AUTHORS: C. Deniel and P. Veyre, Atmosphere program scientists

CNES, 2 place Maurice Quentin, 75039 Paris, France.

Atmosphere

Fig. 1

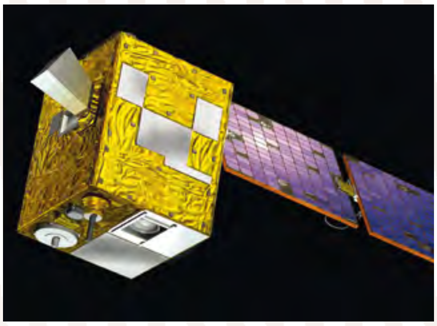

Fig. 2

Fig. 3

One more step with IASI-NG

The Infrared Atmospheric Sounding Interferometer (IASI) instrument developed by the French space agency (CNES) and launched by EUMETSAT onboard the METOP satellite series has already been providing essential inputs since 2006 for weather forecasting and pollution/climate monitoring, owing to its smart combination of large horizontal swath, good spectral resolution and high radiometric performance (Fig. 1).

With the new generation instrument sounder, IASI-NG, currently designed by CNES, a new step will be possible for better weather forecast, atmospheric composition and climate research. Based on the IASI heritage, it aims to improve both the spectral resolution and the signal/noise ratio by at least a factor of two. This will enable the detection of even more species, and make it possible to probe deeper in the troposphere with more accuracy. With the launch of three successive IASI-NG instruments starting from 2020, more than 20 years of observations will be added to the 15 years from IASI. As for IASI, all the data will be freely available to all, almost in real time. IASI-NG will thus strongly improve numerical weather forecast, chemistry and climate communities now connected through the European GMES/*Copernicus* initiative.

Europe now conveys much of its satellite effort for future Earth atmospheric observation from space, with foreseen meteorological payloads with atmospheric chemistry sensors onboard: in 2020 there should be an unprecedented combination of more frequent observations with smaller footprints provided from the geostationary orbit (MTG/SENTINEL-4 program), along with more precise measurements from the polar orbit (METOP-Second Generation satellites as part of the EPS-Second Generation/SENTINEL-5 program).

PARASOL and CALIPSO: a better understanding of the influence of clouds and aerosols on climate

The main objective of space missions PARASOL (CNES) and CALIPSO (NASA-CNES) is to better understand the role of atmospheric aerosols and clouds in climate change. They were initially part of the A-Train, a constellation of five satellites dedicated to the study of atmospheric physics and climate.

PARASOL (Fig. 2), launched in December 2004, and deactivated at the end of 2013, had been providing global measurements of excellent quality on aerosols and clouds for nine years thanks to its Polder-type instrument. After having left the A-Train in December 2009, PARASOL flew on a 10 km underneath orbit in order to minimize risks in case of deficiency. However, PARASOL kept fulfilling its cloud and aerosol observation mission, until its deactivation at the end of 2013. A full reprocessing of the data is planned in 2014.

CALIPSO, launched in April 2006, has been providing global measurements of clouds and aerosols vertical profiles thanks to its lidar (Fig. 4). Today, CALIPSO is still inside the A-Train constellation, and its measurements, in synergy with those of other A-Train sensors, provide unique insights that are improving the understanding of the properties of clouds and aerosols, and markedly improving the performance of models ranging from regional chemical transports to global climate models. At the end of 2013, more than 1 000 scientific publications have appeared that use or reference CALIPSO data. Recognizing this scientific success and the good health of the CALIPSO platform and instruments, NASA and CNES decided last year to extend the CALIPSO mission until the end of 2015.

The thematic consortium ICARE is managing the production and distribution of the scientific outputs of PARASOL and CALIPSO through its Data Center in Lille (CGTD ICARE). In the case of CALIPSO, it acts as a mirror site of NASA. ICARE is a partnership between four French groups: CNES, CNRS, the university of Lille-1 and the Nord-Pas-de-Calais Région.

