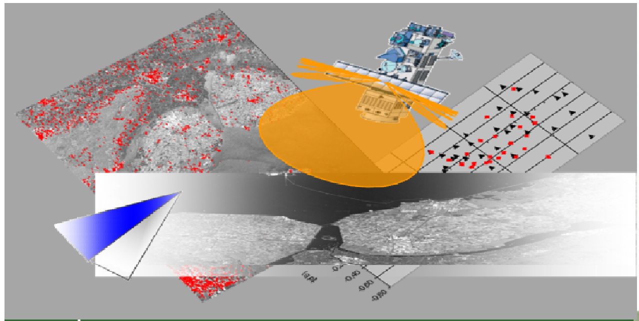

POLITECNICO DI MILANO

Dipartimento di
Elettronica e Informazione

PS calibration: performance enhancement and antenna pattern estimation

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aresys

Project supported by Agenzia Spaziale Italian (ASI), project -1080 - *SAR data Calibration and Validation by Natural Targets*

OUTLINE

- SAR calibration: traditional approach
- PS cal: a complementary cost-effective technique for SAR calibration
- PS calibration technique overview
- PS cal sample results
- Algorithm enhancement: Fast calibration
- Last results:
  - PS cal quality performance by Monte Carlo
  - Differential elevation antenna pattern estimation

Preface

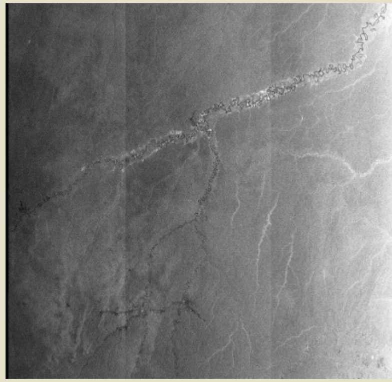
Current SAR radiometric and geometric calibration techniques make use of external references:

- homogeneous stable targets, mainly the rain forest
- active and passive reflectors (transponders, corner reflectors)

☞ Corner and transponders of high quality are expensive

☞ they demand for dedicated acquisitions interfering with operations,

☞ they cannot deployed all over the swath and in many sites, thus limiting the capabilities of monitoring variation along the orbit (ionospheric effects, thermal etc).



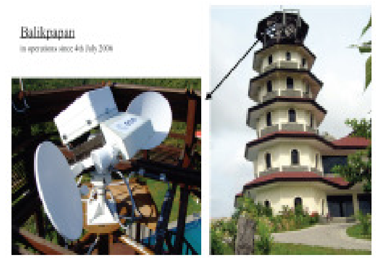
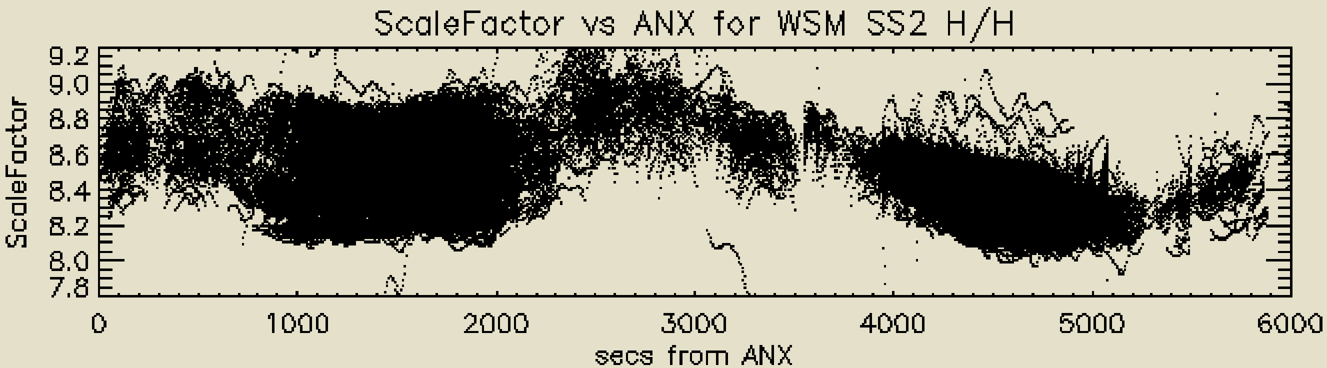
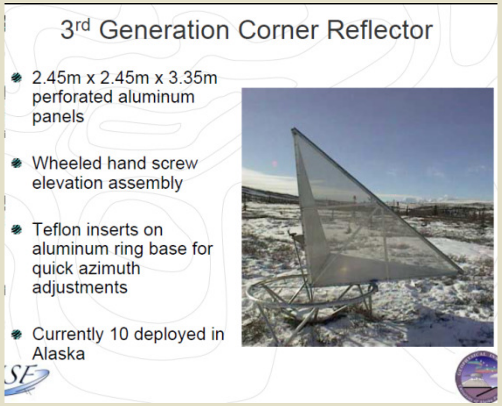


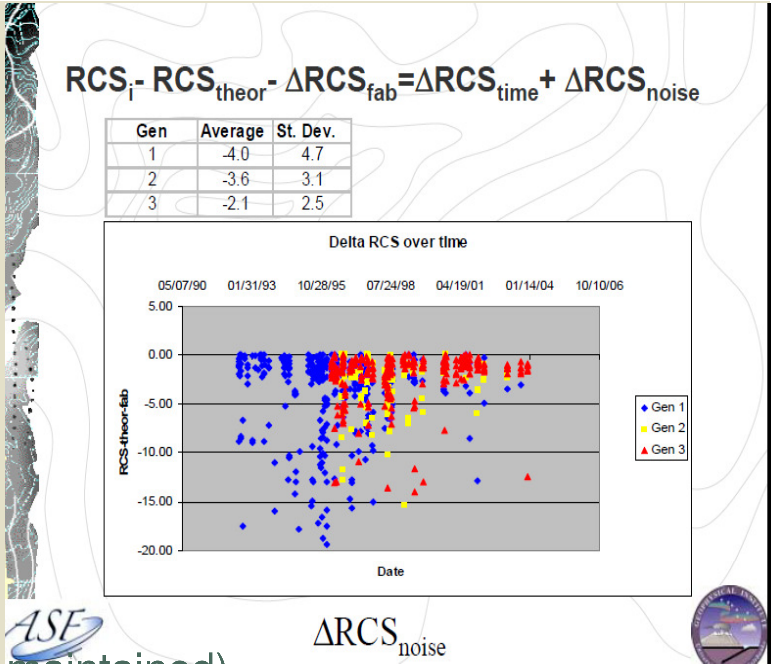
Figure 10. ASAR Transponder set-up at Balikpapan, Indonesia.



