IRS PC compression

Tim Hultberg and Thomas August

PC Compression method

Independent compression of Band 1 and 2

- inter band correlation not exploited → need extra PC scores

Noise normalisation matrix $N = S_y^{1/2}$ (matrix square root of the NCM)

- to uniformize and de-correlate the noise

Eigenvectors built from training set of real measurements (Y)

Number of retained eigenvectors based on spatial correlation of PC scores

→ E a truncated set of eigenvectors of $N^{-1}COV(Y)N^{-1}$

$$p = E^T N^{-1}(y - \bar{y})$$ **PC scores**

$$\tilde{y} = NEp + \bar{y}$$ **Reconstructed radiances**

$$\tilde{y} = Ay + (I - A)\bar{y} \quad \text{where} \quad A = NEE^T N^{-1}$$

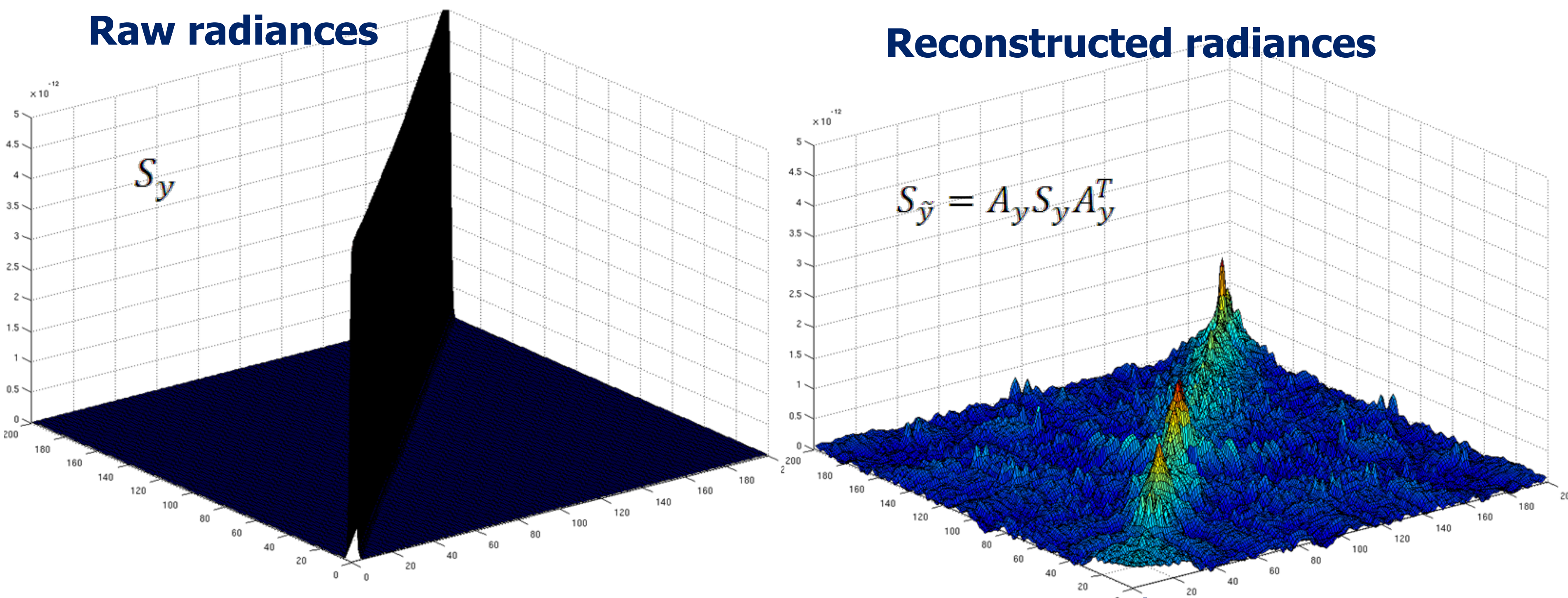
The transformation to reconstructed radiances is a projection!

PC compression (offline and online parts) described in the MTG-IRS L1 ATBD

Raw and reconstructed noise covariance matrices

Raw noise Reconstructed noise Noise in residuals

$$S_y = A\,S_y A^T + (I - A) S_y (I - A)^T$$



Instrument noise covariance (1040-1090 cm^{-1})

PC compression (a spectrum split into four parts)

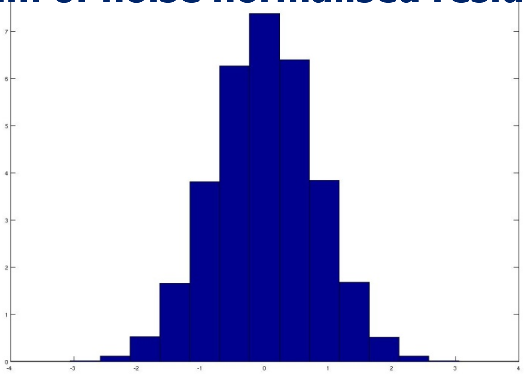
Total		Signal		Noise	
y	$=$	y_0	$+$	ε	Raw radiance
$\tilde{y}$	$=$	$\boxed{\tilde{y}_0}$	$+$	$\boxed{A\varepsilon}$	Reconstructed radiance
$y-\tilde{y}$	$=$	$\boxed{y_0-\tilde{y}_0}$	$+$	$\boxed{(I-A)\varepsilon}$	Residual

Atmospheric signal retained in reconstructed radiance
Instrument noise retained in reconstructed radiance
Atmospheric signal in residual (RECONSTRUCTION ERROR ☹)
Instrument noise in residual

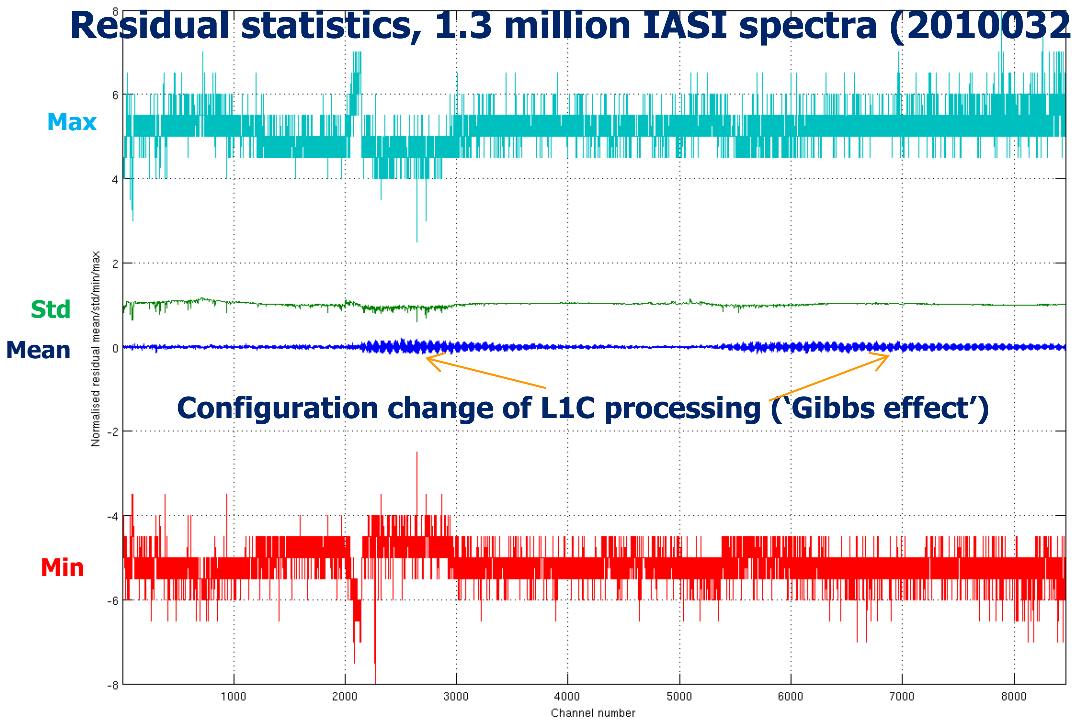
the covariance of the residuals **is the** sum of
the noise in the residuals and the covariance of the reconstruction error

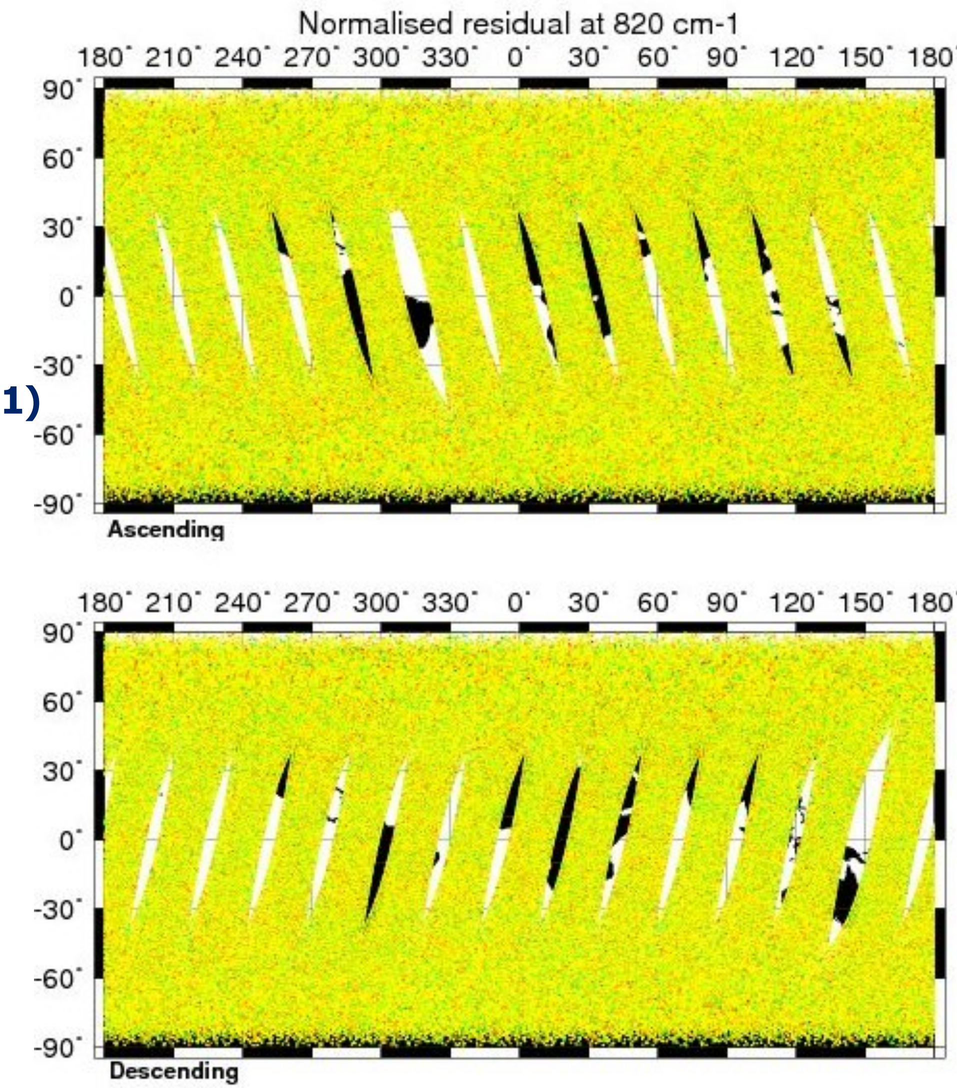
Confirmation of no atmospheric signal in residuals

Histogram of noise normalised residual at 820 cm-1

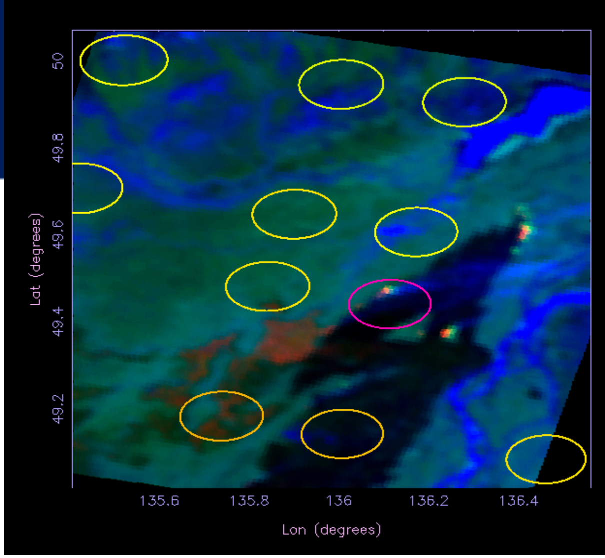


Residual statistics, 1.3 million IASI spectra (20100321)





