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

Channel No.	Wavelength Band	Resolution (Km)
1	0.55 - 0.75 μm	1
2	1.55 - 1.70 μm	1
3	3.7 - 3.95 μm	4
4	6.5 - 7.1 μm	8
5	10.3 - 11.3 μm	4
6	11.3 - 12.50 μm	4

INSAT-3D Sounder

Resolution: 10 km

Channel No.	λ_c ($\Delta\lambda$) (in μm)	Principal absorbing constituents
1	14.71 (0.281)	CO_2 – band
2	14.37 (0.268)	CO_2 – band
3	14.06 (0.256)	CO_2 – band
4	13.96 (0.298)	CO_2 – band
5	13.37 (0.286)	CO_2 – band
6	12.66 (0.481)	water vapor
7	12.02 (0.723)	water vapor
8	11.03 (0.608)	window
9	9.71 (0.235)	ozone
10	7.43 (0.304)	water vapor
11	7.02 (0.394)	water vapor
12	6.51 (0.255)	water vapor
13	4.57 (0.048)	N_2O
14	4.52 (0.047)	N_2O
15	4.45 (0.0456)	CO_2
16	4.13 (0.0683)	CO_2
17	3.98 (0.0663)	window
18	3.74 (0.140)	window
19	0.695 (0.05)	vis

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

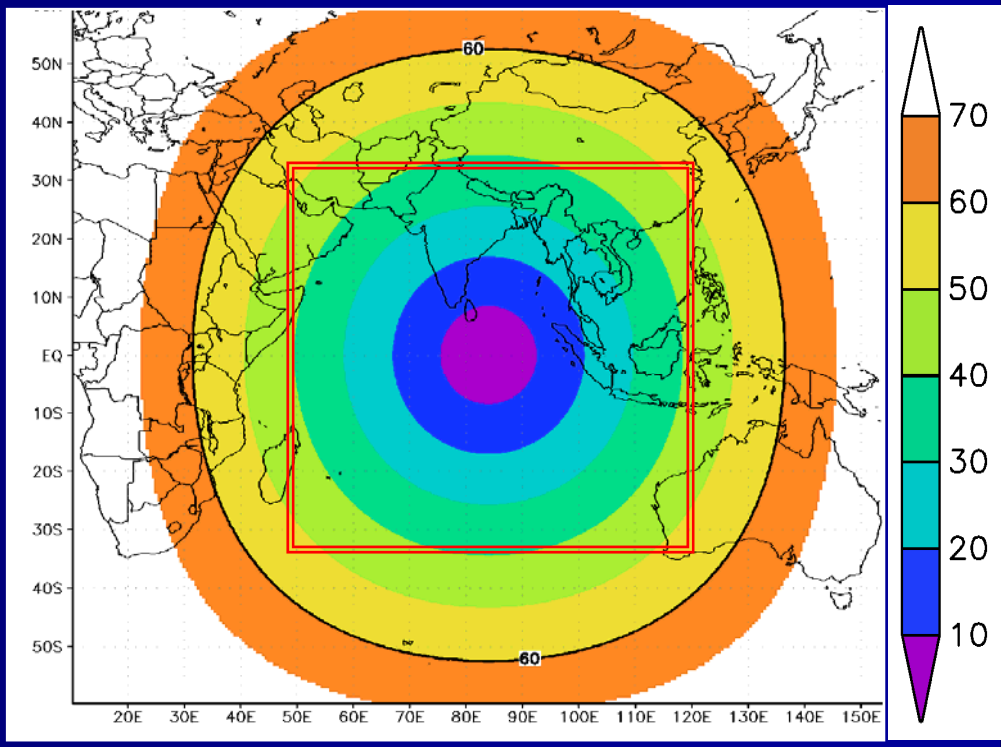
- **Vertical Profiles of:**
  - Temperature
  - Humidity (Surface – 100 hPa)
- **Surface Skin Temperature**
- **Total Ozone**

Pressure Levels (40) in hPa :

