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Very high-resolution numerical modeling for climate extremes in Midwest U.S.

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ENVIRONMENTAL CHANGE INITIATIVE

GREAT LAKES CONSORTIUM FOR PETASCALE COMPUTATION

BLUE WATERS SUSTAINED PETASCALE COMPUTING

NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Why Midwest US?

- Region is home to roughly 70 million people and thousands of native plant and animal species.
- World's most productive agricultural landscapes
- One of the world's largest freshwater ecosystems and several large urban centers
- Presence of the Great Lakes and its location in the middle of the North American continent contribute to large seasonal swing in air temperature and precipitation, including lake effect snow

Why very-high resolution?

- Decision-makers and stakeholders require high-resolution climatological data for planning and enhance preparedness against the social and ecological effects of extreme events.
- Does improving model resolution lead to higher fidelity in climate simulations?

Why Blue Water?

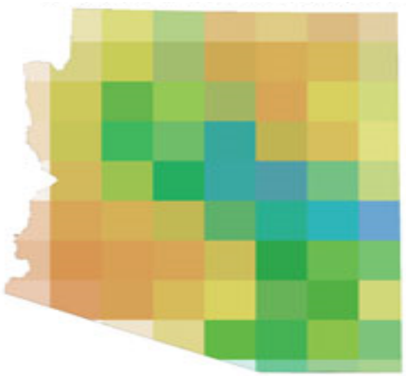
- Numerical simulations are long-term (1981-2010), decadal, very-high resolution; we go up to 1 km resolution for sensitivity analysis
- For resolving convective storms below 10 km resolution
- Study long-term impacts of different landuse on Midwest climate
- Studying climatic extremes in Midwest region
- Study the influence of soil moisture initialization using High Resolution Land Data Assimilation System (HRLDAS)
- Assess the impact of subgrid scale land cover variability
- Study spatial pattern and seasonality of extreme precipitation and temperature by looking at climate data at multiple resolutions
- WRF code is highly parallelized, computationally intensive and scales well on the Blue Waters architecture
- Requires huge data storage and efficient data handling

Climate downscaling

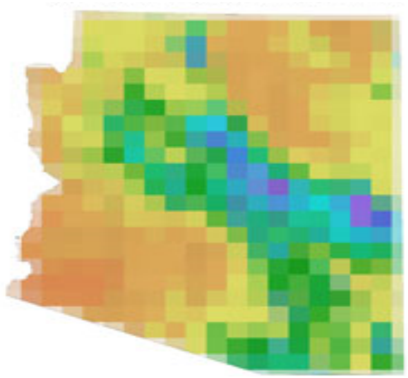
A technique to use fine spatial scale regional (mesoscale) model, e.g. WRF to produce detailed regional and atmospheric data with boundary condition constrained by large-scale regional/global climate model output.

Example:

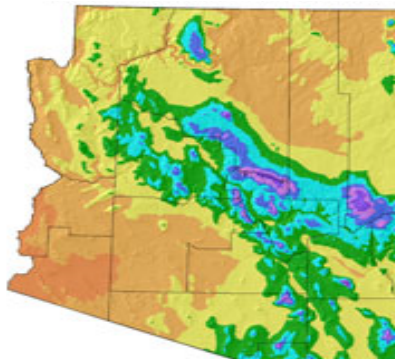
110 x 110 km



30 x 30 km

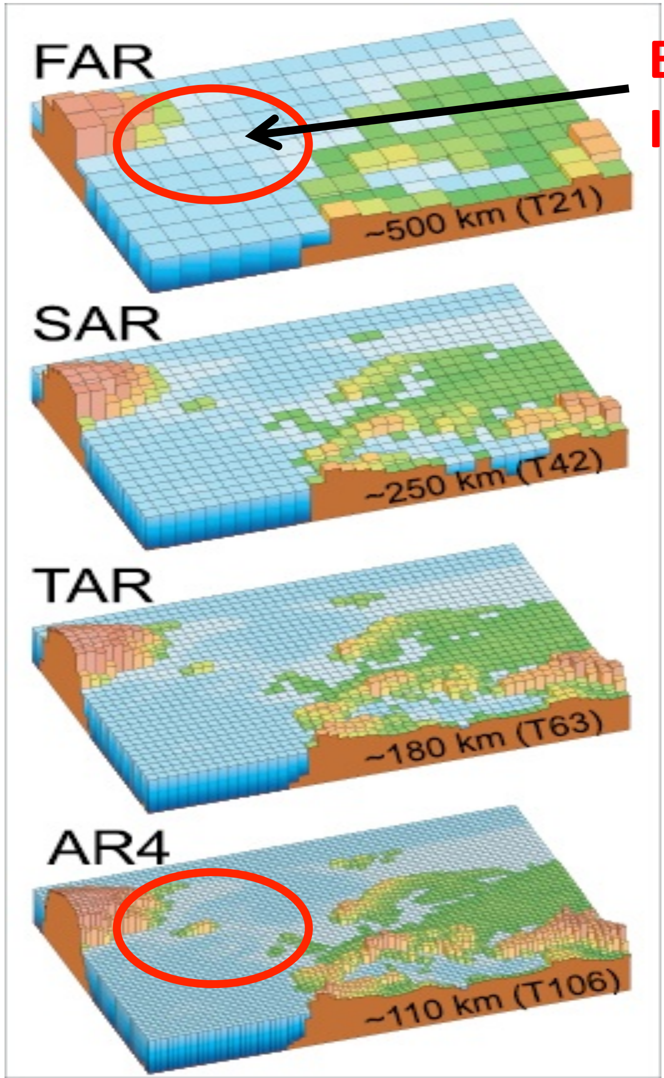


Expected precipitation pattern



Source: PRISM

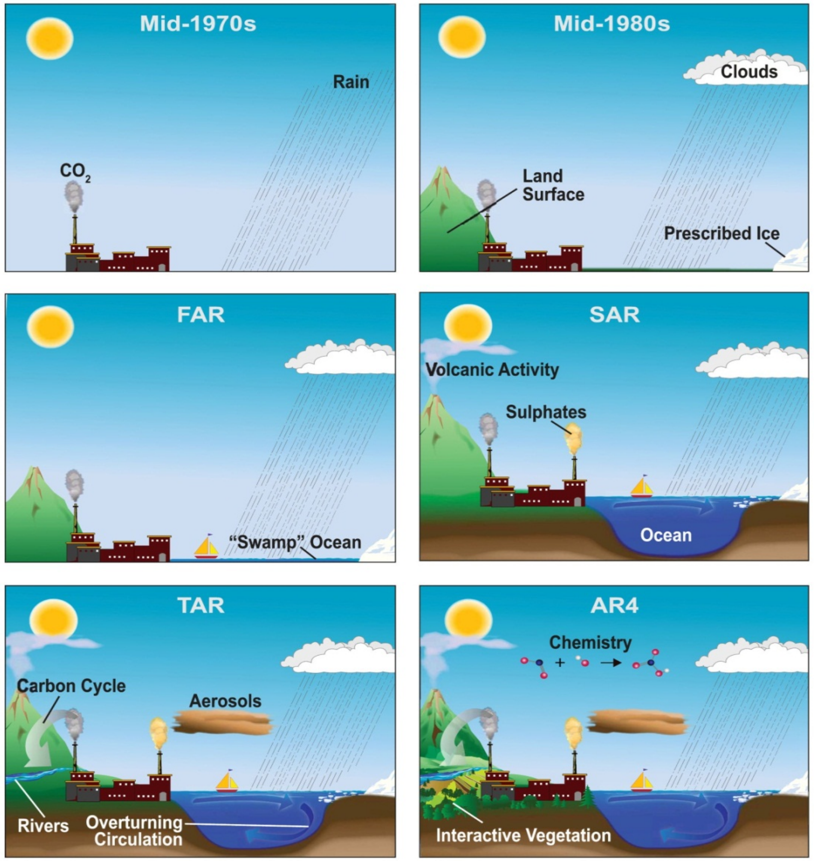
General Circulation Models (GCMs)



England and Iceland ???

IPCC 2007

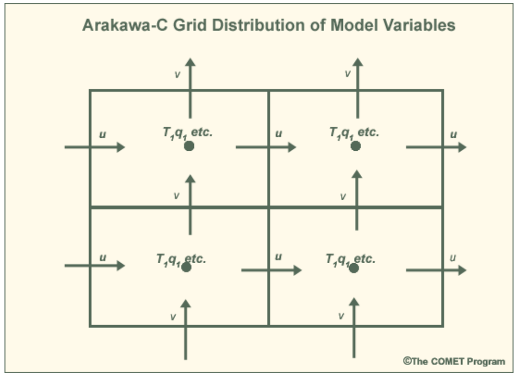
Model complexity in each phase

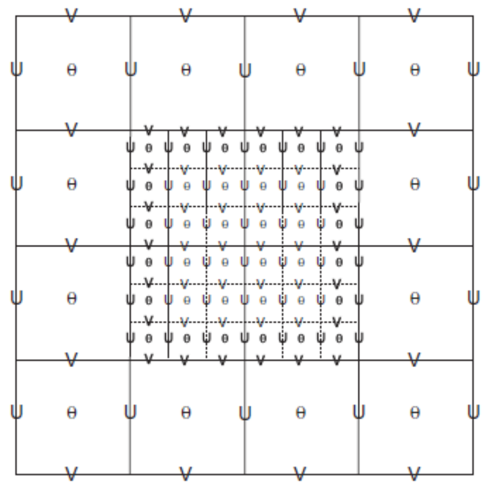


- Long term projection
- Low resolution model produces bias
- GCM: *O*(500 km) to *O*(100 km)