Motivation

Making the RCS stable within **a fraction of the dB** in the long term demands a skillful design and expensive maintainance.





Calibration by natural stable targets (PS) is:

- cost-effective (targets are natural, no need to be maintained),
- robust and accurate (thousands of targets),
- available all over the world with no need of dedicated acquisitions.

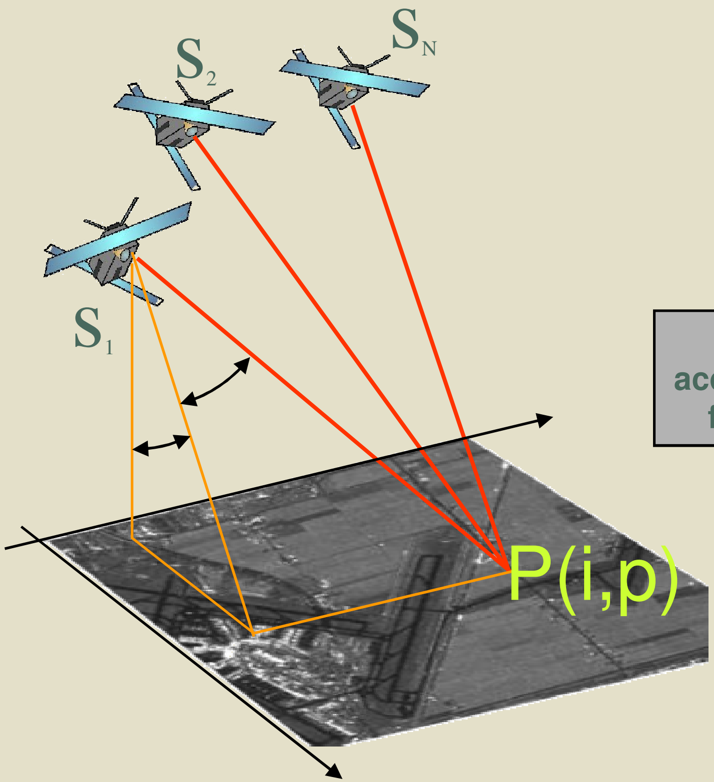
PS cal has other important applications:

- It gives an accuracy on the gains estimate
- can be used to estimate antenna pattern

Reference targets (corners or transponders) are still needed in the commissioning phase to provide absolute calibration of the PS series.

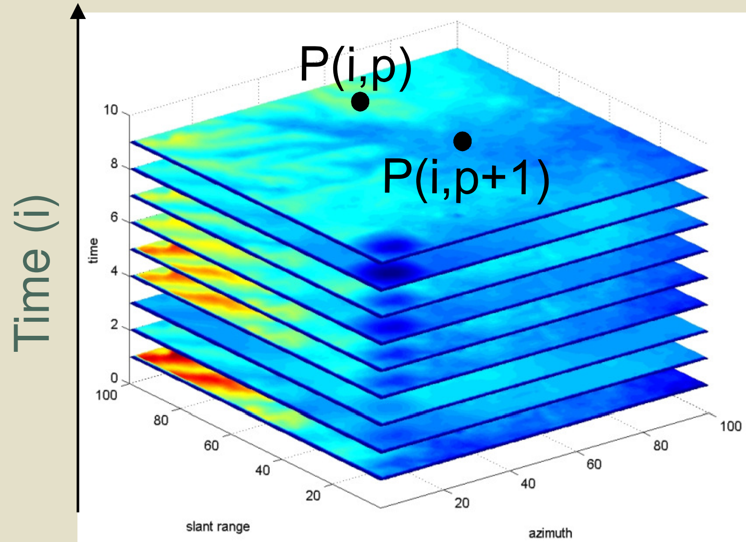
PS cal: Multiple Targets Multiple Images

System geometry



SAR acquisition & focusing

Observations (images stack)



model

PS phases

$$y_i(P_p) = a_i \left(b_p \exp\left(j\varphi_{i,p}\right) + w_{i,p}\right)$$

- $2N_P+N_I$ unknown :
  - **PS amplitude**
  - **PS "quality" (noise variance)**
  - **Images amplitude**
- $N_P \times N_I$ data
- $N_P \times N_I$ unkown phases !

Data stack (SLC) | N_I Images amplitudes | N_P PS (amplitudes) | noise (clutter & thermal)

