The soil moisture budget – should we take care?

cooperation with Jan-Peter Schulz (DWD), Jürgen Helmert (DWD), Daniel Regenass (ETHZ)

Ronny Petrik, Helmholtz-Zentrum Hereon
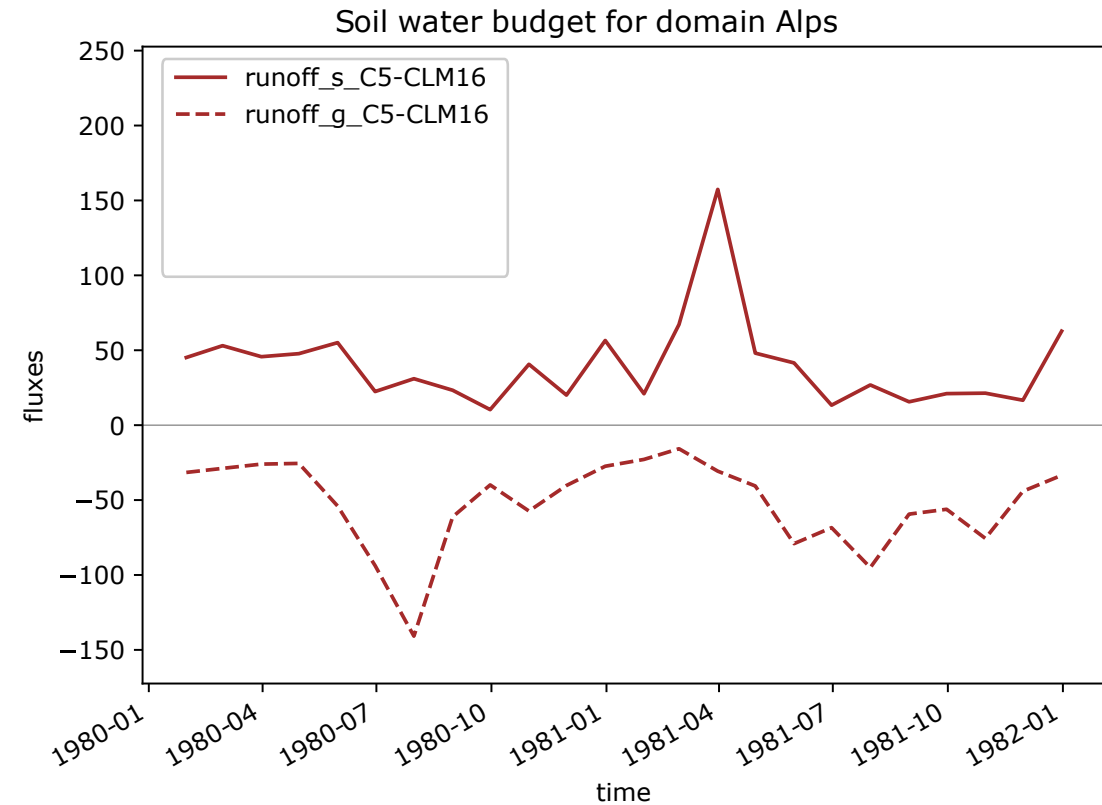
Institute of Coastal Systems -
Analysis and Modeling

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Helmholtz-Zentrum
hereon

Setting the scene
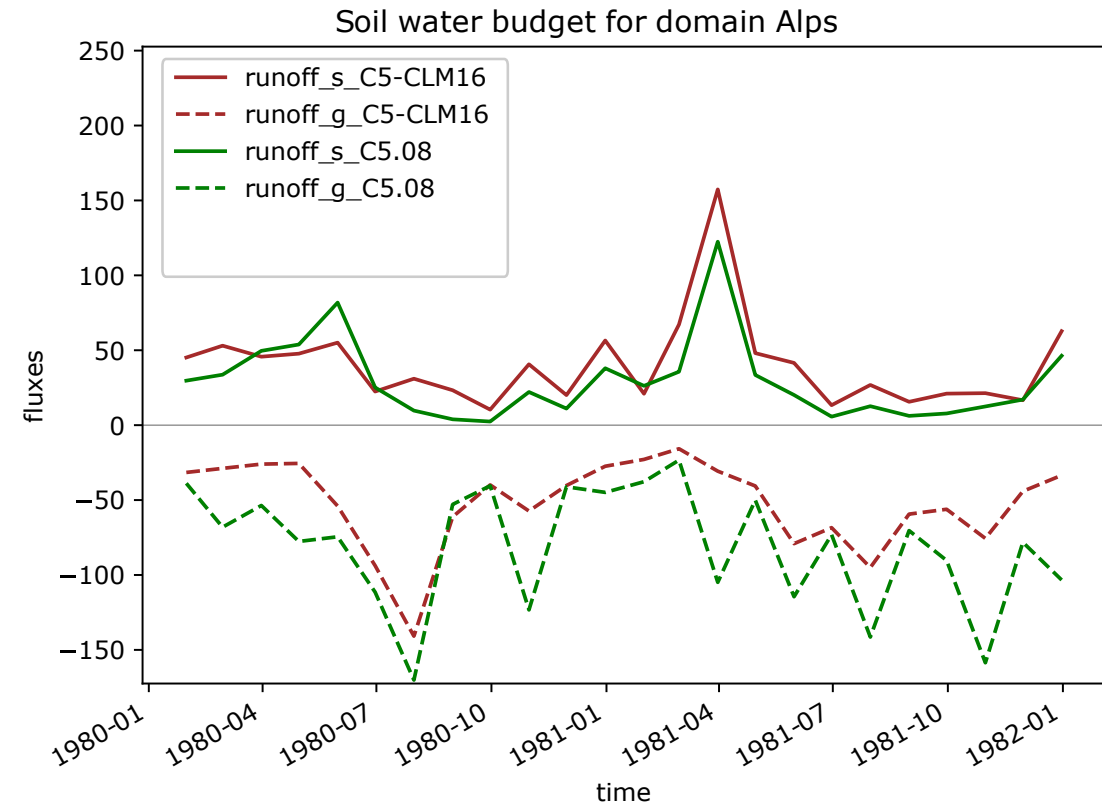
PG-ICON: transition from COSMO-CLM to ICON-CLM

- First tests end of 2020 with ICON-CLM offered some strange results for discharge simulations
- Investigate the runoff simulation of COSMO and ICON

Soil water budget for domain Alps

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Soil water budget for domain Alps

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What is the characteristics of all fluxes and source terms related to the mass content of water in soil? Are there artificial sources and sinks?

Relationship to other investigations

- Study about the ERA-40 surface water budget for the Mackenzie River basin by Betts, Ball, Viterbo (2003)

Soil water budget for domain Alps
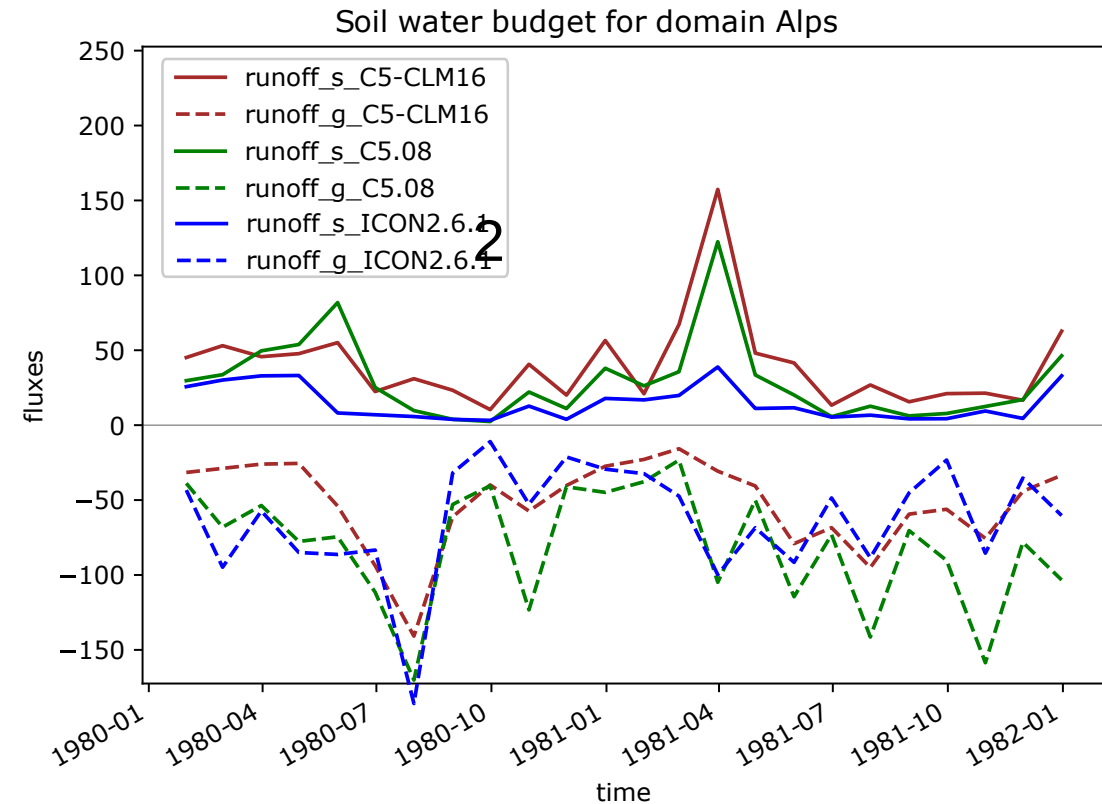
The budget of the soil water content

$$BSW = d_t P_r + d_t P_s - d_t R_g - d_t R_s + d_t E_{grd} + d_t E_{snw} - d_t S_{snow} - d_t S_{icep}$$

