Polarimetric adaptive speckle filtering driven by temporal statistics for PSI applications

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Introduction

Persistent Scatterers Interferometry (PSI)

- Used to measure surface deformation evolution from SAR data
- Select for processing only good quality pixels:
  - Amplitude dispersion index → Persistent Scatterers (point-like, PS)
  - Average coherence → Coherent Pixels (distributed scatterers, DS)
- Urban environments: Mix of PS and DS
  - Estimation of DS parameters → speckle filtering
  - Speckle filtering → loss of PS information due to averaging
- **How to process together PS and DS?**

Introduction

Speckle filtering:

- Boxcar (multi-look) or sliding window:
  - Suitable for homogeneous areas with fully developed speckle
  - Resolution loss → **not suitable for PS analysis**
- Spatial adaptive speckle filters:
  - Adapt to filter only homogeneous areas
  - Driven by spatial statistics → spatial estimation window (**PS loss**)
- Spatial adaptive filters driven by temporal information:
  - Driven by temporal statistics → no initial spatial estimation window
  - **Homogeneous areas are filtered while PS are preserved**
  - Require a sufficient number of SAR images

Introduction

[Ferretti'11] → DespecKS

- Two pixels are considered Statistically Homogeneus Pixels (SHP) based on a two-sample Kolmogorov-Smirnov test:
  - Compares p.d.f. of the pixel amplitudes.
  - P.d.f are estimated from multi-temporal data.
- Pixels with sufficient SHP neighbours are processed as DS.
- Pixels with few SHP neighbours are processed as PS.

Limitations:

– Only takes into account amplitude information

– Conceived for single-pol data

– Multi-channel p.d.f. estimation is not straightforward

Introduction

Objectives:

- Polarimetric, PS preserving adaptive filter approach
- Polarimetric PSI with joint processing of PS and DS

INCREASED MAP DENSITY AND ACCURACY

Algorithm

Algorithm steps:

- Find homogeneous areas: Polarimetric Homogeneity Test
- Discriminate PS and DS
- Polarimetric Optimization. Find polarimetric channel that:
  - Minimizes amplitude dispersion for each PS
  - Maximizes average interferometric coherence for each DS
- Select pixels with good quality → low σ_{ϕ}
- Process using any PSI technique

Polarimetric Homogeneity Test

Target vector (Pauli basis):

$$\mathbf{k} = \frac{1}{\sqrt{2}} \begin{bmatrix} HH + VV \\ HH - VV \\ 2HV \end{bmatrix}$$

Coherency matrix:

$$\mathbf{T} = E[\mathbf{k}\mathbf{k}^{\dagger}] \rightarrow \mathbf{T} = \frac{1}{L} \sum_{l=1}^{L} \mathbf{k}_l \cdot \mathbf{k}_l^{\dagger}$$

$$\mathbf{k} \sim \mathcal{N}_q^{\mathbb{C}}(0, \mathbf{\Sigma}) \longrightarrow \mathbf{T} \sim \mathcal{W}_q^{\mathbb{C}}(L, \mathbf{\Sigma})$$

Temporal coherency matrix:

$$\mathbf{T} = \frac{1}{N} \sum_{n=1}^{N} \mathbf{k}_n \cdot \mathbf{k}_n^{\dagger}$$

N images → N independent samples

Polarimetric Homogeneity Test

Equality test for Wishart distributed matrices [Conradsen et al. 2003]:

- Hypothesis: $\boldsymbol{\Sigma}_i = \boldsymbol{\Sigma}_j$
- Test → Likelihood ratio: $$\Lambda = \frac{|\mathbf{T_i}|^{N_i}\,|\mathbf{T_j}|^{N_j}}{\left|\frac{N_i\mathbf{T_i}+N_j\mathbf{T_j}}{N_i+N_j}\right|^{N_i+N_j}}$$
- Equality condition:

$$\Lambda > c_\beta \qquad P_{fa}\left(c_\beta\right) = P\left(\Lambda \leq c_\beta\right) = \beta$$

Hyphotesis confirmed → Polarimetrically Homogeneous Pixels (PHP)

- Pixels with more than *R* PHP are treated as DS (filtered)
- Pixels with less than *R* PHP are treated as PS (not filtered)

