Relative SRF retrieval - Application to Metop IASI (and MTG-I FCI)

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Agenda

Introduction to SRF

SRF retrieval

Solution

Applications

- Metop IASI
- MTG-I FCI

Discussion and Conclusion

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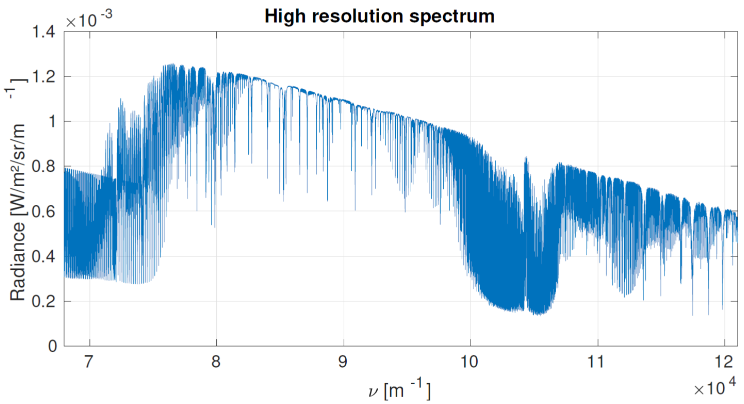
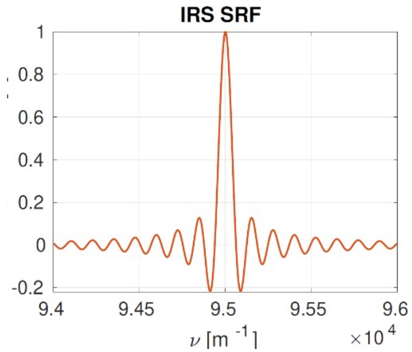
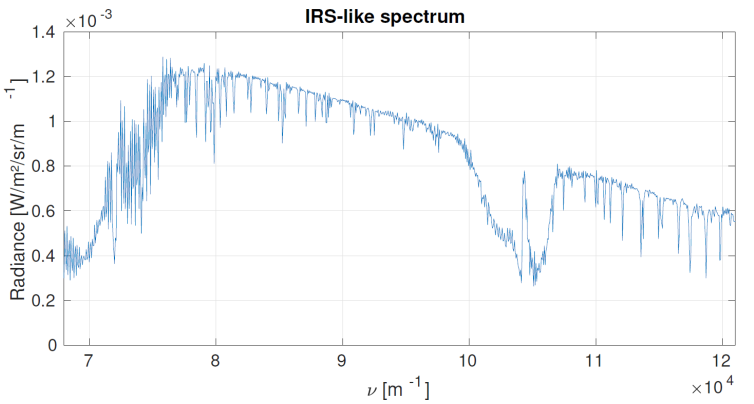
Introduction to Spectral Response Function







Each channel of a hyperspectral instrument record the continuous radiance exiting the top of the atmosphere integrated over the Spectral Response Function (SRF).

For an ideal Fourier Transform Spectrometer, this SRF only depends on:

- The maximum OPD
- The numerical apodisation applied during the L1 processing

But instrumental defects can alter the SRF such as self-apodisation/straylight*, calibration ringing**, spectral shift, ZPD, …

One of the goal of the L1 processing chain is to correct these defects so that every channel of each pixel has the same SRF

*Pierre Dussarrat, Guillaume Deschamps, Sahar Dehnavi, Bertrand Theodore, Dorothée Coppens, "Impact of straylight in Michelson Fourier transform spectrometers," Proc. SPIE 12777, International Conference on Space Optics — ICSO 2022, 127775A (12 July 2023); https://doi.org/10.1117/12.2690995

**Dussarrat P, Deschamps G, Coppens D. Mitigation of Calibration Ringing in the Context of the MTG-S IRS Instrument. *Remote Sens. 2023, 15(11), 2873; https://doi.org/10.3390/rs15112873*

