SAFIRE-A MEASUREMENTS DURING THE ESABC CAMPAIGN

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ABSTRACT

SAFIRE-A (Spectroscopy of the Atmosphere using Far InfraRed Emission – Airborne) is a Far Infrared Fourier Transform spectrometer operating onboard the M-55 Geophysica stratospheric aircraft. The spectrometer is one of the instruments participating to the scientific chemical flights of the ESABC (ENVISAT Stratospheric Aircraft and Balloon campaigns) campaigns held in July and October 2002 from Forlì (Italy). In the October campaign, SAFIRE-A measured successfully the atmospheric emission on all but one chemical flight. VMR (Volume Mixing Ratio) profiles of O_3, N_2O and HNO_3, coming from the data measured during the flight held on the 24th of October, are presented and compared with the results obtained by in-situ instruments during the same flight and with MIPAS/ENVISAT measurements on the same air-mass.

1. THE INSTRUMENT

SAFIRE-A (Spectroscopy of the Atmosphere using Far InfraRed Emission – Airborne) is a Far Infrared Fourier Transform spectrometer operating onboard the M-55 Geophysica stratospheric aircraft. The instrument is a particular implementation of the Martin-Puplett polarising FT spectrometer especially designed for airborne operation. SAFIRE-A records the atmospheric thermal emission using the limb-sounding technique. Some instrumental characteristics are summarised in the table below.

Table 1. SAFIRE-A instrumental specifications

Parameter:	Value:
Instrument type	Polarising FT spectrometer
Dimensions	1800 X 880 X 650 mm
Weight	387 Kg
Interferogram acquisition time	12, 24, 48, 96 s
Number of detectors channels	2
Spectral Range	10 – 250 cm^{-1}
Maximum spectral resolution	0.004 cm^{-1}
Vertical resolution	About 1.5 Km
Vertical field of view	0.57°
Spectral signal-to-noise ratio	>500
Observation technique	Limb-sounding emission

SAFIRE-A is composed by three main modules: the input optics system, the interferometer and the Cold Optics and Detector Module (CODM) that includes the output optics and the detectors. Atmospheric emission is collected through a pointing mirror whose position is controlled by the roll angle information provided by the aircraft navigation system. A calibration system, located at the focus of the input telescope, enables to swap between two calibration blackbodies kept at different temperatures.

The far infrared interferometer is based on a double parallelogram scheme that, through a folding of the optical path and the simultaneous movement of both mirrors, enables to attain a maximum path difference of 125 cm within a cube of 50 cm side (see Fig. 1) [1], [2].

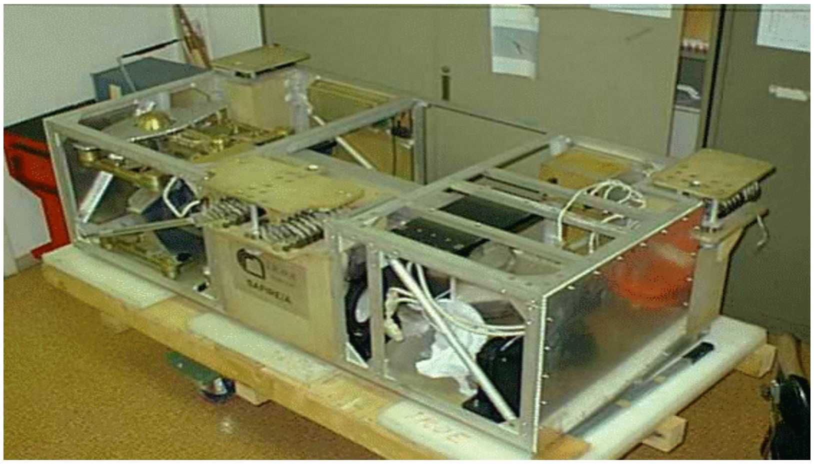

Fig. 1.Picture of the SAFIRE-A instrument (input optics side).

2. ESABC CAMPAIGN MEASUREMENTS

The SAFIRE-A spectrometer is one of the instruments of the M-55 Geophysica chemistry payload that took part to the scientific flights of the aircraft held in July and October 2002, in the frame of the ESABC (ENVISAT Stratospheric Aircraft and Balloon campaigns) activities. All these scientific flights were carried out taking off from the Forlì airport.

