Making Ireland Weather and Climate Prepared

Current Status of ISMON Irish Soil Moisture Observation Network and Future Plans for SM and ET Products

Klara Finkele, Met Eireann, AGMET group members,
Haleh Karabla Ali & Haneen Muhammad

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Department of Housing,
Local Government and Heritage

- Hydrology vs Meteorology
- Soil Moisture Deficit Estimates
- Current Status of ISMON
  - How it came about
  - Cosmic Ray Neutron Sensor
  - Locations and Sample Data
  - Future Plans for SM and ISMON
- Current Work on ET and Future Plans

Hydrology vs Meteorology

- **Water balance**
- **Various hydrological quantities**, infiltration, surface runoff, drainage, later flow driven by meteorological observations
- Spatial **hydrological units** (watershed/river basin etc)

- **Energy Balance,** lesser extent water balance
- Surface Energy Balance to calculate **surface temperature** to provide lower boundary conditions for NWP etc

$$R_n - G_0 = H + LE$$

- Distributed **grid point** models

PILPS in the 1990's onwards

The Project for Intercomparison of Land Surface Parameterization Schemes (PILPS) was a joint research activity sponsored by the GEWEX [Global Energy and Water Cycle Experiment] and the Working Group on Numerical Experimentation (WGNE), which focused on evaluating and improving land surface schemes for climate and weather prediction models.

Outcomes from Phase 1 (offline simulations) using Cabauw data:
Twenty-three land-surface schemes have participated in the experiment. Analyses of the experimental results were focused on the **energy budget, *the water budget, and their linkage***. Although all schemes used identical atmospheric forcing data and the land-surface parameters were specified with great care, the *differences in experimental results among the land-surface schemes and observations were found to be significant*.

Chen, T. H., and Coauthors, 1997: Cabauw Experimental Results from the Project for Intercomparison of Land-Surface Parameterization Schemes. J. Climate, 10, 1194–1215, https://doi.org/10.1175/1520-0442(1997)010<1194:CERFTP>2.0.CO;2.

From: Chen TH, Henderson-Sellers A, Milly PCD, et al. Cabauw Experimental Results from the Project for Intercomparison of Land-Surface Parameterization Schemes. *J. Climate. 1997;10(6):1194-1215. doi:10.1175/1520-0442(1997)010<1194:CERFTP>2.0.CO;2*

DOI: https://doi.org/10.1175/1520-0442(1997)010<1194:CERFTP>2.0.CO;2

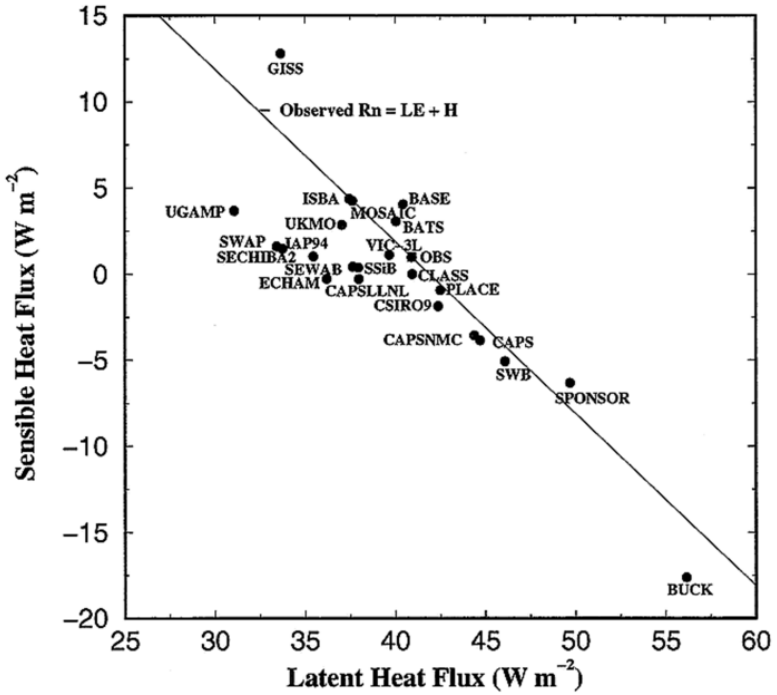
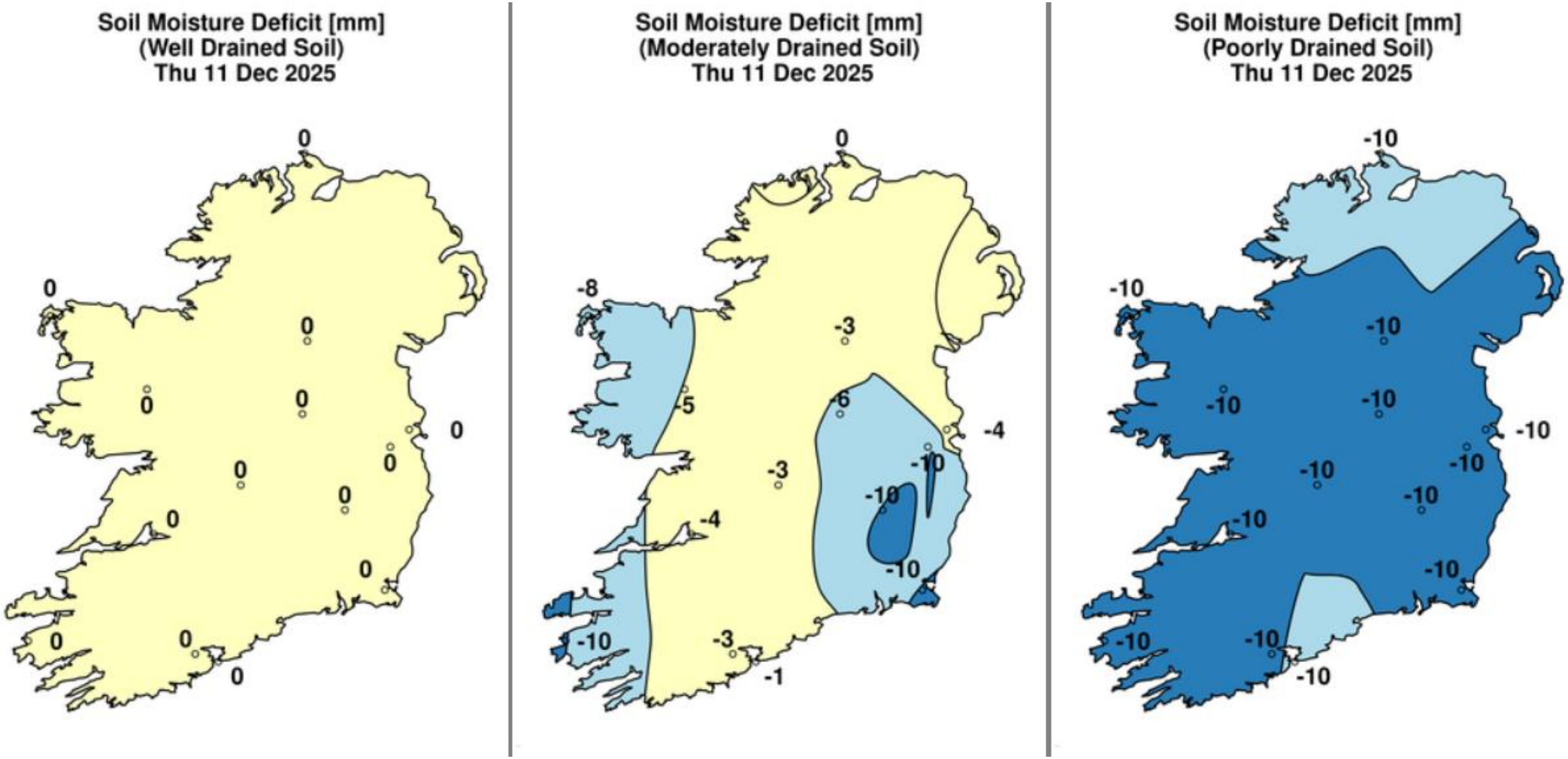


Fig. 5. Annually averaged sensible versus latent heat fluxes (W m−2). Observed annual mean net radiation (=41 W m−2) can be given as the sum of the two coordinates of any single point (latent heat flux + sensible heat flux) on the line.

Soil Moisture Deficit Estimates

On Met.ie based on simple water balance



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R. Schulte, J. Diamond, K. Finkele, N. Holden and Brereton, A.J. 2005 Predicting the soil moisture conditions of Irish grasslands, *Irish Journal of Agricultural and Food Research*, **44**, 95-110

How is Soil Moisture Deficit is Calculated

Water Balance:

New SM = SM - AE + rain – runoff

Or expressed as a deficit:

New SMD = SMD + AE - rain + runoff

Actual evapotranspiration:

- AE is atmospheric demand (potential evapotranspriaton)
  if soil has enough water

- If AE is soil limited, then it's a linear dependence on SM of the atmospheric demand

Current Status of ISMON
Irish Soil Moisture Observation Network
How it came about

- **Why**: don't Met Eireann measure soil moisture?
- **Who**: Agmet group project
- **How**: Review
- **Where**: locations and network umbrella
- **What's Next**: operationalize, long term, gridded SM etc

➢ **Why:** don't Met Eireann measure soil moisture?

Who measures what

- Ground water: GSI (Geological Survey of Ireland)
- Stream flow: OPW (Office of Public Works)
- Water quality: EPA (Environmental Protection Agency)
- Rainfall: Met Eireann

Soil moisture is estimated by Met Eireann *et al* but not measured
Regarded as a black box – how to fill this gap?
In the past, short term research projects but **no long-term SM obs**

Who: AGMET Group established 1984

Joint Working Group on Applied Agricultural Meteorology

Voluntary group with members from Government, Teagasc, Universities etc

https://agmet.ie/
Soil moisture monitoring network:
over 30 people involved

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➢ **How**: Review

The set up of the Irish Soil Moisture Observation Network – ISMON followed similar principles as outlined by Lovett et al. (2007) in which they describe '**The seven habits of highly effective monitoring progams**'

1. **Design the program around clear and compelling scientific questions.**
2. **Include review, feedback, and adaptation in the design.**
3. **Choose measurements carefully and with the future in mind.**
4. Maintain quality and consistency of the data.
5. Plan for the long-term data accessibility and sample archiving.
6. Continually examine, interpret and present the monitoring data
7. Include monitoring within an integrated research program.

