

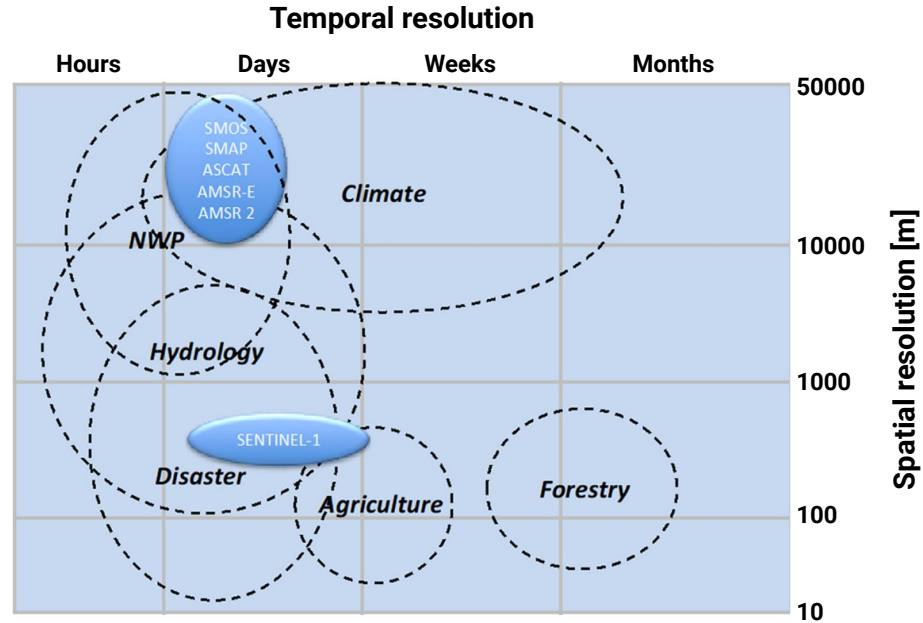
# Gridded Profile Soil Moisture Through Artificial Intelligence

Emulating profile soil moisture from cosmic-ray neutron sensing  
using covariates from high-resolution remote sensing

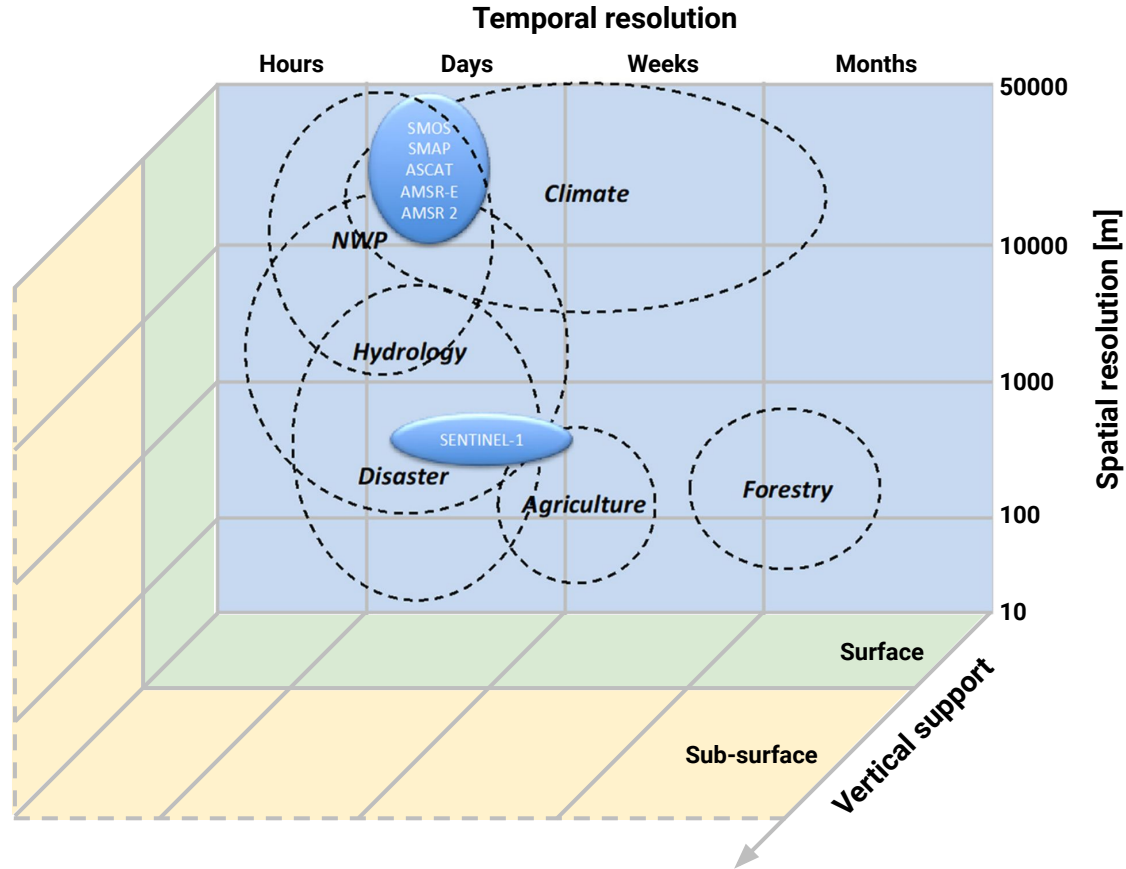
Toni Schmidt, Martin Schrön, Steffen Zacharias, Jian Peng

28 September 2023

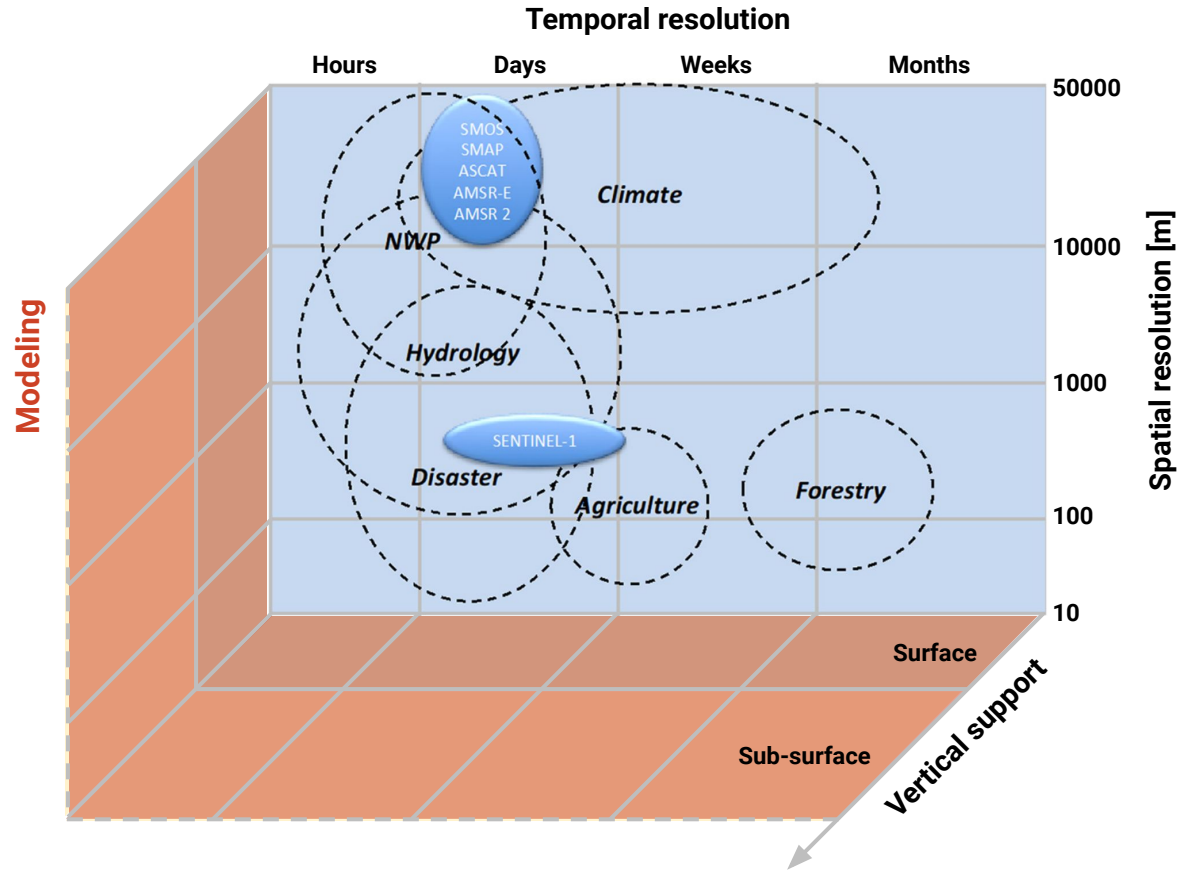
# Applicability of remote sensing soil moisture products



