Mapping grassland age at a national scale using multidecadal satellite time series

Lukas Blickensdörfer[1,2], Tom Brög[1], Felix Lobert[1,2], Patrick Hostert[2,3], Stefan Erasmi[1]
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Klima-Fern Project:

Remote sensing of agricultural land use for enhanced climate reporting

With support from

Federal Ministry of Agriculture, Food and Regional Identity

by decision of the German Bundestag

StatEO 2026 – Frascati (Rome), Italy
06.05.2026

Importance of grassland history

- Grassland type and management intensity directly affect ecosystem function and service provision (Bengtsson et al., 2019)
- Grassland resilience, carbon storage or species composition develops within the initial 15-60 years (Ballesteros et al., 2024; Emde et al., 2024; Snoo et al., 2012; Wagg et al., 2022)
- Still, spatial explicit information on grassland age is rarely available

Objectives

What is the spatial distribution of grassland-age throughout Germany?

We define “grassland-age” as years since initial grassland establishment after land use (LU) change.

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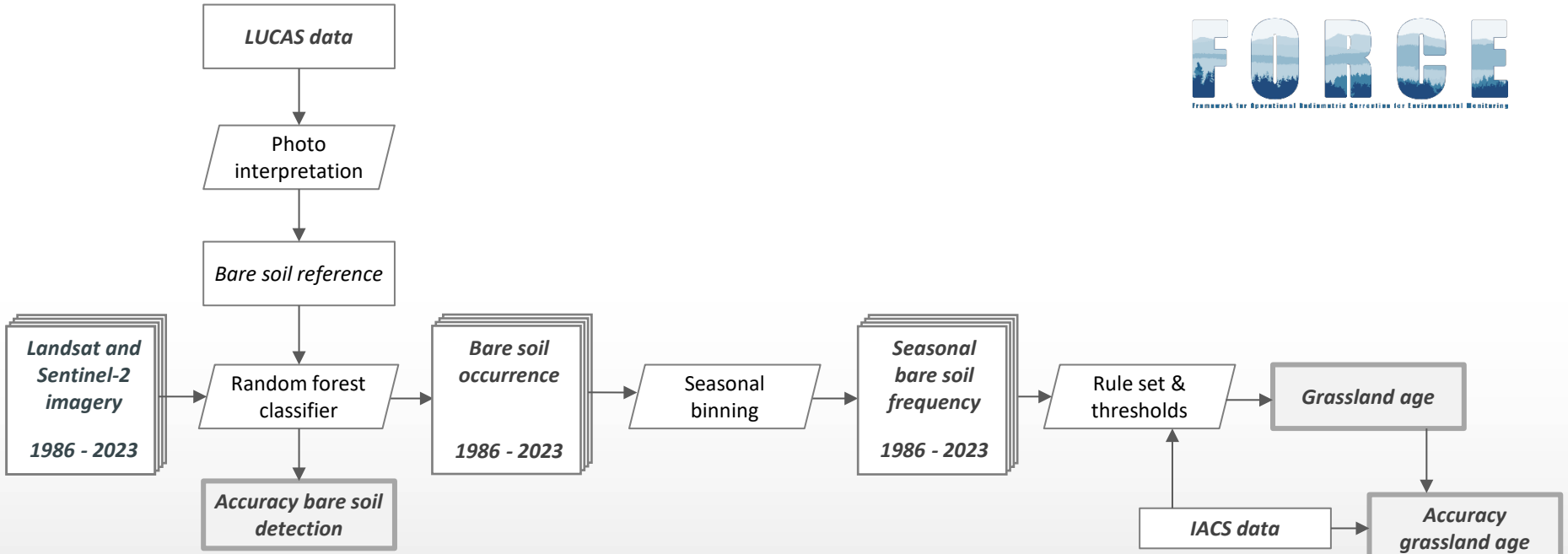
→ One approach is to go via the **detection of bare soil** to capture **grassland conversion**.

Workflow



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Workflow

Landsat and Sentinel-2 imagery

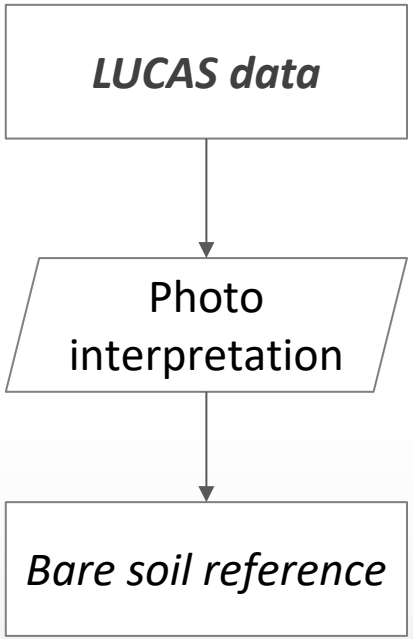
1986 - 2023

FORCE

Framework for Operational Radiometric Correction for Environmental Monitoring

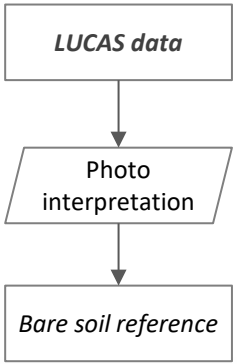
- **Landsat 5-9 and Sentinel-2 for 1986–2023**
- Preprocessed using FORCE (Fantz et al., 2019)
- Landsat adjusted to reflectance of Sentinel-2 following Okujeni et al. (2024)

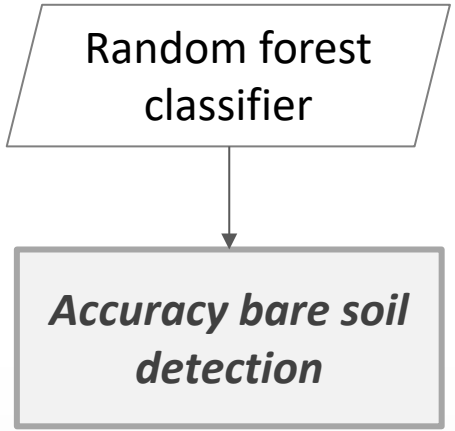
Workflow



Land **U**se and **C**over **A**rea frame **S**urvey 2006-2018 (d'Andrimont et al. 2020)

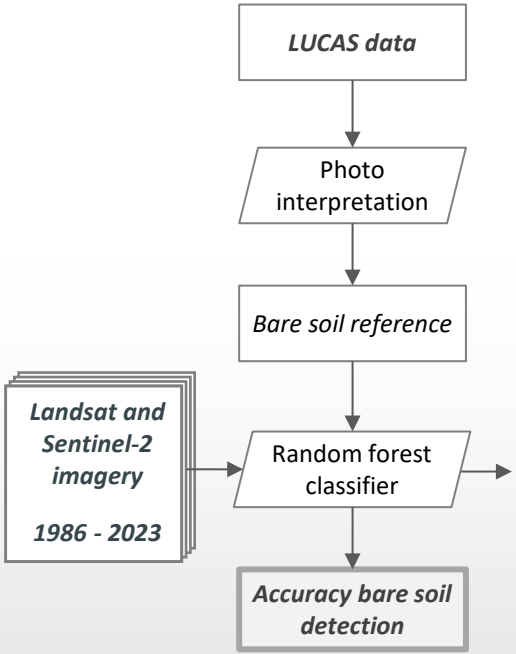
Workflow



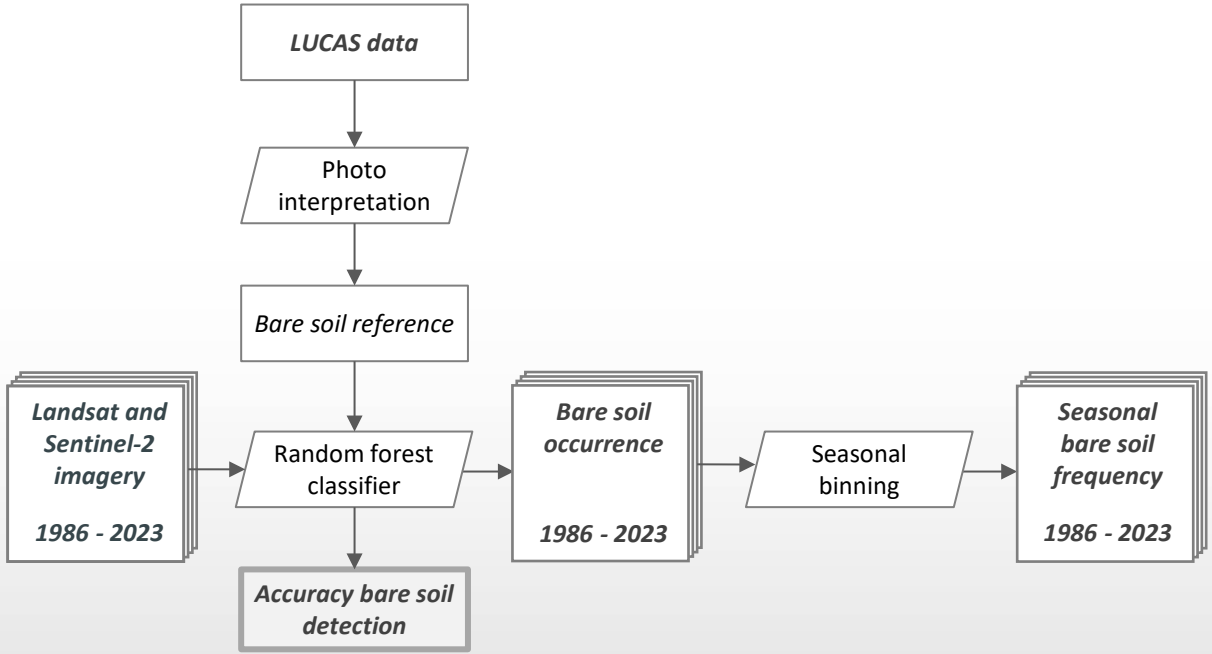


- Random forest model for bare soil detection on each clear sky observation
- Overall Accuracy: **91.87 ± 0.6%**

