WRF-Hydro Development and Performance Testing

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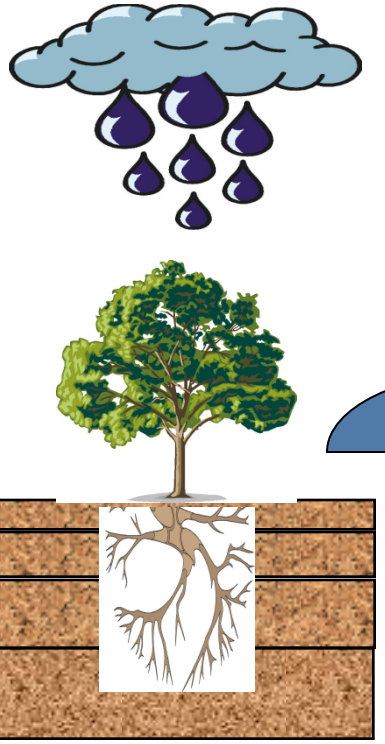
Scientific Motivation

- How does terrain features affect the spatial and temporal distribution of moisture availability?
- How does the spatial distribution of soil moisture in complex terrain impact land-atmosphere fluxes and convective circulations?
- Flash flooding forecast ?

Hydrologically-enhanced Land Surface Models

(Gochis and Chen, 2003, NCAR Tech Note)

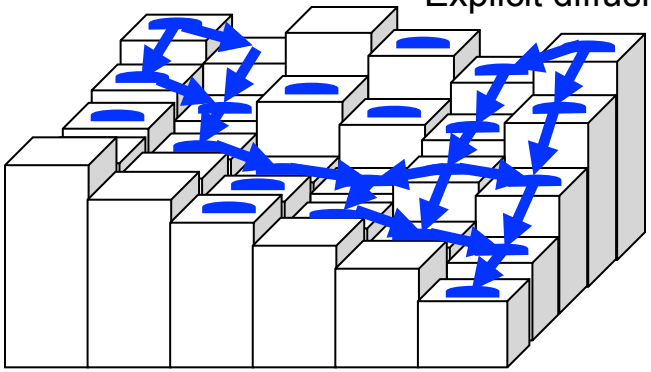
Single Column

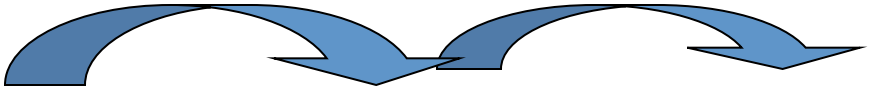


1-D Land Surface ModelS (e.g. 'Noah')

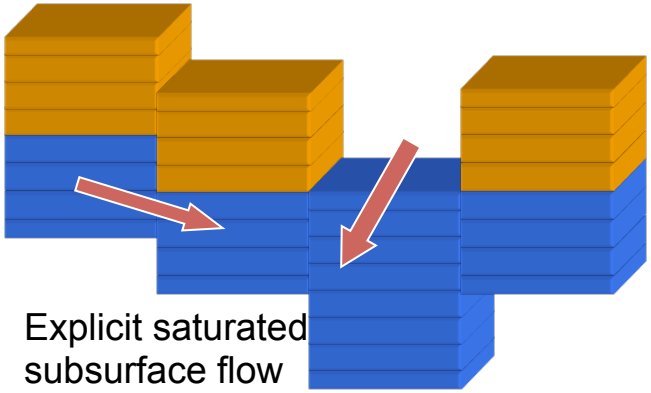
Land Routing

Explicit diffusive wave overland flow



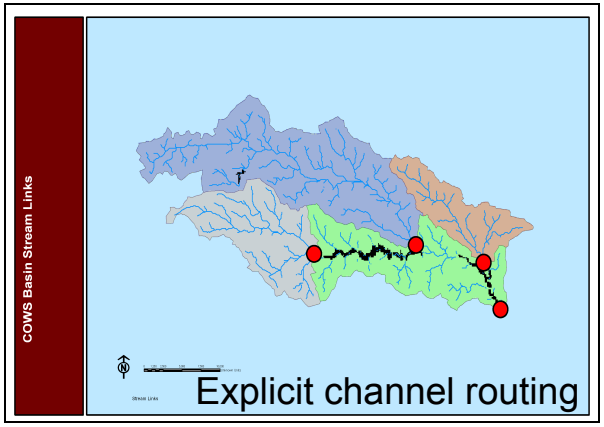


Dynamical Routing Methodologies



Explicit saturated subsurface flow

Channel Routing



Explicit channel routing

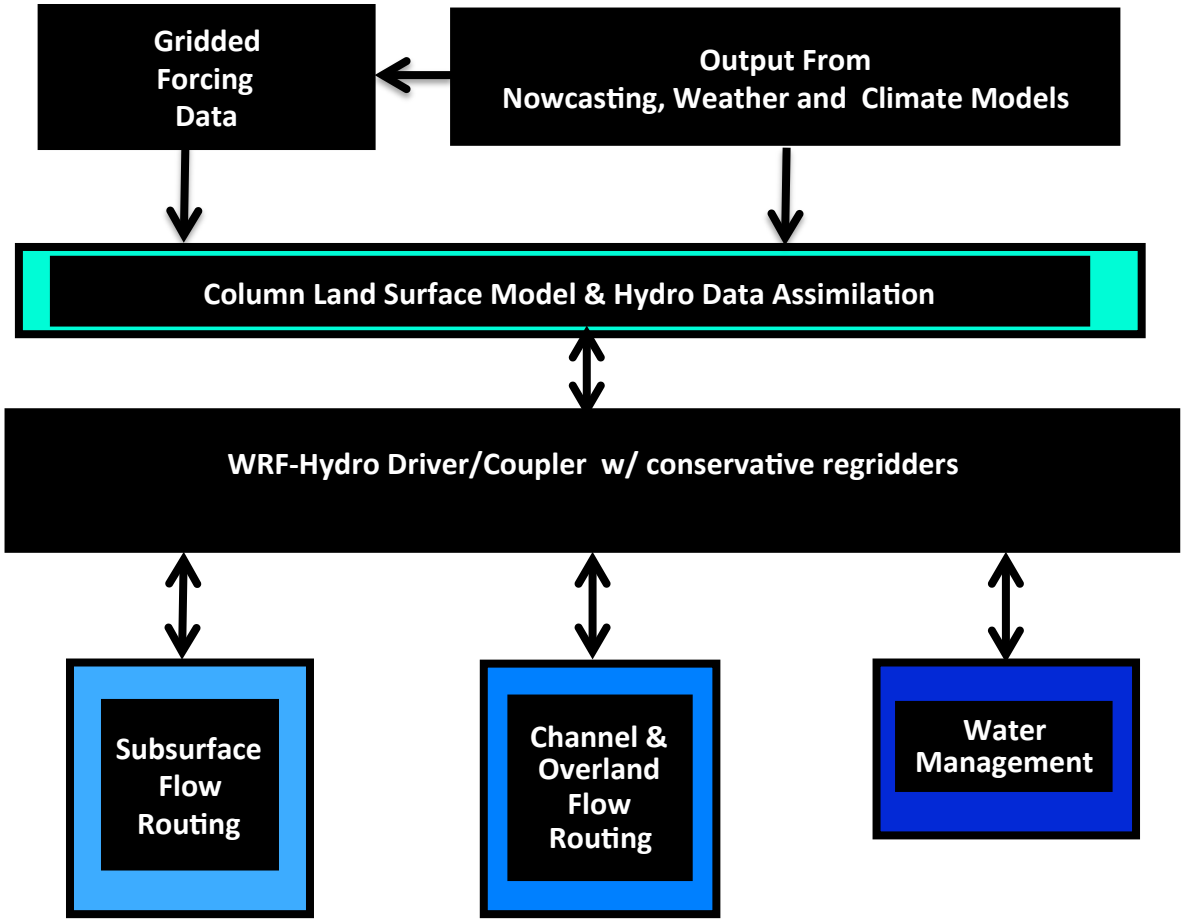
- **fully distributed flow/head**
- **reservoir levels**
- **distributed soil moisture**
- **distributed land/atmo fluxes**
- **distributed snow depth/SWE**

