The WRF-Hydro Modeling System: System Overview and Status Update

January 30, 2015

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A. Wood, M. Clark, R. Rasmussen

NCAR

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Purpose & Outline

Purpose: Provide a brief but comprehensive review of the WRF-Hydro system and its current componentry

Outline:

1. WRF-Hydro System Description
2. Support services

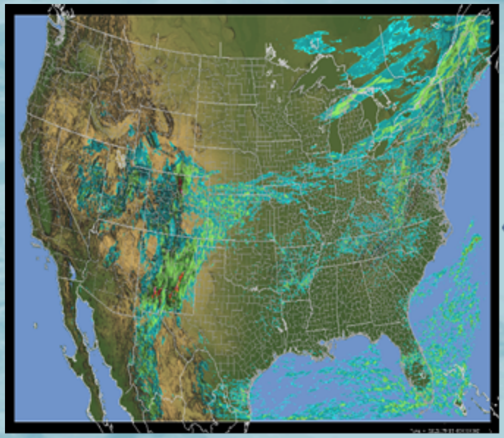
Motivating Research Questions:

1. How do horizontal routing processes impact the partitioning of water and energy at the land-atmosphere interface?
2. How does organization of fine-scale surface heterogeneity impact boundary layer exchange and mesoscale circulation features?
3. How do spatial gradients and variability in meteorological forcing impact terrestrial water dynamics?
4. How will eco-hydrologic processes evolve under various disturbance mechanisms such as landscape and climatic change?
5. What is the 'coupled-system' predictability of extreme hydrological events?

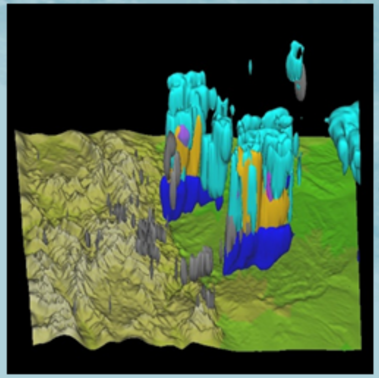
Overarching WRF-Hydro Development Objectives

A community-based, supported coupling architecture designed to provide:

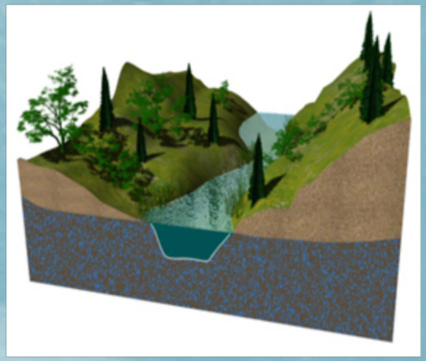
1. An extensible *multi-scale & multi-physics* land-atmosphere modeling capability for conservative, coupled and uncoupled *assimilation & prediction* of major water cycle components such as precipitation, soil moisture, snowpack, groundwater, streamflow, inundation
2. ‘Accurate’ and ‘reliable’ streamflow prediction across scales (from 0-order headwater catchments to continental river basins & minutes to seasons)
3. A robust framework for land-atmosphere coupling studies



1-10’s km



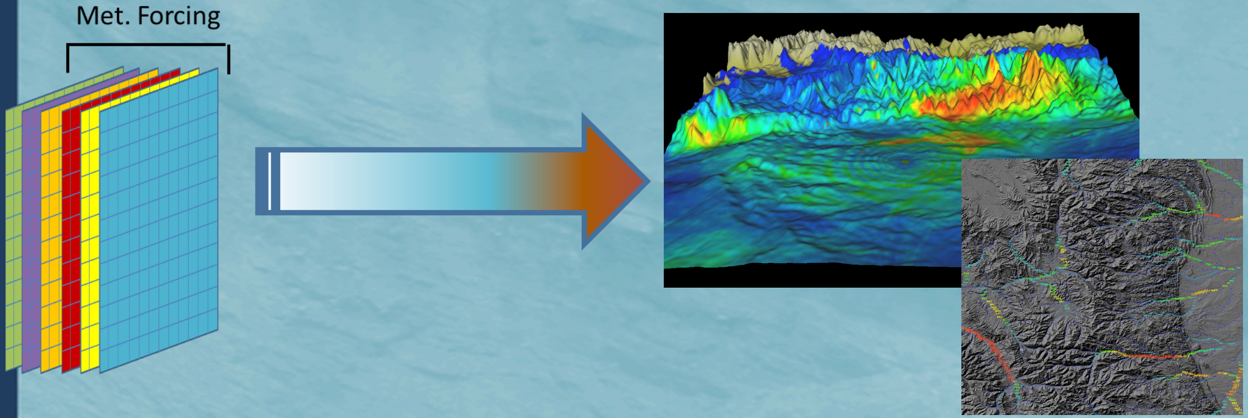
100’s m - 1’s km



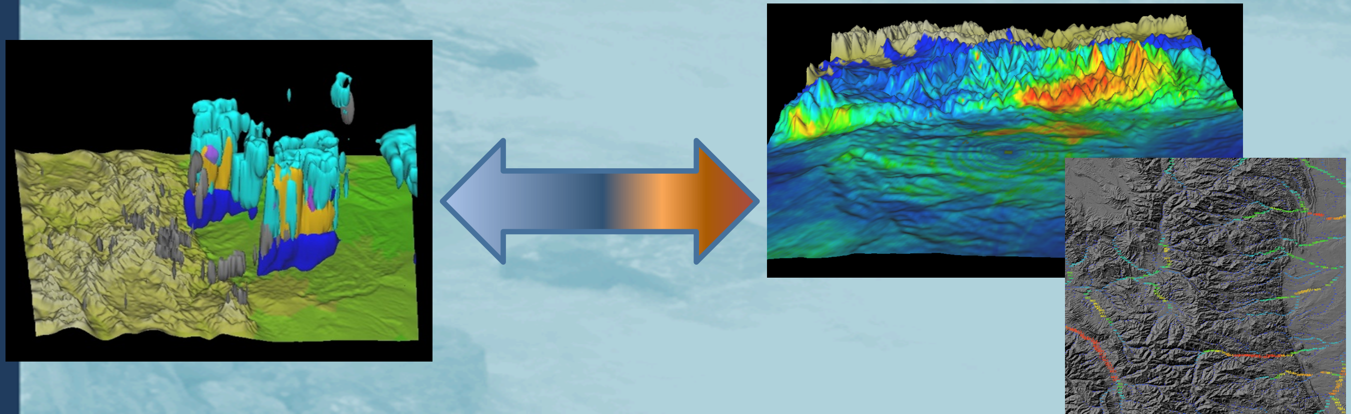
1-10’s m

WRF-Hydro Operates in 2 Major Modes: Coupled or Uncoupled to an Atmospheric Model

One-way ('uncoupled') →



Two-way ('coupled') ↔



- Uncoupled mode critical for spinup, data assimilation and model calibration
- Coupled mode critical for land-atmosphere coupling research and long-term predictions
- Model forcing and feedback components mediated by WRF-Hydro:
  - Forcings: T, Press, Precip., wind, radiation, humidity, BGC-scalars
  - Feedbacks: Sensible, latent, momentum, radiation, BGC-scalars

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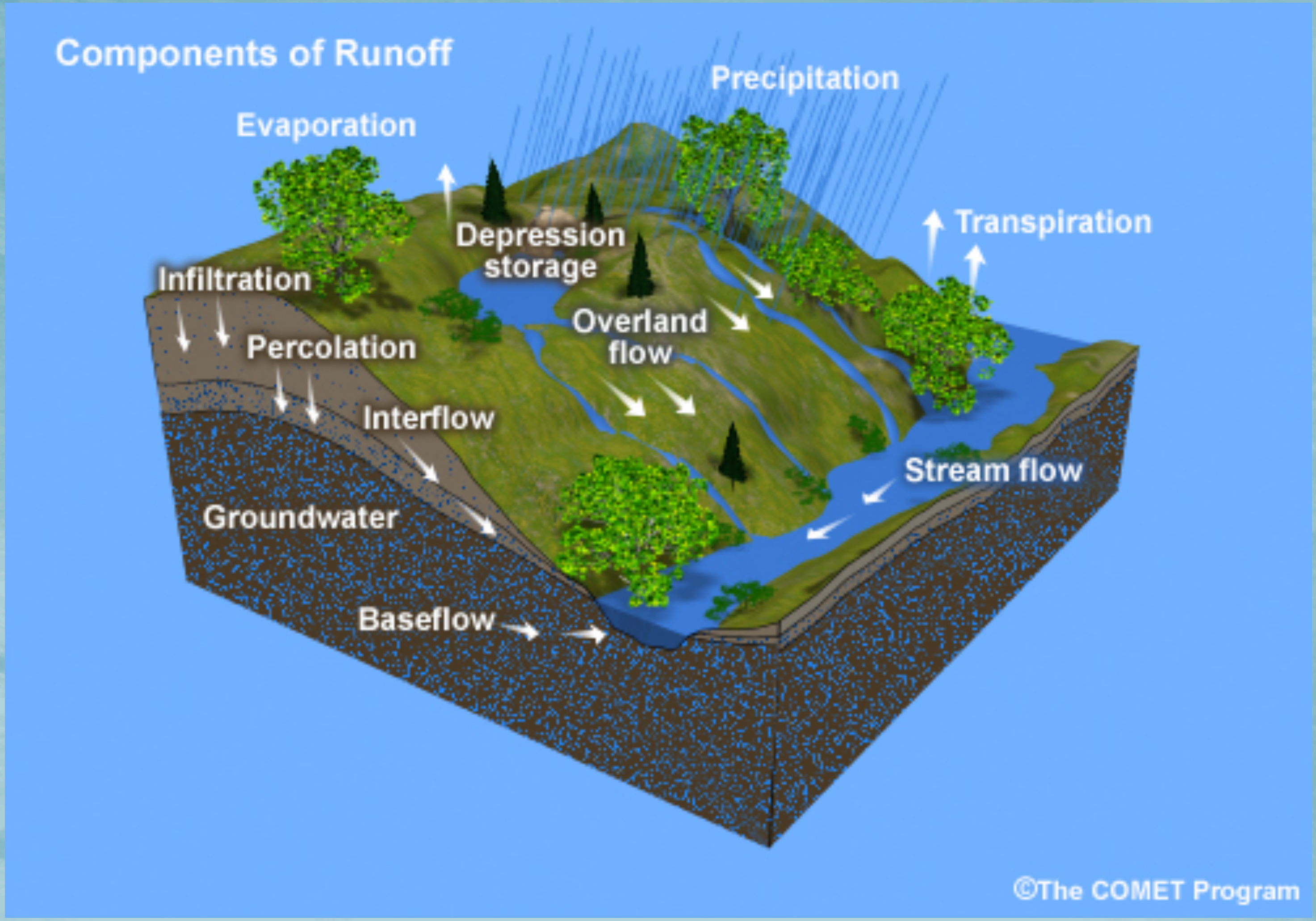
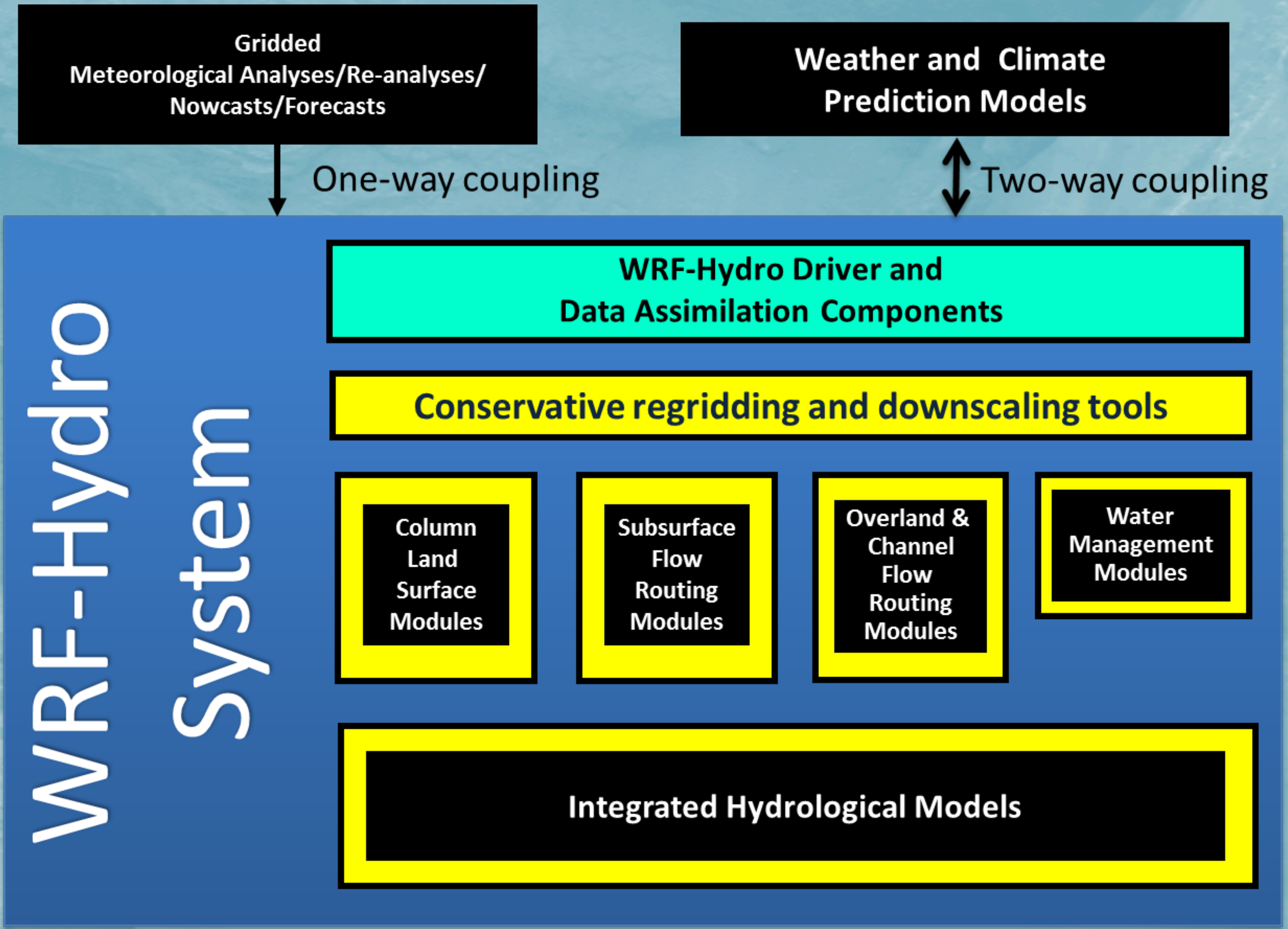
Model Componentry




