[1]Institute for Alpine Environment
[2]Institute for Applied Remote sensing

[3]University of Innsbruck,
Institute for Ecology

The role of soil, topography and vegetation on soil moisture patterns of differently managed mountain grasslands

Giacomo Bertoldi[1], Claudia Notarnicola[2], Johannes Brenner[1], Mariapina Castelli[2], Felix Greifeneder[2], Georg Niedrist[1,3], Julia Seeber[1,3], Ulrike Tappeiner[1,3]

EGU 2016

Outline

- **Monitoring and modeling Soil Moisture Content (SMC) dynamic**:
  open challenges in mountain environments.

- **Case study in Mazia Valley (South Tyrol, Italy):**
  - **Ground observations** (stations / SMC mobile surveys).
  - **Remote sensing**: Synthetic Aperture Radar (SAR).
  - **Hydrological modelling**: GEOtop model.

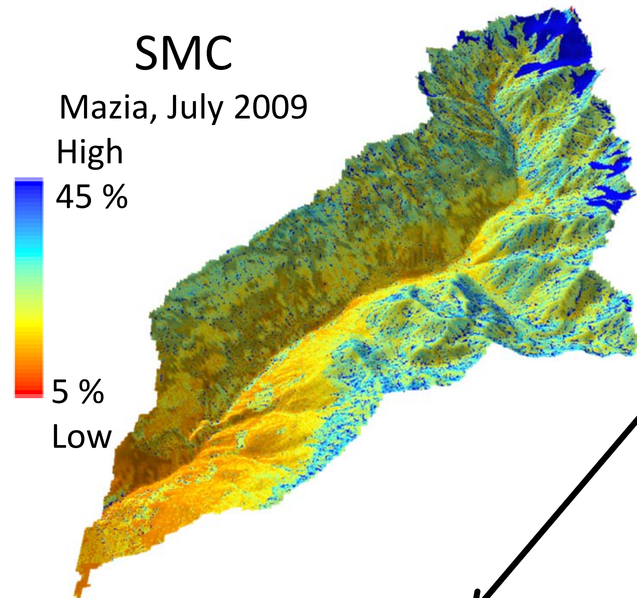
- **Spatial and temporal dynamic of SMC**
  - Impact of different land management on SMC (meadows versus pastures).
- **Model sensitivity analysis**
  - Relationships with climate, soil type and topography.
  - Discuss possible co-evolution mechanisms.

SMC patterns in mountain catchments

Climate (rain/snow, Ta, Rh, U, Rad)

Land use

Vegetation



Microclimate
(Ta, U, Radiation, ET)

?

Topography

Water distribution
(wet–dry locations)

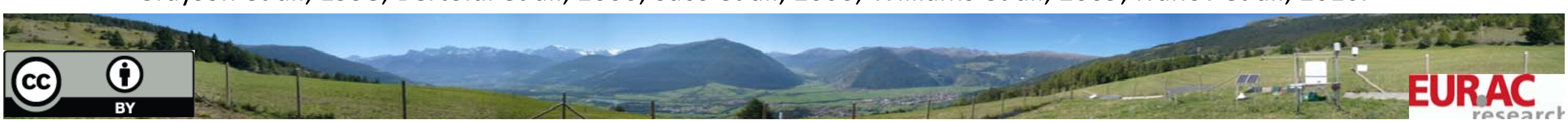
?

Soil properties

Bedrock depth

- ✓ **Heterogeneity** related to soil / land cover / topography.
- ✓ Need of **high-resolution observations** to understand different feedback mechanisms.

Grayson et al., 1998; Bertoldi et al., 2006; Saco et al., 2006; Williams et al., 2009; Ivanov et al., 2010.

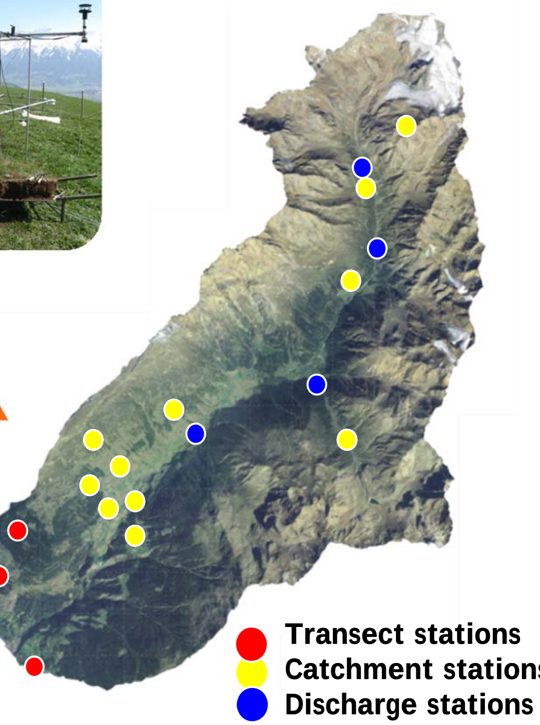


Study area and ground data

Alpine scale

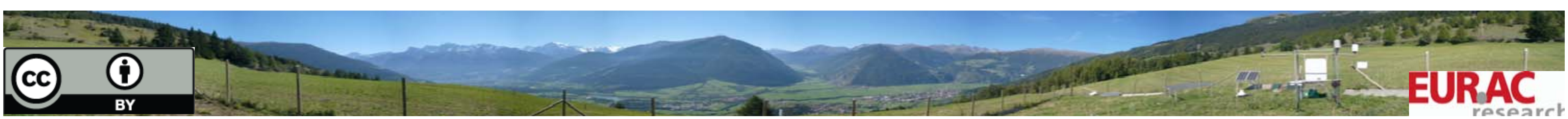
Regional scale
South Tyrol

LTSER Area
Matsch Valley
~100 km²



Station network

- 3 stations: Ta, Rh, Prec, SWC, U, Rsw, Par, Ts, Hsnow
- 7 stations: Ta, Rh, Prec, SWC, U, Rsw, Par
- 6 stations: Ta, Rh, Prec, SWC
- 2 stations: ET (Eddy covariance)



Alpine pastures vs. meadows

Pastures

Located at 1700 to 2400m a.s.l.

Less vegetation (LAI ~ 1 -2)

No irrigation

Steep terrain.

Soils:

Haplic Leptosol (Ranker).

Loamy sand texture

Shallower compact soils.

Meadows

Up to ~ 1700m a.s.l.

Dense vegetation (LAI ~ 4-6)

Intensively managed: cutting, manuring, irrigation.

Soils:

Dystric Cambisol (Brown soil).

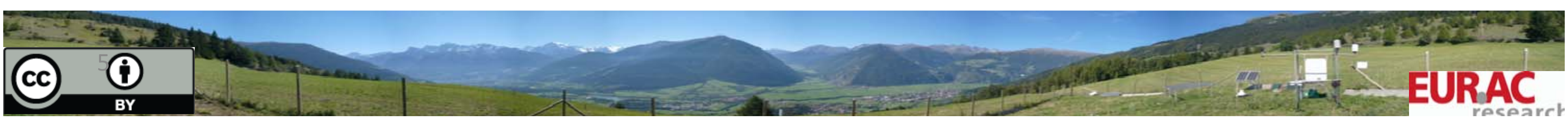
Sandy loam soil texture

Deeper softer soils.

Ecosystem services

Grazing; Erosion control; Carbon storage; Forage production; Water use for irrigation.

Kollmann, K.. Klima- und landnutzungsbedingte Bodenverteilung im Matschertal, Südtirol. *Ms. Thesis*, Universität Innsbruck.(2012).



SMC in alpine grasslands: a feedback mechanism ?

Pastures	Meadows
Steeper locations	Flatter locations
Less developed soil	More developed soil
Soil compaction, erosion, less soil organic matter	Soil manuring, irrigation, more organic matter
Less vegetation (LAI, canopy cover, productivity)	More vegetation (LAI, canopy cover, productivity)
−	+

