Retrieval of the water vapour from nadir sounding measurements in thermal infrared region

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Introduction

The Sentinel 4 and 5 missions of ESA's GMES (Global Monitoring for Environment and Security) program are operational missions conceived to monitor the atmospheric composition in the timeframe 2013-2020 and beyond and focusing on the key issues of ozone layer, air quality and climate.
The geophysical observation requirements for Sentinel 4 and 5 were first established by the ESA project CAPACITY (Composition of the Atmosphere: Progress to Applications in the user CommunITY) and further consolidated by a follow-on study named CAMELOT (Composition of the Atmospheric Mission concEpts and SentineL Observation Techniques). The core objective of CAMELOT consisted in mapping the user requirements (level 2 requirements) identified by CAPACITY for the air quality and climate protocol monitoring parts of the GMES Sentinel 4 and 5 missions into instrument performance requirements (level 1b requirements).
As part of the activities of the CAMELOT project, the IFAC-CNR team carried out a series of sensitivity tests and retrieval simulations to investigate the potential of nadir-viewing observations by thermal infrared sensors operating on future LEO (Low Earth Orbit) or GEO (Geostationary Earth Orbit) satellite platforms for measurements of the water vapour column and vertical distribution in the troposphere and in the boundary layer. Here we report a summary of the H_2O-TIR sensitivity and trade-off studies conducted in the frame of the CAMELOT project and the results obtained for different geophysical scenarios both in clear sky and in cloudy conditions.

Requirements

The CAMELOT study focuses on the user requirements defined for Air Quality and Climate Protocol Monitoring. The requirements Air Quality / Monitoring (B1) and Climate / Monitoring (C1) do not provide any indication for water vapour. As a consequence, CAMELOT H_2O user requirements are derived exclusively from theme / category B2 and B3 (the latter being less critical for operational missions).

	Theme	Category	Driver
B2	Air Quality	Near-Real Time	Air Quality Forecast
B3	Air Quality	Assessment	Oxidising Capacity

The following table reports the complete set of user requirements that applies to the retrieval of water vapour total/partial columns and vertical distribution for both Air Quality Near-Real Time and Assessment.

Product	Horizontal Resolution	Vertical Resolution	Uncertainty
PBL	5/20 km	-	10%
FT	5/20 km	1/3 km	20%
Tropospheric Column	5/20 km	-	10%
Total Column	5/20 km	-	10%

These uncertainty values specify the accuracy (including both the random and the systematic error components) of the water vapour products retrieved from a single measurement.
Different height ranges are adopted to identify the PBL and the Free Troposphere depending on the geophysical scenario.
The setup of H_2O retrieval simulations in the TIR were fixed on the base of the requirements (spectral ranges, spectral resolution, spectral oversampling and radiometric accuracy) for the target species observable in the TIR.

Spectral Band	Spectra Range [cm^{-1}]	Target Species	Spectral Res. [cm^{-1}]	NeDT [K] at 280 K
1-L	800 – 850	C_2H_6	0.125; 0.25; 0.5	0.10; 0.071; 0.05
2-L	860 – 900	HNO_3		
3-L	1030 – 1080	O_3		
4-L	1120 – 1160	Volcanic SO_2		
5-L	1290 – 1390	CH_4		0.20; 0.142; 0.10
6-L	2140 – 2180	CO		0.15; 0.106; 0.075
7-L	2700 – 2760	CH_4 column		0.20; 0.142; 0.10
8-L	2760 – 2900	CH_4 column		

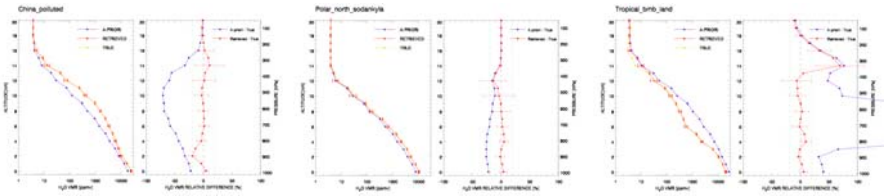
Conclusions of H_2O retrieval tests in the thermal infrared are mostly based on the following assumptions:
•Combined use of the 8 LEO bands selected for the other target species.
•L1B requirements derived from the nominal values of spectral resolution and radiometric accuracy identified for each band.
•Systematic errors due to the interfering species in the 8 LEO bands estimated consistently with the MRD user requirements.
•Verification of the compliance of L2 performances with water vapour user requirements for theme/category B2 and B3.

