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Uncertainties in Total Ozone Retrievals from Dobson Zenith Sky Observations

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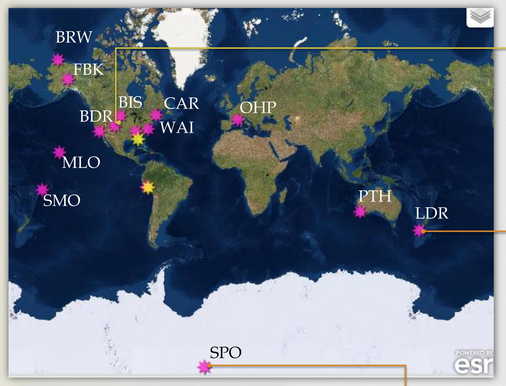
1. Introduction.

The Dobson Ozone Spectrophotometer is used for determination of total column ozone between the instrument and the outer edge of the atmosphere by measuring the intensity difference between selected pairs of wavelengths in the wavelength range 300-340 nm. The instrument has been in use since the 1920s, and grew to a coordinated world-wide network after the International Geophysical Year (1957-58). The time series of these measurements gives information to the state of the ozone layer prior to the satellite measurement programs, and is still a part of the Global effort to monitor the health of the ozone layer through three independent ground based systems, and multiple satellites.



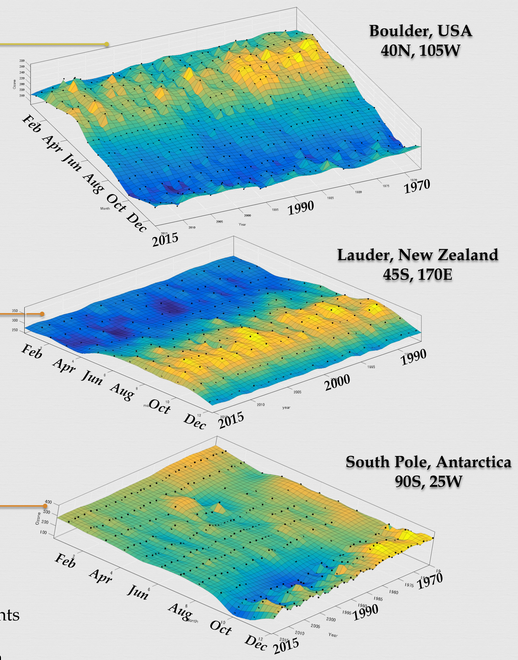


Photo 1. Zenith sky total ozone observations using Dobson instrument. Zenith measurements are made on a 7-degree cone of light emanating from the zenith sky.

Figure 1. Time series of the total ozone from the Dobson instrument observations.

2. Method.

The measurements made on the zenith sky are analyzed to produce total ozone amounts using a procedure not based on the physics of the measurement, as it difficult to determine the actual path through the atmosphere of the light being observed, and the effect of scattered versus absorbed UV light. The initial procedure was to make sets of quasi-simultaneous observations – an observation on the direct sun followed very closely in time by a zenith sky observation. From this data base, an empirical relationship was determined to make the average results of the zenith sky measurements equal the direct sun results. Since AD-DSGQP observations are fundamental, the types of quasi-simultaneous comparison measurements to be made are the following:

AD-DSGQP vs. AD-ZB
AD-DSGQP vs. AD-ZC
AD-DSGQP vs. CD-ZB
AD-DSGQP vs. CD-ZC
AD-DSGQP vs. CC'-ZB
AD-DSGQP vs. CC'-ZC
AD-DSGQP vs. CD-DSGQP
AD-DSGQP vs. CD-DSFI.

a) Calculations of Total Ozone from Measurements on Direct Sun
AD-DSGQP and AD-DSFI
CD-DSGQP and CD-DSFI**

**Multiplying factors applied in converting CD-DSGQP results to the AD-DSGQP level.

$$X_{AD} = \frac{(N_A - N_D)}{1.432\mu} - 0.007\frac{mp}{\mu p_0} - \left[\frac{[(\delta-\delta')_A - (\delta-\delta')_D]}{1.432} * \frac{Sec(SZA)}{\mu} \approx 0\right]$$

$$X_{AD} = \frac{(N_A/\mu_A - N_D/\mu_D)}{1.432} - 0.007\frac{p}{p_0}\frac{(m_A+m_D)}{(\mu_A+\mu_D)}$$

$$X_{CD} = \frac{(N_C/\mu_C - N_D/\mu_D)}{0.459} - 0.011\frac{p}{p_0}\frac{(m_C+m_D)}{(\mu_C+\mu_D)}$$

b) AD-ZB and AD-ZC observations.
Calculation of ozone amounts from AD wavelength measurements on the zenith sky.
The experiential relation between Mu and N are the following equations:

$$X_{ADZ} = A_0 + \frac{A_1}{\mu} + \frac{A_2}{\mu}(N_A - N_D) + A_3(N_A - N_D)$$

where A_0, A_1,A_2, and A_3 are derived by polynomial fitting routine.

