Convection permitting WRF climate simulations
Precipitation statistics and impact of land surface properties

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Introduction

Motivation

Convection-permitting (CP) regional climate models (RCMs) with a more detailed representation of heterogeneous land surface properties, as well as an explicit treatment of deep convection can lead to an improved simulation of meteorological processes and the climate system (Prein et al., 2015).

Questions with focus on precipitation statistics (exp. A)
- How well can observations be reproduced?
- What is the added value of the high resolution runs?
- How does precipitation intensity change in a future climate?

Questions with focus on surface heterogeneity (exp. B)
- What is the impact of the spatial scales of the patterns of land use, soil moisture and orography on CP RCM simulations (atmospheric patterns, domain wide averages)?

Experiments

WRF RCM simulations
- WRF/ARW v3.6.1
- One-way double-nesting setup: 3 km model domain (480x456x50 grid points) inscribed in 12 km pan-European Coordinated Regional Downscaling Experiment (CORDEX) EUR-11 model grid (448x436x50 grid points)
- Main settings: WSM-5 MP, RRTMG radiation, YSU PBL, Grell-Freitas deep convection (off with 3 km), NOAH LSM, up to 20hPa

Exp. A for evaluation and projection runs

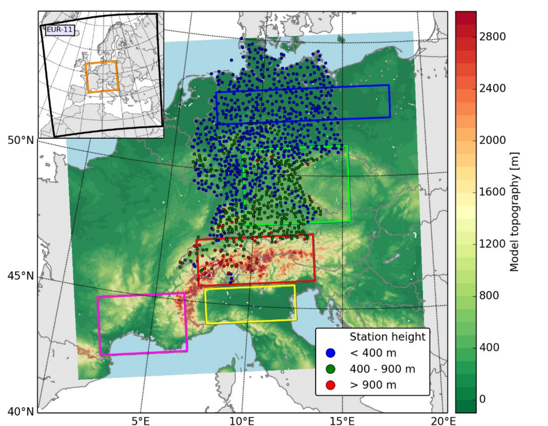


Fig. 1 Central European model domain (3 km grid size) nested into EURO-CORDEX domain (12 km grid size, EUR-11) as shown in small map upper left. Dots show rain gauge stations for different altitude ranges (blue: <400 m, green: 400-900 m, red: >900 m). Colored boxes indicate different analysis regions (blue: Lowlands, green: Uplands, red: Alpine, yellow: Northern Italy, pink: Southern France).

Evaluation runs
- ERA-Interim reanalysis driven (0.75° x 0.75° grid, 60 levels, 6 hourly), time slices: 1993-1995, 2002-2003, 2010-2013

Future scenario runs
- MPI-ESM-LR r1i1p1 (RCP4.5) downscaling, time slices: 1993-2005 (CTRL), 2038-2050 (MOC), 2088-2100 (EOC)

Validation data
- Rain gauge station data of the Deutscher Wetterdienst (DWD) and MeteoSwiss, 1180 stations in total, hourly temporal resolution

Exp. B for the sensitivity studies
- Configuration as above
- Summer (JJA) 2003, strong land-atmosphere coupling conditions
- Five 3 km resolution simulations, same atmosphere setup each
- Different combinations of 12 km and/or 3 km resolved land surface characteristics: a) land use and soil type (P1), b) soil moisture (P2), and c) orography (P3) (see Tab., right column)
- Invariant EUR-11 driving model setup, ERA-Interim driven