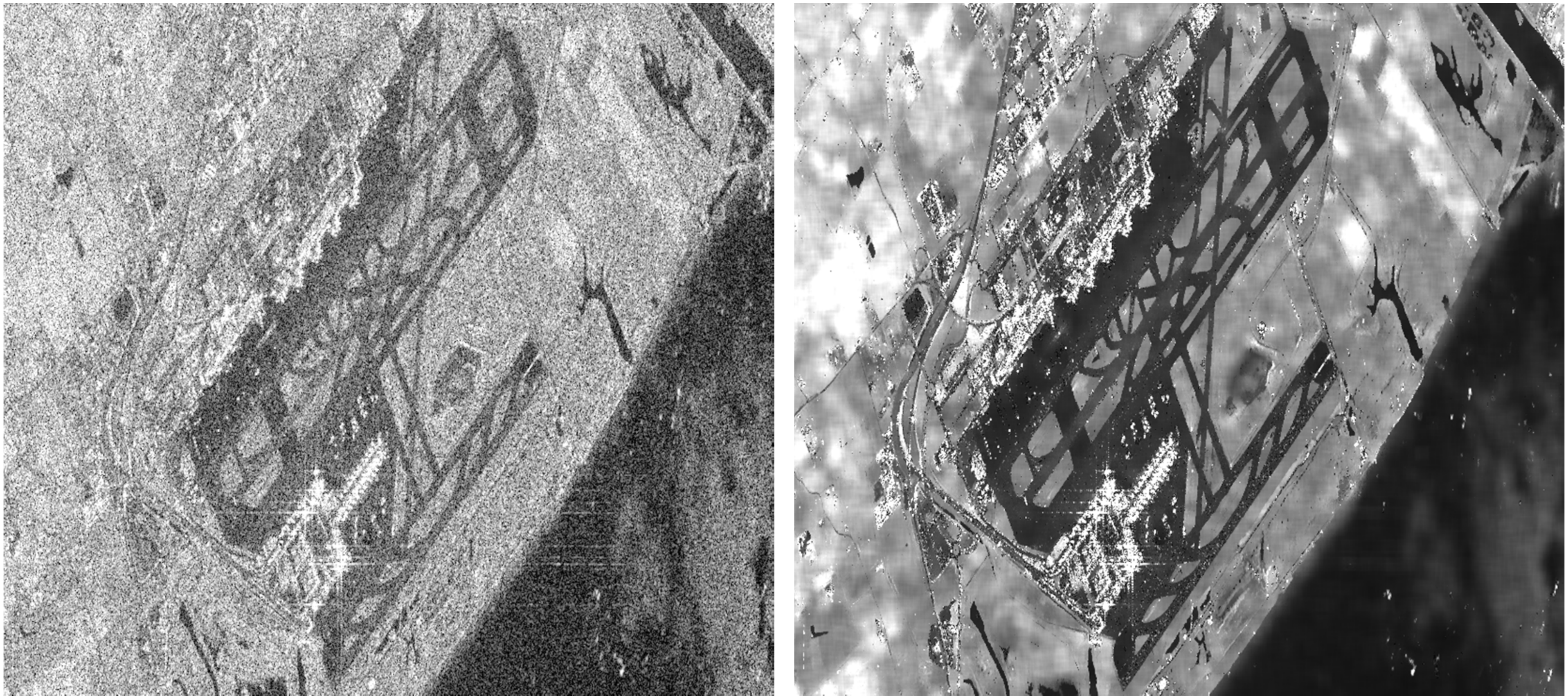
Polarimetric Homogeneity Test

Search window = 15 x 15
log Λ threshold = -20

Number of identified PHP
(Barcelona)

Polarimetric Homogeneity Test

Polarimetric adaptive speckle filter → R = 20



Detail of Barcelona airport. HH+VV amplitude

PSI optimization review

General framework and formulation for vector interferometry [Cloude and Papathanassiou, 1998]:

Projection:

$$\mu = \boldsymbol{\omega}^{\dagger}\mathbf{k}$$

Scattering coefficient (scalar complex) ← μ

$\boldsymbol{\omega}$ → Projection vector (unitary complex vector)

Projection vector parameterization:

$$\boldsymbol{\omega} = \begin{bmatrix} \cos(\alpha) \\ \sin(\alpha)\cos(\beta)e^{j\delta} \\ \sin(\alpha)\sin(\beta)e^{j\psi} \end{bmatrix}, \quad \begin{cases} 0 \leqslant \alpha \leqslant \pi/2 \\ 0 \leqslant \beta \leqslant \pi/2 \\ -\pi \leqslant \delta < \pi \\ -\pi \leqslant \psi < \pi \end{cases}$$

Ranges → Search

ESPO: Exahustive Search Polarimetric Optimization

PSI optimization review

- Average coherence optimization:

Maximize:

$$\overline{|\gamma|} = \frac{1}{K}\sum_{k=1}^{K}|\gamma_k|, \text{ with } \gamma_k(\boldsymbol{\omega}) = \frac{\boldsymbol{\omega}^\dagger \boldsymbol{\Omega}_{ij}\boldsymbol{\omega}}{\sqrt{\boldsymbol{\omega}^\dagger \mathbf{T}_{ii}\boldsymbol{\omega}}\sqrt{\boldsymbol{\omega}^\dagger \mathbf{T}_{jj}\boldsymbol{\omega}}} \quad \begin{cases} \mathbf{T}_{ii} = E[\mathbf{k}_i\mathbf{k}_i^\dagger] \\ \mathbf{T}_{jj} = E[\mathbf{k}_j\mathbf{k}_j^\dagger] \\ \boldsymbol{\Omega}_{ij} = E[\mathbf{k}_i\mathbf{k}_j^\dagger] \end{cases}$$

- Amplitude dispersion optimization:

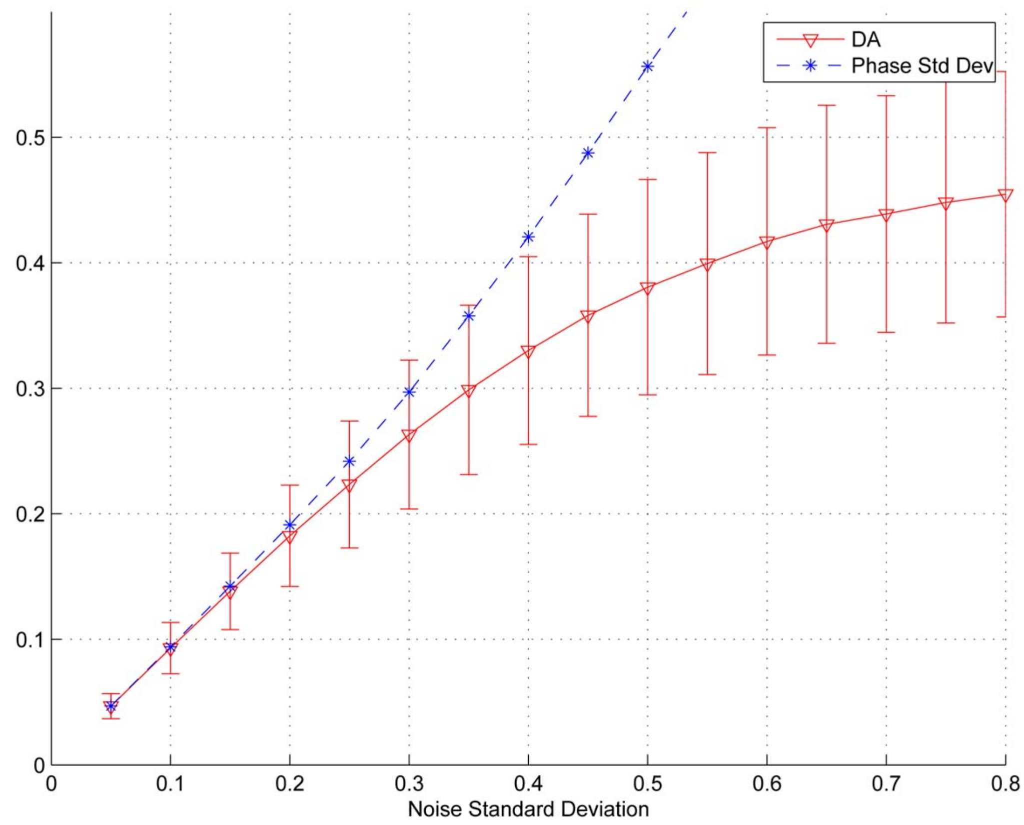
Minimize:

$$D_A = \frac{\sigma_a}{\bar{a}} = \frac{1}{\overline{|\boldsymbol{\omega}^\dagger \mathbf{k}|}\sqrt{N-1}}\sqrt{\sum_{i=1}^{N}\left(|\boldsymbol{\omega}^\dagger \mathbf{k}_i| - \overline{|\boldsymbol{\omega}^\dagger \mathbf{k}|}\right)^2}$$

Constraint: $\omega_i = \omega_j = \omega \ \forall i, j$ → ESM

Joint processing of DS and PS

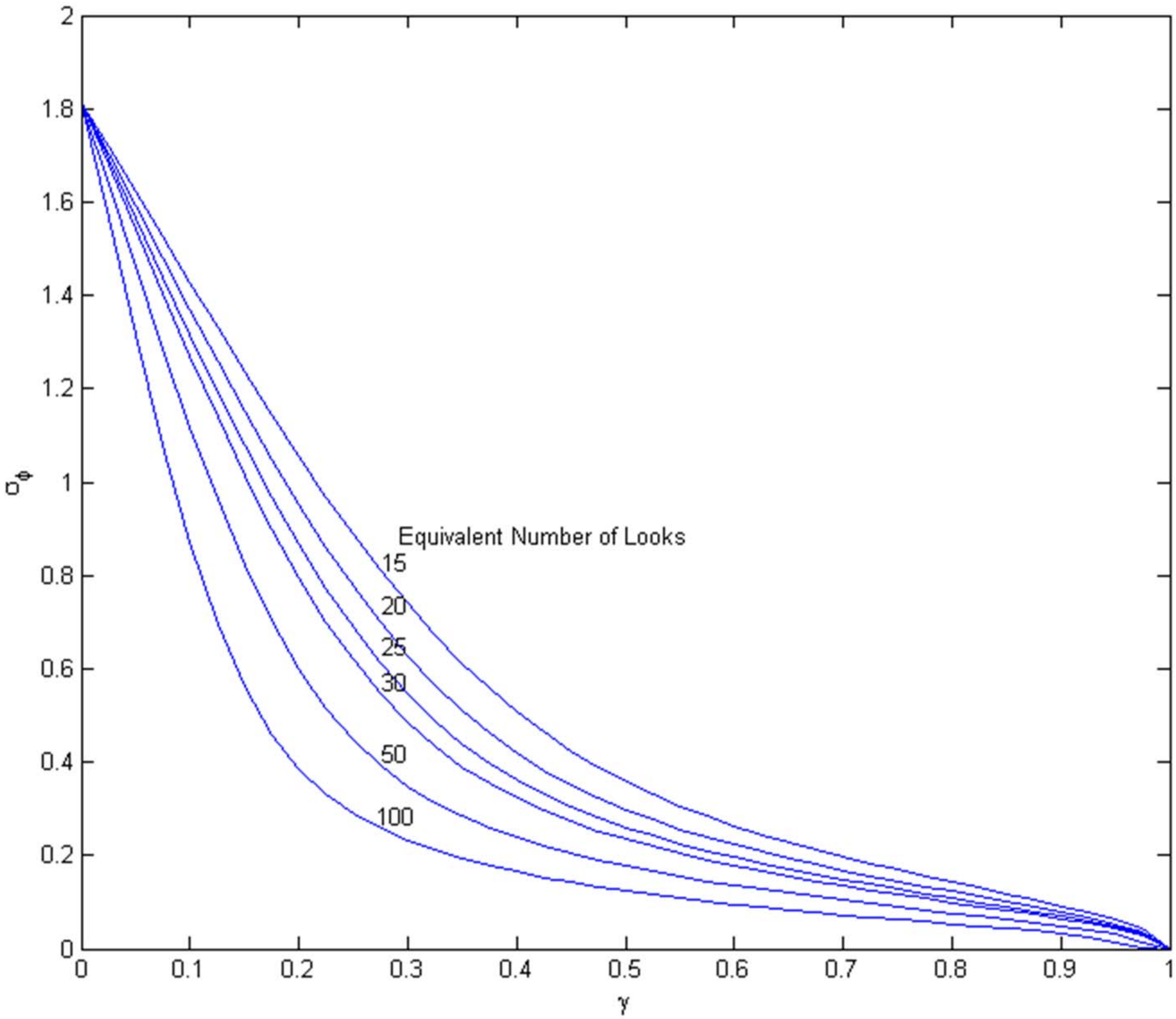
- Common quality criterion → phase standard deviation σ_ϕ
  - Amplitude dispersion: $D_A \approx \sigma_\phi$ for low values of DA (high SNR) [Ferretti et al., 2001]