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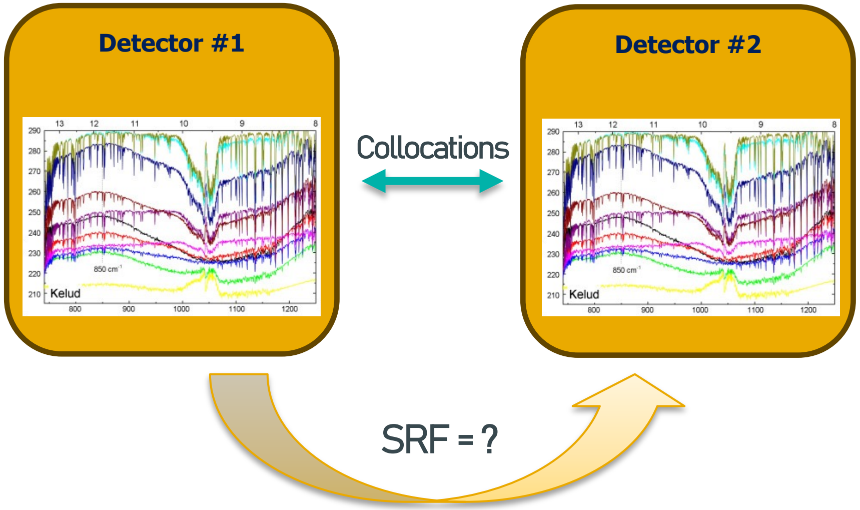
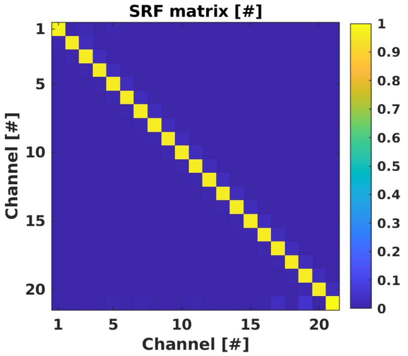
SRF Retrieval

- Hypothesis:
  - 2 similar hyperspectral detectors acquiring contiguous spectral channels
  - Dataset of collocated acquisitions of the 2 detectors over a large diversity of scenes



- Problem description (Linear algebra):
  - (y_1, y_2) = 2 sets of N_s acquisitions (spectra) with N_c channels $(N_s \gg N_c)$.
  - We look for a matrixial solution, $SRF \cong I$, of size (N_c, N_c) that best realizes:

$$\boxed{y_2 = SRF \times y_1}$$



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$$\boxed{y_2 = SRF \times y_1}$$

Many issues		Many solutions
Diversity of acquisitions is limited by the possible ranges of atmospheric and surface states = unstable retrieval	→	Perform sub-setting of the measurements to increase artificially the diversity = cutting each spectrum into many smaller versions
Large datasets	→	Make use of channel covariances $C_{i,j} = \langle y_i y_j^t \rangle$ (small size $N_c \times N_c$ and easy to compute iteratively)
Quality of colocations is limited (not perfect footprint overlapping, line of sight alignment, and time colocations)	→	Design a solution robust to colocation errors between the datasets (theoretical inclusion of the colocation errors into the formalism)
Radiometric noise	→	Design a solution assuming similar noise between the 2 detectors (the solution can also include the noise if characterized)

Solution

- Relative SRF retrieval equation: (*See Equivalent solution in Dussarrat et al., Remote Sensing 2024)

$$\boxed{SRF = (C_{21}C_{11}^{-1}C_{12}C_{22}^{-1})^{-1/2}C_{21}C_{11}^{-1}}^{*}$$

