Toward a decade of dust infrared aerosol properties observed by infrared hyperspectral sounders (AIRS, IASI/Metop-A,IASI/Metop-B) and first analysis of the dust diurnal cycle

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ABSTRACT

Aerosols still represent one of the dominant uncertainties in radiative forcing, partly because they present a very high spatio-temporal variability. In this context, satellite observations may offer a global and continuous observation at high resolution. In particular, remote sensing in the thermal infrared allows characterizing dust aerosols both daytime and nighttime, over desert and, even more important, vertical sounders allow retrieving dust layer mean altitude. In this study, observations from AIRS, Metop-A/IASI, as well as Metop-B/IASI are interpreted in terms of dust aerosol properties (AOD and mean altitude). The method is based on a "Look-Up-Table" (LUT) approach, where all radiative transfer computation is performed once for all and "off-line", for a large selection of atmospheric situations, of observing conditions, of surface characteristics (in particular surface emissivity and temperature), and different aerosol refractive index models. The inversion scheme follows two main steps: first, determination of the observed atmospheric thermodynamic situation, second, simultaneous retrieval of the 10µm coarse-mode AOD, the mean altitude and surface temperature.

A special focus is here given to the variation of aerosol properties within a day. In this context, both IASI and AIRS overpasses are processed, providing two measurements at 9:30AM and PM (equator local time) for IASI and at 1:30 AM and PM for AIRS, each day, opening the way to the analysis of the aerosol diurnal cycle. Comparisons are made with AERONET ground-based measurements of the SDA coarse-mode AOD, when available, in order to 1) evaluate our results, and 2) show the importance of a better knowledge of the aerosol diurnal cycle, especially close to the sources.

Mineral Aerosol Profiling from Infrared Radiances: Recent developments, validation, applications

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ABSTRACT

Desert dust is the most important aerosol in annual mass burden, mainly present in the tropics but reaching Europe from time to time. Dust aerosols are a major actor in the climate: they absorb, scatter and reemit radiation, impacting the Earth energetic balance along the solar and terrestrial spectrum. Their presence in the atmosphere may lead to surface warming or cooling, and to atmospheric warming in the dusty layers, with possible impacts on the atmospheric circulation. Furthermore, dust aerosols are efficient cloud/ice condensation nuclei, therefore impacting the lifetime and physical properties of clouds, and the amount or location of rainfalls. For all these reasons, studies of dust atmospheric load and sources are of great scientific interest. In particular, the vertical distribution of desert dust is currently not well characterised on a global daily scale, and matters much for the mentioned effects of this aerosol.

In the last years, we have developed and improved a retrieval strategy to obtain desert dust aerosols vertical profiles, from thermal infrared nadir measurements by IASI (Vandenbussche et al, AMT 2013 and recent improvements to be published). The evaluation of this retrieval strategy, called Mineral Aerosol Profiling from Infrared Radiances (MAPIR), has been included in the ESA Climate Change Initiative aerosol project. Within that project, MAPIR has been further developed and included in an almost operational processing chain. A Round Robin exercise including three other desert dust retrieval algorithms is ongoing. The processing of the whole IASI time series will be undertaken and result, for the first time, in about 10 years of 3-dimensional distributions of the dust.

In this presentation, we will quickly explain the recent improvements to MAPIR, and discuss its strengths and weaknesses. We will show the first conclusions about its evaluation, and discuss the new long-term dataset of 3D-distributions of the dust aerosols, including possible specific applications.

