Role of correlated uncertainties in vicarious calibration reference harmonisation

GSICS Annual Meeting 2022

Yves Govaerts and Nicolas Misk

Rayference

VISNIR breakout session, 17 March 2022

Background (1)

FIDUCEO project

Harmonised[1] satellite series is one where all the calibrations of the sensors have been done *consistently* relative to **reference datasets** which can be traced back to known reference sources, in an ideal case back to SI.

How to build **reference datasets** for satellite series harmonisation?

(1) Unlike harmonisation, homogenisation is where all satellites are forced to look the same such that when looking at the same location at the same time they would (in theory) give the same signal

Background (2)

1900 IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 42, NO. 9, SEPTEMBER 2004

Operational Calibration of the Meteosat Radiometer VIS Band

Yves M. Govaerts, Marco Clerici, and Nicolas Clerbaux

***Abstract*—An advanced operational algorithm has been developed for the routine calibration of the Meteosat radiometer solar channel. The calibration method relies on calculated radiances over bright desert sites whereas ocean targets are used for consistency checks. Calibration errors are estimated accounting for the uncertainties of both the sensor spectral response characterization and target property description. This algorithm has been used to systematically calibrate Meteosat-5 and -7 observations. Results show that it is possible to calibrate the visible band with an estimated accuracy of about 6% when the sensor response characterization is reliable and to monitor the sensor long-term drift. These results are confirmed by Clouds and the Earth's Radiant Energy System observations.**

***Index Terms*—Calibration, Meteosat.**

I. Introduction

THE METEOSAT satellite system was designed nearly 30 years ago, essentially for operational imagery purposes. The primary objective of this program is the acquisition of earth atmosphere images and their near real-time dissemination to the meteorological user's community. Nevertheless, the potential value of the Meteosat Visible and Infrared Imager (MVIRI) data for climate monitoring should not be underestimated. During the late 1970s and early 1980s, spaceborne observations of the and 3) radiative transfer modeling (e.g., [6]–[8]). These latter studies showed that calculated radiances can be used to derive absolute calibration coefficients on a regular basis with an accuracy comparable to the one derived from airborne campaigns, but also to monitor the sensor long-term drift. So far, none of these methods has been used on an operational basis, although this has been proven to be feasible for the thermal channels [9], [10]. This situation has limited the quantitative exploitation of the VIS band observations and constrained users to develop their own calibration method prior to the derivation of any geophysical parameters (e.g., [7] and [11]). The complexity of consistent calibration coefficient estimation for the seven MVIRI instruments should not be underestimated. One of the major challenging problem concerns the lack of reliable characterization of the VIS band spectral response prior to that on the Meteosat-7 instrument [12], so that postlaunch corrections might be required as is the case for the Advanced Very High Resolution Radiometer instrument onboard the National Oceanic and Atmospheric Administration polar platform [13]. As demonstrated by [14], two spectrally different calibration targets could be used to verify the reliability of the MVIRI VIS band spectral response characterization and to evaluate whether postlaunch adjustments should be envisaged.

SEVIRI **S**olar **C**hannel **C**alibration (SSCC)

The calibration reference relies on simulated radiance over 18 bright desert targets over a 5-day period (plus open ocean for verification).

How to estimate the uncertainty of the calibration reference?

SSCC uncertainty propagation

- 18 bright desert targets (sea as verification)
- 5-day accumulation period
- 4 spectral bands (0.6, 0.8, 1.6, HRVIS)
- Uncertainty propagation (from the state variables to simulated calibration reference) is based on:
  - Separation of random and systematic uncertainties
  - Uncertainties of state variables are assumed uncorrelated;

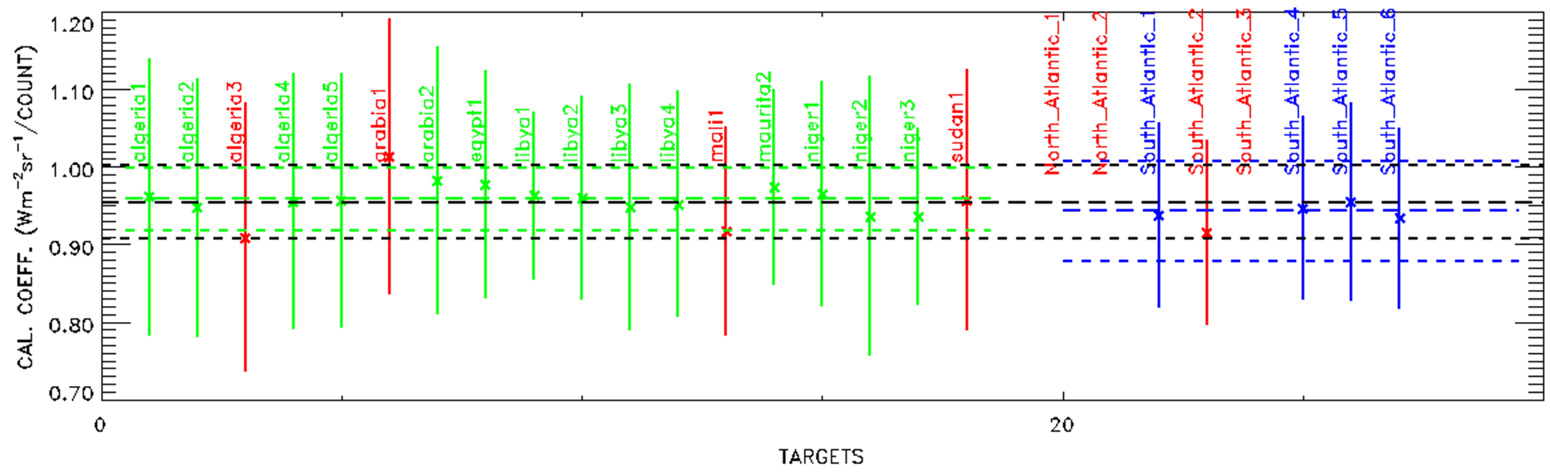
Background (3)

Simple recipe for uncertainty propgaration

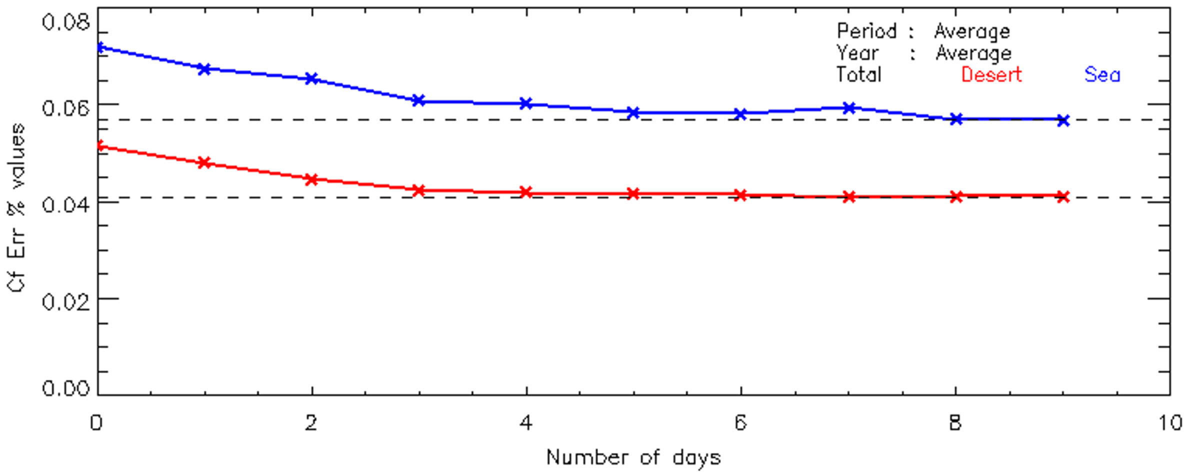
1. Atmospheric parameters are not correlated in time;
2. Surface parameters are not correlated in space;
3. No spectral correlation is accounted for (e.g., aerosol optical thickness or surface anisotropy).

$$\delta R(\lambda) = \sqrt{\sum_{p=1}^{P} \left(\frac{\partial R(\lambda)}{\partial \chi_p} \right)^2 \epsilon_p^2}$$

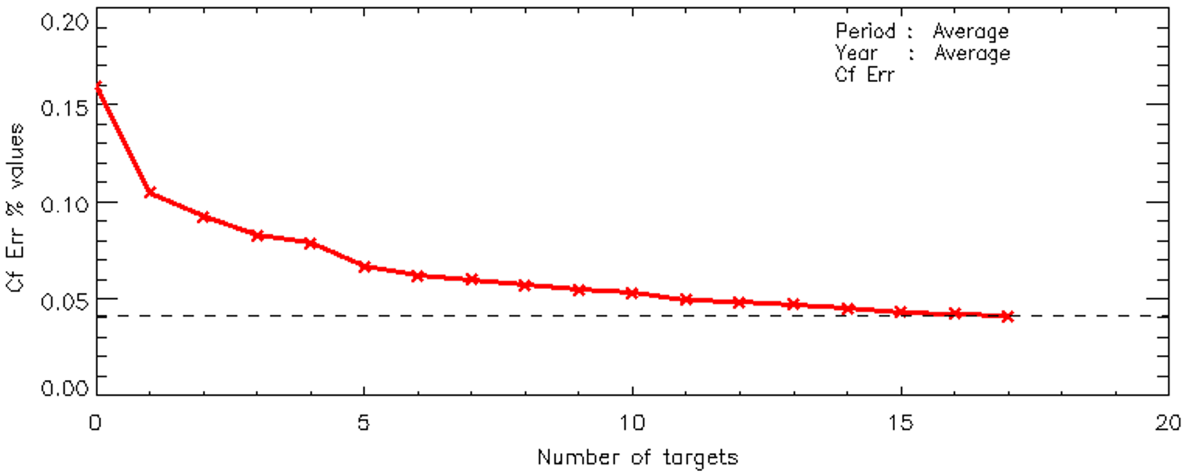
Background (4)



Difference between the targets for one day of (hourly) observations

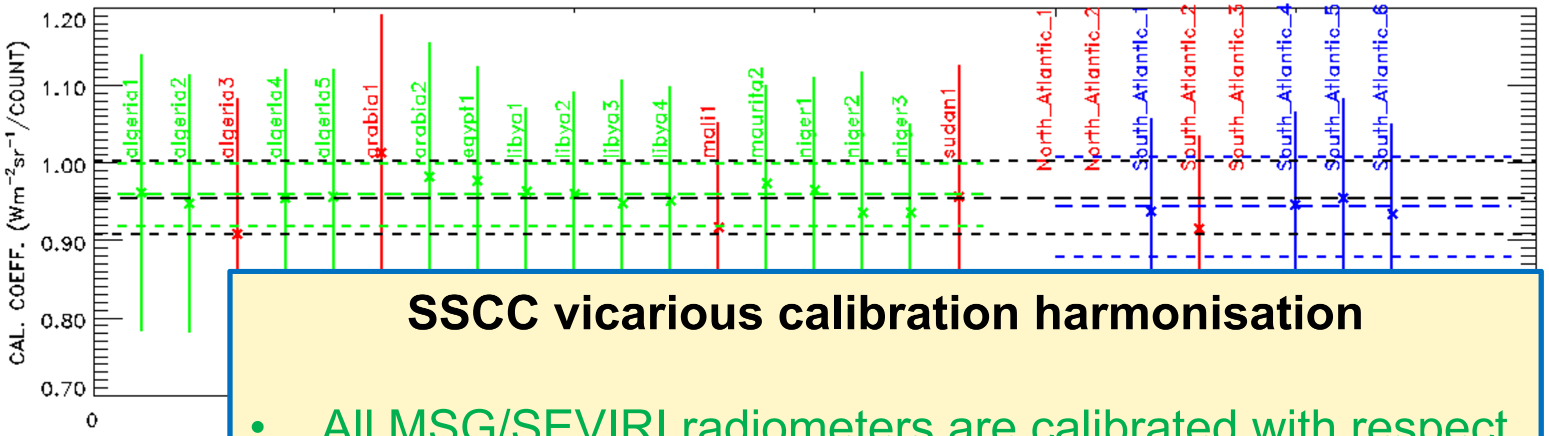


Uncertainty reduction as a number of accumulation days



Uncertainty reduction as a number of desert targets

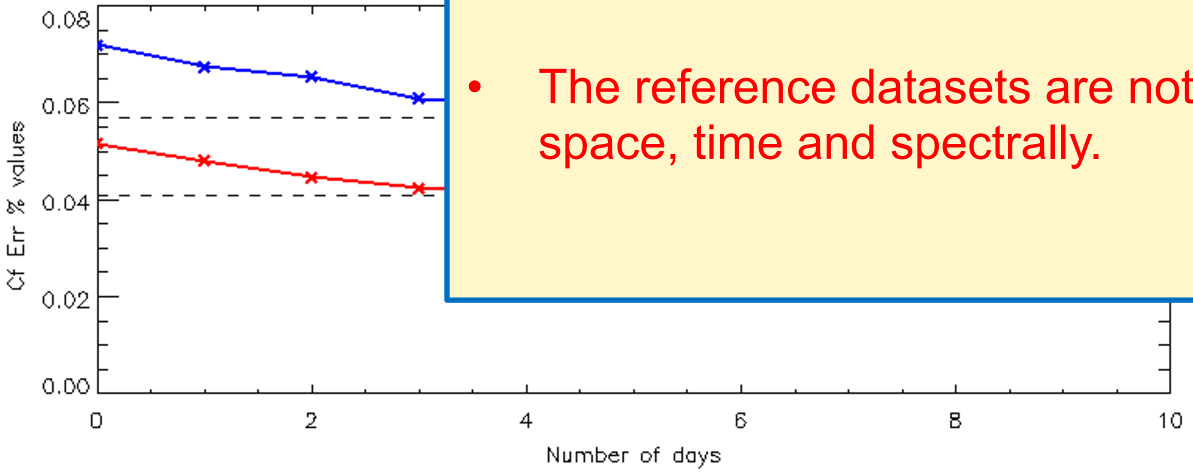
Background (4)

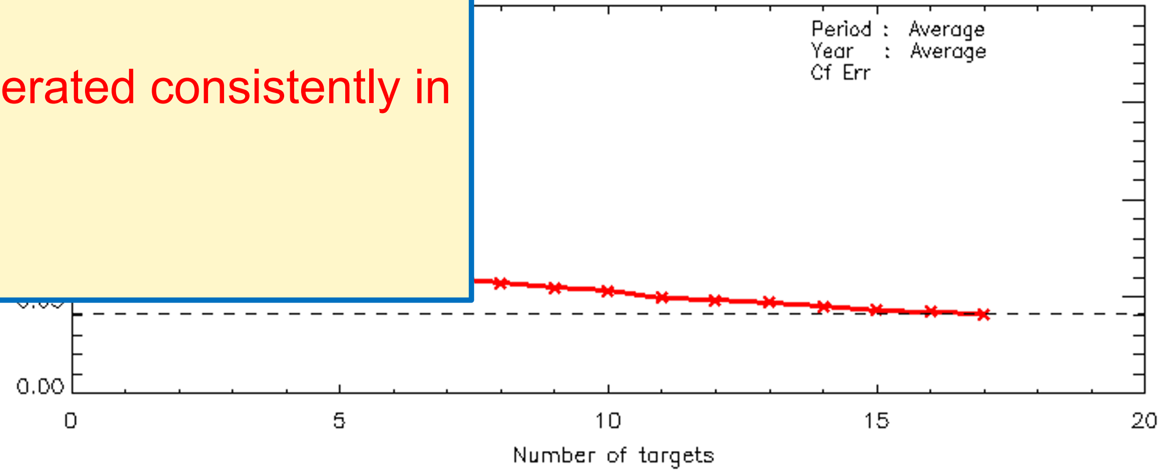


Difference between the targets for one day of (hourly) observations

SSCC vicarious calibration harmonisation

- All MSG/SEVIRI radiometers are calibrated with respect to the same reference datasets
- The reference datasets are not generated consistently in space, time and spectrally.

