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WATER IN SOIL

Mateusz Łukowski¹, Radosław Szlązak², Kamil Szewczak¹

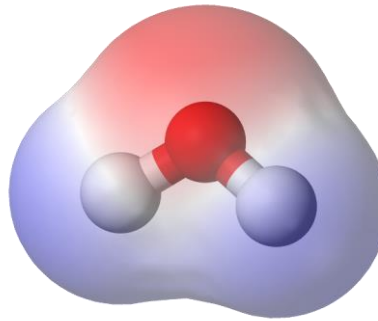
¹ Institute of Agrophysics, Polish Academy of Sciences, Lublin, Poland

² Scitive, Lublin, Poland

Water on Earth, water properties



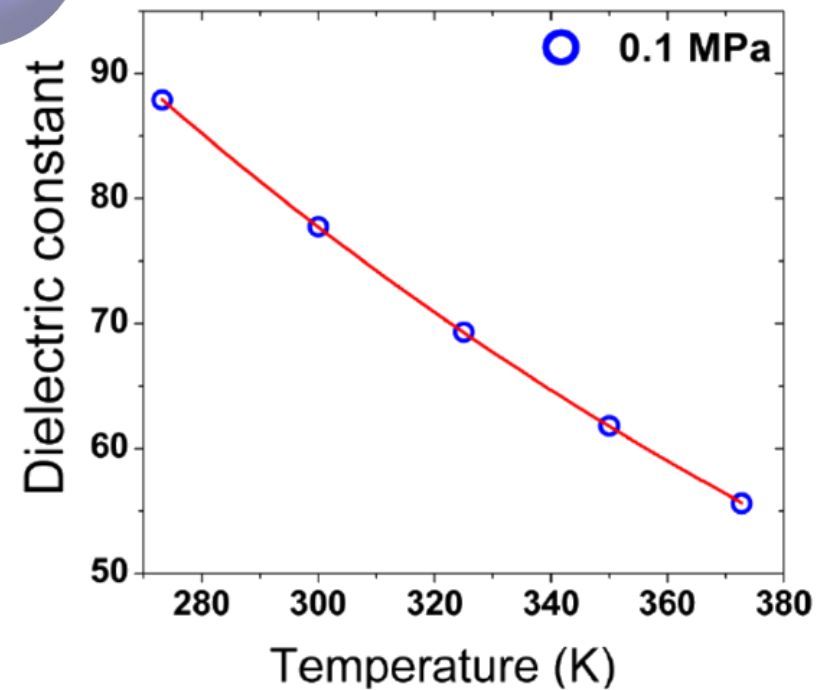
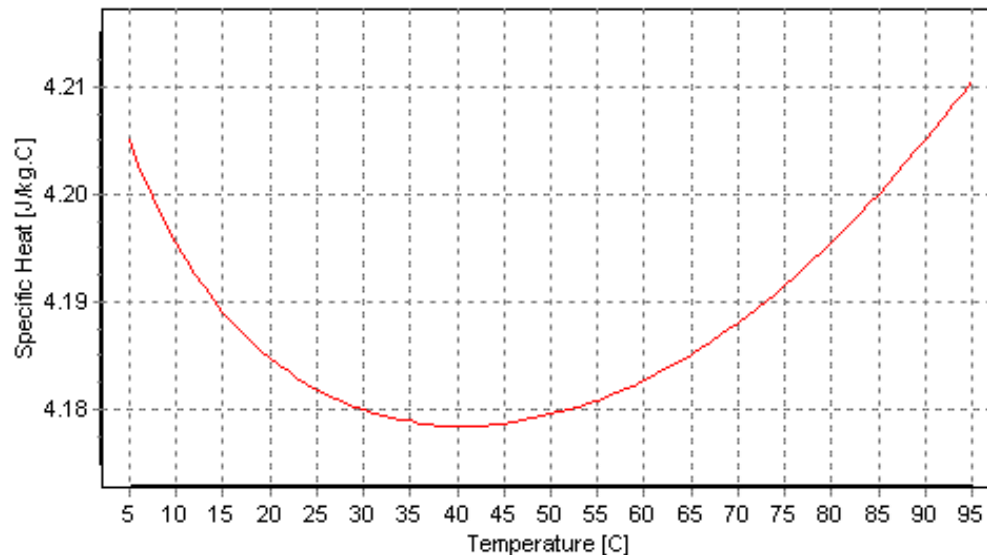
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dreamstime.com

ID 87610248 © 7gengrafik

Water Specific Heat Capacity vs Temperature ($p = 1$ bar)



Arulsamy, Andrew Das, et al. "Polarization induced water molecule dissociation below the first-order electronic-phase transition temperature." PCCP 13.33 (2011): 15175-15181.

Water in soil

(soil moisture, soil water content)



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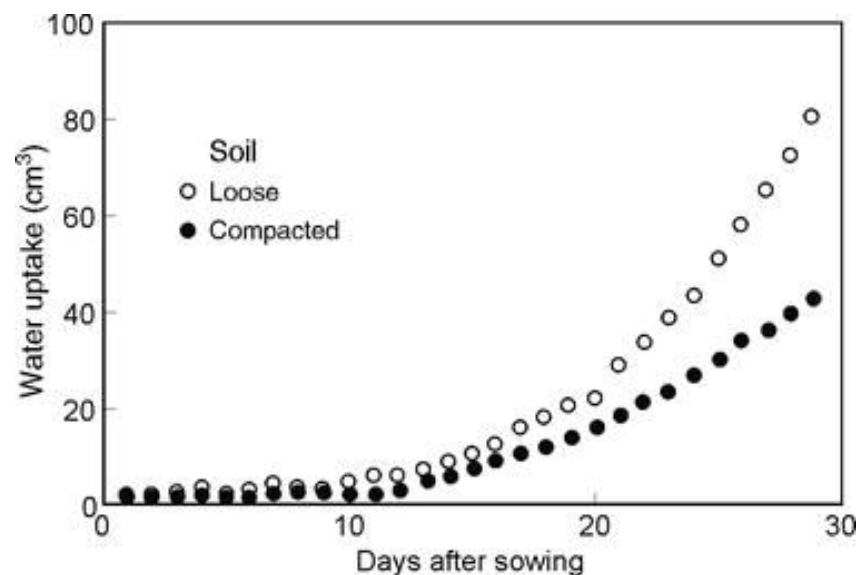
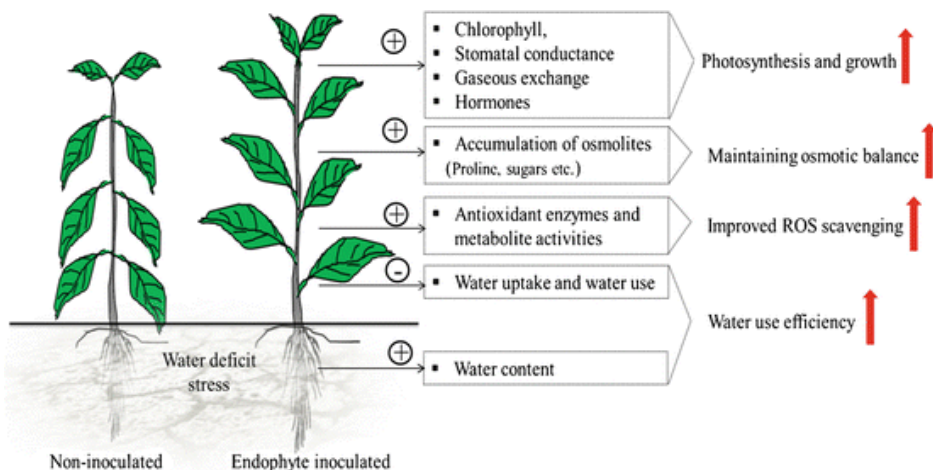
Water source	Water volume, in cubic km	Percent of freshwater	Percent of total water
Oceans, Seas, & Bays	1,338,000,000	--	96.54
Ice caps, Glaciers, & Permanent Snow	24,064,000	68.7	1.74
Groundwater	23,400,000	--	1.69
<i>Fresh</i>	<i>10,530,000</i>	<i>30.1</i>	<i>0.76</i>
<i>Saline</i>	<i>12,870,000</i>	--	<i>0.93</i>
Soil Moisture	16,500	0.05	0.001
Ground Ice & Permafrost	300,000	0.86	0.022
Lakes	176,400	--	0.013
<i>Fresh</i>	<i>91,000</i>	<i>0.26</i>	<i>0.007</i>
<i>Saline</i>	<i>85,400</i>	--	<i>0.006</i>
Atmosphere	12,900	0.04	0.001
Swamp Water	11,470	0.03	0.0008
Rivers	2,120	0.006	0.0002
Biological Water	1,120	0.003	0.0001

Why water in soil is important?



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Soil moisture is a crucial factor for plant growth conditions (including water stress issue)

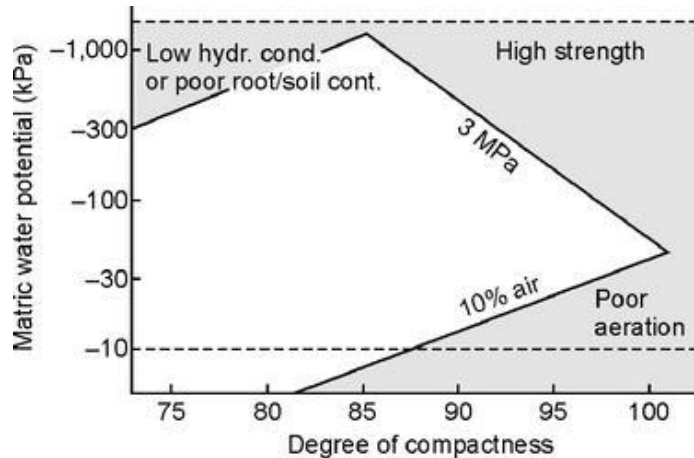


https://link.springer.com/chapter/10.1007/978-981-10-5813-4_8

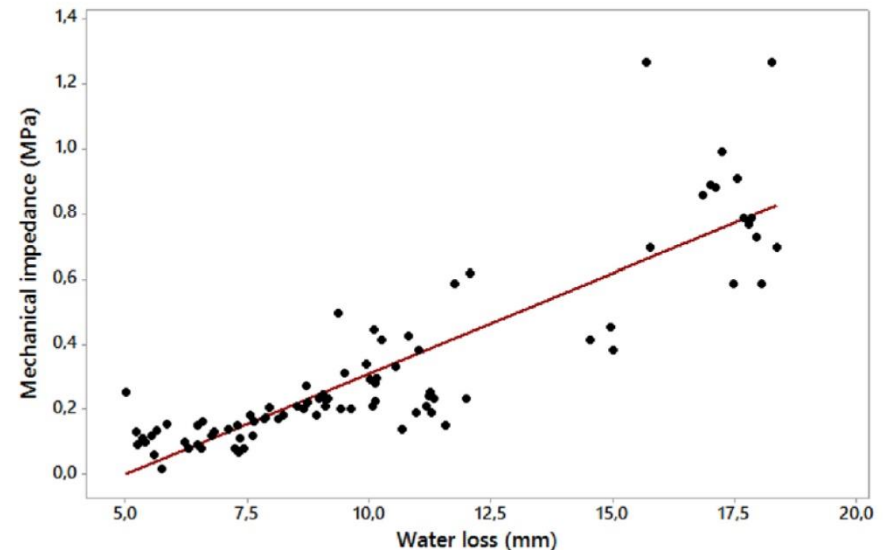
Lipiec J., Nosalewicz A., Pietrusiewicz J. (2011) Crop Responses to Soil Physical Conditions. In: Gliński J., Horabik J., Lipiec J. (eds) Encyclopedia of Agrophysics. Encyclopedia of Earth Sciences Series. Springer, Dordrecht

Why water in soil is important?

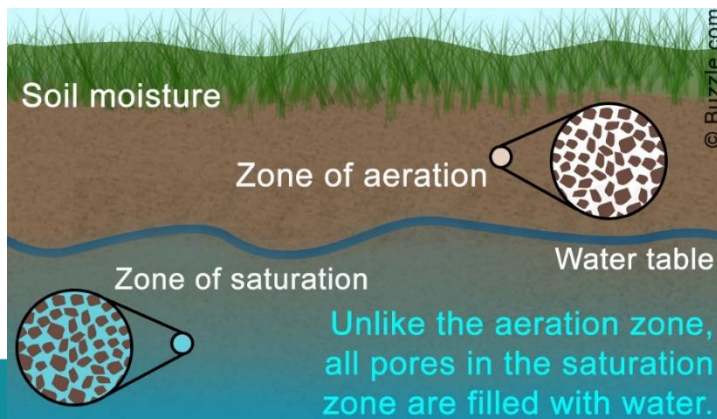
Soil moisture indirectly influences other significant soil properties, including aeration, mechanical impedance, temperature and many other...



Lipiec J., Nosalewicz A., Pietrusiewicz J. (2011) Crop Responses to Soil Physical Conditions. In: Gliński J., Horabik J., Lipiec J. (eds) Encyclopedia of Agrophysics. Encyclopedia of Earth Sciences Series. Springer, Dordrecht



Mas, M., Verdú, A., Ginovart, M., et al. (2017). Seedling emergence through soil surface seals under laboratory conditions: effect of mechanical impedance and seal moisture. *Biologia*, 72(8), pp. 862-868. Retrieved 4 Nov. 2019, from doi:10.1515/biolog-2017-0105

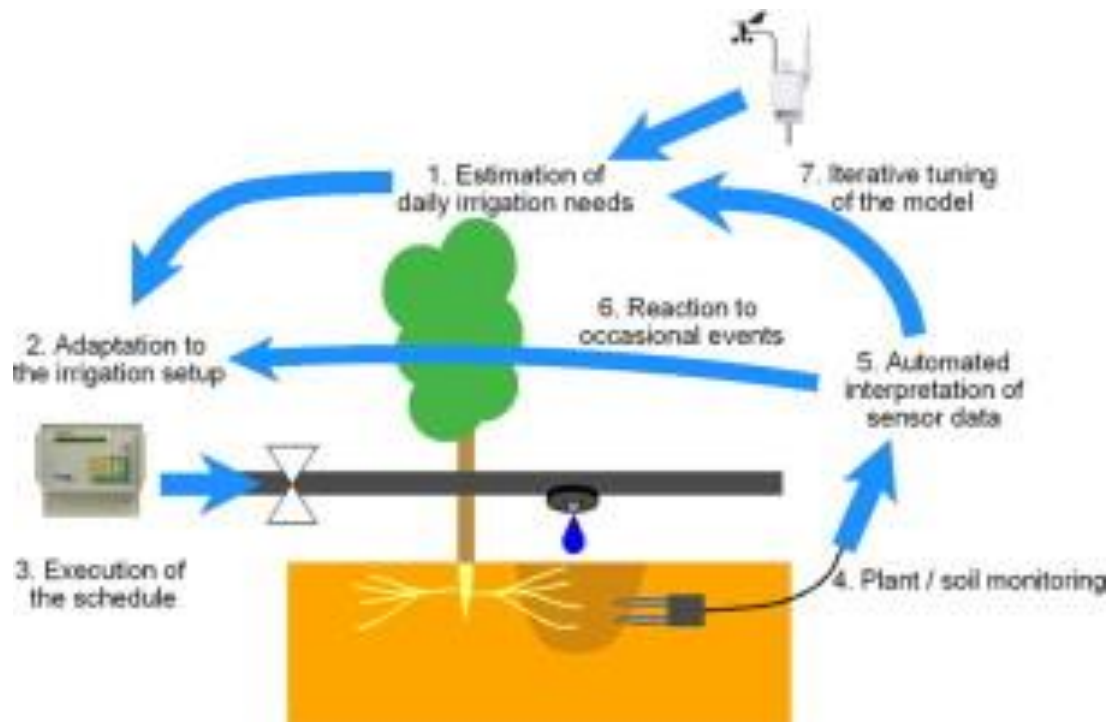


Why soil moisture is important?