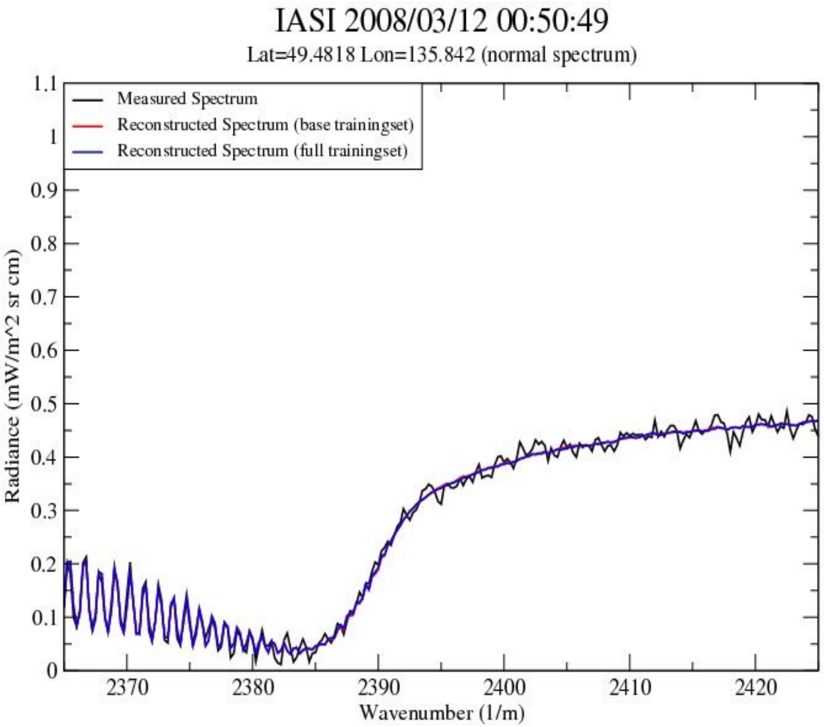
Reconstruction score

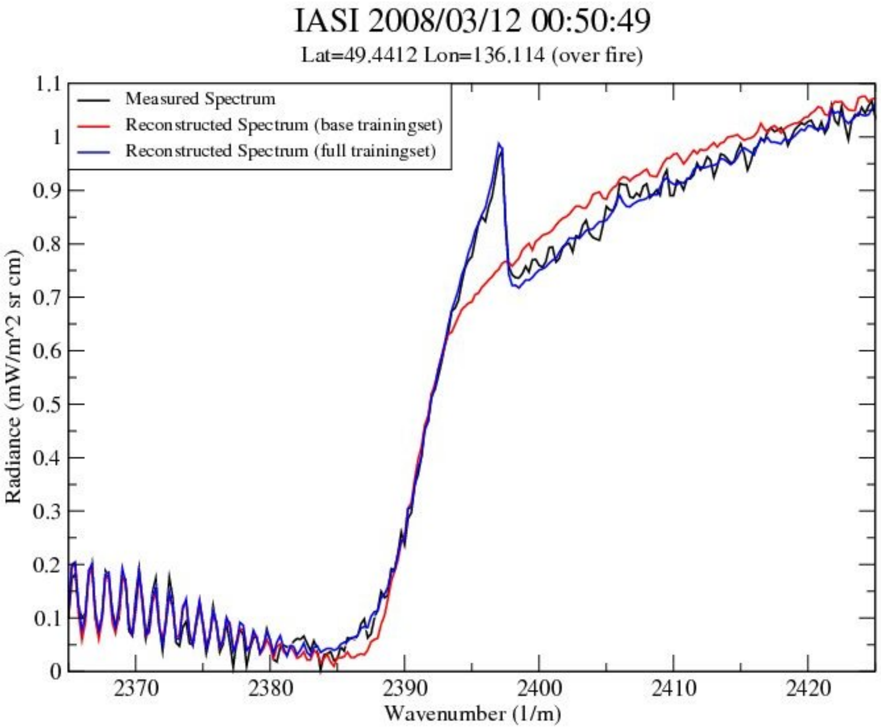


Reconstruction score (RMS of noise normalised residual)

$$\sqrt{\frac{1}{m}\sum_{i=1}^{m} r_i^2} \quad \textbf{where} \quad r = N^{-1}(y - \tilde{y}) \quad \textbf{(the reconstruction residual)}$$

Used to detect outliers (spectra which do not reconstruct well)



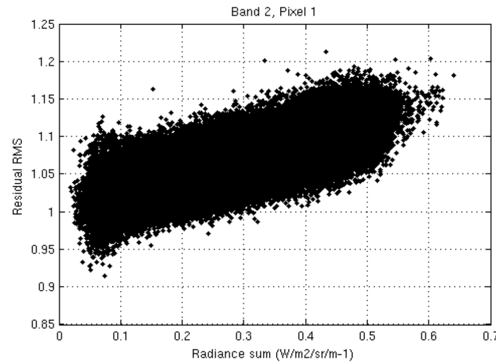


Thresholding for outlier classification

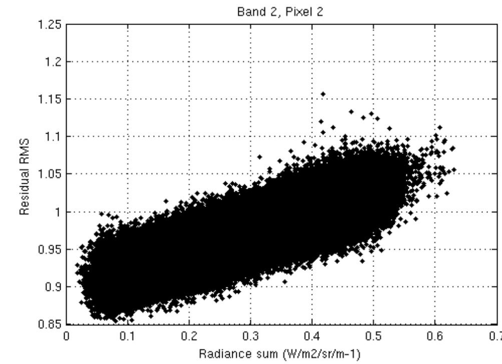
The noise and therefore the expected value of the residual RMS depends on the radiance sum (increase of photonic noise) and the detector

This must be taken into account to get a sensitive detection of outliers.

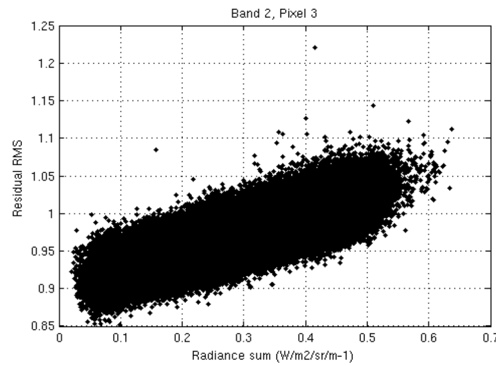
Detector 1



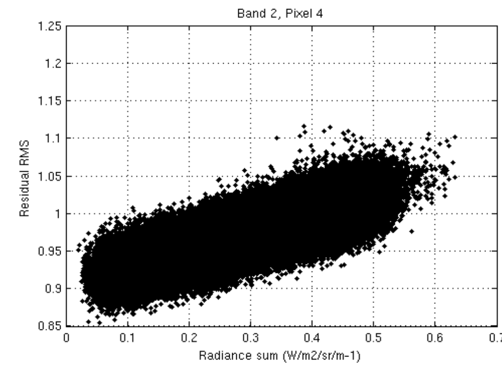
Detector 2



Detector 3



Detector 4



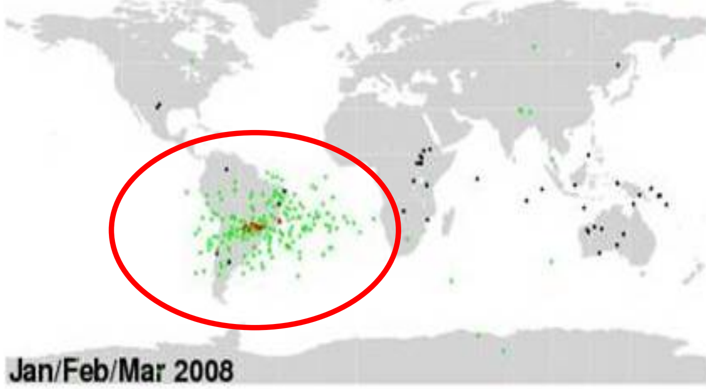
Scatter plots of residual RMS vs. radiance sum (Band 2)

Classified as outlier if:

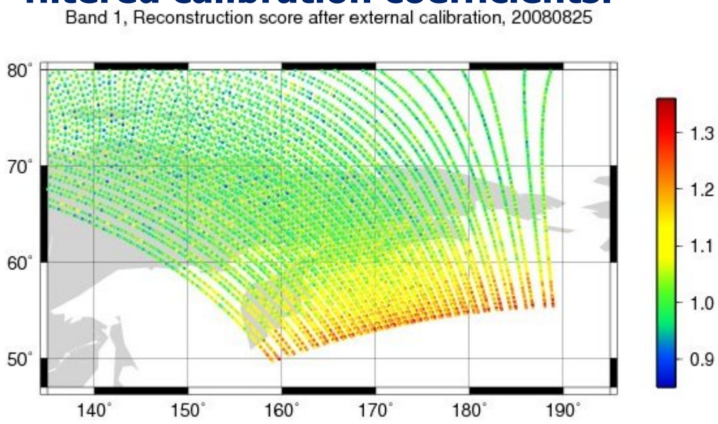
ReconstructionScore > Threshold[detector] + slope * RadianceSum

Most outliers not caused by atmospheric signal

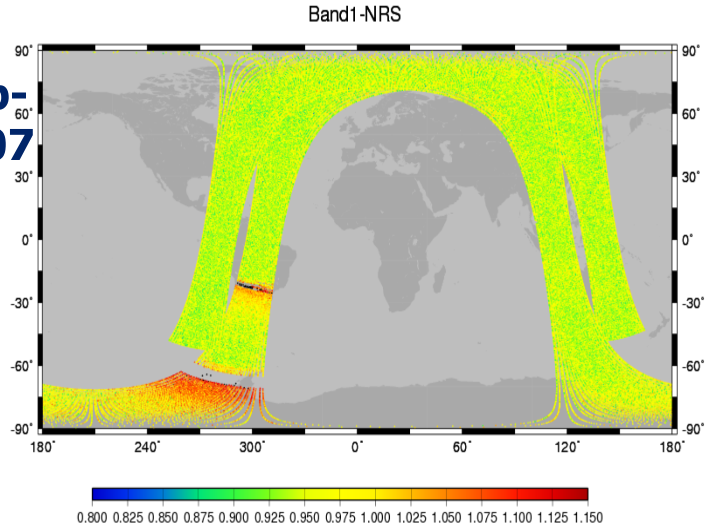
Undetected "spikes":
High-frequency disturbance of the interferogram, most often observed in the South Atlantic Anomaly. (Band 2 outliers)



Back to normal operation after external calibration mode:
No history available for deriving filtered calibration coefficients.

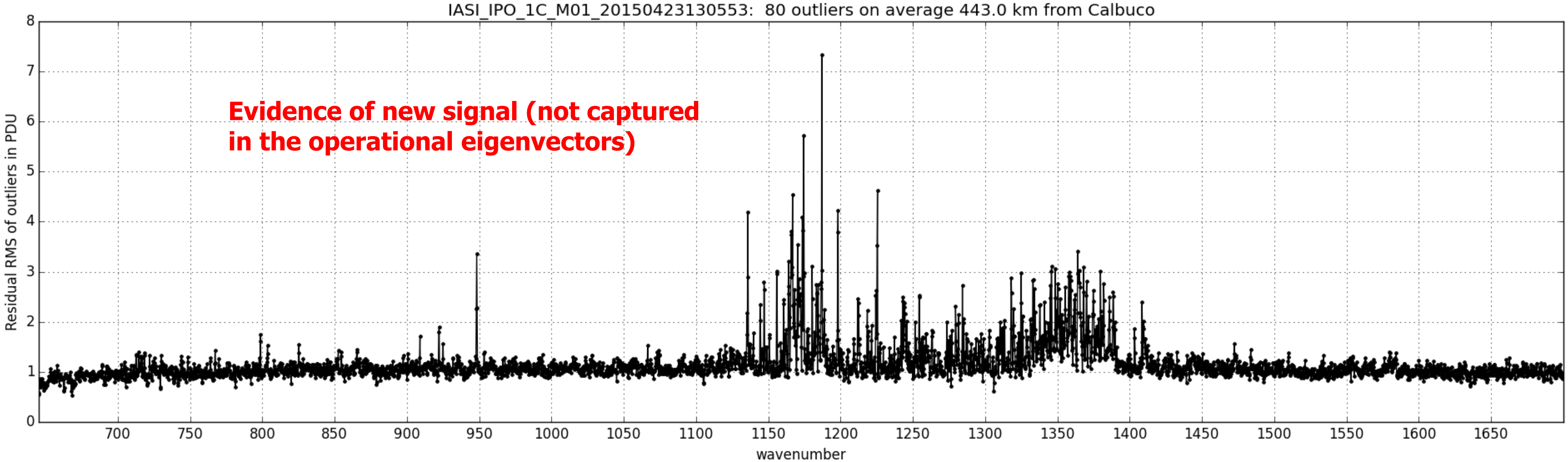


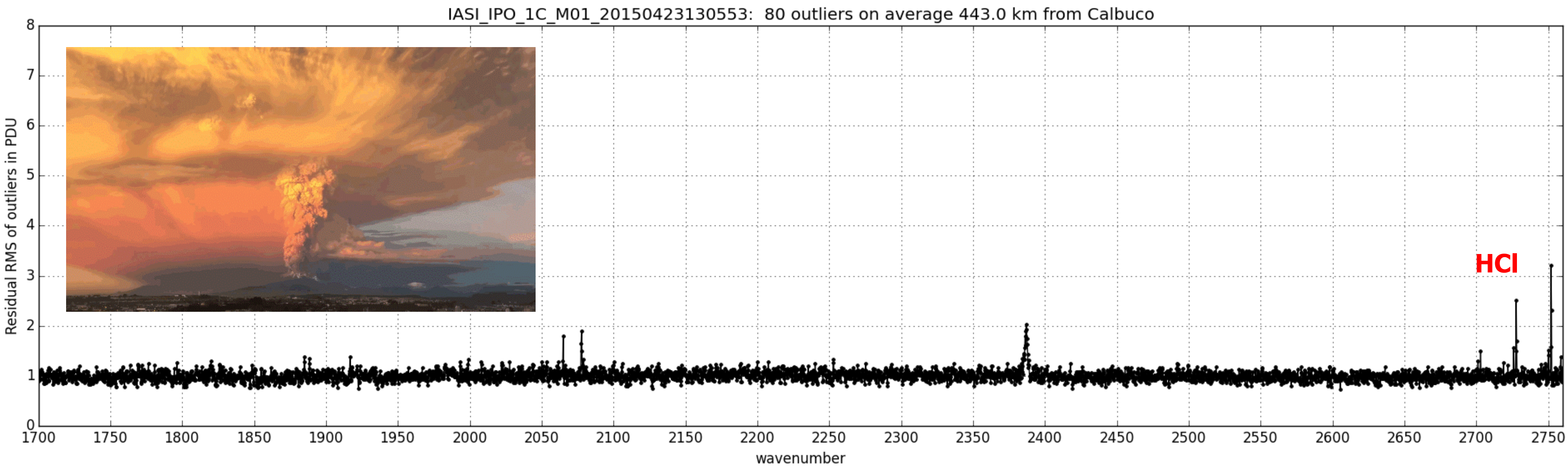
Anomaly related to Metop-B manoeuvre on 20130807 (Met-Office noticed a sudden increase in bias over Brazil when the manoeuvre occurred)