Workflow


LUCAS data
Photo interpretation
Bare soil reference
Landsat and Sentinel-2 imagery
1986 - 2023
Random forest classifier
Accuracy bare soil detection

Workflow



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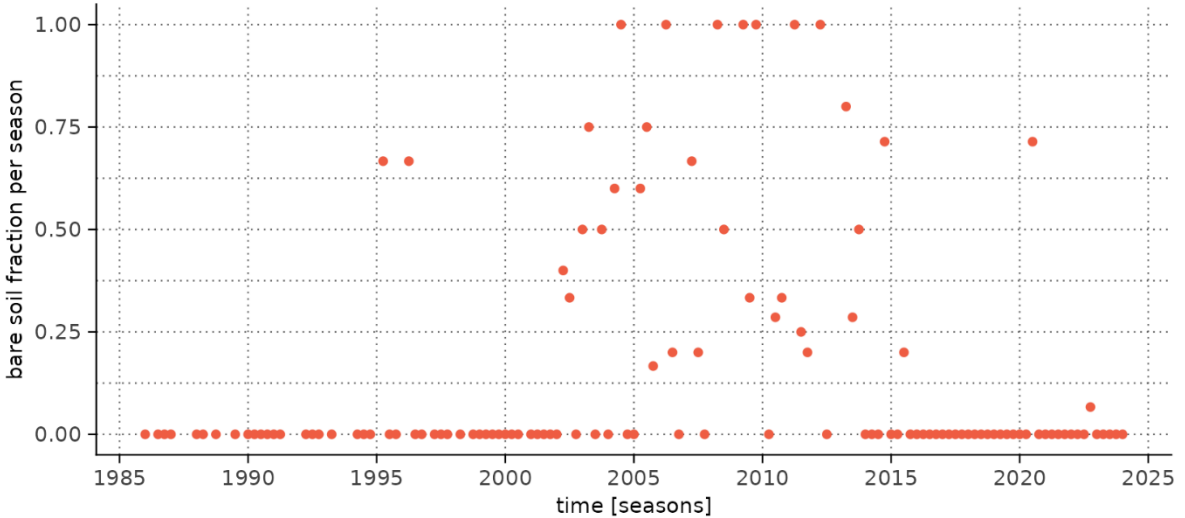
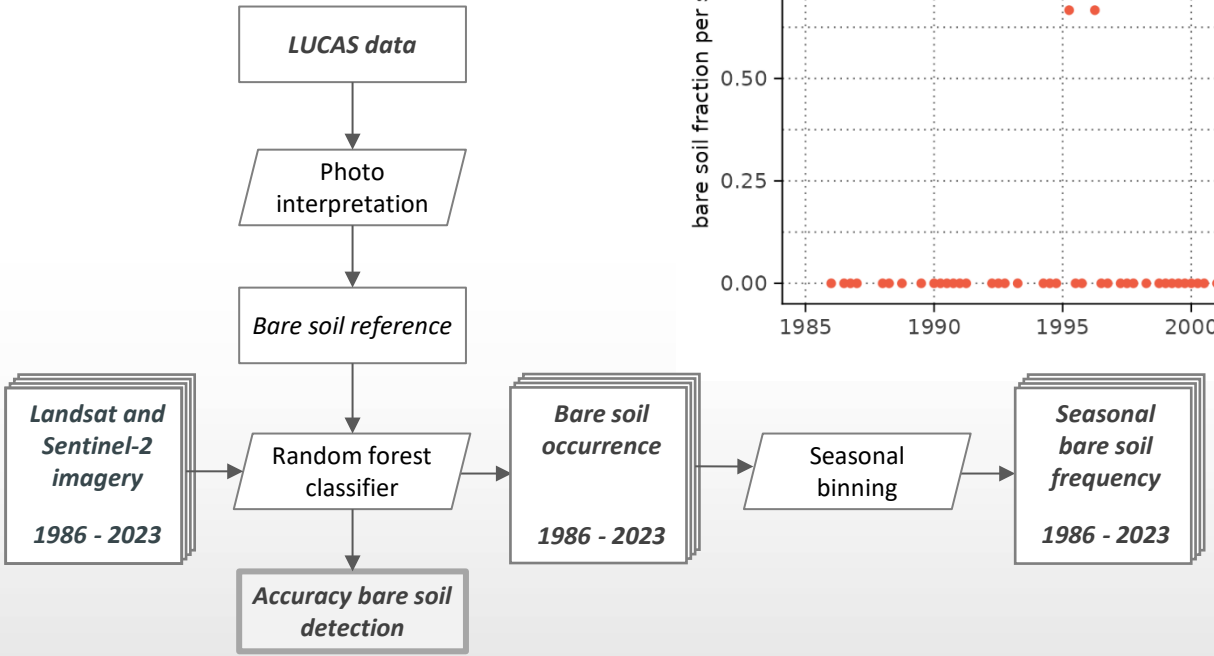
Workflow


1.00
0.75
0.50
0.25
0.00
bare soil fraction per season
1985
1990
1995
2000
2005
2010
2015
2020
2025
time [seasons]


LUCAS data
Photo interpretation
Bare soil reference
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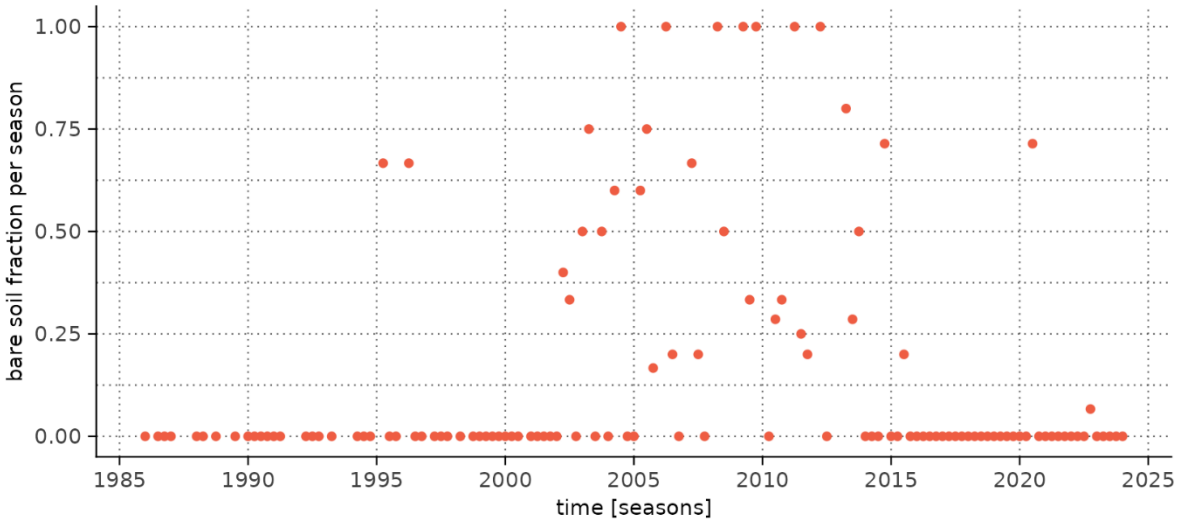
1986 - 2023
Random forest classifier
Accuracy bare soil detection
Bare soil occurrence
1986 - 2023
Seasonal binning
Seasonal bare soil frequency
1986 - 2023

Workflow



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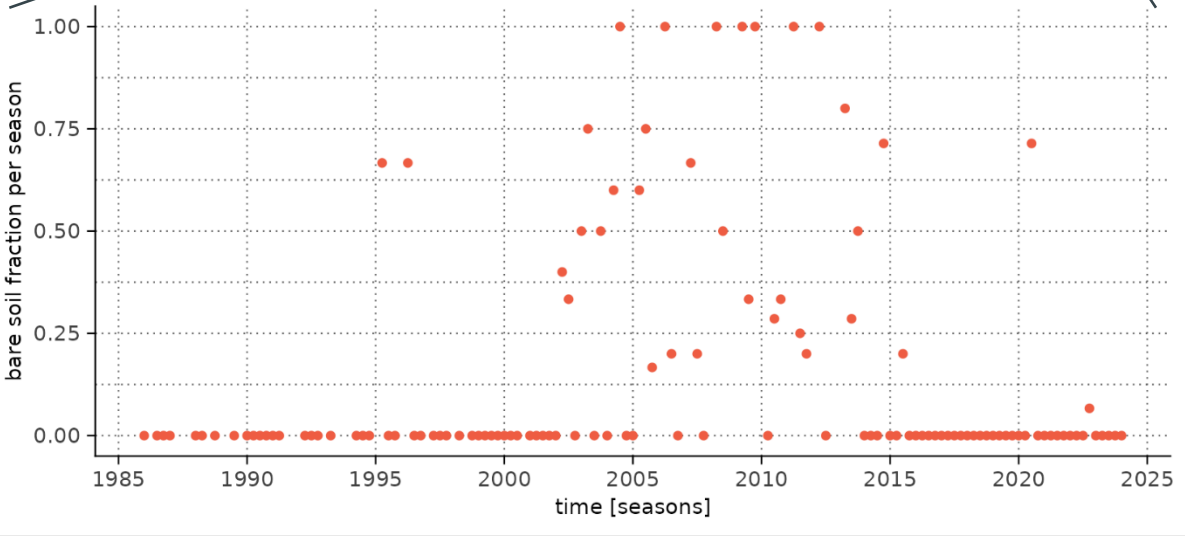
Age estimation

Rule-set to derive grassland age:



Age estimation

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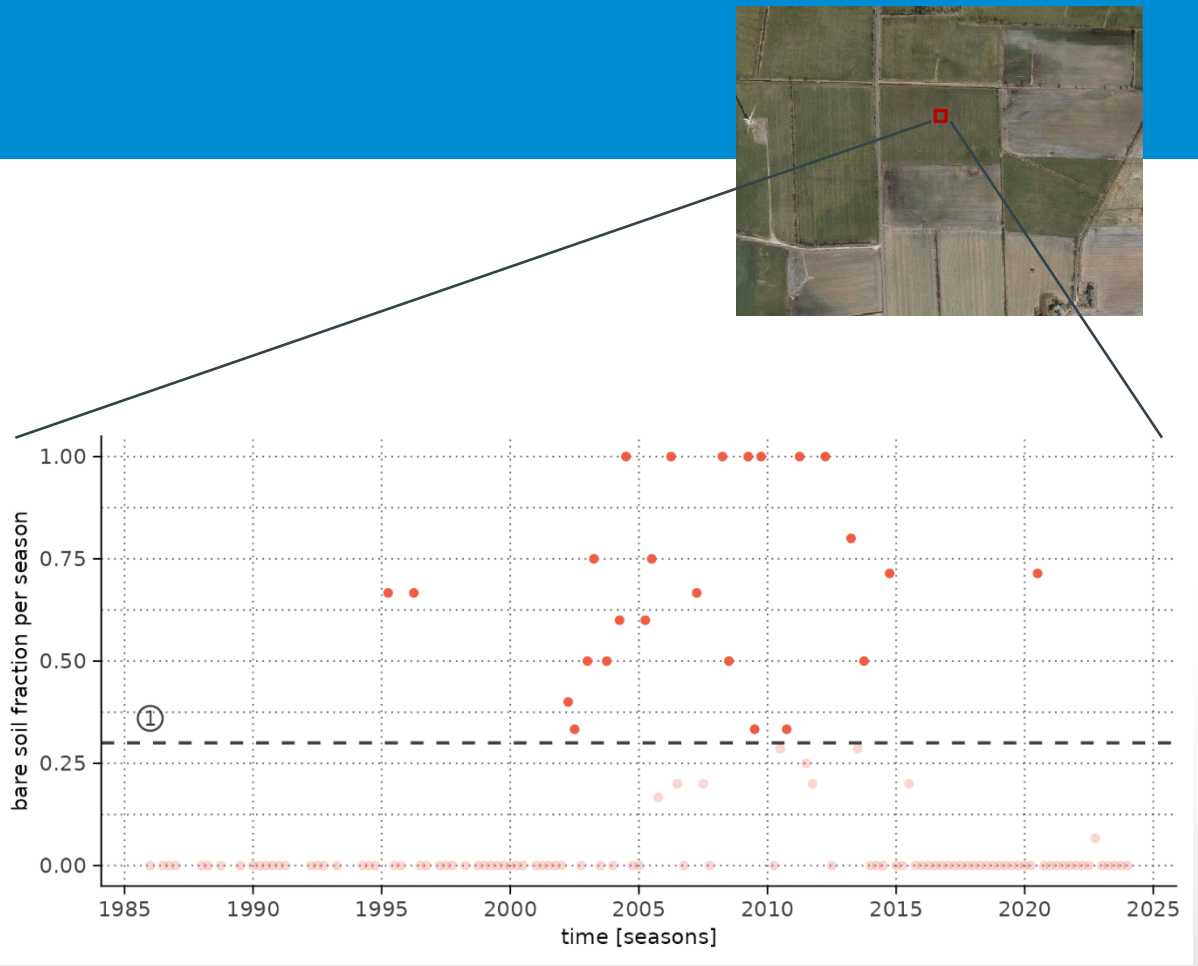

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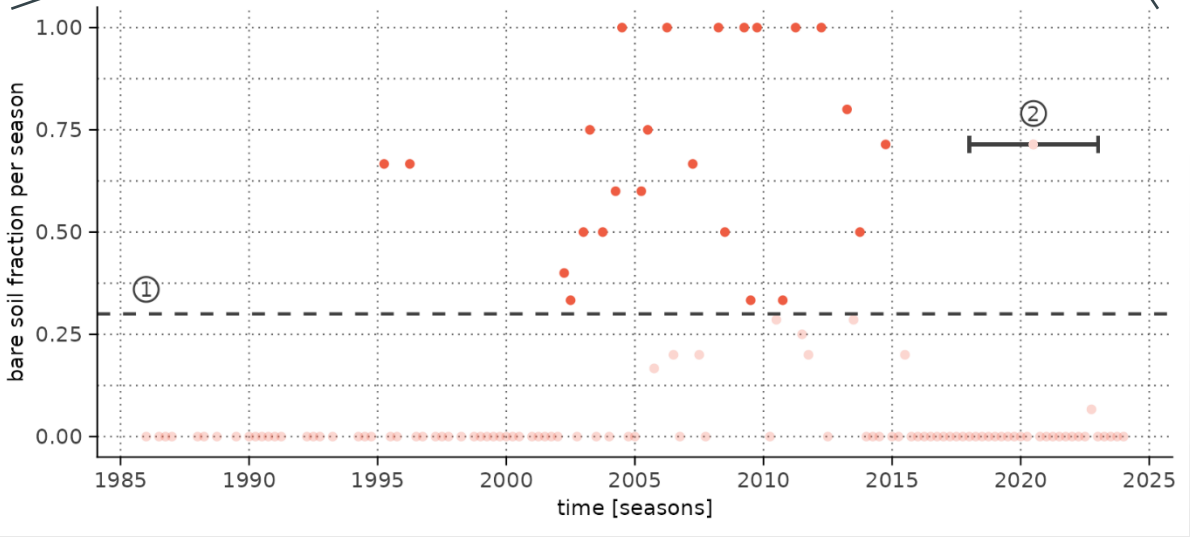
THÜNEN

Age estimation

Rule-set to derive grassland age:

1) Bare soil fraction threshold to **minimize noise**

2) **Exclude management events** by seasonal bare soil count in moving window



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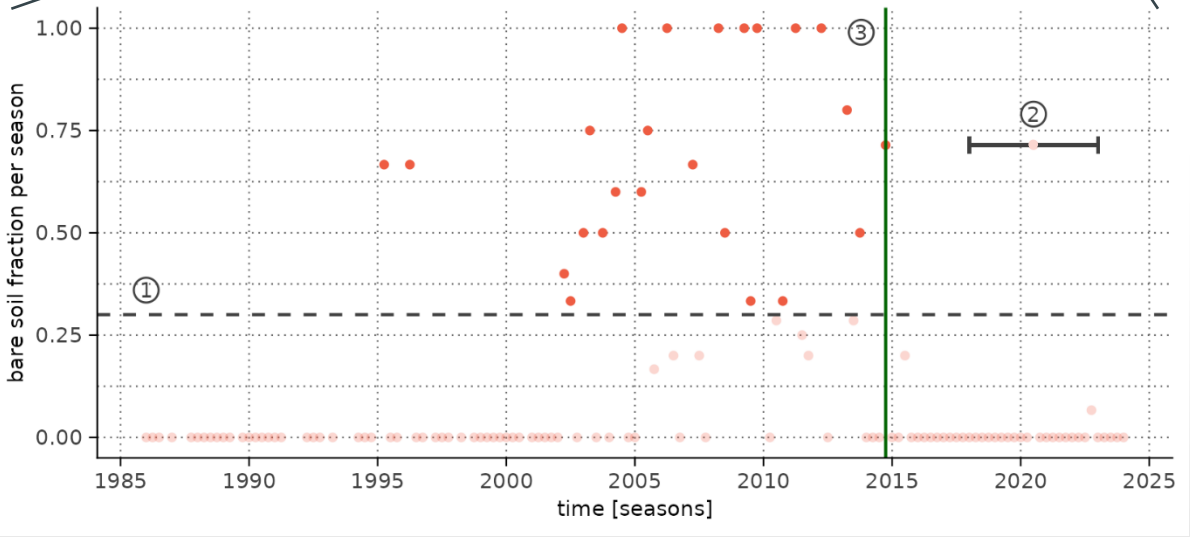
Age estimation

Rule-set to derive grassland age:

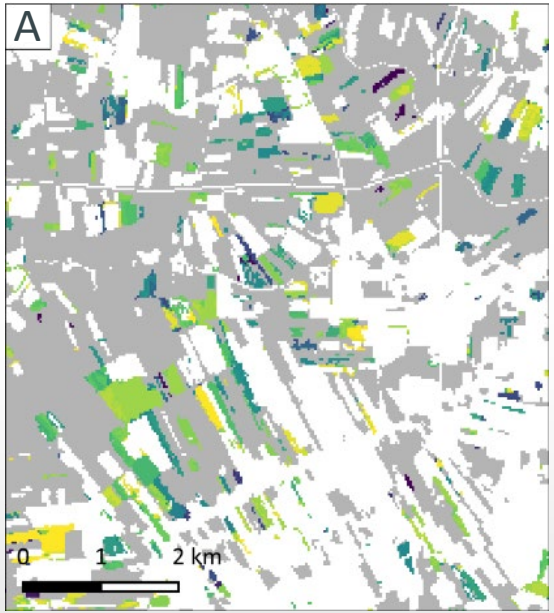
1) Bare soil fraction threshold to **minimize noise**
2) **Exclude management events** by seasonal bare soil count in moving window
3) **Assign grassland establishment** to last bare soil occurrence

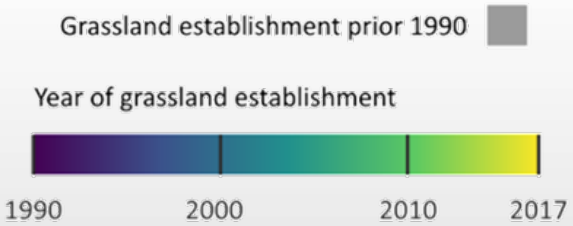
Rule-set parametrization empirically against up to 18 years of LPIS data