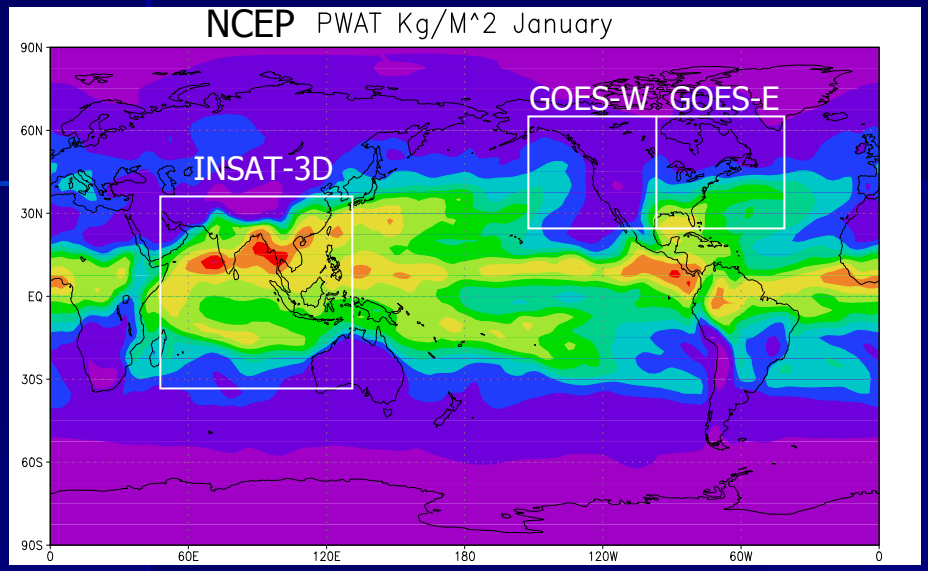
1000, 950, 920, 850, 750, 700, 670, 620, 570, 500, 475, 430, 400, 350, 300, 250, 200, 150, 135, 115, 100, 85,70,60, 50, 30, 25, 20, 15, 10, 7, 5, 4, 3, 2, 1.5, 1, 0.5, 0.2, 0.1

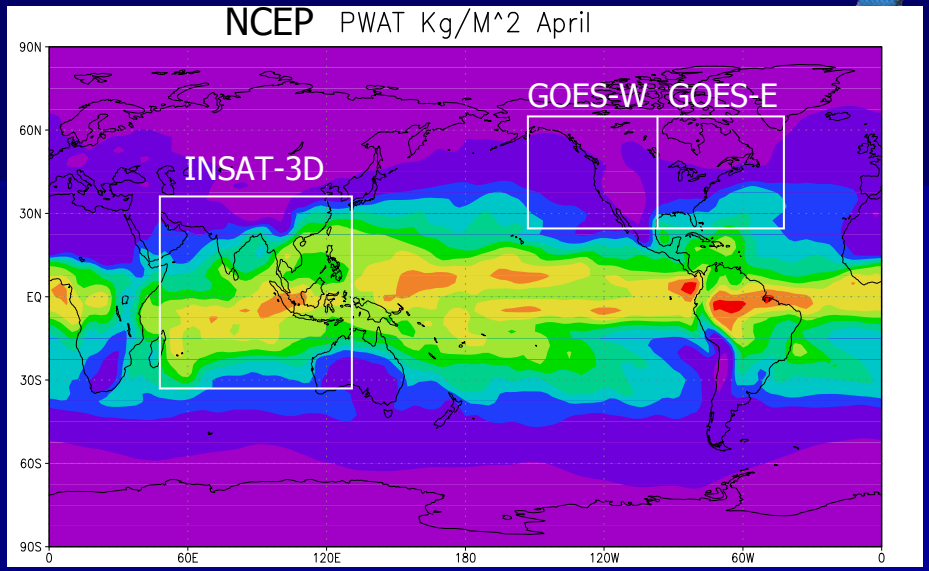
6400 km x 6400 km scan takes 180 minutes

