



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

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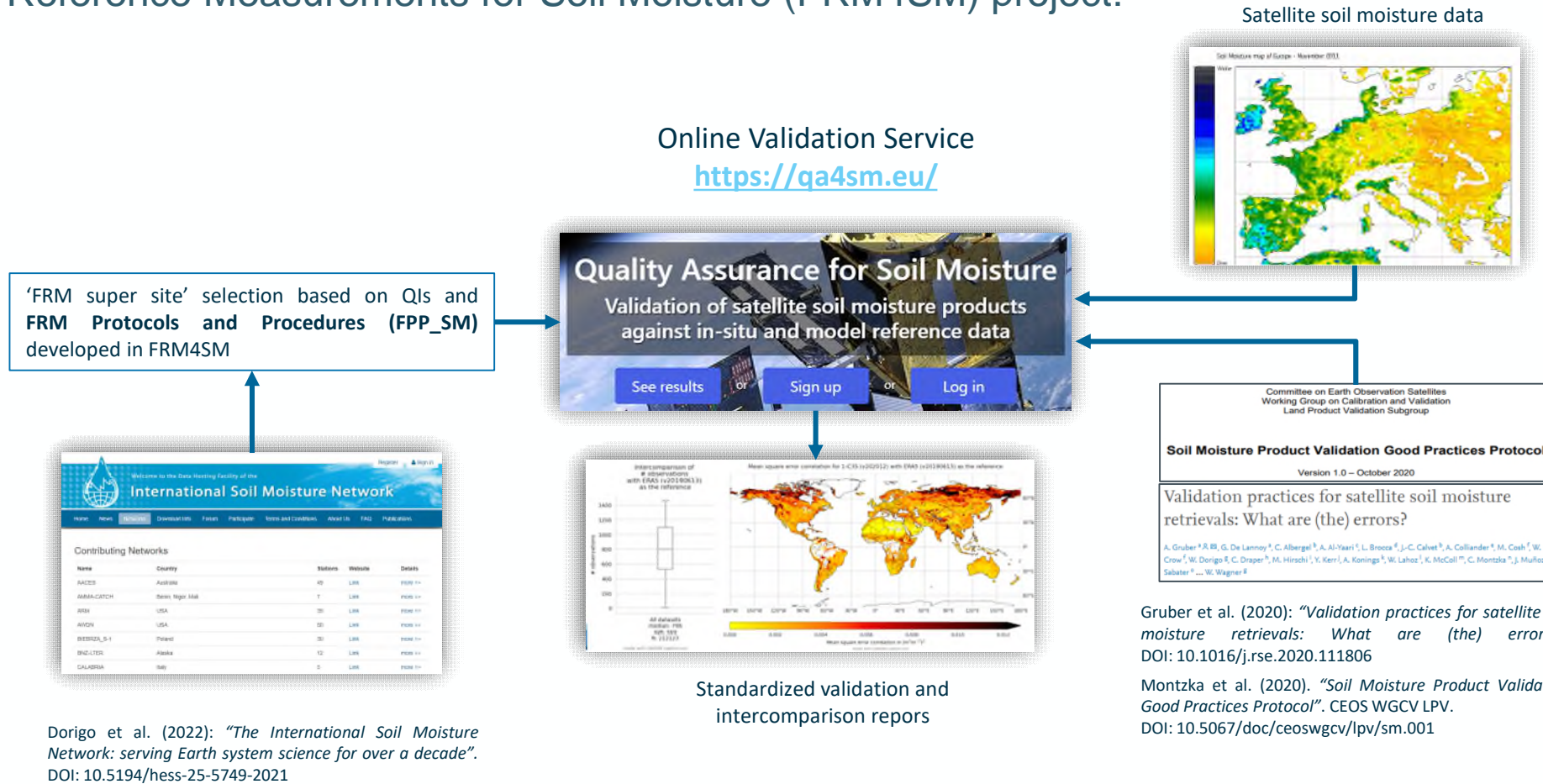
According to the GEO/CEOS Quality Assurance Framework for Earth Observation (QA4EO), Fiducial Reference Measurements (FRMs) should:

- 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 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

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

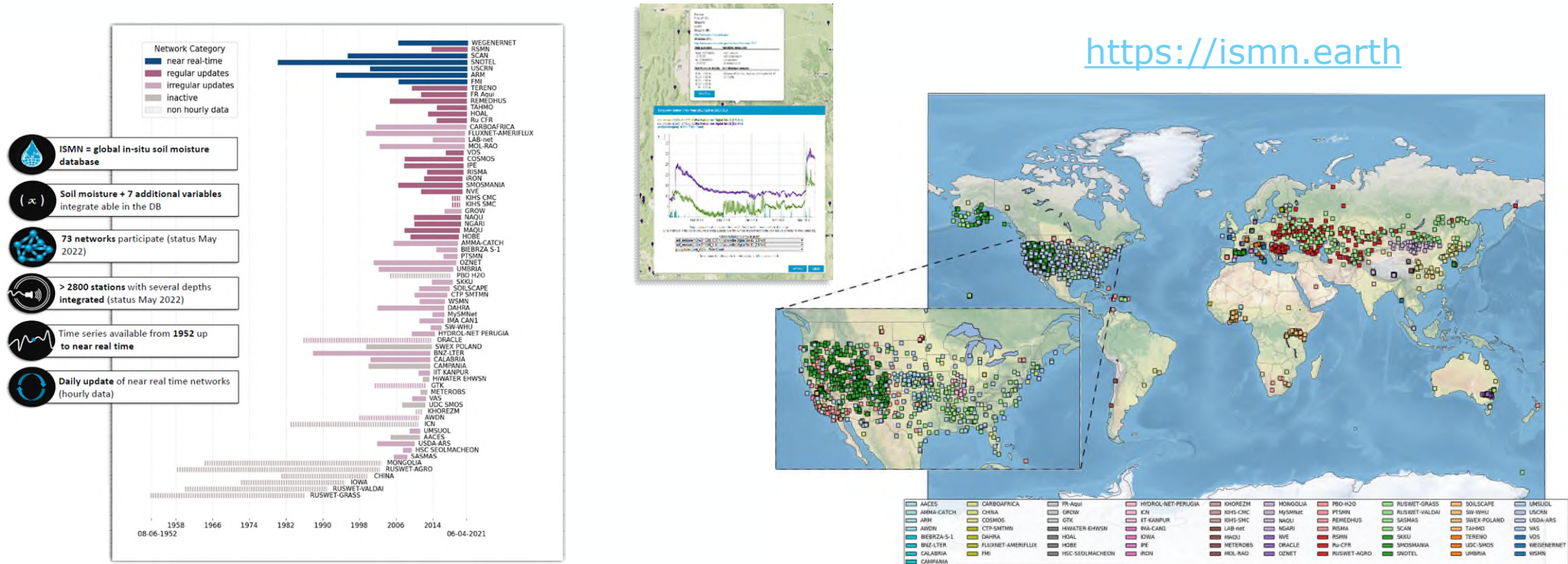


<https://project-frm4sm.geo.tuwien.ac.at>

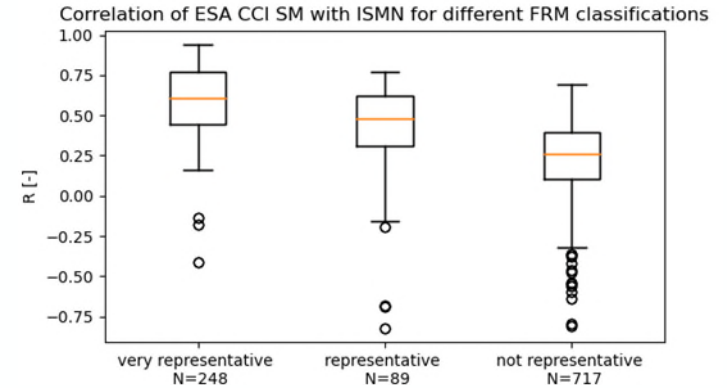
International Soil Moisture Network (ISMN)

