

Assessment of Atmospheric Profiles Retrieved from Satellite

Theory and Case Study

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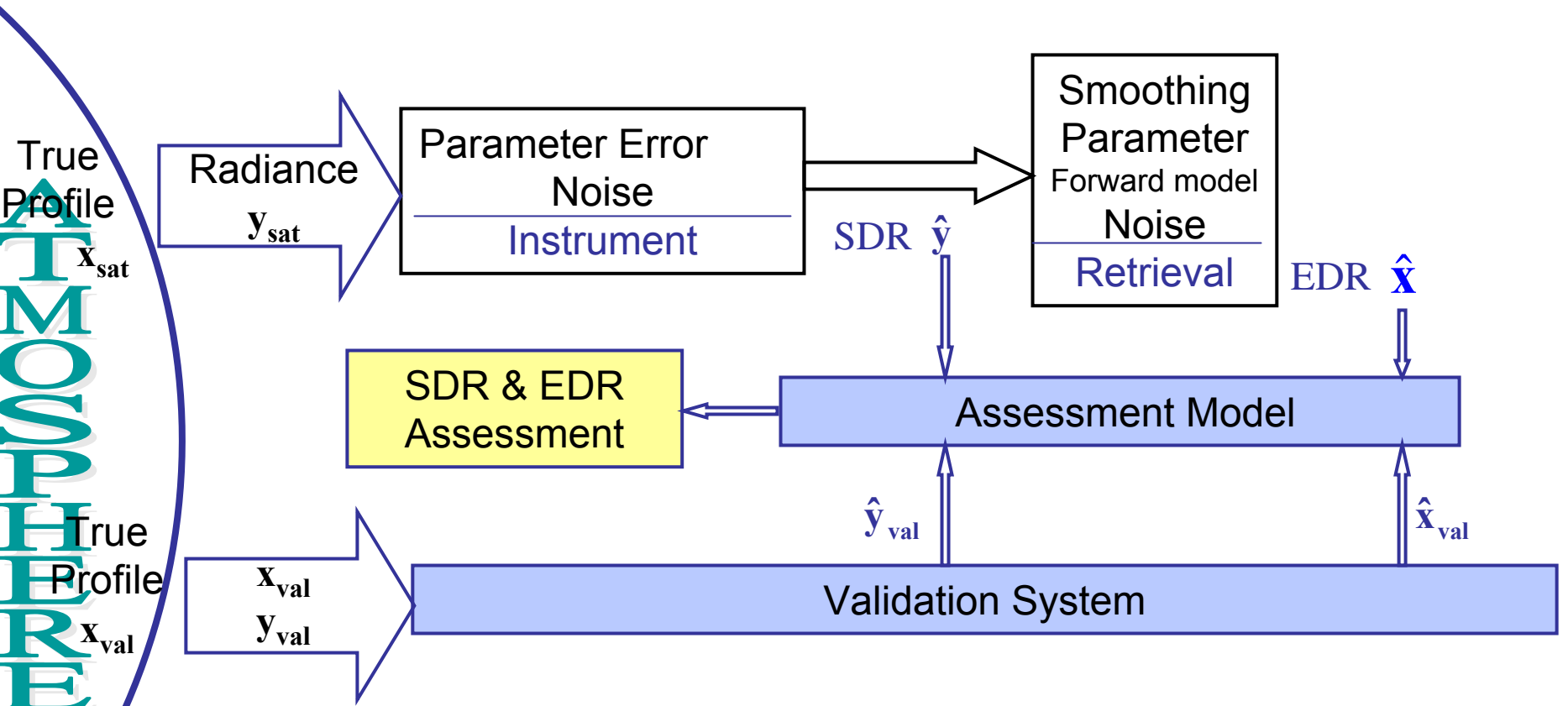
Gail Bingham, Stanislav Kireev, and David Tobin

ITSC-15

Acquafredda Maratea, Italy

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



SDR - Sensor Data Records – Radiances/Spectra

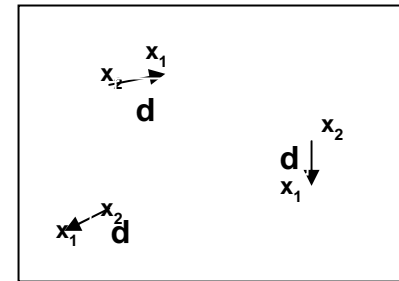
EDR – Environmental Data Records – Retrieved Profiles (in this presentation)

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 \neq 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.