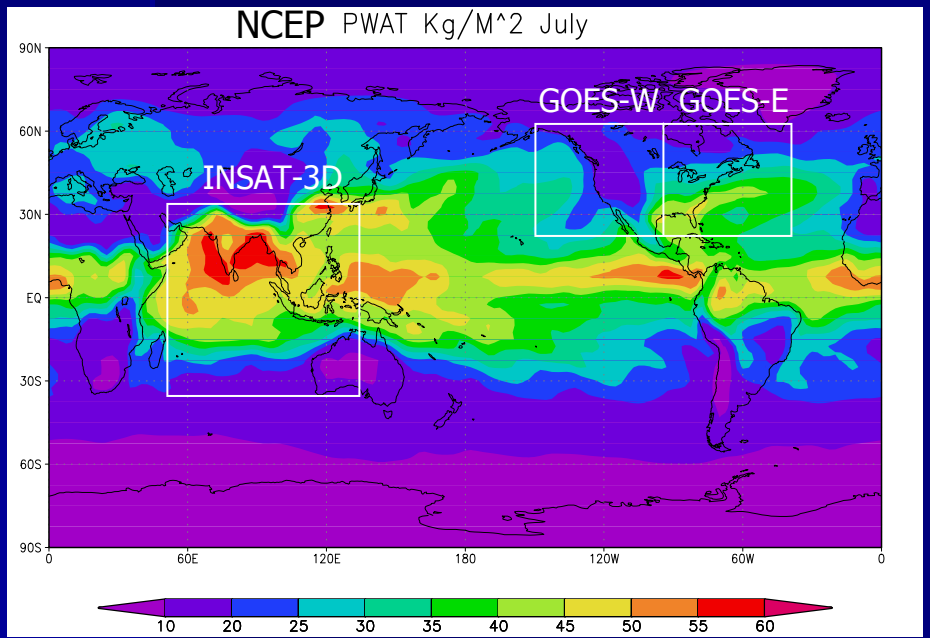
Observation zenith angle, INSAT-3D at 84E

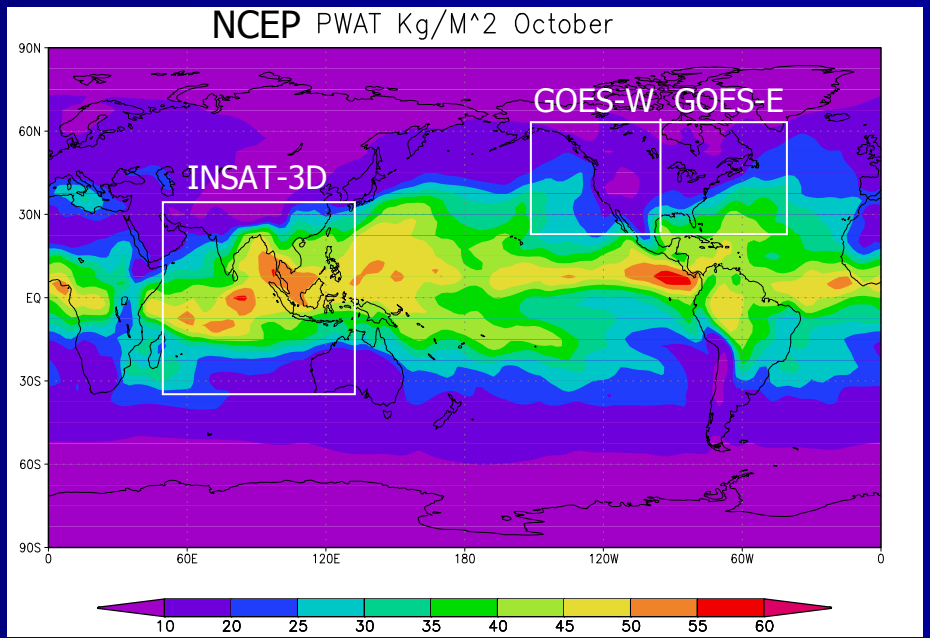


Characteristics of the atmosphere over GOES vs INSAT-3D Observations









Retrieval Algorithm

- **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 ε 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

(Li et al, 2000, JAM; Ma et al, 1997, JAM)

Radiative Transfer simulation
$Y = F(X) + \varepsilon$
$RC = dX.dY^T.(dY.dY^T)^{-1}$

Regression Retrieval
$X_{reg} = X_{mean} + RC.(dY)^T$

Forecast profile (X_{fcst})

Compute W_{fcst}

Compute W_{Reg}

Hybrid First Guess (X_0)
$X_0 = W_{fcst}.X_{fcst} + W_{reg}.X_{reg}$

Compute radiances: $y=F(X_n)$
(For first iteration $X_1 = X_0$)

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

Cloud detection/clearing

clear pixels
< 25 %

Cloudy FOR
Exit

clear pixels
> 25 %

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

Radiance Bias Correction
Rad → Tb **(Y)**

Physical Retrieval

Compare
Calculate residual
(Threshold → NEΔT)

$$r_{n+1}^2 = \sum_{k=1}^{nch} [Y_k - y_k(x_{n+1})]^2 / nch$$

Iteration < 8
Residual > Threshold

Iterate with new profile
(K=∂Y/∂X)

