

Measurements of cloud and aerosol parameters in the framework of ENVISAT validation, by means of the high-altitude aircraft M55-Geophysica: An overview.

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Abstract: Within the framework of the Envisat Stratospheric Aircraft and Balloon Campaign - required to verify the consistency of geophysical parameters measured by Envisat - three campaigns have been planned utilising the high altitude research aircraft *M55-Geophysica*. Two of them (midlatitudes) have already been successfully conducted, while a third one (arctic) will take place in Kiruna, Sweden during January/March 2003. The scientific payload on board the *M55-Geophysica* permits measurements of a wide range of atmospheric chemical constituents as well as characterisation of cloud and aerosol properties. The present paper gives an overview of the flights dedicated to the aerosol and cloud properties during the two midlatitude campaigns (July/October 2002, Forli, Italy), and serves as an introduction to an accompanied paper, that describes in more detail the flights plans and the acquired data of these flights.

1. INTRODUCTION

Following the successful launch of Envisat on 1st March 2002, a series of airborne campaigns dedicated to the validation of various instruments on board the Envisat satellite began to take place. The so-called Envisat Stratospheric Aircraft and Balloon Campaign (ESABC), is required to verify the consistency of a large number of geophysical parameters measured by Envisat with respect to insitu measurements of relevant parameters from the participating airborne platforms. The atmospheric parameters include temperature, pressure, chemical constituents,

cloud and aerosol parameters. Sufficient temporal/spatial coverage of these measurements is essential to optimise the outcome of the validation process.

The high-altitude research aircraft *M55-Geophysica* is one of the selected platforms to participate in ESABC. The aircraft can fly up to an altitude of 21 km, carry scientific payload of around 2000 kg and has a range of approximately 5 hours. It is equipped with a number of in-situ and remote sensing instruments that permit measurements of a large number of chemical constituents and also cloud/aerosol parameters. Three campaigns, by means of the M55-Geophysica were planned within the framework of ESABC: a) *Test and Validation campaign* (Forli, Italy, July, 2002), b) *Mid-latitude Validation campaign* (Forli, Italy, October, 2002) and c) *Arctic Validation Campaign* (Kiruna, Sweden, January/March, 2003). The scientific payload on board the M55-Geophysica permits measurements of chemical species (in situ and remote sensing) and aerosol and cloud parameters. Due to payload weight limitations and the different requirements for the measurements of clouds and aerosols, as opposed to chemical measurements (especially these from the remote sensing instruments), a dual approach in flight planning was adopted: a) flights dedicated to the measurements of chemical species, in particular those measurements from the remote sensing instruments such as MIPAS and SAFIRE, (called hereafter: 'chemical' flights) and b) flights dedicated to the measurements of aerosol and cloud parameters (called hereafter: 'cloud/aerosol' flights). We should note that since the instruments utilised to measure cloud and aerosol parameters are in principle in situ (or quasi in situ) instruments, during the 'cloud/aerosol' flights, the in situ chemical instruments were also kept on board to maximize the scientific outcome of the flights. In this paper, we present an overview of the 'cloud/aerosol' flights. In section 2, a brief description of the instruments is given, while in section 3 we describe briefly the two campaigns conducted so far (*Test and Validation* and *Mid-Latitude campaign*), discuss the flight planning philosophy and the operational status of the instruments. Finally, discussion on the validation of ENVISAT level-2 products and conclusions are presented in sections 4 and 5 respectively.

2. SCIENTIFIC PAYLOAD

The scientific payload on board the M55-Geophysica utilised for the characterisation of aerosol and cloud properties is listed below:

- i. Lidars probing upwards and/or downwards to measure the volume backscatter coefficient and depolarisation ratio of aerosols and clouds at 532 nm, 355 nm, and at Raman-shifted wavelengths (**ABLE, MAL**)
- ii. A backscatter instrument measuring in situ backscattering properties of aerosols and clouds at 532 nm and additionally at 850 nm during night-time measurements. Aerosol depolarisation is measured at 532 nm (**MAS**)
- iii. A **TDL** spectrometer linked to a CVI (Counterflow Virtual Impactor) probe, measuring the water and HNO₃ content in the cloud particles (CVI). Furthermore through an isokinetic inlet, atmospheric trace gases as N₂O and CO can also be measured.
- iv. Two dual channel condensation nuclei counters, which detect and count aerosol particles with sizes above 10 nanometers (**COPAS**), and an Optical Particle Detection System to size and count particles between 0.4 and 40 μm (**FSSP**).