- 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"](#)

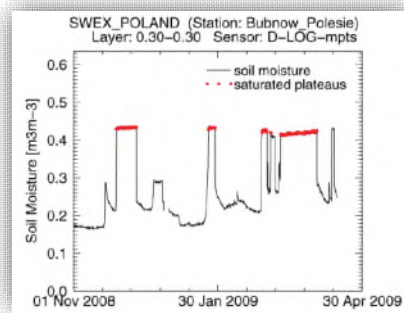
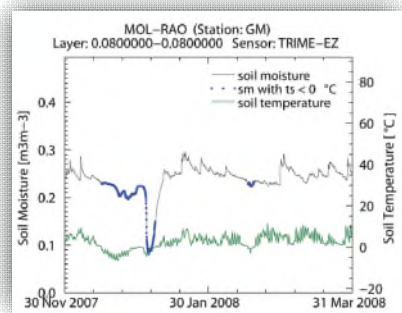
Dorigo et al. (2022): "The International Soil Moisture Network: serving Earth system science for over a decade". DOI: 10.5194/hess-25-5749-2021



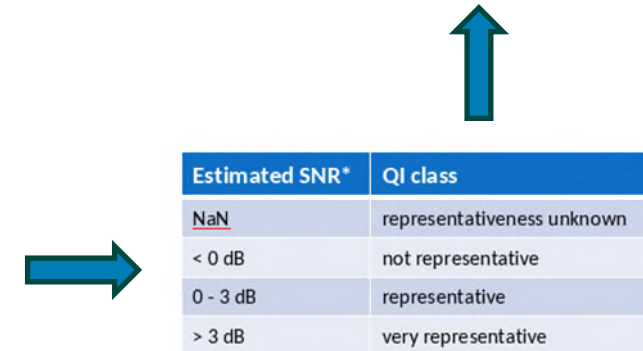
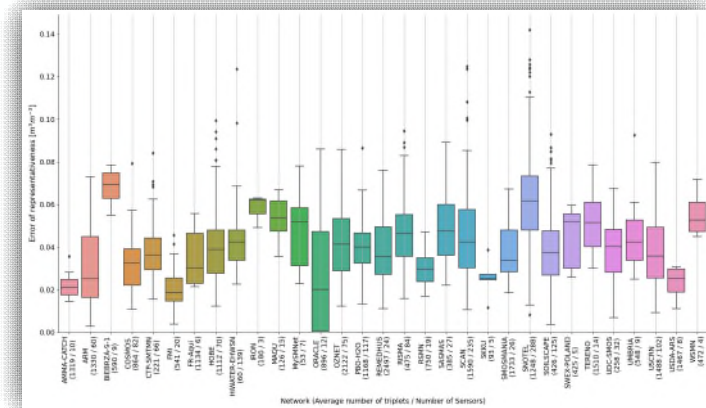
- Automated QC is applied to ISMN measurements
- New quality indicators have been tested and developed in FRM4SM
 - See [DT1-1: "ISMN Flagging/QC R&D"](#)
 - Most important new QI: Spatial representativeness



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)