AGMET obtained Funding from DAFM

Met Eireann
National long term atmospheric measurement infrastructure & expertise

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➢ Cosmic Ray Neutron Sensor: Field Scale ~ 200m Radius

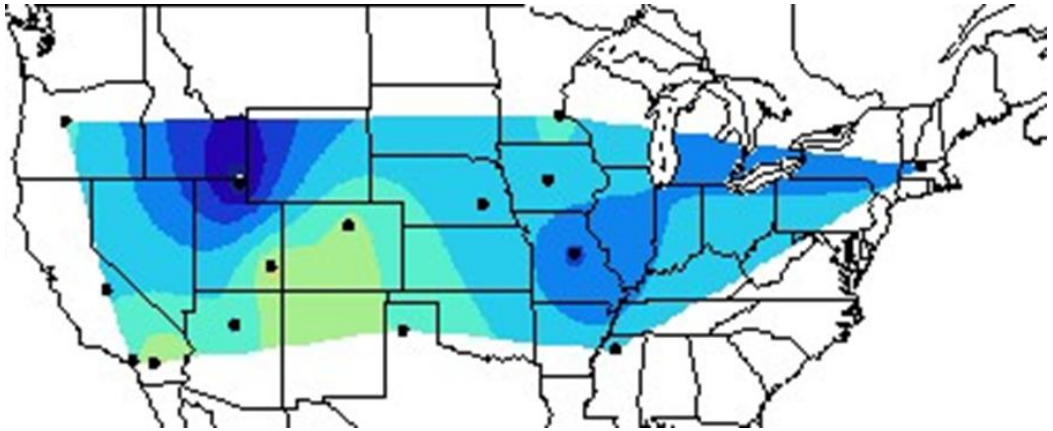
International Networks (also in China, Korea, Denmark), testing by DWD and Meteo France

COSMOS UK ~ 50 sites

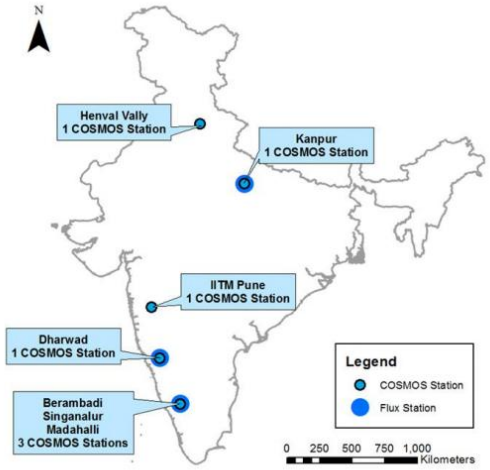
Since 2013

Cooper, H. M., Bennett, E., Blake, J., Blyth, E., Boorman, D., Cooper, E., et al. (2021). COSMOS-UK: National soil moisture and hydrometeorology data for environmental science research. *Earth System Science Data*, **13**(4), 1737–1757. https://doi.org/10.5194/essd-13-1737-2021

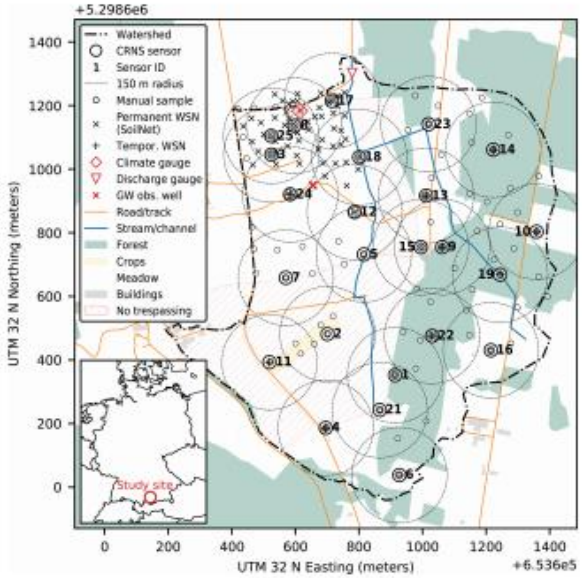
cosmos.hwr.arizona.edu



CEH INCOMPASS & COSMOS-India Sites



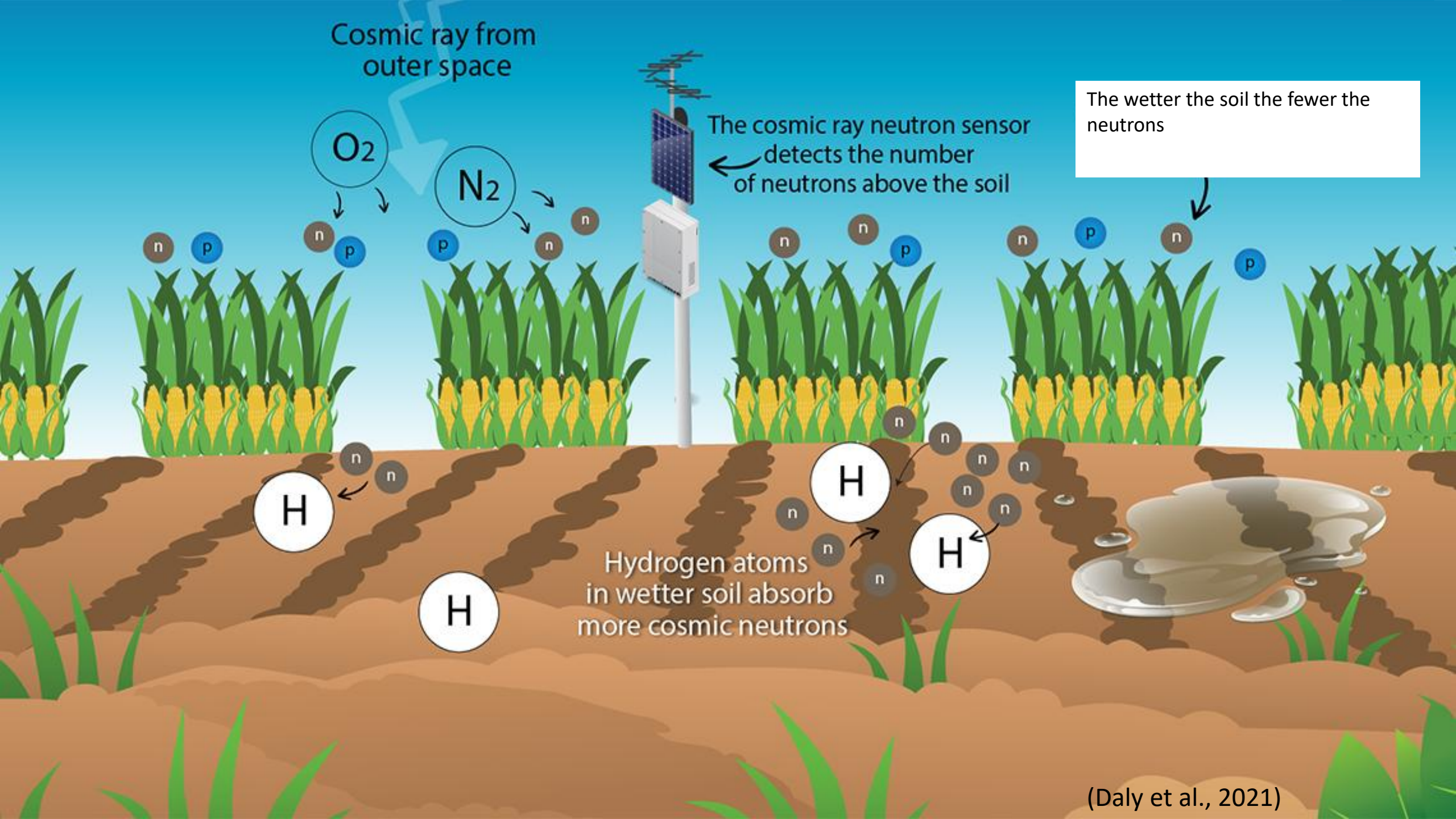
National to Catchment scales



Cosmic Sense

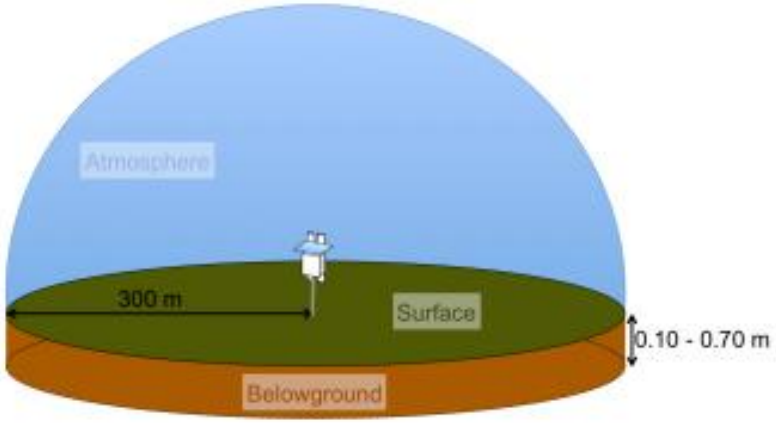
Peisenberg, Germany

Fersch, B., et al, A dense network of cosmic-ray neutron sensors for soil moisture observation in a highly instrumented pre-Alpine headwater catchment in Germany, Earth Syst. Sci. Data, 12, 2289–2309, https://doi.org/10.5194/essd-12-2289-2020, 2020



(Daly et al., 2021)

From Neutron Counts to Soil Moisture Estimates



N_{raw}: Measured raw, uncorrected, neutron counts;
N_0: the theoretical neutron count found in dry conditions.

$$\vartheta_{vol} = \left[\frac{a_0}{\frac{N_{raw} \cdot f_p \cdot f_i \cdot f_v \cdot f_h}{N_0} - a_1} - a_2 - LW - WSOM \right] \frac{\rho_{bd}}{\rho_w}$$

Volumetric Soil Moisture (cm^3/cm^3);

Lattice(chemically bounded mineral) Water (g/g);

Water Equivalent of Soil Organic Carbon (g water/g soil);

Dry soil bulk density (g/cm^3);

Correction Factors:

f_p: Atmospheric air pressure;
f_i: Incoming neutron intensity;
f_h: Atmospheric water vapor;
f_v: Above-ground biomass.

