Odin/SMR

Odin/SMR Diagnostic Dataset: Technical Note

Author(s): Donal Murtagh, Andreas Skyman, Bengt Rydberg, and Patrick Eriksson
Contact: Donal Murtagh <donal.murtagh@chalmers.se>
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Chalmers University of Technology
Department of Space, Earth and Environment

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Chapter 1 | Introduction

1.1 Aim and scope of this document

Odin/SMR performs passive limb measurements of the atmosphere, mainly at wavelengths and frequencies around 0.6 mm and 500 GHz, respectively. From these measurements, profiles of O_3, ClO, N_2O, HNO_3, H_2O, CO, and isotopologues of H_2O, and O_3, that are species that are of interest for studying stratospheric and mesospheric chemistry and dynamics, can be derived. Odin/SMR has been in operation for approximately 16 years, and thus, the Level2 dataset can potentially be applied for scientifically interesting trend analysis.

A new Odin/SMR Level2 product dataset will be generated, and this dataset will be based on updated/revised processing algorithms and input data. A verification dataset (VDS) has been created. The VDS is a representative subset of the Odin/SMR Level1B dataset and collocated correlative measurements from similar instruments, i.e. Level2 data from Odin/OSIRIS, Aura/MLS, ENVISAT/MIPAS, ISS/JEM/SMILES, and Meteor3M/SAGEIII. See Rydberg et al. (2016b) for descriptions of data and instruments included in the VDS.

From the VDS a diagnostic dataset (DDS) has been created, containing Level2 products produced with the updated processing system. The aim of this document is to describe the DDS and the main results of comparing it with the correlatative measurements from other instruments, as well as with the Level2 data from the olver 2.0/2.1 versions of the Odin/SMR processing chain.

1.2 Document structure

This document is organized as follows: Chapter 2 describes the Odin/SMR Level2 data products. Chapter 3 contains comparisons for several of the Odin/SMR frequency modes and their Level2 data products with collocated measurments from various intruments. Chapter 4 contains conlusions, and the appendix contains additional information on the various observation modes of Odin/SMR.

Chapter 2 | Odin/SMR Level2 data products

2.1 The Odin mission

The Odin satellite was launched on the 20th of February 2001, into a sun-synchronous 18:00 hour ascending node orbit, carrying two co-aligned limb sounding instruments: OSIRIS (Optical spectrograph and infrared imaging system) and SMR (Sub-millimetre radiometer) (Murtagh et al., 2002). Originally, Odin was used for both atmospheric and astronomical observations, but since 2007 only its aeronomy mission is active. Odin is a Swedish-led project, in cooperation with Canada, France and Finland. Both of Odin's instruments are still functional, and the present operation of the satellite is partly performed as an ESA third party mission.

2.2 The SMR instrument

The Odin/SMR package is highly flexible (Frisk et al., 2003). In short, the four main receiver chains can be tuned to cover frequencies in the ranges 486–504 GHz and 541–581 GHz, but the maximum total instantaneous bandwidth is only 1.6 GHz. This bandwidth is determined by the two auto-correlation spectrometers (ACs) used for atmospheric observations. The two ACs can be coupled to any of the four front-ends, but only two or three front-ends are used simultaneously. The ACs cover 400 or 800 MHz per front-end, depending on configuration. In the configuration applied for atmospheric sounding, the channels of the ACs have a spacing of 1 MHz, while the frequency resolution is only 2 MHz. To cover all molecular transitions of interest (see Table 2.1 and Table 2.2 for an overview), a number of "observation modes" have been defined. Each observation mode makes use of two or three frequency bands. Single sideband operation is obtained by tunable Martin–Pupplet interferometers. The nominal sideband suppression is better than 19 dB across the image band.

Odin/SMR also has a receiver chain around the 118 GHz oxygen transition that was heavily used during Odin's astronomy mission. For the atmospheric mission, this front-end was planned to be used for retrieving temperature profiles, but a technical problem (drifting LO frequency) and the fact that the analysis requires treatment of Zeeman splitting have given these data low priority.

The main reflector of Odin/SMR has a diameter of 1.1 m, giving a vertical resolution at the tangent point of about 2 km. The vertical scanning of the two instruments' line-of-sight is achieved by a rotation of the satellite platform, with a rate matching a vertical speed of the tangent altitude of 750 m/s. Measurements are performed during both upward and downward scanning. The lower end of the scan is typically at about 7 km, the upper end

Table 2.1: Characteristics of Odin/SMR Level2 main data products for version 2 of the processing chain.

Product	Frequency [GHz]	Vertical coverage	Vertical resolution	Precision	Reference
O_3	501.5	∼19–50 km	∼2 km	0.5–2 ppmv	(Urban et al., 2005)
ClO	501.3	∼19–67 km	1.5–2 km	0.15–0.2 ppbv	(Urban et al., 2005)
N_2O	502.3	∼15–70 km	∼1.5 km	15–35 ppbv	(Urban et al., 2005)
O_3	544.9	∼18–70 km	∼1.5 km	0.2–0.4 ppmv	(Urban et al., 2005)
HNO_3	544.4	∼21–67 km	1.5–2 km	1 ppbv	(Urban et al., 2005)

Table 2.2: Characteristics of Odin/SMR Level2 science data products for version 2 of the processing chain.

Product	Frequency [GHz]	Vertical coverage	Vertical resolution	Precision	Reference
CO	578.6	∼17–110 km	3–4 km	25 ppbv–2 ppmv	(Dupuy et al., 2004)
$H_2{}^{16}O$	556.9	∼40–100 km	∼3 km	0.5–1 ppmv	(Urban et al., 2007)
$H_2{}^{16}O$	488.5	∼20–70 km	∼3 km	0.5–1 ppmv	(Urban et al., 2007)
HDO	490.6	∼20–70 km	3–4 km	0.5 ppbv	(Urban et al., 2007)
$H_2{}^{18}O$	489.1	∼20–65 km	3–4 km	20-30 ppbv	(Urban et al., 2007)
$H_2{}^{17}O$	552.0	∼20–70 km	∼3 km	0.4 ppbv	(Urban et al., 2007)
NO	551.7	∼40–100 km	∼7 km	40 %	(Sheese et al., 2013)
${}^{16}O\,{}^{18}O\,{}^{16}O$	490.4	∼27–41 km	4–6 km	25 %	(Urban et al., 2013)
${}^{16}O\,{}^{16}O\,{}^{18}O$	490.0	∼25–45 km	3–4 km	25 %	(Urban et al., 2013)
${}^{16}O\,{}^{16}O\,{}^{17}O$	490.6	∼31–39 km	5–6 km	25 %	(Urban et al., 2013)

varies between 70 and 110 km, depending on observation mode. In correspondence, the horizontal sampling ranges from 1 scan per 600 km to 1 scan per 1000 km. Measurements are in general performed along the orbit plane, providing a latitude coverage between 82.5°S and 82.5°N. Since the end of 2004 Odin is also pointing off-track during certain periods, e.g. during the austral summer season, allowing the latitudinal coverage to be extended towards the poles.

2.3 Odin/SMR Level2 data products

Odin/SMR data are categorized into main and science Level2 products, and Table 2.1 and Table 2.2 describe the characteristics of these products, respectively. The main products are retrieved from the so called “stratospheric” observation mode of Odin/SMR, and this mode cover approximately 50 % of the Odin/SMR observation time. In this mode spectra in frequency bands around 501 and 544 GHz are collected. The science data products are derived from less frequently applied observation modes (typically applied a few days per month).

2.3.1 Main data products

Ozone, ClO, N_2O, and HNO_3 profiles are the main Odin/SMR Level2 products. ClO and N_2O profiles are retrieved from spectra covering transitions around 501 GHz, and

HNO_3 from spectra around 544 GHz. Ozone can be retrieved from both the 501 and the 544 GHz band. Table 2.1 describes characteristics of these Level2 products that have been derived from earlier Odin/SMR Level2 data studies. The characteristics can not be expected to be changed/improved dramatically for a new Level2 data product, because these characteristics depend on the physics of the measurement and the sensor.

Possibly more important than the characteristics described in Table 2.1 are the accuracy and stability of the profiles, since the latter enable trend studies. The overall aim of the new Level2 data processing also reflects this aspect, and the objective is therefore that the accuracy and stability outperforms that from earlier Odin/SMR Level2 data products.

2.3.2 Science data products

Profiles of H_2O, CO, NO and isotopologues of H_2O, and O_3 are considered as science data products for Odin/SMR, and characteristics of these products are described in Table 2.2. Observations covering the science data products are performed on a less frequent basis than the main data products. The aim of the Level2 processing of the science data products is in principle identical to that for the main data products, although the main data products will be given a higher priority.

Chapter 3 | Comparisons with other instruments

This chapter contains comparisons between the Level2 data products of Odin/SMR and collocated measurements from various instruments. The comparisons are organised primarily on frequency mode, secondarily on data product. For each product, average deviations from the various instruments at different altitudes are investigated, followed by an investigation of the over-all correlation between the measurements and both Odin/SMR v2 and v3. The Odin/SMR measurement response and averaging kernels are also investigated for each data product.

From the correlation some key performance indicators are obtained and presented in a table. Of these the most important are the *Pearson correlation* and *slope*, both of which should be as close as possible to unity for a good match, and the *intercept*, which should ideally be zero.

3.1 Frequency mode 01

3.1.1 Overview

Frequency mode 01 monitors two bands, 501.180–501.580 GHz and 501.980–502.380 GHz. Its main use is retrievals of O_3, ClO and N_2O. This ozone product has previously been used as the main Odin ozone product despite the weak line and thereby noisy profiles. We hope that this reprocessing will make the FM 02 ozone the main product. Spectra from this observation mode are shown in Figure 3.1.

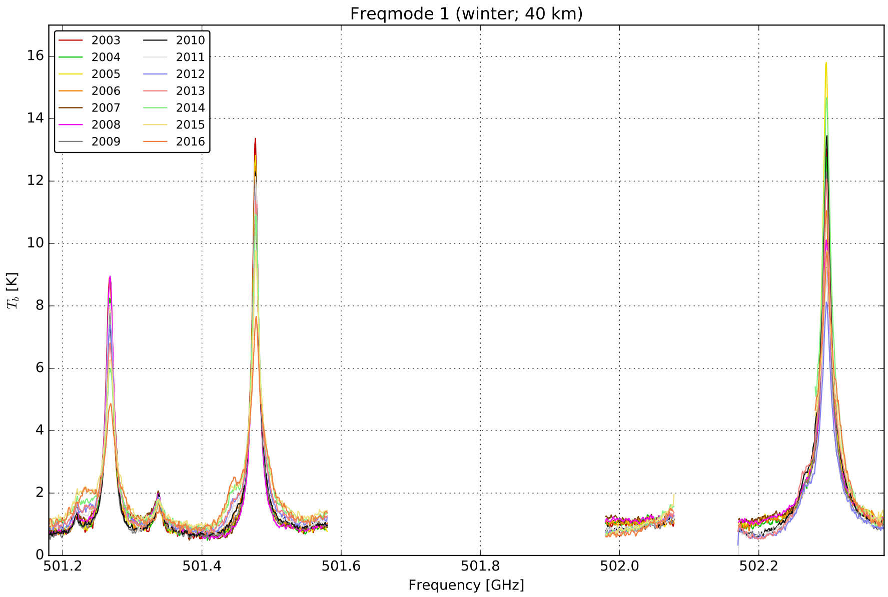


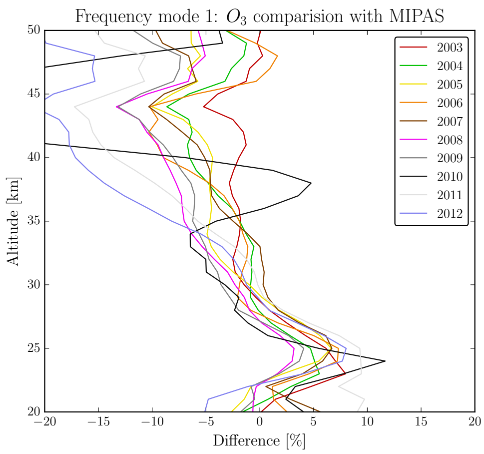
Figure 3.1: Annual median spectra for FM 01 for altitude interval 35–45 km at equatorial latitudes during the arctic winter.

3.1.2 Comparison of retrieved profiles

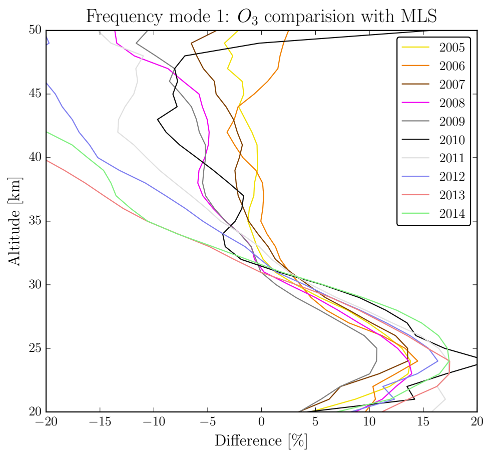
3.1.2.1 O_3

The retrievals for O_3 have been compared with data from the MIPAS, MLS, OSIRIS and SAGE III instruments. Annual average differences to these instruments are shown in Figure 3.2. In Figure 3.3 individual retrievals for the instruments for the entire period are plotted against the retrievals from the new and old versions of the Odin/SMR processing chain. The results show a considerable improvement with the updated version of the processing, with much better over-all correlation and coherrency, and most of the systematic under estimation having been removed compared to all instruments except for SAGE III. Compared to SAGE III, the results were bad for Odin/SMR v2.X, but are even worse for Odin/SMR v3. This may be attributed to the fact that the collocated measurments for SAGE III are all from altitude range 40–50 km, which is the upper range of altitudes for this frequency mode, and the lower range for the SAGE III instrument, as seen in Figure 3.2d.

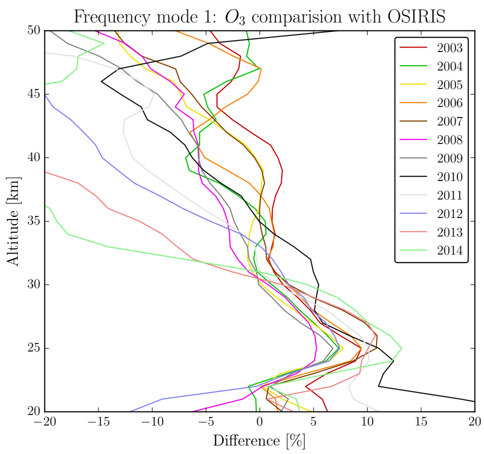
A clear drift in the results is seen after 2009 and data from 2010–2017 should be treated with extreme care. The reason for the drift has now been identified as an instrument problem where an unstable oscillator has widened the instrument line-profile. This may be possible to correct for in a later version of the data. Data from 2018 and onward should be free of this problem thanks to a retuning of some parameters on-board the satellite. The useful range for the product and the vertical resolution is shown in Figure 3.4. The product is useful for the range 19–50 km with a resolution of around 5 km. The resolution is slightly degraded compared to the version 2.x product due to increased vertical correlation used to stabilise the retrievals.



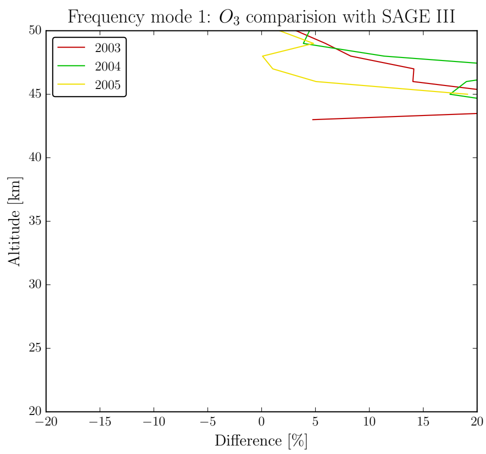
(a) average difference to MIPAS



(b) average difference to MLS



(c) average difference to OSIRIS

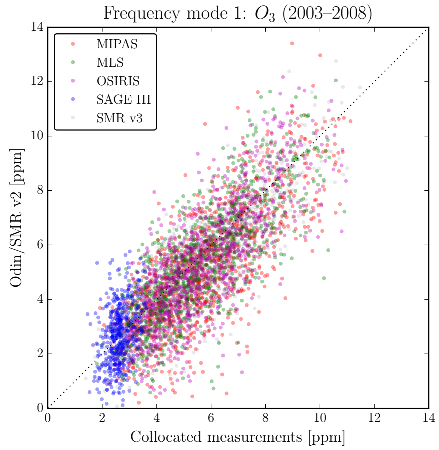


(d) average difference to SAGEIII

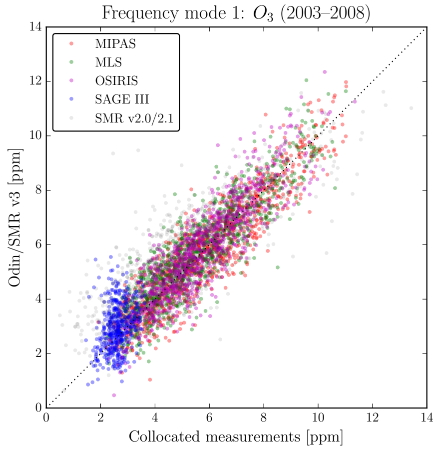
Figure 3.2: Average difference in percent between retrievals of O_3 from Odin/SMR v3 and collocated measurements from various instruments at different altitudes for frequency mode 01.

