# Soil Moisture Droughts Monitoring in Ireland: Evaluating a Dynamic NOAH-MP model against EUMETSAT ASCAT SWI

Kazeem Abiodun Ishola
Kazeem.ishola@mu.ie
Irish Climate Analysis and Research Units/
National Centre for Geocomputation,
Maynooth University, Maynooth, Ireland

## Contributions:

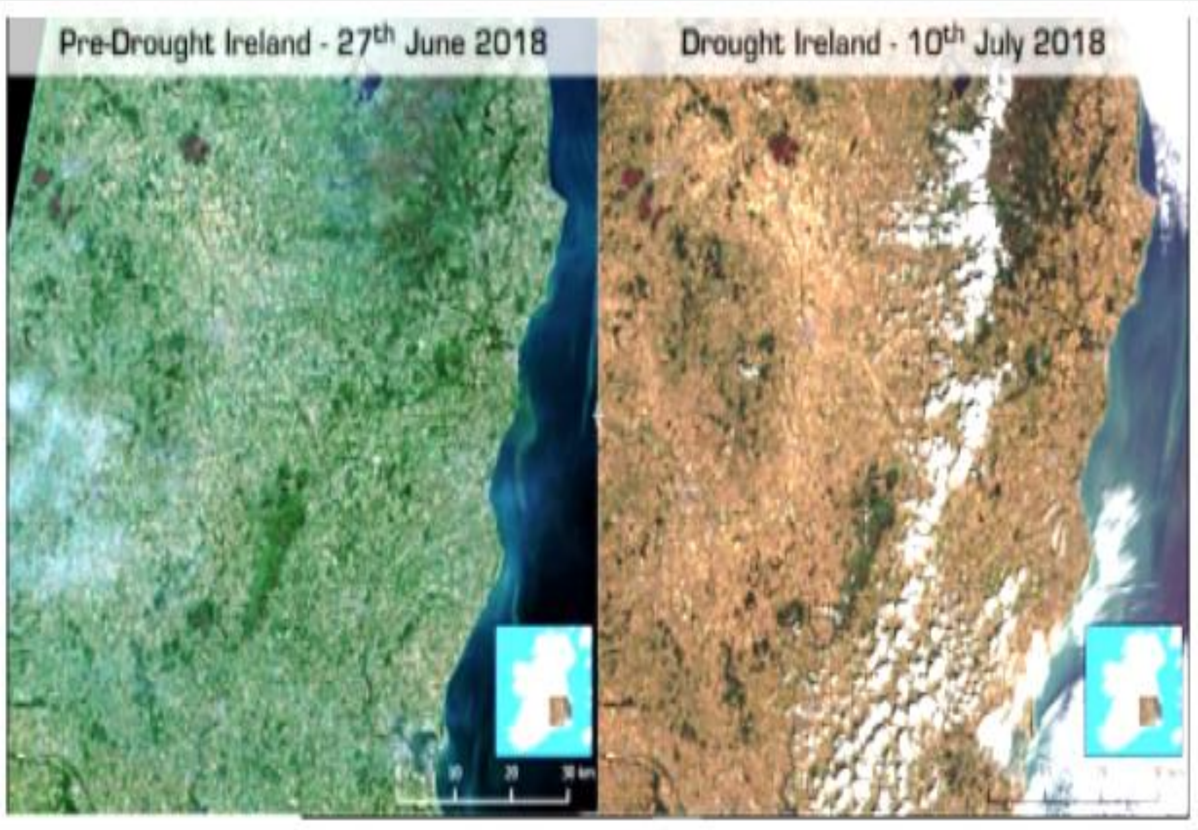
Rowan Fealy (Maynooth University)
Gerald Mills (University College Dublin)
Tim McCarthy (Maynooth University)

## One Take Home Message:

The NOAH-MP model captures soil moisture dynamics, but the soil properties in the model are underrepresented which results in dry biases in the simulated soil moisture and possibly increase the droughts intensity across Ireland.

8th SALGEE and LSA SAF User Workshop on: Monitoring Drought Impacts on Vegetation & Feedback November 25-26, 2024

# Context




Sentinel-2 true color images of south-east, Ireland in summer 2018

- Droughts threaten the society and all sectors of the economy that rely on access to water
- Even in Ireland, where water surpluses are typical.
- Climate evidence suggests that events, such as 2018 summer droughts will be more frequent in the future, as warming enhances droughts through soil moisture-climate feedback

  *Ishola et al., 2023* (**https://doi.org/10.1002/joc.7785**)

- Need to improve approaches informed by observations and models, for addressing drought challenges.

