A Joint Temperature, Humidity, Ozone, and SST Retrieval Processing System for IASI Sensor Data: Properties and Retrieval Performance Analysis

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Outline

1. **METOP – IASI**
   - METOP
   - IASI – Infrared Atmospheric Sounding Interferometer

2. **Forward Model and Retrieval**
   - The forward model RTIASI
   - The Retrieval

3. **Results**
   - Retrieval Setup and Channel Selection
   - Results of the Joint Retrieval

4. **Summary and Outlook**
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4. Summary and Outlook
METOP configuration

METOP – IASI
Forward Model and Retrieval Results
Summary and Outlook

METOP configuration

Source: http://www.esa.int/export/esaME/index.html

METOP specifications

- size: 17.6 m × 6.7 m × 5.4 m
- mass: 4244 kg
- power: 2010 W (eclipse)

orbit

- inclination: 98.7°
- ALTITUDE: ~830 km
- sun-sync. orbit (9:30 local time)
- >14 revolutions/day
- repeat cycle: 29 days – 412 orbits

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instruments on board of METOP

atmospheric instruments
- IASI
- AMSU - A1, A2
- ASCAT
- AVHRR
- GOME-2
- GRAS
- HIRS
- MHS

additional instruments
- A/DCS
- SARP-3
- SARR
- SEM

Source: http://www.space-technology.com/
instruments on board of METOP

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Source: http://www.space-technology.com/
IASI – infrared atmospheric sounding interferometer

IASI characteristics

- scan type: step and dwell
- scan rate: 8 s
- pixel/views: 4
- views/scan: 30
- IFOV: 3.33° (48 km at nadir)
- swath: ±48.3° (±1026 km)
- lifetime: 5 years
- power: 200 W
- mass: 210 kg
- size: 1.2 m × 1.1 m × 1.1 m
IASI - measurement specifications

- spectral range: 645-2760 cm\(^{-1}\)
- 15.5-3.6 \(\mu\)m
- spectral res.: 0.35 - 0.5 cm\(^{-1}\)
- 8461 channels
- separated into 3 bands
- radiometric res.: 0.25 - 0.5 K
- water vapor: 1250 - 2000 cm\(^{-1}\)
- \(\text{CO}_2\): near 645 and 2325 cm\(^{-1}\)
- additional absorption of \(\text{O}_3\), \(\text{CH}_4\), \(\text{N}_2\text{O}\), \(\text{CO}\), \(\text{SO}_2\)

(a) radiances and (b) brightness temperatures of IASI simulated by RTIASI for a us.std.midlatitude summer atmosphere.
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The forward model RTIASI

**RTIASI - an overview**

- Simulation of the IASI measurements at 43 fixed pressure levels between 0.1 and 1013.25 hPa
- Calculation of optical depth’s via a regression scheme
- Calculation of level to space transmittances
- Solution of the radiative transfer equation to estimate brightness temperatures $T_B$ (or radiances, respectively).
- Tangent linear and adjoint model to calculate jacobians for $T$, $q$, $O_3$, and SST - $\frac{\partial T_B}{\partial T}$, $\frac{\partial T_B}{\partial q}$, $\frac{\partial T_B}{\partial O_3}$, and $\frac{\partial T_B}{\partial SST}$. 
The forward model reads

\[ y = f(x) + \epsilon \]  

- \( y, x \): measurement and state vector
- \( f \): forward model operator - jacobian matrix \( K \) times \( x \)
- \( \epsilon \): measurement error vector

The direct inverse reads

\[ x_{\text{retr}} = K^{-g} y \]  

- ill-conditioned problem
- over determined for \( m > n \)
the retrieval

optimal estimation algorithm

- incorporates sensibly *a priori* knowledge
- statistically optimal fusion of unbiased measurements and *a priori* data

linearized iterative optimal estimation scheme

\[ x_{i+1} = x_{ap} + S_i K_i^T S_\epsilon^{-1} \left[ (y - y_i) + K_i (x_i - x_{ap}) \right] \]  
\[ \text{with: } S_i = \left[ S_{ap}^{-1} + K_i^T S_\epsilon^{-1} K_i \right]^{-1}. \]

- \( S_i, S_\epsilon, S_{ap} \): retrieval, measurement, and *a priori* error covariance matrix
- \( x_{i,i+1}, x_{ap} \): iterated (iteration index i) and *a priori* profile
The forward model RTIASI

The Retrieval

Summary and Outlook

The a priori error covariance matrix

- exponential drop off
- correlation length:
  - $T$: 6 km
  - $q$: 3 km
  - $O_3$: 10 km

