IASI L2 processor at EUMETSAT: status and developments

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The IASI instrument

Infrared Fourier transform interferometer
Spectral range: 645 to 2760 cm\(^{-1}\) (15.5-3.62 \(\mu\)m)
Spectral sampling: 0.25 cm\(^{-1}\)
Footprint: 12 km (Nadir)
Swath: ±1000km (± 48.3°)

T profiles

Surface Clouds
Surface Clouds

CO\(_2\)
O\(_3\)
CH\(_4\)
H\(_2\)O
CO
N\(_2\)O
CO\(_2\)
Outline

I. The IASI L2 processor v5 (since 14/09/2010)
   - algorithms overview
   - examples of validation results

II. Cloud screening
    - concurrent detection algorithms
    - impact on L2 quality & yield

III. Current developments towards v6
    - FORLI-CO, SO$_2$, O$_3$ and HNO$_3$
    - New OEM configuration
    - Non-linear IR retrievals
    - MWIR statistical retrievals
1. IASI L2 version 5

Processed and disseminated in NRT (sensing +2h)

| TWT | Temperature (vertical profiles) | Humidity (vertical profiles) | Surface Temperature (Land & Sea) |
| EMS | Surface emissivity              |
| CLD | Cloud detection and characterisation |
| OZO | O₃ total & partial (0-6, 0-12, 0-16 km) columns |
| TRG | CO, N₂O, CH₄, CO₂ Total columns |
| v6  | CO & O₃ profiles + AK, SO₂, HNO₃ |

+ AK
1. Input data pre-processing
2. Cloud detection and characterisation
3. Statistical retrievals: $T$, $q$, $T_s$, $\varepsilon$, CO ($N_2O$, $CH_4$, $CO_2$)
4. Optimal Estimation Method (OEM): $T$, $q$, $T_s$, $O_3$
<table>
<thead>
<tr>
<th>Data type</th>
<th>Origin</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land/Sea mask</td>
<td>AAPP</td>
<td>quadtree</td>
</tr>
<tr>
<td>Surface elevation</td>
<td>GTOPO 30 (US Geological Survey)</td>
<td>30” x 30” (~1 km)</td>
</tr>
<tr>
<td>Emissivity Atlas</td>
<td>Global land surface climatology from IASI measurements (Zhou et al., TGRS 2011)</td>
<td>0.5° x 0.5° Full spectrum (via PCs) Monthly means</td>
</tr>
</tbody>
</table>
1. IASI L2 version 5

- **ECMWF 3h-forecasts**: 00, 03, 06, 09, 12, 15, 18, 21 UTC
  - Up to 1.5h difference with sensing-time
  - Spatial & Temporal interpolation
  - Used in support to cloud detection and characterisation only

- **AVHRR**
  - Integrated cloud-fraction embedded in IASI 1C
  - Used for cloud screening

- **AMSU & MHS 1B**
  - Not used in IASI L2 v5, foreseen in v6
1. IASI L2 version 5

The cloud characterisation

Cloud phase
Determined with BT differences: liquid, ice, mixed
Validation with 672 globally distributed AVHRR scenes
Mixed phases generally classified as ice or liquid clouds

Equivalent cloud-amount

Cloud-top pressure (or cloud-top temperature)
Retrieved with the CO$_2$-slicing algorithm adapted to IASI after Menzel, 1983 and Smith, 1990.

For low contrasted scenes, introduced the "χ$^2$-method" in addition, in the IASI L2 v5.3 (28/02/2012), after Eyre & Menzel, 1989 and Stubenrauch, 1999.
1. IASI L2 version 5

The cloud-top pressure: validation

- September – December 2010
- CALIOP L2 v3 1km resolution
- $\Delta$ time < 10 mn
- $\Delta$ d < 10 km from IASI IFOV centre
- $\sigma$(CALIOP CTP) < 50 hPa within IASI IFOV to isolate single-layer clouds

### IASI CTP (hPa)

### CALIOP CTP (hPa)

### IASI ECA (%)

**Graph:**
- Scatter plot with IASI CTP vs CALIOP CTP for different cloud-top pressures.
- Color coding indicates IASI ECA percentage.
1. IASI L2 version 5

**SST**
- linear regression: Empirical Orthogonal Functions (EOF retrieval)
- Training with synthetic spectra: Le Chevallier climato (ECMWF 2001) + RTIASI
- validation against AATSR
- validation and monitoring with buoys, AVHRR and SEVIRI
- **Contributes to** the Group for High-Resolution SST (GHRSST): IASI L2P SST

