HI-FIVE: High-Resolution Forest Coverage with InSAR & Deforestation Surveillance

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German Aerospace Center

LIVING PLANET FELLOWSHIP
BIOSPHERE

Outline

- Project objectives
- Work plan
- Status at the Mid-Term-Review
- Description of the performed work and results
- Publications
- Plan for the second year

Project objectives

- Scientific objectives
  - **Systematic monitoring** of forested areas
  - Change detection for **deforestation** mapping
  - **Early warning system** for deforestation activities

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- Challenges
  - Measurement availability over the year
  - Provide **time-tagged** maps
  - Mapping at **regular intervals**

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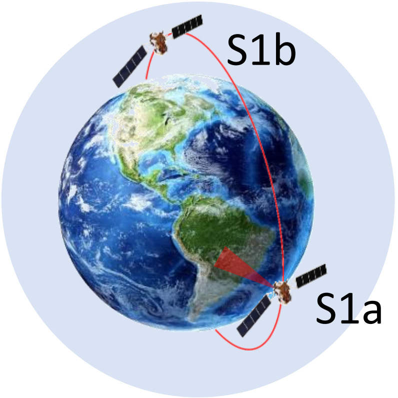
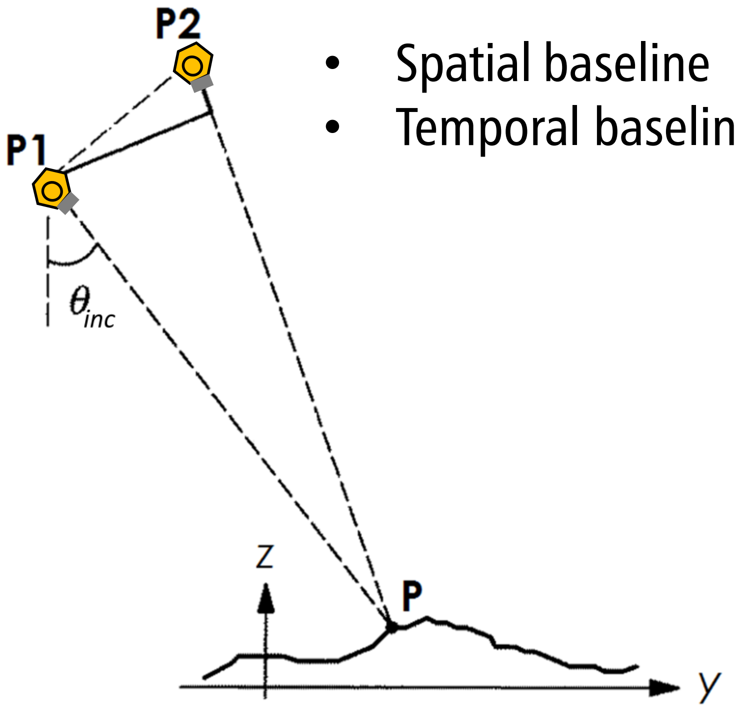
- Sentinel-1 mission
  - Weather independent **Synthetic Aperture Radar** (SAR) acquisitions
  - **Global Coverage**
  - Systematic acquisition with **low revisit time**



Project objectives

- Target
  - Sentinel-1 **interferometric** capabilities
  - Combined use of InSAR **coherence** and **backscatter**
  - Propose an algorithm for the **processing** and the **classification**



- Spatial baseline
- Temporal baseline

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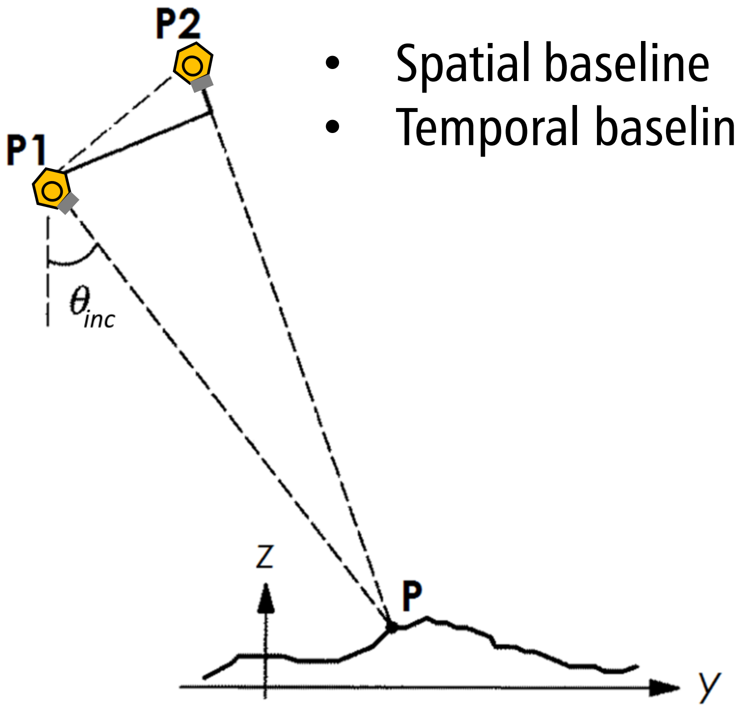

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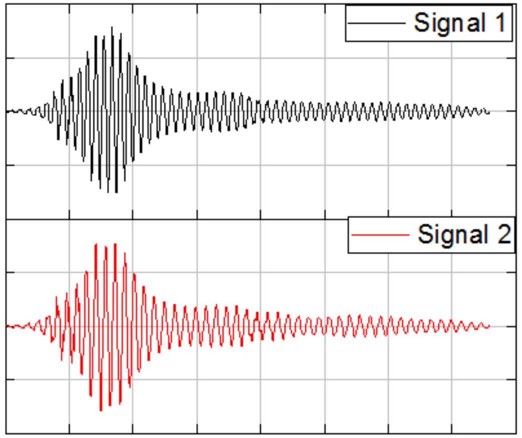
InSAR coherence: similarity



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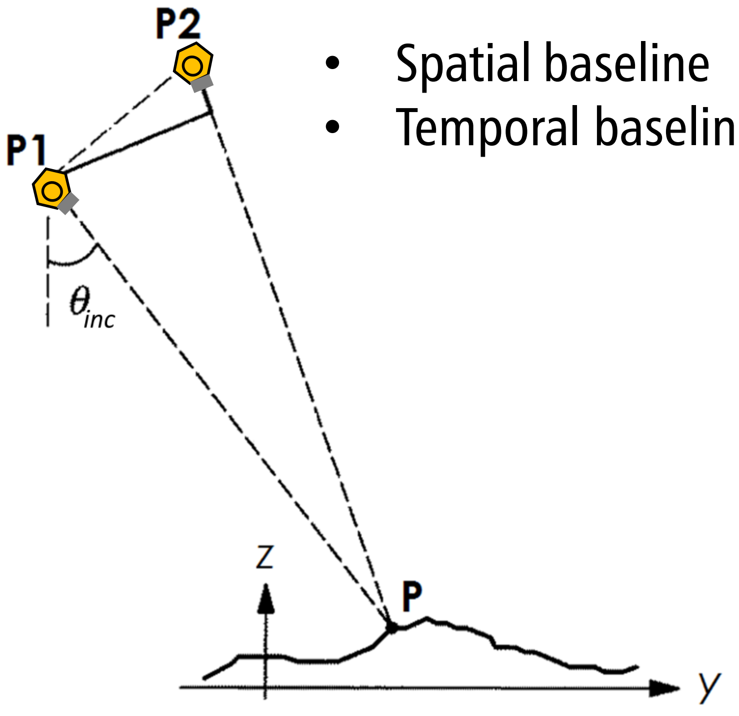

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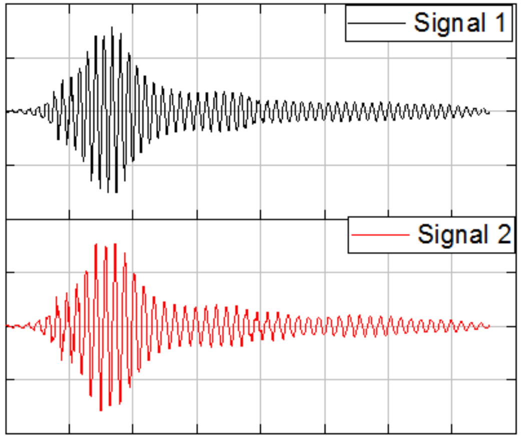

Project objectives

- Exploit interferometric time series: **temporal decorrelation**
    - interferometric coherence decomposition

$$\rho = \rho_{\mathrm{SNR}}\rho_{\mathrm{quant}}\rho_{\mathrm{amb}}\rho_{\mathrm{az}}\rho_{\mathrm{rg}}\rho_{\mathrm{vol}}\rho_{\mathrm{temp}}$$

- Correlation factors
    - Signal to noise ratio
    - Quantization errors
    - SAR ambiguities
    - Azimuth and range bandwidth shifts
    - Volume scattering
    - Temporal

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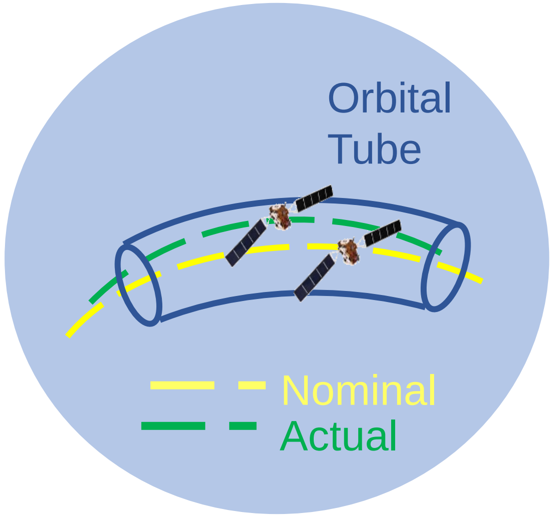

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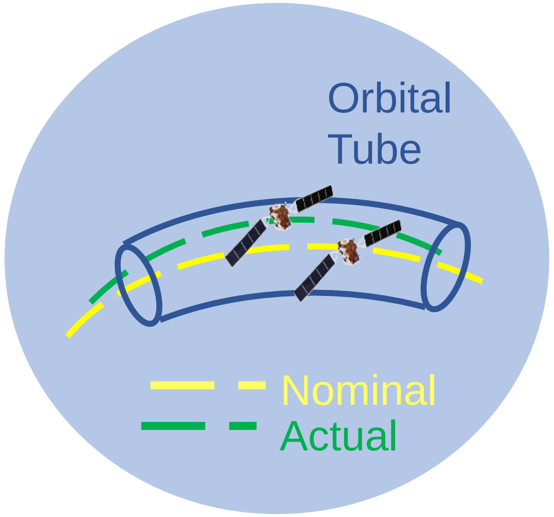