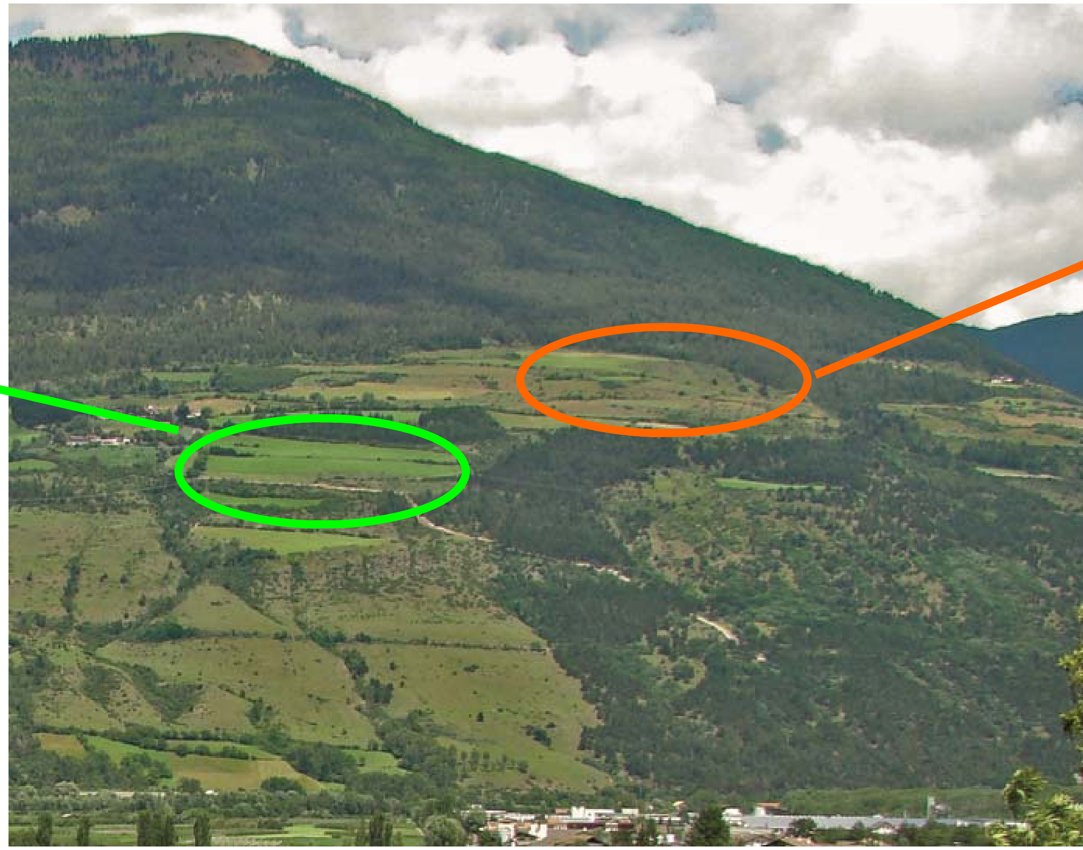
(i. e. Kaligaric et al., FG, 2006; Fatichi et al., WRR, 2014).

Drier ?	**Wetter ?**

There is a quantitative evidence of this coevolution mechanism?
Does it lead to persistent soil moisture patterns?
Which are the main factors controlling soil moisture patterns in pastures vs. meadows?

Observations: experimental setup

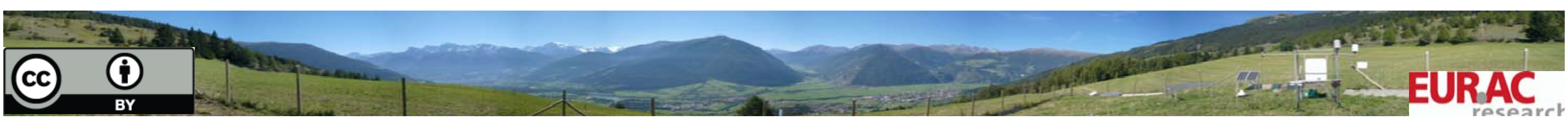
Irrigated meadow B2 station 1470 m



Pasture P2 Station 1520 m

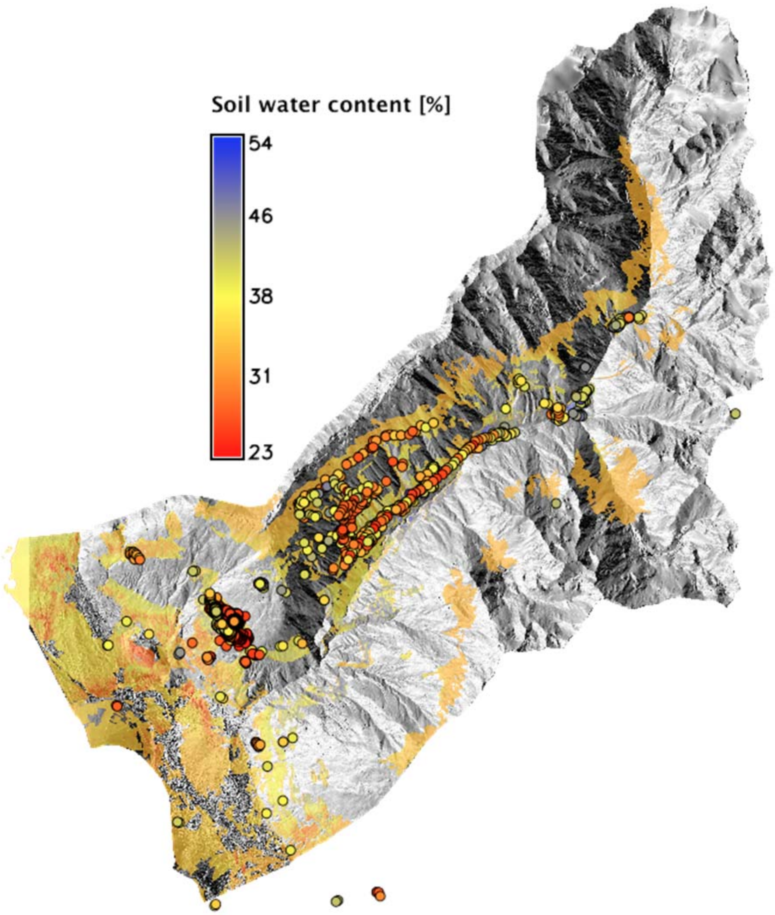
Each site has 1 EC tower for ET and
three stations monitoring SWC @ 2.5, 5, 20 cm depth

(With the support of G. Wohlfhart (UIBK))



Observations: ground surveys

- Monitoring SMC **spatial patterns at hillslope scale;**
- Survey planned to map land cover/topographic features;
- Not possible a grid-based sampling.

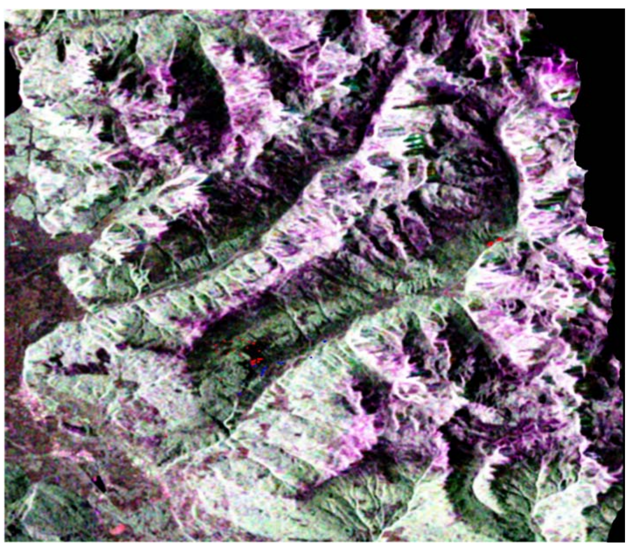


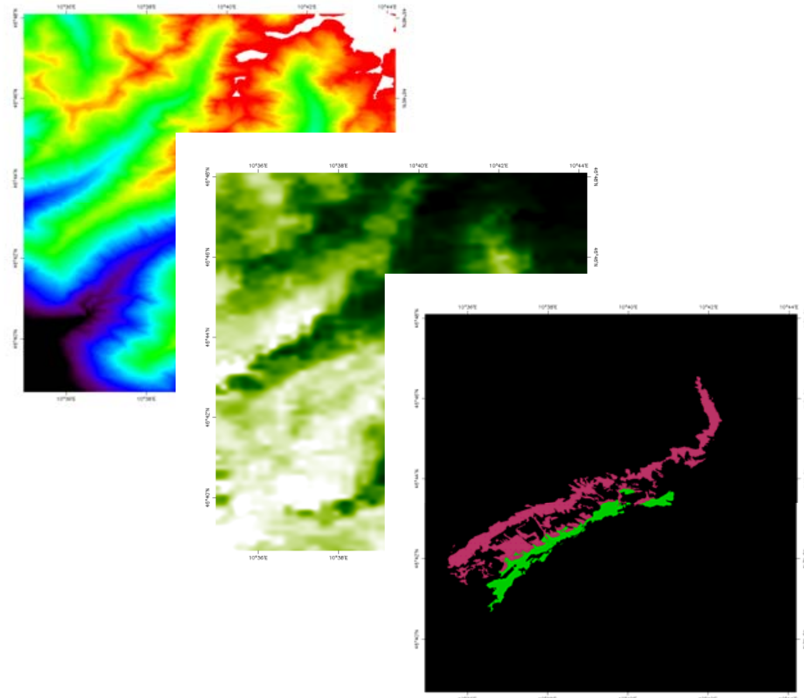
- More than 25 surveys between 2010 and 2015 contemporary to RS images.
- More than 3000 points with mobile TDR sensors 0 – 5 cm depth.
- More than 80 gravimetric samples collected for stations calibration.

Remote sensing: SAR datasets

RADARSAT2 images:

- Four surveys in 2010 and four in 2014.
- Dual polarimetric images (HH-HV)
- **5.5** cm wavelength (C-band radar)
- Almost all images with 30° - 36 ° nominal incidence angle.
- Final spatial resolution **20x20** m^{2}.