MEGHA-TROPIQUES and the water cycle

The French-Indian space mission MEGHA-TROPIQUES (CNES-ISRO) is dedicated to the study of water cycle, energy exchanges and the evolution of climate in the tropics (Fig. 5). Placed on a low inclination orbit, the satellite will measure precipitations, water vapor and radiative fluxes in the tropical

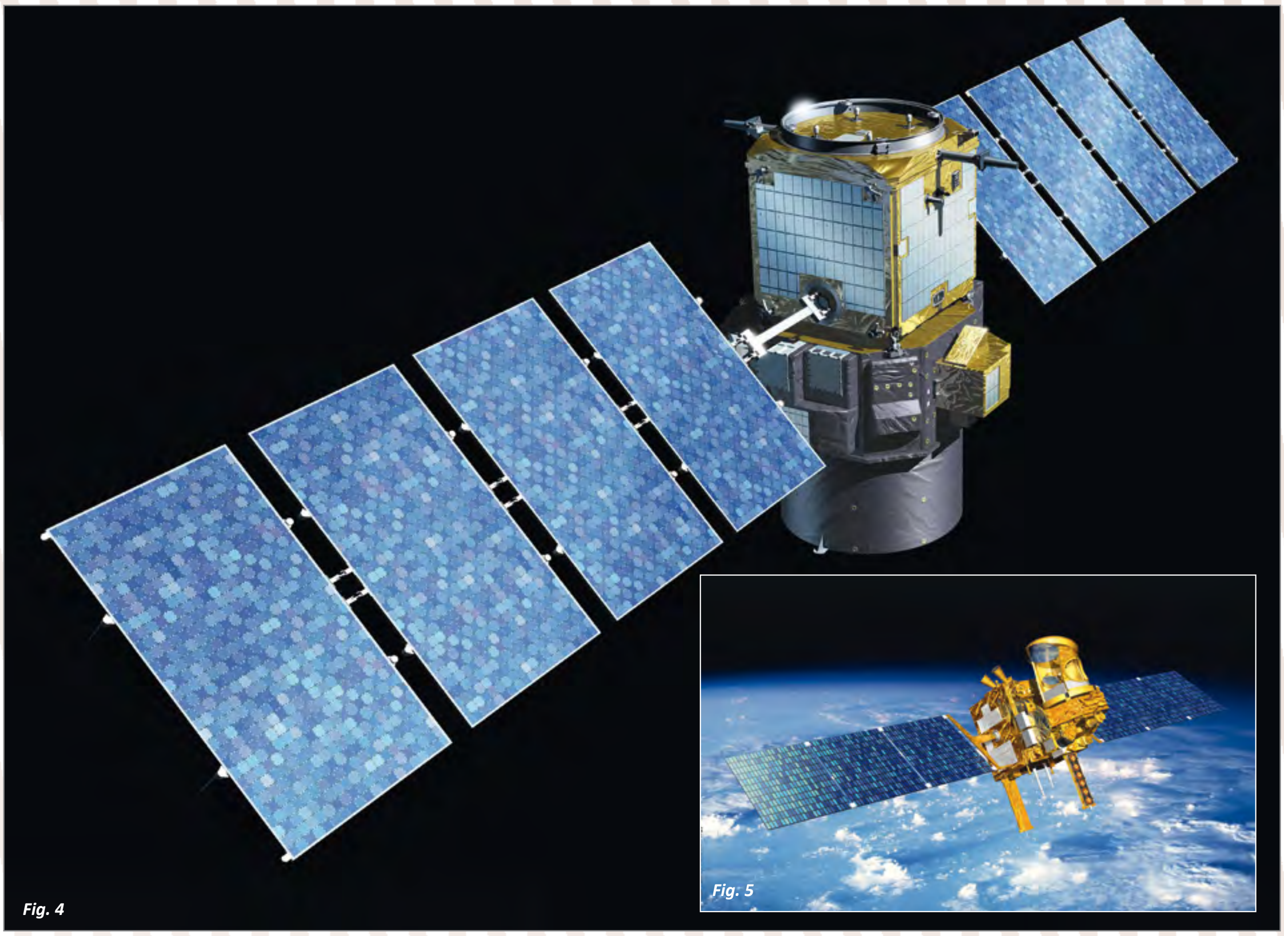

Fig. 4

Fig. 5

atmosphere with a good revisit rate. It carries four instruments: the microwave imager MADRAS (CNES-ISRO), the microwave sounder SAPHIR (CNES), the Earth radiation budget sensor SCARAB (CNES) and a GPS radio-occultation receptor ROSA (provided by ISRO).

The MEGHA-TROPIQUES satellite was launched on October 12, 2011. Since then, SAPHIR and SCARAB instruments have been functioning nominally (Fig. 3). But at the end of 2011, an anomaly occurred on the MADRAS instrument, leading to the intermittent reception of erroneous data, and in January 2013, a permanent failure occurred. ISRO and CNES teams are currently reprocessing the initial data from MADRAS in order to get corrected files from this instrument until January 2013.

The data from SAPHIR is going to be disseminated by EUMETSAT in near real time, via its Eumetcast system.

A partnership agreement between MEGHA-TROPIQUES and the program GPM (NASA-JAXA) has been signed between CNES and NASA and between ISRO and NASA.

New horizon for greenhouse gas observations from space with MERLIN

With the MERLIN project, Germany and France will open a new road by using lidar from space to measure methane (CH_4). Although methane is less present than carbon dioxide in today's atmosphere, it is a 25 times more effective greenhouse gas on a 100-year timescale. Then, it is the second most important component of the global carbon cycle and it contributes significantly to the warming of the Earth's climate. The MERLIN project is based on a lidar instrument, the first in space to measure greenhouse gas, developed under German Space Administration (DLR) responsibility, onboard the first model of Myriade Evolutions platform, which is developed under CNES responsibility. The project is now in phase B and is planned to be launched before 2020.