3.1.2.2 N_2O

The retrievals for N_2O have been compared with data from the MIPAS and MLS instruments. Annual average differences to these instruments are shown in Figure 3.5. In Figure 3.6 individual retrievals for the instruments for the entire period are plotted against the retrievals from the new and old versions of the Odin/SMR processing chain. Only a minor improvement is seen with the updated version of the processing. Figure 3.7 suggests

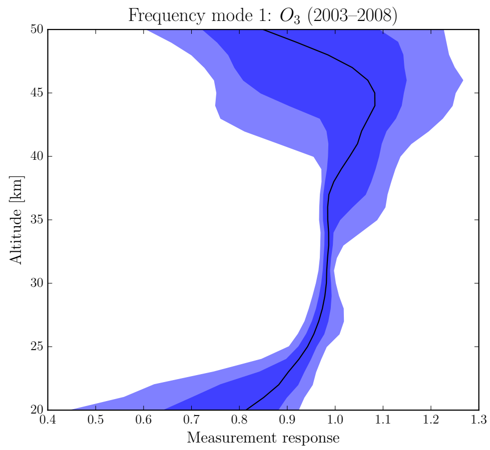


(a) correlation of collcated instruments with Odin/SMR v2.X

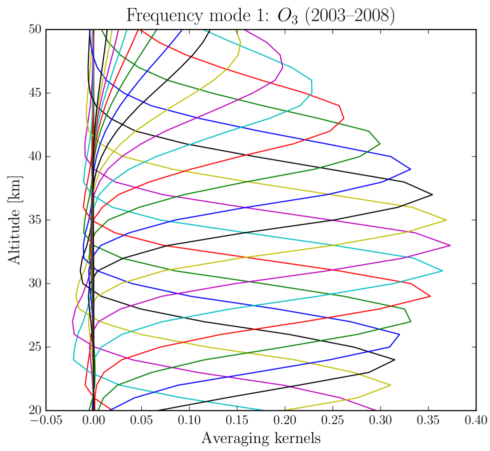


(b) correlation of collcated instruments with Odin/SMR v3

Figure 3.3: Correlation between retrievals of O_3 using Odin/SMR versions 2.X and 3 and collocated measurements from various instruments for frequency mode 01.



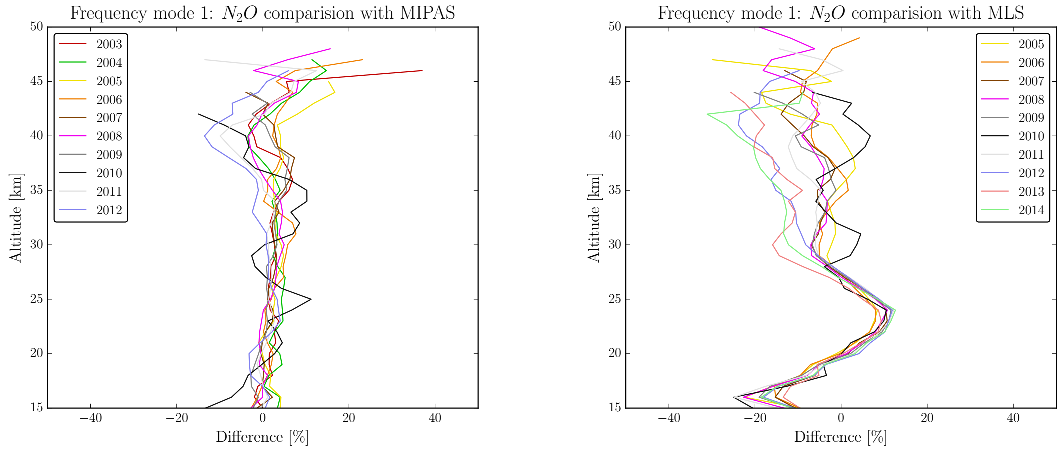
(a) median measurement response with 1σ and 2σ percentiles



(b) median averaging kernels

Figure 3.4: Measurement response and averaging kernels for O_3 retrievals for Odin/SMR v3 at different altitudes for frequency mode 01.

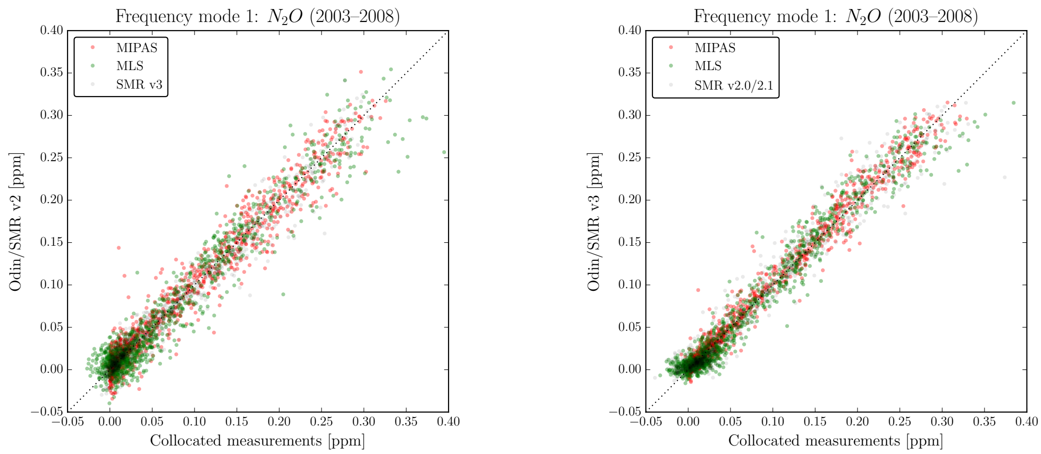
that the product is useful over the range 15–60 km with a vertical resolution of around 5 km.



(a) average difference to MIPAS

(b) average difference to MLS

Figure 3.5: Average difference in percent between retrievals of N_2O from Odin/SMR v3 and collocated measurements from various instruments at different altitudes for frequency mode 01. (Retrievals yielding concentrations ≤ 0.03 ppm have been filtered out.)



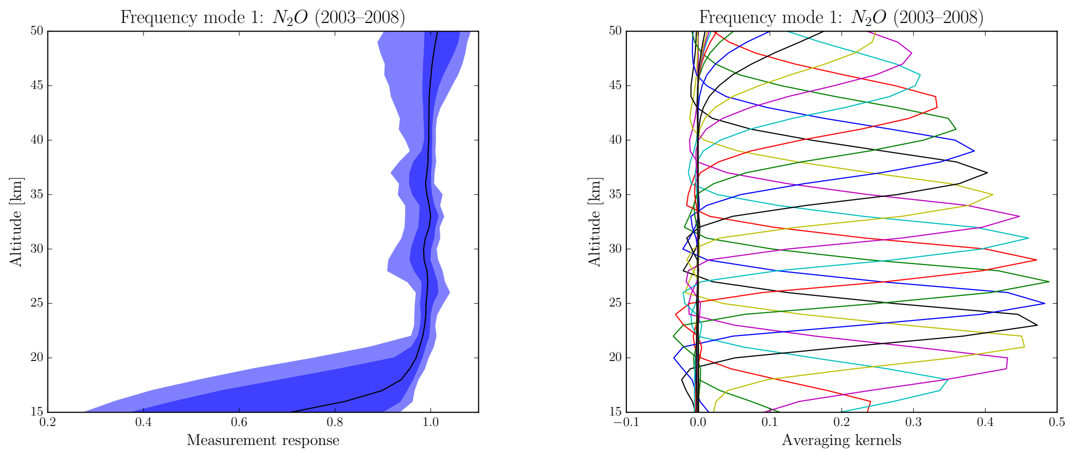
(a) correlation of collcated instruments with Odin/SMR v2.X

(b) correlation of collcated instruments with Odin/SMR v3

Figure 3.6: Correlation between retrievals of N_2O using Odin/SMR versions 2.X and 3 and collocated measurements from various instruments for frequency mode 01.

3.1.2.3 ClO

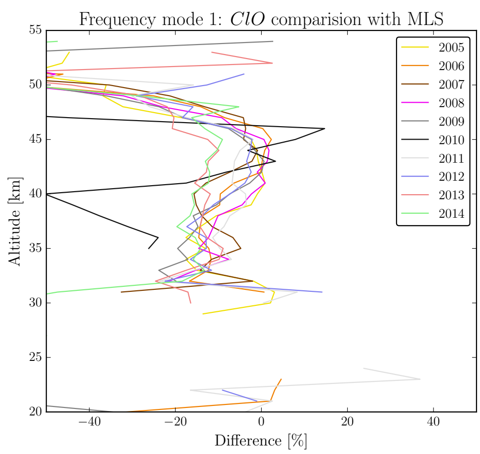
The retrievals for ClO have been compared with data from the MLS instrument. Annual average differences to MLS are shown in Figure 3.8. In Figure 3.9 individual retrievals from MLS for the entire period are plotted against the retrievals from the new and old versions of the Odin/SMR processing chain. No sizeable improvement is seen for the new version of the Odin/SMR processing chain compared to MLS, and the correlation and



(a) median measurement response with 1σ and 2σ percentiles (b) median averaging kernels

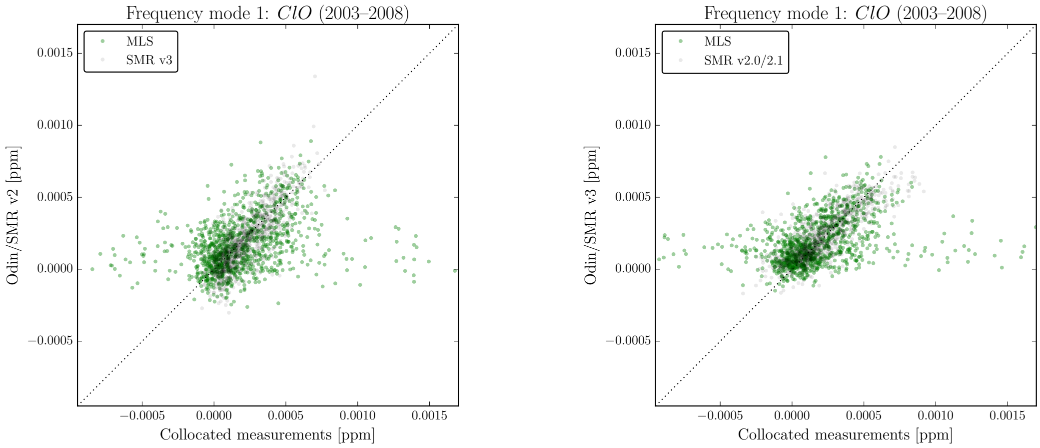
Figure 3.7: Measurement response and averaging kernels for N_2O retrievals for Odin/SMR v3 at different altitudes for frequency mode 01.

coherrency between the two remains poor, however, Figure 3.9 suggests that this is due to noisy nature of the MLS retrievals, which show a very large spread – sometimes even large negative concentrations – for the retrievals where both Odin/SMR versions yield low ClO concentrations. An further explanation is that, since ClO concentrations have a diurnal cycle, collocation in time is very important for comparisons, and due to the orbits of the two instruments, this is only really satisfied near the poles. In this comparison we have not attempted to separate periods of chlorine activation from period with a normal vertical distribution. From previous experience we know that the dirunal effect can be very large in such comparisons. Figure 3.10 suggests that the product is useful in the range 18–58 km with a vertical resolution of around 5 km.



(a) average difference to MLS

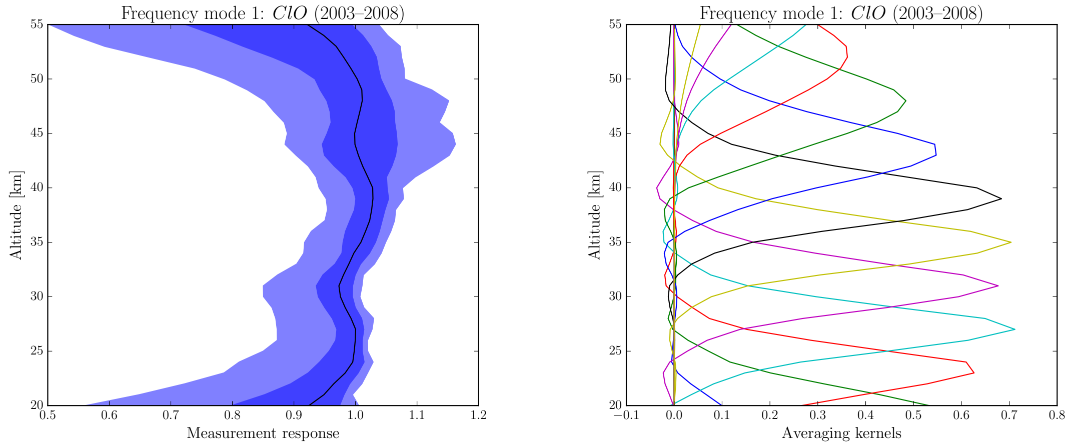
Figure 3.8: Average difference in percent between retrievals of ClO from Odin/SMR v3 and collocated measurements from various instruments at different altitudes for frequency mode 01. (Retrievals yielding concentrations ≤ 0.3 ppb have been filtered out.)



(a) correlation of collcated MLS measurements with Odin/SMR v2.X

(b) correlation of collcated MLS measurements with Odin/SMR v3

Figure 3.9: Correlation between retrievals of ClO using Odin/SMR versions 2.X and 3 and collocated measurements MLS for frequency mode 01.



(a) median measurement response with 1σ and 2σ percentiles

(b) median averaging kernels

Figure 3.10: Measurement response and averaging kernels for ClO retrievals for Odin/SMR v3 at different altitudes for frequency mode 01.

3.1.3 Discussion

The Pearson correlation between the Odin/SMR retrievals and the other instruments was calculated for the entire period for both versions of the processing chain. The results are summarised in Table 3.1, and show that the new algorithm is a improvement compared to all the instruments for all species used in this investigation. The improvement is considerable for the O_3, but only slight for N_2O and ClO, with the latter still showing very poor correlation with the collocated MLS data. This correlations and fits were also calculated for the individual years in the period, but no trends of note were seen until 2009, when a instrument problem occurred or possibly increased which renders retrievals from frequency mode 01 unreliable outside the arctic summer months. The problem caused asymmetric broadening of the lines resulting in bad fits and reduced species concentrations. It may be possible to compensate for the effect in a later reprocessing and rescue the data but this is not yet clear. The problem was fixed late in 2017.

Table 3.1: Pearson correlation and fit parameters of the old and new Odin/SMR retrievals for frequency mode 01, compared with collocated data from other instruments for the period 2003–2008.

Species	**Instrument**	**SMR**	**corr.**	**slope**	**intercept**	**$\|\langle$ res. $\rangle\|$**
O3	MIPAS	v3	0.925	0.949	0.200 ppm	0.814 ppm
		v2.x	0.802	0.905	-0.032 ppm	1.485 ppm
	MLS	v3	0.914	0.963	0.328 ppm	0.833 ppm
		v2.x	0.782	0.915	0.075 ppm	1.430 ppm
	OSIRIS	v3	0.912	0.984	0.158 ppm	0.792 ppm
		v2.x	0.765	0.948	-0.100 ppm	1.438 ppm
	SAGE III	v3	0.286	0.596	1.364 ppm	0.892 ppm
		v2.x	0.347	0.901	0.295 ppm	0.982 ppm
N_2O	MIPAS	v3	0.987	0.988	2.934 ppb	14.363 ppb
		v2.x	0.973	0.976	3.373 ppb	20.004 ppb
	MLS	v3	0.978	0.968	2.084 ppb	18.775 ppb
		v2.x	0.962	0.950	3.218 ppb	24.125 ppb
ClO	MLS	v3	0.275	0.110	0.167 ppb	0.385 ppb
		v2.x	0.256	0.125	0.148 ppb	0.389 ppb

3.1.4 Conclusions

Based on the discussion above, retrievals based on frequency mode 01 can be used with confidence for the species O_3 and N_2O for the period 2003–2008. Retrievals of ClO based on this frequency mode should be used with some caution taking account of the local time of the observations.

For the period 2009–2017 the all retrievals from frequency mode 01 should be be caution if at all, due to the problem discussed in Sec. 3.1.3. The only exception is retrievals from the middle of the arctic summer, which are not affected by this problem due to the sattelite being colder during this period Eriksson and Urban (2006). The problem was fixed in late 2017, wherefore data from 2018 and onwards should have the same quality as that of 2003–2008.

3.2 Frequency mode 02

3.2.1 Overview

Frequency mode 02 monitors the band 544.102–544.902 GHz. Its main use is retrievals of O_3 and HNO_3. This mode was intended to be the main measurement of ozone in the stratosphere but in previous versions of the data products suffered with large systematic biases. We believe that this was caused by an incorrect line broadening constant. This also resulted in an unrealistic pointing offset being derived for this band. In this version of the product the coefficient was adjusted to remove the pointing offset and at the same time greatly improved the ozone values. Spectra from this observation mode are shown in Figure 3.11.

