Analysis of atmospheric properties and surface radiation budget using radiative transfer code MOMO

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Extension of radiative transfer code MOMO and Validation

1-D radiative transfer code MOMO (Matrix-Operator Model, [R1]), has been extended from [0.2 – 3.65 µm] band to the whole [0.2 – 100 µm] spectrum [R2]. MOMO can now be used for computation of full range radiation budgets (shortwave and longwave). This extension to the longwave part of the electromagnetic radiation required to consider radiative transfer processes that are features of the thermal infrared: the spectroscopy of the water vapor self-continuum absorption at 12 µm and the emission of radiation by gases, aerosol, clouds and surface. MOMO's spectroscopy module, CGASA (Coefficient of Gas Absorption), has been developed for computation of gas extinction coefficients, considering continua and spectral line absorption. The extension of the code allows the utilization of MOMO as forward model for remote sensing algorithms in the full range spectrum. Another application is full range radiation budget computations (heating rates or forcings).

Code	Ref	Method	Absorption method	Application
RTTOV	*Saunders et al, 1999a; b*	Predictors	LBL[2] external code (eg GENL2, LBLRTM), channel reg coeff	Remote sensing (fast code)
Streamer	*Key and Schweiger, 1998*	2 Streams, DISORT	LBL computation then ESFT	Radiation budget (fast code)
MODTRAN	*Berk et al, 1989*	2 sreams, DISORT	Statistical band model, k-distribution	Radiation budget, remote sensing
RRTM	*Mlawer et al, 1997*	DISORT	LBL own code LBLRTM, k-distribution method	Radiation budget (GCM[4])
FASDOM	*Dubuisson et al, 2005*	DISORT	LBL ext code XXX, k-distribution	Remote sensing (fast code)
MOMO	*Fell and Fischer, 2001*	matrix operator	LBL own code CGASA, k-distribution	Remote sensing, Radiation budget (precise code)

References

R1- Fell, F. and J. Fischer (JQSRT, 2001) : *Numerical simulation of the light in the atmosphere-ocean system using the matrix operator method*

R2 – Doppler, L., C. Carbajal-Henken, J. Pelon, F. Ravetta, J. Fischer (JQSRT, 2014) : *Extension of radiative transfer Code MOMO to the thermal infrared – Clear air validation by comparison to RTTOV and application to CALIPSO-IIR*

