HPC needs for Integrated Hydrological Models: examples of application of the GEOtop model to the Vienna Scientific Cluster

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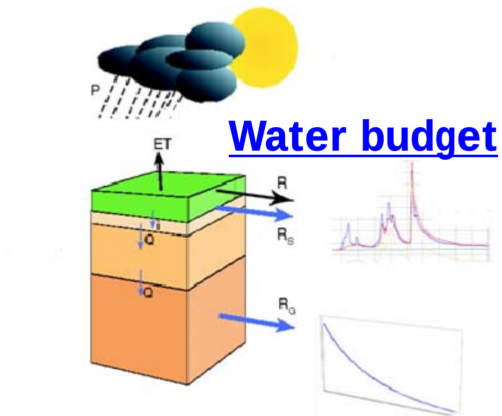
Outline

- **Integrated Hydrologic Modelling Systems**
  - The GEOtop 2.x model.
- **Open challenges for HPC**
  - Solving coupled, non linear equations.
  - Large domains.
  - <u>Optimal parameters identification.</u>
- **Model optimization and sensitivity analysis exercise**
  - Reduce the number of parameter to be optimized.
  - Identify most relevant factors controlling differences among sites.
- **Application to the VSC**
  - Optimization vs. computational needs.
- **Future research directions**

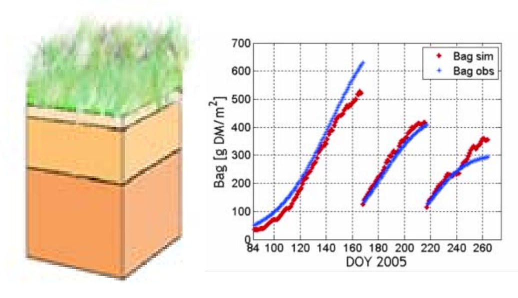
Integrated eco-hydrologic models

Water budget



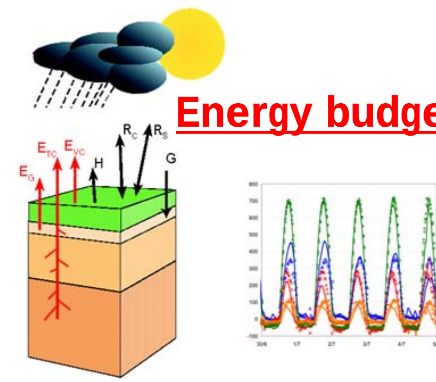
Hydrogeosphere, Therrien & Sudicki, 1996
Parflow, Asby an Falgout, 1996
Cathy, Paniconi and Putti, 1994
DHSVM, Wigmosta et al., 1994

Vegetation dynamics



TRIBS-VEGGIE Fatichi et al., 2012
Montaldo et al., 2005
Eagleson, 2002

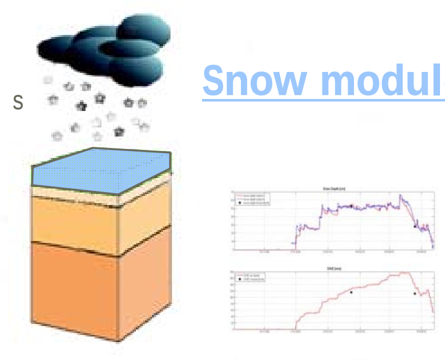
Energy budget



Figures adapted from VIC model (Liang et al., 1994)

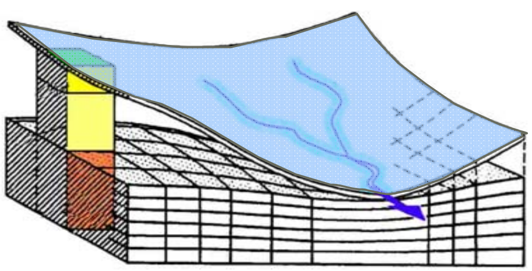
CLM, Dai et al., 2003
SEWAB, Megelkamp et al., 1999
Noah LSM, Chen et al., 1996
LSM, Bonan, 1996
BATS, Dickinson et al., 1986

