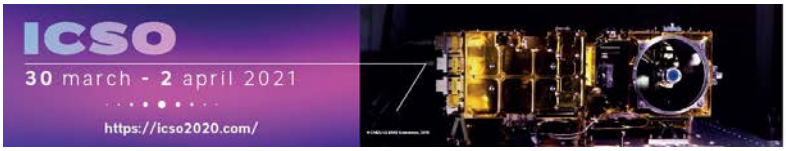
International Conference on Space Optics—ICSO 2020

Virtual Conference

30 March–2 April 2021

Edited by Bruno Cugny, Zoran Sodnik, and Nikos Karafolas



IASI-NG: when improving our understanding of the Earth atmosphere requires to multiply innovations in an operational meteorological programme

International Conference on Space Optics — ICSO 2020, edited by Bruno Cugny, Zoran Sodnik, Nikos Karafolas, Proc. of SPIE Vol. 11852, 1185204 · © 2021 ESA and CNES
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IASI NG A more precise look on the Earth Athmosphere

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Innovation and space sciences in 2021

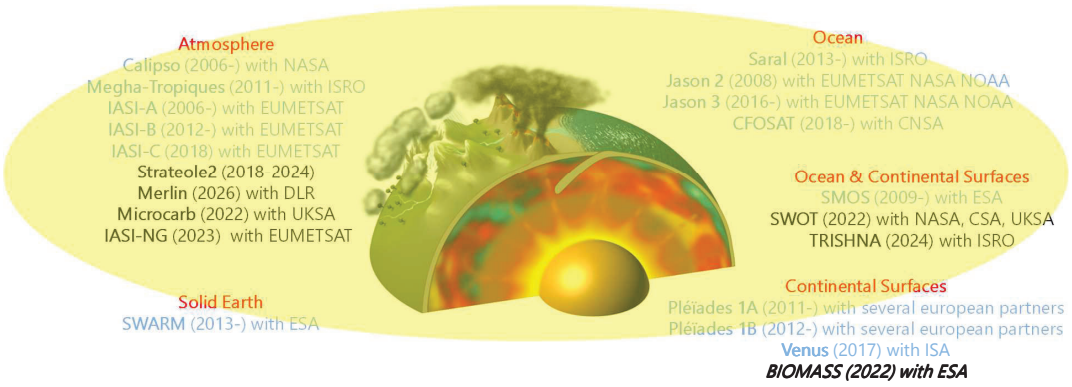
Do the space agencies - and industries - still accept to take risk for the development of space systems ?

Do we accept risks only for nano-satellites or demonstrators ?

… the IASI-NG example partially answers the question…

The Earth Observation Program at CNES

CNES missions under development or in orbit



+ Contribution to Copernicus Sentinels : Sentinel 2, 3 and 6
+ ~ 10 pre-phase A studies conducted every year → Preparation of the future

→ A diversity of partners : NASA, EUMETSAT, DLR, ESA, CNSA, ISRO, ISA, …
→ All components of the Earth System are adressed, and their interactions
→ Several multi-thematic missions : SMOS, SWOT, …

IASI NG
A more precise look on the Earth Atmosphere

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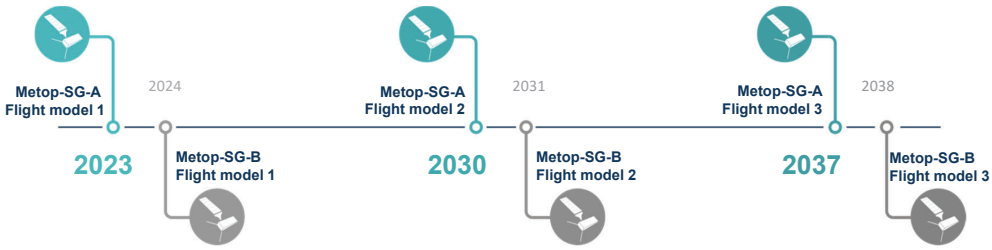
- The IASI-NG program
- From IASI to IASI-NG: new challenges for ambitious scientific goals
- Innovations from the instrumental concept to data processing
- Some perspectives about future atmospheric sounding missions

IASI-NG and EPS-SG

IASI-NG is part of the EUMETSAT EPS-SG program (European Polar Satellites). It will be on board Metop-SG A.
3 identical satellites will be launched in 2023, 2030 and 2037



IASI-NG is an interferometer that will acquire spectra in the thermal infrared wavelength.
It is the successor of IASI … well known for its positive impact on Weather Forecast and Atmospheric Composition studies

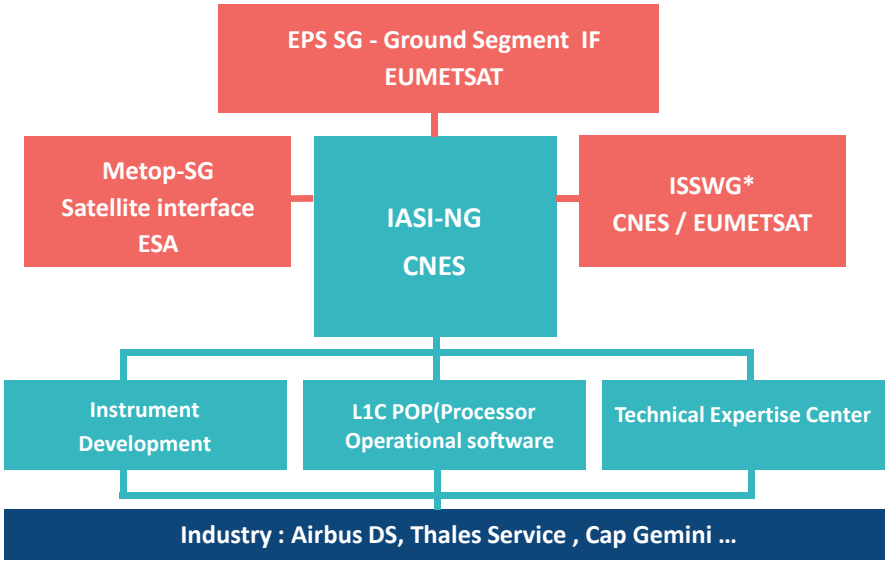
IASI-NG
An international Program

IASI-NG Development :
- 3 instruments to be flown on the series Metop-SG A Satellites
- Level 1 Operational Processor (L1CPOP) processing scientific data up to level 1C
- Technical Expertise Center (IASTEC) performances monitoring in orbit