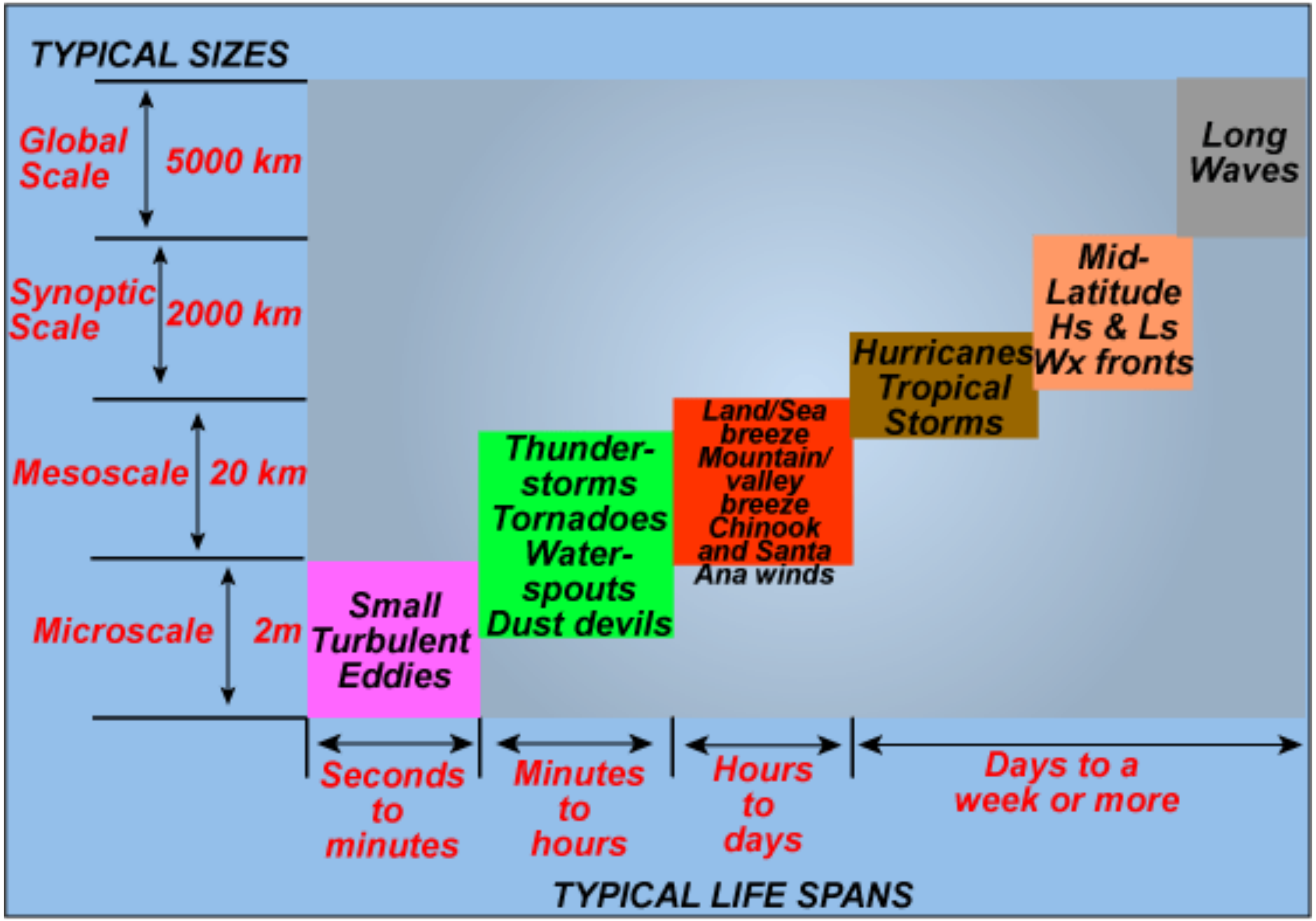
Weather Research & Forecasting (WRF) Model

- **Equations**: Fully compressible, non-hydrostatic
- **Vertical coordinate**: Terrain-following pressure vertical coordinate
- **Horizontal grid**: Arakawa C-grid
- **Time integration**: Time split integration using 3rd order RK scheme
- **Spatial discretization**: 2^{nd}-6^{th} order advection options
- **Initial conditions**: 3D for real data
- **Earth rotation**: Full Coriolis term included
- **Prognostic variables**: Velocities u, v, w; potential temperature, geopotential (optional: TKE, water vapor mixing ratio, rain/snow mixing ratios) etc.
- **Mapping to sphere**: Four projections available
    - Polar; Lamber; Mercator; Lat-lon
- **Nesting**: Multiple level and integer ratio

