CALIBRATION of the UNIVERSITY OF WYOMING BACKSCATTERSONDE 1999

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Abstract. In 1999 a renewed effort was made to obtain a rigorous absolute calibration of the University of Wyoming backscattersonde. The results indicate that the older measurements are in systematic error somewhat in excess of the overall uncertainties. Correction factors have been developed for adjusting previous data and indicate that all previous red channel backscatter ratios (historically denoted by SRR) should be multiplied by .905 and all previous blue channel backscatter ratios (denoted by SRB) should be multiplied by .979. The new calibration indicates that the observed minimum free tropospheric backscatter ratio in the red channel is 1.00e.02 as would be expected for essentially aerosol free air. Thus, calibration cannot be in error in such a way as to further reduce the SRR and SRB values. It is shown that the absolute scattering values and profile structures obtained with the backscattersonde are consistent with the values predicted from SAGE and lidar data.

To avoid confusion between the new and older calibrations, analysis provided by the University of Wyoming will denote the files employing the newer calibration with suffixes .ask and .dsk in place of .asc and .dsc as is in current use for the older calibrations. It is suggested that all users developed a similar method of identifying the files with the newer calibration. All backscattersonde data files submitted to the NDACC data base (www.ndacc.org) reflect the 1999 calibration constants.

1. Introduction

A significant new effort was mounted in 1999 to reexamine the accuracy of the absolute calibration constants associated with the University of Wyoming backscattersonde first described by Rosen and Kjome, [1991]. This effort was motivated by the desire to fully document the backscattersonde calibration, evaluate possible systematic or significant differences with other optical sensors, and to develop the required accuracy or confidence level for decisively identifying a small non-zero tropospheric background mode apparent in sounding averages [Rosen et al., 1997]. The material presented here is a report of our findings and an elaboration of the calibration methods. In addition, a methodology and conversion factors are presented for obtaining other aerosol parameters and scattering properties from the backscattersonde profiles such as might be used for inter-instrument comparisons.

2. Relative Calibration

Although the absolute calibration is the central focus here, it is operationally convenient to first establish a technique for a repeatable relative calibration between all backscattersondes. Our relative calibration procedure is conceptually simple: the ambient surface air signal from each backscattersonde is adjusted (via a calibration constant) to give the same response as a standard backscattersonde maintained in Laramie. In actual practice several further details need to be defined and addressed.

Rather than using a single standard backscattersonde, an ensemble of four standard units are reserved for calibration. In addition, a fraction of the unused and unshipped units are recalibrated during each calibration secession to check the repeatability and general stability of the calibration. Typically, the four standard units and the unused recalibrated units agree within .5-1%. It may be noted that this procedure is not sensitive to drifts for which all backscattersondes would change in sensitivity in exactly the same way after the date of manufacture. However, such a universal or uniform drift would seem relatively improbable.

In addition, the calibration of unused field units returned from distant locations are rechecked to help determine the amount of calibration shifts the sensors might experience in shipping. The results indicate calibrations shifts of 0-5% with an average of 2%. As implied above the units that remain in Laramie do not experience any detectable calibration drifts.

3. Absolute Calibration

3.1 Definition of Absolute Calibration

By absolute calibration, we mean here a procedure by which the backscattersonde signal level for pure molecular scattering is determined. Since the air temperature and pressure are simultaneously measured, the expected molecular signal for any altitude can then be accurately obtained from simple calculation. The accuracy of the temperature and pressure measurements is better than .5 and 1% respectively over the entire sounding range.

3.2 Preliminary Conceptual Approach to Calibration

The absolute calibration of the backscattersonde would be easily accomplished if the sensor could be flown in air that was known to be free of optically active aerosols. However, such clean air conditions would appear to rarely (if ever) exist and a rigorous independent, simultaneous verification of such conditions would be required if such events were to be used for calibration purposes.

Another obviously simple method for absolute calibration would be to operate the backscattersonde in a large closed container flushed with aerosol free air. However, experimentation has shown that the size of the container would need to be impractically large for sufficiently reducing the effect of wall-scattered light (particularly from the surface directly illuminated by the strobe) at the detectors.

3.3 Method of Calibration

Our method of absolute calibration is centered around the use of a backscattersonde-like instrument (prime calibrator) which can operate in a partially closed container with one "wall" being the night sky to eliminate direct wall backscatter. The sensitive volume as defined by the intersection of the beam and detector field of view (FOV) is contained entirely within the semi-closed region which can be made rigorously aerosol free or filled with ambient aerosol buy vigorously flushing with outside air.

