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Investigation of the Arctic upper troposphere and lower stratosphere by mm-wave and infrared limb sounding during the *PremierEx* campaign

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OUTLINE

- The PREMIER mission
- The PACD project
- Overview of the study: objectives and tasks
- Analysis of MARSCHALS mm-wave limb sounding measurements
- Investigation of potential synergy between mm-wave (MARSCHALS) and infrared (MIPAS-STR) limb sounding
- Conclusions

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The PREMIER mission

PRocess **E**xploration through **M**easurements of **I**nfrared and milimetre-wave **E**mitted **R**adiation

PREMIER is one of three **Earth Explorer 7 Core Mission** candidates currently under evaluation within **ESA's Living Planet Programme**

The **primary scientific objective** of PREMIER is to gain a better understanding of the interaction processes linking atmospheric chemistry and dynamics with climate.

Investigation of distribution and transport of trace gases and of the radiative effects of water and clouds in the UTLS (5-25 km).

In order to meet the observation requirements of the PREMIER mission, a **payload of space sensors** is identified based on the combination of an **infrared limb-imaging spectrometer** and a **millimetre-wave heterodyne limb-sounder.**

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PACD project

PREMIER **A**nalysis of **C**ampaign **D**ata

A **series of field campaigns** for the deployment of **airborne precursors** (the limb-sounders MARSCHALS mm-wave heterodyne spectrometer and MIPAS-STR FTIR spectrometer) of PREMIER scientific payload onboard the high altitude research aircraft M-55 Geophysica was carried out:

TC9 campaign:	Oberpfaffenhofen, Germany, November 2009
PremierEx campaign:	Kiruna, Sweden, March 2010
ESSenCe campaign:	Kiruna, Sweden, December 2011

The analysis of data acquired by the mm-wave limb-sounder during these campaigns and the study of potential synergies with the infrared measurements are commissioned by ESA to the **PACD Project** (**PREMIER Analysis of Campaign Data**) coordinated by IFAC-CNR.

PACD Project team

IFAC-CNR	Firenze, Italy	U.Cortesi, S. Del Bianco
ISAC-CNR	Bologna, Italy	B.M. Dinelli, E. Castelli
KIT, IMK-ASF	Karlsruhe, Germany	H. Oelhaf, W. Woiwode
RAL-STFC	Chilton-Didcot, UK	D. Gerber

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Objectives of the study

We report the results of the study conducted on the data acquired during the **PremierEx flight on March 10th, 2010** in the Arctic region aiming at:

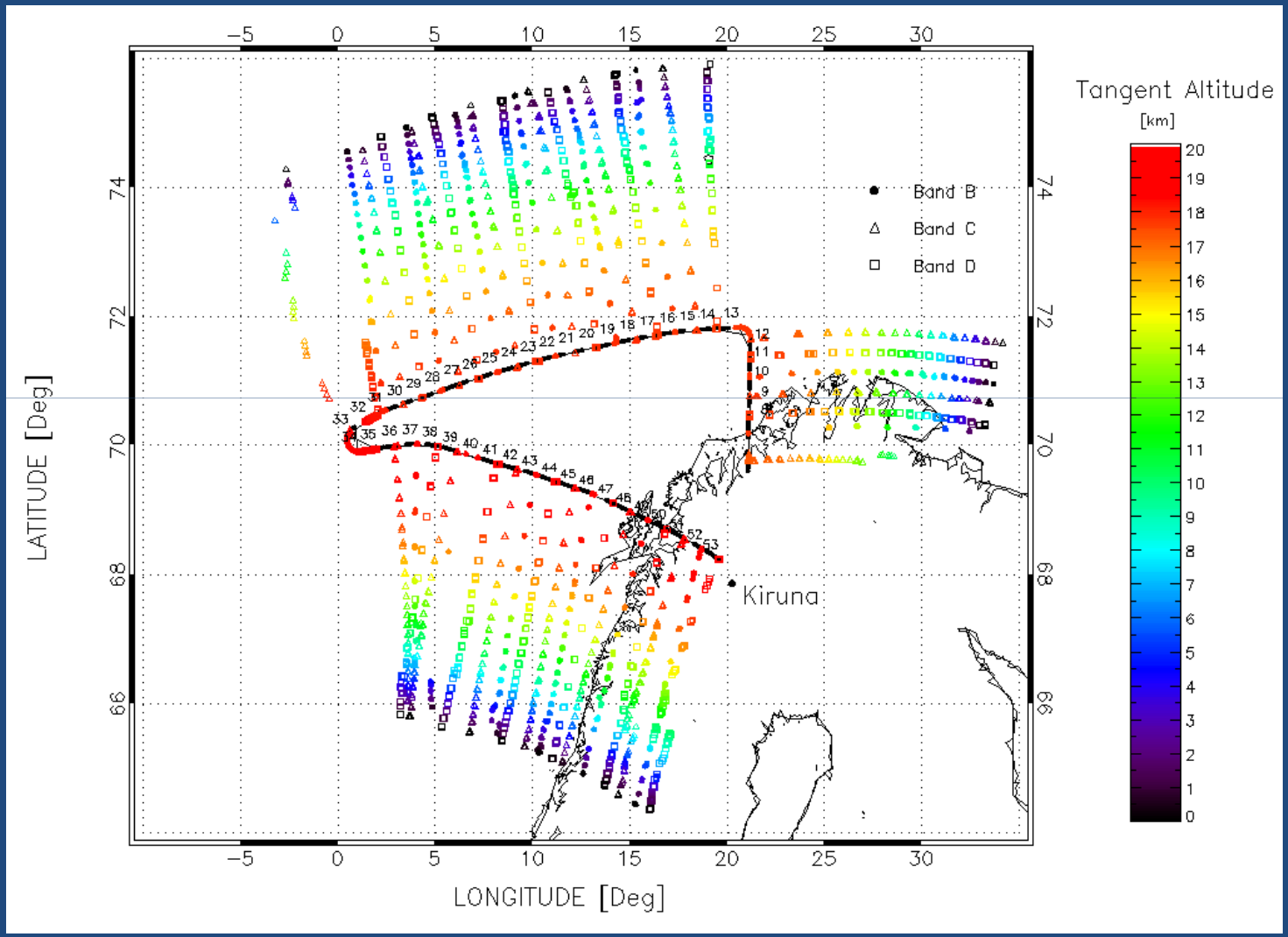
- the analysis of the limb sounding measurements obtained by the MARSCHALS spectrometer in clear and cloudy sky conditions.

- the investigation of the synergy between mm-wave and infrared limb sounding measurements of atmospheric targets.

PREMIEREX scientific flight

Kiruna, Sweden - 10.03.2010
(Lat. 67-8°N, Lon. 20.4°E)

Geolocation of MARSCHALS limb-sounding measurements



Tangent points of limb measurements on different MARSCHALS bands are shown in the map

