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

Next-Gen Science Symposium
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Background

Major flood events in Québec
1996/2011/2017

Major flood events in Bavaria
1999/2002/2005/2013/2016

« 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

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

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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

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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

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Case studies - Climate model domains

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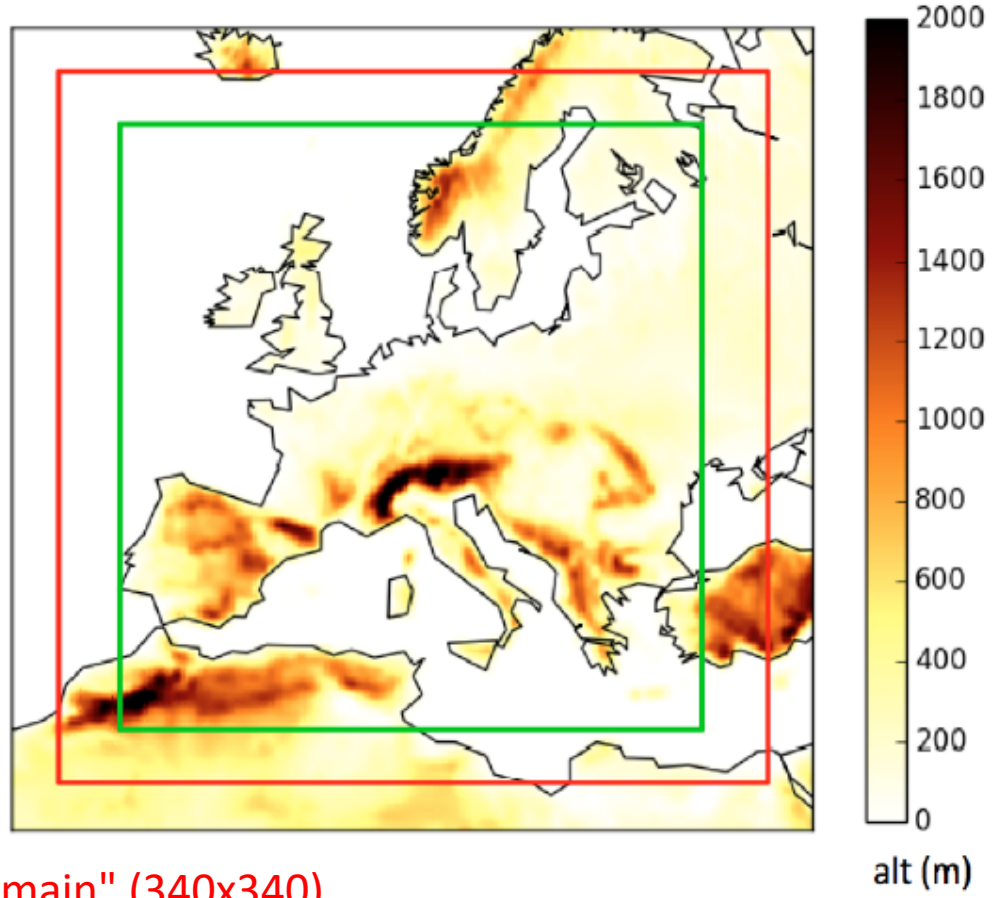
North American Domain

European Domain



"free domain" (340x340)

"analysis domain" (280x280)

Case studies - Hydrological model domains

ClimEx

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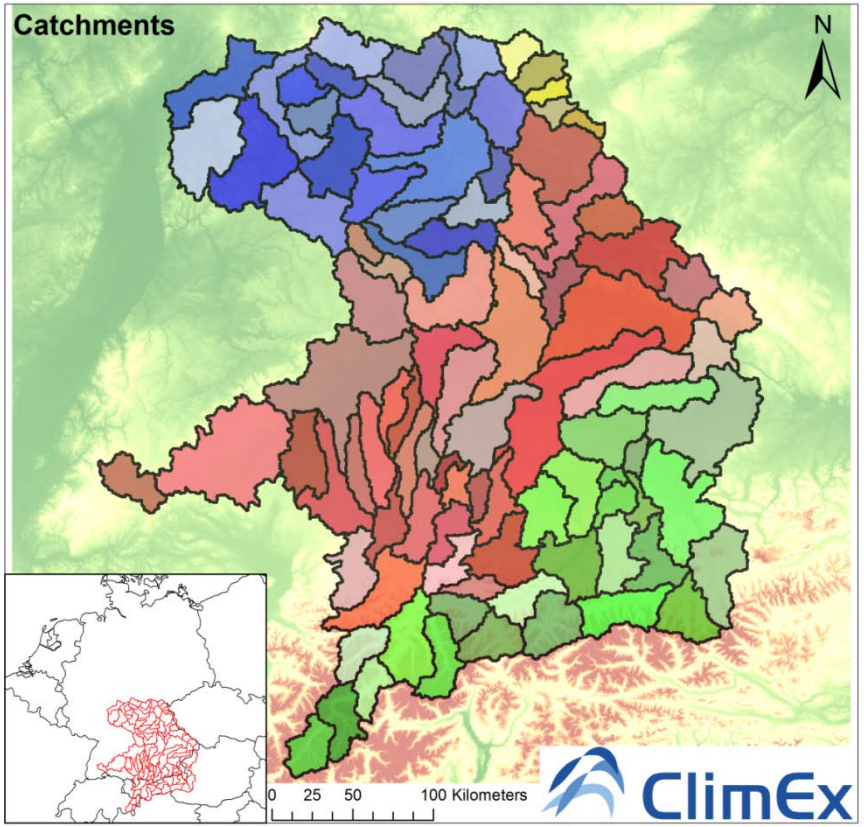
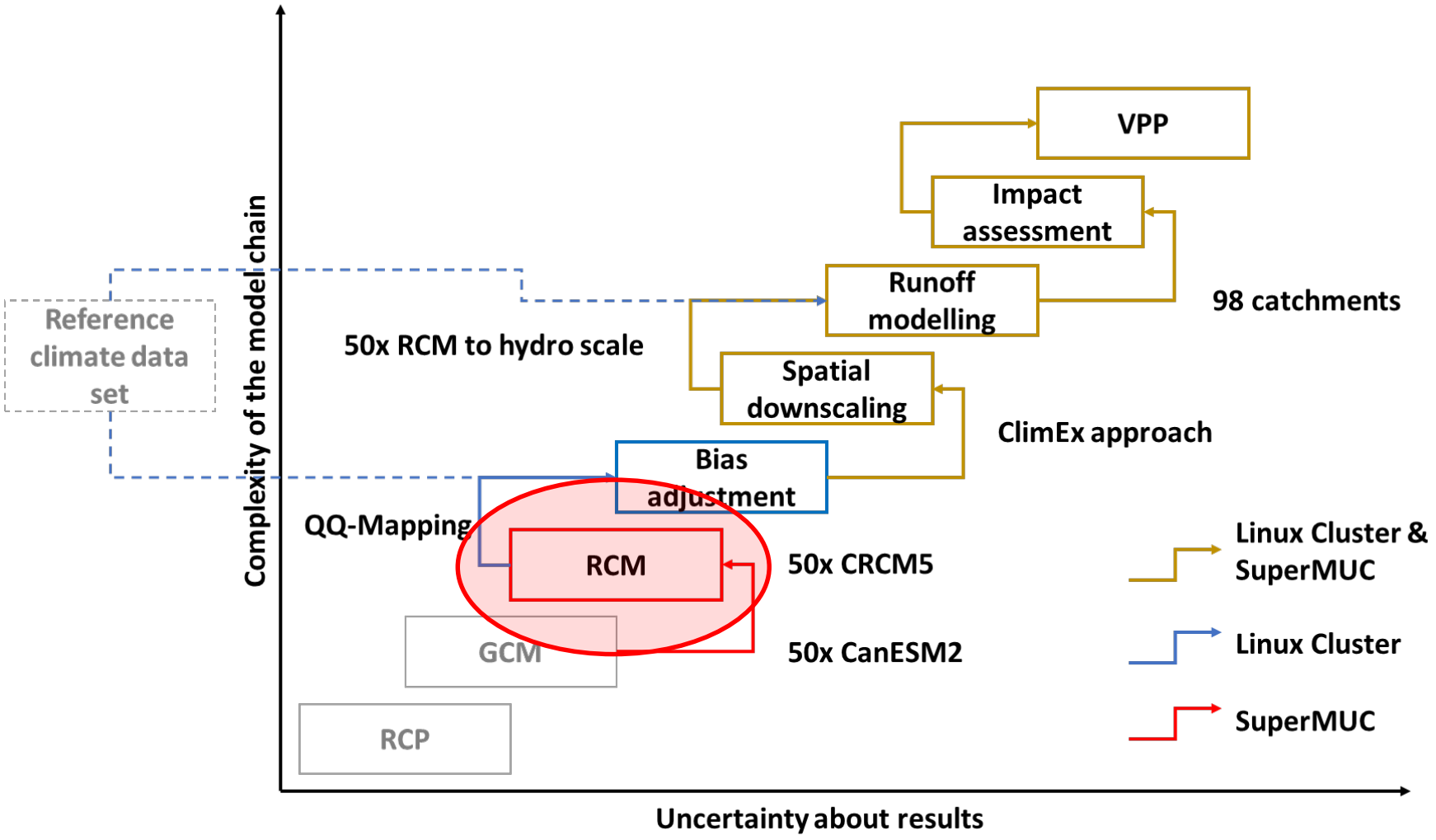
On which spatial and temporal scales do we need to investigate hydrometeorological extreme events?

