PolInSAR-based Retrieval of Paddy Rice Height With Large Baseline TanDEM-X Data

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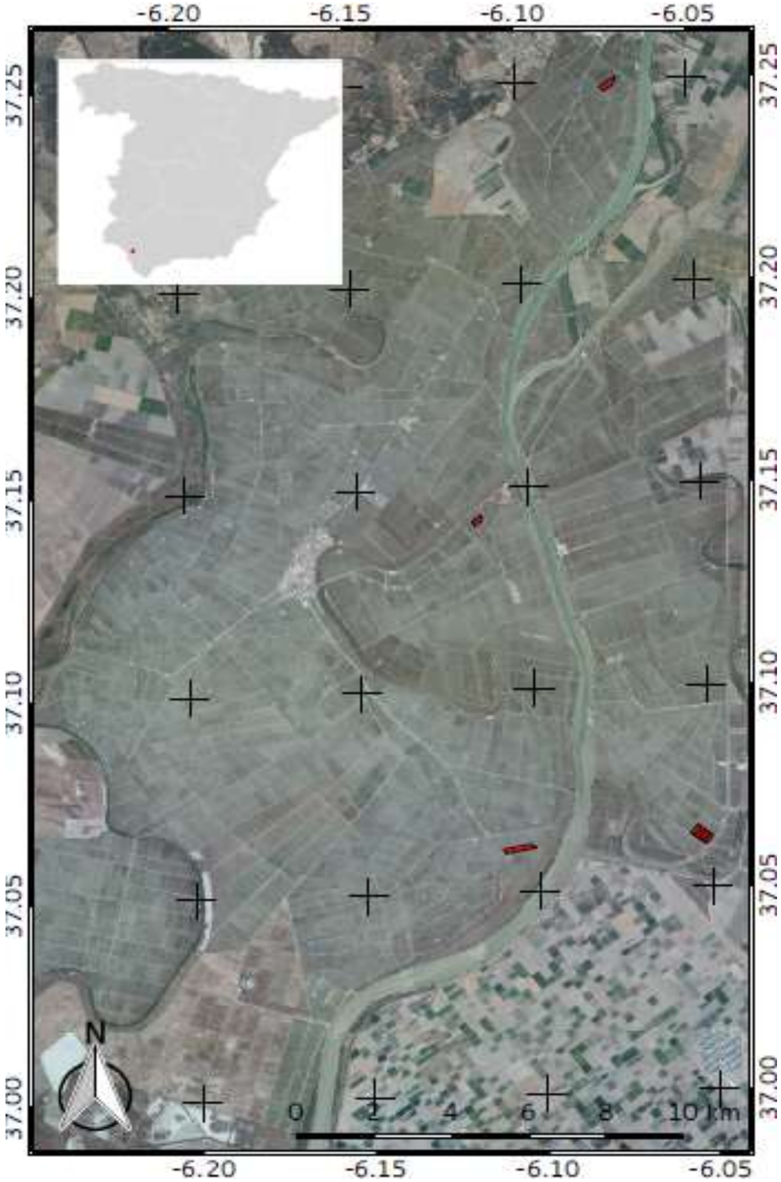
Motivation and contents

- PolInSAR has been used much more for **forests** than for **agriculture**
- First opportunity to PolInSAR-based retrieval of agricultural crop height with **satellite** data: TanDEM-X science phase
- **Rice** is chosen for test: primary crop in the world and well-studied
- Ground return dominated by the **double-bounce** contribution: modified formulation of the direct model with **bistatic** acquisitions
- In this work:
  - **3 different test sites** (variety of rice types, cultivation practices, etc.)
  - Acquisitions along the **whole growth season***
  - New **inversion algorithm** designed for rice: scene with dominant double-bounce ground contribution.

*Single-date example published in [Erten et al, *Rem. Sens. Env.* 2016]

Test site 1: Sevilla (SW Spain)



TEST SITE

Single rice type (up to 1.05 m high)

