IASI-New Generation onboard EPS-SG: Expected impact on accuracy and vertical resolution for atmospheric variables

Cyril Crevoisier, Cathy Clerbaux, Vincent Guidard, Thierry Phulpin, Raymond Armante, Brice Barret, Claude Camy-Peyret, Jean-Pierre Chaboureau, Gaelle Dufour, Juliette Hadji-Lazaro, Hervé Herbin, Nicole Jacquinet, Lydie Lavanant, Sébastien Payan, Eric Péquignot, Clémence Piérangelo, Didier Renaut, Claudia Stubenrauch
IASI onboard MetOp-A

Numerical Weather Prediction
Global NWP, LAM, mesoscale models

Atmospheric composition
More than 20 species detected, some well quantified (O_3, CO, CH_4), some only detected (SO_2, HNO_3, NH_3, formic acid, methanol) in special situations (fires, volcanoes)

Climate
• Essential Climate Variables: T, WV, GHG, Surface characteristics, Clouds, Aerosols.
• Reference for the GSICS.

Lessons learned with IASI onboard MetOp-A:
• IASI benefits three communities that will be more and more connected (eg: MACC-GMES, Essential Climate Variables)
• Covering continuously the whole TIR domain is very useful.
• To retrieve several variables, other atmospheric data (cloud, T, WV) are mandatory.
• Spectral and radiometric stabilities are very important.
• Retrievals over land/sea by day/night.
What's next? IASI-NG as part of Eumetsat EPS-SG

Missions under development


TOVS AQUA GOSAT OCO-2 Flex CarbonSat MTG
ENVISAT AURA CrIS S5P
MetOp-A

EPS-SG

• PFA : MetIMAGE, MWS, IASI-NG, RO, UVNS, 3MI
• PFB : SCATT, MWI, RO

Status:
• Phase-A studies at CNES since January 2010, end in April 2012.
• Two industrial studies are conducted in parallel (Astrium-France and Thales Alenia Space).
**IASI-New Generation**

**Objectives of the mission:**
- To assure the **continuity** of IASI for NWP, atmospheric chemistry and climate applications.
- To **improve** the characterization of the lower part of the troposphere, the UT/LS region and, more generally, of the full atmospheric column.
- To **improve** the precision of the retrievals and to allow the detection of new species.

**Characteristics:**
- Spectral coverage: 645 - 2760 cm\(^{-1}\)
- Spectral resolution: 0.25 cm\(^{-1}\) after apodisation (0.50 cm\(^{-1}\) for IASI)
- Spectral sampling: 0.125 cm\(^{-1}\) (0.25 cm\(^{-1}\) for IASI).
- Reduction of the radiometric noise by a factor of ~2 as compared to IASI.
- Spatial sampling: 12km FOV.

![Radiometric performances (Level1c)](image)

Factor of 2 on the spectral resolution, sampling and the radiometric noise
IASI-NG - Sensitivity analysis - Full spectrum

IASI-NG sensitivities - Tropical TIGR situations

- $T$ (1K)
- $\text{H}_2\text{O}$ (20%)
- $\text{CO}_2$ (1%)
- $\text{O}_3$ (10%)
- $\text{N}_2\text{O}$ (2%)
- CO (10%)
- $\text{CH}_4$ (10%)
- $T_{surf}$ (1 K)
IASI-NG - Sensitivity analysis - Full spectrum

IASI sensitivities - Tropical TIGR situations

Variation of BT (K)

Wave number (cm⁻¹)

T (1K) H₂O (20%) CO₂ (1%) O₃ (10%) N₂O (2%) CO (10%) CH₄ (10%) Tsurf (1 K)
IASI-NG - Sensitivity analysis - Full spectrum

IASI sensitivities - Tropical TIGR situations

T (1K) H₂O (20%) CO₂ (1%) O₃ (10%) N₂O (2%) CO (10%) CH₄ (10%) Tsurf (1 K)
IASI-NG - Sensitivity analysis - Full spectrum

For a 10ppbv CO perturbation:

- IASI-NG
  - CO: ~0.8K
  - Noise: ~0.1K

- IASI
  - CO: ~0.4K
  - Noise: ~0.2K

T (1K)  H₂O (20%)  CO₂ (1%)  O₃ (10%)  N₂O (2%)  CO (10%)  CH₄ (10%)  Tsurf (1 K)
IASI-NG - Sensitivity analysis - Full spectrum

