On the Characterization of Frequency-Persistent Scatterers in Split-Band Interferometry

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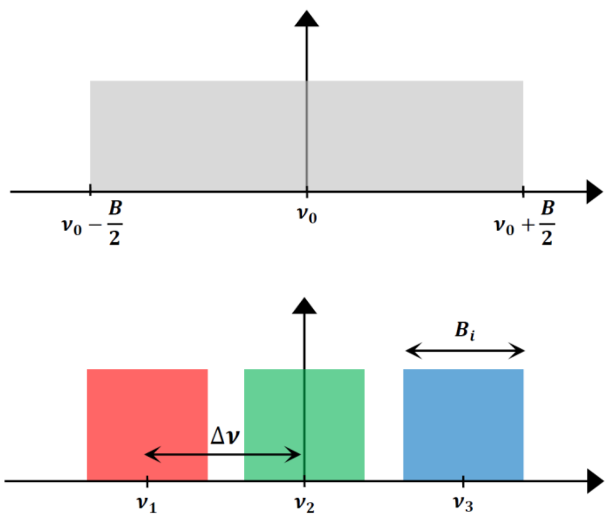
Split-Band Interferometry

Split-Band Interferometry is a three-step process using the dispersive information of SAR images:

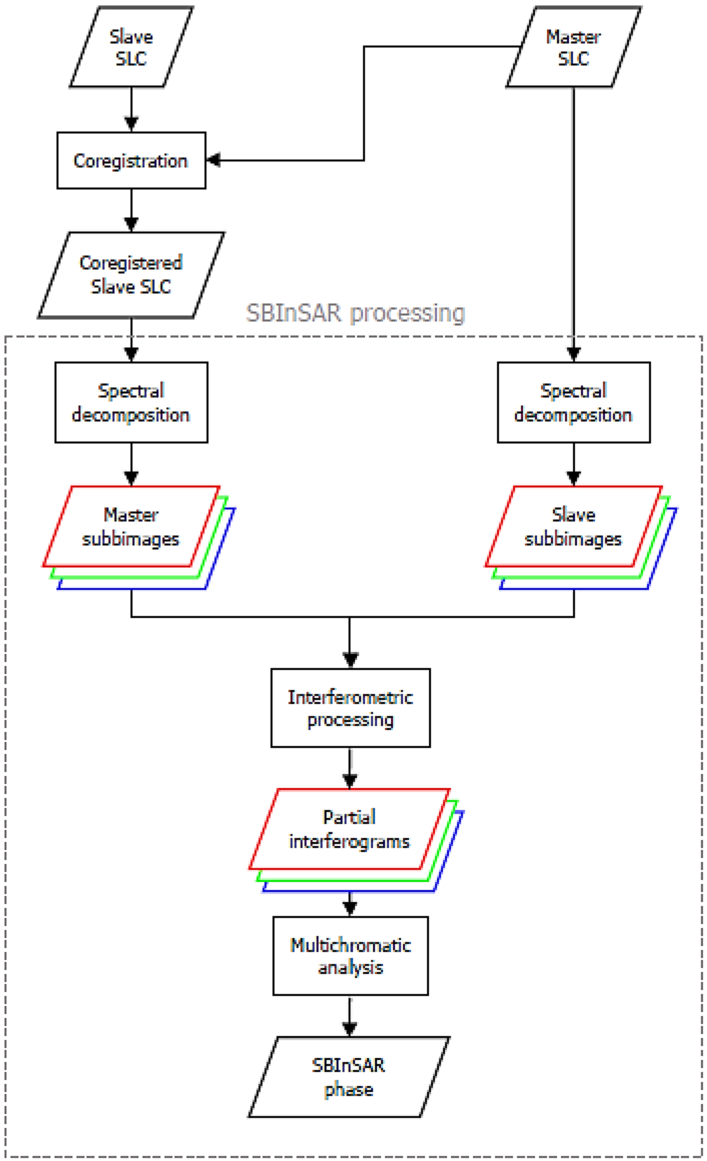
1 – Spectral decomposition of master and slave images

2 – Interferometric processing of subbands scenes

3 – Multichromatic analysis



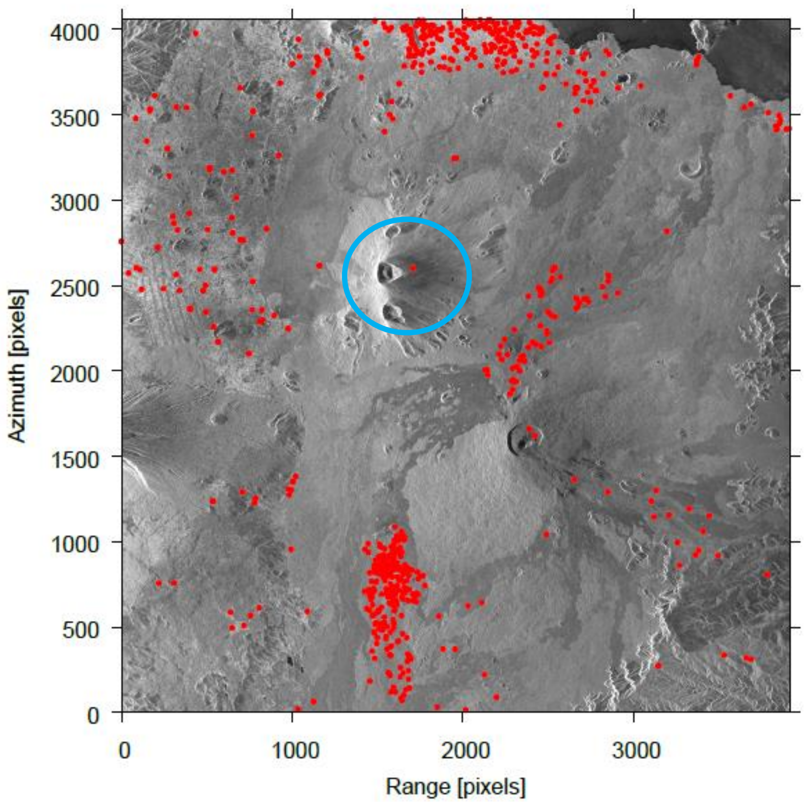
It provides **absolute phase measurements** for targets with a stable phase behaviour across the frequency domain. These targets are usually called **frequency-persistent scatterers (PS$_f$)**.



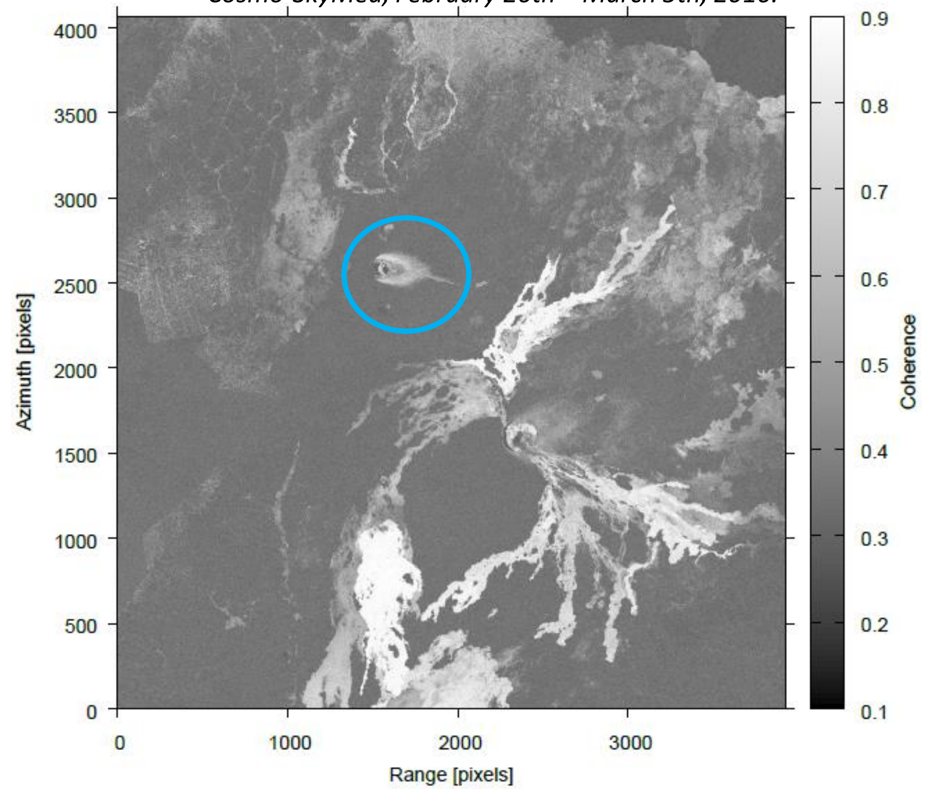
Libert et al. (2017), Split-Band Interferometry-Assisted Phase Unwrapping for the Phase Ambiguities Correction, *Remote Sensing*.

