İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

RECENT STRATOSPHERIC OZONE MEASUREMENTS OVER ANKARA AND EVALUATION OF OZONE PROFILES

M.Sc. Thesis by
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Department : Meteorological Engineering

Programme : Atmospheric Sciences

NOVEMBER 2008

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

ANKARA ÜZERİNDEKİ SON STRATOSFERİK OZON ÖLÇÜMLERİ VE OZON PROFİLLERİNİN DEĞERLENDİRİLMESİ

YÜKSEK LİSANS TEZİ
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PREFACE

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September 2008 **Özlem Özkızılkaya**

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ECC : Electrochemical concentration cell
WMO : World Meteorological Organization
TOMS : Total Ozone Mapping Spectrometer
SAGE : Stratospheric Aerosol and Gas Experiment
OMI : Ozone Monitoring Instrument
MSG : Meteosat Second Generation
SEVIRI : The Spinning Enhanced Visible and InfraRed Imager
GOME : Global Ozone Monitoring Experiment
TSMS : Turkish State Meteorological Service
DU : Dobson Unit
$\Delta\Omega_S$: Total ozone from the sounding
$\Delta\Omega_R$: Residual total ozone
ε_3 : Ratio of molecular masses of ozone and air
g : Acceleration of gravity
$p_i \ldots p_{i+n}$: Ambient pressure, [hPa]
i : Index for a measurement point
$p_{3i} \ldots p_{3i+n}$: Ozone partial pressure [mPa]
M3 : Molar mass of ozone

RECENT STRATOSPHERIC OZONE MEASUREMENTS OVER ANKARA AND EVALUATION OF OZONE PROFILES

ABSTRACT

Ozone is measured by various methods having different technologies. Once ground-based systems and after ozonsonde and advanced satellite technology provide important progresses in ozone measurements. With these improvements, in ozone wathcing programs resolution, spatial and temporal continuity, accuracy of the meaasurements become more important to better understand the global variation and tropospheric and stratospheric variations of ozone

In Turkey, ozone monitoring is carried out primarily by Turkish State Meteorological Service (TSMS) at Ankara twice a month since 1994 using ECC ozonesonde. Also, in order to measure total column ozone at Ankara, Brewer MK III instrument has been operated by TSMS since November 2006. Being the only Brewer in Turkey, it forms an integral part of the WMO ozone monitoring network.

In this study, Brewer(MKIII) spectrophotometer, AURA/OMI and MSG/SEVIRI satellites total ozone data between the period January 2007 to Decemeber 2007 are used to investigate total ozone amounts over Ankara. According to the comparisons, it is found that Brewer and OMI data show good agreement, however MGS data values are greater when compared with Brewer and OMI. To verify these findings, ECC ozonsonde data for 2007 are used. All the ozonesonde data within the period under operation for which Brewer, OMI and MSG data were available for the corresponding days were taken into account. In total 21 total ozone measurements in the January 2007-December 2007 period were used. According to the results, Brewer and OMI data are closer to ECC data but MSG data are greater than ECC data.

To examine the vertical structure of total ozone, an algoritkm which is used to derive total ozone from ECC sounding is applied to tropophere and stratosphere. According to the results of the calculations is has been seen that upper stratospheric ozone compose the biggest part of total ozone and variation of ozone in the atmosphere is strongly dependent on dynamic and thermal processes.

ANKARA ÜZERİNDEKİ SON STRATOSFERİK OZON ÖLÇÜMLERİ VE OZON PROFİLLERİNİN DEĞERLENDİRİLMESİ

ÖZET

Ozon halen teknolojisi birbirinden farklı pek çok yöntemle ölçülmektedir. Önce yere dayalı sistemler ve daha sonra da uçaklar ve ozonsondeler yanı sıra uydu teknolojilerinde meydana gelişmelere paralel olarak uydularla ozonun ölçülmesinde önemli ilerlemeler sağlanmıştır. Bu gelişmelerle beraber ozonun hem küresel hem de troposfer ve stratosfer içerisindeki değişimlerin anlaşılması bakımından yapılan izleme programlarında çözünürlük, yersel ve zamansal süreklilik doğruluk vb özellikler önem kazanmaktadır.

Türkiye'de toplam ozon ölçümleri DMİ tarafından Ankara'da (40^{o}N; 33^{o}E), Ocak 1994'den itibaren ECC ozonsonde ile ayda iki kez yapılmaktadır. Ayrıca, Ankara'daki toplam ozon miktarının ölçülebilmesi amacı ile DMİ Kasım 2006'da Brewer MK III spektrofotometresini işletime almıştır. Türkiye bulunan bu tek Brewer cihazı Dünya Meteoroloji Örgütü'nün (WMO) ozon görüntüleme ağının bir parçasını oluşturmaktadır.

Bu çalışmada, Ankara üzerindeki toplam ozon değişimlerini araştırmak üzere Ocak 2007 – Aralık 2007 dönemindeki ECC, Brewer MKIII ile OMI ve MSG uydularından elde edilen toplam ozon değerleri karşılaştırılmıştır. Yapılan karşılaştırma sonucuna göre Brewer ölçümleri ile OMI ölçümlerinin birbire yakın değerler gösterdiği, MSG uydusunun ölçümlerinin ise Brewer ve OMI ölçümlerinden daha fazla olduğu ortaya konmuştur. Bu bulguları doğrulamak için, 2007 senesine ait toplam 21 adet ECC ozonsonde ölçümü kullanılmıştır. Ozonsonde verilerinin alındığı her gün için o günlere karşılık gelen Brewer, OMI ve MSG verileri değerlendirmeye alınmış ve toplam ozon değerleri karşılaştırılmıştır. Elde edilen sonuçlara göre Brewer ve OMI verilerinin ECC verilerine yakın değerler gösterdiği, MSG verilerinin ise ECC'den fazla olduğu ve bu nedenle iki ölçüm arasında belirgin bir farklılık olduğu saptanmıştır.

Toplam ozonun düşey yapısını incelenmek için, ECC verilerinden toplam ozon elde edilmesinde kullanılan algoritma troposfer ve stratosfere ayrı ayrı uygulanmıştır. Yapılan hesaplar sonucunda, yukarı stratosferik ozonun toplam ozonda en büyük paya sahip olduğu ve ozonun atmosferdeki değişiminin dinamik ve termik proseslere son derece bağlı olduğu görülmüştür.

1. INTRODUCTION

Ozone is a minor atmospheric constituent with particular physical and chemical properties. Among these, the strong absorption of UVB is very important for the biosphere. Indeed, ozone in the stratosphere is an effective protective shield against damaging radiation of the sun in this spectral region. After the discovery of the potential influence of human activities on the ozone layer, efforts have been made to understand the dynamical and chemical properties of atmospheric ozone. Better understanding of the behaviour of ozone in the atmosphere may also help to improve the performance of general atmospheric circulation models, used among others for weather prediction and climate modelling. To achieve these aims high quality measurements of the distribution (in space and time) of atmospheric ozone are needed.[1]

Ozone observation history began in 1860, surface ozone started to be measured at hundreds of locations. Then in 1920, first quantitative measurements of the total ozone content were done. In 1926, six Dobson ozone spectrophotometers are distributed around the world for regular total ozone column measurements. In 1934, ozone sonde on balloon confirms maximum concentration at about 20 km. In 1964, first ever satellite for total ozone measurement launched by US Department of Defense. In 1966, first total ozone measurements from satellites. In 1978, NASA's Nimbus-7 launched carrying ozone and other atmospheric instruments. In 1982, the US's NOAA commits to operational stratospheric ozone monitoring on polar orbiting satellites (POESS followed by NPOESS). In 1984, NASA-SAGE I: Stratospheric ozone profile measurements through solar occultation and in 1991, NASA's Upper Atmospheric Research Satellite launched. In 1995, European Space Agency launches first mapping hyperspectral instrument (GOME) on ERS-2 to measure atmospheric composition. In 1996, Japan launches the ADEOS series and plans follow on GCOM missions to measure ozone and atmospheric chemistry. In 1997, first Limb-scatter measurements of ozone are done throughout the Stratosphere from Space Shuttle.[2]

The abundance of ozone in the atmosphere is measured by a variety of techniques. The techniques make use of ozone's unique optical and chemical properties. One group of instruments is dedicated mainly to determine the ozone column density, the total amount of ozone found in a column from the ground to the top of the atmosphere at a certain location. This quantity is measured from the ground by spectroscopy in the UV part of the spectrum with the Dobson and Brewer instruments, in the visible by SAOZ or in the infrared by FTIR instruments. It may be noted that the UV technique is considered as a reference. Also from satellites, total ozone is determined by the measurement of backscattered light at different spectral resolutions and ranges [3-6].

These measurements give no information on the vertical distribution of ozone in the atmosphere. With the Umkehr technique it is possible to retrieve ozone profiles with a limited number of layers (up to 9) with the Dobson and Brewer instruments. With lidar instruments it is possible to get a better height resolution, but their height range is restricted, and meteorological observation constraints may introduce a bias. Measurements of the vertical distribution are also performed from space, either by the limb scanning or occultation techniques. By the measurement of high resolution backscattered spectra it is hoped to obtain also information on the vertical distribution of trace gases [1-6].

Satellite, Brewer spectrophotometer and ozonsonde measurement systems are widely used in the world to determine total column of ozone and the properties of ozone in the troposphere and the stratosphere. The differences between satellite, Brewer and ECC measurements are popular research area in literature in terms of their techniques and result [7].

The present study deals with the comparison of Aura/OMI, MSG/SEVIRI satellites, Brewer MKIII and ECC (Electrochemical Concentration Cell) total ozone measurements of over Ankara ($39^{o}55'N$; $32^{o}55'E$) and also tropospheric and stratospheric behaviour of total ozone.

In the next chapter of the study ozone and its properties will be presented then in the third chapter the ozone measurement techniques will be given. In chapter 4, comparisons and results of the study will be explained. In the final chapter the conlusion and suggestions will be introduced.

2. OZONE

Ozone plays a key role in atmospheric chemistry and the radiative balance of the atmosphere. In the stratosphere it is the main absorber of ultraviolet radiation. This absorption is responsible for the increasing temperature above the tropopause. In the lower stratosphere and upper troposphere it becomes a powerful greenhouse gas and forcing function for climate change. In the lower troposphere it is a pollutant and is created through complex chemical reactions with anthropogenic gases and sunlight [8,9]

Ozone (O_3) is a relatively unstable molecule made up of three atoms of oxygen (O). It is blue in color and has a strong odor. Normal oxygen, which we breathe, has two oxygen atoms and is colorless and odorless. Ozone is much less common than normal oxygen. Out of each 10 million air molecules, about 2 million are normal oxygen, but only 3 are ozone. It only makes up 0.00006% of the atmosphere. Although it represents only a tiny fraction of the atmosphere, ozone is crucial for life on Earth [8,9].

Depending on where ozone resides, it can protect or harm life on Earth. Most ozone resides in the stratosphere, where it acts as a shield to protect Earth's surface from the sun's harmful ultraviolet radiation. Closer to Earth in the troposphere, ozone is a harmful pollutant that causes damage to lung tissue and plants [9].

2.1 Stratospheric Ozone

Most ozone resides in the stratosphere (a layer of the atmosphere between 10 and 40 km above the ground), where it acts as a shield to protect Earth's surface from the sun's harmful ultraviolet radiation.

As shown in the Figure 2.1, most atmospheric ozone is concentrated in a layer in the stratosphere about 15-30 kilometers above the Earth's surface.

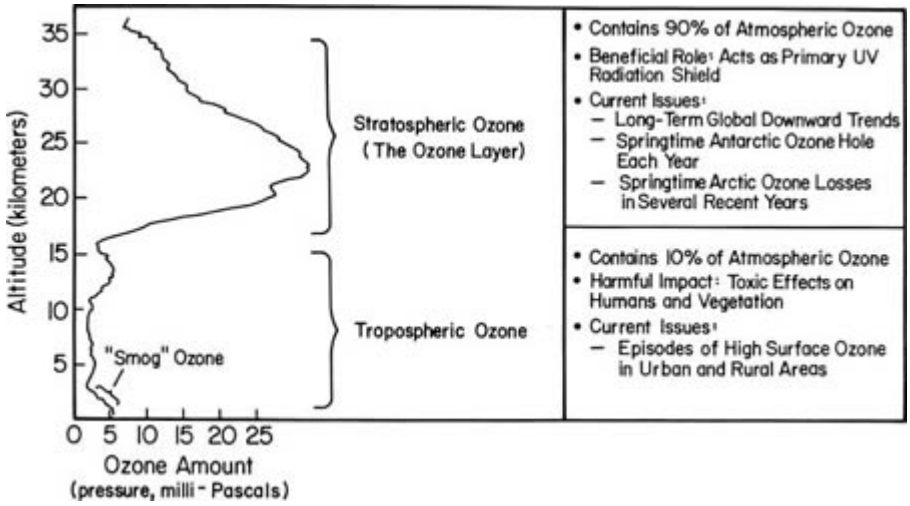

Figure 2.1: Vertical Ozone Profile

However, even the small amount of ozone plays a key role in the atmosphere. The ozone layer absorbs a portion of the radiation from the sun, preventing it from reaching the planet's surface. Most importantly, it absorbs the portion of ultraviolet light called UVB. UVB has been linked to many harmful effects, including various types of skin cancer, cataracts, and harm to some crops, certain materials, and some forms of marine life [8-10].

At any given time, ozone molecules are constantly formed and destroyed in the stratosphere. The total amount, however, remains relatively stable. The concentration of the ozone layer can be thought of as a stream's depth at a particular location. Although water is constantly flowing in and out, the depth remains constant [8-10].

While ozone concentrations vary naturally with sunspots, the seasons, and latitude, these processes are well understood and predictable. Scientists have established records spanning several decades that detail normal ozone levels during these natural cycles. Each natural reduction in ozone levels has been followed by a recovery. Recently, however, convincing scientific evidence has shown that the ozone shield is being depleted well beyond changes due to natural processes [8-10].

2.2 Tropospheric Ozone

Ozone (O_3) is a key constituent of the troposphere. Photochemical and chemical reactions involving it drive many of the chemical processes that occur in the atmosphere by day and by night. At abnormally high concentrations brought about

by human activities (largely the combustion of fossil fuel), it is a pollutant, a constituent of smog. Many highly energetic reactions produce it, ranging from combustion to photocopying. Ozone is a powerful oxidizing agent readily reacting with other chemical compounds to make many possibly toxic oxides.

The troposphere extends to between 10 and 18 kilometers above the surface of the Earth and consists of many layers. Ozone is more concentrated above the mixing layer, or ground layer. Ground-level ozone, though less concentrated than ozone aloft, is more of a problem because of its health effects.

Tropospheric ozone is a greenhouse gas and initiates the chemical removal of methane and other hydrocarbons from the atmosphere thus its concentration affects how long these compounds remain in the air [10,11].

3. OZONE MEASUREMENTS

Knowledge of the distribution of ozone is important to the operational meteorological community both through its role as a contributor to the Earth's radiative balance and through its use as a motion tracer. Advances in meteorological modelling are demonstrating that the inclusion of ozone can lead to improved weather and climate forecasts and, as a result, ozone is beginning to be assimilated in meteorological models. Operational agencies are also increasingly being asked to predict levels of ultraviolet radiation reaching the surface; knowledge of ozone amounts is essential for this purpose [1,2].

It is clear that knowledge of ozone concentrations and its distribution is of fundamental importance given the pivotal role ozone plays in the climate system. Human-induced changes in ozone levels combine to make the accurate long term measurement of ozone a priority for policy makers as well as for the scientific and environmental communities. This places strict demands on measurement systems as they have to be capable of characterising long term trends in the presence of the very large variability that exists on several temporal scales. Better understanding of the behaviour of ozone in the atmosphere may also help to improve the performance of general atmospheric circulation models, used among others for weather prediction and climate modelling. To achieve these aims high quality measurements of the distribution (in space and time) of atmospheric ozone are needed [1,2].

A number of the existing programmes have already been specifically designed to make long term observations of ozone and related parameters including:

- The ground-based Dobson/Brewer/Umkehr network for total ozone and ozone profile measurements, as well as the other surface-based measurements associated with the Global Atmosphere Watch (GAW) network of the World Meteorological Organization

- The ground-based remote-sensing network of instruments associated with the internationally sponsored Network for Detection of Stratospheric Change (NDSC)
- Surface-based in-situ sampling associated with several nationally-operated (but globally distributed) programmes (under the umbrella of WMO-GAW) designed to determine surface-level concentrations of long-lived trace gases
- The balloon-based ozone sonde network of the WMO-GAW and NDSC programmes
- Operational space-based measurement programmes involving mainly the US (TOM, SAGE and measurement programmes and multiple instruments on different platforms sequentially in time. NPOESS) and Europe (ERS-2 and METOP), which include both long term

Ozone measurements can be generally classified into non-satellite and satellite measurement. Non satellite measurements are in-situ measuremens like balloon-borne ozonesondes, airborne UV absorption instruments and ground-based remote sensing measurements such as Brewer, Dobson-Umkehr, lidar and microwave spectrometers. Satellite measurements consist of remote sensing techniques using sensors such as HALOE, MLS, SBUV and SAGE [2].

3.1 In-Situ Ozonsonde Measurements

Ozonesondes, flown with large weather balloons, measure height-resolved profiles of atmospheric ozone from the surface up to the 30-35 km range in the middle stratosphere. They operate regularly in all climatic regions and under severe weather conditions. They have been the backbone of ozone profiling since the 1960s.The observations derived from ozone sondes are of a very high vertical resolution which is unattainable by any of the existing satellite techniques [12,13]

There are about 50 locations around the world that make regular (approximately weekly) ozone vertical profile measurements using ozonesondes (Figure 3.1). For example, four stations in USA, four stations in Canada, three stations in China measure ozone profiles by using ozonesonde. In the world 35 ECC, 8 BM, 6 Japon, 2

India and one OBE sonde systems have been operating. There exist EU supported 32 stations which provide data to Norway based NILU data system.

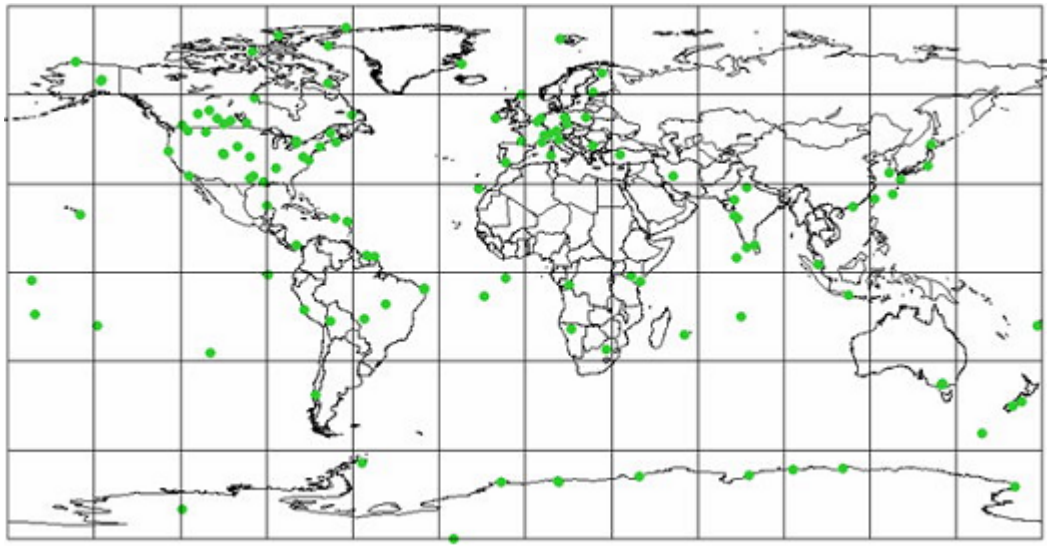

Figure 3.1: ECC measurement stations around the world

Ozonsondes consist of a pump and ozone sensing cell coupled to a standard meteorological radiosonde through an electronics interface. The information from the ozonesonde is telemetered to the ground through the radiosonde transmitter. The parameters normally measured are the ozone concentration, ambient air pressure, temperature, humidity, and, in some cases, the wind direction and speed. Each sounding is made with an individual disposable instrument.