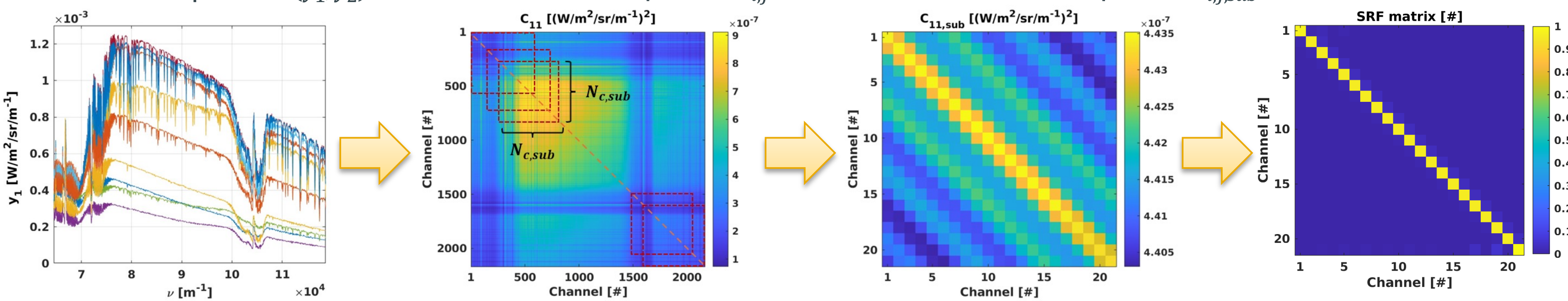
- Using only measurable covariances (and their inverses) computed over the collocated datasets

- Actually using "sub-set" covariances computed by extraction and average of square matrices along the covariances diagonals. We stabilize the retrieval by adding more scene diversity but only access a smaller version of the SRF of size ($N_{c,sub}$×$N_{c,sub}$), generally $N_{c,sub} \ll N_c$

→ SRF needs to be the same over the sub-set of channels

→ SRF extent has to be smaller than $N_{c,sub}$

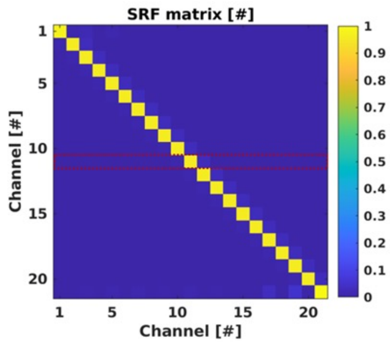
Collocated acquisitions: (y_1, y_2) | Covariances computation: $C_{i,j}$ | Sub-set covariances computation: $C_{i,j,sub}$ | SRF retrieval: SRF

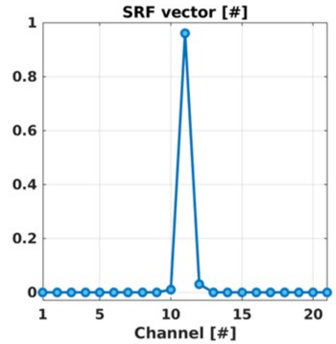


Dussarrat P, Deschamps G, Coppens D. Spectral Response Function Retrieval of Spaceborne Fourier Transform Spectrometers: Application to Metop-IASI. *Remote Sensing*. 2024; 16(23):4449. https://doi.org/10.3390/rs16234449
Dussarrat P, Deschamps G Relative Spectral Response Function Retrieval of Hyperspectral Instruments in Atmospheric Spectrometry arXiv:2504.19708

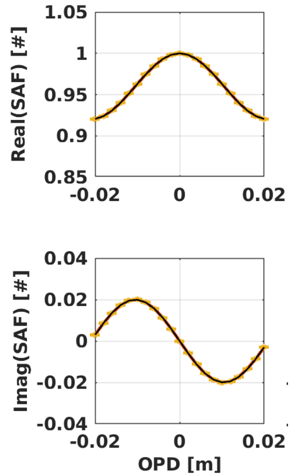
Solution

- From a SRF matrix to a SRF vector, extraction of the central row:





SAF retrieval:



- In Fourier transform spectrometry (FTS), the relative SRF vector can be further processed (Fourier transform) to provide a relative self-apodisation function (SAF):

$$\boxed{SAF(opd) = FT[SRF(\nu)](opd)}$$

- **NB**: The SAF is a complex function, commonly used in FTS, informing visually about detrimental effects occurring at the level of the primary measurements that are the interferograms.