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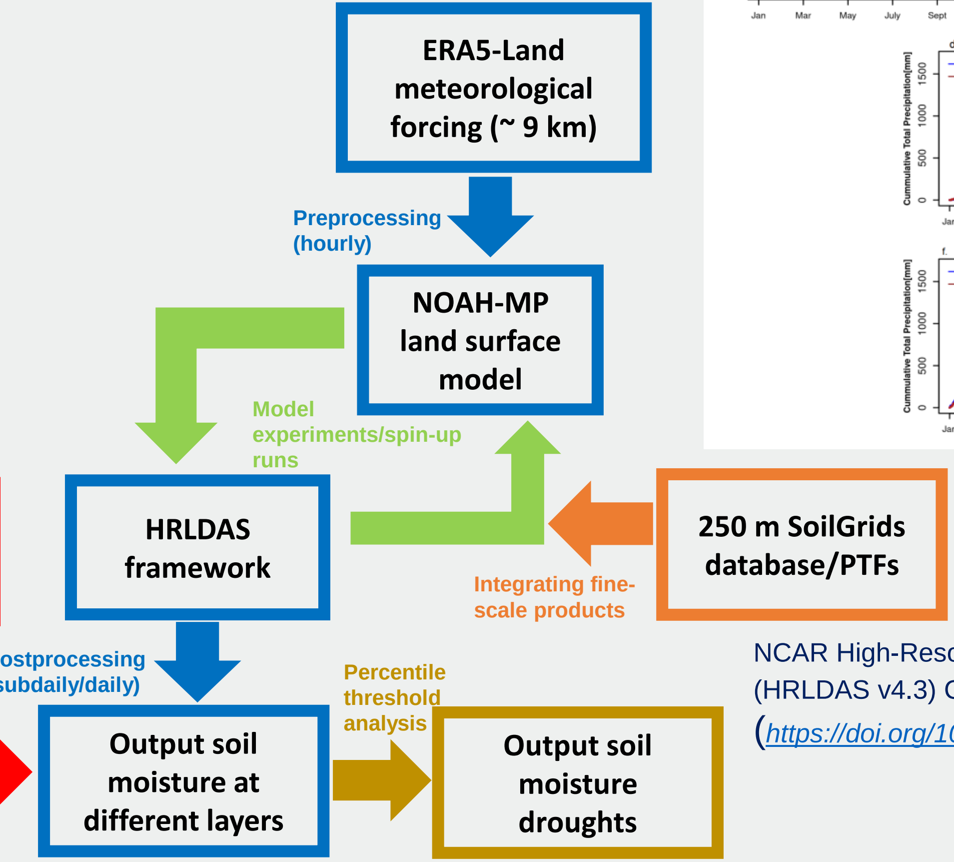
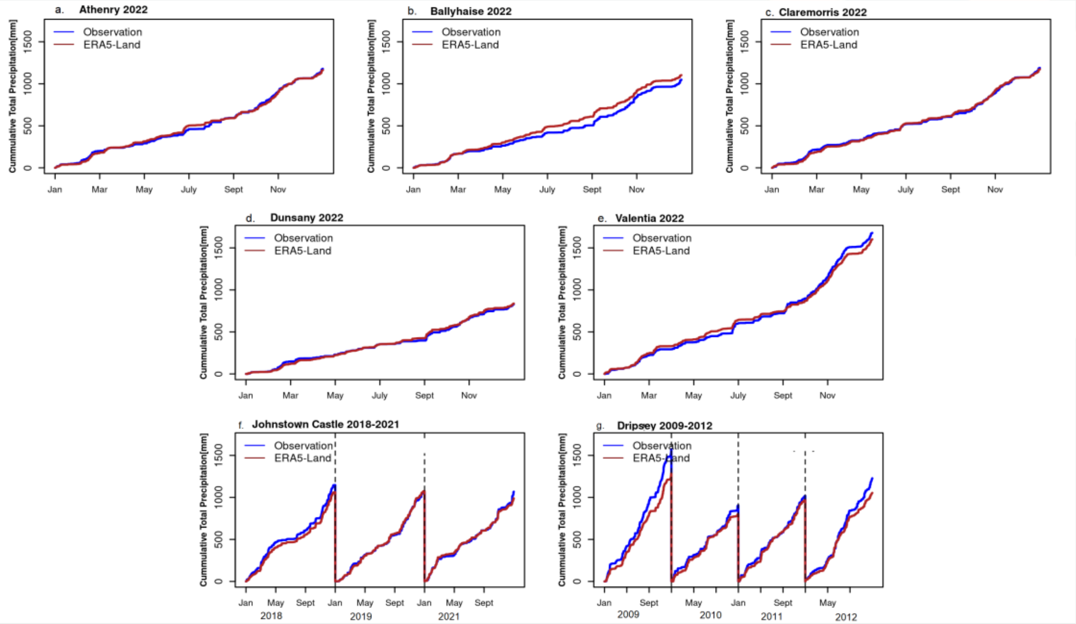
# Overview of Soil Moisture Droughts Modelling




Terrain-AI in-situ network under the ISMON (Fealy et al., 2024)
https://www.epa.ie/publications/research/epa-research-2030-reports/research-460-somosat--soil-moisture-estimates-from--satellite-based-earth-observations.php



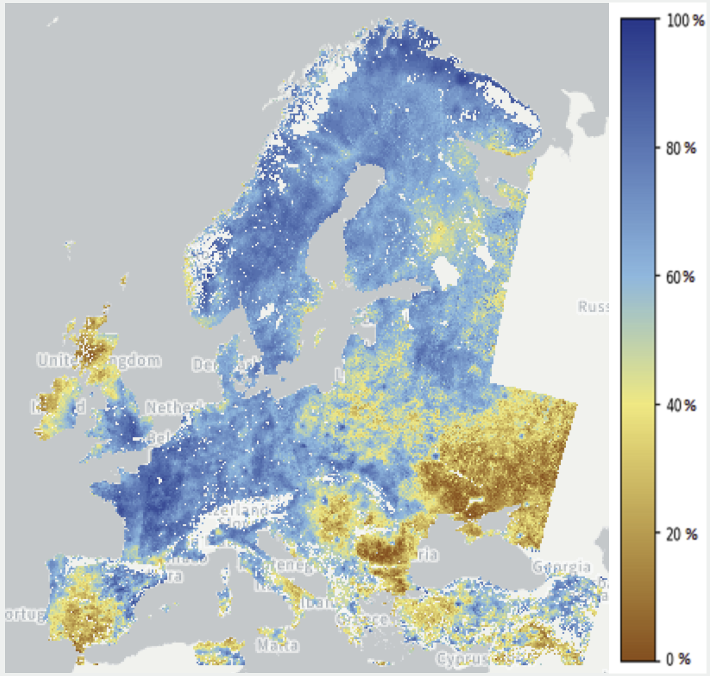




Verification of ERA5-Land daily cummulative precipitation against observations from selected Terrain-AI sites

NCAR High-Resolution Land Data Assimilation System (HRLDAS v4.3) Chen et al., 2007 (*https://doi.org/10.1175/JAM2463.1*)

- Nation-wide map of soil moisture droughts at 1 km by 1 km grid space
- 1 km Surface and subsurface soil moisture outputs evaluated against ASCAT 1 km SWI
- Detailed integration of soil type/textural properties and vegetation
- Stand-alone HRLDAS/NOAH-MP model forced by ERA5-Land (2009-2022)

# Advanced Scatterometer Soil Water Index (ASCAT SWI)




Bauer-Marschallinger et al., 2018 (https://doi.org/10.3390/rs10071030)

Wagner et al., 1999 (https://doi.org/10.1016/S0034-4257(99)00036-X)