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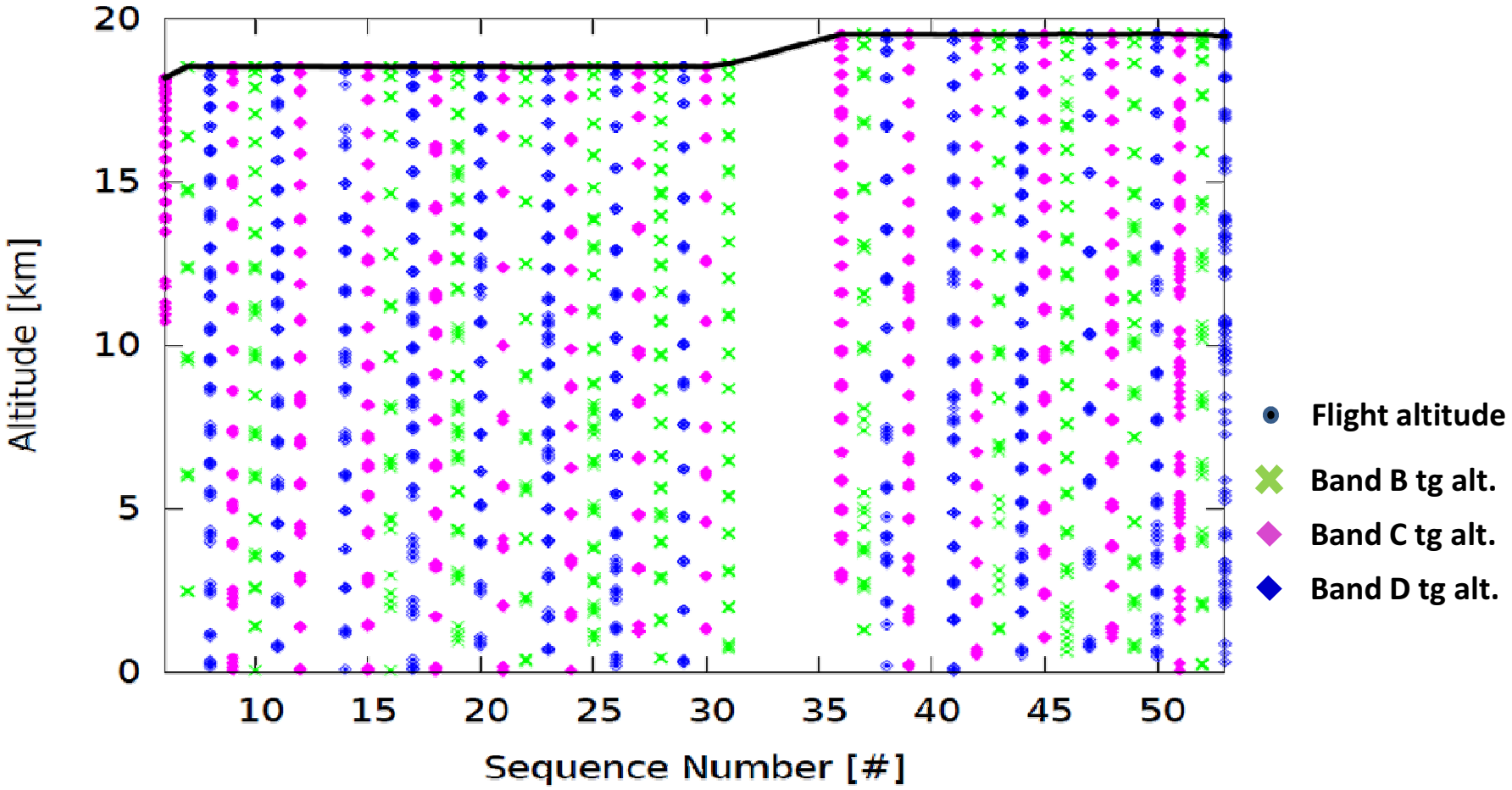
MARSCHALS tangent altitudes



Flight altitude and vertical distribution of MARSCHALS tangent points during the PremierEx scientific flight on 10.03.2010

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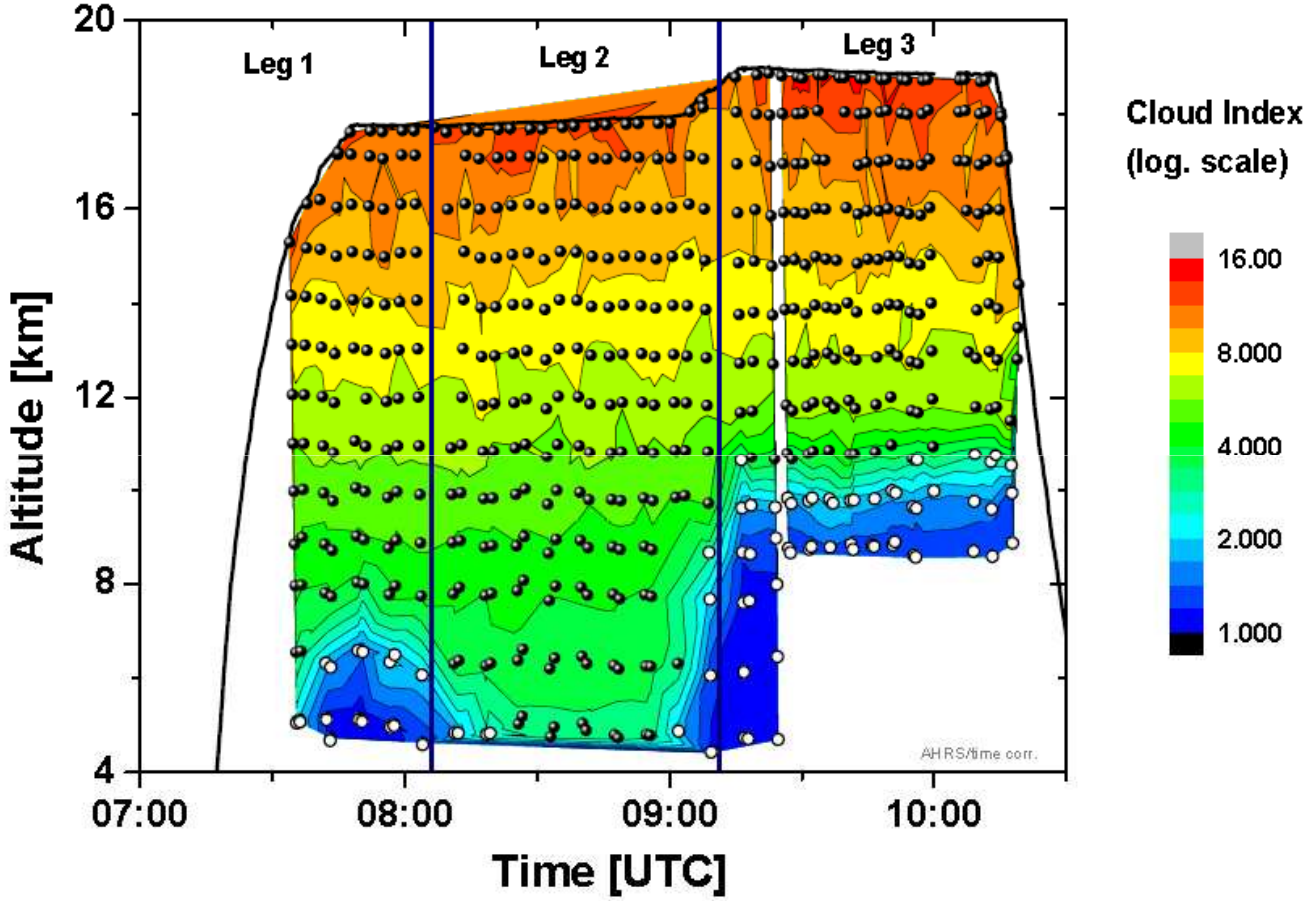
Cloud coverage

Vertical distribution of MIPAS-STR tangent points and Cloud Index values



MIPAS-STR Cloud Index values indicate:

- Presence of clouds with a CTH of about 6 km at the beginning of the flight (Leg 1)
- Presence of clouds with a CTH of about 11 km at the end of the flight (Leg 3)

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MARSCHALS measurement and retrieval strategy

Spectral coverage and spectral resolutiion - MARSCHALS measures the atmospheric emission in three bands with a spectral resolution of 200 MHz:

Band B [296.76–305.36] GHz; **Band C** [317.78–325.38] GHz; **Band D** [341.90–348.10] GHz

Measurement strategy

For each spectral band a full atmospheric scan is performed, as follows:

scan 1, 4, 7, … band B; scan 2, 5, 8, … band C; scan 3, 6, 9 … band D.

Retrieval code and retrieval startegy

The MARSCHALS Atmospheric Retrieval Code (MARC), developed by IFAC and ISAC during a previous ESA project, is used for processing MARSCHALS L1 data. Its main features are:

- Use of the full spectral bands
- Multi-target retrieval
- Optimal Estimation + Marquardt and/or regularization
- Possibility to use the VCM of the Forward Model during the iterative procedure

Band C – Retrieval of scan N : Vertical profiles of T, H_2O, O_3, HNO_3 and external continuum

Band B – Retrieval of scan N+1: Vertical profiles of H_2O, O_3, HNO_3, N_2O, external continuum (T and a priori H_2O profiles from scan N of band C)

Band D – Retrieval of scan N+2: Vertical profiles of H_2O, O_3, HNO_3, CO, external continuum (T and a priori H_2O profiles from scan N of band C)

Scalar values: freq. shift, pointing bias, spectral offset and gain.