Good quality data have been obtained by the instrument during most of the October 2002 flights. Therefore, as a first priority for ENVISAT validation, we focused on these measurements, rather than on the data acquired during the July 2002 campaign, that have been affected by some instrument shortcomings in different subsystems (detector unit, pointing system, etc.) and that might require significant further efforts to be processed and compared with the ENVISAT data and with the data obtained by the other payloads onboard of the Geophysica aircraft.

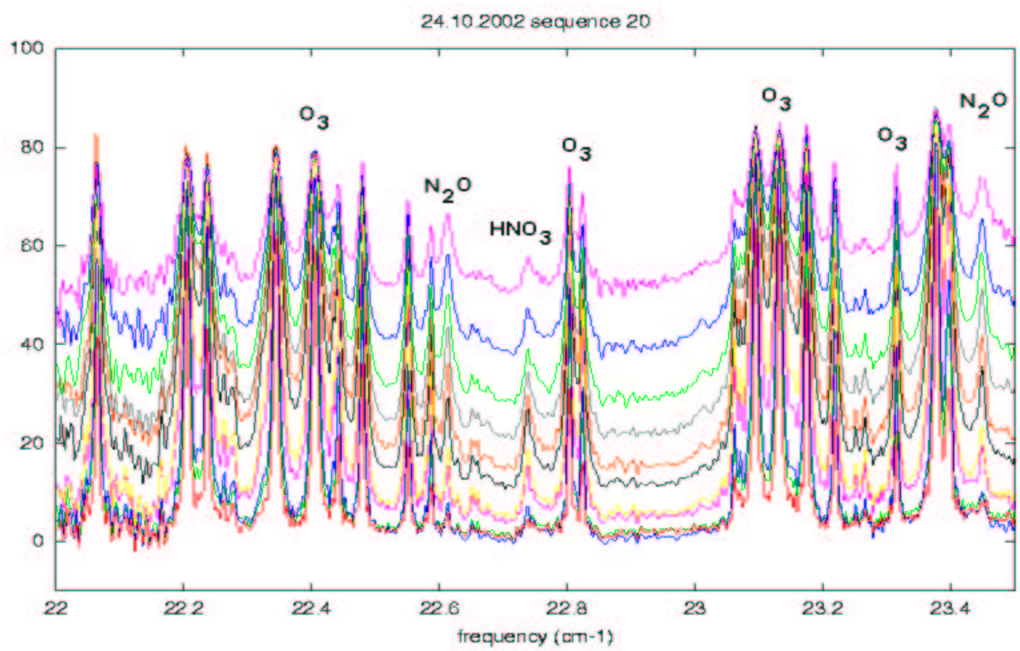

Fig. 2. Limb-scanning sequence of the atmospheric emission spectra in the 22-23.5 cm^{-1} window. Spectral features due to interesting molecular species are marked.

The results shown in this paper are coming from the limb sounding observations of the atmospheric emission over the frequency interval 22 - 23.5 cm^{-1} where spectral features of O_3, ClO, N_2O, and HNO_3 are present. Data from the other spectral band [117-119 cm^{-1}] are still to be reduced and analysed.
A typical limb-scanning sequence spans the atmosphere with angles ranging from 10° above to 2.7° below the aircraft plane; the result is a sequence of 11 emission spectra with a vertical resolution of about 1.5 Km. The acquisition time of a single interferogram is 30 s so that each sequence is recorded in about 5 minutes; considering the aircraft average ground speed of 700 km/h at stratospheric altitude, this translates in an horizontal resolution of about 50 Km, corresponding to 0.5 degrees of latitude. In Fig. 2 we show a typical limb-scanning sequence of the atmospheric emission spectra in the 22-23.5 cm^{-1} region recorded during the flight of the 24^{th} of October.