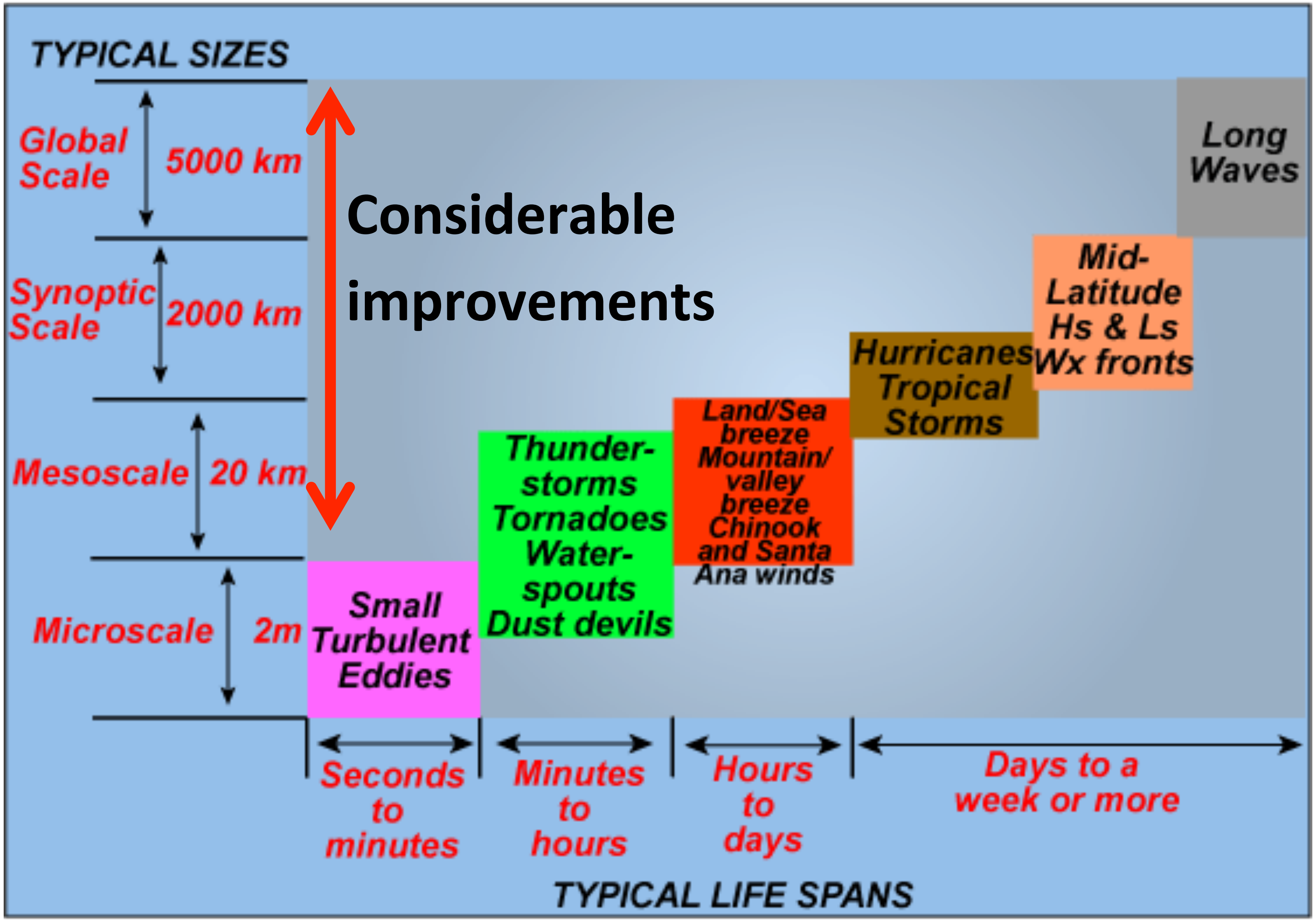




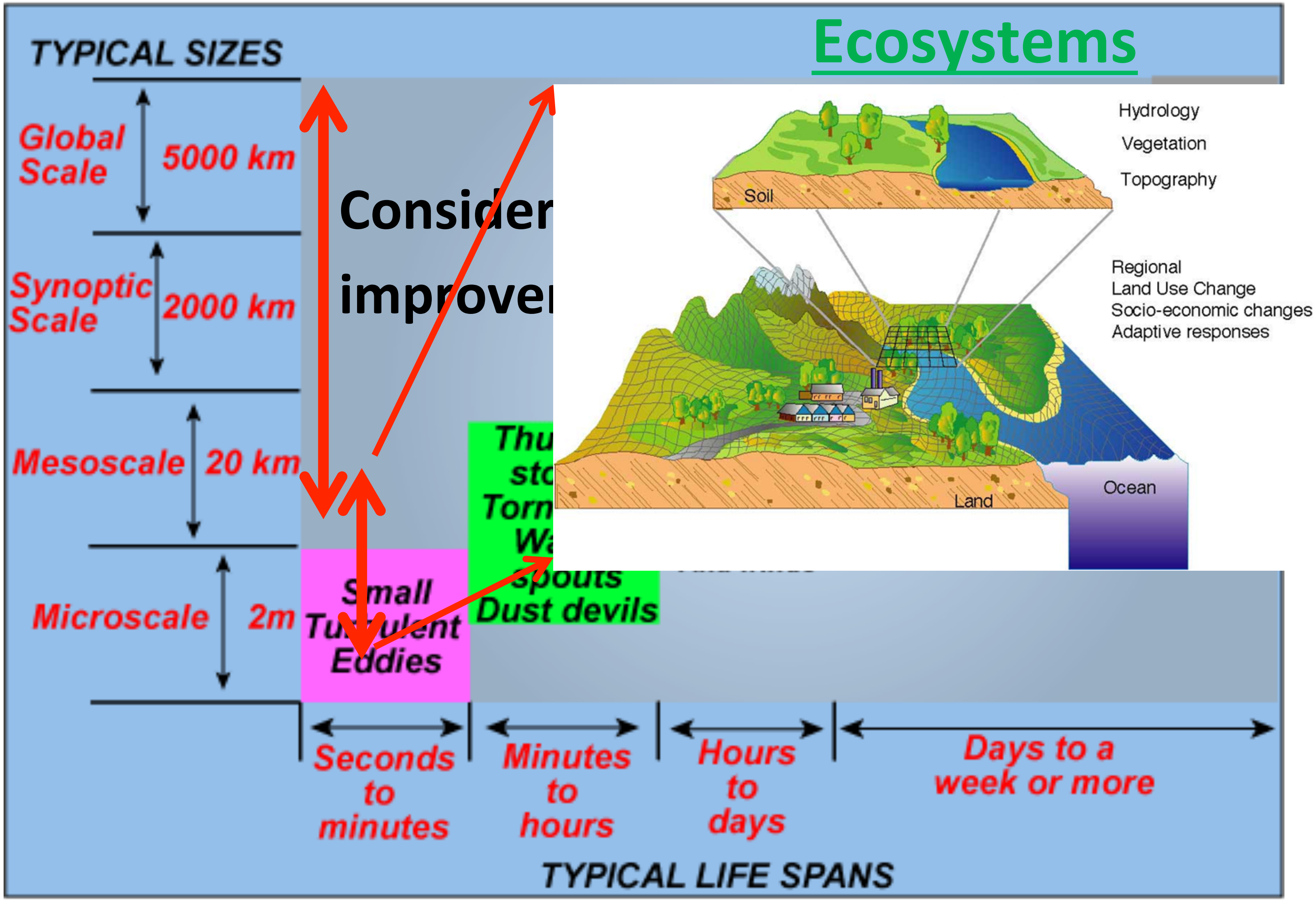
Scales in Atmosphere



Scales in Atmosphere



Scales in Atmosphere

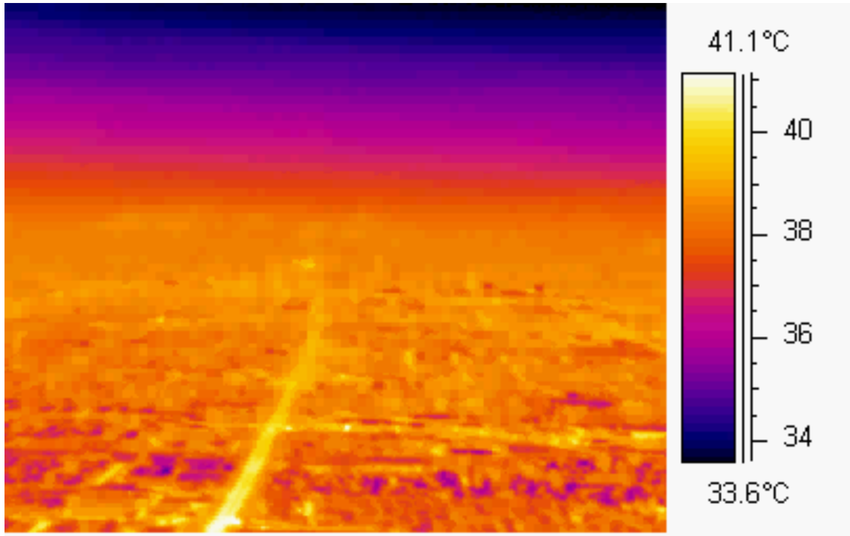


Example: urban heat island

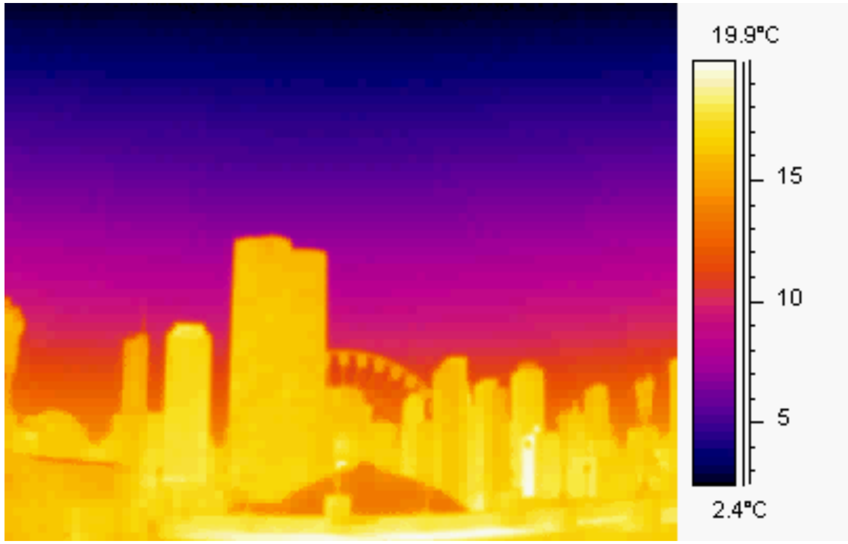
Heat island – Infra Red Imaging

Phoenix

Chicago



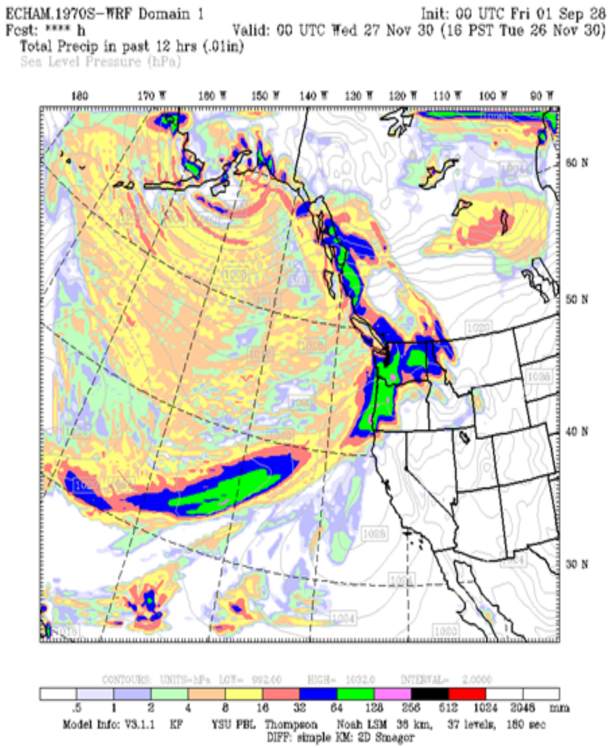
April 2008