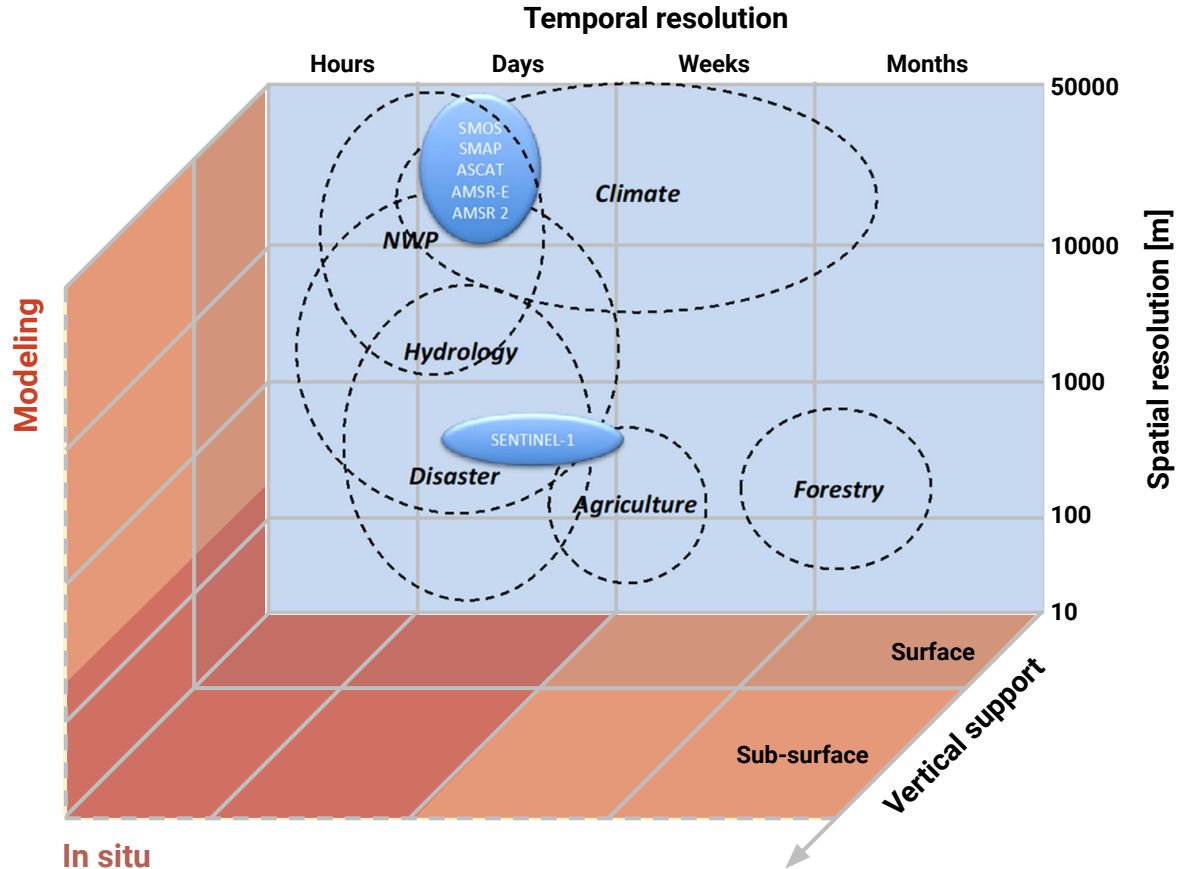
# Soil moisture products have different vertical supports



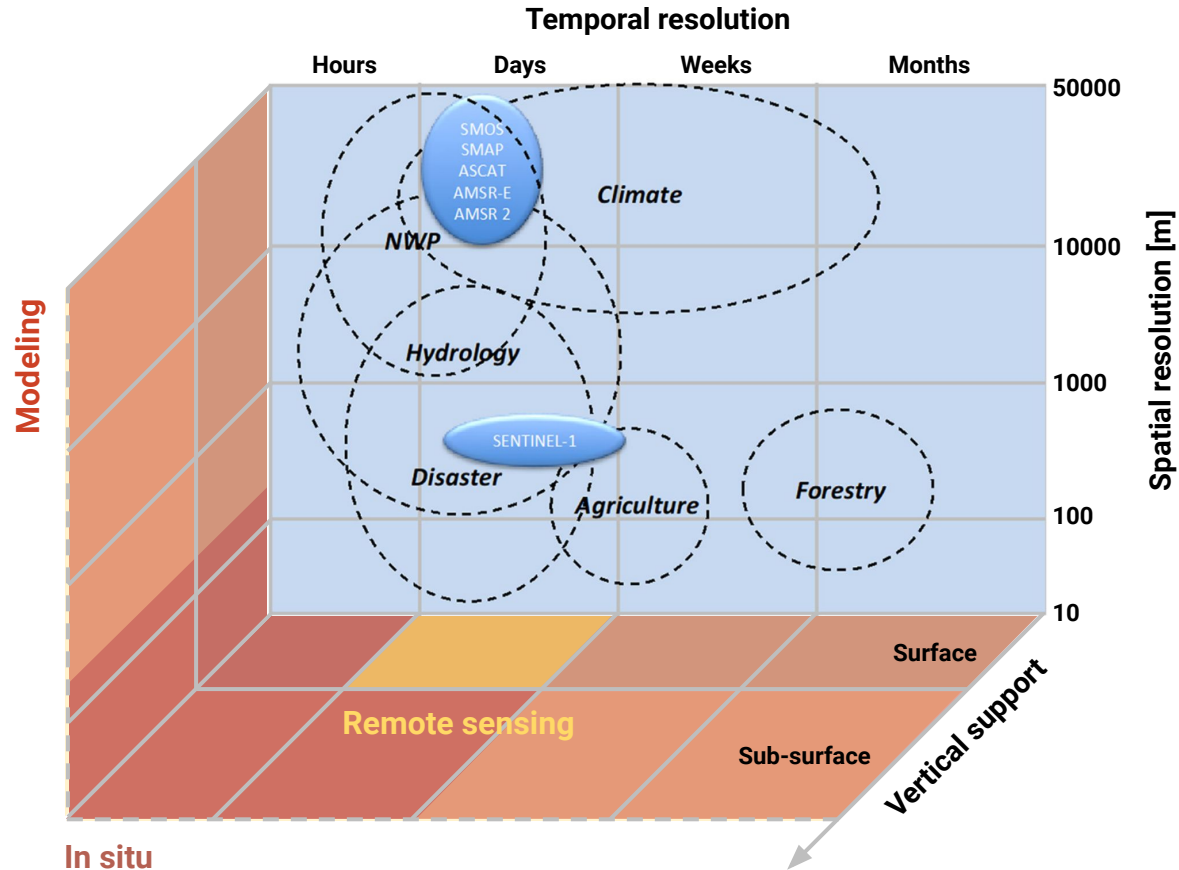
# Models can cover the entire dimensional space



# In-situ methods can have a deep vertical support



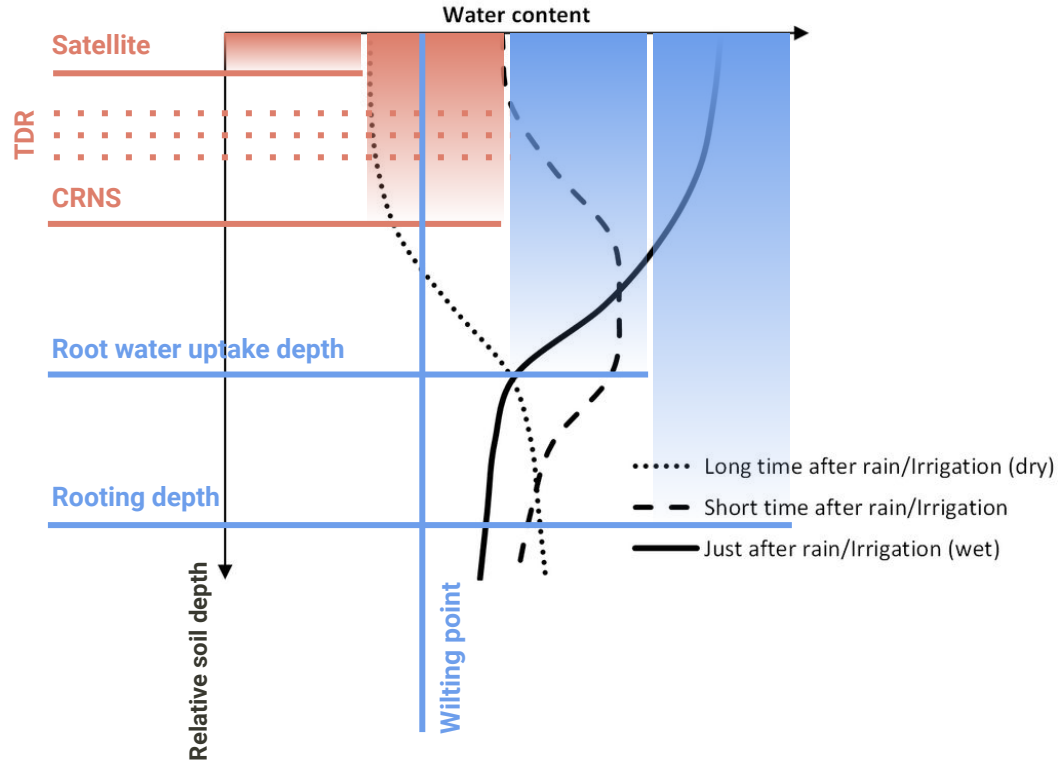
# Remote sensing soil moisture has a shallow support