The reconstruction score detects some bad quality spectra not flagged in L1C

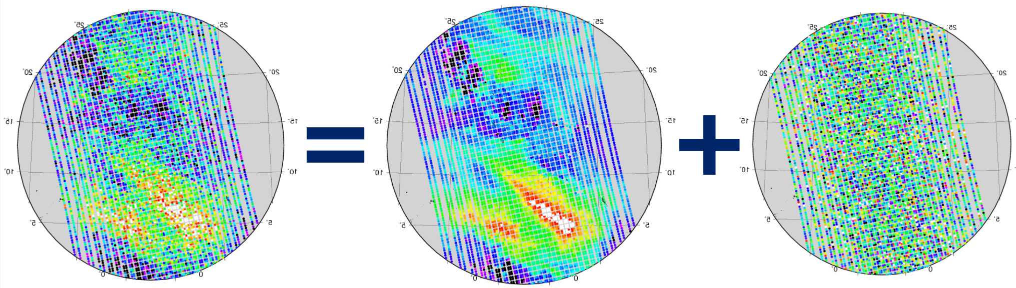
Calbuco eruption 2015.04.22



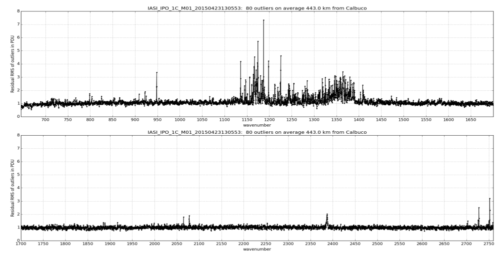


Global or local? Hybrid!

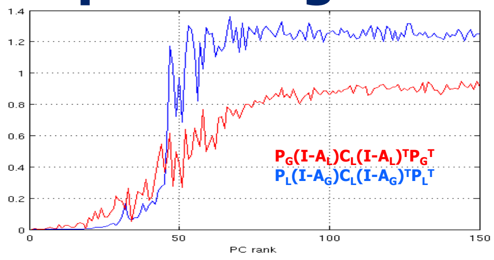
PC compression performed with eigenvectors based on a big global set of past observations works excellent.



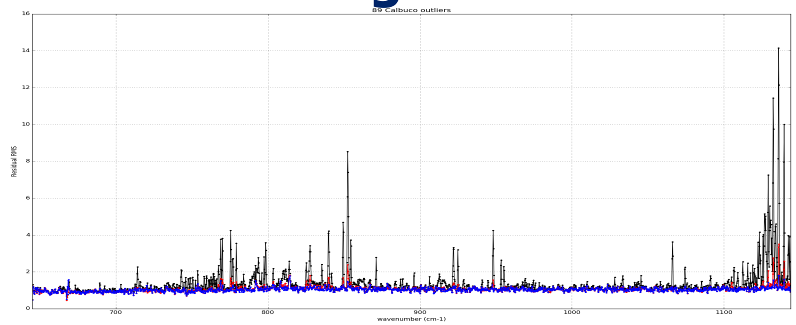
Only in very rare situations new spectral features orthogonal to the previously observed directions occur, which can not be represented well (but are flagged).



Using eigenvectors based on the local set of current observations being compressed would solve this issue, but retain more noise and less atmospheric signal.

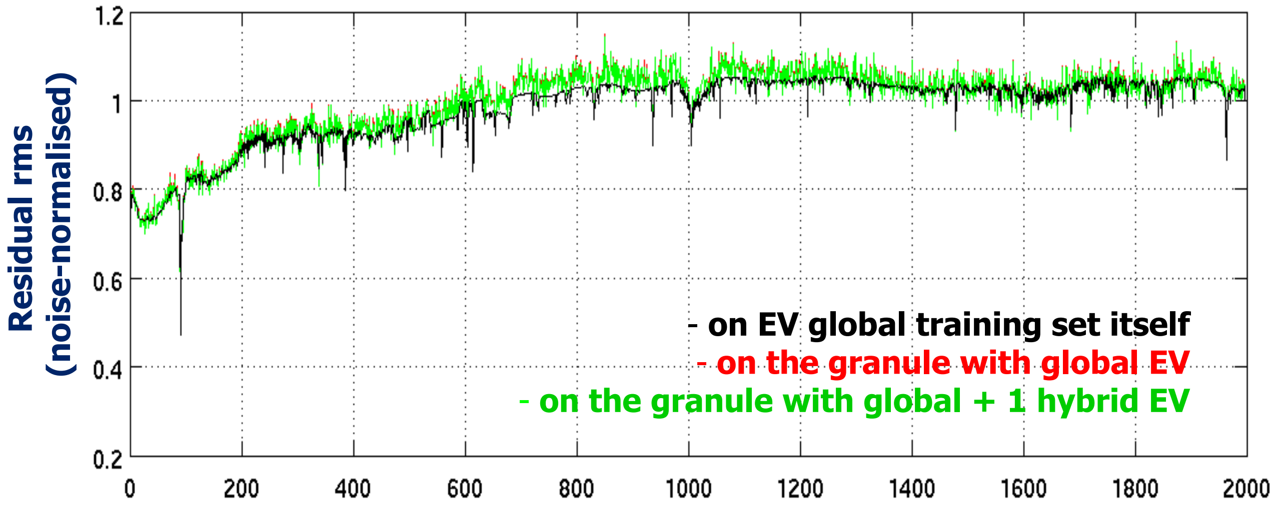


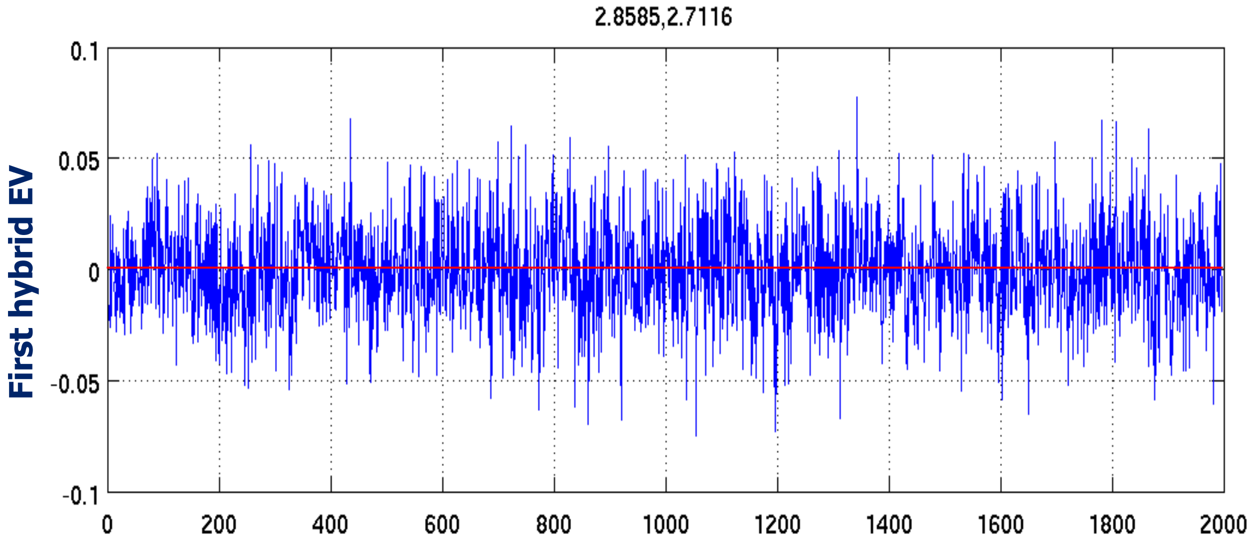
Instead we can supplement the global eigenvectors with a few local eigenvectors, when needed to represent new signals.