ML incoherent estimation

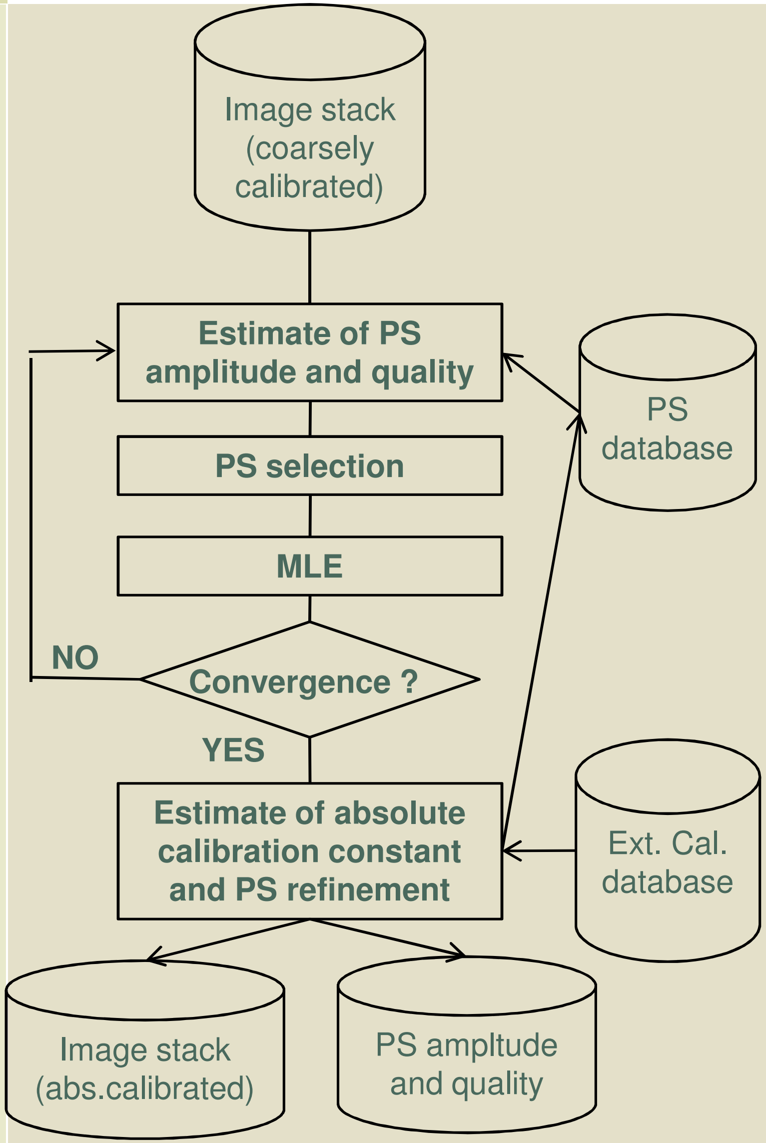
The data model can be expressed in terms of the Kronecker product between the N_I image amplitudes and the N_P PS amplitudes.
The PS phases depends on the target (its 3D location) and the image (PS motion and Atmospheric Phase Screen): we have $N_I \times N_P$

$$\begin{bmatrix} \begin{bmatrix} y_{1,1} \\ \dots \\ y_{1,N_P}\end{bmatrix} \\ \mathbf{y}_2 \\ \dots \\ \mathbf{y}_{N_I}\end{bmatrix} = \begin{bmatrix} \exp(j\varphi_{1,1}) & & & \\ & \dots & & \\ & & \dots & \\ & & & \exp(j\varphi_{N_I,N_P})\end{bmatrix} \cdot \begin{bmatrix} b_1 \begin{bmatrix} a_1\\ \dots \\ a_{N_I}\end{bmatrix} \\ \dots \\ \dots \\ b_{N_P}\begin{bmatrix} a_1\\ \dots\\ a_{N_I}\end{bmatrix}\end{bmatrix} + \begin{bmatrix} w_{1,1} \\ \\ w_{N_P,N_I}\end{bmatrix} \Rightarrow \mathbf{y} = \mathbf{\Phi}\cdot\left(\mathbf{b}\otimes\mathbf{a}\right) + \mathbf{w}$$

We remove phase dependency by taking image amplitudes

We can write the Maximum Likelihood expression, for the estimate of PS amplitudes and qualities and images phases.
There is not a known closed-form solution !

Non coherent ML: iterative approach



ML solution is found by iterating. At each iteration two searches are made :

- first on the images (to estimate PS amplitude + quality, PS detection)
- then on the PSs (to estimate image amplitude)

Convergence is acheived provided that initial calibration is good enough.

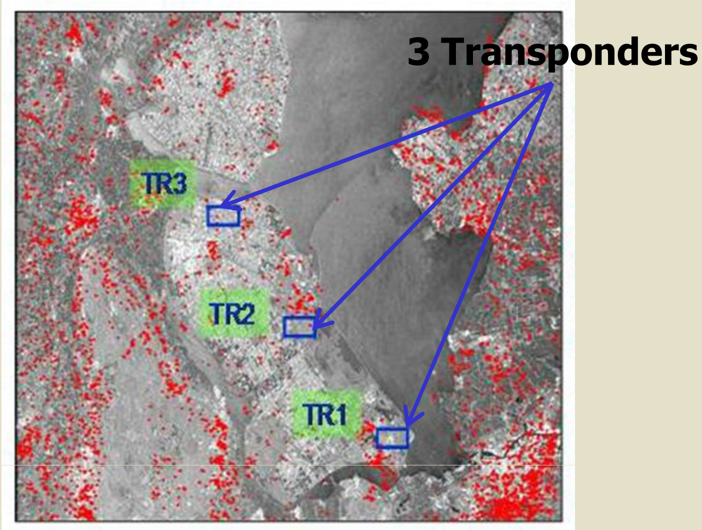
Absolute calibration is then perfomed by exploiting external calibrators.

PSCal : Test Site

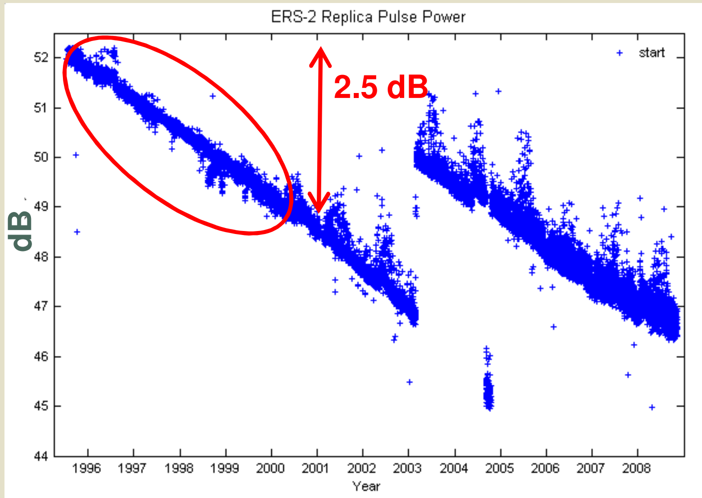
Validation has been performed by ERS data. The site considered is Flevoland.

