The Copernicus Sentinel-5 Mission: Daily Global Data for Air Quality, Climate and Stratospheric Ozone Applications

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ABSTRACT

In the frame of the European Copernicus programme, two series of satellites are dedicated to the monitoring of atmospheric parameters: Sentinel-4 will focus on tropospheric constituents with relevance for European air quality with hourly temporal resolution; Sentinel-5 will observe atmospheric composition on a daily basis with full global coverage. The latter will have a precursor mission Sentinel-5p carrying a slightly simplified instrument.

The purpose of the Sentinel-5 mission is to provide long-term (2022–2040) global coverage of data on atmospheric composition. These will address the information needs of Copernicus services related to air quality, climate forcing and stratospheric ozone / surface UV irradiation.

The Sentinel-5 mission will be accomplished by flying spectrometers in the UV – visible – near infrared – short-wave infrared spectral regions (UVNS) on Eumetsat's Metop-SG series of satellites, and utilising the relevant data from three other instruments on the same platforms, namely the infrared sounder IASI-NG, the multi-spectral imager Metimage and the polarisation imager 3MI.

The UVNS instrument will observe spectral features suitable for retrieval of O3, NO2, SO2, HCHO, CHOCHO, BrO, OClO and surface UV irradiation in the range 270–500 nm, H2O and cloud in the range 685–773 nm, CH4 between 1590–1675 nm as well as 2305–2385 nm, and CO and H2O in the latter band. Aerosol information will be available in all spectral bands, in particular also at 755–773 nm. With a swath width of 2600 km, global coverage will be reached within a day at a spatial resolution of 7 km at nadir (except stratospheric ozone: ~50km). Spectral resolution will be between 0.25 and 1.0 nm.

The observation requirements at Level 1b have been consolidated. The instrument is currently in the detailed design phase and undergoing the preliminary design review.

The operational Level-2 data products have been defined. Accuracy requirements have been refined. The Level 2 processor prototype activity is to be started soon. EUMETSAT will be responsible for the operational processing and dissemination of the UVNS data products.

This paper will provide an overview of the main characteristics and status of the Sentinel-5 mission.

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Abstract Text:

The Atmospheric Infrared Sounder (AIRS) on the EOS Aqua Spacecraft was launched on May 4, 2002. AIRS is a grating spectrometer sounder with 2378 infrared channels between 3.7 µm and 15.4 µm and a spatial resolution of 13.5 km with nearly global daily coverage. The AIRS instrument is in good health and is expected to last the life of the spacecraft anticipated to operate beyond 2022. The radiometric, spectral and spatial calibration of the instrument radiances (L1B product) are excellent and the data continue to be assimilated in operational forecast systems worldwide. Recent developments include release of a new L1C product to reduce instrumental artifacts in the calibrated radiances. The AIRS Version 6 geophysical, L2, data products have been public since March of 2013 and reprocessing is complete with over 13 years of nearly continuous data. Data product validation results will be presented along with a status of the development of L3, climatology, and applications-relevant imagery products.

JPL recently was selected by NASA to develop a CubeSat Infrared Atmospheric Sounder (CIRAS). CIRAS is also a grating spectrometer and operates in the mid-wave spectral region with 625 channels between 4.8 µm and 5.1 µm also with 13.5 km spatial resolution and nearly global daily coverage. The midwave response limits sensitivity to the lower troposphere, but the instrument operates in a 6U CubeSat offering significantly reduced development and launch costs. CIRAS will demonstrate key new technologies in the areas of optics, cryogenic cooling and detectors. The resulting performance is expected to be as good as the legacy IR sounders (AIRS, CrIS and IASI) below 500 mb and is low enough cost to be implemented in a constellation to improve timeliness.

MTG-IRS instrument and level 1 processing overview

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The Meteosat Third Generation (MTG) series of future European geostationary meteorological satellites consists of two types of satellites, the imaging satellites (MTG-I) and the sounding satellites (MTG-S). The Infrared Sounder (IRS) is one of the two instruments hosted on board the MTG-S satellites. The scope of the IRS mission is to provide the user community with information on time evolution of humidity and temperature distribution, as function of latitude, longitude and altitude. Regarding time and space sampling, the entire Earth disk will be covered, with particular focus on Europe, which will be revisited every 30 minutes.

