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Technical Note: Validation of Odin/SMR limb observations of ozone, comparisons with OSIRIS, POAM III, ground-based and balloon-borne instruments

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Abstract. The Odin satellite carries two instruments capable of determining stratospheric ozone profiles by limb sounding: the Sub-Millimetre Radiometer (SMR) and the UV-visible spectrograph of the OSIRIS (Optical Spectrograph and InfraRed Imager System) instrument. A large number of ozone profiles measurements were performed during six years from November 2001 to present. This ozone dataset is here used to make quantitative comparisons with satellite measurements in order to assess the quality of the Odin/SMR ozone measurements. In a first step, we compare Swedish SMR retrievals version 2.1, French SMR ozone retrievals version 222 (both from the 501.8 GHz band), and the OSIRIS retrievals version 3.0, with the operational version 4.0 ozone product from POAM III (Polar Ozone Atmospheric Measurement). In a second step, we refine the Odin/SMR validation by comparisons with ground-based instruments and balloon-borne observations. We use observations carried out within the framework of the Network for Detection of Atmospheric Composition Change (NDACC) and balloon flight missions conducted by the Canadian Space Agency (CSA), the Laboratoire de Physique et de Chimie de l´Environnement (LPCE, Orléans, France), and the Service d'Aéronomie (SA, Paris, France). Coincidence criteria were 5° in latitude$\times$10° in longitude, and 5 h in time in Odin/POAM III comparisons, 12 h in Odin/NDACC comparisons, and 72 h in Odin/balloons comparisons. An agreement is found with the POAM III experiment (10–60 km) within -0.3 ± 0.2 ppmv (bias$\pm$standard deviation) for SMR (v222, v2.1) and within -0.5 ± 0.2 ppmv for OSIRIS (v3.0). Odin ozone mixing ratio products are systematically slightly lower than the POAM III data and show an ozone maximum lower by 1–5 km in altitude. The comparisons with the NDACC data (10–34 km for ozonesonde, 10–50 km for lidar, 10–60 for microwave instruments) yield a good agreement within -0.15 ± 0.3 ppmv for the SMR data

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and −0.3±0.3 ppmv for the OSIRIS data. Finally the comparisons with instruments on large balloons (10–31 km) show a good agreement, within −0.7±1 ppmv. The official SMR v2.1 dataset is consistent in all altitude ranges with POAM III, NDACC and large balloon-borne instruments measurements. In the SMR v2.1 data, no different systematic error has been found in the 0–35km range in comparison with the 35–60 km range. The same feature has been highlighted in both hemispheres in SMR v2.1/POAM III intercomparisons, and no latitudinal dependence has been revealed in SMR v2.1/NDACC intercomparisons.

1 Introduction

Satellite sensors play a crucial role in monitoring the chemical and dynamic structure of the atmosphere thanks to their global spatial and temporal coverage. New space missions are continually necessary to provide information for understanding ozone and climate change.

The atmospheric composition can be measured from space by several techniques that include nadir observations of scattered sunlight, occultation of direct solar and stellar light, and limb measurements of the scattered and thermally emitted radiation. Nadir observations are characterized by excellent geographic coverage but a coarse height resolution, while occultation techniques have good height resolution but in general poor geographic coverage, especially the solar occultation technique. The limb-scattering and limb-emission techniques have the advantage of both high vertical resolution and good geographic coverage but with limited horizontal resolution. The Odin satellite was launched in February 2001 to measure limb-scattered solar radiances and limb thermal emission with the main goal of deriving vertical profiles of minor species in the stratosphere (Murtagh et al., 2002).

Forward models for the sub-mm wavelength range and inversion codes using the Optimal Estimation Method (OEM) permit the retrieval of vertical profiles in the stratosphere and mesosphere. Two codes were developed in parallel, one at the Université Bordeaux 1, Observatoire de Bordeaux, named MOLIERE (Urban et al., 2004a), a second one at the Chalmers University of Technology, Göteborg, Sweden, named ARTS/Qpack (Buehler et al., 2005; Eriksson, 2006). A code based on the technique described by Flittner et al. (2000) and McPeters et al. (2000) was developed to analyse the OSIRIS data and provide vertical profiles of ozone.

It is necessary to assess the quality of the data from the Odin SMR and OSIRIS sensors by well-tested and proven instruments. The assessment also helps to improve the calibration, refine inversion algorithms and detect possible errors. Validation of space-borne sensors is usually carried out with a large amount of correlative data, including high vertical resolution balloon-borne and ground-based measurements with known accuracy, which ideally cover all seasons to obtain good statistics from the comparisons. Furthermore, a criterion should be selected for the comparisons so that the temporal resolution should address the natural variability and the spatial resolution should resolve relevant gradients in the measurements.

The comparisons presented in this study address the quality of the SMR stratospheric ozone profiles for the 4-year period from November 2001 to July 2005. This period is long enough to find seasonal dependencies in the retrievals. The SMR ozone profiles are compared on a monthly basis with data retrieved from the space-borne instruments OSIRIS and POAM III and with ground-based instruments of the Network for Detection of Atmospheric Composition Change (NDACC). This paper is structured in the following manner: (2) a brief description of the Odin mission, (3) statistical monthly intercomparisons of zonally-averaged coincident SMR, OSIRIS and POAM III stratospheric ozone profiles, (4) an evaluation of Odin SMR/OSIRIS ozone measurements against results obtained from well-established and validated ground-based instruments and remote sensors operated onboard stratospheric balloons, providing accurate measurements but with a rather limited coverage in space and time, (5) discussion of the results and concluding remarks.

2 Odin satellite measurements

Odin is a Swedish-led scientific mission that also includes France, Canada, and Finland (Murtagh et al., 2002; Llewellyn et al., 2003). Odin was launched on 20 February 2001 into a polar, sun-synchronous, near-terminator orbit. The maximal latitudinal coverage in the orbit plane ranges from 82.5° N to 82.5° S. The goal of the Odin aeronomy mission is to produce vertical profiles of atmospheric constituents such as O_3, N_2O, OClO, ClO, BrO, CO, HNO_3, H_2O, NO_2, NO, HO_2, isotopes of H_2O and O_3 and aerosols. Nearly 67% of the Odin aeronomy observational time is spent scanning between 7 km and 70 km (stratospheric mode), while the majority of the rest is spent scanning from 7 to 110 km (strato-meso mode).

Odin has two optically co-aligned instruments: the Sub-Millimetre Radiometer (SMR) and the Optical Spectrograph and InfraRed Imager System (OSIRIS). Key elements of SMR are a 1.1 m telescope and four tunable single-sideband Schottky-diode heterodyne receivers that passively measure the limb thermal emission in the spectral range of 486–581 GHz, as well as two high-resolution auto-correlator spectrometers (Frisk et al., 2003; Olberg et al., 2003). Usually measurements are performed in stratospheric mode twice a week, and atmospheric constituents such as O_3, ClO, N_2O, and HNO_3 are retrieved from limb observations in two frequency bands centred at 501.8 GHz and 544.6 GHz (Urban et al., 2004b, 2005).

In this paper, we assess the quality of the main Odin/SMR level 2 ozone products from the 501.8 GHz band, obtained by the two most recent algorithm versions: Version 2.1 (or "Chalmers-v2.1") is the official product of the Chalmers University of Technology, Göteborg, Sweden; Version 222 of the so-called Chaîne de Traitement Scientifique Odin (CTSO) is the reference product initially developed at the Observatoire Aquitain des Sciences de l'Univers, Bordeaux, France and since 2005 at the Laboratoire d'Aérologie, Toulouse, France. This alternative version ("CTSO-v222") serves to evaluate the quality of the operational SMR products.

The OSIRIS spectrograph measures scattered sunlight over the wavelength range 280 nm to 800 nm. The vertical sampling is about 1 km in height at the tangent point. OSIRIS is capable of measuring vertical profiles of stratospheric O_3, NO_2 and aerosols. Ozone number density profiles are retrieved from the OSIRIS limb radiance spectra in the Chappuis absorption band between 10 and 46 km on a 2-km grid using the inversion technique originally developed by Flittner et al. (2000) for the SOLSE/LORE experiment and adapted to OSIRIS by Von Savigny et al. (2003). In this paper we use version 3.0 of the OSIRIS data. The vertical resolution of the OSIRIS measurements varies from about 1 km at 7 km to 2.5 km at 70 km. The total error for the OSIRIS ozone retrievals is estimated to be 6% at about 24 km, increasing roughly linearly to 12–14% at 10 km and 33% at 44 km (Haley et al., 2007).

For the stratospheric mode, SMR vertical sampling corresponds to about ∼1.5 km (below 50 km) in the stratosphere and ∼6 km in the mesosphere. The SMR vertical resolution is about 3 km in the middle stratosphere. Odin scans have a spatial horizontal resolution along the satellite track of ∼500 km. The SMR single-scan precision due to measurement noise is of the order of 0.25–1.5 ppmv (20–25%) and the estimated total systematic error is less than 0.4 ppmv at 25–50 km, and less than 0.75 ppmv below 25 km (Urban et al., 2005).

The following text summarises four recent studies concerning the validation of the SMR ozone data. (1) The improvement of the Chalmers retrieval algorithm has been recently evaluated by Jones et al. (2007). Three versions (v1.2, v2.0 and v2.1) of Odin/SMR ozone have been compared with MIPAS v4.61 and balloon sonde data during 2003. The v2.1 showed the smallest systematic differences compared to both coincident MIPAS and sonde data, especially below 25 km. In this lower stratospheric region, v2.1 was only slightly smaller than MIPAS by less than 0.25 ppmv, while comparisons to sonde measurements showed an agreement within ±0.3 ppmv. The largest systematic differences for this version were seen in the tropics, where a negative bias of 0.7 ppmv between 25–37 km was found. (2) The v222 data have been compared to the ASUR (Airbone Submillimeter Radiometer) instrument deployed onboard the Falcon research aircraft during the SCIAVALUE (September 2002, February/March 2003) and EUPLEx (January/February 2003) campaigns (Kuttippurath et al., 2007). A very good agreement is found in the tropics at 25–34 km, where the difference are within 5%. Above 35 km the deviation is slightly higher, up to 40%. The deviation in the high and mid-latitudes is within ±15% between 20 and 40 km. (3) An intercomparison of O_3, profiles measured by SMR and MLS (Microwave Limb Sounder) on board Aura satellite has been performed by Barret et al., 2006. SMR (v222) and MLS (v1.5) have been compared over a few days in September 2004 and March 2005. SMR is found significantly biased high relative to MLS in the lower stratosphere at and below the ozone peak. Relative biases vary from 9% in the tropics to 18% at high latitudes. An average bias of 5 to 9% is found between 31 (∼25 km) and 10 hPa (∼32 km) in all latitudes and both seasons. (4) A study of the consistency between stratospheric ozone products from the two independent instruments (SMR and OSIRIS) onboard the Odin satellite, was carried out by Brohede et al. (2007). This is relevant for validating the data products, but it is also interesting because the instruments represent fundamentally different measurement techniques: limb emission sounding at submillimetre wavelengths versus UV-visible limb-scatter technique. Since OSIRIS and SMR are mounted on the same platform and are co-aligned, they give perfect matches in time and space. Comparisons are made between OSIRIS version 3.0 and SMR version 2.1 ozone data in order to evaluate the consistency of the Odin ozone data sets. Results show a good agreement between OSIRIS and SMR in the range 25–40 km, where systematic differences are less than 15% for all latitudes and seasons. Larger systematic differences are seen below 25 km, which can be explained by the increase of various error sources and lower signals. The random differences are between 20–30% in the middle stratosphere. There is little variation from year to year, but a slight positive trend in the differences (OSIRIS minus SMR) of 0.045 ppmv/year at 30 km over validation period (2002–2006). The fact that the two fundamentally different measurement techniques agree so well, provides confidence in the robustnes of both techniques.

3 POAM III measurements

3.1 POAM III mission

The Polar Ozone and Aerosol Measurement (POAM) III instrument was developed by the Naval Research Laboratory (NRL) to measure the vertical distribution of atmospheric ozone, water vapour, nitrogen dioxide, aerosol extinction, and temperature. Under cloud-free conditions POAM III routinely measures well down in the troposphere. POAM III measures solar extinction in nine narrow band channels, covering the spectral range from 354 to 1018 nm. Solar extinction by the atmosphere is measured using the solar occultation technique; the Sun is observed through the Earth's

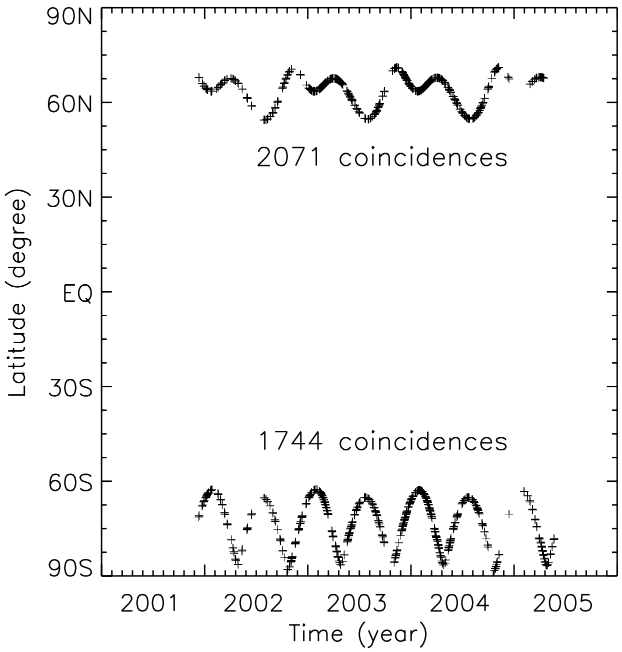

Fig. 1. Latitudes of the POAM III – Odin coincident measurements in the Northern Hemisphere (2071 coincidences) and in the Southern Hemisphere (1744 coincidences) from November 2001 to July 2005.

atmosphere as it rises and sets, as viewed from the satellite. POAM III was launched aboard the French SPOT-4 satellite in March 1998 into a sun-synchronous polar orbit. As seen from the satellite, the Sun rises in the Northern polar region and sets in the Southern polar region 14.2 times per day. Sunrise measurements are made in a latitude band 55–71° North while sunsets occur between 63 and 88° South. The longitude ranges from 0° to 360°. Successive occultations occur around a circle of nearly constant latitude (cf. Fig. 1), and separated by ∼25.4° in longitude. The vertical resolution of the POAM III ozone profiles is 1 km from 15 to 50 km, 1.5 km at 10 km, more than 5 km at 5 km, and reaching 2.5 km by 60 km. The predicted instrumental random error is about 5% or less in the range 12–50 km and increases rapidly below 12 km until 20%, largely due to signal noise. In addition to the random error, error bars include components due to aerosol extinction interference and sunspot artefacts. Sunspots affect the ozone retrievals primarily in the altitude range from 25 to 40 km, but even in this altitude range ≤10% of the ozone data are predicted to suffer from the sunspot artefacts that results in random errors of more than about 10% (Lumpe et al., 2002). Further details about the POAM III instrument can be found in Lucke et al. (1999). The POAM III v3.0 ozone validation has been performed by Randall et al. (2003). In this paper the POAM III-HALOE and POAM III-SAGE II comparisons concluded to an excellent quality of the POAM III data from 13 to 60 km, with an accuracy of 5% and suggest a very small (≤5%) sunrise/sunset bias in the POAM III data from 30 to 60 km (sr≤ss). These results are consistent with the results of Lumpe et al. (2002), who compared measurements from seven different instruments in the SOLVE campaign and found an agreement within 7–10%. In our intercomparsions we use the POAM III v4.0 ozone data. Informations about this last POAM III algorithm can be found in Lumpe et al. (2006).

