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FRINGE 2026

Detecting Forest Leaf-Out from Sentinel-1 Interferometric Coherence: Evidence of Structural Reorganization in Early Spring

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SPRING PHENOLOGY OF DECIDIOUS FOREST

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Sequential greening of forest layers: from the forest floor to the canopy

0 Dormant season
Everything is dormant

1 Green-up of the forest floor
Herbs and mosses green-up

2 Green-up of understory + forest floor
Shrubs and young trees leaf out

3 Canopy leaf-out
Overstory crowns expand

4 Full leaf
All layers fully developed

III. Canopy (trees)	no leaves		leaf emergence	fully green
II. Understory (shrubs, young trees)	dormant / not visible	emergence		fully green
I. Forest floor (herbs, mosses)	mostly brown	green-up	increasing green cover	fully green

Time (spring)

13 April 2025

19 April 2025

Spring creates new scatters in the scenes

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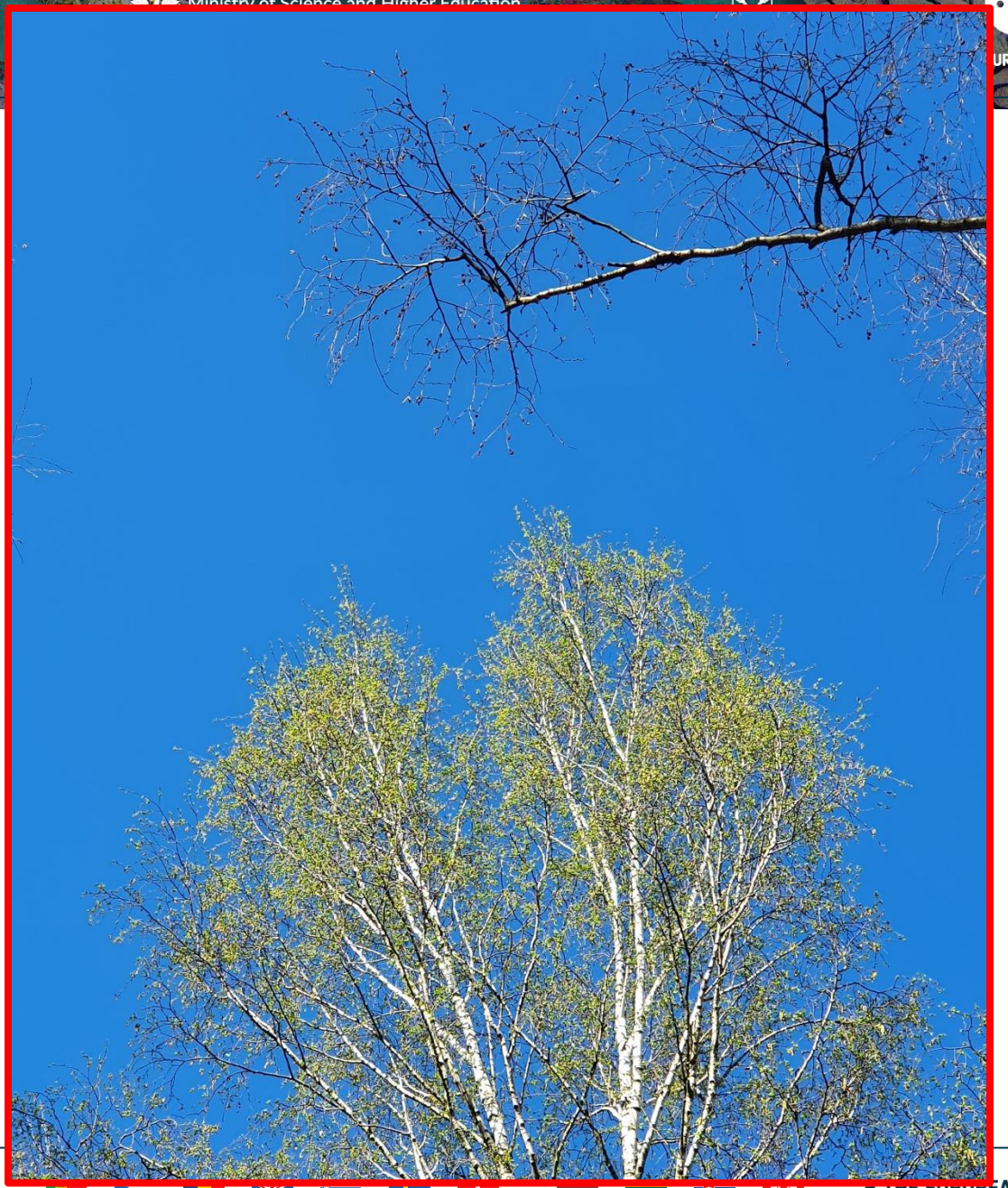
New scatters




CARBON CYCLE
Spring onset marks the beginning of active photosynthesis and increasing carbon uptake by the forest.
CO_2
LAND–ATMOSPHERE EXCHANGE
Leaf emergence changes evapotranspiration and energy exchange between the forest and the atmosphere.
ECOSYSTEM PRODUCTIVITY
The timing of spring onset influences the length of the growing season and overall forest productivity.
SPRING ONSET
SOS
FOOD WEB SYNCHRONY
Many species rely on the timing of spring development to synchronize feeding, reproduction and migration.
CLIMATE CHANGE INDICATORS
Shifts in spring onset are widely used to track ecosystem responses to climate change.
Web of Interactions Triggered by Spring Onset

Ways to detect spring onset

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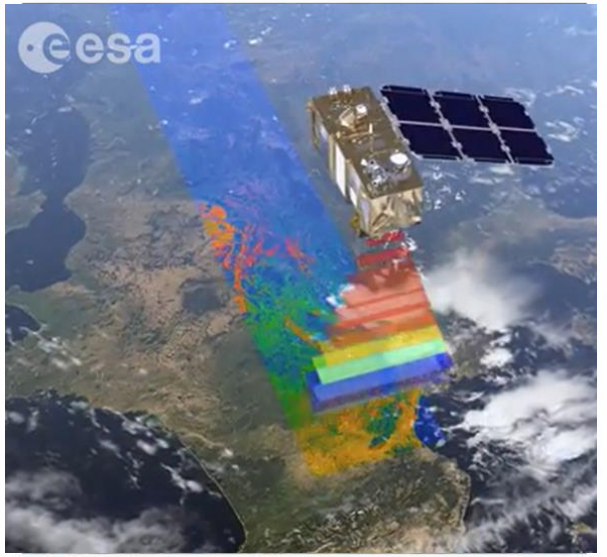
Ground observations

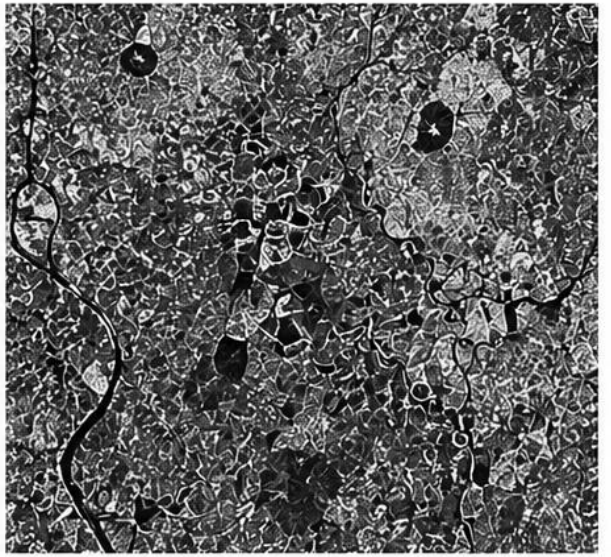
- ✓ Accurate and detailed
- ✗ Local and labour-intensive

Optical satellite (NDVI)



- ✓ Large-scale coverage
- ✗ Sensitive to clouds
- ✗ Greenness ≠ structure

Radar satellite (backscatter)



- ✓ All-weather, day & night
- ✗ Strongly affected by rainfall
- ✗ Hard to isolate vegetation effects

→ Is it possible to use coherence and phase information do detect spring onset?
Are SAR data more sensitive to early spring development than optical data?

