# ENVISAT VALIDATION: INTRODUCTION TO THE CORRELATIVE MEASUREMENTS BY THE CHEMISTRY PAYLOAD ON BOARD THE M-55 GEOPHYSICA


**Cornelis E. Blom (1), Ugo Cortesi (2), Gianluca Redaelli (3)**

*(1) Forschungszentrum Karlsruhe, Postfach 3640, D-76021 Karlsruhe, Germany , Email: cornelis.blom@imk.fzk.de*
*(2) Istituto di Fisica Applicata (IFAC - CNR), Via Panciatichi, 64, I-50127 Firenze, Italy, Email: u.cortesi@ifac.cnr.it*
*(3)Università dell'Aquila, Via Vetoio, Coppito, I-67010 L'Aquila, Italy, Email: gianluca.redaelli@aquila.infn.it*



## ABSTRACT

The Russian high-altitude aircraft M-55 Geophysica has been deployed in several missions to obtain correlative measurements for the geophysical validation of the ENVISAT chemistry instruments MIPAS, SCIAMACHY and GOMOS. The payload of the Geophysica for the measurements of trace species was a unique combination of remote-sensing and in-situ instruments, enabling extensive Geophysica-internal intercomparisons. The correlative measurements were guided by forecasts of meteorological parameters (high-cloud coverage and gradients in the distributions of the atmospheric parameters) and by the expected time and location of the ENVISAT measurements.

This paper gives an overview of the chemistry payload of the Geophysica, the deployments made at middle and high latitudes, the criteria for flight planning and the expected correlative data for ENVISAT validation.


## 1. INTRODUCTION

The deployments of the high-altitude aircraft M-55 Geophysica, equipped with a variety of remote-sensing and in-situ sensors, represented a key component of the ESABC (ENVISAT Stratospheric Aircraft and Balloon Campaigns) programme executed between July 2002 and March 2003 with financial support by the European Space Agency, the European Union and several national agencies.

The operational flexibility of the aircraft platform, that made possible to perform a number of flights optimised for the best spatial and temporal coincidences with the satellite overpasses, and its capability to accommodate various payloads for the validation of the ENVISAT chemical and aerosol products, provided an excellent opportunity for correlative measurements at mid-latitudes and in the Arctic region.

The validation of the products of ENVISAT chemistry instruments was conducted in the frame of ENVISAT AO-114 (Geophysical validation of level-2 products of MIPAS, GOMOS and SCIAMACHY by dedicated campaign of the high-altitude aircraft M-55 Geophysica), by carrying out two field campaigns from the operative base of Forlì, northern Italy, in July and October 2002, and a third mission at high latitudes from Kiruna, Sweden, in February - March 2003.

## 2. THE M-55 GEOPHYSICA "CHEMISTRY PAYLOAD" FOR ENVISAT VALIDATION

### 2.1 Payload Composition

The core of the remote-sensing chemistry payload was composed by two Fourier transform limb sounders, the spectrometers MIPAS-STR [1] and SAFIRE-A [2], operating respectively in the middle and far infrared spectral regions. The two instruments measure a large number of volume-mixing-ratio profiles of atmospheric constituents below flight altitude and their column content above. A third remote sensor, the UV-Visible spectrometer GASCOD-A [3], obtains "quasi in-situ" and columnar data of ozone and $NO_2$, along with actinic fluxes and $J(NO_2)$ values.

Table 1. The M-55 Geophysica chemistry payload: Instruments and products for ENVISAT validation.

| | Instrument | Target species |
|---|---|---|
| **Remote-sensing** | MIPAS-STR | T, $HNO_3$, $O_3$, $H_2O$, $CH_4$, $N_2O$ and several secondary species |
| | SAFIRE-A | $O_3$, $HNO_3$, $H_2O$, $N_2O$ and several secondary species |
| | GASCOD-A | $O_3$, $NO_2$, OClO, BrO |
| | MAL-1, -2 | Cloud top level |
| | ABLE | Cloud top level |
| | MTP (1) | Temperature |
| **In-situ** | FISH | water (total content) |
| | FLASH | water (gas phase only) |
| | FOZAN | Ozone |
| | HAGAR | $N_2O$, $CH_4$, $CO_2$, F-11, F-12, $SF_6$ |
| | HALOX | ClO, BrO and, indirectly, OClO |
| | SIOUX | $NO_y$, NO and, indirectly, $NO_2$ |
| | MAS | Cloud top level |
| | TDC (1) | Temperature and Pressure |