4 fields monitored in 2015

Weekly measurements of height and phenology

TDX DATASET

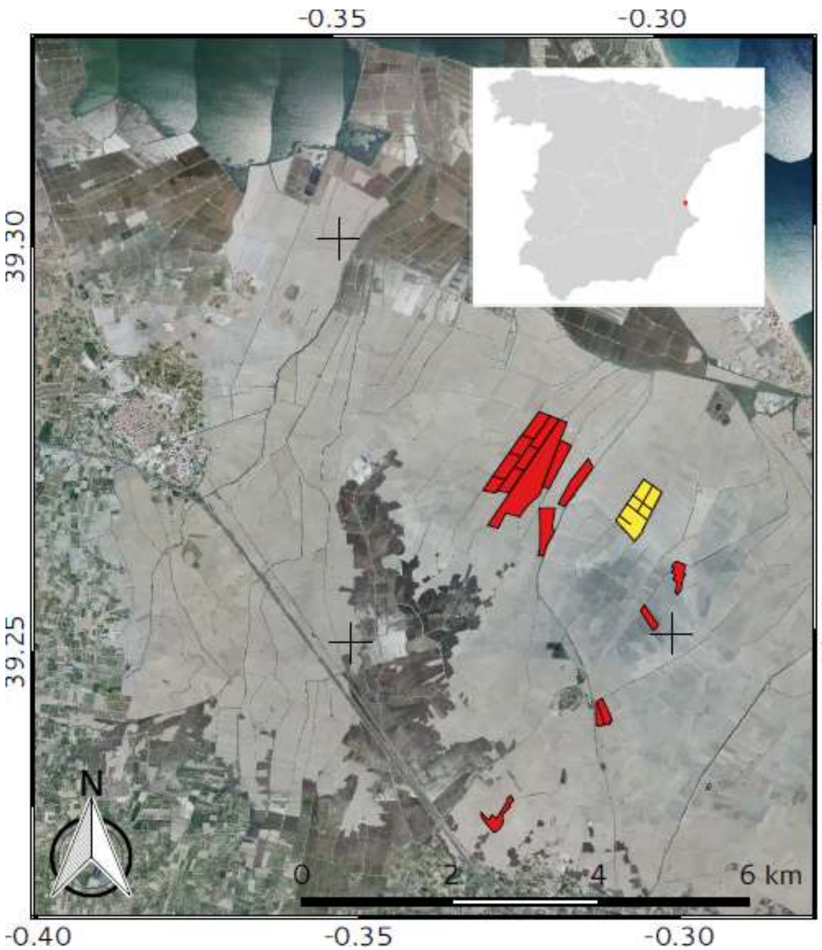
8 bistatic acquisitions, HHVV

Incidence angle: 22.7º

κ_z = 2.48 rad/m

HoA = 2.53 m

Test site 2: Valencia (E Spain)



TEST SITE

Two rice types:

- Senia: up to 0.9 m high
- Bomba: up to 1.7 m high

16+5 fields monitored in 2015

Intensive ground campaigns every 2 weeks in alternate fields

Height measured in 2014, not in 2015

TDX DATASET

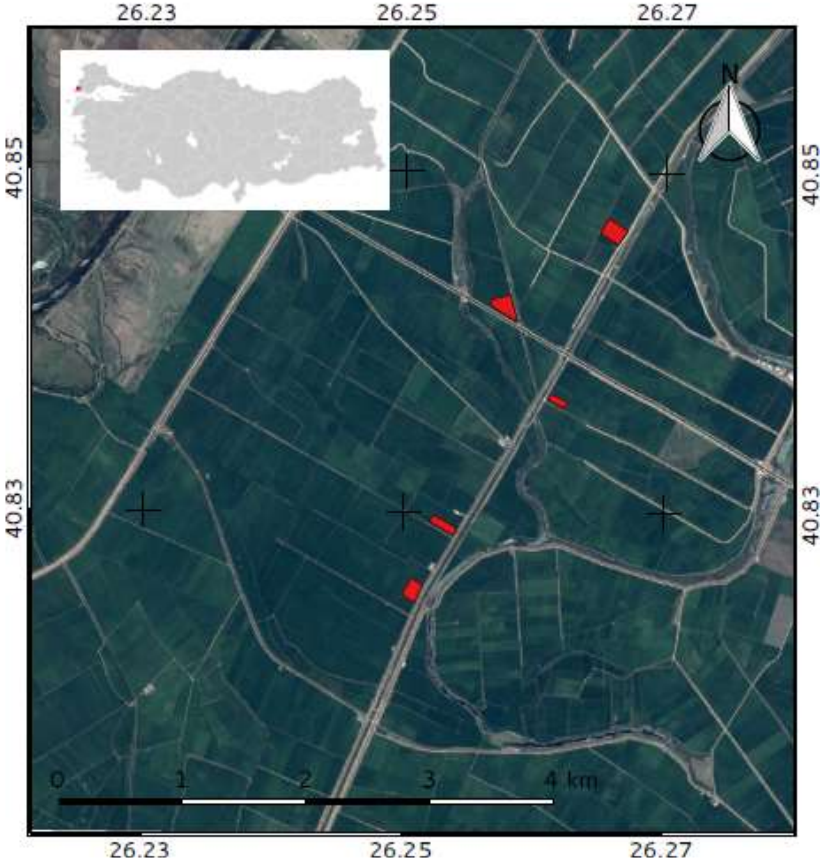
6 bistatic acquisitions, HHVV

Incidence angle: 28.8º

κ_z = 1.83 rad/m

HoA = 3.42 m

Test site 3: Ipsala (W Turkey)



TEST SITE

Single rice type (up to 1.25 m high)

5 fields monitored in 2015

Weekly measurements of height

TDX DATASET

8 bistatic acquisitions, HHVV

Incidence angle: 30º

κ_z = 1.61 rad/m

HoA = 3.89 m

Data processing

Input: Data takes in CoSSC format, dual-pol HHVV

1. Range-spectral filtering (required due to large baselines)
2. Removal of flat Earth and topographic phase terms
   - Extremely flat scenes: use of SRTM or other DEM's usually degrades the data quality
   - A constant topography is assumed for the scene (enough for analysis at parcel scale)
   - Alternatively the main phase ramp can be estimated and removed locally
   - No absolute phase reference is needed (height retrieval is relative)
3. PolInSAR coherency matrix formation and multi-looking (21 x 21 boxcar)
4. Height inversion carried out at all pixels

Analysis: ROI selection of all pixels for each rice field (with eroded borders)

- Statistics of the estimates inside each field: average and std. deviation

Vegetation height inversion

- Main assumption: RVoG model
- General coherence expression in bistatic systems:

$$\tilde{\gamma}(\kappa_Z, \vec{w}) = e^{i\phi_0} \frac{\tilde{\gamma}_V + m_D(\vec{w}) + \frac{\sin k_z h_v}{k_z h_v} m_{DB}(\vec{w})}{1 + m_D(\vec{w}) + m_{DB}(\vec{w})}$$

[Treuhaft et al. 1996, 2000] [Ballester-Berman et al. 2007, 2011]