System Function Overview

- WRF-Hydro offline
  - data assimilation/spin-up
  - Forecasting
- WRF-Hydro fully coupled system
  - WRF model
  - LIS system
  - CESM

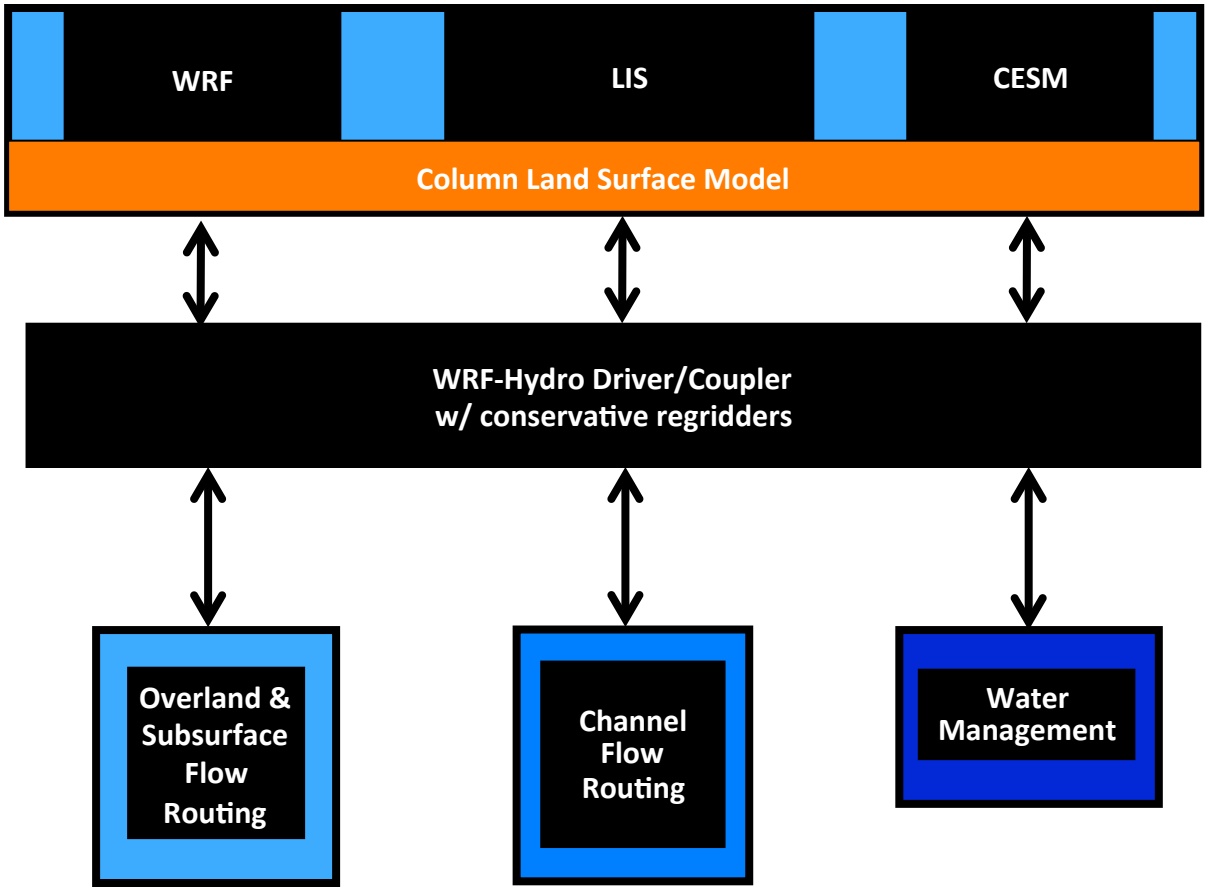
Conceptualization of WRF-Hydro Off-line

- Multi-scale/Multi-physics modeling…



Conceptualization of WRF-Hydro Coupling

- Multi-scale/Multi-physics modeling…



Parallel Implementation

Data Grids

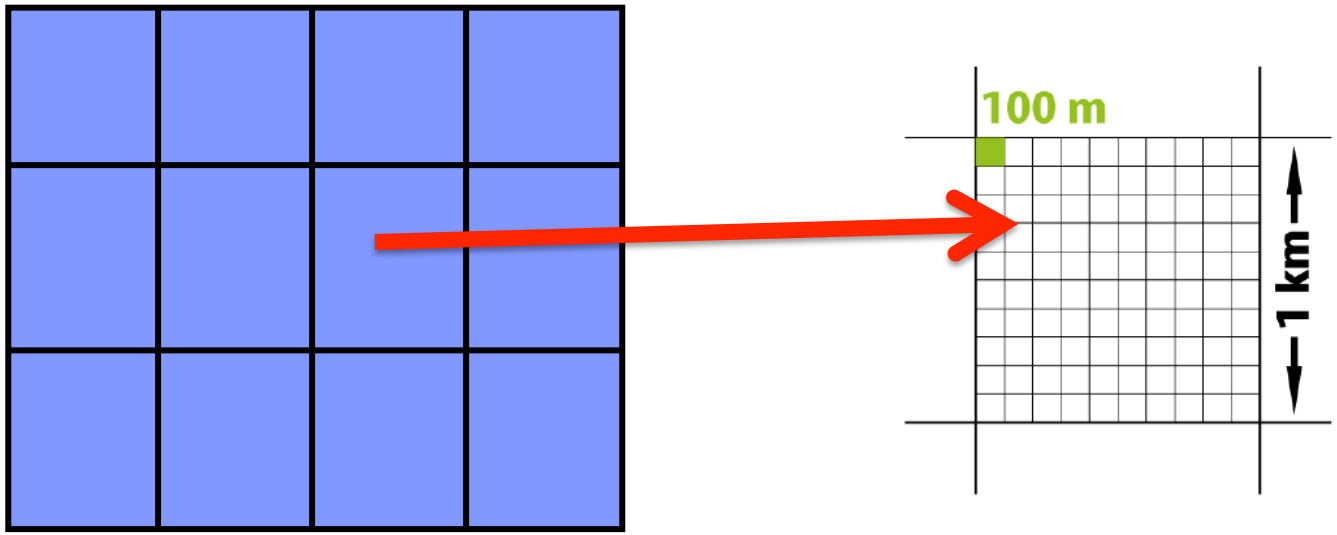
- Three Types of Data Grids

  Land Grids: (ix, jx), (ix, jx, n_soil_layer)