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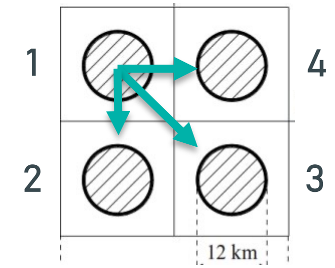
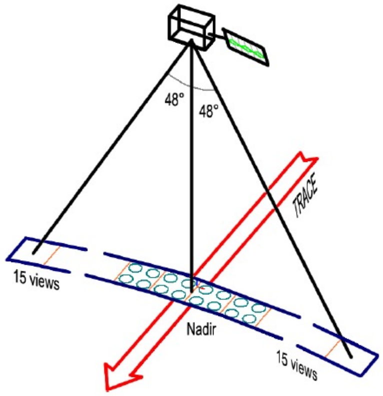
Application to IASI

- Inter-pixel relative SRF characterization of Metop IASI
- All 4 FOV of IASI are always approximately collocated, as the solution is proved robust to colocation errors, one can perform an accurate SRF retrieval.



- We retrieve a relative SRF for every pairs of FOV (SRF_{ij}) and combine them to retrieve one relative SRF per FOV with respect to the others $(SRF_{\#i})$, as follows:

$$SRF_{ij} = \left(C_{ij}C_{jj}^{-1}C_{ji}C_{ii}^{-1}\right)^{-1/2}C_{ij}C_{jj}^{-1} \quad ; \quad SRF_{\#i} = \frac{1}{N_{FOV}}\sum_{j} SRF_{ij}$$



- Computation for 6 sub-bands independently to probe chromatic effects
- Parametrization:
  - Number of acquisitions: $N_s = 60'000$ (one single orbit !)
  - Number of channels: $N_c = 1085$ (per sub-band)
  - Number of sub-set channels: $N_{c,sub} = 23$ (heavy sub-setting)