The main objectives of the aerosol and cloud payload are:

- To measure the background aerosol in the upper troposphere and lower stratosphere under varying atmospheric conditions.
- To determine the geometrical properties of clouds (e.g. cloud top altitude)
- To make multi-wavelength measurements of aerosol scattering, as well as backscatter and aerosol depolarisation vertical profiles close to the aircraft to determine the microphysical and optical properties of aerosols and clouds along the M55-Geophysica flight path.

The aforementioned measurements will be used to check and validate relevant measurements (level-2 products) from the sensors on-board the ENVISAT satellite. The level-2 aerosol/cloud products that can be validated using the M55-Geophysica measurements are summarised in the following table:

Table 1. ENVISAT cloud and aerosol level-2 products (and corresponding instruments) that can be validated using the M55-Geophysica measurements.

PRODUCT	ENVISAT INSTRUMENT
Cloud top pressure (or height)	MERIS, SCIAMACHY, AATSR
Aerosol extinction coefficient	SCIAMACHY, GOMOS
Aerosol Optical Thickness	MERIS
Cloud Optical Thickness	MERIS

3. THE MEASUREMENT CAMPAIGNS

As mentioned earlier, three measurement campaigns, by means of the M55-Geophysica, were scheduled as part of the ESABC activities. The first two (mid-latitudes) were conducted from Italy (Forli airport), during the months of July and October (2002), while the third one (arctic) will be carried out from Kiruna, Sweden, during January/March 2003.

TEST AND VALIDATION CAMPAIGN

The *'Test and validation'* campaign took place between the 1st and 25th of July, 2002, from Forli airport in northern Italy. Four flights were scheduled: two 'cloud/aerosol' flights and two 'chemical' flights. This first measurement campaign served also as a test campaign, since new instruments participated in the aircraft payload for the first time, while some others had undergone significant upgrades. In that respect, two of the four planned flights were test flights. The new chemical instruments include: ALTO (the TDL to measure methane concentrations), SIOUX (measuring chlorine and bromine species) and SIOUX (reactive nitrogen). Furthermore, COPAS has been completely re-designed, after the malfunctioning during the APE-THESEO campaign in 1999. Similarly ABLE has new photo-counting detection chains, while new solutions for avoiding fogging/freezing of the windows has been introduced for MAL. Finally, FSSP-300 has completely new electronics.

Meteorological support and forecasted fields were used on a daily basis in order to choose the appropriate days and preferred paths for each flight according to the different needs and constraints (e.g. presence of high clouds, ground conditions etc.). Forecasted fields with a high time resolution (3 hours), were provided by the University of L'Aquila. Furthermore, calculated cloud top temperatures (used as first approximations to cloud top height) derived from METEOSAT data, were provided every half an hour from IFAC-CNR, Florence.

Given the period and location of the campaign (summer, Mediterranean) it was decided that detection and characterisation of dust aerosol loadings, resulted from Sahara dust outburst events (which exhibit high frequencies during summertime), will be of particular interest for the validation of an instrument like SCIAMACHY. For that reason, synoptic conditions that favour such type of events were closely followed using forecasts available during the period of the campaign. In addition, forecasted dust loads for the greater Mediterranean area were also utilised. These (web-based) forecasts were computed by the University of Athens (<http://www.uoa.gr>) and the Euro-Mediterranean Centre on Insular Coastal Dynamics (<http://www.icod.org.mt>).

Since the instruments that measure aerosol and cloud properties on board the M55-Geophysica are in-situ, or quasi in-situ (e.g. the high power laser ABLE), the planning of the actual flight track was determined by the prevailing meteorological conditions of interest (e.g. location of high clouds and/or Sahara dust aerosol loadings over the Mediterranean) and the overpasses of the ENVISAT instruments under consideration (in our case SCIAMACHY, and

MERIS). In that respect, the ultimate goal was to perform measurements of cloud and aerosol properties within the footprint of the aforementioned instruments at a time as close as possible to the satellite overpass.