The beam geometry of the prime calibrator and backscattersonde as well as the overall calibration configuration is illustrated in Figure 1. A set of blowers is used to force ambient air through high efficiency filters for flushing the tower and sensitive volume with clean air. In the second part of the cycle, the filter blowers are shut off and another set of blowers is used to draw ambient air down through the tower. In this procedure, the true or absolute aerosol backscatter ratio (ABSR) for the prime calibrator can be directly determined by dividing the signal with aerosol by the signal without aerosol. The resulting ABSR can then be compared directly with the standard backscattersonde ABSR, which is operated near the edge of the tower as illustrated in Figure 1.

It must be noted, however, that the ABSR for the standard backscattersonde and the prime calibrator cannot be expected or assumed to be exactly identical because the backscatter geometry and field of view is different. In addition, there are other small differences that may in general prevent the assumption of identical instruments and response. Thus, for example, if the prime calibrator gives an ABSR of 1.5, the same value cannot be assigned to the standard backscattersonde for the same ambient air. This problem is overcome by using the method of analysis described below which depends only on a sufficiently adequate signal correlation between the standard backscattersonde and prime calibrator. A good correlation between the backscattersonde and prime calibrator can be expected (and is observed) because they are very similar instruments and the consequences of their difference have only minor effects in the good proportionality of the respective signals.

3.4 Preliminary Considerations Concerning Calibration Method

Before describing the absolute calibration protocol and the results, a few important details related to potential uncertainties must be described.

3.4.1 Zero Level Signal

The calibration analysis requires the assumption that residual signals from both the backscattersonde and prime calibration would be insignificantly small in the absence of scattering from molecules and aerosols. This assumption can be rigorously tested for the backscattersonde by noting that the low signal strength at the top of a typical sounding is less than 1% of the clean air surface value.

Thus, for calibration purposes, it may be concluded that an insignificant amount of stray light is scattered from parts of the instrument back into the detectors. Since the prime calibrator has similar geometry, the same low background would be expected for this instrument.

3.4.2 Stray Light Signal

Stray light from the prime calibrator tower walls scattered back into the detectors could potentially cause a significant background signal error. The magnitude of this effect was estimated by making successive measurements with and without the tower in place during stable aerosol conditions. We were not able to detect any measurable, systematic difference in signal with or without the tower in place.

3.4.3 Inadvertent Ambient Aerosol Modification

The above test also indicated that ambient air sampled in the tower gives the same aerosol signal as ambient air sampled in the same open air environment. For this reason we argue that the character of the ambient aerosol is not significantly altered by drawing it into the tower and that the aerosol observed by the backscattersonde is essentially the same as the aerosol observed by the prime calibrator.

3.4.4 Filter Efficiency

It is essential to confirm that the high efficiency air filters reduce the aerosol concentration to such low values that aerosol backscatter is undetectable. In a preliminary check all of the filters were leak tested with an optical particle counter and only those filters that were found to pass insignificant number of particles with diameters greater than 0.25 micrometers were used.. A second test of the filter efficiencies was made under field conditions. If the filters are essentially perfect for optically active aerosols, the prime calibrator clean air signal should be independent of the ambient aerosol conditions. With more than a order of magnitude change in ambient air backscatter, we have found no detectable change in the prime calibrator signal in filtered air. If the filters were leaking we would expect to find a positive correlation between ambient air backscatter and the signal during the clean air cycle. Thus, no detectable aerosols appear to be leaking into the tower during the clean air cycle.

3.4.5 Pollution of Clean Air in Tower by Wind

To prevent ambient air currents from corrupting the air in the tower during the clean air cycle, four large filters and blowers are used to achieve sufficient air velocity up the tower. Experimentally it has been found that corrupted air can easily be detected by unusual variations seen in the normally very steady signal associated with the clean air cycle.

3.4.6 Pollution by Exhausted Air

It may also be noted that during the ambient air cycle the air exhausted by the separate blowers for drawing air down the tower is directed such that it does not reenter the top of the tower and corrupt the ambient air sample.

3.5 Calibration Procedure

In a typical calibration procedure, the prime calibration signal is alternated between clean and ambient air every 10 minutes, constituting about 80 individual sample measurements for averaging. Only data that remain stable over many cycles is used to compute the ABSRs for the two instruments. To obtain an estimate of the calibrator clean air signal during the ambient sample time, an average is taken of the previous and following clean air cycle. The two readings that make up this average must be identical within measurement noise for acceptance in further analysis.

