Overview of NDSC data base

- Terry Deshler
- Scientific Steering Committee NDSC
- University of Wyoming

http://www.ndsc.ws/

Network for the Detection of Stratospheric Change (NDSC)

For questions or comments about NDSC:
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The Network for the Detection for Stratospheric Change (**NDSC**) is a set of high-quality remote-sounding research stations for observing and understanding the physical and chemical state of the stratosphere. Ozone and key ozone-related chemical compounds and parameters are targeted for measurement. The NDSC is a major component of the international upper atmosphere research effort and has been endorsed by national and international scientific agencies, including the International Ozone Commission, the United Nations Environment Programme (**UNEP**), and the World Meteorological Organization (**WMO**).

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Lidar Working Group Meeting Oct 6-9, 2003, Rome, Italy. Announcement, Agenda

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- Satellite Chemistry/Atmosphere Missions - updated January 2002
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- Climate Change and Ozone Depletion
- NDSC brochure (33 Meg)
- NDSC newsletter: view ftp

For technical issues or problems with this web site contact J. Wild at Jeannette.Wild@noaa.gov.
This site last updated August 2003.

NDSC: Goals of the Network

The international Network for the Detection of Stratospheric Change (NDSC) was formed to provide a consistent, standardised set of long-term measurements of atmospheric trace gases, particles, and physical parameters via a suite of globally distributed sites.

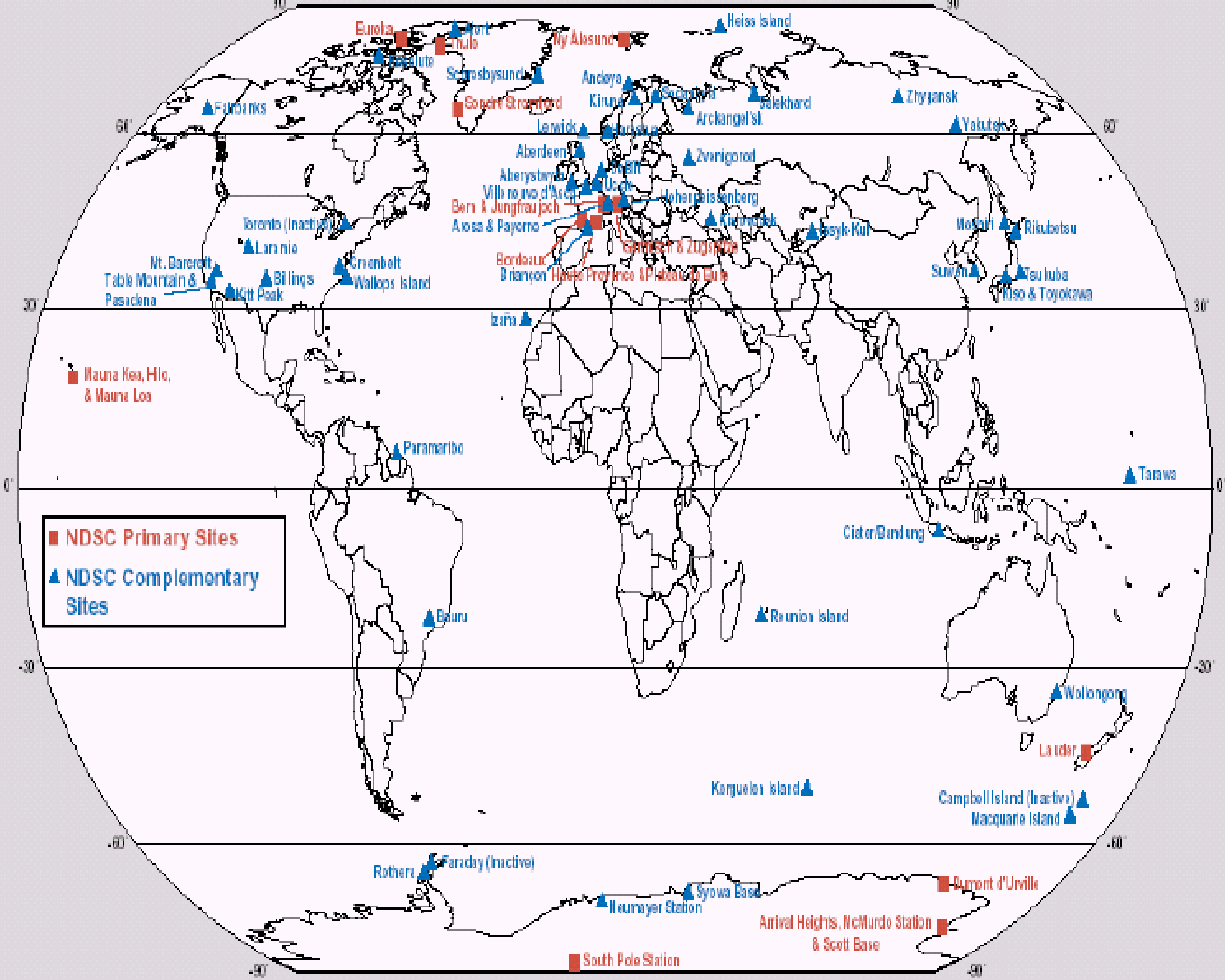
The principal goals of the network are:

- To study the temporal and spatial variability of atmospheric composition and structure in order to provide early detection and subsequent long-term monitoring of changes in the physical and chemical state of the stratosphere and upper troposphere; in particular to provide the means to discern and understand the causes of such changes.
- To establish the links between changes in stratospheric ozone, UV radiation at the ground, tropospheric chemistry, and climate.
- To provide independent calibrations and validations of space-based sensors of the atmosphere and to make complementary measurements.
- To support field campaigns focusing on specific processes occurring at various latitudes and seasons.
- To produce verified data sets for testing and improving multidimensional models of both the stratosphere and the troposphere.

