

# Determination of the experimental error of high spectral resolution infrared observations from spectral residuals: application to IASI

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1. The problem of how to characterize instrument noise directly from observed radiances has received a deal of attention in the past years. Most studies address the problem with heuristic or empirical approaches.
2. In contrast, our analysis is based on a firm statistical approach, which leaves no room to ad hoc assumptions.
3. Our methodology does not address the problem of forward model noise (that is the noise due to instrument and forward model uncertainty and bias), which is the topics of many concurrent studies.
4. We are focused on the instrument noise alone.

# We are focused on the instrument noise alone and have developed two tools, which will be exemplified through application to IASI

## A forward model based approach

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### Infrared atmospheric sounder interferometer radiometric noise assessment from spectral residuals


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## A PCA/BIC based approach


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### PCA determination of the radiometric noise of high spectral resolution infrared observations from spectral residuals: Application to IASI

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# Both Approaches rely on the concept of spectral residuals

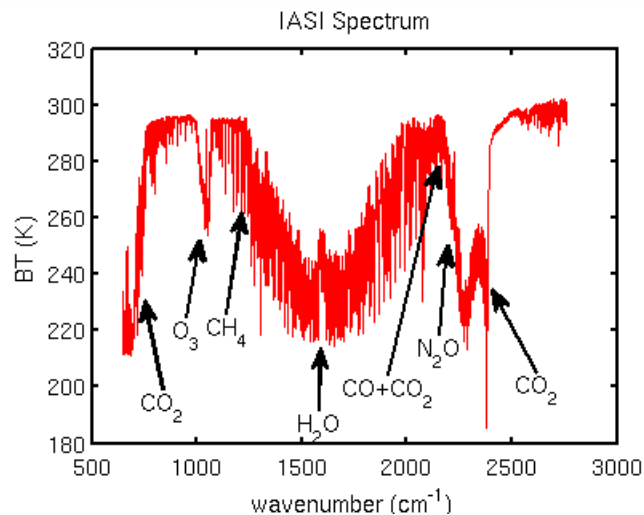
## FM based approach

- $\delta\mathbf{R} = \mathbf{R}_{obs} - F(\mathbf{v})$ ,
- $F$ , the forward model
- $\mathbf{v}$ , the state vector estimated based on a suitable retrieval procedure
  
- After a proper localization, the instrument noise covariance matrix is estimated by
  
- $\widehat{\mathbf{S}}_{\varepsilon} = \langle (\delta\mathbf{R} - \overline{\delta\mathbf{R}})(\delta\mathbf{R} - \overline{\delta\mathbf{R}})^t \rangle$

## PCA approach

- After appropriate centering of the radiance vector,
- $\delta\mathbf{R} = \mathbf{R}_{obs} - \mathbf{U}_{\tau}\mathbf{c}$
- $\mathbf{U}$  orthogonal basis of PCA  $\mathbf{c}$  vector, truncated at  $\tau$
- For a given  $\tau$  and a-priori normalizing covariance,  $\widetilde{\mathbf{S}}_{\varepsilon}$ , the instrument noise covariance is estimated by
- $\widehat{\mathbf{S}}_{\varepsilon} = \widetilde{\mathbf{S}}_{\varepsilon}^{1/2} \mathbf{U}_{-\tau} \mathbf{\Lambda} \mathbf{U}_{-\tau}^t \widetilde{\mathbf{S}}_{\varepsilon}^{t/2}$
- with  $\mathbf{\Lambda}$  the diagonal matrix of eigenvalues,
- $\widetilde{\mathbf{S}}_{\varepsilon}$  is the full IASI covariance matrix according to the EUMETSAT/CNES release.

For both approaches, we use the whole IASI spectral coverage (8461 channels). The FM approach is combined with Random Projections and we simultaneously retrieve parameters and gas species. (Poster 8p.02)

