Using the **Weather Research & Forecasting Model (WRF)** *for* **Surface Dynamics** *and* **Environmental Change Studies**

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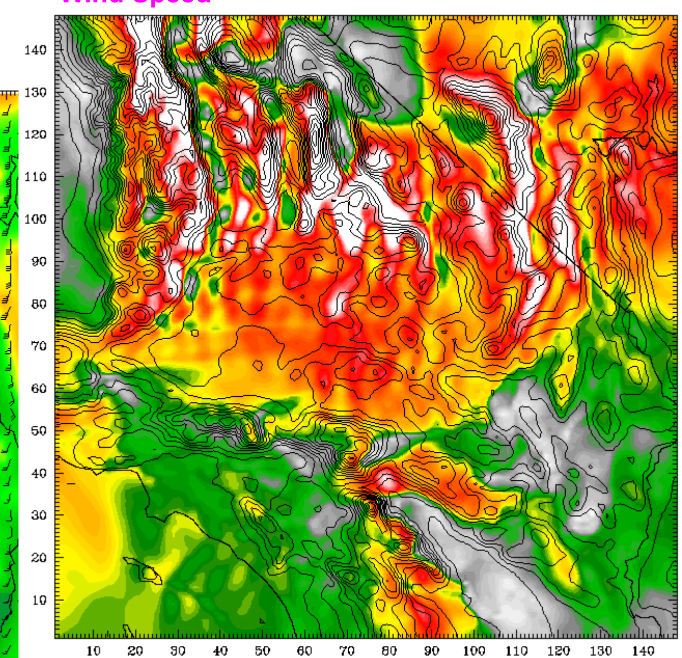
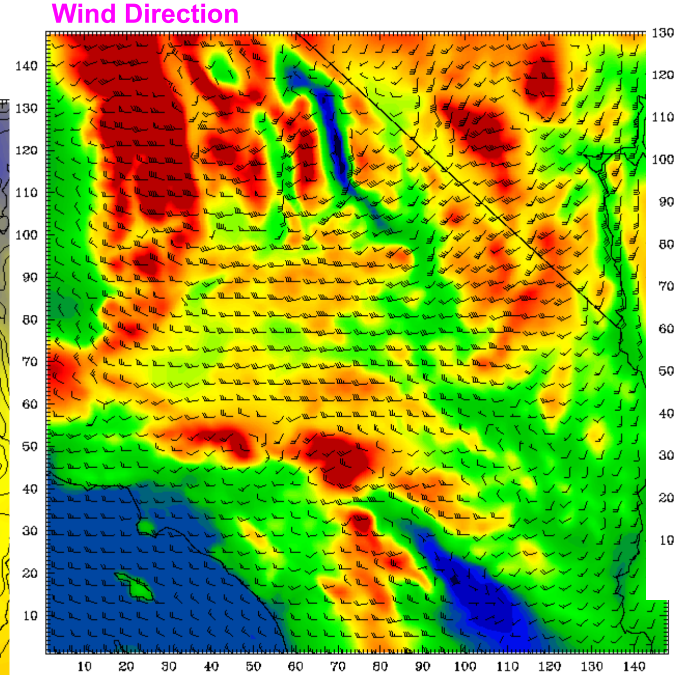
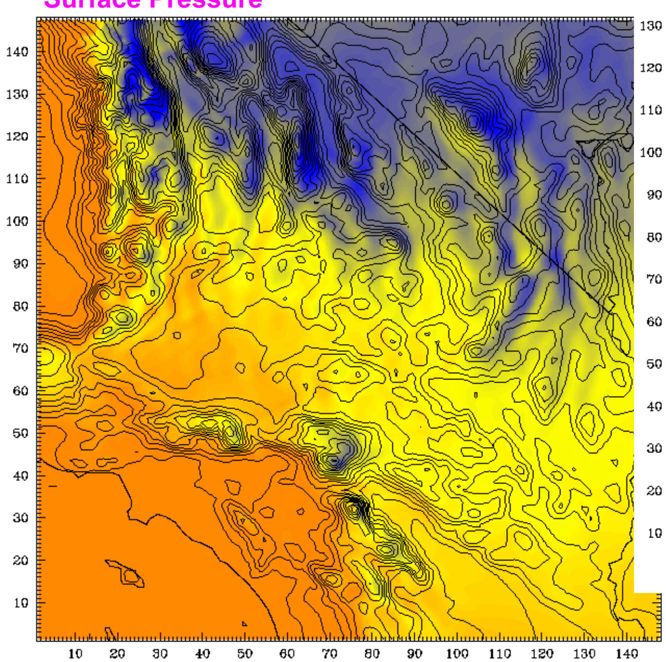
Wind Speed



Wind Direction



Surface Pressure



Weather Research & Forecasting Model

what is this?

- Next-generation mesoscale atmospheric modeling system
  modular, flexible, portable, highly parallel code

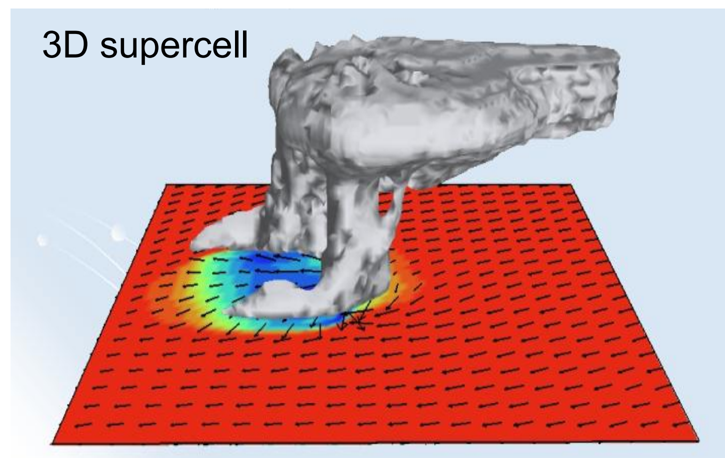
- Community model
  multi-agency (NCAR, NOAA, FAA, AFWA, NRL ...) + university community

- Fully compressible non-hydrostatic Euler equations
  (designed for use at scales ranging from meters to 1000s of kilometers)

Earth
Mars
Titan

- Nesting capability (up to 9 levels)
  (2-way interactive, moving nests)

- Cloud-resolving when dx < 10 km



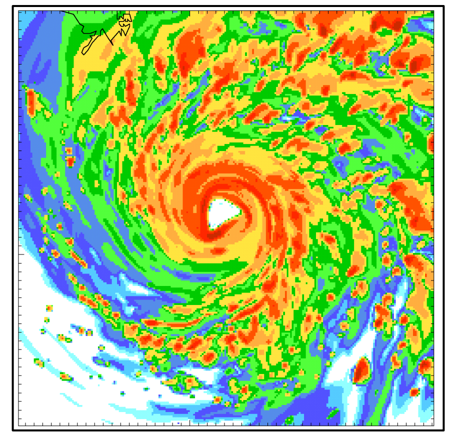
(http://www.wrf-model.org/index.php)

Weather Research & Forecasting Model

what is this?

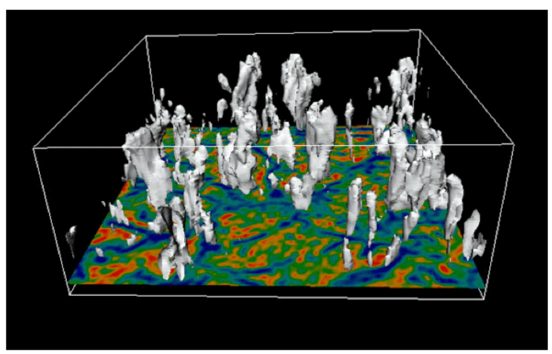
• Advantages

- captures nonlinear mesoscale effects *(convective storms, land-sea breezes, ...)*
- high-temporal resolution allows simulation of extreme events *(intense wind or rain, ...)*
- enables the coupling of processes from global-to-local

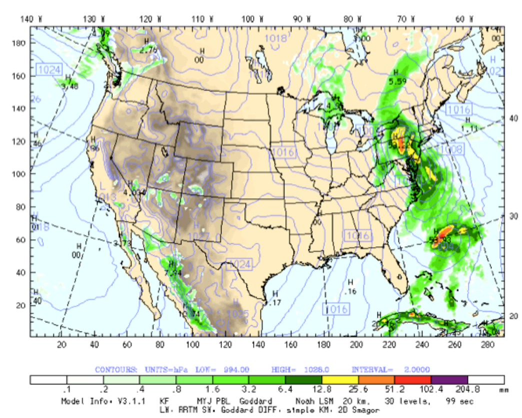


• Suitable for a wide range of applications

- real-time numerical weather prediction
- atmospheric research
- regional climate simulations *(past, present, future)*
- coupled modeling systems *(WRF/CCSM, WRF/ROMS, ...)*

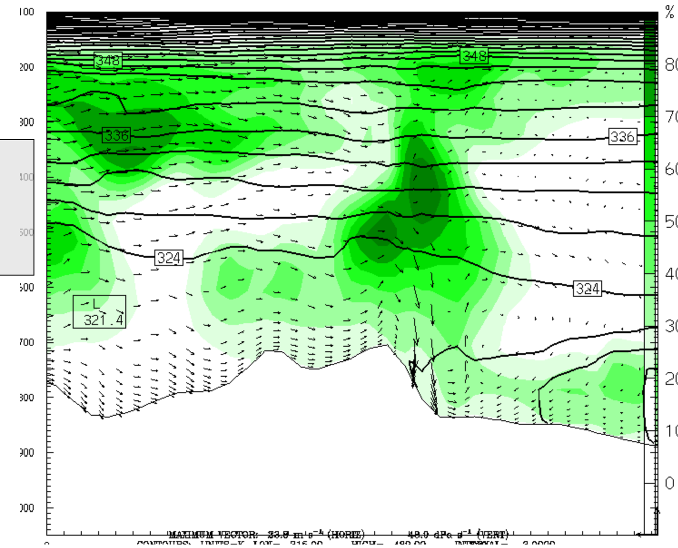


Convective Updraft (Moeng, NCAR)



WRF Physics Modules & Coupling

Dynamics Solver – *integrates the compressible non-hydrostatic Euler equations*



Shortwave Radiation

- *Dudhia, Goddard, GFDL, CCSM3*

Longwave Radiation

- *RRTM, GFDL, CCSM3*

Cloud Microphysics

- *Kessler; Lin et al.; NCEP; WSM 3,5,6 class; Ferrier; Thompson; Morrison*

Cumulus Cloud Parameterization

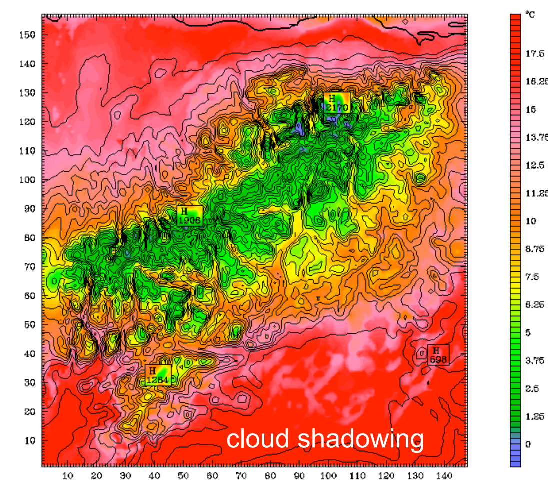
- *Kain-Fritsch, Betts-Miller-Janjic, Grell-Devenvi*

Planetary Boundary Layer

- *YSU, Mellor-Yamada-Janjic, MRF*

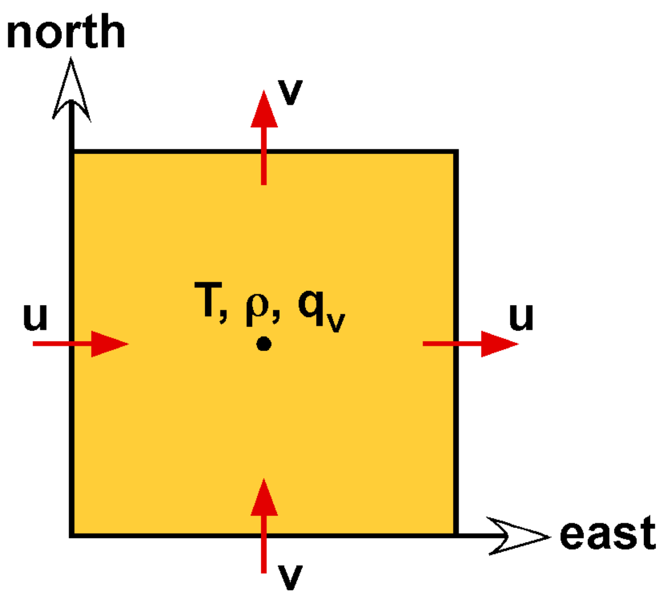
Land Surface Model

- *RUC LSM, Noah LSM, Urban Canopy model, CLM*

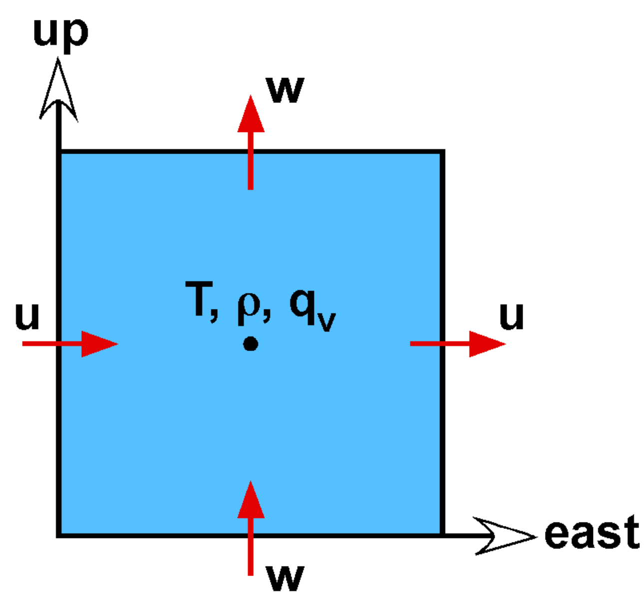


Spatial Discretization

Arakawa C-grid



horizontal



vertical

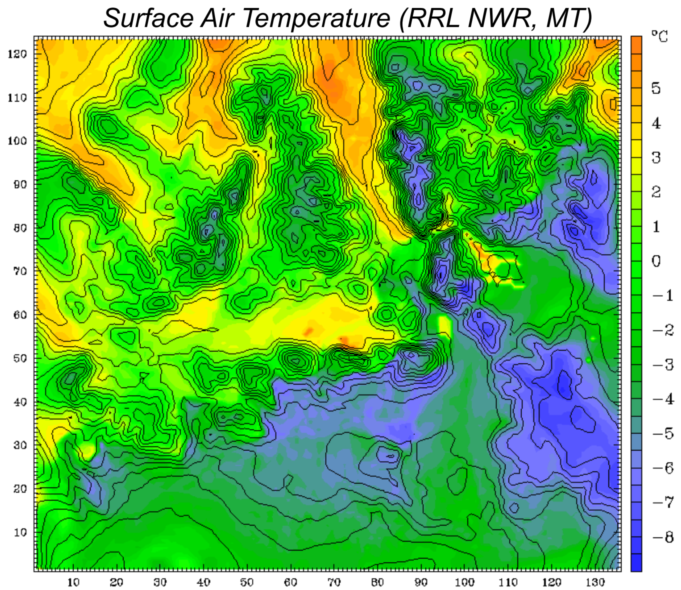
WRF uses the flux-form of the Euler equations
(conserves mass, enthalpy, …)

WRF Output and Diagnostic Fields

- (air) temperature field 3D
- pressure field 3D
- density 3D
- water vapor density 3D
- wind speed & direction 3D
- vorticity
- convective instability

- ground temperature
- soil moisture
- snow cover
- surface dewpoint temperature
- surface frost point temperature
- wind shear
- sensible heat flux
- latent heat flux
- BL relative humidity

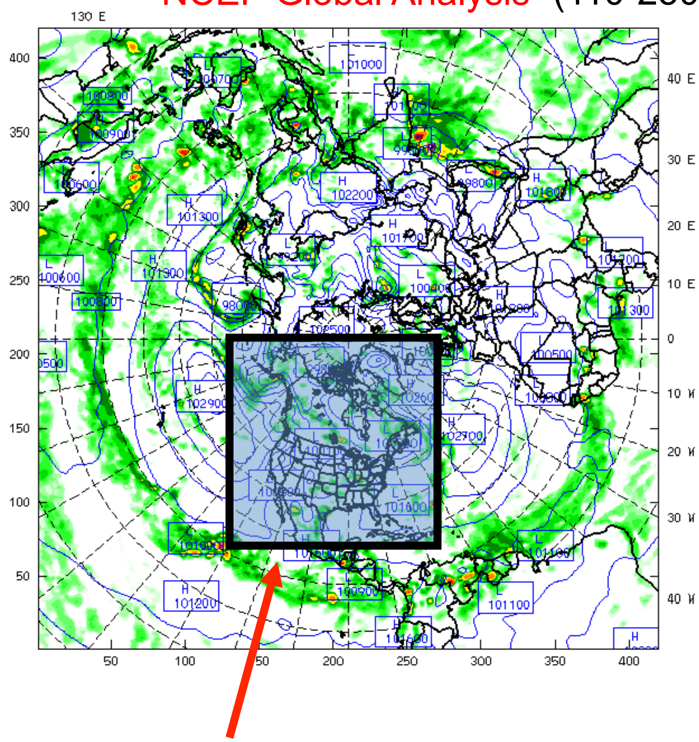
- precipitation
- precip. type (rain, graupel, hail, snow)
- convective vs. non-convective precip.
- column-integrated cloud liquid mass
- cloud cover
- cloud water mixing ratio
- cloud ice mixing ratio
- cloud ceiling
- cloud-top temperature



2 Run Modes

1) Retrospective Analyses

NCEP Global Analysis (110-250 km)

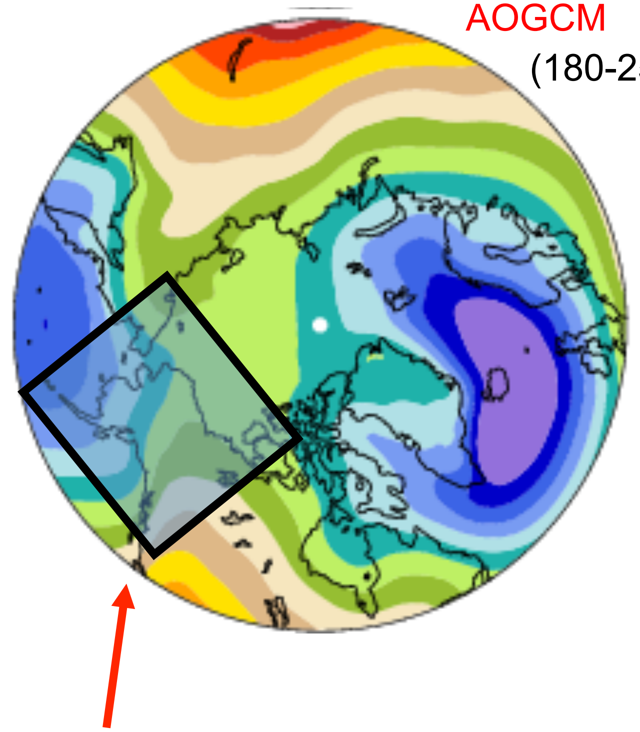


Nest WRF within observed large-scale circulation.

2) Future (Past) Climate Projections

AOGCM

(180-250 km)



Nest WRF within large-scale circulation projected by an AOGCM.

* Do this for an ensemble of AOGCMs.