- Product characteristics
  - Sensor: Sentinel-1 C-SAR (1 km resolution) and Metop ASCAT (25 km resolution)
  - Input: Surface Soil Moisture
  - Approach: fusion algorithm; two-layer water balance model; temporal filtering
  - Layers: 8 (characteristics time length T)
  - Temporal resolution: daily
  - Time coverage: 2015 – present
  - Spatial resolution: 1 km
  - Geographic coverage: Europe continental
  - Version: 1.0
  - Uncertainty threshold: 0.1 $m^3$ $m^{-3}$
  - Limitation: no account of soil texture

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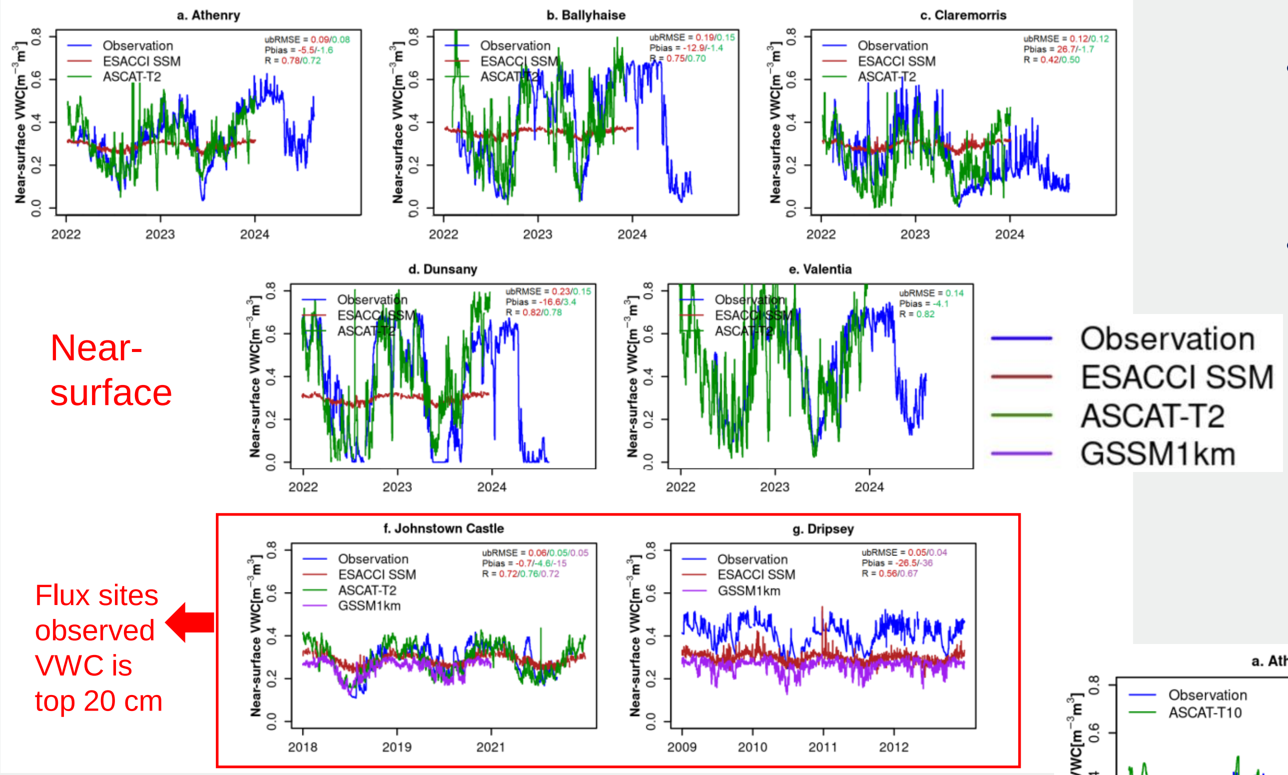
# ASCAT 1 km SWI products evaluation



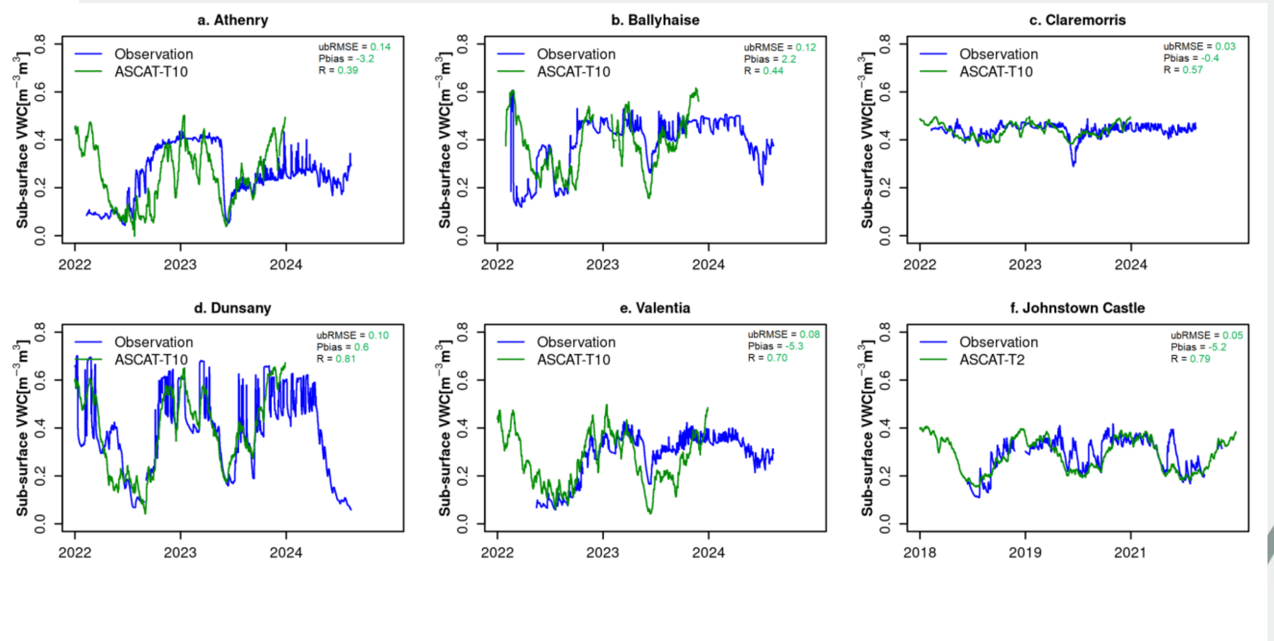

Near-surface

Flux sites observed VWC is top 20 cm

- SWI degree saturation is scaled to reference observations ($m^3$ $m^{-3}$) using variance matching

