Combination of Multi-Track Sentinel-1 Multitemporal InSAR Coherence and Sentinel-2 data in Land Cover and Vegetation Mapping: The SInCohMap Project

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Agenda

- The SInCohMap Project
- SAR Datacubes
- Land cover classification
  - S1/S2 data fusion for landcover mapping
  - Multi-track S1 data for landcover classification
- Multitrack S1 Classification
- Forest Classification and Monitoring using S1 Coherence
- Conclusions

Overview: The SInCohMap Project

- **SInCohMap** Project was conceived in the **ESA SEOM** framework to analyze and develop methodologies for the application of S1 multitemporal InSAR coherence evolution in land cover mapping
- Accurate land cover and vegetation-type maps are obtained using the **intensity + InSAR** coherences derived from S1
- Three different test sites:

1) Doñana (Spain)
2) South Tyrol (Italy)
3) West Wielkopolska (Poland)

Crop Type Classification

Polarisation	VV	VH	VV+VH
Overall Accuracy	85.43%	81.51%	86.74%
Kappa Score	0.81	0.76	0.83

Ground truth

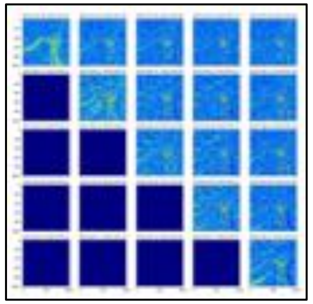
Predicted crop Map

Source: A. Mestre-Quereda et al., *"Sentinel-1 Interferometric Coherence for Crop Classification"*, FRINGE2021

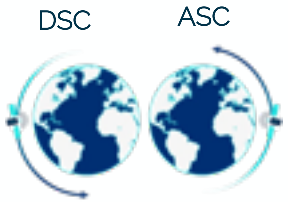
SInCohMap Phase II: Goals

The SInCohMap phase II explored three new aspects:

1. **Fusion of S1 interferometric coherence & S2 images for land cover classification**
    - Exploiting the sensitivity of microwave & multispectral data to biophysical properties of the land cover
2. **Multitrack S1 interferometric coherence for land cover classification**
    - Exploiting incidence angle diversity and optimum mode (ASC/DSC) in land cover classification using S1 interferometric data
3. **Forest classification and monitoring using S1 coherence Information**
    - Exploration of the conditions under which C-band interferometric coherence may improve forest monitoring and classification

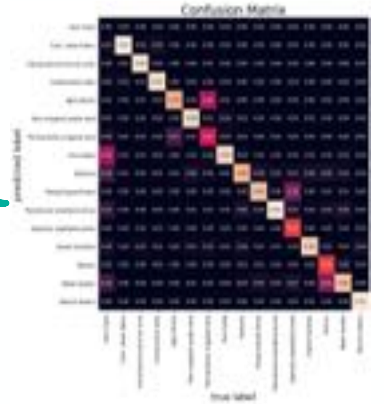


Interferometric Data



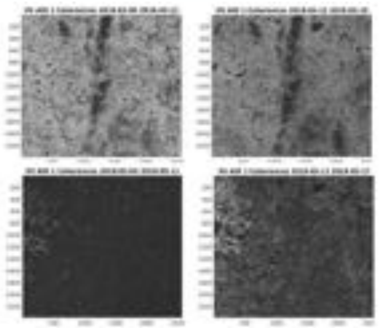
Multitrack data

Multiespectral data

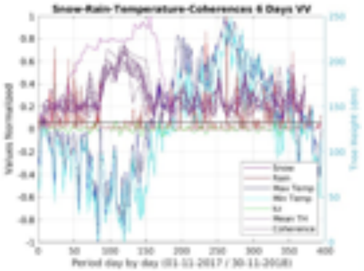


Land cover classification

Forest AOI



Coherences



Coherence Analysis

Data Preprocessing: S1 & S2 Datacubes

- **Generation** of S1 & S2 Datacubes to provide co-registered data that would be used in the project
- SAR Data sets:

  1) **Doñana** site (Spain):
     - S1 2017-2019 Multiple tracks: ASC_147, DSC_154 - S2: 2017-2019 (L1C).

  2) **South Tyrol** site (Italy):
     - S1 2017-2020, Multiple track, ASC_117, DSC_168 - S2: 2017-2020 (L1C):

  3) **Finnish** sites for forest analysis:
     - S1 2017-2018, Single track: DSC_80 . AOI1 and AOI2

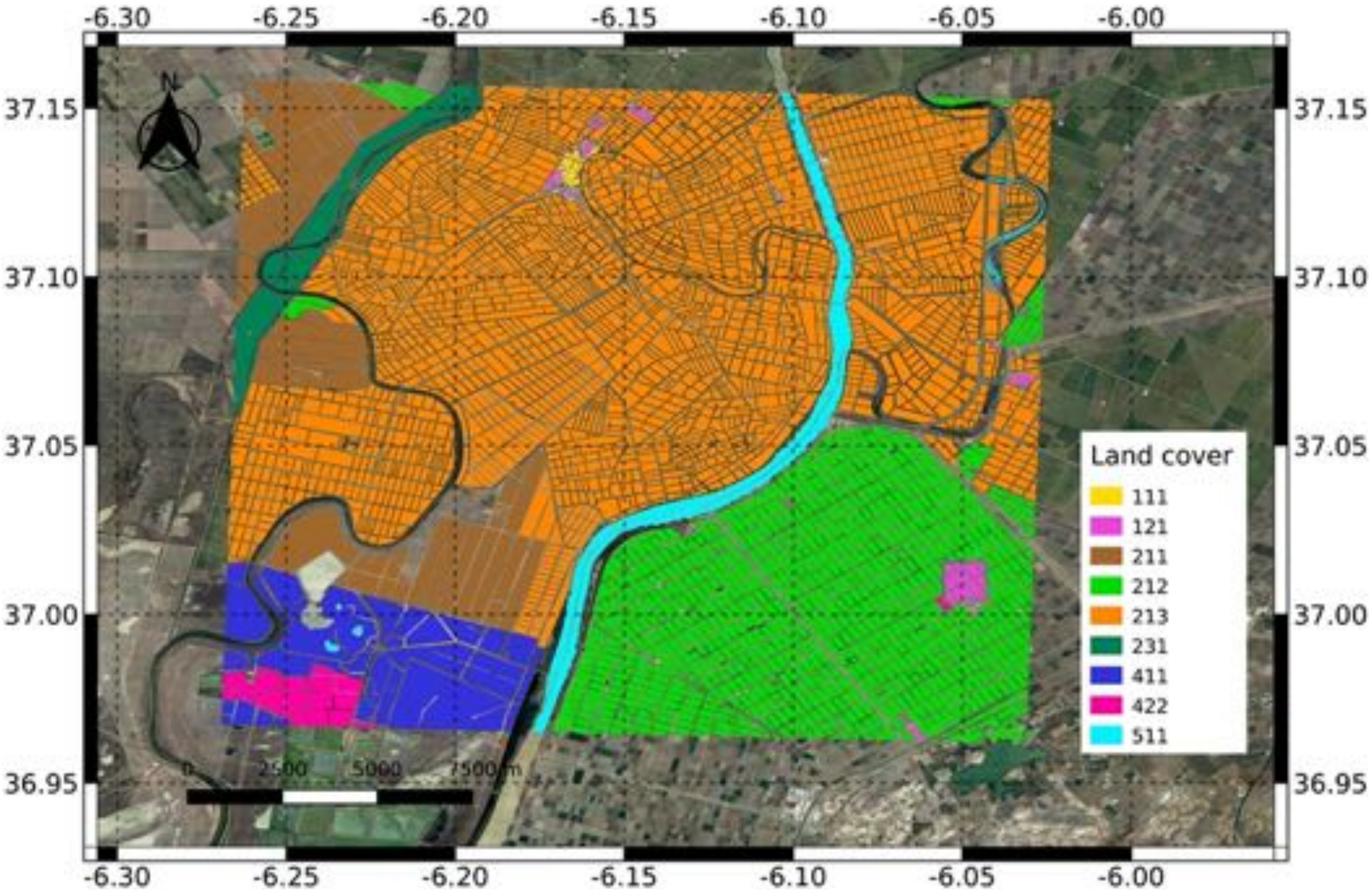
- SInCohMap CCN used the **infrastructure implemented by EURAC in the framework of the SAR2Cube project**
- S1 SLC polarimetric data and S2 bands with a common geographical grid