  Land Routing: (ixrt, jxrt), (ixrt, jxrt, n_soil_layer)

  Channel Routing: (n_nodes), (n_lakes)
- Parallel Scheme
  - Two dimensional domain decomposition
  - Distributed system (MPI) only

WRF-Hydro Multi-Grids Domain Decomposition



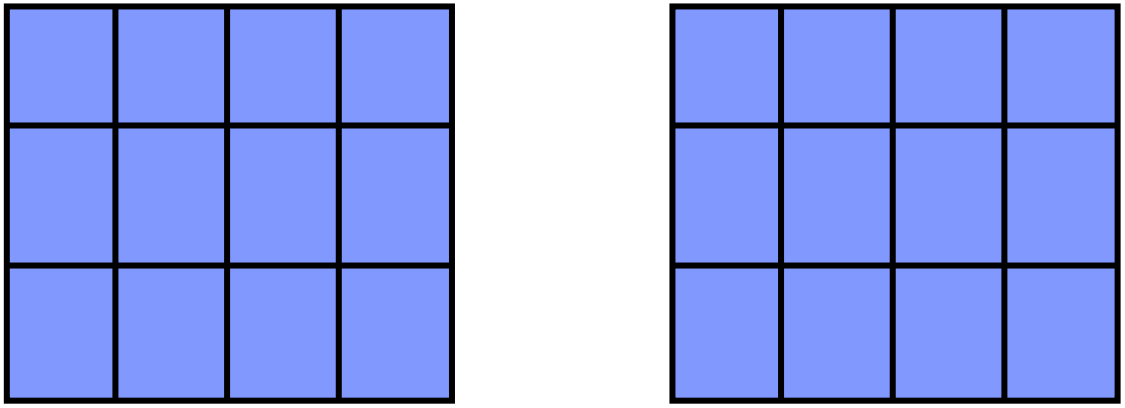
1 km Land grid

Land routing grid cell: regridding

One CPU: Land grid, land routing grid cell, and channel routing nodes.