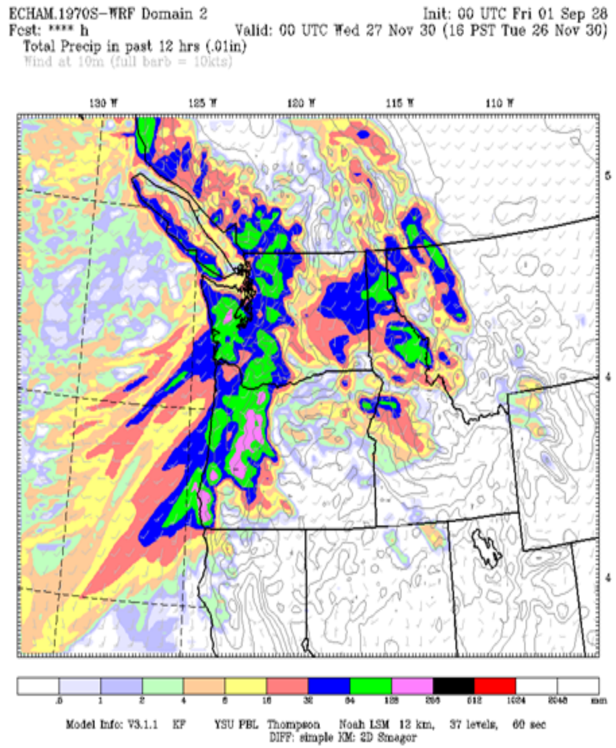
September 2011

Example: Extreme precipitation

36-km simulations

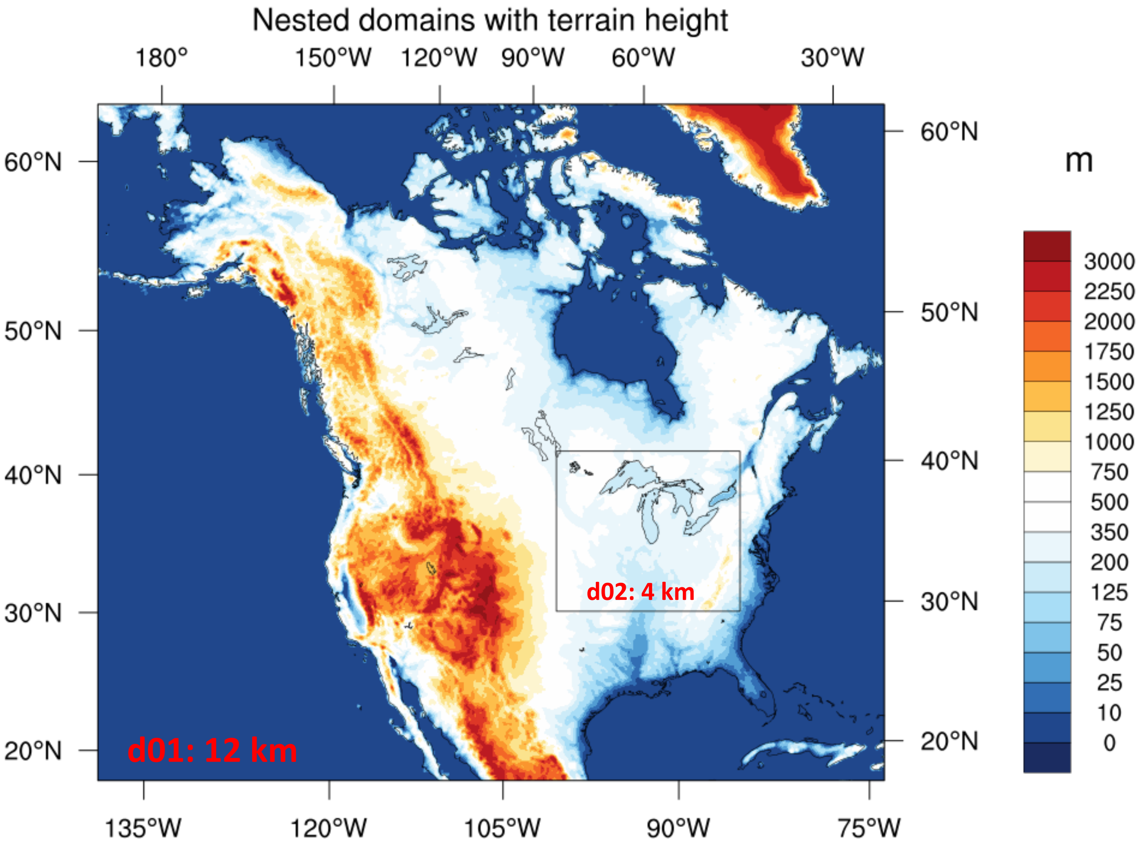


12-km simulations

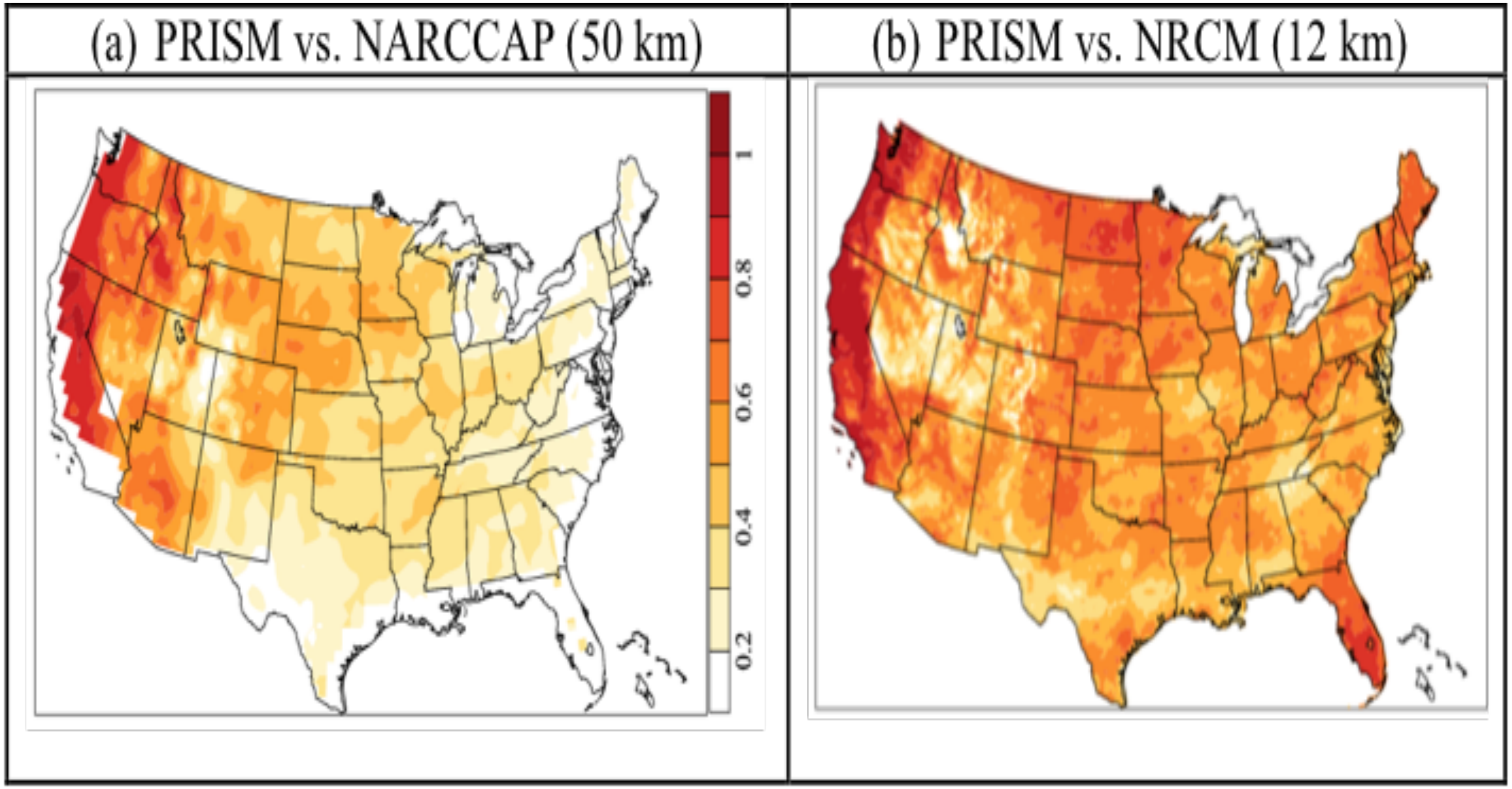


12-hour precipitation totals for a projected atmospheric river event on Nov 27, 2030 over the Cascades Pacific North West (PNW). (Hamlet et al 2014)

