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ENVISAT tropical validation of cloud and ozone parameters by high-altitude aircraft

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SUMMARY. – *The validation of cloud top and ozone vertical column, measured by SCIAMACHY, were carried out respectively by lidars and in-situ and remote-sensing ozone instruments on-board the high altitude Geophysica aircraft. Cloud top and ozone measurements were conducted during the transfer flights of the Geophysica from Europe to Brazil and in the Tropics, from Araçatuba, from January to the end of February 2005. The Validation campaign, financed by ESA, was embedded within a scientific campaign in the frame of two EC projects: APE-INFRA and Troccinox. Validation of MIPAS-ENVISAT products were planned by means of the corresponding instrument MIPAS-STR which was also on-board the Geophysica, and by means of other in-situ instruments. Some results of MIPAS-STR are reported here; however, the MIPAS data from the ENVISAT are not available. In general the validations show some discrepancies between the data collected by the Geophysica and the instruments on board of ENVISAT, which cannot easily be explained by the displacement of the satellite and aircraft measurements.*

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1. Introduction

The pressures of human activity on the climate system and on atmospheric composition have greatly increased the importance of monitoring the atmosphere. Of the radiatively-active components of the atmosphere, it is most important to measure the geographical distribution of those that are not well-mixed; the horizontal and vertical distribution of cloud is particularly important in this respect, since this distribution dictates the spatial variability of both the short-wave albedo and the long-wave emission to space of the Earth system. The horizontal and vertical distribution of ozone is also important, because ozone is radiatively-active (i.e. a greenhouse gas), because stratospheric ozone provides the external uv shield for the biosphere, and because tropospheric ozone is toxic to plants and animals.

One of the most significant efforts in Europe to provide comprehensive monitoring of the atmosphere is the ENVISAT satellite, launched on 1 March 2002. Satellite monitoring of atmospheric composition provides global coverage, and simultaneous retrieval of many atmospheric properties, but the – sometimes indirect – measurement techniques employed by satellite instruments require "ground-truthing" or validation. Since the performance of a satellite instrument or retrieval process may depend on the underlying surface (e.g., ocean, ice, desert, agricultural land, tropical forest, etc.) or on the characteristics of the atmosphere (e.g. ozone column, water vapour profile, etc.), the validation of satellite products must be carried out at widely separated geographical locations. The object of the Geophysica-ENVISAT Validation Project was to carry out such a validation of aerosol, gas and cloud parameters – measured by the instruments on board ENVISAT – by means of the high-altitude aircraft Geophysica and the DLR Falcon across a wide range of latitudes.

Previous campaigns were organized in different time periods at mid- and high latitudes to validate ENVISAT. During January-March 2005, a Transfer campaign from Europe to Brazil was conducted in the frame of the EC project APE-INFRA, directed by L. Stefanutti, and a Tropical Campaign was organized from Araçatuba (São Paulo State, Brazil). This campaign was subdivided into 2 projects: TROCCINOX (Tropical Convection, Cirrus and Nitrogen Oxides Experiment) directed by Prof. Schumann of DLR and the ENVISAT Tropical Validation directed by L. Stefanutti and C. Blom. During the latter, 4 fights were carried out for the validation of MIPAS and SCIAMACHY instruments on 12, 14, 15 and 17 February 2005. For the Tropical campaign in Aracatuba, 3 aircraft were operated: the high altitude aircraft Geophysica, the DLR Falcon, and the Bandeirante of the Brazilian Universidade Estadual do Ceará (UECE) fully instrumented for cloud physics measurements. In this paper we will deal only with the data collected by the Geophysica. Tables 1 and 2 list the instruments which flew in the ENVISAT Validation flights and the parameters which they measured.

Table 1

Instruments on board the Geophysica. Instruments flown in a particular set of flights are shown with (X); those missing are denoted (–)

Instrument	Transfer	Local flights TROCCINOX	Local flights ENVISAT-Validation (ESA)
Number of flights	8	6	2
FOZAN	X	X	X
FISH	X	X	X
FLASH	X	X	X
HAGAR	X	X	X
SIOUX	X	X	X
FOX	X	X	X
HALOX	X	X	X
TDL (CVI-bay)	–	X	–
ALTO-TDL	X	X	X
COPAS (CVI-bay)	–	X	X
COPAS-2	X	X	X
FSSP300	X	X	X
MAS	X	X	X
MAL-1/2	MAL1 only	X	X
TDC(Rosemount)	X	X	X
ABLE	X	X	X
GASCOD	–	1-2 flights	X
WAS	–	4-5 flights	
MIPAS	–	1 flight	X

MIPAS-STR (2,3,26) (a mid-IR Fourier Transform spectrometer) and GASCOD/A4π (5,6,7,25,31) (a UV-Vis spectrometer) were the principal instruments on board the Geophysica, during the tropical mission (a brief description is attached below) for the validation of MIPAS on board of ENVISAT, but other "in situ" instruments measured species of interest for the validation of ENVISAT. Unfortunately, MIPAS-ENVISAT level 2 data products are not available, thus a validation of these products using the correlative measurements from the Geophysica aircraft is still pending. Here we report some results of the SCHIAMACHY validation, relative to cloud-top height or pressure, and total ozone.

SCIAMACHY cloud top was obtained from TEMIS project (www.temis.nl). For this project, the cloud top is derived from GOME and SCIAMACHY measurements with the FRESCO cloud algorithm: The cloud-top pressures and effective cloud fractions (34) are derived from calibrated level-1 reflectivity data of the GOME or SCIAMACHY spectrum of the oxygen A-band (between 758-775 nm). Three one-nanometer wide parts of the oxygen A-band spectrum are used in the FRESCO near-real time retrieval, both inside and outside the oxygen A-band, namely at 758 nm, 761 nm, and 765 nm.