3. DATA ANALYSIS

A new algorithm named RAS (Retrieval Algorithm for SAFIRE-A) was developed for the analysis of SAFIRE-A spectra: through an inversion method (retrieval) the VMR profiles of the gases that have spectral features in the measured spectral regions are obtained.
The radiative transfer calculation implemented in RAS is a line by line and layer by layer model including curvature and refraction effects.
Molecular spectral data used in the line-by-line calculation came from the HITRAN96 database, with the exception of HNO_3 where data taken from JPL database were used.
Pressure and Temperature profiles were obtained by ECMWF data processed at University of Aquila. Temperature and geopotential height distributions with respect to pressure (from 1 to 1000 mbar) on a latitude-longitude grid (latitude step 1.125°, longitude step 1.125°) are provided every six hours (at 00, 06, 12, 18). These profiles were interpolated in longitude, latitude and time in order to provide the most suitable temperature and pressure values for each sequence.
VMR profiles coming from a standard mid-latitude spring atmospheric model were used either as initial guess of the retrieval and to model interfering gases. Since the altitude of the tropopause in the adopted atmospheric model was different from the real one, the VMR profiles were altitude shifted in order to match the real atmospheric behaviour.

4. RESULTS

In this paper we show the results obtained from the analysis of the data recorded by SAFIRE-A during the flight performed by the M-55 Geophysica on the 24^{th} of October. The comparison of the VMR profiles measured by in-situ instruments during take off, dive and landing phases and the corresponding SAFIRE-A retrieved profiles provides an internal validation for our retrieval system.

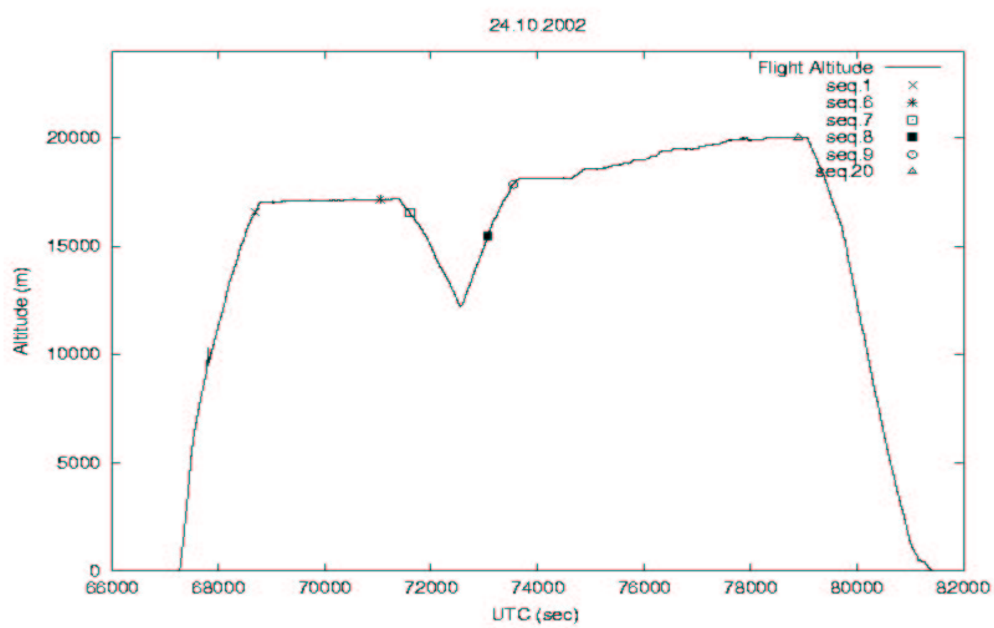

Fig. 3. Position of the selected sequences with respect to the flight altitude vs time.

In Fig. 3 we show the sequences selected for these comparisons. SAFIRE-A data of sequence 1 were compared with in-situ data recorded during the aircraft ascent, data of sequences 6 and 7 with in-situ data taken during the aircraft dive descent, data of sequences 8 and 9 with in-situ data taken during dive ascent and, finally, sequence 20 data with in-situ data taken during landing.
For the purpose of the ENVISAT validation campaign, the profiles obtained with SAFIRE-A measurements have been compared with profiles measured by MIPAS/ENVISAT as close as possible in space and time. For the comparison of the flight performed on the 24th of October, we have selected MIPAS/ENVISAT profiles obtained in the analysis of orbit 3411 acquired on 10/25/2002 (the sequence closer to the latitude of the aircraft measurements has been selected). MIPAS/ENVISAT profiles have been corrected for a systematic offset of 1.1 Km.