Joint processing of DS and PS

- Commo
  - Ave
    [Jon

$$\sigma_\phi = \sqrt{\int_\phi (\cdots}$$



$$\frac{(\phi - \phi_0)}{\cdots_0))^{L_e+1/2}}$$

$$(\phi - \phi_0))$$

Results

Data set:

41 images of Murcia (Spain)
Feb-09 to May-10

- TerraSAR-X dual-pol: HH,VV
- Mean incidence angle: 37.8º
- Resolution: 6.6m Az, 1.17m Rg
- Spacing: 2.44m Az, 0.91m Rg
- Ovs. factors: 2.7 Az, 1.28 Rg

R = HH, G = VV, B = HH-VV

Images provided by DLR under the framework of project GEO0389

Results

Data set:

31 images of Barcelona (Spain)
Jan-10 to Feb-12

- RADARSAT-2 full-pol
- Mean incidence angle: 29º
- Resolution: 7.6m Az, 5.2m Rg
- Spacing: 5.1m Az, 4.7m Rg
- Ovs. factors: 1.49 Az, 1.11 Rg

R = HH-VV
G = 2HV
B = HH+VV

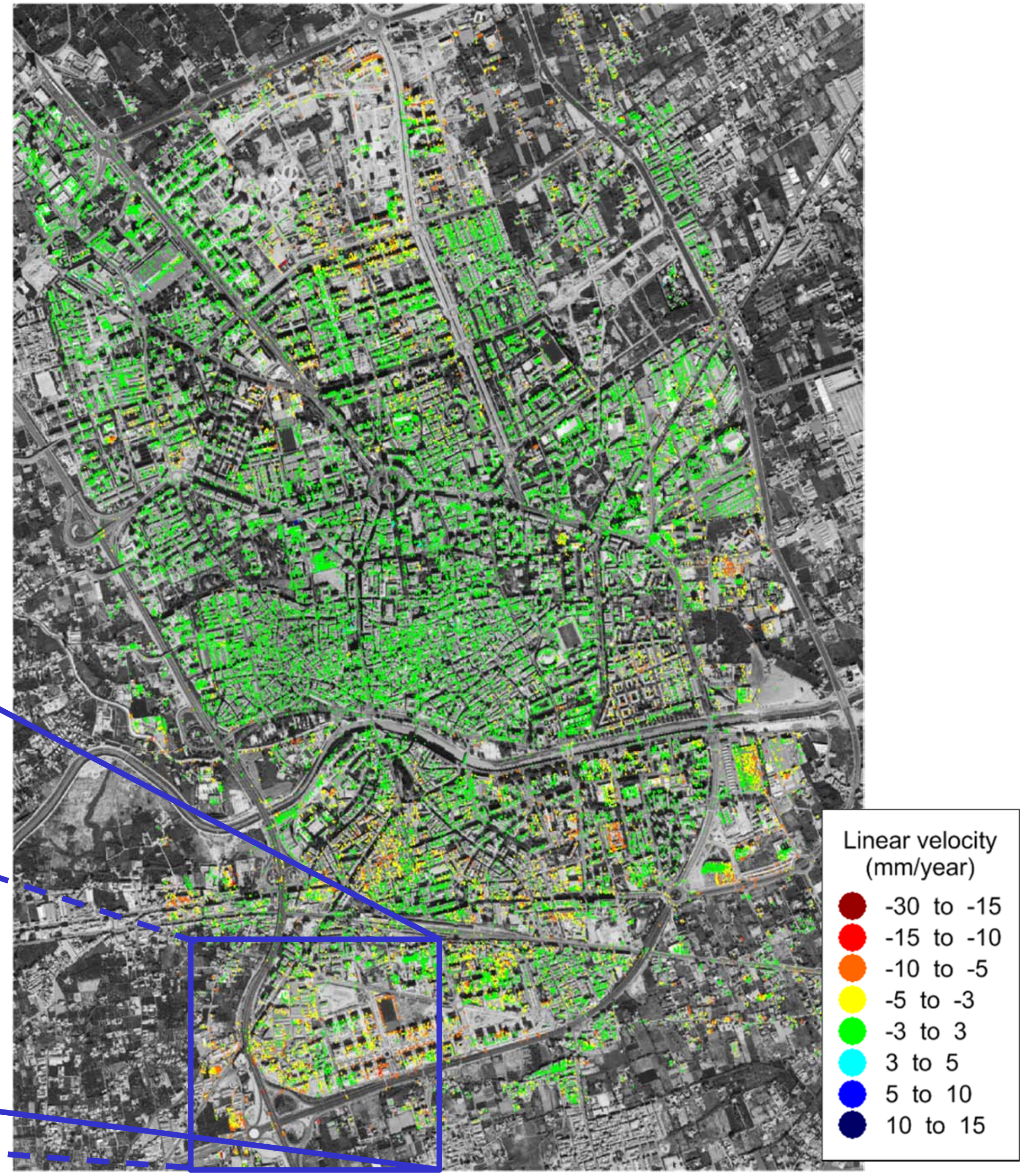
Images provided by MDA under the framework of project SOAR EU 6779