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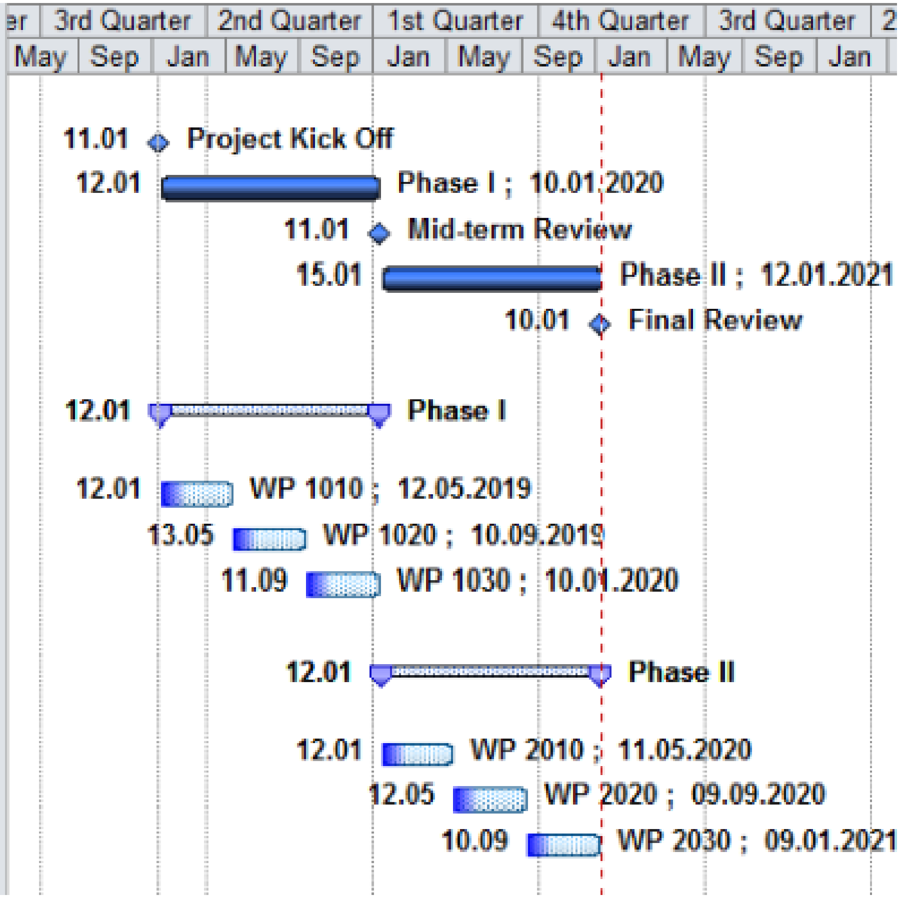
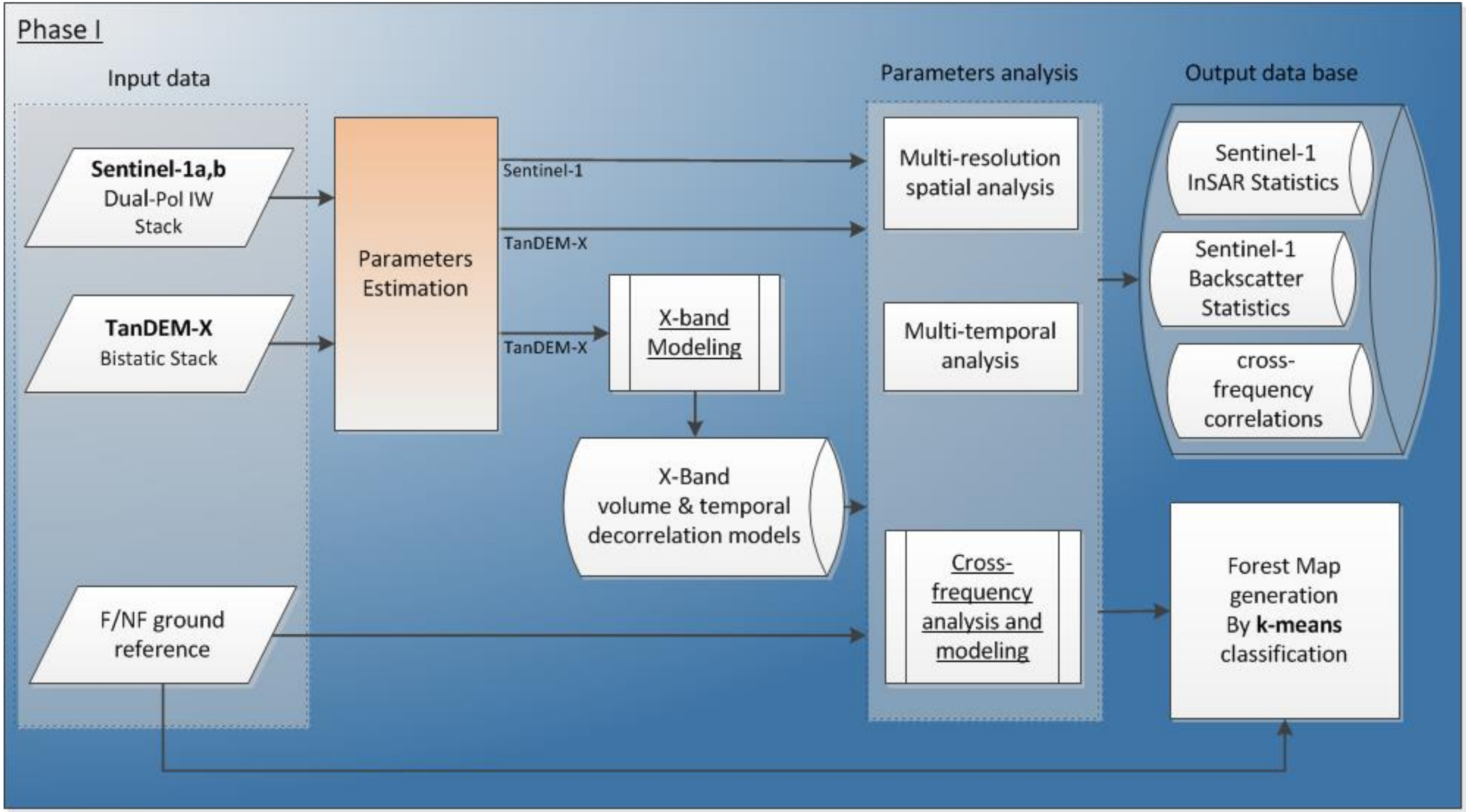
Work plan

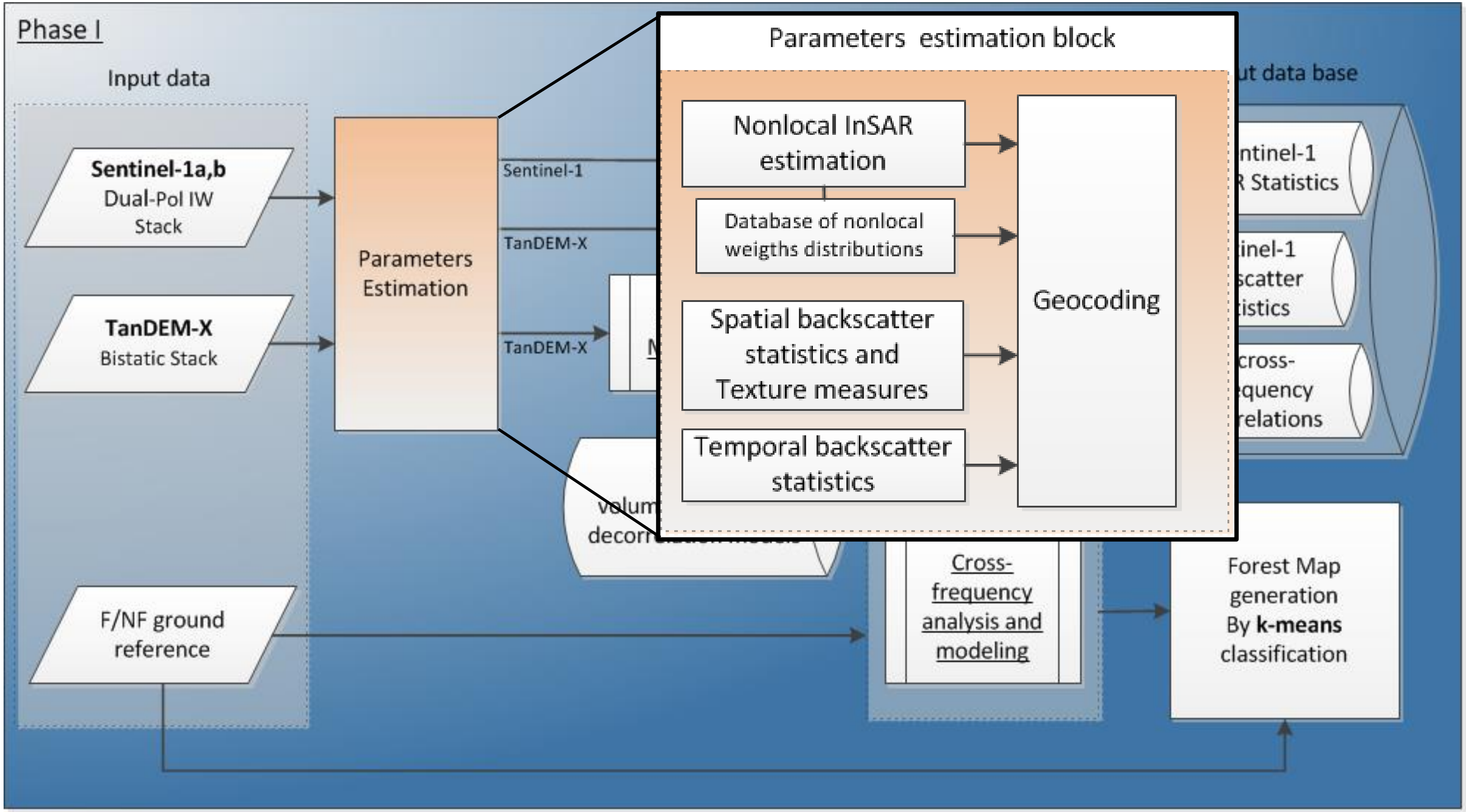
WP	Event	Duration	Start	End	Res
	Project Kick Off	1 dy	Fri 11.01.19	Fri 11.01.19	
	Phase I	364 dys	Sat 12.01.19	Fri 10.01.20	
	Mid-term Review	4 dys	Sat 11.01.20	Tue 14.01.20	
	Phase II	364 dys	Wed 15.01.20	Tue 12.01.21	
	Final Review	1 dy	Sun 10.01.21	Sun 10.01.21	
1000	**Phase I: Data Analysis, Modeling, and Classification**	**364 dys**	**Sat 12.01.19**	**Fri 10.01.20**	
1010	WP 1010	121 dys	Sat 12.01.19	Sun 12.05.19	
1020	WP 1020	121 dys	Mon 13.05.19	Tue 10.09.19	
1030	WP 1030	122 dys	Wed 11.09.19	Fri 10.01.20	
2000	**Phase II: Enhanced Classification, Change detection, and Validation**	**364 dys**	**Sun 12.01.20**	**Sat 09.01.21**	
2010	WP 2010	121 dys	Sun 12.01.20	Mon 11.05.20	
2020	WP 2020	121 dys	Tue 12.05.20	Wed 09.09.20	
2030	WP 2030	122 dys	Thu 10.09.20	Sat 09.01.21	