- ASCAT SWI products are evaluated against in-situ observations and compared with ESA-CCI SSM and machine learning GSSM (Han *et al.*, 2023 https://doi.org/10.1038/s41597-023-02011-7)

Subsurface




- lowest ubRMSE averagely 0.12 $m^3$ $m^{-3}$ at near-surface and sub-surface layers

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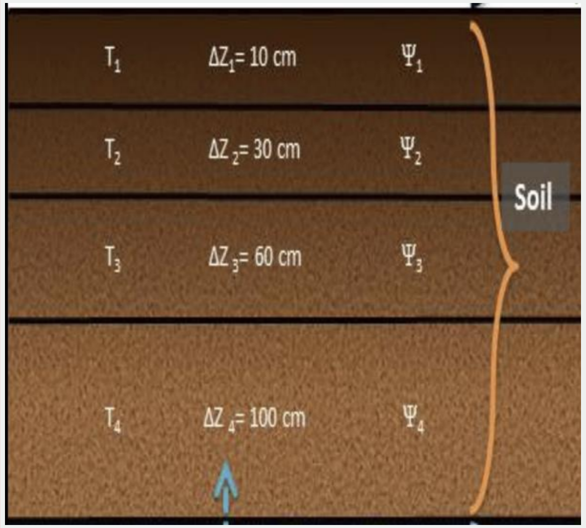
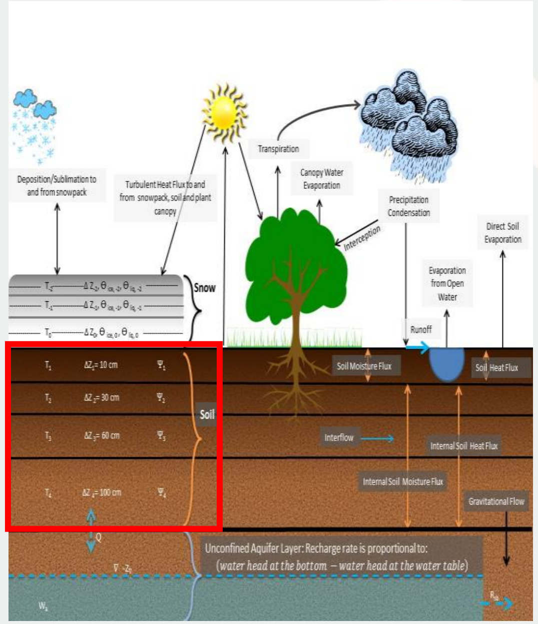
# NOAH-MP Land Surface Model

- NOAH-MP simulates the movement and distribution of soil moisture through multiple soil layers
- Dependent on soil thermal and hydraulic properties.
- The soil layers were refined with a cummulative thickness of 255 cm

Soil layers are refined in NOAH-MP model:

$\Delta Z_1$ = 7 cm
$\Delta Z_2$ = 21 cm
$\Delta Z_3$ = 72 cm
$\Delta Z_4$ = 155 cm




Schematic representation of NOAH-MP soil layer thicknesses

# Incorporating high-resolution global land products

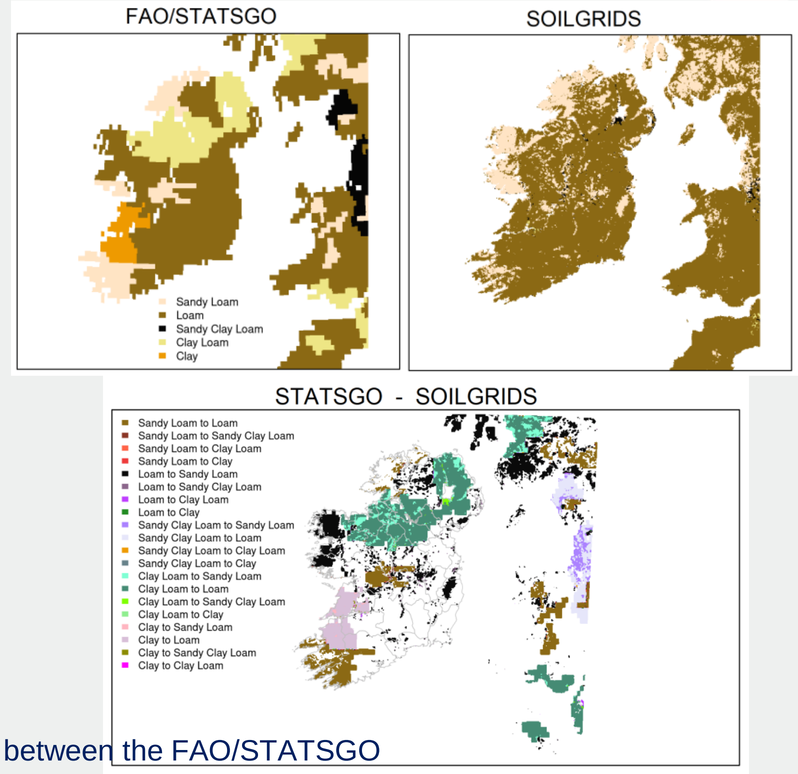
- A high resolution 250 m SoilGrids soil texture database was incorporated.