# All applications benefit from a deeper vertical support

Application	Usage	Accuracy	Soil moisture depth	Temporal resolution	Other
NWP	Assimilation of soil moisture or low-frequency microwave brightness temperature into NWP system	Accurate temporal dynamics	Surface and root zone	Daily or sub-daily	Reliable near real-time products
Climate	Evaluation of model performance and investigation of land-atmosphere interactions	Accurate temporal dynamics	Surface and root zone	Monthly or sub-monthly	Long-term soil moisture climatology
Hydrology	Hydrological modelling and estimation of water cycle components	Accurate absolute soil moisture	Surface and root zone	Sub-daily (e.g., hourly)	Reliable quality information
Agriculture	Precision agriculture and erosion modelling	Accurate absolute soil moisture	Root zone	Weekly and sub-weekly	Reliable quality information
Ecosystem	Ecosystem monitoring and ecological modelling	Accurate absolute soil moisture	Root zone	Weekly	Reliable quality information

# Soil moisture varies depending on depth

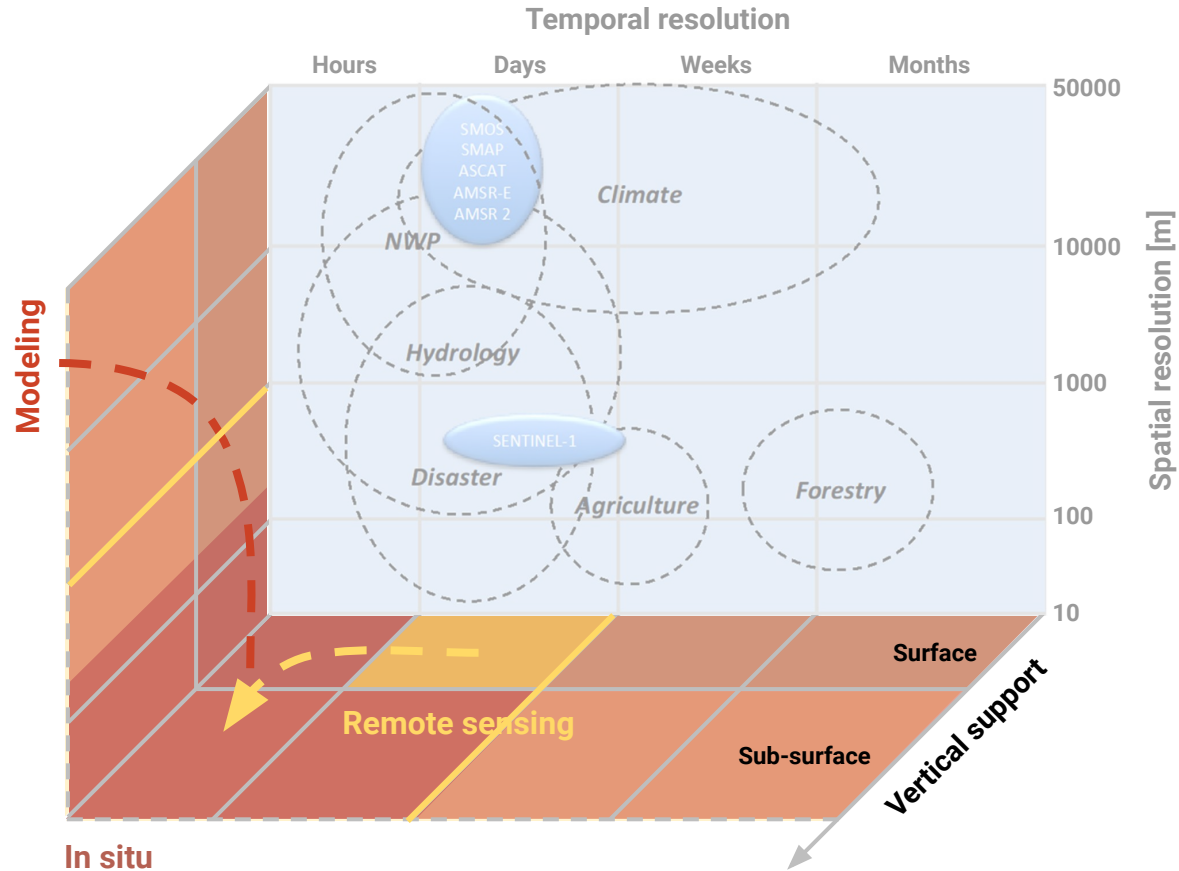




# Droughts have already increased in frequency and severity



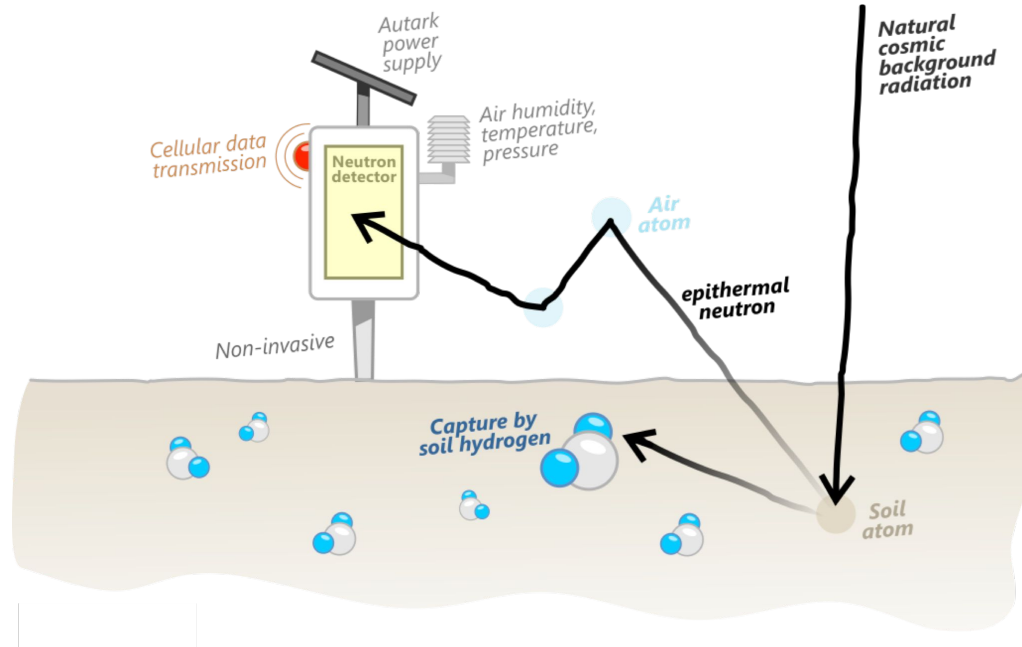
# Combining in-situ with remote sensing soil moisture