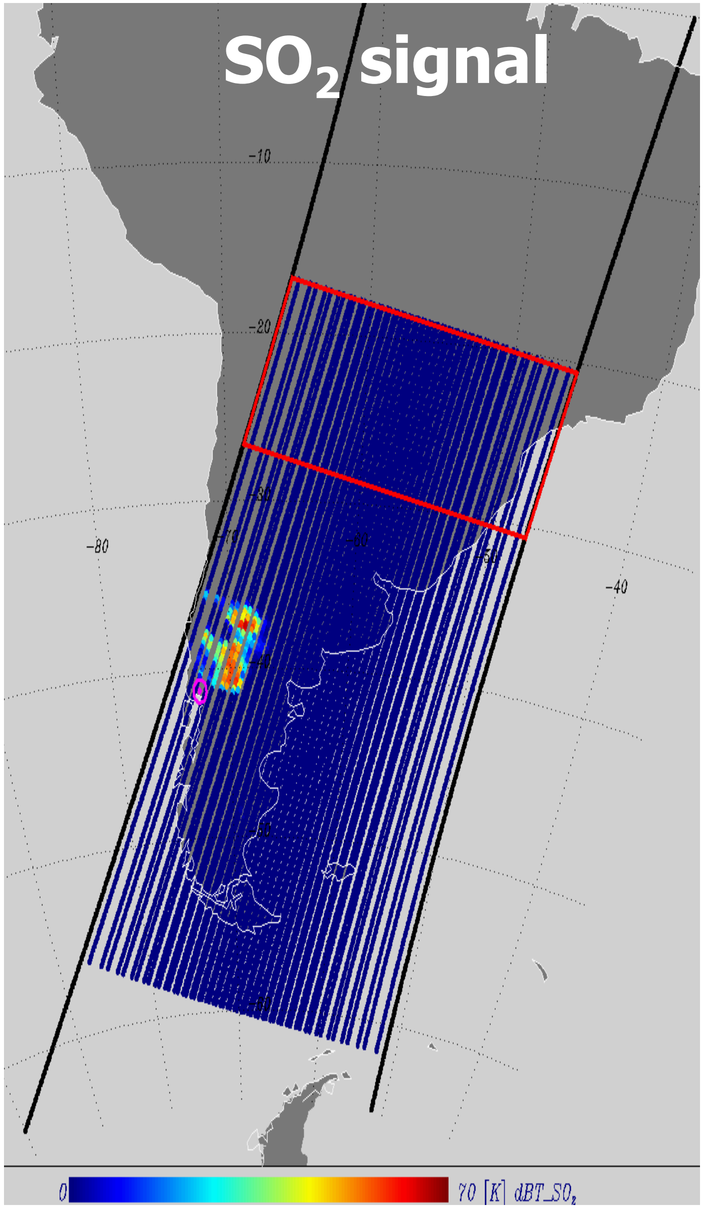


Effect of Hybrid PCs, 4 consecutive PDUs

Volcanic eruption, Calbuco (Chile), 23 April 2015







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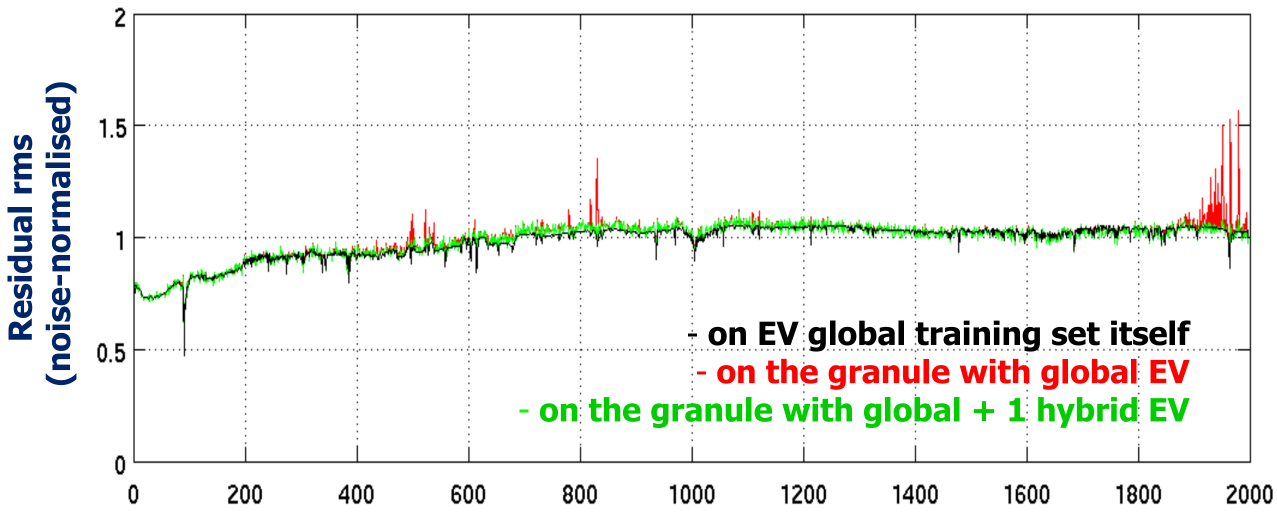
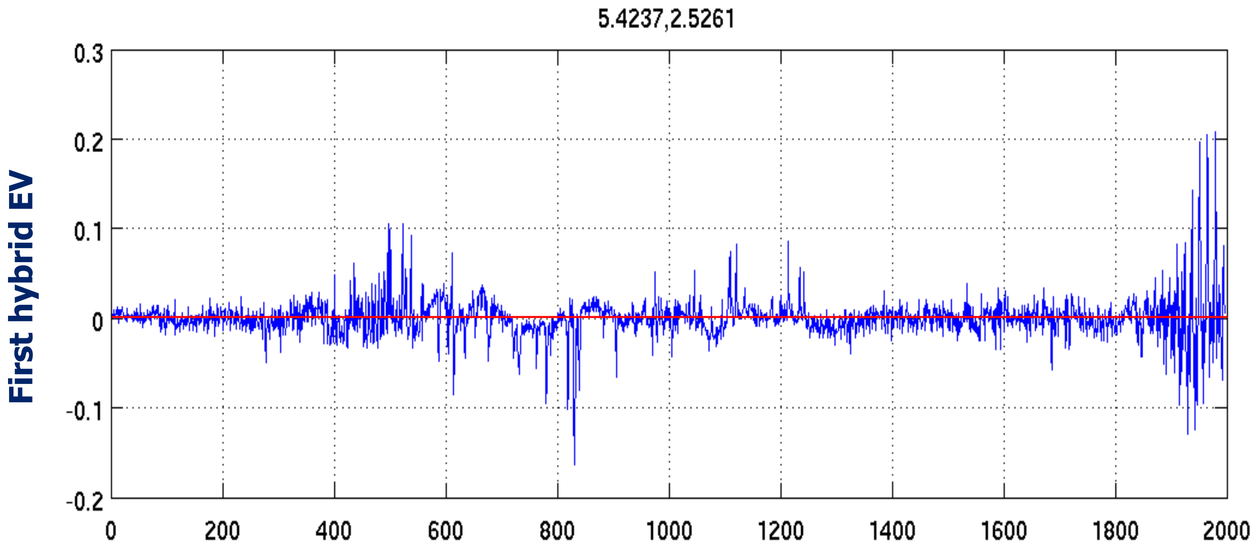
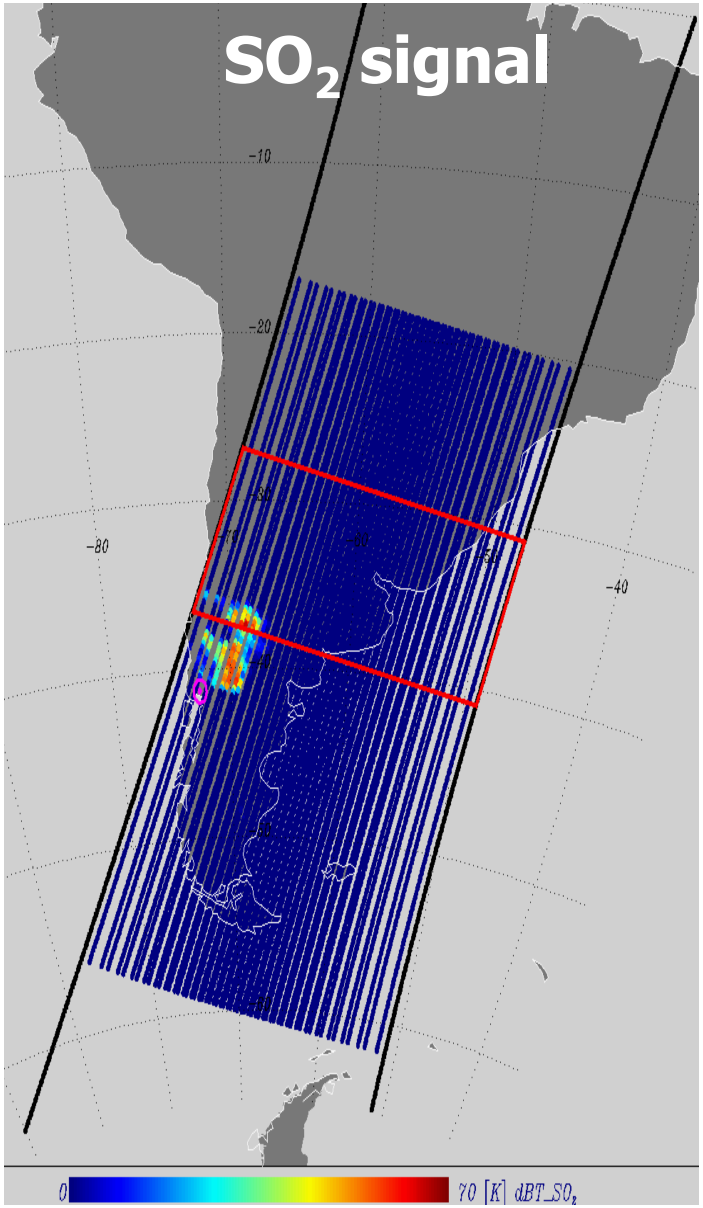
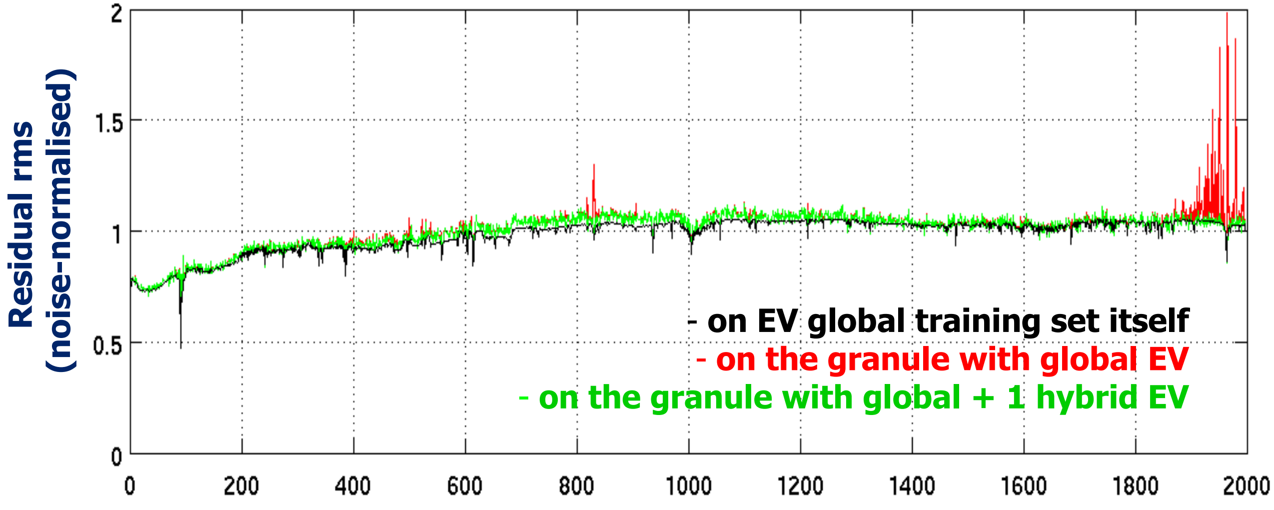