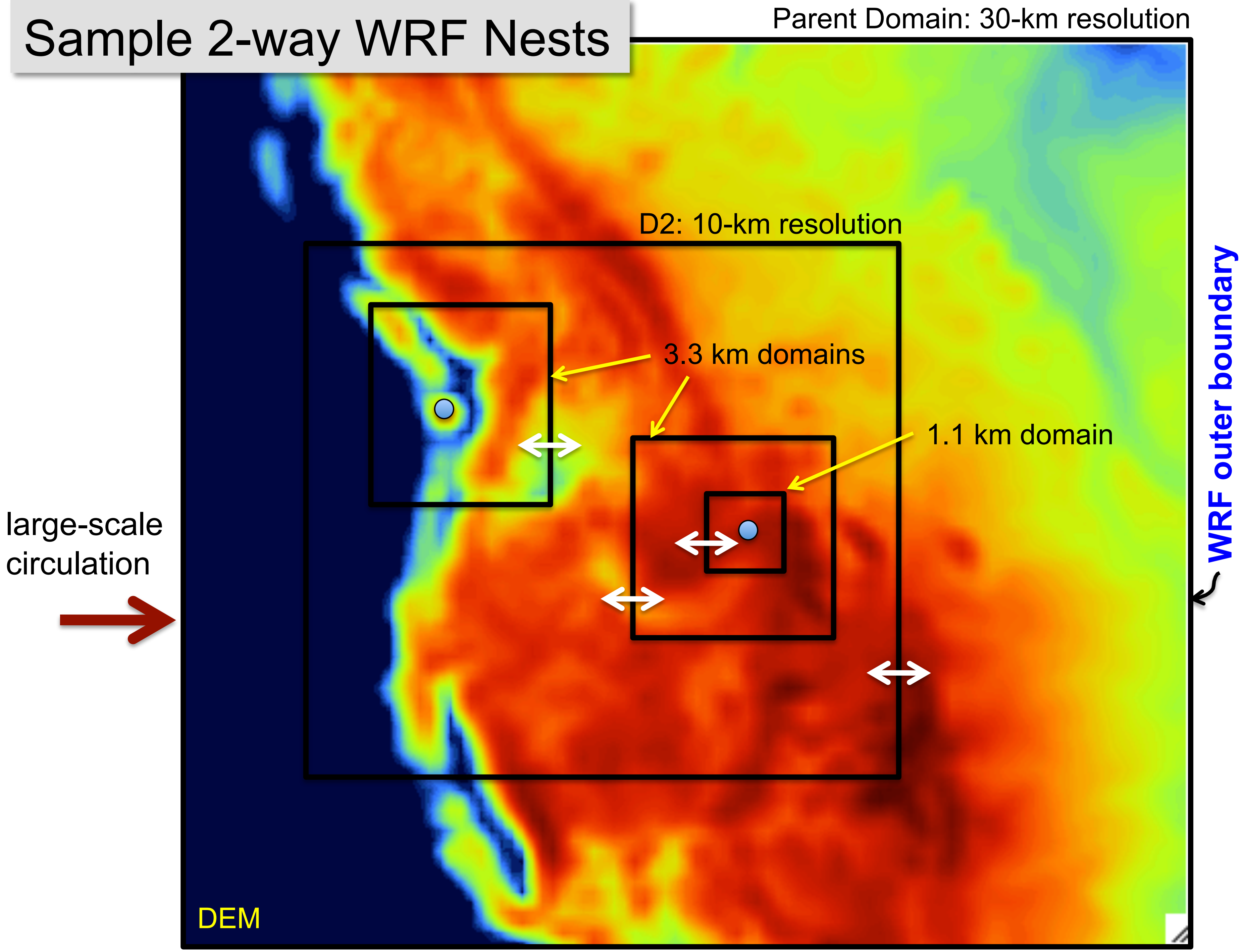
WRF Nesting Capability

This enables us to downscale the large-scale circulation to much finer spatial scales.

- 1-way
- 2-way interactive
- moving nest

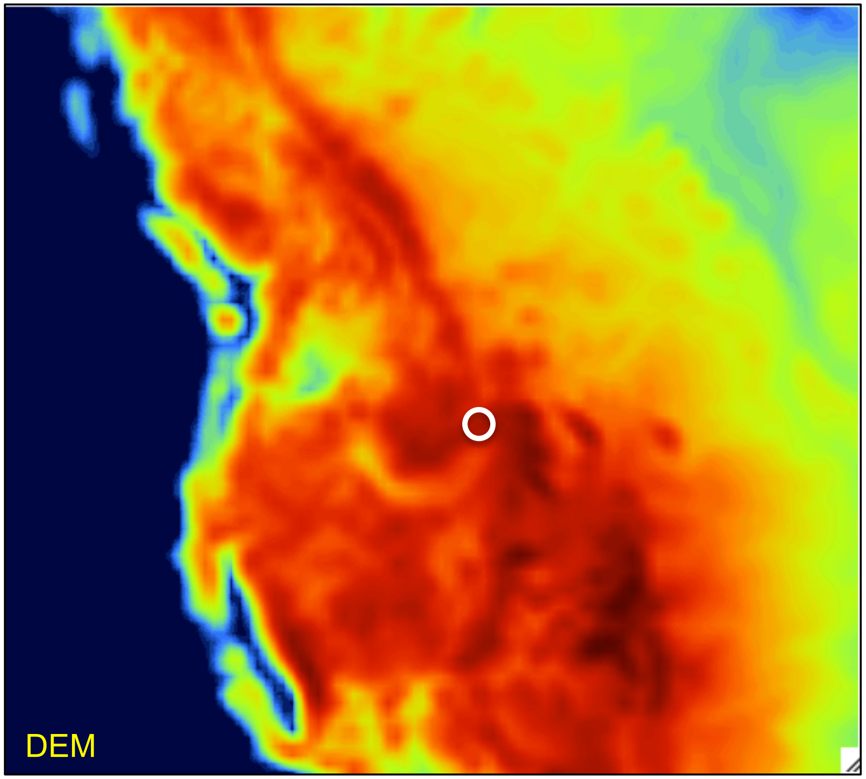
Example 2-way: Red Rock Lakes NWR, Montana

