An Introduction to

PolSAR-Ap: Exploitation of Fully Polarimetric SAR Data for Application Demonstration

Irena Hajnsek, Matteo Pardini, Kostas Papathanassiou, Shane Cloude, Juan M. Lopez-Sanchez, David Ballester-Berman, Thomas Jagdhuber, Elise Koeniguer, Nicolas Trouve, Maurizio Migliaccio, Ferdinando Nunziata, Armando Marino, Giuseppe Parrella, Carlos Lopez-Martinez, Eric Pottier, Andrea Minchella, Yves Louis Desnos

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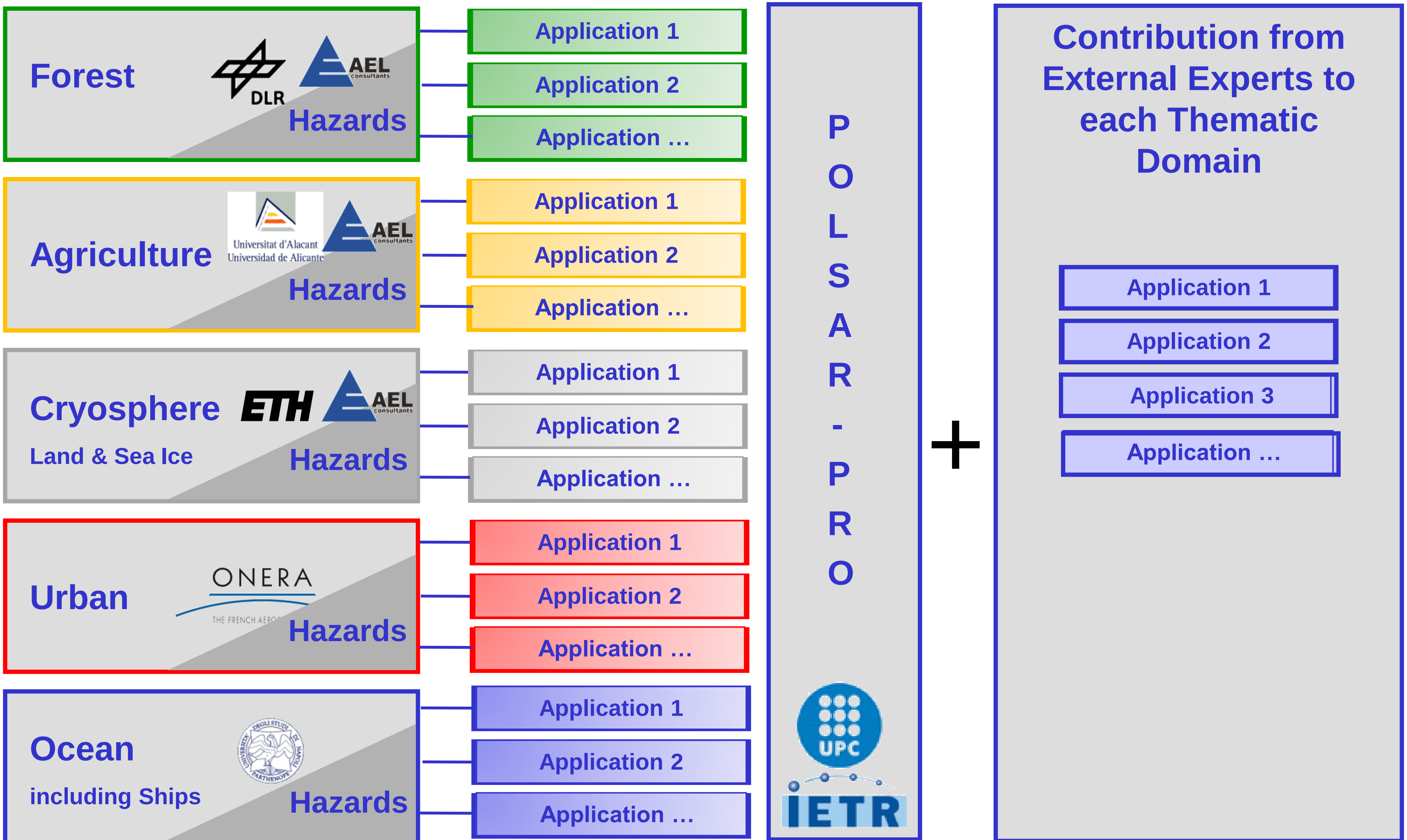
Project Objectives

- **Evaluate and demonstrate the importance of quad-polarimetric SAR data for a wide range of remote sensing applications**
  - Selection of applications with a unique benefit and performance improvement
  - Demonstration on satellite data
  - Software implementation into PolSARPro
  - Open-access book (Springer)