Power et al., 2021

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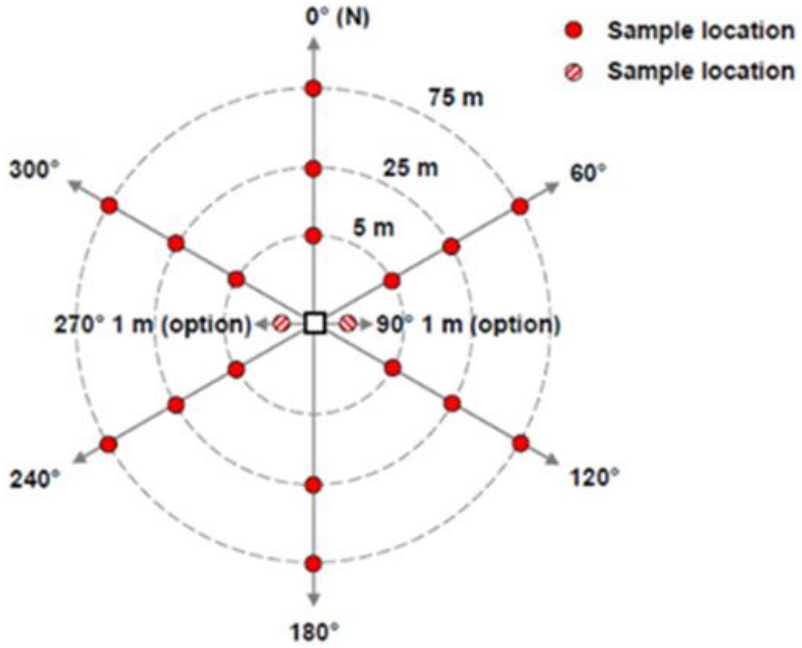
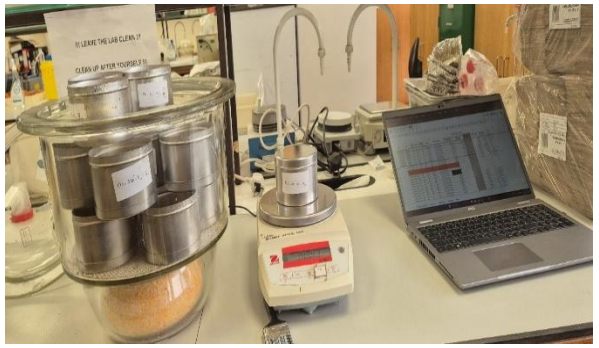
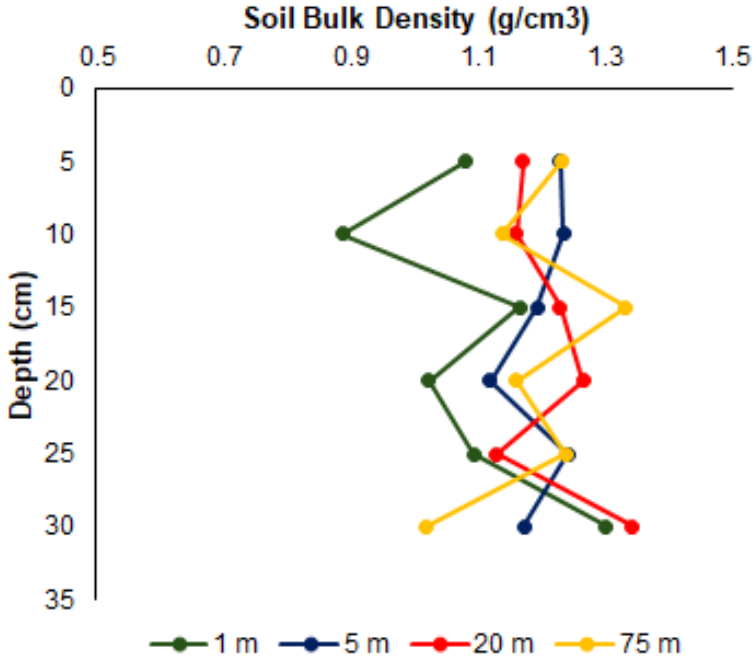
Ground Truthing via In situ Soil Samples







Soil sampling analysis: Laura Gallego-Lorenzo, UCD

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Set up of COSMOS UK Stations
Fivemiletown, NI

Met Éireann

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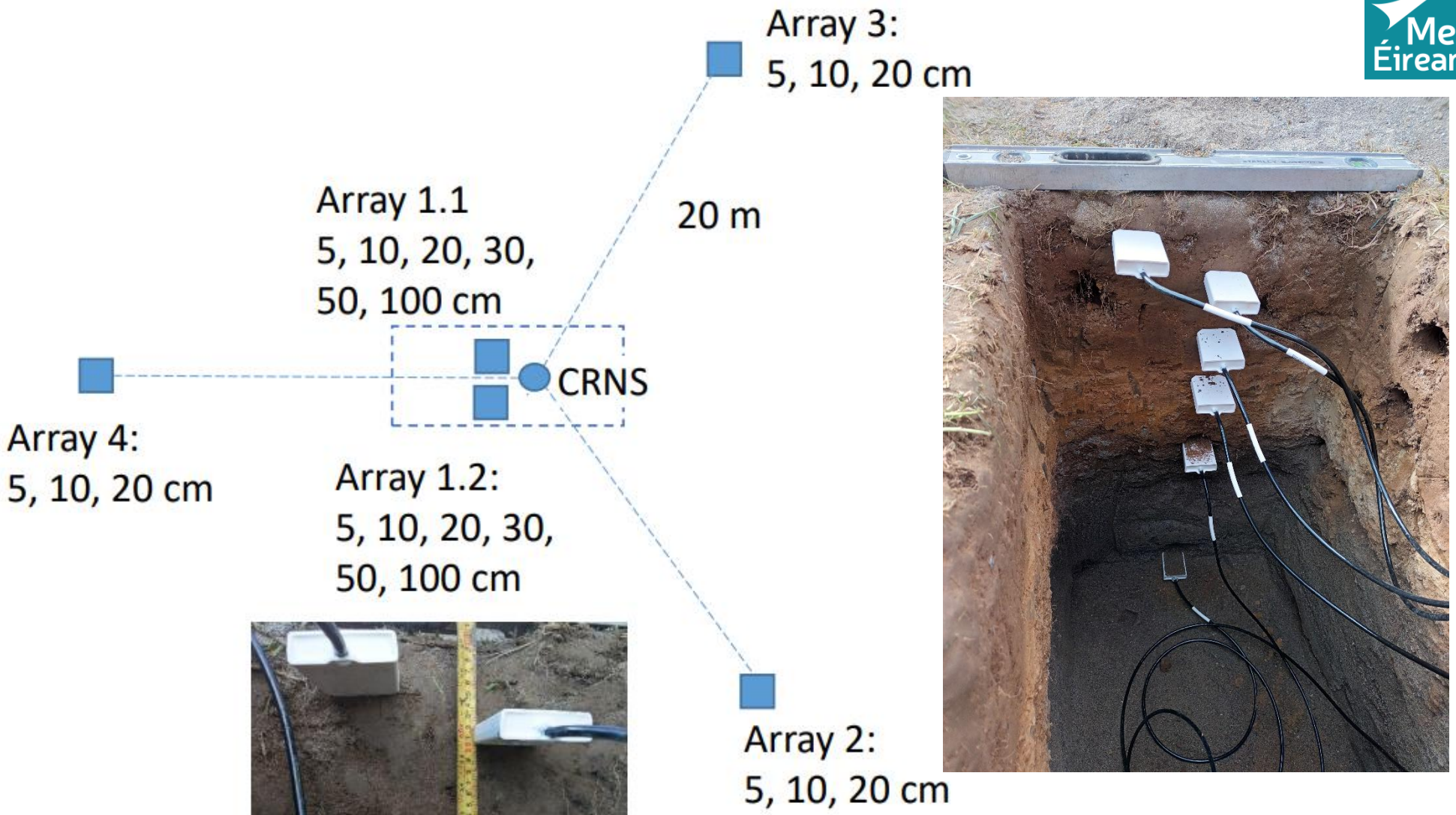
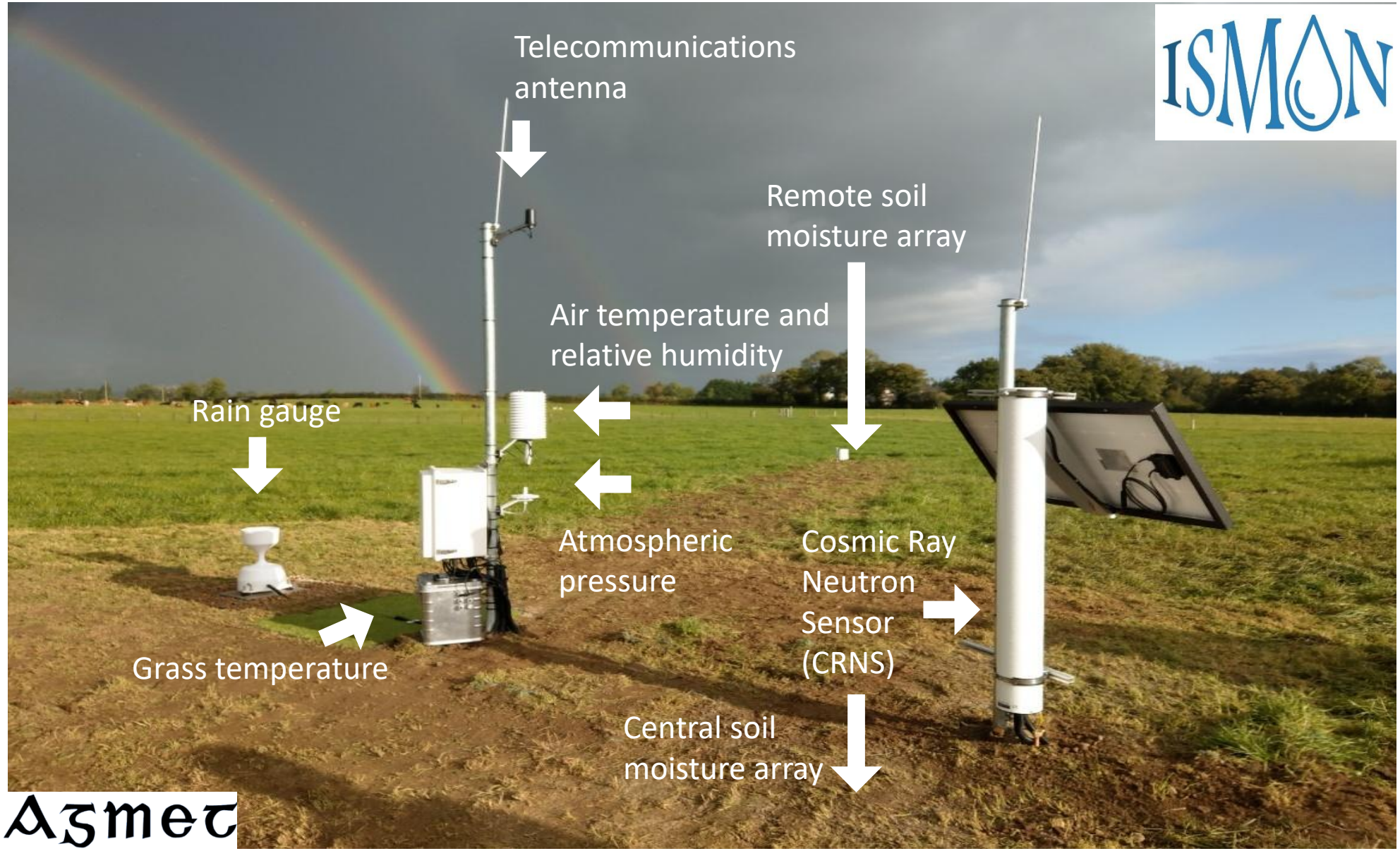
Local Government and Heritage