Sample 2-way WRF Nests



30 km

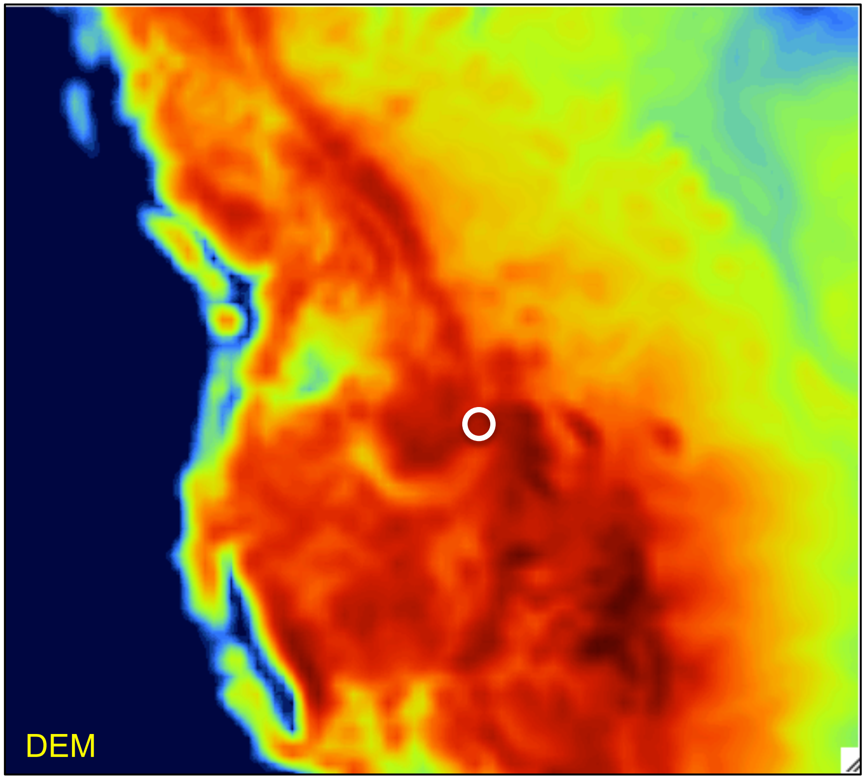
Parent Domain: 150 s



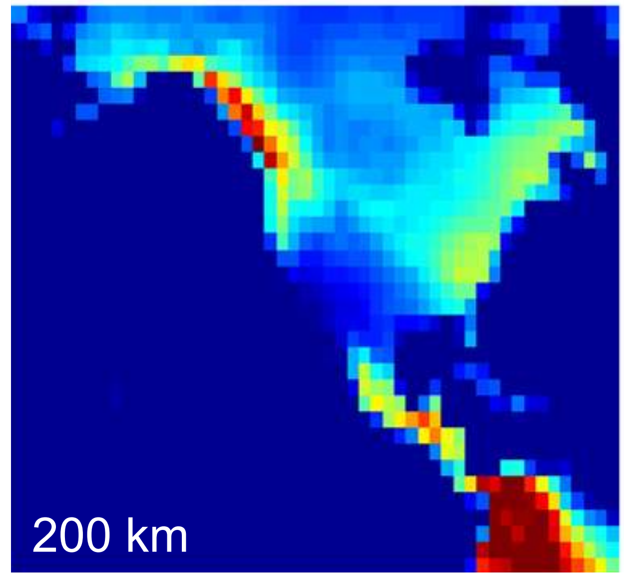
Red Rock Lakes NWR

30 km

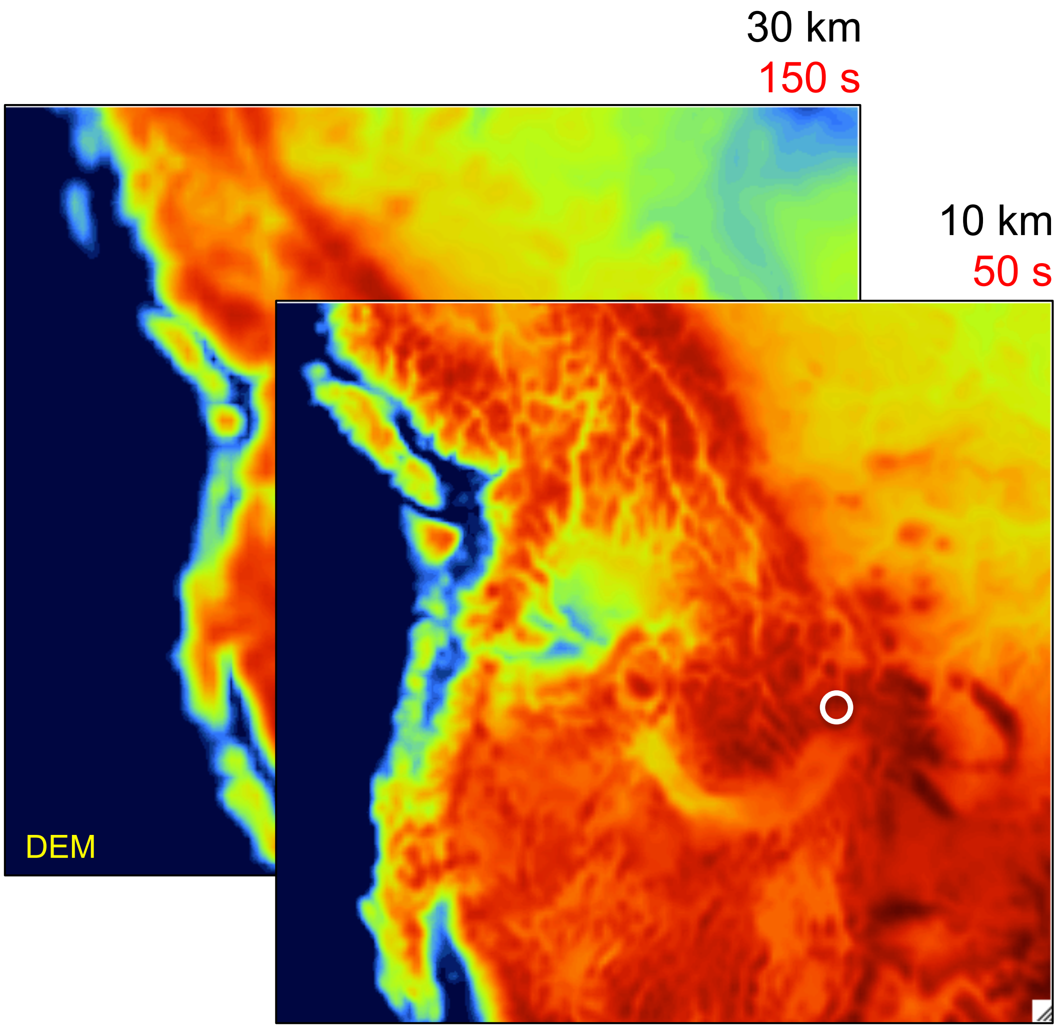
Parent Domain: 150 s



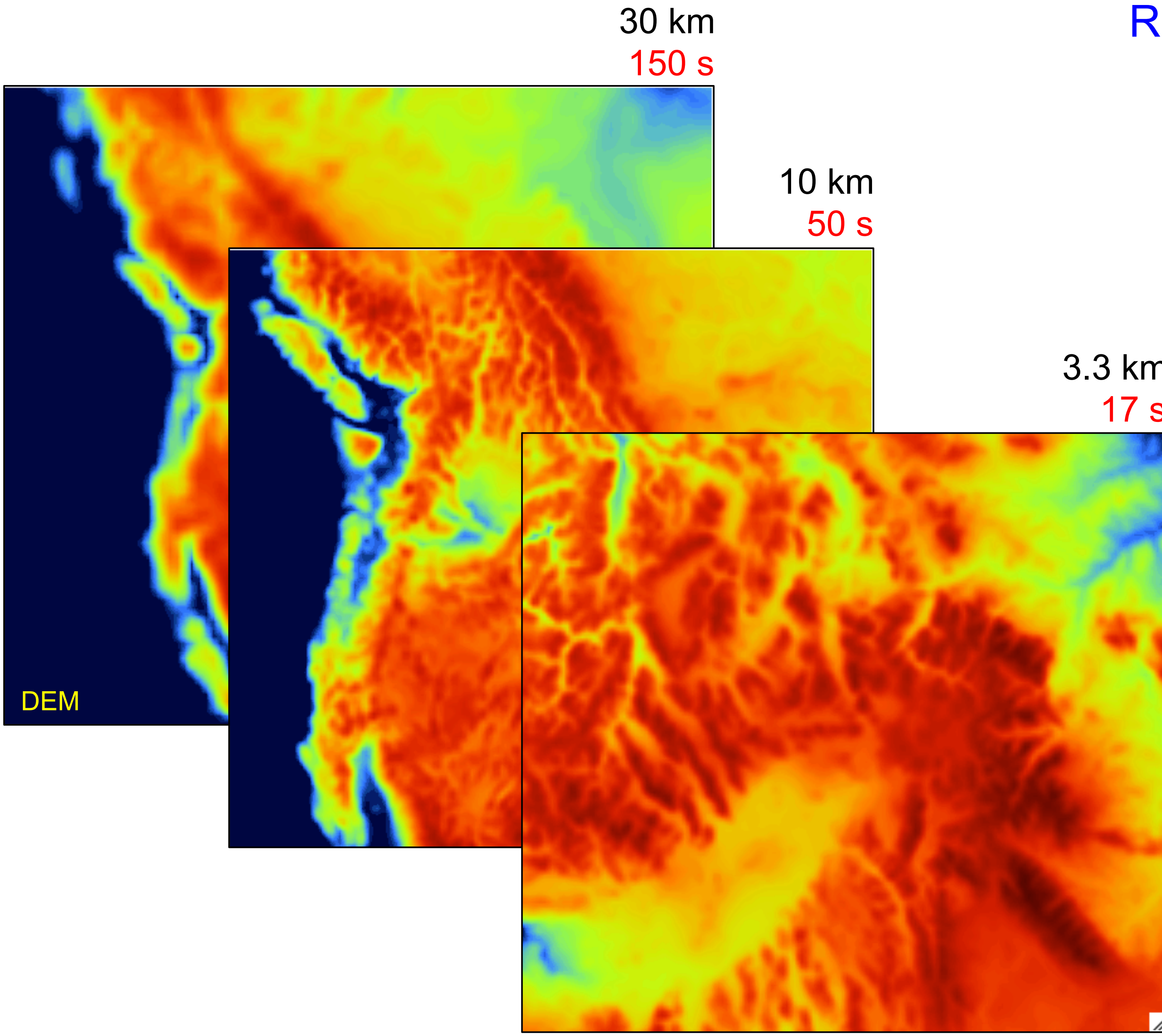
GCM Resolution



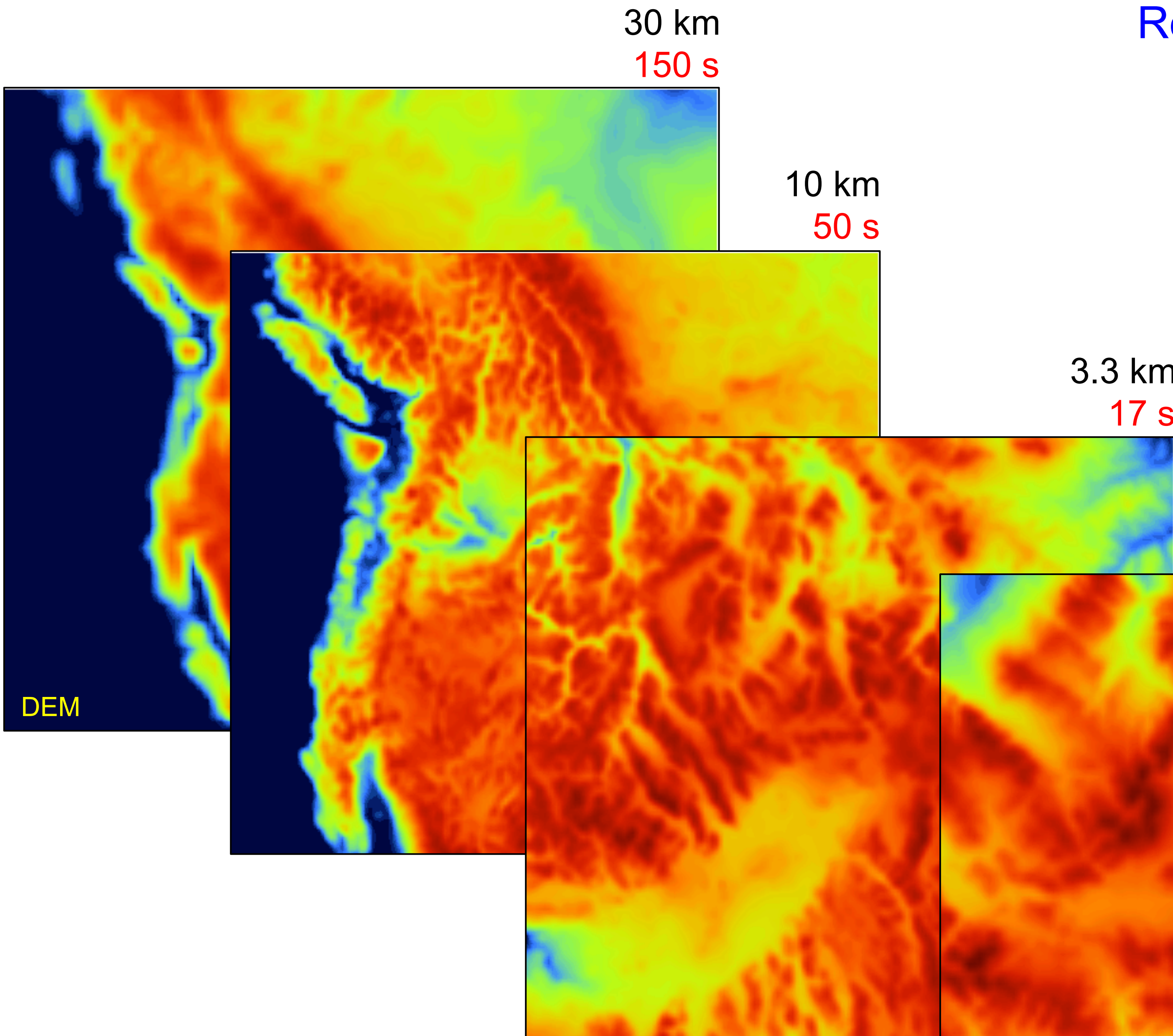
Red Rock Lakes NWR

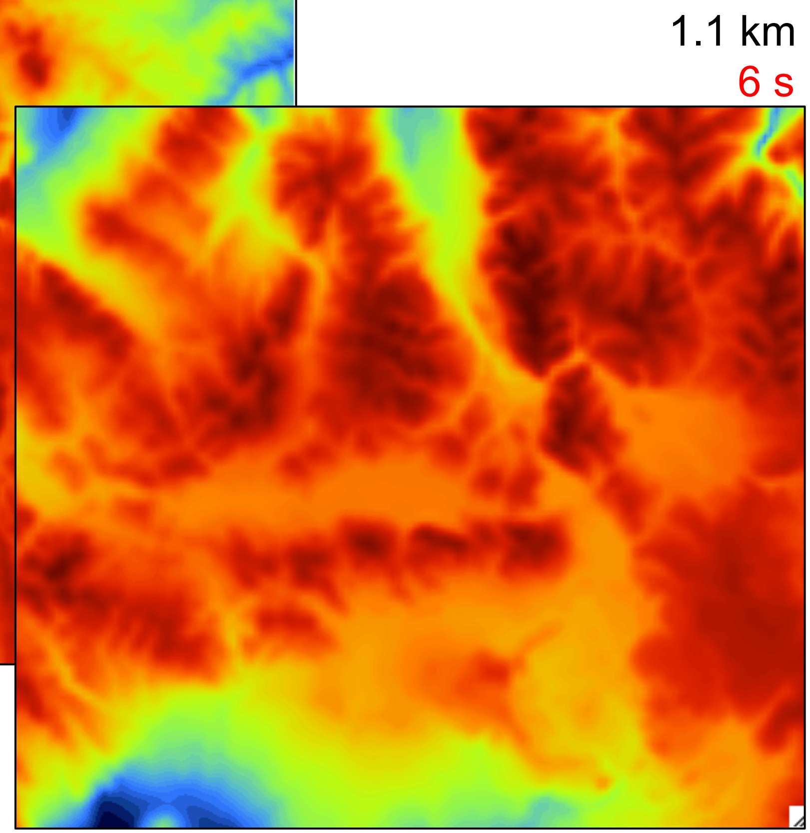


Red Rock Lakes NWR



Red Rock Lakes NWR

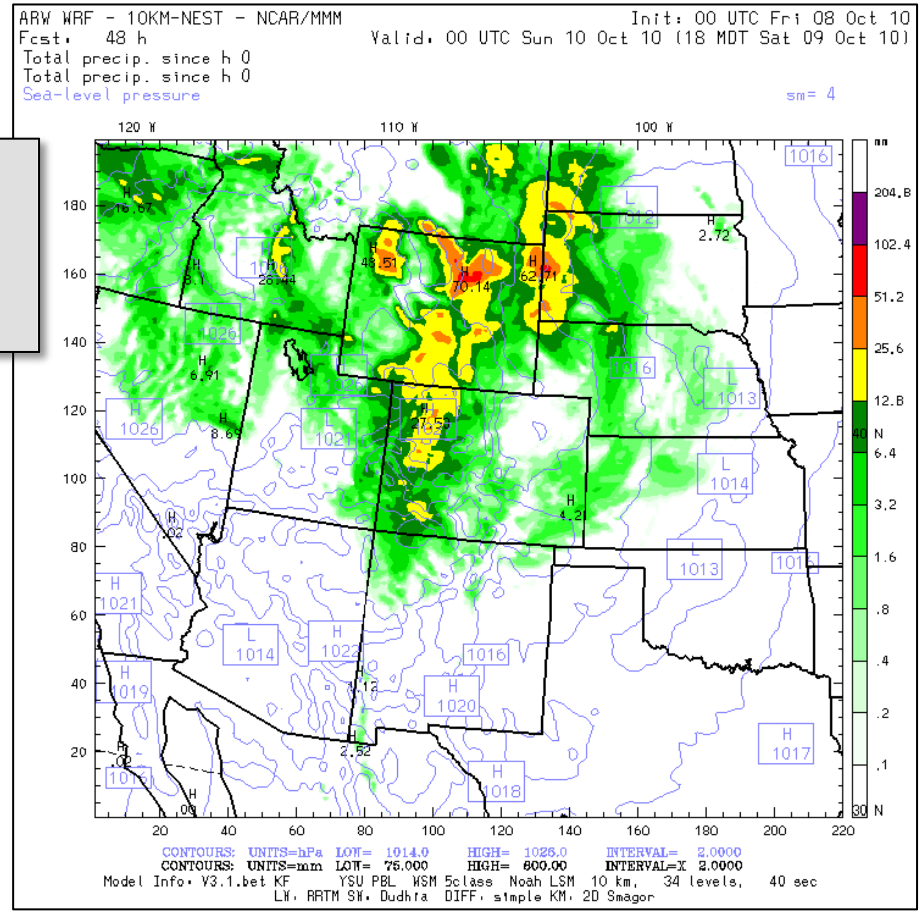


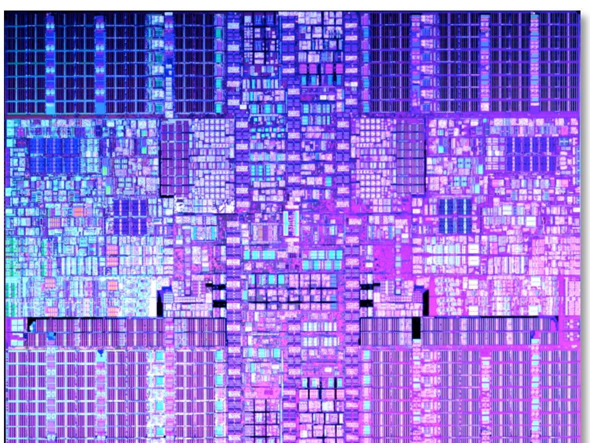


The Need for Parallel

A **48-hr WRF forecast** for the continental U.S. would take **52 hours** to calculate at 12-km resolution on a:

Dual core, 4.7 GHz chip
64-bit floating point precision
16 GB per processor
~ 6 Gflop/s (circa 2008)





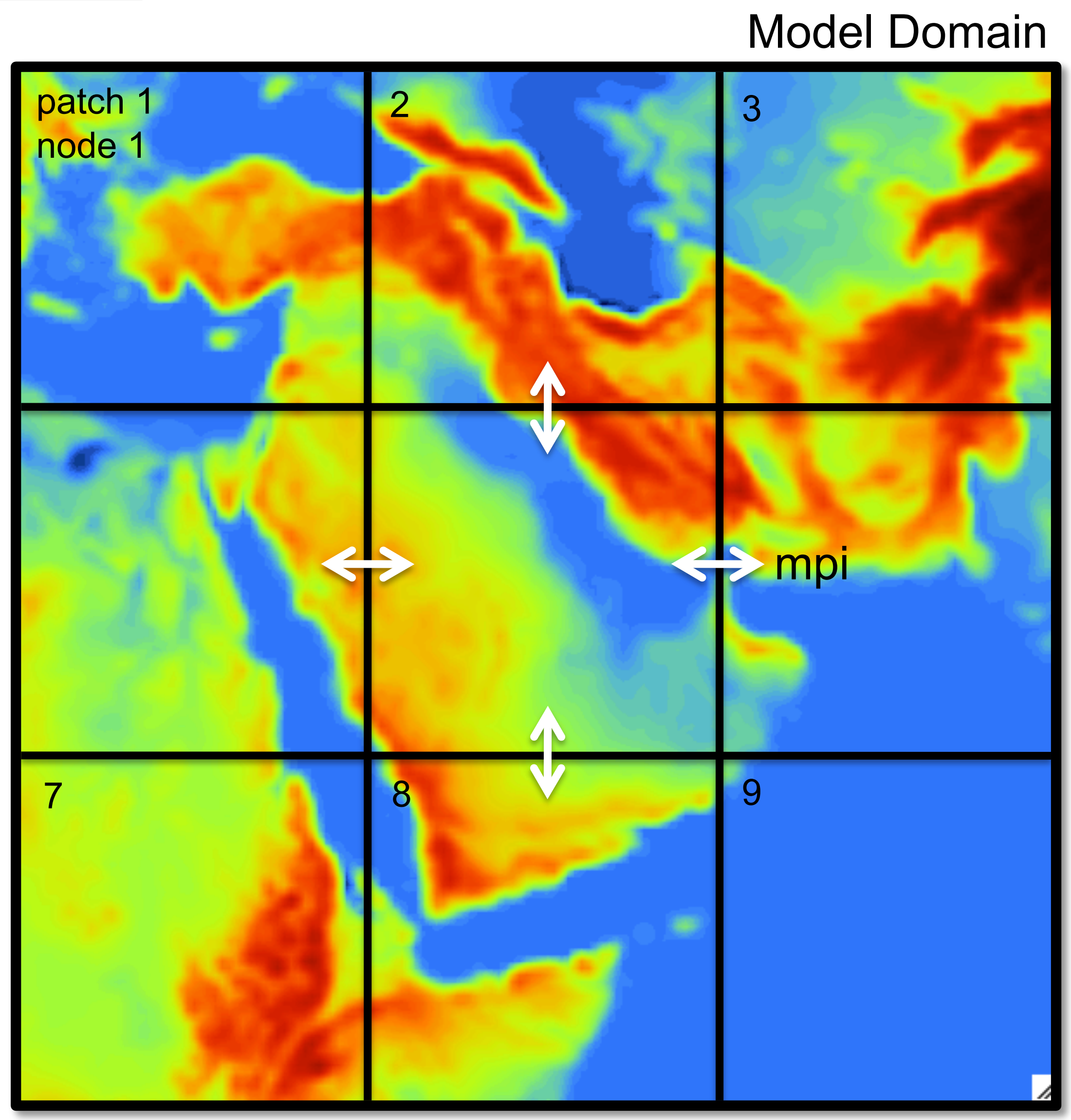
2 Levels of WRF Parallelism

Distributed Memory Parallel

- Model domain is decomposed into Patches, one for each distributed memory Node.

- Communication: MPI

Example: 9 available nodes, 9 patches



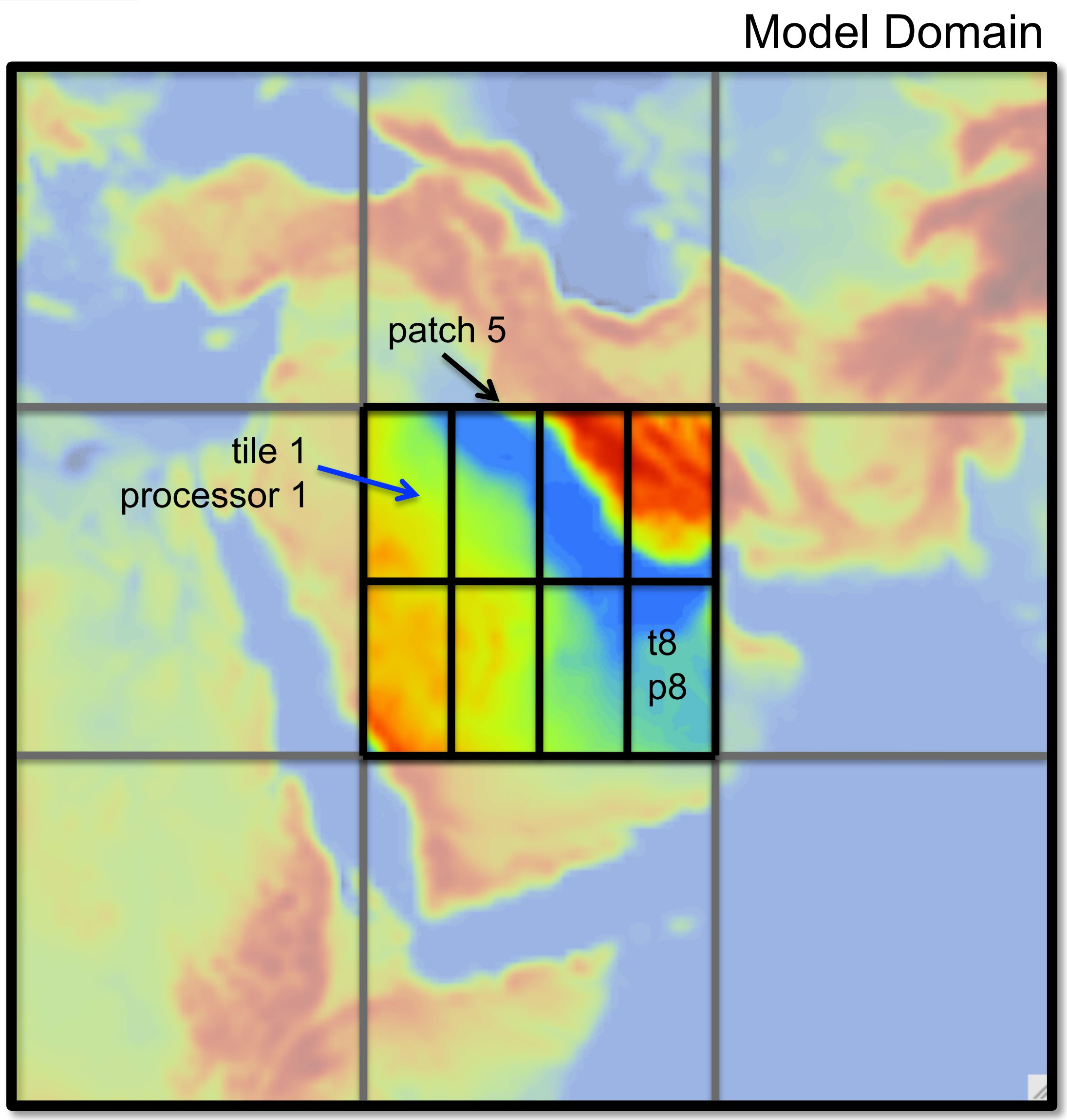
2 Levels of WRF Parallelism

Shared Memory Parallel

- Each patch is decomposed into Tiles, one for each shared memory processor.

- Communication: OpenMP

Example: 8 processors per node



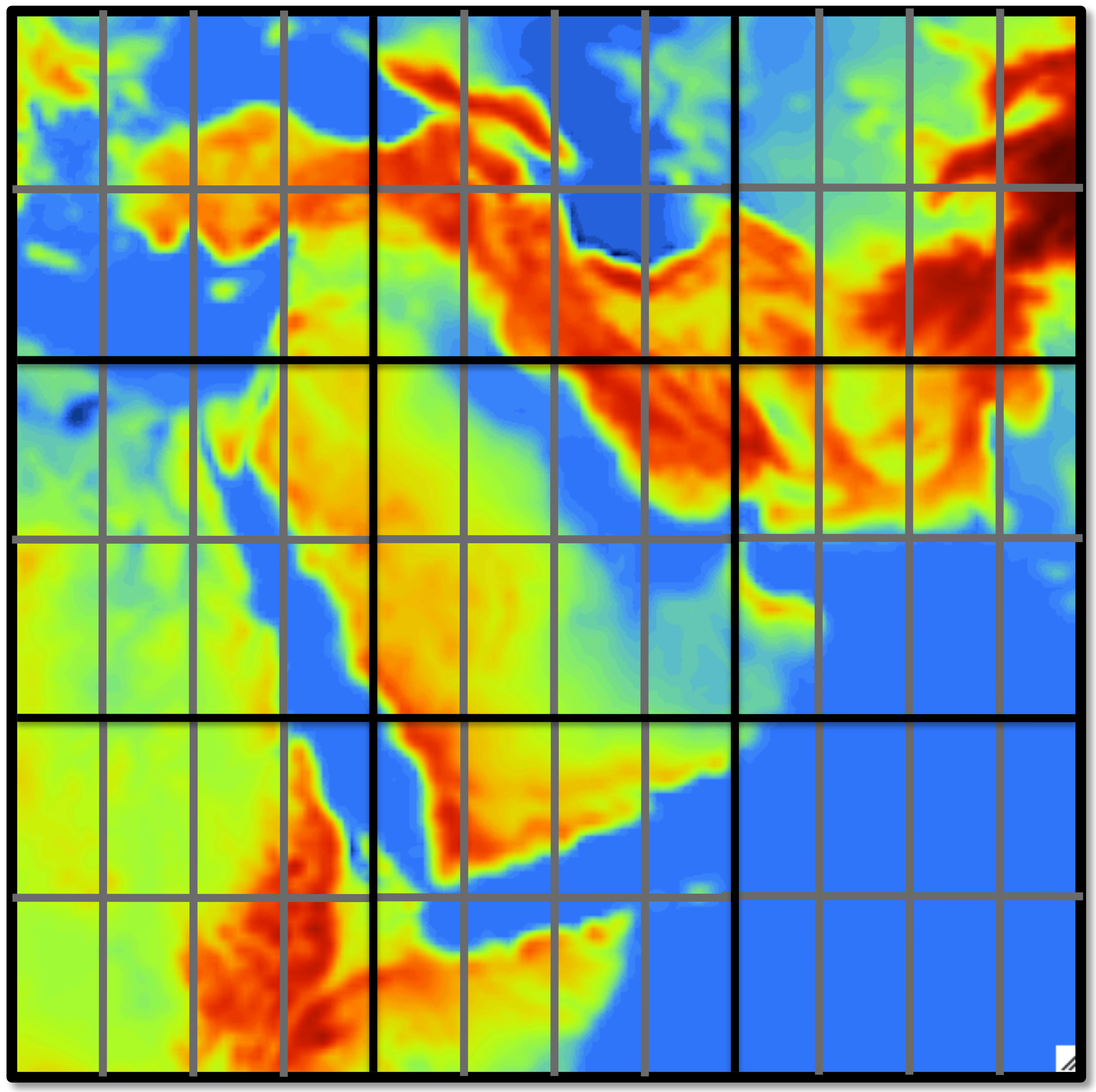
2 Levels of WRF Parallelism

Shared + Distributed Memory Parallel

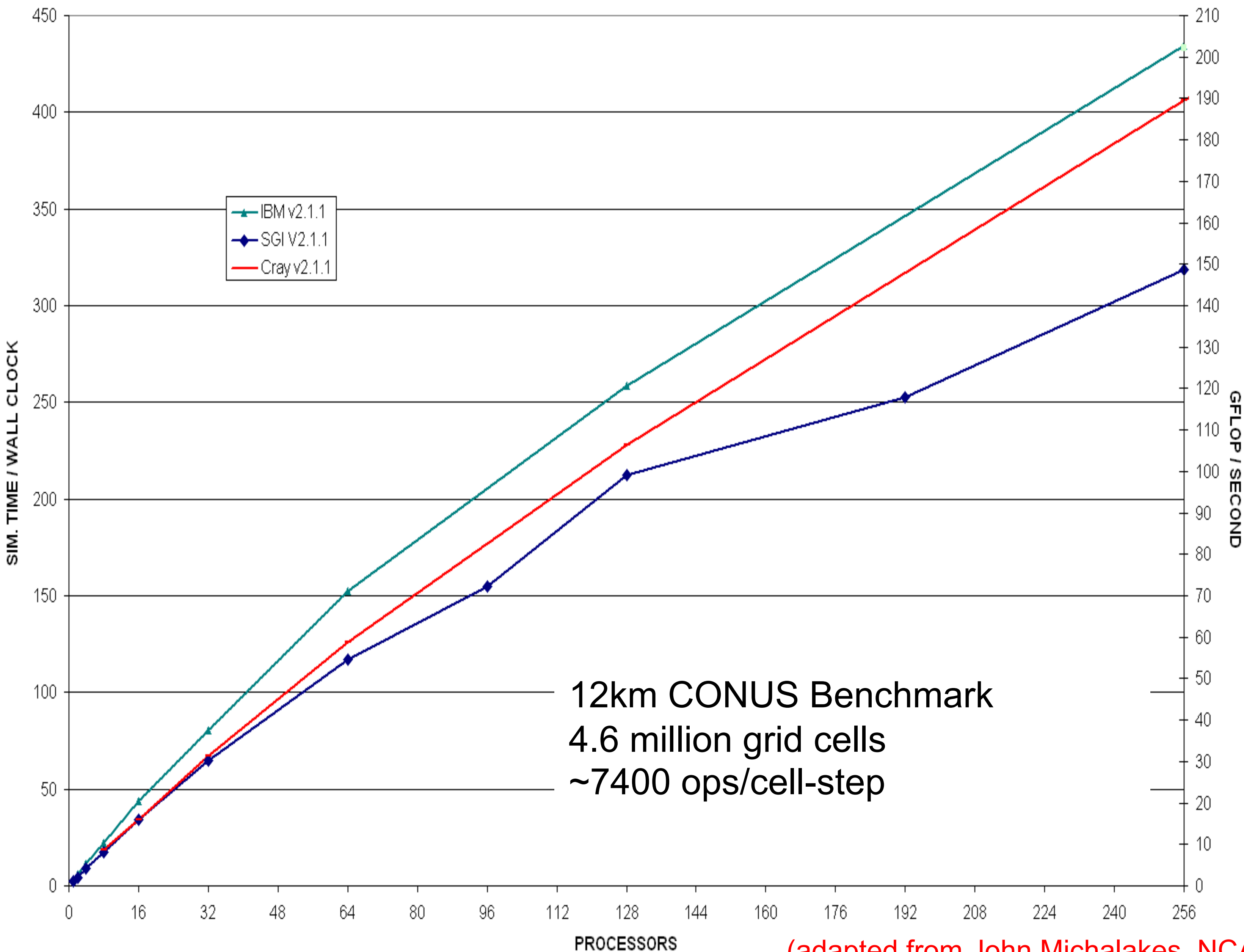
- Model domain is decomposed into Patches & Tiles.
- Communication:

  OpenMP & MPI

Example: 9 available nodes, 72 processors

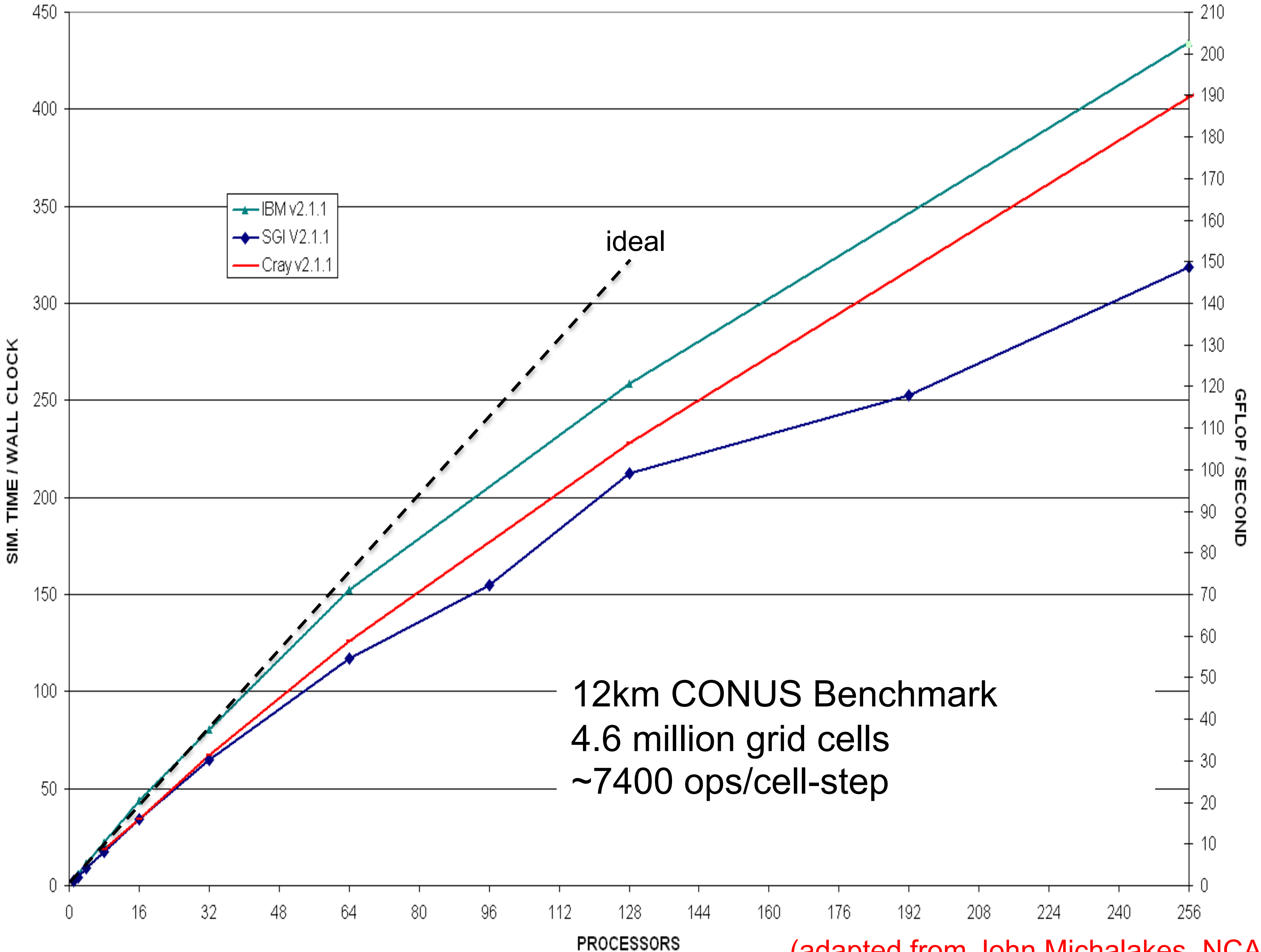


WRF Multiprocessor Performance



(adapted from John Michalakes, NCAR)

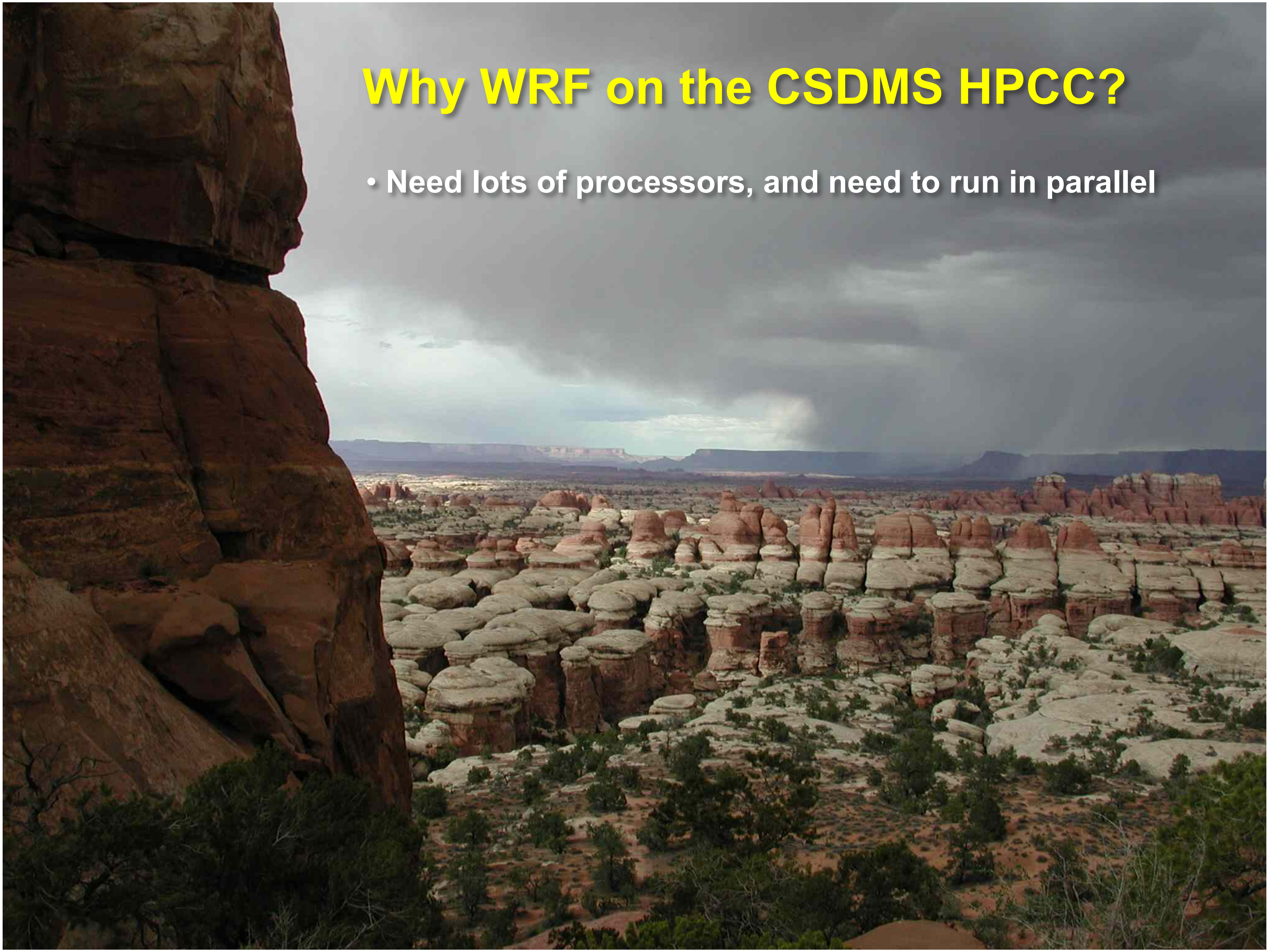
WRF Multiprocessor Performance



(adapted from John Michalakes, NCAR)

Why WRF on the CSDMS HPCC?

- Need lots of processors, and need to run in parallel



Why WRF on the CSDMS HPCC?

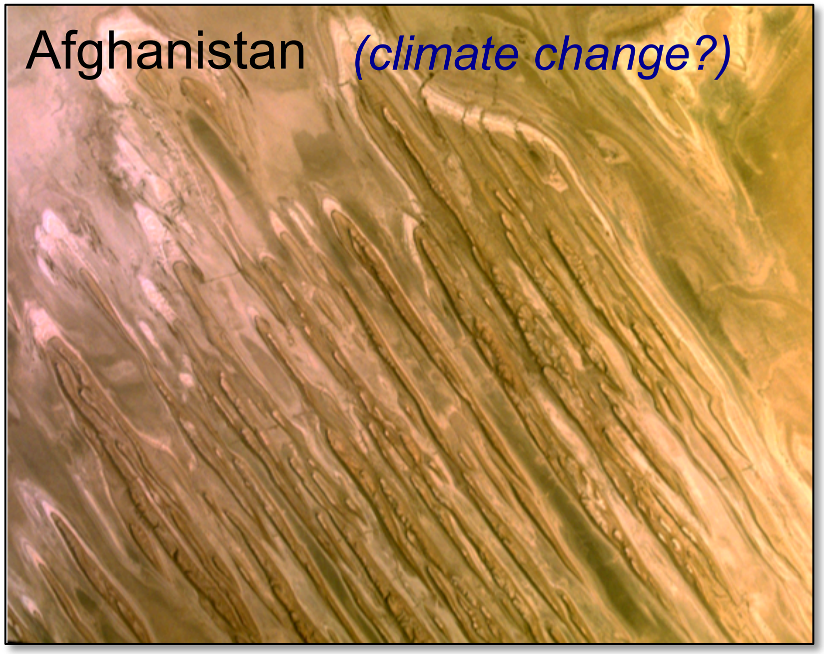
- Need lots of processors, and need to run in parallel
- Coupling to other models

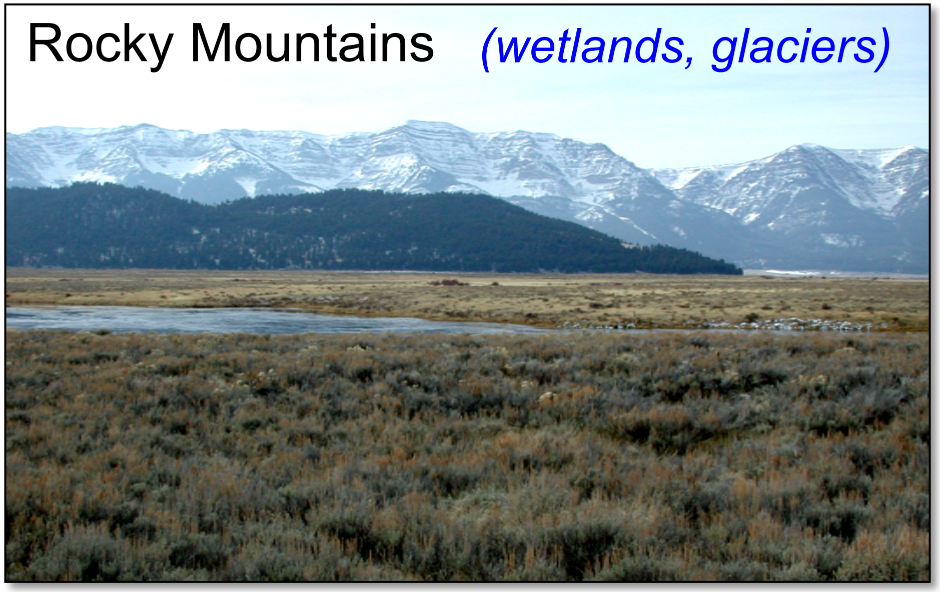
CSDMS
COMMUNITY SURFACE DYNAMICS MODELING SYSTEM

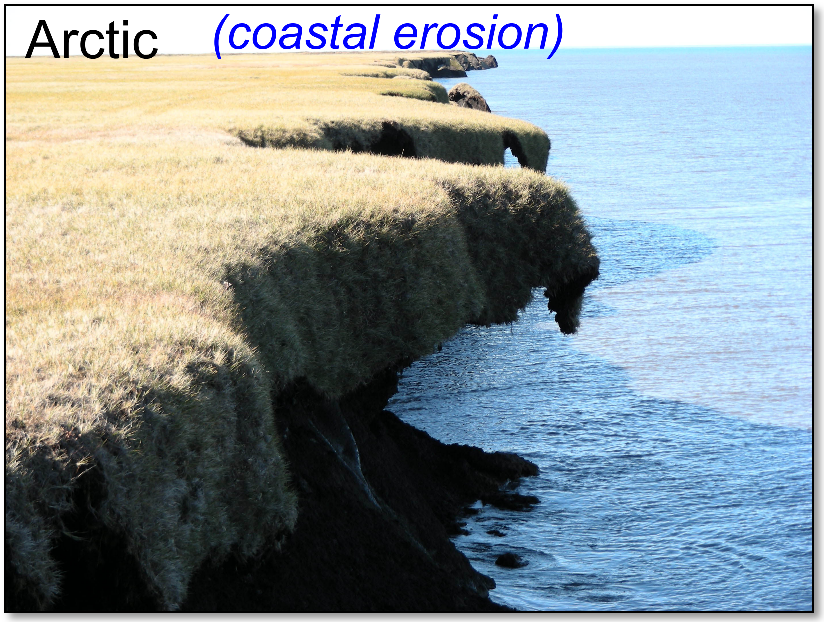
terrestrial
coastal
marine
hydrologic
cabonate