Grassland age accuracy

- Accuracy for the differentiation of persistent grassland and recent grassland: **99.21 ± 0.02%**
- F-score of recent grassland: **78.92 ± 0.64**





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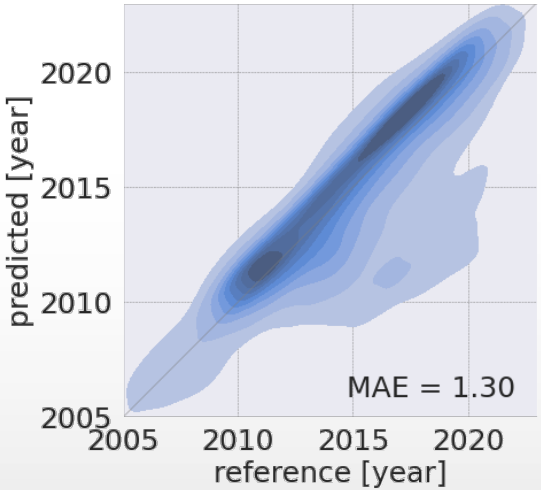
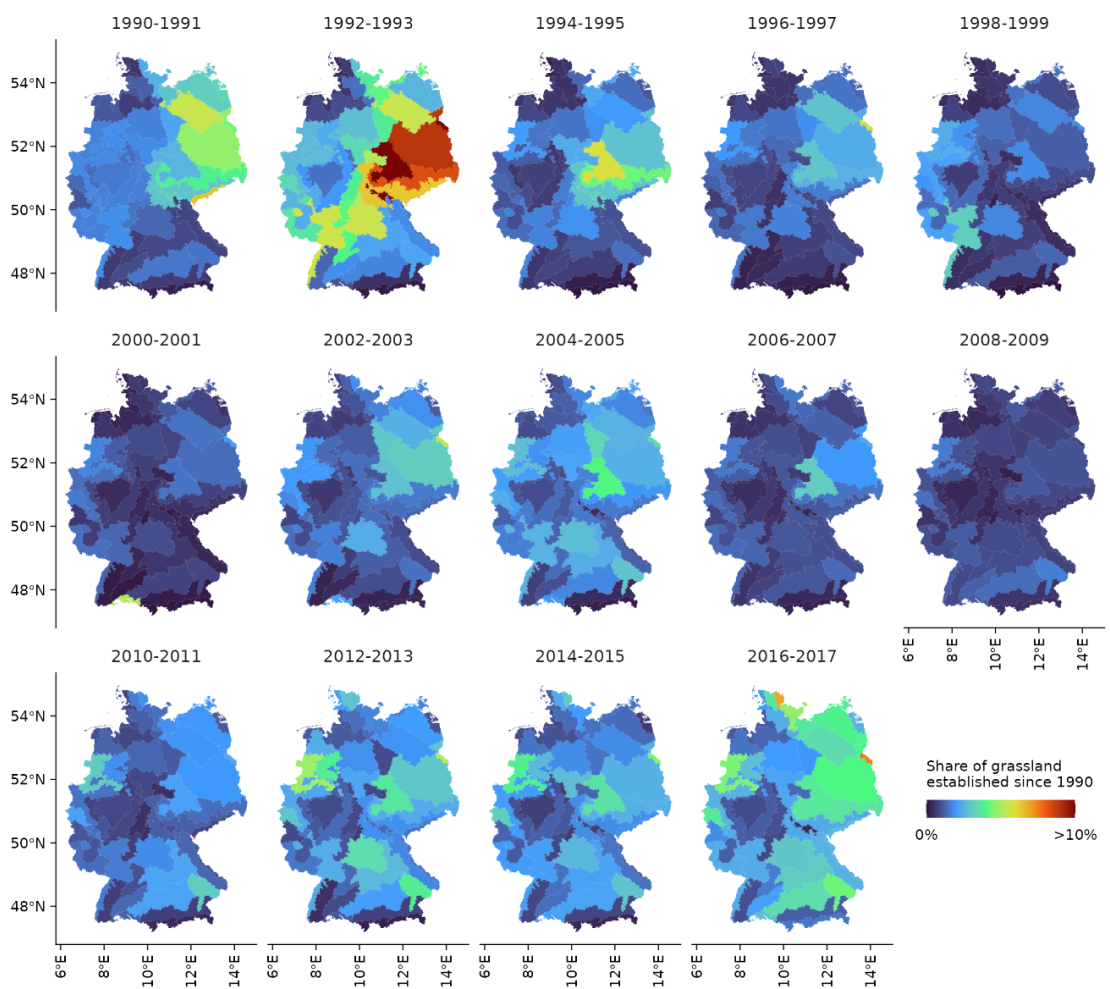


Large scale patterns



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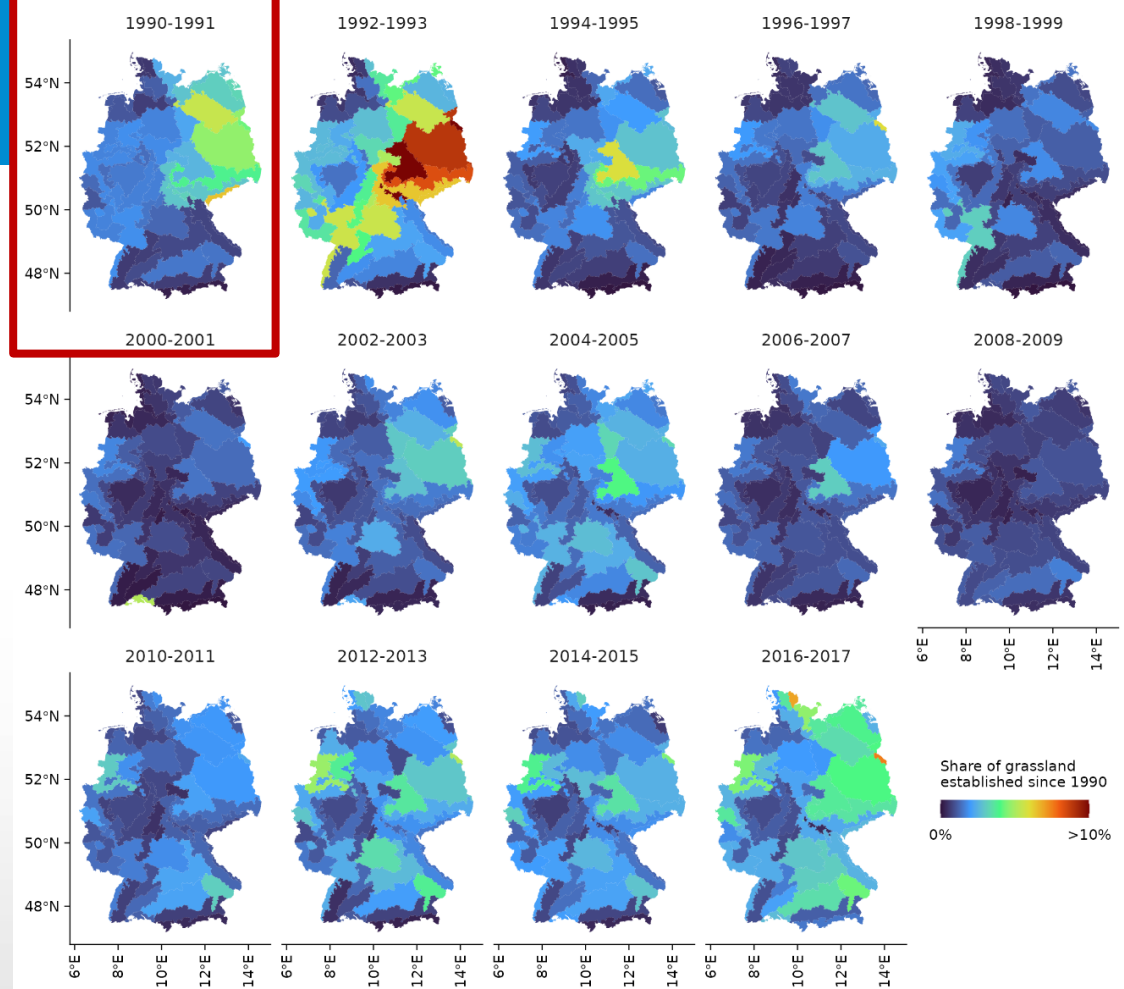
Large scale patterns

- 1990: higher rates of land abandonment/decline in harvested areas after the collapse of the GDR



