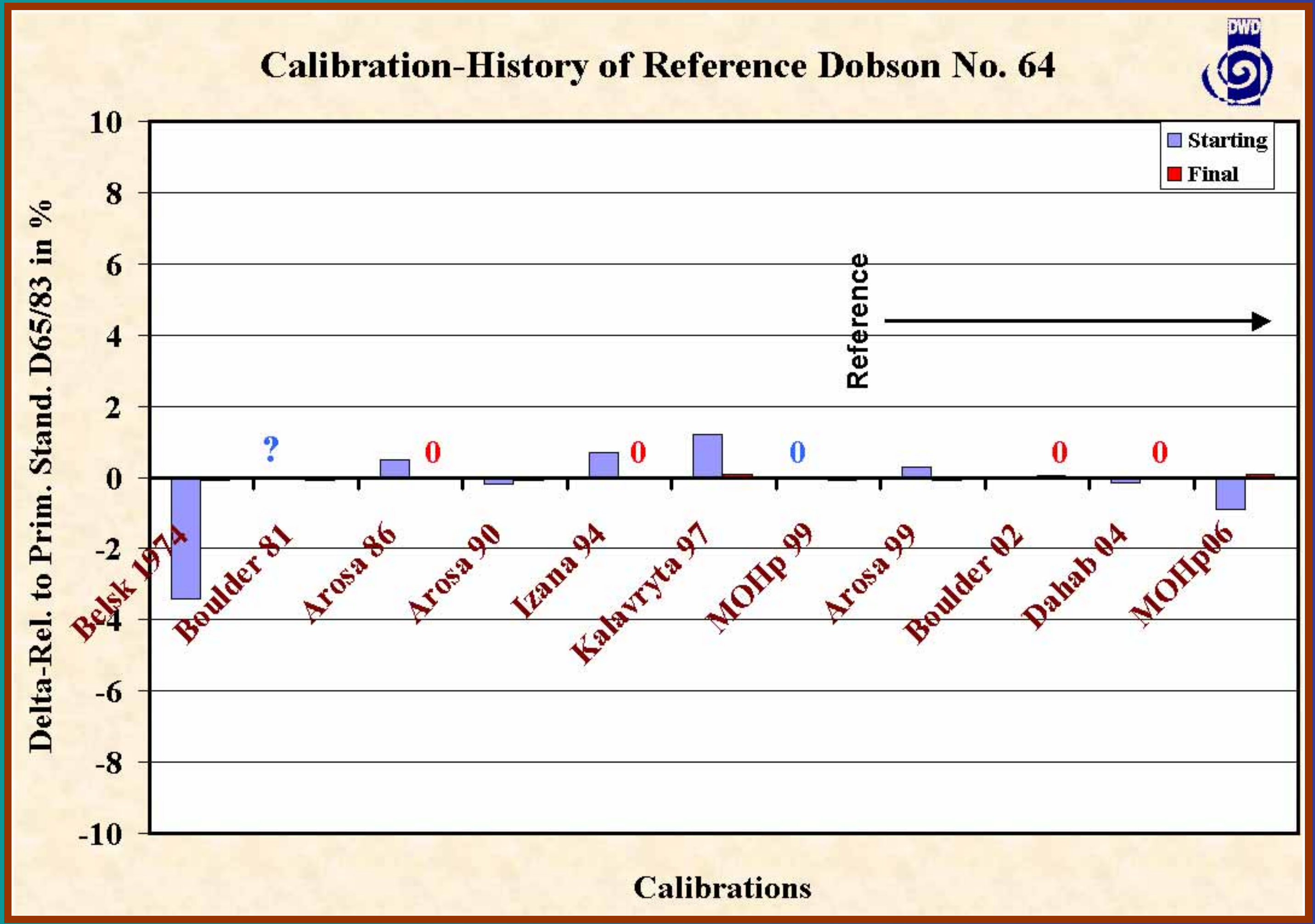
History of Calibrations of D083 vs D065, 1995 to 2006

The difference is based on the difference in the ADDS sun measurements in the μ range 1.15 to 3.2, normalized to 300 Dobson Units of total ozone. Calculated by (D065-D083)/D083

D083 calibration maintained by Langley plot method with +/- 0.5%

10 Year average: -0.3%

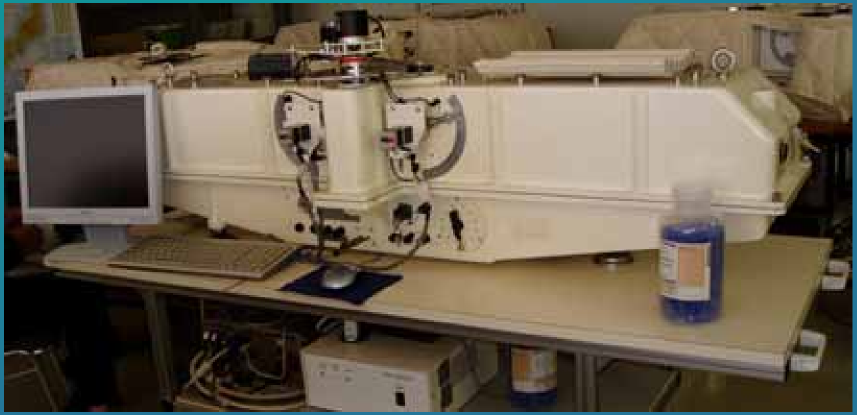
D064 is the European regional standard, and was calibrated since its definition as the reference at MOHp (RDCC-E started in 1999) against the primary standard D083 in June 2002 at Boulder, Colorado. D065 and D064 were compared in 2004 at Dahab, Egypt with essentially no AD difference. D064 is completely manually operated.



Zenith Observations

- The instrument can be used to make observations on the zenith.
- Total ozone is estimated based on the empirical relationship between direct sun and zenith observations made close in time.
- Observations of the Umkehr effect can produce an ozone profile.
- Each of the these subjects is complex and worthy of lengthy discussion, but not immediately relevant to this discussion of the SAUNA campaign.

Thank you for your attention.



Most advanced automated Dobson instrument in use – developed by the Japanese Meteorological Agency.

Still the same optical bits inside.