Work plan


Phase I
Input data
Sentinel-1a,b
Dual-Pol IW
Stack
TanDEM-X
Bistatic Stack
F/NF ground
reference
Parameters
Estimation
Sentinel-1
TanDEM-X
TanDEM-X
X-band
Modeling
X-Band
volume & temporal
decorrelation models
Parameters analysis
Multi-resolution
spatial analysis
Multi-temporal
analysis
Cross-
frequency
analysis and
modeling
Output data base
Sentinel-1
InSAR Statistics
Sentinel-1
Backscatter
Statistics
cross-
frequency
correlations
Forest Map
generation
By k-means
classification

Work plan



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Sentinel-1
TanDEM-X
TanDEM-X
Parameters estimation block
Nonlocal InSAR
estimation
Database of nonlocal
weigths distributions
Spatial backscatter
statistics and
Texture measures
Temporal backscatter
statistics
Geocoding
ut data base
ntinel-1
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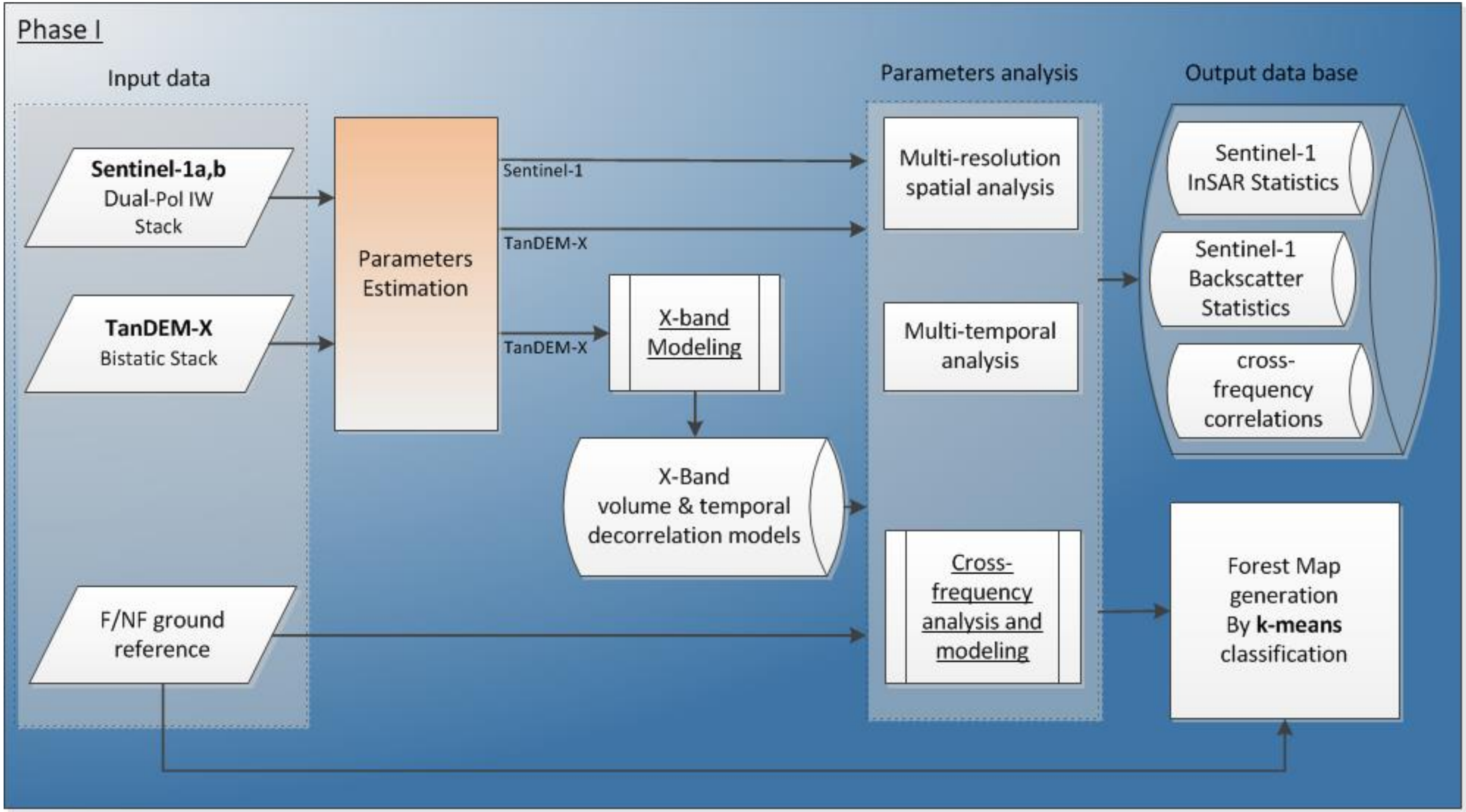

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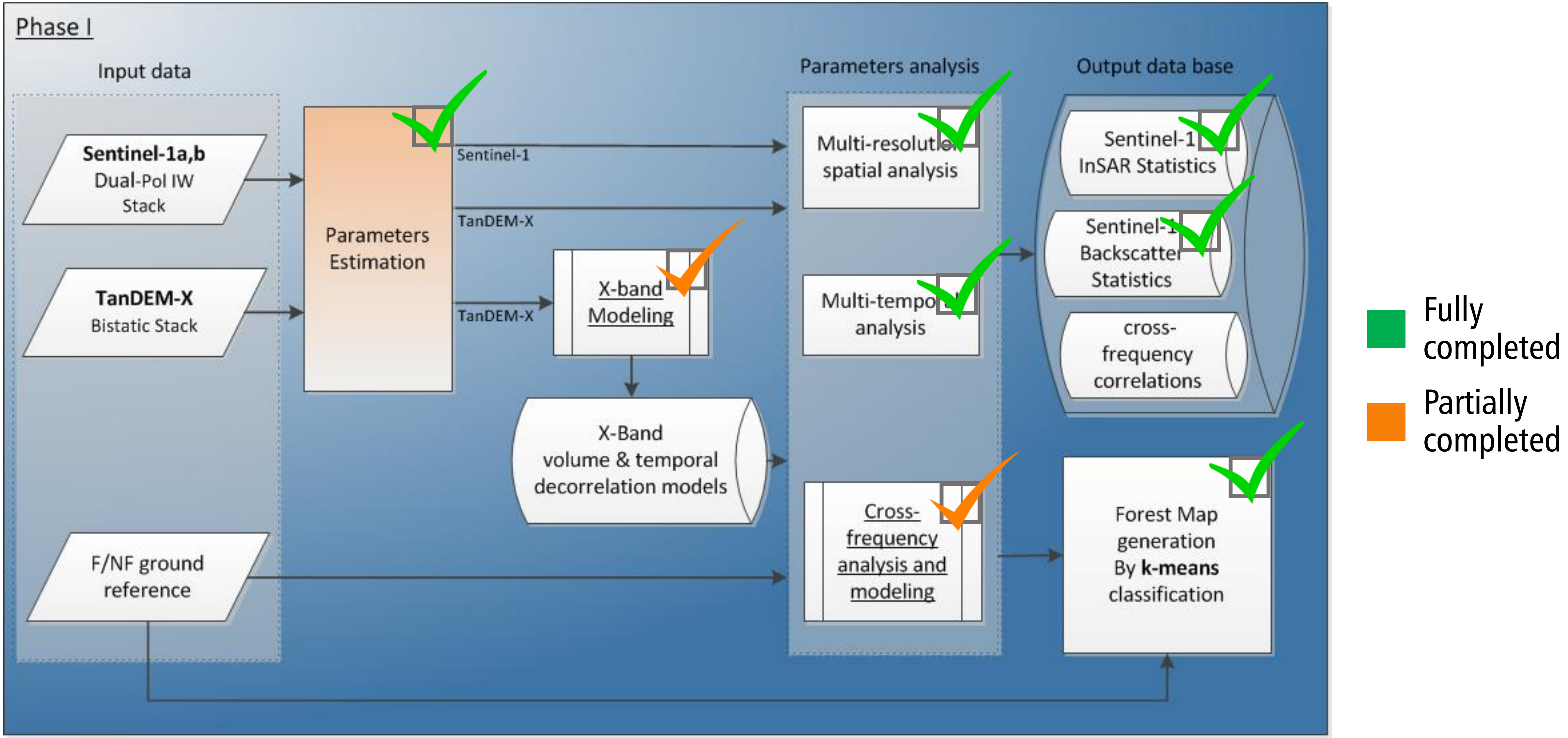

