Principle Component Analysis of IASI spectra

David Tobin, Hank Revercomb, Paolo Antonelli
CIMSS/SSEC/U.Wisconsin-Madison

IASI Conference, Anglet, France, 13-16 November 2007

Executive Summary of this presentation

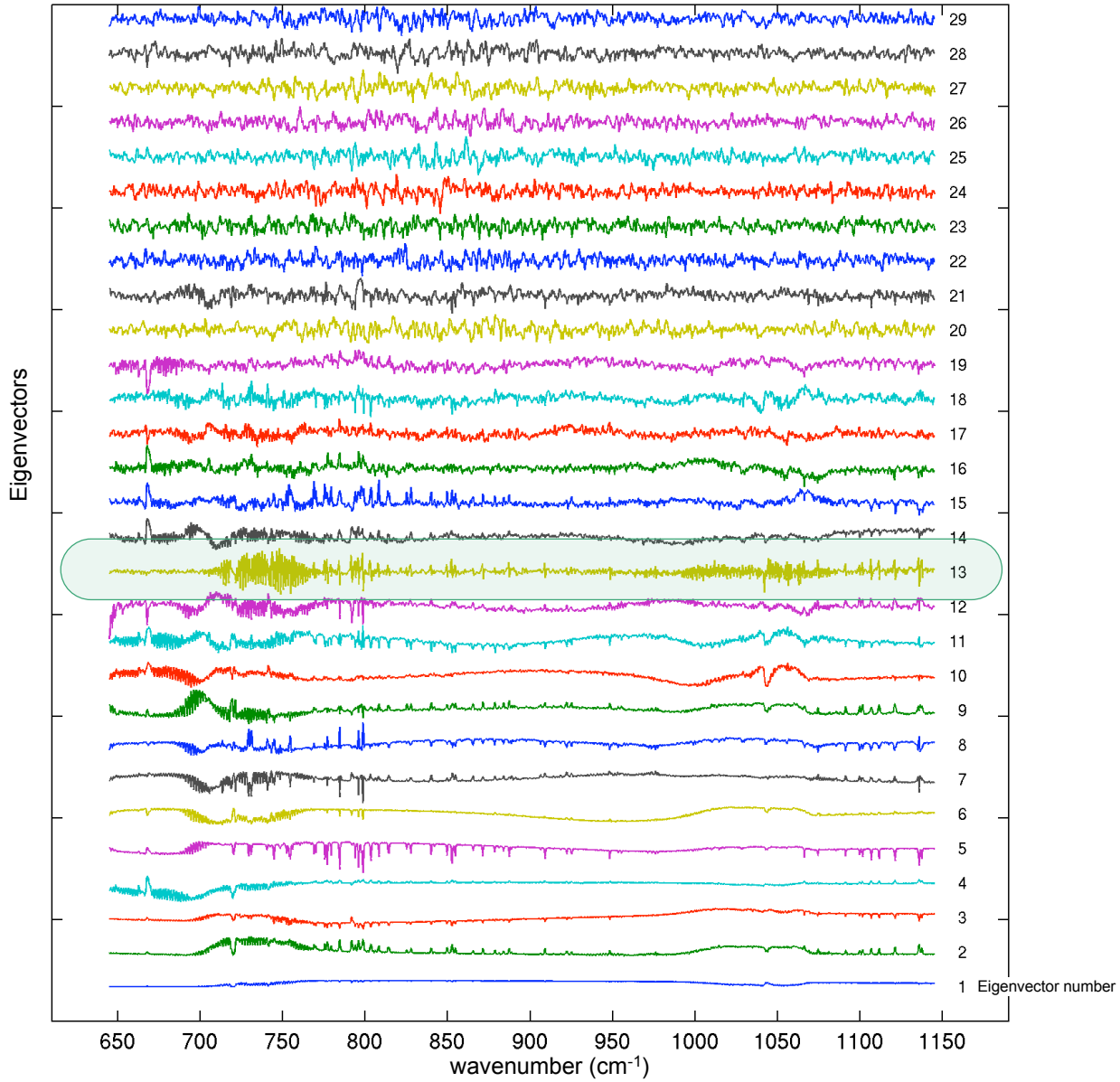
In the principle component analysis of IASI spectra presented here, the spectral and spatial characteristics of (a) non-uniform scene ILS effects and (b) small inter-FOV spectral calibration differences are found to be, to a large degree, represented by a single principle component.

This provides an interesting way to identify and characterize these effects.

Reconstruction of the spectra without this component of variability produces spectra without the primary effects of non-uniform scene ILS effects and inter-FOV spectral calibration differences.

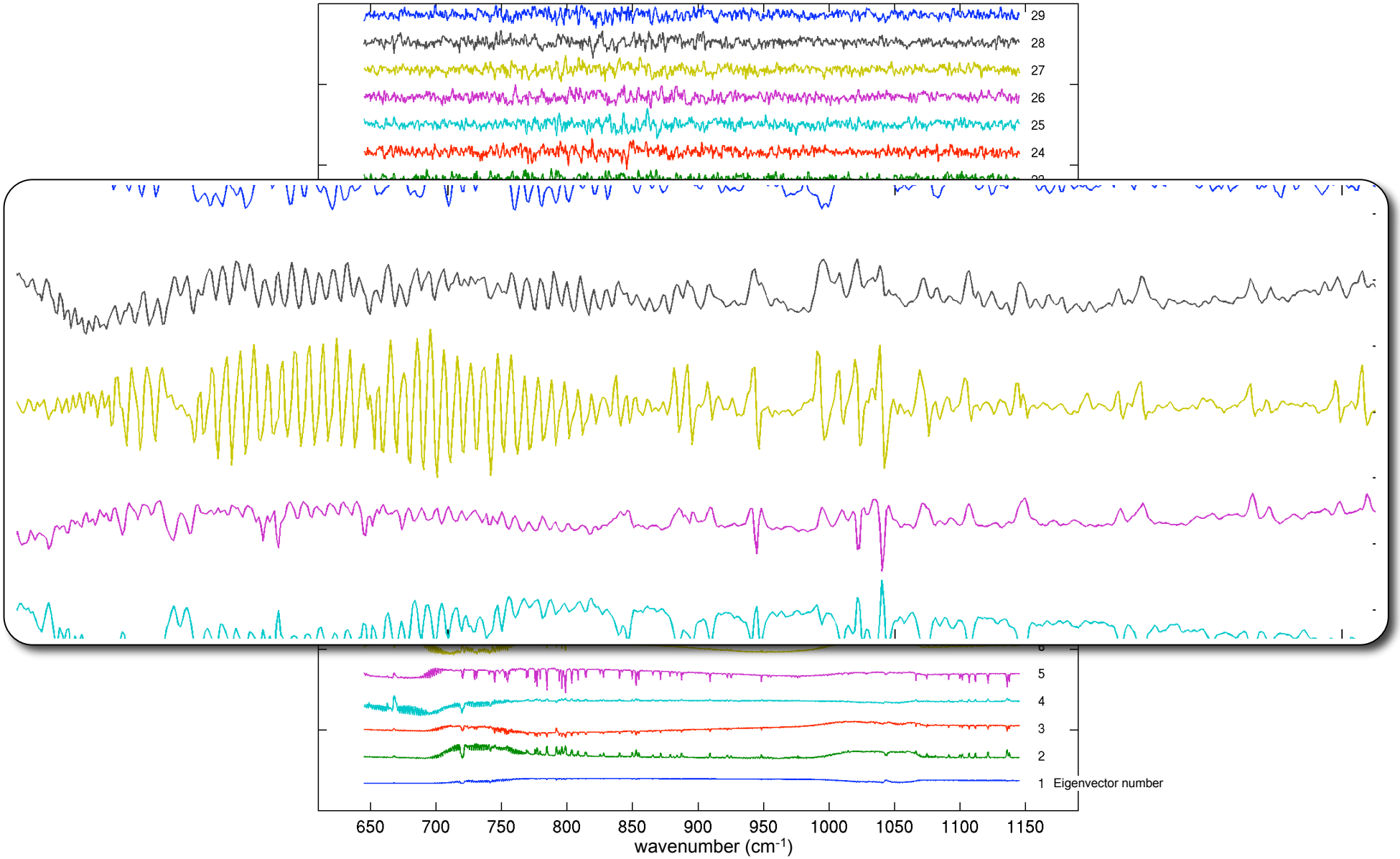
The accuracy and robustness of this correction approach is under investigation.

Example Longwave Band Principle Components



Principle Component #13 contains dispersive signatures which are consistent with non-uniform scene and/or inter-FOV spectral calibration effects

Example Longwave Principle Components



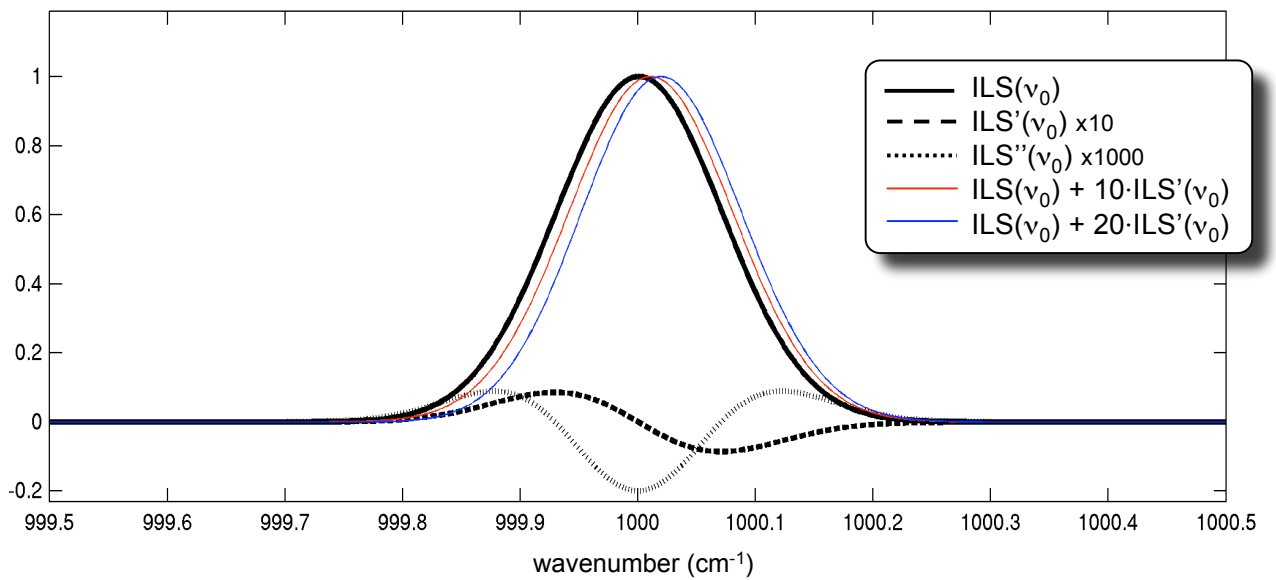
Principle Component #13 contains dispersive signatures which are consistent with non-uniform scene and/or inter-FOV spectral calibration effects

Why this works …

The dispersive “spectral shift” nature of the variability introduced by non-uniform scene ILS effects and by inter-FOV spectral calibration differences is orthogonal to the signatures of variability expected from real atmospheric, cloud, and surface effects.

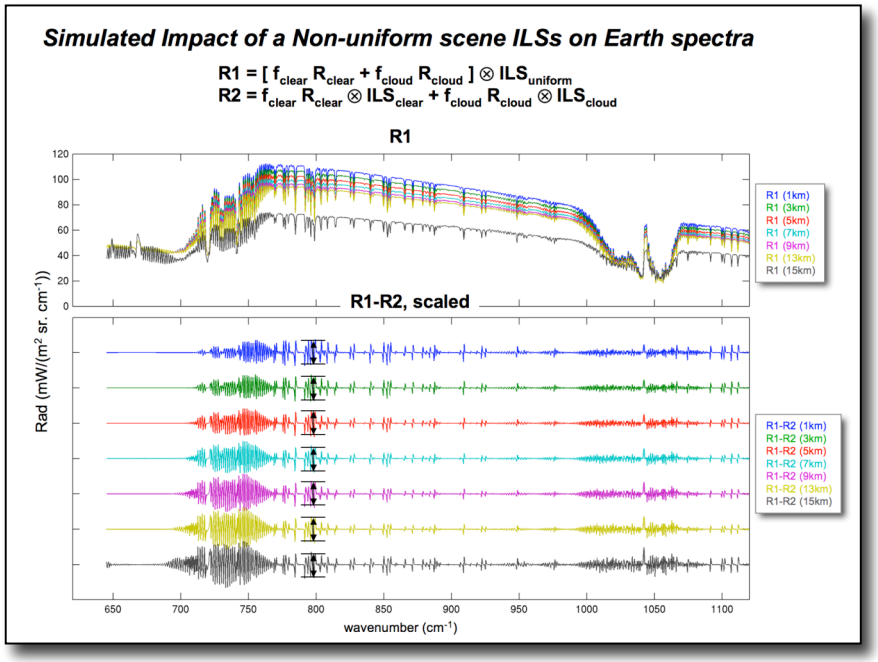
And

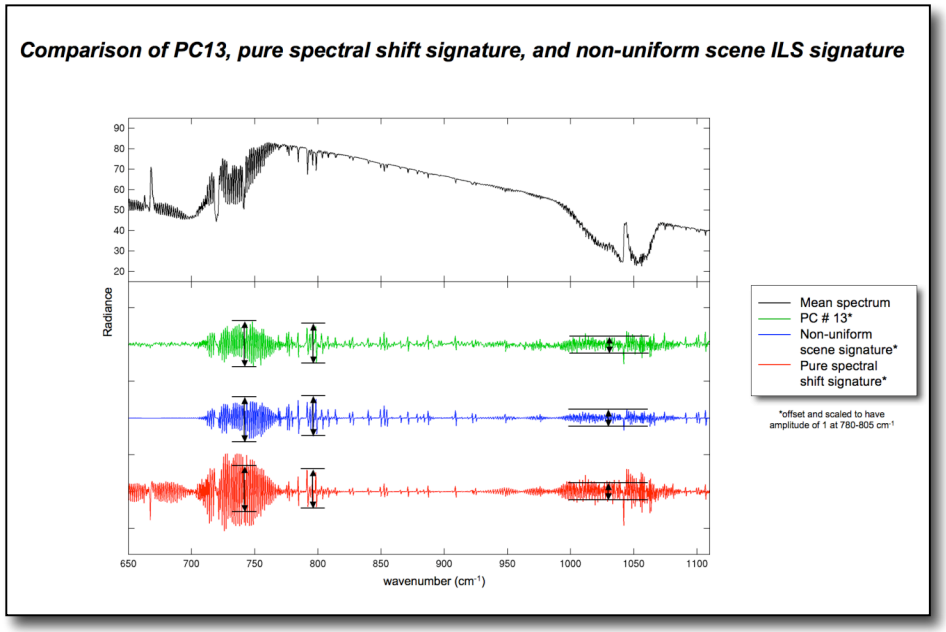
A spectrally shifted signature can be approximated as an unshifted signature plus a dispersive component



Why this doesn't work …

The spectral signatures of non-uniform scene ILSs for various scenes (e.g. cloud heights and geometric distributions within the FOV) and of inter-FOV spectral calibration differences are not unique.





… causing the effects/variability to be be distributed among other principle components.