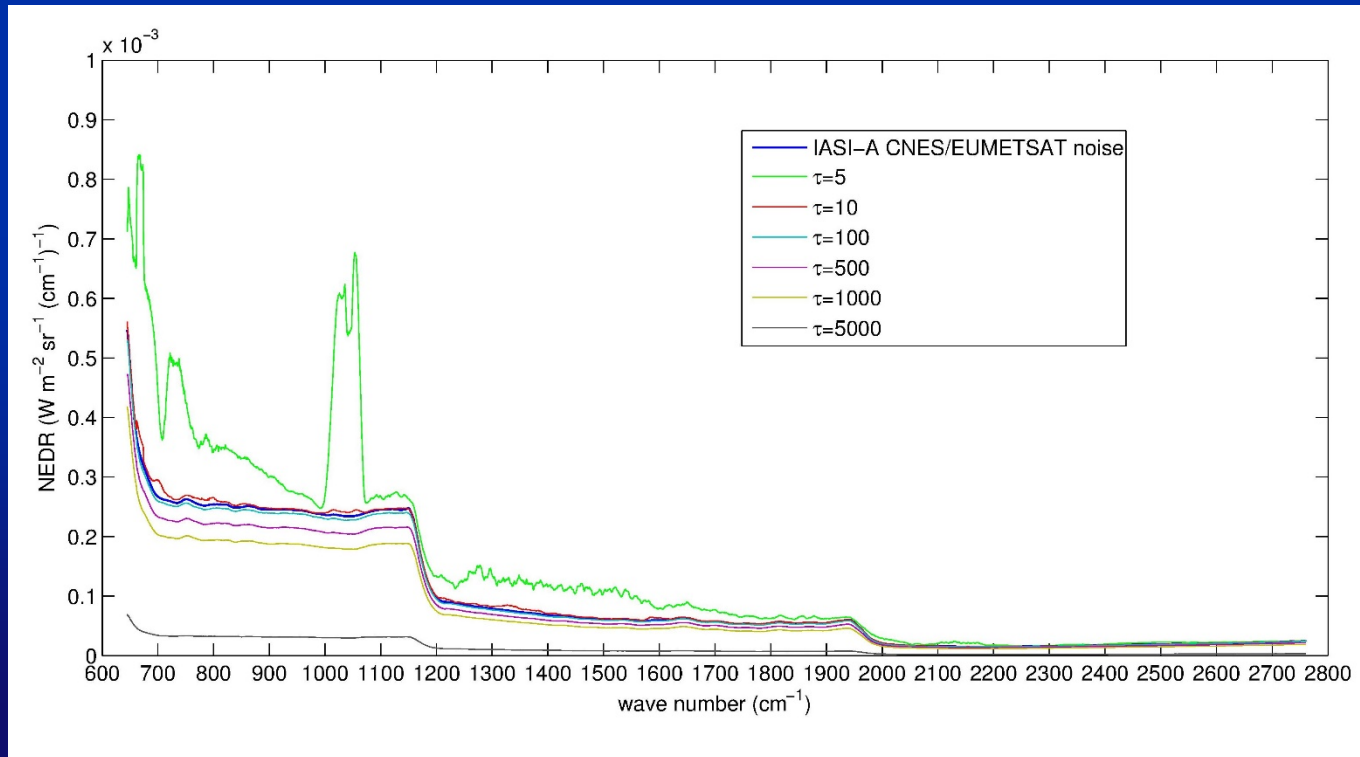


Retrieved parameters and species include

- Surface
  - Temperature
  - Emissivity (spectrum)
- Atmospheric Profiles of
  - Temperature
  - H<sub>2</sub>O
  - O<sub>3</sub>
  - HDO
  - CO<sub>2</sub>
  - N<sub>2</sub>O
  - CO
  - CH<sub>4</sub>
  - SO<sub>2</sub>
  - HNO<sub>3</sub>
  - NH<sub>3</sub>
  - OCS
  - CF<sub>4</sub>

## PCA approach; application to IASI A: simulation

The PCA approach estimator is fully analytical, we do not need for each truncation point  $\tau$  to re-compute the spectral residuals. However it critically depends on the given  $\tau$  and the estimator is biased



# Develop an approach, which simultaneously and optimally estimates noise and truncation point

**Step 1:** Write the PCA problem in a probabilistic fashion using the formalism of latent variables

$$\mathbf{x} = \mathbf{H}\mathbf{w} + \boldsymbol{\eta}$$

**Step 2:** Define a log-likelihood cost function

$$\mathcal{L} = \frac{N}{2} (d \log(2\pi) + \log(|\mathbf{S}_x|) + \text{tr}(\mathbf{S}_x^{-1}\mathbf{S}))$$

**Step 3:** Compute the Bayesian Information Criterion, BIC and get the optimal solution by seeking for BIC minimum

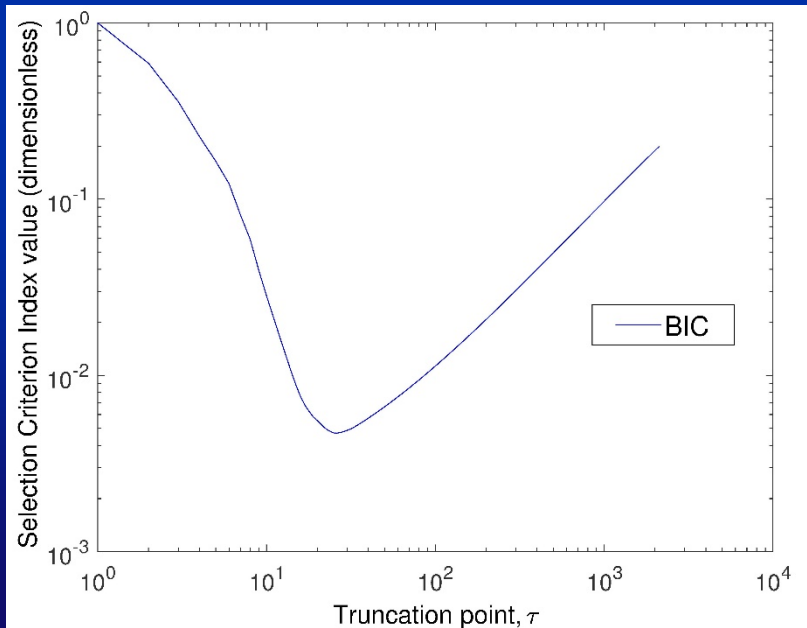
$$\text{BIC} = -2 \log p(\mathbf{x}|\boldsymbol{\tau})$$

Gideon Schwarz, Estimating the Dimension of a Model, Ann. Statist. Volume 6, Number 2 (1978), 461-464.