[Fig. 1]
IASI instrument at Thales Alenia Space.
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[Fig. 2]
Artist view of PARASOL microsatellite.
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[Fig. 3]
Preparation of the SAPHIR instrument for thermal vacuum tests at Intespace.
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[Fig. 4]
Artist view of minisatellite CALIPSO.
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[Fig. 5]
Artist view of MEGHA-TROPIQUES satellite.
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AUTHORS: R. Roca[(1)] and the members of the MEGHA-TROPIQUES mission
[(1)] LEGOS, UMR 5566, 14 avenue Edouard Belin, 31400 Toulouse, France.

Laboratory contribution

Atmosphere

The MEGHA-TROPIQUES mission: a tool to study the tropical water and energy cycles

La mission Megha-Tropiques pour l'étude du cycle de l'eau et de l'énergie dans les tropiques

➔ **Abstract:** *MEGHA-TROPIQUES carries on board a suite of payloads dedicated to atmospheric water under all its forms (humidity, clouds, and precipitation) as well as to radiation budget measurement. The mission is on a low inclined orbit that allows a high revisit capability in lines with the fast fluctuations of tropical convection. After more than two years in operation, the very good instrumental and geophysical performances of the mission are summarized.*

➔ **Résumé :** Megha-Tropiques emporte à son bord une série d'instruments dédiés à l'étude de l'eau atmosphérique sous toutes ses formes (humidité, nuages et précipitations) et à la mesure du bilan radiatif. La mission opère sur une orbite faiblement inclinée sur l'équateur qui lui confère une capacité de revisite élevée en adéquation avec les fluctuations rapides de la convection tropicale. Après plus de deux ans en opérations, les très bonnes performances instrumentales et géophysiques sont résumées ci-dessus.