- **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



Hydrological Bavaria

Project structure - workflow



Functioning of the RCM

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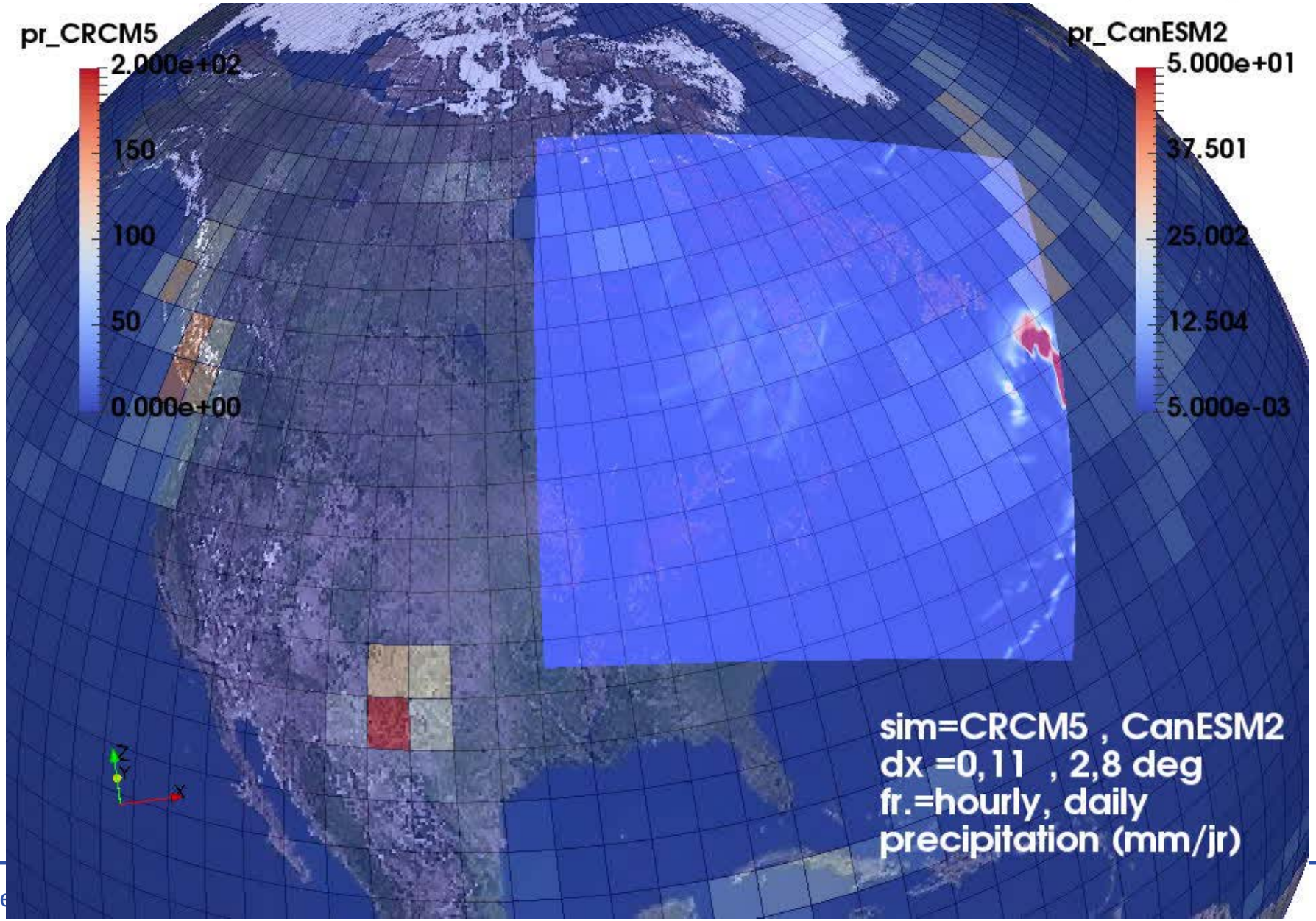
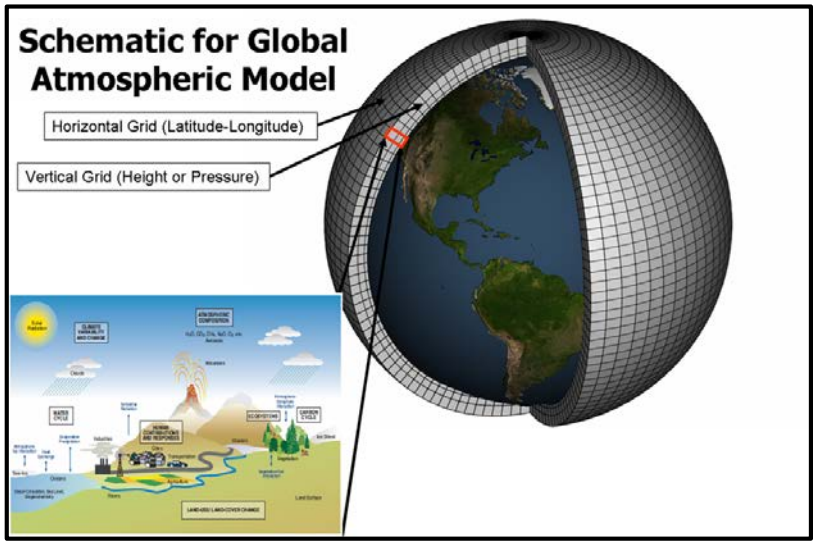
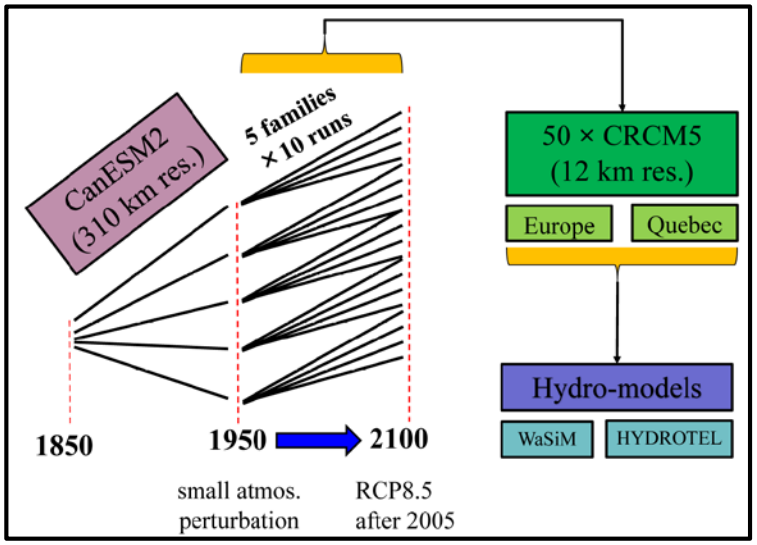
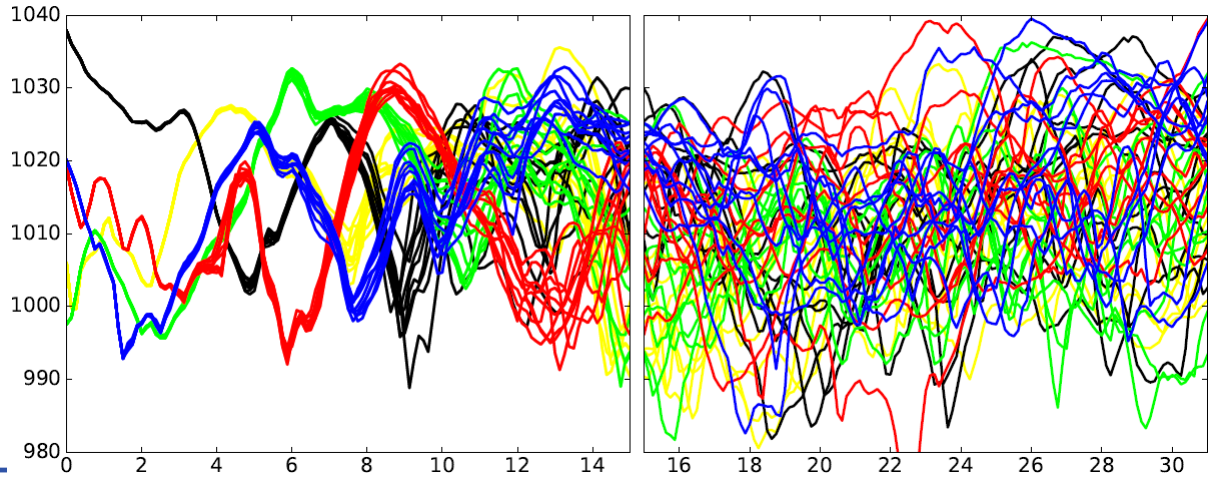