Snow module



Alpine3D, Lehning et al., 2006
CROCUS, Brun et al., 1992
SNTHERM, Jordan, 1991

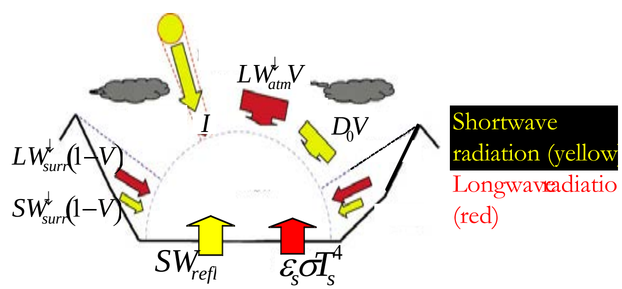
Catchment scale: 3D grid



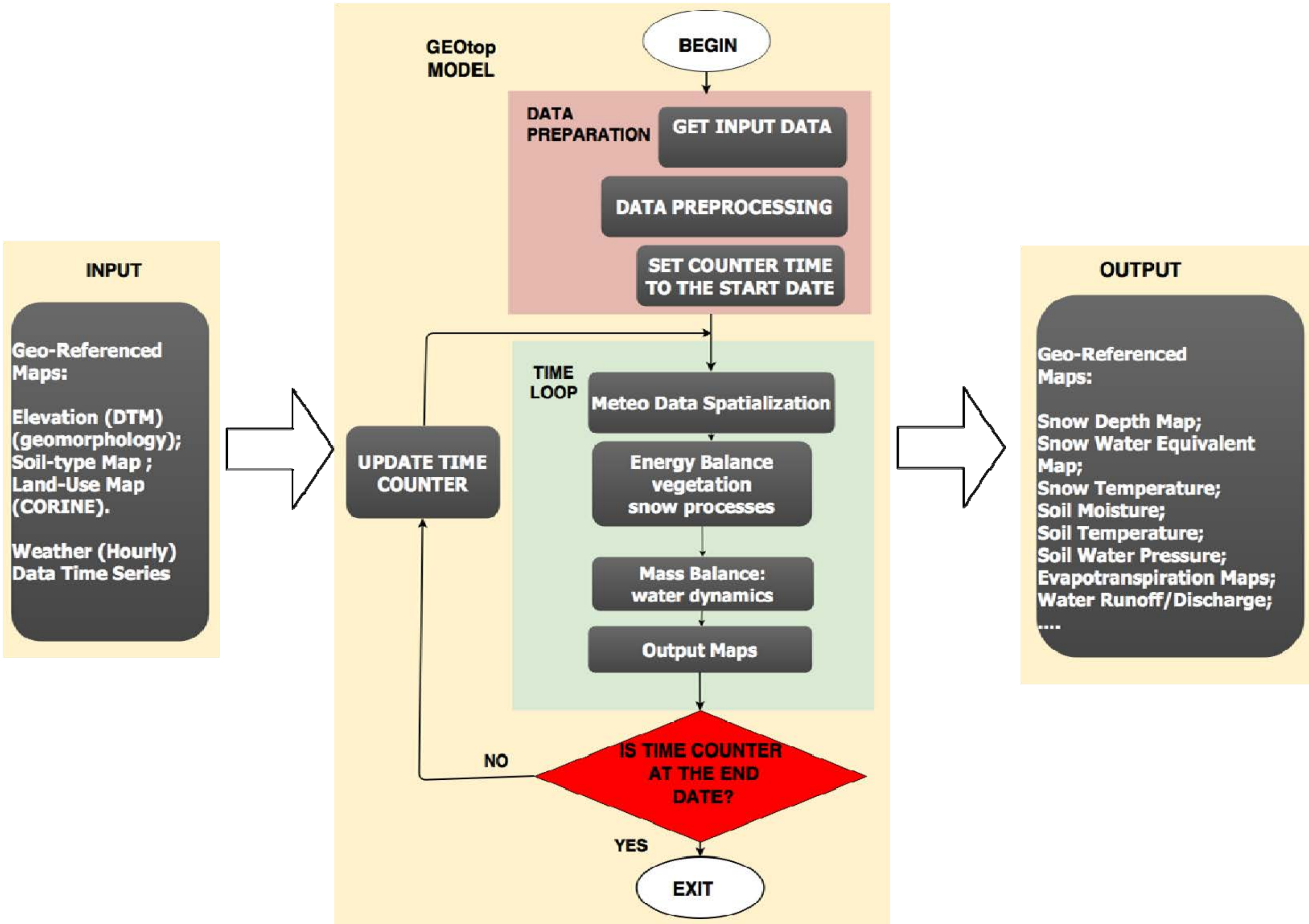
From SHE model (Abbot et al., 1986)

Catflow, Zehe et al., 2001
WaSim-ETH, Shulla 1997
SHE, Abbot et al. 1986

Complex topography



Corripio, 2010.
Erbs et al., 1983.
Iqbal, 1981.



More info:
Endrizzi et al. (2014): GEOtop 2.0. Geosci. Model Dev.

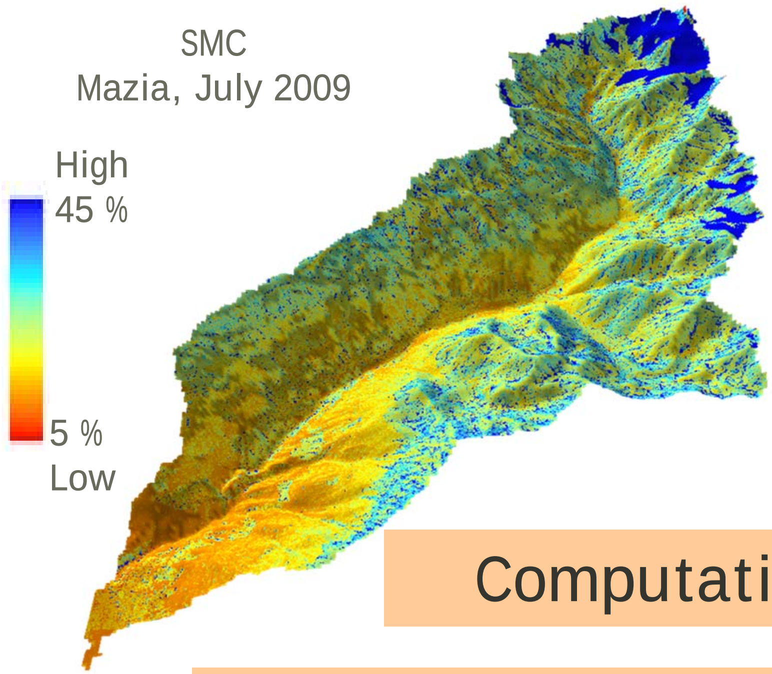
Open Source C/C++ code Github repository:
http://geotopmodel.github.io/geotop/

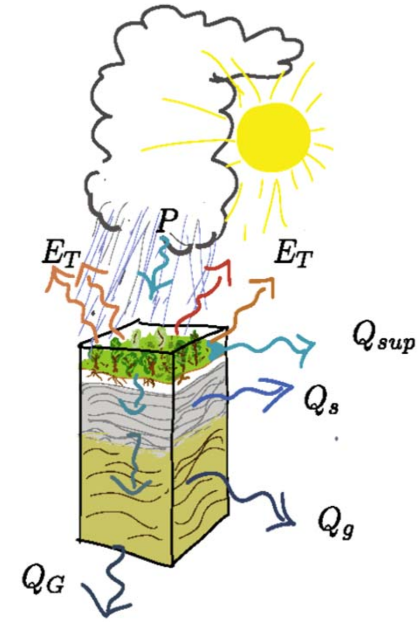
EURAC research

Open challenges for HPC

Full 3d Application

~ 10^6 cells = 10 layers x 10^5 1d columns





Computational needs

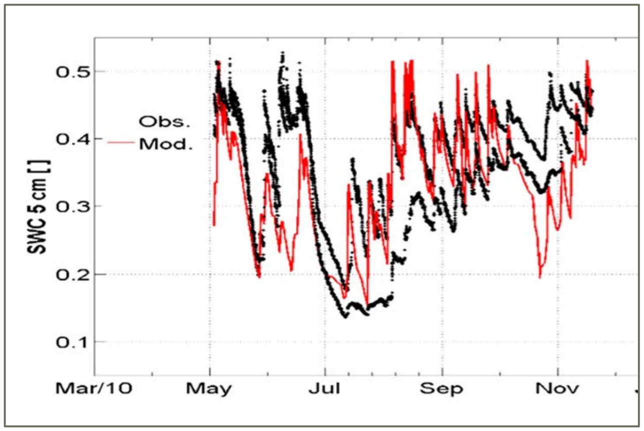
- ❖ large domains;
- ❖ long simulations periods;
- ❖ <u>numerous model parameters</u>;

✓ Need of automatic model sensitivity and optimization tools.

