IASI-NG Status of development and preparatory activities by the mission team

T. Phulpin, M. Saccoccio and S. Rousseau

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Outline

1- IASI-NG Mission rationale and Objectives

2- IASI-NG Mission requirements

3- The french mission group : MENINGE

4- IASI-NG feasibility studies

5- Consequences of the successful IASI-NG feasibility studies

6- IASI-NG Schedule
IASI-NG mission rationale

Expressed in the Position papers collected by Eumetsat
In France proposed by scientists to CNES AO for new missions in 2009

■ Continuity of IASI.
  - Justified by Operational use of NWP centers, and other emerging services (MACC, VAAC), and long term trends monitoring as well.
    ⇒ Same performances as IASI used as thresholds for follow-on
    ⇒ Same viewing geometry required

■ Improved performances to tackle issues unsolved with IASI.
  - More precise humidity profiles
  - More documented atmospheric layers near surface (BL), or around tropopause (UTLS).
  - Better use of information in cloudy conditions
  - More detailed profiles of minor components
  - Detect other species
Dominant rationale and consequence

EUM : operational meteorology
F : AC and climate

Balance between these applications

Priority has been given to
• Continuity (full spectrum, + imager)
• Improved performances in radiometry and spectral resolution
Lessons learned from IASI for Atmospheric Composition and Climate

- All spectrum very useful
- Other atmospheric data mandatory (cloud, temperature, humidity)
- Large swath => Very good coverage.
- Stability is very important.

- No convincing products remaining to be improved
- CO₂ limited to upper troposphere
- Most of products good in upper troposphere but of coarser quality in lower troposphere or BL (e.g. O₃, CO) hampering strong development of AQ applications

- Improve NeDT and Spectral resolution would help to detect and quantify more species and also obtain profiles.
STUDIES TO JUSTIFY REQUIREMENTS

- Two rounds:
  - In phase 0 by CNES and French scientists,
  - In phase A to consolidate the requirements (see further studies by MENINGE group)

- Main results: Resolution/2 and radiometric noise /2 >
  - Better accuracy of T(z) in near surface layers
  - More information on CO and CH₄
  - Slight improvement on H₂O (?)
IASI-NG performance objective versus Post EPS MRD

Spectral resolution (level 1b)

- IASI-NG SPEC level 0
- MRD NWP breakthrough V2.E
- MRD CHEM breakthrough V2.E

**Priority**
- NWP Pri 1
- Chem Pri 1
- MWP or Chem Pri >=2

**IRS**
- IRS0: Water vap Prof
- IRS1: Temp Profl
- IRS2: Temp & Water vapour profiles, surf & cloud
- IRS3: Water vapour profile
- IRS4: Surf & cloud
- IRS5: Water vapour profile
- IRS6: Water vapour profile NO2 Column
- IRS7: CO col
- IRS7: CO Profile
- IRS8: Temp profile, N2O & CO2 col
- IRS9: Temp profile
- IRS10: SST, surfaces and cloud properties
- IRS11: CH4 col

**OPD**
- OPD CHEM=4cm

Spec IASI-NG With Self-Apodisation
Spec NWP With Self-Apodisation
Spec CHEM without Self-apodisation (0.6/OPD)
Activities of MENINGE during phase A

- MENINGE: A french mission team
  But with links with Eumetsat, with ISSWG, with Sentinel 5 etc…

- 10 meetings during phase A
  - Well informed of the progress
  - It performed consolidation studies
    - About needs and requirements
    - About expected performances of Level 2 or + products
    - For trade-off in the requirements for Phase B
  - It contributed to decision making
    - Presentation at User consultation meeting (Darmstadt)
    - Document to TOSCA
Impact of IASI-NG: performances at Level 2
Example 1: O$_3$

Courtesy: G. Dufour
Impact of IASI-NG: performances at Level 2
Example 2: NH₃

Thermal contrast: 11.5 K

Différence en température de brillance entre un spectre IASI-NG simulé sans NH₃ et un spectre IASI-NG simulé à partir de l’atmosphère standard en multipliant NH₃ par 1, 1,5 et 2.