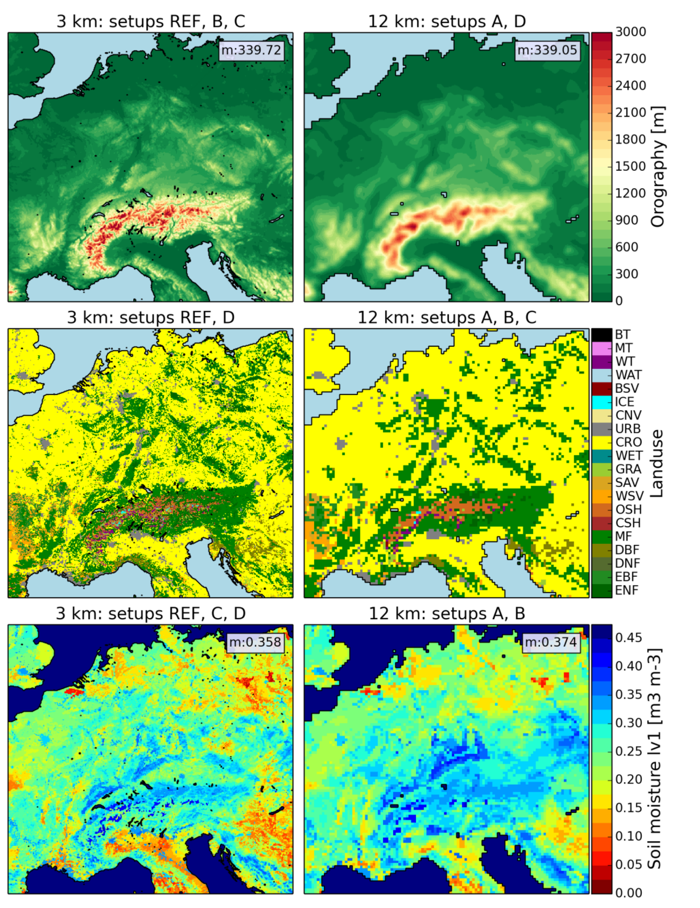


Fig. 2 Model orography (1st row), land use (2nd row) and initial soil moisture (3rd row) in 3 km (left column) and 12 km (right column) resolution (right column). Dominant land use types within the model domain are ENF: evergreen needleleaf forest; EBF: evergreen broadleaf forest; MF: mixed forest; WSV: wooded savanna; SAV: savanna; GRA: grasslands; WET: wetlands; CRO: cropland; URB: urban; ICE: snow or ice; BSV: barely/sparsely vegetated; WAT: water; WT: wooded tundra; MT: mixed tundra.

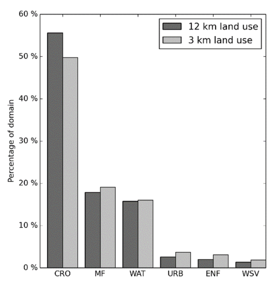
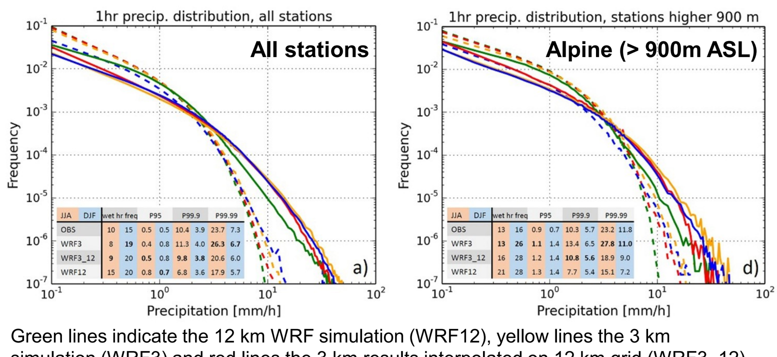


Fig. 3 Percentage of the most represented land use types within the central European model domain in 3 km and 12 km resolution.

Added value CP resolution (Exp. A)

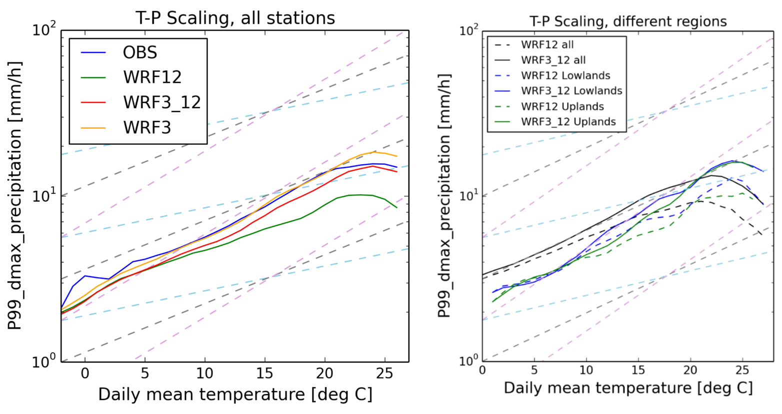
Evaluation hourly precipitation intensities



Green lines indicate the 12 km WRF simulation (WRF12), yellow lines the 3 km simulation (WRF3) and red lines the 3 km results interpolated on 12 km grid (WRF3_12).