✓ Need to develop efficient codes for parallel architecture.

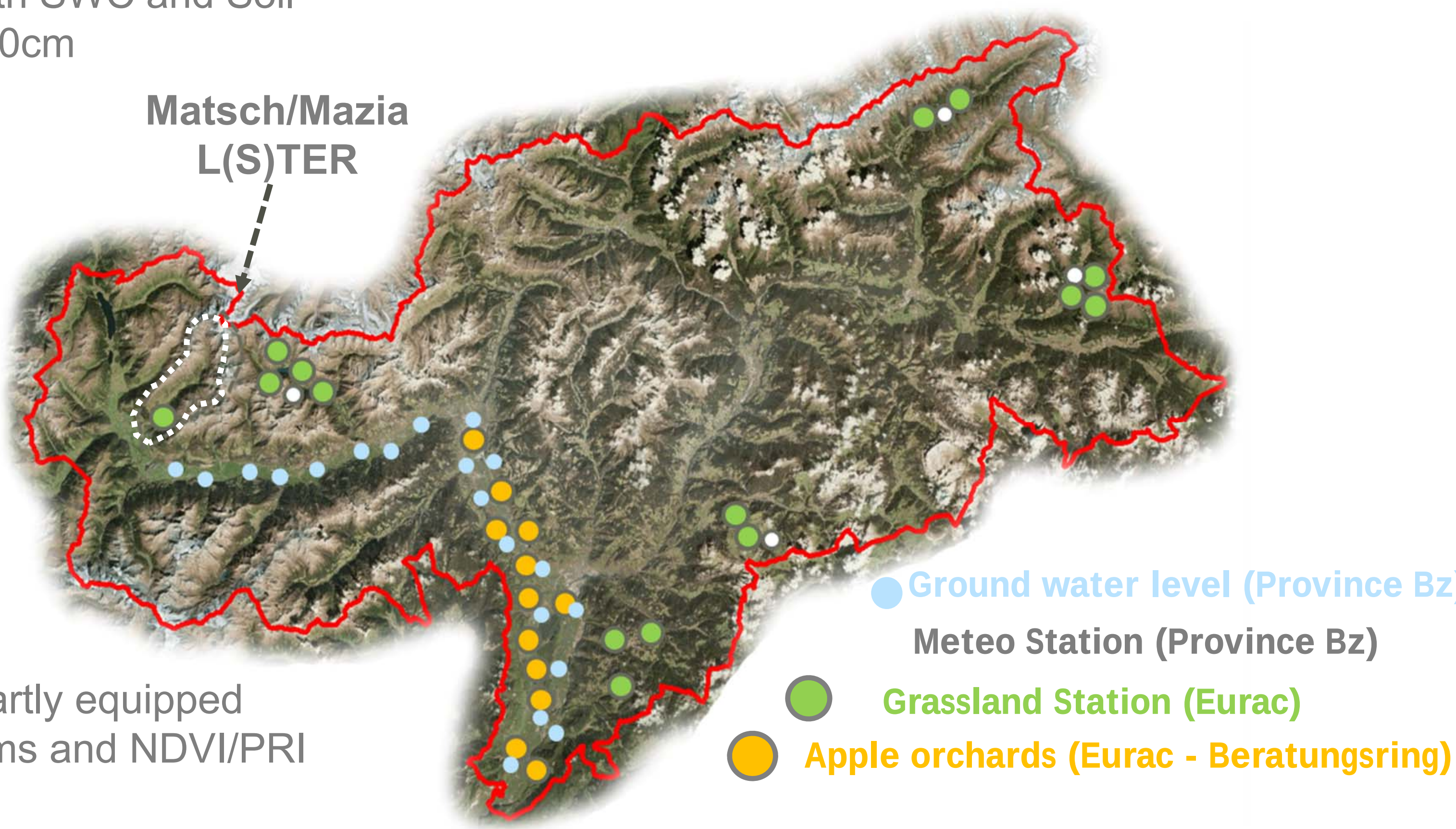
Specific aims of our research

I. To present an approach for improving 1D calibration of soil moisture content (SMC).
II. To identify the most sensitive parameters.
III. Identify relevant factors controlling temporal and spatial differences among sites.
IV. To simulate relevant climatic / water management scenarios.