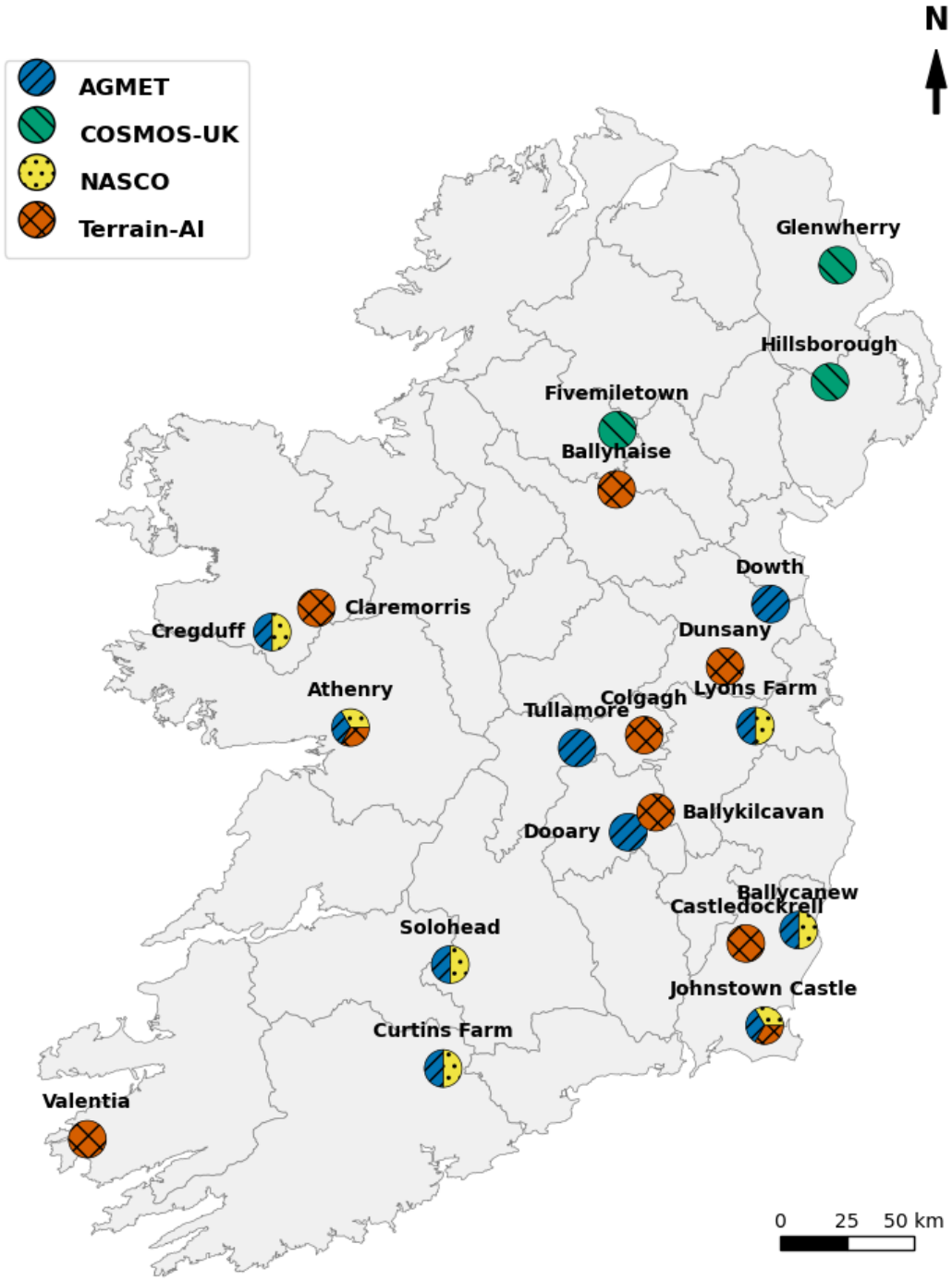
TDR Array Arrangement of AGMET Sites



Slide and picture by T. Hochstrasser, UCD



Tullamore installation of ISMON



AGMET Initiative ISMON

Irish Soil Moisture Observation Network

ISMON

ISMON Sites

- **AGMET:** 10 sites
- **Cosmos-UK:** 3 sites in NI
- **Teagasc NASCO:** 7 sites collocated with AGMET (National Agricultural Soil Carbon Observatory)
- **Terrain AI:** 9 sites, mostly at Met Eireann sites

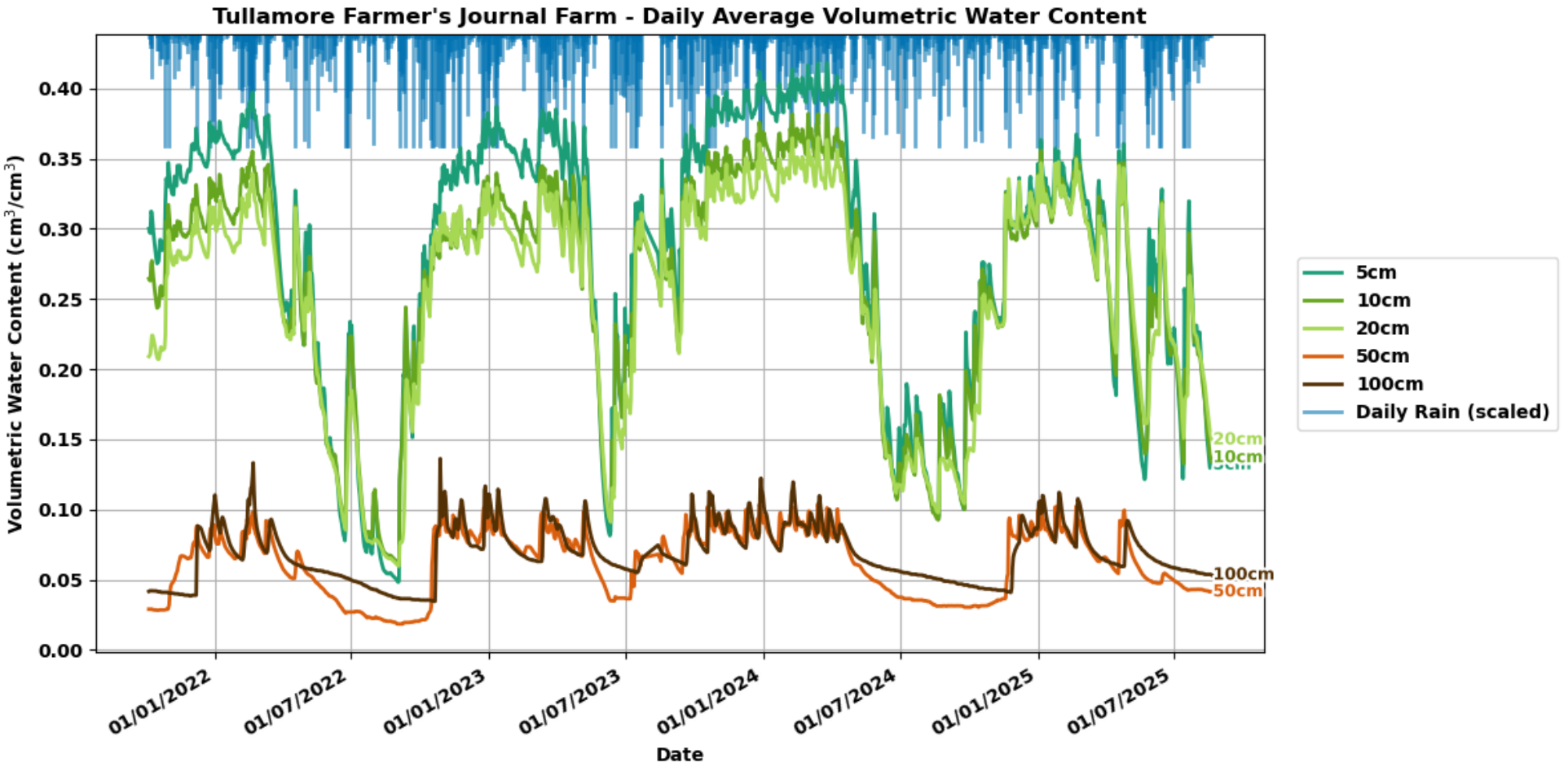
Dooray Forest, July 2023
Ground Truthing Campaign
Wettest July on record ☹

Paul Schattan's Finapp CRNS at Howth Harbour as saturation reference in July 2023