4.1 Ozone

Ozone retrieval has been performed on five microwindows (MWs) whose frequency boundaries are shown in Table 2. The retrieval was performed at all the tangent altitudes of the measurements. In order to exploit at their best the information coming from the measurements looking above the aircraft, two altitudes levels (22 and 26 Km), located well above the aircraft flight altitude, were added in the retrieval grid.

Table 2. Ozone MWs.

	Frequency range [cm^{-1}]
MW1	22.290 - 22.500
MW2	22.520 - 22.570
MW3	22.770 - 22.880
MW4	23.000 - 23.250
MW5	23.270 - 23.350

As an example of the obtained results, in Fig. 4 we show the comparison between the retrieved Ozone vertical profile for SAFIRE sequence 1 (24.10.02 at 19.08 UTC) with the ones obtained by MIPAS/ENVISAT (relative to 25.10.02 at 09.07 UTC) and by FOZAN (Fast Ozone Analyser), a chemiluminescent ozone sensor [3] (24.10.02 at 18.47 UTC).

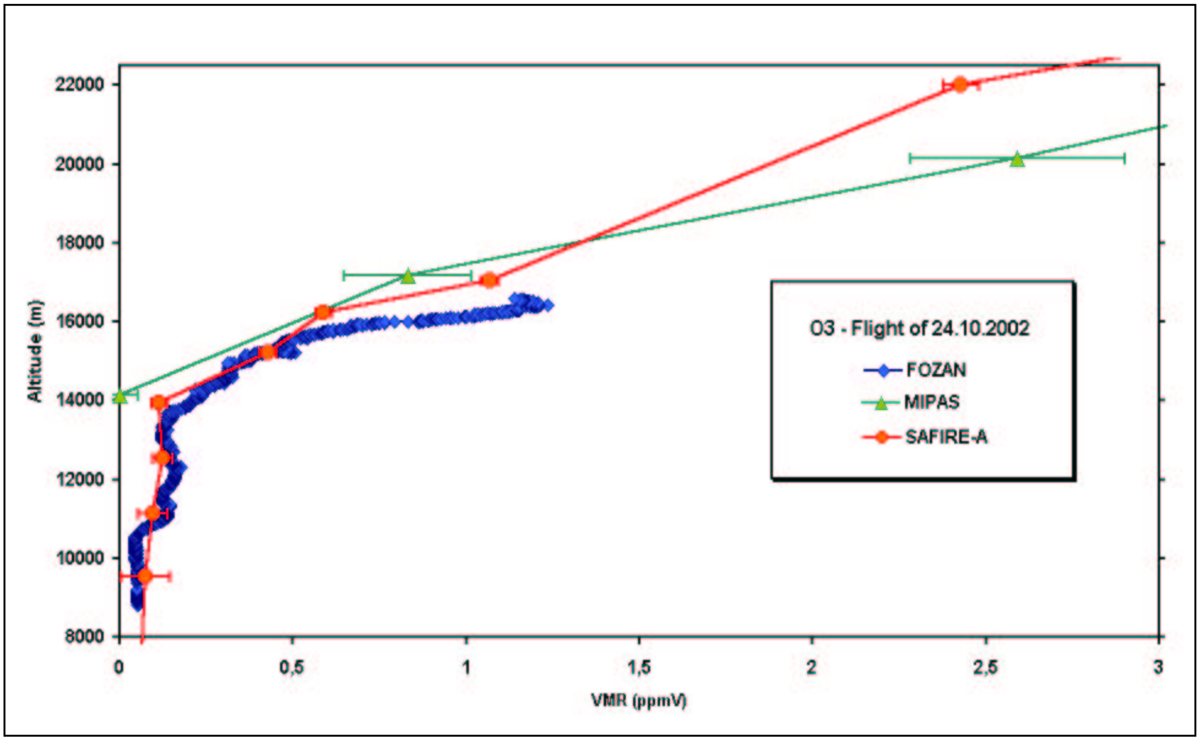

Fig. 4. Comparison between ozone profiles for SAFIRE-A sequence 1 (red line), FOZAN data during take-off (blue dots) and MIPAS/ENVISAT data (orbit 3411 - lat. 41.15) (green line).