Methodology & data

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Ground observations

2025
2026

- Reference canopy leaf-out dates (SOS)

Sentinel-2

2025
2026

- NDVI

Sentinel-1

2025
2026

- Coherence
- Resultant length

TerraSAR-X

2026

- Coherence
- Resultant length

Meteorological data*

2025
2026

- Growing Degree Days (GDD)

Smoothing and calcualation of SOS (Start of Season)
for each data source

Comparison with ground observations
Evaluation of agreement in SOS dates

*

$$GDD = \frac{T_{max} + T_{min}}{2} - T_{base}$$

T_{max} – daily maximum temperature
T_{min} – daily minimum temperature
T_{base} – base temperature for plant growth (5°C)

→ the amount of heat available for plant growth

Key observables:

NDVI
measure of vegetation greeness
NDVI ≈ 0 - little or no green vegetation
NDVI → 1 - dense, healthy green vegetation

Coherence (γ)
measure of similarity between two SAR acquisitions
γ → 1 – identical radar scattering conditions
γ → 0 – complete temporal decorrelation

Resultant length (R)
measure of phase-angle concentration
R → 1 – identical phase angles (high concentration)
R → 0 – random phase distribution (low concentration)

Study area

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Betula pendula

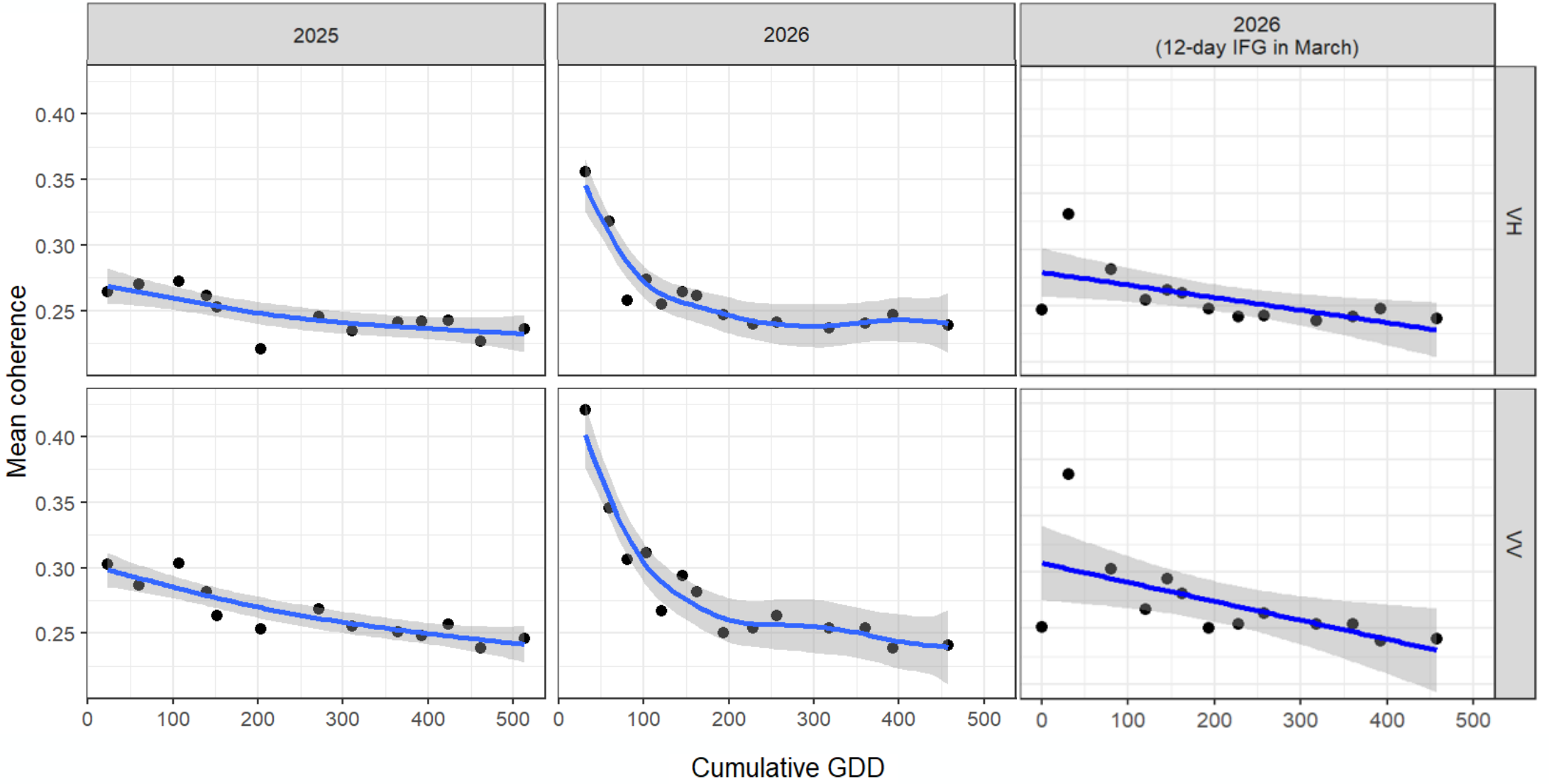
Photo by Piotr Gach

COUNTRY
Poland

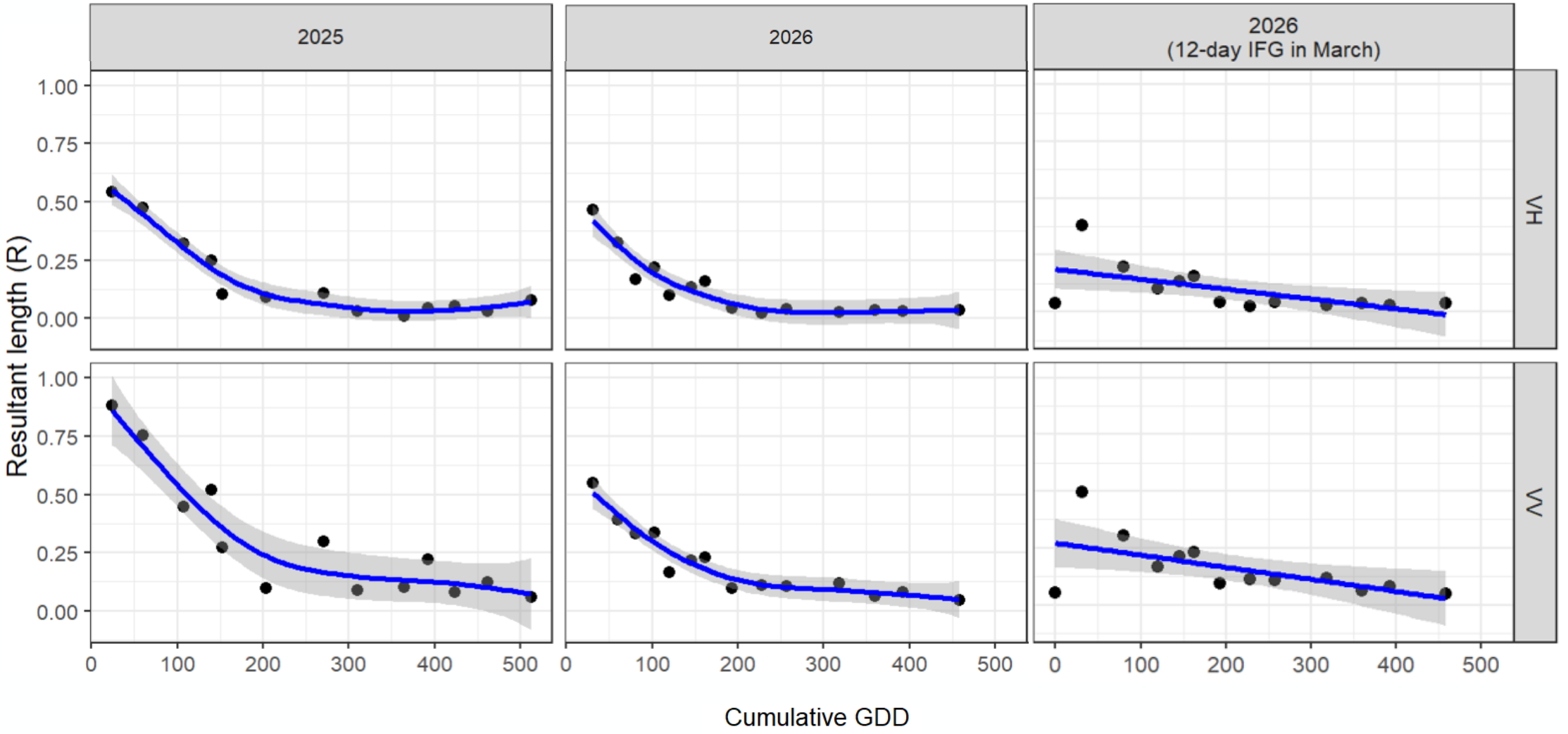
FOREST DISTRICT
Czerniejewo

DOMINANT SPECIES
Betula pendula
(100% area)

GDD against Radar metrics



GDD against Radar metrics



GDD against Radar metrics

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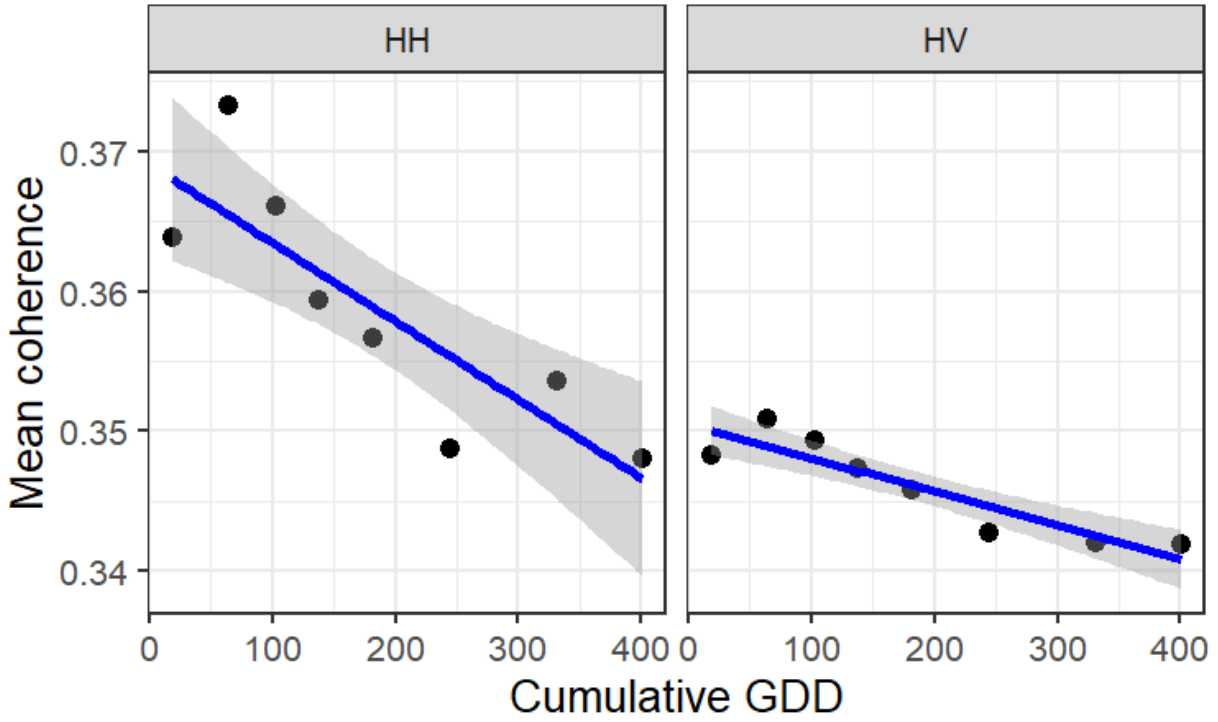
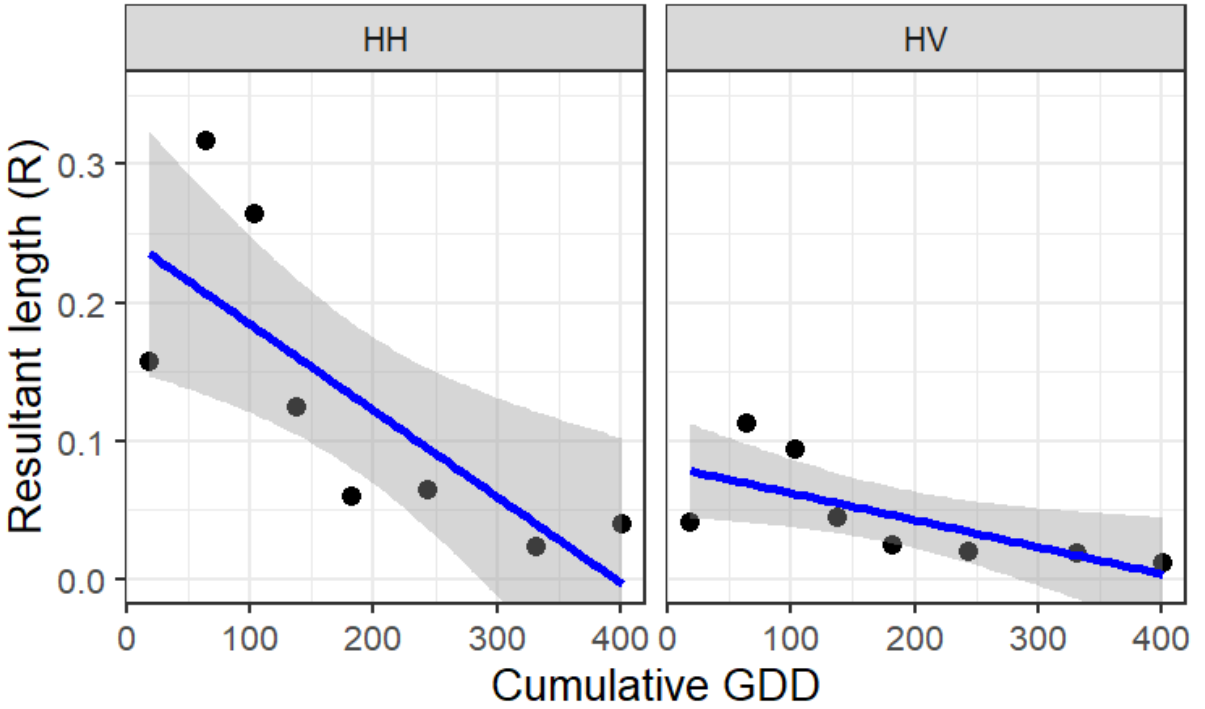
TerraSAR - X