The three sonde types are generally used for ozone measurements. These are, the electrochemical concentration cell (ECC), the Brewer-Mast (BM) and the Japanese ozonesonde (KC). In this study, the electrochemical concentration cell (ECC) measurements is used. [12,13]

3.1.1 Electrochemical Concentration Cell (ECC) Ozonesonde

The ECC ozonesonde was developed by Komhyr. The ECC ozone sensor is an electrochemical cell consisting of two half cells, made of Teflon, which serve as cathode and anode chamber, respectively. Both half cells contain a platinum mesh serving as electrodes (Figure 3.2). They are immersed in KI (potassium iodide) solution of different concentrations. The two chambers are linked together by an ion

bridge in order to provide an ion pathway and to prevent mixing of the cathode and anode electrolytes [13, 14].

The ECC does not require an external electrical potential. The ECC gets its driving electromotive force from the difference in the concentration of the KI solution in the cathode and anode chamber, 0.06 Mol/l (1%KI) and 8.0 Mol/l (saturated KI) respectively. A non-reactive gas sampling pump, made of Teflon, forces ozone (flow ~220 sccm/min.) in ambient air through the cathode cell with the lower concentration of KI solution causing an increase of free iodine (I_2) according to the redox reaction . At the surface of the Pt cathode, I_2 will be converted to I- through the uptake of two electrons, while at the anode surface, I- is converted to I_2 through the release of two electrons [13, 14].

Ozonesonde measurements are the most accurate means of determining at what heights ozone variations are occurring. The detection limit of the instrument is less than 2 parts per billion. Measurement uncertainty is about 10% in the troposphere, 5% in the stratosphere up to 10 hPa and about 25% above that. In Figure 3.3 an ozone profile of ECC ozone sounding is given.

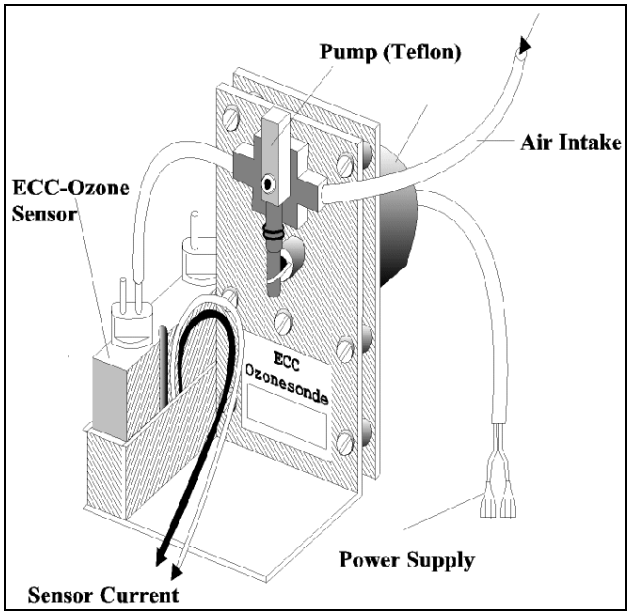

Figure 3.2: Ozondesonde

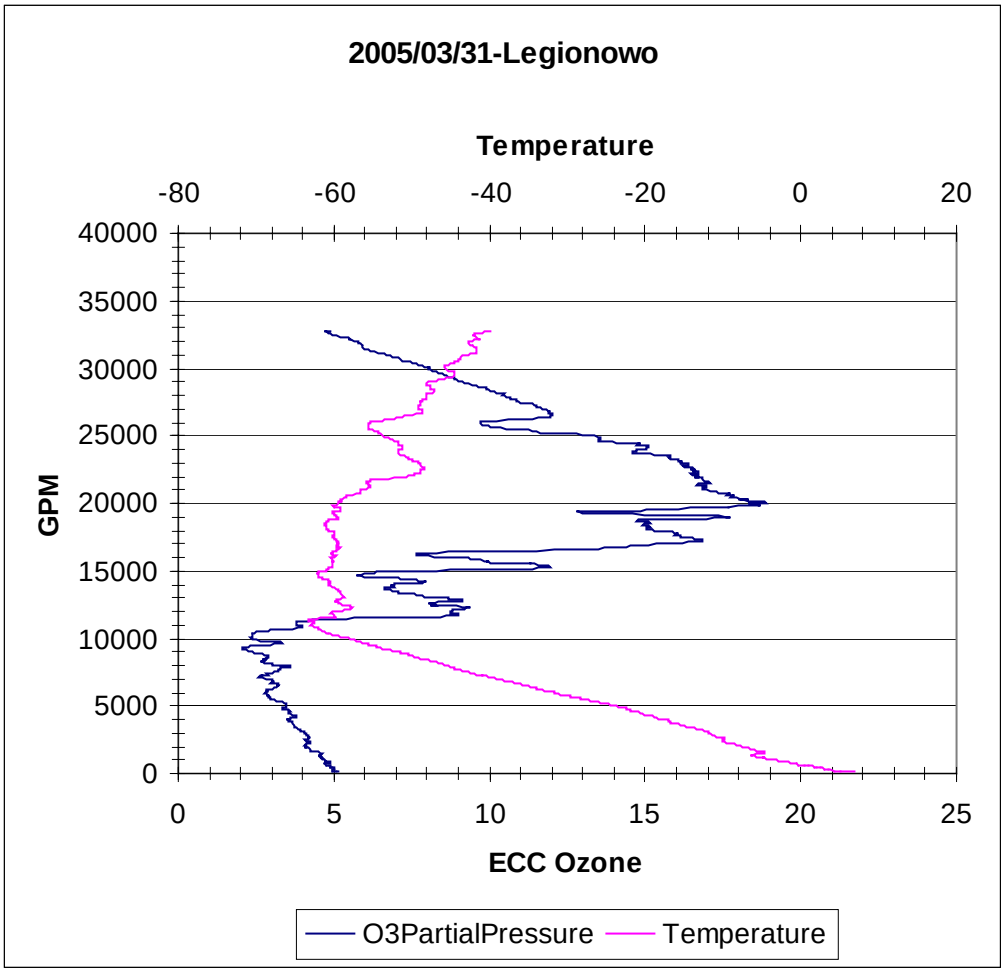

Figure 3.3: ECC Ozone Profile

3.2 Ground Based Remote Measurements

Ground-based instruments measure the ozone profile on a routine basis by using remote-sensing techniques. Measurements of solar UV light from the zenith sky during twilight made by a Dobson or Brewer ozone spectrophotometer are used to determine ozone profiles using the Umkehr inversion method. Ultraviolet LIDAR systems were developed in the 1980s and have been in operation at several sites since. Ground-based LIDAR instruments, as well as the microwave instruments, operate from inside a laboratory. Measurements are usually made on the zenith sky through a roof hatch or dome. In some instances, LIDAR measures in other directions by pointing the laser beam and detector. LIDAR instruments must be located in such a way as to avoid interference from other UV sources, and microwave instruments must avoid interference which may come from microwave

radio transmitters. The LIDAR technique is usually limited to operating at night when there is not an appreciable amount of cloud cover. A profile measurement is derived from the integration of many laser shots taken over a period of several hours [15-16].

3.2.1 Lidar

Lidars are used to obtain profiles of atmospheric variables in both the stratosphere and troposphere with one to two kilometer resolution. In the stratosphere they are used to measure profiles of ozone and temperature at over 15 locations world wide. These instruments produce valid data in the range of 15-50 km for ozone and up to 80 km for temperature.

They are used primarily to measure tropospheric ozone profiles and, at some stations, water vapour profiles in the upper troposphere. Lidars also make important contributions to the long term observation of stratospheric aerosols. An international lidar network has been developed which provides very extensive spatial coverage, although as with all ground-based instruments, measurements are restricted to land-covered areas. Observations from developing countries and remote territories are much fewer than from more populated, developed areas [15-16].

3.2.2 Microwave

Microwave Radiometers are used to observe ozone profiles from the stratosphere up to the mesosphere and are able to make measurements under most weather conditions. Microwave radiometers measure the thermal radiation of a pressure broadened ozone emission line. The line width depends on pressure and temperature and is used to determine the altitude of the emitting gas. The measurement height extends from ~20km to 75km. In contrast to lidars, microwave radiometers are not strongly weather dependent and measure during daylight. Microwave profiles are measured on about 20 days per month. The integration time of one microwave profile varies from ~30 minutes to 4-5 hours according to the individual instrument [15-16].

Microwave observations of diurnal variations and at the South Pole have been particularly important as such instruments can also be used to make measurements of

a range of trace constituents, the most important of which are H2O and ClO, as well as long-lived molecules like N2O. The vertical resolution of these instruments is typically fairly broad (5-10 kilometers) which places constraints on the usefulness of their data in regions of strong vertical gradients [15,16].

3.2.3 Dobson Spectrophotometer

The Dobson Spectrophotometer measures total column ozone from the ground to the top of the atmosphere in a column by measuring the amount of sunlight reaching Earth's surface in the region of the electromagnetic spectrum where ozone absorption occurs. This absorption by ozone occurs in the 290 to 320 nanometer wavelength region. It is the ultraviolet-B (UV-B) region. Since the presence of clouds, pollution, and aerosols (such as smoke) also affect the amount of light (shortwave radiation) reaching the ground, a region of the spectrum where ozone does not absorb is also simultaneously measured [2].

3.2.4 Brewer Spectrophotometer

The Brewer ozone spectrophotometer is a scientific instrument that measures UV radiation in the solar spectrum. By examining the differential absorption of selected wavelengths in the UVB portion of the spectrum, determinations of the total column ozone and total column sulfur dioxide can be inferred. In addition, the accurate spectral intensity profiles of UVB radiation in the range 290 nm to 325 nm are measured. The Brewer ozone spectrophotometer system is composed of a spectrophotometer, a solar tracker, and computer controlling the instruments and data logging software. The Brewer ozone spectrophotometer is supplied with a complete set of programs that control all aspects of data collection and some analysis [17].

The Brewer spectrophotometer measures ozone based on the same technique as the Dobson instrument. Unlike the Dobson instrument, however, the Brewer spectrophotometer is completely automated and can be programmed by a computer to make measurements at any given time during the day. Most Brewer instruments are programmed to take measurements at regular observation times. (This takes into account the angle of the Sun.) The instrument measures ultraviolet light at five wavelengths (306, 310, 313, 317, 320 nm). The total column ozone amount is calculated by using a more complicated form of equation used for the Dobson

instrument that includes terms for sulfur dioxide. The absolute accuracy for a total ozone measurement made by a well calibrated Brewer instrument is estimated to be +/- 2.0% [10].

Since the first World Meteorological Organization (WMO) consultation meeting in Arosa, many Brewer Spectrophotometers have been installed all over the world. In Figure 3.4, Brewer measurement stations around the world is given. The addition of Brewer Spectrophotometers to the Global Ozone Monitoring Network strengthened ground observations of total ozone, which have long been carried out by Dobson Spectrophotometers. Comparing against the Dobson, the Brewer has strengths and weaknesses. The Brewer is fully automatic and the daily observation schedule can be programmed. Hence stations located at remote monitoring sites which have little manpower or expertise can also contribute to WMO routine observations. Another strength of the Brewer is that it is more versatile. It can perform UV spectral scanning and report UV index, SO_2 column and aerosol optical depth (AOD). On the other hand, the Brewer is more difficult to maintain due largely to its being installed outside in all weather conditions. As for other spectrophotometers, it is sensitive to humidity. Regular replacement of desiccant allows operating a Brewer at a stable calibration even under humid conditions. At present, about 200 Brewers have been sold in the world but the number of stations reporting Brewer total ozone data to the World Ozone and Ultraviolet Radiation Data Center (WOUDC) is less than 50 [18].

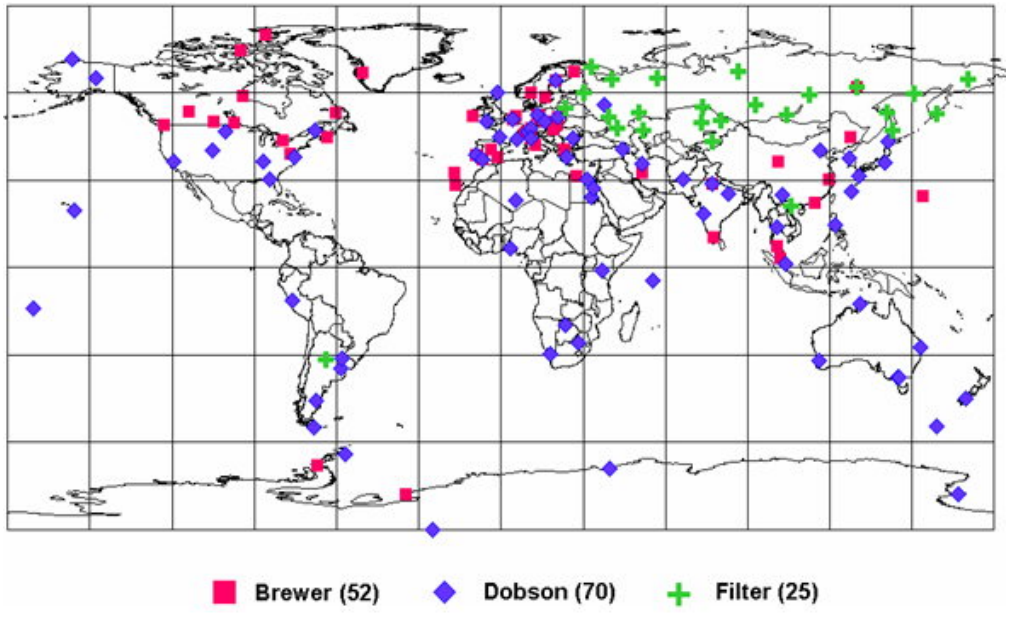

Figure 3.4: Brewer measurement stations around the world

The Brewer spectrophotometer was originally designed for total ozone measurements. Total ozone is derived by comparing direct Sun signals measured at the wavelengths of 306.3, 310.1, 313.5, 316.8, and 320.1 nm. The retrieval scheme is similar to that used for the Dobson spectrophotometer; the derived total ozone values are independent of the aerosol amount and of the absolute instrumental responsivity. The Brewer spectrophotometer is also capable to measure spectral ultraviolet irradiance, detected through a teflon diffuser enclosed in a quartz dome [19].

The Brewer MKIII is a double monochromator spectrometer: a substantial improvement in the quality of UV measurements below 305 nm with respect to the single-monochromator measurements, due to the better stray light suppression, has been achieved with this spectrometer. The instrument measures hemispheric UV irradiances betwen 286 and 363 nm through the teflon diffuser collector; spectral resolution is around 0.55 nm, and measurements are recorded at every 0.5 nm interval. The uncertainty on the observed irradiance is estimated to be around 4–5%. The uncertainty on total ozone, for cloud-free conditions, is around 1%. A method to derive aerosol optical depth from the Brewer direct Sun regular ozone measurements has been also implemented [20].

Figure 3.5: Brewer MK III Spectrophotometer

The total ozone amount in the atmosphere is measured with the Brewer ozone spectrophotometer in terms of the thickness of the layer that would have been formed by the entire ozone of the atmosphere and is reduced to a standard pressure of 1013

hPa and a standard temperature of $0^{\circ}C$. The quantity 10^{-3}cm STP is defined as Dobson Unit (DU)

3.3 Satellite Measurements

Large-scale monitoring of atmospheric ozone is performed by remote-sensing instruments from satellites. These programmes can be divided according to lifetime into the long-term operational monitoring systems that generate large (global) data sets used both for trend analyses and for operational mapping of ozone, and into temporary experimental missions.

The satellite instruments can be grouped according to the technology of detection of the radiation to be used for determination of ozone. In one group there are nadir-viewing instruments that scan scattered UV radiation, to specifically derive total ozone. Instruments of another group measure vertical profiles of ozone by solar, lunar, or stellar occultation in different parts of the spectrum, or by scanning microwave thermal emissions through the atmospheric limb [15].

Since 1978 when the first ozone space observations started with the Total Ozone Mapping Spectrometer (TOMS) instrument (Heath, Krueger and Park, 1978) much progress has been achieved in monitoring ozone from space. After that, Stratospheric Aerosol and Gas Experiment (SAGE) III, NASA's National Polar-Orbiting Operational Environmental Satellite System (NPOESS), The European Space Agency's ENVISAT-1, The European Space Agency and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) like such as MSG and MetOp, National Space Development Agency of Japan (NASDA) ADEOS-II (short for Advanced Earth Observing Satellite-II) satellites have been launched and since that time and several others are scheduled for the coming decade. Also the technologies and parameters of these space-borne systems have been improved with respect to vertical and horizontal resolution, spectral resolution, algorithms for processing the observations, and number of atmospheric species monitored [15].

Satellite based instruments such as the Solar Backscatter Ultraviolet spectrometer, the Total Ozone Mapping Spectrometer (TOMS), the Global Ozone Monitoring Experiment, and the Ozone Monitoring Instrument (OMI) onboard the Earth Observing System Aura satellite have greatly extended our knowledge of ozone's

global distribution. However, these instruments use backscattered solar UV light and, thus, cannot measure ozone at night. Moreover, these polar-orbiting platforms are limited in their temporal coverage at low to middle latitudes. Another approach is to use brightness temperatures (BTs) measured by infrared (IR) detectors onboard low Earth orbit or geostationary satellites. The Spinning Enhanced Visible and InfraRed Imager (SEVIRI) onboard MSG (METEOSAT 8), which was launched on August 28, 2002, is the best available proxy for testing the total ozone [21].

In this chapter, Aura (OMI), MSG (SEVIRI) and MetOp (GOME2) satellites ozone measurement techniques will be explained.

3.3.1 Aura

Aura (Latin for breeze) was launched July 15, 2004. The design life is five years with an operational goal of six years. Aura is part of the Earth Science Projects Division, a program dedicated to monitoring the complex interactions that affect the globe using NASA satellites and data systems.

Aura's four instruments study the atmosphere's chemistry and dynamics. Aura's measurements enable to investigate questions about ozone trends, air quality changes and their linkage to climate change.

The Aura spacecraft was launched into a near polar, sun-synchronous orbit with a period of approximately 100 minutes. The spacecraft repeats its ground track every 16 days to provide atmospheric measurements over virtually every point on the Earth in a repeatable pattern, permitting assessment of atmospheric phenomena changes in the same geographic locations throughout the life of the mission.

The Aura spacecraft is designed for a six-year lifetime. The spacecraft orbits at 705 km in a sun-synchronous orbit (98^{o} inclination) with a 1:45 PM ±15 minute equator crossing time. Aura limb instruments are all designed to observe roughly along the orbit plane. MLS is on the front of the spacecraft (the forward velocity direction) while HIRDLS, TES and OMI are mounted on the nadir side.

EOS Aura's Instruments OMI, HIRDLS, MLS, TES contain advanced technologies that have been developed for use on environmental satellites. Each instrument provides unique and complementary capabilities that will enable daily global

observations of Earth's atmospheric ozone layer, air quality, and key climate parameters [22].

3.3.1.1 OMI

The Ozone Monitoring Instrument (OMI), a contribution of the Netherlands Agency for Aerospace Programs (NIVR) in collaboration with Finnish Meteorological Institute (FMI) to the Nationa Aeronautics and Space Administration's (NASA) Aura mission, is orbiting the Earth on the Aura spacecraft. Aura is part of NASA's long-term Earth Observing System (EOS) mission and was launched in July 2004 from Vandenberg Air Force base in California into a polar sun-synchronous orbit [23].

The OMI instrument is a nadir-viewing imaging spectrometer that measures the solar radiation backscattered by the Earth's atmosphere and surface over the entire wavelength range from 270–500 nm, with a spectral resolution of about 0.5 nm. The spectral sampling distance ranges from 0.15–0.3 nm/pixel, depending on wavelength. In OMI a scrambler is used to depolarize the radiation. The 114 viewing angle of the telescope perpendicular to the flight direction corresponds to a 2600-km-wide swath on the Earth's surface, which enables measurements with a daily global coverage. In the normal operation mode, the OMI pixel size is 13 km to 24 km at nadir (along across track); however, in the zoom mode the spatial resolution can be reduced to 13 km to 12 km [23].

OMI ozone data are retrieved using both the TOMS technique developed by NASA and a differential optical absorption spectroscopy (DOAS) technique developed by KNMI. Both algorithms provide OMI ozone data of the same quality as TOMS ozone data in order to ensure continuity of ozone trends detected to date. The longterm goal is to eliminate any bias between the two algorithms. Experience with TOMS and DOAS suggests that the algorithms are capable of producing total ozone with an rms error of about 2%, though these errors are not identical and necessarily randomly distributed over the globe [23].