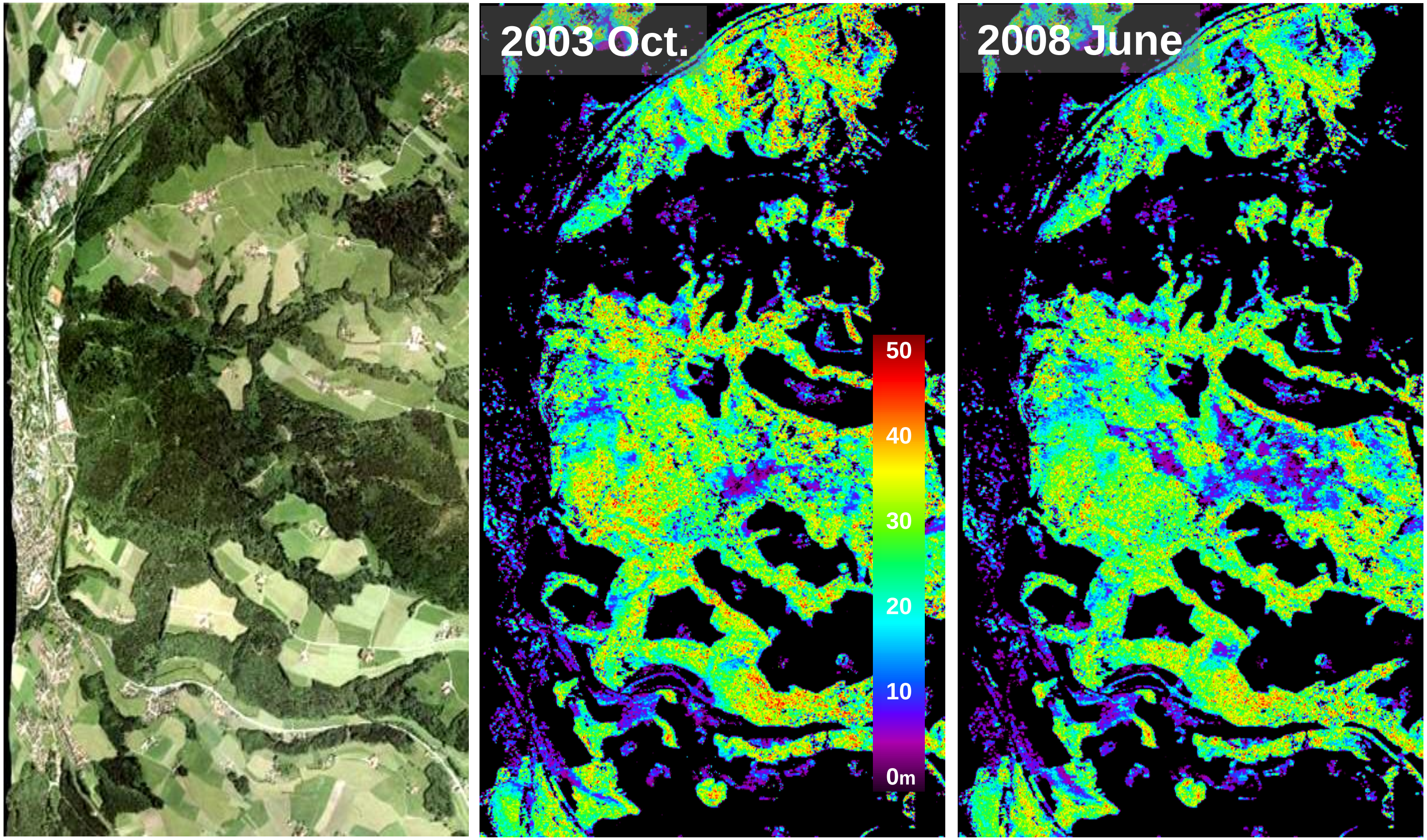
Thematic Domains

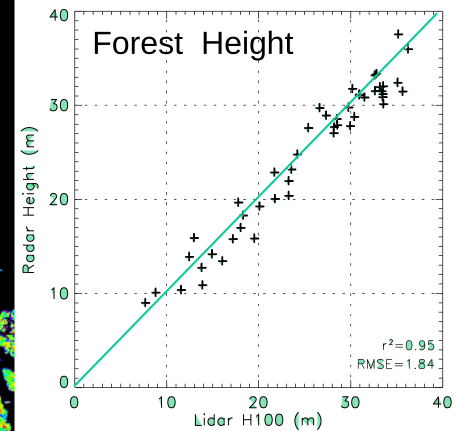


Thematic Domains: Forest

Domain	Application / Product	Test site - Radar data	Reference data
Forestry	Above ground biomass from allometric relationships	Traunstein (Germany) DLR E-SAR, L	Ground inventory
	Stand height	Krycklan (Sweden) TanDEM-X	LiDAR measurements
		Traunstein (Germany) Mawas (Indonesia) DLR E-SAR, L / P	
	Vertical structure	Traunstein (Germany) DLR E-SAR, L / P	Biomass vertical profiles from ground inventory

