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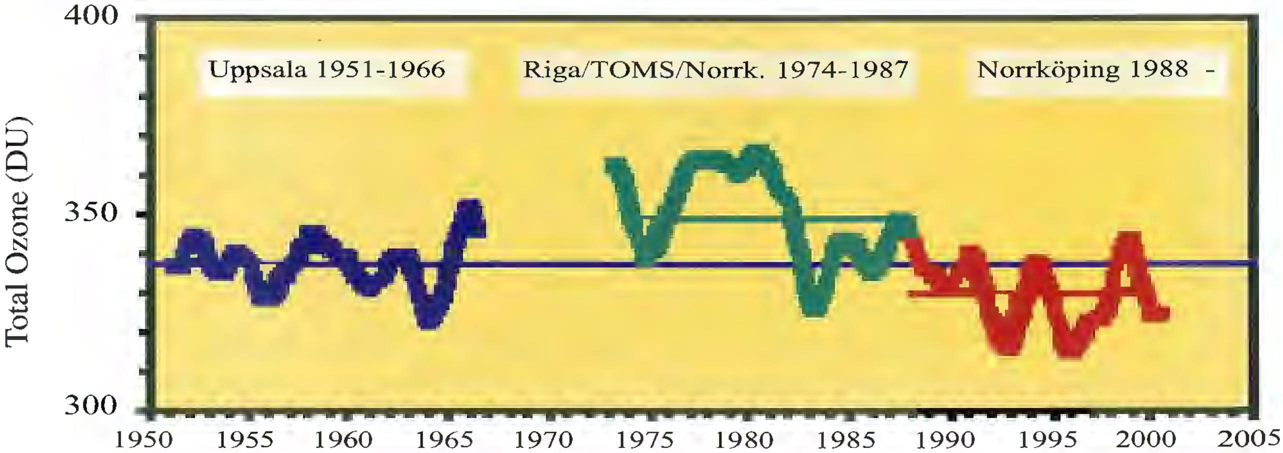

Measurements of total ozone 1997-1999

Weine Josefsson

Cover

The long-term variation of total ozone over the Baltic region. Original monthly mean values are based on measurements from Uppsala May 1951 to July 1966, Riga March 1973 to December 1987, TOMS Version 7 November 1978 to January 1988 and from Norrköping February 1988 to July 2000. A two-year triangular filter smooths the monthly values. Long-term average values, for the periods indicated, are given by horizontal lines.

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Weine JOSEFSSON

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Measurements of total ozone 1997 – 1999

Abstract/Sammandrag

A summary of the quality control, quality assurance and measurements of total ozone at Norrköping and Vindeln during the period 1997-1999 is made. The Brewer #006 and Brewer #128 were compared to the travelling reference Brewer #017 at Vindeln in 1999. Major changes in the measurements and instruments are discussed. The reprocessing of all Brewer data since 1996 and the introduction of the new format recommended by WOUDC at the end of 1999 are documented.

At the end of this three-year period the ozone layer has shown an increase after many years with several periods of considerable depletion. Therefore, the previous downward trend that was as large as -8% per decade has disappeared. The data set consists of 12 years of almost uninterrupted data at Norrköping. Most of the gaps have been possible to fill with satellite data to have monthly values based on a complete set of daily values. An intercomparison between ground based and TOMS Version 7 satellite based data shows an astonishing agreement in most cases.

Data recorded at Abisko in 1926 and 1927 on the initiative of G.M.B. Dobson was found in the archive. They were recomputed to modern scales and the result shows that the thickness of the ozone layer at that time is similar to the present thickness. The long-term data sets now available from Vindeln and Norrköping give the opportunity to study the temporal and in some respect also the spatial characteristics of the total ozone. Both the spatial correlation and the auto-correlation vary considerably over time.

The Web-site for total ozone (under http://www.smhi.se) has made measurements available for a lot of people in almost real-time. Ozone data can be viewed as graphs or transferred by ftp. There are also some pages with general information as well as some links to related sites. In particular, this method for distribution of information has been found to be useful for the public, media and decision-makers.

Key words/sök-, nyckelord

Total ozone, measurements, Brewer, Dobson, ozonespectrophotometer, TOMS, comparison, long-term

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Contents

1 Introduction

The main goal of the project of monitoring total ozone, i.e. the content of ozone in a vertical column throughout the atmosphere, is to perform regular and accurate observations. The Swedish Environmental Protection Agency (NV) has been funding this project since 1987. In 1988 regular measurements started in Norrköping at SMHI and in 1991 at Vindeln Experimental Forest Station. The measurements are reported by Josefsson (1989, 1990, 1991, 1992a, 1994, 1995 and 1996) and Josefsson and Karlsson (1997). These measurements will be used for studies of the variations and possible trends of the amount of total ozone as well as for studies of modelled and measured ultraviolet solar radiation. Another important aspect of the monitoring is to observe and report episodes with a thin ozone layer. During such episodes the UV-radiation may reach high levels. Therefore, the ozone data are used in a model to calculate the UV-index, which is a measure of the level of the erythemally active UV-irradiance. Daily data of total ozone and UV-index forecasts are available on the web-site http://www.smhi.se

Data are also delivered to the World Ozone and Ultraviolet Radiation Data Centre (WOUDC) and the stations are included in the Global Ozone Observing System (GO_3OS). In the winter and spring data from Norrköping are sent to WMO GO_3OS ozone mapping centre at Thessaloniki in Greece where daily maps are produced. These near real-time maps are very valuable and may be compared with the satellite total ozone retrieved from GOME (Global Ozone Monitoring Experiment), TOVS (TIROS Operational Vertical Sounder) and TOMS (Total Ozone Mapping Spectrometer). Although the ground based network is sparse in some areas the maps give a good overview of the ozone situation in the Northern Hemisphere.

Table 1.1. The locations and periods of the measurements of total ozone in Sweden using the Dobson and Brewer ozone spectrophotometers. Note that the frequency of observations were often low and variable for the earlier periods.

STATION	LATITUDE	LONGITUDE	HEIGHT (a.s.l.)	INSTRUMENT	PERIOD
ABISKO	68.33°N	18.83°E	386 m	Dobson ?	1926-27
UPPSALA	59.87°N	17.63°E	15 m	Dobson #030	1951-66
NORRKÖPING	58.58°N	16.15°E	43 m	Brewer #006	1982-86 *
				Brewer #006	1988-96
				Brewer #128	1996-
VINDELN	64.24°N	19.77°E	225 m	Dobson #030	1991-
				Brewer #006	1996-

* Sporadic measurements

This report will present the monitoring during the years 1997-1999. But, there will also be some processing of the long term series as well as some intercomparisons between satellite and ground based observations. Some technical events of importance have occurred during the three years. The intercomparison in 1999 at Vindeln of the Brewer instruments is of course the major one. It will be presented separately below. The more unpleasant occurrences of breaks in the measurements due to failures in the electronics will also be noted and how the gaps in the measurements are dealt with.

2 Tests and maintenance

2.1 Brewer #006

Several tests are performed regularly each day to ensure that a Brewer instrument is in good condition. To simplify the testing two lamps are available inside the case of the instrument. The daily variation of the temperature and also mechanical movements of the instrument affects the wavelength setting. Therefore, a mercury spectral line is scanned and compared with a corresponding tabulated one. In this way the wavelength setting is checked and if needed adjusted several times a day. A step motor is used for the scan and for an eventual adjustment of the wavelength setting by moving the grating. The Brewer #006 has one monochromator and a cut-off filter to remove longer wavelengths. In the Brewer #128, which is a double monochromator, there are two step motors and no cut-off filter. For the single monochromator Brewer a relation (second degree polynomia) between number of motor steps from a fixed starting position and the wavelength position is found from known spectral lines. Roughly, one motor step corresponds to 0.007 nm. The potential precision of the wavelength setting (closest step position) will therefore be better than ½*0.007 nm. The accuracy of the wavelength setting depends on the goodness of the relation, actual temperature, mechanical stresses etc. It is estimated to be within 0.05 nm for scanning the UV. This has been demonstrated for Brewer #128 at the NOGIC-1996 campaign, Slaper and Koskela (1997). For measuring the total ozone the wavelength setting procedure is more accurate and should normally be within three motor steps, i.e. 0.01 nm.

The absolute output of the mercury lamp varies over the year mainly depending of the temperature. From all mercury scans of a day the average count rate of the maximum of the selected mercury line is plotted in Figure 2.1.1. Also plotted are the highest and lowest temperature, connected to a scan, of each day. There seems to be a degradation of the lamp output. The last winter the high temperatures have been more frequently above 10°C. This change is due to a better clamping of the heaters to the optical frame, which was done at the

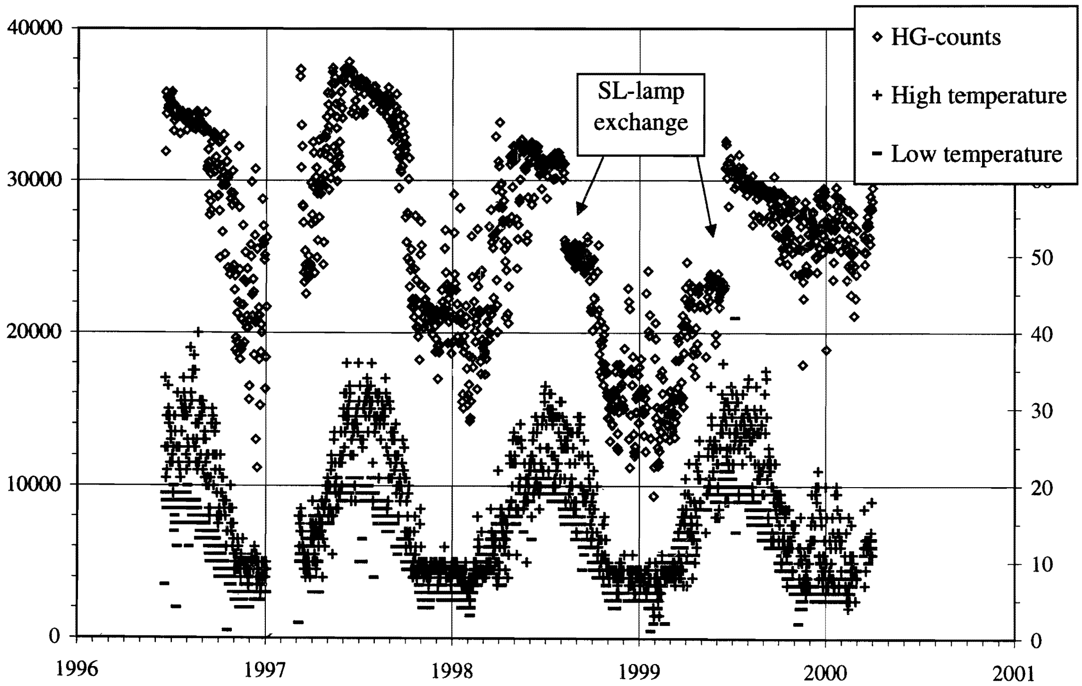

Figure 2.1.1. Mercury lamp output (counts, left) for Brewer #006 and the period 1996 to early 2000 and the corresponding temperature range (°C, right).

service in the summer of 1999. The effect of the higher temperature is clearly seen in the higher average count rate during the winter of 1999/2000. The graph also illustrates the harsh environmental stress of the Brewer. One should remember that the thermistor measuring the temperature is positioned in the cut-off filter in front of the photo-multiplier tube. The temperature may vary considerably between different parts of the instrument. In the summer temperatures above 30°C always occurs. In the winter the internal heater limit the temperature drop to about +5°C. In Vindeln the air-temperature often is below -20°C.

A halogen lamp, in this context also called standard lamp, is used as a reference of the relative sensitivity. Two values from this test, corresponding to the values of ozone (R6) and sulphur dioxide (R5), are recorded daily and compared with the same values from previous tests. The plot in Figure 2.1.2 summarises the variation of these values for the period. These values should be within ±15 units of the long-term averages. Large changes may occur when the lamp is exchanged, moved, the lamp house is opened or when the optics are cleaned. Unexplained changes should imply that a real change of the sensitivity has occurred and a need of a new calibration. Normally, the R6-values scatter some ± 5 units and the R5-values slightly more. This is within the level of tolerance. Probable causes of this variation are dependence on temperature, instability of the lamp, ageing of the lamp and of course a true change of the relative sensitivity of the instrument. The observed sudden jumps in the R5 and R6 values during this period are connected with certain events and can thus be explained. It should also be noted that small jumps and changes often are within the level of tolerance. Additional measurements are needed to gain sufficient information if a real change has occurred. If the output of the halogen lamp is stable the R6-values are assumed to be directly related to the measurements of total ozone by the relation

$$\Omega_{cor} = \Omega_{uc} (SL_{REF} - SL_{OBS}) / (10 * \mu * \delta\alpha),$$

where Ω_{cor} is the corrected value of total ozone, Ω_{uc} is the uncorrected value, SL_{REF} the reference R6–value, SL_{OBS} the R6-value of the day, μ the relative optical path length and $\delta\alpha$ the differential ozone absorption coefficient. For the Brewer #006 the present value of $\delta\alpha$ is 0.3509. The reference R6-value is the standard lamp test result connected with an intercomparison. Very roughly, a tolerance of 15 units in the standard lamp test results corresponds to 1% in the total ozone. From the normal scatter in the R6-value of about 5 units one understands that the standard lamp test is a very sensitive method to track the instrument.

For Brewer #006 there are several notable jumps that can be seen in Figure 2.1.2. The ones before 1997 are discussed in Josefsson and Karlsson (1997). A burn-out in the main power supply of the instrument caused a gap in early 1997. Also some other electronic boards were affected and they had to be replaced. This caused several weeks of interuption in the measurements. Fortunately, it occurred in midwinter when ozone observations cannot be made. Later in May of 1997 there is a cluster of data points below the others. These outliers are probably connected with humidity problems. After an exchange of dessicant on May 26 the problem disappeared for more than a year.

In June and July of 1998 it was noted that the standard lamp test results became noisy. An investigation of the output showed that the lamp had changed its output considerably. Therefore, it was decided to make a lamp exchange. As can be seen some of the scatter also may be caused by humidity problems. The operators at Vindeln had noted that the blue desiccant went pink and had to be replaced frequently. A change of the standard lamp will cause a change in the test values as can be seen in the beginning of August 1998.

The standard lamp behaved relatively well for a while. But, some outliers now and then indicated problems. The main cause of this was a leakage that caused water to enter through the quartz window. The leakage was not localised until the lamp ceased to work prior to the intercomparison in June of 1999. Then, the leakage was repaired (the sealing of the quartz window) and the broken lamp was replaced by a new one.

The uncertainty of the sulphur dioxide measurements (±5 DU) is roughly of the same magnitude as the prevailing atmospheric column amount at our measuring sites (0-5 DU). However, at special occasions with enhanced levels, >5 DU, the increase is detectable. This may occur after major volcanic eruptions or when severely polluted air is advected into our region.

The standard lamp is also used for some other tests. One is the Run and Stop test. It is done to check the performance of the slit mask. In normal operation the slit mask is moving (Run) and exposes the exit slits one by one. One cycle of measurement is done in about one second. The movement of the slit mask has to be co-ordinated with the reading of the photomultiplier. Otherwise the slit will not be fully exposed when the measurement at a specific wavelength is taken. This co-ordination is controlled by an appropriate delay of the slit mask positioned in front of the exit slits. Most sensitive to changes in the shutter performance is the dark position, where the dark count of the photomultiplier is measured. The measured dark count is normally

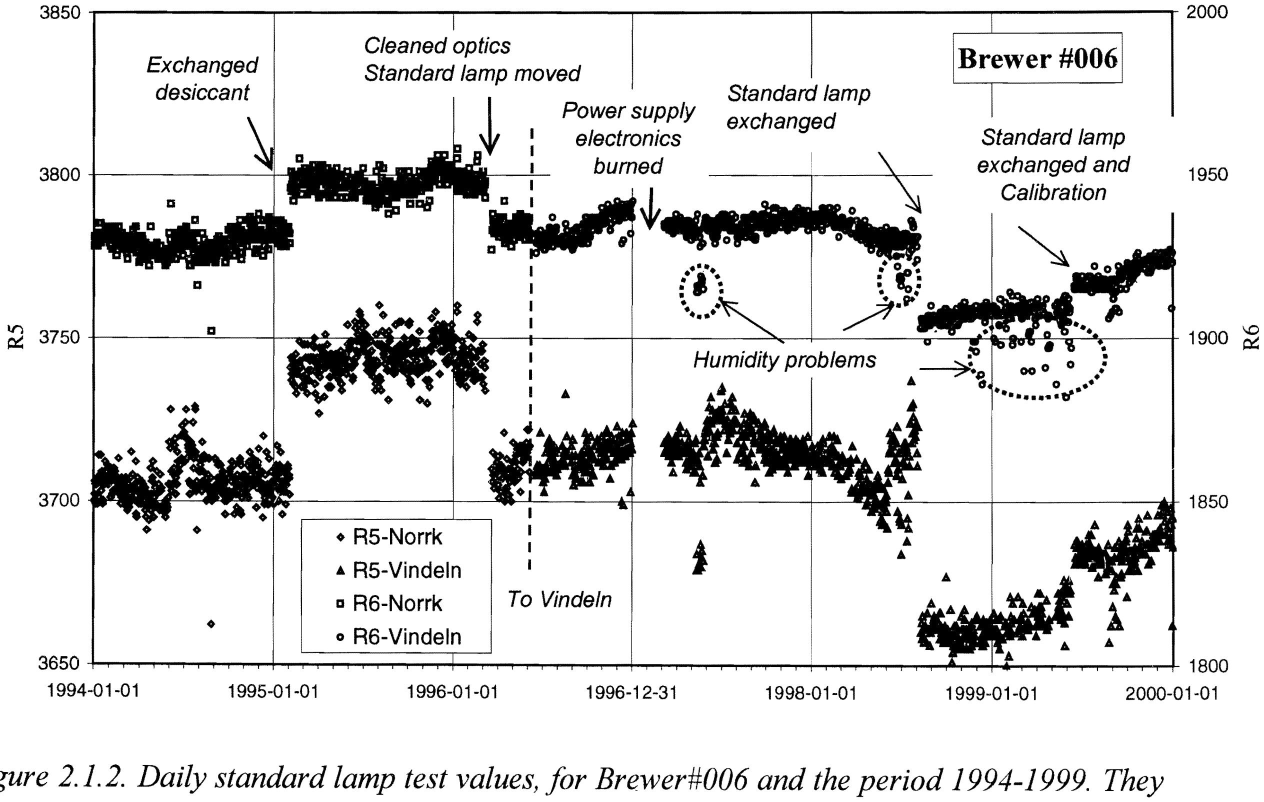

Figure 2.1.2. Daily standard lamp test values, for Brewer#006 and the period 1994-1999. They are used as indicators of the stability of the instrument. The level of tolerance is ± 15 units. The R5-value corresponds to the sulphur dioxide and the R6-value to the total ozone.

of the order of a few pulses if the temperature of the instrument is below +20°C. Above +30°C it increases quite rapidly with temperature. The program corrects for this effect and compared to measured number of counts it is normally almost negligible. But, as an indicator of the slit mask performance it can be regarded as very sensitive, since even a small change in the dark count changes the ratio. The last time the Run and Stop test indicated a problem for Brewer #006 was in late 1991.