Introduction

Principle Component Analysis (PCA)

$\boldsymbol{Y}$ = N columns of $\boldsymbol{y-\langle y\rangle}$

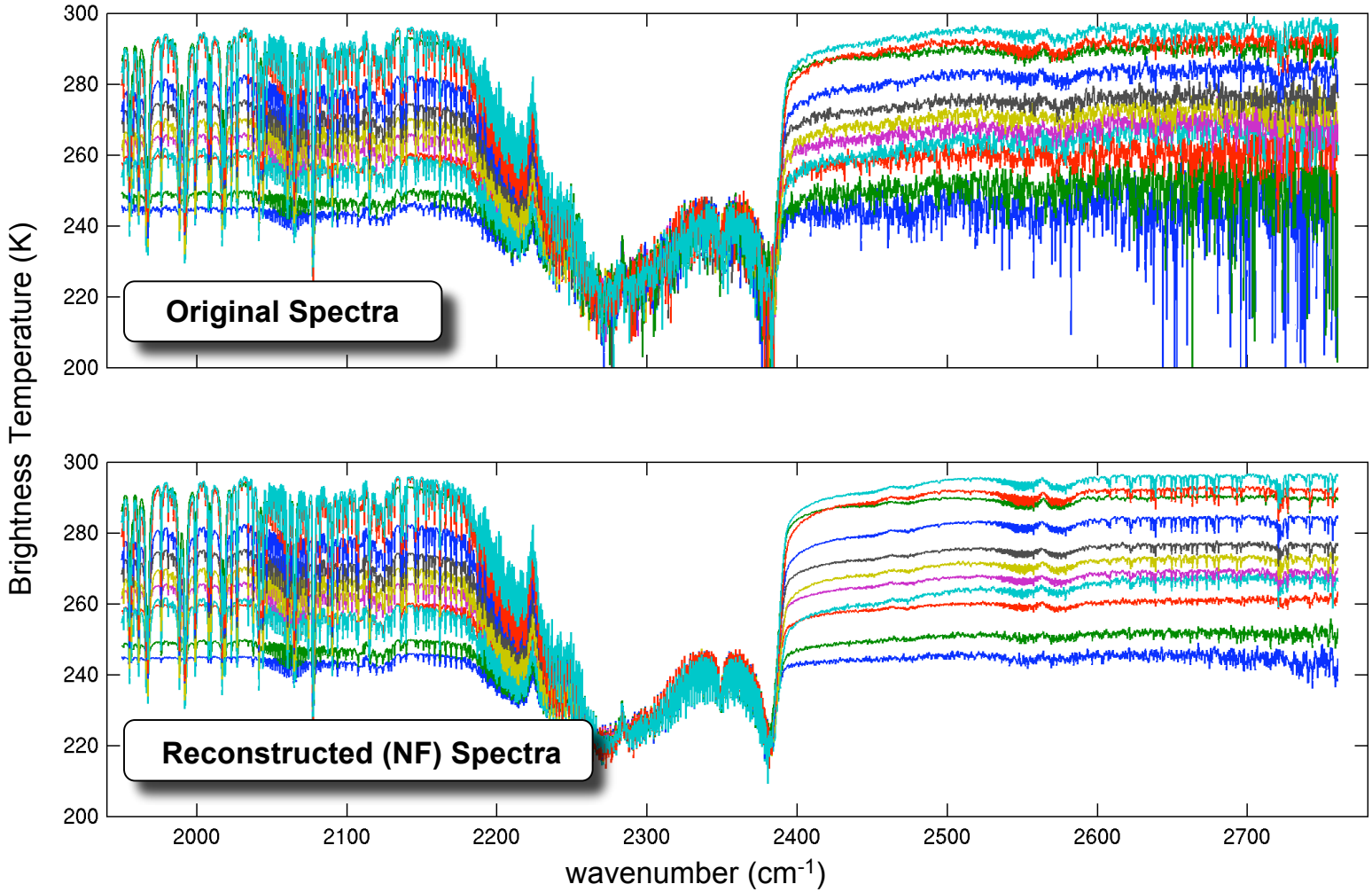
Singular Value Decomposition gives $\boldsymbol{U}$, Λ, and $\boldsymbol{V}$ such that $\boldsymbol{Y = U\Lambda V^T}$
where $\boldsymbol{D}$ is diagonal and $\boldsymbol{U^TU = V^TV = I}$

The $\boldsymbol{j^{th}}$ spectrum $\boldsymbol{y_j}$ can then be reconstructed as a sum of vectors (components) $\boldsymbol{u_i}$ with coefficients $\boldsymbol{c_{ij} = \lambda_i v_{ij}^T = U^T(y_j-\langle y\rangle)}$:

$$\boxed{\boldsymbol{y_j = \langle y\rangle + \Sigma_i\, c_{ij}\, u_i}}$$

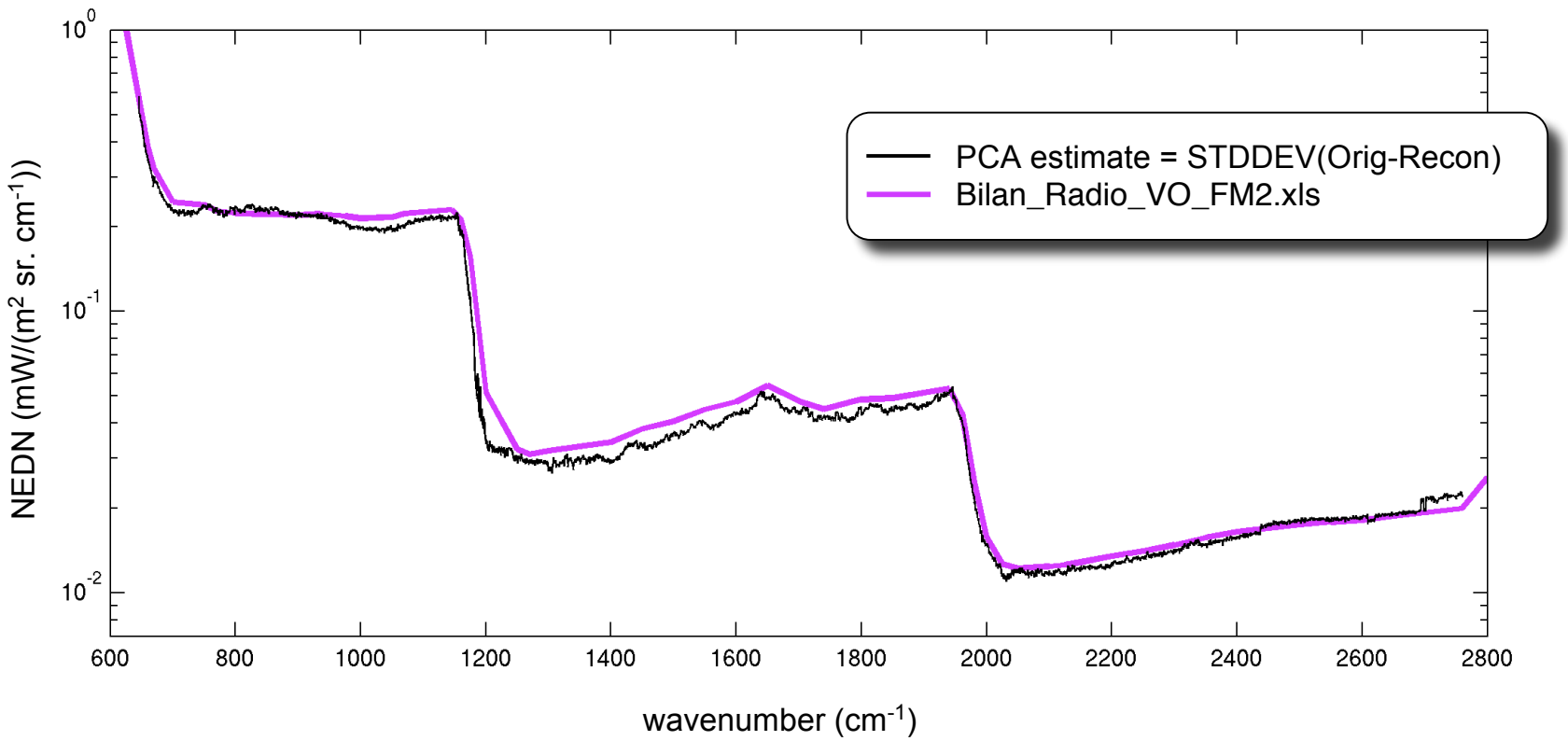
Considerations:
- The sample size
- Dependent vs. Independent set PCs
- Noise normalization (***y/NEDN*** vs. ***y***)
- The number of PCs to use in the reconstructions
- Entire spectrum or band by band

Noise Filtering (NF)



The spectra can be reconstructed from the first significant vectors …

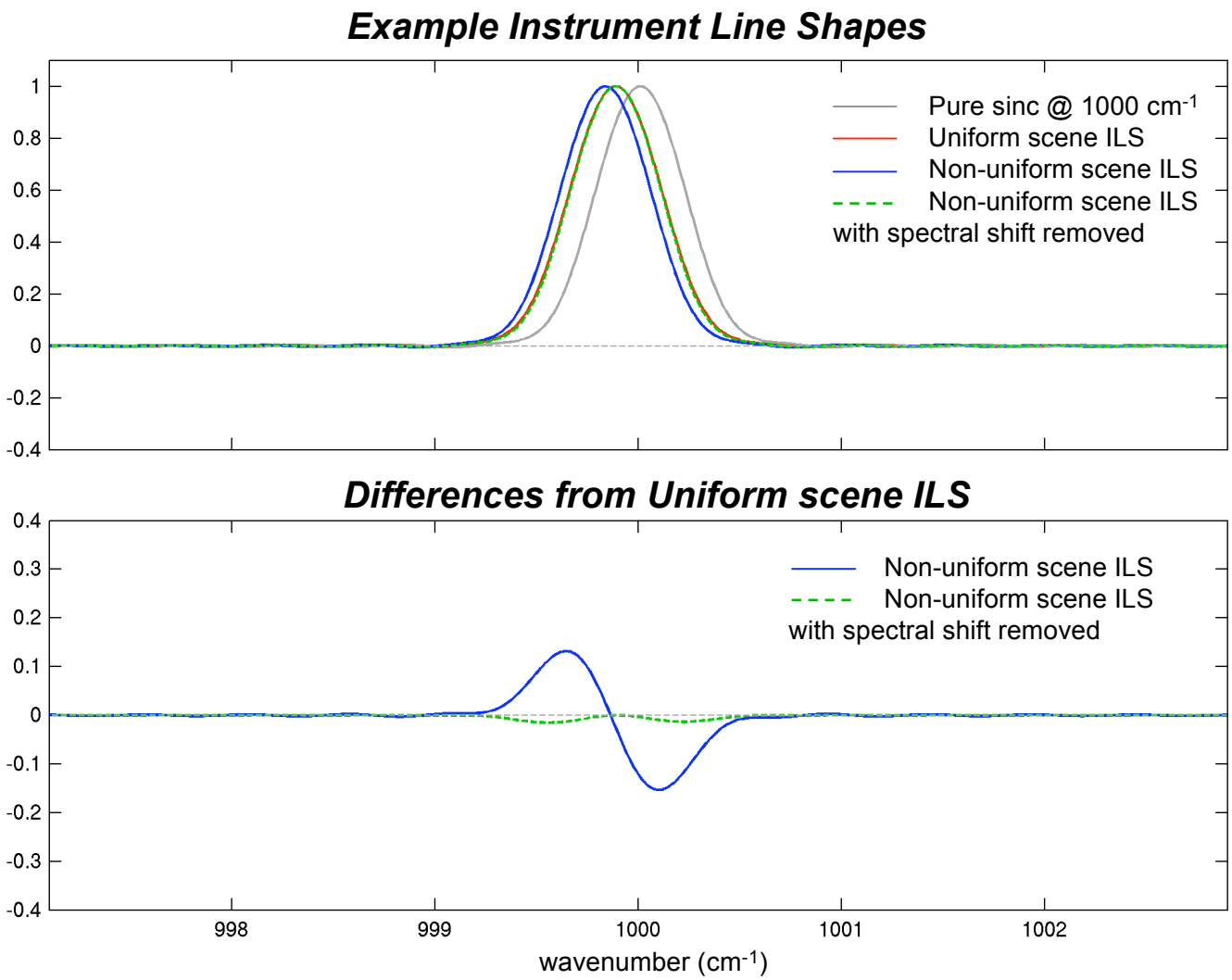
Noise Estimation

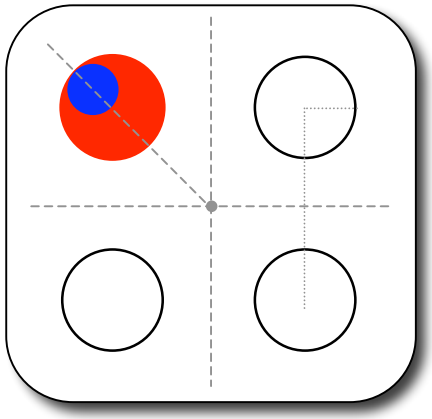


… and the (random) noise can be reconstructed from the rest.

Non-uniform scene ILS effects

Simulated Impact of a Non-uniform scene on the Instrument Line Shape

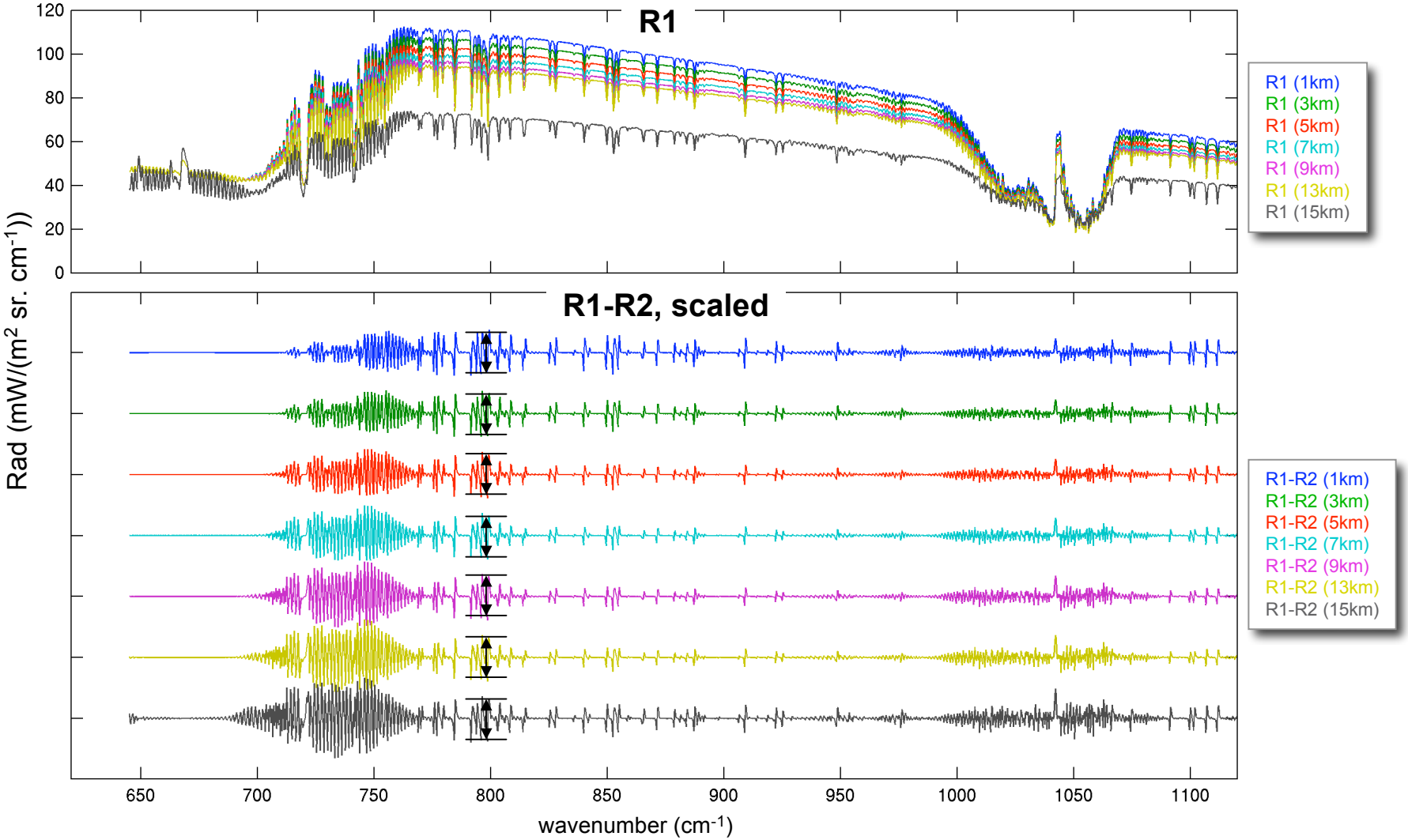




The primary effect of a non-uniform scene on the ILS is a spectral shift;
ILS *shape* effects are secondary.