**Land surface T and ε**
- linear regression (EOF) retrieval, after Dan Zhou et al, TGRS 2011
- Training set based on the soil IR emissivity database, University of Wisconsin (Seemann et al, Journal of Applied Met. And Clim, 2007)
- Emissivities retrieved in principal components domain
- **LST evaluated** against MODIS, SEVIRI LST and in-situ measurements
- ε qualitatively assessed against MODIS IR emis. atlas (Seeman, Borbas et al.)
1. IASI L2 version 5

Statistical retrievals: T, q profiles

- Temperature, humidity profiles
  - EOF retrieval (*D. Zhou et al., 2005, GRL*), Linear regression on IASI radiances principal components
  - Trained with synthetic cloudy radiances
  - Different sets of coefficients for different viewing angle
  - Full profiles available under clear and partly cloudy conditions
  - Clear-sky IFOVs: **first-guess in the final iterative retrieval**
  - Clear-sky IFOVs: **q profiles enters final L2 products**
  - Cloudy IFOVs: after users request, the **T,q profiles retrieved in partially cloudy IFOVs** are added to the final IASI L2 products.
  
Distributed since v5.1.0 (02/12/2010).
1. IASI L2 version 5

- Standard **Optimal Estimation Method** (OEM) after Rodgers:
  \[ J = (x - x_a)^T \cdot S_a^{-1} \cdot (x - x_a) + (F(x) - y)^T \cdot S_y^{-1} \cdot (F(x) - y) \]
  Marquardt-Levenberg minimisation (5 iterations max.)

- Active parameters: \( T_{\text{skin}} \) and \( T, q \) & \( O_3 \) profiles

- **Background term** computed in the **EOF space** of the atmospheric parameters: \( T \rightarrow 28 \) PCs, \( q \rightarrow 18 \) PCs, \( O_3 \rightarrow 9 \) PCs

- One unique **global a priori** and **covariance matrix**

- **316 channels** after Collard (*Collard et al., QJRMS 2007*)

- **global radiance tuning** and **measurement error covariance matrix**: prior clear sky OBS-CALC

- **Forward model**: **RTIASI, RTTOV-10** since v5.2 (20/10/2011)

- **First guess**: statistical retrievals
1. IASI L2 version 5

Sea Surface Temperature: validation

19-24 March 2010

AATSR – IASI (v5)

ECMWF - IASI

Global figures

Cold bias: 0.4 K
σ ~ 0.4 K

Outside aerosol areas

Cold bias: 0.25 K
σ < 0.3 K
1. IASI L2 version 5

**Land Surface Temperature: validation**

**LST**

Retrieved vs In-situ measurements

IR radiometers measuring ground and sky brightness temperature from 9.6 to 11.5 micrometers, operated by Folke Olesen and Frank Goettsche (IMK/KIT)

3 validation sites:
Evora (Portugal), Gobabeb and RMZ-farm (Namibia)
1. IASI L2 version 5

Land Surface Temperature: validation

LST
Retrieved vs In-situ measurements

Gobabeb (Namib desert)
405m asl

- IASI L2
- ECMWF

B. Theodore
1. IASI L2 version 5

Land Surface Temperature: validation

IASI L2 version 5

LST

Retrieved

vs

In-situ measurements

Evora (Portugal)

300m asl

- IASI L2
- ECMWF

August 2010

Day

Night

LST IASI (°C)

LST Station (°C)
1. IASI L2 version 5

Land Surface Temperature: validation

LST
Retrieved vs In-situ measurements

RMZ-Farm (Namibia)
1360m asl

- IASI L2
- ECMWF

August 2010

LST, $\varepsilon$ joint OEM retrieval
Credits: Dan Zhou (NASA)
1. IASI L2 version 5

Total column retrieved with ANN

Inter-comparison with MOPITT/Terra

August 2008

CO, comparison with MOPITT

Total column retrieved with ANN

Inter-comparison with MOPITT/Terra

August 2008
1. IASI L2 version 5

Statistical retrievals: CO total column

Russian wild fires 2010

- AIRS
- MOPITT
- IASI UMBC
- IASI EUM

Yurganov et al., “Satellite- and ground-based CO total column observations over 2010 Russian fires: accuracy of top-down estimates based on thermal IR satellite data”, ACP 2011

Credits: L. Yurganov (UMBC)
Validation campaign, Lindenberg & Sodankyla (Pougatchev et al, ACP 2009 and Calbet, AMT 2011)