* https://www.opendatacube.org/

** https://openeo.org/

Land Cover Classification in Doñana

Doñana site – Land cover ground-truth



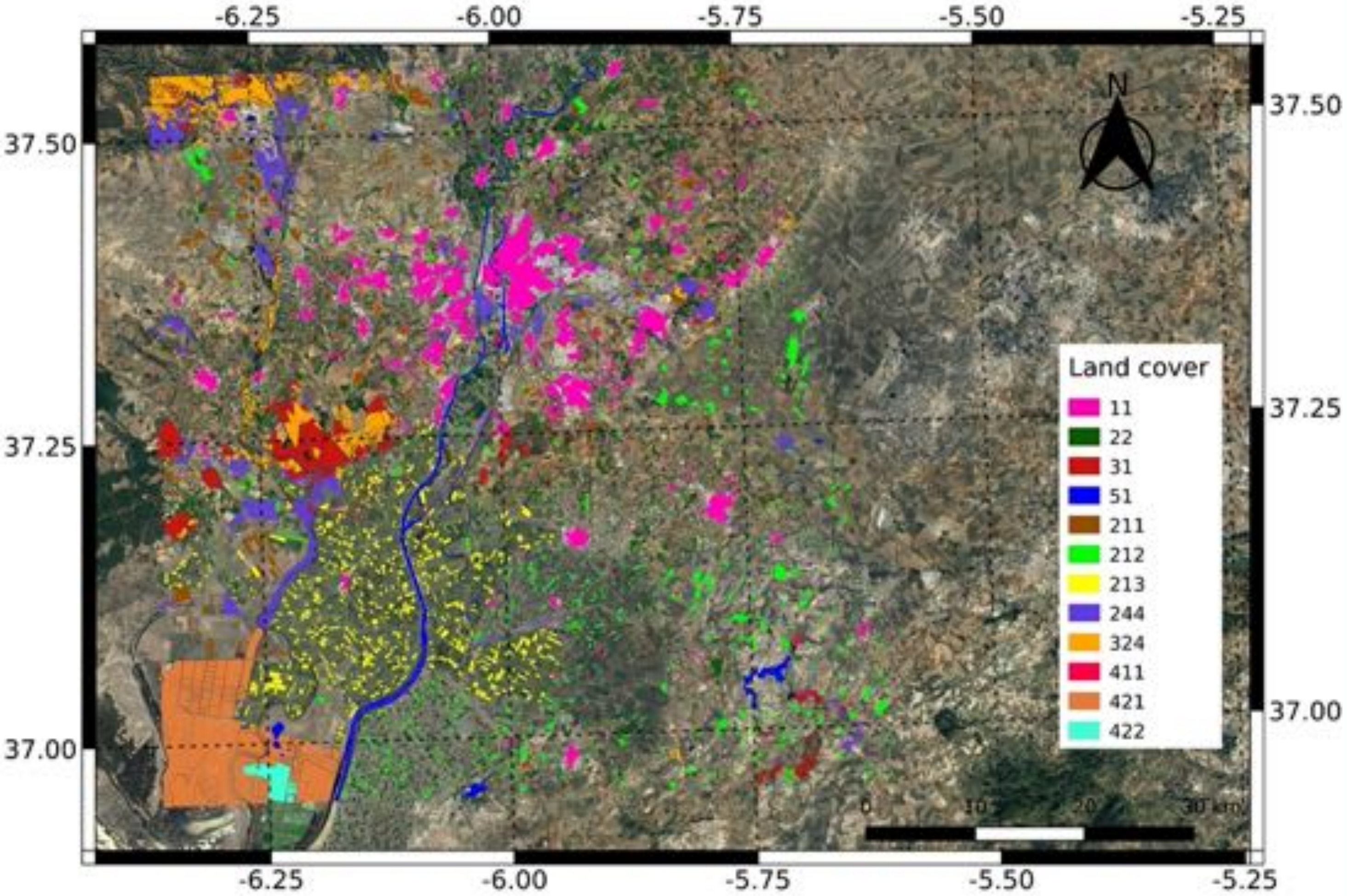
Original test site (2017-18-19)

- 9 land cover classes
- CORINE from 2018 used as ground truth

Land cover code	Class	Nr. polygons (2017, 2018 ,2019)
111	Continuous Urban fabric	31
121	Industrial/commercial units	43
211	Non-irrigated arable land	99
212	Permanently irrigated land	885
213	Rice fields	2248
231	Pastures	26
411	Inland marshes	38
422	Peat bogs	18
511	Water	23

Land Cover Classification in Doñana

Doñana site – Land cover ground-truth (extended)



Extended test site: 2019
- 12 land cover classes
- Cadastral data + CORINE 2018 as ground truth
- Manual revision

Land cover	Class	Nº polygons
11	Urban fabric (111 + 112)	546
22	Olive groves (223) + Fruit trees (222)	1447
31	Mixed forest (313) + Coniferous forest (312) + Broad-leaved forest (311)	401
51	Water courses (511) + Water bodies (512)	151
211	Non-irrigated arable land	683
212	Permanently irrigated land	947
213	Rice fields	825
244	Agro-forestry areas	728
324	Transitional woodland/shrub	581
411	Inland marshes	22
421	Marshes	175
422	Salines	5

Land Cover Classification in Doñana

Doñana site - Classification Methodology:

- Supervised classification method: **random forests**
- Initial training/test division at **polygon level** based on 50% of reference data
- For training all classes are reduced to the same number of pixels (samples): **equitable random sampling**
- **Evaluation at pixel level**: Overall accuracy and F1-score (class accuracy)
- Repetition of the whole procedure 10 times to avoid specific examples
- Evaluation of sets of features for 3 years (2017, 18, 19) coming from two S1 tracks (ASC & DSC) and from S2:
  - Dual-pol backscattering coefficients at each track of S1: σ_{0VV} and σ_{0VH}.
  - Dual-pol 6-day interferometric coherence at each track of S1: γ_{VV} and γ_{VH}.
  - Reflectance bands from S2: all 13 bands