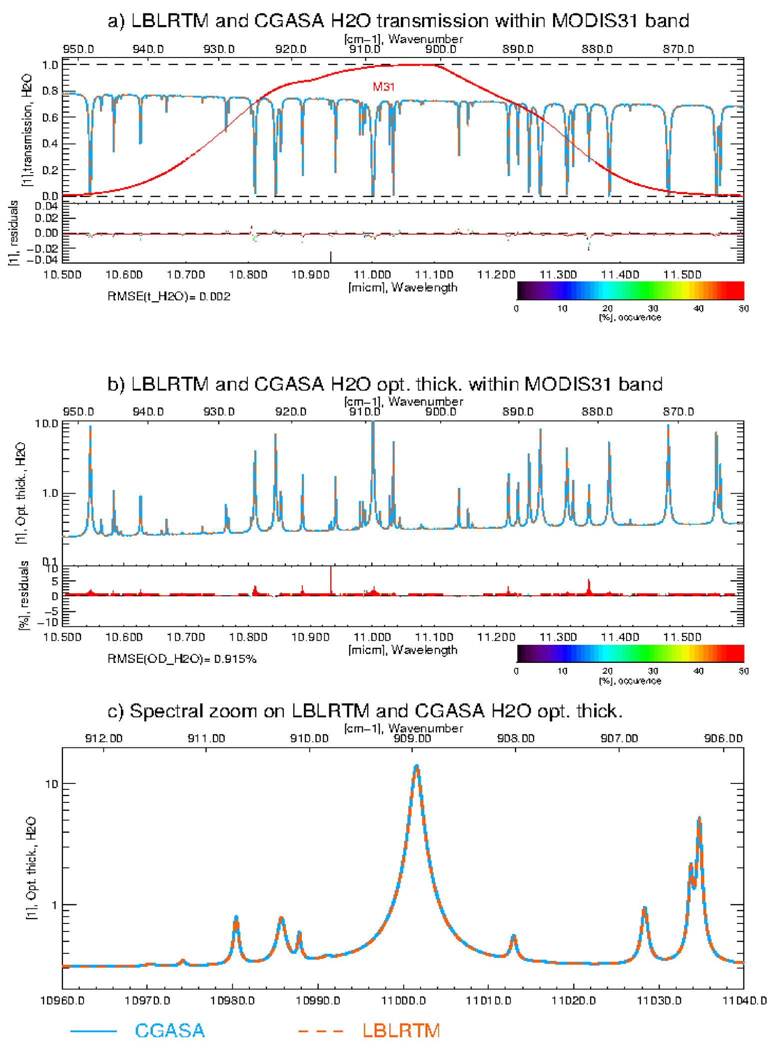

Fig.1 Agreement of LBLRTM (dashed orange)/CGASA (blue) for water vapor spectroscopy within MODIS 31 channel. (a) water vapor transmission. Spectral response function Of MODIS 31 is in red. (b) water vapor absorption OD (optical depth) within MODIS 31 channel. (c) Zoom on a 80 nm wide band for the water vapor spectrum.

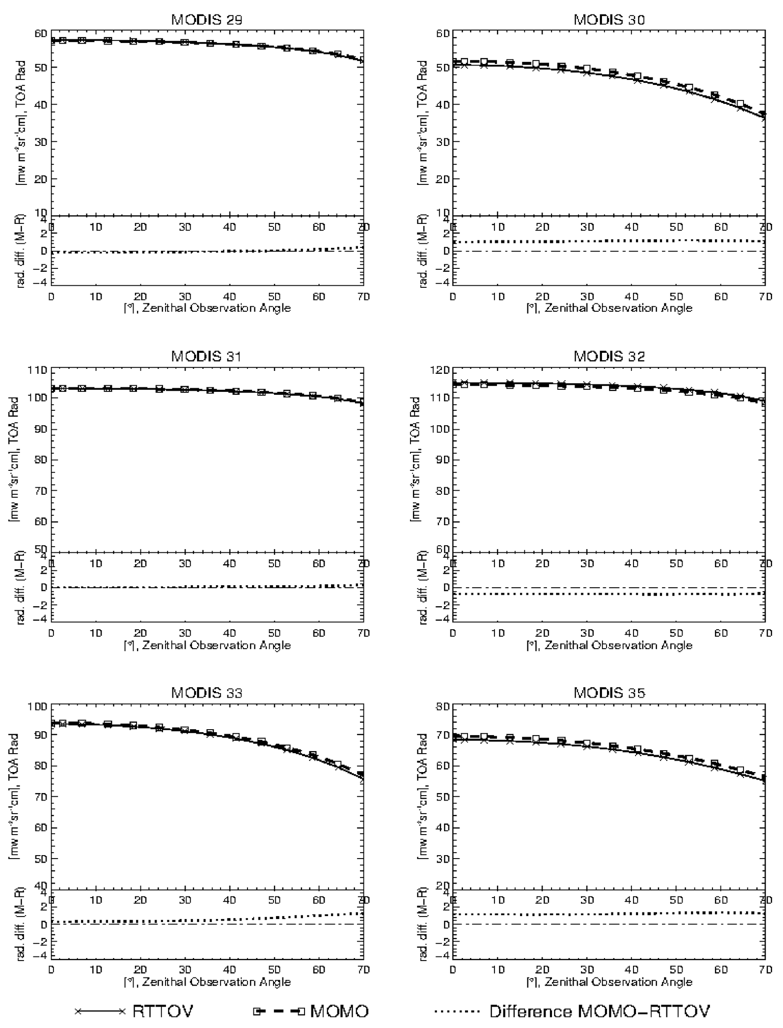

Fig. 2 Results of the comparision of MOMO to RTTOV, for 6 MODIS channels. Plain line : top of the atmosphere Spectral radiance computed by RTTOV, dashe line : top of The atmosphere spectral radiance computed by MOMO. Dotted line : spectral radiance difference MOMO-RTTOV.

