File Revision Date:
October 25, 2017

Data Set Description:
PI: James M. Rosen and collaborators (see list below)
Instrument: Dustsonde (OPC25)
Sites: Minneapolis, MN and Laramie WY
Instrument History: see section below
Measurement Quantities: aerosol concentration in 2 to 5 size ranges, pressure, temperature, geopotential height (calculated from pressure and temperature), relative humidity reported as frost point, and ozone partial pressure.

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INSTRUMENT DESCRIPTION

SCOPE

This document, covering data collection from August 1963 to July 1988, is relevant to a particular instrument conventionally referred to as a dustsonde (and later as an OPC25) which is a balloon borne optical particle counter developed in the early 1960's and gradually phased out in the late 1980s in favor of similar but more advanced instruments covering an enhanced size range (Deshler et al., 2003,2006). The NDACC profiles for the dustsonde reflect the full altitude resolution of the original data and do not contain highly derived parameters such as size distribution parameters. This document covers the period from 1963 to July, 1988.

Many descriptions of this instrument along with observations have been given in standard journals (Rosen, 1964, Hofmann, et al., 1975, Deshler et al., 2003, Deshler et al., 2006 and references therein). It may seem unnecessary to elaborate further, but there are some additional details that may be required to address later questions that could arise concerning the utility of the data in new and evolving areas of interest. The following is a summary of the instrument functionality as well as some unpublished details and comments.

BACKGROUND, HISTORY, AND DEVELOPMENT

Development of the first dustsonde began at the University of Minnesota in 1961. The first sounding was conducted in August of 1963, and the first publication appeared in 1964 (Rosen, 1964). In the late 1960's the dustsonde program moved to the University of Wyoming and has continued there until the time of this writing (2014).

An important original design goal of the dustsonde was to focus on achieving as close a forward angle scattering as possible without extraneous internal scattering from the walls or from other parts of the optics, with the background being determined by molecular scattering from the internal volume. This led to an instrument with an average scattering angle of 25 deg. (ranging from ~ 12 to ~ 35 deg.) and a background light level that was 98% molecular scattering as determined from low pressure tests. A ‘white’ light source was used from a straight filament incandescent bulb operated at an over voltage giving it about a 4 hour lifetime.

At lower pressures the flow pattern through the sensitive scattering region can take on a very different pattern, passing only partially through the illuminated region. In the development process, visual observation of the flow pattern (using smoky air) was accomplished using a glass bell jar and windows in the scattering chamber. Adjustments to the intake and sheath flow were made so that virtually all the sampled air passed through the defined scattering region. Furthermore, it was found that additional adjustments needed to be made to the sheath air geometry and flow rate to prevent escape of incoming sampled particles which would cause spurious counts. In a continuing effort, during flight aerosol free air was periodically introduce into the sample stream to detect and eliminate such possibilities.

The counting efficiency of the dustsonde vs altitude was tested in an environmental chamber. The usual method involved first operating at ambient conditions with a surrounding non-volatile aerosol.

When the pressure was reduced relatively quickly by a factor of two, a resultant factor of two decrease in the counting rate should also be observed for 100% efficiency. This incremental change in pressure was done at successively lower pressures.

In addition to the scattering chamber geometry and tests, several other aspects are relevant for documentation here:

The pumps drawing air through the scattering chamber needed to be smooth flowing (non-pulsating), be able to produce the required head pressure, have a flow rate independent of altitude, and require low power consumption. A type of gear pump with high tolerances was developed for this application.

Photomultiplier tubes were employed in the light pulse detecting system which required high voltage power supplies. The presence of high voltage (greater than ~300 volts) on balloon flights can lead to numerous types of spurious signals, sometimes imitating the data itself. The effort put into encapsulating and low pressure testing high voltage light detector units was a major part of dustsonde construction.

Initially the scattering chambers had significant volume â€œdead spaceâ€� which contained expanding air as the balloon rises and must be taken into account in the sample flow rate. This effect was greatly reduce by using a smaller scattering chamber with the same optical characteristics.

In part, the traditional dustsonde is characterized by the employment of just 2 channels for particle size discrimination. The smallest size was determined by setting the detector threshold as low as possible without an excessive background counting rate. The largest size was set so that a significant number of particles would be counted as constrained by the pump and flow rate. Also, as discussed below, the threshold for larger particles could not be significantly larger because of the double response region of the optical scattering relevant to the dustsonde. In addition, for larger sizes more consideration would need to be given to sedimentation and impaction losses in the sampling geometry of the intake system.