IASI 2016 Abstract

Measuring volcanic ash and windblown sand with IASI

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ABSTRACT

Satellite sounders are ideal for measuring the highly variable global atmospheric aerosol distributions. IASI is slowly putting infrared aerosol sounding on the map and proving to be a valuable complement to the more traditional SWIR/UV/VIS aerosol measurements. Here we present our recent progress in the sounding of volcanic ash and windblown sand aerosols from this instrument. Aerosol detection and retrieval techniques are reviewed, leading up to the presentation of a new dust retrieval algorithm. The retrieval combines a well-tuned detection algorithm with a feedforward neural network, rigorously accounting for surface effects (emissivity, temperature) as well as the state of the atmosphere. By explaining the underlying principles we demonstrate the inherent advantages of the approach, but also highlight some of its disadvantages such as its dependence on accurate ancillary data. The resulting 8-year dataset of dust optical depth from IASI is presented. We derive global distributions, a monthly climatology and timeseries over selected regions. We end this talk with example validation efforts using both aircraft and ground-based data.

PHYSICAL PROPERTIES OF MESOSCALE HIGH CLOUD SYSTEMS IN RELATION TO THEIR ATMOSPHERIC ENVIRONMENT DEDUCED FROM SOUNDERS

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Representing about 40% of the Earth’s total cloud cover, clouds in the upper troposphere play a crucial role in the climate system by modulating the Earth's energy budget and heat transport. These clouds often form mesoscale systems extending over several hundred kilometres. Cirrus (semi-transparent ice clouds in the upper troposphere) emerge as the outflow of convective and frontal systems or form in cold air supersaturated with water. Both their evolution with climate change and their feedback can only be reliably estimated if these cloud systems are adequately represented in climate models.

Only satellite instruments are able to give a global picture of these systems. The good spectral resolution of the Atmospheric InfraRed Sounder (AIRS), aboard Aqua since 2002, and of the InfraRed Atmospheric Sounding Interferometer (IASI), aboard the MetOp platforms since 2006, allows reliable cirrus identification, both from day and night-time observations. The LMD cloud property retrievals for AIRS and IASI are based on a weighted χ^2 method using spectral channels sounding along the 15 micron CO_2 absorption band. Recently, we have developed a modular cloud retrieval code, which can be applied to any current IR sounder. At present, we are processing IASI data, starting from 2008, and extending the AIRS cloud climatology up to 2014.

By using a spatial composite technique on the retrieved high-altitude clouds we have composed mesoscale high-altitude cloud systems. Convective core, cirrus anvil and thin cirrus within these systems are distinguished by cloud emissivity. A comparison with precipitation rate data from the microwave sounder AMR-E aboard Aqua has already shown that maximum rain rates appear in cores with cloud emissivity near 1 and low cloud top temperature. As the vertical structure of these cloud systems is essential for the determination of the heating rates and active instruments (CALIPSO lidar and CloudSat radar synchronous with AIRS) only have a small nadir sampling coverage, we develop a statistical model of vertical structure in dependence of cloud emissivity and distance to convective core. This data set is being complemented by mesoscale winds and atmospheric profiles from ERA Interim meteorological reanalyses and is being explored within the framework of the GEWEX Process Evaluation Study on Upper Tropospheric Clouds and Convection (UTCC PROES).

A first proxy of convective strength is the minimum temperature within the convective core(s) of a system, and we could show that the horizontal extent of the anvil increases with the convective strength of the system. We will present results on the variability of high-altitude cloud systems with their surrounding atmosphere and radiative effects of the anvil cirrus.

Principal Component Analysis (PCA) for detection and classification of aerosols and clouds from hyperspectral infrared sounders.

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Aerosols and clouds are important components of the Earth-atmosphere system, affecting meteorology, climate and air quality through different mechanisms. However, due to their large spatio-temporal and chemical variabilities, their mineralogical diversities, form or size distributions, their radiative impact remains up to now incertain.

Satellites remote sensing is the only tool able to obtain geophysical parameters from local to global scale. In particular, high spectral resolution infrared sounders are currently used to retrieve gaseous concentrations and some recent studies have shown their potential for particles analysis. However,the huge quantity of data, the radiative transfer complexity (absorption, scattering,...) and calculation time for the inversion process, explain why applications are until now particularly sparse.