This paper presents a synthetic overview of the mission and the instrument, and will go through the level 1 processing chain which takes instrument raw data to obtain spectrally and radiometrically calibrated and geolocalised radiances, called level 1b products. Those products will be compressed in Principal Components to be disseminated to the user community.

Global Ammonia Concentrations Seen by the 13-years AIRS Measurements

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Ammonia is an integral part of the nitrogen cycle and is projected to be the largest single contributor to each of acidification, eutrophication and secondary particulate matter in Europe by 2020 (Sutton *et al*., 2008). The impacts of NH_3 also include: aerosol production affecting global radiative forcing, increases in emissions of the greenhouse gases nitrous oxide (N_2O) and methane (CH_4), and modification of the transport and deposition patterns of SO_2 and NO_x. Therefore, monitoring NH_3 global distribution of sources is vitally important to human health with respect to both air and water quality and climate change. We have developed new daily and global ammonia (NH_3) products from AIRS hyperspectral measurements. These products add value to AIRS's existing products that have made significant contributions to weather forecasts, climate studies, and air quality monitoring. With longer than 13 years of data records, these measurements have been used not only for daily monitoring purposes but also for inter-annual variability and short-term trend studies. We will discuss the global NH_3 emission sources from biogenic and anthropogenic activities over many emission regions captured by AIRS. We will focus their variability in the last 13 years. Comparison with IASI published NH_3 results will also be presented.

Potential of the multispectral synergism for observing ozone pollution combining measurements of IASI-NG and UVNS onboard EPS-SG

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ABSTRACT

Current and future satellite observations offer a great potential for monitoring air quality on daily and global basis. However, measurements from currently in orbit sensors offer a limited capacity to probe surface concentrations of gaseous pollutants such as tropospheric ozone. Using single-band approaches based on IASI spaceborne thermal infrared measurements, only ozone down to the lower troposphere (3-4 km of altitude at lowest) may be observed (Eremenko et al., 2008). A recent multispectral method combining IASI and GOME-2 (both onboard MetOp satellites) spectra, respectively from the IR and UV, has shown enhanced sensitivity for probing ozone at the lowermost troposphere, but with maximum sensitivity around 2 km at lowest (Cuesta et al., 2013). Future spatial missions will be launched in the upcoming years, such as EPS-SG, carrying new generation sensors like IASI-NG and UVNS that will enhance the capacity to observe ozone pollution, and particularly when combining them through a multispectral synergism.

This work presents an analysis of the potential of the multispectral synergism of IASI-NG and UVNS future spaceborne measurements for observing ozone pollution, performed in the framework of SURVEYOZON project (funded by the French Space Agency, CNES). For this, we develop a simulator of synthetic multispectral retrievals or pseudo-observations (referred as OSSE, Observing System Simulation Experiment) derived from IASI-NG+UVNS that will be compared to those from IASI+GOME2.

In the first step of the OSSE, we create a pseudo-reality with simulations from the chemical-transport model MOCAGE (provided by CERFACS laboratory), where real O3 data from IASI and surface network stations have been assimilated for a realistic representation of ozone variability at the surface and the free troposphere. We focus on the high pollution event occurred in Europe on 10 July 2010. We use the coupled algorithms KOPRA+VLIDORT to simulate the spectra emitted, scattered and absorbed by the surface and atmospheric components and simulate the spectral measurements of IASI and GOME2. These spectra as used to retrieve O3 profiles that are then compared with the pseudo-reality. These pseudo-observations enable us to estimate the performances and associated errors of the innovative multispectral methodology implemented with IASI-NG (with finer spectral resolution and lower noise than IASI) and UVNS (with lower noise and finer horizontal resolution than GOME-2). In a second step, these pseudo-observations will be used to quantify the improvement in regional air pollution forecasts, when assimilating this new multispectral O3 product in a second chemical transport model (CHIMERE) independent from MOCAGE.