Soil water content (soil moisture) is triggering variable in irrigation scheduling



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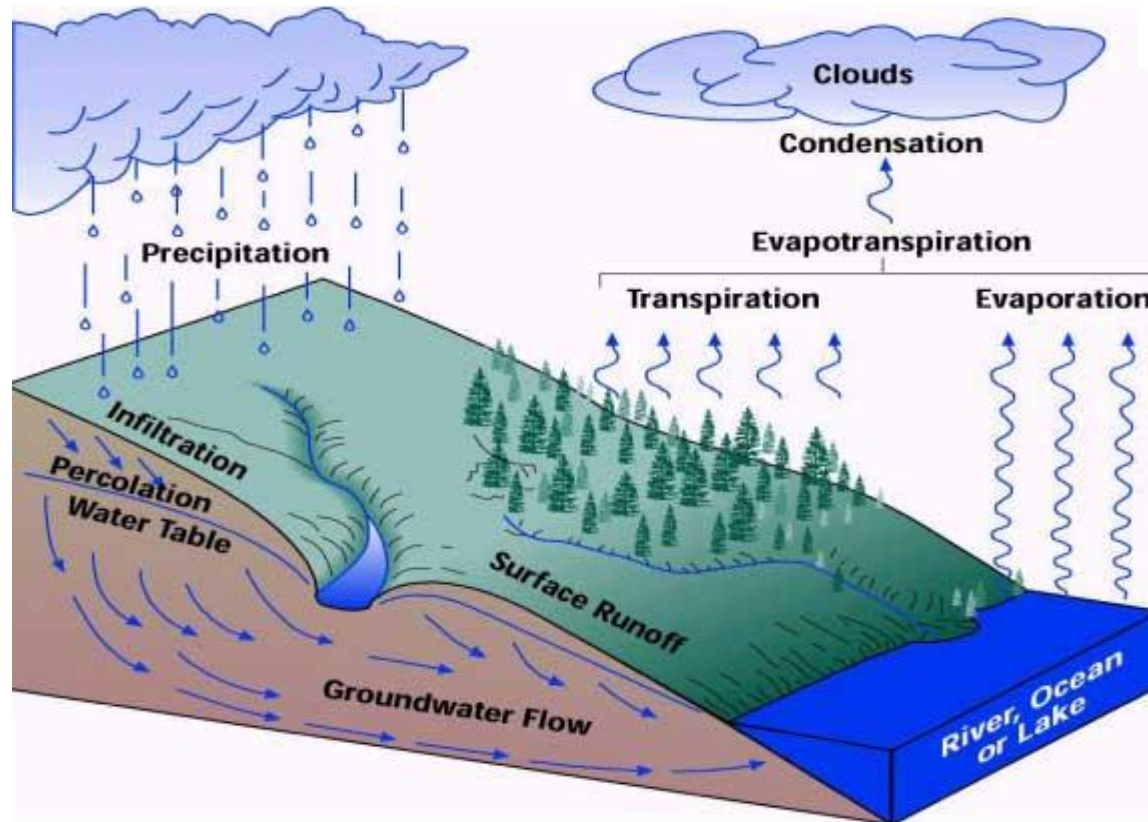
<https://www.sciencedirect.com/science/article/pii/S016816991200018X>

Why soil moisture is important?



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Soil moisture conditions are an important factor in precipitation splitting (re-distribution) of into runoff, infiltration, and ground water recharge



Why soil moisture is important?



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Saturated soil can be a warning of subsequent flooding due to the limited ability to store more water



© Gary Naylor



<https://crops.extension.iastate.edu/cropnews/2008/06/effect-flooding-emerged-soybeans>

Why soil moisture is important?

Information about soil moisture allows predicting droughts and erosion



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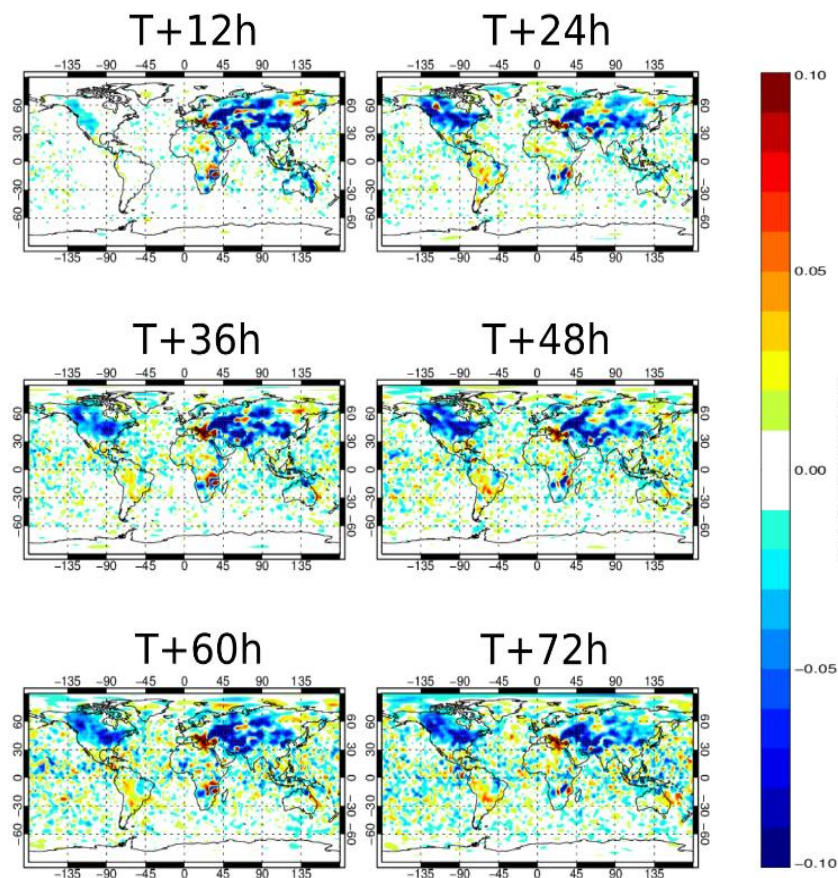


Why soil moisture is important?



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Data on soil moisture are a key variable in numerical weather forecasts



Challenge

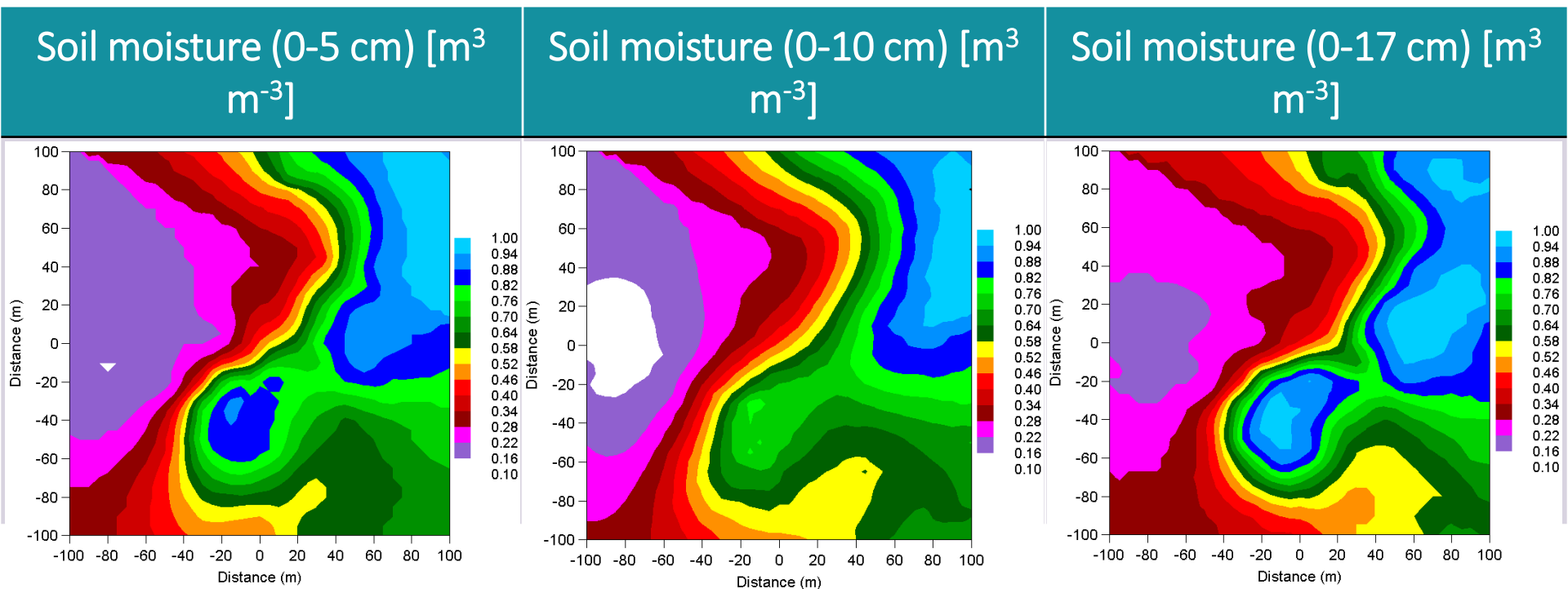
Soil moisture can be spatially variable →
at large scale we need lots of field
measurements → very time consuming



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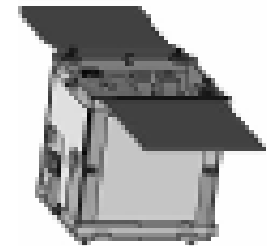
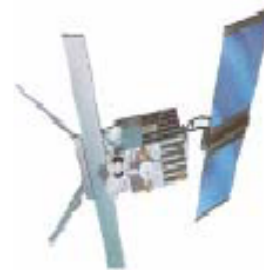
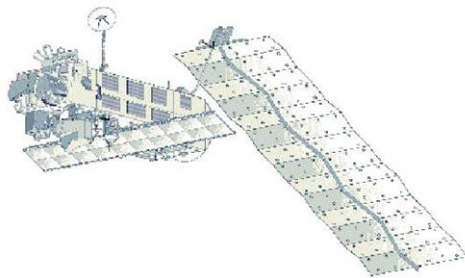
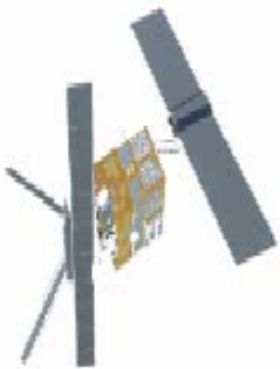
- Manual measurements of soil moisture distribution in layers via TDR, geostatistical analyses

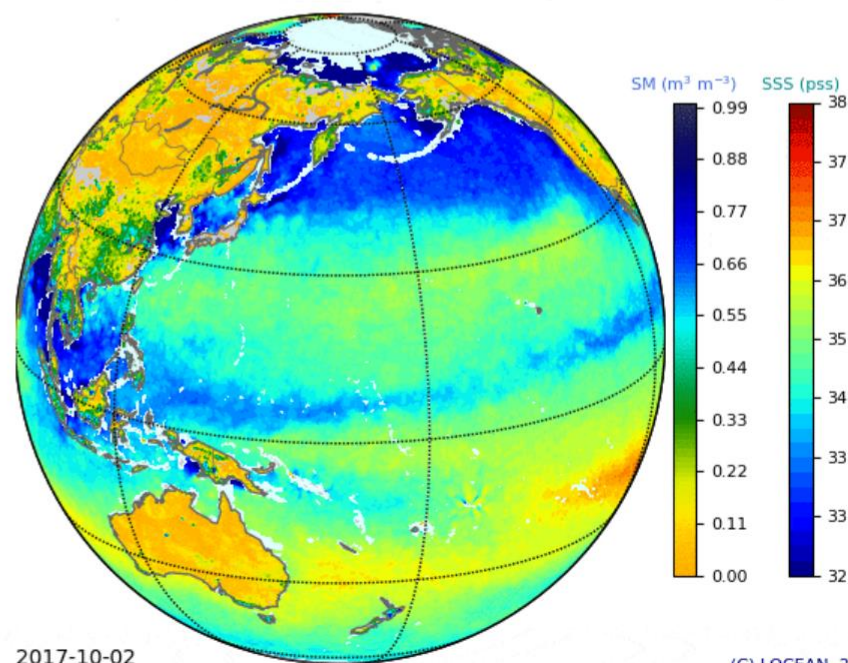
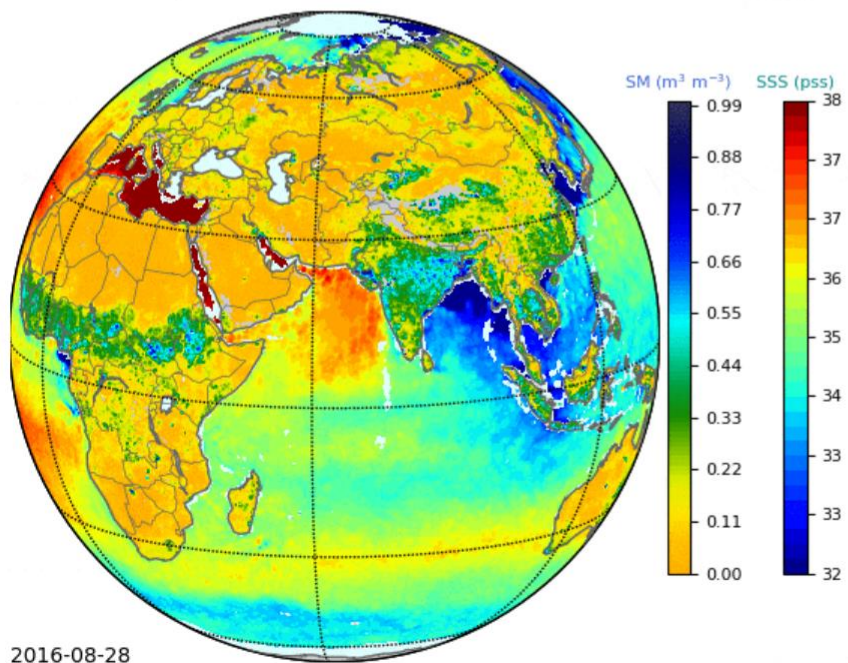
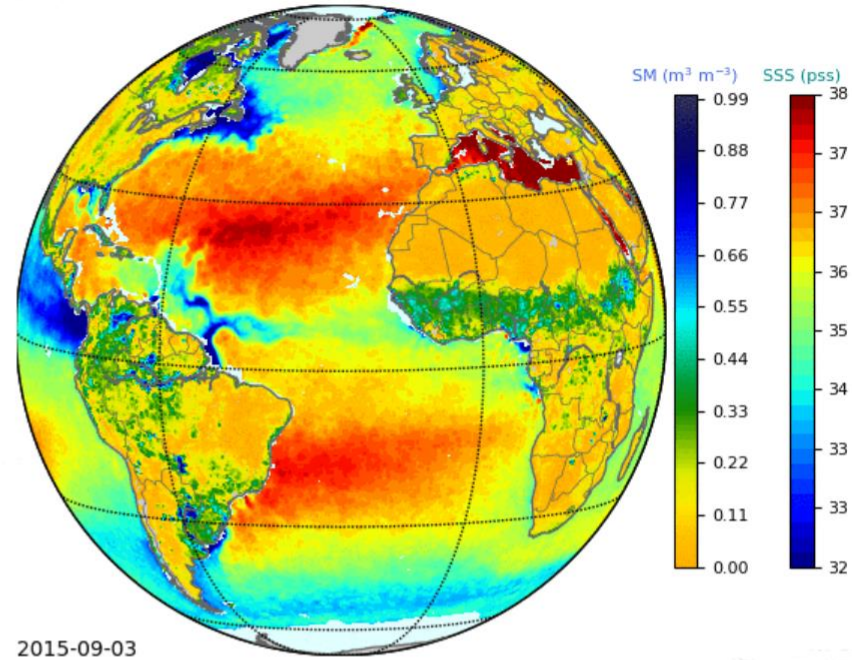
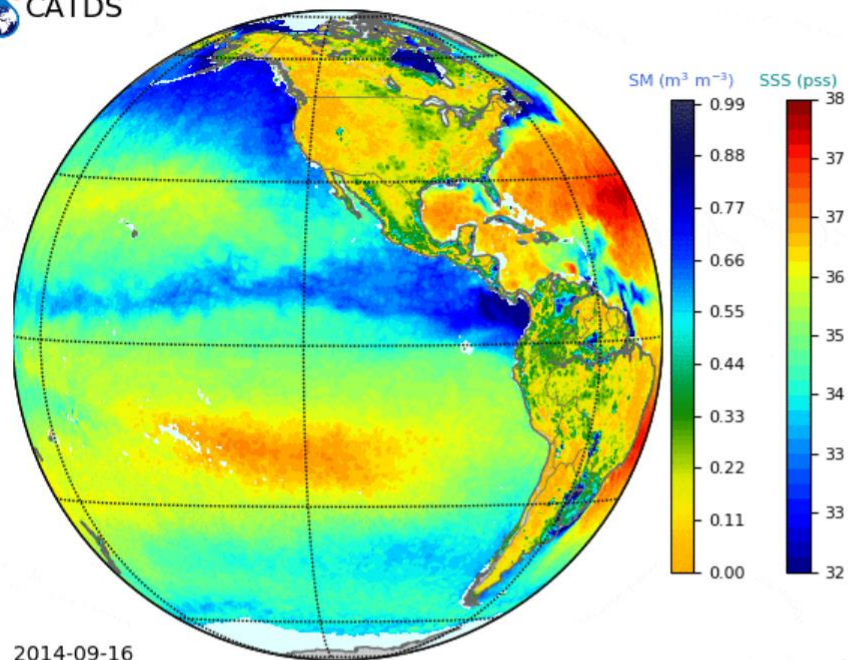


Point measurements of soil moisture are fairly accurate, however inadequate on large scales

Satellite data

- Large region of measurement
- Spatial continuity
- Consistency
- Cost effectiveness