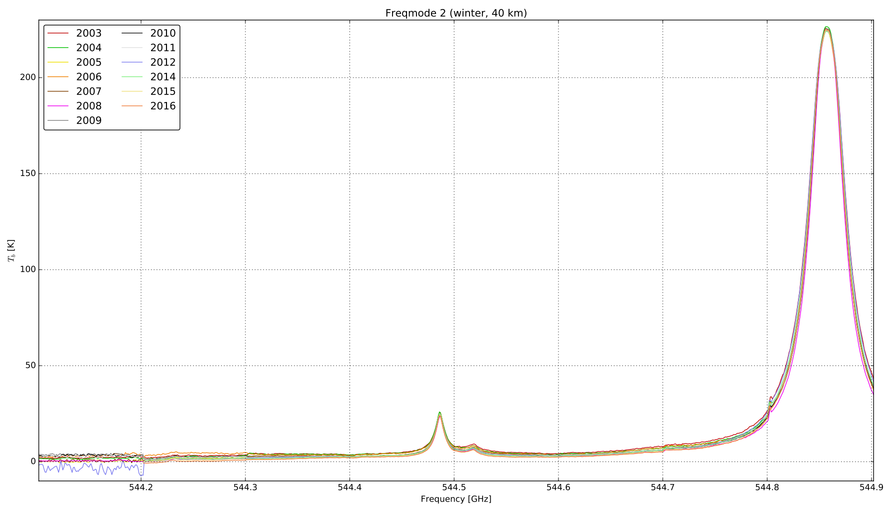
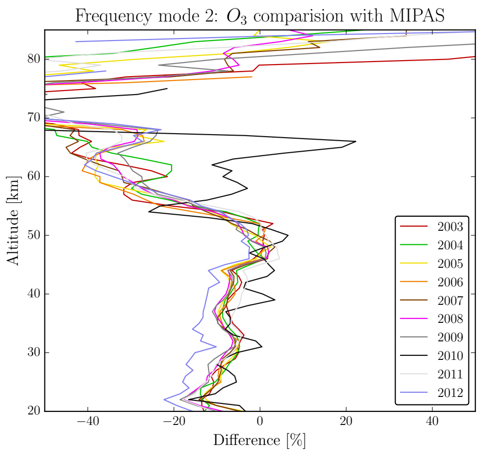


Figure 3.11: Annual median spectra for FM 02 for altitude interval 35–45 km at equatorial latitudes during the arctic winter.

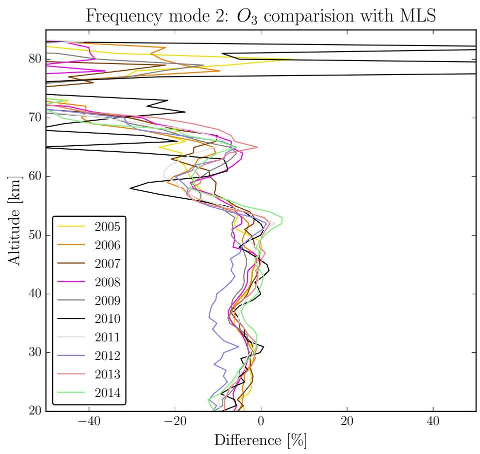
3.2.2 Comparison of retrieved profiles

3.2.2.1 O_3

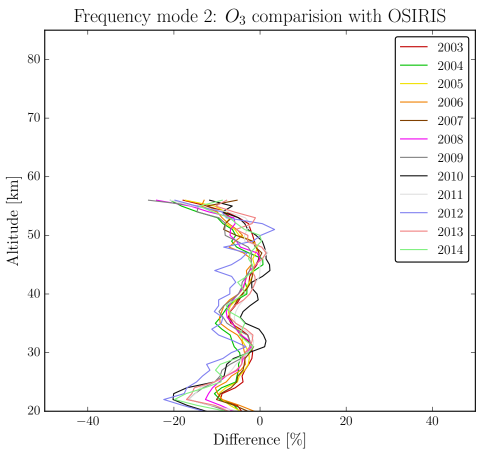
The retrievals for O_3 have been compared with data from the MIPAS, MLS, OSIRIS and SAGE III instruments. Annual average differences to these instruments are shown in Figure 3.12. In Figure 3.13 individual retrievals for the instruments for the entire period are plotted against the retrievals from the new and old versions of the Odin/SMR processing chain. The results show a considerable improvement with the updated version of the processing, with much better over-all correlation and coherency, and most of the systematic under estimation having been removed compared to all the considered instruments. The largest improvement is compared to SAGE III, though, as seen in Figure 3.12d, there are still large systematic differences depending on the altitude. This could be a result of the difference in local time at the measurement location. At these altitudes ozone starts to exhibit a dirunal variation. This speculation could be supported by the good agreement with SAGE since it is a occultation instrument and therefore measures closest to Odin's local time. Figure 3.14 suggests that the product is useful over the range 17–77 km with a vertical resolution of around 3.5 km.



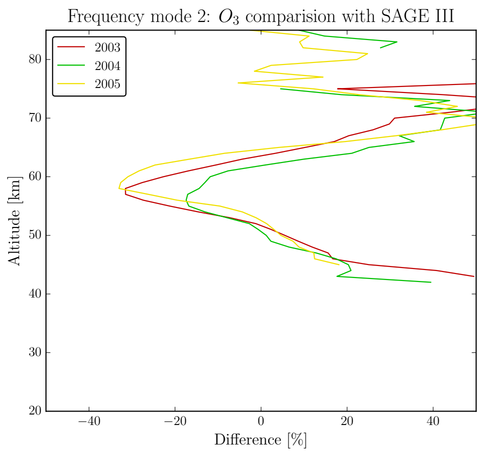
(a) average difference to MIPAS



(b) average difference to MLS



(c) average difference to OSIRIS

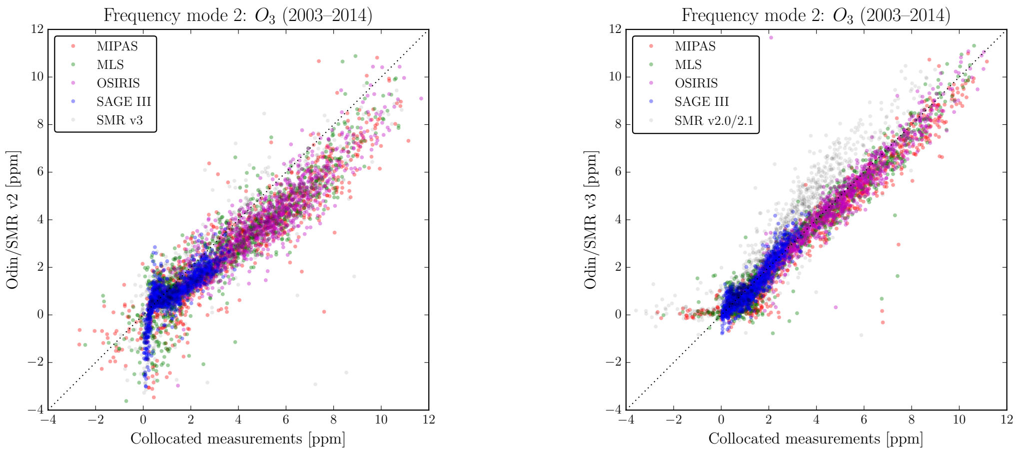


(d) average difference to SAGE III

Figure 3.12: Average difference in percent between retrievals of O_3 from Odin/SMR v3 and collocated measurements from various instruments at different altitudes for frequency mode 02. (Retrievals yielding concentrations ≤ 0.1 ppm have been filtered out.)

3.2.2.2 HNO_3

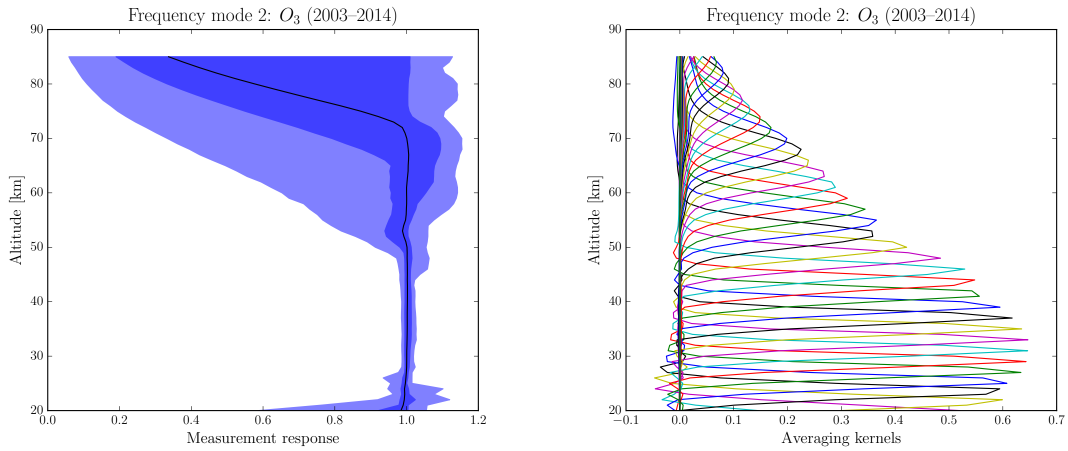
The retrievals for HNO_3 have been compared with data from the MIPAS and MLS instruments. Annual average differences to these instruments are shown in Figure 3.15. In Figure 3.16 individual retrievals for the instruments for the entire period are plotted against the retrievals from the new and old versions of the Odin/SMR processing chain. The results show a considerable improvement with the updated version of the processing compared to both considered instruments with respect to the over-all correlation and coherency is much better, However a large altitude dependent difference seems to have been introduced, resulting in Odin/SMR over estimating the concentrations. The reason for this has not been identified. Figure 3.17 suggests that the product is useful over the range 20–60 km with a vertical resolution of around 6 km.



(a) correlation of collcated instruments with Odin/SMR v2.X

(b) correlation of collcated instruments with Odin/SMR v3

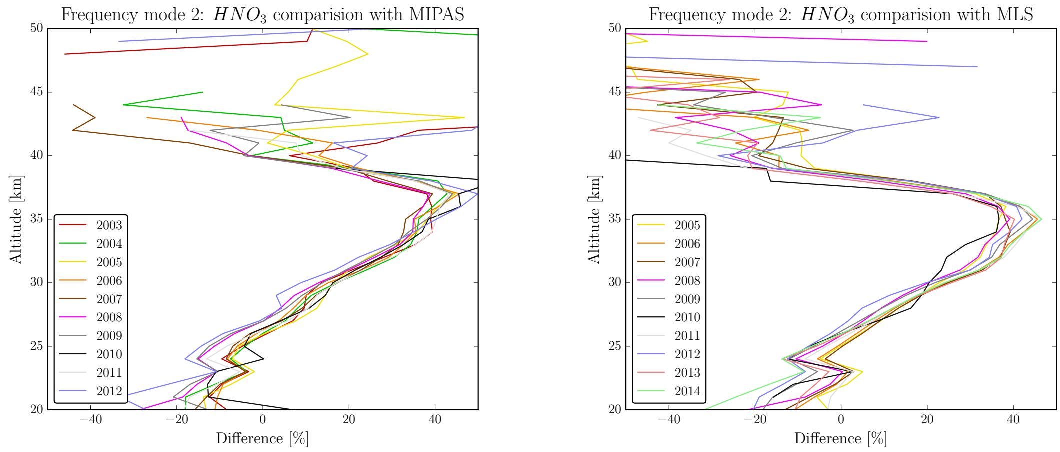
Figure 3.13: Correlation between retrievals of O_3 using Odin/SMR versions 2.X and 3 and collocated measurements from various instruments for frequency mode 02.



(a) median measurement response with 1σ and 2σ percentiles

(b) median averaging kernels

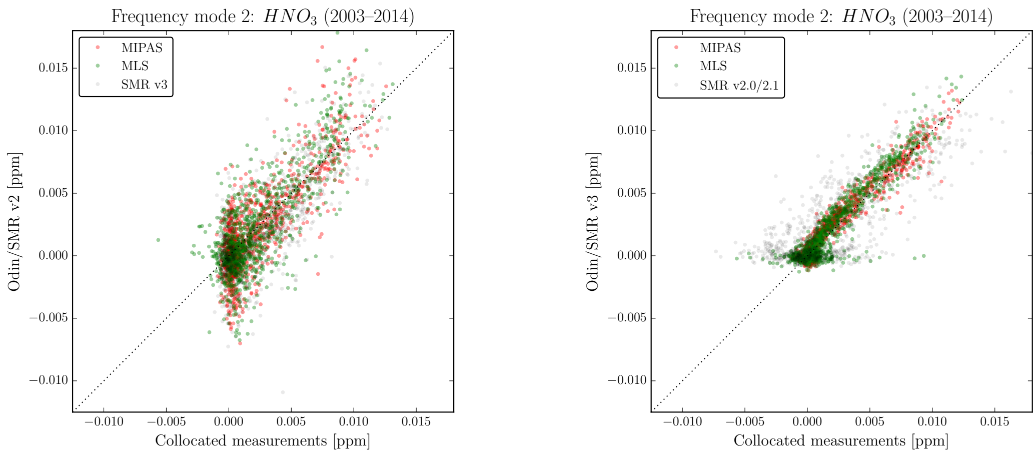
Figure 3.14: Measurement response and averaging kernels for O_3 retrievals for Odin/SMR v3 at different altitudes for frequency mode 02.



(a) average difference to MIPAS

(b) average difference to MLS

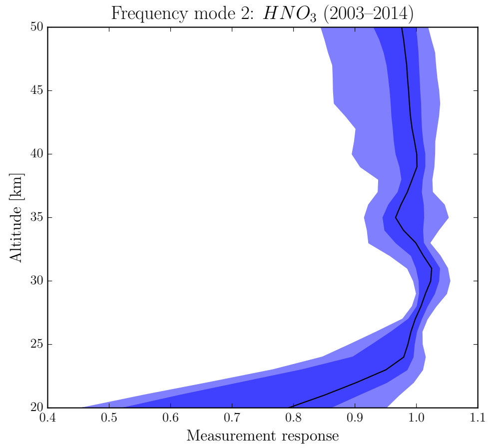
Figure 3.15: Average difference in percent between retrievals of HNO_3 from Odin/SMR v3 and collocated measurements from various instruments at different altitudes. (Retrievals yielding concentrations ≤ 0.5 ppb have been filtered out.)



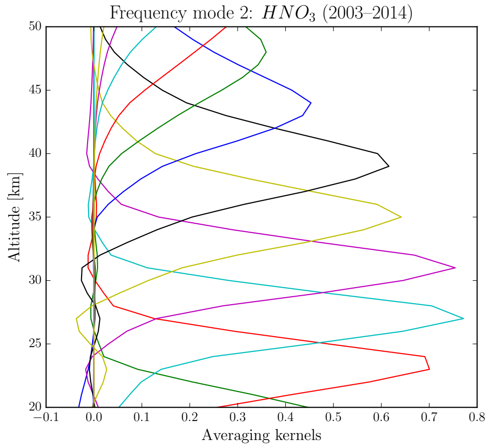
(a) correlation of collcated instruments with Odin/SMR v2.X

(b) correlation of collcated instruments with Odin/SMR v3

Figure 3.16: Correlation between retrievals of HNO_3 using Odin/SMR versions 2.X and 3 and collocated measurements from various instruments.



(a) median measurement response with 1σ and 2σ percentiles

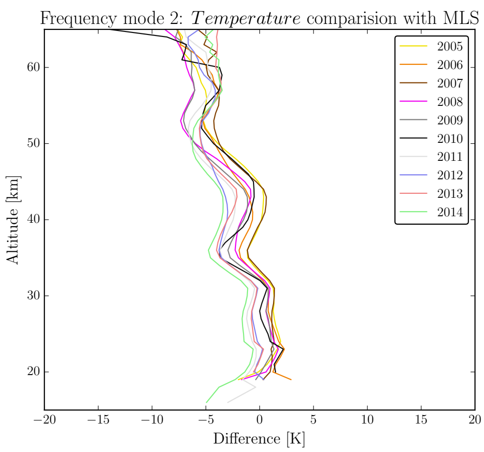


(b) median averaging kernels

Figure 3.17: Measurement response and averaging kernels for HNO_3 retrievals for Odin/SMR v3 at different altitudes for frequency mode 02.

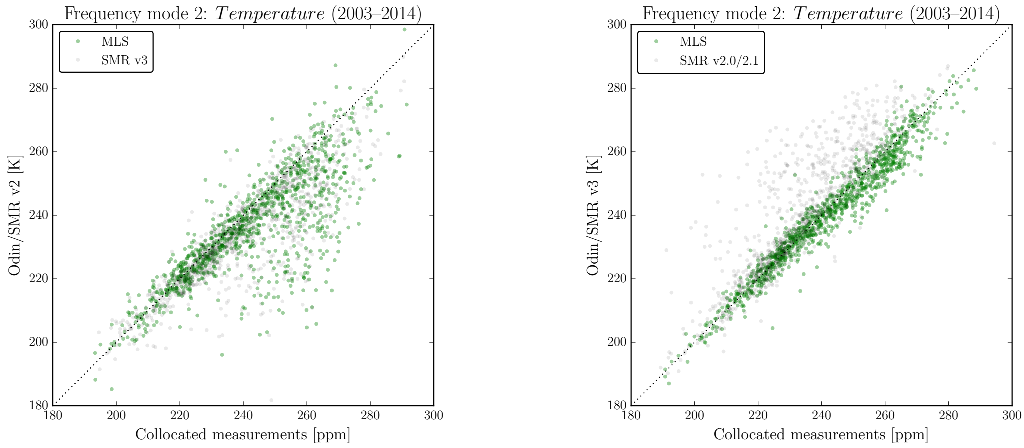
3.2.2.3 Temperature

The retrievals for temperature have been compared with data from the MLS instrument. Annual average differences to this instruments are shown in Figure 3.18. In Figure 3.19 individual retrievals from MLS for the entire period are plotted against the retrievals from the new and old versions of the Odin/SMR processing chain. The results show a considerable improvement with the updated version of the processing, with much better over-all correlation and coherrency, though a small systematic under estimation of the temperature remains, in particular at high altitudes. Figure 3.20 suggests that the product is useful over the range 20–60 km with a vertical resolution of around 7.5 km.