EURAC - AlpEnv Monitoring sites

Apple orchards:
12 stations with SWC and Soil temp. at 20+40cm

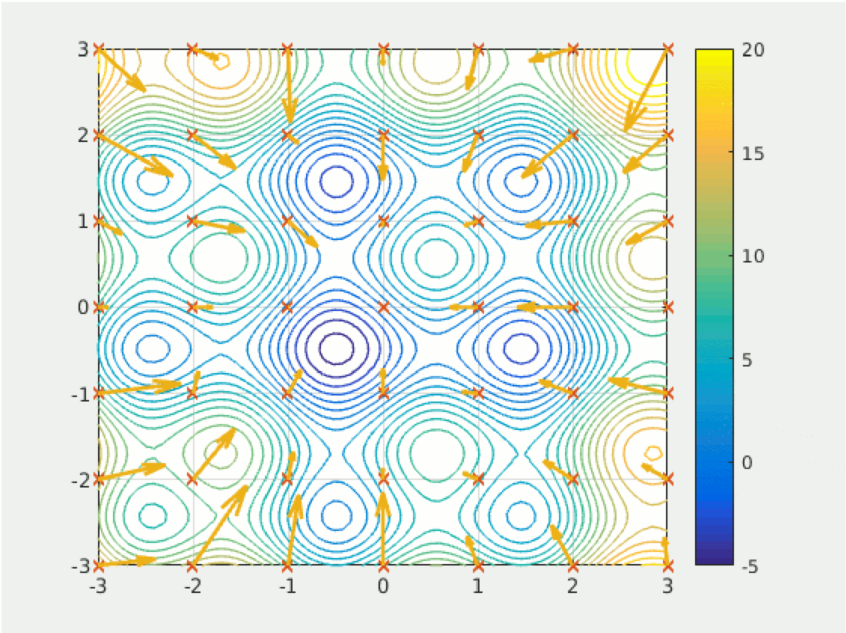


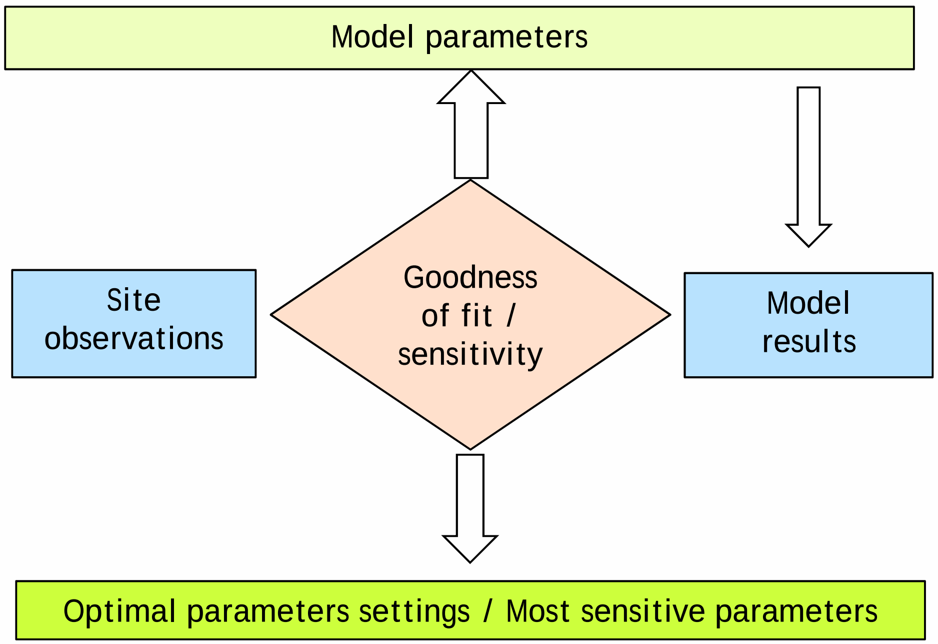
Grassland:
15 stations, partly equipped with phenocams and NDVI/PRI sensors

- ✓ Test the hydrological model in sites with different characteristics.
- ✓ Optimize the model with respect to soil / vegetation parameters.
- ✓ Simulate scenarios (best irrigation practices).

Sensitivity and optimization approach

- Development of an automatic model calibration tool: **GEOtopOptim**
- Published as a R package on https://github.com/EURAC-Ecohydro/geotopOptim2.
- Based on the Particle Swarm Optimization approach ("hydroPSO" R package; *Zambrano & Rojas,2013,2014*).
- MPI parallel implementation on the Vienna Scientific Cluster.





Sensitivity and optimization approach

Methodological Open issues

1. Choice of parameters to identify.
2. Choice of target function (RMSE, NSE, KGE).
3. Optimization settings *(# particles*, *# of iterations*, …).
4. The traditional PSO approach uses many iterations, few particles.

Goals of parallelization of PSO on VSC

1. Efficiency vs. effectiveness.
2. Good usage of nodes.
3. Right core hours usage.
4. Low wallclock time.

Approach

1. Usage particles = working processes.
2. Test different number of cores.
3. Check numbers of iterations needed.
4. Started with 4 test cases.

Parameters sensitivity analysis results

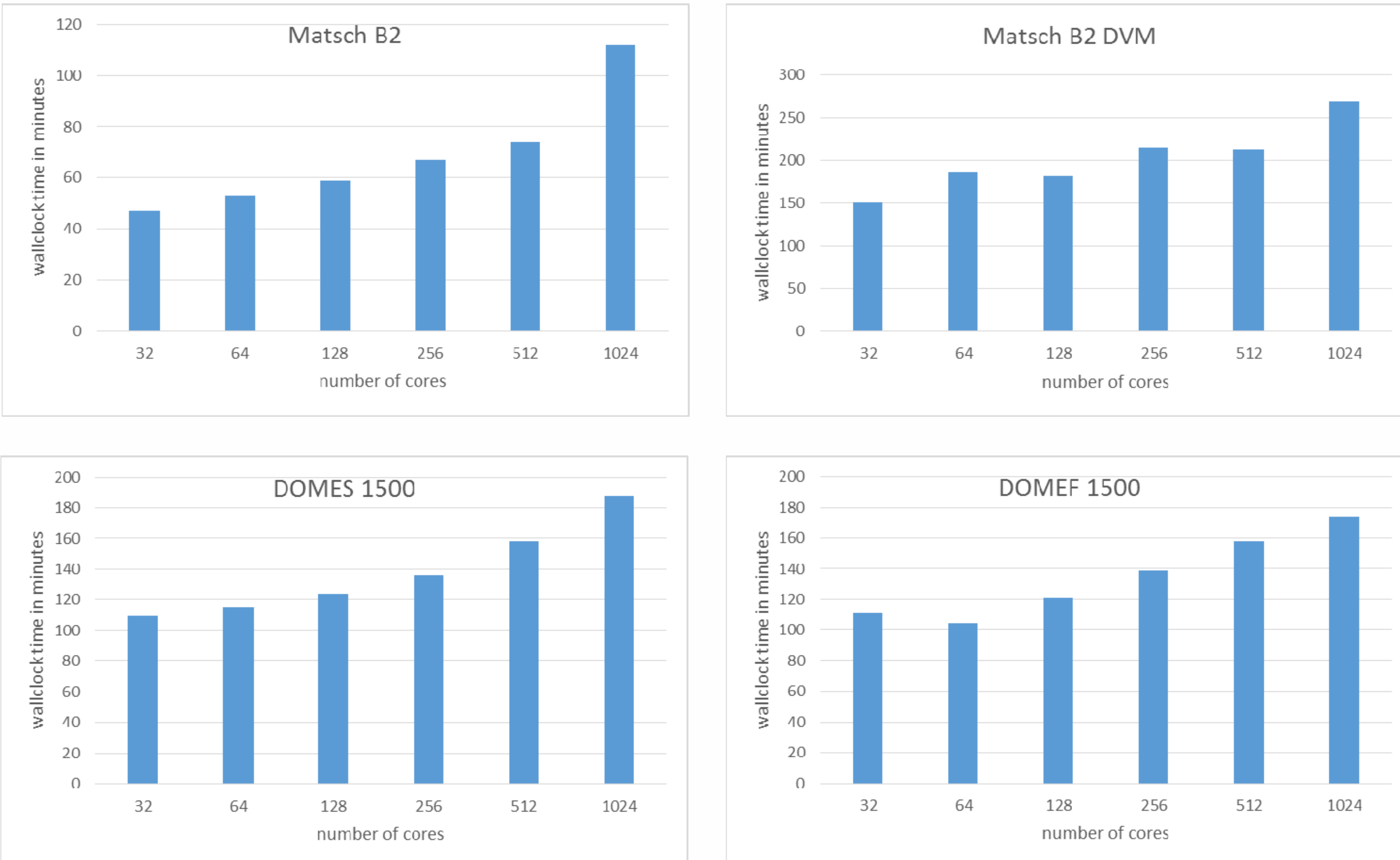
Latin Hypercube One factor At Time (LHOAT) parameters sensitivity

