Real-Time High-Resolution Weather Modeling in “Rugged” Regions

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Overview

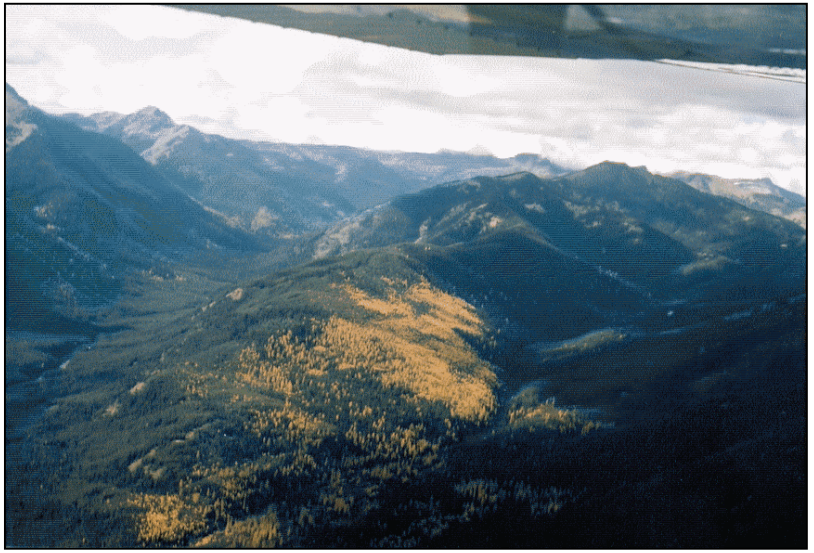
- Motivation for this work
- Weather in “rugged” regions
- Weather Research and Forecast (WRF) model
- Performance testing

Acknowledgements

- Peter Johnsen and Frank Chism – Cray
- Arctic Region Supercomputing Center
- USDA Forest Service, Fire Sciences Lab
- National Weather Service, Missoula Weather Forecast Office

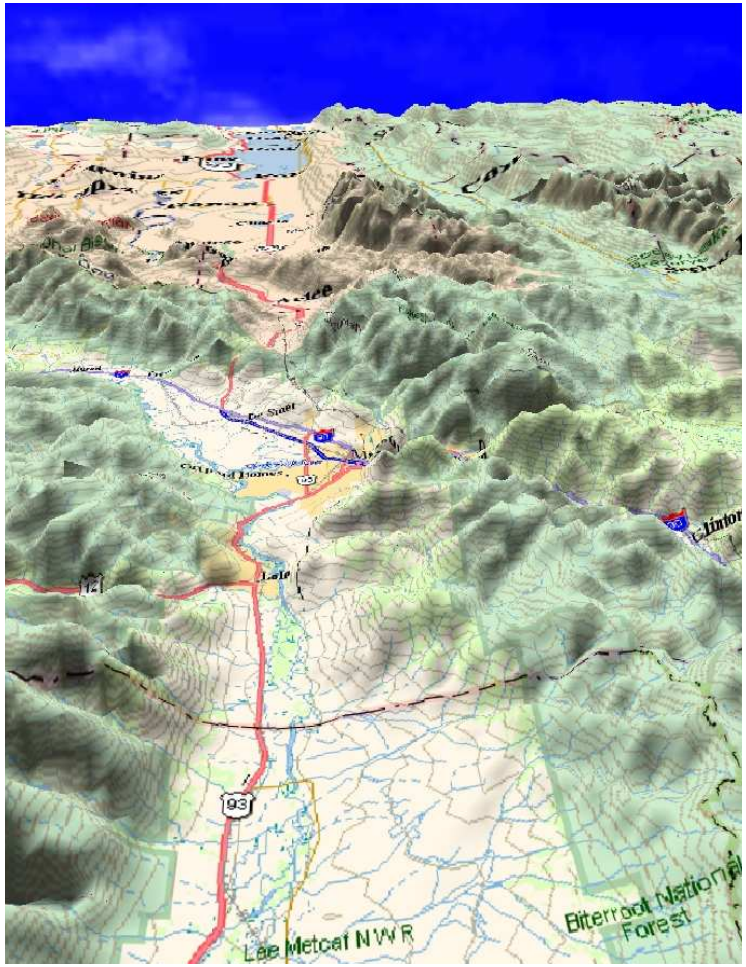
Motivations

- Background in computer science, interests in application to physical sciences
- HPC experience
- Fascination with weather
- Aviation interests



Weather in “Rugged” Regions

- Missoula, Montana

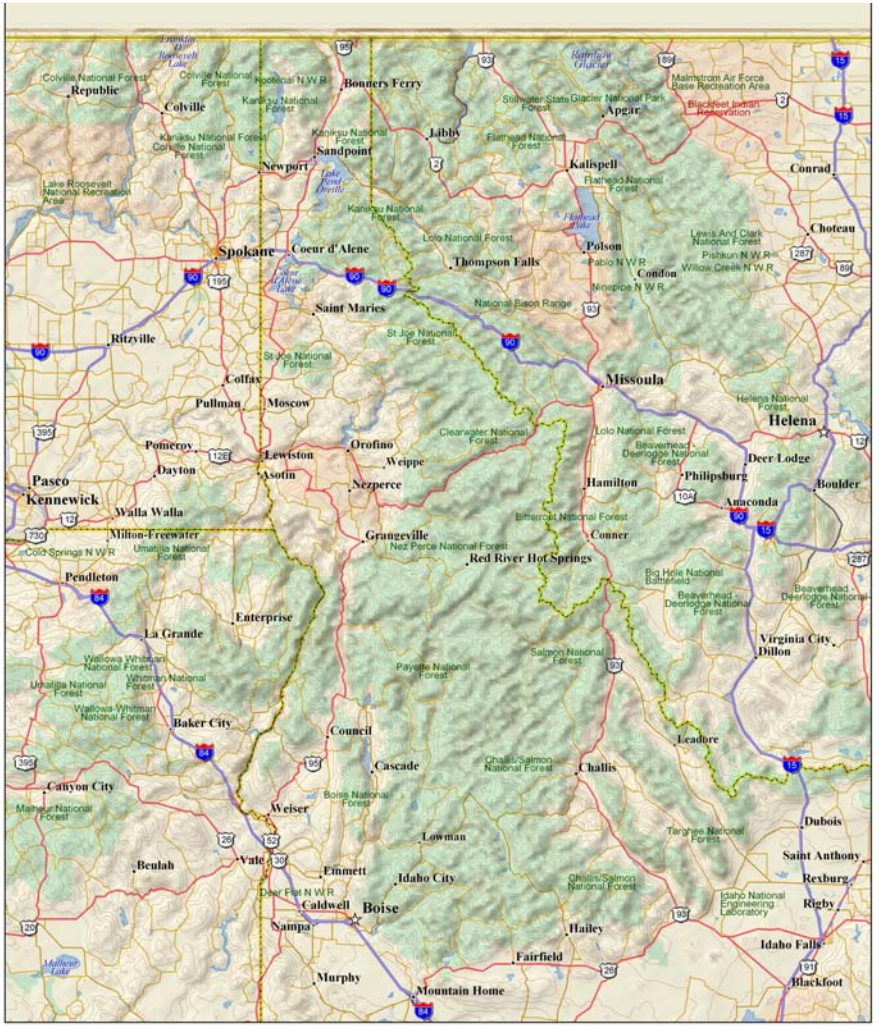


Weather Features Near Missoula

- Hellgate Winds
- Inversions
  - Visibility issues
  - Wind issues
- The “Lolo Tumble” and the “Evarro Tumble”

Bigger Picture

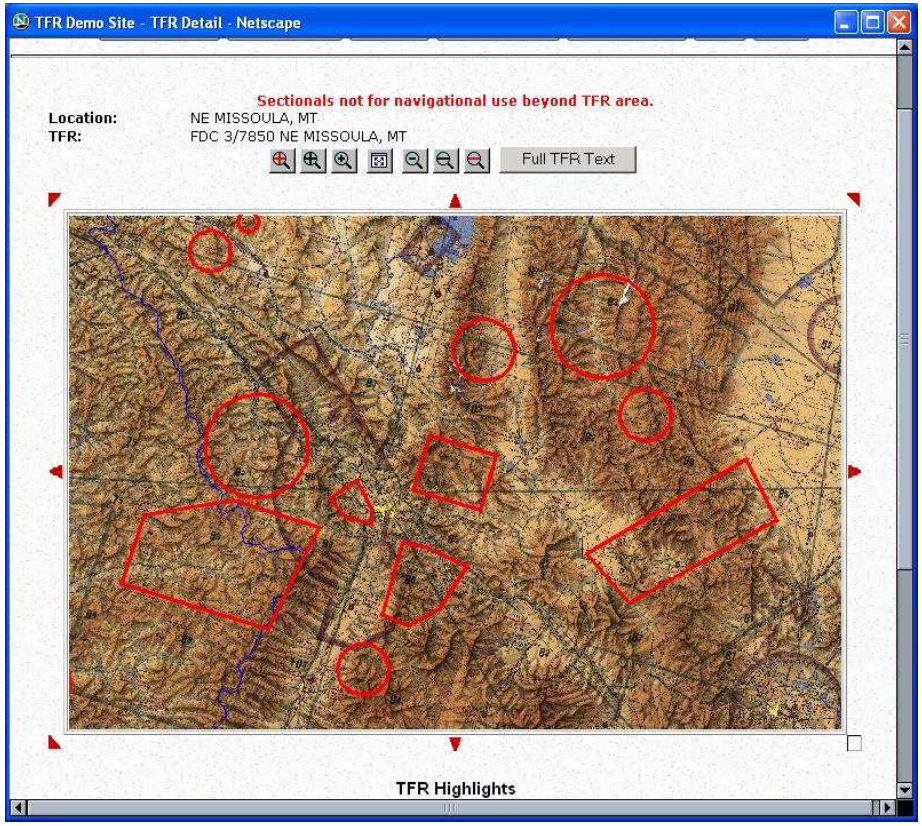
- Missoula experiences relatively benign weather
- Much of the area is a lot more rugged
- Our goal
  - Capture the small-scale behavior not resolved in typical national and regional weather models