$$RC = \frac{\partial q_{sw}}{\partial t} + \frac{\partial q_{si}}{\partial t}$$

$P_r / P_s:$ Sedimentation flux of liquid / frozen hydrometeors

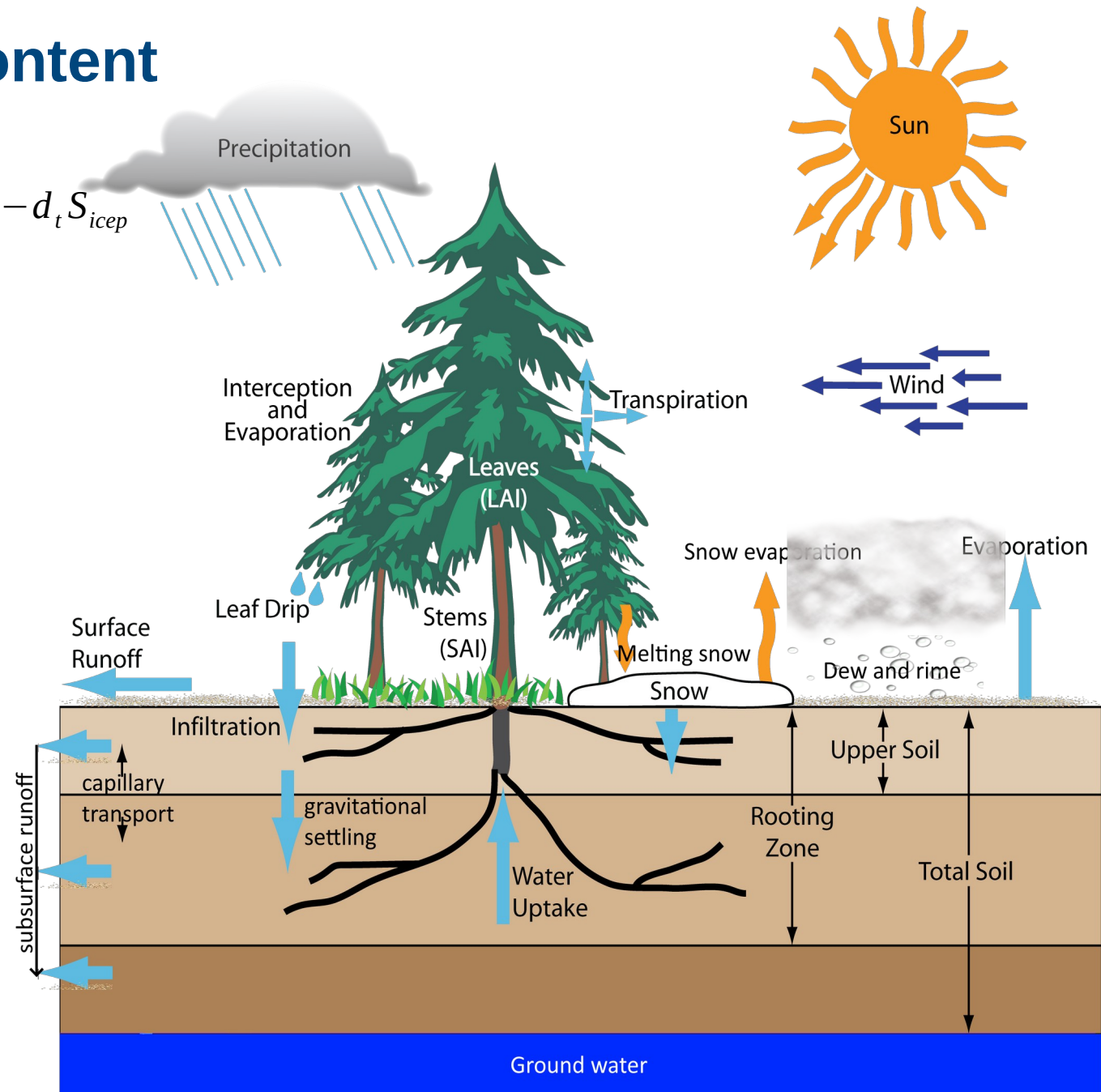$R_g / R_s:$ Surface / subsurface runoff flux

$E_{grd} / E_{snw}:$ Evaporation flux over ground / snow

$S_{snow}:$ Snow storage (accu./melt.)

$S_{icep}:$ Interception water storage

$q_{sw}, q_{si}:$ Liquid / frozen Soil water content

$RC - BSW = R:$ Residuum of soil water budget (recharge - budget_soil_water)
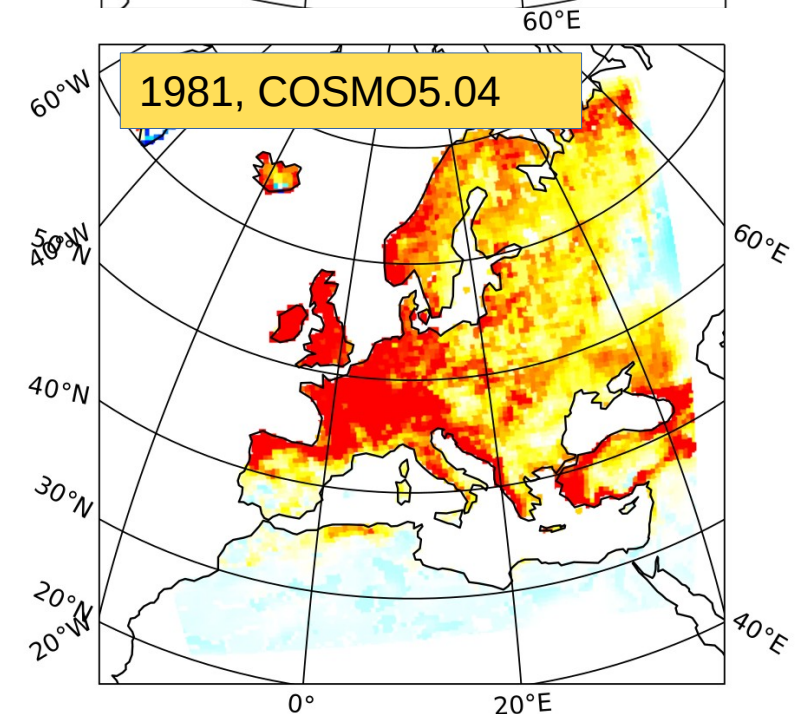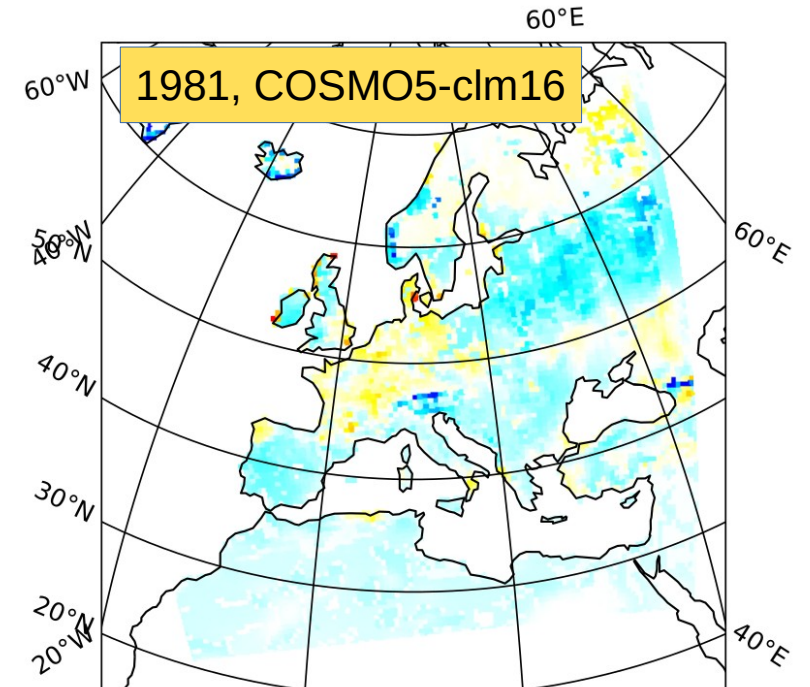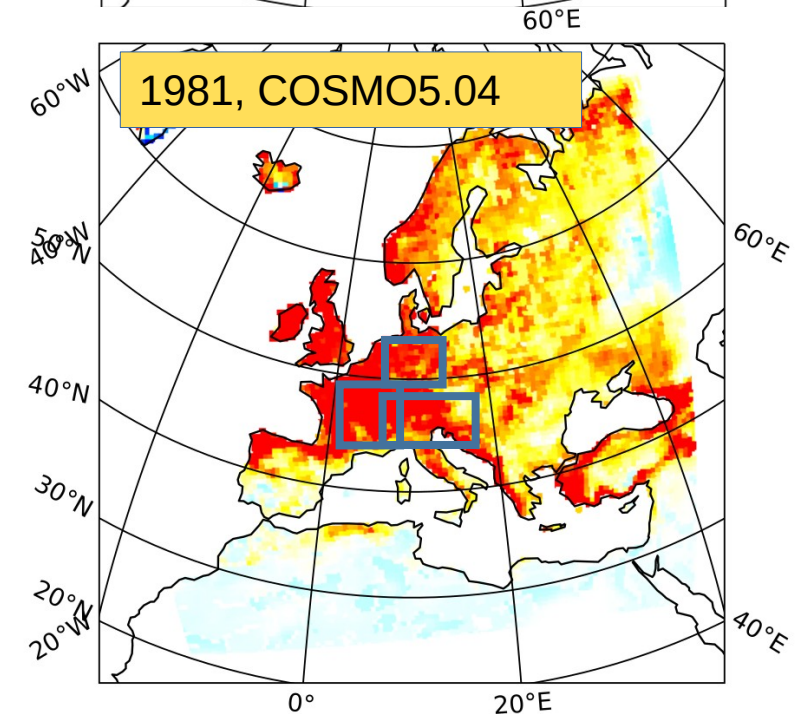
Determination of soil water budget

Method A: model output
- Extract all source terms and fluxes from the model output with a frequency of 1 month
- Be ware of the temporal staggering between the different outputs and the soil texture distribution (land + lakes + ocean)

Strategy for model setup and simulation
- Bench of simulations with SPICE and SUBCHAIN considering COSMO5-CLM16, COSMO5.04, COSMO5.04f, COSMO5.08, COSMO5.09, ICON2.6.2, ICON2.6.3, ICON2.6.4
- One year spinup (1979) + 5 years simulation (1980-1984)
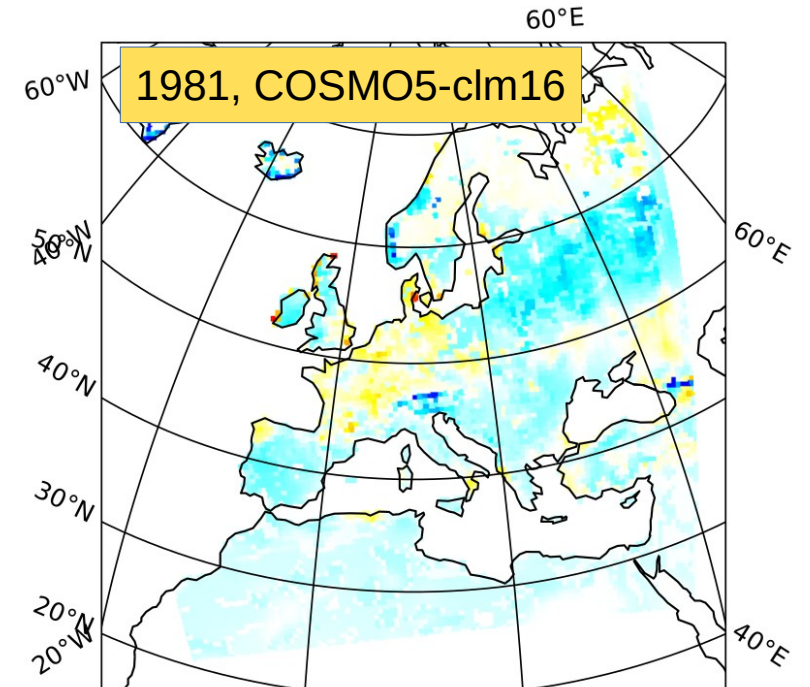- ERAInterim forcing and EURO-CORDEX domain with 0.44° resolution