Split-Band Interferometry

Split-Band Interferometry relies on the need for reliable frequency-persistent scatterers within the studied scene, ***while we do not know exactly what is a PS_f.***



Cosmo-SkyMed, February 26th – March 5th, 2016.



Questions:

- What is the **physical nature** of a frequency-persistent scatterer ? What **feature** makes it stable with respect to the frequency ?

- Is a frequency-persistent scatterer **stable** in time ? Is the spectral stability **stationary** ?

- Could frequency-persistent scatterers be used for **monitoring** ? Could we create **artificial** PS_f, like corner reflectors or transponders ?

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↳ **Temporal analysis**

↳ **Investigation of the backscattering mechanisms**

Temporal analysis

Data set: 5 TerraSAR-X Stripmap acquisitions over the **Virunga Volcanic Province** in Democratic Republic of Congo.

150 MHz bandwidth - incidence angle of 26° - horizontal co-polarization (HH)

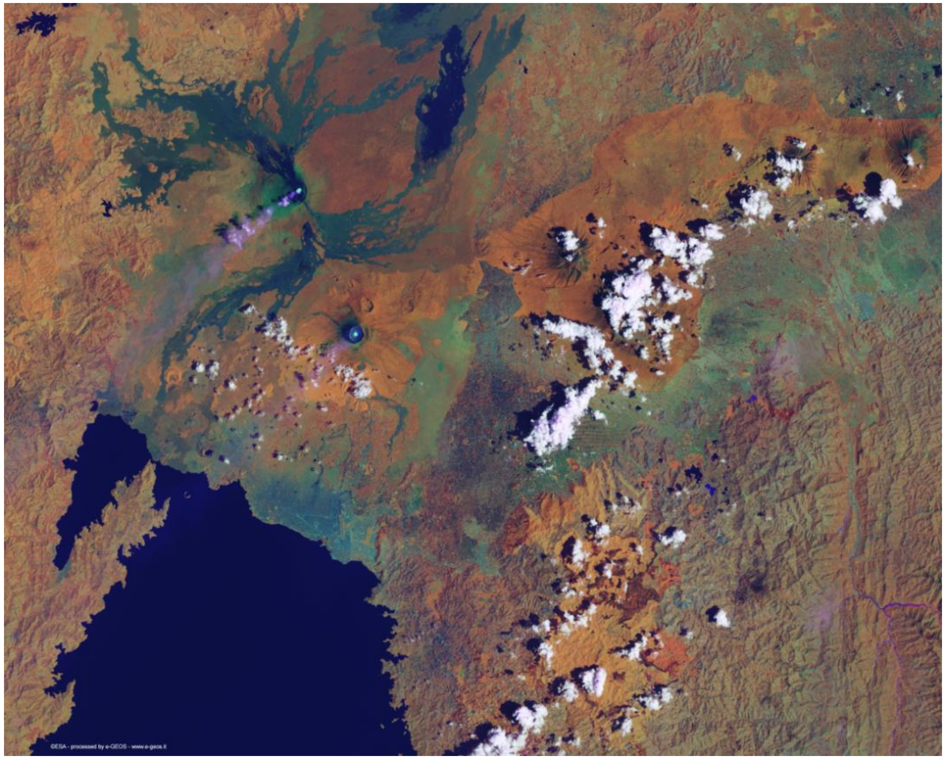
Processing: 4 pairs with a common master image → **Temporal reference**

Spectral decomposition: 5 non-overlapping subbands of 30 MHz

PS_f detection: slope standard deviation

→ **4 PS_f populations corresponding to different dates**

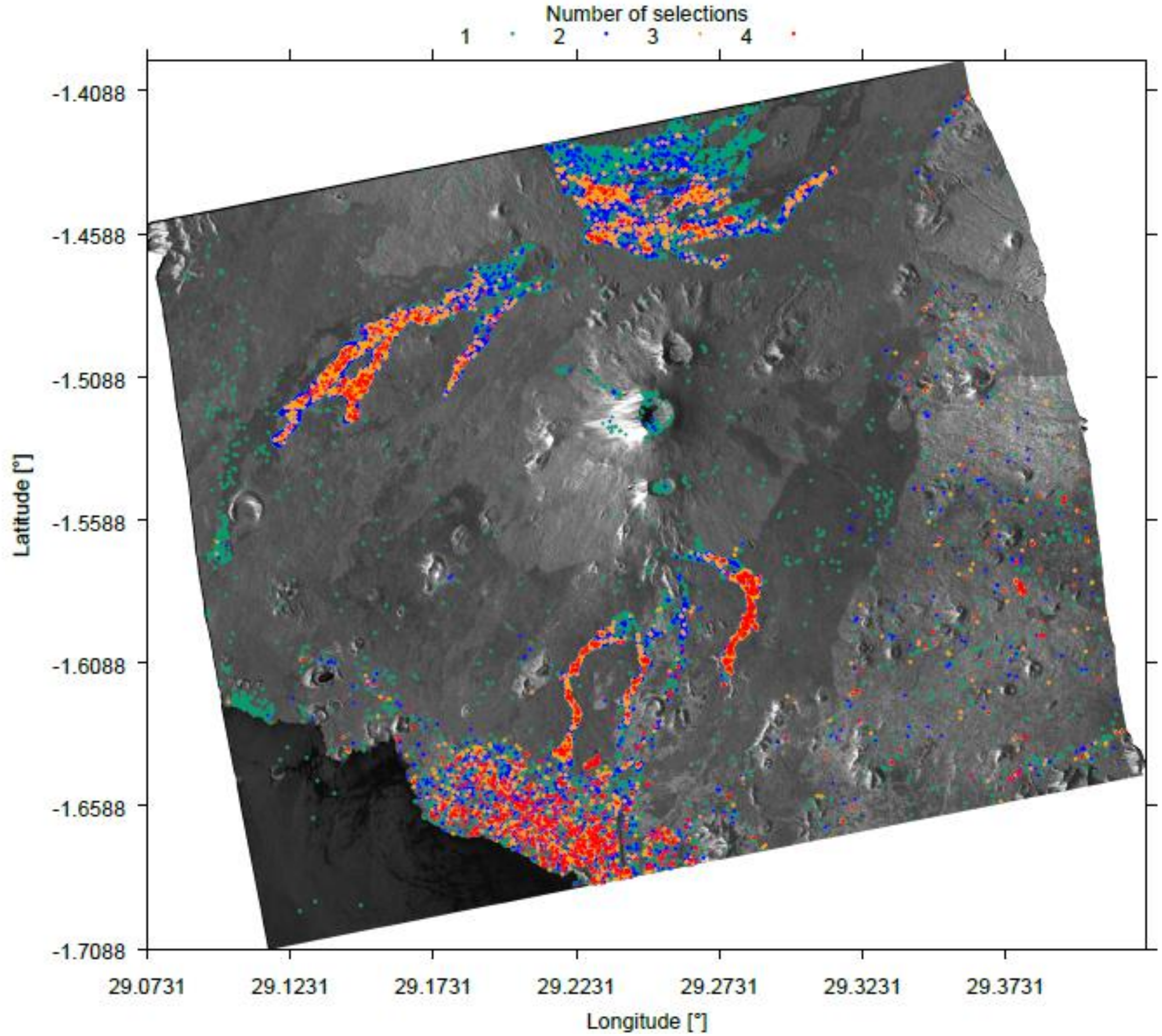
Master Date	Slave Date
July 3rd, 2008	April 4th, 2008
July 3rd, 2008	May 9th, 2008
July 3rd, 2008	June 22nd, 2008
July 3rd, 2008	July 25th, 2008