CLEAR SKY: H_2O TIR retrieval using 8 LEO bands

Retrieval tests carried out using nominal values of spectral resolution ($\Delta\sigma$ = 0.25 cm^{-1}) and noise equivalent temperature difference show that L2 performances are mostly compliant with water vapour user requirement for all the geophysical scenarios under investigation.

Vertical profile
The vertical profile is retrieved with a vertical resolution better than 3 km and an uncertainty lower than 20% in the free troposphere, with the only exception of the uppermost layers (typically above 10 km). In some cases, the retrieved profiles below 2 km are affected by biases of the order of 5-10%.

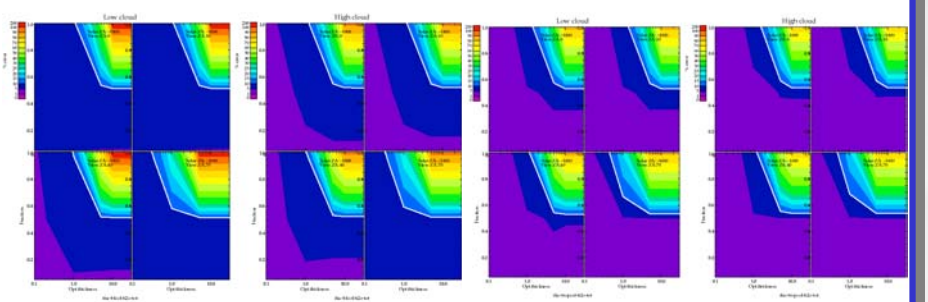
Total and partial columns
The error on the retrieval of total, tropospheric and PBL column varies from 2% to 5% depending on the geophysical scenario.
The occasionally reduced capability to properly retrieve the water vapour content at the lowest levels may introduce a bias in the retrieved columns. Overall L2 performances remain generally compliant with the 10% uncertainty on total and partial columns fixed by the user requirements.



Results of the retrieval of H2O profiles for the selected sub-set of CAMELOT scenarios.

CLOUDY SKY: Cloud sensitivity LUTs

In the frame of the CAMELOT study, Look-Up-Tables (LUTs) have been built which define when a retrieval performance meets user requirements, as a function of various geophysical parameters:
• Cloud fraction (0, 0.05, 0.1, 0.5, and 1)
• Cloud optical thickness(1, 5, 10, and 30)
• Cloud location (3 and 9 km).
All tests have been conducted on the European background geophysical scenario using a multitarget retrieval approach with target parameters including H_2O, O_3, CO_2, HNO_3, CH_4, N_2O, C_2H_6, SO_2, CO, T and surface temperature.
The precision includes the contribution of the measurement noise and of the a priori uncertainties on the fitted parameters.
The accuracy is obtained by mapping error spectra associated to the following uncertainties:
• uncertainties on cloud properties values (optical thickness, cloud fraction and cloud top height, as above specified)
• Error on the ILS (modelled as a sinc function) given by a 5% sinc2 function
• radiometric calibration error: offset (about 0.002 the spectral radiance) and gain (0.2%).
In general retrievals are compliant with requirements provided the cloud fraction is less than 0.5 and / or the cloud is optically thin.
While accuracy, as defined above, is by definition larger than the ESD, in general introduction of the additional error source only leads to a slight increase in retrieval error. The dominant error therefore appears to be caused by obscuration of the tropospheric or boundary layer column by cloud. Similarly, differences between the effect of low and high cloud are small.



Cloud sensitivity LUT for H_2O accuracy: Boundary Layer column and Tropospheric column.