WRF-Hydro: Coupling with WRF

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What is WRF-Hydro:

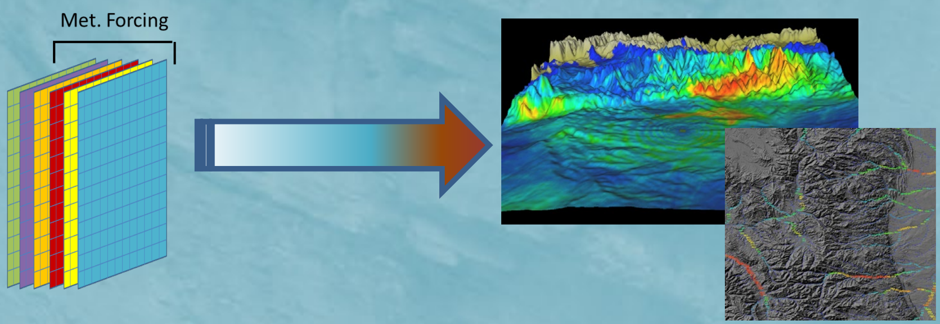
WRF-Hydro is a community-based, supported coupling architecture design to couple multi-scale process models of the atmosphere and terrestrial hydrology

It also seeks to provide:

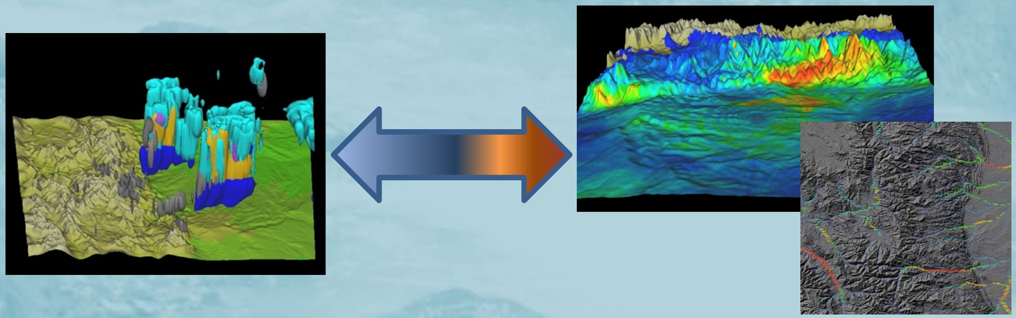
1. A capability to perform coupled and uncoupled multi-physics simulations and predictions
2. Fully utilize high-performance computing platforms
3. Leverage existing and emerging standards in data formats and pre-/post-processing workflows
4. An extensible, portable and scalable environment for hypothesis testing, sensitivity analysis, data assimilation and observation impact research

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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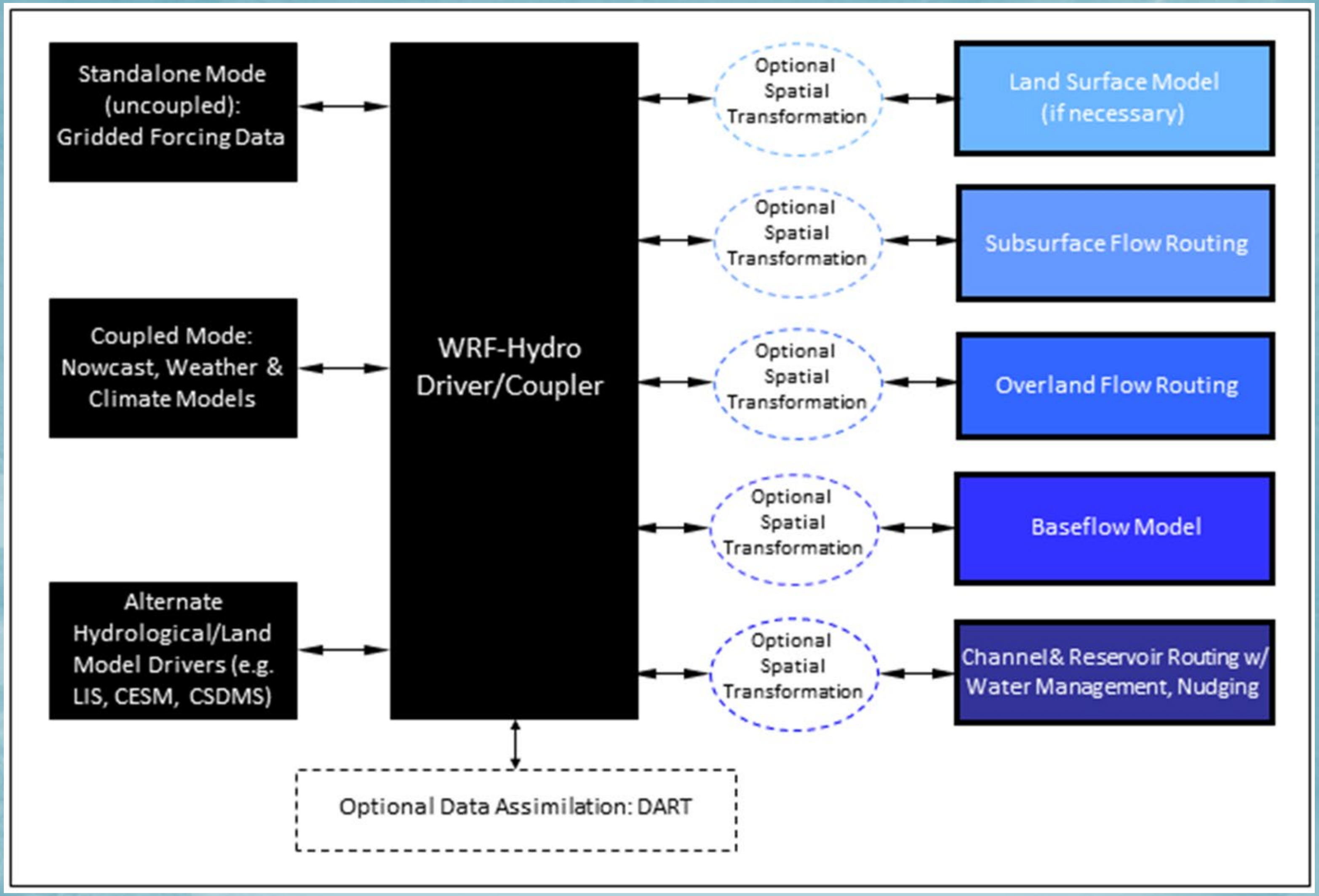
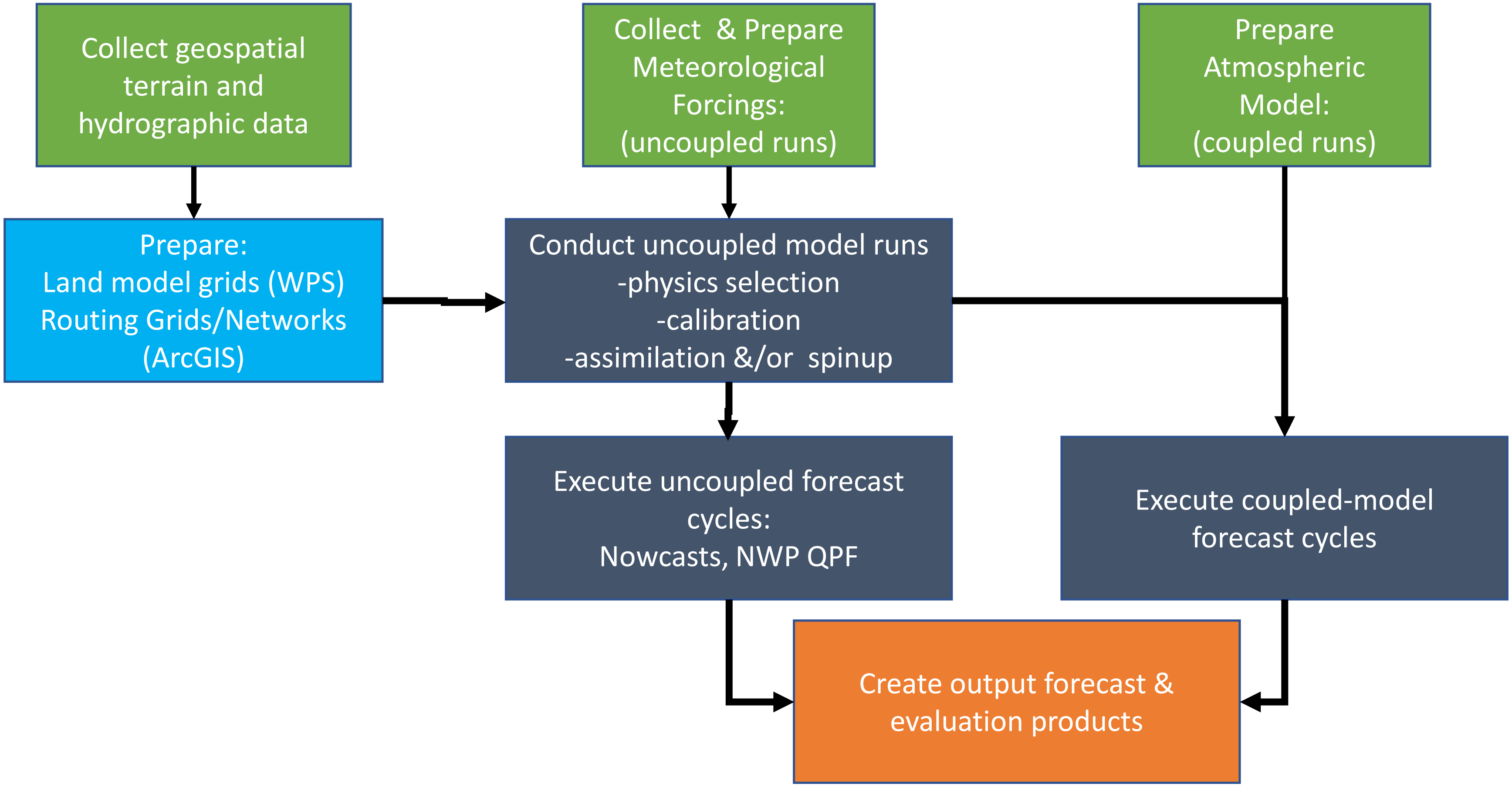
Conceptualization of WRF-Hydro:

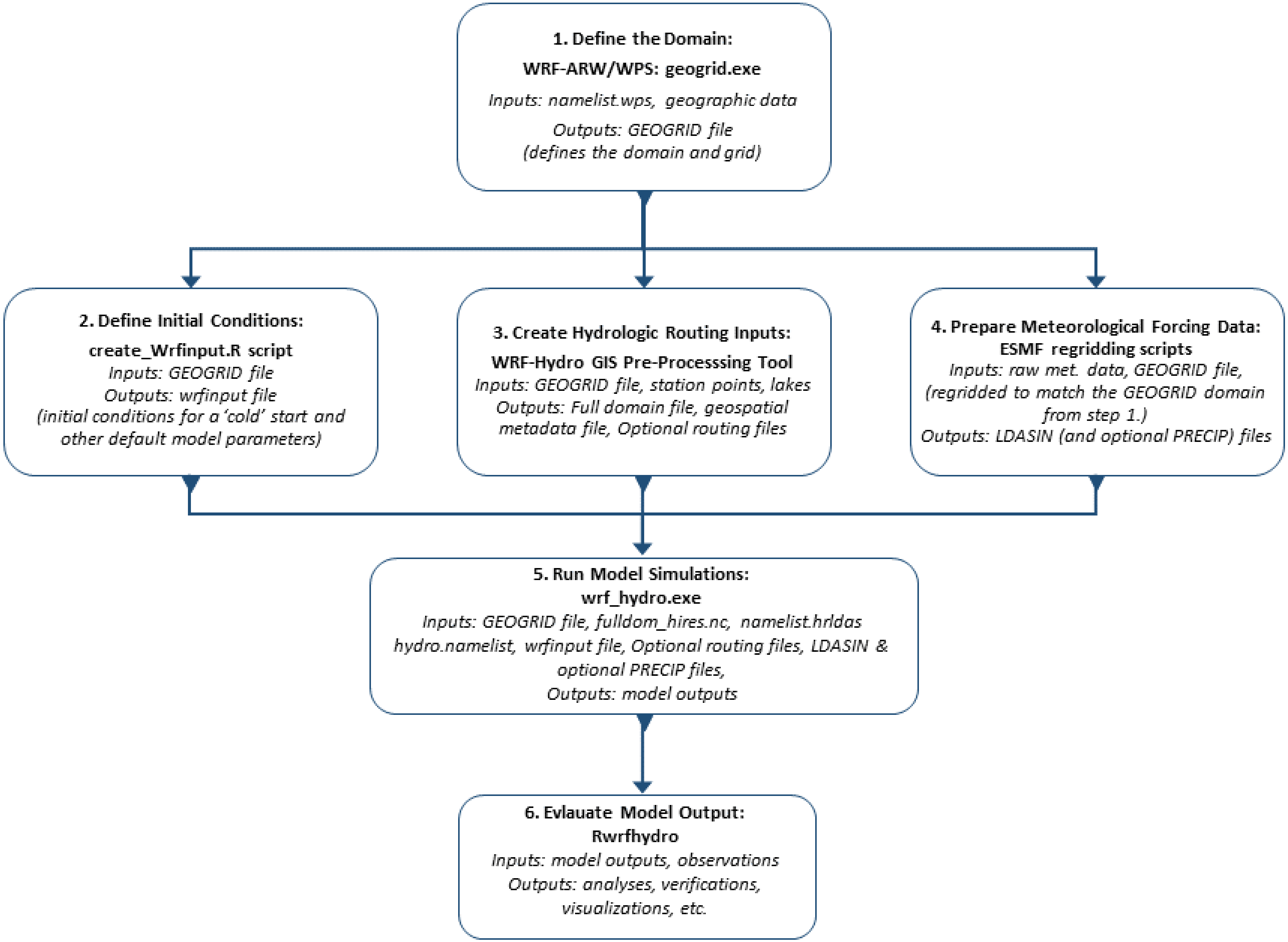
- Multi-scale/Multi-physics modeling…



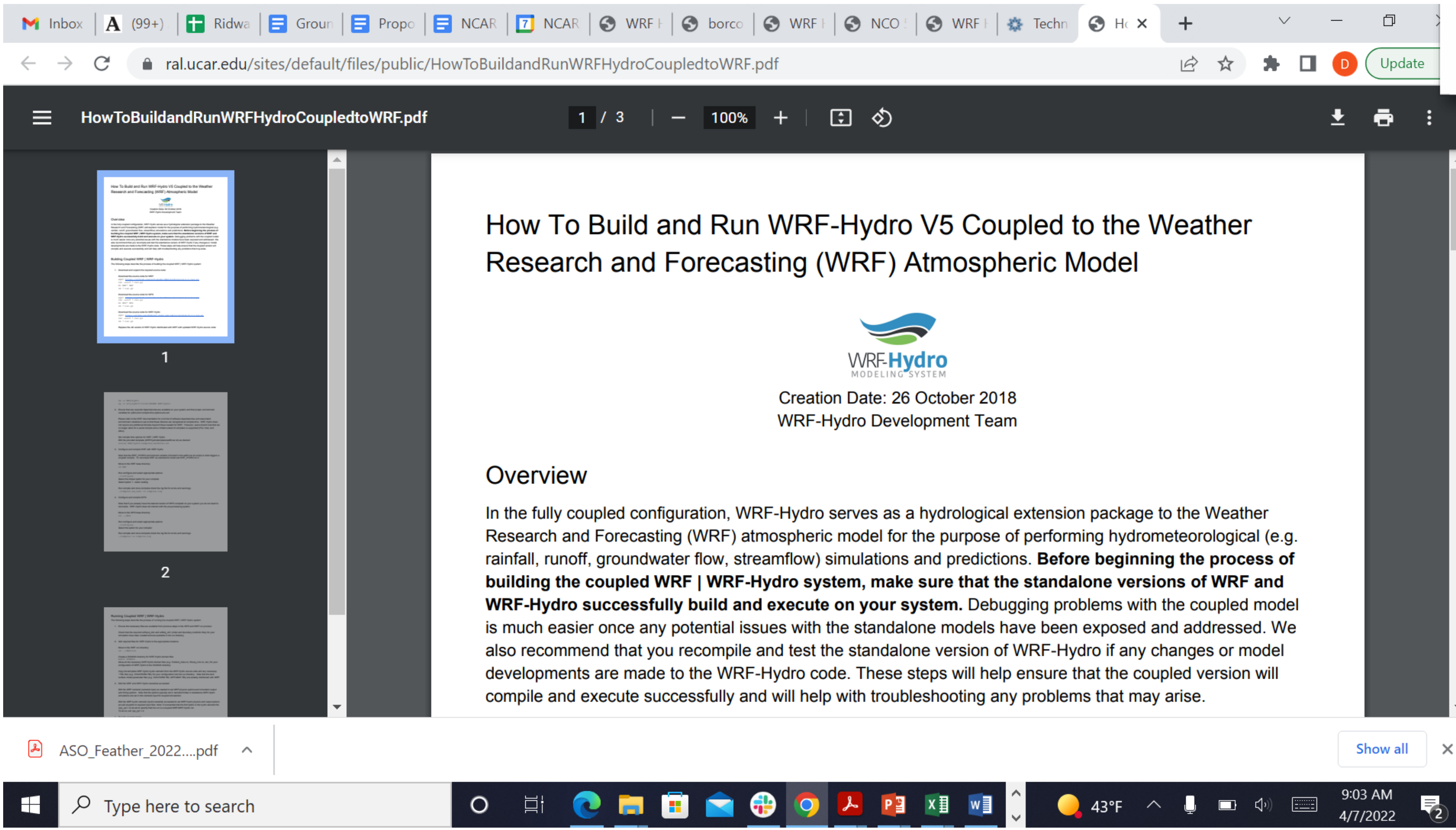
WRF-Hydro Implementation Workflow



WRF-Hydro Workflow



WRF/WRF-Hydro



Introduction to the Weather Research and Forecasting Model (WRF)

April 2022

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National Center for Atmospheric Research

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Weather Research and Forecasting Model (WRF):

- Modeling system for atmospheric research and operational prediction
- Provide many core functionalities:
  - Data pre-processing (model initialization and boundary conditions)
  - 3-d non-hydrostatic, multi-physics, multi-scale atmospheric model
  - Fully-parallelized for high performance computing applications
  - Data assimilation frameworks (EnKF, grid nudging, 3d/4d variational analysis)
  - Post-processing to produce standardized datasets for ingest into many analysis and visualization software
- Directly ingestible into the Model Evaluation Tools (MET) software for verification

WRF Model Structure:

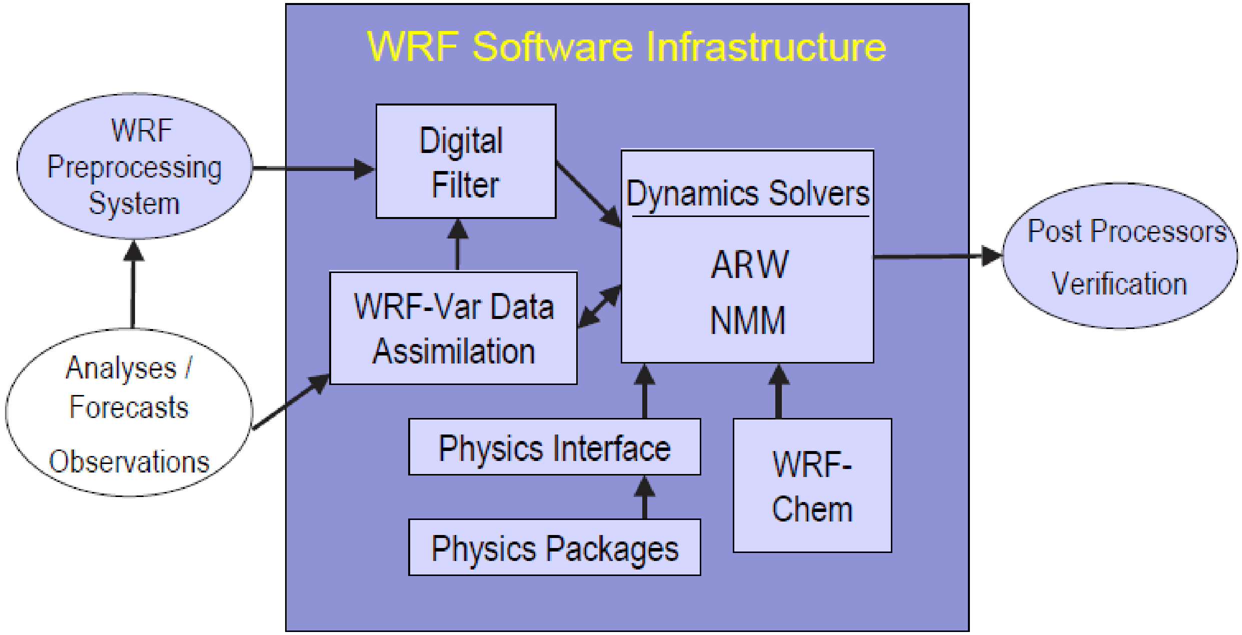


Figure 1.1: WRF system components.