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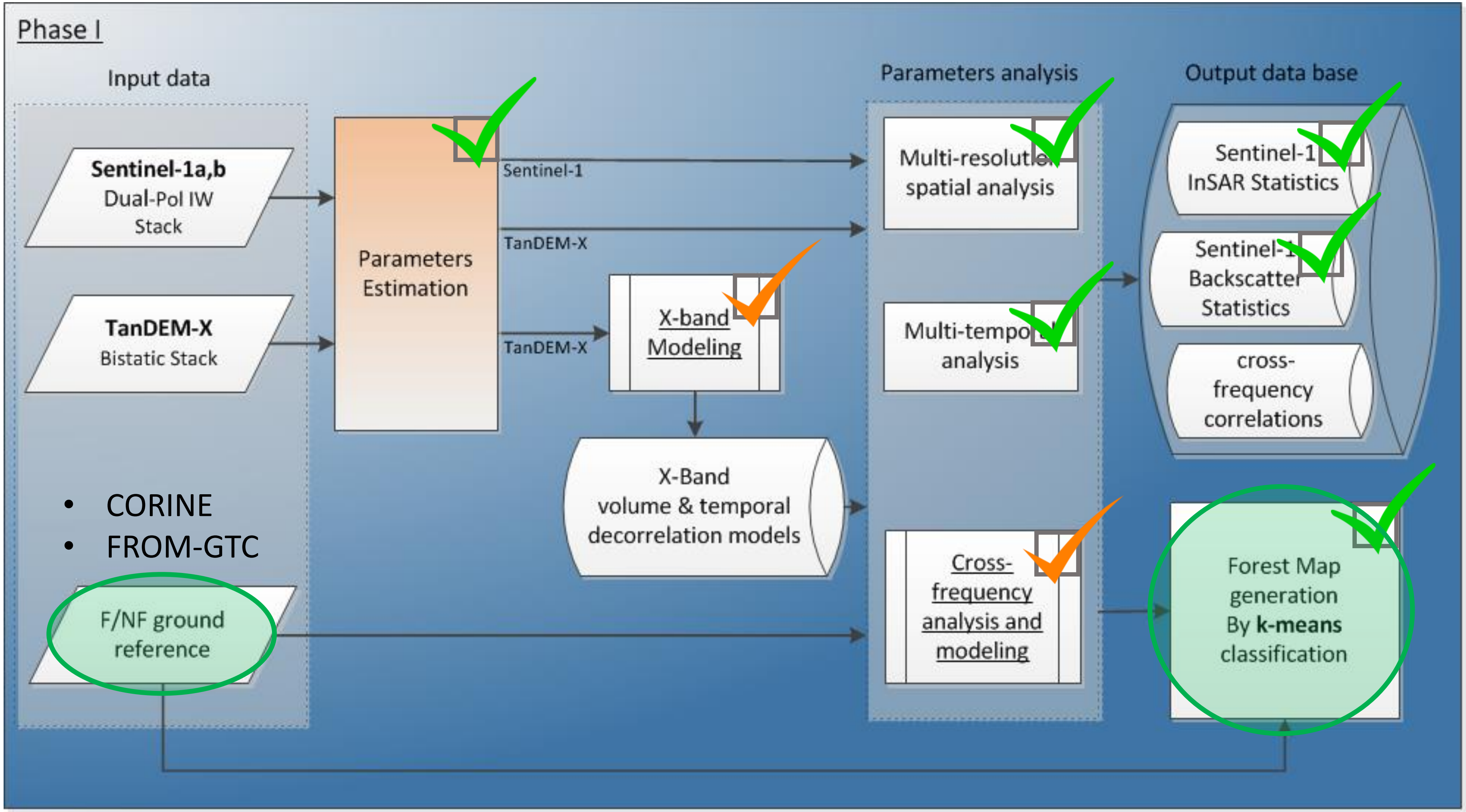
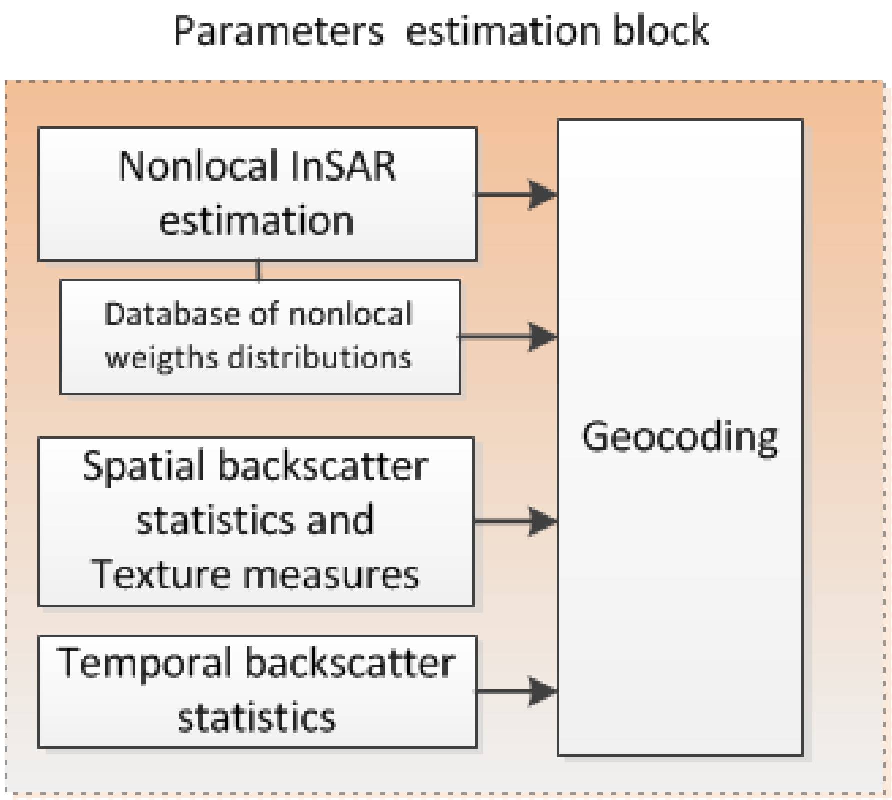


Fully completed

Partially completed

- Random Forest classifier

Status at the Mid-Term-Review



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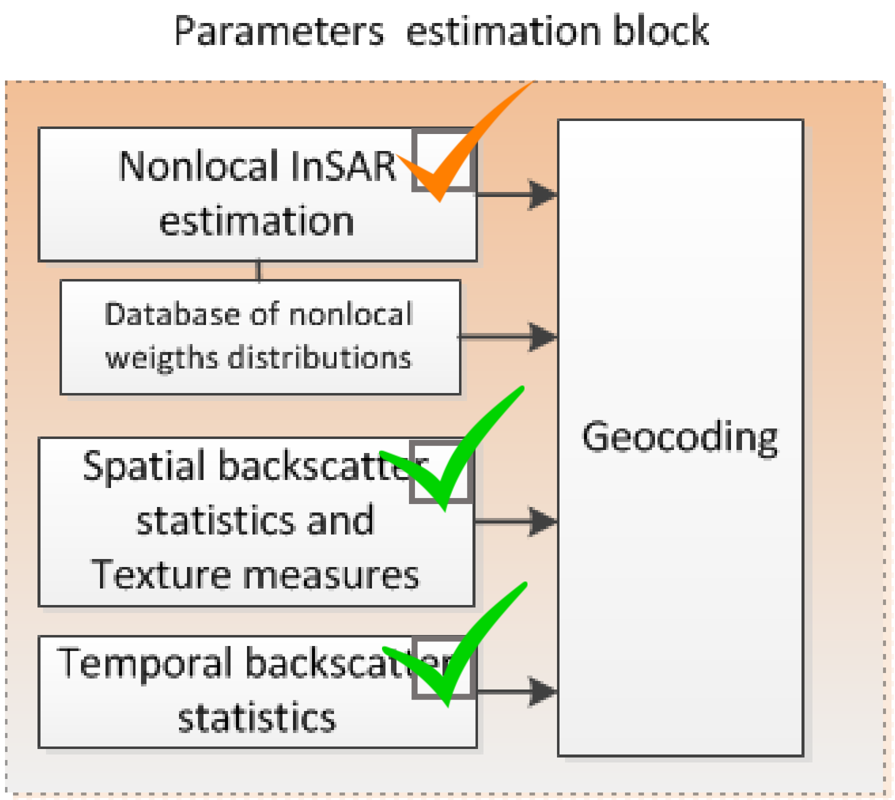

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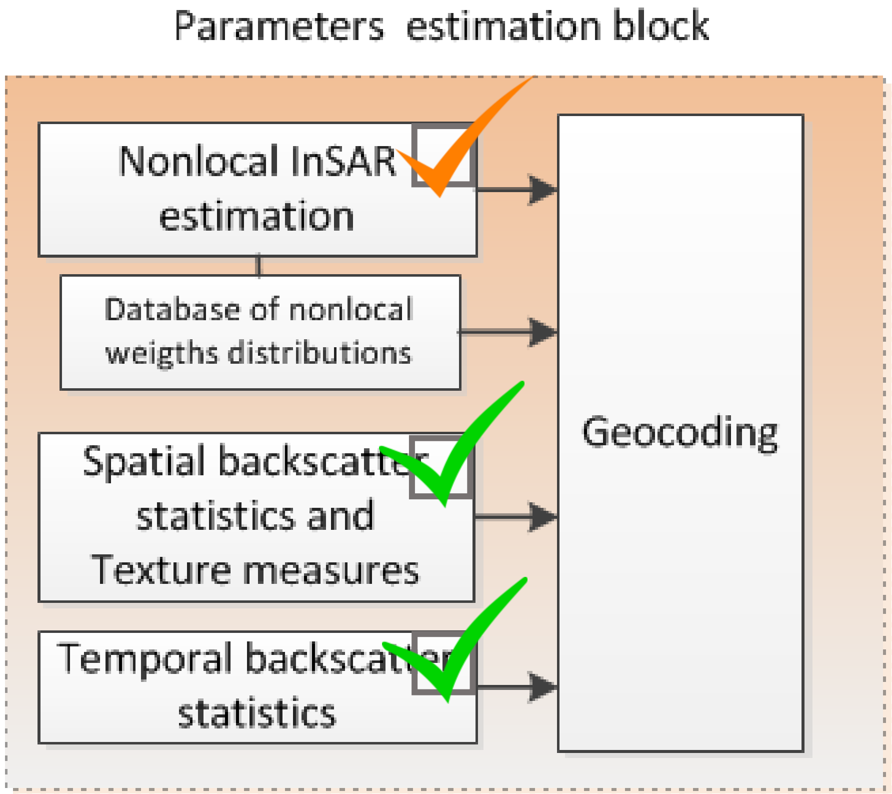

- Nonlocal InSAR estimation
  - Computational cost
  - Coverage versus full resolution mapping trade-off
  - Faster deep learning solutions
- X-band modeling
  - Higher temporal decorrelation w.r.t. C-band
  - Need of shorter revisit-time
  - Joint analysis with PAZ data

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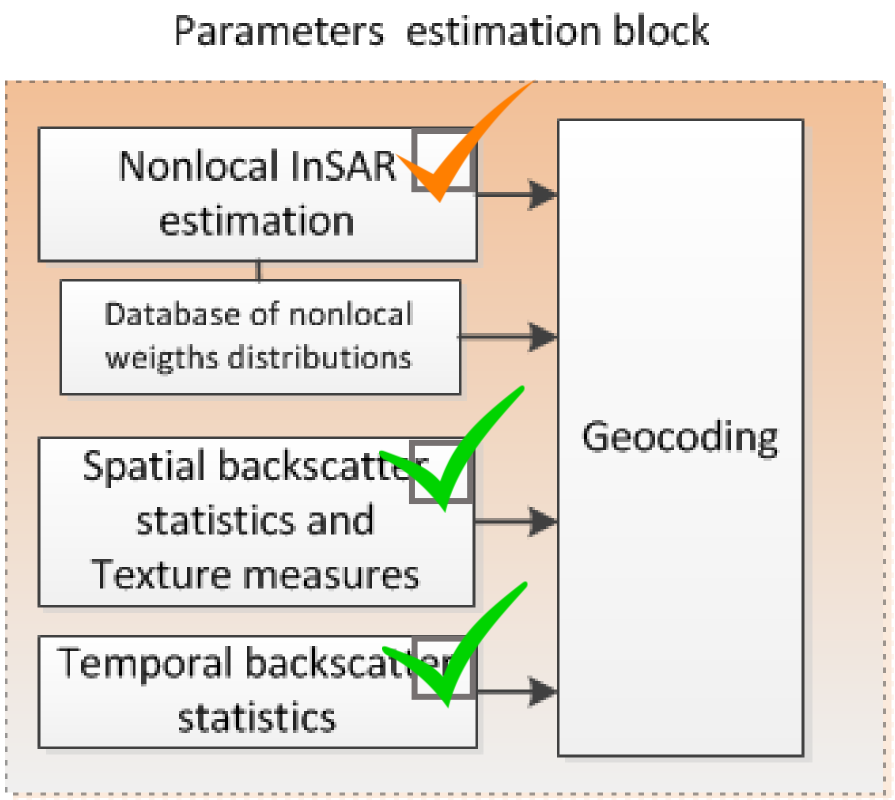