The first of the two flights dedicated to aerosol measurements took place on the 15th of July. The main objective of this flight (test flight) was to determine the operational status of the new and upgraded instruments. Nevertheless, considerations related to suitable satellite overpasses and favourable meteorological conditions were also incorporated in the flight planning to optimise the outcome. In that respect, the test flight was treated as a scientific/validation flight and this particular date was chosen because of a pronounced (forecasted) Saharan dust outbreak event in the southern Mediterranean, which was also located within the footprint of SCIAMACHY and MERIS. With such an approach, any useful data acquired during the test flight can also be used for the purpose of ENVISAT validation. Given the fact that the signal sensitivity of the lidars on board the M55-Geophysica (especially for this type of measurements) is much higher under night-time conditions (due to lower background radiation), it was decided to perform the measurements during the night. Since Saharan dust aerosol outbreaks have a typical lifetime of around 2-3 days, the detection and characterisation of such aerosol loadings, which are relatively homogeneous, can be compared with SCIAMACHY daytime measurements, from the same geographical area (with a time difference less of 12 hours), as it was the case for the 15th of July. Furthermore, ground based measurements of dust aerosols from Lampedusa (south Mediterranean) and back trajectory analyses were also employed to characterise more accurately the event and the movement of air masses. In this flight, as well as in the second 'aerosol' (validation) flight, a dive down to 6 km (from the cruise altitude of 17 km) coincided with the overpass of the satellite, was planned in order to acquire profiles of chemical constituents and aerosol/cloud parameters taken from the in-situ instruments.

The operational status of the instruments on board the M55-Geophysica for this flight is summarised (together with the rest of the flights) in **Table 2**. Overall, the test flight can be characterised as successful since the vast majority of instruments worked well, acquired good quality data, while problems and malfunctions of few instruments were detected and addressed by the scientific teams. Furthermore, detection of an aerosol layer near Sicily was also detected in accordance with the forecasted fields. Additional verification of the Sahara dust event comes from the ground-based lidar measurements in Lampedusa.

The second 'aerosol' flight (validation flight) took place on the 18th of July, 2002. Forecasted fields showed a quite pronounced Saharan dust outbreak covering most of southern Mediterranean and the area around Sicily. Furthermore, medium/high clouds were forecasted over southern/central Italy. Given the aforementioned meteorological situation and a suitable SCIAMACHY overpass, a flight was planned towards the African coast (up to the island of Lampedusa) and then over Sicily, (where a dive coinciding with the satellite overpass took place), and finally back to Forli, following a route over the area of forecasted clouds. The flight was mostly a night flight, to permit high quality measurements of the aerosol layer from the lidars on board. The operational status of the instrument during this flight is shown in **Table 2**. The flight was successful; almost all instruments worked fine, while collected data indicate detection of the aerosol layer in the southern leg of the flight and detection of clouds during the last (return) part of the flight. For a detailed description of the 2 flights and the measurements obtained, the reader is referred to [1].

We should note that during the 'aerosol/cloud' flights in July, all in-situ chemical instruments were kept on board in order to maximize the amount of data collected. In that respect, valuable measurements both at cruise altitude, but also during the dives were collected, that can be used for ENVISAT validation and also to characterise better the atmospheric conditions during the period of the flights.

MID LATITUDE VALIDATION CAMPAIGN

During October 2002, the mid-latitude ENVISAT validation campaign, utilising the high altitude aircraft M55-Geophysica, took place as planned from Forli airport, in northern Italy. Between the 1st and 28th of October, 6 flights related to the ESABC activities were conducted. In addition, a 7th flight took place during that period (17th of October) coordinated by the University of Lancaster, UK. This particular flight, funded by the UK's National Environmental Research Council (NERC), was related to the investigation of aircraft pollution and particle formation in the vicinity of

Table 2. Operational status of all in-situ instruments on board the M55-Geophysica during the Test and Validation campaign (July 2002) and the Mid-latitude Validation campaign (October 2002). (*pa*: indicates that the instrument acquired data for only part of the flight)