The initial dustsonde flights indicated the presence of a mysterious background counting rate that needed to be subtracted from the aerosol counting rate. This background was determined to be from Cherenkov radiation (cosmic rays passing through the glass in the photomultiplier tubes and lenses) which had a maximum in the stratosphere from secondary production. The problem was eliminated with the use of a coincidence system requiring two independent photomultiplier tubes (including power supplies) to produce simultaneous pulses. This resulted in a huge improvement in reduced background counting rates from all sources but considerably increased the complication and expense of dustsonde construction. Coincidence counting started with the flight on April, 28, 1965 (the first 6 flights did not use coincidence) and allowed the pulse height discriminators to be set at a lower equivalent size level, as is documented in the NDACC files. In addition the first two dustsonde flights from Minneapolis reported in the NDACC data base only employed one particle size.

TELEMETRY SYSTEMS

VIZ Radiosonde Analog Telemetry

Until July 1984, a standard VIZ radiosonde was used (with relatively minor modifications) to transmit the data which was then displayed on chart recorders, often using multiple sub-carrier frequencies to simplify analog analysis. The aerosol data was presented as step-ramps on the chart recording with one step being 4 counts and a reset every 512 counts. Thus, it was not necessary to observe a particular channel continuously since the cumulative count could be inferred accurately over time. Occasionally the ramp would take sudden quantum jumps which were interpreted as noise from stray particles trapped in the scattering chamber and therefore neglected in the analysis. Each aerosol data point in the analog analysis therefore represented about 512 particles, or near maximum altitude a significant fraction of 512 particles. This integration procedure reduced the amount of statistical fluctuations and spurious noise as compared to the digital system described below. Thus, users of this data will see what appears to be a much smoother profile in the earlier analog data. Another peculiarity of the pre-July 1984 data related to the smoothing is the apparent altitude resolution of 100 meters. Originally the data was read out at uneven pressure levels and a separate file was made for each parameter, which proved to be very inconvenient, especially for tabulated visual inspection. The data presented for NDACC is a merging of all parameters into one flight file with appropriate interpolation to standard levels. However, one can easily identify the original data points in plots of the merged data so that essentially no information has been lost.

Because the early telemetry system involved visual recording of data from chart recordings, it was subject to inadvertent reading errors. During the 1980s a systematic effort was made to eliminate any such readings with a detailed examination of individual plots and checking suspicious outlying tabulated data points with the original record. Although about 1000 errors were found, this is insignificant to the total number of entries in the overall data set. Therefore, if the users of this NDACC data find a particular point questionable or unusual, very likely it has been given due consideration and left in the profile purposely.

With the VIZ radiosonde, normal flight procedure involved noting launch time as well as chart speed so that time after launch could be ascertained. However, the original archived profiles have no time information with them (pressure was the independent variable) and the chart records are now unavailable for the recovery of time data. Nevertheless, a reasonably accurate flight time has been reconstructed using a standard balloon rise rate profile for all soundings prior to June 20, 1984. As will be noted, the NDACC data set employs time after launch as the independent variable.

Vaisala RS-80 Digital Data Logging Telemetry

In 1984 an effort was begun to utilize a micro-processor controlled all digital data logging and telemetry system incorporating the Vaisala RS-80 radiosonde system, During the changeover, data was transmitted both through the analog system and the digital system to ensure uniformity. The new system eliminated hand reading errors and provided much better pressure measurements both in terms of accuracy and resolution with a data frame about every 10 seconds. However, at low concentrations the frequent readings cause problems with statistical fluctuations, requiring appropriate data averaging, especially for viewing a full resolution plot. In addition, the spurious quantum jumps mentioned above could not be identified and removed. Therefore single data frame aerosol values with unusually high counts may not reflect reality. In the NDACC data set, the data frames with zero counts have been averaged with surrounding non-zero data frames which may result in highly variable, very low concentration numbers and poorer altitude resolution. See further discussion below on the validity of very low counting rates.