# AI-based soil moisture products exist already

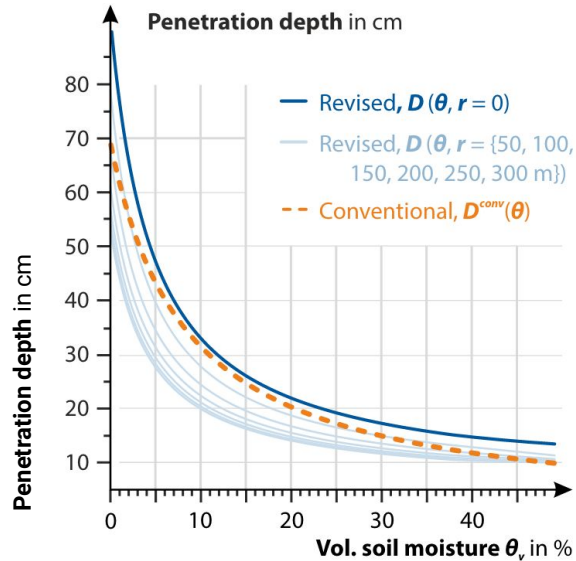


# Novelty: target cosmic-ray neutron sensing (CRNS) soil moisture

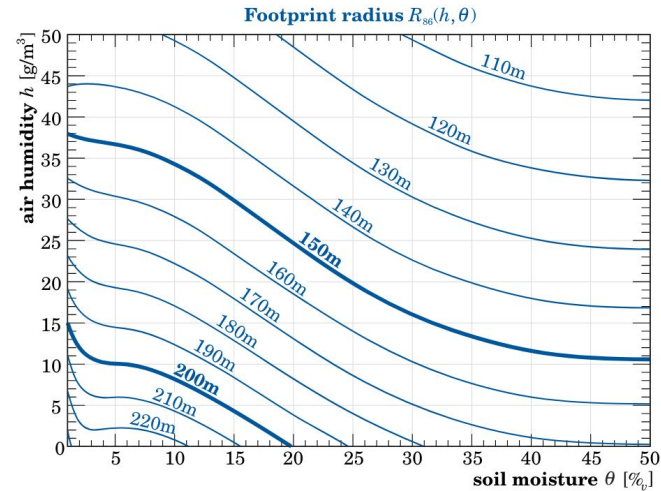


# CRNS has a dynamic footprint

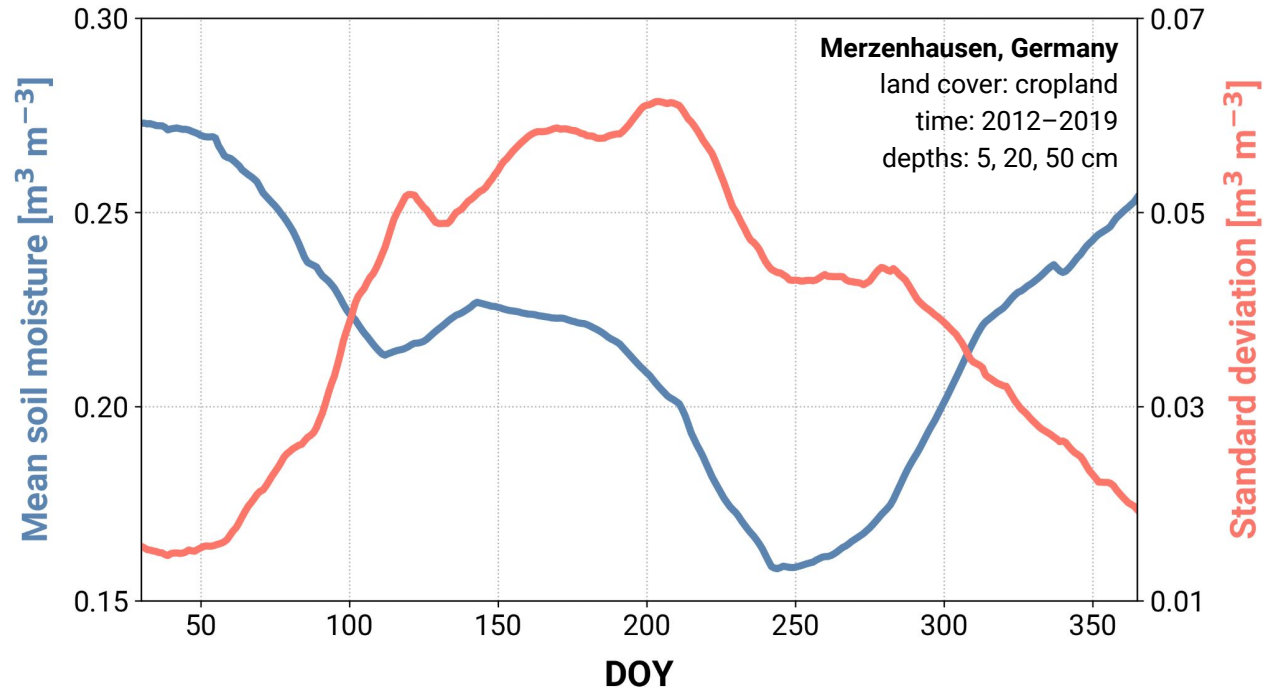
Vertically  $\updownarrow$   
10~50 cm



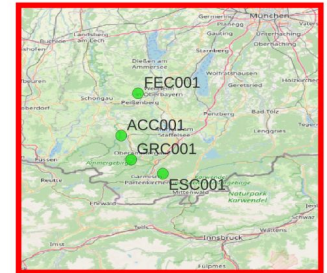
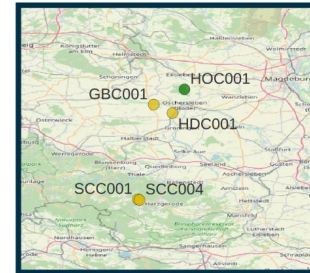
Horizontally  $\leftrightarrow$   
200~400 m



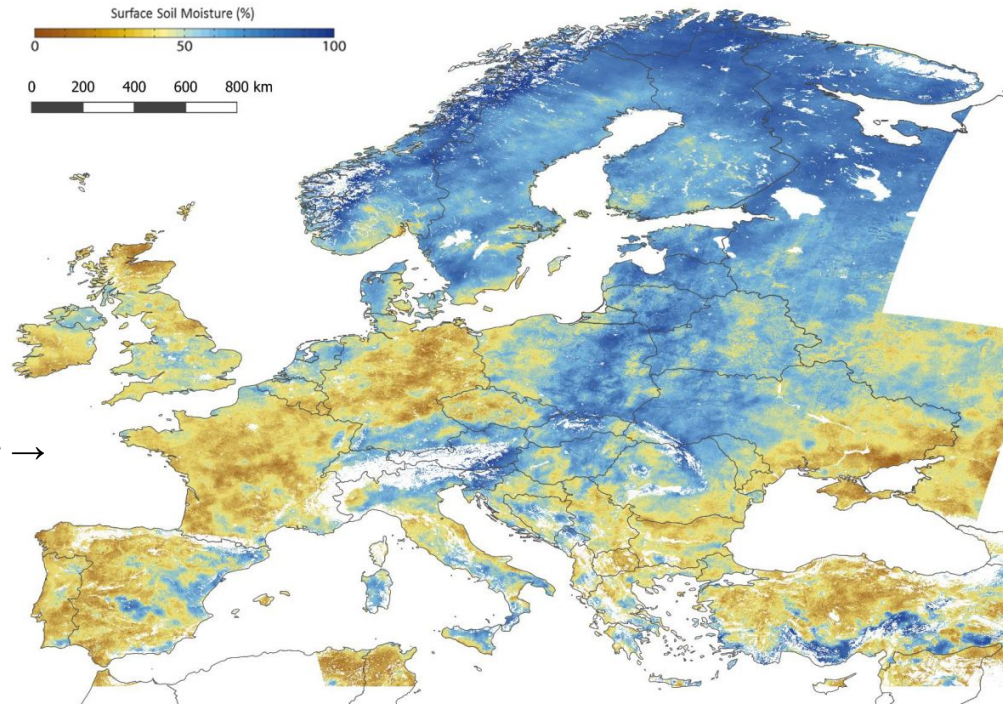
# Variability across depth decreases during wet periods