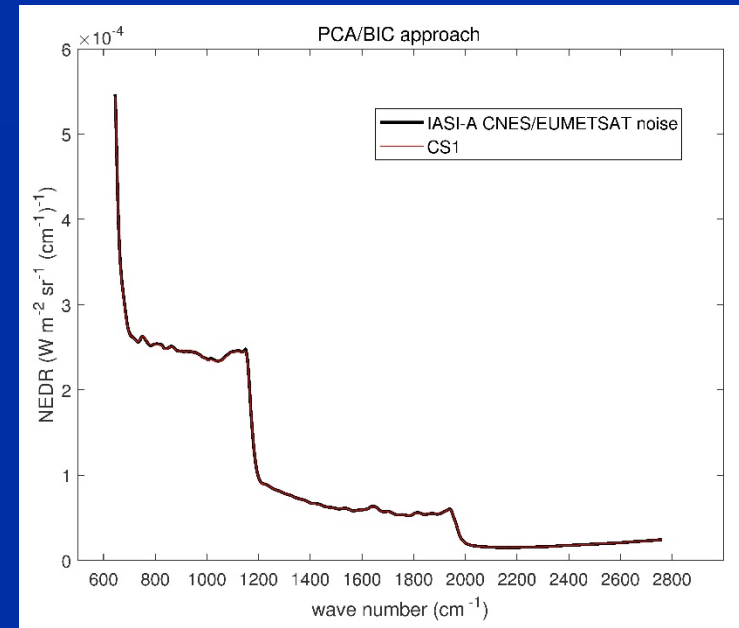
$$\begin{aligned} \text{BIC}(\boldsymbol{\tau}) &= -2 \log(p(\mathbf{X}|\boldsymbol{\tau})) \\ &= N \sum_{j=1}^d \log \lambda_j + N(d - \boldsymbol{\tau}) \log \left( \frac{1}{d - \boldsymbol{\tau}} \sum_{j=\boldsymbol{\tau}+1}^d \lambda_j \right) \\ &\quad + (\boldsymbol{\tau} + k) \log N \end{aligned}$$