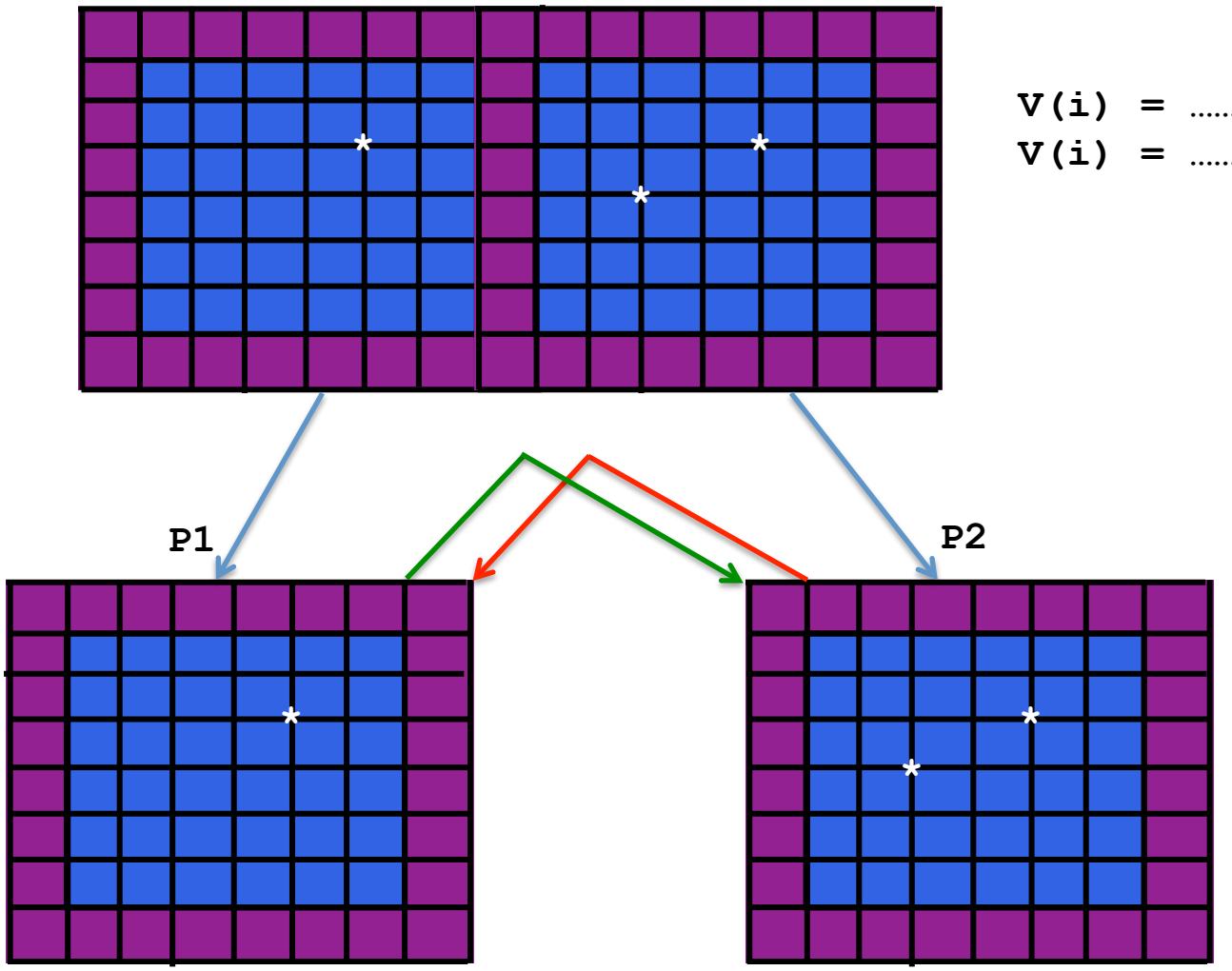
Distributed Memory Communications

Land Grid



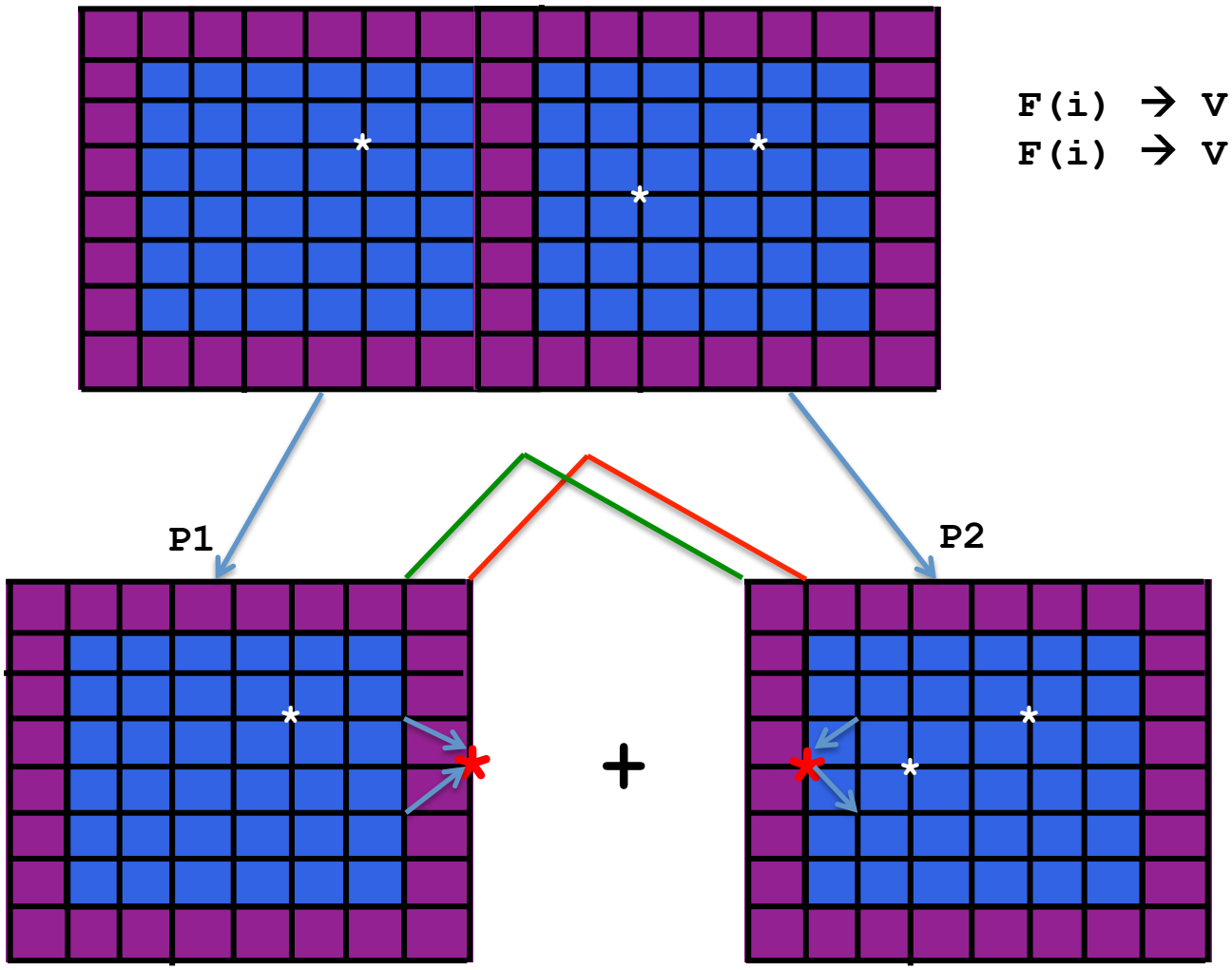
No overlap of the grids.
No memory communication between neighbor processors.

Land Routing Grid Memory Communications (1)



1) Replace the hello variables

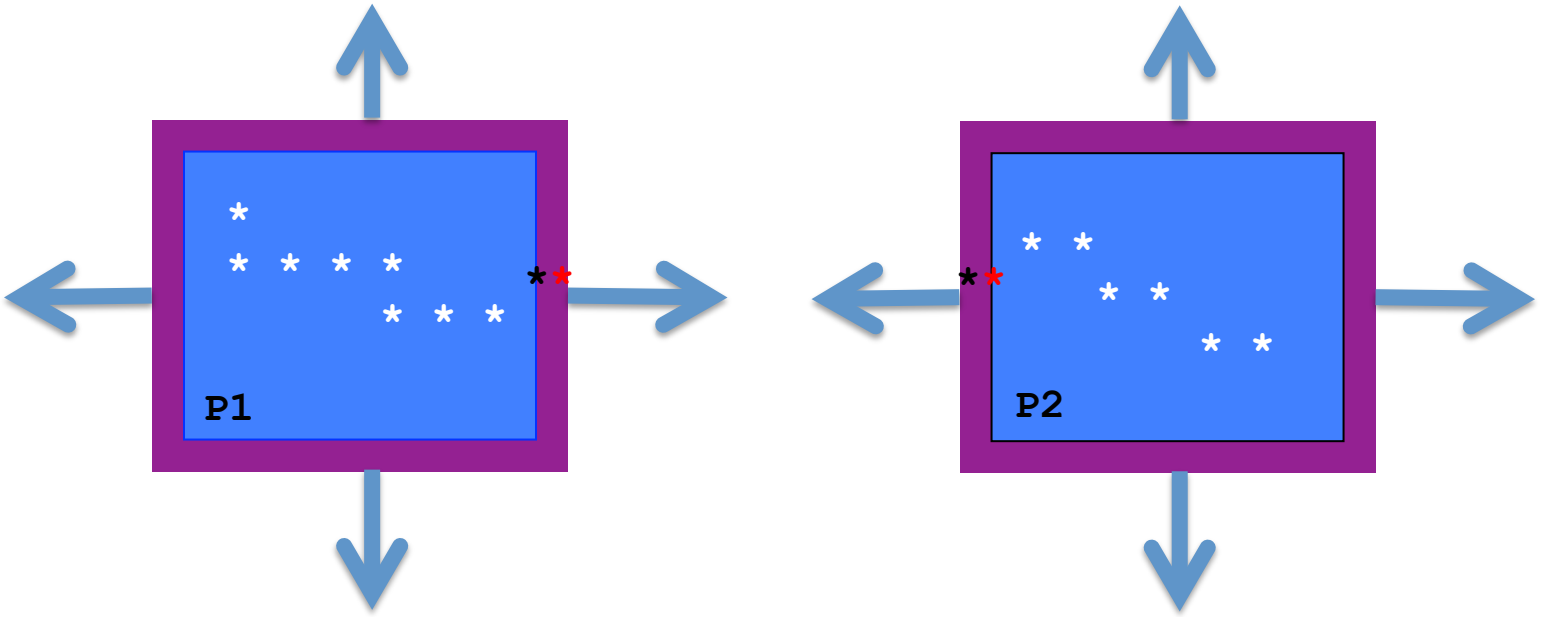
Land Routing Grid Memory Communications (2)