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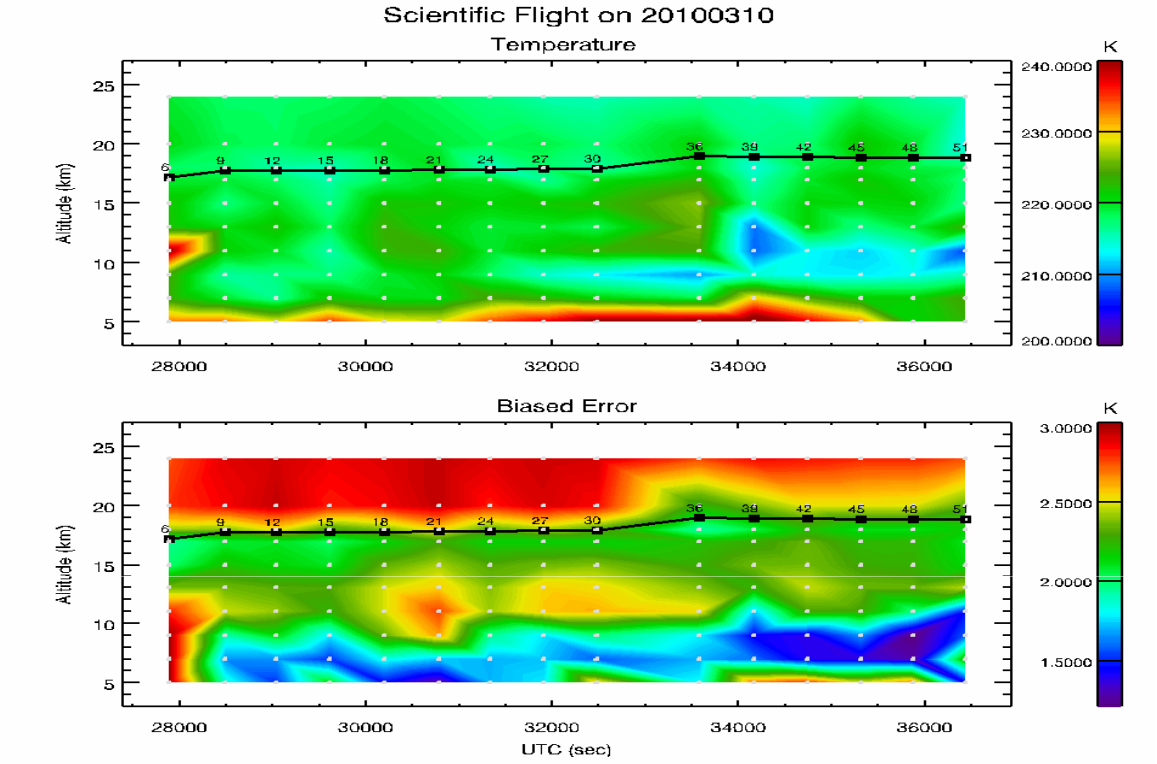
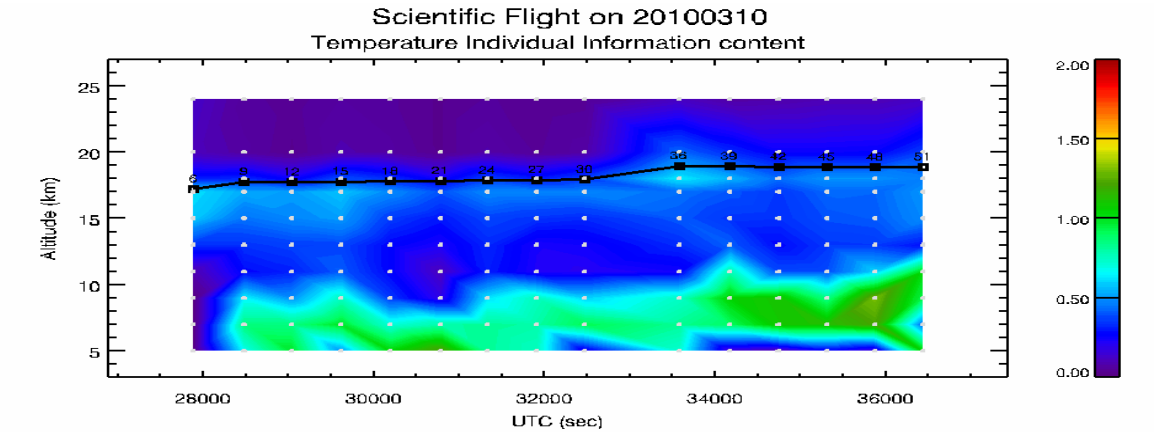
Temperature





Temperature is retrieved from measurements in **Band C only**.

Little information is present in band B and D, where retrieval products are dominated by the a priori profile.

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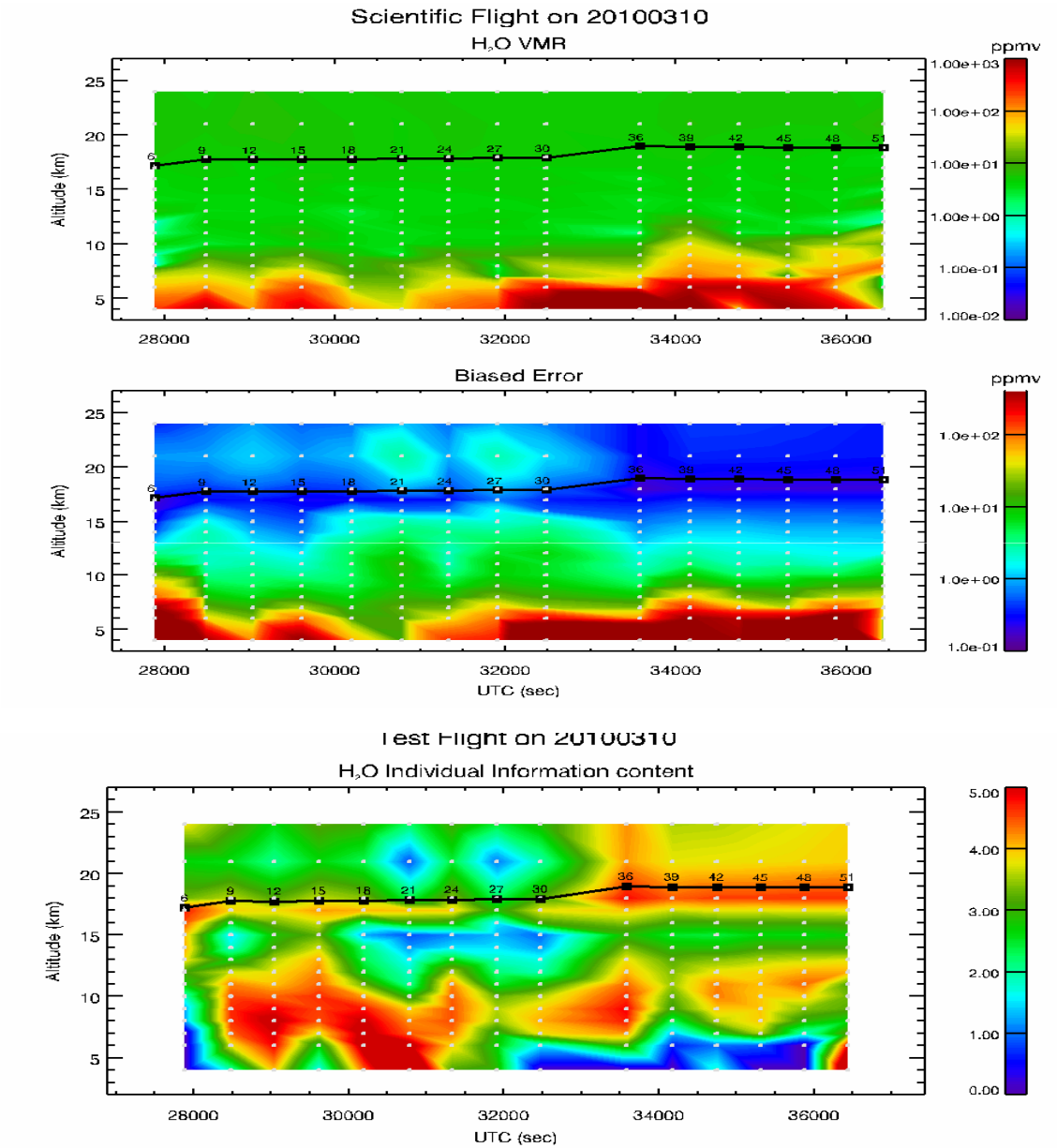
Water Vapor



Temperature is retrieved from measurements in **band C**, where the max. information is available.

