Assessment of Atmospheric Profiles Retrieved from Satellite

Theory and Case Study

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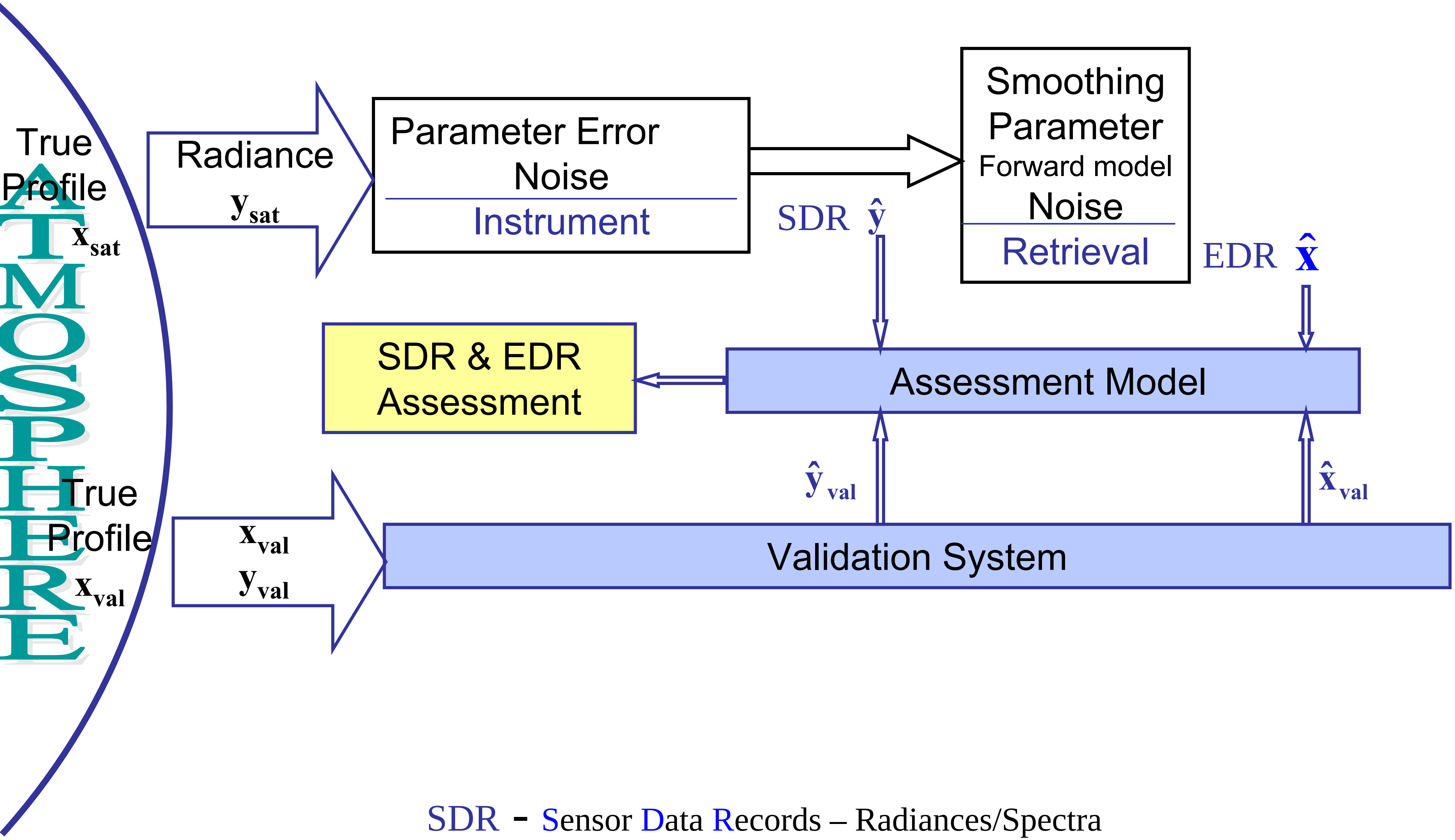
Assessment=End-to-End Error Modeling Atmosphere, Signal, Retrieval and Validation



SDR - Sensor Data Records – Radiances/Spectra

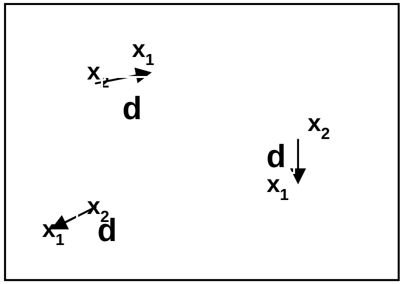
EDR – Environmental Data Records – Retrieved Profiles (in this presentation)

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.