(a) average difference to MLS

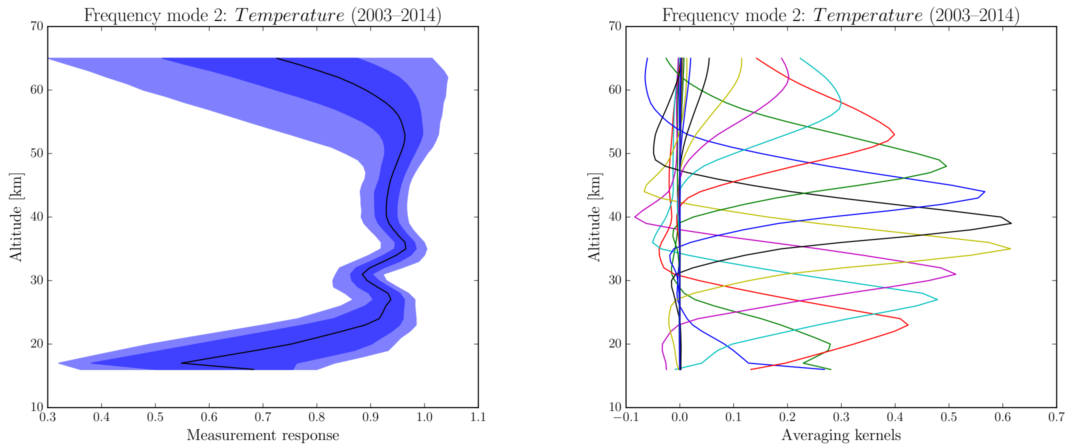
Figure 3.18: Average difference in K between retrievals of temperature from Odin/SMR v3 and collocated measurements from MLS at different altitudes.



(a) correlation of collcated instruments with Odin/SMR v2.X

(b) correlation of collcated instruments with Odin/SMR v3

Figure 3.19: Correlation between retrievals of temperature using Odin/SMR versions 2.X and 3 and collocated measurements from various instruments.



(a) median measurement response with 1σ and 2σ percentiles

(b) median averaging kernels

Figure 3.20: Measurement response and averaging kernels for temperature retrievals for Odin/SMR v3 at different altitudes for frequency mode 02.

3.2.3 Discussion

The Pearson correlation between the Odin/SMR retrievals and the other instruments was calculated for the entire period for both versions of the processing chain. The results are summarised in Table 3.2, and show that the new algorithm is a improvement compared to all the instruments for all species used in this investigation. The improvement is considerable for both O_3 and HNO_3.

Table 3.2: Pearson correlation and fit parameters of the old and new Odin/SMR retrievals for frequency mode 02, compared with collocated data from other instruments for the period 2003–2014.

Species	**Instrument**	**SMR**	**corr.**	**slope**	**intercept**	**$\|\langle$ res. $\rangle\|$**
O3	MIPAS	v3	0.966	0.925	-0.070 ppm	0.792 ppm
		v2.x	0.924	0.802	-0.271 ppm	1.449 ppm
	MLS	v3	0.969	0.955	-0.014 ppm	0.681 ppm
		v2.x	0.913	0.822	-0.219 ppm	1.343 ppm
	OSIRIS	v3	0.968	0.948	0.029 ppm	0.587 ppm
		v2.x	0.918	0.812	-0.187 ppm	1.376 ppm
	SAGE III	v3	0.928	1.065	-0.110 ppm	0.391 ppm
		v2.x	0.742	0.795	-0.152 ppm	0.780 ppm
HNO_3	MIPAS	v3	0.960	0.978	0.180 ppb	0.861 ppb
		v2.x	0.819	1.049	-0.395 ppb	2.207 ppb
	MLS	v3	0.924	0.976	0.280 ppb	1.188 ppb
		v2.x	0.781	1.047	-0.251 ppb	2.442 ppb
Temp.	MLS	v3	0.956	0.936	12.856 K	6.002 K
		v2.x	0.786	0.697	66.735 K	13.794 K

3.2.4 Conclusions

Based on the discussion above, retrievals based on frequency mode 02 can be used with confidence for the species O_3 and HNO_3, as well as for temperature.

3.3 Frequency mode 08

3.3.1 Overview

Frequency mode 08 monitors two bands, 488.950–489.350 GHz and 488.350–488.750 GHz. Its main use is retrievals of water vapour in the lower stratosphere. O_3 is also retrieved. This mode showed considerable sideband leakage and served as the model for a new sideband correction that has been applied to all bands. Spectra from this observation mode are shown in Figure 3.21.

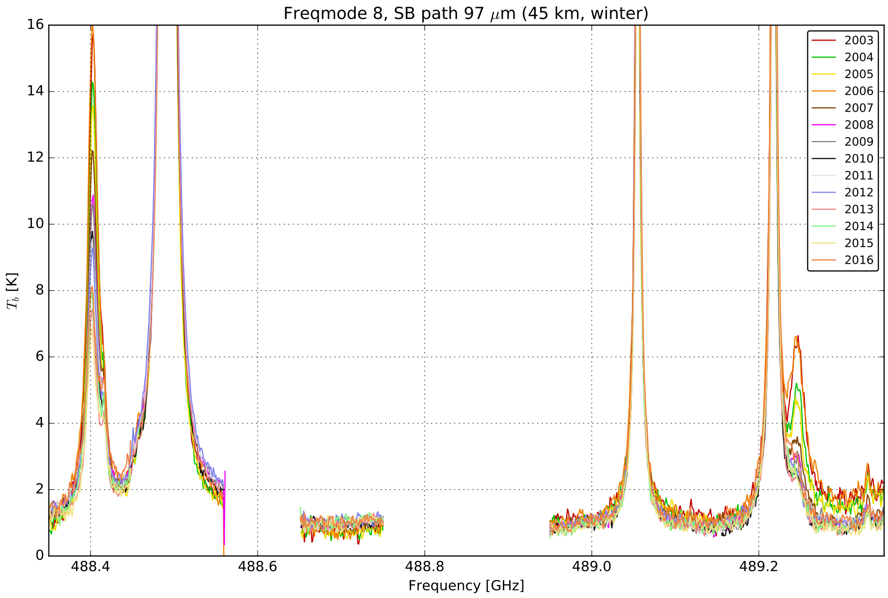


Figure 3.21: Annual median spectra for FM 08 for altitude interval 40–50 km at equatorial latitudes for the 97 μm sideband path during the arctic winter.

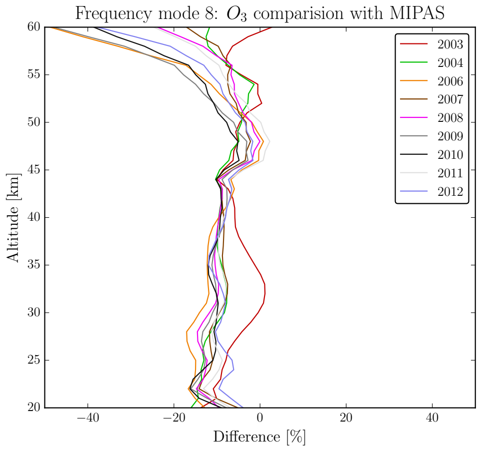
3.3.2 Comparison of retrieved profiles

3.3.2.1 O_3

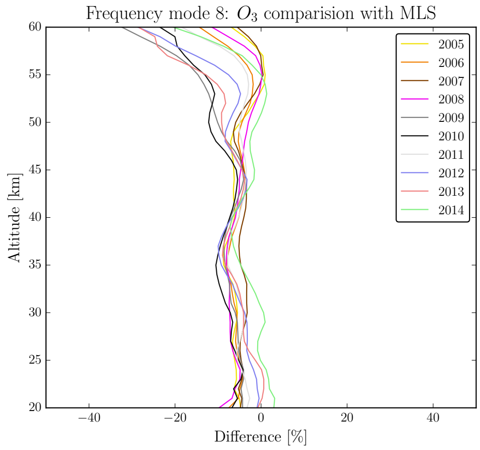
The retrievals for O_3 have been compared with data from the MIPAS, MLS, OSIRIS and SAGE III instruments. Annual average differences to these instruments are shown in Figure 3.22. In Figure 3.23 individual retrievals for the instruments for the entire period are plotted against the retrievals from the new and old versions of the Odin/SMR processing chain. The results show a considerable improvement with the updated version of the processing compared to all considered instruments. The over-all correlation and coherency is much better, though a systematic under estimation remains. Figure 3.24 suggests that the product is useful over the range 16–70 km with a vertical resolution of around 5 km.

3.3.2.2 H_2O

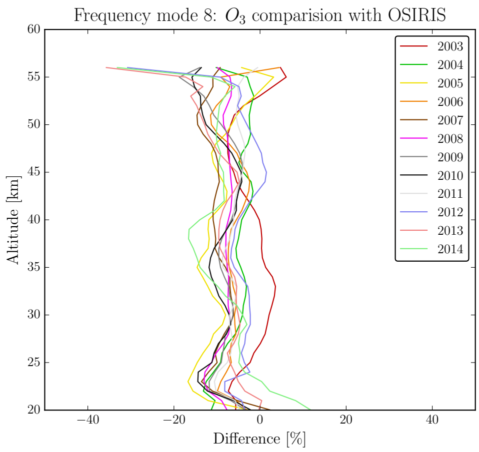
The retrievals for H_2O have been compared with data from the MIPAS, MLS and SAGE III instruments. Annual average differences to these instruments are shown in Figure 3.25.



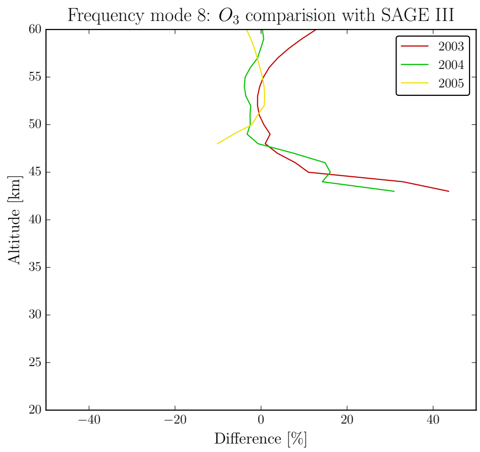
(a) average difference to MIPAS



(b) average difference to MLS

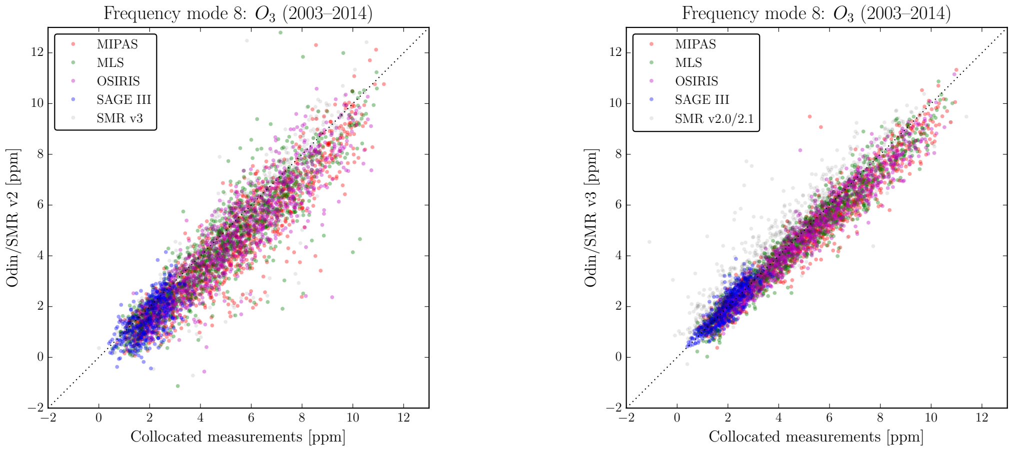


(c) average difference to OSIRIS



(d) average difference to SAGE III

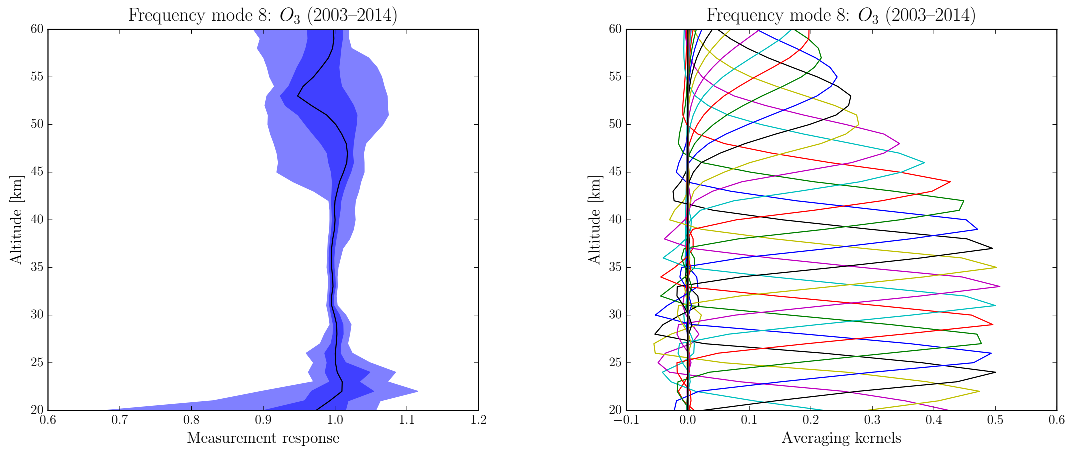
Figure 3.22: Average difference in percent between retrievals of O_3 from Odin/SMR v3 and collocated measurements from various instruments at different altitudes for frequency mode 08.



(a) correlation of collcated instruments with Odin/SMR v2.X

(b) correlation of collcated instruments with Odin/SMR v3

Figure 3.23: Correlation between retrievals of O_3 using Odin/SMR versions 2.X and 3 and collocated measurements from various instruments for frequency mode 08.

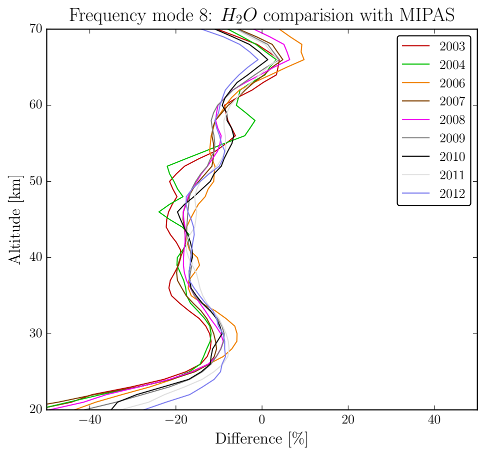


(a) median measurement response with 1σ and 2σ percentiles

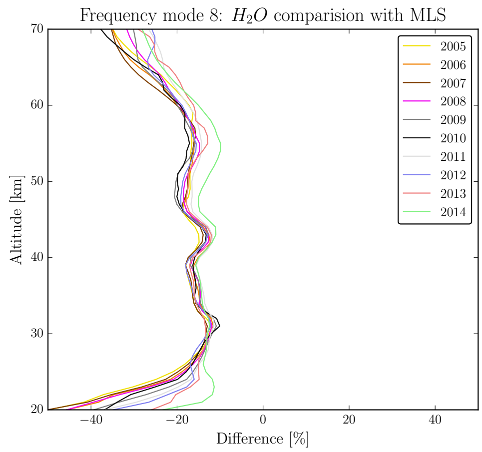
(b) median averaging kernels

Figure 3.24: Measurement response and averaging kernels for O_3 retrievals for Odin/SMR v3 at different altitudes for frequency mode 08.

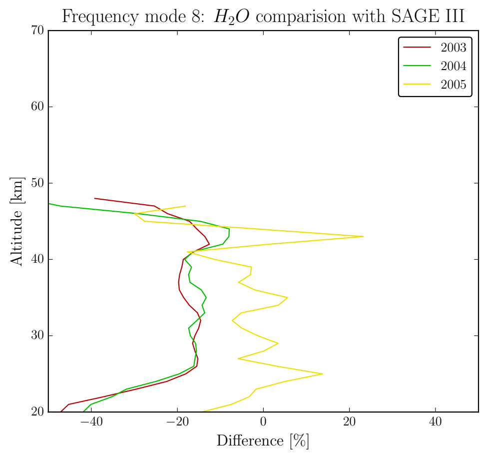
In Figure 3.26 individual retrievals for the instruments for the entire period are plotted against the retrievals from the new and old versions of the Odin/SMR processing chain. Though the results show a considerably improved coherency with the updated version of the processing compared to all considered instruments, the correlation is still poor, and the water content is still systematically underestimated, in particular for higher concentrations. Figure 3.27 suggests that the product is useful over the range 19–78 km with a vertical resolution of around 4.5 km.