Domain setup



- Advanced Research WRF dynamic core, version 3.3.1
- Initial and boundary conditions: NCEP-DOE AMIP II reanalysis data (NCEP-R2)
- SST: 6-hourly and 0.5° × 0.5° Climate Forecast System Reanalysis data (CFSR)
- Nesting in step of 3
- 1991-2000: yearly initialization

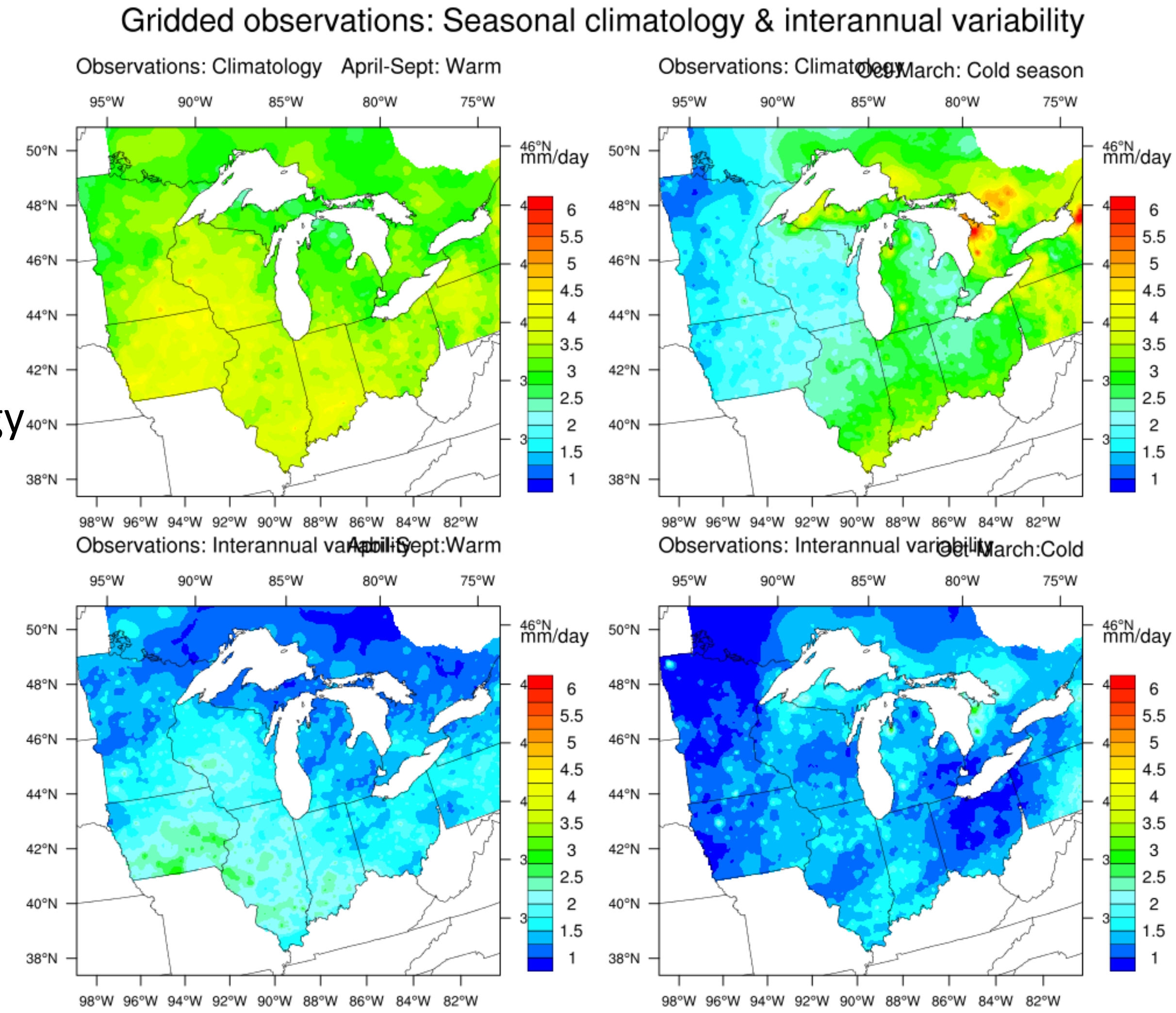


Wang et al 2014

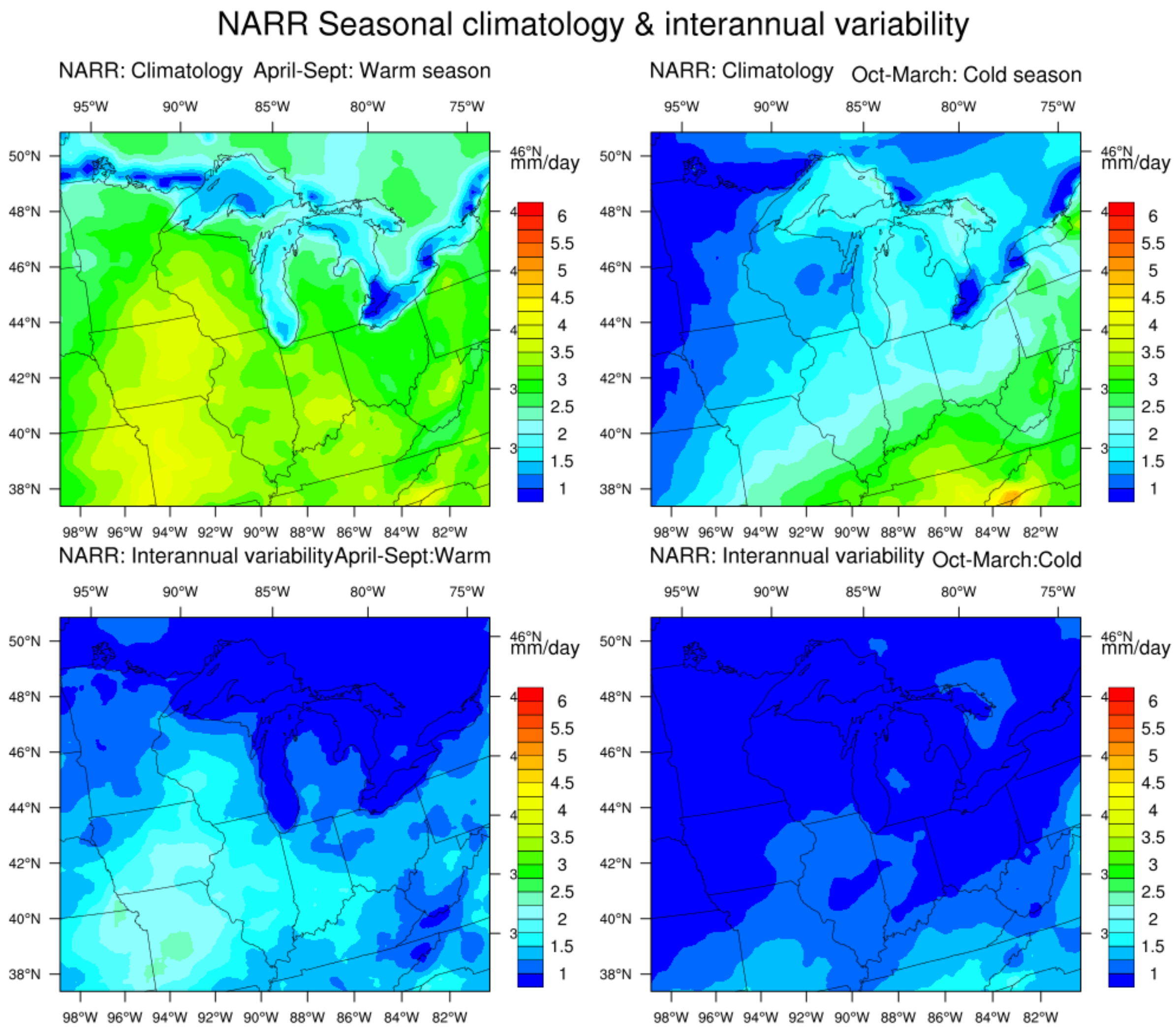
Gridded observations

- **With bias corrected precipitation for using surface winds (Hamlet et al)**

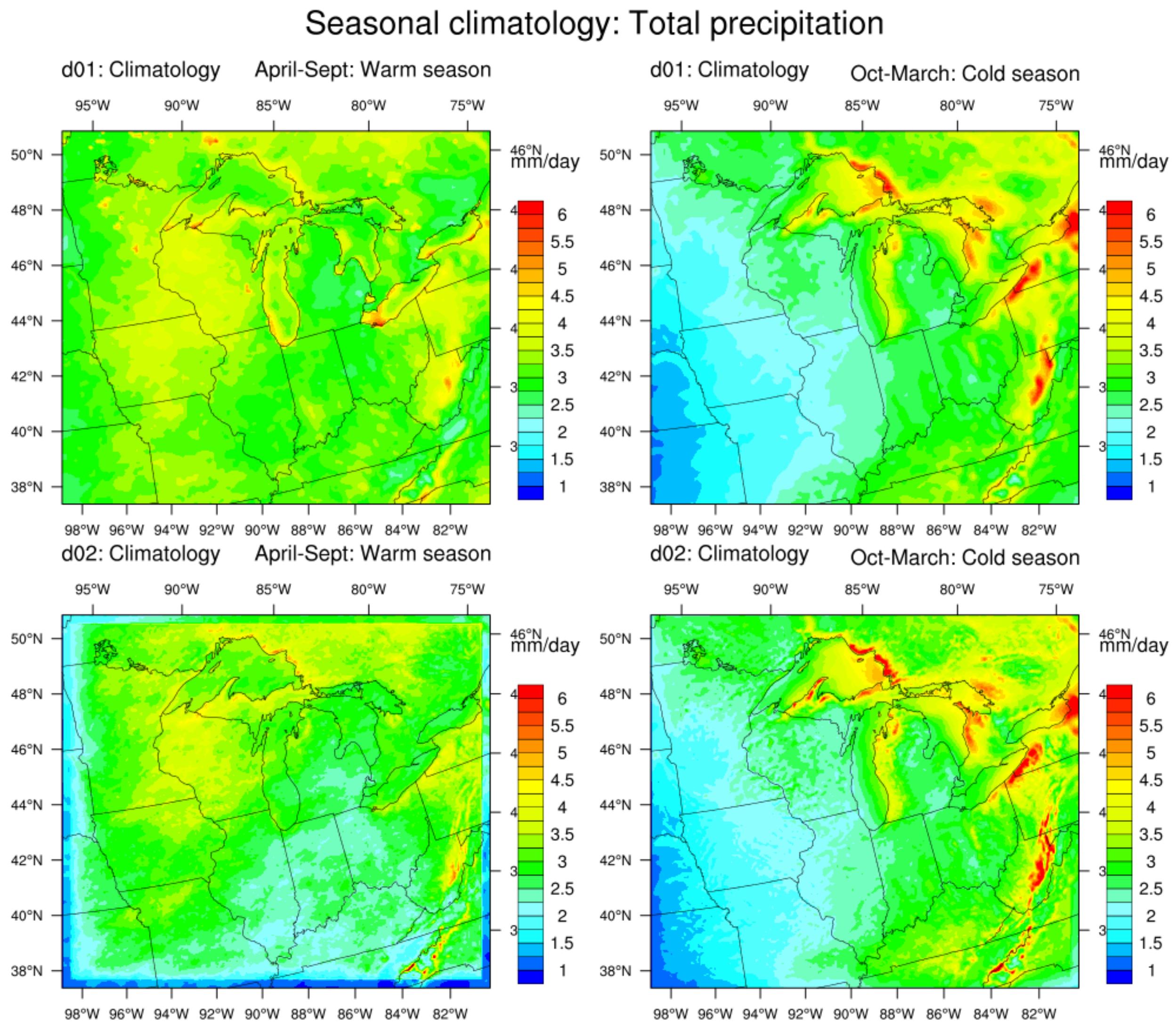
GHCN (Global Historical Climatology Network)-Daily



NARR datasets



WRF simulations



12 km

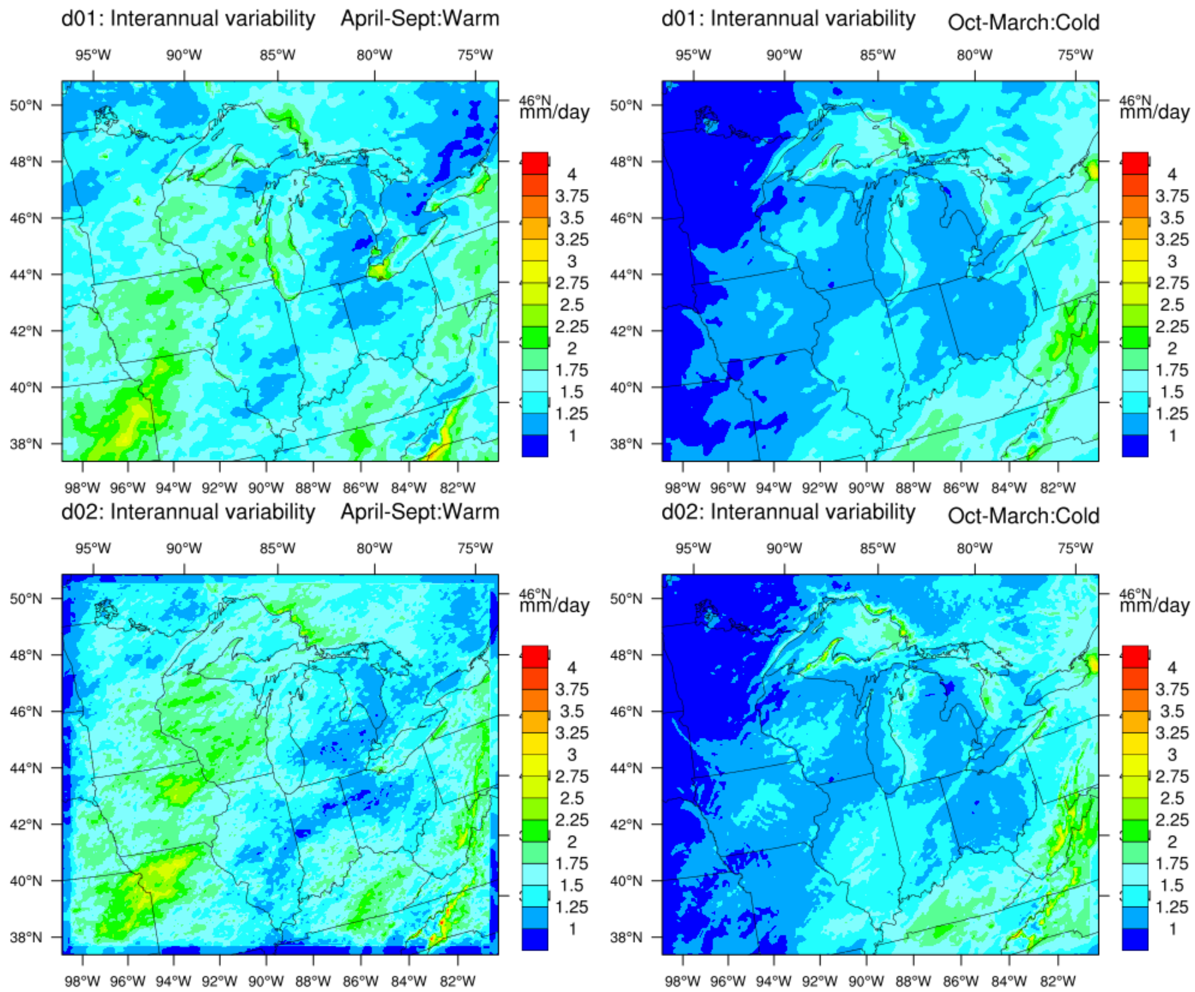
4 km

WRF simulations

Seasonal interannual variability: Total precipitation

12 km

4 km



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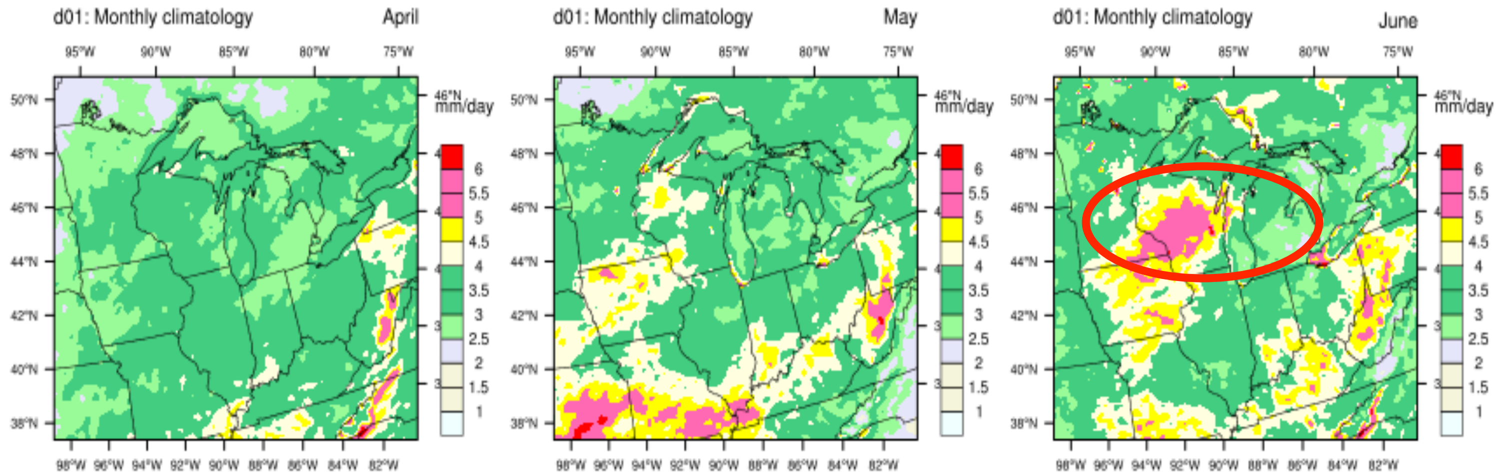
WRF simulations: Convective precipitation

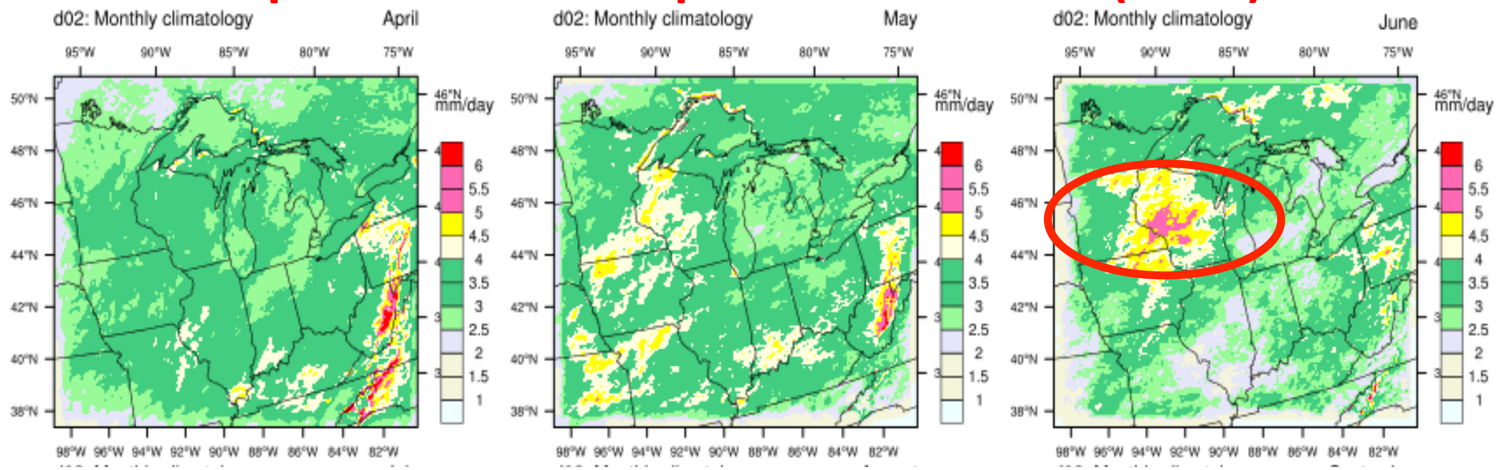
d01: With explicit convective parameterization (12 km)