	Flevoland
Acquisition dates	1995-2000
Number of images	42
Image size (range, azimuth)	60x100km
Number of PS (threshold > 4.1)	17611
Normal Baseline	560 m.
Temporal Baseline	1.4 years
Doppler centroid span	120 Hz

Incoherent averages the images (PS are marked with red dots)



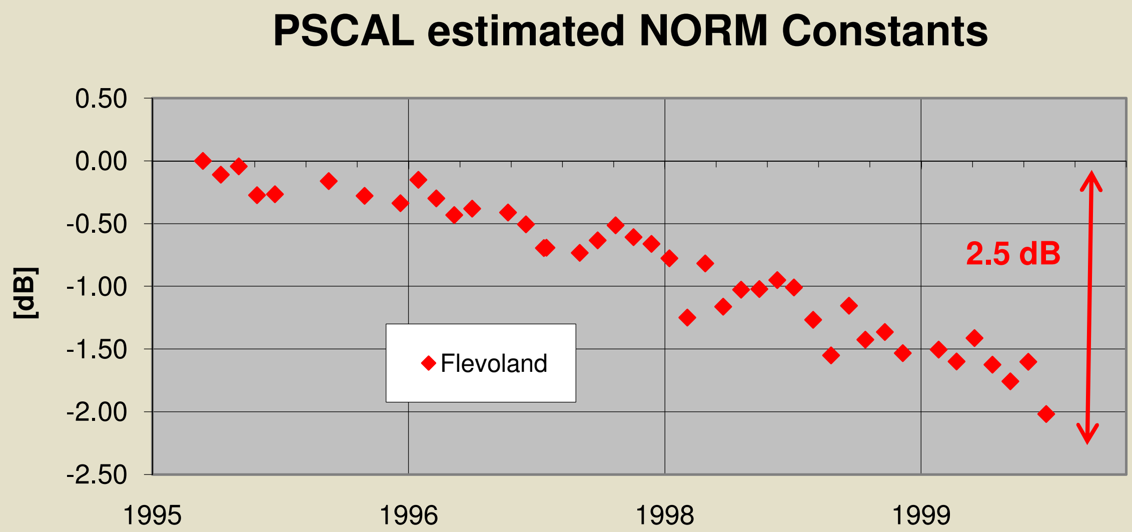
Flevoland



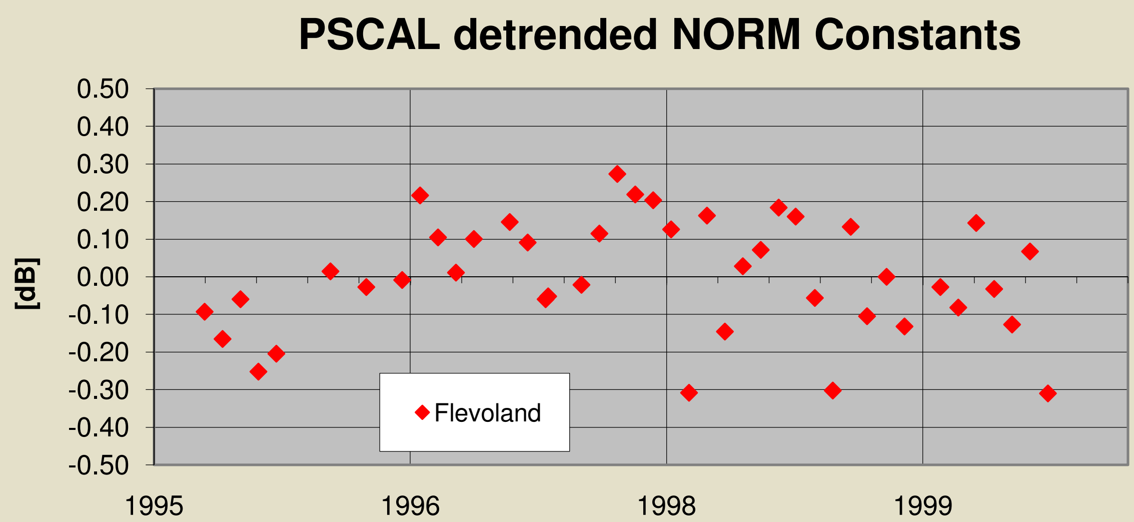
Trend of ERS-2 pulse powers (Meadows et al.)