Missoula County Warning Area (CWA)

Benefits of High-Resolution Weather Models

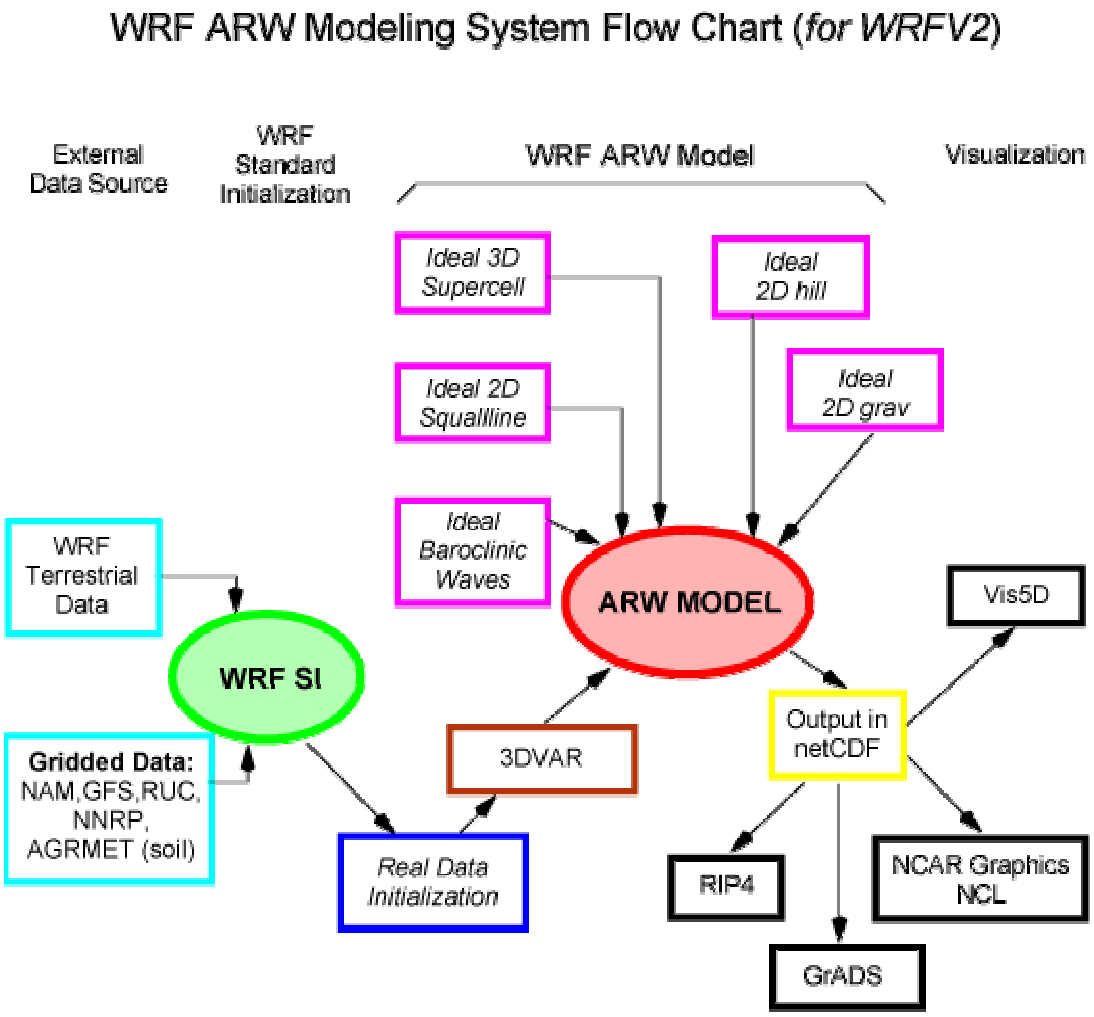
- Firefighting
- Aviation
- Interesting research area



Weather Research and Forecast (WRF) Model

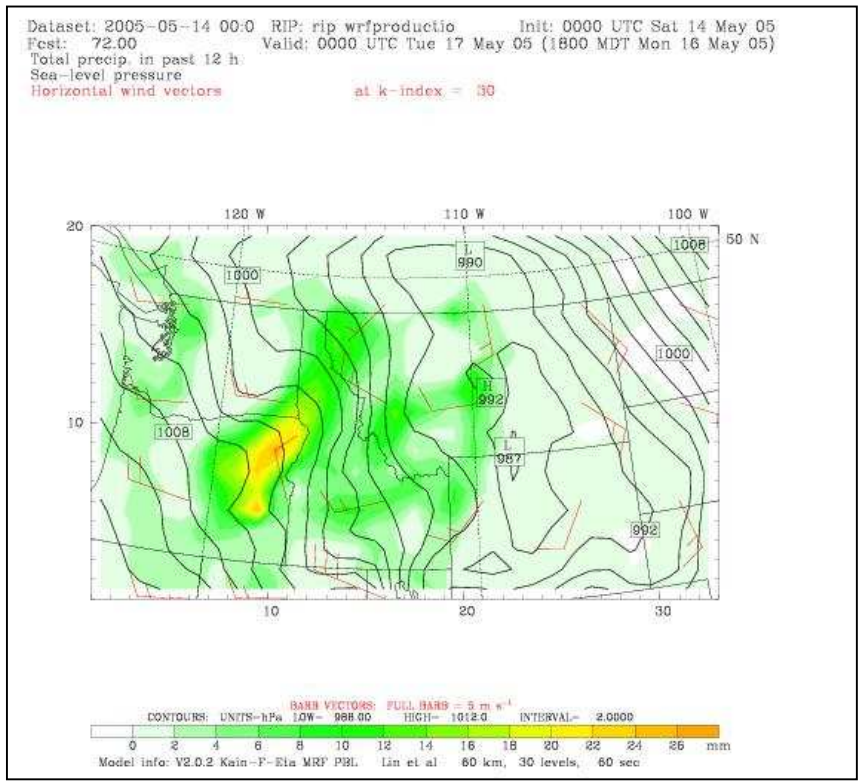
- Next generation mesoscale NWP system
- Designed to support operational forecasting and atmospheric research needs
- Features
  - Multiple dynamic cores
  - 3-dimensional variational data assimilation
  - Software architecture for computational parallelism and system extensibility
- Suitable for scales from meters to thousands of kilometers
- *http://www.wrf-model.org/*

