SMOS L1PP Performance Analysis with MIRAS Data from Validation Campaigns

(SO-HO-DME-L1PP-0064)

L1PP Team

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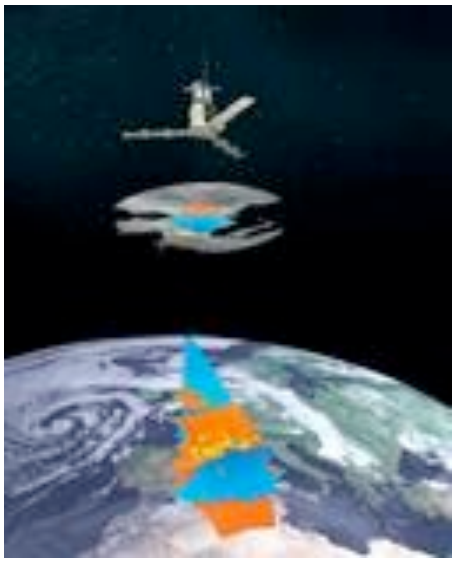
(1) Deimos Engenharia
(2) Critical Software

SMOS Overview

Instrument	Microwave Imaging Radiometer using Aperture Synthesis – MIRAS
Instrument concept	Passive microwave 2D-interferometer
Frequency	L-band (21 cm-1.4 GHz)
Number of receivers	69
Receiver spacing	0.875 lambda = 18.37 cm
Polarisation	H & V (polarimetric mode optional)
Integration Time	1.2 seconds
Spatial resolution	35 km at centre of field of view
Tilt angle	32.5 degrees
Radiometric resolution	0.8 - 2.2 K
Angular range	0-55 degrees
Temporal resolution	3 days revisit at Equator
Orbit	Sun-synchronous, dawn/dusk, circular orbit at altitude 755 km. 06.00 hrs local solar time at ascending node



Level 1 Prototype Processor (L1PP)

L1PP Outline

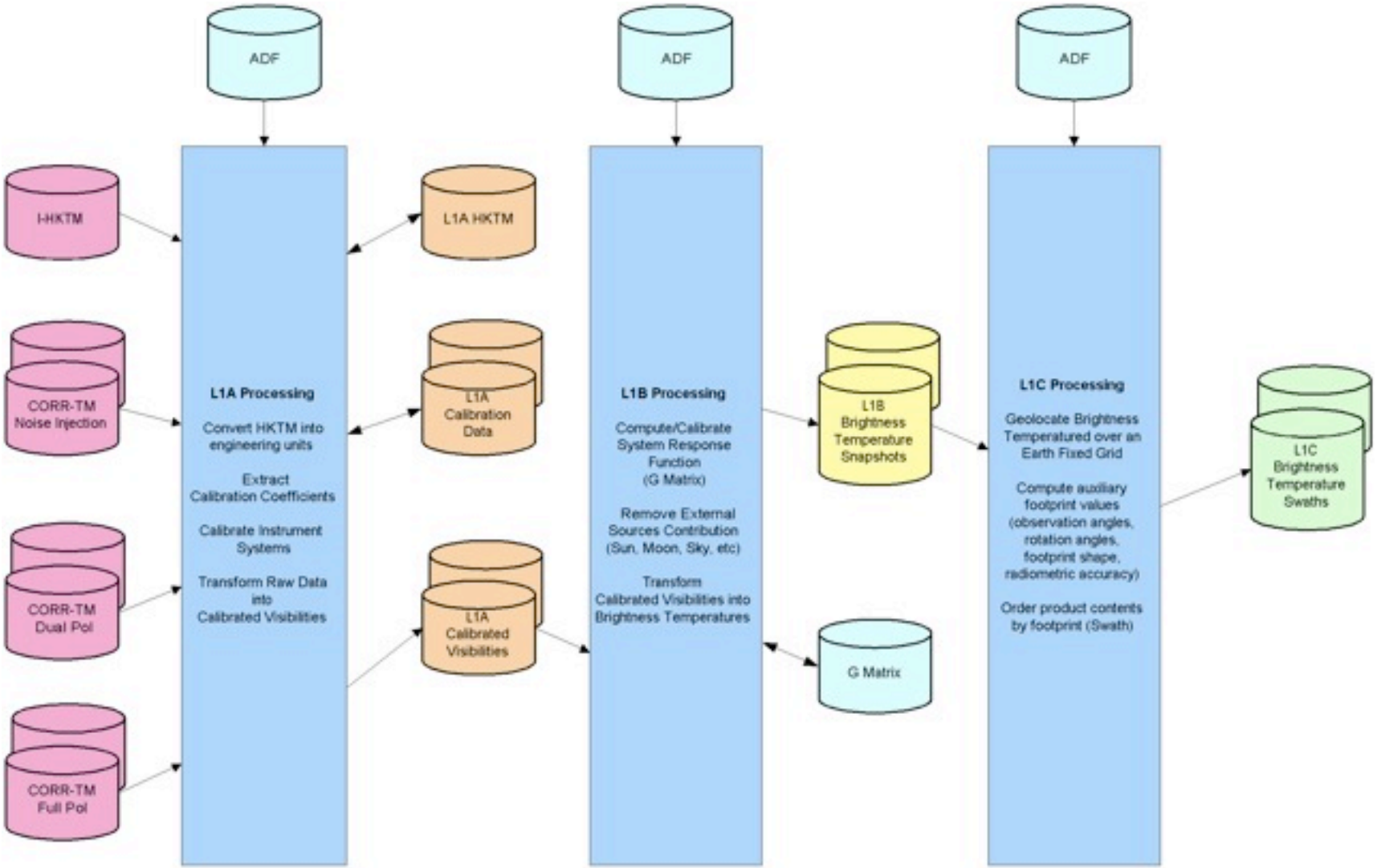
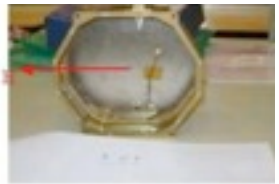
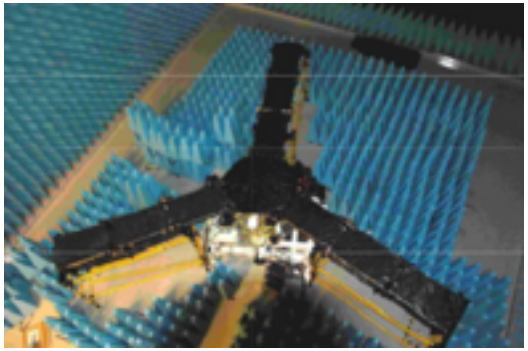
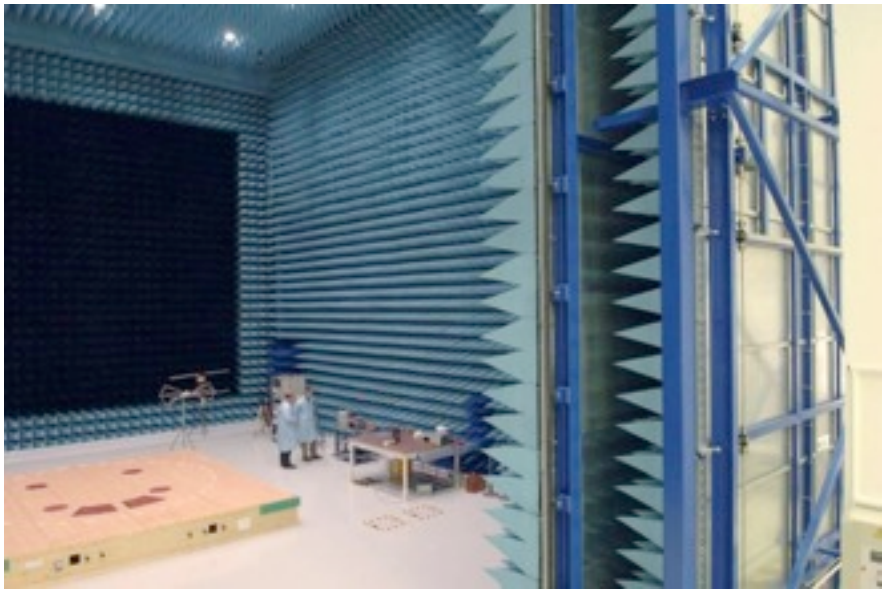