1981, COSMO5-clm16

1981, COSMO5.04

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1981, COSMO5-clm16

1981, COSMO5.04

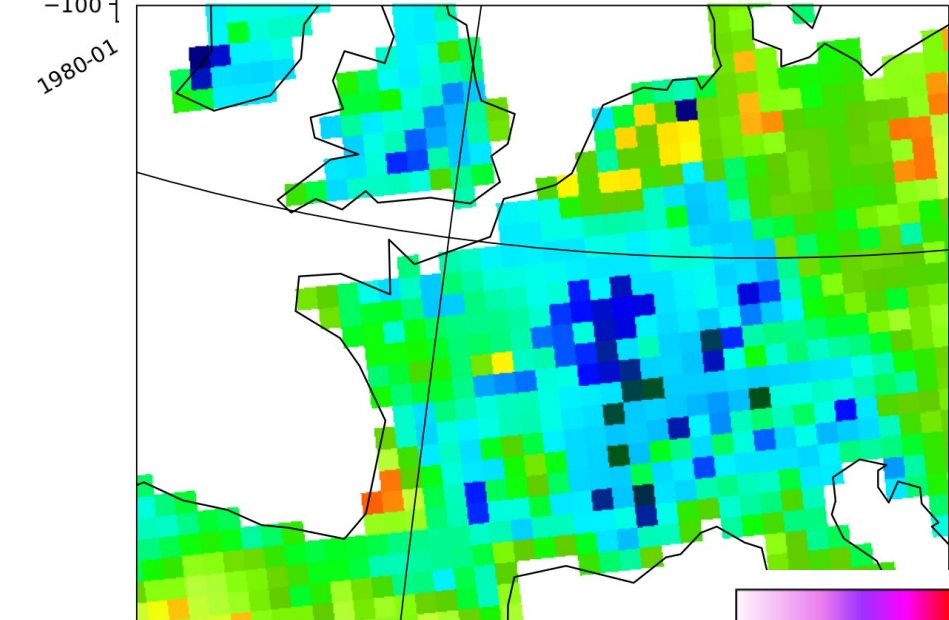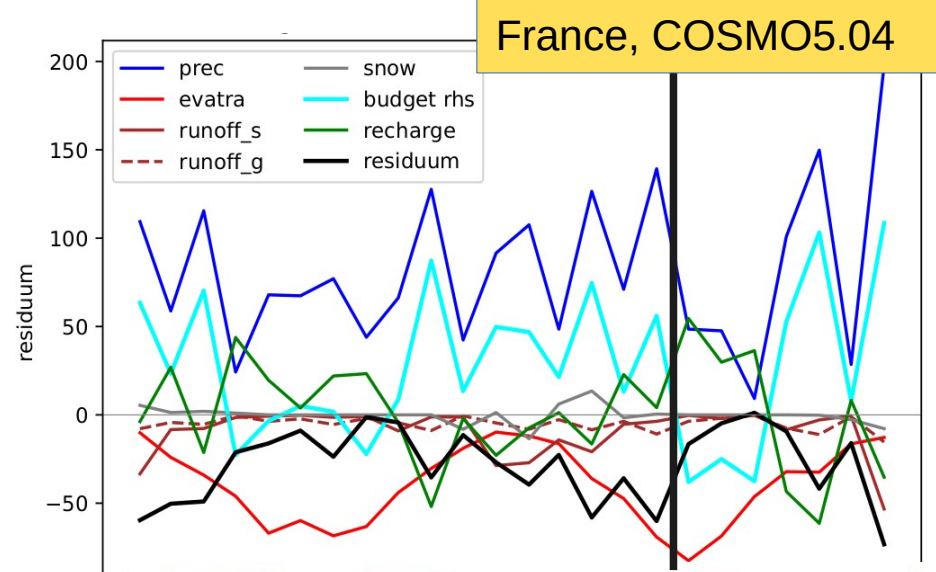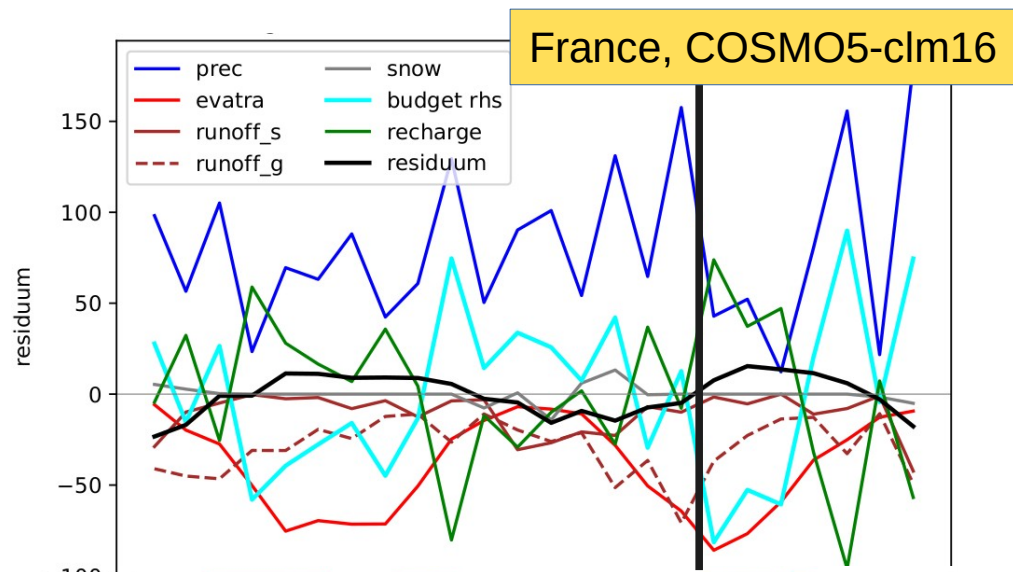# The complete budget of soil water content II
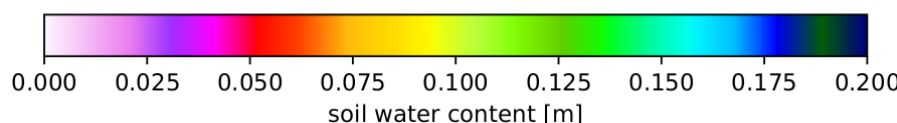

France, COSMO5-clm16
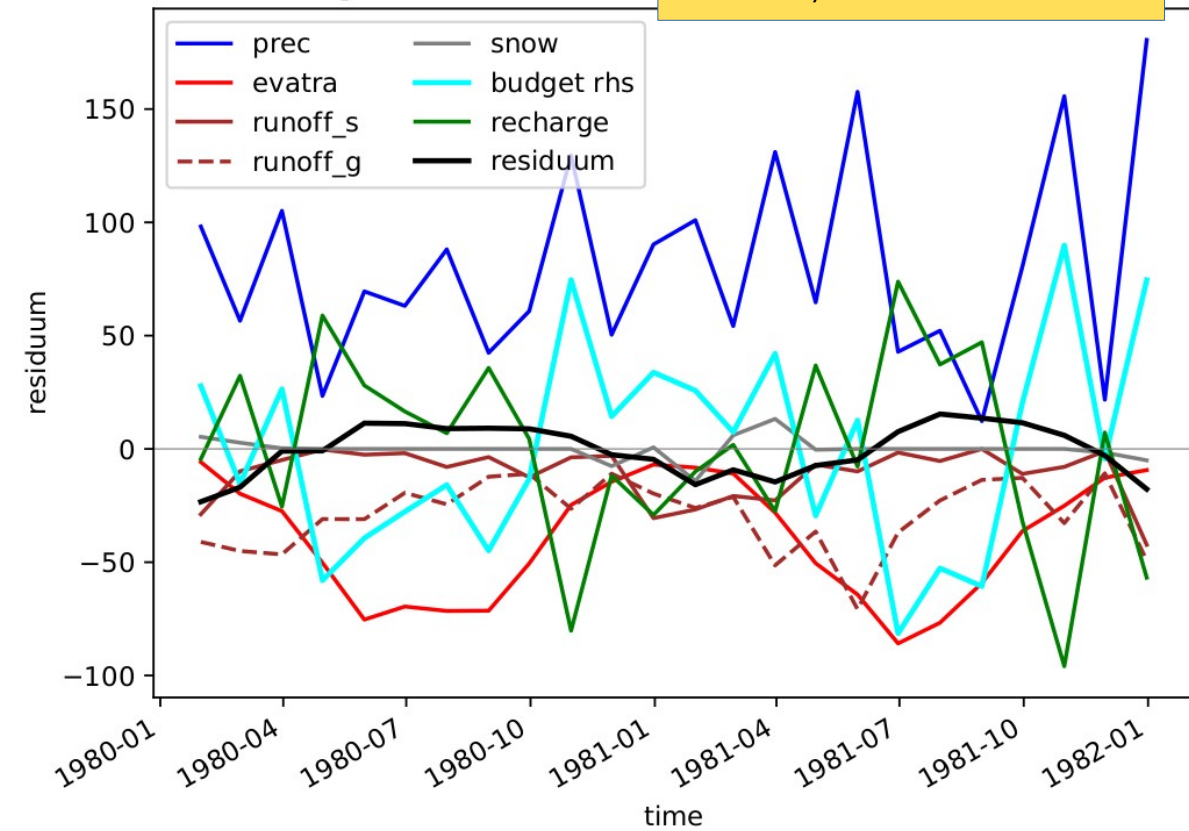
France, COSMO5.04
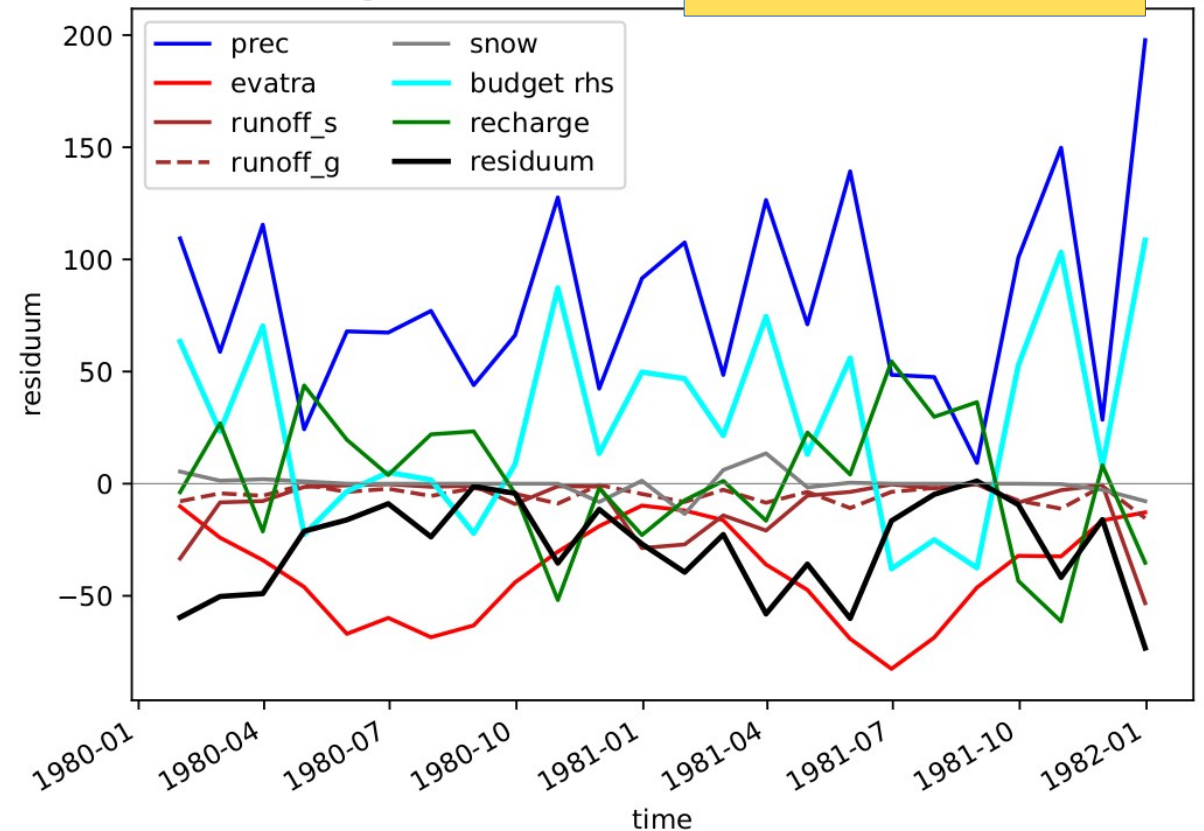
- COSMO5.04: recharge in 1981 often smaller than positive budget
- → What are the consequences for the soil water content?

