Fiducial Reference Measurements for Soil Moisture (FRM4SM): Where do we stand?

A. Gruber, I. Himmelbauer, W. Preimesberger, P. Stradiotti, D. Aberer, W. Dorigo, A. Boresch, M. Tercjak, F. Gibon, A. Mialon, P. Richaume, Y. Kerr, R. Crapolicchio, R. Sabia, R. Díez-García, K. Scipal, and P. Goryl

Fiducial reference measurements

According to the GEO/CEOS Quality Assurance Framework for Earth Observation (QA4EO), Fiducial Reference Measurements (FRMs) should:

- have **documented SI traceability** using metrology standards and/or community-recognized best practices
- have **documented and maintained uncertainty budgets** that are openly available
- be **independent** from the satellite geophysical retrieval process
- accompanied by **measurement protocols, procedures, and community-wide management practices** that are defined, published, and adhered to by FRM instrument operators
- be **accessible to other researchers** allowing the independent verification of processing systems
- be **used to to quantify the in-orbit uncertainty characteristics** of satellite geophysical measurements via **independent validation activities**

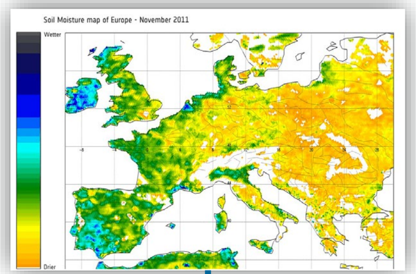
Traceability according to the International Vocabulary for Metrology (VIM):

- property of a measurement result whereby the result can be related to a reference through a **documented unbroken chain of calibrations**, each contributing to the measurement uncertainty

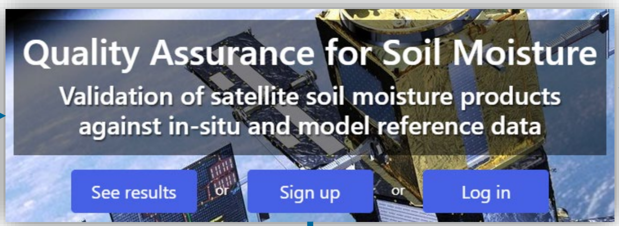
Fiducial reference measurements for soil moisture

The Fiducial Reference Measurements for Soil Moisture (FRM4SM) project:

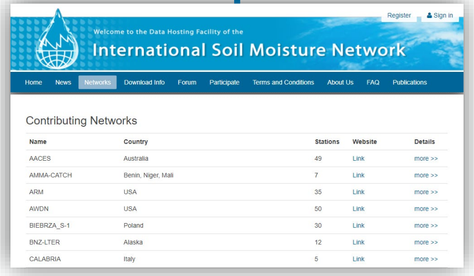
Satellite soil moisture data



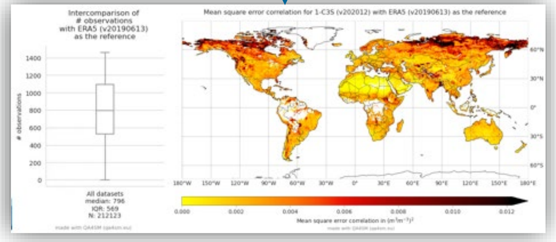
Online Validation Service
https://qa4sm.eu/



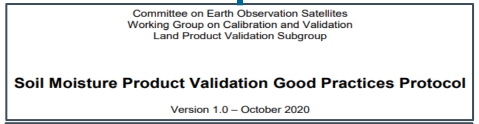
‘FRM super site’ selection based on QIs and **FRM Protocols and Procedures (FPP_SM)** developed in FRM4SM



Dorigo et al. (2022): *“The International Soil Moisture Network: serving Earth system science for over a decade”.* DOI: 10.5194/hess-25-5749-2021

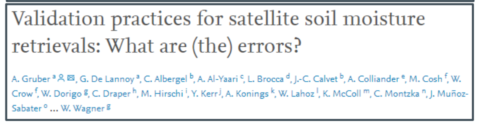


Standardized validation and intercomparison repors


Committee on Earth Observation Satellites
Working Group on Calibration and Validation
Land Product Validation Subgroup

Soil Moisture Product Validation Good Practices Protocol

Version 1.0 – October 2020


Validation practices for satellite soil moisture retrievals: What are (the) errors?