Another test checks and monitors the dead time of the photomultiplier. It is a measure of the time it takes for the photomultiplier to respond to a signal. A pre-set value of the dead time is used to correct the measured counts. Also this test has shown no indication of problem during this period. There is a small yearly variation probably connected with the temperature and some jumps when the standard lamp have been exchanged. Once a day after sunset the Run and Stop test and the Dead Time test are done. Varying the delay time of the slit mask to check the setting of this parameter can also be tested. It is done about once a year to confirm that the used value does not have to be altered.

As already discussed the desiccants of the instrument have to be checked and replaced now and then. An indicator of the state of the desiccant is possible to view through an inspection window. Anyhow, to avoid problems from humidity in the instrument, the desiccant is regularly exchanged once a month, if the weather permits.

To increase the speed of the scan a new board was inserted as well as some changes in the operating program. This change was done at the intercomparison in 1999.

2.2 Brewer #128

The principles of testing the performance of a Brewer are mentioned in the previous section and will not be repeated here. The R5 and R6 values for Brewer #128, Figure 2.2.1, is roughly one third in magnitude compared to the corresponding values of Brewer #006. The graphs have the same resolution on the y-axis whilst the time periods differ. Also in this case there are interuptions and sudden jumps that can be connected to certain events.

Over the first three years there has been a decreasing trend in the standard test lamp results. It corresponds to an effect of about 3% in the total ozone values. This is corrected for in the reprocessing of the total ozone. The events connected with four interuptions are also indicated in Figure 2.2.1. The one of June 1999 will be discussed in the following. When the instrument returned from the intercomparison at Vindeln in late June of 1999 a very large change in the test results was noted. Yet, no good explanation has been found for this behaviour. A probable explanation may be a mechanical shock during transportation. It was apparent that the new calibration from Vindeln no longer was valid. After thourough investigation it was decided to correct the calibration accordning to the standard lamp results.

The decision is based on the assumtion that the standard lamp was unchanged. Although, the method of correction may have some uncertainty it will be traceable. A new calibration at once was not possible. But, the instrument will be calibrated in connection with the NOGIC2000 in June 2000. A rough estimate of the soundness of the correction is to compare with the TOMS overpass data for Norrköping as is presented in section 4.2.

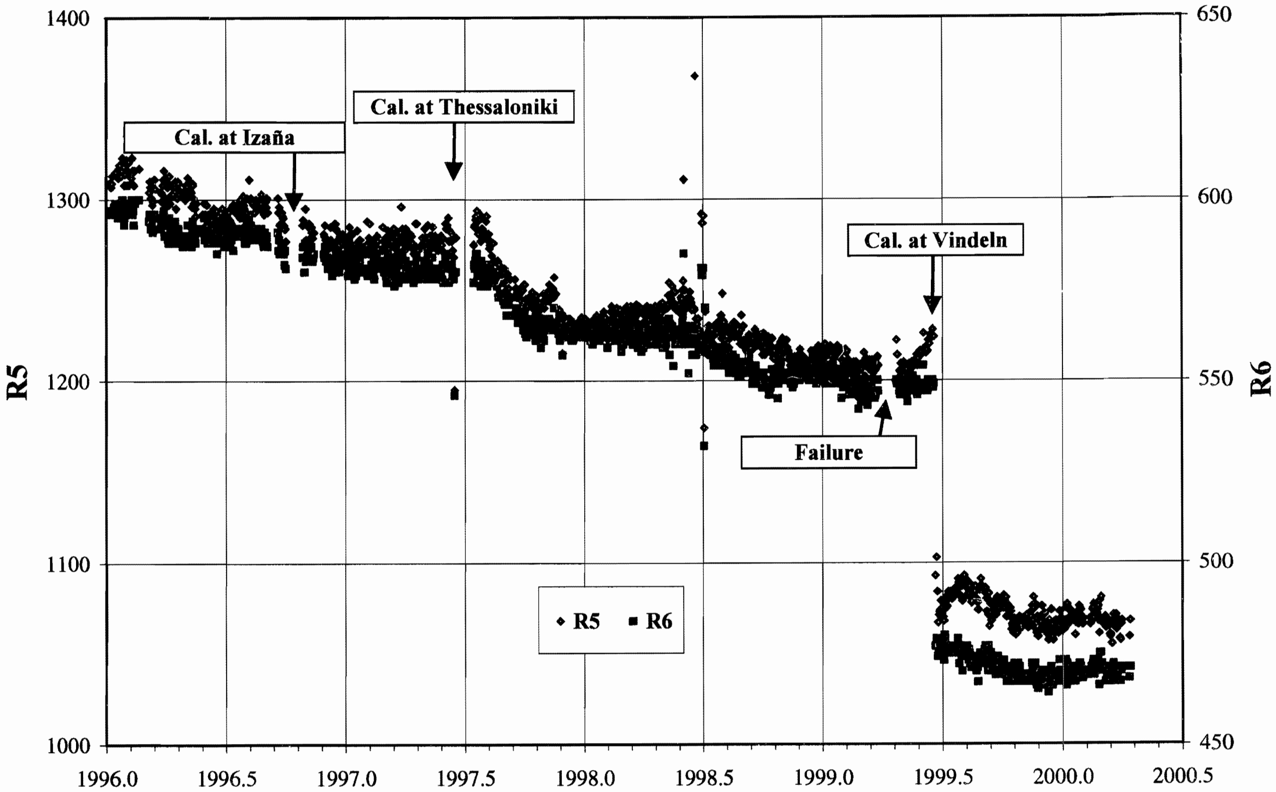

Figure 2.2.1. Daily standard lamp test values, for Brewer#128 during 1996 to early 2000. They are used as an indicator of the stability of the instrument. The level of tolerance is ± 15 units. The R5-values corresponds to the sulphur dioxide and the R6-values to the total ozone. Events connected with sudden jumps are indicated.

2.3 Dobson #030

The Dobson instrument has now been in routine operation at Vindeln during nine years, since 1991. During wintertime the low sun prevents accurate measurements. The necessary manual procedure limits measurements to be taken only on working days. Once a month, in the winter, measurement using the full moon would be possible. However, cloudy weather often prevents the observations. Starting in February focused sun-measurement are done using the CD-wavelength pairs. The fundamental AD-wavelength pairs is used as soon as possible and most of the observations are recorded using this type of observation. The letters A, C, C' and D are used to denote specific pairs of wavelengths used for measurements with the Dobson spectrophotometer. Thus AD is a combination of two wavelength pairs. As will be shown in Table 3.2.3 in section 3.2 the terminology for Dobson observations also includes some other capital letters. The type of observation is often given by capital letters e.g. DS for direct sun observations and DS-FI for direct sun focused image.

To make ozone observations with the Dobson for a specific wavelength pair two levers, called Q1 and Q2, are rotated. The settings of the levers varies with temperature and air pressure. Therefore correcting tables, Q-tables, are established. Also other changes in the instrument would affect the settings of the levers. The proper setting can be tracked by using lamps. The correction to the setting of these levers for each wavelength pair (A, C, C' and D) is presented in Figure 2.3. Due to the manual procedure these lamp tests are only performed once a month. First a mercury lamp is always used to check the wavelength setting. Then, a set of standard lamps is operated to check the stability. The procedure is to run one of the lamps, denoted 30-Q1, each month and a second one, 30-Q2 every half year. Two spare ones 30-Q4 and 30-Q5 are only used once a year or every second year. Lamp 30-Q3 is stored in Boulder, USA. One should note that the letter Q refers to quartz halogene lamp and the preceeding number 30 refers to the Dobson instrument number. It has nothing to do with the Q-levers. Compilations of the calibrations are shown in Figure 2.3.1. The result of the lamp tests indicates a slow degradation of the instrument. This change in the calibration is corrected for in the calculation of the total ozone in a similar manner as for the Brewers. As will be shown below the total ozone from the Dobson #30 have shown a relatively stable difference when compared with both the Brewer #006 and the TOMS Earth-Probe data, section 4.2.

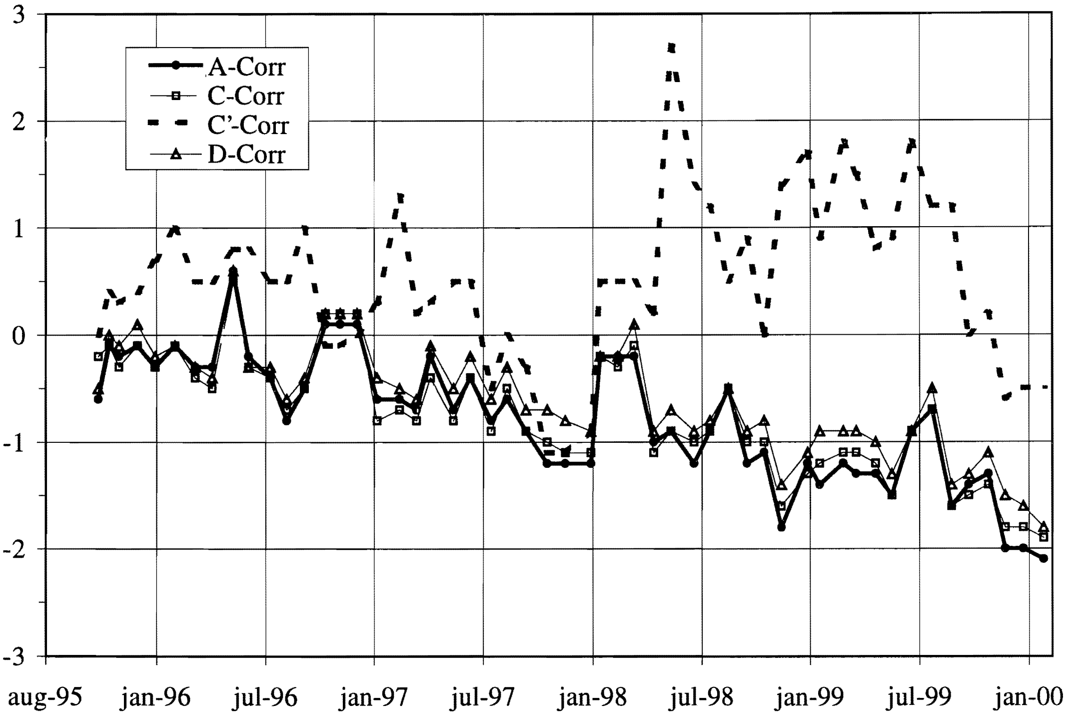

Figure 2.3. Lamp tests of Dobson #030 using lamp 30Q1 for each wavelength-pair.

The instrument has been calibrated twice. The first time was at the refurbishment in Boulder in 1990 and the second time at the intercomparison in Arosa in 1995. Returning from an intercomparison controls are made using the standard lamps and the mercury lamp. Adjustments of the Q-tables are done according to the test results and for the site altitude, which normally differ from the altitude of the calibration site. As a result the Q-tables retrieved at Arosa had to be changed by +1.5. These tables have been used up to present. One of the effects of the cut in the funding in 1997 was that the Dobson #30 did not participate in the last intercomparison at Arosa in 1999. It has also affected the frequency of observations, Table 3.2.3, in next section.

The lamp-test values have been within an acceptable range of variation and there is a slow trend. Tests are performed on a regular basis and the instrument has been working well without any notable problems. The results of the lamp tests have shown that the correction for the C'-wavelength varies more than for the other ones. As this wavelength pair is not used for the observations with this instrument the result is only logged.

3 Data

3.1 Measurements

A brief summary of the type of measurements will be given here. More detailed descriptions can be found in earlier yearly reports, e.g. Josefsson (1994). Principles of measurements and terminology are identical for the Brewer and Dobson instruments. The preferable method of measuring total ozone is to use the sun as light source and to perform a direct sun observation, *ds*. This type of observation is also used when comparing (calibrating) a specific instrument versus a reference. Other types of observations are focused sun, *fs*, and focused moon, *fm*, observations. The focused sun/moon observations are done by removing a quarts diffusor plate from the optical path and accurately focusing the solar/moon image on the entrance slit of the spectrometer part of the instrument. This requires a very good sun/moon tracking. The use of the diffusor plate has two reasons. One is too decrease the demand of the accuracy of the tracking. The other one is to diffuse the light of the sun. The importance of the latter one is to make the instrument insensitive to from which part of the solar disk the light has originated. In the focused sun mode the image of the sun will be positioned on the entrance slit of the spectrometer and only the parts of the sun that cover the slit will enter the spectrometer. As the UV-radiance is not homogeneous over the solar disk this may cause differences in the measurement due to this in-homogeniety. There is no study of the potential magnitude of this effect known by the author.

Another type of observation is the so-called zenith sky observation, *zs*. This is particular important during cloudy conditions. Normally, it is a less accurate method and therefore these observations are only used for days when no other types of observations are available. In this case total ozone is derived from empirical relationships between long-term quasi-simultaneous observations of direct sun and zenith sky. Such a relationship has to be established for each station. The method is dependent of solar elevation (relative optical air-mass), amount of total ozone, amount of aerosol, ground reflectance as well as the cloud optical depth and the height distributions of some of these variables.

Data of total ozone in this report refers to the so-called Bass and Paur Scale. Before the 1st of January 1992 total ozone values were referring to the so called Vigroux scale that were adopted in conjunction with the IGY (International Geophysical Year) 1st of July 1957. The name of those scales refers to the ozone absorption coefficients applied. Pre IGY data, e.g. from Abisko, refer to older absorption coefficients. Changing from Vigroux to Bass-Paur there was a change of a few percent in the total ozone, WODC (1996).

All types of data recorded by the Brewer instruments are primarily stored on the hard disk of a PC and on a paper form for the Dobson instrument. Copies are done regularly. The data are sent to a total ozone data bank at the WOUDC, Atmospheric Environment Service (AES) in Canada.

For the Brewers one controlled and selected value per day of total ozone is stored on a backup secured disk of SMHI. The procedure is manual and thus slightly subjective. The main rule for the selection is to find the amount of total ozone at noon, i.e. around 11 UTC. If it was impossible to select a value measured close to that time the most accurate value of that day was selected. A cloudy day may for instance be represented by a focused moon observation taken in the night instead of a low quality zenith sky observation. Usually, the zenith sky observations are better than the focused moon observations. But, in wintertime with a low sun the moon observations can be the only reliable observations at high latitudes. These selected daily data are plotted in Figure 3.1.1-3.1.6 and they are also given in Appendices 1 and 2.

When selecting a value that is representative of a day the priority for the Brewer observations is normally:

Direct sun $\mu < 3$, no clouds interfering
Direct sun $3 < \mu < 4$ or disturbing clouds
Focused sun
Focused moon
Zenith sky $\mu < 4$

where μ is the relative optical path length through the layer of ozone. As solar radiation traverses the atmosphere its constituents attenuate it, e.g. molecules and aerosols. The μ-value represents the relative abundance of ozone along the path of radiation compared to that of a vertical column with the same cross section.

The manual Dobson observations are mostly taken around noon. The higher the solar elevation the better will the measured signal be. Of course a cloud free sky offer the possibility of making the fundamental direct sun observation so these occasions are preferred. Total ozone values recorded by the Dobson instrument at Vindeln are sent to SMHI after the end of each month. The direct sun, focused sun and zenith blue observations are filled into a standard form and then sent to WOUDC. In the year 2000 data files will probably replace these forms. The raw data as well as processed data are stored at Vindeln and daily values of total ozone are stored on a disk at SMHI. Since July 1996 the Brewer #006 is operated along with the Dobson #030. The parallel record will be used to ensure that no significant inhomogeneities will occur.

Observational results from Uppsala, (Rindert, 1976) are also found in Figures 3.1.1 to 3.1.6. A solid line connects the smoothed average daily mean values for the period, May 1951 - July 1966, representing the average yearly variation. For the same period smoothed values of the standard deviation for daily values have been estimated. The standard deviation of daily values is thought to represent the typical range of variation of daily values.