atmosphere

WRF Examples

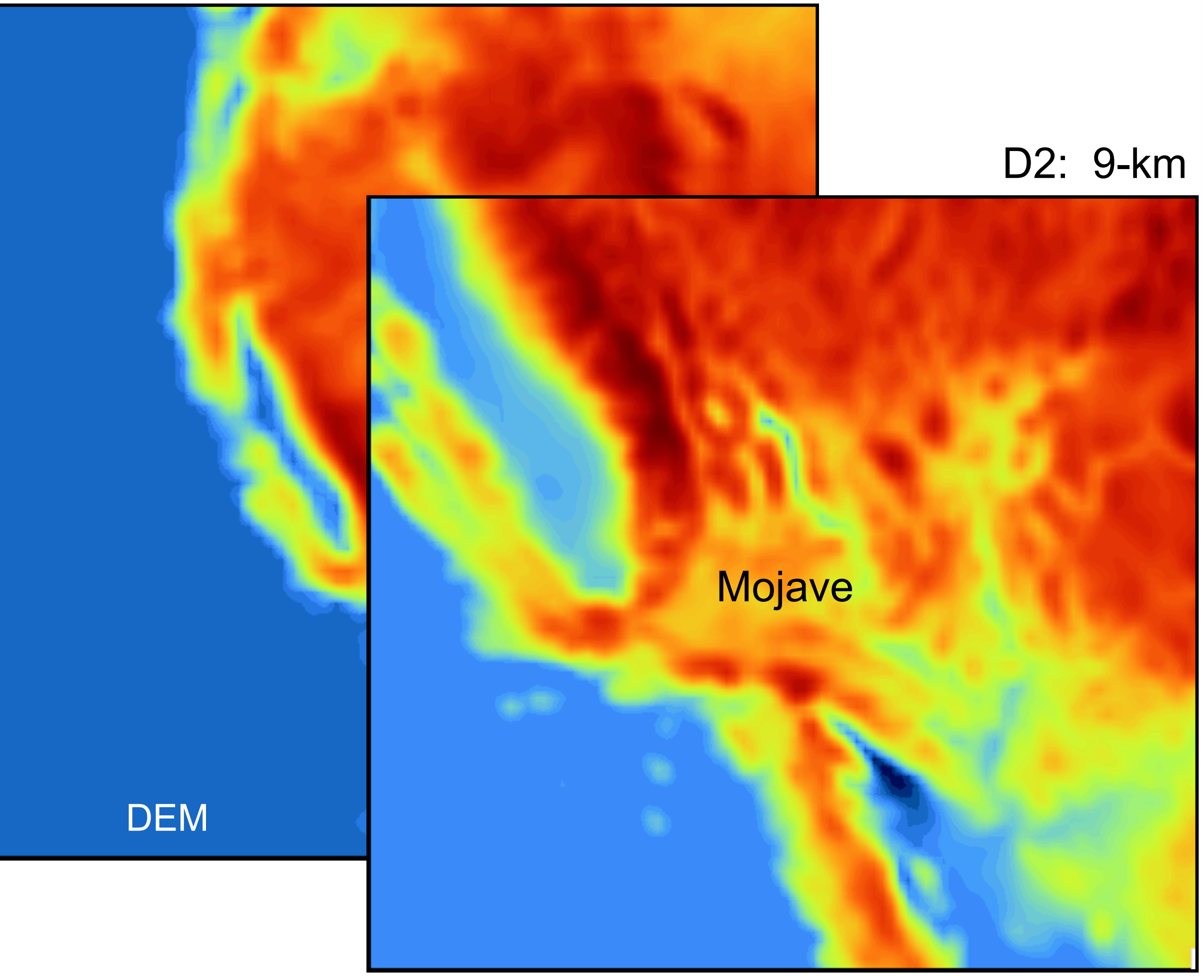






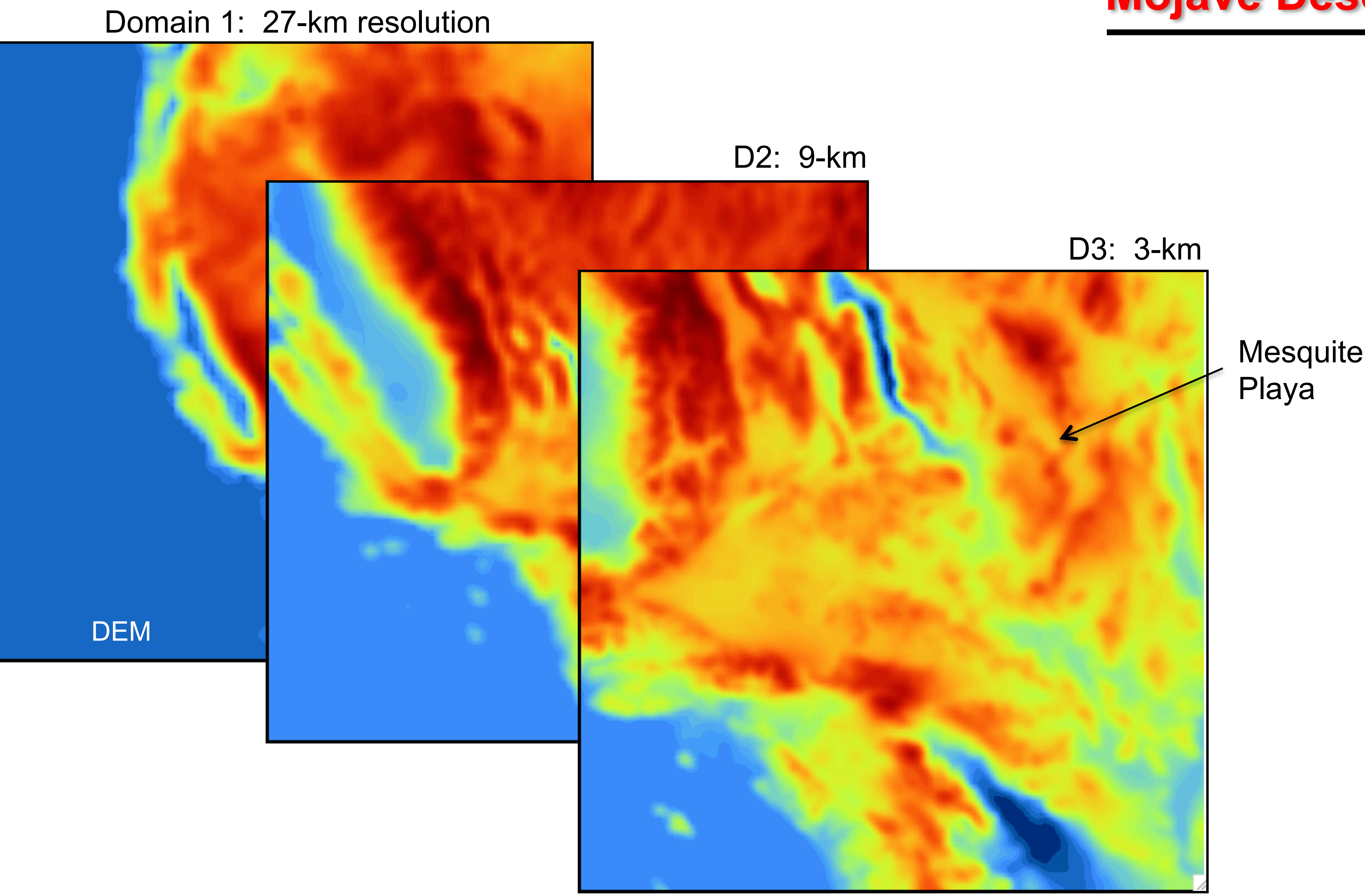
Domain 1: 27-km resolution

D2: 9-km

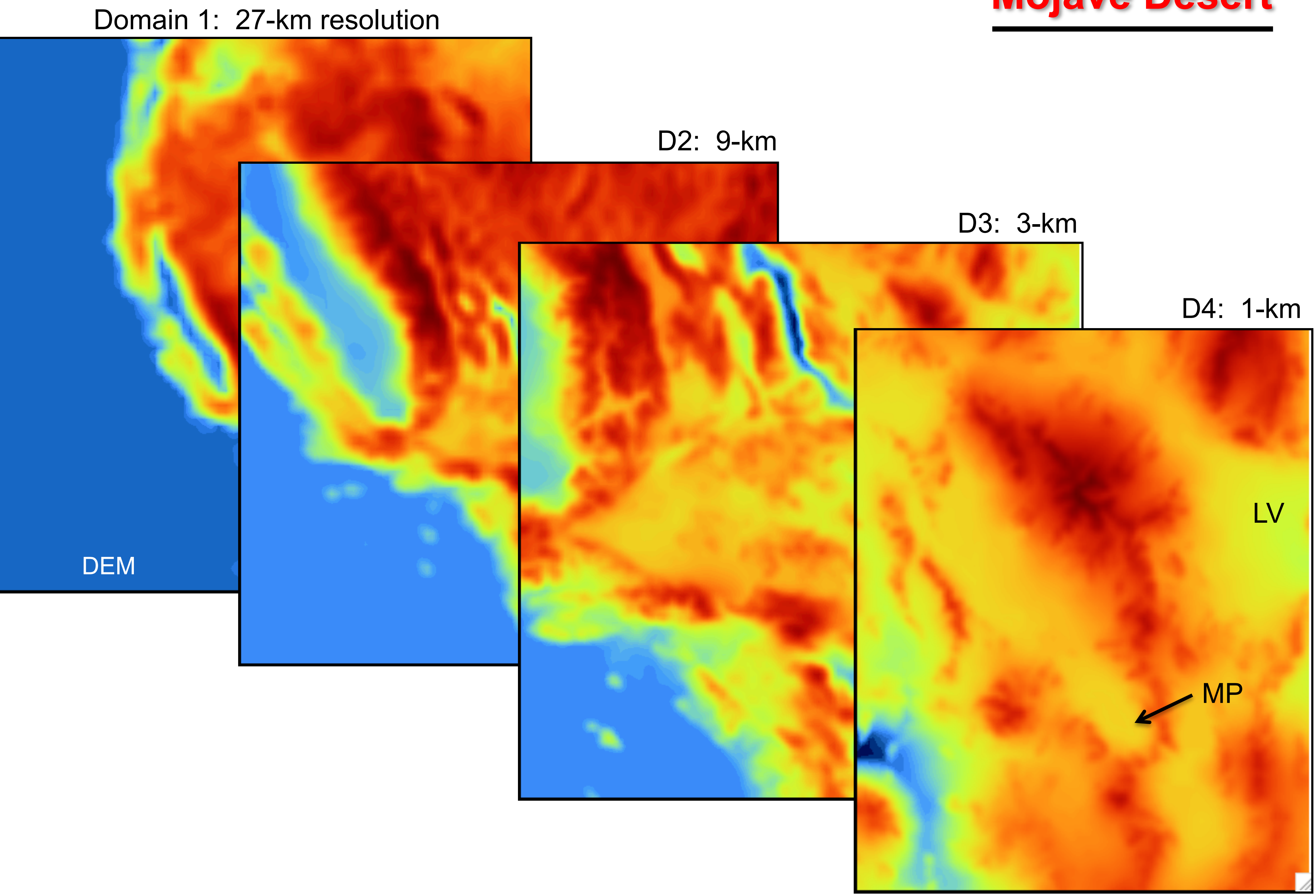


- Assess ability of the wind to lift materials at potential source sites during high-wind events.
- Determine dust-transport pathways.
- Investigate the influence of terrain on the wind field in the Mojave Desert at a variety of scales.

Mojave Desert



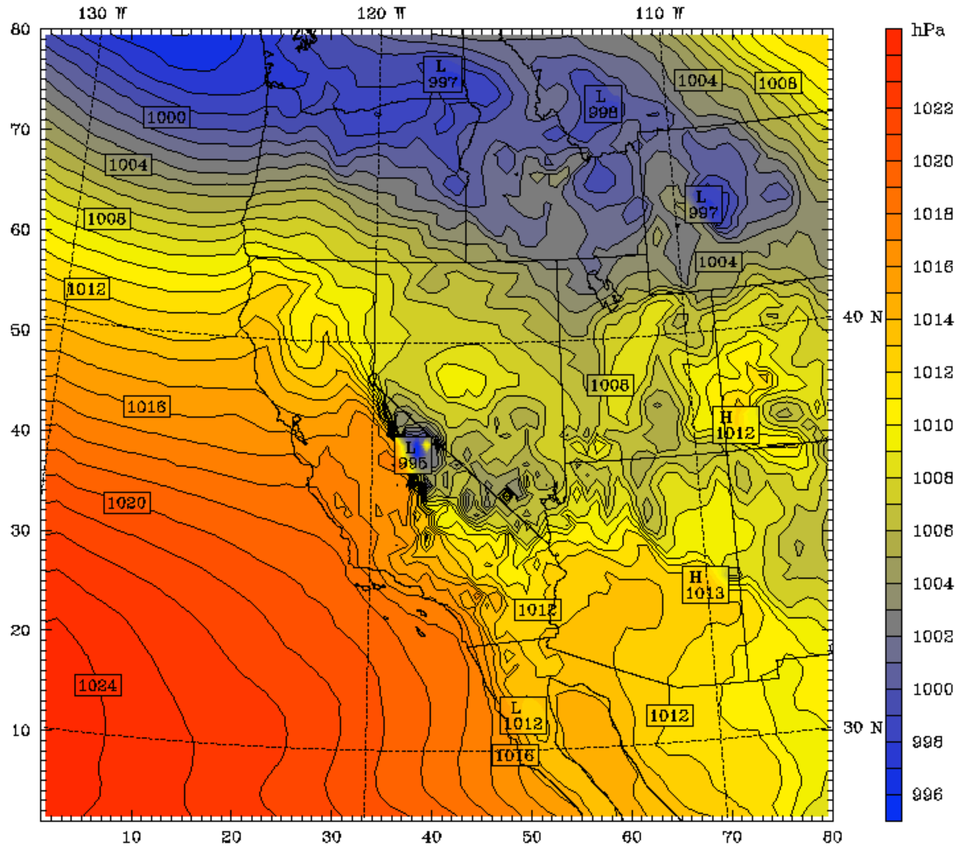
Mojave Desert



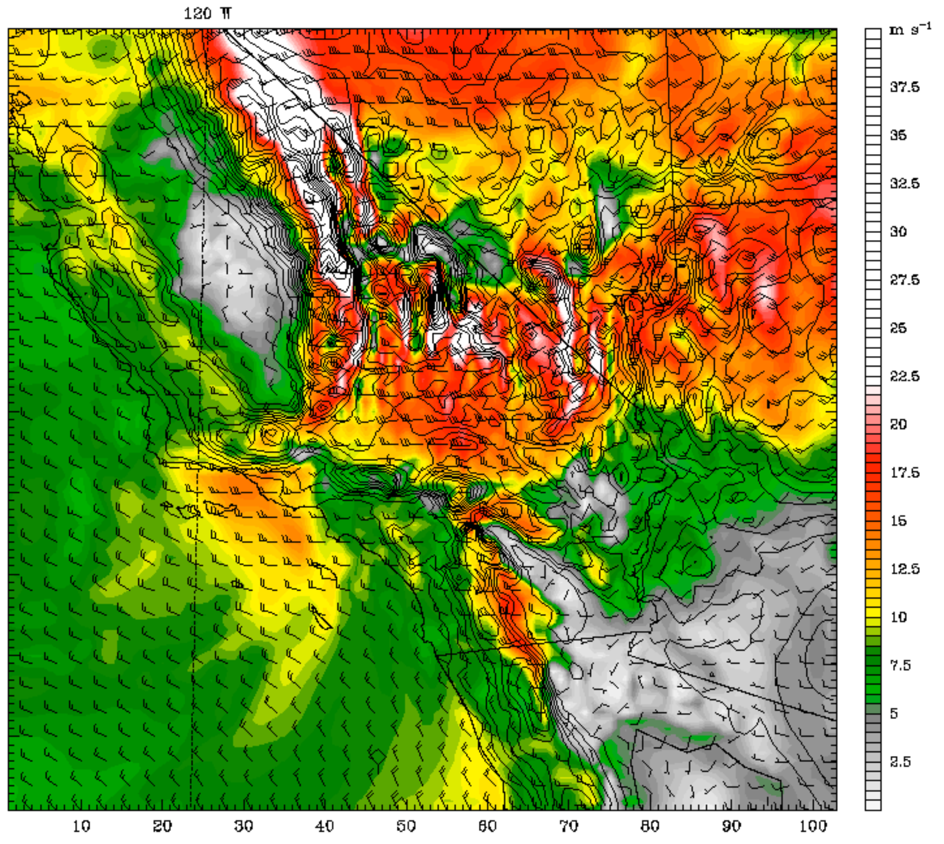
Wind Event: 25 Feb 2007, 1400 PST

Mojave Desert

Sea-Level Pressure (D1: 27-km)



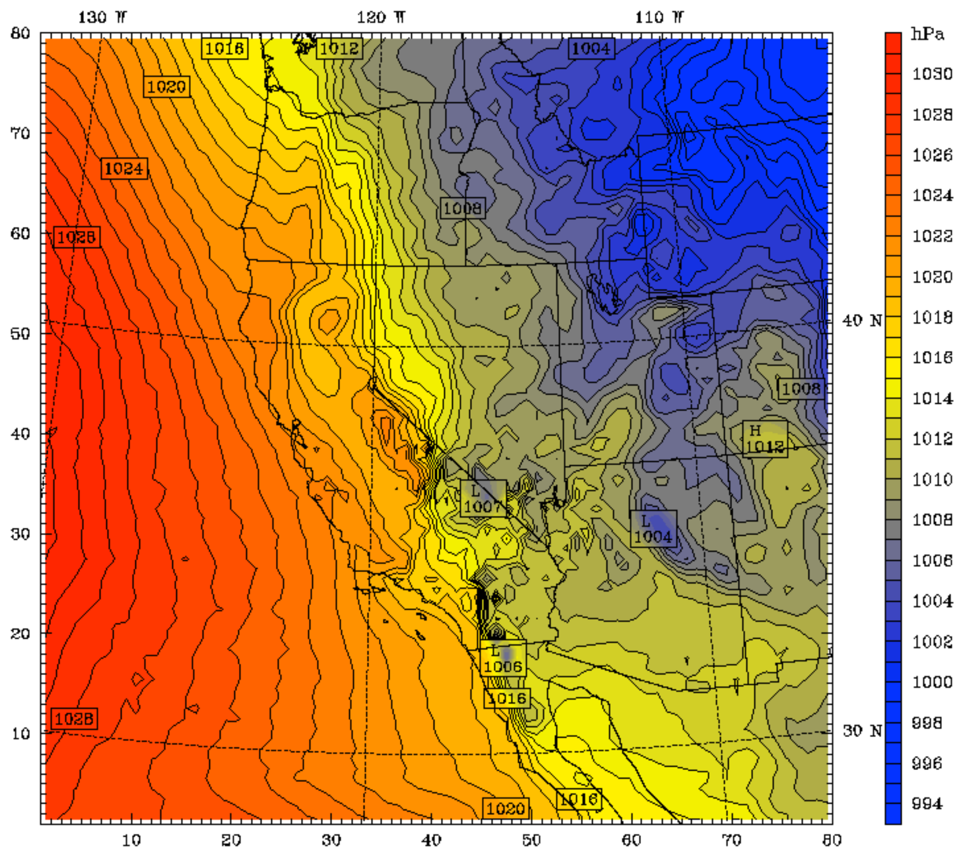
Surface Winds (D2: 9-km)



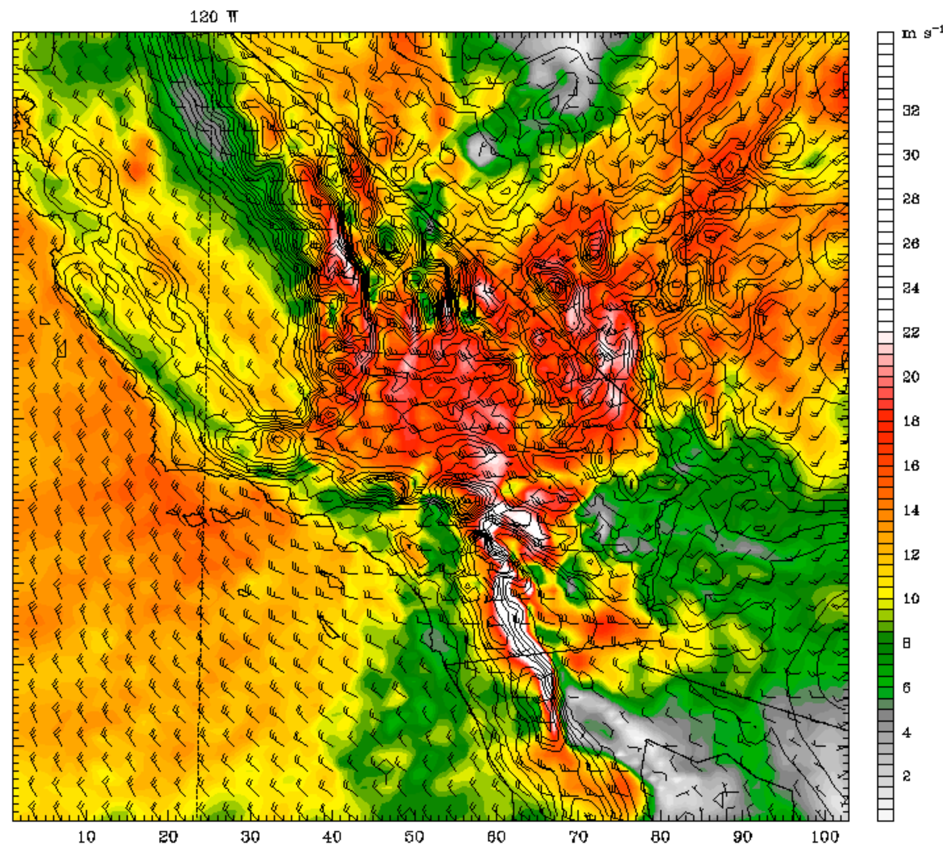
Wind Event: 22 Mar 2009, 1000 PST

Mojave Desert

Sea-Level Pressure
(D1: 27-km)



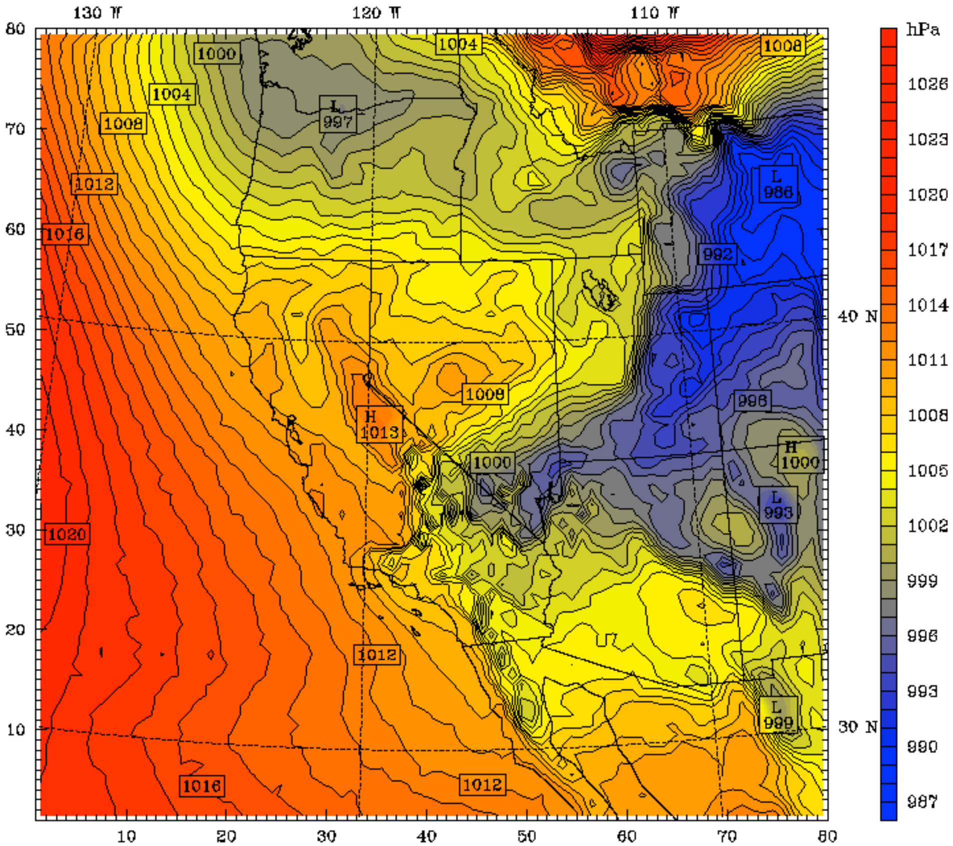
Surface Winds
(D2: 9-km)