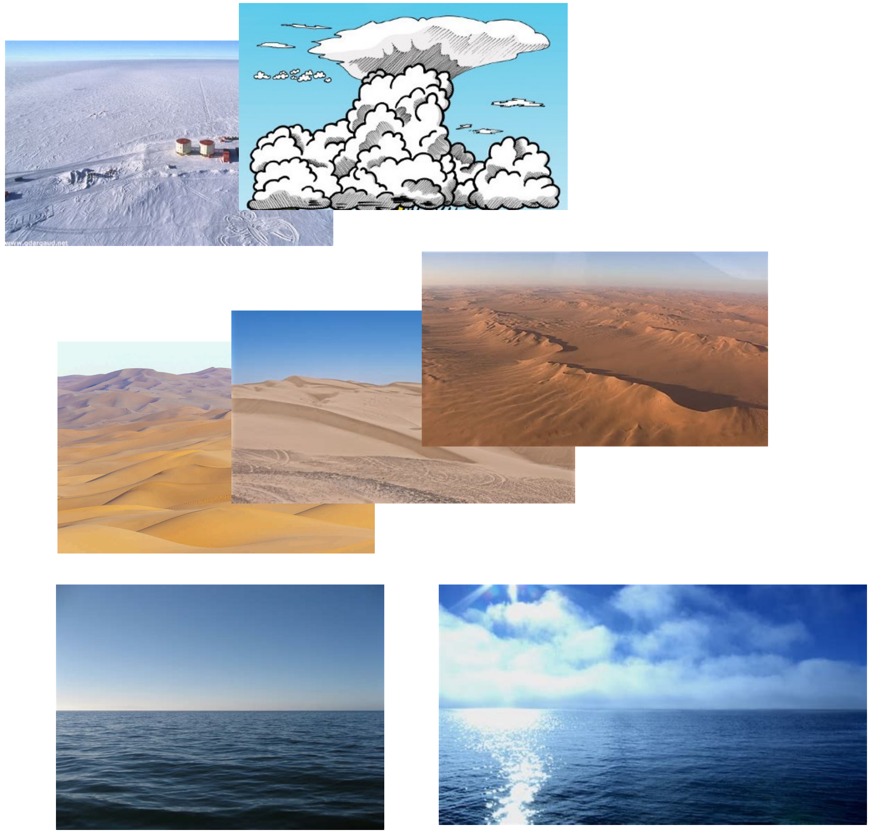


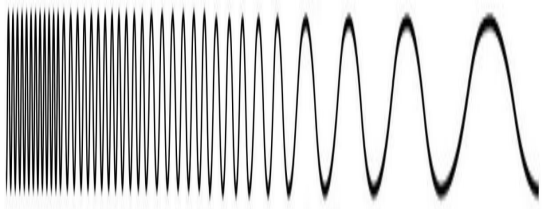


Uncertainty reduction as a number of accumulation days

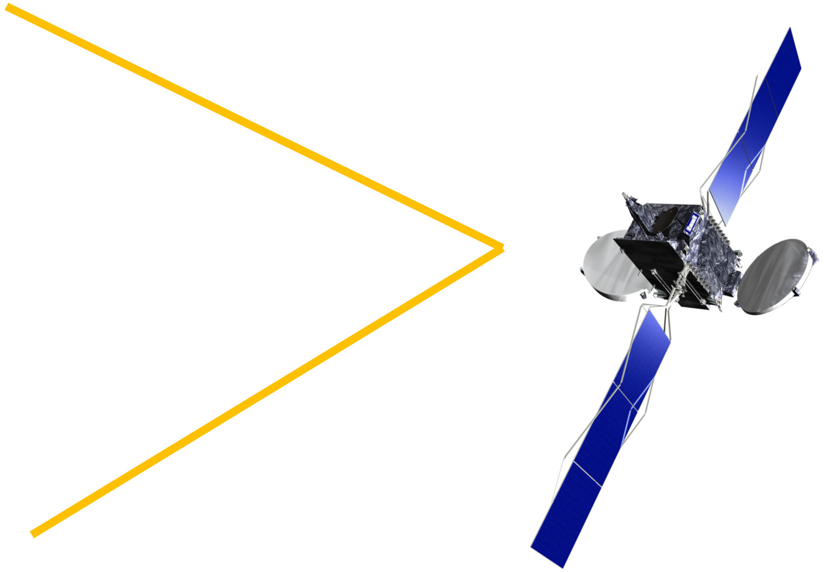
Uncertainty reduction as a number of desert targets

Background (5)





How to harmonise different calibration targets in a consistent and traceable **vicarious calibration reference**?



Proposed approach

Issues

- How to combine (harmonise) desert targets as a single calibration reference (surface and atmospheric spatial correlation)?
- How to combine different observations (temporal/spatial correlation)?
- Are there spectral correlations?

Approach

- Define **correlated uncertainties** between state variables;
- **Propagade** uncertainties accounting for these correlations.

Our sponsor

IDEAS-QA4EO

ATBD FOR MOON AND PICS CALIBRATION REFERENCE HOMOGENISATION

Authors :	Yves Govaerts, Nicolas Misk, Sindy Sterckx and Stefan Adriaensen
Date :	01/03/2022
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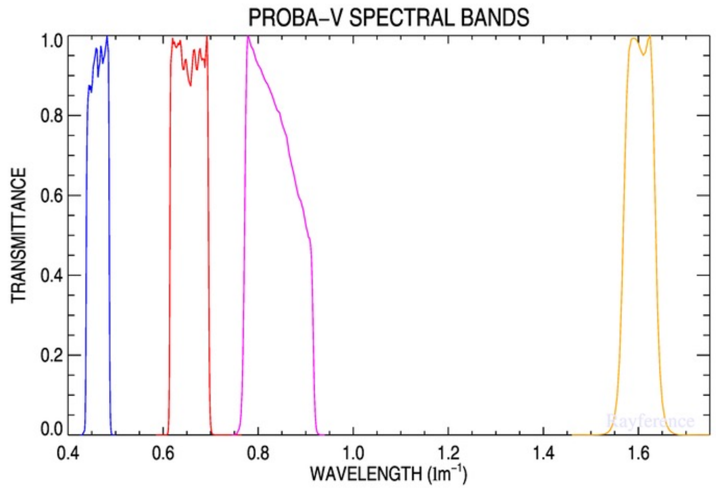
WP :	2310
Document Ref.:	QA4EO_ATBD_WP2310

IDEAS-QA4EO

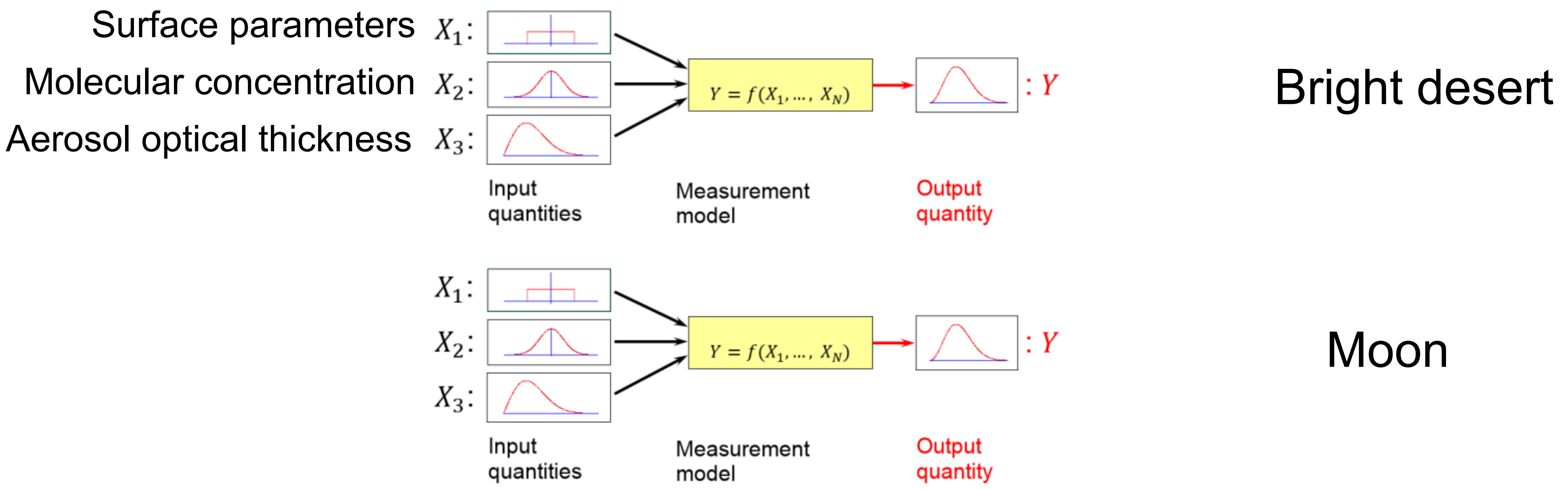
Definition of the theory
Application to the PROBA-V observations (blue, red, NIR, SWIR 1.6)



Propagation of uncertainties

Following the GUM and the formalism adopted by Mittaz et al. (2019), two methods can be used for the propagation of uncertainties.

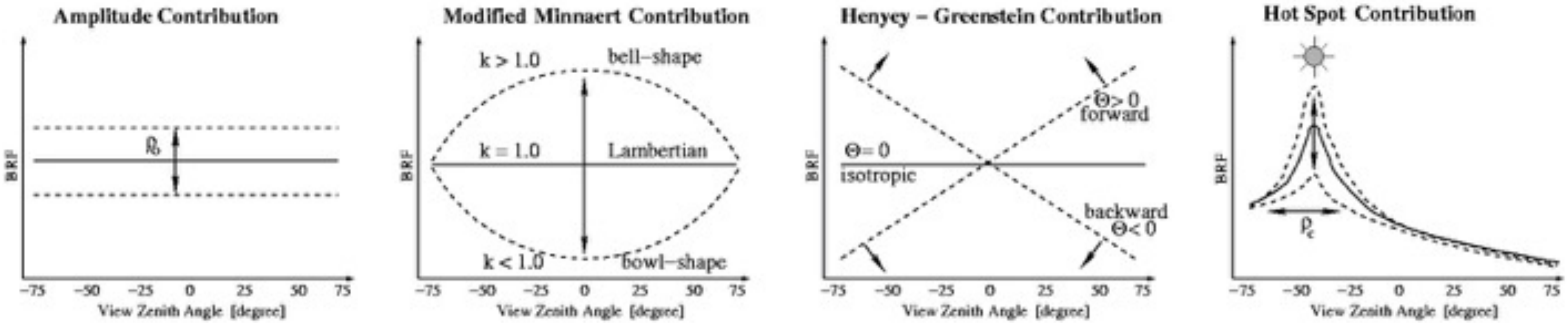
- The first one is referred to as the ‘Law of Propagation of Uncertainty’ (**LPU**)
- The second uncertainty propagation approach relies on Monte Carlo Methods (**MCM**).



After Wolliams et al.