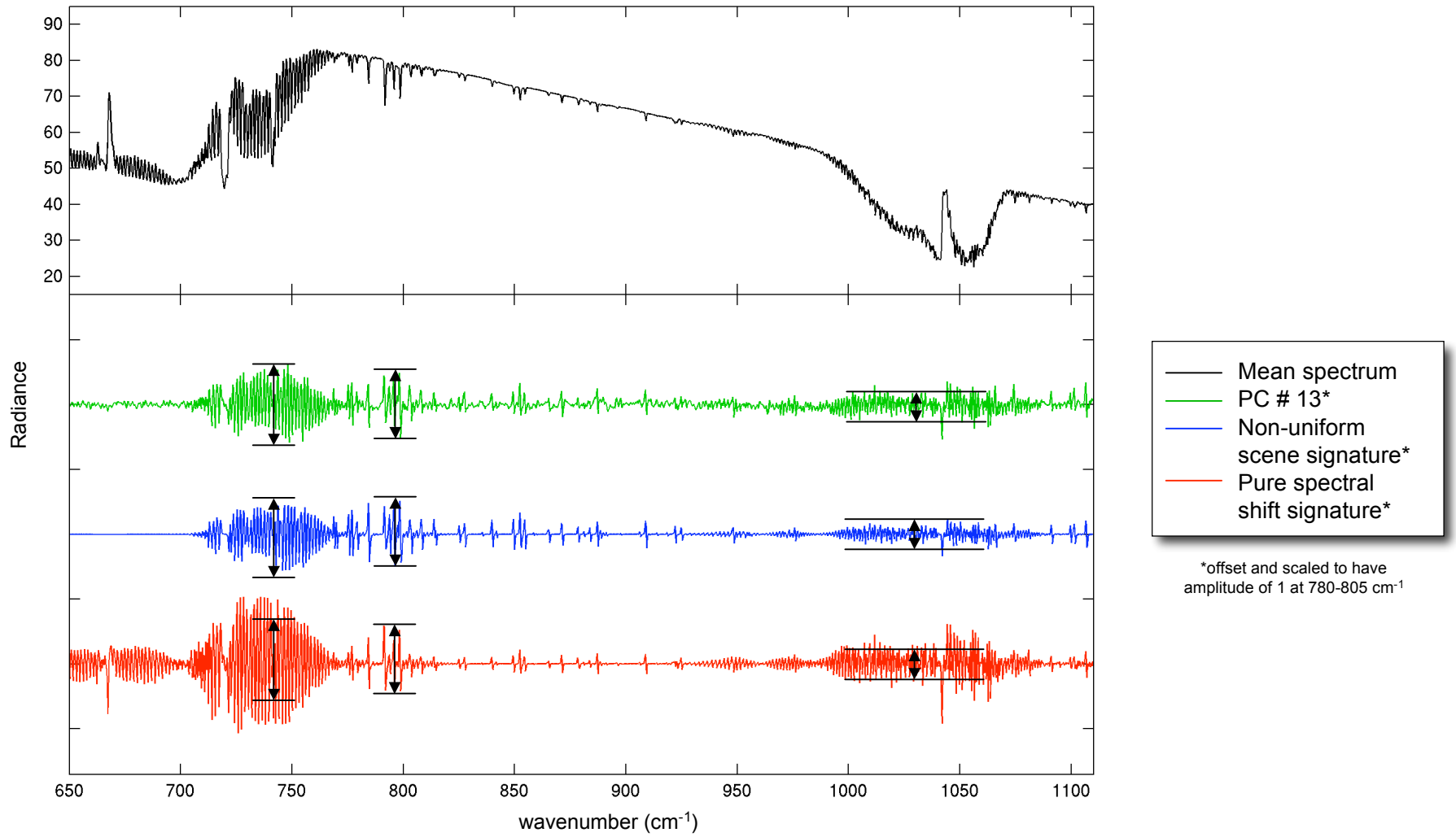
Simulated Impact of Non-uniform scene ILSs on Earth spectra

$$R1 = [\, f_{clear}\, R_{clear} + f_{cloud}\, R_{cloud} \,] \otimes ILS_{uniform}$$
$$R2 = f_{clear}\, R_{clear} \otimes ILS_{clear} + f_{cloud}\, R_{cloud} \otimes ILS_{cloud}$$



The shape of the non-uniform scene ILS effect varies with cloud height, cloud geometry within the FOV, etc …

Comparison of PC13, a pure spectral shift signature, and a non-uniform scene ILS signature

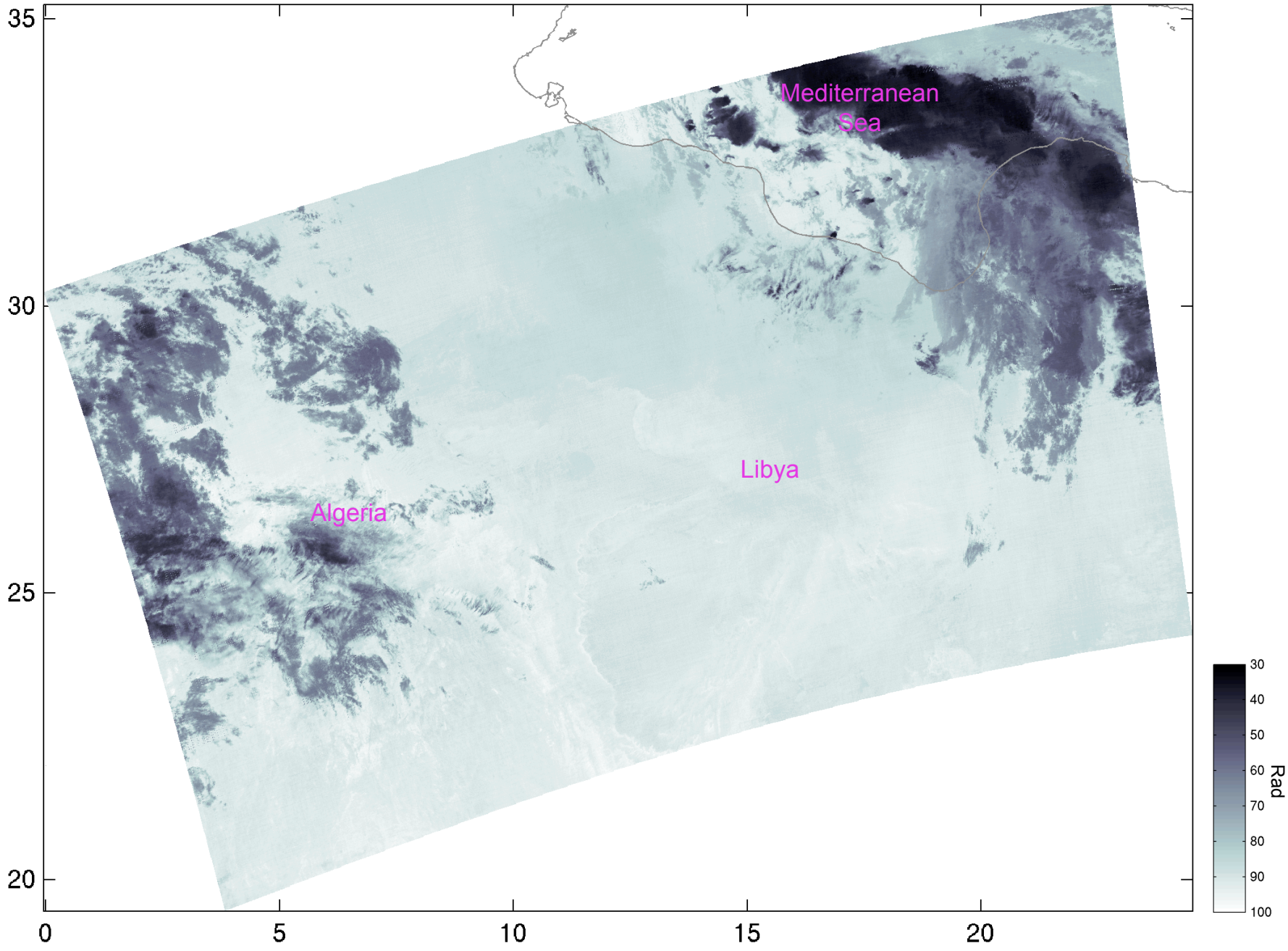


The PCA results show that the “spectral shift” PC represents a combination of non-uniform scene ILS and spectral calibration signatures.