# PCA/BIC approach, application to IASI in simulation

Seek for BIC minimum

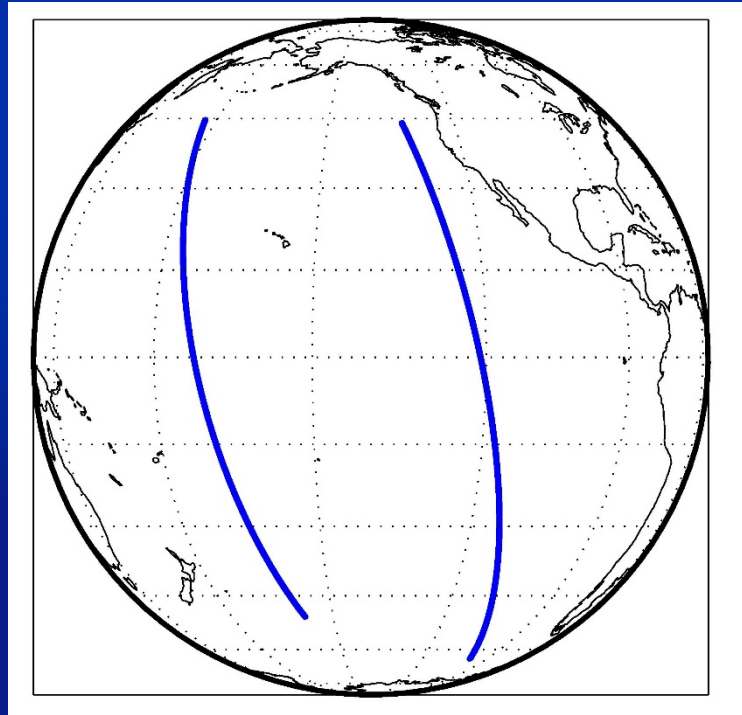


Estimated radiometric noise at the BIC minimum,  $\tau = 26$

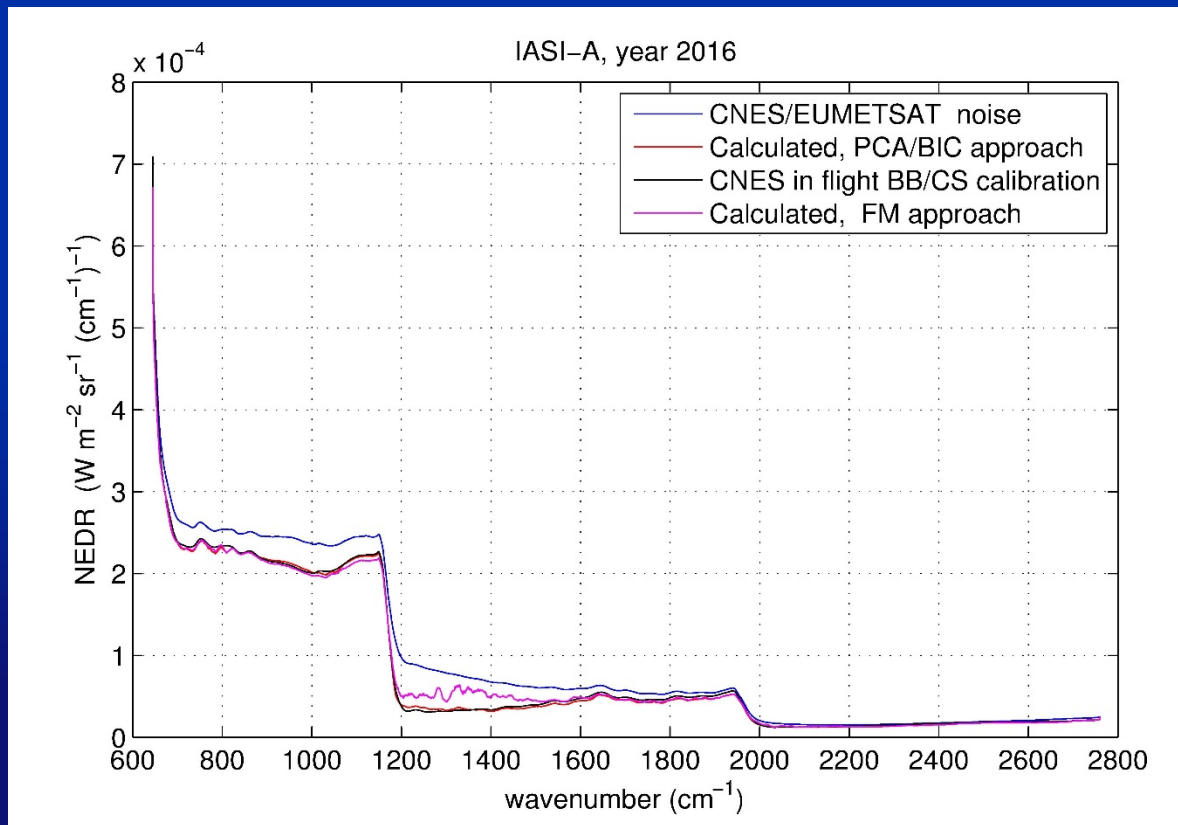




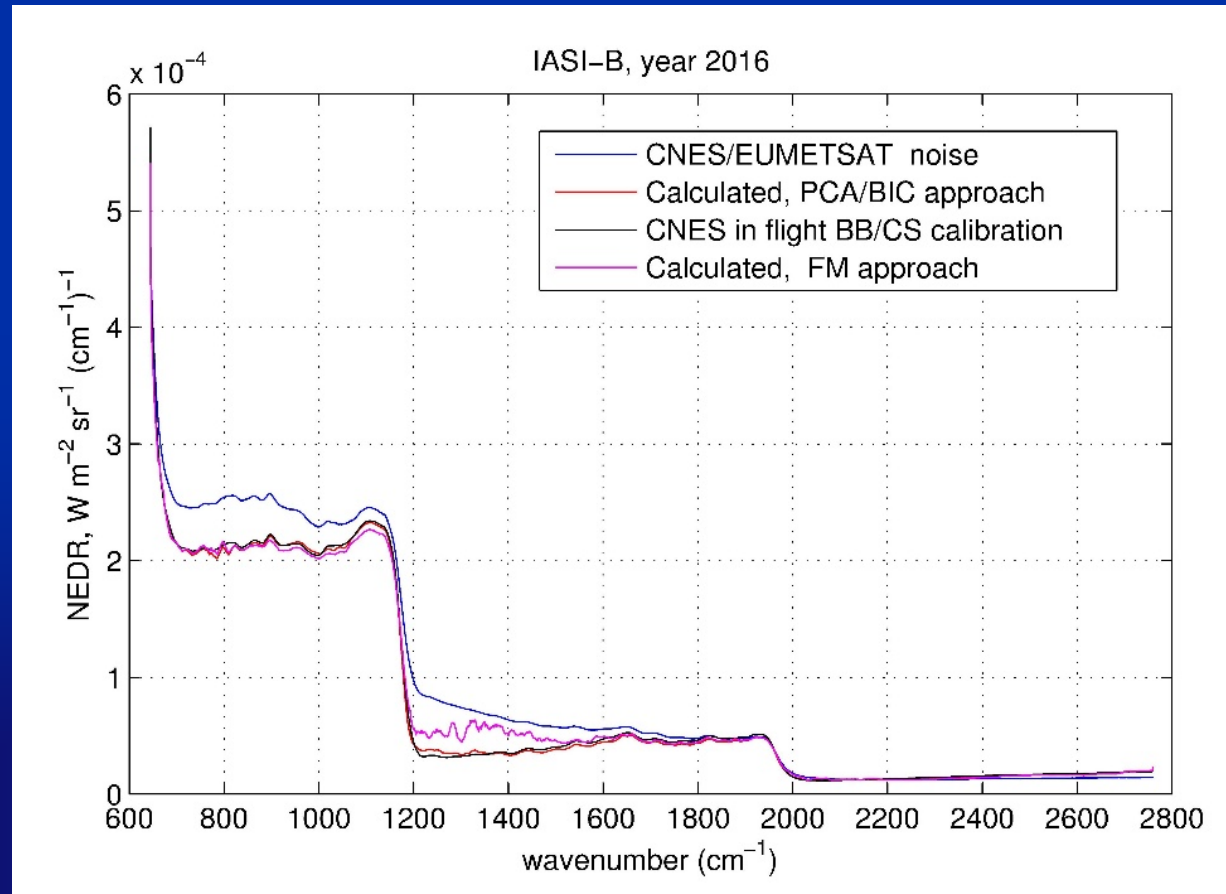
# Application to IASI: IASI data in external calibration (ExtCal) mode for the year 2016