Bright desert calibration reference

- Surface
  - Surface reflectance simulated with the RPV model $\rho_0(p,\lambda), k(p,\lambda), \Omega(p,\lambda), \rho_c(p,\lambda)$



- Atmosphere
  - US standard vertical profile
  - Rescaling of the water vapour and ozone concentration ($U_{H2O}(p,t)$, $U_{O3}(p,t)$)
  - Sahara desert aerosol type (non spherical particles)
  - Aerosol optical thickness ($\tau_{550}(p,t)$)

Calibration reference harmonisation

$r(t_1, p_1, \lambda_1)$

One observation over one target in one spectral band:

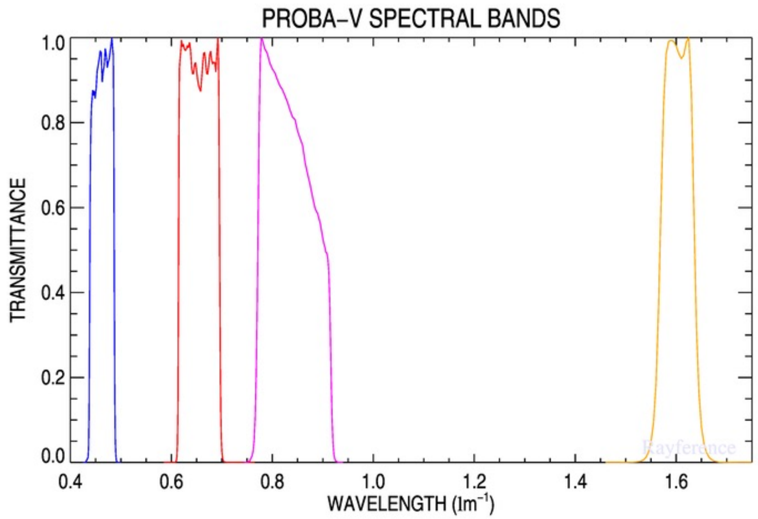
- Correlation between $\rho_0(t_1, p_1, \lambda_1), \Omega(t_1, p_1, \lambda_1), k(t_1, p_1, \lambda_1), \rho_c(t_1, p_1, \lambda_1)$
- Correlation between $U_{H2O}(p_1, t_1)$, $U_{O3}(p_1, t_1)$, $\tau_{550}(p_1, t_1)$

Calibration reference harmonisation

$r(t_1,p_1,\lambda_1)$	$r(t_1,p_1,\lambda_2)$	$r(t_1,p_1,\lambda_3)$	$r(t_1,p_1,\lambda_4)$

$\longleftrightarrow$

λ_i



One observation over one target in **all spectral bands**:

- Spectral correlation between $\rho_0(t_1,p_1,\lambda_i), \Omega(t_1,p_1,\lambda_i), k(t_1,p_1,\lambda_i), \rho_c(t_1,p_1,\lambda_i)$
- Correlation between U_{H2O} (p_1,t_1), $U_{O3}(p_1,t_1)$ (molecular absorption)
- Aerosol optical thickness τ_{550} (p_1,t_1) : spectral correlation imposed by the aerosol model

Calibration reference harmonisation

t_j

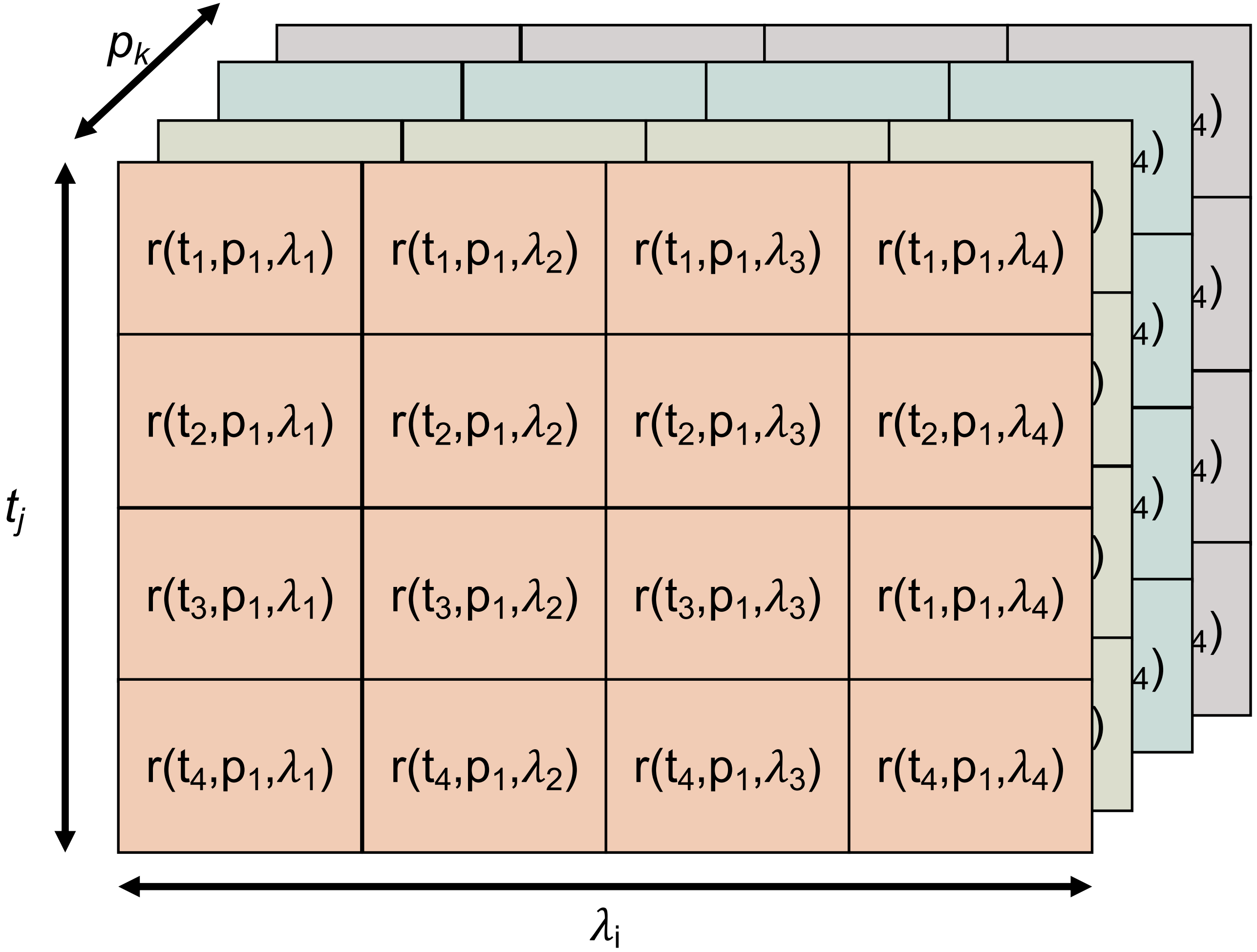
$r(t_1,p_1,\lambda_1)$	$r(t_1,p_1,\lambda_2)$	$r(t_1,p_1,\lambda_3)$	$r(t_1,p_1,\lambda_4)$
$r(t_2,p_1,\lambda_1)$	$r(t_2,p_1,\lambda_2)$	$r(t_2,p_1,\lambda_3)$	$r(t_2,p_1,\lambda_4)$
$r(t_3,p_1,\lambda_1)$	$r(t_3,p_1,\lambda_2)$	$r(t_3,p_1,\lambda_3)$	$r(t_1,p_1,\lambda_4)$
$r(t_4,p_1,\lambda_1)$	$r(t_4,p_1,\lambda_2)$	$r(t_4,p_1,\lambda_3)$	$r(t_4,p_1,\lambda_4)$

λ_i

Time series of observations over one target in all spectral bands:

- temporal correlation between $\rho_0(t_j, p_1, \lambda_i), \Omega(t_j, p_1, \lambda_i), k(t_j, p_1, \lambda_i), \rho_c(t_j, p_1, \lambda_i)$
- Temporal correlation between $U_{H2O}(t_j, p_1)$, $U_{O3}(t_j, p_1)$ (molecular absorption)
- Temporal aerosol optical thickness $\tau_{550}(t_j, p_1)$ correlation

Calibration reference harmonisation

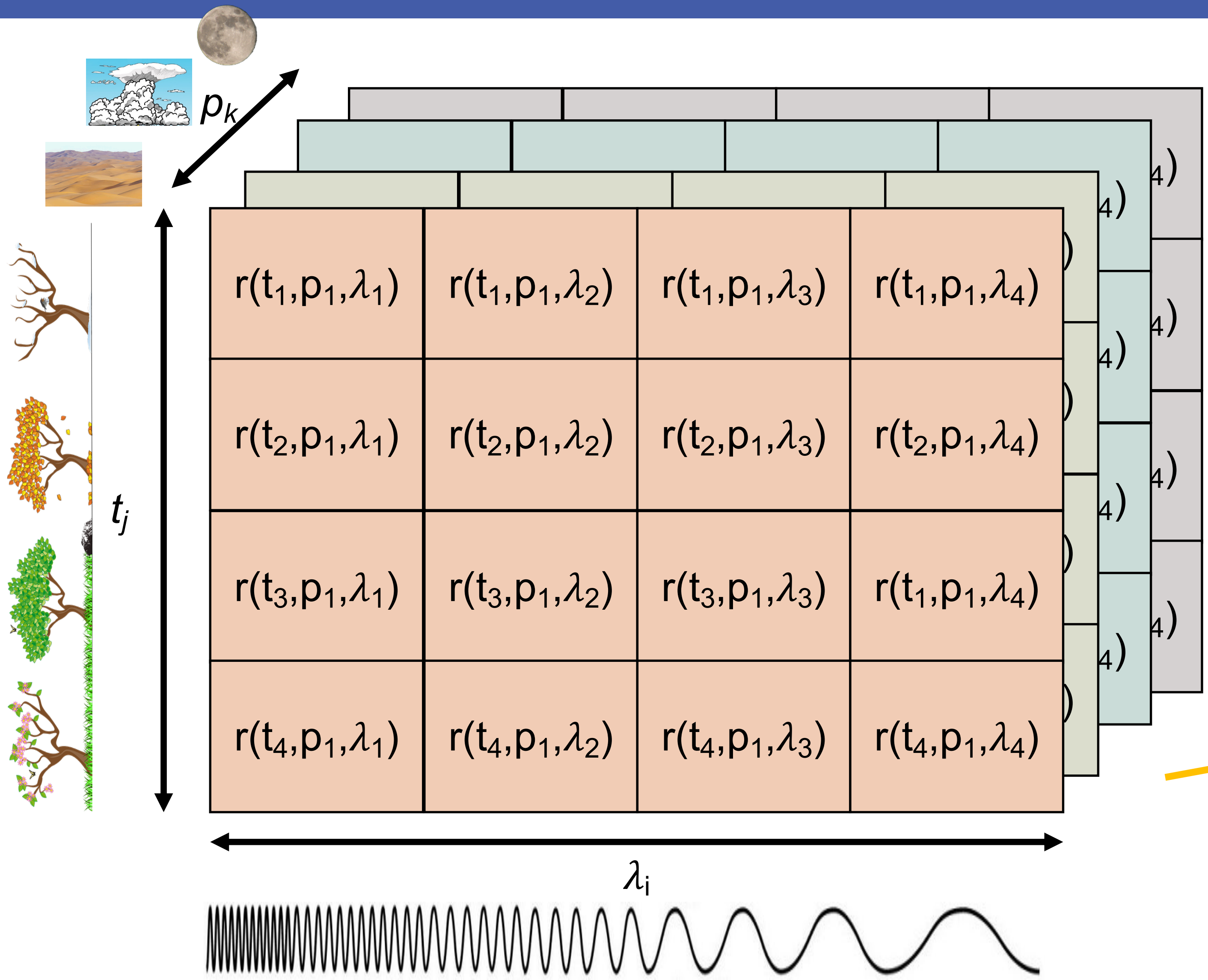


Vicarious calibration reference

Time series of observations over **several targets** in all spectral bands:

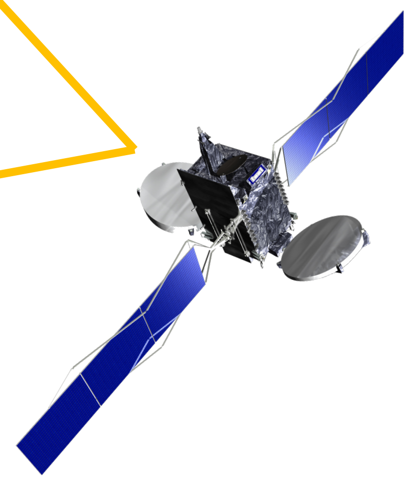
- spatial correlation between $\rho_0(t_j, pk, \lambda_i), \Omega(t_j, pk, \lambda_i), k(t_j, pk, \lambda_i), \rho_c(t_j, pk, \lambda$
- Spatial correlation between U_{H2O} (t_j, p_k), $U_{O3}(t_j, p_k)$ (molecular absorption)
- Spatial aerosol optical thickness τ_{550} (t_j, p_k) correlation

Calibration reference harmonisation



Vicarious calibration reference

Definition of a harmonised calibration reference with traceable uncertainty propagation

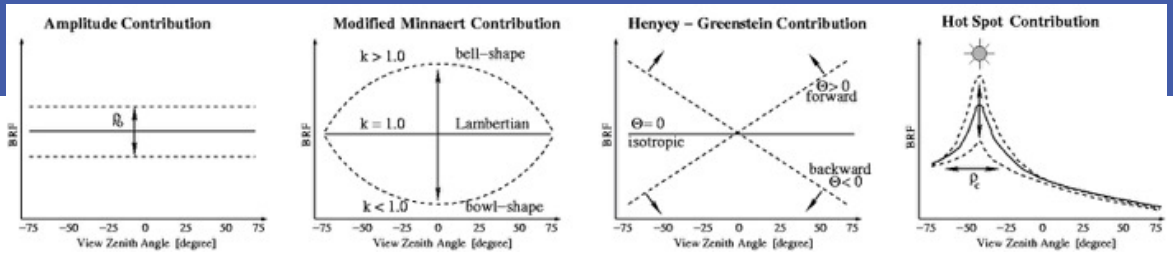


Combining several targets

- Similar targets types (e.g., bright desert)
  - When the same approach is used to characterise the target optical properties, the uncertainty correlation between the targets is very high;

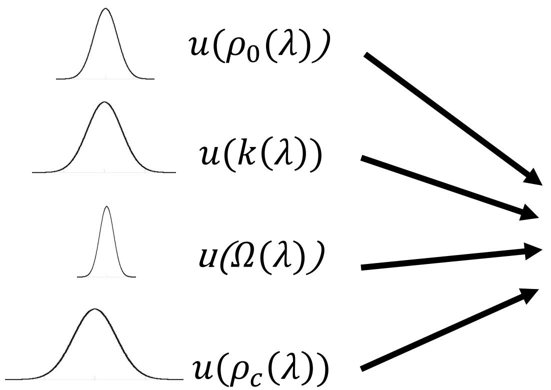
- Different target types
  - When the target types are different (e.g. bright desert and Rayleigh over open ocean), the uncertainty correlation between the targets is very unlikely (to the exception of atmospheric parameters).
  - Uncertainty over different targets might be correlated if the **same model** is used.
  - Bright desert and moon calibration reference are completely uncorrelated (different state variables, different models).