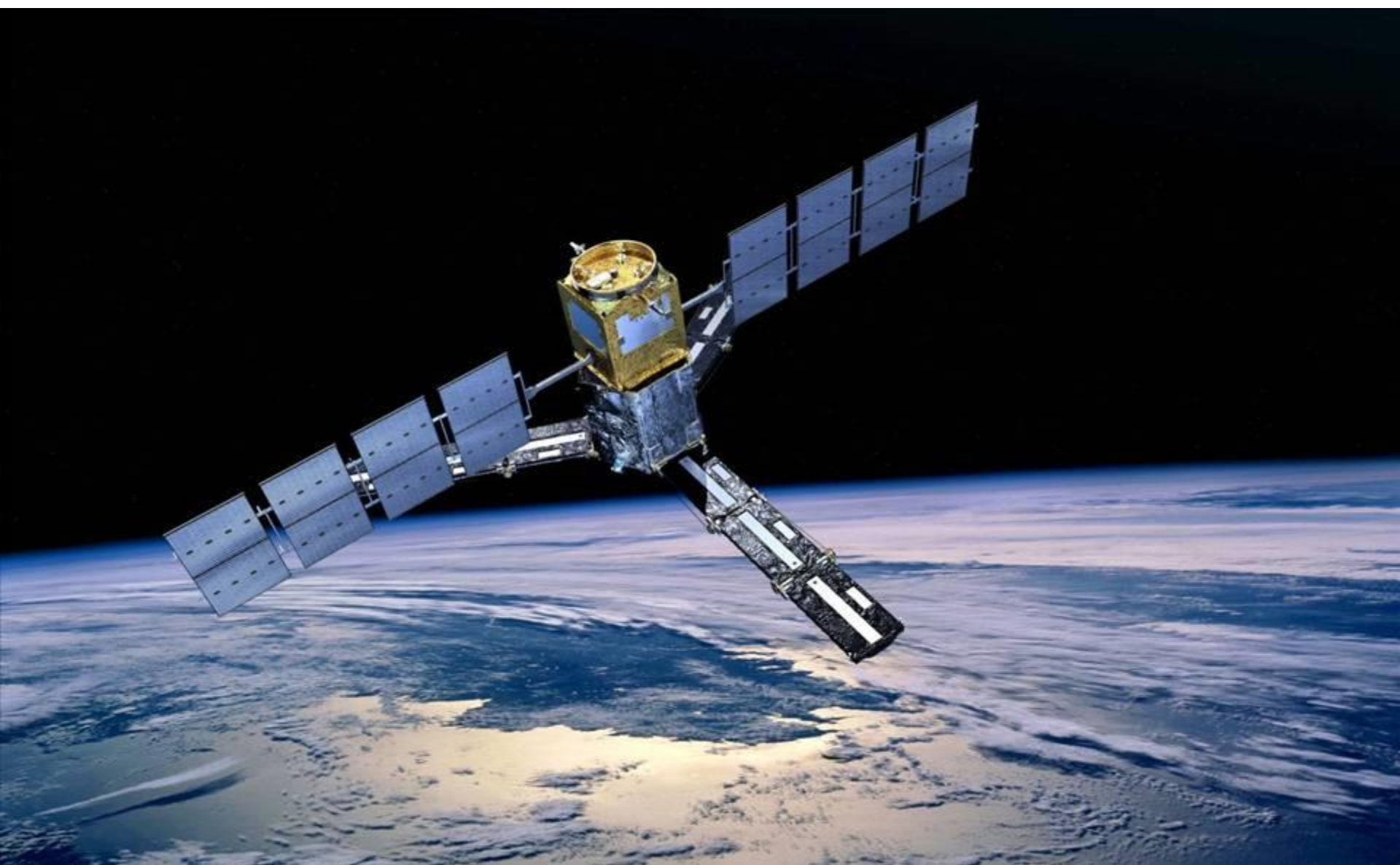


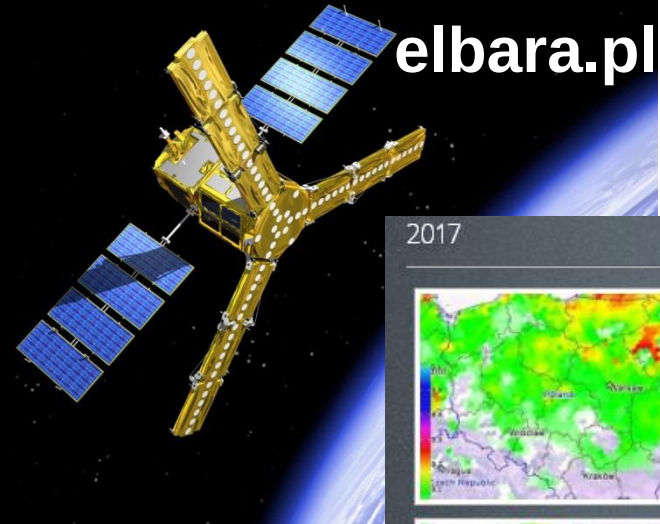
Soil Moisture and Ocean Salinity (SMOS)

Launched in November 2009 (15 years now!!!)

Parameters:

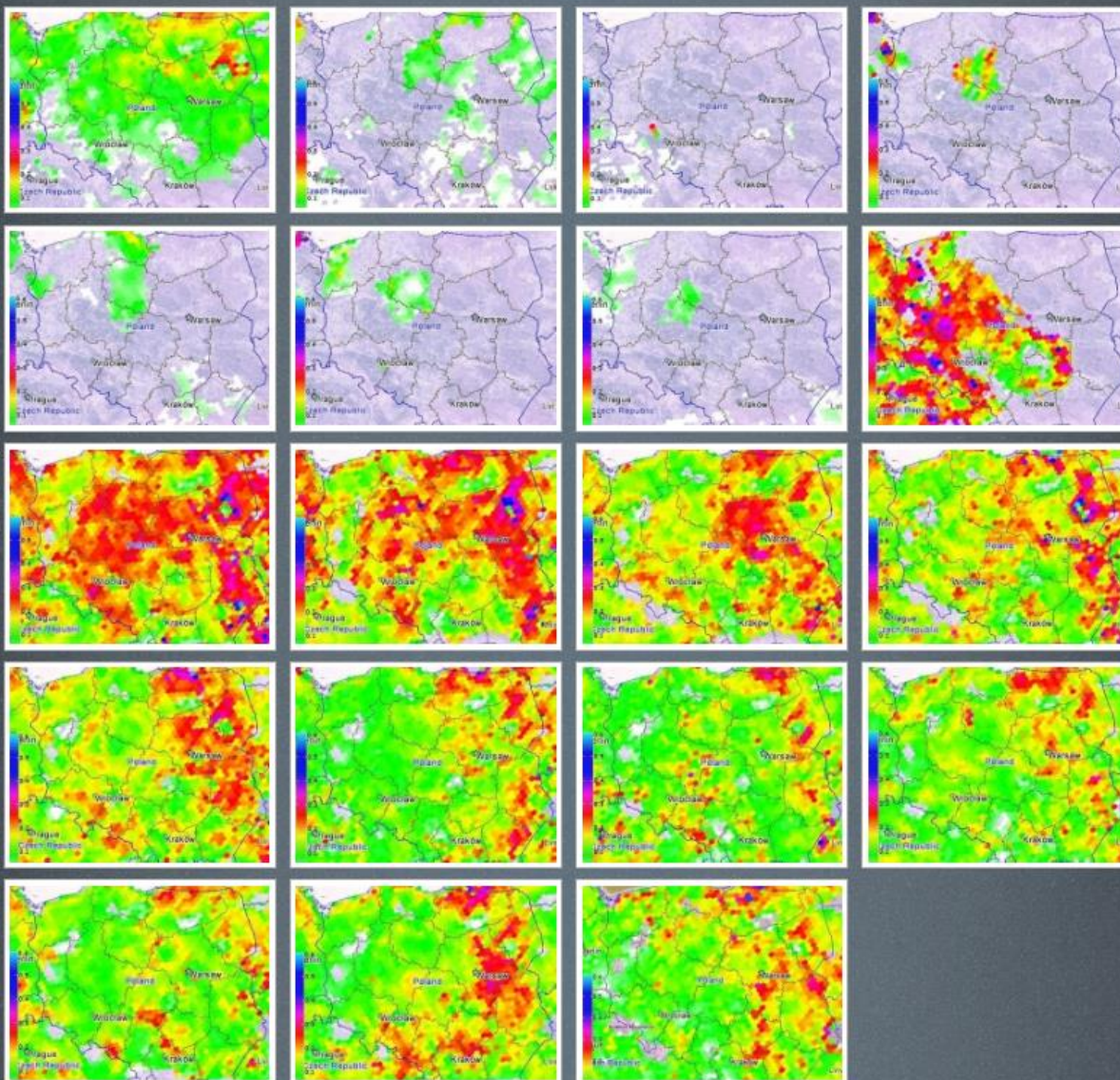
- Precision: 4% volumetric water content
- Pixel area: 40x40 km
- Temporal resolution: 3 days





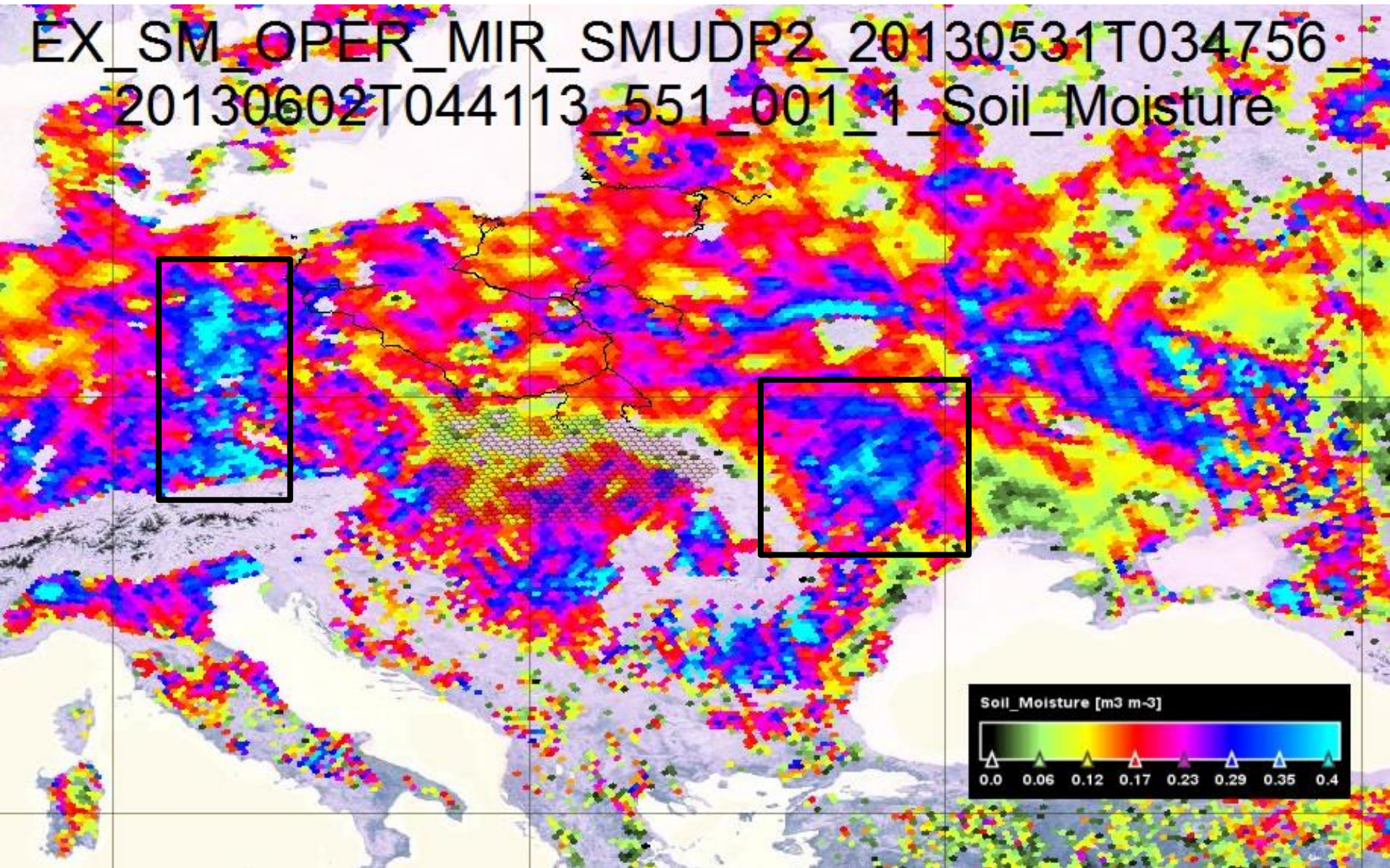
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2017



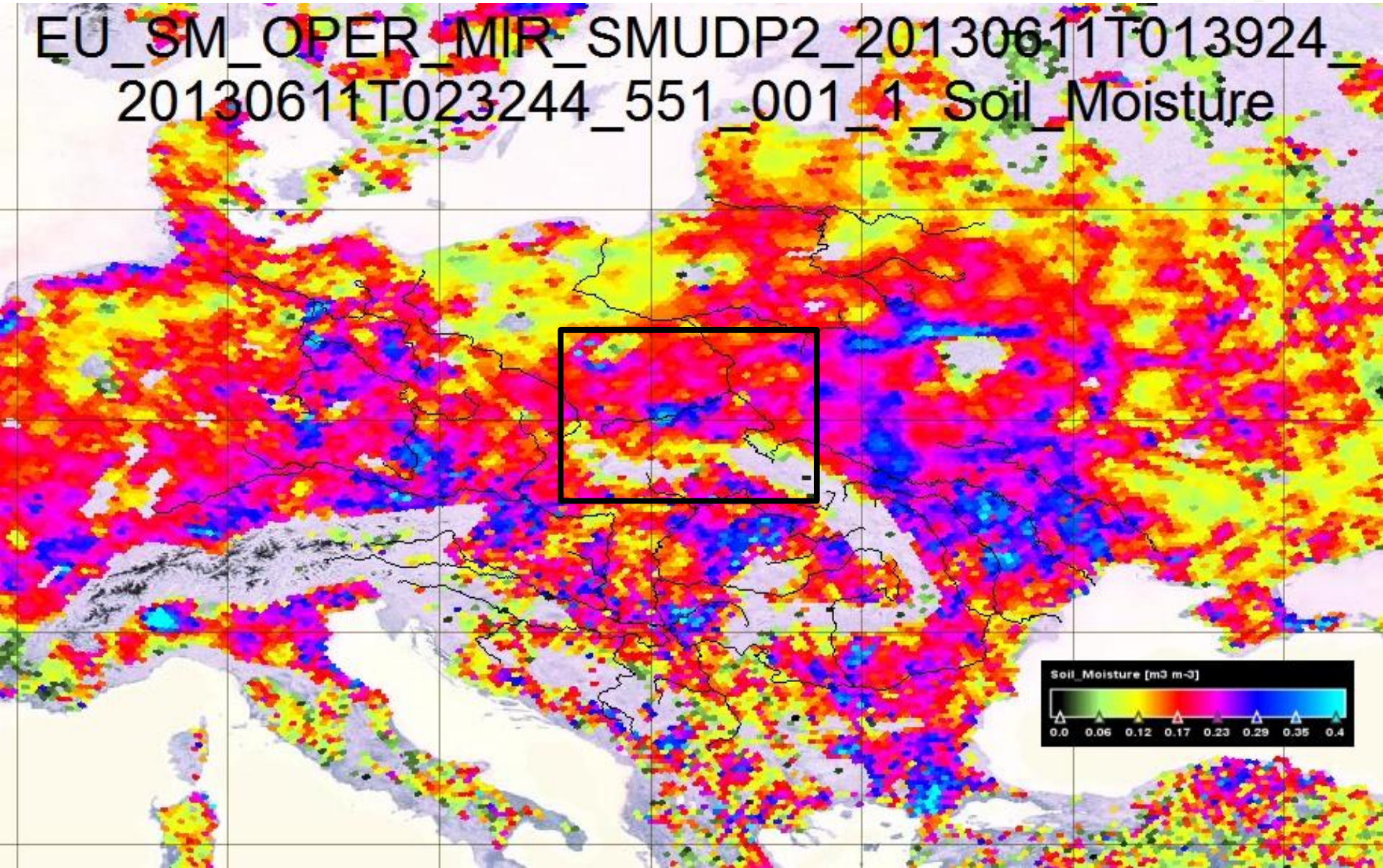
Approaching flood in Europe (31/05 – 02/06/2013)