Forest Height Estimation





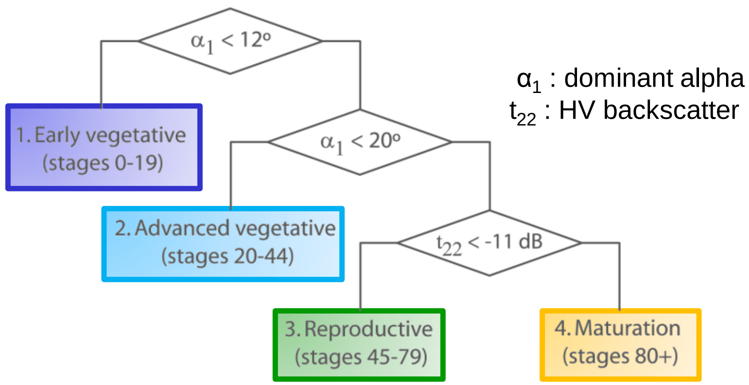
- Dual-pol (and Compact-pol) inversion: inversion possible, but compromised in dense forest and/or terrain slope conditions leading to, depending on the frequency, biased estimates, and/or increased variance, and/or inversion failure.
- Single-pol inversion with an acceptable performance is possible only in areas with a available ground elevation model.

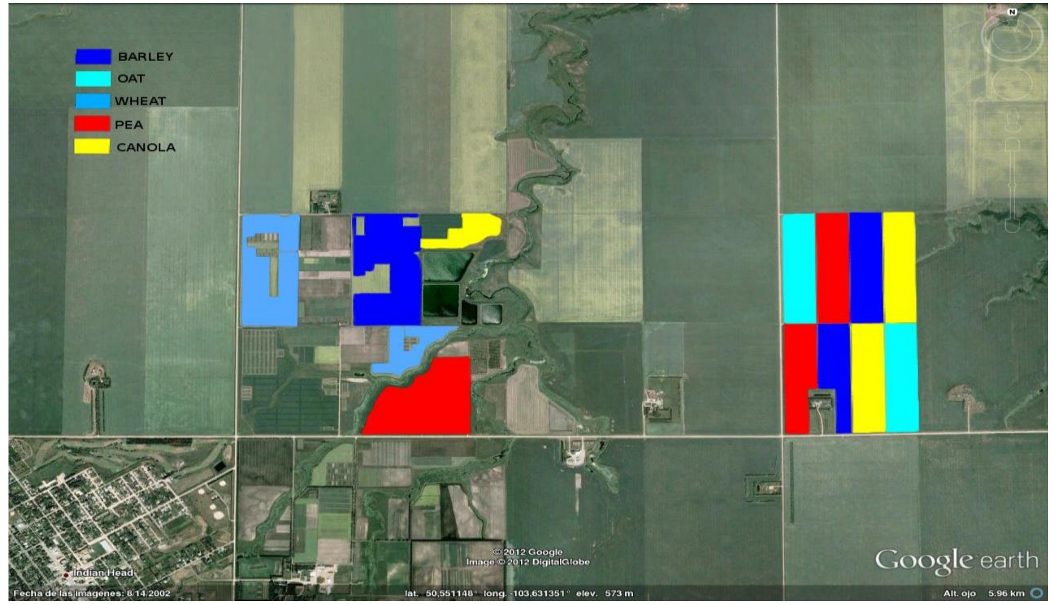
Thematic Domains: Agriculture

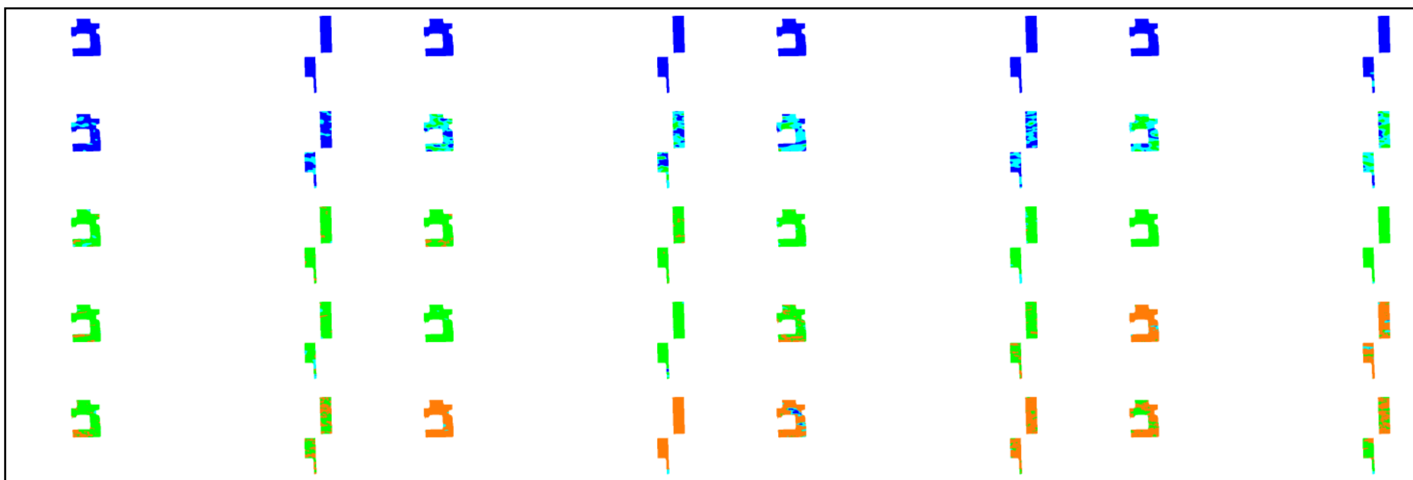
Domain	Application / Product	Test site - Radar data	Reference data
Agriculture	Soil moisture	Flevoland (The Netherlands), Indian Head (Canada) RadarSAT-2, C	Ground measurements
		Demmin, Weisseritz (Germany) DLR E-SAR, L	
	Phenology determination	Indian Head (Canada) RadarSAT-2, C	Ground surveys
	Wetland delineation	Pleine Fougeres (France) RadarSAT-2, C	Ground measurements ALOS-PRISM / AVNIR-2 images, meteorological info