Gridded
Meteorological Analyses/Re-analyses/
Nowcasts/Forecasts
Weather and Climate
Prediction Models
One-way coupling
Two-way coupling
WRF-Hydro System
WRF-Hydro Driver and
Data Assimilation Components
Conservative regridding and downscaling tools
Column Land Surface Modules
Subsurface Flow Routing Modules
Overland & Channel Flow Routing Modules
Water Management Modules
Integrated Hydrological Models

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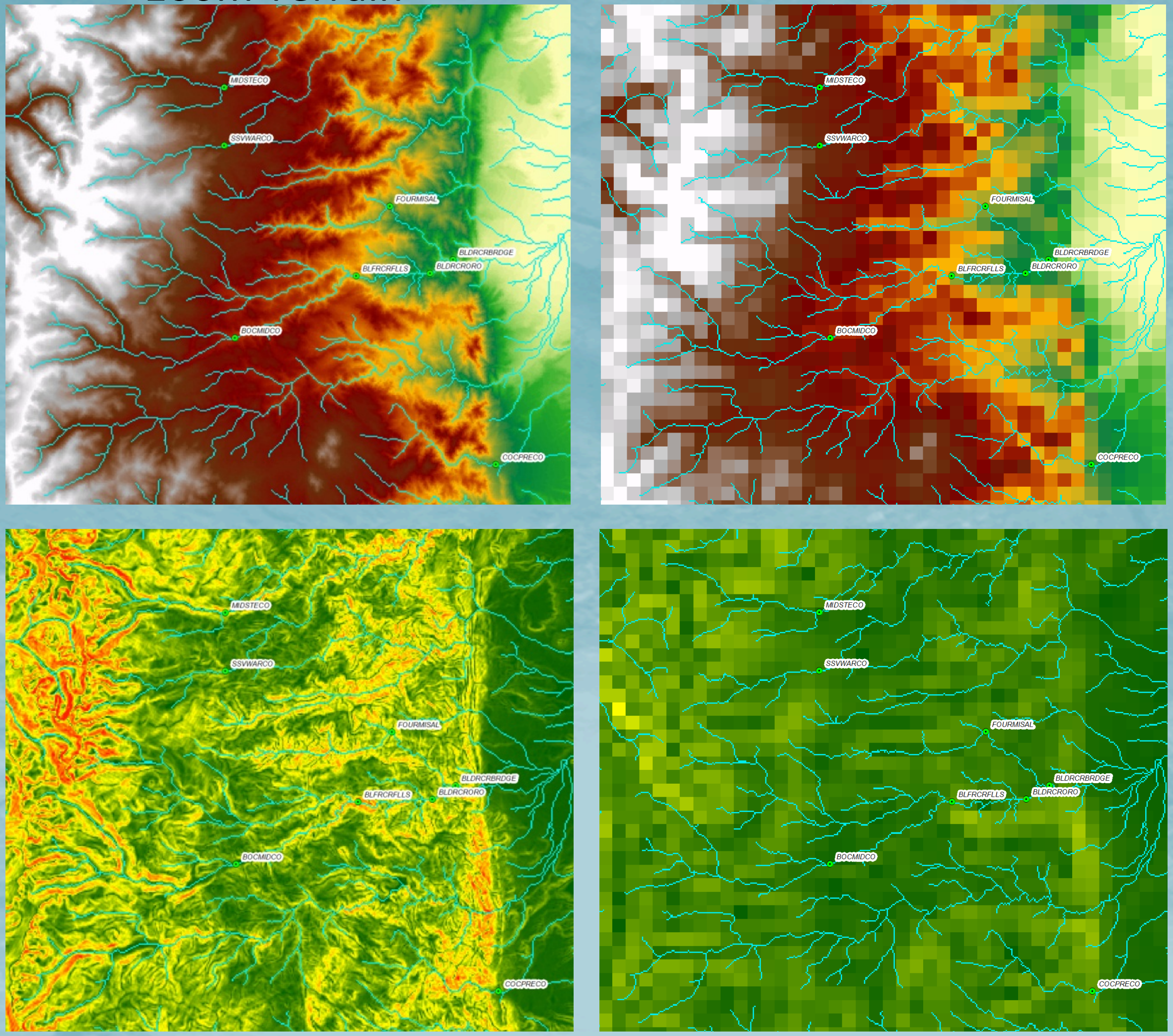
WRF-Hydro v2.0 Physics Components:

- Multi-scale aggregation/disaggregation:

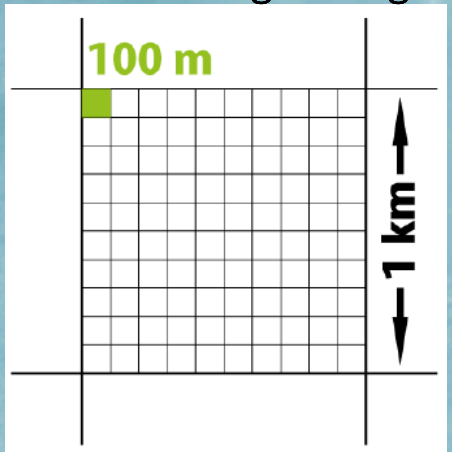
100m Terrain

1 km Terrain

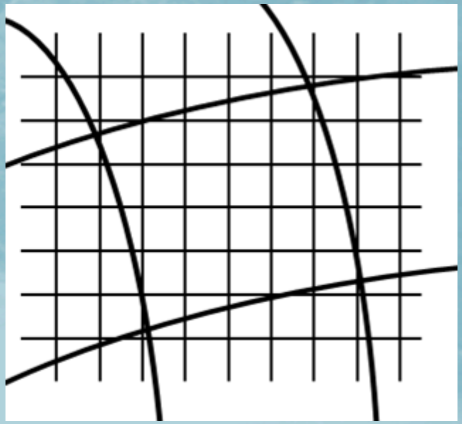


Terrain slope (0-45 deg)

Current ‘Regridding’



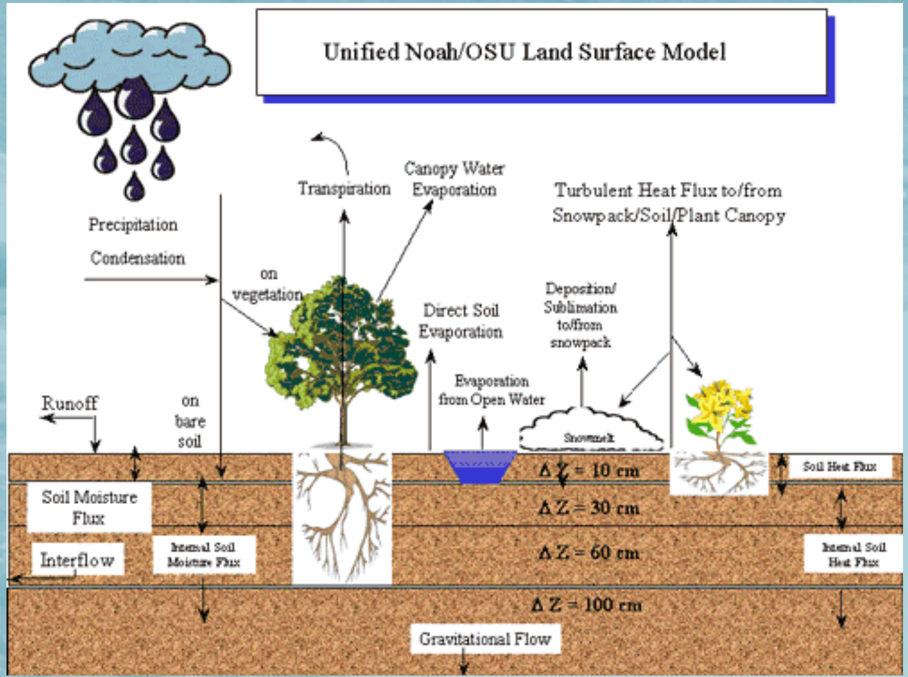
Implementing ESMF Regridders (v2.1)

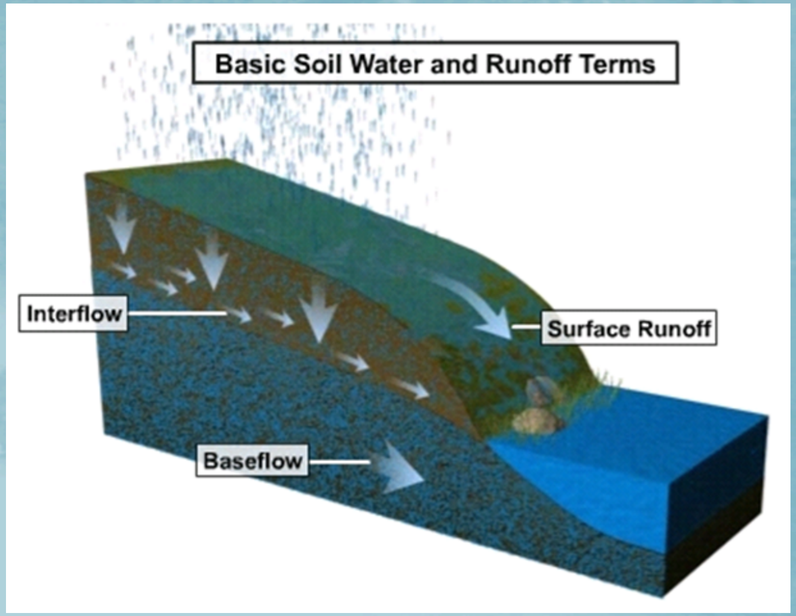


WRF-Hydro v2.0 Physics Components:

Column Land Models:

- WRF-coupled and offline Noah and Noah-MP now supported as of April, 2014
- CLM coupling supported through CESM architecture (in progress under DOE project)
- NOAA SAC-HTET (in progress under OHD project)





WRF-Hydro v2.0 Physics Components:

- Surface routing: Explicit overland flow

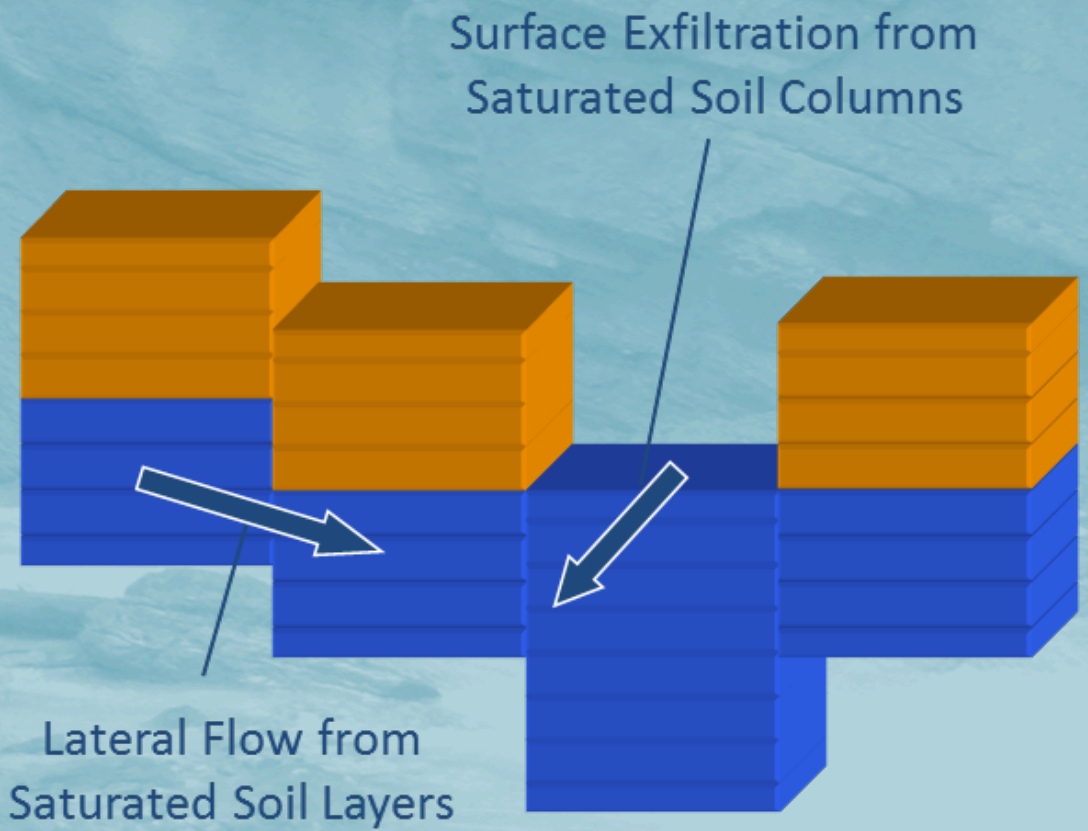
Infiltration excess
available for hydraulic routing

Adapted from:
Julian et al, 1995 – CASC2D, GSSHA

- Pixel-to-pixel routing
  - Steepest descent (1d) or 2d
  - Diffusive wave/backwater permitting
  - Kinematic wave (in progress)
  - Explicit solution
- Ponded water (surface head) can be fully-interactive with land model
- Sub-grid variability of ponded water on routing grid is preserved between land model calls

WRF-Hydro v2.0 Physics Components:

- Subsurface routing:



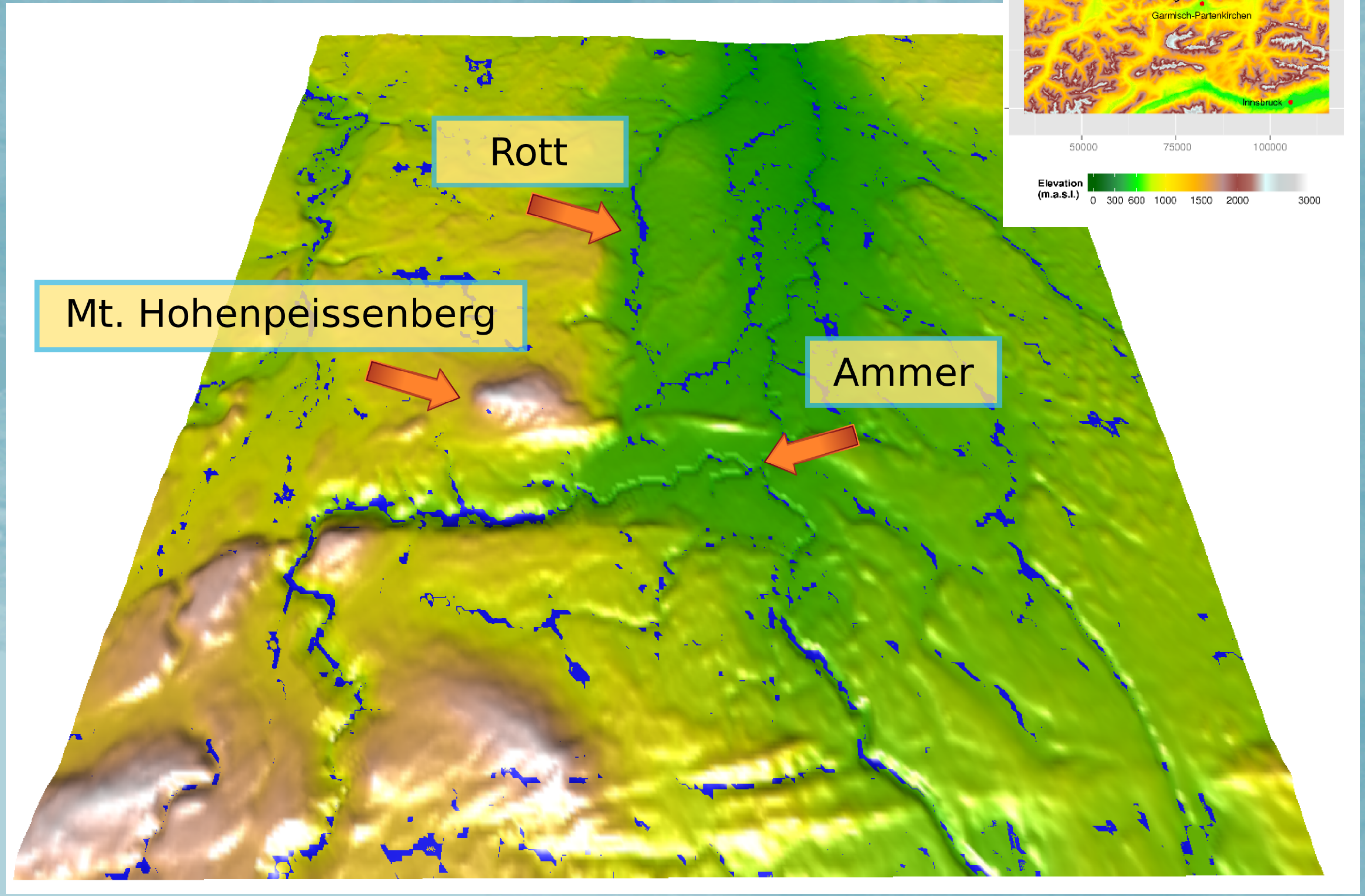
Adapted from:
Wigmosta et. al, 1994

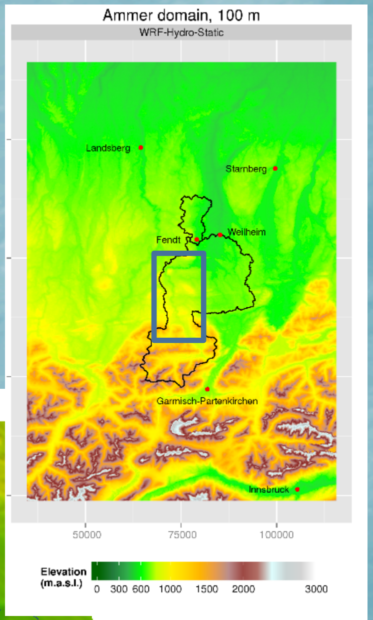
- Quasi steady-state, Boussinesq saturated flow model
- Exfiltration from fully-saturated soil columns to overland flow
- Anisotropy in vertical and horizontal Ksat
- No ‘perched’ flow
- Soil depth is uniform

- **Critical initialization value: water table depth**

WRF-Hydro v2.0 Physics Components:

- Subsurface routing:
  - 2d groundwater model
  - Coupled to bottom of LSM soil column through Darcy-flux parameterization
  - Independent hydraulic characteristics vs. soil column
  - Full coupling to gridded channel model through assumed channel depth and channel head
  - Detailed representation of wetlands





Surface ponded water from coupled groundwater in WRF-Hydro B. Fersch, KIT, Germany

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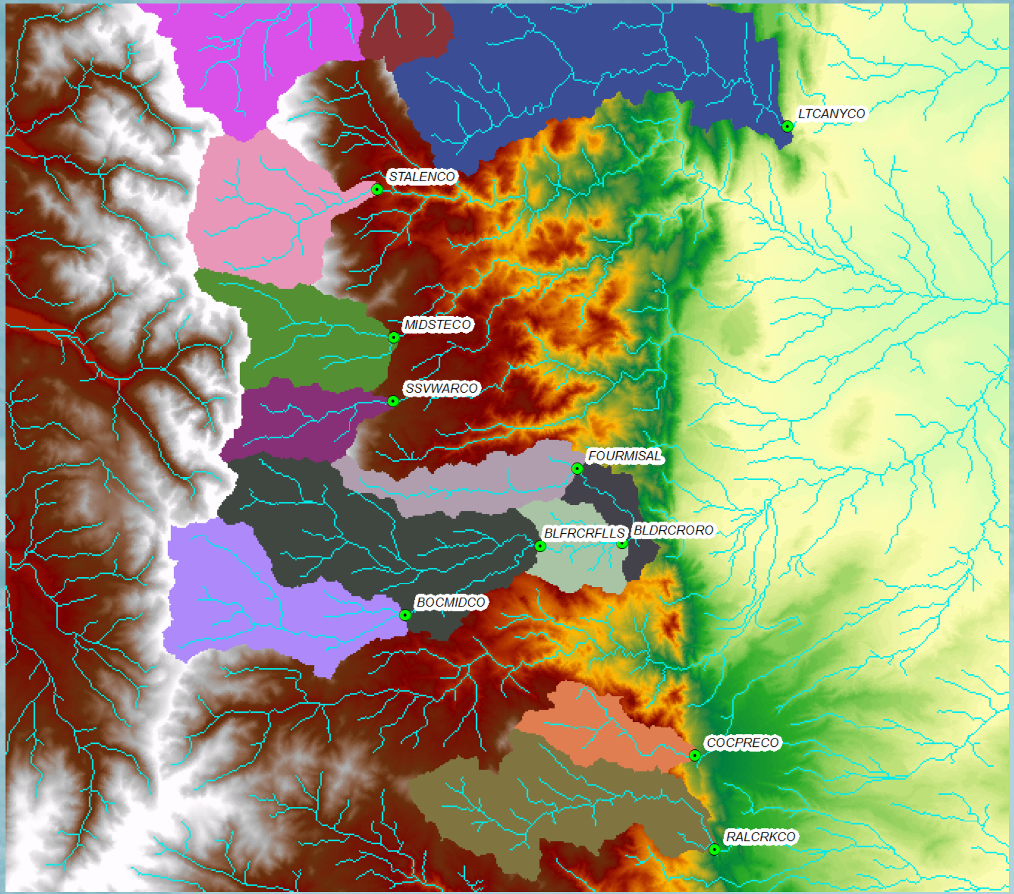
WRF-Hydro v2.0 Physics Components:

- Simple routing: simple catchment aggregated channel inflow (very fast)

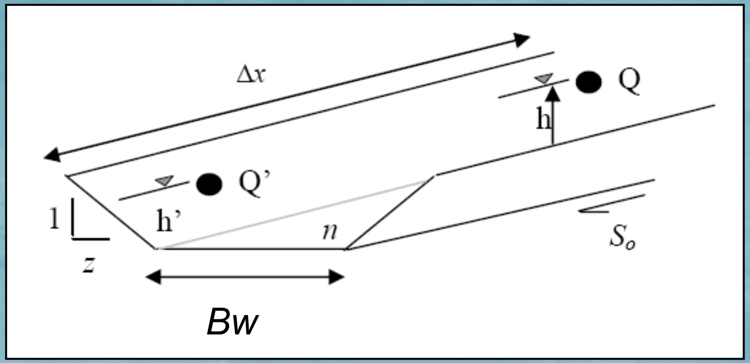


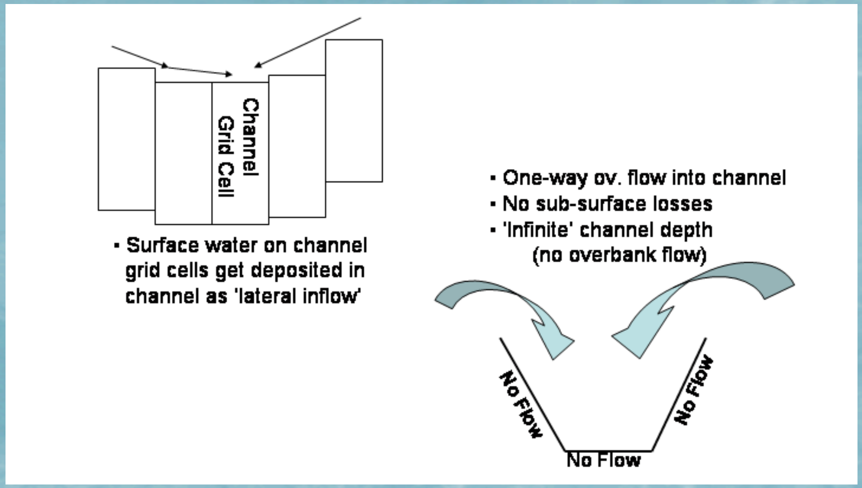
Adapted from:
RAPID , David et al., 2011

- Collects 'infiltration excess' and 'soil drainage' from pre-defined basins and dumps directly into channel network
- Most applicable for small catchment networks (e.g. NHDPlus, HUC10+, etc.)
- Supports lumped/catchment hydrological model formulations