INTRODUCTION OF THE CONDENSATION NUCLEI (CN) COUNTER

A distinct limitation of the dustsonde itself was the inability to sense particles smaller than about 0.15 um radius. This problem was addressed by preconditioning the intake aerosol in a chamber that enlarged the particles by condensation of ethylene glycol onto essentially all particles present to form larger particles that could be easily detected by the dustsonde (Rosen and Hofmann, 1977, 1983). Measurement of this parameter began December 19, 1973 and enhanced the limited knowledge of aerosol size distributions. The efficiency of the CN counter as a function of altitude was measured in an environmental chamber following the same approach as used to test the dustsonde by itself. After some experimentation, it was found that the CN counter could be made to function at high efficiency over balloon altitudes.

INTRODUCTION OF THE LARGE AEROSOL COUNTER (LAC)

Another disadvantage of the standard dustsonde was its inability to determine the concentration of particles larger than about 0.5 micrometers diameter, a knowledge of which is needed for adequately defining/constraining size distribution models. Since the concentration of the larger particles is generally much lower than that normally detected, a much larger flow rate is required for a significant sample to be obtained on a rising balloon. To this end, a high flow rate pump was developed (~ 1 liter/sec) and the sensitive scattering volume of the dustsonde was enlarged somewhat but otherwise the scattering geometry and detection system were unchanged. Separate large flow rate dustsondes were dedicated to the measurement of particles in four radius size ranges: greater than ~0.25, 0.95, 1.20, and 1.80 um. The smallest size duplicated one of the standard dustsonde measurements and served as a confidence check in the overall measurement. As later discovered, the 0.95 size channel was set too close to the double value optical response of the dustsonde and yielded undecipherable results. Thus, only the two largest size channels are useful and only these are reported in the NDACC data set. It may be noted that even with a sample flow rate of 1 liter/sec it is often challenging to obtain data that will do much more than set constraining limits on the size/concentration values for the free troposphere and normal stratosphere, let alone the upper stratosphere. Further discussion of the LAC and its usefulness in size distribution studies can be found in Rosen and Hofmann (1986). This instrument was used in about 40 soundings from November 20, 1980 to July 31, 1986 which covers a period with an onset of volcanic injection and subsequent decay.

SUPPORTING MEASUREMENTS: Ozone, Humidity/Frost Point

Ozone

Although it was recognized early on that simultaneous measurements of ozone could prove to be indispensable for the interpretation of the aerosol layers (Rosen, 1966) it was not until 1986 that it was included in the soundings on a fairly regular basis. The exact calibration protocol of the early ozone measurements are not well documented although the manufacturer's preparation procedure was followed (which evolved over the years). The ozone values/profiles associated with the dustsonde are for aiding in the interpretation of atmospheric phenomena observed in the sounding and are not intended to be used for monitoring purposes unless clearly stated otherwise.

Humidity/Frost point

Although the VIZ radiosonde system employed a humidity sensor, it did not prove to be useful. The humidity sensor in the Vaisala RS-80 radiosonde, on the other hand, gave promise to making useful measurements in the troposphere: ascent and descent comparisons as well as multiple sensors agreed well enough to believe that real values were actually being measured. However, the absolute value of the humidity appeared to be somewhat in error and needed correction, as has been reported by others (Miloshevich et al., 2006). The University of Wyoming group developed a general correction algorithm by adjusting the in-cloud relative humidity given by the sensor to be 100%. The backscattersonde (from another UW program) was used to detect in-cloud conditions, since the dustsonde channels did not respond in an easily identifiable manner to clouds. In the dustsonde NDACC data, the moisture profile is present as frost point (over water) for economy in displaying temperature profiles since the frost point can be included as well. Experience indicates that when the corrected frost point is within ~ 1 deg C of the air temperature, the balloon is likely in a cloud. Sounding opportunities have been available to compare the algorithmic RS-80 frost point sensor with a direct frost point measurement (Rosen, Oltmans, and Evans, 1989). The moisture measurements are included to aid in the understanding of the atmospheric conditions and are not qualified to be used in a monitoring application.

The algorithm for calculating frost point from the Vaisala RS-80 RH sensor is given here for completeness but has unproven utility outside of the UW data set and low moisture values. Also, later versions of the Vaisala radiosonde would be expected to have a different correction mechanism.

Relative humidity correction factor (RHcf):

RHcf=1+1.3*exp{-(70+TempModC)/13.48}

Corrected relative humidity (RHc):

RHc = (RH-RHmin)*RHcf+2.0

Where:

TempModC is a modified air temperature (deg. C) which follows the ambient temperature while it is decreasing and holds the value until the succeeding temperatures have dropped below the hold point. Typically TempModC essentially follows the air temperature to the tropopause and then stays constant to ceiling. This procedure prevents false variations in the final frost point due solely to large air temperature variations. Temperature profiles showing a smoothly decreasing temperature and no tropopause structure may prove problematic for the algorithm since no tropopause would be detected.