Megha stands for clouds in Sanskrit and *Tropiques* for tropics in French and both clearly convey the core interest of the mission: convective clouds in the tropical climate system. The MEGHA-TROPIQUES (MT) mission is jointly operated by CNES and ISRO. The launch took place on October 12, 2011 from Sriharicota, India. The scientific objectives of the mission are structured into four topics. The first deals with the quantification and monitoring of the water and energy budget over the intertropical belt and relies on the MT mission itself as well as international partnerships with various agencies operating other radiation budget instruments and the participants to the Global Precipitation Measurement constellation of which MT is an official member. The second objective is processes-oriented and focuses on the understanding of tropical storms' life cycle. The third concerns continental hydrology and flooding risk. Finally, the MT mission also serves operational perspectives thanks to real time delivery of the radiometer data via EUMETSAT to numerical weather prediction centers for assimilation purposes.

To achieve these objectives, a suite of three main instruments has been developed. The MADRAS radiometer is a conical scanning multi frequency microwave imager dedicated to rainfall and precipitable water measurements and includes an original 157 GHz channel for ice clouds monitoring (this instrument stopped delivering scientific data on January 26, 2013). The SAPHIR radiometer is an across-track 6 channels sounder centered around 183 GHz and designed for humidity profiling. The SCARAB instrument is a broad band radiometer operating in the long wave and shortwave spectrum to access the Earth radiation budget at the top of the atmosphere. In complement, a radio-occultation GPS receiver ROSA is profiling the atmosphere. The mission operates from an 867 km height on a quasi-circular orbit at 20° on the equator. The combined effect of the instrument swath and orbit yields to a unique sampling pattern with up to 5-6 overpasses a day over the 10°-15° latitude band.

The monitoring of the on-board calibration of MADRAS and SAPHIR indicates very stable and low noise performances well within the specifications. A specific campaign of collocation of the SCARAB radiances together with the CERES instrument TERRA on board took place in spring 2012. For each forecasted crossing of the two satellites, an alert was sent to NASA that resulted in an *on-the-fly* reprogramming of the scanning angle of CERES to insure similar observing geometry for both instruments, hence maximizing the valid comparison point number. Statistics show that the two instruments, based on different technologies, do agree with each other within their own instrumental uncertainties: < 1% in the longwave and < 2% in the shortwave, confirming the excellent calibration of SCARAB radiances.

A suite of retrieval algorithms has been developed at the Laboratoire de Météorologie Dynamique and the Laboratoire Atmosphères, Milieux, Observations Spatiales from the Institut Pierre Simon Laplace to take advantage of all these measurements and has been implemented for production on the ICARE facility in Lille. Fig. 1 shows a snap shot of hurricane Sandy over the Caribbean islands using the suite of products. Note that during its early phase, Sandy was sampled 16 times by MT: more than the sum of observations from the DMSP and the TRMM satellites. The instantaneous measurements are furthered combined with the geostationary satellite imagery to compute daily accumulated precipitation, composite storms life cycle statistics, etc. An extensive validation effort has been performed based on systematic comparisons with ground-based data with emphasis on the West African and Indian monsoon region. Polarimetric and weather radars, rain gauges networks and radiosondes have been confronted