http://www.e-geos.it

Temporal analysis

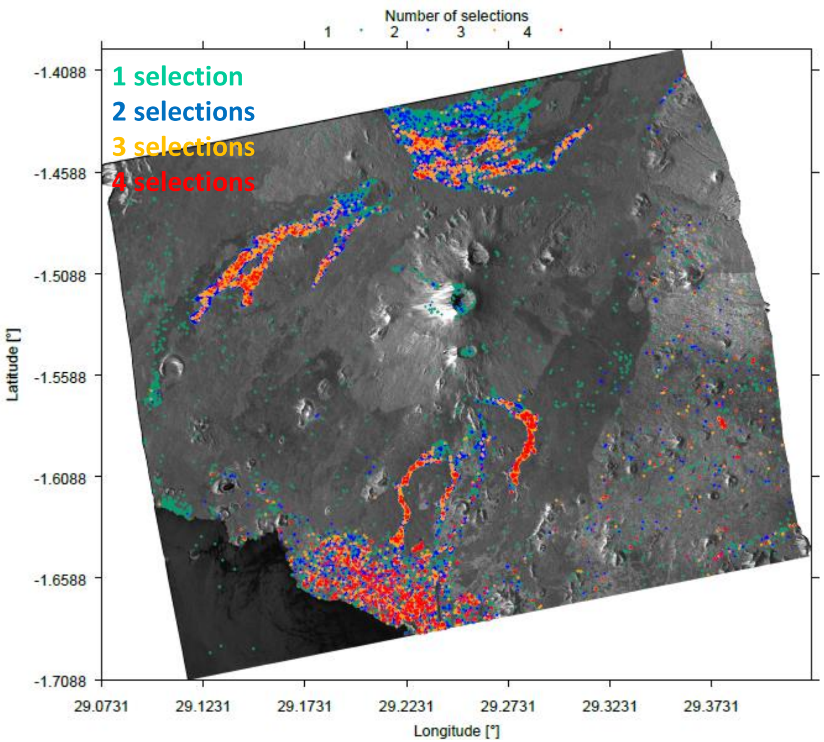
Are frequency-persistent scatterers detected at **all times** ?

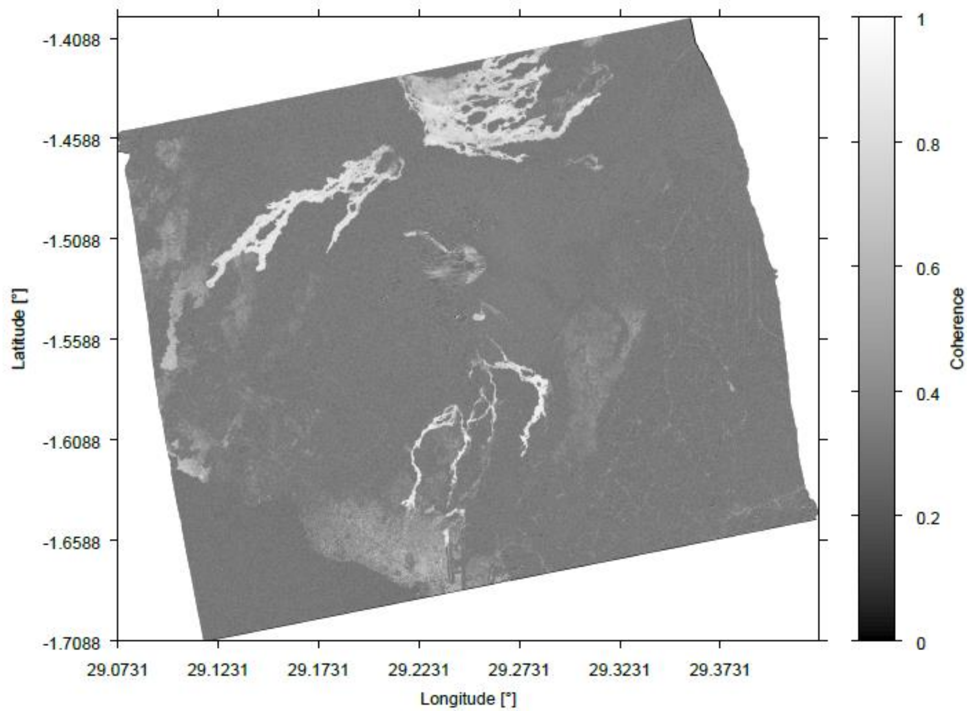


1 selection
2 selections
3 selections
4 selections

Temporal analysis

- Frequency-persistent scatterers are mostly located in **highly coherent** areas.
- Multiple detections are the **exception** rather than the rule.
- A priori, PS_f **do not persist** over time.
- Frequency-persistent scatterers detected in the four pairs are called **persistent PS_f**.





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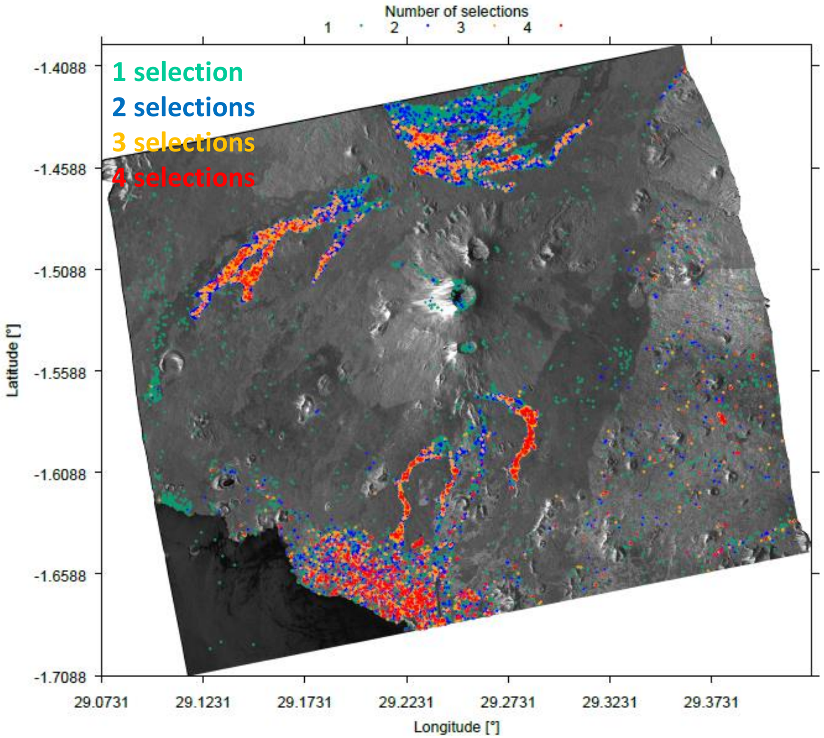
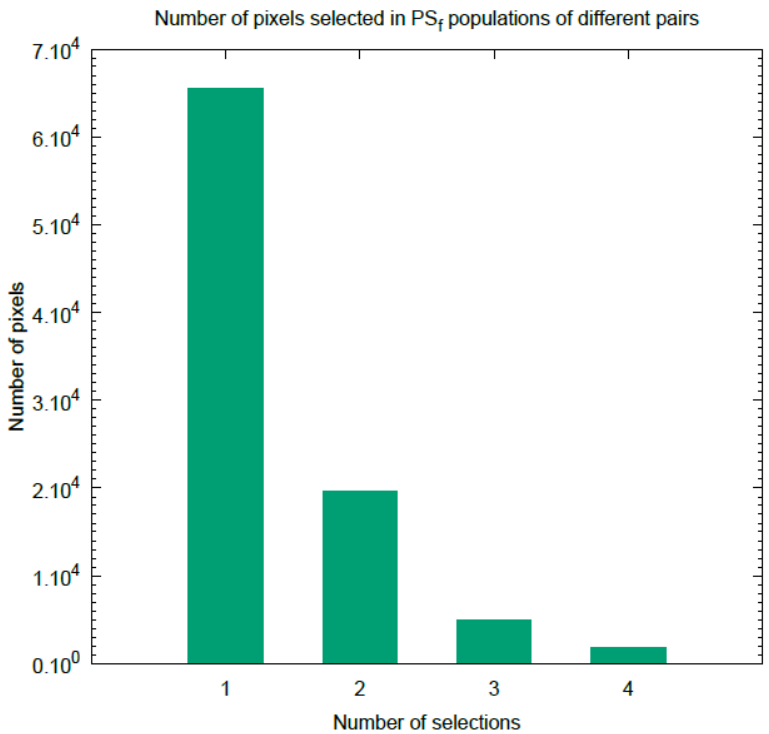




