Development of Algorithm for the Retrieval of Atmospheric Profiles from Infrared Sounder onboard INSAT-3D

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INSAT-3D Satellite/Sensor

- 3-Axis Stabilized Geostationary Meteorological Satellite (India)
- Location: TBD
- Launch Date: Dec. 2010

INSAT-3D Imager

<table>
<thead>
<tr>
<th>Channel No.</th>
<th>Wavelength Band (μm)</th>
<th>Resolution (Km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.55 - 0.75</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1.55 - 1.70</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>3.7 - 3.95</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>6.5 - 7.1</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>10.3 - 11.3</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>11.3 - 12.50</td>
<td>4</td>
</tr>
</tbody>
</table>

INSAT-3D Sounder
Resolution: 10 km

<table>
<thead>
<tr>
<th>Channel No.</th>
<th>λc (Δλ) (in μm)</th>
<th>Principal absorbing constituents</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14.71 (0.281)</td>
<td>CO2 – band</td>
</tr>
<tr>
<td>2</td>
<td>14.37 (0.268)</td>
<td>CO2 – band</td>
</tr>
<tr>
<td>3</td>
<td>14.06 (0.256)</td>
<td>CO2 – band</td>
</tr>
<tr>
<td>4</td>
<td>13.96 (0.298)</td>
<td>CO2 – band</td>
</tr>
<tr>
<td>5</td>
<td>13.37 (0.286)</td>
<td>CO2 – band</td>
</tr>
<tr>
<td>6</td>
<td>12.66 (0.481)</td>
<td>water vapor</td>
</tr>
<tr>
<td>7</td>
<td>12.02 (0.723)</td>
<td>water vapor</td>
</tr>
<tr>
<td>8</td>
<td>11.03 (0.608)</td>
<td>window</td>
</tr>
<tr>
<td>9</td>
<td>9.71 (0.235)</td>
<td>ozone</td>
</tr>
<tr>
<td>10</td>
<td>7.43 (0.304)</td>
<td>water vapor</td>
</tr>
<tr>
<td>11</td>
<td>7.02 (0.394)</td>
<td>water vapor</td>
</tr>
<tr>
<td>12</td>
<td>6.51 (0.255)</td>
<td>water vapor</td>
</tr>
<tr>
<td>13</td>
<td>4.57 (0.048)</td>
<td>N2O</td>
</tr>
<tr>
<td>14</td>
<td>4.52 (0.047)</td>
<td>N2O</td>
</tr>
<tr>
<td>15</td>
<td>4.45 (0.0456)</td>
<td>CO2</td>
</tr>
<tr>
<td>16</td>
<td>4.13 (0.0683)</td>
<td>CO2</td>
</tr>
<tr>
<td>17</td>
<td>3.98 (0.0663)</td>
<td>window</td>
</tr>
<tr>
<td>18</td>
<td>3.74 (0.140)</td>
<td>window</td>
</tr>
<tr>
<td>19</td>
<td>0.695 (0.05)</td>
<td>vis</td>
</tr>
</tbody>
</table>
INSAT-3D Sounder Specifications

- System weight: 153 kg
- System Power: < 100 Watts
- IFOV: 280 μrad (E-W) x 280 μrad (N-S) ~10km
- No. of simultaneous sounding per channel: 4
- Field of Regard (FOR): 24° E-W x 21° N-S
- Step size: E-W: 278.9 μrad, N-S: 1115.6 μrad
- Active Scan Coverage: E-W and N-S from ~1° (64 steps) to ~10° (640 steps)
- Signal quantization: 14 Bits/sample
- Downlink datarate: 40K Bits/Sec
- Blackbody calibration: Every 30 minutes or ground command
Objectives

- **Vertical Profiles of:**
  - Temperature
  - Humidity (Surface – 100 hPa)
- **Surface Skin Temperature**
- **Total Ozone**

**Pressure Levels (40) in hPa:**
1000, 950, 920, 850, 750, 700, 670, 620, 570, 500, 475, 430, 400, 350, 300, 250, 200, 150, 135, 115, 100, 85, 70, 60, 50, 30, 25, 20, 15, 10, 7, 5, 4, 3, 2, 1.5, 1, 0.5, 0.2, 0.1

6400 km x 6400 km scan takes 180 minutes

Observation zenith angle, INSAT-3D at 84E
Characteristics of the atmosphere over GOES vs INSAT-3D Observations

NCEP PWAT Kg/M^2

January

April

July

October
Two-step retrieval algorithm of CIMSS/ UW

- Regression retrieval followed by Physical retrieval (Jun Li et al. 2000)

Different modules include:

- Fast RT model – PFAAST (Haal Woolf)
- Sounder Radiance bias correction – Linear Regression (Obs vs Sim Tb)
- Cloud detection routine (McMillan & Dean, 1982)
- $P_s$ from forecast and $\varepsilon$ from SSEC/UW dataset at sounder pixel
- Hybrid First Guess: Linear combination of Regression and Forecast
- Physical retrieval (Jun Li et al. 2000)
- Total Ozone from Separate Regression Routine (Jun Li et al. 2001)