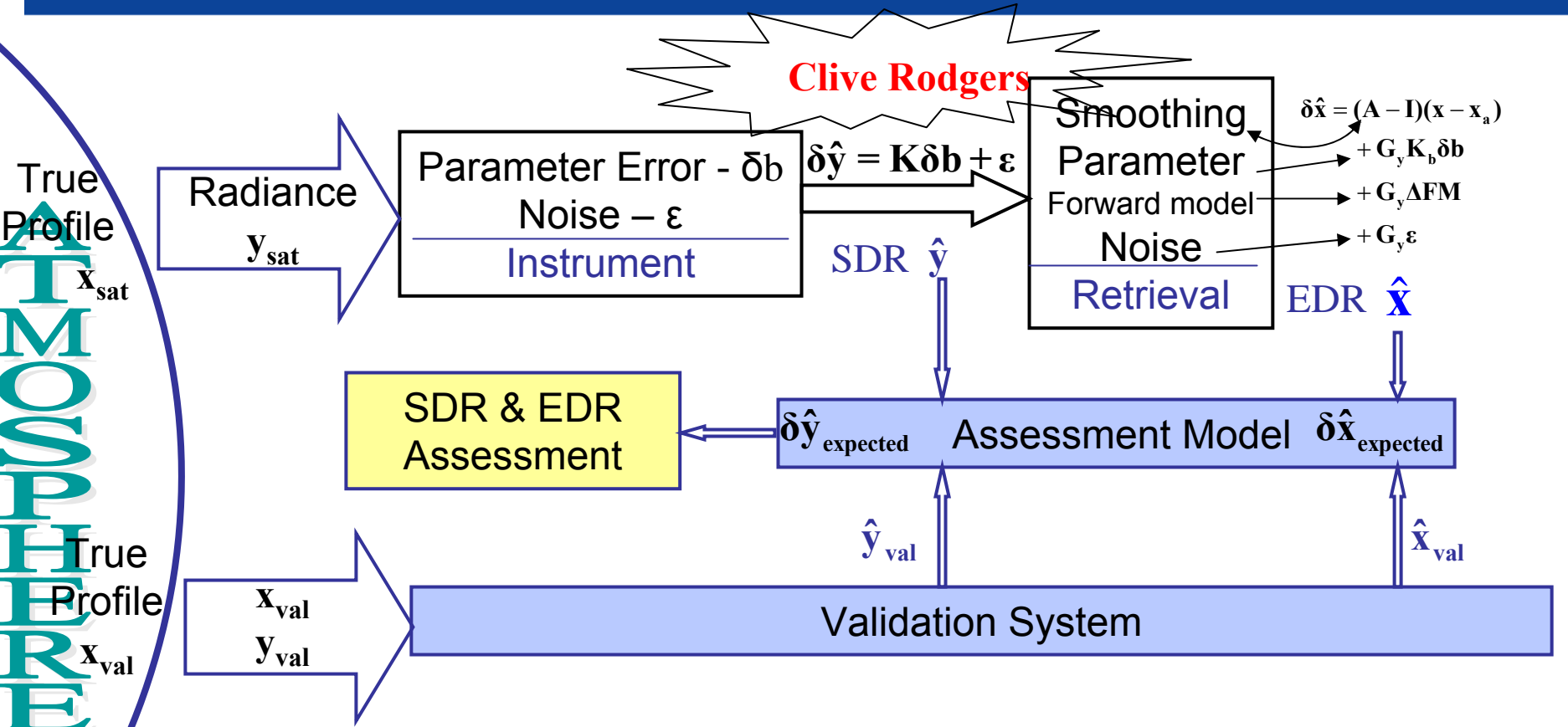
EDRAM Concept

- The validated system performs a set of measurements on an ensemble of true states \mathbf{x}