IASI-NG sensitivities - Tropical TIGR situations

T (1K)  H₂O (20%)  CO₂ (1%)  O₃ (10%)  N₂O (2%)  CO (10%)  CH₄ (10%)  Tsurf (1 K)
Impact of IASI-NG on Temperature profile sounding

- The T profile is retrieved 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 the a priori uncertainty, the contribution of IASI-NG is about twice the contribution of IASI.
Impact of IASI-NG on Temperature profile sounding

Contribution of spectral resolution and radiometric noise

![Graph showing relative gain and spectral resolution comparison]

- 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.
Retrieval of ozone partial columns

- Design of OSSEs experiment, based on KOPRA RT code.
- The retrieval scheme is based on the one developed for IASI (Eremenko et al., GRL, 2008; Dufour et al., ACP, 2010)

For ozone [0-6 km]: IASI-NG will bring 50% more info on the vertical and sensitivity 1 km lower + gain 30% on accuracy
Retrieval of carbon monoxide

Summary of the Sensitivity analyses

- Study of retrieval performances by varying spectral resolution and noise
- Use of CO retrieval scheme from George et al., ACP, 2009.

**DOFS**

- Improved vertical resolution

**Total column error**

- Improved accuracy

- a priori variability
Retrieval of CO₂ integrated content

• Using the LMD inference scheme (Crevoisier et al., ACP, 2009), we have studied the evolution of the precision with various configurations compared to the IASI current precision (which uses the 15 µm band only):

<table>
<thead>
<tr>
<th>Spectral bands for IASI-NG</th>
<th>Noise</th>
<th>Improvement of the precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 µm</td>
<td>IASI/2</td>
<td>30 %</td>
</tr>
<tr>
<td>4.3 µm</td>
<td>IASI/2</td>
<td>0 %</td>
</tr>
<tr>
<td>15 + 4.3 µm</td>
<td></td>
<td>45 %</td>
</tr>
</tbody>
</table>

• IASI-NG will enable the use of 4.3 µm channels, giving access to a lower part of the atmosphere, with a much improved precision.

• Strong and needed complementarity with SWIR obs. (GOSAT, OCO-2, UVNS).
Detection of trace gases

• **Ammonia [0-2 km]:** gain of 40 % on the detection limit.

![](image1.png)

• **SO$_2$:** a 45 % gain on the detection threshold + some information on the vertical structure of the plumes.

• **Volcanic ash:** improvement on the detection limit.

→ Improvement of volcanic eruption alert
(and more species will be retrieved: SO$_2$, H$_2$S, H$_2$SO$_4$, ash)
<table>
<thead>
<tr>
<th></th>
<th>IASI</th>
<th></th>
<th>IASI-NG</th>
<th></th>
<th>What the ‘NG’ brings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry</td>
<td>DOFs</td>
<td>Error (%)</td>
<td>DOFs</td>
<td>Error (%)</td>
<td></td>
</tr>
<tr>
<td>O₃</td>
<td>3-4</td>
<td>PBL : 60% Tropo : 11%</td>
<td>4-5</td>
<td>PBL : 40% Tropo : 8%</td>
<td>More information in PBL</td>
</tr>
<tr>
<td>CO</td>
<td>1-2</td>
<td>PBL : 16% Tropo : 8%</td>
<td>2-3</td>
<td>PBL : 10% Tropo : 6%</td>
<td>More information in PBL</td>
</tr>
<tr>
<td>HNO₃</td>
<td>1 or less</td>
<td></td>
<td>2</td>
<td></td>
<td>Both tropo and strato</td>
</tr>
<tr>
<td>NH₃</td>
<td>detected</td>
<td>-</td>
<td>measured</td>
<td>-</td>
<td>&gt; instrumental noise</td>
</tr>
<tr>
<td>Methanol</td>
<td>detected</td>
<td>-</td>
<td>measured</td>
<td>-</td>
<td>&gt; instrumental noise</td>
</tr>
<tr>
<td>C₂H₄</td>
<td>detected</td>
<td>-</td>
<td>measured</td>
<td>-</td>
<td>&gt; instrumental noise</td>
</tr>
<tr>
<td>SO₂-volcanos</td>
<td>If &gt; 2DU</td>
<td>-</td>
<td>If &gt; 1 DU</td>
<td>-</td>
<td>+ Altitude of the plume</td>
</tr>
<tr>
<td></td>
<td>Climate</td>
<td>DOFs</td>
<td>Error (%)</td>
<td>DOFs</td>
<td>Error (%)</td>
</tr>
<tr>
<td>H₂O</td>
<td>5-6</td>
<td>~13%</td>
<td>6-7</td>
<td>~10%</td>
<td>Error improved by 1.5</td>
</tr>
<tr>
<td>T</td>
<td>6</td>
<td>~0.6K</td>
<td>12</td>
<td>~0.45 K</td>
<td>Error improved by 2.5</td>
</tr>
<tr>
<td>CO₂</td>
<td>1 or less</td>
<td>~1%</td>
<td>1-2</td>
<td>&lt;1%</td>
<td>Low troposphere</td>
</tr>
<tr>
<td>CH₄</td>
<td>1 or less</td>
<td>~3%</td>
<td>1-2</td>
<td></td>
<td>Less interferences</td>
</tr>
<tr>
<td>N₂O</td>
<td>detected</td>
<td>-</td>
<td>measured</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Aerosols</td>
<td>dust</td>
<td></td>
<td></td>
<td></td>
<td>More types</td>
</tr>
<tr>
<td>Emissivity</td>
<td>0.04 @4µm</td>
<td></td>
<td>0.02 @4µm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusions

• The improved spectral resolution and radiometric noise of IASI-NG will enable:
  (1) a better coverage of the vertical, especially in the lower part of the troposphere;
  (2) an improvement of the accuracy of the retrieved variables because of less interferences between the species in the channels and a better signal to noise ratio.

• The increase of spectral resolution has a clear impact on several signatures: sharper CO ‘lines’, easier separation of CH$_4$ vs. H$_2$O, etc.

• The lower the noise, the better! That really matters for the weak spectral features embedded in stronger ones (CO$_2$, CH$_4$, N$_2$O, and most of other chemical species only detected by IASI).
  → The reduction of the noise is a priority in the SW.

• The retrieval of several variables will depend on:
  (1) the synergy between IASI-NG and EPS-SG/MWS, EPS-SG/Vis.
  (2) the knowledge of surface characteristics, which will be the key for using new spectral regions (SW).
  (3) spectroscopy compliable with the evolution of new generation instruments.
IASI-NG improved contributions to...

**Atmospheric profiling**

**Essential Climate Variables monitoring and understanding**
Clouds, GHG, aerosols

**Improvement on pollution forecast**
3 EU controlled pollutants (CO, O₃ and NH₃)

**Better tracking of long range pollution** (e.g. fire emissions)

**Improved volcano alerts**
Early alerts possible + SO₂ and ash tracking

IASI-NG has the potential for strongly benefiting the NWP, chemistry and climate communities, in addition to assuring the continuity of high quality observations delivery.
IASI-New Generation: improved volcanoes alerts

CNRM: N. Fourrié, V. Guidard, F. Rabier
LA: B. Barret, J.-P. Chaboureau
LATMOS: C. Clerbaux, J. Hadji-Lazaro, M. George
LISA: J. Cuesta, G. Dufour
LMD: R. Armante, V. Capelle, A. Chédin, C. Crevoisier, N. Jacquinet, N. Scott, C. Stubenrauch
LOA: H. Herbin
LPMAA: C. Camy-Peyret, S. Payan
LSCE: F. Chevallier

ECMWF: T. McNally, V.-H. Peuch, A. Simmons, J.-N. Thépaut
MetOffice: J. Eyre, F. Hilton, J. Taylor
NOAA: C. Barnett, A. Gambacorta, M. Goldberg.
University of Basilicata: C. Serio
ULB: P. Coheur, D. Hurtmans
University of Toronto: K. Waker, J. Mc Connell
University of York: P. Bernath
University of Edinburg: P. Palmer
Dalhousie University: R. Martin
KNMI: P. Levelt
NCAR: D. Edwards, L. Emmons

+ ECMWF, MACC, MeteoFrance and the MetOffice support letters

Volcanic Ash Advisory Centers/ London VAAC (UK Met Office): R. Saunders
MetOffice, UK: J. Haywood
U.S. Geological Survey, Alaska Volcano Observatory: D. Schneider
Meteorological Authority, Civil Aviation Authority of New Zealand: P. Lechner
Operational coordinator, VAAC Montreal: D. Bensimon
VAAC Toulouse, MeteoFrance: Ph. Husson
University of Alaska Fairbanks (Anchorage VAAC): P. Webley
German Airline Pilots’ Association: K. Sievers