Coherence results

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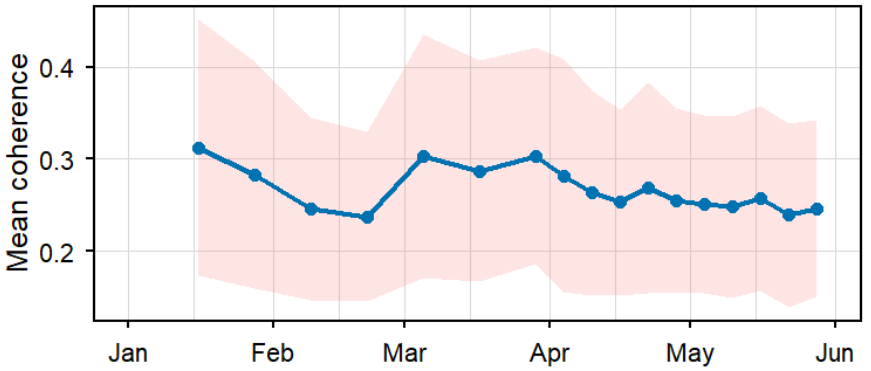
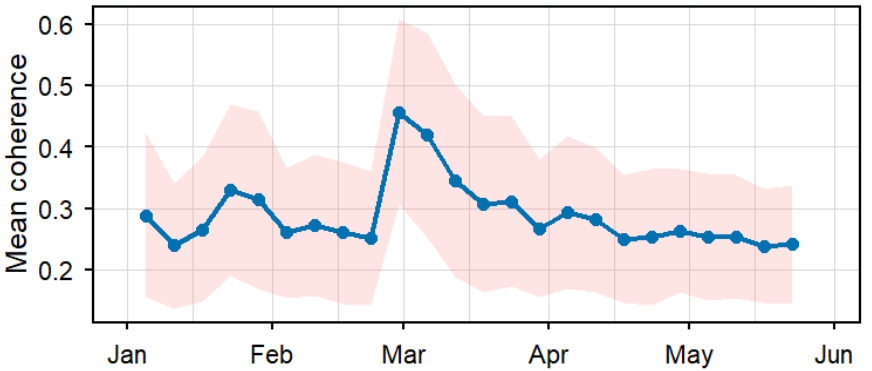
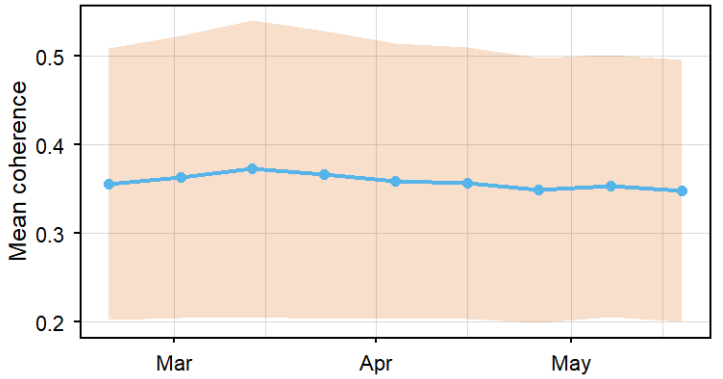
Sentinel – 1 (VV) 2025



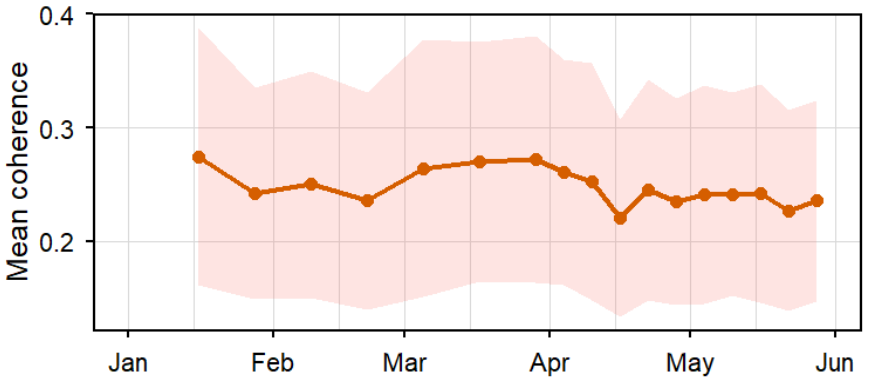
Sentinel – 1 (VV) 2026



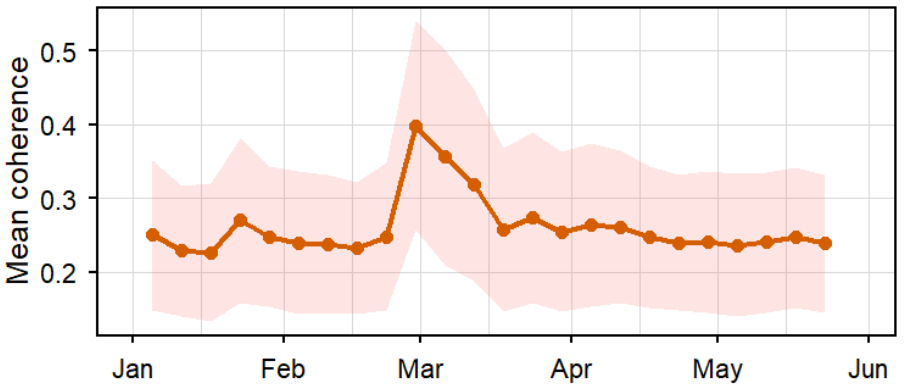
TerraSAR – X (HH) 2026



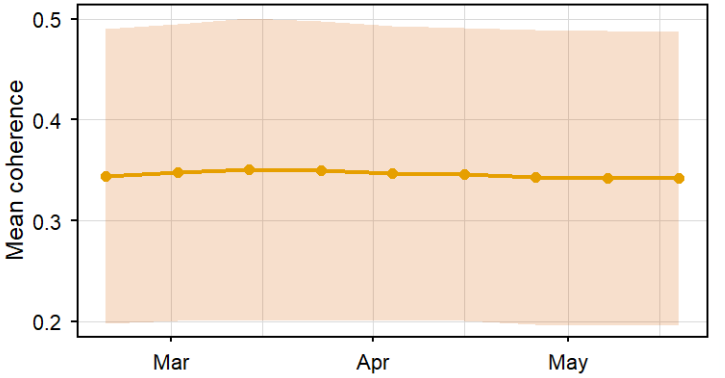
Sentinel – 1 (VV) 2025



Sentinel – 1 (VH) 2026



TerraSAR – X (HV) 2026



Resultant length

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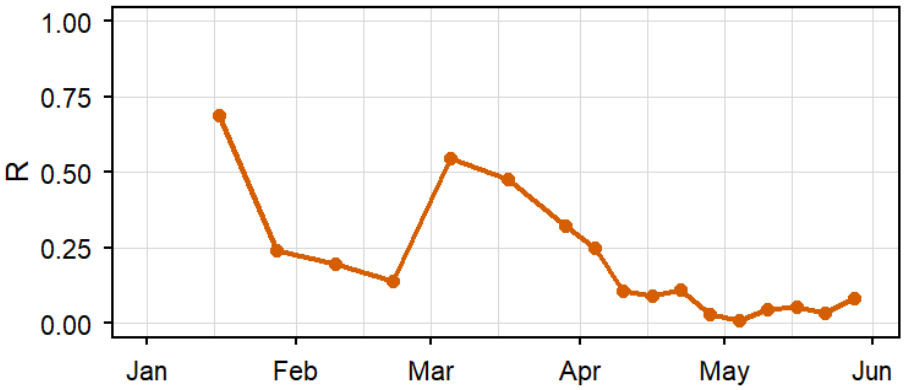
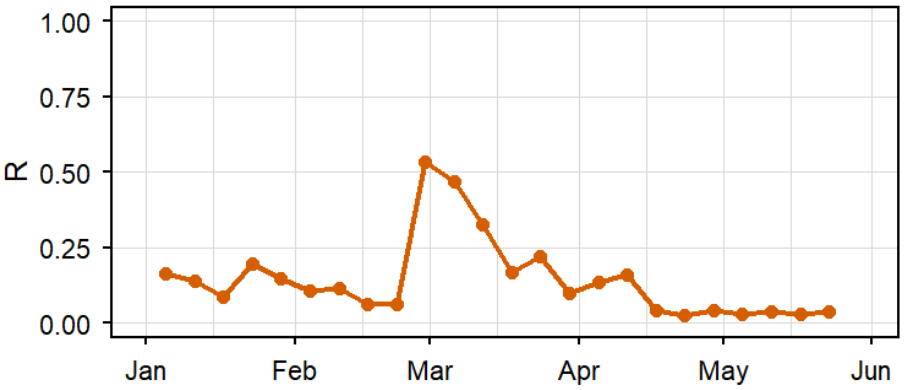
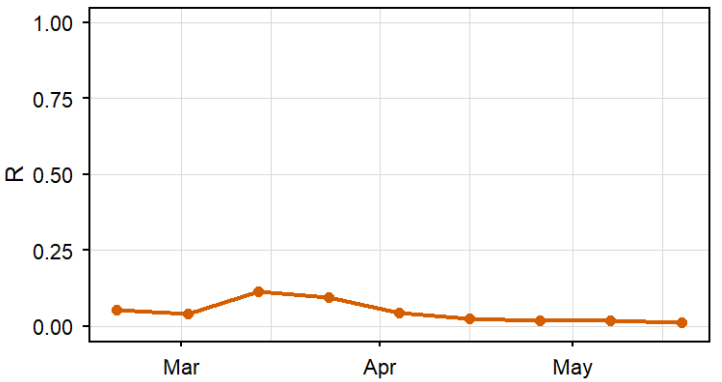
Sentinel – 1 (VV) 2025