Natural variability?

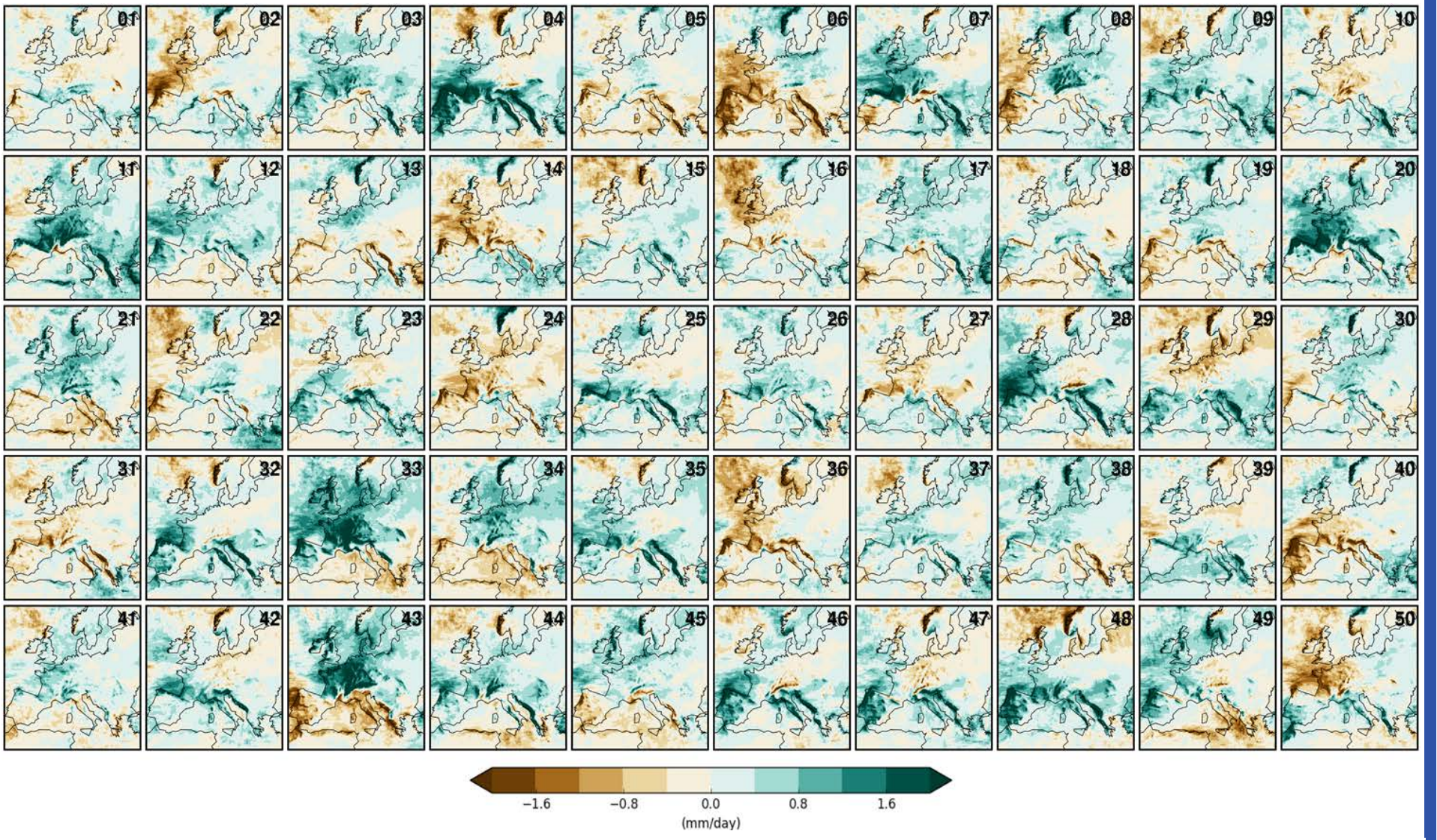
How does it look like in a Large Scale Single Model Ensemble?





