Assessment of Atmospheric Profiles Retrieved from Satellite

Theory and Case Study

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Assessment = End-to-End Error Modeling
Atmosphere, Signal, Retrieval and Validation

- True Profile $x_{\text{sat}}$
- Radiance $y_{\text{sat}}$
- True Profile $x_{\text{val}}$
- $y_{\text{val}}$

SDR & EDR Assessment

Parameter Error
Noise Instrument

Assessment Model

Smoothing Parameter
Forward model
Noise Retrieval

Validation System

SDR $\hat{y}$
EDR $\hat{x}$

$\hat{y}_{\text{val}}$
$\hat{x}_{\text{val}}$

SDR – Sensor Data Records – Radiances/Spectra
EDR – Environmental Data Records – Retrieved Profiles (in this presentation)
Linear Assessment Model
Concept

• Atmospheric, Instrument, Forward Model, and Retrieval parameters and their errors are **random** variables

• Variations and errors are characterized by **Covariances**

• Vertical resolution is characterized by **Averaging Kernels**

• Variations and errors propagate **Linearly** through **Atmosphere – Instrument – Signal – Retrieval-Validation**
EDR Assessment Model – EDRAM

- Linear mathematical error model for the Post-launch/Validation assessment of atmospheric profile retrievals.
- Assessment ≠ Comparison/Book-Keeping
- Assessment = Scientifically accurate relation between true state of the atmosphere and measurements
- Validated and validating data differ by:
  - Time and location
  - vertical resolution and grid
  - absolute accuracy and noise level

EDRAM makes the assessment accurate by allowing for the difference.
EDRAM Concept

- The validated system performs a set of measurements on an ensemble of true states \( x \)
  \[ \hat{x} = r(x) + e \]

- \( r(x) \) is a nominal retrieval with the absence of any errors in the measured signal and in the forward model

- \( e \) represents retrieval errors characterized by its mean value \( E\{e\} = \Delta \) (Bias) and covariance \( S_e \) (retrieval Noise)

- The goal of the EDRAM is to assess actual **Bias** and **Noise** of validated system by simulating its nominal retrieval based on validating data and to estimate the error of the assessment.
Linear Assessment Model
Atmosphere, Signal, Retrieval and Validation

Parameter Error - \( \delta b \)
Noise - \( \varepsilon \)
Instrument

\[ \delta \hat{y} = K \delta b + \varepsilon \]

SDR & EDR Assessment

\[ \delta \hat{y}_{\text{expected}} \]

Assessment Model
\[ \delta \hat{x}_{\text{expected}} \]

Validation System

\[ \hat{y}_{\text{val}} \]

\[ \hat{x}_{\text{val}} \]

True Profile \( x_{\text{sat}} \)
Radiance \( y_{\text{sat}} \)

Clive Rodgers

Forward model Noise

True Profile \( x_{\text{val}} \)

EDR \( \hat{x} \)

SDR \( \hat{y} \)

Retrieval System

\[ \delta \hat{x} = (A - I)(x - x_{\text{sat}}) \]

\[ + G_y K_y \delta b \]

\[ + G_y \Delta FM \]

\[ + G_y \varepsilon \]
EDRAM – Data Flow

Statistical Characteristics of true states
\{\bar{x}_1 S_{x_1}\}; \{\bar{x}_2 S_{x_2}\}; S_{12}

Validated Retrieval Characterization \hat{x}_1 A_1; a S_{\varepsilon_1}

Validating Data Characterization \hat{x}_2 A_2; S_{\varepsilon_2}

Estimation of Bias $\Delta \hat{x}_1 \pm Err$

Noise $S_{\varepsilon_1}$
The goal of the EDRAM is to assess actual Bias $\Delta\hat{x}_i$ and Noise $\sum_{\varepsilon_i}$ of validated system.
EDRAM - Theoretical background
Relation between Atmospheric States

\[ \bar{x}_1 \delta x_1 \text{ and } \bar{x}_2 \delta x_2 \]