Simulation DOMEF 1500 meadow site: sensitivity with respect SMC at 20 and 5 cm

RankingNmbr	ParameterName	RelativeImportance	RelativeImportance.Norm
1	SOIL__N	103.6437118	0.621998554
2	SOIL__ThetaSat	27.15707285	0.162978146
3	SOIL__ThetaRes	9.214202075	0.055297328
4	SCALAR__SoilEmissiv	8.642920875	0.05186889
5	SOIL__NormalHydrConductivity_V_L0003	6.366923984	0.038209916
6	SCALAR__MinStomatalRes	2.042555173	0.012258017
7	SOIL__Alpha	1.555375865	0.0093343
8	SCALAR__SoilAlbVisDry	1.539420301	0.009238546
9	SCALAR__CanopyFraction	1.460412554	0.008764396
10	SCALAR__CanDensSurface	1.095941372	0.006577089
11	SCALAR__SoilRoughness	0.936654235	0.005621157
12	SCALAR__SoilAlbNIRDry	0.79711539	0.00478374
13	SCALAR__LSAI	0.742982396	0.004458871
14	SOIL__NormalHydrConductivity_V_L0004	0.717430158	0.004305524
15	SOIL__NormalHydrConductivity_V_L0005	0.717430158	0.004305524
32	SOIL__LateralHydrConductivity	0	0
32	SCALAR__DecayCoeffCanopy	0	0
32	SCALAR__RootDepth	0	0
32	SCALAR__VegReflectVis	0	0
32	SCALAR__VegReflNIR	0	0
32	SCALAR__VegTransVis	0	0

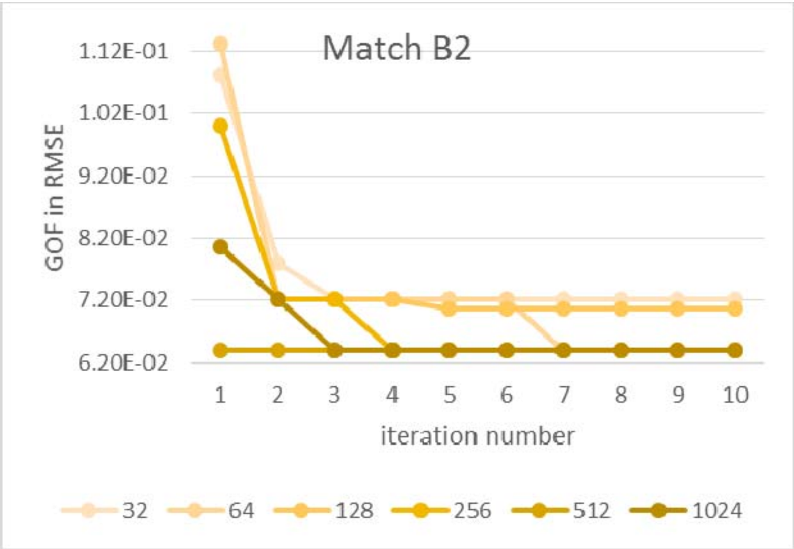
Most relevant parameters depend on specific sites/climatic conditions