EX_SM_OPER_MIR_SMUDP2_20130531T034756_
20130602T044113_551_001_1_Soil_Moisture



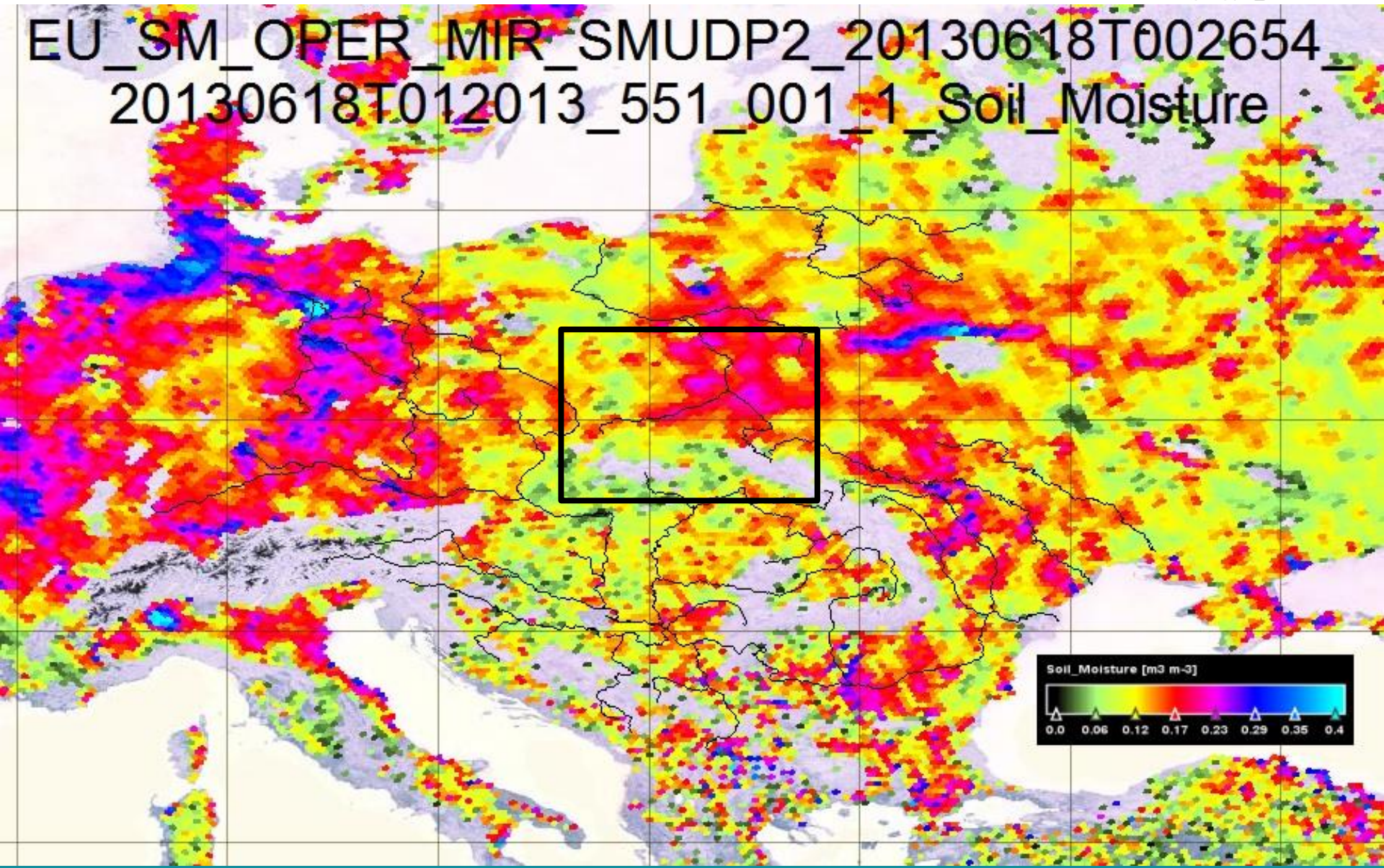
Dangerous soil saturation near Krakow in Poland (11/06/2013)

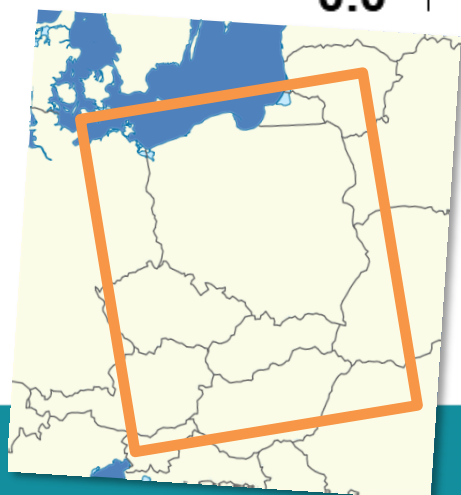
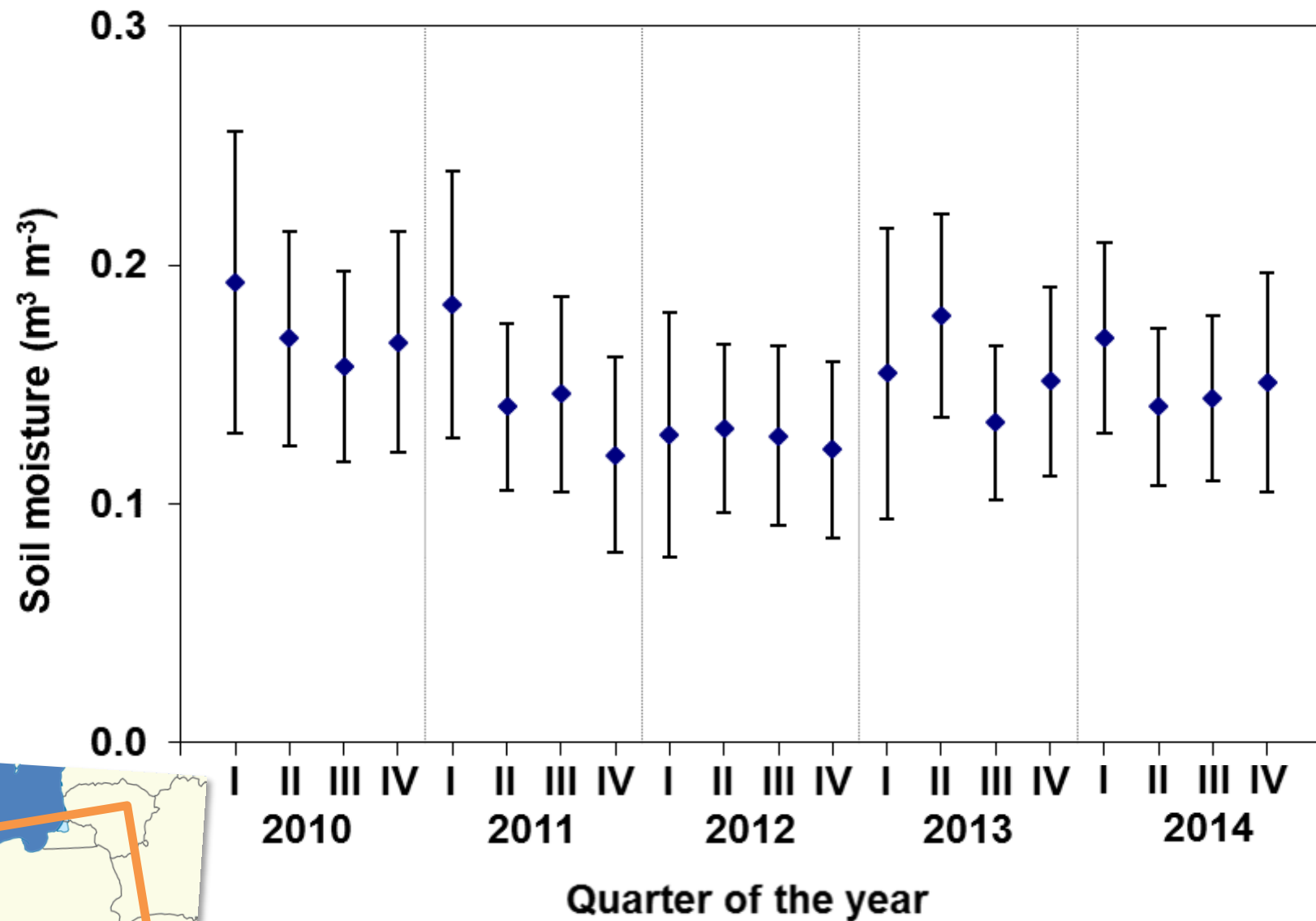
EU_SM_OPER_MIR_SMUDP2_20130611T013924_
20130611T023244_551_001_1_Soil_Moisture



Dangerous soil saturation near Krakow – discharge (18/06/2013)

EU_SM_OPER_MIR_SMUDP2_20130618T002654_
20130618T012013_551_001_1_Soil_Moisture

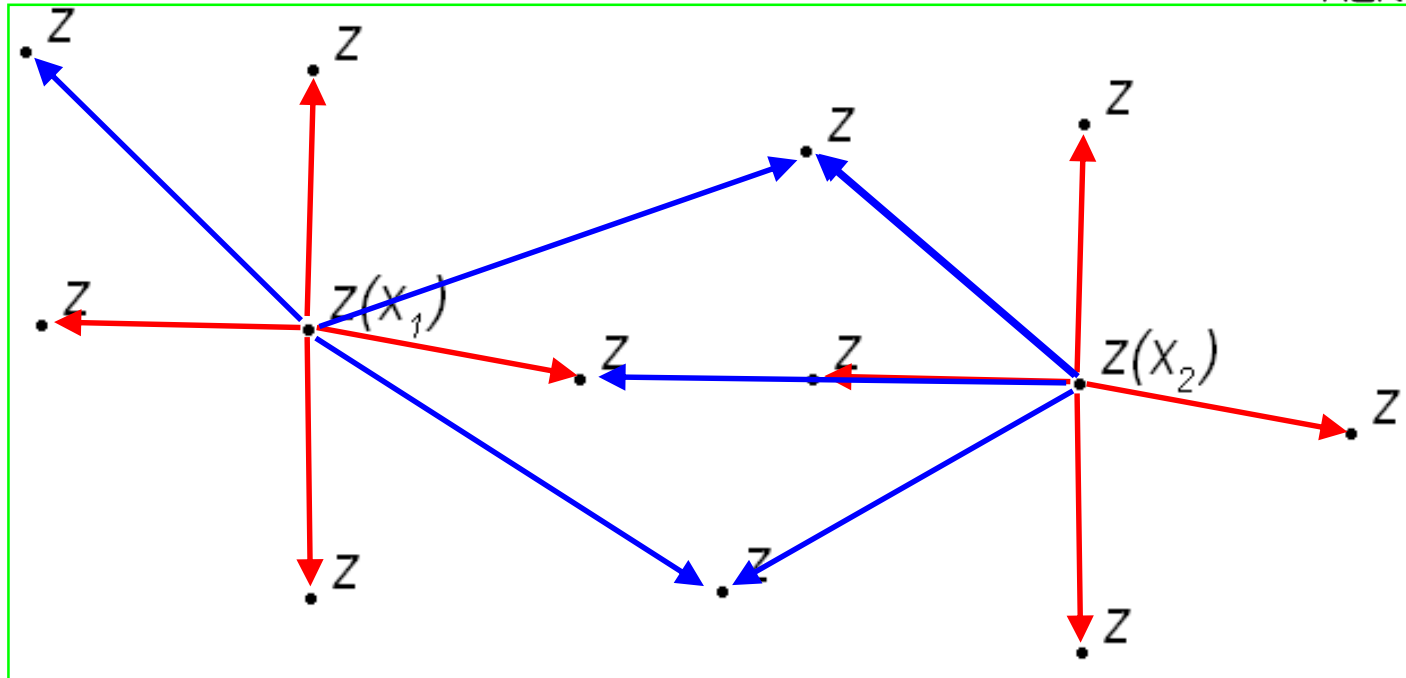




Spatial analyses – geostatistical methods



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The empirical semivariograms $\gamma(h)$ for distance h were calculated from:

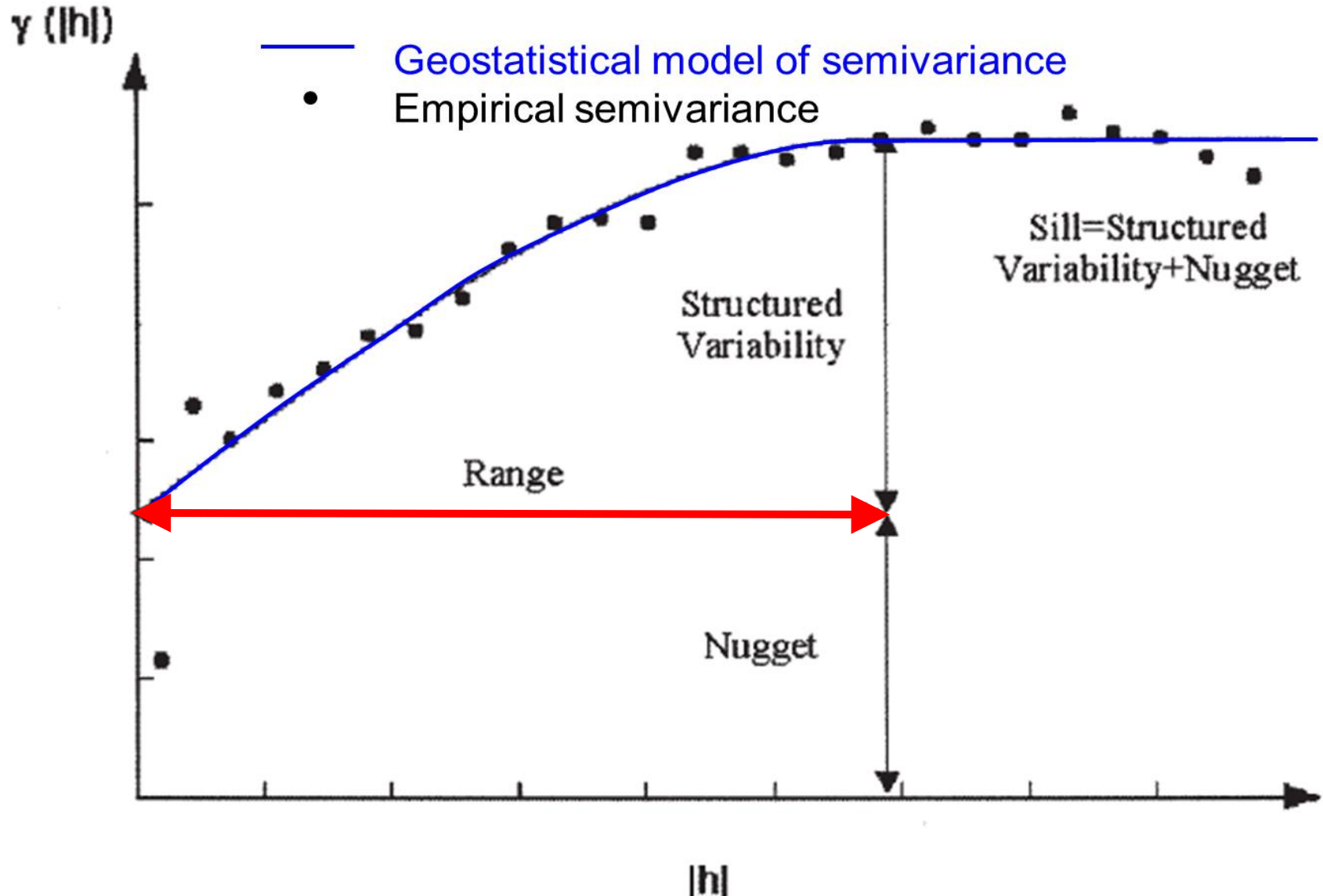
$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2$$

where $N(h)$ is the number of pairs of points $z(x_i)$ separated by the distance h .

Spatial analyses – geostatistical methods



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Geostatistical results

Rok	Season	Range (°)	$C_0/(C_0+C)$	R^2
2010	winter	0.999	0.003	0.999
	spring	1.617	0.001	0.995
	summer	1.542	0.017	0.989
	autumn	1.881	0.063	0.994
2011	winter	2.733	0.298	0.985
	spring	1.728	0.060	0.989
	summer	1.704	0.002	0.990
	autumn	2.394	0.113	0.972
2012	winter	2.034	0.209	0.985
	spring	1.626	0.106	0.984
	summer	2.731	0.644	0.941
	autumn	3.853	0.683	0.985
2013	winter	1.809	0.163	0.978
	spring	2.100	0.000	0.993
	summer	1.867	0.621	0.912
	autumn	4.083	0.569	0.997
2014	winter	1.491	0.001	0.982
	spring	1.593	0.001	0.991
	summer	2.543	0.652	0.988
	autumn	1.725	0.503	0.977



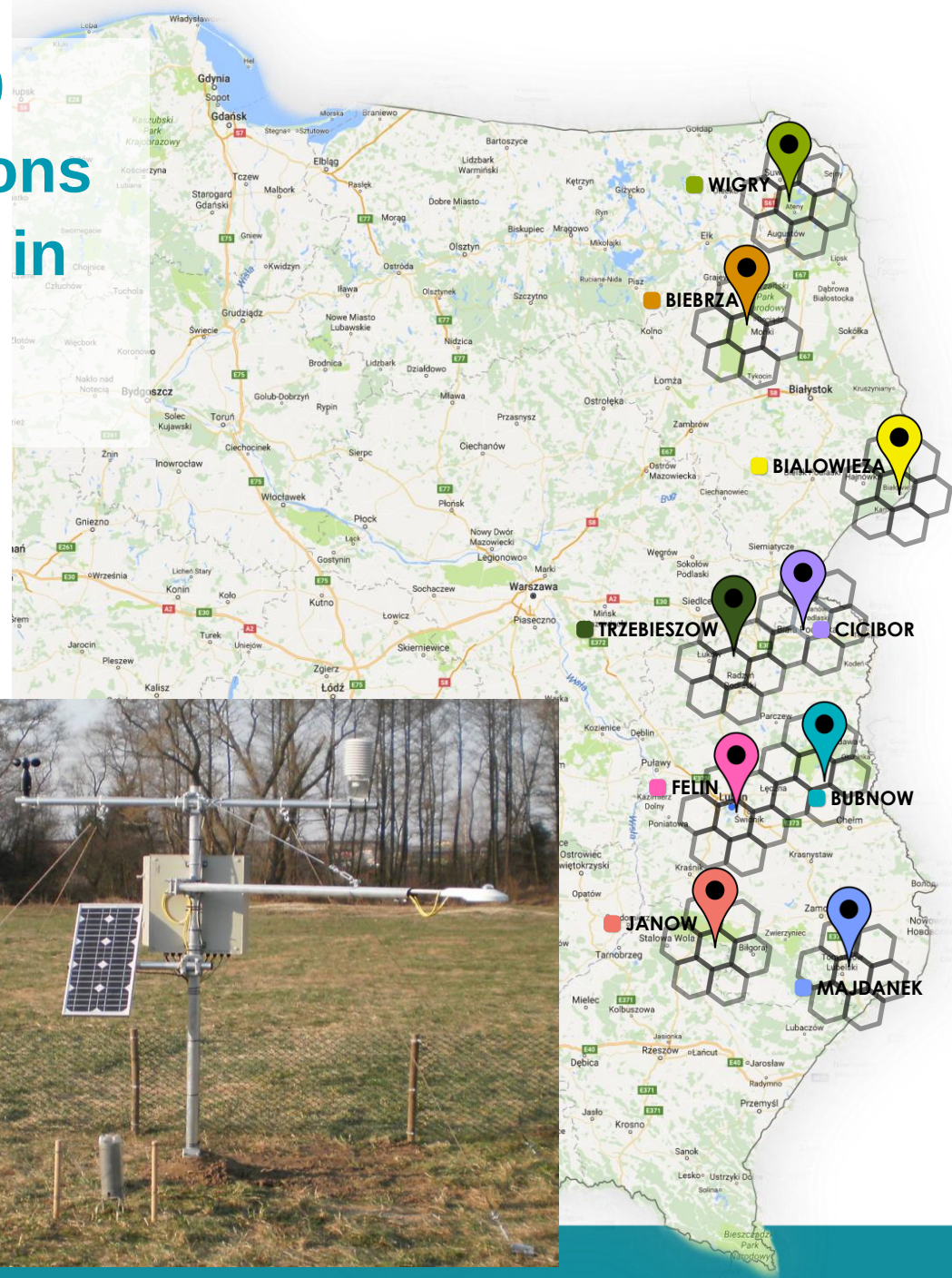
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Is that truth?