3.2 Comparisons with POAM III satellite observations

A statistical analysis of comparisons between Odin retrievals from SMR (version 2.1, version 222) and OSIRIS (version 3.0) and POAM III (version 4.0) measurements has been performed. For statistical analyses with correlative satellite data, coincidence criteria were 5° in latitude x 10° in longitude and 5 h in time. We have not applied a vortex location criterion because the statistical results for the large number of coincidences studied here are insensitive to this criterion. Average profiles are created by selecting all the measurements satisfying the coincidence criteria. A preliminary selection for each instrument based on the quality flag has been done to eliminate questionable data due to bad radiance fits. This flag contains status information for various error, warning or informative purposes. For Odin data these errors are divided into different groups: moon in or near field of view, self-contained in or near the South Atlantic anomaly, potential temperature problem (≥2 km offset) and optical bench temperature ≤15°C (potential point spread function problems). Only measurements with quality flag assigned to zero (no error detected) have been selected. To refine this first selection, only good quality measurements have been retained with measurement response larger than 0.75 to ensure a minor contribution of the climatological a priori profile in the retrieved value. When the measurement response is zero, all the information comes from the a priori profile, needed in the OEM retrieval. The higher the measurement response is, the larger is the contribution of the measurement to the retrieved values.

In general SMR profiles show measurement responses larger than 0.75 above 20 km but in some cases down to 10 km. We show comparisons in the 10–60 km range keeping in mind that profiles below 20 km are averaged over a smaller number of profiles. Numbers of profiles indicated on the different figures concern the 20–60 km range. The OSIRIS data are converted in volume mixing ratio (VMR) units by using the ECMWF (P,T) fields provided in the Odin products.

Odin and POAM III Profiles are linearly interpolated as a function of log-pressure, to the fixed SMR/v222 2-km grid. We compare SMR/OSIRIS and POAM III profile by profile with the selected criteria before calculating for each instruments, 12 monthly mean profiles weighted by the total error (measurement noise and systematic errors). Calculations are made from January to December, over the whole period: 45 months from November 2001 to July 2005. As POAM III is

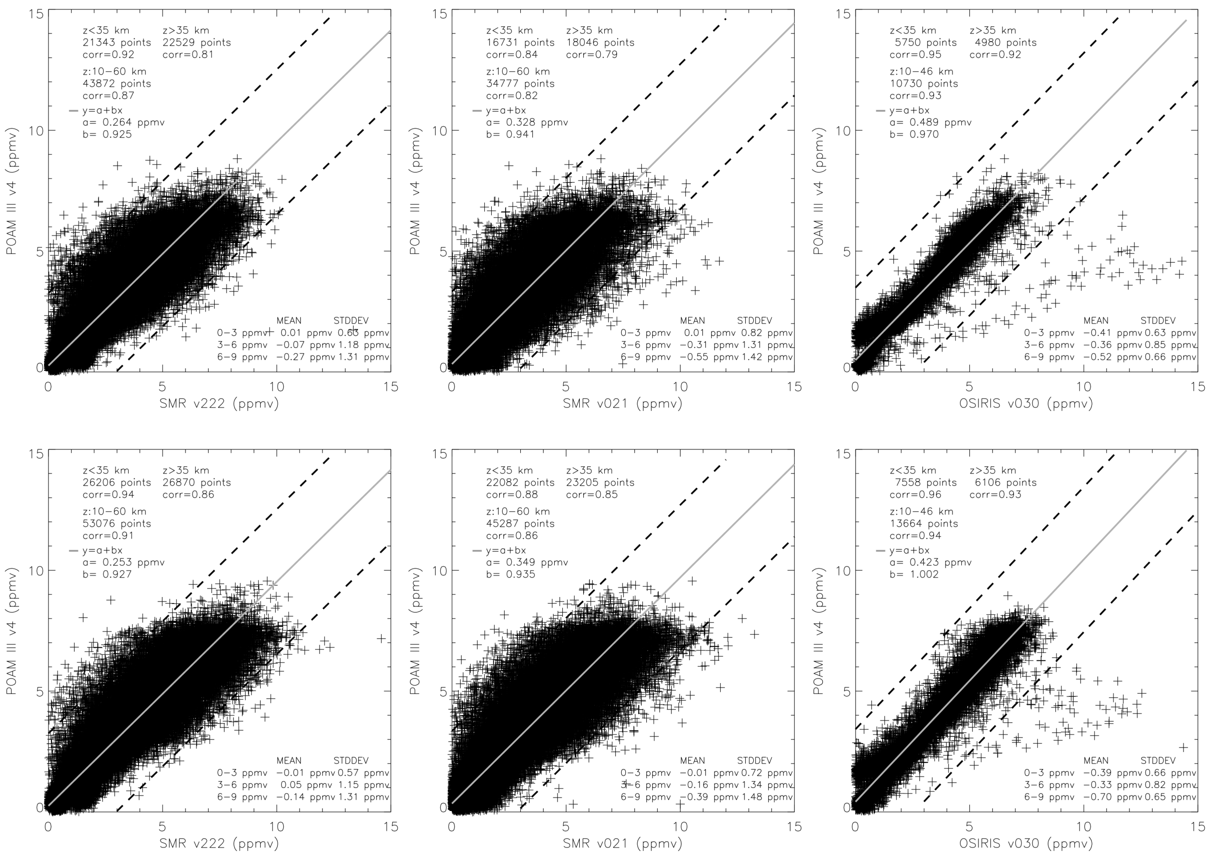

Fig. 2. Scatterplot of Odin/SMR and OSIRIS O_3 versus POAM III measurements. Left: Odin/SMR v222 data; middle: Odin/SMR v2.1 data; right: Odin/OSIRIS v3.0 data. Top: Southern Hemisphere; bottom: Northern Hemisphere. Mean differences and standard deviations are indicated for the different ranges of the O_3 mixing ratio. The dotted lines delimit deviations of ± 3 ppmv for clarity. The solid gray line indicates the linear fit to the data.

a solar occultation instrument, measurements are constrained to relatively narrow latitudinal bands. Consequently, most of the coincidences between POAM III and Odin measurements occurred in the high latitude, sunlit hemispheres.

Comparisons are performed separately for satellite sunrise and sunset occultations. Note that all POAM sunrise occultations occur in the Northern Hemisphere (NH) whereas all POAM sunset occultations occur in the Southern Hemisphere (SH). Local times for the POAM measurements correspond to local sunsets throughout the year in the NH, to local sunrise in the SH from April through August, and to local sunset in the SH from September through March. We have studied separately two ranges of altitudes (10–35 km and 35–60 km) to detect a possible altitude discrepancy.

We have applied our coincidence criteria successively to the SMR v222, SMR v2.1 and OSIRIS v3.0 profiles. Considering that the quality of the different ozone profiles is independent, the number of coincidences varies in terms of instruments and retrieval methods. As OSIRIS measurements are constrained to the illuminated hemisphere no coincidence is found during winter seasons. This explains the lowest number of coincidences found in the OSIRIS comparisons compared to the SMR comparisons, throughout the validation study. The total number of monthly coincidences between SMR and POAM III varies from 40 in September in the Southern Hemisphere to 368 in January in the Northern Hemisphere. For OSIRIS and POAM III comparison coincidences vary from 41 in October to 171 in March in the Northern Hemisphere. A summary of OSIRIS/SMR/POAM III annually and monthly coincidences is given in Table 1. In this table we show the absolute difference between the Odin and POAM III measurements considered as references. The numbers in the Table 1 represent the mean and standard deviation of the absolute difference profiles for the two range of altitudes: 10–35 km and 35–48 or 60 km.

In order to evaluate the Odin data quality against POAM III data, we combine all data in the form of a scatterplot. Results are plotted in Fig. 2. Each point in the scatterplot shows an ozone mixing ratio measured by Odin (SMR or OSIRIS instrument) and the corresponding measurement reported by the comparison instrument irregardless of the altitude associated with the pair of measurements. Negative values due to measurement noise are not shown in this figure but are used for the fit. For a more quantitative estimation of the

Table 1. Comparisons POAM III/Odin for the period November 2001 to July 2005 for Northern and Southern high-latitude measurements. (1) Mean latitude and spatial dispersion. (2) Number of profiles used for the POAM III/Odin comparisons for the different versions SMR/v222, SMR/v2.1 and OSIRIS/v3.0. (3)(4)(5) Averages ($\bar{\Delta X}=\frac{1}{n}\sum_{i=1}^{n}\Delta X_i$) and standard deviations (stddev=$\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\Delta X_i^2-\bar{\Delta X}^2)}$, number in brackets) of the absolute difference (ΔX=Odin-POAM III) are given over the two height ranges 10–35 km and 35–60 km.

Southern Hemisphere								
Month	(1) Latitude	(2) v222/v2.1/v3.0	(3) v3.0-POAM III		(4) v222-POAM III		(5) v2.1-POAM III	
			10–35 km	35–48 km	10–35 km	35–60 km	10–35 km	35–60 km
January	−64.4°±1.3°	218/186/78	−0.34 (0.24)	-0.53 (0.15)	0.05 (0.14)	−0.40 (0.11)	−0.12 (0.30)	−0.46 (0.12)
February	−72.0°±3.0°	192/171/113	−0.23 (0.16)	−0.52 (0.12)	0.10 (0.18)	−0.40 (0.11)	−0.08 (0.20)	−0.46 (0.16)
March	−83.7°±2.6°	170/134/0	−0.12 (0.21)	0.20 (0.20)	0.12 (0.28)	−0.08 (0.26)	−0.01 (0.17)	−0.21 (0.10)
April	−79.6°±3.3°	153/131/0			0.13 (0.33)	0.07 (0.40)	−0.07 (0.21)	−0.02 (0.30)
May	−70.4°±2.3°	94/88/0			−0.00 (0.29)	−0.04 (0.61)	−0.14 (0.14)	0.06 (0.48)
June	−67.6°±1.5°	167/121/0			0.12 (0.37)	−0.26 (0.65)	−0.20 (0.15)	0.05 (0.54)
July	−65.5°±0.4°	80/70/0			−0.04 (0.33)	0.08 (0.51)	−0.21 (0.15)	0.21 (0.40)
August	−76.1°±2.9°	117/89/0			−0.03 (0.44)	0.05 (0.43)	−0.14 (0.14)	0.01 (0.18)
September	−85.7°±2.0°	40/21/0			0.19 (0.44)	−0.42 (0.20)	−0.08 (0.21)	−0.35 (0.17)
October	−80.2°±3.3°	150/96/59	−0.05 (0.28)	−0.42 (0.19)	0.23 (0.29)	−0.32 (0.12)	0.14 (0.28)	-0.40 (0.08)
November	−69.9°±2.5°	188/152/120	−0.35 (0.21)	−0.58 (0.14)	0.17 (0.16)	−0.33 (0.16)	−0.11 (0.20)	−0.39 (0.12)
December	−63.7°±0.9°	175/152/75	−0.32 (0.21)	−0.55 (0.17)	0.16 (0.19)	−0.32 (0.13)	−0.07 (0.17)	−0.40 (0.10)
Annual	−73.4°±7.7°	1744/1411/456	−0.12 (0.31)	−0.10 (0.12)	−0.09 (0.23)	−0.19 (0.17)	−0.10 (0.15)	−0.20 (0.10)
Northern Hemisphere								
Month	Latitude	v222/v2.1/v3.0	v3.0-POAM III		v222-POAM III		v2.1-POAM III	
			10–35 km	35–48 km	10–35 km	35–60 km	10–35 km	35–60 km
January	64.8°±0.8°	368/316/0			0.13 (0.31)	−0.12 (0.30)	−0.02 (0.20)	-0.30 (0.18)
February	67.1°±0.5°	224/210/20	−0.26 (0.32)	−0.78 (0.30)	0.10 (0.28)	−0.06 (0.40)	−0.03 (0.20)	−0.21 (0.20)
March	67.1°±0.6°	326/302/171	−0.23 (0.10)	−0.83 (0.10)	0.11 (0.26)	−0.20 (0.23)	−0.05 (0.14)	−0.26 (0.14)
April	63.5°±1.4°	112/105/77	−0.23 (0.17)	−0.66 (0.17)	0.04 (0.22)	−0.28 (0.13)	−0.09 (0.17)	−0.31 (0.17)
May	58.8°±1.4°	120/115/68	−0.35 (0.25)	−0.81 (0.29)	0.06 (0.26)	−0.33 (0.14)	−0.09 (0.14)	−0.25 (0.16)
June	55.1°±0.5°	74/63/44	−0.40 (0.29)	−0.75 (0.35)	0.11 (0.25)	−0.31 (0.14)	0.06 (0.29)	−0.23 (0.09)
July	55.6°±0.8°	177/150/82	−0.33 (0.26)	−0.72 (0.34)	0.14 (0.25)	−0.38 (0.12)	−0.01 (0.13)	−0.29 (0.11)
August	60.8°±2.1°	134/117/45	−0.31 (0.22)	−0.62 (0.22)	0.18 (0.20)	−0.43 (0.16)	−0.06 (0.17)	−0.39 (0.14)
September	67.9°±1.8°	77/66/50	−0.24 (0.16)	−0.66 (0.10)	0.20 (0.25)	−0.24 (0.17)	0.04 (0.19)	−0.34 (0.13)
October	70.6°±0.5°	101/73/41	−0.12 (0.12)	−0.60 (0.11)	0.17 (0.25)	−0.10 (0.31)	0.02 (0.21)	0.14 (0.28)
November	66.9°±1.3°	148/124/0			0.18 (0.21)	0.03 (0.42)	−0.03 (0.22)	−0.05 (0.24)
December	63.8°±0.4°	225/182/0			0.28 (0.38)	0.06 (0.26)	0.11 (0.21)	−0.05 (0.17)
Annual	63.5°±4.8°	2071/1808/603	−0.39 (0.22)	−0.54 (0.12)	0.09 (0.26)	−0.20 (0.21)	−0.05 (0.11)	−0.23 (0.12)