The error bars shown for the SAFIRE-A measurement represent the random error due to spectral noise. As can be seen in the figure, SAFIRE-A measurements are in a fairly good agreement with the in-situ values. The same behaviour was observed for all selected sequences, thus providing an useful information for an internal validation of our inversion method. Moreover, as can be seen in Fig. 4, SAFIRE-A ozone profile is in agreement with MIPAS/ENVISAT data too, even if there is a 12 hours delay between the two measurements.
In Fig. 5 we show all SAFIRE-A results for ozone for the whole flight mapped against the time of their measurements (time in seconds UTC). The flight altitude of the aircraft when each sequence has been recorded is superimposed to the map.

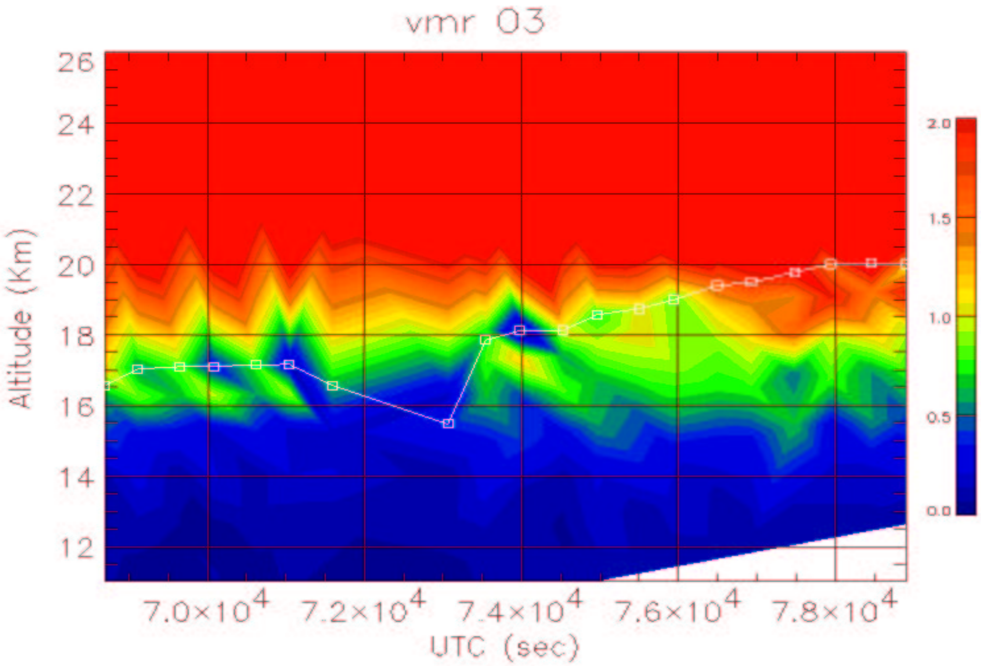

Fig. 5. Ozone VMR (ppmv) map for the 24th October 2002 flight.

4.2 N_2O

N_2O analysis could be performed over two MWs whose frequency boundaries are shown in table 4. For our analysis we have used only the first one, because the second is affected by a strong interference with a nearby water line (that is outside the measured frequency range). The retrieval has been performed at tangent altitudes and extended to a further point, above the flight altitude, located at 22 Km.

Table 3. N_2O microwindows.

	Frequency range [cm^{-1}]
MW1	22.560 - 22.660
MW2	23.420 - 23.500

In Fig. 6 we show the comparison (for the same sequence as in Fig. 4) between the SAFIRE-A N_2O vertical profile and the ones obtained by MIPAS/ENVISAT and HAGAR (High Altitudes Gas AnalyseR), a multi-tracer instrument [4]. The N_2O profile agrees well with the MIPAS/ENVISAT result at high altitudes, while there is a systematic shift between SAFIRE data and HAGAR data at altitudes below 16 km. The reason for this shift is still under investigation.
In Fig. 7 we show the N_2O map (VMR values in ppmv) for the same flight. As in Fig. 5, the horizontal axis represents the flight time in seconds UTC, and the flight altitude of the aircraft when each sequence has been recorded is superimposed to the map.