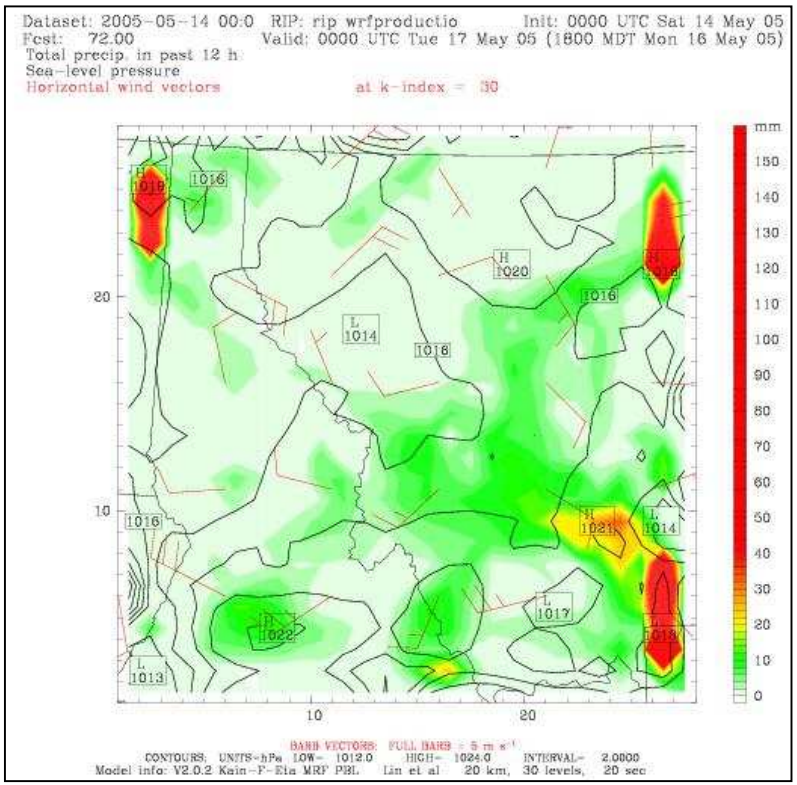
WRF Architecture



Current Uses of WRF

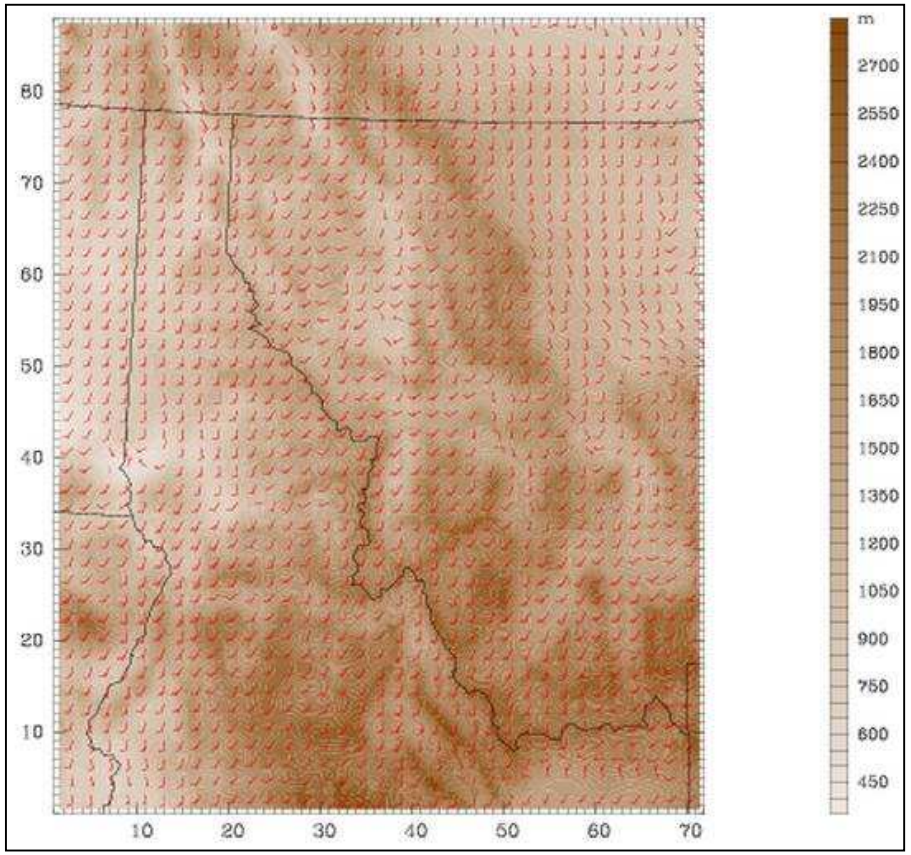
- Daily 60km with 20km nest
  - 1 GHz Pentium III
  - 72-hour forecast takes about 7½ hours

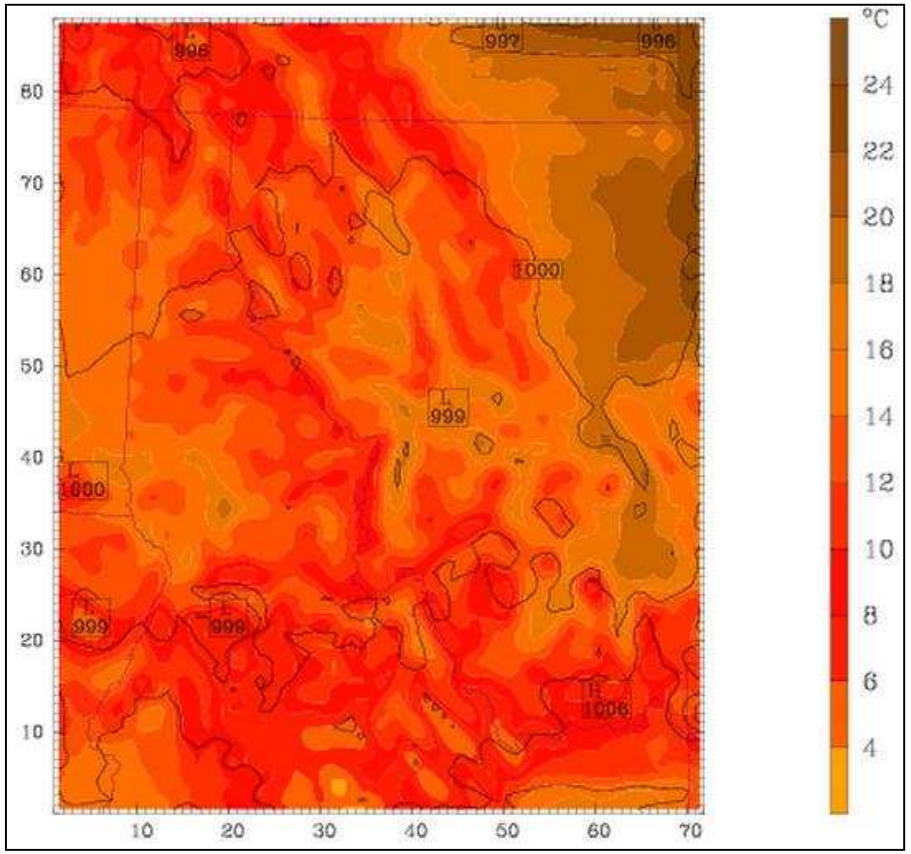




Current Uses of WRF

- Daily 7.5km (73x86x75 grid)
  - Linux cluster, 4-CPU, 2.8 GHz Intel Xeon
  - 72-hour forecast takes about 12 hours





Porting to HPC Platforms

- Want to execute numerous high-resolution simulations over Missoula CWA, in real-time, and compare results with meteorological observations
- Need to understand what kind of resolution is realistic given available resources

Porting to HPC Platforms

- Cray XD1
  - Acquired by USDA FS Fire Sciences Lab (FiSL) in Autumn 2004 for smoke plume simulations
  - 12 dual-CPU nodes with 2.2 GHz AMD Opteron processors. Each node supported by 2 GB memory
  - WRF compiled with PGI 5.2 / MPI – default options

Porting to HPC Platforms

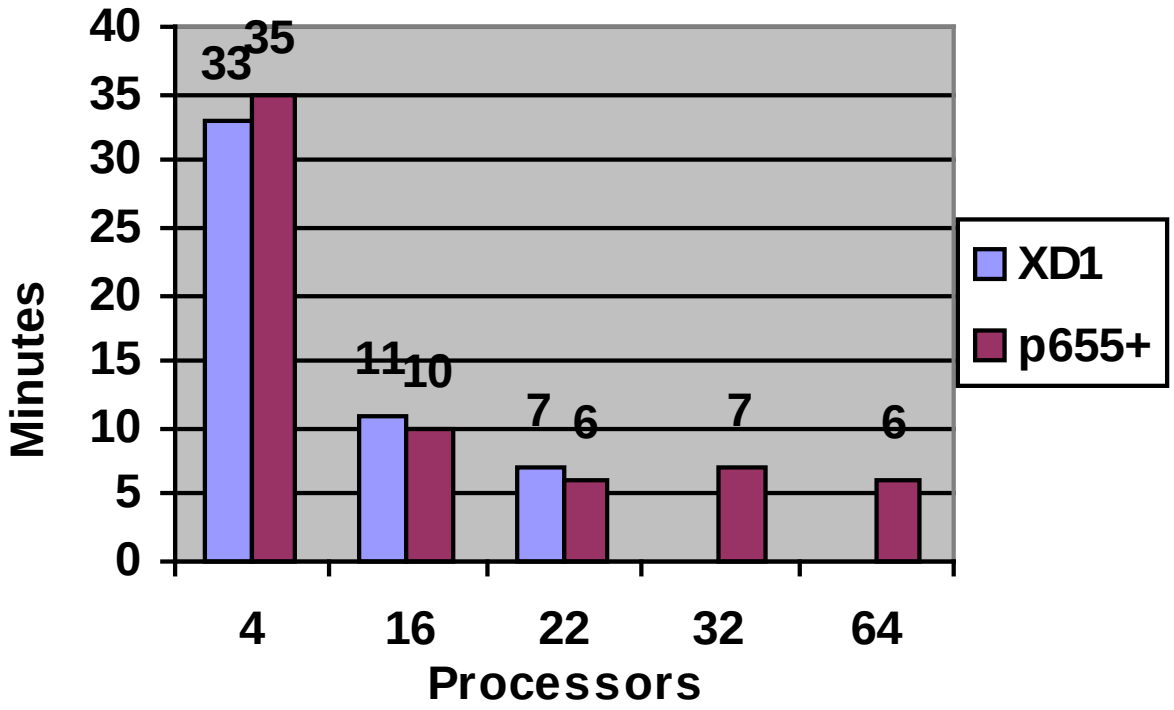
- IBM p655+ Servers
  - Arctic Region Supercomputing Center
  - Each of 92 servers possesses eight 1.5GHz Power4 CPUs with 16 GB memory
  - WRF compiled with xlf90 / MPI using default options