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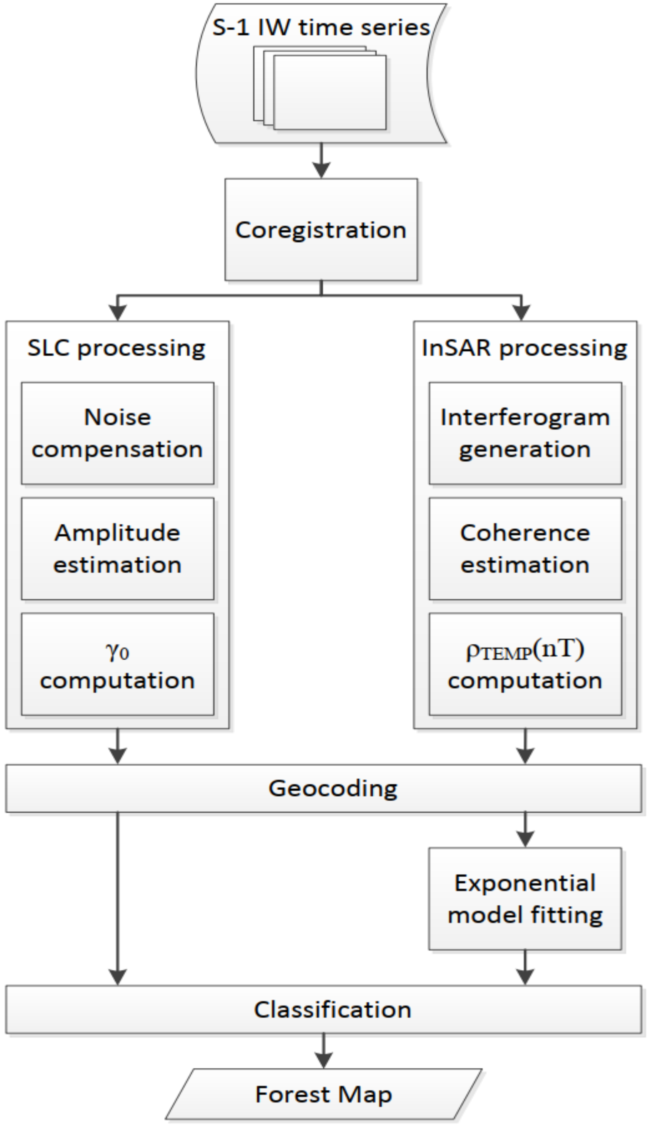
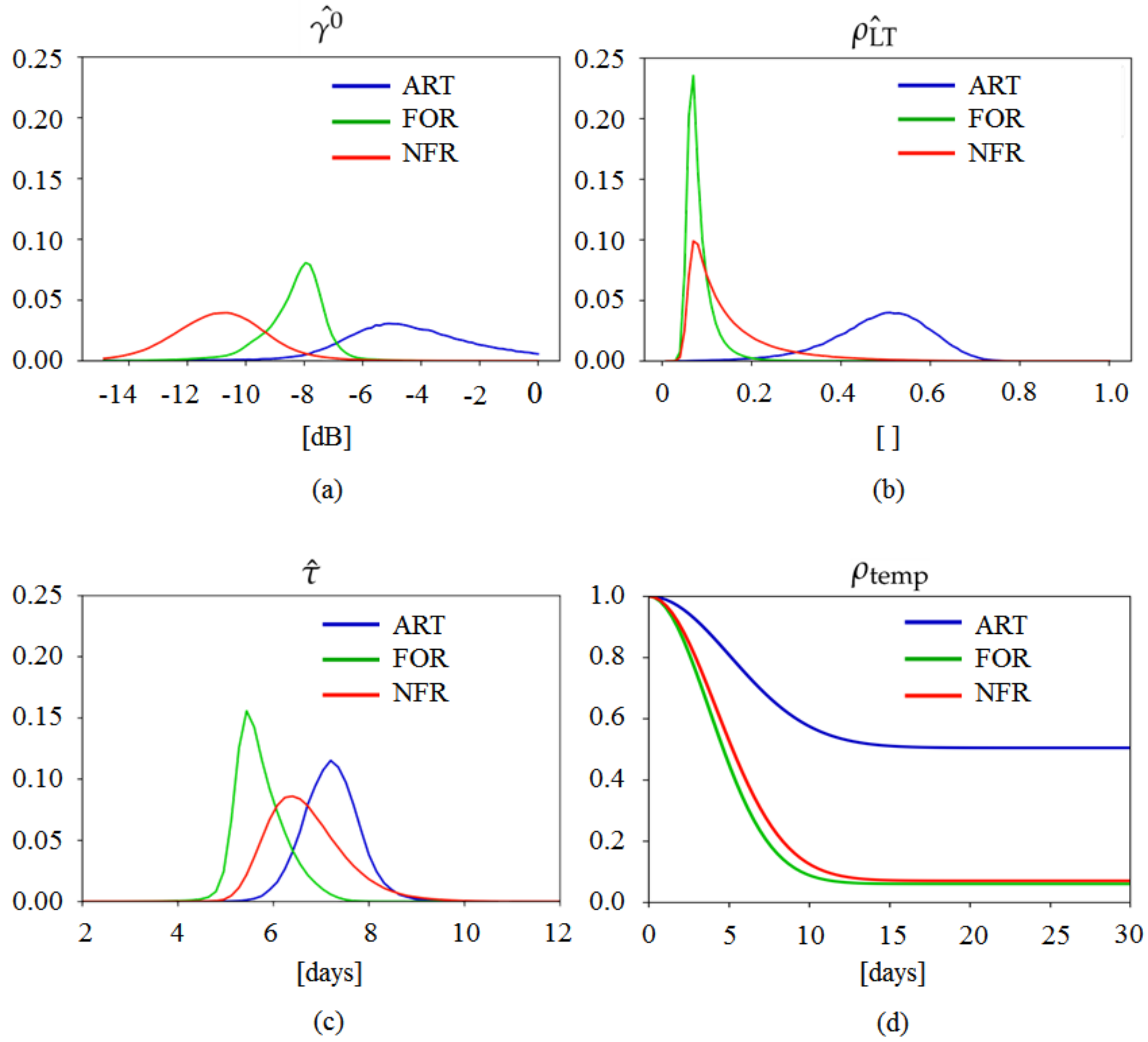
Description of the performed work

- Main achieved milestones
  - Development and implementation of the **framework for land cover classification** by exploiting Sentinel-1 interferometric wide-swath time-series
  - Investigation of **backscatter**, **multi-temporal coherence** and **texture-derived features**
  - Application of the classification methodology to two data sets over **Europe** and **Brazil**.
  - Publication of the results in the **Remote Sensing of Environment** peer-reviewed journal

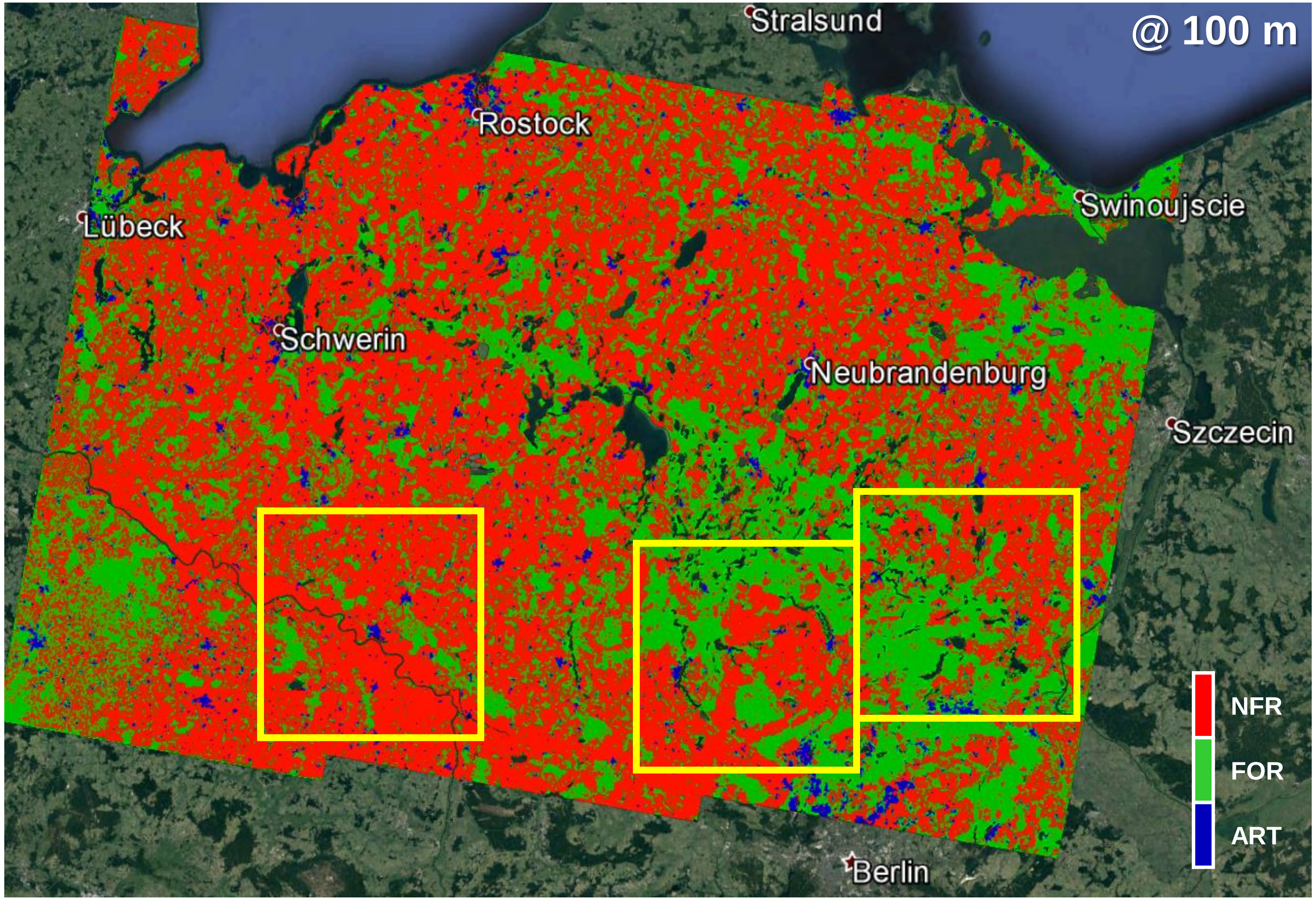


Results

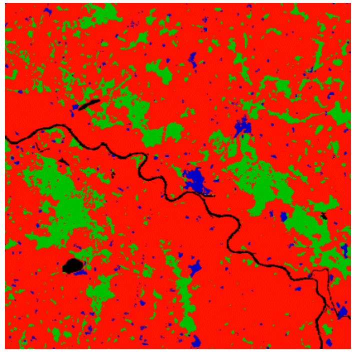
- Analysis over Europe: Germany
- Histograms of the computed features
- Random Forest classification
- CORINE land cover map used as reference
- Feature importance defined by means of ablation studies