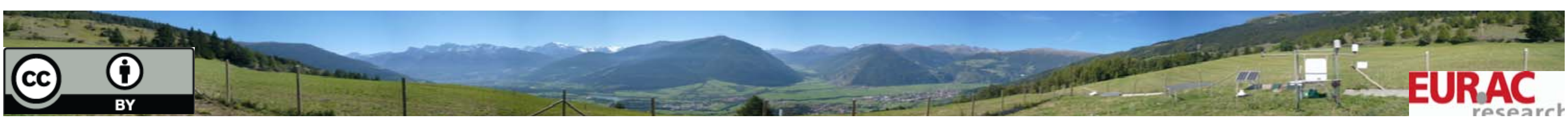




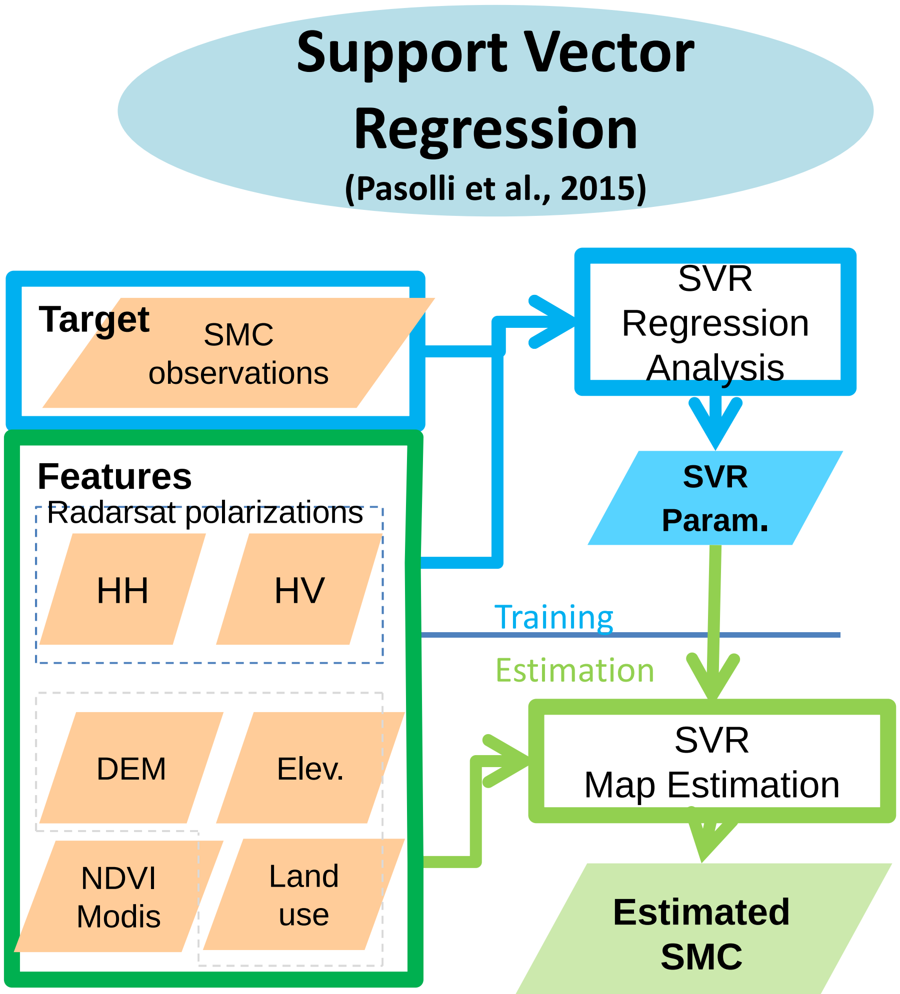
(RADARSAT-2 Data and Products© MacDonald, Dettwiler and Associates Ltd. (2010) – All Rights Reserved)

Auxiliary RS data

- DEM (5x5 m^2)
- NDVI from MODIS (250x250 m^2) High resolution
- Land use map (25x25 m^2)

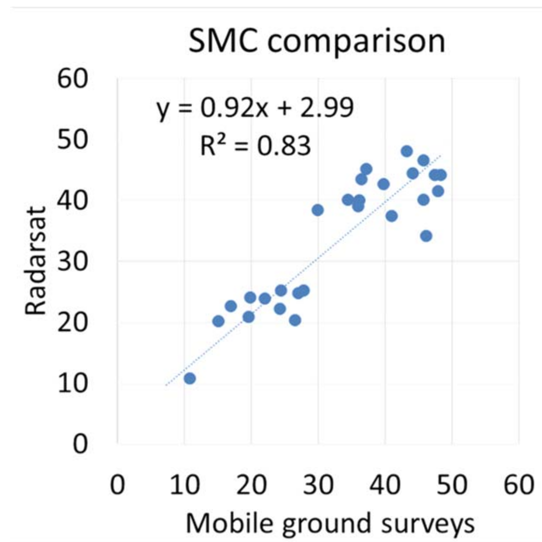


Remote sensing: the retrieval system for SMC

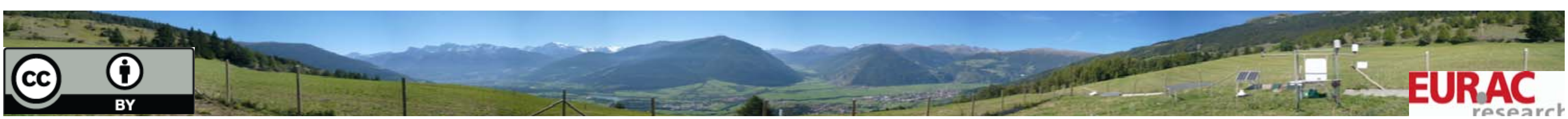


SAR signals in Alpine areas are significantly affected by:

- Local topography (local altitude and local incidence angle).
- Land use / land cover heterogeneity.
- Variable surface roughness.
- Presence of vegetation.



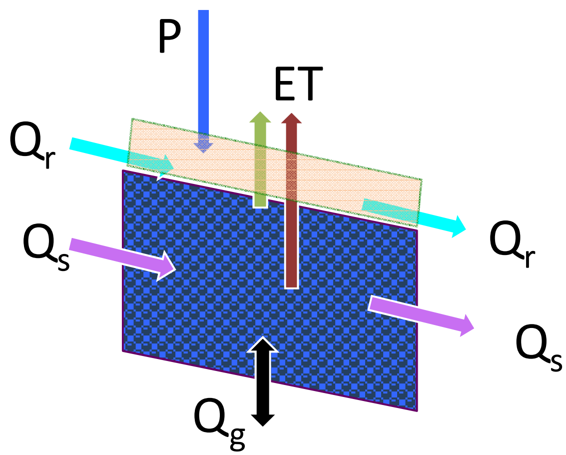
- L. Pasolli, C. Notarnicola, G. Bertoldi, L. Bruzzone, R. Remelgado, F. Greifeneder, G. Niedrist, S. Della Chiesa, U. Tappeiner and M. Zebisch, Estimation of soil moisture in mountain areas using SVR technique applied to multiscale active radar images at C band, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 01/2015; 8(1):262-283.



Hydrological modeling: GEOtop SMC simulation

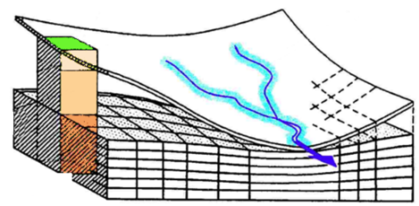
Plot scale water budget

$$\frac{\partial SMC}{\partial t} = P - ET - Q_r - Q_s - Q_g$$



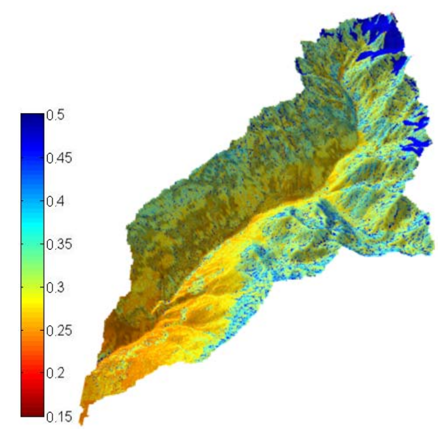
GEOtop model

Rigon et al., JHM, 2006.
Endrizzi et al., GMD, 2014.



3D Richard's eq.