Phenology Determination

- 4 stage phenology can be distinguished using PolSAR
- Example: Barley (Indian Head Test Site, RadarSAT-2)







Time series analysis of phenological stages of barley @ Full-pol

- Full-pol: best performance, less ambiguities
- Slightly worse perfomance in compact-pol

Thematic Domains: Cryosphere

Domain	Application / Product	Test site - Radar data	Reference data
Cryosphere	Snow water equivalent	Sodankylae (Finland) TerraSAR-X	Ground measurements
		Churchill (Canada) RadarSAT-2, C	
	Land ice extinction	Svalbard (Norway) DLR E-SAR, L / P	GPR measurements
	Sea ice surface char.	Svalbard (Norway) DLR E-SAR	-

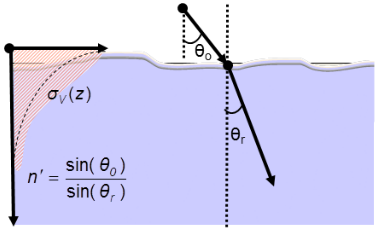
Ice Extinction Estimation

- Ice extinction can be derived from Pol-InSAR techniques provided an adequate scattering model
- ICESAR 2007 campaign

IceSAR Campaign 2007 @ ~80°N

- Only full-pol data can guarantee an observation space adequate for the model inversion and the full charcaterization of the ice volume

Two Layer Ice Model: Ground + Infinite Volume



Interferometric (Volume) Coherence:

$$\tilde{\gamma}(\vec{w}) = \exp(i\varphi_0)\frac{\tilde{\gamma}_V + m(\vec{w})}{1 + m(\vec{w})}$$

$$\tilde{\gamma}_V = \frac{I}{I_0} = \frac{2\sigma}{2\sigma - i\kappa_z\cos(\theta_r)} = \frac{1}{1 - i\kappa_z d_{2z}}$$

$$I = \int_0^\infty \exp(i\kappa_z z')\exp\left(\frac{2\sigma z'}{\cos\theta_0}\right)dz' \qquad I_0 = \int_0^\infty \exp\left(\frac{2\sigma z'}{\cos\theta_0}\right)dz'$$

Penetration Depth: $d_{2z} = \frac{1}{2\sigma}\cos(\theta_r)$

G/V R: $m(\vec{w}) = \frac{m_G(\vec{w})}{m_V(\vec{w})T_{a-v}(\vec{w})}$

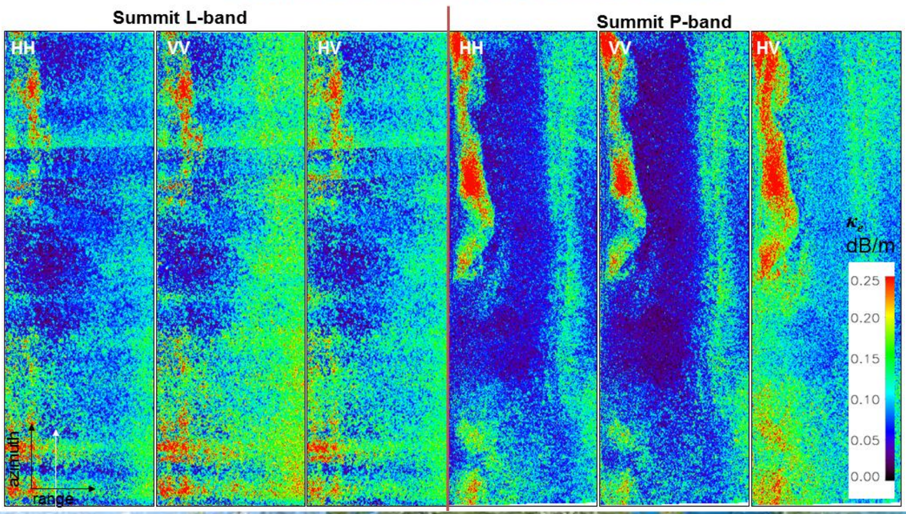
Vertical Wavenumber: $\kappa_z = \frac{\kappa\Delta\theta_r}{\sin(\theta_r)}$