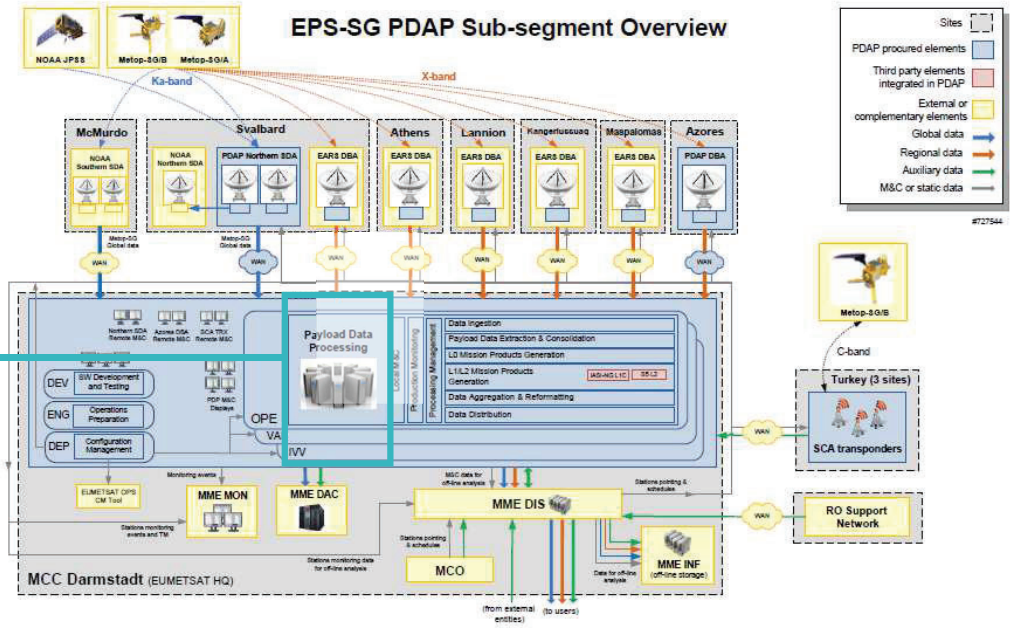
Partners
- Eumetsat : EPS-SG system development,
- ESA : Metop-SG A & B Satellite development.
- Norway, UK, Swiss Space Agencies

Industry
Different instrument concepts trade-off performed : A Mertz interferometer allowing a field Effect compensation concept selected from Airbus DS proposal

Project organisation



L1C POP
Development



IASI-NG L1C POP

Integrated in Payload Data Acquisition and Processing component within EPS-SG overall ground segment at EUMETSAT

DATA FLOW
MOVIE

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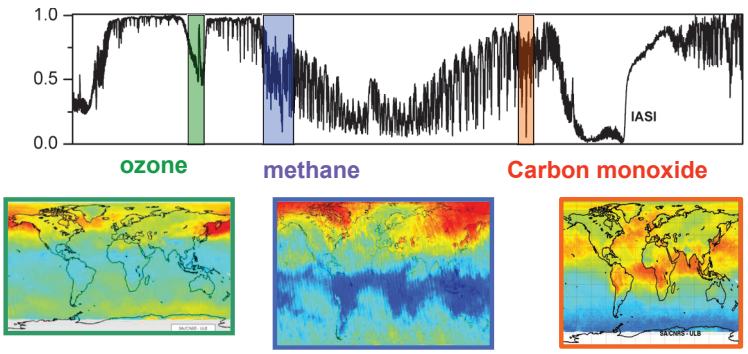
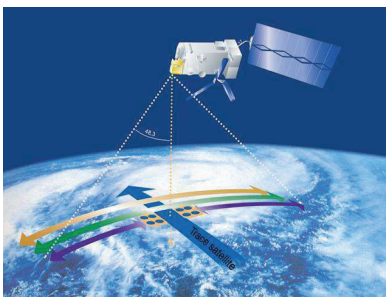
Atmospheric sounding

- Passive measurements of Earth-atmosphere radiations
- Detection and quantification of gases based on measurements of absorption features in the spectrum
- Retrieval of concentrations profiles thanks to the high spectral resolution





C. Clerbaux LATMOS/ULB

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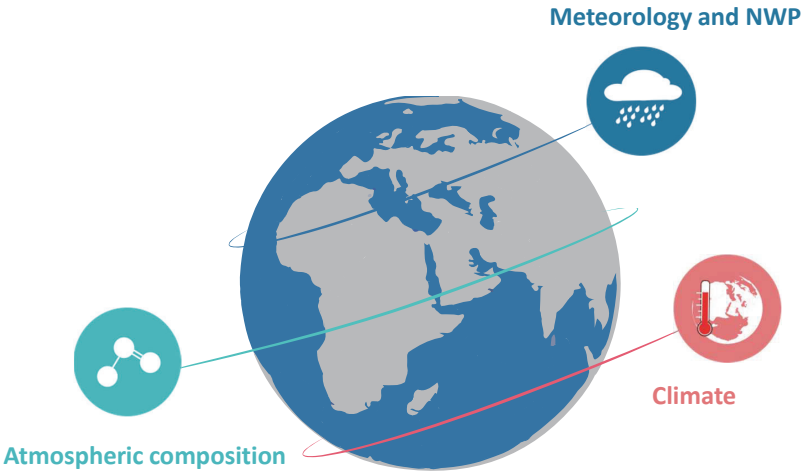
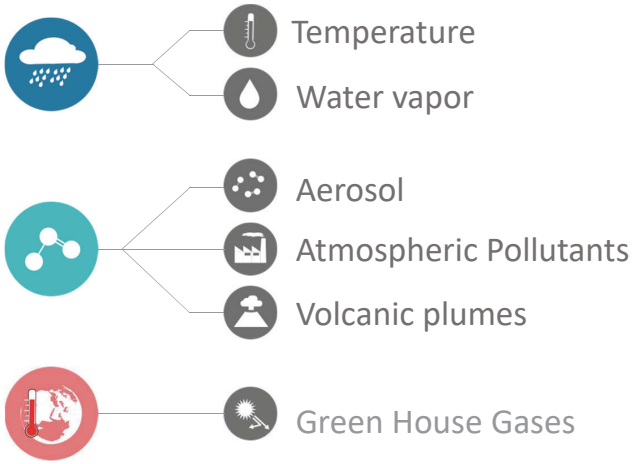
The targeted applications for IASI and IASI-NG are the same:

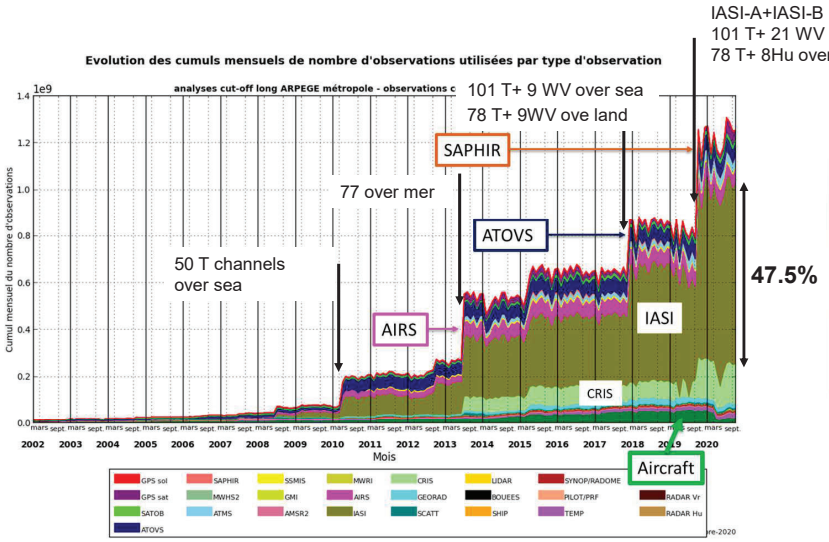


The breakthrough will be on the data quality (radiometric and spectral resolution)…

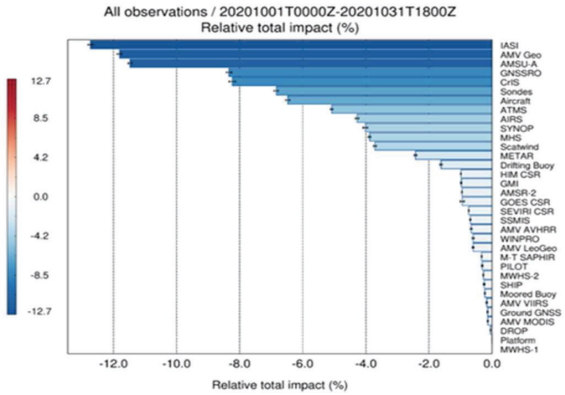
Several geophysical parameters may be retrieved from IASI spectra:



Importance of IASI data in the assimilation schemes for NWP



Météo-France

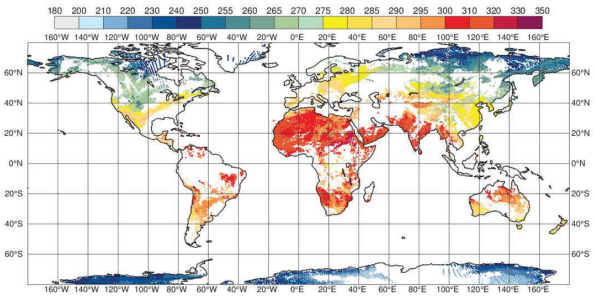


UK MetOffice

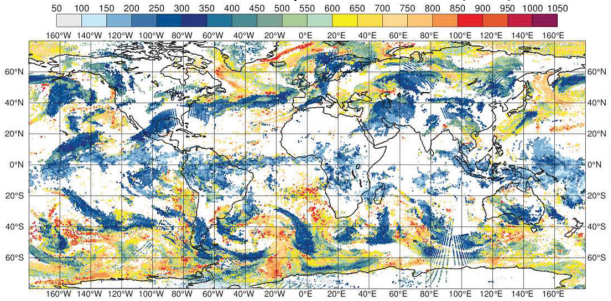
The new challenges of NWP .. for which IASI-NG should be helpful

Surfaces and clouds

Retrieved temperature in K (clear sky)



Pressure on top of the clouds (hPa)