2) Update the inflow/outflow variables in boundary: P1 + P2

Distributed Memory Communications

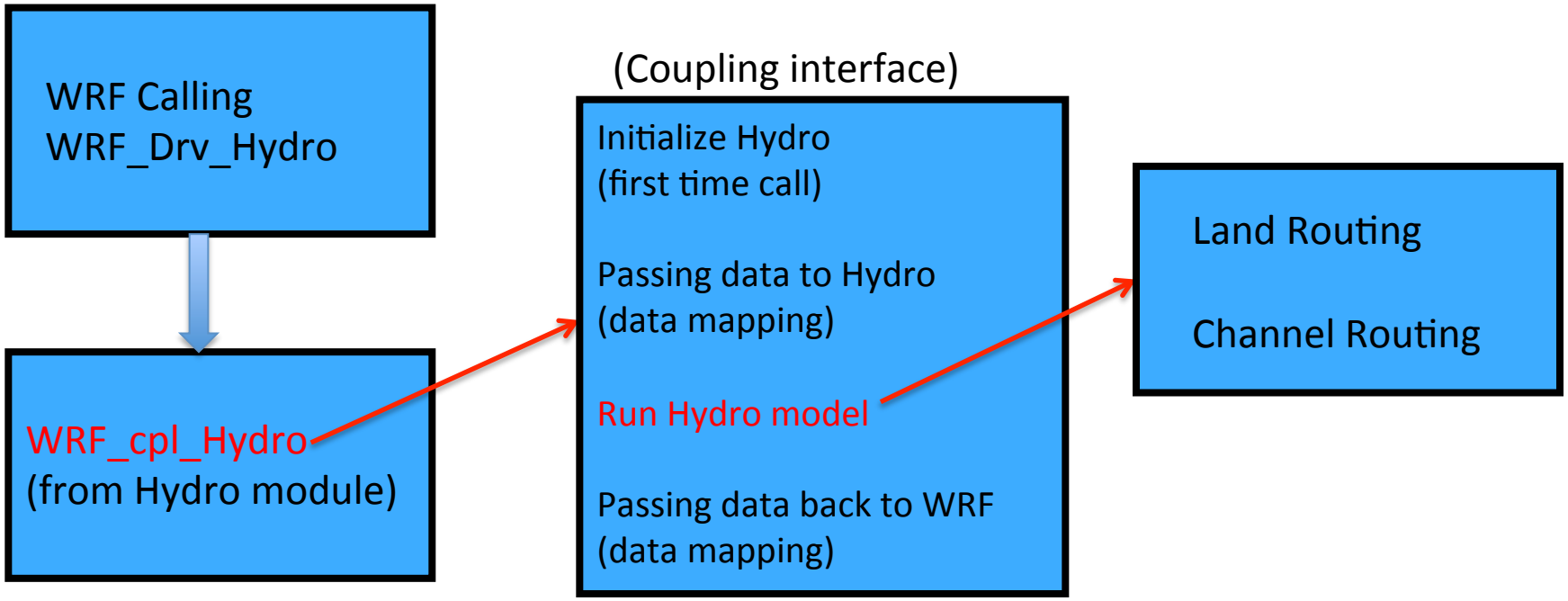
Channel Routing



Update of red and black nodes for both P1 and P2:

inflow/outflow to red and black nodes in P1 + value from P2

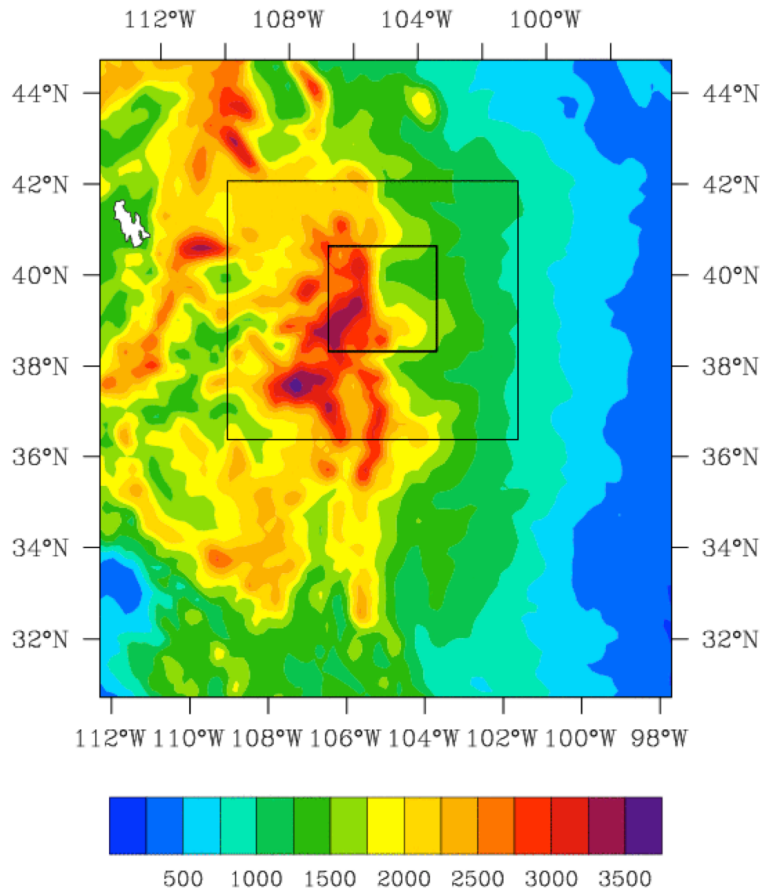
Implementation of Coupling



Compiling and Run

- Configure
  - Choose compiler options
  - When coupled with WRF, WRF-Hydro will be controlled from WRF side.
- Compiling
  - WRF-Hydro will always be compiled as a library and called by other components as an external function.
- Run (constant files and one namelist file)
  - Offline
  - Coupled with other systems

Testing Domain



D1: 16 km (90 X 100)
D2: 4 km (181 X 161)
D3: 1 km (269 X 261)