Practical example



Let's consider the surface parameters

Param./ Symbol	Unit	Description	Correlation			Remark
			Spectral	Spatial	Tempor.	
$\rho_0(\lambda)$	-	Intensity	Yes	(1)	Yes	The parameters are weakly correlated between themselves. This correlation can be neglected for spectral bands distant of more than 500nm.
$k(\lambda)$	-	Shape	Yes	(1)	Yes	
$\Omega(\lambda)$	-	Forward/backward	Yes	(1)	Yes	
$\rho_c(\lambda)$	-	Hot spot	Yes	(1)	Yes	



$$y = \mathrm{RPV}(\rho_0(\lambda)$$

$$u(y) = \sqrt{\begin{pmatrix} c_1 & \cdots & c_n \end{pmatrix} \begin{pmatrix} u^2(x_1) & u(x_1, x_2) & \cdots & \\ u(x_2, x_1) & u^2(x_2) & \cdots & \\ \vdots & \vdots & \ddots & \\ & & & u^2(x_n) \end{pmatrix} \begin{pmatrix} c_1 \\ \vdots \\ c_n \end{pmatrix}}$$

Practical example

Example of uncertainty covariance matrix in the blue spectral region.

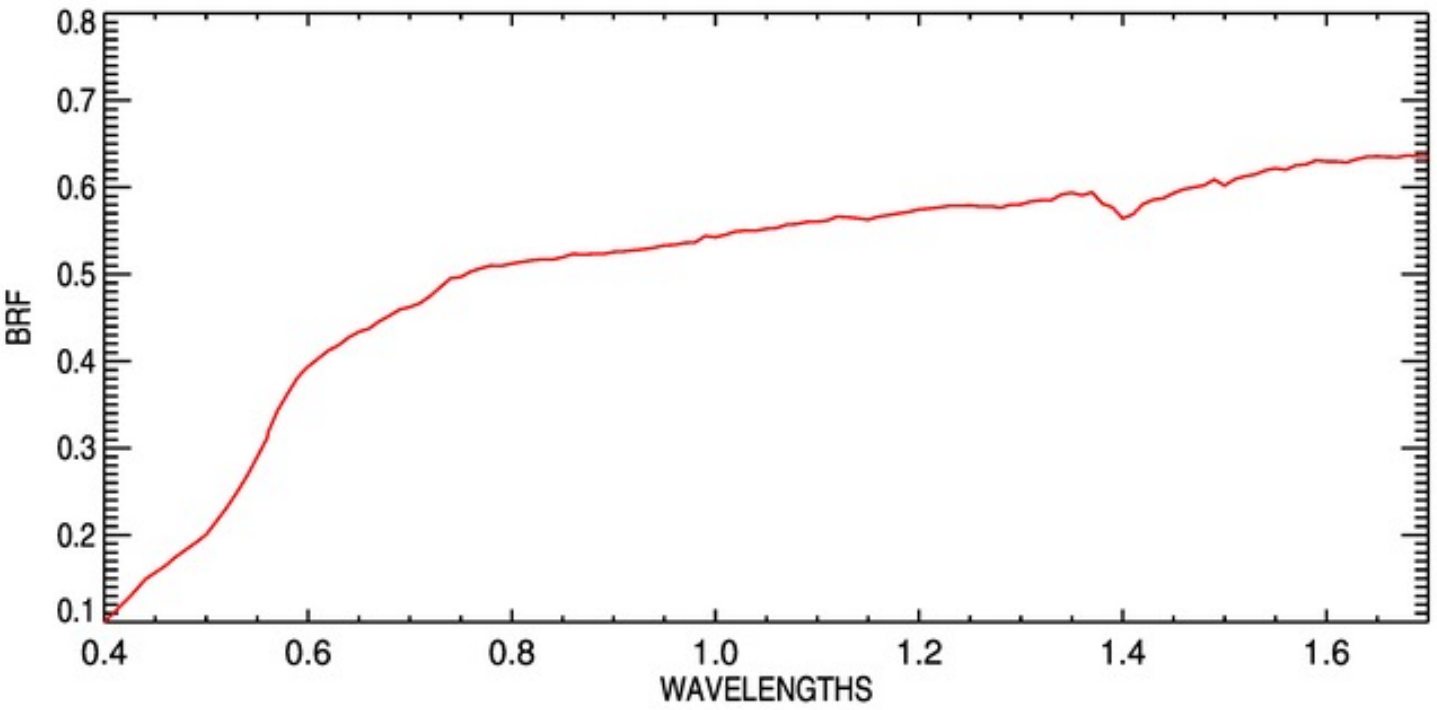
$$\boldsymbol{U}_{\mathrm{RPV}}\big(\rho_0(\lambda),\Omega(\lambda),\mathrm{k}(\lambda),\rho_c(\lambda)\big) = \begin{pmatrix} u^2\big(\rho_0(\lambda)\big) & u\big(\rho_0(\lambda),\Omega(\lambda)\big) & u\big(\rho_0(\lambda),\mathrm{k}(\lambda)\big) & u\big(\rho_0(\lambda),\rho_c(\lambda)\big) \\ u\big(\Omega(\lambda),\rho_0(\lambda)\big) & u^2\big(\Omega(\lambda)\big) & u\big(\Omega(\lambda),\mathrm{k}(\lambda)\big) & u\big(\Omega(\lambda),\rho_c(\lambda)\big) \\ u\big(\mathrm{k}(\lambda),\rho_0(\lambda)\big) & u\big(\mathrm{k}(\lambda),\Omega(\lambda)\big) & u^2\big(\mathrm{k}(\lambda)\big) & u\big(\mathrm{k}(\lambda),\rho_c(\lambda)\big) \\ u\big(\rho_c(\lambda),\rho_0(\lambda)\big) & u\big(\rho_c(\lambda),\Omega(\lambda)\big) & u\big(\rho_c(\lambda),\mathrm{k}(\lambda)\big) & u^2\big(\rho_c(\lambda)\big) \end{pmatrix}$$

$$\boldsymbol{U}_{\mathrm{RPV}}\big(\rho_0(\lambda),\Omega(\lambda),\mathrm{k}(\lambda),\rho_c(\lambda)\big) = \begin{pmatrix} 0.0001347 & 0.0000528 & 0.0000191 & 0.0001253 \\ 0.0000528 & 0.0023413 & 0.0000032 & 0.0000084 \\ 0.0000191 & 0.0000032 & 0.0000983 & -0.0000047 \\ 0.0001253 & 0.0000084 & -0.0000047 & 0.0024824 \end{pmatrix}$$

Correlation matrix

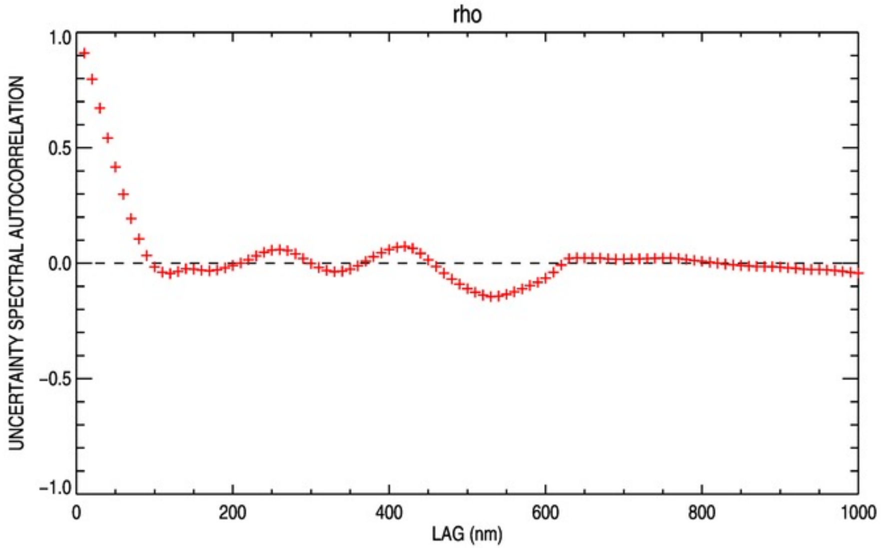
$$\boldsymbol{R}_{\mathrm{RPV}}\big(\rho_0(\lambda),\Omega(\lambda),\mathrm{k}(\lambda),\rho_c(\lambda)\big) = \begin{pmatrix} 1.000 & 0.094 & 0.166 & 0.217 \\ 0.094 & 1.000 & 0.007 & 0.003 \\ 0.166 & 0.007 & 1.000 & -0.009 \\ 0.217 & 0.003 & -0.009 & 1.000 \end{pmatrix}$$

