Atmospheric Sounding Campaign of the EUMETSAT Polar System (EPS) took place in Sodankylä, Finland from June 4 until September 5, 2007. During the three month time period we made frequent measurements of high vertical resolution temperature, water vapor and ozone profiles by balloon borne in situ instruments as the primary goal of the campaign. Water vapor and temperature measurements were timed to two overpasses per each campaign day, while ozone profiles were measured three times per week. In situ instruments were the RS92-SGP radiosondes with the new attachment method, which reduces the radiation effect on the daytime humidity measurements; the ECC ENSCI z type ozonesondes; and the cryogenic frost point hygrometers (CFH), which provide accurate measurement of water vapor in upper troposphere and lower stratosphere. In addition to the balloon borne observations, the campaign provided data from ground based continuous measurements of tropospheric water vapor and temperature profiles, cloudiness, surface weather parameters, total ozone, aerosol optical depth and total column of water vapor. The paper presents an overview of the data obtained during the campaign and the initial water vapor and ozone data comparisons to assure the quality of the acquired measurements.

INTRODUCTION

Confidence in satellite observations is based on independent validation measurements. A large data set of ground based measurements suitable for satellite validation was collected during the Atmospheric Sounding Campaign of the EUMETSAT Polar System (EPS) in Sodankylä, Finland in summer 2007. The site of measurements is representative of high-latitude conditions and has a well-developed infrastructure suitable for atmospheric campaigns. Here we first provide a short description of the site and information on the satellite validation activities in Sodankylä. Secondly we present an overview of the data obtained during the EPS validation campaign in Sodankylä.

SITE DESCRIPTION

The Finnish Meteorological Institute's (FMI) Arctic Research Centre (ARC) is located at Sodankylä in northern Finland (location: 67.368 °N, 26.633 °E, 179 m above mean sea level). Sodankylä area is usually classified to boreal region. However, with regard to the stratospheric meteorology, Sodankylä can be considered to be an Arctic site, often lying beneath the middle or the edge of the stratospheric polar vortex and in the zone of polar stratospheric ozone depletion. The Sodankylä site has a long history extending back to 19th century as a boreal- sub arctic meteorological and magnetic observatory. Continuous, homogenized time series of the key Sodankylä weather parameters start from the year 1908 and the radiosonde record, also homogenized to the extent possible, goes back to
1949. In the present time FMI-ARC executes ground based observation program serving operational weather forecasting and atmospheric research, arctic global change research program, technical development and support functions and satellite data receiving, processing and archiving functions. FMI has operated a satellite reception system since 2003. We are receiving X-band direct broadcast dissemination from three satellites: Aura, Terra and Aqua. Direct broadcast dissemination gives us instant access to data covering area extending from the North Pole to the Mediterranean. Because of our northern location we are able to receive polar data from over 10 orbits per day for each satellite. An example of satellite data receiving and processing activities is shown in Figure 1. The total ozone map in Figure 1 is based on the FMI’s very fast delivery (VFD) product of the Ozone Monitoring Instrument (OMI) on board NASA’s EOS Aura satellite (Hassinen et al., 2008; Leppelmeier et al., 2006). The map is selected from the time of the EPS campaign in Sodankylä and is related to the ozone profile measurements that are presented in the paper (Figures 5-7). The OMI-VFD products are also available through the EPS database concerning the time period of the campaign held in Sodankylä.

In the past two decades the research group at FMI-ARC has participated in all major European polar ozone campaigns and in several international atmospheric research projects. Satellite validation and satellite operations in general are an emerging topic, which have gradually expanded especially over the last 10 years. For example, FMI-ARC has submitted Sodankylä data for the validation of almost all polar orbiting ozone satellites and has been an active partner in the validation of e.g. ENVISAT mission of ESA and recently hosted a total ozone intercomparison and validation campaign SAUNA for Ozone Monitoring Instrument onboard the EOS AURA satellite of NASA. FMI-ARC has also hosted the LAUTLOS intercomparison campaign for the balloon borne humidity sensors, which involved the most commonly used radiosonde humidity sensors and research grade frost point and alpha-lyman humidity sensors (Deuber et al., 2005; Vömel et al., 2007a; Vömel et al., 2007b; Suortti et al., 2008;).

**Figure 1 :** An example of the OMI-VFD total ozone product on June 27, 2007 at 11:05 UTC.

**ATMOSPHERIC SOUNCING CAMPAIGN OF THE EUMETSAT POLAR SYSTEM**

The Atmospheric Sounding Campaign of the EUMETSAT Polar System in Sodankylä took place during the time period June 4- September 5, 2007.