c) CD-ZB and CD-ZC observations.
Is the same as in b), but for CD wavelength measurements.

$$X_{CDZ} = A_0 + \frac{A_1}{\mu} + \frac{A_2}{\mu}(N_C - N_D) + A_3(N_C - N_D)$$

d) CC′-ZB and CC′-ZC observations.
The polynomial for Cloud Corrections (dNCC) are made from AD-DSGQP and NC′ measurement comparison. If the sky is perfectly clear, the correction dNCC should equal zero (Fig. 3). For another instrument, these values will normally be shifted by a constant.
Calculation of ozone amounts from CC′ wavelength measurements on the zenith sky. The experiential relation between Mu and NC are the following equations.

$$X_{CC'Z} = A_0 + \frac{A_1}{\mu} + \frac{A_2}{\mu}(N_C - dN_{CC}) + A_3(N_C - dN_{CC})$$

Calculation of the ozone amounts from CC' wavelength measurements on the zenith sky was updated to optimization processing from the conventional method which uses a cloud correction chart.

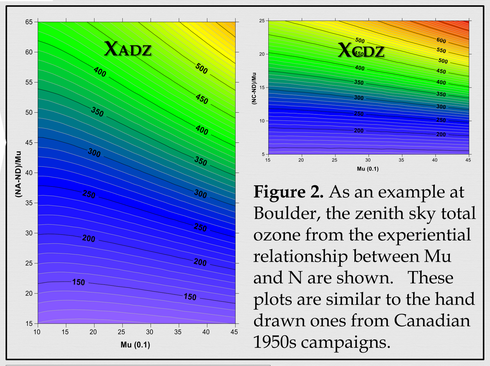


Figure 2. As an example at Boulder, the zenith sky total ozone from the experiential relationship between Mu and N are shown. These plots are similar to the hand drawn ones from Canadian 1950s campaigns.

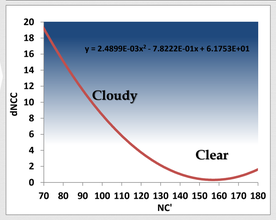


Figure 3. The polynomial for the cloud corrections to NC value.

Table 1. Possible Types of Total Ozone Observations. Polynomial based on comparison with AD-DS types.

Type of Obs.	Wavelength Pairs	Light Source	Observing Range
AD-DSGQP	A and D	Direct sun, using GQP	1.15<μ<3.0
AD-DSGQP*	A and D	Direct sun, using GQP*	1.015<μ<1.15
CD-DSGQP	C and D	Direct sun, using GQP	2.4<μ<3.5
AD-DSFI	A and D	Focused image of sun	2.5<μ<4.0
CD-DSFI	C and D	Focused image of sun	2.5<μ<6.0
AD-ZB	A and D	Blue zenith	1.15<μ<4.0
CD-ZB	C and D	Blue zenith	1.8<μ<5.8
CC'-ZB	C and C'	Blue zenith	1.0<μ<4.4
AD-ZC	A and D	Cloudy zenith	1.15<μ<2.4
CD-ZC	C and D	Cloudy zenith	1.8<μ<5.8
CC'-ZC	C and C'	Cloudy zenith	1.0<μ<4.4
AD-RMFI	A and D	Focused image of moon	1.15<μ<3.0
CD-RMFI	C and D	Focused image of moon	1.15<μ<3.5
D-RMFI	D	Focused image of moon**	3.0<μ<5.0

*[Lens should be removed from the sun director (see Section 6.2.4.1).]
** [This observation is made only in Polar Regions (see Section 7.1).]

Table 2. Ozone Absorption and Molecular Scattering coefficients for Use with Dobson ozone spectrophotometers Beginning 1 January 1992.