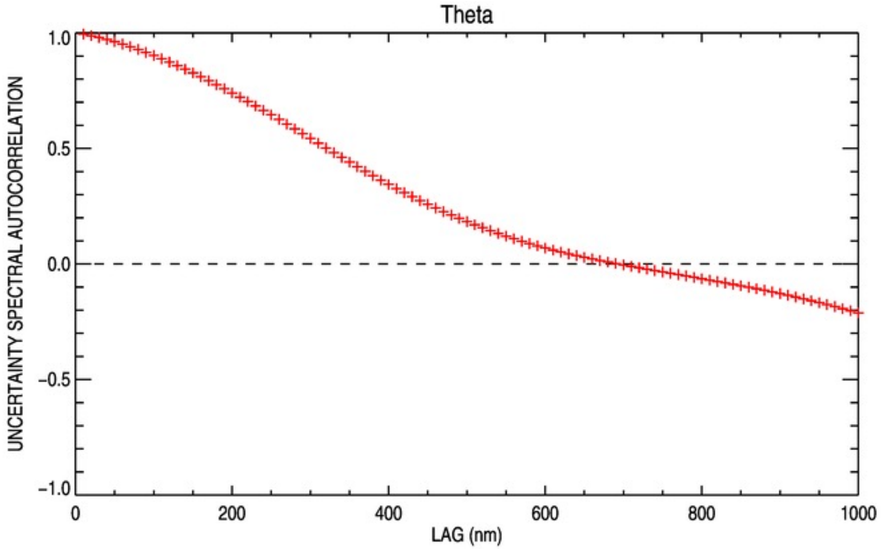
Practical example



Surface reflectance

Spectral correlation

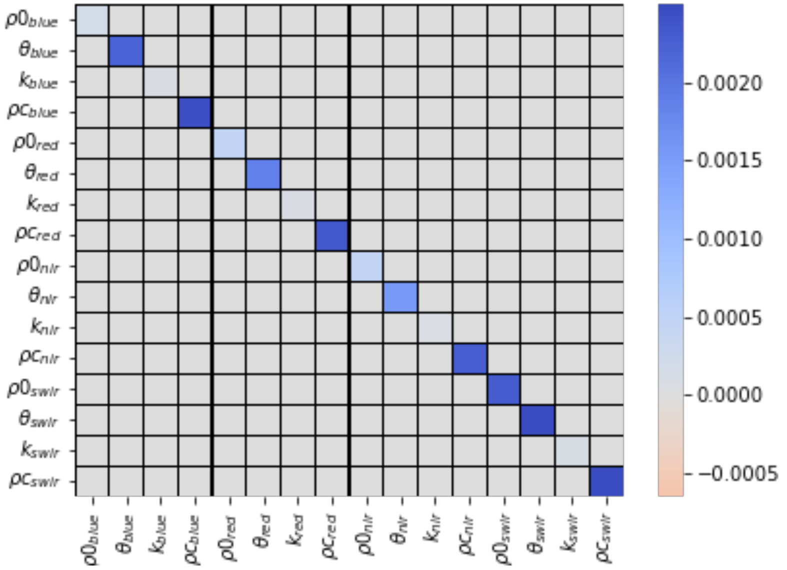




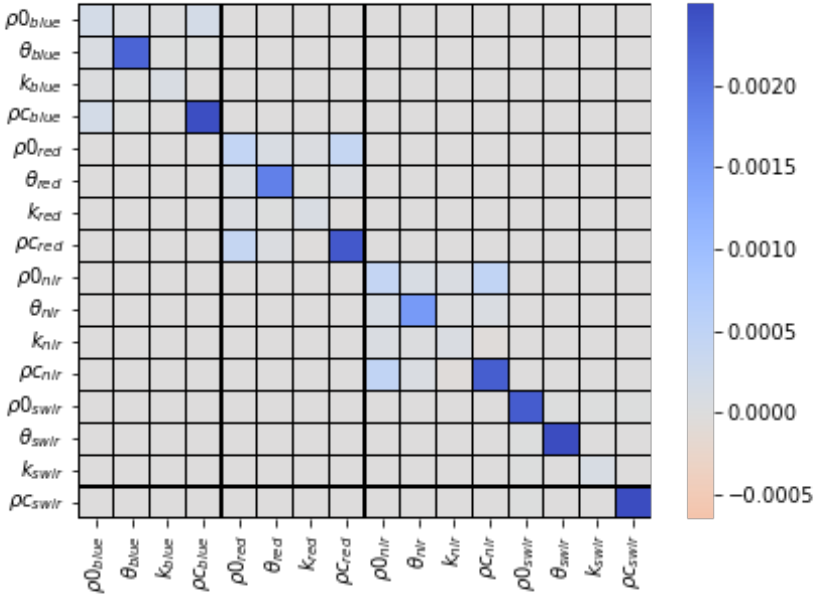
Covariance matrix

PROBA-V observation on 08/10/2014 over Libya-4

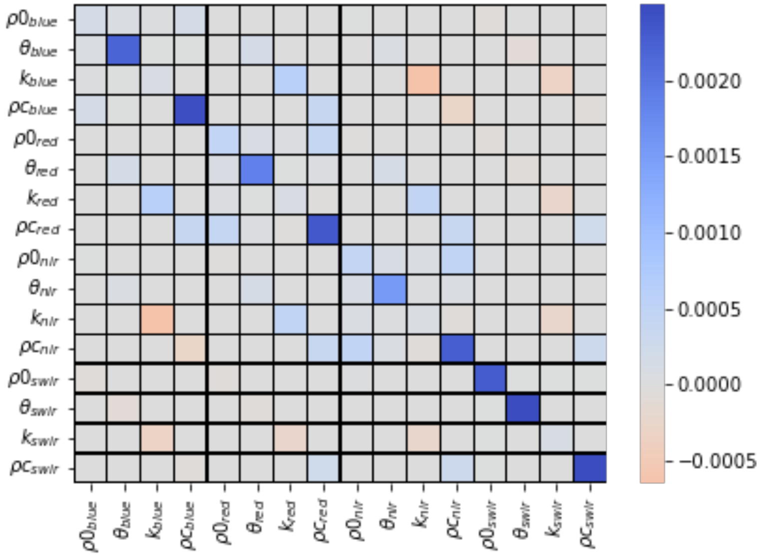
No correlation



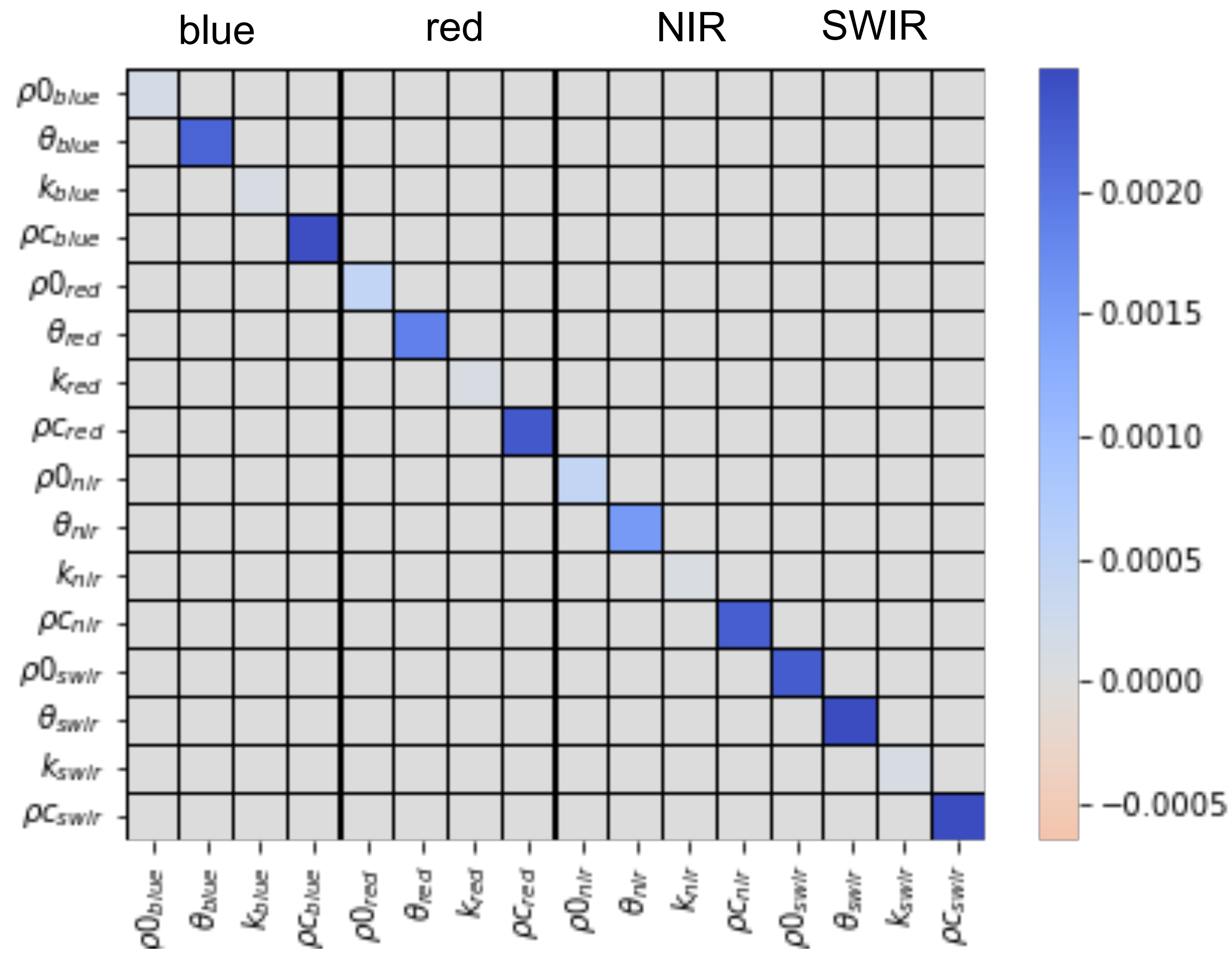
Correlation between RPV
No spectral correlation



Full correlation



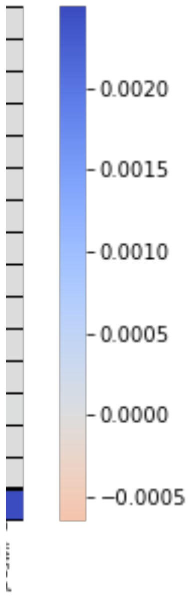
Covariance matrix



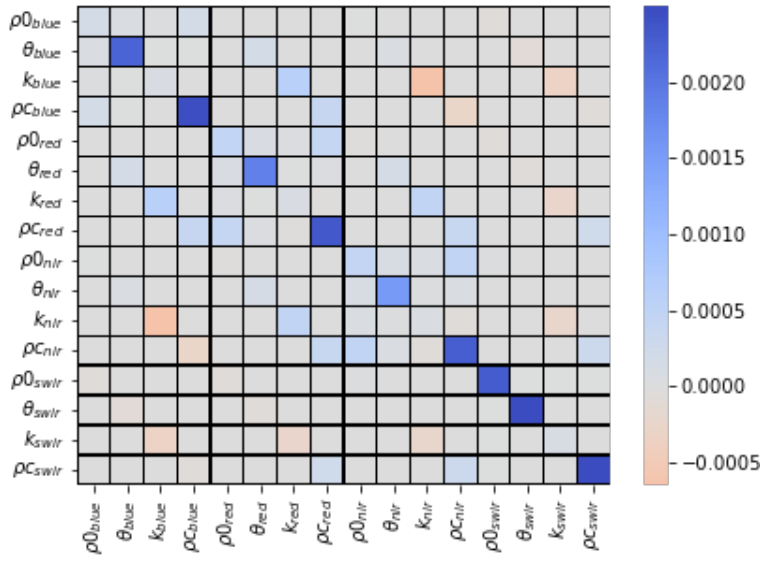
ver Libya-4

PV

n

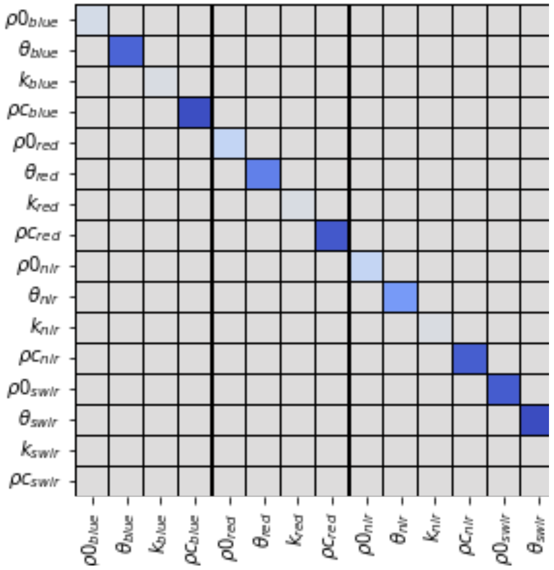


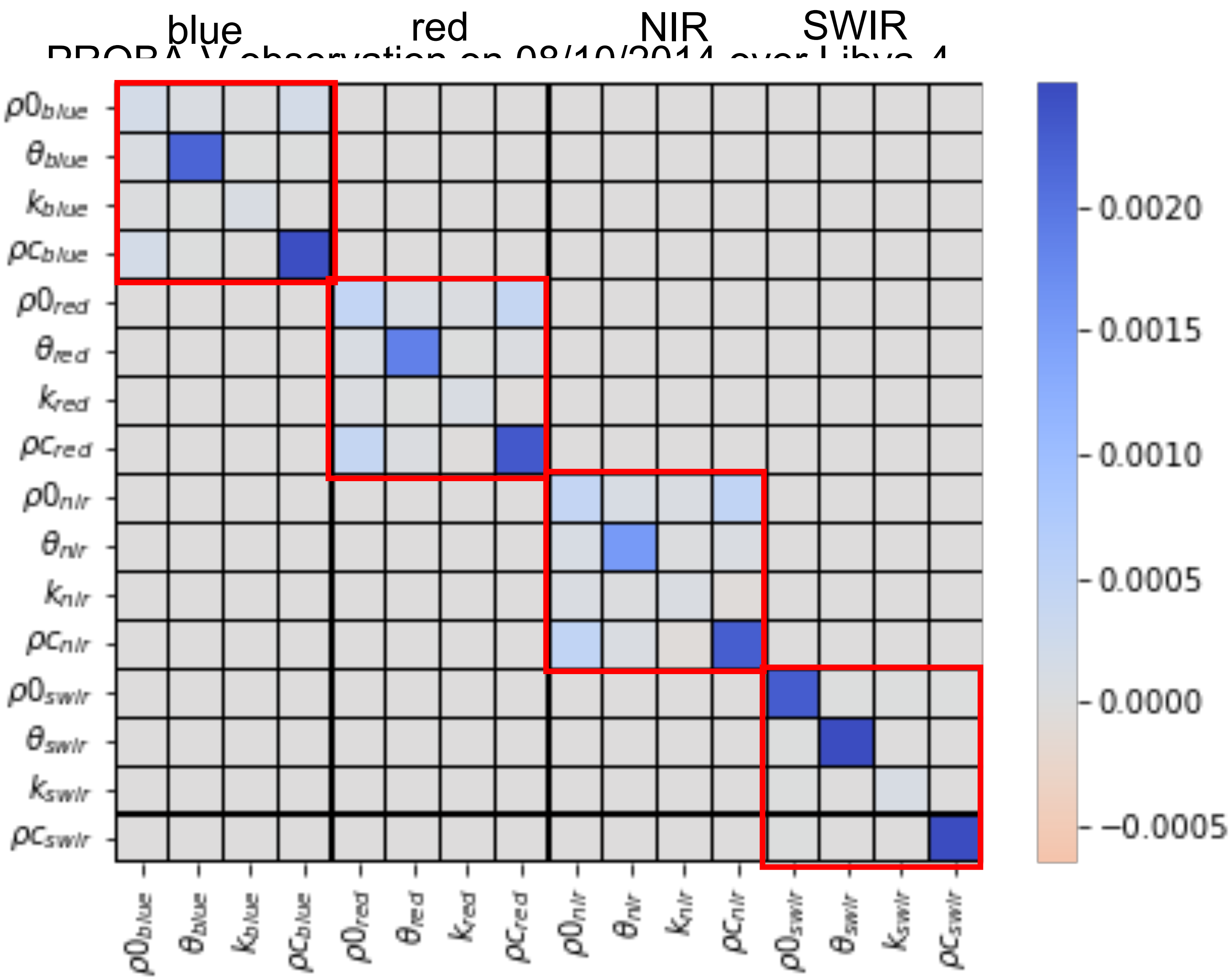
Full correlation



Covariance matrix

No correlation





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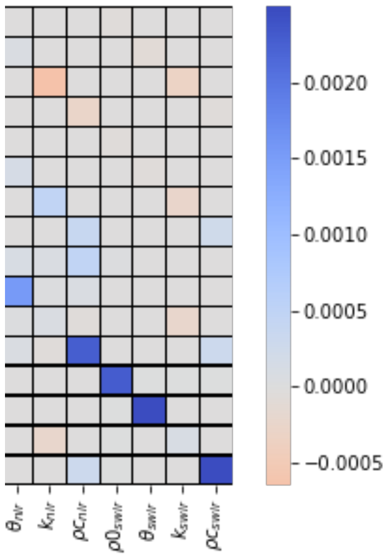
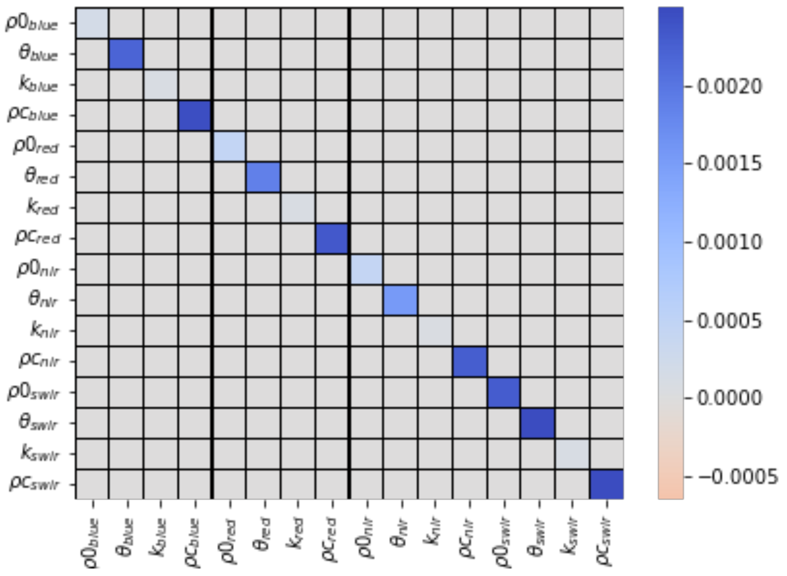