systematic effects in the data, the mean and the standard deviation of the (Odin-POAM III) differences are calculated for each SMR and OSIRIS version for the three ranges of ozone mixing ratio: 0–3 ppmv, 3–6 ppmv and 6–9 ppmv. For the low mixing ratios of ozone (range 0–3 ppmv), i.e. the extreme lower and higher altitudes, we find a standard deviation smaller than 0.7, 0.8 and 0.7 ppmv for version SMR v222, SMR v2.1 and OSIRIS v3.0, respectively. SMR retrievals show here similar mixing ratios (difference: ±0.01 ppmv) as the POAM III measurements whereas OSIRIS profiles show smaller values (difference: −0.4 ppmv). In the intermediate range (3-6 ppmv), SMR measurements are in general lower than POAM III mixing ratios (difference: ±0.05 ppmv for v222 data, ∼0.3 ppmv for v2.1 data) and the standard deviation is of the order of 1.2 ppmv for the v2.1 data and 1.35 ppmv for the v222 data. OSIRIS profiles show lower mixing ratio (difference: −0.35 ppmv) than the POAM III measurements with a standard deviation of 0.85 ppmv. In the greatest ozone mixing ratio range (6–9 ppmv), corresponding to the ozone peak vicinity, SMR profiles still exhibit lower mean values of the order of 0.1–0.3 ppmv for v222 and 0.4–0.6 ppmv for v2.1 data. We find a standard deviation smaller than 1.4 ppmv and 1.5 ppmv for the SMR v222 and v2.1 versions respectively. OSIRIS profiles also show lower values (difference: ∼0.6 ppmv) with a standard deviation below 0.7 ppmv. In general, smaller standard deviations are found for OSIRIS v3.0 and SMR v222 data. Nevertheless OSIRIS results show a larger difference compared to the

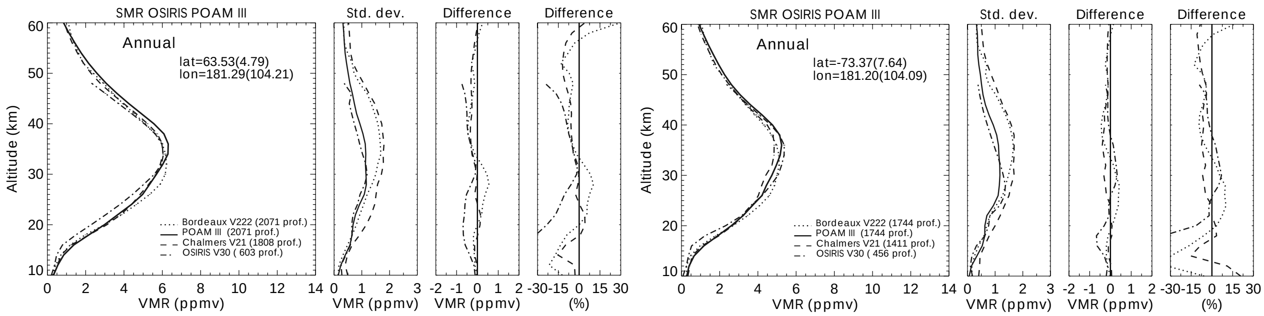

Fig. 3. Zonal mean comparisons between SMR/v222, SMR/v2.1, OSIRIS/v3.0 and POAM III/v4.0 ozone profiles performed for the period November 2001 to July 2005 for the Northern (left) and Southern (right) Hemispheres. The left plot shows the mean of coincident profiles for SMR/v222 (dotted), SMR/v2.1 (dashed), OSIRIS/v3.0 (dashed-dotted) and POAM III (solid). Error bars represent the calculated total error from n individual total errors: $\sigma(z)^2 = \sum_{i=0}^{n} \sigma_i(z)^2$. In annual comparisons the total error is within the line thickness. The three other plots show respectively the standard deviation in VMR (ppmv), the absolute (Odin – POAM III) and relative ((Odin – POAM III)/POAM III x 100) difference expressed in VMR (ppmv) and percentage, respectively. The number of coincident profiles used for the comparisons and the latitude-longitude coverage are indicated.

SMR versions. In summary, Odin data agree well with the POAM III v4.0 data in terms of standard deviation, within 1.5 ppmv (v2.1), 1.3 ppmv (v222) and 0.7 ppmv (v3.0) in the whole exploitable range. We also calculate correlation coefficients in two ranges of altitudes: 10–35 km and 35–48/60 (OSIRIS/SMR) km. The last results (shown in Fig. 2) are confirmed by these correlation coefficients which are systematically larger for the OSIRIS data (~ 0.95) compared to the SMR v222 ($\sim$0.9) and the SMR v2.1 ($\sim$0.85) data, reflecting mainly the noise in the individual mixing ratios.

To refine quantitatively our comparisons we calculate zonal average profiles for both latitude ranges over the complete period (cf. Fig. 3) and over 6 selected months (cf. Figs. 4 and 5). These plots show the really good agreement between Odin and POAM III profiles though both missions use different techniques and algorithms. In the annual comparisons (cf. Fig. 3) 2071 POAM III profiles in the Northern Hemisphere and 1744 POAM III profiles in the Southern Hemisphere are compared to the mean profiles. The first characteristic is the systematically lower values of the Odin profiles with respect to POAM III profiles: OSIRIS (-0.4 ± 0.2 ppmv), SMR v2.1 (-0.1 ± 0.15 ppmv) in the 10–35 km range. The SMR v222 data do not show a systematic tendency with a 0.1 ± 0.2 ppmv bias in the Northern Hemisphere and a -0.1 ± 0.2 ppmv bias in the Southern Hemisphere. In the 35-60 km range the Odin profiles show the same feature: OSIRIS (-0.6 ± 0.1 ppmv), SMR v222 (-0.2 ± 0.2 ppmv), SMR v2.1 (-0.2 ± 0.1 ppmv)).

Such annual comparisons are confirmed by the monthly comparisons shown in Figs. 4 and 5. OSIRIS and POAM III monthly profiles agree within 0.4 ± 0.3 ppmv between 10 and 35 km and within 0.8 ± 0.3 ppmv above 35 km in both hemispheres (Table 1). A negative bias is observed at all altitudes between OSIRIS and POAM III. It is consistent with the error analysis performed by Von Savigny et al. (2003) who have demonstrated that the OSIRIS retrieval method is less sensitive to ozone above 40 km. For OSIRIS, there is a know underestimation at higher altitudes that does not appear to be associated with a pointing problem, but rather a retrieval problem. There is, however, what seems to be a pointing problem in the May-July period (likely in some way related to satellite eclipse) as well as at other sporadic times during the mission. See McLinden et al. (2007) for more information.

The POAM III monthly profiles are closer to the SMR profile structures and especially to the v2.1 data with an agreement within -0.2 ± 0.15 ppmv between 10 and 35 km and within -0.4 ± 0.2ppmv between 35 and 60 km. The SMR/v222 retrievals systematically overestimate the ozone amounts below 35 km with a positive bias of 0.3 ± 0.3ppmv. In the 35–60 km range the SMR/v222 data show the same agreement of -0.4 ± 0.2ppmv as the SMR/v2.1 data. Such a positive bias ($\leq$10%) has already been detected below 10 hPa ($\sim$32 km), between SMR/v222 and MLS/v1.5 (Microwave Limb Sounder (Aura Satellite)) ozone profiles by Barret et al. (2006).

An additional feature of the comparisons is the discrepancy with respect to the maximum ozone altitude. In both hemispheres this altitude is systematically displaced to lower altitudes by 1–3 km for OSIRIS and SMR/v2.1 and by 1–5 km for SMR/v222 compared to POAM III. This offset could not be explained by the well-known Odin random error of 100–300 meters at the observed tangent point. This discrepancy was already highlighted during the initial OSIRIS ozone validation (Petelina et al., 2004, 2005). We have used OSIRIS v3.0 data based on reconstructed orbit data. Nevertheless an altitude offset of the ozone peak is again detected in OSIRIS data. In addition, most plots exhibit higher POAM III ozone values from the ozone maximum up to the mesosphere. The two SMR products are very similar from the ozone maximum to the top altitude (60 km) of the comparisons. In this altitude range POAM III profiles are in general

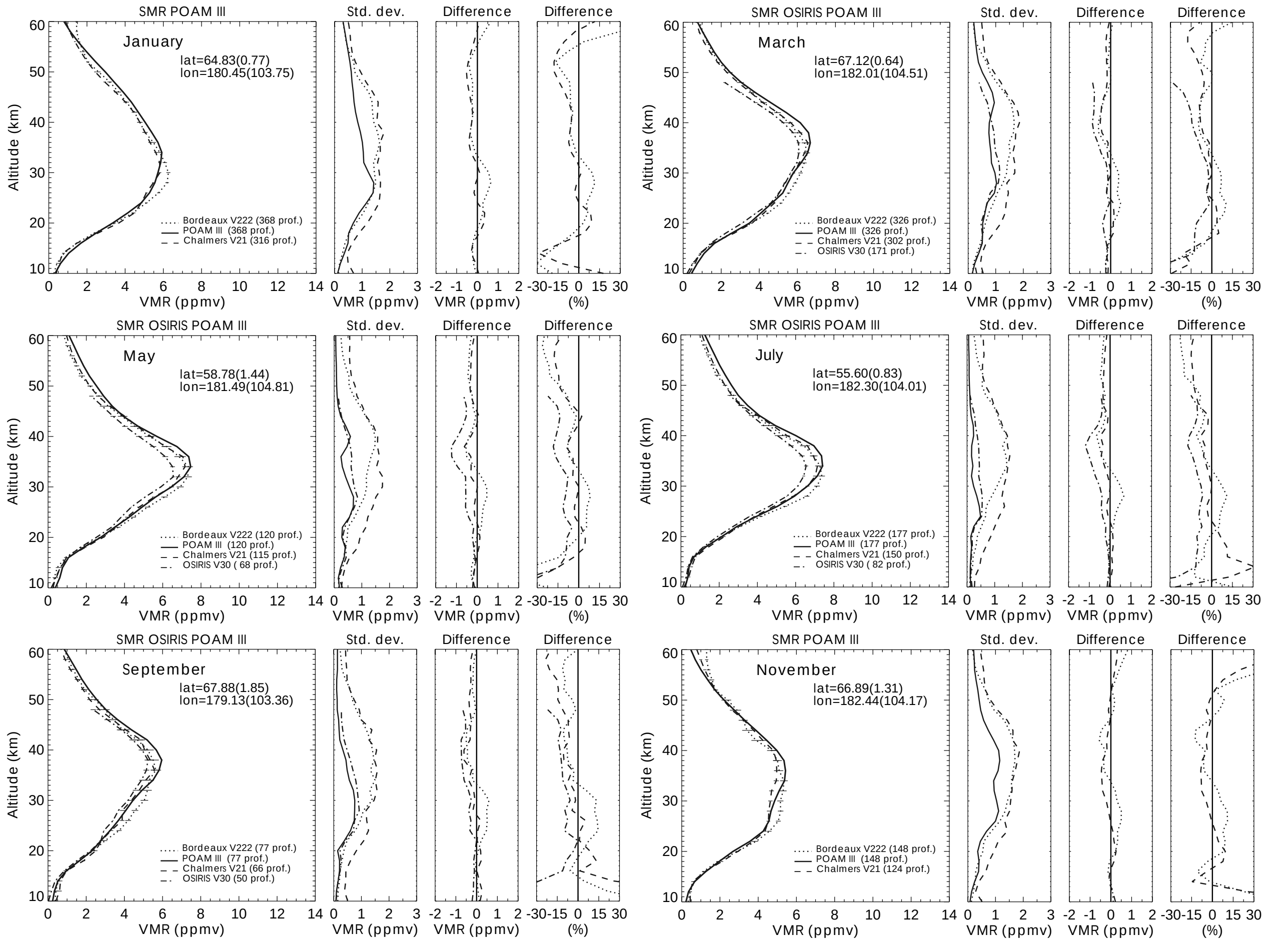

Fig. 4. Same as Fig. 3 but for monthly mean comparisons between ozone SMR/v222, SMR/v2.1, OSIRIS/v3.0 and POAM III/v4.0 coincident profiles performed for January, March, May, July, September and November for the full dataset in the Northern high latitudes 63.5°(±4.8°).

$\sim$0.5 ppmv larger than SMR profiles. This difference is reduced in the winter Northern Hemisphere (October–March) and reversely in the Southern Hemisphere (April-August) with a 0.5 ppmv positive bias between 45 and 60 km. From the ozone maximum to 48 km, the OSIRIS profiles follow quite well the SMR profiles with a slightly negative bias, maximal in the summer Northern Hemisphere (0.5–1 ppmv). This feature does not exist in the Southern Hemisphere. The new ozone retrieval code for OSIRIS, SaskMART, recently developed at the University of Saskatchewan could be the opportunity to investigate the origin of this discrepancy.