Model Structure: Model Physics

- Microphysics: Schemes ranging from simplified physics suitable for idealized studies to sophisticated mixed-phase physics suitable for process studies and NWP.
- Cumulus parameterizations: Adjustment and mass-flux schemes for mesoscale modeling. (dx > ~5km)
- Surface physics: Multi-layer land surface models ranging from a simple thermal model to full vegetation and soil moisture models, including snow cover and sea ice.
- Planetary boundary layer physics: Turbulent kinetic energy prediction or non-local K schemes.
- Atmospheric radiation physics: Longwave and shortwave schemes with multiple spectral bands and a simple shortwave scheme suitable for climate and weather applications. Cloud effects and surface fluxes are included.

Model Structure: Model Domain

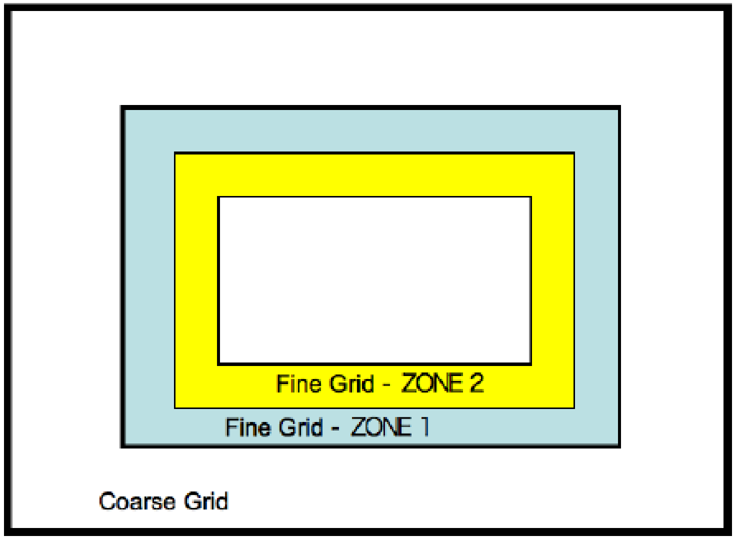
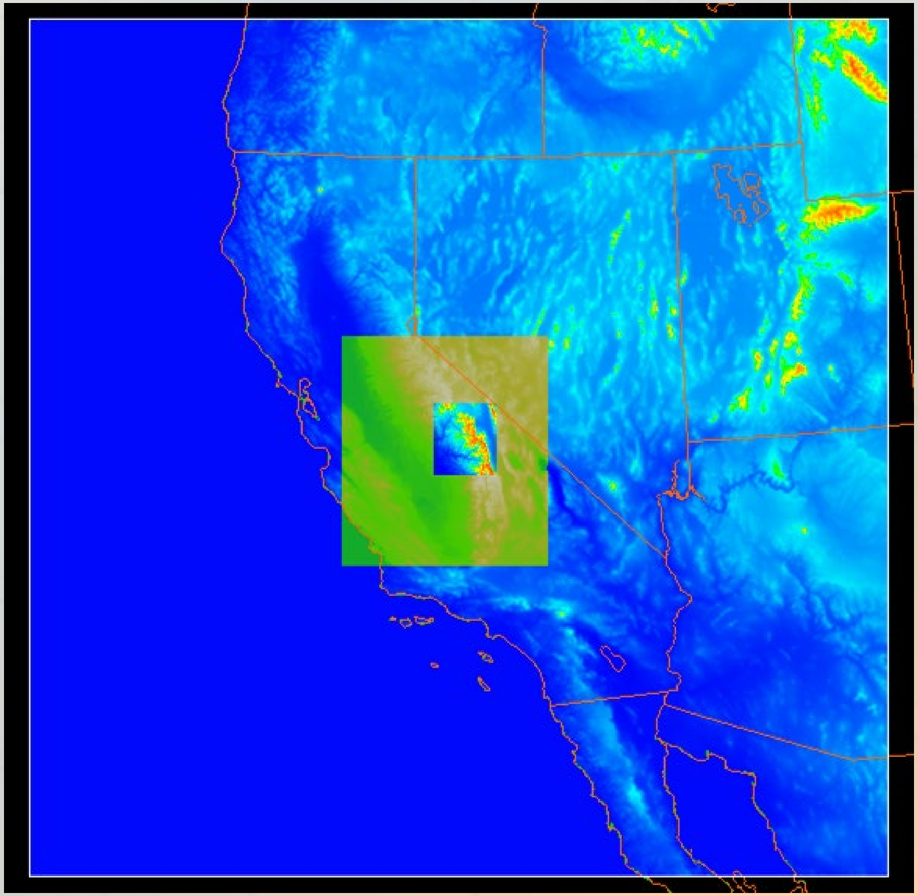


Figure 7.6: Zones of topographic blending for a fine grid. In the fine grid, the first zone is entirely interpolated from the coarse grid topography. In the second zone, the topography is linearly weighted between the coarse grid and the fine grid.

Model Structure: Model Domain



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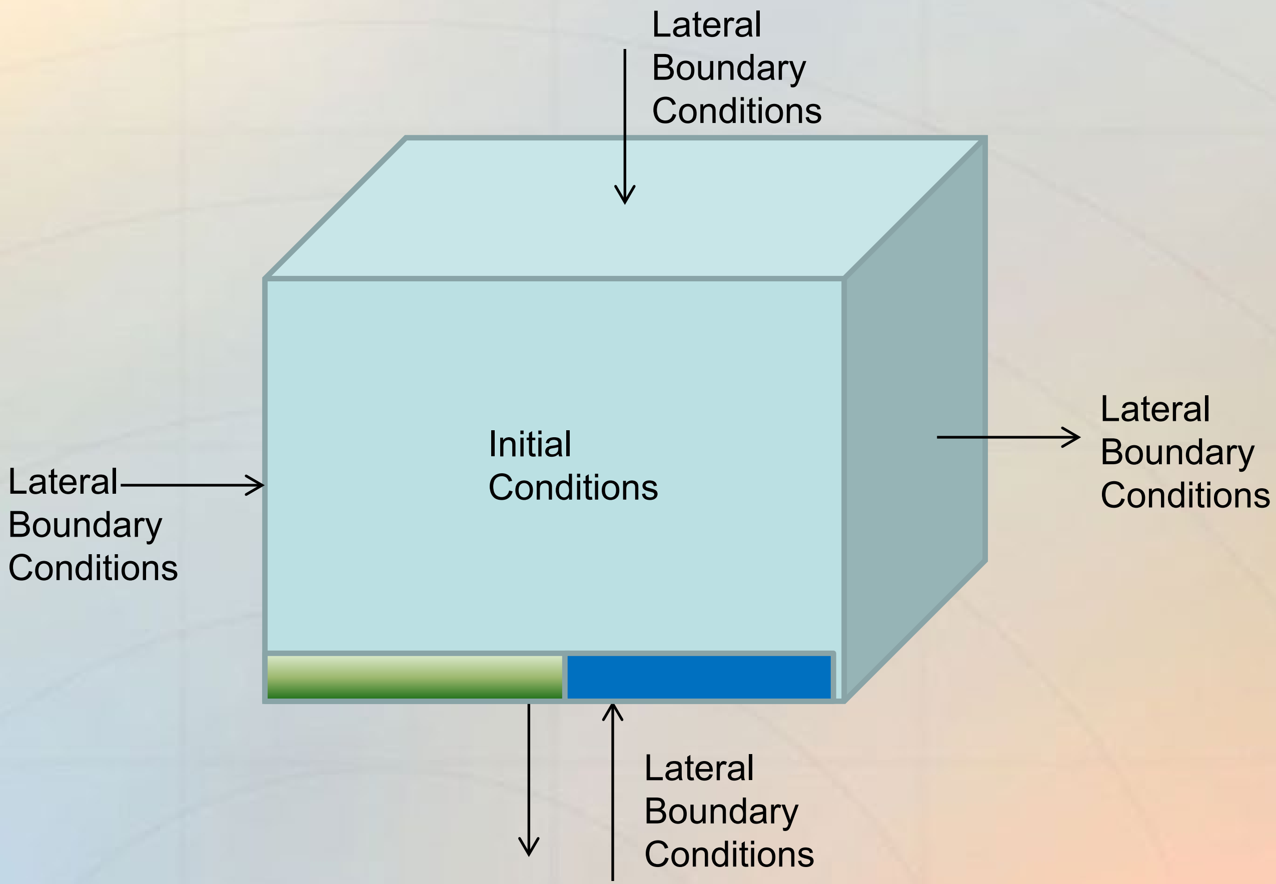
Model Structure: Model Domain