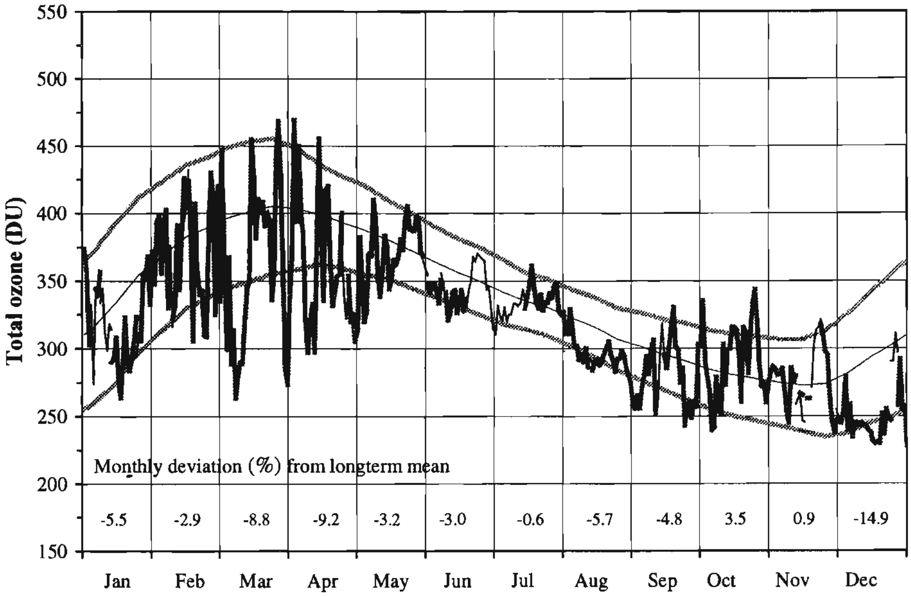

Figure 3.1.1. Daily 'noon' values of total ozone recorded by Brewer #128 at Norrköping in 1997. Long-term mean and standard deviations are from Uppsala 1951-1966. The values at the bottom are the monthly deviations (percent) from the long-term monthly means. All data refer to the Bass-Paur Scale. Missing values are replaced by satellite data (thin line).

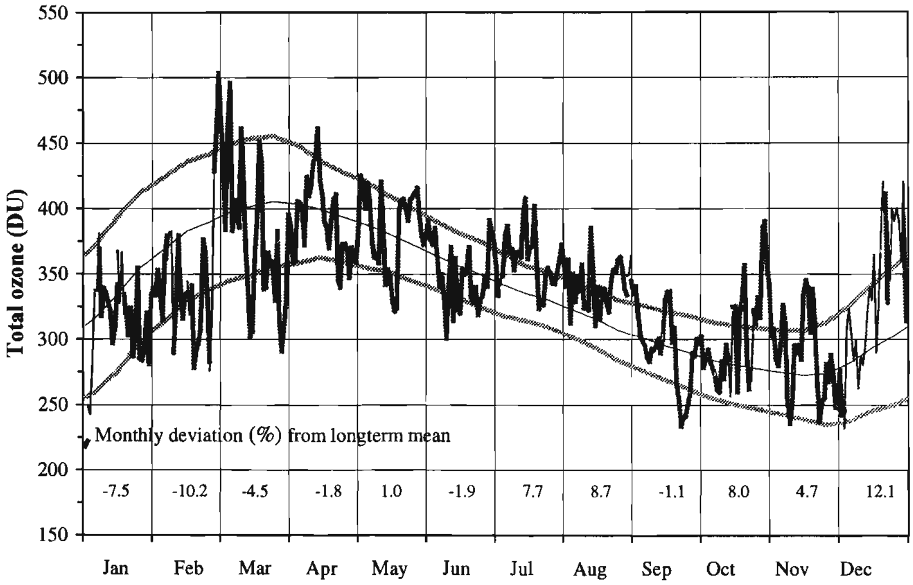

Figure 3.1.2. Daily 'noon' values of total ozone recorded by Brewer #128 at Norrköping in 1998. Long-term mean and standard deviations are from Uppsala 1951-1966. The values at the bottom are the monthly deviations (percent) from the long-term monthly means. All data refer to the Bass-Paur Scale. Missing values are replaced by satellite data (thin line).

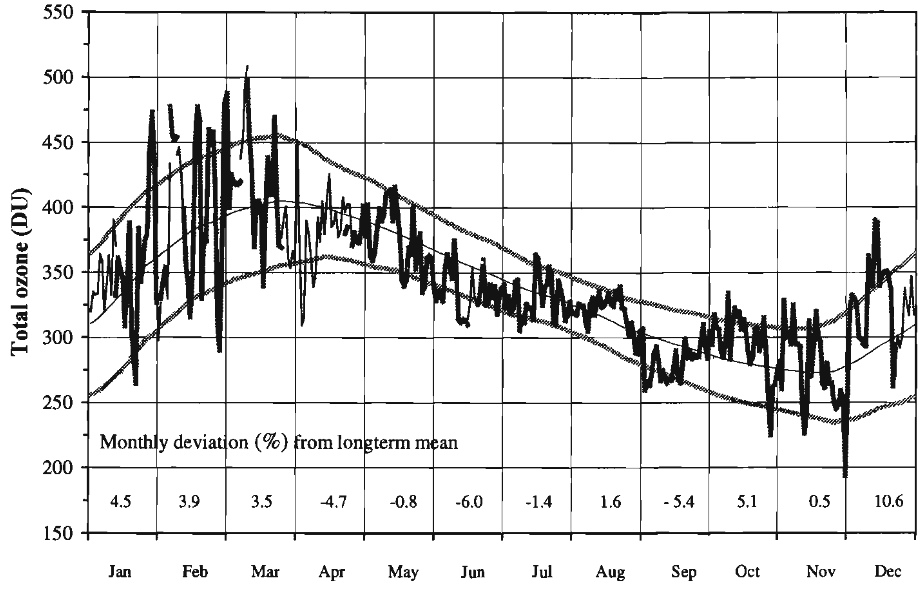

Figure 3.1.3. Daily 'noon' values of total ozone recorded by Brewer #128 at Norrköping in 1999. Long-term mean and standard deviations are from Uppsala 1951-1966. The values at the bottom are the monthly deviations (percent) from the long-term monthly means. All data refer to the Bass-Paur Scale. Missing values are replaced by satellite data (thin line).

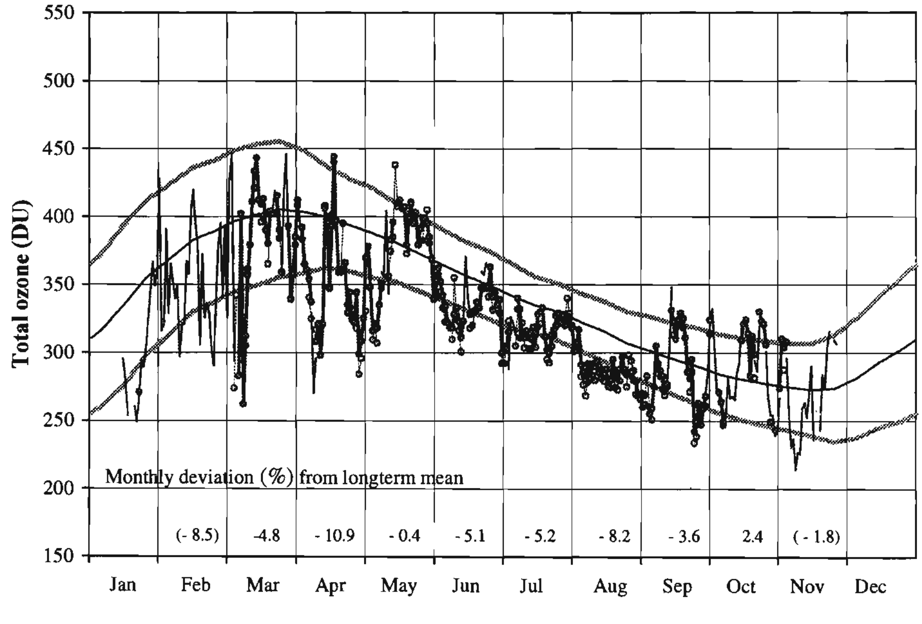

Figure 3.1.4. Daily 'noon' values of total ozone recorded by Dobson #30 and Brewer #006 at Vindeln in 1997. Long-term mean and standard deviations are from Uppsala 1951-1966. The values at the bottom are the monthly deviations (percent) from the long-term monthly means. All data refer to the Bass-Paur Scale. Missing values are replaced by satellite data (thin line).

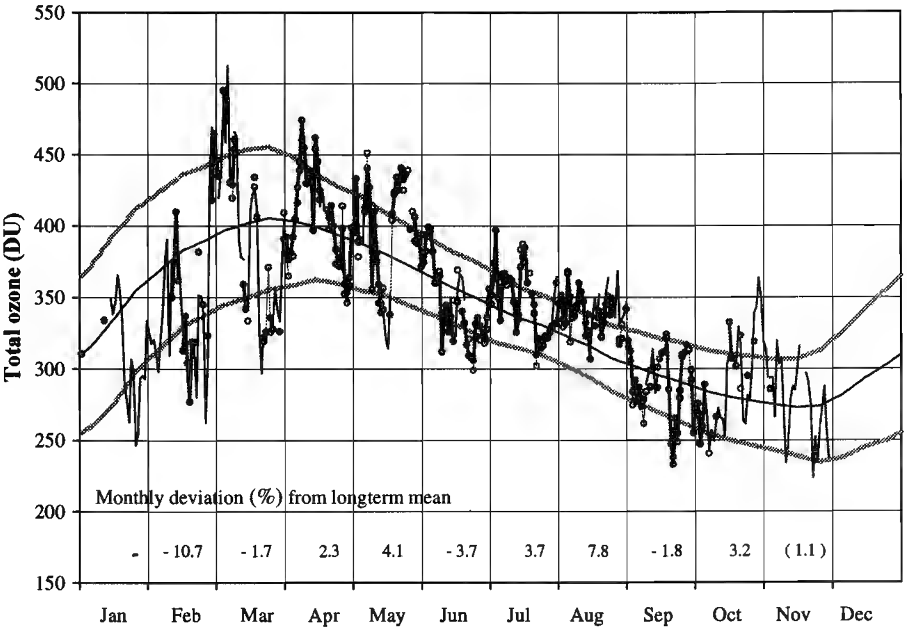

Figure 3.1.5. Daily 'noon' values of total ozone recorded by Dobson #30 and Brewer #006 at Vindeln in 1998. Long-term mean and standard deviations are from Uppsala 1951-1966. The values at the bottom are the monthly deviations (percent) from the long-term monthly means. All data refer to the Bass-Paur Scale. Missing values are replaced by satellite data (thin line).

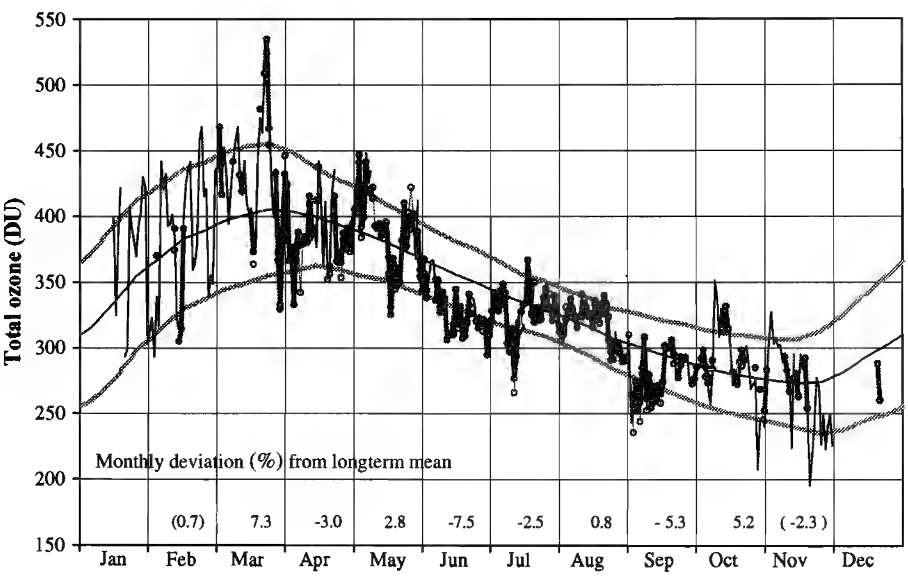

Figure 3.1.6. Daily 'noon' values of total ozone recorded by Dobson #30 and Brewer #006 at Vindeln in 1999. Long-term mean and standard deviations are from Uppsala 1951-1966. The values at the bottom are the monthly deviations (percent) from the long-term monthly means. All data refer to the Bass-Paur Scale. Missing values are replaced by satellite data (thin line).

3.2 Data availability

In an environmental monitoring project there are several aspects on the observations that are important. The observations should have a certain quality and they should be recorded at sites that are representative of the environmental issue of interest. In the case of total ozone, the sites were selected to fit in the global network as well as considering the need of proper daily maintanance. The quality is maintained by participating in intercomparisons and by daily checks. For a correct interpretation of the data also simple quantities as the number of observations, frequency of observations, type of observations and finally the availability of the data play an important role. Therefore, some simple statistics is given in this section.

Table 3.2.1. Number of observations with Brewer #128 for the period 1996-1999 in Norrköping. In 1996 there are also observations by Brewer #006. Separate columns are given for the direct sun measurement ds, the focused sun measurement fs, the focused moon observations fm and the zenith sky observations zs respectively.

Year	Number of days with obs.	ds	fs	fm	zs	Nbr Obs before selection
1996	319	214	27	5	73	12026
1997	317	221	22	0	74	14282
1998	329	218	28	1	82	17721
1999	308	203	35	4	66	17468

Table 3.2.2. Number of observations with Brewer #006 for the period 1996-1999 in Vindeln. In 1996 there are also observation taken by Dobson #030. Separate columns are given for the direct sun measurement ds, the focused sun measurement fs, the focused moon observations fm and the zenith sky observations zs respectively.

Year	Number of days with obs.	ds	fs	fm	zs	Nbr Obs before selection
1996	203	153	2	3	45	7994
1997	209	208	0	0	1	-
1998	199	194	3	1	1	13098
1999	208	196	9	3	0	16921

Table 3.2.3. Number of observations with Dobson #30 for the period 1996-1999. Separate columns are given for the direct sun measurement AD-DSGQP, *the focused sun measurement* CD-DSFI, *the zenith sky observation for clear sky* AD-ZB *and cloudy sky* AD-ZC *respectively. The abbreviations using capital letters is briefly discussed in section 2.3.*

Year	Total number of obs.	AD-DS GQP	AD-ZB	AD-ZC	CD-DS FI	Others	Rejected (e.g. large μ)
1996	255	89	80	83	3	0	10
1997	239	93	73	67	4	2	7
1998	177	54	40	83	0	0	8
1999	180	62	51	66	1	0	7

As already noted an important aspect of an environmental monitoring project is to present and transfer data to those interested. Doing so one must consider a balance between a quick delivery and the quality of the data. If there will be future changes confusion may arise if there are different versions of the data available. In respect of the total ozone monitoring there are several control tools helping the observer to detect if data are in error more or less on a real-time basis. Small drifts or changes (<3%) can not be detected immediately.

The public interest of the depletion of the ozone layer issue has shown that almost real time data should be available. For this purpose small eventual errors are of minor importance. However, for trend studies even small errors must be removed. It has been decided to take this risk of distributing eventually erroneous data because of the large interest. The experience so far is that there has been no need to do any major revisions afterwards, see next section. Only a few occasions with typing errors have been detected.

Data and graphs are available on-line using the Internet. The exact address may change but it can be found starting at the main home page of SMHI, which is http://www.smhi.se.

3.3 Reprocessing of Norrköping data

There were a number of reasons to initiate a reprocessing of the Norrköping data. One was the result of the calibration in the summer of 1999 along with the abrupt change of the instrument that followed upon the home transport. An important impetus was the change of the format of submitting data to the WOUDC. A small but not unimportant fact was that there are many observations recorded each day. There is an interest to make a compilation of as many observations as possible. The obstacle of doing this has been the varying quality of the automatically retrieved data. To be useful, data has to be controlled and rejected if not within certain quality specifications.

Now, an attempt to cope with all these questions started. The period (1996 June up to 1999) during which data had been stored on diskettes was processed. Prior to that date, observations were sampled by a PET-computer, having a limited storage capacity, and printed on paper. Software was developed to reprocess most of the data since 1996. Observations were selected according to certain quality conditions. However, despite some iterative processing it was not possible to write the ultimate software. A manual control, rejection and correction procedure of the data was necessary. Naturally, this is a rather time consuming process. But, the final database will hopefully be both useful and of a high quality.

The daily data set is similar to the old one as presented in earlier reports and on the web-site. The data set with all available and accepted observations may be used for special studies, e.g. variation of the ozone during the day, intercomparison of the different types of observations.

3.4 Abisko data set

Dobson initiated a small network for the observation of the total ozone in the 1920-ties. It was part of his idea to study if the variations in ozone might be related to variations in atmospheric pressure and regional scale weather systems. To test this idea he had several spectrometers constructed and distributed throughout Europe. One of the selected sites was Abisko in the northernmost of Sweden.

By a lucky coincidence there was a clean out in the institute library, where some letters and documents were found. It was the correspondence between Dobson and our institute regarding the measurements made at Abisko during the years of 1926 and 1927. In one of the tables data were revised. This table included data from Oxford (England), Valentia (Ireland), Lerwick (Shetland Isles), Arosa (Switzerland), Lindenberg (Germany) and Abisko (Sweden). In the following data of this table are assumed to be comparable.

Although the values were given in 0.001 cm of pure ozone at N.T.P. (normal temperature and pressure) they are not directly comparable to modern values in Dobson Units, where1 DU = 10^{-5} m ozone at STP (standard temperature and pressure). At that time the instruments used slightly other wavelengths and also another set of ozone absorption coefficients and Rayleigh scattering coefficients. Fortunately, a homogenisation of the Arosa data has already been done, Birrer (1975), Staehelin et al. (1998). Monthly values of the corrected and homogenised data are available on the web. Therefore, by applying the single assumption that the data in the revised table from Dobson are given on the same scale, it was possible to directly retrieve a corrected set of data from Abisko. The monthly correction factors for 1926 and 1927 were found to vary between 1.17 and 1.24. No particular pattern could be seen. Therefore the average, which was 1.21, was applied to the Abisko values.