Influence of the resolution loss on the PS_f detection

Subband products have a **coarser resolution** because their bandwidth is degraded with respect to the original product. If the resolution loss becomes too important, **decorrelation noise** can overcome the stable signal and frequency-persistent scatterers can become **undetectable**.

Quantification of the spatial decorrelation : correlated-to-decorrelated ratio (CDR)

$$\rho = \frac{1}{1+\frac{|c|^2}{|d|^2}} = \frac{1}{1+\frac{1}{\mathrm{CDR}}}$$

$$\rho = 1 - \frac{c|B_\perp|}{\lambda r_m B_i \tan\theta}$$

$$\boxed{\mathrm{CDR} = \frac{\lambda B_i r_m \tan\theta}{c|B_\perp|} - 1}$$

Equivalent to spatial coherence, expression similar to SNR

Temporal analysis

Quantification of the spatial decorrelation : CDR

$$\boxed{\mathrm{CDR} = \frac{\lambda B_i r_m \tan\theta}{c|B_\perp|} - 1}$$

Sensor	Mode	λ	θ	r_m	B_i	CDR	ρ_s
TerraSAR-X	Stripmap	3.1 cm	26.4°	564 km	30.0 MHz	7.68	0.88
TerraSAR-X	Spotlight	3.1 cm	33.3°	615 km	60.0 MHz	24.05	0.96
Cosmo-SkyMed	Stripmap HIMAGE	3.1 cm	35.5°	753 km	19.2 MHz	9.66	0.91
Cosmo-SkyMed	Stripmap HIMAGE	3.1 cm	26.6°	693 km	25.8 MHz	8.25	0.89
Radarsat-2	Fine	5.5 cm	35.5°	949 km	6.0 MHz	6.44	0.87
Radarsat-2	Ultra-Fine	5.5 cm	36.9°	964 km	20.0 MHz	25.15	0.96
Sentinel-1	Interferometric Wide	5.5 cm	33.4°	825 km	11.2 MHz	10.17	0.91

Better contrast of the CDR than the spatial coherence

Temporal analysis

Quantification of the spatial decorrelation : CDR

$$\mathrm{CDR} = \frac{\lambda B_i r_m \tan\theta}{c|B_\perp|} - 1$$

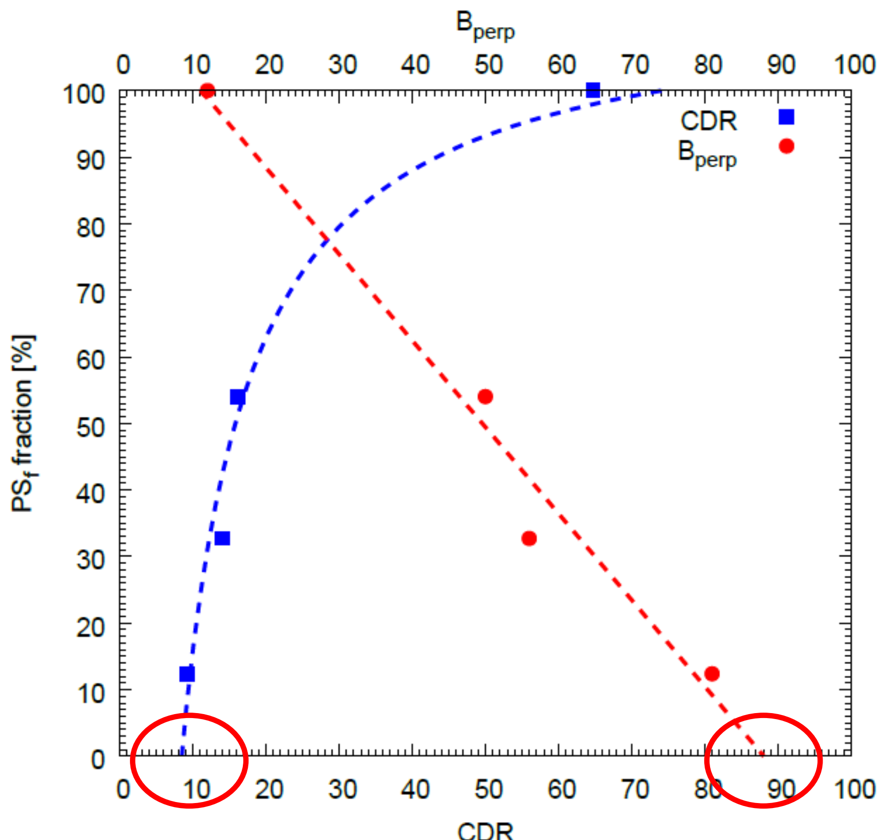
Master Date	Slave Date	$\lvert B_\perp \rvert$	CDR
July 3rd, 2008	April 4th, 2008	81 m	9.55
July 3rd, 2008	May 9th, 2008	56 m	14.25
July 3rd, 2008	June 22nd, 2008	13 m	64.71
July 3rd, 2008	July 25th, 2008	50 m	16.09

Can the loss of resolution induces missed detections ?
Is it the reason of the low amount of multiple detections ?

Limit of detection

What is the limit below which no more PS_f can be detected ?

In this case, the fraction of detected PS_f should fall to zero for a perpendicular baseline of 88 m and a CDR of 8.65.