Very low information in band B and D (only at very low altitudes through the wing of the water vapor line of band C).

Information on Water Vapor could be extracted from band B and band D data, by using band C retrieved profile as a priori.

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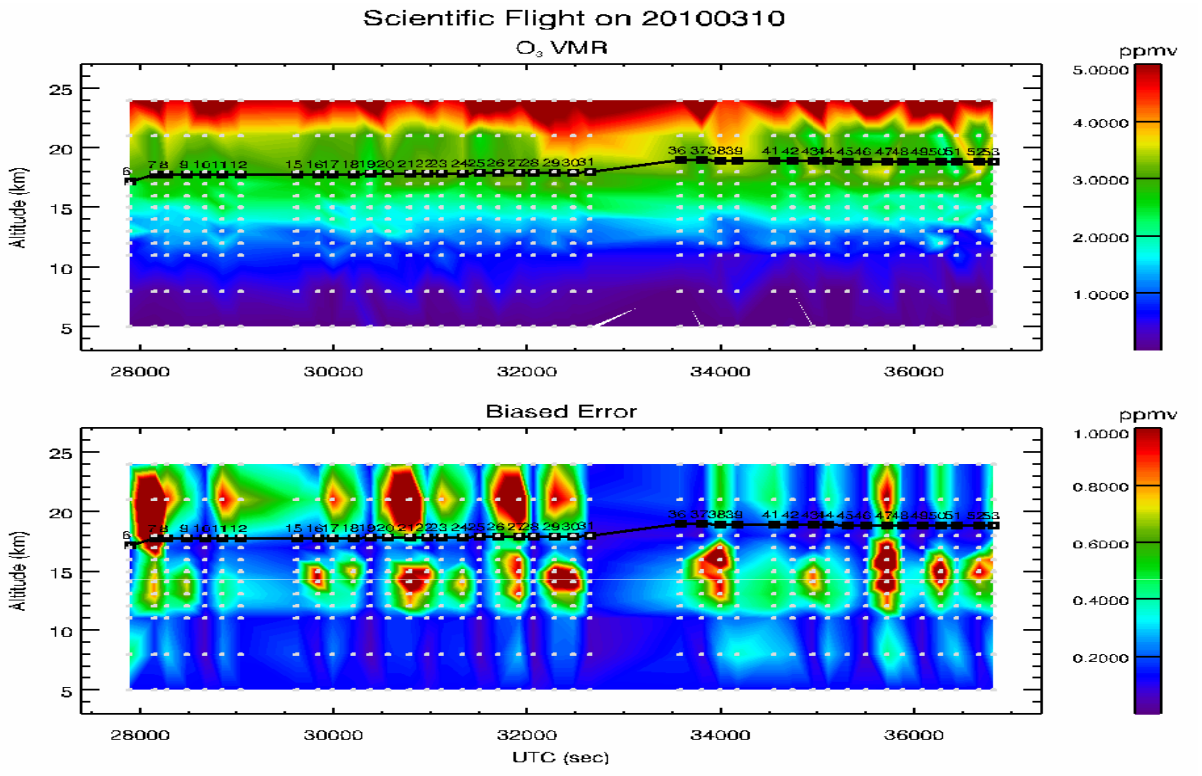
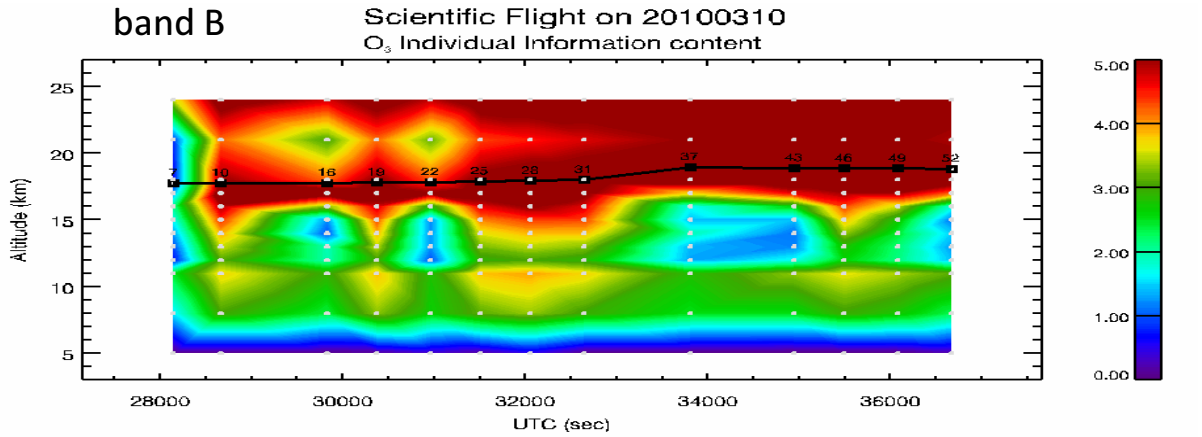
Ozone



band B



Ozone can be retrieved from all the three bands.

Max information in **band B**.
Min information in **band D**.

Recursive retrievals starting from a band B scan produce the most homogeneous results.

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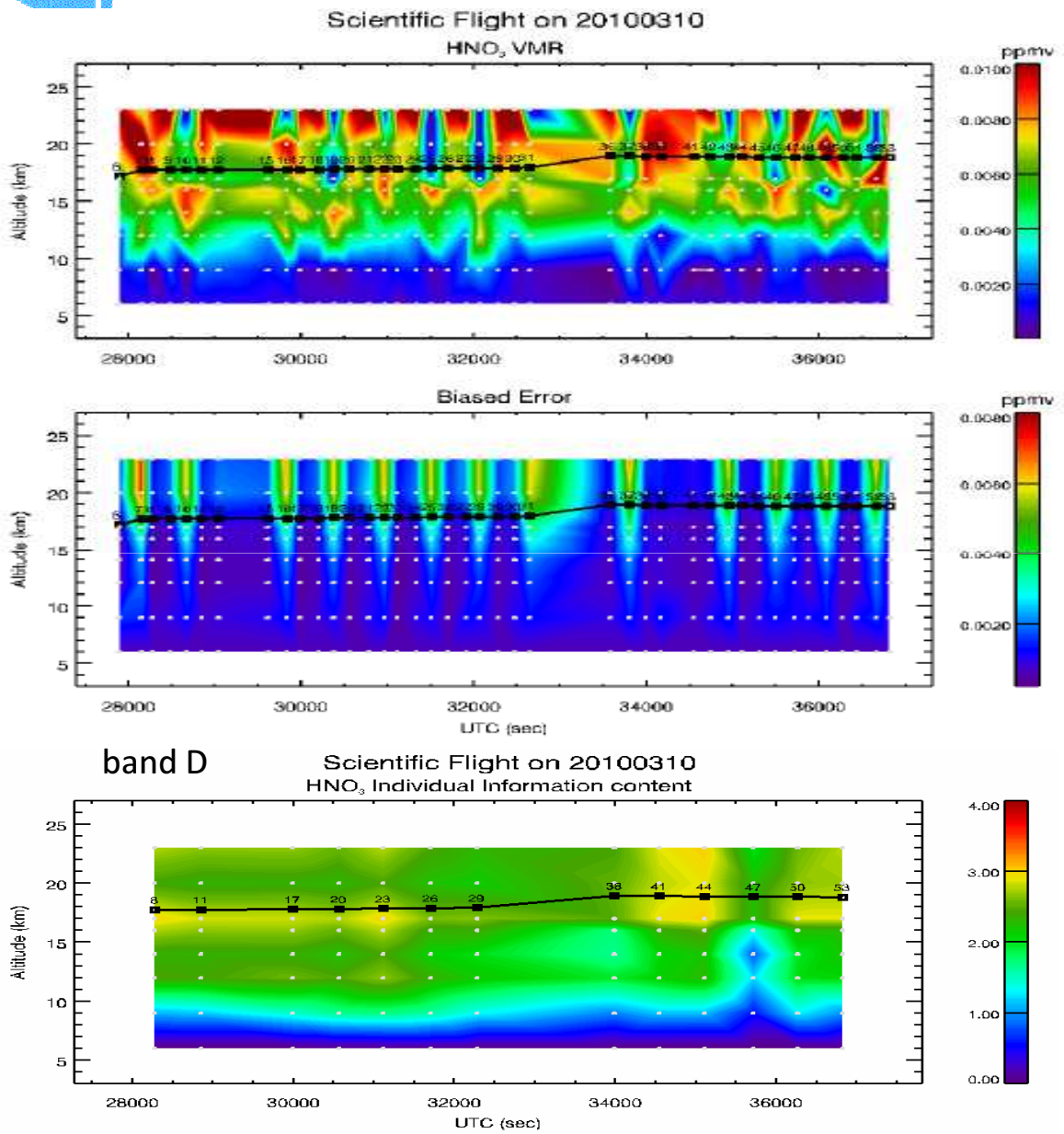
Nitric Acid



HNO_3 can be retrieved from **band C** and **band D** only.