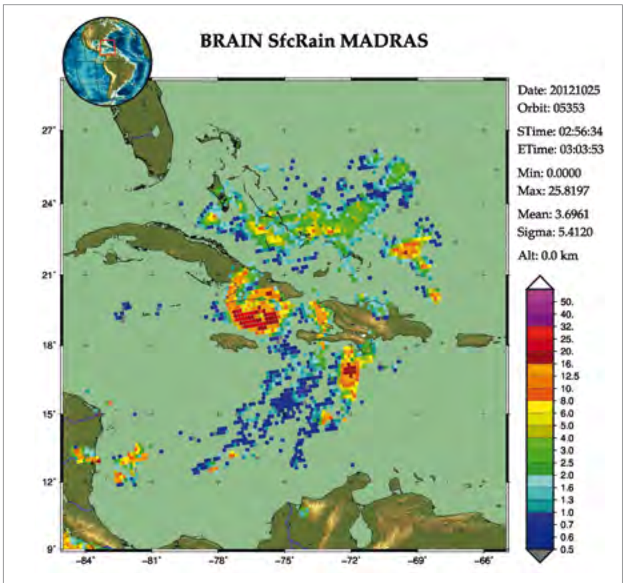

Fig. 1a

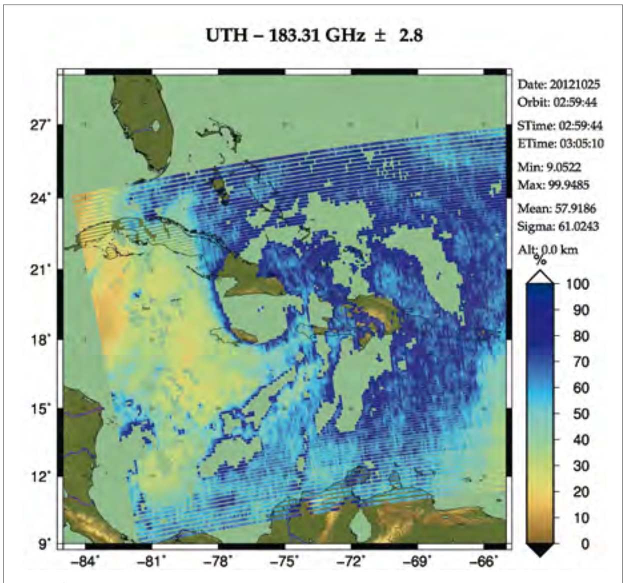

Fig. 1b

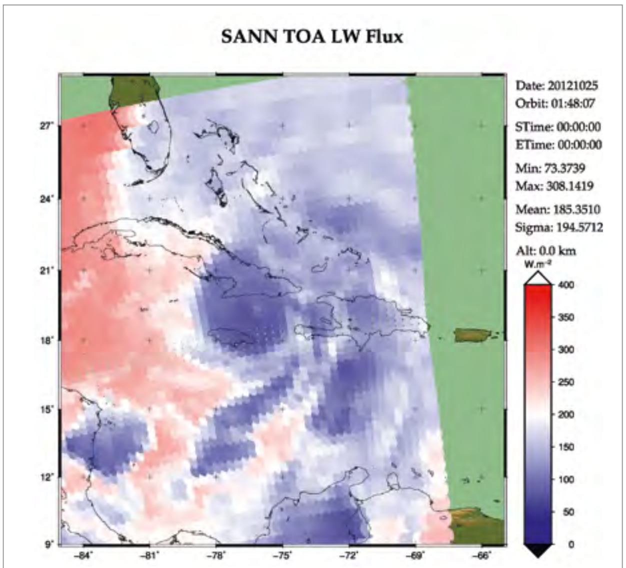

Fig. 1c

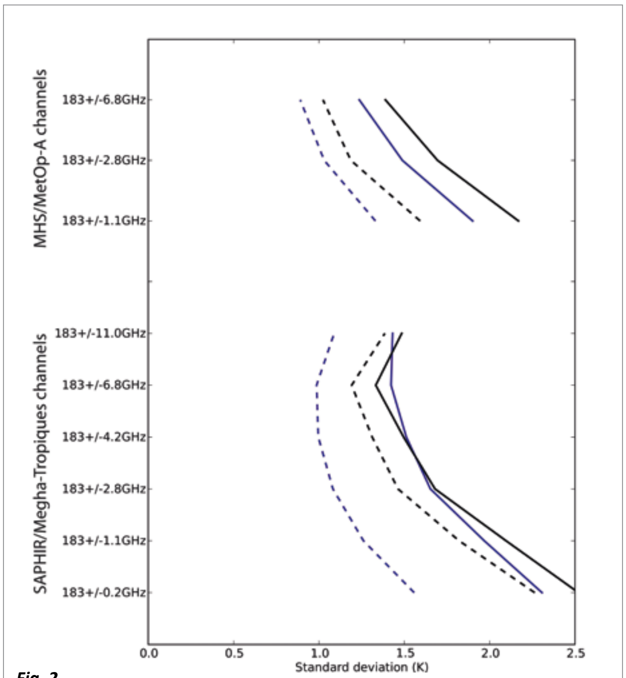

Fig. 2

to the satellite derived quantities. Daily rainfall is shown to agree well to the surface network exhibiting high temporal correlation, low bias and rms (~10-20%). Note that the inclusion of the MADRAS derived instantaneous rain rate estimate in the accumulated product improves significantly the comparison with *in situ* data. Similarly, layered relative humidity from SAPHIR is characterized by an excellent agreement with the large collection of high quality soundings obtained during the CINDY/DYNAMO campaign (RMS < 10%). Radiation budget estimates have been shown to agree with the CERES flux products within a small 6%. Preliminary assimilation test of the SAPHIR radiances in the METEO-FRANCE forecast system reveals the benefit to the overall system (Fig. 2). The positive impact of SAPHIR data is seen in the forecast of the lower level humidity distribution up to five days.

After a long commissioning phase, the MEGHA-TROPIQUES mission is now ready so that both the scientific and the operational communities can benefit from its excellent performances.

[Fig. 1]
Hurricane Sandy observed by MEGHA-TROPIQUES. a) rainfall (mm/h) from MADRAS, b) upper tropospheric humidity from SAPHIR (%) and c) outgoing longwave radiation from SCARAB (Wm-2).
© Courtesy of Nicolas Viltard, LATMOS/CNRS

[Fig. 2]
Improvements of innovation statistics of MHS/METOP-A and SAPHIR/MT when SAPHIR is assimilated into the ARPEGE global model operational at METEO-FRANCE. Innovation statistics are defined as the standard deviation of difference: observation minus model-simulated observations. In full lines, the simulated observations are based on short-range model forecasts and in dashed lines they are based on model analysis. Black lines are for the control experiment, and blue lines correspond to the experiment with SAPHIR data assimilated.
© Courtesy of Philippe Chambon, CNRM/METEO-FRANCE