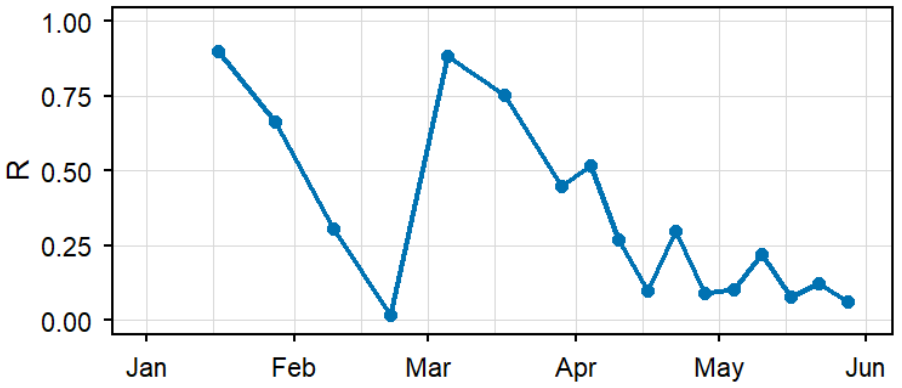
Sentinel – 1 (VV) 2026



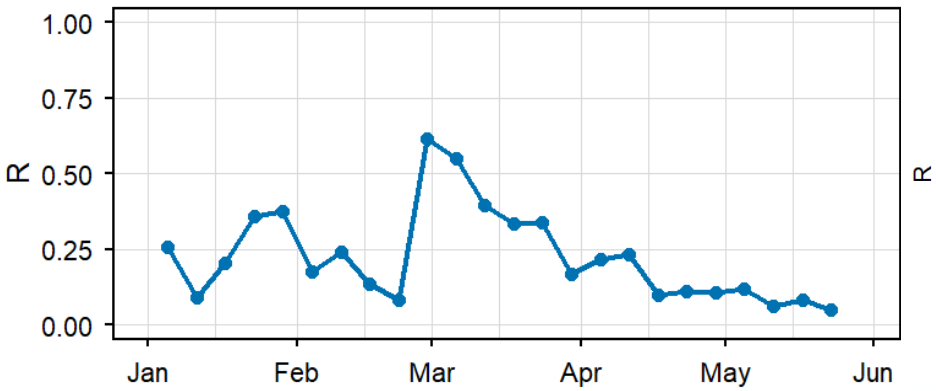
TerraSAR – X (HH) 2026



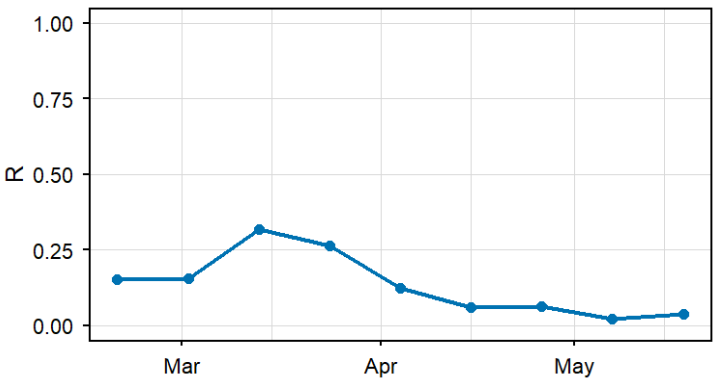
Sentinel – 1 (VV) 2025



Sentinel – 1 (VH) 2026

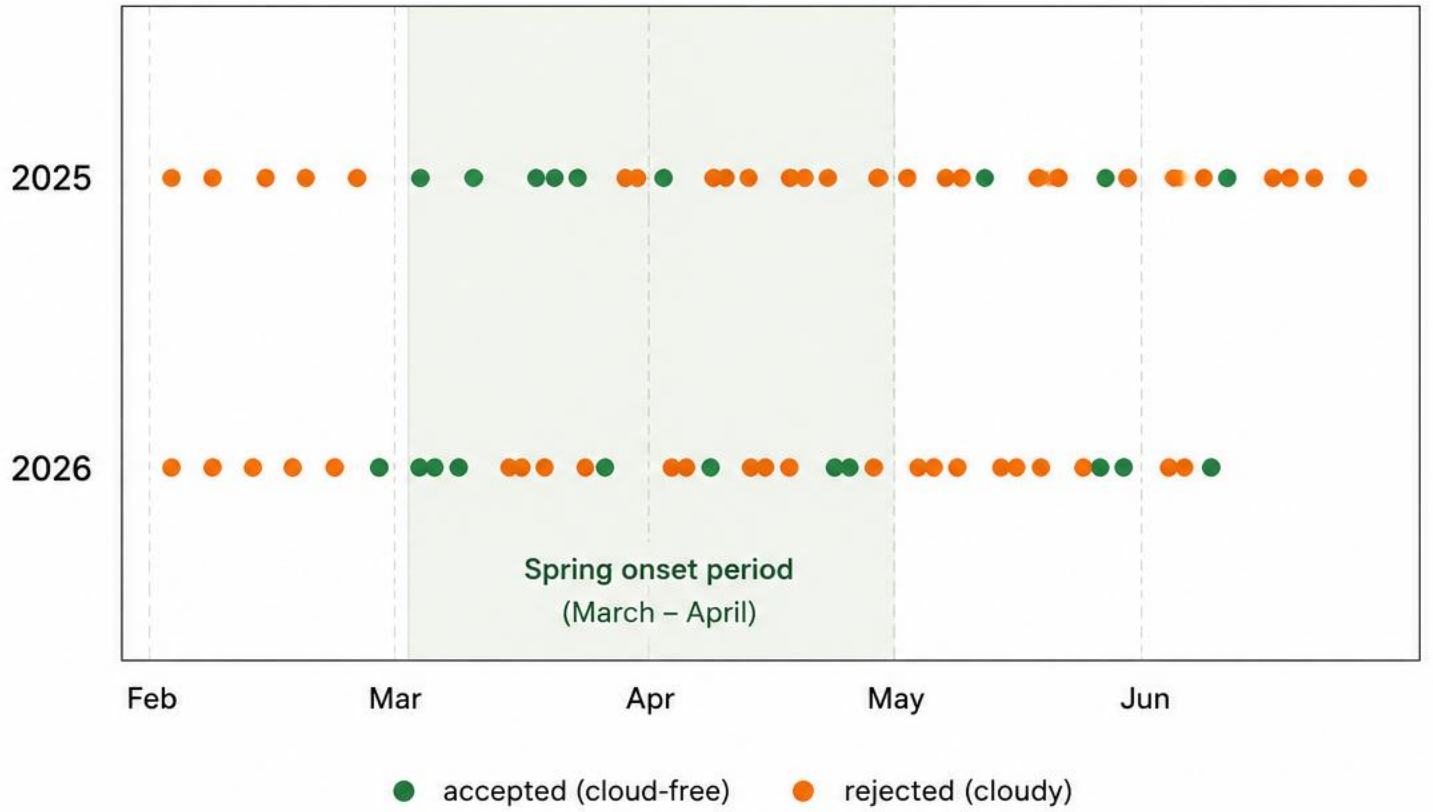


TerraSAR – X (HV) 2026



Smoothing and calcualation of SOS (Start of Season)
for each data source → RESULTS

Cloud-free observations during spring from S2



2025

- 40 total acquisitions
- 10 cloud-free

25 % usable

2026

- 35 total acquisitions
- 11 cloud-free

31 % usable

Only 25–31% of Sentinel-2 observations met the cloud-cover criterion.