Table 2
Geophysica payload for the ENVISAT-Tropical Validation campaign

Instrument	Measured Parameter	Principal Investigator	Technique	Averaging time	Accuracy	Precision
FOZAN	O_3	Fabrizio Ravegnani CNR	Dye chemiluminescensce + ECC	1 s	0,01 ppmv	8%
FOX	O_3	Hans Schlager DLR	UV absorption	2 s	5%	2%
FISH	H_2O (total)	Cornelius Schiller FZJ	Lyman-a photo-fragment flourescence	1 s	0.2 ppmv	4%
FLASH	H_2O (gas phase)	Vladimir Yushkov CAO	Lyman-α	8 s	0.2 ppm	6%
SIOUX	NO NOy Particle NOy	Hans Schlager DLR	Chemiluminescence, + Au-converter + Subisokinetic inlet	1 s 1 s	10% 15%	3% 5%
HALOX	ClO BrO, $ClONO_2$	Fred Stroh FZJ	Chemical-conversion resonance fluorescence + thermal dissociation	20 s 100 s	20% 35%	5% 20%
HAGAR	N_2O, CFC 12, CFC11 Halon 1211 SF_6 CH_4 CO CO_2	C. Michael Volk Uni Frankfurt	GC/ECD GC/ECD GC/ECD GC/ECD GC/ECD IR absorption	70 s 70 s 140 s 140 s 140 s 5 s	2% 5% 4% 2% 10 ppb 0.05%	1% 4% 3% 1% 5 ppb 0.04%
MIPAS	O_3, CFCs, CCl4, H_2O, CH_4, OCS, HNO_3, NO, N_2O_5, $ClONO_2$	Cornelis Blom	Mid-Infrared Fourier Transform Spectrometer			
ALTO	N_2O, CH_4 CO	Piero Mazzinghi INOA	TDL	5 s 1 s 5 s	5% 4% 5	2% 1% 2%
COPAS	Condensation nuclei (CN-total , CN-non-volatile)	Stephan Borrmann Uni Mainz	2-channel CN counter, one inlet heated	1 s	10%	5%
FSSP3000	Size speciated aerosols (0.4-40µm)	Stephan Borrmann Uni Mainz	Laser-particle spectrometer	20 s	20%	10%
MAS	Aerosol optical properties	Francesco Cairo CNR	Multi-wavelength Scattering	10 s	5%	5%
MAL 1 & 2	Remote Aerosol Profile (2 km from aircraft altitude)	Valentin Mitev Obs. Neuchatel	Microjoule-lidar	30-120 s	10%	10%
ABLE	Remote aerosol Profile	Giorgio Fiocco Uni Roma	Backscattering lidar			
WAS	Trace gas isotopes	Thomas Röckmann MPI-Heidelberg	Whole air sampler			
TDC (Rosemount)	Temperature, horizontal wind	Vladimir Yushkov CAO	PT100, 5-hole probe	0,1 s 0.1 s	0,5 K 1 m/s	0,1 K 0.1 m/s
GASCOD-A/4π	Column measurements of O3, NO2, OCIO, BrO Radiation		UV-Vis Spectrometer	1 s – 120 s	–	–

The reflectivity outside the oxygen A-band is almost independent of cloud-top pressure, but depends mainly on cloud fraction, cloud optical thickness, and surface albedo. The reflectivities inside the band depend on cloud-top pressure, and are used to derive cloud-top pressure. An effective cloud fraction and cloud-top pressure are derived for each GOME or SCIAMACHY pixel using non-linear least-squares fitting of a measured spectrum to a simulated spectrum.

The effective cloud fractions are derived by assuming that the clouds have an albedo of 0.8, and must therefore be interpreted as effective cloud fractions. Note that the derived cloud-top pressures are rather insensitive to the assumed cloud albedo. For areas with effective cloud fractions smaller than 0.05, cloud-top pressures cannot be derived reliably. These areas show up in blue in the effective cloud fraction and cloud-top pressure maps. No attempt is made to account for the presence of snow, ice, or sun-glint. Thus if cloud-free land or ocean is covered by snow or ice shelves, or if a pixel is affected by sun-glint, these areas will show up as having low-altitude clouds with high cloud coverage. The range of cloud top height is 0-15 km. Clouds with altitude higher than 15 km are not present in FRESCO data.

2. Methods and problems

2.1 – *Flight planning*

A major goal was to adjust the in-situ and remote measurements from the two aircraft to the location and time of the Envisat measurements, in particular to those of MIPAS. Due to the sledge problems of MIPAS, which occurred in 2004, ESA changed the measurement strategy with latitude-fixed tangent points. For this reason, MIPAS was not operating full-time, but was switched on and off, according to a plan decided by ESA in agreement with the users and the validating teams. This way of operating made it impossible to have MIPAS operating during all the GEOPHYSICA flights. As the distribution by ESA of the Excel sheets with the footprints stopped with this change, we tried two ways to obtain the location of the tangent points: Former Excel sheets were extrapolated to the actual flight dates and compared with the tracks of the footprints derived from the ESA-produced ESOV data visualization tool (http://earth.esa.int/esov/). Figure 1 shows the two tracks in the Araçatuba region for 15.02.05 together with a planned flight track. The blue line is the track derived from ESOV, the brown line is the extrapolated track of the Excel sheets. Depending on the latitude, the difference varies between 100 and 250 km.

During the preparation phase we decided to fly along the Envisat track, so that the line of sight of MIPAS-STR is perpendicular to that of MIPAS-Envisat. Gradients in the trace gas distribution along the Envisat line of sight could then be resolved and validated by the MIPAS-STR measurements. This geometry also compensates the uncertainty of the actual position of an Envisat limb scan along the track when no latitude fixing is made.

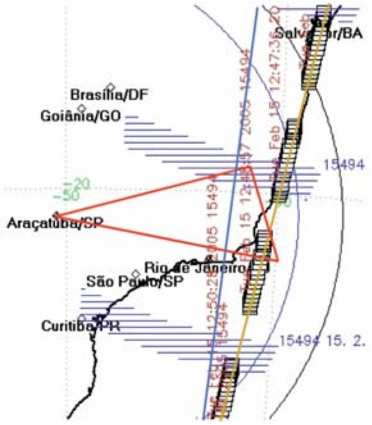

FIG. 1

Screenshot of our flight planning tool: the flight of February, 15th as an example.

As not only the tangent point position along the track was unknown, but the also the location of the track itself was uncertain, we changed the planning and decided to fly perpendicular to the Envisat track. This offered the chance to cross the two predicted tracks and to perform measurements on both positions. As the MIPAS-STR profiles are measured on 'constant' latitude and varying longitude, for validation the MIPAS-Envisat profiles - which have 'constant' longitude and varying latitude - have to be interpolated or averaged for the correct latitude. The first validation flight on 15 February 2005 was performed following the strategy described above, and is described in section 3.3. During the campaign, we obtained information that the ESOV prediction was probably wrong but that extrapolation of the Excel sheets still gave the correct position of the track of the tangent points. Accordingly, the second validation flight on 17.2.2005 was performed with the original strategy. To plan an Envisat validation flight, we normally plotted the predicted footprints of the tangent points of MIPAS (open black squares) and SCIAMACHY in limb mode (blue hatching) on a local map. They were printed together with the planned flight track (red triangles) and the maximum range of the Geophysica, with and without a dive (the two grey concentric circles centered at the airbase (Araçatuba)).