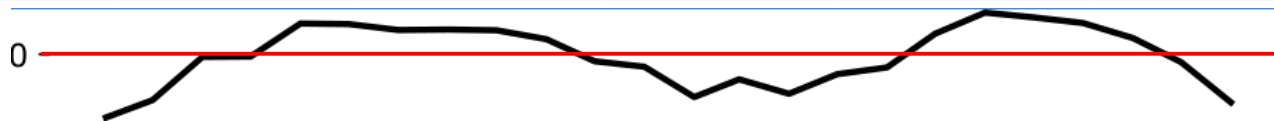# The complete budget of soil water content
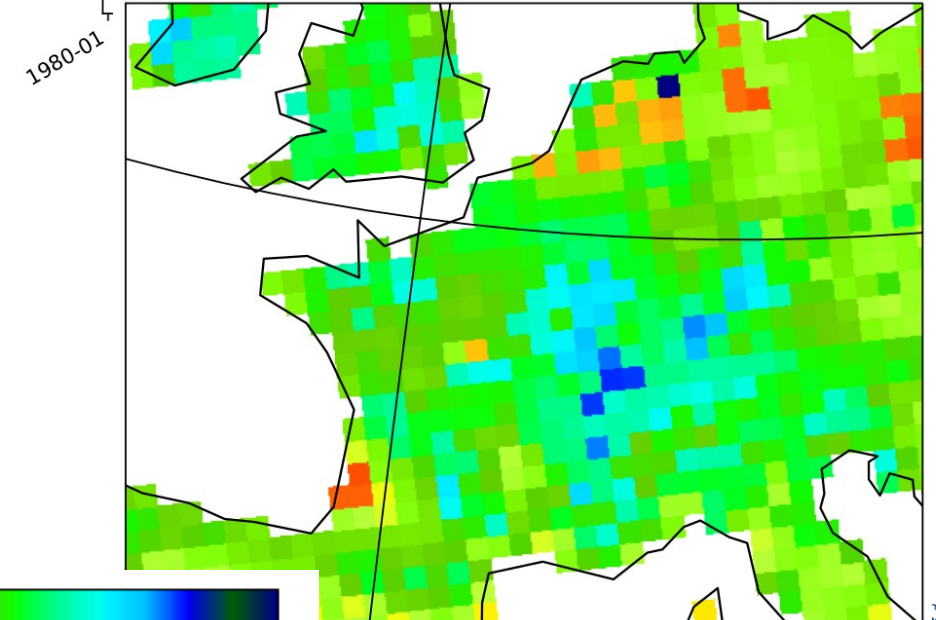
# Soil water budget – Wrap up

Method A: model output

- Residuum and related terms depends on COSMO version
- COSMO5-clm16 provides the most balanced budget

Model 1981	COSMO5-CLM16	COSMO 5.04	COSMO 5.08	ICON2.6.2 1tile	ICON2.6.2 3tiles
DE	-16 mm	-193 mm	38 mm	21 mm	16 mm
France	-16 mm	-368 mm	195 mm	48 mm	40 mm
Alps	14 mm	-375mm	210 mm	110 mm	146 mm

Tackling the residua → Method B: Timestep analysis

- Extract all the fluxes and tendencies from internal source code of TERRA
--> implementation of diagnostics in ICON and COSMO
- no temporal staggering between output routines / physical calc.

1981, COSMO5-clm16

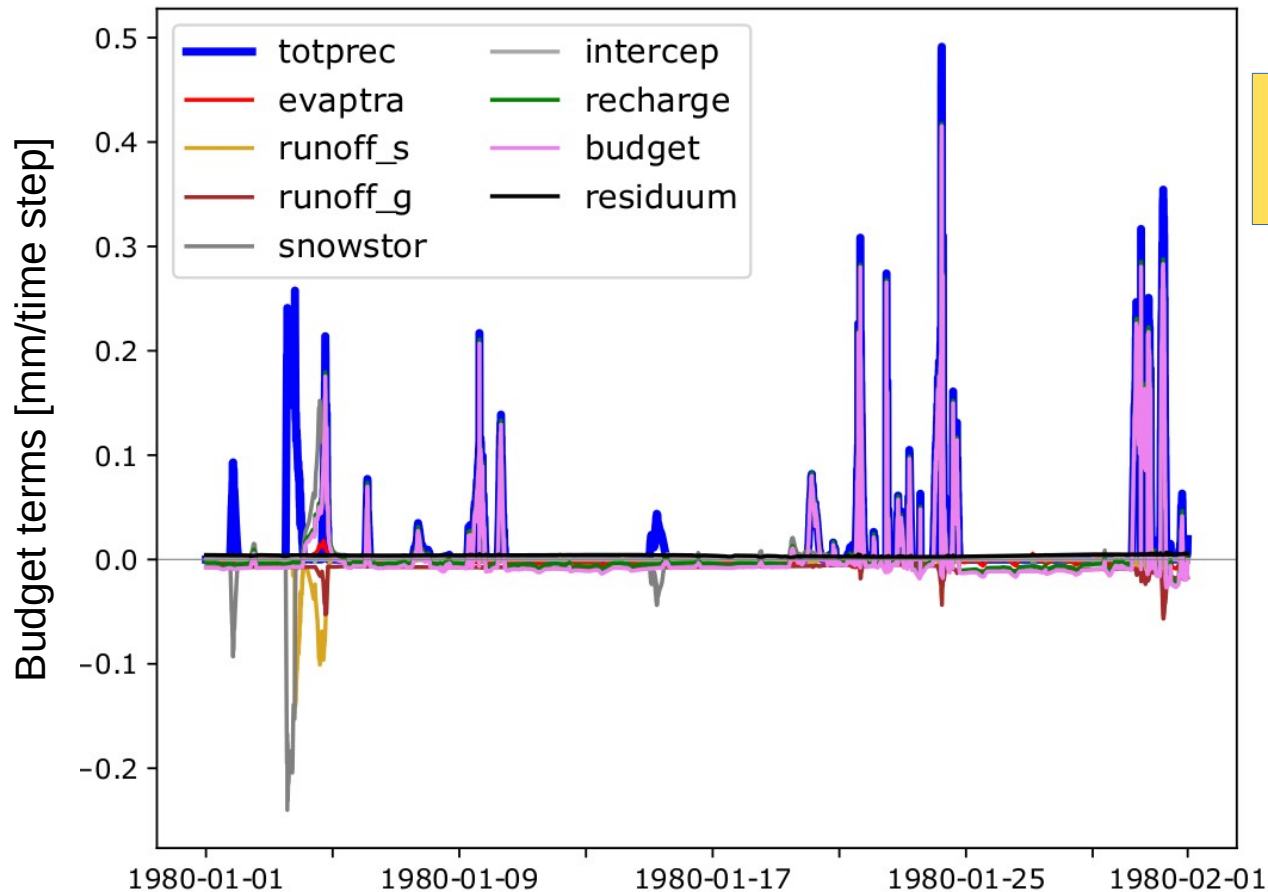COSMO5.04

1981, COSMO5.08
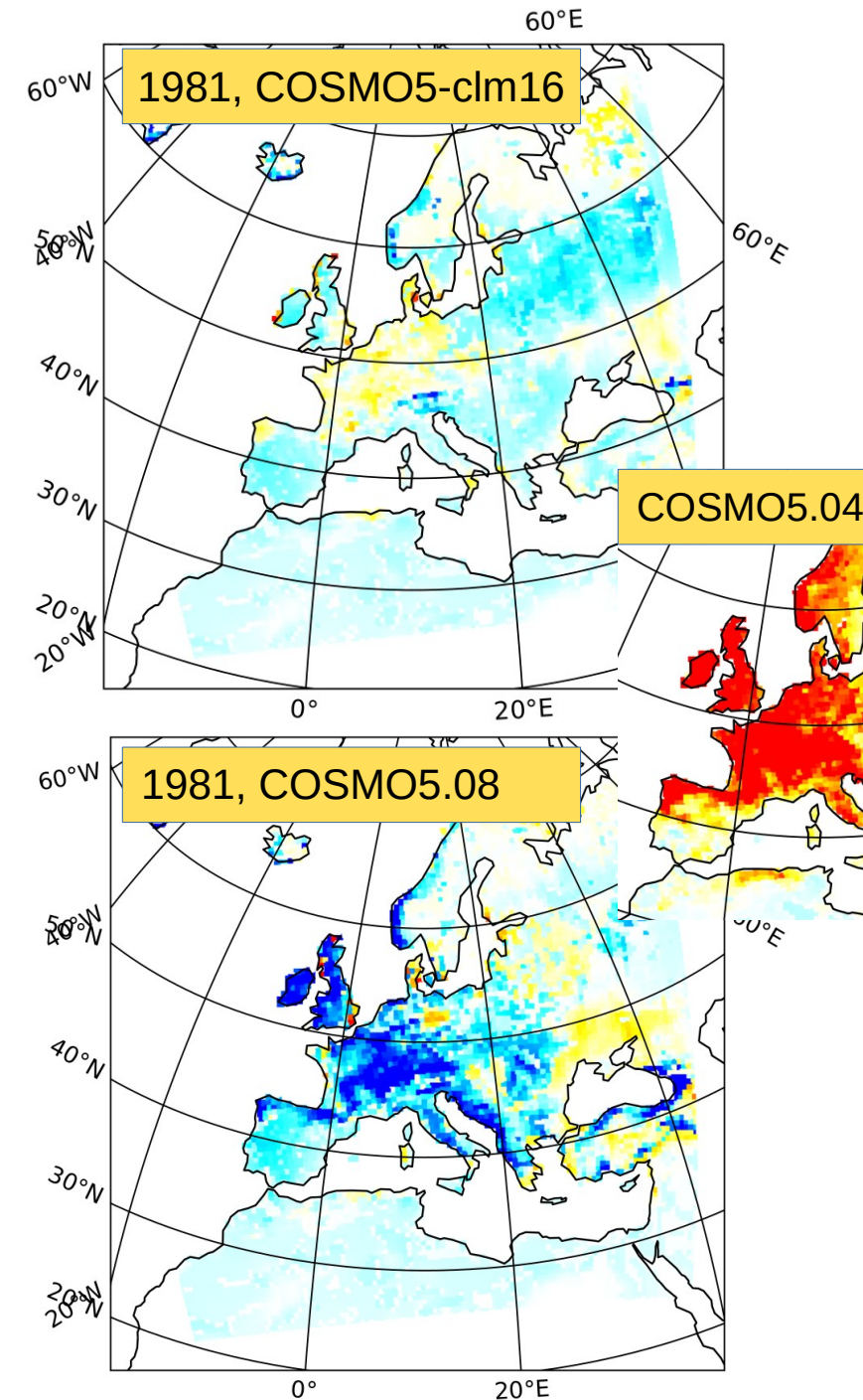
TERRA - Digging in the dirt