# We use data from 52 COSMOS-Europe sites...



# ...to create a 1-km daily profile soil moisture product



**ASCAT/Sentinel-1 SWI (Copernicus)**

August 2018



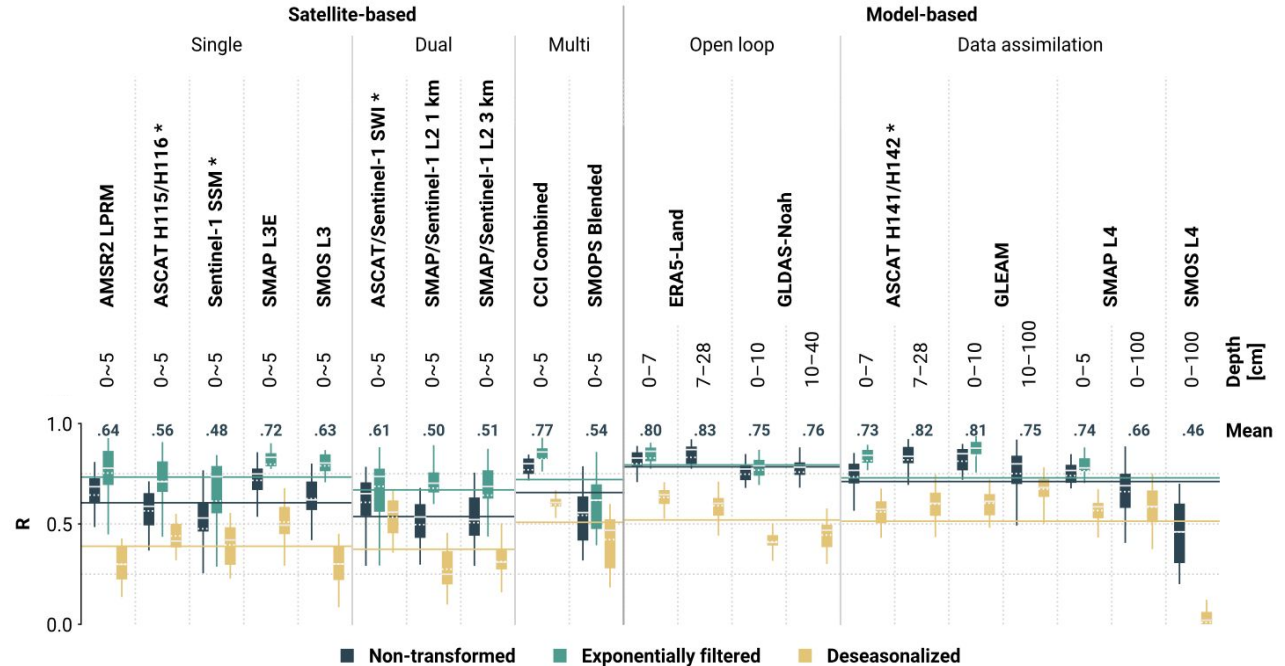
# Surface soil moisture products capture seasonal variations well

## Best agreement with CRNS

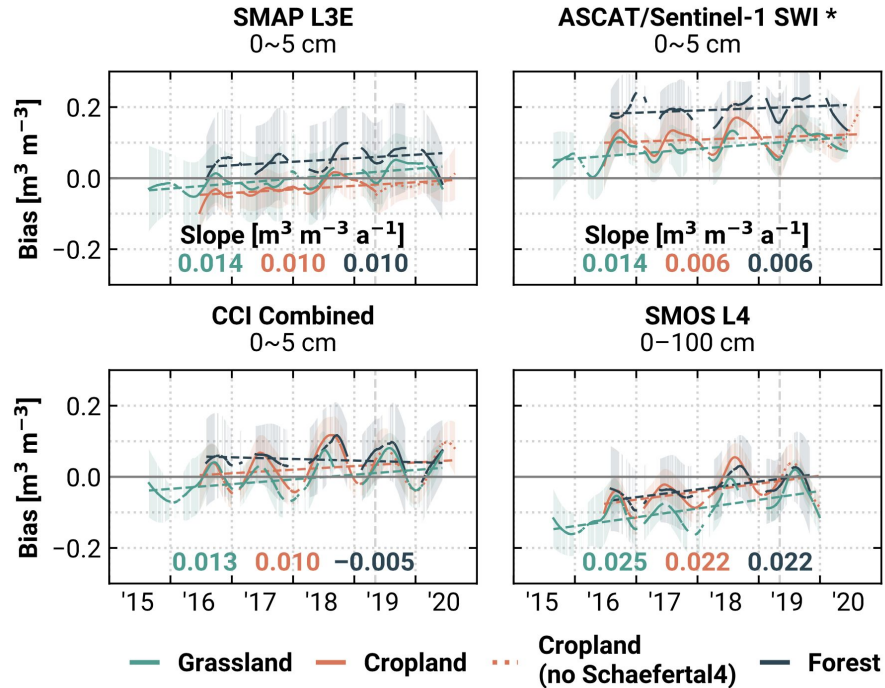
- Model-based products
- CCI Combined
- SMAP L3E