Max information in **band D**.
Min information in **band B**.

Recursive retrieval starting from a band D scan can be used to extract the low information contained in the scans of band B.

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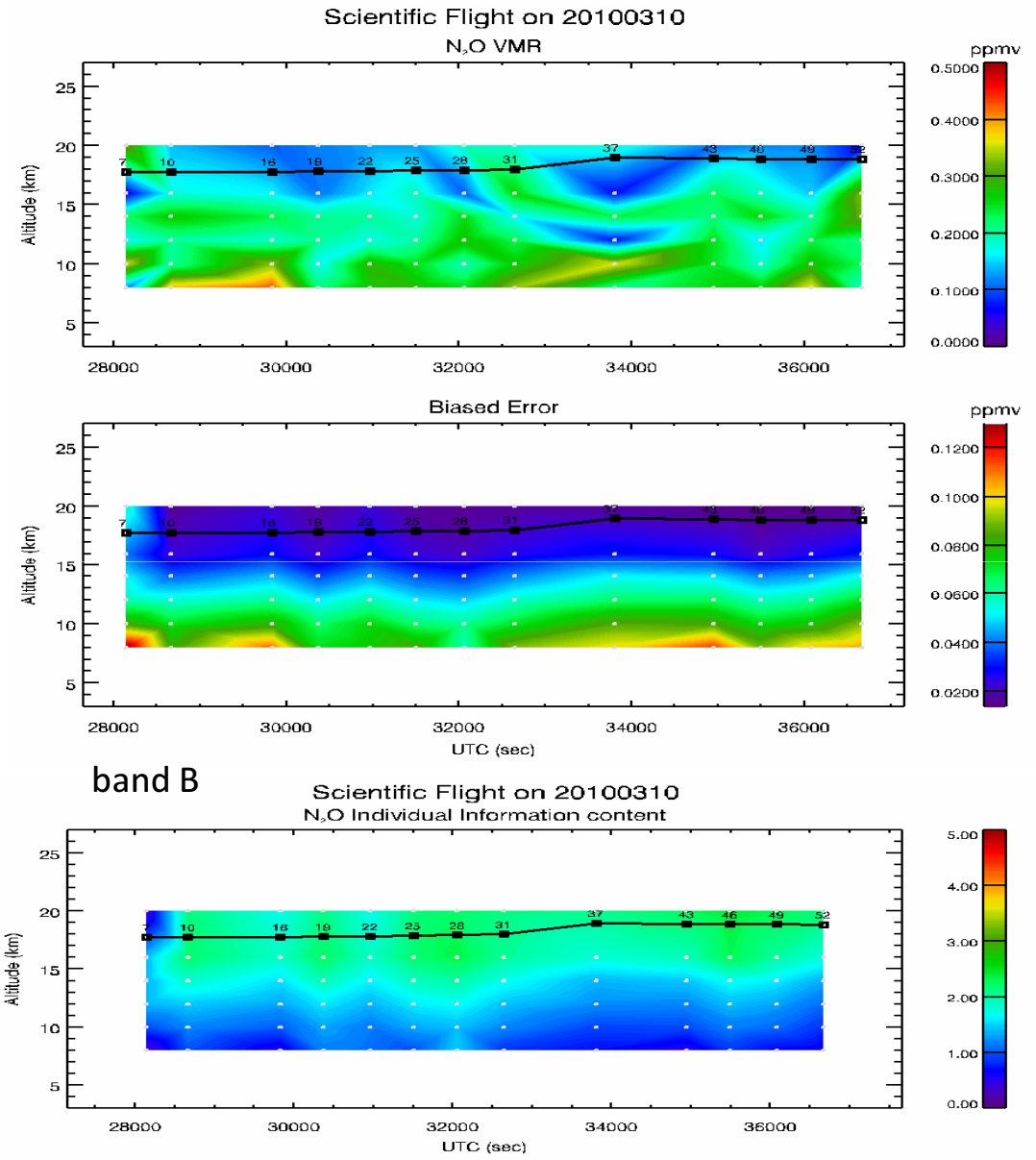
Nitrogen Dioxide



N_2O can be retrieved from **band B** only.

Despite the strong oscillations shown in the retrieved profiles, the results are consistent with N_2O in situ measurements by HAGAR onboard the M-55 Geophysica aircraft.

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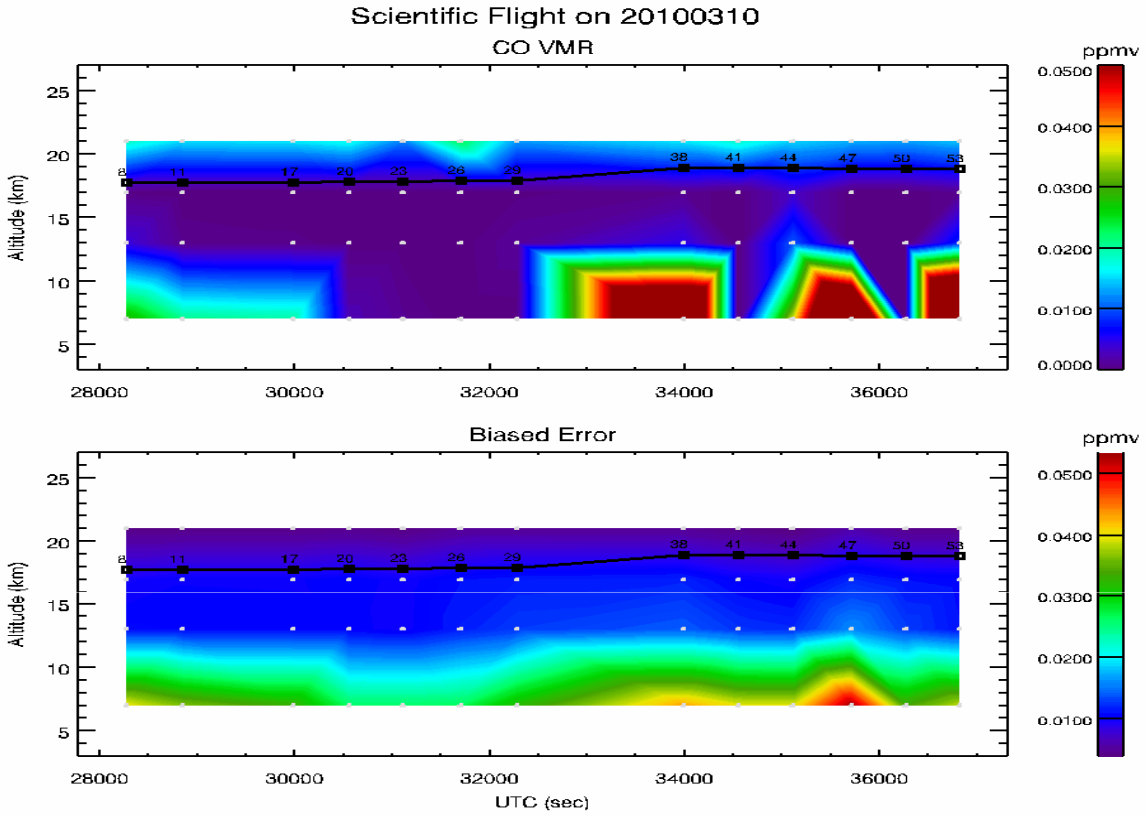
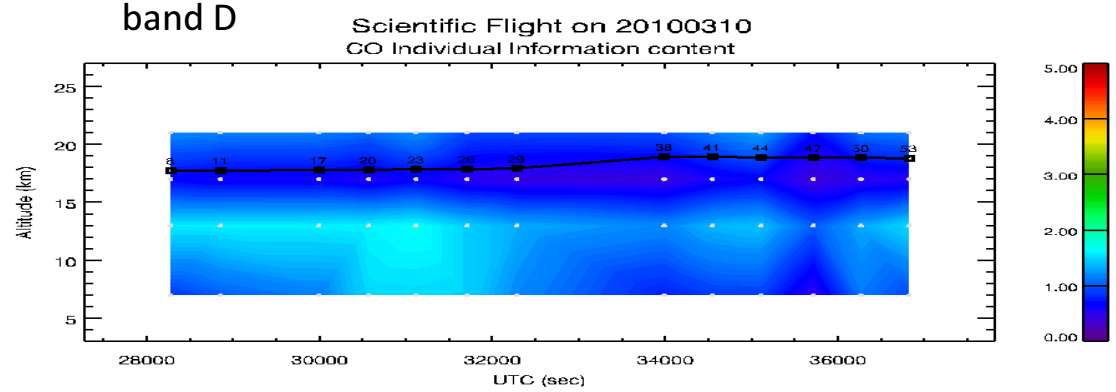
Carbon Monoxide



band D



CO can be retrieved from **band D** only.