  *Poggio et al., 2021* (https://doi.org/10.5194/soil-7-217-2021)

- SoilGrids soil texture compositions were used with PTFs to compute soil hydraulic properties

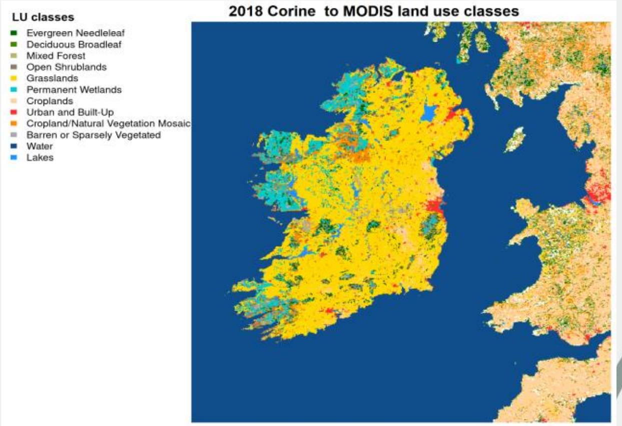
  *Saxton and Rawls, 2006* (https://doi.org/10.2136/sssaj2005.0117)

- The extent to which the difference in the soil databases and soil physics options contribute to uncertainty in NOAH-MP model is evaluated




Difference between the FAO/STATSGO and SoilGrids topsoil texture for Ireland

- Refined land use classes based on 2018 Corine land cover data

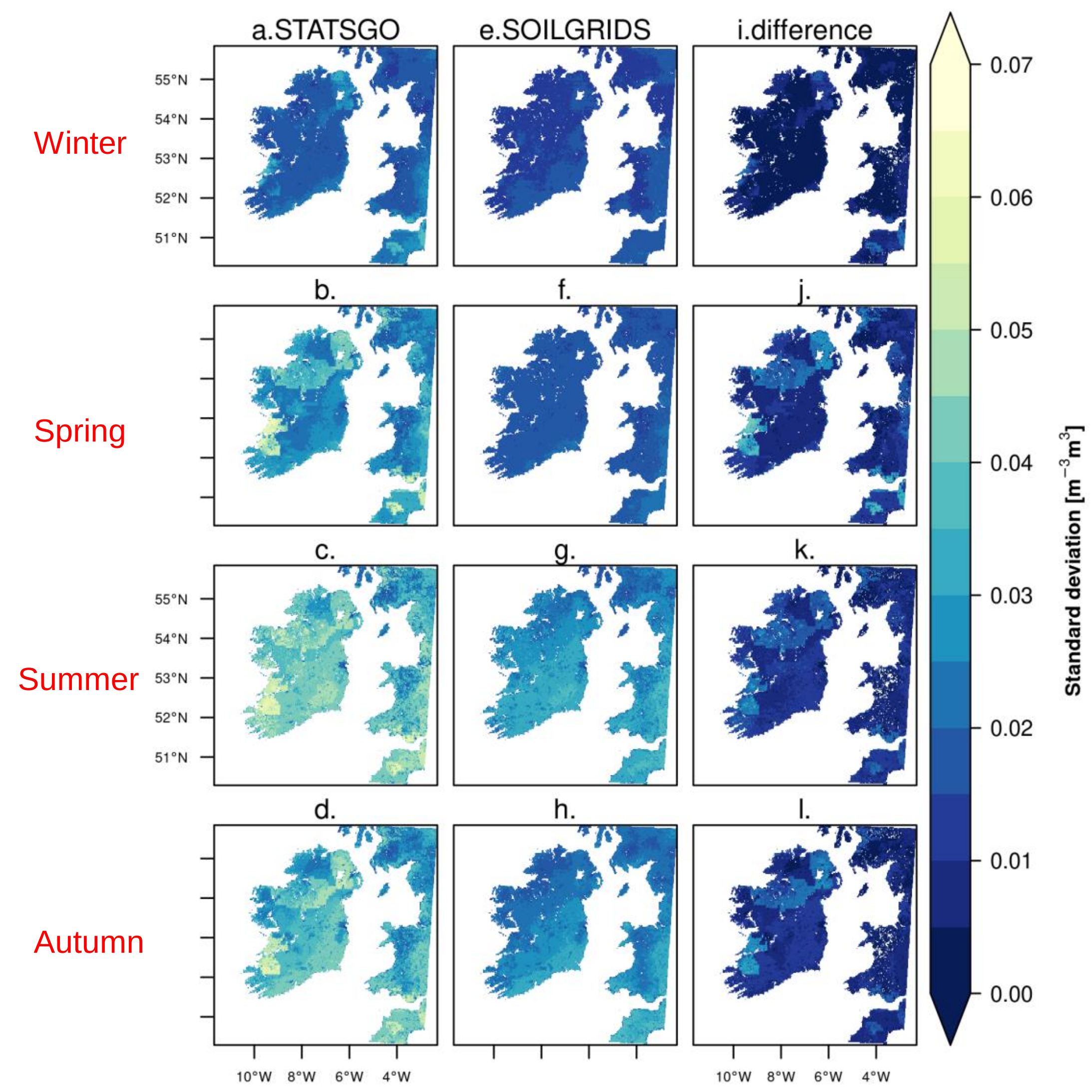



**2018 Corine Land Use (100 m)**

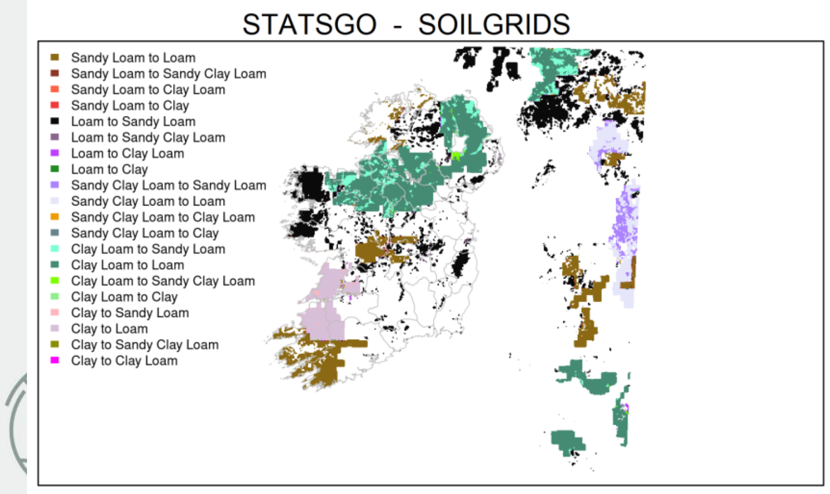
https://land.copernicus.eu/pan-european/corine-land-cover/clc2018

# Simulated near-surface SM variability

- The near-surface soil moisture have higher variability in STATSGO than SOILGRIDS, evident from spring to Autumn.
- The difference in soil texture compositions exert great influence on model variability of soil moisture.
- Model variability is generally low, suggesting that the system is stable over a long period.