IASI-NG Program: General Status Overview

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ABSTRACT

With notable improvements on spectral and radiometric performances compared with IASI first generation, CNES will develop the New Generation of the Infrared Atmospheric Sounding Interferometer (IASI-NG) key element of the future European meteorological polar system, i.e. the EUMETSAT Polar System Second Generation (EPS-SG).

For the IASI-NG program, a cooperation agreement will be implemented between CNES and EUMETSAT. Under this agreement, CNES has technical oversight responsibility for the development and procurement of the instruments, the definition of instrument in flight operations, the development of the Level 1 Product operational Processor (L1C POP) and the IASI NG Technical Expertise Centre (IASTEC) in charge of the IASI-NG in-flight calibration, validation and performance monitoring. EUMETSAT will be in charge of operating IASI-NG instrument and L1C POP, archiving and distributing data to the users.

IASI NG program has reached an important milestone in spring 2015 with the successful completion of the Instrument Preliminary Definition Review. This review conducted with the instrument prime Airbus Defense and Space France, allowed the program to move to instrument Phase C/D activities.

Bread boards of most critical sub-system (detectors, full video chain, metrology …) have been delivered to instrument prime to start early 2016 a first validation at instrument level. Instrument preliminary performances were confirmed at the instrument PDR but full Flight Model representative performances demonstration will be done along the next two years on the Instrument Engineering Model (EM) which is now started. First EM sub-systems will be available from spring 2016 until 2017. The Instrument Critical Definition Review is planned mid 2017.

An Infra-Red Interferometer Simulator (IRIS) which objective is to validate the algorithms of the On board/On ground processing's and the mission performances budget has completed its requirement specification phase. The IRIS Requirement Review has been successfully held in November 2015. The ITT for simulators development activities will be issued early 2016.

In the meantime CNES consolidated the definition of the Level 0 and Level 1 Processing simultaneously with the specification of the L1 Operational processor and the Technical Expertise Centre. A system preliminary definition review is planned in March 2016 to conclude the IASI-NG system phase B activities.

The present paper reports on latest general status overview of IASI NG program, focusing on CNES involvements in this cooperation.

Validation of IASI-NG Level 1 processing: strategy and state of progress

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ABSTRACT

The definition and the development of the IASI-NG Level 1 processing are under responsibility of CNES. Whereas the information about the algorithms constituting the Level 1 Processor are given in the paper named "IASI-NG processing overview" (Pequignot et al.), this papers aims at presenting the strategy adopted for the validation of the processing chains.

In order to validate the different steps needed to obtained geo-located spectra, spectrally and radiometrically calibrated (Level 1 products) from uncalibrated raw spectra (Level 0 products), a simulator has been developed. In a first part, we present this simulator, developed for CNES by Noveltis. Thanks to this tool, raw interferograms can be simulated, then transformed into complex spectra in the on-board processing and finally calibrated during the on-ground processing. This simulator has already been used to establish performances budgets for the IASI-NG system.

Then, we describe the strategy adopted to validate, functionally and scientifically, the Level 1 processing chain using this simulator through different sensitivity studies. In particular, we present the scheme for the equalization of the instrument spectral response function then we assess the impact of several instrumental defaults (microvibrations, wave-front errors, refractive index variations) on this equalization.

Other steps of the level 1 processing chains have been studied, such as the radiometric calibration of the spectra.

Development of a hyperspectral temperature and water vapor sounder at 5μ.

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Among the large number of instruments used in the ECMWF and UK Met Office data assimilation systems, AIRS and IASI are the only instruments which provide temperature and water vapor profiles in the lower troposphere. They are also the two instruments with the largest positive forecast impact. We use IASI data, Degree of Freedom and Contribution function analysis to show that a sounder which covers only a narrow region around 5μ (1960-2090 cm^{-1}) has the same temperature and water vapor profile sensitivity in the lower troposphere as AIRS and IASI, which depend on 7μ-15μ data. The use of the 5μ regions brings with it a number of technology advantages: Much more mature detector array technology, less cooling requirements and a much smaller instrument, with the potential for hyperspectral sounding from Polar orbit within the constraints of a CubeSat, with footprints as small as 1 km. The CubeSat Atmospheric Infrared Sounder, CIRAS, is funded by NASA for launch into polar orbit in 2019.