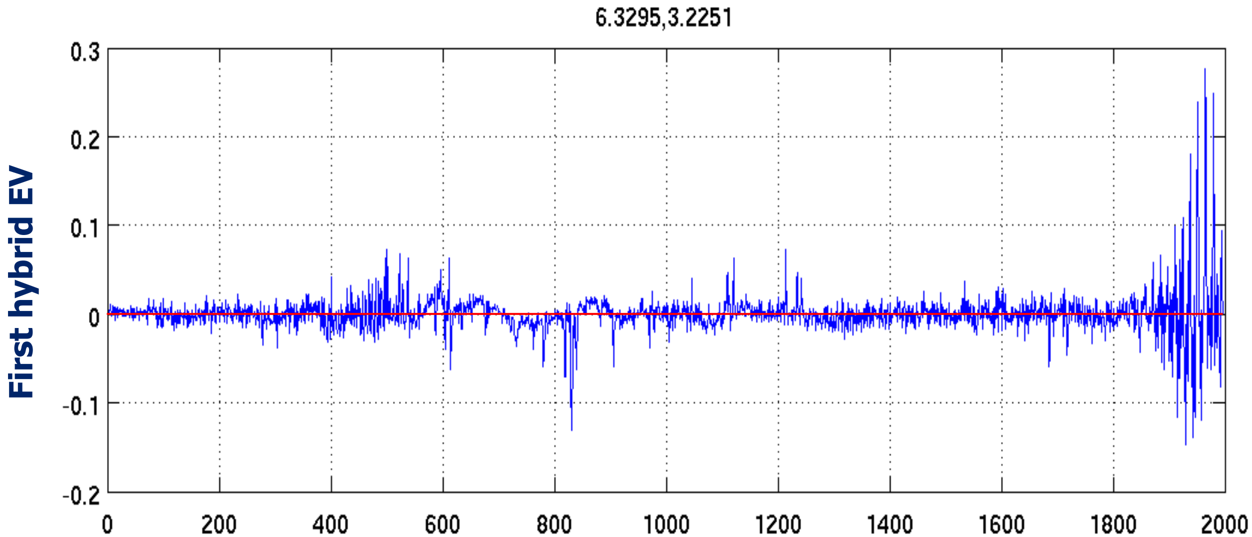


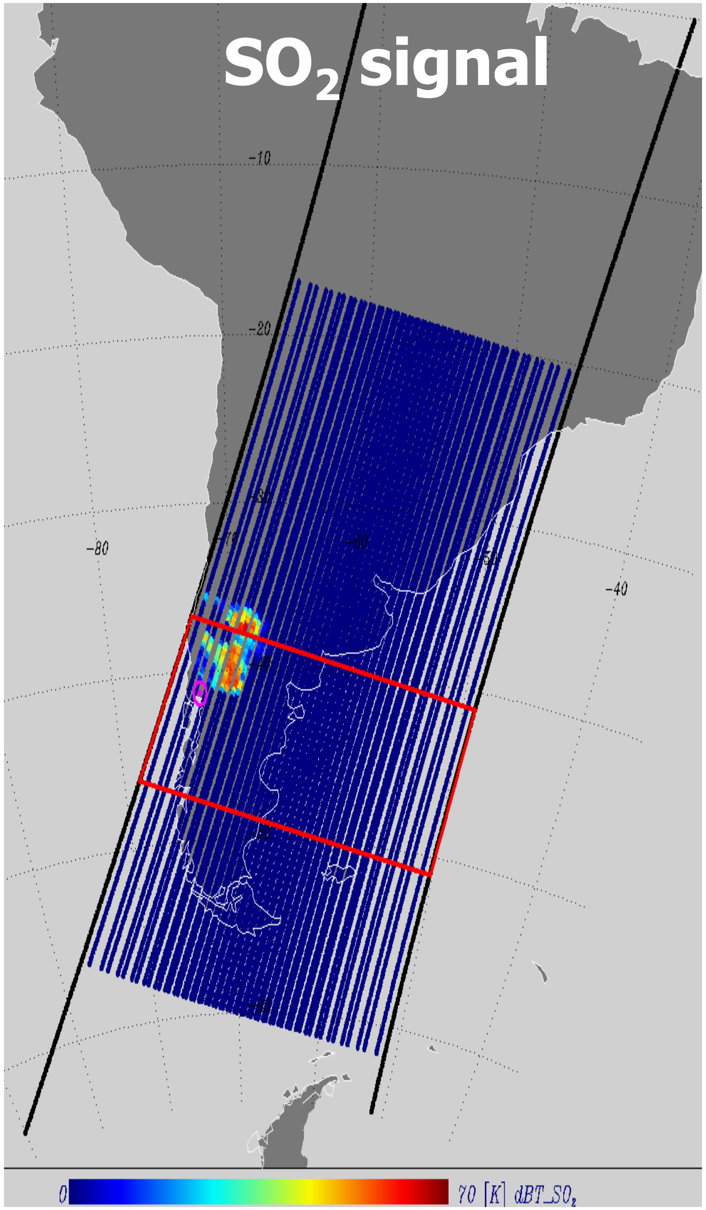


Effect of Hybrid PCs, 4 consecutive PDUs

Volcanic eruption, Calbuco (Chile), 23 April 2015

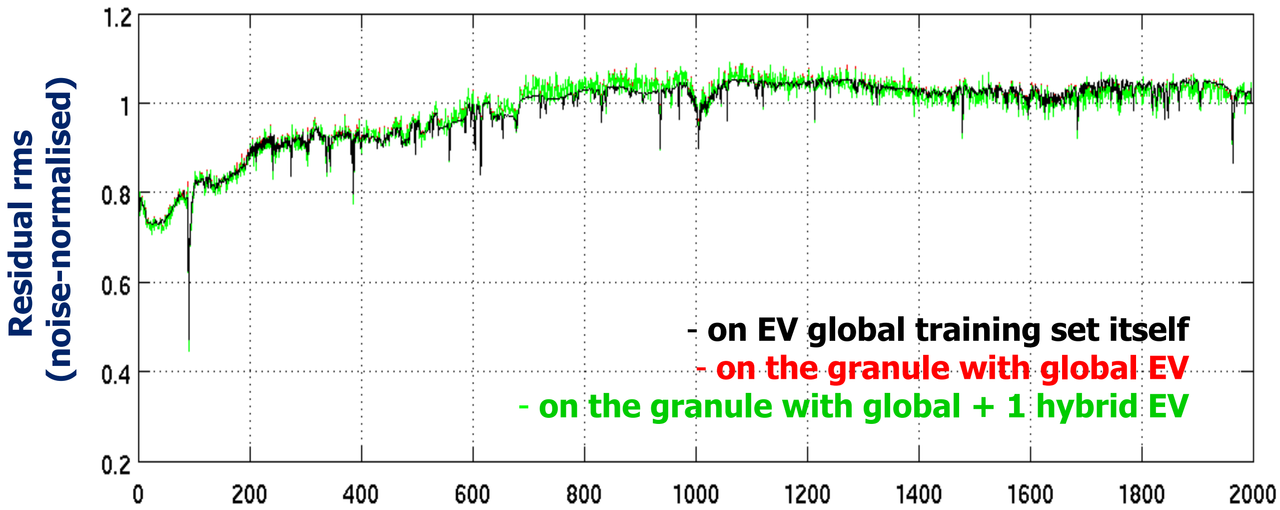


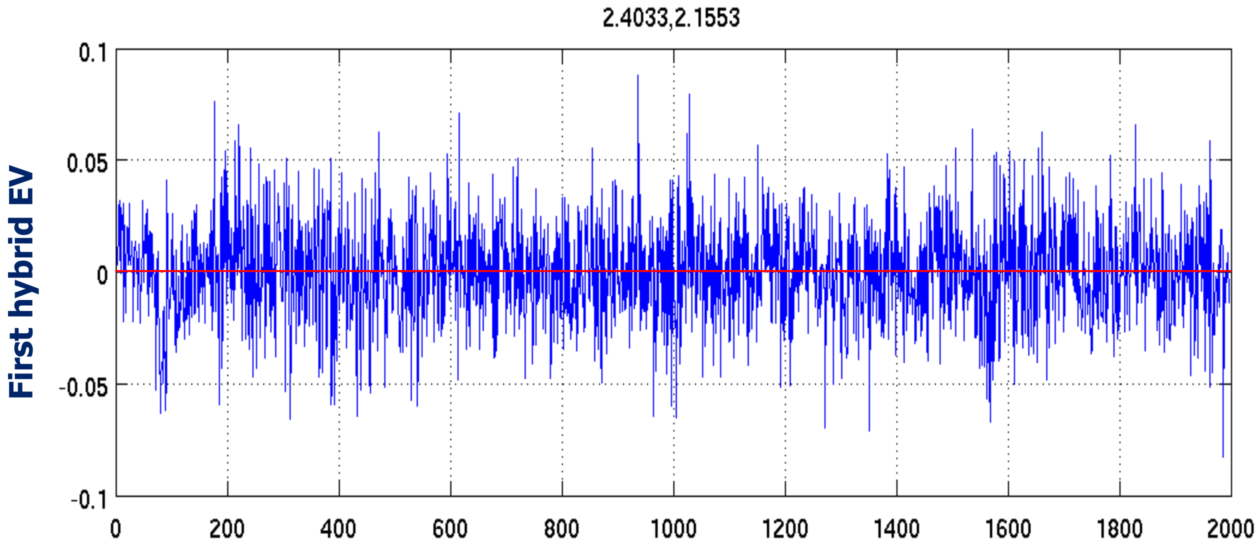


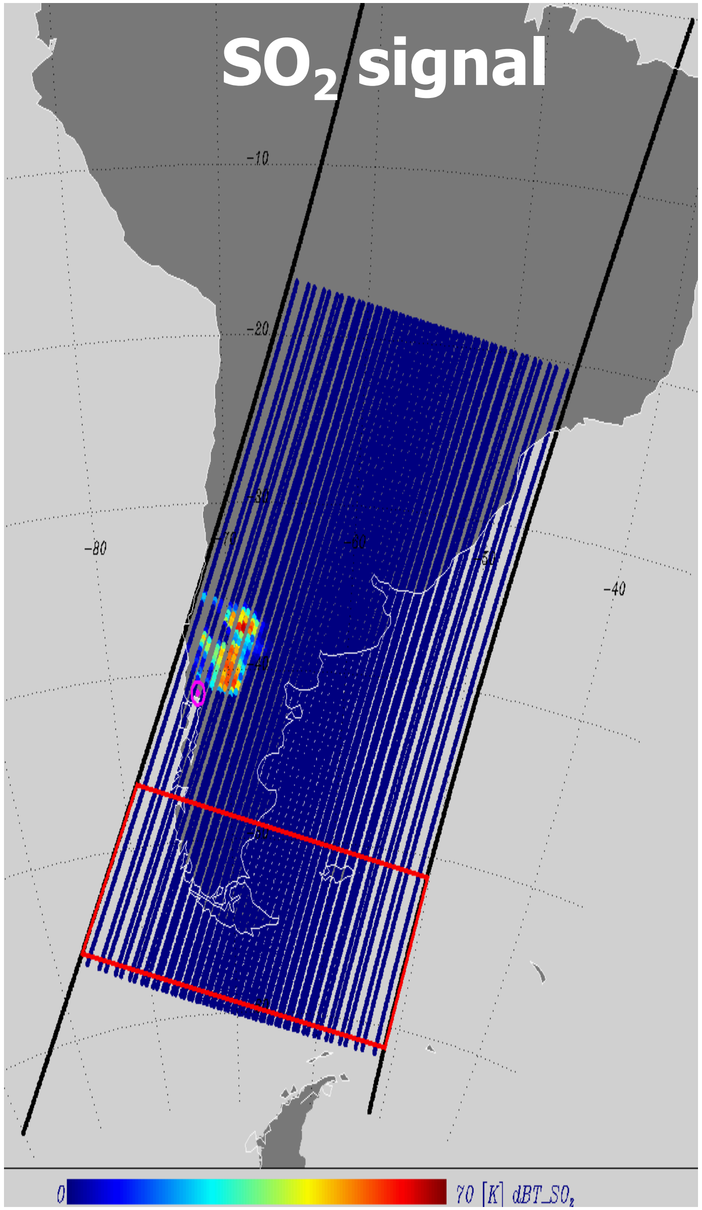


Effect of Hybrid PCs, 4 consecutive PDUs

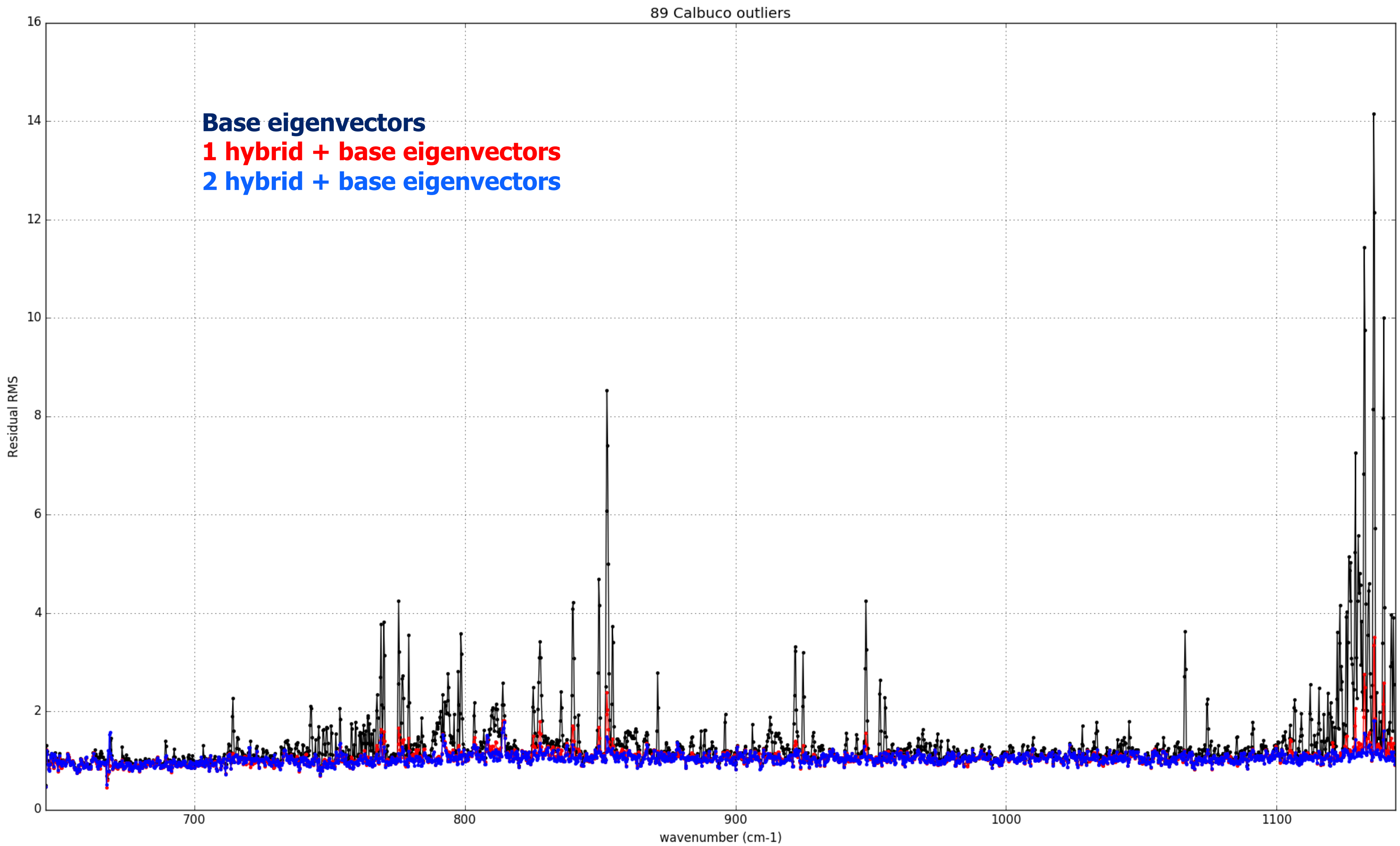
Volcanic eruption, Calbuco (Chile), 23 April 2015







Noise normalised residual RMS for 89 outliers

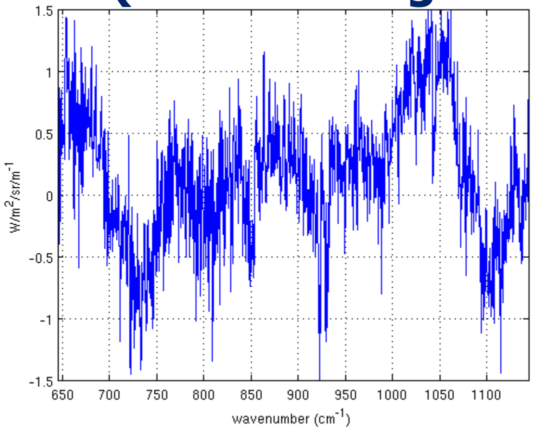


Summary

- Basics of PC compression
- Global eigenvectors for better compression
- Hybrid approach supplementing the global PC scores with a few local PC scores when needed to retain new signal
- (Maybe next time: Homogenisation by identification of similar directions among all detectors for partial (optional) removal of instrument artefacts)

Last slide / Questions? / The end!