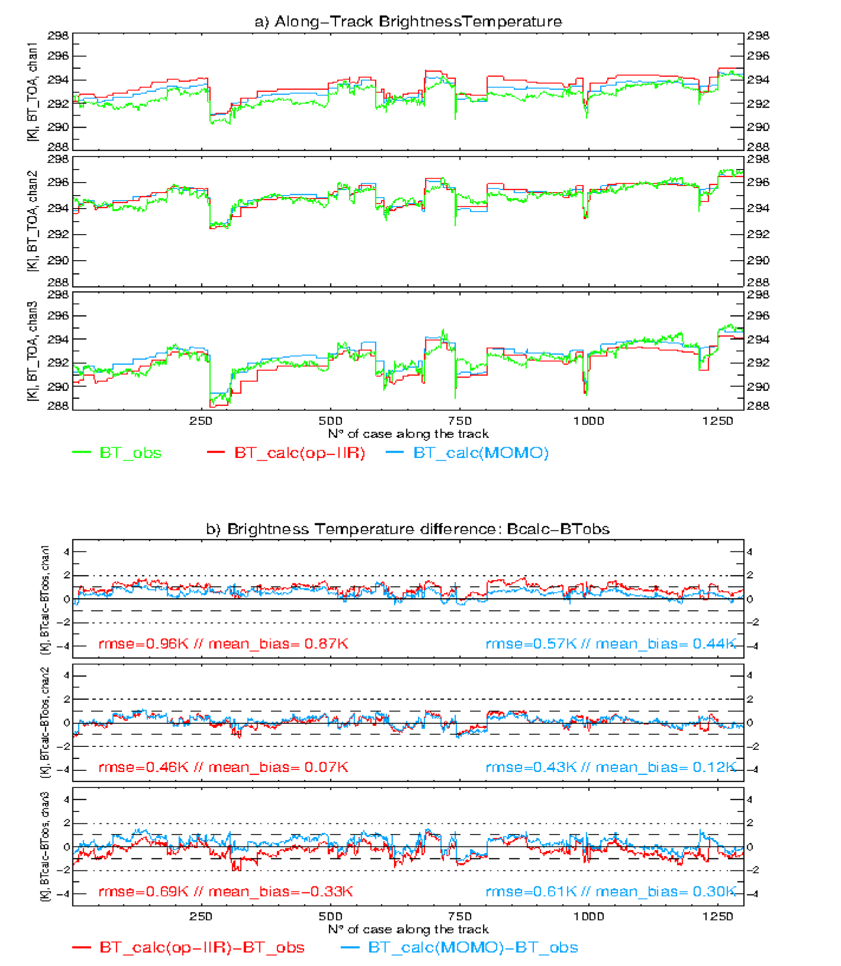

Fig.3 Results of the comparison of MOMO to CALIPSO-IIR observations. (a) Top of atmosphere brightness temperature observed by Calipso-IIR (green), computed with MOMO (blue), computed by SPIRS operational code (red) for CALIPSO Channels 1-3 (from top to bottom). (b) Differences between the observed and the modelled (in blue with MOMO, in red with SPIRS) brightness temperature at the top of the Atmosphere for CALIPSO channels 1-3.

Application to IAOOS project combining ground-based and space observations

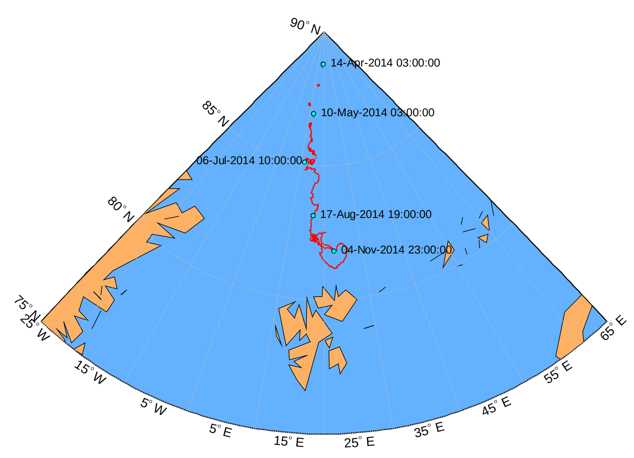

Fig. 4 Drift example of a IAOOS buoy (trajectory in red).