Results

Murcia (TERRASAR-X, DP)

σ_ϕ threshold = 0.25 (≈ D_A 0.25)

HH	4.29 %
ESPO, DP	9.81 %
LR Filter + ESPO	15.02 %



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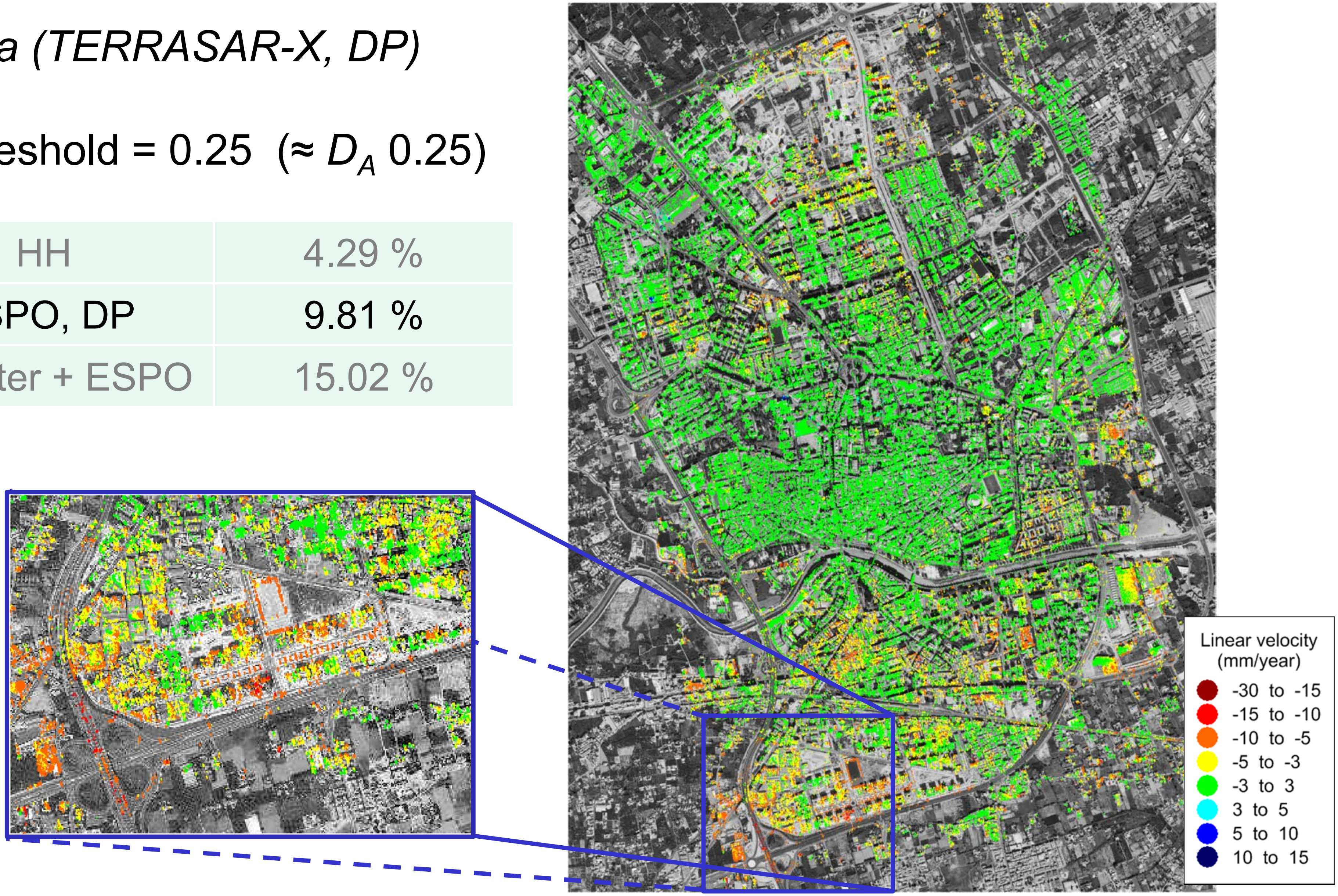