Wavenumber: $\kappa = \frac{4\pi n'}{\lambda}$

4 Parameters:

Extinction	σ
Ref. Index	n'
Topography	φ_0
G/V Ratio	$m(\vec{w})$

Extinction Inversion Results



Thematic Domains: Urban

Domain	Application / Product	Test site - Radar data	Reference data
Urban	Mapping / Classification	Toulouse (France) TerraSAR-X	Cadastral registers (Building footprints)
		San Francisco (France) TerraSAR-X	Info from city hall websites and planning departments
	3-D Rendering (PolInSAR)	Toulouse (France) RAMSES-SETHI, X	3D representation of the city (Building elevations)

3-D Urban Rendering

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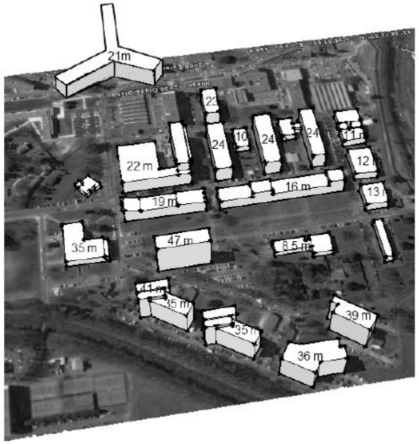
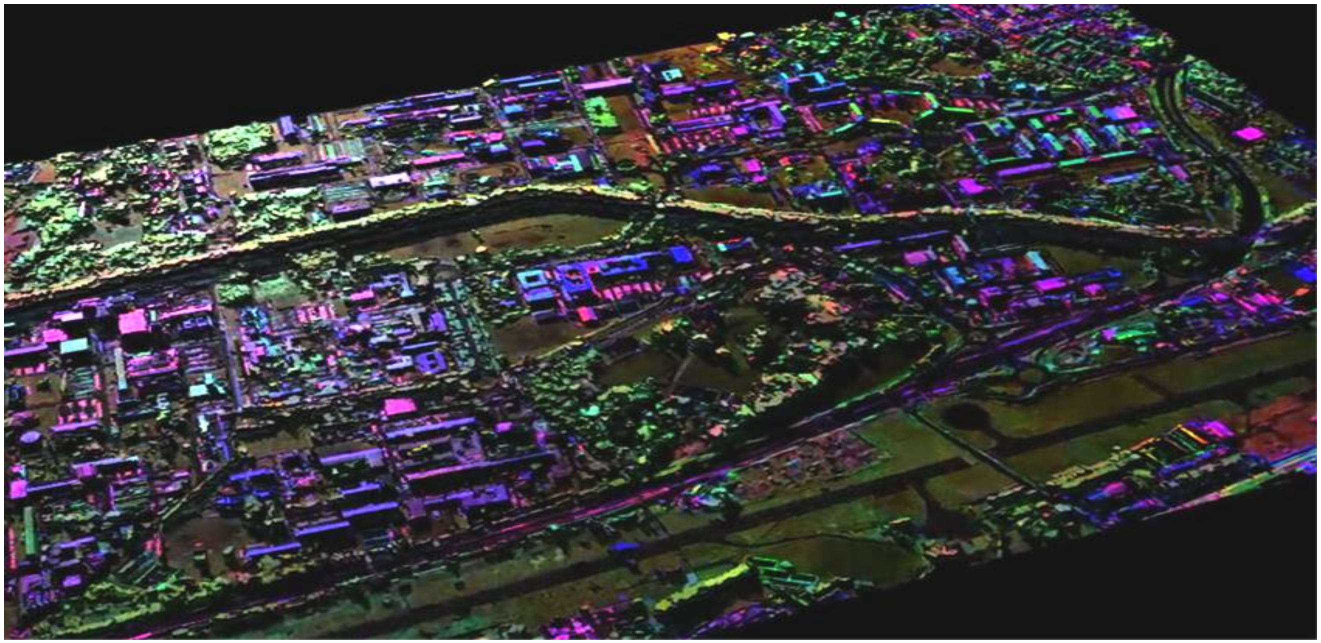
- High resolution imaging is needed to obtain significant information about 3D rendering
- Example: 3D rendering using polarimetric X-band (RAMSES-SETHI)



Ground truth delivered on a small area



3-D reconstruction over Toulouse after building segmentation (colors code height)

- Polarimetry improves the precision obtained on the height estimates of a factor of two. RMSE reduces, too.
- Full polarimetry improves the RMSE versus dual polarimetry.
- Among all single polarizations, HV gives the best results.