## Vertical scale mismatch

- Better fit through exponential filter



# Limitations in capturing deep droughts



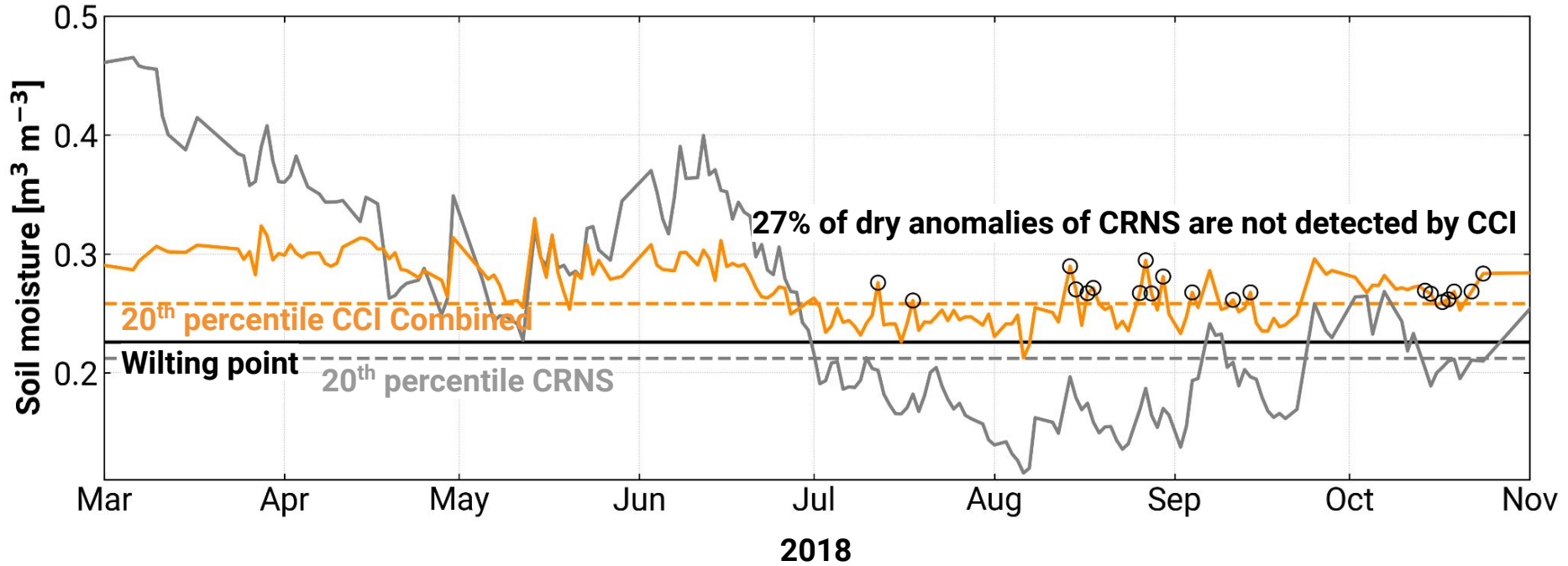
## Limitations to replicate dry-down

- Biases peak in summer
- Positive trends of biases

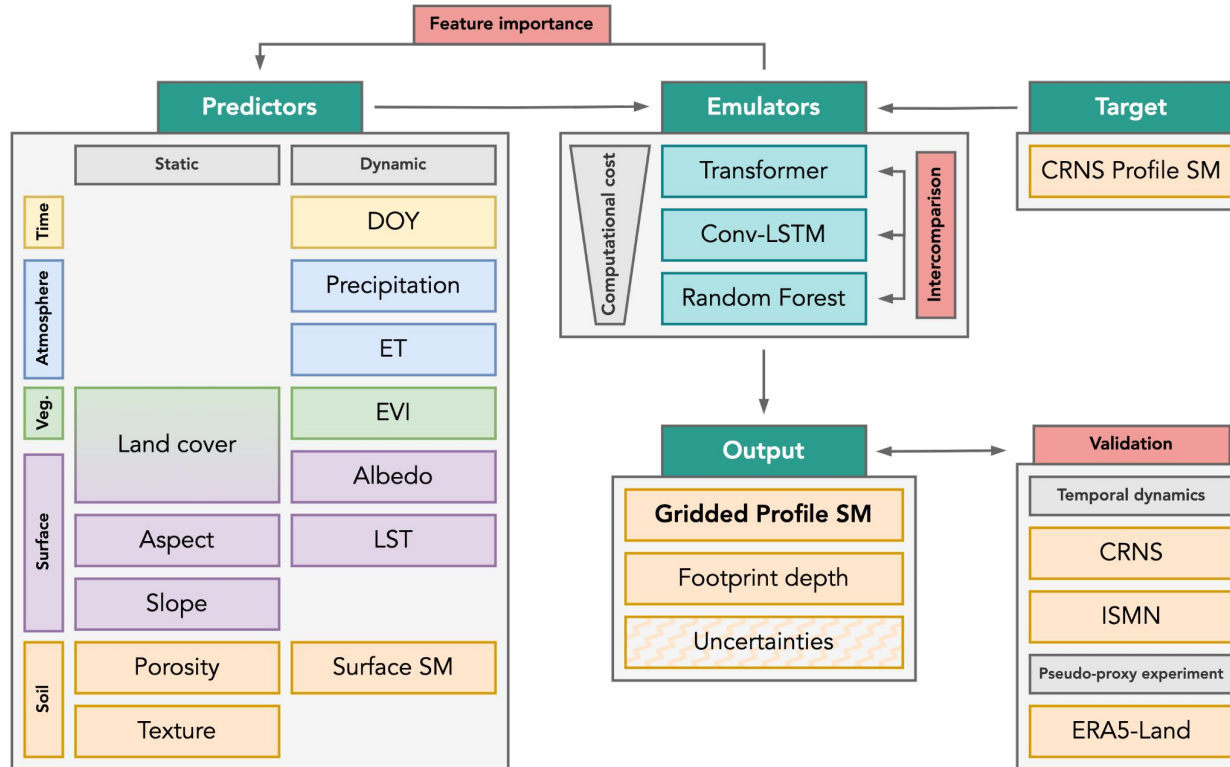
## Implies multi-scale data fusion

- Integration of ground-based with satellite estimates

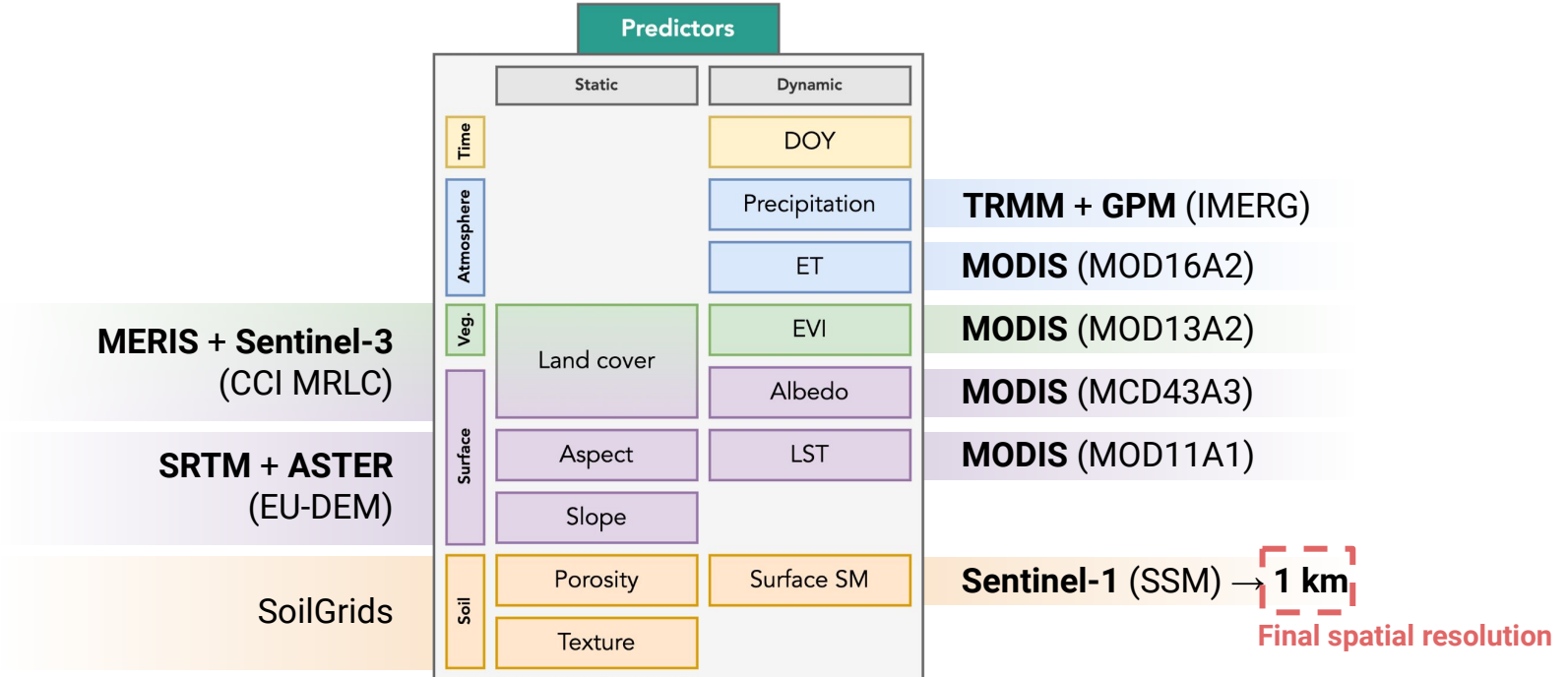
# Cropland case study (Schoeneseiffen, Germany)



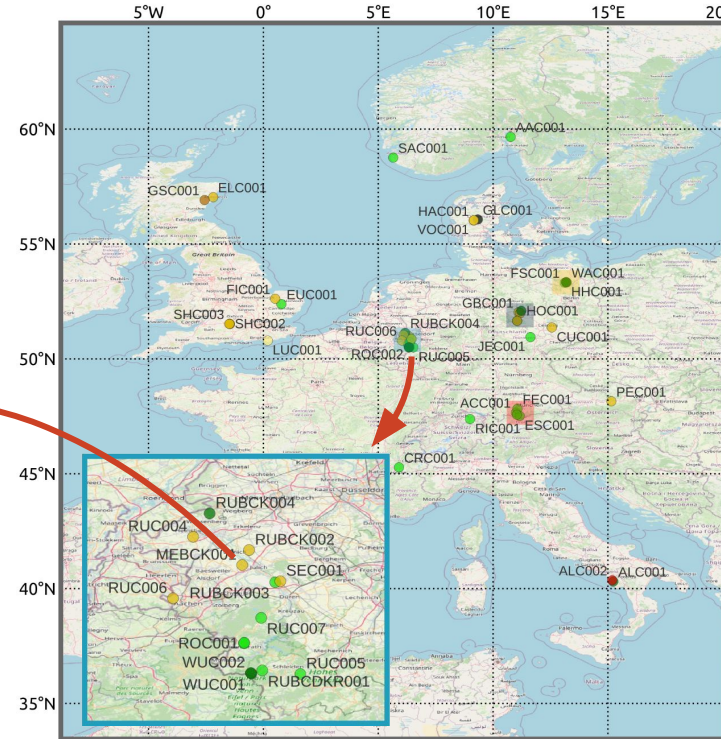
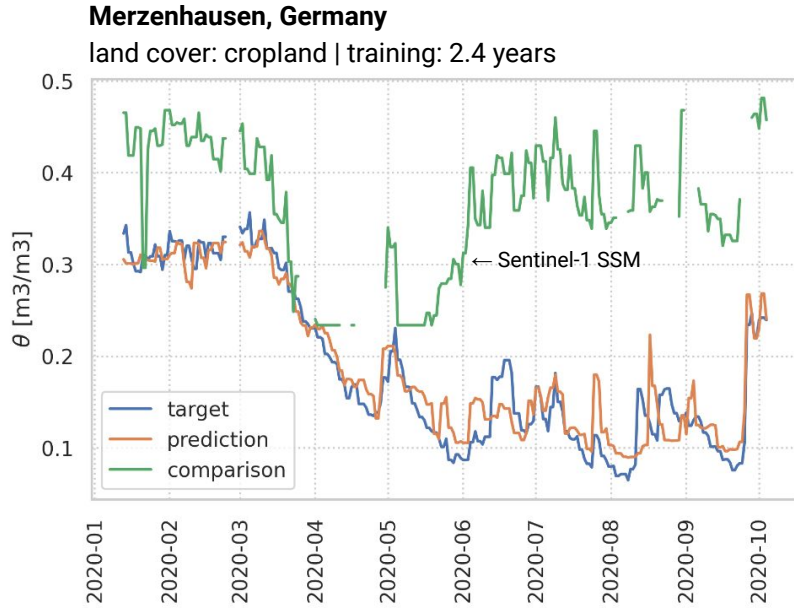
# Framework for an AI-based profile soil moisture product