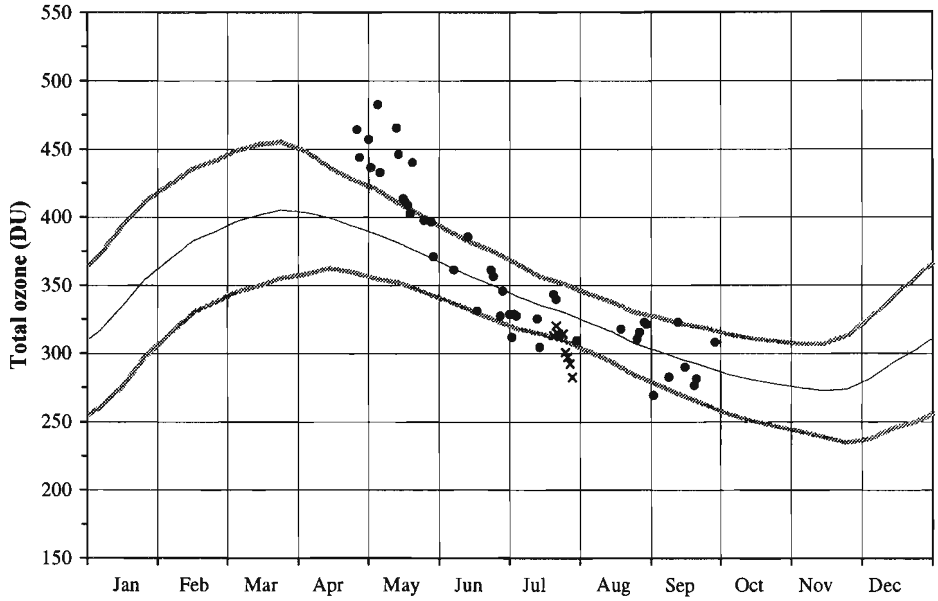

Figure 3.4.1. Measurements of the total ozone at Abisko in 1926 (x) *and 1927* (•). *Also plotted is the climatology for Uppsala 1951-1966.*

There were very few observations from 1926. But, the observations in the summer half-year of 1927 are sufficient in number to give an impression of the yearly course. All values are plotted in Figure 3.4.1 along with the same climatology from Uppsala that is used for the data from Vindeln and Norrköping. The values seem to fit quite well in the pattern giving support to the applied correction. There exists no firm proof of the quality of the values. To achieve that more information is needed, e.g. instrument characteristics, type of observation and time of observation. The slightly higher, than average from Uppsala, values in late April and early May are in correspondence with the typical climatological behaviour. During spring the total ozone increase with latitude from the equator up to about 75° N.

Even though the uncertainty may be large in the corrected Abisko values there is an indication that the thickness of the ozone layer was about the same as today in those years of the past. Beside of the Dobson observations in the 1920-ties there were a french group that made spectrographic observations in the winter 1934-1935 at Abisko, Vassy and Vassy (1950). It has not yet been possible to convert their numbers of total ozone into a modern scale.

4 Results

4.1 Monthly values and mean values

The monthly mean values from Vindeln and Norrköping are given in Table 4.1.1 and 4.1.2. The reprocessing has introduced small differences in the Norrköping values. But the largest eventual differences are due to the inclusion of satellite data when data were missing. This is done to retrieve more representative monthly values.

An intercomparison between the satellite total ozone, from TOMS Version 7 overpass data, and the ground based total ozone, from Vindeln and Norrköping, is presented in section 4.2 and 4.3 respectively. The general agreement for the TOMS total ozone data from the Version 7 algorithms is much better than for previous algorithms, see e.g. Josefsson (1991, 1996). In any case it is assumed that the satellite data catch the general variation of the total ozone for the missing days and thus contributes to give a better monthly mean value than without the satellite values. Therefore, the monthly mean value is not always equal to the average of the individual daily observations recorded by the Brewer or Dobson instruments. If more than 10 days of a month are from satellite data, i.e. not observed by the ground based instrument, the monthly value is presented on a shaded background.

Yearly means, seasonal means and half-year means are calculated by weighting each month by the number of days in the month. The long-term means (for each column: months, year and seasons) are simply arithmetic means of the available years. The standard deviations of these values are given in absolute numbers and in percentages.

For each column (months, year and seasons) the maximum and minimum are indicated by bold and bold italic respectively.

Some interesting features may be noted from the Table 4.1.1 for Norrköping. For the period 1988 to 1999 the standard deviation for monthly values is almost 30 DU in January and February. For the months from July to November it is much lower, almost 10 DU. Similar results are obtained at Vindeln for the period 1991 to 1999.

In lowest row of Table 4.1.2 the deviation (%) from the Uppsala means (1951-1966) of the mean values of Vindeln for the period 1991 to 1999 are given. All numbers are negative showing that this period in Vindeln on the average had a lower amount of total ozone than the Uppsala period. The largest deviations occurred in February, March and April. The fact that the deviations of the averages are relatively small shows that there has not yet been any dramatic and persistent change in the total ozone. Due to the large natural variation, the long-term deviations are of the same magnitude as are the standard deviation of the monthly values. However, it is notable that within the longer period there has been periods showing large deficits of total ozone. They can be found in particular during the years of 1992, 1993 and 1996.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ymean	Winter	Spring	Summer	Autumn
1982					371.9	353.2	337.2			274.1	279.0						
1983		333.1	364.1	400.9	359.4	341.7				318.2							
1984			402.6	387.4	389.6	358.6	331.4	303.8	309.7	306.3	285.3						
1985			410.9	397.3	351.4	350.6	339.0	299.6	305.2	262.7							
1986				406.1	351.5				304.8	280.2							
1987																	
1988	333.64	380.67	**418.48**	393.33	366.65	343.03	336.26	319.48	286.50	275.00	283.29	326.13	338.4		**392.8**	332.8	281.5
1989	306.61	**394.47**	391.40	383.73	371.13	347.72	335.87	322.52	287.71	278.70	280.10	313.96	334.1	340.7	382.1	335.2	282.1
1990	322.82	346.40	383.51	381.75	355.73	343.62	331.14	312.89	295.80	280.94	**302.52**	310.53	330.5	327.1	373.6	329.1	293.0
1991	361.64	383.10	376.10	**400.23**	**393.17**	**377.15**	332.81	321.39	298.86	286.21	286.39	287.86	**341.8**	350.7	389.7	343.4	290.4
1992	***265.79***	343.80	365.80	392.17	352.29	336.80	326.85	300.30	279.77	293.02	284.36	295.66	319.5	***298.2***	369.8	321.1	285.8
1993	316.74	***296.63***	342.82	***335.11***	***340.26***	340.85	326.14	315.68	283.97	286.85	297.89	302.04	***315.6***	303.2	***339.4***	327.4	289.5
1994	363.60	388.06	369.15	397.87	376.16	358.54	***322.18***	320.42	**320.04**	284.09	283.00	315.65	341.2	350.0	380.9	333.4	295.6
1995	310.52	370.22	370.00	377.95	360.36	***323.09***	323.66	***295.75***	288.78	270.50	***271.90***	297.03	321.3	330.9	369.3	***314.1***	277.0
1996	287.87	341.61	***332.48***	337.67	363.76	346.19	341.42	300.71	284.26	***270.34***	279.38	302.64	315.6	308.1	344.7	329.3	***277.9***
1997	318.17	369.04	365.54	361.69	367.68	345.76	333.09	296.35	280.99	290.66	276.65	***250.10***	321.0	328.6	365.0	324.8	282.9
1998	311.41	341.29	383.07	391.12	383.56	349.74	**361.00**	**341.61**	292.16	**303.15**	287.03	**329.48**	339.6	299.6	385.9	**350.8**	**294.2**
1999	**351.83**	394.79	414.93	379.73	376.65	335.11	330.46	319.47	***279.23***	295.14	275.65	325.18	339.6	**357.5**	390.6	328.3	283.5
mean 88-99	**320.9**	**362.5**	**376.1**	**377.7**	**367.3**	**345.6**	**333.4**	**313.9**	**289.8**	**284.6**	**284.0**	**304.7**	**329.9**	**326.8**	**373.7**	**330.8**	**286.1**
SD(DU)	28.9	29.2	25.1	21.9	14.4	13.2	10.3	13.5	11.3	10.1	8.8	21.6	10.5	21.7	17.3	9.6	6.3
SD(%)	9.0	8.1	6.7	5.8	3.9	3.8	3.1	4,3	3.9	3.5	3.1	7.1	3.2	6.7	4.6	2.9	2.2

Table 4.1.1. Monthly, yearly and season-values of total ozone (DU) *recorded at Norrköping 1982-1999. The values with a shaded background are based on a considerable number of TOMS data. Bold face indicates maximum values and italic bold face minimum values for the period 1988-1999. At the bottom the mean and the standard deviation* (SD) *for the period 1988-1999 are given.*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ymean	Winter	Spring	Summer	Autumn
1991	-	360.26	366.72	403.53	**398.31**	**373.14**	330.28	315.75	305.28	[illegible]	273.48	-	-	-	389.4	339.4	[illegible]
1992	-	[illegible]	355.11	**409.01**	348.33	330.35	328.63	307.71	279.38	277.07	[illegible]	-	-	-	370.4	322.1	277.1
1993	323.63	[illegible]	339.29	331.68	***334.48***	348.03	308.33	303.21	273.73	[illegible]	-	-	-	-	***335.2***	319.6	-
1994	-	370,29	347.44	400.62	379.50	356.82	***308.22***	300.15	**310.80**	[illegible]	-	-	-	-	375.6	321.3	-
1995	-	-	347.17	375.19	354.20	***319.05***	-	[illegible]	280.41	[illegible]	-	-	-	-	358.7	-	-
1996	-	-	***337.32***	330.79	361.09	336.40	329.68	291.86	***271.30***	264.75	[illegible]	-	-	-	343.2	319.1	***271.5***
1997	-	[illegible]	381.65	355.17	378.38	338.27	317.83	288.58	284.68	287.48	[illegible]	-	-	-	371.9	***314.6***	280.5
1998	-	[illegible]	394.28	407.71	395.51	343.56	**347.71**	**338.98**	290.03	**289.69**	[illegible]	-	-	-	399.1	**343.4**	285.8
1999	-	382.75	**430.03**	386.45	390.38	329.77	326.78	317.01	279.68	289.08	[illegible]	-	-	-	**402.5**	324.5	279.0
Mean 91-99	-	[illegible]	**366.56**	**377.79**	**371.13**	**341.71**	**324.68**	**304.58**	**286.14**	[illegible]	[illegible]	-			**371.78**	**325.50**	[illegible]
SD(DU)		33.0	30.6	31.6	22.6	16.1	13.0	18.1	13.6	13.4	4.3				23.3	10.3	5.6
SD(%)		9.6	8.4	8.4	6.1	4.7	4.0	5.9	4.8	4.9	1.6				6.3	3.2	2.0
Deviation (%) fr. U-a 1951-66		-9.7	-8.6	-5.2	-2.2	-4.1	-3.1	-3.1	-3.0	[illegible]	[illegible]						

Table 4.1.2. Monthly, yearly and season-values of total ozone (DU) recorded at Vindeln 1991-1999. The values with a shaded background are based on a considerable number of TOMS data. Bold face indicates maximum values and italic bold face minimum values for some monthly and seasonal values of the period 1991-1999. At the bottom the mean and the standard deviation (SD) *for the period 1991-1999 are given. The last row shows the deviation of the mean from the mean of the Uppsala period 1951-1966 (this differs from Table 4.1.1).*

4.2 Comparison of Dobson #30, Brewer #006 and TOMS EP

The old Dobson #30 was used at Uppsala in the period 1951 to 1966. It was refurbished and recalibrated in 1990 at Boulder. From 1991 it has been in located at Vindeln (64.24°N, 19.77°E, 225 m), Sweden. The operational procedure is manual and thus observations are usually only taken once a day during working days. This gave a relatively low frequency. Therefore, it was decided to start automatic observations using the Brewer #006 instrument, and from the summer of 1996 there are now two instruments operating in parallel at Vindeln.

This opens the possibility for an intercomparison, almost day by day, over the period 1996 up to 1999. Relatively early it was noted that there existed a small systematic difference between the Dobson and the Brewer. In Figure 4.2.1 direct sun observations from all years are included. As can be seen the Dobson gives 2-3% lower values than the Brewer instrument, with no significant trend over the years or over the year.

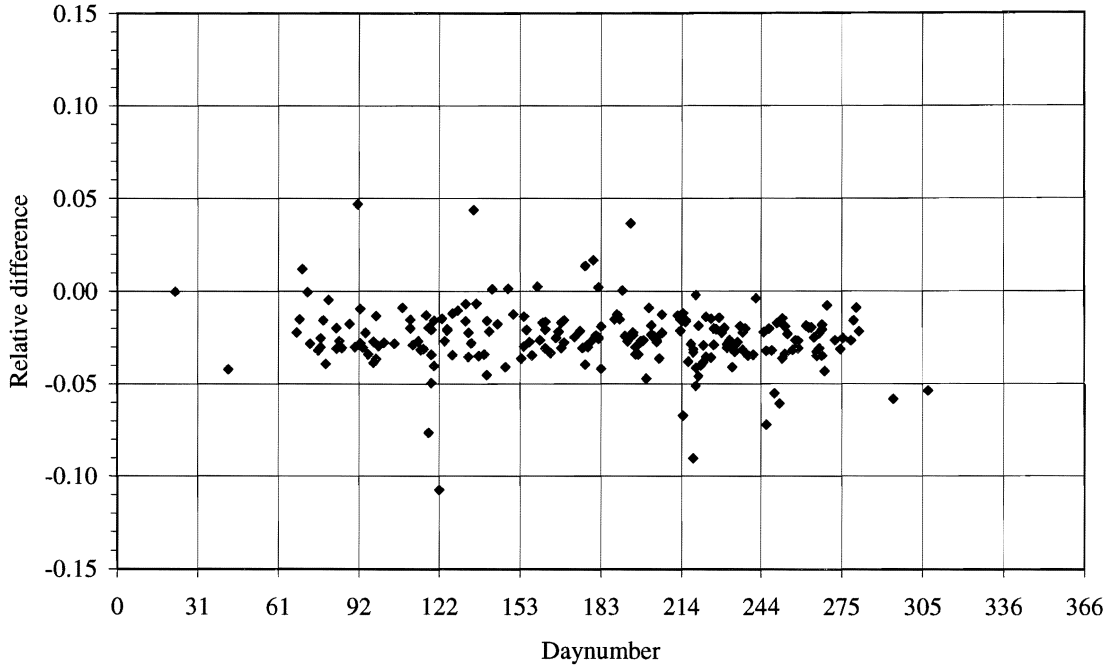

Figure 4.2.1. Relative difference ((Dobson-Brewer)/Brewer) in ds-ozone measurements by Brewer #006 and Dobson #30 recorded at Vindeln 1996-1999 versus daynumber.

Having two instruments deviating from each other will always rise the question: Which one is the correct one. Fortunately, there are also total ozone data available from satellite based instruments. One type of instrument the TOMS (Total Ozone Mapping Spectrometer) has been flown on several satellites, including the Earth Probe (EP), since late 1978. The radiance observations has been processed by several algorithms over the years and the one used in this report is denoted Version 7, McPeters et al. (1998). Data has kindly been made available by the ozone processing team at NASA's Goddard Space Flight Center. It can be found on their web-site where so called Overpass TOMS data is posted for each ground based station. One should keep in mind that the random uncertainty in the total ozone values from the TOMS EP is estimated to be 2% or higher for large solar zenith angles, McPeters et al. (1998). In addition there are the systematic errors of the same magnitude contributing to the total uncertainty. The absolute error is estimated to be ±3%, McPeters et al. (1998). It has also been found that the TOMS EP V.7 total ozone was about 1% higher than for 30 ground-based stations. Total ozone from TOMS Nimbus-7 V.7 is about 0.5% higher than a similar ground based network and Meteor-3 TOMS is not significantly different from the same network.

None of the TOMS ozone data sets show any significant drift relative to the ground-based networks, McPeters and Labow (1996).

In this case, the existence of TOMS EP overpass data has been a convenient data set to apply. To avoid problems connected with clouds only days with ds-observations have been used. In this selected data set there still remains some scatter due to non-synchronous data. The TOMS EP observations are usually taken around 9 UTC, which is about one and a half-hour before noon in Vindeln. The Brewer and Dobson are, on the other hand, mostly recorded close to noon. But, they are not necessarily time-co-ordinated. The overpass data refer to the nearest, relative to Vindeln, TOMS EP data point. A small test for Norrköping (Jan-Aug 1999) showed that the overpass data in average agreed (within 0.1 percent) with the corresponding data given by interpolation to the site of Norrköping from data gridded into 1 degree latitude zones by 1.25 degree longitude. But, there is a scatter with a standard deviation of about 1.5%. This amount of scatter is what can be expected on a spatial scale of one hundred km. In analogy there will probably be a scatter of the same magnitude due to non-synchronous observations. A conclusion is that one can expect a scatter in the intercomparison between the ground-based data and the satellite overpass data of the order a few percent due to these factors for ds-observations. Of more general interest will the systematic differences be and their eventual dependencies on time, air-mass and total ozone amount.

