Results from the first deployment of the MARSCHALS mm-wave UTLS limb-sounder in SCOUT-O3

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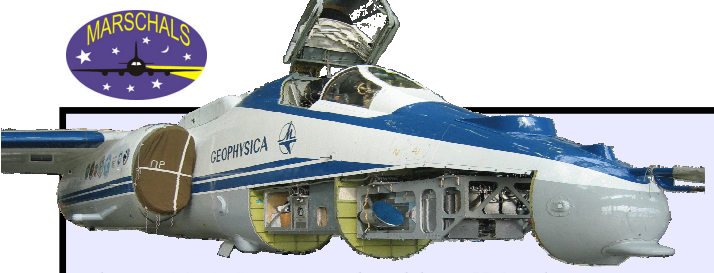


The MARSCHALS instrument aboard the M-55 Geophysica

Abstract

MARSCHALS is a multi-band, millimetre-wave spectrometer designed to remotely measure the distribution of different species in the lower stratosphere and the upper troposphere (UTLS). MARSCHALS is deployed from an airborne platform, from where it performs vertical scans of the atmospheric limb. The millimetre-wave region is well suited for observations in the UTLS because it offers a good vertical resolution and is much less sensitive to clouds than observations at shorter wavelengths, a very strong argument especially in the troposphere.

The development of MARSCHALS is funded by ESA with the intention to (a) simulate the future satellite implementation MASTER which is meant to operate at the same wavelengths and (b) increase our understanding of chemical and dynamical processes within the UTLS by contributing to different scientific missions. The target molecules for the three currently implemented frequency bands are O_3 in band B, H_2O in band C and CO in band D, but there are also emission lines from O_2, N_2O and other minor species in the frequency ranges covered by MARSCHALS.

We will report on the first scientific deployment of MARSCHALS on occasion of the tropical SCOUT-O3 campaign which took place in Nov/Dec 2005 in Darwin, Australia. The SCOUT-O3 campaign had the Russian M-55 Geophysica aircraft, prime carrier of the MARSCHALS instrument and capable of flying at stratospheric altitudes, operating in coordination with other, lower flying airborne platforms, satellites and balloon sondes with the aim of investigating tropical convection, stratosphere-troposphere exchange (STE) and the chemical composition of the tropical tropopause layer (TTL). MARSCHALS had two deployments in SCOUT-O3 on 25th Nov and on 5th Dec 2005. The flight of 5th Dec was specifically to suit three remote sensing instruments MIPAS, CRISTA and MARSCHALS aboard the Geophysica. We will present a first look at the results obtained from this "remote sensing flight".

Operation of MARSCHALS during SCOUT

MARSCHALS has a single "back-end" spectrometer which is switched between 3 bands:

- Band B: 294-305 GHz; primary target ozone (O_3), and oxygen (O_2) for instrument pointing
- Band C: 316.5-325.5 GHz; primary target water vapour (H_2O)
- Band D: 342.8-348.8 GHz; primary target carbon monoxide

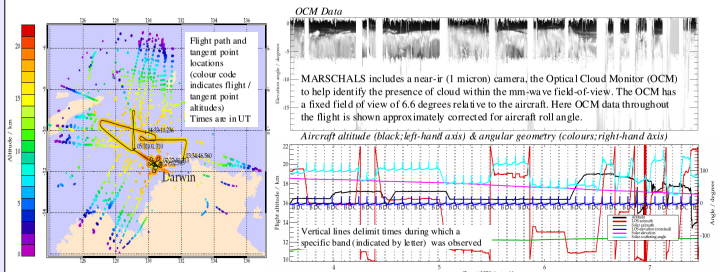
Prior to the SCOUT campaign it had been identified that the instrument gain varied rapidly in the first few seconds after a band-switch and therefore a scan sequence was defined for scout with minimal band-switching: Complete scan sequences for low-high elevation were performed for each band individually. 8 Measurements are made of each of calibration views and the atmosphere at each tangent height. This number of observations was chosen in order to (a) give an noise-equivalent spectral radiance of ~1K on the mean atmospheric spectrum at each tangent height (b) allow a number of diagnostic tests to be performed to assess the instruments radiometric performance.

During SCOUT, test measurements on the ground indicated the band D receiver was not operating properly and so the scan sequence for flight was focused on bands B and C.