Performance Testing on Uniform Grids over Missoula CWA

- Attempted simulations
  - 7.5 km resolution – 73x86 (6,278 points) on 75 levels (20s timestep)
  - 2.5 km resolution – 216x264 (57,024 points) on 75 levels (8s timestep)
  - 833 m resolution – 635x789 (501,015 points) on 75 levels (3s timestep)
- Hoped-for simulations
  - 278 m resolution
  - 93 m resolution

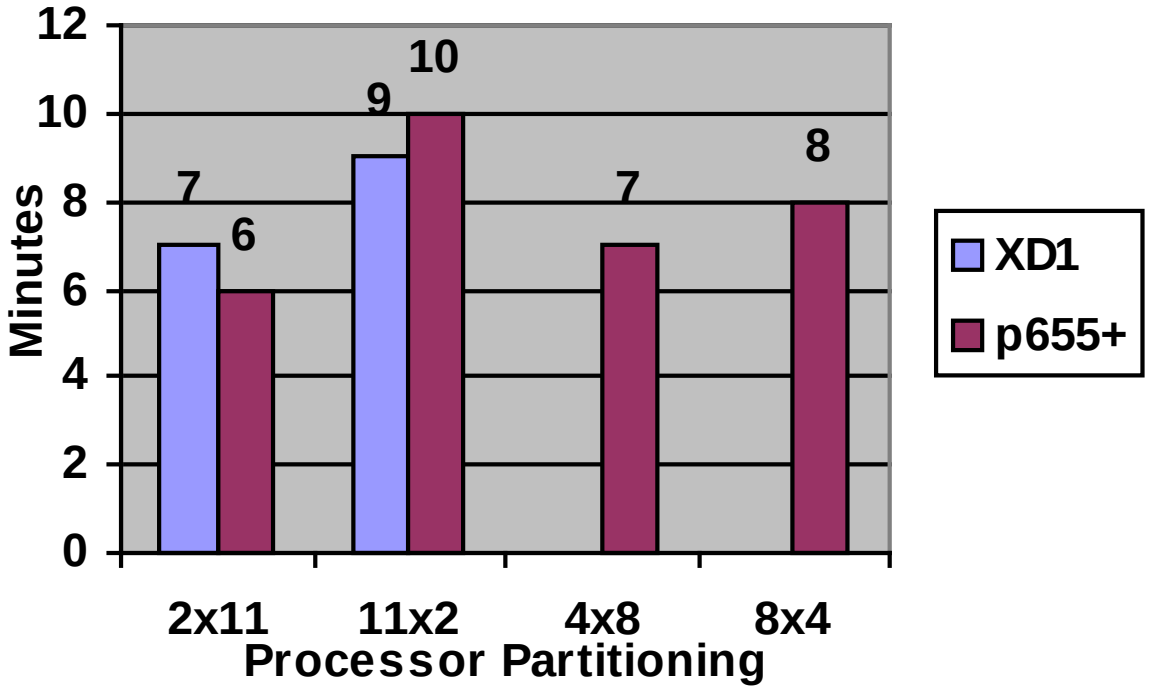
7.5km Grid

- 73x86 (6,278) points on each of 75 levels
- 6-hour forecast, 20 second timestep



Performance vs. Partitioning

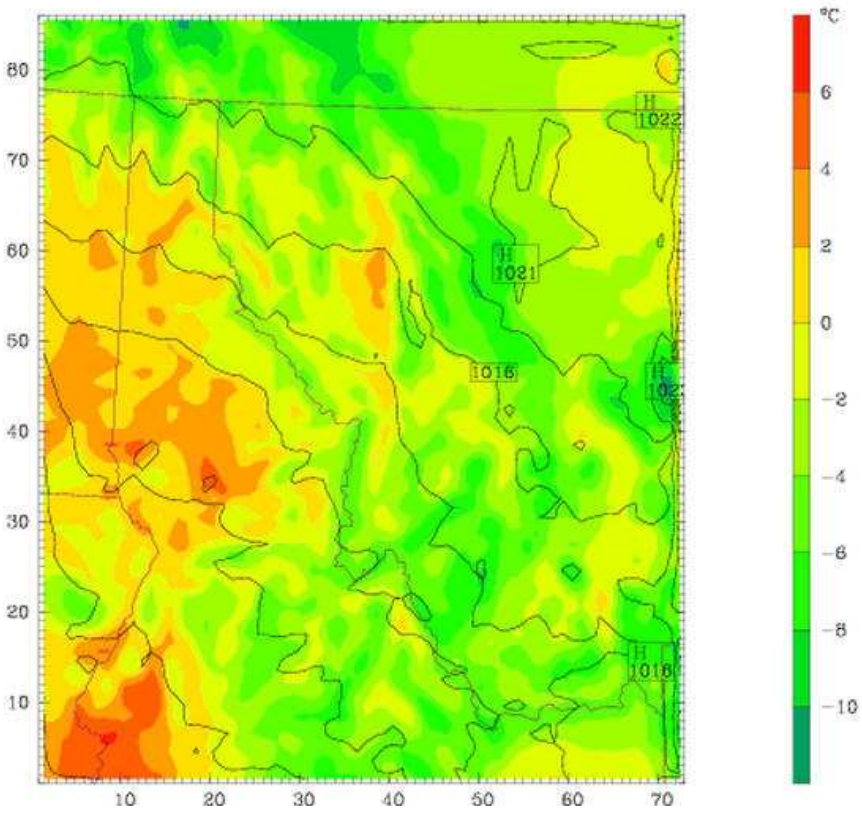
- 7.5km, 6-hour simulation, 20s timestep