Catchment scale SMC
@ 5cm



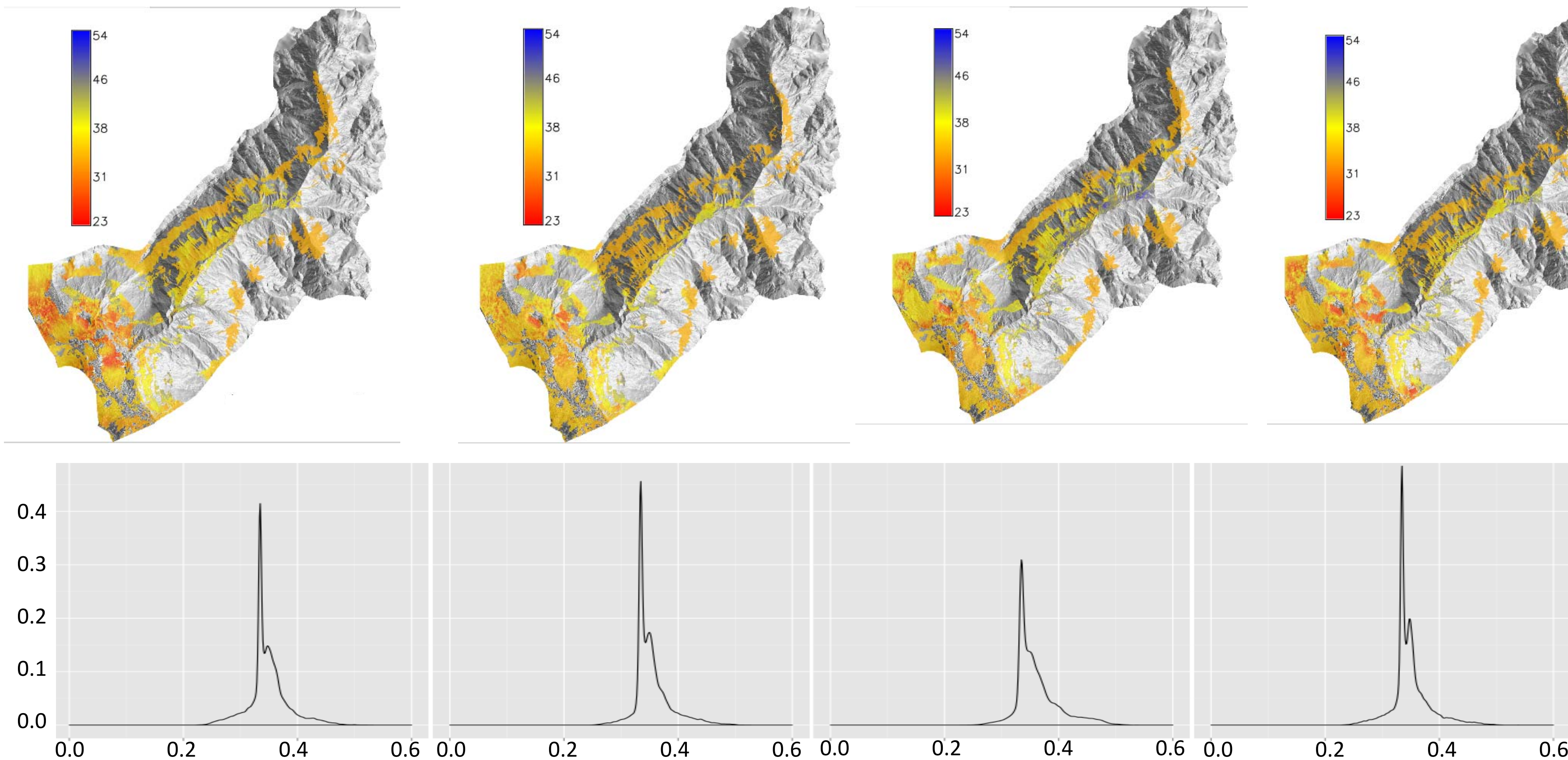
- **Two main soil types**: Haplic Leptosol (**loamy sand**) mainly in pastures and Dystric Cambisol (**sandy loam**) mainly in meadows (*Van Genuchten, 1980*).
- Two land cover types: **grassland**, **meadows** (LAI, canopy height and cover).
- Input **meteorological forcing** (P, Ta, RH, U, Rsw) from 6 stations (only **one irrigated**).

Endrizzi, S., et al. GEOtop 2.0: simulating the combined energy and water balance at and below the land surface accounting for soil freezing, snow cover and terrain effects. Geosci. Model Dev. 6, 6279–6341 (2014).

Rigon, R, et al. GEOtop: a distributed hydrological model with coupled water and energy budgets. J. Hydrometeorol. 7 (3), 371–388 (2006).

Results: Radarsat SMC maps

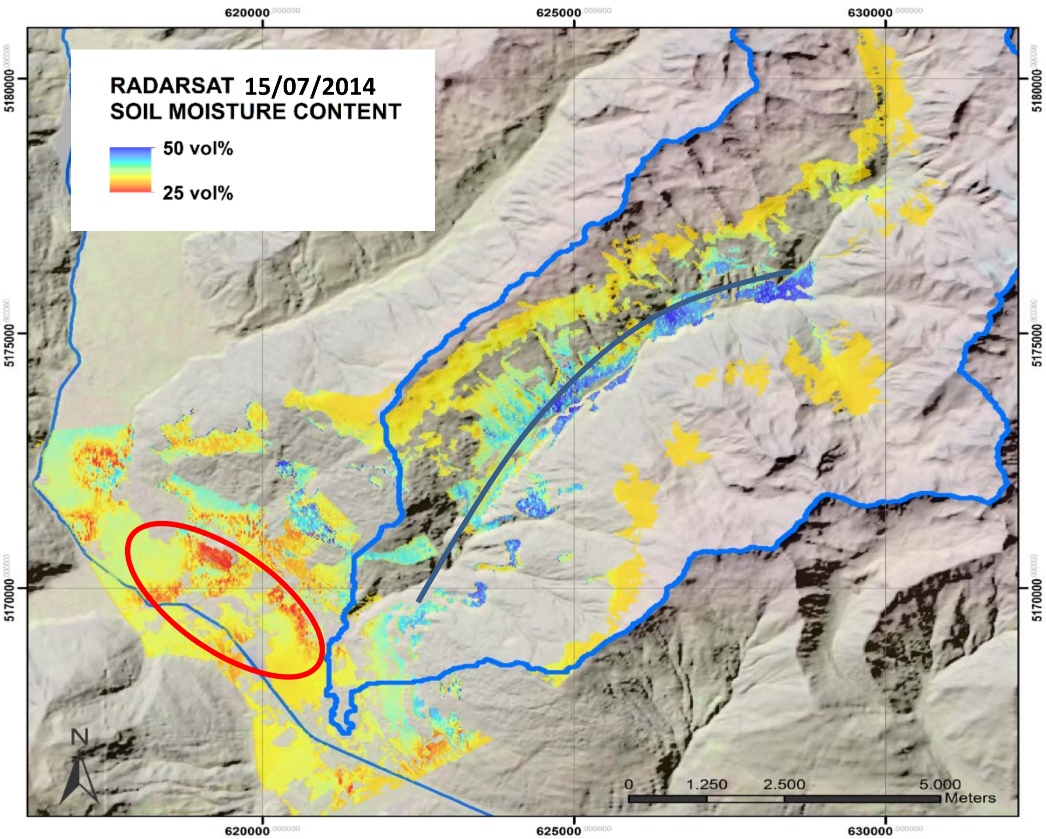
SMC (%)	21 June 2014	24 June 2014	15 Jul 2014	18 Jul 2014
	P_{10dd} = 8.6 mm	P_{10dd} = 19.1 mm	P_{10dd} = 41.2 mn	P_{10dd} = 38 mm

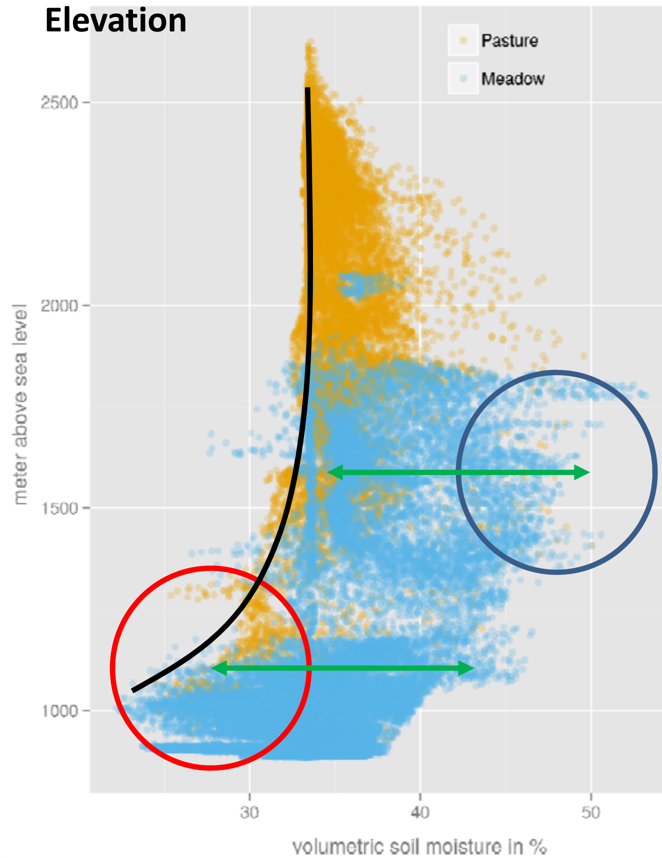


SMC [-]

- **Temporal stability** of soil moisture patterns (Vachaud et al., 1985, SSSAJ; Brocca et al., 2010 WRR)

Results: SMC maps spatial patterns

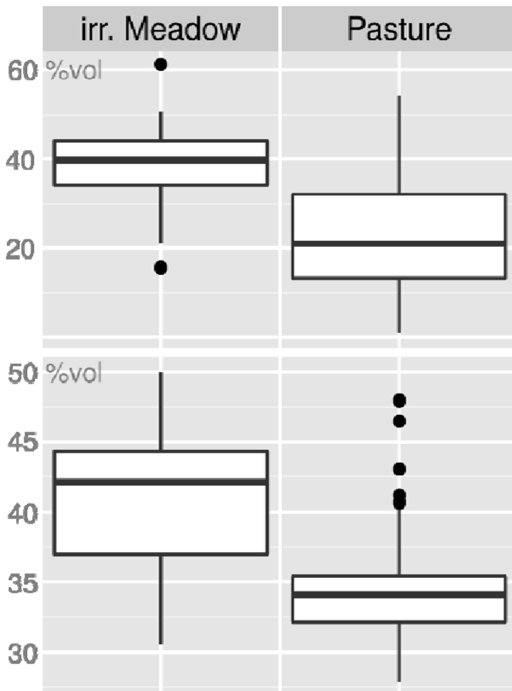




Wettest locations are along the valley bottom and in irrigated areas.
Driest locations are south-facing low elevation pastures and not-irrigated meadows.
Elevation controls minimum SMC: increasing trend with elevation (ET).
Irrigation alters the distribution of SMC with altitude.