(1) On board during the Arctic flights only

The in-situ sensors of the chemistry payload provide the horizontal distribution of various trace species at flight level along with vertical profiles obtained during the ascent, descent, and occasional 'dives'.
In-situ measurements of ozone and water were made, respectively, by the chemiluminsecent ozone sonde FOZAN [4] and by the Lyman-α photofragment-fluorescence hygrometers FISH [5] and FLASH [6]. Various tracers were measured by the gaschromatograph HAGAR [7], whilst measurements of NO and $NO_y$ and of ClO and BrO were made, respectively, by the chemiluminescence and autoconversion experiment SIOUX [8] and by the chemical-conversion resonance fluorescence instrument HALOX [9].
Apart from the chemistry instruments listed above, the Lidars MAL-1, MAL-2 [10] and ABLE [11] and the aerosol scatterometer MAS [12] provided information on the cloud height. During the 2003 Arctic flights highly accurate temperature information was obtained by the temperature profiler MTP [13] and the TDC instrument [14].
A list of the target species measured for ENVISAT validation by this unique payload is given in Table 1.

### 2.2 Meteorological an modelling support

A dedicated web page containing forecast and analyses of various atmospheric fields, including winds, temperatures, cloud coverage and potential vorticity, provided by the University of L'Aquila, supported the flight operations. The data were based on NCEP Aviation Model fields, and updates were performed twice a day, with forecasts up to 5 days and 3 hours time resolution. In addition to this, the UNIVAQ Global Trajectory Model [15] was operated to select air masses sampled by both satellite and airborne instruments, even if at different time or locations.

### 2.3 Synergy of simultaneous in-situ and remote-sensing measurements

The high degree of redundancy and complementarity of the data simultaneously obtained by the large suite of in-situ and remote-sensing instruments on board this high-altitude platform is of crucial importance when dealing with satellite validation measurements.
Beside of the clear advantages deriving from multiple internal comparisons, i.e. to identify systematic effects in the measurements and the possibility to derive the budgets of the trace gas families, a significant improvement in the quality of the data set can be achieved by combining the high accuracy and high spatial resolution of the in-situ measurements with the more extensive coverage and profiling capabilities of the limb sounders. This requires a fine tuning of the flight trajectories which is only feasible when operating this scientific payload onboard a manoeuvrable platform such as the M-55 Geophysica aircraft.

## 3. THE 2002/2003 ENVISAT VALIDATION CAMPAIGNS OF THE M-55 GEOPHYSICA

Between July 2002 and March 2003, three validation campaigns have been conducted with the chemistry payload of the Geophysica. Emphasis was put on validating MIPAS, although coincidences with GOMOS and SCIAMACHY observations were also considered. A complete list of satellite overpasses selected for the flights is given in the annex. The table includes flights made with the aerosol payload of the Geophysica, where only part of the chemistry payload was on board. Not listed are the EUPLEX flights (15.1 - 8.2.2003), conducted outside the framework of the ESABC.

### 3.1 Criteria for the flight planning

Apart from the readiness of the airborne instruments, the ground weather conditions and other constraints relevant for aircraft and payload operations, the definition of the M-55 flight plans has been basically driven by three kinds of information.

**Coincidences with the ENVISAT overpasses**

Usually, the best temporal and spatial overlap between the MIPAS observations and the measurements from the aircraft has been accomplished by selecting several MIPAS scans within the range of the Geophysica. The geolocation of the tangent points between 6 and 20 km was matched either with the air masses explored by the airborne limb-sounders or with those sampled by the in-situ chemistry payload. Whenever possible, the overlap with the areas covered by the SCIAMACHY limb observations was also optimised.

**Meteorological parameters**

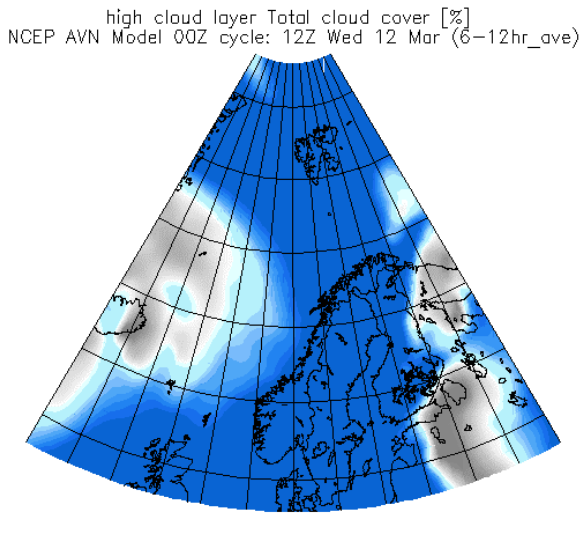


Fig. 1 - A map of the high altitude cloud coverage used for the M-55 planning of the March $12^{th}$ 2003 flight.