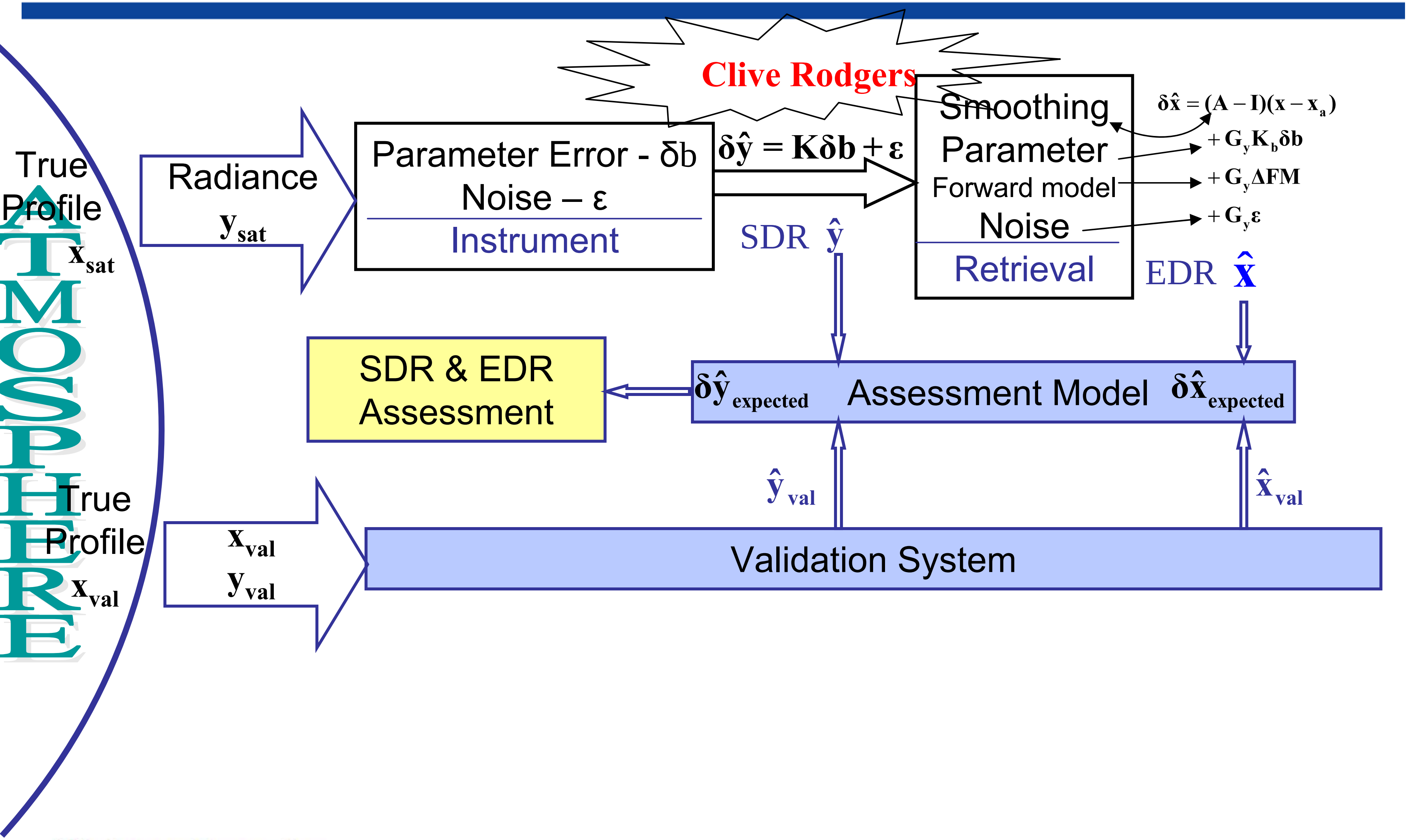
EDRAM Concept

- The validated system performs a set of measurements on an ensemble of true states **x**