Image Validation Tests

Image Validation Tests







The Image Validation Tests (IVT) took place in the Summer of 2007 at the ESTEC's Anechoic Maxwell Chamber and provided a repository of real data to validate L1PP algorithms

IVT Objectives

The L1PP team was involved more in depth in the following tests:

Instrument check

Test the calibration sequences and generate Auxiliary Data Files (ADFs) to be used during the subsequent campaigns.

Stability Test

Analyse the correlations looking at the empty chamber ceiling in dual and full polarisation mode.
The image reconstructed with this observation permitted the analysis of a real flat scene (as opposed to SEPS-GS simulated data).

Lamp Test

Validate L1PP by generating a near field image.

Some L1PP Nomenclature

$$V_{kj}^{pq}(u,v) = \iint_{\xi^2+\eta^2 \le 1} \frac{F_{n,k}^{p}(\xi,\eta) F_{n,j}^{q*}(\xi,\eta)}{\sqrt{\Omega_k^p \Omega_j^q}} \frac{T_B^{pq}(\xi,\eta) - T_{rec}\delta^{pq}}{\sqrt{1-\xi^2-\eta^2}} \tilde{r}_{kj}\left(-\frac{u\xi+v\eta+w\sqrt{1-\xi^2-\eta^2}}{f_0}\right) e^{-j2\pi\left(u\xi+v\eta+w\sqrt{1-\xi^2-\eta^2}\right)} d\xi d\eta$$

G and J+ Matrices

The G matrix is the System Response function defined on a regular antenna grid and that transforms brightness temperatures to visibilities.
The J-matrix is obtained by changing the domain of the G-matrix and its pseudo-inverse, the J+, is responsible for the basic equation in the image reconstruction process $T = J^{+}V$

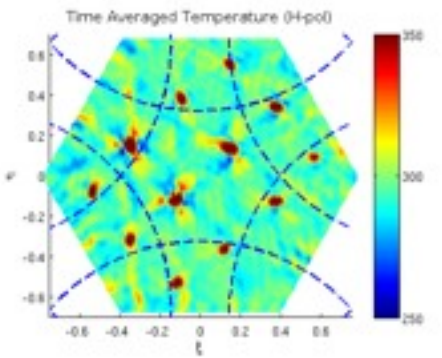
Flat Target Transformation (FTT)

Image produced by the instrument when observing a constant source (for example, the cold Sky). The Flat Target Response (FTR) will be used by the Image Reconstruction Module to reduce the errors introduced by to the Antenna Patterns

The Near Field Algorithm

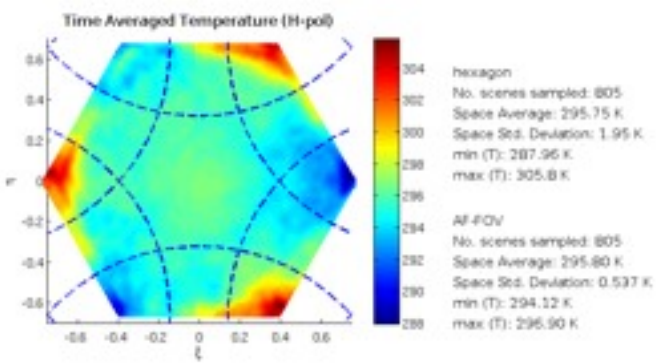
A Near Field Algorithm was derived in order to be able to image the (not-so) Empty Chamber.

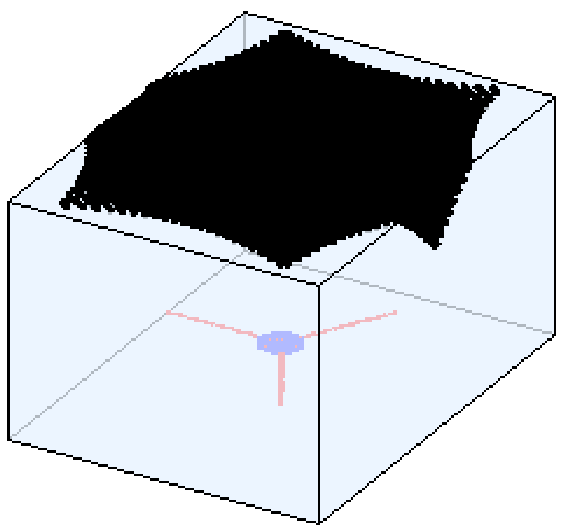
- A new flavour of the System Response Function (G-matrix) computation was created to this particular case and it has been used through all the analysis of IVT data, providing excellent results.