- With dominant double-bounce ground contribution

Extra decorrelation term γ_{DB}

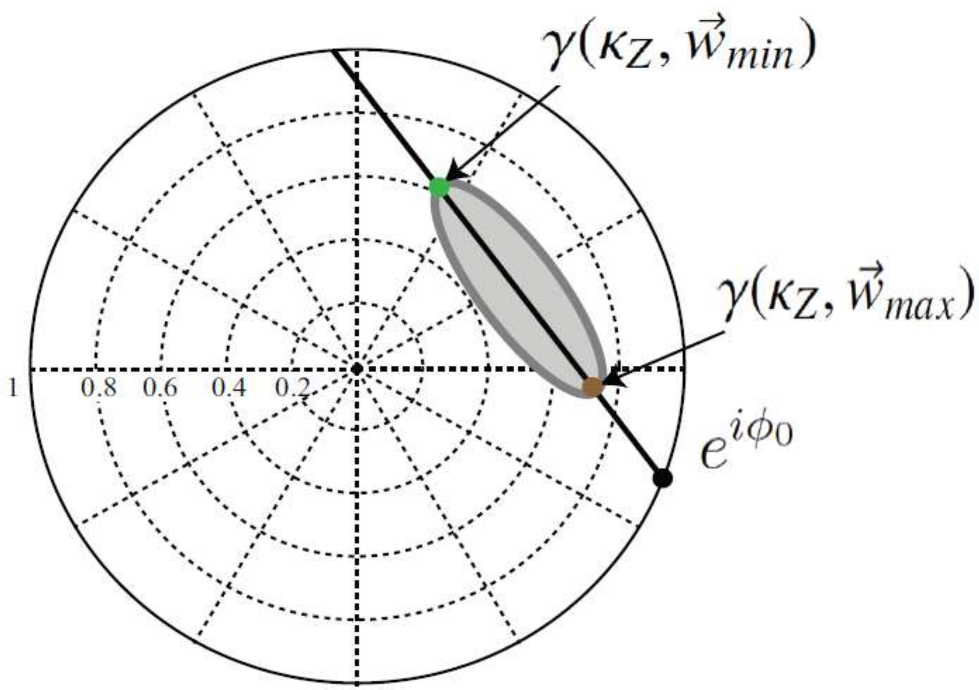
$$\tilde{\gamma}(\kappa_Z, \vec{w}) = e^{i\phi_0} \frac{\tilde{\gamma}_V + \frac{\sin k_z h_v}{k_z h_v} m_{DB}(\vec{w})}{1 + m_{DB}(\vec{w})}$$

$$k_z = \kappa_Z \sin^2 \theta_0$$

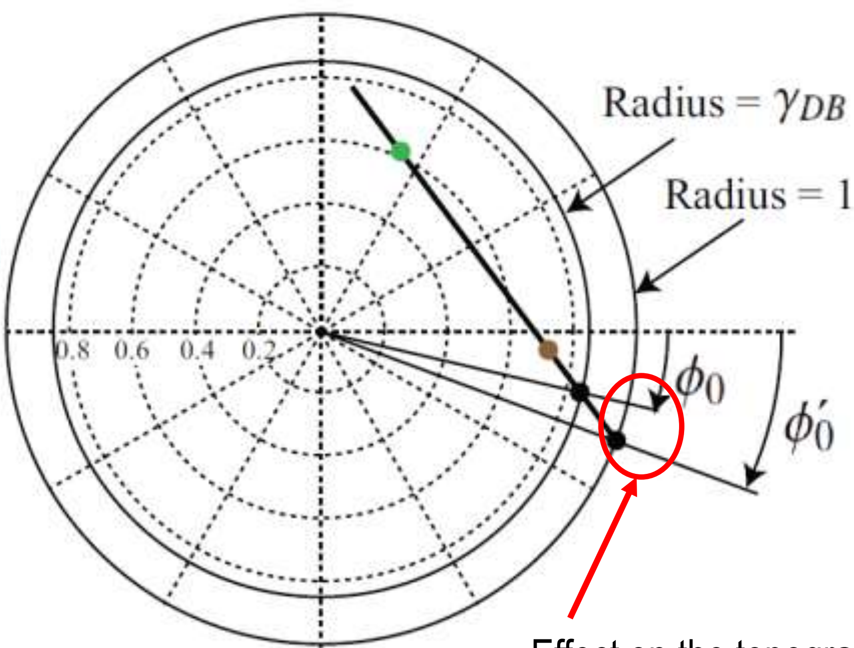
Vegetation height inversion

- Coherences on the complex plane

Conventional RVoG
(valid for repeat-pass or
dominant direct ground)



RVoG for bistatic systems with
dominant double-bounce ground



Effect on the topography
estimation with line fit

Vegetation height inversion: algorithm

1. Line fit to the region of coherences:

   Selection of two coherences with maximum and minimum ground contributions $\gamma(\kappa_Z, \vec{w}_{max})$ and $\gamma(\kappa_Z, \vec{w}_{min})$

2. Compensation of the two coherences for SNR and quantisation decorrelation

$$\gamma_{\mathrm{SNR}}(\vec{w}) = \sqrt{\left(\frac{\mathrm{SNR}_1(\vec{w})}{1+\mathrm{SNR}_1(\vec{w})}\right)\cdot\left(\frac{\mathrm{SNR}_2(\vec{w})}{1+\mathrm{SNR}_2(\vec{w})}\right)}$$

[Kugler at al. 2014]