Daniel Rasche and Konstantin Shishkin at Ballycanew in July 2023

Second Ground Truthing campaign 2024 at Tullamore, Met Eireann team, Brian Tobin, Eve Daly

Tullamore Farmer’s Journal Farm
Daily Average Volumetric Soil Moisture by Haleh Karbala Ali



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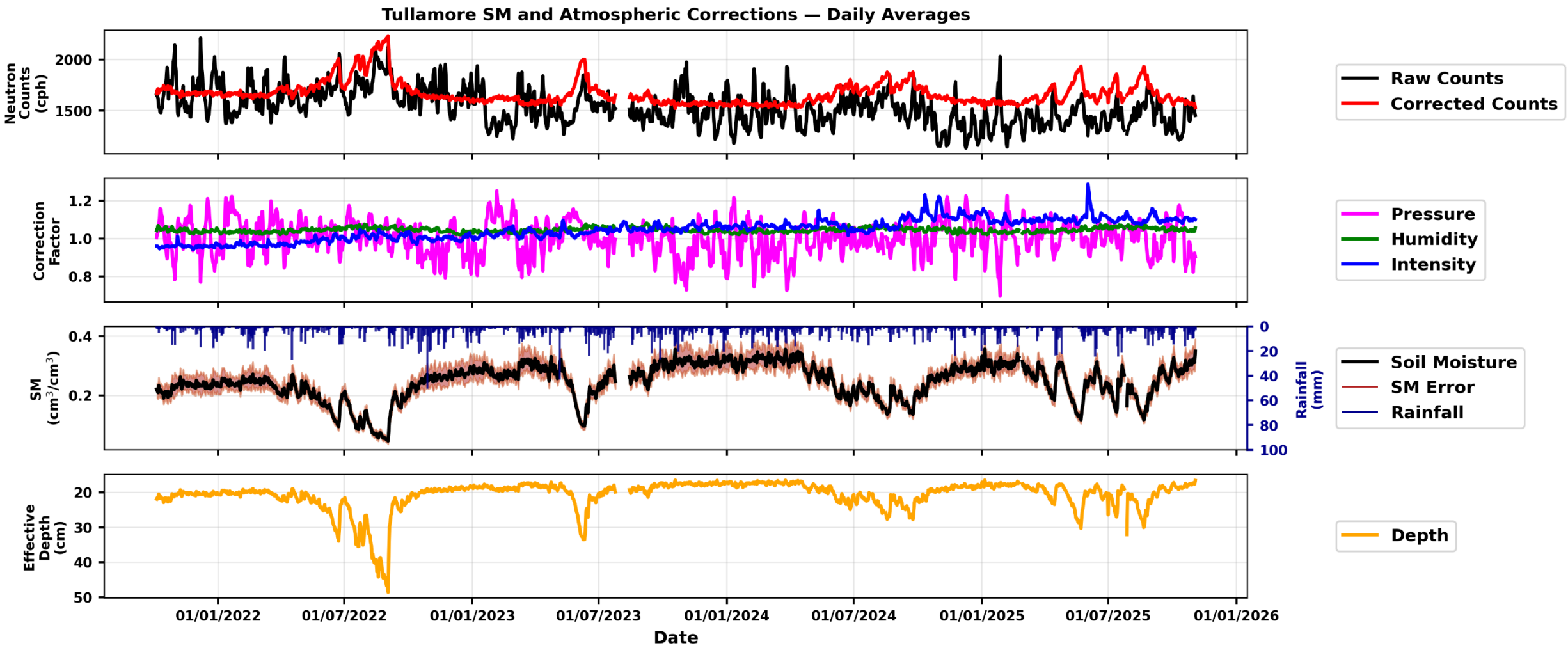
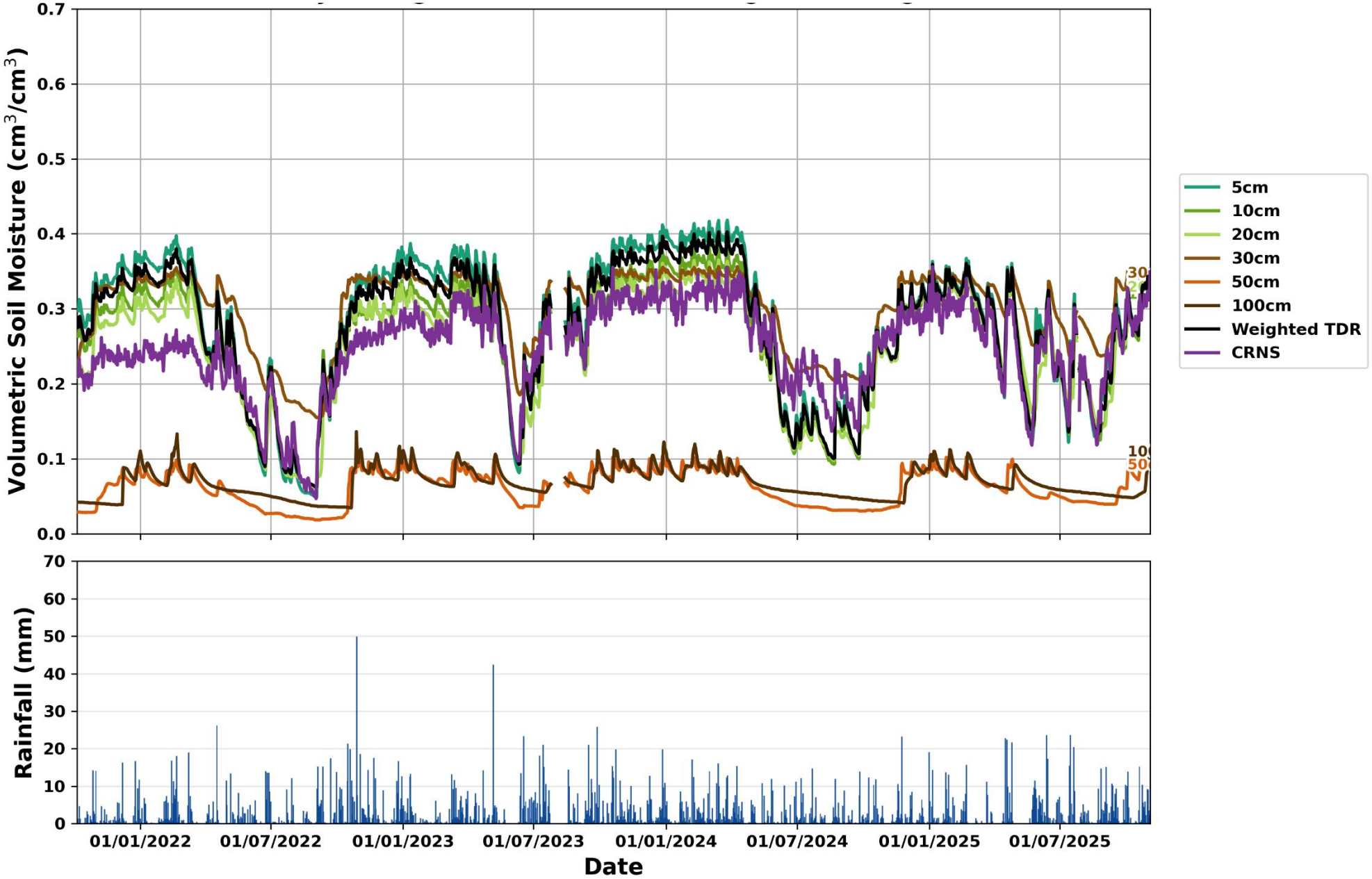
Karbala Ali, H., Finkele, K., Rosolem, R., Evans, J., Schrön, M., Tobin, B., and Daly, E.: Challenges and Opportunities with Soil Moisture Measurement in Ireland using Cosmic-Ray Neutron Sensing: Examples from an agriculture and a forest site, EGU General Assembly 2025, Vienna, Austria, 27 Apr–2 May 2025, EGU25-3236, https://doi.org/10.5194/egusphere-egu25-3236, 2025.

Raw Neutron Count Conversion to Daily Soil Moisture at Tullamore Farm



Soil Moisture at Tullamore Farmer's Journal Farm



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Local Government a

CRNS Sites	veg	Owner	Met Data	Co-location	Ground Truth	*Met & TDR Data avail.*	*CRNS Data*
Tullamore	grass	Farmers Journal	**AGMET**		2023, 2024	later this year ...	After publication
Dooray	**forest**	UCD	**AGMET**	ICOS	2023, 2024	Difficult site	After publication
Lyons Farm	grass	UCD	**AGMET**	**NASCO**	2023, K. Shishkin	Probably in 2027	Probably in 2027
Athenry	grass	Teagasc	**NASCO**	**Terrain AI**	K. Shishkin	Probably in 2027	Probably in 2027
Johnstown Castle	grass	Teagasc	**NASCO**	**Terrain AI**	K. Shishkin	Probably in 2027	Probably in 2027
Moorpark	grass	Teagasc	**NASCO**		K. Shishkin	Probably in 2027	Probably in 2027
Solohead	grass	Teagasc	**NASCO**		*Planned 2026*	Connection Issues	Probably in 2027
Ballycanew	grass	Teagasc	**NASCO**	ACP	2023, *Planned 2026*	Connection Issues	
Cregduff	grass	Teagasc	**NASCO**	ACP	*Planned 2026*	Logger Issues	
Dowth	grass	NPWS	Maynooth University		*Planned 2026*	Probably in 2027	

Konstantin Shishkin, O. Fenton, M. Schrön, K. Finkele, T. Hochstrasser, P. Murphy: Capturing Field-Scale Soil Moisture Dynamics in Ireland Using Cosmic-Ray Neutron Sensing, submitted to European Journal of Soil Science

Karbala Ali, et al. 2025. Review of Soil Moisture Measurements for Irish Observation Network. Technical Note No. 70 Met Éireann https://hdl.handle.net/20.500.14765/117465

Currently: data streaming, operationalizing, assesing

Lovett et al. (2007) in which they describe
'**The seven habits of highly effective monitoring progams**'

1. Design the program around clear and compelling scientific questions.
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National long term atmospheric measurement infrastructure & expertise

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Future Plans for Soil Moisture and ISMON