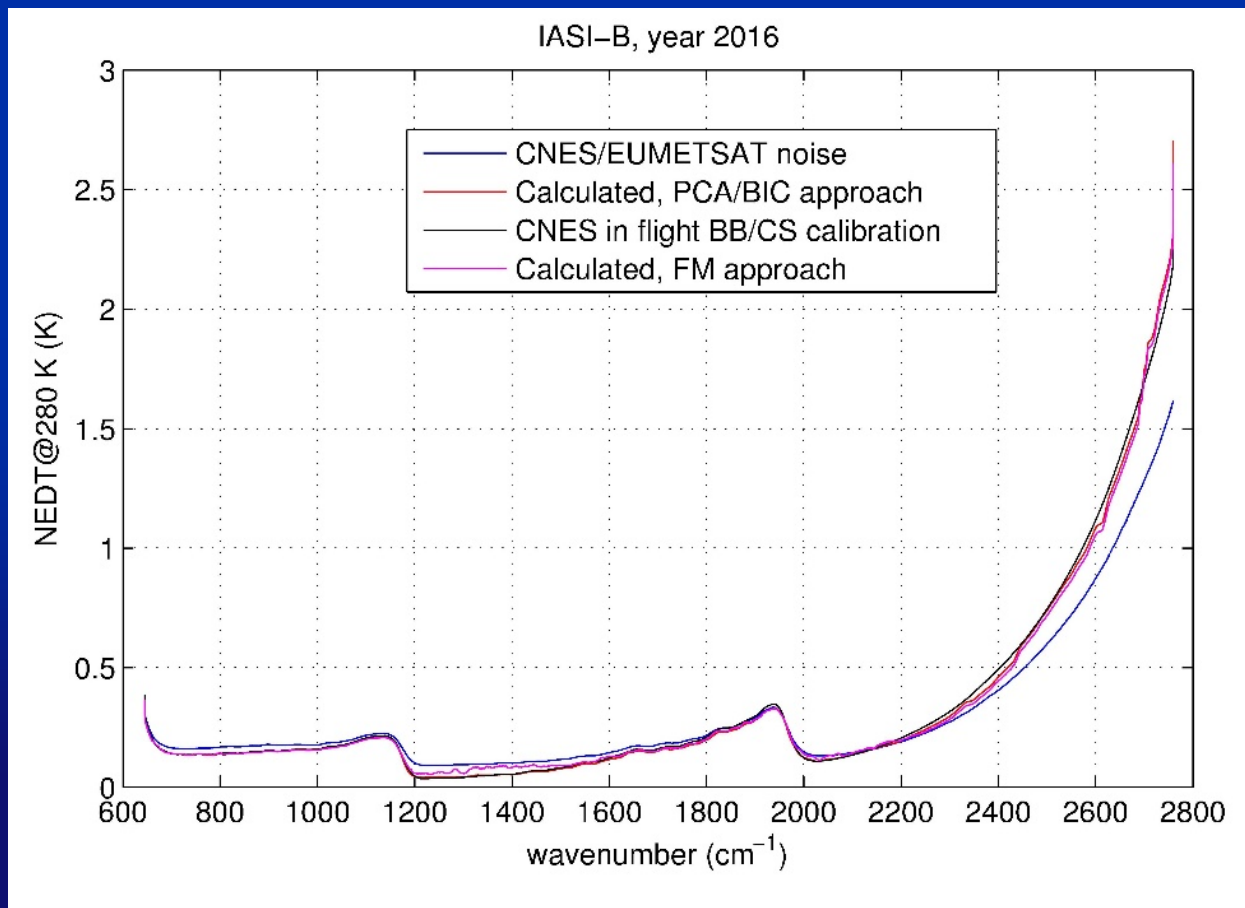
# IASI-A, PCA/BIC perfectly matches BB in flight calibration. Data averaged over the whole year 2016



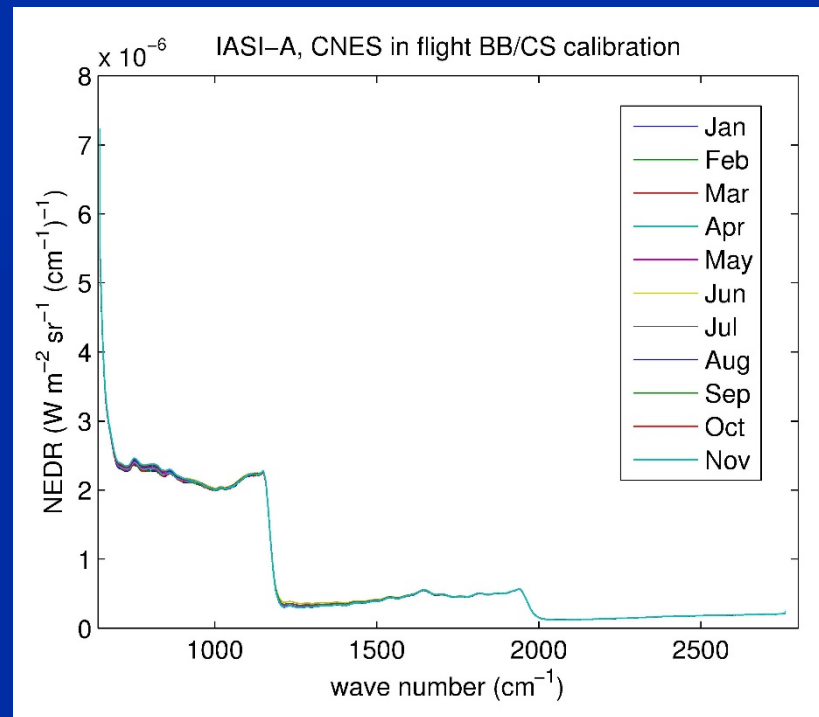
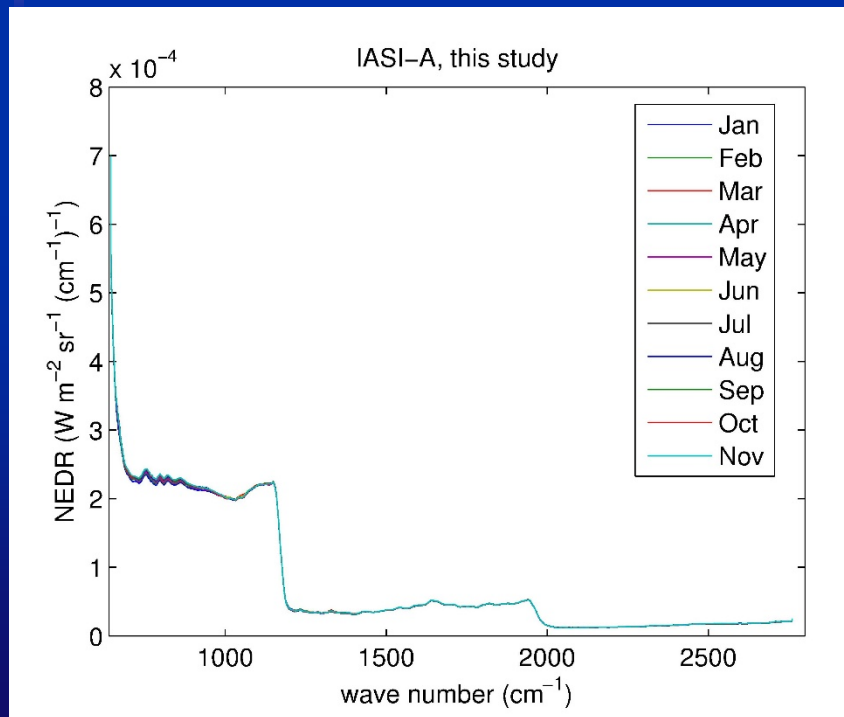
# IASI-B, PCA/BIC perfectly matches BB in flight calibration. Data averaged over the whole year 2016