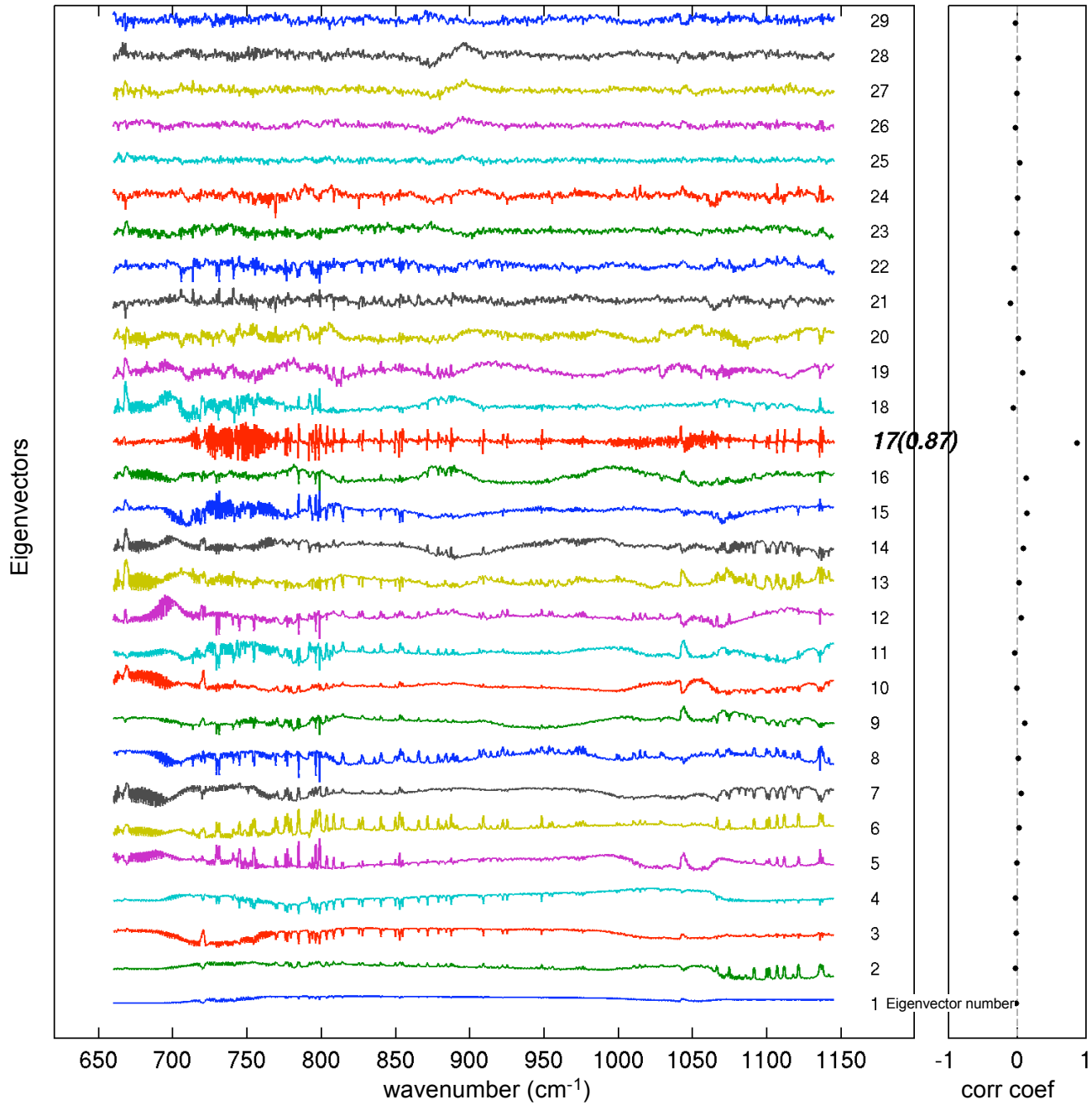
PCA of IASI spectra

- Example results for a typical granule

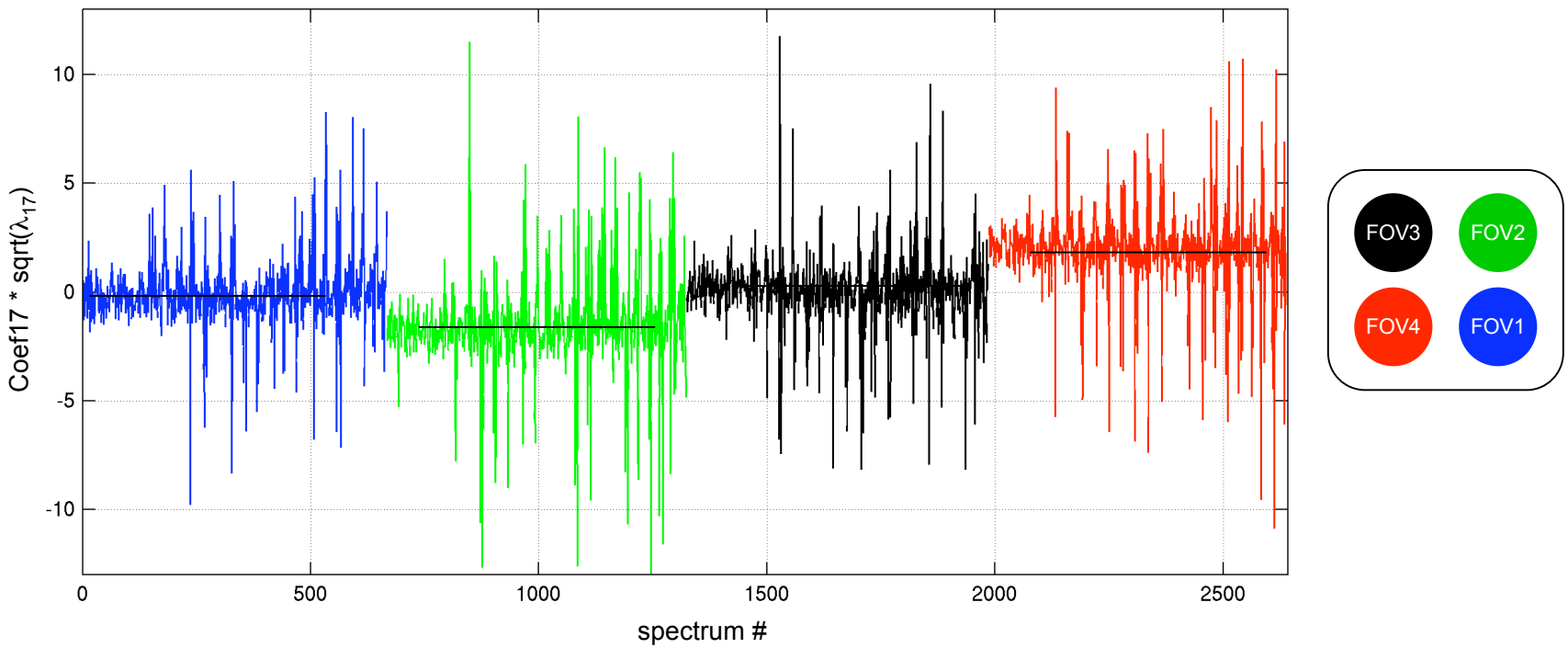
2007.10.15 ~22 UTC, IASI Imager data



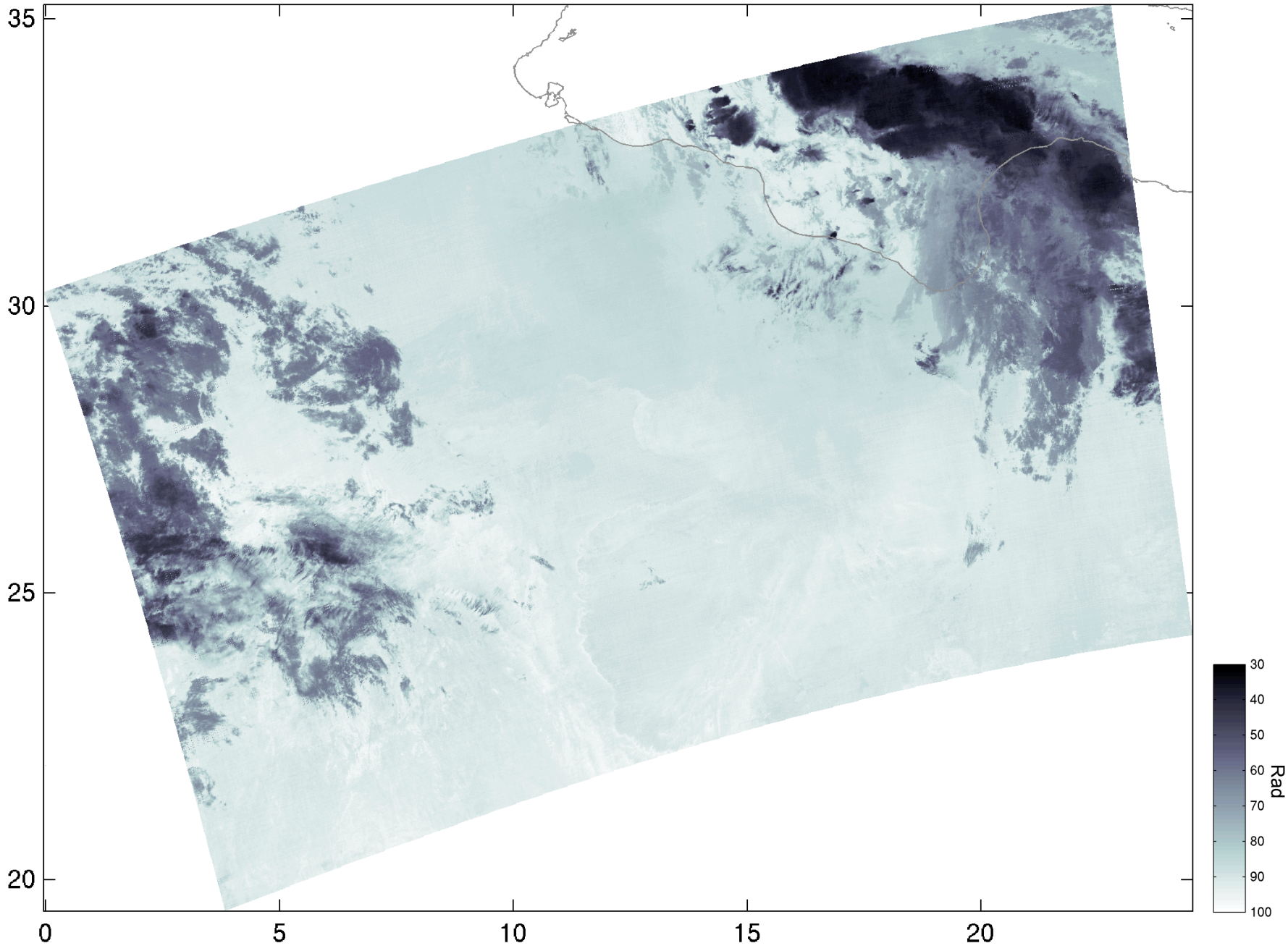
Longwave Principle Components



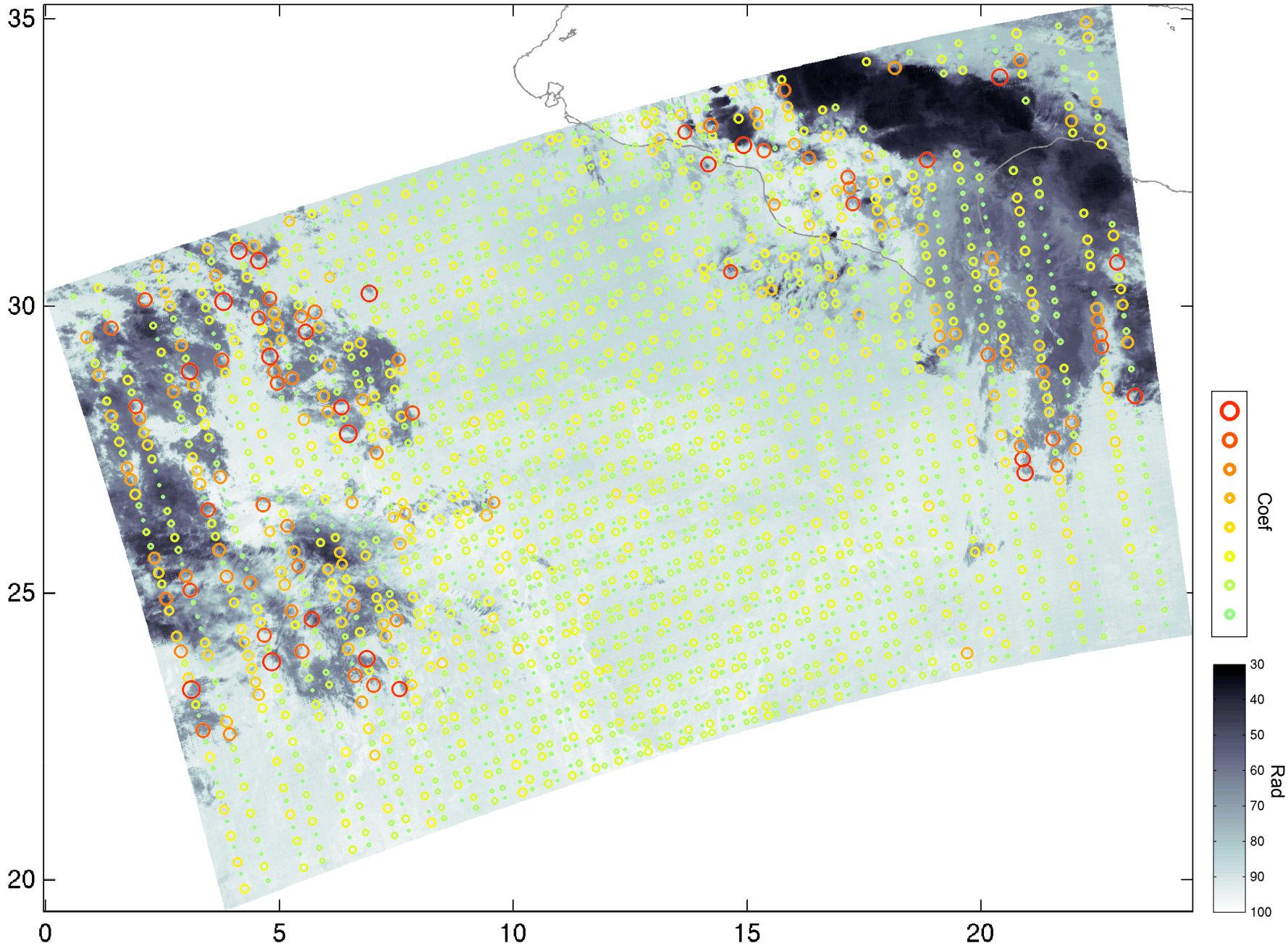
LW Principle Component #17 coefficients



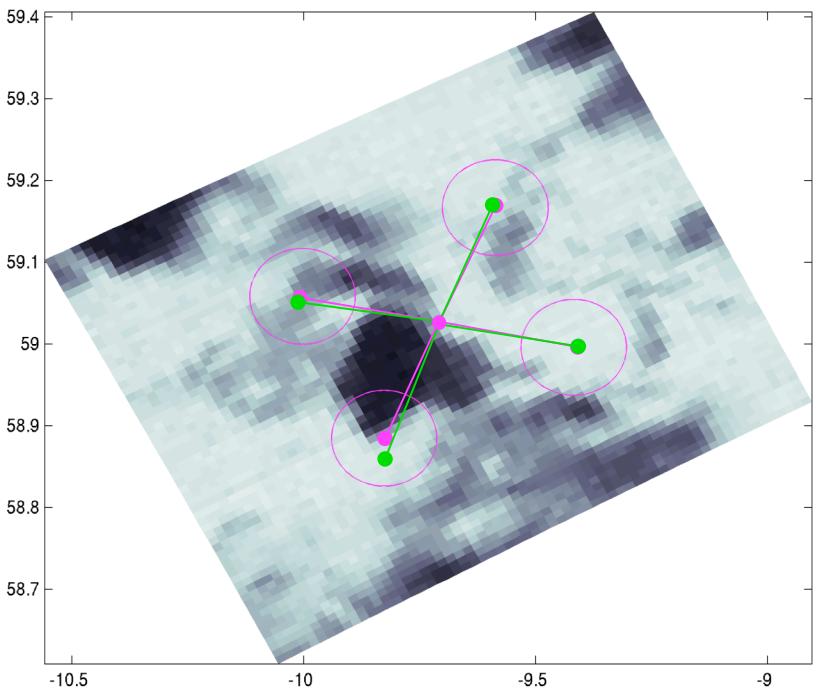
IASI Imager data



IASI Imager data overlaid with LW Principle Component #17 Coefficients



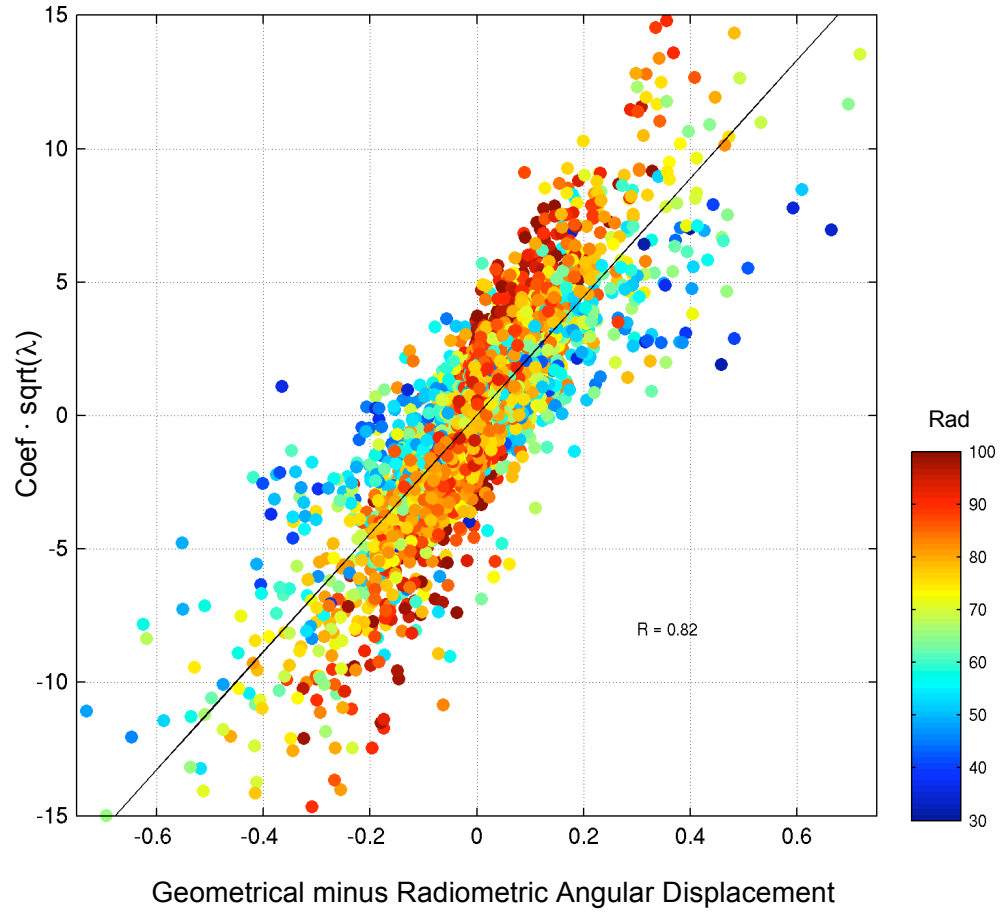
Geometrical versus Radiometric FOV centers computed with the Imager data