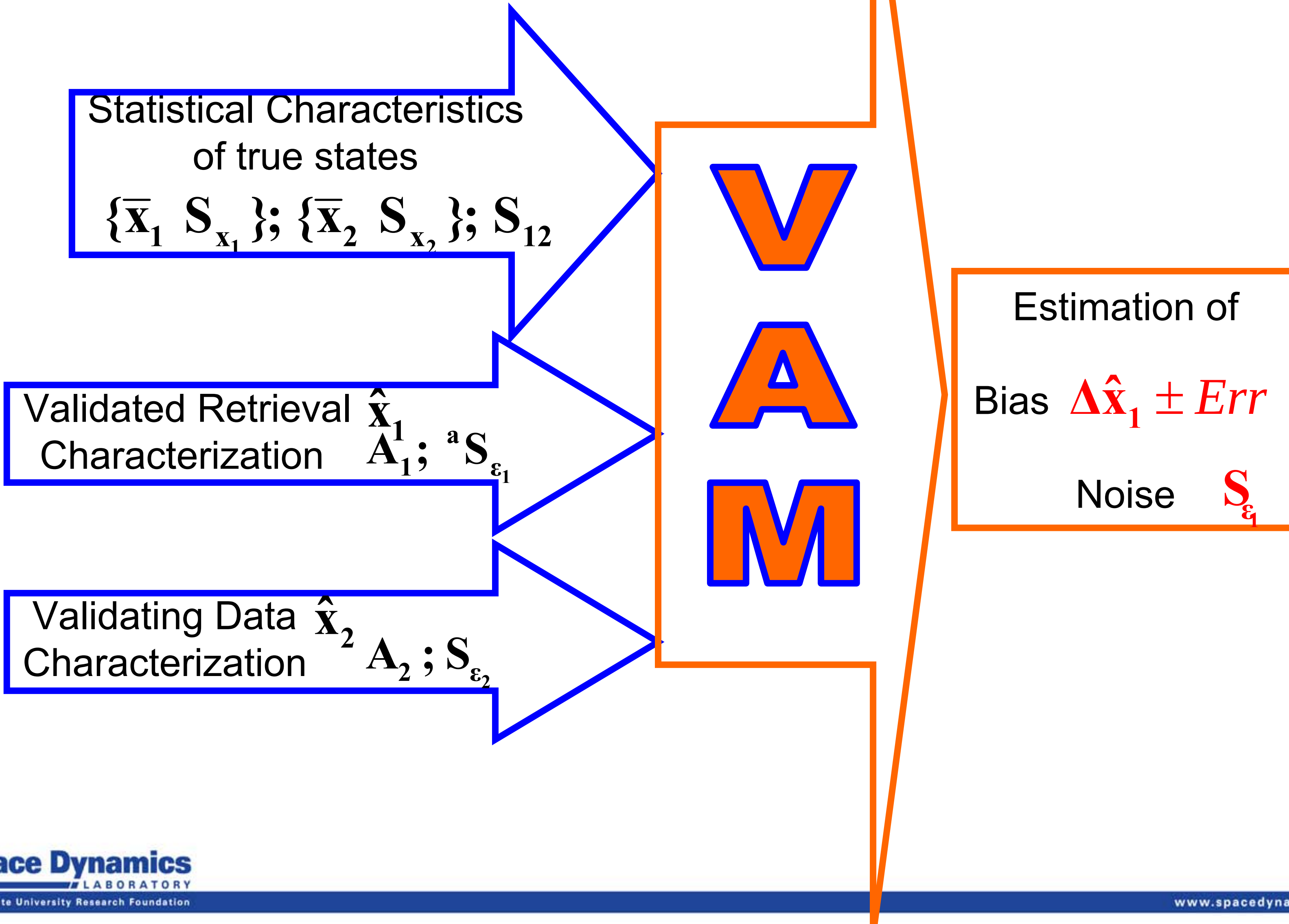
$$\hat{\mathbf{x}} = \mathbf{r}(\mathbf{x}) + \mathbf{e}$$

- **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 $E\{\mathbf{e}\} = \mathbf{\Delta}$ (**Bias**) and covariance $\mathbf{S_e}$ (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



EDRAM – Data Flow



EDRAM -Theoretical background
Retrieval Model

Retrieval/Measurements → $$\hat{\mathbf{x}}_i = \mathbf{x}_{ai} + \mathbf{A}_i(\mathbf{x}_i - \mathbf{x}_{ai}) + \Delta\hat{\mathbf{x}}_i + \boldsymbol{\varepsilon}_i$$

Averaging Kernel

True state

A priori

Bias

Noise

i=1	Validated data
i=2	Validating Data

The goal of the EDRAM is to assess actual Bias $\Delta\hat{\mathbf{x}}_1$ and Noise $\mathbf{S}_{\varepsilon_1}$ of validated system.