Evaluation against ECMWF analyses, 3 datasets:
- “One Year” orbits centred on analyses synoptic times
- “Focus days” (8 Sep 2007, 5 March and 9 May 2008)
- **19-24 March 2010**
  - Detailed results in Tech.Note EUM/MET/TEN/09/0448

External monitoring: e.g. NOAA/NPROVS, Italian Met Services

Campaign data: ConcordIasi (presented at EUM Conference 2011)
1. IASI L2 version 5

19-24 March 2010
Temperature profiles

**IASI L2 – ECMWF Analysis**

**Intertropical Ocean cases**

**NWP forecast monitoring**

*Courtesy F. Rabier (Meteo-France)*

- v5
- v4

**rms ~ 0.7 K**
1. IASI L2 version 5

T, q profiles: monitoring at NOAA

Credits: NOAA / NESDIS Center for Satellite Applications and Research.
1. IASI L2 version 5

**References**

- **Papers**
  - August et al, “IASI on Metop-A: Operational Level 2 retrievals after five years in orbit”, JQSRT 2012
  - Pougatchev et al, “IASI temperature and water vapor retrievals; error assessment and validation”, ACP 2009
  - ...

- **Validation reports (SST, LST, T&q, CO, O3...)**
  eumetsat.int/Home/Main/DataProducts/Resources/index.htm#val_reports

- **Product Generation Specification**
  eumetsat.int/groups/ops/documents/document/PDF_TEN_990013-EPS-IASIL2-PGS.pdf

- **Product Guide**
  eumetsat.int/Home/Main/DataProducts/Resources/index.htm#productguides
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   - validation results summary

II. Cloud screening
   - concurrent detection algorithms
   - impact on L2 quality & yield

III. Current developments: prototypes & new products
   - FORLI-CO
   - New OEM configuration
   - Non-linear IR retrievals
   - MWIR statistical retrievals
2. Cloud screening

Cloud detection in v5

- **NWP cloud test**
  - **OBS – CALC**\(NWP, \text{ems, ...}\) in window channels
  - Cloudy if \(|OBS-CALC| > 1K\)
  - Relies on accurate forecasts and surface ems

- **AVHRR integrated cloud-fraction**
  - IASI PSF weighted count of AVHRR cloudy pixels
  - Cloudy if CFR > 2%
  - Confused by ice/Snow covers
2. Cloud screening

Concurrent detection algorithms
2. Cloud screening

Concurrent detection algorithms

19-24 March 2010 Agreement rate: ANN vs AVHRR

- snow, Ts, T&q profiles
- mineral dust
- q profiles
- ems, Tskin

M. Crapeau
2. Cloud screening

Concurrent detection algorithms

ANN test  NWP test  AVHRR test

White: cloudy  Black: clear
2. Cloud screening

Objectives: Relate cloudiness estimate to IASI L2 quality indicator

### Cloudiness flag in v6

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Clear-sky</td>
</tr>
<tr>
<td>2</td>
<td>Potential small cloud contamination, cloud not characterised with confidence</td>
</tr>
<tr>
<td></td>
<td><strong>High confidence</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Low yield</strong></td>
</tr>
<tr>
<td>3</td>
<td>IFOV partially cloudy</td>
</tr>
<tr>
<td>4</td>
<td>IFOV fully cloudy</td>
</tr>
</tbody>
</table>

Impact on IASI L2 yield and quality

- NWP test
- AVHRR test
- ANN test

Clear-sky identification

- Q1
- Q2

Some area may be systematically excluded.
2. Cloud screening

Impact on yield and quality: T profiles

Current clear
Q1 OEM clear
Q2 OEM clear
Current cloudy

Southern oceans

19-24/03/2012
2. Cloud screening

Impact on yield and quality: q profiles

Current clear

Q1 EOF
Q2 EOF

Southern oceans

19-24/03/2012
2. Cloud screening

Summary

√ Quality improved/preserved in Q1
√ Quality improved in Q2
√ Overall yield increased

Future work

➢ Include cloud parameters in the retrievals
➢ Improve T retrievals in lower levels
➢ Improve q retrievals (esp. bias) in low tropo
➢ Repeat the study with radio-sondes data
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3. Current developments

New products: CO, O$_3$, SO$_2$, HNO$_3$

Implementation in the EPS ground segment of a series of atmospheric composition products developed by Clerbaux & Coheur (ULB/LATMOS).