Cloud and aerosols in the arctic atmosphere are key parameters in the surface energy budget but their properties and their modifications are poorly known. The Artic region is experiencing a strong warming and few measurements are currently performed in this region to develop a proper knowledge of the couplings between ocean and atmosphere. Jointky led by LOCEAN and LATMOS, the aim of the IAOOS project (Ice – Atmosphere - Arctic Ocean Observing System) is to bridge this gap by implementing multi-disciplinary autonomous systems on a network of buoys in central arctic. The atmospheric measurements within IAOOS are aiming at bringing new information on cloud and aerosol properties in the low atmosphere setting a network of small automated profiling lidar systems embarked on buoys. It is complemented by in situ and radiometric observations which contribute to satellite ground truth. Example of analyses started in this frame to link satellite and surface observations are discussed below. Two main approaches are considered :

- retrieval of cloud properties from RTManalysis using ground-based radiometric meaurements (lidar and ODS) and comparison with satellite retrievals ;
- retrieval of surface temperature fromsatellite and comparison to *in situ* measurements ; for validation and identification of possible biases.

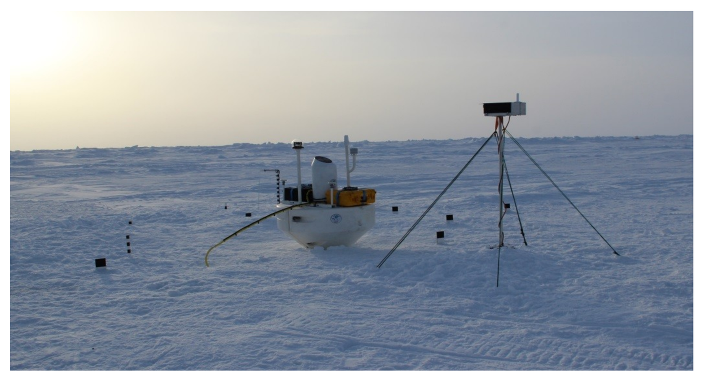

Fig. 5 Exemple of a IAOOS deployed in the Artic. More information on http://www.iaoos-equipex.upmc.fr/

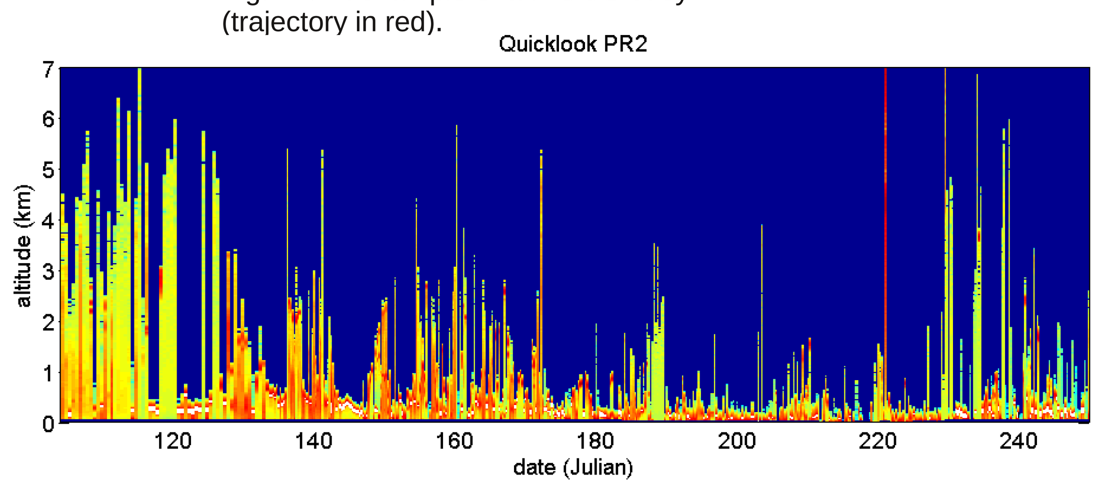

Fig. 6 Vertical cross section of range corrected IAOOS lidar profiles (range corrected signal PR2, arbitrary units) in the Artic over almost seven months. Deep blues areas stand for background level (no backscattered signal). Range detection is usually low, due to low-level clouds. Observed Amplification Factor (OAF) of spectral luminance at the bottom of the atmosphere due to low-level clouds is estimated through the ratio of background measurements with clouds to background measurements in clear sky conditions.