3.6 Calibration Data Set

The data produced from all of the calibration measurements are shown in Figure 2. For economy of illustration, the analysis has assumed a value for the standard backscattersonde molecular signal that will turn out to be equivalent to the calibration results given below. The size of the data points reflects the overall uncertainty, which includes repeatability during several cycles and statistical fluctuations related to the signal itself. The scatter in the points reflect different aerosol types and show that the responses of the two instruments are highly correlated but are not strictly identical, as consistent with discussion and expectation given above.

3.7 Analysis of Results

Figure 2 illustrates the method and implied assumptions of the calibration technique. With the correct calibration of the backscattersonde, the data points must be consistent with a line passing through the origin (1,1) because both instruments must concurrently indicate aerosol free air. The calibration of the backscattersonde therefore needs to be adjusted until a best fit line passes through the origin (within experimental error). A straight line least squares fit technique has been used to determine the origin intercept implied by the data points. The circle at the origin indicates the standard error in the predicted intercept (about 2.5%) and is indicative of the calibration uncertainty.

An assumption has been made that the points in Figure 2 are adequately characterized by a straight-line fit. If both instruments were identical, or the calibration aerosol did not vary in character except for concentration, the assumption would be rigorous. Since the response of both instruments is quite similar and minimal extrapolation is required, we believe that the straight-line assumption does not introduce significant error for the determining the calibration constants.

Calibration of the blue channel was also investigated with results similar to those shown in Figure 2. Therefore, these results will not be specifically illustrated here.

3.8 Summary of New Calibration Results

The new absolute calibration results indicate that the previous calibration constants (SRRbar and SRBbar) are somewhat in error, the significance of which is discussed below. Since all of the backscattersondes are in good relative calibration, it is possible to adjust all of the previous soundings to the new calibration values. The correction factors are as follows:

All previous red channel ABSR (SRR in data files) should be multiplied by 0.905

All previous blue channel ABSR (SRB in data files) should be multiplied by 0.979

or equivalently

SRRbar(new)=(1/0.905) x SRRbar(old)
SRBbar(new)=(1/0.979) x SRBbar(old)

Impact of New Calibration Constants

As can be seen, the calibration error in the red channel leads to about 9% error in the BSR. For large aerosol signals such as those experienced after sizable volcanic eruptions, in well-developed polar stratospheric clouds (PSCs) and for most boundary layer aerosols, this will result in only slightly more than about 9% error in the ABSR, which, for most applications will not be significant. However, at low aerosol concentrations the effect of the calibration error is larger and may need to be taken into account. For example, the 1999 stratospheric red channel background BSR is about 1.35 (or ABSR=0.35) as implied by the original calibration factor. Applying the new calibration factor the stratospheric background BSR drops to 1.22 (ABSR=0.22) or a drop of about 30% in the ABSR.

3.9 General Constraints on Calibration Constants

An obvious strict lower limit to all backscattersonde BSR values is 1.00, which is the condition for no aerosols. However, statistical fluctuations in the signal and calibration constants would allow for values differing from 1.00 by a few percent or maybe even larger for units that receive rough shipping treatment. To investigate the minimum tropospheric signal observed over Laramie we have identified 9 of the 94 soundings made that indicate the most minimal tropospheric aerosol and at the same time have no suspected sensitivity drift or calibration change. The cumulative tropospheric BSR for these soundings (considered as an ensemble of data points) and for the new (1999) calibration constants is shown in Figure 3. The dashed line is an estimate of the true data with the effects of the "smearing" caused by the calibration variation and data noise removed. It will be noted that the dashed line intercept is very close to a BSR of 1.00, which corresponds to aerosol free air. Thus the calibration cannot be in error in such a way as to further reduce the backscattersonde values since unphysical results would occur.

4. Verification of Backscattersonde Values

4.1 Definition of 'Verification'

Although the backscattersonde signal is independently calibrated in terms of molecular scattering, it is nevertheless important to verify that the instrument and technique produce data consistent with other independent sensors measuring similar aerosol properties. For this effort we will primarily compare the backscattersonde values with ground based lidar backscatter results and extinction values obtained from the SAGE satellite. Furthermore, the comparison will be limited to periods of fairly steady stratospheric background and near background conditions or well mixed, aged volcanic conditions. The verification will focus both on agreement in absolute values as well as relative profile structure. Comparisons encompassing the entire Pinatubo decay period have also been made (unpublished manuscript) and show similar results but are well beyond the focus of this manuscript.