The NASA OMI algorithm is the TOMS Version 8 algorithm applied to OMI. This version uses only two wavelengths (317.5 and 331.2 nm) to derive total ozone. Four other TOMS wavelengths are used for diagnostics and error correction. V8 was used to reprocess all SBUV and TOMS total ozone data taken since April 1970. Therefore, it is being applied to OMI to ensure continuity of the data record. This

algorithm will remain in operation until an algorithm is developed that is demonstrated to be more accurate because it uses the enhanced capabilities of OMI.
The KNMI total ozone algorithm is based on the DOAS technique that has been widely used to measure trace gases from ground. It has been applied successfully to process data from the GOME and SCIAMACHY instrument that are currently flying on the European Remote Sensing 2 (ERS-2) and ENVISAT satellites. This ozone column is estimated from longer wavelengths than those used in the TOMS algorithm. In principle, DOAS is less sensitive to disturbing effects by absorbing aerosols, SO , and calibration errors than the TOMS algorithm. The OMI DOAS algorithm uses a different spectral window (331.6–336.6 nm) to GOME and SCIAMACHY, chosen such that the retrieval does not depend on external information of atmospheric temperatures [23].

3.3.2 MSG (Meteosat Second Generation)

The first of the new generation of Meteosat satellites, known as Meteosat Second Generation (MSG), was launched in August 2002 from the Kourou launch site in French Guiana. Figure 3.6 shows a picture of the satellite. MSG-1 became operational on 29 January 2004, when it was redesignated Meteosat-8. Since then it has continuously returned highly detailed imagery of Europe, the North Atlantic and Africa every 15 minutes, for operational use by meteorologists. The second MSG was launched on 21 December 2005 on the type of launcher as its predecessor. It is currently in the same fixed section of orbital space as MSG-1 in geostationary orbit. The reason for the duplication is simply to guarantee continuity of service in case of satellite failure. Weather satellites have become so crucial a part of daily life that any long gap in service coverage has become inconceivable [24,25].

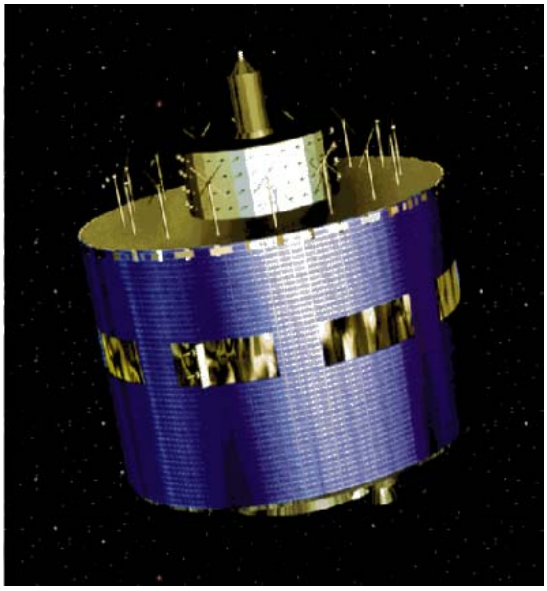

Figure 3.6: The first MSG satellite

The primary mission of the second-generation Meteosat satellites is the continuous observation of the Earth's full disk with a multi-spectral imager. The satellite's 12 channel imager, known formally as the spinning enhanced visible and infrared imager (SEVIRI) observes the full disk of the Earth with an unprecedented repeat cycle of 15 minutes in 12 spectral wavelength regions or channels. For comparison, the first-generation Meteosat satellite covers only three spectral channels and has an imaging repeat cycle of 30 minutes [25].

3.3.2.1 Spinning Enhanced Visible and Infra-red Imager (SEVIRI)

The main MSG instrument is called the Spinning Enhanced Visible and Infrared Imager (SEVIRI). SEVIRI has eight spectral channels in the thermal infrared (IR), three channels in the solar spectrum, and a broadband high resolution visible channel. Table 3.1 provides more details of the characteristics of these channels, and indicates how each channel is used. Figure 3.7 and 3.8 show the location of the SEVIRI bands on top of a solar and typical thermal energy spectrum, respectively. The ozone channel is a novel feature on a geostationary imaging instrument and provides information on the total ozone content of the atmosphere. It is also useful for observing the dynamics of the stratosphere and the height of the tropopause layer [24,25].

Table 3.1: Spectral channel characteristics of SEVIRI in terms of central, minimum and maximum wavelength of the channels and the main application areas of each channel.

Channel No.	Spectral Band (μm)	Characteristics of Spectral Band (μm)			Main observational application
		λ_{cen}	λ_{min}	λ_{max}	
1	VIS0.6	0.635	0.56	0.71	Surface, clouds, wind fields
2	VIS0.8	0.81	0.74	0.88	Surface, clouds, wind fields
3	NIR1.6	1.64	1.50	1.78	Surface, cloud phase
4	IR3.9	3.90	3.48	4.36	Surface, clouds, wind fields
5	WV6.2	6.25	5.35	7.15	Water vapor, high level clouds, atmospheric instability
6	WV7.3	7.35	6.85	7.85	Water vapor, atmospheric instability
7	IR8.7	8.70	8.30	9.1	Surface, clouds, atmospheric instability
8	IR9.7	9.66	9.38	9.94	Ozone
9	IR10.8	10.80	9.80	11.80	Surface, clouds, wind fields, atmospheric instability
10	IR12.0	12.00	11.00	13.00	Surface, clouds, atmospheric instability
11	IR13.4	13.40	12.40	14.40	Cirrus cloud height, atmospheric instability
12	HRV	Broadband (about 0.4 – 1.1 μm)			Surface, clouds

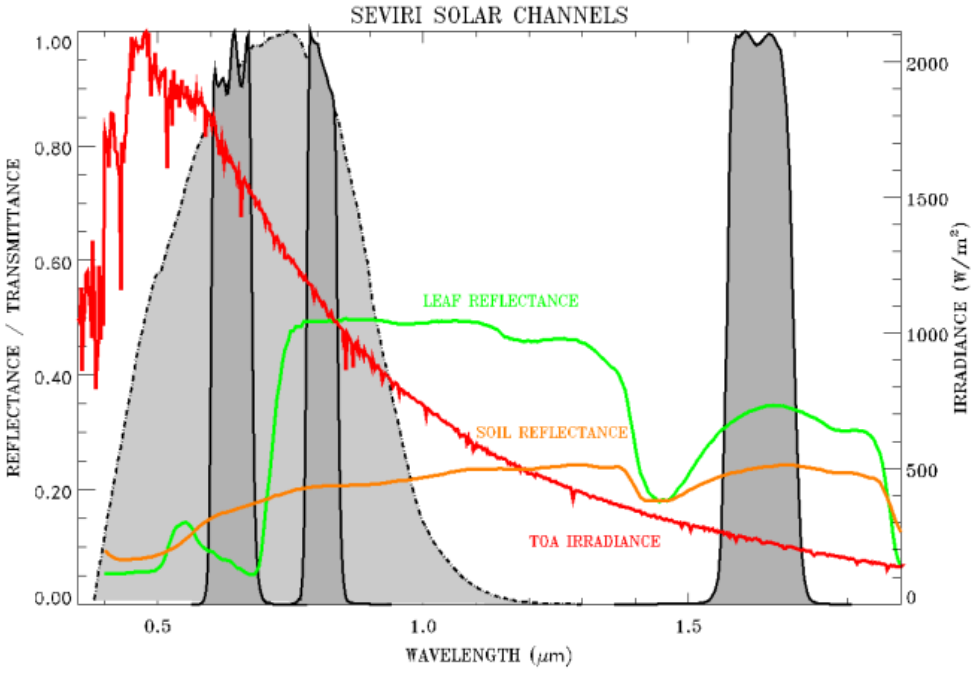

Figure 3.7 : MSG SEVIRI spectral response functions for the solar channels [plotted with the spectral reflectance of vegetation (green) and bare soil (brown) and the spectral irradiance at the top of the atmosphere (red)].

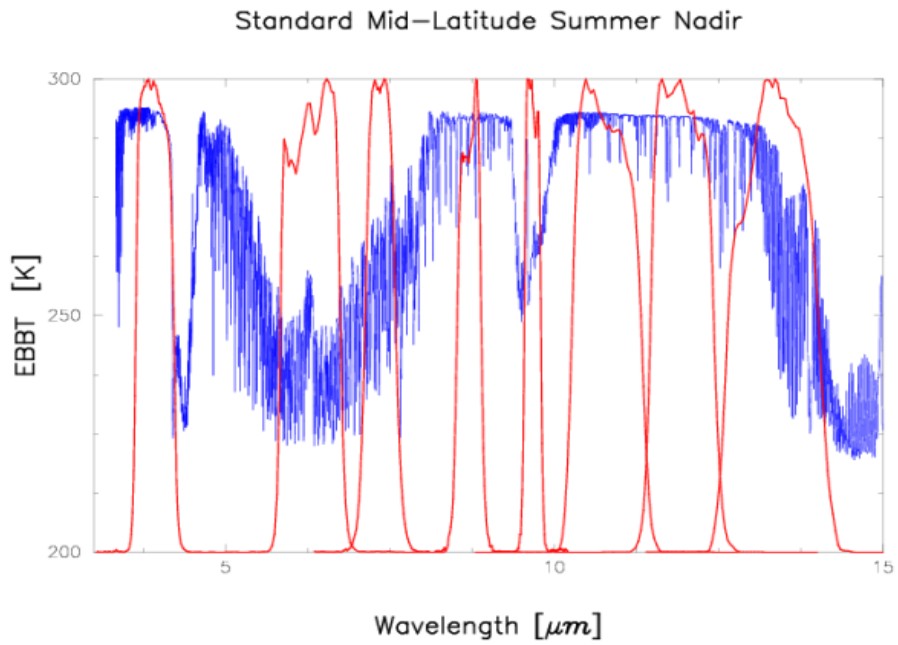

Figure 3.8: Thermal terrestrial spectrum and MSG SEVIRI spectral response functions for the thermal channels.

The launch of Meteosat-8 gave a new opportunity to study the variations in this important species, while monitoring ozone distribution on an operational basis. The key to this is SEVIRI IR 9.7 (Ch08), together with the many other channels needed to identify clouds that might contaminate the ozone measurements. Figure 3.9 is a full Earth disc image of the total column ozone across the MSG field-of-view. It has been generated, together with those shown in Figure 3.10, in the context of the development of the EUMETSAT SAF on Ozone Monitoring. The method is based on analysis of the differences between the SEVIRI IR 9.7 (Ch08) and IR 10.8 (Ch09) channels with corrections including those needed for the underlying background radiation and slanting field of view. Experiments have shown that the data are well suited to analysis of the partial column ozone in the layer from 400 to 40 hPa. This provides a unique perspective of this part of the Earth's atmosphere [26].

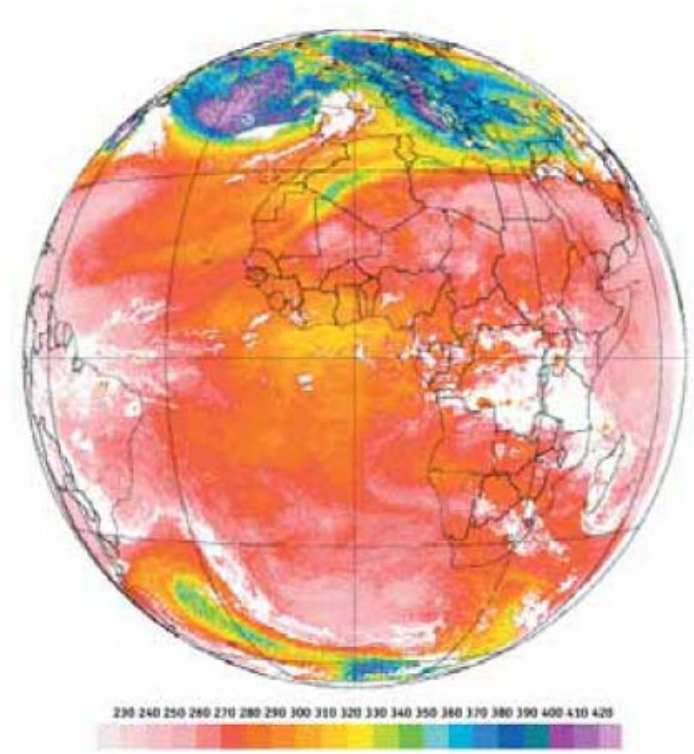

Figure 3.9: Total column ozone derived from SEVIRI's IR 9.7 (Ch08), at 00:00 UTC on 12 March 2004 (Meteo France)

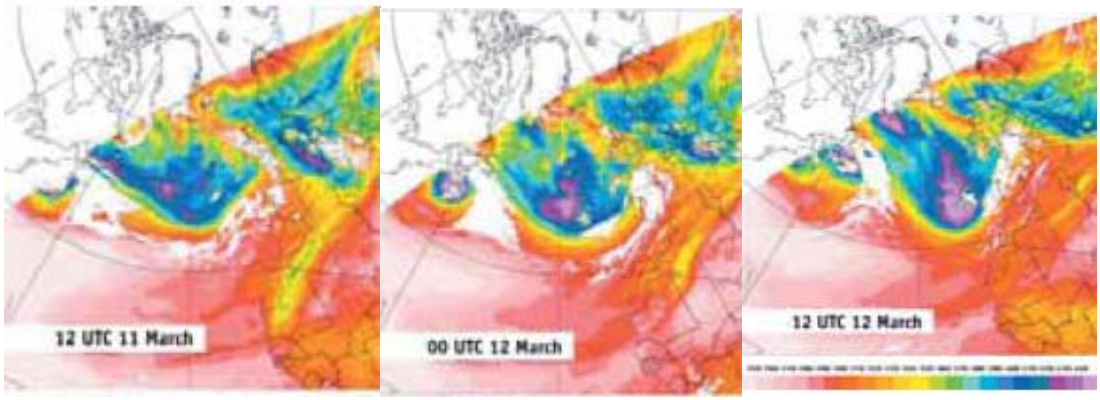

Figure 3.10: Three images showing total column ozone derived from the SEVIRI 9.7 μm channel at 12-hour intervals from 12:00 UTC on 11-12 March 2004. (Météo-France)

What makes this capability of special importance is the fact that ozone maps of this type can be generated every 15 minutes, giving unprecedented opportunities to study the dynamics of this important atmospheric constituent. This is illustrated in the series of images in Figure 3.10, which show total column ozone over the North Atlantic, Europe and Africa at 12-hour intervals. The evolution of the ozone patterns during this period of 24 hours is obvious, while these rapid changes also provide

important information on stratospheric dynamics that is not readily available by other means. This promises to be of use for short period weather forecasting as well as for the more obvious purpose of monitoring atmospheric ozone. The operational nature of the mission means that the long-term evolution of stratospheric ozone can be closely monitored by a series of near-identical satellites [26].

3.3.3 MetOp

MetOp is a series of polar orbiting meteorological satellites operated by the European Organisation for the Exploitation of Meteorological Satellites. In Table 3.2 properties of MetOp are given. The satellites are all part af the EUMETSAT Polar System. It is intended to replace the soon to be retired TIROS (The Television Infrared Observation Satellite) network. The satellites, the first of which was launched on October 19, 2006, are equipped with the same equipment as the TIROS satellites, plus extra atmospheric measuring instruments. MetOp is Europe's second largest Earth-observation satellite, after ENVISAT which was launched in 2002. MetOp-A was declared fully operational in mid-May 2007 and the full data of its 11 scientific instruments are available to its users on operational basis [27-29].

Table 3.2: Properties of MetOp

Organization:	EUMETSAT
Mission type:	Earth Science
Satellite of:	Earth
Launch:	October 19, 2006 at 16:28:00 UTC
Launch vehicle:	Soyuz ST Fregat
Mission duration:	October 25, 2006- planned 5 years
Mass:	4093 kg
Payload Mass:	812 kg
Dimensions:	6.2 × 3.4 × 3.4 metres (under the launcher fairing) 17.6 × 6.5 × 5.2 metres (deployed in orbit)
Orbit:	Sun synchronous orbit
Inclination:	98.7° to the Equator
Orbital period:	101 minutes

The first EPS MetOp satellite (MetOp-A) flies in a sun-synchronous polar orbit at an altitude of about 840 km, circling the planet 14 times each day and crossing the equator at 09:30 local (sun) time on each descending (south-bound) orbit. Successive orbits are displaced westward due to the Earth's own rotation, giving global coverage of most parameters at least twice each day, once in daylight and once at night.

The spacecraft carries a comprehensive set of instrumentation (Figure 3.11), designed primarily to support operational meteorology and climate monitoring, but also supporting many additional applications [27,29].

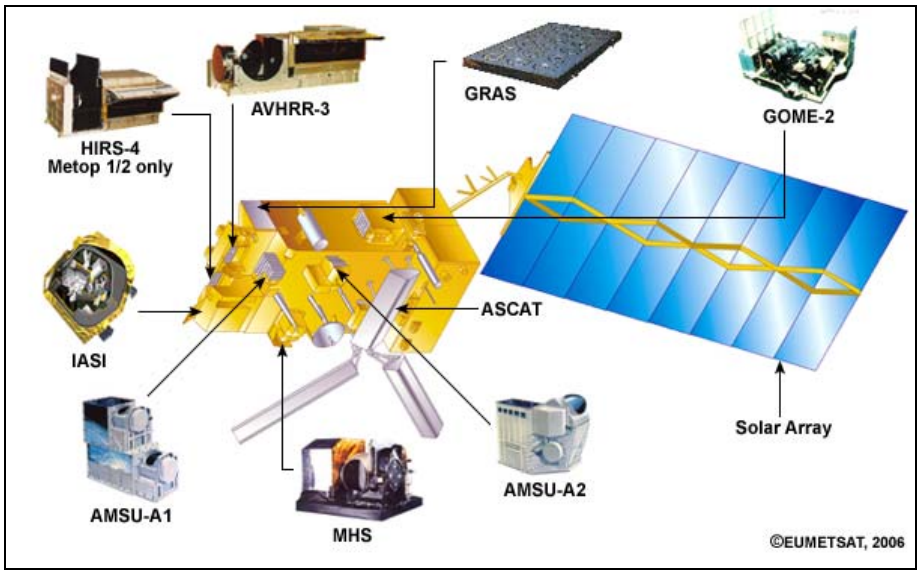

Figure 3.11: MetOp Satellite Instrumentation

In the thesis, we have hot used the MetOp data yet due to some difficulties in preparing the algorithms of the data.

3.3.3.1 The Global Ozone Monitoring Experiment (GOME-2)

The Global Ozone Monitoring Experiment (GOME) was first launched on ESA's ERS-2 spacecraft on 20 April 1995. It is still operating successfully, providing ozone and other valuable data even two years beyond its original design lifetime. As the only European ozone-monitoring instrument with an actual flight heritage, GOME was therefore selected for the Metop series of satellites being jointly developed by ESA and Eumetsat for operational meteorology and climate monitoring. The features of this second-generation sensor, known as GOME-2, are presented here [28].

This instrument is designed to measure the total column and profiles of atmospheric ozone and the distribution of other key atmospheric constituents. It flies on the first two METOP spacecraft, with an updated instrument planned for the follow-on satellites. GOME-2 is a nadir viewing across-track scanning spectrometer with a atmosphere and the surface of the Earth in the ultraviolet and visible range. The instrument uses four channels to cover the full spectral range from 200 to 790 nm with a spectral sampling of 0.11 nm at the lower end of the range, rising to 0.22 nm at the higher end. The instrument employs a mirror mechanism which scans across the satellite track with a maximum scan angle that can be varied from ground control, and three multi-spectral samples per scan. The ground pixel size of GOME-2 is 80 x 40 km² for the shortest integration times, but is usually 8 times larger for the detector measuring the shortest UV wavelengths.Table 3.3 summarizes the properties of GOME-2 instrument [28-29].