AUTHOR: C. Crevoisier[1]

Laboratory contribution

[1] Laboratoire de Météorologie Dynamique (LMD), Ecole Polytechnique, UMR 8359, route de Saclay, 91128 Palaiseau Cedex, France.

Atmosphere

IASI, an extraordinary asset to monitor essential climate variables

Iasi, un atout extraordinaire pour le suivi des variables climatiques essentielles

➔ **Abstract:** *Launched onboard METOP-A in 2006 and METOP-B in 2012, the Infrared Atmospheric Sounding Interferometer (IASI) developed by CNES in collaboration with EUMETSAT has demonstrated its capability to establish robust long term data records of several essential climate variables, to assess potential trends, and to detect signatures of specific climate events, such as ENSO, at both global and regional scales.*

➔ **Résumé :** Lancé à bord des satellites Metop-A en 2006 et Metop-B en 2012, l'Interféromètre Atmosphérique de Sondage Infrarouge (Iasi), développé par le CNES en collaboration avec EUMETSAT a d'ores et déjà démontré sa capacité à suivre sur le long terme de nombreuses variables climatiques essentielles, à repérer leurs tendances potentielles et à détecter les signatures de certains évènements climatiques tel l'Enso, à des échelles tant régionales que globales.

Infrared sounders are a key element of space observation of the Earth system. They enable the monitoring of several thermodynamic, chemistry and climate variables over land and sea, both night and day. In particular, the Infrared Atmospheric Sounding Interferometer (IASI), flying onboard METOP-A since October 2006 and METOP-B since September 2012, has demonstrated the possibility to retrieve or detect several chemistry and climate variables from hyperspectral infrared observation [1] on both regional and global scales. IASI has given access to species that had never previously been observed from space on a global scale and enables the monitoring of key gases for climate and atmospheric chemistry in quasi near real time. IASI has also highlighted the benefit of high-performance infrared sounders for numerical weather prevision applications.