12 km

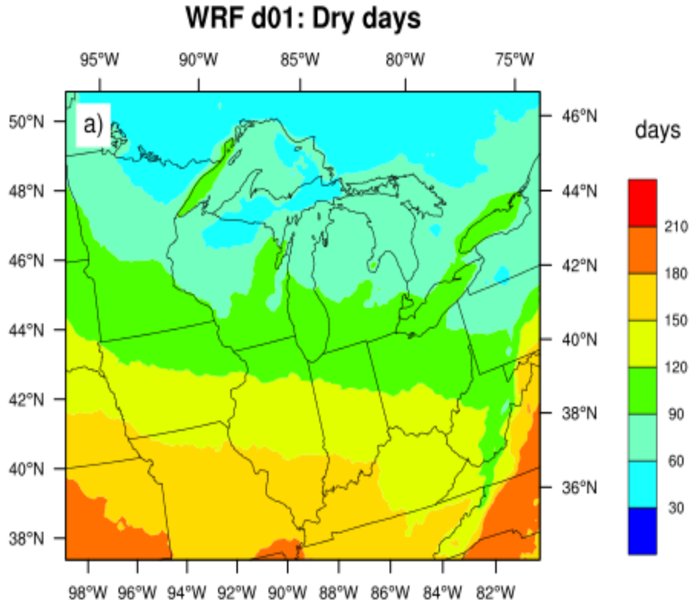


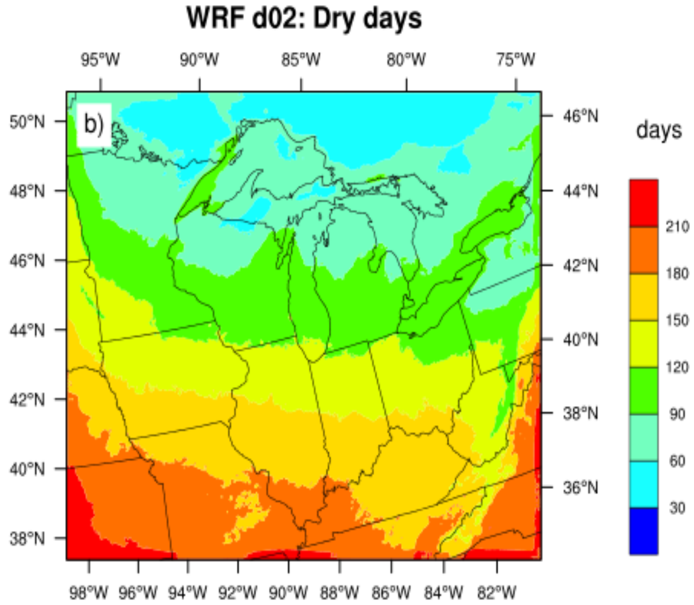
d02: Without explicit convective parameterization (4 km)

4 km



WRF simulations: Dry days



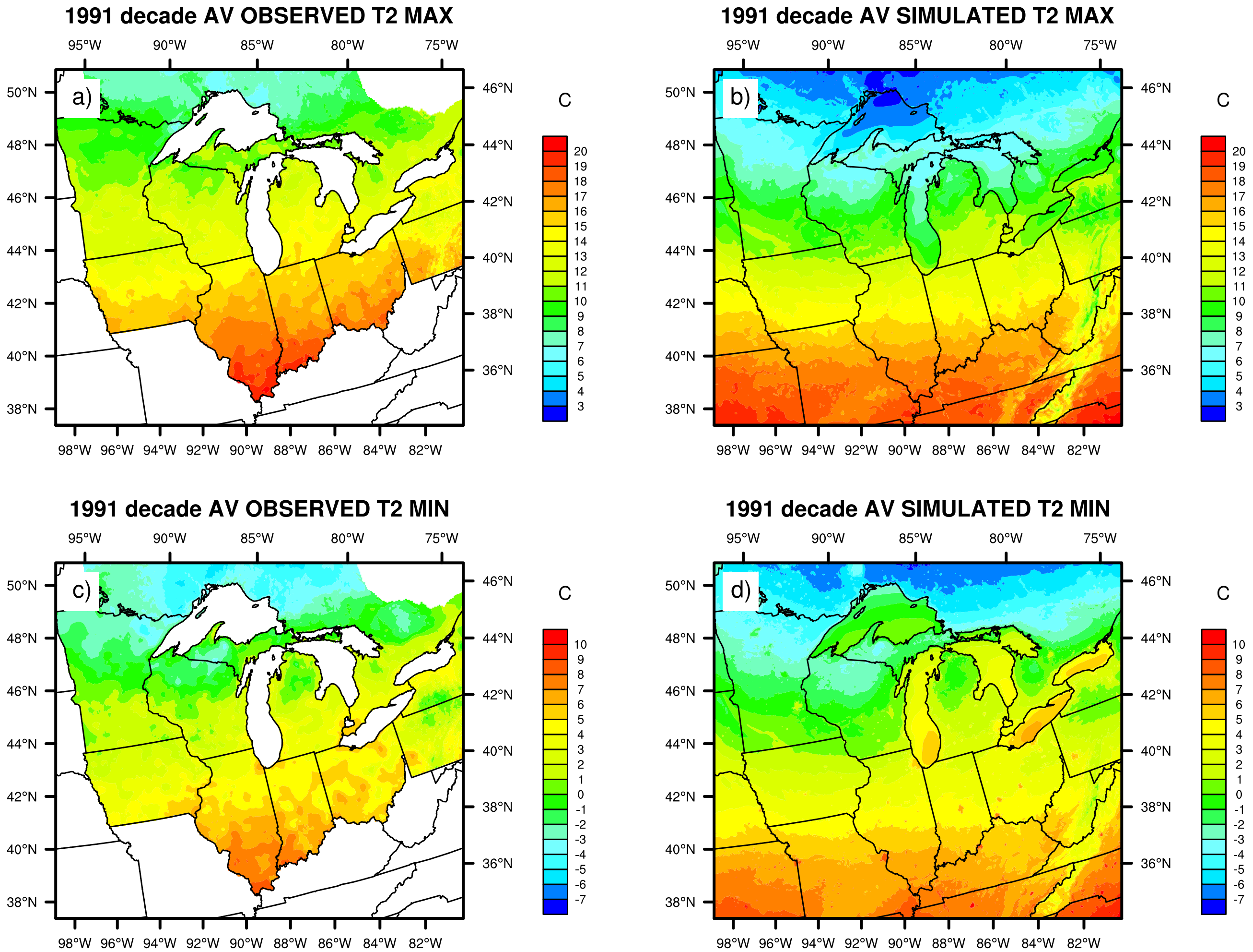


Artificial convective precipitation leads to less dry days in 12 km.

WRF simulations: Surface temperature

12 km

4 km



Domain setup

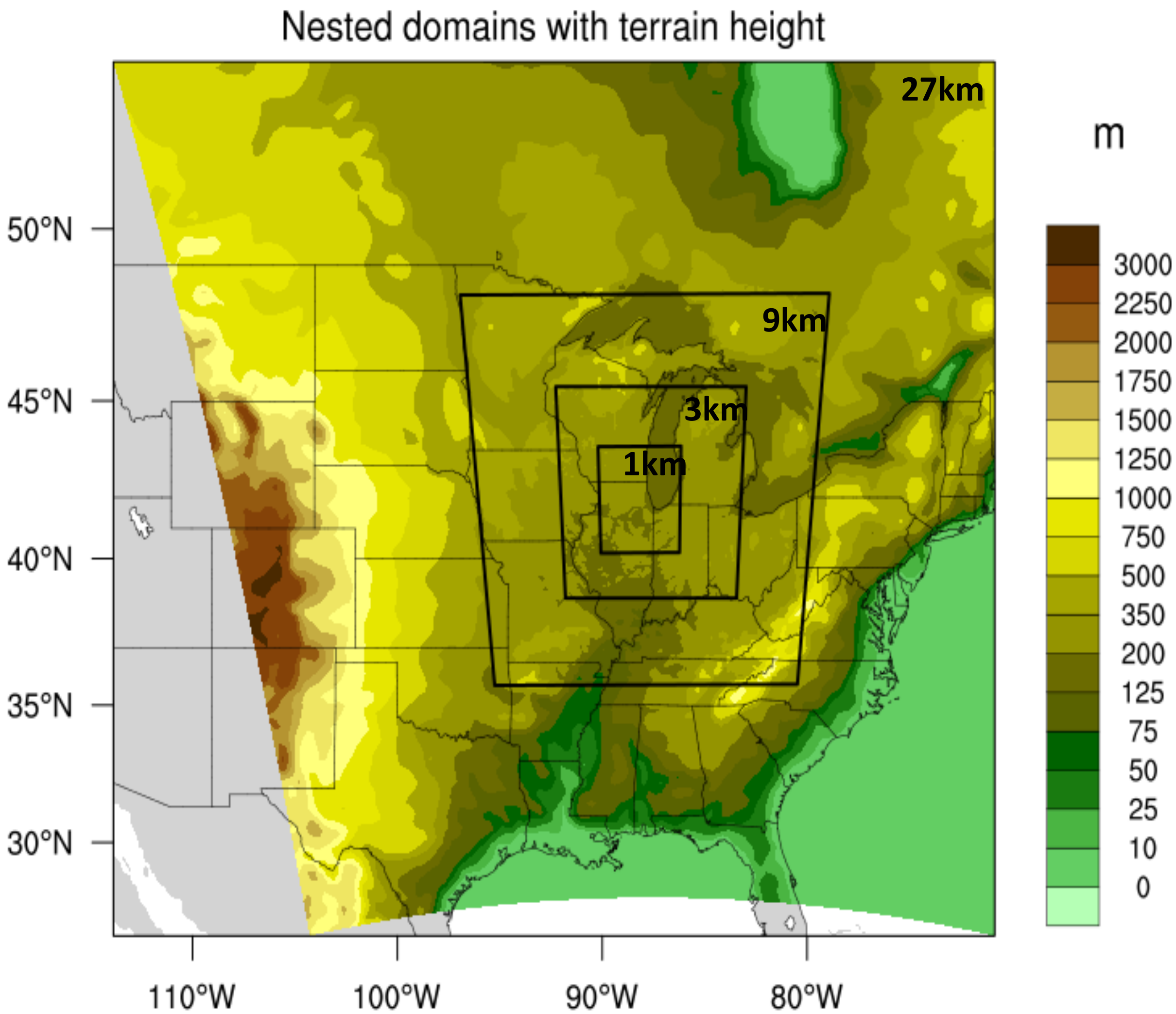
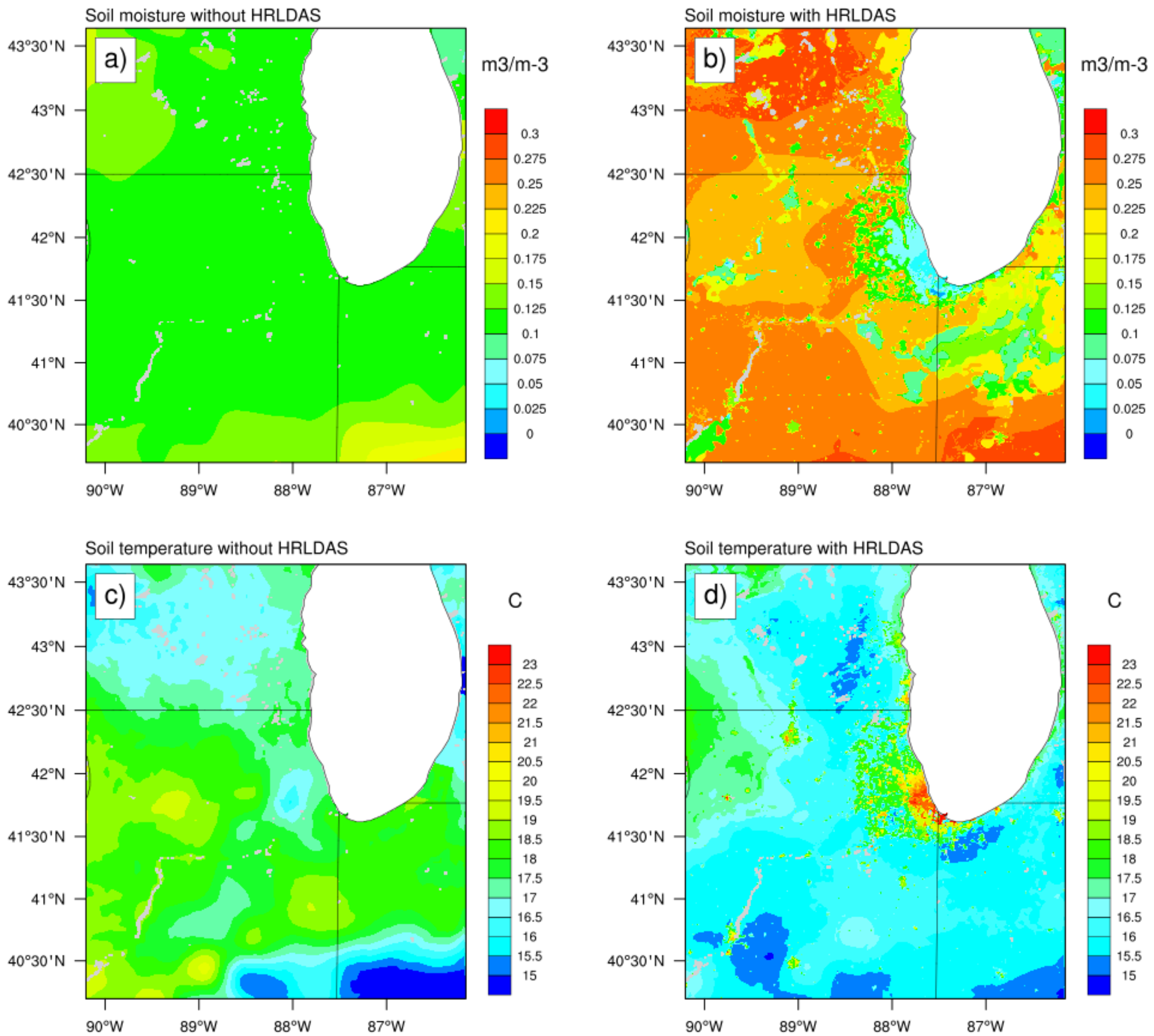