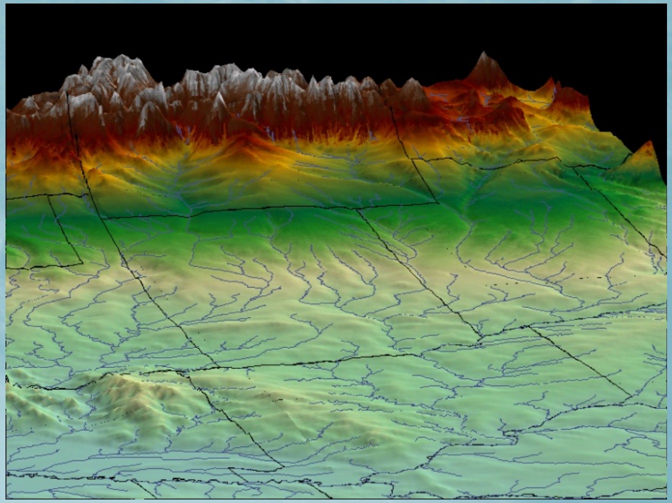
WRF-Hydro v2.0 Physics Components:

- Channel routing: Gridded vs. Reach-based



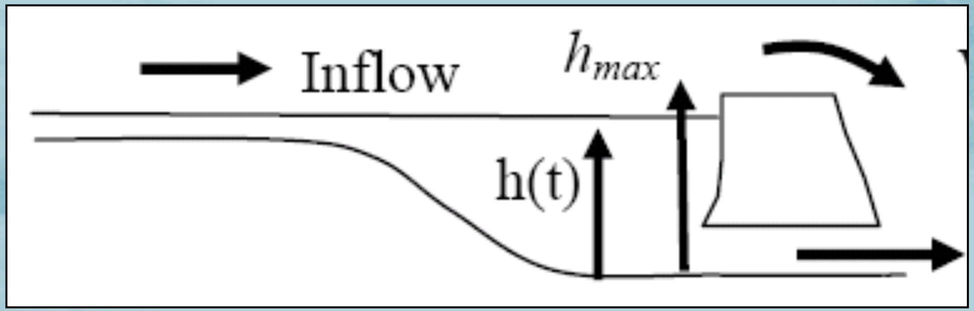


- Solution Methods:
  - Gridded diffusive wave (slower)
  - ROUTPIX, Kinematic (in progress under OHD project)
  - Reach-based Muskingam methods, custom & RAPID (NHDPlusV2).....(very fast)
- Parameters:
  - A priori function of Strahler order or fully gridded (v2.1)
  - Trapezoidal channel (bottom width, side slope)
  - Channel roughness



WRF-Hydro v2.0 Physics Components:

- Optional lake/reservoir model:
  - Level-pool routing (i.e. no lagging of wave or gradient in pool elevation)
  - Inflows via channel and overland flow
  - Discharge via orifice and spillway to channel network
  - Parameters: lake and orifice elevations, max. pool elevation, spillway and orifice characteristics; specified via parameter table
  - Active management can be added via an operations table
  - Presently no seepage or evaporative loss functions

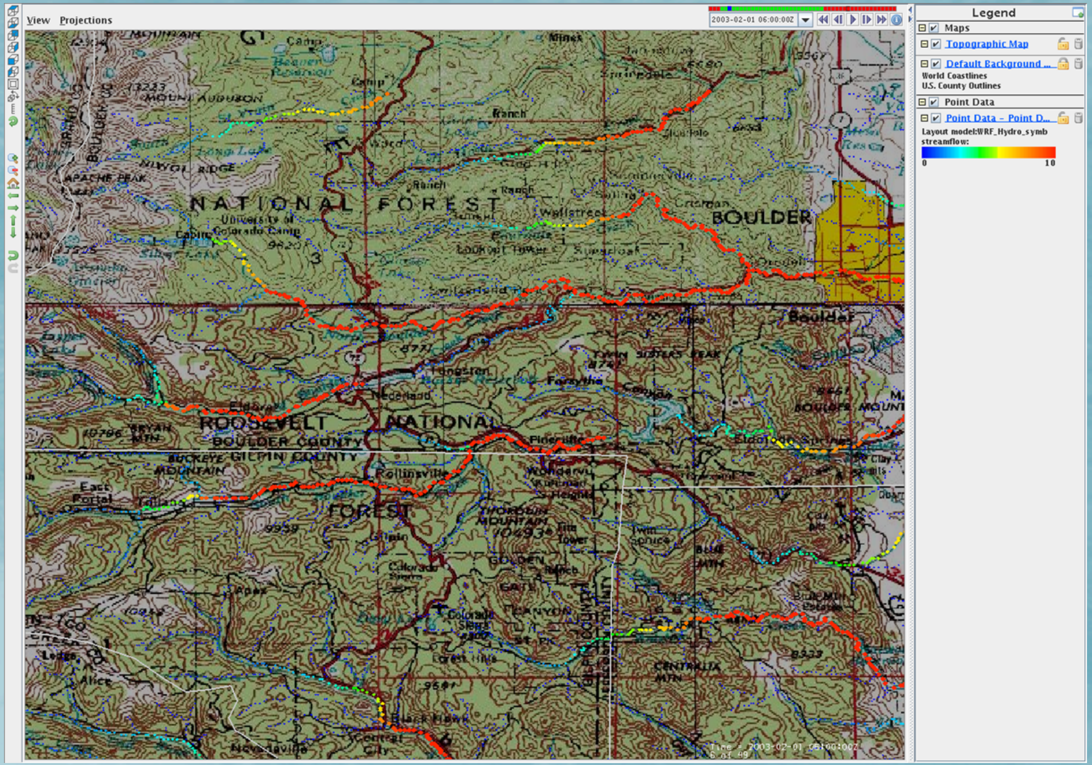


Moving beyond 'natural flows' towards explicit accounting of infrastructure

Including the control effects of, and impacts on infrastructure:

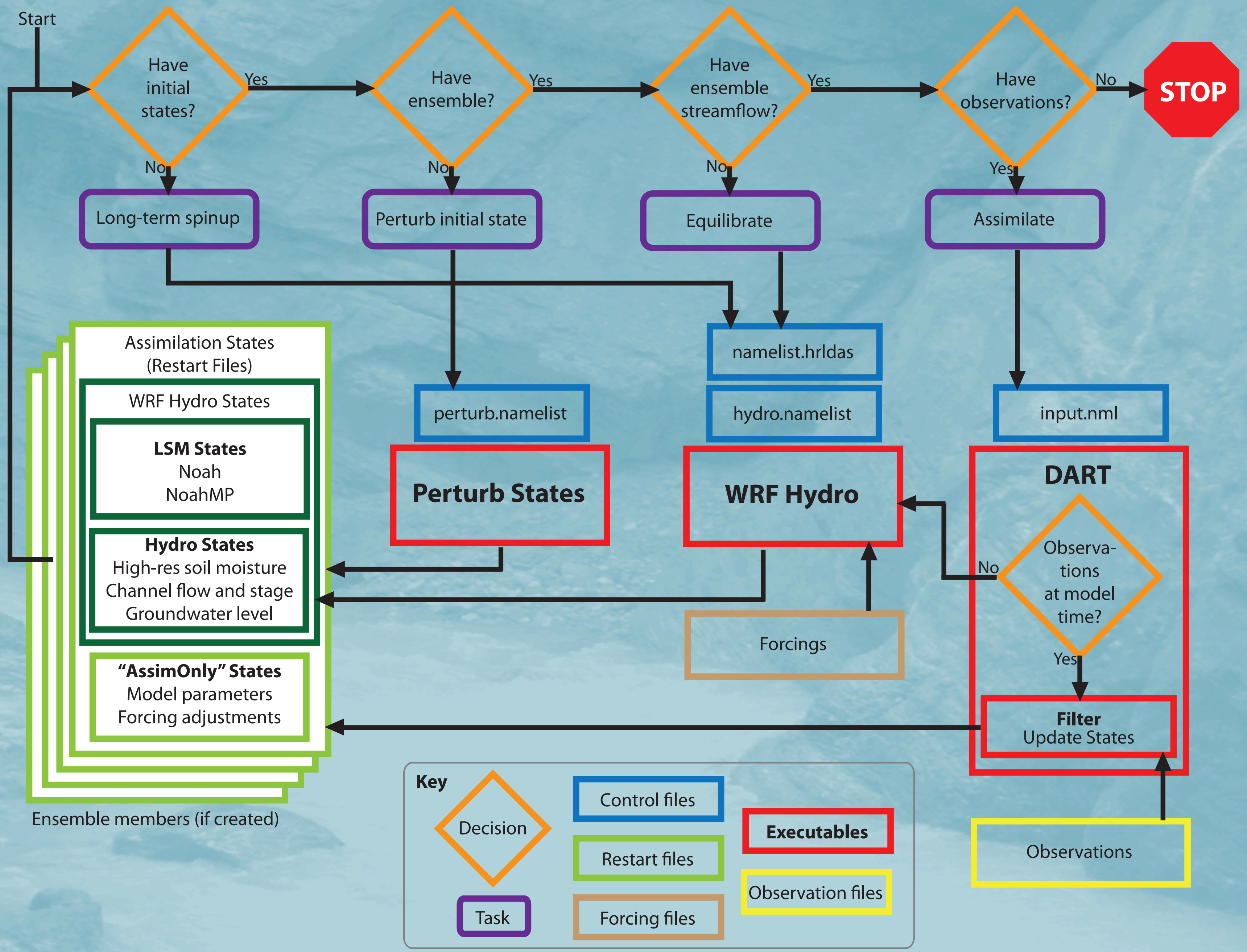
- Dams and reservoirs (passive and actively managed)
- Overbank storage and attenuation
- Diversion structures, headgates
- Levees, dikes
- Failures of infrastructure (exceeding design capacity)

*** Needs Infrastructure & Operations Data Standards**



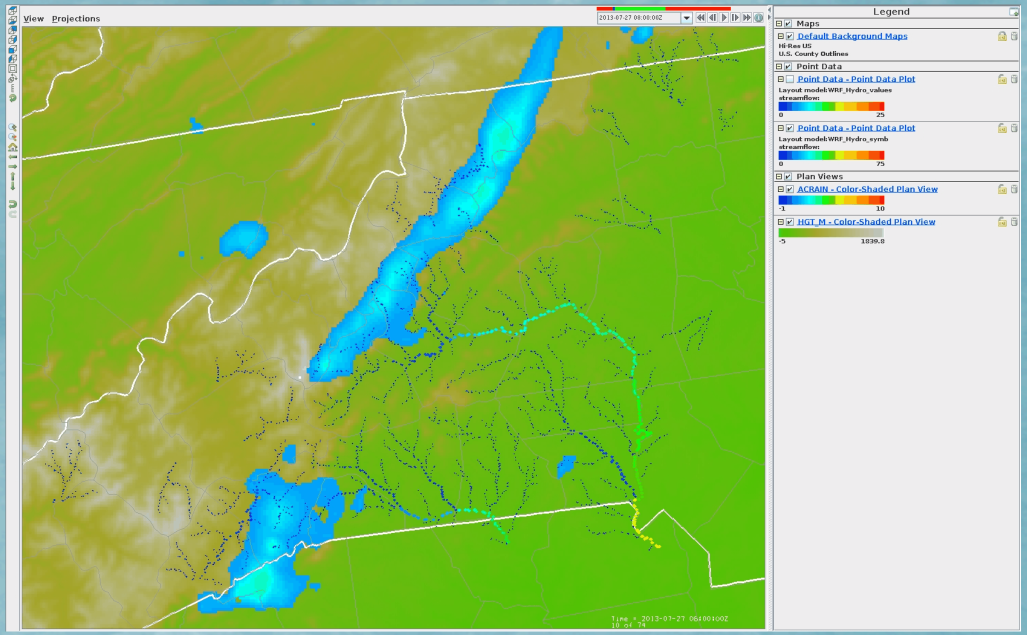
Design storm streamflow capture by Barker Reservoir and Gross Reservoirs. Colorado Front Range

HydroDART Overview



‘WRF-Hydro’ Process Permutations and System Features:

- ~180 possible ‘physics’ component configurations for streamflow prediction:
  - 3 up-to-date column physics land models (Noah, NoahMP, CLM)
  - 3 overland flow schemes (Diffusive Wave, Kinematic Wave, Direct basin aggregation)
  - 4 lateral/baseflow groundwater schemes (Boussinesq shallow-saturated flow, 2d aquifer model, Direct Aggregation Storage-Release: pass-through or exponential model
  - 5 channel flow schemes: Diffusive wave, Kinematic Wave, RAPID-Muskingam for NHDPlus, Custom Network Muskingam/Muskingam Cunge



Ensemble Flood Forecasting in the Southeast U.S. with WRF-Hydro
***2014 WRF User’s Workshop*, K. Mahoney (NOAA-ESRL)**