Top-soil soil moisture internal variability between STATSGO [a-d] and SOILGRIDS [e-h] for the period 2009-2022. The rows represent Winter to Autumn

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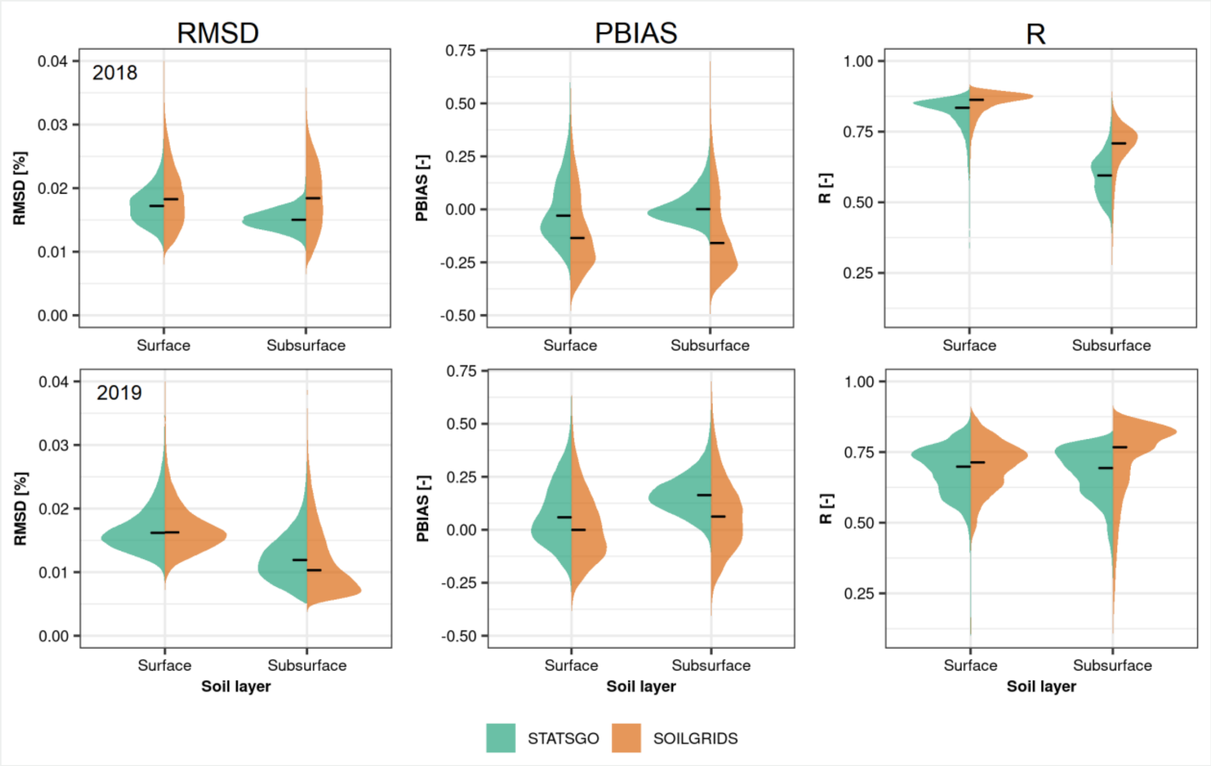
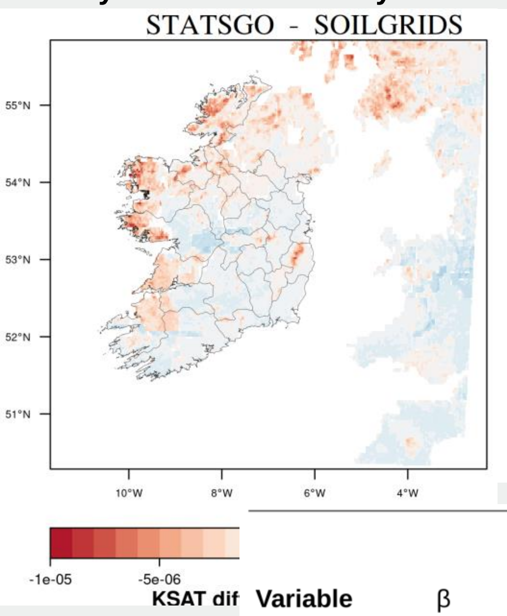
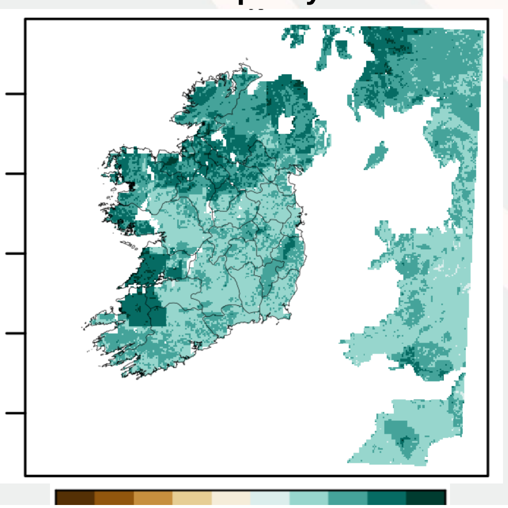
# Model validation against ASCAT SWI products




| | $\overline{\Delta\theta}_{i,j}$ | | | $\Delta\sigma_{i,j}$ | | |
|---|---|---|---|---|---|---|
| Variable | β | SSE | AIC | β | SSE | AIC |
| intercept | 0.323* | | | -0.202* | | |
| $\Delta soil_{txt}$ | 0.253* | 147.38 | -675731 | 0.297* | 211.65 | -599004 |
| $\Delta\theta_S$ | 0.594* | 315.94 | -655084 | 0.236* | 51.51 | -610094 |
| $\Delta\theta_F$ | -0.932* | 79.80 | -684958 | -0.321* | **9.85** | **-613127** |
| $\Delta\theta_W$ | 0.662* | 43.36 | -690203 | 0.529* | 29.04 | -611722 |
| $\Delta K_{SAT}$ | -0.217* | **9.78** | **-695216** | 0.370* | 30.07 | -611647 |
| ε | 0.081* | | | 0.116* | | |