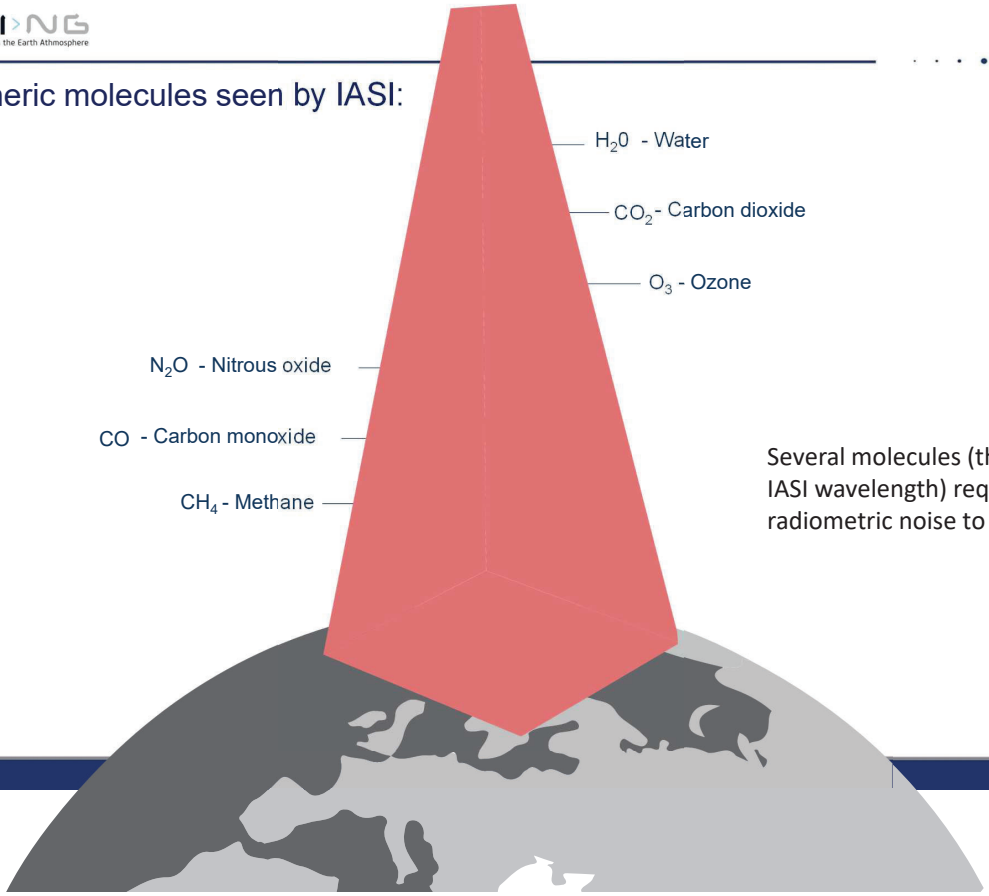


Chemistry: ozone, CO_2, CH_4, CO, N_2O

Towards an integrated Earth system …

=> **Increasing number of IASI channels that are operationally assimilated**

Atmospheric molecules seen by IASI:



Several molecules (that absorb in the IASI wavelength) require very low radiometric noise to be quantified

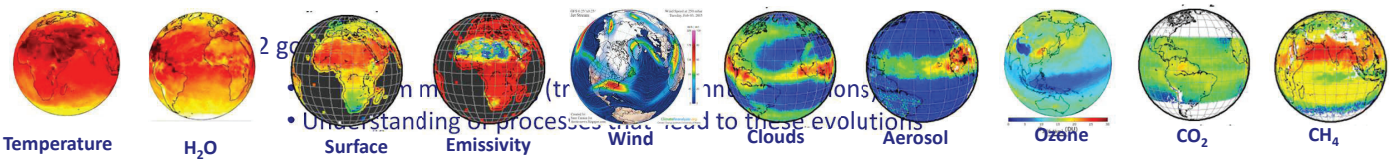
Climate

Most of atmospheric Essential Climate Variables (ECV) can be observed by IASI, day and night.

The Essential Climate Variables

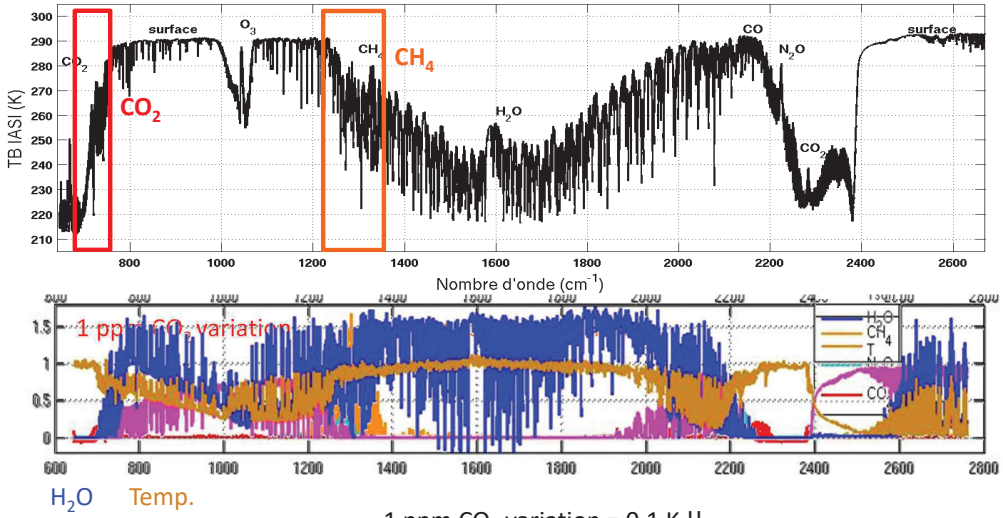
Domain	Essential Climate Variables	
Atmospheric (over land, sea and ice)	Surface:	Air temperature, precipitation, air pressure, surface radiation budget, wind speed and direction, water vapour.
	Upper air:	Earth radiation budget (including solar irradiance), upper air temperature (including MSU radiances), wind speed and direction, water vapour, cloud properties.
	Composition:	Carbon dioxide, methane, ozone, other long-lived greenhouse gases, aerosol properties.

17 atmospheric ECV



2 go
• Understanding of processes that lead to these evolutions

The trends to be observe are very small



1 ppm CO_2 variation = 0,1 K !!
Trend : ~ 2ppm.an^{-1} = 0,2 K.an^{-1} !!
→ **A very accurate calibration of the instrument is needed**

IASI-NG will acquire spectra in the same wavelength as IASI does

- With a two times better spectral resolution
- A two times lower radiometric noise

Which gain for the scientific applications ?

- Better estimation of atmospheric species (especially in the troposphere)
- Trace gases retrieval in an higher number of atmospheric levels

innovations from the instrumental concept to data processing

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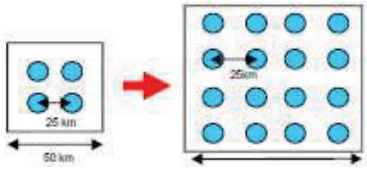
From IASI to IASI-NG: innovations and new challenges

IASI-NG Level 1 main characteristics

Main figures	IASI	IASI-NG
Radiometric Resolution (NeDT)		IASI/2
Spectral resolution	0.5 cm^{-1}	IASI/2 (0.25 cm^{-1}@L1C)
Absolute Radiometric Calibration	< 0,5K	IASI/2 (<0,25K@280K)
Spectral bands	3 bands	4 bands
Number of sounder pixels per acquisition	4 pixels	16 pixels
Ground Pixel diameter	12 km	12 km
Ground sampling	25 km	25 km