Results: comparison ground surveys – Radarsat patterns

All sampling locations for the four overpasses



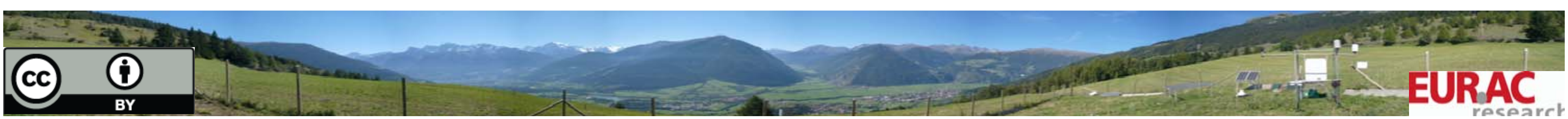
	Elevation	Slope	TWI
Ground surveys	$\rho = 0.22$	$\rho = -0.31$	$\rho = 0.01$
Radarsat estimations	$\rho = 0.12$	$\rho = -0.36$	$\rho = 0.03$

Land use is the major control on SMC patterns.

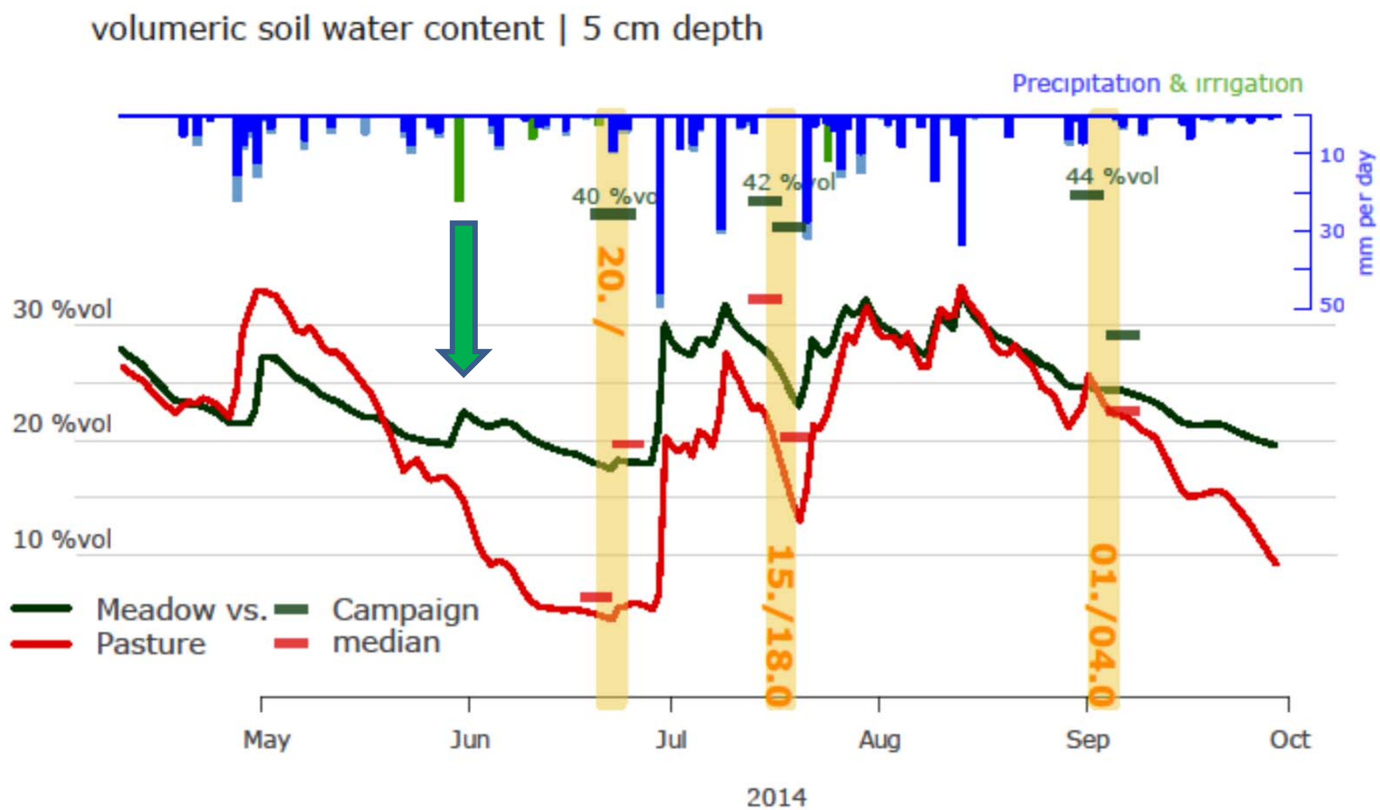
It exists a weak positive correlation of SMC with elevation and a negative with slope.

TWI = log (A/slope) exerts almost no control on SMC.

Observed SMC patterns reflect (I) land use / vegetation (II) slope and (III) elevation
Radarsat estimations in survey location reproduce the observed behavior.



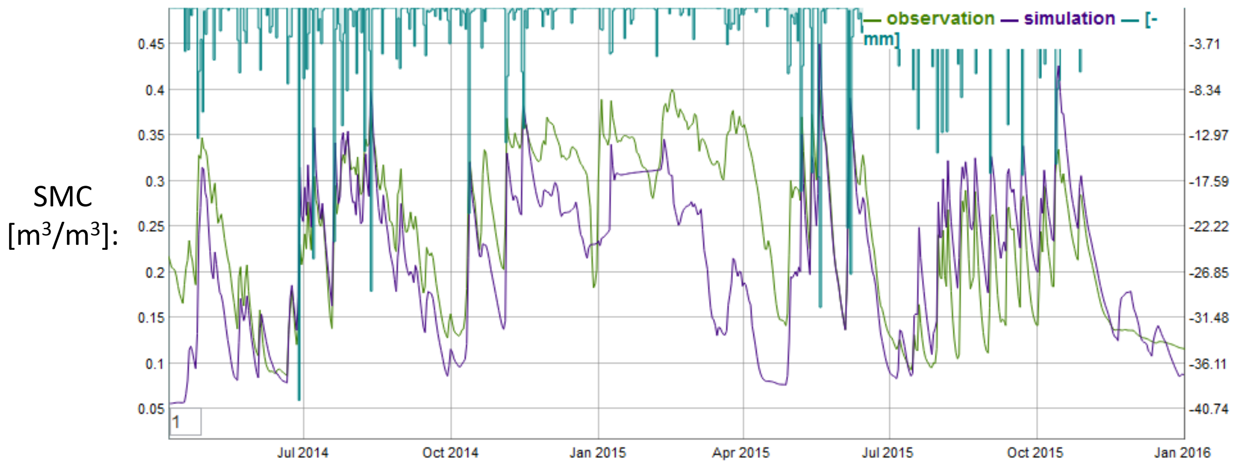
Results: station’s SMC temporal dynamic



- Ground stations: monitoring SMC **temporal dynamic.**
- **Clear contrast between meadow and pastures.**
- Impact of **irrigation!**
- But how much **soil and vegetation** properties are relevant?

