Joint Temperature, Humidity, and Sea Surface Temperature Retrieval from IASI Sensor Data

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Joint Temperature, Humidity, and SST Data from IASI Measurements

Outline:

- Metop - IASI
- Forward Model and Retrieval
- Results
- Summary and Outlook
Joint Temperature, Humidity, and SST Data from IASI Measurements

Metop - IASI
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Instruments on board of Metop

- IASI
- AMSU – A
- ASCAT
- AVHRR
- GOME – 2
- GRAS
- HIRS
- MHS

Spectral Range: 645 – 2760 cm\(^{-1}\)
Data Rate: 1.5 Mbits/s
Lifetime: 5 years
Power: 200 Watt
Mass: 210 kg
Size: 1.2m x 1.1m x 1.1m

Source: www.esa.int

Source: www.space-technology.com/
Metop - IASI

**iasi – infrared atmospheric sounding interferometer**

- 8461 channels, divided into 3 bands
- water vapor absorption: 1250 – 2000 cm\(^{-1}\)
- CO\(_2\) absorption: near 645 and 2325 cm\(^{-1}\)
- additional absorption of O\(_3\), CH\(_4\), N\(_2\)O, CO, SO\(_2\)

a) IASI scanning procedure.

b) brightness temperature spectrum of IASI simulated by RTIASI
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Forward Model and Retrieval
Forward Model and Retrieval

the fast radiative transfer model RTIASI:

- simulation of the IASI measurements at 43 pressure levels between 0.1 and 1013.25 hPa
- Calculation of regression coefficients
- 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 —
  $\partial T_B/\partial T$, $\partial T_B/\partial \ln q$, $\partial T_B/\partial \ln O_3$, and $\partial T_B/\partial \text{SST}$
Forward Model and Retrieval

connecting the forward model and the retrieval

• the forward model reads

\[ y = F(x) + \varepsilon \]

- \( y, x \) ... measurement and state vector
- \( F \) ... forward model operator, Jacobian matrix \( K \) times \( x \)
- \( \varepsilon \) ... measurement error vector
- rows of Jacobian \( K \) can be interpreted as “weighting functions”

• the direct inversion reads

\[ x_r = K^{-g} y \]

- ill-conditioned problem
- over-determined for \( m>n \)
Forward Model and Retrieval

- Optimal estimation
  - incorporates sensibly a priori knowledge
  - statistically optimal combination of unbiased measurements and prior data
- Linearized iterative optimal estimation scheme

\[
x_{i+1} = x_{ap} + S_i K_i S_{\varepsilon}^{-1} \left[ (y - y_i) + K_i (x_i - x_{ap}) \right]
\]

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

- \( S_{\varepsilon} \) ... observation and forward modeling error covariance matrix
- \( S_i \) ... retrieval error covariance matrix
- \( S_{ap} \) ... a priori error covariance matrix
- \( x_{ap} \) ... a priori profile
- \( x_{i+1} \) ... retrieved profile (iteration \( i \))
the a priori error covariance matrix

• for temperature:
  off diagonal elements:
  ➢ exponential drop off
  ➢ 6 km correlation length

• for humidity:
  off diagonal elements:
  ➢ exponential drop off
  ➢ 3 km correlation length
Forward Model and Retrieval

the measurement error covariance matrix

• diagonal elements:
  ➢ IASI 1c noise levels
  ➢ adapted to actual brightness temperature
  ➢ + 0.2 K forward model error

• off diagonal elements:
  correlation of 3 nearest neighbor channels:
  1) - * 0.75
  2) - * 0.25
  3) - * 0.04
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Results
Results

the simulation of the measurement vector

- calculation with the fast radiative transfer model RTIASI
- superposition of radiometric noise $\Delta y$, consistent with $S_\varepsilon$, according to iasi-1c noise levels to get quasi realistic data
Results

channel selection

• removal of channels over 2500 cm⁻¹ and of channels with trace gas absorption:

  975–1100 cm⁻¹: \( \text{O}_3 \)
  1220–1370 cm⁻¹: \( \text{CH}_4 \)
  2085–2200 cm⁻¹: \( \text{CO}, \text{O}_3 \)

  \( \rightarrow 5781 \text{ channels} \)

• information content theory:

  \[ H = \frac{1}{2} \log |S_{ap}S^{-1}| \]

  with:

  \[ S_i = \left( K_i^T S^{-1}_e K_i + S^{-1}_{ap} \right)^{-1} \]

• maximum sensitivity approach:

  \[ M = S_{e}^{-\frac{1}{2}} K \]
Results

simulation region
Results

humidity profiles

a) true humidity profile, b) a priori humidity profile, c) specific humidity difference (ap - true) [%].

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Ste-Adele, Quebec, Canada
Results

humidity profiles – estimation comparison

a) IC – few channels, b) MS – few channels, c) IC – many channels, d) humidity only retrieval.
Results

humidity profiles – error analysis

a) IC – few channels, b) MS – few channels, c) IC – many channels, d) humidity only retrieval.
Results

humidity profiles UTH - estimation comparison

a) IC – few channels, b) UTH – IC – few channels.
Results

humidity profiles – UTH

a) IC – few channels, b) UTH – IC – few channels.
Results

temperature profiles

a) true temperature profile, b) a priori temperature profile, c) temperature difference (ap - true) [K].
Results

temperature profiles - estimation comparison

a) IC – few channels, b) MS – few channels, c) IC – many channels, d) temperature only retrieval.
Results

temperature profiles – error analysis

a) IC – few channels, b) MS – few channels, c) IC – many channels, d) temperature only retrieval.
Results

Sea surface temperature

a) true surface skin temperature, b) a priori – true surface skin temperature [K].
Results

Sea surface temperature - estimation comparison

a) IC – few channels, b) sst only retrieval.

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Results

**sea surface temperature – error analysis**

a) IC – few channels, b) sst only retrieval, c) IC – many channels.
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Summary and Outlook
Summary and Outlook

• IASI is the most advanced IR sounder to be launched in the near future.
• The IC based channel reduction makes the retrieval efficient – reduction from >8400 to ~3 % only (~250).
• The joint algorithm shows an clearly improved performance compared to more specific retrieval setups.
• Retrieval accuracy: ~1K (T) and 15% (q) at 1 – 3 km in the troposphere.
• A priori data exhibit important influence in the stratosphere.
• Some challenging areas are found in the mid-latitude regions and at heights with weak sensitivity of the weighting functions.
Summary and Outlook

• improvements:
  ➢ direct use of the relevant ECMWF a priori covariance matrices for T and q.
  ➢ testing with another ground track region.

• next steps:
  ➢ inclusion of an ozone retrieval into the joint algorithm.
  ➢ application of the algorithm to AIRS data is planned.
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Thank You!