In summary, the Odin measurements and the POAM III ozone peak altitude are shifted by a few kilometres which create a difference in amplitude which continues up to the mesosphere. Odin SMR and OSIRIS maximum ozone peak values are mostly of the order of 0.5–1 ppmv smaller than POAM III values and located a few kilometres lower, but not in a systematic way. This feature continues up to the mesosphere with seasonal and hemispheric differences. In general, the Odin and POAM III measurements agree in monthly mean comparisons within -0.5 ± 0.2 ppmv (OSIRIS) and -0.3 ± 0.2 ppmv (SMR). SMR profiles do not show any altitude range with systematic discrepancy except the v222 positive bias in the 20–30 km range. The SMR v2.1 profiles are the Odin products which present the best overall agreement with POAM III profiles from the lower stratosphere to the mesosphere, in both hemispheres.

4 Ground-based and balloon-borne measurements

4.1 Measurement sites

Ground-based and balloon-borne data used for Odin SMR validation have a dual origin. First, we use experiment data pertaining to the NDACC. NDACC is a set of high-quality remote sensing research stations for the observation and understanding the physical and chemical state of the atmosphere. Ozone and key ozone-related chemical compounds and parameters are targeted for measurements. NDACC is a major component of the international upper atmosphere research effort. One of the principal goals of the network is to provide

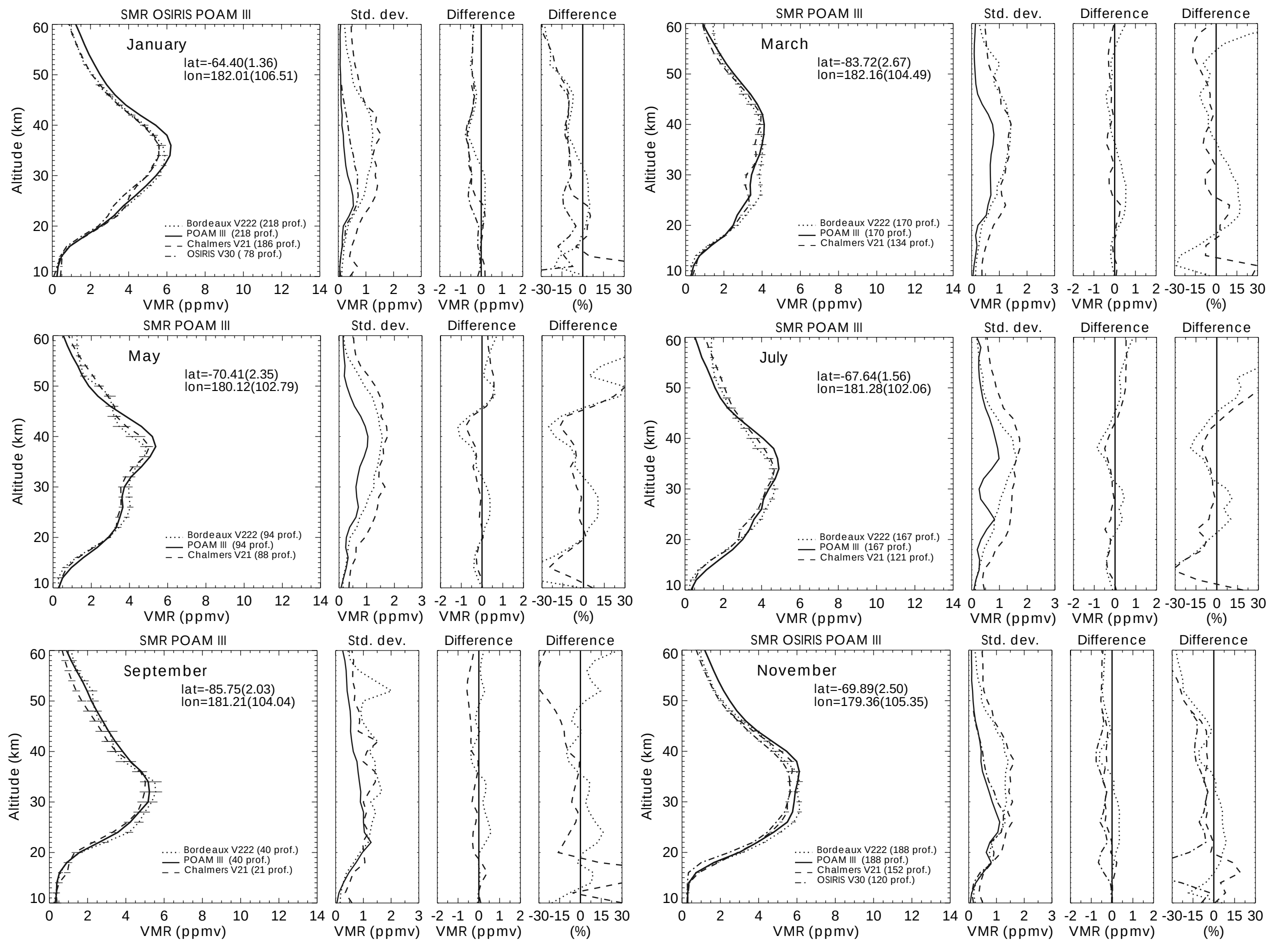

Fig. 5. Same as Fig. 4 but for monthly mean comparisons between ozone SMR/v222, SMR/v2.1, OSIRIS/v3.0 and POAM III/v4.0 coincident profiles performed for January, March, May, July, September and November for the full dataset in the Southern high latitudes −73.4°(±7.7°).

independent calibrations and validations of space-based sensors of the atmosphere and to make complementary measurements. The ground-based instruments used in the following comparisons are: (1) ozone lidars, (2) ozone microwave radiometers and (3) ozone sondes.

The NDACC brings together 87 stations dispersed in both hemispheres with prominent weight in the Northern mid-latitudes. We selected 32 stations (12 primary stations, 20 complementary stations). In Table 2 we give information about all selected stations: location, technique employed, number and range of selected dates, vertical range of comparison and the number of profiles retained. Sometimes a few Odin profiles are missing due to the poor quality of the observations or non-existent data. In general the available measurements for the comparisons spread over one to four years from November 2001 to July 2005.

Second, other data used for SMR validation were obtained by selective balloon-borne experiments. Three balloon-flights, AMON, SALOMON and SPIRALE were conducted by the Laboratoire of Physique et Chimie de l´Environnement (Orléans, France)) in Kiruna (Sweden) and Aire sur l´Adour (France). We also use data from the MANTRA 2002 campaign performed in Vanscoy (Canada) by the Canadian Space Agency and observations from two SAOZ flights conducted in Bauru (Brasil) by the Service d'Aéronomie (France). We summarise characteristics of these experiments at the end of Table 2. Figure 6 shows the selected NDACC stations and the five balloon flight site locations.

A selection for the Odin products based on the quality flag has also been done. For both sets of data we have compared ozone profiles over the largest possible range of altitudes. In general, SMR profiles are significant above the altitude 15–20 km and the NDACC observations do not really exceed 40 km for ozone sonde experiments, 50 km and 60 km respectively for lidar and microwave measurements. The maximum altitude of the balloon-borne ozone profiles is comprised between 29 and 36 km. So, we have validated SMR profiles with ground-based and balloon-borne observations over different altitude ranges from 15–20 km to 60 km. All plots are respectively gathered in Figs. 7 and 8 for the NDACC and in Figs. 10, 11, and 12 for the balloon flight inter-comparisons.

Table 2. Information about **(a)** the NDACC instruments and **(b)** balloon flight sites, employed techniques, number of coincidences and periods of the inter-comparisons. * M-W: micro-wave technique.

(a) NDACC sites					
Station	Techique	Coordinates	# of profiles	Upper altitude (km)	Temporal range
Alert, Canada	Sonde	82.5° N 117.7° W	26	48	16/01/2002–23/06/2004
Andoya, Norway	Lidar	69.3° N 16° E	35	48	17/01/2002–05/01/2005
Bern, Switzerland	M-W*	46.9° N 7.4° E	1394	58	09/11/2001–31/10/2003
Bordeaux, France	M-W	44.8° N 0.4° W	191	57	09/11/2001–23/05/2003
Boulder, USA	Sonde	40.0° N 74.7° W	39	36	07/12/2001–24/06/2005
Debilt, The Netherlands	Sonde	52.1° N 5.2° E	52	34	22/11/2001–07/07/2005
Dumont D'Urville, Antarctica	Sonde	66.4° S 140.0° E	26	32	04/07/2002–25/06/2005
Eureka, Canada	Sonde	80.0° N 86.4° W	22	46	24/12/2001–21/07/2005
Hilo, Hawaii USA	Sonde	19.7° N 155.1° W	40	46	31/2001/02–19/05/2005
Hohenpeissenberg, Germany	Sonde	47.8° N 11.0° E	98	46	09/11/2001–26/07/2004
id.	Lidar	id.	97	46	31/01/2002–19/05/2005
Izana, Tenerife Spain	Sonde	28.3° N 16.5° W	36	34	28/11/2001–05/01/2005
Lauder, New Zealand	Lidar	45.04° S 169.68° E	48	48	09/12/2001–11/12/2004
id.	M-W	id.	461	60	25/12/2001–07/07/2005
id.	Sonde	id.	48	32	03/11/2001–06/10/2004
Legionowo, Poland	Sonde	52.4° N 21.0° E	16	36	21/11/2001–24/11/2004
McMurdo, Antarctica	Sonde	77.8° S 166.6° E	2	30	26/09/2003–06/10/2004
Mauna Loa, Hawaii USA	Lidar	19.5° N 155.6° W	98	58	21/11/2001–16/06/2005
id.	M-W	id.	779	58	03/12/2001–22/07/2005
Natal, Brazil	Sonde	5.9° S 35.2° W	98	32	06/11/2001–29/03/2005
Neumayer, Antarctica	Sonde	70.6° S 8.4° E	69	32	21/11/2001–04/05/2005
Ny Alesund, Spitsberg	Lidar	78.9° N 11.9° E	48	50	28/11/2001–24/11/2004
id.	M-W	id.	1585	54	01/02/2002–30/11/2003
id.	sonde	id.	94	34	21/11/2001–05/05/2005
OHP, France	Lidar	43.5° N 5° 4'E	115	46	21/11/2001–16/06/2005
Paramaribo, Suriname	Sonde	5.75° N 55.2° W	42	32	21/11/2001–06/07/2005
Payerne, Switzerland	Sonde	46.82° N 6.9° E	147	34	09/11/2001–13/05/2005
id.	M-W	id.	4022	58	07/01/2004–26/01/2005
Prague, Czech Republic	Sonde	50.0° N 14.4° E	11	34	16/01/2004–05/01/2005
Samoa Islands	Sonde	14.2° S 189.4° E	28	38	10/11/2001–19/05/2005
Scoresbysund, Greenland	Sonde	70.5° N 158.0° W	43	34	09/11/2001–05/01/2005
Sodankyla, Finland	Sonde	67.4° N 26.7° E	36	36	21/11/2001–04/08/2004
South Pole, Antarctica	Sonde	90° S	16	32	19/09/2002–10/10/2004
Table Mountain, USA	Lidar	34.4° N 117.7° W	1161	58	10/11/2001–16/06/2005
Thule, Greenland	Sonde	76.5° N 68.7° W	16	34	08/03/2002–24/09/2004
id.	M-W	id.	19	58	25/01/2002–21/02/2003
Tsukuba, Japan	Lidar	36.0° N 140.1° E	20	38	27/11/2001–05/01/2005
Uccle, Belgium	Sonde	50.8° N 4.3° E	123	32	09/11/2001–05/01/2005
Wallops Island, USA	Sonde	38.9° N 76.7° W	51	34	21/11/2001–06/07/2005
(b) Balloon-borne experiment sites					
Launch site	Technique	Coordinates	# of profiles	Upper altitude (km)	Balloon-launch dates
Aire sur l´Adour, France	balloon	43.4° N 0.1° W	2	32–36	19/09/2002–02/10/2002
Kiruna, Sweden	balloon	67.5° N 21.0° E	3	27–33	21/01/2003–01/03/2003 20/01/2006
Vanscoy, Canada	balloon	52.0° N 107.0° W	5	26–38	15/08/2002–02/09/2002
Teresina, Brasil	balloon	5.0° N 43.2° W	1	33	22/06/2005
Bauru, Brasil	balloon	22.3° S 49.0° W	1	29	18/02/2003–31/01/2004

A statistical analysis of comparisons between Odin retrievals from SMR (CTSO/version 222, Chalmers/version 2.1), OSIRIS (version 3.0) and NDACC has been performed with different coincidence criteria. Since NDACC measurements are in general only conducted daily (except lidar and microwave measurements), we chose a broad time range coincidence criteria of less than 12 h, but the same spatial coincidence criteria of $\leq 5°$ in latitude and $\leq 10°$ in longitude as in the POAM III study. The time criterion has been extended to 1–3 days to find Odin/balloon-borne mission coincidences. Considering the average stratospheric wind speeds, the Odin satellite has a reasonable probability of encountering the same airmass measured by the ground-based and balloon-borne instruments within this time-distance criterion. However, under polar vortex conditions, large differences in the mixing ratios inside and outside the vortex are found. Consequently, in the case of individual profile comparisons, great care has been taken in comparing ozone profiles only when they are either both inside or both outside the polar vortex.

We recall that limb profiles are usually the intrinsic average along the observational line of sight, which sets a limitation to the horizontal resolution of the measurements. The Earth's limb is viewed in the flight direction covering about 500–1000 km around the tangent point.

4.2 NDACC observations

4.2.1 Techniques

Ozone sondes are launched more or less regularly on board of small meteorological balloons and yield the vertical distribution of ozone volume mixing ratio (VMR) from the ground up to the burst point (~30 km). Ozone VMR recorded at a typical vertical resolution of 100–150 m is converted into ozone number density using pressure and temperature data recorded onboard the same balloon. Typical error estimates are: systematic error from 3% (0–20 km) to 5% (20–35 km); precision from 5% (0–20 km) to 7% (20–35 km) (De Clercq et al., 2007).