EDRAM - Theoretical background
Relation between Atmospheric States

i=1 Validated data
i=2 Validating Data

$\bar{x}_1 \;\; \delta x_1$ and $\bar{x}_2 \;\; \delta x_2$ ← Mean and variation about mean of **true states**

$S_{x_1} \;\; S_{x_2}$ ← Auto-covariance of **true states**

$S_{12} = S_{21}^T$ ← Cross-covariance between **true states**

Relation between true states

Variation at validated point →

$$\delta x_1 = B\delta x_2 + \xi$$

Correlated

$$S_{x_1} = BS_{x_2}B^T + S_\xi$$

← Un-Correlated

$$cov(x_2, \xi) = 0$$

$$B = S_{12}S_{x_2}^{-1}$$

Theoretical background

(Continued)

Simulating $\hat{\mathbf{x}}_1$ with $\hat{\mathbf{x}}_2$

$$\hat{\mathbf{x}}_{12} = \mathbf{A}_1\mathbf{B}\hat{\mathbf{x}}_2 = \mathbf{A}_1\mathbf{B}(\mathbf{I}-\mathbf{A}_2)\mathbf{x}_{a_2} + \mathbf{A}_1\mathbf{B}\mathbf{A}_2\mathbf{x}_2 + \mathbf{A}_1\mathbf{B}\varepsilon_2$$

Validated Measurement

Analyzed Difference

$$\delta\hat{\mathbf{x}} \equiv \hat{\mathbf{x}}_1 - \hat{\mathbf{x}}_{12}$$

Simulated Validated Measurement!

$$\delta\overline{\hat{\mathbf{x}}} \equiv \overline{\hat{\mathbf{x}}}_1 - \overline{\hat{\mathbf{x}}}_{12} = [(\mathbf{I}-\mathbf{A}_1)\mathbf{x}_{a1} - \mathbf{A}_1\mathbf{B}(\mathbf{I}-\mathbf{A}_2)\mathbf{x}_{a2}] + \mathbf{A}_1\overline{\mathbf{x}}_1 - \mathbf{A}_1\mathbf{B}\mathbf{A}_2\overline{\mathbf{x}}_2 + \Delta\hat{\mathbf{x}}_1$$

Mean Difference

Mean Expected Difference ${}^{e}\delta\overline{\hat{\mathbf{x}}}$

Bias

$$\mathbf{S}_{\delta\hat{\mathbf{x}}} = (\mathbf{A}_1\mathbf{B}(\mathbf{I}-\mathbf{A}_2))\mathbf{S}_{\mathbf{x}_2}(\mathbf{A}_1\mathbf{B}(\mathbf{I}-\mathbf{A}_2))^T + \mathbf{A}_1\mathbf{S}_\xi\mathbf{A}_1^T + \mathbf{S}_{\varepsilon_1} + (\mathbf{A}_1\mathbf{B})\mathbf{S}_{\varepsilon_2}(\mathbf{A}_1\mathbf{B})^T$$

Covariance of the Analyzed Difference

Case Study

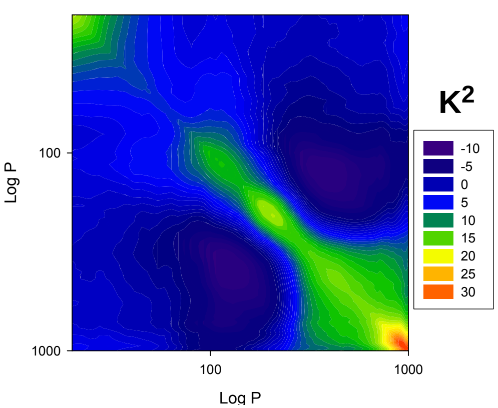
- *Validation Data Set* – radiosondes at ARM Southern Great Plain (SGP) site; July – December 2002 (416 sondes).
- *Validated parameter* – Atmospheric Temperature Vertical Profile.
- *Validated System* – characterized by AIRS* averaging kernels.

Auto- and Cross-Correlation

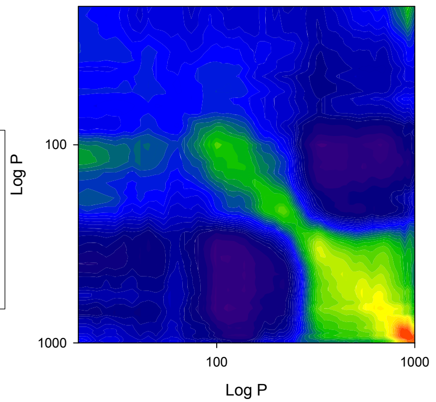
$$\mathbf{S}_{\mathbf{x}_2} = E\{(\mathbf{x}_2 - \bar{\mathbf{x}}_2)(\mathbf{x}_2 - \bar{\mathbf{x}}_2)^T\}$$

$$\mathbf{S}_{12} = E\{(\mathbf{x}_1 - \bar{\mathbf{x}}_1)(\mathbf{x}_2 - \bar{\mathbf{x}}_2)^T\}$$