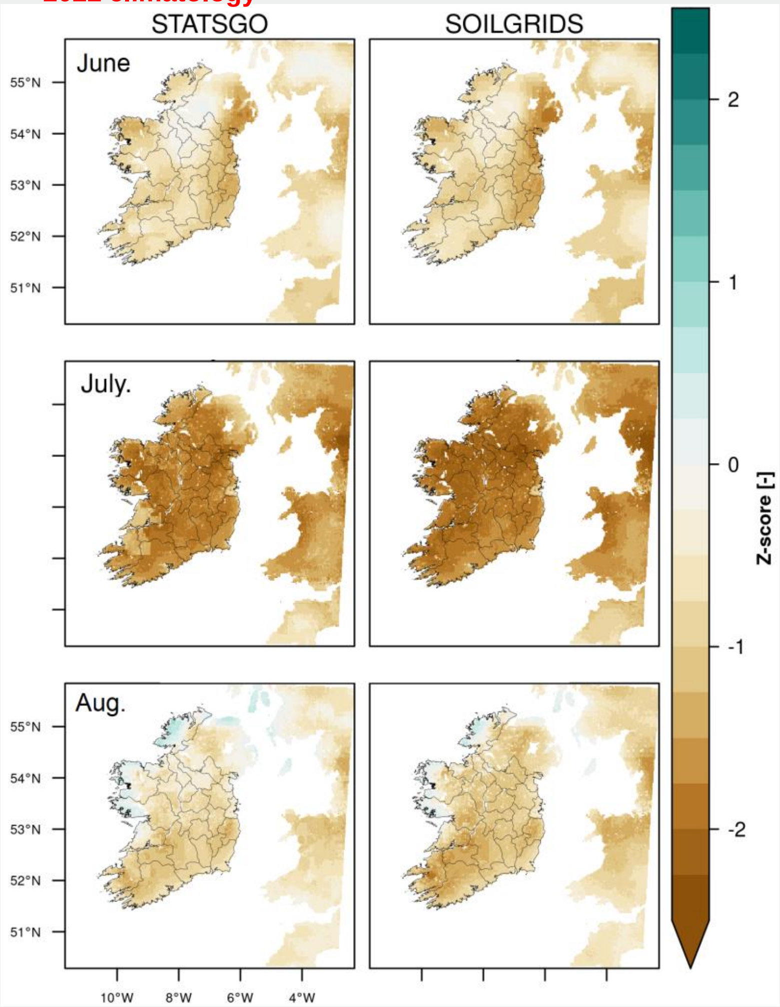
- Near-surface and subsurface soil moisture outputs evaluated against the T2 (0-10cm) and T10 (10-30cm) ASCAT SWI data, respectively for 2018 (top) and 2019 (bottom).

- SOILGRIDS systematically underestimates soil moisture values (in 2018), but have higher temporal dynamics.

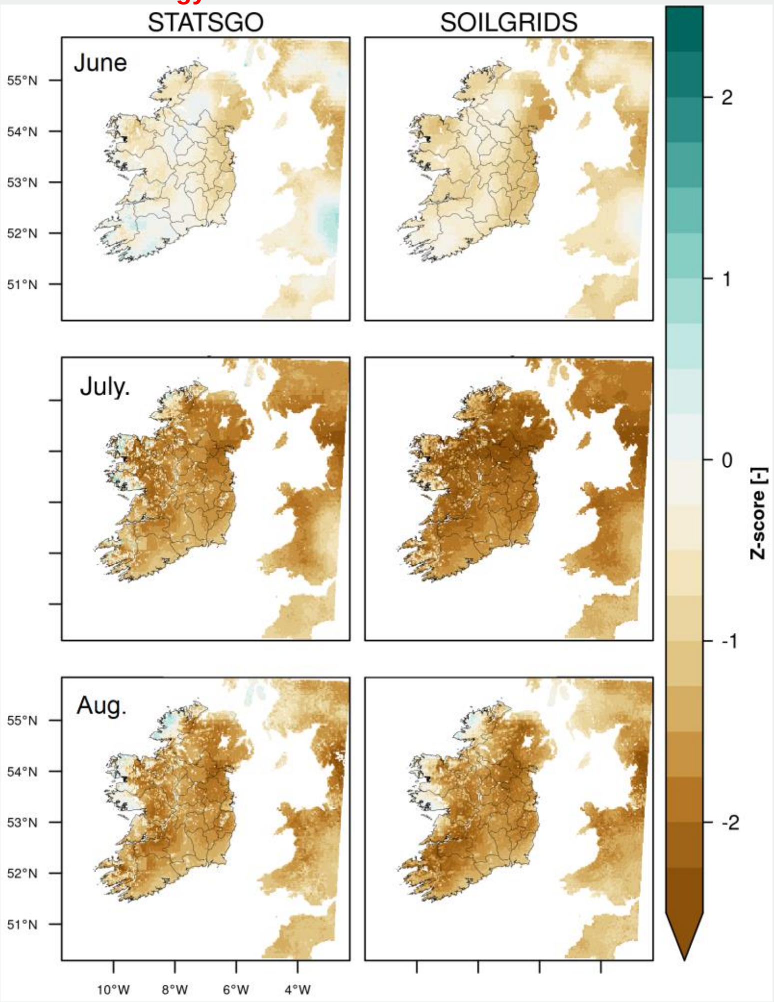
- Overall, model shows good performance with R > 0.6 on median.