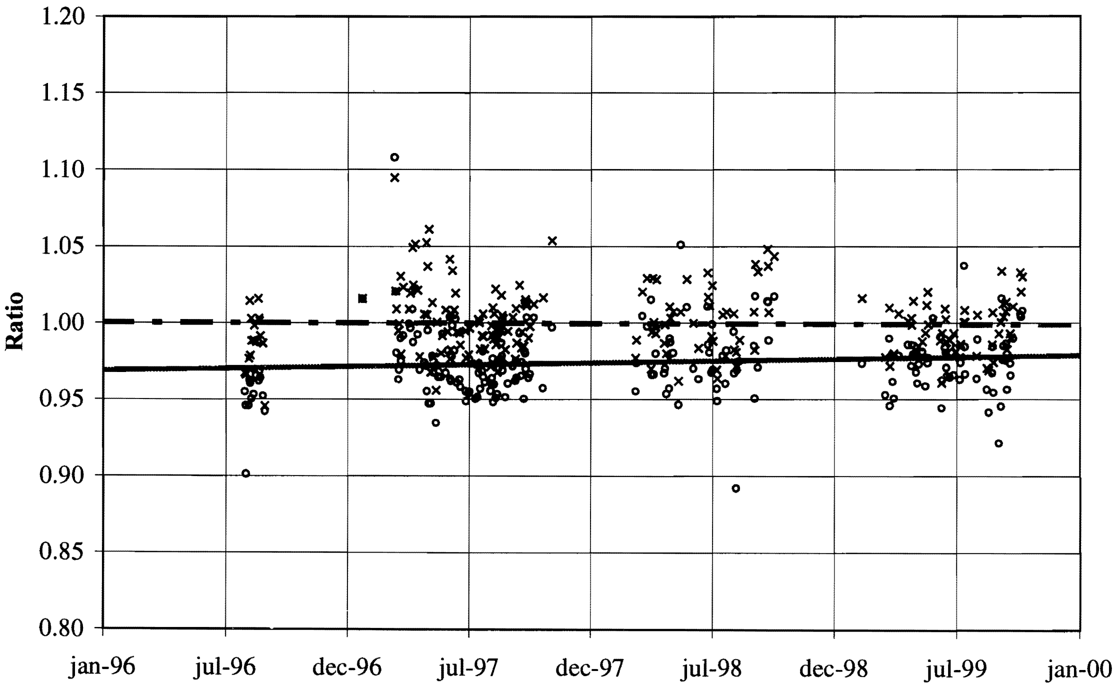

Figure 4.2.2. Ratio (Brewer#006/TOMS EP, x*) and (Dobson#30/TOMS EP,* o*) at Vindeln 1996 - 1999 only direct sun observations are included. Linear fitting is done for both data sets. For the Brewer/TOMS the line almost coincides with Ratio=1 and for Dobson/TOMS it is close to horizontal at the Ratio 0.97-0.98.*

In Figure 4.2.2 the direct sun observations from Brewer #006 and Dobson #30 are compared with TOMS EP overpass data. The scatter is a couple of percent and the average ratio seems to be stable over the period. This confirms that there is a systematic difference between the Dobson #30 and the Brewer #006.

Although the agreement between TOMS EP and Brewer #006 is closer than the one between Dobson #30 and TOMS EP the difference is too small to decide which instrument is the most correct one. As already mentioned the uncertainty, caused by systematic errors, of TOMS EP total ozone at non-high solar zenith angles is of the order a few percent. This is of the same magnitude as for the ground-based instruments using the direct sun observations. Therefore differences up to about four percent will be within the limits of these uncertainties.

The most valuable result is the strong indication that both instruments have been stable over the period 1996 to 1999. A useful result is that TOMS EP overpass data seems to agree well with ground based observations even for large solar zenith angles.

4.3 Comparison of Brewer and TOMS data at Norrköping

The Brewer MK II #006 was used for regular measurements of total ozone at Norrköping from February 1988 until it was moved to Vindeln in June 1996. Its successor the Brewer MK III #128 has been in operation since 1996. The present experience shows that the Brewer #128 is more delicate and not as robust as the old Brewer #006 is. In particular after the intercomparison in June 1999 after which a large change occurred as expressed in the standard lamp test values. The stability of the instrument is questionable and it has to be carefully tracked and examined. The result shown in the previous section where the TOMS EP, Dobson #30 and Brewer #006 at Vindeln were compared encourage a similar study to be made for Brewer #128 in Norrköping. As the monitoring started in 1988 it will also include data from Brewer #006 as well as TOMS data from the satellites Nimbus-7 and Meteor-3.

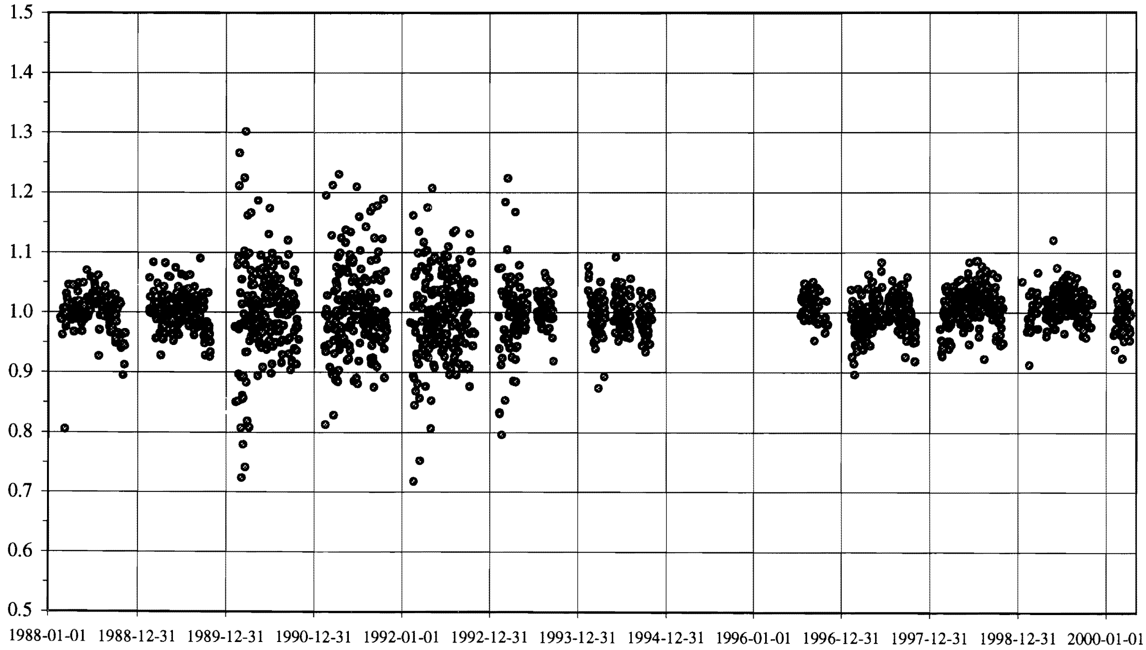

Figure 4.3.1. The ratio between TOMS Version 7 overpass data and Brewer direct sun total ozone for Norrköping for the period February 1988 to early April 2000. During mid-winter the solar elevation is too low for the direct sun observation. Before 1996 Brewer #006 and after 1996 Brewer #128 was used. Note other scale than in Figure 4.2.1 and Figure 4.3.2.

For the full period 1988 to early 2000 the most reliable data recorded by the Brewer instruments, which are the direct sun observations, were selected. The Brewer MK II #006 data are used until 1994 and from 1996 data from Brewer MK III #128 are used. In Figure 4.3.1 the ratio between the TOMS overpass data and the Brewer direct sun total ozone is plotted. Note in Figure 4.2.2. TOMS's values were in the denominator. Until 6th of May 1993

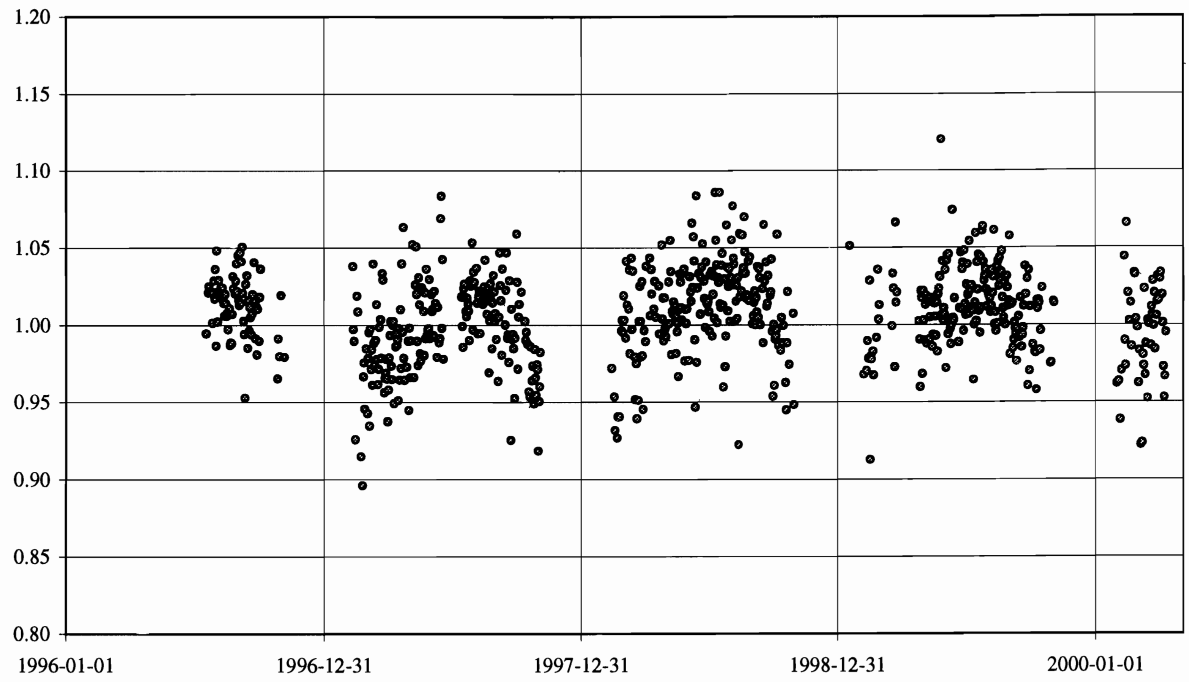

Figure 4.3.2. The ratio (note enlarged scale) from previous figure for the period of TOMS EP and for Brewer #128.

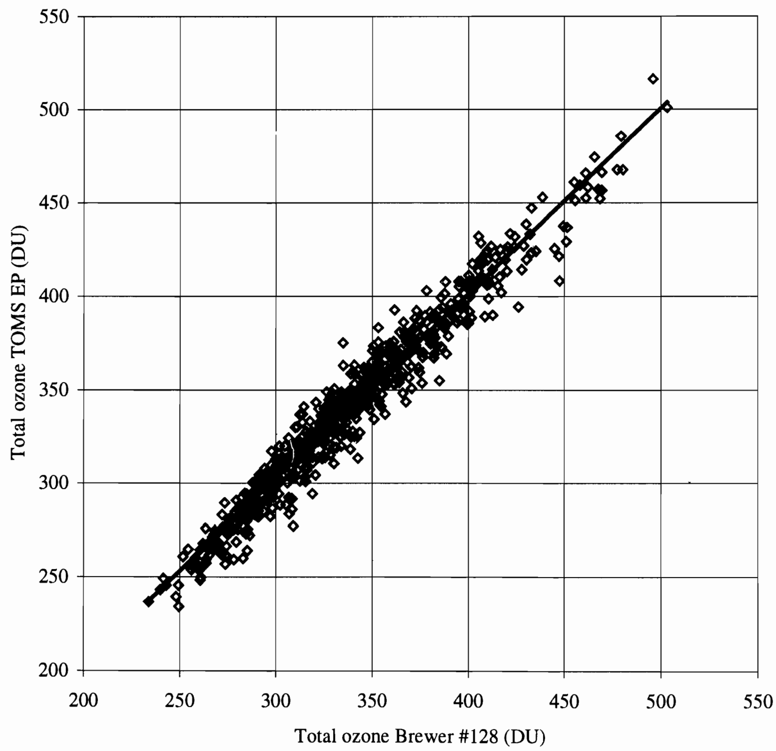

Figure 4.3.3. The total ozone of TOMS EP versus the total ozone from direct sun observations recorded by Brewer #128 at Norrköping mid July 1996 to early April 2000. A linear fit is also shown.

data are from TOMS on Nimbus-7. Then from the 7th of May 1993 until 24th of November data are from TOMS on Meteor-3. The last period with total ozone data starting in 1996 is from TOMS on Earth Probe. There are more data points available for each year in Norrköping than for Vindeln mainly due to the lower latitude. In general the agreement is very good. But the last years from Nimbus-7 (1990- May 1993) show a larger scatter. In Figure 4.3.2 the Earth Probe period is presented on the same scale as for Vindeln in Figure 4.2.2. A slight annual variation can be seen as well as an indication of a larger scatter than for Vindeln. Remember that in Figure 4.2.2 the Dobson data, which are displaced by a few percent, contribute to an apparent scatter. The reason for the annual variation may be a small μ-dependence in the Brewer #128 instrument. It is not known if this is the case. So the question will be open until the next calibration. More important at the moment is that the data collected after the calibration in June 1999 seems to give a similar ratio as those collected before that date. This strongly indicates that the correction of the data has been successful.

Finally, in Figure 4.3.3 a scatter plot show that TOMS EP and Brewer #128 total ozone is well correlated. A linear fit is very close to the one to one line and no particular outliers can be seen. The results above show that TOMS V.7 data are in good agreement with ground based observations in Sweden during days with direct sun observations.

4.4 Some characteristics of total ozone

Atmospheric ozone is used as input in radiation models. Ozone has absorption bands in several parts of the spectrum, in the UV, visible and in the far infrared. Of particular interest is to use total ozone as input in models for UV-index. These models may either be operated in a forecast mode or in a diagnostic mode. There are two slightly different, but related, aspects on the retrieval of the input data. One is how to forecast the total ozone. The other one is how to estimate total ozone at sites where no data are measured.

Using ground based data from Vindeln and Norrköping a brief discussion on different approaches is presented below. To reduce the influence of the seasonal variation the daily mean values (from the Uppsala period 1951-1966) has been subtracted day by day from both series. Then the values have been normalised by the mean value of the whole period, 1951-1966.

A simple approach is to use persistence as a forecast of the total ozone. Having a data set with discrete daily values it is possible to get an idea of the quality of persistence forecasting by studying the autocorrelation for different lag in the data. The smallest lag is of course one day. In many studies only a single number is produced for each data set. In Figure 4.4.1 the autocorrelation is computed for a running 60-day period (window) and for various lag times. In the graph the autocorrelation for lag times of one (AC1), two (AC2), five (AC5) and ten days (AC10) were studied. The fact that the autocorrelation is larger for shorter lag times is evident. A forecast one day ahead of the total ozone assuming persistence is usually a rather good one. More interesting in Figure 4.4.1 is the strong variation over the years. There is no typical seasonal pattern. Periods with high as well as low autocorrelation occur in all seasons indicating that stable periods have the same probability in all seasons. For lag times larger than two days the squared correlation is usually too low to admit persistence to be useful as a forecast.

How representative is a total ozone value measured in Vindeln for the site in Norrköping? The correlation between those two sites (700 km apart) has been studied for the period 1991 to

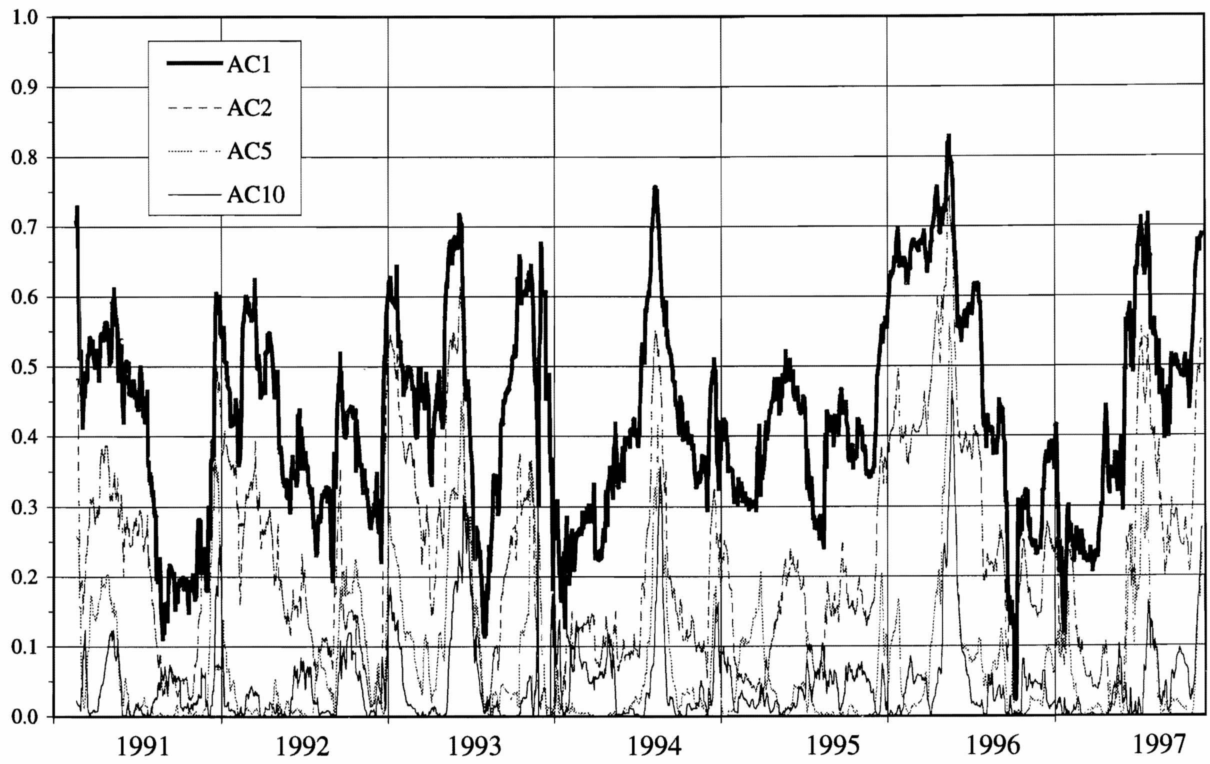

Figure 4.4.1. The squared autocorrelation for deseasonalised and normalised total ozone at Norrköping 1991-1997 as seen through a two-month window. The different curves correspond to various shifts in the autocorrelation. The uppermost line AC1 *is one-day lag and the next one* AC2 *is two-day lag. The two lower ones* AC5 *and* AC10 *are five-day and ten-day lags respectively.*

1997. Also these data are plotted using a window and for different averaging periods, Figure 4.4.2. For short periods, about a week, the total ozone at Vindeln and Norrköping may be correlated or anti-correlated. In general the positive correlation is in majority. Over longer time periods, more than a month, the positive correlation dominates. But, even for the longest period presented in Figure 4.4.2 there is a correlation close to zero in the summer of 1993.

A common way to present the correlation between two variables is in a scatter plot as in Figure 4.4.3. To reduce the influence of the seasonal variation the mean value (from the Uppsala period 1951-1966) has been subtracted day by day from both series. Then the values have been normalised by the same mean value. It can be seen in Figure 4.4.3 that both the Norrköping and the Vindeln data for the period 1991 to 1997 are on average off set from the Uppsala series. The gravity of the data is displaced towards the lower left, which corresponds to lower total ozone at both sites than at Uppsala. A linear model is fitted to the data.