Soil moisture data from 9 agrometeorological stations (SWEX_Poland) installed in Eastern Poland were compared with SMOS



Air humidity, temperature

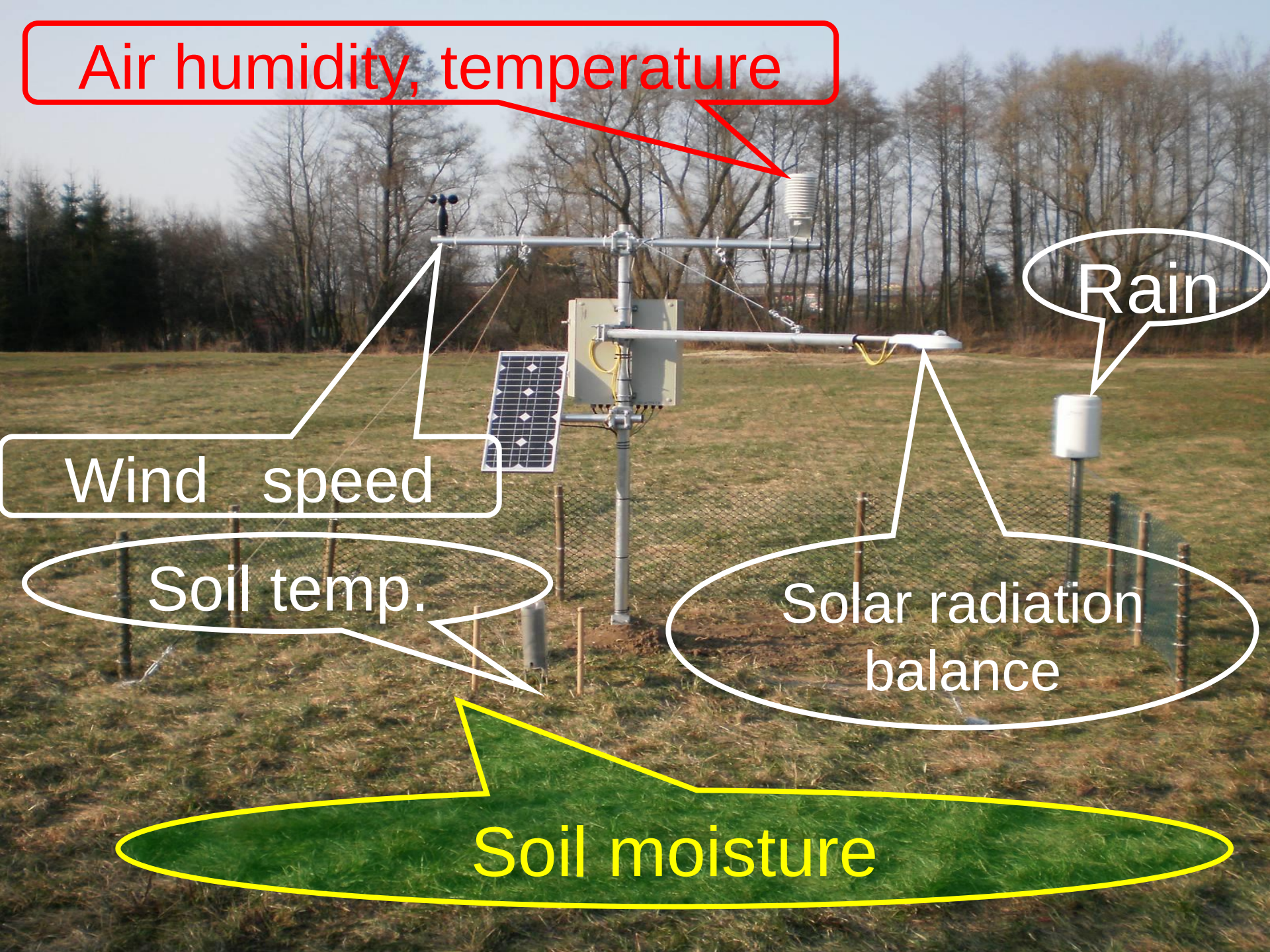
Wind speed

Soil temp.

Rain

Solar radiation
balance

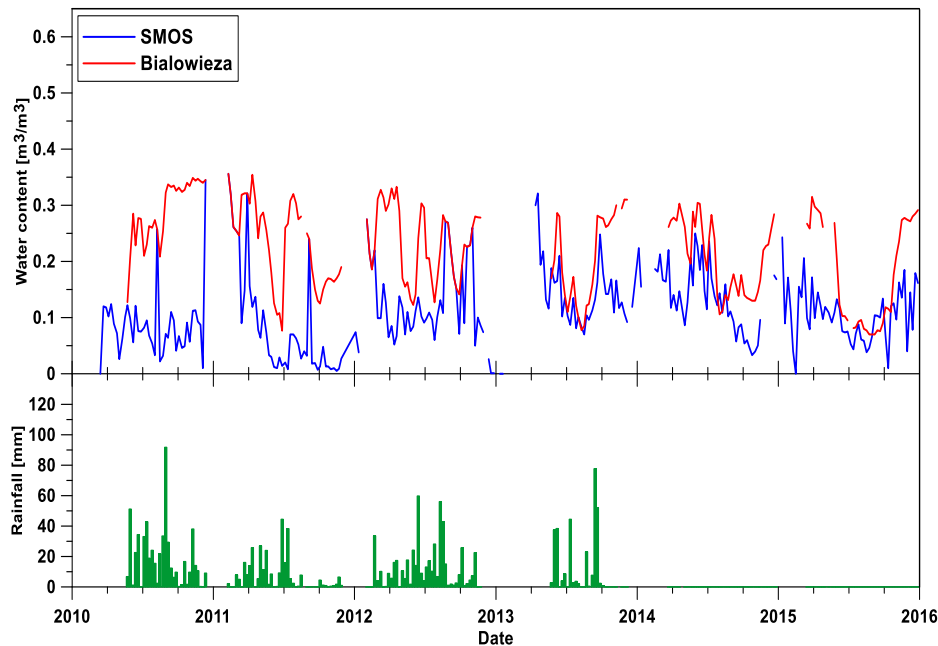
Soil moisture



SMOS vs. *in situ* soil moisture: time-series comparison

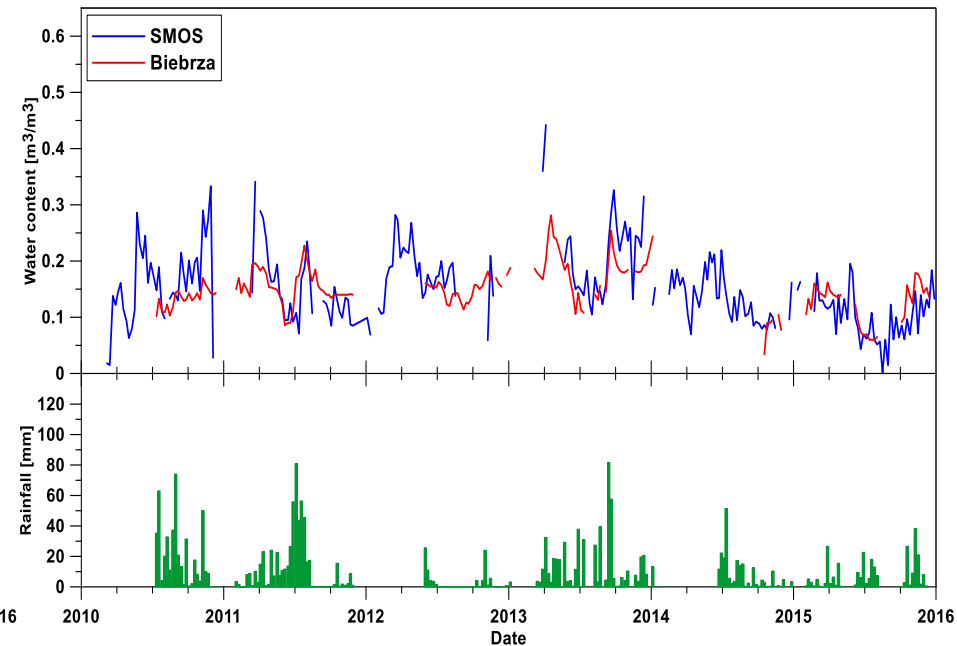
BIALOWIEZA

Coordinates: 23.75°E, 52.57°N
Sand: 68%, silt: 28%, clay: 4%
Sensor depth: 10 cm



BIEBRZA

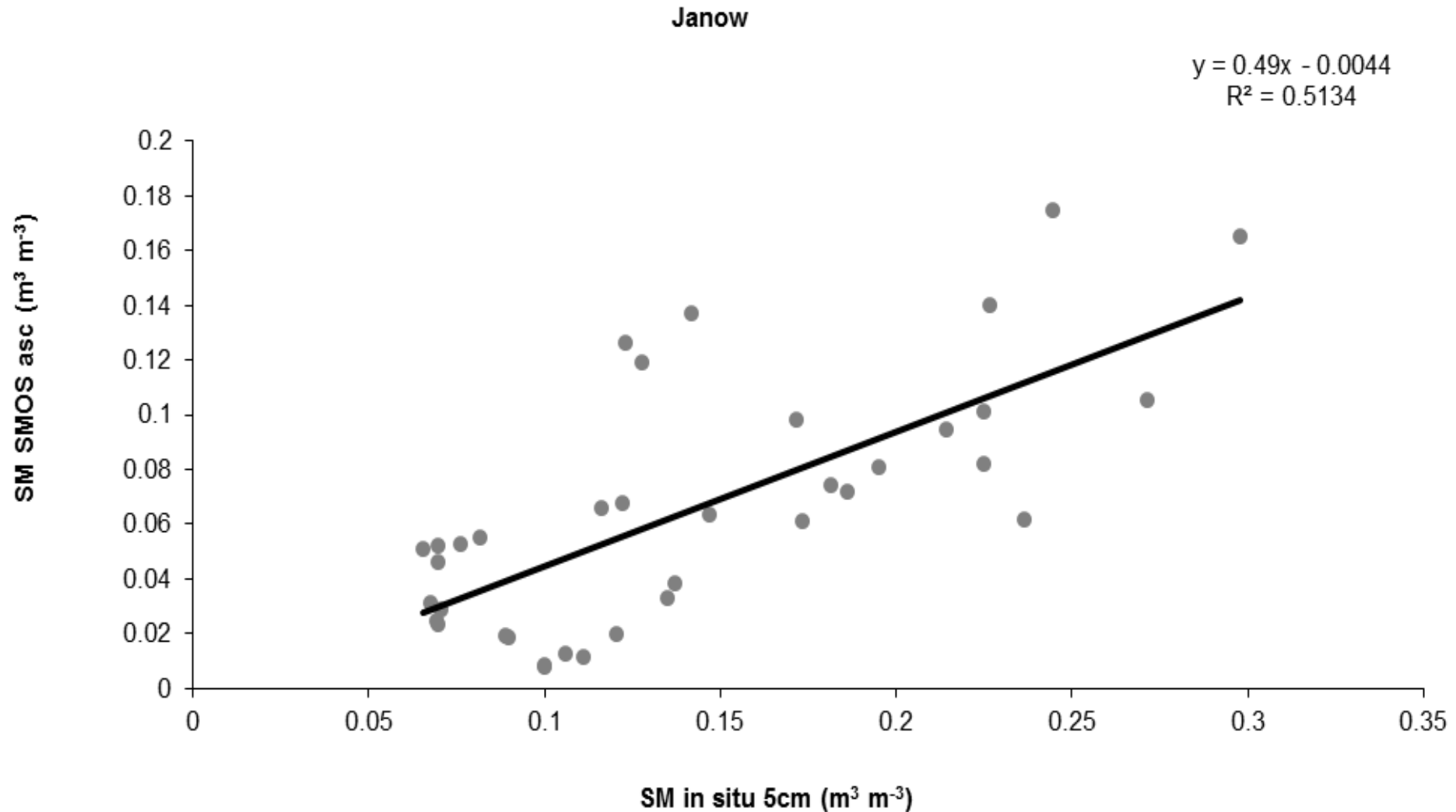
Coordinates: 22.66°E, 53.47°N
Sand: 97%, silt: 1%, clay: 2%
Sensor depth: 10 cm



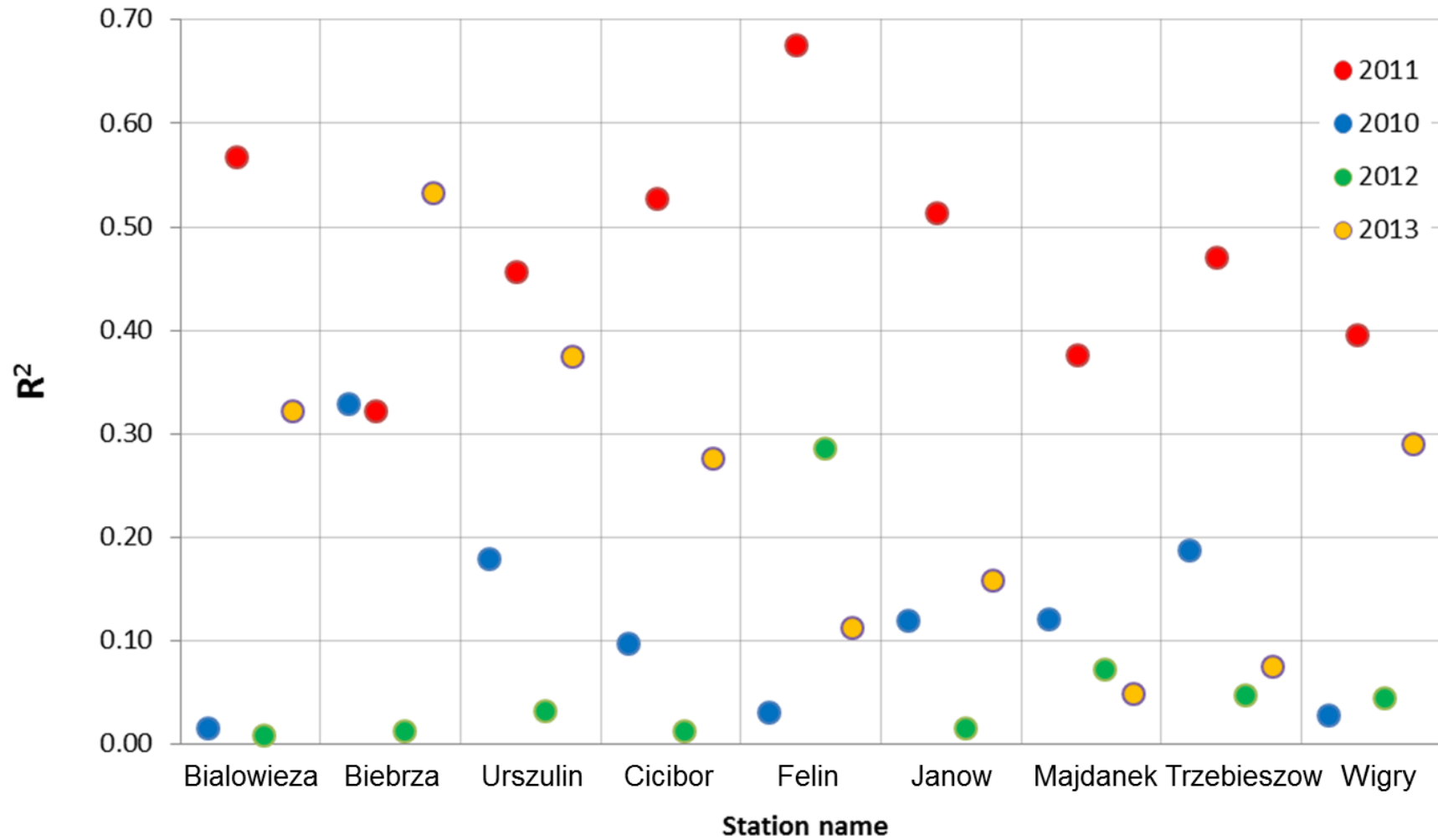
SMOS vs. *in situ* soil moisture: time-series comparison (R^2)