Very small information during the PremierEx flight.

The information content was higher during the TC9 flight and we could retrieve the CO profile on 5 altitude levels.

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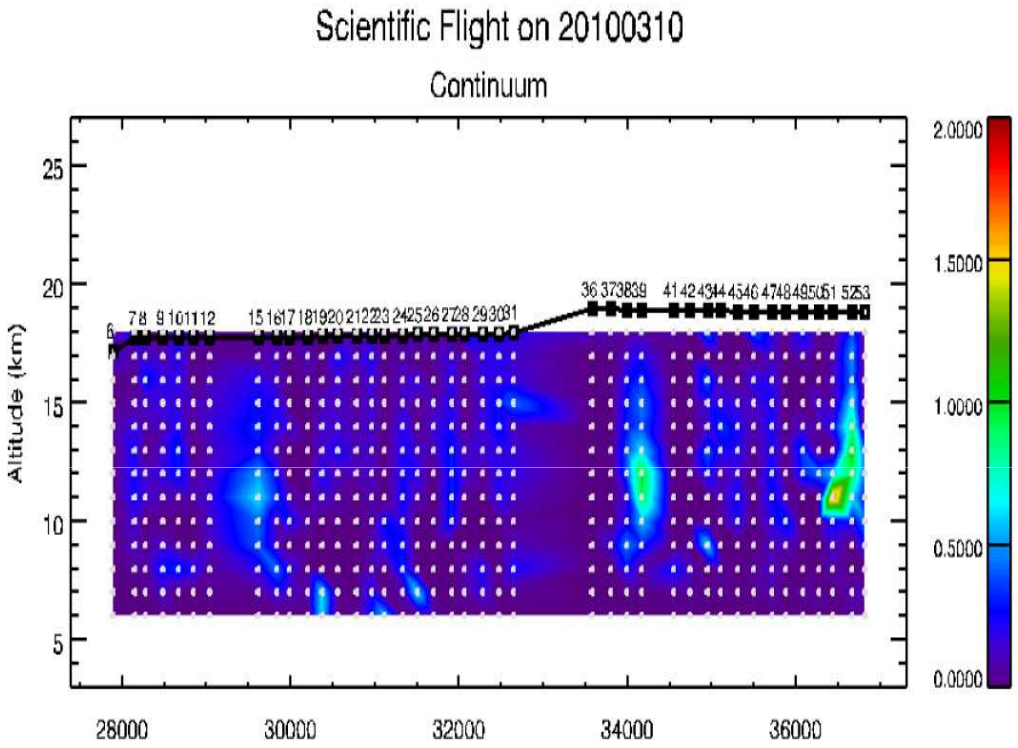
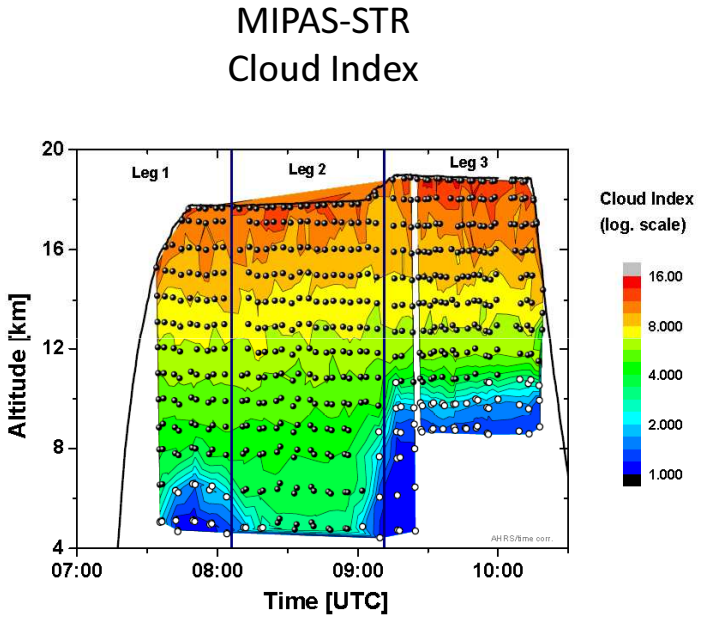
External Continuum





The retrieved external continuum shows that the cloud coverage seen during the flight did not produce opacity a part from few scans. However, even for those scans, clouds do not seem to produce opacity that cannot be reproduced by just a continuum level.

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Conclusions of the analysis

TEMPERATURE – the retrieval works properly only for the scans of band C. Temperature profiles retrieved from band B are, on average, too low at high altitude and unstable at low altitudes; band D retrieval is dominated by the a priori profile).

WATER VAPOUR – good performances are obtained only for the scans of band C.
Little information on water vapour from band B and D, that can be extracted by using band C retrieved values as a priori profile.

OZONE – O_3 can be retrieved from all the three bands, but band B shows the highest information content; recursive retrievals starting from a band B scan produce the most homogeneous results.

NITRIC ACID - HNO_3 can be retrieved from band C and D only. Recursive retrieval strategy starting from a band D scan can be used to extract the low information contained in the scans of band B.

NITROGEN DIOXIDE – N_2O can be retrieved from band B measurements only and the retrieved profiles show oscillations that may or may not be real.

CARBON MONOXIDE – CO can be retrieved from band D measurements only. The information content during the Scientific Flight was very small, probably because its concentration was very low. For the Test Flight the information content was higher and we could retrieve it on a 5 altitude levels.

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Investigation of potential synergy between mm-wave and infrared limb-sounding

DATA FUSION METHODS

Alternative approaches have been used to investigate the synergy between MIPAS-STR and MARSCHALS measurements: the **(L1+L2) method** and the **MSS (Measurement Space Solution) method** for data fusion.

INDIVIDUAL AND SYNERGISTIC RETRIEVALS

For each method, we performed individual and synergistic retrievals of the selected atmospheric target (i.e. O_3, HNO_3 and H_2O for the (L1+L2) method and O_3 for the MSS method),in order to obtain MIPAS-STR, MARSCHALS and data fusion products.

PERFORMANCE QUANTIFIERS

We evaluated the performances of individual and synergistic retrievals based on a suitable set of quantifiers (**Gain of Information, Degrees Of Freedom** and **Total Retrieval Error**) and cross-comparison of resulting values provided an estimate of improvements due to data fusion.

BENEFIT OF DATA FUSION

The adopted strategy mainly focused on demonstrating the benefit of the synergy between mm-wave and IR measurements with respect to individual retrievals. The comparison of the capabilities of infrared and millimeter-wave measurements is out of the scope of this study.

COMPARISON OF DATA FUSION METHODS

As a result of the study, a comparative evaluation of the effectiveness of the alternative approaches to data fusion (i.e. (L1+L2) method and MSS method) has been performed.