RHmin is the typical or average stratospheric minimum value reported by the sensor using the manufacturer's calibration. Typically it is between +5% and -5%.

The constant â€œ2.0â€� forces RHc to approach what might be considered reasonable values for the stratosphere.

Using the value of RHc, the frost point is calculated from standard tables.

BASIC SENSORS: Pressure, Temperature

The VIZ type radiosonde

Temperature and pressure measurements for the early dustsondes were obtained using standard weather bureau systems employing the well-known white rod thermistor and the pressure baro-switch, which was calibrated over the entire pressure range before each flight. The standard thermistor-temperature calculator was used for the temperature analysis. The baro-switch only provided pressure information at quasi regular intervals and interpolation was required to obtain pressure values at desired data points. The relativity humidity values provided by these sondes was not useful.

The Vaisala RS-80

The Vaisala system provided a huge improvement over the relatively crude and awkward to interface VIZ radiosonde. A full data frame could be obtained every few seconds with a concurrent accurate pressure value as well as temperature and humidity. A new dimension of analysis was made possible with the ability to clearly identify spectacular uniform oscillations in the balloon rise rates, presumably associated with mountain lea waves.

Altitude - a derived parameter

The following formula was used to compute the increment in altitude between data frames or pressure increments:

DeltaZ(m)=29.0274*Tbar(K)*DeltaP(kPa)/Pbar(kPa)

where

DeltaZ is the increment in altitude (meters)

Tbar is the average interval (data frame) temperature

DeltaP is the pressure change

Pbar is the average pressure during the data frame

The value â€œ29.0274â€ may differ somewhat in various algorithms used by various groups to obtain altitude from air temperature and pressure. Also, an initial launch altitude is required which could be slightly different in various analysis of the same data.

PARTICLE SIZE CALIBRATION and ASSOCIATED ISSUES

The Minneapolis soundings in the series mn630820 to mn680123 were calibrated with an aerosol made by atomizing a solution of nigrosin dye into a large metal chamber. The size and concentration was determined by quantitative filter sampling and microscope analysis of the filter while at the same time sampling the chamber with the dustsonde. A size distribution curve was subsequently developed and cross compared with the concentration indicated by the dustsonde. In later work, described by Pinnick et al., 1973, 1976, the optical response of the dustsonde to particles of a given size and refractive index was determined allowing the size setting for each channel to be redefined for aerosols of known refractive index. The NDACC size settings have been taken for an aerosol refractive index of 1.45 believed to be relevant to stratospheric aerosol particles. However, one can use the published response curve of the dustsonde to adjust the channel sizes to another index of refraction.

The earlier approach to size calibration is relatively crude and subject to more uncertainty than the standard method use in the Laramie (lm) series. Rather than nigrosin dye, uniform 1.01 diameter polystyrene spheres were atomized to form an aerosol of known particle size and the least sensitive channel (AE2) was set to count just half the total aerosol present (the total aerosol count can be determined from the most sensitive channel (AE1) counting rate). According to the response characteristics of the dustsonde, a 1.01 um diameter polystyrene particle will produce the same pulse height as a 0.5 um diameter stratospheric aerosol particle. In this way, for an ideal OPC, a slight decrease in the sizing threshold would result in a full particle count and a slight increase in the threshold would result in no counts. The NDACC dustsonde data from Laramie reflects a 1: 10 fixed pulse height ratio between AE1 and AE2. In a few early

Laramie soundings, a 20:1 pulse height ratio was used but the NDACC data has been adjusted for this effect (see Hofmann et al., 1975).

A slight complication arises for coincidence counting in that the individual detector circuits must be set so that after coincidence the counting rate is still half the maximum. Also pulse width and quantum counting efficiencies need to be considered. These further calibration issues are) relatively minor and have been discussed by Hofmann et al., 1975 and Deshler et al., 2003).

ACCURACY and ERRORS

Concentration and Size

The uncertainty in the size and concentration measurements are believed to be about +/- 10% (Deshler et al., 2003). An additional uncertainty arises when the number of counts per data point drops below a few hundred as determined by Poisson counting statistics. For example, a data point associated with 100 counts would have a statistical uncertainty of 10%. The statistical errors can be estimated from the data itself by using the associated sample flow rate and may become so large as to limit the usefulness of the data.