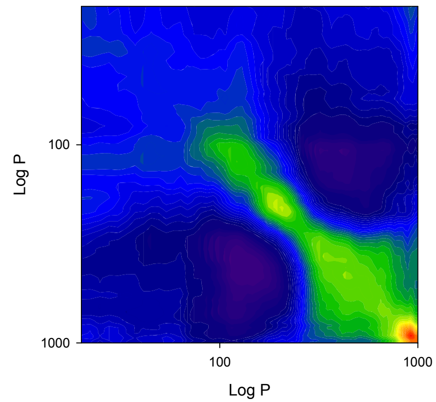
Auto-Covariance S_{x2}



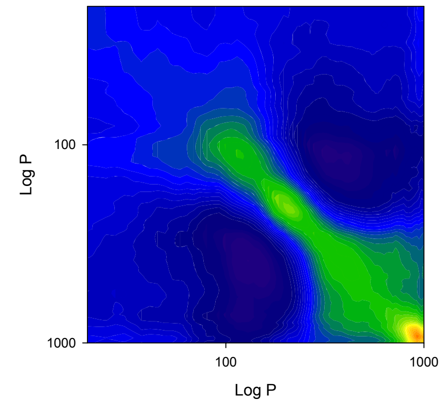
3 hours



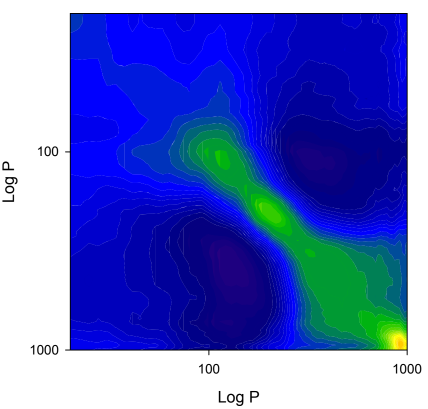
6 hours



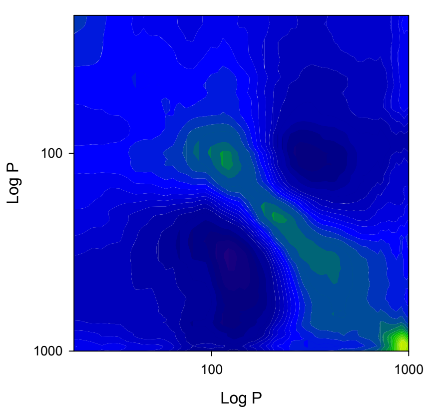
12 hours



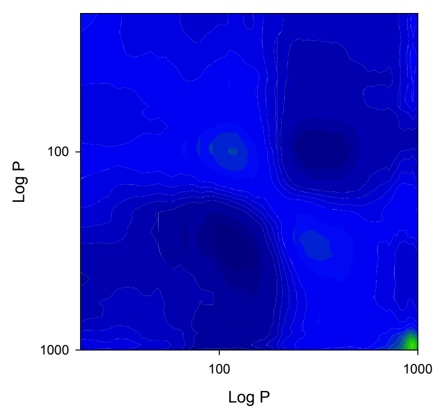
24 hours



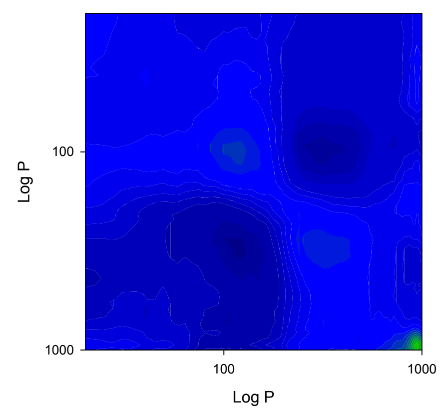
2 days



4 days



5 days



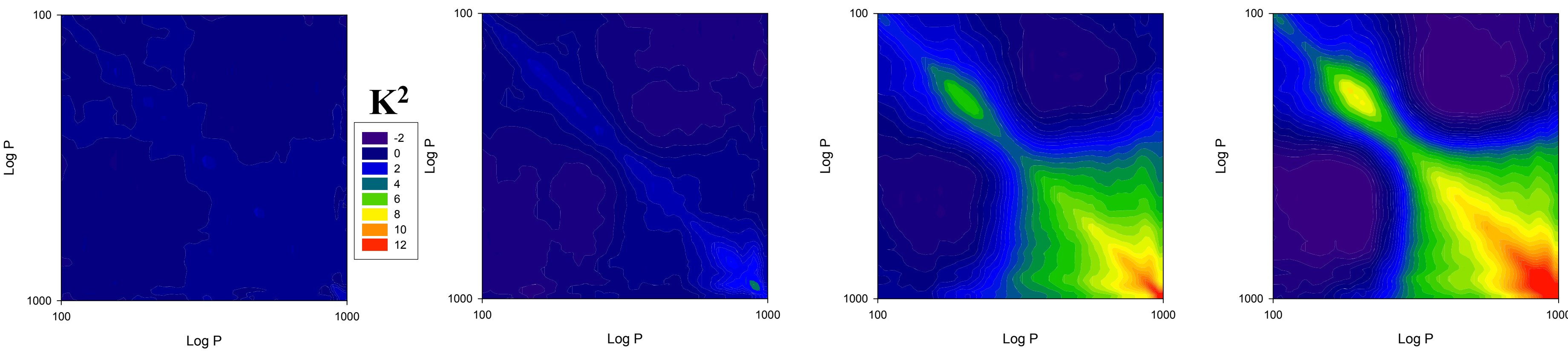
Non-Coincidence Error