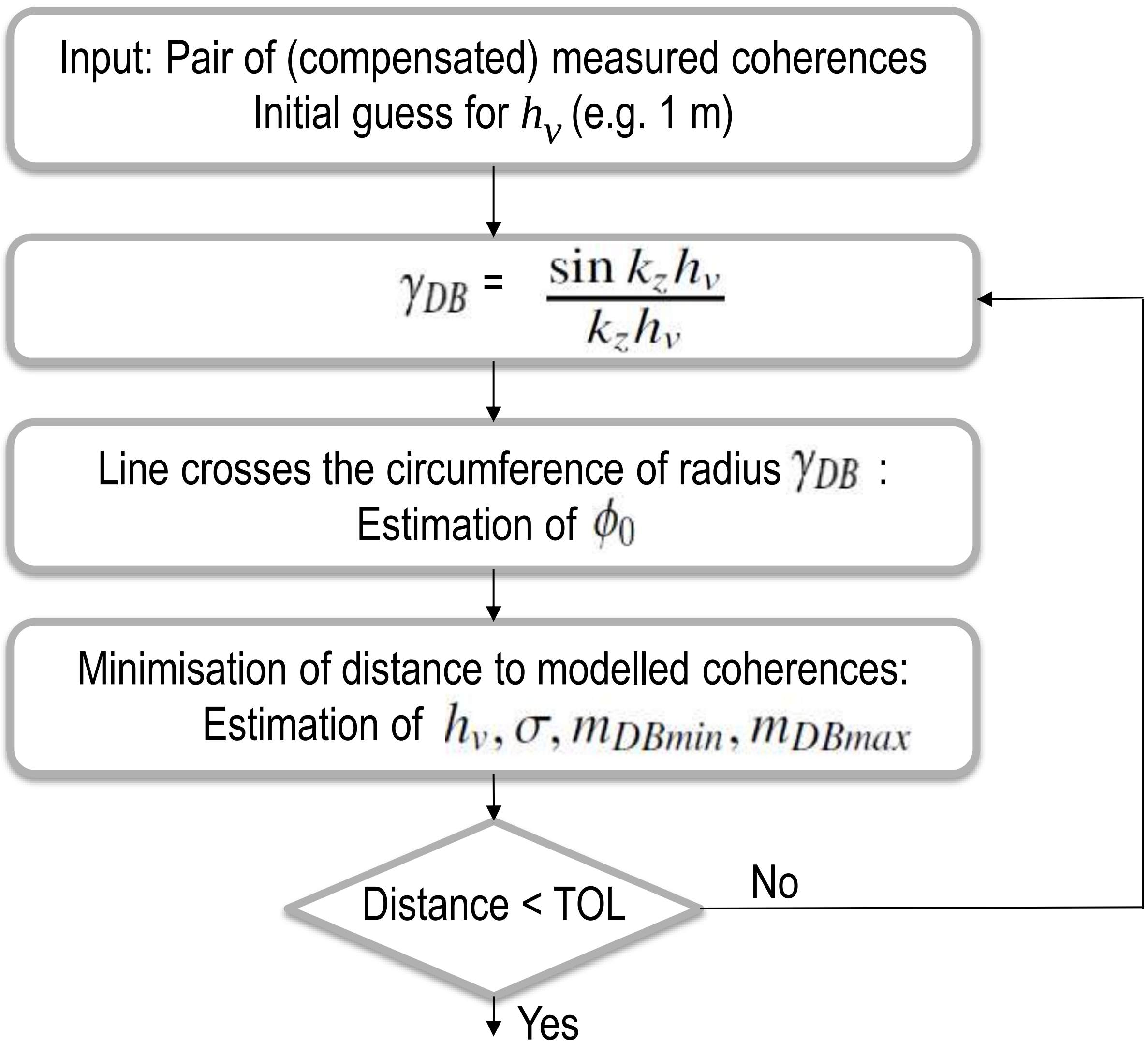
$$\gamma_{\mathrm{BQ}} \approx 0.965$$

[Martone et al. 2015]

3. Iterative estimation of topographic phase and rest of parameters by minimising the distance to the model

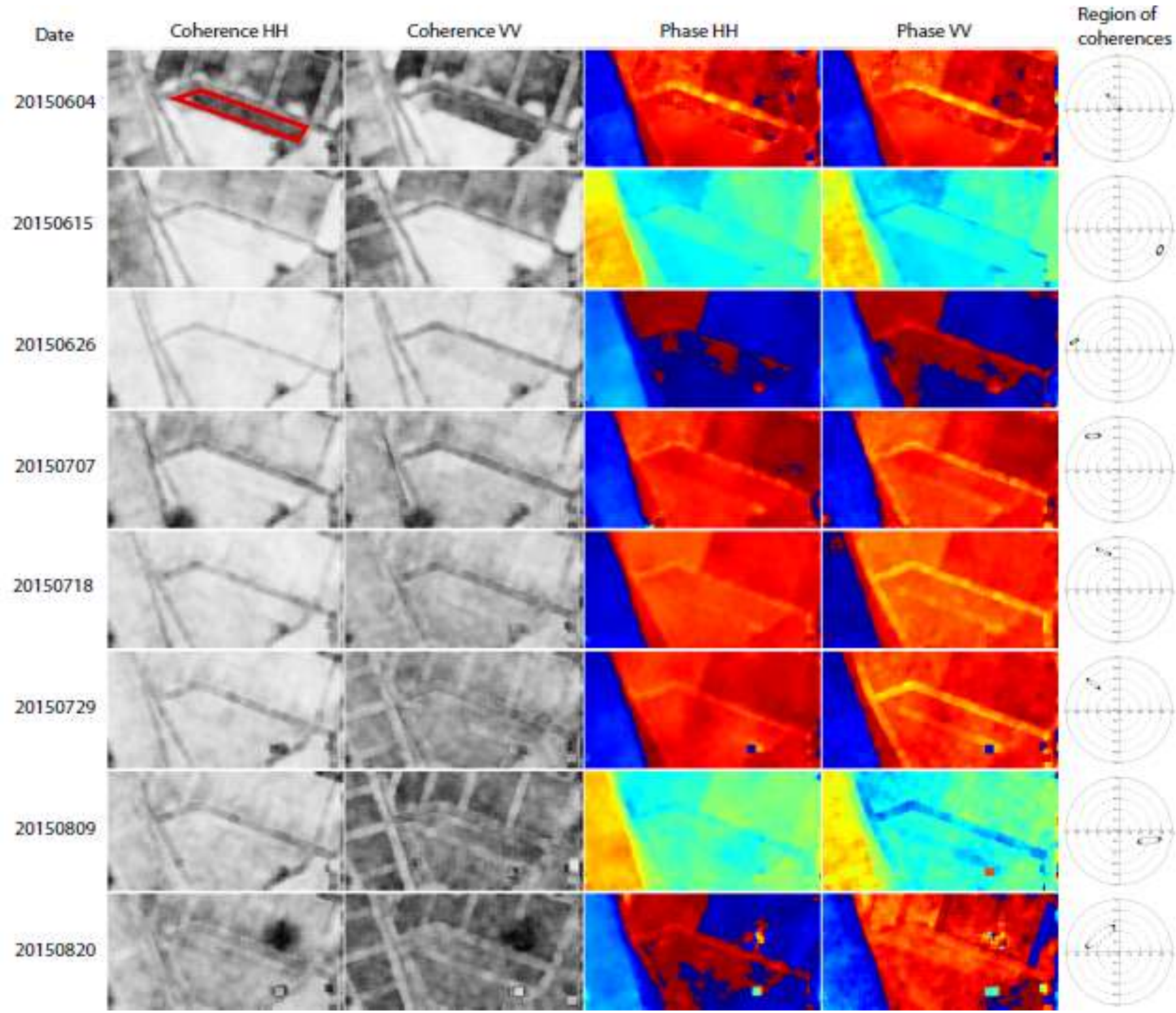
$$\min_{\phi_0, h_v, \sigma, m_{DBmin}, m_{DBmax}} \left\| \begin{matrix} \gamma(\kappa_Z, \vec{w}_{max}) - \tilde{\gamma}(\kappa_Z, \phi_0, h_v, \sigma, m_{DBmax}) \\ \gamma(\kappa_Z, \vec{w}_{min}) - \tilde{\gamma}(\kappa_Z, \phi_0, h_v, \sigma, m_{DBmin}) \end{matrix} \right\| \Rightarrow \phi_0, h_v, \sigma, m_{DBmin}, m_{DBmax}$$