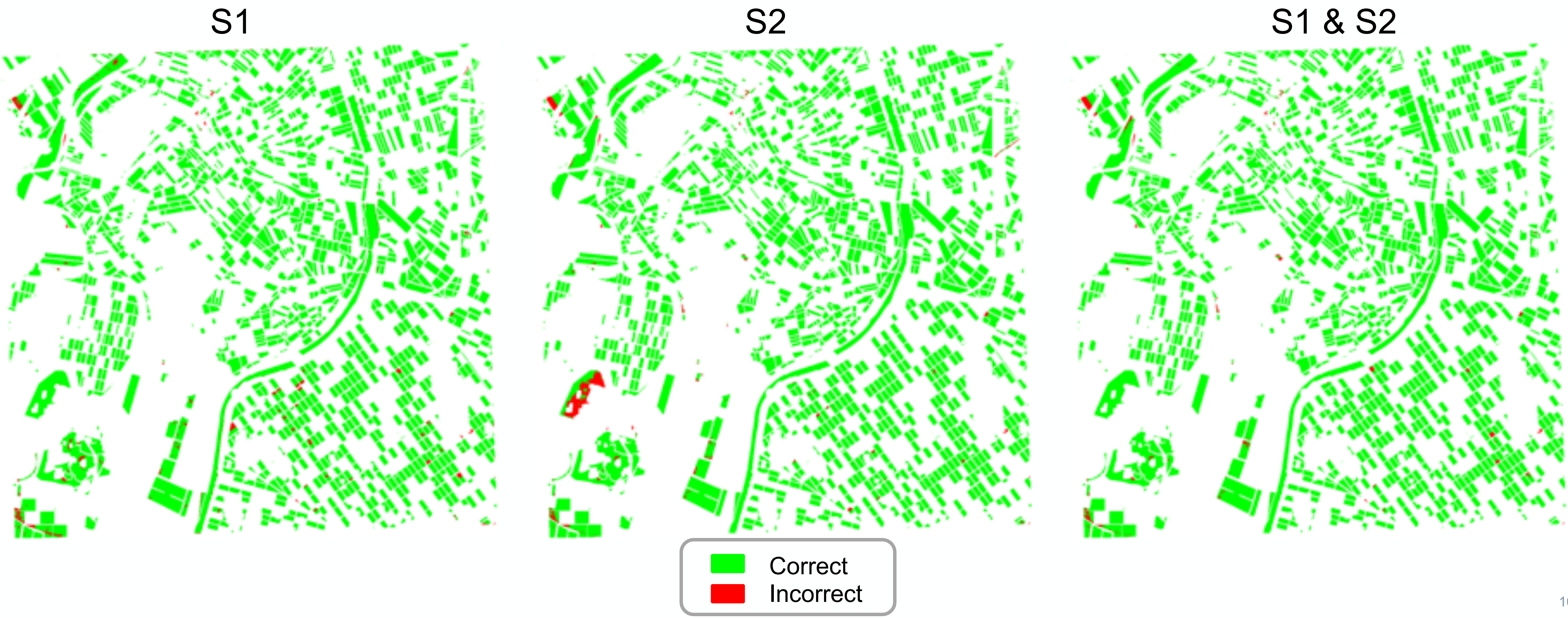
Fusion carried out at input level: **stacked sets of features**

Doñana: S1/S2 Data Fusion for Landcover Mapping

Doñana site – Prediction maps

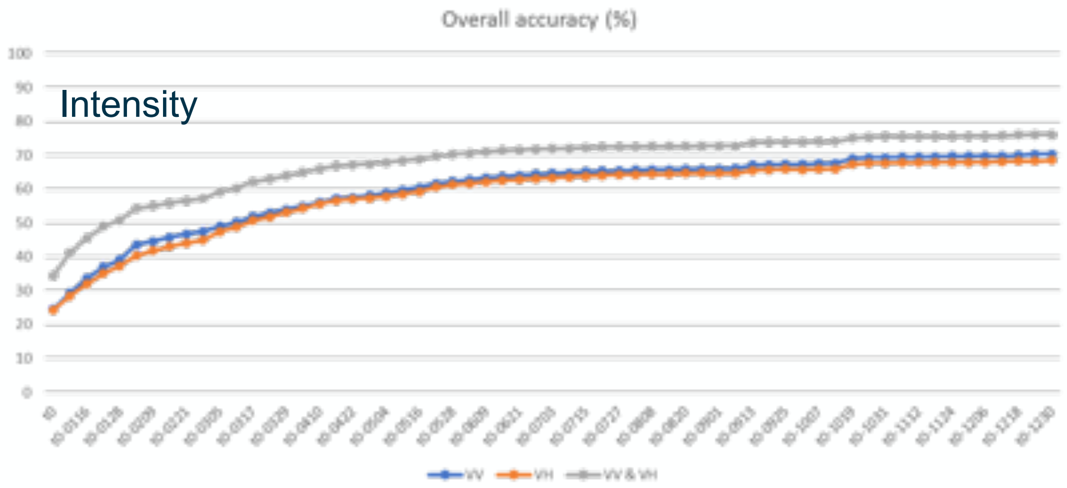
Doñana: S1/S2 Data Fusion for Landcover Mapping