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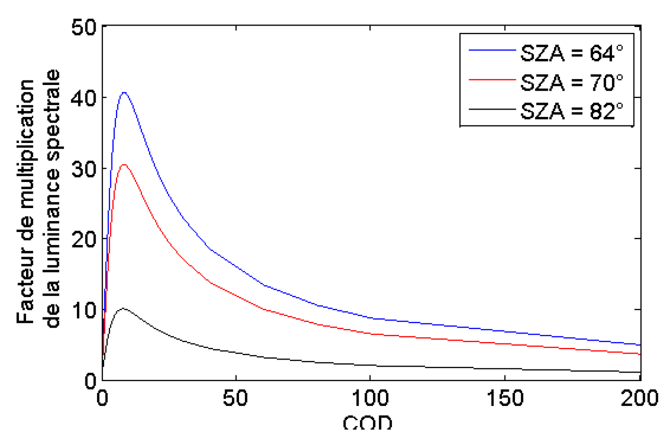

Fig. 7 Modelled Amplification Factor (MAF) of spectral luminance at the bottom of the atmosphere computed with MOMO against cloud optical depth (COD) for several solar zenith angles.

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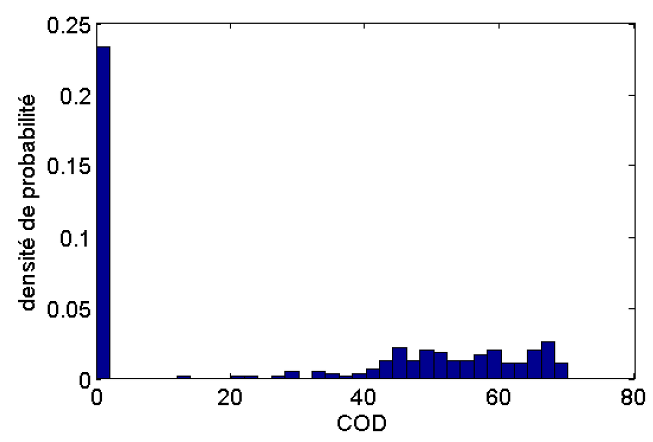

Fig. 8 Probability density function of cloud optical depth (COD) derived from the comparison of Observed and MOMO-modelled amplification Factor (see Fig. 7). The COD values found for these low-level clouds are rather high. Sensitivity studies are under way in order to better constrain the microphysical parameters used in MOMO simulations.

Satellite information from IASI can be obtained simultaneously overthe pole and provide information on meteorological parameters (including clouds)

Close coincidences between IASI spectral and IAOOS temperature profile measurements allow to compare the snow surface temperature derived from IMB (Ice Mass Balance) profile and the surface temperature derived from the IASI spectrum. Surface temperature was obtained from operational retrievals, (Figure 9) and derived from IASI spectra analysis (see Figure 11) using line-free microwindows and by optimal estimation. First comparison of results is given in Figure 10.

Ether web site http://www.pole-ether.fr
IPSL-mesocentre computing facilities were used
In the analyses presented here (quick-looks and IASI spectra)

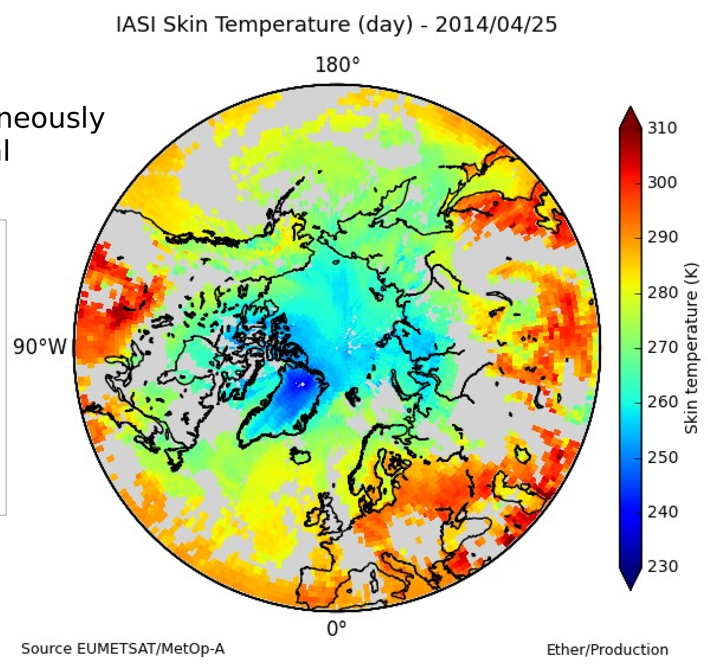

Fig 9 IASI data : example of skin temperature measured by IASI on 25 April2014 (ETHER archive at IPSL)