Stratospheric water vapor microwave radiometer at Table Mountain Observatory (34 °N, 118 °W). Photo courtesy of I.S. McDermid (JPL, USA).

The primary instruments and measurements are:

- Ozone lidar (vertical profiles of ozone from the tropopause to at least 40 km altitude; in some cases tropospheric ozone will also be measured)
- Temperature lidar (vertical profiles of temperature from about 30 to 80 km)
- Aerosol lidar (vertical profiles of aerosol optical depth in the lower stratosphere)
- Water vapor lidar (vertical profiles of water vapor in the lower stratosphere)
- Ozone microwave (vertical profiles of stratospheric ozone from 20 to 70 km)
- H2O microwave (vertical profiles water vapor from about 20 to 80 km)
- CLO microwave (vertical profiles of CLO from about 25 to 45 km, depending on latitude)
- Ultraviolet/Visible spectrograph (column abundance of ozone, NO2, and, at some latitudes, OCLO and BrO)
- Fourier Transform Infrared spectrometer (column abundances of a broad range of species including ozone, HCL, NO, NO2, CLONO2, and HNO3)



NDSC Primary Sites
NDSC Complementary Sites
Eureka
Alert
Thule
Resolute
Ny Alesund
Heiss Island
Scoresbysund
Søndre Strømfjord
Kiruna
Salekhard
Arckangel'sk
Zhyjansk
Yakutsk
Fairbanks
Lerwick
Aberdeen
Zvenigorod
Aberystwyth
Uccle
Hohenpeissenberg
Bern & Jungfraujoch
Arosa & Payerne
Bordeaux
Briançon
Haute Provence & Plateau de Bure
Izaña
Issyk-Kul
Moshiri
Rikubetsu
Suwon
Tsukuba
Kiso & Toyokawa
Toronto (Inactive)
Laramie
Mt. Barcroft
Table Mountain &
Pasadena
Billings
Kitt Peak
Greenbelt
Wallops Island
Mauna Kea, Hilo,
& Mauna Loa
Paramaribo
Tarawa
Cister/Bandung
Bauru
Reunion Island
Wollongong
Lauder
Kerguelen Island
Campbell Island (Inactive)
Macquarie Island
Faraday (Inactive)
Rothera
Syowa Base
Neumayer Station
Dumont d'Urville
Arrival Heights, McMurdo Station
& Scott Base
South Pole Station
60°
30°
0°
-30°
-60°
-90°
90°

Ny Alesund (79 N, 12 E)	Lidar	Ozone Profiles	Neuber	Seasonal	91 - 02
		Temperature Profiles	Schrems	Seasonal	95 - 03
		Aerosol Profiles	Schrems	Seasonal	91 - 03
	Microwave	Ozone Profiles	Kunzi	Seasonal Full year	94-95, 02-03 96-01
		ClO Profiles	Kunzi	Seasonal	95 - 00
	UV Vis	Total Column: NO_2, O_3	Braathen	Seasonal	91 - 98
	UV Vis	Total Column: NO_2, O_3	Burrows		95 - 01
	FTIR	Total Column: 19 species	Schrems		92 - 02
	Ozonesonde	Ozone Profiles	von der Gathen		92 - 02
	Aerosolsonde	Aerosol Profiles	Rosen	Seasonal	96 - 00

Mauna Loa (20 N, 156 W)	Lidar	Ozone Profiles	McDermid		93 - 03
		Temperature Profiles	McDermid		93 - 03
		Aerosol Profiles	McDermid	353 nm	93 - 99
				355 nm	01 - 03
		Aerosol Profiles	Barnes		94 - 01
	Microwave	H_2O Profiles	Nedoluha		96 - 02
		Ozone Profiles	Parrish		95 - 02
	UV Vis	Total Column: NO_2	Johnston		96 - 01
	FTIR	Total Column: HNO_3, HCl, O_3, N_2O, F_{22}	Murcray	Bomen Terminated	91 - 95
		Total Column: O_3, N_2O, C_2H_2, C_2H_6, CH_4, CO, CHF_2Cl, HCN, HF, HNO_3, NO_2, NO, HCl	Murcray	Bruker	95 - 00
	Dobson	Total Column Ozone	Evans		70 - 02
	UV Spectral	Erythemally Weighted UV	McKenzie		96 - 02

Lauder (45 S, 170 E)	Lidar	Ozone Profiles	Swart		94 - 03
		Temperature Profiles	Swart		97
		Aerosol Profiles	Uchino		92 - 99
		Aerosol Profiles	Adriani		94 - 97
	Microwave	Ozone Profiles	Parrish		92 - 02
		H_2O Profiles	Nedoluha		92 - 02
	UV Vis	Total Column: NO_2	Johnston		80 - 02
	FTIR	Total Column: HCl, HF, HNO_3, O_3	Jones		90 - 95, 02
	Dobson	Total Column O_3	Boyd		87 - 02
	Ozonesonde	Ozone Profiles	Matthews		86 - 01
	Aerosolsonde	Aerosol Profiles	Rosen		92 - 00
	UV Spectral	Erythemally Weighted UV	McKenzie		91 - 02