Left: Lamps on the ceiling of the Maxwell Chamber

Bottom: Empty Chamber Imaging





Note that the edges of the hexagon are projected on the wall

L1PP Nomenclature

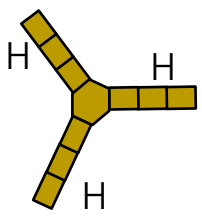
Instrument Modes

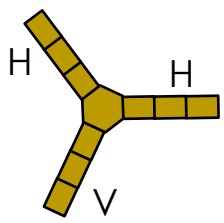
Dual Polarisation

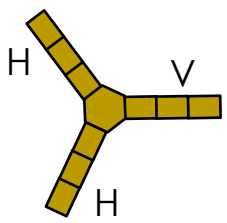
During the 1.2 seconds of the scene acquisition time, all arms of MIRAS are in the same polarisation (being either H- or V-pol) producing what is called a Pure Scene.

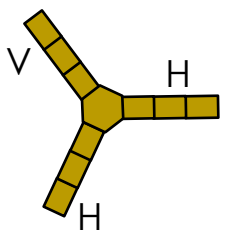
Full Polarisation

The 1.2 seconds are split in intervals of 0.4 seconds where the instrument's arms are rotating their polarisation.









1.2	H	H	H
H			
H			
H			

0.4	H	H	V	0.4	V	H	H	0.4	H	V	H
H				V				H			
H				H				V			
V				H				H			

1.2:	H-pol Scene			✓
	0.8	0.4	0.4	
	0.4	0.8	0.4	
	0.4	0.4	0.8	

1.2:	V-pol Scene			×
	0.4			
		0.4		
			0.4	

Pure H-pol Scene

Mixed H-pol Scene

Discarded V-pol scene

Repeat with the sequence **VVH, HVV, VHV** to obtain the next HV scene, as well as a Mixed V-pol scene and a discarded H-pol scene

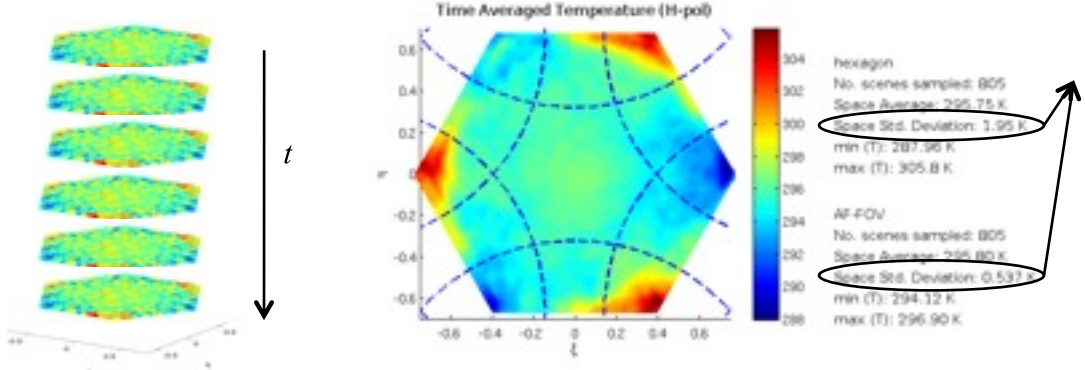
IVT – Empty Chamber Analysis

The Empty Chamber (IVT)

The Empty Chamber tests are the equivalent to Flat Scene Scenarios generated by SEPS-GS.
They provide a way to validate the statistics expected for such case.

1. Time Averaged Temperature

$$\overline{T}^{p}(\xi,\eta)=\frac{1}{N}\sum_{n=1}^{N}T_{n}^{p}(\xi,\eta)$$

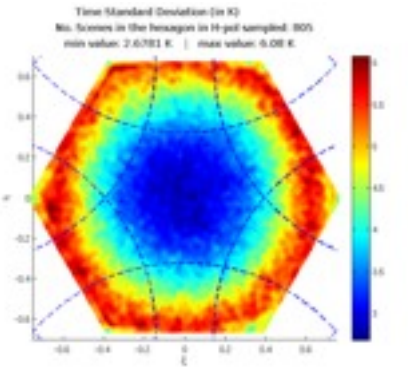


2. Space Standard Deviation
- Also corresponds to the Pixel Bias for a flat scene

$$\tilde{\sigma}\left[\overline{T}^{p}\right]=\sqrt{\frac{1}{|D|}\sum_{(\xi,\eta)\in D}\left(\overline{T}^{p}(\xi,\eta)\right)^{2}-\langle T^{p}\rangle^{2}}$$

3. Time Standard Deviation
- Also corresponds to the Radiometric Sensitivity

$$\overline{\sigma}^{p}(\xi,\eta)=\sqrt{\frac{1}{N}\left(\sum_{n=1}^{N}T_{n}^{p}(\xi,\eta)^{2}\right)-\overline{T}^{p}(\xi,\eta)^{2}}$$



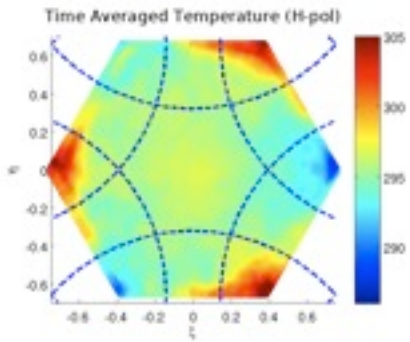
The Empty Chamber (IVT)

The Empty Chamber has been processed with several combinations of options in the image reconstruction algorithm.