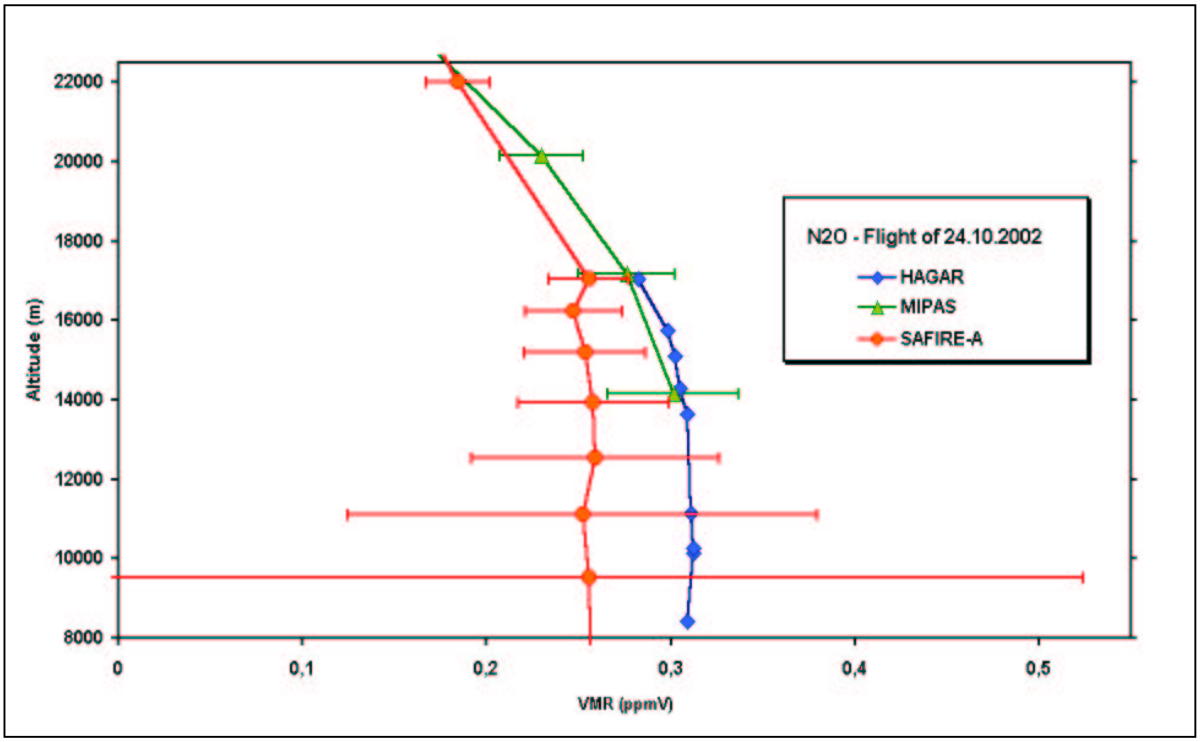

Fig. 6. Comparison between N_2O profiles for SAFIRE-A sequence 1 (red line), HAGAR data during take-off (blue dots) and MIPAS/ENVISAT data (orbit 3411 - lat. 41.15) (green line).