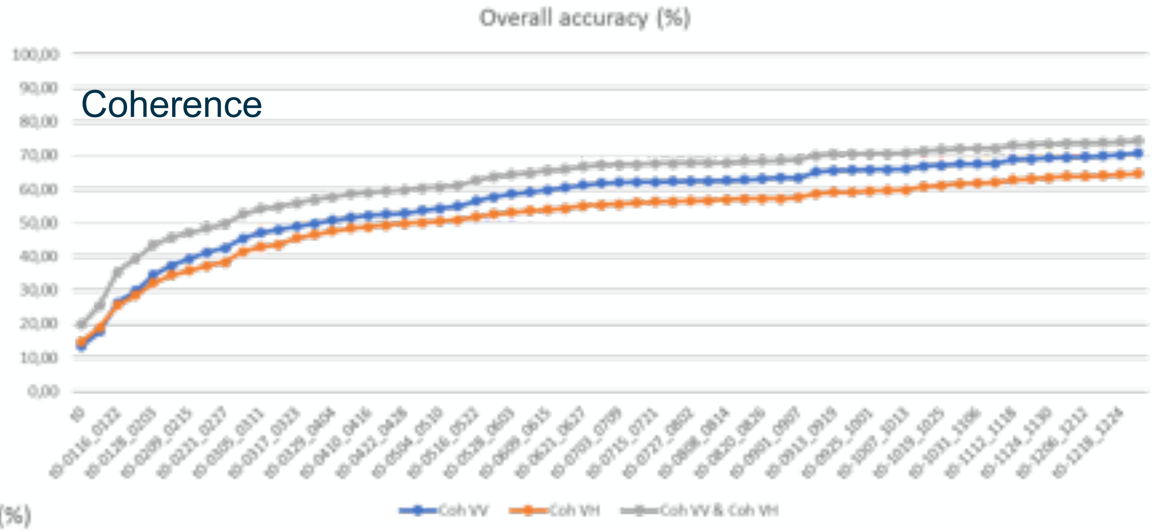
Doñana site – Assessment maps



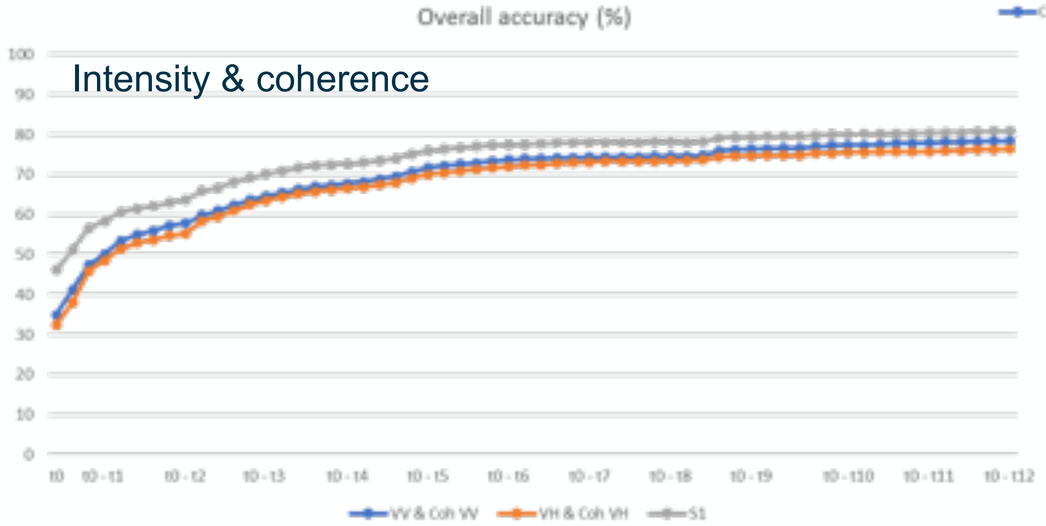
Doñana: S1/S2 Data Fusion for Landcover Mapping

Doñana site – Evolution of Overall accuracy with incremental datasets of S1





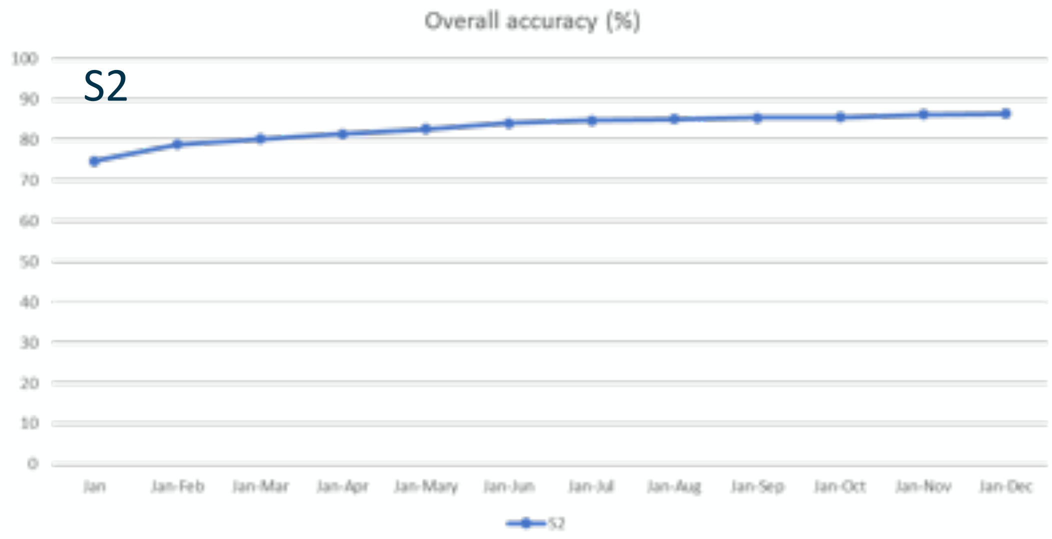
Tests with incremental datasets (2019)



Coherence is slower than intensity and never saturates

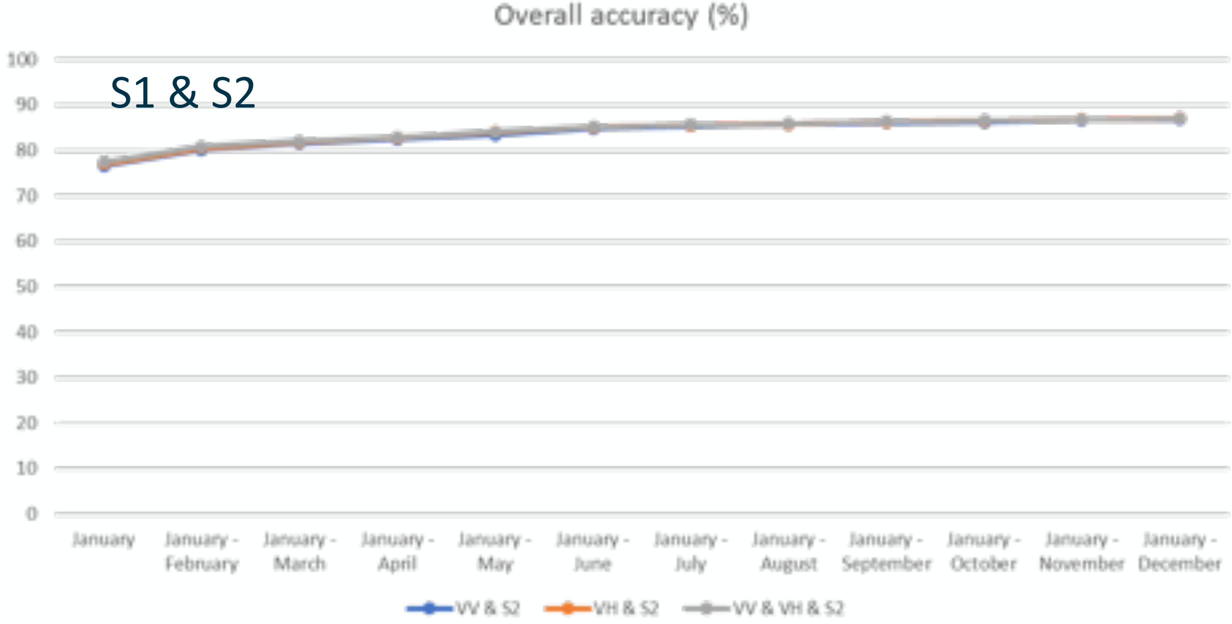
Doñana: S1/S2 Data Fusion for Landcover Mapping

Doñana site – Evolution of Overall accuracy with incremental datasets S1+S2



Tests with incremental datasets (2019)

Slight improvement in OA with S1+S2 in comparison to S2 alone



Doñana: Multi-track S1 Data Fusion for Landcover Classification

Doñana site – Overall accuracy using Multi-track S1 datasets

- Overall accuracy (%): Original (2017, 2018, 2019*) and Extended (2019)

Features	2017	2018	2019*	2019-EXT
VV 147	93.39	94.04	90.98	70.38
VH 147	95.59	94.59	91.77	68.35
VV 154	94.85	95.10	92.35	70.71
VH 154	95.79	94.95	91.77	70.47
Coher VV 147	94.49	93.09	90.68	70.62
Coher VH 147	92.13	90.62	86.99	64.87
Coher VV 154	94.65	92.85	90.35	72.10
Coher VH 154	92.10	89.95	87.03	65.28
VV 147 & VH 147	96.37	95.47	94.25	75.99
VV 154 & VH 154	96.67	96.16	94.41	76.63
Coher VV 147 & Coher VH 147	95.10	93.55	91.21	74.49
Coher VV 154 & Coher VH 154	95.30	93.25	91.22	75.74
VV 147 & VH 147 & VV 154 & VH_154	97.03	96.27	95.09	79.66
Coher VV 147 & Coher VH 147 & Coher_VV 154 & Coher VH 154	95.72	94.00	91.26	78.81
VV 147 & VH 147 & Coher VV 147 & Coher VH 147	97.84	96.66	95.17	80.88
VV 154 & VH 154 & Coher VV 154 & Coher VH 154	97.79	97.00	95.33	81.49
8 independent features of S1	98.16	97.10	95.52	83.43