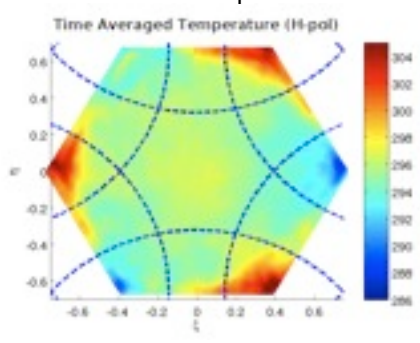
However, some aspects are common in all of the results.

* Time Average Temperature map for Dual Pol scenes, Pure and Mixed scenes is the same

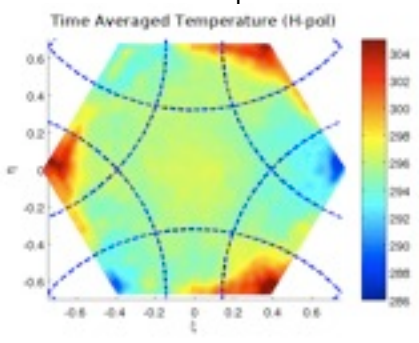
Dual | No FTT



Pure Scene | No FTT

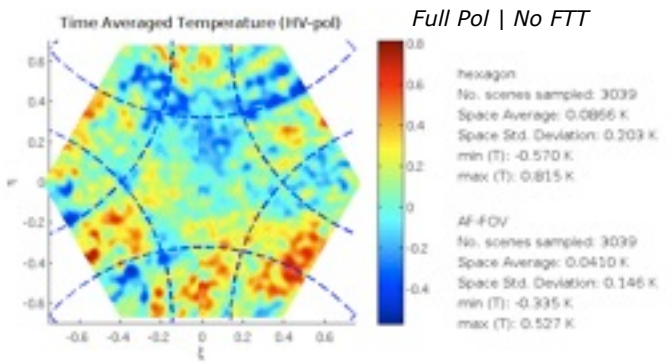


Mixed Scene | No FTT

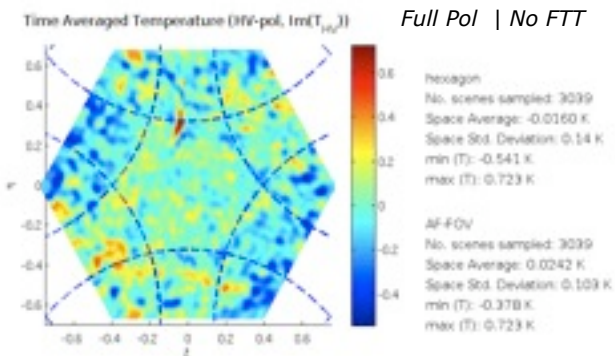


* The real and imaginary parts for T_{HV} image reconstruction resemble a random noise distribution.

Full Pol | No FTT

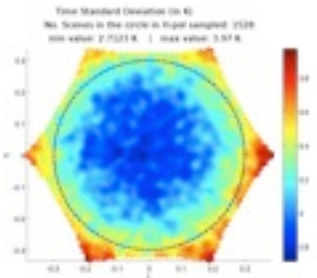


Full Pol | No FTT

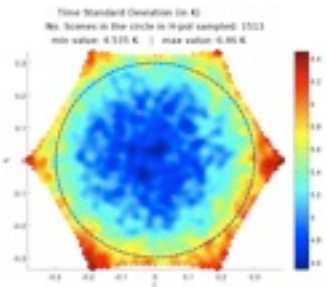


The Empty Chamber (IVT)

Time Standard Deviation makes the distinction between Pure Scenes and Mixed Scenes

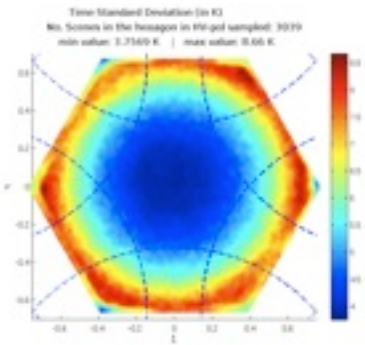


Pure Scene



Mixed Scene

Time Standard Deviation in the hexagon shows the effect of the changes needed to implement the Near Field algorithm. In the edges of the hexagon there is an increase of this statistic that is not noticeable in the Far Field imaging.



The limits of the Time Standard Deviation are associated with the Radiometric Sensitivity

Algorithm	Instrument Mode											
	Dual				Full							
	H-pol		V-pol		H-pol		V-pol		Re (HV)		Im (HV)	
	min	max	min	max	min	max	min	max	min	max	min	max
Near Field G/J$^+$ matrices	2.67	3.90	2.70	3.97	3.78	5.36	3.78	5.44	3.76	5.17	3.76	4.66
Near Field J$^+$ Matrix and FTT	2.67	3.97	2.70	3.96	3.78	5.36	3.77	5.44	3.76	5.17	3.76	4.66
Far Field G/ J$^+$ Matrices	2.48	3.68	2.55	3.68	3.69	5.10	3.70	5.09	3.45	4.59	3.45	4.20

Results for the AF-FOV in good agreement with the expected values of 2.5-3K *[SMOS-MRD]*

The Empty Chamber (IVT)

It is known that "*SMOS should provide an average radiometric resolution of 0.4 K (…) by averaging individual measurements both in space and time.*" *[SMOS-MRD]*.

The Space Standard Deviation of the Time Averaged Temperature for the following reconstruction configurations is:

Algorithm	Instrument Mode					
	Dual		Full			
	H-pol	V-pol	H-pol	V-pol	Re (HV)	Im (HV)
Near Field G/J$^+$ matrices	0.45	0.65	0.45	0.63	0.141	0.010
Near Field J$^+$ Matrix and FTT	0.31	0.37	0.31	0.37	0.141	0.010
Far Field G/ J$^+$ Matrices	0.34	0.36	0.26	0.38	0.117	0.130

* For the Near Field algorithm, the requirement is only obtained when applying the Flat Target Transformation

* With the Far Field reconstruction, even leaving all the errors introduced by the antenna patterns, the 0.4 K of radiometric resolution is achieved by L1PP's reconstruction of a flat scene.