- Simple level-pool reservoir with management
- DART, filter-based hydrologic data assimilation

WRF-Hydro System-Level Coupling Capabilities

Completed:
- Stand-alone, 'Un-coupled' (1-d Noah & NoahMP land model driver)
- Coupled with the Weather Research and Forecasting Model WRF-ARW)
- Coupled with LIS (WRF-Hydro v1.0, LISv6.1)
- Coupled into DART…

In Progress:
- NOAA/NEMS (NOAA Environmental Modeling System-Cecilia DeLuca)
- Update of LIS coupling to LIS v7/WRF-Hydro v2.1
- Coupled with CLM under CESM coupler (working on recent release of CLM in WRF)

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‘WRF-Hydro’ Software Features:

- Modularized F90/95 (and later)
- Coupling options are specified at compilation and WRF-Hydro is compiled as a new library in WRF when run in coupled mode
- Physics options are switch-activated though a namelist/ configuration file
- Options to output sub-grid state and flux fields to standards-based netcdf point and grid files
- **Fully-parallelized** to HPC systems (e.g. NCAR supercomputer) and ‘good’ scaling performance
- Ported to Intel, IBM and MacOS systems and a variety of compilers (pg, gfort, ifort)

Wei Yu (RAL) – lead engineer

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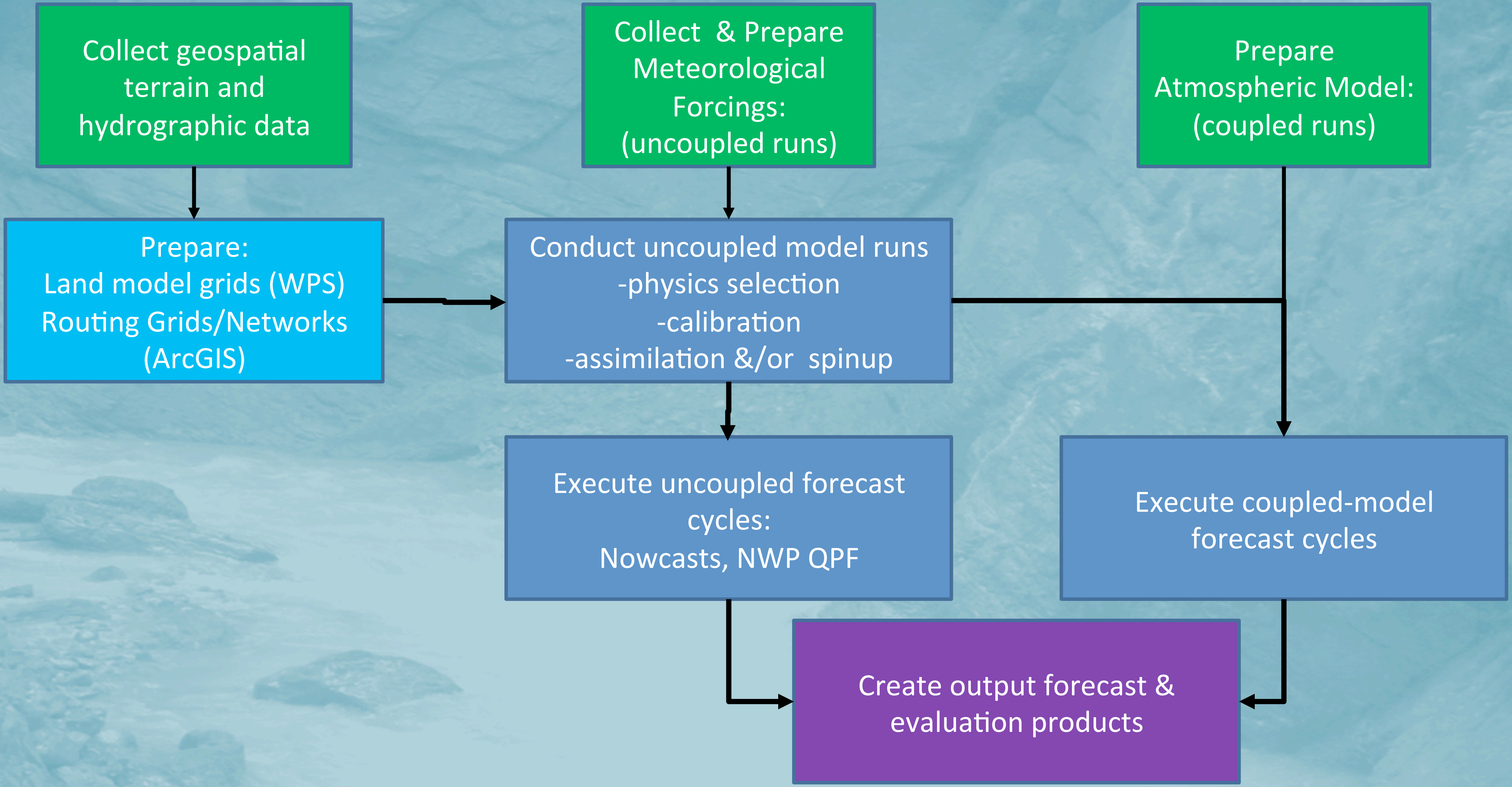
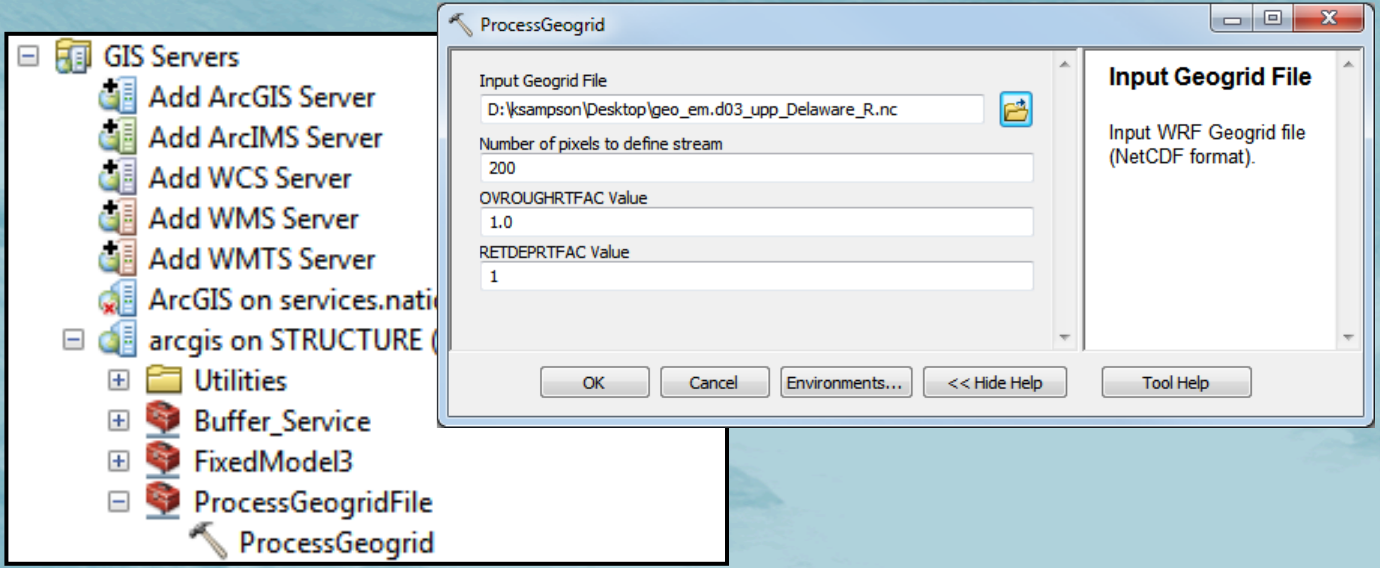
The WRF-Hydro Workflow

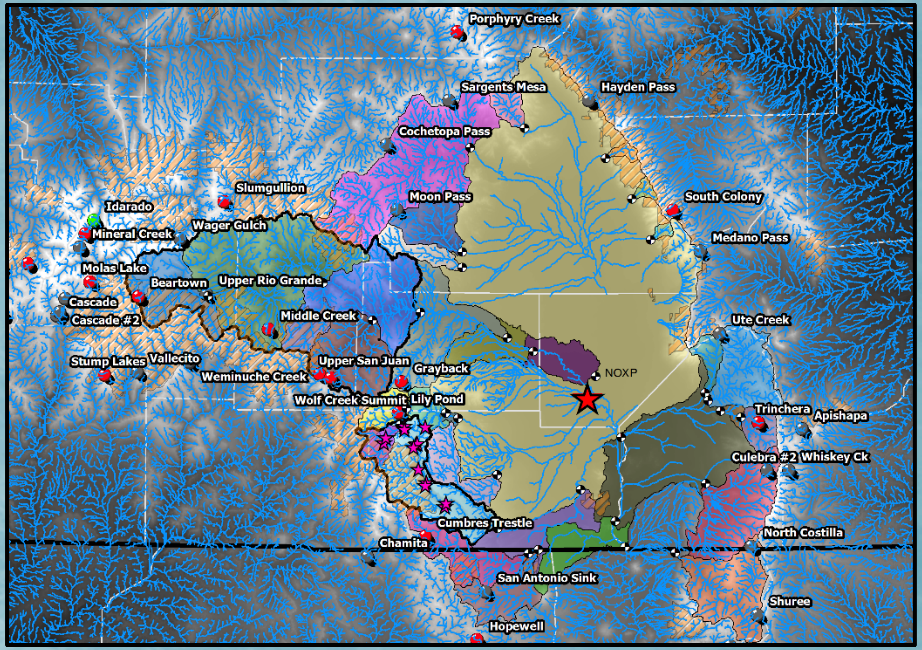
WRF-Hydro Implementation Workflow:



WRF-Hydro Setup and Parameterization: Python Pre-Processing Toolkit: K. Sampson - developer

- Python-based scripts
- ESRI ArcGIS geospatial processing functions
  - Support of multiple terrain datasets
    - NHDPlus, Hydrosheds, EuroDEM

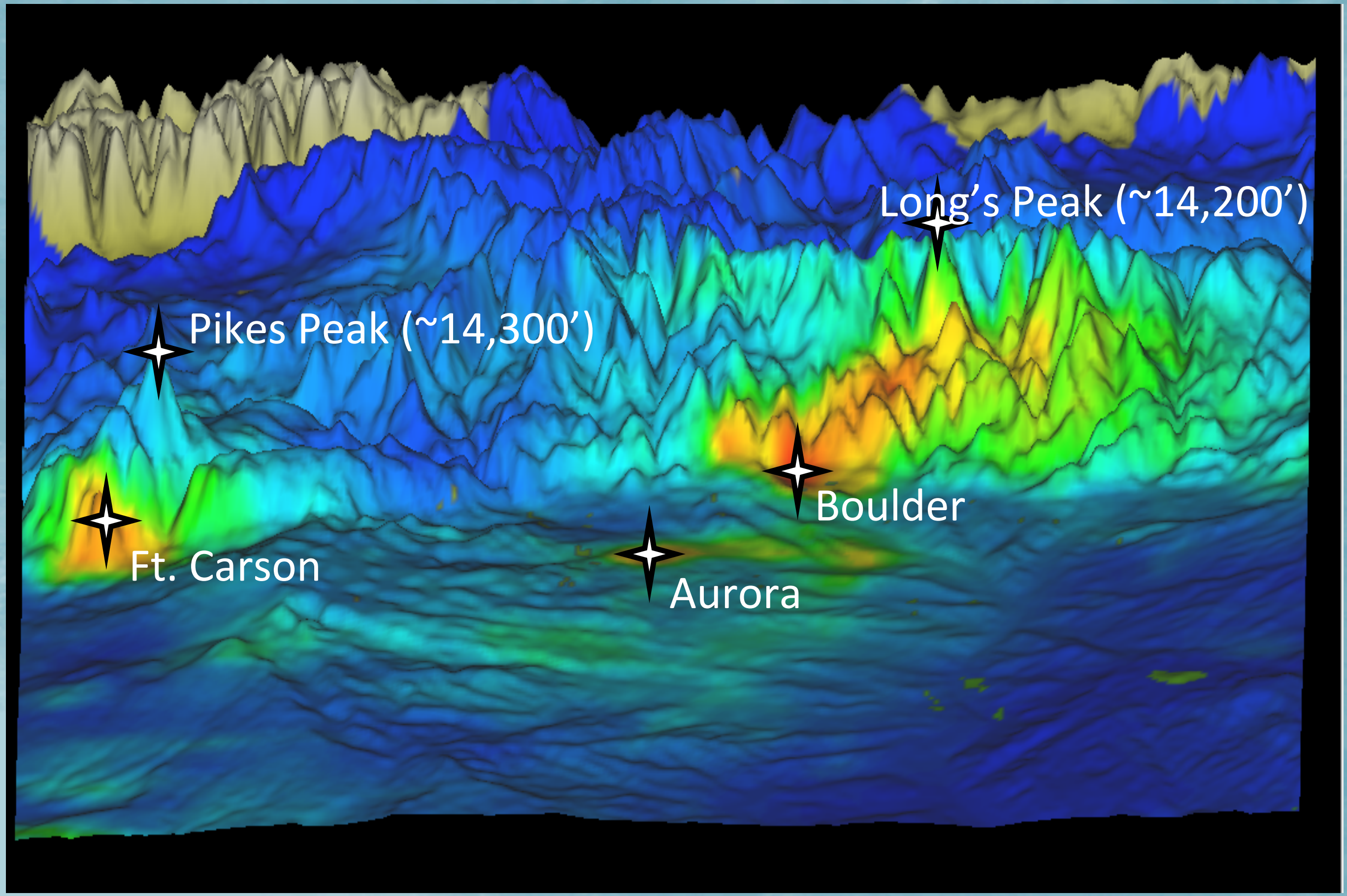




Outputs: topography, flowdirection, watersheds, gridded channels, river reaches, lakes, various parameters