Selected NDSC data is now available to the public:

The NDSC **Data Protocol** states:

> Since the nature of small trends detection requires an extremely high level of measurement confidence, the Data Protocol recognizes that multiple seasonal analyses may be required for observations from both individual and multiple sites. **It is expected that such a procedure shall yield the verifiable product referred to as "NDSC data" within a two-year period after acquisition.** Co-authorship shall be offered on publications resulting from the verification procedure to those investigators participating in the process.
>
> **After the above verification, NDSC data will be available to anyone through centralized scientific data archiving and distribution facilities.**

In this spirit, data that has been so verified and given the status of NDSC data, and is more than two years old, is now available to the general public. NDSC datasets are outlined in the NDSC **Measurements and Analyses Directory**. Access to this data is now available through anonymous ftp to ndsc.wwb.noaa.gov in the subdirectory /pub. It is expected that data users will consult the on line documentation and reference articles to fully understand the scope and limitations of the instruments and resulting data. Scientific users of the data are encouraged to directly contact the NDSC Principal Investigator listed in the data documentation to insure the proper use of specific datasets.

People who use NDSC data in a publication are requested to include the following acknowledgment: "The data used in this publication was obtained as part of the Network for the Detection of Stratospheric Change (NDSC) and is publicly available (see http://www.ndsc.ncep.noaa.gov)."

Please also send notification of publication to J. Wild (jeannette.wild@noaa.gov) so that we may add the publication to our publications list.

Get data via ftp

NDSC Protocols

- Steering Committee Appointments and Elections
- Data Protocol
- Validation Protocol
- Appendix I: Lidar Instruments
- Appendix II: UV/Visible Instruments   1999 update
- Appendix III: Microwave Instruments
- Appendix IV: Infrared Instruments (FTIRS)
- Appendix V: Ultraviolet Spectro-Radiometry
- Instrument Intercomparisons Protocol
- Protocol for Theory and Analysis
- Complementary Measurements Protocol

Lidar Instruments

Lidar spectroscopy is an analytical technique with a long history in environmental science and chemistry. This method has been used widely in atmospheric chemistry and has a heritage in ground-based as well as space-based instruments. The lidar technique needs no further justification as a primary technique for the NDSC; however, individual instruments must still be validated. This description is intended to apply to the determination of vertical ozone column amounts and temperature and aerosol vertical distributions.

Quality Criteria for the Evaluation of New Primary and Complementary Instruments and Instrument Teams

Independent Evaluation of the Instrument Design and Data Analysis

The NDSC has accepted lidar measurement techniques as valid methods for measuring and monitoring stratospheric temperature, aerosols, and ozone, and tropospheric ozone. Prior to a formal intercomparison of the new instrument(s), the Investigator should supply the NDSC Lidar Working Group (LWG) with a detailed technical description of the instrument and its general operating parameters.

Instrument and Data Analysis Intercomparison

There are several ways lidar instruments (temperature, aerosols, ozone) within the NDSC can be validated:

- Blind intercomparison of lidar systems located at the same site for a given period of time may be conducted. Such validations can be made either through a validation exercise using an NDSC mobile lidar system, or by comparing a new instrument with an already established lidar system at a given NDSC site. Such intercomparisons should follow the rules of the NDSC Intercomparison Protocol.
- Intercomparisons on a statistical basis with a satellite-borne instrument measuring the same quantity as the lidar can also be performed (for example, SAGE-type instruments for ozone and/or aerosols measurements). Such intercomparisons have to be made on the long term to remove much of the natural variability. In this respect, the satellite instrument is used as a traveling standard between the various lidar stations.
- Intercomparisons on a statistical long-term basis may occur with other lidar instruments located at complementary sites in the vicinity of NDSC primary sites.
- Side-by-side intercomparison with other instruments measuring the same atmospheric variable on the same NDSC site also are recommended.
- Algorithm intercomparisons also can be performed using a common database established within the NDSC Lidar Instrument Group, which includes

- Side-by-side intercomparison with other instruments measuring the same atmospheric variable on the same NDSC site also are recommended.
- Algorithm intercomparisons also can be performed using a common database established within the NDSC Lidar Instrument Group, which includes synthetic data derived from atmospheric and instrument models, raw data provided by validated lidar systems within the NDSC, and the ancillary data required for data inversion.

It is mandatory within the NDSC that a given lidar system has at least undergone satellite and algorithm validations. A plan also should be established for a blind intercomparison validation within the first three years of operation.

Quality Criteria for the Evaluation of Continuing Primary and Complementary Instruments and Instrument Teams

The validation record of a given instrument will be evaluated on a two-year basis by the LWG. Lidar Investigators should provide the following information.

- A document describing the instrument and data acquisition procedures.
- A document describing the algorithm to be used, including the forward and retrieval models, the method of error analysis, and the ancillary data (spectroscopic data, atmospheric parameters) used for the inversion.
- The validation record of the instrument.

In addition, NDSC lidar Instrument Investigators are required to participate in ongoing validation exercises such as algorithm intercomparisons and satellite data long-term analysis.