Covariance matrix

PROBA-V observ

No correlation



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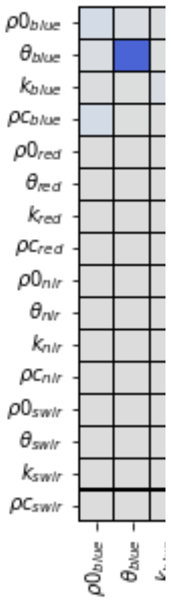
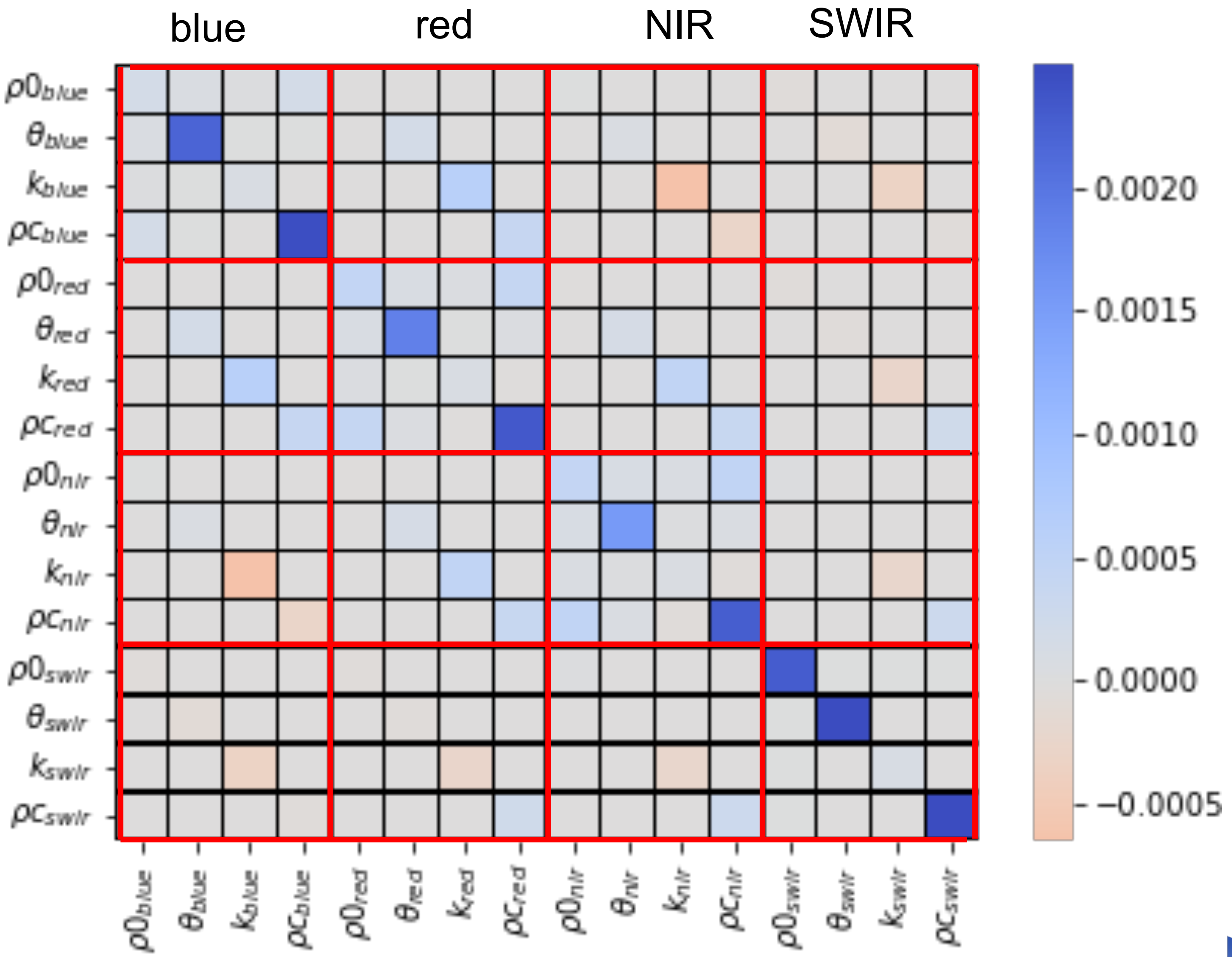
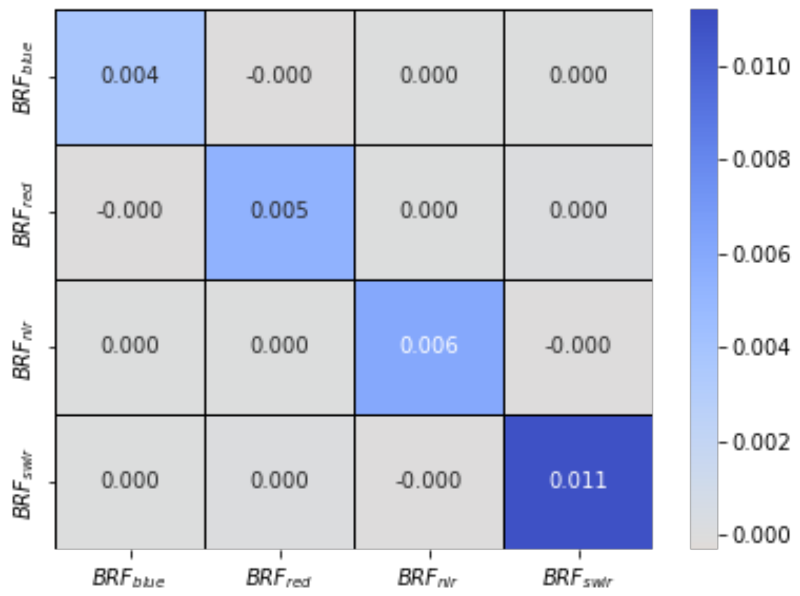