In compliance with recommendations from international programs, such as the World Climate Research Program (WCRP) or the Global Climate Observing System (GCOS), IASI contributes to the establishment of robust long term data records of several Essential Climate Variables (ECVs). Out of the 16 atmospheric ECVs as defined by GCOS, 12 are actually monitored by IASI. Among them, we can mention:

(i) clouds properties: pressure, temperature, emissivity of all clouds, as well as ice water path, effective particle size and indication of particle shape of semi-transparent cirrus, day and night. These properties are then used to understand cloud formation in combination with upper tropospheric relative humidity, aerosols and cloud radiative budget;
(ii) greenhouse gases [2]: mid-tropospheric columns of CO_2, CH_4 and CO over both land and sea, day and night, with the aim of better understanding surface sources and sinks and related processes (transport, fire emissions);
(iii) dust aerosols properties [3] at 10 μm (preferential detection of dust aerosol coarse mode): optical depth, vertical distribution, size and analysis of their interaction with the climate system;
(iv) continental surface characteristics [4]: surface temperature and emissivity continuous spectrum at 0.05 μm resolution between 3.7 and 14.0 μm in order to improve the retrieval of tropospheric properties and to estimate the radiative budget.

The climatologies of these ECVs derived over six years (2007-2012) from METOP-A IASI observations at the Laboratoire de Météorologie Dynamique are plotted in Fig.1. Their analyses have particularly highlighted the potential of IASI not only to monitor the evolution of ECVs on the long-term, but also to assess their potential trends, and to detect signatures of specific climate events. For instance, a severe drought occurred in the Amazon region from mid-2009 to the end of 2010 originating from the combination of El Niño conditions during the wet season followed by a warming of the tropical North Atlantic during the dry season (Fig. 2). This drought induced a decrease of CH_4 atmospheric burden seen by IASI coming from a decrease in wetland emissions; it also induced a strong increase in CO and CO_2 atmospheric burdens because of a strong increase in fire activity, especially in the so-called "arc of deforestation". This example shows that the simultaneous monitoring of several variables can help a better characterization of regional climate events.

The capability of IASI to accurately monitor the variability and evolution of climate stems from two elements:

(i) properly documented and well calibrated observations associated to outstanding spectral and radiometric stability,

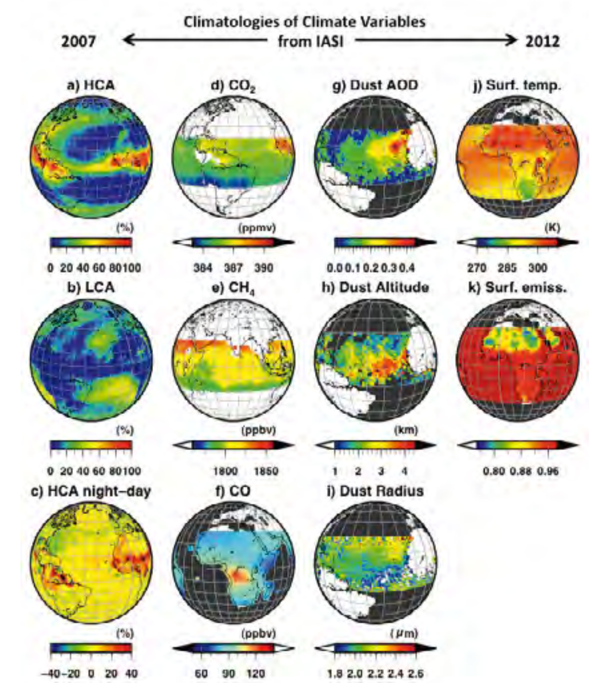

Fig. 1

[Fig. 1]
Climatologies over 6 years (2007-2012) of several essential climate variables from METOP-A/IASI: (a) high, (b) low and (c) diurnal variation of high cloud amounts; mid-tropospheric columns of (d) CO_2, (e) CH_4 and (f) CO; optical depth (g), mean altitude (h) and radius (i) of dust aerosols; surface temperature (j) and emissivity (k).
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which have led to IASI becoming the reference for the Global Space-based Inter-Calibration System (GSICS) of WMO;
(ii) permanent validation and improvement of key elements of the processing chains of satellite observations, which include: spectroscopic databases and radiative transfer codes (such as GEISA and 4A which are respectively the official database and code for IASI Cal/Val activities at CNES), development of dedicated cloud and aerosol detection schemes, retrieval processes, and validation activities.