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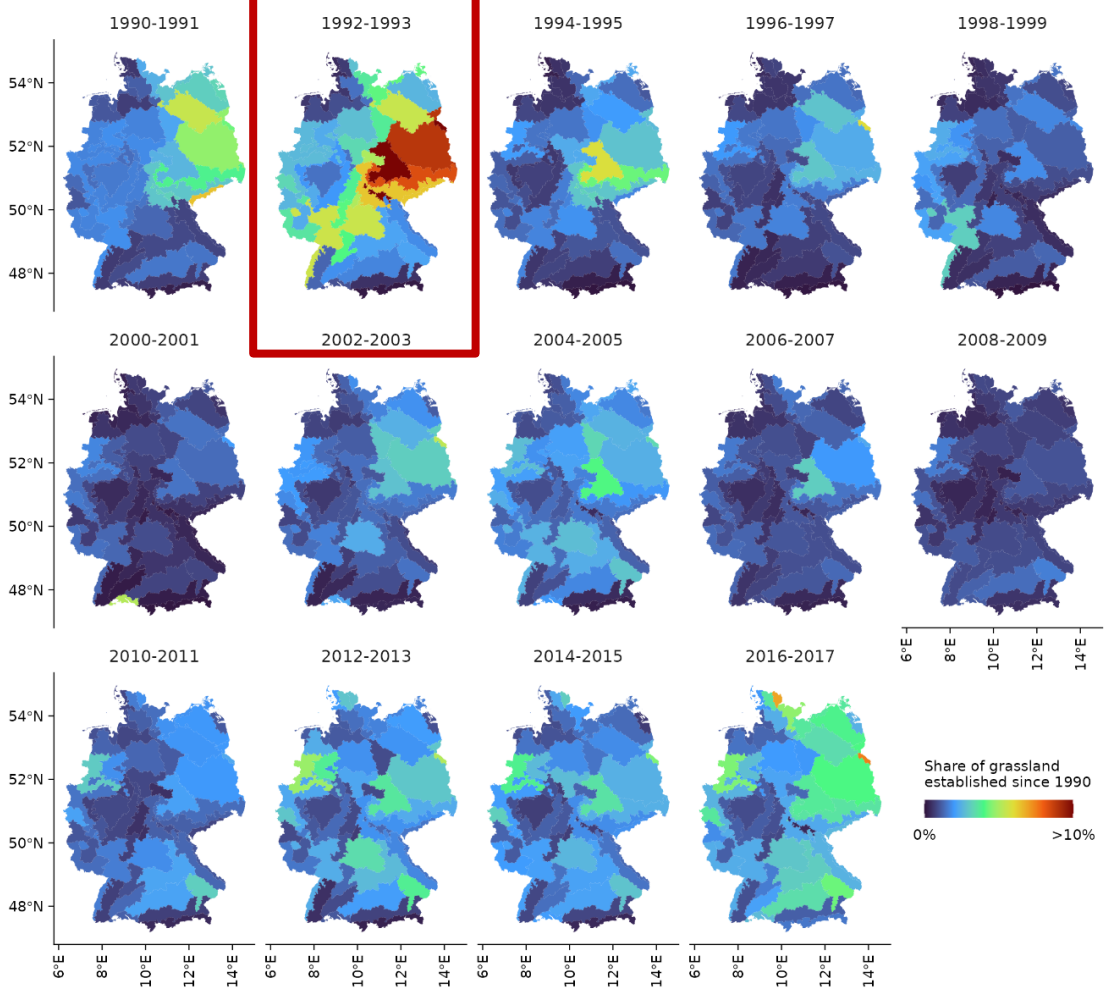
Large scale patterns

- 1990: higher rates of land abandonment/decline in harvested areas after the collapse of the GDR
- 1992: CAP McSharry-Reform, exclude arable land from intensive production



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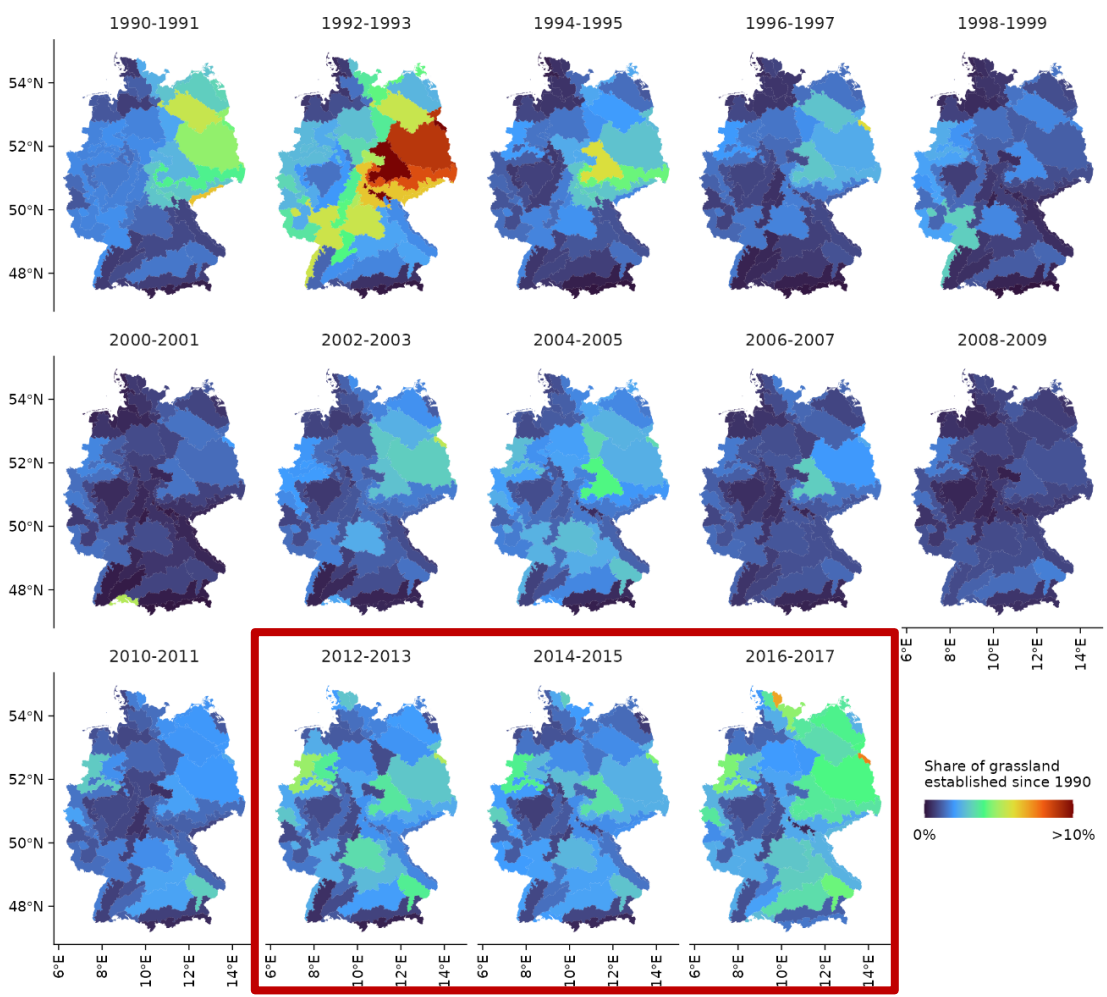
Large scale patterns

- 1990: higher rates of land abandonment/decline in harvested areas after the collapse of the GDR
- 1992: CAP McSharry-Reform, exclude arable land from intensive production
- 2013 CAP reform, measures to limit the conversion of grassland to arable land



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Limitations

- The accuracy of grassland age **estimates depends on clear-sky observations** before LU change
- Differentiating bare soil and vegetation land cover is crucial; highest error rates are expected in areas dominated by **non-photosynthetically active vegetation and dry soil**
- Approach **is focused on** grassland establishment within **the agricultural landscape**

Concluding:

- High accuracy and spatial consistency, even in observation-sparse periods
  - ➢ **Potential data for climate reporting from 1990 onwards**

- Distinct spatial and temporal grassland age patterns
  - ➢ **Spatially explicit data important**

- Extendable to soil management events
  - ➢ **Reliable reference data needed**

Looking forward to discussions!
Feel free to get in touch:

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Thünen Institute of Farm Economics; Humboldt-Universität zu Berlin

www.thuenen.de/theo

References

Azzari, G., Grassini, P., Edreira, J.I.R., Conley, S., Mourtzinis, S., Lobell, D.B., 2019. Satellite mapping of tillage practices in the North Central US region from 2005 to 2016. Remote Sens. Environ. 221, 417–429. https://doi.org/10.1016/j.rse.2018.11.010.

d'Andrimont, R., Yordanov, M., Martinez-Sanchez, L., Eiselt, B., Palmieri, A., Dominici, P., Gallego, J., Reuter, H.I., Joebges, C., Lemoine, G., van der Velde, M., 2020. Harmonised LUCAS in-situ land cover and use database for field surveys from 2006 to 2018 in the European Union. Sci. Data 7, 352. https://doi.org/10.1038/s41597-020-00675-z.

d'Andrimont, R., Yordanov, M., Martinez-Sanchez, L., Haub, P., Buck, O., Haub, C., Eiselt, B., van der Velde, M., 2022. LUCAS cover photos 2006–2018 over the EU: 874 646 spatially distributed geo-tagged close-up photos with land cover and plant species label. Earth System Science Data, 14, 4463–4472. https://dx.doi.org/10.5194/essd-14-4463-2022.

Frantz, D., 2019. FORCE—Landsat + Sentinel-2 Analysis Ready Data and Beyond. Remote Sens. 11, 1124. https://doi.org/10.3390/rs11091124.

Okujeni, A., Kowalski, K., Lewińska, K.E., Schneidereit, S., Hostert, P., 2024. Multidecadal grassland fractional cover time series retrieval for Germany from the Landsat and Sentinel-2 archives. Remote Sens. Environ. 302, 113980. https://doi.org/10.1016/j.rse.2023.113980.