Aerosol Instruments	July campaign	October campaign	Chemical Instruments	July campaign	October campaign
ABLE- lidar (University of Rome)	July 13, OK July 15, OK July 18, OK July 22, OK	October 8, OK October 11,OK October 14,OK October 17,OK October 22,OK October 24,OK October 27,OK	FISH Lyman- α to measure total water (CAO)	July 13, OK July 15, NO July 18, OK July 22, OK	October 8, OK October 11,OK October 14,OK October 17,OK October 22,OK October 24,OK October 27,OK
MAL up- microjoule lidar (Observatoire Neuchatel)	July 13, OK July 15, pa OK July 18, OK July 22, OK	October 8, OK October 11,OK October 14,OK October 17,OK October 22,OK October 24,OK October 27,OK	FLASH Lyman- α to measure gasphase water (FZJ)	July 13, OK July 15, OK pa July 18, OK pa July 22, OK pa	October 8, OK October 14,OK October 14,OK October 17,OK October 22,OK October 24,OK October 27,OK
MAL down-microjoule lidar (Observatoire Neuchatel)	July 13, pa OK July 15, pa OK July 18, OK July 22, OK	October 8, OK October 11,OK October 14,OK October 17,OK October 22,OK October 24,OK October 27,OK	FOZAN chemiluminescence ozone sensor (CAO/ISAC-CNR)	July 13, no July 15, OK July 18, OK July 22, OK	October 8, NO October 11,OK October 14,OK October 17,OK October 22,OK October 24,OK October 27,OK
MAS-laser backscattersonde (ISAC-CNR)	July 13, OK July 15, OK July 18, OK July 22, OK	October 8, OK October 11,OK October 14,OK October 17,OK October 22,OK October 24,OK October 27,OK	ECC ozone sonde	Not installed	October 8, NO October 11,OK October 14,OK October 17,OK October 22,OK October 24,OK October 27,OK
FSSP-300 foreword scattering probe (University of Mainz)	July 13, partially July 15, partially July 18, partially July 22, OK	October 8, OK October 11,OK October 14,OK October 17,NO October 22,OK October 24,OK October 27,OK	GASCOD-A UV-Vis spectrometer (ISAC-CNR)	July 13, OK July 15, NO July 18, OK July 22, OK	October 8, OK October 11,OK October 14,OK October 17,OK October 22,OK October 24, nig October 27,OK
COPAS condensation nuclei counter (University of Mainz)	July 13, OK July 15, OK July 18, OK July 22, OK	October 8, OK October 11,OK October 14,OK October 17,OK October 22,NO October 24,OK October 27,OK	CH ₄ TDL (INOA)	July 15, test July 18, test July 22, test	October 8, OK October 11, NO October 14,OK October 17,OK October 22,OK October 24,OK October 27,OK
			N ₂ O TDL (INOA)	July 15, test July 18, test July 22, test	October 8, NO October 11, OK October 17,OK October 22,not October 24,not October 27,not
			SIoux NO/NO _y instrument (DLR)	July 13, OK July 15, OK July 18, OK July 22, OK	October 8, OK October 11,OK October 14,OK October 17,OK October 24,NO October 27,NO
			HALOX ClO/BrO instrument	July 13, 15,18,22 partially	October 8, OK October 11, OK October 14,OK October 17,OK October 27,OK
			HAGAR gas chromatograph to measure CFC-11, CFC12, SF ₆ , N ₂ O (University of Frankfurt)	July 13, OK July 15, OK July 18, OK July 22, OK	October 8, par October 11,OK October 14,OK October 17,OK

					October 24, OK October 27, OK

air corridors. Between the 14th and the 25th of October, the DLR Falcon-20 was also based in the airport of Forli, conducting a number of flights, also related to the ENVISAT validation. During that period, 3 coordinated flights were performed utilising both aircrafts, in order to optimise the outcome of the present campaign. The main objective of these flights was the validation of MIPAS; therefore, the flights were conducted in a way to permit maximum spatial/temporal coverage of close-by MIPAS overpasses. Similar approach was followed also for the last M55-Geophysica flight (28th), but in this case the DLR Falcon-20 flew over from its base in Oberpfaffenhofen (southern Germany), and followed a path similar to the one taken by M55 over the Italian/French airspace.

As during the ‘*Test and Validation*’ campaign, meteorological support and forecasted fields were extensively used on a daily basis in order to choose the appropriate days and preferred paths for each flight according to the different needs and constraints (e.g. presence of high clouds, ground conditions etc.). Forecasted fields were provided by the University of L’Aquila, and from the Royal Dutch Met Office (KNMI). Furthermore, as previously, calculated cloud top temperatures (used as first approximations to cloud top height) derived from METEOSAT data, were provided every half an hour from IFAC-CNR, Florence.

The objectives of the ‘*Mid-latitude validation*’ campaign regarding the ‘aerosol/cloud’ flights (2 flights) were quite different from the ones during the ‘*Test and validation*’ campaign. The meteorological conditions during the period of October over southern Europe do not favour the frequent occurrence of dust-aerosol outbreaks over the Mediterranean from the Saharan desert. On the other hand the prevailing synoptic situation favours cloud formation associated with pronounced frontal activity. Therefore, it was decided to focus on the detection and characterisation of cloud parameters of relevance to ENVISAT validation (e.g. existence of clouds, cloud top and base, optical depth). In that respect, SCIAMACHY and MERIS (and to a lesser extent AATSR) were the main ENVISAT instruments under consideration.

The 1st flight took place on the 8th of October. This was a test flight (in addition to the originally planned 6 flights), in order to check the readiness of the instruments and small adjustments since the July campaign. A simple flight path was followed west of Italy. Although it was a test flight, the flight path and take off time was chosen taking into account the satellite overpass (in particular the SCIAMACHY and MERIS footprint). Thus, good quality measurements obtained during this test flight can also be used for the purpose of ENVISAT validation. The flight was successful, since the status of almost all instruments found to be satisfactory according to the quick looks and checks performed by the scientists immediately after the termination of the flight. The operational status of the instruments during that flight is shown in **Table 2**.