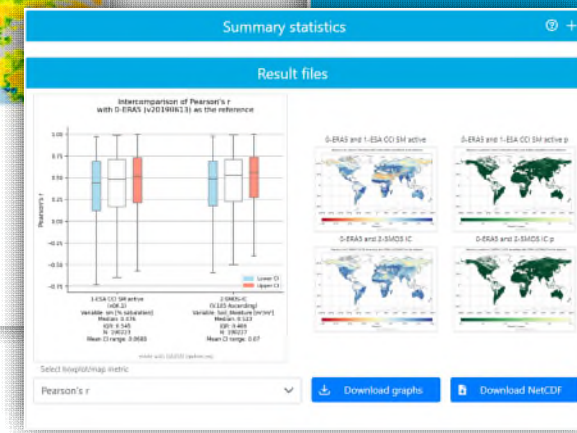
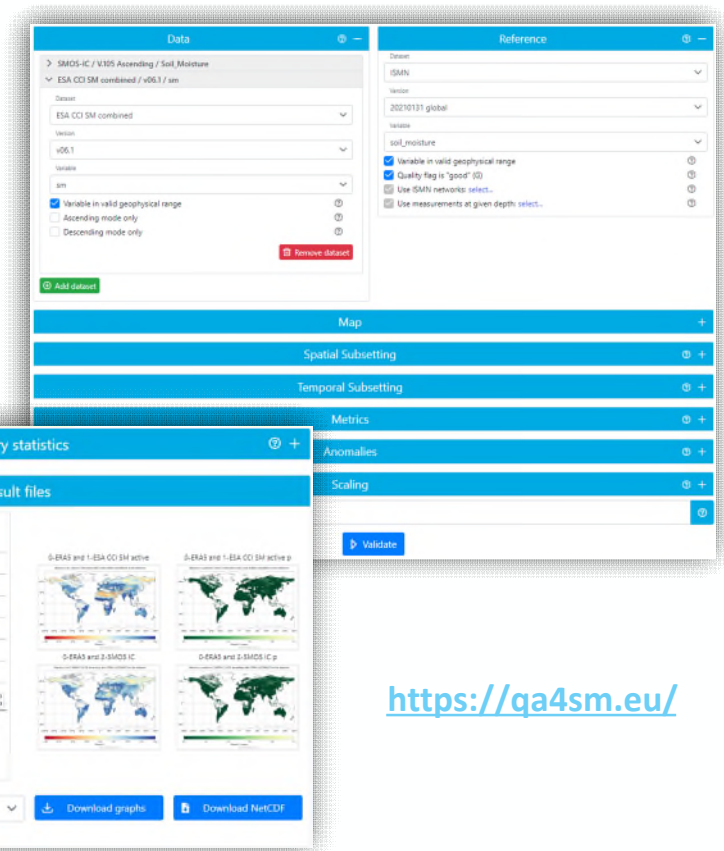
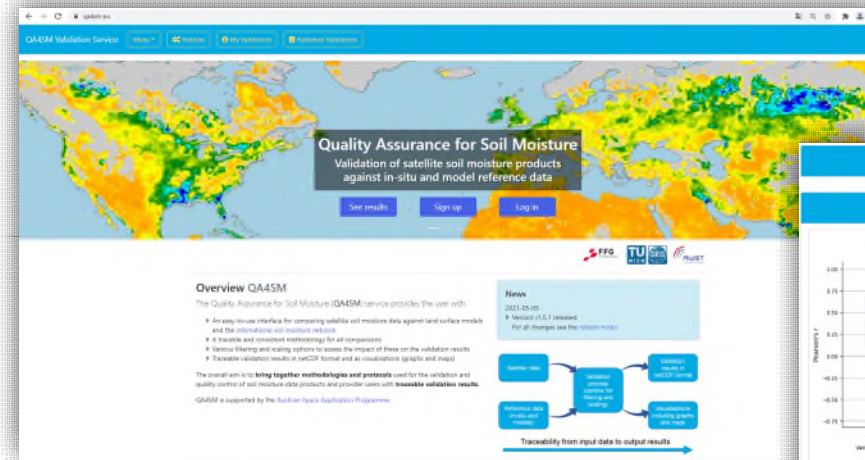
The QA4SM framework is developed to foster the application of community-agreed good practice guidelines

- 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**



Gruber et al. (2020). "Validation practices for satellite soil moisture retrievals: What are (the) errors?". DOI: 10.1016/j.rse.2020.111806

Montzka et al. (2020). "Soil Moisture Product Validation Good Practices Protocol". CEOS WGCV LPV. DOI: 10.5067/doc/ceoswgcvlpv/sm.001