In Figure 4.4.4 three methods of estimating the total ozone for a day at Norrköping are compared. The results are expressed as Root Mean Squared Errors (%), which are averaged over 11-days. Data are plotted for the period 1991 to 1997. The first method is to use the climatological value for the day, the second one is to use the value measured at Vindeln and the third one is to use the value measured at Norrköping the day prior to the actual day (persistence). During the winter values are not available for Vindeln so unfortunately there are gaps in this method. In general climatology is not very good during the winter due to the relatively large variation in total ozone at this time of the year. In the summer the methods often give similar results. But, as a general conclusion the persistence method is slightly better than the others are, for the studied data.

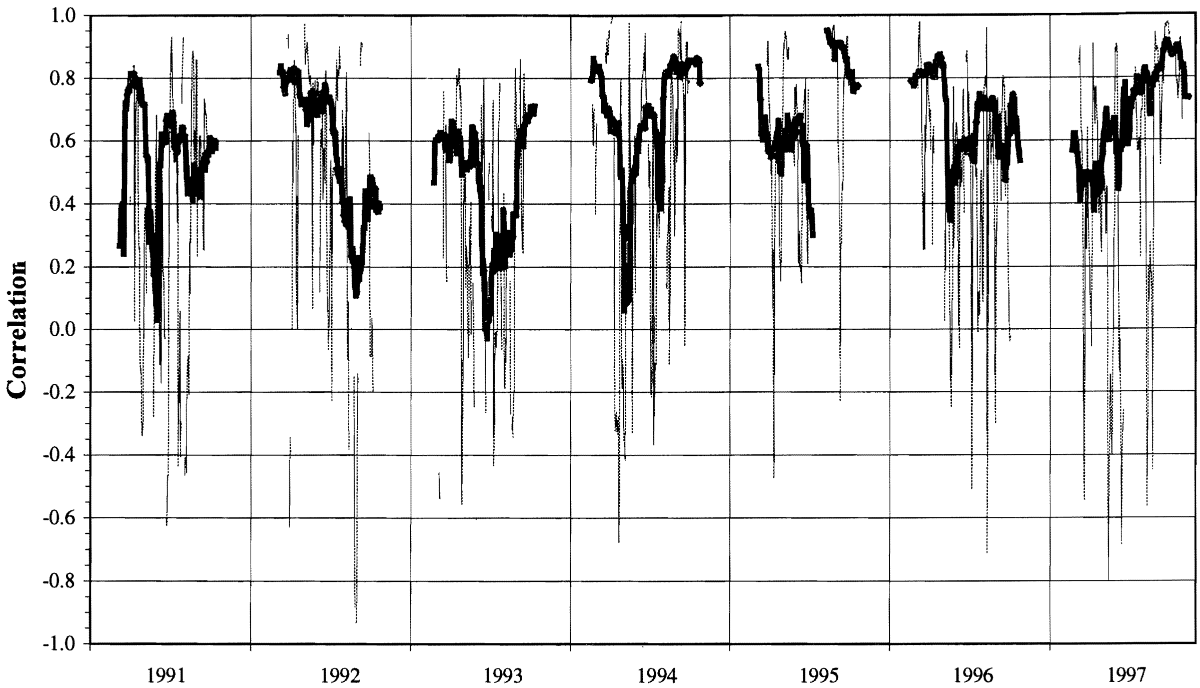

Figure 4.4.2. Correlation between deseasonalised and normalised total ozone measured at Vindeln and Norrköping as a function of time for the years 1991 to 1997. Thick line data are seen through a 60day window (more than 15 days at both sides). Thin line data are seen through a 15day window (more than 5 days at both sides).

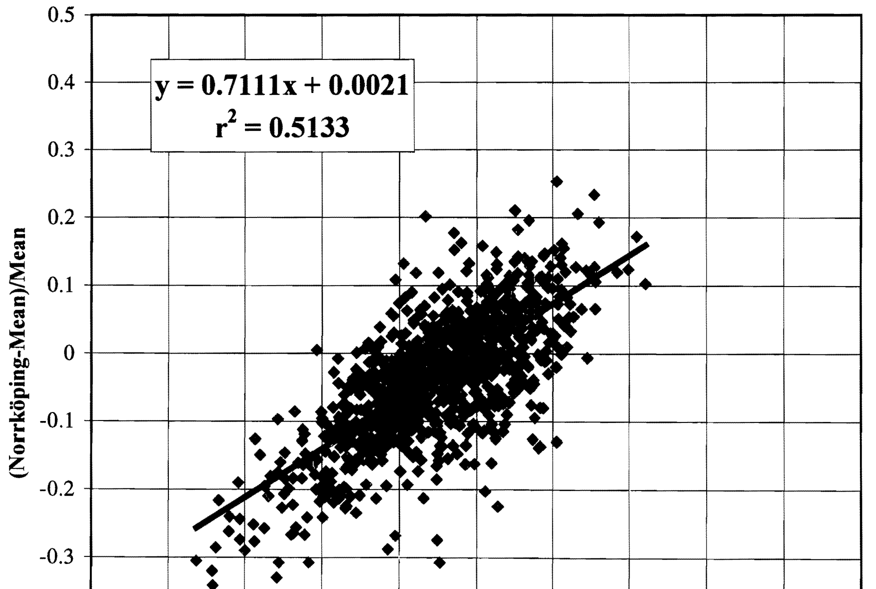

Figure 4.4.3. Norrköping and Vindeln total ozone relative deviations from long-term means at Uppsala plotted versus each other. A linear fit is included.

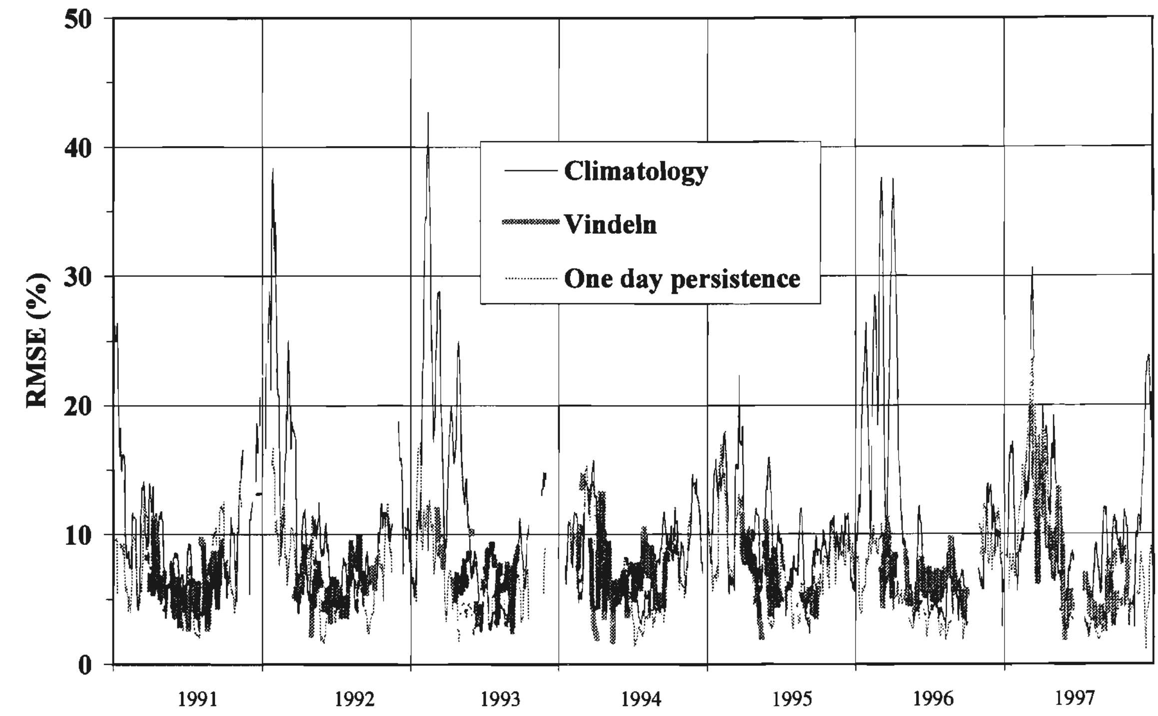

Figure 4.4.4. The variation of the RMSE (%) as seen through an eleven days window over a period of seven years for different methods of estimating the total ozone at Norrköping. Climatology is mostly the uppermost line. Using data from Vindeln (extrapolation) and one-day persistence are the other methods.

4.5 Long-term variation

In this section long-term refers to the whole period of observations, i.e. decades. The observed variations may be due to natural and anthropogenic factors as well as uncertainties in the measurements. Therefore, an observed variation or deviation from some reference or mean value can not easily be attributed to a specific factor unless a thorough analysis is done. A brief background to various factors affecting the long-term variation on different time-scales can be found in Josefsson (1994). Monthly mean values of total ozone at Norrköping and at Vindeln are given in Tables 4.1.1 and 4.1.2. The corresponding values from Uppsala can be found in Josefsson (1994).

In Norrköping, the last two years, 1998 and 1999, have shown periods of high values of total ozone. For the period 1988 to 1999 the highest summer, autumn and winter values have been recorded in these two years. An analysis of the linear trend for this period gives a value close to zero.

Daily values for the period 1988 January to 1999 December are plotted in the upper panel of Figure 4.5.1. Missing values are replaced by satellite values. The bold solid line surrounded by two thin lines are the long term average from Uppsala and the corresponding standard deviation of daily values from this average. In the lower panel of the graph the absolute deviations from the long-term mean of Uppsala are given for each individual day and as a smoothed value. The smoothing is done with a running 25-day triangular filter. In the upper panel the large daily variability and the yearly course of the total ozone are the dominant features. The smoothed curve of the lower panel indicates that the years 1992, 1993 and 1996 were years with a large deficit of total ozone. Starting with the summer of 1998 and including the early parts of 1999 there was a period with a surplus of total ozone.

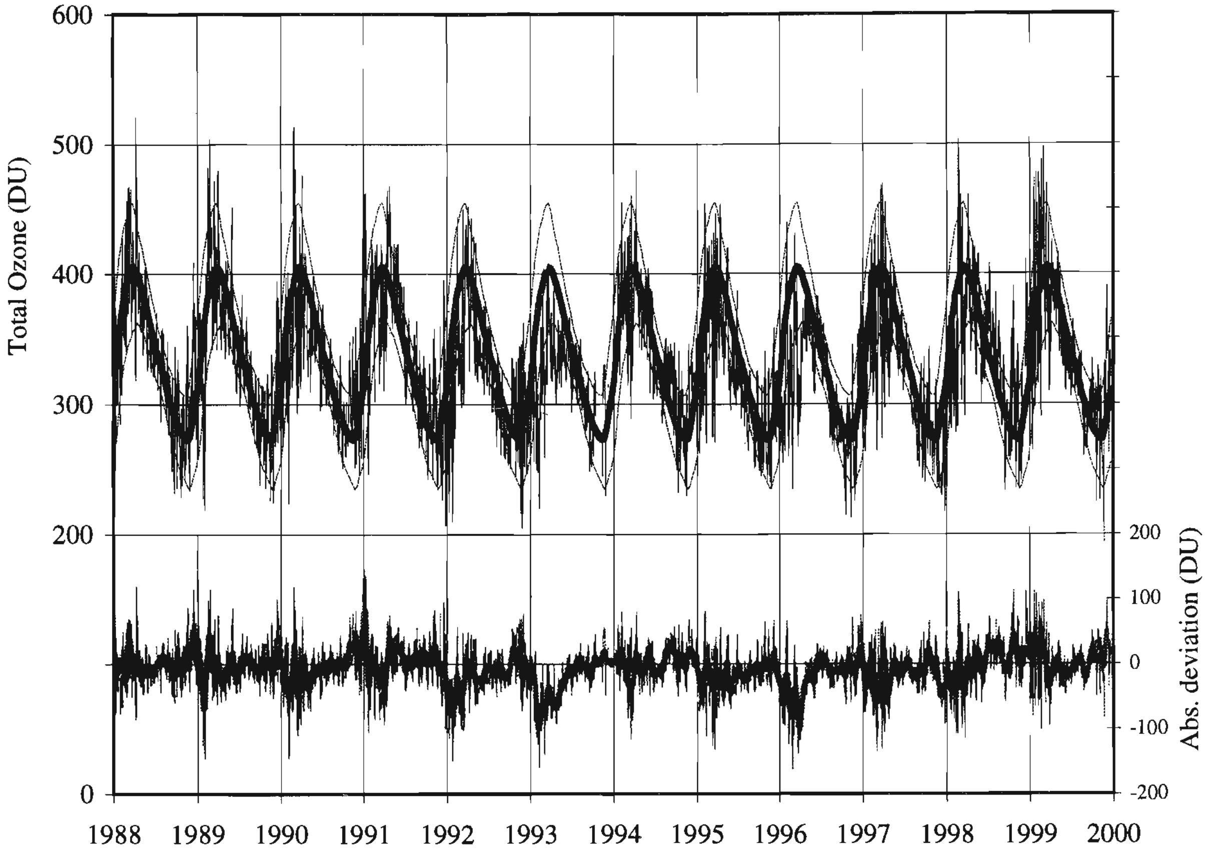

Figure 4.5.1. Daily total ozone (D.U.) *recorded at Norrköping 1988-1999* (*upper panel*). *Also plotted are the long-term mean from Uppsala 1951-1966* (*solid bold line*) *and the range of one standard deviation* (*thin lines*). *In the lower panel are the absolute deviation from the long-term mean at Uppsala for each day and a bold line for a smoothing of the deviations.*

It can be seen from the long-term averages and the corresponding standard deviation that one can expect a larger variation in the winter. To take this into account and to remove the yearly variation the daily values were standardised, by dividing the deviation from the long-term average for each day by the standard deviation for that day.

Frequency distributions of the standardised deviations of daily values of total ozone from the long-term means of Uppsala are plotted in Figure 4.5.2. Original data of daily total ozone are binned in a number of intervals denoted by horizontal thick lines. There is one distribution for the Uppsala series 1951-1966 and another one for Norrköping 1988 to 1999. Also included in the graph is the idealised standardised normal distribution (thin solid line). The mean and the median are 0.0 and the standard deviation is 1.0 of this curve. The Uppsala distribution (dashed line) differs slightly from the idealised curve. The Uppsala data has a mean value of 0, a median of –0.07 and a standard deviation of 0.96. So the frequency distribution of total ozone at Uppsala is approximately a normal (gaussian) distribution.

The Norrköping frequency distribution is standardised using the Uppsala mean and standard deviation values. The mean value is –0.19, the median –0.24 and the standard deviation is 0.96. The shape and characteristics of the distribution is very similar to the Uppsala distribution. The main difference is the shift towards lower values of the mean and the median values. This is of course what could be expected due to the thinning of the ozone layer. However, the interesting point is that all values, low as well as high deviations, have been shifted in the same direction. For example, another scenario would have been that the low values would have been even lower and the high values would have been unaffected. This would have produced a skewed distribution.

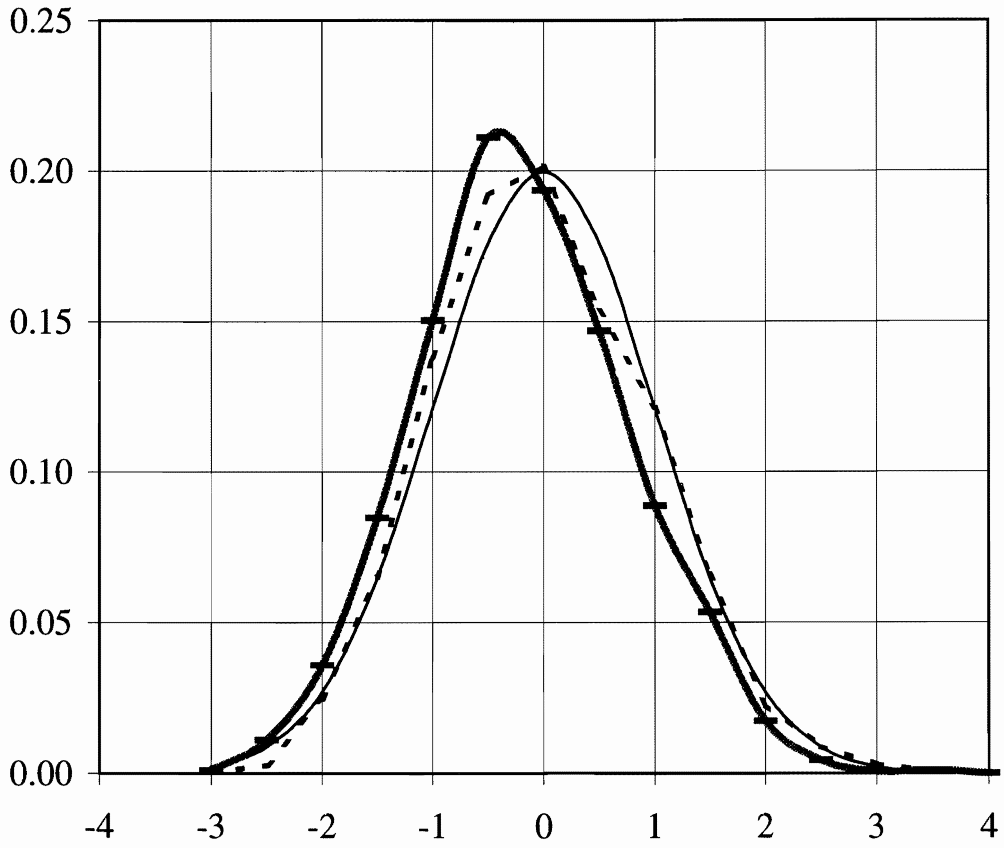

Figure 4.5.2. Frequency distributions of standardised daily total ozone in Norrköping 1988-1999 (thick solid line), *for Uppsala 1951-1966* (dashed line) *and idealised standardised normal distribution* (thin solid line).