To observe upper stratospheric ozone, most NDACC stations use either Differential Absorption Lidar (DIAL) or microwave radiometer systems. DIAL systems measure the ozone absorption of an atmospheric layer by comparing atmospheric return signals from the top and bottom of the layer, at two (or more) wavelengths (Pelon and Mégie, 1982). A summary of many validation exercises within the NDACC framework (Keckhut et al., 2004) shows that the accuracy of a typical stratospheric ozone profile measured by lidar is approximately 3% at 35 km, and 10% at 40 km, depending on averaging time, system power, and other factors (McDermid et al., 1998; McPeters et al., 1999). Altitude resolution is of the order of 1 km at 30 km altitude and 5 km at 40 km (Godin et al., 1999; Keckhut et al., 2004). Precision and altitude resolution become poorer with increasing altitude. Most systems do not provide reliable data above 50 to 55 km. Lidars need clear nights for their measurements, but this has not been a relevant drawback for long-term monitoring.

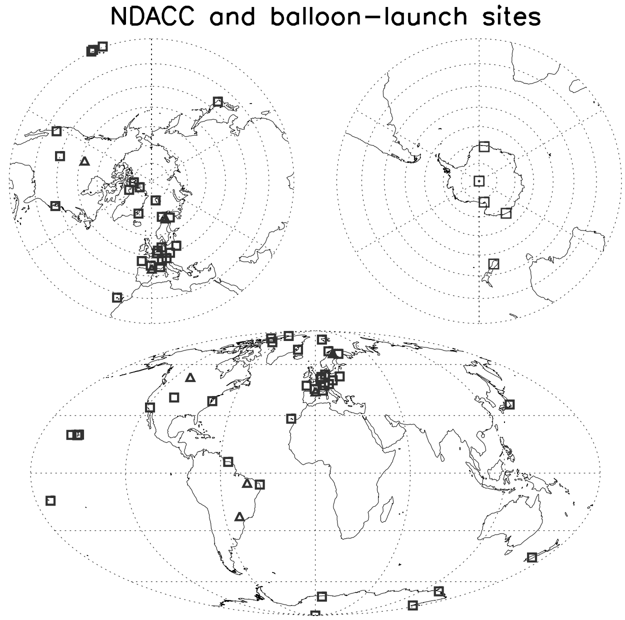

Fig. 6. NDACC sites (squares) and balloons launches (triangles) providing data for comparisons with Odin.

Microwave radiometers record emission spectra from thermally induced rotational transitions of atmospheric ozone, typically around 110 or 142 GHz (Parrish et al., 1992; Kämpfer, 1995; Connor et al., 1995; Schneider et al., 2003). Since the recorded transition lines are broadened by pressure, the recorded line shape contains information on the vertical distribution of ozone. A great advantage is that ground-based microwave radiometers are fairly independent of weather conditions and take measurements around the clock, with a typical time resolution of one or two hours. Altitude resolution and accuracy of the retrieved stratospheric ozone profiles are 7 to 10 km and 7 to 10%, respectively. Many studies have validated ozone profiles from microwave radiometers (e.g., McDermid et al., 1998; McPeters et al., 1999; Tsou et al., 2000). More detailed descriptions of the Lidar and Microwave NDACC instruments are given by Steinbrecht et al. (2006).

4.2.2 Comparisons

We selected a first set of 23 stations where ozone sonde experiments are conducted from the surface to a maximum altitude in the range 33–38 km. Figure 7 shows eight of these ozone sonde intercomparisons (Paramaribo, Natal, Boulder, Neumeyer, South Pole, Izana, Hilo). A second set of stations where lidar measurements are performed has been chosen to extend the validation up to the middle stratosphere. Microwave data were used to validate the Odin/SMR stratospheric measurements up to 60 km. Figure 8 illustrates

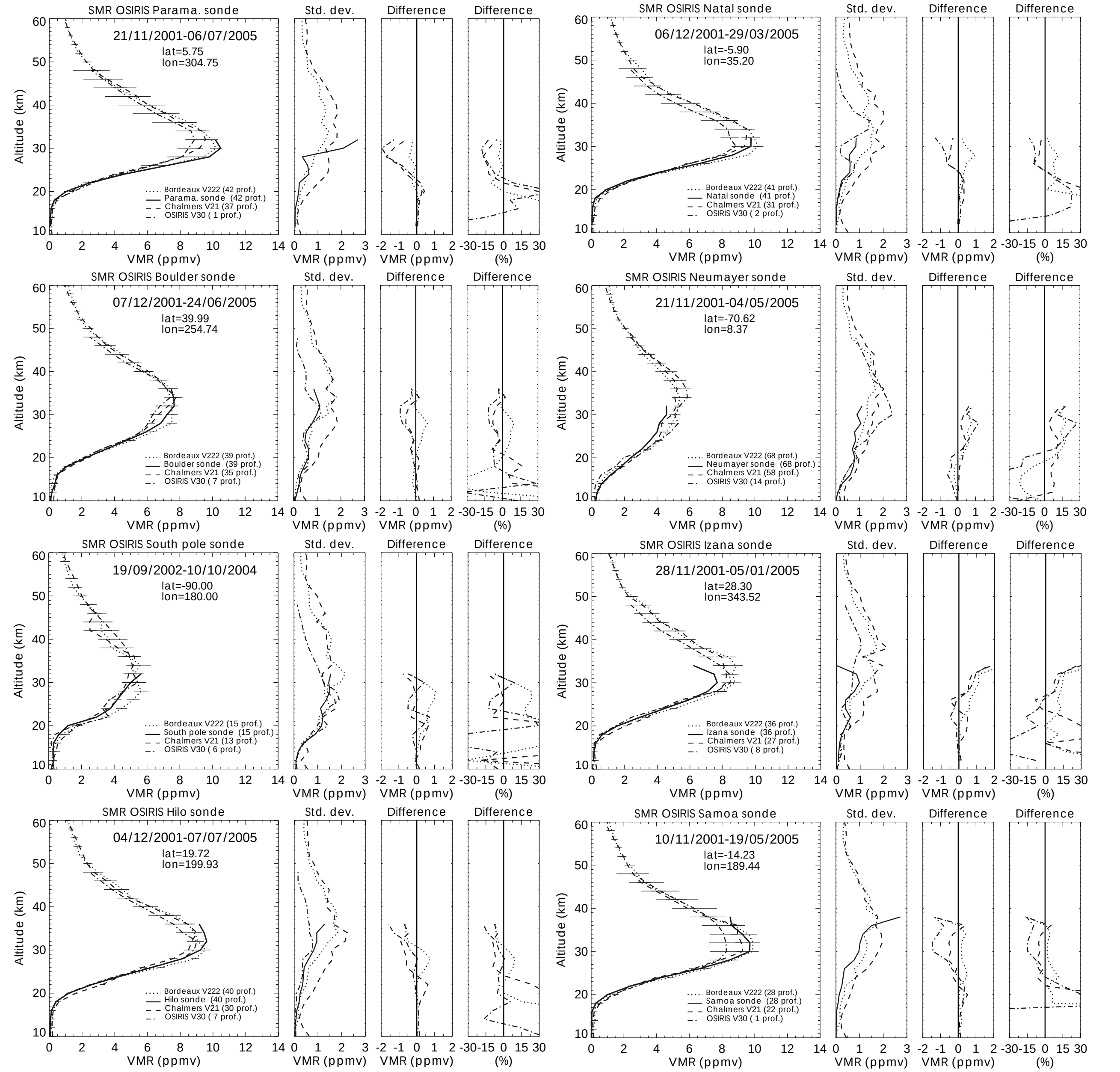

Fig. 7. Same as Fig. 3 but for monthly mean OSIRIS,SMR and ozone sonde profiles for eight NDACC stations: Paramaribo, Natal, Boulder, Neumeyer, South Pole, Izana, Hilo and Samoa Islands.

results from four lidar (Ny Alesund, Payerne, Bern, Lauder) and four microwave (Mauna Loa, Andoya, OHP, Tsukuba). NDACC and Odin data are compared over the whole available period for each station. Individual coincidences are found within the selected criteria. NDACC profiles are linearly interpolated as a function of log-pressure, to the fixed SMR/v222 2-km grid, before calculating the average profiles, shown on Figs. 7 and 8. Mean profiles are calculated taking into account the total error defined above. The number of profiles involved in the mean profiles is indicated on these figures.

The Odin/SMRv222 high bias below 10 hPa ($\sim$22–32 km) is again found in most cases. On the contrary, the altitude offset of the Odin ozone maximum detected in the POAM III comparisons is not systematically found. Table 3 summarizes the Odin/NDACC intercomparison results for the selected stations shown in Figs. 7 and 8.

Figure 7 shows that SMR and OSIRIS profiles are in agreement with the ozone sonde data within $\pm$0.5 ppmv. The SMR/v222 and the SMR/v2.1 data agree within 0.2$\pm$0.3 ppmv and 0$\pm$0.4 ppmv below 35 km, respectively. In general the SMR/v2.1 products reveal better agreement

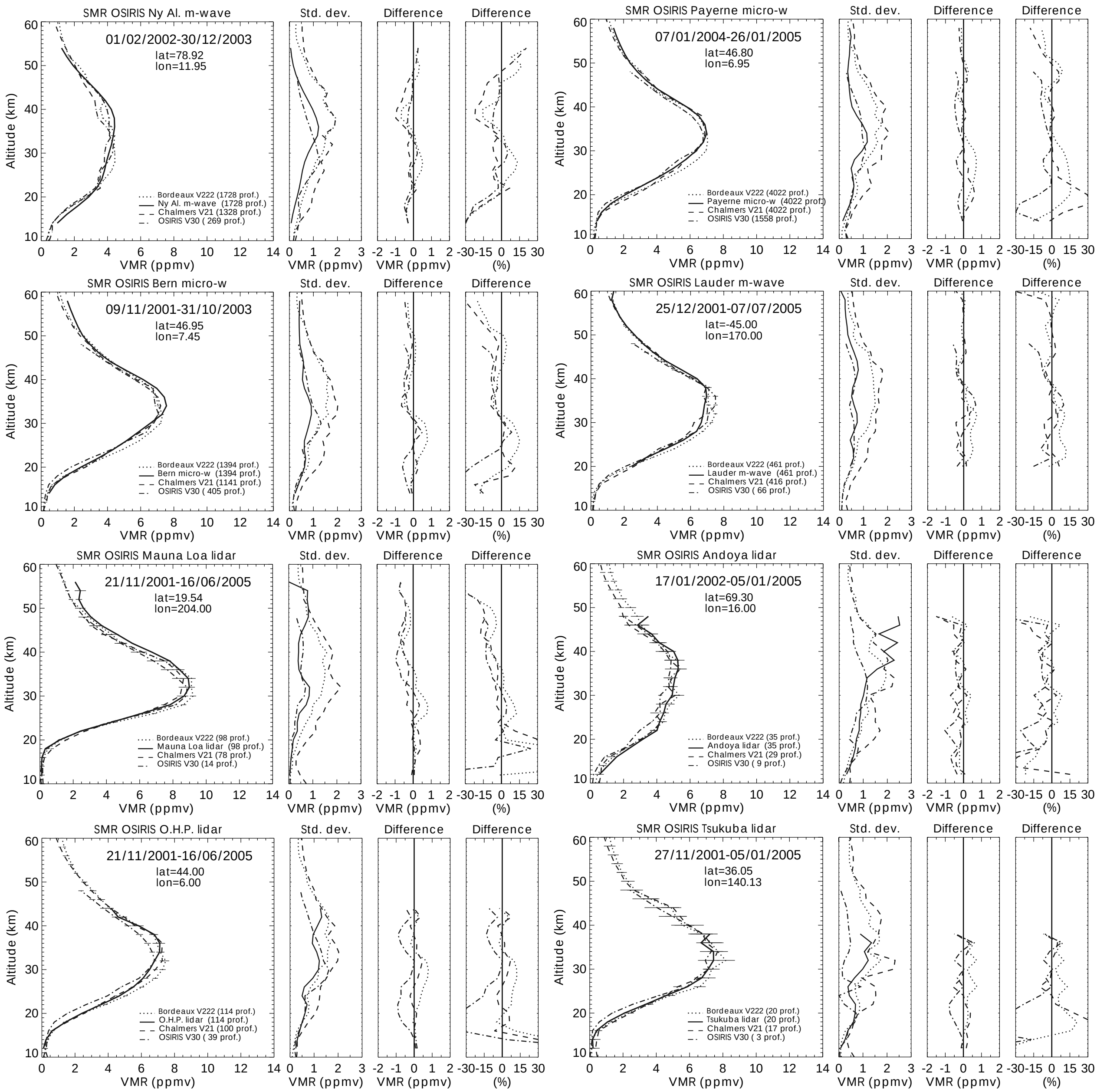

Fig. 8. Same as Fig. 7 but for comparisons of monthly mean OSIRIS,SMR and NDACC profiles performed in four microwave (Ny Alesund, Payerne, Bern, Lauder) and four lidar NAADC stations (OHP, Tsukuba, Mauna Loa, Andoya).

with the ozone sonde products than the other Odin products. Nevertheless in some cases the SMR/v222 data are the Odin products that are closest to the ozone sonde profiles. For example, the Paramaribo mean profile (cf. Fig. 7) shows the same SMR/v222 positive bias below 10 hPa (∼32 km) compared to the SMR/v2.1 data. The difference reaches 1.5 ppmv around the ozone profile maximum near 30 km. This altitude is 2 km higher in the SMR/v2.1 profiles. This new feature, also detected in the Odin/Samoa Islands comparisons (cf. Fig. 7), casts some doubt on the reality of the SMR/v222 positive bias below 10 hPa (∼32 km).