(a) average difference to MIPAS



(b) average difference to MLS

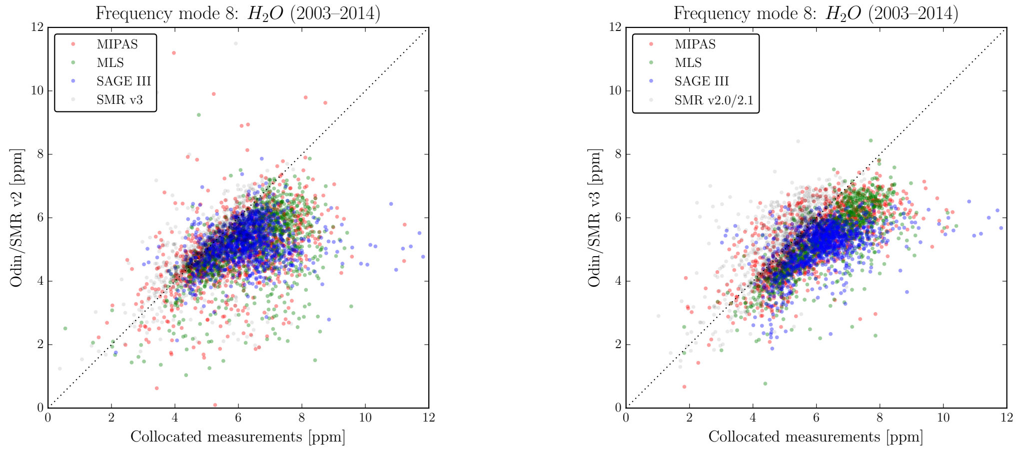


(c) average difference to SAGE III

Figure 3.25: Average difference in percent between retrievals of H_2O from Odin/SMR v3 and collocated measurements from various instruments at different altitudes for frequency mode 08.

3.3.3 Discussion

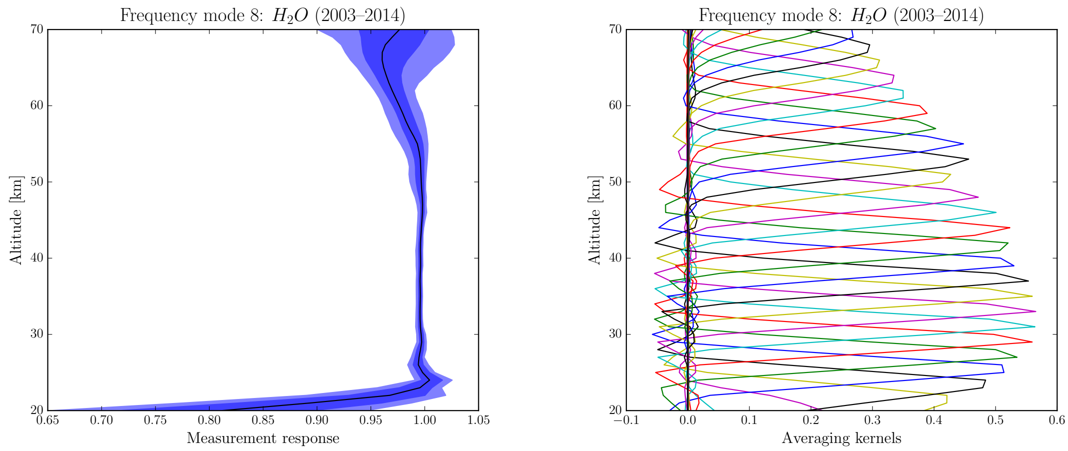
The Pearson correlation between the Odin/SMR retrievals and the other instruments was calculated for the entire period for both versions of the processing chain. The results are summarised in Table 3.3, and show that the new algorithm is a improvement compared to all the instruments for all species used in this investigation. The improvement is considerable for both O_3 and H_2O. However there still seems to be a systematic underestimation



(a) correlation of collcated instruments with Odin/SMR v2.X

(b) correlation of collcated instruments with Odin/SMR v3

Figure 3.26: Correlation between retrievals of H_2O using Odin/SMR versions 2.X and 3 and collocated measurements from various instruments for frequency mode 08.



(a) median measurement response with 1σ and 2σ percentiles

(b) median averaging kernels

Figure 3.27: Measurement response and averaging kernels for H_2O retrievals for Odin/SMR v3 at different altitudes for frequency mode 08.

of both products. It is unclear if this is due to spectroscopic problems or some sort of underestimation of the intensity.

Table 3.3: Pearson correlation and fit parameters of the old and new Odin/SMR retrievals for frequency mode 08, compared with collocated data from other instruments for the period 2003–2014.

Species	**Instrument**	**SMR**	**corr.**	**slope**	**intercept**	**$\lvert\langle$ res. $\rangle\rvert$**
O3	MIPAS	v3	0.977	0.905	0.056 ppm	0.656 ppm
		v2.x	0.922	0.897	-0.274 ppm	1.239 ppm
	MLS	v3	0.979	0.933	0.066 ppm	0.540 ppm
		v2.x	0.911	0.916	-0.173 ppm	1.129 ppm
	OSIRIS	v3	0.973	0.923	0.057 ppm	0.609 ppm
		v2.x	0.916	0.925	-0.283 ppm	1.127 ppm
	SAGE III	v3	0.884	0.956	0.134 ppm	0.357 ppm
		v2.x	0.658	0.804	-0.026 ppm	0.752 ppm
H_2O	MIPAS	v3	0.701	0.567	1.843 ppm	1.229 ppm
		v2.x	0.468	0.370	2.769 ppm	1.616 ppm
	MLS	v3	0.811	0.690	0.894 ppm	1.314 ppm
		v2.x	0.473	0.422	2.424 ppm	1.749 ppm
	SAGE III	v3	0.528	0.317	3.061 ppm	1.593 ppm
		v2.x	0.242	0.128	4.353 ppm	1.657 ppm

3.3.4 Conclusions

Based on the discussion above, retrievals based on frequency mode 08 can be used with confidence for the species O_3 while noting that the values may be underestimated bu 5–10 %. The data should be used with some caution for H_2O but this requires more investigation.

3.4 Frequency mode 13

3.4.1 Overview

Frequency mode 13 monitors the band 556.598–557.398 GHz. Its main use is retrievals of H_2O and O_3. This is the strongest water vapour line available in the sub-mm wave spectrum and is used to reach the the highest possible altitude particularly to study water vapour around the mesopause region. The line centre is saturated up to approximately 90 km and therefore temperatures can be derived throughout the mesosphere. This band and FM 19 remain problematic and require a dedicated study to understand the presumably instrumental effects. Spectra from this observation mode are shown in Figure 3.28.

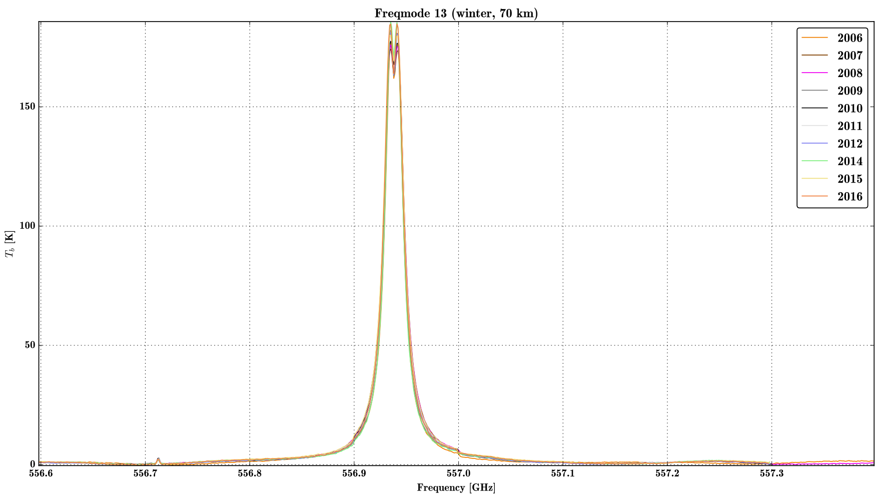


Figure 3.28: Annual median spectra for FM 13 for altitude interval 65–75 km at equatorial latitudes during the arctic winter.

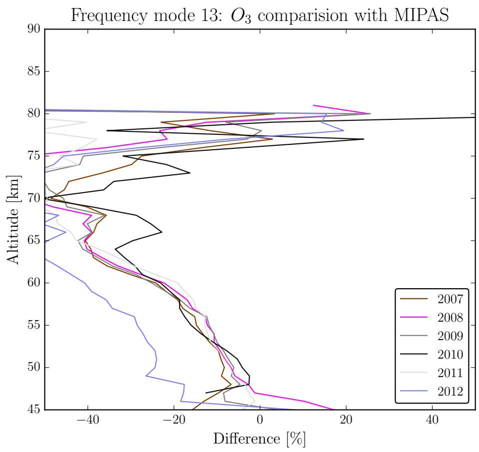
3.4.2 Comparison of retrieved profiles

3.4.2.1 O_3

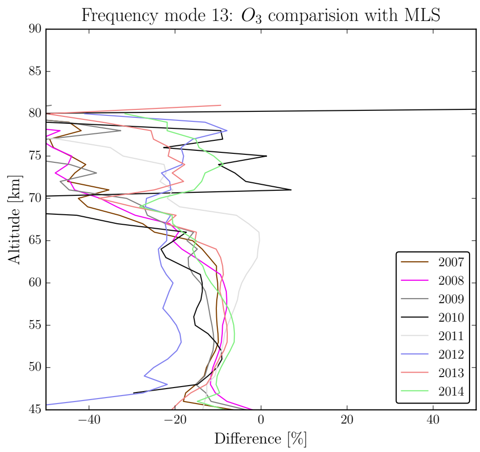
The retrievals for O_3 have been compared with data from the MIPAS, MLS and OSIRIS instruments. Annual average differences to these instruments are shown in Figure 3.29. In Figure 3.30 individual retrievals for the instruments for the entire period are plotted against the retrievals from the new and old versions of the Odin/SMR processing chain. The results show a better over-all coherency with the updated version of the processing compared to all considered instruments, but a systematic under estimation of the concentrations has been introduced. The reason for this is that an emprical correction to the intensities has bee remove since there was no physical basis for its inclusion. We suspect that some sort of non-linearity is causing the underestimation. Figure 3.31 suggests that the product is useful over the range 44–80 km with a vertical resolution of around 6 km.

3.4.2.2 H_2O

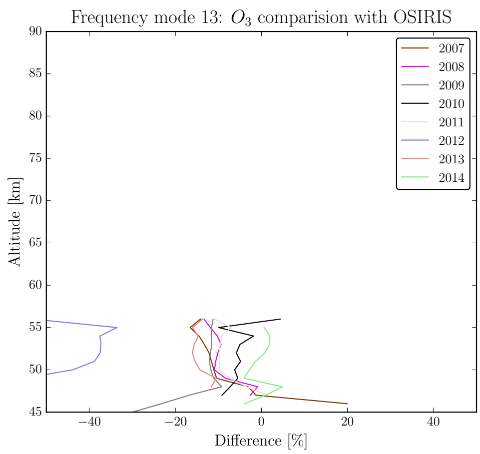
The retrievals for H_2O have been compared with data from the MIPAS and MLS instruments. Annual average differences to these instruments are shown in Figure 3.32.



(a) average difference to MIPAS

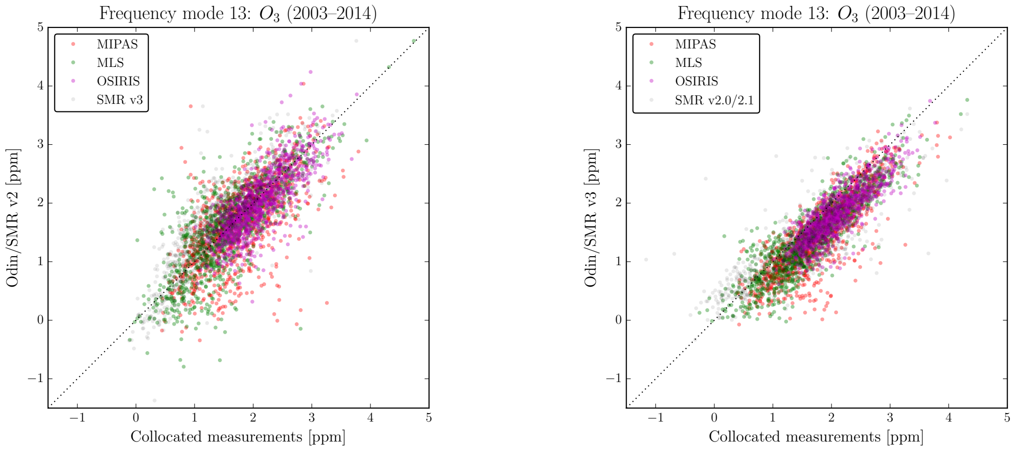


(b) average difference to MLS



(c) average difference to OSIRIS

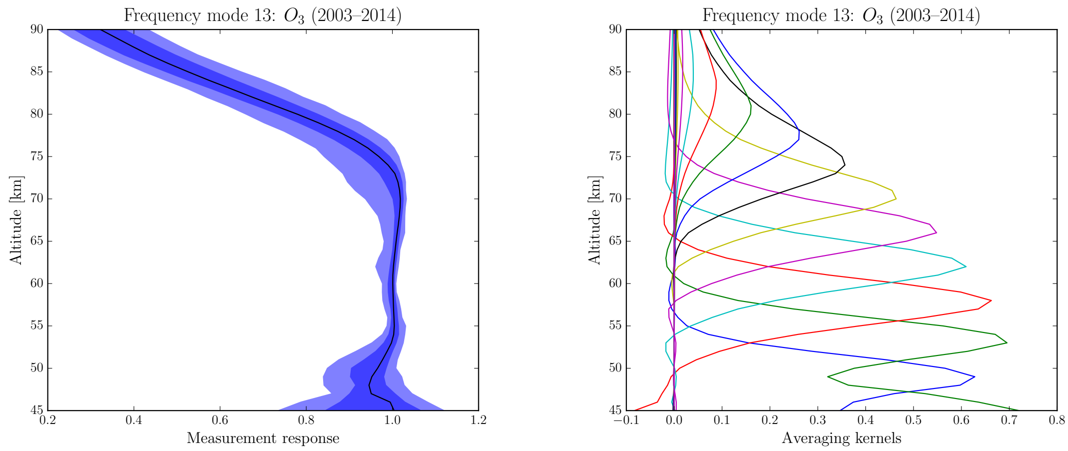
Figure 3.29: Average difference in percent between retrievals of O_3 from Odin/SMR v3 and collocated measurements from various instruments at different altitudes for frequency mode 13.



(a) correlation of collcated instruments with Odin/SMR v2.X

(b) correlation of collcated instruments with Odin/SMR v3

Figure 3.30: Correlation between retrievals of O_3 using Odin/SMR versions 2.X and 3 and collocated measurements from various instruments for frequency mode 13.

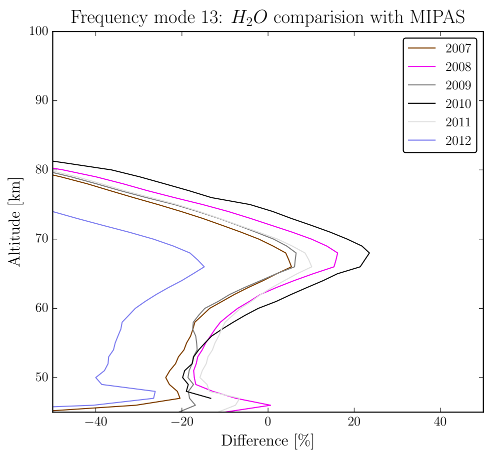


(a) median measurement response with 1σ and 2σ percentiles

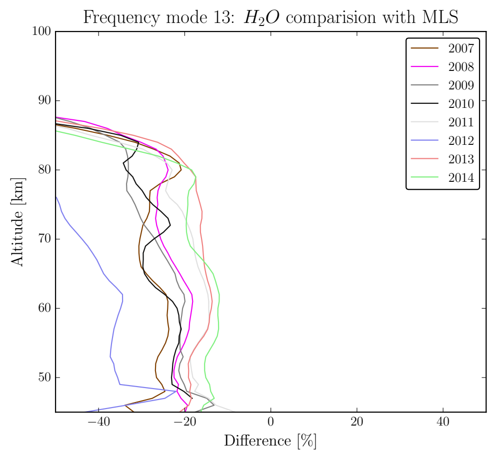
(b) median averaging kernels

Figure 3.31: Measurement response and averaging kernels for O_3 retrievals for Odin/SMR v3 at different altitudes for frequency mode 13.

In Figure 3.33 individual retrievals for the instruments for the entire period are plotted against the retrievals from the new and old versions of the Odin/SMR processing chain. The results show a slightly improved over-all coherency with the updated version of the processing compared to both considered instruments, but a systematic under estimation of the concentrations has been introduced, and the correlation, in particular with MIPAS, remains poor. This would suggest that the MIPAS values are unreliable for this data product. Figure 3.34 suggests that the product is useful over the range 44–110 km with a vertical resolution of around 4.5 km.

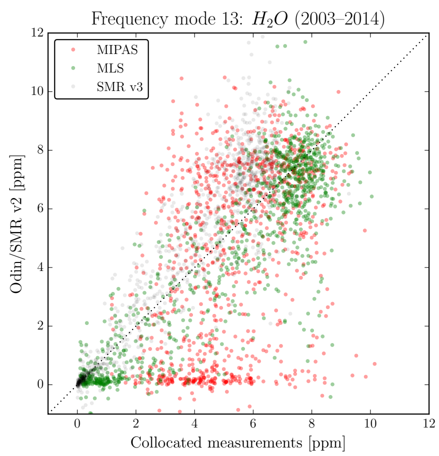


(a) average difference to MIPAS

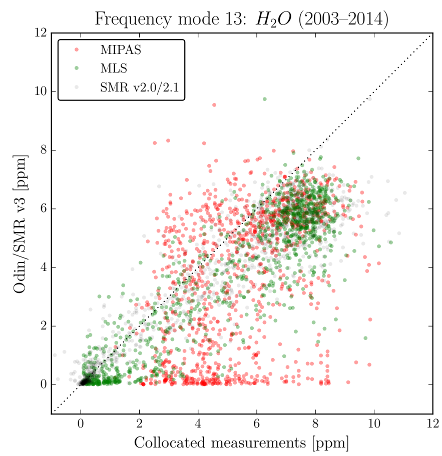


(b) average difference to MLS

Figure 3.32: Average difference in percent between retrievals of H_2O from Odin/SMR v3 and collocated measurements from various instruments at different altitudes for frequency mode 13.