A. Gruber, G. De Lannoy, C. Albergel, A. Al-Yaari, L. Brocca, J.-C. Calvet, A. Colliander, M. Cosh, W. Crow, W. Dorigo, C. Draper, M. Hirschi, Y. Kerr, A. Konings, W. Lahoz, K. McColl, C. Montzka, J. Muñoz-Sabater ... W. Wagner

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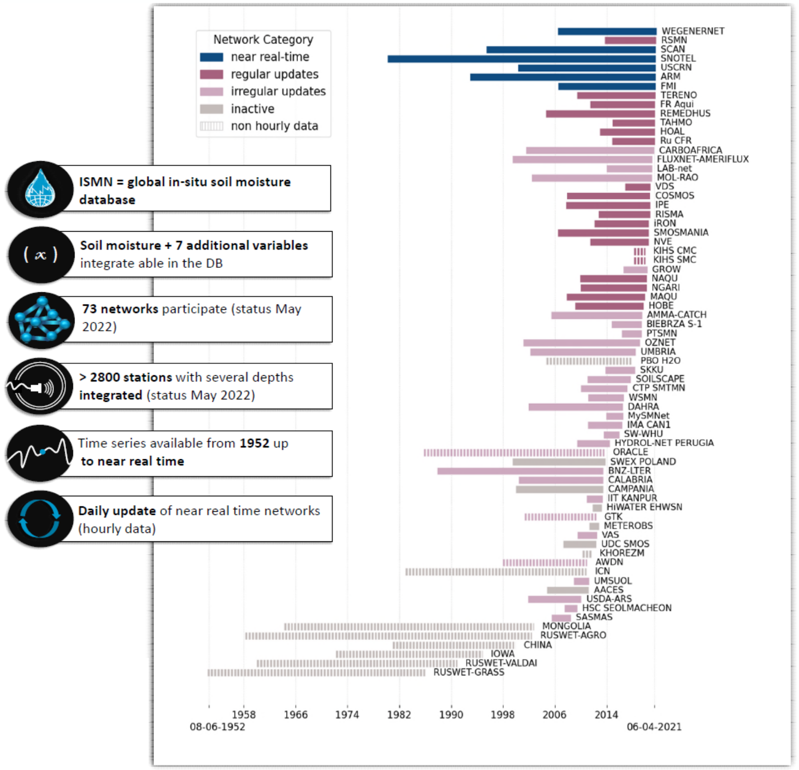
Montzka et al. (2020). *“Soil Moisture Product Validation Good Practices Protocol”*. CEOS WGCV LPV. DOI: 10.5067/doc/ceoswgcv/lpv/sm.001

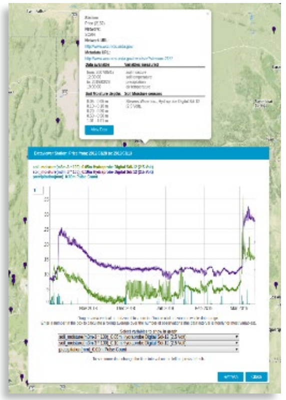
https://project-frm4sm.geo.tuwien.ac.at

International Soil Moisture Network (ISMN)