The choice for the best flight opportunities was primarily based on the high-altitude cloud coverage. To avoid contamination of the satellite and aircraft remote-sensing data by clouds, we searched for clear sky conditions, using cloud coverage forecast from NCEP (see Fig. 1) and from the German DWD.

Occasionally, the fine-tuning of the flight pattern was made using trajectory calculations based on NCEP forecasts of the direction and intensity of the winds. Backward and forward isentropic trajectories, starting from the expected MIPAS tangent points, were calculated and used as input for selecting those flight tracks allowing the same air masses to be sampled by both satellite and airborne instruments, even if at different time and locations (see Fig. 2).

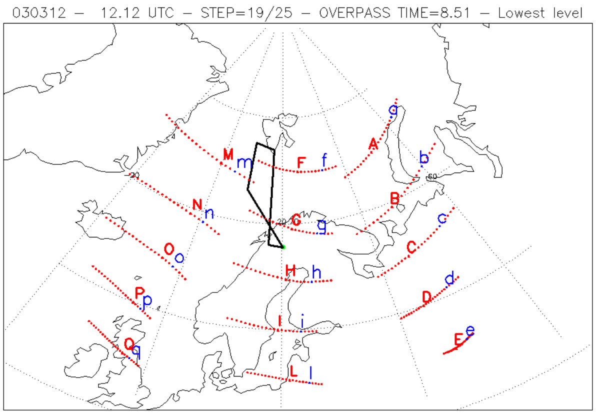


Fig. 2 - Location of the MIPAS tangent points at 15 km altitude of 3 orbits (upper case letters) and relative air mass trajectories (dots) and positions at selected time (12:12 UTC, lower case letters), together with the track of the March 12th 2003 Geophysica flight.

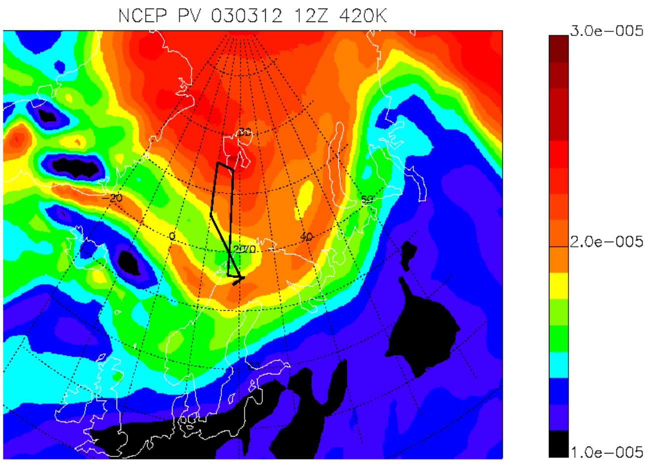


Fig. 3 - NCEP Potential Vorticity analysis on the 420K isentropic surface, together with the flight track for March 12th 2003. Scale : PV units ($m^2$ K $s^{-1}$ $kg^{-1}$).

**Gradients**

For the flights performed in presence of strong horizontal and vertical gradients, i.e. those planned from Kiruna in February - March 2003, care was taken in choosing a suitable observation strategy avoiding sampling across inhomogeneous air masses. Based on the forecasted potential vorticity maps, the flight were planned therefore, whenever possible, with direction parallel to the PV gradient (see Fig. 3).

### 3.2 The middle and high latitude deployments

**July 2002: Early validation of standard products**

The first campaign was performed from Forlì, Italy, (44°N, 20°E) in July 2002, just four months after the ENVISAT launch. The campaign was an extension of a test campaign and aimed at early validation of standard ENVISAT chemical products. Results of the validation flight of the chemistry payload on July 22nd have been presented at the December 2002 ENVISAT workshop in Frascati and published in its proceedings [16-17].