During the onset phase only a few cloud-free observations were available, limiting the temporal detail of NDVI-based phenology.

NDVI-based phenological metrics

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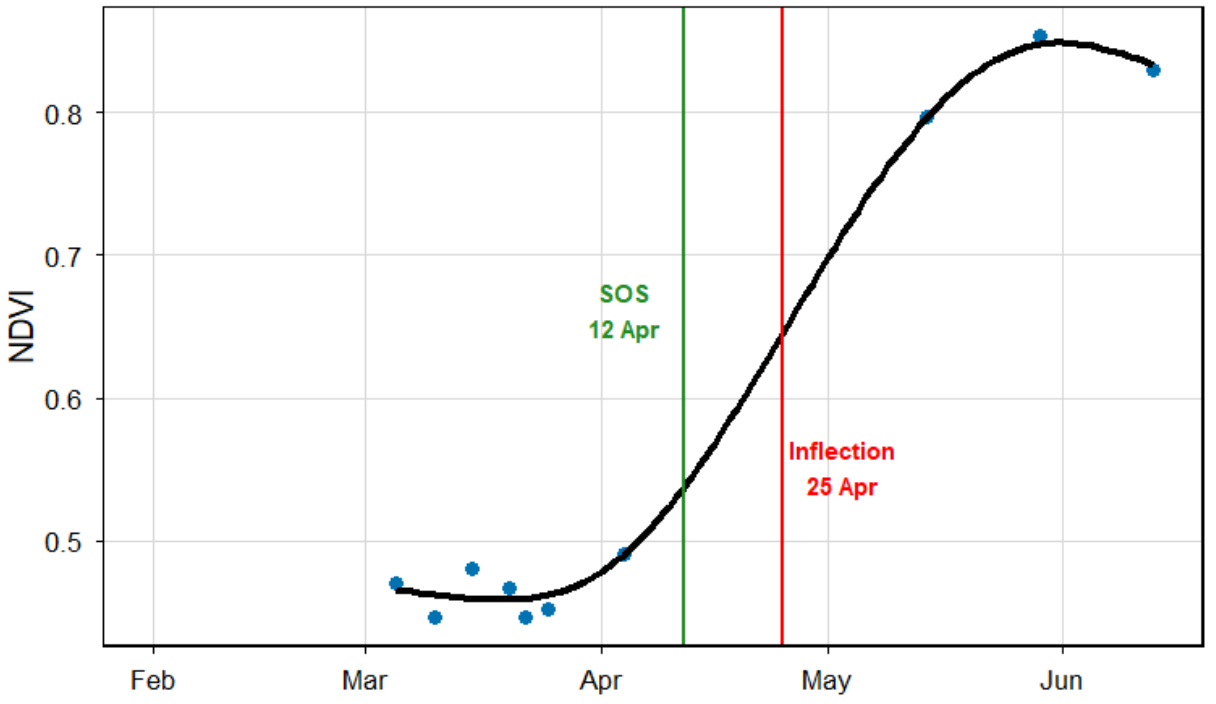
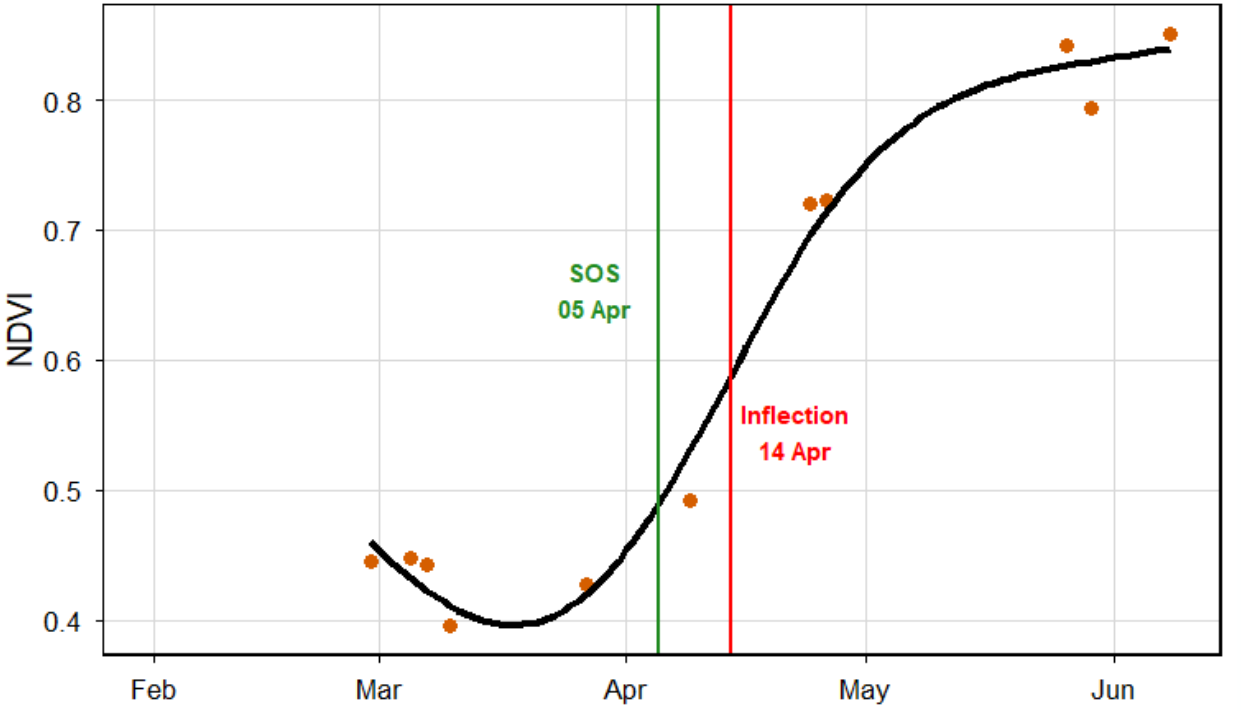
2025