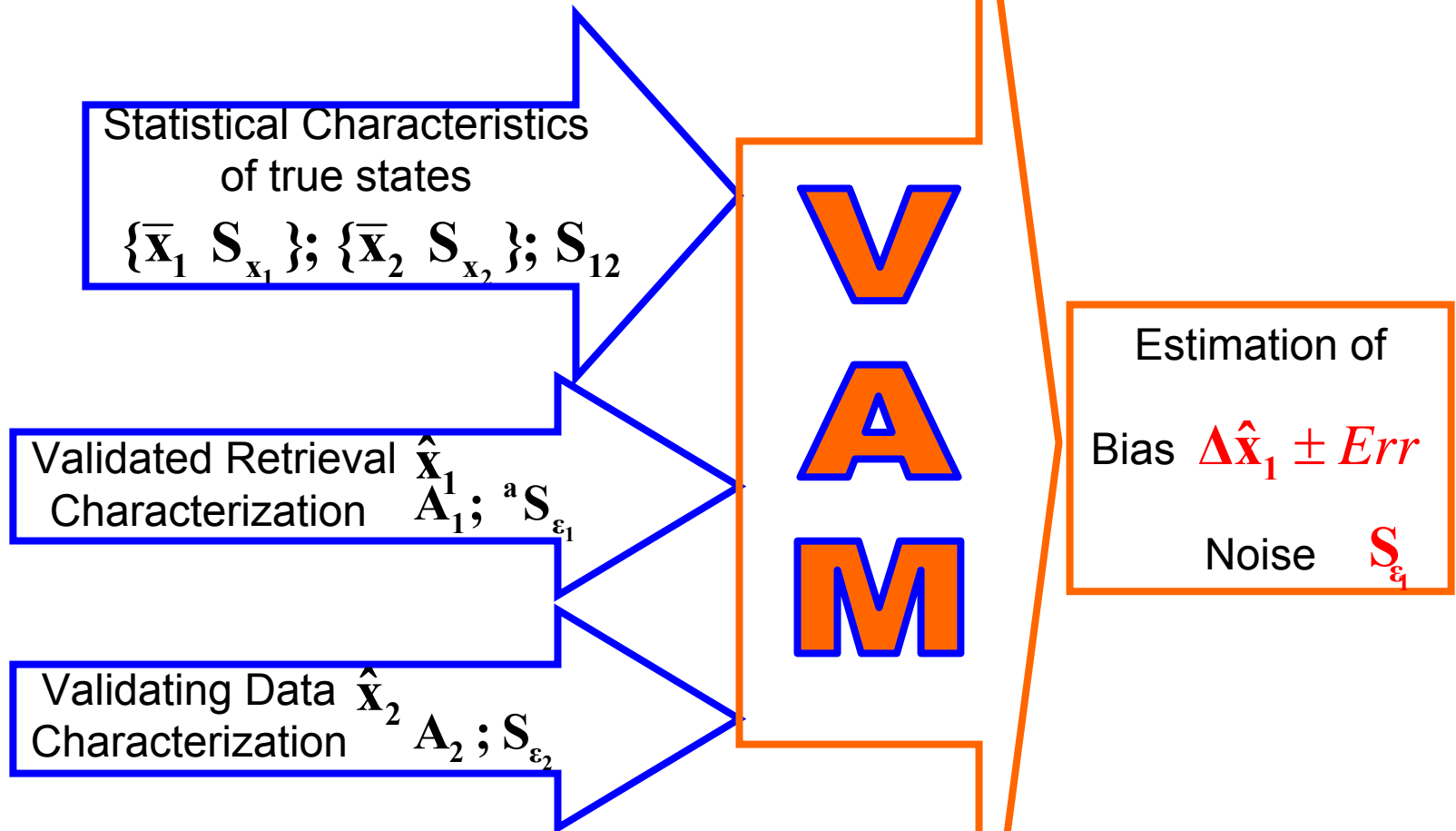
$$\hat{\mathbf{x}} = \mathbf{r}(\mathbf{x}) + \mathbf{e}$$

- $\mathbf{r}(\mathbf{x})$ is a nominal retrieval with the absence of any errors in the measured signal and in the forward model
- \mathbf{e} represents retrieval errors characterized by its mean value $E\{\mathbf{e}\} = \Delta$ (**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.

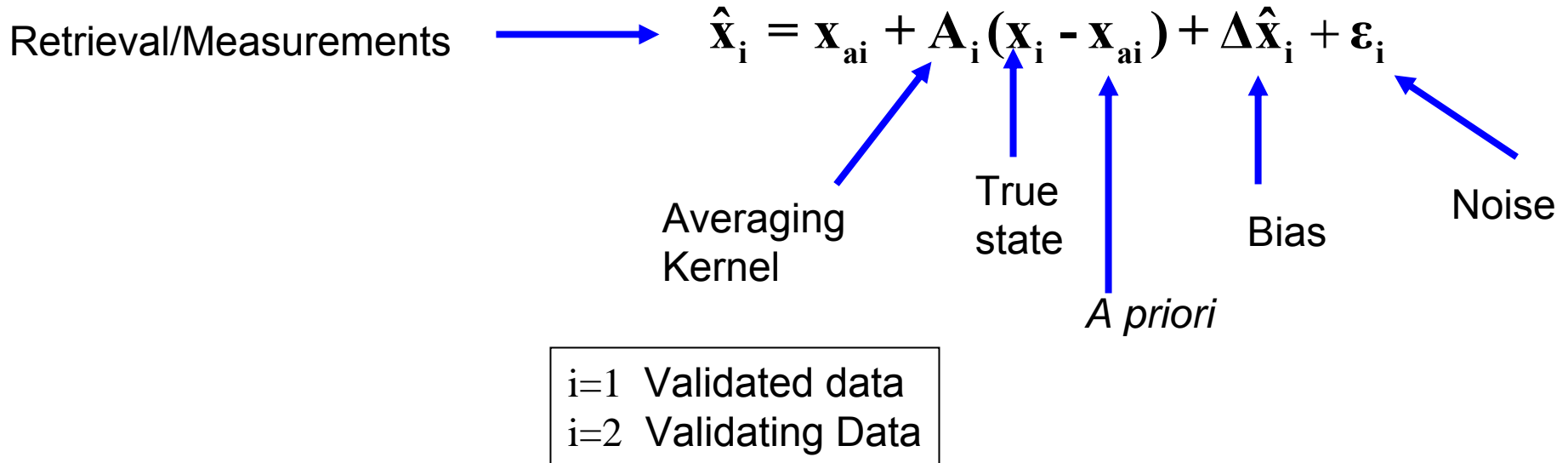
Linear Assessment Model Atmosphere, Signal, Retrieval and Validation