# IASI-B, PCA/BIC perfectly matches BB in flight calibration. Data averaged over the whole year 2016. NEDT Analysis

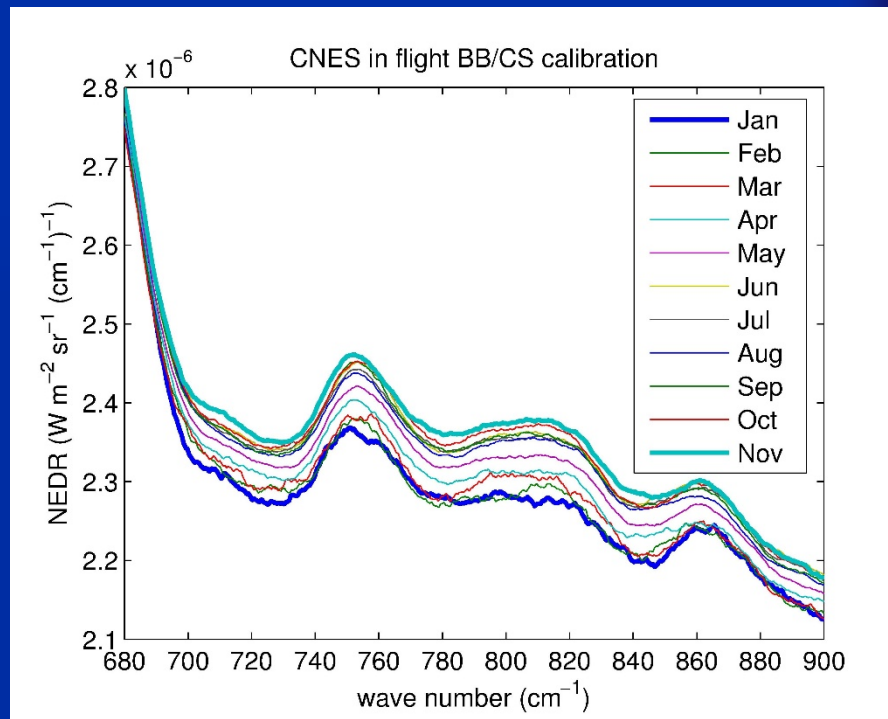
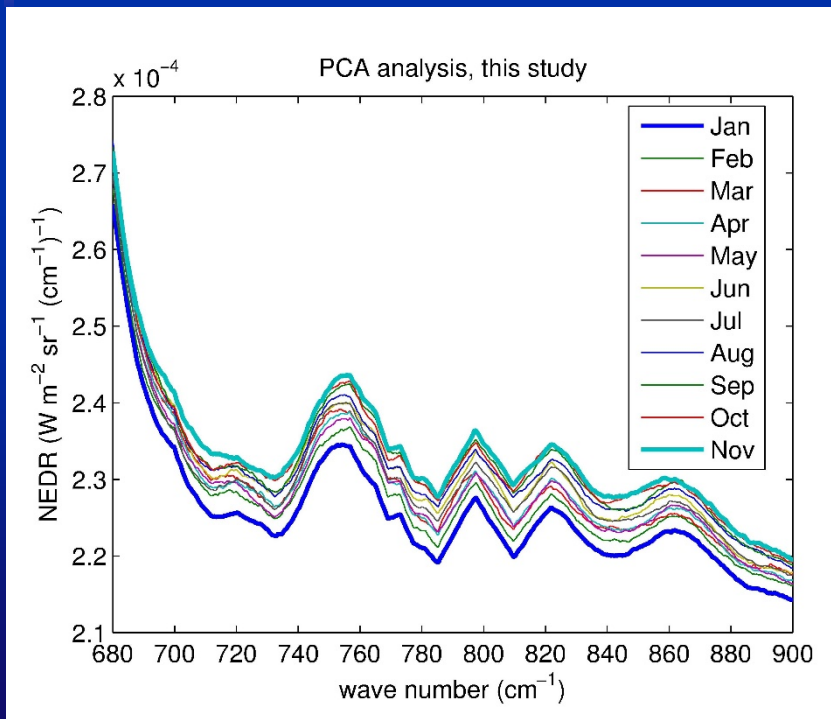