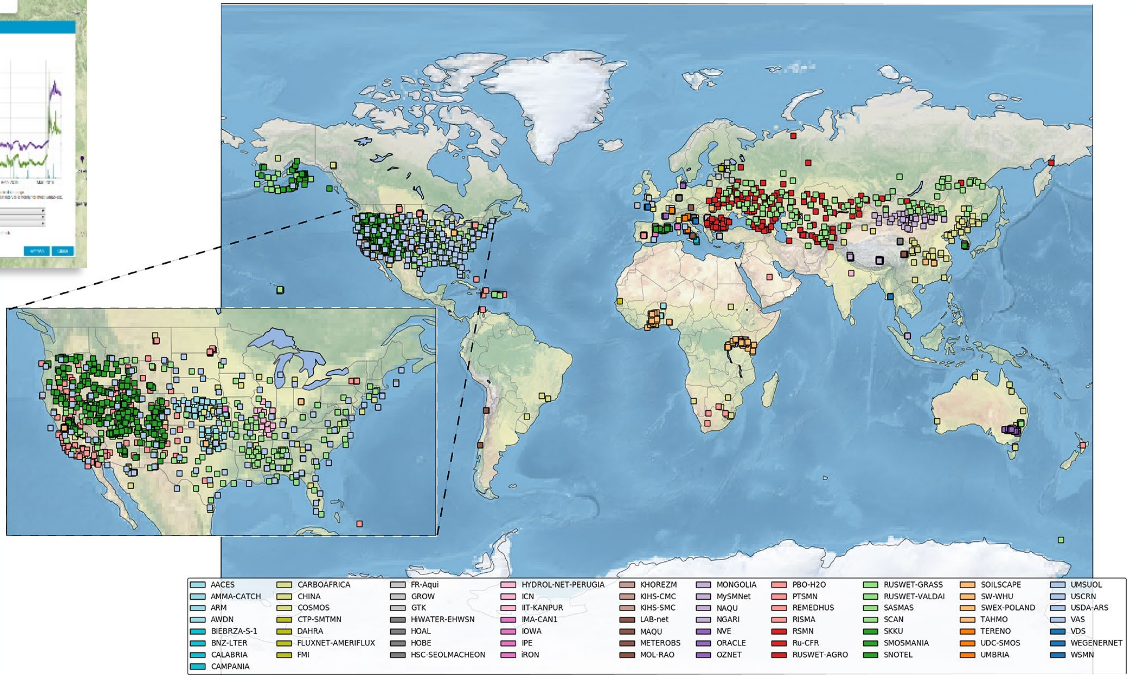
- The largest freely accessible data base for soil moisture ground measurements
- Data versioning system (DOI) developed as part of FRM4SM
    - See DT1-1: “ISMN Flagging/QC R&D”

Dorigo et al. (2022): *“The International Soil Moisture Network: serving Earth system science for over a decade”.* DOI: 10.5194/hess-25-5749-2021



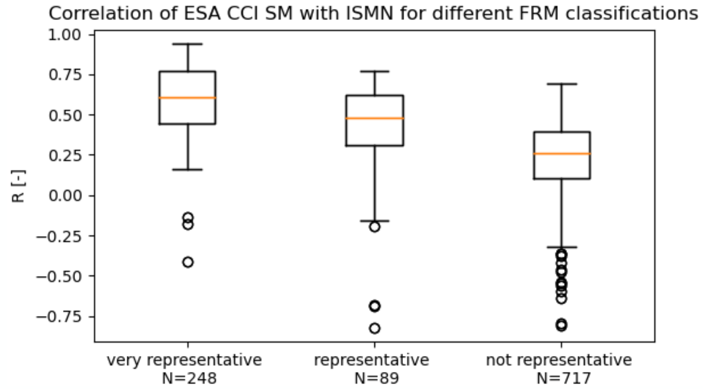


https://ismn.earth

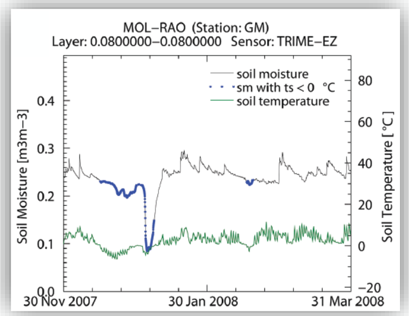


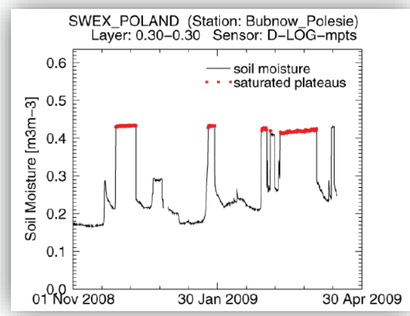
International Soil Moisture Network (ISMN)

- Automated QC is applied to ISMN measurements
- New quality indicators have been tested and developed in FRM4SM
  - See [DT1-1: "ISMN Flagging/QC R&D"]
  - Most important new QI: Spatial representativeness