Table 3.3: Gome-2 Properties

Spectrometer type	double spectrometer with pre-disperser prism and four holographic gratings
Spectral range	240 –790 nm
Field of view	0.286° (across track) x 2.75° (along track)
Entrance slit	0.2 mm (across track) x 9.6 mm (along track)
Channels (Bands) & sampling & resolution	1a: 203 – 306 nm & 0.14 - 0.11 nm & 0.24 – 0.29 nm 1b: 306 – 322 nm & +/- 0.11 nm & 0.24 – 0.29 nm 2a: 290 – 399 nm & +/- 0.13 nm & 0.26 – 0.28 nm 2b: 299 – 412 nm & +/- 0.13 nm & 0.26 – 0.28 nm 3: 391 – 607 nm & +/- 0.22 nm & 0.44 – 0.53 nm 4: 584 – 798 nm & +/- 0.22 nm & 0.44 – 0.53 nm
Polarisation monitoring unit	250 detector pixels 312 – 790 nm in 12 programmable bands spectral resolution: 2.8 nm at 312 nm to 40 nm at 790 nm
Swath widths	1920 km (nominal mode), 960 km, 320 km, 240 km, 120 km
Solar calibration	Once per day
Spectral calibration	fixed angle (once per day to once per month)
White Light Source Dark signal	fixed angle (night side of the orbit)
Default spatial resolution and integration time	Band 1a: 640 km x 40 km (1920 km swath and integration time of 1.5 s) Band 1b – 4: 80 km x 40 km (1920 km swath and int. time of 0.1875 s) PMD: 10 km x 40 km (for polarisation monitoring)

In Figure 3.12 , ozone vertical column density retrieved from GOME-2/MetOP is given.

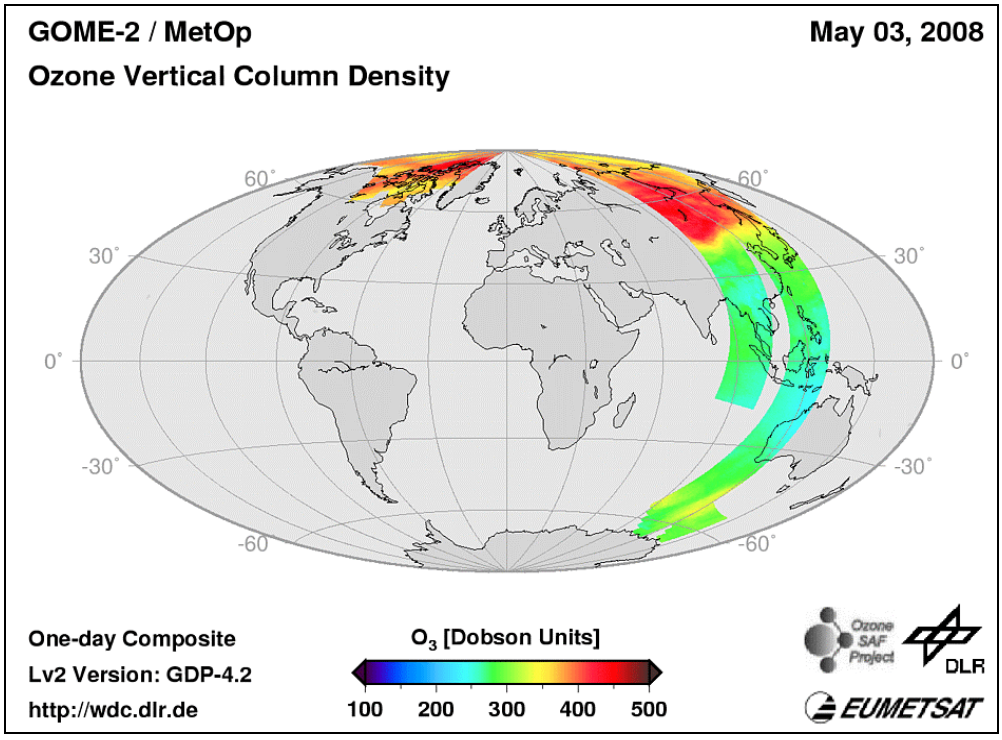

Figure 3.12: Ozone Vertical Column Density retrieved from GOME-2/MetOP

4. COMPARISON of DIFFERENT OZONE MEASUREMENTS OVER ANKARA

Intercomparison of different ozone masurement techniques help us to verify the data obtained by different techniques and to undertand which techniques give the most accurate results. For example, the data measured by ozonesondes are very useful to verify the data obtained by remote sensing methods such as TOMS satellite and Ozone LIDAR [30]. For this reason, a lot of comparison studies of different ozone measurement techniques have been done throughout the world.

In 1998, De Backer et. al have compared simultanous BM and Z-ECC ozonsondes data between 1996-1998 at Uccle. They have concluded that the use of an appropriate correction procedure, accounting for the loss of pump efficiency with decreasing pressure and temperature, it is possible to reduce the mean difference between ozone profiles obtained with both types of sondes below 3%, which is statistically insignificant over nearly the whole operational altitude range (from the ground to 32km) [7].

In 2002, Dorokhov et al. are compared ozone profiles obtained at Yakutsk, Eastern Siberia by balloon-borne 2ZECC ozone sondes with total ozone readings of the Brewer instrument at the same location. Ozone data series obtained by Brewer at Yakutsk have been used for validation of the satellite-based TOMS ozone spectrometer. The comparison between satellite and ground-based measurements allows better understanding of the characteristics and weaknesses of each data set. Combined analysis of TOMS and Brewer data records highlights several sources of the discrepancies [31].

In 2004, V.W.J.H Kirchhoff et. al. have compared ground-based Brewer total column ozone measurements with Dobson and TOMS data from 1997 to 2003 at Natal. They have observed that all data series have showed good agreement until 2001, but the comparison with TOMS has changed after 2001, the comparison between Brewer and Dobson has showed no significant changes [32].

In 2006, Gi-Man Hong and Chun-Ho Cho have determined daily total ozone and weekly vertical ozone profile using Brewer spectrophotometer ve ECC ozonsonde. To determine the total ozone amount, they have used Brewer data measured between 1994-2005 and have compared with TOMS data. They have concluded that the results were similar [17].

This study deals with the comparison of Brewer, OMI, MSG and ECC total ozone measurements to determine which measurement system is the most accurate one. On the other hand, using a total ozone retrieval algorithm, tropospheric, lower and upper stratospheric total ozone amounts are calculated based on ECC measurements over Ankara ($39^{o}55'N$; $32^{o}55'E$) located at the centre of Anatolia.

In this chapter, ozone data for Ankara will be presented, comparisons of the different instrument measurements will be discussed and the variations of the tropospheric and stratospheric total ozone will be analysed.

4.1 Data

In Turkey, ozone monitoring is carried out primarily by Turkish State Meteorological Service (TSMS). TSMS began its observation in 1994 by using a different ECC systems at Ankara. The location of the station is $39^{o}55'N$; $32^{o}55'E$ 890 m above mean sea level. Between the years 1994-1997, ECC 5A model by EN-SCI; between 1997-2002, Z-ECC model by EN-SCI and since 2003, ECC 6A model from Science Pump Corporation (SCP) have been operating. Vertical profiles of ozone were obtained at Ankara by balloon borne electrochemical concentration cell (ECC) ozonesondes. Balloon soundings are conducted at Ankara twice a month at local noon basis and generally reflect the ozone profile within 30 km of Ankara . In this study to examine the variation of tropospheric and stratospheric total amount of ozone, ozone data measured by the ECC were analyzed from January 2007 to December 2007. Totally 21 ECC measurements are used.

Also, in order to measure total column ozone at Ankara, Brewer MK III instrument has been operated by TSMS since November 2006. Being the only Brewer in Turkey, it forms an integral part of the WMO ozone monitoring network. Brewer data can be taken to 50 km by two km intervals continously. To examine the average monthly variation of the total amount of ozone, Brewer data, the Aura/OMI and

MSG/SEVIRI satellites data from January 2007 to December 2007 are taken into account. In this study, MSG ozone data which are very new, are used for the first time in the analysis of total ozone comparisons over Ankara.

All the ozonesonde data within the period under operation for which Brewer MK III, OMI and MSG data were available for the corresponding days were taken into account in order to compare and show which measurement system gives the most similar result when compared with ECC total ozone amount.

4.2 Comparisons and Results

In this section, Brewer, OMI, MSG and ECC total ozone comparisons will be presented, also tropospheric and stratospheric total ozone calculations will be given.

4.2.1 Total Ozone Comparisons and Results

To examine variation of the total amount of ozone, Brewer data, the Aura/OMI and MSG/SEVIRI satellites data from January 2007 to December 2007 are analysed. Based on daily measurement data of each instrument, monthly average total ozone amounts are obtained (Table 4.1).

Table 4.1: Average Monthly Total Ozone Amounts

	Total Ozone (DU)		
2007	**BREWER**	**OMI**	**MSG**
JANUARY	321	327	337
FEBRUARY	333	353	364
MARCH	375	368	398
APRIL	390	387	419
MAY	340	330	377
JUIN	326	317	357
JULY	302	296	351
AUGUST	296	291	334
SEPTEMBER	285	284	342
OCTOBER	267	287	322
NOVEMBER	289	289	316
DECEMBER	306	302	354

As it can be seen from the table , Brewer and OMI data show good agreement while MSG data show greater values for each month. To better understand how the data

differ from each other, the percentage differences between them are given in Table 4.2-4.4.

Table 4.2: Percentage difference between Brewer and OMI ozone data

2007	BREWER	OMI	% Difference
JANUARY	321	327	**-1,9**
FEBRUARY	333	353	**-5,9**
MARCH	375	368	**1,9**
APRIL	390	387	**0,9**
MAY	340	330	**2,9**
JUIN	326	317	**2,8**
JULY	302	296	**2,0**
AUGUST	296	291	**1,8**
SEPTEMBER	285	284	**0,3**
OCTOBER	267	287	**-7,3**
NOVEMBER	289	289	**-0,1**
DECEMBER	306	302	**1,4**

Table 4.3: Percentage difference between MSG and Brewer ozone data

2007	MSG	BREWER	% Difference
JANUARY	337	321	**4,8**
FEBRUARY	364	333	**8,6**
MARCH	398	375	**5,7**
APRIL	419	390	**6,9**
MAY	377	340	**9,7**
JUIN	357	326	**8,7**
JULY	351	302	**13,9**
AUGUST	334	296	**11,3**
SEPTEMBER	342	285	**16,6**
OCTOBER	322	267	**17,0**
NOVEMBER	316	289	**8,6**
DECEMBER	354	306	**13,5**

Table 4.4: Percentage difference between MSG and OMI ozone data

2007	MSG	OMI	% Difference
JANUARY	337	327	**2,9**
FEBRUARY	364	353	**3,2**
MARCH	398	368	**7,5**
APRIL	419	387	**7,8**
MAY	377	330	**12,3**
JUIN	357	317	**11,3**
JULY	351	296	**15,6**
AUGUST	334	291	**12,9**
SEPTEMBER	342	284	**16,9**
OCTOBER	322	287	**10,9**
NOVEMBER	316	289	**8,5**
DECEMBER	354	302	**14,7**

When the percentage differences between the data are examined, it can be concluded that the mean absolute difference between Brewer and OMI data is 2.4% whereas the difference between MSG and Brewer is %10.4. The difference between MSG and OMI is the same as MSG-Brewer (%10.4). It can be seen that the differences between the measurements increase in summertime.

Fig. 4.1 shows the monthly mean variation total ozone amount over Ankara from January 2007 to December 2007 measured by Brewer, OMI and MSG. The whole annual variation of the total amount of ozone shows an obvious seasonal variation with spring-time ascending stepwise and autumn descending as expected in mid-latitudes. Total ozone amount in spring can be over 400 DU whereas in winter time it can be as low as 250 DU as shown in the graphic. Furthermore, the deviation of the total amount of ozone is greater in the springtime and wintertime than in summertime or autumn. This reason is explained to vertical propagation of wave and fluctuation of its stratospheric Brewer-Dobson circulation. The ozone is transported to high latitude through diabatic Brewer-Dobson circulation of stratosphere. This is to induce seasonal variation of total ozone amount measuring mid and high latitude region [17]. As can be seen in Fig. 4.1 the total ozone amount measurements show variations on monthly timescale.

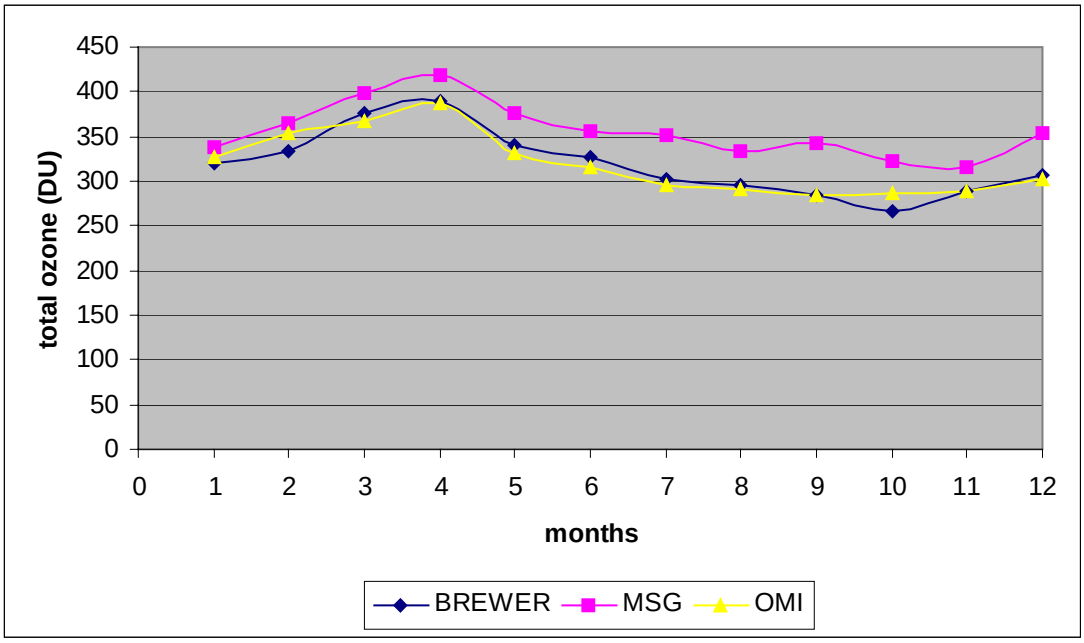

Figure 4.1: Monthly variation of total ozone amount over Ankara from January to December 2007

The data measured by ozonesondes are very useful to verify the data obtained by remote sensing methods. For this reason, 21 daily ECC total ozone measurements from January 2007 to December 2007 are compared to Brewer, OMI and MSG data for the corresponding days (Table 4.5).

Table 4.5: Comparison of ECC total ozone data with Brewer, OMI and MSG data for ECC measurements in 2007.

	Daily Total Ozone (DU)			
date	**ECC**	**BREWER**	**OMI**	**MSG**
10.01	330	347	347	350
24.01	268	268	262	306
07.02	318	322	330	326
21.02	305	317	334	418
07.03	277	319	315	357
21.03	339	363	360	404
04.04	381	397	393	462
18.04	386	430	409	423
09.05	334	345	331	380
23.05	303	324	313	394
06.06	297	314	314	293
20.06	331	319	314	344
04.07	319	315	304	372
18.07	301	290	293	334
08.08	309	299	298	343
22.08	290	288	280	341
05.09	276	283	281	333
19.09	271	288	284	345
26.09	271	277	278	342
10.10.	274	287	289	321
31.10.	296	296	322	348
14.11	252	279	280	316
28.11	258	282	276	297
12.12	301	290	288	313
26.12	283	295	288	387

As it can be seen from the table, OMI and Brewer data show good agreement with ECC data however MSG data show greater values. To demonstrate which of these data sets is much closer to ECC measurements, the percentage differences between data sets are calculated and given in Tables 4.6-4.8.

Table 4.6: Percentage differences between ECC and Brewer data for ECC measurements in Ankara in 2007

	Daily Total Ozone (DU)		
date	**ECC**	**BREWER**	**% Difference**
10.01	330	347	-5%
24.01	268	268	0%
07.02	318	322	-1%
21.02	305	317	-4%
07.03	277	319	-15%
21.03	339	363	-7%
04.04	381	397	-4%
18.04	386	430	-11%
09.05	334	345	-3%
23.05	303	324	-7%
06.06	297	314	-6%
20.06	331	319	3%
04.07	319	315	1%
18.07	301	290	3%
08.08	309	299	3%
22.08	290	288	1%
05.09	276	283	-3%
19.09	271	288	-6%
26.09	271	277	-2%
10.10.	274	287	-4%
31.10.	296	296	0%
14.11	252	279	-11%
28.11	258	282	-9%
12.12	301	290	4%
26.12	283	295	-4%

Table 4.7: Percentage differences between ECC and OMI data for ECC measurements days in 2007

	Daily Total Ozone (DU)		
date	**ECC**	**OMI**	**% Difference**
10.01	330	347	-5%
24.01	268	262	2%
07.02	318	330	-4%
21.02	305	334	-10%
07.03	277	315	-14%
21.03	339	360	-6%
04.04	381	393	-3%
18.04	386	409	-6%
09.05	334	331	1%
23.05	303	313	-3%
06.06	297	314	-6%
20.06	331	314	5%
04.07	319	304	5%
18.07	301	293	3%
08.08	309	298	4%
22.08	290	280	3%
05.09	276	281	-2%
19.09	271	284	-5%
26.09	271	278	-2%
10.10.	274	289	-5%
31.10.	296	322	-9%
14.11	252	280	-11%
28.11	258	276	-7%
12.12	301	288	4%
26.12	283	288	-2%

Table 4.8: Percentage differences between ECC and MSG data sets for ECC measurements in 2007

	Daily Total Ozone (DU)		
date	**ECC**	**MSG**	**% Difference**
10.01	330	350	-6%
24.01	268	306	-14%
07.02	318	326	-2%
21.02	305	418	-37%
07.03	277	357	-29%
21.03	339	404	-19%
04.04	381	462	-21%
18.04	386	423	-10%
09.05	334	380	-14%
23.05	303	394	-30%
06.06	297	293	2%
20.06	331	344	-4%
04.07	319	372	-17%
18.07	301	334	-11%
08.08	309	343	-11%
22.08	290	341	-18%
05.09	276	333	-21%
19.09	271	345	-27%
26.09	271	342	-26%
10.10.	274	321	-17%
31.10.	296	348	-17%
14.11	252	316	-26%
28.11	258	297	-15%
12.12	301	313	-4%
26.12	283	387	-37%

The mean absolute percentage difference of Brewer and OMI data from ECC data is % 5, but for MSG data this difference is %14. Maximum differences generally occur in February and March, summertime variations are smaller. In Figure 4.2, total ozone variations among the year 2007 is given the according to the measurement number.

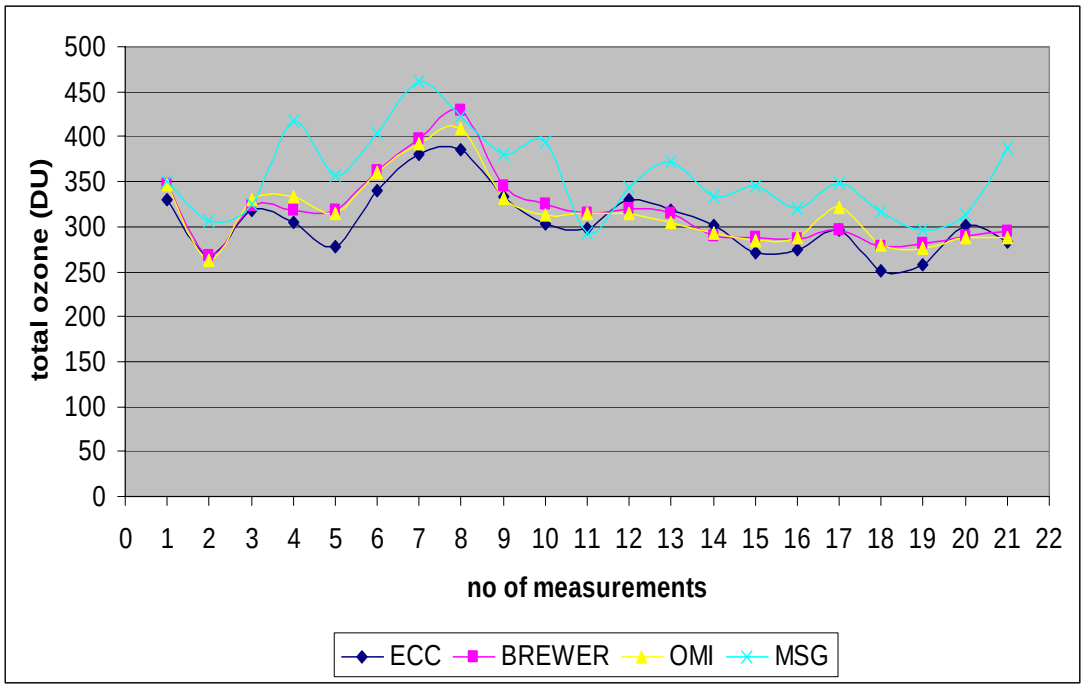

Figure 4.2: Daily total ozone variation of ECC, Brewer, OMI and MSG measurements for Ankara in 2007

As shown in the figure, Brewer and OMI data are very closed to ECC, but there is a remarquable difference in MSG data. When the total ozone measurement differences are investigated, it was found that the results are similar with other studies. Fioletov et al. (1999) used the direct sun total ozone measurements available from the World Ozone and Ultraviolet Radiation Data Center and found that the standard deviations of monthly mean difference between Brewer and TOMS (now OMI) is 2.2%. McPeters et al. (1998) report that TOMS ozone is about 1% higher than a 30 station network of ground measurements. Furthermore, the difference exhibits a seasonal variation. The difference narrows to 1% in wintertime, whereas in summertime, the difference increases to 3–10%. Probe satellite observes UV from space, so cloud influence is an important factor in the ozone retrieval algorithm. Second, the Brewer spectrophotometer is vulnerable to large temperature changes. In summer, the temperature inside the spectrophotometer can drop to 25°C on wet days and rise to above 40°C on sunny days. When the temperature becomes too high, external lamp tests indicate that the Brewer tends to exhibit decreased sensitivity [32].