Model Structure: Initial and Boundary Conditions

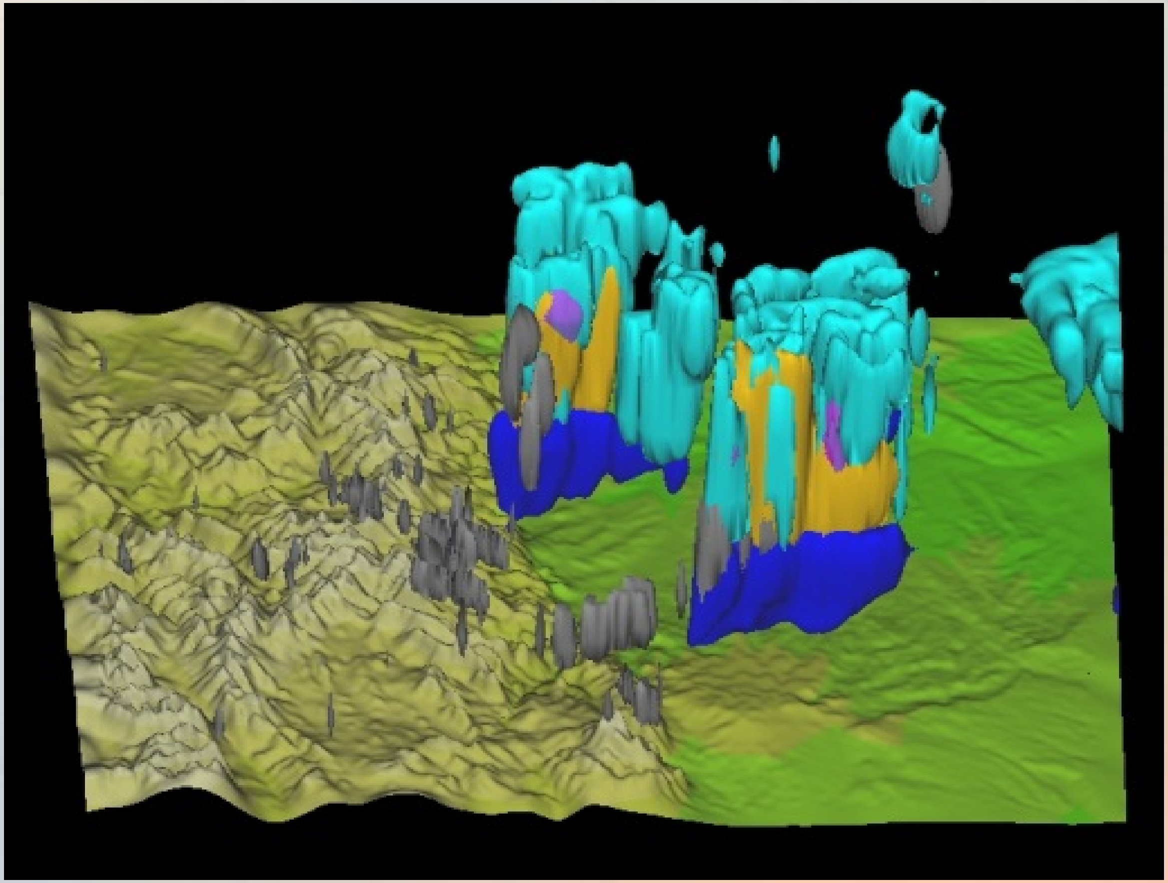
- Initial conditions: Provides the initial 'state' of the atmosphere and land surface at time = 0.
- Lateral boundary conditions: Provides 'forcing' to the regional domain from the 'sides' of the model, necessary condition for any forward-integrating numerical modeling problem
- The impacts of initial conditions can be very important or not very important depending on the problem and the variable of interest.
  - NWP – 'initial value problem', meaning the impact of initial conditions plays a 'dominant' role in the model solution along with model physics
  - 'Climate modeling' – 'boundary value problem', meaning the final solution is not as sensitive to initial conditions but, instead, more sensitive to boundary forcing and the model physics

WRF Model Workflow:

1. Pull/point to data for 'geogrid.exe' execution: this is the WRF-WPS database
2. Dynamically edit the 'namelist.wps' file
3. Execute 'geogrid.exe' to create surface data
4. Get meteorological boundary condition data from a global server
5. Pull/point to data for 'metgrid.exe'
6. Run 'ungrib.exe' from the WPS directory to prepare data for metgrid.
7. Execute 'metgrid.exe' to prepare atmospheric boundary conditions
8. Edit principle WRF model namelist for model setup (namelist.input)
9. Run executables: 'real.exe; and 'wrf.exe'
10. Post-process results…

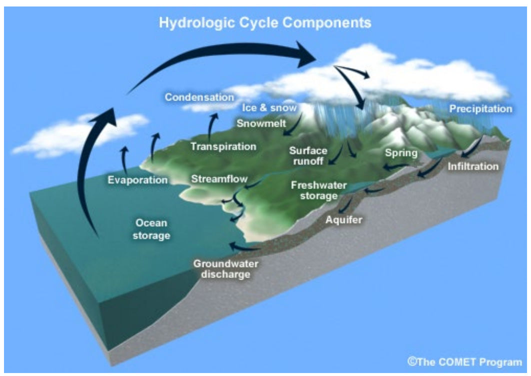
WRF Model Products:

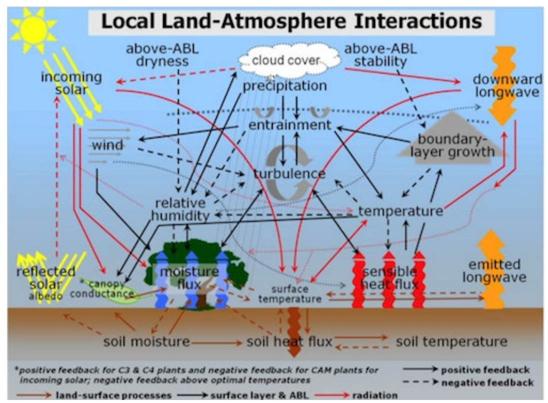
- Detailed, physically-robust depictions of atmospheric phenomena for research and prediction applications