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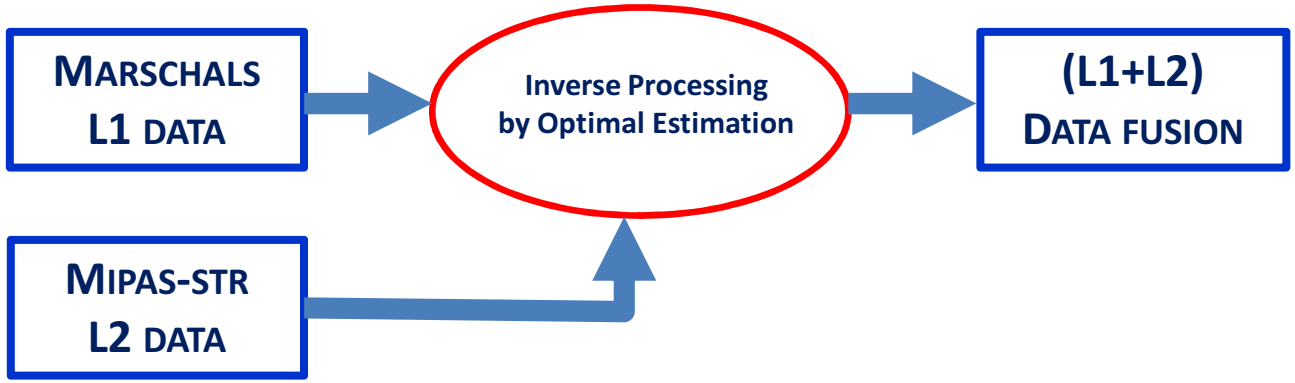
Data fusion by using the (L1+L2) method

The **(L1+L2) method**, consisted in the retrieval processing of MARSCHALS L1 data using Optimal Estimation, with MIPAS-STR L2 products as a priori information.



INDIVIDUAL RETRIEVALS

MIPAS-STR Tikhonov-Phillips 1st order Regularization

MARSCHALS Optimal Estimation making use of a climatological information.

SYNERGISTIC RETRIEVAL

(L1+L2) METHOD Inverse processing of MARSCHALS L1 data by Optimal Estimation using MIPAS-STR L2 data as a priori information.

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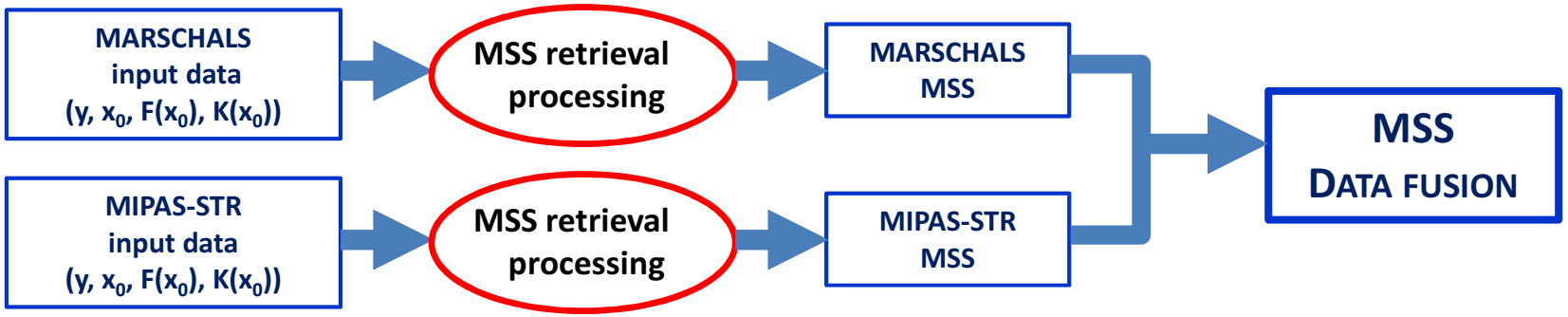
Data fusion by using the MSS method

The **MSS method**, consisted in post-retrieval processing of MIPAS-STR and MARSCHALS L2 data using the *Measurement Space Solution* algorithm.

(see http:/ga.ifac.cnr.it/ for detailed description and references on the MSS algorithm)



INDIVIDUAL RETRIEVALS

MIPAS-STR Optimal Estimation making use of a climatological information.

MARSCHALS Optimal Estimation making use of a climatological information.

SYNERGISTIC RETRIEVAL

MSS METHOD MSS component of the fused profile obtained from MSS components of the individual products and combined with the a priori information from the common climatological profile.

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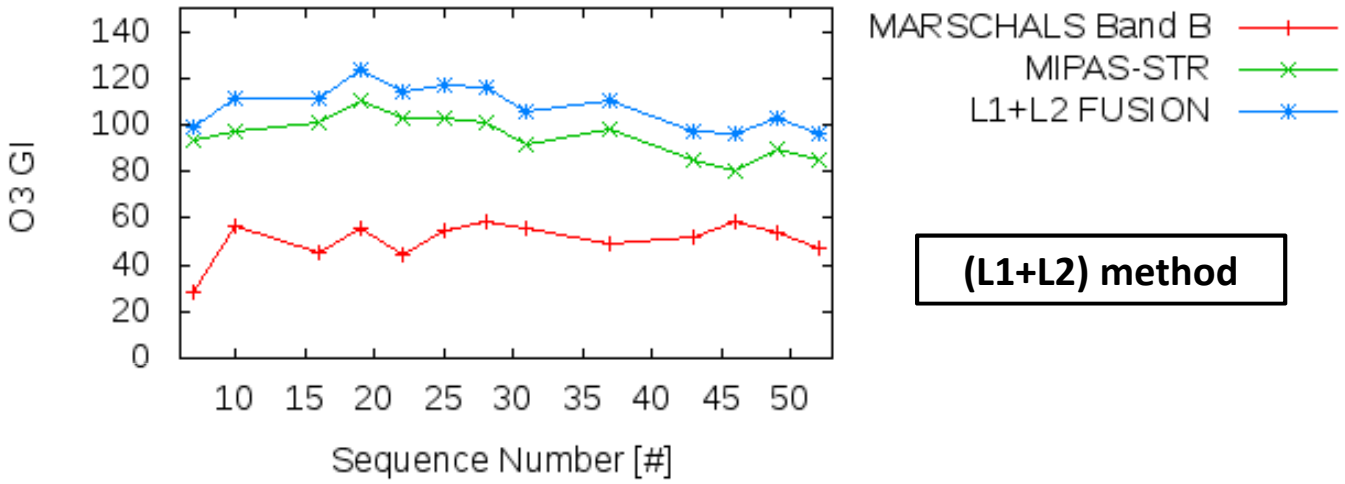
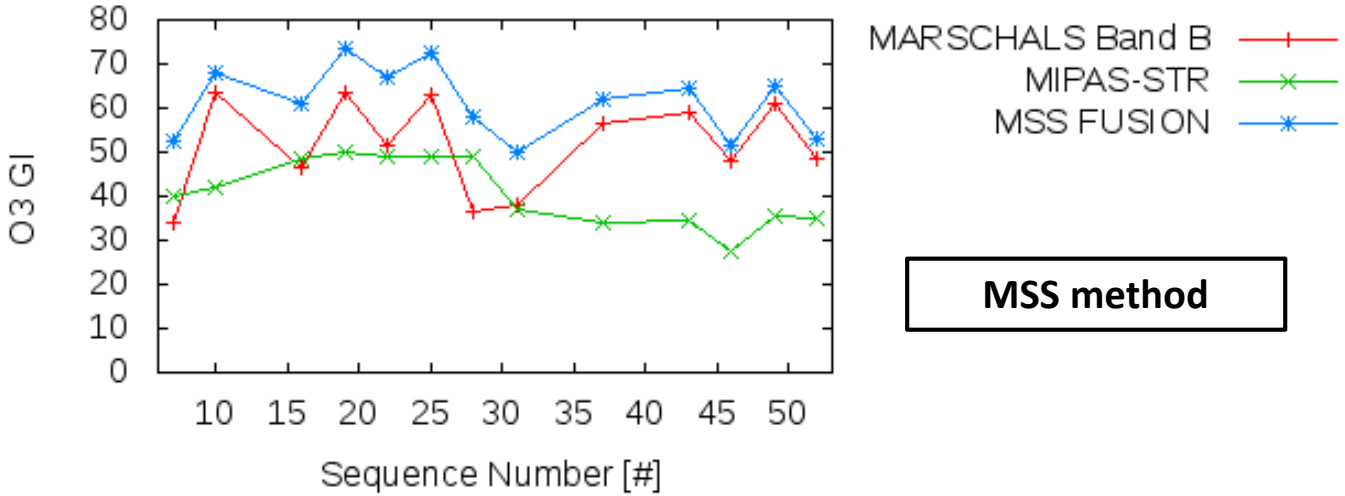
Comparison of (L1+L2) and MSS data fusion

