HPC boosting Climate Science: Results and Perspectives from the ClimEx-project

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Background

“Extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will very likely become more intense and more frequent.” - IPCC AR5 report

Major flood events in Québec
1996/2011/2017

Major flood events in Bavaria
Research objectives

Provide unprecedented high-resolution climate model datasets to …

• Confirm knowledge on whether and how climate change contributes to higher magnitudes and frequencies of extreme events
• Distinguish between the effects of internal variability and a ‘clear’ climate change signal
• Improve methods to analyse hydro-meteorological extreme events and provide robust estimates of HQx flood events

ClimEx...

• employs High Performance Computing (HPC) to produce a large scale single model ensemble (CanESM2-CRCM5, 50 members), resulting in a high-resolution (0.11°), transient climate dataset (1951-2100)
• will provides, for the first time, a statistically robust analysis and comparison of natural climate variability and climate change
HPC challenges and implementation

Experiment requires great computing power and storage capacity...

- GCS project granted in 2016 (88 MCPU-h, 500 Tbyte)
- transfer of CRCM5 from Tier1 “Guillimin” to Tier0 “SuperMUC”
- CRCM5 contains two components: “dynamics” uses MPI communications, “physics” scales fully under OpenMP → hybrid scheme
- “embarrassingly parallel”-simulations started in 03/2016
- LRZ provided two islands (16,384 cores) in 09/2016, completed 02/2017
- remaining CPU-time was used for special experiments

www.lrz.de/services/datenhaltung/bigdata/
HPC challenges and implementation

Experiment requires great computing power and storage capacity...

- multiple variables stored in high temporal resolution (1h - 1d)
- 500TByte for both domains on tape
- Data Science Storage (DSS) provided by LRZ for the Bavarian RCM data
- data stored in **NetCDF4** format; efficient way to store georeferenced spatial data (time, latitude, longitude; meteorological variable for n time steps)
- further downscaling to hydrological application scale (from 12km to 500m...)
- overall data demand will be in the range of several PBytes
Case studies - Climate model domains

North American Domain

European Domain

"free domain" (340x340)
"analysis domain" (280x280)
Case studies - Hydrological model domains

On which spatial and temporal scales do we need to investigate hydrometeorological extreme events?

- **Challenge**: Investigate the variability and climate change dependency of extreme events in ca 100 Bavarian river basins (ca. 100,000 km²)

- **Goal**: Improved process understanding and provisioning of measures for water resources management and river authorities to reduce extreme risks

- **Conduct**: Hydrological simulations using WaSiM (50 members of CRCM5 transient simulations 1950-2100), 500m and 3h resolution
Project structure - workflow

- Reference climate data set
- 50x RCM to hydro scale
  - Spatial downscaling
  - Bias adjustment
  - RCM
  - GCM
- 50x CRCM5
- 50x CanESM2
- QQ-Mapping
- RCP
- Uncertainty about results
- Complexity of the model chain
- VPP
- Impact assessment
- Runoff modelling
- Climag approach

- 98 catchments
- Linux Cluster & SuperMUC
- Linux Cluster
- SuperMUC
Functioning of the RCM

sim=CRCM5, CanESM2
dx = 0.11, 2.8 deg
tr. = hourly, daily
precipitation (mm/jr)
How does it look like in a Large Scale Single Model Ensemble?

Natural variability?

With 50 model members, we are practically increasing the database 50-fold; e.g. to estimate the robustness of natural variability in the time frame of 1981-2010, we possess not 30 but 1500 (model years) in high temporal and spatial resolution (1-3h, 12km) → estimation of rare extreme events in a given time period becomes much more robust…
50 possible future changes for PRC (in %) between 2020-2039 and 2000-2019 over Europe from CanESM2-CRCM5 at a 12-km resolution
Climate change - T & P over Europe

Monthly change of temperature and precipitation (2080-2099 vs. 2000-2019)
(50 member mean)
Climate change - Rx3h over Europe

Rx3h Time of Emergence (S/N>1)

Rx3h S/N ratio (2070-2099)
ClimEx - Weather Patterns (Vb-Tracking)

Using Machine Learning to search for extreme weather patterns in the ClimEx database

JRA-55 - 700 hPa geopotential - 29.05.2013 12:00

ClimEx - 700 hPa geopotential - 29.05.2013 12:00

Source: ZAMG, Hofstätter et al. 2017
www.rda.ucar.edu
Increasing relevance for extreme precipitation events (EPE) linked to Vb-tracks in all seasons.

Significant seasonal shifts of Vb-related EPEs from summer to spring.
ClimEx - Further observations

Winter Precipitation in Bavaria  |  Summer Precipitation in Bavaria  |  # of 11-day droughts in Bavaria  |  Length of heat waves in Bavaria

© Fabian von Trentini
ClimEx - Visualization

Europe in May 1999; CRCM5 driven with Reanalysis data

© Jens Weismüller
ClimEx - Visualization

DEM + satellite imagery + accumulated ClimEx precipitation

Kolb et al. 2018
ClimEx - going SuperMUC-NG...

- assessing the impacts of climate change through multiple single model large ensembles of high-resolution convection permitting models...

- robust representation of extreme events on smaller scales, e.g. flash floods, hail, icing rain, erosion, ...

- near-realtime simulations for virtual perfect prediction

Prein et al. (2015)
ClimEx - beyond SuperMUC-NG...

- Fully coupled high-resolution earth system models...

- Fully integrated assessment of human-environment systems...
  (including land use dynamics, management, biogeochemical cycles)

→ near-realtime global simulations for virtual perfect prediction

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ClimEx - beyond SuperMUC-NG...

- Fully coupled high-resolution earth system models...

Thank you!

www.climex-project.org

- Fully integrated assessment of human-environment systems...
  (including land use dynamics, management, biogeochemical cycles)

→ near-realtime global simulations for virtual perfect prediction
Visit us: www.climex-project.org

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Thank you!