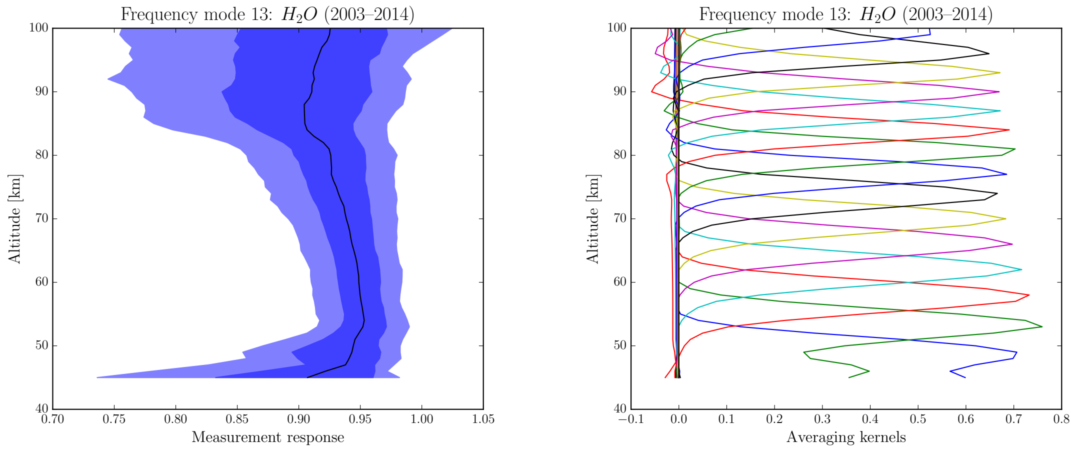


(a) correlation of collcated instruments with Odin/SMR v2.X



(b) correlation of collcated instruments with Odin/SMR v3

Figure 3.33: Correlation between retrievals of H_2O using Odin/SMR versions 2.X and 3 and collocated measurements from various instruments for frequency mode 13.



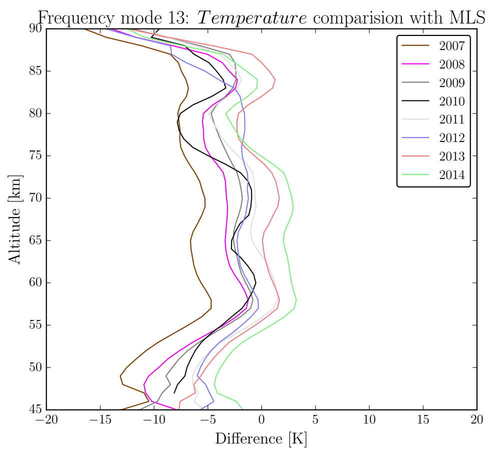
(a) median measurement response with 1σ and 2σ percentiles

(b) median averaging kernels

Figure 3.34: Measurement response and averaging kernels for H_2O retrievals for Odin/SMR v3 at different altitudes for frequency mode 13.

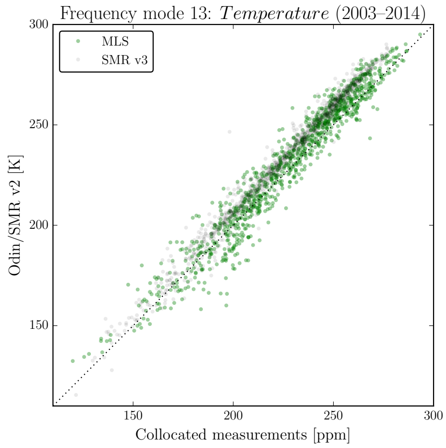
3.4.2.3 Temperature

The retrievals for temperature have been compared with data from the MLS instrument. Annual average differences to this instruments are shown in Figure 3.35. In Figure 3.36 individual retrievals from MLS for the entire period are plotted against the retrievals from the new and old versions of the Odin/SMR processing chain. The results show little or no improvement with the updated version of the processing. Whereas with the previous version of the system, the temperature was systematically over estimated, a small under estimation of the temperature is now seen. This is a result of the removal of the arbitrary scaling factor. Figure 3.37 suggests that the product is useful over the range 44–95 km with a vertical resolution of around 5.5 km.

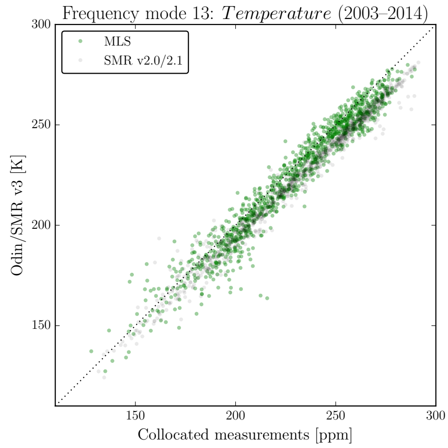


(a) average difference to MLS

Figure 3.35: Average difference in K between retrievals of temperature from Odin/SMR v3 and collocated measurements from MLS at different altitudes.

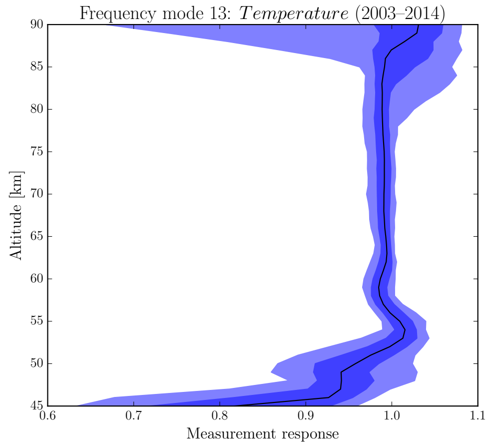


(a) correlation of collcated instruments with Odin/SMR v2.X

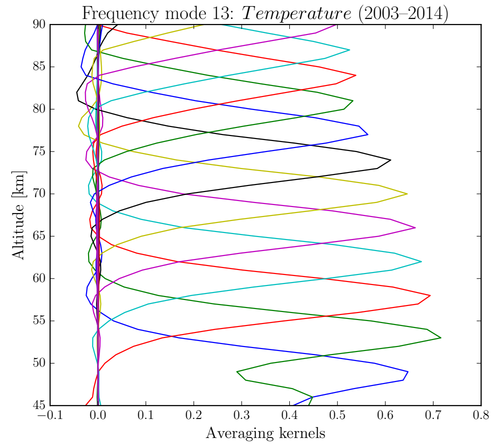


(b) correlation of collcated instruments with Odin/SMR v3

Figure 3.36: Correlation between retrievals of temperature using Odin/SMR versions 2.X and 3 and collocated measurements from various instruments.



(a) median measurement response with 1σ and 2σ percentiles



(b) median averaging kernels

Figure 3.37: Measurement response and averaging kernels for temperature retrievals for Odin/SMR v3 at different altitudes for frequency mode 13.

3.4.3 Discussion

The Pearson correlation between the Odin/SMR retrievals and the other instruments was calculated for the entire period for both versions of the processing chain. The results are summarised in Table 3.4, and show that the new algorithm shows little or no improvement compared to all the instruments for the species used in this investigation.

Table 3.4: Pearson correlation and fit parameters of the old and new Odin/SMR retrievals for frequency mode 13, compared with collocated data from other instruments for the period 2003–2014.

Species	**Instrument**	**SMR**	**corr.**	**slope**	**intercept**	$\|\langle$ **res.** $\rangle\|$
O3	MIPAS	v3	0.795	0.757	0.026 ppm	0.596 ppm
		v2.x	0.687	0.827	0.185 ppm	0.558 ppm
	MLS	v3	0.738	0.625	0.509 ppm	0.645 ppm
		v2.x	0.782	0.900	0.097 ppm	0.509 ppm
	OSIRIS	v3	0.773	0.829	0.083 ppm	0.461 ppm
		v2.x	0.779	0.916	0.083 ppm	0.355 ppm
H_2O	MIPAS	v3	0.471	0.673	-0.154 ppm	2.924 ppm
		v2.x	0.411	0.710	0.758 ppm	2.965 ppm
	MLS	v3	0.890	0.776	-0.134 ppm	1.756 ppm
		v2.x	0.877	0.940	-0.224 ppm	1.591 ppm
Temp.	MLS	v3	0.959	0.986	-0.250 K	9.090 K
		v2.x	0.972	1.032	-4.156 K	8.535 K

3.4.4 Conclusions

Based on the discussion above, retrievals based on frequency mode 13 should be used with caution for both O_3 and H_2O. The temperature retrievals, on the other hand, appear reliable albeit with a cold bias of 3–5 K. For water vapour he comparisons with MLS seem to suggest a consistent -20 % bias.

3.5 Frequency mode 19

3.5.1 Overview

Frequency mode 19 monitors the band 556.598–557.398 GHz. Its main use is retrievals of H_2O and O_3. FM 19 is an alternative mode for measuring water vapour in the mesosphere. As with FM 13 we suspect some non-linearity problems that we have not yet managed to track down. Indications of this are the underestimation of temperature and water vapour itself. Spectra from this observation mode are shown in Figure 3.38.

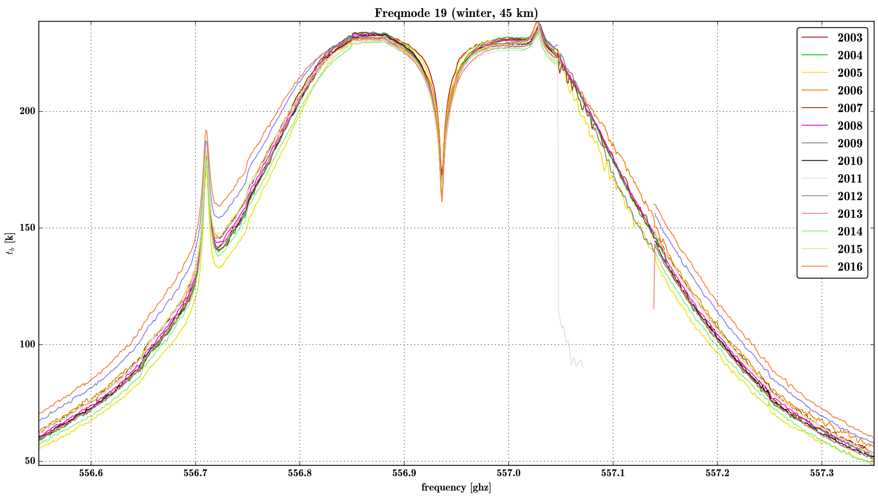


Figure 3.38: Annual median spectra for FM 19 for altitude interval 42–48 km at equatorial latitudes during the arctic winter.

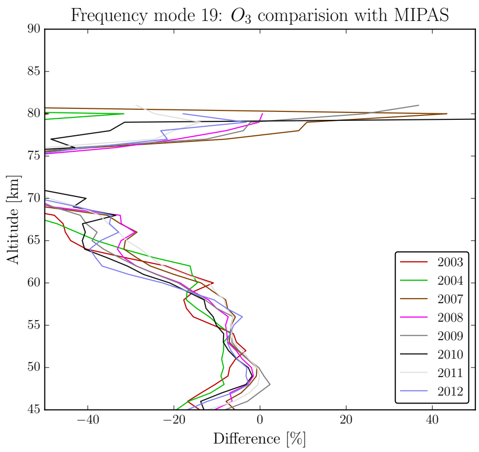
3.5.2 Comparison of retrieved profiles

3.5.2.1 O_3

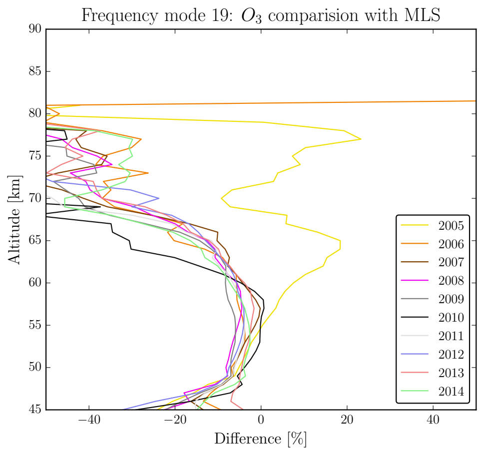
The retrievals for O_3 have been compared with data from the MIPAS, MLS, OSIRIS and SAGE III instruments. Annual average differences to these instruments are shown in Figure 3.39. In Figure 3.40 individual retrievals for the instruments for the entire period are plotted against the retrievals from the new and old versions of the Odin/SMR processing chain. The results show a better over-all coherrency with the updated version of the processing compared to SAGE III and OSIRIS, but worse correlation with MIPAS and MLS, and a systematic under estimation of the concentrations remains compared to all considered instruments. Figure 3.41 suggests that the product is useful over the range 44–80 km with a vertical resolution of around 6 km.

3.5.2.2 H_2O

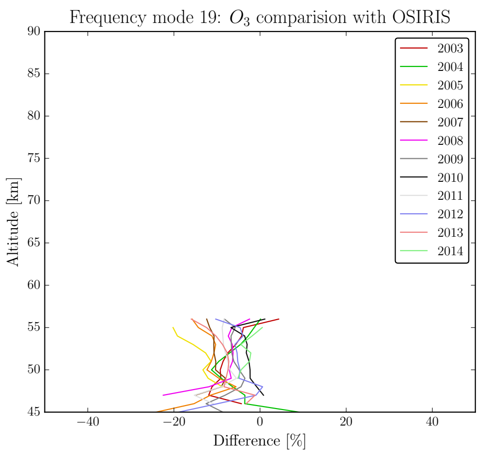
The retrievals for H_2O have been compared with data from the MIPAS and MLS instruments. Annual average differences to these instruments are shown in Figure 3.42. In Figure 3.43 individual retrievals for the instruments for the entire period are plotted against the retrievals from the new and old versions of the Odin/SMR processing chain. The results show a slightly improved over-all coherency with the updated version of the



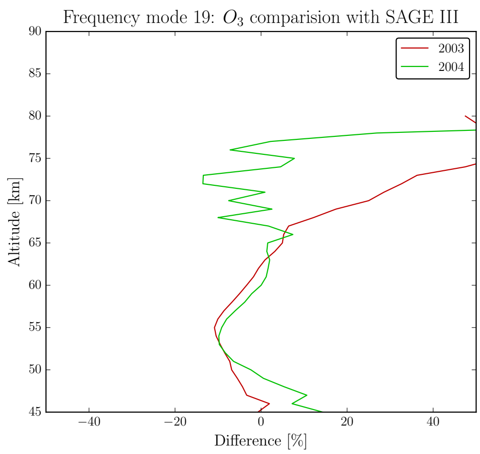
(a) average difference to MIPAS



(b) average difference to MLS

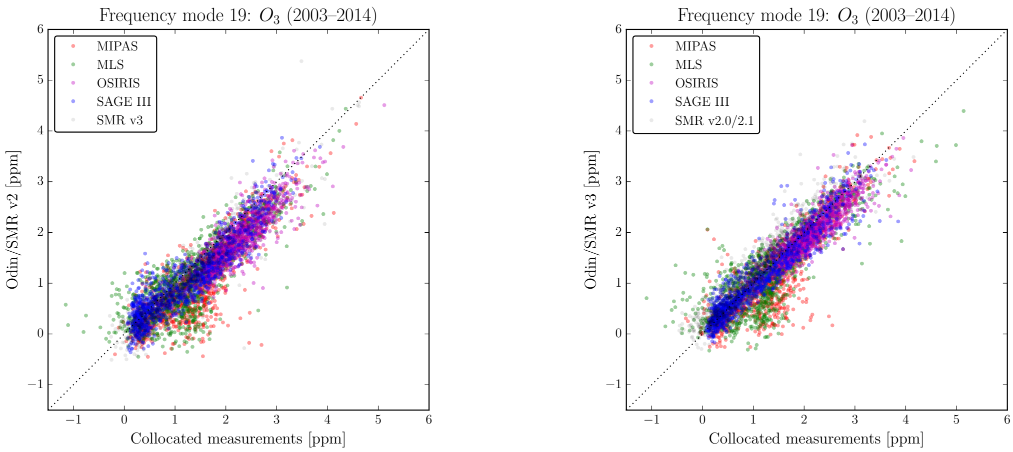


(c) average difference to OSIRIS



(d) average difference to SAGE III

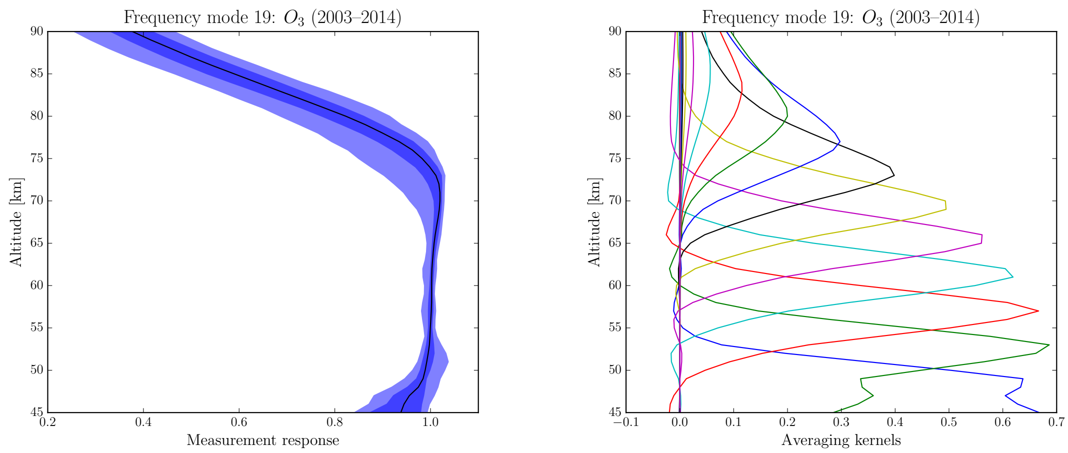
Figure 3.39: Average difference in percent between retrievals of O_3 from Odin/SMR v3 and collocated measurements from various instruments at different altitudes for frequency mode 19.