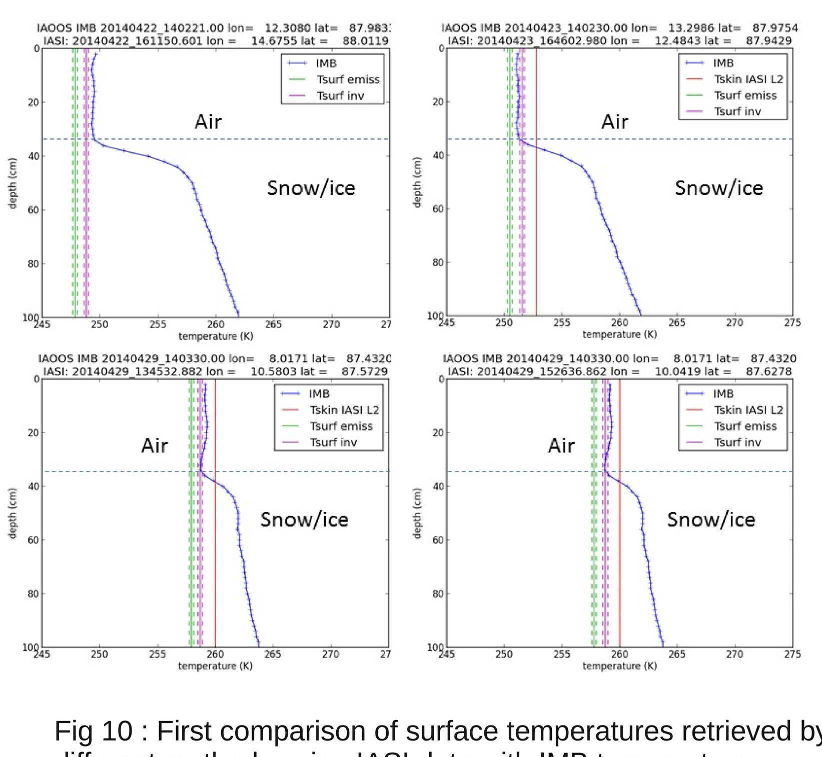

Fig 10 : First comparison of surface temperatures retrieved by different methods using IASI data with IMB temperature measurements (courtesy of N. Sennechael, LOCEAN/UPMC), on 22 and 29 April 2014 identified as clear Days by IAOOS lidar

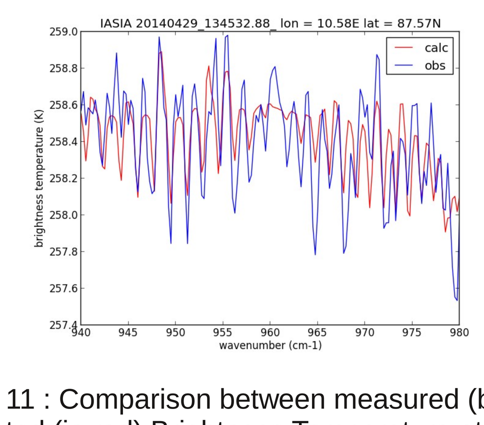

Figure 11 : Comparison between measured (blueline) and calculated (in red) Brightness Temperature at the Top-of-the-atmosphere

In the RTM analyses snow emissivity from the MODIS UCSB emissivity database was used. For the optical estimation, LARA radiative transfer and retrieval code was used

Preliminary studies (see Figure10) show a good agreement between *in situ* IMB surface temperature measurements and surface temperatures retrieved from IASI spectra.

Conclusions and Perspectives

The MOMO code was developed to allow analysis in both visible and IR spectral domains. It is used here as an illustration to study Arctic radiation budget at the ice/snow-atmosphere interface.
We showed that MOMO could be a valuable integration tool combining IAOOS *in situ* measurements, satellite measurements (IASI, AVHRR, ...) and radiative transfer simulations to:

- compare satellite skin surface temperature products or infrared images with in situ measurements using operational and research satellite products for validation ;
- check values of critical parameters such as snow/ice emissivity using temperature retrievals ;
- infer cloud properties from IAOOS lidar and radiometric measurements.

This will further allow to analyse surface radiation fluxes (SW and LW) contributing to the energy budget at the ice/snow atmosphere interface.

Combination of ground-based, airborne and satellite observations will be applied to better constrain or validate MOMO radiative transfer simulations to estimate radiative forcing and heating rates in the atmosphere, especially for highly variable conditions (clouds and aerosol layers).