Intensity: VH similar to VV

Coherence: VV > VH

Both tracks provide similar performance (154 sightly better)

All dual-pol combinations of the same feature improve OA

All combinations of the same track improve OA

Best result

Doñana: S1/S2 Data Fusion for Landcover Mapping

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Doñana site – Overall Accuracy

Overall accuracy (%): Original (2017, 2018, 2019*) and Extended (2019)

Features	2017	2018	2019*	2019-Ext
8 independent features of S1	98.16	97.10	95.45	83.43
13 independent features of S2	97.33	97.20	96.67	86.50
S1 and S2	98.29	97.73	96.85	87.44

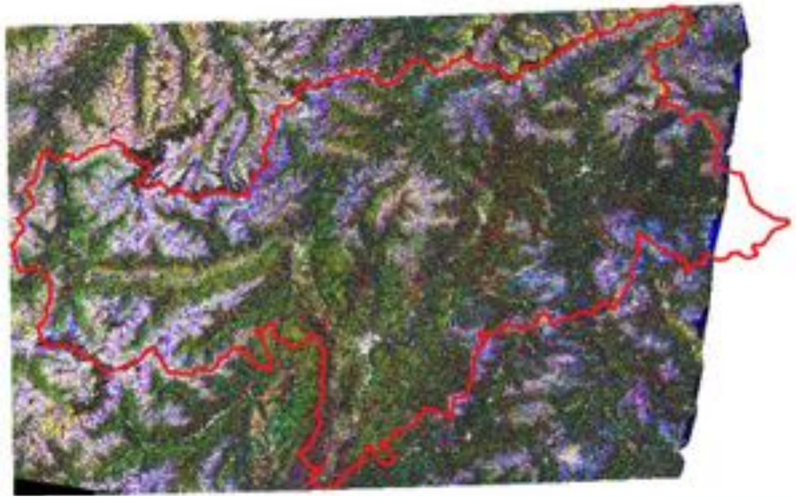
* Outdated reference data

Multitrack S1 Classification

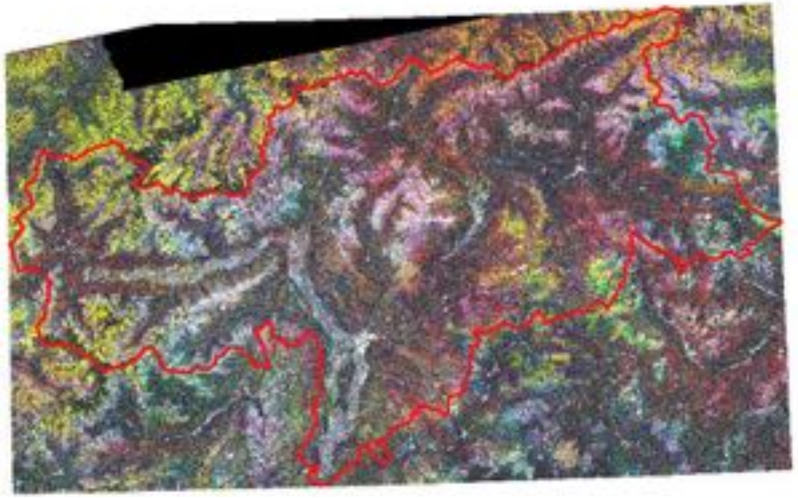
South-Tyrol site

Sentinel-1 DSC (168) Intensity (August 2017)

Sentinel-1 ASC (117) Intensity (August 2017)



Sentinel-1 DSC (168) Coherence (August 2017)

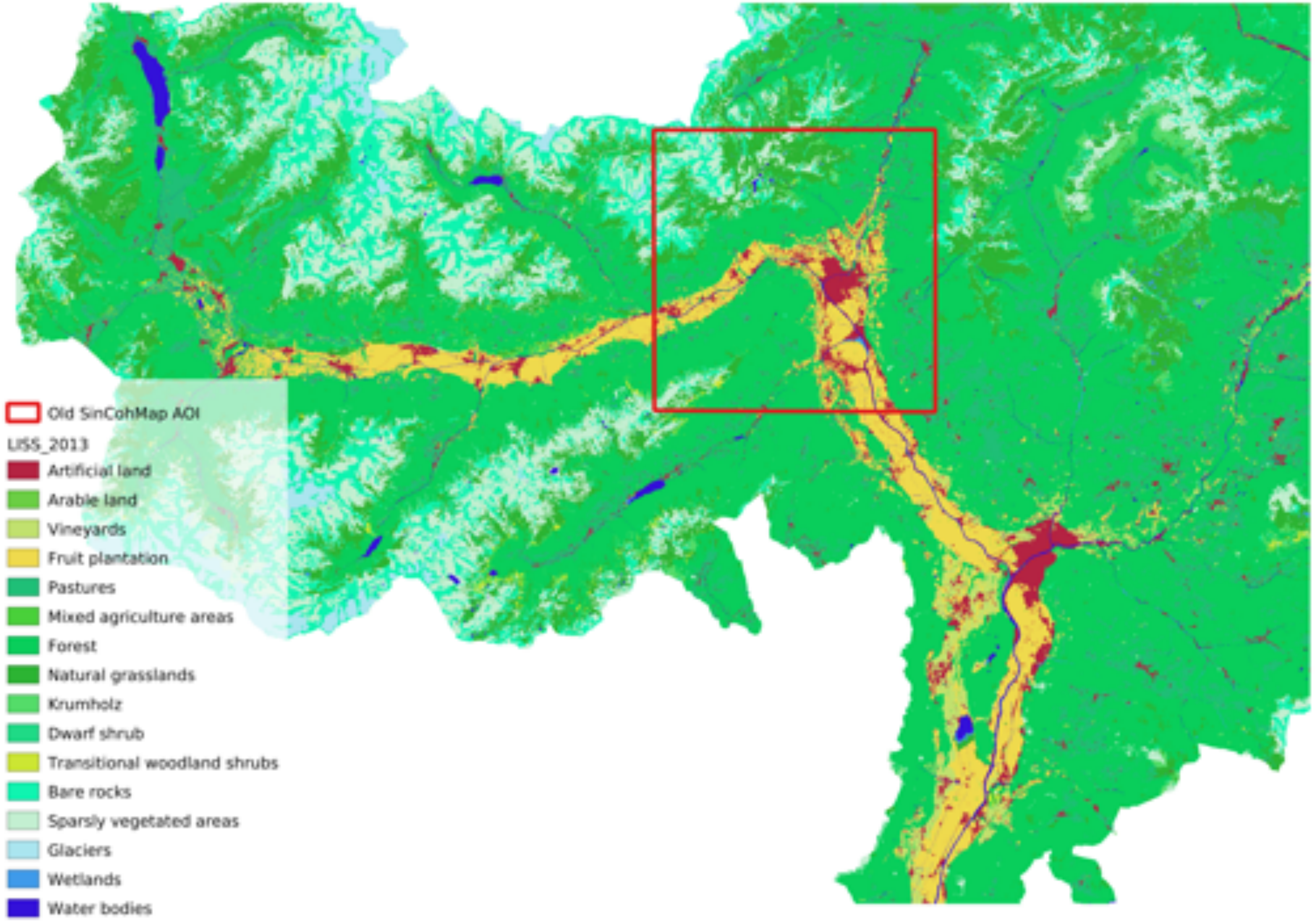


Sentinel-1 ASC (117) Coherence (August 2017)

Multitrack S1 Classification

South-Tyrol site - Land cover ground-truth

LISS layer (2013) is the most accurate land cover map for South Tyrol currently available.