# Predictors from remote sensing



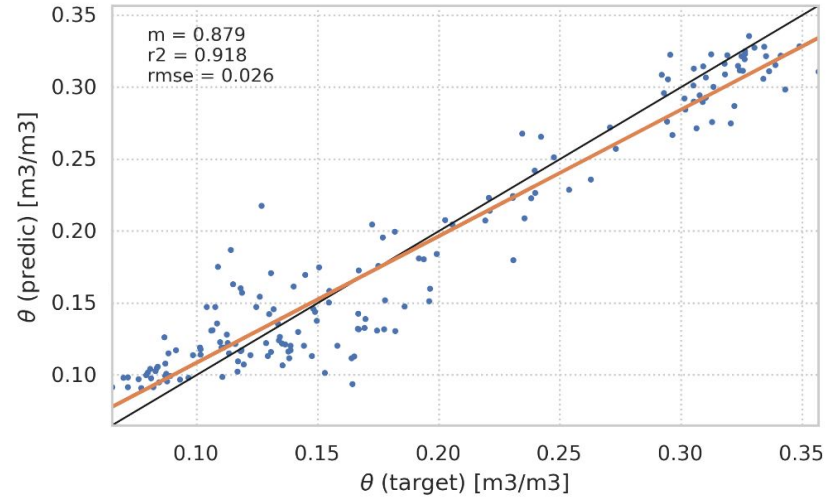
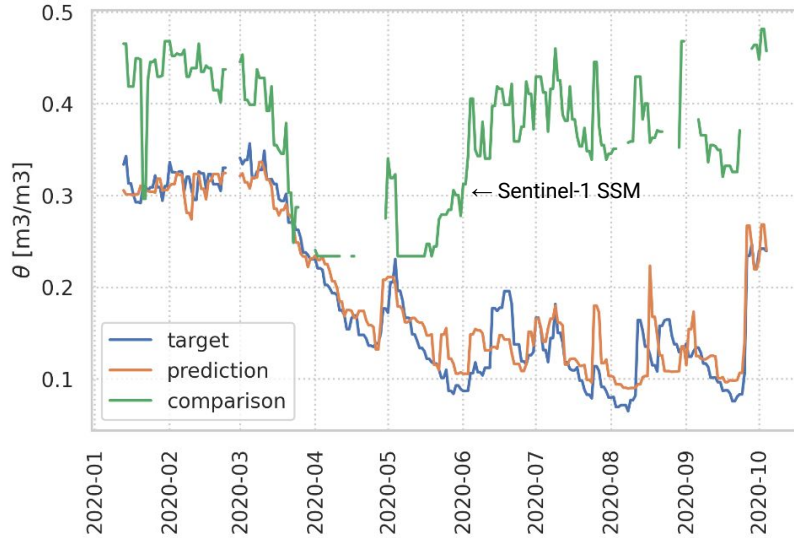
# 1D Random Forest captures CRNS soil moisture well



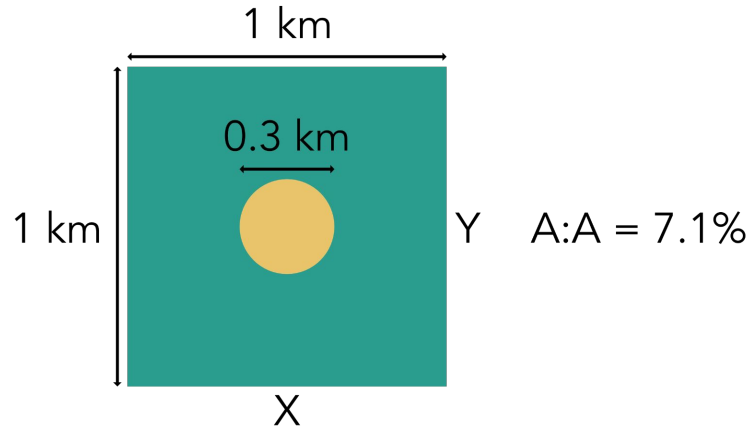
# Correlation is high, error is low

## Merzenhausen, Germany

land cover: cropland | training: 2.4 years



# But: tackling representativeness mismatches



■ Sentinel-1 SSM   ■ COSMOS

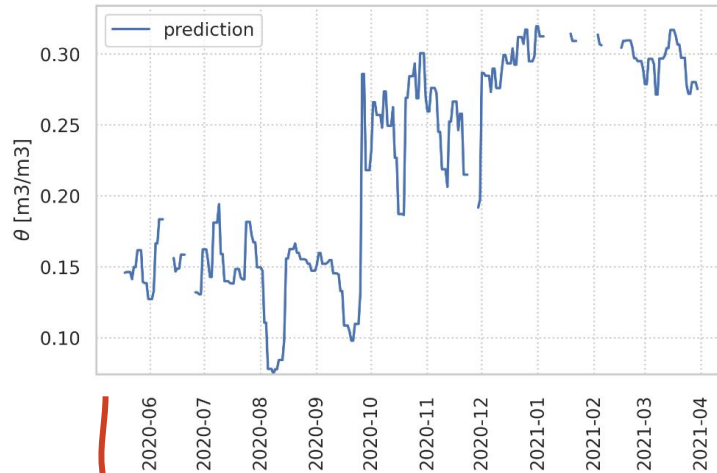
→ **Sub-pixel scaling**

1. Estimating soil moisture separately for each sub-pixel  
→ *Defined by sub-1-km predictors*

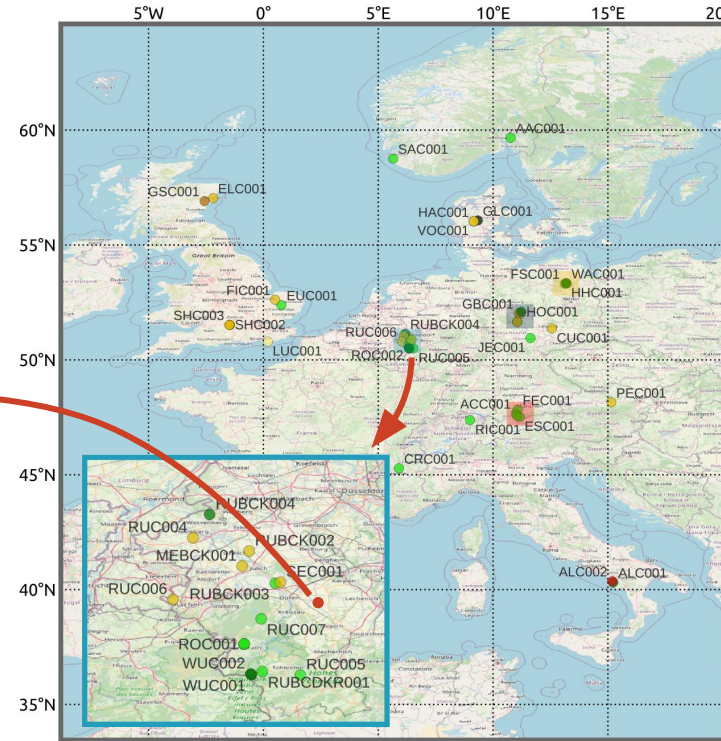
2. Averaging the sub-pixel estimates to obtain a pixel-level estimate



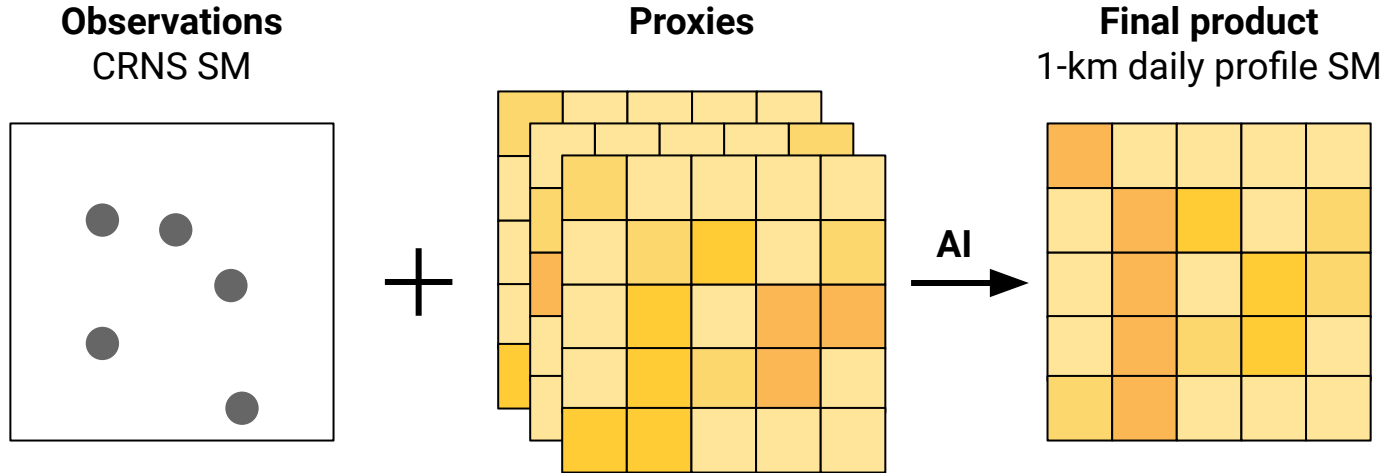
# “Off site” case study



How do we know it is right?