In Table 4.9, ozone measurements from OMI and SEVIRI are compared. As it can be seen, SEVIRI spatial and resolution is better than OMI. Previous studies have shown that the accuracy of ozone estimates using more IR bands is better than using fewer

bands [21]. The 9.7 μm SEVIRI ozone absorption band offers excellent possibilities to monitor atmospheric content at time intervals of 15 minutes [34].

One of the important difference between them is that OMI perform UV radiaiton measurement however SEVIRI working spectrum is infrared. Due to their measurement principles, their error sources are different.

Table 4.9: OMI and SEVIRI measurement principles comparison

	AURA/OMI	**MSG/SEVIRI**
Spatial resolution (km)	13 km	3 km
Temporal resolution	Once a day	15 min.
Spatial coverage	Strip of 2600 km	Full disk
Working spectrum	UV	Infrared
Influenced by clouds	All sky	Clear sky only

According to Drouin et. al, errors of the total ozone determination from SEVIRI are the instrumental noise included in the measurement of the radiance in each channel, residual errors performed by the regression equations used in the algorithm, the uncertainty of the top of cloud properties as well as on surface parameters, the errors of spectroscopic data used to perform synthetic radiance spectra. In addition, the atmospheric profile conditions play a significant role in amplifying the errors listed above. If the background and foreground temperatures are very close together, the accuracy of the determination is very low because the difference of these temperatures is used as adividing factor in the determination of the transmission [35].

The error analysis of an electrochemical ozone sounding is not an easy matter, because of the multitude of possible errors at different altitude levels of the sounding. Three systematic errors were identified by De Muer: the response time of the electrochemical cell, the change of air temperature inside the sampling pump, and the change of the sensor sensitivity [36]. The buffered KI solution has been hypothesized to produce side reactions that may over-estimate the amount of ozone measured by the sonde [37].

4.2.2 Tropospheric and Stratospheric Ozone Comparisons

In this thesis, we tried to calculate the ozone content in both stratosphere and troposphere in order to understand the ozone variation and their reasons using vertical ozone profiles in Ankara. The calculation of tropospheric and stratospheric

ozone is done by applying total ozone algorithm to ECC sounding data from January 2007 to December 2007. Total ozone is the integrated ozone in a column, extending from the bottom to the top of the atmosphere. Thus, it is the sum of measured total ozone from the sounding and the estimated residual ozone (for example, total ozone after burst) as expressed in the equation (1). The results of total ozone calculation are given in Dobson Units (DU) [38].

$$TOTAL\ OZONE = \Delta\Omega_S + \Delta\Omega_R \quad \textbf{(1)}$$

where

$\Delta\Omega_S$ = Total ozone from the sounding

$\Delta\Omega_R$ = Residual total ozone

The total ozone from the sounding is calculated by summing up the amounts of ozone in the layers between two measurement points as expressed in Equation 2. When using the units indicated in the list below, the equation gives total ozone in units of grams per square meter (g/m^2).

$$\Delta\Omega_s = \frac{\varepsilon_3}{g}\int_{p_i} p_3 d\ln p_i = \sum_i \frac{\varepsilon_3}{g}\frac{(p_3 + p_{3+i})}{2}\ln\left(\frac{p_i}{p_{i+1}}\right) \quad \textbf{(2)}$$

where

ε_3 = 1,6571, ratio of molecular masses of ozone and air

g = 9,80665 m/s^2, acceleration of gravity

$p_i...p_{i+n}$ = Ambient pressure, [hPa]

i = Index for a measurement point

$p_{3i}...p_{3i+n}$ = Ozone partial pressure [mPa]

M3 = 48.000 g/mol, molar mass of ozone

When the constants are inserted into the equation, it reduces to:

$$\Delta\Omega_S = \sum_i 0.0845 * (p_3 + p_{3+i})\ln\left(\frac{p_i}{p_{i+1}}\right) \quad \textbf{(3)}$$

The equation above gives the ozone in grams per square meter (g/m^2). The commonly used unit for total ozone is Dobson Unit (DU = $2.687*10^{20}$molecules/m^2). To get the result in DUs, ozone grams must first be divided by molar mass of ozone 48.000 g/mol and then multiplied by Avogadro's number $6.02217*10^{23}$ molecules/mol. The result is ozone in molecules/m^2. The unit relation above is used to convert this to DUs. The final equation (4) gives the result in DUs when the partial pressures are given in mPa and ambient pressures in hPa.

$$\Delta\Omega_S = \sum_i 3.9449 * (p_3 + p_{3+i}) \ln\left(\frac{p_i}{p_{i+1}}\right) \quad \textbf{(4)}$$

After the balloon burst level ozone is estimated by using Equation 4 with a constant mixing ratio ($p_{3i} = p_{3i+1} = p_{3END}$) up to ambient pressure 0 hPa. The equation changes to:

$$\Delta\Omega_R = \frac{\varepsilon_3}{g} * p_{3end} \approx 7.8899 * p_{3end} \quad \textbf{(5)}$$

When the pressure is given in hPa, equation 5 gives the residual total ozone in DU [38].

To apply these equations for the determination of tropospheric and stratospheric ozone, thermal tropopause height is used. In Table 4.10, tropospheric and stratospheric total ozone amount of the corresponding ECC soundings are given.

Table 4.10: ECC Tropospheric and stratospheric total ozone (DU) in 2007 for Ankara

ECC	tropopause height (km)	O3 tropos.	% in total	O3 strato.	% in total	total O3
Jan 10	10	25	8%	305	92%	330
Jan 24	12	25	9%	244	91%	268
Feb 07	11	26	8%	292	92%	318
Feb 21	12	29	10%	275	90%	305
Mar 07	12	30	11%	247	89%	277
Mar 21	12	30	9%	309	91%	339
Apr 04	11	36	10%	344	90%	380
Apr 18	8	25	6%	361	94%	386
May 09	12	49	15%	284	85%	334
May 23	11	46	15%	256	85%	303
Jun 06	12	35	12%	262	88%	297
Jun 20	13	52	16%	278	84%	331
Jul 04	16	69	22%	250	78%	319
Jul 18	16	65	22%	236	78%	300
Sep 19	11	33	12%	239	88%	271
Oct 10	11	28	10%	246	90%	274
Oct 31	12	26	9%	271	91%	296
Nov 14	11	24	10%	227	90%	252
Nov 28	11	27	10%	231	90%	258
Dec 12	11	27	9%	275	91%	301
Dec 26	10	25	9%	258	91%	283

It can be seen from the table that stratospheric ozone forms approximately 90% of the total ozone. It has its maximum value at spring time and minimum value in

summer-time. In Figure 4.3, the variation of tropospheric and stratospheric total ozone according the number of measurements is given.

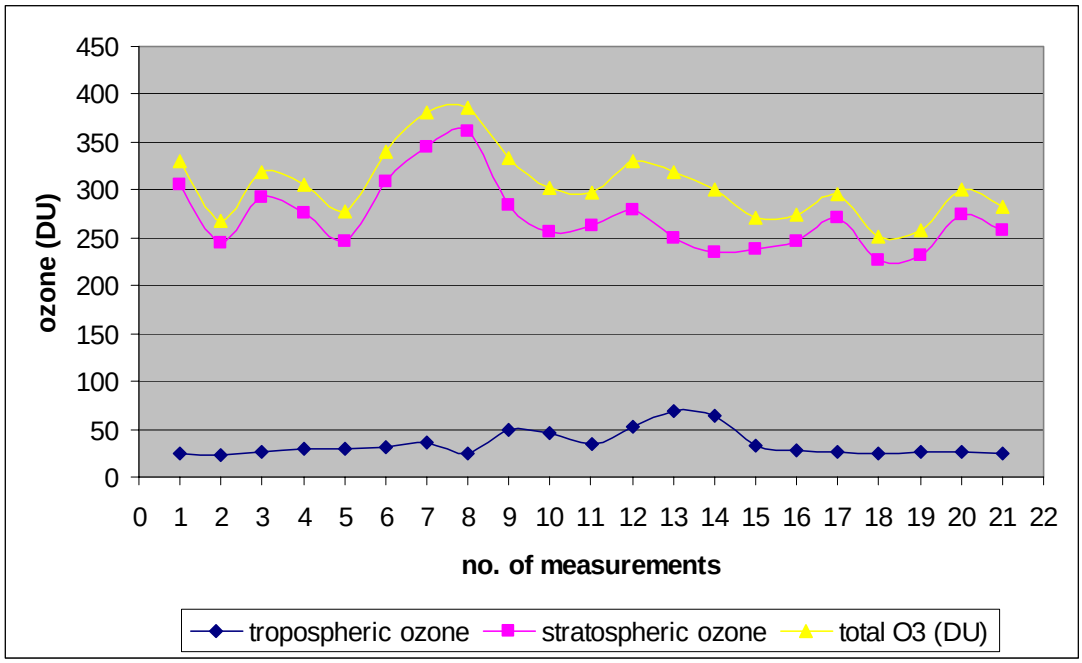

Figure 4.3: Tropospheric, stratospheric and total ozone variation based on ECC data

As shown in the figure, total ozone variation is strongly influenced by stratospheric ozone. In spring time, the increase in the stratospheric ozone is very clear, on the other hand, in summertime there is an evident increase in tropospheric ozone.

4.2.2.1 Lower and Upper Stratospheric Ozone Comparisons

To better understand the variations of stratospheric ozone, stratosphere is analysed in two parts: lower stratosphere and upper stratosphere. The mid-latitude lower stratosphere is a region of the atmosphere dominated by dynamical changes in ozone and other long-lived tracers. Shifting dynamical behaviour in the region between the tropopause and approximately 20 km, where the influence of the troposphere ends and the control of the mean circulation begins, has impacted on recorded ozone values in the last two decades [39]. In Table 4.11, tropospheric, lower and upper stratospheric ozone values and their percentage in the total ozone are given.

Table 4.11: ECC tropospheric, lower and upper stratospheric ozone amounts (DU)

ECC	O_3 tropos.	% in total	lower st. O_3 (<20km)	% in total	upper st. O_3 (>20 km)	% in total	total O_3
Jan 10	25	8%	90	27%	215	65%	330
Jan 24	25	9%	45	17%	199	74%	268
Feb 07	26	8%	77	24%	215	68%	318
Feb 21	29	10%	83	27%	193	63%	305
Mar 07	30	11%	58	21%	190	68%	277
Mar 21	30	9%	94	28%	215	63%	339
Apr 04	36	10%	131	35%	213	56%	381
Apr 18	25	6%	150	39%	211	55%	386
May 09	49	15%	71	21%	214	64%	334
May 23	46	15%	47	16%	209	69%	303
Jun 06	35	12%	57	19%	206	69%	297
Jun 20	52	16%	44	13%	234	71%	331
Jul 04	69	22%	23	7%	227	71%	319
Jul 18	65	22%	22	7%	214	71%	301
Sep 19	33	12%	44	16%	195	72%	271
Oct 10	28	10%	51	19%	195	71%	274
Oct 31	26	9%	67	23%	203	69%	296
Nov 14	24	10%	50	20%	177	70%	252
Nov 28	27	10%	58	23%	173	67%	258
Dec 12	27	9%	58	19%	217	72%	301
Dec 26	25	9%	74	26%	184	65%	283

As shown in the tables, the high ozone concentration is located at upper stratophere. Especially, a maximum concentration layer of stratospheric ozone existed from January to March, while the ozone concentration of troposphere is shown to be relatively small. The maximum stratospheric ozone is the highest in summertime and the lowest in wintertime. Generally, the temporal and spatial variations of the stratospheric ozone show a variety of forms according to the dynamic and atmospheric chemical conditions in the troposphere and stratosphere. On the other hand, a high concentration of ozone in the wintertime and springtime is measured within lower stratosphere. Also, as summertime goes on, the ozone concentration in the troposphere is high.

The vertical distribution of tropospheric ozone throughout the atmosphere is highly variable in space and time. Dynamical and photochemical considerations such as long and short range transport of high or low ozone-laden air, stratosphere-troposphere exchange (STE), and photochemical production/loss of ozone are responsible for the extent of this variability. Generally, tropospheric ozone

concentrations increase during the summer months when photochemical production and oxidation of Volatile Organic Compounds (VOCs) in the presence of NOx are a maximum. As a consequence, local natural and anthropogenic emissions of NOx and VOCs and their transport are crucial indicators of ozone concentrations [37].

In the troposphere, the seasonal cycle of ozone peaks in the summer months. Integrating the column ozone from the ground to the tropopause using data from the ozonesondes provides an accurate measure of the tropospheric ozone column. The increase in tropospheric column ozone in the summer is due to two main factors: an increase in the photochemical production of ozone and a corresponding increase in the height of the average tropopause. An increase occurs in early spring as a result of stratosphere-troposphere exchange, and likely the initiation of photochemistry following the relative dormancy of winter . The second increase in the summer with an annual peak in tropospheric ozone in July and August. This second increase corresponds to the strong influence of the natural and anthropogenic emissions of ozone precursors in the summer months [37].

The ozone concentration peaks in the stratosphere at an altitude of 20 to 25 km. The distribution of ozone is maintained by a balance between its production and loss and by the transport of ozone from regions of net production to those of net loss. The transport of ozone is driven by the variable wind fields of the stratosphere, which give rise to daily fluctuations, seasonal variations, and interannual variability in ozone amounts [40].

Over mid-latitudes strong variability in total ozone occurs with the passage of low and high pressure systems. Due to the dynamical constraints on the large- scale flow, a surface low/high pressure system is associated with a distinct structure in the upper-troposphere lower-stratosphere. Similar to the surface pressure the tropopause pressure is an integral measure of the flow changes. Within a positive/negative potential vorticity anomaly vertical vortex tubes are stretched/shrinked and hence due to mass conservation the total mass (and similar total ozone mass) above a unit square is increased/reduced as reflected in an enhanced/reduced tropopause pressure. Hence from dynamical constrains one expects a simple linear relation between variability in tropopause pressure and total mass of ozone in the lower stratosphere which contributes substantially to the total ozone value [41].

On multi-annual time scales European winter climate is strongly linked with the North-Atlantic Oscillation which is typically measured with an index representing the strength of the meridional surface pressure difference across the North-Atlantic. NAO-like variability occurs in a large number of atmospheric and oceanic key climate variables and others and encompasses the entire troposphere-stratosphere system. During positive NAO phases tropopause pressure is higher at high latitudes and lower at mid-latitudes, as would be expected from an enhanced Icelandic low and Azores high pressure system. Since tropopause pressure variations are proportional to total ozone variations one expects a similar space dependent correlation between NAO and total ozone.

To better understand the vertical ozone structure, in Appendix A, the daily vertical distribution of the ozone partial pressure and wind speeds measured by ozonesondes from January to December 2007 are given. The ozone profiles measured by ozonesondes, particularly those observed in late winter and early spring, do not display a smooth shape below the maximum of the ozone layer. Very often the occurrence of weak undulations and/or relatively narrow layers of substantially increased or depleted ozone concentration are observed. These layers are called laminae, positive laminae in the former (enhanced ozone concentration) and negative laminae in the latter case. The laminar structure of ozone profiles was first described by Dobson [1973] on the basis of ozonesonde data. Laminae occur most frequently at heights around 14 km according to Reid and Vaughan. The laminae at high and middle latitudes are predominantly associated with the exchange processes in the vicinity of the vortex edge and therefore with the transport of polar air in the form of oblique filaments toward the midlatitudes. The filamentary structures are a part of ozone sheets, vertically tilted in the shear zone in the vicinity of the polar jet. Thin laminar structures (positive or negative laminae) in the tracer vertical profiles appear as the result of isentropic wrapping and vertical shearing of such tracer sheets [42]. When the profiles are examined, laminae generally occur at the region where wind speeds variations are greater. This can influence the amount of tropospheric, lower and upper startospheric total ozone.

Table 4.12 summarizes the vertical structure of total ozone. Tropopause height, number of positive and negative laminae, percentage of ozone amount of each level are given for each measurement days in order to understand the variations in total

ozone amounts of troposphere, lower and upper stratosphere. As it can be seen from the table that, most of the laminae occur in the lower stratosphere and lower stratospheric ozone amount is higher when laminae occur. Especially, in March, April and May the number of laminae increases and lower tropospheric ozone amount also increases, however upper stratospheric total ozone amount tends to decrease.

Table 4.12: ECC ozone amounts of troposphere, lower and upper stratosphere, their percentage and the number of laminae

ECC	tropopause height (km)	O_3 tropos.	% in total	no.of laminae (+)	no. of laminae (-)	lower st. O_3	% in total	no. of laminae (+)	no. of laminae (-)	upper st. O_3	% in total	no.of laminae (+)	no.of laminae (-)
Jan 10	**10**	25	8%	**0**	**0**	90	27%	**1**	**1**	215	65%	**0**	**0**
Jan 24	**12**	25	9%	**0**	**0**	45	17%	**0**	**0**	199	74%	**1**	**1**
Feb 07	**11**	26	8%	**0**	**0**	77	24%	**0**	**1**	215	68%	**0**	**0**
Feb 21	**12**	29	10%	**0**	**0**	83	27%	**1**	**0**	193	63%	**0**	**0**
Mar 07	**12**	30	11%	**0**	**0**	58	21%	**0**	**1**	190	68%	**1**	**1**
Mar 21	**12**	30	9%	**0**	**0**	94	28%	**0**	**1**	215	63%	**0**	**0**
Apr 04	**11**	36	10%	**0**	**0**	131	35%	**0**	**1**	213	56%	**0**	**0**
Apr 18	**8**	25	6%	**0**	**0**	150	39%	**1**	**2**	211	55%	**0**	**0**
May 09	**12**	49	15%	**0**	**0**	71	21%	**1**	**1**	214	64%	**0**	**0**
May 23	**11**	46	15%	**0**	**0**	47	16%	**2**	**0**	209	69%	**0**	**0**
Jun 06	**12**	35	12%	**0**	**0**	57	19%	**1**	**1**	206	69%	**0**	**0**
Jun 20	**13**	52	16%	**0**	**0**	44	13%	**1**	**0**	234	71%	**0**	**0**
Jul 04	**16**	69	22%	**0**	**0**	23	7%	**0**	**0**	227	71%	**0**	**0**
Jul 18	**16**	65	22%	**0**	**0**	22	7%	**0**	**0**	214	71%	**0**	**0**
Sep 19	**11**	33	12%	**0**	**0**	44	16%	**0**	**0**	195	72%	**0**	**0**
Oct 10	11	28	10%	**0**	**0**	51	19%	**0**	**0**	195	71%	**0**	**0**
Oct 31	**12**	26	9%	**0**	**0**	67	23%	**0**	**0**	203	69%	**0**	**0**
Nov 14	**11**	24	10%	**0**	**0**	50	20%	**0**	**0**	177	70%	**0**	**0**
Nov 28	**11**	27	10%	**0**	**0**	58	23%	**0**	**0**	173	67%	**0**	**0**
Dec 12	**11**	27	9%	**0**	**0**	58	19%	**0**	**0**	217	72%	**0**	**0**
Dec 26	**10**	25	9%	**0**	**0**	74	26%	**0**	**1**	184	65%	**0**	**0**

5. CONCLUSION

Better understanding of the behaviour of ozone in the atmosphere helps to improve the performance of general atmospheric circulation models, used among others for weather prediction and climate modelling. To achieve these aims high quality measurements of the distribution in space and time of atmospheric ozone are needed.