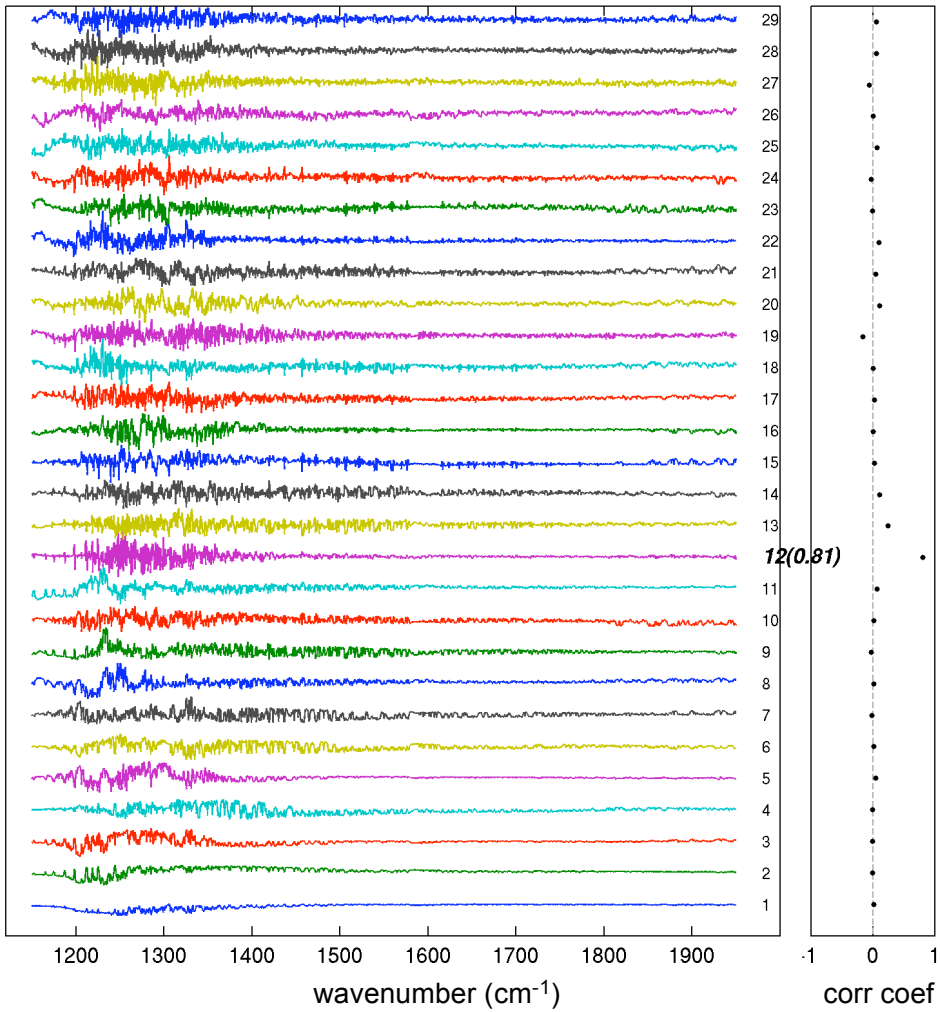
Angular distance from center of FOR to geometrical center of FOV

Angular distance from center of FOR to radiometric center of FOV

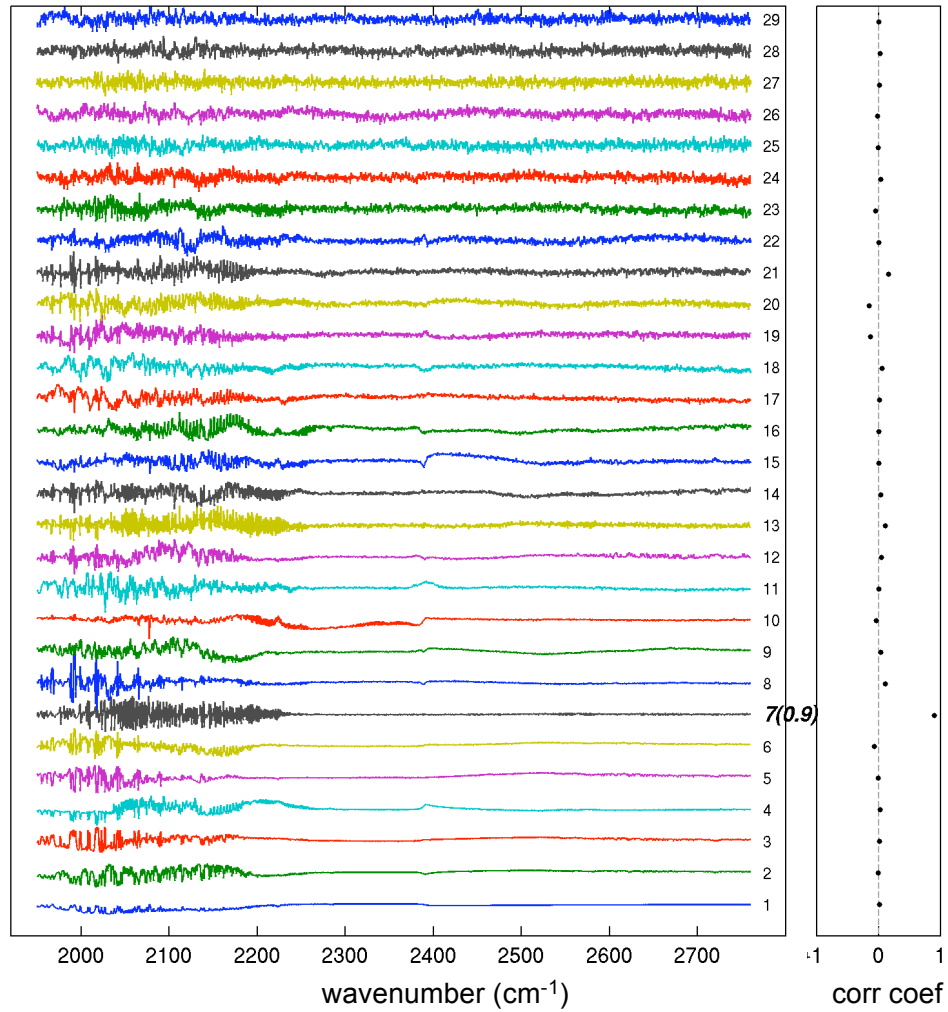
PC coefficients versus Imager analysis of scene radial non-uniformity



Midwave PCs



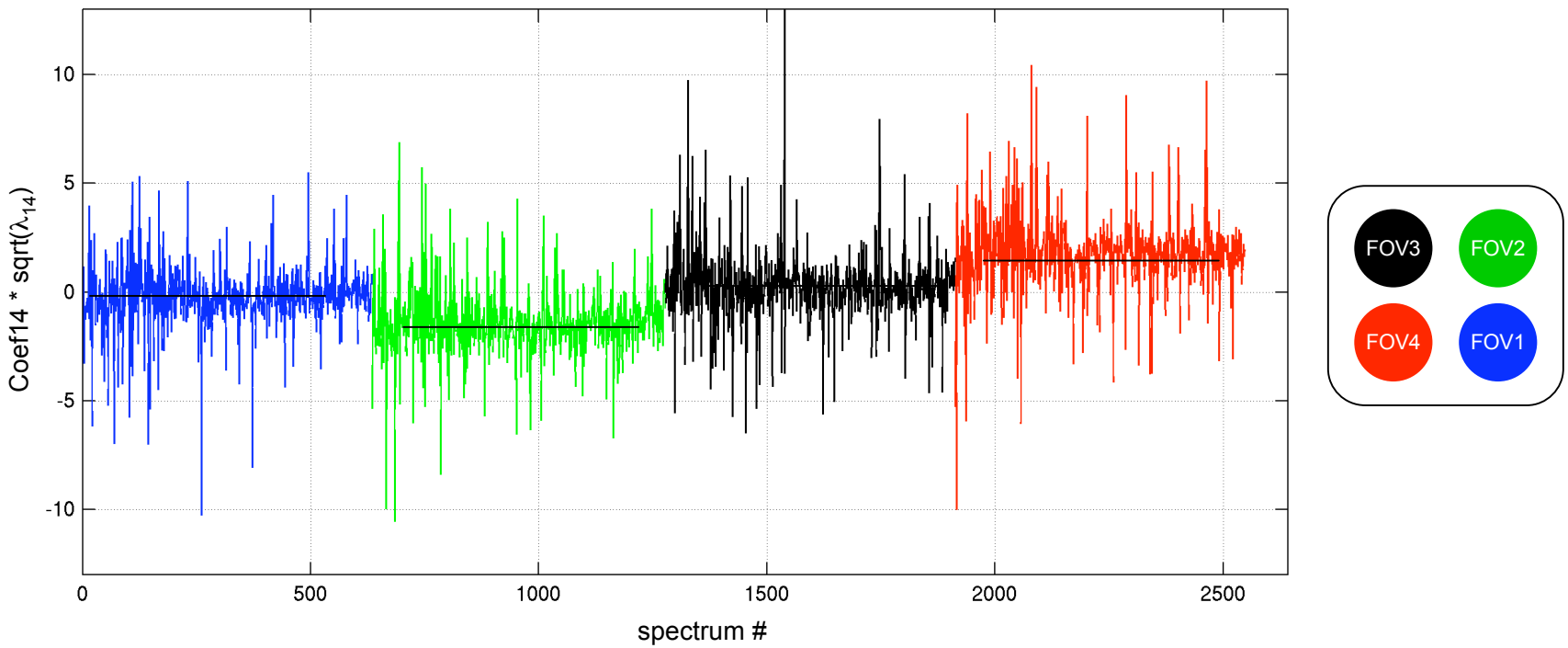
Shortwave PCs



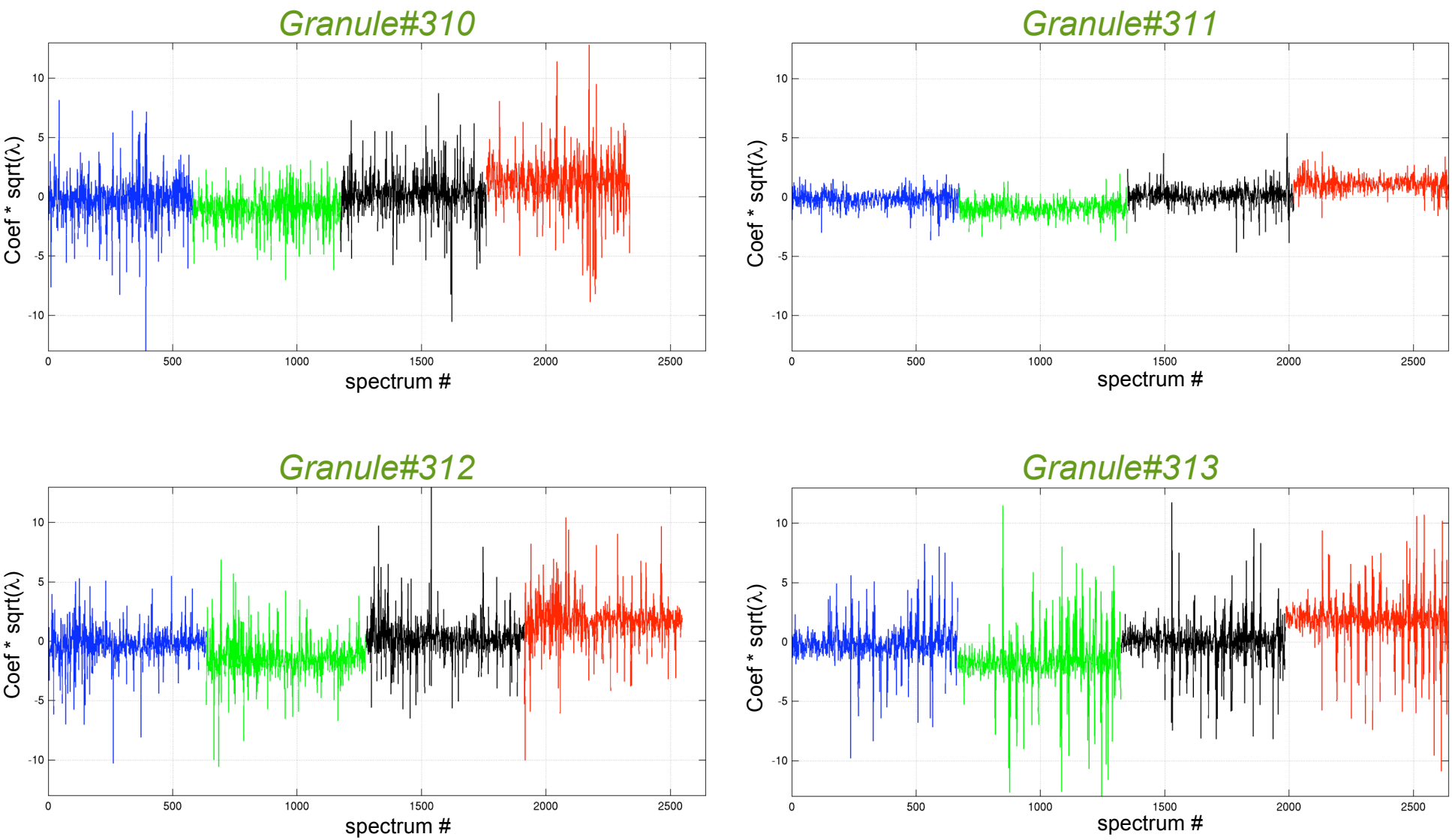
Same basic characteristics observed for midwave and shortwave bands, with the exception of the mean inter-FOV coefficient differences.

Inter-FOV spectral calibration

Longwave Principle Component #14 coefficients



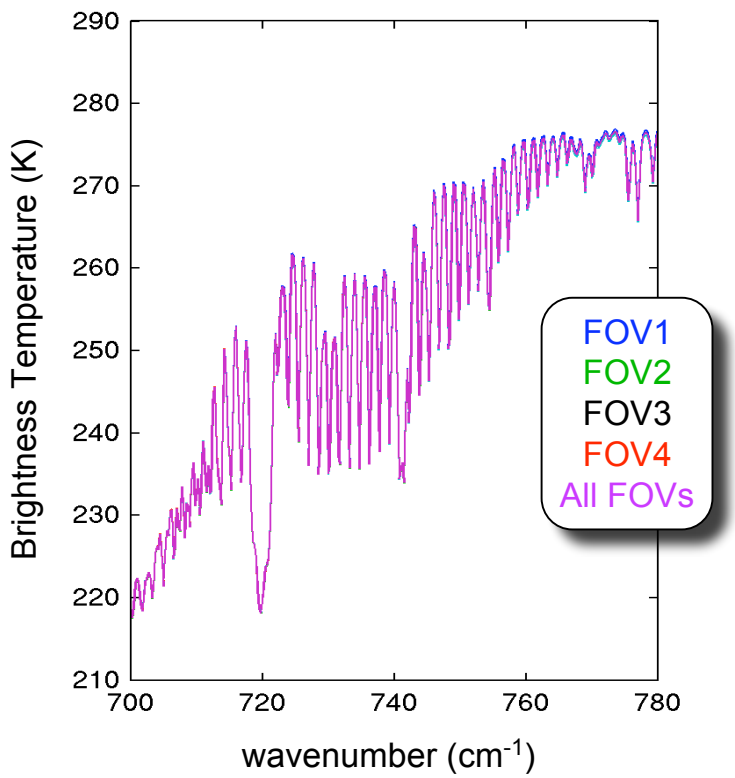
Mean difference in coefficients from FOV to FOV suggests spectral calibration differences from FOV to FOV.