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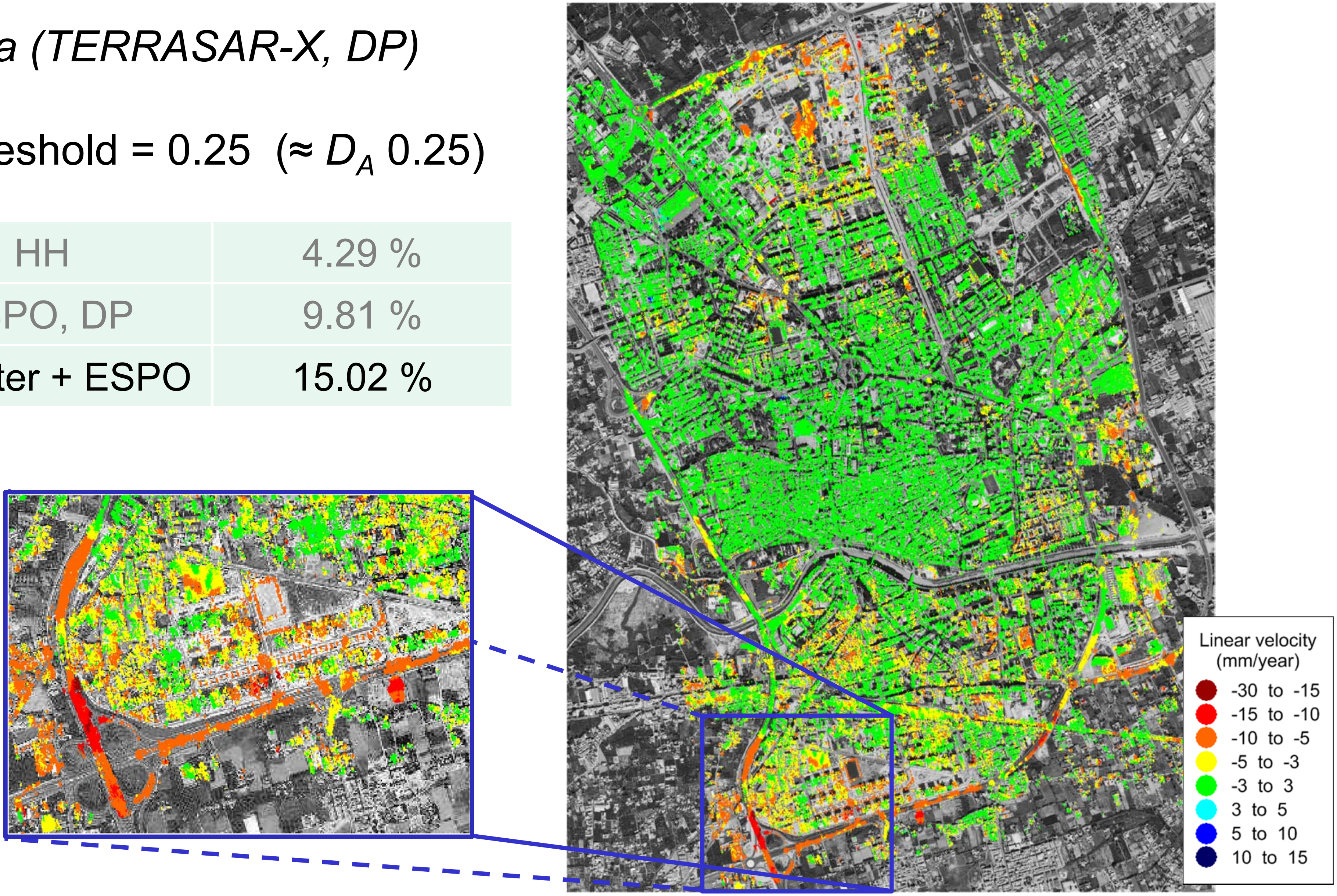
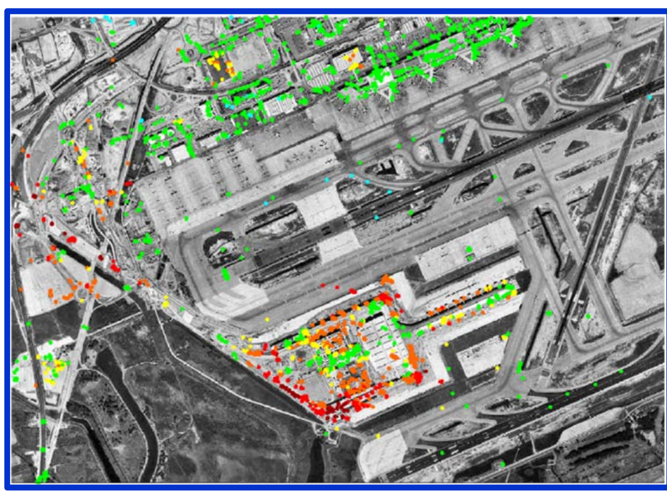