For this flight, initially planned together with the IBEX balloon flight from Sicily to Spain [18], ESA initiated the latitudinal tuning of the MIPAS scans. Although the longitude of the July 22nd scans (orbit 2051) was slightly east of the expected, the exact knowledge of the location of the tangent points appeared extremely useful for the planning of all subsequent balloon and aircraft missions of the ESABC programme.

**October 2002: Standard and special products**

A second mid-latitude validation campaign was carried out from Forlì in October 2002, with one test flight and three scientific flights of the M-55 chemistry payload, aiming at the validation of MIPAS, GOMOS and SCIAMACHY standard and special products. Because of the unavailability of MIPAS in the beginning, the three flights of the Geophysica chemistry payload were delayed to the last week of the campaign.

Fig. 4 shows, as an example, the flight tracks of the Geophysica and of the German Falcon on October 24th, 2002. The two aircraft operated simultaneously and probed air masses at the location of the lower tangent heights of two MIPAS scans of orbit 3404. The Falcon took off only 15 minutes after the Geophysica to allow intercomparison of the in-situ temperature and chemical sensors of both aircraft during ascent. At flight level on the southbound leg, the Geophysica flew above the Falcon for similar intercomparisons of the Falcon water Lidar with in-situ water measurements by FLASH and FISH at the Geophysica flight level.

A dive down to 12 km was performed by the M-55 aircraft at the southernmost point of the flight, with the in-situ payload sampling air masses in exact spatial coincidence with the MIPAS limb scan over Sicily.

After the dive, the Geophysica continued at a distance of 150 to 200 km from the location of a second MIPAS scan over Central Italy, thus allowing the limb sounders (viewing in flight direction to the right) to measure the same air masses. The Falcon flew an inner square to accumulate correlative data by the water lidar and the in-situ instruments on board.

First results obtained by airborne limb-sounding measurements during the October 24th 2002 have been presented at the Frascati workshop [19].

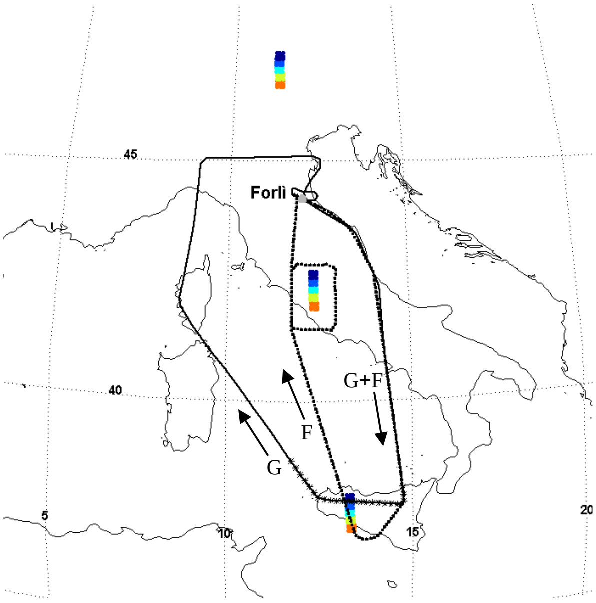


Fig. 4 - Flight tracks of the Geophysica (G) and the Falcon (F) on October 24th 2002 with the location of the MIPAS tangent points of orbit 3404 for 6 – 20 km tangent heights.

## February and March 2003: Validation in the Arctic

Correlative measurements of the ENVISAT standard products in the Arctic region and validation of the chemistry instruments in presence of strong horizontal gradients across the edge of the polar vortex have been the primary goals of the high latitude flights executed by the M-55 Geophysica aircraft in February - March 2003 from the operational base of Kiruna (68°N, 20°E). One test flight and four validation flights have been performed with the Geophysica chemistry payload during this Arctic campaign. All the information and tools needed for the preparation of the flight plan (i.e. the Excel sheets for the exact location of the MIPAS scans, along with the support from the modelling for meteo data and trajectory calculations) were available during the campaign.

As an example we describe here the high-latitude flight performed on March 12th, 2003. The flight path matched two daytime overpasses of ENVISAT and was again made together with a flight of the Falcon. The Geophysica flight (see Fig. 5) was optimised according to the requirements of the limb-sounding instruments, with several legs at constant high altitude and no dives. The flight was tuned to spatially match several MIPAS scans of orbits 5386 and 5387. To obtain the best temporal coincidence, one of the MIPAS scans of orbit 5386 (at 74.5°N; 17°E) was matched exactly (at 8:50 UTC) whereas five other scans were reached within one hour from the respective overpasses times. An excellent time and space matching was also obtained for the observations of the Geophysica limb sounders with limb measurements made by SCIAMACHY. Profile measurements made at ascent by the in-situ instruments, representative for the MIPAS scan at 69°N of orbit 5386, mismatched by 90 min and 150 km only.