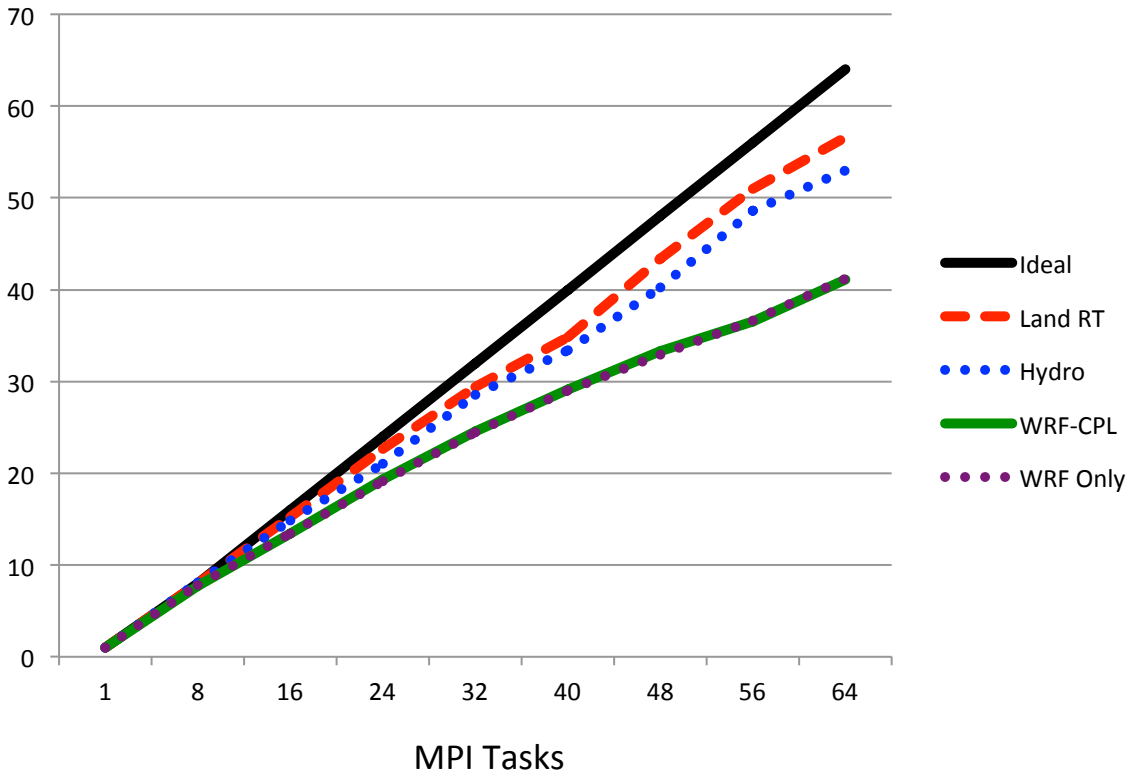
WRF-Hydro Performance Testing

MPI Tasks	Offline 6 hours forecast (wall clock time: seconds)				WRF (Fully Coupled) 2 hours forecast (wall clock time: seconds)			
	Land & Channel RT		Land RT Only		WRF Only		WRF Fully Coupled	
	Wall Clock: Seconds	Scalability	Wall Clock: Seconds	Scalability	Wall Clock: Seconds	Scalability	Wall Clock: Seconds	Scalability
1	10161.64	1	9222.48	1	27340	1	31204	1
4	2540.41	4	2305.62	4	6835	4	7801	4
8	1257.42	8.08	1153.47	7.00	3510	7.79	4055	7.70
16	684.52	14.85	606.64	15.20	2036	13.43	2328	13.40
24	482.3	21.07	407.42	22.64	1428	19.15	1618	19.29
32	356.12	28.53	313.55	29.41	1119	24.43	1270	24.57
40	304.35	33.39	264.54	34.86	943	28.99	1070	29.16
48	252.67	40.22	212.79	43.34	831	32.90	938	33.27
56	208.97	48.63	180.94	50.97	747	36.60	853	36.58
64	191.73	53.00	162.94	56.60	663	41.24	760	41.06

WRF-Hydro Performance Speedup

Time of Sequential Run

Time of Parallel Run



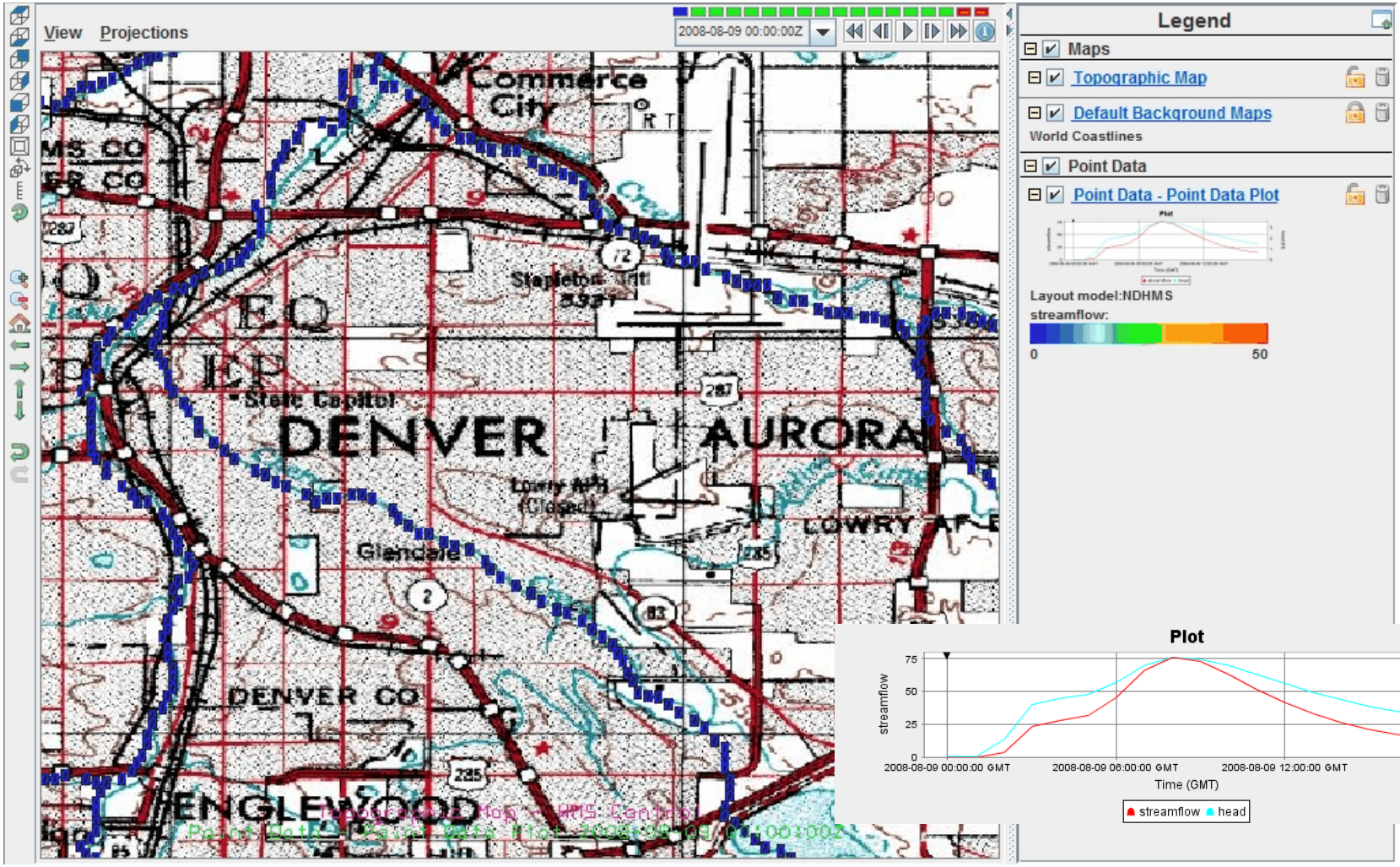
Scientific Application

First formal release with WRF3.5

- Real time forecast
  - Offline
  - WRF fully coupled system
- Regional Climate research
  - Offline
  - LIS and CESM (CLM) Coupling

Initial Results: WRF-Hydro Simulations

- Evaluation of simulated streamflow using multiple precipitation products: Aug. 8, 2008