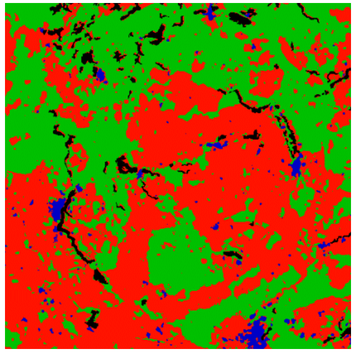
Results


Stralsund
@ 100 m
Rostock
Lübeck
Swinoujscie
Schwerin
Neubrandenburg
Szczecin
NFR
FOR
ART
Berlin

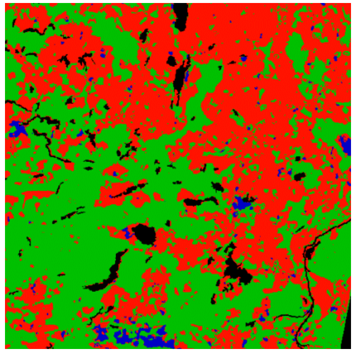
(a)



(b)



(c)



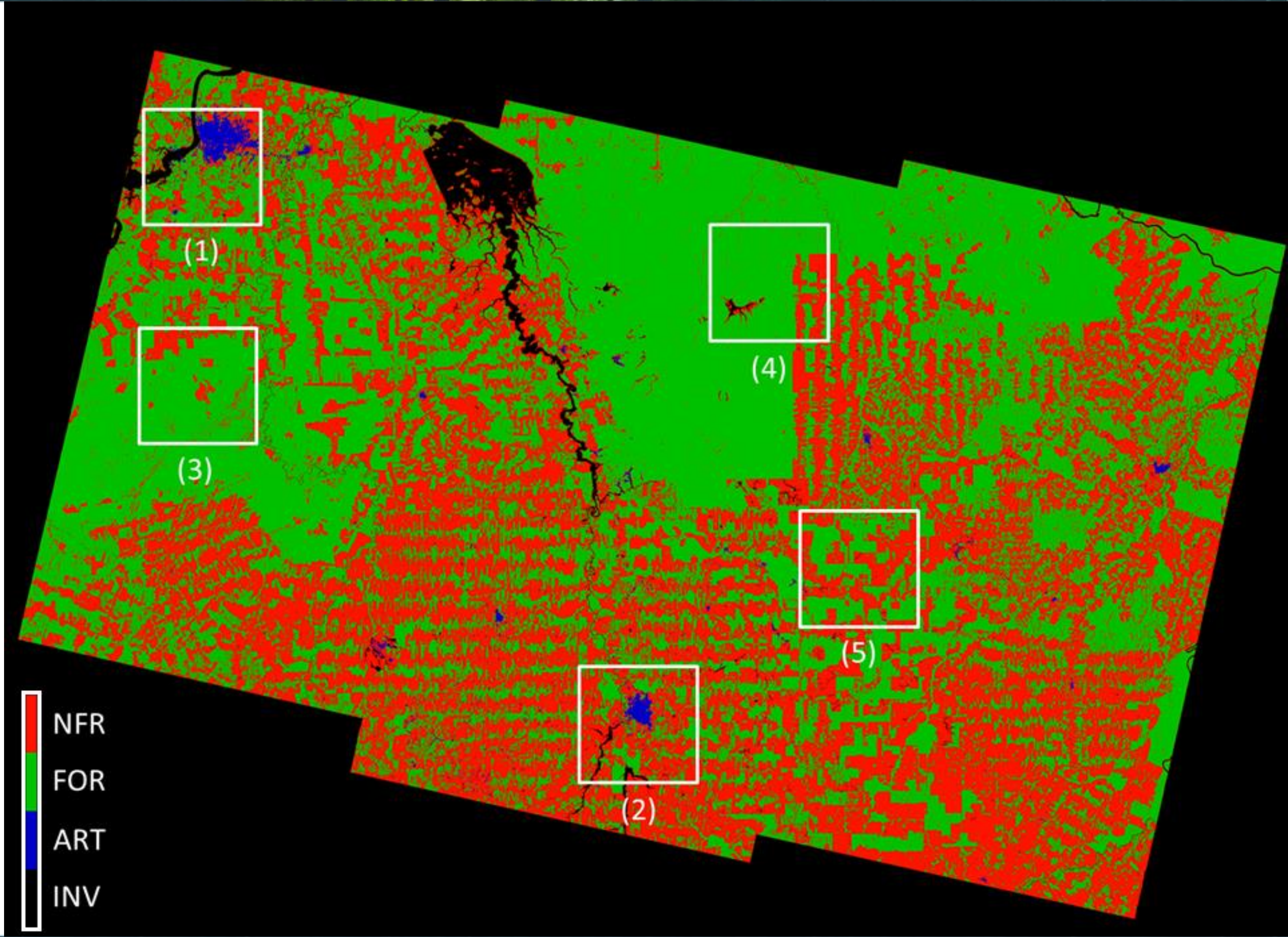
Results

➢ Classification accuracy

Input parameters	patch (a)	patch (b)	patch (c)	Overall
$\hat{\gamma}^0 \quad \theta_{inc}$	76.02%	79.93%	76.86%	88.73
$\hat{\tau} \ \ \rho_{\hat{\mathrm{LT}}} \ \ \theta_{inc}$	79.30%	77.98%	71.43%	78.77%
$\hat{\gamma}^0 \ \ \hat{\tau} \ \ \rho_{\hat{\mathrm{LT}}} \ \ \theta_{inc}$	83.28%	86.84%	82.90%	91.85%

Results

- Analysis over the Rondonia state
- Random Forest classification
- Finer Resolution Observation and Monitoring of Global Land Cover (FROM-GLC, 2017) used as reference
- Use of backscatter, interferometric parameters and textures



Results

- Classification accuracy

	patch 1	patch 2	patch 3	patch 4	patch 5
No-texture	72.12%	80.34%	95.40%	92.36%	91.42%
texture	72.88%	81.46%	96.10%	95.66%	93.54%

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Publications

➢ The project has produced the following publications:

- Sica, F., Pulella, A., Nannini, M., Pinheiro, M., Rizzoli, P. (2019). Repeat-pass SAR interferometry for land cover classification: A methodology using Sentinel-1 Short-Time-Series. *Remote Sensing of Environment*, 232, 111277.
- Sica, F., Pulella, A., Rizzoli, P. (2019, July). Forest Classification and Deforestation Mapping by Means of Sentinel-1 InSAR Stacks. In *IGARSS 2019 IEEE International Geoscience and Remote Sensing Symposium* (pp. 2635-2638). IEEE.
- Bueso Bello, J. L., Rizzoli, P., Sica, F. (2019). Estimating the Deforestation Rate in the Amazon Rainforest from Sentinel-1 and TanDEM-X Multi-Temporal Stacks. In *International Geoscience and Remote Sensing Symposium* (IGARSS).
- Rizzoli, P., Bello, J. L. B., Pulella, A., Sica, F., Zink, M. (2018, July). A Novel Approach to Monitor Deforestation in the Amazon Rainforest by Means of Sentinel-1 and Tandem-X Data. In *IGARSS 2018 IEEE International Geoscience and Remote Sensing Symposium* (pp. 192-195). IEEE.

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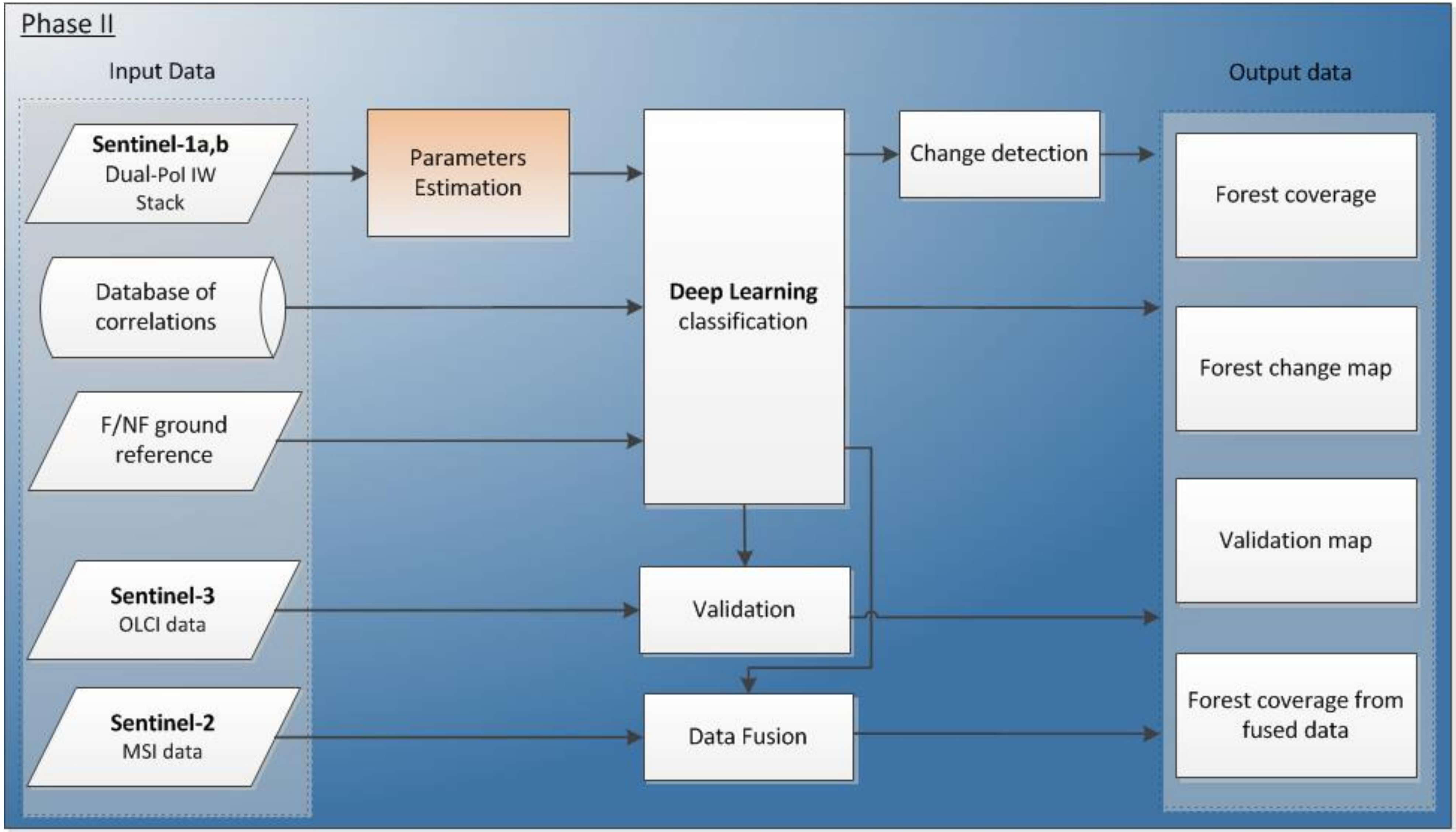
Plan for the second year

- Follow on from Phase I:
  - Resolution improvement and class definition
  - Deep learning solution for the estimation of the coherence
  - X-band modeling

- Phase II:
  - Investigate deep learning solutions for high-resolution forest mapping and deforestation
  - Investigate the use of synthetic data for the training of the network
  - Validate the results by means of Sentinel-2 and -3 data

Plan for the second year



Thank you for your attention!

