Spatio-temporal variability of 3 anthropogenic greenhouse gases (CO₂, CH₄ and N₂O) in the mid-troposphere as seen from IASI onboard Metop-A and Metop-B

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Why monitoring GHG from space?

Increase since pre-industrial era:

<table>
<thead>
<tr>
<th>Source</th>
<th>Sinks</th>
<th>SWIR sat. Obs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>Fossil fuel, fire, respiration</td>
<td>Vegetation, ocean</td>
</tr>
<tr>
<td>CH₄</td>
<td>Wetland, rice paddies, fire</td>
<td>Destruction by OH</td>
</tr>
<tr>
<td>N₂O</td>
<td>Agriculture, watse</td>
<td>Photolysis and oxidation</td>
</tr>
</tbody>
</table>

GHG average concentrations mostly reflect the balance between their sources and sinks.
The very small seasonal variability of these gases compared to their background values, combined to the strong dependence of IR radiances to atmospheric temperature and the simultaneous sensitivity of the channels to several gases, makes their retrieval challenging.
IASI sensitivities to GHG

- Retrieval procedure (Crevoisier et al., 2009ab, 2013):
  - Non linear inference scheme based on neural networks (Chédin et al., 2003).
  - Based on the 4A RT code and the latest edition of the GEISA database.
  - Systematic radiative biases between RT simulations and IASI observations are computed using the ARSA database.
  - Gas and T(p) are intimately correlated in the IR.
    - Use of IR (IASI) and MW (AMSU) observations to decorrelate T from gas variations.
      - 89 channels for CO₂ (@15µm) and 24 channels for CH₄ (@7.7µm)
      - AMSU 6 and 8
  - The decorrelation between T/gas is easier to do in the tropics.
    - Better precision in the tropical region.

- We retrieve a mid-tropospheric content:
  - Clear sky only (no clouds, no aerosols)
  - By day and night
  - Over land and over sea
Mid-tropospheric CH$_4$

At IASI 3rd conference back in 2013: retrieval restricted to the tropics, from Metop-A

15 Sept. 2015
Mid-tropospheric CH$_4$

At IASI 3rd conference back in 2013: retrieval restricted to the tropics, from Metop-A

Since then: extension to extra-tropical regions for CH$_4$
Mid-tropospheric CH₄

At IASI 3rd conference back in 2013: retrieval restricted to the tropics, from Metop-A

Since then: extension to extra-tropical regions for CH₄
extension to Metop-B for both CH₄ and CO₂

Metop-A + Metop-B provide full coverage in one day.

15 Sept. 2015
Mid-tropospheric CH$_4$

At IASI 3rd conference back in 2013: retrieval restricted to the tropics, from Metop-A

Since then: extension to global coverage for CH$_4$
extension to Metop-B for both CH$_4$ and CO$_2$
near-real time delivery (D+1) for both CH$_4$ and CO$_2$

→ NRT data daily delivered to Copernicus Atmospheric Service for assimilation at ECMWF
  → See S. Massart’s talk later today
→ Contribution to ESA-Climate Change Initiative-GHG (CO$_2$ and CH$_4$)
A very important step: radiative monitoring of the instruments through computation of “calc-obs” residuals using co-located simulations (ARSA+4A) and IASI observations.

Monthly evolution

Impact on retrieved CO$_2$

AMSU 6
AMSU 8

see N. A. Scott’s poster #81
Retrieval scheme

Characterization of radiative behavior according to scan angle

IASI channels

Impact on retrieved CO₂

without correction
correcting IASI
correcting IASI + AMSU
correcting AMSU
Mid-tropospheric CH$_4$

8 years from IASI/Metop-A (July 2007-June 2015)

- Retrieval accuracy ~12 ppbv
- Usually lower std in the southern than in the northern hemisphere. → Lower variability of CH$_4$. 
Mid-tropospheric CH$_4$

8 years from IASI/Metop-A (July 2007-June 2015)

- In the tropics: max @ 250 hPa (~11 km) while tropopause @ 16 km.
- In the mid-lat: max @ 400 hPa (~7 km) while tropopause @ 8 km.
Mid-tropospheric CH$_4$

Analysis of retrieved fields

- Strong emission of CH$_4$ by rice paddies in summer
- Rapid uplift to the mid-troposphere due to monsoon convection.
- Then Southward transport towards Indonesia.
Mid-tropospheric CH$_4$

Analysis of retrieved fields

- Summer: transport of emissions from Asia Westwards.
- Fall/winter: wetland emissions (tropical forest).
Mid-tropospheric CH$_4$

Analysis of retrieved fields

Amazonia  Africa  Asia

JFM  AMJ  JAS  OND

winter: wetland emissions in Amazonia.
Mid-tropospheric CH$_4$

Analysis of retrieved fields

Although sensitive to the mid-troposphere, IASI does provide information of surface fluxes
Mid-tropospheric CO₂

8 years of mid-tropospheric CO₂ from IASI/Metop-A (July 2007-June 2015)

- Biomass burnings emission.
- Strong seasonal variations and inter hemispheric gradient.