From 1995 to 2000 the system shows a loss of about 2.5 dB

PSCal ERS-2: Flevoland

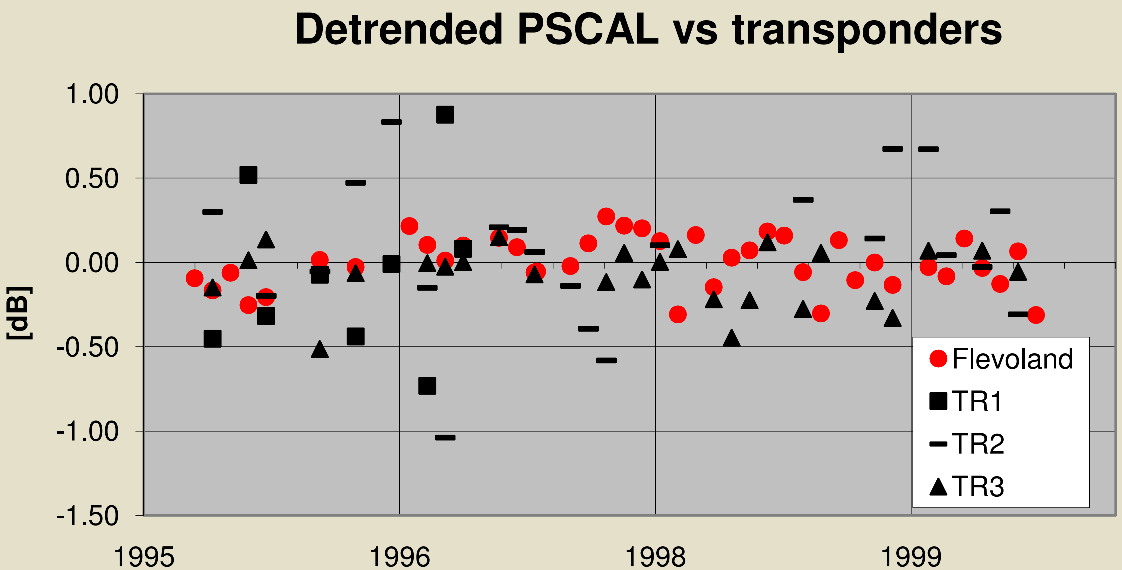


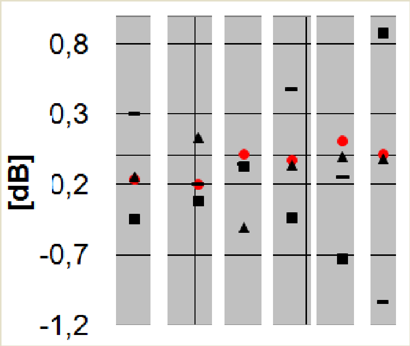
PS calibration technique shows the same loss



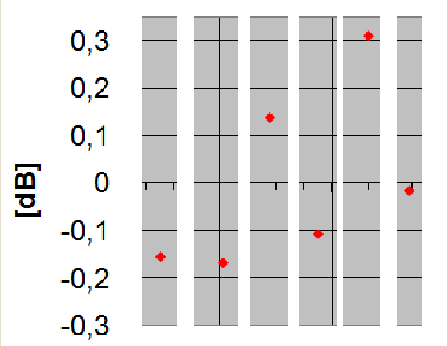
Std of the detrended NORM Constants: 0.16 dB

PSCal ERS-2: Flevoland vs. Transponders





Gain measured by the PS and that of the three transponders on the same dates.



Difference between the PS gains and the average of the three transponders.

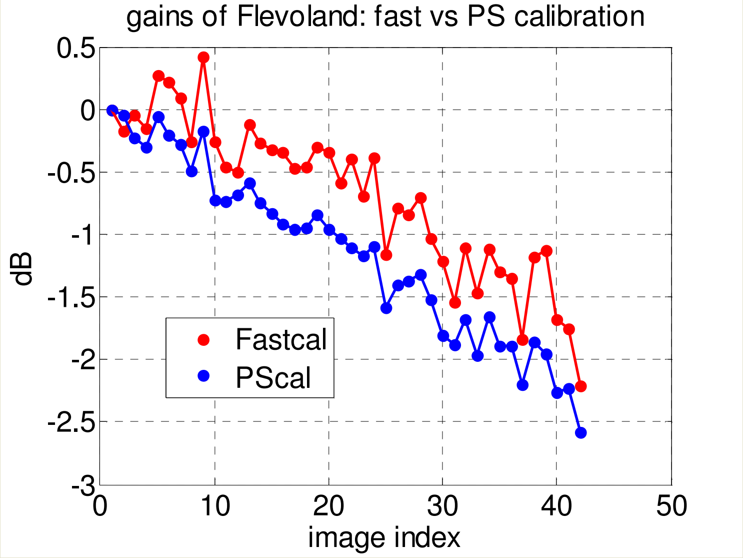
Dispersion of the 3 transponders w.r.t. the PS calibration.

- **TR1: 0.51 [dB]**
- **TR2: 0.65 [dB]**
- **TR3: 0.35 [dB]**
- **PScal: 0.16 [dB]**

Fast calibration

The calibration problem (i.e. the estimate of the gains of images) can be solved approximately through singular value decomposition.

PS model	Exact solution	Approximate solution
$y_i(P_p) = a_i\left(b_p \exp\left(j\varphi_{i,p}\right) + w_{i,p}\right)$	MLE	SVD



Flevoland gains: red ones are got through SVD, blue ones through MLE

The mathematical problem solved through SVD is

$$\min_{\alpha_i,\beta_p} \sum_{i=1}^{N_I} \sum_{p=1}^{N_P} \left(\left| y_i(P_p) \right| - \alpha_i \beta_p \right)^2$$