The vertical distribution of ozone throughout the atmosphere is highly variable in space and time. Dynamical and photochemical considerations such as long and short range transport, stratosphere-troposphere exchange and photochemical production/loss of ozone are responsible for the extent of this variability.

Intercomparison of different ozone measurement techniques help us to verify the data obtained by different techniques and to undertand which techniques give the most accurate results. For this reason, a lot of comparison studies of different ozone measurement techniques have been done throughout the world. Recently MSG and MetOp measuremenrs have been included in ozone measurements.

In this study, Brewer(MKIII) spectrophotometer, AURA/OMI and MSG/SEVIRI satellites total ozone data between the period from 01 January to 31 December 2007 are used to compare total ozone amounts over Ankara. According to the comparisons, it is found that Brewer and OMI data show good agreement, however MGS data values are greater when compared with Brewer and OMI. To verify these findings, ECC ozonsonde data for 2007 are used. All the ozonesonde data within the period under operation for which Brewer, OMI and MSG data were available for the corresponding days were taken into account. In total 21 total ozone measurements in the January 2007-December 2007 period were used. According to the results, Brewer and OMI data are closer to ECC data but MSG data are greater than ECC data.

Furthermore, in order to understand ozone content, both troposphere and stratosphere are examined. To examine the vertical structure of total ozone, an algorithm which is used to derive total ozone from ECC sounding is applied to tropophere and

stratosphere. The results of the calculations verify that upper stratospheric ozone compose the biggest part of total ozone.

It can be suggusted that this study can be developped by making intercomparisons between Brewer, ECC and MetOp satellite ozone profiles to better understand the tropospheric and stratospheric behaviour of the sensors and their accuracies.