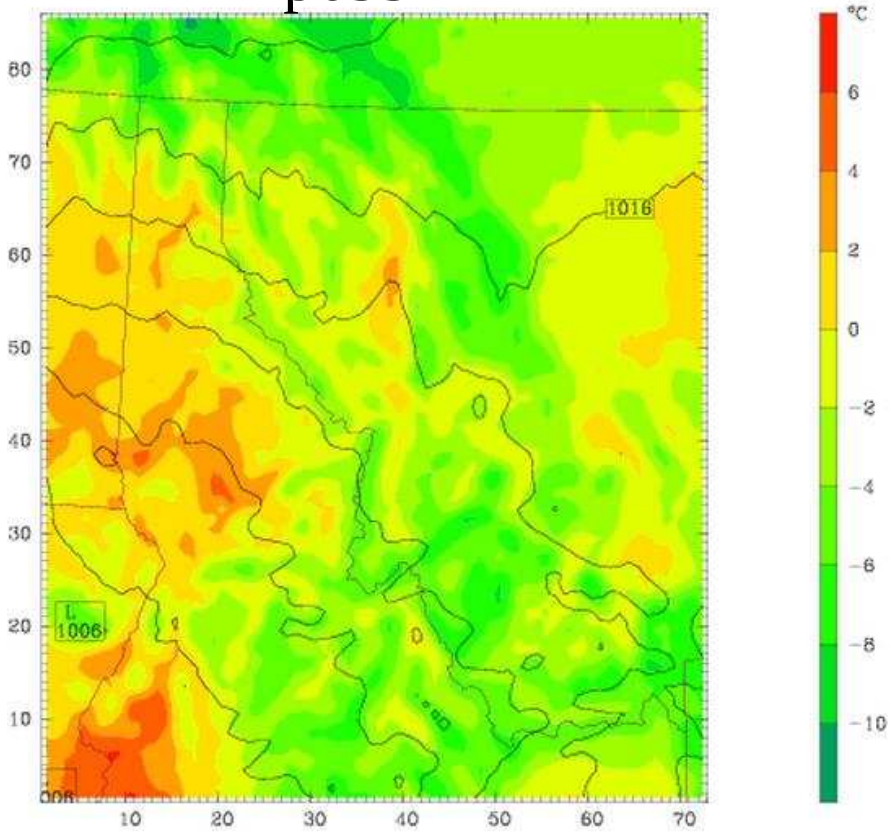
7.5km, Comparison of Output

- Hour 3 of simulation

XD1

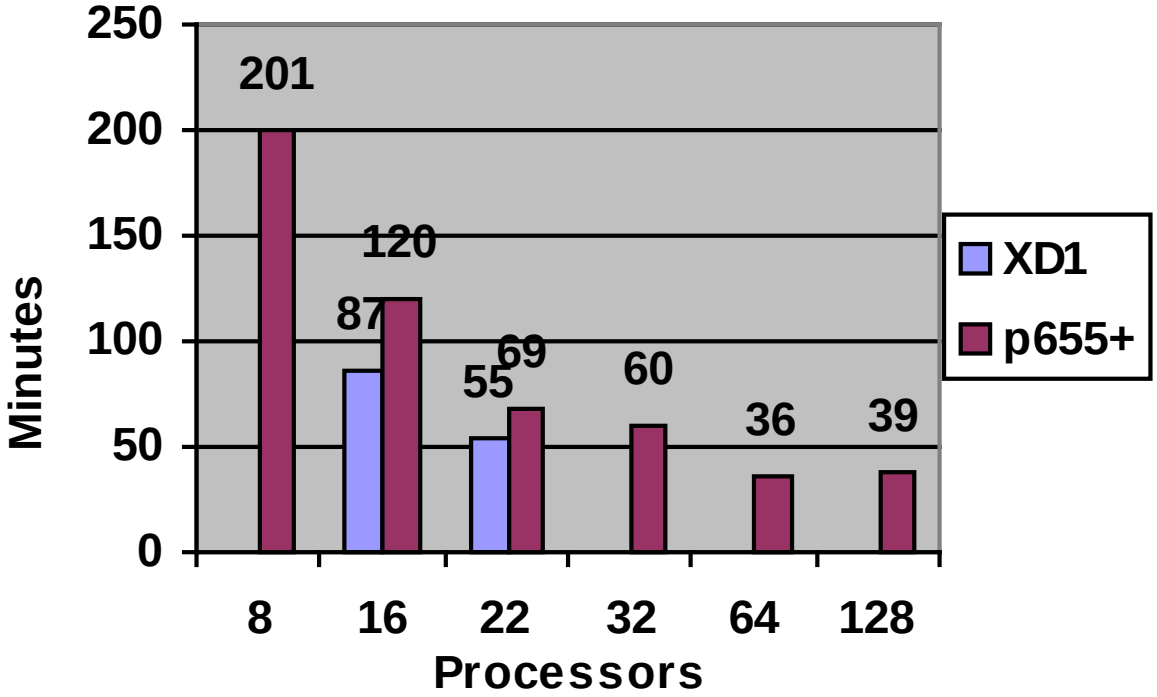


p655+



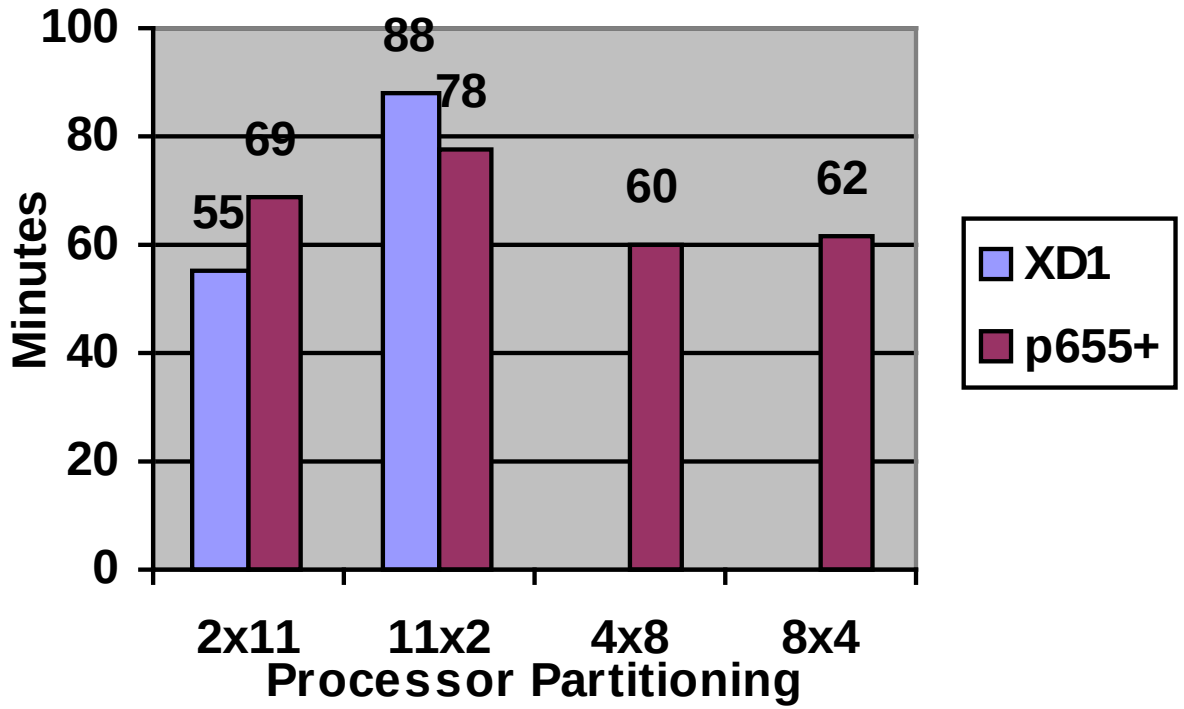
2.5km Grid

- 216x264 (57,024) points on each of 75 levels
- 3-hour forecast, 8 second timestep



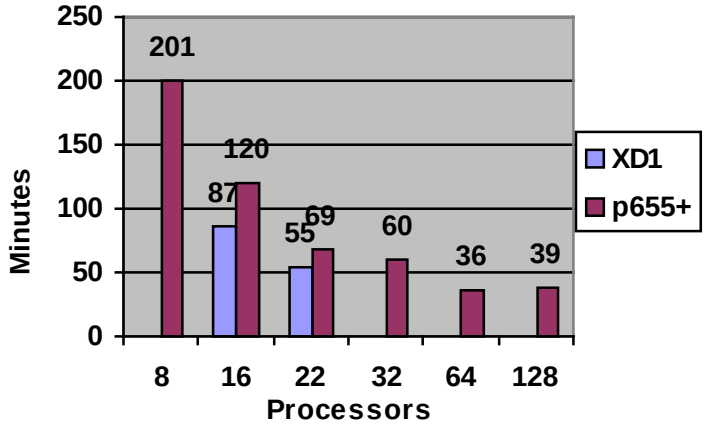
Performance vs. Partitioning

- 2.5km, 3-hour simulation, 8s timestep

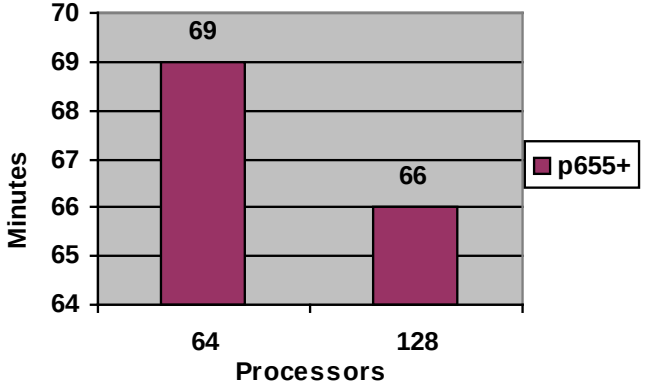


Observations on 2.5km Simulation

- Time = *real.exe* + *wrf.exe*
- On small problems, cost of *real.exe* is negligible relative to *wrf.exe*
- On larger problems (lots of points and/or nesting and/or lots of processors), *real.exe* might take over 50% of the time for a 3-hour simulation