Core atmospheric parameters of the campaign were the vertical profile of air temperature measured in situ and vertical profile of atmospheric humidity measured in situ. Additional atmospheric parameters were the vertical profile of ozone concentration, measured in situ; vertical profile of water vapour measured from the surface; total columnar amount of water vapour measured from the surface; total columnar amount of ozone measured from the surface. Core surface parameters were surface temperature with an accuracy better than 0.2K; air temperature with an accuracy better than 0.2K;
relative humidity with an accuracy better than 5%; surface pressure with an accuracy better than 0.1 hPa; cloud amount as cloudy fraction of the whole sky at the station; visual estimation of cloud bottom and top height. Additional surface parameters were the wind speed and direction at 10m; precipitation rate in mm/h and the atmosphere optical thickness obtained by sun photometer.

The balloon borne in situ instruments used in the campaign were the RS92-SGP radiosondes by Vaisala (PTU sondes), the reference level cryogenic frost point hygrometers (CFH) and the ECC ozonesondes by ENSCI.

During the campaign in total 360 PTU sondes, 40 ozone sondes and 7 frost-point hygrometers were flown. These 360 PTU sondes correspond to two Meteorological Operational Satellite (Metop) passes on each calendar day, assuming 2 soundings per each overpass during three months of operation. Ozone sondes were launched 3 times per week, CFH sondes in average two times per month. Each CFH sonde payload included also an ozonesonde and one or more PTU sondes. The measurements were made with the purpose to provide validation data for T, Q and O3 parameters at given levels for the EPS L2 products at the location of the campaign site.

Figure 2 illustrates the balloon launch strategy applied during the campaign. The first PTU launch took place 1 hour and the second PTU launch 5 minutes before each selected Metop overpass. We performed in total 4 overpass launches each day, first during the morning overpass and the second one during the evening overpass. In addition, regular PTU sondes were launched at 23:30 and 11:30 UT on each day. The ozonesonde and the CFH sondes were launched during the morning overpass and as the first sonde (one hour before the satellite overpass). During the balloon launches continuous measurements of the temperature and water vapor profiles were obtained by a ground based microwave radiometer and cloud base was measured by a ceilometer.

Air temperature

Vertical profiles of air temperature were measured by balloon borne Vaisala RS92 radiosonde. RS92 is the newest digital radiosonde based on the RS80-RS90 sonde family, which is widely used in the WMO meteorological network since early 1980s. The temperature accuracy of those sondes given by Vaisala is ±0.2 °C at the 2-sigma level throughout the troposphere for night time measurements (Paukkunen et al., 2001). This is consistent with the detailed uncertainty analysis given by Luers for the sonde RS90 (1997). Vertical resolution of the data recording is 2 seconds, which leads to 8-10 m vertical resolution given the typical balloon ascent of 4-5 m/s.

Water vapor

Vertical profiles of atmospheric humidity were measured by the RS92 radiosonde in the troposphere and by the CFH sonde in the troposphere and stratosphere. Humidity measurement by the CFH instrument is based on the chilled mirror principle (Vömel et al., 2007c). The measurement uncertainty of the CFH is about 0.5°C in frost-point temperature. The Vaisala RS92 humidity sensor is a thin-film capacitor that directly measures relative humidity. It consists of two sensors, which are alternately
measuring and being heated, thus eliminating coating of the sensor by ice or liquid inside clouds. Miloshevich et al. (2006) tested a number of operational radiosondes. They found that RS92 humidity was the most accurate among the tested sondes. They suggested corrections to the standard humidity product, after which the RS92 mean accuracy relative to the reference instrument was found to be better than 1% in the lower troposphere, <2% in the middle troposphere, and <3% in the upper troposphere. During the EPS campaign we used a newer version of the humidity sensor with improved attachment method. The method reduces the radiation dry bias of the sonde daytime measurements. We tested the radiosonde humidity measurements by performing seven radiosonde comparison flights during the campaign. Each of the flights included both the new and old version of the humidity sensor and the reference instrument. These flights confirmed improved humidity measurement by the new sensor. An example of simultaneous measurements of the CFH instrument and the RS92 humidity sensor is presented in Figure 3. In addition to the profile comparisons, we performed total water vapor comparison with the GPS water vapor retrieval. The GPS receiver in the nearby (20 km) Finnish Geodetic Institute (FGI) station was utilized in the campaign. The GPS data and parallel AWS weather data were relayed directly through FGI to EUREF Permanent Network (EPN) and Zenith Total Delay and Total columnar amount of water vapor from this data were retrieved by Geoforschungszentrum Podsdam (GFZ) through bilateral cooperation with FMI. The accuracy of the integrated water vapor measurement is 1-2 mm. The GPS showed generally good agreement with the sondes, in average the ratio GPS/sonde total water vapor was 1.018 +/- 0.071.