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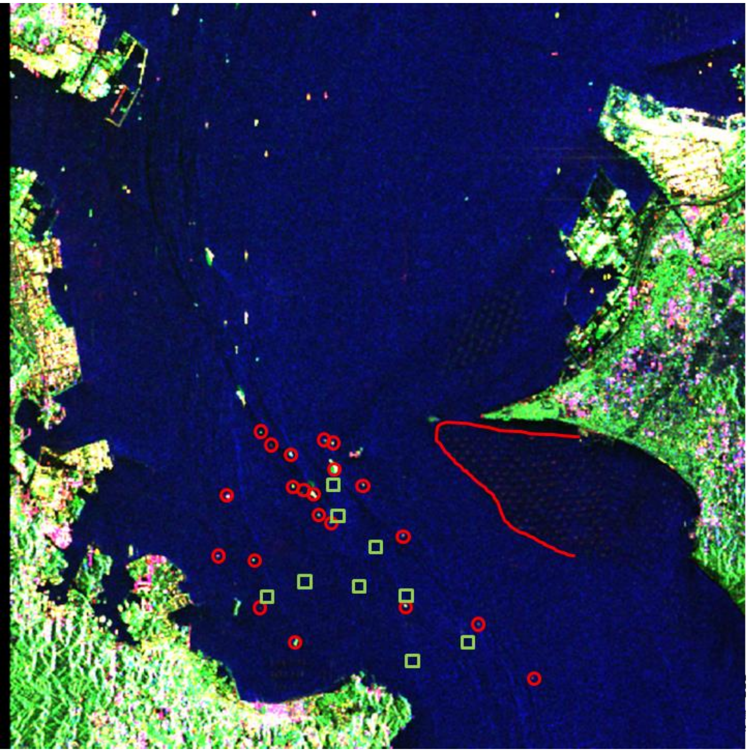
Thematic Domains: Ocean

Domain	Application / Product	Test site - Radar data	Reference data
Ocean	Oil at sea observation	Gulf of Mexico RadarSAT-2, C UAVSAR, L	Information about oil seeps and Deep Water Horizon oil slick
	Metallic targets at sea observation	Gulf of Mexico RadarSAT-2, C	Google Earth maps

Ship Detection

- Ship detection with a polarimeteric detector (GP-PNF:Geometrical Perturbation Polarimetric Notch Filter)
- Example: Tokyo Bay (ALOS)



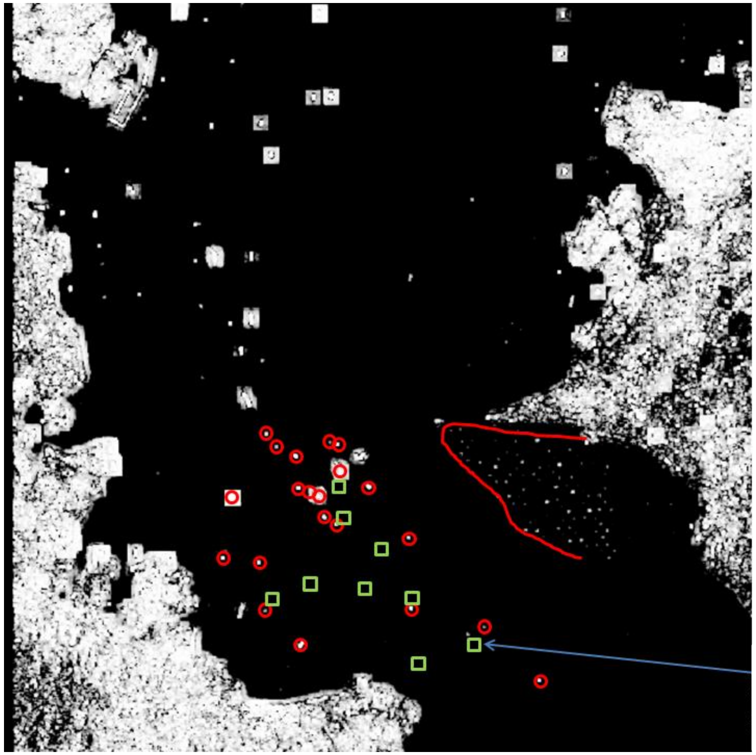
RGB PAULI

Tokyo Bay
(35,294451; 139,785816)

Red: HH-VV
Green: 2*HV
Blue: HH+VV

Sigma nought
1000x1000 pixels
Multi-look 1x5
Image size ~ 30x30km.

□ Present in the ground data but not in the Pauli RGB
□ O present in the ground data and Pauli RGB



GP-PNF QUAD

Detected: 22
Missed: 8 (15)
False: 0

$$RedR = 5 \cdot 10^{-5}$$
$$T = 0.98$$

This is likely to be a wrong positioning of the rectangle in the ground survey due to the fact that no points are visible in the RGB

- Single / dual-pol detectors can reach the same correct detection probability of the quad-pol detectors at the expenses of the false alarm rate.