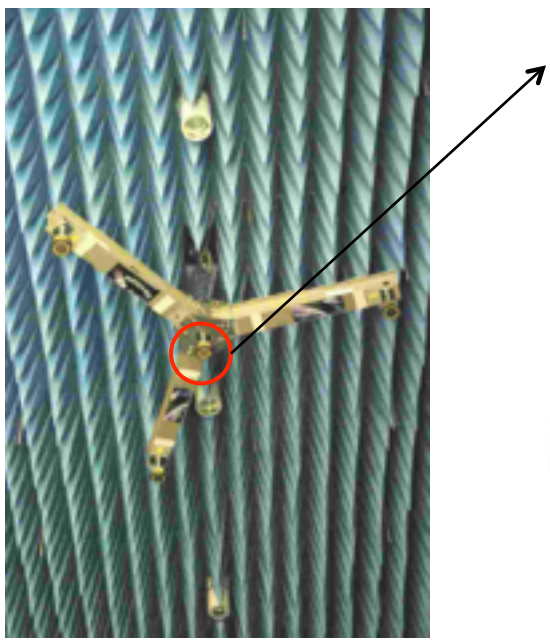
IVT – Probe O Studies

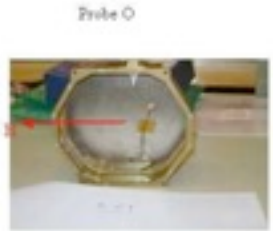
Probe O Studies (IVT)

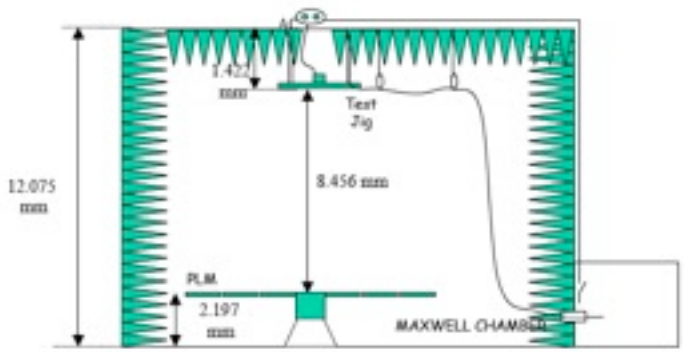
The test jig installed on the roof allowed the deployment of a LICEF acting as an emitter that provided data for validation in several aspects

- G/J+ matrices correctness: if the matrices are not properly focused on the test jig, then the resulting images would be blurred;

- Stokes parameters analysis: Aims to analyse instrument response to the total energy radiated





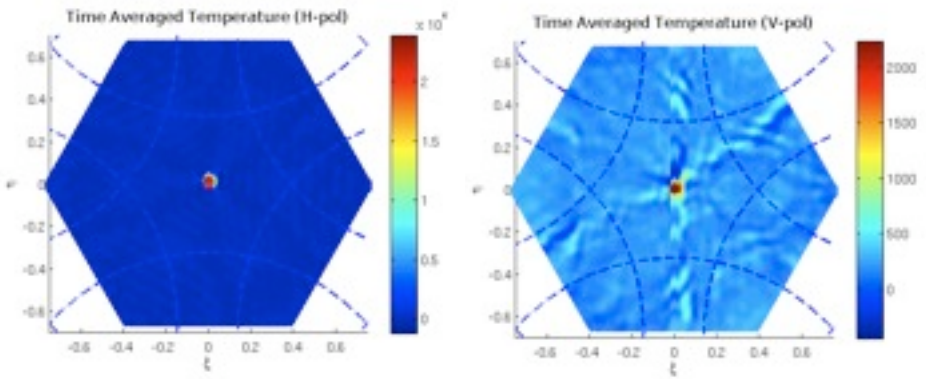


The orientation of the polarisation angle wrt the PLM permits a study of the expected vs. the received emission and a validation of conservation of energy

Probe O Studies (IVT)

Some Image Results

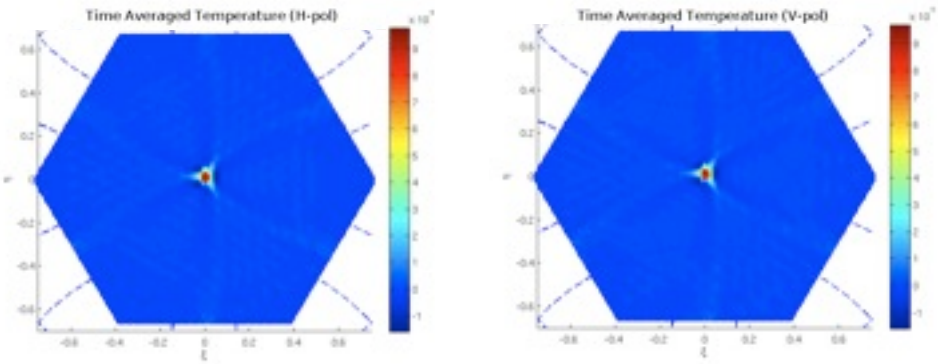
The following results are for Probe O at 0º using the G/J+ matrices focused on the test jig.



* H-pol image perfectly focused and no smearing in the image

* V- and HV show the same triangular structure

These are the results of Probe O rotated 45º but using G/J+ matrices focused on the room ceiling.



* Note that there is smearing since the probe is not focused;

* Although quantitatively the results are not correct, qualitatively it can be see that the emission in H-pol is the same as in V-pol

Probe O Studies (IVT)

Stokes Parameters

The Stokes Parameters are used to characterise the polarisation state of electromagnetic radiation.