Essentially OEM based on FORLI (Fast Optimal Retrievals on Layers for IASI, Hurtmans et al., JQSRT 2012)

- CO profiles + AK (2013)
- SO$_2$ column
- O$_3$ profiles + AK
- HNO$_3$ profiles

 Courtesy of C. Clerbaux ULB/LATMOS
3. Current developments

New OEM configuration

J = (x - x_a) T S_a^(-1) (x - x_a) + (F(x) – y) T S_y^(-1) (F(x) – y)

3. Current developments

New OEM configuration

State vector represented
• In PC space \([T,T_s,q,\Omega]_3\)
• In variable pressure grid

So far ~ OBS – CALC (NWP)

Pb: meas. error over-estimated (collocation & model errors)

PCA, EV decomposition into model and observation subspaces
• \(Y = Y_{\text{obs}} \cap \text{mod} + Y_{\text{obs}} \perp \text{mod} + Y_{\text{mod}} \perp \text{obs} + Y_{\text{mod}} \perp \text{obs}\)
• New channel selection: using reconstructed radiances \(\Rightarrow\) using PCs if channels carefully chosen (methodology presented at ITSC-18).
Expecting increased sensitivity to low tropo.
• \(S_y = S_{\text{INST}} + S_{\text{RTM}} + S_{\text{SV}}\) projected onto observation space \(\Rightarrow\) off-diagonal terms

New channel selection in IASI Band 1?
3. Current developments

New OEM configuration: test case

Tropical case
19/03/2010
Comparison to ECMWF analyses

Clear-sky
Night-time
Ocean

BG and FG: global mean climatology
Non-linear T,q statistical retrieval (NLR)

- External study lead by X. Calbet (EUM) performed University of Valencia (G. Camps-Valls et al.)
- Combination of EOF, ANN and support vector machines (SVM)
- Input: IASI radiances
- Training base: synthetic clear-sky IASI radiances simulated with OSS RTM and climatological database (Le Chevallier, ECMWF).
- Retrieved parameters: T, q, Ts, O3

!! More accurate than Linear Regression
!! Precision comparable to OE
!! Speed-up computations by 300
All sky, linear regression retrievals of T, q and O₃ profiles from co-located IASI, AMSU and AVHRR measurements.

T. Hultberg

80 predictors:
- Secant of satellite zenith angle
- Surface height
- Radiance in 14 AMSU channels (channel 7 excluded)
- 30 leading IASI band 1 PC scores
- 30 leading IASI band 2 PC scores
- Standard deviation and mean of AVHRR channel 4 radiance within IASI FOV
- Standard deviation and mean of AVHRR channel 5 radiance within IASI FOV

276 predictands:
- Ta (K)
- Wa (K)
- Ts (K)
- T profile (K) at 91 model levels
- W profile (K) dew point temperature at 91 model levels
- O profile (K) “dew point temperature” (W formula) at 91 model levels
3. Current developments

- Training set: Satellite measurements & co-located ECMWF forecasts from 5 days (in different months).
- 24 regression classes. The classes are determined solely by the AMSU radiance in channel 2 and 4 and the first two PC scores in IASI band 2.
- Error estimate: Regression coefficients to predict the sum of the absolute values of retrieval errors of Ta, Wa and Ts are computed, which allows for an estimation of the quality of each individual retrieval.
3. Current developments

Assessment of new T retrievals

Q1 OEM
Q1 NLR
Q1 MWIR

19-24/03/2010

Northern oceans
3. Current developments

Assessment of new T retrievals

Q1 OEM
Q1 NLR
Q1 MWIR

19-24/03/2010

Intertrop. lands
3. Current developments

Assessment of new T retrievals

Q2 OEM clear
Q2 NLR clear
Q2 MWIR

19-24/03/2010

Intertrop. oceans

Q3 OEM clear
Q3 NLR clear
Q3 MWIR
3. Current developments  
Assessment of new WV retrievals

**19-24/03/2010**  
Southern oceans

Q1 OEM clear
Q1 NLR clear
Q1 MWIR

**19-24/03/2010**  
Intertrop. oceans
3. Current developments  Assessment of new WV retrievals

Q2 OEM clear
Q2 NLR clear
Q2 MWIR

19-24/03/2010 Southern oceans

19-24/03/2010 Intertrop. oceans
3. Current developments  
Assessment of new WV retrievals

Q3 OEM clear
Q3 NLR clear
Q3 MWIR

19-24/03/2010  
Southern oceans

19-24/03/2010  
Intertrop. oceans
Summary & Outlook

✓ PPFv5 operational since 14/09/2010
✓ Significant improvements: T, LST, clouds, CO, O₃

Coming in 2013:
- Cal/Val IASI L2 / Metop-B
- Conclusion of the version 6 (new algorithms & products)