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APPENDIX-A

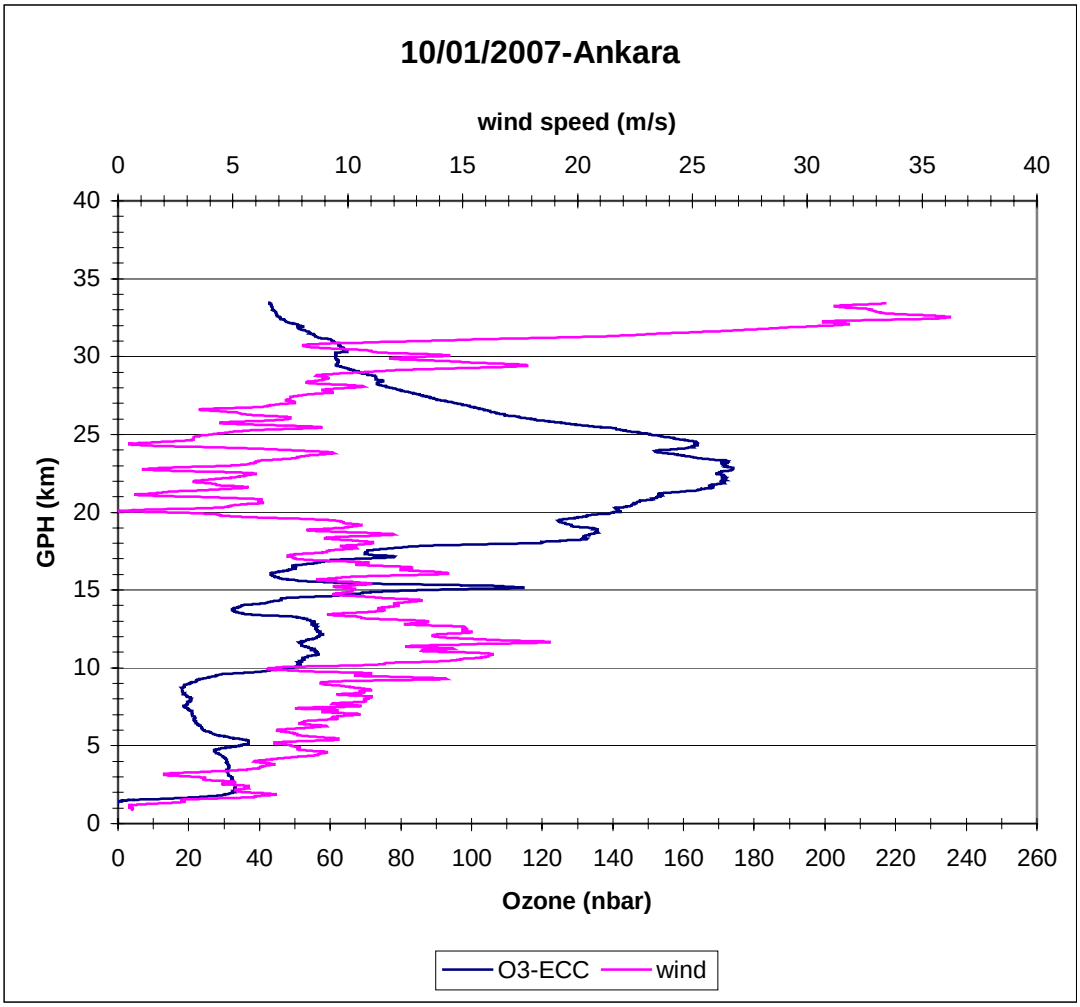

Figure A.1: ECC ozone and wind profile for Ankara on 10.01.2007

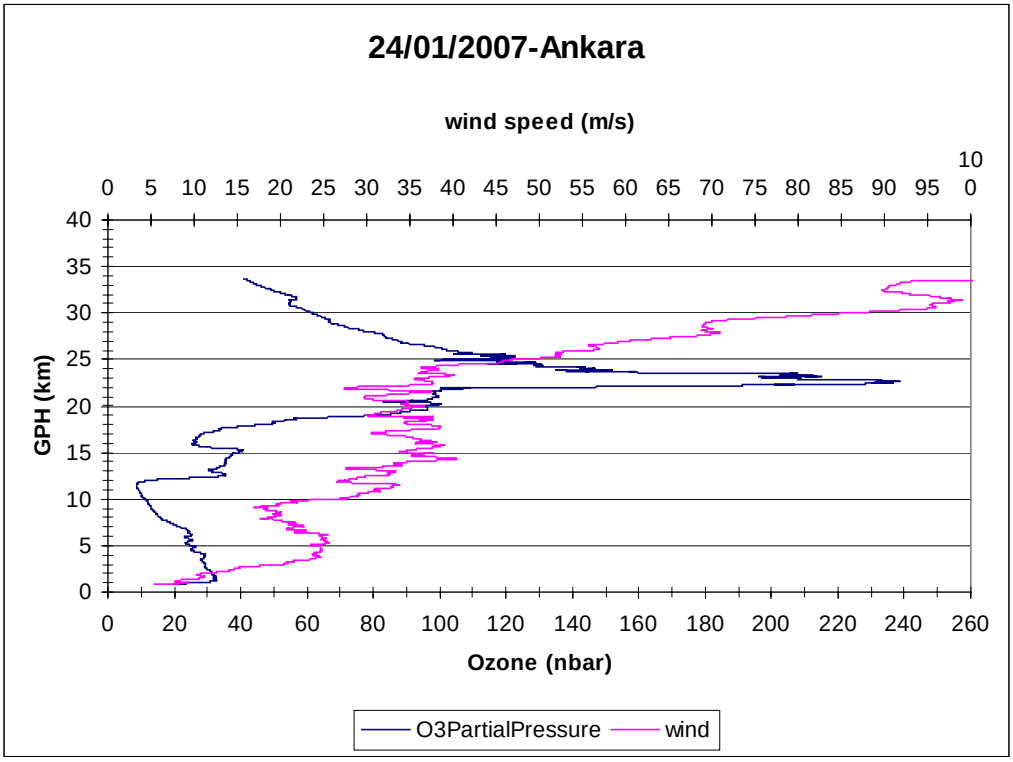

Figure A.2: ECC ozone and wind profile for Ankara on 24.01.2007

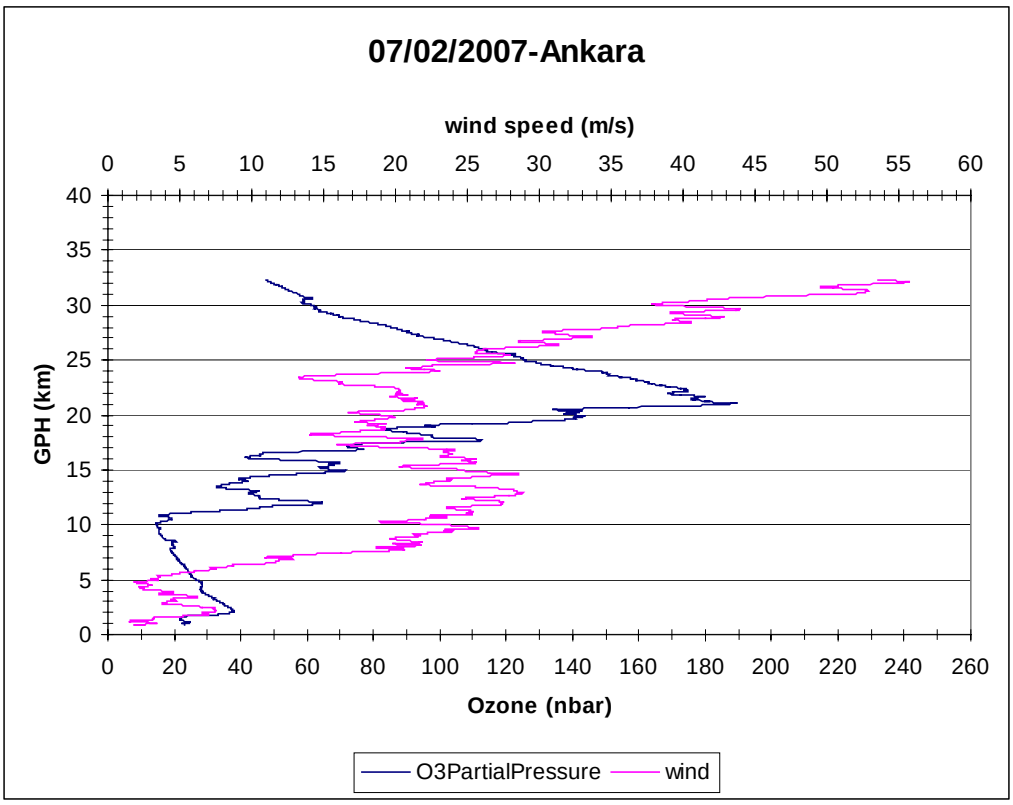

Figure A.3: ECC ozone and wind profile for Ankara on 07.02.2007

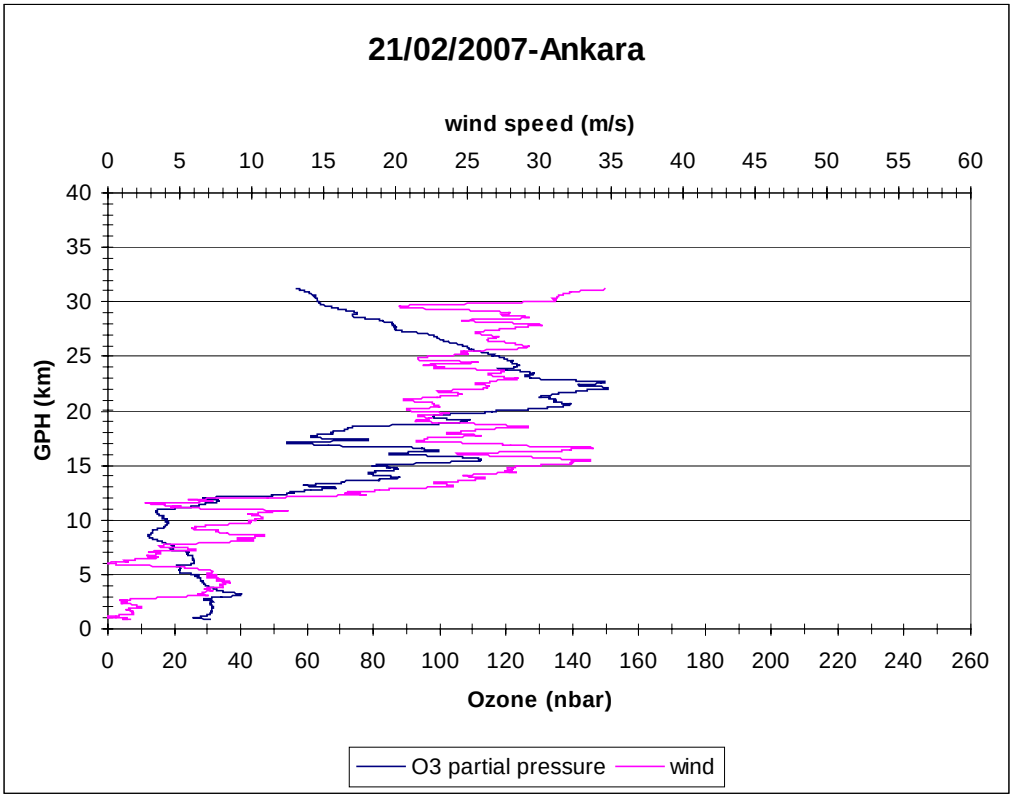

Figure A.4: ECC ozone and wind profile for Ankara on 07.02.2007

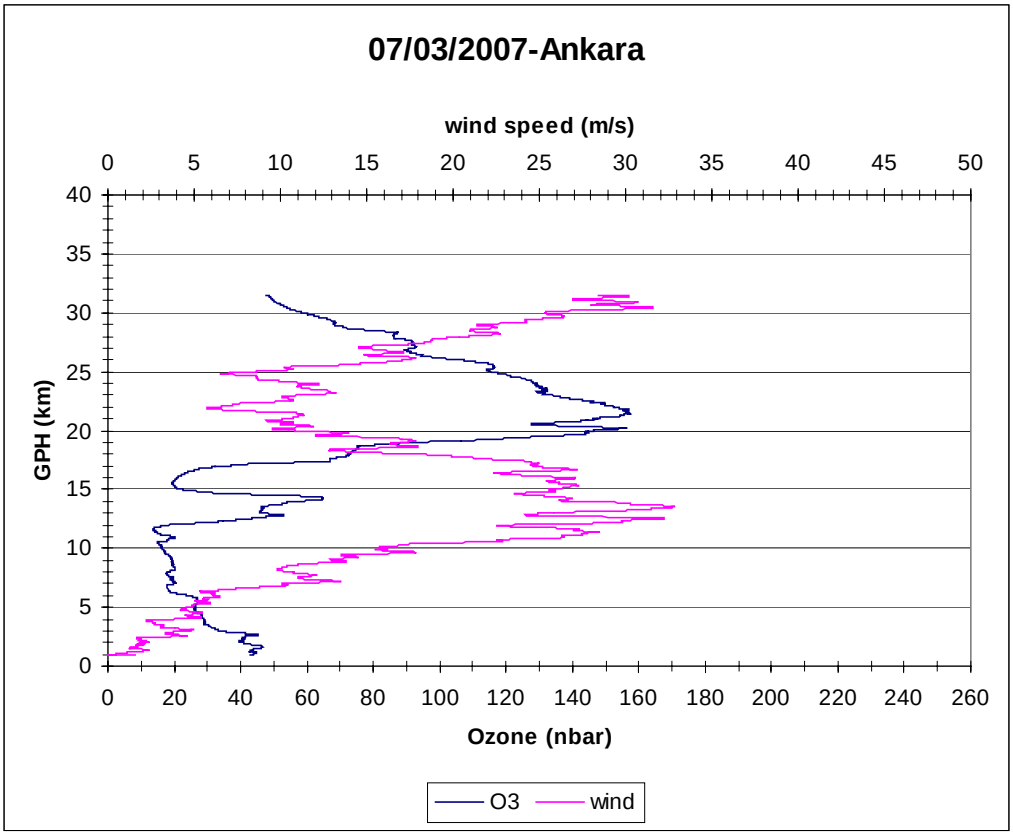

Figure A.5: ECC ozone and wind profile for Ankara on 07.03.2007

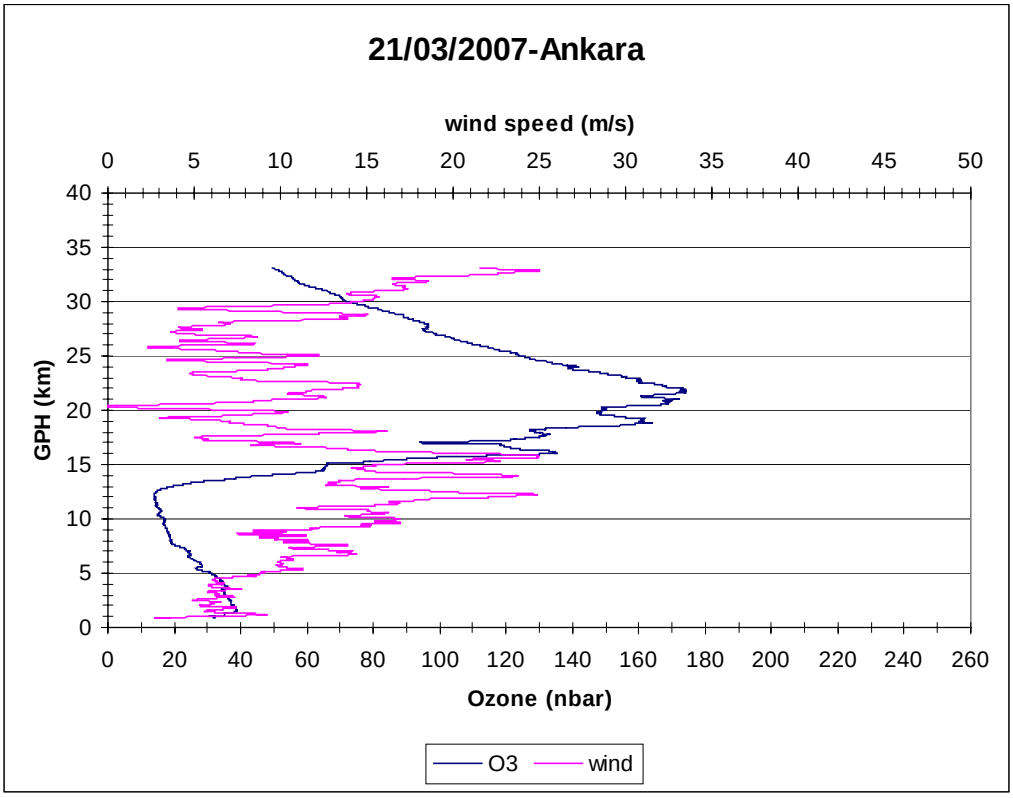

Figure A.6: ECC ozone and wind profile for Ankara on 21.03.2007

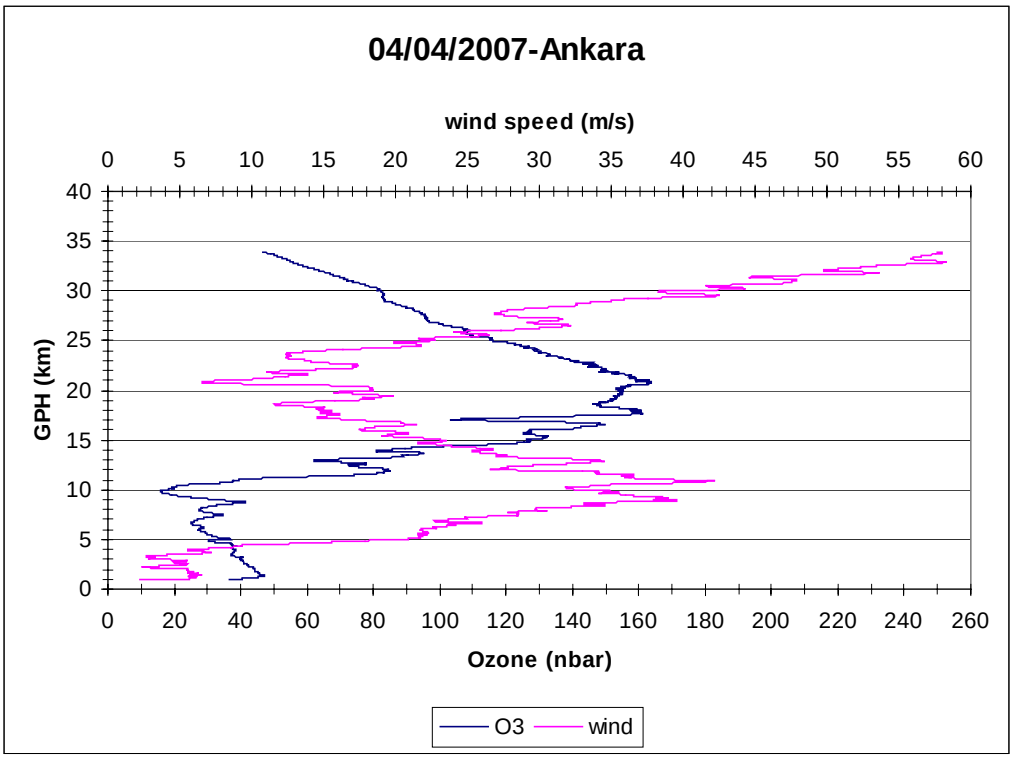

Figure A.7: ECC ozone and wind profile for Ankara on 04.04.2007

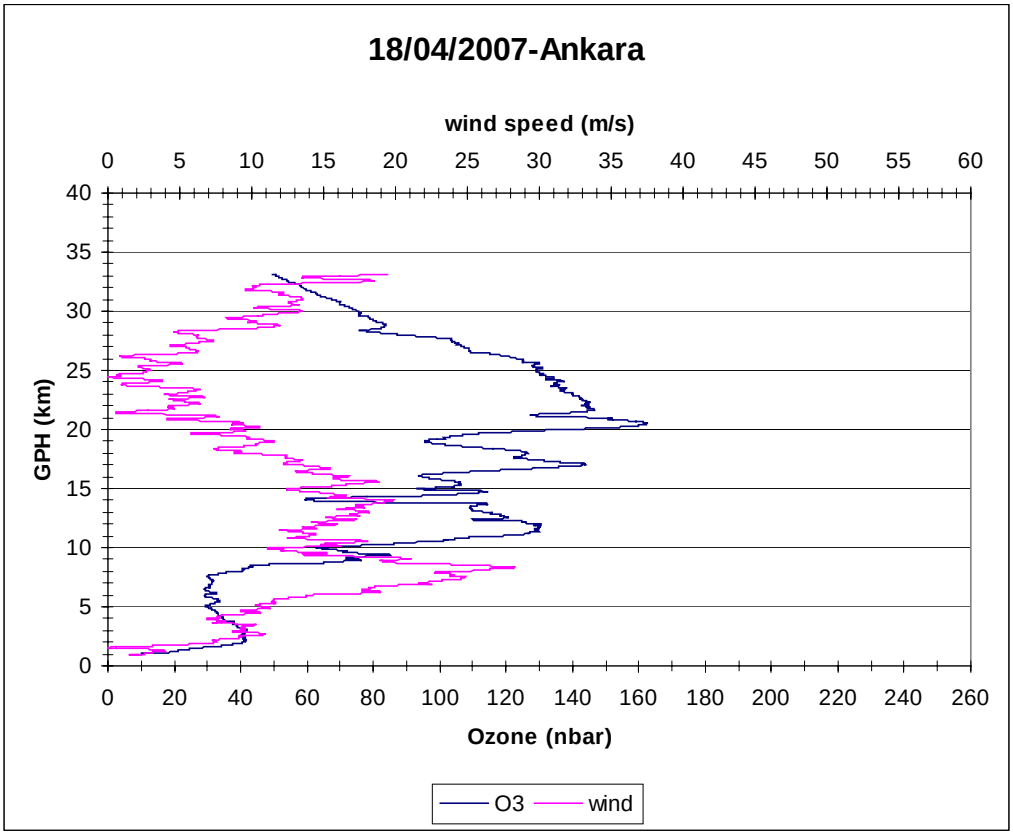

Figure A.8: ECC ozone and wind profile for Ankara on 18.04.2007

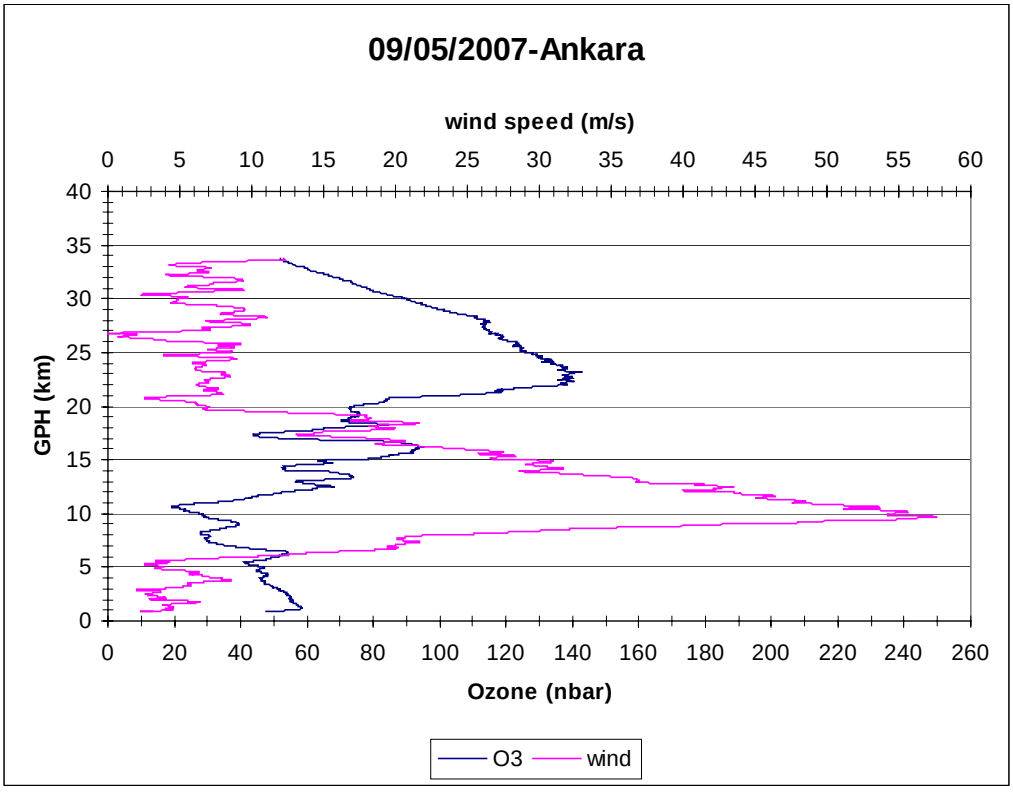

Figure A.9: ECC ozone and wind profile for Ankara on 09.05.2007

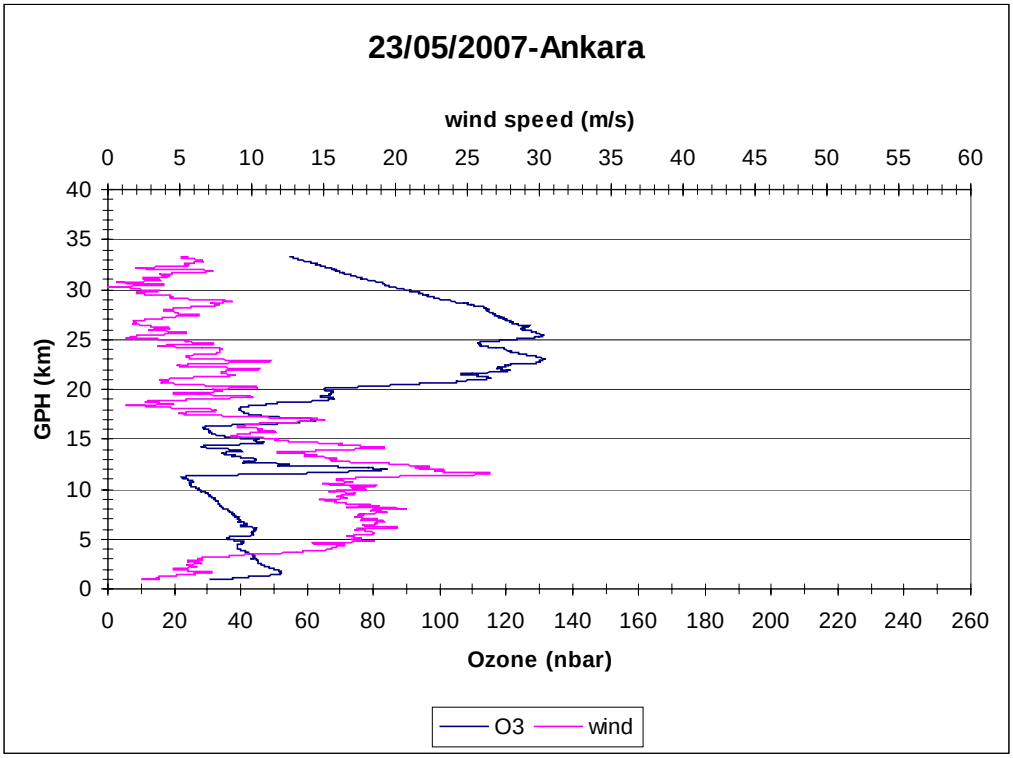

Figure A.10: ECC ozone and wind profile for Ankara on 23.05.2007

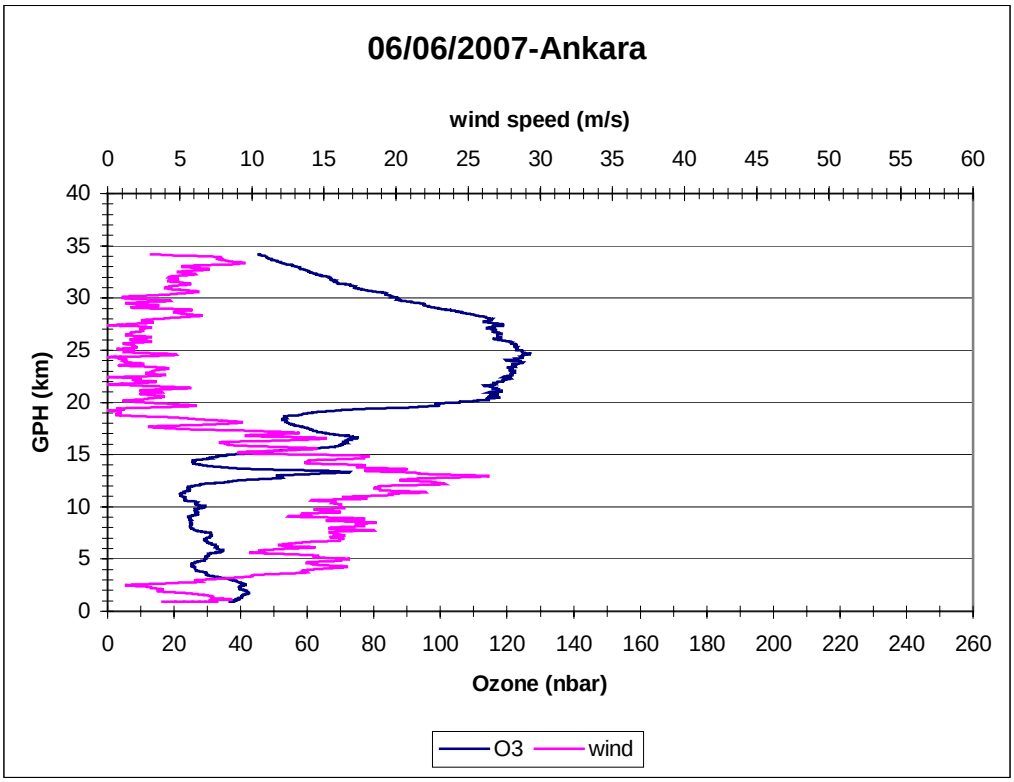

Figure A.11: ECC ozone and wind profile for Ankara on 06.06.2007

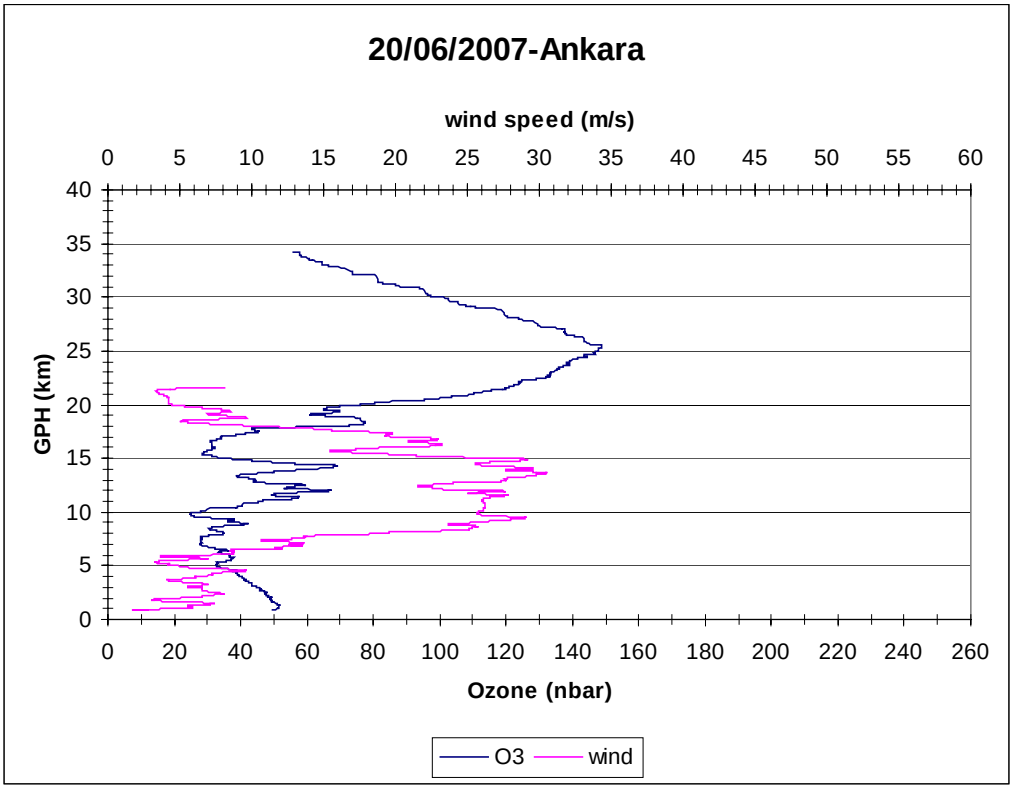

Figure A.12: ECC ozone and wind profile for Ankara on 20.06.2007

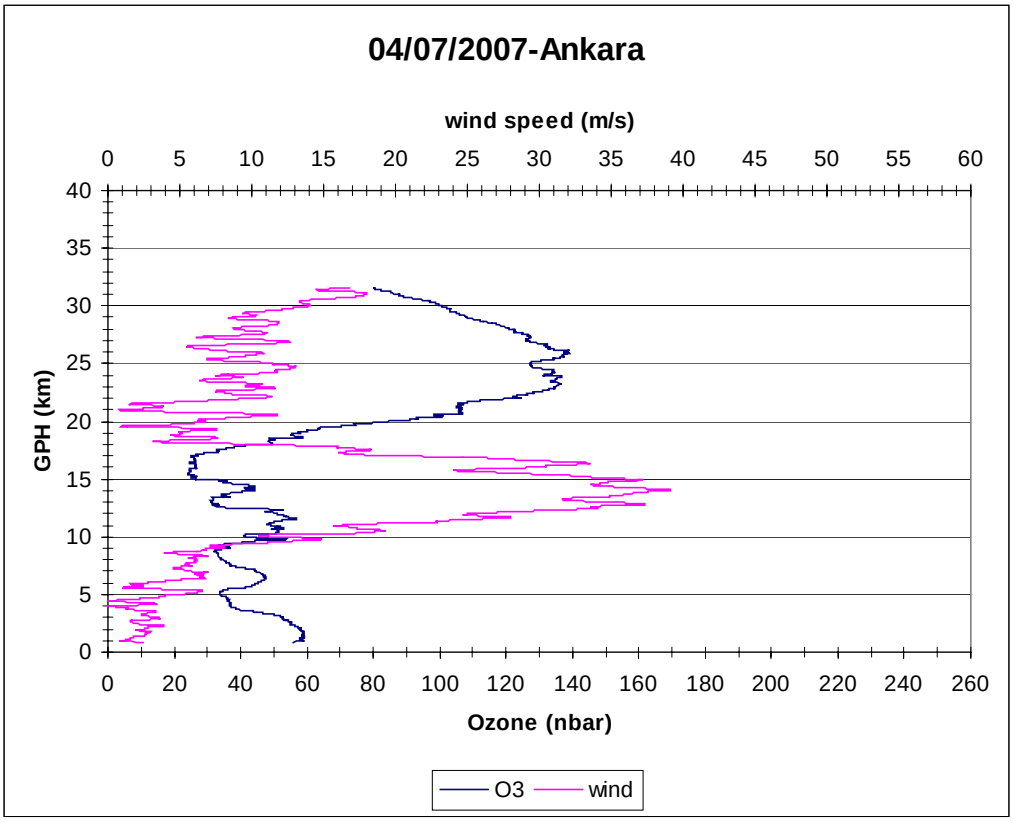

Figure A.13: ECC ozone and wind profile for Ankara on 04.07.2007

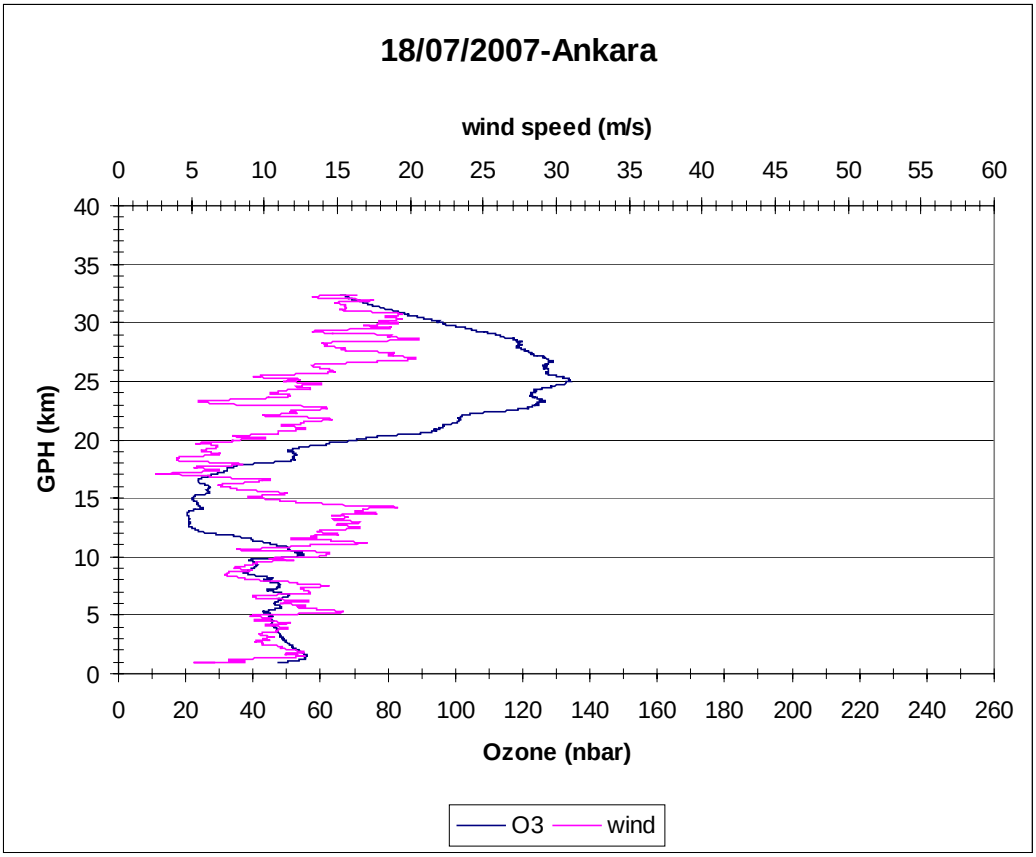