Initial Results: WRF-Hydro Simulations

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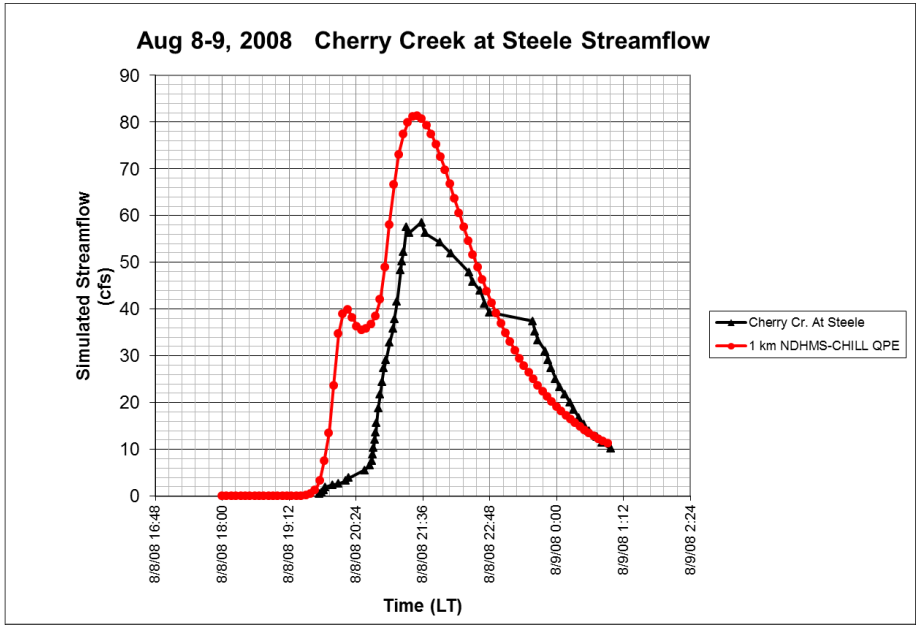
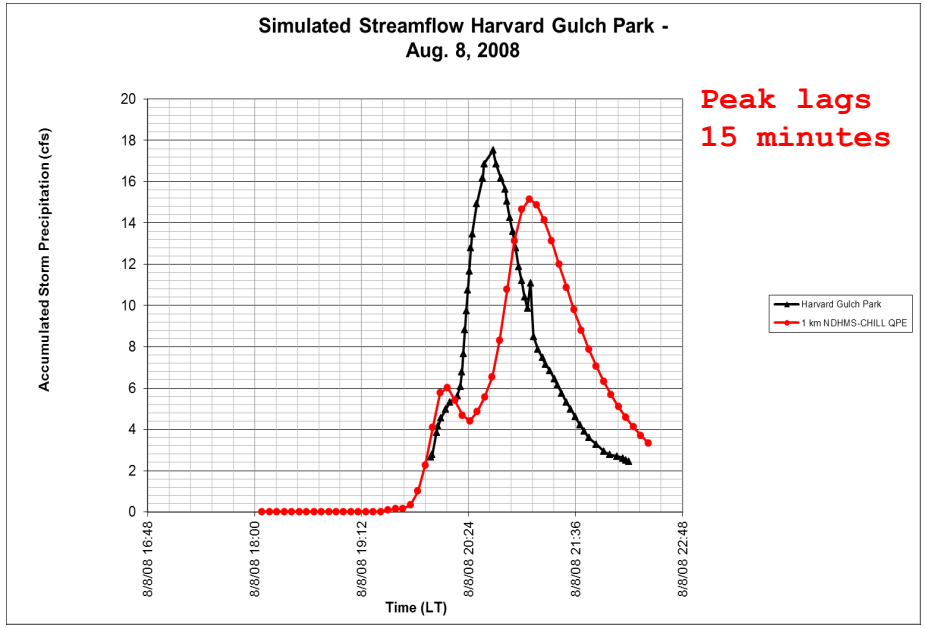
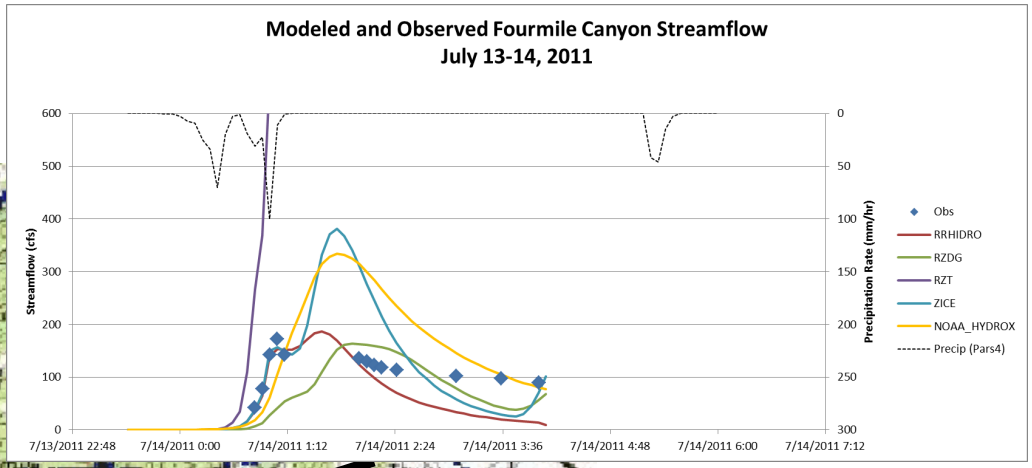
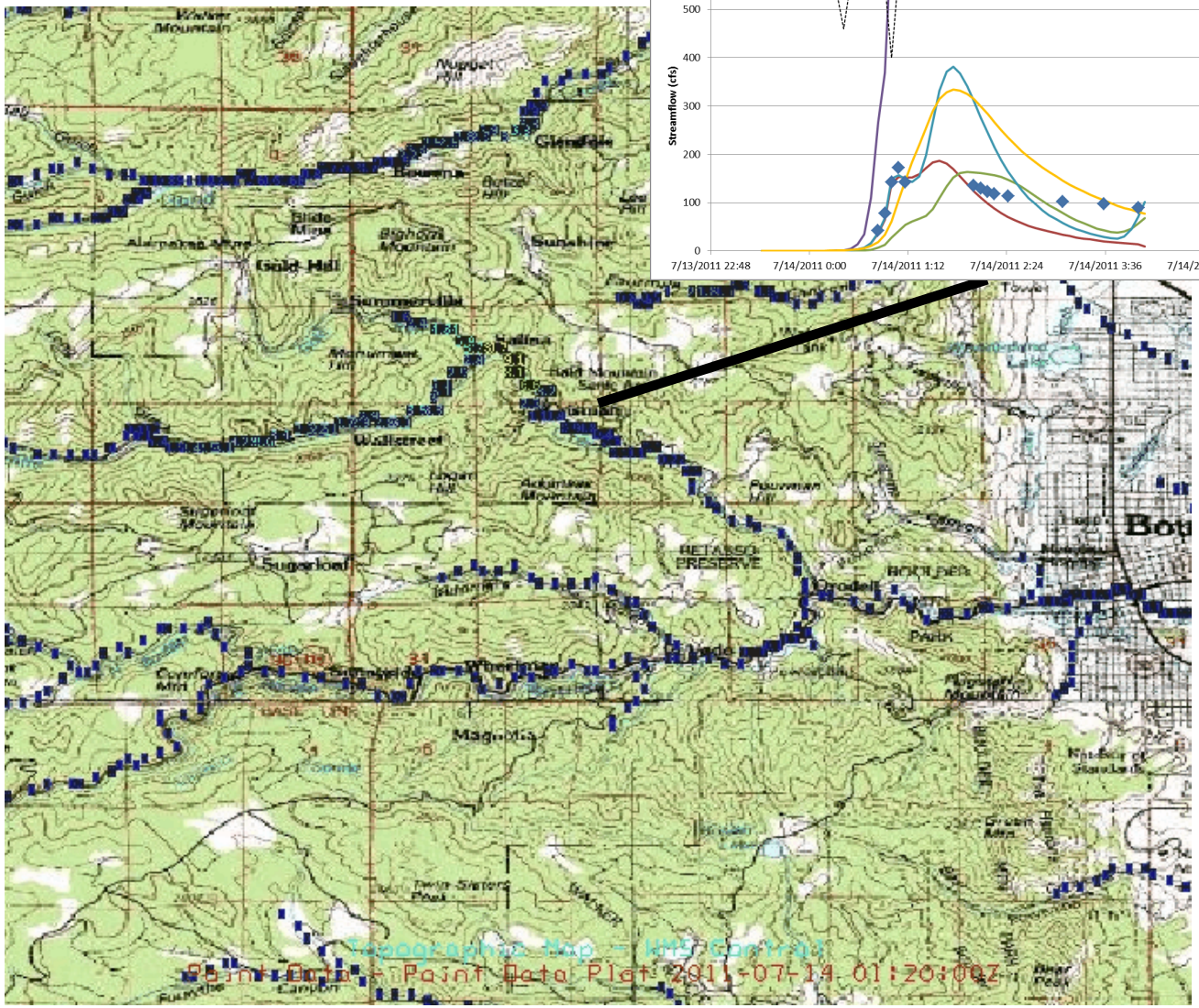