EDRAM – Data Flow



EDRAM - Theoretical background Retrieval Model



The goal of the **EDRAM** is to assess actual Bias $\Delta \hat{\mathbf{x}}_1$ and Noise $\mathbf{S}_{\boldsymbol{\varepsilon}_1}$ 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

$$\delta x_1 = \mathbf{B} \delta x_2 + \xi$$

Correlated

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

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

Un-Correlated
 $\text{cov}(x_2, \xi) = 0$

Variation at validated point →

Theoretical background

(Continued)

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

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

Validated Measurement

Analyzed Difference

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

Simulated Validated Measurement!

$$\delta \bar{\mathbf{x}} \equiv \bar{\mathbf{x}}_1 - \bar{\mathbf{x}}_{12} = \underbrace{[(\mathbf{I} - \mathbf{A}_1) \mathbf{x}_{a_1} - \mathbf{A}_1 \mathbf{B} (\mathbf{I} - \mathbf{A}_2) \mathbf{x}_{a_2}]}_{\text{Mean Expected Difference } e \delta \bar{\mathbf{x}}} + \mathbf{A}_1 \bar{\mathbf{x}}_1 - \mathbf{A}_1 \mathbf{B} \mathbf{A}_2 \bar{\mathbf{x}}_2 + \Delta \hat{\mathbf{x}}_1$$

Mean Difference

Mean Expected Difference $e \delta \bar{\mathbf{x}}$

Bias

$$\mathbf{S}_{\delta \hat{\mathbf{x}}} = \underbrace{(\mathbf{A}_1 \mathbf{B} (\mathbf{I} - \mathbf{A}_2)) \mathbf{S}_{x_2} (\mathbf{A}_1 \mathbf{B} (\mathbf{I} - \mathbf{A}_2))^T + \mathbf{A}_1 \mathbf{S}_{\xi} \mathbf{A}_1^T + \mathbf{S}_{\varepsilon_1} + (\mathbf{A}_1 \mathbf{B}) \mathbf{S}_{\varepsilon_2} (\mathbf{A}_1 \mathbf{B})^T}_{\text{Covariance of the Analyzed Difference}}$$

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

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

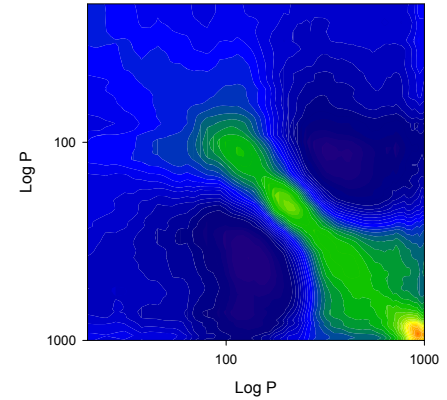
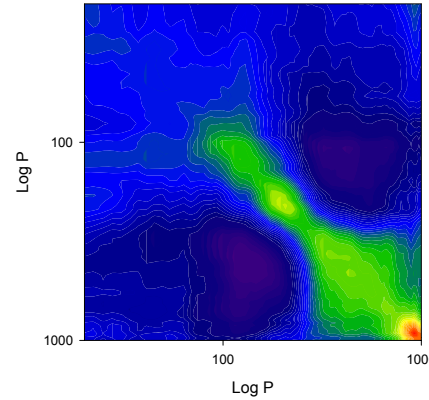
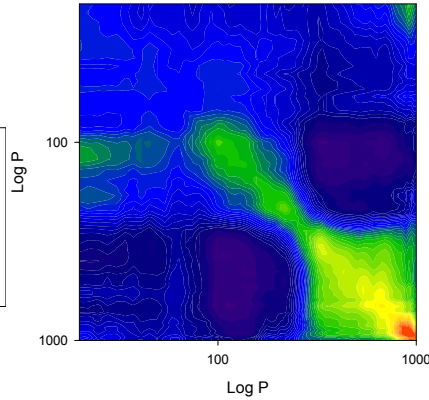
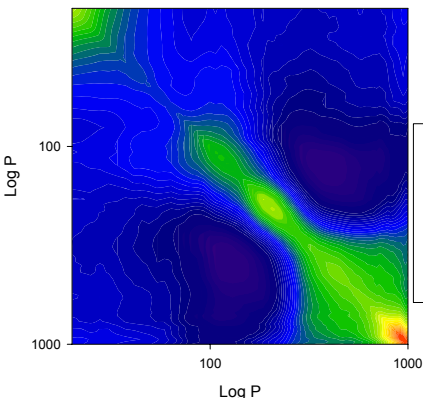
Auto-Covariance S_{x_2}