In Remote Sensing, T_h ,T_v $Re(T_{hv})$ and $Im(T_{hv})$ can be used to write the Stokes parameters as:

$$I = T_V + T_H$$
$$Q = T_V - T_H$$
$$U = 2\,\mathrm{Re}(T_{HV})$$
$$V = 2\,\mathrm{Im}(T_{HV})$$

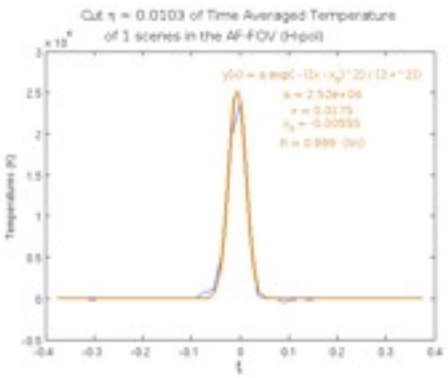
Only three out of these four parameters are independent, forming an equation of conservation $I^2 = Q^2 + U^2 + V^2$

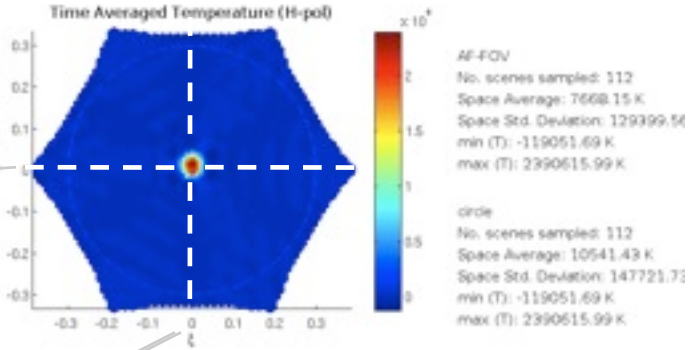
L1PP provides this set of temperatures and with them the Stokes Parameters analysis can be done.

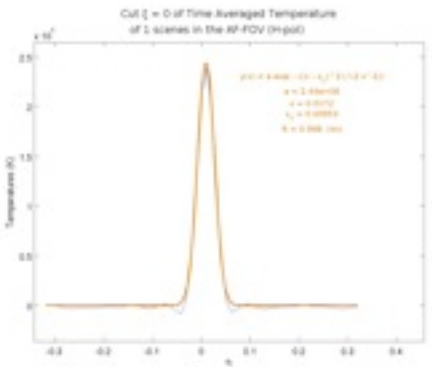
Probe O Studies (IVT)

Probe Analysis Methodology

Taking 2D cuts of (ξ, η) where $T = T_{max}$ a Gaussian fit is applied to the temperature distribution







Assuming that the distribution is symmetrical, a circular area defined by

$$(\xi - \xi_{\text{ProbeCentre}})^2 + (\eta - \eta_{\text{ProbeCentre}})^2 < 3\left(2\sqrt{2\ln 2}\sigma\right)$$

is removed from the Time Averaged Temperature and the remaining temperature map is studied.

The symmetrical statement allows us to estimate σ as

$$\sigma = avg\left\{\sigma_{\xi=\text{ProbeCentre}}, \sigma_{\eta=\text{ProbeCentre}}\right\}$$

Probe O Studies (IVT)

Using the peak values taken from the Gaussian fits, the Stokes parameters are calculated and the equation of conservation it can be seen that

$$I^2 = Q^2 + U^2 + V^2$$

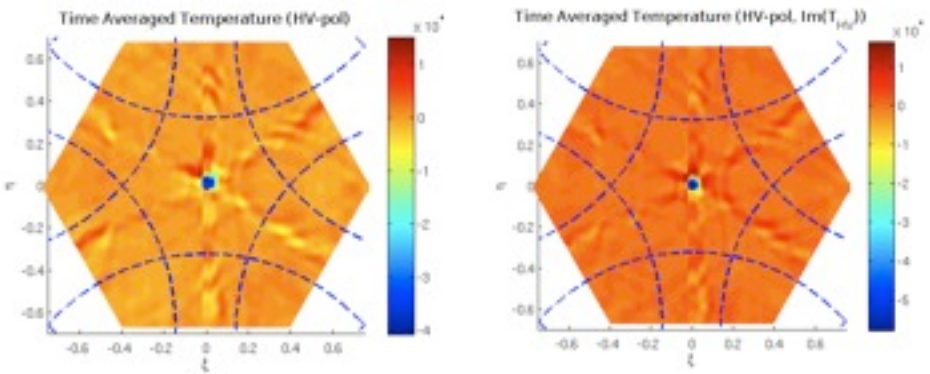
Polarisation	I^2	$Q^2 + U^2 + V^2$	$I^2 - (Q^2 + U^2 + V^2)$	
0º	6.16×10^{12}	6.16×10^{12}	-6.60×10^{8}	~0.01%
45º	6.48×10^{12}	6.65×10^{12}	-1.79×10^{11}	~2.62%
90º	6.20×10^{12}	6.19×10^{12}	1.79×10^{9}	~0.27%

* The differences between I^2 and $Q^2 + U^2 + V^2$ can be assumed as residual in the 0º and 90º case;

* At 45º it still is a very low %, but NOT if compared to its pairs.

For completion, the Full Pol images for Probe O at 0º using the G/J^+ matrices focused on the test jig.

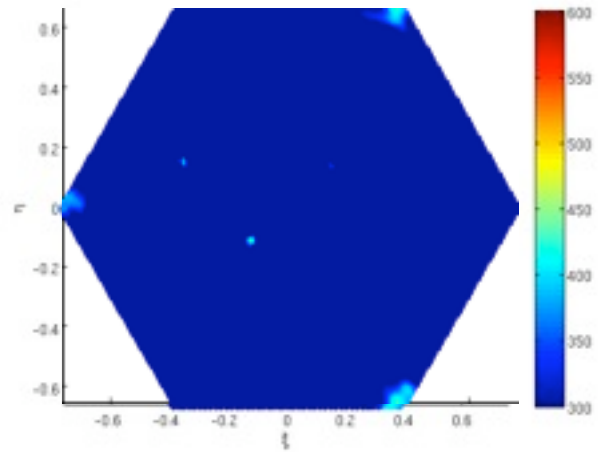
Though the Probe is placed at 0º, there is some emission in HV-pol



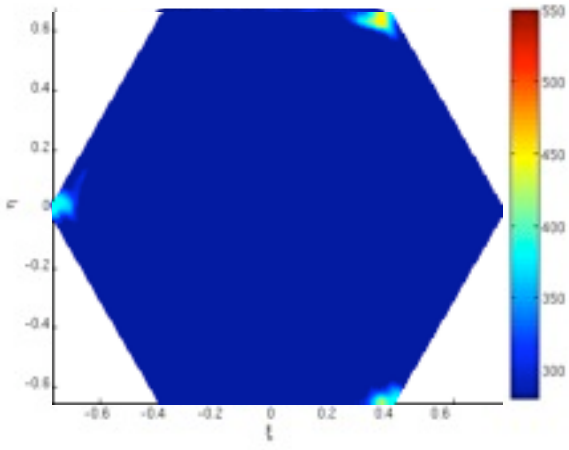
Lights Imaging (IVT)