Application to IASI

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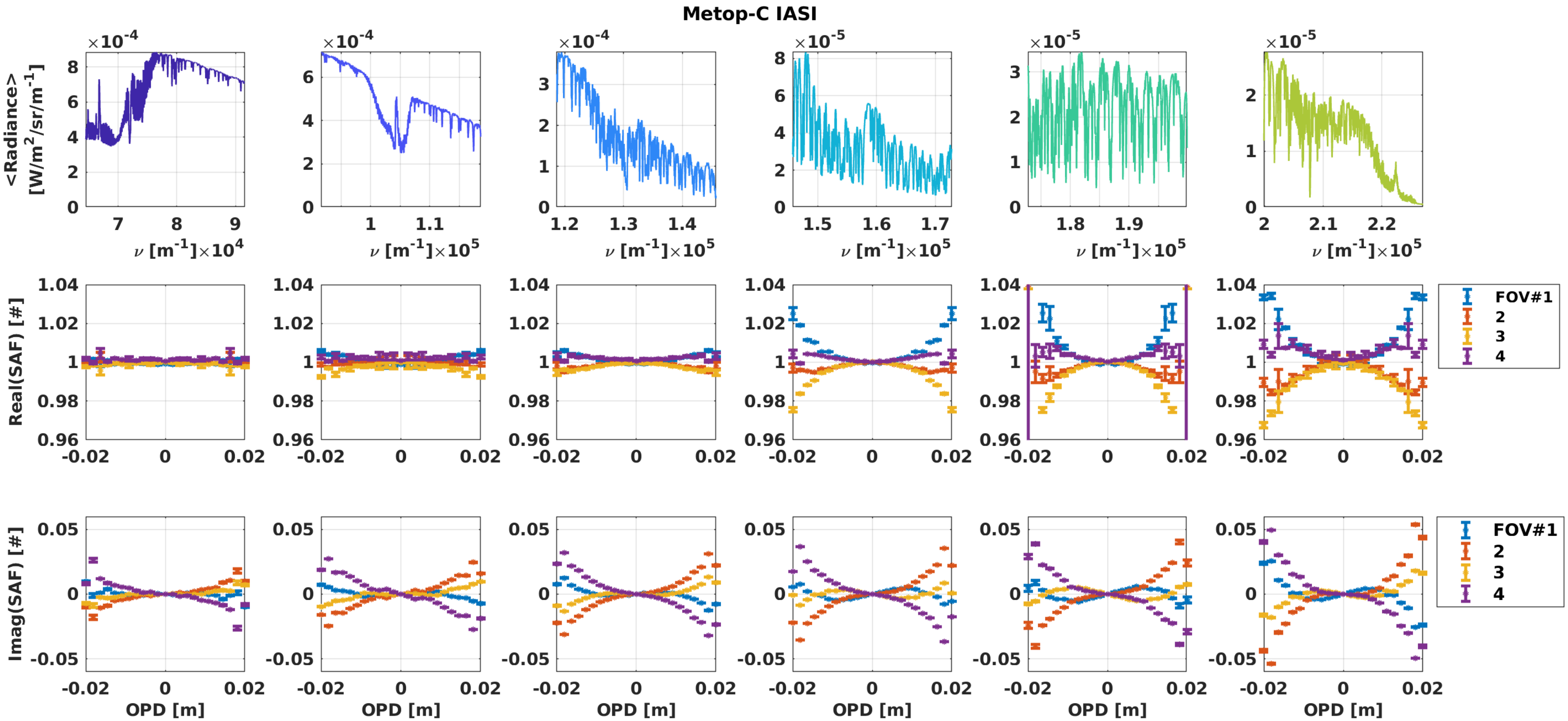
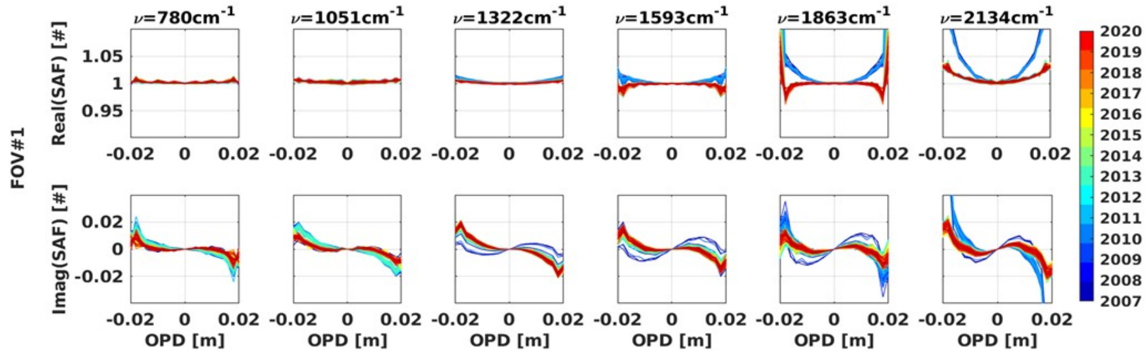
- First characterization of IASI relative SRF and SAF – for 6 sub-bands
- Accurate characterisation with only one orbit of data
- Revealing vey small discrepancies between FOV (mis-alignment residual, straylight ?)
  ~0.01K level but nonetheless quantifiable (to be used to harmonize further the IASI data ?)