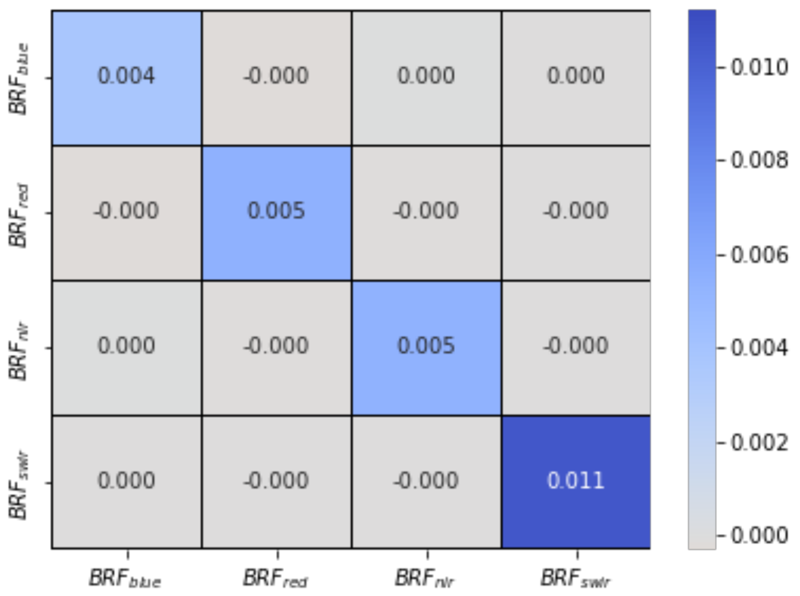
Covariance matrix

PROBA-V observation on 08/10/2014 over Libya-4

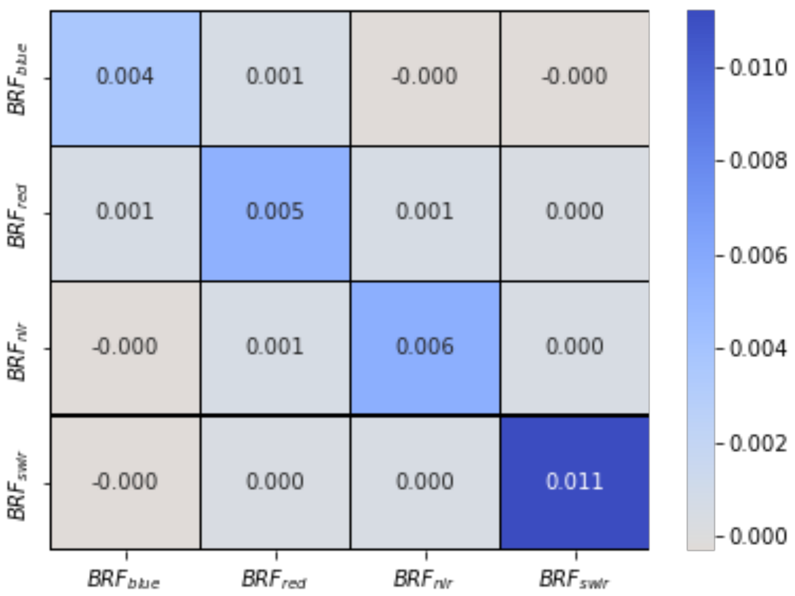
No correlation



Correlation between RPV
No spectral correlation



Full correlation

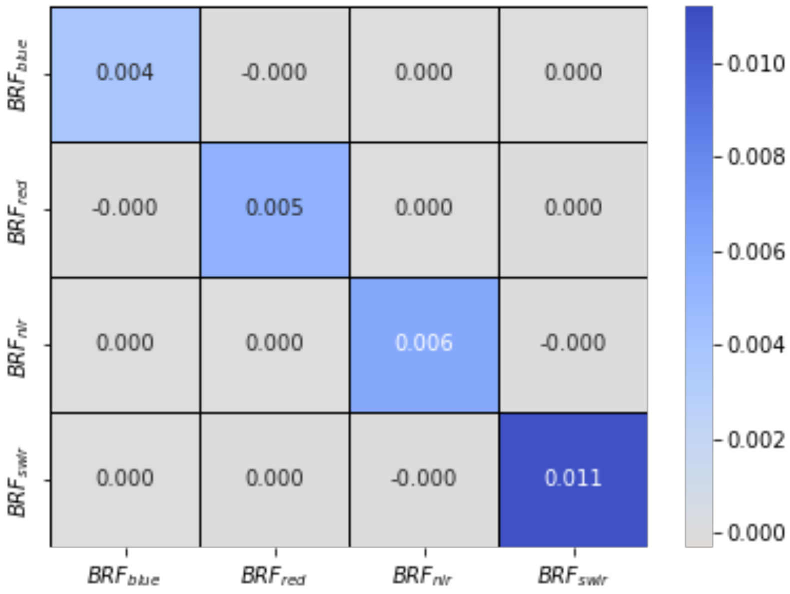


Reference dataset uncertainty matrix

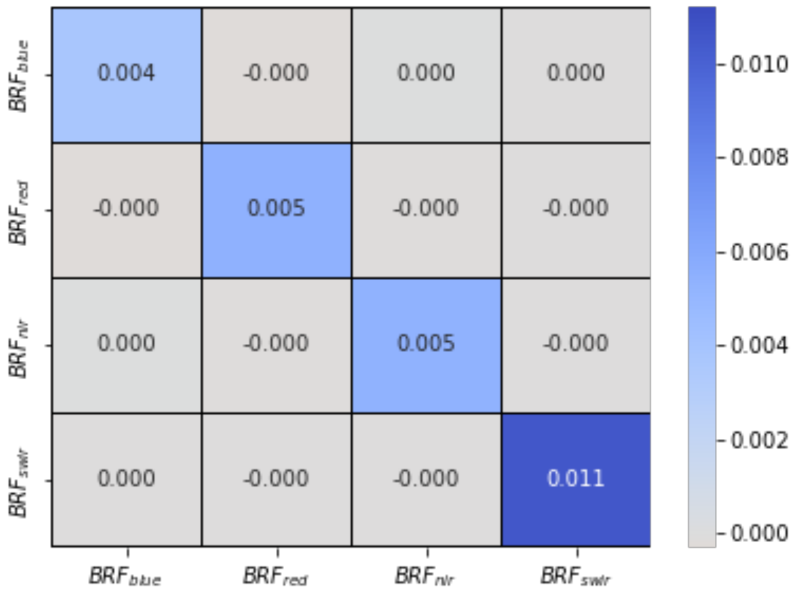
Covariance matrix

PROBA-V observation on 08/10/2014 over Libya-4

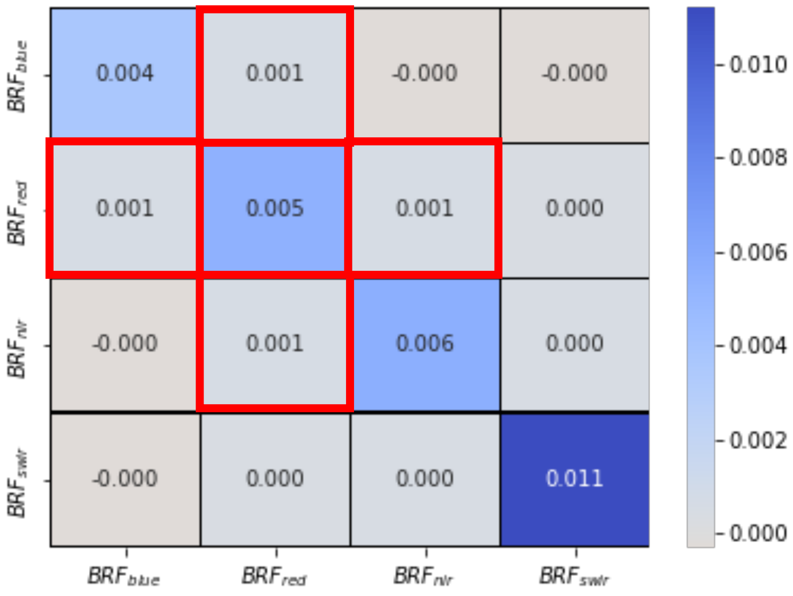
No correlation



Correlation between RPV
No spectral correlation

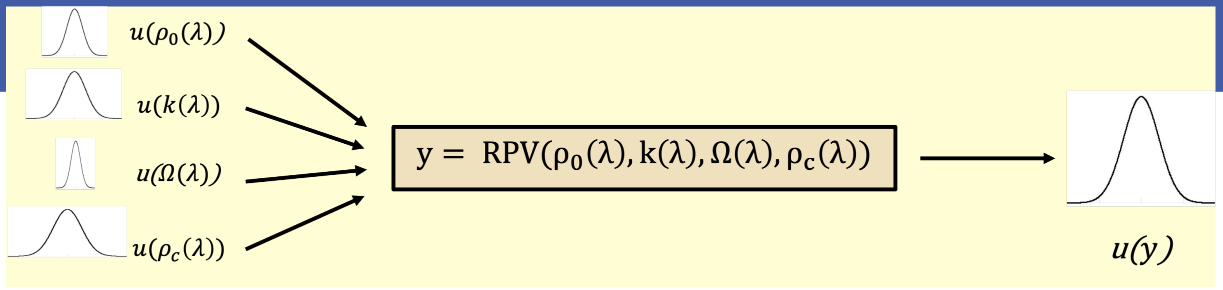


Full correlation



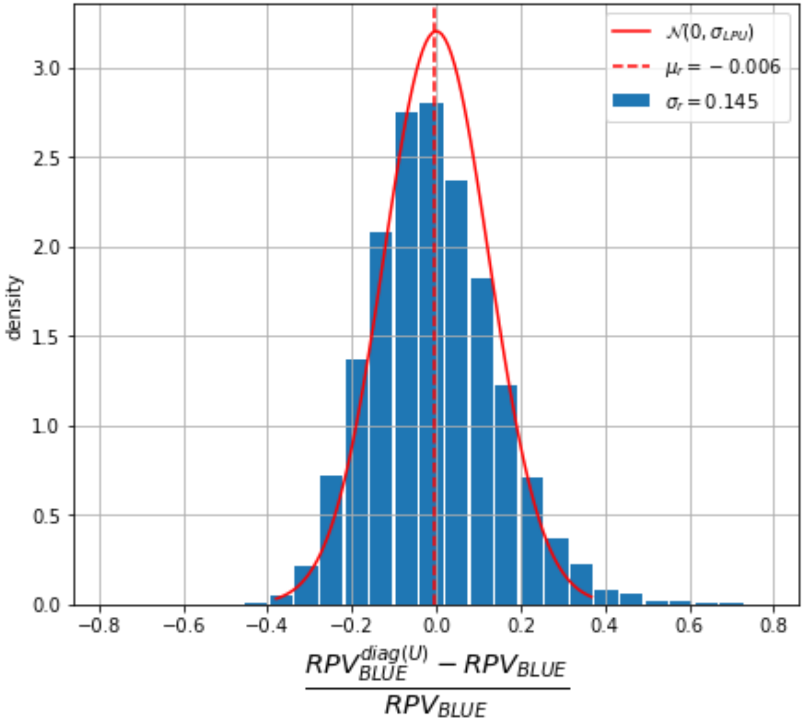
Reference data uncertainty matrix

Error distribution

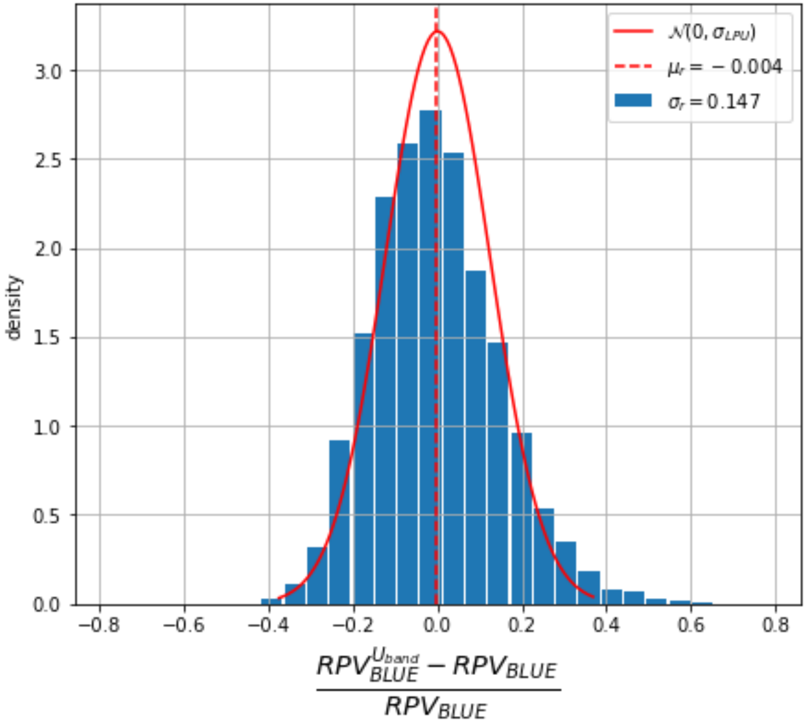


LPU (solid line)
MCM (histogram)

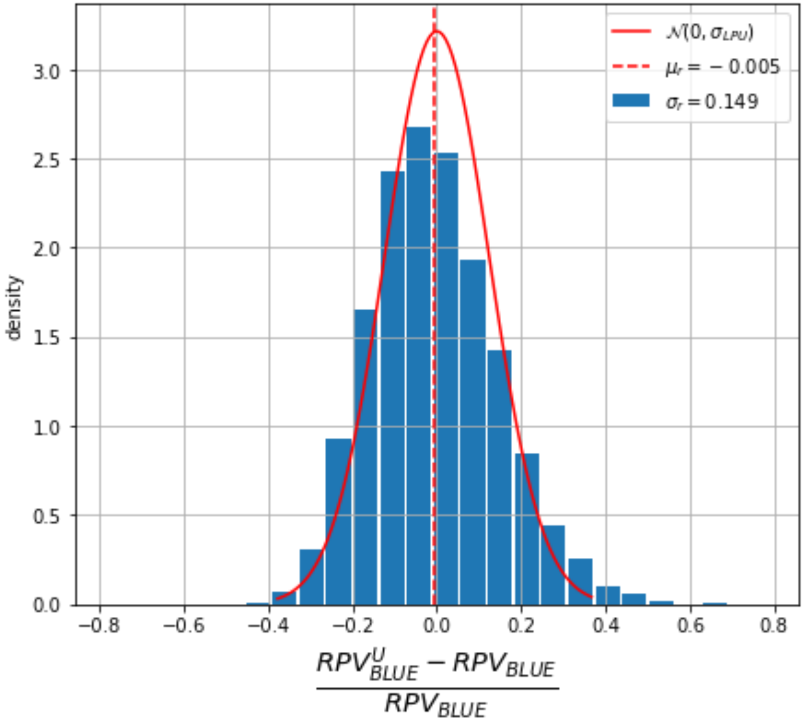
PROBA-V blue band, simulation of one observation over Libya-4



No correlation

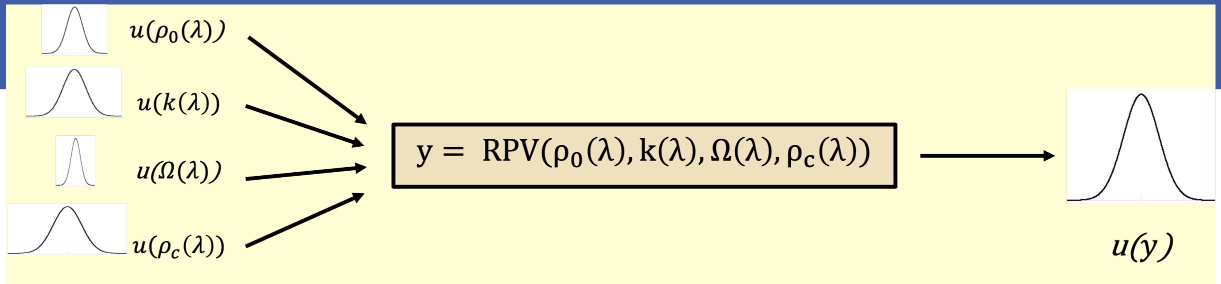


Correlation between RPV
No spectral correlation



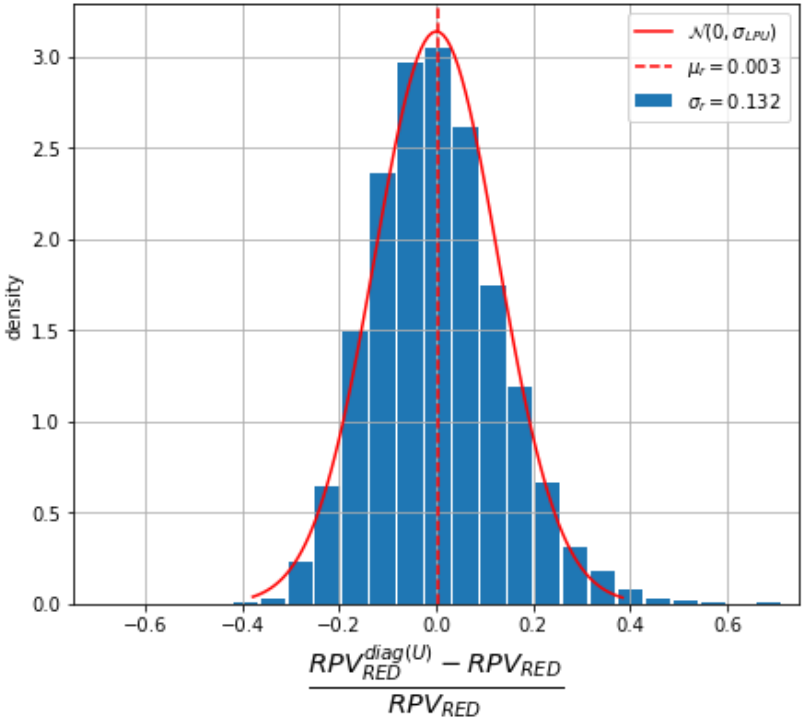
Full correlation

Error distribution

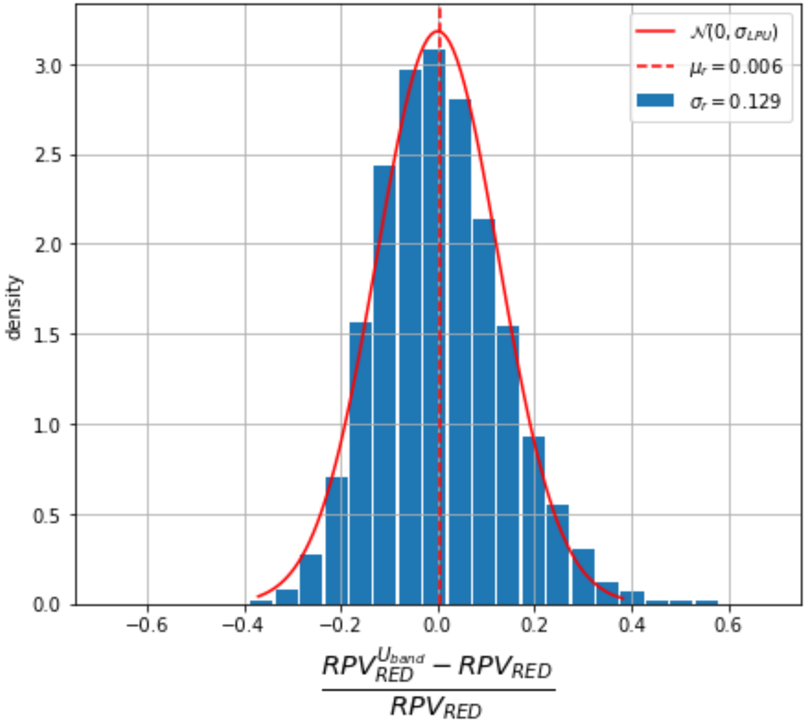


LPU (solid line)
MCM (histogram)

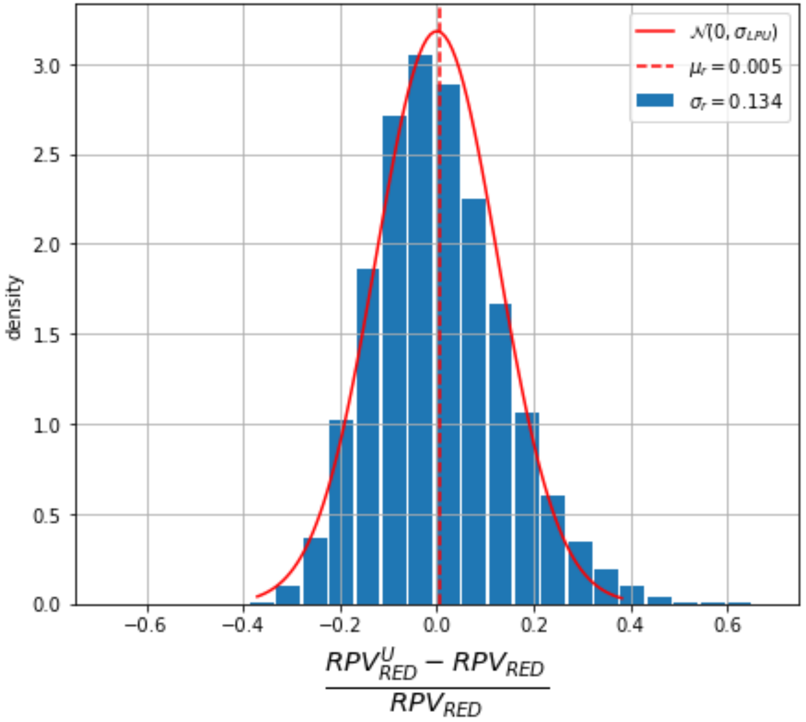
PROBA-V red band, simulation of one observation over Libya-4