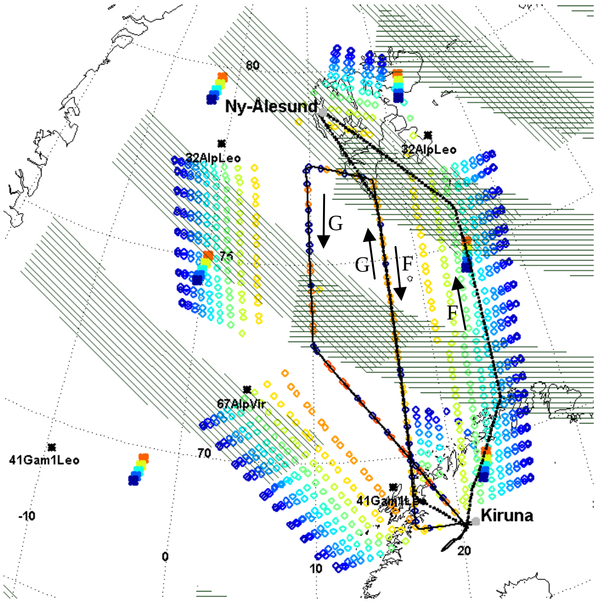


Fig. 5 - Flight tracks of the Geophysica (G) and the Falcon (F) on March 12th 2003 together with the location of the MIPAS tangent points (6 - 20 km) of orbits 5386 and 5387, the areas of SCIAMACHY profile measurements (shaded) and the lower tangent positions of the GOMOS star occultations. Tangent points of the MIPAS-STR have been added to illustrate the coverage of the Geophysica limb sounders.

The Falcon, equipped with the ozone Lidar OLEX, the multi axis AMAXDOAS and the microwave profiler ASUR, took off shortly after the Geophysica and flew on its northbound leg further east, at the position of the two MIPAS scans of orbit 5386, probing the same air masses as the Geophysica limb sounders. In the north it went to Ny-Ålesund, where an ozonesonde had been launched shortly before. After turning, the Falcon flew along the northbound leg of the Geophysica flight.

## 4. ACKNOWLEDGEMENTS

Financial support for this project by the European Space Agency (contracts 10249/01/NL/SF and 16039/02/NL/SF), the European Union (APE-INFRA: EVR1-CT-2001-40020), the German Federal Ministry of Education and Research (FKZ 01SF9953/8 and 50EE0203) and the Italian Space Agency (CNR/ASI I/R/27/00, I/R/073/01 and I/R/186/02) is gratefully acknowledged.
The authors wish to thank Stefano Balestri (ERS - Srl.) for excellent logistical support, Diana Galimberti for supporting the research groups during the Arctic campaign and Corneli Keim for providing the Annex. We appreciated the ESABC coordination by Patrick Wursteisen and helpful discussions with Herbert Nett, Berthyl Duesmann and Manuel Sanchez (all ESA) on the latitudinal tuning of the MIPAS. It was a pleasure to work with Andreas Fix and Heinz Finkenzeller (both DLR) of the Falcon team and with the many scientists (http://ape.iroe.fi.cnr.it/apeartic/index.htm) involved in AO-114. No correlative data would have been obtained without the excellent work of the test pilots Oleg Kononenko, Oleg Shchepetkov and Roman Taskaev and the always reliable MDB team lead by Leonid Sokolov and Boris Lepukhov.
This project is part of the activities of the Geophysica-EEIG, directed by Leopoldo Stefanutti.


## 5. REFERENCES


1. Piesch C. et al., Design of a MIPAS instrument for high-altitude aircraft, *Proceedings. of the 2nd Internat. Airborne Remote Sensing Conference and Exhibition*, ERIM, Ann Arbor, MI, Vol. II, 199-208, 1996.

2. Carli, B. et al., SAFIRE-A: Spectroscopy of the Atmosphere Using Far-Infrared Emission/Airborne, *Journal of Atmospheric and Oceanic Technology*, Vol. 16, 1313-1328, 1999.