<https://qa4sm.eu/>

- 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!**

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

- Traceability diagram and effects table
 - For details, see [DT2-1: FRM Protocols and Procedures for Soil Moisture](#)

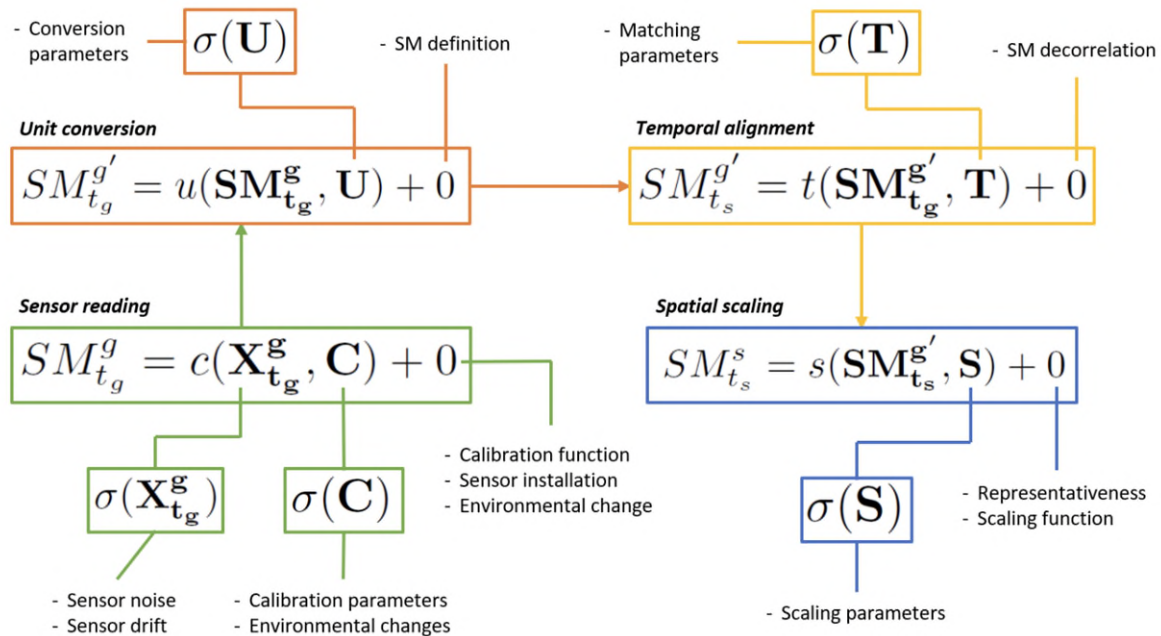
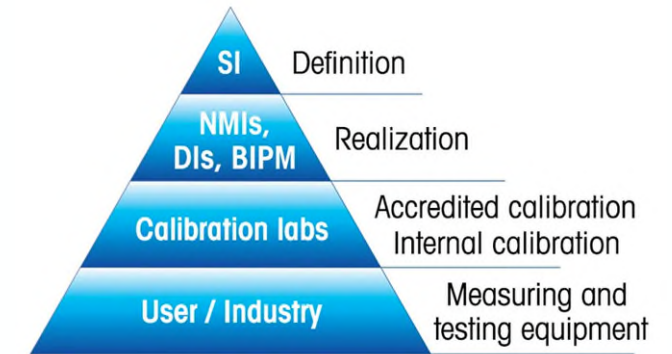


Table 1: Effects table. The following coding is used. Type: R=Random, S=Systematic; Correlated: Y=Yes, N=No, P=Potentially; Confidence: 0=Effects identified, no quantification; 1=Estimates only; 2: Some analysis performed to evaluate; 3: Rigorous analysis performed. Magnitudes are given in $m^3 m^{-3}$; * 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

- Obstacles 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**

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

¹Tue, 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

- 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 recommendations¹ and in collaboration with the community

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



Q&A