To meet these challenging requirements, innovations were needed…



IASI IASI-NG

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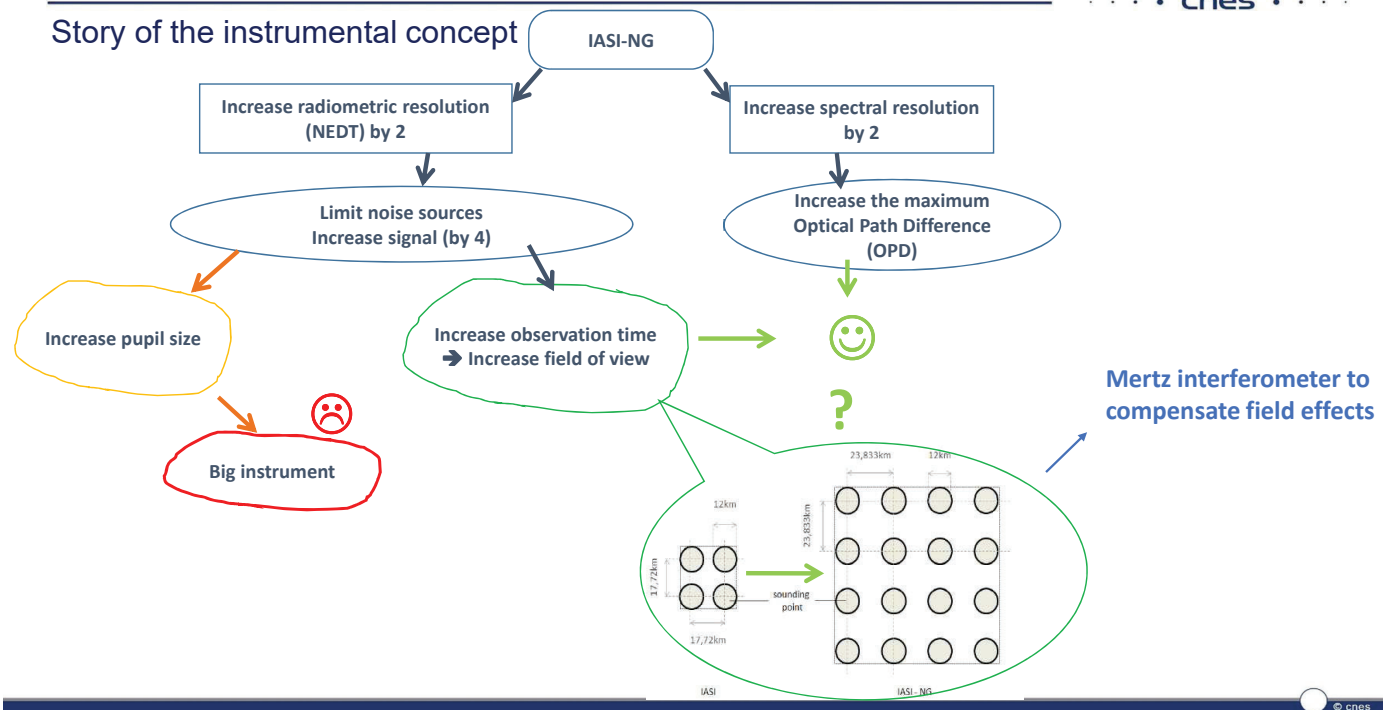
Story of the instrumental concept



From IASI to IASI-NG: innovations and new challenges

- **IASI vs IASI-NG ?**

→ **With great performance comes great complexity**

IASI interferometer

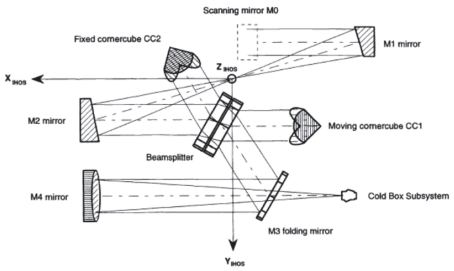
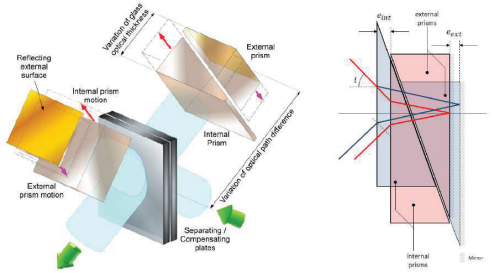


Figure 3.1-1 : IHOS optical configuration

- 4 optical components
- 1 moving corner cube
- nearly achromatic / all reflective design
- 1 laser trigs the acquisition