# Radiometric noise as a function of month. The case of IASI-A

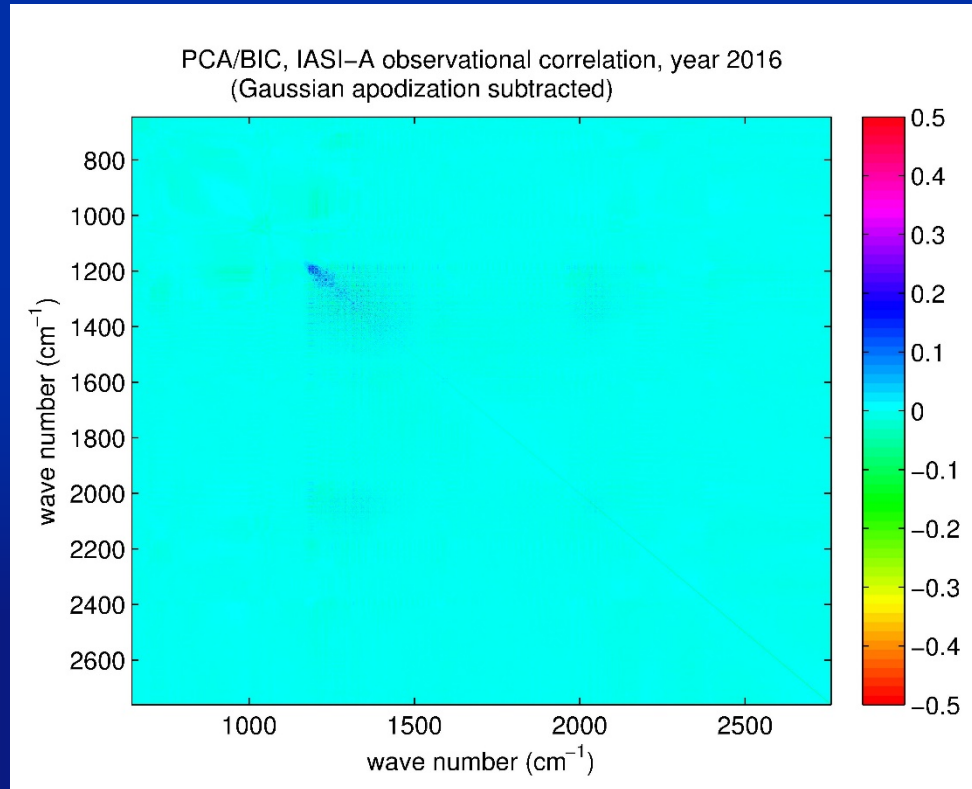


# Radiometric noise as a function of month. The case of IASI-A.

## PCA/BIC can track differences as small as that due to icing



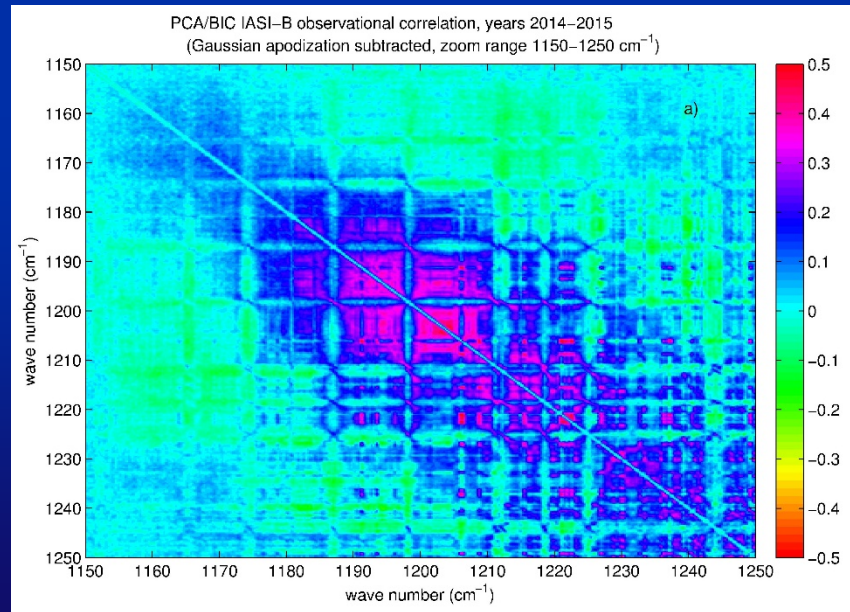
# COVARIANCE MATRIX, IASI-A



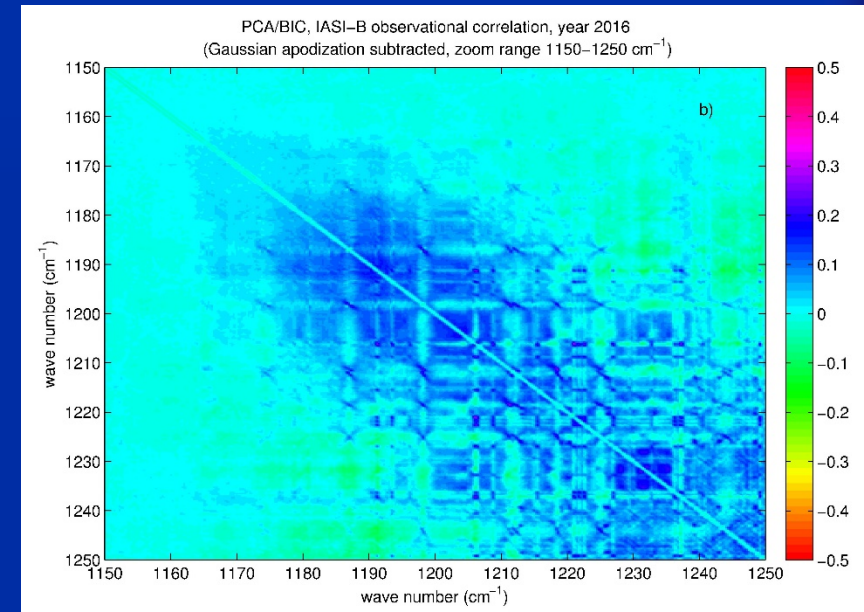


# IASI-A, comparison CD ON vs CD OFF

## CD ON



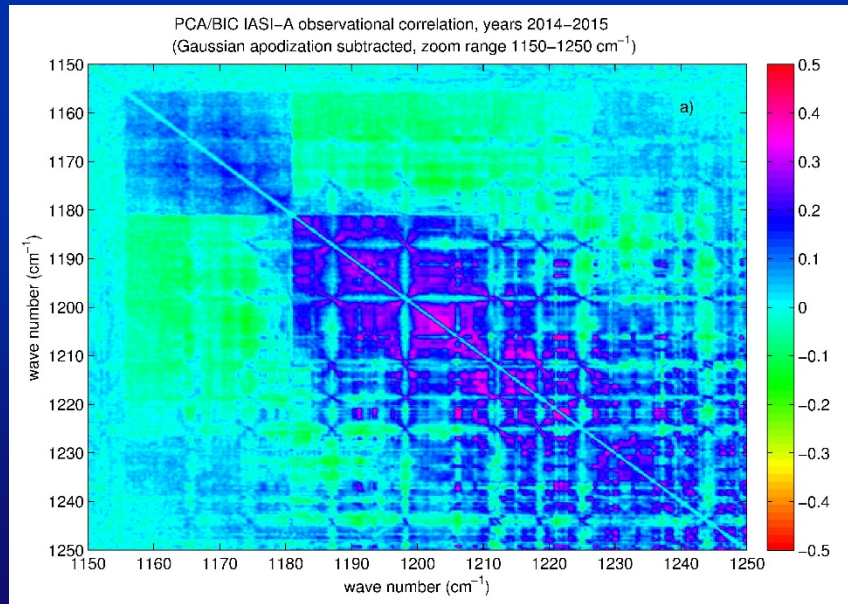
## CD OFF



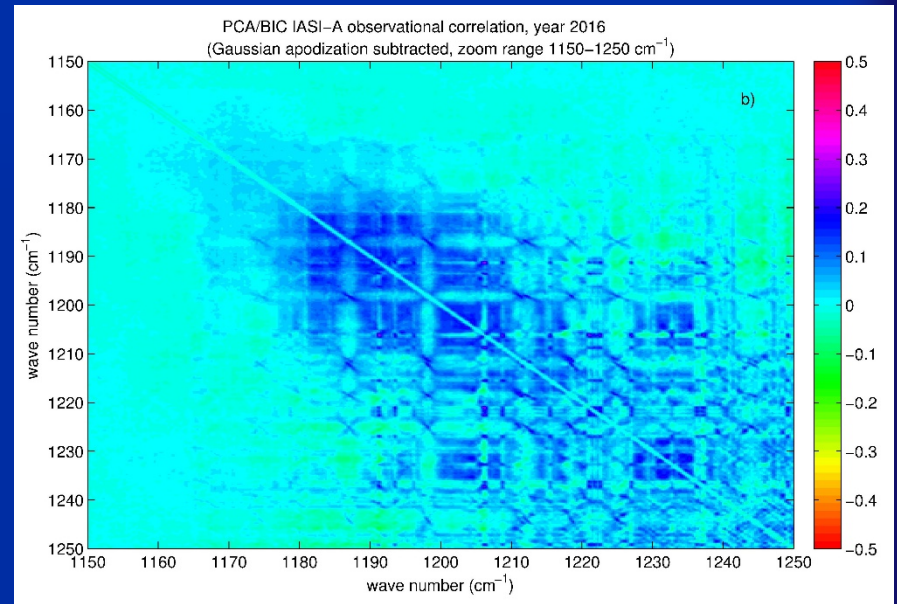


# IASI-B, comparison CD ON vs CD OFF

## CD ON



## CD OFF



# Conclusions

- IASI is spectrally and radiometrically stable. The spectral quality has improved after switching off the CD mechanism.
- The FM and PCA/BIC approaches complete each other, the PCA/BIC is much faster.
- There are a lot of lessons learned by applying the PCA/BIC, which, e.g., are important for PCA compression,
  - In case of IASI, the normalization to the diagonal of the covariance matrix yields the worst results, the dimensionality is artificially increased! Normalization to the diagonal is even worse than not considering normalization at all. The best way to normalize is to use the correct covariance matrix we have estimated with the PCA/BIC approach.
- In addition, the IASI covariance provided by us should be used when IASI is used for spectroscopy.
- We are planning to apply PCA/BIC methodology to AIRS, CrIs, possibly FY-A4 and hopefully ESA-Forum Mission Explorer in the far infrared.