Klima-Fern Project

Gefördert durch:

Bundesministerium für Ernährung und Landwirtschaft

aufgrund eines Beschlusses des Deutschen Bundestages

Remote sensing of agricultural land use for enhanced climate reporting

SP1: Humus retention and build-up in arable land

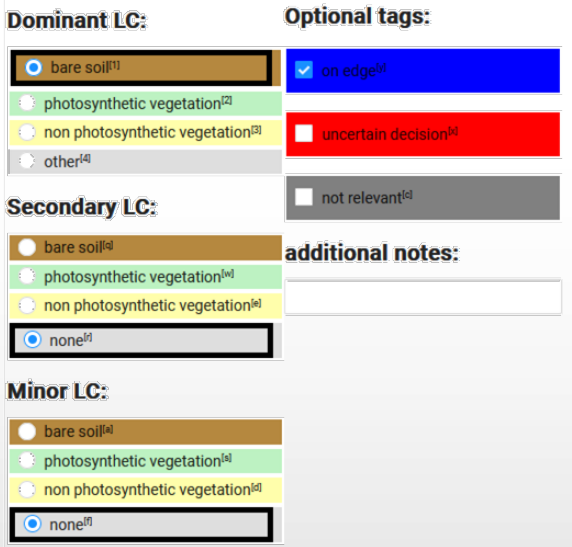
SP2: Conservation of permanent grassland

SP3: Soil carbon content in arable land

Reference data - LUCAS

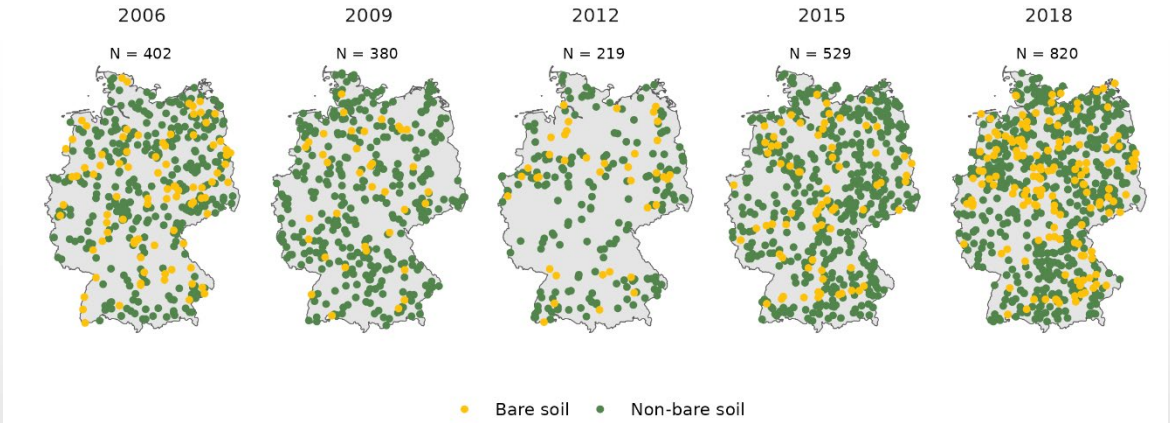
Land Use and Cover Area frame Survey (LUCAS)

- 2006, 2009, 2012, 2015, 2018
- Based on systematic sampling grid and harmonized (d'Andrimont et al. 2020)
- Systematic photo collection of survey point (d'Andrimont et al. 2022)



Reference data - LUCAS

- Random sample of 2.500 survey plots with landscape photo
  - Grassland and Cropland land cover type
  - Clear sky observation within 2 weeks of survey date



Sentinel-2 and Landsat data

- **Landsat 5-9 and Sentinel-2 for 1986–2023**
- Preprocessed using FORCE (Fantz et al., 2019)
- Landsat adjusted to reflectance of Sentinel-2 following Okujeni et al. (2024)
- Feature selection following Azzari et al. (2019)

→ Random forest model for bare soil detection on each clear sky observation

Indices	Formula	Source
NBR2	$(SWIR1 - SWIR2)/(SWIR1 + SWIR2)$	Broeg et al. (2024), Zepp et al. (2023), Azzari et al. (2019), Sorenson et al. (2021)
NDVI	$(NIR - RED)/(NIR + RED)$	Broeg et al. (2024), Sorenson et al. (2021), Mzid et al. (2021)
BCC	$BLUE/(RED + GREEN + BLUE)$	Broeg et al. (2024)
RG_diff	$RED - GREEN$	Broeg et al. (2024)
NDWI	$(GREEN - NIR)/(GREEN + NIR)$	Sorenson et al. (2021)
NDI7	$(NIR - SWIR2)/(NIR + SWIR2)$	Sorenson et al. (2021), Azzari et al. (2019)
PV_BLUE	$((NIR - RED)/(NIR + RED)) + ((NIR - BLUE)/(NIR + BLUE))$	Zepp et al. (2023)
PV_IR2	$((NIR - RED)/(NIR + RED)) + ((NIR - SWIR2)/(NIR + SWIR2))$	Zepp et al. (2023)
BSI	$((SWIR1 + RED) - (NIR + BLUE))/((SWIR1 + RED) + (NIR + BLUE))$	Mzid et al. (2021)
EVI	$2.5 * (NIR - RED)/(NIR + 6 * RED - 7.5 * BLUE + 1)$	Azzari et al. (2019)
GCVI	$(NIR/GREEN) - 1$	Azzari et al. (2019)
NDI5	$(NIR - SWIR1)/(NIR + SWIR1)$	Azzari et al. (2019)
CRC	$(SWIR1 - GREEN)/(SWIR1 + GREEN)$	Azzari et al. (2019)
STI	$SWIR1/SWIR2$	Azzari et al. (2019)

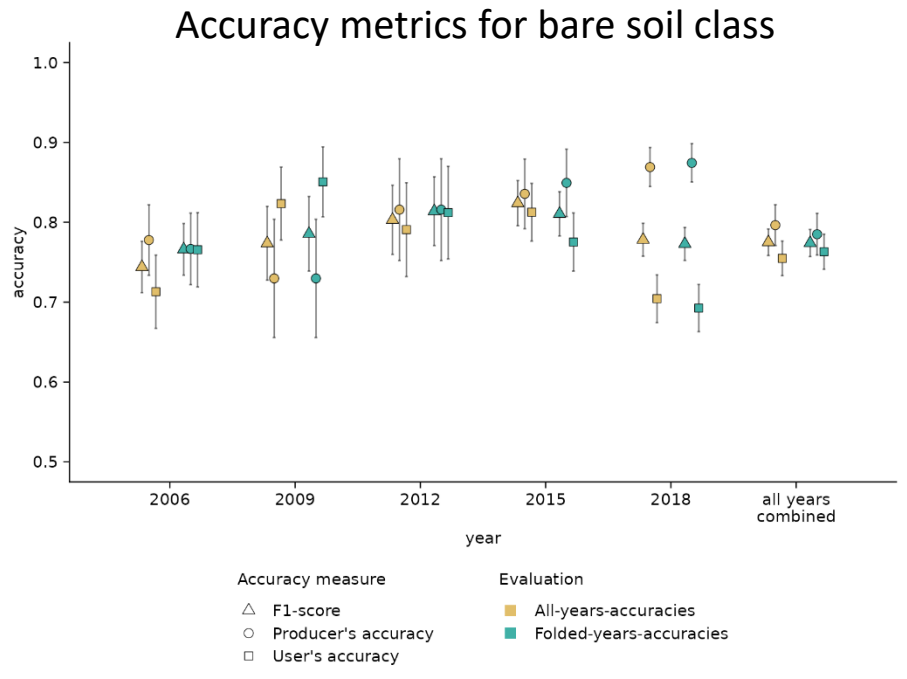
Results – Quality of Bare Soil Detection

Final features:

NBR2, RG_diff, NDWI, and NDI5

Overall Accuracy: 92.34 ± 0.6%

Overall Accuracy – folded: 91.87 ± 0.6%



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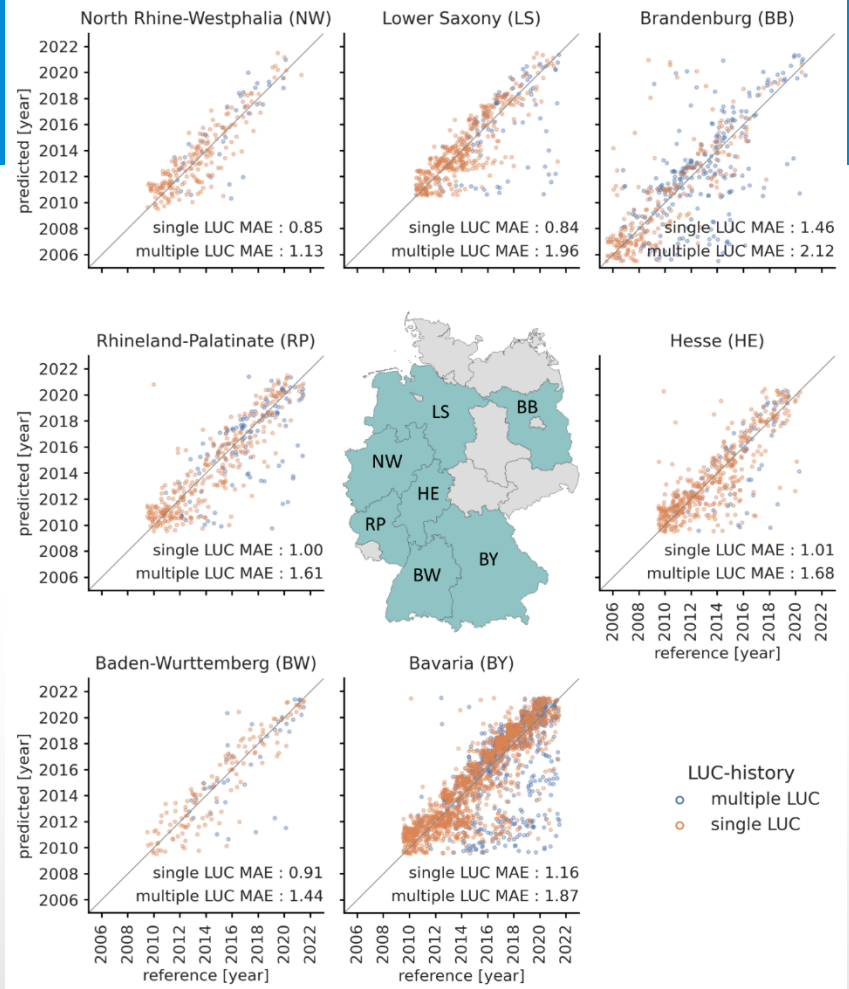