Besides the arrangement of coincident measurements between MIPAS on the satellite and the aircraft, there were several requirements and restrictions for the flights:

- the operation of the airport limited the validation to daytime overpasses;
- limitations on the permitted area of operation for both aircraft (Fig. 2);
- in-situ and remote sensing measurements from the Geophysica and the Falcon had to be co-located to enable internal validation of the validating instruments;

- for the measurement of profiles by the in-situ instruments aboard, dives were needed when the location of the Envisat measurements was far from Araçatuba;
- the flight readiness of the instruments and the aircraft;
- since MIPAS-Envisat is not able to observe through clouds, validation measurements had to be made in regions without high clouds. High clouds are ubiquitous in the moist tropics in general (11), and in the campaign region in particular (12), and are very difficult to forecast (13);
- a final restriction was to avoid direct sun in the field of view of the MIPAS-STR instrument while at the same time diffused solar radiation was needed for the GASCOD/A4pi measurements.

Some of the above criteria were predictable, so a set of possible flight tracks was prepared before the campaign. Only criteria which change from day to day had to be considered during the campaign. Of these, instrument readiness and high-cloud cover were the most significant.

FIG. 2

Location of the operational base at Araçatuba (green star) with the approximate range of the two aircraft (white circle). The bold black lines show the permitted area of operation.

2.2 – *Modification of the MIPAS-STR instrument for tropical conditions*

A previous campaign in Forlí, Italy (26), in summer 2002, demonstrated that MIPAS-STR required adaptations to function well in the very humid conditions in the tropics. Since MIPAS-STR is a cryogenic instrument, in wet conditions the temperature of the outer skin is below the dew point. Water slowly migrates to the cooled optics inside. Furthermore, corrosion of metal parts on the outside fairing could produce malfunction of electrical connections. Therefore we designed a heating system for the fairing and all electrical connectors.

A further change, which also affected the dome of the dorsal bay of the Geophysica, concerned provisions for an improved deep-space calibration. At mid-latitudes and in Polar Regions the atmospheric contribution in spectra measured at 10° elevation is relatively small and can be corrected. In the tropics the atmospheric contribution is much larger and hence more difficult to simulate. Therefore the design of the instrument and the dome has been modified to enable zenith measurements which substantially reduce the air mass factors for the deep-space calibration measurements.

3. ENVISAT validation

Overpasses for the instruments Sciamachy and MIPAS were requested both for the transfer flights and for all the days scheduled for the TROCCINOX mission. Due to technical reasons, MIPAS-STR was switched on during the transfer flight Seville – Cape Verde of January 23rd, 2005, but it was off during the Oberpfaffenhofen – Seville Flight. It was turned on again for the remaining flights.

The coincidences between the ENVISAT overpasses and the Geophysica flights are given below for the flights in Brazil.

Table 3
Coincidences between ENVISAT overpasses and the Geophysica sorties in the ENVISAT-Tropical Validation campaign.

Date dd.mm.yy	Geophysica Take-off - landing UTC	SCIAMACHY Overpass UTC	MIPAS Overpass UTC	Comments
20.01.05	10:00-14:00	10:51	–	Oberpfaffenhofen-Seville. Good coincidence
23.01.05	09:15-13:30	11:00		Seville-Sal-Recife, Good coincidence
01.02.05	15:20-19:30	13:12	–	Close to SCIAMACHY (>3hrs late)
04.02.05	17:00-21:20	13:18	–	5 hrs after SCIAMACHY
05.02.05	17:00-21:30	12:46	–	5hrs after SCIAMACHY
08.02.05	13:00-17:30	12:53	–	Good coincidence
12.02.05	09:00-13:40	12:27	12:42	1 hr after SCIAMACHY and MIPAS
15.02.05	10:18-18:05	12:32	12:48	Good coincidence (time/loc)
17.02.05	09:40-14:15	13:09	13:25	Good coincidence (time/loc)
18.02.05	17:55-21:45	12:38	12:54	5 hrs after SCIAMACHY and MIPAS
27.02.05				Recife-Sal
27.02.05				Sal-Seville
02.03.05				Seville-Oberpfaffenhofen

The measurements made during the campaign provide the most extensive data set for the validation of ENVISAT in the tropics to date.

3.1 – *First Transfer Flight: 20 January 2005*

This flight provided an opportunity for a validation of SCIAMACHY cloud-top heights in the middle latitudes in winter. Fig. 3 shows a comparison of SCIAMACHY and Geophysica cloud-top heights. The Geophysica cloud-top heights are derived from the ABLE (10) lidar instrument (1).

The results in Fig. 3 are encouraging, because the cloud-tops measured simultaneously by ABLE and SCIAMACHY are in good agreement. Both instruments measured cloud top at 3 km.

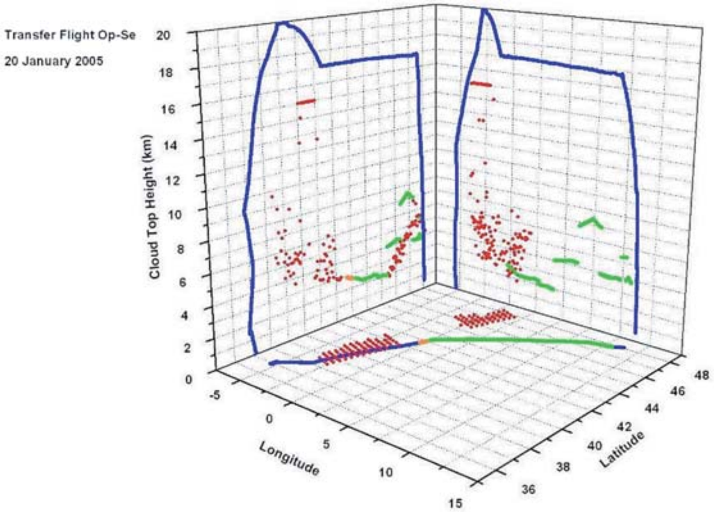

FIG. 3

Comparison of SCIAMACHY and Geophysica cloud-top on 20 January 2005, projected onto the latitude-longitude, longitude-altitude, and latitude-altitude planes. The flight pattern of the Geophysica is given in blue and orange, SCIAMACHY cloud tops are shown in red, and ABLE cloud tops are shown in green. In the orange the flight-section, there is coincidence-in-time with the satellite. The SCIAMACHY data on the vertical planes (red dots) are for measurements closest to the flight path.

During the first part of the flight, the two lidar instruments mounted on the Geophysica, MAL and ABLE, detected some clouds at 12 km, 7 km and 4 km (Fig. 4), but the Geophysica crossed this area before the overpass of SCIAMACHY. Considering the approximate wind velocity (15 m/s) and wind direction (330 degrees), the clouds detected by the instruments installed on the Geophysica are consistent with those measured some time later by SCIAMACHY in a zone located at 330.30 degrees from the flight track.