Changes in Instruments and Data Analysis

Since one of the major goals of the NDSC is the detection of long-term trends, care should be used with any modifications of the instrument or data analysis which may affect the results. Once the regular operation of aprimary or complementary instrument has begun, such changes should notbe undertaken lightly, consultation with the LWG is recommended. The primary data (interferograms or spectra) should be retained by the Investigator indefinitely (although not deposited in the NDSC archive), so that improved data-retrieval processes, including improved spectral line parameters, can be applied retrospectively to the earlier data. In such cases,the entire dataset should be reprocessed and archived, along with (at least) reference to earlier versions.

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UV/Vis Instrument Specific Appendix

P. V. Johnston, J-P. Pommereau and H. K. Roscoe

Revision - November 1998 (finalised August 1999)

Introduction

This document describes the validation process for new zenith viewing UV/Vis instruments, and the criteria for maintaining data quality from existing instruments. It is written to cover measurements of the species NO_2 and ozone, which are the ones most accurately measured using the zenith sky viewing technique at this time. However, much of this document will also apply to measurements of the species OClO and BrO. NO_2 and ozone were the primary species measured at the most recent NDSC UV/Vis Instrument Intercomparison which was held at the Observatoire de Haute-Provence (OHP), France, in June 1996, and this revison of the appendix includes new procedures advanced after discussions with the UV/Vis community at OHP. The SCUVS-3 BrO working group also held a BrO measurement intercomparison at OHP in 1996 following the formal NDSC intercomparison, and the resulting report is expected to be a reference for future NDSC BrO measurement intercomparisons. The reports on the UV/Vis Data Analysis Intercomparison in 1991, the Lauder Instrument Intercomparison in 1992 and the OHP Instrument Intercomparison, should be read with this document (see references).

Because UV/Vis spectroscopic measurements are used to answer a variety of scientific questions, this appendix will attempt to define the certification of groups and their instruments for two applications: (Further ones should be defined in the future.)

(1) NDSC trend determination and global studies;

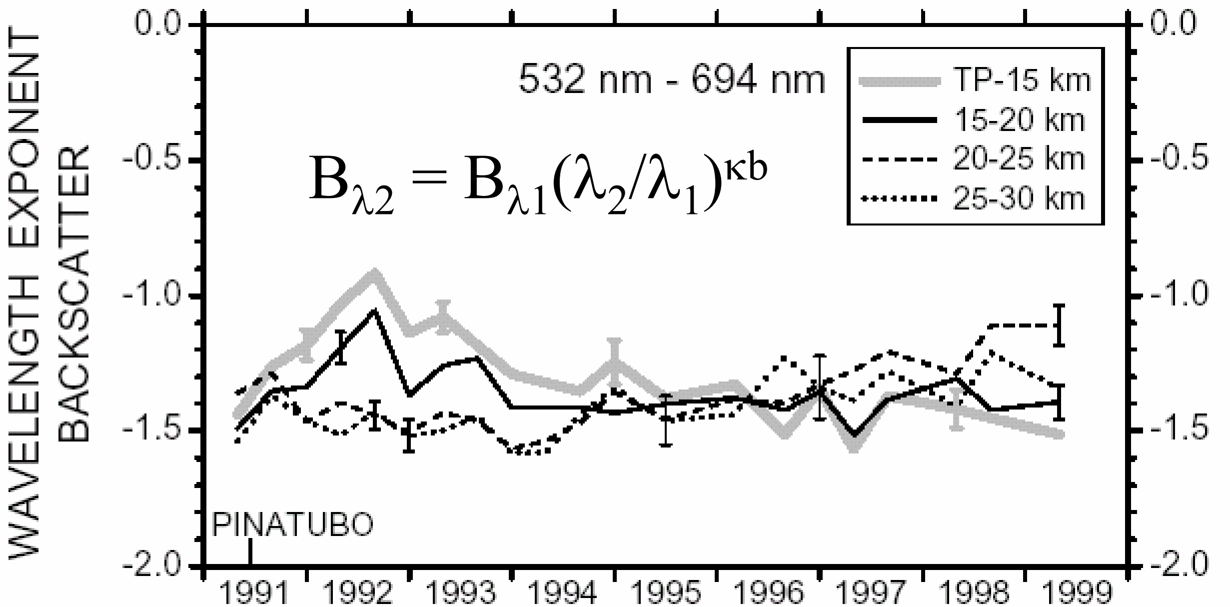
(2) NDSC stratospheric chemistry process studies and satellite validation