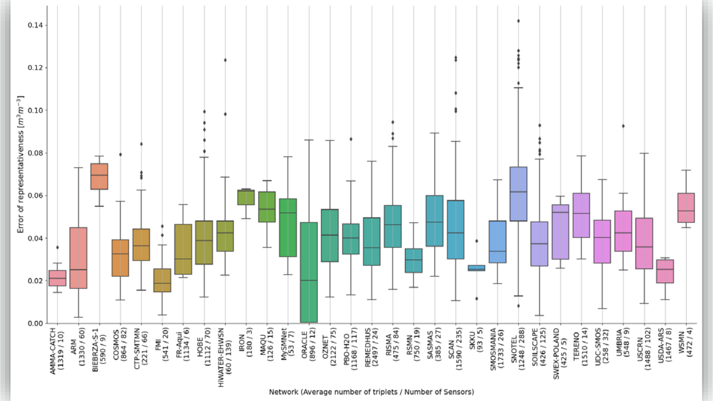


Automated flagging





Estimates of spatial representativeness



Estimated SNR*	QI class
NaN	representativeness unknown
< 0 dB	not representative
0 - 3 dB	representative
> 3 dB	very representative

Set SNR to NaN if:
\# samples < 100
CI(80%) > 3dB

Dorigo et al. (2013): *"Global Automated Quality Control of In Situ Soil Moisture Data from the International Soil Moisture Network"*. DOI: 10.2136/vzj2012.0097

Quality Assurance for Soil Moisture (QA4SM)

The QA4SM framework is developed to foster the application of community-agreed good practice guidelines

- An online platform to Make. It. Easy.
- Utilizing the most reliable ISMN FRM subset
- Implementing good practice guidelines endorsed by CEOS,…
- **Poster and live demo will be given by Wolfgang Preimesberger**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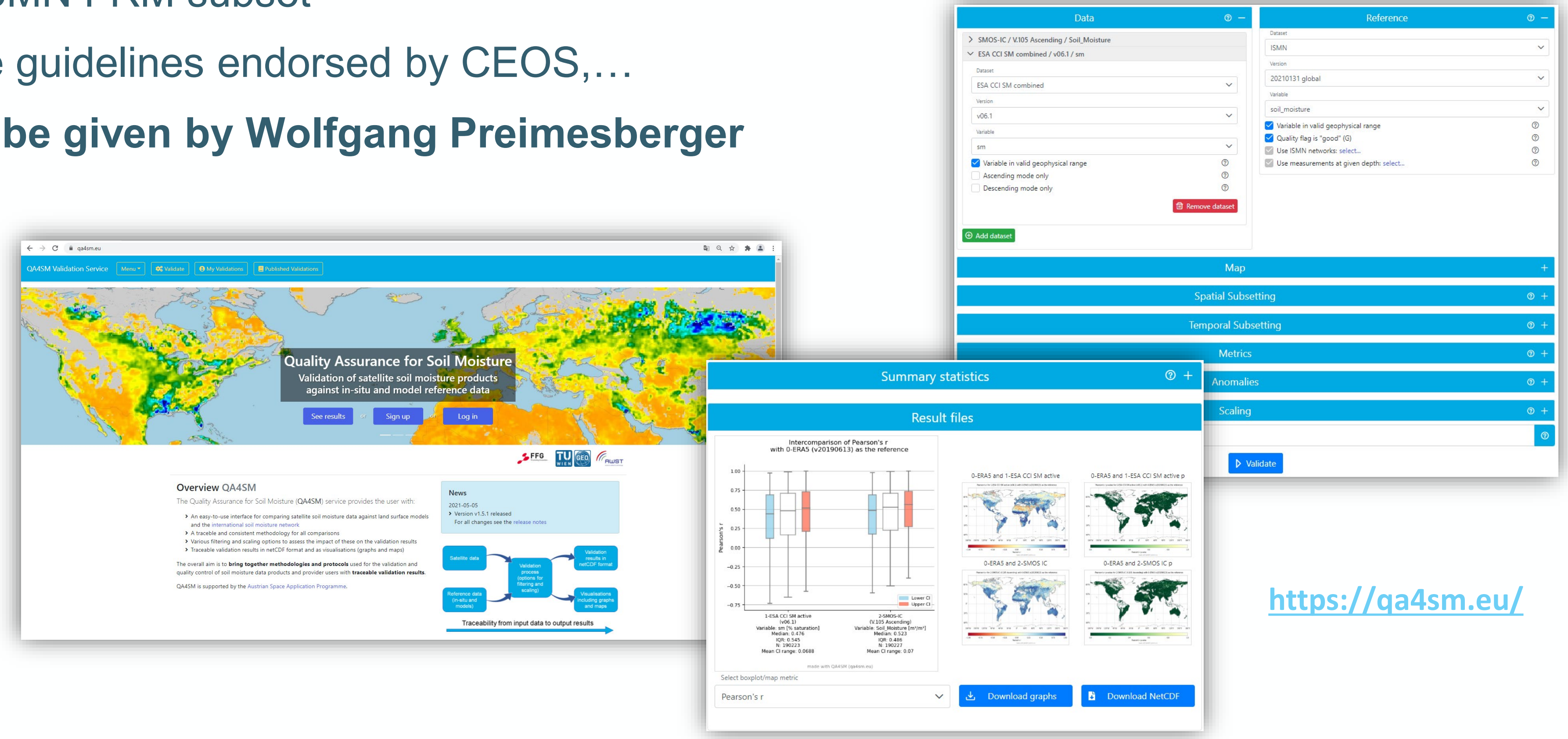