During the second part of the flight, the satellite detected widespread cloud cover, with cloud tops at altitudes ranging from 3 km to >15 km, with a great deal of variation in the cloud-top height from pixel to pixel. For the same portion of the flight, the Geophysica instrumentation observed a cloud-free atmosphere. This apparent discrepancy could be due to the poor time-coincidence between the aircraft and the satellite. However, the velocity of the wind is 7.25 m s^{-1} in this zone and the wind direction is 286 degrees. Since the time difference is about 1935 sec from the passage of the satellite to the passage of the aircraft, this means that the clouds have moved only 0.12 degrees of longitude. The instruments on the Geophysica should have detected these clouds unless they dissipated in the interim. Furthermore, the existence of cloud tops at >15 km in middle latitudes in January, as suggested by the SCIAMACHY data, is hard to rationalize climatologically.

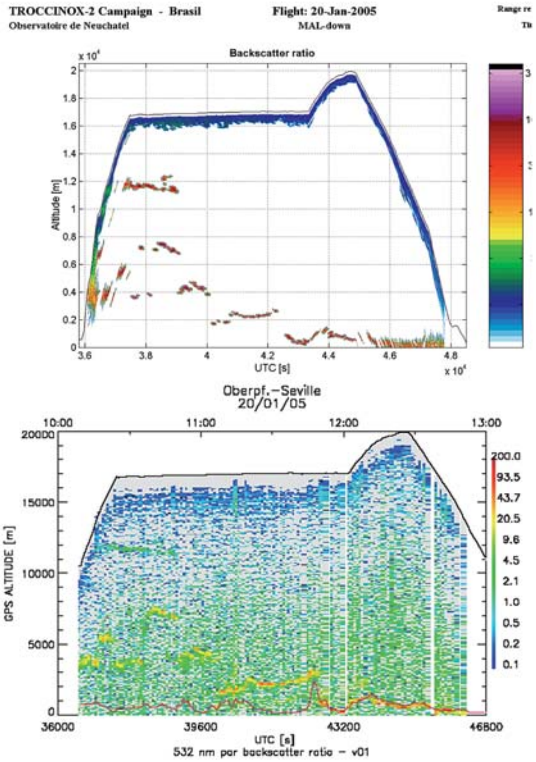

FIG. 4

MAL (top panel) and ABLE (bottom panel) backscatter ratio for the flight on 20 January 2005.

Solid line at the bottom of the lower panel indicates the ground profile.

The climatological tropopause at these latitudes is at about 12-14 km; the 00Z soundings from Nimes-Courbessac, southern France, for 20 and 21 January 2005, show a tropopause at about 12.5 km and lower stratospheric temperatures of about 210 km This information on the tropopause height is consistent with the observation of clouds at 12 km at the beginning of the flight, which had formed probably just beneath the tropopause. (http://weather.uwyo.edu/upperair/sounding.html).

It is very unlikely that clouds would form 2.5 km into the stratosphere at these latitudes and temperatures. Meteosat images for 20 January also do not show high cloud over Spain (http://www.sat.dundee.ac.uk/).

3.2 – *Second Transfer Flight: 23 January 2005.*

This flight provided an opportunity for a validation of SCIAMACHY cloud-top heights through the sub-tropics and across the equator, in northern hemisphere winter. In this case, we have a perfect coincidence-in-time between the flight and the passage of the satellite at 32 °N and 349 °E. SCIAMACHY and the lidars ABLE and MAL (figures 5 and 6), detect clouds between 6 and 7 km. The SCIAMACHY cloud product again shows much more pixel-to-pixel variability than the aircraft data (Fig. 5) and cloud tops up to 3 km above the local tropopause (Gibralter 00Z soundings, http://weather.uwyo.edu/upperair/sounding.html).

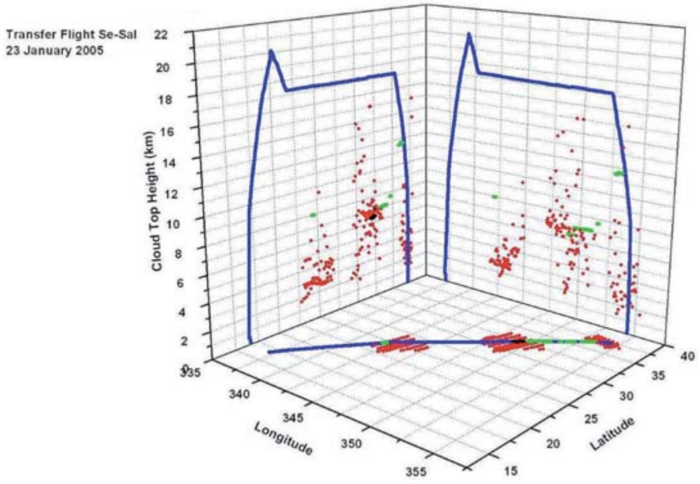

FIG. 5

As for figure 3. In black is the flight-section where there is coincidence-in-time with the satellite.

During the ascent, MAL measured a cloud layer at a height of 11.5 km, close to the tropopause (Fig. 6), which does not appear in the SCIAMACHY data, while cloud tops between 2 and 8 km were instead reported by the satellite. This might be due to the fact that there is poor coincidence-in-time (i.e., a difference of about 1 hour between aircraft and satellite measurements). Lower clouds during the flight measured by SCIAMACHY could not have been measured by ABLE and MAL, which suffered from poor signal-to-noise ratio at this time, caused by the high elevation of the sun. One should, therefore, regard this flight as a test of the SCIAMACHY cloud-top algorithm for high clouds only. ABLE data for the first hour or so of the flight are not available.

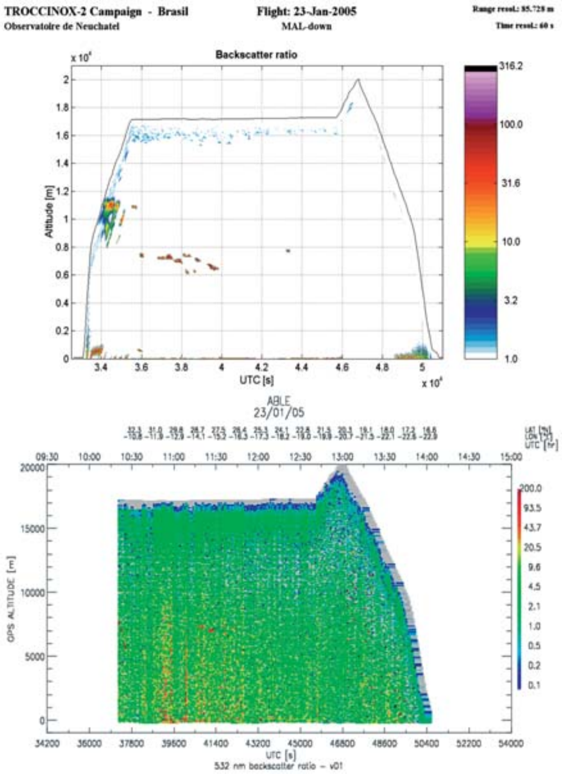

FIG. 6

MAL (top panel) and ABLE (bottom panel) backscatter ratio for the flight on 23 January 2005.