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

Residual < Threshold

Output (X)
Physical retrieval successful

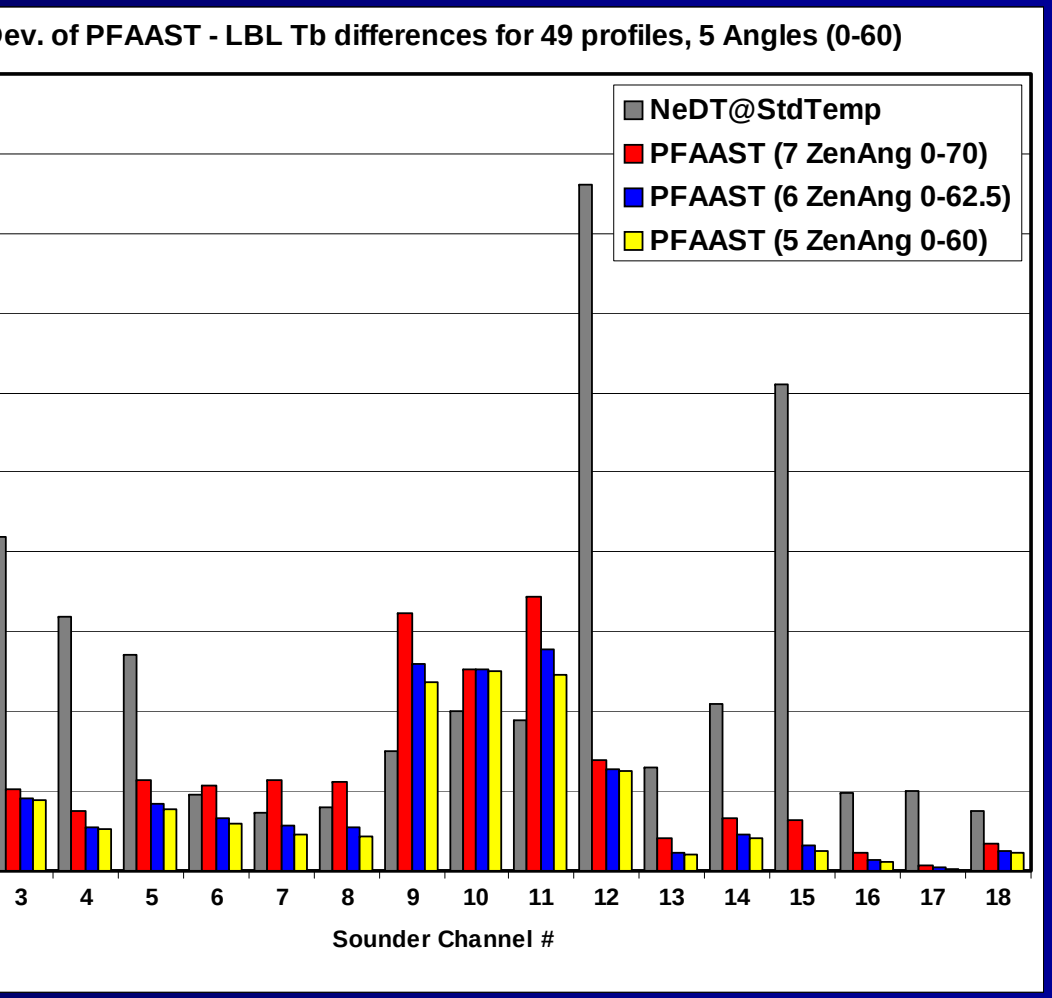
Iteration = 8
Residual > Threshold

Exit
Physical retrieval fail
Regression as final retrieval

PFAAST RT Model

PFAAST (Pressure-layer Fast Algorithm for Atmospheric Transmittances)