Method B: Timestep analysis
- Identify very problematic points and analyze their budget
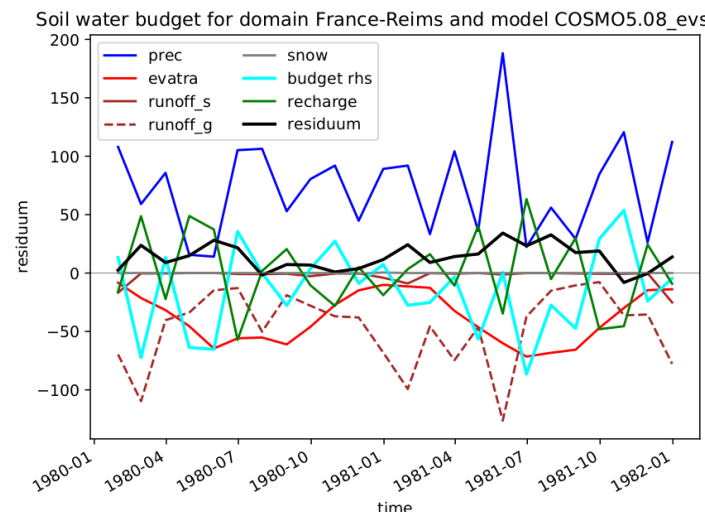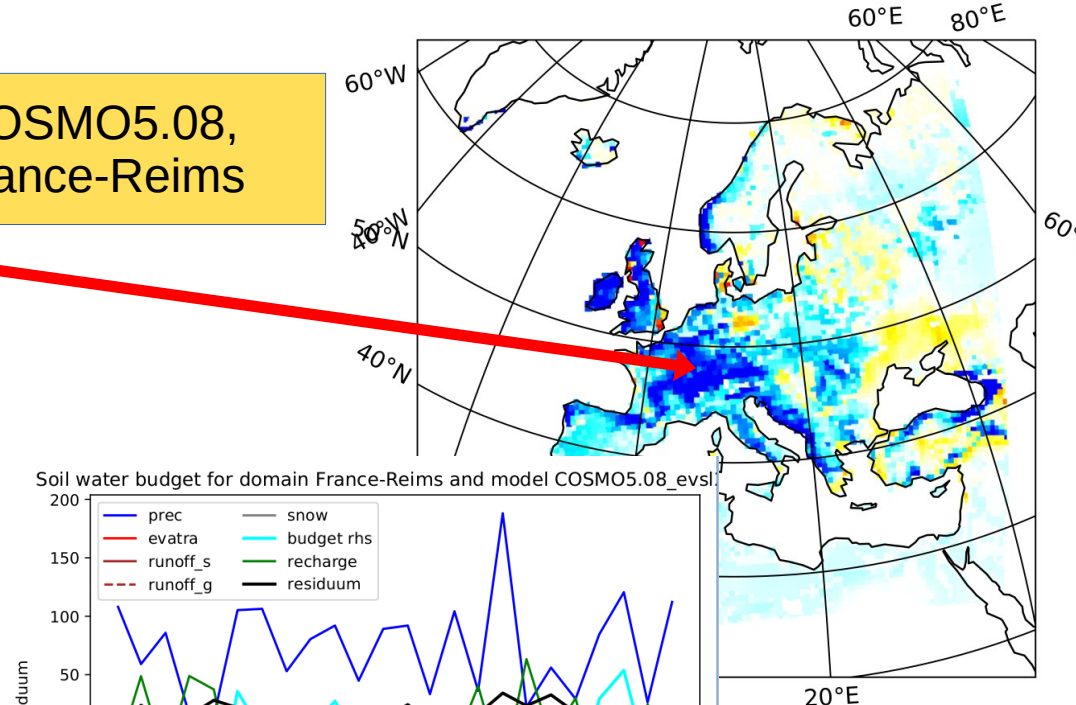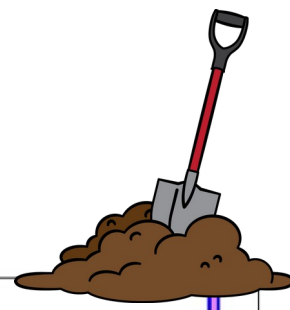- COSMO5.08 as the most recent COSMO version (end of 2020)

COSMO5.08,
France-Reims

Soil water budget for domain France-Reims and model COSMO5.08_evsl

TERRA - Digging in the dirt of France

COSMO5.08, France-Reims
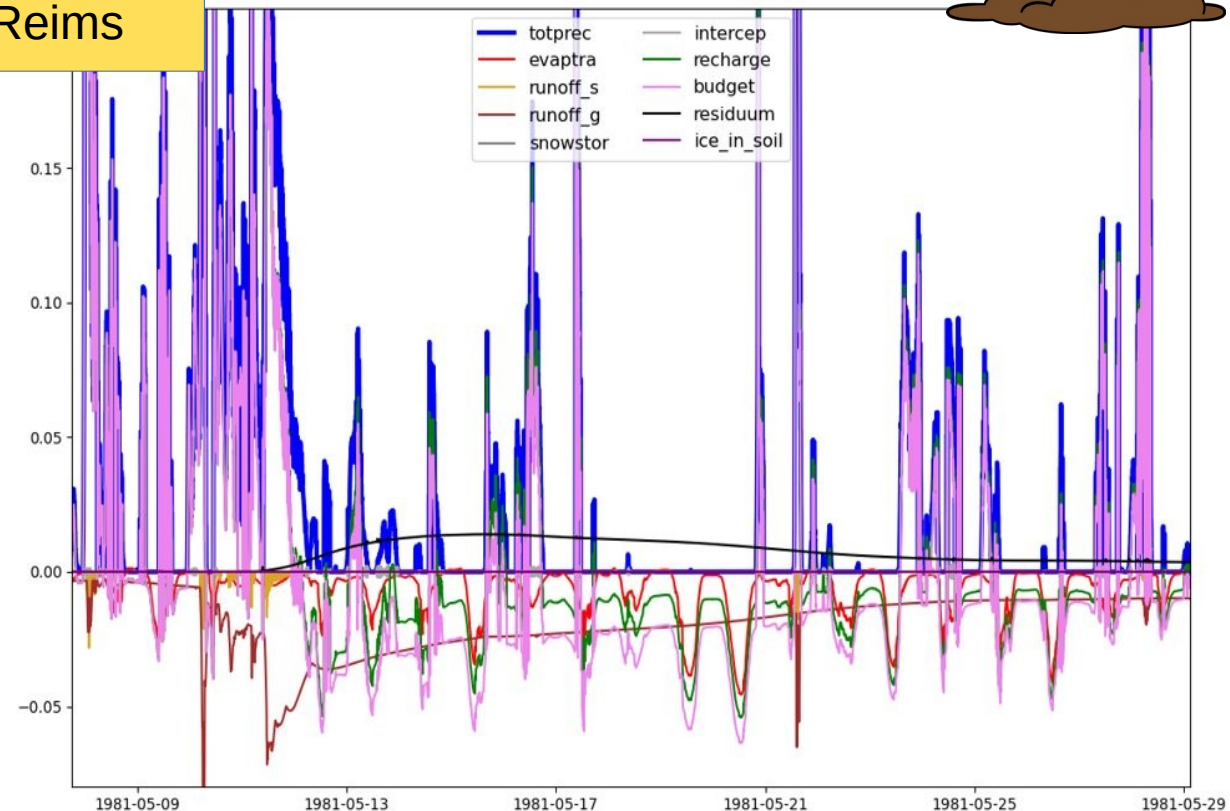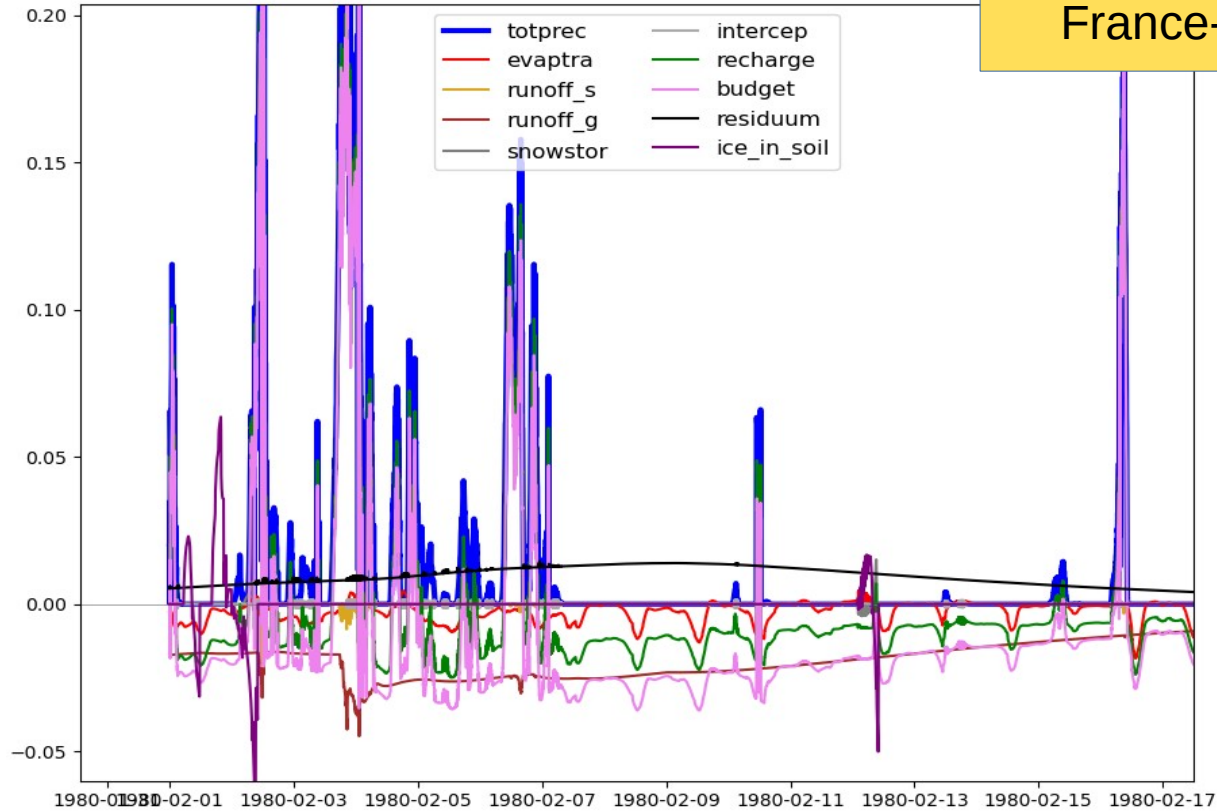
non-consistent relationship between recharge and groundwater runoff after 'heavy' precipitation event → TERRA source code buggy?

Reconsideration of source code

- Runoff calculation with respect to the hydrologically active layers
- The lower boundary is dispersive only for the gravitational settling (to ground-water aquifer)

Energy (kesoil)

Water (kesoil_hy)

gravitational drainage

constant temperature
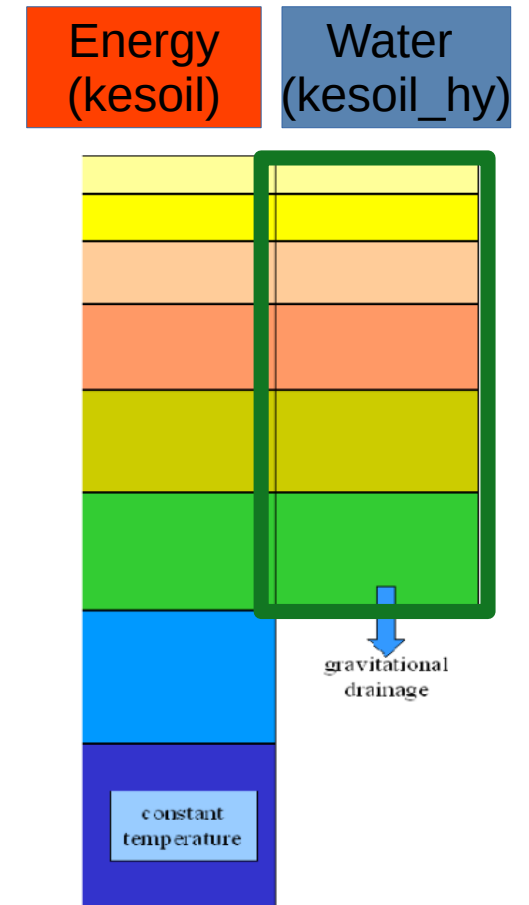
@COSMO-Documen-tation, Part 2 (2021)

Reconsideration of source code

- Runoff calculation with respect to the hydrologically active layers
- The lower boundary is dispersive only for the gravitational settling (to ground-water aquifer)