Courtesy: J. Hadji-Lazaro
Resources specifications for IASI-NG Phase A studies

**MASS**
- IASI = 235 kg
- IASI-NG spec : 350 kg (including 20% margin)

**VOLUME**
- IASI : one sensor module + deported IMS/DPS inside the satellite ==> total = 1.7 m³
- IASI-NG spec : 1500 mm x 1500 mm x 1200 mm

**POWER (EOL):**
- IASI = 240 W
- IASI-NG spec : 500 W (including 20% margin)

**TM DATA RATE:**
- IASI : 1.5 Mbit/s
- IASI-NG spec : 6 Mbit/s

These requirements were given to 2 industrial companies for the phase A feasibility studies (competitive studies).
Instrument specifications in phase A

- Based on MRD breakthrough + additional requirements e.g. about pseudo noise.

- Pseudo noise allocation derived from IASI requirements
  - Main noise provided by detection chain (NeDT)
  - Instrument defaults (ISRF shape, centroid, PSF, …) specified as pseudo noise
    - Each default shall not represent more than 25% of the NeDT (globally each default contribute to few percent of the global performance) for homogeneous scenes
    - Default impact only heterogeneous scene has been sized to 50% of the NeDT

- Definition of typical heterogeneous scenes
  - At sounder pixel level : two half field with 10 K difference
    - Direct impact on heterogeneous scenes (sized to 50%)
  - At instrument field of view : one sounder pixel clear, the other part of the field is cloudy
    - Potential impact on homogeneous scenes (sized to 25%)
How to improve IASI performances for IASI-NG?

- Improve Radiometric Noise By a factor 2
- Improve Spectral Resolution By a factor 2
- Increase signal by a factor 4
- Increase mechanism range by a factor 2

- Increase pupil size
- Increase observation duration ➔ Increase FOV

- Self-apodisation increases Spectral Resolution decreases

- Fied compensated interferometer
2 competitive industrial studies started early 2010 and finished early 2012:

- 2 x 3 instrument types first studied (all Fourier Transformed spectrometer with Field Compensation interferometers but with various types of field compensation)
- Then each company focused on its best solution (choice based on the following criteria: performances, resources, schedule, risks, costs).
- Feasibility and design optimization studies were then consolidated during 2 years
- These deeper studies allowed to consolidate resources budgets and optimize cost evaluation
- These studies were completed by risk reduction activities on the most sensitive/innovative points (pre-development, mock-up, test, simulation...).

Both industrial concepts have been considered feasible at the end of the phase A studies, by the CNES project team and an independent review board.
A few potential non-compliances to phase A IASI-NG Instrument requirements at the end of phase A studies have been analyzed by MENINGE group:

- Local NeDT non compliance
- Absolute radiometric calibration above 2400 cm⁻¹
- Spectral/spatial co-registration requirements
- Absolute spectral calibration

These few non-compliances at instrument level are fully acceptable at mission level.
Résultats Etudes MENINGE
(profils verticaux T, humidité et optimisation bandes B2-B3…)
- Known lines in this spectral range?
  
  H\textsubscript{2}O and isotopologues, NO, NO\textsubscript{2}, NH\textsubscript{3}, PH\textsubscript{3}, OH, OCS, C\textsubscript{2}H\textsubscript{2}, C\textsubscript{2}H\textsubscript{4}, HCN, COF\textsubscript{2}

- Who are the users?
  
  Sometimes used to inverse H\textsubscript{2}O

- What is the impact of radiometric noise?
  
  For NO (1950 cm\textsuperscript{-1}) signal too weak to be detectable except after averaging (=> noise lowered down). Noise can potentially impact OCS retrieval (2035-2040 cm\textsuperscript{-1}).