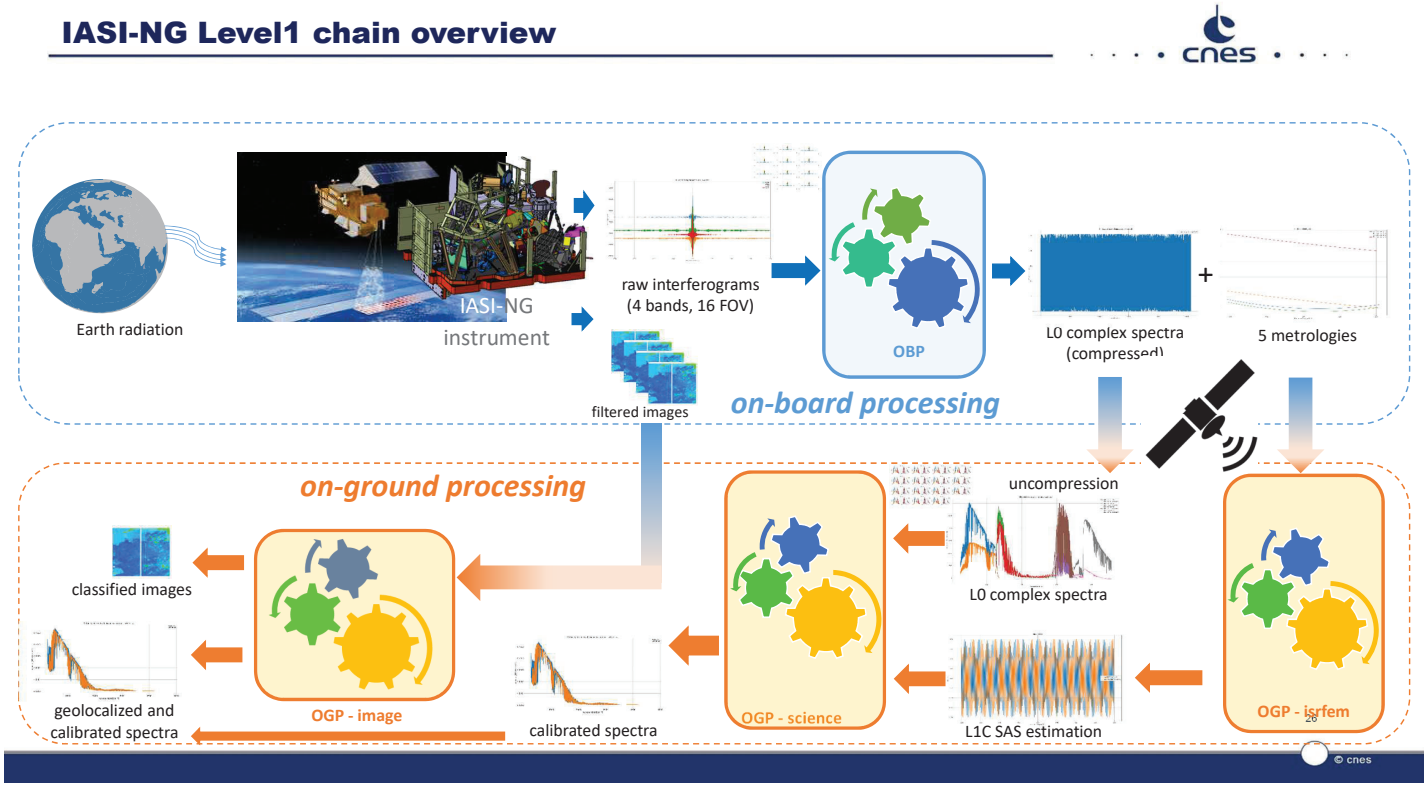
IASI-NG interferometer



- 6 optical components
- 4 moving prisms, simultaneously
- chromatic and refractive design
- 1 laser trigs the acquisition, 4 additionnal lasers for opd estimation

F. Henault, C. Buil and al. – spaceborn infrared interferometer of the IASI instrument. Proc SPIE 3437, Infrared Spaceborn Remote Sensing VI. 18/11/1998

INSTRUMENT MOVIE



DATA PROCESSING MOVIE

The ISRF – Estimation Model

- **ISRF estimation: the second main innovation**
  - ISRF is estimated for every set of 16x4 acquisitions

estimating the ISRF = knowing the science opd

Airbus D&S shows that the opd for every wavelength in the science band can be approximated by a linear combination of the 5 metrologies opd :

$$\mathbf{opd}(\boldsymbol{\sigma}) = \left(\mathbf{A_{cal}}(\boldsymbol{\sigma}) - \mathbf{C_0}(\boldsymbol{\sigma}, \mathbf{Z_0})\right).\mathbf{Z_0} + \sum_{\mathbf{i=1}}^{\mathbf{4}} \mathbf{C_i}(\boldsymbol{\sigma}, \mathbf{Z_0}).\mathbf{Z_i} + \mathbf{OFFSET}(\boldsymbol{\sigma}, \mathbf{Z_0})$$

$\mathbf{Z_{i=1..4}}$: metrologies opd
$\mathbf{Z_0}$: reference metrology opd
$\mathbf{C_{i=0..5}}$: opd coefficients

The ISRF – Estimation Model

- **IASI-NG ISRF estimation principle**

  - **ISRF-Estimation Model parameters - Coefficients**

$$\mathbf{opd}(\sigma) = \left(\mathbf{A_{cal}}(\sigma) - \mathbf{C_0}(\sigma, \mathbf{Z_0})\right).\mathbf{Z_0} + \sum_{\mathbf{i=1}}^{\mathbf{4}} \mathbf{C_i}(\sigma, \mathbf{Z_0}).\mathbf{Z_i} + \mathbf{OFFSET}(\sigma, \mathbf{Z_0})$$

$\mathbf{Z_{i=0..4}}$: metrologies opd
$\mathbf{Z_5} = \mathbf{1}$
$\mathbf{C_{i=0..5}}$: opd coefficients

They are a combination of :

Computed coefficients

- Using a numerical model of the interferometer
- Parameters of the model can be updated in-orbit using WFS

The ISRF – Estimation Model

- **IASI-NG ISRF estimation principle**

  - **ISRF-Estimation Model parameters - Coefficients**

$$\mathbf{opd}(\sigma) = \left(\mathbf{A_{cal}}(\sigma) - \mathbf{C_0}(\sigma, \mathbf{Z_0})\right).\mathbf{Z_0} + \sum_{\mathbf{i=1}}^{\mathbf{4}} \mathbf{C_i}(\sigma, \mathbf{Z_0}).\mathbf{Z_i} + \mathbf{OFFSET}(\sigma, \mathbf{Z_0})$$

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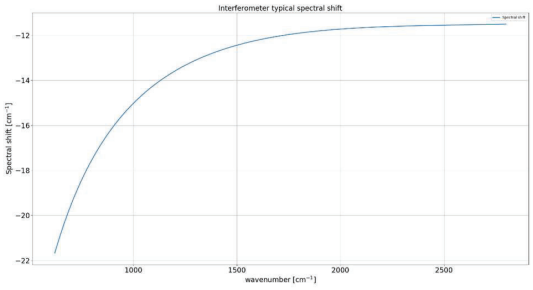


Measured coefficient

- On-ground spectral shift (first guest)
- In-orbit determination using dedicated acquisitions sequences (atmospheric spectra correlation + FPI)

The ISRF – Estimation Model

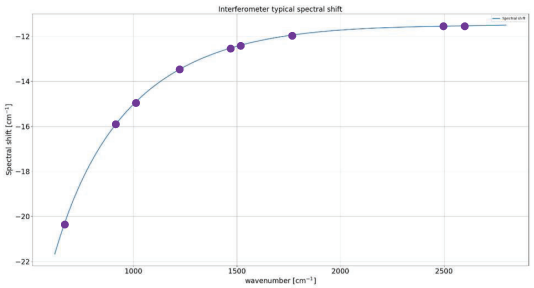
- **IASI-NG ISRF estimation principle**

➢ **ISRF-Estimation Model parameters – Coefficients – A_{cal}**

The A_{cal} coefficient is related to the spectral shift $\Delta\sigma$ throught the simple relation :

$$\mathbf{A_{cal}(\sigma)} = \frac{\Delta\sigma}{\sigma}$$

1- $\mathbf{A_{cal}(\sigma)}$ values are computed for few wavenumbers (anchor points) across the IASI-NG band using correlation between observed and modeled spectra.



