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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METOP configuration

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

**METOP specifications**
- size: \( 17.6 \text{ m} \times 6.7 \text{ m} \times 5.4 \text{ m} \)
- mass: 4244 kg
- power: 2010 W (eclipse)
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instruments on board of METOP

Source: http://www.space-technology.com/

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

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

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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

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

- 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$^{-1}$
- CO$_2$: near 645 and 2325 cm$^{-1}$
- additional absorption of O$_3$, CH$_4$, N$_2$O, CO, SO$_2$
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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

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

- 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

\[ x_{i+1} = x_{ap} + S_i K_i^T S_\epsilon^{-1} [(y - y_i) + K_i(x_i - x_{ap})] \] (3)

with:

\[ S_i = \left[ S_{ap}^{-1} + K_i^T S_\epsilon^{-1} K_i \right]^{-1} \] (4)

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

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

A priori error covariance matrices for temperature, humidity and ozone.
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**
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- adapted to the actual brightness temperature
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**off diagonal elements**
correlation of the three nearest neighbor channels:
1 0.75
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the simulation of the measurement vector

calculation with the fast radiative transfer model RTIASI
superposition of radiometric noise $\Delta y$, consistent with $S_\epsilon$, according to IASI level 1c noise to get quasi realistic data
channel selection

removal of channel regions

\[
\begin{align*}
> 2500 \text{ cm}^{-1} & : \text{ sun, inst.
oise} \\
1220 - 1370 \text{ cm}^{-1} & : \text{ N}_2\text{O, CH}_4, \text{ SO}_2 \\
2085 - 2200 \text{ cm}^{-1} & : \text{ CO, N}_2\text{O}
\end{align*}
\]
\[\implies \sim 6200 \text{ channels (5)}\]

information content theory

\[
H_i = \frac{1}{2} \log_2 \left| \hat{S}_i^{-1} \hat{S}_{i-1} \right|, \quad (6)
\]

maximum sensitivity approach

\[
H = S_{\epsilon}^{-\frac{1}{2}} K, \quad (7)
\]
the simulation region
a priori minus true – 24h forecast
a priori minus true – 24h forecast/ error data

- Temperature Error [K] vs. Pressure [hPa]
- Specific Humidity Error [%] vs. Pressure [hPa]
- Ozone Error [%] vs. Pressure [hPa]
METOP – IASI
Forward Model and Retrieval
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Retrieval Setup and Channel Selection
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a priori minus true – true perturbed

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a priori minus true – true perturbed/ error data

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temperature profiles – error analysis
humidity profiles – error analysis

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Ozone profiles – error analysis

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SST – error analysis
single parameter retrieval – temperature
single parameter retrieval – humidity

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single parameter retrieval – SST

(a) Bias and 2 standard deviations of mean and standard deviation.

(b) RMS errors for empirical and apriori boundary conditions.
channel selection – a comparison

**numerical efficiency**

<table>
<thead>
<tr>
<th>set</th>
<th>IC</th>
<th>MS</th>
</tr>
</thead>
<tbody>
<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 (1)**

- 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 ~3.5% (~300).
- Retrieval accuracy:
  - **Temperature**: 1 K at 1-3 km
  - **Humidity**: 15-20% at 1-3 km
  - **SST**: ~0.1 K
  - **Ozone**: Improvements in the stratosphere in heights with high concentration of O₃.
Summary (2)

- *a priori* data exhibit important influence from the tropopause upwards
- the joint algorithm shows an 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 \textit{a priori} error covariance matrices, e.g., direct use of the relevant ECMWF \textit{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
Anhang

EM-Spectrum

measured spectrum

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

GOME-2 AVHRR
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