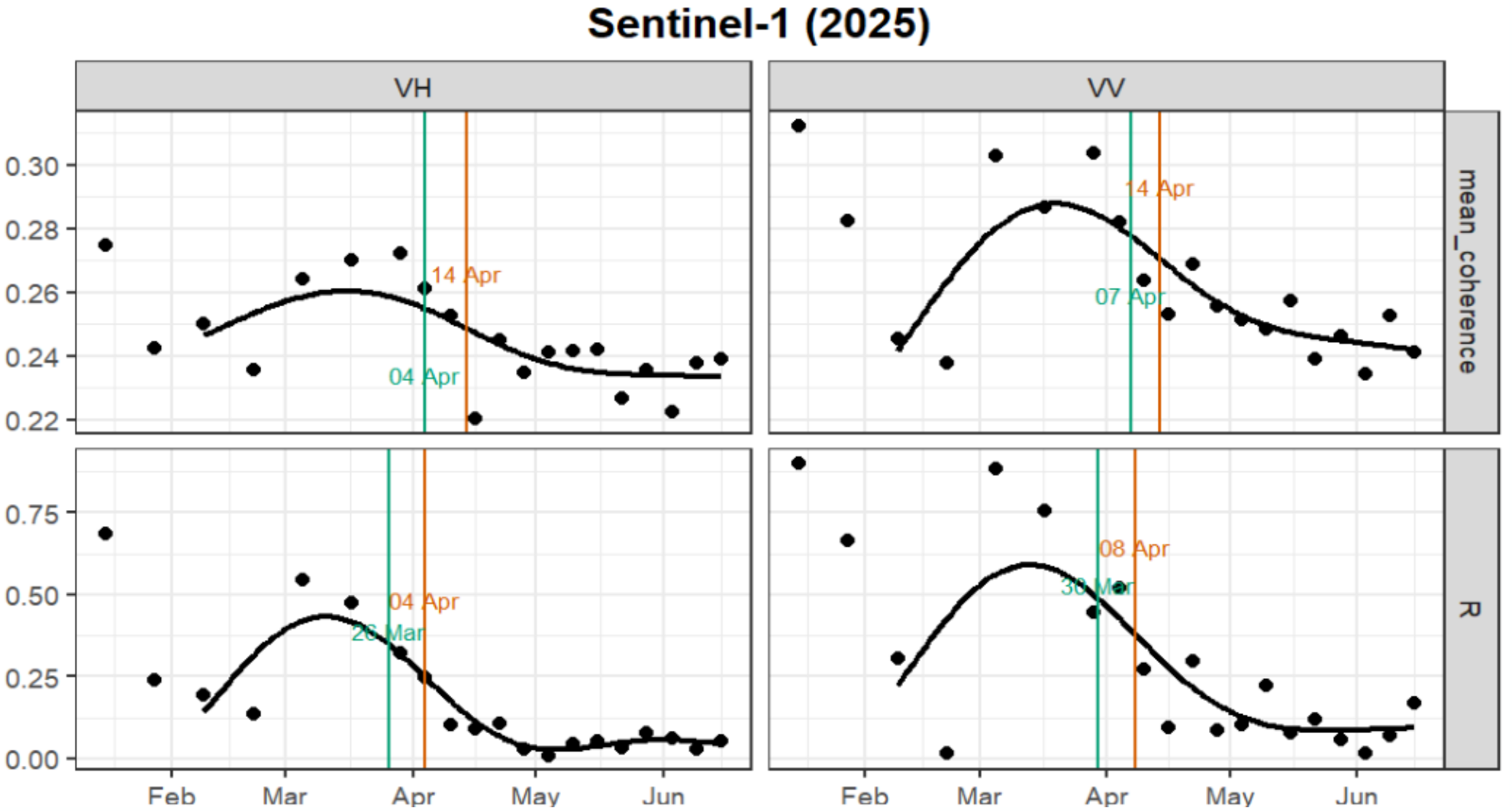
2026



SOS (Start of Season)
The first day on which the smoothed NDVI curve reaches 20% of the NDVI increase between the minimum and maximum values observed during the study period (March–June).

Inflection point
The moment when NDVI is increasing at its fastest rate, so vegetation greenness and biomass are developing most rapidly

Radar based phenological metrics



Radar based phenological metrics

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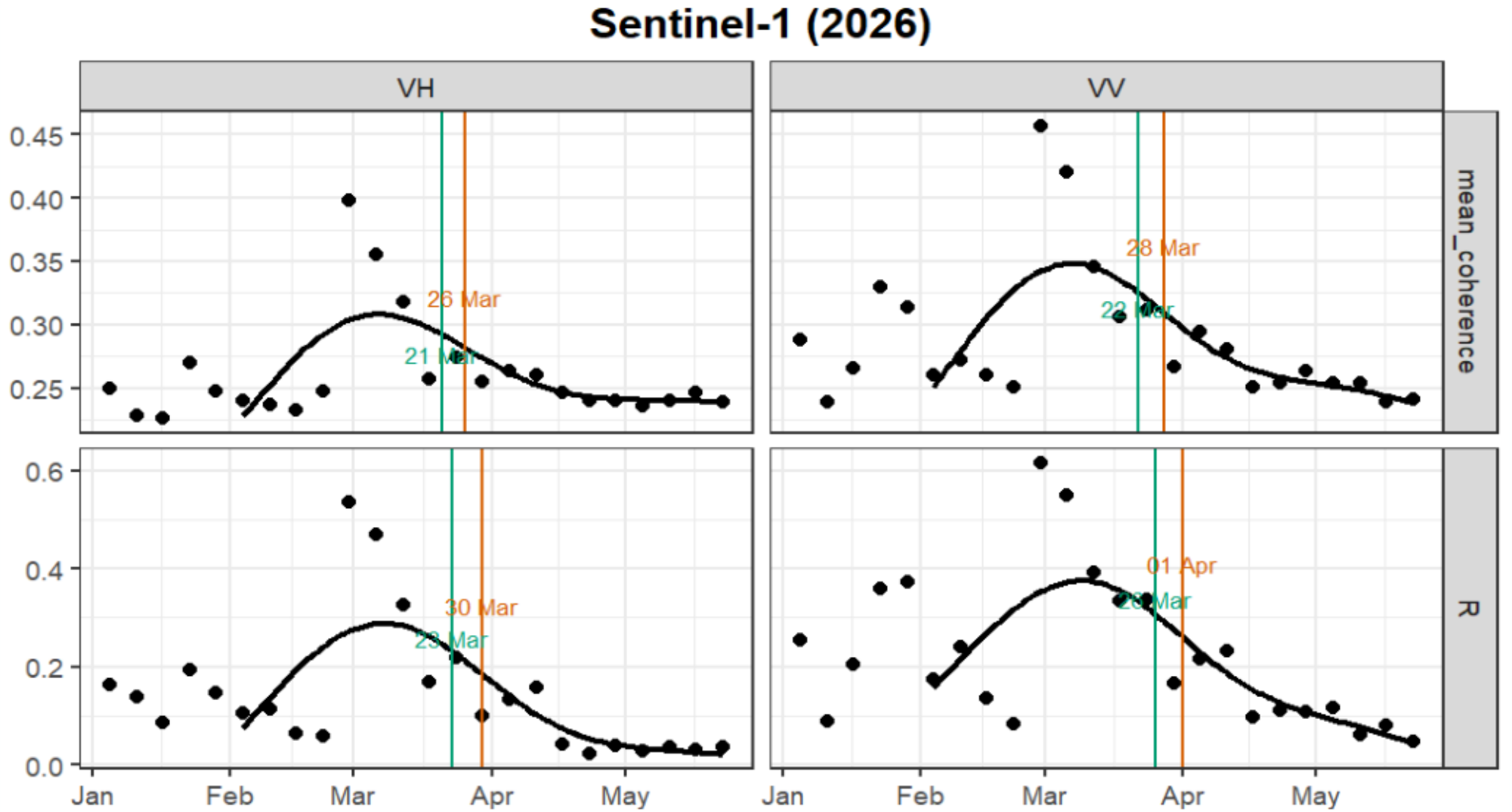