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

3 hours

6 hours

12 hours

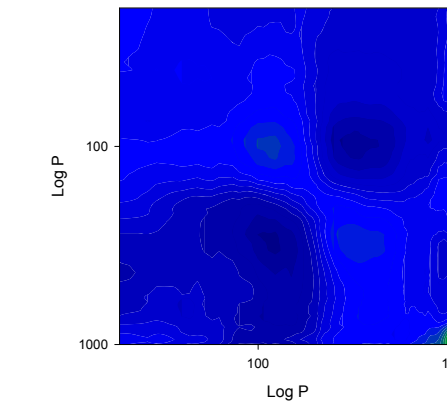
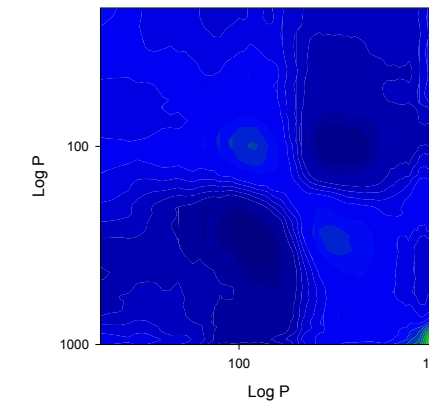
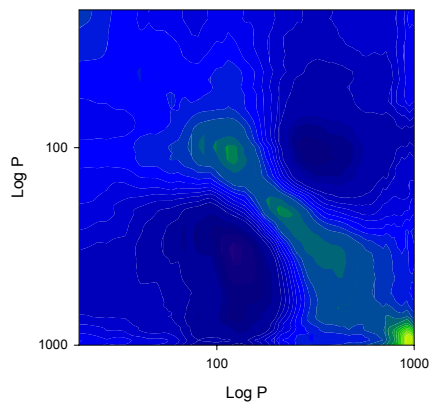
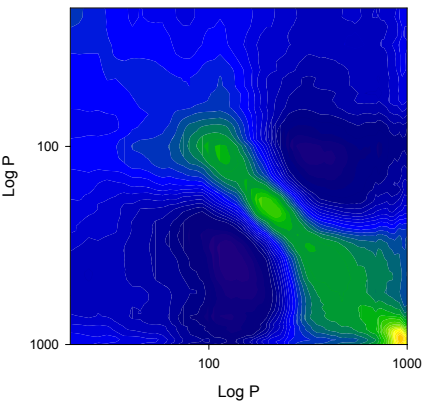


24 hours

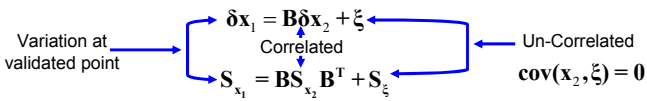
2 days

4 days

5 days



Non-Coincidence Error



Uncorrelated/Residual error

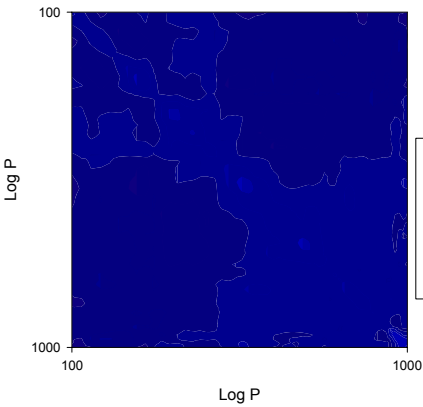
$$S_{\xi} = S_{x_1} - \mathbf{B} S_{x_2} \mathbf{B}^T$$