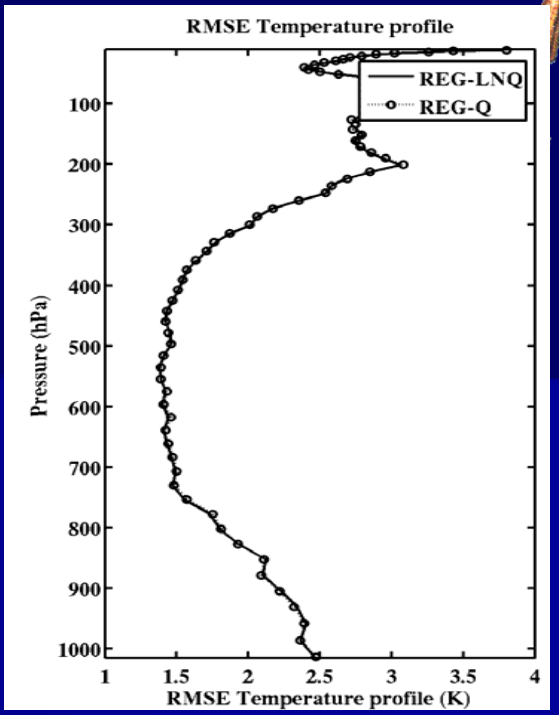
Improvement in PFAAST by restricting domain upto zenith angle 60°