3. Kostadinov, I. et al., UV-Vis spectroradiometric system for actinic measurements aboard of Geophysica aircraft, in M. Colacino and G. Giovanelli (Eds.), *8th Workshop Italian Research on Antarctic Atmosphere*, Bologna Editrice Compositori (SIF Conference Proceedings 69), Bologna, 293-303, 1999.

4. Yuskov, V. et al., A Chemiluminescent Analyzer for Stratospheric Measurements of the Ozone Concentration (FOZAN), *Journal of Atmospheric and Oceanic Technology*, Vol. 16, 1345-1350, 1999.

5. Zöger M. et al., Fast in situ stratospheric hygrometers: A new family of balloonborne and airborne Lyman-α photofragment fluorescence hygrometers, *J. Geophys. Res*., Vol. 104, 1807-1816, 1999.

6. Yuskov, V. et al., Measurements of the Ozone and Water Vapor Contents in the Stratospheric Antarctic Cyclone from the High-Altitude M55 Geophysica Aircraft, *Izv. Atmos. Ocean. Phys.*, Vol. 37, 275-280 2001.

7. Riediger O., Entwicklung und Einsatz eines flugzeuggetragenen Instrumentes zur in-situ-Messung langlebiger Spurengase in der Stratosphäre, *Dissertation, J.W. Goethe-Universität Frankfurt am Main*, 2000.

8. Schlager, H. , et al., Aircraft measurements of extensive denitrification in the 2002-2003 Arctic winter stratosphere, manuscript in preparation for J. Geophys. Res., 2003.

9. Stroh, F. et al.,. HALOX: An Instrument for the In-situ Measurement of ClO Dimer and Chlorine Nitrate, in preparation.

10. Mitev, V. et al., Miniature backscatter lidar for cloud and aerosol observation from high altitude aircraft, *Recent Res. Devel. Geophysics*, Vol 4, 207-223, 2002.

11. Fiocco, G. et al., ABLE: Development of an airborne Lidar, *Journal of Atmospheric and Oceanic Technology*, Vol. 16, 1337-1344, 1999.

12. Adriani, A. et al., Multiwavelength Aerosol Scatterometer for Airborne Experiments to Study the Optical Properties of the Stratospheric Aerosol, *Journal of Atmospheric and Oceanic Technology*, Vol. 16, 1329-1336, 1999.

13. Denning, R. F. et al., Instrument Description of the Airborne Microwave Temperature Profiler, *Journal of Geophysical Research, Vol. 94*, 16757-16765, 1989.

14. Shur, G. et al., TDC : Thermodynamical Complex for aircraft measurements, 2003, in preparation.

15. Redaelli G., Lagrangian techniques for the analysis of stratospheric measurements, PhD thesis, Univ. of L'Aquila, Italy, 1997.

16. Liu, G.Y. et al., Validation of MIPAS on ENVISAT by correlative measurements of MIPAS-STR, Proceedings of the ENVISAT Validation Workshop, Frascati, December 2002, ESA Volume SP-531, 2003.

17. Heland, J. et al., Validation of MIPAS on ENVISAT by in situ instruments on the M55-Geophysica, Proceedings of the ENVISAT Validation Workshop, Frascati, December 2002, ESA Volume SP-531, 2003.

18. Mencaraglia, F. et al., IBEX: Vertical profiles of minor atmospheric constituents measured from a balloon-borne FIR interferometer over the Mediterranean region, Proceedings of the ENVISAT Validation Workshop, Frascati, December 2002, ESA Volume SP-531, 2003.

19. Cortesi, U. et al., SAFIRE-A measurements during the ESABC campaigns, Proceedings of the ENVISAT Validation Workshop, Frascati, December 2002, ESA Volume SP-531, 2003.