The noisy signals on this flight – shown by large areas of white in the top panel and large pixel-to-pixel colour variation in the bottom panel – are due to the high solar elevation.

3.3 – *Local Flight: 15 February 2005*

This flight provided an opportunity for a validation of MIPAS and SCIAMACHY in the sub-tropics in southern hemisphere summer. As mentioned above (Fig. 1), the flight of the Geophysica was perpendicular to the ENVISAT track, the first part roughly west-east, the last section almost east-west (Fig. 7). In the shorter north-south leg a dive was made for ENVISAT validation by the in-situ instruments. The dive also enables an internal validation of the MIPAS-STR data using the in-situ measurements. The time of the ENVISAT overpass was at the most south-westerly location, at the end of the dive. The Falcon aircraft followed the Geophysica in the first leg (east-west) and returned to Araçatuba on the same track. Unfortunately the first channel of MIPAS-STR broke down after the dive, so only the last sequences before the dive can be used for validation purpose. These sequences were closely coincident-in-space with the satellite measurements, and made about 30 minutes before the overpass of ENVISAT.

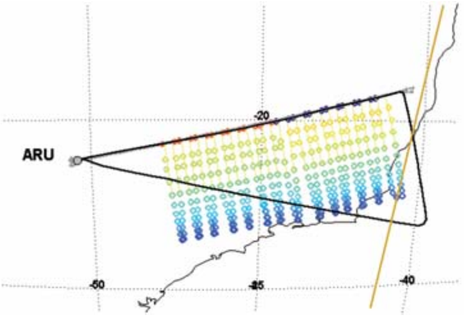

FIG. 7

The track of the Geophysica on February 15, 2005, and the location of the tangent points of the MIPAS-STR instrument. The tangent points have been color-coded, dark blue for the lowest one (6 km) to orange for the highest one close to the aircraft flight level. The plot includes the location of the MIPAS ENVISAT measurements (brown line) and flight track of the Falcon (grey line).

Figure 8 shows the overlap of Geophysica and SCIAMACHY measurements. Fig. 9 shows SCIAMACHY cloud tops for those pixels close to the Geophysica flight path; no cloud tops appear above 10 km, but one region shows a few pixels with cloud-top at 8-9 km, and another region shows cloud-top at 3-5 km.

The day was clear, and both the MAL lidar (Fig. 10) and SCHIAMACHY (Fig. 9) do not measure any cloud in the upper troposphere. MAL measured at take off an indication of haze up to above 6 km (Fig. 10), with scattering ratios in the green between 3 and 6, with a more marked region at heights between 2 and 4 km. An indication of a possible layer between 1 and 1.5 km persists for the first part of the flight (before the dive) and also in the return leg there are very faint indications of layers around 1000 and 4000 meters altitude. The altitude of Araçatuba above sea level is of the order of 600 meters, as shown also from the coordinates of take off and landing in Fig. 9. The low-level cloud top measurements performed by SCIAMACHY in the region of validation indicate a cloud top at about 2000 meters altitude. SCIAMACHY data seem thus to overestimate the height of the cloud top by approximately 1000 meters.

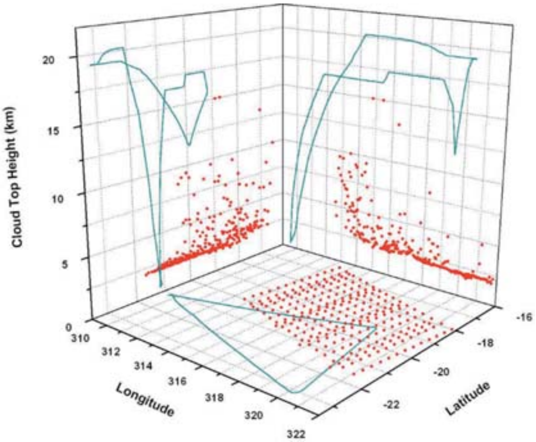

FIG. 8

As for Fig. 3. Flight pattern of the Geophysica. In the horizontal plane is the raster of the SCIAMACHY measurements, while on the two vertical sides are the projections of the cloud top heights.

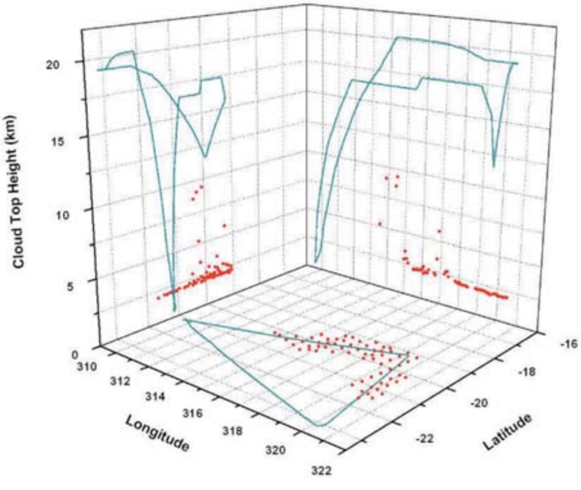

FIG. 9

As for Fig. 8, but only the cloud tops relative to the locations close to the overpass are indicated.

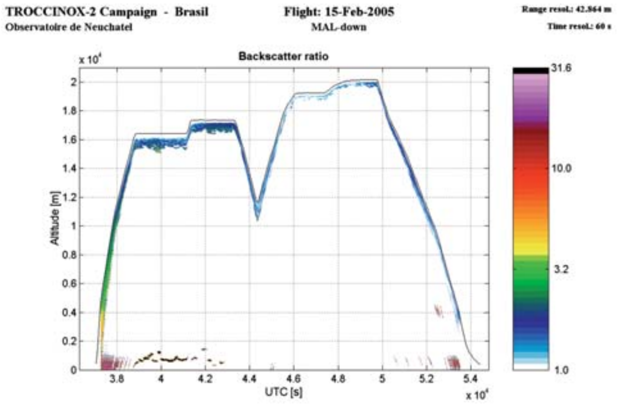

FIG. 10

MAL backscatter ratio for the flight of February 15, 2005.