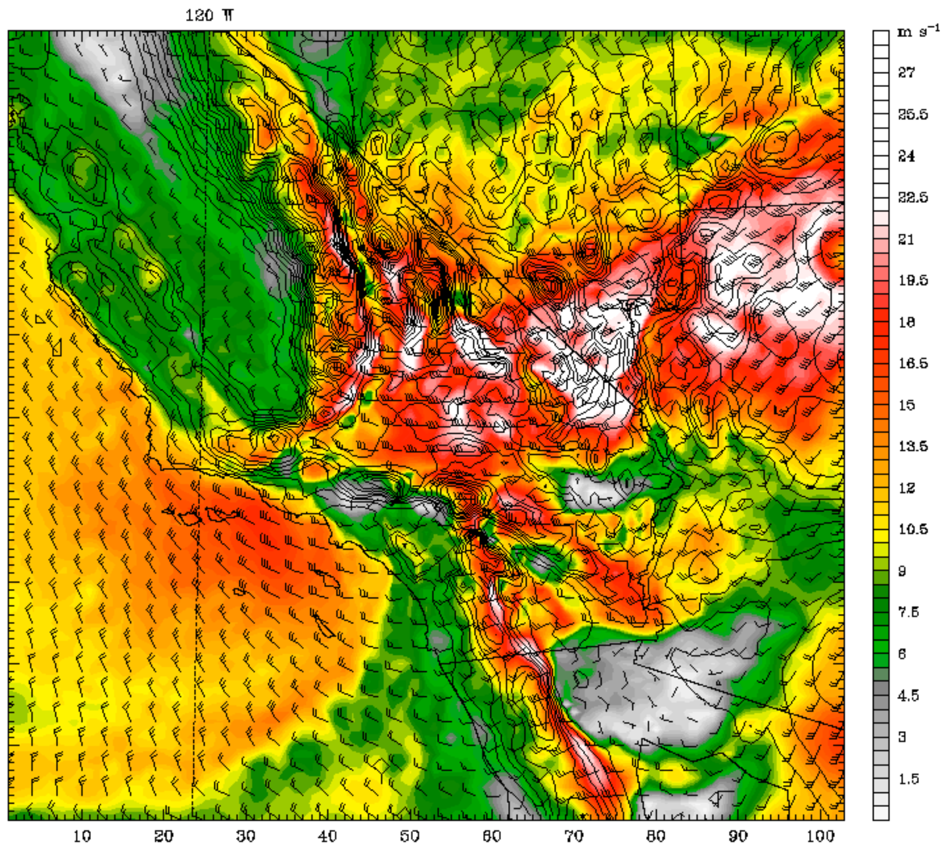
Wind Event: 13 Dec 2008, 1400 PST

Mojave Desert

Sea-Level Pressure (D1: 27-km)



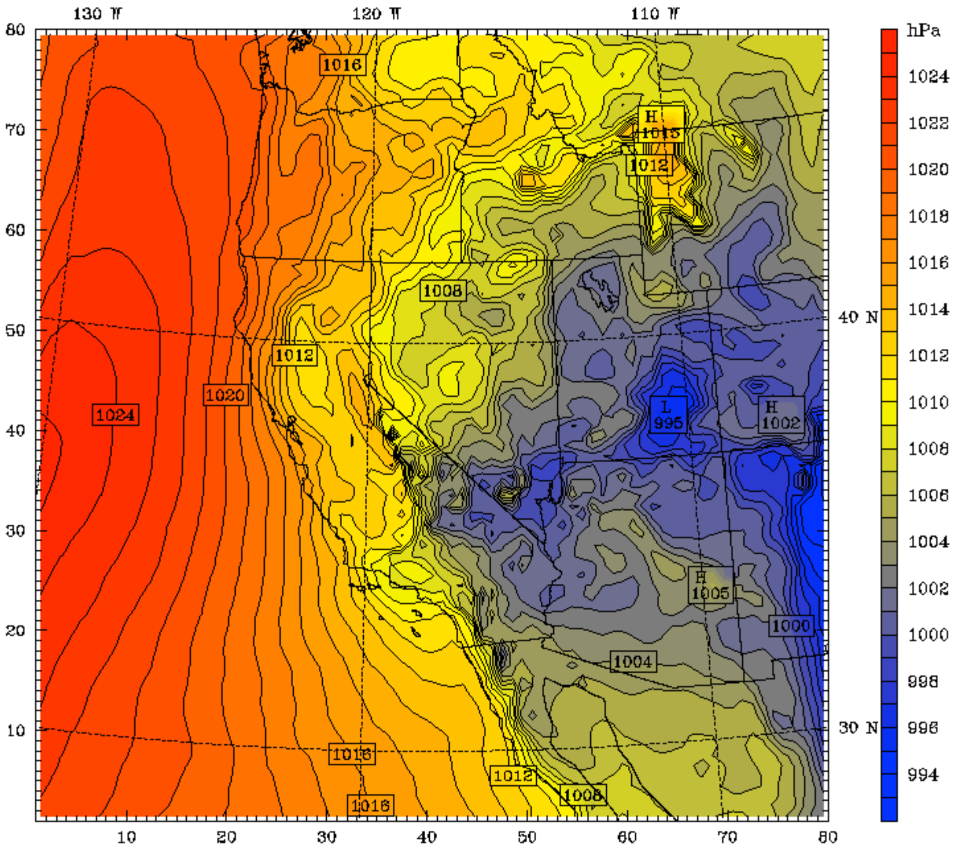
Surface Winds (D2: 9-km)



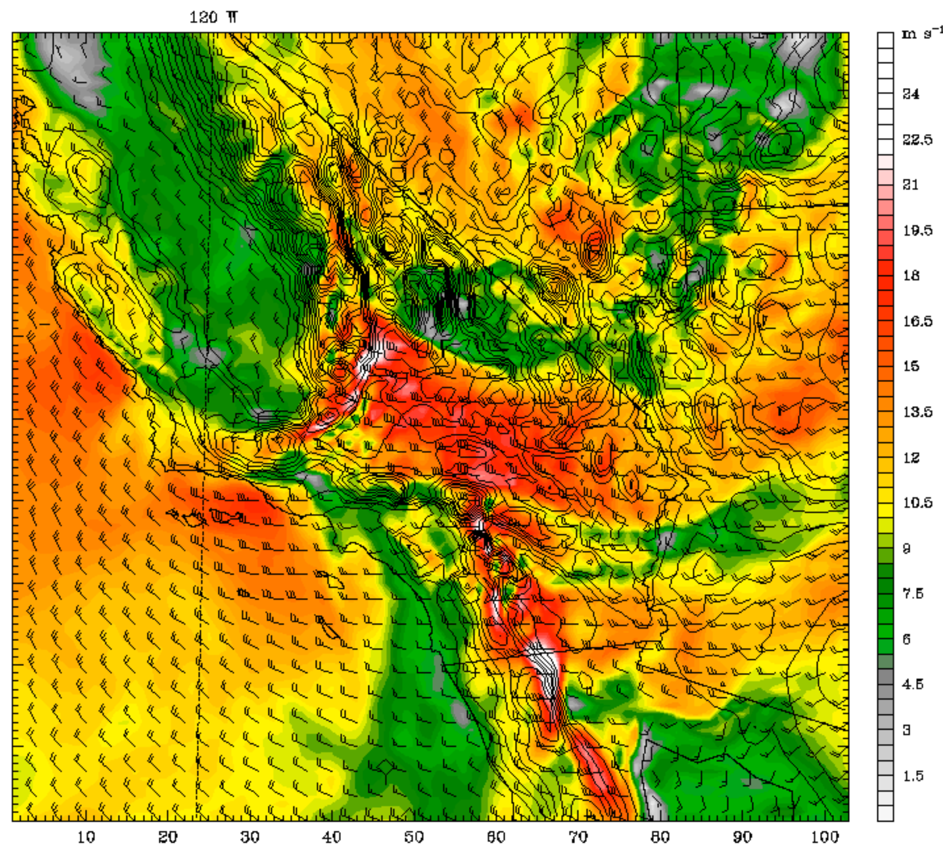
Wind Event: 4 May 2007, 1700 PDT

Mojave Desert

Sea-Level Pressure (D1: 27-km)



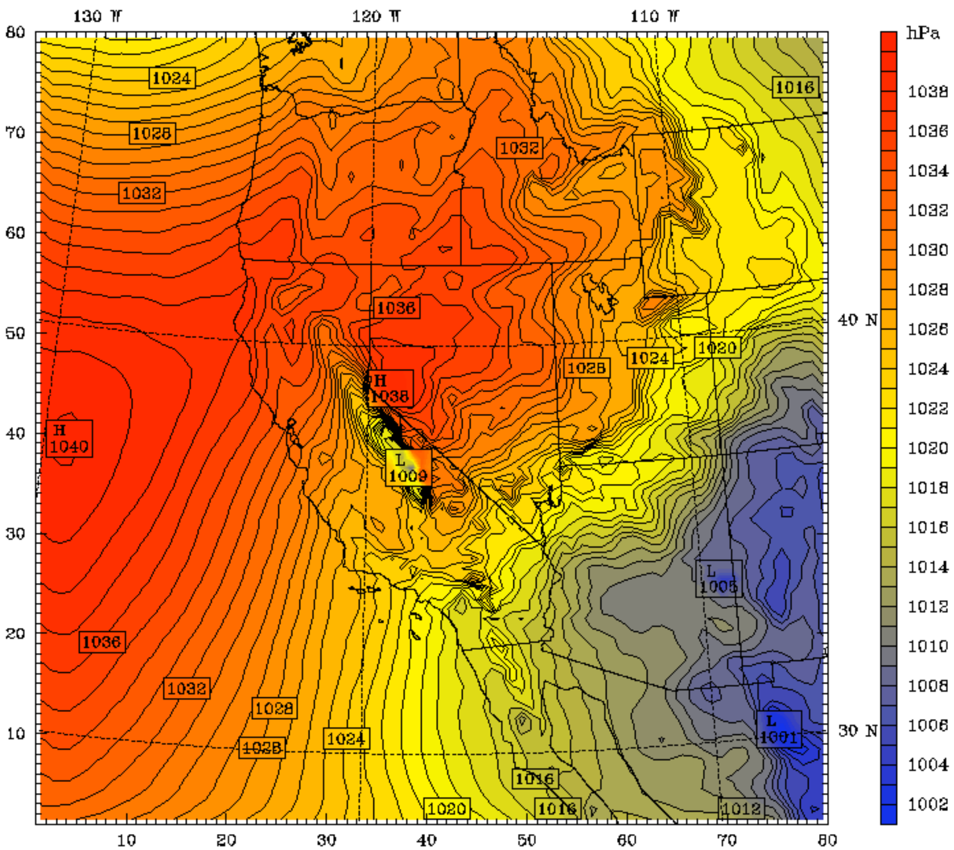
Surface Winds (D2: 9-km)



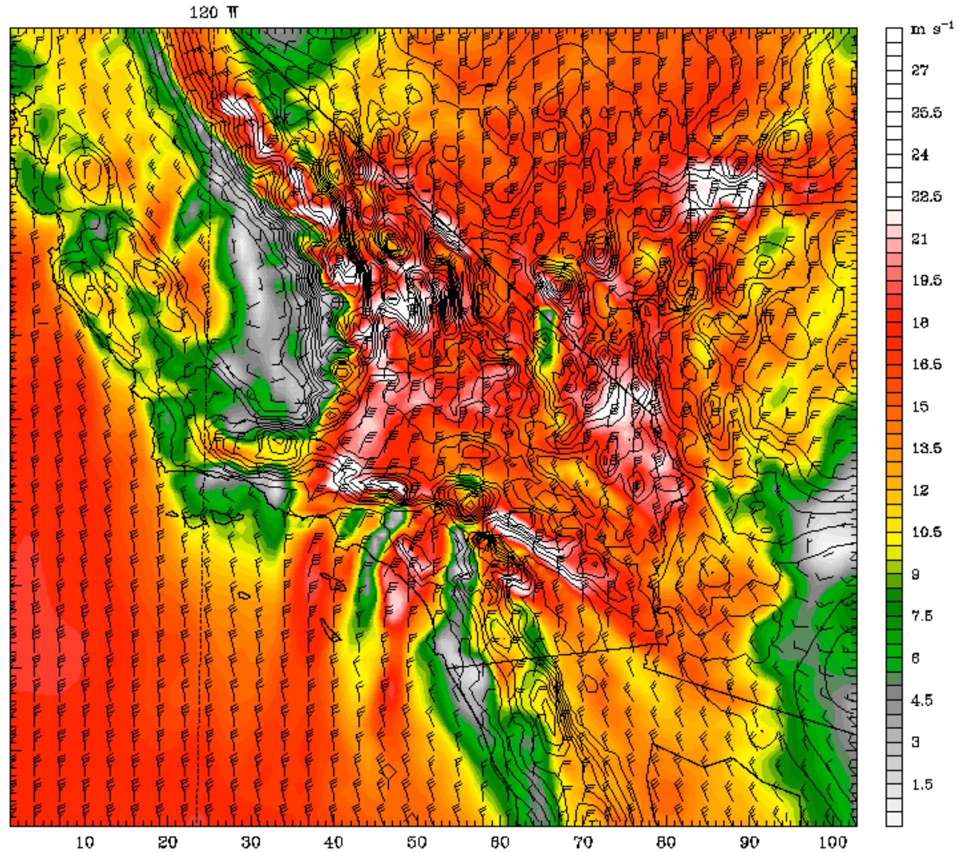
Wind Event: 5 Jan 2007, 1000 PST

Mojave Desert

Sea-Level Pressure (D1: 27-km)



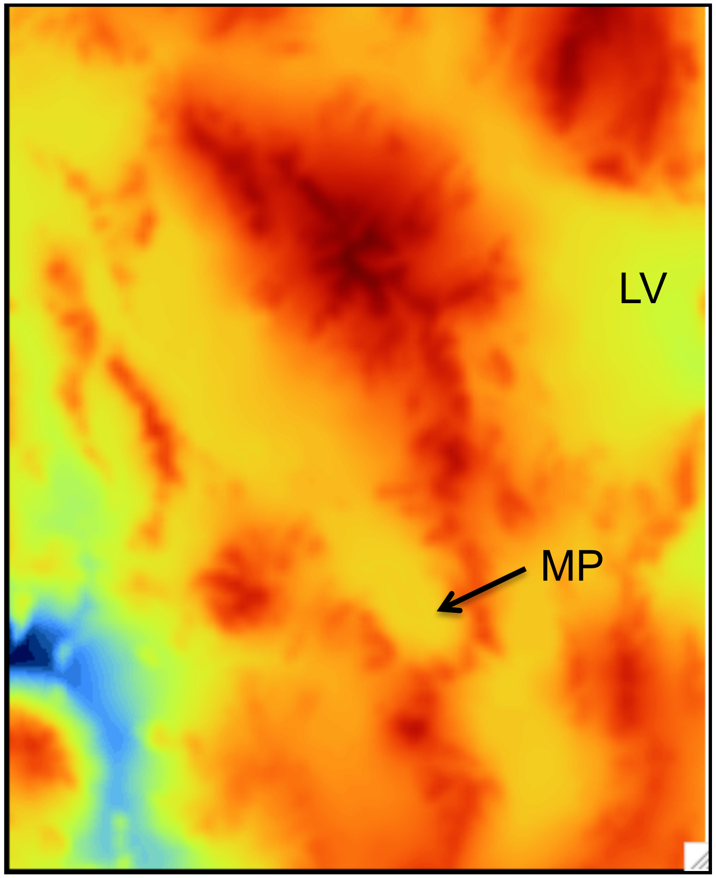
Surface Winds (D2: 9-km)



Mojave Desert

Mesquite Playa
22 Mar, 2009

D4: 1-km

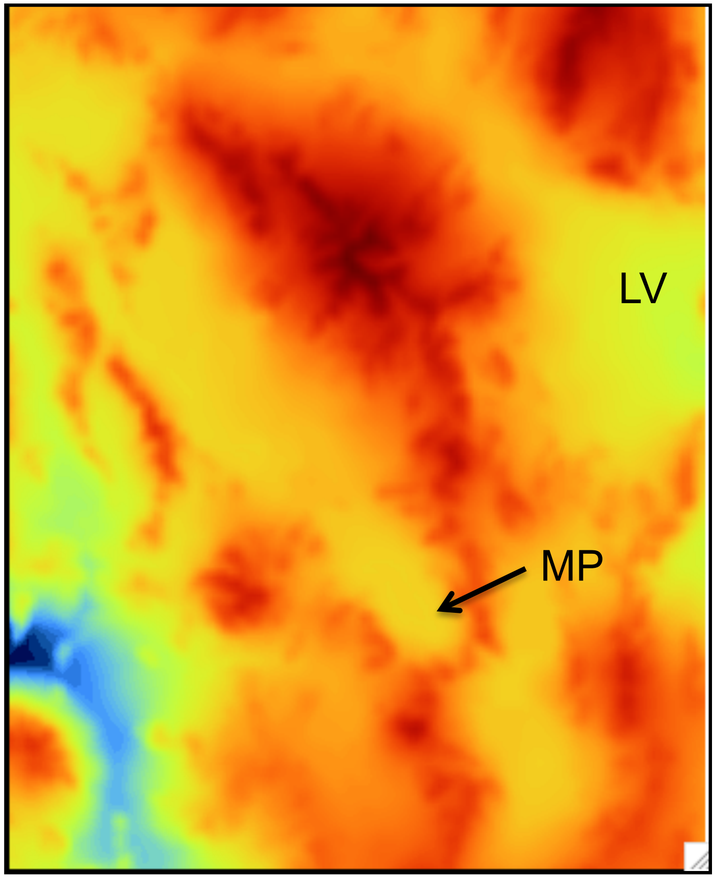


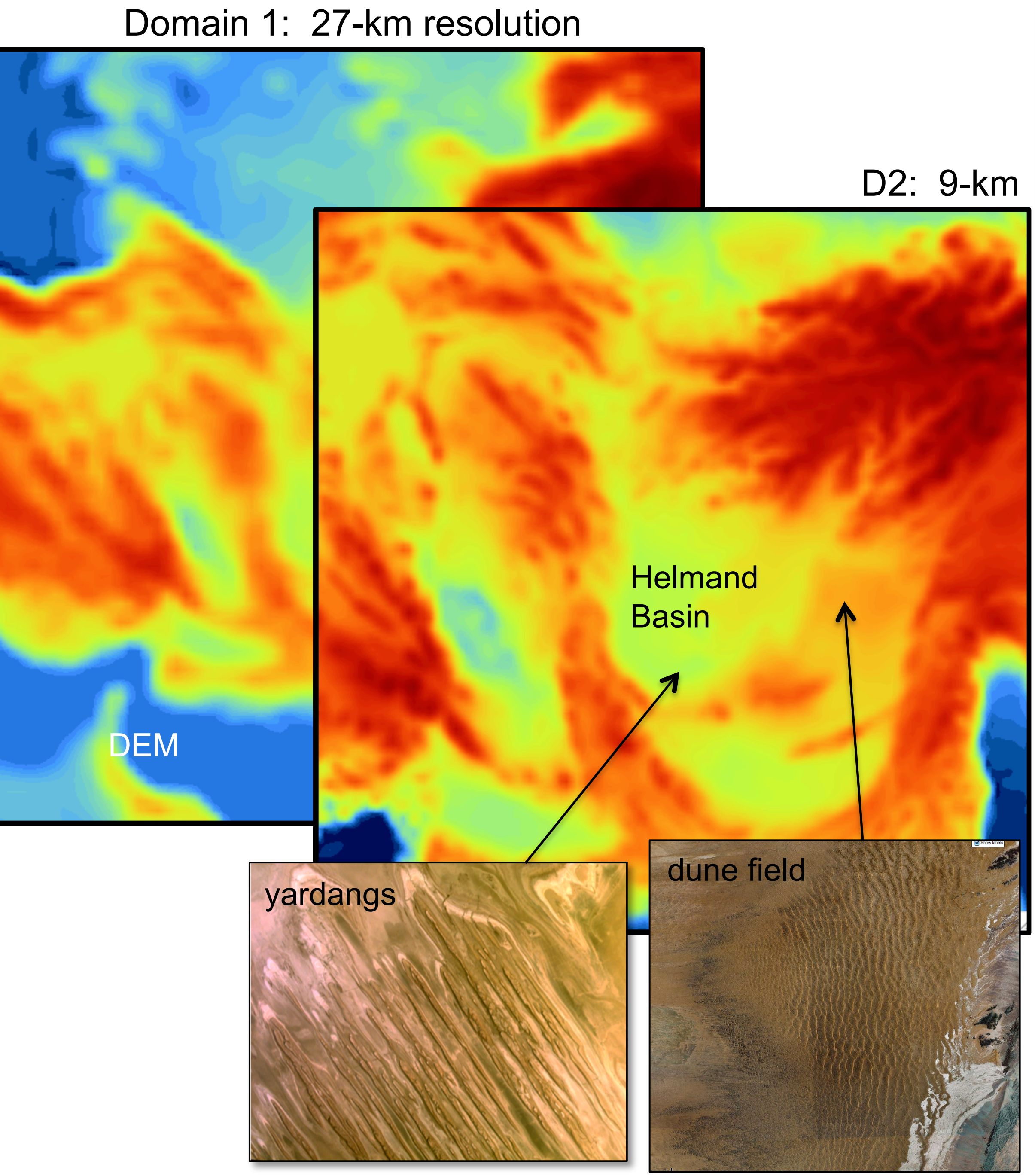
Mojave Desert

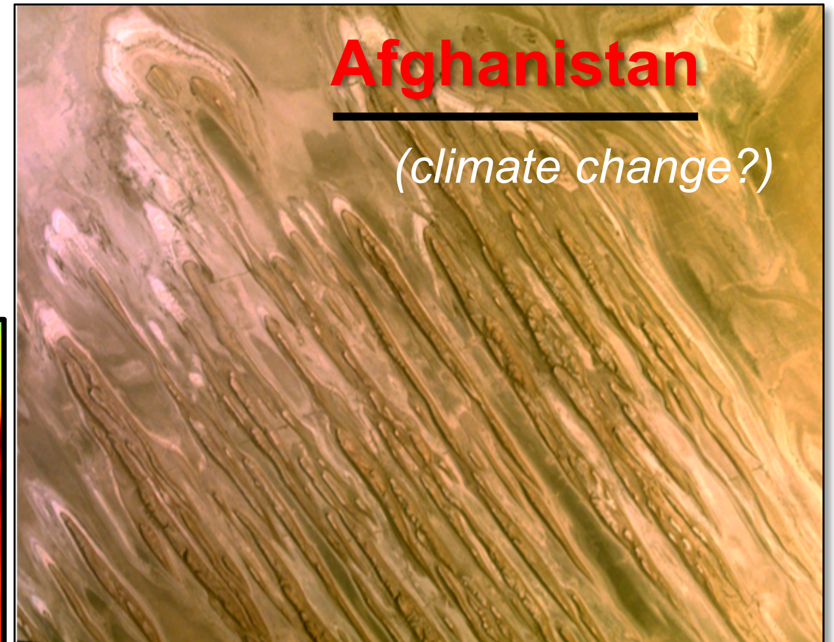
Degree of flow deflection depends on the nondimensional flow parameter,