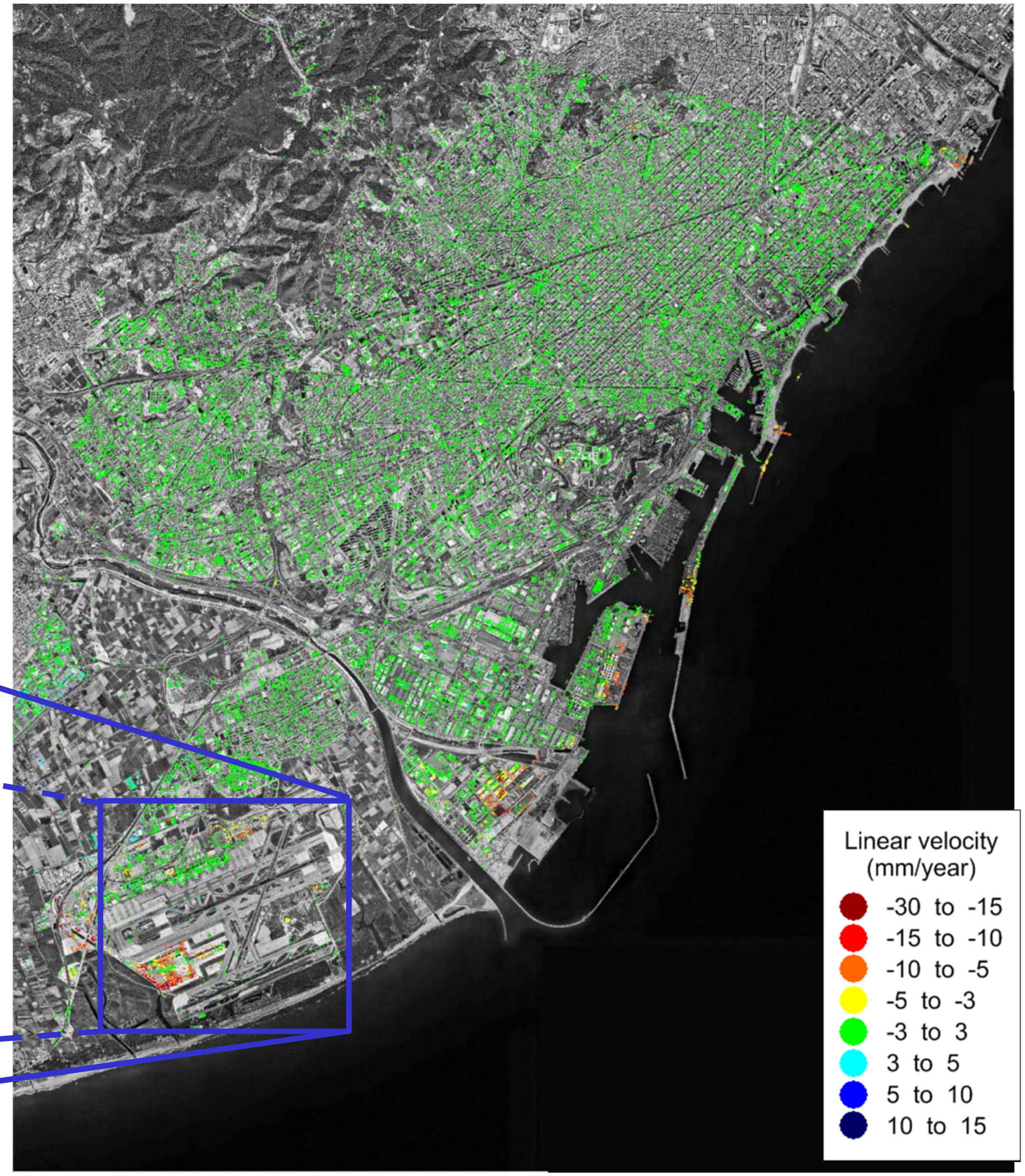
Results

Barcelona (RADARSAT-2, QP)

σ_ϕ threshold = 0.25 (≈ D_A 0.25)

HH	2.01%
ESPO, QP	13.83 %
LR Filter + ESPO	18.62 %





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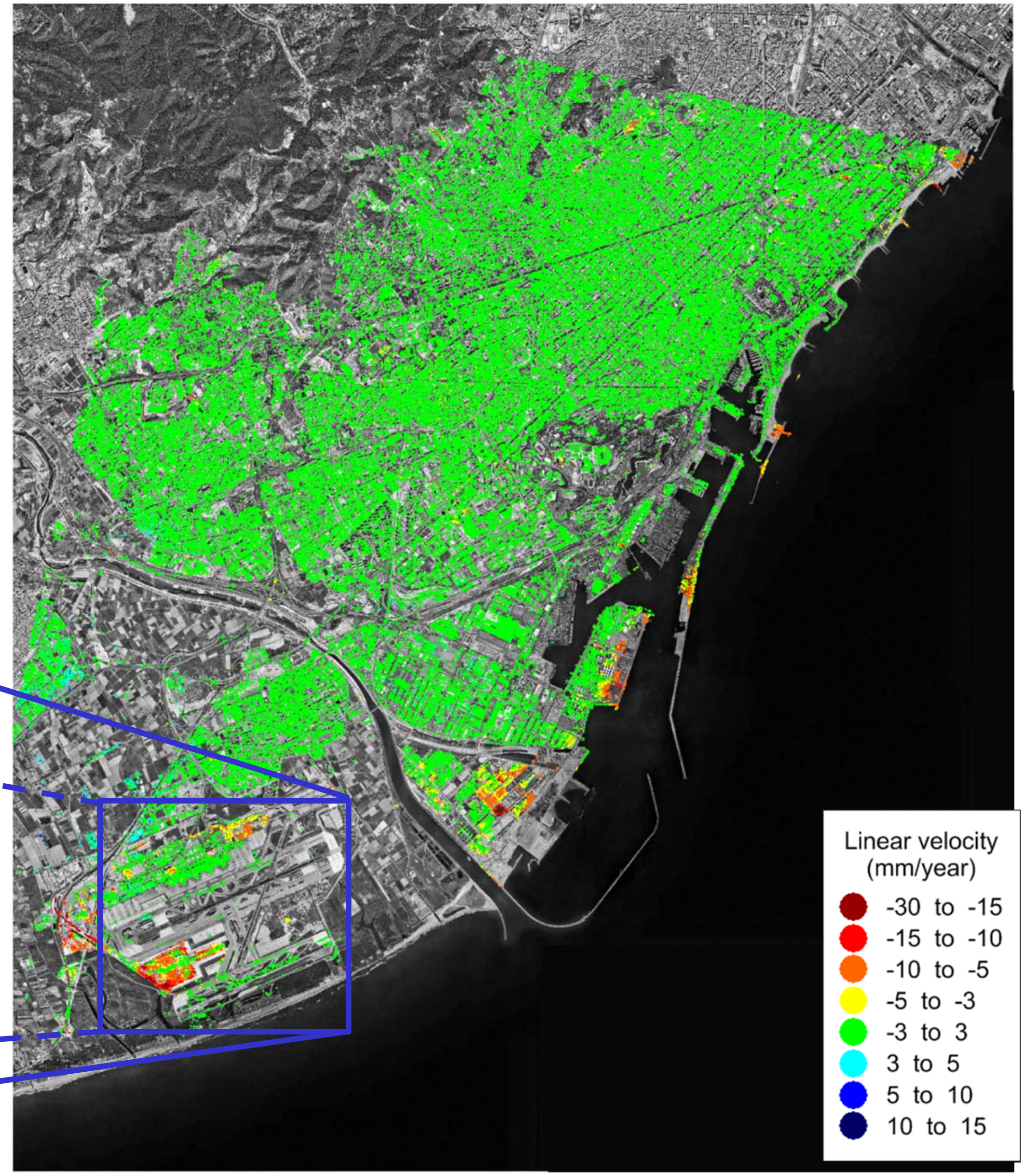