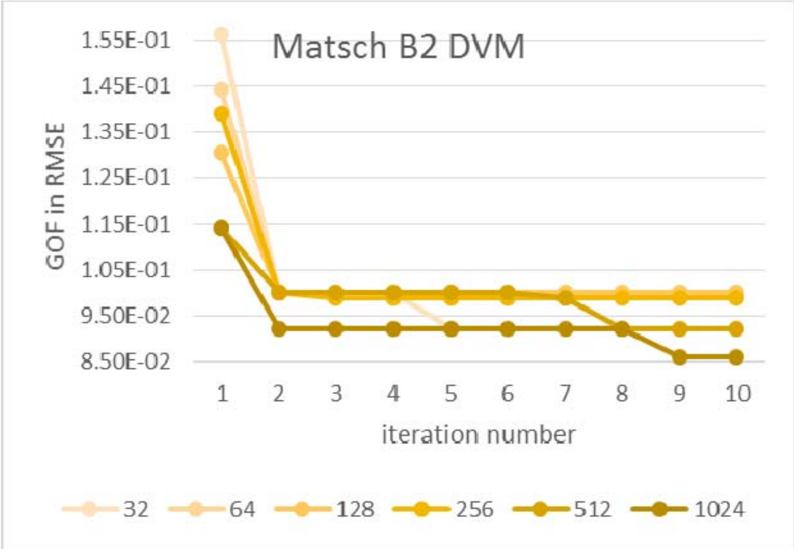
Computational performances

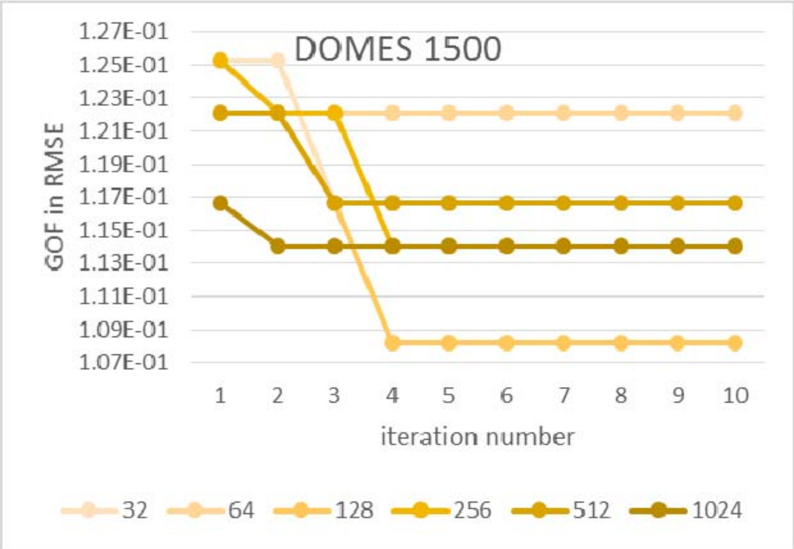


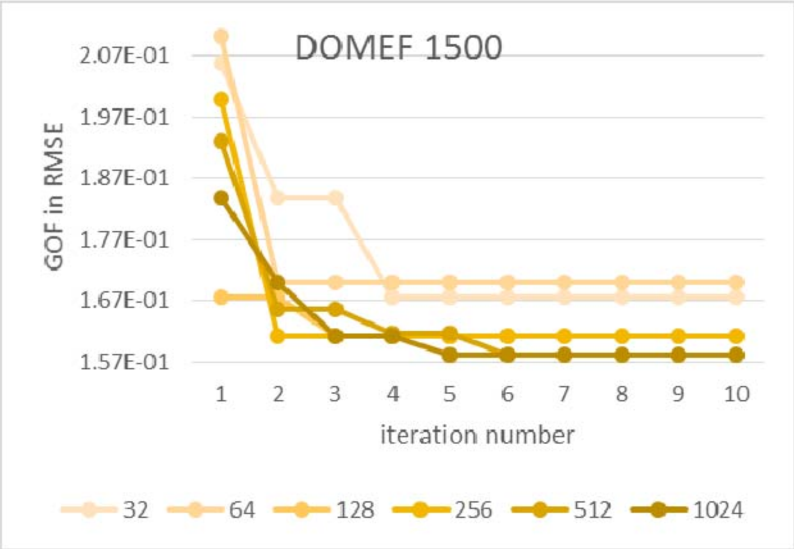
Limited increase wallclock time vs. # of cores (10 iterations)