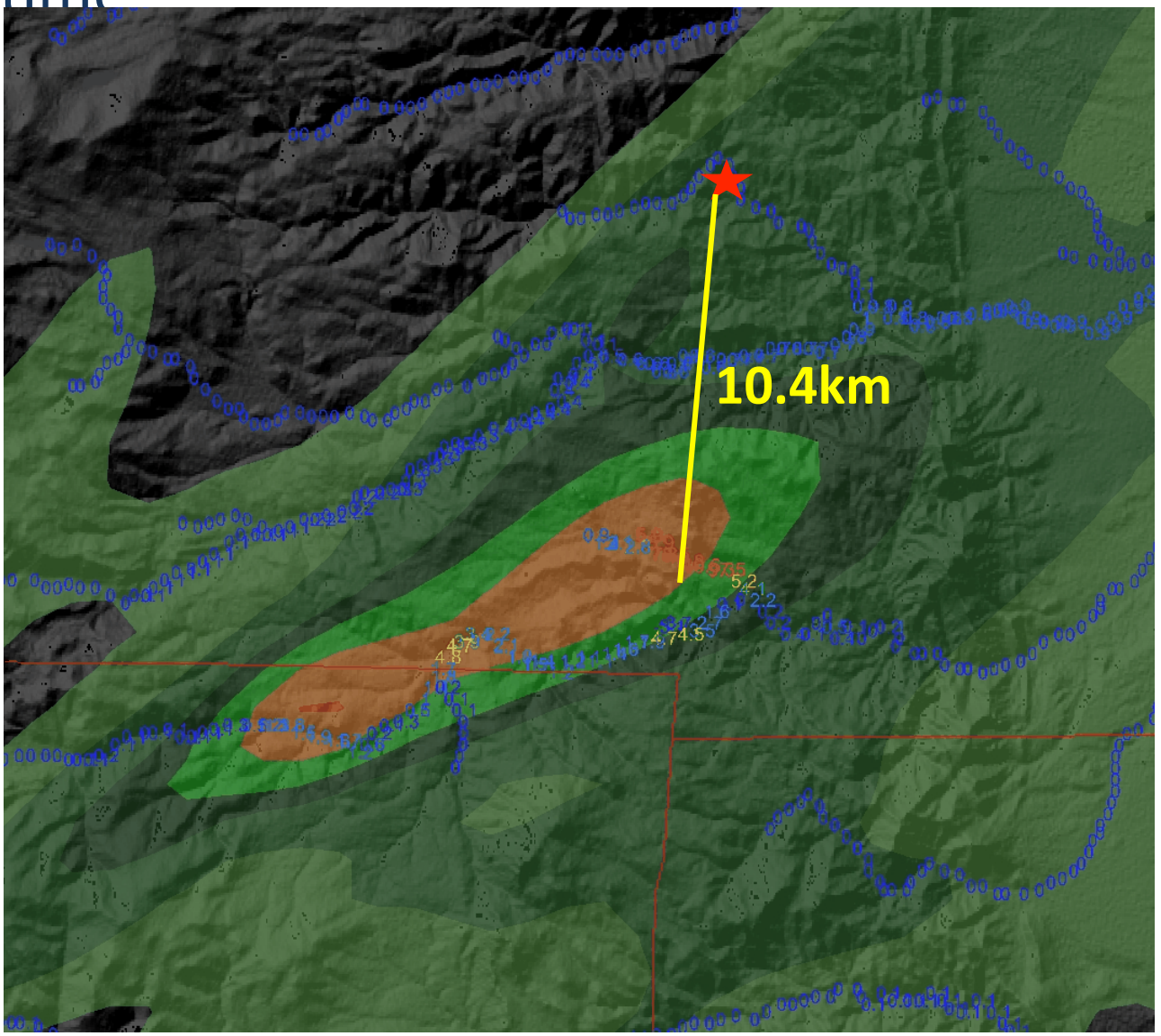
- Here the QPE is provided by the CSU-CHILL dual-polarimetric radar.
- Noah and CHILL QPE precipitation on a 1km grid, NDHMS routing executed on a 100m
- NDHMS-Noah is un-calibrated
- LIS-NDHMS coupling near complete…

July 13, 2011 Fourmile Canyon Flood Event: Hydrologic Simulation





July 13, 2011 Fourmile Canyon Flood Event: Coupled WRF-Hydro/RTFDDA model prediction…~12 hour lead time



WRF-Hydro Software Features

- Modularized F90 and integrated in the WRF, HLDAS, CESM systems and NASA-LIS
- Coupling options are specified at compilation and WRF-Hydro is compiled as a new library in WRF
- Physics options are switch-activated though a namelist
- Fully-parallelized to HPC systems (e.g. NCAR supercomputer) and 'very good' scaling performance
- Ported to different systems and a variety of compilers
- WRF-Hydro model can represent better the important hydrological process over complicated topography and facilitate the streamflow forecasting, as well as the regional climate research

Future Work

- Model Scheme
  - Load balance
  - IO for large area application
  - Implicit time integration scheme for channel routing
- Data Assimilation
  - Surface radar data

Thank you !