COSMO5.08,
France-Reims, Mai1981

COSMO5.08improved,
France-Reims, Mai1981
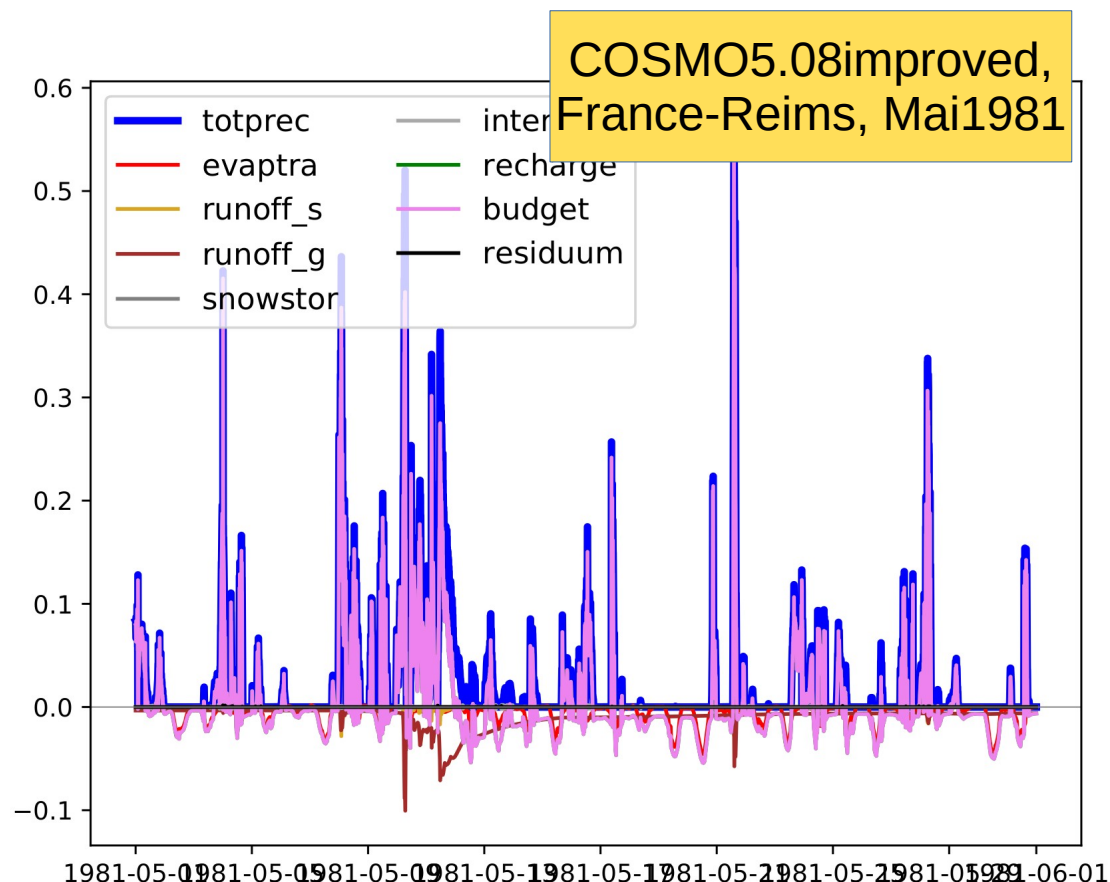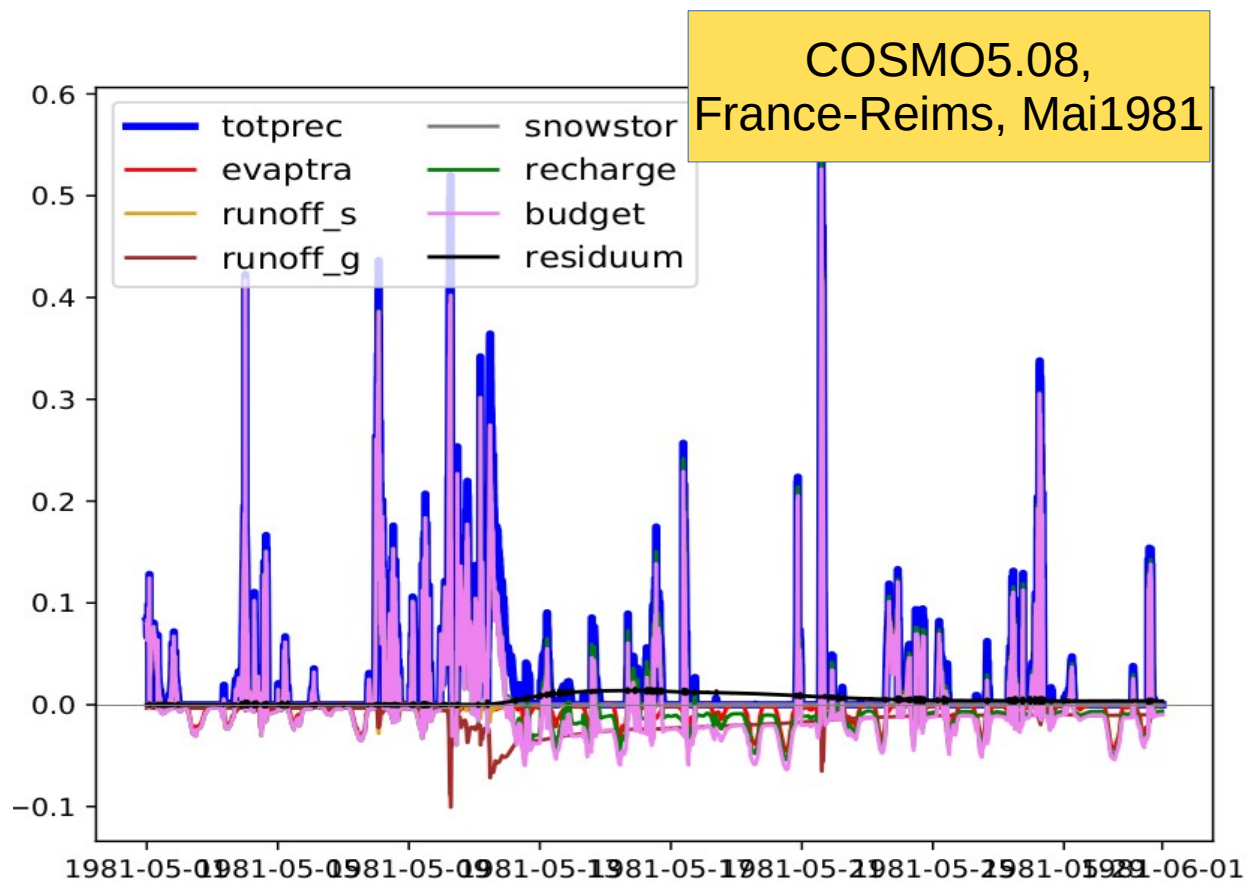
Reconsideration of source code

- Runoff calculation with respect to the hydrologically active layers
- The lower boundary is dispersive only for the gravitational settling (to ground-water aquifer)

France-Reims	COSMO5.08 standard	COSMO5.08 improved
Q1/1980	88.8 mm	-0.2 mm
Q2/1980	6.2 mm	<0.1 mm
Q3/1980	24.9 mm	<0.1 mm
Q4/1980	53.8 mm	0.7 mm
Q1/1981	68.7 mm	<0.1 mm
Q2/1981	53.3 mm	0.1 mm
Q3/1981	0.1 mm	< 0.1 mm
Q4/1981	61.8 mm	-0.7 mm
Totalsum	**357 mm**	**-1.2 mm**
Precipitation	**1800 mm**	

- Results also improve for COSMO5.09 (not shown)
- ICON is writing its own history

Soil moisture budget fix – Impact on ICON? (out of gitlab)

- The distribution between the soil moisture related fluxes differs from COSMO, i.e. a „death" of surface runoff
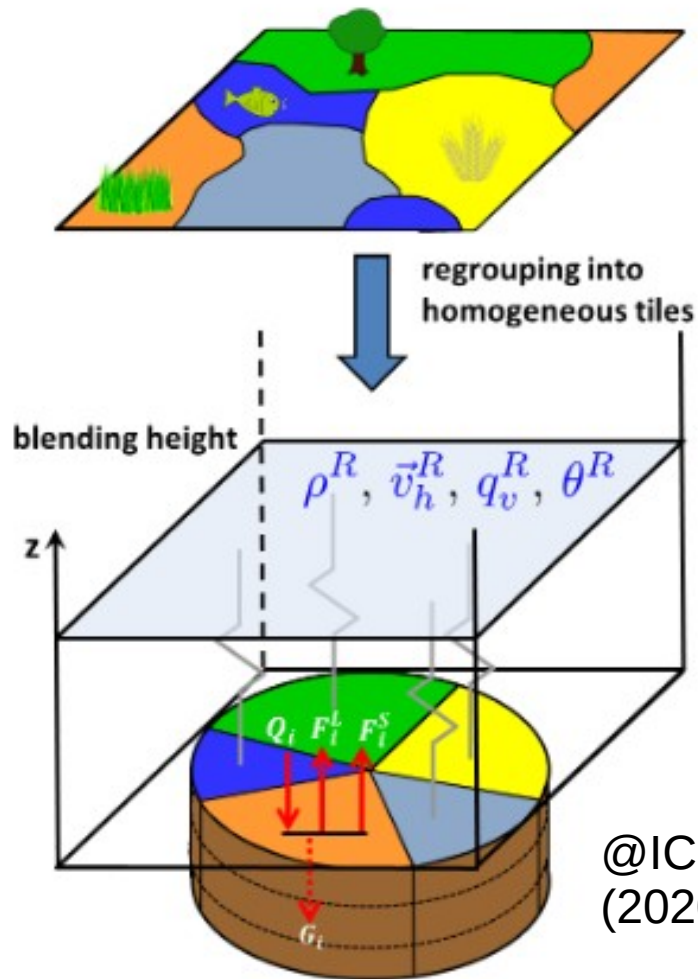- Nevertheless, still an impact of the bugfix by a factor of 50 and more