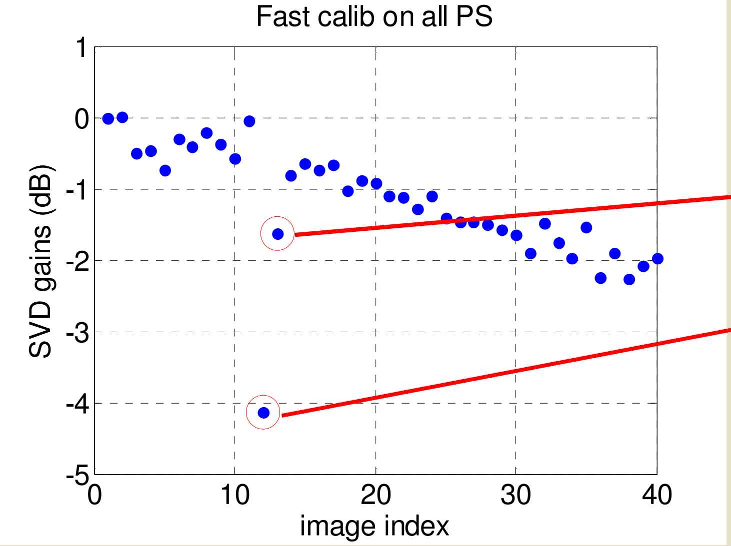
with the constraint $\alpha_1 = 1$

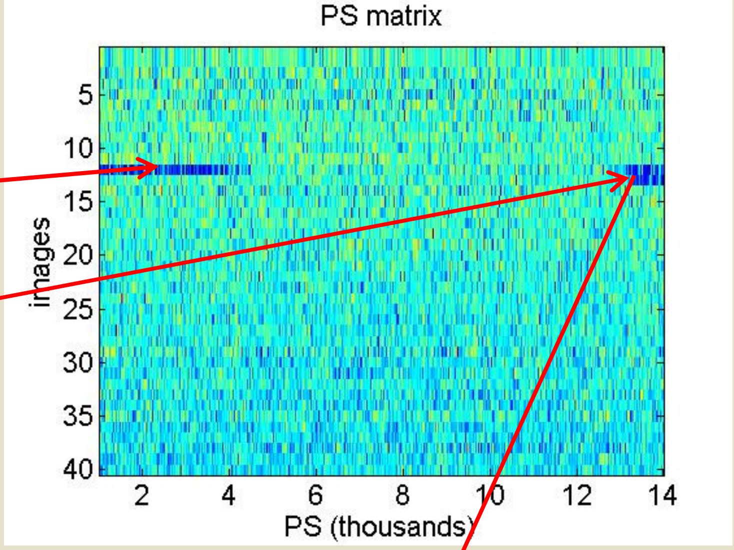
Fast calibration can be used as the initial guess to solve the MLE iterative system.

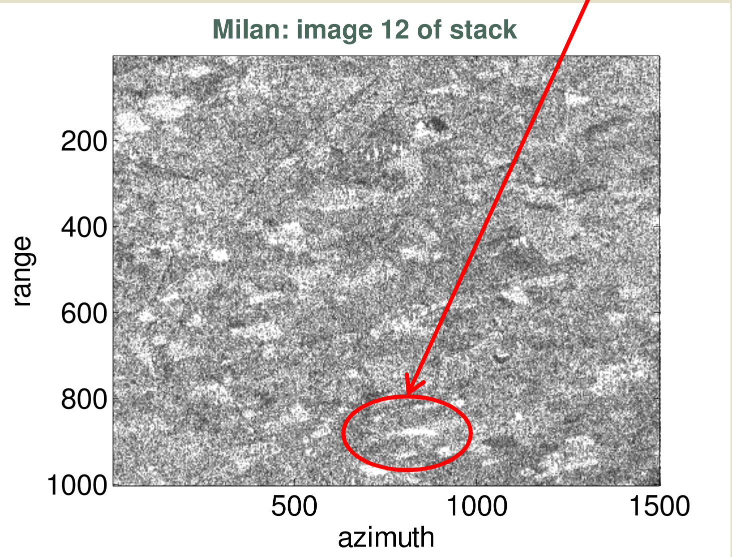
Since the initial point is very closed to the actual solution few steps are required in order to achieve the convergence

Fast cal: detection of artifacts

Fast calibration can detect problem on focused images!







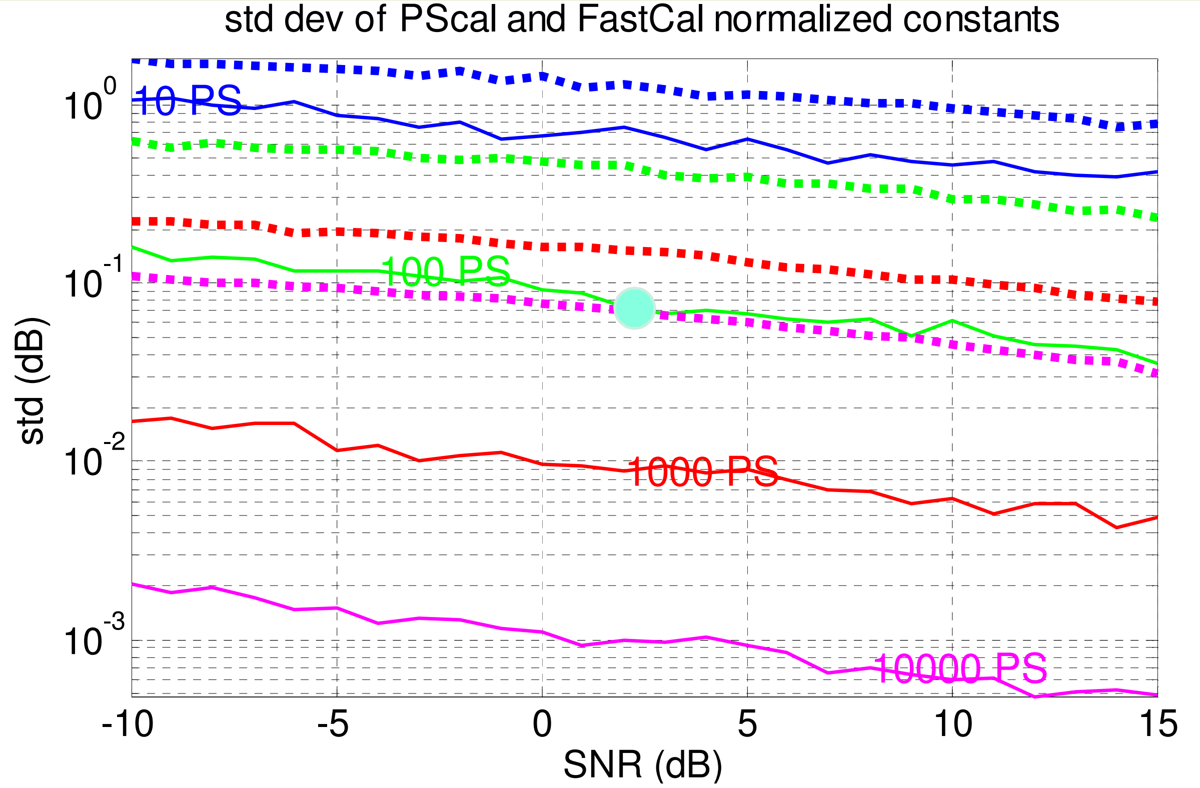
Fast calibration has been applied on all the PSs available. The images 12 and 13 result outliers w.r.t. a normal distribution of the residuals.