Lights On

H-pol

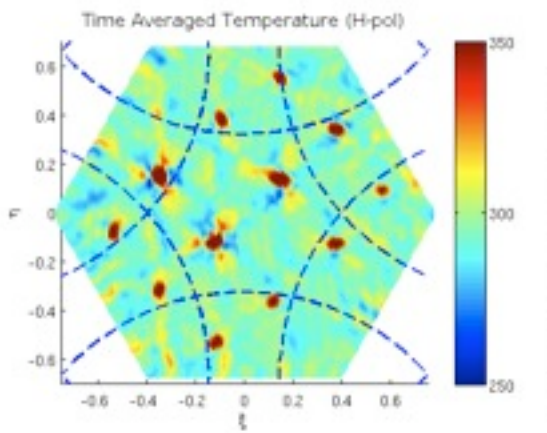


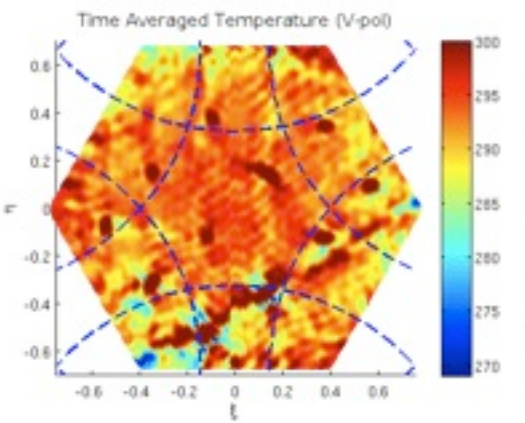
V-pol



Real time imaging of the scenes

* Gibbs effect





* Images scaled to reasonable values, consistent with the Empty Chamber;

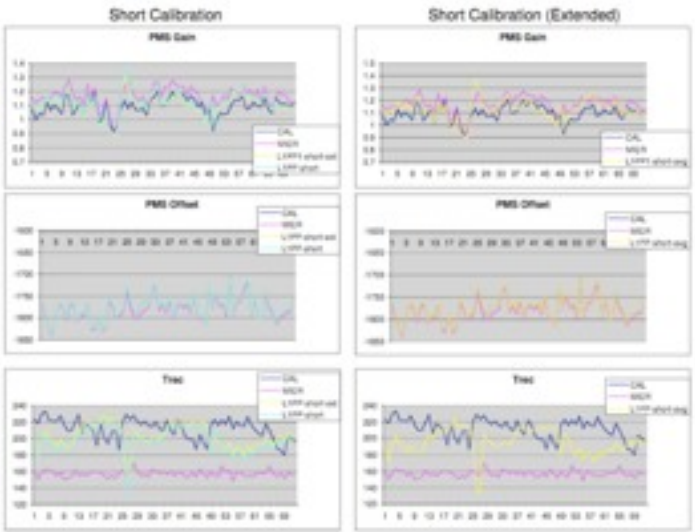
* Gibbs effect between the Lamps and the Ceiling is enough to contaminate the background -> no Gibbs analysis performed.

Commissioning Phase

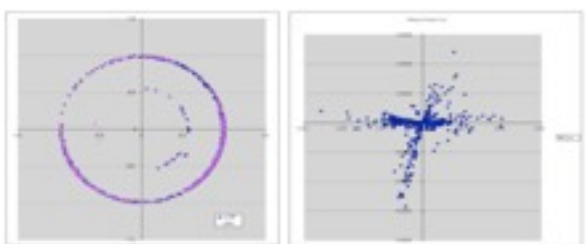
Commissioning Phase

During the IOCP the L1PP team will be involved in several tasks.

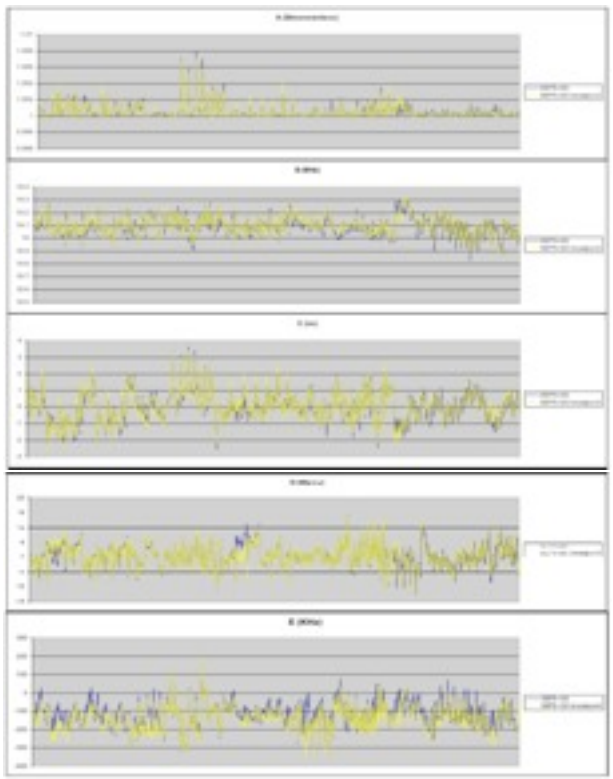
As in the IVT campaigns, Deimos Engenharia will be involved in validations in L1a algorithms, calibration sequences and overall results.