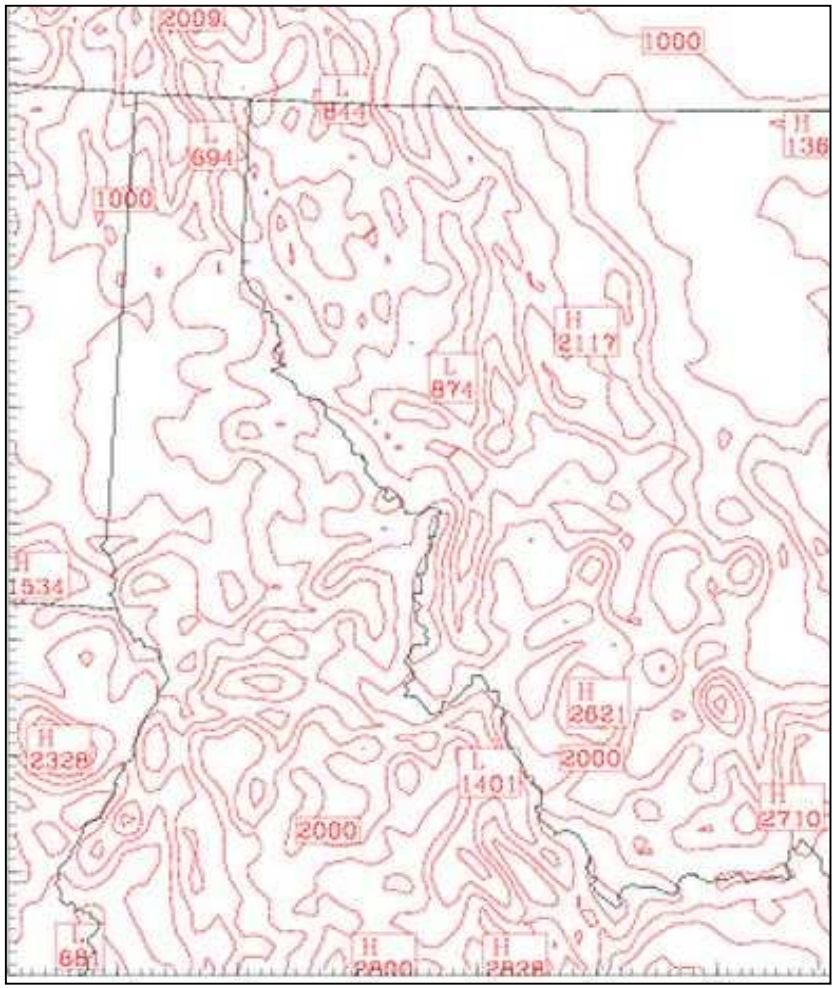
3-hour simulation

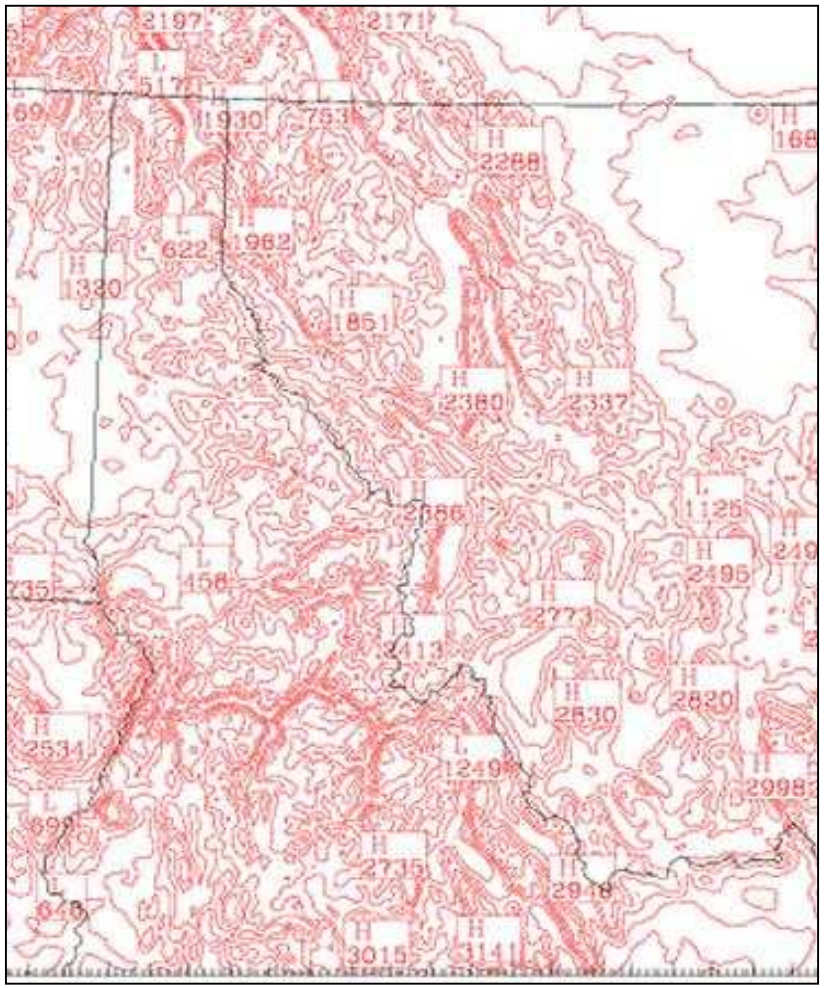


6-hour simulation

7.5km vs. 2.5km

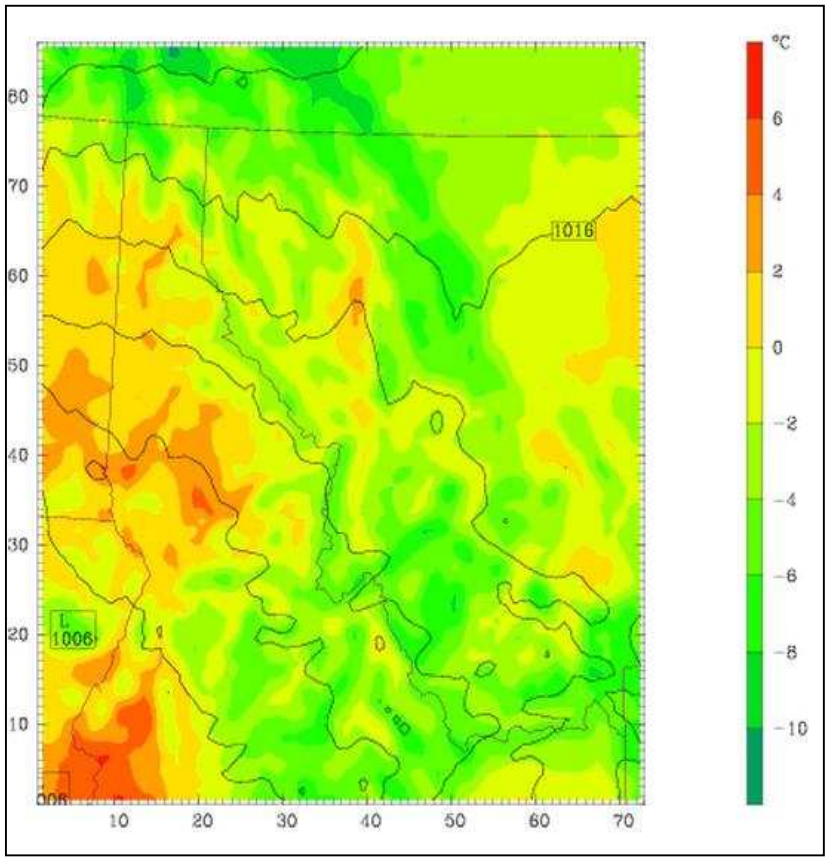
- Missoula CWA Topography

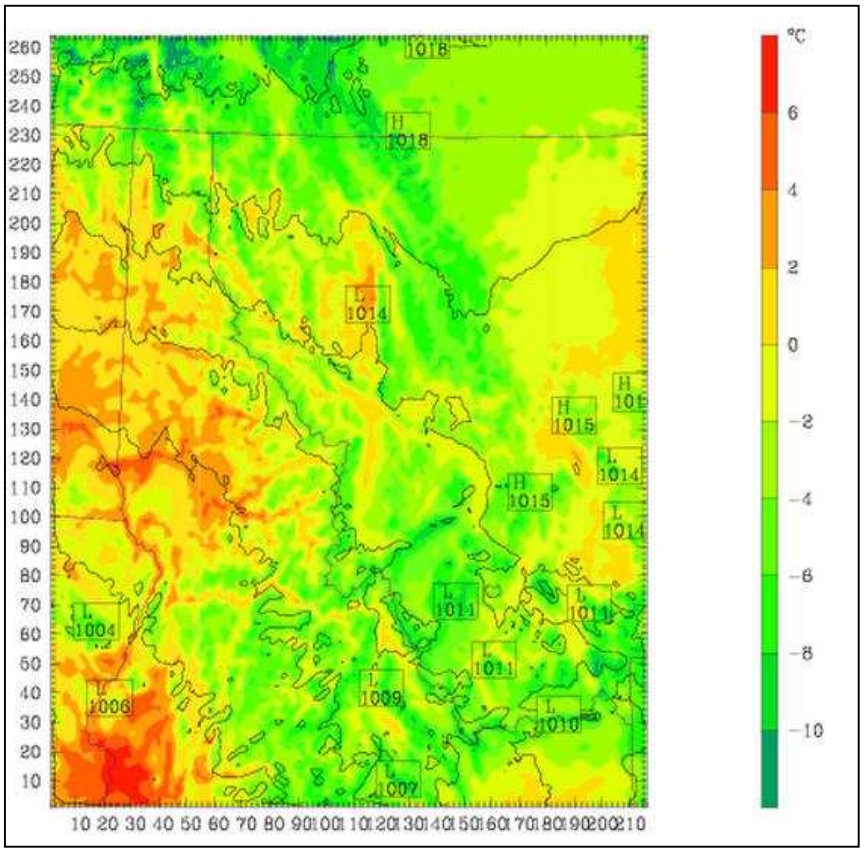




7.5km vs. 2.5km

- Surface pressure and temperature at 3 hours



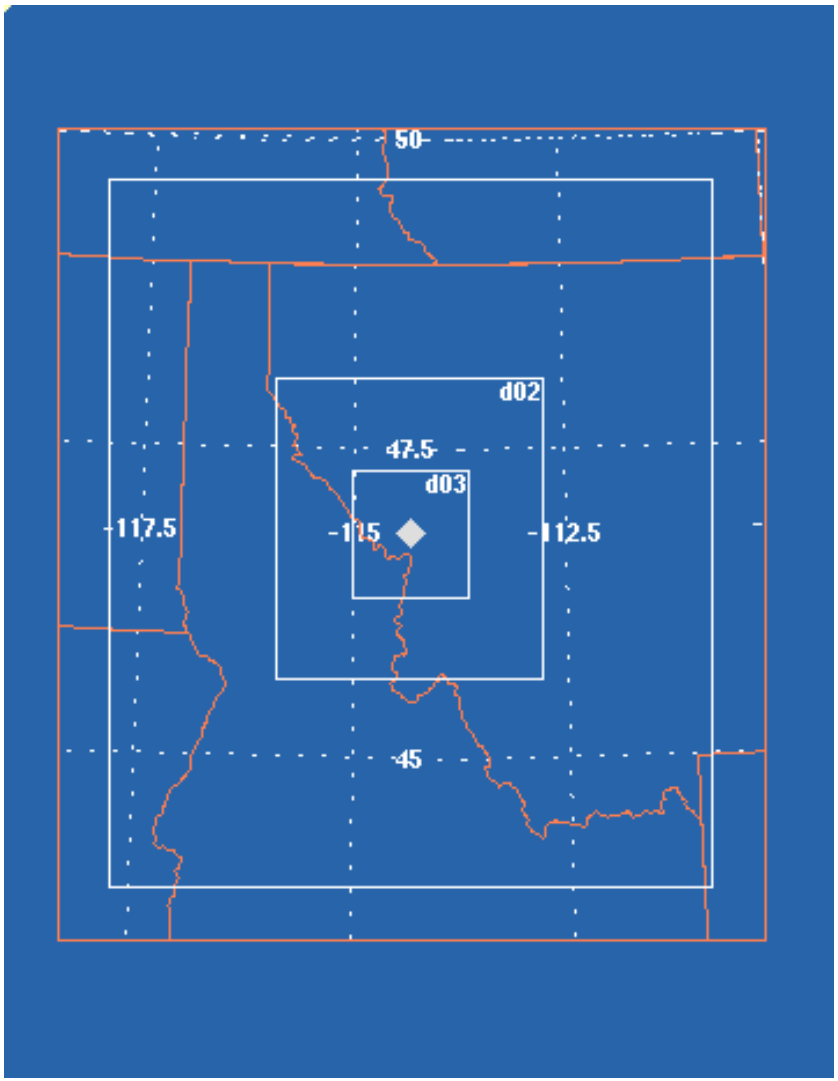


833m Grid

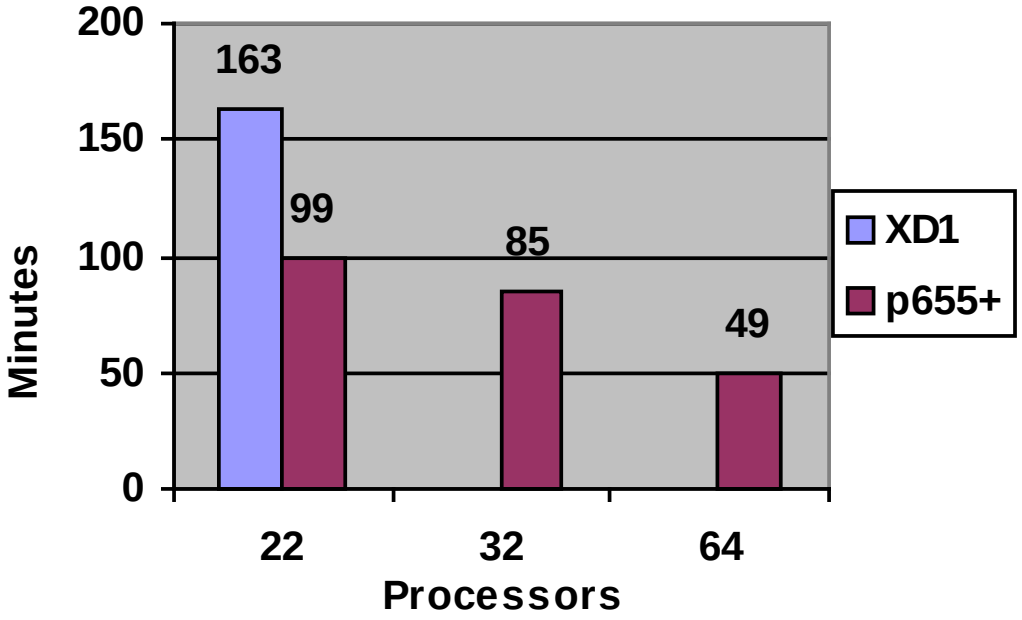
- 635x789 (501,015) points on each of 75 levels
- It was a bust on both machines ☹
  - On p655+, unable to prep input files
  - On XD1, aborted *real.exe* after 20 hours walltime