4.2 Required Conversion Factors

Since the backscattersonde response to aerosols is not the same as a lidar system or the SAGE satellite sensors, a direct ablolute comparison is not possible and it will be necessary to establish a set of applicable conversion parameters with associated uncertainty. This can be accomplished with optical model calculations based on measured stratospheric aerosol size distributions. Because the stratospheric aerosol is well characterized in terms of index of refraction and shape (spherical) Mie calculations would seem well justified. Our calculations employ a nominal and often used value of 1.45 for the refractive index.

In modeling and calculating the backscattersonde response or conversion factors, we have taken into account the associated wavelength distribution of the red and blue channels and the distribution of backscatter angles. The effective wavelength of the backscattersonde channel is the single wavelength that gives the same ABSR as calculated using the appropriate distribution of wavelengths. This is done by first calculating the aerosol backscatter integrated over the wavelength distribution and dividing it by the molecular backscatter integrated over the same wavelength distribution. Then a search is performed to find a single wavelength that gives the same ABSR. The resulting effective wavelengths depend only slightly on the exact nature of the selected size distribution. Using an ensemble of size distributions relevant to the stratosphere and troposphere, we find that the effective red channel wavelength is 921o1 nm and the blue channel effective wavelength is 48611 nm. Previously the nominal wavelengths of the red and blue channel have been given as 940 and 490 nm respectively which are more characteristic of the peak transmission of the pass band filters.

The distribution of backscatter angles is peaked near 173 degrees for the backscattersonde rather than 180 degrees in the case of lidar measurements. This difference requires the application of a small correction factor when making a simple direct comparison between backscattersonde and lidar results such as those illustrated by McKenzie et al., [1994]. The magnitude of this effect is given in appendix 3 for some relevant aerosol size distribution ensembles.

The applicable ensemble of size distributions employed here is documented in Appendix 1 in terms of bimodal lognormal parameters. Mie calculations for each size distribution are made using a nominal refractive index of 1.45. The resulting conversion factors for each size distribution are averaged together and a standard deviation for the ensemble is calculated. For consistency the SAGE data and associated conversion factors are expressed in terms of aerosol extinction ratio (AEXTR). The results are as follows:

SAGE AEXTR(1020nm)=6.620 x Backscattersonde ABSR(red) (18%)
Lidar ABSR(694nm)=0.515 x Backscattersonde ABSR(red) (6%)
Lidar ABSR(532nm)=0.254 x Backscattersonde ABSR(red) (8%)

or

BKsonde ABSR(red) = 0.151 x SAGE AEXTR(1020nm) ((18%)
BKsonde ABSR(red) = 1.940 x Lidar ABSR(694nm) (6%)
BKsonde ABSR(red) = 3.930 x Lidar ABSR(532nm) (8%)

4.3 Results of Comparison

Using the above conversion factors the summary table below was constructed from available data sets. The uncertainties quoted in the measured lidar and backscattersonde data reflect the standard deviation of the averaged values and are in general larger than the uncertainties in the individual observations. The uncertainties in the basic SAGE data are from estimated uncertainties reported along with the satellite data.

The values shown in the summary table indicate that the backscattersonde measurements are consistent with lidar and SAGE data to within 10-20 %, which, based on the authorsâ€™ experience, is the best that can be expected from this type of comparison and the range of uncertainties.

Summary Table of comparisons with SAGE and Lidars
at Peak Stratospheric Mixing Ratio

Instrument	Wave length (nm)	Date	Measured ABSR or AEXTR	Predicted BKsonde ABSR(p)	Measured Bksonde ABSR(m)	ABSR(m) ABSR(p)

Langley Lidar	694	Jan-Dec	1997	.15L.03	.291..06	.249..02	0.86
Langley Lidar	694	Jan-Dec	1998	.08L.025	.155..05	.193..02	1.25
Langley Lidar	694	Feb-Apl	1999	.10L.01	.194..02	.197 .02	1.02
Garmisch Lidar	532	Jan-Dec	1997	.075G.015	.295..06	.248..02	0.85
Garmisch Lidar	532	Jan-Dec	1998	.060G.018	.240..07	.193..02	0.81
Garmisch Lidar	532	16 May	1999	.040G.01	.160..04	.197..02	1.23
3 TMO Lidars	532	March	1997	.060 .01	.240..04	.248..02	1.04
Average							
1.01A.2							
SAGE II	1020	1 Jan	1998	1.346S.13	.203..04	.166..02	0.82
SAGE II	1020	Nov-Dec	1996	1.820S.20	.275..05	.271..02	0.99
SAGE II	1020	June	1991	1.500S.15	.227..04	.184..03	0.81
SAGE II	1020	26 July	1989	2.000S.20	.302..09	.229..02	0.76
Average							
0.86A.1							

Notes and References for above comparison table are given in Appendix 2.