Figure 8 shows that Odin profiles are in agreement with the lidar and microwave sonde data within -0.3 ± 0.3 ppmv (OSIRIS), 0.2 ± 0.3 ppmv (SMR/v222), -0.1 ± 0.3 ppmv (SMR/v2.1) for the 10–35 km range and within -0.3 ± 0.4 ppmv (OSIRIS), 0 ± 0.4 ppmv (SMR/v222), -0.2 ± 0.3 ppmv (SMR/v2.1) for the 35–60 km. The SMR/v222 positive bias below 10 hPa (∼32 km) is clearly seen in Fig. 8 in the low and middle latitude comparisons (Tsukuba, Mauna Loa, OHP, Bern, Lauder, Andoya) but not for the high-latitude stations (Ny Alesund, Andoya). This positive bias is systematically followed by

Table 3. Comparisons of NDACC ground-based and Odin measurements for periods described in Table 2 for the microwave instruments (top), lidars (middle) and ozone sondes (bottom), respectively. Averages and standard deviations (number in brackets) of the absolute difference (Odin-NDACC (ppmv)) are given over the two height ranges 10–35 km and 35–60 km.

NDACC sites						
Station	v3.0-Station		v222-Station		v2.1-Station	
	10–35 km	35–48 km	10–35 km	35–60 km	10–35 km	35–60 km
Microwave instruments						
Ny Alesund	-0.18 (0.34)	−0.12 (0.02)	-0.06 (0.25)	−0.03 (0.29)	−0.41 (0.21)	−0.26 (0.39)
Payerne	−0.06 (0.21)	−0.15 (0.12)	0.34 (0.29)	−0.06 (0.15)	0.19 (0.24)	−0.05 (0.16)
Bern	−0.14(0.28)	−0.32 (0.13)	0.20 (0.41)	−0.11 (0.19)	−0.02 (0.27)	−0.31 (0.15)
Lauder	0.05 (0.37)	−0.26 (0.40)	0.41 (0.24)	−0.06 (0.14)	−0.05 (0.26)	−0.09 (0.14)
Lidars						
Mauna Loa	−0.07 (0.26)	-0.76 (0.43)	0.38 (0.39)	−0.21 (0.26)	−0.11 (0.23)	−0.33 (0.22)
Andoya	−0.44 (0.27)	−0.24 (0.53)	−0.12 (0.21)	−0.13 (0.35)	−0.31 (0.25)	−0.49 (0.47)
O.H.P.	−0.39 (0.31)	−0.35 (0.18)	0.30 (0.28)	0.02 (0.14)	0.13 (0.18)	0.11 (0.22)
Tsukuba	−0.38 (0.27)	0.10 (0.56)	0.28 (0.25)	−0.03 (0.69)	0.08 (0.25)	0.08 (0.36)
Ozonesondes						
Paramaribo	−0.49 (0.81)		−0.11 (0.18)		−0.41 (0.67)	
Natal	−0.26 (0.52)		0.27 (0.27)		−0.04 (0.34)	
Boulder	−0.27 (0.34)		0.11 (0.25)		−0.09 (0.28)	
Neumeyer	0.18 (0.58)		0.28 (0.38)		0.21 (0.19)	
South Pole	−0.04 (0.37)		0.36 (0.44)		−0.01 (0.37)	
Izana	0.22 (0.63)		0.60 (0.76)		0.37 (0.56)	
Hilo	−0.21 (0.38)		0.08 (0.35)		−0.11 (0.47)	
Samoa	−0.33 (0.64)		0.19 (0.16)		−0.08 (0.33)	

an altitude offset around the ozone peak. The SMR/v222 ozone maximum is lower by about 1–5 km compared to the lidar and microwave measurements. In the 35–60 km altitude range lidar and microwave observations are in good agreement with the Odin products with no latitudinal dependence.

We combine the results obtained from the comparisons with the NDACC data in Fig. 9. Mean and standard deviations are again calculated for the three range of the ozone mixing ratio. At low ozone mixing ratios (range 0–3 ppmv), we find differences of 0.1±0.15 ppmv and 0.15±0.25 for SMR v222 and v2.1, while OSIRIS v3.0 shows a negative difference of −0.25±0.2. Standard deviations are in order of 0.6–1.2 ppmv, 0.8–1.0 ppmv, 0.5–0.7 ppmv, for SMR v222, SMR v2.1 and OSIRIS v3.0, respectively. For the intermediate range (range 3-6 ppmv) differences of 0.2±0.1 ppmv, ±0.15 ppmv, −0.15±0.15 ppmv, and standard deviations of 1.1–1.3 ppmv, 1.4–1.5 ppmv, and 0.9-1.0 ppmv, for SMR v222, SMR v2.1 and OSIRIS v3.0, respectively. At high ozone mixing ratios (6–9 ppmv), the corresponding differences are −0.1±0.1 ppmv, −0.5±0.2 ppmv, and −0.45±0.2 ppmv, and standard deviations of 1.4–1.7 ppmv, 1.7–1.9 ppmv, and 0.9–1.2 ppmv. A curious feature that looks like the thumb on a mitten appears on the OSIRIS/ozonesonde and OSIRIS/microwave scatterplots. There is a concentration of OSIRIS values at about 4 ppmv while corresponding ozonesonde and microwave values vary up to 7 ppmv. This discrepancy is the consequence of the low quality of the maximum altitude values of several NDACC measurements. This feature is not detected in the SMR/NDACC scatterplot because of the large oscillations in the individual SMR profiles.

In summary, the NDACC/Odin comparisons confirm that a positive bias exists most of the time in the SMR/v222 data between 22 and 32 km (0.2±0.3 ppmv). Such an overestimation cannot be generalised because this discrepancy completely disappears at some latitudes (tropical and Northern high latitude stations). The negative bias of the OSIRIS profiles is still found (−0.3±0.3 ppmv) at all altitudes. This discrepancy is more important in the middle atmosphere ($z \geq 40$ km) where ozone values are lower. The SMR/v2.1 profiles are the Odin products showing the best agreement with the NDACC dataset (−0.15±0.3 ppmv) over all altitudes because neither an ozone altitude peak offset nor an amplitude difference were detected.

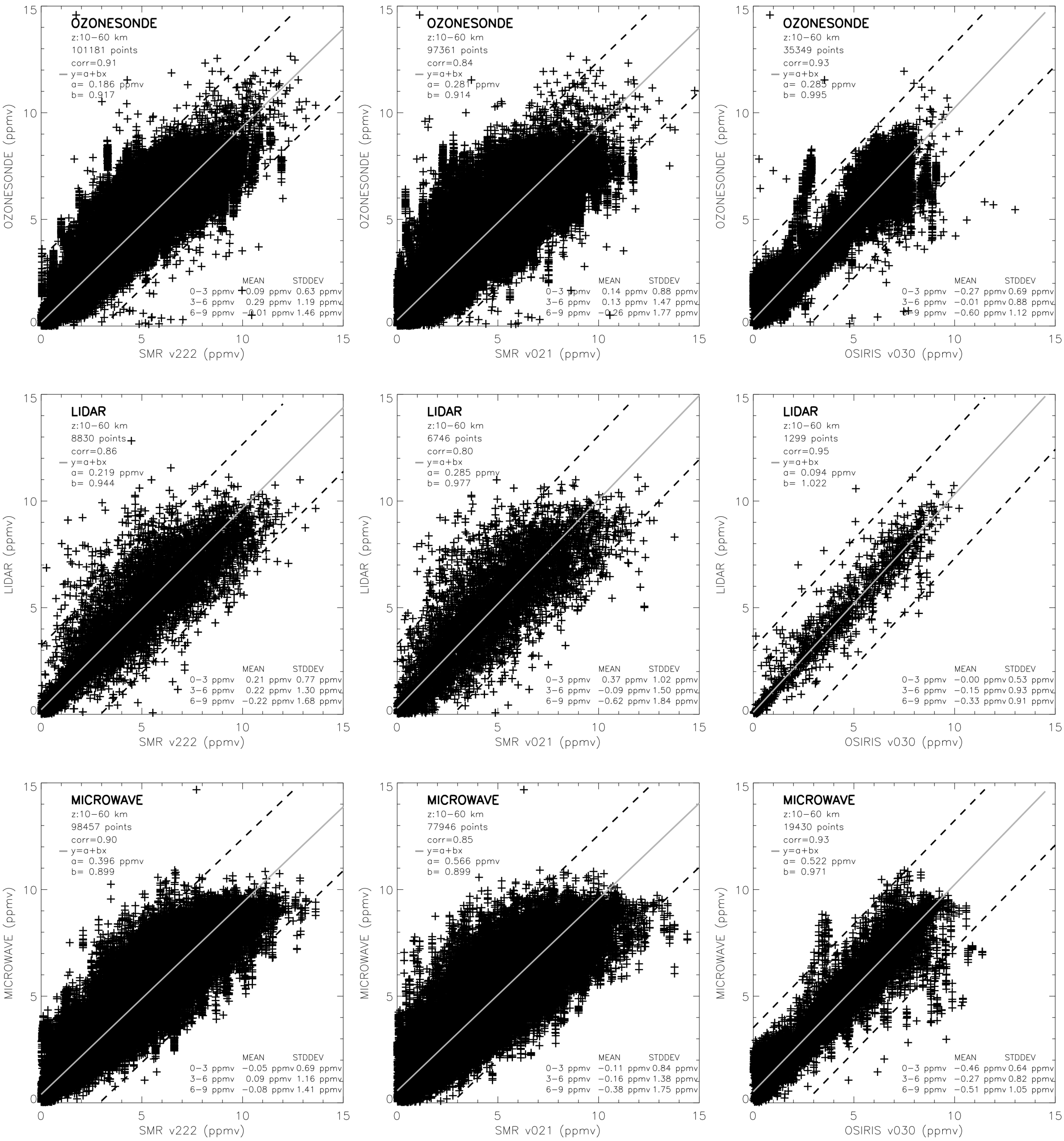

Fig. 9. Scatterplot of Odin/SMR and OSIRIS O_3 versus NDACC measurements. Left: Odin/SMR v222 data; middle: Odin/SMR v2.1 data; right: Odin/OSIRIS v3.0 data. Top: Ozonesonde, Middle: Lidar, Bottom: Micro-wave. Mean differences and standard deviations are indicated for the different ranges of the O_3 mixing ratio. The dotted lines delimit deviations of ± 3 ppmv for clarity. The solid gray line indicates the linear fit to the data.

Table 4. Comparisons of balloon flight and Odin measurements for periods described in Table 2 for the LPCE (top), MANTRA (middle) and SAOZ (bottom) missions, respectively. Averages and standard deviations (number in brackets) of the absolute difference (Odin-balloon (ppmv)) are given over the two height ranges 10–35 km and 35–60 km.

Balloons flights			
Date	v3.0-Balloon 10–35 km	v222-Balloon 10–35 km	v2.1-Balloon 10–35 km
LPCE missions			
SALOMON 2002	−0.19 (0.56)	0.80 (1.04)	0.77 (1.02)
SPIRALE 2002	0.25 (1.29)	0.03 (1.09)	0.14 (1.01)
SPIRALE 2003		0.23 (1.05)	0.27 (0.98)
AMON 2003		−0.58 (0.59)	0.04 (1.00)
SPIRALE 2005	–0.10 (0.48)		−0.05 (1.90)
SPIRALE 2006			−0.26 (1.25)
2002 MANTRA missions			
15/08		-0.21 (1.07)	0.30 (1.20)
24/08		−0.14 (0.45)	−0.10 (1.15)
17/08	−0.35 (0.35)		−0.34 (1.45)
27/08			−0.03 (1.00)
02/09		0.08 (1.33)	−0.03 (0.98)
15/08–02/09		-0.02 (0.77)	−0.13 (0.75)
SAOZ missions			
18/02/2003		0.65 (0.69)	0.69 (1.42)
31/01/2004		0.70 (0.65)	0.38 (0.97)

4.3 Large balloon-borne experiments

Correlative measurements by balloon-borne sensors are available from experiments conducted by the LPCE (AMON, SALOMON, SPIRALE instrument flights), by the Canadian Space Agency (MANTRA flights) and by the Service d´Aéronomie (SAOZ instrument flights). The obtained profiles have a high vertical resolution compared to that of individual SMR/Odin profiles. Furthermore high noise is present in individual SMR profiles due to measurement noise (Figs. 10, 11 and 12). However these balloon-borne measurements are the opportunity to investigate the accuracy of the individual Odin/SMR profiles. Table 4 summarizes the Odin/balloon-borne instrument intercomparison results for the LPCE, MANTRA, and SAOZ missions.

AMON (French acronym for Absorption par les Minoritaires Ozone et Nox) and SALOMON (French acronym for Spectroscopie d'Absorption Lunaire pour l'Observation des Minoritaires Ozone et Nox) are two UV-visible spectrometers used aboard stratospheric balloons (Renard et al.,1996, 2000, 2007). These experiments measure O_3, NO_2, NO_3, and OClO vertical profiles and aerosol extinction coefficients, between 15 and 40 km. A balloon carrying the SALOMON spectrometer was launched on 19 September 2002 from Aire sur l´Adour (Southern France). High-latitude flight of the balloon-borne AMON instrument was performed on 1 March 2003 starting from Kiruna (Northern Sweden) at the edge of the polar vortex. The AMON observations have a vertical resolution between a few hundred meters in the middle stratosphere and around 1 km in the lower stratosphere. Accuracy of the AMON ozone measurements is better than 5%. Due to the apparent size of the Moon (0.5°) SALOMON does not allow a vertical resolution better than 1–2 km (Berthet et al., 2003). Accuracy of the SALOMON ozone measurements is 6–14%. These flights were planned within the validation campaign for the ENVISAT satellite. These measurements are shown in Fig. 10a, b along with ozone data from Odin/SMR and OSIRIS. The time coincidences are 7 h for the AMON/Odin and 4 h for the SALOMON/Odin intercomparisons. The spatial coincidence criteria are $\leq$5° in latitude and $\leq$10° in longitude.

The AMON profile Fig. 10a and the Odin/SMR measurements are in a good agreement from 11 to 31 km within $\pm$1.0 ppmv. The SMR and AMON profiles show the same features: a decrease between 22–23 km and 27–28 km followed by an increase at the upper altitude (29–31 km). Polar Stratospheric Clouds (PSC) detected during this experiment, could explain the ozone decrease in the 22–23 km altitude range.