Iterative procedure



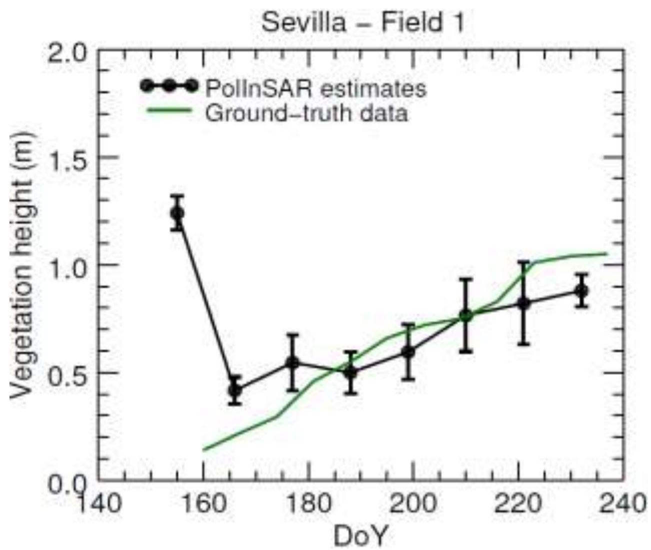
SOLUTION: $\phi_0, h_v, \sigma, m_{DBmin}, m_{DBmax}$