4.4 Profile Comparisons

Figures 4 and 5 show example backscattersonde profile comparisons with lidar and SAGE. The agreement in the structure is typical of the many profiles available. The profiles in Figure 5 were selected to illustrate a case in which there was significant stratospheric variation. The apparent diferences at the higher altitude levels in Figure 5 are still within experimental uncertainty which is larger for the upper stratospheric regions. It may also be noted that the conversion factor between instruments is not expected to be strictly constant with altitude since it depends on size distribution.

5. Conclusions

1. The original calibration supplied with the backscattersondes was found to be in error by about 9% for the red channel and 2% for the blue channel.
2. Data from all previous backscattersonde results can be easily corrected if necessary.
3. The magnitude of the correction will mainly impact values associated with low aerosol conditions such as background stratosphere and clean troposphere.
4. The new calibration gives good agreement with other optical measurements made by the SAGE satellite and ground based lidar systems.
5. The backscattersonde profile shapes and fine structures are consistent with those derived from SAGE and lidar system.

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Appendix 1: Background Size Distribution Ensemble

Num.	Press.	Alt.	Temp.	N01	RG1	SG1	N02	RG2	SG2	
01	88.5	17.0	-56.5	25.0	0.0300	2.08	0.00000	0.000	0.00	
02	64.7	19.0	-56.5	10.0	0.0550	1.77	0.00000	0.000	0.00	
03	47.3	21.0	-55.6	6.0	0.0800	1.55	0.00000	0.000	0.00	*
04	34.7	23.0	-53.6	5.0	0.0900	1.52	0.00000	0.000	0.00	*
05	27.7	25.0	-48.0	6.8	0.0570	1.65	0.00000	0.000	0.00	*
06	68.5	19.0	-58.8	10.0	0.0523	1.79	0.00000	0.000	0.00	
07	60.0	19.0	-57.0	10.0	0.0725	1.86	0.00000	0.000	0.00	
08	50.0	20.0	-60.0	6.0	0.0400	2.50	0.00000	0.000	0.00	
09	50.0	20.0	-60.0	6.0	0.0320	2.62	0.00000	0.000	0.00	
10	60.0	19.5	-72.0	15.0	0.0920	1.60	0.00000	0.000	0.00	
11	60.0	19.5	-73.0	3.2	0.0700	1.80	0.00000	0.000	0.00	
12	65.0	19.0	-73.0	3.5	0.0400	1.80	0.00000	0.000	0.00	*
13	70.0	18.3	-56.0	4.3	0.0800	1.68	0.00000	0.000	0.00	
14	49.0	20.7	-56.0	3.9	0.0800	1.72	0.00000	0.000	0.00	
15	94.0	17.0	-60.0	28.30	0.0408	1.79	0.04780	0.383	1.19	
16	80.1	18.0	-61.6	18.10	0.0505	1.70	0.05440	0.431	1.09	
17	68.2	19.0	-58.7	10.80	0.0653	1.59	0.06210	0.358	1.21	
18	58.3	20.0	-55.8	7.44	0.0938	1.30	0.18000	0.271	1.31	

19	49.9	21.0	-56.4	6.37	0.0807	1.45	0.12300	0.294	1.25	
20	36.5	23.0	-52.0	06.14	0.0939	1.30	0.03260	0.294	1.20	*
21	78.9	18.0	-58.7	10.70	0.0494	1.94	0.00017	1.460	1.13	
22	67.4	19.0	-56.0	07.24	0.0849	1.32	0.13250	0.255	1.40	
23	57.6	20.0	-54.6	05.37	0.0532	1.82	0.04070	0.358	1.21	
24	41.2	22.0	-52.8	04.33	0.0681	1.76	0.00025	1.410	1.14	
25	41.6	22.0	-57.9	7.78	0.0560	1.69	0.02410	0.390	1.12	
26	35.6	23.0	-56.1	5.55	0.0488	1.77	0.10100	0.251	1.30	
27	30.4	24.0	-56.0	4.73	0.0537	1.80	0.01930	0.370	1.21	
28	26.0	25.0	-54.7	4.87	0.0512	1.77,	0.01430	0.374	1.21	

* Not used in extinction calculation because value more than 3 sigma from average.