Variation at validated point → $\delta x_1 = B\delta x_2 + \xi$ ↔ (Correlated) ↔ $S_{x_1} = BS_{x_2}B^T + S_\xi$ ← Un-Correlated $cov(x_2,\xi) = 0$

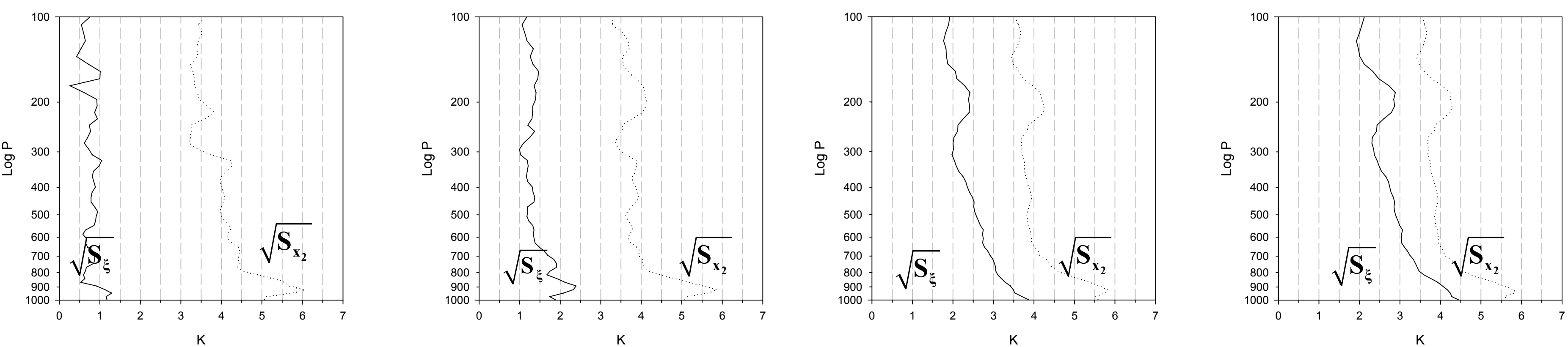
Uncorrelated/Residual error

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

3 hours | 6 hours | 12 hours | 24 hours



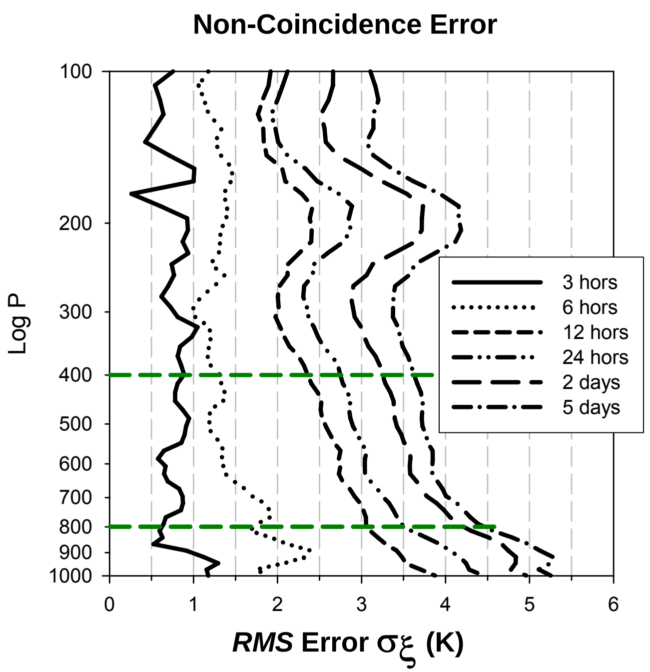
$$\sqrt{S_\xi \;\; and \;\; S_{x_2} \; (diagonals)}$$