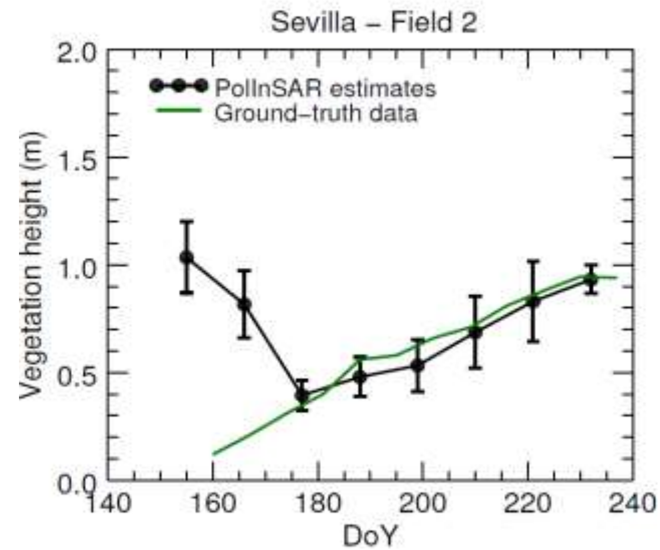
Data inspection

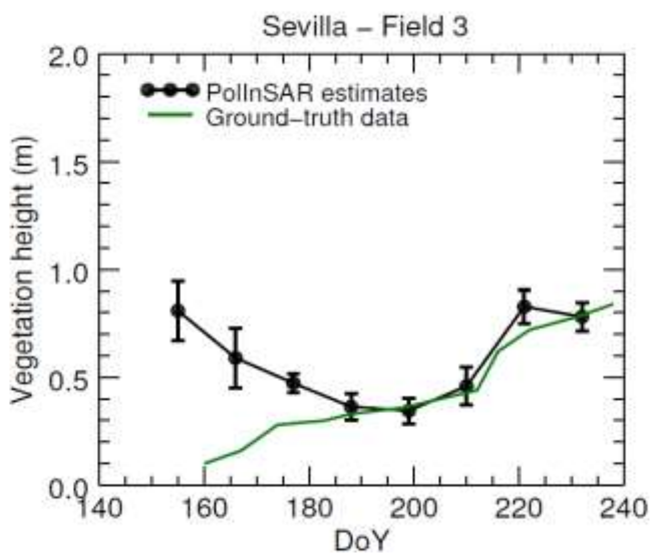


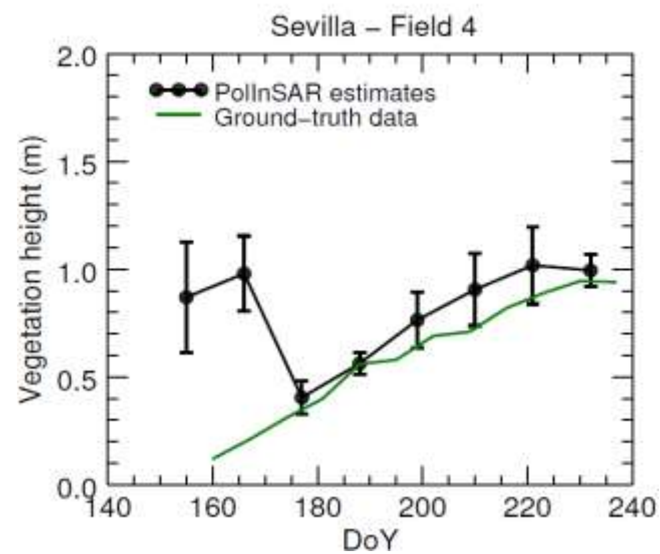
Results: Temporal evolution of estimates