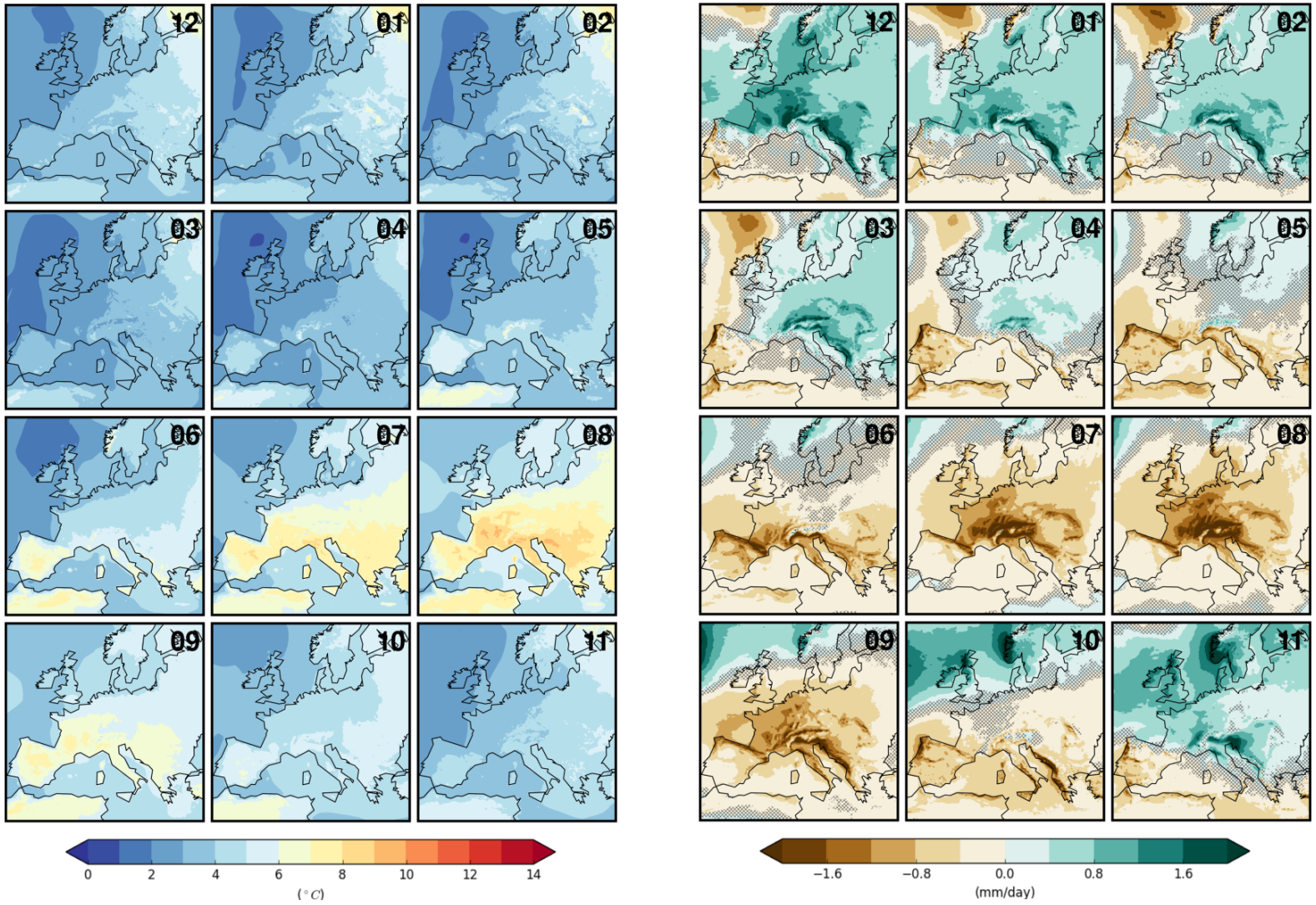


Natural variability - P over Europe



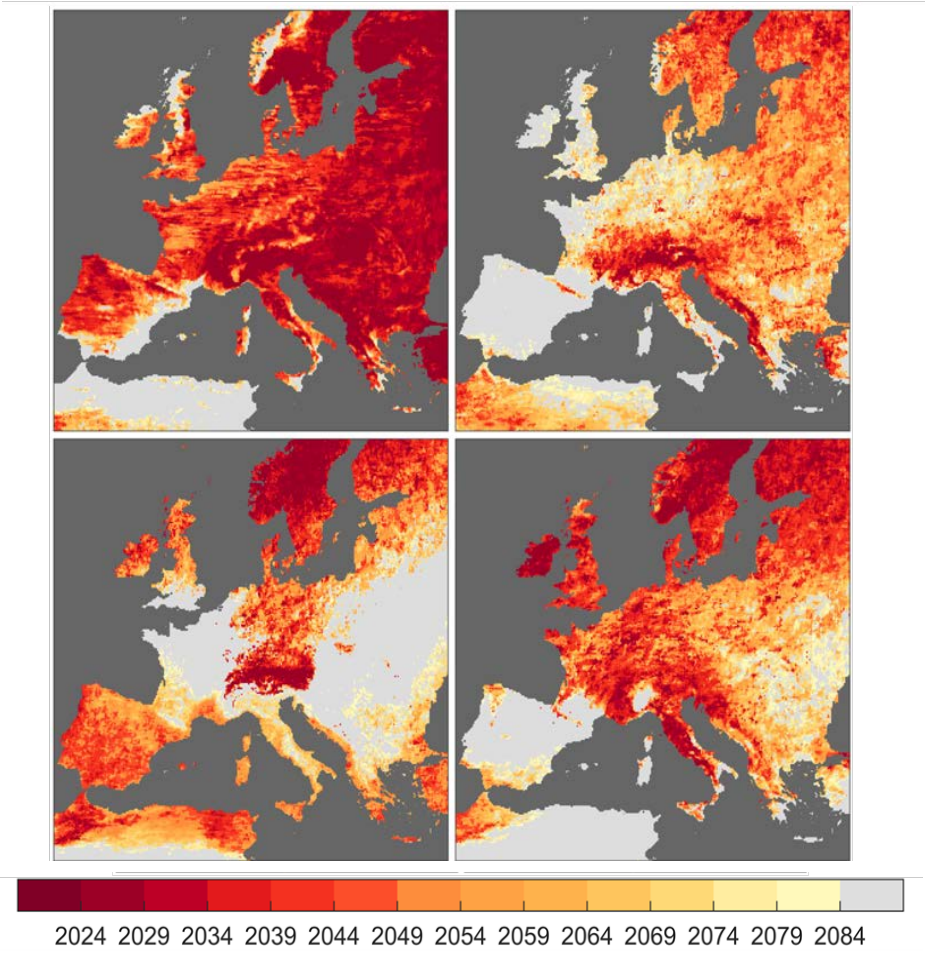
50 possible future changes for PRC (in %) between 2020-2039 and 2000-2019 over Europe from CanESM2-CRCM5 at a 12-km resolution

Climate change – T & P over Europe

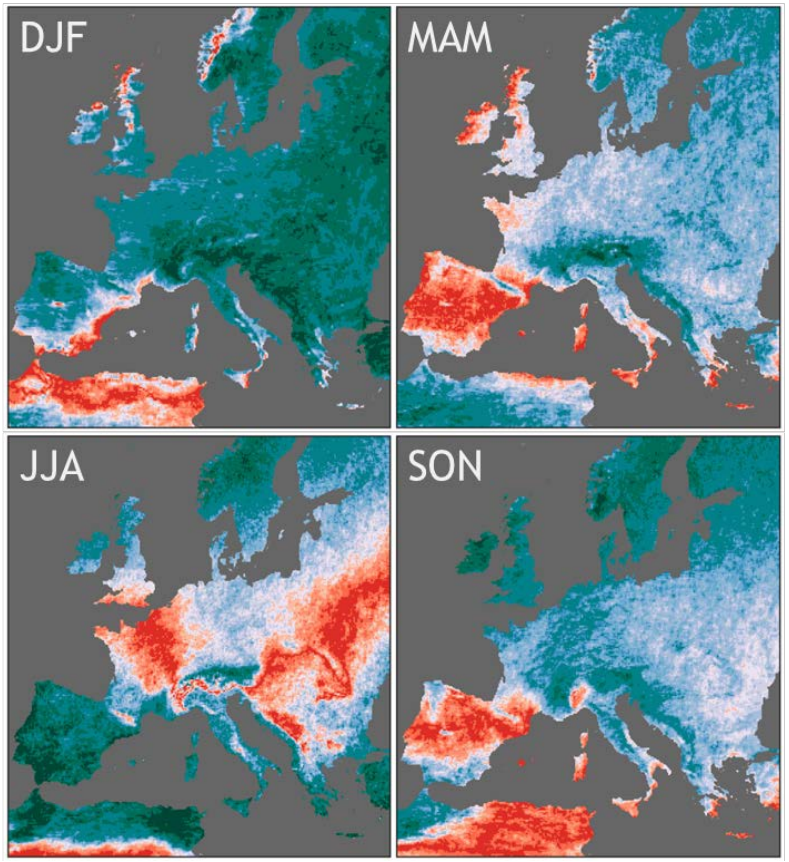


Monthly change of temperature and precipitation (2080-2099 vs. 2000-2019)
(50 member mean)

Climate change – Rx3h over Europe



Rx3h Time of Emergence (S/N>1)



Rx3h S/N ratio (2070-2099)

ClimEx – Weather Patterns (Vb-Tracking)