CDR = 8.65

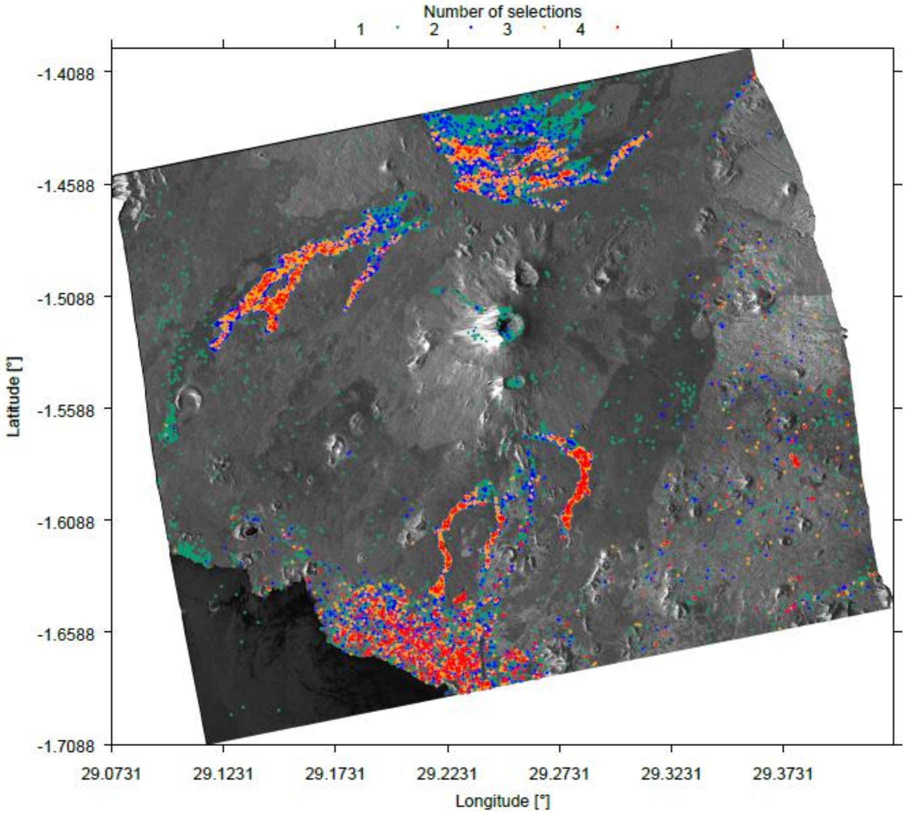
B_{perp} = 88 m

Fraction of PS_f defined with respect to the best pair

Temporal analysis

*Are **frequency-persistent scatterers** and **permanent scatterers** the same ?*

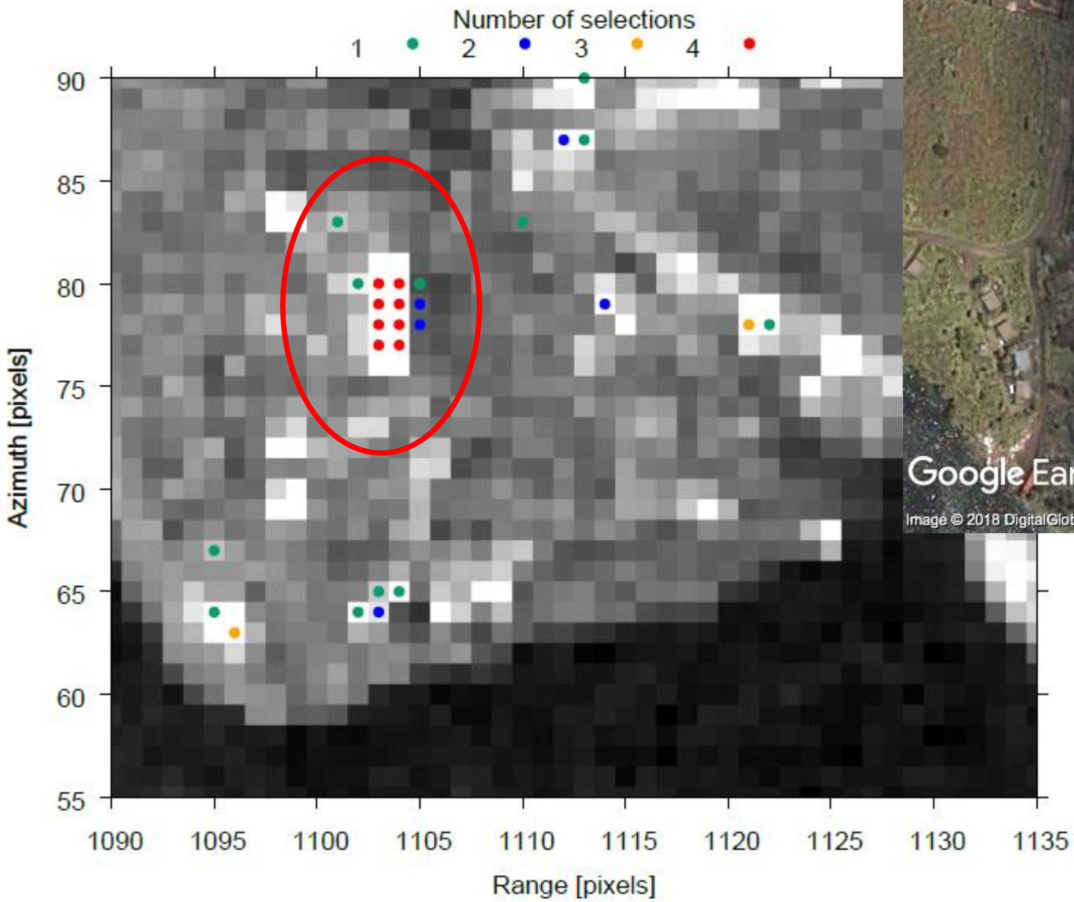
*Is the **spectral stability** a **stationary** feature of a target ?*



Take care of the name **frequency-<u>persistent</u> scatterer** !