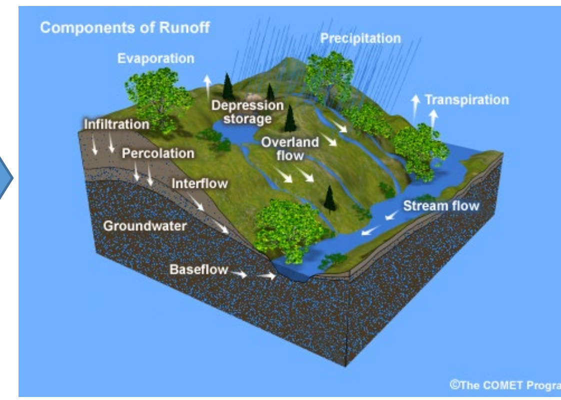


- Conceptual Framework: Linking the Water Cycle Across Scales…

Tight coupling between energy and water cycles at multiple scales







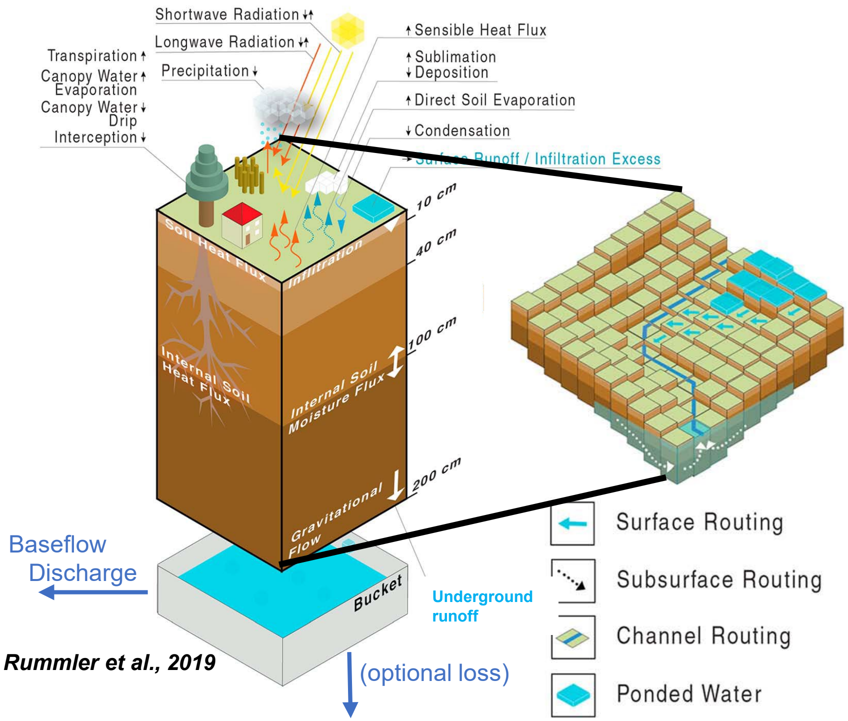
Hydrologic cycle is a fundamental component of weather and climate systems and…the basis for life.

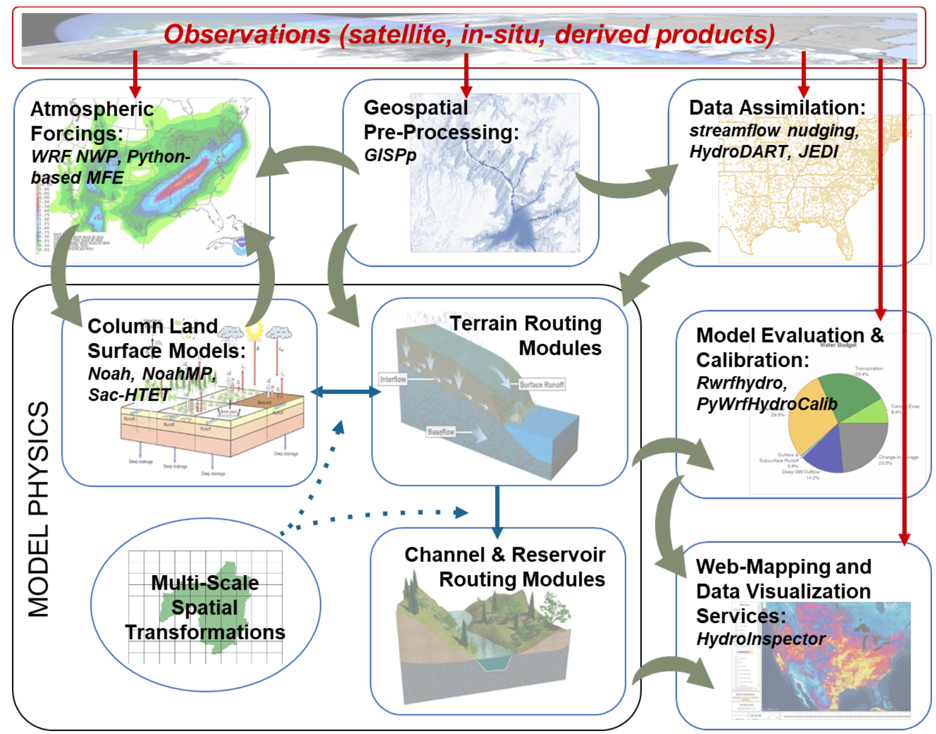
Courtesy: M. Ek

Fine-scale process drivers….

- Timing, distribution and availability of water
- Co-evolved with landcape patterns
- Predominantly responsible for flooding impacts

1. Multi-scale Modeling: WRF-Hydro Community Model Ecosystem



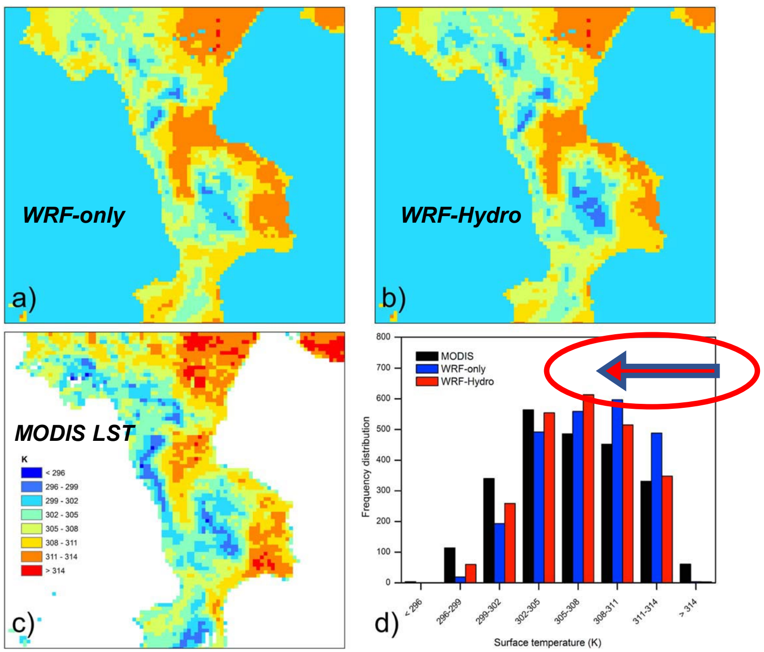


- State of the art column land surface physics
- Dynamic, hyper-resolution terrestrial overland, sub-surface and channel routing
- Multi-spatial framework support
- Interfaced with modern data assimilation systems (DART, JEDI)