Efficiency vs. number of cores

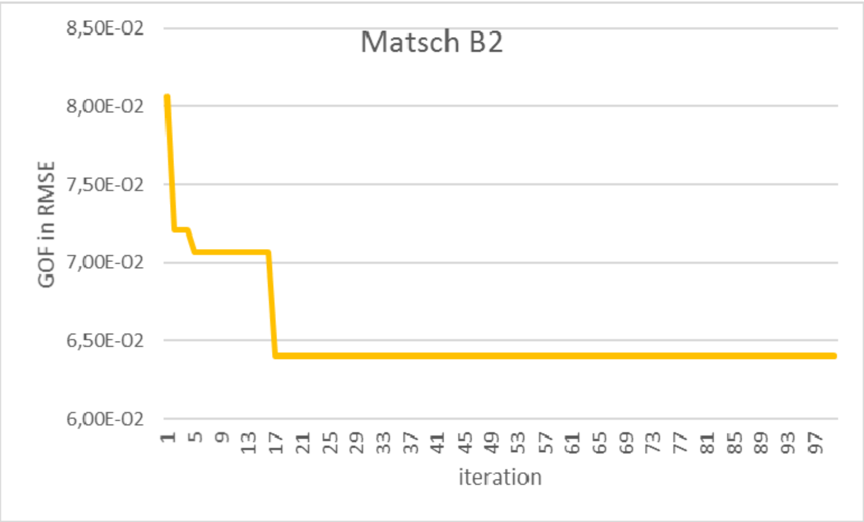


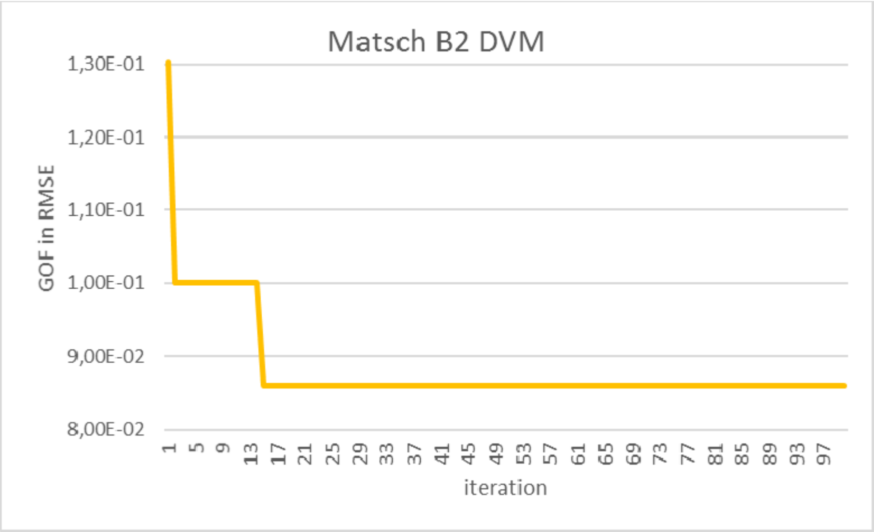


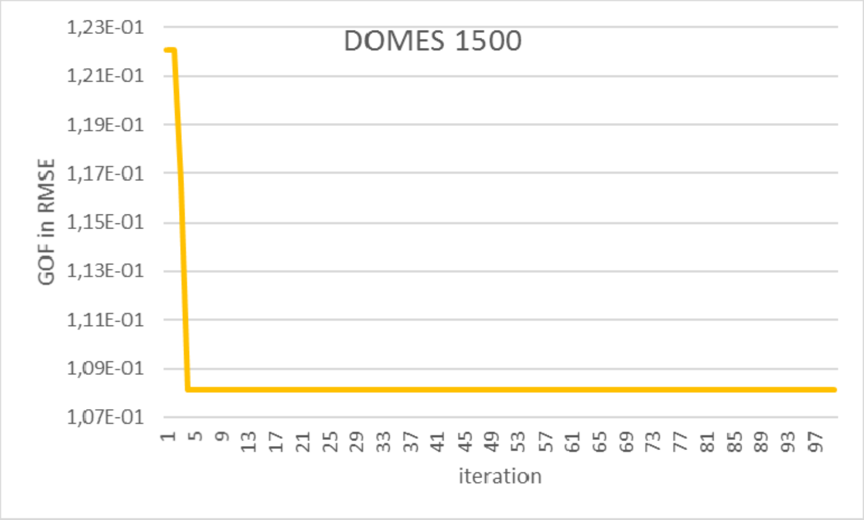


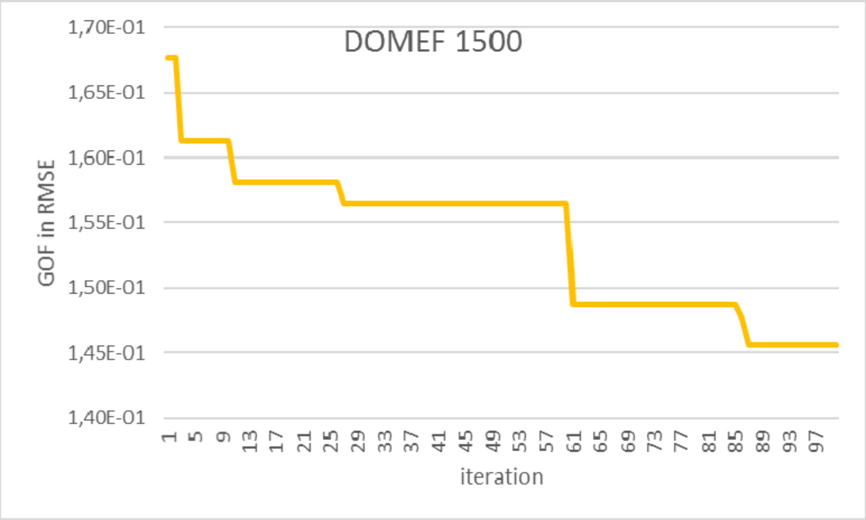


Efficiency vs. number of iterations









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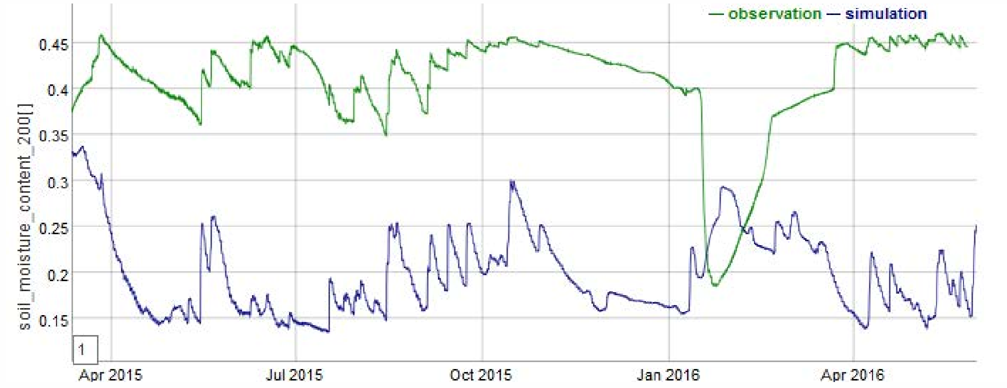
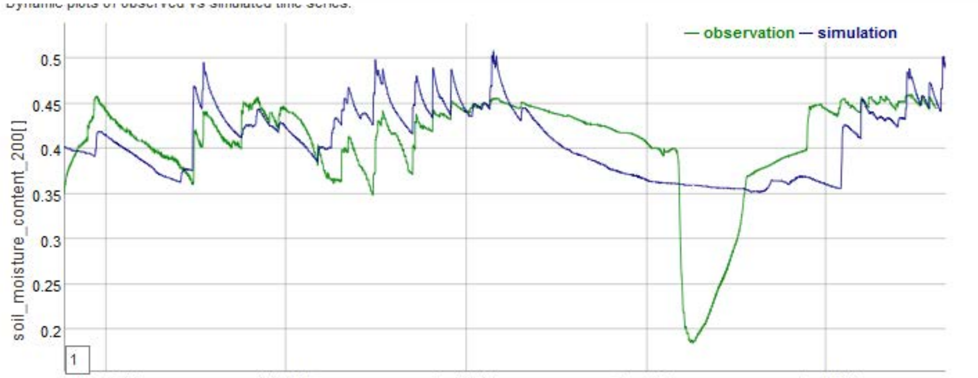
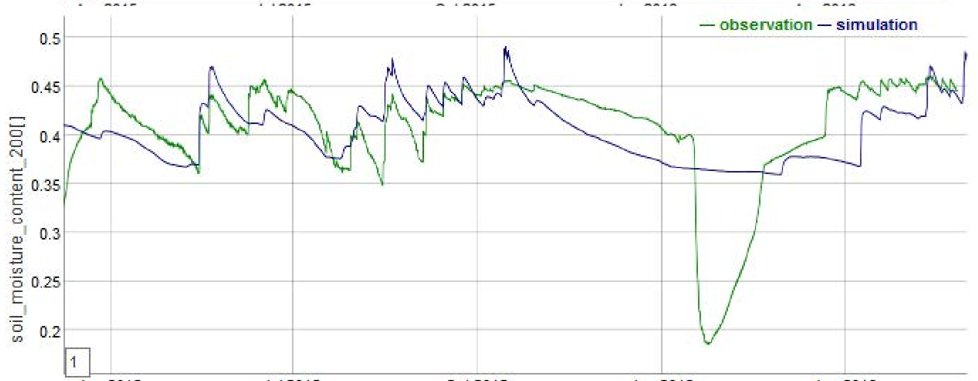
Application: DOMEF site optimization