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SMOS vs. *in situ* soil moisture: time-series comparison (R^2) – summary



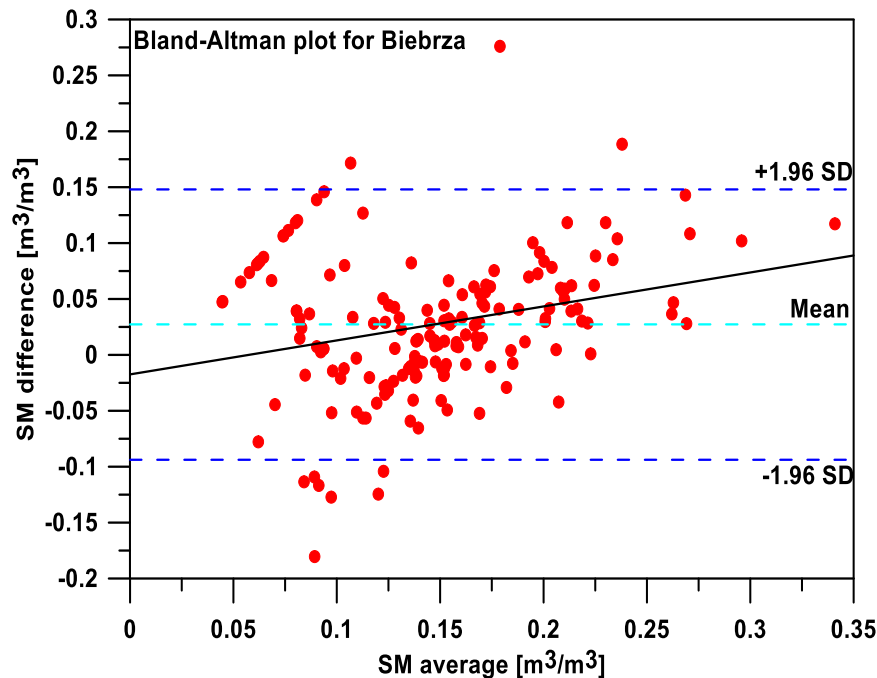
SMOS vs. *in situ* soil moisture: Bland-Altman method of comparison



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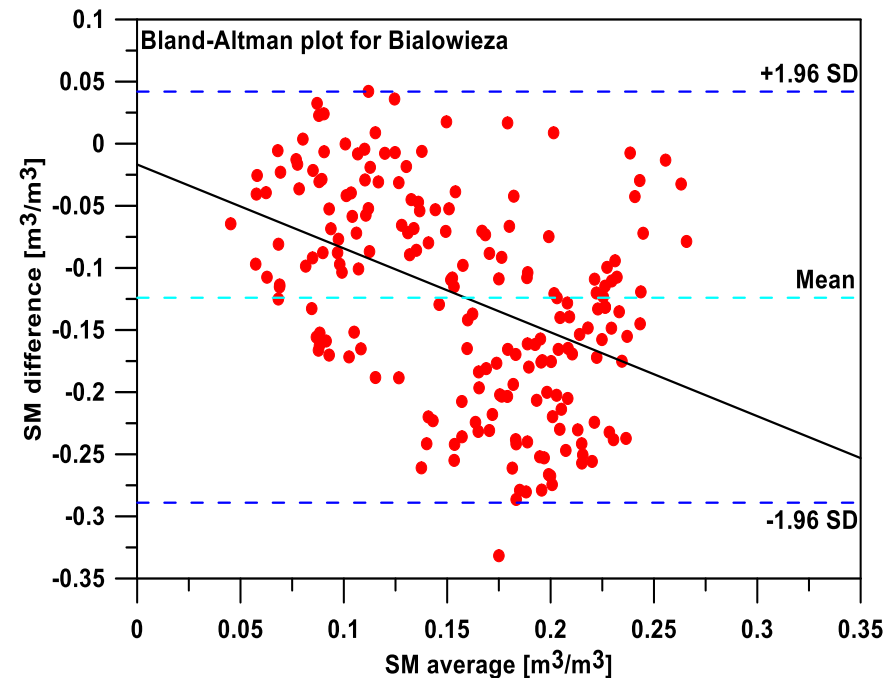
■ BIALOWIEZA ■

Coordinates: 23.75°E, 52.57°N
Sand: 68%, silt: 28%, clay: 4%
Sensor depth: 10 cm



■ BIEBRZA ■

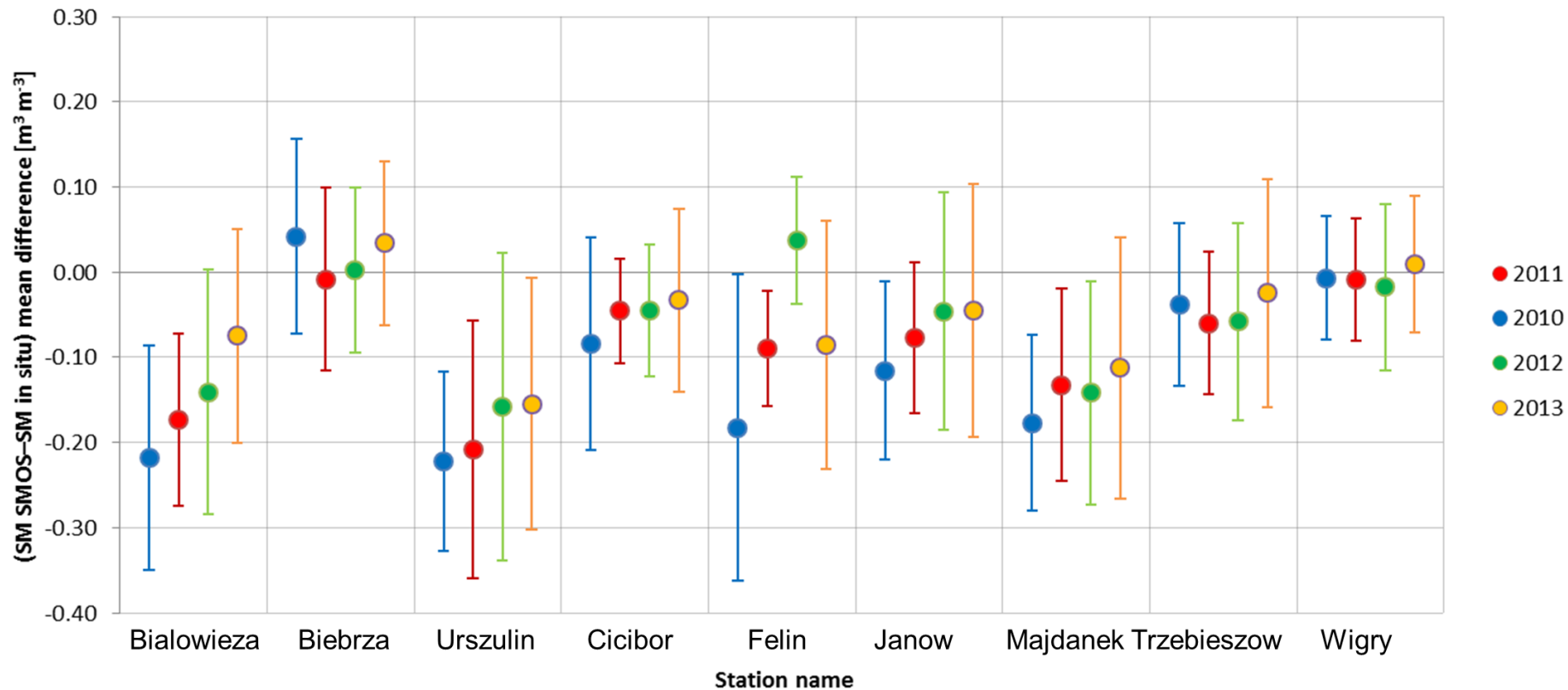
Coordinates: 22.66°E, 53.47°N
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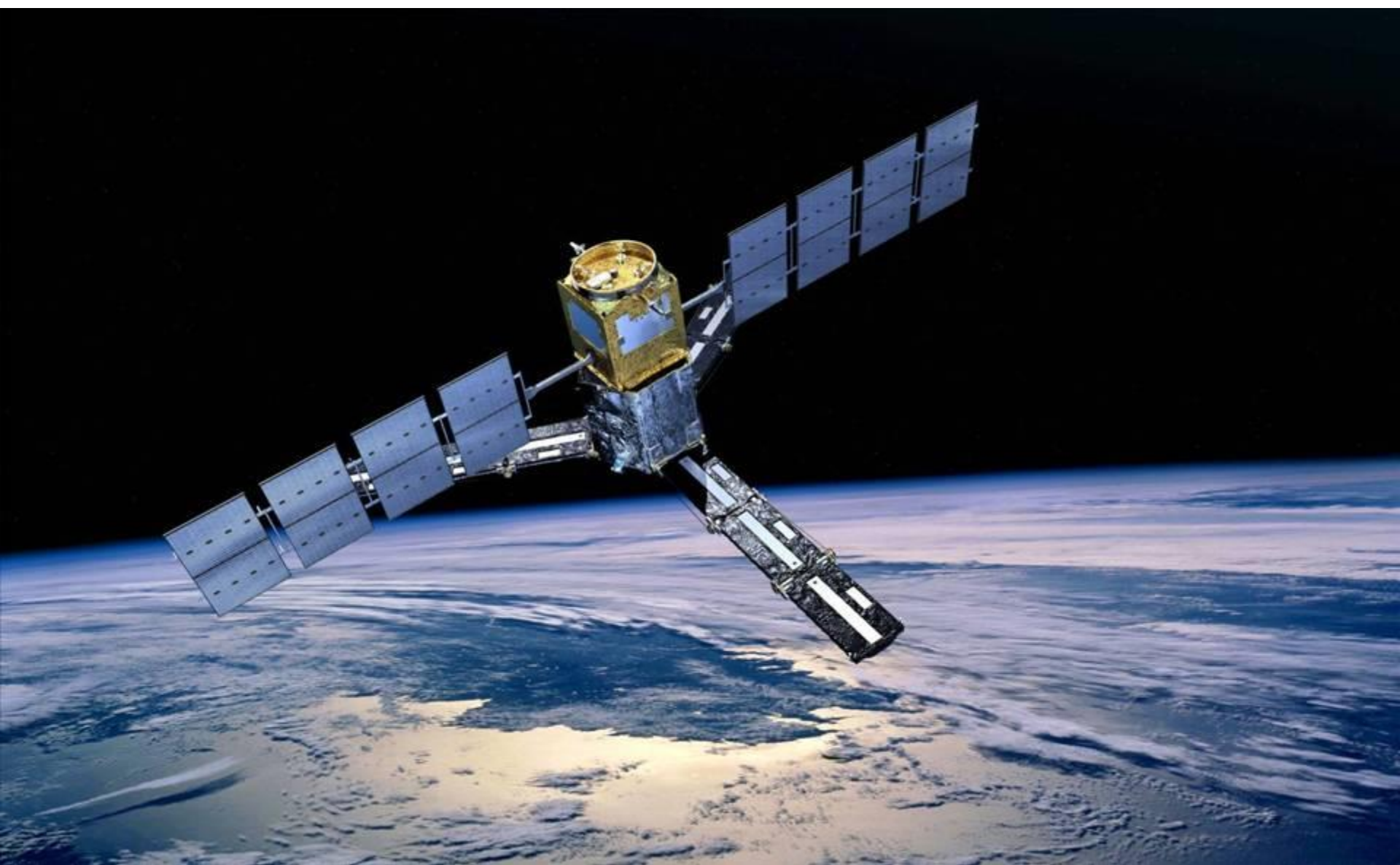


SMOS vs. *in situ* soil moisture: Bland-Altman method of comparison – summary



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ELBARA – "single SMOS antenna"



ELBARA Poland – Bubnów Wetland, 60 km from Lublin (Poland)



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ESA (European Space Agency)

L-Band (band L, microwaves in 1 to 2 GHz range)

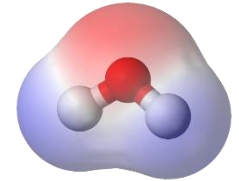
Radiometer (instrument recording the intensity of electromagnetic radiation)

Radiometer

- Very sensitive receiver of heat radiation
- Remote, passive sensor (as opposed to active radar, FDR, TDR etc.)

What is measured?

- Radiance – **Thermal radiation** in a given wavelength range (microwaves) called **brightness temperature** T_B^p ($p = H, V$) associated with **thermodynamic temperature** T .



Space-borne radiometer (SMOS)



Air-borne (PLMR)



Ground-based (ELBARA)