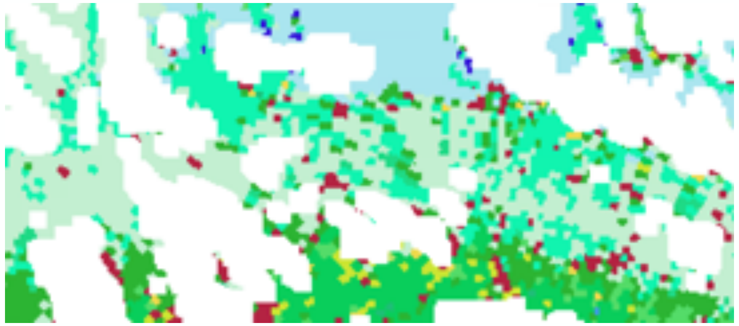


Multitrack S1 Classification

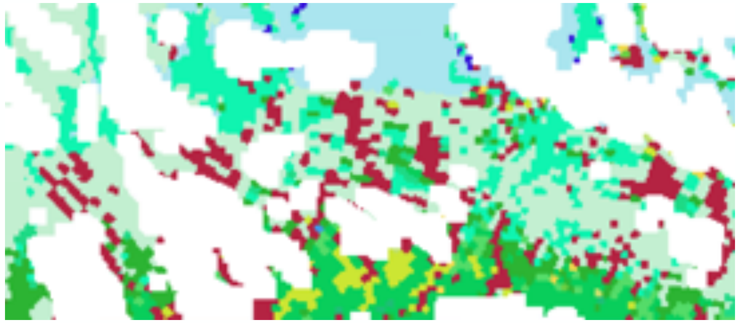
South-Tyrol site - Classification Methodology:

- Supervised classification method: **random forests**
- Selection of the **best training pixels candidates via S2 data analysis** with AI4EBV (Artificial Intelligence for Essential Biodiversity Variables)
- This approach **improved the classification** compared with a random sampling

S1 DSC Coherence and Intensity classified using training pixels selection based on Sentinel-2 data



S1 DSC Coherence and Intensity classified with random training pixels selection



Sentinel-2 RGB composite

South-Tyrol: Data Fusion for Landcover Mapping

South-Tyrol site – Data fusion:

- Tests with pre- and post- classification fusion approaches of each track

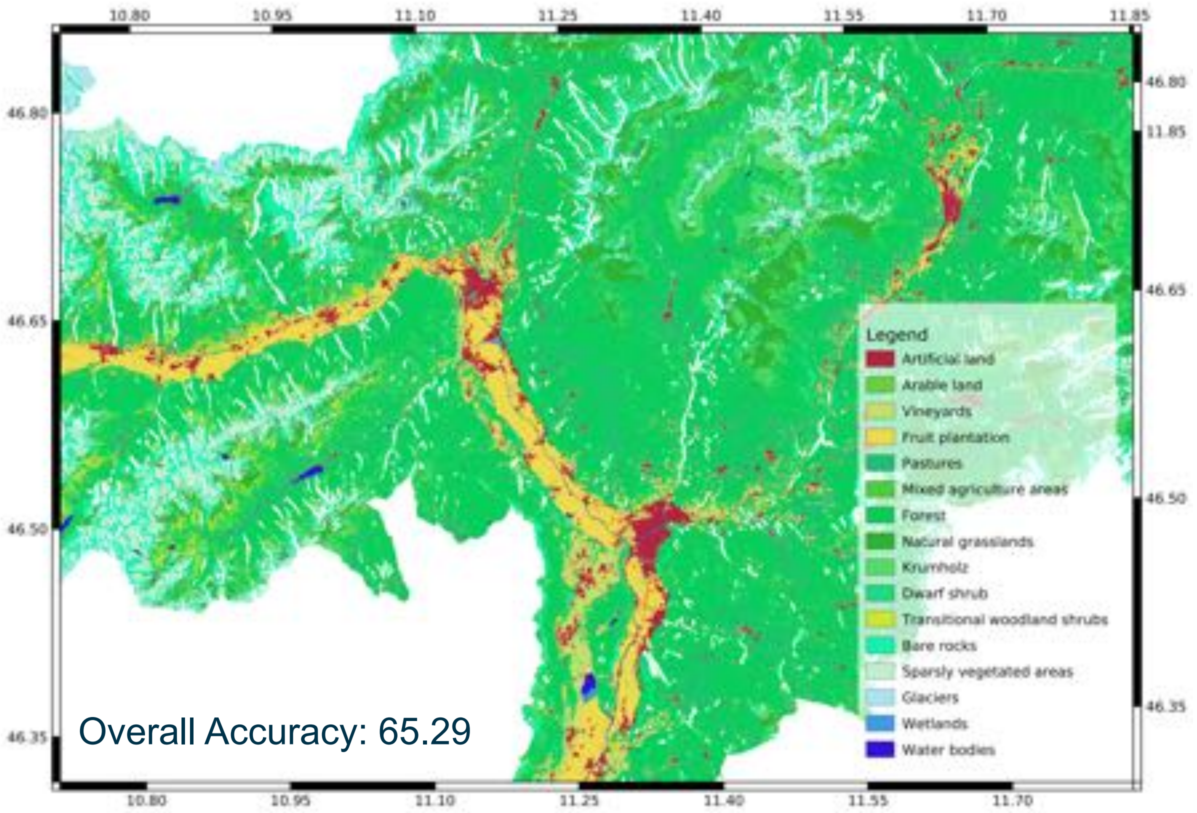
Sentinel-1 DSC orbit

Sentinel-1 ASC orbit

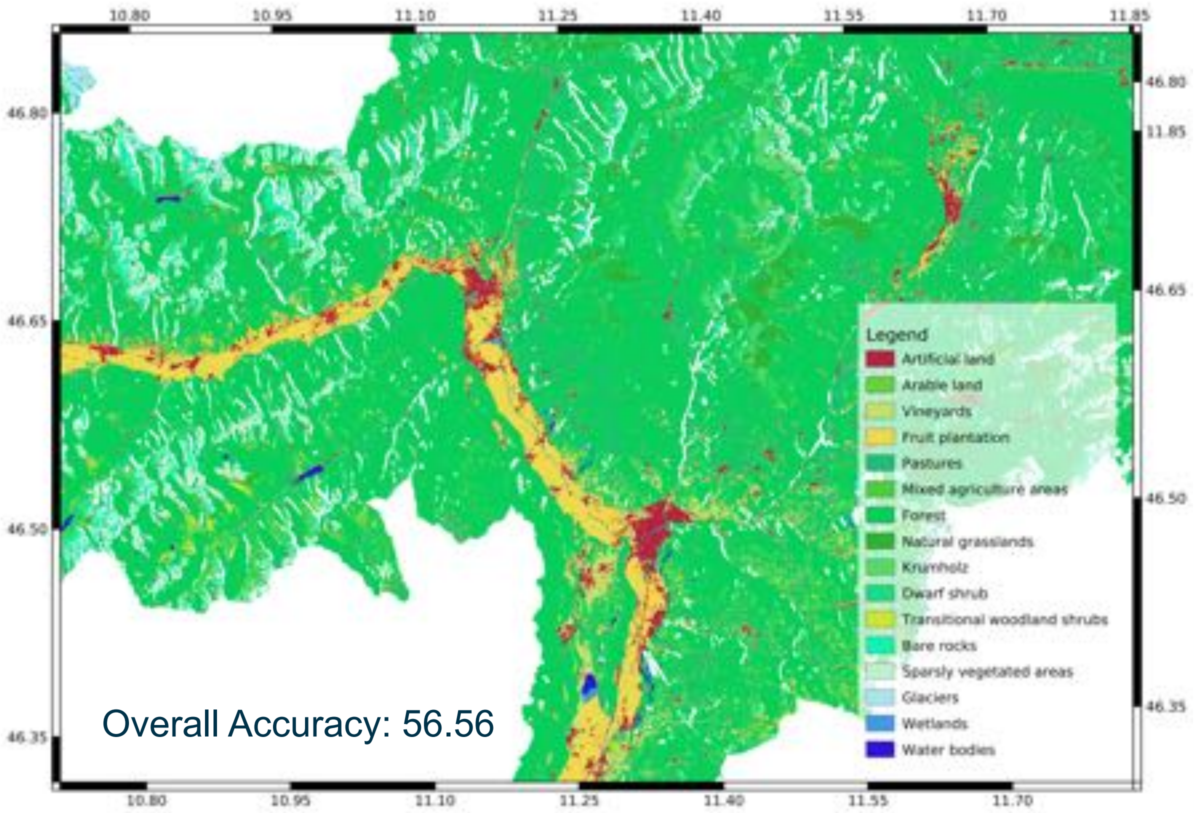
DSC valid pixels 9,633,524
ASC valid pixels 14,041,516