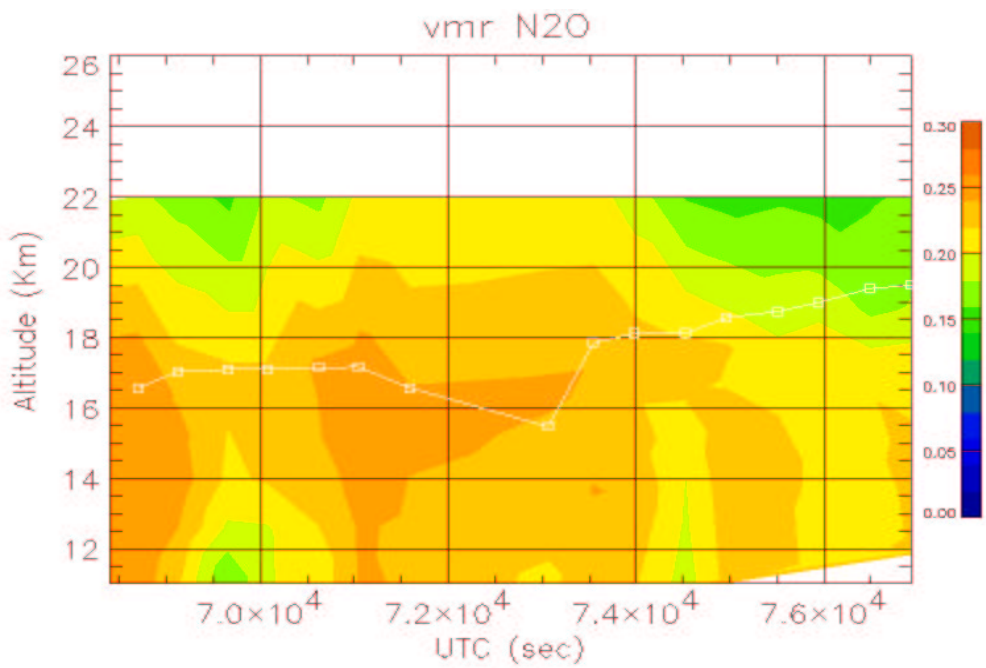

Fig. 7. N_2O VMR (ppmv) map for the 24th October 2002 flight.

4.3 HNO_3

For the HNO_3 data analysis there is only one microwindow in the first channel, whose frequency range is from 22.65 to 22.77 cm^{-1}. In the retrieval, the same retrieval grid as for N_2O was used. Since there are no in-situ data available for

HNO_3 for this flight, SAFIRE-A profiles can be compared only with the MIPAS/ENVISAT ones. As for the other species, Fig. 8 shows this comparison for SAFIRE-A sequence 1. In Fig. 9 we show the HNO_3 map (VMR values in ppmV) for the same flight.