  - Further investigation needed!

Performance Testing on Nested Grids

- Concentrate highest resolution (and most computations) in regions of interest
- Missoula CWA partitioning
  - Outer – 73x86 at 7.5km, 20s timestep
  - Middle – 97x109 at 2.5km, ~7s timestep
  - Inner – 124x139 at 833m, ~2s timestep



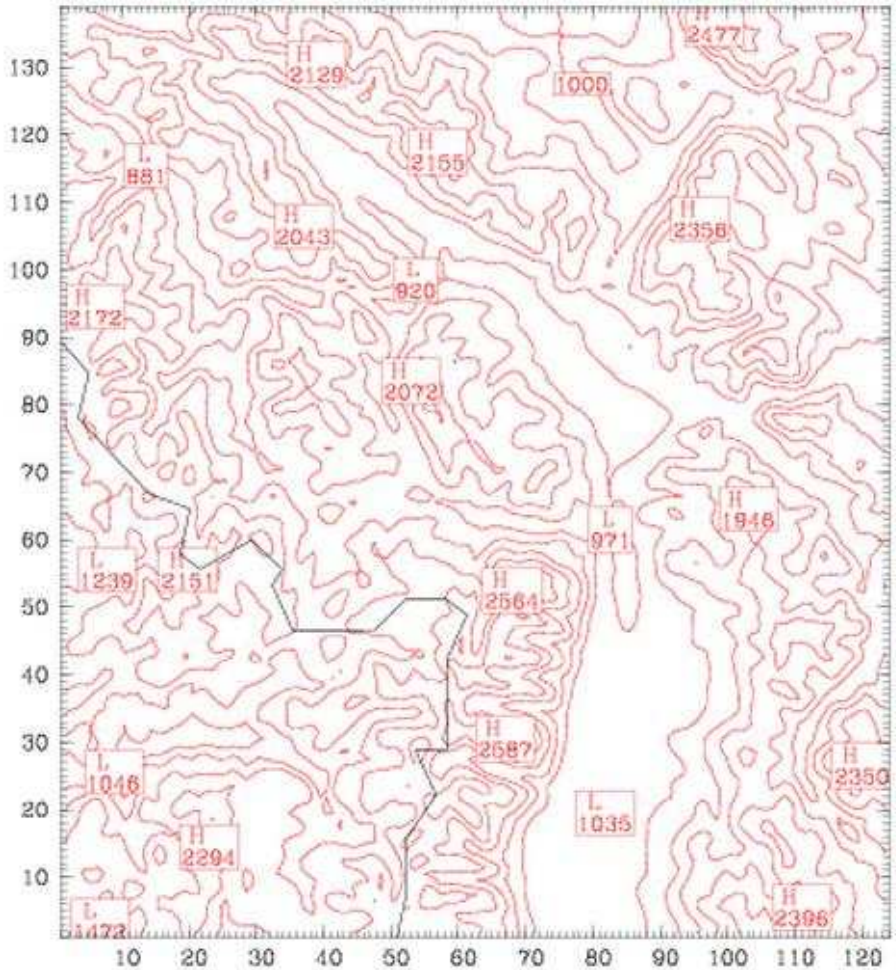
Performance Testing on Nested Grids

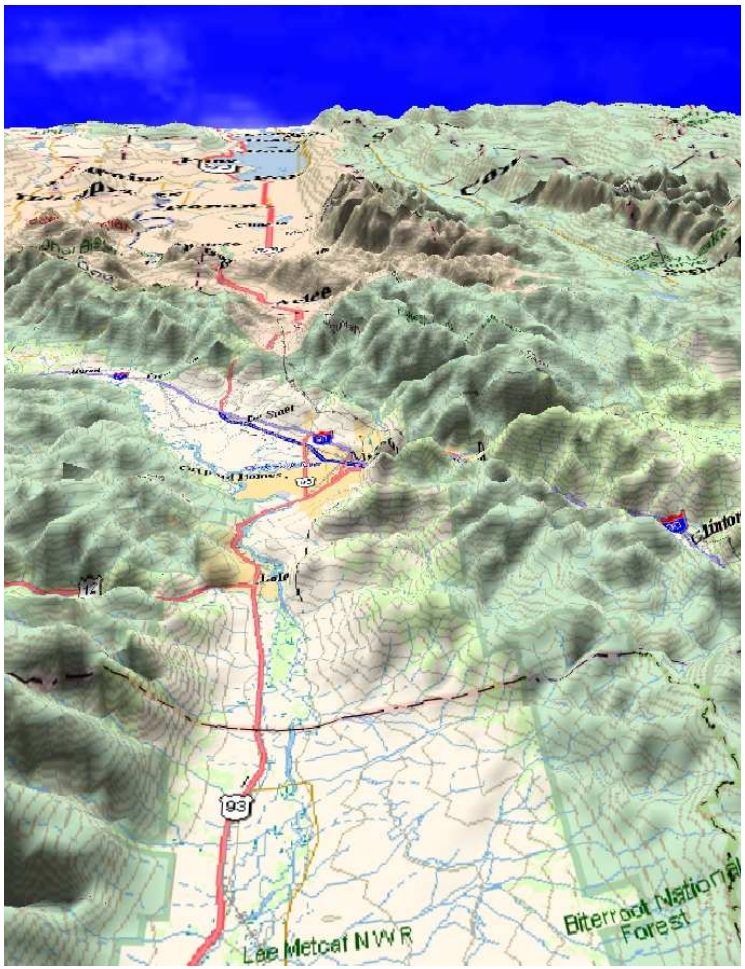


- 3-hour simulation
- The current configuration of the XD1 is not suitable for real-time forecasts, but an upgrade might put us in the ballpark