- Staff resources:
  - Cofunded Walsh Scholar Konstantin Shiskhin is finishing in September 2026
  - Post doc since April 2024, Haleh Karabala Ali
  - Senior Researcher and Researcher due to start
- Data is streamed to Met Eireann BUT not yet fully QC'd yet
- Phased release of data (internal, expert users, public) of
  - TDR data first
  - CRNS late. once we have sufficiently analysed the data
- Submitting SM data to the International Soil Moisture Data Base

Future Plans for Soil Moisture and ISMON

- Spatial coverage within the country
- Higher rainfall regimes in the west (increased sensitive CRNS)
- Soil types, especially peat (Gamma Ray Sensor)
- Soil moisture modelling and validation of CRNS data
- Data fusion of all network partner SM with satellite products to generate a **1km gridded daily SM estimate**

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International
Soil Moisture
Network

Current Work on ET and Future Plans

- Haneen Muhammad, Cofunded Walsh Scholar supervised by Conor Sweeny UCD, Gary Lanigan Teagasc, Klara Finkele & Padraig Flattery Met Eireann
- The plan is to use
  - NASCO and other flux tower obs of ET
  - Reanalysis data
  - Satellite data
  - SURFEX (Met Eireann operational NWP land surface model)
  - Machine learning

And produce a **1km gridded daily ET estimate**

How is ET Estimated? by Haneen Muhammad

Direct Measurements

- **Example:**

  Flux towers & Lysimeters

- **Pros:**

  ✅ Accurate

- **Cons:**

  ❌ Expensive

  ❌ Hard to maintain

  ❌ Point-scale

Equations

- **Example:**

  FAO-56 Penman-Monteith

- **Pros:**

  ✅ Accurate (when data is available)

- **Cons:**

  ❌ Requires local weather data

  ❌ Point-scale

Remote Sensing & Reanalysis

- **Example:**

  GLEAM, MOD16, ERA5, MERRA2

- **Pros:**

  ✅ Spatial coverage (regional/global)

- **Cons:**

  ❌ High uncertainty due to: sensors, algorithms, inputs

Need for Improved ET

- **Possible Solutions:**

❑ **Data Fusion**:

Correct and combine different ET sources.

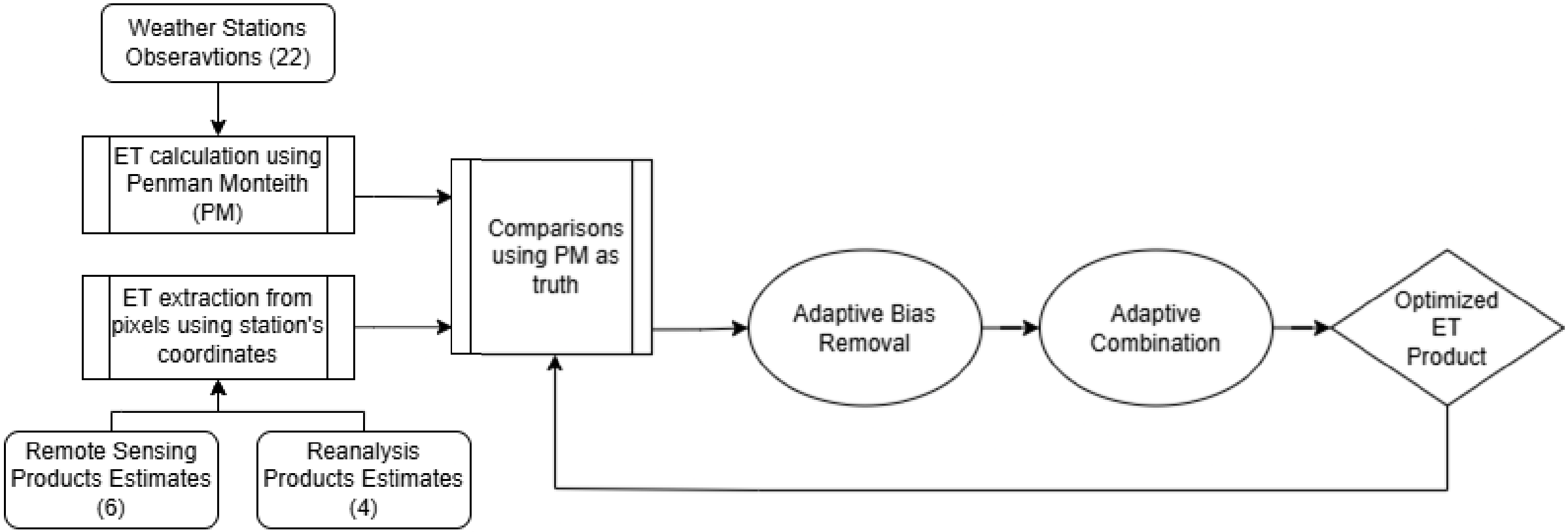
❑ **Land Surface Modelling**:

Calibrate model to local conditions.

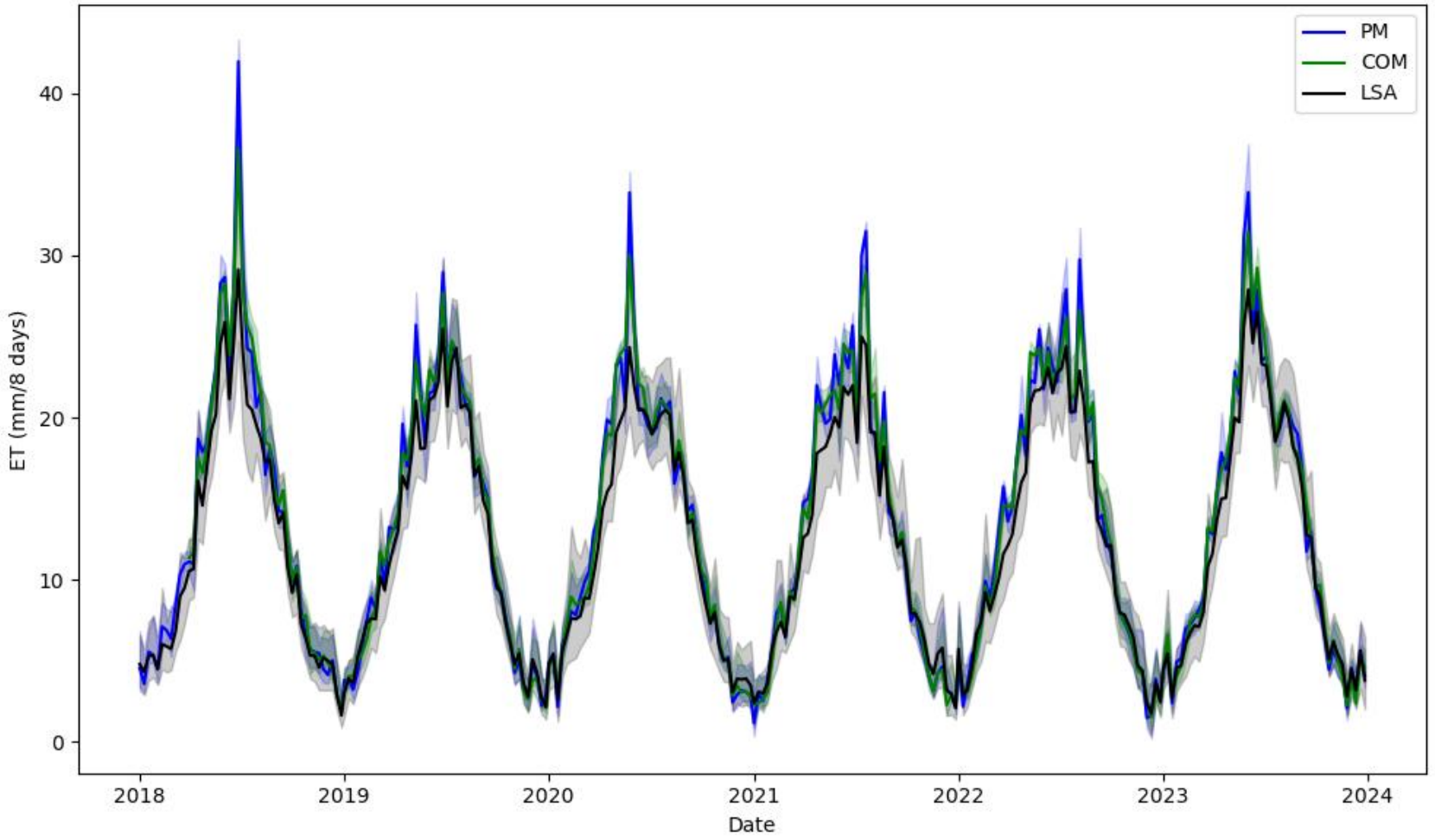
❑ **Machine Learning**:

Enhance ET estimates using multi-source data.

Paper 1 - An Adaptive Method to Estimate ET Using Satellite and Reanalysis Products