3 hours

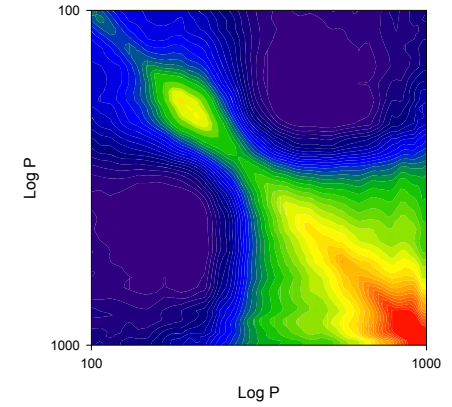
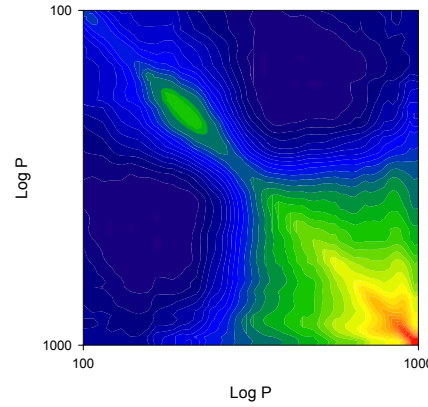
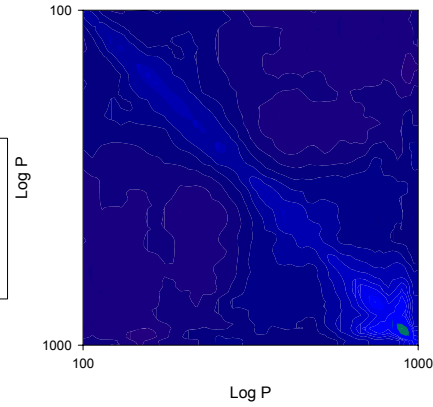
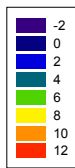
6 hours

12 hours

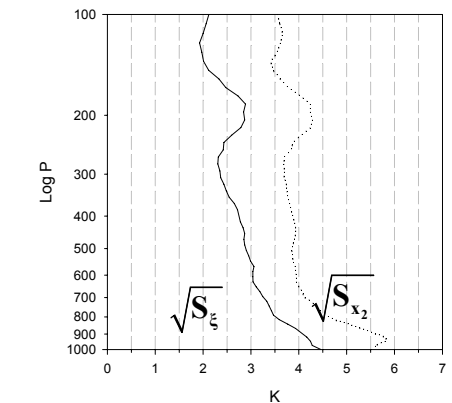
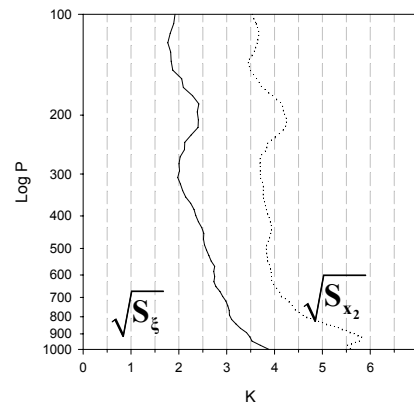
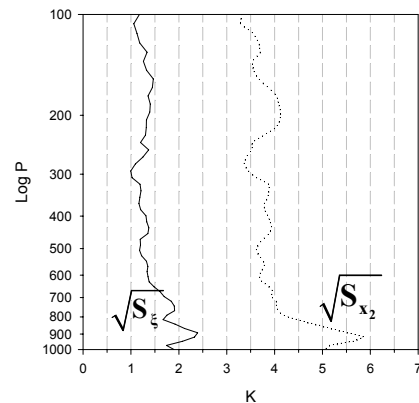
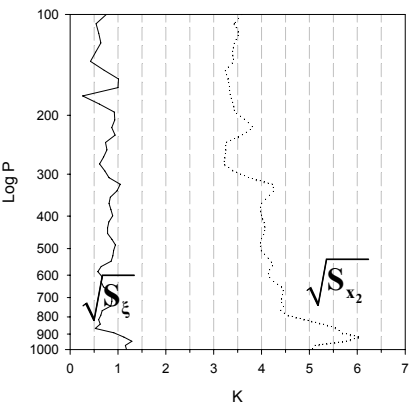
24 hours