833m Grid

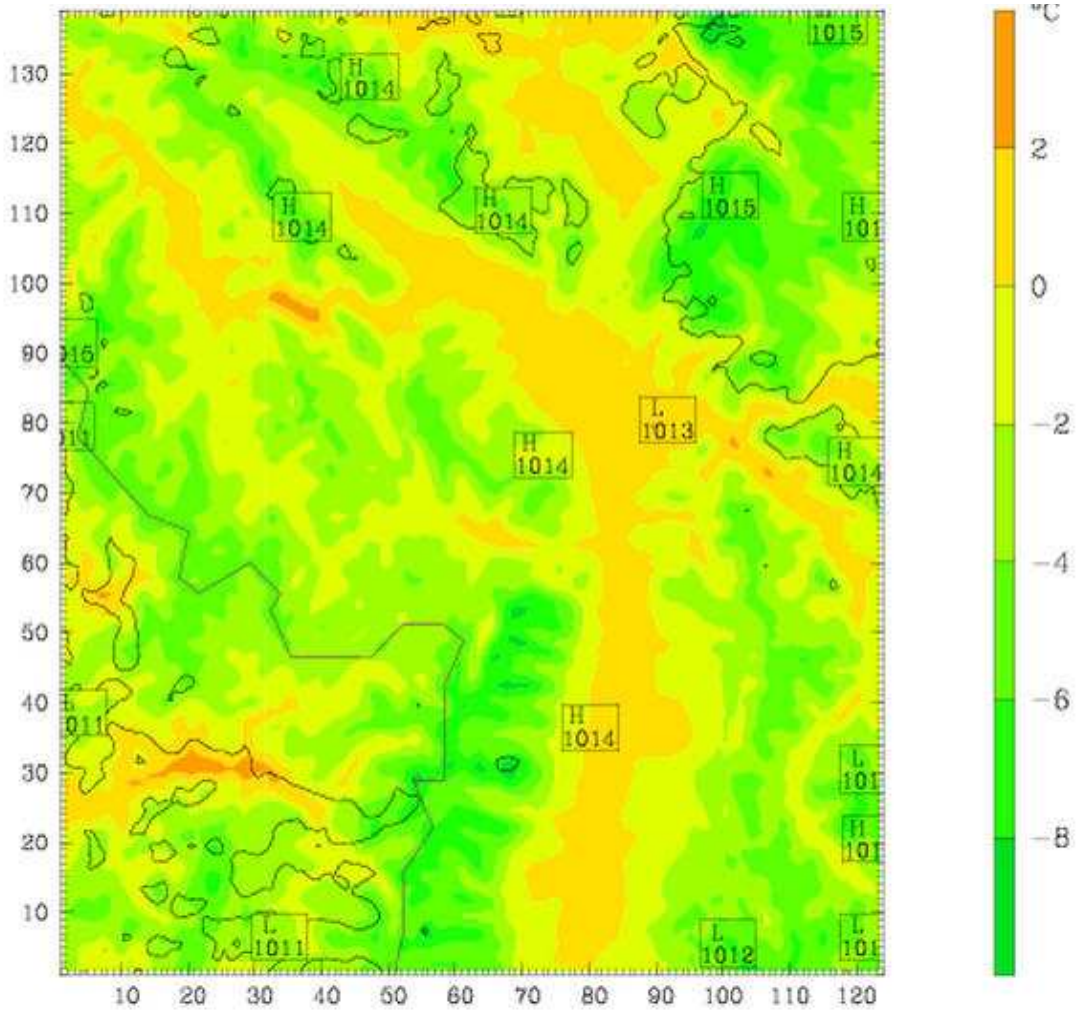
- Topography





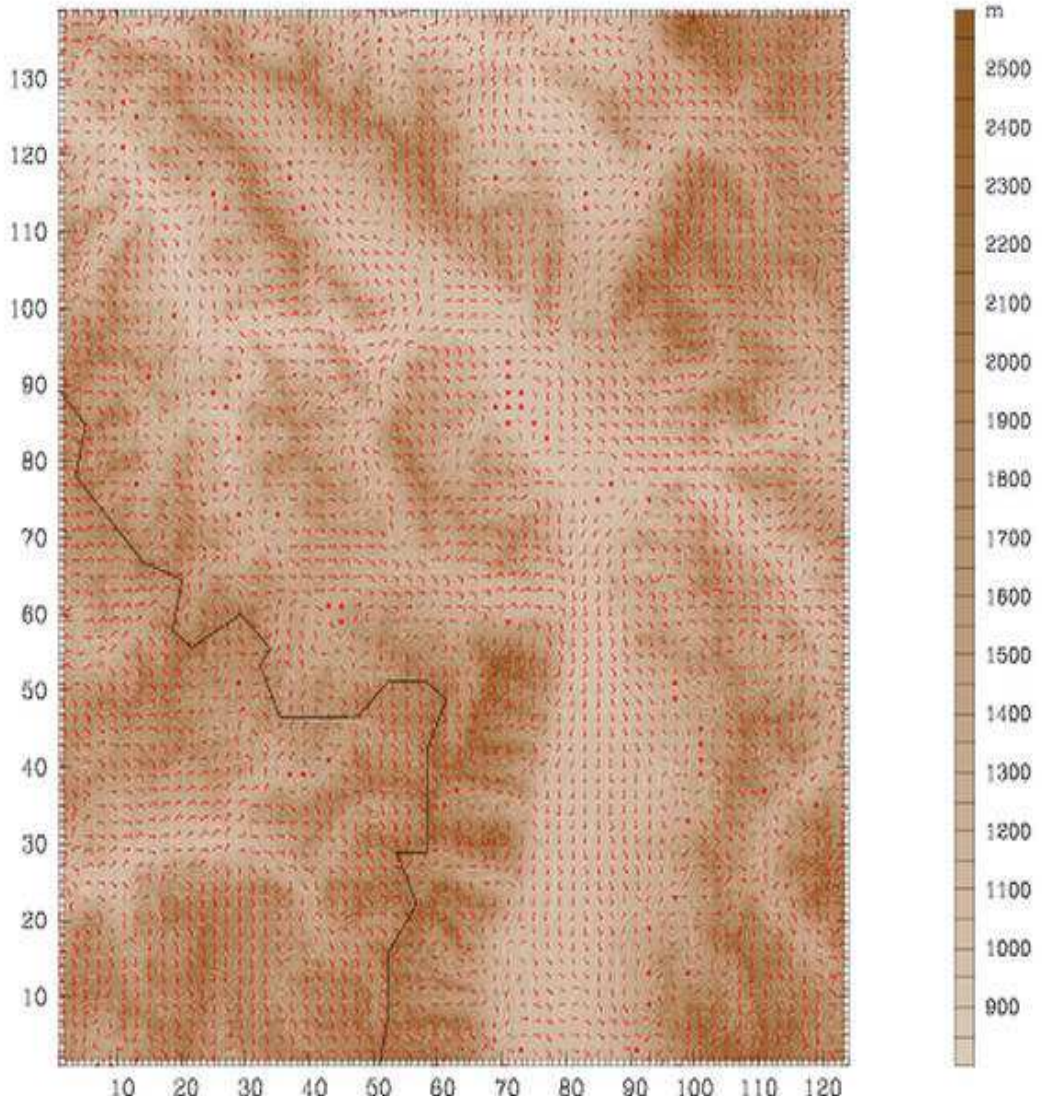
833m Grid

- Surface pressure and temperature



833m Grid

- Wind fields



Conclusions

- We want to capture “mountain weather” in our numerical weather simulations, and we need high resolution to do this
- With the current XD1 (24 cpus, 22 usable for parallel jobs), at 2.5km resolution, we can simulate 1/3 real-time (1 hour computation for a 3-hour simulation)
- Results suggest that the XD1 will be scalable, and might experience better performance than the p655+ (2.2 GHz vs. 1.5 GHz CPU), so an upgrade to the XD1 just might allow us to consider nested runs with 833m resolution
- We won’t be happy until we can achieve 100m resolutions!

Future Directions

- Become more intimate with the details of WRF and compilation on different architectures
- Achieve better initial and boundary conditions through the assimilation of weather observations into the simulations