In this context, we present a method able to classify each IASI spectrum such as follow : "Clear skies", "Aerosols", "Ice Clouds", "Water Clouds" and "Mixed Clouds" in near real time (NRT) conditions. Our approach is based on Principal Component Analysis. The latter is currently used for remote sensing, especially for compressing onboard datas and removing noise. Here, we show for the first time its applications on aerosols and clouds detection.

We focus also of the potential of this method on several studies cases, from local scale on dust and volcanics scenes and, at global scale, during the 24^{th}, April 2015. Finally, we compare our results with other NRT methods.

Three-dimensional distribution of a major Saharan dust outbreak in June 2011 derived from IASI satellite observations

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ABSTRACT

The Sahara is the world's largest source of mineral dust in the atmosphere, which is a key player of the Earth system. At the regional scale, the environmental impacts of desert dust strongly depend on the three-dimensional (3D) distribution of dust plumes resulting from long-range transport. Dust layers can impact chemical balances, atmospheric stability or cloud properties depending on the altitude at which they are transported. Near the surface, dust can directly affect air quality and settle down on the surface by dry deposition. The quantification of such impacts are highly uncertain, particularly due to the sporadic character of dust emissions as well as the large variability of dust properties and occurrence linked to the meteorological controls. A better understanding of the 3D distribution of Saharan dust and the associated mechanisms for uplifting and redistributing it in the vertical is fundamental for quantifying its environmental impacts.

This research work presents the first observation of the 3D distribution of a major Saharan dust outbreak over the Sahara in June 2011, using new aerosol retrievals derived from IASI (Infrared Atmospheric Sounding Interferometer). For this, we use a novel auto-adaptive Tikhonov-Philips-type approach called AEROIASI to retrieve vertical profiles of dust extinction coefficient at 10 µm for most cloud-free IASI pixels, both over land (including bright desert surfaces) and ocean. The dust vertical distribution derived from AEROIASI is shown to agree remarkably well with along track transects of CALIOP space-borne lidar vertical profiles as well as with aerosol optical depth derived from AERONET sun photometer measurements over West Africa. A comparison is as well made with airborne lidar and in situ measurements over the Sahara performed in the framework of the FENNEC field campaign. We also compare AEROIASI with several satellite retrievals available over the Sahara (e.g. MODIS-DeepBlue, OMI, SEVIRI).

Using AEROIASI observations, we analyse the 3D pathways of the Saharan dust plumes as they are transported across the Sahara. Particularly, we focus our study on the role of cold pools generated by mesoscale convective system, convective mixing in the Saharan atmospheric boundary layer and strong Harmattan winds as mechanisms for vertically redistributing the Saharan dust plumes.

Frequency and Vertical distribution of Tropical high clouds:
VIS and IR geostationary satellite observations
coupled with lidar and IR sounders observations from polar orbiting satellites

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The visible and infrared imaging radiometers on-board GOES, MTSAT, Meteosat (1-st and 2-nd generation) geostationary satellites can observe high clouds and their environment on a timescale from a quarter-hour (over Africa and Atlantic) to about an hour. High temporal sampling and spatial resolution provided by geostationary instruments is essential for the study of cumulonimbus towers spatial distribution, extension and altitude of cirrus anvils, and overshoot frequencies during the life cycle of convective systems.

However, the information retrieved from visible/infrared radiometric observations needs to be evaluated and corrected/supplemented by more accurate measurements of the cloud top height and cloud optical and geometric thickness. Moreover, sub-visual cirrus with optical thickness smaller than < 0.3 are below the detection threshold of the visible/infrared imaging radiometers. Recently, active measurements from the CALIOP lidar, CloudSat radar and from the AIRS sounders of the A-Train mission on board the polar orbiting satellite Aqua have given a new insight both on the thin cirrus occurrence frequency and on their vertical distribution. However, these instruments observe the same region just twice a day (at 1:30 AM/PM local time) and the lidar/radar field of view is small, so their picture of the convective system life cycle is incomplete. Two additional observation times are available by including IASI observations aboard the Metop satellites with 9:30 AM/PM local time at equator crossing.