Wavelength (nm)	α (atm-cm)$^{-1}$	β (atm)$^{-1}$	(β)/(α) (atm-cm/atm)
305.5		0.489	
325.0		0.375	
A	1.806	0.114	0.063
308.9		0.466	
329.1		0.355	
B	1.192	0.111	0.093
311.5		0.450	
332.4		0.341	
C	0.833	0.109	0.131
317.5		0.414	
339.9		0.310	
D	0.374	0.104	0.278
332.4		0.341	
453.5		-	
C'		-	
AD	1.432	0.010	0.007
BD	0.818	0.007	0.009
CD	0.459	0.005	0.011

3. Summary.

The new method improves results to achieve ~91% of zenith sky derived total ozone (AD-ZB) to fall Within 2% of the co-incident direct sun ozone column (AD-DSGQP). This is an improvement over the 78% quoted in the 2006 Operations Handbook.

AD-ZB Observations					
Difference:	1.5%	<=1%	<=2%	<=3%	<=4%
Frequency	85%	74%	91%	96%	98%

AD-ZC Observations					
Difference:	2.3%	<=1%	<=2%	<=3%	<=4%
Frequency	85%	61%	81%	90%	94%

CD-ZB Observations					
Difference:	2.5%	<=1%	<=2%	<=3%	<=4%
Frequency	85%	54%	78%	90%	95%

CD-ZC Observations					
Difference:	3.0%	<=1%	<=2%	<=3%	<=4%
Frequency	85%	47%	72%	86%	92%

CC′-ZB Observations					
Difference:	3.3%	<=1%	<=2%	<=3%	<=4%
Frequency	85%	55%	74%	84%	90%

CC′-ZC Observations					
Difference:	3.3%	<=1%	<=2%	<=3%	<=4%
Frequency	85%	41%	68%	82%	91%

CD-DS Observations					
Difference:	2.5%	<=1%	<=2%	<=3%	<=4%
Frequency	85%	56%	79%	90%	95%

Table 3. As in Figure 4.
Results are the average of 12 stations in the NOAA network (Barrow, Fairbanks, Caribou, Bismarck, Haute Provence, Boulder, Wallops Island, Mauna Loa, Tutuila, Perth, Lauder and South Pole).

Difference (%)	AD-ZB	AD-ZC	CD-ZB	CD-ZC	CD-DS	CC′-ZB	CC′-ZC
0	33%	25%	22%	20%	22%	20%	14%
1	74%	61%	54%	47%	56%	55%	41%
2	91%	81%	78%	72%	79%	74%	68%
3	96%	90%	90%	86%	90%	84%	82%
4	98%	94%	95%	92%	95%	90%	91%
5	99%	96%	97%	96%	97%	94%	96%
6	99%	97%	98%	97%	98%	95%	98%
7	99%	98%	99%	98%	98%	96%	98%
8	100%	99%	100%	98%	99%	96%	98%
9	100%	99%	100%	99%	99%	96%	99%
10	100%	99%	100%	99%	99%	96%	99%

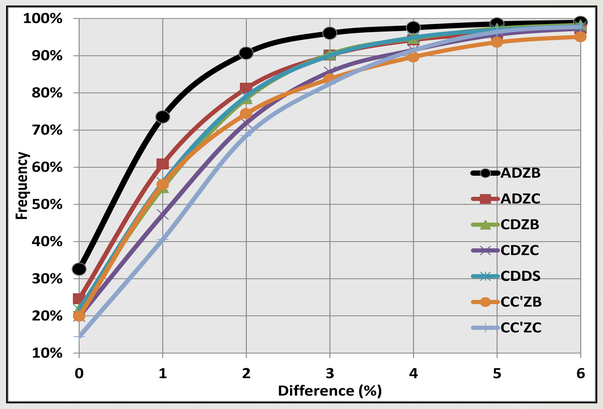


Figure 4. Distribution of differences between results from direct sun (AD-DSGQP) compared to zenith measurements on the same day. The frequency of compared zenith and AD-DSGQP total ozone (shown on y-axes) is accumulated between 0 to 6 % (shown on the X-axes). Results are shown for other types of zenith sky measurements denoted by colors in the legend. Results are the average of 12 stations in the NOAA network , except for the CC′ result, which is from the South pole station only.

Displayed are results by station using the polynomial technique. The analysis of the CC′ type of observation has only been completed for the South Pole station.