Forcing data supported:

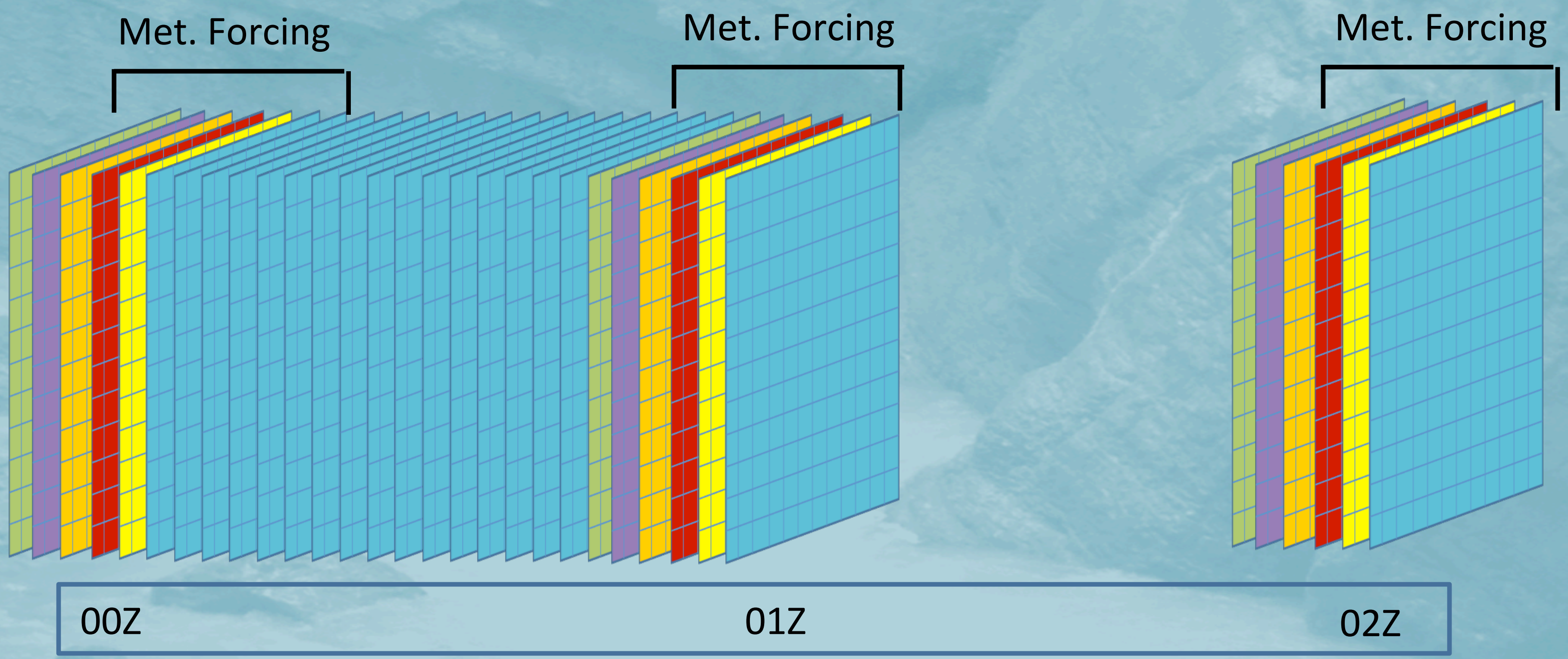
- NLDAS, NARR analyses
- QPE products: MPE, StgIV, NCDC-served, dual-pol, Q3/ MRMS, gauge analyses
- NOAA QPF products: GFS, NAM, RAP, HRRR, ExREF
- Nowcast (NCAR Trident/ TITAN)
- NOHRSC SNODAS
- ESMF/ncl regridding tools



Regridded MPE precipitation during the 2013 Colorado Floods
Unidata IDV display

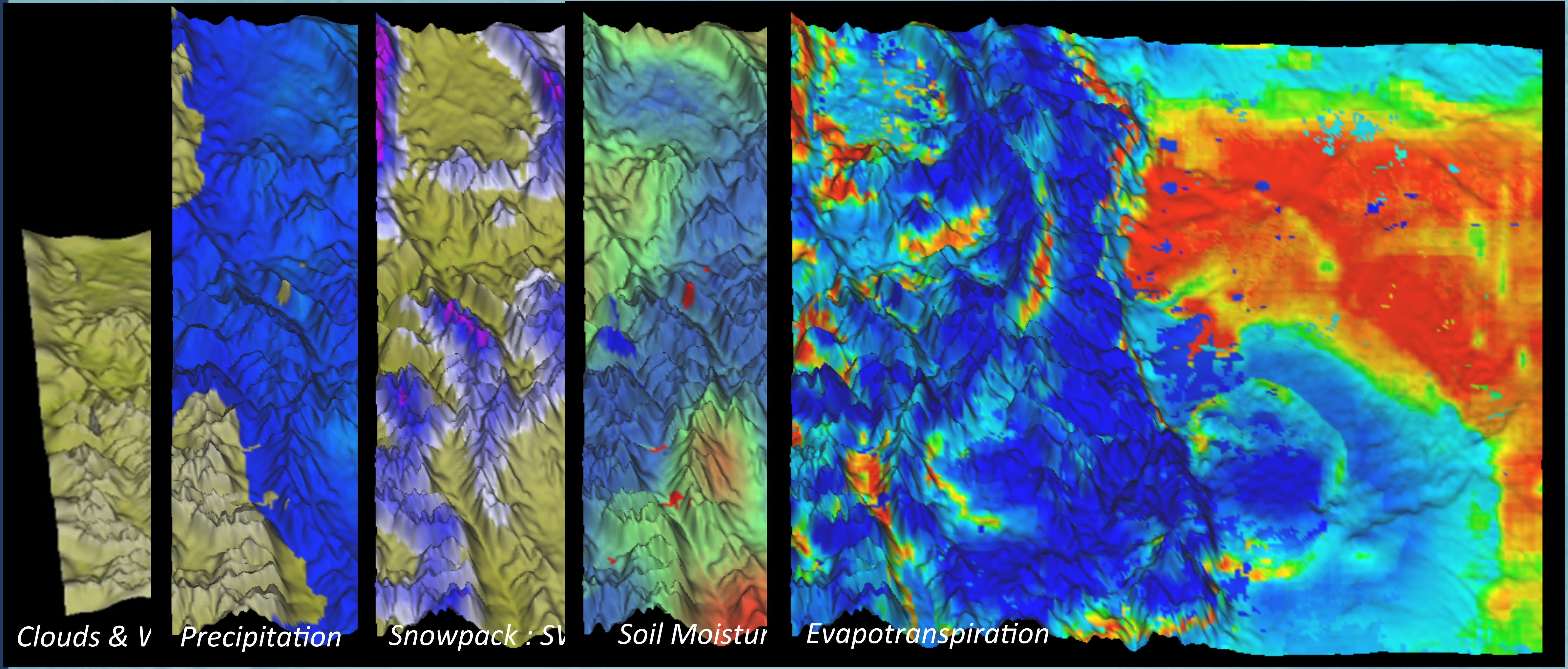
Input Forcing Data Requirements:

- Data Requirements:
  - Forcing Input: Forecast Example…



WRF-Hydro output products: Forecasts of water cycle components

Maps of precipitation, soil moisture, ET, snowpack, inundation depth, groundwater depth, streamflow



Unidata IDV display

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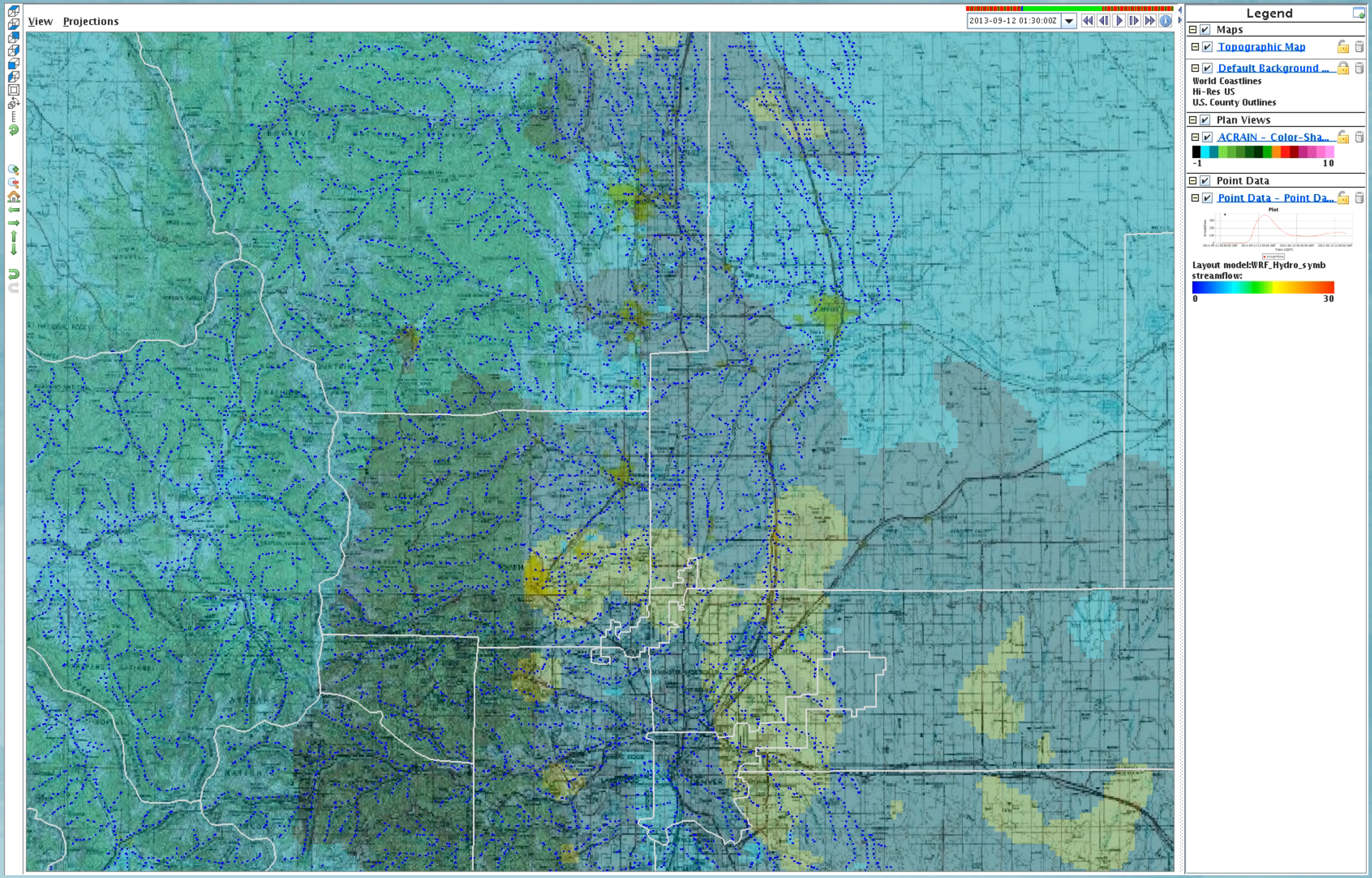
WRF-Hydro output Products: Forecasts of spatially-explicit water cycle components

- **MPE-driven streamflow during the 2013 Colorado Floods**
- **Unidata IDV Display of gridded and point netcdf output**