Residuum soil moisture ICON2.6.3-clm3, January 1979

Soil water budget for domain Alps

[mm/month]
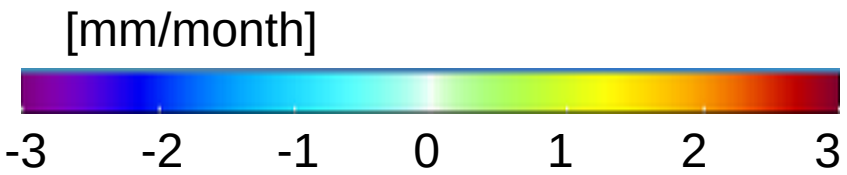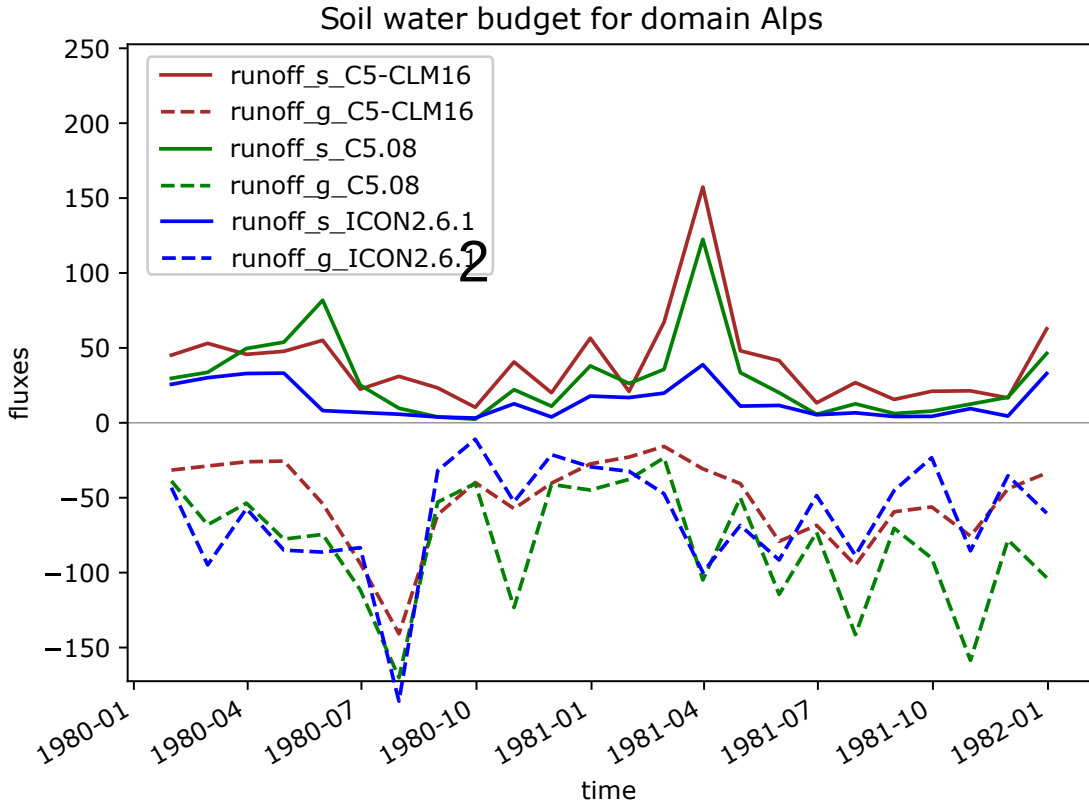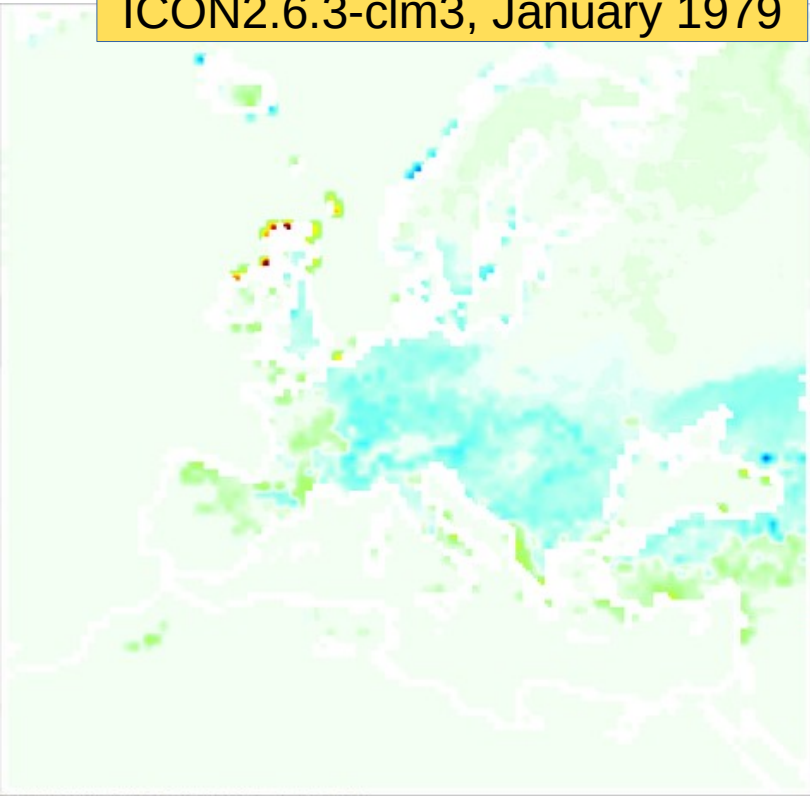
Soil moisture budget fix – special to ICON

Tile approach implemented in ICON → many surface / soil fluxes are separately calculated for each tile

regrouping into homogeneous tiles

blending height

$\rho^R,\ \vec{v}_h^R,\ q_v^R,\ \theta^R$

z

$Q_i,\ F_i^L,\ F_i^S$

G_i

@ICON-Documentation (2020)

Exemplary time series for surface runoff (sum over January)

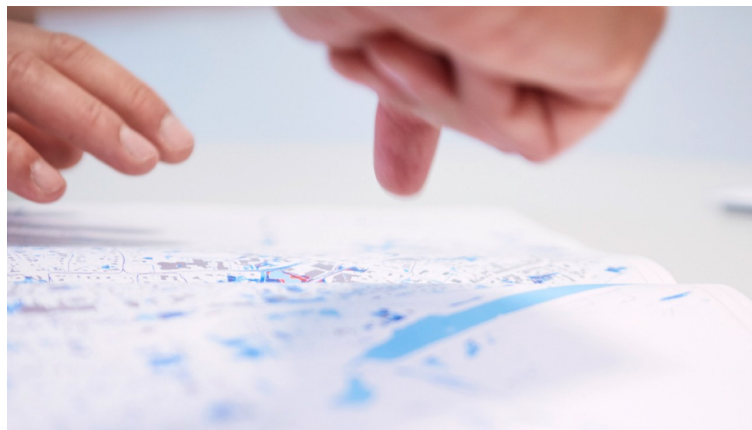Standard ICON, 2.6.3

consolidated ICON, 2.6.3
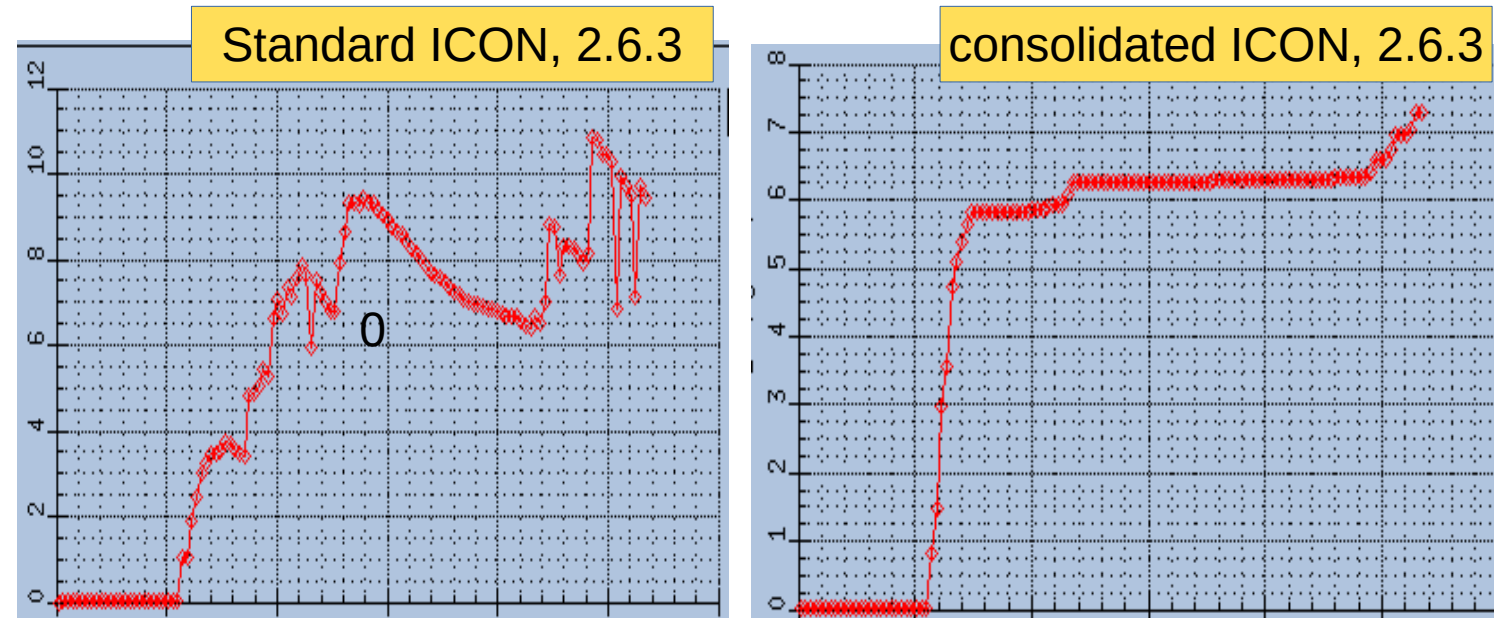
Conclusions
(HEREON style)

COSMO/ICON

Implement a first diagnostics for the soil water budget and close the budget from the physical point of view (there is still a residuum in the simulations)

Improved budget by magnitudes for COSMO-CLM5.09b and ICON-release 2.6.4

ICON

Tile approach fix to correctly calculate the runoffs and residua

Implemented in release 2.6.4

Burning issues

Understanding the fluxes and sources related to the soil moisture budget in ICON-CLM simulations (and differences to COSMO-CLM)

A closed budget does not mean a good model

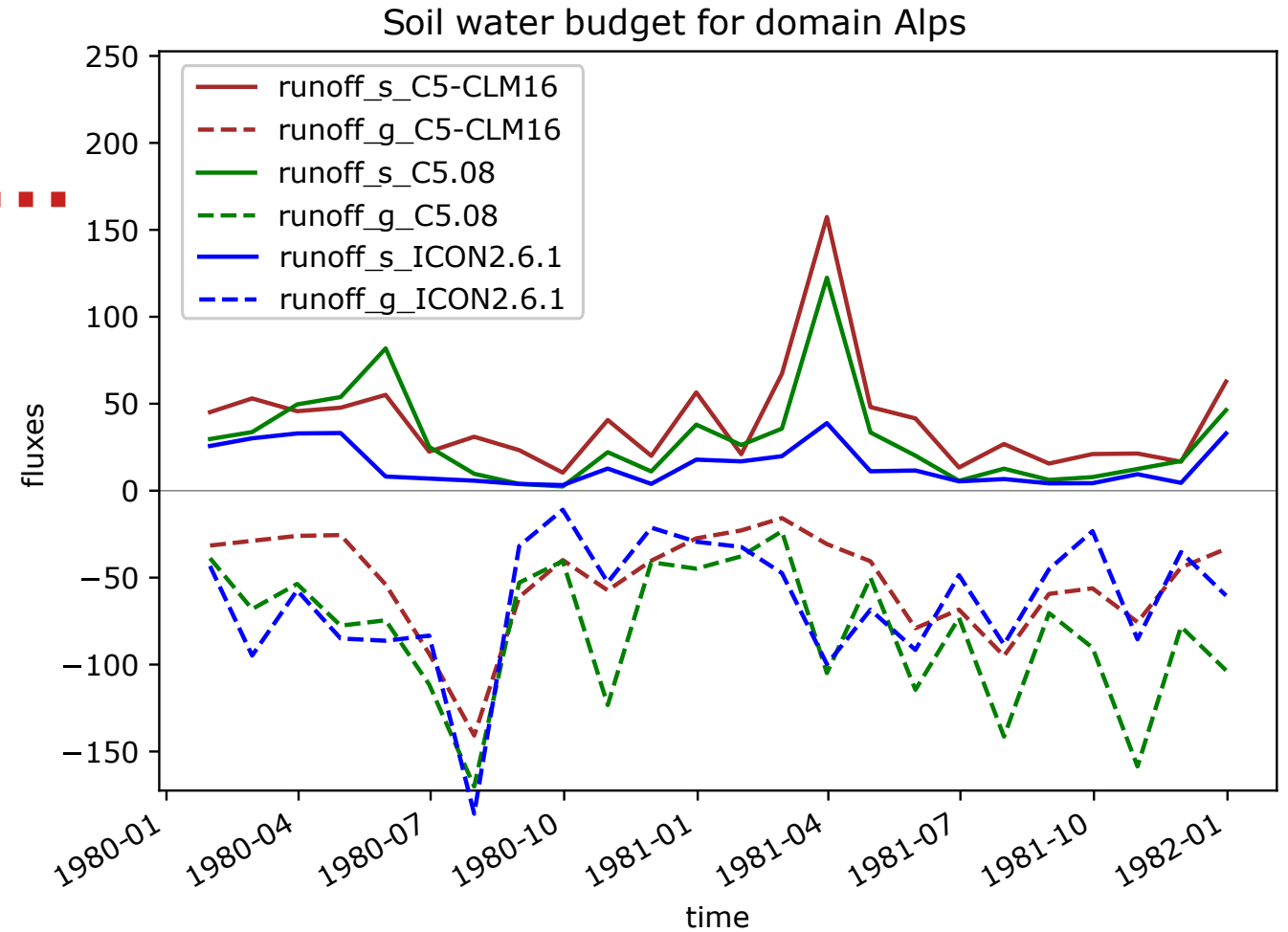Recommandation: **Use the output variable resid_wso**