Roughly, if a quantity is normally distributed and if there is no trend a random sample would give about 95% of the cases between ±2 s.d. (standard deviations). Five percent of 365 days (a year) corresponds to about 18 days. For a real year there will be a random variation in this number. Positive and negative deviations would be equally distributed over a longer period. However, if there is a trend the pattern will be different. In this case it is plausible that there will be a higher frequency in large deviations having a specific sign and a corresponding lower frequency of deviations having the opposite sign. In the case of the Norrköping series (1988-1999) there is 106 cases below –2 s.d. and 54 above +2 s.d. This apparent skewness is mainly due to the fact that the Norrköping series is offset from the Uppsala series. If the Norrköping data is related to its own mean value the result is more symmetrical.

Looking at the time series of the Norrköping standardised deviations, Figure 4.5.3, the first four years 1988 to 1991 showed no significant deviation of the extreme values from the old Uppsala record. However, for the following period 1992 to 1996 the number of days having a deficit of total ozone was much larger than those days having a surplus. This could be interpreted as an indication of a downward trend. A strong decline in total ozone was reported for the mid- and high-latitudes of the Northern Hemisphere including the year 1996. In the years of 1998 and

1999 the strong downward trend was broken. In general, for the Northern Hemisphere the values of total ozone remained relatively low, but the decline stopped. In particular, in the late 1998 a number of occasions, with thick ozone layer, were observed at Norrköping, Figure 4.5.3. If the observed high values is an indication of a recovery cannot be stated from the Norrköping series alone. An explanation of the observed ozone variations must include global observations, ozone photochemistry and meteorological dynamics.

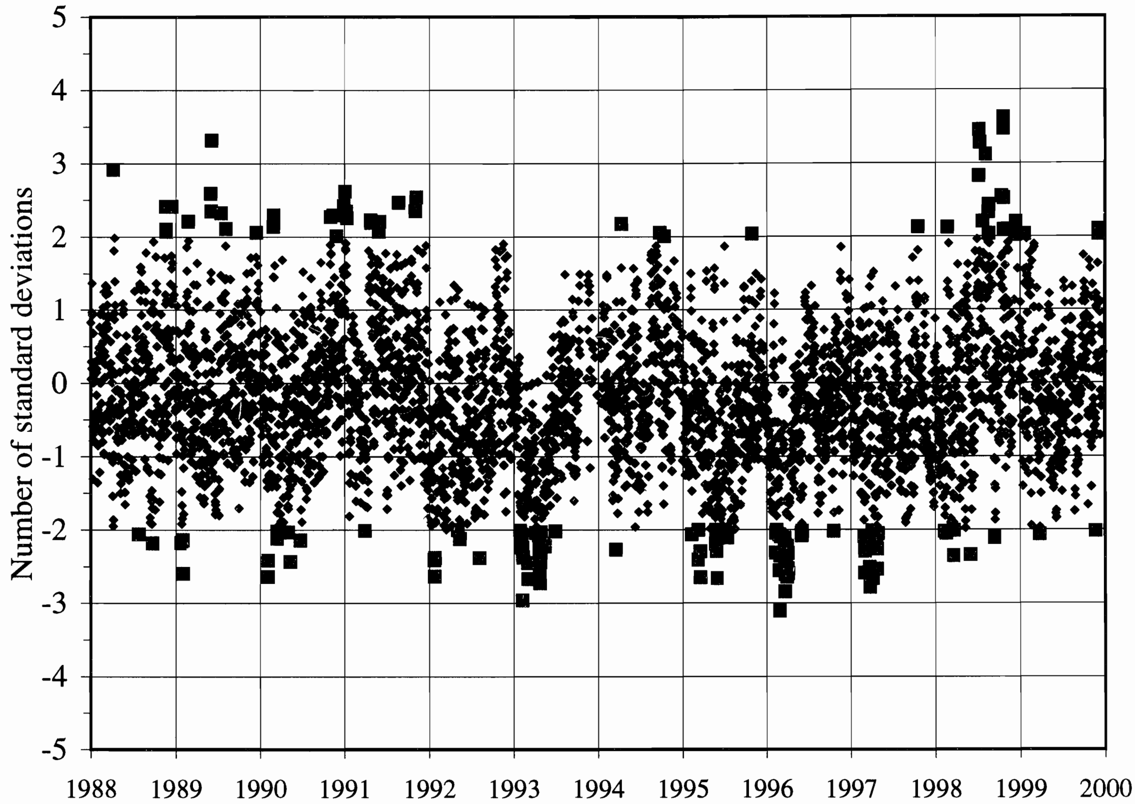

Figure 4.5.3. Deviation in daily total ozone in Norrköping 1988-1999 from long-term mean in Uppsala divided by the standard deviation (S.D.). This relative unit has no dimension. Deviations larger than 2 S.D. are denoted by squares.

There is a general consensus that the thinning of the ozone layer is mainly due to anthropogenic influence, WMO (1998). The peak of this influence (at stratospheric levels) is expected around the year 2000. Then the total ozone is supposed to slowly recover and return to its un-perturbed values around the year 2050. Probably, we will have to be patient to see the onset of the recovery. Because, a trend in total ozone of less than 5% per decade will need more than a decade of observations to be detected at the 95% probability level at Nordic latitudes, see e.g. Josefsson (1988a). This because, the high natural variation of the total ozone at high latitudes combined with the uncertainty in the measurements set a limit for the early detection of a slow recovery. During this time data quality must be ensured.

5 Conclusions

- The main objective, which is to measure accurately and observe regularly the total ozone, has been fulfilled at Vindeln and Norrköping during the period 1997 to 1999. There have been some unexpected gaps in the data records. Vindeln has proved to fill a gap in the global total ozone network and with the Brewer #006 in operation more up to date and frequent data is available.

- In general there has been a deficit of total ozone for the 1990-ties in Sweden. In the winter and spring it is about 5 to 10 % and in the summer it was between 0 and 5 %. In the autumn it is close to 0 or even a slight surplus.
- On a yearly **average** the last decade of the 20th century does not show any extreme losses of ozone in Sweden as compared to the measurements of the period 1951 to 1966. However, there have been episodes lasting for a week or so with deficits larger than 25%.

- The Dobson #30 and the Brewer #006 operated in parallel at Vindeln during the period 1996 to 1999 show a good agreement but with a slight systematic difference, which on average is 2-3 %.

- Comparison of the Dobson #30 with the TOMS EP overpass data for Vindeln and for the same period gives a difference of similar magnitude.

- Comparison of the Brewer #006 with the TOMS EP overpass data for Vindeln and for the same period shows a fairly nice agreement.

- The differences between the Dobson, the Brewer and the TOMS total ozone data are within the absolute uncertainty limits of the observations. Therefore, it is not possible to determine which one that is closest to the true value.

- The differences are on average constant over the period indicating long term stability of all instruments. This also gives a qualitative measure of precision in the observations. The magnitude of the precision in the measurements affects the possibilities for trend detection.

- The low number of observations the Dobson data measured at Abisko in 1926 and 1927 show no significant deviation from what could be expected nowadays. Despite the small sample the result is an indication that the ozone layer had about the same thickness in the summer half years of 1926 and 1927 as it has today.

- The reprocessing of the twelve years of Norrköping data has not outdated the measurements from Uppsala. They are still of great importance as a reference of past climate. Present and future variations in the amount of total ozone will still be compared with it.

- Estimates of the daily total ozone at Norrköping using one day persistence or the value measured at Vindeln (distance 750 km) gave almost the same error, RMSE 5-10%. Using the climatological average for the day was almost as good during the summer. But, it was considerably worse during the winter season.

- The squared autocorrelation in daily normalised and deseasonalised total ozone for a lag of one day may for some periods be larger than 0.5. For larger lag times it is rarely that large, which implies that persistence forecasts may only be useful for one day.

- An early detection, in the Norrköping/Vindeln data, of the expected recovery of the total ozone will be hampered by the high natural variation of the total ozone at high latitudes combined with the uncertainty in the measurements.

6 Acknowledgements

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TOMS data were produced by the Ozone Processing Team at NASA's Goddard Space Flight Center. Please accept my humble gratitude for your permission to use your valuable data that I found at your nice web-site http://toms.gsfc.nasa.gov/.

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Appendix 1

TOTAL OZONE

NORRKÖPING	Latitude: 58.58°N Longitude: 16.15°E Height: 45m Instrument: Brewer MK III #128
VINDELN	Latitude: 64.24°N Longitude: 19.77°E Height: 225m Instrument: Brewer MK II #006 Instrument: Dobson #030
Period:	1997 January -- 1999 December

Data from 1988 up to 1996 are published in Josefsson (1988b, 1990, 1991, 1992, 1994 and 1996) and in Josefsson and Karlsson (1997). Data are also freely available from WOUDC and they are posted under http://www.smhi.se. One value is given for each day normally it is recorded close to noontime. The amount of total ozone is given in Dobson units, Bass-Paur Scale.

Days without reliable measurements are indicated by - .

TOTAL OZONE: The thickness of a layer of pure ozone at standard pressure and temperature (STP: 0°C, 101325 Pa). The number of molecules in that layer equals the number in a vertical column above the point of observation. The total ozone varies during the day, the year and in space. Typical extremes for Vindeln/Norrköping/Uppsala are about 200 and 550 DU.

A common unit for total ozone is the Dobson Unit (D.U.).

1 DU	$= 10^{-5}$ m ozone at STP
	$= 10^{-3}$ atm cm
	$= 268.7 \cdot 10^{18}$ molecules m^{-2}
	$= 21415$ μg m^{-2}

Total ozone (DU) Norrköping 1997 Brewer #128

1997	Jan	Feb	Mar	Apr	Maj	Jun	Jul	Aug	Sep	Okt	Nov	Dec
1	374.0	347.8	420.0	273.8	305.3	-	-	327.0	258.2	302.0	283.0	-
2	355.0	393.5	335.0	339.1	314.0	347.3	-	311.0	256.1	335.3	286.5	245.0
3	303.0	399.0	447.1	370.2	382.3	341.1	-	311.0	265.0	290.5	284.8	253.0
4	307.1	356.0	370.6	469.5	352.0	348.0	-	329.0	256.1	278.3	280.3	279.0
5	-	391.9	299.3	394.3	320.0	347.8	-	316.0	271.9	268.8	281.1	240.0
6	344.3	402.5	367.5	449.4	327.6	342.2	-	301.0	280.3	240.0	285.0	259.0
7	339.4	330.0	288.8	399.3	370.0	333.7	-	302.0	294.2	242.0	271.0	235.0
8	357.0	-	313.5	382.9	369.0	350.9	-	292.0	281.4	278.8	253.2	245.0
9	-	322.0	263.7	319.1	410.0	-	-	295.0	299.8	258.0	245.0	245.0
10	-	331.8	279.5	297.2	395.0	341.8	-	290.0	306.1	252.0	285.5	243.0
11	-	391.1	289.4	320.0	352.9	321.1	-	300.0	251.6	303.0	275.0	245.0
12	-	343.8	289.1	332.6	338.7	325.8	-	286.0	275.0	273.4	280.0	243.0
13	290.0	382.0	319.4	297.4	359.5	341.2	-	-	-	299.0	-	242.0
14	292.8	426.0	344.6	380.6	383.5	342.8	-	284.0	-	299.7	267.0	240.0
15	308.3	-	349.8	455.5	375.0	326.5	329.7	291.0	295.4	315.7	265.7	238.0
16	274.9	424.0	455.0	388.5	344.2	335.1	339.0	292.0	285.7	315.0	-	232.0
17	264.0	386.6	432.7	335.5	352.1	343.0	347.0	288.0	301.7	313.3	263.0	230.0
18	289.0	305.7	381.9	417.0	365.3	327.7	361.3	291.0	317.9	295.0	263.0	231.0
19	323.0	407.3	410.4	419.9	362.4	336.6	346.6	296.0	330.4	261.0	-	230.0
20	290.0	355.0	400.8	364.1	367.7	-	334.4	300.0	301.6	315.5	-	252.0
21	284.0	340.0	408.2	332.0	380.7	-	329.9	305.0	299.0	311.4	315.0	237.0
22	294.0	342.6	391.2	342.4	373.4	-	339.8	295.0	275.0	282.0	-	255.0
23	307.0	310.0	400.5	353.3	395.3	-	328.2	291.0	285.3	312.5	318.0	249.0
24	323.5	309.1	394.9	355.2	405.2	-	333.6	283.0	243.0	333.9	310.0	247.0
25	-	385.9	336.3	400.0	388.6	-	334.0	292.0	258.5	343.6	298.0	-
26	306.0	430.1	355.0	-	387.5	-	340.6	293.0	260.1	320.7	295.0	-
27	354.0	412.6	444.9	-	387.2	-	337.4	298.0	249.3	289.0	265.0	258.0
28	352.0	325.0	468.4	353.7	397.5	-	346.0	295.0	260.7	272.4	247.0	292.0
29	367.8		427.6	320.0	396.2	-	348.3	285.0	257.3	274.1	238.0	255.0
30	332.7		361.2	325.4	371.7	-	328.2	280.0	303.0	260.2	247.0	257.0
31	371.8		285.4		368.2		325.0	275.0		274.3		228.0

Total ozone (DU) Norrköping 1998 Brewer #128

1998	Jan	Feb	Mar	Apr	Maj	Jun	Jul	Aug	Sep	Okt	Nov	Dec
1	218.0	334.0	503.4	395.6	359.2	380.0	374.7	359.1	335.0	302.3	303.0	276.0
2	222.0	352.7	465.7	387.3	381.7	390.0	355.5	340.6	340.4	278.8	308.0	242.0
3	-	334.0	431.9	359.2	425.0	376.2	333.5	361.0	319.3	284.4	285.0	245.0
4	-	315.0	384.0	360.0	420.0	372.7	-	312.6	303.3	291.9	280.0	-
5	-	364.4	462.1	405.0	400.1	384.7	348.4	350.1	298.5	283.2	294.7	-
6	-	379.1	496.0	404.0	419.1	362.0	379.6	328.8	295.3	278.3	326.2	-
7	369.0	-	383.3	400.0	406.4	340.8	386.5	348.1	286.1	273.4	311.7	-
8	318.0	-	395.0	372.2	374.5	349.6	366.6	337.0	283.1	261.4	252.0	-
9	339.0	290.0	406.3	423.8	362.9	329.4	369.0	357.2	292.7	259.6	235.9	-
10	335.0	323.0	385.7	409.8	365.2	300.7	353.1	324.3	292.5	283.0	250.0	-
11	328.0	379.4	461.1	416.6	358.6	342.1	366.2	327.3	295.2	270.0	295.0	-
12	321.0	340.0	427.0	435.0	420.2	370.6	366.9	322.5	300.3	295.5	290.0	-
13	297.0	316.2	372.5	440.0	387.6	314.6	362.7	384.9	289.8	284.0	295.0	-
14	310.0	334.0	338.1	461.0	341.8	361.9	396.0	350.2	300.0	-	285.0	-
15	342.0	336.0	302.5	421.6	353.3	323.1	407.6	310.6	330.0	324.9	335.0	-
16	-	-	306.0	410.0	347.8	320.0	361.6	340.1	336.2	325.6	345.0	349.0
17	-	341.2	360.0	390.1	329.7	353.6	369.3	316.0	336.6	260.0	340.0	-
18	334.1	278.2	394.2	385.0	321.9	350.0	371.3	339.0	297.8	320.0	305.0	-
19	320.0	290.6	451.0	370.0	324.1	354.6	401.9	338.1	308.7	331.5	338.1	-
20	303.0	297.0	435.0	390.0	397.6	370.2	357.1	327.2	265.0	356.8	312.1	400.0
21	324.1	308.6	338.7	406.4	405.5	332.5	323.4	320.9	254.4	289.9	268.4	411.0
22	287.0	376.0	340.0	410.4	407.0	328.4	328.4	345.8	233.9	262.1	236.9	328.0
23	304.0	367.6	366.0	345.0	401.2	340.0	326.7	352.8	239.8	-	252.0	-
24	354.6	330.2	357.1	340.0	390.7	318.7	348.8	351.6	241.5	322.3	255.0	-
25	285.5	283.0	359.0	373.0	406.6	329.7	354.4	360.4	250.0	312.0	281.0	-
26	284.2	-	329.8	372.6	409.0	333.7	350.8	362.7	260.0	332.0	268.0	-
27	291.5	428.7	382.5	369.2	411.8	347.5	343.1	353.2	289.0	316.9	288.0	-
28	320.0	458.1	312.2	347.6	415.3	340.7	342.6	338.8	287.9	385.4	273.0	-
29	281.1	-	290.9	370.1	394.7	390.8	351.8	334.2	300.0	390.0	248.0	392.0
30	334.3	-	308.5	363.1	379.4	383.3	360.4	-	297.0	355.7	254.0	314.0
31	339.3		329.7		372.5	374.7	372.2	345.0		341.9		-