Nh/u

D4: 1-km





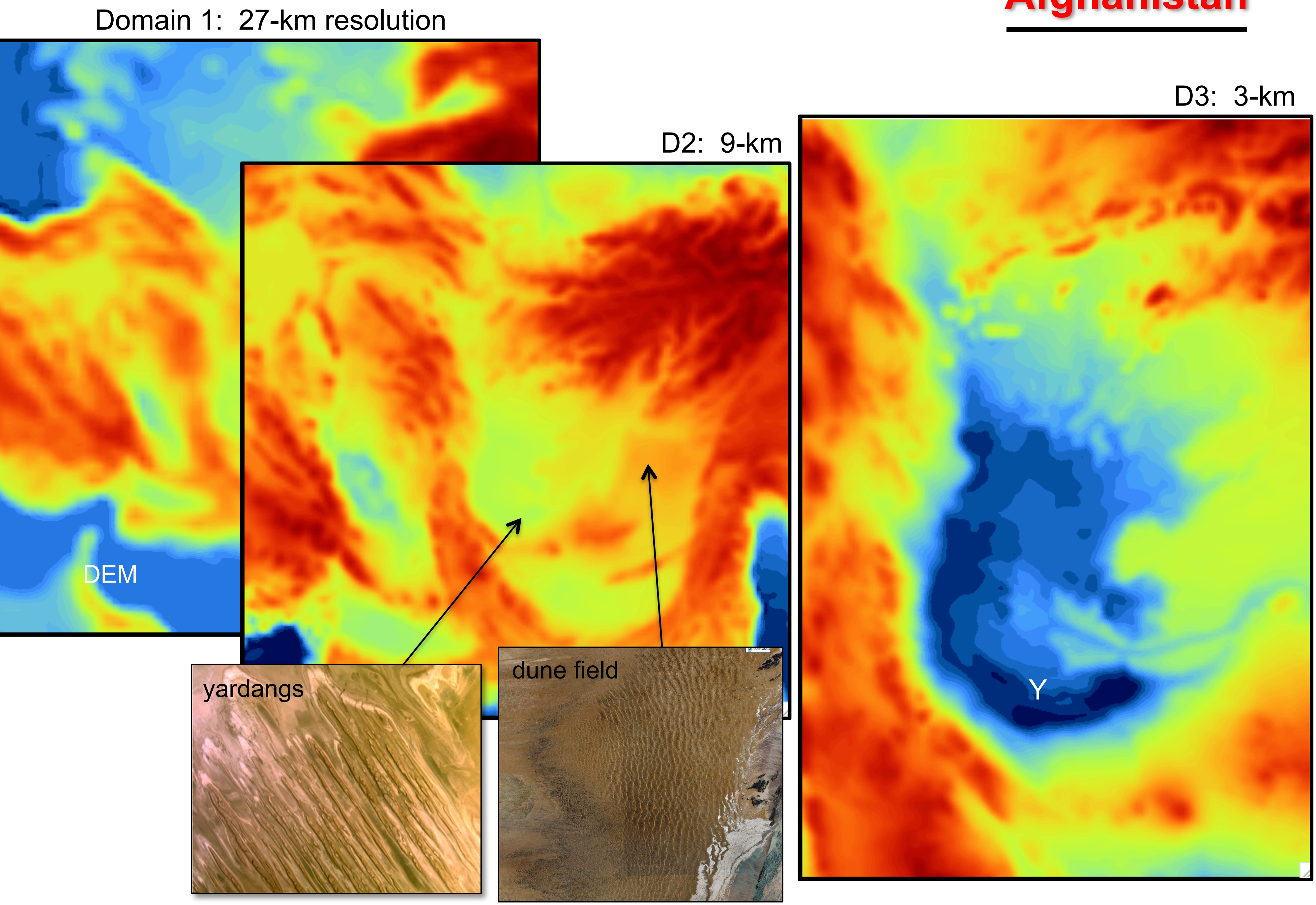


- What can landforms tell us about the past behavior of the atmosphere?

—·—·—·—·—·—·—·—

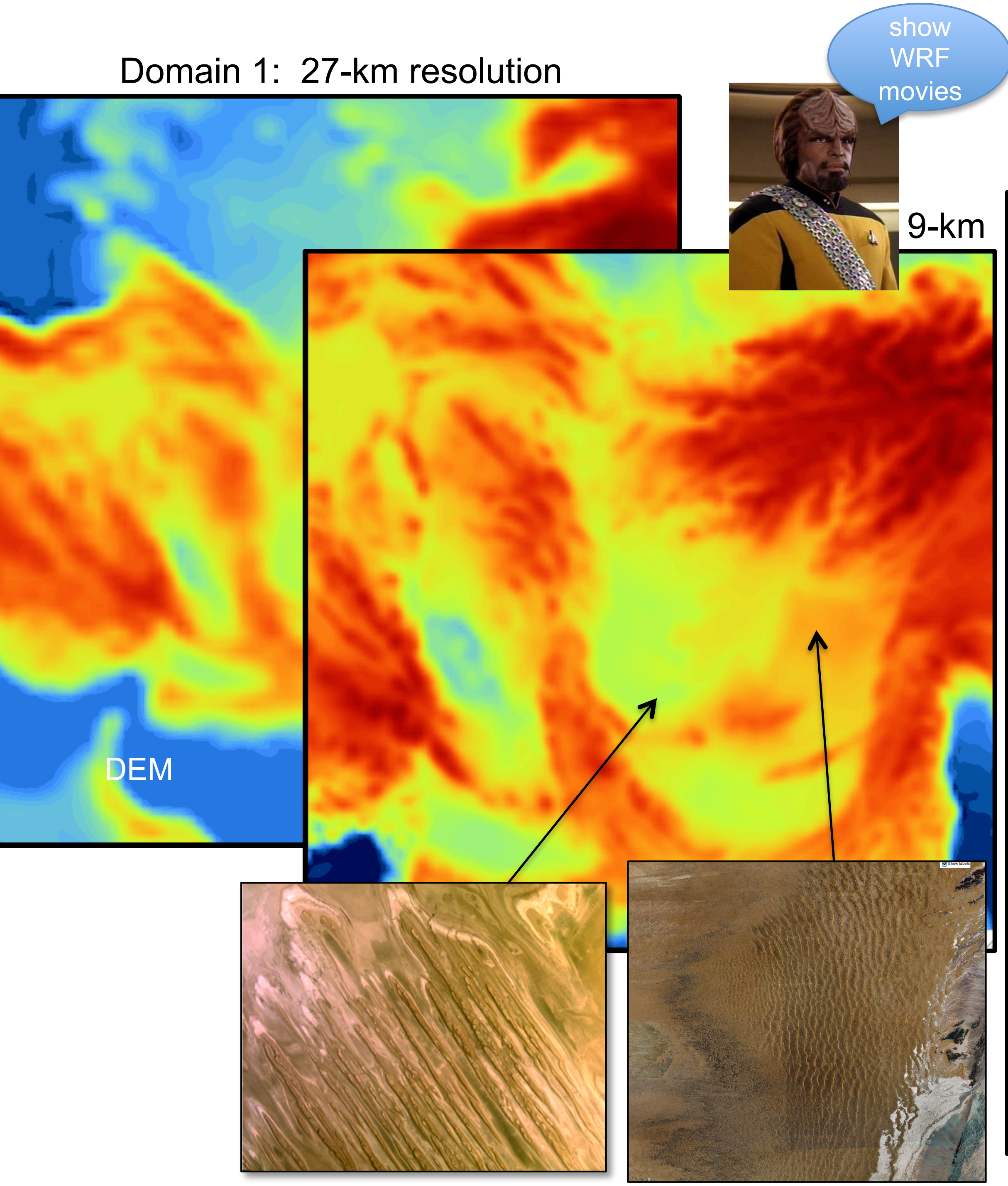
- Yardangs are good recorders of the wind direction during strong wind events.
- Question: Was the wind field different when these yardangs formed?

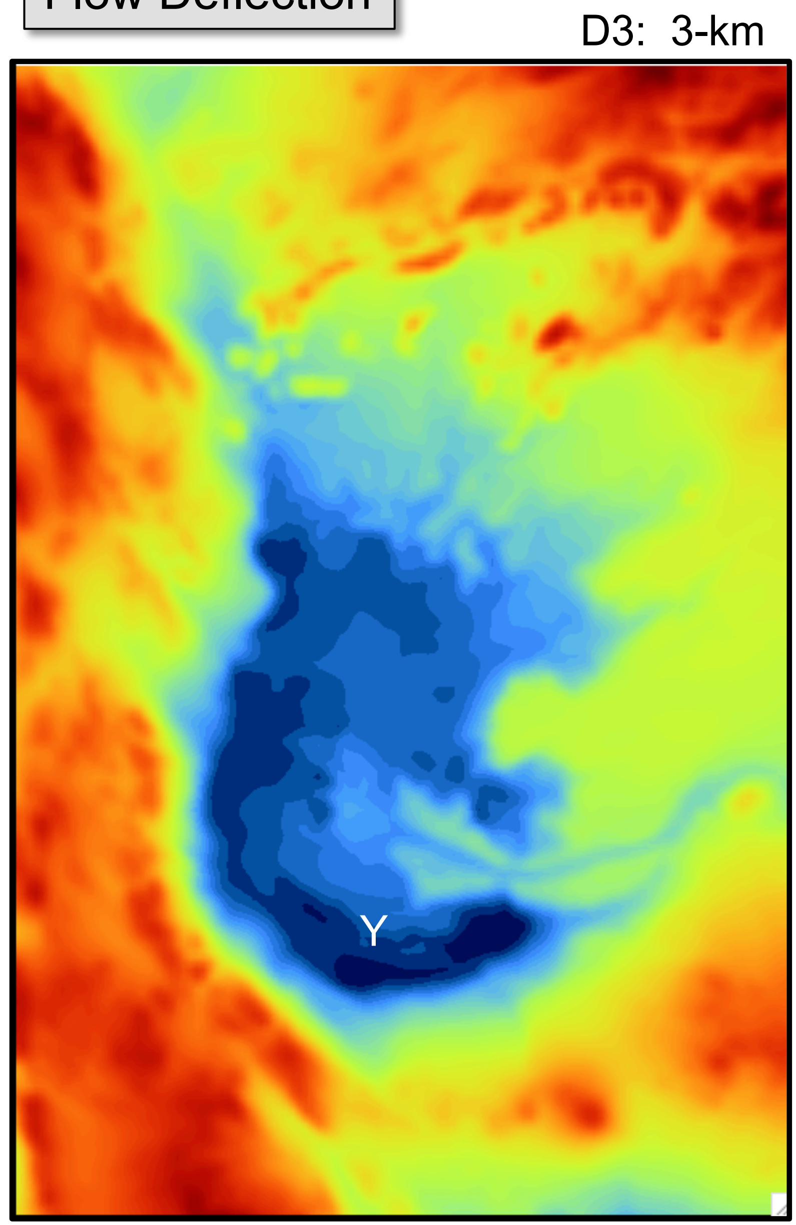
Afghanistan

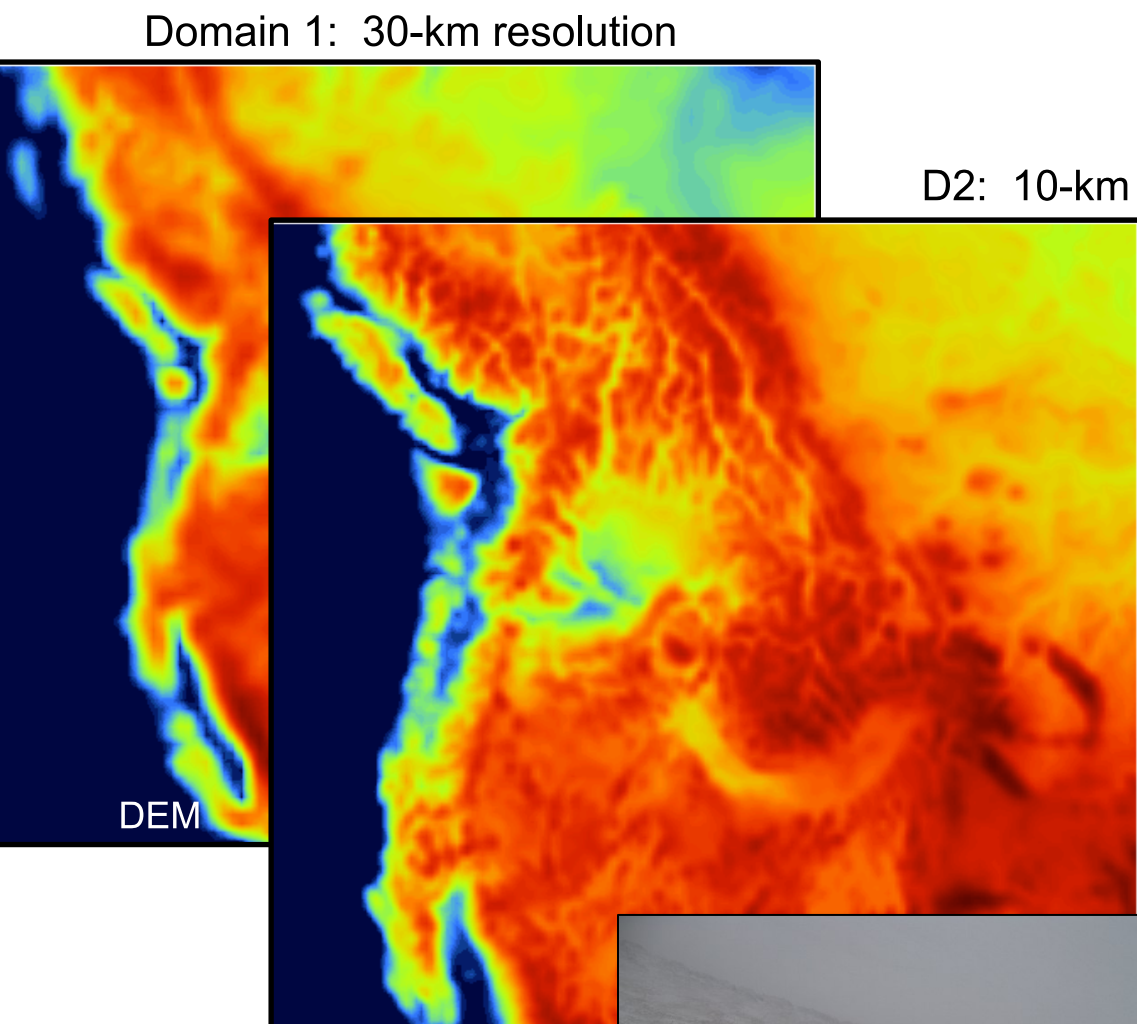


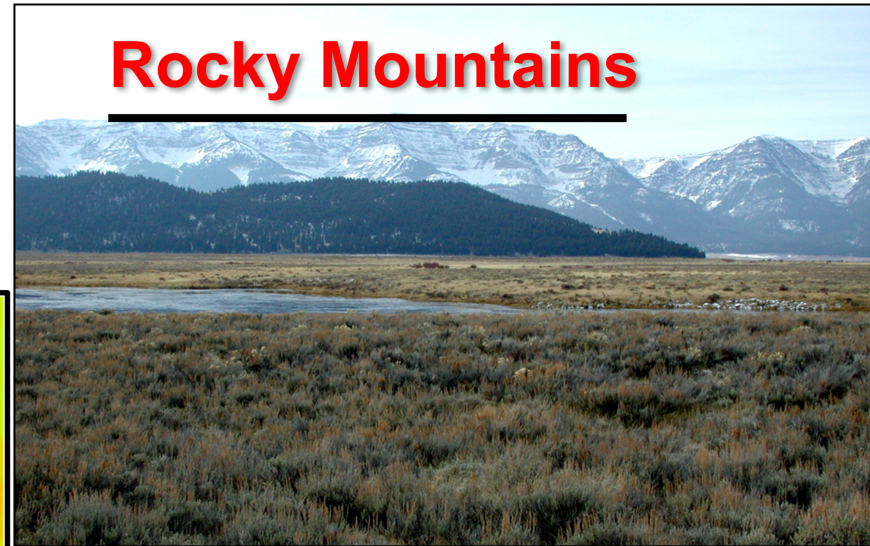
Afghanistan

Flow Deflection









- What will be the impact of future climate change on wetlands and glaciers in the Rocky Mountains?