Targets identification

Identification of persistent PS_f in Google Earth view



Targets identification

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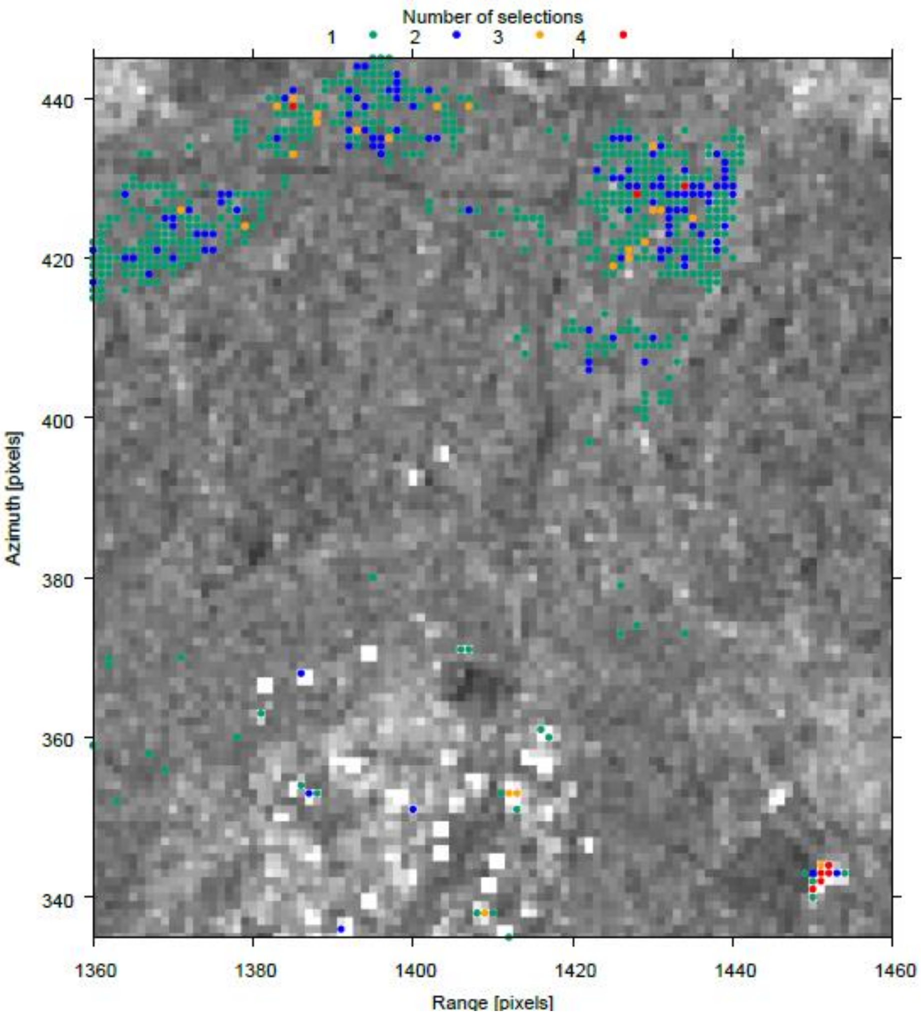
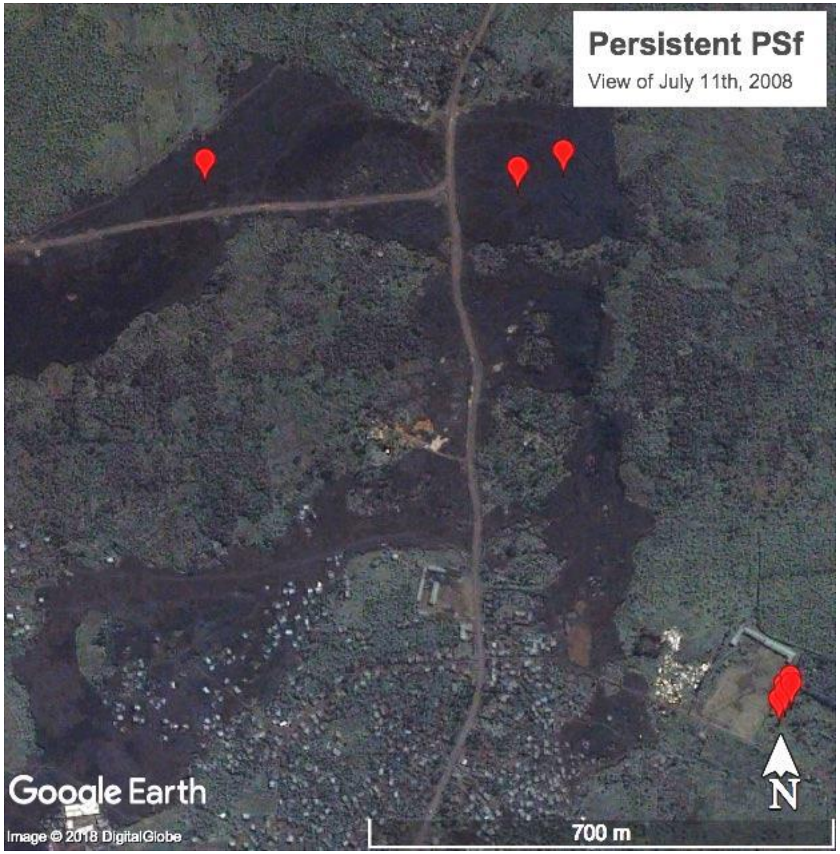
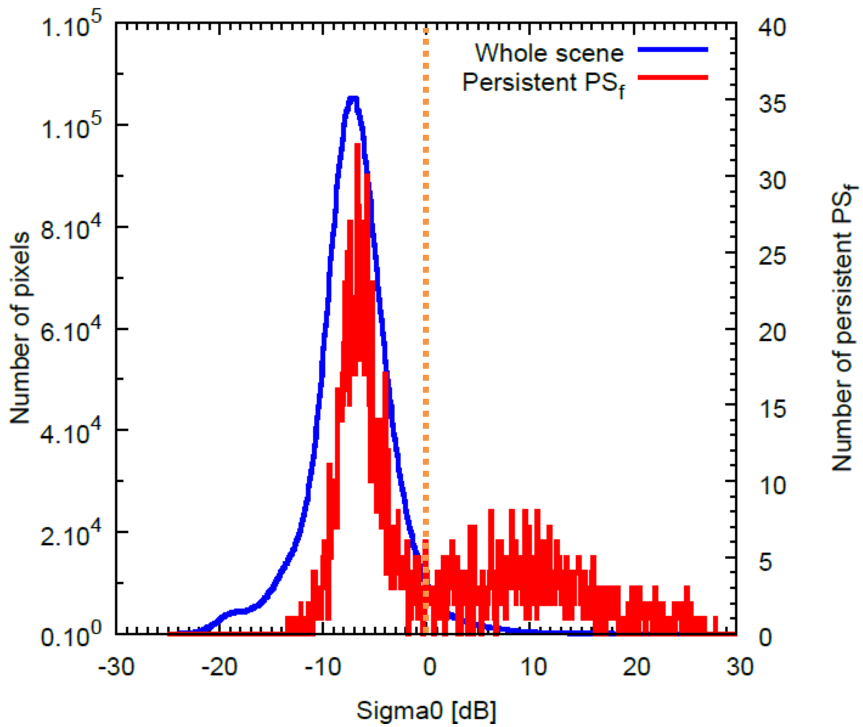




Reflectivity

Sigma-nought image of July 3rd, 2008

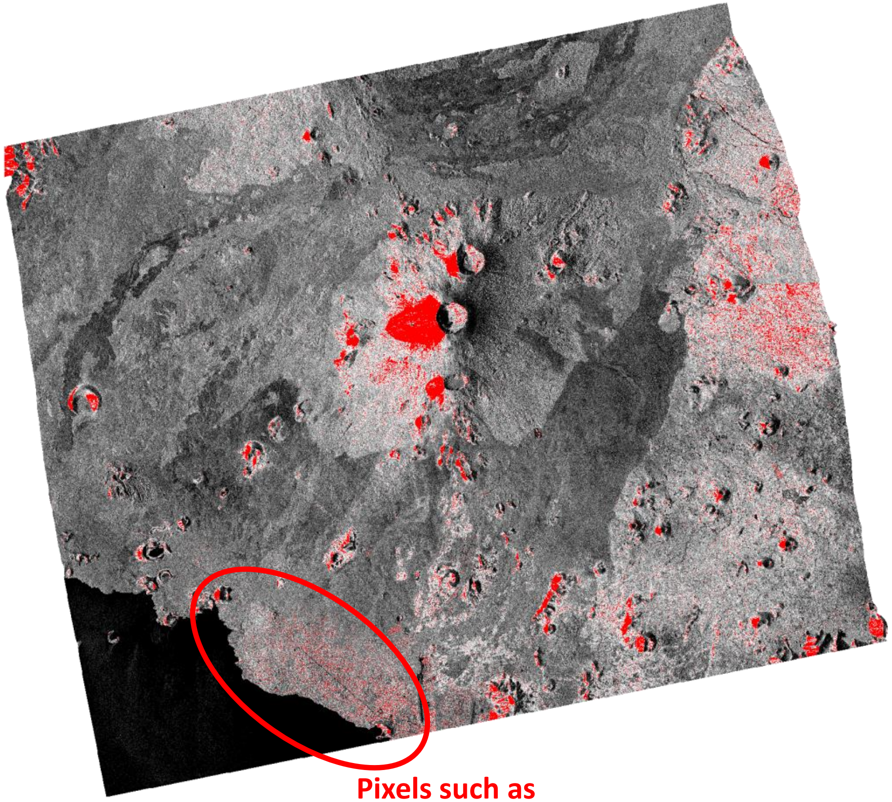
- **Whole scene** → peak around -10 dB
- **Persistent PS_f** → peak around -10 dB **+ population with sigma-nought larger than 0 dB**