Raw radiance (minus background)



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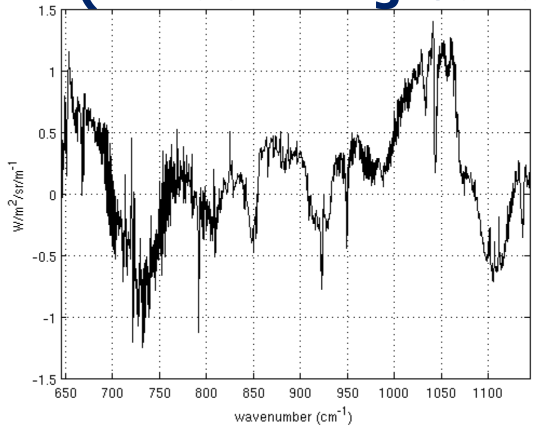
Reconstructed radiance (minus background)



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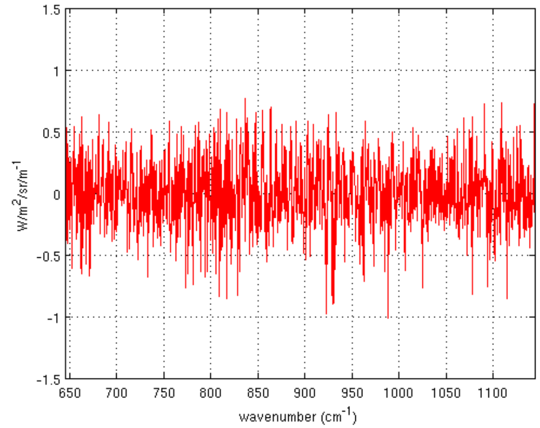
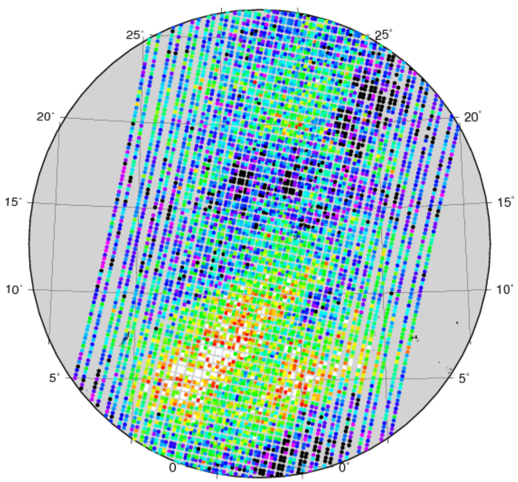
Residual



Raw radiance



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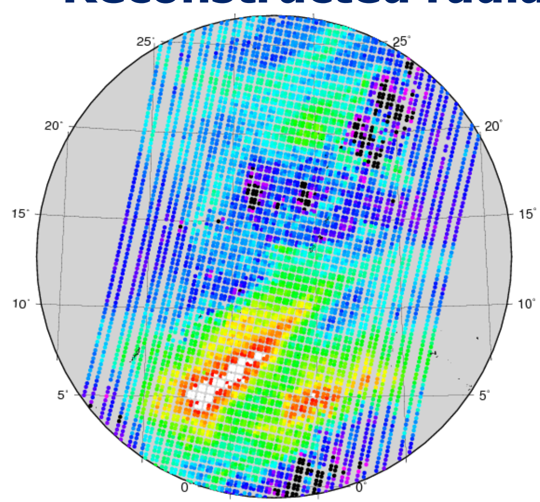
Reconstructed radiance



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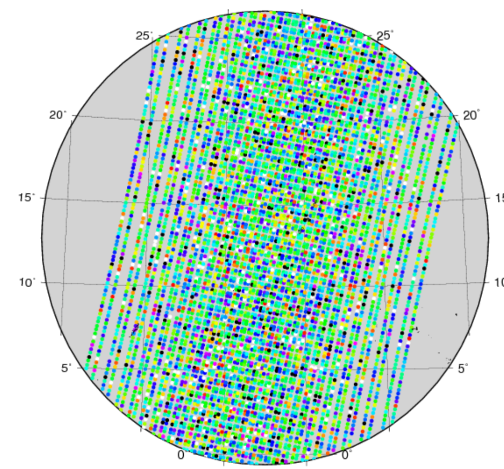
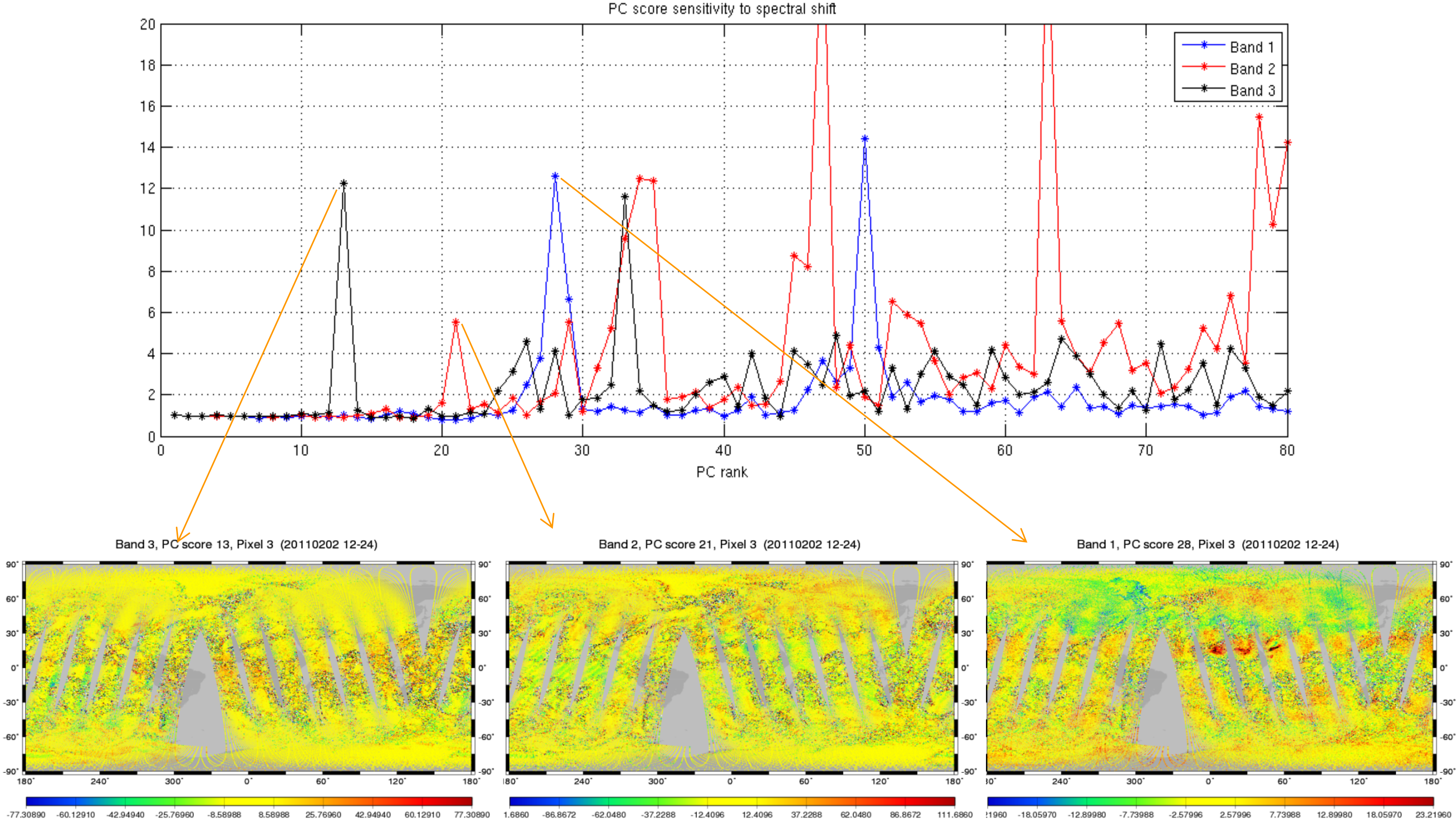
Residual



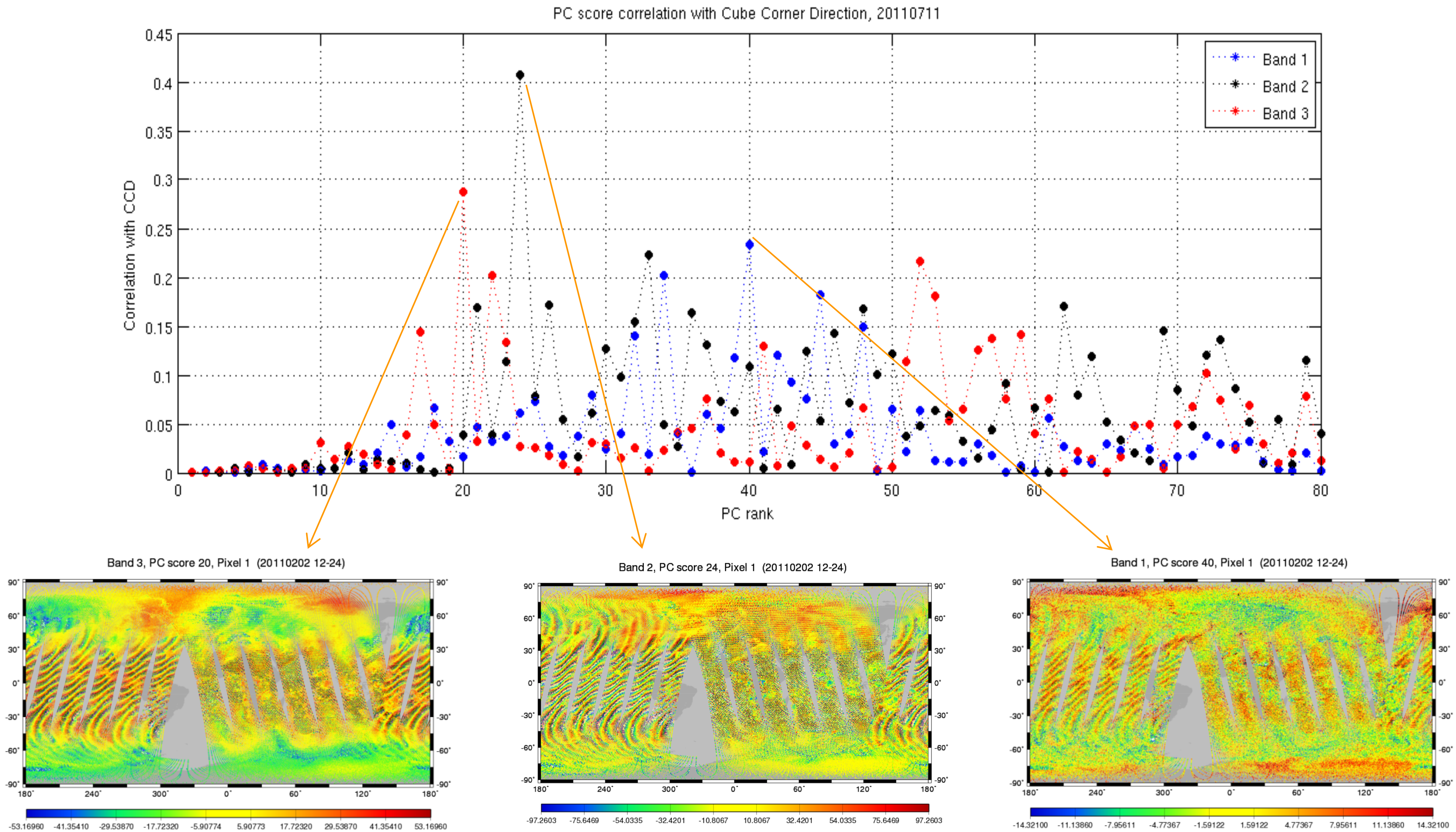
Spare slides – For next time

Non-uniform scene ILS effects

PC score sensitivity to spectral shift (measured by the variance of the PC score computed from spectrally shifted spectra divided by the original variance)



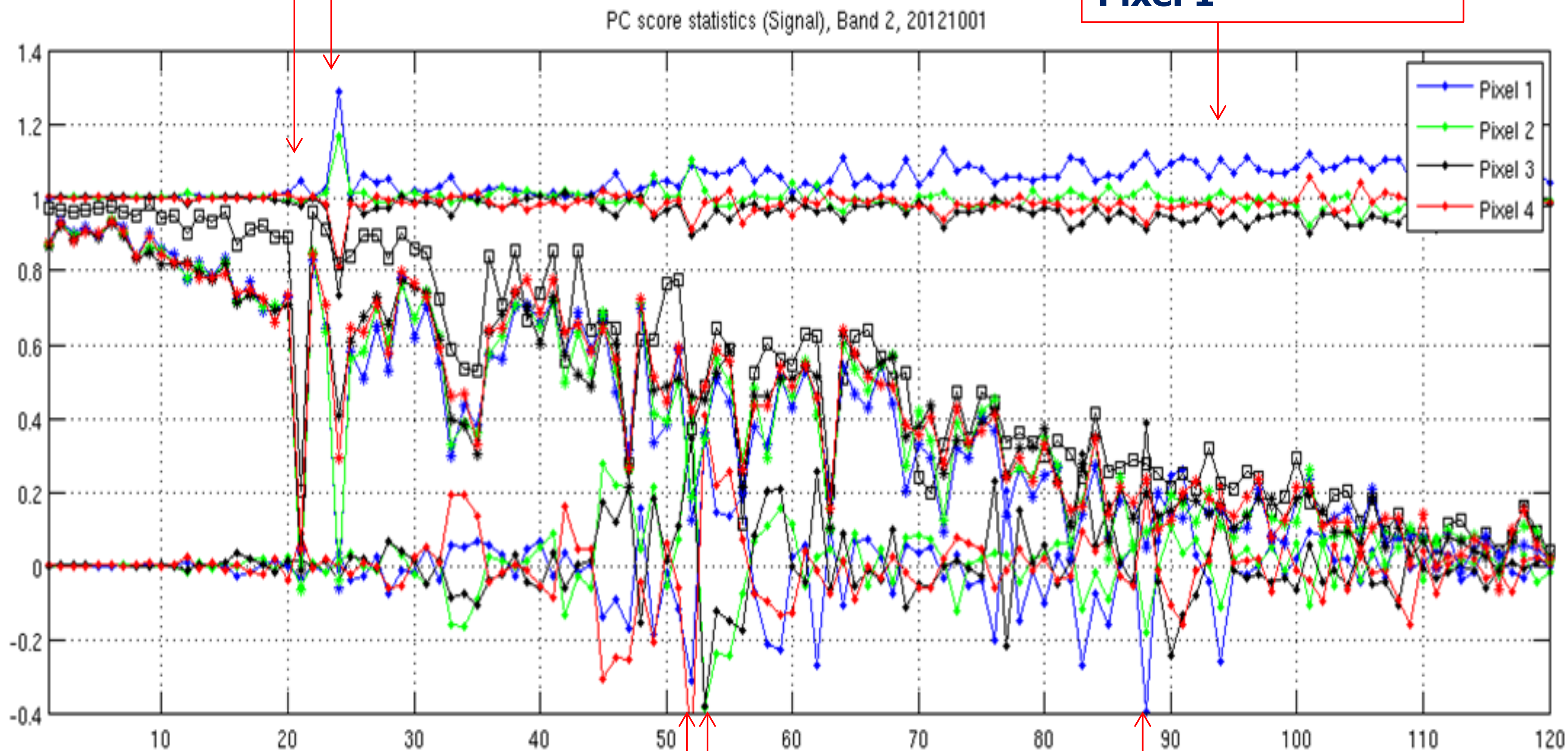
PC score correlation with IASI's cube corner direction



PC statistics highlight detector differences

Very low spatial correlation for score 21 and 24

Noise highest in Pixel 1



Several directions with very different means in the 4 pixels

Canonical angles between subspaces

Consider two subspaces determined by a truncated set of eigenvectors of the covariance matrices of different ensembles of radiances

$$E_S \in R^{m \times p} \qquad E_F \in R^{m \times p}$$

The intersection of the two subspaces is likely to be empty. But directions close to each other can be identified in the two subspaces.