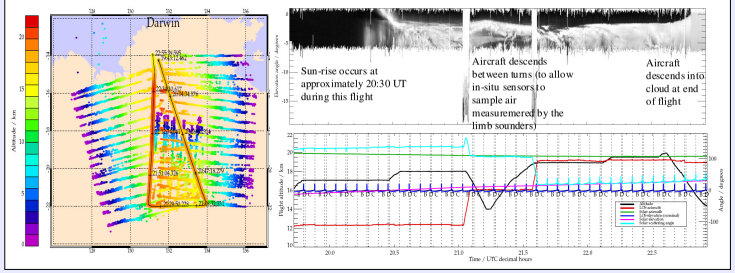
MARSCHALS is equipped with its own gyro to provide precise information on the pointing of the line-of-sight. While the gyro accurately tracks rapid changes in aircraft roll, it is prone to slowly varying bias which must be corrected using the Geophysica's own attitude data. The corrected roll angle is then normally used to control the antenna. During the 25 November flight this active pointing control system was operated, however serious sporadic errors were detected and for the 5 December flight active pointing control was disabled: The antenna was pointed at a set of nominal elevation angles without taking account of aircraft roll, however the gyro data was stored for future analysis.

Since SCOUT the errors in the active pointing control have been diagnosed to be due to incorrect interpretation of the aircraft attitude information and accurate, corrected pointing data has been generated to enable spectra from both flights to be analysed.

25 November 2005: *Flight unsuited to limb sounding due to complicated manoeuvres around cloud.*



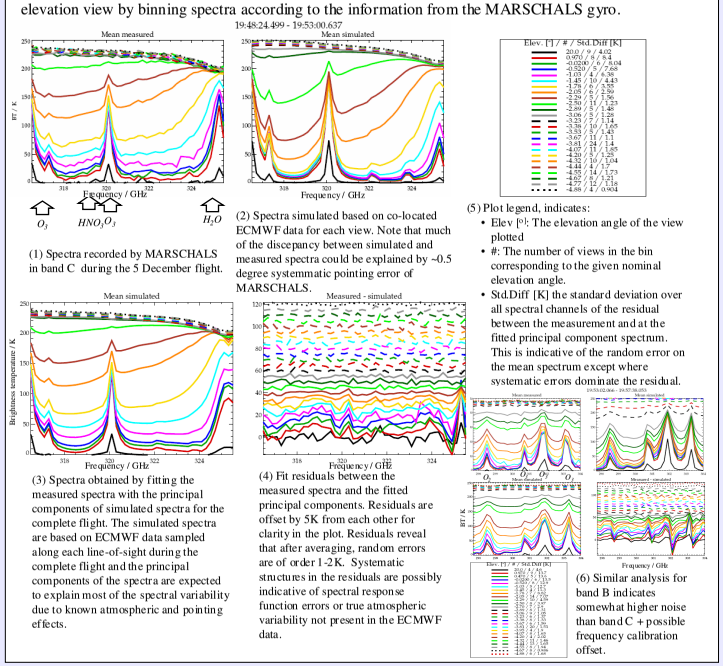
5 December 2005: *Flight-plan optimised for the remote-sensing instruments*



Analysis of measurements for 5 December Flight (1)

Spectra from the 5 December remote sensing flight are currently being analysed to assess the radiometric performance of MARSCHALS (retrievals of atmospheric constituents will then follow in due course). This assessment includes comparison of measured spectra with spectra simulated using the in-house RAL radiative transfer code "FM2D" based on the atmospheric state given by ECMWF analyses for the time and location of each MARSCHALS line-of-sight (LOS).

Since active pointing control was not enabled the LOS of each view are offset from the nominal commanded elevation by the aircraft roll. Here mean spectra are obtained corresponding to each nominal elevation view by binning spectra according to the information from the MARSCHALS gyro.



(1) Spectra recorded by MARSCHALS in band C during the 5 December flight.

(2) Spectra simulated based on co-located ECMWF data for each view. Note that much of the discepancy between simulated and measured spectra could be explained by ~0.5 degree systemmatic pointing error of MARSCHALS.