The SMR profiles show rapid variations of concentration in altitude but in general the amplitude of these changes is larger than these observed in the balloon profiles. The AMON upper altitude is 2 km lower than the SMR maximum ozone peak. The SALOMON and Odin/SMR comparison does not exhibit such a good agreement as seen in Fig. 10b. The agreement is within 0.8$\pm$1 ppmv with two different altitude features. The SALOMON profiles are systematically greater ($\leq$0.5 ppmv) from 16 to 22 km and lower ($\leq$1.5 ppmv) from 22 to 36 km. OSIRIS profiles are lower within 0.2$\pm$0.6 ppmv in the 22–32 km altitude range. The SALOMON profile is located between SMR and OSIRIS profiles from 15–32 km with SMR lower than SALOMON from 15–22 km and OSIRIS lower than SALOMON from 22–32 km. The SALOMON profile is lower than that of the Odin products between 32 and 39 km, without going out of the SMR error bars. In the 32–39 km altitude range the low values (0.5–1 ppmv) of the OSIRIS profile from 22 to 32 km show a better agreement with the SALOMON profile ($\pm$0.5 ppmv).

SPIRALE (French acronym for SPectroscopie InfraRouge par Absorption de Lasers Embarqués) is a tunable diode laser spectrometer used to measure chemical trace species from the high troposphere up to middle stratosphere (35 km) (Berthet al., 2006, Huret et al., 2006). Vertical concentration profiles of twelve species (O_3, CH_4, CO, CO_2, N_2O, HNO_3, NO_2, NO, HCl, HOCl, H_2O_2, CO_2) were measured with a high vertical resolution ($\leq$5 m). Accuracy of the ozone measurements is 3–5%. Four SPIRALE instrument flights occurred from 2002 to 2006: two in Kiruna, Sweden (21 January 2003, 20 January 2006), one in Aire sur l´Adour, France (2 October 2002), and one in Teresina, Brasil (22 June 2005).

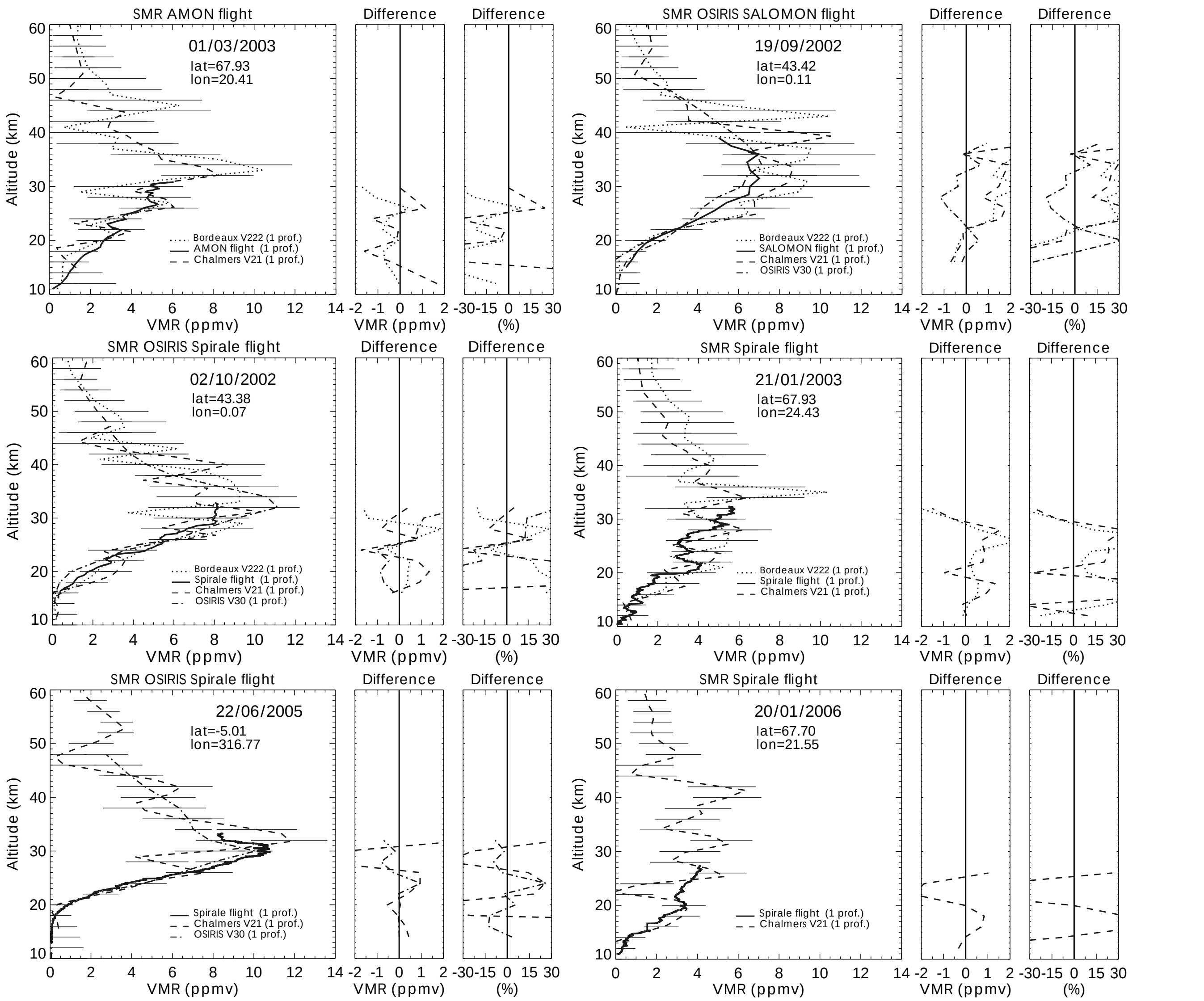

Fig. 10. Same as Fig. 8 but for comparisons of OSIRIS,SMR ozone with measurements of the balloon-borne AMON **(a)**, SALOMON **(b)**, SPIRALE **(c, d, e, f)** instruments measured during flights performed between 19 September 2002 and 22 June 2006.

Figure 10c shows the comparison of Odin/SMR and OSIRIS measurements of ozone with mid-latitude observations of the balloon-borne SPIRALE instrument performed on 2 October 2002 in Aire sur l´Adour, France. The temporal coincidence is 5 h and the spatial coincidences are $\leq 5°$ in latitude and $\leq 10°$ in longitude. The SPIRALE profile is characterised by a constant increase from 18 to 29 km with two slight amplitude inversions at 22 and 27 km. This complex vertical structure has been already highlighted during the Odin N_2O validation (Urban et al., 2005). A CH_4-N_2O correlation has been used to investigate the origin of air masses. A more detailed study on air mass origin, using the same tracer correlations, have been made by Huret et al. (2006). Different origins were found for air masses measured at low altitudes and high altitudes. At the top of the profile a maximum ozone value of 8 ppmv spread over 4 km (29–33 km). We find a reasonable average agreement with OSIRIS (0.25 ± 1.3 ppmv), SMR/v222 (0.03 ± 1.1 ppmv) and SMR/v2.1 (0.14 ± 1.0 ppmv) profiles from 16 km to 32 km. The Odin profiles in this case do not detect the two inversions at 22 and 28 km and show a maximum ozone peak 2–3 km higher in altitude.

Figure 10d shows the comparison of Odin/SMR measurement of ozone with a SPIRALE profile obtained on 21 January 2003 in Kiruna (Sweden) near the edge of the polar vortex. The temporal coincidence is 10 h and the spatial coincidences are $\leq 5°$ in latitude and $\leq 10°$ in longitude. In view of the complex structure of the SPIRALE profile, we investigate the location of the observations in relation to the polar vortex. To achieve this, we use a simulation of potential vorticity obtained with the MIMOSA model (Hauchecorne et al., 2002) developed at the Service d'Aéronomie (France), which reproduces the dynamics of the vortex situation during the SPIRALE flight. Odin profiles are found near the inside edge of the polar vortex. The SPIRALE profile is outside the polar vortex below 23 km and inside the polar vortex above. This point could be the explanation of the relative high difference between SPIRALE and Odin profiles below 23 km. The SPIRALE profile structure is divided in two parts: a first part with low values increasing from 0–2 ppmv in the 10–20 km altitude range and a second part above 20 km with a very sudden increase of the order of 2 ppmv over only 2 km. This ozone doubling corresponds to the change of the dynamic regime. The 22–33 km altitude range is characterised by two roughly constant ozone regions respectively of the order of 3.5 ppmv (22–27 km) and 5.4 ppmv (29–32 km) which surround a second sudden increase. The SMR profiles are greater than the SPIRALE profile except near the two ozone maxima ($\sim$21 and 29 km). The average agreement is within 0.25 ± 1.0 ppmv for both SMR versions.

Figure 10e shows the comparison of SMR measurement of ozone with a SPIRALE profile obtained on 22 June 2005 in Teresina (Brasil). The temporal coincidence has been released to 72 h to find some available coincidences. The spatial coincidences are $\leq5°$ in latitude and $\leq10°$ in longitude. We found two Odin dates, 19 and 24 June 2005, when comparisons could be performed. We note that good agreement occurs only with the 19 June Odin profile. We conclude that a change in air mass characteristics occurred a few days after the SPIRALE observation. The SPIRALE profile has an expected structure with extremely low values from 10 to 18 km with a rapid and monotonic increase from 18 to 29 km. The 10.5 ppmv ozone peak maximum at 30 km is followed by a quick decrease down to 8.2 ppmv at 33 km. Odin profiles show slightly lower values within 0.05 ± 1.9 ppmv for SMR/v2.1 and 0.10 ± 0.5 ppmv for OSIRIS. The OSIRIS ozone maximum altitude corresponds to the SPIRALE one with an amplitude slightly 0.7 ppmv lower. The SMR/v2.1 ozone maximum is located 2 km higher with a greater amplitude of 1 ppmv. In this case the Odin/OSIRIS product has the best agreement with the SPIRALE profile.

Figure 10f shows the comparison of a SMR measurement of O_3 with a SPIRALE profile obtained on 20 January 2006 in Kiruna (Sweden). The SPIRALE profile does not exhibit the large variations detected in the Kiruna 2003 profile. Nevertheless two features characterise this profile: a constant amplitude from 14 to 17 km and two successive inversions at 20 and 22 km. The agreement is quite good from 10 to 20 km whereas the SMR/v2.1 profile shows large oscillations (noise) up to 60 km. The average agreement is within 0.25 ± 1.25 ppmv. Figure 10f is a good example of the limitation of individual comparisons due to oscillations in SMR profiles.

The MANTRA (Middle Atmosphere Nitrogen TRend Assessment) series of high-altitude balloon flights has been undertaken to investigate changes in the concentration of mid-latitude stratospheric ozone, nitrogen and chlorine compounds which play a role in the ozone chemistry. Four campaigns have been undertaken since August 1998, all from Vanscoy, Saskatchewan, Canada (52° N, 107° W). Each flight carried a payload of instruments to measure vertical concentration profiles of stratospheric trace gases, and made observations from a float altitude of about 35 km during one day. The third MANTRA flight was launched on 3 September 2002 and measurements were made by 11 instruments. In addition, four ground-based spectrometers were deployed at Vanscoy approximatively two weeks prior to this flight between 15 August and 5 September, and a total of 15 independent Electrochemical Concentration Cell (ECC) ozone sonde flights were launched. The ECC sonde measurement technique is based on the reaction of ozone with the potassium iodine in an aqueous solution to yield molecular iodine. The iodine is detected via electrochemical means, and is directly related to the ozone abundance (Komhyr et al., 1969; Davis et al., 2000). Typically, the ozone partial pressure is measured at 50–100 m vertical resolution with an accuracy of $\pm10\%$. For more details about the MANTRA 2002 balloon flight from Vanscoy, see Strong et al. (2003, 2005). Five ozone sonde profiles, on 15, 17, 24, 27 August and 2 September 2002 are within our 24-h time comparison criterion. The spatial coincidences are $\leq5°$ in latitude and $\leq10°$ in longitude. Figure 11a shows mean ozone profiles measured on 15–17 August 2002 and 2 September 2002 when both SMR/v222 and SMR/v2.1 coincidences are found. In this mean comparison (Fig. 11a), we find an excellent agreement from 12 to 36 km within 0.15 ± 0.8 ppmv. We observe a positive bias of SMR/v222 between 24 and 32 km and a negative bias of SMR/v2.1 between 20 and 30 km, reversed below 20 km. Overall, for Fig. 11a, the mean MANTRA profile is situated between both versions of SMR profiles within the SMR error bar. The SMR and MANTRA ozone maximum peaks are very similar with the same altitude (34 km) and amplitude (7.8 ppmv).