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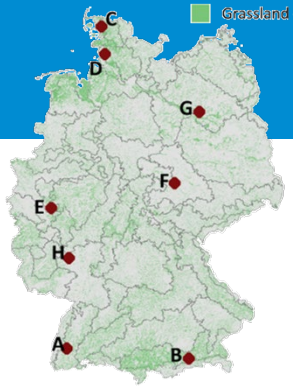
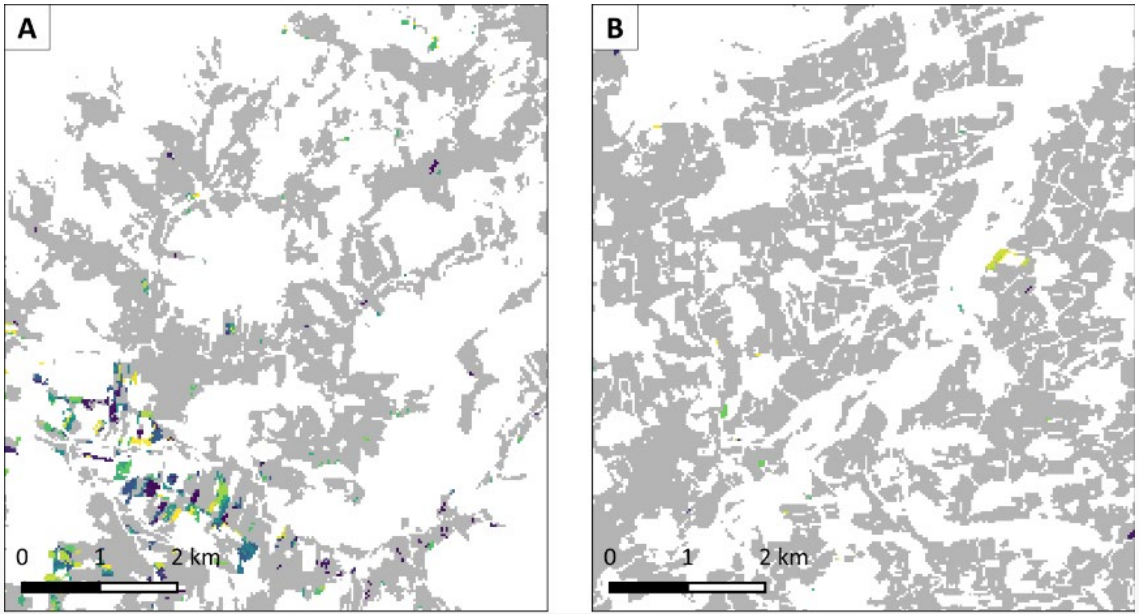
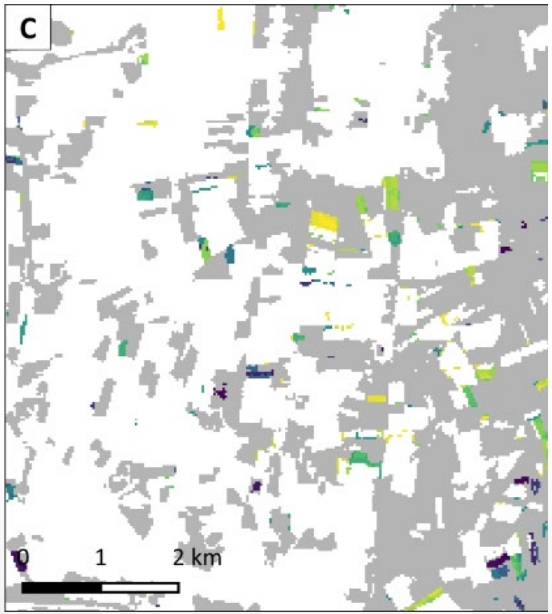
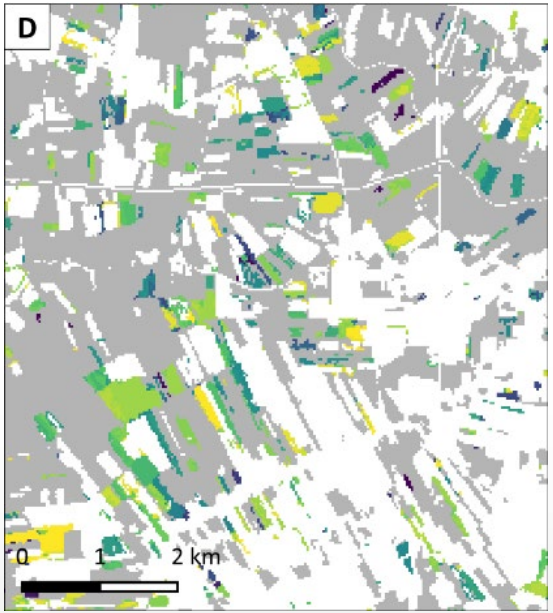
Mountainous landscape