Within the framework of the MEGHA-TROPIQUES mission launched in October 2011, a geostationary cloud data set has been developed in collaboration with H. Legleau and M. Derrien (MeteoFrance/SAFNWC). This data set consists of a cloud classification and cloud top pressure fields retrieved with the help of the SAFNWC algorithm from the multi-spectral SEVIRI radiometer (2-nd generation of METEOSAT) measurements and from the GOES-E, GOES-W and MTSAT satellite data (Sèze et al. 2015). The combined data set contains cloud parameters in the tropical belt (35°S-35°N) sampled at less than one-hour intervals.

In this work, we use summer and winter geostationary data in combination with CALIOP and AIRS/IASI measurements to analyze the occurrence frequency of high clouds and its distribution in convective towers and cirrus of variable optical thickness. For these variables, we discuss the differences for day, night, land, and ocean for all participating data sets.

Cirrus Clouds Retrieved from IASI and AIRS Observations: Diurnal Variation and Microphysical Properties

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ABSTRACT

Cirrus clouds cover about 30% of the globe and play an important role in the climate system, affecting the heating of the upper troposphere and preventing escape of the Earth's infrared (IR) radiation to space.

Satellite observations provide a continuous survey of clouds over the whole globe and IR sounders have been observing our planet since 1979. These instruments are sensitive to cirrus clouds both day and night that makes them an ideal tool for studying this type of clouds.

The CIRS-LMD cloud property retrieval approach is based on a weighted χ^2 method and uses the channels around the 15 μm CO_2 absorption band [Stubenrauch et al., 2010 and references therein], providing cloud pressure and emissivity of a single cloud layer (which is the uppermost one in the case of multi-layer clouds). We applied it to cloud retrievals from IASI and AIRS (Atmospheric InfraRed Sounder) observations. The retrieval quality was estimated using the information from active sounders: the AIRS instrument is a part of the NASA Afternoon Constellation (A-Train) mission, which includes a two-wavelength polarization-sensitive nadir viewing lidar, providing high-resolution vertical profiles of aerosols and clouds.

Once the cloud physical properties (cloud pressure and IR emissivity) are known, cirrus bulk microphysical properties (De and IWP) are determined from spectral emissivity differences between 8 and 12 μm [Guignard et al. 2012].

In this work, we present cloud pressure and cover and bulk microphysical properties retrieved from IASI and AIRS observations (9:30 AM and 9:30 PM and 1:30 AM and 1:30 PM local time, respectively) and discuss their diurnal variation.

References:

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Aerosol detection with IASI, AIRS and CrIS measurements in the weather forecast

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ABSTRACT

Brightness temperature observations from IASI, CrIS and AIRS are assimilated operationally at ECMWF and are known to improve the quality of numerical weather forecasts. In addition, atmospheric composition products derived from IASI are used to produce analyses of atmospheric species in the MACC project.

High resolution spectra measured by these instruments can be significantly affected by the presence of aerosols which, if unaccounted for in the assimilation, will damage the NWP analyses of temperature and humidity.

Currently aerosol affected situations are identified and rejected as part of the operational ECMWF cloud screening process.

This poster shows the effectiveness of the current detection algorithm and demonstrates some recent improvements that have made for the particular case of desert dust and volcanic ash.

It also demonstrates the importance to evaluate the altitude of aerosol to keep a part of the spectrum which is not affected by aerosol presence like is done for clouds.

Retrieving Volcanic Ash Properties from the Infrared Atmospheric Sounding Interferometer

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ABSTRACT

The Infrared Atmospheric Sounding Interferometer (IASI), on board both the MetOp-A and MetOp-B platforms, is a Fourier transform spectrometer covering the mid-infrared (IR) with a spectral resolution of 0.5cm^{-1} (apodised) and a pixel diameter at nadir of 12km. These characteristics allow global coverage to be achieved twice daily for each instrument and make IASI a very useful tool for the observation of larger aerosol particles (such as desert dust and volcanic ash) and the tracking of volcanic plumes.