The ISRF – Estimation Model

- **IASI-NG ISRF estimation principle**

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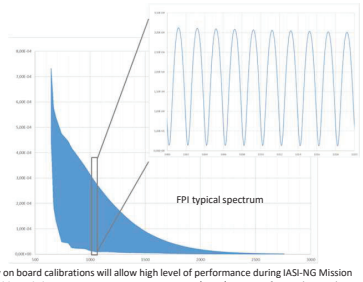
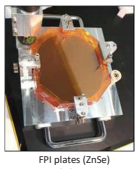
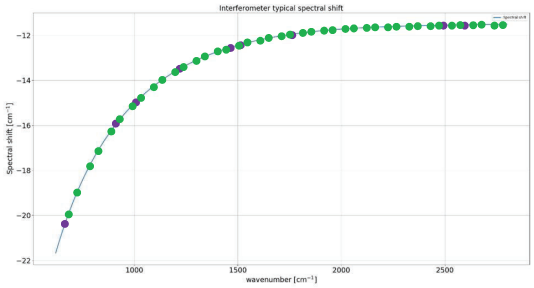


How on board calibrations will allow high level of performance during IASI-NG Mission
E. Baldit and al – Poster session – Joint EUMETSAT/AMS/NOAA conf. 2019 (Boston)

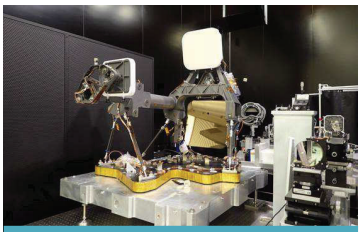


FPI plates (ZnSe)
Winlight optics



IASI-NG Instrument Flight Model Integration and Test

FPCA PFM

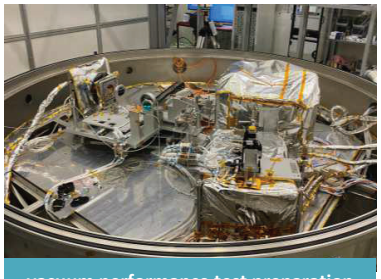


ATA telescope aligned

Integration of the electronic module

Focal plane and Cryo-cooler assembly and IFM integration on Optical Module

Integration of the Scan on the mezzanine



vacuum performance test preparation with the PFM interferometer

System performances budget

- **Synthesis of the current performances budget (compared to specifications at mission level) for the main requirements**

Mission Measurement Requirement	Corresponding System Requirement	Description	Specified value / calculated value	Status
SRD.IAS_20	SYS_ISRFM_070_SPACE SYS_ISRFM_080_SYS	Interpixel ISRF stability ISRF shift knowledge	1E10-4 / 3.3E10-5 1E10-6 / 1.145E10-6 (WC)	compliant (partially)
SRD.IAS_60	SYS_ISRFM_080_SYS SYS_ISRFM_130_SYS	ISRF shift knowledge Shape error	1E10-6 / 1.145E10-6 (WC) See Figure 2	Marginally NC
SRD_IAS.90	SYS_PIPR_020_SPACE SYS_PIPR_065_GRND	Radiometric noise	See Figure 5	Marginally NC
SRD_IAS.100	SYS_PIPR_075_SYS	Absolute radiometric calibration	0.25 K (O) and 0.5 K (T) / 0.24K	compliant
SRD_IAS.110	SYS_PIPR_100_SPACE	Radiometric bias	0.1 K (O) and 0.05 K (T) / 0.125K	Non compliant
SRD_IAS.120	SYS_PIPR_110_SPACE	Lifetime radiometric stability	0.1K / 0.42K	Non compliant
SRD_IAS.130	SYS_PIPR_120_SPACE	Interchannel radiometric bias	0.1K / 0.084K	compliant
SRD_IAS.140	SYS_PIPR_130_SPACE	Intersscan/interpixel radiometric bias	0.1K/ 0.07K	compliant

Mission Measurement Requirement	Corresponding System Requirement	Description	Specified value / calculated value	Status
SRD_IAS.150	SYS_GEOM_010_SPACE	Spatial coverage	By design	compliant
SRD_IAS.160	SYS_GEOM_090_SPACE	Spatial resolution	11.5 +/- 0.5 km / 11.8km	compliant
SRD_IAS.170	SYS_GEOM_100_SPACE	Off nadir resolution	-	compliant
SRD.IAS_180	SYS_GEOM_040_SPACE	Pointing stability	0.1 mrad / 0.062 mrad	compliant
SRD_IAS.190 SRD_IAS.195	SYS_FMISSION_040_SYS SYS_FMISSION_045_SYS	Sounder geolocation	1-5km / 601-950m 1.745mrad/1.188mrad	compliant
	SYS_LV1_110_GRND	Geolocation in degraded case	5km / 916 m	compliant
SRD_IAS.200	SYS_GEOM_070_SPACE	Pointing knowledge	+/- 3 mrad / 0.9mrad	compliant
SRD_IAS.220	SYS_GEOM_020_SYS	Angular distance	[25-50mrad] / [26.74 - 43.26mard]	compliant
SRD_IAS.230	SYS_GEOM_100_SPACE	Off nadir sampling	-	compliant
SRD_IAS.235	SYS_GEOM_030_SPACE	Pointing accuracy	+/- 3 mrad / 0.64mrad	compliant
SRD_IAS.250	SYS_PIPSF_040_SPACE	PSF uniformity knowledge	+/- 10 % / 8% in typical case	compliant

Other IASI-NG presentations in this conference

Session 38 Spectrometer 7 – on Thursday, at 16:00 (France time):

- Talk 221. IASI-NG instrument development and performance status
Elisa Baldit, CNES

- Talk 328. IASI NG Flight model development status
Bertrand Calvel, Airbus Defense and Space

IASI NG
A more precise look on the Earth Athmosphere

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CNES is supporting the ESA and EUMETSAT programs

The future IR sounding in Europe is mainly ensured by the EPS-SG and MSG (Meteosat Third Generation) programs

+ FORUM mission (Earth Explorer 9) in Far Infrared

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A more precise look on the Earth Athmosphere

Some perspectives

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In addition of these ambitious programs, CNES is focusing on miniaturized instrument concepts

The need of meteorological users if to increase revisit
→constellation of small satellites can be a solution

The miniaturization of IR interferometers is a challenge…
Different R&D and pre-development studies are on-going at CNES

Some perspectives on IR sounding

On-going studies on IR sounding missions aim at answering two different questions:

- How can we miniaturize interferometers without degrading the data quality ?
  → partial interferograms ?