The off diagonal elements

*a priori* error covariance matrices for temperature, humidity and ozone.
The forward model RTIASI

The Retrieval

Summary and Outlook

The measurement error covariance matrix

**diagonal elements**
- IASI level 1c noise values
- adapted to the actual brightness temperature
- +0.2 K forward model error

**off diagonal elements**

Correlation of the three nearest neighbor channels:
1. 0.75
2. 0.25
3. 0.04
the measurement error covariance matrix

**diagonal elements**
- IASI level 1c noise values
- adapted to the actual brightness temperature
- +0.2 K forward model error

**off diagonal elements**
correlation of the three nearest neighbor channels:
1 0.75
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4. Summary and Outlook
calculation with the fast radiative transfer model RTIASI
superposition of radiometric noise $\Delta y$, consistent with $S_\varepsilon$, according to IASI level 1c noise to get quasi realistic data
channel selection

removal of channel regions

\[ \begin{align*}
> 2500 \text{ cm}^{-1} & : \text{sun, inst. noise} \\
1220 - 1370 \text{ cm}^{-1} & : \text{N}_2\text{O, CH}_4, \text{SO}_2 \\
2085 - 2200 \text{ cm}^{-1} & : \text{CO, N}_2\text{O}
\end{align*} \]

\[ \implies \sim 6200 \text{ channels} \]

(5)

information content theory

\[ H_i = \frac{1}{2} \log_2 \left| \hat{S}_i^{-1} \hat{S}_{i-1} \right|, \]

(6)

maximum sensitivity approach

\[ H = S^{-\frac{1}{2}} K, \]

(7)
true fields

METOP – IASI Forward Model and Retrieval Results

Summary and Outlook

Retrieval Setup and Channel Selection

Results of the Joint Retrieval

true fields

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a priori minus true – 24h forecast

Ap. - True Temperature Profiles

Specific Humidity Difference (Ap. - True)

Ap. - True Surface-Skin Temperature

Ozone Difference (Ap. - True)
a priori minus true – 24h forecast/ error data
a priori minus true – true perturbed
a priori minus true – true perturbed/ error data
temperature profiles – error analysis
humidity profiles – error analysis
ozone profiles – error analysis
SST – error analysis

-6  -4  -2  0  2  4  6

SST Error [K]

(a)

(b)

(c)
single parameter retrieval – temperature
single parameter retrieval – humidity
single parameter retrieval – SST

Retrieval Setup and Channel Selection
Results of the Joint Retrieval

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channel selection – a comparison

numerical efficiency

<table>
<thead>
<tr>
<th>set</th>
<th>IC</th>
<th>MS</th>
</tr>
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<tr>
<td>300</td>
<td>1.00</td>
<td>0.98</td>
</tr>
<tr>
<td>887</td>
<td>3.74</td>
<td>4.25</td>
</tr>
<tr>
<td>1808</td>
<td>11.25</td>
<td>13.13</td>
</tr>
</tbody>
</table>

a) IC – ~300 chan.
b) IC – ~900 chan.
c) IC – ~1800 chan.
d) MS – ~300 chan.
e) MS – ~900 chan.
f) MS – ~1800 chan.
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Summary

IASI is the most advanced infrared sounder to be launched in the near future.

The IC based channel reduction makes the retrieval efficient –
reduction from >8400 to \( \sim3.5\% \) (\( \sim300 \))

Retrieval accuracy:

- Temperature: 1 K at 1-3 km
- Humidity: 15-20% at 1-3 km
- SST: \( \sim0.1\) K
- Ozone: improvements in the stratosphere in heights with high concentration of \( \text{O}_3 \)
Summary

Summary (2)
- *a priori* data exhibit important influence from the tropopause upwards
- the joint algorithm shows a clearly improved performance compared to more specific retrieval setups
- temperature, humidity, and SST results are quite independent from the initial guess of ozone (a few 10% uncertainty level)
Outlook

**Improvements:**
- statistical model of the *a priori* error covariance matrices, e.g., direct use of the relevant ECMWF *a priori* covariance matrices for T and q
- usage of the newest forward model RTIASI

**next steps:**
- application of the algorithm to AIRS data is planned
Thank You!
Outline

5 Anhang
   EM-Spectrum
measured spectrum

GOME-2 AVHRR
HIRS
IASI
AMSU-A1, A2
ASCAT
GRAS
MHS

Source: http://www.giangrandi.ch/optics/spectrum/spectrum.shtml