↓

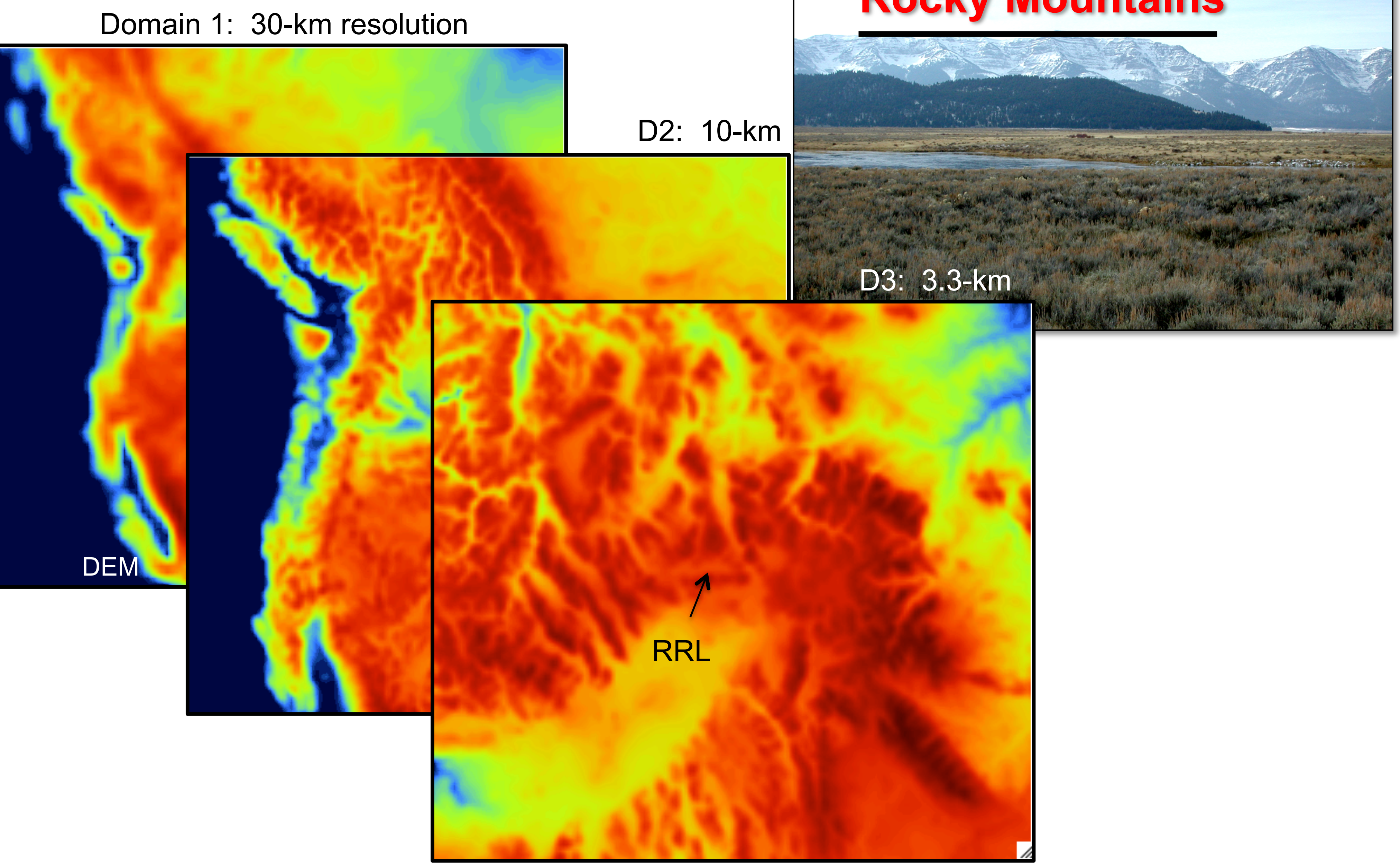
- We will need:

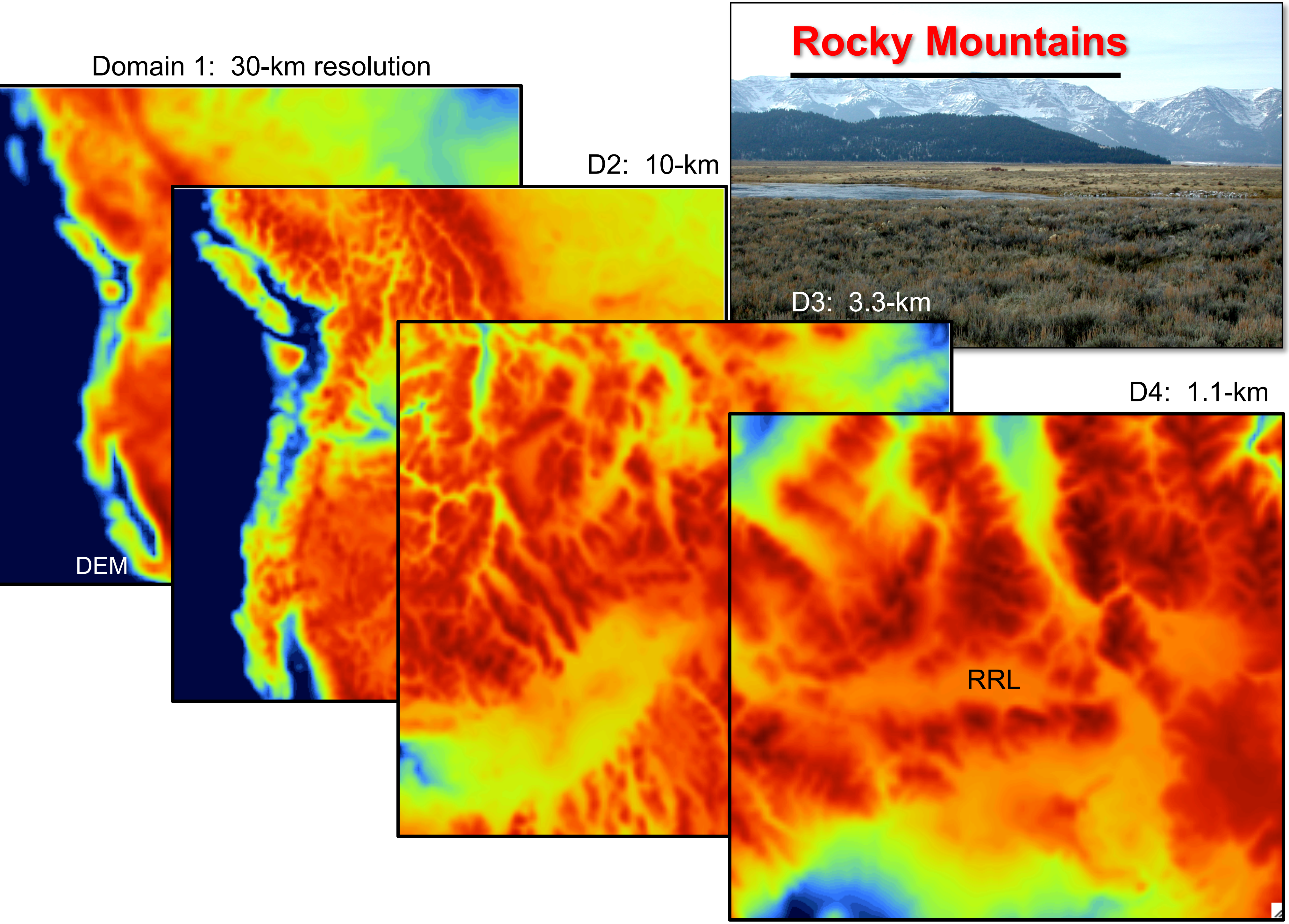
  hi-res RCM (e.g. WRF)

  blowing snow model(s)

  hydrologic models

  glacier models


Domain 1: 30-km resolution
D2: 10-km
Rocky Mountains
D3: 3.3-km
DEM
RRL

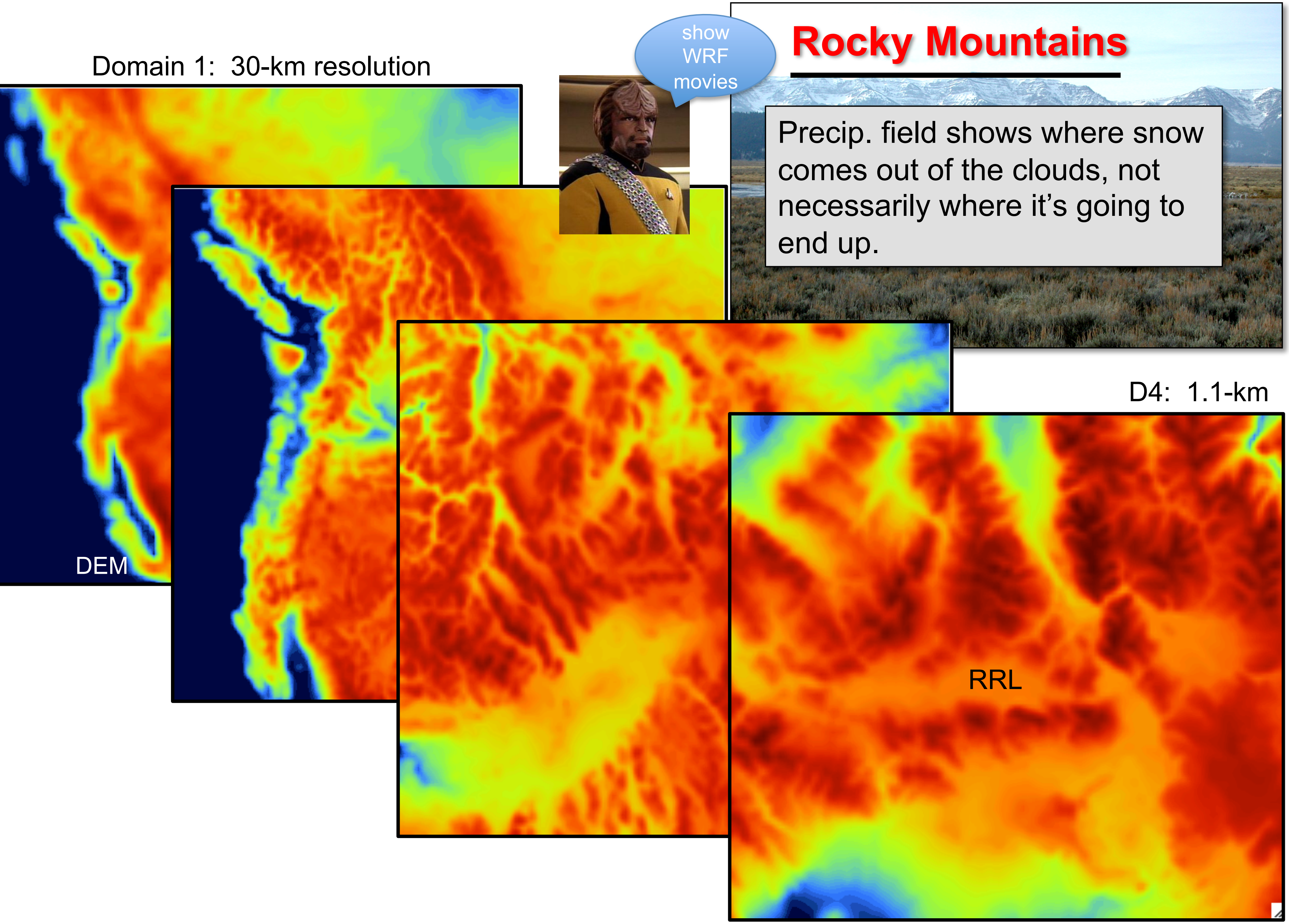

Rocky Mountains
Domain 1: 30-km resolution
D2: 10-km
D3: 3.3-km
D4: 1.1-km
DEM
RRL

Rocky Mountains

Precip. field shows where snow comes out of the clouds, not necessarily where it's going to end up.

Domain 1: 30-km resolution

D4: 1.1-km

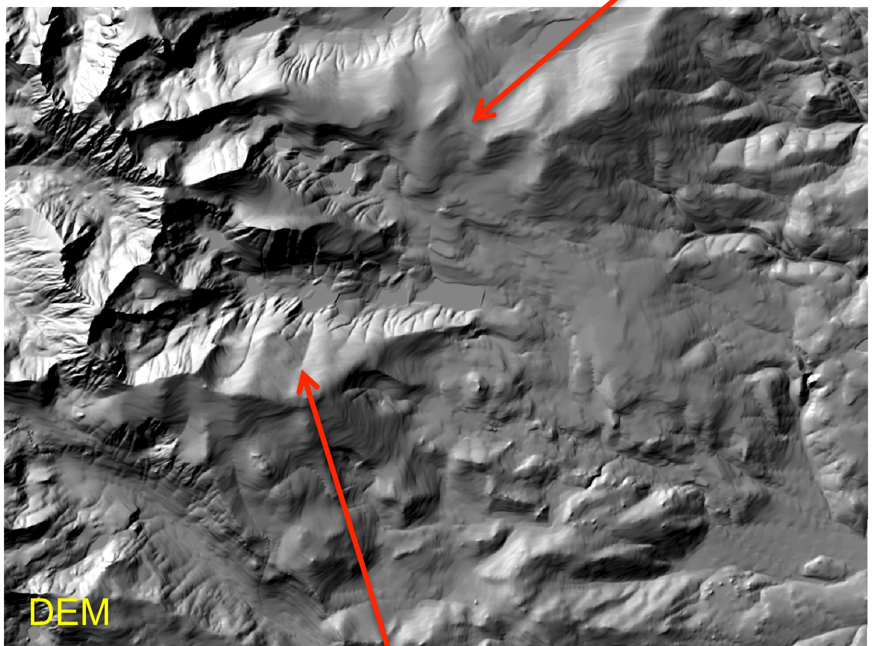


Rocky Mountains

glaciers

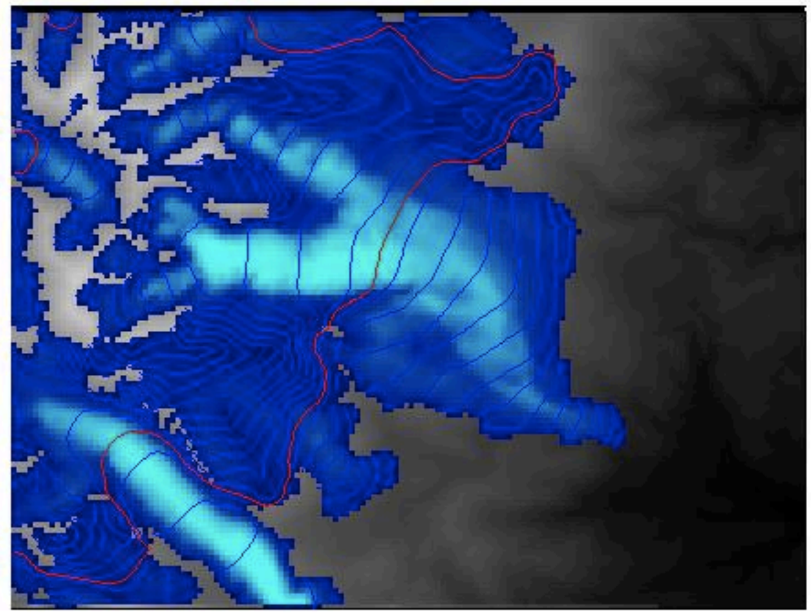
Indian Peaks Wilderness

Niwot Ridge



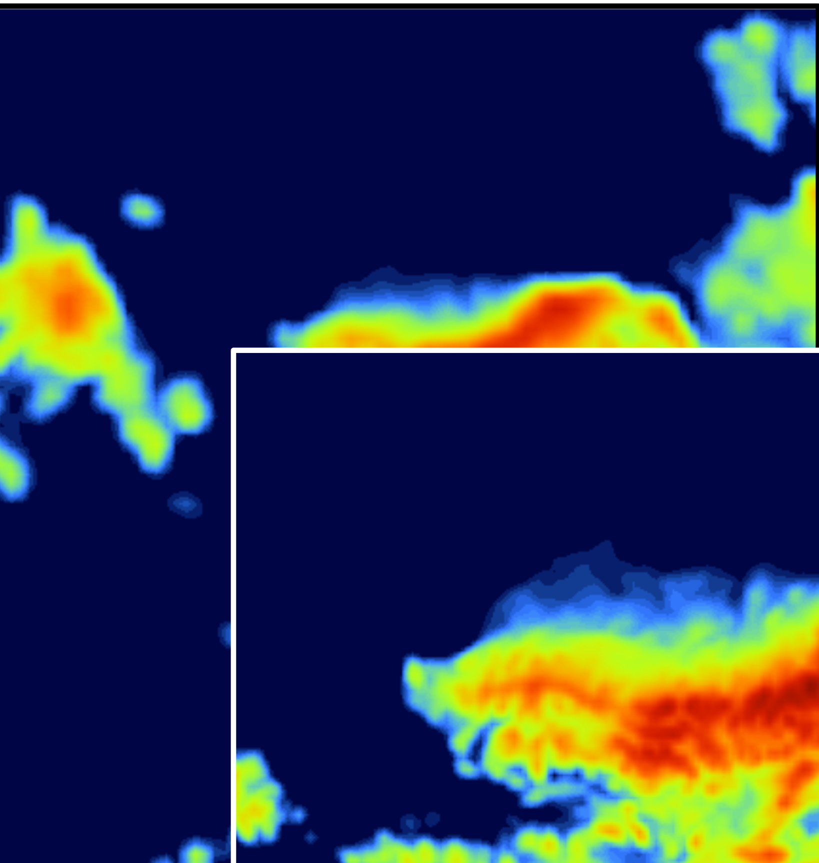
Caribou Mtn

Extent, Year=280, ELA=3400 m, AAR=0.60

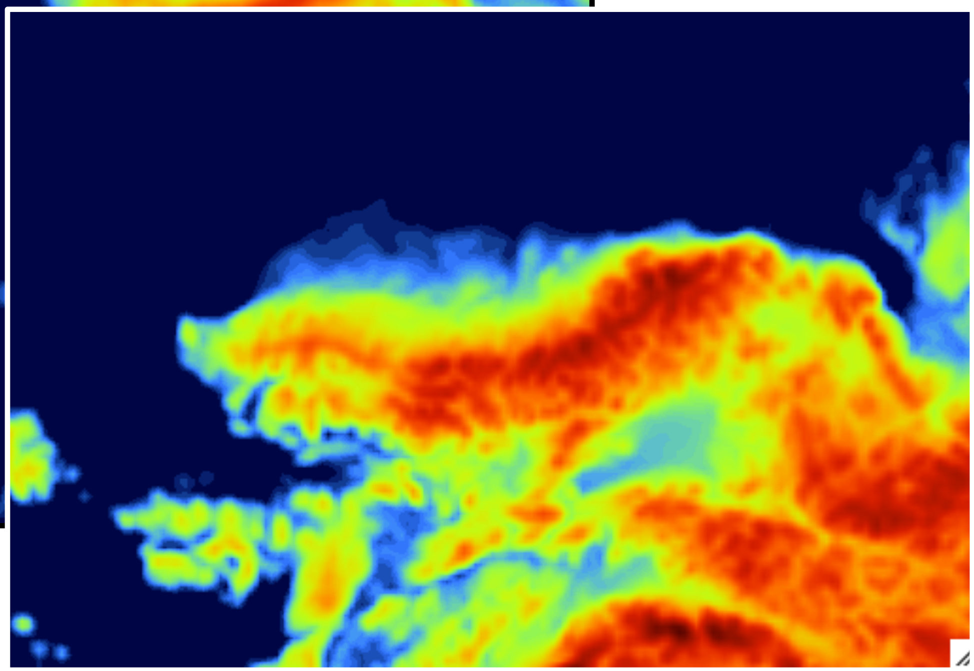


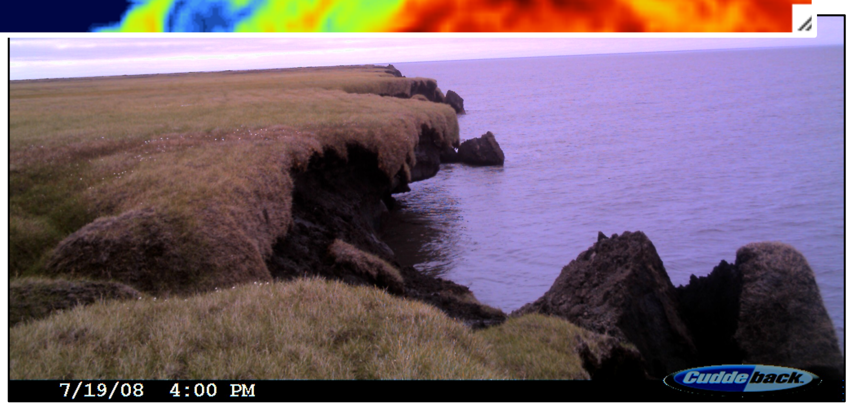
Ice extent during the Last Glacial Maximum produced by glacier model-gc2d.

Domain 1: 27-km resolution



D2: 9-km





- What will be the impact of future climate change on coastal erosion rates in the Arctic?

↓

- We will need:

  hi-res RCM (e.g. WRF)

  wave model

  ocean current & temp. model

  permafrost model


Thank you!
D. Lawrence