Annual trend: 2.1 ppm yr⁻¹
Validation with aircraft measurements: CONTRAIL (1/4)

Comprehensive Observation Network for Trace gases by AIRLiner

JAL commercial flights from 2006 to 2009 at an altitude of 10-12 km.

Validation with aircraft measurements: CONTRAIL (2/4)

Mid-tropospheric CH$_4$

Every FOV within 5°×5° of an aircraft measurement for the same day is kept.
Valida$on with aircraft measurements: CONTRAIL (3/4)

Mid-tropospheric CH₄

IASI CH₄ – CONTRAIL CH₄

\[ \text{IASI CH}_4 - \text{CONTRAIL CH}_4 = -0.89 \pm 16.13 \text{ ppbv (R = 0.81)} \]

(over 311 pairs)

But need of full profile measurements for proper validation.

→ see Membrive’s talk (Thursday, 14:20) on L2 validation with aircraft and balloon instruments
Validation with aircraft measurements: CONTRAIL (4/4)

Mid-tropospheric $\text{CO}_2$

Excellent stability between IASI/Metop-A and IASI/Metop-B...

$\text{CO}_2 (\text{ppmv})$ by latitude band
IASI vs JAL/CONTRAIL

$\text{CO}_2 : \text{IASI vs JAL/CONTRAIL}$
$R = 0.96$, $\text{diff}(q_{\text{co2, jai}} - q_{\text{co2, iasi}}) = 0.567 \pm 0.990$ ppmv

Fit: $0.996 \times x + 1.00$

$I\text{ASI CO}_2 (\text{ppmv})$

$380 \quad 385 \quad 390 \quad 395 \quad 400$

$380 \quad 385 \quad 390 \quad 395 \quad 400$

$I\text{ASI CO}_2 - \text{CONTRAIL CO}_2 = 0.57 \pm 0.99$ ppmv ($R = 0.96$)
(over 311 pairs)
Validation through radiative transfer simulations

- Use of fixed or retrieved CO₂/CH₄ mid-tropospheric columns as inputs to RT 4A simulations on ARSA radiosounding database.
- Comparison with IASI co-located observations.

> Using the retrieved column cancels the CO₂/CH₄ signature in the calc – obs difference (residuals of ~0.1K).

→ see Armante’s talk (Thursday, 13:20) on L2 validation through RT simulations
Mid-tropospheric CH₄: From Metop-A to Metop-B

2 year of CH₄ mid-tropospheric column from Metop-B

• The inference scheme has been adapted to IASI/AMSU onboard Metop-B and 2 years have been processed (Feb. 2013-Jan. 2014).
• Same networks.
• Systematic radiative biases computed for each platform.

Seasonal maps of mid-tropospheric CH₄ column for 2014

Metop-A

Metop-B
Mid-tropospheric N₂O

Preliminary results: simultaneous retrieval of CH₄ and N₂O

Seasonal mid-tropospheric N₂O (ppb) column from IASI/Metop-A

- Jan-Feb-Mar 2014
- Apr-May-Jun 2014
- Jul-Aug-Sep 2014
- Oct-Nov-Dec 2014

- Based on 7.7μm CH₄ channels’ sensitivity to N₂O.
- Networks trained to retrieve simultaneously CH₄ and N₂O.
  → CH₄ fields not affected while delivering N₂O fields.
Mid-tropospheric N$_2$O

**Preliminary results:** simultaneous retrieval of CH$_4$ and N$_2$O

Seasonal mid-tropospheric N$_2$O (ppb) column from IASI/Metop-A

... and comparison with state-of-the-art LMDz4 atmospheric transport model

(R. Thompson, comm. pers.)
<table>
<thead>
<tr>
<th>Gas</th>
<th>CO₂</th>
<th>CH₄</th>
<th>N₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial</td>
<td>30N:30S</td>
<td>70N:70S</td>
<td>30N:30S</td>
</tr>
<tr>
<td>Temporal</td>
<td>NRT (D+1)</td>
<td>NRT (D+1)</td>
<td>Preliminary</td>
</tr>
<tr>
<td>Metop-B</td>
<td>2013-now</td>
<td>2013-now</td>
<td>-</td>
</tr>
<tr>
<td>Users</td>
<td>CAMS, ESA-CCI-GHG</td>
<td>CAMS, ESA-CCI-GHG, Surface fluxes</td>
<td>-</td>
</tr>
</tbody>
</table>

Main issue: loss of both AMSU 7 and 8 channels on Metop-A…
→ Need to rely on AMSU 6 only: OK for CH₄, not for CO₂
→ Update and reprocessing needed.