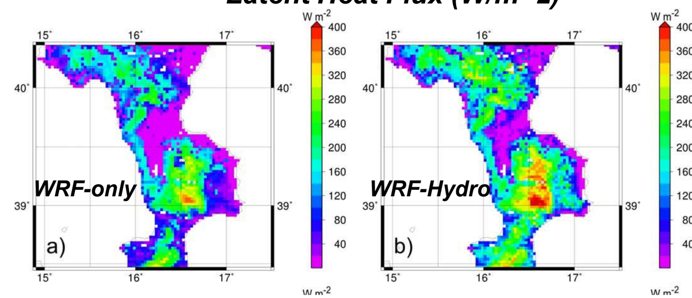
Fully coupled WRF/WRF-Hydro Applications: ***(Senatore et al., 2016)***

- Enhanced terrestrial flow routing provides enhanced *localization* of spatial and temporal patterns and magnitudes of soil moisture, surface temperature, precipitation and runoff

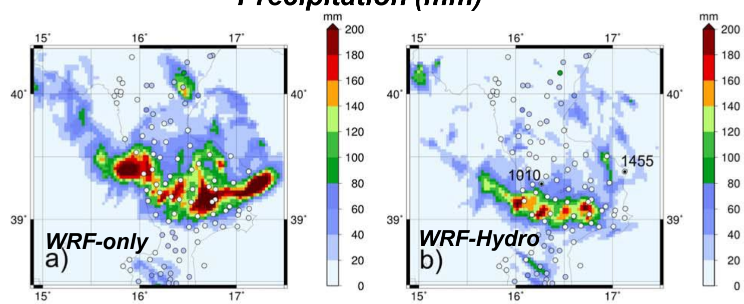
Surface skin temperature (deg K)



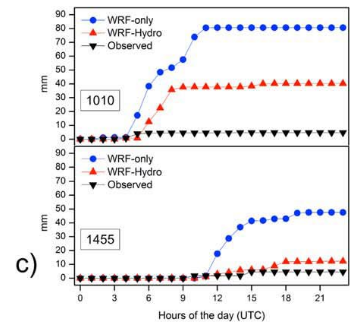
Latent Heat Flux (W/m^2)



Precipitation (mm)



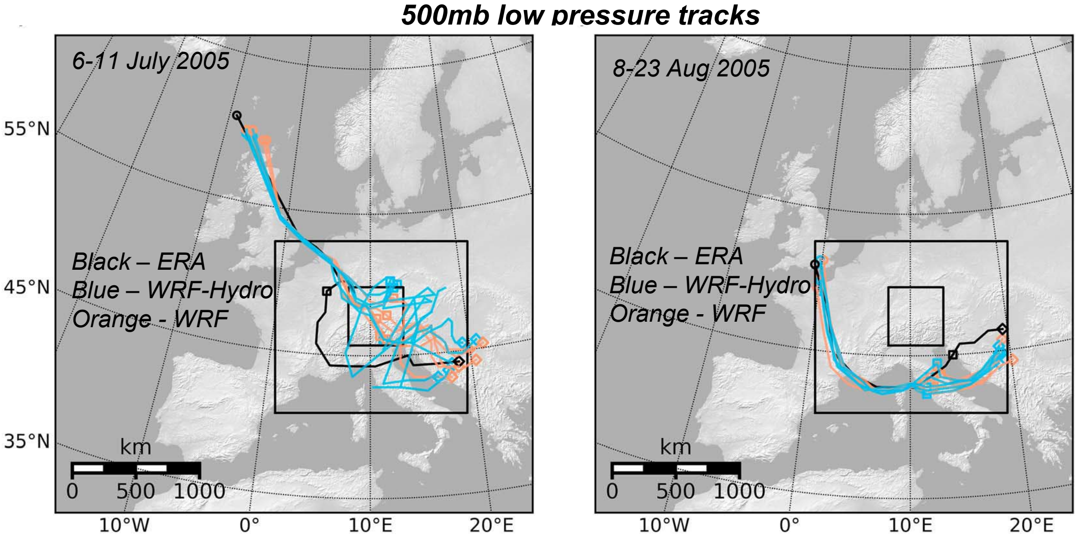
Accumulated runoff (mm)

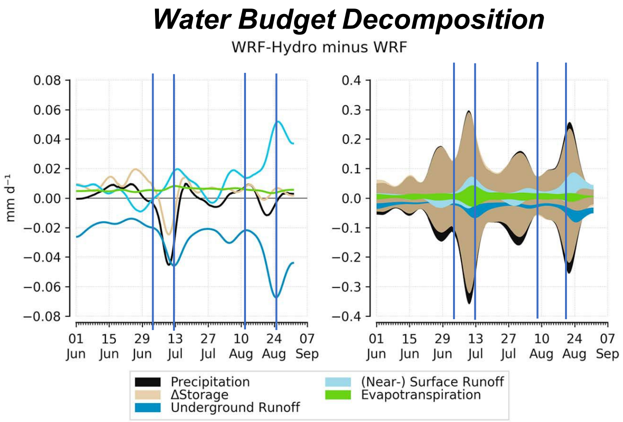


See also: Yucel et al., 2015; Givati et al., 2016; Fredj et al., 2016; Verri et al., 2017; Li et al., 2017; Arnault et al., 2016

Fully coupled WRF/WRF-Hydro Applications:

- Enhance flow routing provides enhanced *localization* of spatial and temporal patterns and magnitudes of soil moisture, surface temperature, precipitation and runoff
- Internal variability caused by routing physics can, in certain situations, drive "potential" large changes in storm tracks, atmospheric water vapor fluxes and regional moisture recycling…