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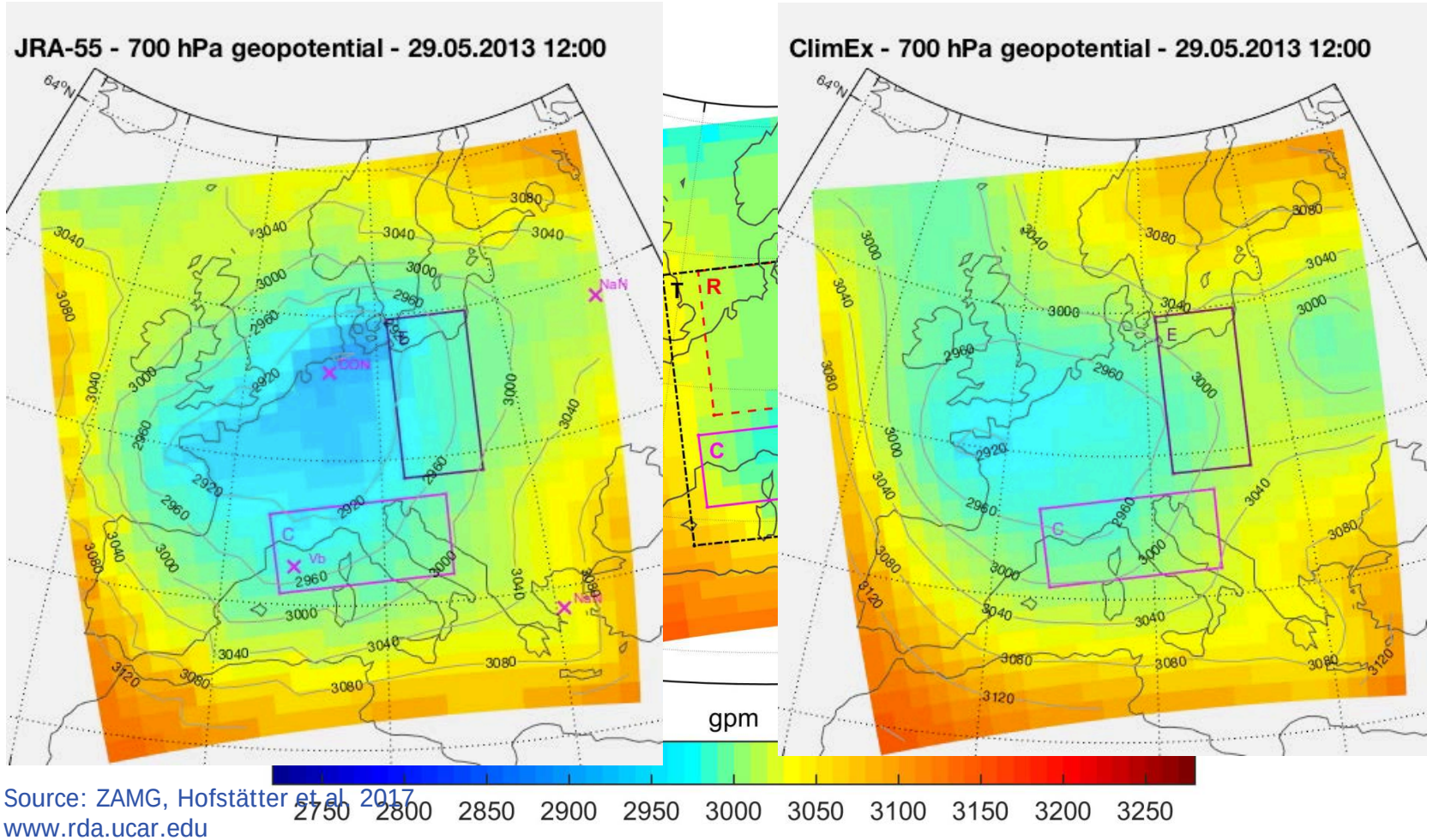
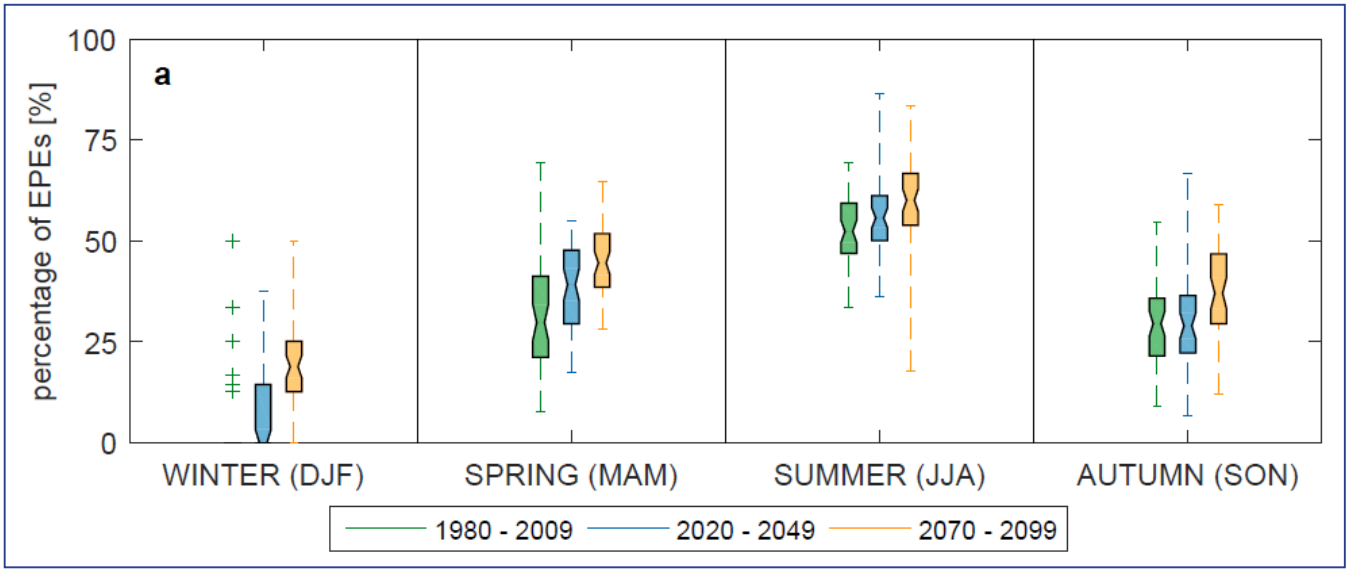
Using Machine Learning to search for extreme weather patterns in the ClimEx database

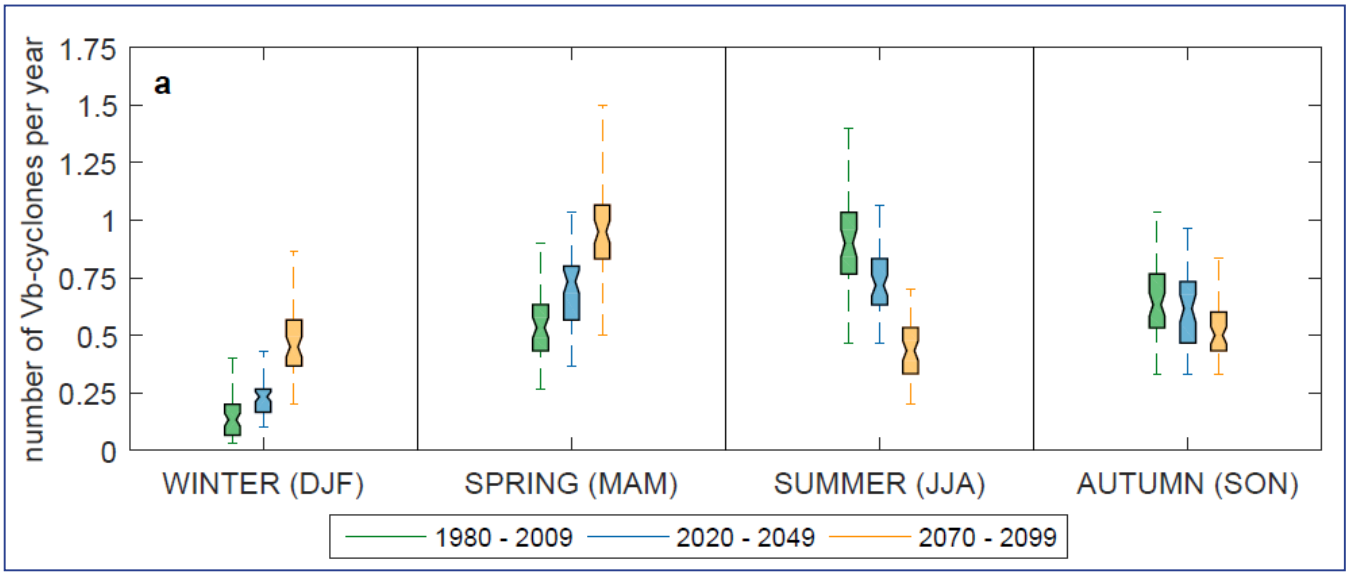


Source: ZAMG, Hofstätter et al. 2017
www.rda.ucar.edu

ClimEx – Weather Patterns (Vb-Tracking)