Results: GEOtop model SMC temporal dynamic

Model parameterized with observed soil / land cover properties

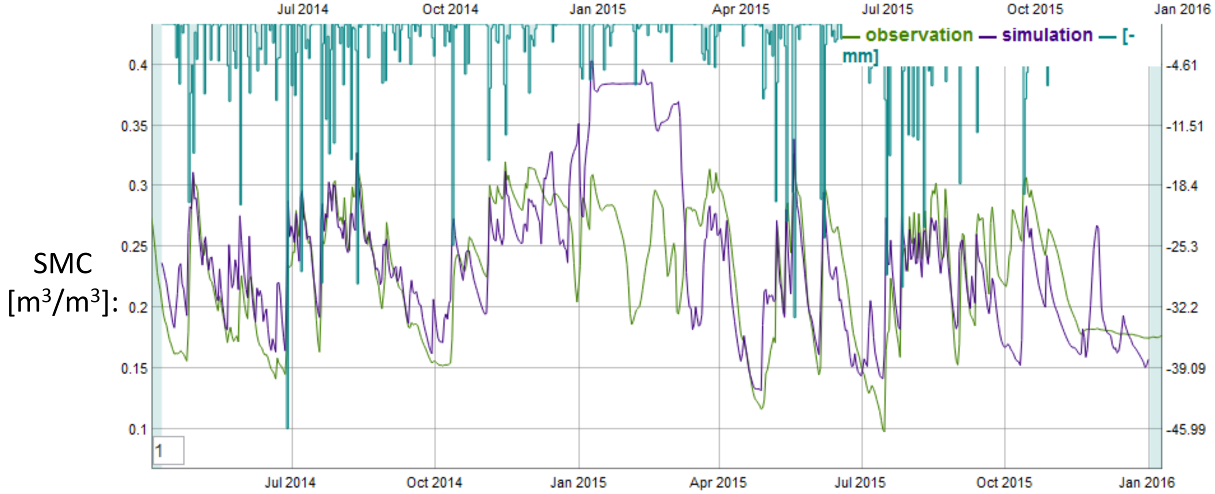


P
[mm]
Yearly total
860 mm

SMC **Pasture** @ 5 cm

Bias -0.03 m^3/m^3

RMSE 0.07 m^3/m^3



P
[mm]
Yearly total
1092 mm

SMC **Meadow** @ 5 cm

Bias 0.01 m^3/m^3

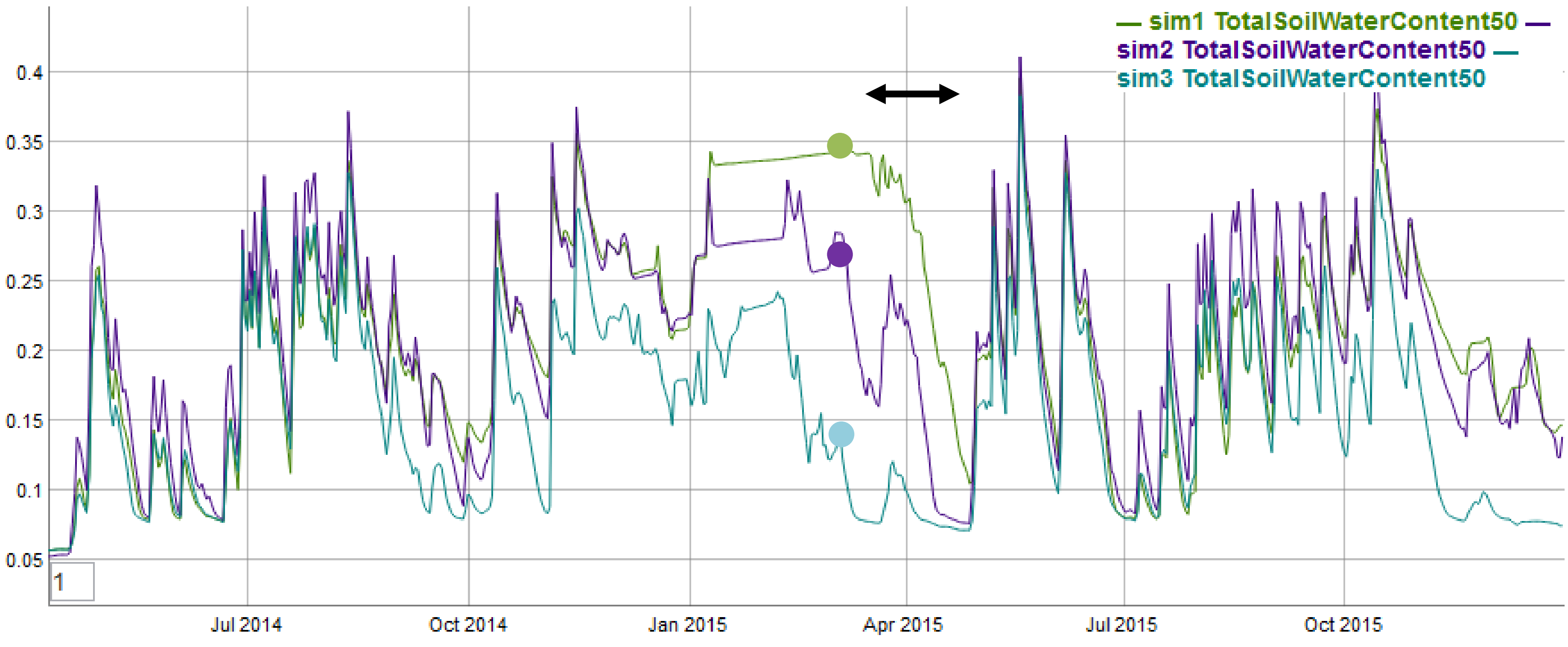
RMSE 0.05 m^3/m^3

Let´s **play with the model** to investigate the different controlling factors !

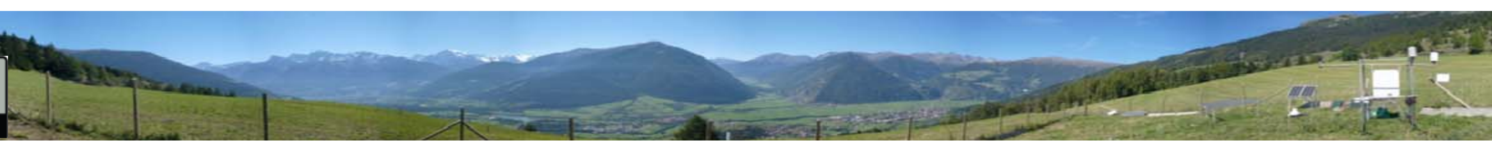
Results: GEOtop model sensitivity: slope/aspect

Numerical experiment: 1. North aspect, slope 30º; 2. Flat; 3. South aspect.

SMC Averages [m^3/m^3]: **North: 0.22** **Flat: 0.21** **South: 0.16**



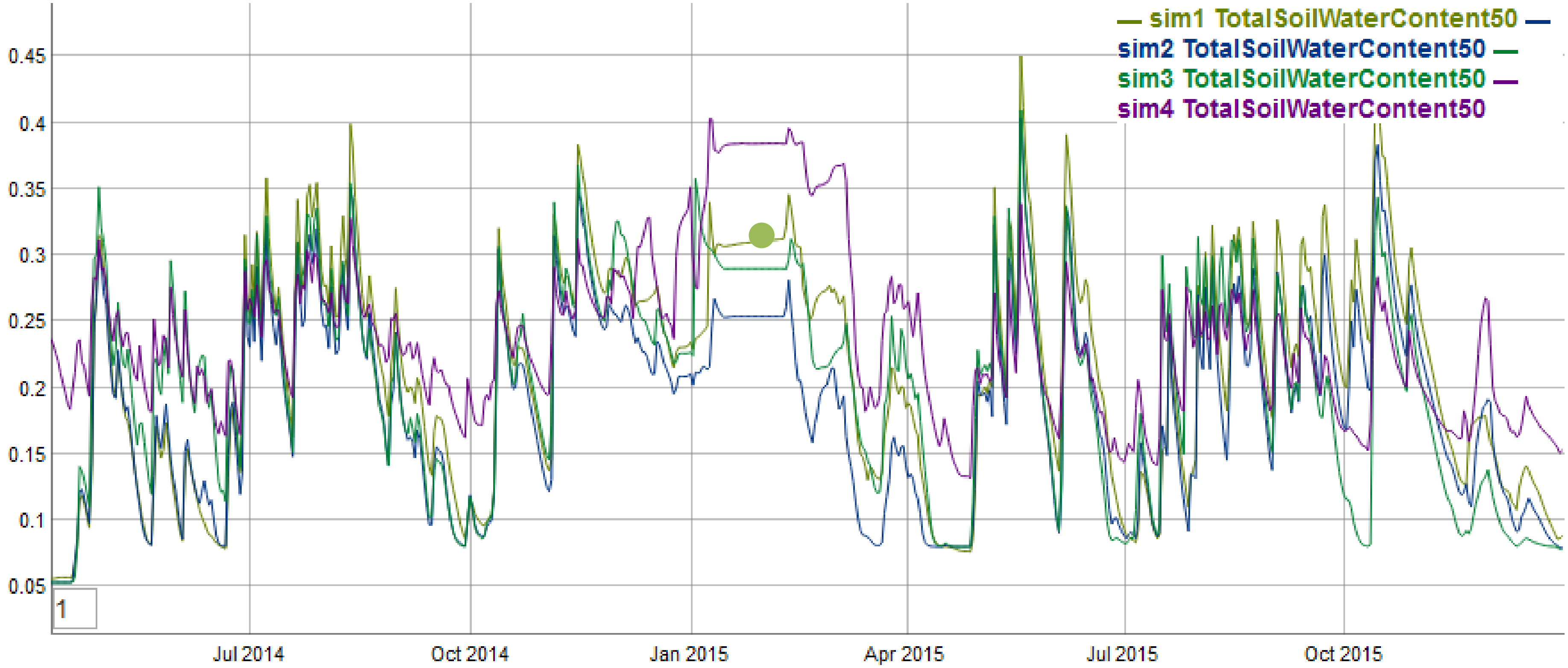
Strength of slope/aspect control on SMC seems to be seasonally-dependent.
Effect of steep slopes on radiation (ET) and precipitation by unit area (993 to 666 mm)