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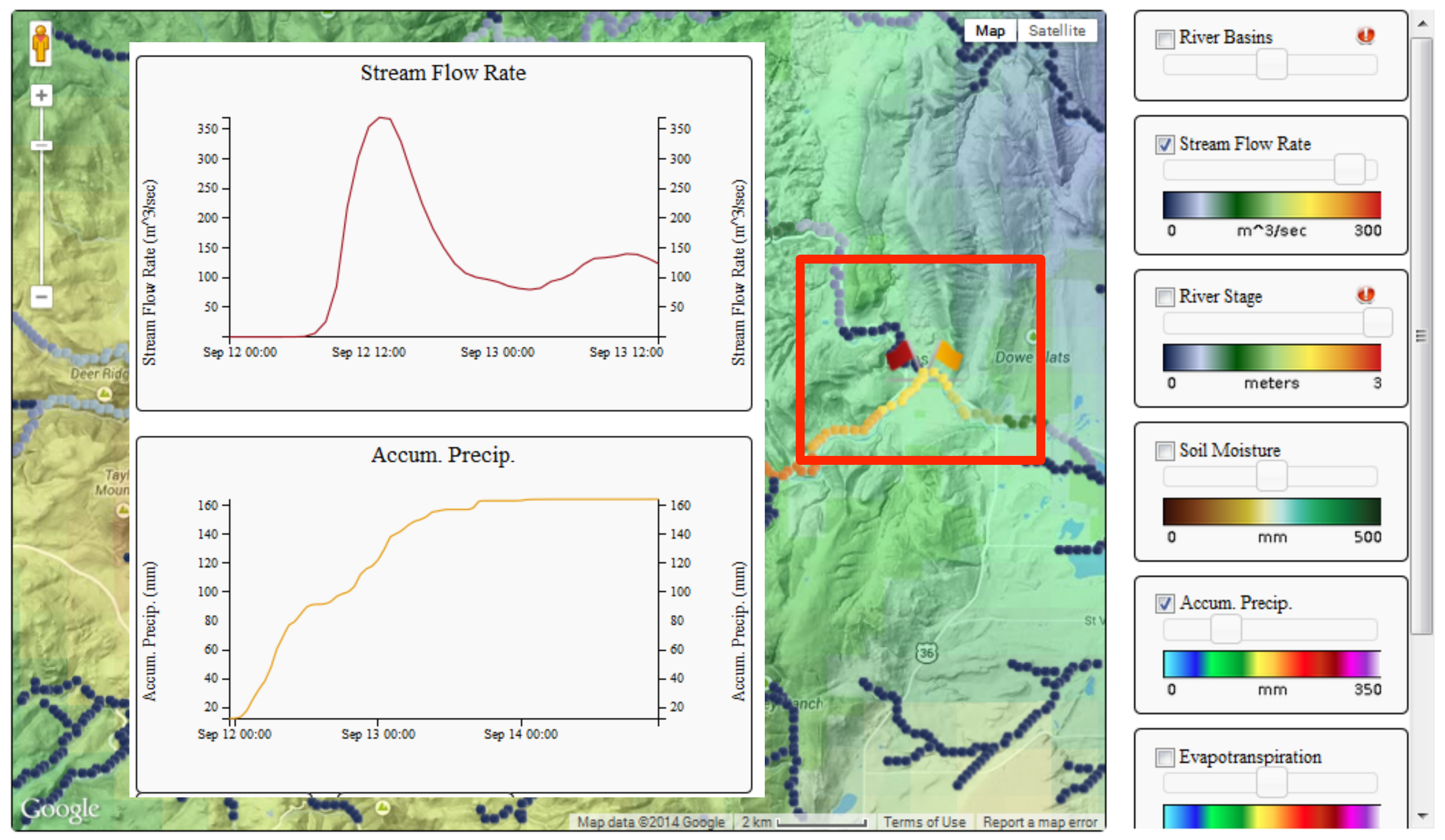
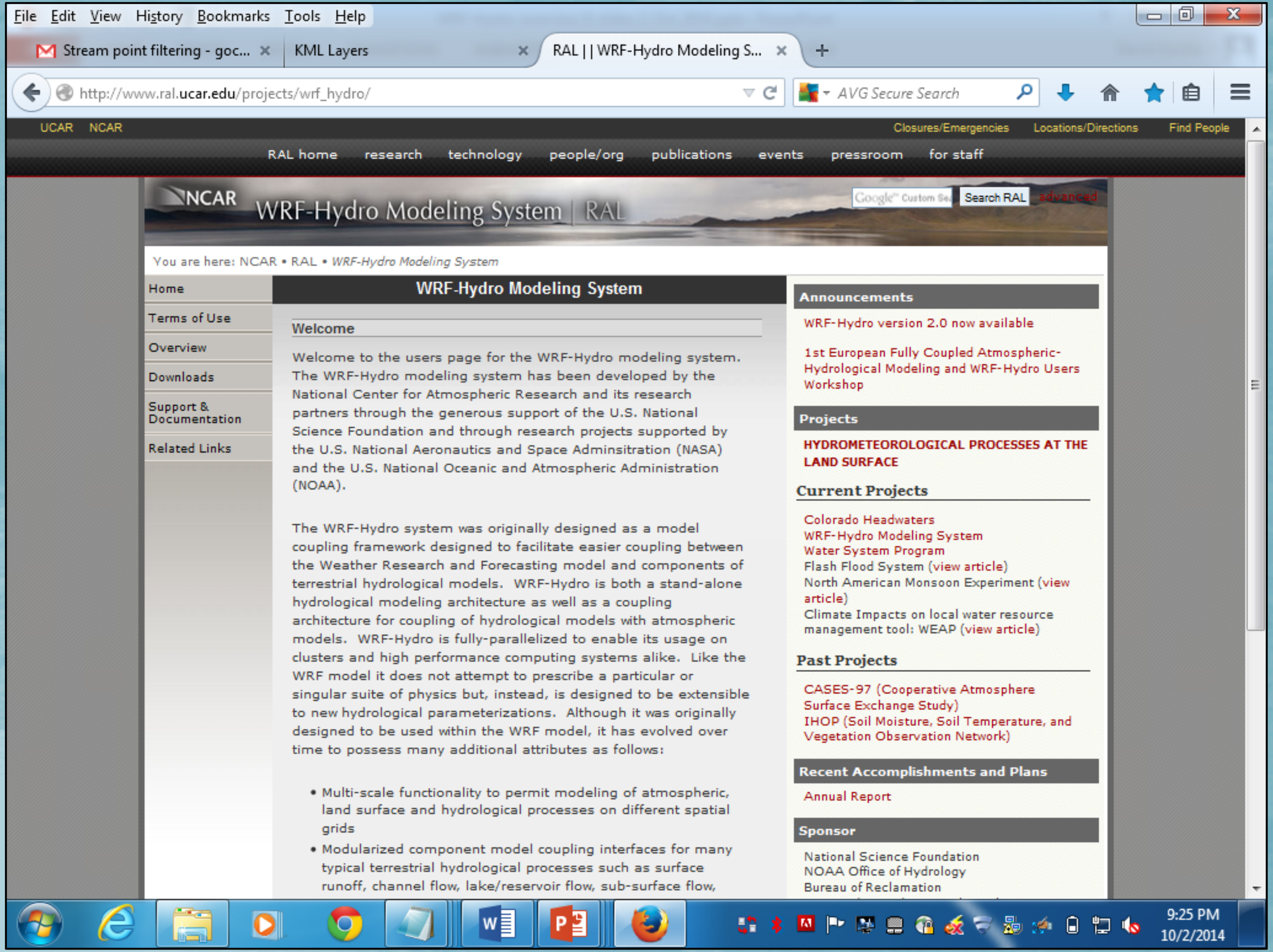
Visual forecast products…Web map service interfaces: GoogleMaps/Earth , ESRI ArcGIS, OpenLayers



GoogleEarth, GoogleMaps. ArcGIS WMS display

WRF-Hydro Support Services

- Web Page:
  - Code distribution (GIT repository)
  - Documentation (v2, 120 pages)
  - Test cases (coupled and uncoupled)
  - Script Library (file prep, reformatting, viz)
  - ArcGIS preparation tools
  - Email help support (staff limited)
  - Google analytics (Jan 1 - Oct 1, 2014)
    - Total page views: 14,664
    - Downloads: 1, 735
    - (Stats have major gap in recording during Oct. 2013)