In recent years, following the eruption of Eyjafjallajökull, interest in the ability to detect and characterise volcanic ash plumes has peaked due to the hazards to aviation. The thermal infrared spectra shows a rapid variation with wavelength due to absorption lines from atmospheric and volcanic gases as well as broad scale features principally due to particulate absorption. The ash signature depends upon both the composition and size distribution of ash particles as well as the altitude of the volcanic plume.

An optimal estimation (OE) algorithm for the retrieval of volcanic ash properties has been developed for use with hyperspectral satellite instruments such as IASI, which analyses the brightness temperature spectra in the wavenumber range 680–1200cm^{-1}. Initially, IASI pixels are flagged for the presence of volcanic ash using a linear retrieval detection method based on departures from a background state. Given a positive ash signal, the RTTOV output for a clean atmosphere (containing atmospheric gases but no cloud or aerosol/ash) is combined with an ash layer using the same scheme as for the Optimal Retrieval of Aerosol and Cloud (ORAC) algorithm. The retrieved parameters are ash optical depth (at a reference wavelength of 550nm), ash effective radius, plume altitude and surface temperature. A comprehensive error budget is also obtained for each pixel. In order to improve retrievals in cloudy conditions, the retrieval algorithm uses two measurement error covariance matrices, trained with either clear-sky or cloudy scenes. The former is preferable due to the smaller variance contained within it, however, if the retrieval fails to pass quality control tests, the cloudy covariance matrix is implemented.

The retrieval algorithm is applied to scenes from the Eyjafjallajökull eruption in 2010 and the Grimsvötn eruption in 2011 and the retrieved parameters have been validated against alternative sources, e.g. Moderate-resolution Imaging Spectroradiometer (MODIS) retrievals using ORAC, measurements from the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) instrument and aircraft measurements from the Facility for Airborne Atmospheric Measurements (FAAM).

IASI Dust algorithm inter-comparison within ESA's Climate Change Initiative

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In the Aerosol_cci project of the Climate Change Initiative of the European Space Agency (ESA) it is envisaged to produce a full-mission (~10 years) dataset of dust AOD from IASI with four different algorithms, which are based on different retrieval techniques. A major task within the project is the first inter-comparison of those IASI dust retrieval algorithms on the basis of a large set of observations. For this purpose one year of IASI observations (2013) over the major dust belt of the Northern hemisphere, including the Northern Atlantic Ocean, the Sahara desert, the Arabian Peninsula as well as the Central Asian desert regions, is consistently processed with all four algorithms and similar retrieval output (visible and infrared AOD, AOD uncertainty, retrieval quality, cloud flags) is generated in order to facilitate the comparison of results.

The retrieval inter-comparison, called Round Robin exercise, consists of an analysis of the different sensitivities of the four algorithms to dust and environmental conditions. The retrieval methods are based on different retrieval strategies such as look-up tables, optimal estimation, neural network and singular value decomposition. The sensitivity analysis will reveal the major uncertainties of infrared dust remote sensing from space as well as specific strengths and weaknesses of the different retrieval approaches under varying environmental conditions and can be used to identify and/or mix the best-suited approach for specific conditions (for example atmospheric moisture or surface characteristics).

The Round Robin exercise includes the evaluation of retrieval results from the four different algorithms with external data. AERONET sun photometers are used for evaluation as well as observations from the German SALTRACE campaign over the tropical Atlantic Ocean in summer 2013. Evaluation of subsets will thus allow for an improved understanding of the feasibility of hyperspectral infrared dust remote sensing with different approaches under varying conditions.