- Conclusion: Noise slightly above the current requirement is acceptable. It could allow a small shift of the band limit (not higher than 2030 cm\textsuperscript{-1})
Recent Progress of IASI-NG project

- Two feasible industrial solutions fully compliant with the IASI-NG mission requirements have been studied and are proposed for phase B-C-D-E.
- MENINGE group and EUMETSAT EPS-SG project confirmed the acceptability of the IASI-NG expected performances.
- CNES commitment in April 2012 to provide IASI-NG instruments to EUMETSAT for the EPS-SG program.
- IASI-NG ITT for B-C-D-E phases launched in June 2012 (after an update to new interface requirements evolutions coming from ESA following the MetOp-SG PRR).
- Only 2 candidates (the 2 industrial companies who worked on the IASI-NG Phase A).
- Presentation to ISSWG which will become the Mission group for IASI-NG.
- Cooperation agreement between CNES and EUMETSAT prepared for signature.

Selection of the best industrial proposal for B-C-D-E phases on going.
IASI-NG Schedule

Phase A/B1
- Start: Oct 2009
- Kick-Off Industrial Studies: Early 2010
- Preliminary feasibility studies
- End 2010
- Choice Of Nominal Solutions
- Deeper feasibility studies + Risk Mitigation Activities: March 2012
- PRR
- ITT Candidates selection: April 2012
- ITT Launch: June 2012

Phase B2/C/D/E1
- Mid 2013: ITT
- 2nd half of 2014
- 2016
- End 2018
- IASI-NG FM1 delivery
- End 2020
- METOP-SG A launch
Next steps for the project and for scientific activities

- Choice of Manufacturer and concept shortly
- Start of phase B in fall 2013.
- Meeting of MENINGE group
- Science plan for IASI-NG tb established by ISSWG
- Start studies of ISSWG
- Final agreement btw CNES and EUMETSAT
- Studies on synergy with Sentinel 5 and other instruments
- Approval of EPS-SG programme by EUMETSAT Council mid 2014
Back-up slides
Profile retrieval using the 15 µm and 4 µm CO₂ bands
• Tropical atmosphere
• Noise contribution from uncertainties on surface temperature and emissivity, humidity profile.
• *A priori* covariance from ECMWF

With respect to *a priori* uncertainty, IASI-NG contribution is about twice IASI contribution

**Temperature profile sounding**

![Graph showing temperature profile error and DOFS values](image)

- T profile error
- P (hPa)
- IRS 1
- IRS 2
- a priori

**DOFS**
- IRS 1
- IRS 2
- a priori

**Values**
- DOFS = 5.9
- DOFS = 10.7

(K)
The relative gain (or error reduction) is defined as 
\[(a \text{ posteriori} - a \text{ priori})/a \text{ priori}\]
It is in the range 5 - 25%.

Spectral resolution improves the instrument contribution, beyond noise reduction by increasing the number of channels \(\sqrt{n}\).
Atmospheric chemistry: CO profile (2140-2180 cm⁻¹)

<table>
<thead>
<tr>
<th></th>
<th>MRD threshold</th>
<th>MRD breakthrough</th>
<th>IASI</th>
<th>IASI-NG reference</th>
<th>IASI-NG with cold bench</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral resolution (cm⁻¹)</td>
<td>0.15</td>
<td>0.1</td>
<td>0.5</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Spectral sampling (cm⁻¹)</td>
<td>0.124</td>
<td>0.083</td>
<td>0.25</td>
<td>0.125</td>
<td>0.125</td>
</tr>
<tr>
<td>NeDT (K)</td>
<td>0.15</td>
<td>0.1</td>
<td>0.28</td>
<td>0.16</td>
<td>0.12</td>
</tr>
<tr>
<td>DOFS</td>
<td>2.84</td>
<td>3.78</td>
<td>1.88</td>
<td>2.51</td>
<td>2.69</td>
</tr>
<tr>
<td>Tropospheric column (0-12 km) (%)</td>
<td>2.14</td>
<td>1.95</td>
<td>3.39</td>
<td>2.24</td>
<td>2.15</td>
</tr>
<tr>
<td>Boundary layer (0-3 km) (%)</td>
<td>10.2</td>
<td>7.8</td>
<td>16.05</td>
<td>10.7</td>
<td>10.1</td>
</tr>
</tbody>
</table>

IASI instrument is not sufficient to provide a vertical profile (less than 2 DOFS). IASI-NG, though not meeting the level 1 requirements, is close to the threshold level 2 performances (especially for the cold bench configuration).
Atmospheric chemistry : CH$_4$ column (1280-1360 cm$^{-1}$)