At low counting rates (low concentrations) anomalous background counts may also become important. Concentration profiles for the larger sizes above the stratospheric maxim which show constant rather than sharply decreasing values (as in the smaller sizes) are suspect and probably represent an upper limit unless independent supporting measurements are available. A constant low value counting rate could reflect instrumental noise. However, such information is still valuable in setting upper limits and therefore has been included in the data set.

Pressure, Temperature, Relative Humidity, Ozone, Altitude

VIZ radiosonde:

Pressure: a few kPa (mb) at ground level to ~0.5 kPa (mb) at 30 km

Pressure reading about 1 to 2 per minute.

Temperature: ~ 1 deg C

Temperature reading about 1 per 30 sec.

Humidity sensor: not used

Vaisala RS-80

Pressure: 0.5kPa (mb) or 1%, whichever is smaller

Pressure resolution: 0.01 kPa (mb) reading every data frame (~10 sec.)
Temperature: ~0.2 deg. C as indicated by manufacturer. ~ 1 deg. C from experience.
Temperature resolution: ~0.1 deg. C, reading every data frame
Frost point (after corrections) ~ 1 deg. C at values near saturation (troposphere only)

Ozone
Accuracy ~ 10% or better
Resolution 0.1 mPa

Altitude (as calculated): typically 1-20 meters depending on altitude and algorithm.

CONSISTANCY CHECKS

During stable periods of minimal volcanic activity, the stratospheric aerosol mixing ratio (number/ mg of ambient air) near the maximum tends to change very slowly. Consequently, successive soundings would be expected to show little change during these periods and could be used to test and monitor the overall repeatability of the instrument and its calibration. Such occasions occur in soundings 790404 to 790919, 810526 to 810622, 810627 to 810814, 820217 to 820722, and 880524 to 880701, with the last series showing a slight aerosol decay from beginning to end. These measurements suggest that the measurements are very repeatable.
Comparative sounding with two instruments are routinely made and show good agreement. However, these soundings have not in general been included in the NDACC data base because of their repetitive and internal monitoring nature. An exception are the two soundings lm850624.t10 and lm850624.t12 which illustrate the degree of consistency.

LONG TERM STABILITY

Ideally long term stability should be confirmed by comparing accepted standard flight units against working flight instruments during an actual sounding. In practice this is not possible because any standard instrument could suffer known and unknown changes during the rigors of flight including violent descents and impact. Nevertheless, some instruments have been set aside for occasional use in such comparison soundings and have been used to examine the data continuity between older and newer versions of the instruments (Deshler et al, 2003).

COMPARISONS

Long term comparisons between a diverse set of instruments and measurements can also be used to address instrument stability and provide confidence in the instruments' credibility of trends and variations as well as the instruments themselves. Earlier studies of this type have been given by Northam et al., 1974, Russell et al., 1984, Rosen and Hofmann, 1986 and Osborn et al., 1989. A more recent and comprehensive study has been given by Deshler et al., 2006. The results of these studies support the use of dustsonde data in delineating long term variations.

SIZE DISTRIBUTIONS - Stratosphere

A knowledge of the size distribution is generally necessary to make quantitative comparisons between diverse instruments. Size distribution parameters would be a highly derived and potentially uncertain quantities for the measurements made before ~1989 and are not included in the NDACC data set for this reason. An effort to find useful size distributions fitting the earlier measurements has been given by Rosen and Hofmann, 1986. Since size distribution is such an important quantity, it is desirable to establish agreement between many sources. In a general approach, Stevermer et al., 2000 have shown how the size distributions derived from the dustsonde and a variety of other measurements are self-consistent in predicting relationships/conversions between various optical and mass quantities.

SIZE DISTRIBUTIONS - troposphere

Since the aerosols in the troposphere are not as well characterized in terms of shape and composition as in the stratosphere, the dustsonde size measurements are subject to additional uncertainty for the planetary boundary layer and free troposhpere. However, the measurements are still useful for defining layers, transport phenomena /activity, correlations with other parameters, and general aerosol concentration/characteristics that could be useful over the long term. In spite of these limitations, relatively satisfactory results have been obtained in using the dustsonde data to model simultaneously measured optical properties in the lower atmosphere (Rosen et al., 1992).

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