## 6. APPENDIX: COINCIDENCES OF THE ENVISAT AND GEOPHYSICA MEASUREMENTS

| | M55 Geophysica flights | | | ENV. | MIPAS | GOMOS | | SCIAMACHY |
|---|---|---|---|---|---|---|---|---|
| Period | Date | Type | Time (UTC) | Orbit | UTC of the scans | Star | UTC | UTC |
| 13 – 22 July 2002 | 13.07.02 | T - C | 07:00 - 10:44 | 1922 | 09:02 | - | - | Switched off |
| | 15.07.02 | T - A | 17:49 -2 1:21 | 1958 | 20:55 20:57 20:58 | 24AlpPsA | 22:36 | |
| | 18.07.02 | V - A | 16:31 - 21:51 | 2001 | 21:00 21:02 21:03 21:04 | | | 20:49 |
| | | | | 2002 | | 24AlpPsA | 22:42 | |
| | 22.07.02 | V - C | 05:46 - 10:14 | 2050 | - | 34AlpAqqr | 07:33 | - |
| | | | | 2051 | 09:19 09:20 | - | - | 09:05 09:08 |
| | | | | 2052 | - | - | - | 10:44 10:46 |
| 8 – 28 October 2002 | 08.10.02 | T - C | 08:57 - 11:19 | 3167 | Switched off | 13AlpAri | 08:26 | - |
| | | | | 3168 | Switched off | - | - | 09:52 09:54 |
| | 11.10.02 | V - A | 07:50-11:35 | 3210 | | 43BetAnd | 08:32 | |
| | | | | 3211 | | | | 9:59 |
| | 14.10.02 | V - A | 08:14 - 12:36 | 3253 | | 43BetAnd | 08:38 | |
| | | | | 3254 | | | | 10:04 |
| | 17.10.02 | N - A | 08:17 - 12:54 | 3296 | 08:44 08:46 08:47 | | | 8:32 |
| | | | | 3297 | | | | 10:11 |
| | 22.20.02 | V - C | 06:47 - 11:22 | 3368 | 09:27 09:29 09:30 | Far away | | 09:13 09:16 |
| | 24.10.02 | V - C | 18:29 - 22:39 | 3404 | 21:21 21:23 21:24 | Far away | | Night |
| | 28.10.02 | V - C | 06:29 - 11:03 | 3454 | 09:39 09:40 | Far away | | 09:25 |
| 9-11 Feb 03 | 09.02.03 | V - A | 09:23 - 14:25 | 4942 | 06:43 | - | - | 08:08 08:09 |
| | | | | 4943 | | - | - | 09:47 09:48 09:49 |
| | 11.02.03 | V - A | 09:29 - 13:02 | 4971 | 07:21 | - | - | |
| | | | | 4972 | | - | - | 10:26 10:27 |
| 28 February – 16 March 2003 | 28.02.03 | T - C | 07:21 - 11:22 | 5213 | - | 32AlpLeo | 06:44 | - |
| | | | | 5214 | 08:24 08:26 | 32AlpLeo | 08:25 | - |
| | | | | 5215 | 10:05 10:07 | - | - | 09:50 09:51 |
| | | | | 5216 | - | - | - | 11:30 11:31 |
| | 02.03.03 | V - C | 18:41 - 23:05 | 5248 | - | | | 17:02 |
| | | | | 5249 | - | - | - | 18:42 18:43 |
| | | | | 5250 | 20:34 20:35 20:36 | - | - | 20:22 |
| | | | | 5251 | - | 2EpsCrv | 22:15 | - |
| | | | | 5252 | - | 41Gam1Leo | 23:57 | - |
| | 08.03.03 | V - C | 06:29 - 10:49 | 5328 | LOS Prime | 32AlpLeo | 07:33 | - |
| | | | | | | 41Gam1Leo | 07:35 | |
| | | | | 5329 | LOS Prime | 32AlpLeo | 09:13 | 08:58 9:01 |
| | | | | | | 41Gam1Leo | 09:15 | |
| | | | | 5330 | - | - | - | 10:38 10:41 |
| | | | | 5334 | - | 30AlpHya | 17:31 | - |
| | | | | 5335 | - | 30AlpHya | 19:11 | - |
| | 12.03.03 | V - C | 07:13 - 11:47 | 5384 | - | 67AlpVir | 05:21 | - |
| | | | | 5386 | 08:46 08:47 08:49 | 32AlpLeo | 08:47 | - |
| | | | | | | 41Gam1Leo | 08:50 | |
| | | | | 5387 | 10:27 10:28 10:30 | 32AlpLeo | 10:28 | 10:12 10:13 10:14 |
| | | | | | | 41Gam1Leo | 10:30 | |
| | | | | 5388 | - | - | - | 11:51 11:53 11:54 11:54 |
| | 16.03.03 | V - C | 05:57 - 10:14 | ENVISAT switched -off | | | | |

Type: T = test flight V = validation flight C = chemistry payload A = aerosol payload N = NERC flight (not part of ESABC)