3.4 – *Local Flight: 17 February 2005*

This flight provided another opportunity for a validation of MIPAS and SCIAMACHY in the sub-tropics in southern hemisphere summer. Again, the primary objective was to conduct measurements in an area of a suitable MIPAS and SCIAMACHY measurement point. Take-off was at 09:40 UTC, and the flight duration was approximately 5 hours. The path followed by the Geophysica is shown in Fig. 11. The maximum cruise altitude of the Geophysica was 20 km.

The flight was performed parallel to the ENVISAT track on the northbound leg, and returned on a track which permitted the MIPAS-STR measurements to cover, in principle, several scans of MIPAS-ENVISAT (Fig. 11). No dive was made, because the descent for landing was exactly at the predicted track of the MIPAS-ENVISAT tangent points.

The ENVISAT overpass and the Geophysica flight path coincided in space and time at the most southern point of the track, at the beginning of the descent. The Falcon followed the Geophysica in the first northbound leg, went slightly further north, and returned to Araçatuba on the same track.

During the first half of the flight, MIPAS-STR was not operating to avoid direct illumination by the rising sun. This part of the flight was used for in-situ (cloud) measurements. In the northern part of the southbound track high clouds were again observed, but at the end of the southbound leg, several limb scans were made in “cloud free” locations. These measurements were made within a few minutes of the overpass of the satellite at the expected location of the MIPAS-Envisat tangent points track. We therefore concentrate our work for ENVISAT validation (see below) on this part of the measurements in Brazil.

Figures 12 shows profiles retrieved from the MIPAS-STR measurements in the most southerly part of the southbound track on 17 February 2005. Retrieval was made with the Karlsruhe KOPRA package (2). For water vapour (Fig. 12), the local maximum at 13.5 km is likely an indication of moistening of the base of the tropical tropopause layer (TTL) by convection. This process has also been diagnosed from an analysis of in-situ water vapour and cloud measurements in the TroCCiNOx campaign (13). This interpretation is supported by the shallow local minimum in ozone at the same altitude (Fig. 12), because convection brings up air that is high in moisture but low in ozone from the surface to the base of the TTL. The CFC profiles retrieved (Figs. 12d, e) show the effect of the different lifetimes on the CFC vertical profiles; the shorter-lived CFC-11 decaying to 2/3 of its tropopause value by the top of the profile, at which point the longer-lived CFC-12 is still 4/5 of its tropopause value. The nitric acid mixing ratios retrieved are rather low compared to mid- and high-latitude profiles, reflecting the fact that the stratospheric source of nitric acid – breakdown of nitrous oxide – occurs slowly as air moves slowly from equator to pole via the Brewer-Dobson circulation. The increase in nitric acid mixing ratios between 12 km and 16 km is likely the combined effect of a local lightning source from convection and mixing of air from the stratosphere, particularly in the region of the sub-tropical jet.

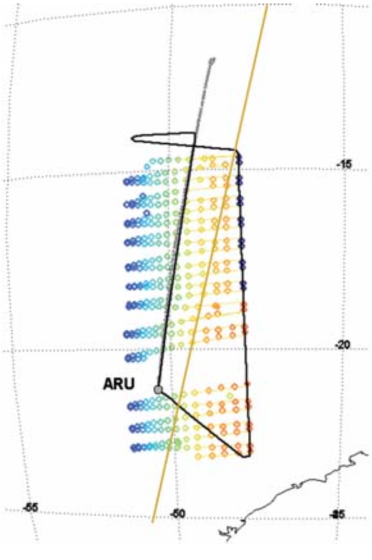

FIG. 11

The track of the Geophysica on February 17, 2005, and the location of the tangent points of the MIPAS-STR instrument. The tangent points have been color-coded, dark blue for the lowest (6 km) to orange for the highest close to the aircraft flight level. The plot includes the location of the MIPAS Envisat measurements (brown line) and flight track of the Falcon (grey line).

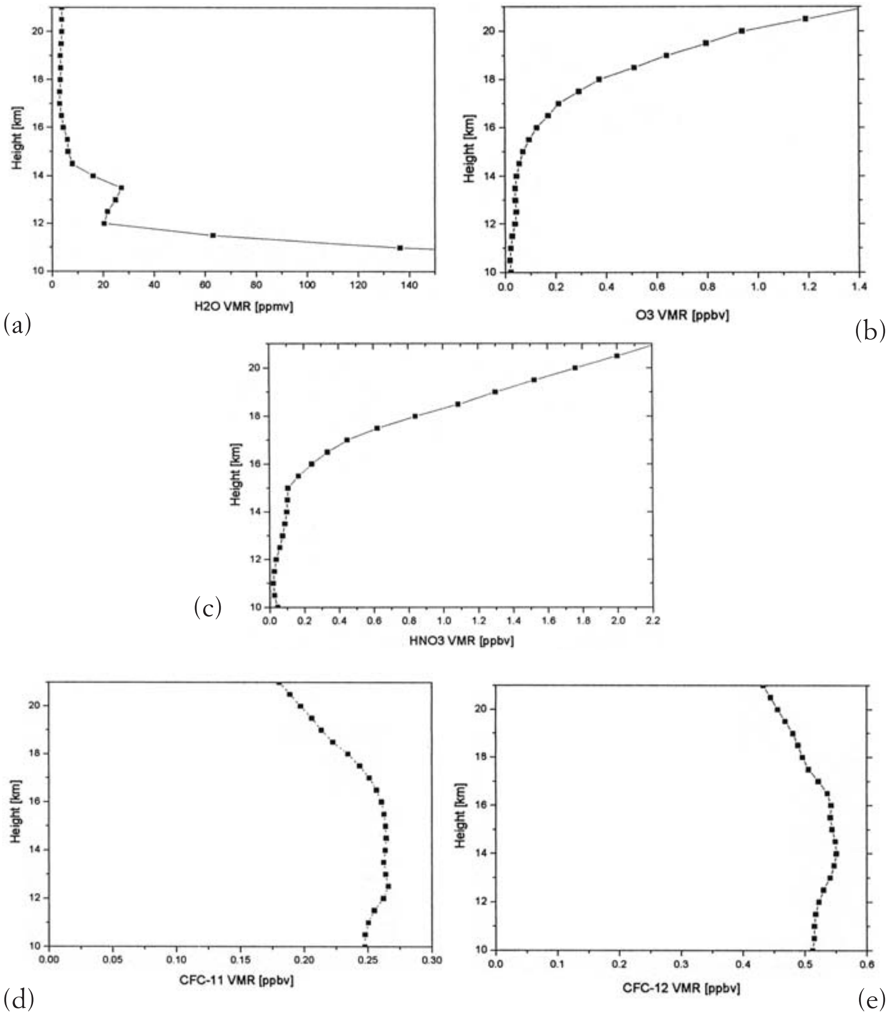

FIG. 12

Profile of H_2O (a), O_3 (b), HNO_3 (c), CFC-11 (d) and CFC-12 (e) from MIPAS-STR measurements on February 17, 2005.