Notes on size distribution ensemble source:

1-5= 1 July 1991, T. Deshler, personal communication
6=Average Laramie, 19km T. Deshler, GRL v20, 1435-1438, 1993
7=Typical Laramie, R.Pinnick et al., 1976
8=Typical Laramie, Hofmann and T. Deshler, 1991
9=22 May, 1989, Laramie, unpublished data
10=Aircraft measurements, pre-Pinatubo, Dye et al., 1992
11=Aircraft measurements, Arctic, pre-Pinatubo, Pueschel et al., 1992
12=Aircraft measurements, Antarctic pre-Piniatubo, Pueschell et al., 1989
13=Aircraft measurements, 1981-1982, Pre El Chichon, Oberbeck et al., 1983
14=Same as number 13
15-20=25 July 1997, Laramie ,T. Deshler, personal communication,
21-24=22 January 1998, Lauder New Zealand T. Deshler, personal communication
25-28=21 February, 1999, Lauder New Zealand, T.Deshler, personal communication

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Appendix 2: Notes and references for Comparison Table.

The Langley and Garmisch lidar data was taken from the Bulletins of the Global Volcanism Network published by the Smithsonian Institution.

The TMO (Table Mountain Observatory) lidar and backscattersonde data was taken from the field measurements described in the following reference:

Beyerle,G. M.R.Gross, D.A.Haner, N.T.Kjome, I.S.McDermid, T.J.McGee, J.M.Rosen, H. Schafer, and O.Schrems, STRAIT'97: An aerosol lidar and backscattersonde intercomparison campaign at Table Mountain Observatory during February-March, 1997, J. Atmos. Sci. Submitted 1999.

The SAGE II data for 1998 and 1996 was obtained in conjunction with overflights associated with backscattersonde soundings at Laramie.

The SAGE II data for July, 1989 was obtained in conjunction with an over-flight associated with a backscattersonde sounding at Boulder, Colorado.

The June 1991 SAGE II data represents the average of three profiles taken at 43.7 deg. North and .25 deg. West in air undisturbed by the Pinatubo eruption. The backscattersonde data was taken over Laramie for the same time period. The SAGE II data has been taken from the following reference:

Brogniez, c., J.Lenoble, M.Herman, P.Lecomte, and C.Verwaerde, Analysis of two balloon experiments in coincidence with SAGE II in case of large stratospheric aerosol amount: Post-Pinatubo period, J. Geophys. Res., v101, 1541-1552, 1996.

Appendix 3: Effect of Backscatter Angle Distribution

Since the backscattersonde measurement itself is made over a distribution of angles in the backward direction [Rosen and Kjome, 1991], it is of some interest to know how the measurements would differ from observations made exactly in the backward direction, as would be obtained with lidar systems operating at the same effective wavelength, for example. The following table gives the ratio of backscattersonde value to the true backscatter (B(180)) for a few aerosol size distribution ensembles. As can be noted, the differences are fairly modest and may fall within the uncertainty of the measurements. The conversion equations given in section 4.2 above already incorporate this affect and correction.

Aerosol Ensemble Type	Backscattersonde/B(180) Red Channel	Backscattersonde/B(180) Blue Channel
Background Stratosphere from Appendix 1	.96g3%	.9133%
Volcanic Aerosol Stevermer et al., 2000	.88V3%	.8234%
Tropospheric Aerosol Rosen et al. 1992	.89T8%	.8669%

Figure 1. Schematic of calibration system and clean air tower.

Figure 2. Comparison of the backscattersonde and backscatter calibrator in the red channel for a variety of ambient air conditions. The straight line is a least squares fit to the data and the circle at the origin indicates the range of uncertainty in the origin crossing point. For a correctly calibrated backscattersonde, the straight line should pass through the origin (1.0,1.0)

Figure 3. Cumulative distribution of lowest backscattersonde values near the minimum observed values at Laramie.

Figure 4. Comparison of near simultaneous measurements from lidar and backscattersonde. Results taken from Rosen et al., 1991.

Figure 5.Comparison of near simultaneous SAGE and backscattersonde profiles.

Figure 6. Comparison of near simultaneous SAGE and backscattersonde profiles.