- Mean and variation about mean of true states
- Auto-covariance of true states
- Cross-covariance between true states

\[ S_{x_1} S_{x_2} \]

\[ S_{12} = S_{21}^T \]

**Relation between true states**

\[ \delta x_1 = B \delta x_2 + \xi \]

- Correlated

\[ S_{x_1} = B S_{x_2} B^T + S_\xi \]

- Un-Correlated

\[ \text{cov}(x_2, \xi) = 0 \]

\[ B = S_{12} S_{x_2}^{-1} \]
Theoretical background
(Continued)

Simulating with \( \hat{x}_1 \) and \( \hat{x}_2 \)

\( \hat{x}_{12} = A_1 B \hat{x}_2 = A_1 B (I - A_2)x_{a_2} + A_1 B A_2 x_2 + A_1 B \varepsilon_2 \)

Validated Measurement

\( \delta \hat{x} \equiv \hat{x}_1 - \hat{x}_{12} \)

Simulated Validated Measurement!

\( \delta \hat{x} \equiv \hat{x}_1 - \hat{x}_{12} = [(I - A_1)x_{a_1} - A_1 B (I - A_2)x_{a_2}] + A_1 \bar{x}_1 - A_1 B A_2 \bar{x}_2 + \Delta \hat{x}_1 \)

Analyzed Difference

Mean Difference

Mean Expected Difference \( \bar{e} \delta \hat{x} \)

Bias

Covariance of the Analyzed Difference

\( S_{\delta \hat{x}} = (A_1 B (I - A_2))s_{x_2} (A_1 B (I - A_2))^T + A_1 s_{\xi} A_1^T + s_{\varepsilon_1} + (A_1 B) s_{\varepsilon_2} (A_1 B)^T \)
Case Study

• *Validation Data Set* – radiosondes at ARM Southern Great Plain (SGP) site; July – December 2002 (416 sondes).

• *Validated parameter* – Atmospheric Temperature Vertical Profile.

• *Validated System* – characterized by AIRS* averaging kernels.
Auto- and Cross-Correlation

\[ S_{x_2} = E\{(x_2 - \bar{x}_2)(x_2 - \bar{x}_2)^T\} \]

Auto-Covariance \( S_{x_2} \)

\[ S_{12} = E\{(x_1 - \bar{x}_1)(x_2 - \bar{x}_2)^T\} \]

3 hours 6 hours 12 hours

24 hours 2 days 4 days 5 days
Non-Coincidence Error

\[ \delta x_i = B \delta x + \xi \]

Variation at validated point

Correlated

\[ S_{\delta x} = BS_{\xi}B^T + S_{\xi} \]

Uncorrelated/Residual error

\[ S_{\xi} = S_{x_1} - BS_{x_2}B^T \]

\[ \sqrt{S_{\xi}} \text{ and } S_{x_2} \text{ (diagonals)} \]
AIRS global estimate 0.8 K (± 3 hour, ± 100 km)  
Chahine et al., 2006

\[ \sigma_{\xi} = (0.22\tau + 0.14) K \]
Averaging Kernels for Temperature Profile
AIRS Spectral Channels, ILS, and SNR
Optimal Estimation (Clive Rodgers)
"Satellite Retrievals" vs. Radiosondes

\[ \delta \hat{x} = A_1 x_1 - A_1 B x_2 \]

Non-Coincidence 6 hours Error

\[ \delta \hat{x} = x_1 - B x_2 \]

Square Root Diagonals - RMS
Conclusions

• **Non-Coincidence Error** analysis is applicable to Radiances (SDR) and retrievals (EDR) assessment.

• **EDRAM** provides scientific basis and **practical tool** for accurate comparison of atmospheric profiles of different vertical resolution and taken at different times and locations.

• **EDRAM** estimates retrieval **bias and noise** as well as statistical significance of the estimates based on the comparison.

• **EDRAM** can be used for evaluation of a satellite EDR for **Earth System and Climate** studies by accurately referencing them to other data sets with known accuracy and precision.