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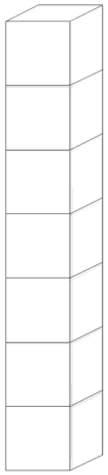
Method

- Combine backscatter and coherence
- Interferometric Wide-Swath data
- M acquisition for each scene

For the single target (resolution cell)

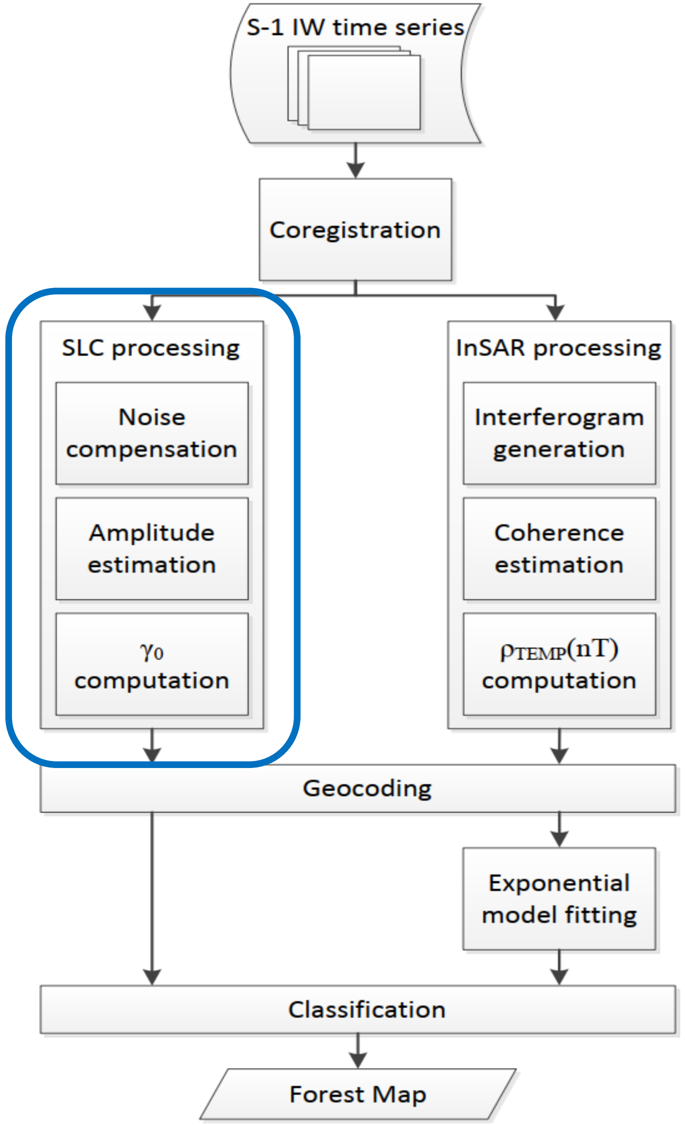
- SLC processing



$$\hat{\gamma}^0_m = K\hat{A}_m \tan\left(\theta_{inc}\right)$$

$\boxed{\hat{\gamma}^0}$ average over m

K	calibration factor
A	amplitude
θ_{inc}	incidence angle



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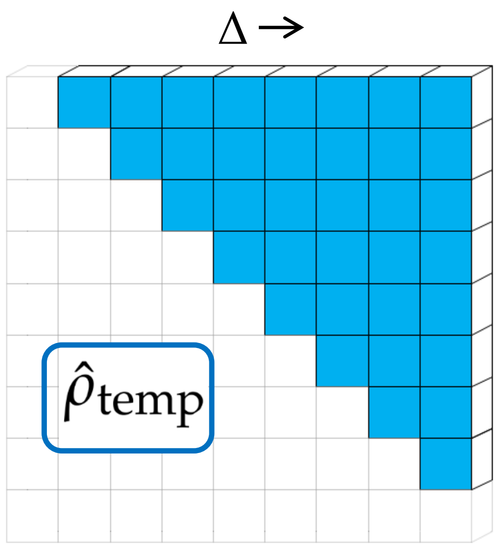
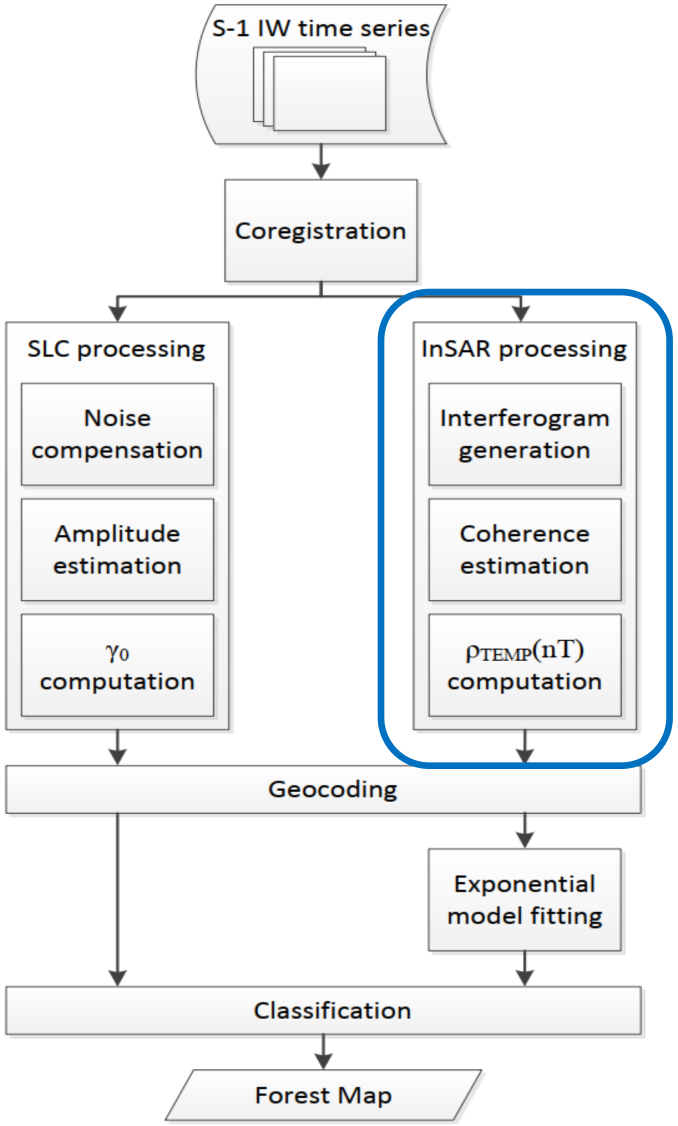
For the single target (resolution cell)

- InSAR processing



- $\Delta = nT$
- T – revisit time
- $n \in [1,N]$
- N – number of samples



Method

- Exponential model fitting

$$\rho_{temp}\left(t\right) = \left(1-\rho_{\mathrm{LT}}\right) e^{-\left(\frac{t}{\tau}\right)^2} + \rho_{\mathrm{LT}}$$

τ Decorrelation constant

ρ_{LT} Long term coherence

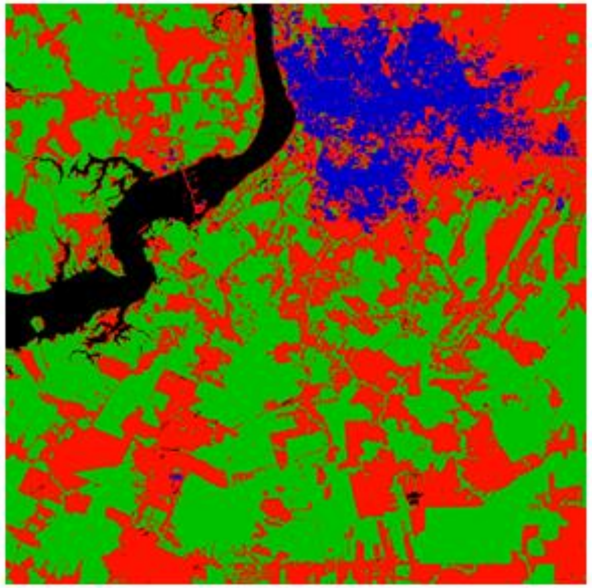
Least square fitting

$$\left(\hat{\tau}\ ,\ \hat{\rho_{\mathrm{LT}}}\right) = \underset{\tau\ ,\ \rho_{\mathrm{LT}}}{\arg\min}\left\{\sum_{n=1}^{N}\sum_{i=1}^{N-n}\sum_{j\in\Omega(p)}\left(\left(1-\rho_{\mathrm{LT}}\right) e^{-\left(\frac{nT}{\tau}\right)^2} + \rho_{\mathrm{LT}} - \hat{\rho}_{\mathrm{temp}}[n,i,j]\right)^2\right\}$$

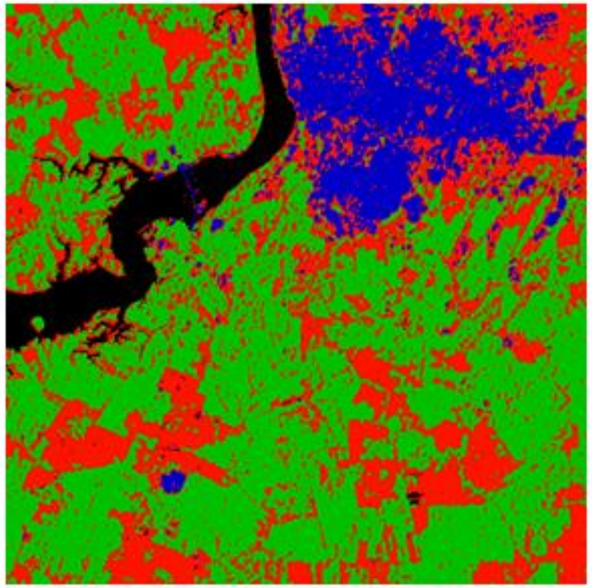
Results

Optical (Google)