Radar based phenological metrics

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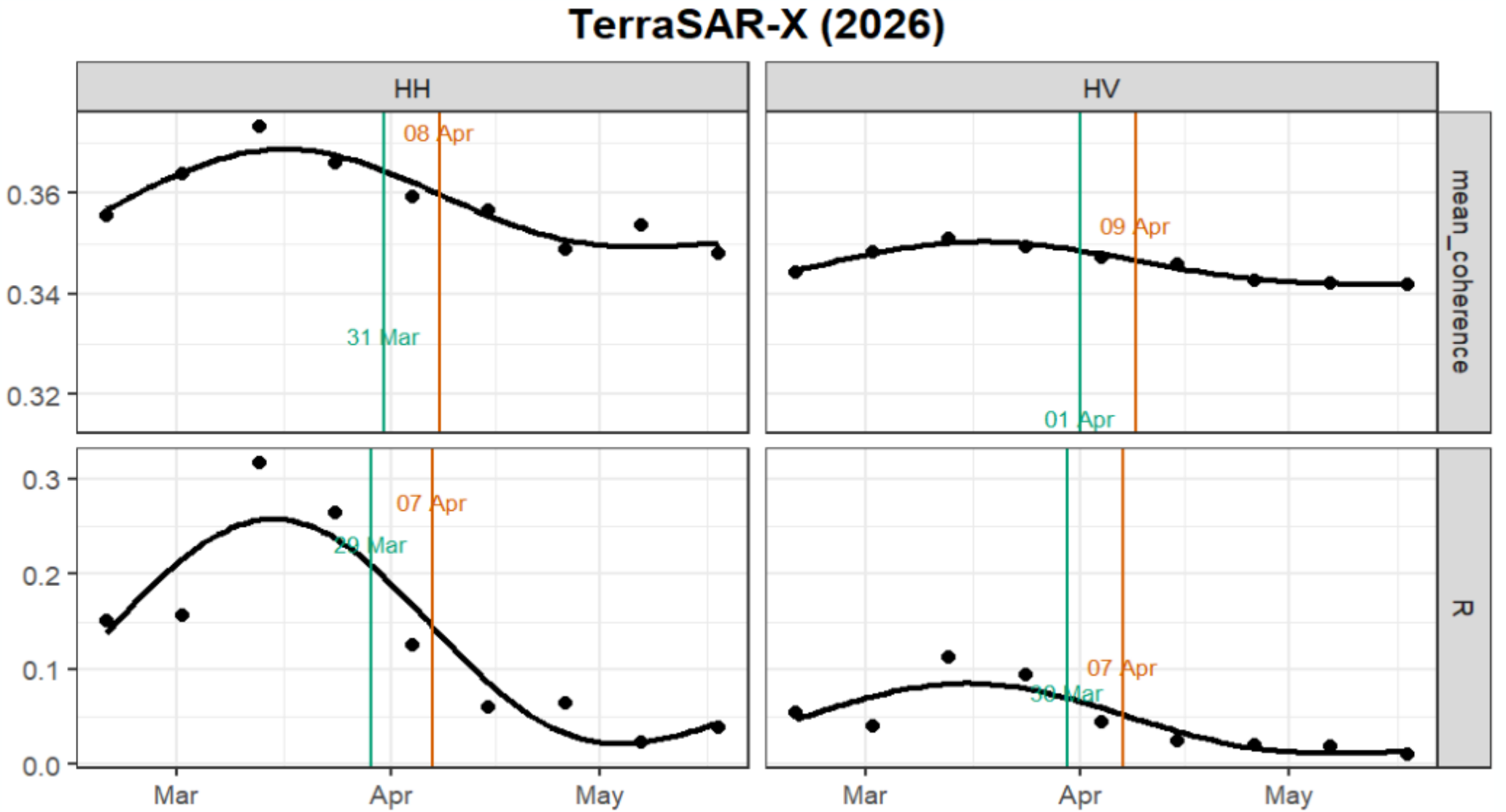
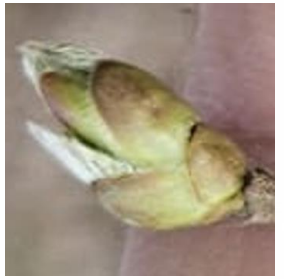


Comparison with ground observations
Evaluation of agreement in SOS dates

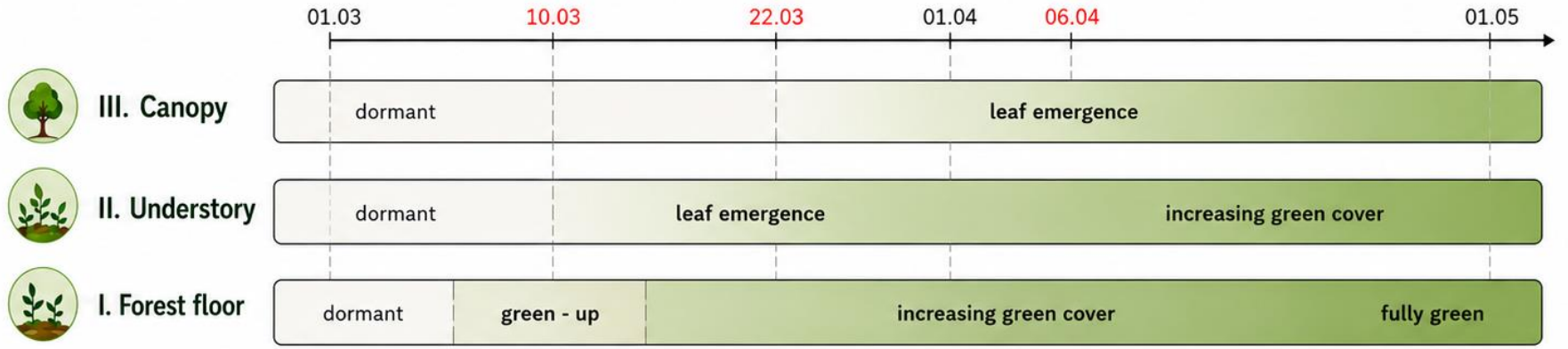
Comparison of SOS Estimates Across Sensors for 2026

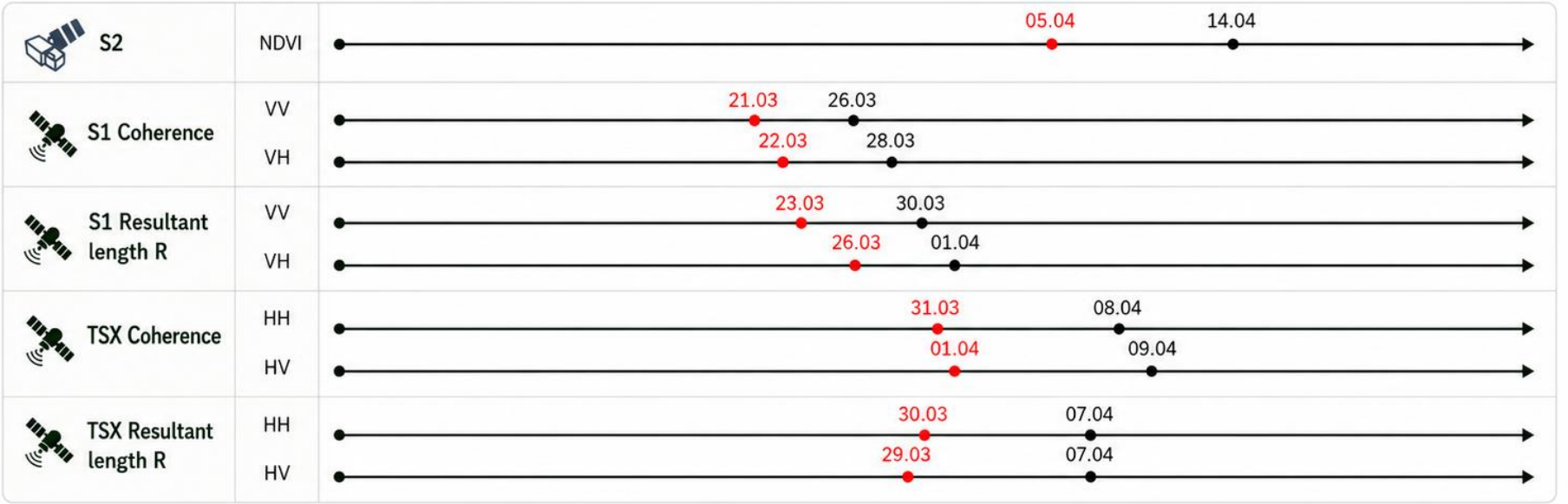
10.03


22.03

06.04



● Start of Season

26 March 2026

2 April 2026

CONCLUSIONS

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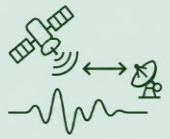
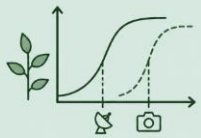
Spring phenology develops over a short time window, highlighting the importance of frequent observations

Coherence and resultant length revealed clear spring transitions in both Sentinel-1 and TerraSAR-X datasets

Similar SOS estimates were obtained across radar sensors, frequencies and metrics



Radar-derived SOS consistently occurred earlier than NDVI-based SOS



This earlier response suggests that SAR observations capture structural changes associated with early spring development before strong canopy greening becomes visible in optical data

Thank you for your attention! ☺

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