Fig. 4 Intensity distribution of hourly precipitation based on all rain gauge stations (blue lines); left: based on all stations, right: Alpine stations (> 900 m). For each station the nearest model grid point is taken into account. Solid lines show results for summer (JJA), dashed lines for winter (DJF).

Temperature–extreme precipitation scaling



Using ERA-Interim driven evaluation simulations, overall 9 years

Fig. 5 Temperature – extreme precipitation scaling in WRF12 and WRF3_12 compared to station observations (left) and for different regions (right). For each grid point nearest to a station daily maximum hourly precipitation is discretized into one-degree bins of daily mean temperature. For each temperature bin with a sample size larger than 100 the 99th percentile of the precipitation values (P99_dmax) is calculated and averaged over all stations (or grid points). Light blue, grey and pink dashed lines indicate a scaling of 3.5% K-1, 7%K-1 and 10.5%K-1 (according 0.5, 1 and 1.5 times C-C scaling rate), respectively.

Projected changes

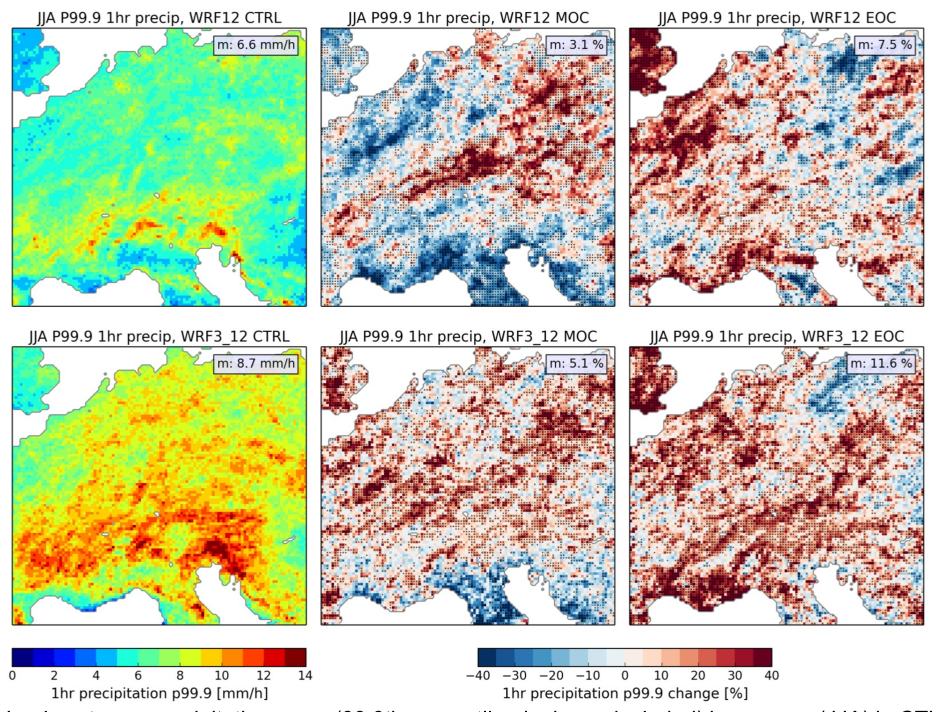


Fig. 6 Hourly extreme precipitation sums (99.9th percentile, dry hours included) in summer (JJA) in CTRL simulation time period (left) and its relative change in MOC (middle) and EOC (right) for the WRF12 (upper row) and WRF3_12 (lower row).