Example of PMS calibration comparison



Example of FWF(0) correlations comparison



Example of FWF shape coefficients comparison

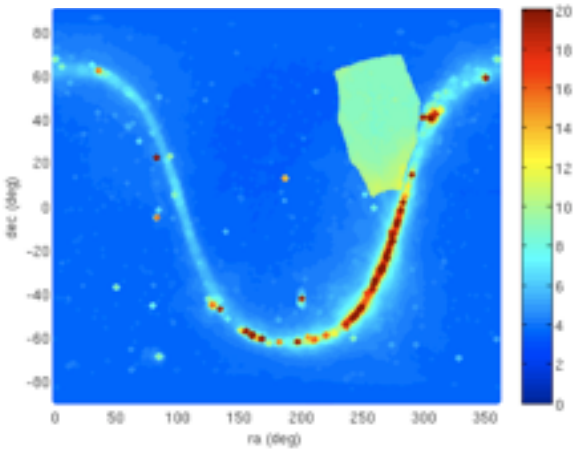
Commissioning Phase

For the **L1b** module, the L1PP team is responsible for:

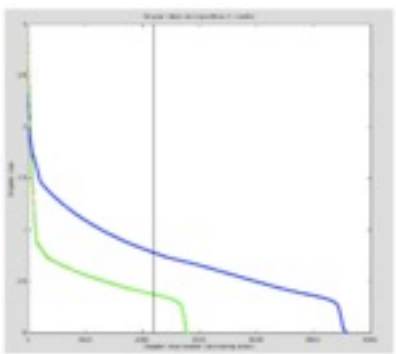
* Provide ADFs, namely the G/J+ matrices and the FTT, as soon as calibration data exists;

* Compute a rough estimate of MIRAS' accuracy through the use of a Galaxy Map Comparison Tool by inspecting the differences from an L1b scene against the Galaxy Map;

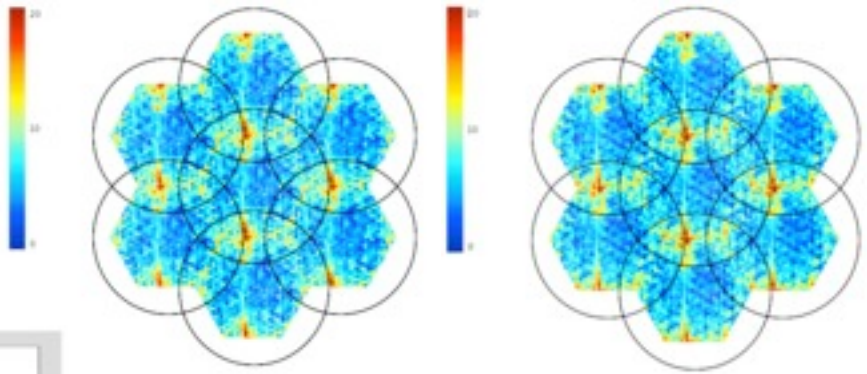
* Assess if the performances of the Foreign Sources removal are as expected.



300 Scenes and the Galaxy Map ADF



Example of SVD plots



Example of L1b Inverse Fourier Transform

Commissioning Phase

In the Geolocation process (**L1c**)the L1PP team will:

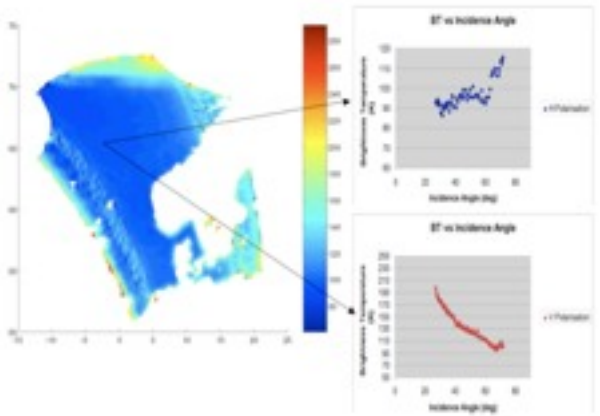
* Be involved in scientific studies with L2 teams;

* Perform studies to estimate the errors in brightness temps

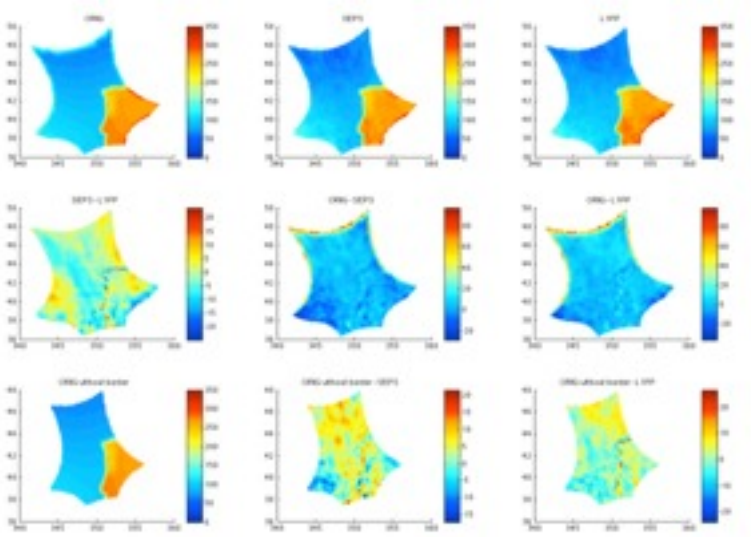
* RFI analysis.

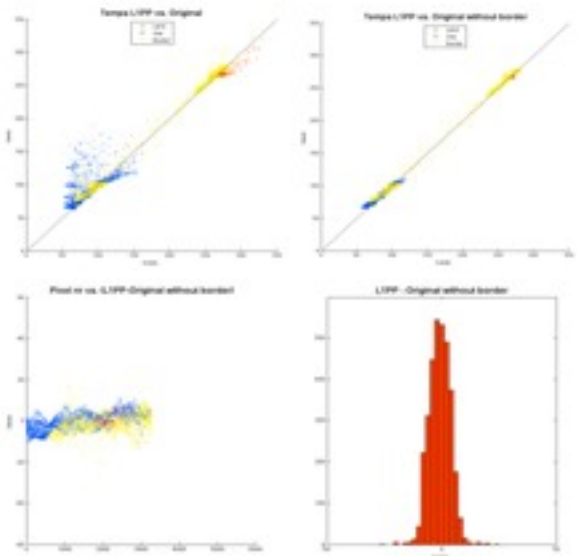
* Comparison with Forward Models;

If so, similar plots as the ones performed now for L1PP-SEPS-GS cross- validation are possible, showing scene bias, pixel bias, AF-FOV analysis and histograms.



Example of L1c pixel plots





Example of a Dual Pol scene

Study performed comparing the Simulated scene with the reconstructed one using Flat Target Transformation [L1PP 1610 test scenario]

Thank you