Fig. WRF nested domains with terrain height.

- 3-hourly NARR 32x32 km forcing data.
- Simulation period (3 days): 16-18 August 2013
- Analyze hourly output
- Spin up: 12 hrs
- Nesting: in steps of 3

HRLDAS for RCM run

- **1 km resolution: Ultra-high resolution**



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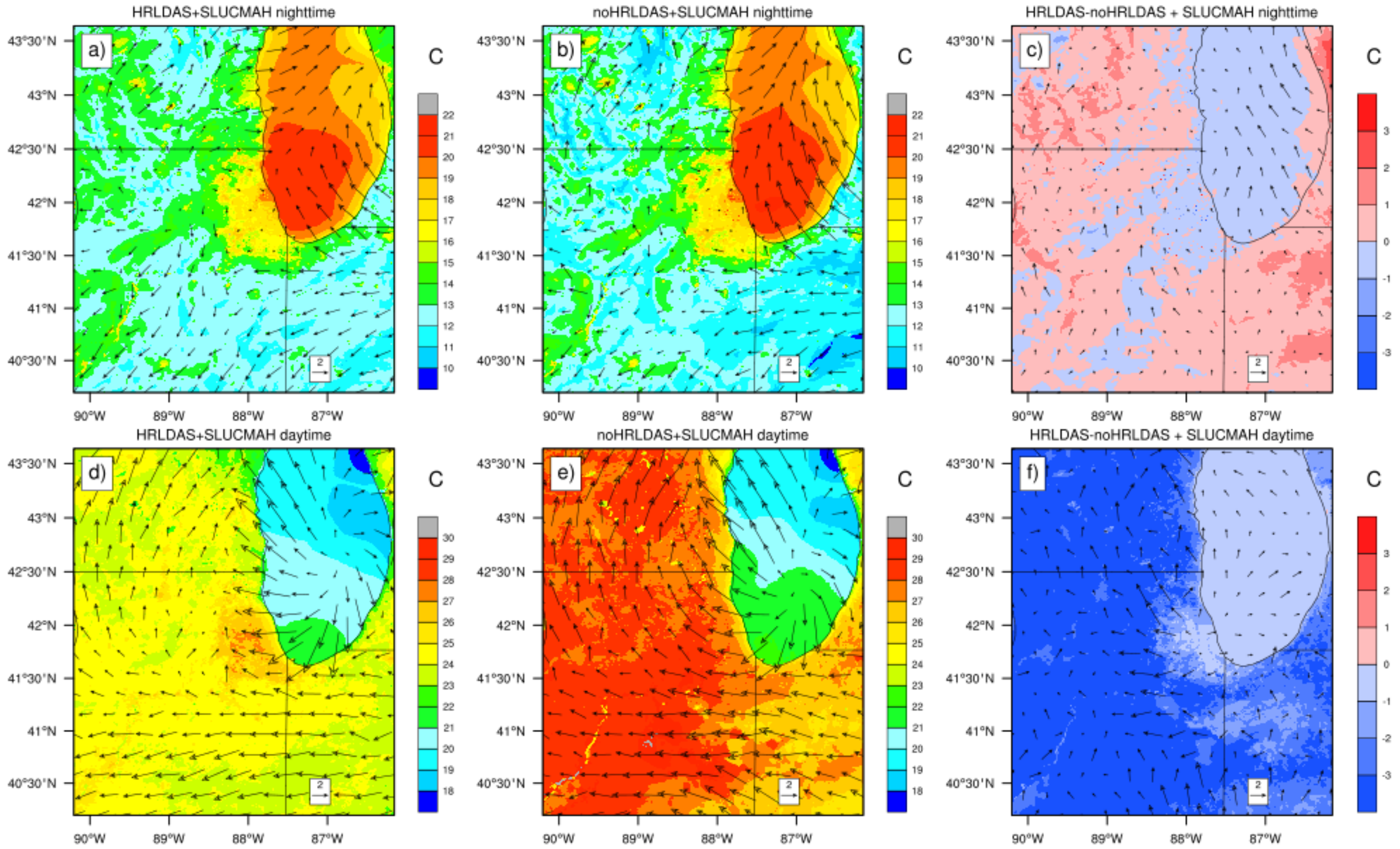
Sensitivity of HRLDAS



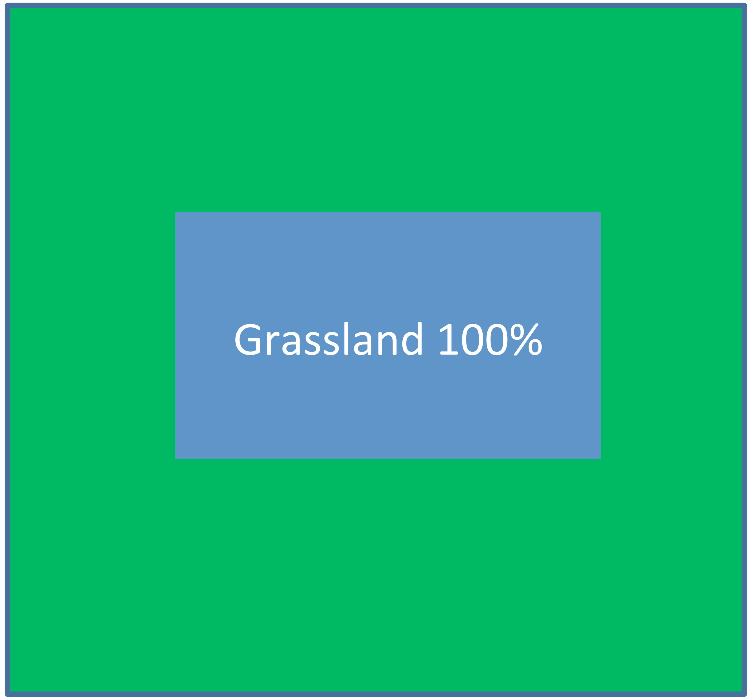
Subgrid scale land cover variability

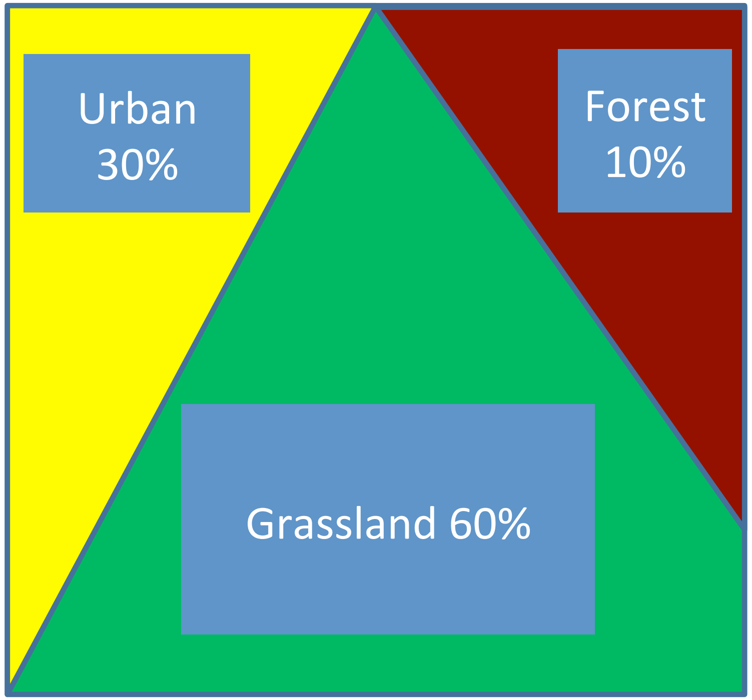
Real World: multiple "tiles" within a "grid cell"