Turning to clouds, Meteosat images for 17 February 2005 (Fig. 13) show that the South Atlantic Convergence Zone was to the north of Araçatuba, and no local convective activity was reported. Three layers of clouds were detected during the first part of the flight as we can see in Fig. 14: a level of haze in the first kilometer, a layer at about 5 km altitude and a strong layer between 15 and 16 km. High altitude clouds were measured by MAL for a long track at heights between 15 and 16 km. For the clouds at 5 km altitude there is a good coincidence between the data measured by MAL (blue dots) and those measured by SCIAMACHY (red dots) – see Figs. 15 and 16. The main problem occurs with the high clouds. Recall that the FRESCO algorithm cannot assign cloud altitudes above 15 km, so a continuous line of dots at 15 km can be seen in the figure. Due to the bad signal-to-noise ratio for aerosols and clouds far from the aircraft, no clouds can be detected in the second part of the flight.

Note that the very low clouds measured by MAL, at an altitude between 500 and 1000 m, are probably not clouds at all, but rather the ground signal, which, as has already been mentioned, has an altitude in the region of Araçatuba of about 600 meters.

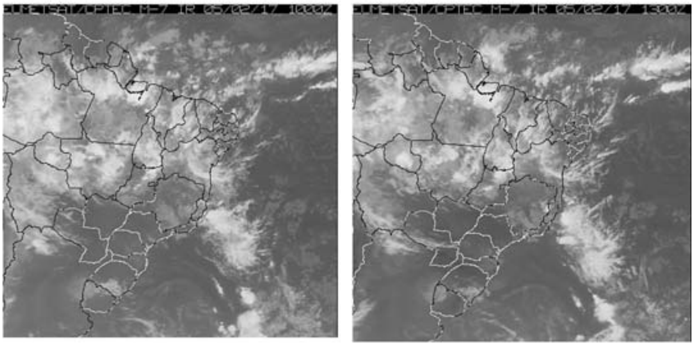

FIG. 13

Meteosat images of cloud cover
on 17 February at 10 a.m. (left) and 1 p.m. (right).

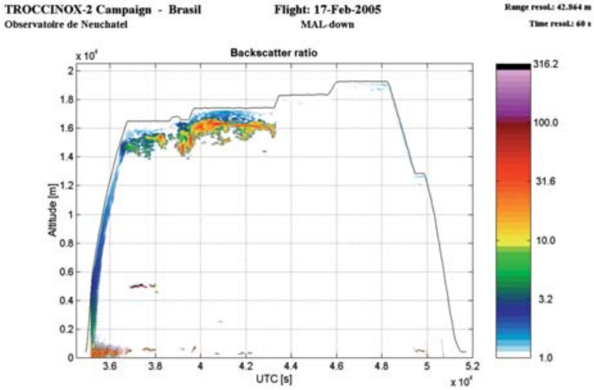

FIG. 14

MAL backscatter ratio during the flight of February 17, 2005

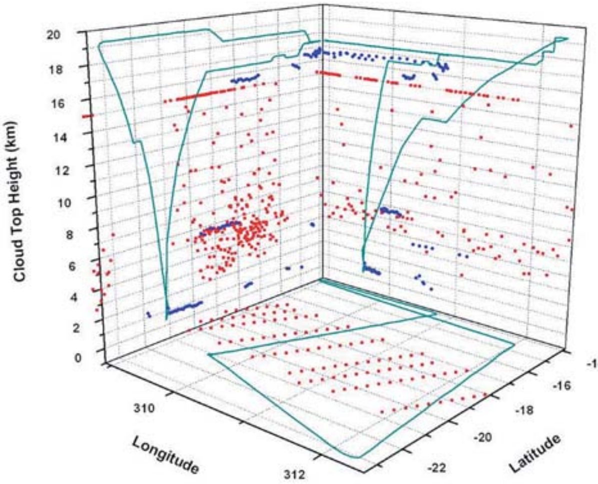

FIG. 15

Flight pattern of the Geophysica (green) with SCIAMACHY overpass in the horizontal plane (red), while on the two vertical sizes are the projections of the cloud top heights of SCIAMACHY in red and MAL in blue.

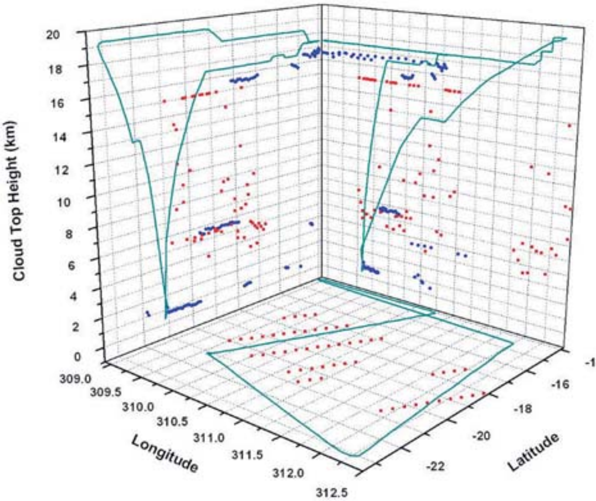

FIG. 16

As for Fig. 15, but only the cloud tops relative to the locations close to the overpass are indicated

3.5 – *Local flight: 18 February 2005*

This flight provided an opportunity for a validation of MIPAS and SCIAMACHY in tropical convection. Strong cloud coverage was observed during this day, as shown by Meteosat satellite imagery (not shown) and confirmed by the MAL data (Fig. 17). Clouds were present in the altitude range 10 to 14 km and a lower layer was observed close to the ground. Due to the long time difference (5 hours, Table 1) between the SCHIAMACHY overpass and the lidar data, the validation of cloud cover in this flight is only indicative. However, one positive aspect of this flight, because of its timing, is that the solar zenith angle was sufficiently large to allow GASCOD/A4π to perform vertical measurements used further to retrieve ozone column above the aircraft, by applying the DOAS methodology.

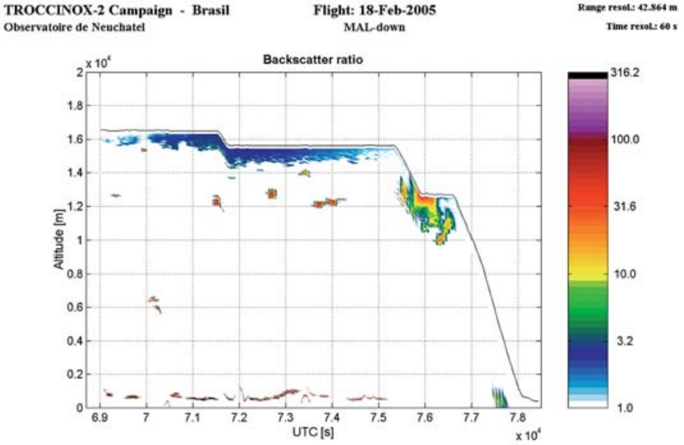

FIG. 17

MAL backscatter ratio for 18 February 2005.
The solid line shows the GPS altitude of the Geophysica.