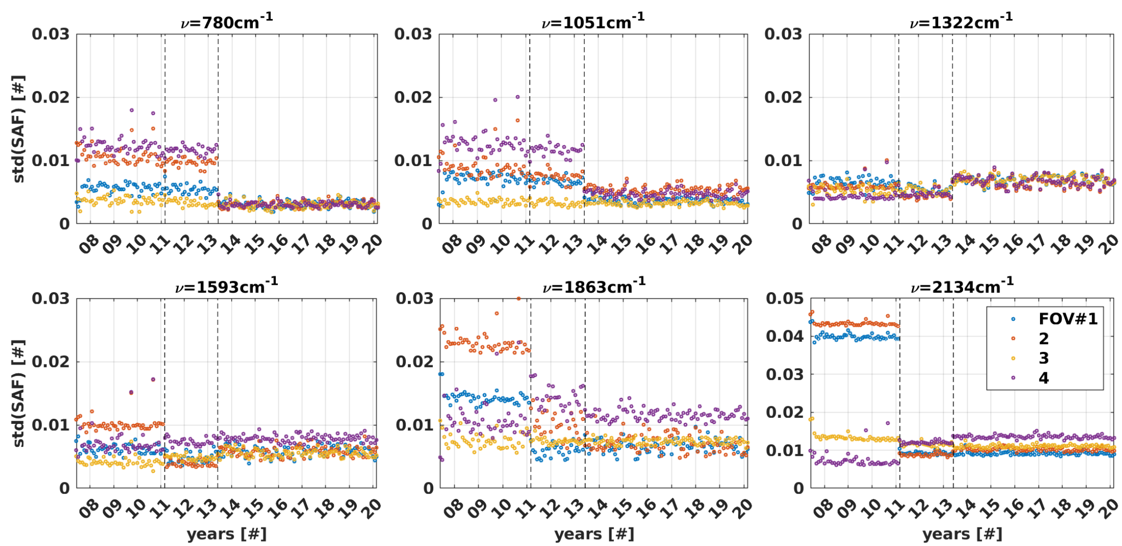


Application to IASI

- Application to Metop-A, 13 years of operation, from 2007 to 2020.
- Processing of the first orbit every months.
- Detection of two sudden changes in February 2011 and June 2013, linked to on-ground processing updates aiming at improving discrepancies between FOV.
- No long-term evolutions detected.
- Our methodology is extremely sensitive and therefore well-suited to monitor instrument and processing status.



SAF standard deviation:



Application to MTG-I FCI

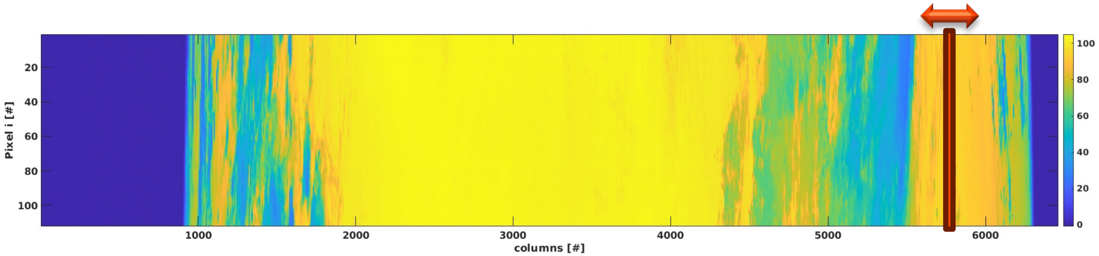
- Application to gain equalization of imagers as the MTG-I1 FCI infrared-channels (COM anomaly = no access to BB and therefore no individual calibration of all the FOV)

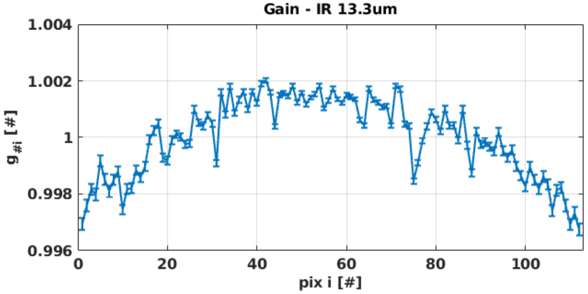
- Simplification of the SRF retrieval equation to mono-channel detectors (FCI channels considered independently)