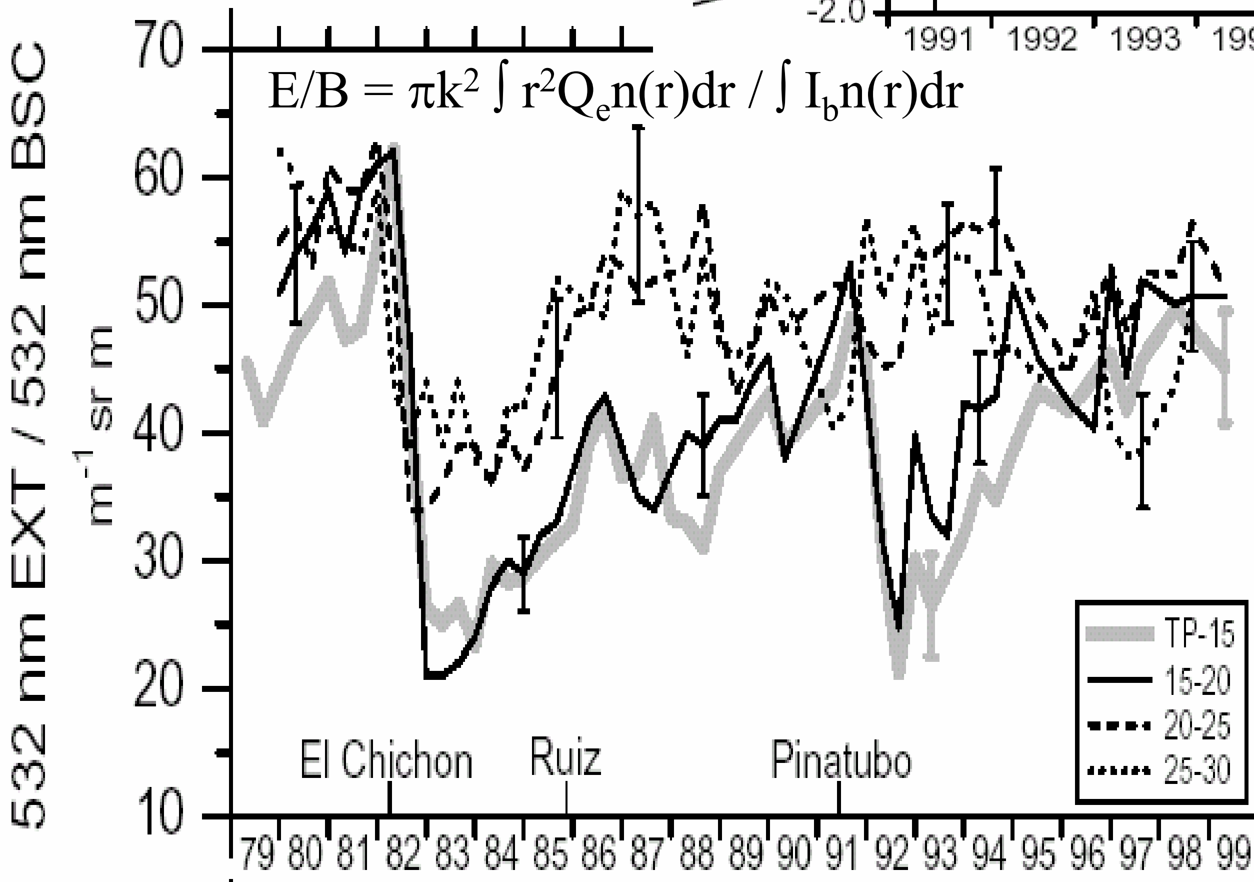
Trend measurements and global studies require a long term dedicated approach to the maintenance of the quality of the measurements and the archiving of data. To determine long term trends requires stable and well calibrated instruments operated by groups that have a thorough understanding of the measurement technique and who have demonstrated competence in the management of long term programmes. Global studies include, for example, identifying possible interhemispheric asymmetries of species such as NO_2, which requires the maintenance of good inter-instrument calibration. Type (1) measurements of the highest possible accuracy at solar zenith angles up to 95° in the visible are the most suitable for NO_2 vertical profiling (Preston et al., in preparation). Because type (1) studies would probably

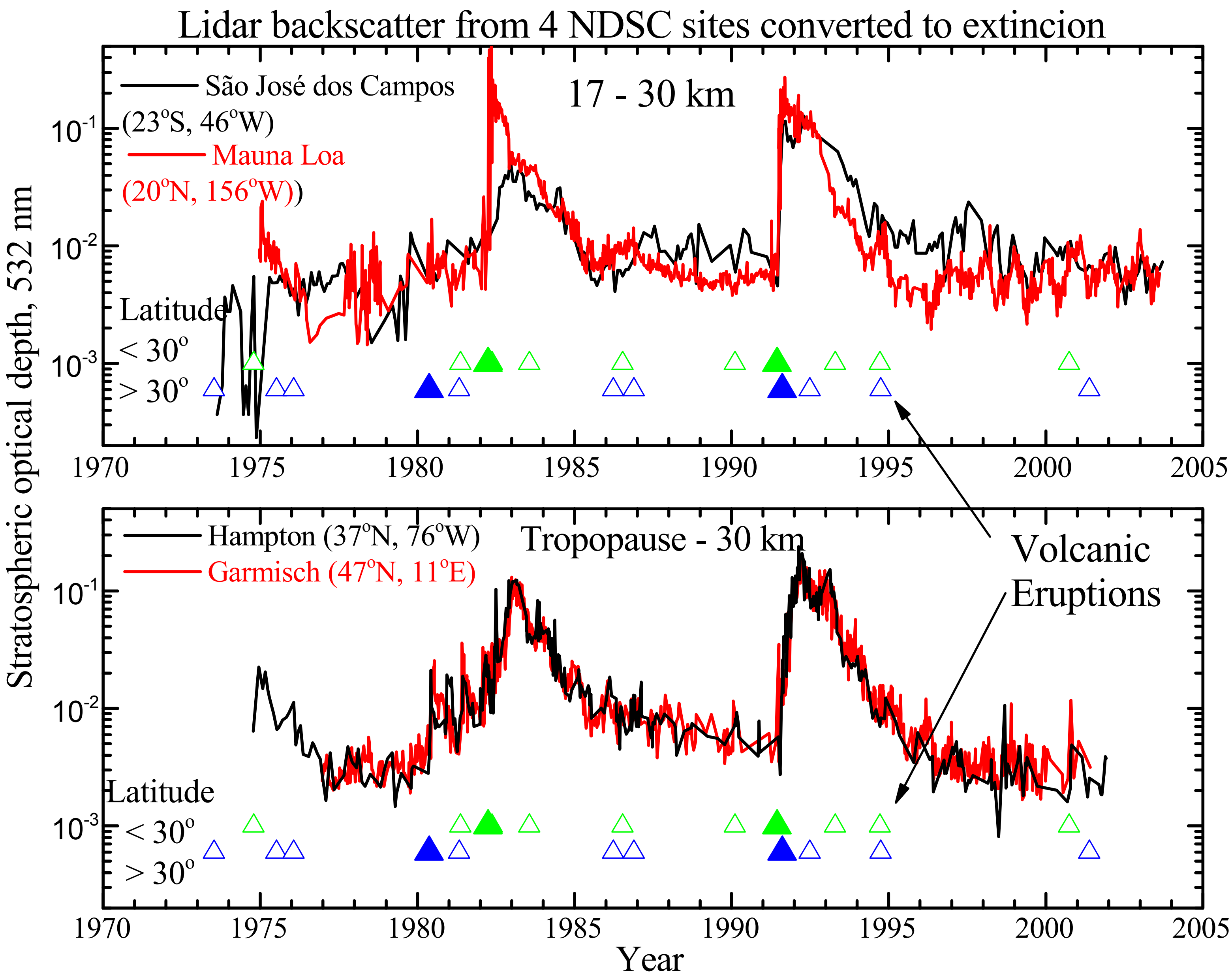
Example stratospheric optical depth from 4 NDSC aerosol lidars