# Soil moisture anomalies

**June-August 2018 soil moisture anomalies layer 1 w.r.t. 2009-2022 climatology**



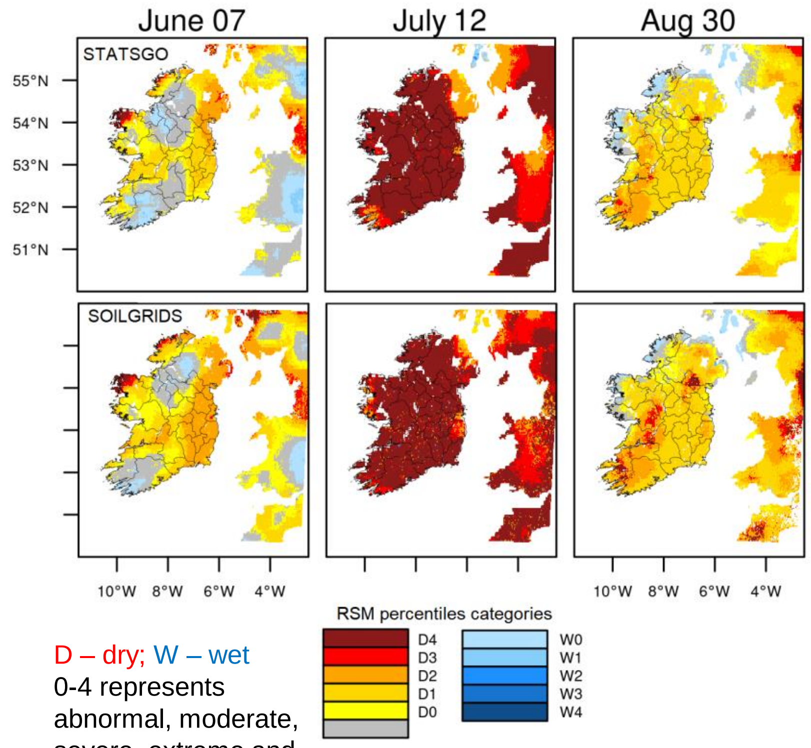

**June-August 2018 soil moisture anomalies layer 3 w.r.t. 2009-2022 climatology**



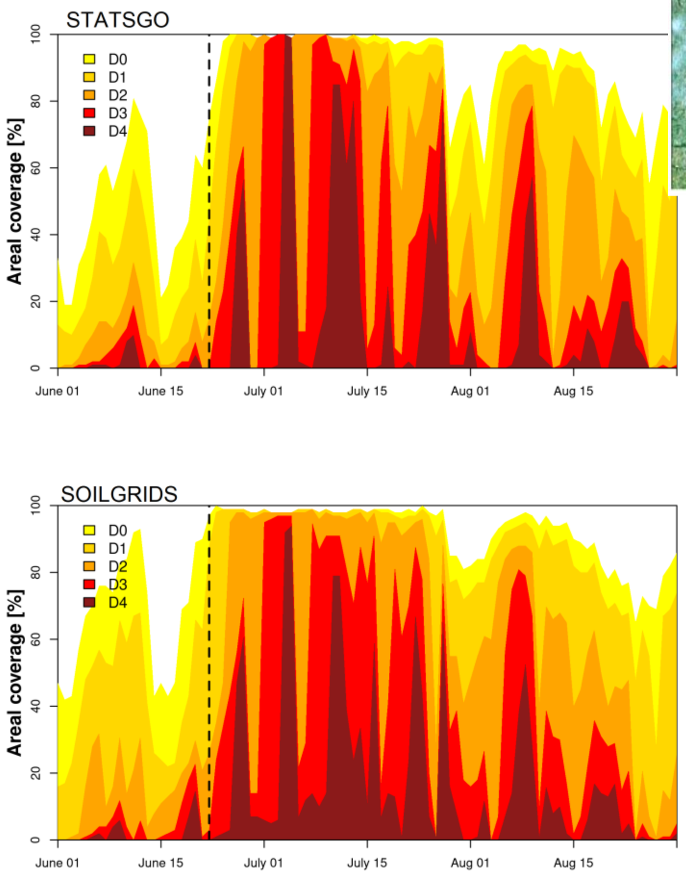

- Widespread soil water stress in July 2018, extending to August in the rootzone.
- Both STATSGO and SOILGRIDS are spatially consistent, but drier conditions in SOILGRIDS

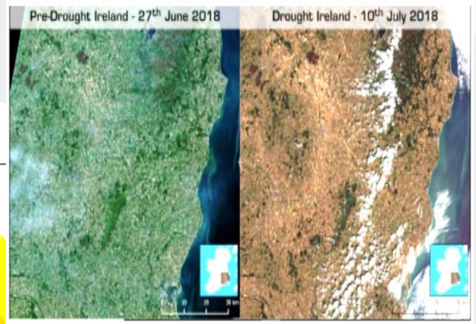
# 2018 Summer Agricultural Droughts in Ireland

2018 Summer (0-100 cm) RSM percentile-based drought categories




D – dry; W – wet
0-4 represents abnormal, moderate, severe, extreme and exceptional




- Derived daily spatial RSM percentiles are classified into different drought categories
- extreme to exceptional soil moisture droughts evolved effectively from last week in June, covering the large part of the country by mid-July.
- A higher drought intensity in SOILGRIDS than STATSGO due to drier bias of the SOILGRIDS associated with underepresented soil properties.

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# Summary

- ASCAT 1 km SWI products (2015-2023) agree well with in situ soil moisture data (R > 0.7) from selected locations.

- Model-derived soil moisture dynamics (2009-2022) based on different global soil databases (SoilGrids and FAO/STATSGO) are evaluated at 1 km in an offline HRLDAS/NOAH-MP model

- High temporal correlations with ASCAT at 1 km grids, but systematically underestimates the soil moisture values possibly due to misrepresentation of soil properties

- Widespread negative soil moisture anomalies (relative to 2009-2022 climatology) extended to 2018 August in the root zone

- Model-derived relative soil moisture percentile thresholds captured the 2018 July exceptional drought events across Ireland, more widespread in SoilGrids than FAO/STATSGO

- Regardless of the global soil data, accurate representation of soil properties (e.g. field capacity, hydraulic conductivity) is important to improve soil moisture simulations in NOAH-MP model

- Model capacity can be used to monitor soil moisture droughts, effectively

EUMETSAT LSA SAF

# Acknowledgment

Fondúireacht Eolaíochta Éireann
Dá bhfuil romhainn
Science Foundation Ireland
For what's next

Microsoft

Terrain-AI

# Thanks for listening

## Related paper:

Ishola, K., Mills, G., Sati, A., Obe, B., Demuzere, M., Upreti, D., Misra, G., Lewis, P., Walsh, D., McCarthy, T., and Fealy, R.: Implementation of global soil databases in NOAH-MP model and the effects on simulated mean and extreme soil hydrothermal changes, *Hydrol. Earth Syst. Sci. Discuss*. [preprint], https://doi.org/10.5194/hess-2023-304, in review, 2024