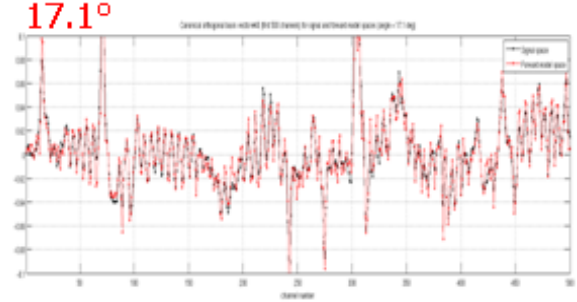
$$E_S{}^T E_F = USV^T$$

$$\widehat{E_S} = E_S U \qquad \widehat{E_F} = E_F V$$

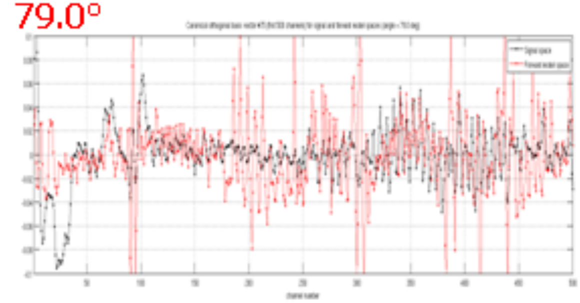
$\hat{E}_F$ and $\hat{E}_S$ are bi-orthogonal and the canonical angles between the two subspaces are given by arccos(S_{ii}) in ascending order

New bases for the two subspaces, in which similar directions are identified and ordered according to their degree of similarity

17.1°

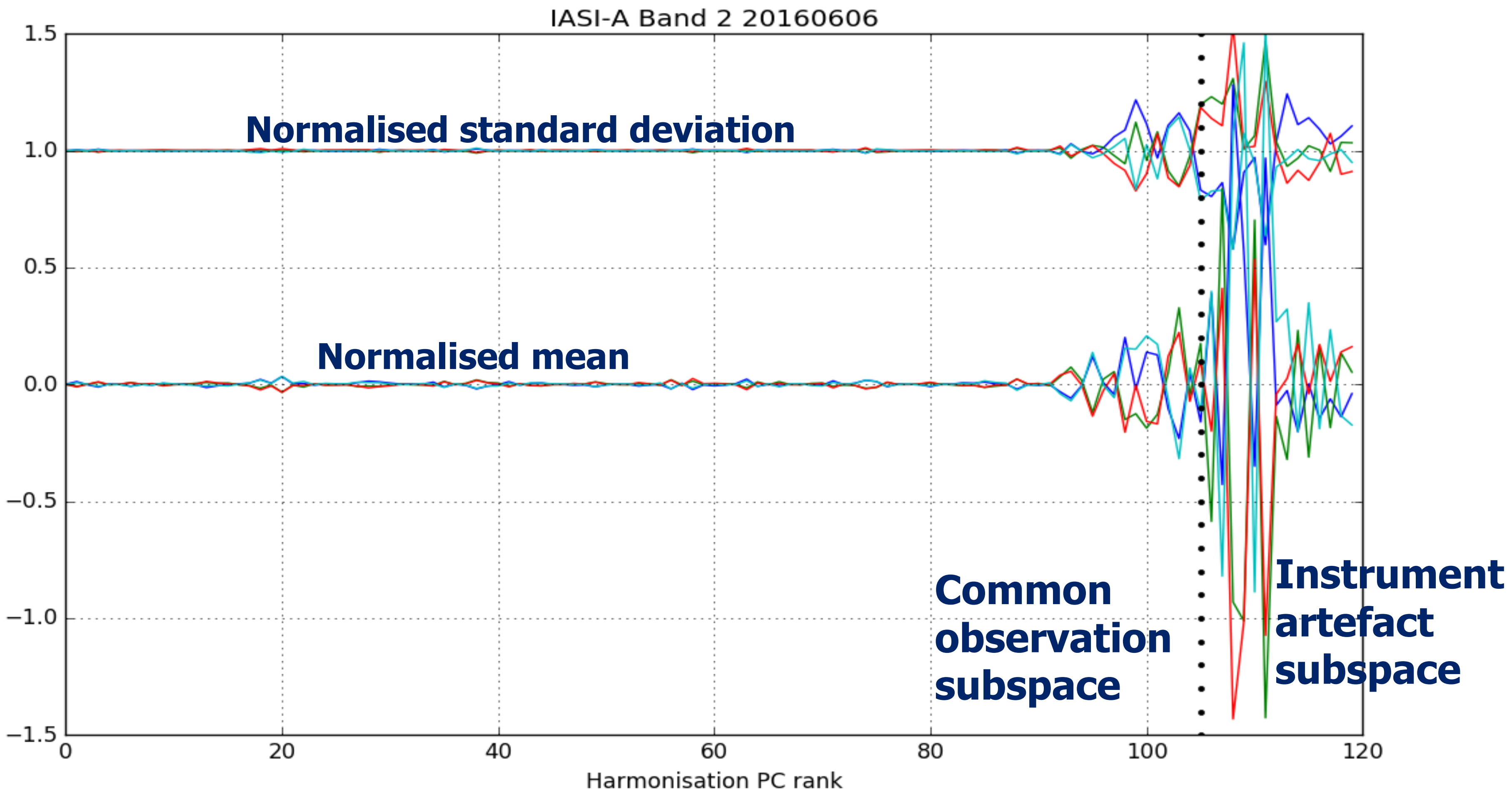


79.0°

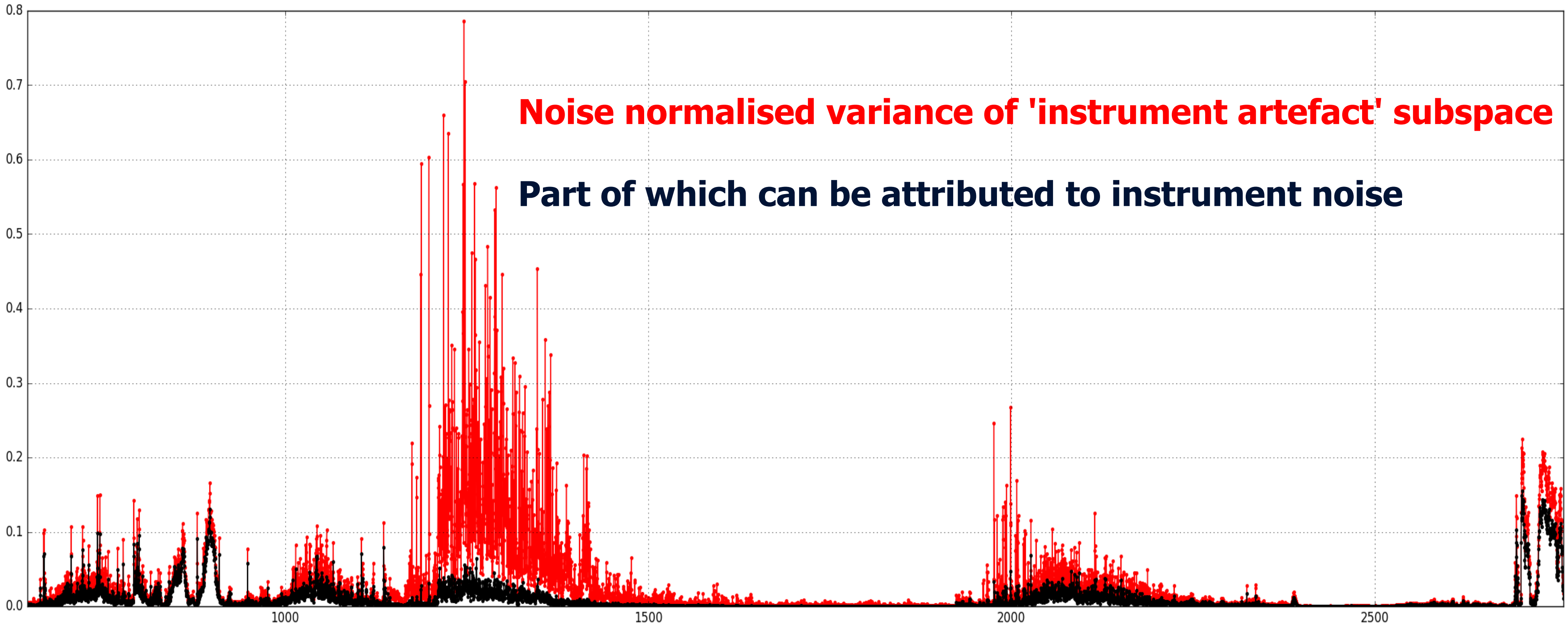


Homogenisation experiment with 16 (4 detectors times 2 satellites times 2 cube corner directions) *virtual* IASI detectors (in each band)

Detector differences of homogenisation basis scores



Homogenisation experiment with 16 (4 detectors times 2 satellites times 2 cube corner directions) *virtual* IASI detectors (in each band)



Common subspace has 60, 105 and 57 basis directions (in Band 1, 2 and 3) when using a threshold of 45 degrees for the canonical angles.

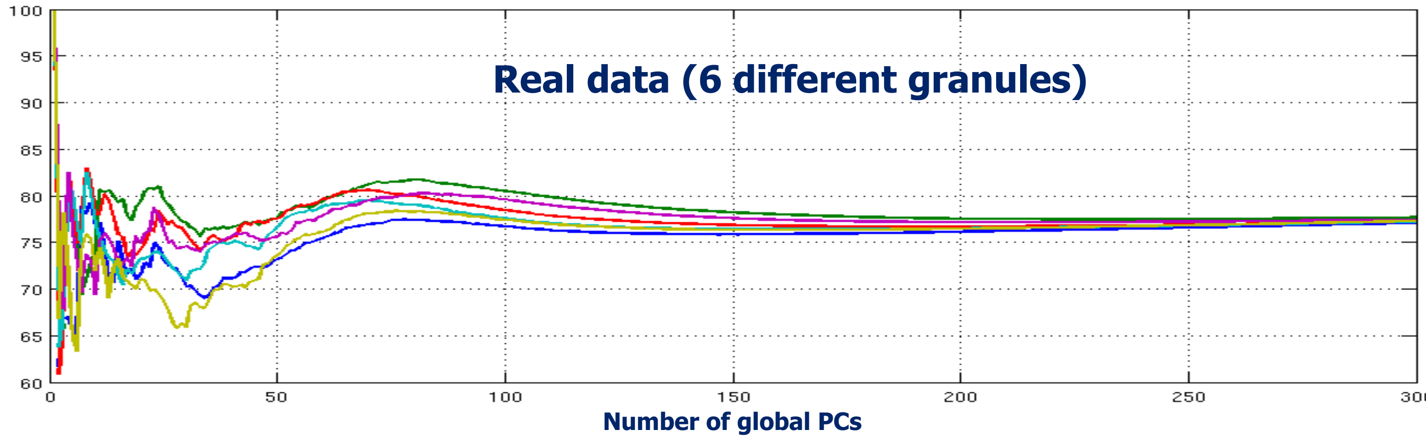
Spare Slides →

Noise or signal – what do we want to keep?