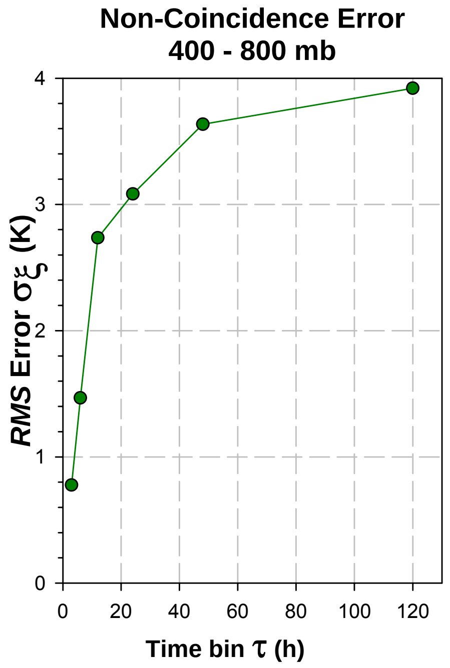


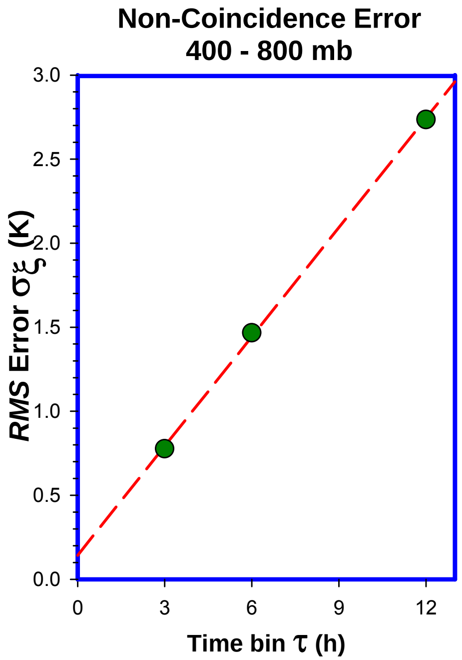
Non-Coincidence Error
(continued)