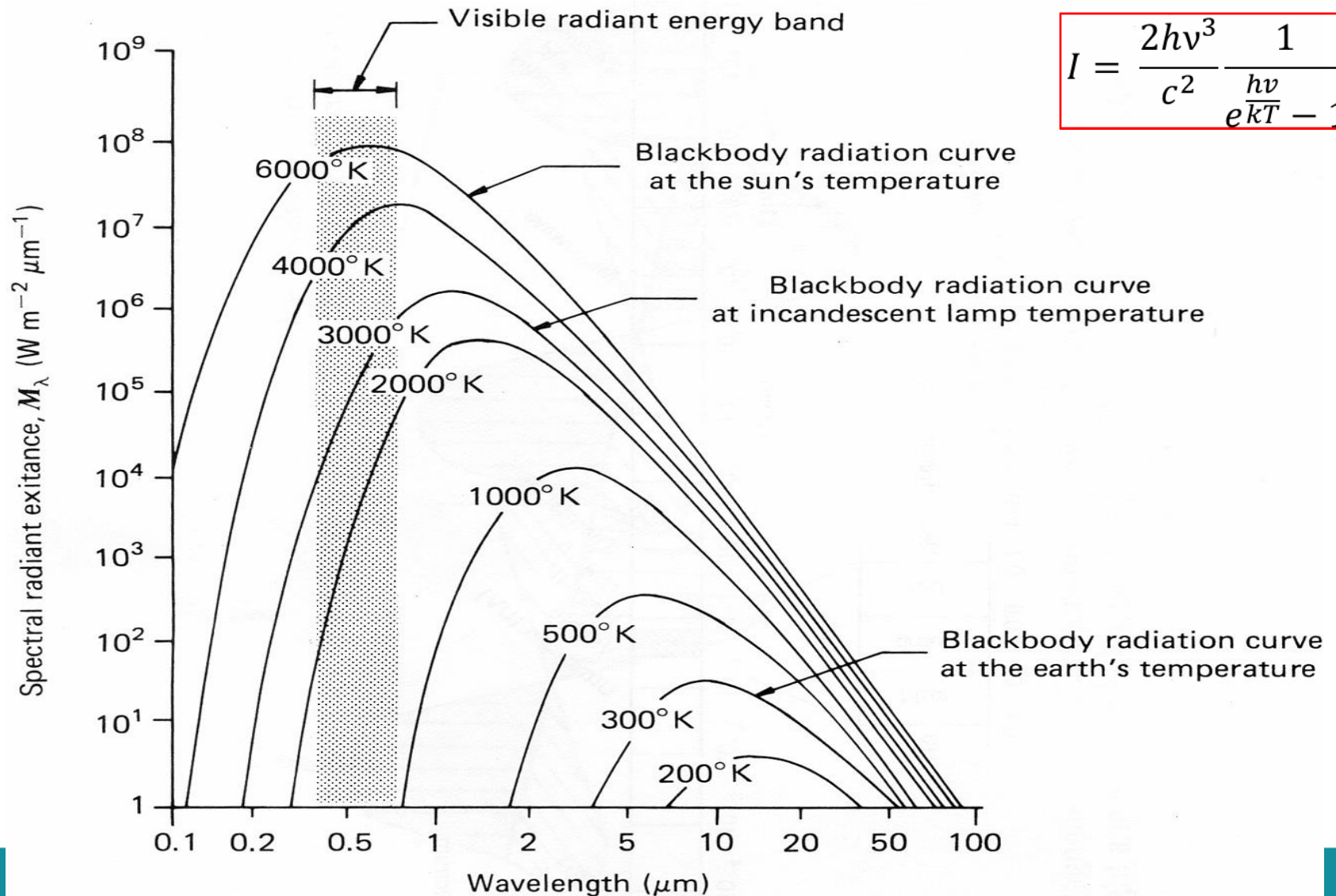


Planck's Law



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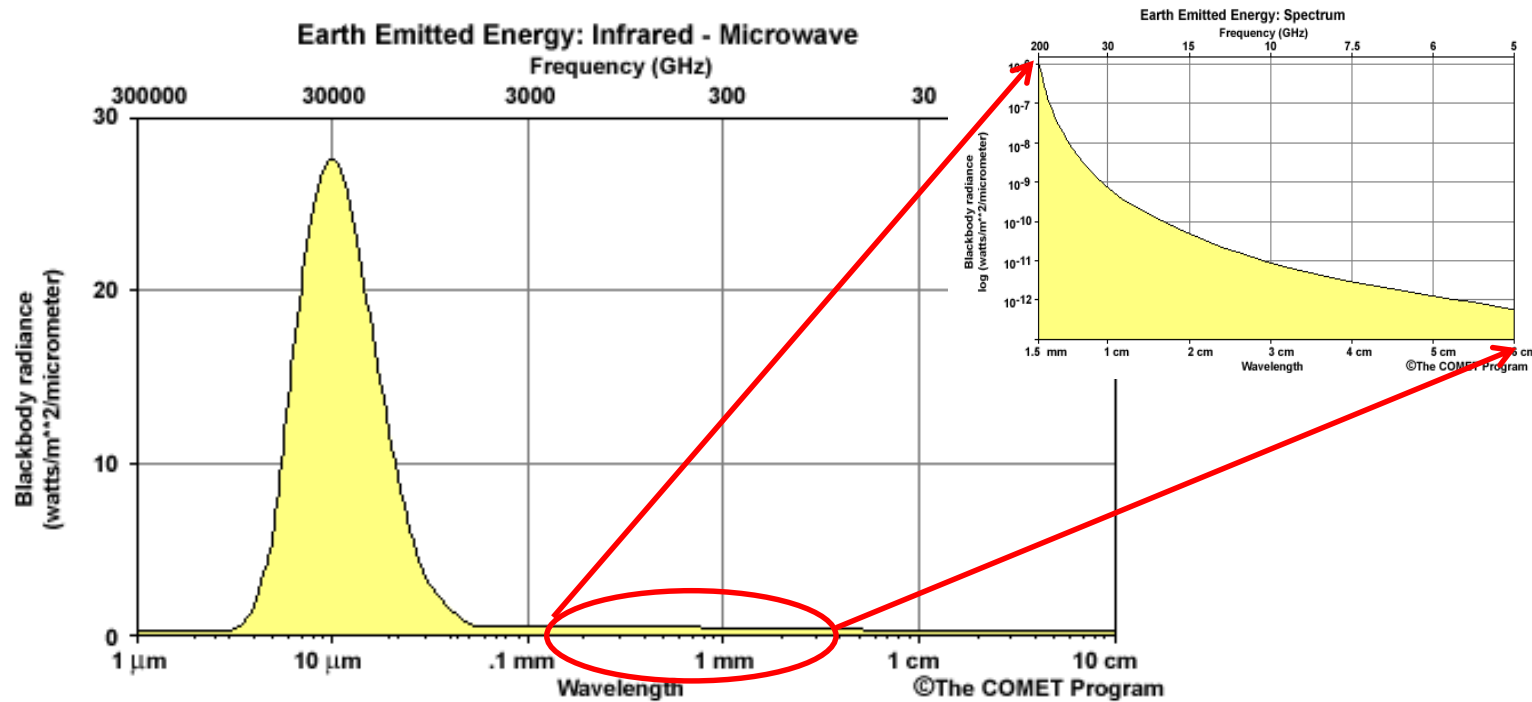
$$I = \frac{2hv^3}{c^2} \frac{1}{e^{\frac{hv}{kT}} - 1}$$



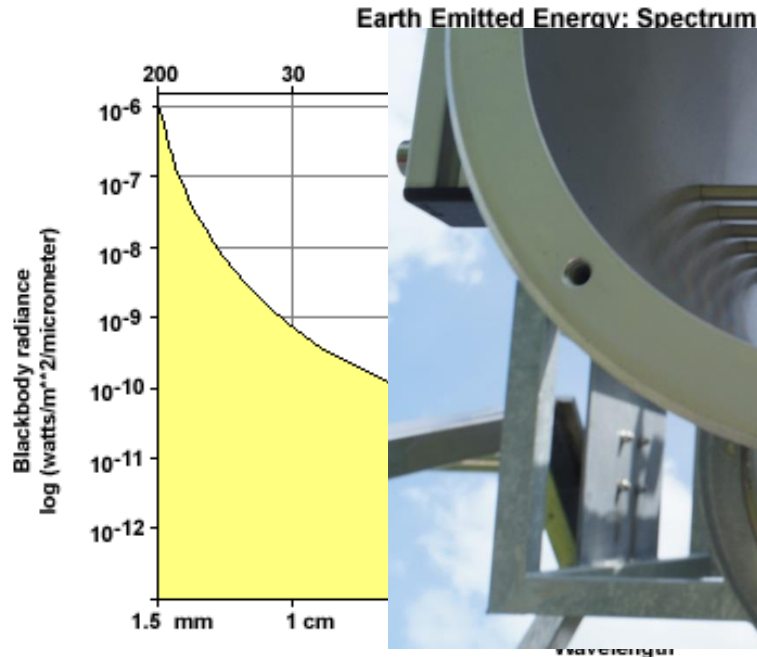
Planck's Law



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Rayleigh-Jeans approximation



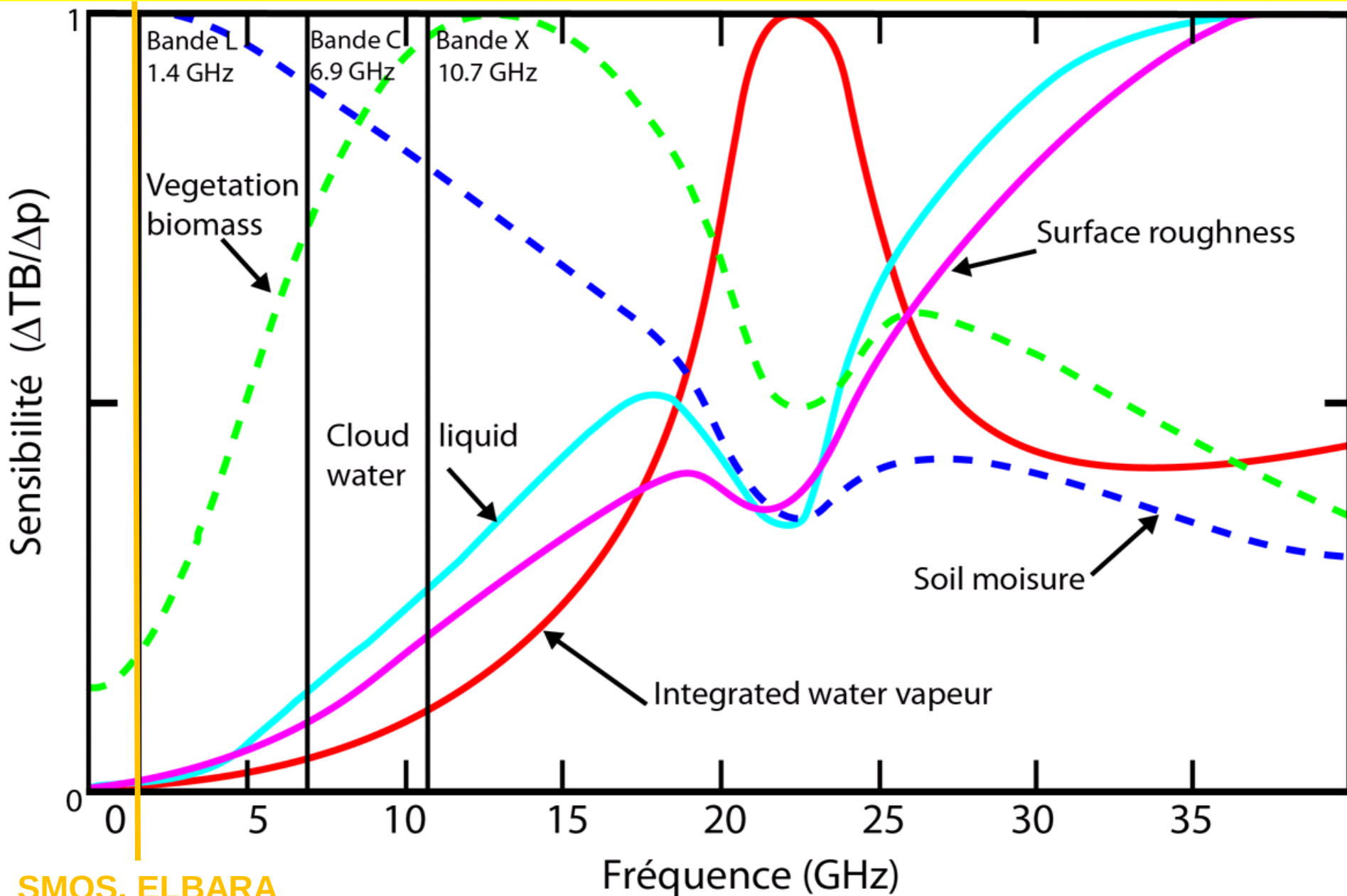
$$P = k T B \approx 10^{-13} \text{ W (!!!)}$$

$$k = 1.380658 \cdot 10^{-23} \text{ J K}^{-1} \text{ (Boltzmann const.)}$$

$$T \approx 300 \text{ K (physical surface temperature)}$$

$$B = 27 \text{ MHz (bandwidth)}$$

Why L-band?



Why 1.4 GHz ($\lambda=21$ cm)?

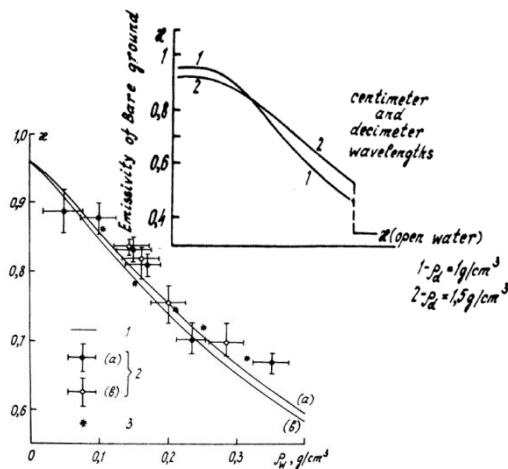
$f = 1400\text{-}1427$ MHz is suitable to observe the Earth's surface from space:

- Protected band (thanks to radio-astronomers!)
- Transparent atmosphere
- Sensitive to liquid water
- Relatively large emission depth
- Strong interaction between liquid water and microwaves!

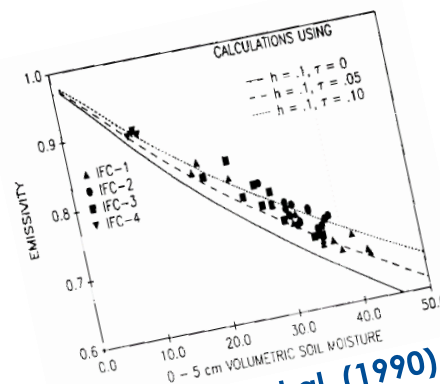
$\Rightarrow$ Microwaves are sensitive to water



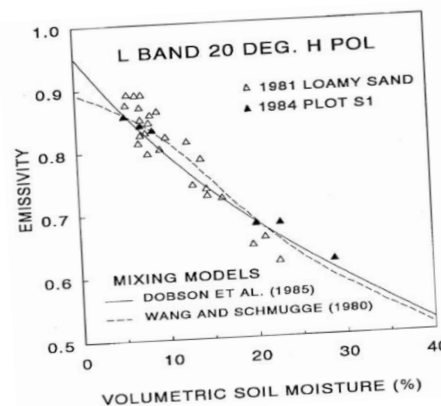
Soil moisture vs. brightness temperature



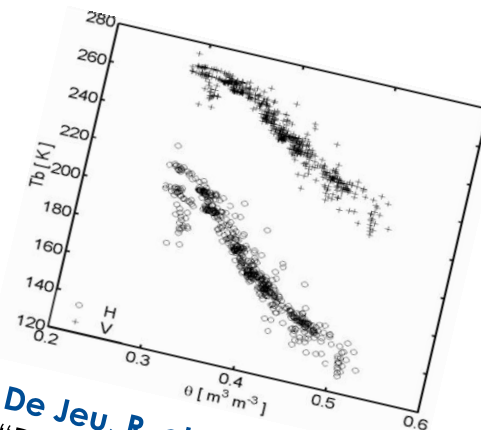
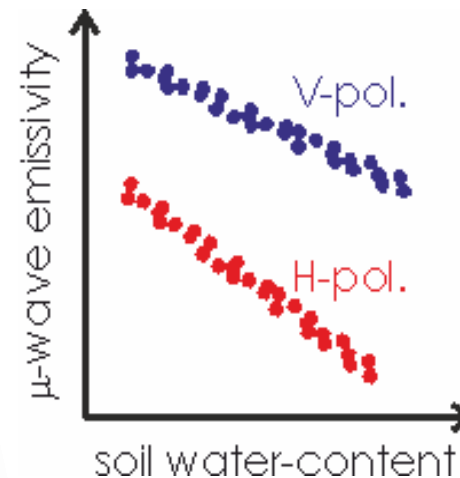
Shutko, A. M. (1982) "Microwave radiometry of lands under natural and artificial moistening."



Wang, J.R. et al. (1990) "The L-band PBMR measurements of surface soil moisture in FIFE"

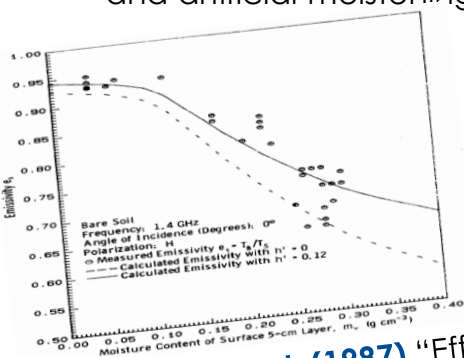


Jackson, T.J. et al. (1987) "Salinity effects on the microwave emission of soils"

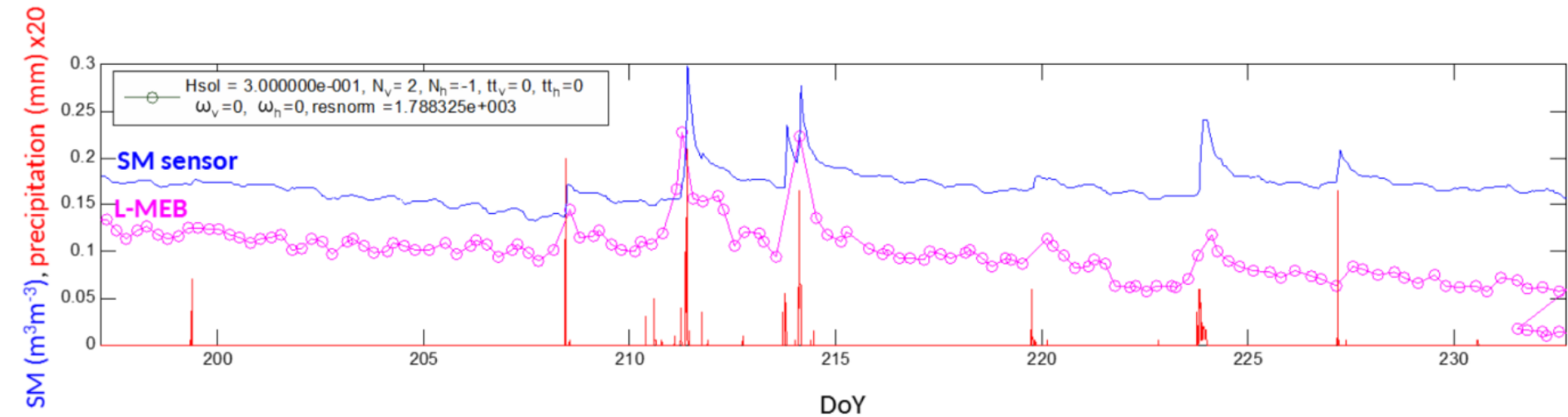


De Jeu, R. et al. (2004) "Deriving land surface parameters from 3 different vegetated sites with the ELBARA 1.4 GHz passive microwave radiometer."