- Computation of "relative gain" g_{ij} for all pairs of pixels of the FCI detectors using a day of normal acquisitions and then combined into a "corrective" gain per pixel $g_{\#i}$:

$$\boxed{g_{ij} = \sqrt{\langle y_i^2 \rangle / \langle y_j^2 \rangle} \quad \rightarrow \quad g_{\#i} = \frac{1}{N_{fov}} \sum_j g_{ij}}$$

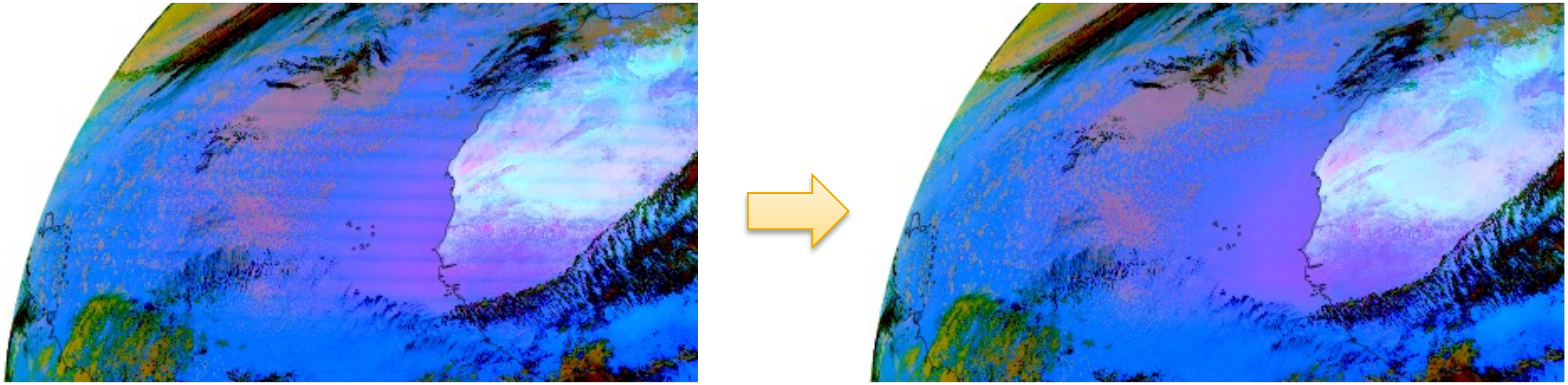
- Very simple solution, yet proved to be accurate as robust to colocation errors
- Example: MTG-I FCI 13.3μm channel – 1 full swath





Application to MTG-I FCI

- Gain equalization of the MTGI1 FCI infrared channels
- Example on dust RGB → Efficient removal of striping / calibration artefacts (see pink areas)
- Correction operational since early March 2025



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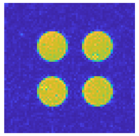
Conclusion

- We have derived a novel solution to compute relative SRF between similar hyperspectral detectors by analysis of colocations

- As the solution has been designed to be robust to colocation errors, we can apply the methodology to different detectors within the same instrument or between different platforms even if they never probe the exact same locations.

- Application to Metop-IASI → see Dussarrat et al. Remote Sensing. 2024, revealing extremely small discrepancies between FOV
- Application to the infrared channels of MTG-I FCI (mono-channel) to derive relative gain corrections (de-striping / calibration artefact removal)
- Other applications: grating spectrometers, straylight retrieval (application to spatial instead of spectral samples)



- This opens the way of:
  - New monitoring: Track in-flight relative discrepancies of responses between detectors
  - Post-processing: Harmonize the responses of different detectors using the relative SRF

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Thank you!

Questions are welcome.