Thank you for your attention

The story continues …

Dr. Ronny Petrik
KSR

Max-Planck-Straße 1 | 21502
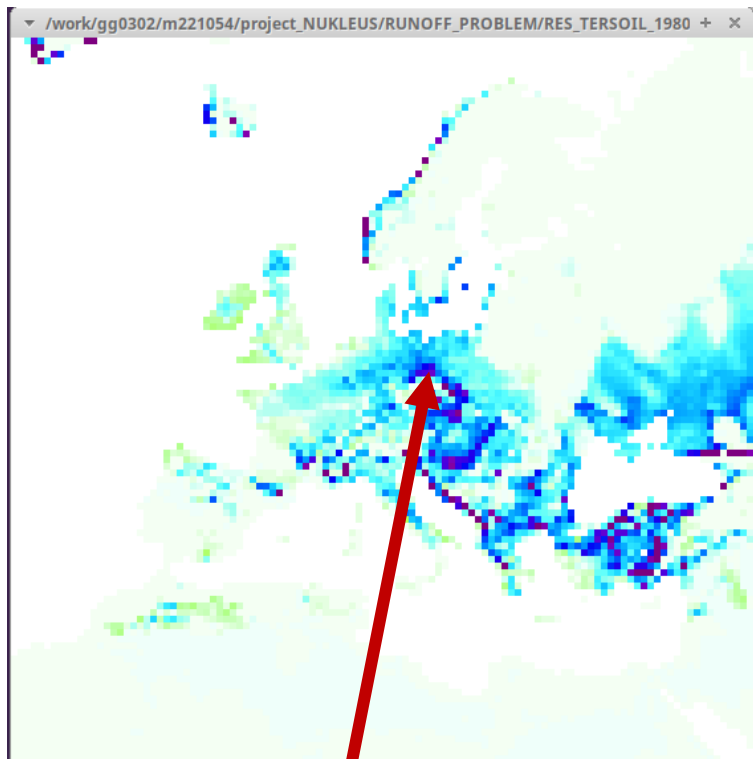Geesthacht
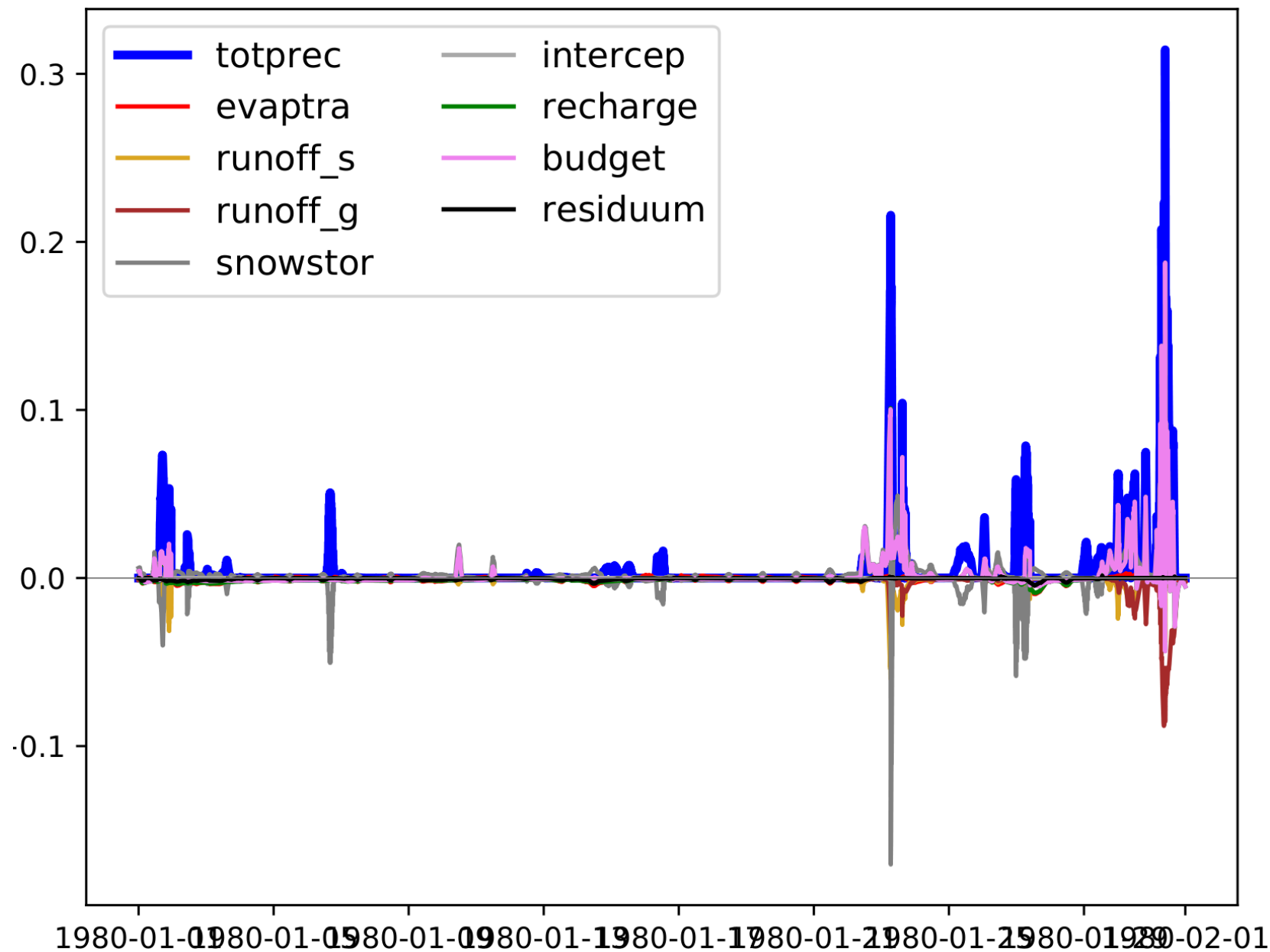ronny.petrik@hereon.de

www.hereon.de

ADDONS

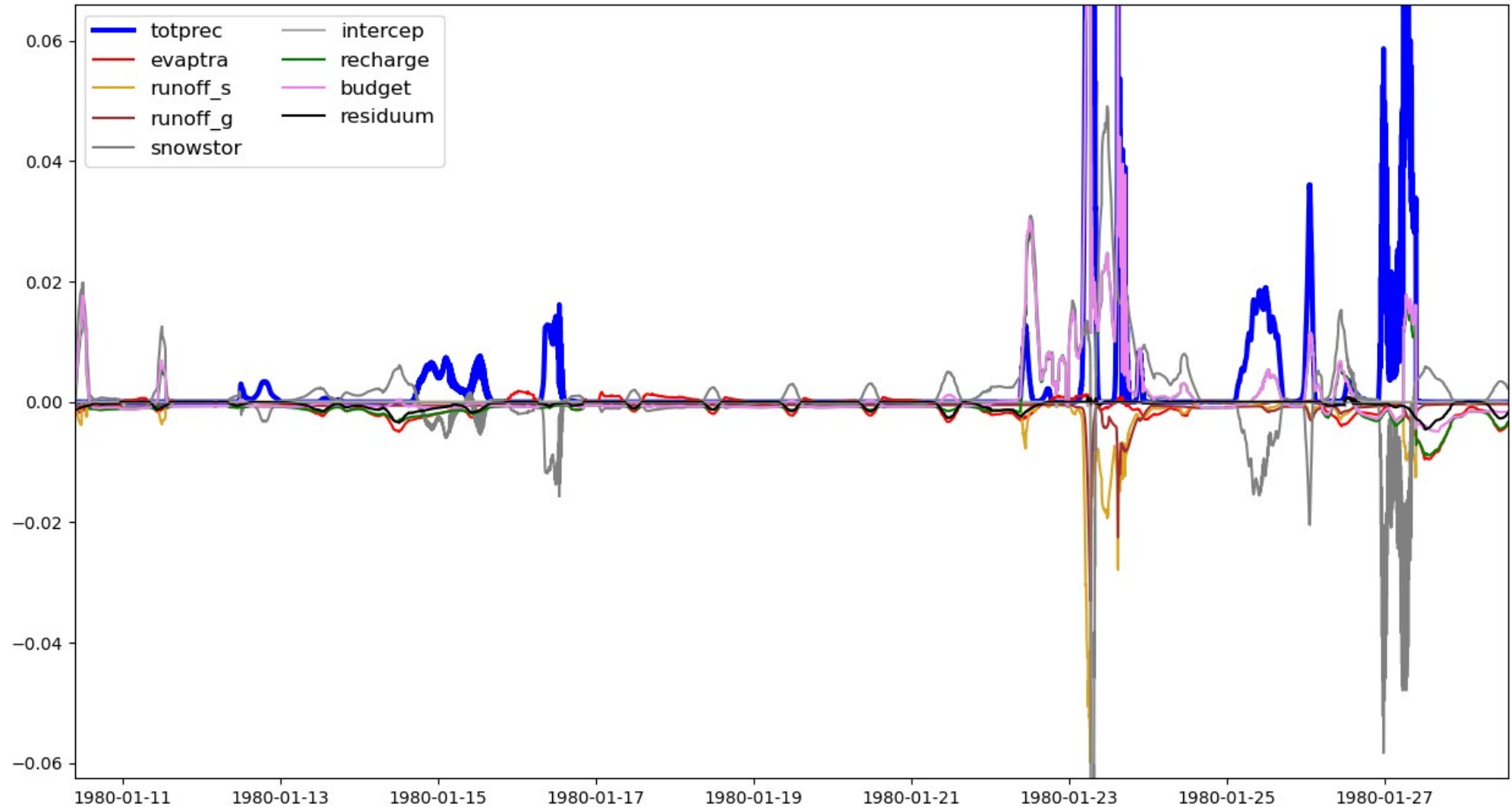# Cause of the residua?

mm/timestep

Poland Soren

Poland Soren, January 1980

Still problems in the fixed version of COSMO and ICON

Future

- The calculation of subsurface runoff fixed (regarding hydrological active layers)
- The yearly residua decrease by a factor of nearly 500

BUT

- A small residua of nearly -10 mm is left for some areas in Europe
- Cause: melting processes in wintertime, low frequency phenomena
- Problem independent on parameterization (Schlemmer vs. Standard)
- Physical explanation: for many cases with negative residua the budget (RHS) is zero but there is a negative change of soil water content
- Questions: Is the surface runoff treated correctly? Too much evapotranspiration over melting snow surfaces?