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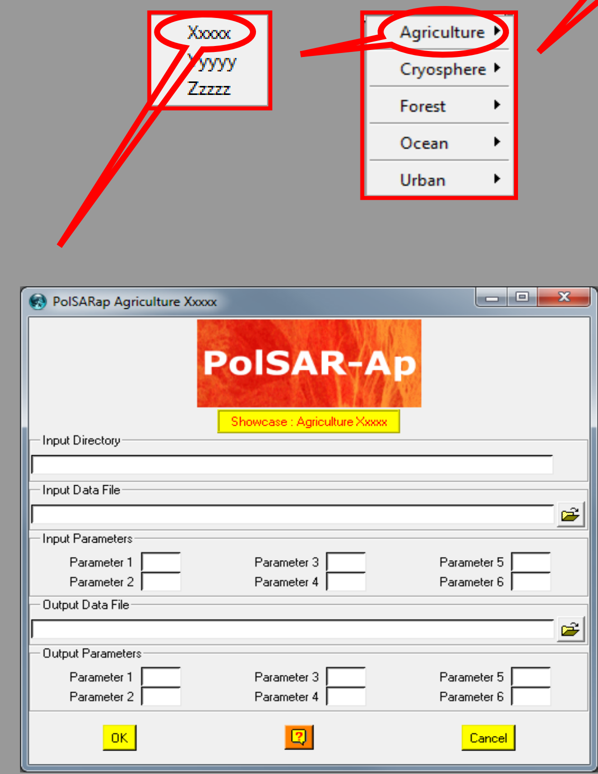
Software Implementation in PolSARpro

Polarimetric SAR Data Processing and Educational Tool v5.0 - Menu

Domain	Selected application	Methodology
Forest	Stand height	Pol-InSAR dual-baseline inversion
Agriculture and Wetlands	Soil moisture estimation under vegetation cover	PolSAR model-based decomposition and inversion
Cryosphere	Land ice extinction	PolInSAR single-baseline inversion
Urban	Detection of built-up areas	Threshold on PolInSAR optimized coherences
Ocean	Ship detection	Geometrical perturbation notch filter

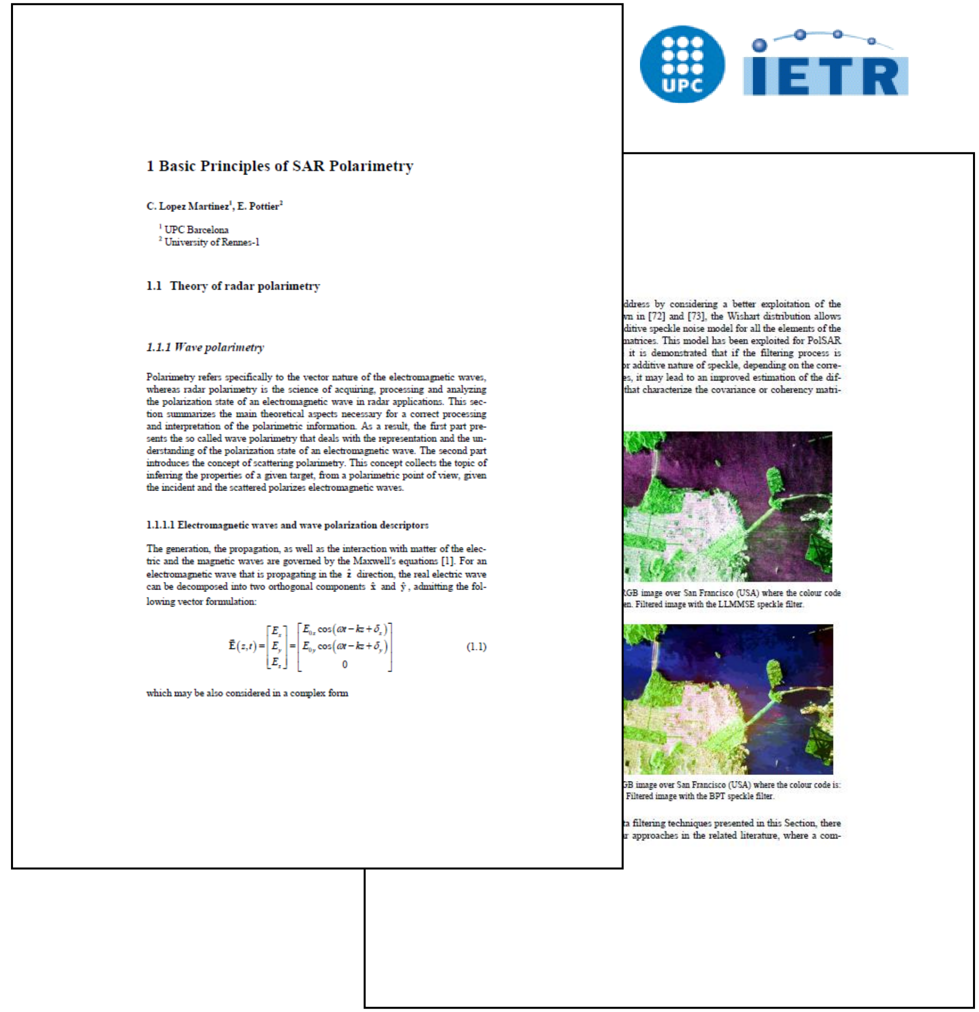


PolSARpro
The Polarimetric SAR Data Processing and Educational Tool

PolSARpro v5.0 - Run Trace
Open Window Warning
Close Window Warning

Open-access book

- All showcases have been compiled in the book **"Principles and Applications of SAR Polarimetry"**
- Editors: Y. L. Desnos and I. Hajnsek
- Open-access publication (Springer)
- One chapter for each application domain + theoretical review of PolSAR principles (C. Lopez Martinez, E. Pottier)
- Additional material (software, „Do It Yourself", etc.) will be available on a dedicated web page