AIRS global estimate 0.8 K($\pm 3\,hour, \pm 100\,km$)
Chahine et al., 2006

$$\sigma_{\xi} = (0.22\tau + 0.14)\,K$$





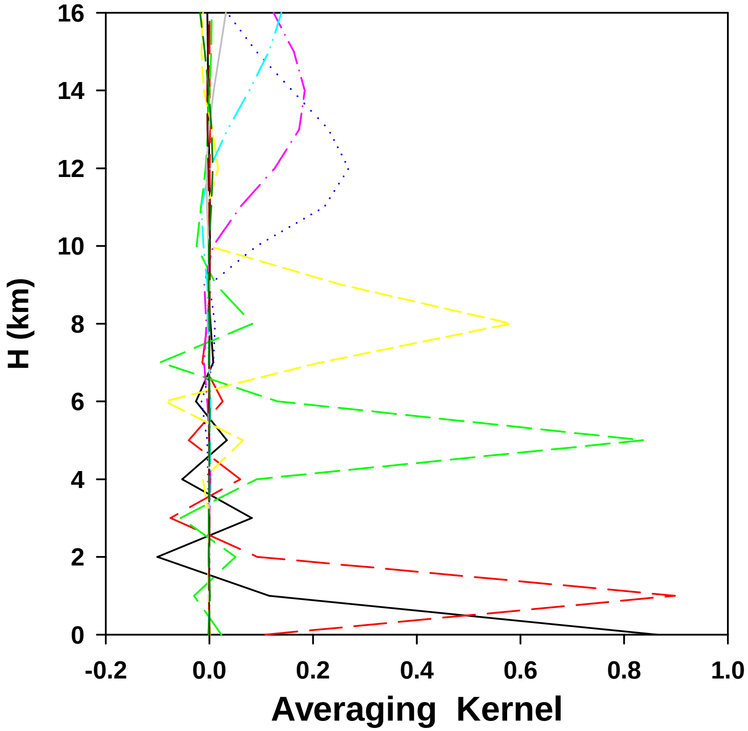


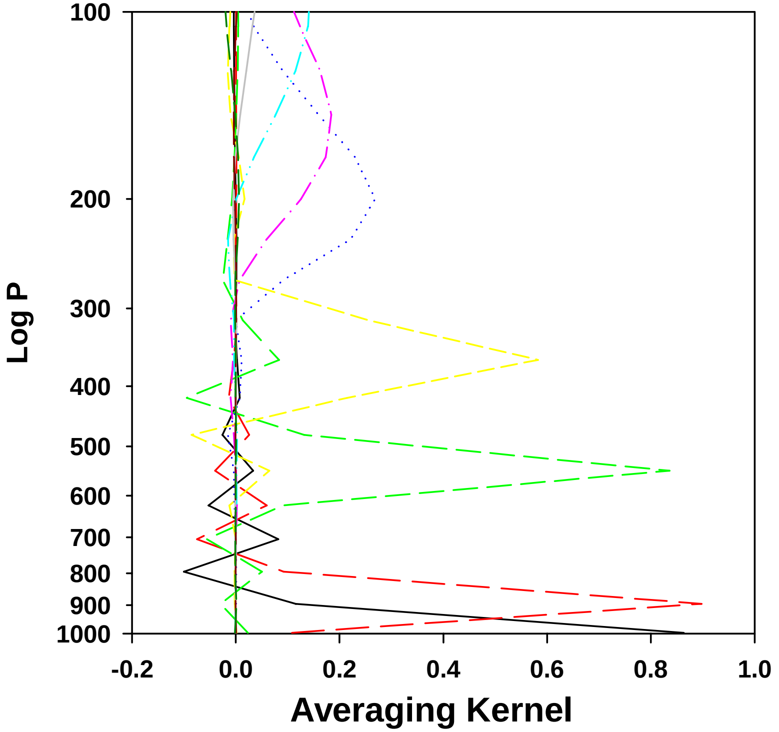
Averaging Kernels

Averaging Kernels for Temperature Profile

AIRS Spectral Channels, ILS, and SNR

Optimal Estimation (Clive Rodgers)

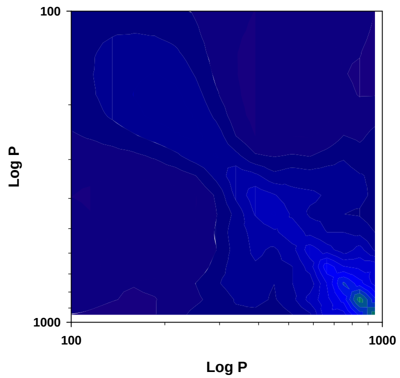




“Satellite Retrievals” vs. Radiosondes *RMS*

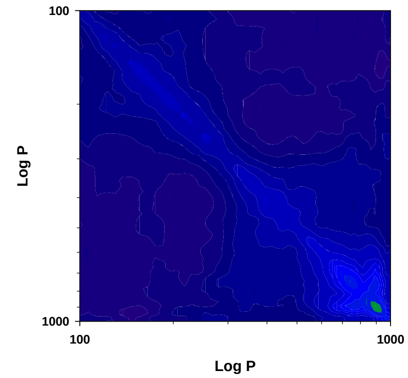
Non-Coincidence 6 hours & Smoothing Error

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

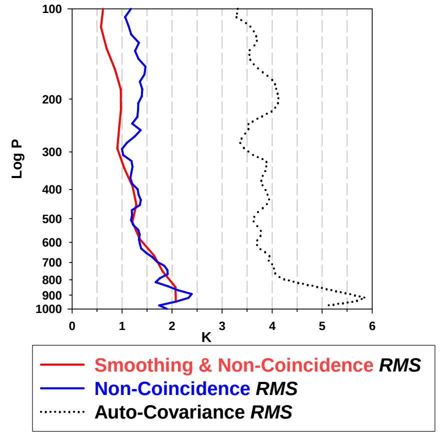


Non-Coincidence 6 hours Error

$$\delta\hat{x} = x_1 - B x_2$$



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.

International TOVS Study Conference, 15th, ITSC-15, Maratea,Italy, 4-10 October 2006
Madison, WI, University of Wisconsin-Madison, Space Science and Engineering Center,
Cooperative Institute for Meteorological Satellite Studies, 2006.