Scientific Benefits of Spatial Resolution for Next Generation Infrared Hyperspectral Sounder Instruments

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Hyperspectral infrared (IR) radiance measurements from satellite sensors contain valuable information on atmospheric temperature and humidity profiles, greenhouse gases, clouds, and surface characteristics. These measurements are used not only to retrieve atmospheric temperature and humidity profiles, but more importantly, to be directly assimilated into numerical weather prediction (NWP) models as inputs for weather forecasting. Combined with the microwave sounders together, hyperspectral infrared (IR) sounders, provide basic information on atmospheric temperature and humidity for NWP models, especially at the region where conventional weather observations are not available. The current global NWP and regional models have horizontal resolutions of about 16 km. In the near future, it is under plan to further improve the global model resolution to 3-5 km. Given the fact that current operational IR sounders – Crosstrack Infrared Sounder (CrIS) and Infrared Atmospheric Sounding Interferometer – have an field of view (FOV) size of 14 km and 12km at nadir, it is essential to improve spatial resolution of hyperspectral sounder instruments to match NWP model resolutions by reducing the field of size to 8 km or below.

From a perspective of data utilization for NWP models, this study explores probably scientific benefits of spatial resolution for next generation IR hyperspectral sounders from the view of data utilization for NWP models. First, since clear-sky measurements from IR sounders are mainly used for data assimilation, smaller FOV size will provide more clear measurements for NWP models. Second, smaller FOV size increases scene uniformity, which will reduce the spectral calibration uncertainties of IR spectra. Finally, smaller FOV size affects measurements noise for unapodized IR spectra. Specifically, we will use the Visible Infrared Imager Radiometer Suite (VIIRS) radiance measurements and cloud mask products (VCM) to test different FOV configurations (including the change of FOV size and number) to examine the statistics how the clear and uniform cloudy scene measurements vary. In addition, theoretical analysis and model simulation will be presented the benefits that smaller reduced FOV sizes improve the hyperspectra IR data quality. The study will provide basic scientific information on spatial resolution for future hyperspectral IR sounder instrument design.

Potential of Laser Heterodyne Radiometry for Numerical Weather Prediction

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Since the beginning of this century significant improvements in weather forecasting skill have been realised through the use of hyperspectral infrared observations from satellite platforms. Currently these observations provide the most beneficial information assimilated by forecast models. As computing power increases and models can be run on increasingly fine temporal and spatial grids future improvements in forecast skill will be determined by our ability to make observations on similarly fine grids. However, financial constraints mean that this cannot be achieved by deploying more of the current generation of satellite instrument, which are large, heavy and expensive to build and launch. The laser heterodyne radiometer (LHR) is a compact and lightweight instrument that has been developed during the last ten years by RAL Space. The LHR is small enough to deploy on relatively cheap small satellite platforms, or piggyback on other missions and so has the potential to meet the challenge of providing more observations compared to the current generation of instruments within the same budget.

This presentation describes initial simulation experiments to determine whether the LHR could provide observations that can be used for temperature and humidity profiling on a nadir-viewing satellite platform. Simulated observations will be used to understand how much information could be provided by LHR measurements. To provide a useful comparison the LHR's performance will be benchmarked against IASI and IASI-NG.

Calibration Accuracy Improvements for CrIS on JPSS

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ABSTRACT

The Cross-track Infrared Sounder (CrIS) on Suomi National Polar-orbiting Partnership Satellite (S-NPP) is a Fourier transform spectrometer, measuring Earth view interferograms at 30 cross-track positions, each with 3x3 arrays of Field-of-Views (FOVs). It provides a total of 1305 channels in the normal mode for sounding the atmosphere. CrIS can also be operated in the full spectral resolution (FSR) mode, in which the mid-wave (MWIR) and short-wave (SWIR) band interferograms are recorded with the same maximum path difference as the long-wave (LWIR) band and with spectral resolution of 0.625 cm^{-1} for all three bands (total 2211 channels). NOAA operated CrIS in FSR mode from normal mode on December 4, 2014 for S-NPP, and will operate CrIS in FSR mode for the Joint Polar Satellite System (JPSS). Based on CrIS Algorithm Development Library (ADL), CrIS full resolution Processing System (CRPS) has been developed to generate the FSR Sensor Data Record (SDR). This code can also be run for normal mode and truncation mode SDRs.