- São José dos Campos, Brazil (23°S)
- Mauna Loa, Hawaii, USA (20°N)
- Hampton, Virginia, USA (37°N)
- Garmisch-Partenkirchen, Germany (48°N)

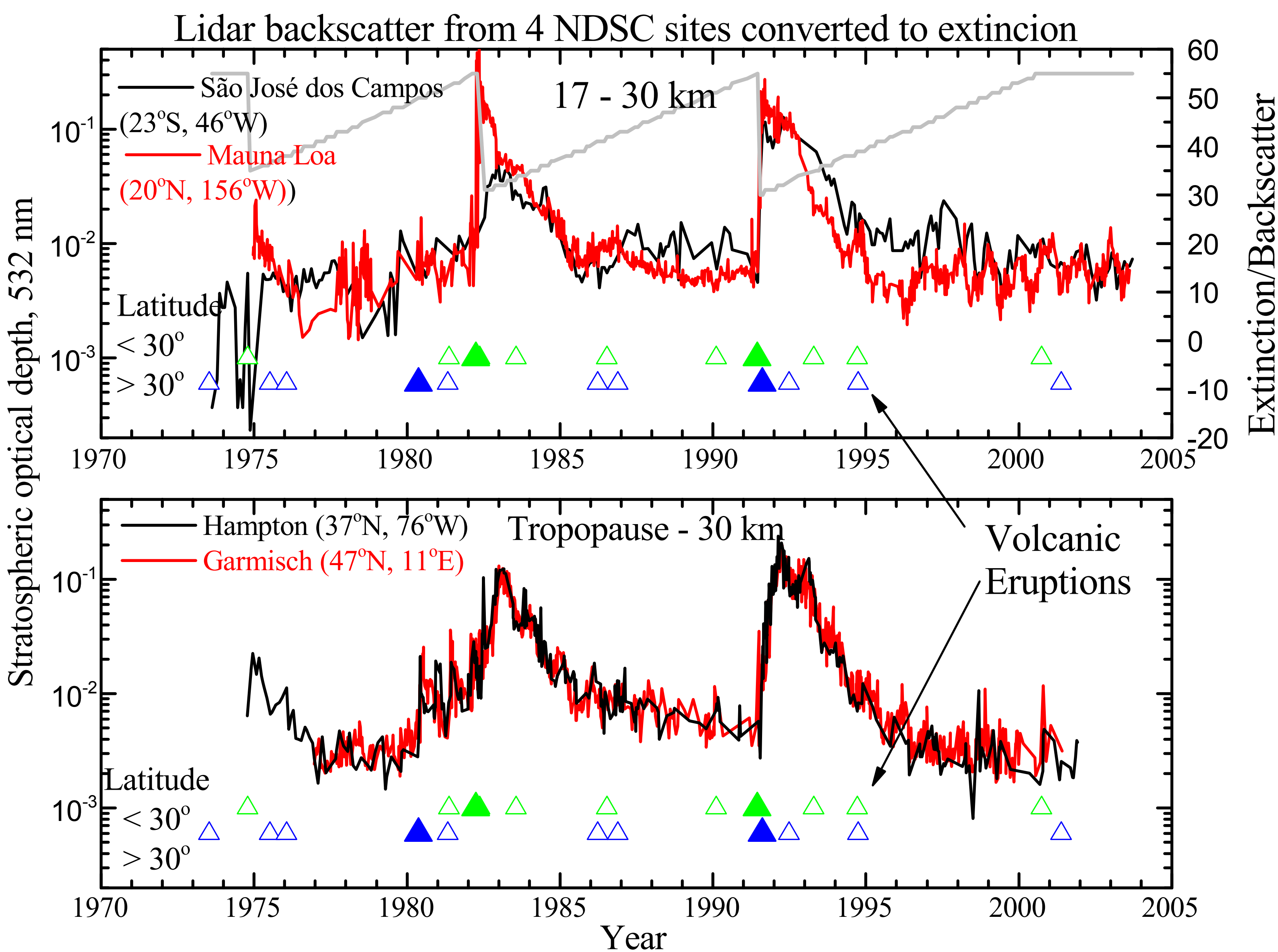
Jäger, H., and T. Deshler, *Geophys. Res. Lett.*, *29(19)*, 1929, 2002.