https://qa4sm.eu/

Traceability

- Establishing traceability following the QA4EO guidelines:
  - Defining the measurand and the measurement model
  - Using a traceability diagram to identify all possible sources of uncertainty (“effects”)
  - Assessing the magnitudes of these effects and the confidence in these estimates
  - Calculating an uncertainty budget according to metrological best practices defined in the [Guide to the Expression of Uncertainty in Measurement (GUM)]

- The measurand is **soil moisture at the satellite footprint scale**!

$SM^{g}_{t_g} = c(\mathbf{X}^{\mathbf{g}}_{\mathbf{t_g}}, \mathrm{C}) + 0$	➢ SM(ground scale, ground sampling time, sensor unit)	***Sensor reading***
$SM^{g'}_{t_g} = u(\mathbf{SM}^{\mathbf{g}}_{\mathbf{t_g}}, \mathrm{U}) + 0$	➢ *SM(ground scale, ground sampling time, satellite unit)*	***Unit conversion***
$SM^{g'}_{t_s} = t(\mathbf{SM}^{\mathbf{g'}}_{\mathbf{t_g}}, \mathrm{T}) + 0$	➢ *SM(ground scale, satellite overpass time, sensor unit)*	***Temporal alignment***
$SM^{s}_{t_s} = s(\mathbf{SM}^{\mathbf{g'}}_{\mathbf{t_s}}, \mathrm{S}) + 0$	➢ *SM(satellite scale, satellite overpass time, sensor unit)*	***Spatial scaling***

Traceability

- Traceability diagram and effects table
  - For details, see DT2-1: FRM Protocols and Procedures for Soil Moisture

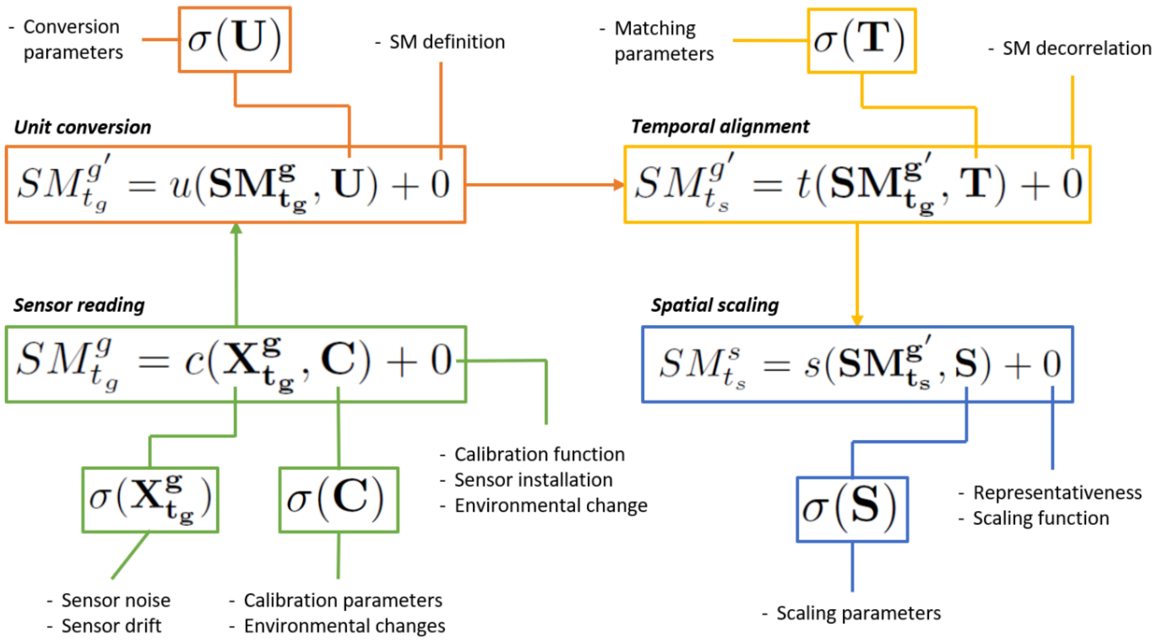
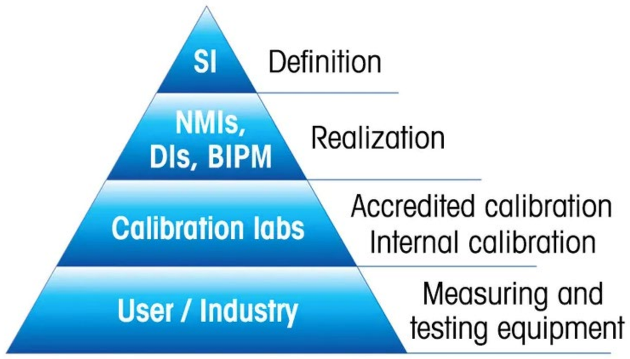