Total ozone (DU) Norrköping 1999 Brewer #128

1999	Jan	Feb	Mar	Apr	Maj	Jun	Jul	Aug	Sep	Okt	Nov	Dec
1	-	330.0	479.4	-	401.4	339.4	338.4	319.0	306.7	304.6	281.7	257.6
2	-	343.4	488.0	-	378.2	328.7	340.5	318.6	259.9	294.6	260.6	323.3
3	-	354.0	400.0	-	402.0	335.7	323.5	317.4	266.2	317.7	328.4	332.1
4	-	-	425.0	-	362.4	331.8	331.7	325.9	263.4	307.3	300.0	330.0
5	-	477.7	420.0	-	359.6	328.2	319.0	324.0	272.5	306.0	302.9	325.8
6	-	456.4	418.0	-	364.9	354.3	322.4	324.3	287.4	290.0	295.0	300.0
7	-	451.4	418.0	-	382.7	364.3	342.9	311.9	293.1	284.9	325.0	298.4
8	-	454.1	420.0	-	399.2	354.8	344.6	305.4	282.5	297.5	295.0	295.0
9	-	-	-	-	390.0	345.8	305.6	325.2	267.2	334.1	295.0	293.4
10	348.1	-	-	-	395.0	374.9	314.0	330.4	274.8	283.4	292.8	362.5
11	-	399.1	497.6	-	410.8	349.8	311.3	317.4	270.1	308.9	246.4	340.0
12	332.0	358.2	453.3	-	412.3	313.8	325.6	327.5	265.1	322.6	226.2	340.0
13	361.0	340.0	430.0	-	413.8	311.7	323.1	335.6	267.3	316.9	243.5	390.0
14	352.0	315.8	370.0	-	390.0	313.8	323.5	323.7	267.1	319.2	312.5	388.6
15	345.0	353.3	405.0	-	416.2	313.2	313.9	324.8	276.4	306.6	270.3	340.0
16	309.0	447.4	405.0	-	396.1	310.0	363.8	328.6	290.0	313.4	291.5	347.0
17	342.3	477.4	400.0	-	376.9	-	361.2	333.6	267.9	303.5	320.0	350.0
18	388.0	467.5	340.0	-	344.3	-	341.1	326.7	265.5	289.0	300.0	350.8
19	308.0	330.0	398.8	-	339.6	-	325.1	324.1	280.1	280.0	297.0	345.0
20	282.0	376.5	438.4	-	345.2	-	338.9	335.9	299.1	285.0	265.0	336.6
21	265.0	374.1	409.9	-	369.5	328.0	341.6	329.9	284.2	306.1	261.6	262.5
22	384.1	460.0	410.0	-	364.4	343.5	354.7	339.3	290.0	307.0	280.0	294.2
23	343.0	450.0	469.5	380.0	400.5	360.0	348.8	323.1	283.9	290.0	265.0	-
24	355.0	458.0	405.2	385.0	352.8	325.4	311.2	321.9	286.8	295.0	265.0	-
25	375.0	409.6	371.2	-	367.7	327.7	310.1	311.4	285.0	315.0	250.0	-
26	380.0	312.0	369.2	370.7	380.1	340.9	343.8	302.0	285.1	290.0	245.0	-
27	445.0	290.3	-	380.6	335.0	330.8	337.1	311.5	298.4	254.9	248.2	-
28	473.2	364.2	-	374.6	339.6	339.5	328.7	303.0	310.0	225.0	259.0	-
29	436.0		-	372.9	361.2	317.9	313.4	288.5	293.7	262.2	253.0	-
30	327.0		-	382.1	363.3	332.1	317.3	287.7	284.4	263.9	193.8	-
31	-		-		361.5	338.4	327.6	305.2		275.0		332.7

Total ozone (DU) Vindeln 1997 Brewer #006

1997	Jan	Feb	Mar	Apr	Maj	Jun	Jul	Aug	Sep	Okt	Nov	Dec
1	-	-	-	385	325	339	300	318	260	324	274	-
2	-	-	-	412	370	353	305	301	262	-	310	-
3	-	-	-	-	378	362	303	307	-	-	304	-
4	-	-	-	392	348	352	315	317	255	-	308	-
5	-	-	-	365	316	342	-	291	259	271	-	-
6	-	-	-	361	319	334	-	286	275	264	-	-
7	-	-	283	354	318	322	-	280	305	249	-	-
8	-	-	402	337	335	318	340	292	288	-	-	-
9	-	-	262	-	351	318	332	281	287	-	-	-
10	-	-	312	308	-	328	312	292	283	-	-	-
11	-	-	357	321	-	333	311	290	275	-	-	-
12	-	-	379	298	-	323	316	294	277	-	-	-
13	-	-	411	321	383	311	311	290	-	-	-	-
14	-	-	433	406	396	323	310	287	331	-	-	-
15	-	-	443	396	-	-	319	285	323	309	-	-
16	-	-	412	348	410	-	315	288	310	321	-	-
17	-	-	409	393	412	328	328	275	324	324	-	-
18	-	-	413	444	406	329	330	280	329	314	-	-
19	-	-	390	397	407	331	333	295	325	283	-	-
20	-	-	380	359	379	337	312	282	311	312	-	-
21	-	-	404	361	399	333	302	281	286	299	-	-
22	271	-	402	-	410	347	300	288	281	-	-	-
23	-	-	-	366	395	-	313	297	295	330	-	-
24	-	-	415	329	403	347	317	288	242	323	-	-
25	-	-	384	344	379	349	327	284	249	321	-	-
26	-	-	-	324	391	363	329	-	263	306	-	-
27	-	-	-	322	399	341	322	286	247	-	-	-
28	-	-	-	344	398	344	328	280	259	249	-	-
29	-		393	299	395	335	320	279	268	-	-	-
30	-		339	308	385	339	324	268	-	243	-	-
31	-		358		369	300	326	266		-		-

Total ozone (DU) Vindeln 1997 Dobson #030

1997	Jan	Feb	Mar	Apr	Maj	Jun	Jul	Aug	Sep	Okt	Nov	Dec
1	-	-	-	379	-	-	292.3	320	270	313.85	-	-
2	-	-	-	408.12	330.22	340.16	292.24	-	269	-	-	-
3	-	-	-	-	-	357.09	303	301.95	283	-	287.63	-
4	-	-	-	383.24	-	344.69	323	304.95	260	-	-	-
5	-	-	273.69	-	309.33	332.66	-	282.73	250.72	-	-	-
6	-	-	341.89	-	321	322.43	-	276.54	-	-	-	-
7	-	-	-	340.35	307.02	-	305.1	268.41	-	246.81	-	-
8	-	-	-	324.67	-	-	332	278.57	292	-	-	-
9	-	-	-	-	347.38	309.62	311	-	282.84	-	-	-
10	-	-	305	317	-	355	322	283.47	273.41	-	-	-
11	-	-	361.3	312.1	-	327.5	303.49	279.73	268.69	-	-	-
12	-	-	-	-	356	316	-	291	275	-	-	-
13	-	-	410.86	-	374.44	300.63	303	285.7	-	-	-	-
14	-	-	420.74	408	384.88	-	303.11	281.2	-	-	-	-
15	-	-	-	384.78	438	-	309.38	279.2	313.05	-	-	-
16	-	-	-	347	407.3	-	304.22	-	318	-	-	-
17	-	-	395.89	401	-	317.96	318.94	-	-	-	-	-
18	-	-	400.55	440.07	-	319.9	321.27	274.46	322.87	-	-	-
19	-	-	-	-	-	330	-	285.99	318.61	-	-	-
20	-	-	365.08	-	372.93	-	-	274.57	-	-	-	-
21	-	-	402.15	359	400	-	294.95	272.9	-	281.6	-	-
22	270.97	-	-	395	410.48	-	292.72	279.62	271.2	-	-	-
23	-	-	-	-	401	-	304.67	-	285.87	-	-	-
24	-	-	402.16	335	-	-	313	-	233.59	-	-	-
25	-	-	390	333.13	-	341	319.67	274.99	238.25	-	-	-
26	-	-	359	-	382	348.63	-	298	261.01	-	-	-
27	-	-	-	-	382.65	331.21	-	294	-	-	-	-
28	-	-	-	317.7	396	-	-	287	-	-	-	-
29	-		-	284.17	405	-	328	269.4	260.92	-	-	-
30	-		-	295.58	380.24	329	340	-	-	-	-	-
31	-		-		-	292.3	329	-		-		-

Total ozone (DU) Vindeln 1998 Brewer #006

1998	Jan	Feb	Mar	Apr	Maj	Jun	Jul	Aug	Sep	Okt	Nov	Dec
1	-	-	464.6	390.9	398.7	371.6	355.8	345.1	319.6	-	-	-
2	-	-	445.8	392	394.9	374.3	351.6	351.4	312.4	275.6	-	-
3	-	-	434.8	376.4	433.2	393.8	363.3	334.7	283.8	247.1	285.7	-
4	-	-	-	381.2	388.7	-	396.7	332.2	292.1	259.4	-	-
5	-	-	495.1	392.1	389.8	398.3	349.8	366.7	277.3	288.8	-	-
6	-	-	473.7	404.5	-	381.8	334	350.6	286.7	-	-	-
7	-	-	-	426.9	409.8	359.9	363.8	336.2	273.5	-	-	-
8	-	-	430.3	444.7	440.4	-	366.4	336.9	278.5	-	-	-
9	-	-	429	474.1	426.8	364.9	363.9	344.1	-	-	-	-
10	-	350	460.6	454.7	355.6	311.8	363.4	359.9	-	266.2	-	-
11	334	373.8	-	429.6	409.8	339.1	361.5	353.7	287.2	-	-	-
12	-	409.6	-	434	381.1	344.3	346.7	346.9	-	-	-	-
13	-	361.6	-	438.3	358.9	325.8	325.5	323.1	-	-	-	-
14	-	-	359	396.8	339.4	336.2	334.7	326.9	286.7	-	-	-
15	-	312.9	342	461.7	341.5	319.4	371.1	306.7	-	-	-	-
16	-	336.9	-	445.1	-	-	378.2	-	-	332.6	-	-
17	-	304	-	418.2	-	346.8	384.7	330	-	307	-	-
18	-	277.1	-	-	-	-	360	-	322	-	-	-
19	-	318.9	434	-	408.3	340.1	-	340	285.5	301.7	-	-
20	-	318.6	-	-	423.5	332.1	352.6	322.8	247.4	-	-	-
21	-	-	-	406	434.1	316.9	345	331.9	233	323.1	-	-
22	-	381.7	-	414.1	425.2	309.4	309.8	344.9	265.4	-	-	-
23	-	-	319.4	399.9	440.6	307.8	321.1	350.6	254.6	-	-	-
24	-	345.1	-	383.5	432.6	305.8	314.7	337.6	284.6	294.9	-	-
25	-	-	-	372.3	436	331.6	316.4	342.3	308.4	-	-	-
26	-	323.1	335.9	371.4	-	335.7	323	-	311.1	-	-	-
27	-	-	327.8	398.1	397.4	330.3	321.8	-	316.7	319	-	-
28	-	418	-	359.4	-	323.3	325.5	317.2	-	-	-	-
29	-		-	353.8	406	322.3	327.9	321.2	299.1	-	-	-
30	-		326.3	363.8	387.7	335.7	-	-	255	-	-	-
31	-		-		391.1	355.8	332.1	-		-		-

Total ozone (DU) Vindeln 1998 Dobson #030

1998	Jan	Feb	Mar	Apr	Maj	Jun	Jul	Aug	Sep	Okt	Nov	Dec
1	310.6	-	-	409.18	-	-	346.93	-	315	-	-	-
2	-	-	-	381.03	-	379	344.94	347.27	305.53	268.66	-	-
3	-	-	-	364.97	-	382.08	374	329.48	274.68	-	-	-
4	-	-	-	-	378.29	399	-	344	286.2	-	-	-
5	-	-	-	378.76	-	396	-	368	-	-	-	-
6	-	-	-	-	-	-	357	318.94	-	-	-	-
7	-	-	-	416	413	-	366	335.51	276	240.63	-	-
8	-	-	-	438.8	451	-	361.77	-	261.61	-	-	-
9	-	-	419.45	460.11	-	368	358.38	-	284	-	-	-
10	-	-	453.66	-	-	339	-	-	-	-	-	-
11	-	-	-	-	400	332.11	-	348.82	299	-	-	-
12	-	-	-	-	374.94	332	-	-	-	-	-	-
13	-	-	-	-	346.19	-	344	332	-	-	-	-
14	-	-	-	-	346	-	338	338	301	-	-	-
15	-	-	-	454	356.39	348	383	-	307	-	-	-
16	-	-	333.69	445	-	-	387	-	311	-	-	-
17	-	-	-	425	-	369	374.4	-	312	-	-	-
18	-	-	-	-	337.68	-	-	-	324	-	-	-
19	-	-	427.26	-	404	-	367	339	-	-	-	-
20	-	-	406.03	411	422	-	-	322	-	-	-	-
21	-	-	-	397.94	-	-	338.65	337	238	286	-	-
22	-	-	-	402.13	-	321	302.04	-	256.75	-	-	-
23	-	-	322	-	-	-	-	-	248.83	-	-	-
24	-	-	326	373.21	424.91	299.25	-	346	279.43	-	-	-
25	-	-	371	-	-	321.44	-	-	310	-	-	-
26	-	-	325.62	-	439	-	323	-	-	-	-	-
27	-	-	-	414	-	320.34	-	-	-	-	-	-
28	-	-	-	352.31	410	-	-	321	313	-	-	-
29	-		-	346.48	389	318	330	331	292	-	-	-
30	-		-	358.04	-	327.67	-	-	-	-	-	-
31	-		-		-	346.93	360	342		-		-

Total ozone (DU) Vindeln 1999 Brewer #006

1999	Jan	Feb	Mar	Apr	Maj	Jun	Jul	Aug	Sep	Okt	Nov	Dec
1	-	-	-	432.1	394	343.4	309.7	317.1	-	285.5	283.1	-
2	-	-	-	424.3	405.1	356.4	321.2	310.8	-	-	-	-
3	-	370.2	467.9	366.3	408.5	338.4	342.1	310.1	253.8	291.8	-	-
4	-	-	416.5	376	446.9	-	339.5	321.7	274.3	298.3	-	-
5	-	-	-	333.1	391.7	-	328.3	326.1	252.1	285.6	-	-
6	-	-	-	377.2	399.1	-	332.3	337.3	258.2	277.4	-	-
7	-	-	-	387.9	441.1	336.4	348.7	329.3	284.6	-	-	-
8	-	-	-	-	-	350.9	341.8	324.6	308.2	290.3	-	-
9	-	-	441.8	381.3	420.7	327.3	303.3	315.5	261.5	-	293	-
10	-	-	-	384.4	413.6	342.6	297	-	279.3	-	282.9	-
11	-	390.7	-	380.5	-	337.7	314.6	323.7	254.4	-	266.6	-
12	-	-	431.4	415.4	393.4	306.3	276.5	334.2	258.1	-	-	-
13	-	305.1	419.2	389.1	394.3	309.2	293.3	327.3	270.6	317.8	276.7	-
14	-	314.4	-	391.2	385.6	311.1	319.4	324.4	271.2	331.6	280.2	-
15	-	390.5	-	-	391.7	318.1	327.4	326.1	265.1	314.4	262.9	-
16	-	-	-	437.8	395.4	344.5	333.4	320.3	273.9	-	-	-
17	-	-	401.1	-	368.7	320.3	334.2	333	301.6	281.5	-	-
18	-	-	373	-	325.4	331.6	366.7	324.5	299.6	275.1	292	-
19	-	-	-	-	367.8	307.4	347.2	328.2	301.1	274.2	253.8	-
20	-	-	-	-	361.1	308.7	326.8	329.6	306	288.9	-	288
21	-	-	481.6	361.7	357.6	318.7	319.5	340.1	295.4	298.1	-	260
22	-	-	-	-	349.5	340.9	330.6	333.3	-	290.2	-	-
23	-	-	508.6	415.3	381.7	-	328.2	306	277.2	-	-	-
24	-	-	534.8	366.1	410	-	321.6	296.4	293.1	-	-	-
25	-	-	466.7	365	377.2	320.4	338.3	297.8	-	-	-	-
26	-	-	-	365	395.8	315.6	345.5	303.9	292.7	-	-	-
27	-	-	-	387.1	390.6	322.3	329.7	-	-	284.9	-	-
28	-	-	432.8	375.3	401.2	321.5	330.8	296.1	-	-	-	-
29	-		372.8	390.9	-	318	321.1	289.6	272.7	268.3	-	-
30	-		329.6	375.7	388.2	294.7	339	-	276.4	-	-	-
31	-		387.7		359.3	309.7	322.6	-		252.1		-

Total ozone (DU) Vindeln 1999 Dobson #030

1999	Jan	Feb	Mar	Apr	Maj	Jun	Jul	Aug	Sep	Okt	Nov	Dec
1	-	-	-	446	-	360	310.38	312.26	310	-	-	-
2	-	-	-	-	-	367	328	305.87	264	-	-	-
3	-	-	-	-	402.49	344	-	312	235.49	-	-	-
4	-	-	-	-	441	-	-	331	-	-	-	-
5	-	-	-	-	383.72	-	337	-	-	278.01	-	-
6	-	-	-	373	-	-	344	-	243.97	273.01	-	-
7	-	-	-	377.37	435.86	352	343.45	-	279.72	-	-	-
8	-	-	-	342	-	351.83	337.56	-	308	284.01	-	-
9	-	-	-	379	-	331	-	-	252.01	-	-	-
10	-	-	-	-	422	336.77	-	-	274.01	-	-	-
11	-	374.2	-	-	393	327.27	-	341	-	-	-	-
12	-	-	-	409	390.73	-	266	-	-	-	-	-
13	-	-	-	387	-	-	304.04	331	262.01	312	-	-
14	-	-	-	-	-	-	311.86	-	264.01	-	-	-
15	-	-	-	412	-	310.1	316.23	-	258.01	314	-	-
16	-	-	-	412	-	336.99	-	315.73	-	-	-	-
17	-	-	-	-	355.82	314.88	-	336	-	-	-	-
18	-	-	363.6	-	331	326.45	-	-	-	-	-	-
19	-	-	-	-	355.24	-	350	318.88	-	272	-	-
20	-	-	-	352	344.7	-	325	326	300.01	-	-	-
21	-	-	-	356.15	349.85	321	350	-	288.01	286	-	-
22	-	-	-	-	-	332.5	-	-	-	-	-	-
23	-	-	-	-	-	326	321	324	-	-	-	-
24	-	-	524.14	-	-	-	-	290.82	287.01	-	-	-
25	-	-	454.21	-	388	-	-	291.18	-	-	-	-
26	-	-	-	353.62	403	-	-	297.77	-	-	-	-
27	-	-	-	382.1	422	-	332	-	-	-	-	-
28	-	-	-	378	401.81	312.69	341	-	-	-	-	-
29	-		366.22	377.51	-	-	-	-	-	-	-	-
30	-		333	373	-	311	340	290	-	-	-	-
31	-		376.04		354	310.38	-	-		-		-

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SMHI

Swedish Meteorological and Hydrological Institute
SE 601 76 Norrköping, Sweden.
Tel +46 11-495 80 00. Fax +46 11-495 80 01

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