(a) correlation of collcated instruments with Odin/SMR v2.X

(b) correlation of collcated instruments with Odin/SMR v3

Figure 3.40: Correlation between retrievals of O_3 using Odin/SMR versions 2.X and 3 and collocated measurements from various instruments for frequency mode 19.



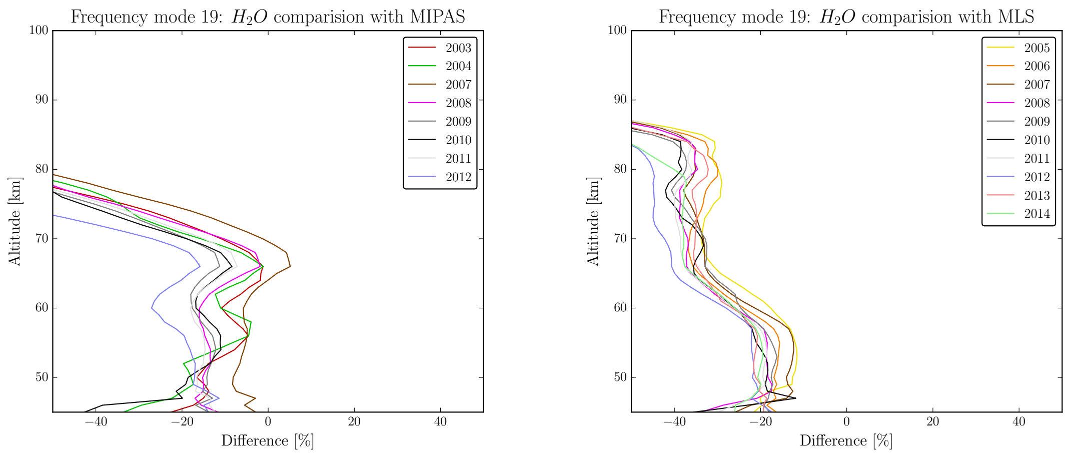
(a) median measurement response with 1σ and 2σ percentiles

(b) median averaging kernels

Figure 3.41: Measurement response and averaging kernels for O_3 retrievals for Odin/SMR v3 at different altitudes for frequency mode 19.

processing compared to both considered instruments, but a systematic under estimation of the concentrations has been introduced. Comparisons with MLS suggest a -20 % bias as with FM13 but with a increasing bias with altitude. The MIPAS product used seems to be unreliable at thes altitudes

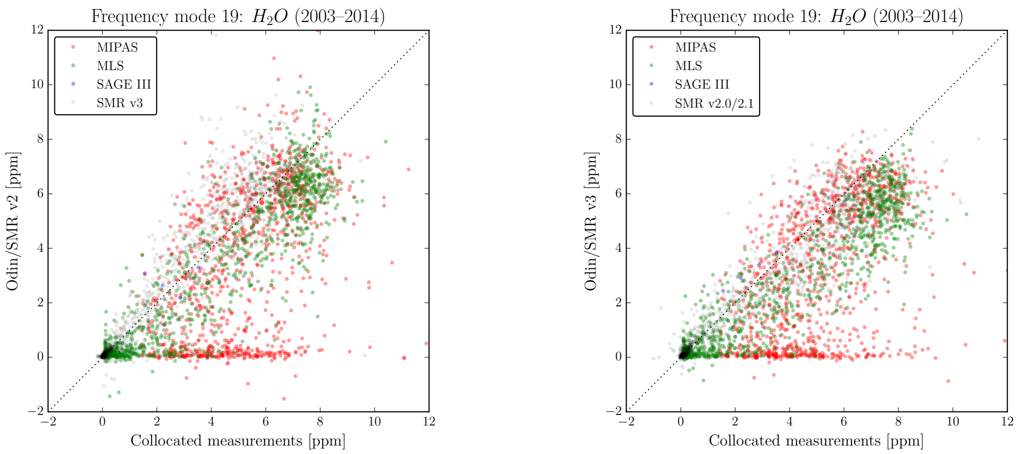
The SAGE III instrument also measures H_2O, but the there are too few collocated measurements wit frequency mode 19 for a relevant analysis. Figure 3.44 suggests that the product is useful over the range 44–110 km with a vertical resolution of around 4 km.



(a) average difference to MIPAS

(b) average difference to MLS

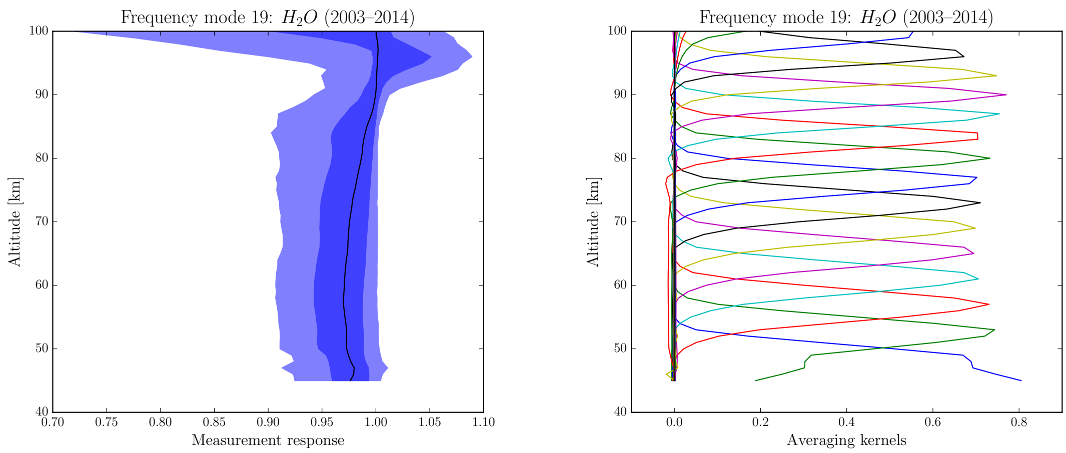
Figure 3.42: Average difference in percent between retrievals of H_2O from Odin/SMR v3 and collocated measurements from various instruments at different altitudes for frequency mode 19.



(a) correlation of collcated instruments with Odin/SMR v2.X

(b) correlation of collcated instruments with Odin/SMR v3

Figure 3.43: Correlation between retrievals of H_2O using Odin/SMR versions 2.X and 3 and collocated measurements from various instruments for frequency mode 19.



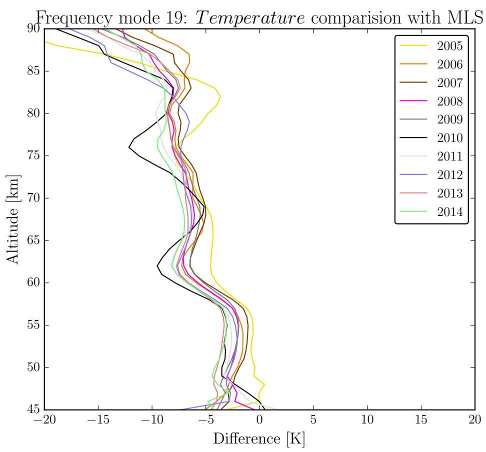
(a) median measurement response with 1σ and 2σ percentiles

(b) median averaging kernels

Figure 3.44: Measurement response and averaging kernels for H_2O retrievals for Odin/SMR v3 at different altitudes for frequency mode 19.

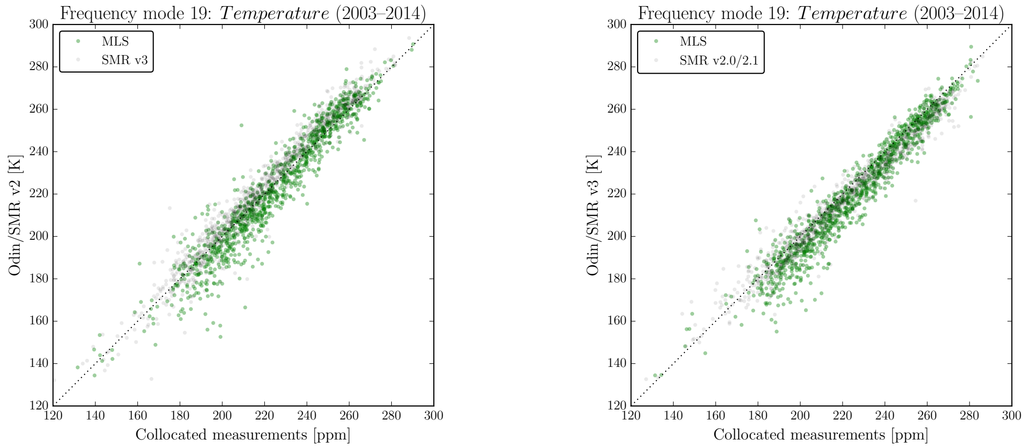
3.5.2.3 Temperature

The retrievals for temperature have been compared with data from the MLS instrument. Annual average differences to this instruments are shown in Figure 3.45. In Figure 3.36 individual retrievals from MLS for the entire period are plotted against the retrievals from the new and old versions of the Odin/SMR processing chain. The results show a little or no improvement with the updated version of the processing. Whereas with the previous version of the system, the temperature was under estimated for lower temperatures and over estimated for higher, and a small systematic under estimation of the temperature is still seen. Figure 3.47 suggests that the product is useful over the range 44–95 km with a vertical resolution of around 5 km.



(a) average difference to MLS

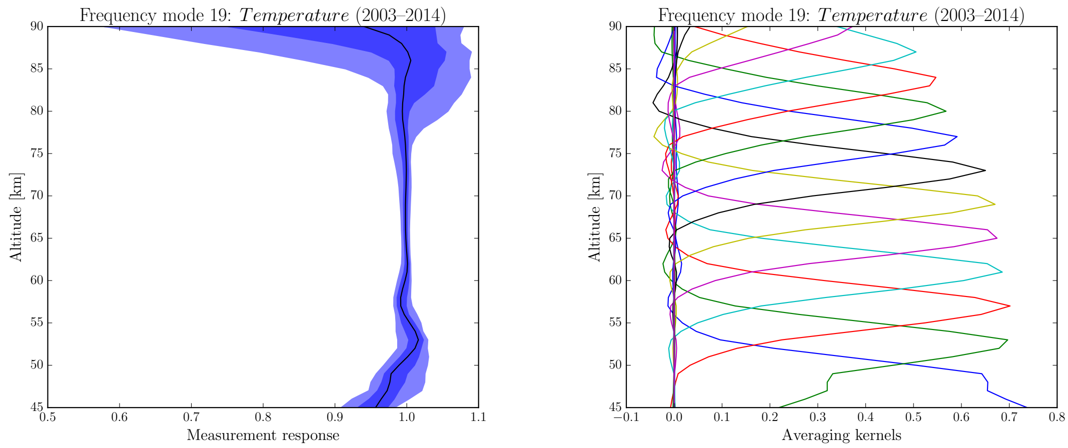
Figure 3.45: Average difference in K between retrievals of temperature from Odin/SMR v3 and collocated measurements from MLS at different altitudes.



(a) correlation of collcated instruments with Odin/SMR v2.X

(b) correlation of collcated instruments with Odin/SMR v3

Figure 3.46: Correlation between retrievals of temperature using Odin/SMR versions 2.X and 3 and collocated measurements from various instruments.



(a) median measurement response with 1σ and 2σ percentiles

(b) median averaging kernels

Figure 3.47: Measurement response and averaging kernels for temperature retrievals for Odin/SMR v3 at different altitudes for frequency mode 19.

3.5.3 Discussion

The Pearson correlation between the Odin/SMR retrievals and the other instruments was calculated for the entire period for both versions of the processing chain. The results are summarised in Table 3.5, and show that the new algorithm is a improvement compared to all the instruments for all species used in this investigation. The improvement is considerable for both O_3 and H_2O.

Table 3.5: Pearson correlation and fit parameters of the old and new Odin/SMR retrievals for frequency mode 19, compared with collocated data from other instruments for the period 2003–2014.

Species	**Instrument**	**SMR**	**corr.**	**slope**	**intercept**	**$\|\langle$ res. $\rangle\|$**
O3	MIPAS	v3	0.796	0.762	0.067 ppm	0.589 ppm
		v2.x	0.833	0.848	-0.194 ppm	0.606 ppm
	MLS	v3	0.763	0.657	0.306 ppm	0.632 ppm
		v2.x	0.814	0.746	0.066 ppm	0.577 ppm
	OSIRIS	v3	0.884	0.828	0.298 ppm	0.298 ppm
		v2.x	0.862	0.874	-0.090 ppm	0.466 ppm
	SAGE III	v3	0.950	0.893	0.089 ppm	0.270 ppm
		v2.x	0.924	0.861	0.005 ppm	0.350 ppm
H_2O	MIPAS	v3	0.500	0.649	-0.188 ppm	2.977 ppm
		v2.x	0.475	0.694	-0.078 ppm	2.963 ppm
	MLS	v3	0.901	0.747	-0.186 ppm	1.825 ppm
		v2.x	0.885	0.840	-0.216 ppm	1.636 ppm
Temp.	MLS	v3	0.964	1.043	-15.869 K	10.423 K
		v2.x	0.961	1.079	-19.820 K	8.696 K

3.5.4 Conclusions

Based on the discussion above, retrievals based on frequency mode 19 should be used with caution for both O_3 and H_2O, but can be used with confidence for temperature retrievals.

Chapter 4 | Conclusions

4.1 General comments

Table 4.1 shows an overview of the characteristics of the main data products from the updated Odin/SMR processing chain for the frequency modes investigated in Chapter 3. The vertical coverage has been defined as the altitude interval where the *measurement response* for the retrievals is > 0.8. The vertical resolution and precision are calculated from the $\pm 2\sigma$ percentiles of the *full widths at half maximum* of the averaging kernels and the *total error* respectively.

The results presented in Table 4.1 should be compared with the results for the old processing chain, presented in Tables 2.1 and 2.2.

Table 4.1: Characteristics of Odin/SMR Level2 main data products.

Product	**Frequency [GHz]**	**Vertical coverage**	**Vertical resolution**	**Precision**
O_3	501.5 (FM 01)	19–53 km	5.3–5.5 km	0.70–0.85 ppmv
ClO	501.3 (FM 01)	18–58 km	5.3–5.6 km	0.07–0.08 ppbv
N_2O	502.3 (FM 01)	15–62 km	4.4–5.6 km	5.00–6.10 ppbv
O_3	544.9 (FM 02)	17–77 km	2.9–4.9 km	0.18–0.26 ppmv
HNO_3	544.4 (FM 02)	20–61 km	5.0–7.2 km	0.24–0.28 ppbv
Temperature	544.9 (FM 02)	21–64 km	7.5–7.9 km	1.13–2.18 K
O_3	489.2 (FM 08)	16–71 km	4.1–6.0 km	0.29–0.39 ppmv
H_2O	489.5 (FM 08)	19–78 km	4.0–4.7 km	0.32–0.55 ppmv
O_3	556.9 (FM 13)	44–80 km	6.1–6.7 km	0.19–0.24 ppmv
H_2O	556.7 (FM 13)	44–110 km	4.3–4.8 km	0.06–0.33 ppbv
Temperature	556.9 (FM 13)	44–95 km	5.3–5.6 km	1.85–2.73 K
O_3	556.9 (FM 19)	43–81 km	5.8–6.6 km	0.19–0.24 ppmv
H_2O	556.7 (FM 19)	43–109 km	4.1–4.4 km	0.13–0.26 ppbv
Temperature	556.9 (FM 19)	43–93 km	5.2–5.5 km	1.72–2.65 K

4.2 Recomendations

4.2.1 Ozone

The best ozone product for general use is that from FM 02. The new product is in much better agreement with other instruments and does not seem to show any temporal drifts although a thorough analysis of drifts has not yet been attempted. The other ozone products show some biases but could be used in conjunction with simultaneously measured products if account is taken of this.

4.2.2 Chlorine Monoxide

The ClO product should be reliable until 2009 and after January 2018. Unfortunately a gradually deteriorating instrument malfunction has disturbed the intervening period. We will attempt to correct for this as soon as possible

4.2.3 Water vapour

Water vapour continues to be a difficult product. the FM 08 product has improved and is stable over time although shows a 15 % low bias compared to MLS. For the upper stratosphere and mesosphere FM 13 appears to be the best product, but also shows a small bias of around 15 % and som variability above 70 km that needs further investigation.