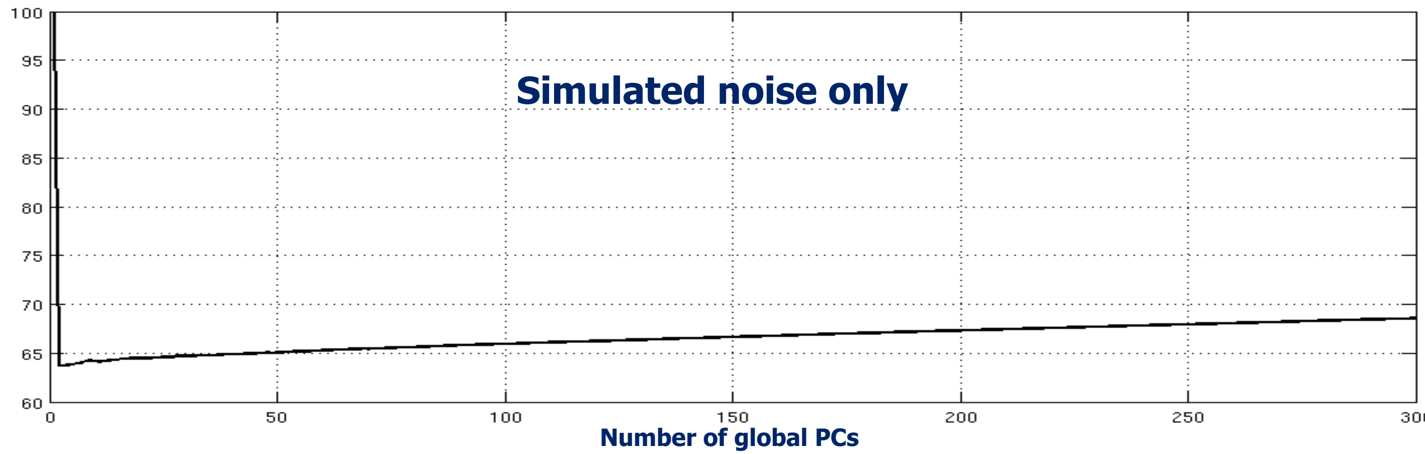
A naïve approach: select number of PCs based on residual RMS

Residual RMS: $\sqrt{\frac{1}{m}\sum_{i=1}^{m} r_i^2}$ **with** $r = N^{-\frac{1}{2}}(y - \tilde{y})$ **(the reconstruction residual)**

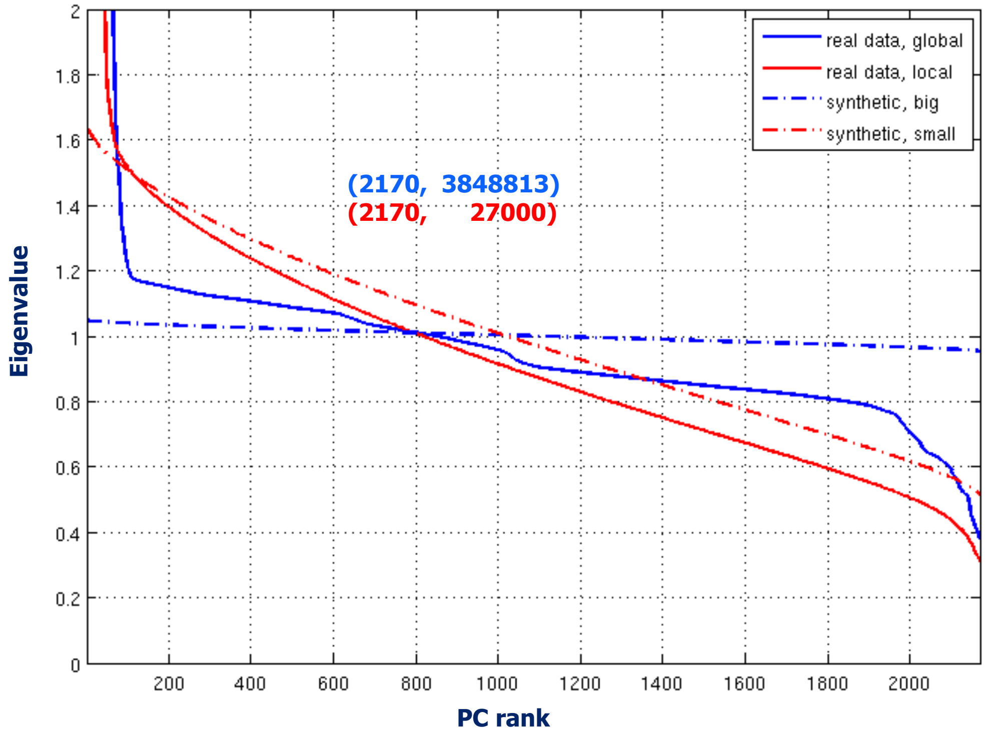
Percentage of PCs required to reach same residual RMS with local PCs as for global PCs



Percentage of PCs required to reach same residual RMS with local PCs as for global PCs



Eigenvalues with real and synthetic pure noise data

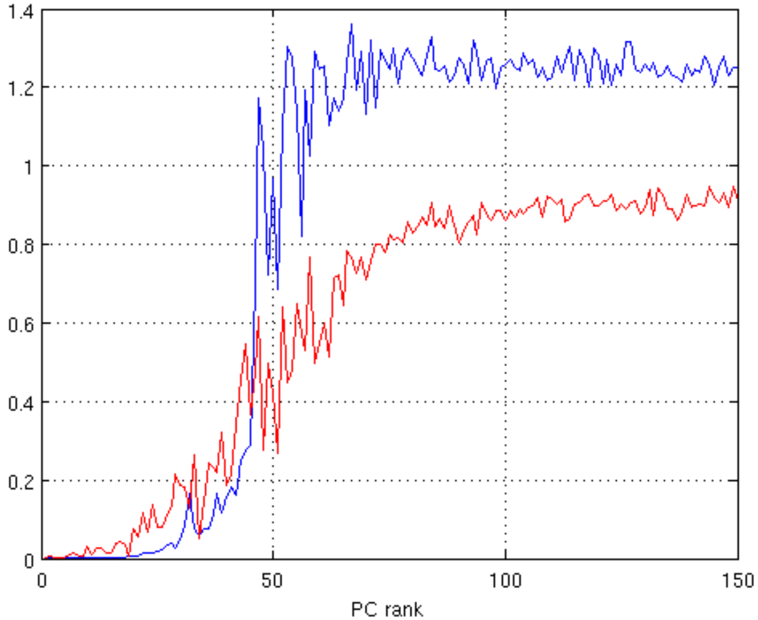


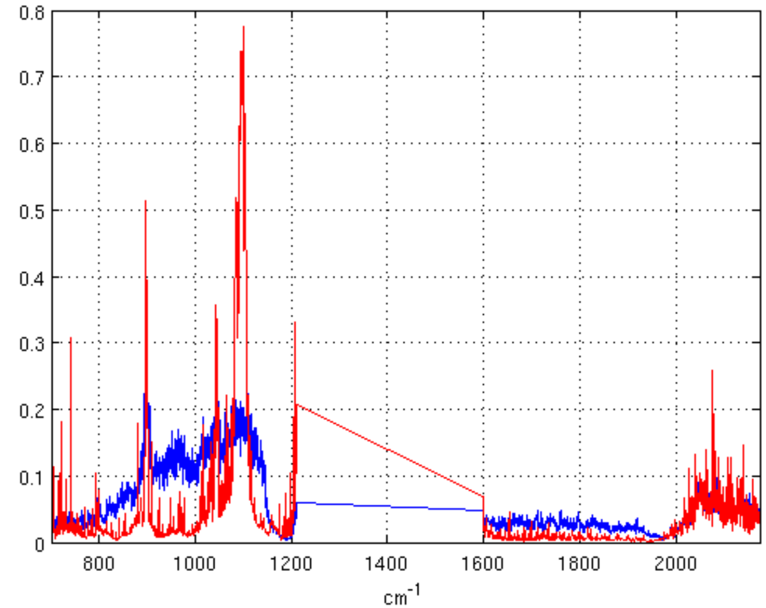
More noise in leading eigenvectors with smaller size of the training set

Equal number of PCs for local and global. Which retains most atmospheric signal?

$P_G(I-A_L)C_L(I-A_L)^T P_G^T$ Thrown away by local, retained by global $A_G(I-A_L)C_L(I-A_L)^T A_G^T$

$P_L(I-A_G)C_L(I-A_G)^T P_L^T$ Thrown away by global, retained by local $A_L(I-A_G)C_L(I-A_G)^T A_L^T$





Local PCs throw away more signal and keep more noise

How about local eigenvectors?

Naively one might think that computing eigenvectors for each individual granule (local in time and space) would result in the need of less PC scores and therefore a higher compression ratio. I will try to explain why this is not the case.

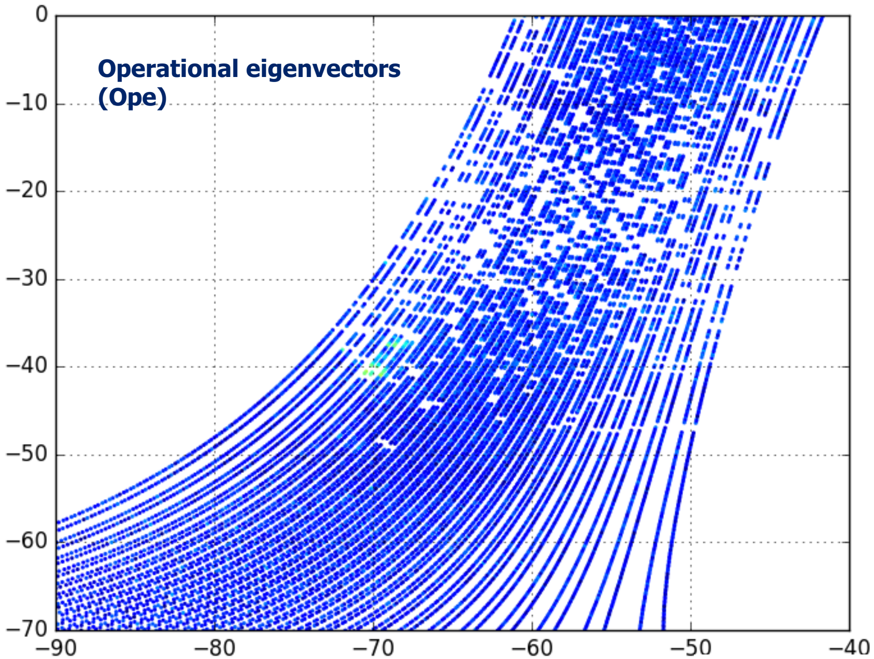
• Lets say there is a PC capturing SO2 signal. If there is no SO2 in the local granule, you do not need to disseminate the corresponding score. True, but for most of the PCs we have reduced variance within a local granule, not zero variance.

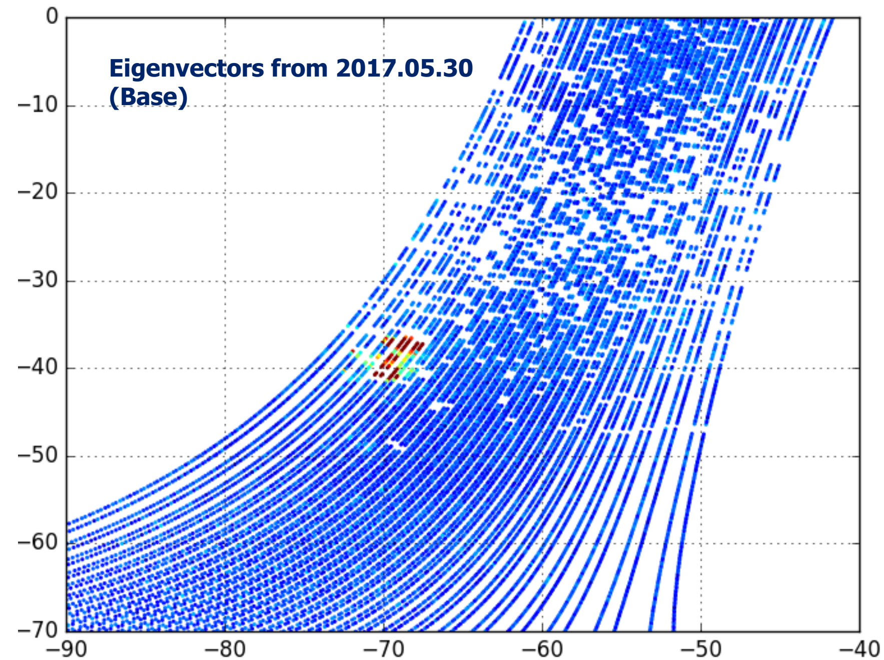
• The PCs are orthogonal directions. There is no way to join two PCs into a single one.

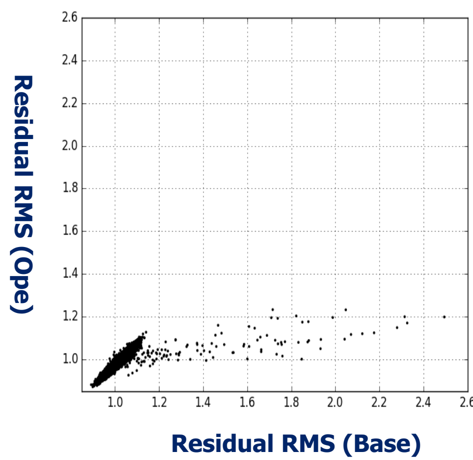
• The data volume of the (quantised) PC scores depends on their variability. Reduced local variability gives smaller PC score products also for global PCs. The number of PC scores alone does not determine the data volume to be disseminated.

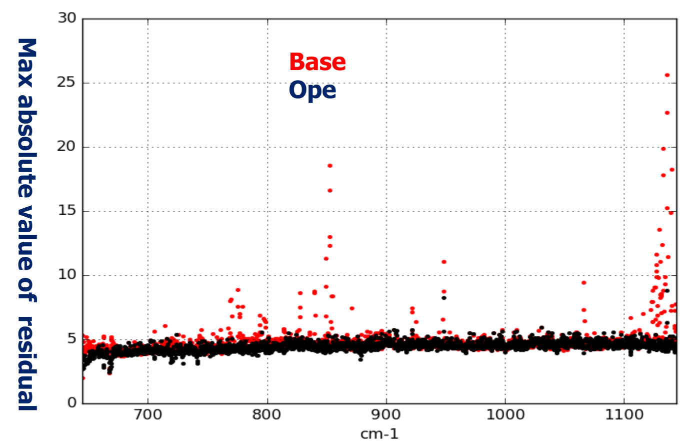
One orbit of IASI-B passing over Calbuco eruption

Reconstructed with two sets of eigenvectors









Noise normalised residual for a single outlier