We developed the CrIS FSR SDR Validation System to quantify the CrIS radiometric and spectral accuracies, since they are crucial for improving its data assimilation in the numerical weather prediction, and for retrieving atmospheric trace gases. There are ringing artifacts appeared from current SDR unapodized spectra when spectra are compared among the 9 FOVs, between forward and reverse sweep directions, and between observed and simulated spectra. Major sources of these ringing artifacts are due to non-circular onboard Finite Impulse Response (FIR) digital filter, suboptimal calibration equation, and missing the instrument responsivity function for simulating CrIS spectra using radiative transfer models. The solutions to address these issues have been developed and implemented in the CrIS JPSS SDR processing, and will improve the SDR calibration accuracy for CrIS on JPSS.

Calibration/Validation Studies for Advanced Infrared Sounder IRFS-2 on "Meteor-M" №2

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ABSTRACT

One of key instruments for operational meteorology onboard "Meteor-M" №2 satellite (launched July, 8th, 2014) is the advanced infrared sounder IRFS-2. The hyperspectral IR sounder IRFS-2 is a Fourier-transform spectrometer, measuring the IR radiance spectra (2701 channels in the range 667–2000 cm^{-1} or 5.0–15.0 μm). Spatial resolution is about 35 km in sub-satellite point. Ground based processing of IRFS-2 raw measurements (interferograms) provides level 1c data, i. e. calibrated apodized radiances spectra with resolution ~ 0.4-0.7 cm^{-1}. During the "Meteor-M" №2 commissioning phase and later the cal/val studies were performed to assess the spectral resolution, as well as to examine a status of radiometric, spectral and geometric performances, and geo-location accuracy. Evaluation of the spectral resolution, spectral and radiometric calibration accuracy was performed through inter-comparison with line-by-line radiative transfer model simulations using adequate atmospheric model (NWP data) for scenes with clear-sky conditions over sea. Radiometric calibration reliability of IRFS-2 level 1c data was evaluated by comparing collocated SEVIRI/Meteosat-10 measurements and IRFS-2 level 1c data. In these inter-comparison studies the IRFS-2 radiances spectra were integrated over spectral response functions of SEVIRI channels 7-10. Along with this the inter-comparison of IRFS-2 spectra with Metop IASI-A, -B data has been performed using a variety of techniques. As a result, the IRFS-2 performance characteristics proved to be in accordance with the prelaunch specification.

CO2 retrieval from METEOR-M #2 measurements

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ABSTRACT

The new Russian infrared Fourier-spectrometer IRFS-2 on board Meteor-M #2 meteorological satellite can be used for detecting the variations of atmospheric carbon dioxide concentrations. The ability to retrieve atmospheric CO_2 mixing ratio (XCO2) from satellite measurements is of significant importance in the context of global carbon cycle research, climate change studies due to sparse network of ground-based CO_2 observations. The main objectives of our studies were as follows: − development of the technique for XCO2 retrieval from IRFS-2 data in combination with high spatial resolution measurements of MSU-MR instrument (boarded on the same satellite) as well as with a prognostic temperature profile from NCEP GFS; − validation of satellite based XCO2 retrievals against ground-based CO_2 measurements.

A new method of XCO2 retrieval is proposed. It is based on derivation of CO_2 optical thickness in several IRFS-2 channels near 12.5 μm for specially selected atmospheric scenes. The choice of channels has been realized using LBLRTM radiative transfer model. Atmospheric scenes are selected from MSU-MR measurements. The criterion of selection is the small variation of brightness temperatures in the MSU-MR fifth channel (10.5-11.5 μm) within IRFS-2 pixel. The first results of validation for developed method look promising and have been obtained by comparison of XCO2 estimates with collocated in situ observations for two geographical regions: Central Siberia (the Zotino tall tower observation facility, Turuhansky region), and Hawaii (NOAA Mauna Loa Observatory).