Retrieval package is ready and installed at SAC

Improvement in humidity sounding achieved

Further work under ISRO-SSEC MoU
**INSAT-3D Retrieval Algorithm - Flowchart**

**Radiative Transfer simulation**
\[ Y = F(X) + \epsilon \]
\[ RC = dX.dY^T.(dY.dY^T)^{-1} \]

**Forecast profile** \((X_{fcst})\)
Compute \(W_{fcst}\)

**Hybrid First Guess** \((X_0)\)
\[ X_0 = W_{fcst}.X_{fcst} + W_{reg}.X_{reg} \]

**Regression Retrieval**
\[ X_{reg} = X_{mean} + RC.(dY)^T \]

**Sounder Radiances**
(FOR: 4x4, 2x2, or single pixel)

**Cloud detection/clearing**
Clear pixels \(< 25\%\)
Clear pixels \(> 25\%\)

**Average Radiances of all clear pixels in FOR**

**Radiance Bias Correction**
\[ \text{Rad} \rightarrow \text{Tb (Y)} \]

**Physical Retrieval**
\[ X_{n+1} = X_0 + \left( K_n^{-1} E^{-1} K_n + \gamma I \right)^{-1} \]
\[ \begin{aligned} &\left( K_n^{-1} E^{-1} \delta Y_n^m + \\
&K_n (X_n - X_0) + \\
&\gamma (X_n - X_0) \right) \\
&\delta Y_n^m = \frac{\partial Y}{\partial X} \end{aligned} \]

**Compare**

**Calculate residual**
(Threshold \(\rightarrow\) NE\(\Delta\)T)
\[ \sum_{k=1}^{nch} [Y_k - y_k(X_{n+1})]^2 / nch \]

**Physical retrieval fail**
Regression as final retrieval

**Exit**

**Output** \((X)\)
Physical retrieval successful

(Li et al, 2000, JAM; Ma et al, 1997, JAM)
PFAAST RT Model

PFAAST (Pressure-layer Fast Algorithm for Atmospheric Transmittances)

Improvement in PFAAST by restricting domain upto zenith angle 60°
Regression Retrieval

- Coefficients at different zenith angles (150 classes from 0-65°)
- 3 different latitude zones (0-20, 20-40, 40-60 in N/S)
- Different coefficients for land and ocean (Emissivity difference)
- Spectral emissivity as predictor over land
- Non-linear term ($T_b^2$) and $P_s$ as predictor
- $q$ and $\ln(q)$ as predictand for hybrid regression retrieval

Statistics (independent testing dataset 30N-30S)
- RMSE TS : 0.64 K, RMSE Total O$_3$: 14 Dob,
- RMSE TPW: REG_LNQ: 0.71 cm, REG_HYB: 0.56 cm
**Physical Retrieval**

(Jun Li et al. 2000)

- **Cost Function:**
  \[ J(X) = [Y^m - Y(X)]^T E^{-1} [Y^m - Y(X)] + (X - X_0)^T H (X - X_0) \]
  
  \(X_0\) is the first guess profile, \(Y^m\) radiance measurements, and \(Y(X)\) is forward model.  
  
  \(H\) is a priori matrix that constrains the solution (e.g. first guess error cov. matrix).  
  
  \(E\) is expected radiance error covariance matrix.

- **Minimization of the cost function using nonlinear Newtonian iteration yields**
  
  the following iterative solution:

  \[ X_{n+1} = X_0 + (K_n^T E^{-1} K_n + \gamma_n I)^{-1} \{ K_n^T E^{-1} [\delta Y_n^m + K_n (X_n - X_0)] + \gamma_n (X_n - X_0) \} \]

- **Iterative solution in terms of eigenvectors is:**

  \[ f_{n+1} = (\xi_n^T E^{-1} \xi_n + \gamma_n I)^{-1} \{ \xi_n^T E^{-1} [\delta Y_n^m + \xi_n.f_n] + \gamma_n.f_n \} \]

  where, \(\xi = K.V\), and \(V\) is eigenvector matrix, and \(f\) is coefficient vector  
  
  \(V\) contains 5 EOFs for temperature profile, 3 EOFs for humidity profile.
Convergence Test

- Expansion coefficient convergence test:
  - $d_{n+1} = (f_{n+1} - f_n)^T \cdot (\xi_n \cdot E^{-1} \cdot \xi_n + \gamma_n I)^{-1} \cdot (f_{n+1} - f_n)$
  - $d_{n+1} \rightarrow 0$ solution converges (i.e., $f_{n+1} \rightarrow f_n$).
  - Iteration stops when $(d_{n+1} - d_n) < \text{threshold} \approx 0.1$.
  - If $d_{n+1} > d_n$ then $\gamma_n$ is increased.

- Brightness temperature residual test:
  - RMS radiance residual is defined as:
    \[
    r_{n+1}^2 = \sum_{k=1}^{nch} \left[ Y_k - y_k (x_{n+1}) \right]^2 \div nch
    \]
  - If $r_{n+1} \leq r_n$ the iteration continues until $r_{n+1}$ is acceptably small (less than NEDT).
SUMMARY

- INSAT-3D having 19 channel Sounder is scheduled for launch in Dec 2010
- Retrieval package based on two-step algorithm ready for INSAT-3D
- Accuracies of the retrieved products are comparable to the similar products from other missions (Simulation study).
- Algorithm to be developed for cloud property retrieval/cloudy sky retrievals.
- Further improvements/developments under ISRO-SSEC MoU
Special Thanks to....

- ITWG for financial support to attend ITSC-17
- SSEC/UW for providing visiting fellowship (2005-06)
- Allen Huang and Jun Li for providing guidance and support in the retrieval algorithm
- Haal Woolf for the RT Model
- S Suzane and E Borbas for the SeeBor dataset and spectral emissivity dataset