- What kind of constellation (orbit/ number of satellites) can provide data where "classic" data are missing the most ?
  →Experiment with Meteo-France (CMIM currently in phase 0)

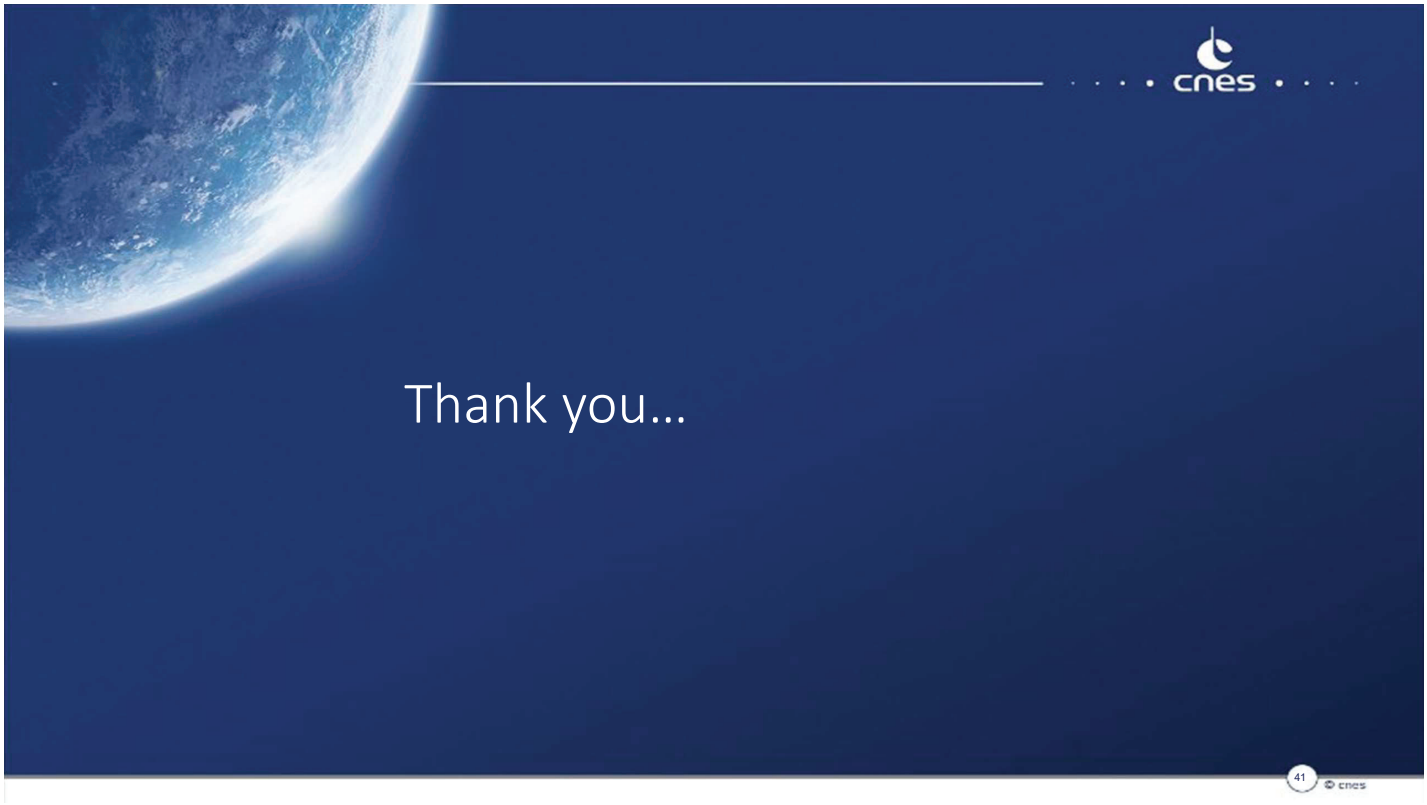
Phases 0 and A in Earth Observation at CNES

- **Phases A :**
  - ❑ WISA : wide-swath altimetry concept for Sentinel-3NG
  - ❑ SKIM : Ocean currents
  - ❑ ACCP (with NASA, C²OMODO/Tandem of MW radiometers)
  - ❑ C³IEL (Study of cloud in 4D at decametric resolution, with ISA)
  - ❑ SMASH (constellation of low-cost, miniaturized altimeters for operational hydrology)

- **Transitioning to phase A :**
  - ❑ Nanomagsat (magnetic fields measured from nanosats)
  - ❑ Hyperspectral
  - ❑ SMOS-HR revisité ->SMOS Next phase A1 –(Soil Moisture and Ocean Salinity at higher spatial resolution)

Phase 0

- ❑ MARVEL : Mass And Reference Variations for Earth Lookout
- ❑ CARIOQA – continuation of GRICE
- ❑ ARGC : « Architecture Réactive pour la Gestion des Catastrophes »
- ❑ MALBEC : Meteor Automated Light Ballon Experimental Camera
- ❑ EXPE-VAL (lidar/hyperspectral – forets)
- ❑ CHIMERE (hyperspectral, coastal,vegetation)
- ❑ SCALE (new lidar concept)
- ❑ CMIM – Constellation of Miniaturized IR sounders for Meteorology
- ❑ TIR on HAPS
- ❑ IGC– TIR miniaturized imager for Aérosols, T and H2O (with TAS)


cnes
Thank you…
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