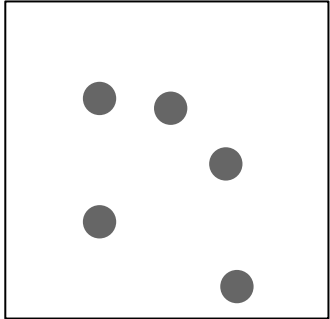


# Pseudoproxy experiment with ERA5-Land



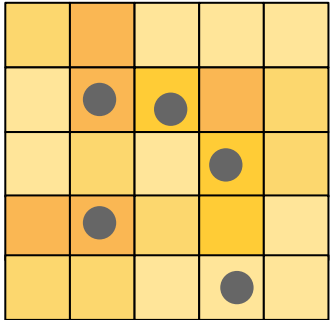
# Pseudoproxy experiment with ERA5-Land

**Observations**  
CRNS SM



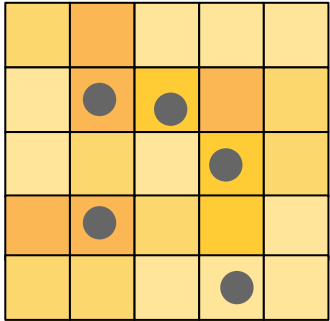
# Pseudoproxy experiment with ERA5-Land

**Pseudoproxy**  
ERA5-Land SM

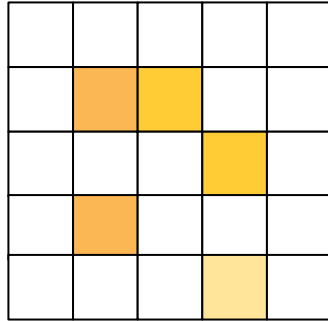


# Pseudoproxy experiment with ERA5-Land

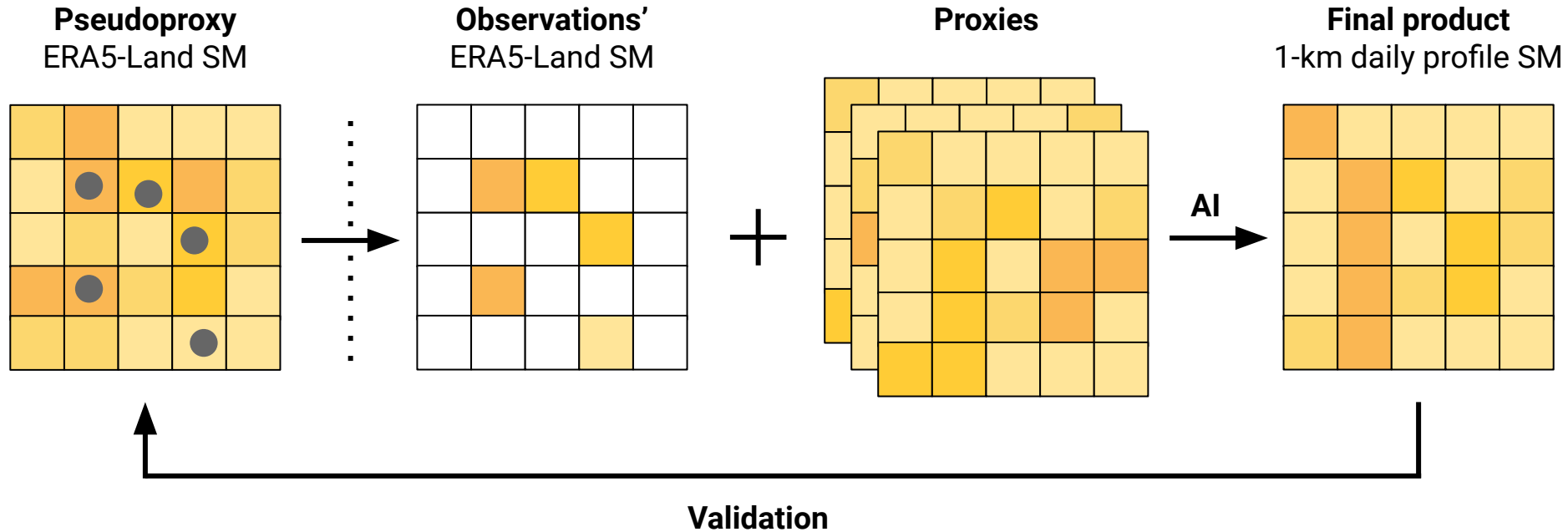
**Pseudoproxy**  
ERA5-Land SM



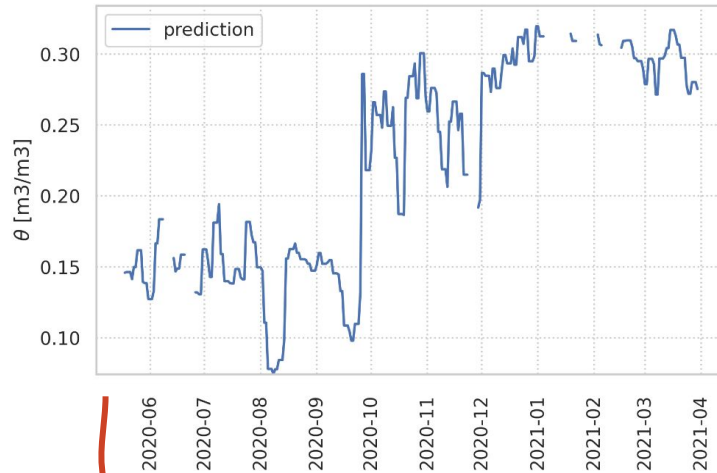
**Observations'**  
ERA5-Land SM



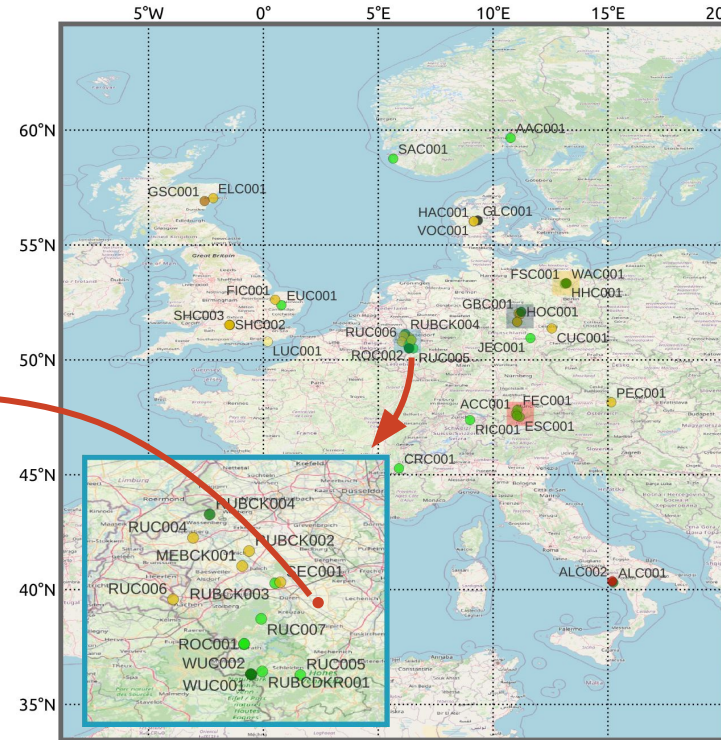
# Pseudoproxy experiment with ERA5-Land



# “Off site” case study



Do we know it is right? → *Not yet ...*



# Gridded profile soil moisture through artificial intelligence

Emulating profile soil moisture from cosmic-ray neutron sensing using covariates from high-resolution remote sensing

Toni Schmidt ([toni.schmidt@ufz.de](mailto:toni.schmidt@ufz.de)), Martin Schrön, Steffen Zacharias, Jian Peng

## Result

- 1D Random Forest model captures CRNS soil moisture well

## Next steps

- Sub-pixel scaling: to tackle representativeness mismatches
- Pseudoproxy experiment: to validate off-site locations
- Neural networks: to account for spatial autocorrelation