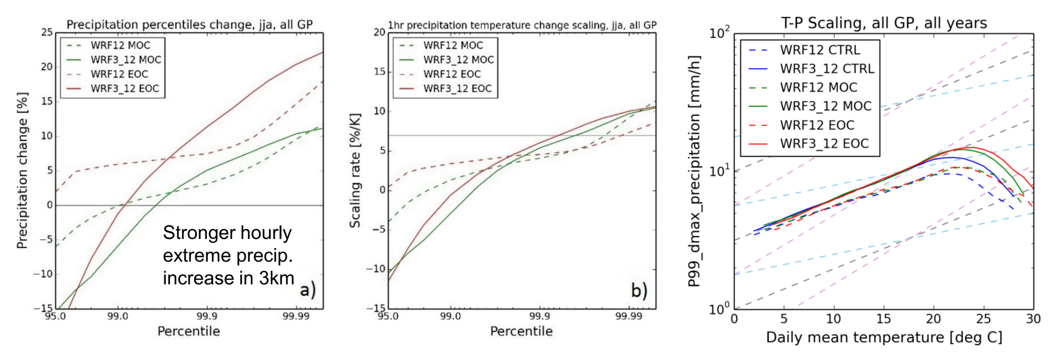


Fig. 7 Left: Percentage change of hourly precipitation percentiles (JJA) in MOC (green) and EOC (red) as difference to CTRL for both WRF12 (dashed) and WRF3_12 (solid) based on the spatial average of all grid point relative changes. Middle: Scaling rate of percentage change of hourly precipitation percentiles (JJA) normed by local mean temperature change in MOC (green) and EOC (red) as difference to CTRL for both WRF12 (dashed) and WRF3_12 (solid) based on the spatial average of all grid point relative scaling rates. Right: Temperature – extreme precipitation scaling in WRF12 (dashed) and WRF3_12 (solid) for simulation time period CTRL (blue), MOC (green) and EOC (red). Same method as in Fig. 5, but averaged over all domain grid points.

Results, experiment A, on precipitation statistics
- Added value in the 3 km runs at the sub-daily scale (intensity, diurnal cycle, spatial extent); wet-bias remains (Fig. 4)
- Differences are largest over mountainous regions and during summer months with high convective activity (data not shown)
- Changes in precipitation intensity distributions and extreme precip. indices in projections; +20% for P99.99 in EOC (Fig. 6; Fig. 7, left)
- Better reproduction of temperature-extreme precipitation scaling in 3 km resolution (Fig. 5)
- With higher mean temperature in projections: increase in extreme precipitation exceeding scaling rates of 7%/K according to the Clausius-Clapeyron (C-C) relation (Fig. 7, middle)
- Shifted temperature – P99_dmax hourly precipitation scaling curves in projection according to C-C scaling (Fig. 7, right)
- Good overall qualitative agreement with results, e.g., by Kendon et al. (2012) and Ban et al. (2014)

Impacts of heterogeneity (Exp. B)

Different resolution land surface properties combinations per exp. REF, A, B, C, D
Properties: P1 = land use and soil type; P2 = initial soil moisture; P3 = orography
Always 3 km simulation but spatial pattern either in 3 km or 12 km resolution