Modelling World: dominant vs mosaic

WRF-Noah

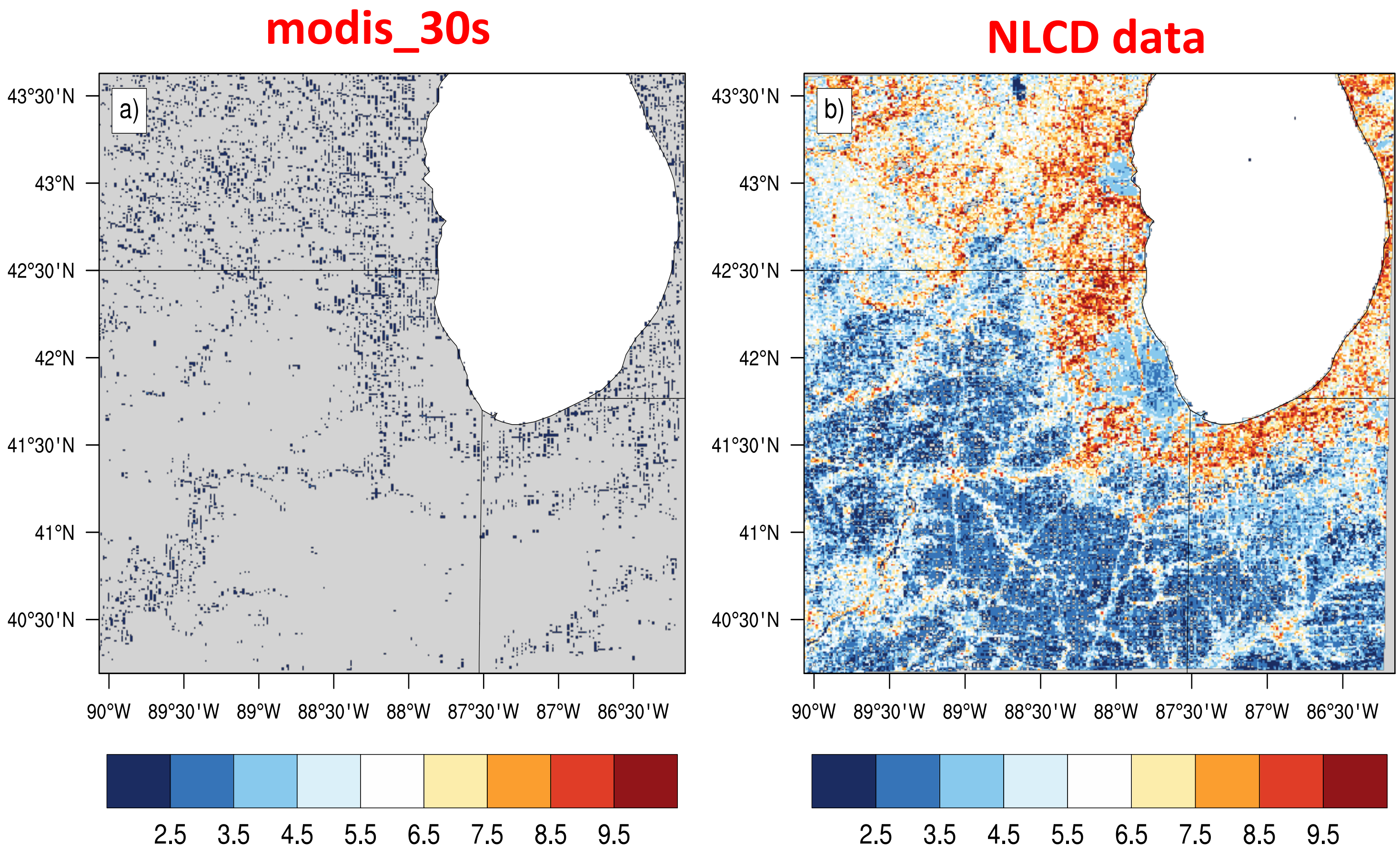
WRF-Noah-mosaic (N=3)

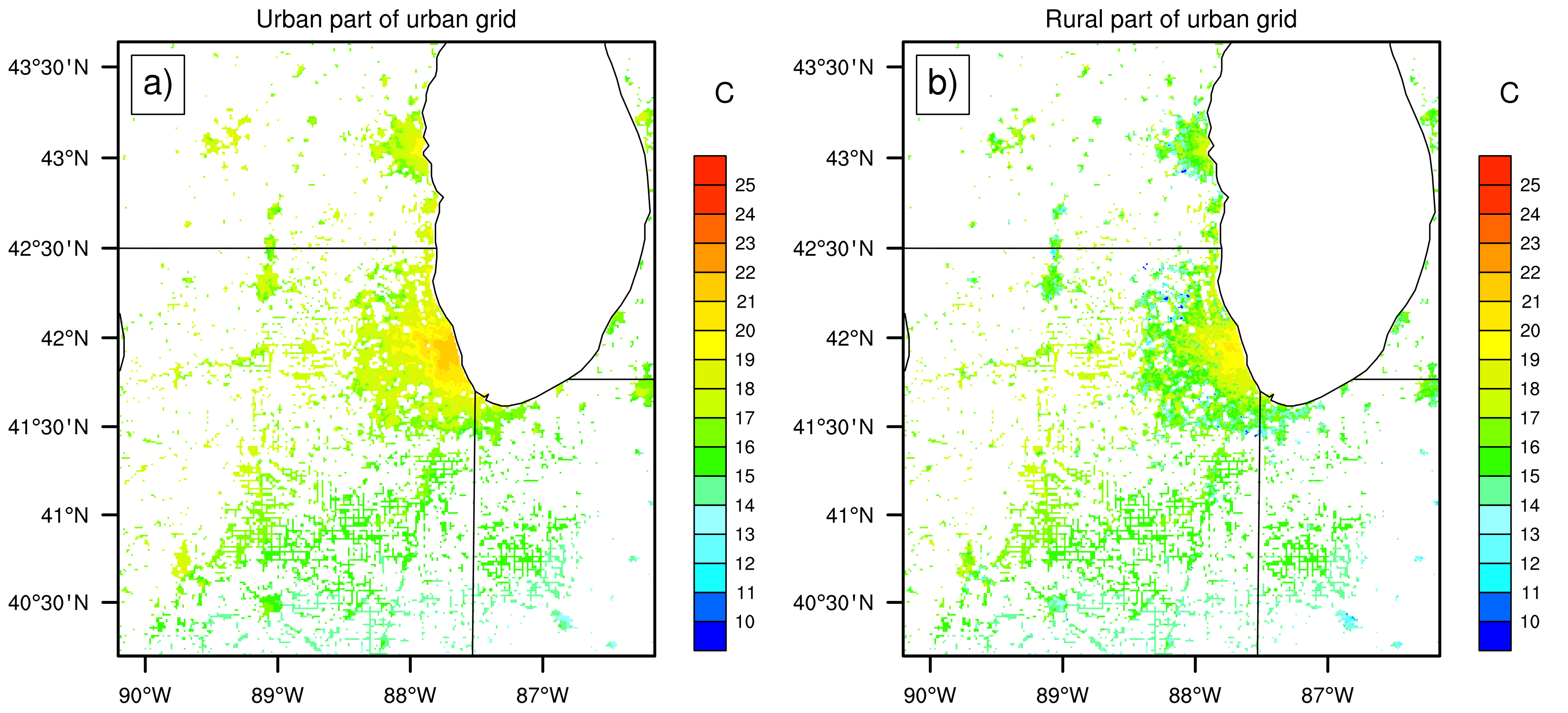




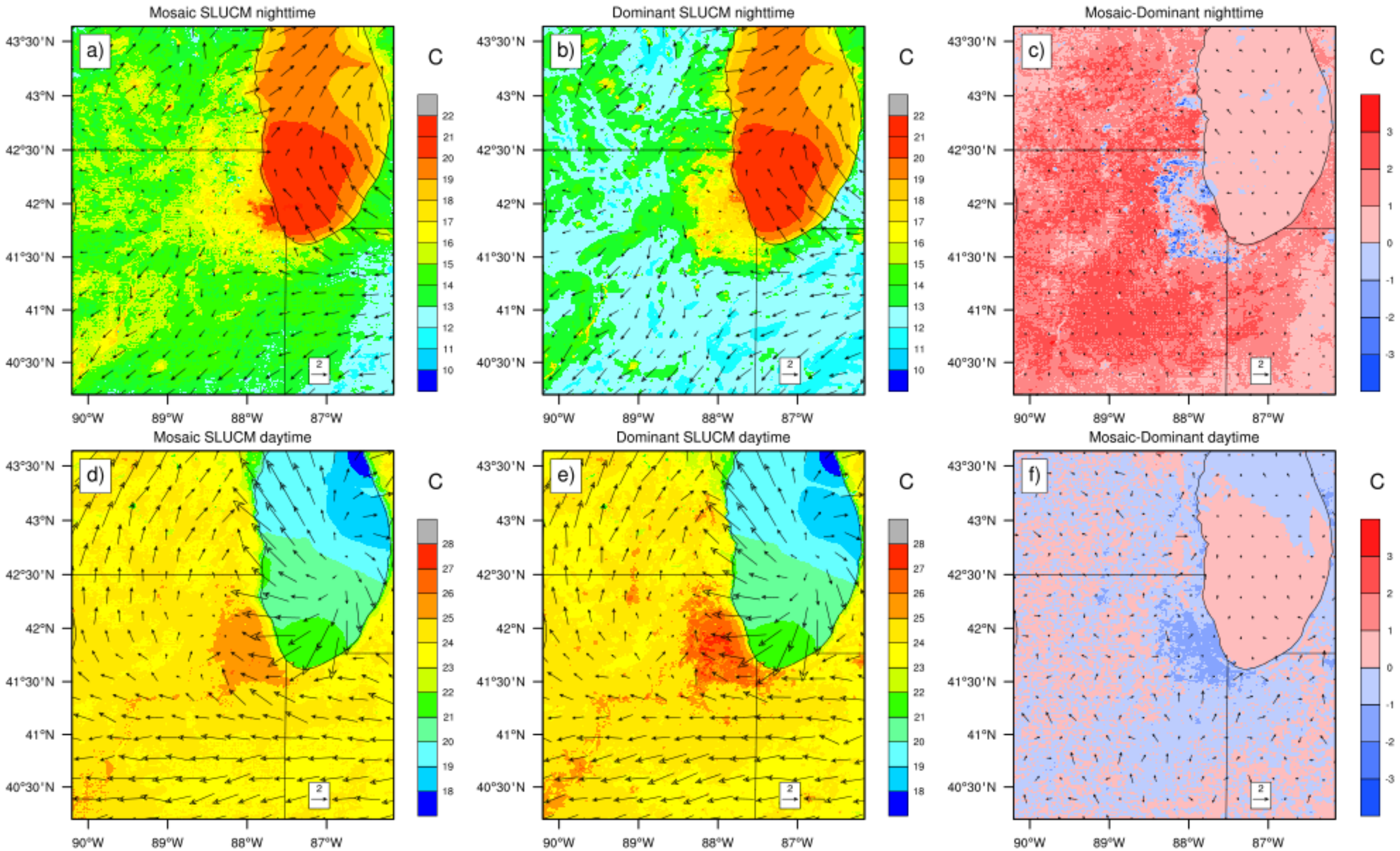
Li et al (2014)

Subgrid scale land cover variability




Urban part of urban grid
a)
Rural part of urban grid
b)
43°30'N
43°N
42°30'N
42°N
41°30'N
41°N
40°30'N
90°W
89°W
88°W
87°W
C
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10

Mosaic/Dominant



Conclusions and future work

Conclusions:

- Extreme events are not only likely to be dictated by changes in large-scale climate dynamics but also by climate system modifiers at very fine/local scales
- Observational gridded datasets can show us the pattern, but may mute/amplify hydrometeorological intensities.
- High resolution NARR datasets are poor for snow.
- Soil moisture initialization using HRLDAS removes uncertainty of poor surface initial conditions.
- Mosaic approach includes surface heterogeneity in land surface and thus shows better estimates of surface characteristics.

Future work

- One article in JAMC press and another in review; one in preparation (to be submitted late summer)
- Perform future climate simulations: 2045-2055 (RCP4.5/8.5), and 2085-2095 (RCP4.5/8.5).

Thank you

Thanks to:

- The Great Lakes Consortium for Petascale Computation (GLCPC) for the award;
- Mark Straka and the NCSA team