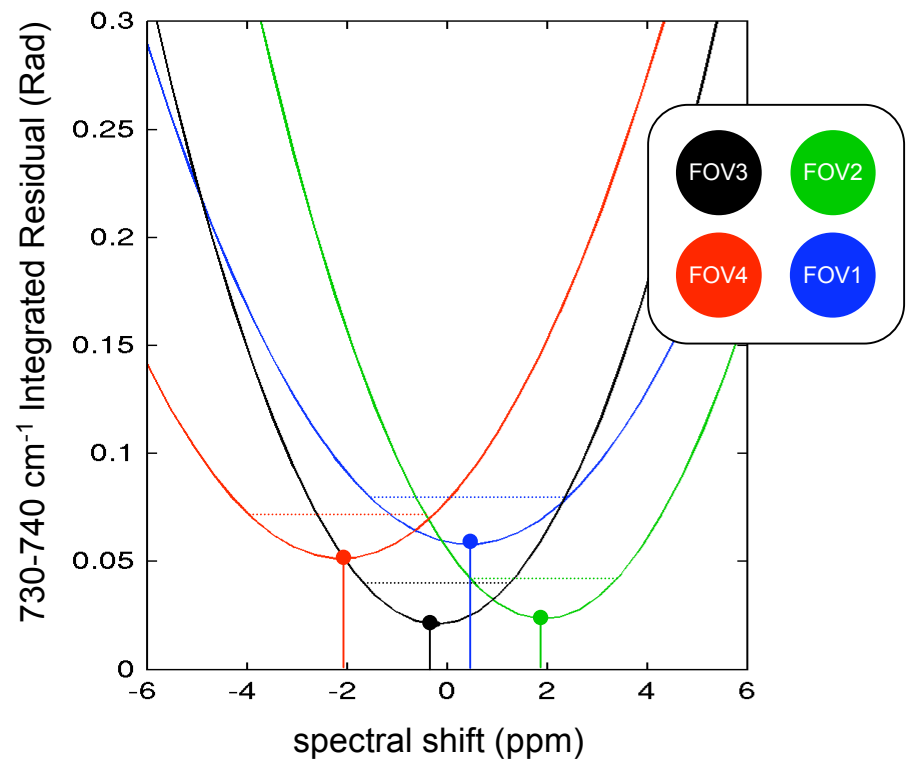
Same message from other granules

Inter-FOV Spectral Calibration Assessment Approach

Compute mean spectra for a granule:



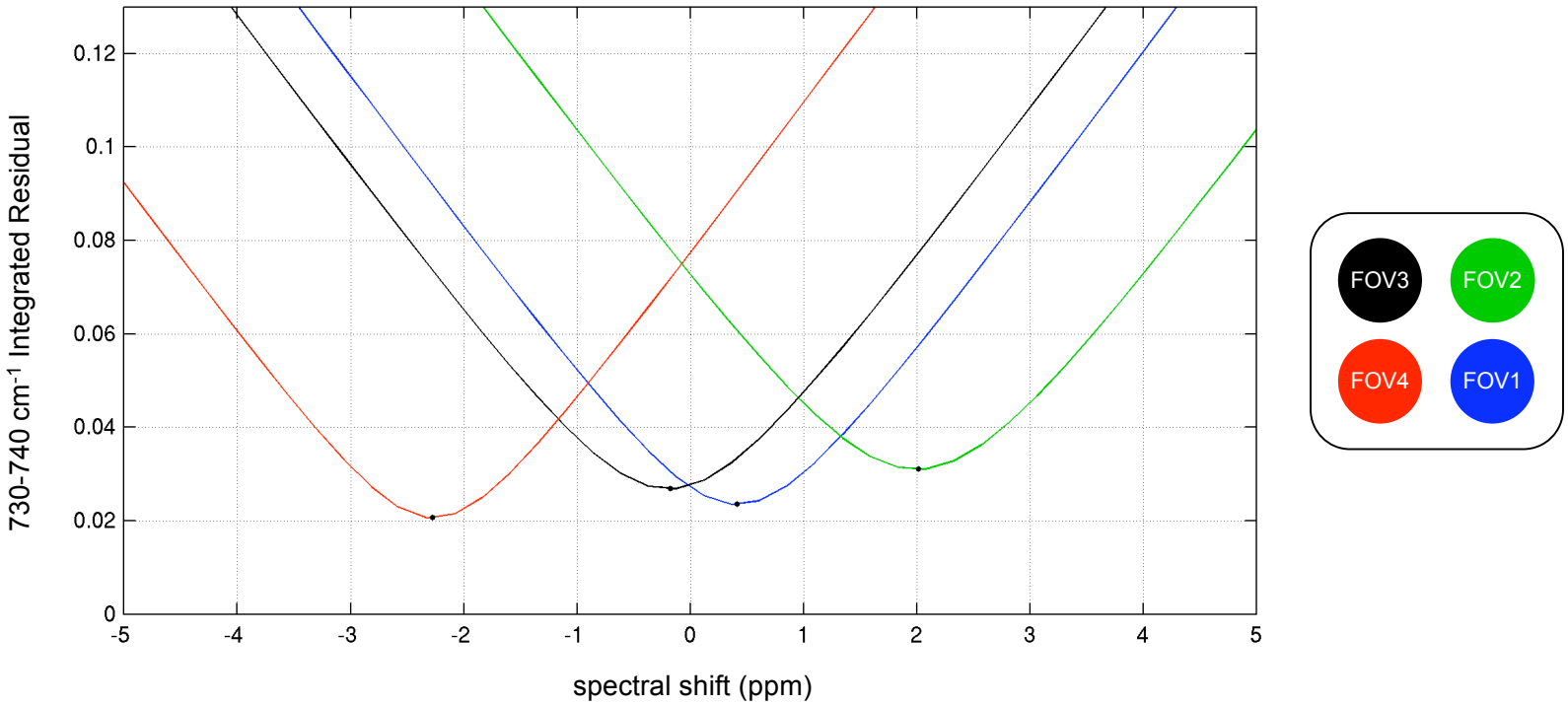
Compute [integrated residuals over a selected wavenumber region with respect to the mean spectrum for all FOVs] as a function of spectral shift



Record the spectral shift for the minimum integrated residual and curvature of residuals around the minimum

Granule#311, Longwave (730-740 cm^{-1}) Inter-FOV spectral calibration

Spectral shifts of mean spectra for each FOV relative to the mean spectrum of the granule

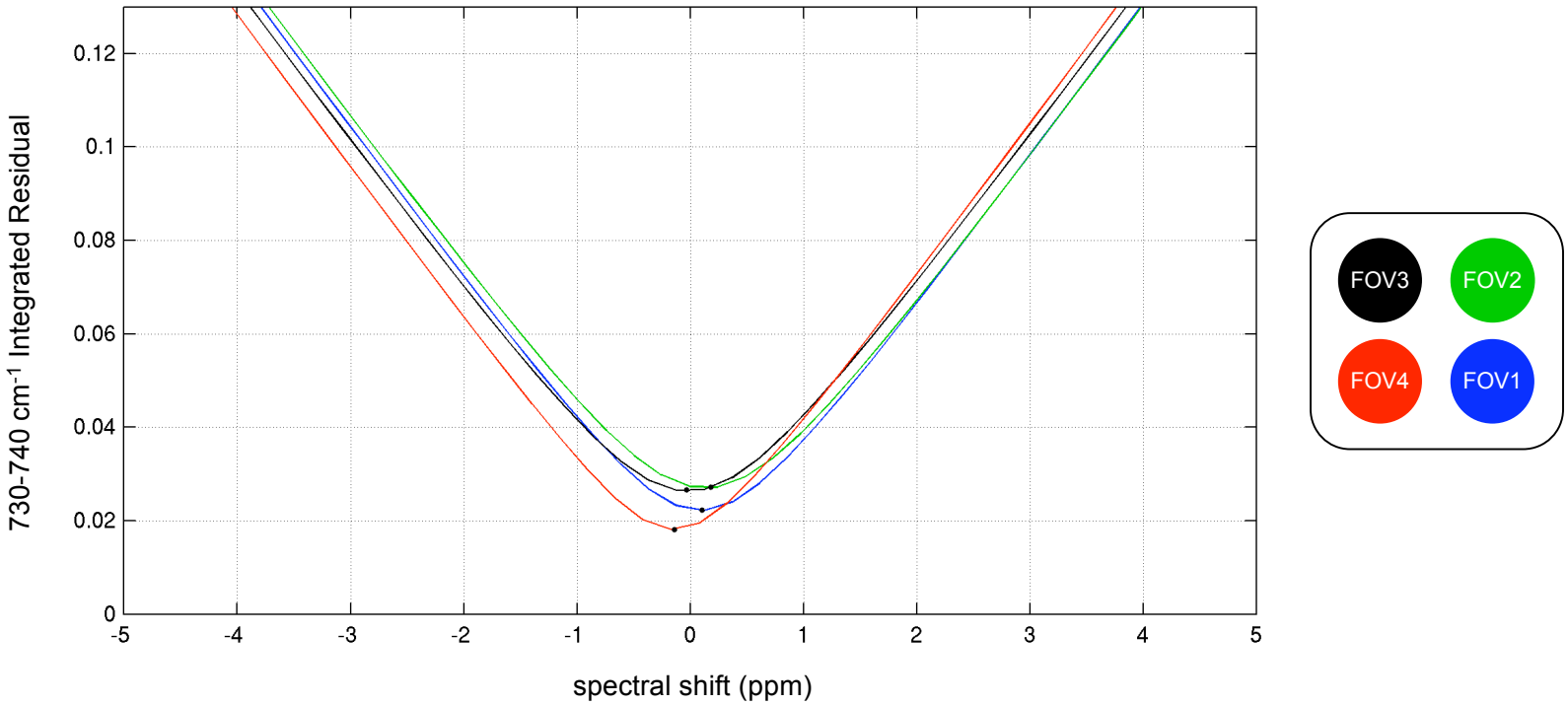


Inter-FOV spectral calibration differences for LW band also identified with traditional spectral calibration analysis

With PCA corrections

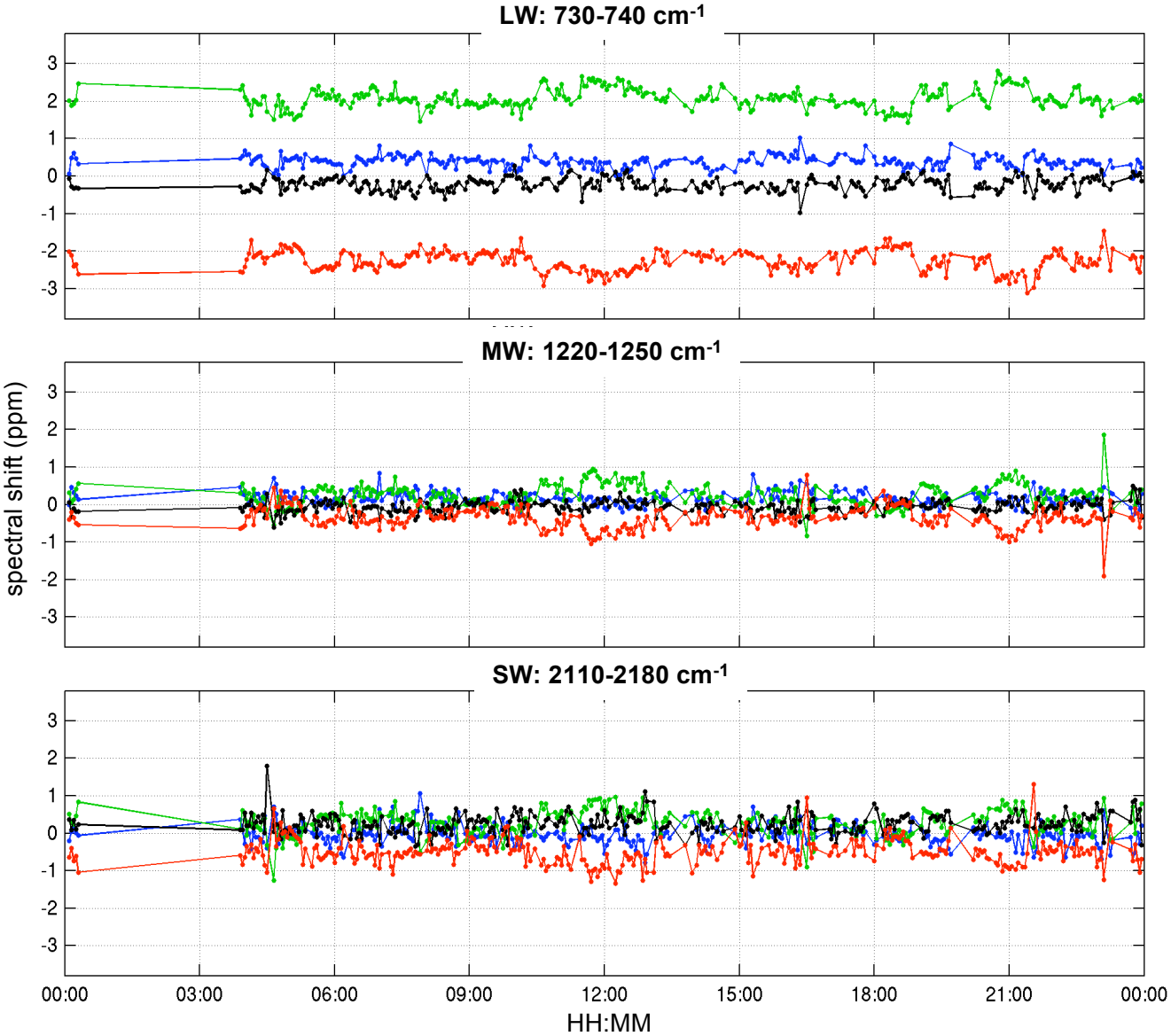
Granule#311, Longwave (730-740 cm^{-1}) Inter-FOV spectral calibration

Spectral shifts of mean spectra for each FOV relative to the mean spectrum of the granule

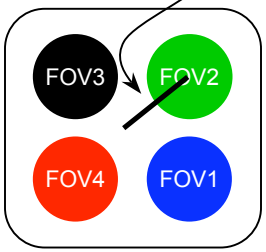


2007.10.15, Inter-FOV spectral calibration

Spectral shifts of mean spectra for each FOV relative to the mean spectrum of each granule