![Figure 3: An example of simultaneous humidity profile measurements by the RS92 radiosonde (red) and the cryogenic frost point hygrometer CFH (in black color), balloon was launched on June 13, 2007 at 08:46 UT.](image)
Ozone measurements

During the campaign in Sodankylä the ENSCI type of electrochemical concentration cell (ECC) ozonesondes were flown using the 0.5 % KI buffered sensor solution. The ozonesondes were interfaced to Vaisala RS-92 SGP radiosondes with a digital OIF-92 interface. The ozonesonde payloads were flown by TA1200 rubber balloons manufactured by Totex. The Vaisala DigiCORA
Sounding System MW31 was used to receive and process radiosonde data, including ozone sensor data processing and GPS geolocation retrievals. The accuracy of the ozonesonde measurements in the stratosphere is 5%. An example of a single ozonesonde profile from the campaign is shown in Figure 5. The corresponding total ozone map from the day of the profile measurement is presented in Figure 1, as obtained by the OMI-VFD algorithm. This example was chosen in order to show the climatological minimum in ozone profiles at 15 km in June (Kivi et al., 2007) and secondly an event of strong positive ozone laminae between the tropopause and the climatological minimum.

![Sounding System MW31](image)

**Figure 5:** An example of ozone profile measurement during the campaign. The sounding time corresponds to the OMI-VFD retrieval shown in Figure 1.

The sequence of ozonesonde profiles from the three month campaign period is presented in Figure 6. The figure shows that most of the sondes were ascending well above the layer of maximum ozone concentration at around the altitude of 20 km. The given sequence of ozone profiles serves as an indicator of short term dynamical variability in the upper troposphere and lower stratosphere, which is related to the variability in the synoptic scale weather systems. A good proxy for the dynamical variability is the altitude of the thermal tropopause, which is shown by a black line in Figure 6.

At Sodankylä the total column ozone was measured by Brewer spectrophotometer. This instrument is a modified Ebert type grating spectrometer, it uses five wavelengths in the spectral range 306.3 and 320.1 nm for the standard ozone retrieval. The accuracy of the direct sun (DS) measurements is ±1 %. In addition to the DS measurements we obtained the zenith sky (ZS) measurements, which can fill the measurement gaps during the cloudy periods. ZS data are not recommended to be used for validation purposes. The bias of ZS measurements is clear from the total ozone time series presented in Figure 7. There are strong variations in absolute amount of total ozone during the campaign which correlates with the variability of the synoptic scale dynamical processes, approximated by the tropopause altitude (Figure 6).

During the campaign the sondes reached the average altitude of 8.7 hPa (about 33 km). This allowed reliable estimates of total column ozone from the sondes and thus comparison with total column observations by the ground based Brewer spectrophotometer located in Sodankylä. The total ozone comparison was made also with the space born total ozone monitoring instrument (OMI) on board the Aura satellite. We found that during the campaign the Brewer/sonde total ozone ratio was 0.989 ± 0.024, OMI/sonde total ozone ratio was 0.991 ± 0.025.
Figure 6: Ozonesonde profiles measured during the campaign. The white colour represents missing data, which is usually above the balloon burst altitude; the black line corresponds to the altitude of thermal tropopause.

Figure 7: Time series of the quality controlled total ozone measurements at Sodankylä site during the campaign period. OMI retrieval uses the TO3 algorithm, all OMI overpass data is shown.
CONCLUDING REMARKS

Atmospheric Sounding Campaign of the EUMETSAT Polar System (EPS) took place in Sodankylä, Finland during the time period June 4- September 5, 2007. As the result of the campaign we obtained a large data set of temperature, humidity and ozone measurements that were timed to the overpass of Metop satellite, which is the Europe’s first polar orbiting operational meteorological satellite. In total we acquired 360 PTU, 40 ozonesonde and 7 reference class CFH hygrometer profiles, added by continuous measurements of total water vapor and total ozone. We found that during the campaign the Brewer/sonde total ozone ratio was 0.989 ± 0.024, OMI/sonde total ozone ratio was 0.991 ± 0.025; the average GPS/sonde total water vapor ratio was 1.018 ± 0.071. The Sodankylä campaign data is currently being used for validation of measurements on board Metop-A satellite. The described dataset has a potential to be applied for validation of instruments on board other polar orbiting satellites.

REFERENCES