A further investigation on PS matrix shows that some PSs are wrong.

From PS matrix is possible to identify the area of the image affected by errors.

Fast cal accuracy vs PS cal

MC simulations show the impact of SNR and PS number on std of gain estimate.



- Behavior of std of gains for different levels of PS SNR and different number of PS.
- Dotted lines concern the Fast calibration, continuous lines the PS calibration.

Estimated gains (PS or Fast)

$$20\log_{10}\left[1+\sqrt{E\left(\frac{\hat{a}}{a}-1\right)^2}\right]$$

Expectation

Simulated gains

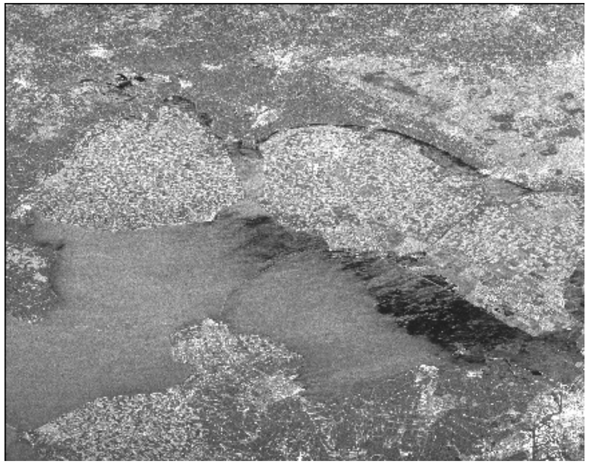
100 PS (with 3 dB of mean SNR) guarantee a dispersion < 0.05 dB !

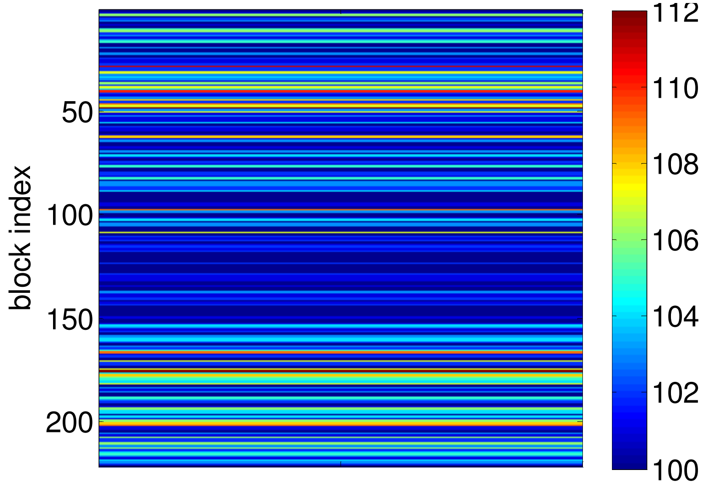
Pattern Antenna Estimate

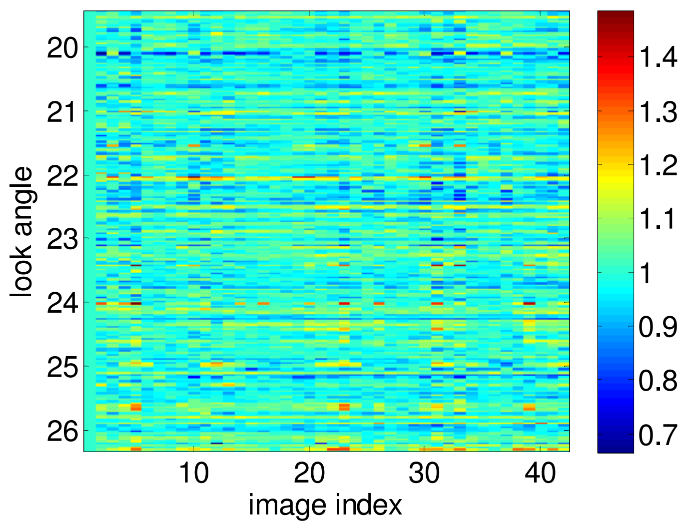
PS calibration can be applied to each azimuth block to estimate differential antenna pattern.

The stack has been decomposed into 221 blocks with at least 100 PS for each block.

Flevoland





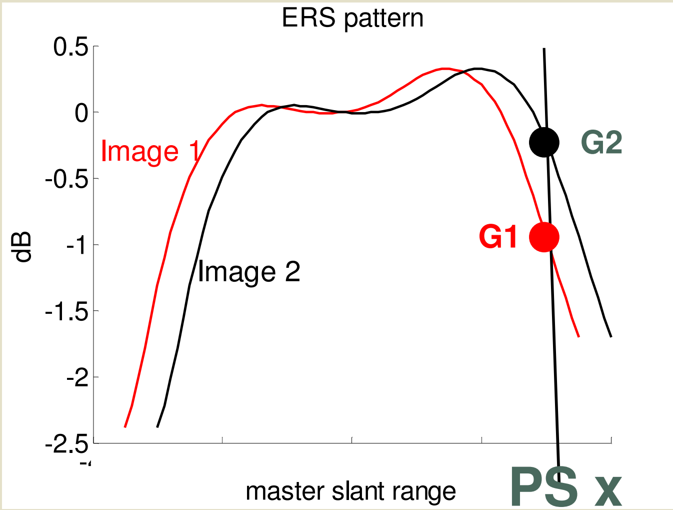


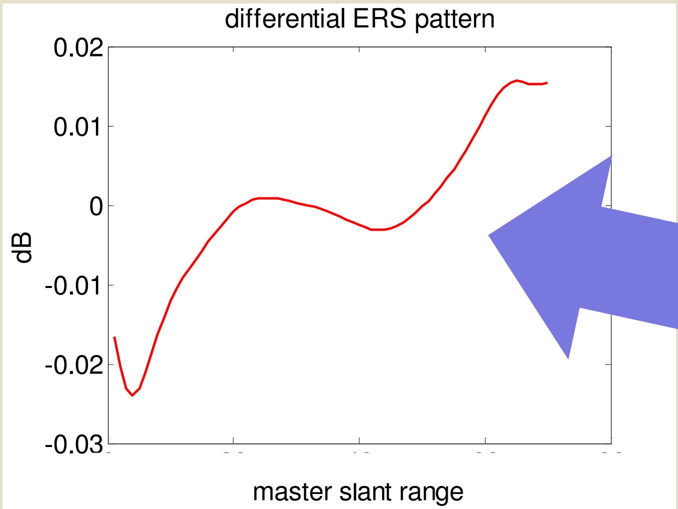
PS calibration technique has been applied to each block in order to evaluate the gains and each azimuth index has been mapped into an angle.