Lidar backscatter from 4 NDSC sites converted to extincion
São José dos Campos (23°S, 46°W)
Mauna Loa (20°N, 156°W))
17 - 30 km
Latitude
< 30°
> 30°
Hampton (37°N, 76°W)
Garmisch (47°N, 11°E)
Tropopause - 30 km
Volcanic Eruptions
Stratospheric optical depth, 532 nm
Year
1970
1975
1980
1985
1990
1995
2000
2005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> 30°
Hampton (37°N, 76°W)
Garmisch (47°N, 11°E)
Tropopause - 30 km
Volcanic
Eruptions
Stratospheric optical depth, 532 nm
Extinction/Backscatter
Year
1970
1975
1980
1985
1990
1995
2000
2005

Evaluation of Instrument Design and Data Analysis

Before a formal intercomparison with a certified instrument is planned, the group whose instrument is being assessed may be asked to supply the following to the NDSC steering committee's UV/Vis Instrument Group or designated representative.

- A detailed technical description of the instrument including sensitivity limits and general operating parameters.

- An outline of the spectral analysis technique used with particular details of the number and source of the cross sections used. If the cross sections are not published or those commonly used by the UV/Vis community, a comparison between the cross section normally used and a generally accepted one is required. Sufficient information is required so that it can be seen that the laboratory cross sections used are of sufficient resolution that their convolution with the measured instrument (slit) function will produce sufficiently accurate analysis cross sections.

- An example of a raw measured spectrum, a ratio spectrum of a twilight spectrum (near 90 degrees SZA) to a midday spectrum, and a spectrum demonstrating the quality of the cross sections fit to the ratio spectrum.

- Spectra or data showing the instrument resolution (slit function), an estimate of the stray light levels and the instrument polarisation characteristics, in the wavelength interval expected to be used for the intercomparison. This would normally consist of:

  (1) one or more spectra containing lines from spectral lamps (e.g., low pressure mercury, neon, argon, krypton or xenon) or a laser;

  (2) clear sky spectra measured using fixed detector gain, with and without suitable Schott glass short λ cut filters;

  (3) two or three spectra showing the relative transmission of the instrument for different polarisation axes that has been measured using a white light source filling the field of view together with a suitable film polariser. For instruments not using an input fibre optic cable, the polariser is positioned at the entrance aperture and two measurements are made with the polariser orientated parallel and normal to the grating ruling. For instruments using a fibre optic cable, normal and parallel to the grating ruling has no meaning at the entrance to the fibre where the film polariser must be placed for the polarisation measurement. This is because many fibre optics cables partially randomise the polarisation, a characteristic that is often used to reduce the sensitivity of zenith viewing spectrometers to sky polarisation effects. In this case, the polariser is positioned at the entrance of the fibre optic cable and three measurements are made with the polariser rotated 45 degrees between them.

Instrument Intercomparison

The instrument intercomparison must follow the "blindness" rules detailed below and adhere to the general philosophy of the NDSC Instrument Intercomparison Protocol. The instrument specific requirements of this protocol follow. In the general case, one or more new instruments are to be evaluated by comparison with an already certified instrument or instruments (called the reference instrument(s) in the following) under the supervision of an impartial referee. The certified instrument(s) to be used will be designated by the Instrument Group.

- The intercomparison should be conducted at a site that is reasonably free from tropospheric NO_2 contamination. Rapidly changing contamination due to a close source is unacceptable, making it essential that the site chosen for the intercomparison is remote from emissions such as those from cities and industrial plants. Some tropospheric contamination may be acceptable if it is only present for part of the day, such as in the late afternoon when it only affects only the evening measurements. Clean morning measurements can be sufficient for some assessments. The site should also be one that would normally experience both clear (>30% expectation) and cloudy days over the intercomparison period. Measurements during both clear and cloudy conditions are important to ensure that different skies do not introduce errors in the results.

- The intercomparison should be conducted for a period of not less than 10 days with all instruments operating correctly.

- Measurements, taken by the one or more instruments being evaluated and the reference instrument(s), should be made over the whole day if possible, and not less than the SZA range 70 to 95 degrees (or as dark as acceptable signal to noise dictates) together with a period near midday, for both morning and evening twilight periods, each day of the intercomparison. The measurement integration period should be less than the time taken for a 1 degree change of solar zenith angle at twilight (5 minutes at midlatitudes) or a maximum of 5 minutes.

- Measurements taken by the instrument(s) being evaluated and the reference instrument(s) should be coincident in time. If this is not possible the compared data sets must be interpolated for comparison using a formula agreed to by the Instrument Group. Also, the effects that changing light intensity and changing column amount have on the results must be properly understood. The resulting error in the compared column amounts due to the use of different integration methods must be demonstrated to be small. For the 1992 Lauder Intercomparison such errors were calculated to be less than 1%.

- The wavelength interval used should be the same for the instrument(s) being evaluated and the reference instrument(s). This requirement may be difficult, but without it close comparison accuracy (better than 5%) may not be possible. This could create unnecessary doubts about the instrument being evaluated.

- The cross sections used in the analysis must be from the same laboratory measured source, or have been previously intercompared at a similar resolution.