	REF	A	B	C	D
P1	3	12	12	12	3
P2	3	12	12	3	3
P3	3	12	3	3	12

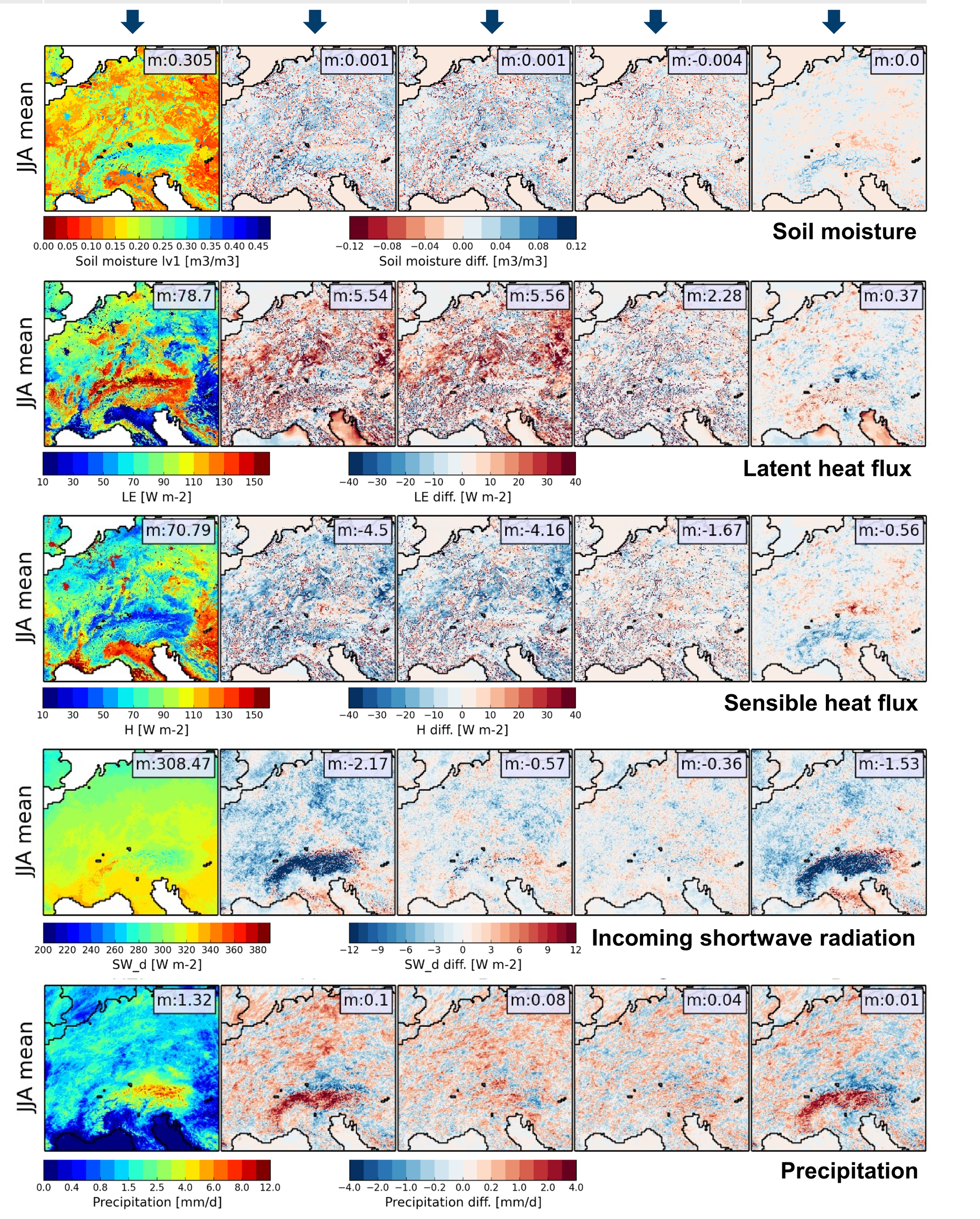


Fig. 8 Spatial distribution of JJA means in the REF simulation and in the setups A to D displayed as difference to REF. Domain averages and differences are shown in the upper right corner. Top to bottom: Soil moisture, latent heat flux, sensible heat flux, shortwave radiation, precipitation.