The suite of long time series of climate variables retrieved from IASI continues to expand. Beyond the IASI program, CNES, in collaboration with EUMETSAT, has already begun the conception of the IASI-New Generation (IASI-NG) mission as part of the Earth Polar System-Second Generation (EPS-SG) program. Based on improved spectral and radiometric characteristics [5], IASI-NG main objectives will be:

(i) continuity of the IASI series;
(ii) improvement of the vertical coverage and resolution, especially in the lower troposphere;
(iii) improvement of the precision and detection threshold of several variables.

Owing to their exceptional spectral and radiometric stability, and to their ability to characterize simultaneously several climate variables, IASI and IASI-NG will play a major role in the monitoring and understanding of climate evolution and variability over the next 40 years.

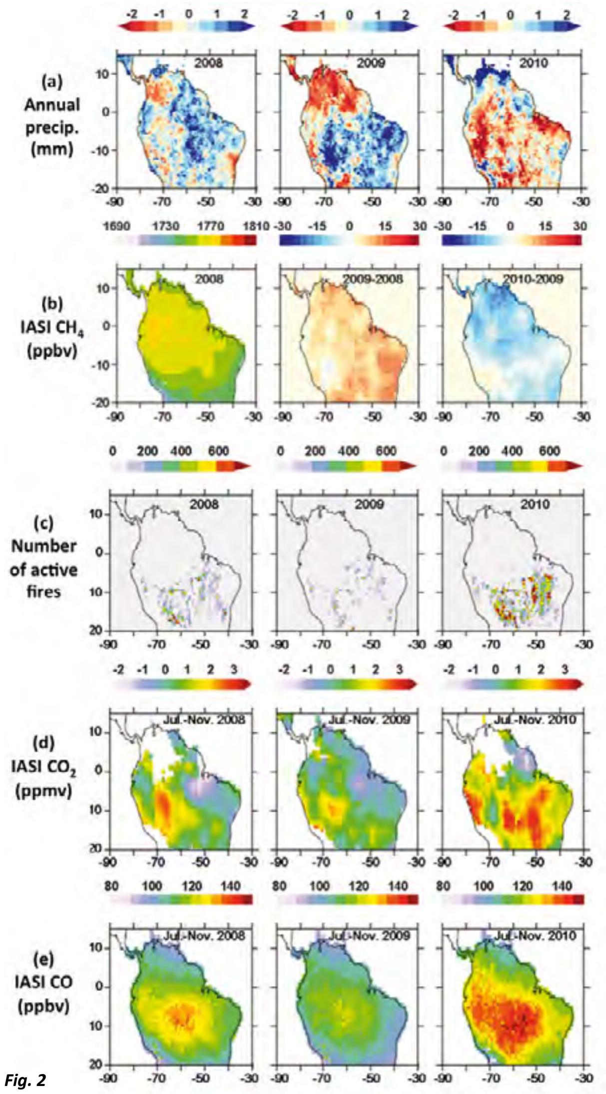

Fig. 2

[Fig. 2]
2008-2010 evolution over the Amazon region: (a) Annual precipitation from TRMM; (b) mid-tropospheric column of CH_4 as retrieved from IASI for 2008 and difference between 2009-2008 and 2010-2009; (c) Number of active fires from MODIS; mid-tropospheric columns of (d) CO_2 and (e) CO as retrieved from IASI during the fire season.
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