4.2.4 Temperature

FM 02 provides stratospheric temperatures with a possible increasing bias with altitude. There does not appear to be any systematic drift with time. For higher altitudes FM 13 can be used with knowledge of a possible cold bias of 3–5 K

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Appendix A | API decription

This section describes the API calls used to get data from from the DDS. The data is accessed through a hierarcical REST API where deeper URIs return more specific data. All call URIs have a common root `rest_api/v5`, which has been omitted below for clarity. All GET calls return JSON objects unless otherwise noted. Key/value pairs are listed as name of the key along with the type of the corresponding value within parantheses, followed by a brief description of the contents. See the sections on the different data sources for specifications on the structure of their respective JSON objects. This description is only for the Odin/SMR version 3 Level2 data. For details on how to access the collocated measurements from the VDS, see Rydberg et al. (2016b), for more details on the Level2 data format see Rydberg et al. (2016a); Pérot et al. (2017), and for a more general description of the Odin/SMR API, see `http://odin.rss.chalmers.se/apidocs/index.html`.

A.1 API calls

A.1.1 `level2/DDS/`

Method: *GET*

Get project information.

A.1.1.0.1 Parameters: None.

A.1.1.0.2 Data structure: Returns JSON object with the following structure:

```
{
  "Data": [
    {
      "FreqMode": <int>,
      "URLS": {
        "URL-comment": <string: URL for comments for scans>,
        "URL-failed": <string: URL for failed scans>,
        "URL-scans": <string: URL for scans>
      }
    },
    ...
  ],
  "Count": <int: number of FreqModes in project>,
  "Type": "level2_project_freqmode"
}
```

A.1.2 `level2/DDS/area`

Method: *GET*

Get data in provided area.

A.1.2.0.1 Parameters:

- product *(array of strings)*: Return data only for these products
- min_lat *(float)*: Minimum latitude (-90 to 90)
- max_lat *(float)*: Maximum latitude (-90 to 90)
- min_lon *(float)*: Minimum longitude (0 to 360)
- max_lon *(float)*: Maximum longitude (0 to 360)
- min_pressure *(float)*: Minimum pressure (Pa)
- max_pressure *(float)*: Maximum pressure (Pa)
- min_altitude *(float)*: Minimum altitude (m)
- max_altitude *(float)*: Maximum altitude (m)
- start_time *(date)*: Return data after this date (inclusive)
- end_time *(date)*: Return data before this date (exclusive)

Provide latitude and/or longitude limits to get data for a certain area of the earth. If no latitude or longitude limits are provided, data for the whole earth is returned. Choose between min/max altitude and min/max pressure.

A.1.2.0.2 Data structure:

Returns JSON object with the following structure:

```
{
  "Data": <array of Level2 Data Structures as described below>,
  "Count": <int: number of matching data>,
  "Type": "L2"
}
```

A.1.3 level2/DDS/locations

Method: *GET*

Get data close to provided location.

A.1.3.0.1 Parameters:

- product *(array of strings)*: Return data only for these products
- location *(array of strings; required)*: Return data close to these locations ('lat,lon').
- radius *(float; required)*: Return data within this radius from the provided locations (km).
- min_pressure *(float)*: Minimum pressure (Pa)
- max_pressure *(float)*: Maximum pressure (Pa)
- min_altitude *(float)*: Minimum altitude (m)
- max_altitude *(float)*: Maximum altitude (m)

- start_time *(date)*: Return data after this date (inclusive)
- end_time *(date)*: Return data before this date (exclusive)

Provide one or more locations and a radius to get data within the resulting circles on the earth surface. Choose between min/max altitude and min/max pressure.

A.1.3.0.2 Data structure: Returns JSON object with the same structure as endpoint A.1.2.

A.1.4 `level2/DDS/products/`

Method: *GET*
Get available products.

A.1.4.0.1 Parameters: None.

A.1.4.0.2 Data structure: Returns JSON object with the following structure:

```
{
  "Data": <array of strings: product names>,
  "Count": <int: number of available products>,
  "Type": "level2_product_name"
}
```

A.1.5 `level2/DDS/<string:date>/`

Method: *GET*
Get data for the provided date.

A.1.5.0.1 Parameters:

- product *(array of strings)*: Return data only for these products
- min_pressure *(float)*: Minimum pressure (Pa)
- max_pressure *(float)*: Maximum pressure (Pa)
- min_altitude *(float)*: Minimum altitude (m)
- max_altitude *(float)*: Maximum altitude (m)
- start_time *(date)*: Return data after this date (inclusive)
- end_time *(date)*: Return data before this date (exclusive)

Choose between min/max altitude and min/max pressure.

A.1.5.0.2 Data structure: Returns JSON object with the same structure as endpoint A.1.2.

A.1.6 `level2/DDS/<int:frequencymode>/comments/`

Method: *GET*
Get list of comments for a frequency mode.

A.1.6.0.1 Parameters:

- offset *(int)*: Skip scans before returning
- limit *(int; default: 1000)*: Number of scans to return

A.1.6.0.2 Data structure: Returns JSON object with the following structure:

```
{
  "Data": [
    {
      "Comment": <string: comment from processing>,
      "URLS": {
        "URL-failed": <string: URL for failed scans with comment>,
        "URL-scans": <string: URL for successful scans with comment>
      }
    },
    ...
  ],
  "Count": <int: number of unique comments>,
  "Type": "level2_scan_comment"
}
```

A.1.7 `level2/DDS/<int:frequencymode>/failed/`

Method: *GET*

Get list of matching scans that failed the level2 processing.

A.1.7.0.1 Parameters:

- start_time *(date)*: Return data after this date (inclusive)
- end_time *(date)*: Return data before this date (exclusive)
- comment *(string)*: Return scans with this comment
- offset *(int)*: Skip scans before returning
- limit *(int; default: 1000)*: Number of scans to return

A.1.7.0.2 Data structure: Returns JSON object with the following structure:

```
{
  "Data": [
    {
      "Date": <string: date>,
      "Error": <string: error message>,
      "ScanID": <int: scan number>,
      "URLS": {
        "URL-ancillary": <string: URL for Level2 ancillary data>,
        "URL-level2": <string: URL for Level2 data>,
        "URL-log": <string: URL for Level1 log data>,
        "URL-spectra": <string: URL for Level1 spectra>
      }
    },
    ...
  ],
  "Count": <int: number of matching scans>,
  "Type": "level2_failed_scan_info"
}
```

A.1.8 level2/DDS/<int:frequencymode>/products/

Method: *GET*

Get available products for a given project and frequency mode.

A.1.8.0.1 Parameters: None.

A.1.8.0.2 Data structure: Returns JSON object with the same structure as endpoint A.1.4.

A.1.9 level2/DDS/<int:frequencymode>/scans/

Method: *GET*

Get list of matching scans.

A.1.9.0.1 Parameters:

- start_time *(date)*: Return data after this date (inclusive)
- end_time *(date)*: Return data before this date (exclusive)
- comment *(string)*: Return scans with this comment
- offset *(int)*: Skip scans before returning
- limit *(int; default: 1000)*: Number of scans to return

A.1.9.0.2 Data structure: Returns JSON object with the following structure:

```
{
  "Data": [
    {
      "Date": <string: date>,
      "ScanID": <int: scan number>,
      "URLS": {
        "URL-ancillary": <string: URL for Level2 ancillary data>,
        "URL-level2": <string: URL for Level2 data>,
        "URL-log": <string: URL for Level1 log data>,
        "URL-spectra": <string: URL for Level1 spectra>
      }
    },
    ...
  ],
  "Count": <int: number of matching scans>,
  "Type": "level2_scan_info"
}
```

A.1.10 level2/DDS/<int:frequencymode>/<int:scannumber>/

Method: *GET*

Get level2 data, info, comments, and ancillary data for one scan and frequency mode.

A.1.10.0.1 Parameters: None.

A.1.10.0.2 Data structure: Returns JSON object with the following structure:

```
{
  "Data": {
    "L2": <Level2 Data Structure as described below>,
    "L2anc": <Level2 Ancillary Data Structure as described below>,
    "L2c": <Level2 Comments Data Structure as described below>,
    "L2i": <Level2 Info Data Structure as described below>,
  },
  "Count": null,
  "Type": "mixed"
}
```

A.1.11 level2/DDS/<frequencymode>/<scannumber>/L2/

Method: *GET*

Get level2 data for one scan and frequency mode.

A.1.11.0.1 Parameters :

- product *(array of strings)*: Return data only for these products

A.1.11.0.2 Data structure: Returns JSON object with the following structure:

```
{
  "Data": [
    {
      "AVK": <array of arrays of floats: averaging kernels at altitudes>,
      "Altitude": <array of floats: altitudes>,
      "Apriori": <array of floats: apriori data at altitudes>,
      "ErrorNoise": <array of floats: noise error at altitudes>,
      "ErrorTotal": <array of floats: total error at altitudes>,
      "FreqMode": <int: frequency mode>,
      "InvMode": "string",
      "Lat1D": <float: approximate latitude of retrieval>,
      "Latitude": <array of floats: latitudes for retrieval at altitudes>,
      "Lon1D": <float: approximate latitude of retrieval>,
      "Longitude": <array of floats: longitude for retrieval at altitudes>,
      "MJD": <float: Modified Julian Date for retrieval>,
      "MeasResponse": <array of floats: measurement response at altitudes>,
      "Pressure": <array of floats: pressure at altitudes [Pa]>,
      "Product": <string: product name>,
      "Quality": <int: quality flag>,
      "ScanID": <int: scan number>,
      "Temperature": <array of float: retrieved temperature at altitudes [K]>,
      "VMR": <array of float: retrieved volumetric mixing ratio at altitudes>
    }
  ],
  "Count": null,
  "Type": "L2"
}
```

A.1.12 level2/DDS/<int:frequencymode>/<int:scannumber>/L2anc/

Method: *GET*

Get ancillary data for one scan and frequency mode.

A.1.12.0.1 Parameters: None.

A.1.12.0.2 Data structure: Returns JSON object with the following structure:


```
{
  "Data": [
    {
      "FreqMode": <int: freqcuency mode>,
      "InvMode": <string: inversion mode used in retrieval>,
      "LST": <float: local solar time>,
      "Lat1D": <float: approximate latitude of retrieval>,
      "Latitude": <array of floats: latitudes for retrieval at altitudes>,
      "Lon1D": <float: approximate latitude of retrieval>,
      "Longitude": <array of floats: longitude for retrieval at altitudes>,
      "MJD": <float: Modified Julian Date for retrieval>,
      "Orbit": <int: orbit number>,
      "Pressure": <array of floats: pressure at altitudes [Pa]>,
      "SZA": <array of floats: solar zenith angle for retrieval at altitudes>,
      "SZA1D": <float: approximate solar zenith angle for retrieval>,
      "ScanID": <int: scan number>,
      "Theta": <array of floats: potential temperature>
    }
  ],
  "Count": 1,
  "Type": "string"
}
```


A.1.13 level2/DDS/<int:frequencymode>/<int:scannumber>/L2i/

Method: *GET*

Get level2 auxiliary data for one scan and frequency mode.

A.1.13.0.1 Parameters: None.

A.1.13.0.2 Data structure: Returns JSON object with the following structure:


```
{
  "Data": {
    "BlineOffset": <array of arrays of floats: baseline offsets for spectra>,
    "ChannelsID": <array of floats: channel identifier>,
    "FitSpectrum": <array of arrays     of floats: fitted spectra [K]>
    "FreqMode": <int: frequency mode>,
    "FreqOffset": <float: retrieved LO frequency offset [Hz]>,
    "InvMode": <string: inversion mode used in retrieval>,
    "LOFreq": <array of floats: LO frequency for each spectrum in scan [Hz]>,
    "MinLmFactor": <float: minimum Levenberg-Marquard factor of OEM>,
    "PointOffset": <float: retrieved pointing offset [degree],
    "Residual": <float: residual of retrieved and measured spectra>,
    "SBpath": <float: sideband path used for retrieving spectra [m]>,
    "STW": <array of floats: satellite time words for spectra>,
    "ScanID": <int: scan number>,
    "Tsat": <float: satellite onboard temperature [K]>,
    "URLS": {
      "URL-ancillary": <string: URL for Level2 ancillary data>,
      "URL-level2": <string: URL for Level2 data>,
      "URL-log": <string: URL for Level1 log data>,
      "URL-spectra": <string: URL for Level1 spectra>
    }
  },
  "Count": null,
  "Type": "L2i"
```

}

A.1.14 level2/DDS/<int:frequencymode>/<int:scannumber>/L2c/

Method: *GET*
Get level2 comments for one scan and frequency mode.

A.1.14.0.1 Parameters: None.

A.1.14.0.2 Data structure: Returns JSON object with the following structure:

```
{
  "Data": <array of strings: comments>
  "Count": <int: number of comments for scan>,
  "Type": L2c
}
```

A.2 Example usage

This is a brief example of how to use the Odin/SMR API to access the DDS in Python. The basic procedure for navigating the call hierarchy is the same in all major programming languages and browsers.

```python
# Setup the name space:
import requests

# Start by making a request to the root URI of the DDS API:
r0 = requests.get('http://odin.rss.chalmers.se/rest_api/v5/level2/DDS/')

# The request contains the returned JSON object, which in Python is a
# dictionary, which can be printed or inspected to find out its keys and
# contents. Let's assume that we have done that, or that we have read
# the API documentation, so that we know that 'FreqMode' is a key.
# Use this to single out the frequency mode of interest, in this case 2:
FM2 = [x for x in r0.json()['Data'] if x['FreqMode'] == 2][0]

# Make a new request using the URI provided in the JSON object:
r1 = requests.get(FM2["URLS"]["URL-scans"])

# Filter out data from 2012-03-11 and fetch the level2 data for the
# first scan in the list:
day = [x for x in r1.json()['Data'] if x['Date'] == '2012-03-11']
r2 = requests.get(day[0]['URLS']['URL-level2'])

# The Level2 data available to us, along with the ancillary and
# auxilliary data:

L2 = r2.json()['Data']['L2']
L2anc = r2.json()['Data']['L2anc']
L2aux = r2.json()['Data']['L2i']

# Now we have the data at hand and can proceed with crunching it!
```

Appendix B | Observation modes

Table B.1: Odin/SMR operational modes in aeronomy for AC1 and AC2 and the sub-mm frontends (FM = frequency mode)

Backend	Frontend	LO freq [GHz]	Source mode	FM
AC1	495 A2	492.750	Transport	23
		499.698	Transport	25
	549 A1	548.502	Stratospheric	02
		553.050	Water isotope	19
		547.752	Water isotope	21
		553.302	Transport	23
	555 B2	553.298	Summer mesosphere	13
	572 B1	572.762	Transport	24
AC2	495 A2	497.880	Stratospheric	01
		492.750	Water isoptope	08
		494.750	Water isotope	17
		499.698	Transport	25
	572 B1	572.762	Summer mesosphere	14
		572.964	Transport	22

Table B.2: Odin/SMR frontend and backend frequency specification for modes that are measured during part of the summer (when only backend AC2 is used, which is the case for 2013 and onwards). These modes are normally measured by backend AC1 (e.g. FM 102 and FM 2, FM 119 and FM 19, FM 121 and FM 21, and FM 113 and 13, are all identical except the Backend used).

Backend	Frontend	LO freq [GHz]	Source mode	FM
AC2	549 A1	548.502	Stratospheric	102
		553.050	Water isotope	119
		547.752	Water isotope	121
	555 B2	553.298	Summer mesosphere	113

Table B.3: Odin/SMR frontend and backend frequency specification

FM	SMR mode	LO Freq. [GHz]	Freq. Range [GHz]	Species	Name / ID
01	s1a or sc1a	497.880	501.180–501.580	ClO, O_3, N_2O	SM-AC2a / 01
			501.980–502.380		SM-AC2b / 02
					SM-AC2ab / 29
02	s1a	548.502	544.102–544.902	HNO_3, O_3	SM-AC1e / 03
08	w3a or w5a	492.750	488.950–489.350	$H_2^{18}O$, O_3,$H_2^{16}O$	IM-AC2a / 13
			488.350–488.750		IM-AC2b / 14
					IM-AC2ab / 30
17	w4a or w5b	494.250	489.950–490.750	HDO, 18^{O}_{3}	IM-AC2c / 21
19	w3a or w4a	553.050	556.550–557.350	H_2O, O_3	IM-AC1c / 22
21	w5a or w5b	547.752	551.152–551.552	NO, O_3, $H_2^{17}O$	IM-AC1de / 31
			551.752–552.152		
13	sm1a	553.298	556.598–557.398	$H_2^{16}O$, O_3	HM-AC1c / 19
14	sm1a	572.762	576.062–576.862	CO, O_3	HM-AC2c /20
22	co1a	572.964	576.254–576.654	CO, O_3, HO_2,$^{18}O_3$	HM-AC2ab / 32
			577.069–577.469		
23	co1a	492.750	488.350–488.750	$H_2^{16}0$, O_3	HM-AC1d / 33
		553.302	556.702–557.102		HM-AC1e / 34
24	sc1a	572.762	576.062–576.862	CO, O_3	HM-AC1e / 35
25	ut1a	499.698	502.998–504.198	$H_2^{16}O$, O_3	TM-ACs1 / 36

Table B.4: Order of sub-bands from lowest frequency range to highest for some of the most common frequency modes. Sub-bands that are in bad condition have been *emphasised*, broken bands are in ***bold***.

FM	Freq. Range [GHz]	Sub-band order
01	501.180–501.585	2 1 5 6
	501.980–502.380	4 ***3*** *7* 8
02	544.102–544.902	***1*** *2* 6 5 8 7 3 4
08	488.950–489.350	8 *7* ***3*** 4 6 5 1 2
17	489.950–490.750	8 *7* ***3*** 4 6 5 1 2
19	556.550–557.350	4 3 7 8 *2* ***1*** 5 6
21	551.152–551.552	4 3 7 8
	551.752–552.152	*2* ***1*** 5 6