Table 1: Effects table. The following coding is used. Type: R=Random, S=Systematic; Correlated: Y=Yes, N=No, P=Potentially; Confidence: 0=Effects identified, no quantification; 1=Estimates only; 2: Some analysis performed to evaluate; 3: Rigorous analysis performed. Magnitudes are given in $m^3\,m^{-3}$; * assuming that some experience with sensor installation is given; ** not including total sensor loss

Effect	Type	Correlated	Magnitude	Confidence
Sensor drift	S	N	0	1
Calibration function	S	P	0.01–0.07	2
Calibration parameters	S	P	0.0–0.07	2
Sensor installation	S	P	0–0.5*	1
Environmental factors	R+S	P	0–0.7**	1
Conversion parameters	S	P	0.01 –0.03	1
SM definition	S	P		0
Matching parameters	S	P	0–0.01	1
SM decorrelation	R	P	0–0.04	2
Scaling parameters	S	P	0.05–0.1	1
Scaling function	S	P	0.05–0.1	1
Spatial representativeness	R	P	0.01–0.07	3

Traceability

- Obstracles for **traceability to SI**
  - Sensor manufacturer information often obscure
  - Little known to account for lab-to-field transition
    - Soil types, etc.
  - Little known about the change in uncertainty over time
    - Environmental wear
    - Re-calibration
    - Sensor replacement



Source: q&more

- **Controlled long-term field experiments are needed to obtain reliable estimates for the uncertainty associated with the above-mentioned effects**

Where do we stand?

FRMs ought to:

✓ be **independent** from the satellite geophysical retrieval process

✓ be **accessible to other researchers**

✓ be used to to **quantify the uncertainty** of satellite measurements via **independent validation activities**[1]

❍ be accompanied by **measurement protocols, procedures, and community-wide management practices** that are defined, published, and adhered to by FRM instrument operators

❍ have **documented SI traceability** using metrology standards and/or community-recognized best practices

- have **documented and maintained uncertainty budgets** that are openly available

[1]Tue, 13 June, 12:20: "*Uncertainty budget analysis of the validation of soil moisture estimated by coarse resolution remote sensing: application to SMOS" by* François Gibon

FRM4SM roadmap

- New QIs for in situ measurements and stations will be developed
- Gaps in validation good practice guidelines will be filled
- The QA4SM will be developed further to better accommodate user's needs and to provide a documented and maintained uncertainty budget for the reference data available on the platform
- Uncertainty effects will be investigated further to approach a high-confidence end-to-end uncertainty budget
- Guidelines for what is needed to establish ground reference networks that can be considered "fiducial reference networks" for satellite soil moisture validation will be developed building on existing recommendations[1] and in collaboration with the community

[1]Thorne et al. (2018): *"Towards a global land surface climate fiducial reference measurements network"*. DOI: 10.1002/joc.5458


Q&A