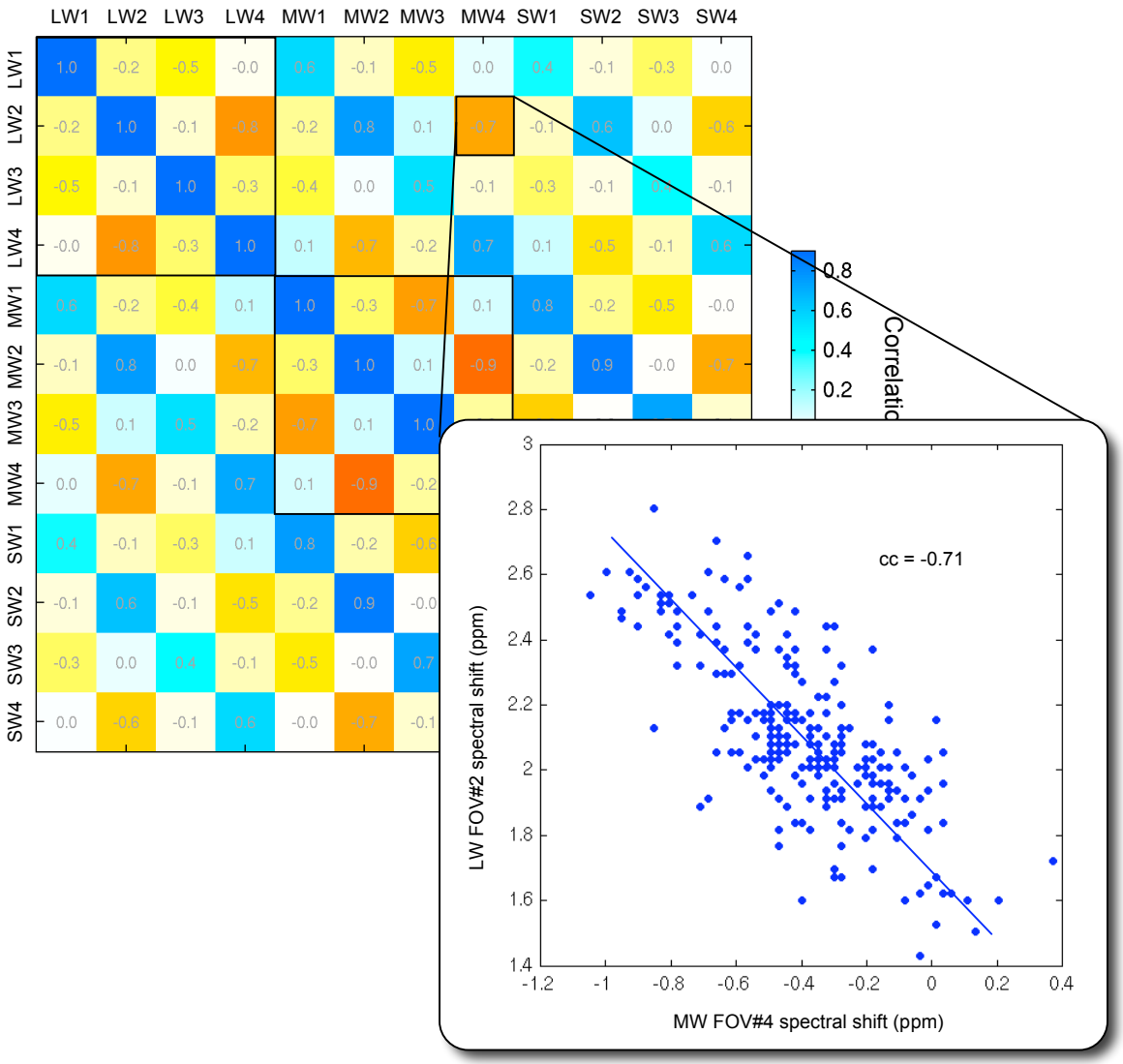
Mean off axis angle
~14.7 mrad



1 ppm ↔ ~0.1 mrad

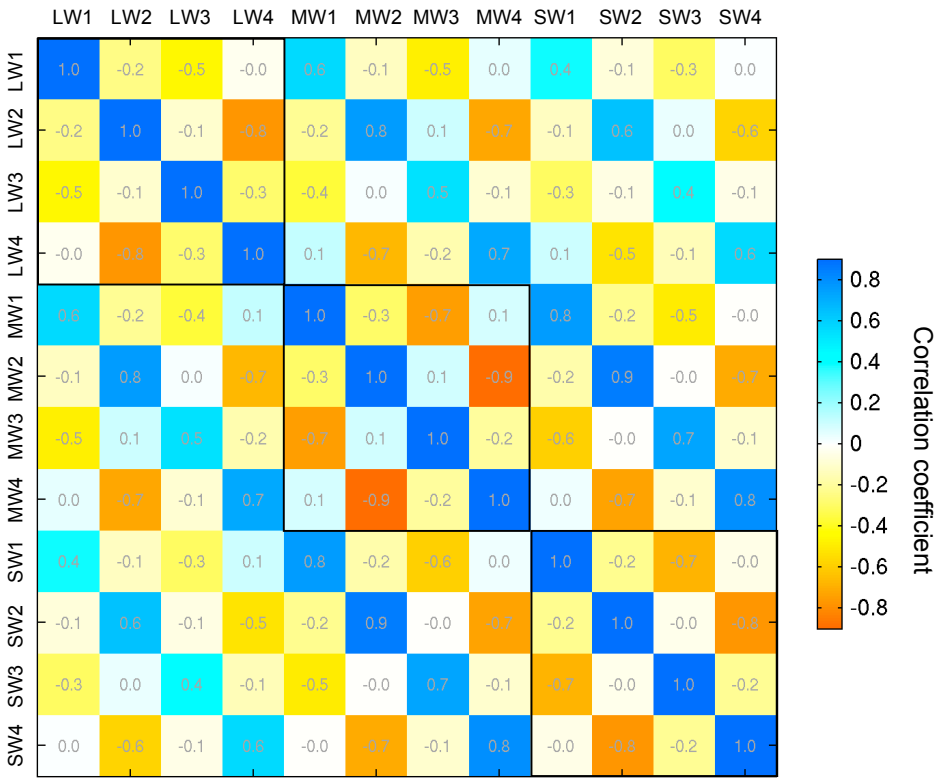
2007.10.15, Inter-FOV spectral calibration

Correlation of spectral shifts from FOV to FOV



2007.10.15, Inter-FOV spectral calibration

Correlation of spectral shifts from FOV to FOV



High degree of correlation/anti-correlation of measured spectral shifts from FOV to FOV within LW, MW, and SW bands, and also from LW to MW to SW. Suggests variations are due to (very small) movement of FPA assembly with respect to the IFR.

Inter-FOV Spectral Calibration Summary

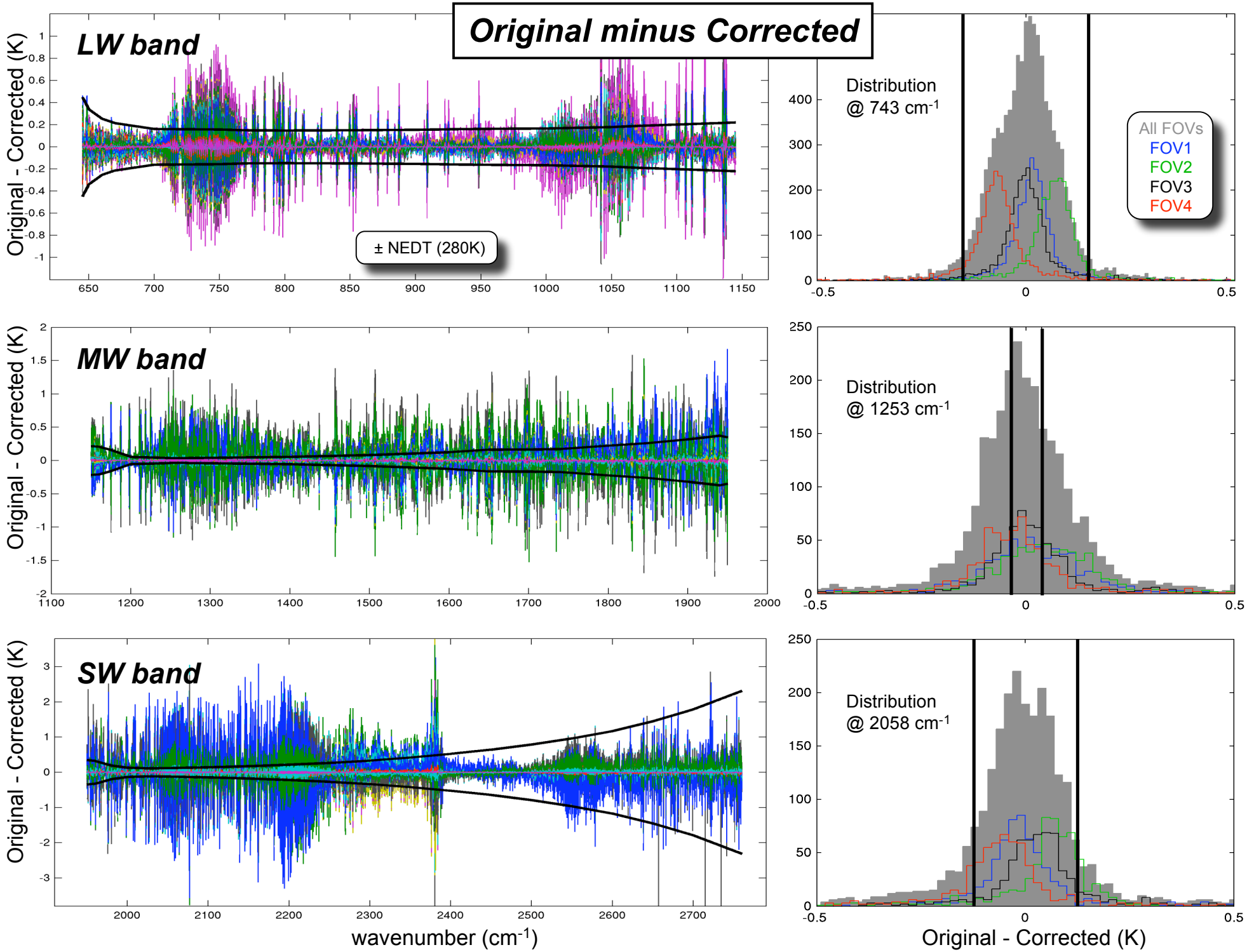
Mean results consistent with the PCA approach, with measurable inter-FOV differences, most notably between LW FOVs 2 and 4 (~3.5 ppm). (Also consistent with L. Strow analyses using clear sky calculations as reference.)

Small short term variations (~0.2 ppm STDDEV) in the inter-FOV spectral shifts are observed. These are correlated among the 12 FOVs and consistent with variations in the FPA assembly with respect to the IFR axis.

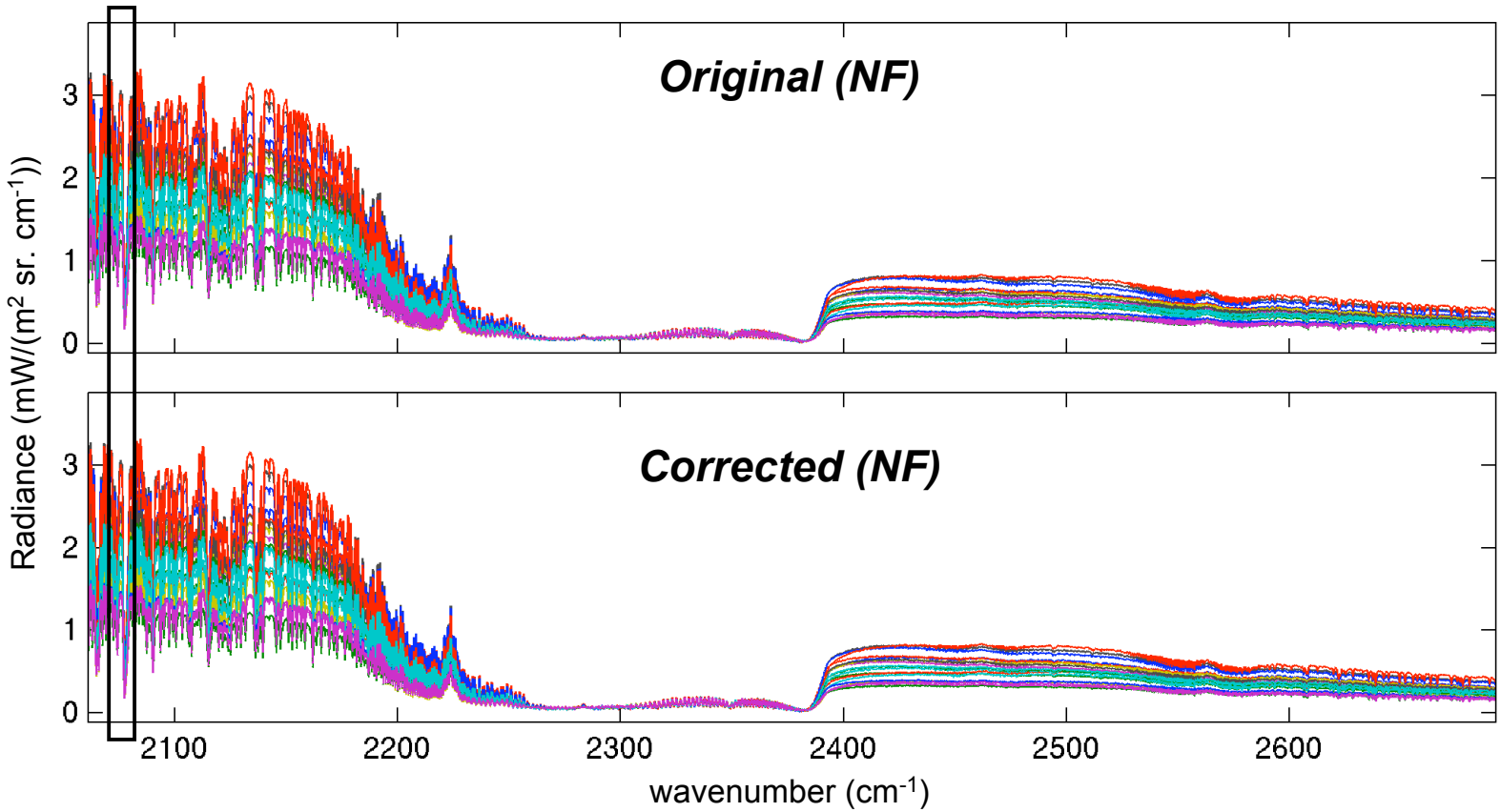
The same analysis over ~6 months (not shown) shows no change in the inter-FOV spectral calibration (or long term drift of the FPA assembly with respect to the IFR axis). The short and long term magnitude of these variations suggest very good spectral fidelity of the IASI data.