Greenhouse gases information content analysis from high spectral measurements in the thermal infrared (IASI like) in the presence of ice cloud

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ABSTRACT

The survey at global scale of greenhouse gases is of particular interest for monitoring their evolution in the context of global warming. Beside their strong contribution to weather forecast improvement through data assimilation, thermal infrared sounders onboard polar-orbiting platforms (such as IASI) are now playing a key role in monitoring atmospheric composition changes. However, it is notoriously known that clear sky observations are only a small part of the entire set of measurements. The aerosol and/or cloud scattering contamination is therefore a major source of error for greenhouse gases retrievals.

The present study aims in quantifying the effect of the presence of an ice cloud layer on the H_2O, CO_2 and CH_4 column information content and errors budget. Based on a previous study by Herbin et al. (2013), we will show how the gaseous column information is affected by the presence of an ice cloud layer as a function of its opacity and the a-priori knowledge of its optical properties. The synthetic measurements will be simulated by a line-by-line model developed at the Laboratoire d'Optique Atmospherique (ARAHMIS), and the multiple scattering by the open source radiative transfer code VLIDORT (Spurr et al., 2008). The ice cloud microphysics will be simulated by the ensemble model developed by Baran and Labonnote (2007).

Evaluation of the cloudy parameters with the CO2-Slicing algorithm for IASI in global and mesoscale models

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Abstract :

Satellite data currently represent the vast majority of observations assimilated into NWP models. However, their exploitation remains suboptimal, only 10% of the total volume is operational in assimilation. Furthermore, about 80% of the infrared data are affected by clouds and it is essential to develop the assimilation of satellite observations in cloudy areas. Météo-France NWP models are using since February 2009 AIRS (Atmospheric Infra-Red Sounder) cloudy radiances and since 2012 IASI (Infrared Atmospheric Sounding Interferometer) cloudy radiances. The exploitation of the infrared hyperspectral sounder IASI has already improved weather predictions, thanks to its precision and information content never equalled. Nevertheless, its use in storm areas remains very complex because of the strong nonlinearity of cloud processes in the infrared spectrum.

The used method for assimilation of cloudy radiances in the present research work is based on the characterization of Cloud parameters with CO2-slicing. This method consists in a cloud top pressure and cloud fraction retrieval using the observations and the brightness temperature simulations for clear sky and cloudy sky.

For evaluating the performance of CO2-Slicing algorithm, we have used the validation data SEVIRI. The first the evaluation is done in model ARPEGE, then in AROME, and finally we have made the comparison of cloudy detection for common IASI pixels in ARPEGE and AROME. In all of this work we have used several situations (land/sea, day/night).

The evaluation of CO2-slicing with respect to SEVIRI validation data gave us encouraging results.

In ARPEGE case, we had a better correlation over land than over sea and better correlation during day time than during night time over ocean.

In addition, the middle and high cloud are well placed. The CO2-slicing weakly detect the low clouds whilst it can detect clouds top pressure of less than 800 hPa if clouds are stratiform clouds. This was the case when the clouds fraction equal to 1.

In clear case or in case of cloud non-detection by IASI, the observed clouds by SEVIRI are mainly fractionated and semi-transparent which is difficult to detect with the CO2-Slicing method.

In AROME model, the correlation between IASI and the validation data is better than in ARPEGE model. The algorithm also detects more low clouds and less high clouds with larger correlation over sea than over land, and during night time than during day time, contrary to what was found in ARPEGE.

In the comparison of IASI in AROME/ARPEGE, we always obtain different cloud top pressures for the low and high clouds.

After these results, we have spread out our study on the mext operational suite, which experienced recently a top level modification of the model.

Our work has also studied the effect of 50-minute phase shift between IASI from MetopA and MetopB on the cloud detection. MetopA puts more of low cloud that Metop B, while the latter puts more of high clouds. The obtained results have encouraged us to develop our study, using another source of validation in order to reveal the source of those differences between the two of IASI on board Metops A and B.