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

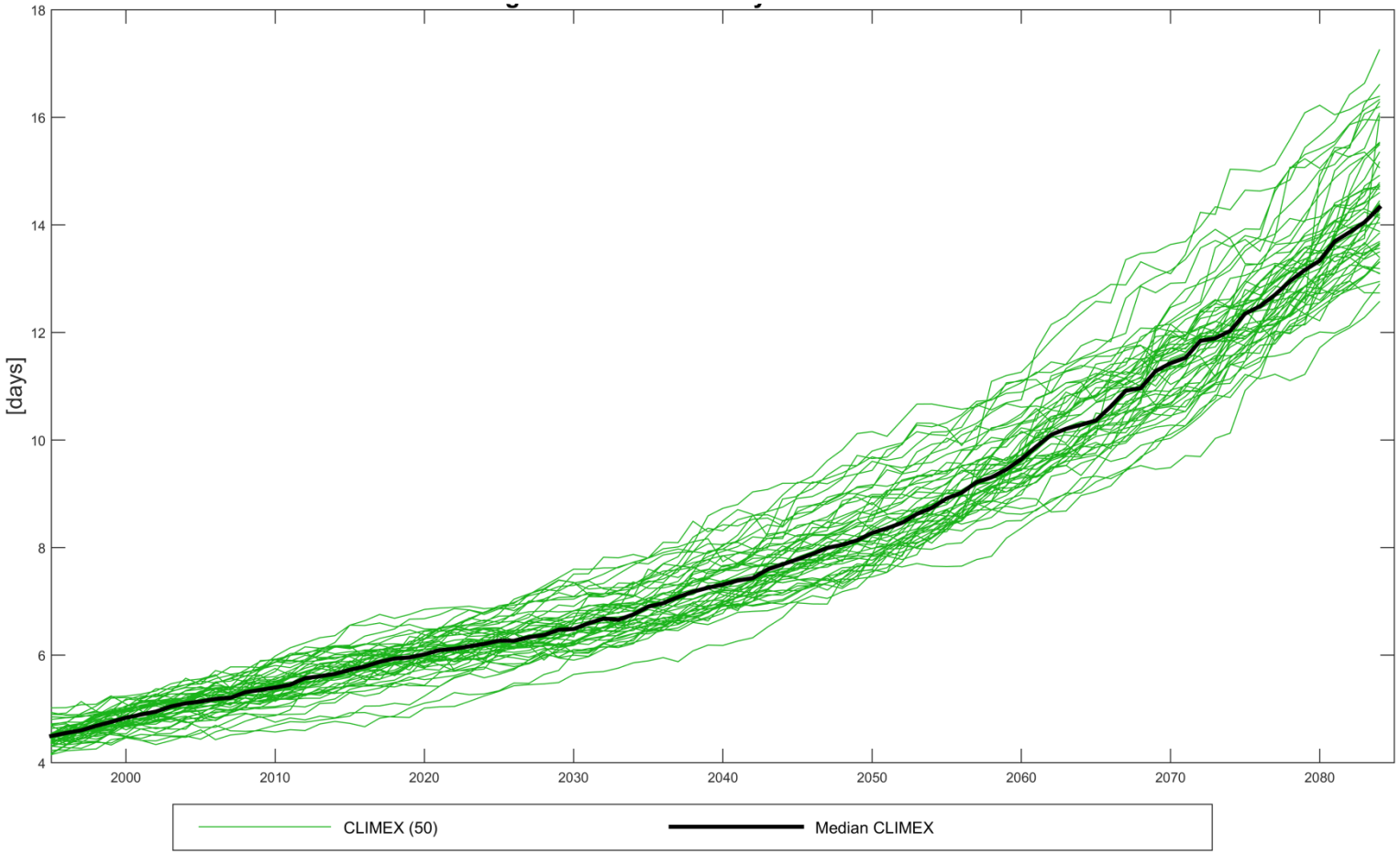
ClimEx – Further observations

Winter Precipitation in Bavaria

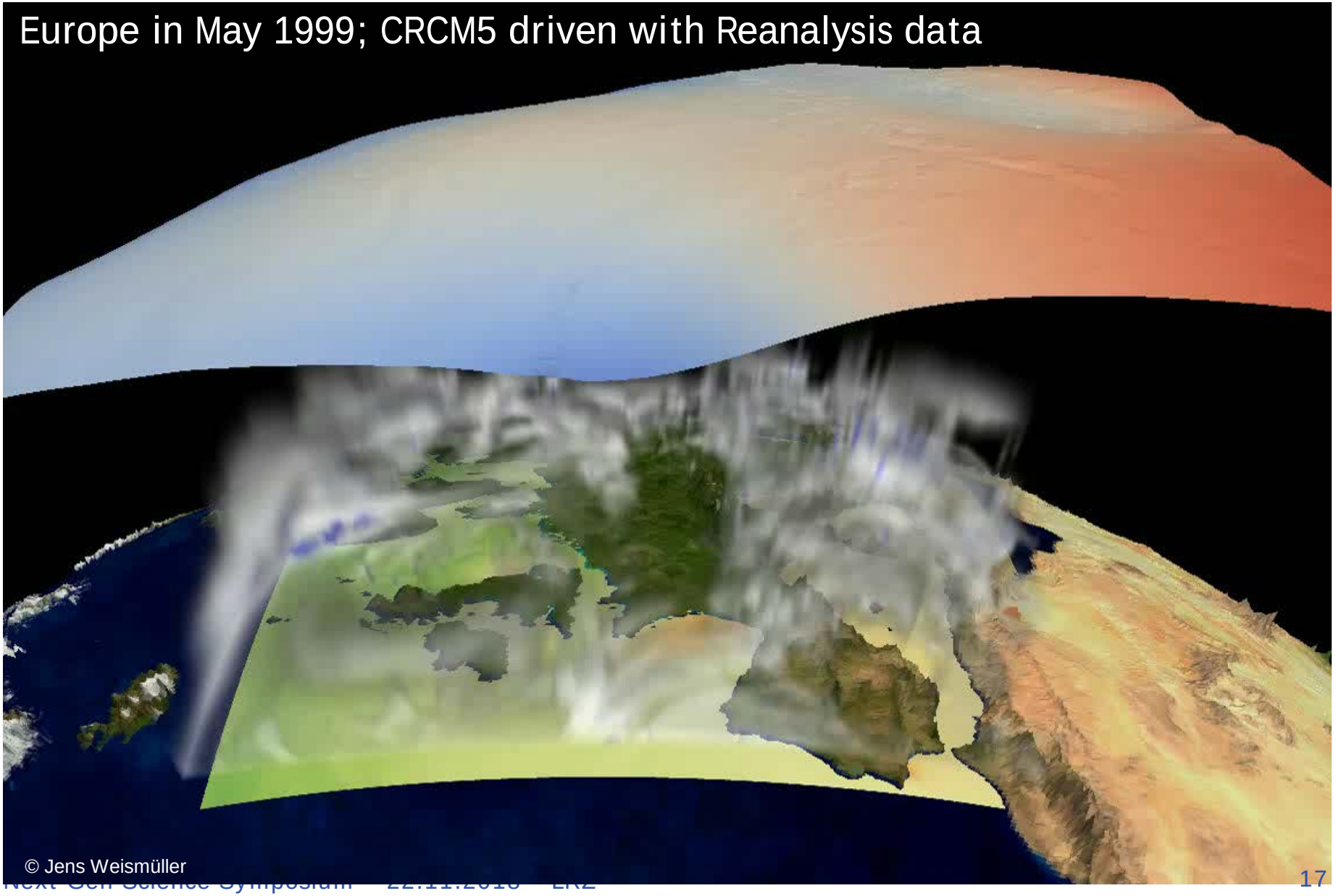
Summer Precipitation in Bavaria

# of 11-day droughts in Bavaria

Length of heat waves in Bavaria

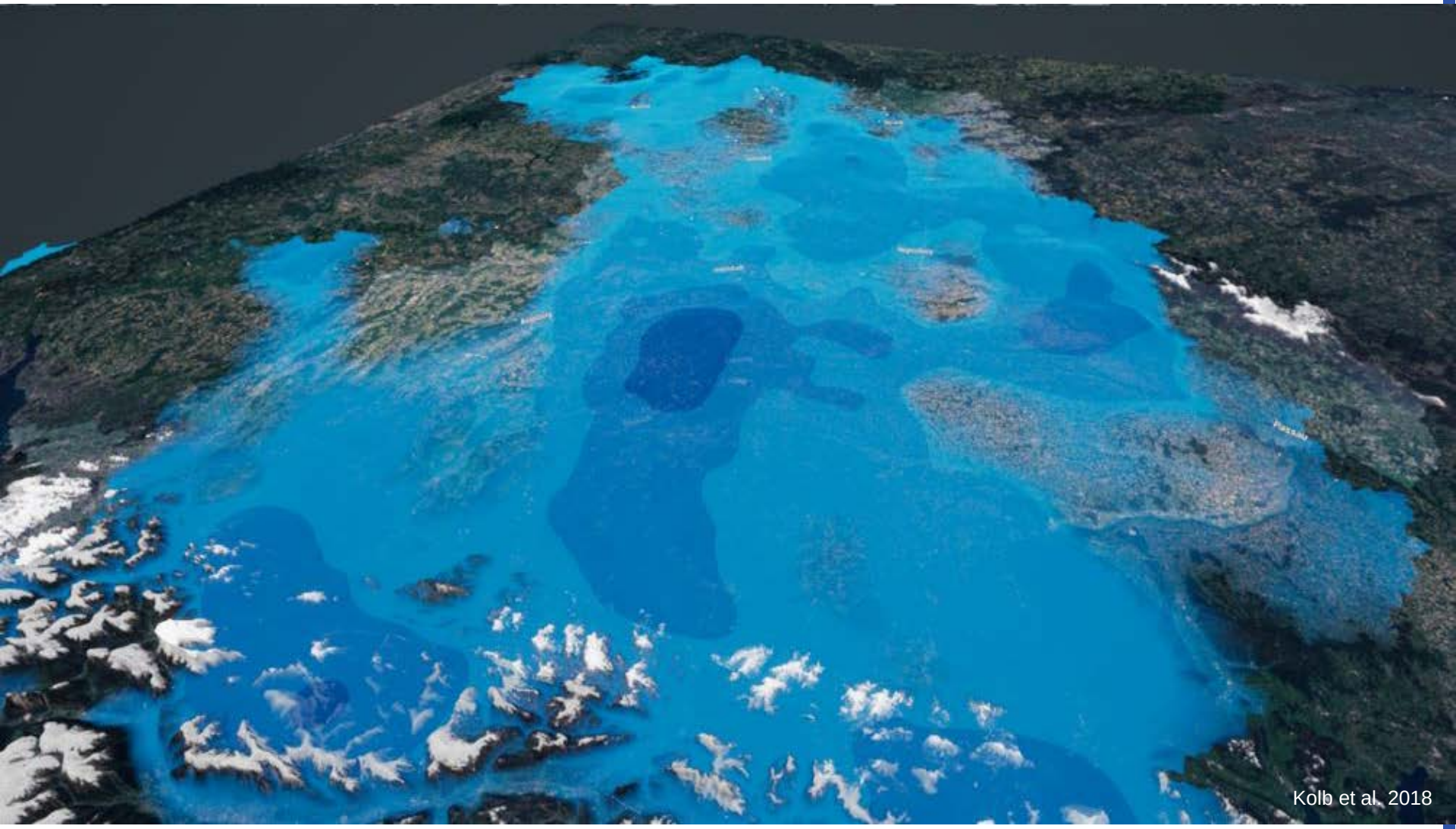