O_3

GAIN OF INFORMATION



(L1+L2) method



MSS method

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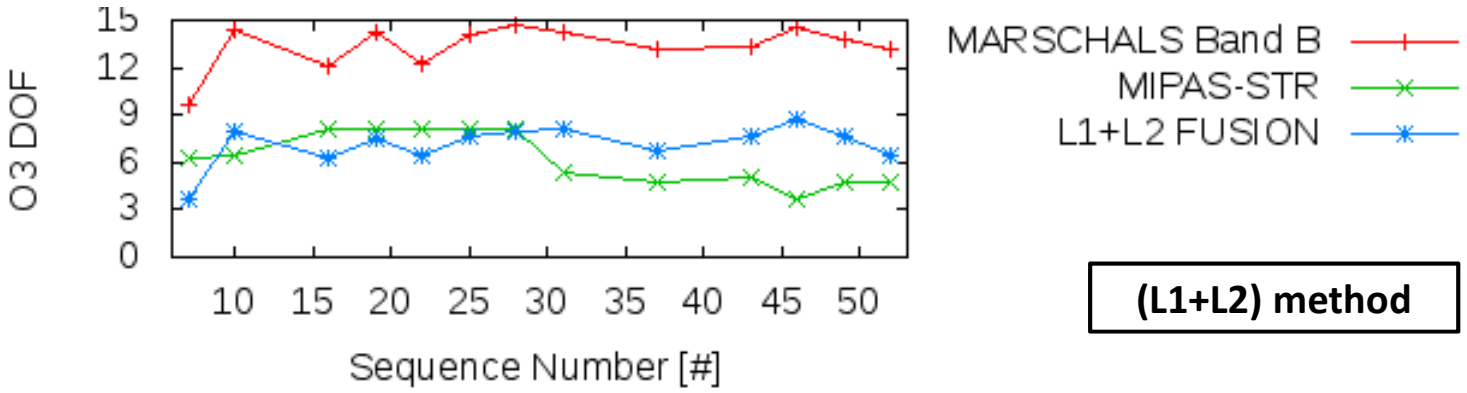
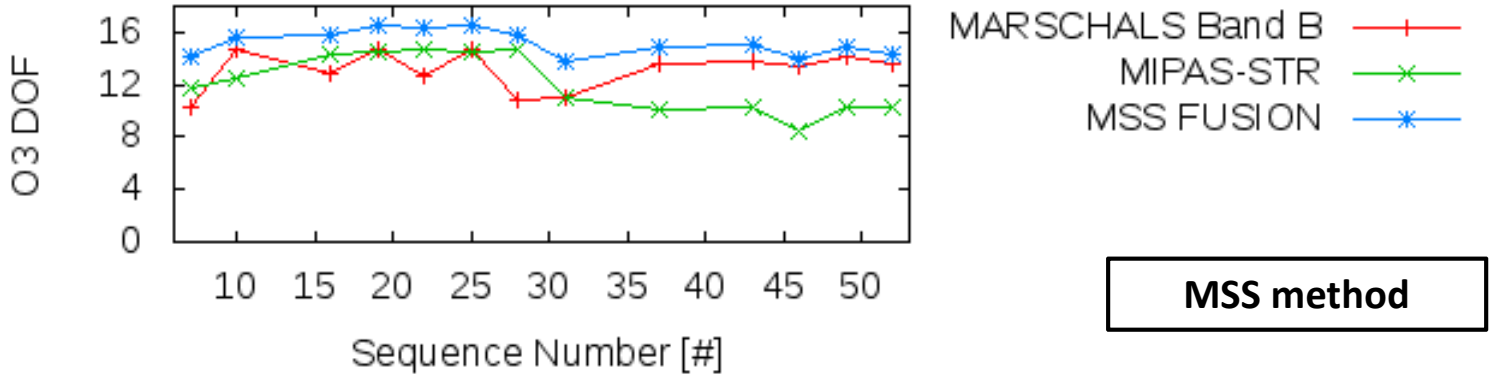
Comparison of (L1+L2) and MSS data fusion

O_3

DEGREES OF FREEDOM



(L1+L2) method



MSS method

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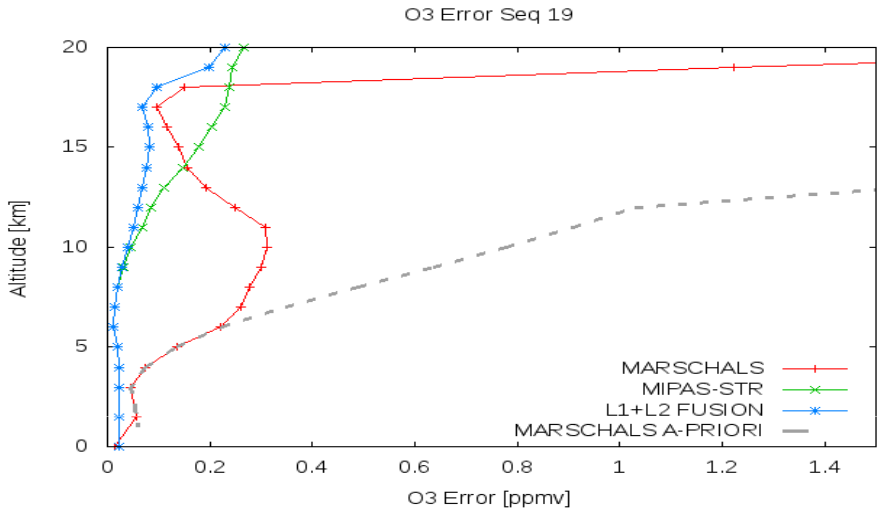
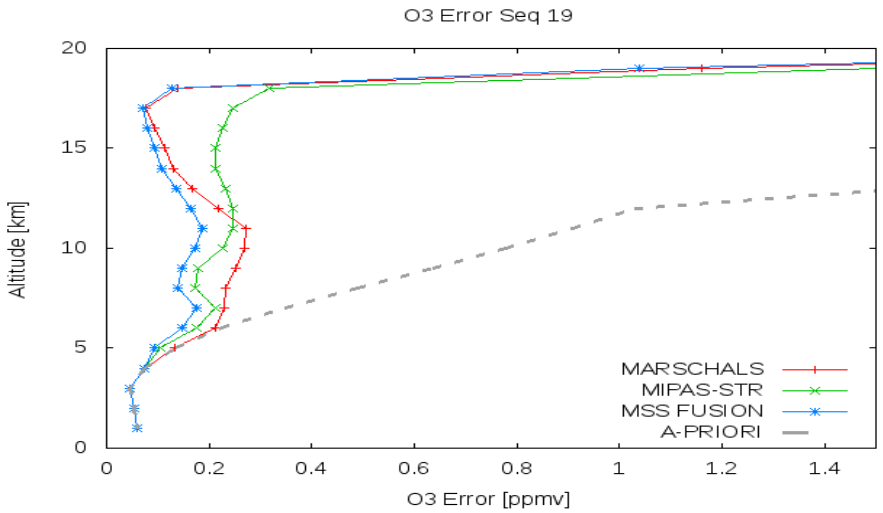
Comparison of (L1+L2) and MSS data fusion

O_3

TOTAL RETRIEVAL ERROR



(L1+L2) method



MSS method

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Conclusions on mm-wave and IR data synergy

- Data synergy of infrared and millimeter-wave limb-sounding has been investigated, by using collocated and independent measurements acquired by MIPAS-STR and MARSCHALS instruments during the PremierEx campaign.

- Two alternative methods have been applied to test potential synergy of Ozone measurements: the (L1+L2) method and the MSS method. The (L1+L2) analysis has been extended to HNO_3 and H_2O datasets (not shown).

- The performances of individual and synergistic retrievals have been evaluated using suitable quantifiers such as GI, DOFs and total error.

- Results of (L1+L2) data fusion show a significant improvement in the quality of the retrieval products for O_3 in all MARSCHALS bands (particularly in band B).

- Results of MSS data fusion confirmed the outcome of the analysis conducted on the O_3 profiles using the (L1+L2) method and the peculiar features observed in clear sky compared to cloudy sky conditions.

- The comparative evaluation of the performances of (L1+L2) and MSS data fusion indicates that the MSS method is more effective to demonstrate the advantage of combining independent and complementary measurements of the same target.

References

More details on the results of the study can be found in:

U. Cortesi et al, *PREMIER Analysis of Campaign Data*, Special Issue of IFAC TSSR (Technical and Scientific Research Reports), Vol. 4, 79-239, ISSN 2035-5831, 2012.

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Thank you for your attention!