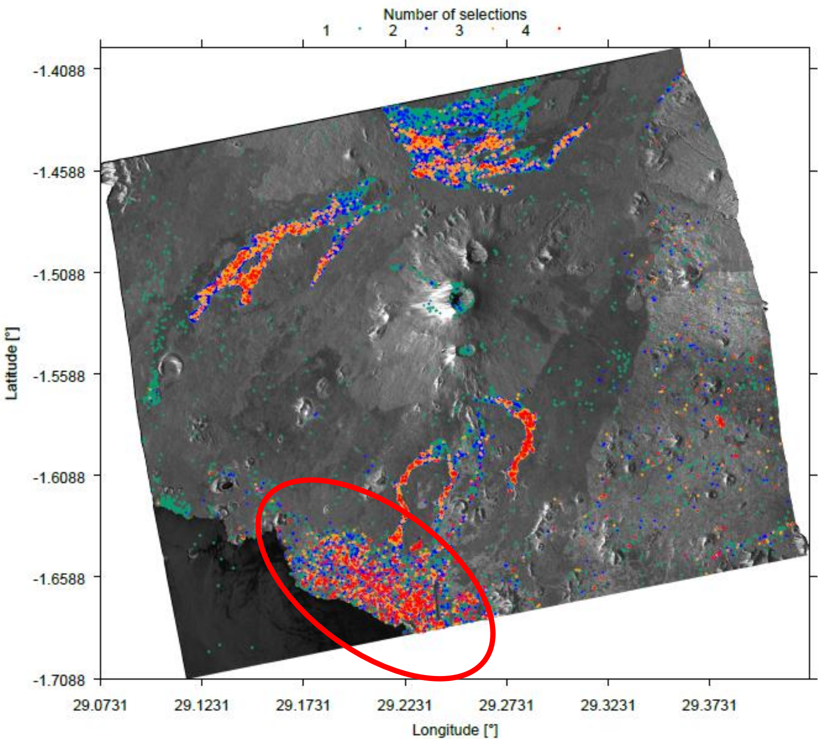


Reflectivity

Bright persistent PS_f are located over the city. ➔ **Double bounce**

Those with a **lower reflectivity** are mostly located over lava flows. ➔ **Diffuse scattering**





Spectral coherence

Spectral coherence is an estimator of the coherence between subimages of a **same scene**.

$$\boxed{\gamma_s^{ij} = 1 - \frac{(\nu_i - \nu_j)}{B_i}}$$

= 0 for non-overlapping subbands

= 1 for completely overlapping subbands

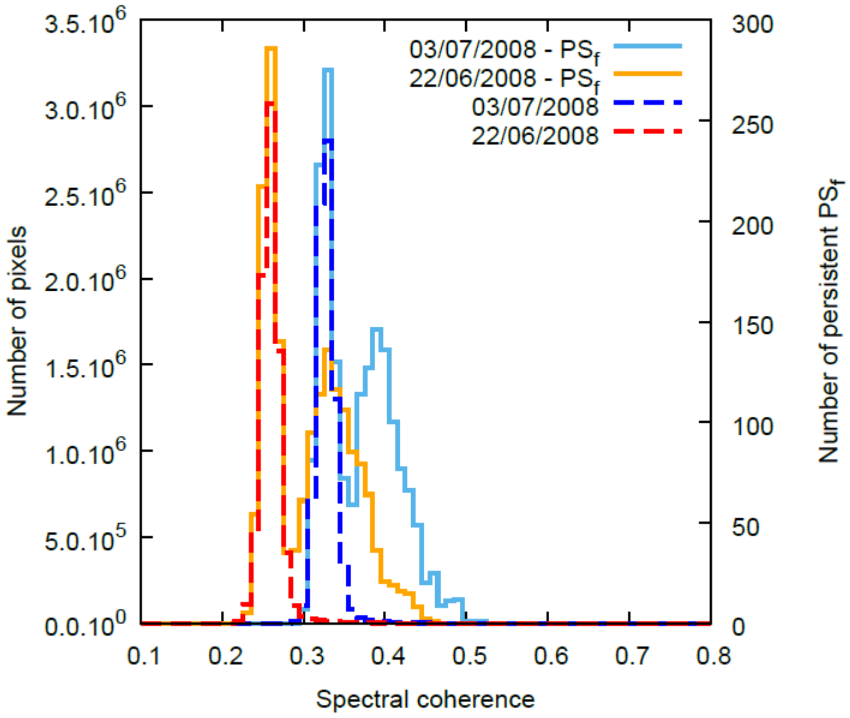
Assumption: ***uniform and uncorrelated distribution of surface scatterers***.

If the studied scatterers depart from this distribution, spectral coherence may be preserved even for non-overlapping subbands, depending on the degree of divergence from a distribution of random surface scatterers.

Spectral coherence

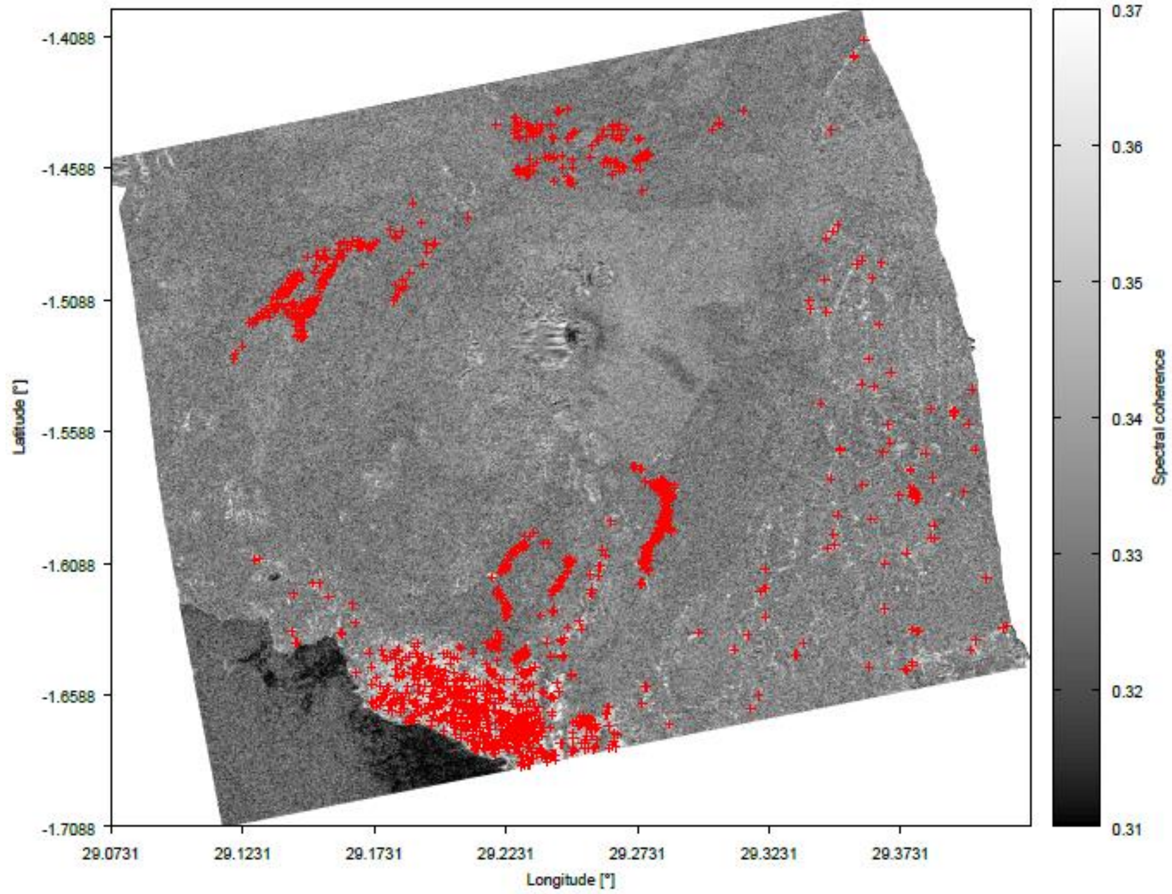
- **Data set:** July 3rd and June 22nd, 2008.
- **Spectral decomposition:** 9 non-overlapping subbands of 16.66 MHz
- **Observations:**

- Similar shapes for the two dates, shifted by 0.05
- **Additional peak at higher coherence** for persistent PS_f



In practice, spectral coherence is calculated for all possible combinations of subbands and then averaged to obtain a mean spectral coherence.