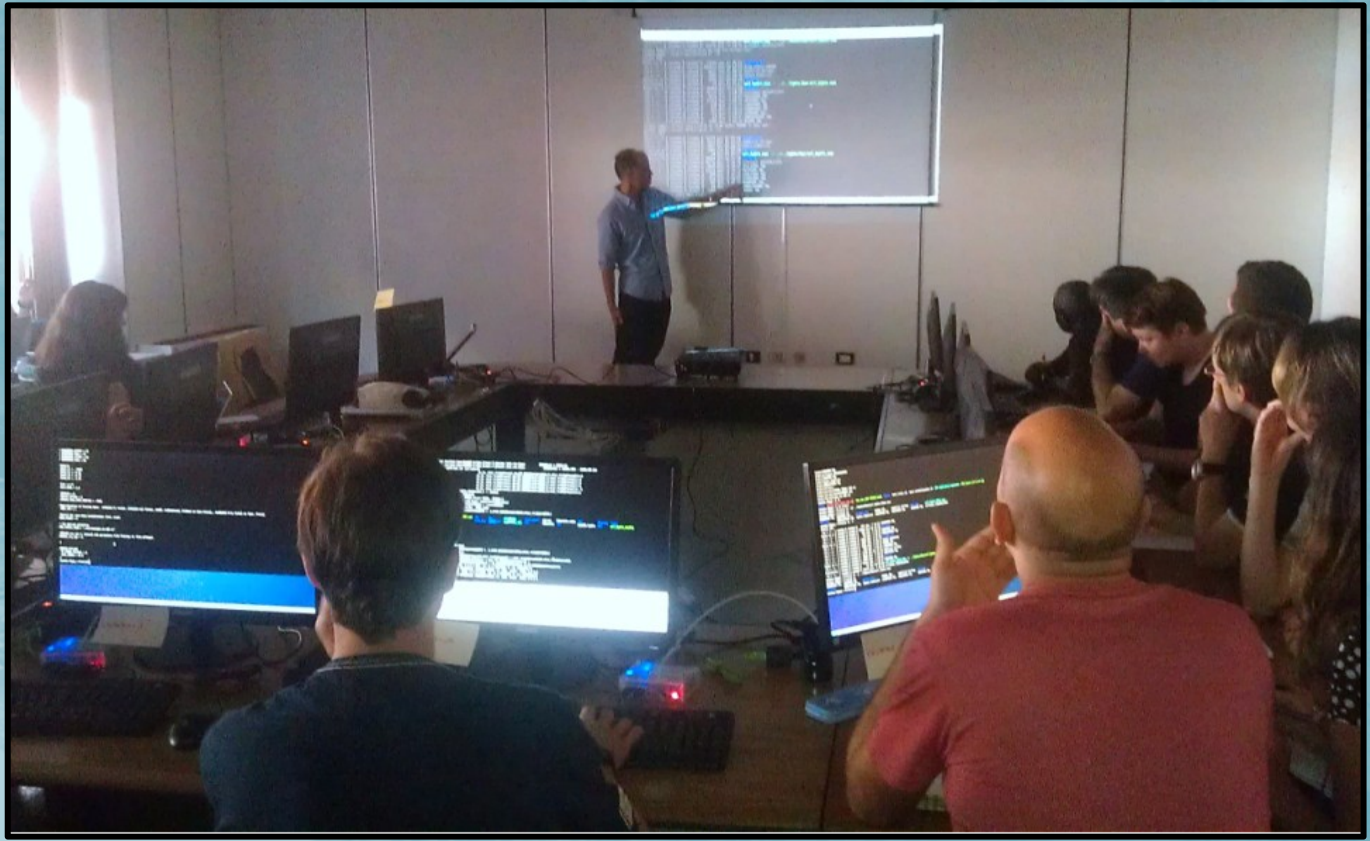


http://www.ral.ucar.edu/projects/wrf_hydro/

WRF-Hydro Support Services

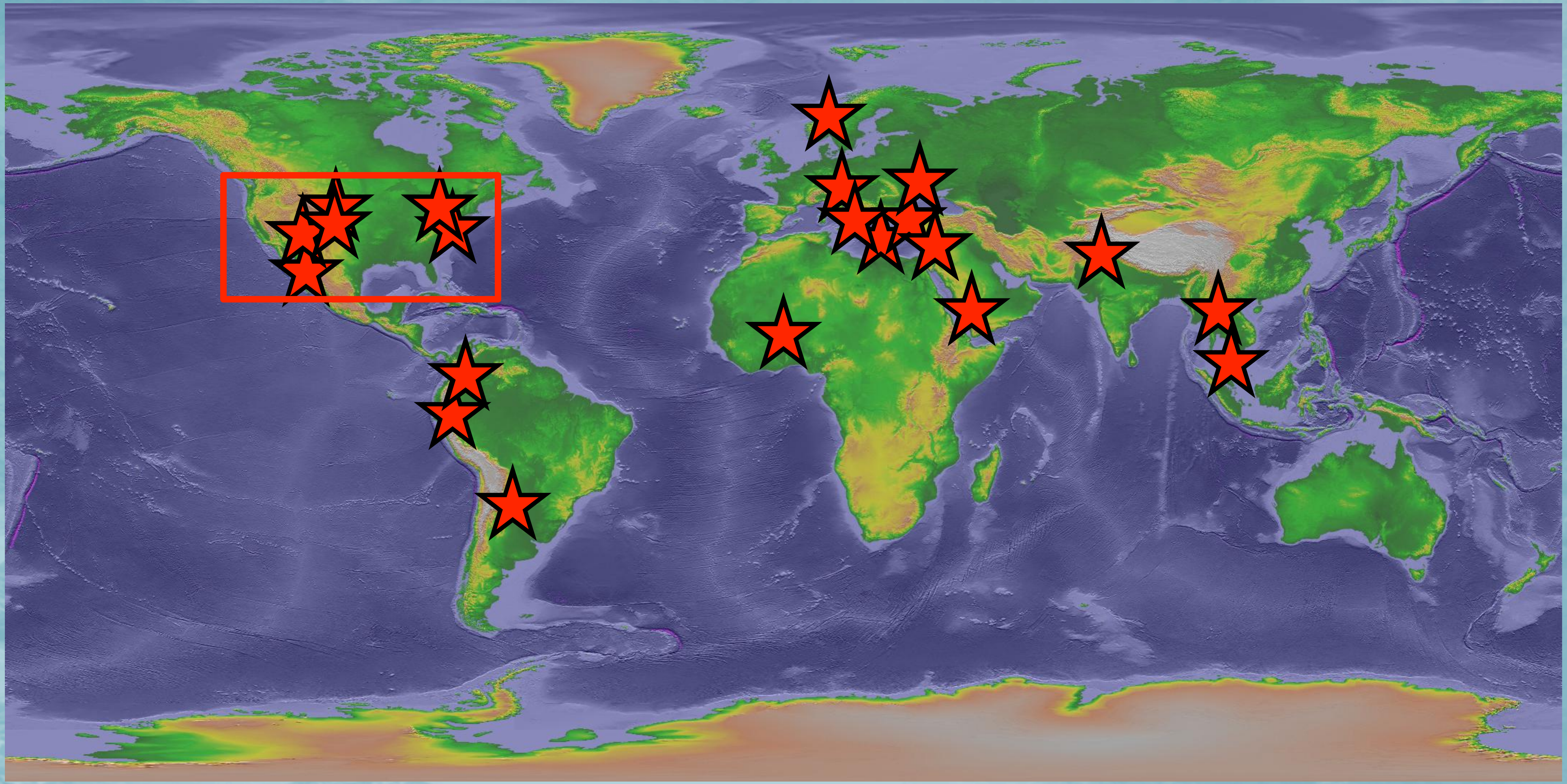
- Training classes:
  - Semi-annual WRF tutorial training sessions (short 1-hr system overviews)
  - University hosted visits (~1-2/yr on the order of 1-3 days)
  - International training seminars and colloquia (~1-2/yr, on the order of 1-3 days)

  - Next Training is May 4-7, 2015 in Boulder (sponsored by CUAHSI)



1st European Fully Coupled Atmospheric-Hydrological Modeling and WRF-Hydro Users workshop, U. of Calabria, Italy, June 2014

WRF-Hydro Community of Developers & Users:



★ Past or current implementations

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Current WRF-Hydro Applications around the world:

1. Operational Streamflow Forecasting:
   - U.S. National Weather Service, National Water Center
   - Israeli Hydrological Service
   - State of Colorado-Upper Rio Grande River Basin (CWCB, NSSL)
   - NCAR-STEP Hydrometeorological Prediction Group
   - U. of Calabria reservoir inflow forecasting
2. Streamflow prediction research (U. Ankara, Arizona State U., Karlsruhe Inst. Tech.)
3. Diagnosing climate change impacts on water resources
   - Himalayan Mountain Front (Bierknes Inst.)
   - Colorado Headwaters (U. Colorado)
   - Bureau of Reclamation Dam Safety Group (USBR,NOAA/CIRES)
4. Diagnosing land-atmosphere coupling behavior in mountain-front regions of the U.S. and Mexico (Arizona State U., U. Arizona)
5. Diagnosing the impacts of disturbed landscapes on coupled hydrometeorlogical predictions
   - Western U.S. Fires (USGS)
   - West African Monsoon (Karlsruhe Inst. Tech)
   - S. America Paraná river (U. Arizona)
   - Texas Dust Emissions (Texas A&M U.)
   - Landslide Hazard Modeling (USGS)
6. Hydrologic Data Assimilation, WRF-Hydro/DART coupling

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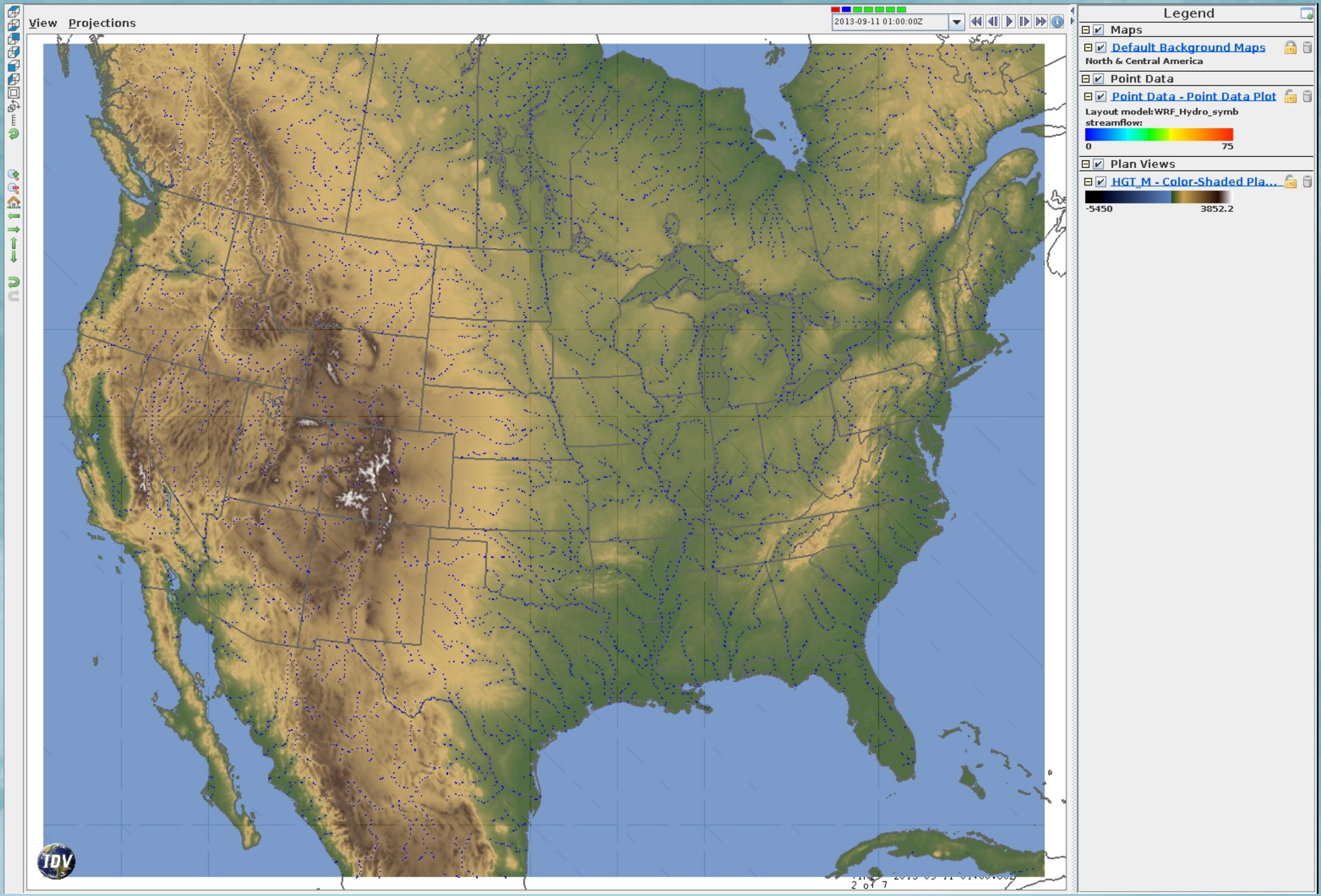
Continental Domain Water Prediction

- **Initial tests…**
  - **Streamflow from cold start**
  - **250m channel pixels, 2^{nd} order and higher filesize 575MB ea.**



CONUS+ 250m channel flow (thinned to 5^{th} order and higher channels)

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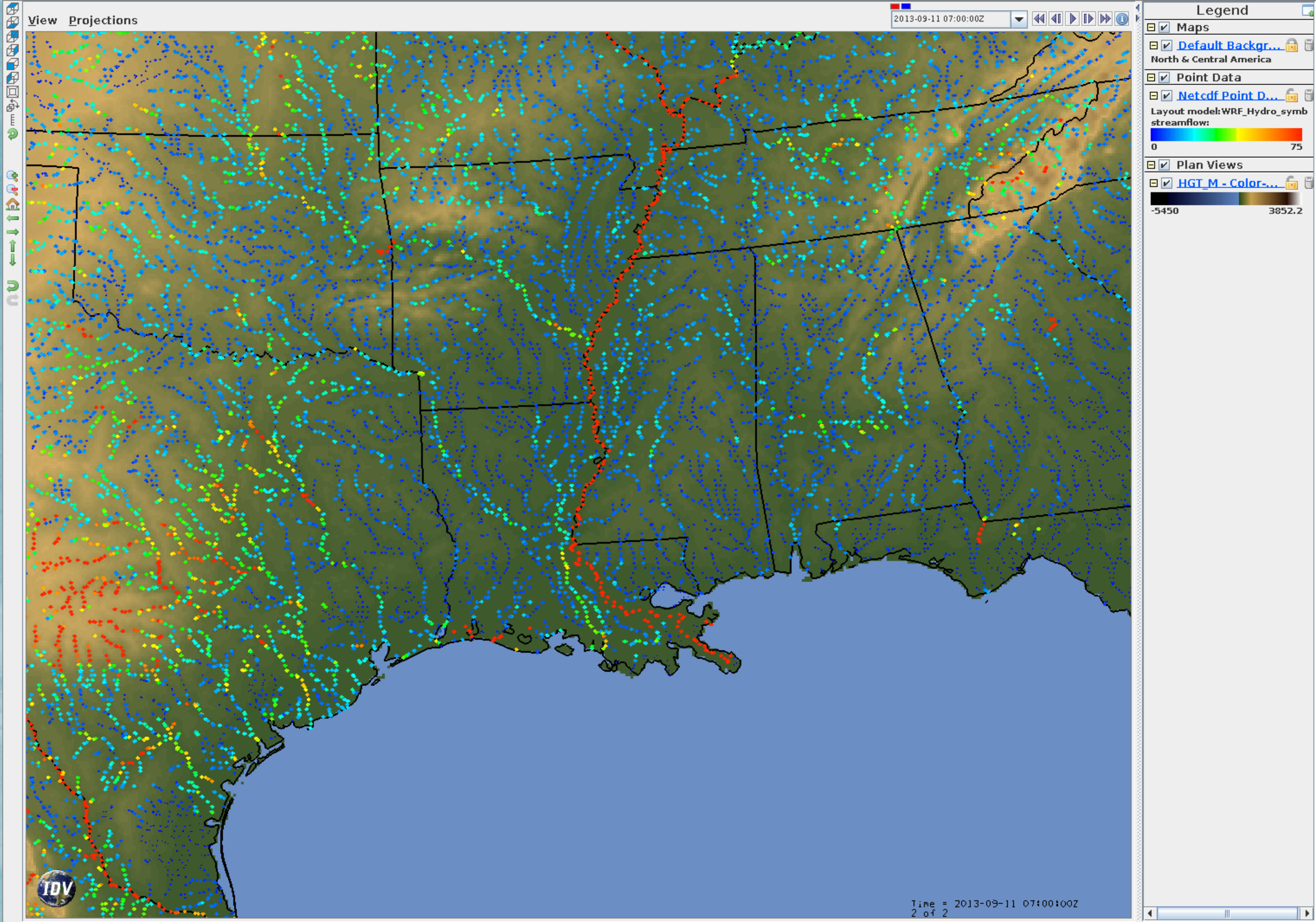
IDV images Regional Views



CONUS+ 250m channel flow (thinned to 4th order and higher channels)

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Acknowledgements

NCAR Development, Evaluation and Advising Team:

Wei Yu, David Yates, Kevin Sampson, Aubrey Dugger, James McCreight, Mike Barlage, Yongxin Zhang, Mukul Tewari, Roy Rasmussen, Andy Wood, Fei Chen, Martyn Clark, Matthias Steiner

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- CUAHSI
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- USBR WaterSmart & Dam Safety Programs
- Colorado Water Conservation Board
- Texas Dept. of Environmental Quality & Texas A&M U.

End

WRF-Hydro: http://www.ral.ucar.edu/projects/wrf_hydro/

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K. Sampson (GIS Specialist)
J. McCreight (Post-doc)
A. Dugger (Post-doc)
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