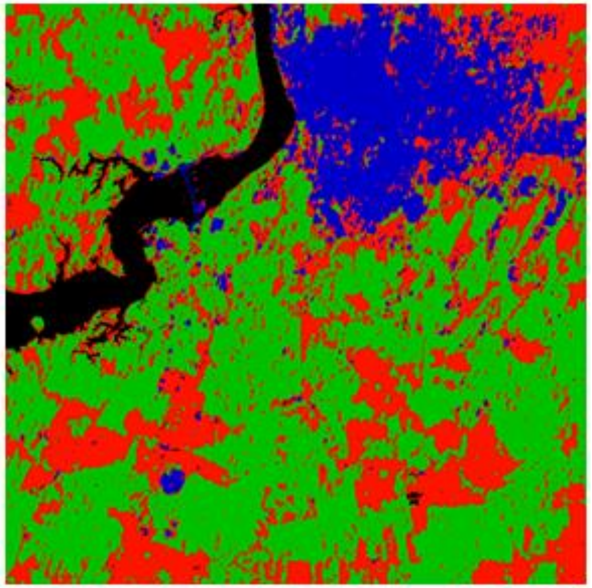
Reference



no texture



with texture



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Results

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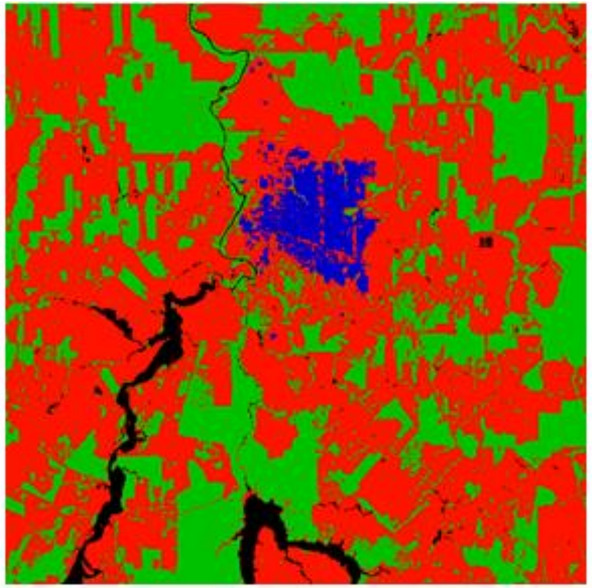

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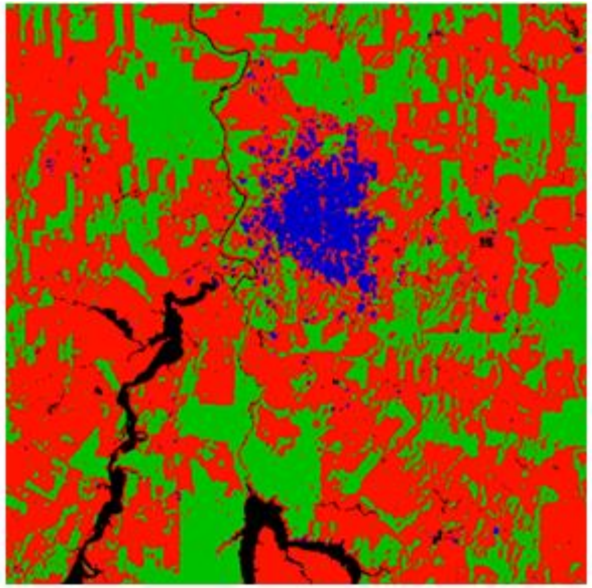

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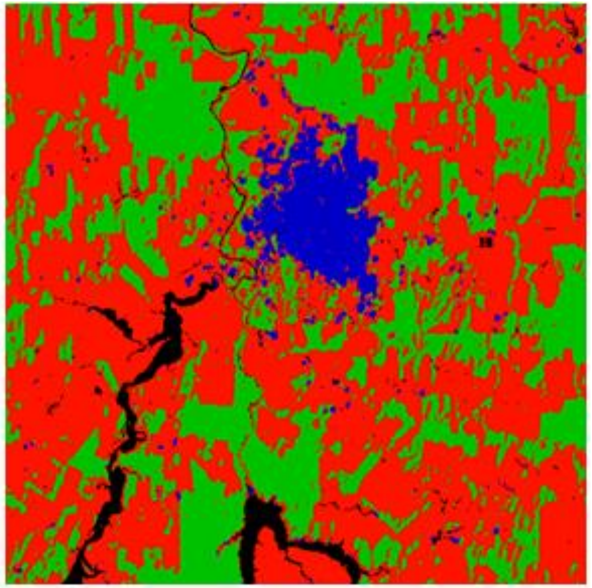

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Results

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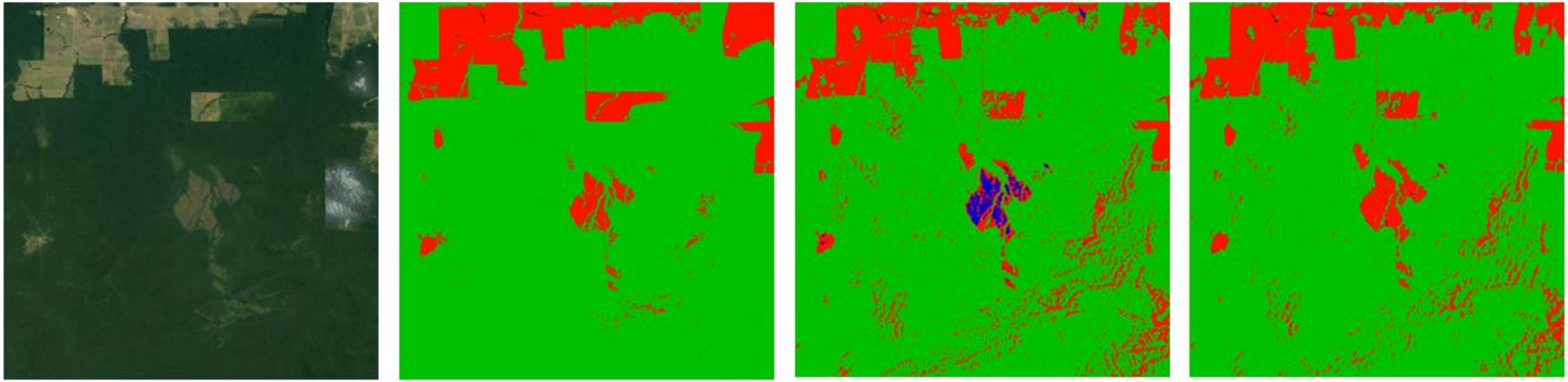

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Results

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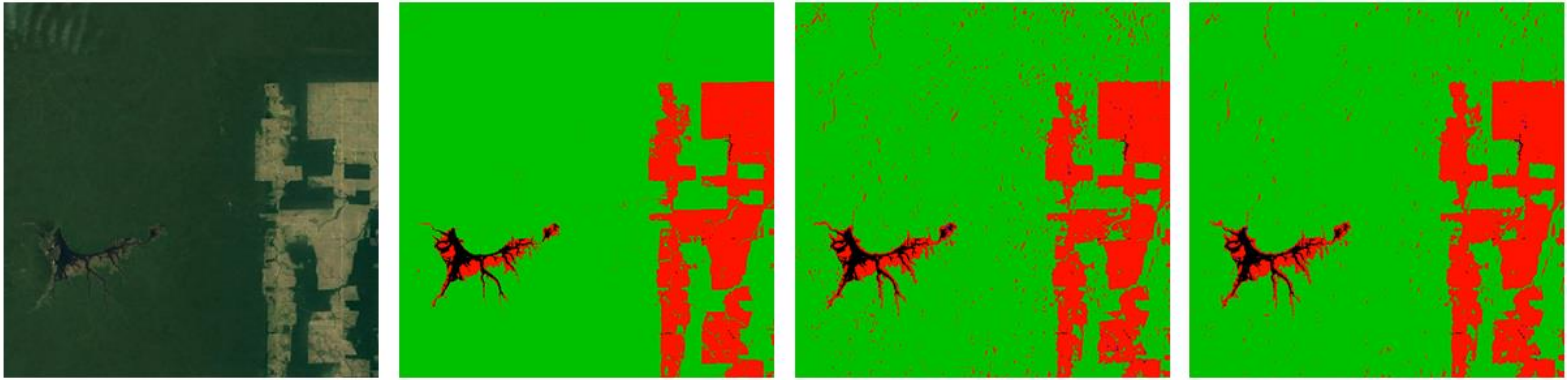

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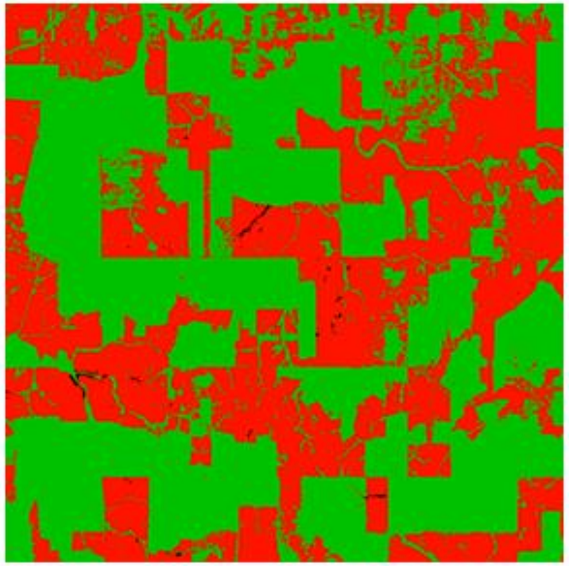

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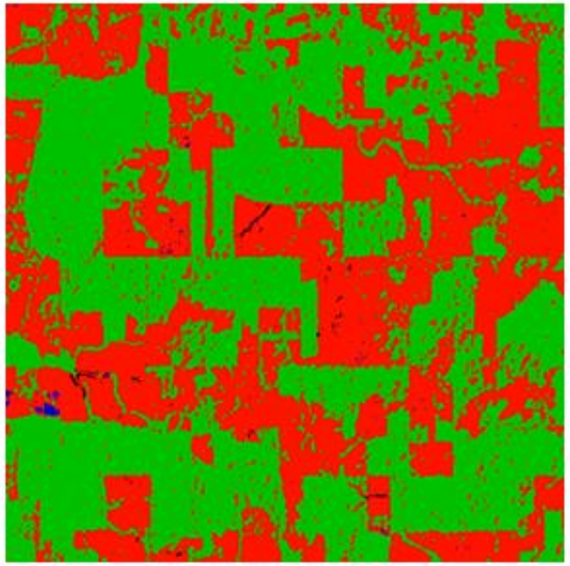

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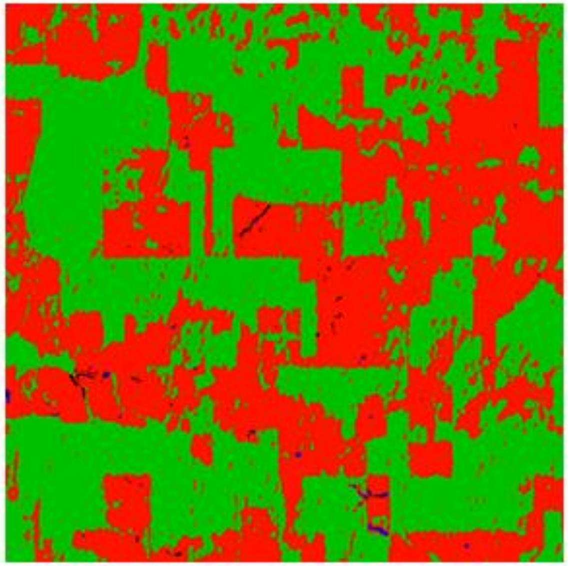

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