<table>
<thead>
<tr>
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<th>MRD breakthrough</th>
<th>IASI</th>
<th>IASI-NG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral resolution (cm$^{-1}$)</td>
<td>0.3</td>
<td>0.15</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Spectral sampling (cm$^{-1}$)</td>
<td>0.248</td>
<td>0.124</td>
<td>0.25</td>
<td>0.125</td>
</tr>
<tr>
<td>NeDT (K)</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
<td>0.05</td>
</tr>
<tr>
<td>Total column (%)</td>
<td>13.1</td>
<td>6.9</td>
<td>9.9</td>
<td>4.6</td>
</tr>
</tbody>
</table>

The CH$_4$ column can be retrieved with a precision in agreement with the MRD threshold (resp. breakthrough) from IASI (resp. IASI-NG) observations.
IASI-NG: radiometric and spectral improvements

**Radiometry**

- **Entrance pupil diameter** Increase (⇒ flux):
  - IASI-NG = 120 mm versus IASI = 80 mm
- **Instrument Field of view** Increase (⇒ integration time):
  - IASI-NG = 75 km × 75 km (9 pixels) versus IASI = 50 km × 50 km (4 pixels) ⇒ acquisition duration for each interferogram = 450 ms versus 150 ms for IASI
- **Detectors temperature** reduction (active cooling):
  - IASI-NG T detector < 65 K versus IASI = 92 K

**Spectral resolution**

**Optical Path difference** increase by factor 2:
- single sided interferometer
  - one mobile cube having the same IASI stroke
  - TWO mobile cubes having the IASI stroke / 2
- double sided interferometer
  - one mobile cubes having the IASI stroke × 2
  - TWO mobile cubes having the same IASI stroke

**BUT: «self-apodisation»**

For the spectral resolution, both the Optical Path Difference **AND** the self-apodisation must be improved.
IASI-NG: Optical signal in the detectors plane for $\nu=2760$ cm$^{-1}$ and $\text{OPD}_{\text{max}}=4$ cm

The use of IASI like pixel acquisition concept is not possible. Two options has been studied.

Split the sounder pixel into many smaller pixels → Matrix detectors

Suppress/mitigate the self-apodisation effect → self-apodisation compensation

• For each of the 9 sounding pixel, acquisition of sub-pixels interferograms (typically 5x5 sub-pixels), then combination of the interferograms by resampling at “constant” OPD + filtering to generate one sounding pixel interferogram
• Final Self-apodisation for the corner pixels = IASI one

IASI-NG CNES Phase 0 Reference option

• Introduce, in the interferometer, a specific mechanism that works in synchronization with the Corner Cube Mechanism and that corrects, for each sounding pixel (but the center one), the Optical Path Difference by:
  $\delta_0 (1 - \cos \theta)$, where $\delta_0$ is the OPD for a zero field → ALL the pixels should have a similar behavior than the central pixel
Evolution of a corner pixel optical signal for monochromatic ray at 4 µm, for OPD variation of 1 µm, (between max and min signal (λ/4)) at OPD of 4cm

Optical simulation with and without active optical field compensation

Without compensation

With compensation

Without compensation

With compensation

 CONTRAST

0 0.5 1 1.5 2 2.5 3 3.5 4

DIFFÉRENCE DE MARCHE (cm)

IRS-2C
Lambda = 3.5 microns
Pixel de 12 km
IASI-NG: Baseline characteristics (CNES phase 0)

- Ground Pixel diameter of 12 km (IASI)
- Ground sampling of 25 km (both axis)
- Number of sounder pixels per acquisition = 9 (IASI=4)
- Number of earth view per line = 20 (30 IASI)
- Interferogram acquisition duration = 450 ms (IASI=150 ms)

- Inlet PUPIL = 120 mm (IASI=80 mm)

- Focal plane:
  - 4 bands (IASI=3)
  - 9 sounder pixels per band (IASI=4)
  - PV detectors for all bands (IASI PC for B1; PV for B2/B3)
  - detectors cooled at 65 K with one active cooler (LPTC) (IASI=92 K passive)
  - IASI like cold optic concept