No correlation



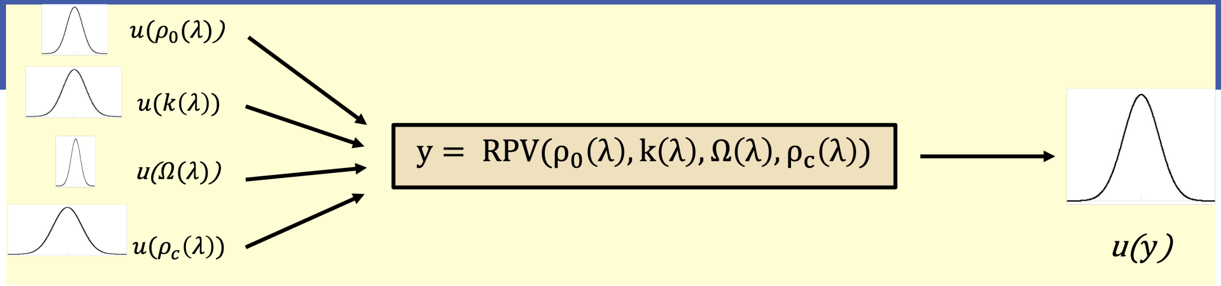
Correlation between RPV
No spectral correlation



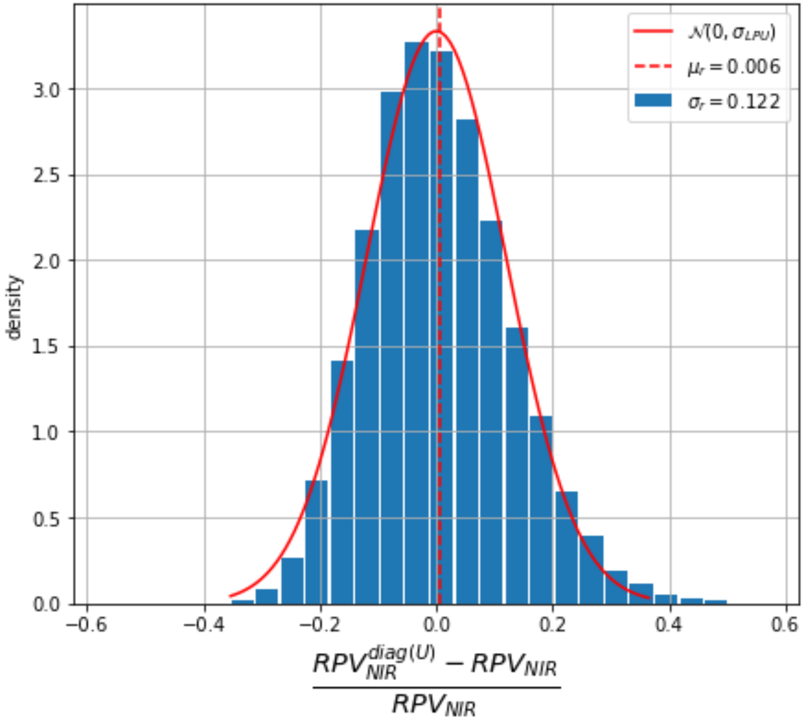
Full correlation

Error distribution

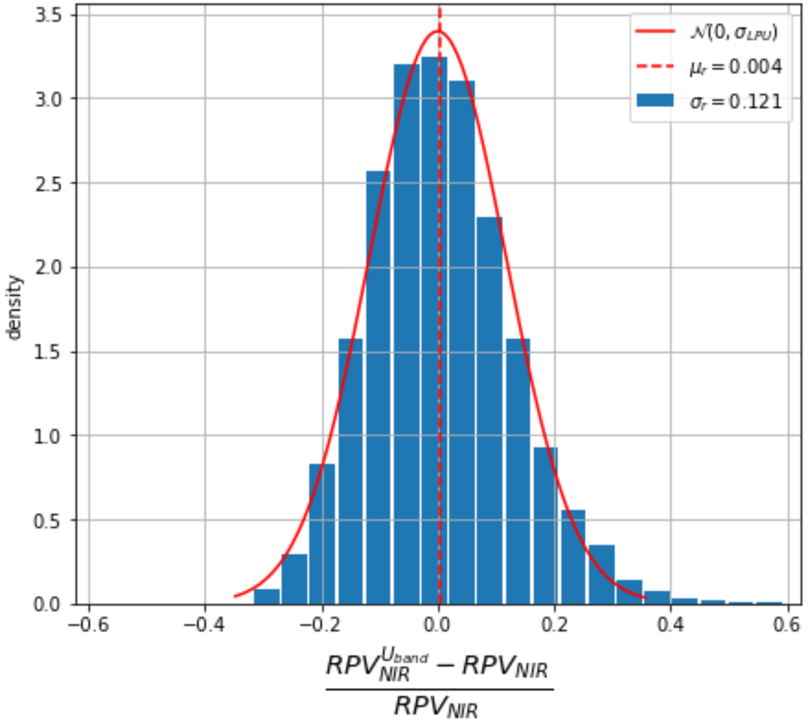
LPU (solid line)
MCM (histogram)



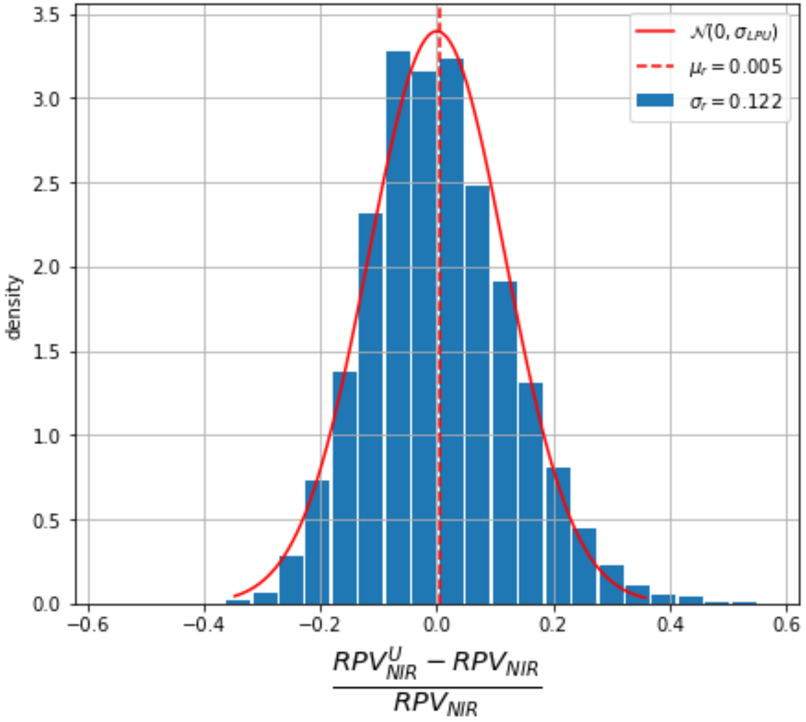
PROBA-V NIR band, simulation of one observation over Libya-4



No correlation



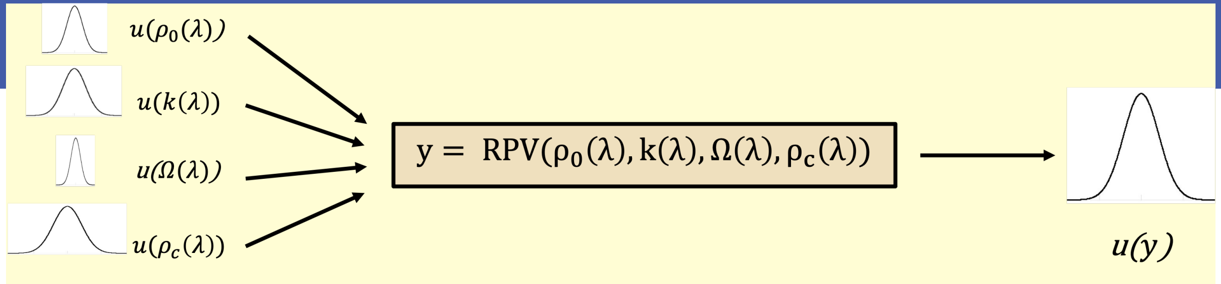
Correlation between RPV
No spectral correlation



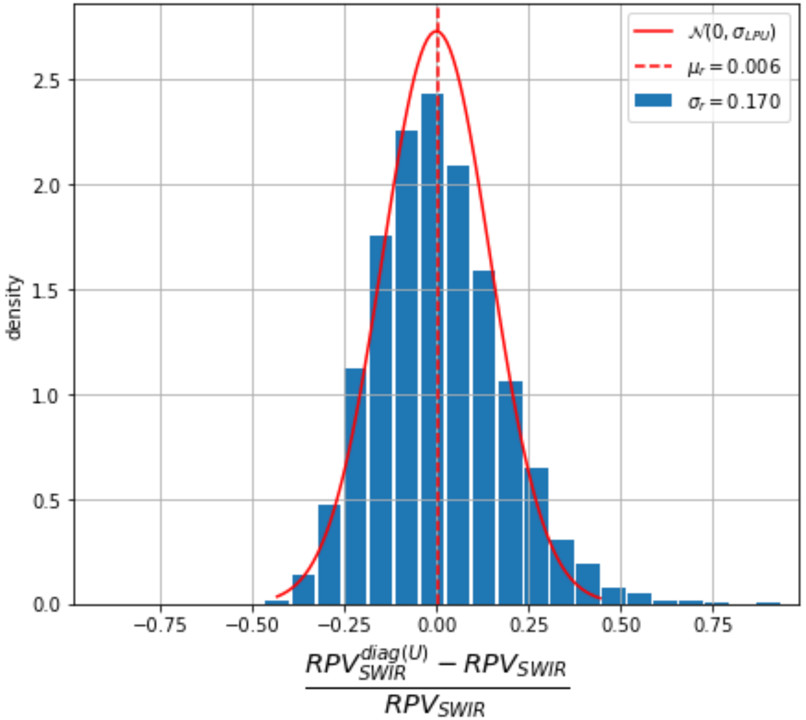
Full correlation

Error distribution

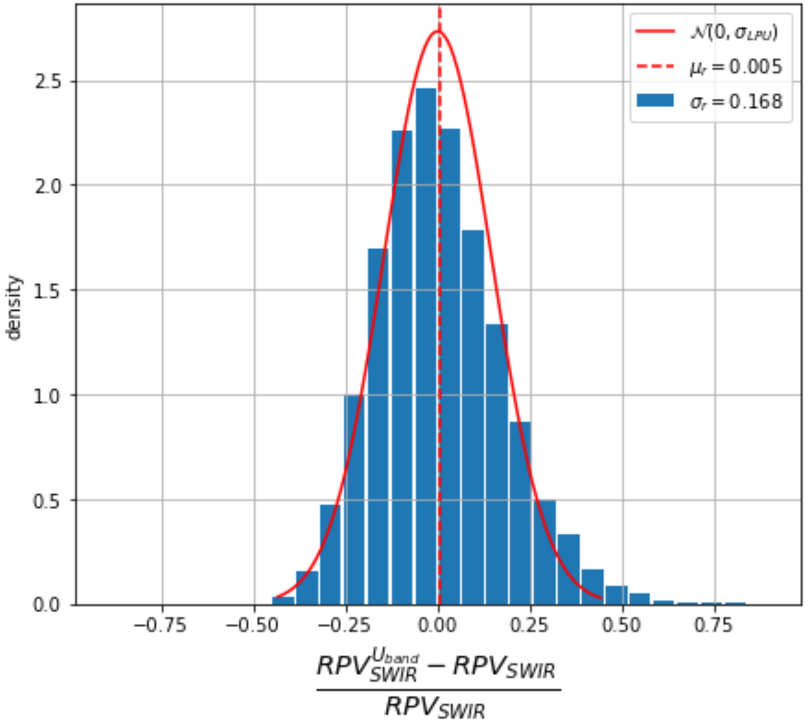
LPU (solid line)
MCM (histogram)



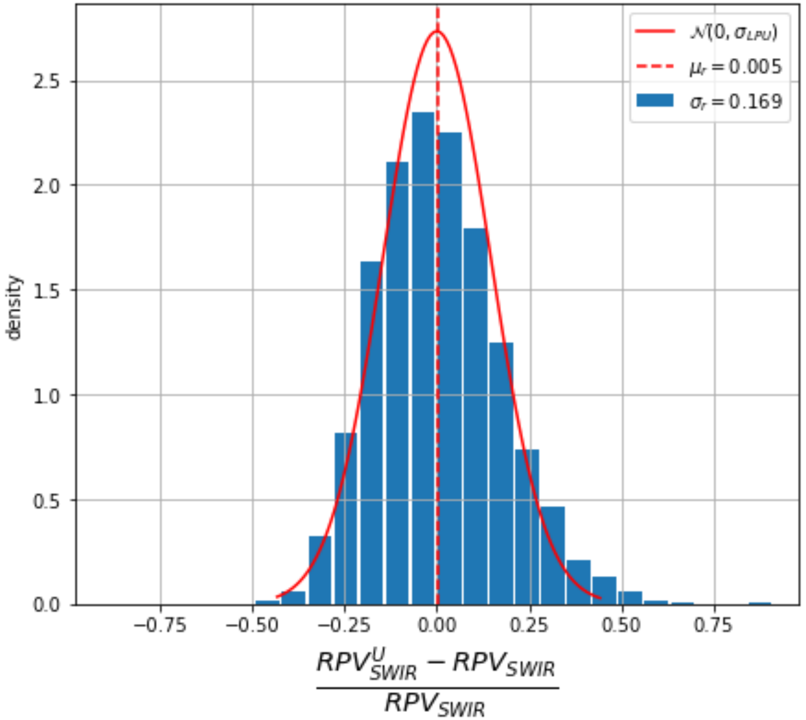
PROBA-V SWIR band, simulation of one observation over Libya-4



No correlation



Correlation between RPV
No spectral correlation



Full correlation

Conclusions

- Elaboration of a harmonisation method for different vicarious calibration targets;
- Both Low of Propagation of Uncertainty (**LPU**) and Monte Carlo Method (**MCM**) provide very similar results when applied on the RPV model;
- **MCM** shows minor departure from the Gaussian distribution assumed in the LPU method.
- **MCM** is recommended for a first sensitivity analysis.
- Spectral covariance uncertainty affects adjacent spectral bands;
- Need to be applied to all variables with correlation in all dimensions (spectral, temporal and spatial/targets), but only with MCM.
- Impact of RTM uncertainties still needs to be accounted for.