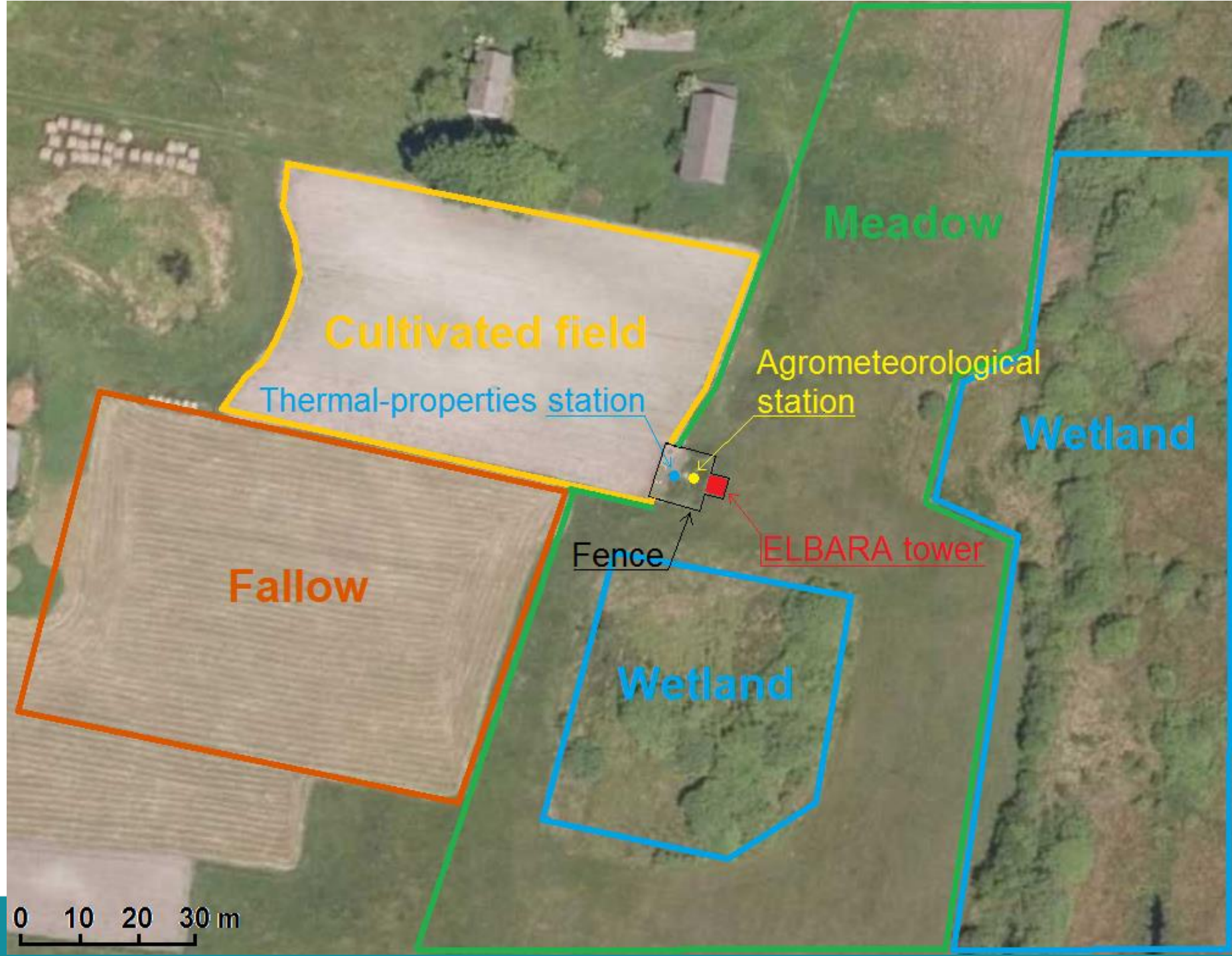
Ulaby, F.T. et al. (1987) "Effects of vegetation cover on the microwave radiometric sensitivity to soil moisture"



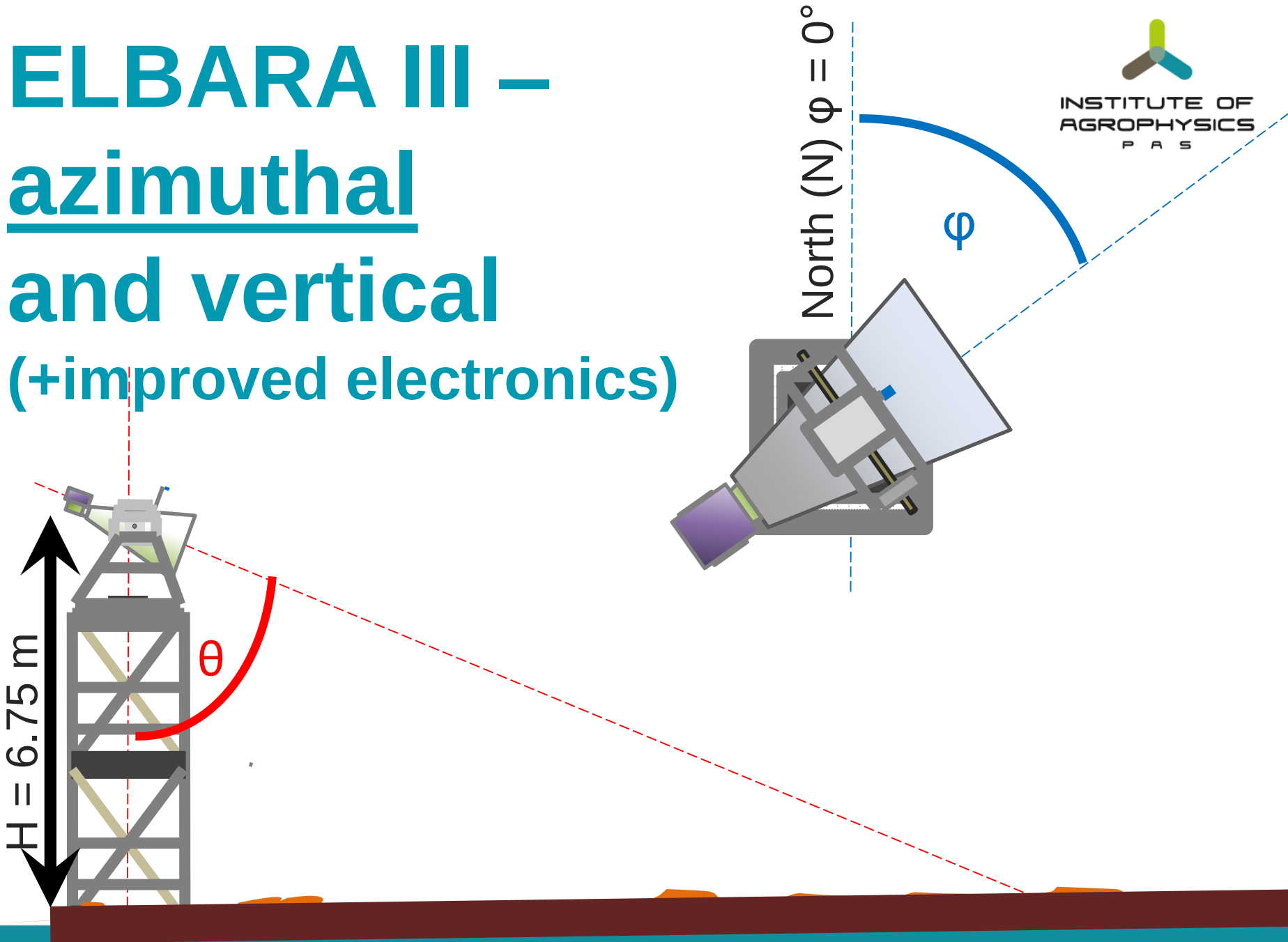
Soil Moisture retrieved with L-MEB model (from Brightness Temperature)



Temporal dependences of SM measured with a sensor and retrieved with L-MEB model. Red, narrow vertical lines indicate precipitation events. SM values were obtained from microwave brightness temperatures measured at azimuth angle 290°. The retrieval has been done assuming T_{GC} , τ_{nad} and SM as free parameters while $H_r = 0.3$.



ELBARA III – azimuthal and vertical (+improved electronics)



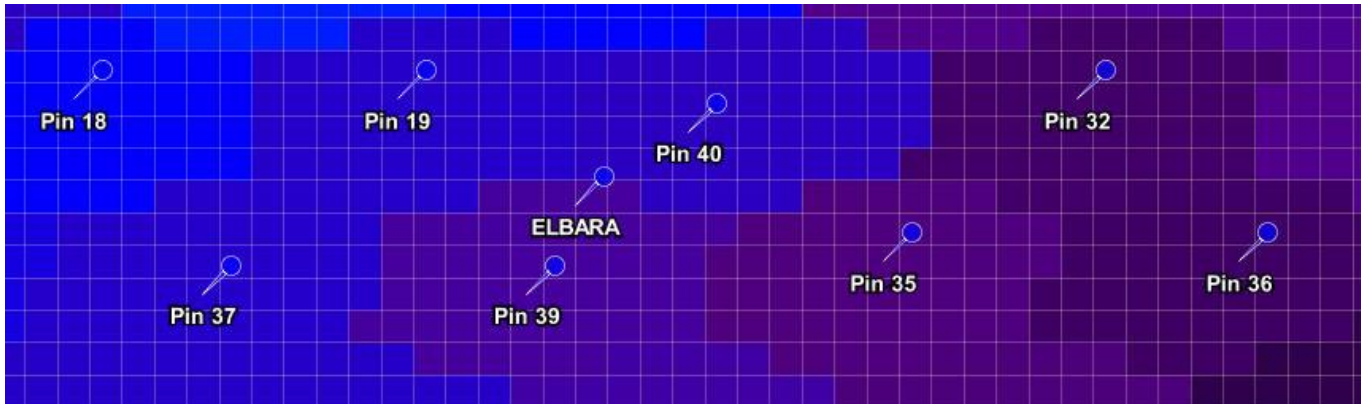
Bubnow Wetland



SMOS vs. ELBARA comparison



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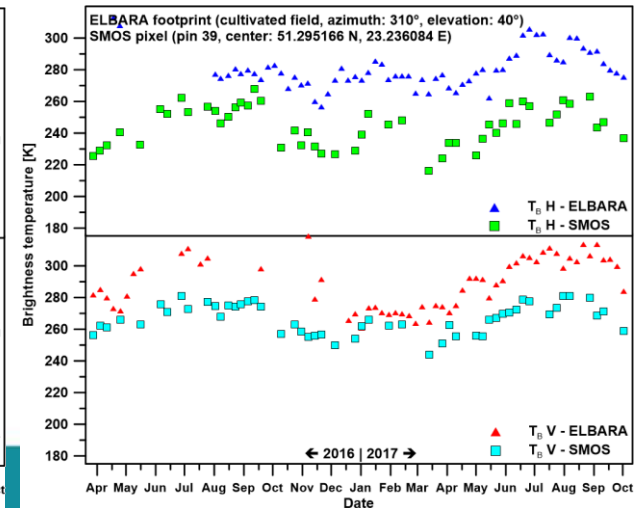
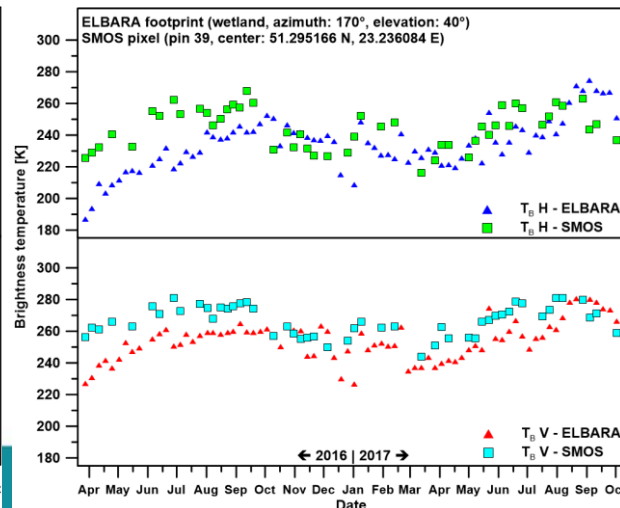
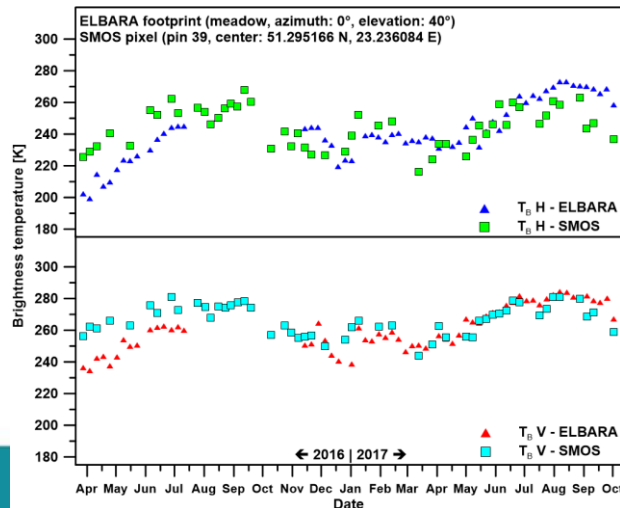
MEADOW



WETLAND



CULTIVATED FIELD

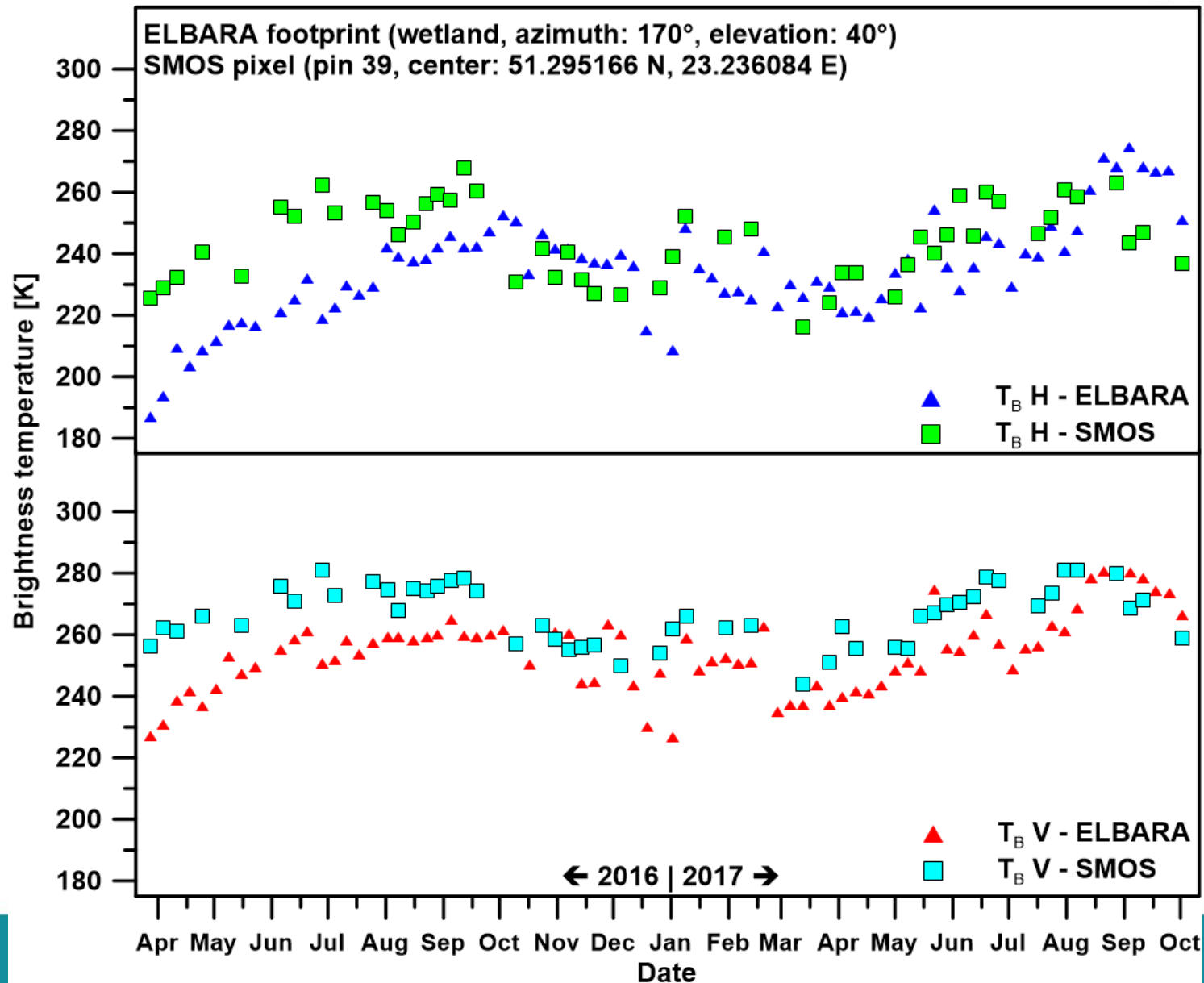


SMOS vs. ELBARA comparison



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ELBARA_PD (Penetration Depth)



HR EXCELLENCE IN RESEARCH

- The team: Mateusz Łukowski, Bogusław Usowicz, Jerzy Lipiec, Edyta Rojek, Radosław Szlązak, Łukasz Gluba, Joanna Sagan, *Wojciech Marczewski, Ewa Słomińska, Jan Słomiński, Andrzej Kotarba, Krystyna Stankiewicz*
- **II 2013 – VII 2017**
- Financed from PECS (Plan for European Cooperating States, between Government of Poland and European Space Agency)

Technical Support for the fabrication and deployment of the radiometer ELBARA-III in Bubnow, Poland



HR EXCELLENCE IN RESEARCH

- The team: Mateusz Łukowski, Bogusław Usowicz, Jerzy Usowicz, Edyta Rojek, Radosław Szlązak, *Andreas Wiesmann, Mike Schwank, Charles Werner*
- **II 2015 – VII 2016**
- Financed by European Space Agency
- The ELBARA instrument goes from one research team to another under a loan agreement with ESA. Thanks to this project ELBARA III was built specifically for Poland!



Publications

- Szewczak, K.; Łukowski, M. (2024). *Medium-Scale Soil Moisture Retrievals Using an ELBARA L-Band Radiometer Using Time-Dependent Parameters for Wetland-Meadow-Cropland Site*. Remote Sens. 2024, 16, 2200. <https://doi.org/10.3390/rs16122200>
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THANK YOU FOR ATTENTION😊



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