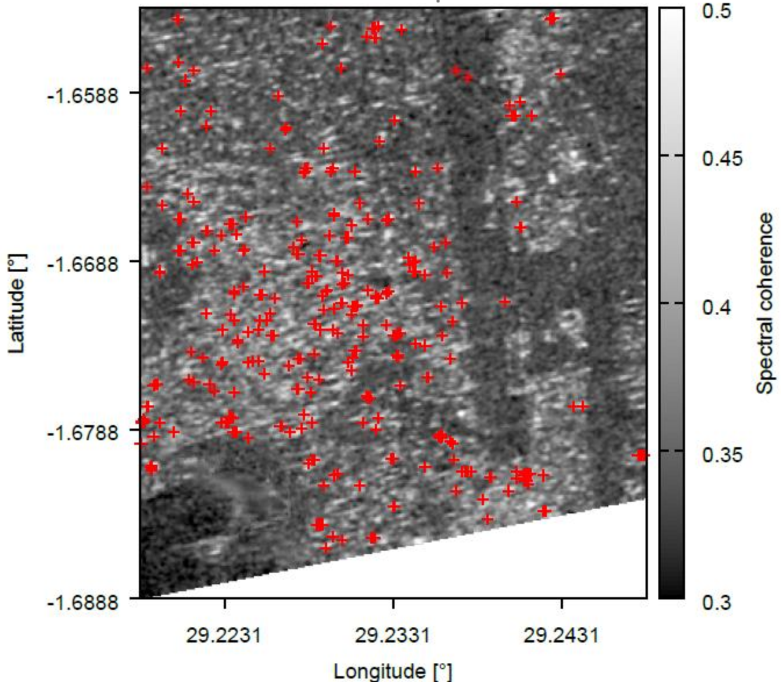
Spectral coherence

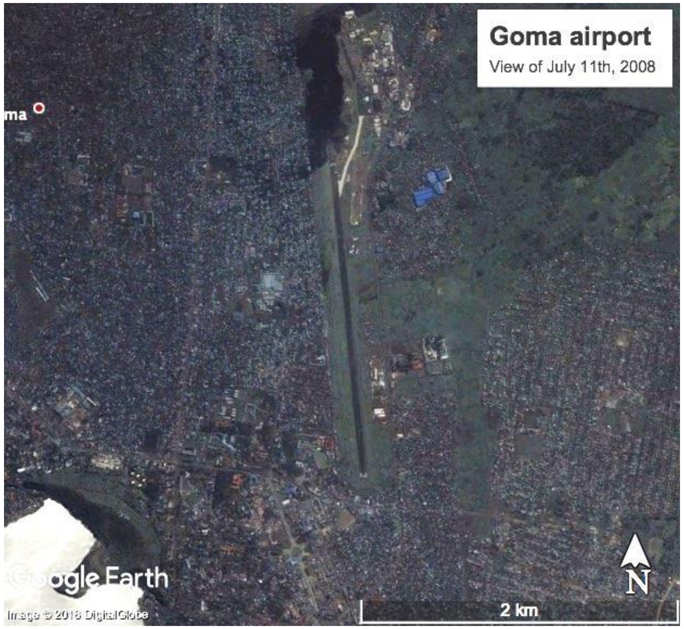


Spectral coherence

Peak of higher coherence correspond to urban targets. These are single point targets, different from distribution of random surface scatterers.

Spectral coherence over the Goma airport





Spectral coherence

Scattering over the rough surface of lava is very close to the assumption of random surface scatterers.

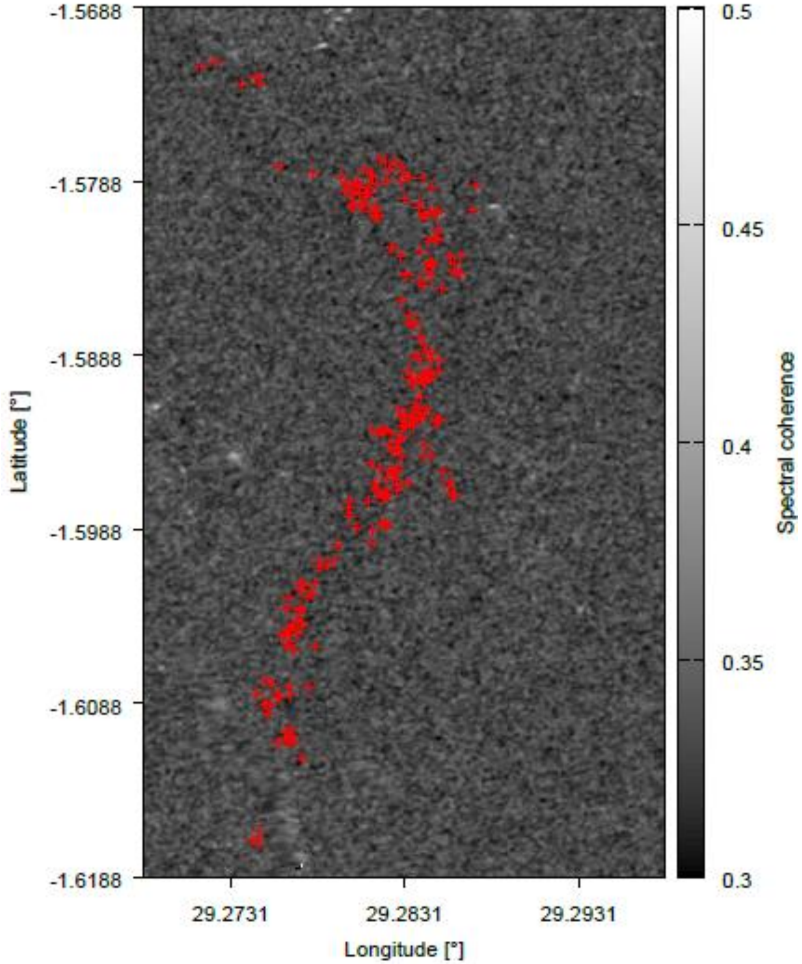
➔ Lower coherence

Two types of persistent PS_f populations:

- Single point targets over the city
- Distribution of surface scatterers over lava flows.

It is therefore ill-advised to talk of ***frequency-persistent scatterers***, we should talk about **frequency-stable pixels** instead.

Spectral coherence over the Nyiragongo lava flow



Conclusions and perspectives

Based on our temporal analysis, we were not able to define what is a frequency-persistent scatterer. Nevertheless, we could determine what it is **not**:

- A frequency-persistent scatterer is **not a permanent scatterer.**
- Spectral stability is **not a stationary** feature of a target

Analysis of the reflectivity and the spectral coherence, combined Google Earth views, have shown that there exists **two types of populations** that are spectrally-stable:

- Single point targets, associated to double bounce scattering.
- Distributions of surface scatterers, associated to diffuse scattering.

Consequently, frequency-persistent scatterers are not associated to a particular type of target. Moreover, the name *frequency-persistent scatterer* is not well chosen. We should prefer ***frequency-stable*** or ***spectrally-stable pixel***.

Future work will focus on the use of spectrally-stable targets for monitoring and the possible use of artificial PS_f. A polarimetric study could be performed to further characterize frequency-stable pixels.

Thank you for your attention.

Questions ?