1 Basic Principles of SAR Polarimetry

C. Lopez Martinez[1], E. Pottier[2]

[1] UPC Barcelona
[2] University of Rennes-1

1.1 Theory of radar polarimetry

1.1.1 Wave polarimetry

Polarimetry refers specifically to the vector nature of the electromagnetic waves, whereas radar polarimetry is the science of acquiring, processing and analyzing the polarization state of an electromagnetic wave in radar applications. This section summarizes the main theoretical aspects necessary for a correct processing and interpretation of the polarimetric information. As a result, the first part presents the so called wave polarimetry that deals with the representation and the understanding of the polarization state of an electromagnetic wave. The second part introduces the concept of scattering polarimetry. This concept collects the topic of inferring the properties of a given target, from a polarimetric point of view, given the incident and the scattered polarizes electromagnetic waves.

1.1.1.1 Electromagnetic waves and wave polarization descriptors

The generation, the propagation, as well as the interaction with matter of the electric and the magnetic waves are governed by the Maxwell's equations [1]. For an electromagnetic wave that is propagating in the $\hat{\mathbf{z}}$ direction, the real electric wave can be decomposed into two orthogonal components $\hat{\mathbf{x}}$ and $\hat{\mathbf{y}}$, admitting the following vector formulation:

$$\vec{\mathbf{E}}(z,t) = \begin{bmatrix} E_x \\ E_y \\ E_z \end{bmatrix} = \begin{bmatrix} E_{0x}\cos(\omega t - kz + \delta_x) \\ E_{0y}\cos(\omega t - kz + \delta_y) \\ 0 \end{bmatrix} \quad (1.1)$$

which may be also considered in a complex form

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Appendix

External Experts: Forest

Forest

Application	Institution	Contact person
Fire scar slassification	Canadian Forest Service	D. Goodenough
AG biomass estimation from empirical rel.	FOI / Chalmers Univ.	L. Ulander
Forest classification	SARVision	D. Hoekman
	University of Rennes	L. Ferro-Famil
Polarimetric tomography	PoliMi	S. Tebaldini
Forest structure parameters estimation	JPL	M. Neumann

External experts: Agriculture

Agriculture

Application	Institution	Contact person
Crop type mapping	Agriculture and Agri-Food Canada	H. McNairn
	Technical University of Denmark	H. Skriver
Wetlands delineation and characterisation	CCRS-NRC	R. Touzi
	University of Miami	S. Wdowinski
Flood delineation and evolution	Niigata University, JAXA	Y. Yamaguchi

External experts: Cryosphere

Cryosphere

Application	Institution	Contact person
Sea ice characterisation	University of Tromso	T. Eltoft
	Chalmers University	L. Eriksson
Sea ice classification	Southwest Research Inst.	M. Necsoiu
Permafrost	Tohoku University	M. Watanabe

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External experts: Urban

Urban

Application	Institution	Contact person
Classification	Niigata University	Y. Yamaguchi
3-D Rendering (Tomography)	University of Rennes-1	L. Ferro-Famil
Persistent Scatterer Interferometry (deformations)	UPC Barcelona	C. Lopez-Martinez
	University of Alicante	J. M. Lopez-Sanchez

External experts: Ocean

Ocean

Application	Institution	Contact person
Oil slick observation	University of Tromso	C. Brekke
Target detection	ETH Zürich, Institute of Environmental Engineering	A.Marino Data courtesy of K. Ouchi (JAXA)

Software implementation in PolSARpro

Domain	Selected application	Methodology	Contributors
Forest	**Stand height**	Pol-InSAR dual-baseline inversion	F. Kugler, K. Papathanassiou
Agriculture and Wetlands	**Soil moisture estimation under vegetation cover**	PolSAR model-based decomposition and inversion	T. Jagdhuber, I. Hajnsek, K. Papathanassiou
Cryosphere	**Land ice extinction**	PolInSAR single-baseline inversion	G. Parrella, I. Hajnsek
Urban	**Detection of built-up areas**	Threshold on PolInSAR optimized coherences	E Koniguer, N. Trouve
Ocean	**Ship detection**	Geometrical perturbation notch filter	A. Marino

What are the applications with a high maturity based on PolSAR?

Domain	Application / Product	Application Maturity (Polarimetry)
Forestry	Above Ground Biomass	Medium
	Stand Height	High
	Vertical Structure	Medium
	Thematic Maps	High
	Change Detection	High
Agriculture	Crop Type Mapping	Medium
	Soil Moisture	High
	Phenology Determination	Medium
	Wetland Delineation	Medium
	Flooding Mapping	Medium
Cryosphere	Snow Volume	Medium
	Land Ice Extinction	Low
	Sea Ice Surface Char.	Low
Urban	Mapping / Classification	Medium
	3D Rendering	Medium
	Subsidence	Medium
Ocean	Oil Slick Detection	Medium
	Metallic Targets	Medium