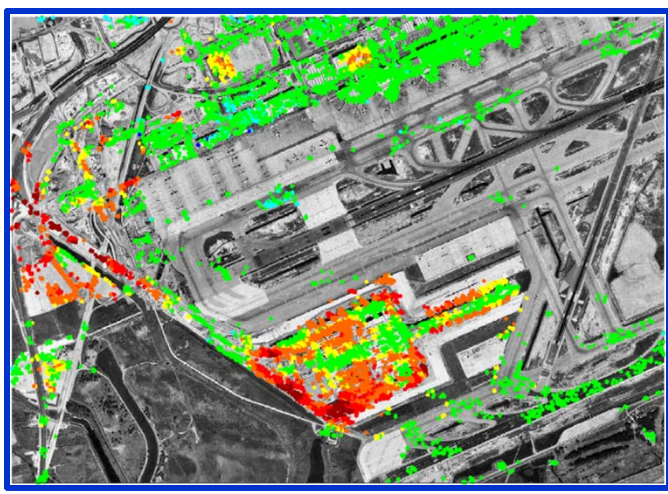

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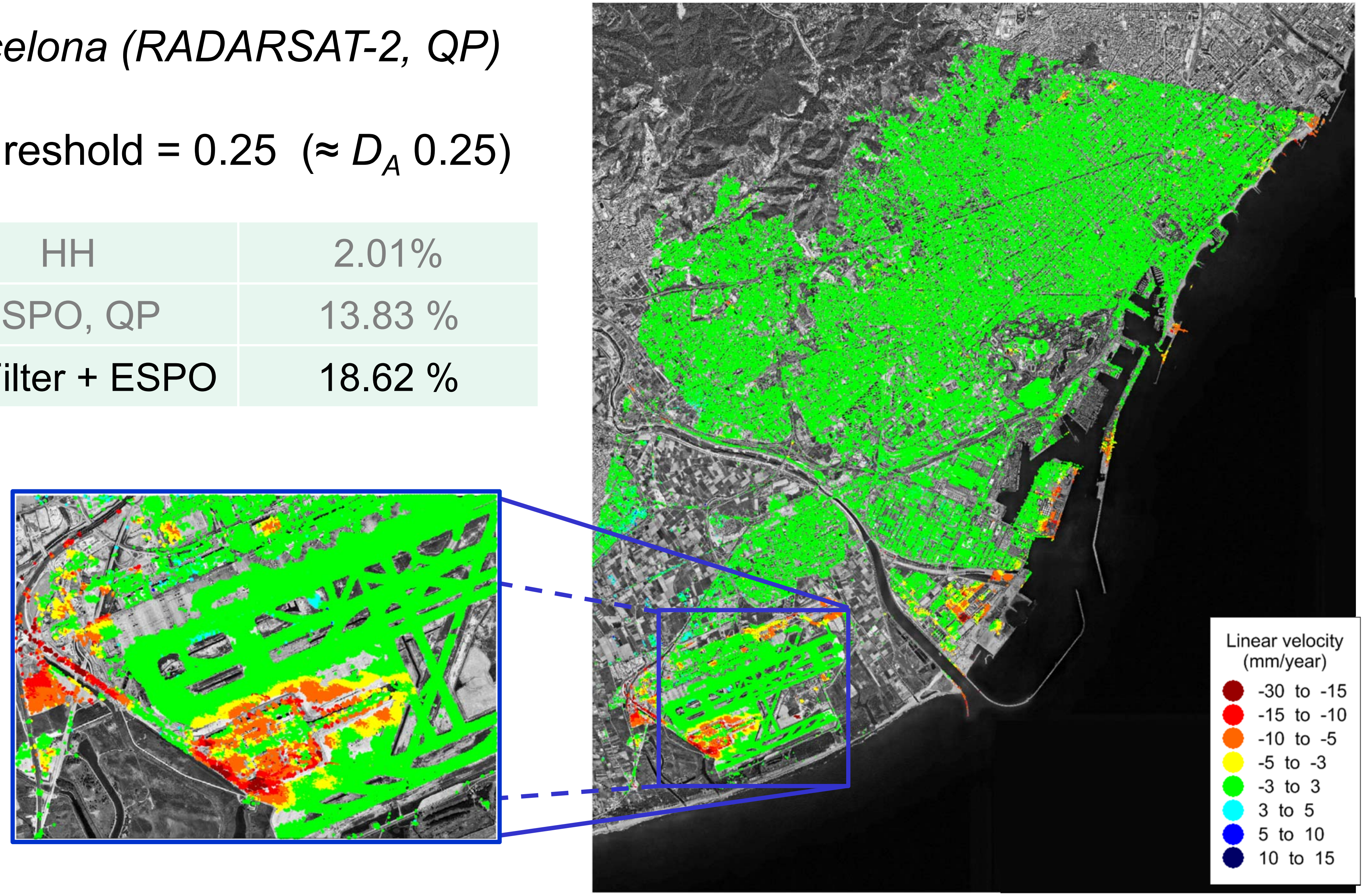

Summary

- An adaptive speckle filtering approach has been presented:
  - Polarimetric
  - PS compatible
- Methodology for joint processing of PS and DS proposed
- Important increase of deformation maps density:
  - TerraSAR-X dual-pol
    - 1.53 times increase w.r.t. ESPO optimized data
    - 3.50 times increase w.r.t. single-pol (HH)
  - RADARSAT-2 full-pol
    - 1.35 times increase w.r.t. ESPO optimized data
    - 9.26 times increase w.r.t. single-pol (HH)

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