South-Tyrol site – Data fusion:

- Tests with pre- and post- classification fusion approaches of each track



Pre-classification merge approach
(i.e., data fusion)



Post-classification merge approach

South-Tyrol: Multi-track S1 Data Fusion for Landcover Mapping

South-Tyrol site – Multi-track S1 land cover mapping

- Validation using manually extracted points

Year		2017	2018	2019	2020	2021
Overall accuracy		59.1%	57.5%	58.3%	56.8%	56.3%
Artificial land	120	84.5%	85.3%	85.7%	81.3%	81.3%
Vineyards	221	65.2%	62.7%	64.3%	64.7%	59.6%
Fruit plantations	222	83.2%	77.0%	81.3%	80.7%	78.0%
Pastures	231	86.7%	89.0%	87.0%	83.0%	89.0%
Forest	315	88.4%	91.0%	92.3%	86.7%	87.6%
Dwarf shrubs	323	22.3%	20.7%	21.3%	22.3%	20.6%
Bare rocks	332	38.2%	31.0%	31.0%	30.7%	32.0%
Woodland shrubs	324	4.5%	3.3%	3.0%	5.0%	2.6%
Glaciers	430	61.7%	67.3%	69.0%	69.0%	39.0%
Water bodies	520	31.7%	31.7%	29.7%	37.3%	31.0%

South-Tyrol: S1/S2 Data Fusion For Landcover Mapping

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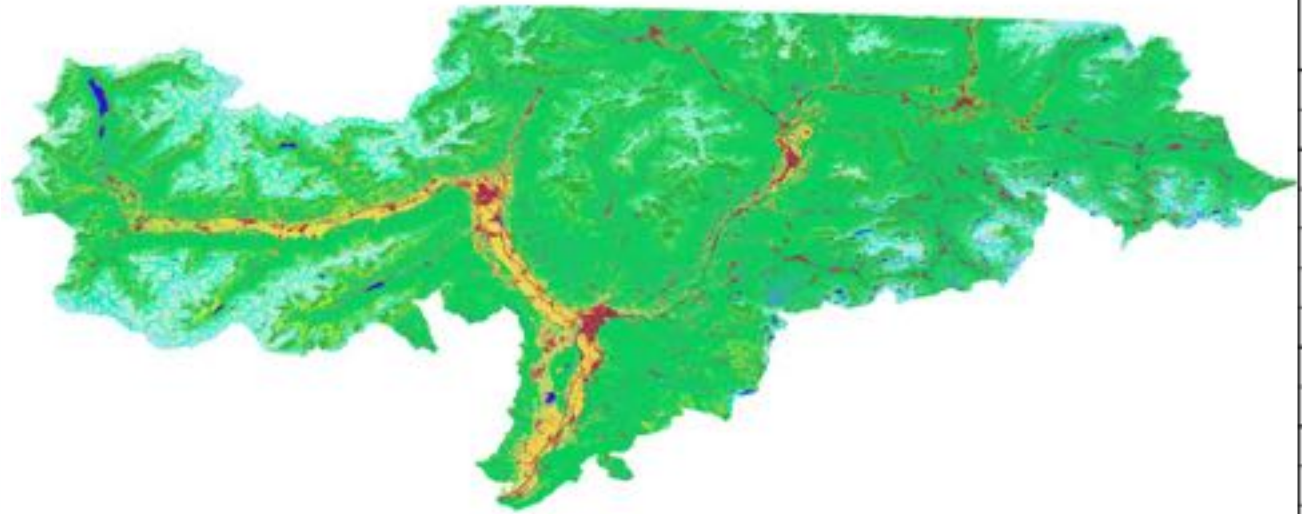
South-Tyrol site – S1 and S2 data fusion for land cover mapping



Land use map for 2021 using Sentinel 1 ASC & DSC Coherence + ASC & DSC Intensity + Sentinel-2 bands (Red, Green, Blue, NIR, SWIR1, SWIR2).

Features		Sentinel-2 (Blue, Green, Red, NIR, SWIR-1, SWIR-2)		Sentinel-1 (Coher VV + VH 168 & Coher VV + VH 117 & VV + VH 168 & VV + VH 117)		Sentinel-1 and Sentinel-2 (Blue, Green, Red, NIR, SWIR-1, SWIR-2, Coher VV + VH 168 & Coher VV + VH 117 & VV + VH 168 & VV + VH 117)	
Overall accuracy [%]		71.44		65.29		71.94	
Kappa hat classification		0.63		0.55		0.64	
Classes		PA [%]	UA [%]	PA [%]	UA [%]	PA [%]	UA [%]
Artificial land	120	75.96	43.28	60.20	57.69	74.00	50.29
Arable land	210	59.70	28.60	29.17	33.49	60.41	27.30
Vineyards	221	81.30	46.69	74.10	39.30	84.58	44.34
Fruit plantations	222	76.95	72.37	73.91	79.00	76.08	81.38
Pastures	231	71.38	76.95	61.78	58.19	71.70	77.08
Mixed agriculture	250	30.31	5.79	27.30	78.58	28.32	6.98
Forest	315	81.57	96.88	80.52	88.85	82.48	96.69
Natural grasslands	321	57.24	77.84	42.53	67.30	57.51	76.65
Krumholz	322	61.88	21.02	46.96	16.53	63.98	20.91
Dwarf shrubs	323	60.97	24.49	40.42	20.78	60.14	25.83
Woodland shrubs	324	46.14	4.42	30.53	3.46	49.18	4.42
Bare rocks	332	55.19	63.94	51.57	43.26	56.29	62.46
Sparsly vegetated	333	58.32	65.18	55.46	60.82	57.58	65.49
Glaciers	430	86.27	46.13	78.86	59.46	86.00	48.78
Wetlands	510	45.35	7.15	34.34	9.70	44.70	7.79
Water bodies	520	54.16	54.59	33.99	50.09	52.79	56.58

Forest Classification & Monitoring using S1 Coherence

Objective: Exploration of the conditions under S1 interferometric coherence may improve forest classification and monitoring