ClimEx - Visualization



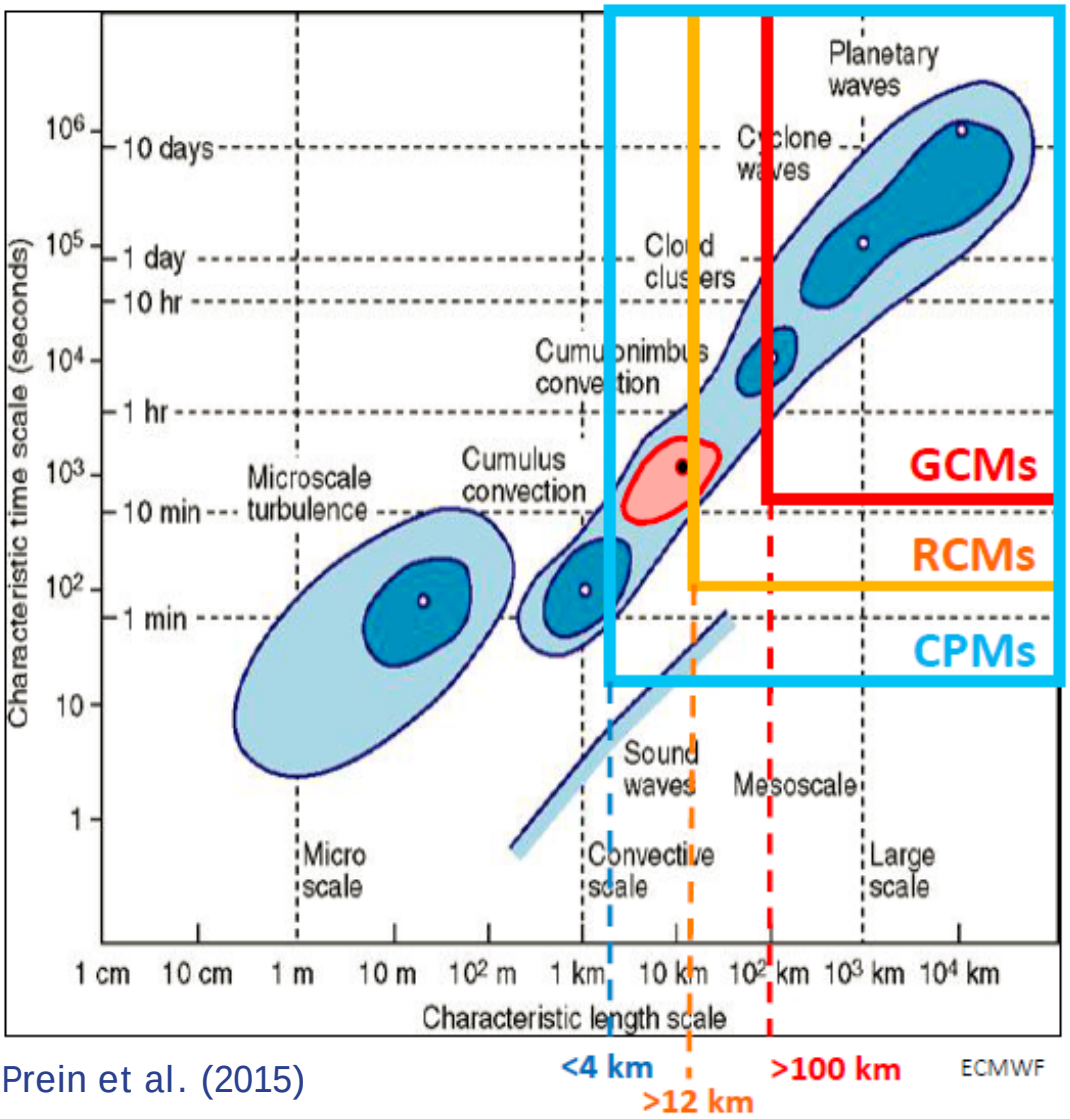
ClimEx - Visualization

DEM + satellite imagery + accumulated ClimEx precipitation



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



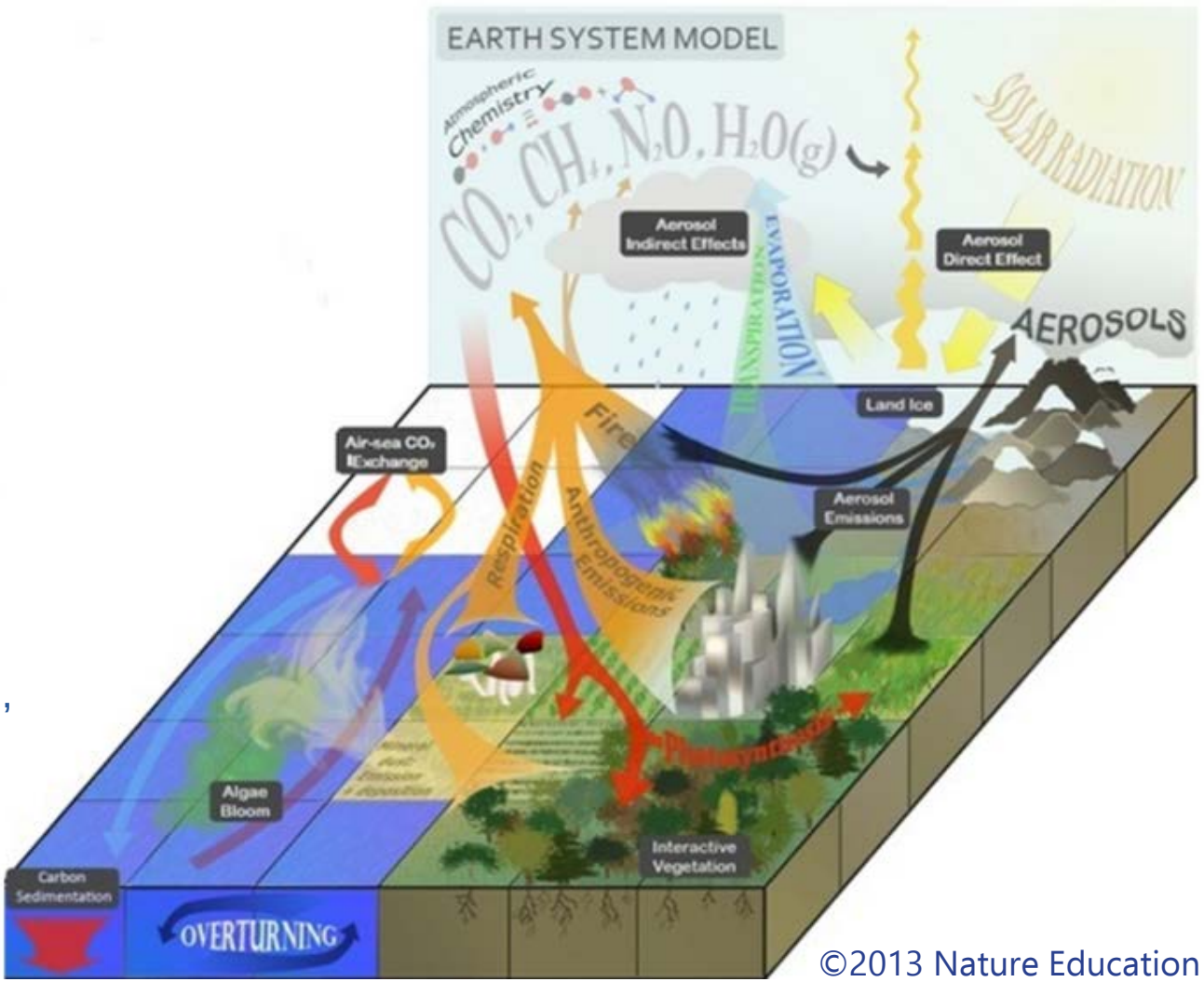
Prein et al. (2015)

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