Sevilla



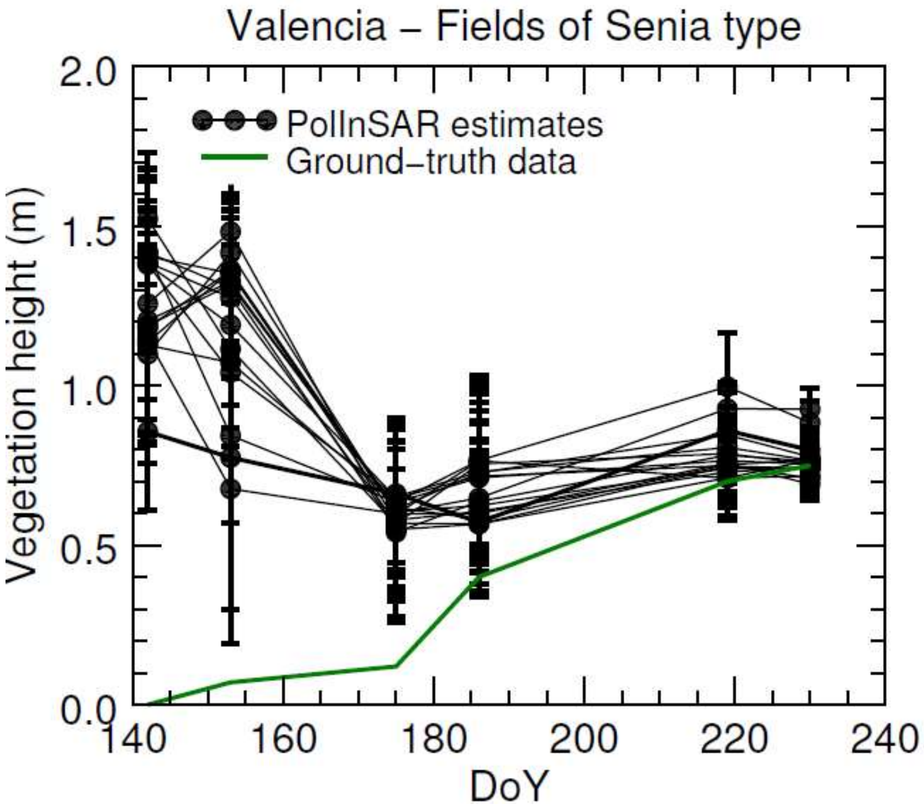


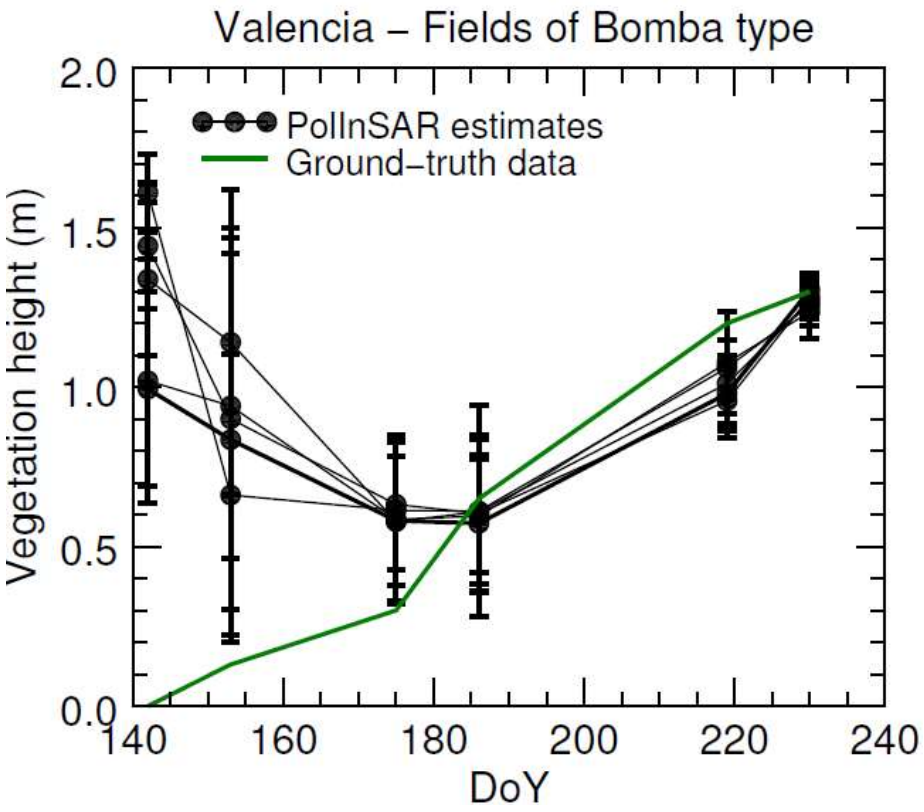




Results: Temporal evolution of estimates

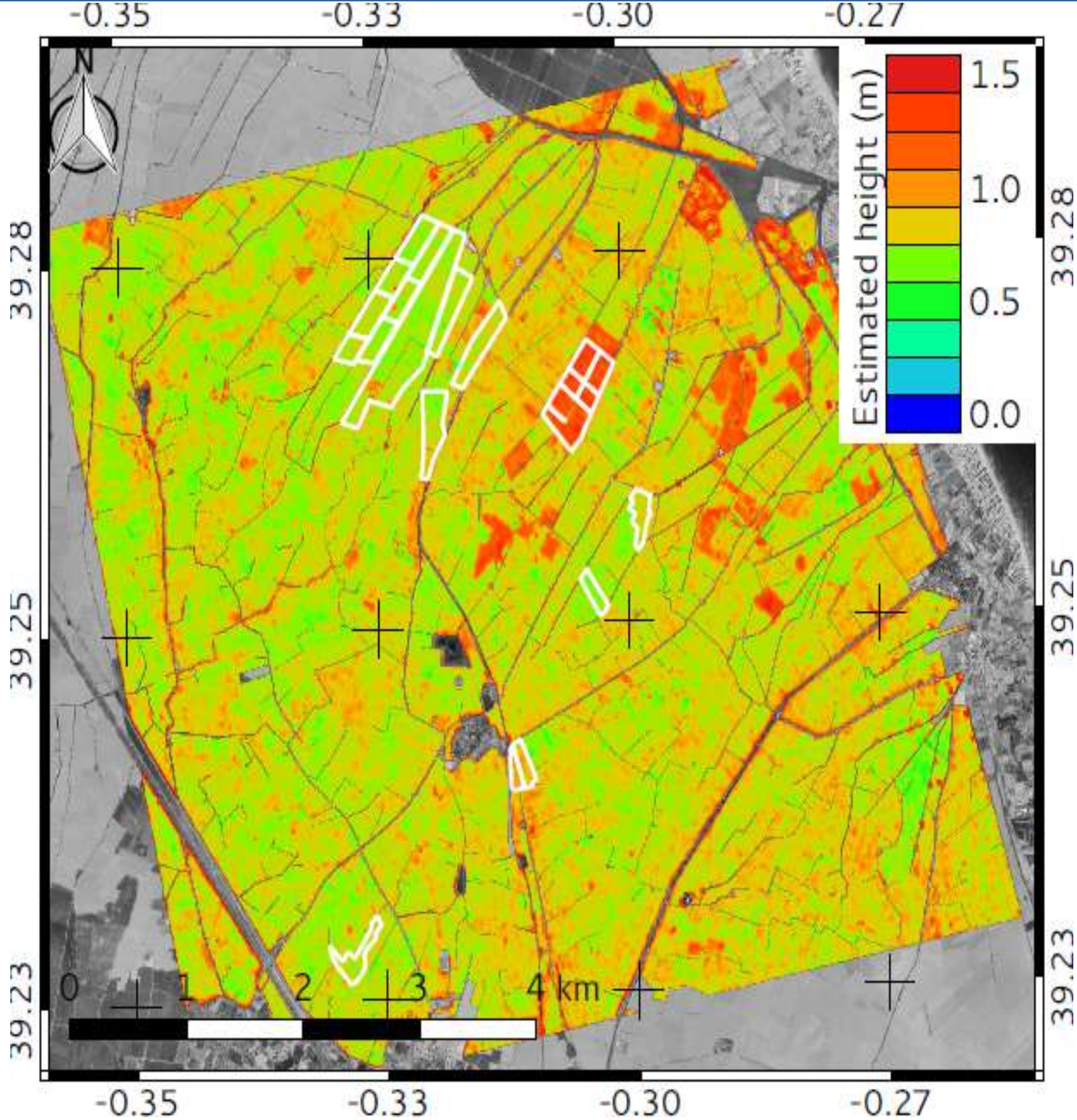
Valencia





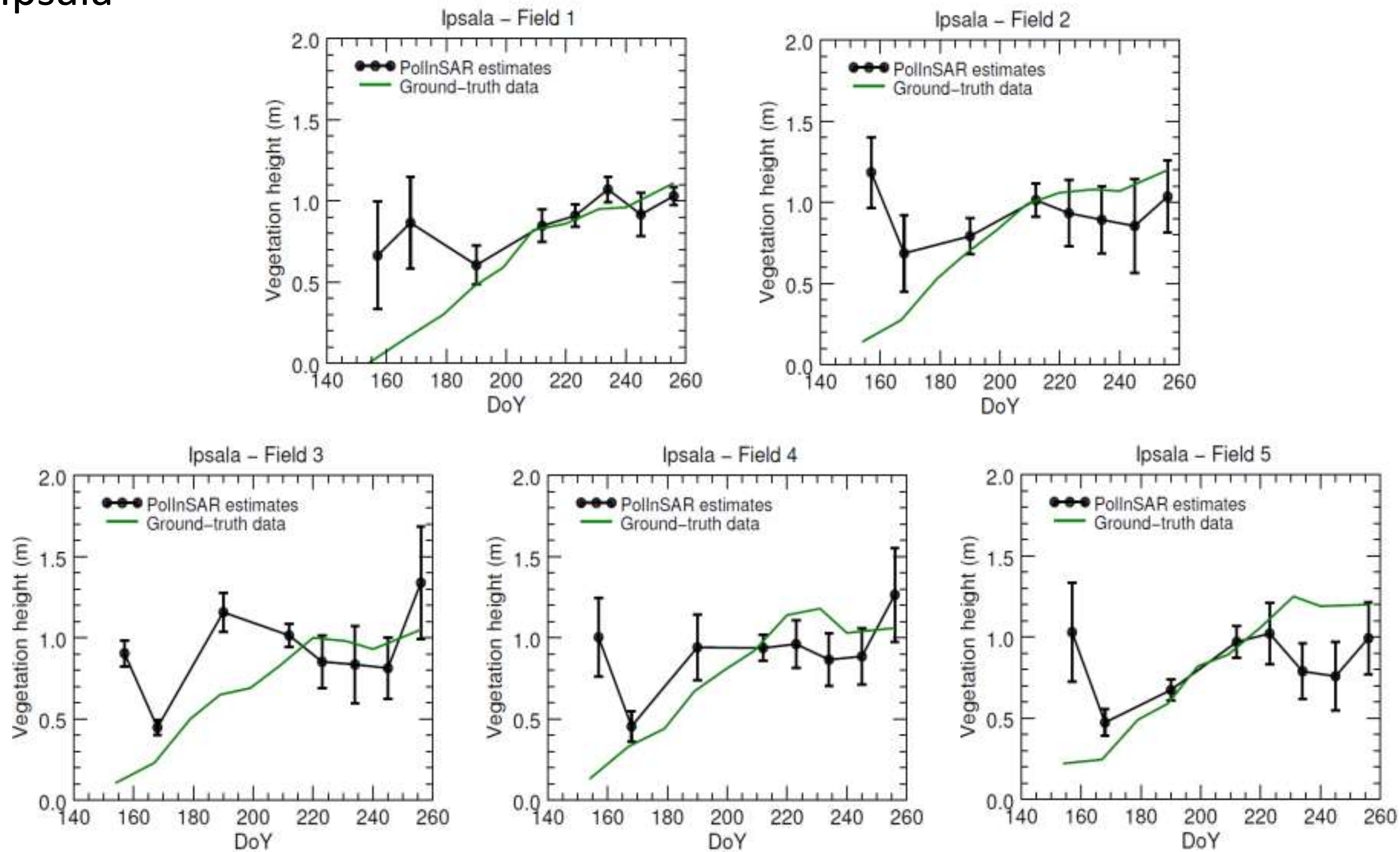
Results: Map at a fixed date

Valencia



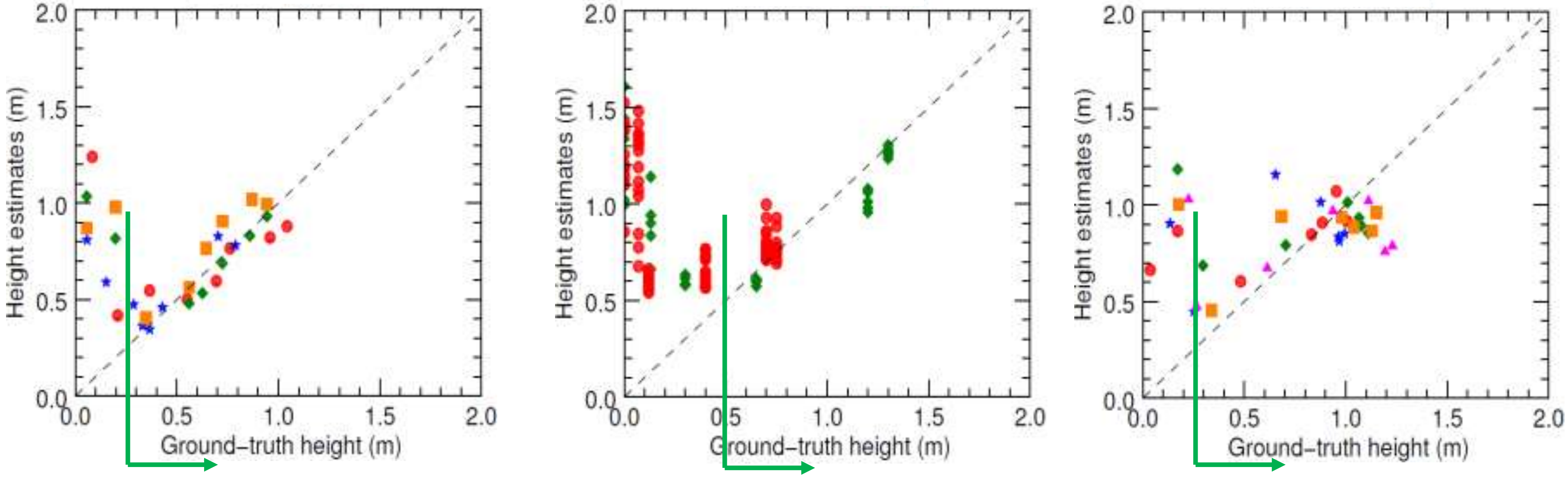
Results: Temporal evolution of estimates

Ipsala



Results: Comparison with ground data

Sevilla | Valencia | Ipsala



Statistics for valid ranges

	Sevilla	Valencia	Ipsala
h_v threshold (cm)	25	40-60	25
k_v threshold	0.3	0.37-0.55	0.2
R^2	0.81	0.79	0.44
RMSE (cm)	9.9	10.0	21.1
n	24	47	29

Sensitivity parameter

$$k_v = \kappa_Z h_v / 2$$

Recommended range

k_v: [1, 1.5]

[Cloude2009]

Conclusions and perspectives

- The proposed methodology is useful to monitor the growth of rice:
  - Good results have been obtained in two test sites: Sevilla and Valencia
  - But performance in Ipsala is worse.
- Limitation: vertical sensitivity -> short heights cannot be retrieved by PolInSAR alone, even with the baselines provided during the science phase
- To be studied next:
  - More elaborated inversion approach (ranges of values)
  - Analysis and physical interpretation of the estimates of the rest of model parameters: extinction, ground-to-volume ratios
  - Influence of baseline and incidence angle
  - Limitations due to the RVoG assumption: effect of differential extinction, etc.
  - Other crops (no flooded ground)

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