The two flights that followed the test flight, were dedicated to the measurements of cloud parameters. The first of these two flights took place on the 11th of October. The M55-Geophysica flew from Forli, towards Florence and Elba and then in the air space between Corsica and France. The primary objective of this particular flight was the detection and characterisation of high clouds forecasted in the area north of Corsica/southern France in association with the footprint of SCIAMACHY and MERIS (see also [1]). The cruise altitude was 17.5 km, while a dive down to 9 km was performed, in coincidence with the ENVISAT overpass, to acquire vertical profiles of chemical species, and in-situ measurements of cloud parameters. Take off time was 8:30 UTC while the duration of the flight was 3 hours and 5 minutes. Preliminary results show that high clouds were indeed detected during most of the flight and also during the dive. The operational status of the instruments during the flight is also summarised in **Table 2**.

The second ‘aerosol/cloud’ flight took place on the 14th of October. The M55-Geophysica flew from Forli, towards Ferrara and then entered the Austrian and German airspace. Again the primary objective of the flight was the detection and characterisation of clouds associated with a broad frontal system forecasted over Austria/southern Germany in association with SCIAMACHY and MERIS footprints. A dive was performed over southern Germany, in coincidence with the satellite overpass, in order to acquire vertical profiles of chemical constituents. Take off time was 8:41 UTC and the duration of the flight was approximately 4 hours. The operational status of the instruments is summarised in **Table 2**.

4. VALIDATION OF LEVEL-2 AEROSOL/CLOUD PRODUCTS

Measurements of cloud and aerosol parameters collected during these two campaigns are being analysed and cross-checked. Results from the July campaign (see [1]) and also preliminary results from the October campaign indicate that a high degree of consistency exists between the various instruments. The collected data can be used to validate the

existence of clouds in a satellite pixel (cloud 'flags') and also the geometrical properties of clouds (e.g. cloud top). Furthermore, validation of parameters such as extinction coefficient/optical thickness of clouds and aerosol layers can also be performed; however, special attention is required for the validation of such parameters, due to the relatively high uncertainties embedded in the calculation of such parameters.

More precisely, the extinction coefficient at the laser wavelength may be obtained by applying to the lidar signature Klett derived routines [2] which permit to obtain and average extinction to backscatter coefficient, thus to determine the extinction coefficient of the cloud. Such data, being in the same wavelength region of SCIAMACHY (at 532 nm) will permit to validate not only cloud top pressure, but also the extinction coefficient. The depolarisation measurements of the lidars (ABLE, MAL, and MAS) permit the characterisation of clouds (e.g. if they are formed by ice particles or by water). This is a further indication to establish the error that one may commit by assuming Mie scattering theory in the retrieval of the lidar signatures. To pass from the extinction coefficient at one given wavelength to another, (e.g. in the case for instance of the daytime measurement of ABLE at 1064 nm), it is necessary to make assumptions, which might lead to results with significant errors. First of all, if the signatures are available and not too noisy at all 3 wavelengths, in the hypothesis of a mono-modal size distribution, it is possible, by using Mie scattering to obtain a particle size distribution and thus obtain the required extinction at the requested wavelength. Collected data from the FSSP-300 are therefore of great importance to get an independent estimation of the size distribution.

If the particles are aspherical and the lidar signal have a large depolarised component, T-Matrix procedures can be used; but the uncertainty becomes very large. We therefore intend in the future to limit the determination of the extinction only to those cases which will result relatively simple and where we can assume that the committed error will not be large.

5. CONCLUSIONS

Within the framework of ESABC activities, two campaigns utilizing the high-altitude research aircraft M55-Geophysica have been performed from Forli, Italy, while a third one is planned in January/March 2003 (Sweden). A total of 11 flights were performed during which a significant amount of data has been collected and will be utilized for the validation of various ENVISAT level-2 atmospheric parameters. The organization and flight strategy followed during these two campaigns permitted the optimum exploitation of flight hours, leading to the maximum collection of cloud/aerosol parameters and chemical constituents. Regarding the measurements of aerosol and cloud parameters, the overall performance of the instruments was satisfactory. Extensive cross-checking of the collected data during the first campaign (and also preliminary results from the second) revealed a high degree of consistency between the instruments on board the M55-Geophysica. Comparison between the M55-Geophysica results and ENVISAT level-2 cloud/aerosol products is expected to start within the following months, as relevant satellite data will become available.

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