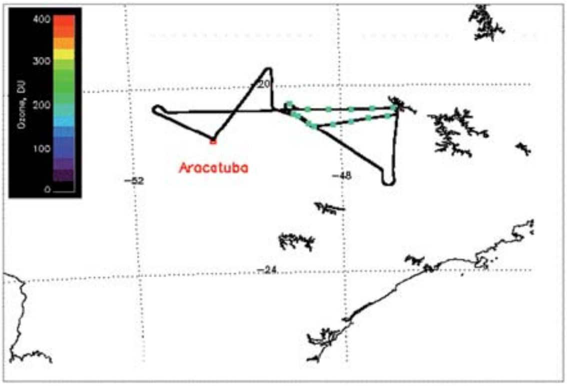

FIG. 18

O_3 vertical column (DU), retrieved from GASCOD measurements,
for the flight of 18 February 2005.

The total ozone measured by GASCOD/A4π above the aircraft (i.e., above 16 km) was approximately 190 Dobson Units; the spatial distribution of measurements is shown in Fig. 18, a more detailed time series is shown in Fig. 19. SCIAMACHY measured 215 Dobson Units, as shown by the SCIAMACHY Total Ozone (Fig. 20).

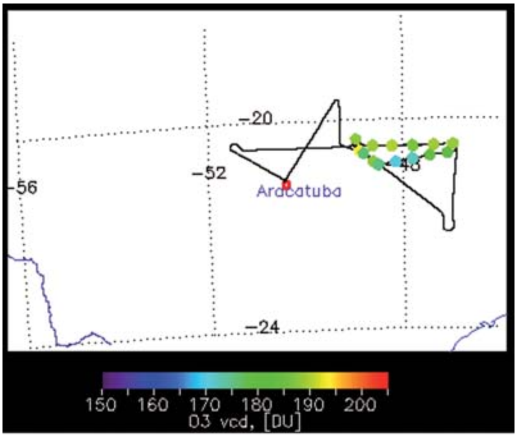

FIG. 19

The O_3 vertical column is plotted together with geographic co-ordinates, flight altitude and SZA.

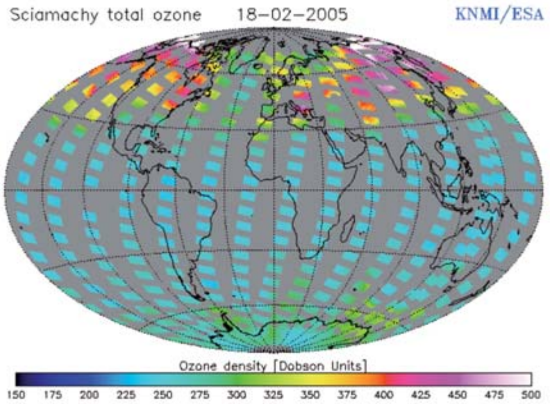

FIG. 20

SCIAMACHY Total Ozone data for 18 February 2005.

For the validation of the SCIAMACHY data, we have considered the total vertical ozone column, i.e. the sum of the stratospheric and tropospheric ozone contribution. GASCOD/A4π provides only the stratospheric ozone column, that is, about 190 DU at an altitude of 16.5 km as shown in Fig. 19. To calculate the total vertical column, we have added the ozone vertical profiles obtained from FOZAN data during the ascent from the ground to the flight level at 16.5 km of altitude (Fig. 21). The tropospheric contribution of ozone, from FOZAN data, is 32.9 DU. The sum of GASCOD/A4π and FOZAN partial ozone columns is therefore about 223 DU, which is in good agreement with the satellite data.

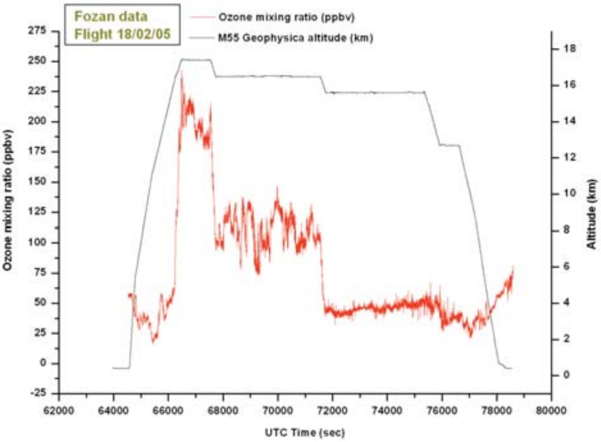

FIG. 21

Ozone mixing ratio measured by FOZAN, plotted together with altitude on 18 February 2005.

4. Conclusions

Two flights for ENVISAT validation were made in Brazil, in February 2005; additional validation opportunities were afforded by collaboration with the APE-INFRA and TroCCiNOx science missions. The two dedicated flights – performed on 15 and 17 February 2005 – were carefully planned with all available tools and gave excellent overlap in time and location with the ENVISAT measurements of MIPAS and SCIAMACHY. As expected in the tropics, clouds at high altitudes reduce the number of direct intercomparisons of chemical species between the aircraft and satellite measurements but there are at least two regions were excellent Envisat validation can be made. Also several flights conducted in the framework of the EU TroCCiNOx campaign can be used for ENVISAT validation.

Lidar measurements of cloud-top height have identified shortcomings in the FRESCO cloud algorithm used in SCIAMACHY operational retrievals. The FRESCO cloud-top retrievals are very noisy, show a substantial number of unphysical cloud-tops (e.g. 3-4 km into the stratosphere at temperatures around 210 K), and are limited in the tropics by the 15-km limit for cloud tops.

In the last part of the flight of 17 February 2005, 'cloud-free' measurements with an excellent co-location were made by MIPAS-STR. These measurements show the structure of the tropical upper troposphere and lower stratosphere, particularly the chemical characteristics of the tropical tropopause layer. Validation of the profiles of MIPAS-ENVISAT and SCIAMACHY is planned as soon as the satellite data are made available.

In-situ instruments were also operated during the validation flights, providing an opportunity to cross-check validation products from the remote-sensing instruments. The in-situ data have been processed, quality checked, and submitted to the TroCCiNOx data base, where they are stored for future validation of ENVISAT data products.

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