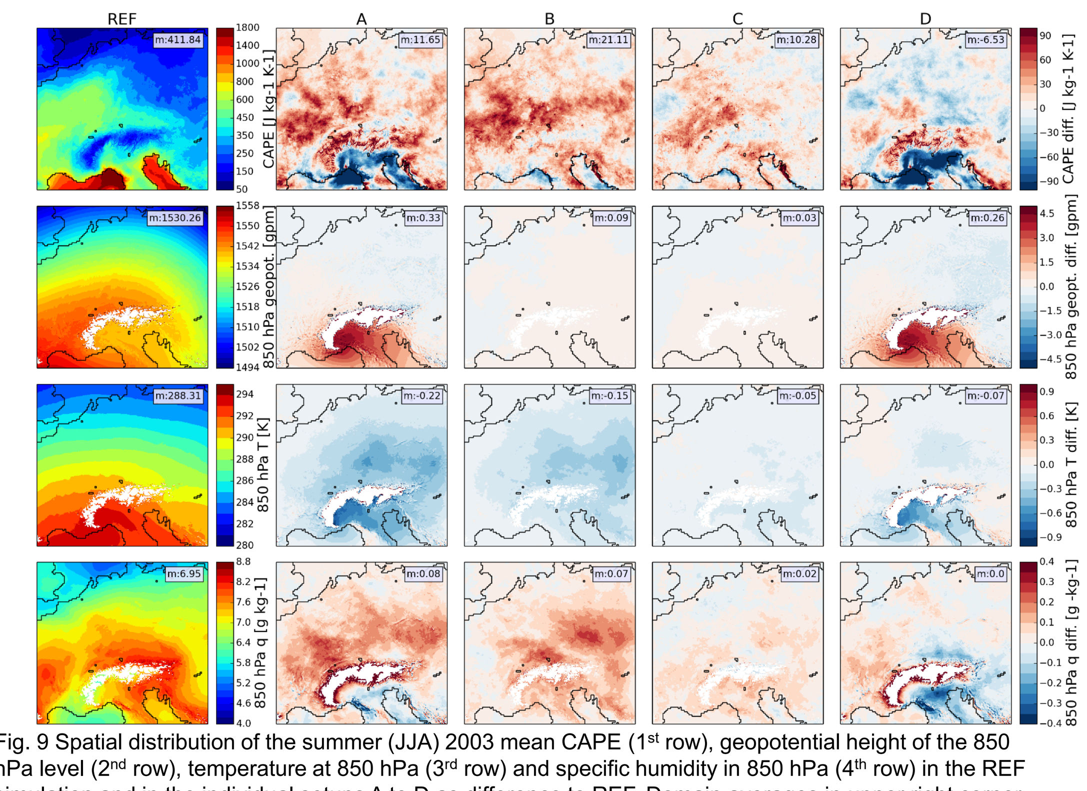


Fig. 9 Spatial distribution of the summer (JJA) 2003 mean CAPE (1st row), geopotential height of the 850 hPa level (2nd row), temperature at 850 hPa (3rd row) and specific humidity in 850 hPa (4th row) in the REF simulation and in the individual setups A to D as difference to REF. Domain averages in upper right corner.

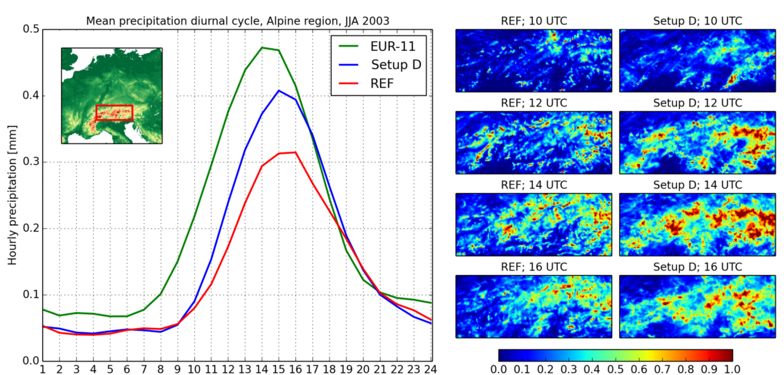


Fig. 10 Mean diurnal cycle of precipitation in the Alpine region (red box in upper left corner) in setup D, REF and EUR-11 (left); spatial distribution of mean hourly precipitation at 10, 12, 14 and 16 UTC in REF (left column) and setup D (right column).

Results, experiment B, on impacts of surface heterogeneity
- Coarser-resolved orography alters large scale flow pattern and results in a weaker Föhn and in enhanced locally generated convective precipitation, peaking earlier in afternoon
- Effect of a coarser-resolved land use map is mainly related to changes in overall percentages rather than loss of heterogeneity
- Soil moisture initial conditions have a higher impact (3 vs 12 km)
- Differences caused by coarse land surface patterns (in 3 km runs) much smaller than differences with 3 vs 12 km atmosphere

Acknowledgements

Work has been sponsored through a research and development cooperation on hydrometeorology between the Federal Institute of Hydrology, Koblenz, Germany, and the Meteorological Institute, University of Bonn, Bonn, Germany and through the EC-funded project eLTER H2020 (GA: 654359 - H2020 INFRAIA call 2014-2015).The authors gratefully acknowledge the computing time granted by the JARA-HPC Vergabegremium and VSR commission on the supercomputer JURECA at Forschungszentrum Jülich through compute time project JJSC15.

NIC Symposium 2018
FZJ, Juelich, Germany, 22/23 February 2018

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