- An accurate monitoring of forest degradation processes like deforestation in equatorial areas, worldwide forest fires, pest outbreaks, etc.
- The **use of interferometric information is quite limited due to low values** of coherence obtained in forests with C-band data.
- Benefits that interferometric coherence may afford in forest monitoring and classification

Test site: Two areas in Finland (Nov 2017 – Nov 2018)

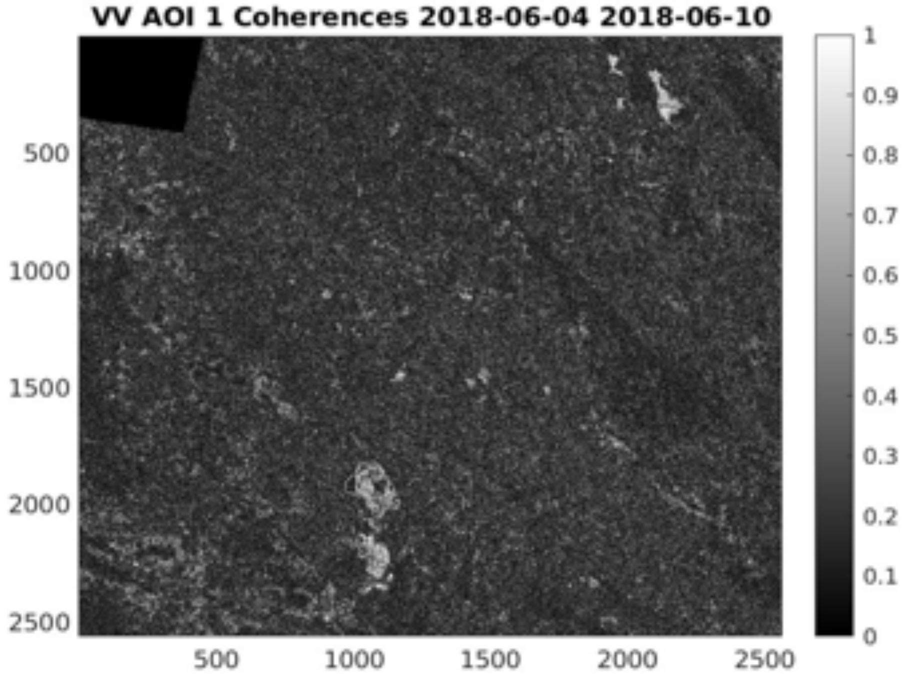
Analysis:

- Derivation of the VV and VH datacubes for the two considered areas on Finland for **boreal forests**
- **Pixel and Area based** analysis of temporal and spatial variance of the interferometric coherence
- Analysis of **temporal decorrelation** for C-band coherence on boreal forests

Finland Testsite

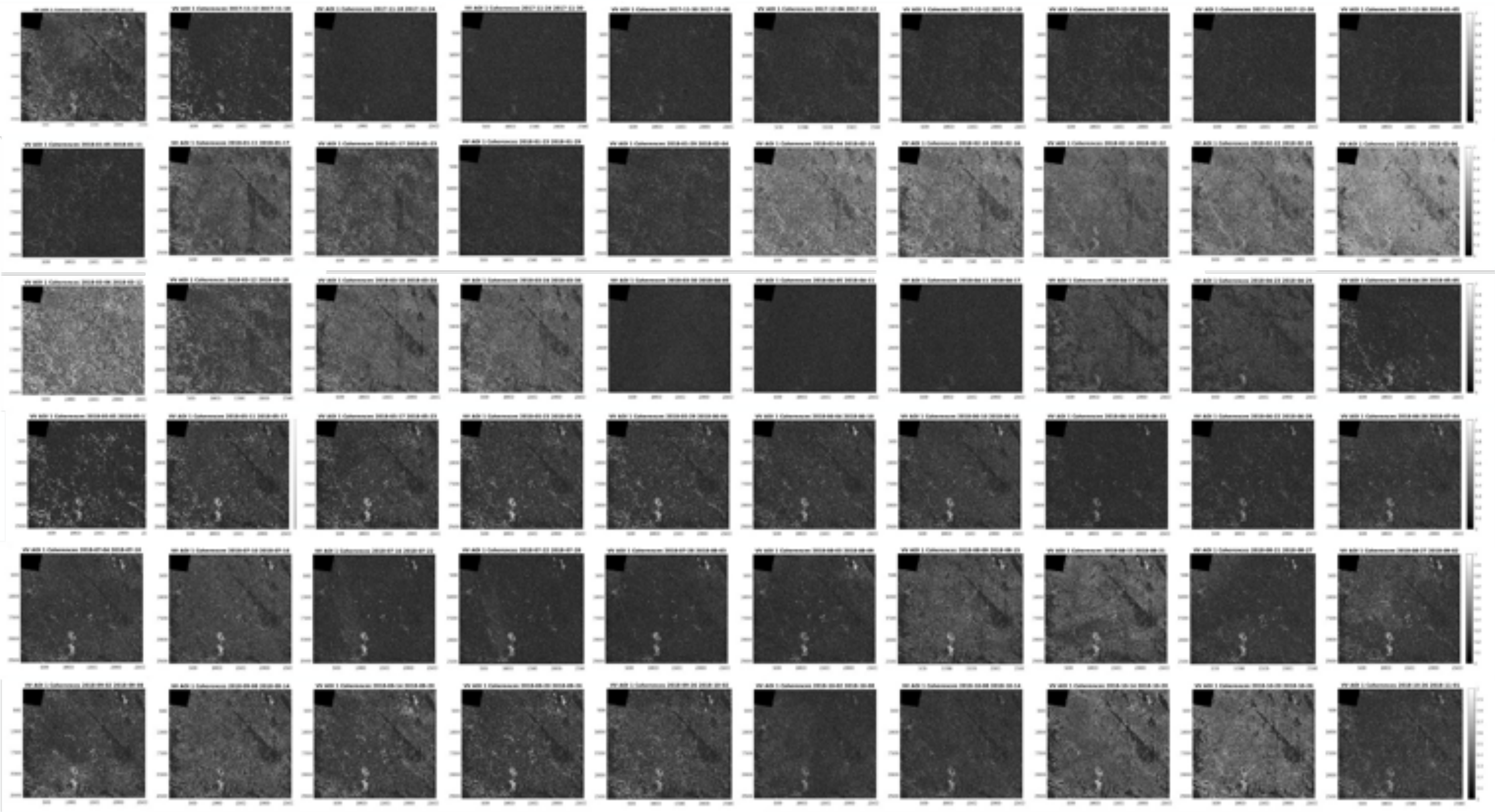
Boreal forest testsite

Sentinel-1 Area



6 day coherence

Forest Classification & Monitoring using S1 Coherence



Continuous one year 6-day coherence

Conclusions

- S1/S2 data fusion for land cover classification:
  - Two test sites analyzed: Doñana (flat, crops) & South Tyrol (mountainous, several vegetation classes)
  - Classification with S2 outperforms S1 but…:
    - Difference depends on test site and case
    - There are crop classes for which S1 is better than S2.
    - There is always an improvement when combined
    - Incremental experiments demonstrate that S1 requires time series more than S2 does
    - For crops, monthly averages of S2 (may be required due to cloud coverage) are worse than all dates, and are well complemented by time series of S1
    - Using both orbits filled up most of the gaps in mountainous areas due to the side-looking geometry with a reliable result
- S1 coherence for forest classification
  - Coherence low for forests due to temporal decorrelation effects