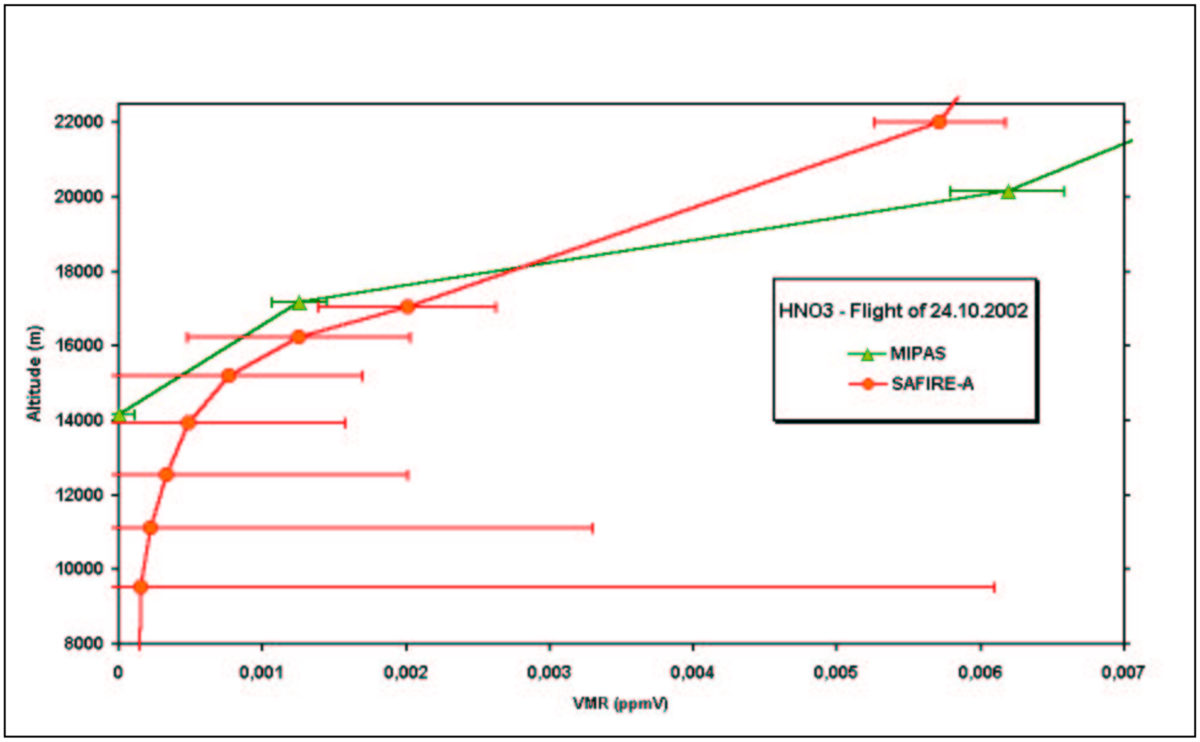

Fig. 8. Comparison between HNO_3 profiles for SAFIRE-A sequence 1 (red line) and MIPAS/ENVISAT data (orbit 3411 - lat. 41.15) (green line).

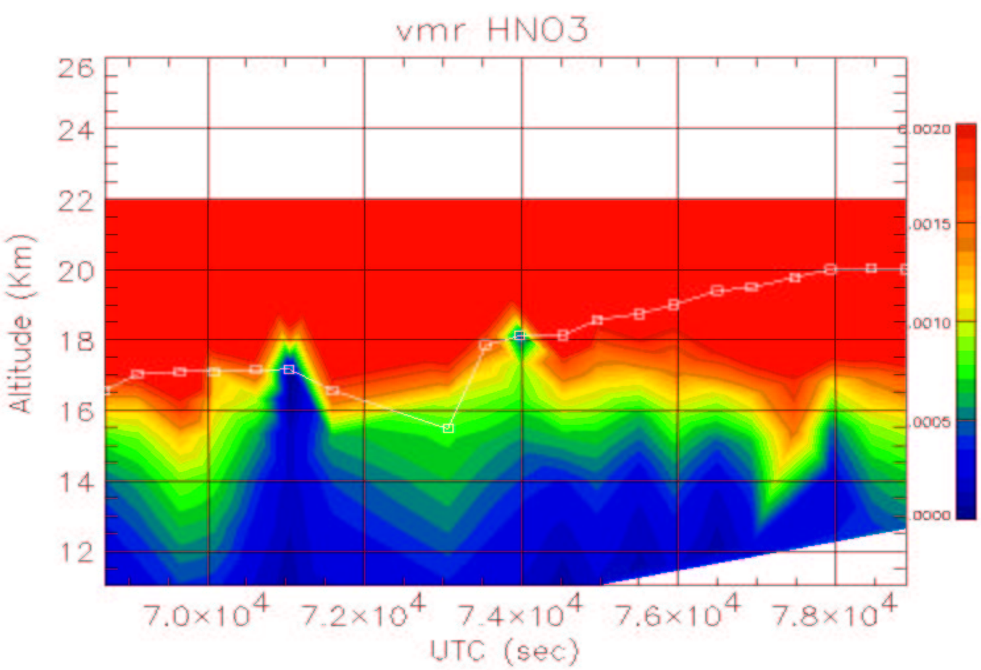

Fig. 9. HNO_3 VMR (ppmv) map for the 24^{th} October 2002 flight.

5. CONCLUSIONS

From the analysis of data acquired by the SAFIRE-A spectrometer during the ESABC campaign performed in October from Northern Italy with the M-55 Geophysica aircraft, detailed geographic-vertical mapping of volume mixing ratio of O_3, N_2O, HNO_3 have been obtained. SAFIRE-A results from the flight on 24th October 2002 have been used to perform comparison with both in-situ instruments operating onboard of the aircraft and with MIPAS/ENVISAT data.
In both cases, we obtained indications of a general agreement with some discrepancies, as in the case of N_2O profiles, that will be subject of further investigations.

6. REFERENCES

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