Results - Time Series

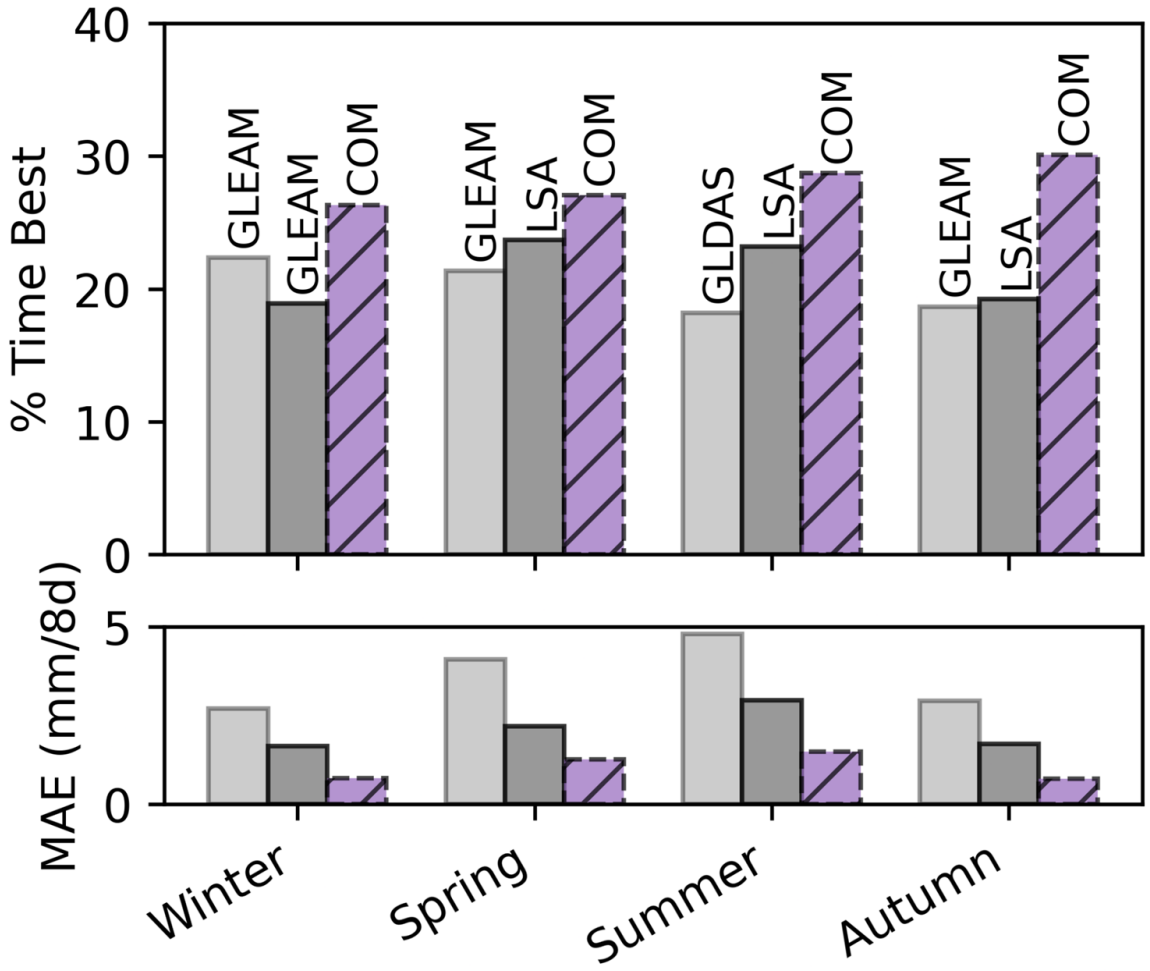


Single Product ✗

Static COM Product ✗

Adaptive COM product ✓

Results - Seasonality



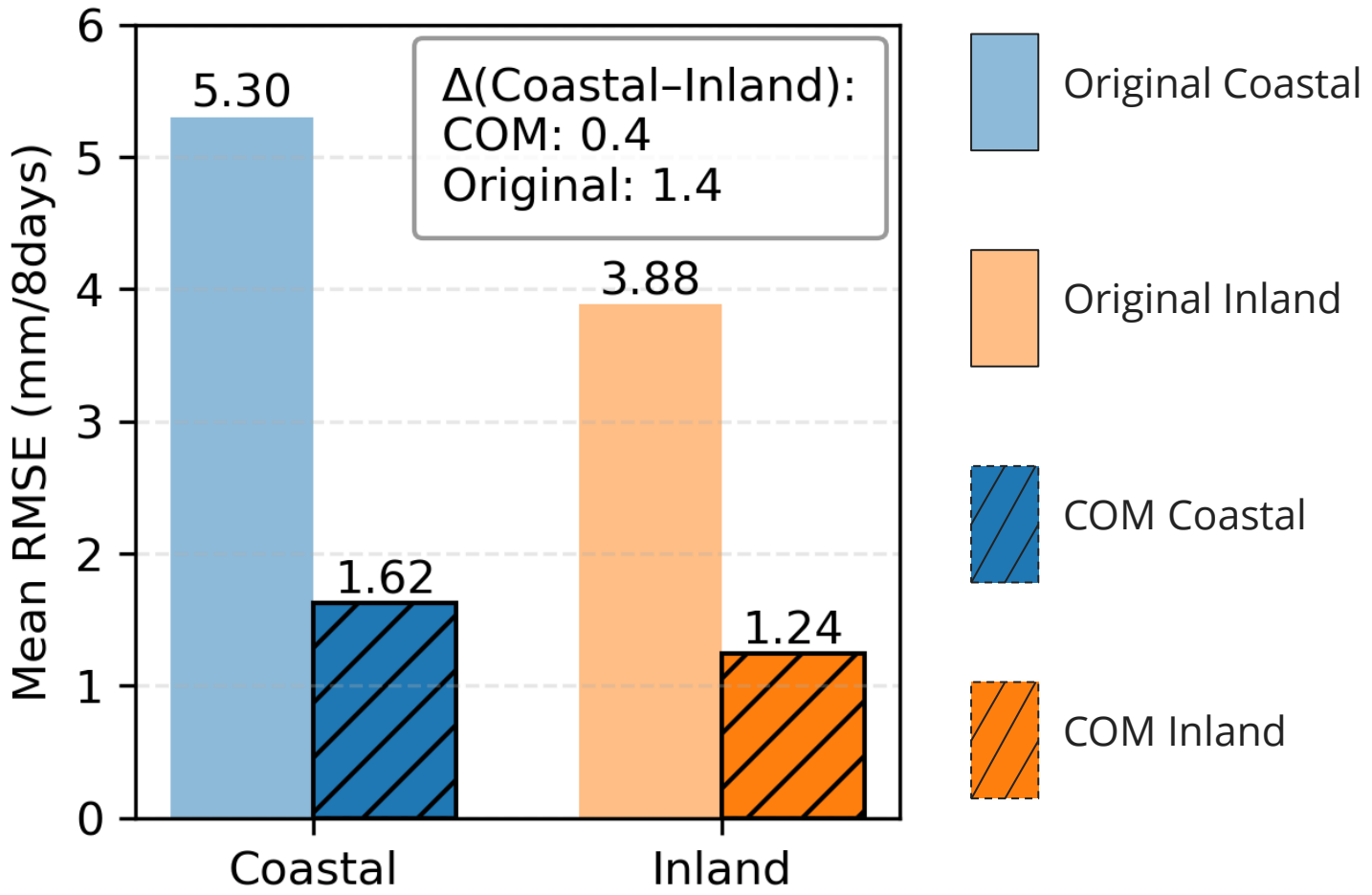
Original Product

AB Product

COM Product

COM was best during all Seasons

Results - Coastal and Inland

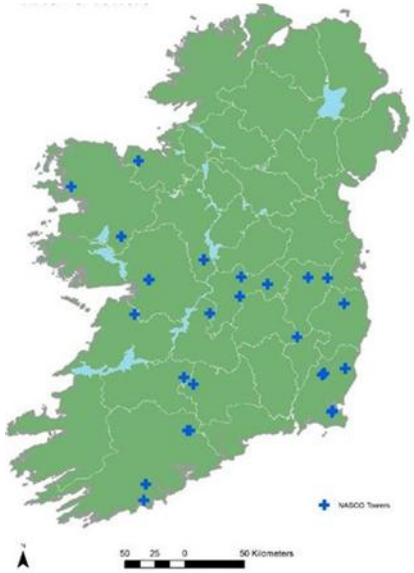


COM reduced the coastal-inland bias

Paper 1 - Under Review for HESS

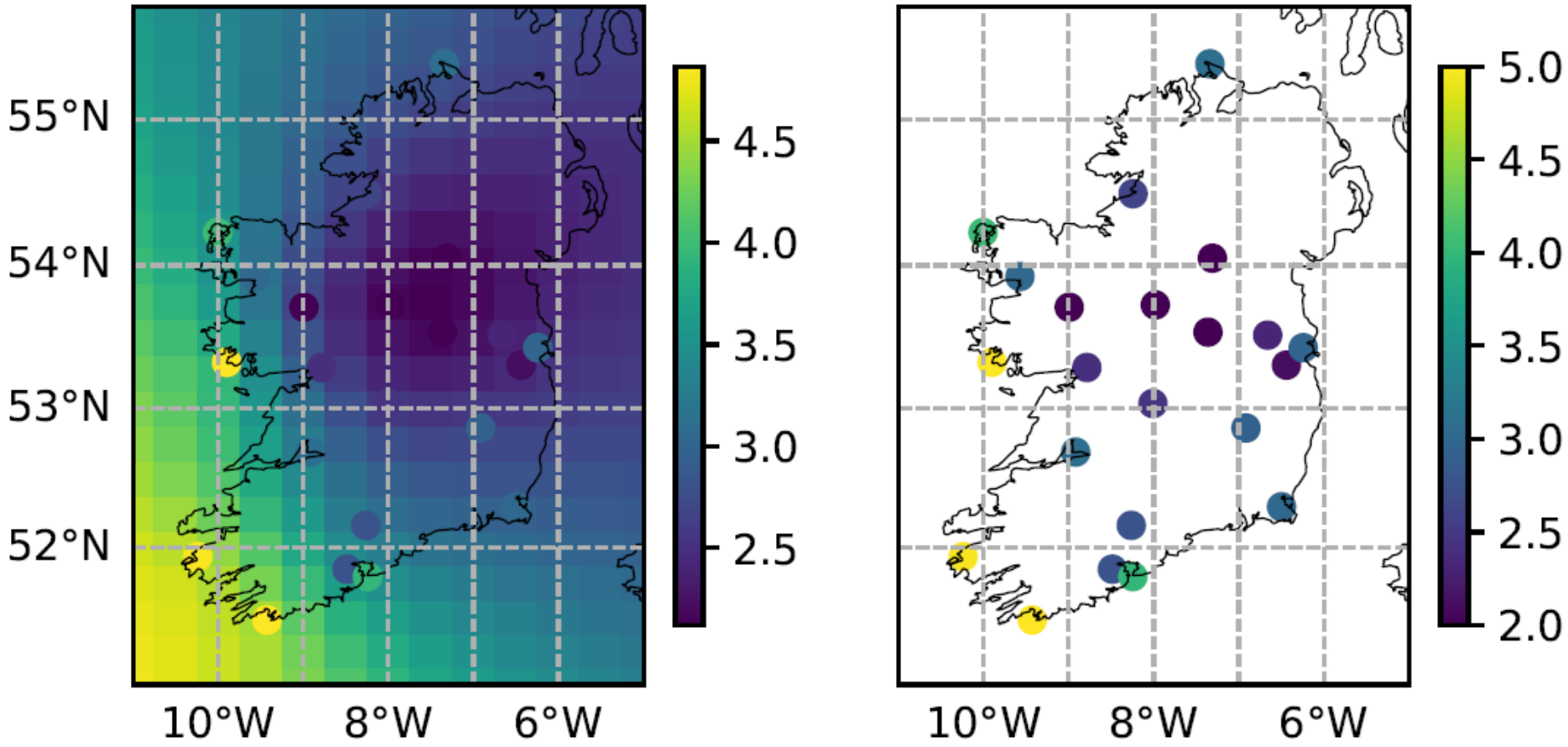
Next Steps …..