Original Simulation
RMSE 0.21
PBIAS -47.5
KGE -0.17
NSE -14.45



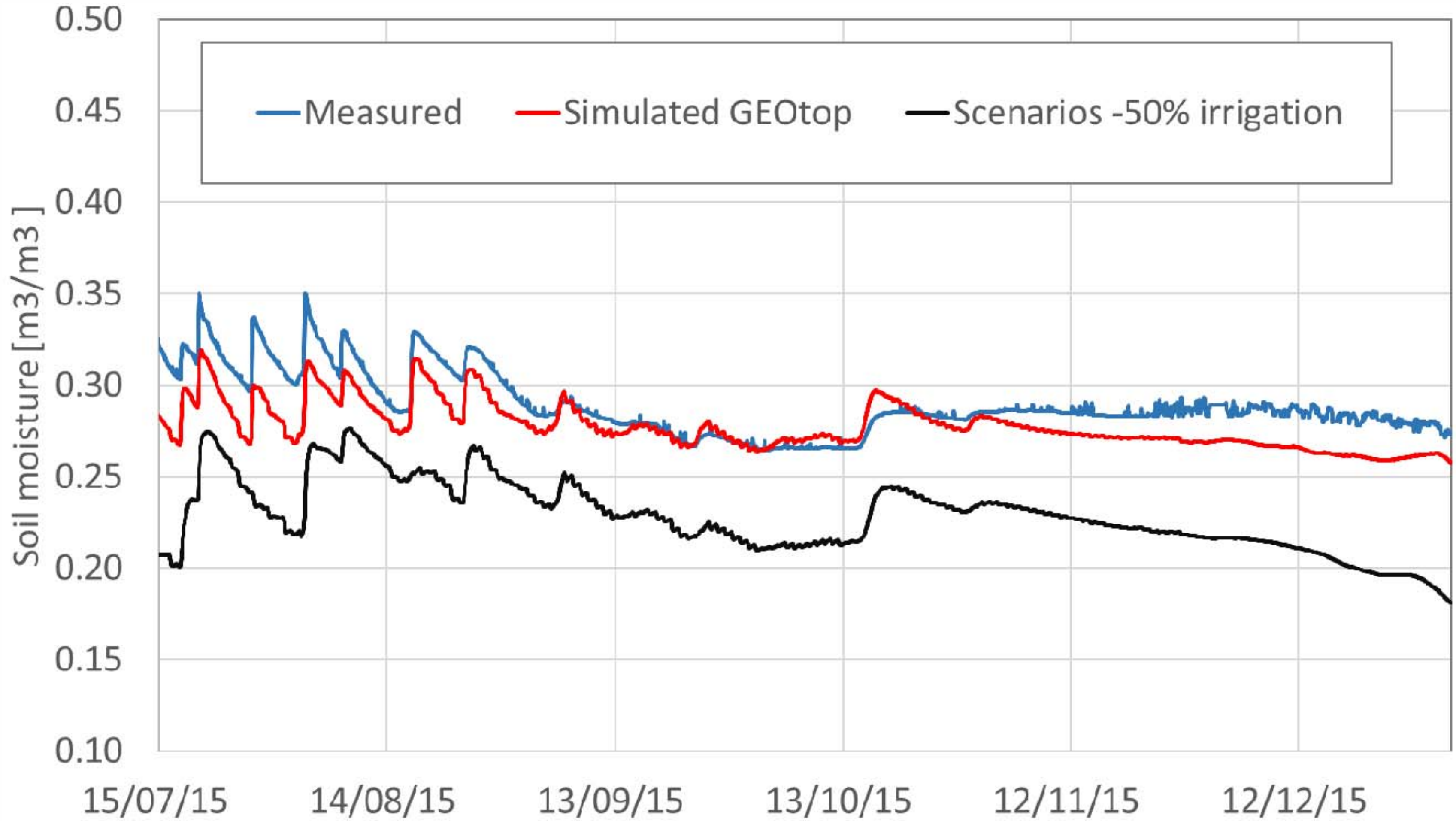
10 Iterations
RMSE 0.05
PBIAS 0.5
KGE 0.47
NSE 0.28



100 Iterations
RMSE 0.04
PBIAS -0.4
KGE 0.42
NSE 0.35

Application: irrigation scenarios

Impact of a reduction of 50 % in irrigation frequency
Latsch (BZ, Italy) apple orchard site



Conclusions and Outlook

Conclusions

- Development of automatic optimization tool for the GEOtop hydrological model.
- The method allows to identify most sensitive model parameters.
- Optimization settings and specific sites properties control optimization performances.
- Using a higher particles # and lower iterations # allows an efficient use of the VSC without loosing effectiveness.

Outlook

Model optimization for all experimental sites

- Optimal model parameters identification.
- Multi-objective optimization (ET, SMC, ...)
- Production of optimal irrigation scenarios.

Towards a parallel code for spatially-distributed 3D applications

- Domain decomposition.
- Full parallel resolution of 3d Richard´s water flow equations.

Acknowledgment

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We thank also the VSC for the computing time granted.

EURAC Alpine Ecohydrology Modelling Githhub repository

https://github.com/EURAC-Ecohydro

Thank you for your attention!

MONALISA

EURAC research