Results: GEOtop model sensitivity: meadows vs. pastures

Factorial numerical experiment

1. Pasture soil, microclimate and vegetation: SMC average 0.21 [m³/m³]:

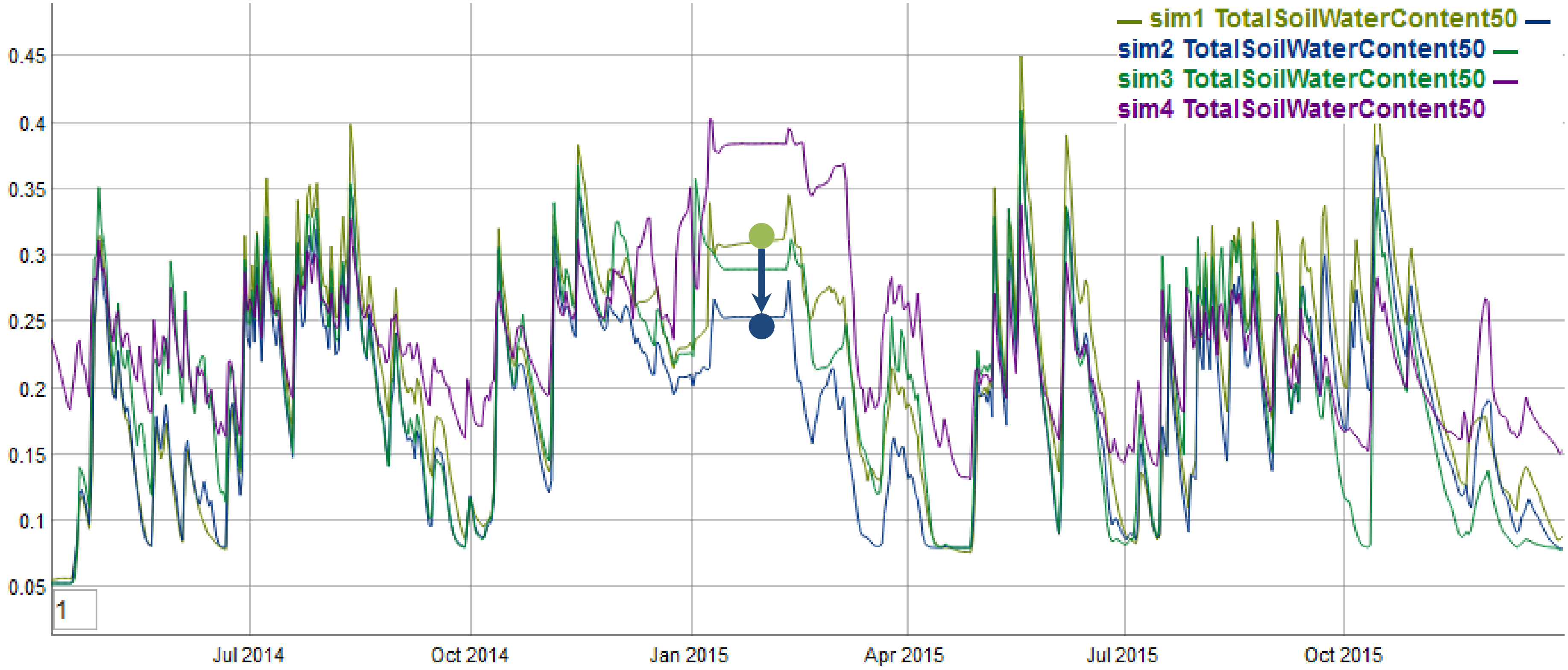


" Evolution " from pastures toward meadows conditions.
Denser vegetation reduces SMC.
Soil type change increases SMC.

Results: GEOtop model sensitivity: meadows vs. pastures

Factorial numerical experiment

2. Meadow vegetation: SMC average 0.18 [m^3/m^3]:



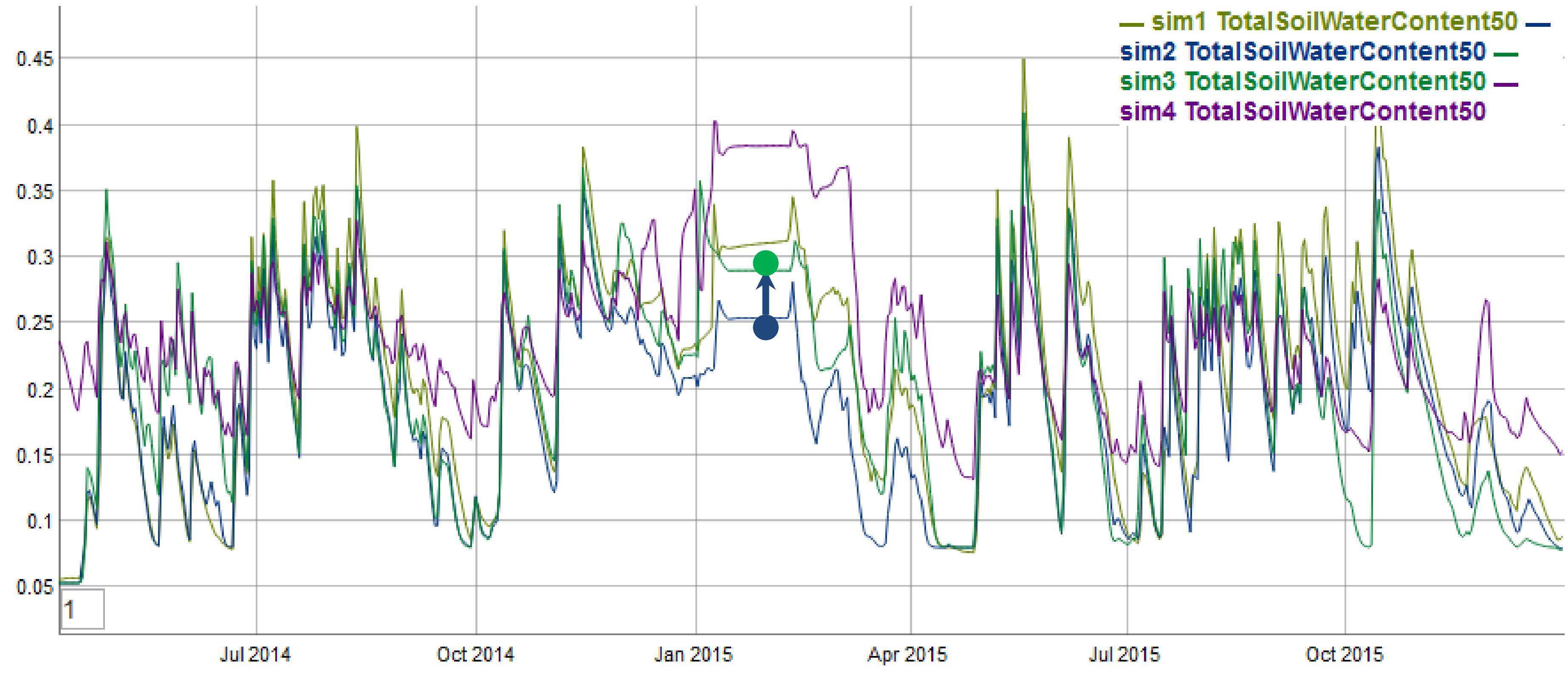
" Evolution " from pastures toward meadows conditions.
Denser vegetation reduces SMC.
Soil type change increases SMC.

EURAC research

Results: GEOtop model sensitivity: meadows vs. pastures

Factorial numerical experiment

3. Irrigation: SMC average 0.21 [m³/m³]:

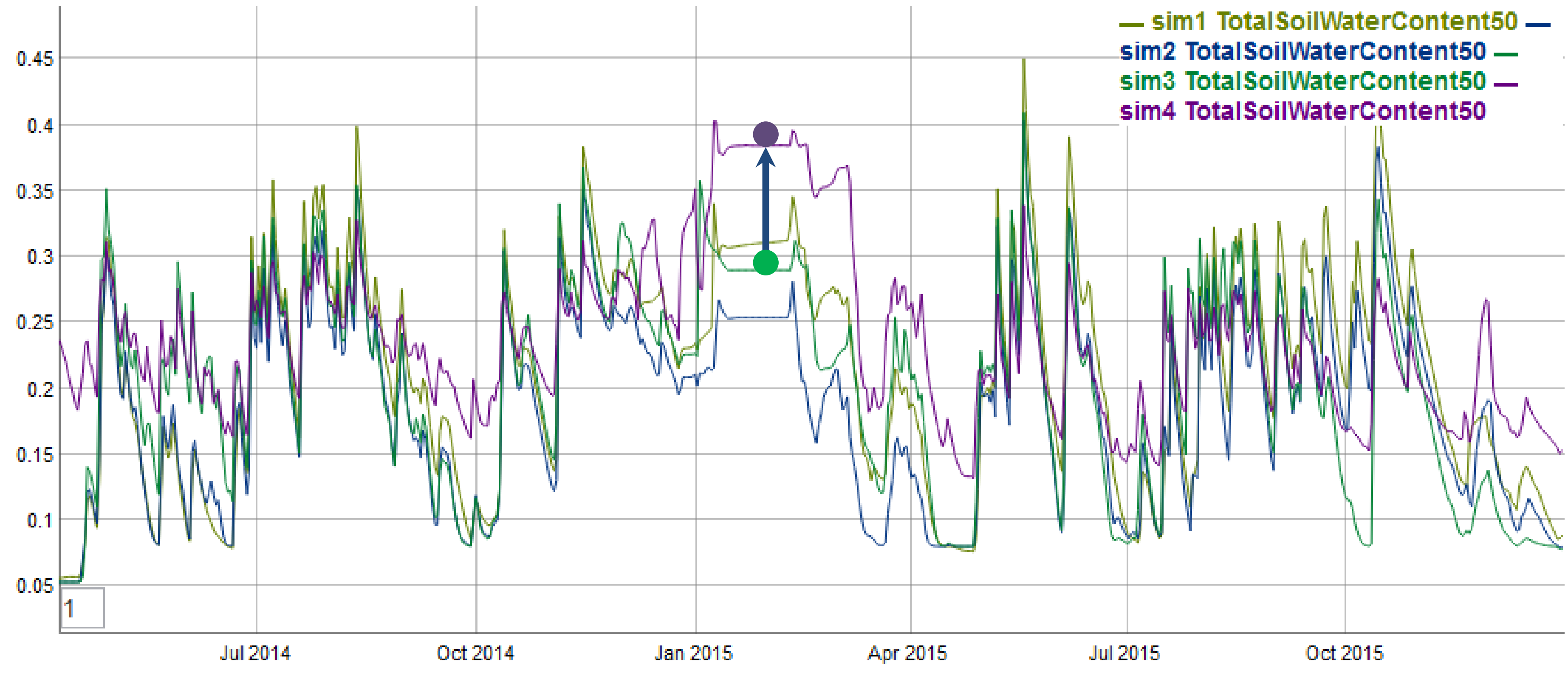


" Evolution " from pastures toward meadows conditions.
Denser vegetation reduces SMC.
Soil type change increases SMC.