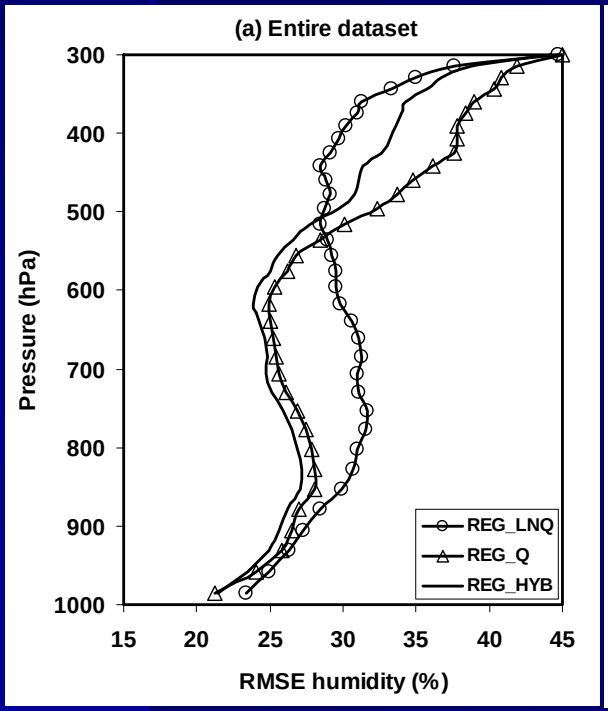


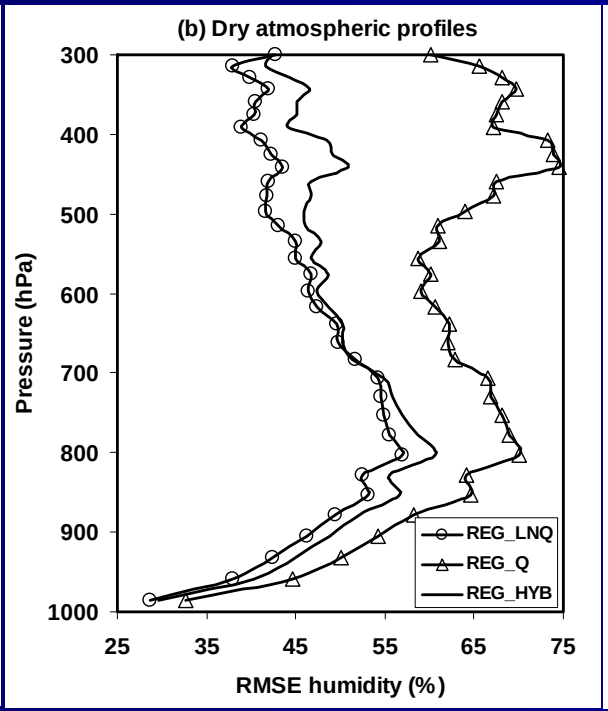
Regression Retrieval

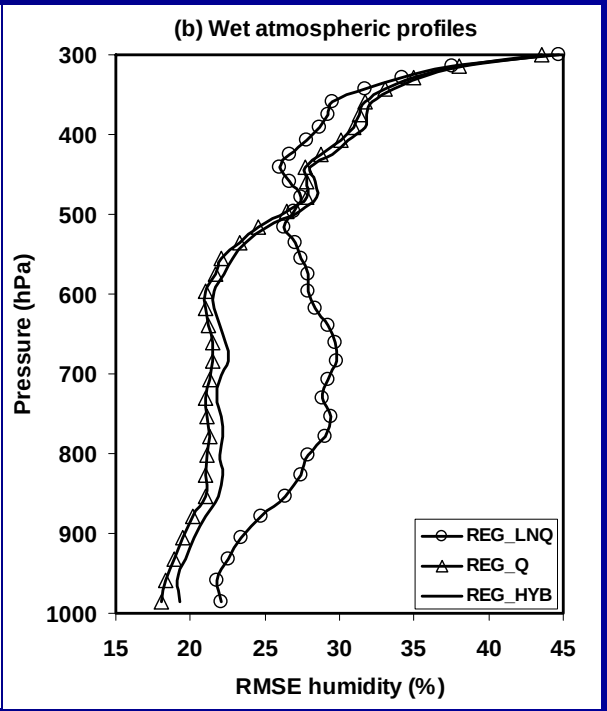
- Coefficients at different zenith angles (150 classes from 0-65°)
- 3 different latitude zones (0-20, 20-40, 40-60 in N/S)
- Different coefficients for land and ocean (Emissivity difference)
- Spectral emissivity as predictor over land
- Non-linear term (Tb^2) and P_s as predictor
- q and ln(q) as predictand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

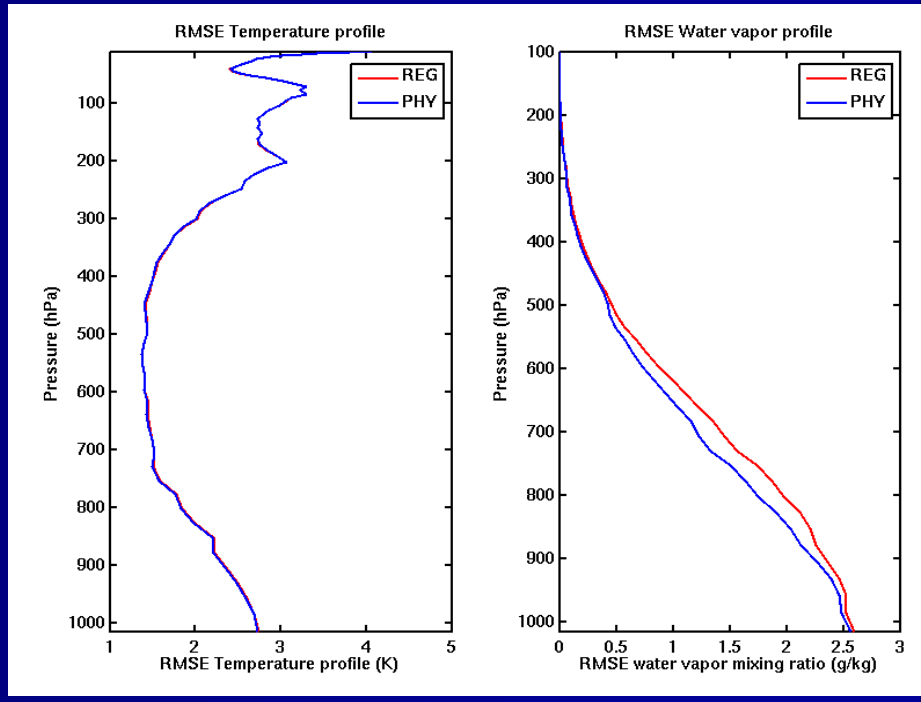
Convergence Test

- Expansion coefficient convergence test:
  - $d_{n+1} = (f_{n+1} - f_n)^T.(\xi_n^T E^{-1} \xi_n + \gamma_n I)^{-1}.(f_{n+1} - f_n)$
  - $d_{n+1} \rightarrow 0$ solution converges (i.e., $f_{n+1} \rightarrow f_n$).
  - Iteration stops when $(d_{n+1} - d_n) <$ threshold (~ 0.1).
  - If $d_{n+1} > d_n$ then γ_n is increased.
- Brightness temperature residual test:
  - RMS radiance residual is defined as:

$$r_{n+1}^2 = \sum_{k=1}^{nch} [Y_k - y_k(x_{n+1})]^2 / nch$$

  - If $r_{n+1} \leq r_n$ the iteration continues until r_{n+1} is acceptably small (less then NEDT)

Sample Result



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**

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