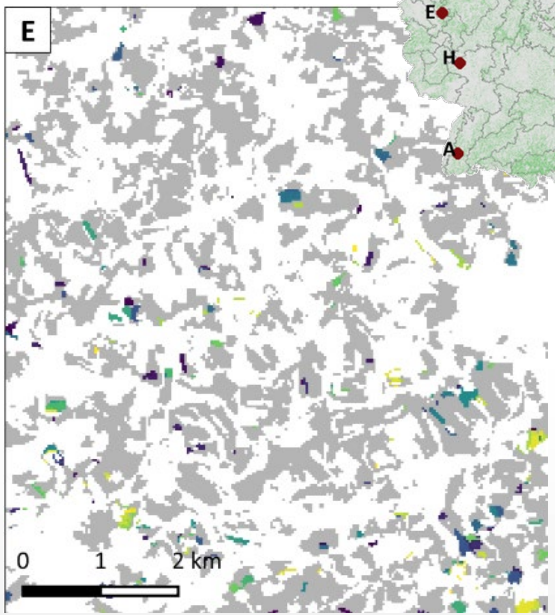


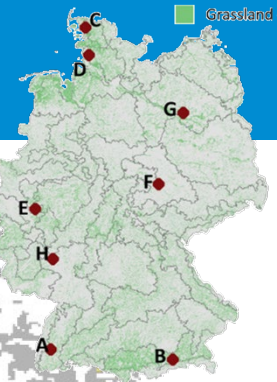


Costal + low-lying landscape







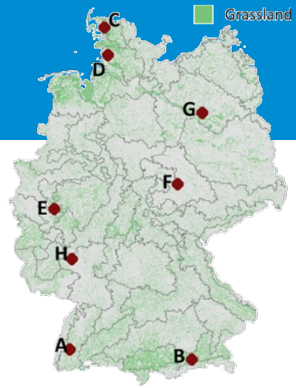


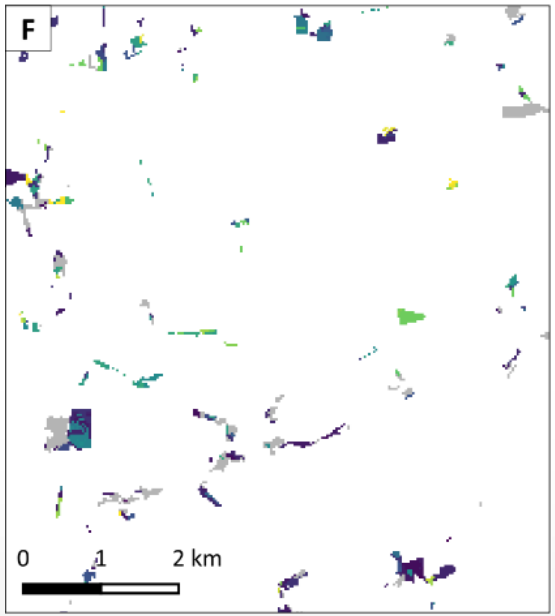
Grassland establishment prior 1990

Year of grassland establishment

1990 2000 2010 2017

Cropland dominated region





Year of grassland establishment

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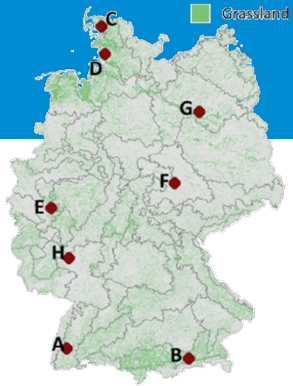
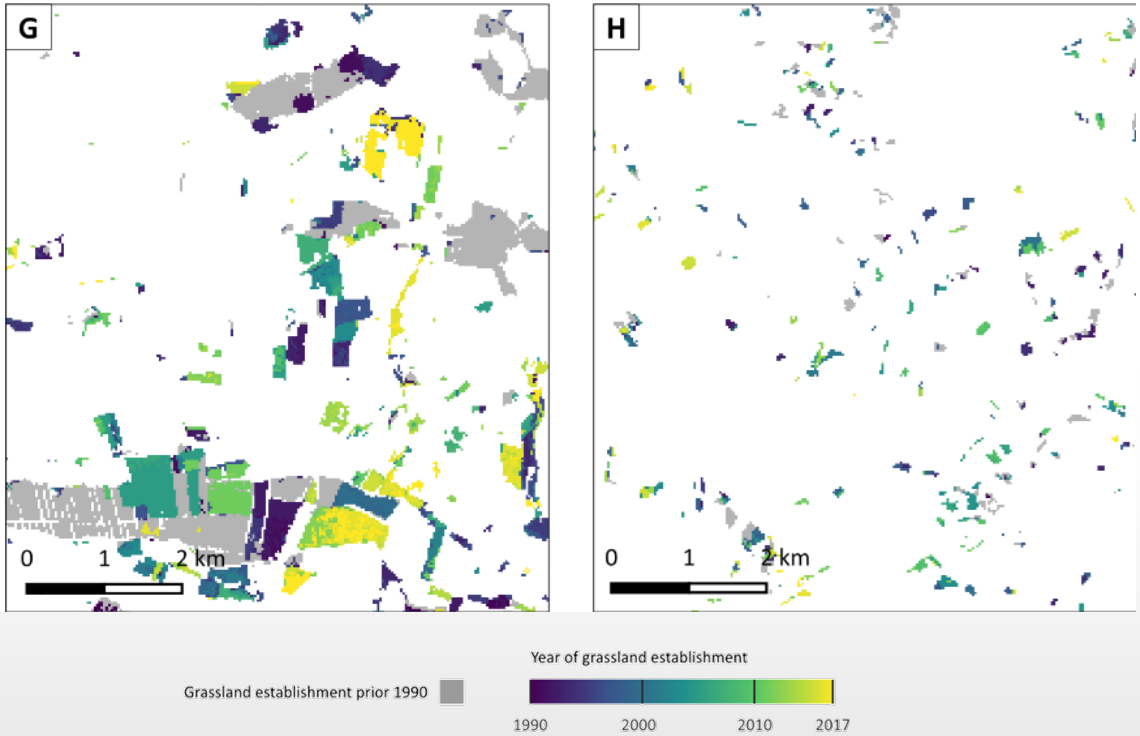
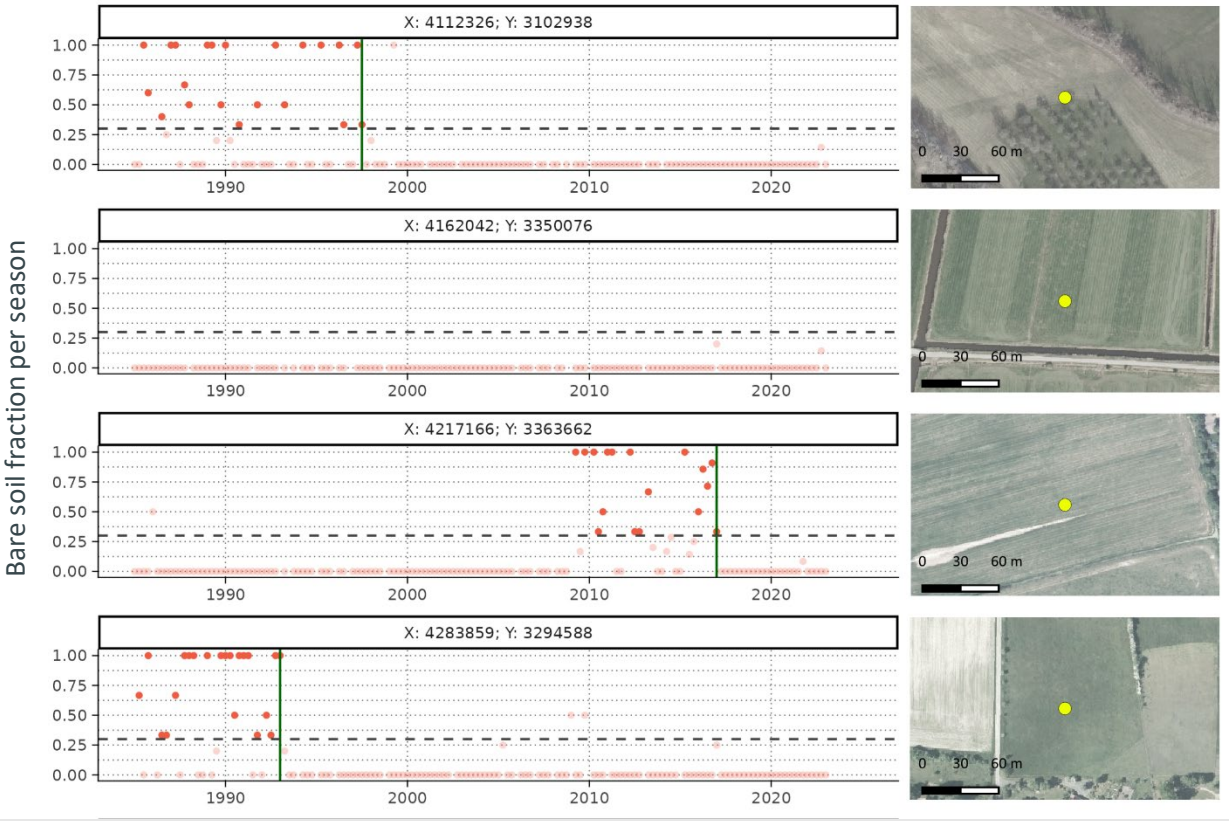
Regions with variable field sizes







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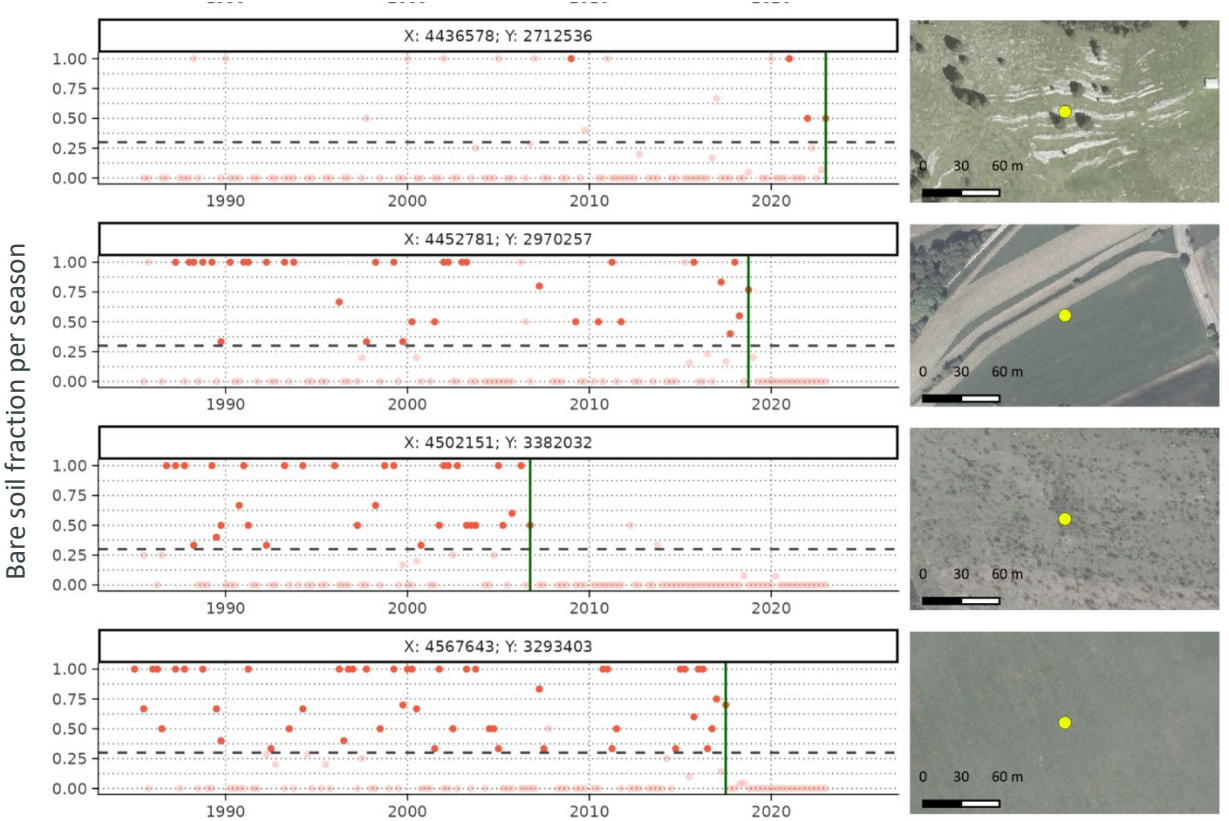
Bare soil fraction per season
X: 4436578; Y: 2712536
X: 4452781; Y: 2970257
X: 4502151; Y: 3382032
X: 4567643; Y: 3293403
1.00
0.75
0.50
0.25
0.00
1990
2000
2010
2020
0 30 60 m

IACS reference data

Federal state	Years	IACS-training sample *Grassland persistent/recent*	IACS-validation sample *Grassland persistent/recent*
Brandenburg	2006–2022	72,910 / 3,951	31,247 / 1,693
Baden-Wurttemberg	2010–2022	81,500 / 1,180	34,929 / 506
Bavaria	2010–2022	324,210 / 9,660	138,947 / 4,140
Hesse	2010–2021	127,609 / 3,602	54,690 / 1,544
Lower Saxony	2011–2022	110,073 / 2,055	47,174 / 880
North Rhine-Westphalia	2010–2022	68,267 / 1,250	29,257 / 536
Rhineland-Palatinate	2010–2022	52,064 / 3,270	22,313 / 1,402

Data availability

	1986-1998	1999-2011	2012	2013-2014	2015-2016	2017-2020	2021-2023
Satellite	Landsat 5	Landsat 5 Landsat 7	Landsat 7	Landsat 7 Landsat 8	Landsat 7 Landsat 8 Sentinel-2A	Landsat 7 Landsat 8 Sentinel-2A Sentinel-2B	Landsat 8 Landsat 9 Sentinel-2A Sentinel-2B
∅ CSO-count:							
Dez. - Feb.	0.6	0.9	0.2	1.2	1.9	5.1	5.2
Mar. - May	2.3	3.6	2.4	3.6	6.4	14.1	15.9
Jun. - Aug.	2.9	4.1	1.4	5.5	9.3	14.6	16.5
Sep. - Nov.	1.7	3.4	1.9	2.8	6.6	10.7	10.9

Results – Grassland Sod-Renewal/Tillage