Results: GEOtop model sensitivity: meadows vs. pastures

Factorial numerical experiment

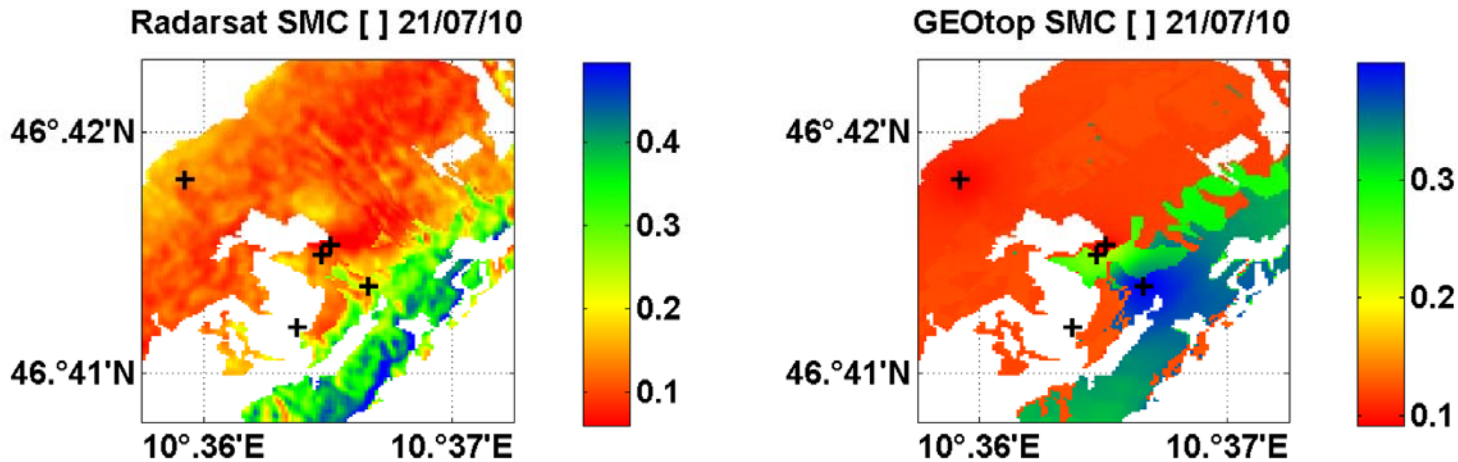
4. Meadow soil: SMC average 0.24 [m^3/m^3]:

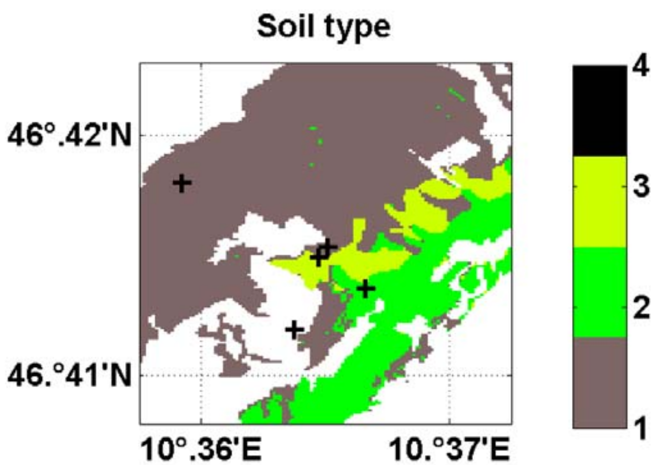


“ Evolution “ from pastures toward meadows conditions.
Denser vegetation reduces SMC.
Soil type change increases SMC.

Results: GEOtop model SMC spatial patterns

Topography, soil type or land use?





Bertoldi et al., JH (2014)

GEOtop model spatial SMC patterns are dominated by **soil hydrological properties**.

Bertoldi, G., Della Chiesa, S., Notarnicola, C., Pasolli, L., Niedrist, G., & Tappeiner, U.: Estimation of soil moisture patterns in mountain grasslands by means of SAR RADARSAT2 images and hydrological modeling. *Journal of Hydrology*, 2014

Conclusions and Outlook

Conclusions

- Coupling between natural and anthropogenic (different management) controlling factors leads to persistent SMC patterns in mountain grasslands.
- Clear difference between wetter meadows and drier pastures.
- Seasonally dependent sensitivity to slope/aspect and elevation.
- Negative sensitivity of vegetation density on SMC.
- The strong control of soil hydrologic properties suggests a possible coevolution mechanism between soil and vegetation in mountain grassland.

Outlook

- High resolution surveys and modelling trough UAV, GPR, CRP.
- Sensitivity analysis of the driving factors at the spatial level.
- Implementation of dynamic vegetation and soil evolution model (soil type, soil thickness) to test possible co-evolution mechanism.

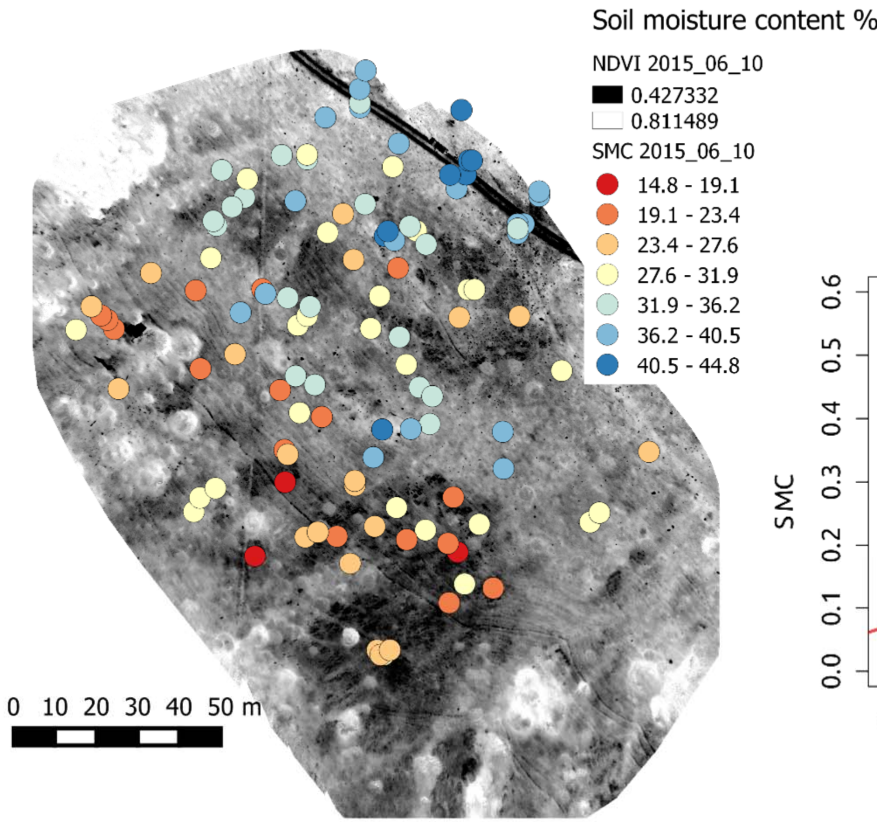
EURAC research

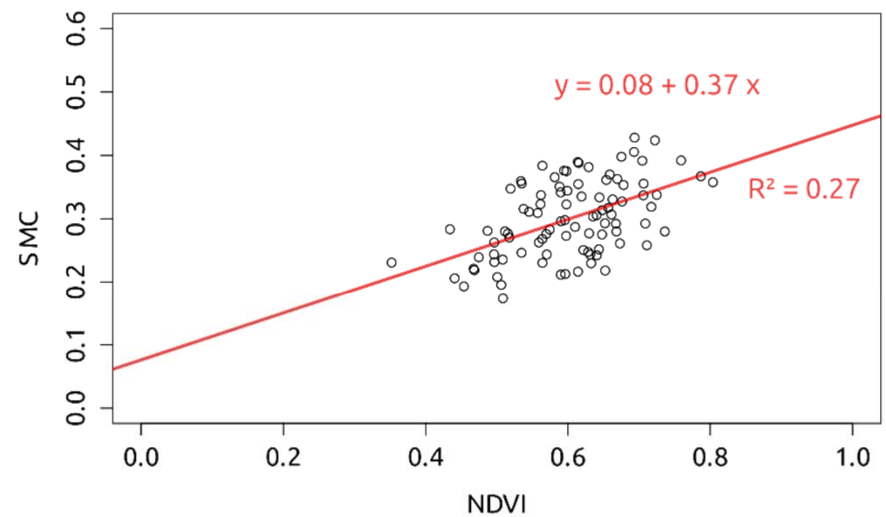
Ongoing work: high-res SMC mapping

Preliminary results:

High spatial resolution (~ 1m) SMC vs. NDVI from UAV.

UAV-based plant´s traits estimation (Castelli et al., in prep)





EURAC research

Acknowledgment

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S. Endrizzi, University of Zurich, for the GEOtop model code development.