(3) Spectra obtained by fitting the measured spectra with the principal components of simulated spectra for the complete flight. The simulated spectra are based on ECMWF data sampled along each line-of-sight during the complete flight and the principal components of the spectra are expected to explain most of the spectral variability due to known atmospheric and pointing effects.

(4) Fit residuals between the measured spectra and the fitted principal components. Residuals are offset by 5K from each other for clarity in the plot. Residuals reveal that after averaging, random errors are of order 1-2K. Systematic structures in the residuals are possibly indicative of spectral response function errors or true atmospheric variability not present in the ECMWF data.

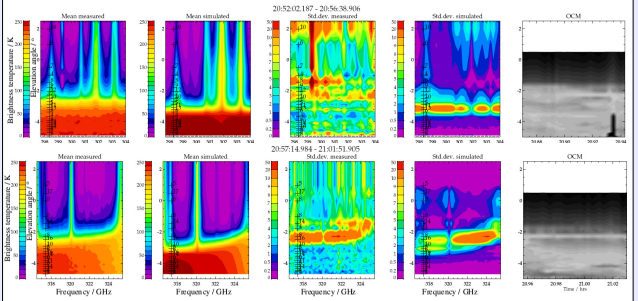
(5) Plot legend, indicates:

- Elev [°]: The elevation angle of the view plotted
- #: The number of views in the bin corresponding to the given nominal elevation angle.
- Std.Diff [K] the standard deviation over all spectral channels of the residual between the measurement and at the fitted principal component spectrum. This is indicative of the random error on the mean spectrum except where systematic errors dominate the residual.

(6) Similar analysis for band B indicates somewhat higher noise than band C + possible frequency calibration offset.

Analysis of measurements for 5 December Flight (2)

Comparison of observed and simulated mean radiance profiles and variances and OCM data.



Upper and lower panel show results from a single limb scan sequence in band B and band C, respectively. Panels from left to right are as follows:

- Mean measured radiance as colour contour as function of frequency and elecation angle. Number indicated towards the left of the panel indicates the number of views in the given elevation angle bin.
- Mean simulated radiance for same set of views
- Standard deviation in the mean of the measurements, over all views considered at each elevation
- Standard deviation in the mean of the simulated spectra.
- Mean OCM observation (uncalibrated black & white image) acquired during the time of the limb scan shown (note that lower elevation angles are acquired at earlier times during this period).

Note that:

- The standard deviation in the simulated views indicates the variation to be expected due to pointing variations within the bin and is therefore large where the radiance gradient is largest
- Assuming the simulations to be correct, there appears to be a systematic pointing offset of order 0.5 degrees (It is expected that absolute pointing bias, as opposed to "jitter", can be recovered during the retrieval of trace-gas amounts in due course).
- MARSCHALS records spectral structure in views which are affected by cloud, providing (preliminarily) confirmation of the relative insensitivity of mm-wave observations to cloud. This will be the subject of further study. In particular the relative performance of MARSCHALS and the ir-limb sounders (MIPAS and CRISTA) under the pervasive cloud conditions affecting this flight will be assessed.
- The maximum radiance observed at low elevation angles is lower than the corresponding simulated radiance, indicating relatively high opacity in the true atmosphere compared to the ECMWF based simulation - possibly due to cloud or a low bias in the ECMWF H_2O field.
- The minimum level of the observed standard deviation field indicates a noise level on individual observations of 2-4K which is consistent with the random error on averaged spectra determined by fitting principal components of simulated spectra, described opposite.

Conclusions

In its flight on the Geophysika from Darwin on 6th Dec'05 during SCOUT, MARSCHALS performed limb-sounding from stratospheric flight altitudes for the first time. Spectra in the 300 and 325 GHz bands observed simultaneously with near-IR images demonstrate that upper tropospheric limb-paths remain semi-transparent in the mm-wave in the presence of cirrus, which will allow water vapour and ozone to be profiled in these as well as cloud-free conditions. In the same flight, limb-sounding measurements were made concurrently by two IR spectrometers onboard the Geophysika: MIPAS-STR and CRISTA-NF. MARSCHALS data from the 5th Dec'05 flight will be intercompared and synergy between the mm-wave and IR spectrometers and the near-IR limb-imager will be explored in data analysis. In future flights, MARSCHALS will deploy a third receiver (345 GHz) to observe limb-emission from carbon monoxide and nitric acid in addition.

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