The five individual comparisons (Fig. 11b, c, d, e, f) do not show such a good agreement for two reasons: (1) individual SMR profiles are characterised by large oscillations which are reduced in the mean profiles, (2) the individual ozone sonde profiles show some fine structures that are smoothed in the mean profiles. An inversion is detected near 25 km in the MANTRA profiles while it is not detected in the SMR observations due to limited altitude resolution and measurement noise. Nevertheless the regular ozone increase is similar in all individual MANTRA and Odin profiles from 10 to 38 km and the average agreement is -0.1 ± 0.9 ppmv for SMR/v222, within ±0.8 ppmv for SMR/v2.1 and OSIRIS. No discrepancy is found in the altitude and amplitude of the ozone maximum peak. We find that the altitude of the maximum ozone is between 33 and 34 km with an amplitude

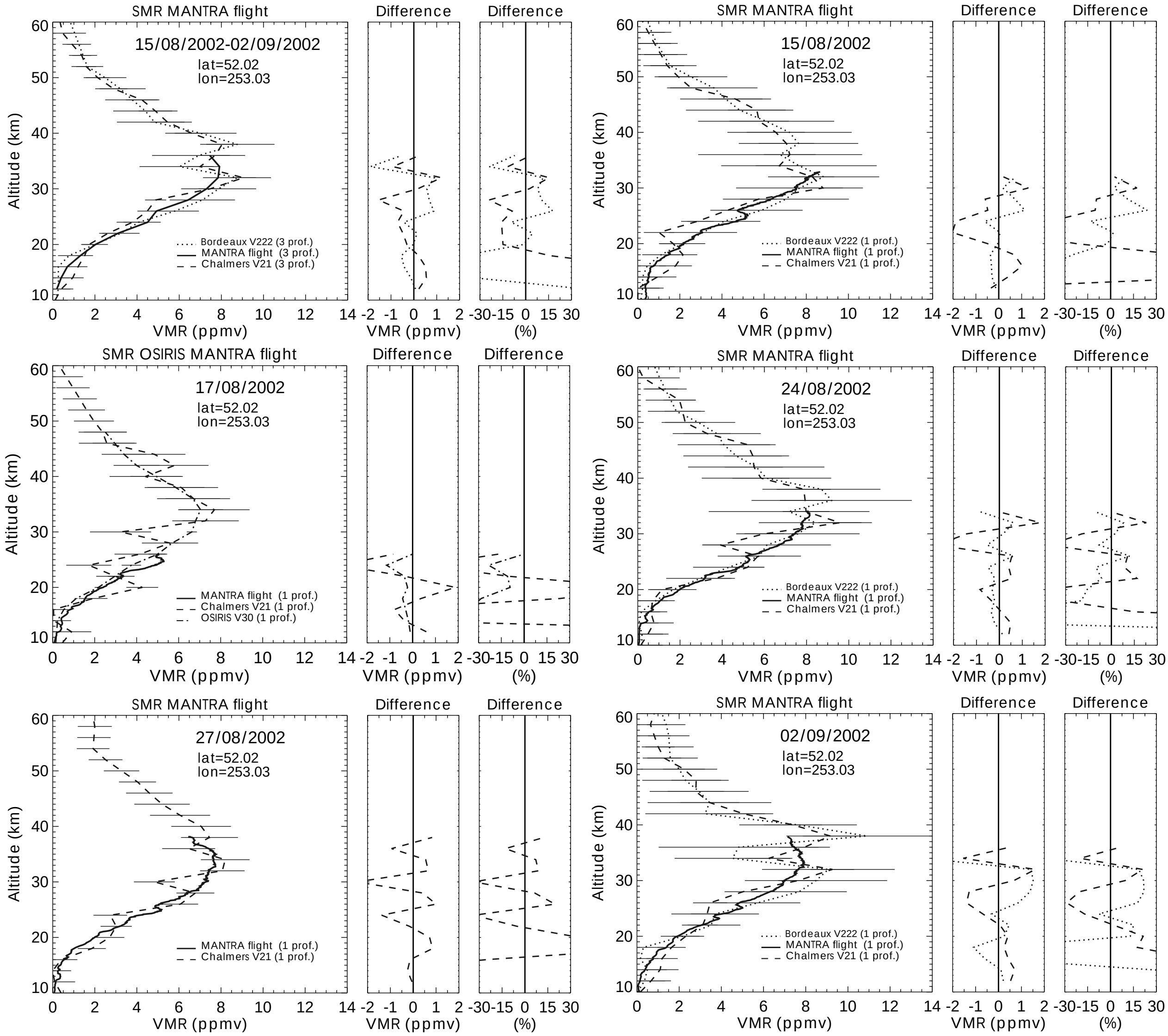

Fig. 11. Same as Fig. 10 but for comparisons of OSIRIS and SMR ozone with measurements of the balloon-borne MANTRA instrument measured during flights performed between 15 August 2002 and 2 September 2002. Figure **(a)** shows the average profiles over the period 15 August–2 September when the two SMR versions are presented.

within 7.8–8.5 ppmv. Odin products detect a surprising low ozone maximum of the order of 7 ppmv at 34 km on 17 August 2002. Unfortunately the MANTRA profile upper altitude (26 km) on 17 August 2002, does not give the opportunity to validate the sudden ozone decrease. But Odin and sonde ozone peaks match well on other days, which suggests a real rapid ozone decrease on 17 August 2002. A persistent minimum at 30 km in v2.1 data is found from 17 August 2002 to 2 September 2002. The origin of this minimum is not clearly explained and could probably be noise.

SAOZ (French acronym for Systeme d'Analyse et d'Observation Zénithales) is a balloon-borne diode array UV-visible spectrometer for remote ozone and NO_2 observations by solar occultation (Pommereau and Piquard, 1994). The precision of the measurements is estimated to be better than 2% (3.5% accuracy) in the stratosphere and 5–6% (12% and 25% accuracy at 15 km and 10 km respectively) in the troposphere with an altitude uncertainty of -30 ± 25 m (Borchi et al.,2005). The data used here are those obtained by two flights launched from Bauru at 22° S in Brasil during the SH summer season in January–February 2003 and 2004. The first flight on 18 February 2003 was launched in preparation for the HIBISCUS campaign (Borchi et al., 2007), and the second one on 31 January 2004 was launched during the main campaign. The first flight was performed at sunrise (20 km tangent height at 09:00) 4 h ahead SMR, whilst the second was at sunset (20 km tangent height at 22:00), 09:20 after SMR. SAOZ profiles are characterised

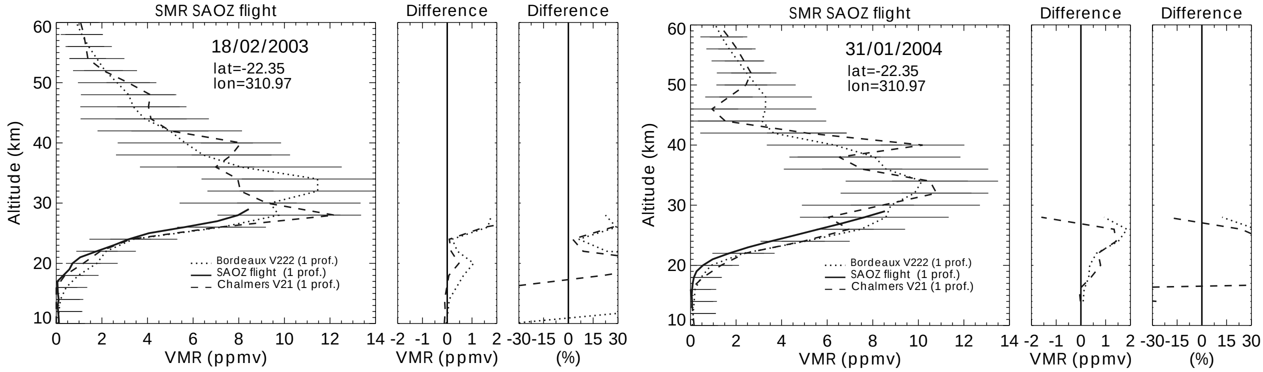

Fig. 12. Same as Fig. 11 but for comparisons of Odin/SMR ozone with measurements of the balloon-borne SAOZ instrument measured during flights launched in Bauru (Brasil) o*n 18 February 2003 the morning **(a)** and 31 January 2004 the evening **(b)**.

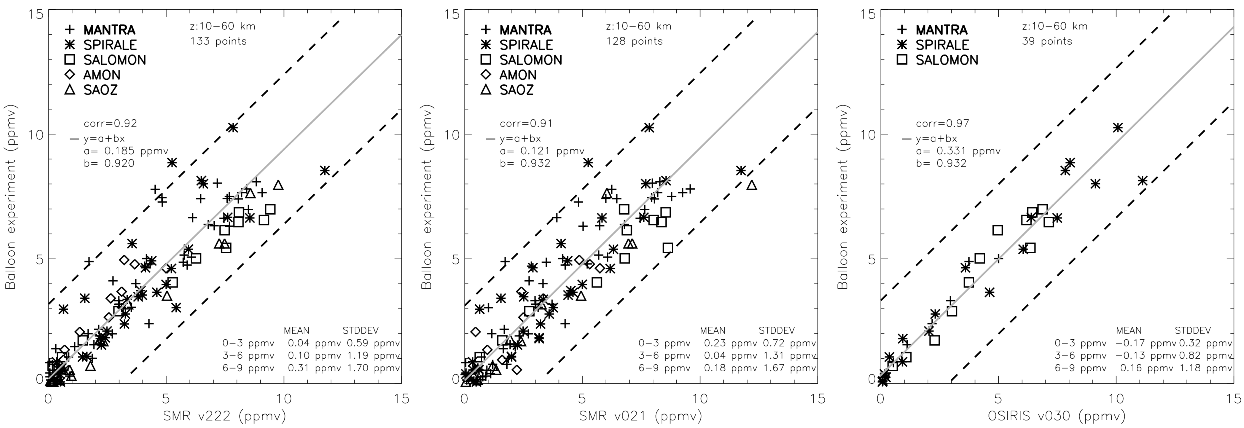

Fig. 13. Scatterplot of Odin/SMR and OSIRIS O_3 versus Balloon measurements. Left: Odin/SMR v222 data; middle: Odin/SMR v2.1 data; right: Odin/OSIRIS v3.0 data. Mean differences and standard deviations are indicated for the different ranges of the O_3 mixing ratio. The dotted lines delimit deviations of ±3 ppmv for clarity. The solid gray line indicates the linear fit to the data.

by a regular increase from 10 to 29 km with a maximum ozone amplitude of 8.5–9 ppmv. Reasonable agreement is found between SMR and SAOZ profiles 0.7±0.7 ppmv for v222 and 0.6±1.2 ppmv for v2.1. The SMR profiles systematically overestimate the SAOZ observations except the SMR/v2.1 2004 profile in the upper 3 km. In spite of this feature, SAOZ values are always within the SMR error bars (cf. Fig. 12a, b).

Finally, the differences between Odin products and Balloon-borne experiments are estimated quantitatively. Figure 13 combines all the results obtained from the balloon comparisons from August 2002 to January 2006. For low mixing ratios of ozone (range 0–3 ppmv), we find differences within 0.05±0.6 ppmv, 0.2±0.7 ppmv, and −0.2±0.3 ppmv, for SMR v222, SMR v2.1 and OSIRIS v3.0, respectively. In the intermediate range (3–6 ppmv), the deviations are 0.1±1.2 ppmv, 0.05±1.3 ppmv, for SMR version 222 and 2.1 and −0.15±0.8 ppmv for OSIRIS v3.0. High ozone mixing ratios (range 6–9 ppmv) show differences of 0.3±1.7 ppmv, 0.2±1.7 ppmv, and 0.15±1.2 ppmv, for version SMR 222, SMR 2.1 and OSIRIS 3.0.

In summary, the balloon/Odin comparisons prove that individual SMR profiles show reasonable agreement with high vertical resolution profiles. In some cases rapid ozone variations are simultaneously detected in SMR and balloon profiles. Balloon profiles are always within the SMR error bar. Average agreements over the available altitude ranges are within ±1 ppmv for AMON, 0.8±1 ppmv for SALOMON, 0.25±1.3 ppmv for SPIRALE, 0.15±0.8 ppmv for MANTRA and 0.6±1.2 ppmv for SAOZ instruments.

5 Summary and conclusions

The Sub-Millimeter-Radiometer on board the Odin satellite, launched in February 2001, provides a quasi-continuous global dataset of stratospheric ozone profiles starting in November 2001. We present an assessment of the quality of the latest level 2 data version (Chalmers SMR/v2.1) of the 501.8 GHz band product with correlative measurements performed by ground-based, balloon-borne and space-borne sensors. Odin/SMR retrievals are in good agreement with ozone mixing ratios obtained by the POAM III v4.0 level

2 off-line processor. The cross-comparison shows a negative bias of the Odin/SMR and OSIRIS ozone measurements compared to the POAM III v4.0 data. For SMR versions 2.1 and v222, standard deviation of the (Odin-POAM III) differences are within 1.3 ppmv and the agreement is better than 0.3 ppmv. OSIRIS v3.0 shows a standard deviation of the (Odin-POAM III) difference within 0.9 ppmv and an agreement better than 0.5 ppmv. SMR v222 profiles are found to be higher ($\leq$10%) than POAM III mixing ratios below 10 hPa ($\sim$32 km). This positive bias has already been highlighted by Barret et al. (2006) in SMR/MLS intercomparisons. The Odin ozone maximum peak is lower than that of POAM III $\sim$1–3 km (OSIRIS) and $\sim$1–5 km (SMR).

An agreement with the NDACC experiments is found within 0.5 ppmv for all Odin data. A positive bias at pressures below 10 hPa ($\sim$32 km) is found in SMR v222 data. This positive bias is mainly detected in tropical and Northern high latitudes. OSIRIS data are smaller than NDACC measurements with a -0.3 ± 0.3 ppmv bias. SMR v2.1 data are in general in agreement within -0.15 ± 0.3 ppmv.

The cross-comparison with large balloon-borne instruments at Southern tropical and Northern middle and high latitudes shows a good agreement of the order of 0.7 ± 1 ppmv for all Odin products. The individual profile comparisons show large oscillations. Averaging of SMR profiles reduces such oscillations. With average SMR profiles comparisons show that fine structures can be investigated by looking for the origin of air masses.

In general, no discrepancy has been detected in SMR v2.1 data indicating ranges of altitude (or latitude) with wrong ozone amounts compared with POAM III, NDACC and large balloon-borne instruments measurements. In the SMR v2.1 data, no different systematic error has been found in the 0–35km range in comparison with the 35–60 km range. The same feature has been highlighted in both hemispheres in SMR v2.1/POAM III intercomparisons, and no latitudinal dependence has been revealed in SMR v2.1/NDACC intercomparisons.

In conclusion, we can describe the status of the SMR ozone level 2 data products by evaluating the quality of both presently available data versions: Chalmers v2.1 and CTSO v222. Version 2.1, the most recent and advanced version, appears to be better according to this validation study. Chalmers SMR v2.1 data have the advantage of avoiding an overestimation in the 20–30 km altitude range and to be processed over the whole Odin measurement period. The CTSO SMR v222 data have been processed through July 2005 and have been validated in Barret et al. (2006). SMR version v222 profiles show better agreement compared to the SMR v2.1 data only in some cases, e.g., in the tropical regions. We recommend therefore to use the Chalmers SMR v2.1 data.

In general, only good quality SMR profiles (assigned flag QUALITY=0) should be used for scientific studies and the measurement response associated with each retrieval should be larger than 0.75, to ensure that the information comes primarily from measurements and not from the contribution of the climatological a priori profiles used by the OEM retrieval. Improvements are still in progress in Sweden to obtain a convergent version of the SMR ozone level 2 data. In the future, the Odin/SMR ozone multi-year climatology, based on operational v2.1 data, will provide a useful dataset for the climate modelling community to validate their simulations and to improve our understanding of the climate system.

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