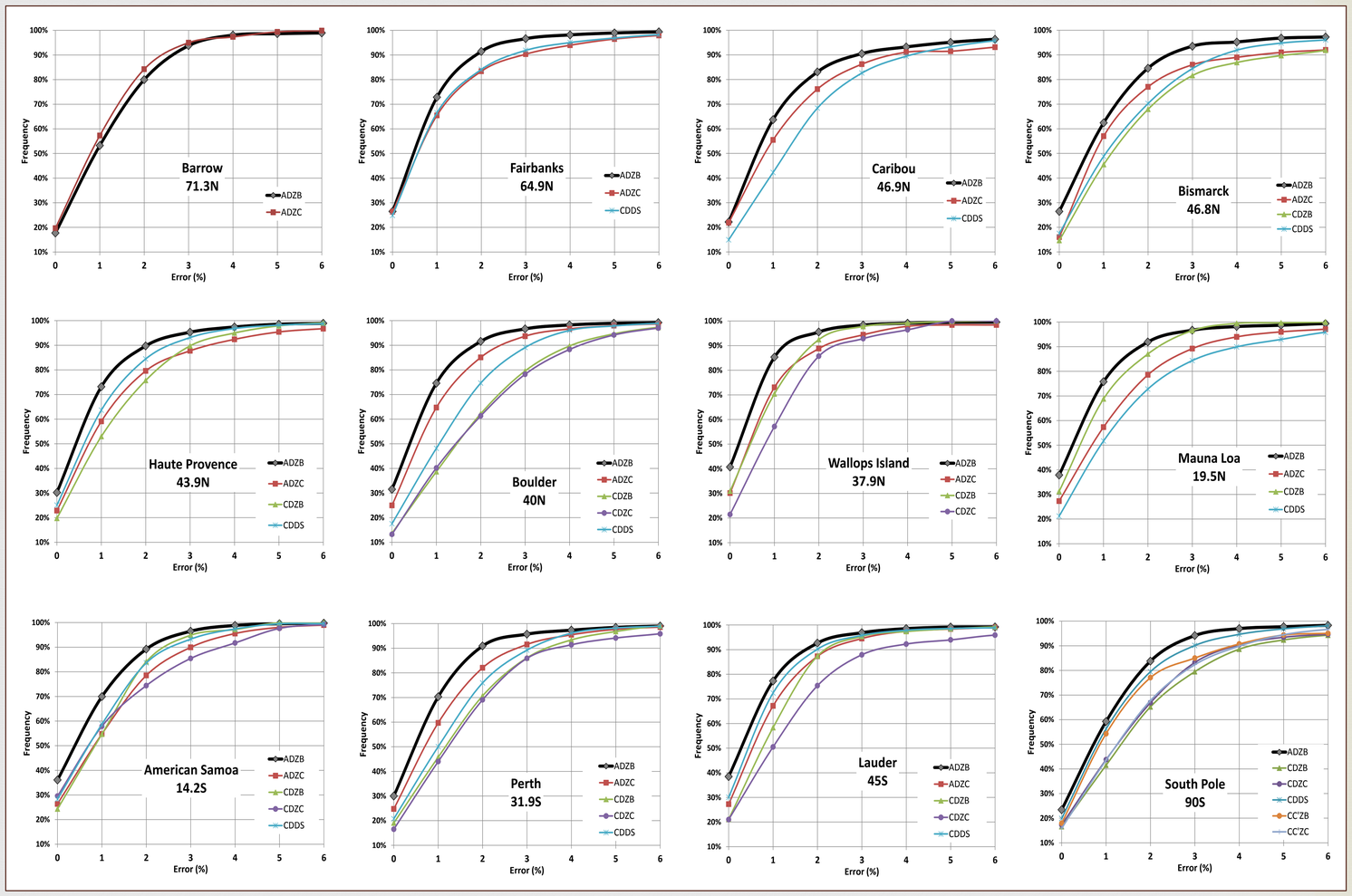


Figure 5. Distribution of differences between results from direct sun (AD-DSGQP) compared to zenith measurements on the same day. The frequency of compared zenith and AD-DSGQP total ozone (shown on y-axes) is accumulated between 0 to 6 % (shown on the X-axes). Results are shown for other types of zenith sky measurements denoted by colors in the legend.

References.

Evans, R. D., Operations Handbook - Ozone Observations with a Dobson Spectrophotometer - revised version, WMO/GAW Report No., 183, 2008.

Komhyr, W.D., Operations Handbook - Ozone Observations with a Dobson Spectrophotometer. WMO Global Ozone Research and Monitoring Project, Report No. 6, 1980. http://www.cmdl.noaa.gov/dobson/report6/report6.html

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