K^2



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

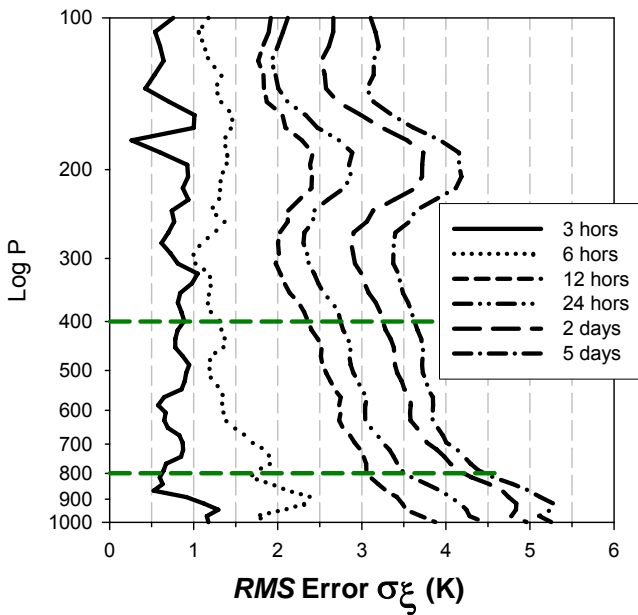


Non-Coincidence Error (continued)

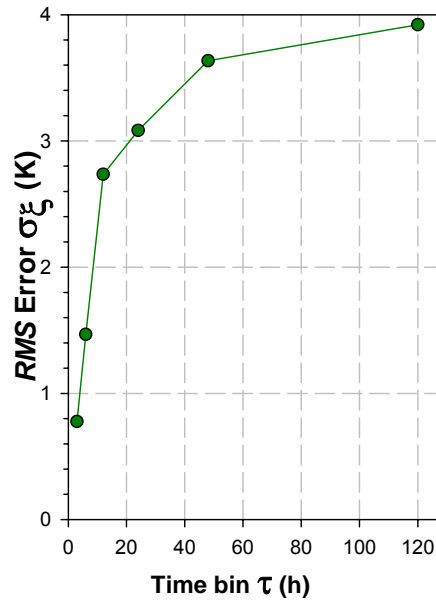
AIRS global estimate 0.8 K (± 3 hour, ± 100 km)
Chahine et al., 2006