Acceptance Criteria for New, Primary and Complementary Instruments

The Instrument Group or its designated representative(s) will examine the results of the Intercomparison and make a recommendation to the NDSC Steering Committee. While a number of factors may enter the considerations, the principal criteria for the two types of certification currently used are as follows.

Type (1), Global studies and Trend Measurements

Because no absolute calibration is possible, accuracy is determined by quantifying the accuracy of each instrument being considered for certification, relative to the designated reference instrument(s) and, as appropriate, other instruments that are assessed as producing high quality results.

Spectral measurements made during the intercomparison period will be analysed by all participants using agreed criteria (wavelength interval, cross sections, etc.) to obtain their intercomparison results. A reliable method to determine which instruments meet this certification type is a regression analysis (Roscoe et al., 1998). This intercompares, using linear regression, all combinations of the twilight sets of measurements. Each set must include the results for a range of measurement SZAs, typically 70 to 93 degrees. Matrices of residual error, slope and intercept are generated in order to identify the instruments that agree most closely. The results from these instruments can then be used as the reference results for comparing the results of the other participating instruments against. In 1996 at the OHP intercomparison, the NO_2 results from three instruments, (one was the designated reference instrument) agreed to within 1.00 (+0.00 -0.02) in slope and 0.00 (+0.02 -0.07) cm-2 in intercept in one analysis (same wavelength interval and NO_2 cross sections), with similar or better ozone results. This close agreement is the basis for choosing the following figures as reasonably achievable at this time:

<u>NO_2 Regression Accuracy</u>

Slope = 1.00 ± 0.05

Intercept = ± 0.15 x 10^{16} cm-2

Residual <= 0.10 x 10^{16} cm-2

<u>Ozone Regression Accuracy</u>

General Acceptance Criteria for type (1) Certification

The following provides guidelines for the assessment. While some criteria must be met others can be applied as required to meet the overall goals of the assessment.

- The general instrument tests to measure resolution (slit function), polarisation characteristics, and stray light levels must be acceptable. See the discussion in the following section **Instrument Tests** for further information.

- Good result self consistency: this can be assessed by examining the "smoothness" of the twilight data series, especially when varying cloud conditions occur (as long as the troposphere is clear).

- At campaigns where the NO_2 or ozone amounts measured at each SZA don't vary noticeably over several days (as occurred at Lauder in 1992 - see Hofmann, 1995), overlaying the results plotted against SZA can quantify an instrument's uncertainty over a wide range of values .

- Low midday result variations during variable cloud periods and between midday values on clear and cloudy days. At clean sites these are naturally small, < $1x10^{15}$ cm^{-2} for NO_2 and < $1x10^{18}$ cm^{-2} for ozone slant columns, so large variations can indicate instrument or analysis problems.

- Acceptable signal to noise at high (near 95 degrees for spectra in the visible) and small (near 70 degrees) SZAs. This can be estimated by examining residual spectra or the "smoothness" of the result series (above). The reference instrument(s) errors at these solar zenith angles can be used as guide for acceptance. An important reason for considering high/low solar zenith angle results is that at midlatitude intercomparison sites, where there is normally plenty of NO_2 , they provide a good estimate of performance at high latitudes where NO_2 is lesser.

- Good consistency between the results obtained using the daily reference spectrum and the results obtained using the campaign single midday reference spectrum. This helps identify problems caused by long period (10 day) drifts in the instrument function or spectral wavelength repeatability. The reference instrument errors can be used as a guide for acceptance.

- Low (< $2x10^{15}$ cm-2 NO_2 , < $1x10^{18}$ cm^{-2} ozone, slant columns) systematic errors. These are difficult to quantify, but examination of residual spectra, and comparisons of results obtained by using different wavelength subsets in the spectra, can be carried out.

Type (2), Process Studies and Satellite Validation

Other methods to analyse intercomparison results can also be used to determine certification. One method that is being developed is to use measurements taken over the more limited range of SZAs, 85 to 91 degrees. These are converted to one vertical column result for each twilight measurement set by averaging the 85 to 91 degrees measurements after scaling each one by the air mass factor for the SZA of the measurement. Most instruments produce their most accurate measurements in this SZA range. Such an intercomparison method is a variation on the "fractional difference" technique used in the 1996 OHP intercomparison (Roscoe et al., 1998). It is expected that this technique is more suitable for certifying type (2) instruments. Using airmass factor weighted values also allows results obtained using different wavelength intervals to be compared (subject to the errors arising from the airmass calculations).

Ratios of the derived (airmass factor weighted) vertical columns are used to measure the agreement between the reference and compared instruments. For a 10 day intercomparison, 20 twilight periods, and therefore 20 such ratios, provide sufficient data from which a mean ratio and a fractional standard deviation of this mean ratio can be estimated. These statistics are used to assess the agreement of both NO_2 and ozone measurements.

Because both AM and PM results are available from the NO_2 measurements intercomparison, an offset value can be estimated by using a linear regression on the campaigns (>= 10 days) results. Because AM mid-latitude NO2 values are typically 0.6 times the PM values, the error on such an estimate is expected to be acceptable in determining the offset tabled below for NO_2.

A suggested accuracy for certification is:

<u>NO_2 Agreement</u>

Ratio = 1.00 ± 0.10

Standard Deviation <= 0.05

Offset = $\pm 0.25 \times 10^{16}$ cm-2

<u>Ozone Agreement</u>

Ratio = 1.00 ± 0.05