ClimEx – beyond SuperMUC-NG…

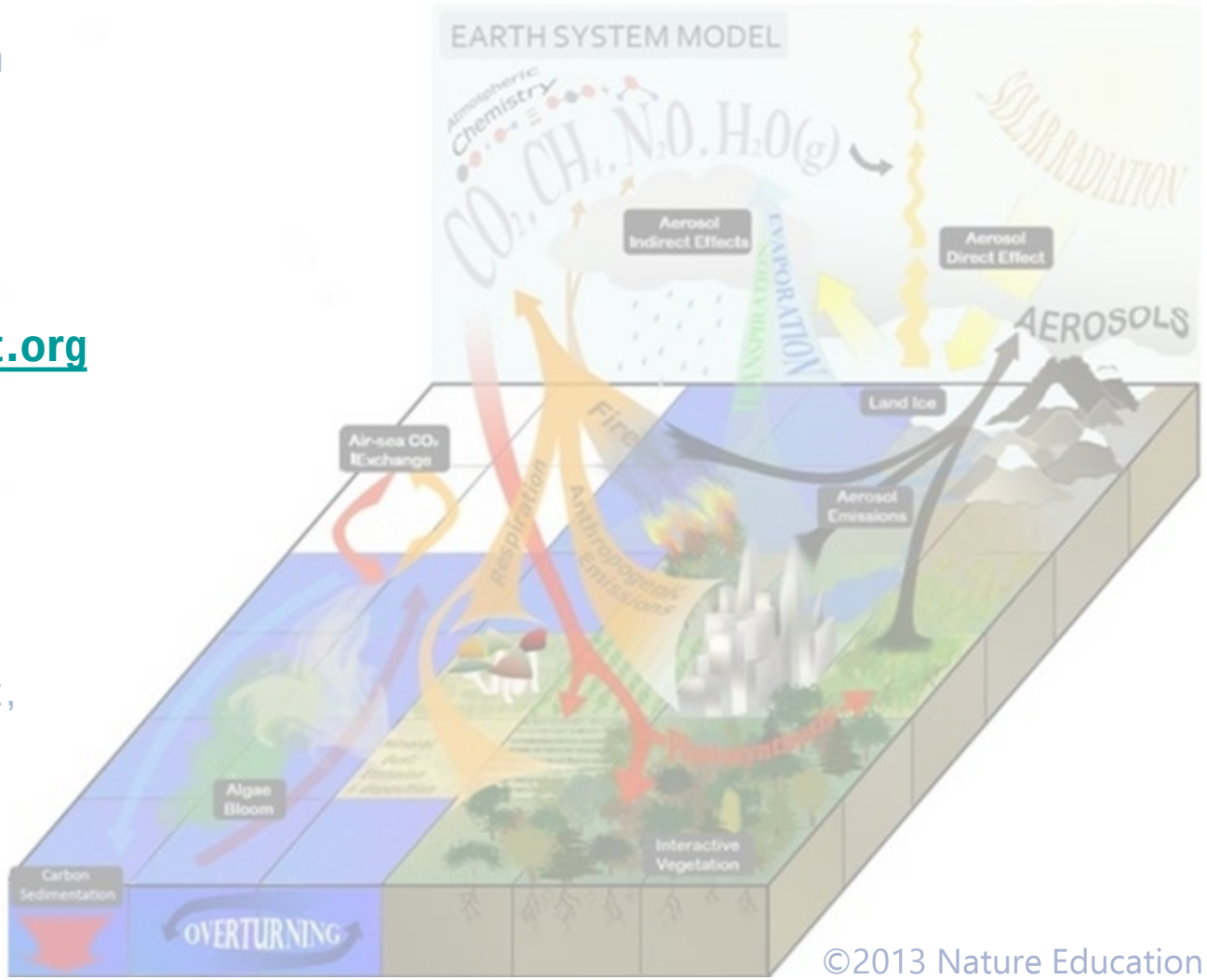
- Fully coupled high-resolution earth system models …

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



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Thank you!

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