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

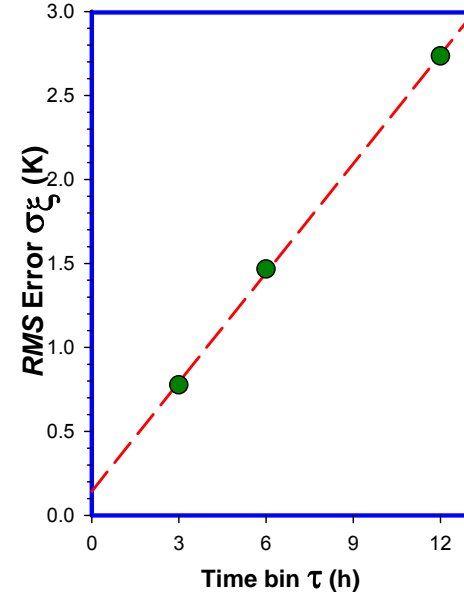
Non-Coincidence Error



Non-Coincidence Error
400 - 800 mb

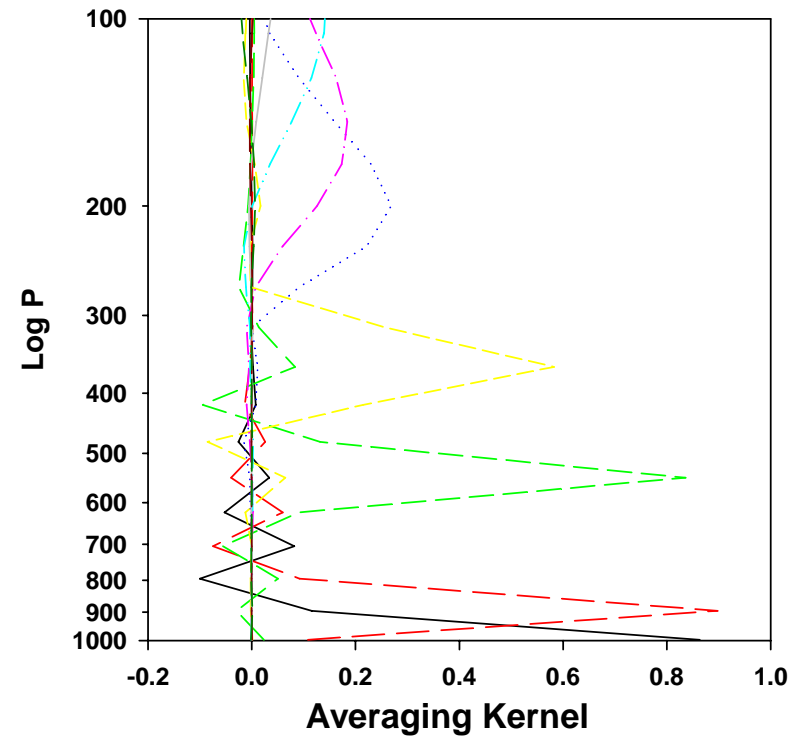
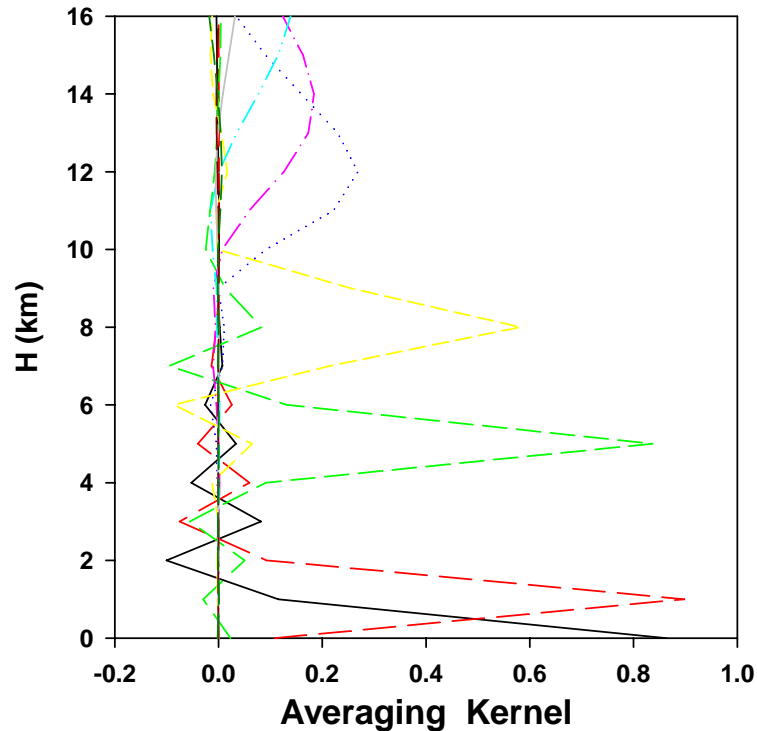


Non-Coincidence Error
400 - 800 mb



Averaging Kernels

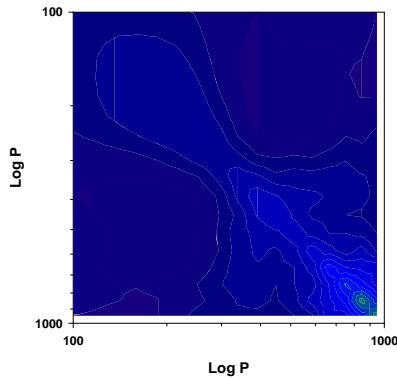
Averaging Kernels for Temperature Profile AIRS Spectral Channels, ILS, and SNR Optimal Estimation (Clive Rodgers)



“Satellite Retrievals” vs. Radiosondes *RMS*

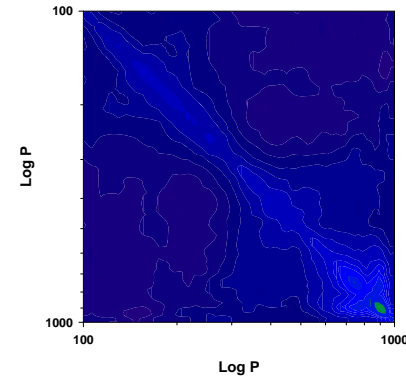
Non-Coincidence 6 hours
&
Smoothing Error

$$\delta \hat{\mathbf{x}} = \mathbf{A}_1 \mathbf{x}_1 - \mathbf{A}_1 \mathbf{B} \mathbf{x}_2$$

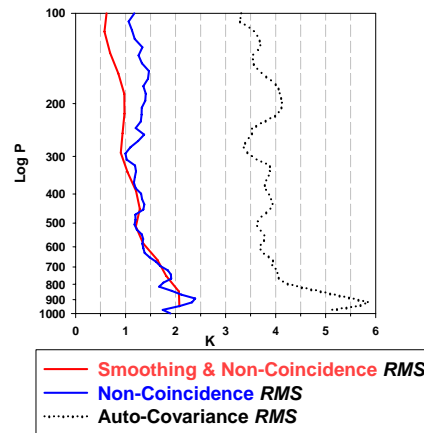


Non-Coincidence 6 hours Error

$$\delta \hat{\mathbf{x}} = \mathbf{x}_1 - \mathbf{B} \mathbf{x}_2$$



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.