Differential Pattern Antenna

For this test we used a stack of SLC data **not radiometrically corrected**

This means that, due to the different acquisition geometries (baseline), the same PS has been acquired under a slightly different antenna (and spreading loss) gain





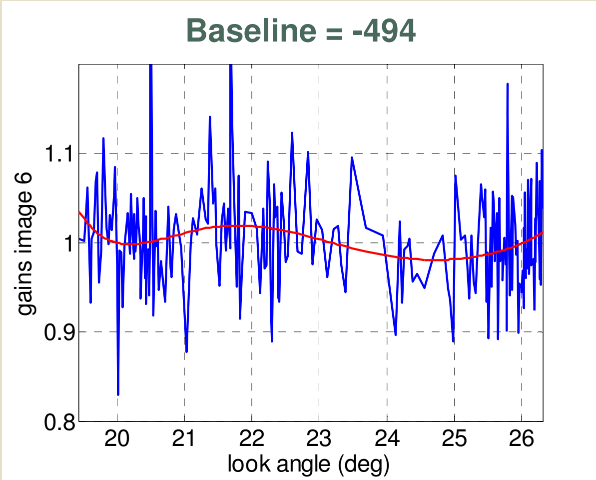
Block-wise PSCAL analysis should then retrieve the range-variant difference of gain

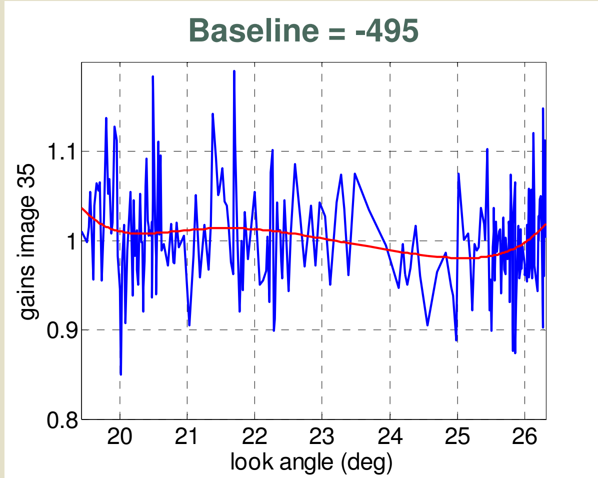
(differences are here exaggerated to simplify the understanding)

Differential Pattern Antenna

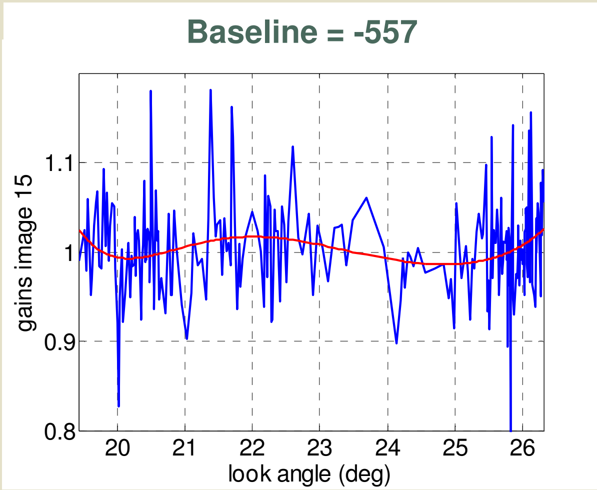
Sample range variant calibration constants 4 interferometric pairs

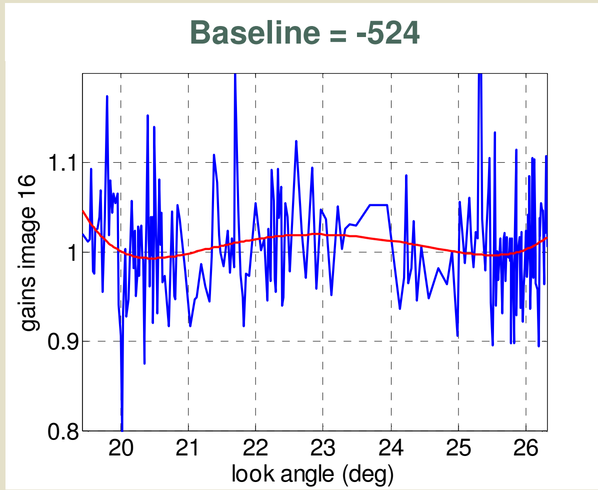
Data (blue lines) have been fitted with fourth order polynomial (red one).





Different images show the same pattern behavior.





Next step: quantitative comparison with theoretical differential pattern !

Conclusions

Up to now, PS calibration technique has shown some important features.

1. It allows for a large number of costless calibration sites, all around the world, without interfering with mission operations.
2. Preliminary validation on ERS-2 series shows an accuracy comparable with the best results selected form a set of three transponders (0.06 dB).

New features have been shown:

1. The PS calibration can be enhanced through the Fast calibration
2. The number of PS necessary to achieved an accuracy of 0.05 dB on gains is about 100
3. Multi block analysis can be exploited to estimate the differential antenna elevation pattern

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Thank you