Non-uniform scene ILS corrections

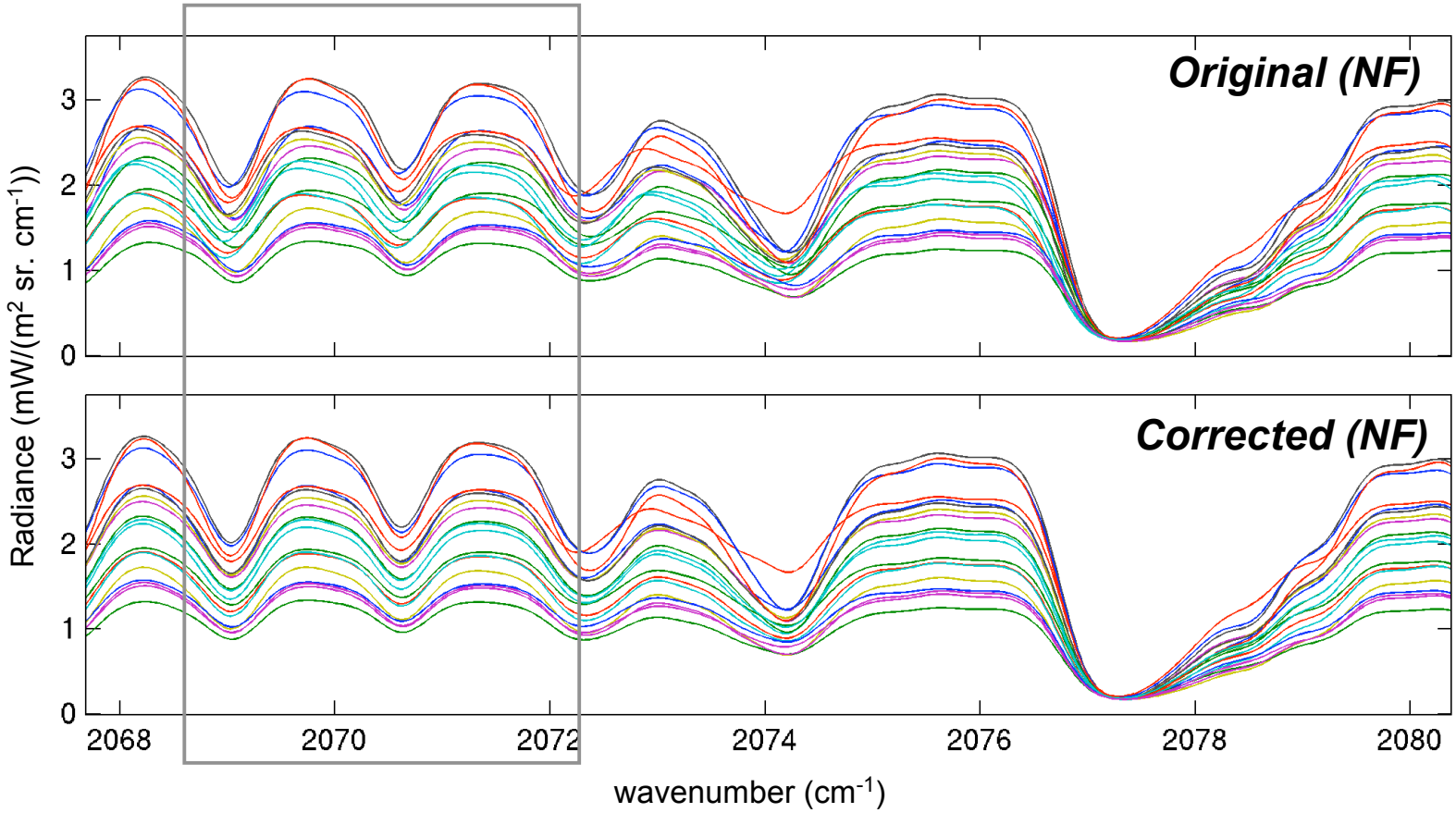
- Reconstruct the spectra with the “spectral shift” PC coefficients set to zero

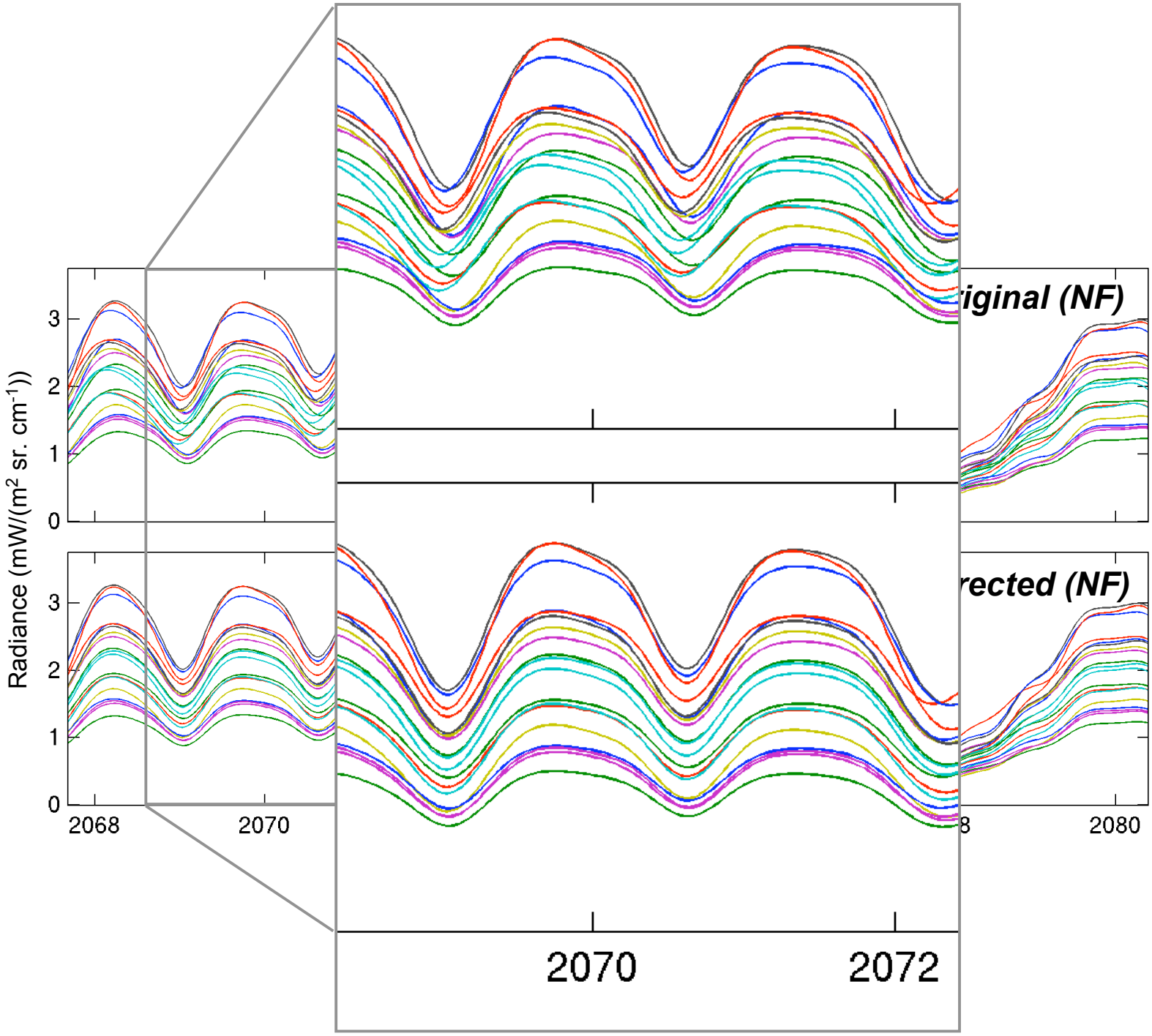

Original minus Corrected
LW band
MW band
SW band
± NEDT (280K)
Distribution @ 743 cm-1
Distribution @ 1253 cm-1
Distribution @ 2058 cm-1
All FOVs
FOV1
FOV2
FOV3
FOV4
Original - Corrected (K)
wavenumber (cm-1)
Original - Corrected (K)

Oversampled SW Spectra



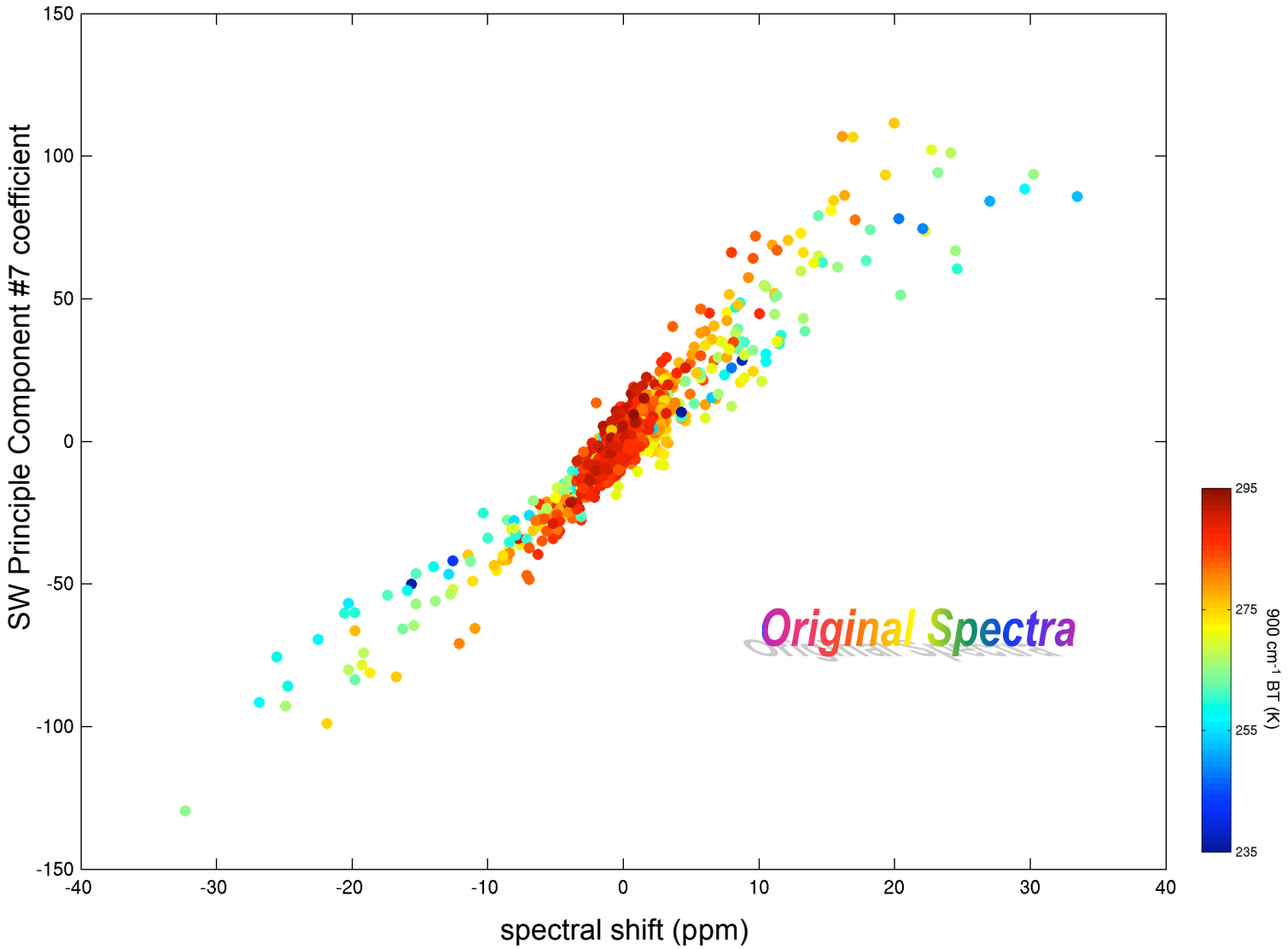
Oversampled SW Spectra




Radiance (mW/(m2 sr. cm-1))
0
1
2
3
2068
2070
2080
iginal (NF)
rected (NF)
2070
2072

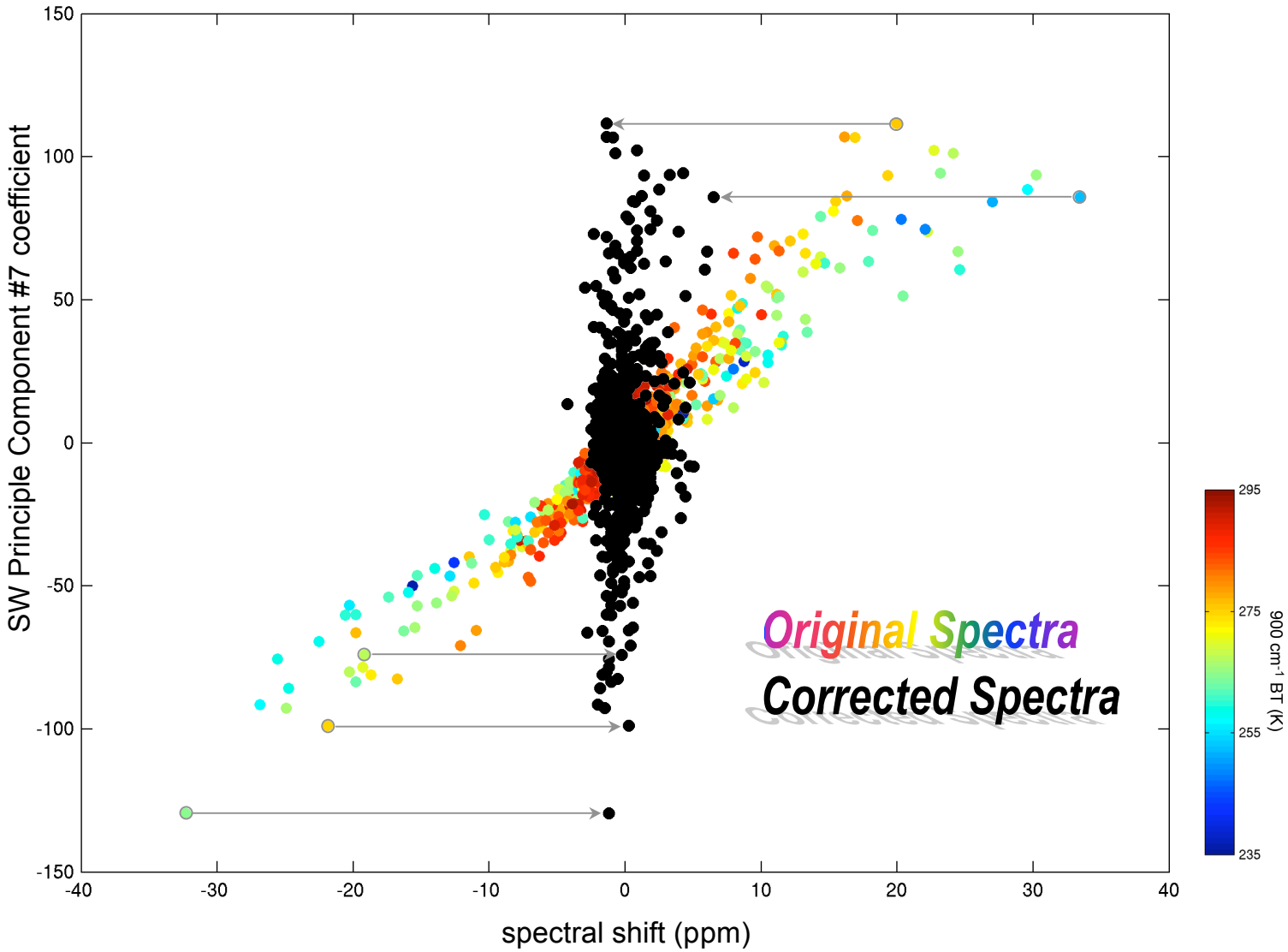
Spectral Calibration Analysis of Original and Corrected Spectra

Spectral shifts of Granule 313 spectra w/r/t a reference spectrum



Spectral Calibration Analysis of Original and Corrected Spectra

Spectral shifts of Granule 313 spectra w/r/t a reference spectrum



±30 ppm shifts reduced to ±4 ppm

Some Questions

Are effects other than spectral calibration and/or non-uniform scene ILS effects present in the “spectral shift” Principle Components ?

Are spectral calibration and/or non-uniform scene ILS effects present in other Principle Components ?

How do we quantify the accuracy of the PCA corrections given these issues ?

Can the corrections be performed using synthetic signatures of the non-uniform scene ILS effects (in an Independent set PCA mode) ?

Conclusions

PCA is a useful tool for identifying and characterizing sensor characteristics. This investigation focuses on the effects of scene non-uniformity on the ILS.

Scene non-uniformity within the IASI footprints manifests primarily in spectral shift artifacts, and these are found to be largely characterized by a single PC/eigenvector when using dependent set PCA.

Preliminary results suggest that spectra reconstructed with this “spectral shift” PC excluded have a large portion of the non-uniform scene ILS effects removed. For the example granule shown here, ±30 ppm shifts are reduced to ±4 ppm.

More work needs to be done to study the accuracy, robustness, and computational efficiency of this correction approach, including (a) the use of synthetic principle components, (b) comparison with physics-based corrections, and (c) the impact of the corrected data on retrievals.

Acknowledgements

- Dave Turner, Bill Smith, Elisabeth Weisz, Steve Dutcher, Bob Holz, Allen Huang, Bob Knuteson, Joe Taylor, Fred Best
- Larrabee Strow
- Denis Blumstein
- the Integrated Program Office

Fin.

Merci beaucoup