Figure A.14: ECC ozone and wind profile for Ankara on 18.07.2007

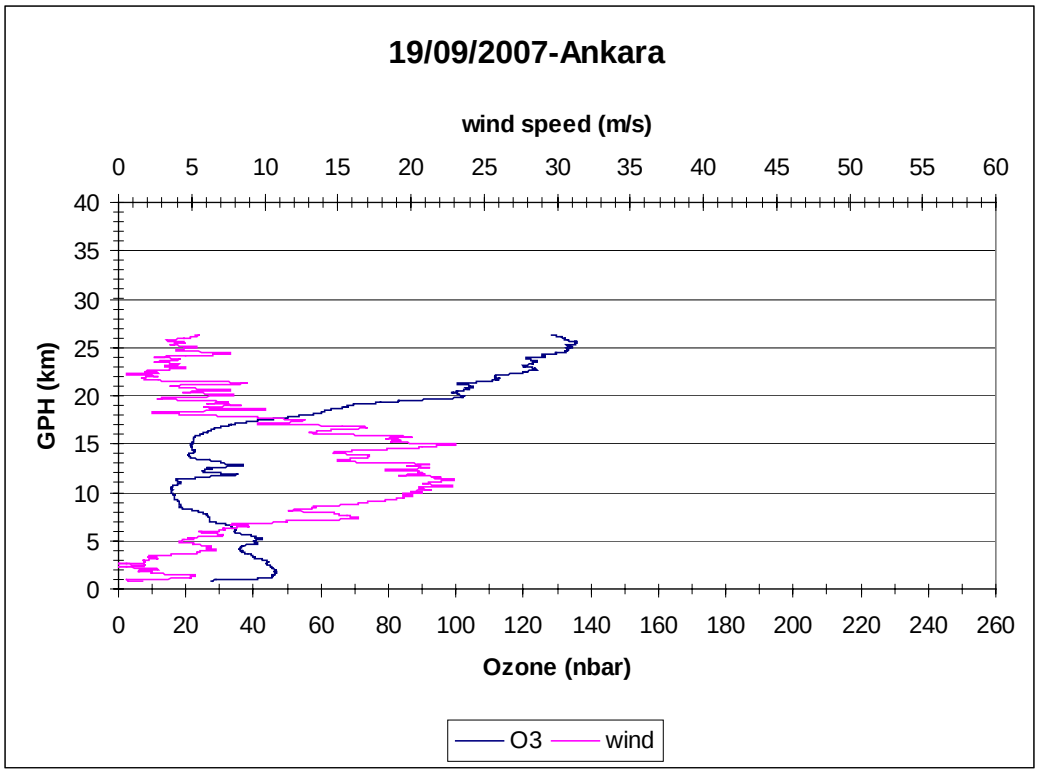

Figure A.15: ECC ozone and wind profile for Ankara on 19.09.2007

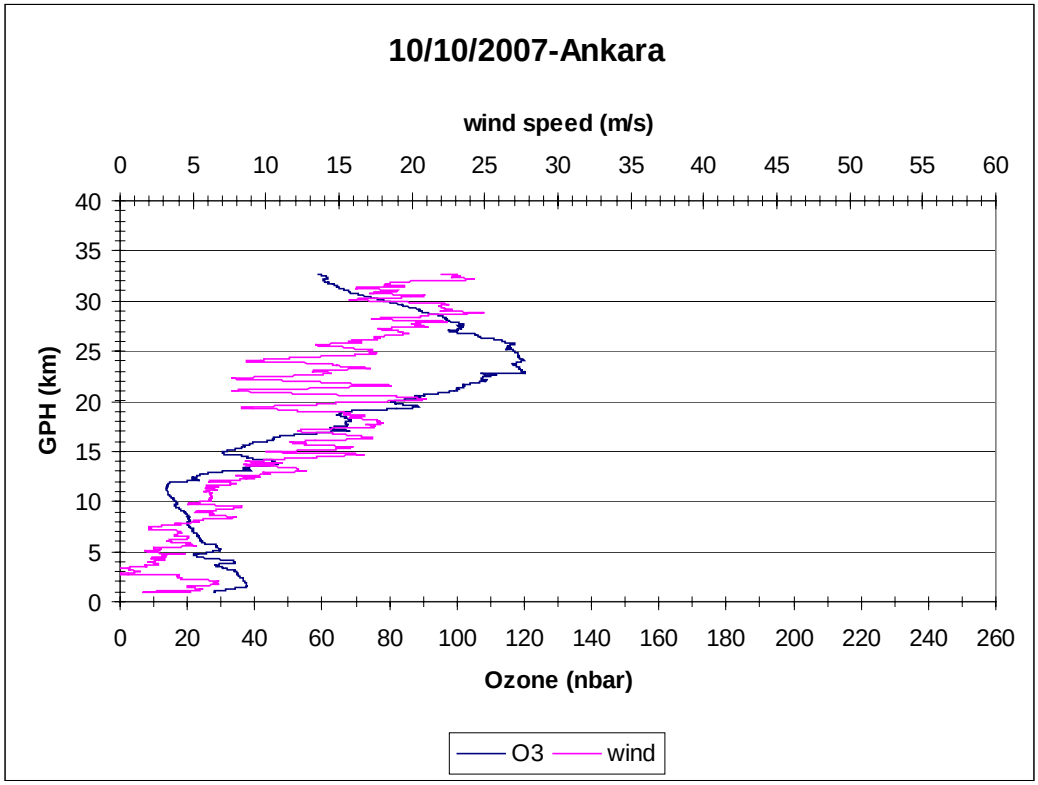

Figure A.16: ECC ozone and wind profile for Ankara on 10.10.2007

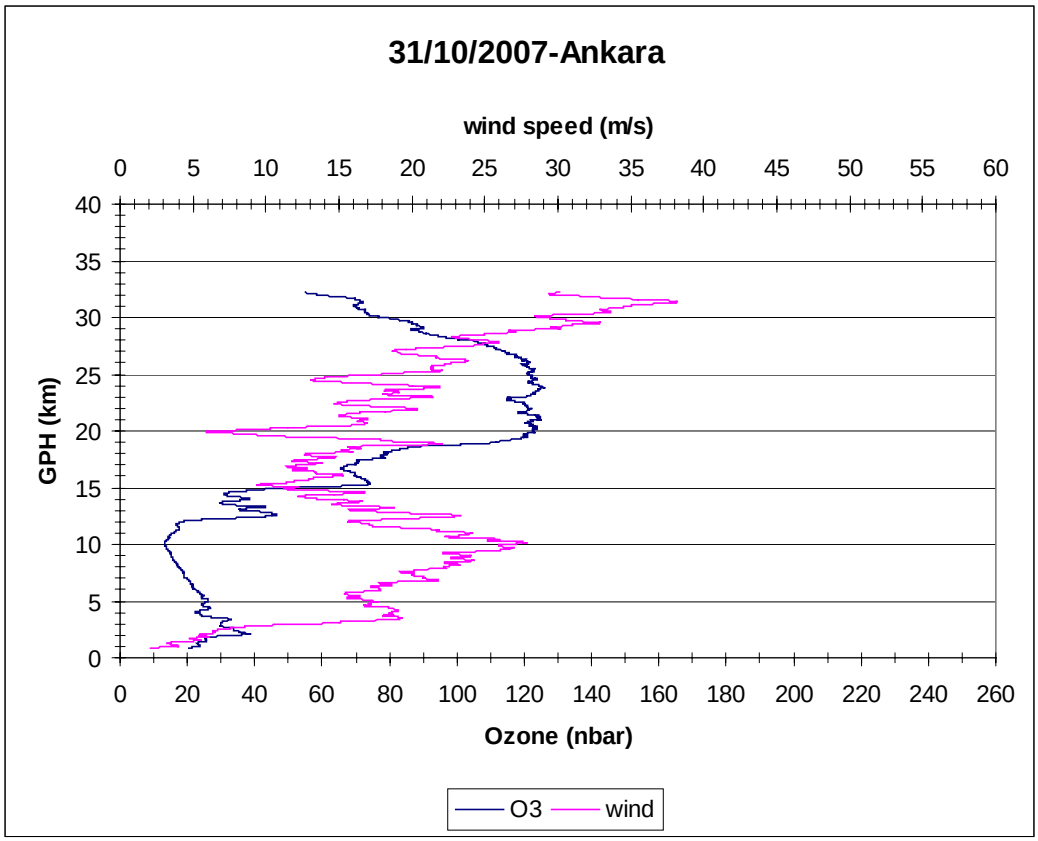

Figure A.17: ECC ozone and wind profile for Ankara on 31.10.2007

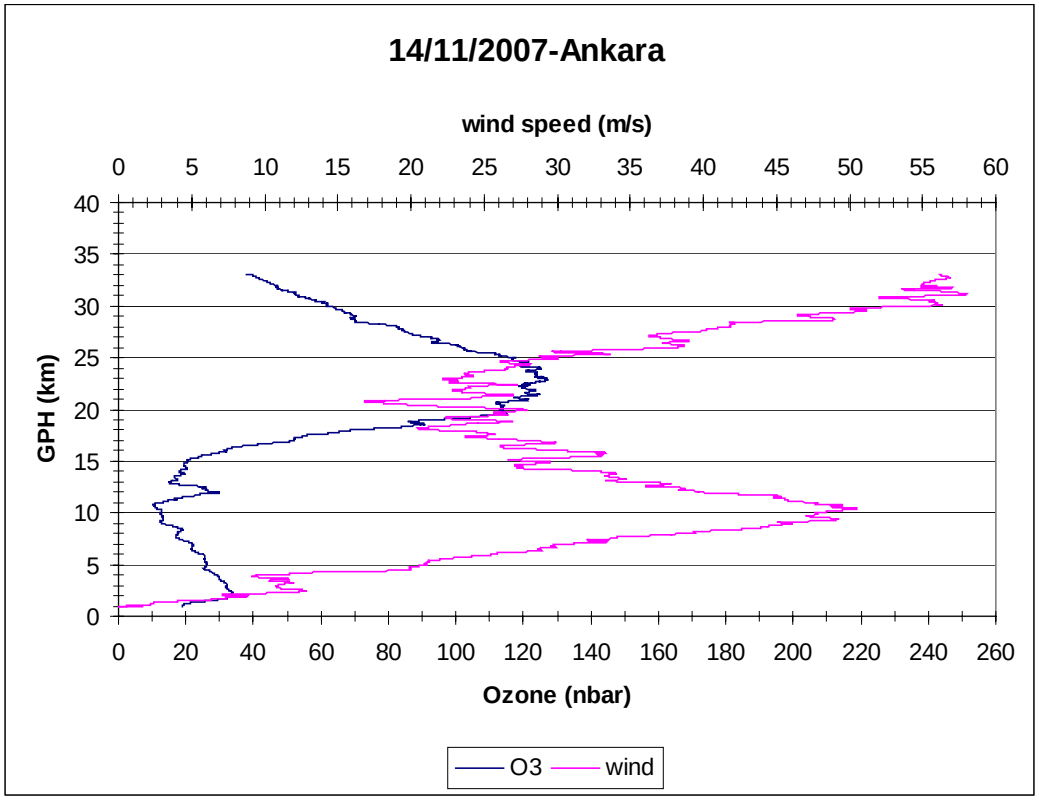

Figure A.18: ECC ozone and wind profile for Ankara on 14.11.2007

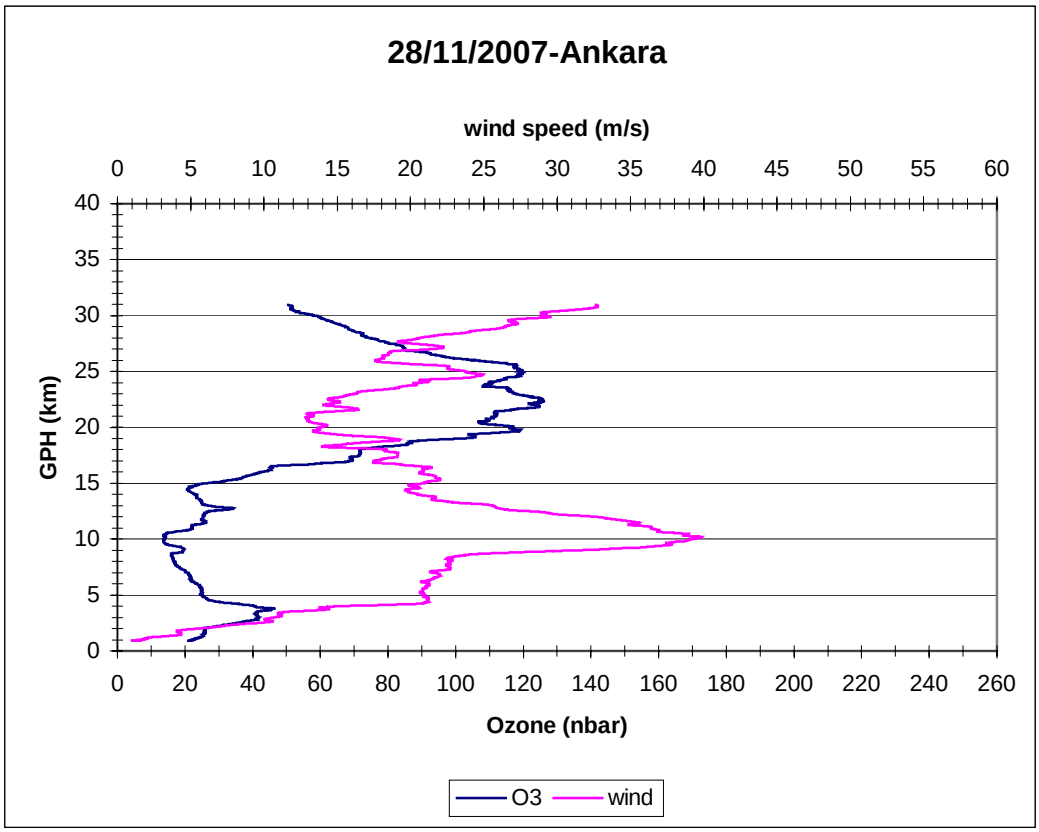

Figure A.19: ECC ozone and wind profile for Ankara on 28.11.2007

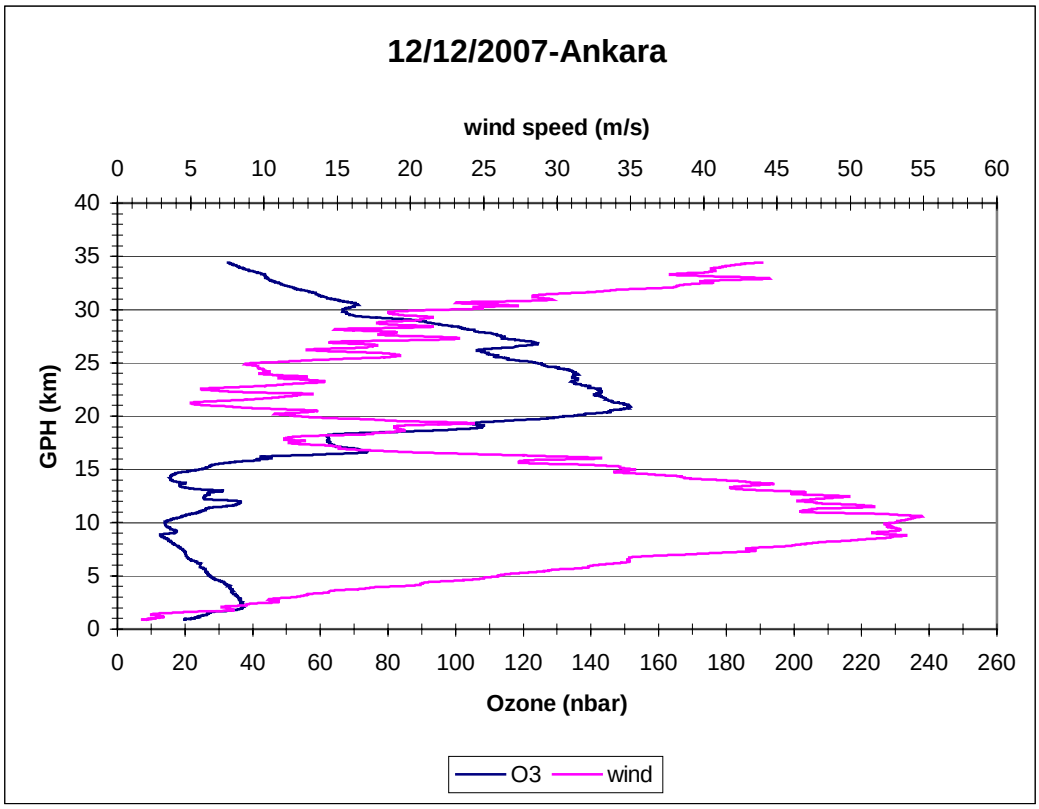

Figure A.20: ECC ozone and wind profile for Ankara on 12.12.2007

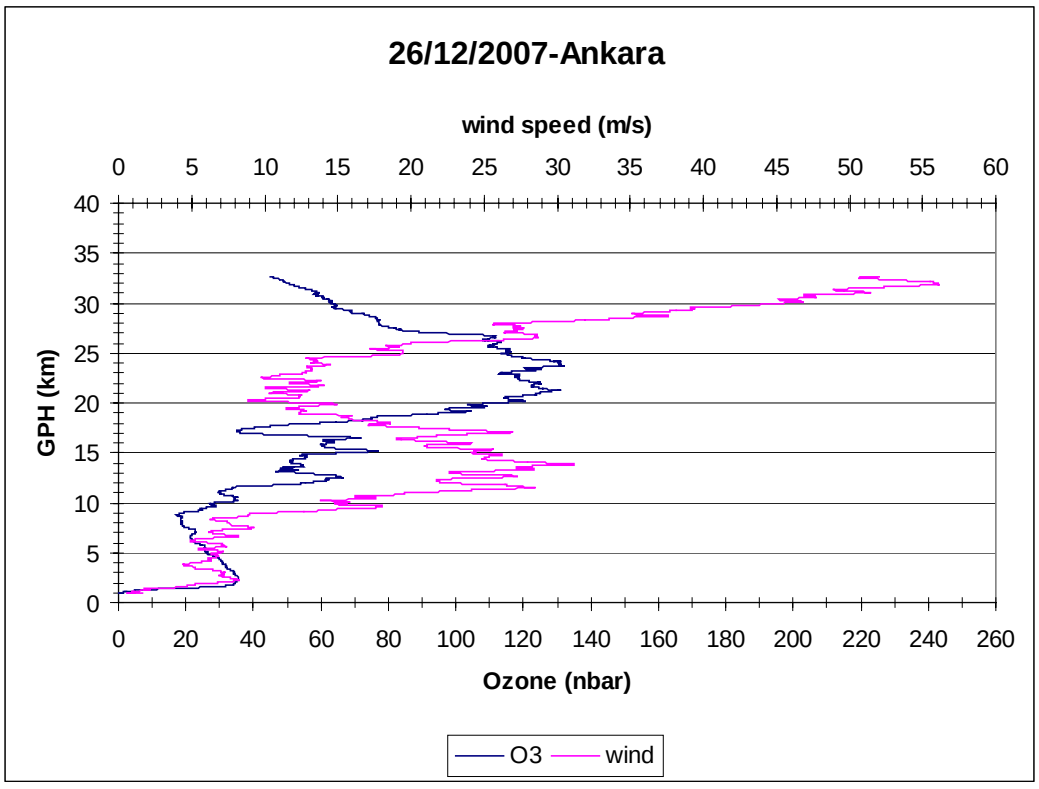

Figure A.21: ECC ozone and wind profile for Ankara on 26.12.2007

RESUME

Özlem Özkızılkaya was born in Istanbul in 1980. She completed her secondary and high school education at Sainte Pulchérie French Secondary School (1996) and Saint Benoit French High School (1999) respectively. In 1999, she attended to Meteorological Engineering in İstanbul Technical University and received her Bachelor degree in 2005. In January 2008, she received her MSc. Degree in Energy Science and Technology Program at ITU Institute of Energy where she works as reseacrh assistant since 2005. Then she attended to the Energy Science and Technology PhD. program. She is also MSc. student in Atmospheric Sciences program at ITU Institute of Science and Technology.