- Using NASCO and other flux tower obs of ET as the truth and apply the COM method

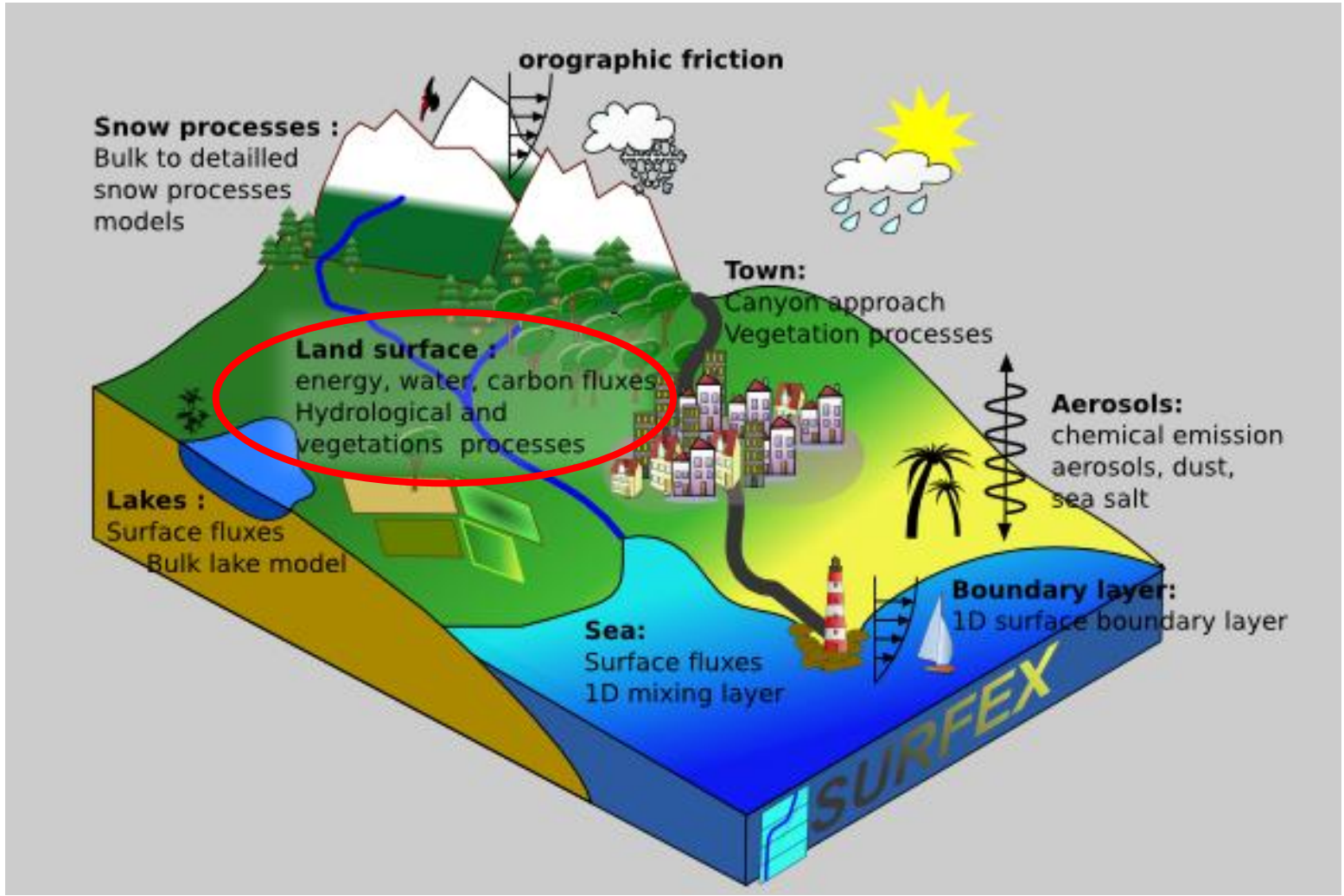


- Then use SURFEX and
  - Reanalysis data
  - Satellite data
  - SURFEX (Met Eireann operational NWP land surface model)
  - Machine learning

Paper 2 - Spatial Mapping

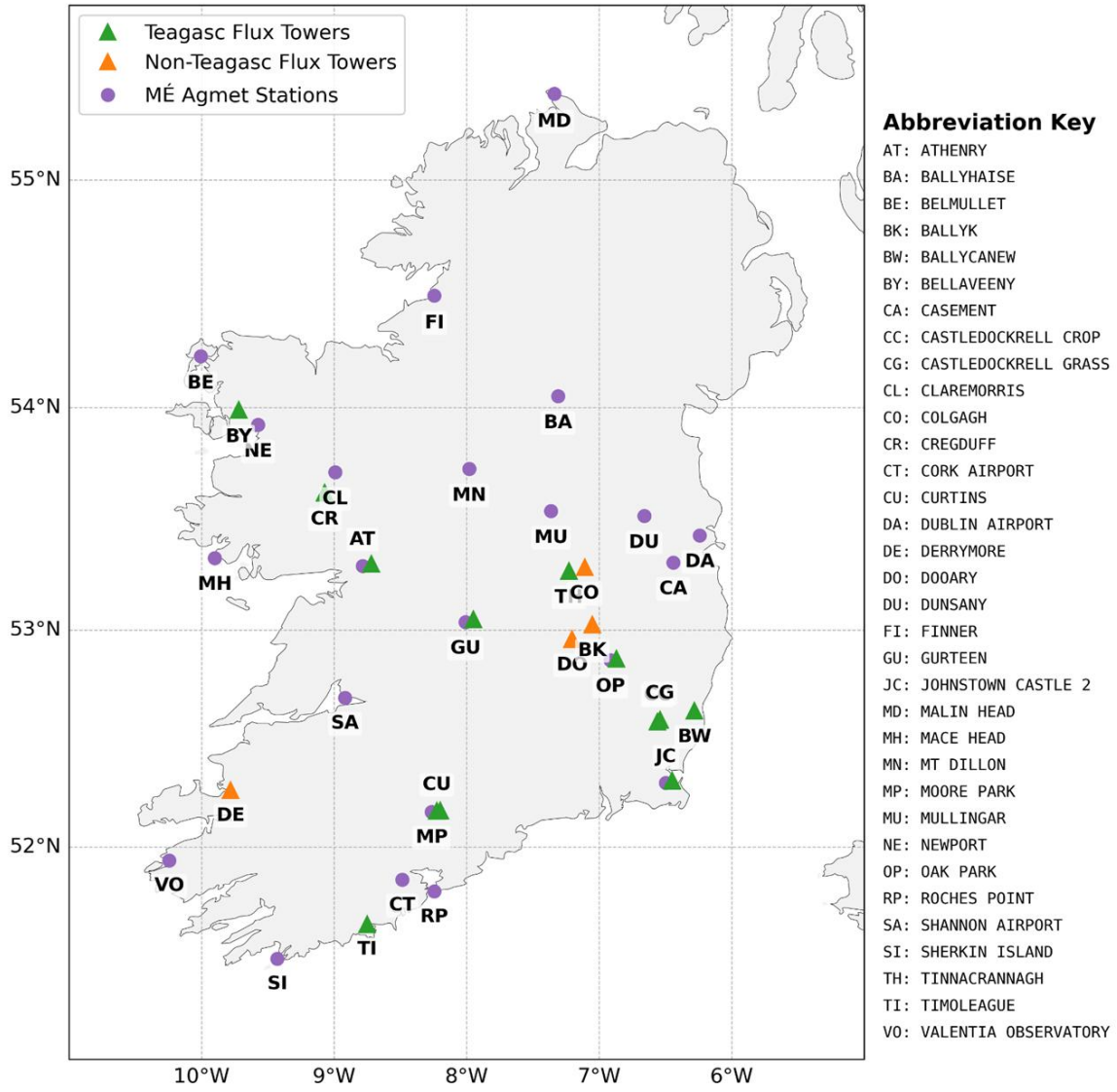


Paper 2 - Land Surface Modeling



Flux Towers Validation Sites

- 17 Sites:
  - 13 Teagasc.
  - 4 Non-Teagasc.
- Types:
  - 10 Grass.
  - 2 Tillage.
  - 2 Peat.
  - 2 Forest.
  - 1 Saltmarsh.



Thank you!

Terrain AI: TDR probe is a 1m SoilVuw10 https://s.campbellsci.com/documents/us/manuals/soilvue10.pdf

Volumetric water content (VWC), electrical conductivity (EC), permittivity, and temperature measurements at six depths over 0.5 m or nine depths over 1.0 m using one probe

SoilVue™10

Complete Soil Profiler

ISMON	Model	
Cosmic Ray Neutron Sensor (CRNS)	CRS2000/B moderated sensor from Hydroinnova (average power consumption 47 mA)	
Soil moisture probes measuring: • Soil electrical conductivity (EZZZC) • Relative dielectric permittivity • Volumetric water content (VWC) • Soil temperature	CS655 (Time-domain reflectometer) – 12 cm rods Accuracy: ±1% (with soil-specific calibration) where solution EC < 3 dS/m ±3% (typical with factory VWC model) where solution EC < 10 dS/m.	
Atmospheric pressure	PTB210: Vaisala instruments. Range: 500-1100 hPa Resolution: 0.01 hPa Power consumption <8mA	A 
High precision rain gauge	Campbell Scientific ARG 314 Resolution: 0.1 mm/ tip	
Air and grass platinum resistance thermometer	PT100 corresponding to IEC60751 Class B specifications. Resolution 0.001 degree C. Air temperature is mounted in a Stevenson screen at 1.25 m height. Grass temperature sensor is mounted in the middle of a 1x1 m patch of artificial grass.	
Relative humidity	Vaisala's HMP155 (3 mA power consumption). Settling time is: 20 seconds at 63% humidity;60 seconds at 90% humidity	