Various parts of the processing chain, with direct or indirect positive impact on the T,q profiles are being upgraded
- cloud detection
- Ems
- New atmospheric composition products

More accurate T,q sounding in lower tropo and in cloud-contaminated IFOVs, increased L2 yield expected.
### Summary & Outlook

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Algorithm</th>
<th>Status</th>
<th>Plans for V6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cloud detection</td>
<td>NWP, AVHRR</td>
<td>Operational</td>
<td>NWP+AVHRR+ANN</td>
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<tr>
<td>Cloud fraction &amp; height</td>
<td>CO$_2$-slicing + $\chi^2$</td>
<td>Operational</td>
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<tr>
<td>Cloud phase</td>
<td>BT difference</td>
<td>Trial</td>
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<tr>
<td>T profiles</td>
<td>OEM</td>
<td>Operational</td>
<td>NLR, MWIR OEM(q) reconstructed rads AK</td>
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<tr>
<td>q profiles</td>
<td>EOF</td>
<td>Operational</td>
<td></td>
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<tr>
<td>SST / LST</td>
<td>EOF</td>
<td>Operational</td>
<td>Fix angular variation OEM(LST &amp; ems)</td>
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<tr>
<td>Emissivity</td>
<td>EOF</td>
<td>Trial</td>
<td></td>
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<tr>
<td>O$_3$ total column</td>
<td>OEM</td>
<td>Operational</td>
<td>Profiles + AK</td>
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<tr>
<td>O$_3$ partial columns</td>
<td>OEM</td>
<td>Trial</td>
<td></td>
</tr>
<tr>
<td>CO</td>
<td>ANN</td>
<td>Operational</td>
<td>Profiles + AK</td>
</tr>
<tr>
<td>N$_2$O, CH$_4$, CO$_2$</td>
<td>ANN</td>
<td>Experimental</td>
<td>SO2, HNO3, ??</td>
</tr>
</tbody>
</table>
Open questions

¿ clouds/aerosol detection/simulation from IR and impact on sounding quality?

¿ What WV products references for the validation of satellite retrieved profiles with ground resolution of 12-30 km?

¿ Calibration instrument/RTM, esp. in WV channels and characterisation of the observation error matrix?

¿ Retrieving GHG with IASI?
1. IASI L2 version 5

The radiances filtering

Raw L1C

Ammonia: Reconstructed

“Potential for the use of reconstructed IASI radiances in the detection of atmospheric trace gases”, N. C. Atkinson, F. I. Hilton, S. M. Illingworth, J. R. Eyre, and T. Hultberg, AMT 2010
1. IASI L2 version 5

The cloud fraction: validation

Cloud fraction
NW Atlantic

Retrieval vs
Whole-Sky Imager
(Lindenberg)

Match-up criteria
Time: 10 min intervals
Space: 1° x 1°

IASI L2 version 5

ASHHR/10.8, CFR PPF IASI CO2 slicing, overpass_20070620190941

Effective cloud cover (%)
1. IASI L2 version 5

Cloud-top pressure

Retrieved vs ground-based radar (Lindenberg)

Match-up criteria
Space: within 50km
Single layer clouds
2. Cloud products

The cloud-top pressure

IASI CTP vs CALIOP Middle of Top Cloud Layer
bias: 10 hPa, std: 141 hPa (4232/5641 IFOVs)
1. IASI L2 version 5

Sea Surface Temperature

19-24 March 2010

AATSR – IASI (v5)

• EOF retrieval
• predictors = Band 1 and 2 PCs
• Training set: synthetic cases, calculated with RTIASI and climatology (F. Chevallier atmospheric dataset, ECMWF)
• Radiance tuning
• validation against AATSR
• validation and monitoring with buoys, AVHRR and SEVIRI
• Contributes to the Group for High-Resolution SST (GHRSST): IASI L2P SST

AATSR – IASI (prototype v6)

• ANN retrieval (2 hidden layers, 5 neurons each)
• predictors = PCs Bands 1, 2 and 3 (night) + Ps + sec(satZen)
• Training set: synthetic cases, calculated with RTTOV 10.2 and climatology (F. Chevallier atmospheric dataset, ECMWF)
• No radiance tuning yet
19-24 March 2010 :: Day
(LANDSAF_MSG – IASI)
\[ \rho \sim 0.97 \quad \text{bias} \sim -0.6 \text{ K} \quad \sigma \sim 2.4 \text{ K} \]
19-24 March 2010 :: Night
(LANDSAF_MSG – IASI)
ρ ~ 0.99    bias ~ -1.6 K    σ ~ 1.6 K