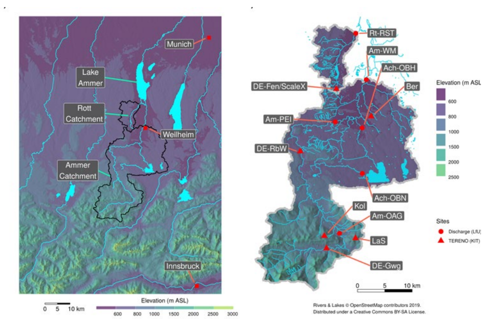


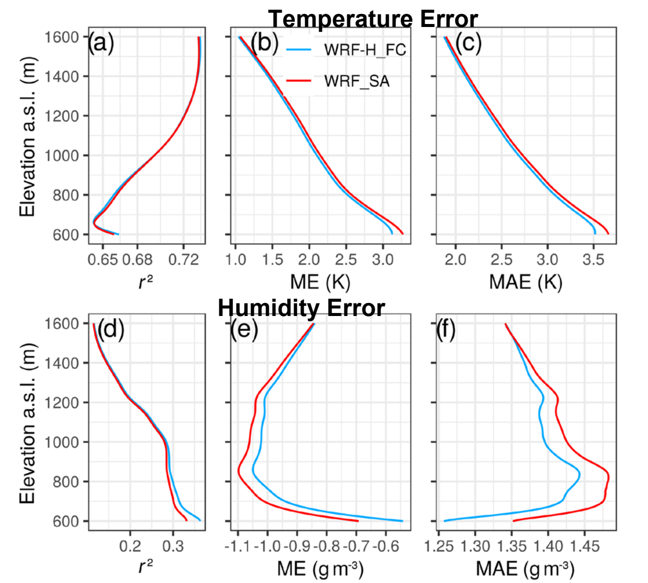


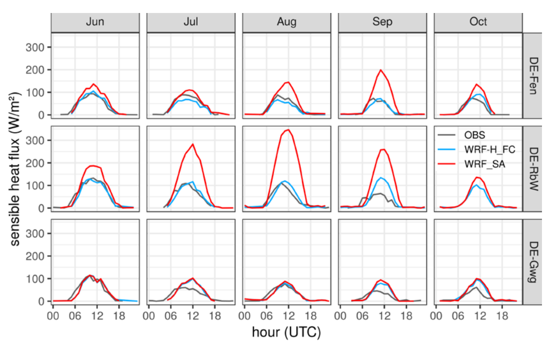
Rummler et al., 2019

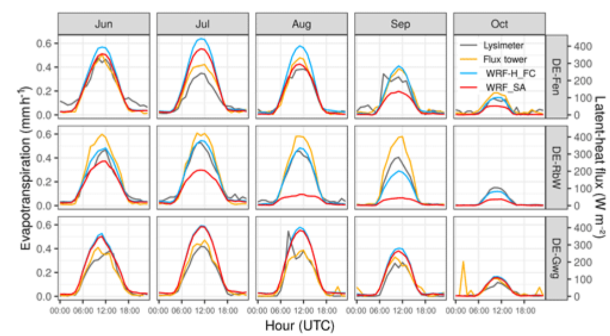
1. Multi-scale Modeling: WRF-Hydro Predictions…Coupled atmo-hydro prediction in the pre-Alpine

- TERRENO-preAlpine multiscale observation campaign (southern Germany)
- Compared:
    - Traditional 1-d LSM (NoahMP)
    - Fully coupled WRF/NoahMP/WRF-Hydro
- Modeled surface energy and mass fluxes vs. field observations:
    - Fully coupled model outperformed traditional WRF-lsm configuration with respect to:
    - Evapotranspiration,
    - Sensible and ground heat fluxes
    - 2m mixing ratio, air temp
    - PBL air temp and humidity profile



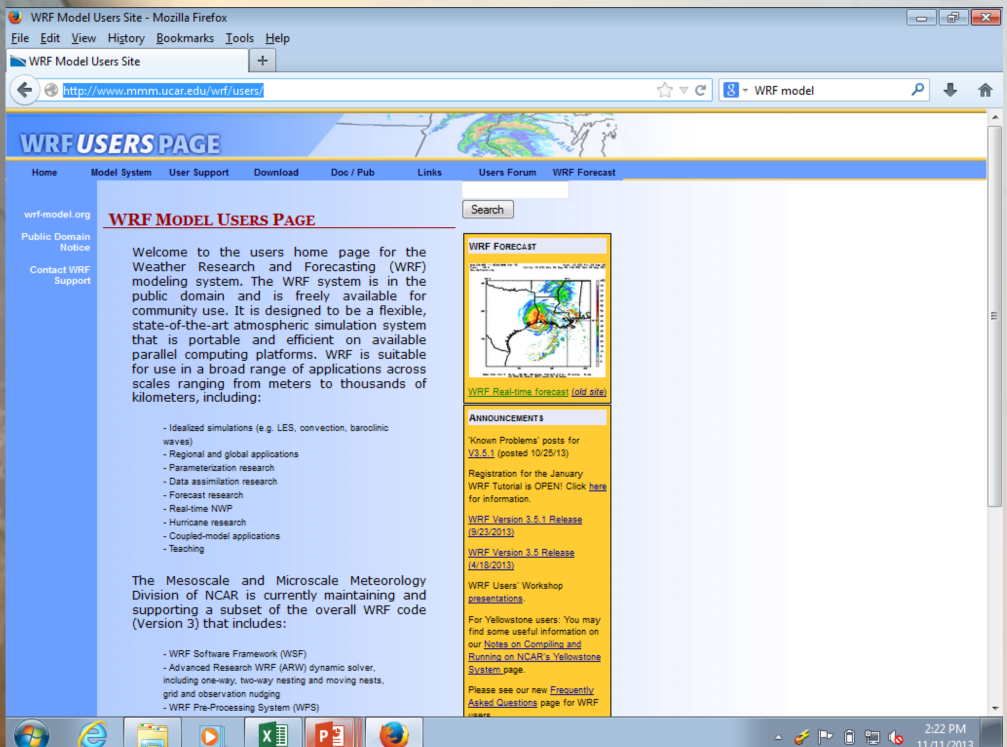






Fersch et al., 2019 HESS

WRF Model Resources and Training:



- Web site for code, documentation, data, real-time forecasts, etc.

- Training material, model tutorials are available through website
- Lots to WRF model utility tools available through the website
- WRF model development team holds 2 week-long tutorials 2x per year
- Annual WRF User's workshop
- Many international training workshops each year

http://www.mmm.ucar.edu/wrf/users/

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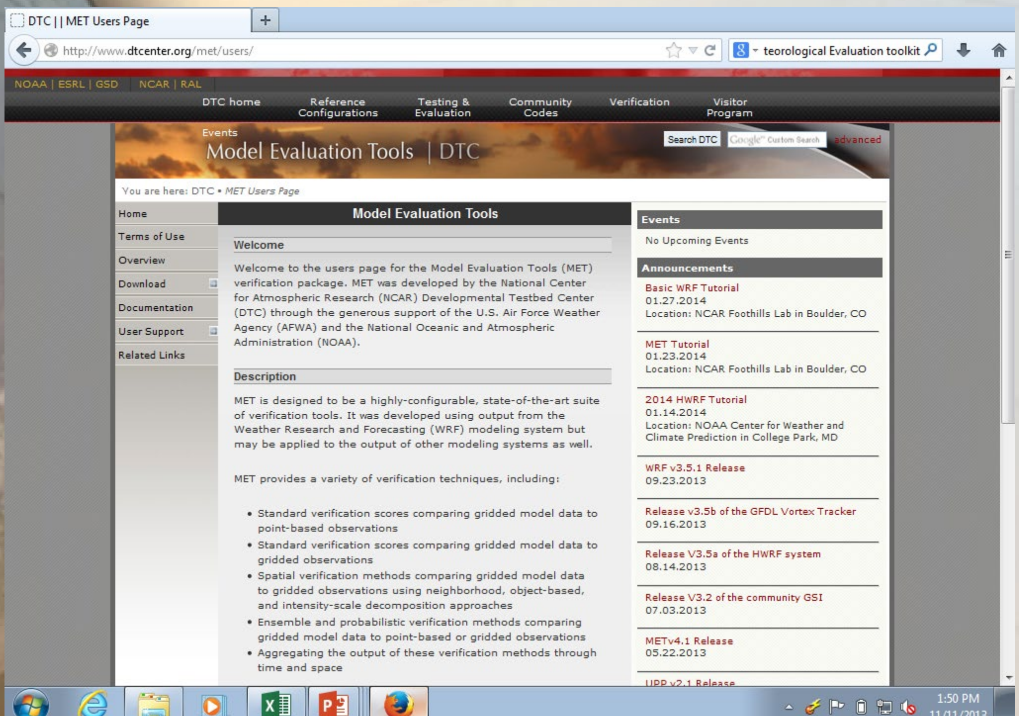
MET for all things Verification:



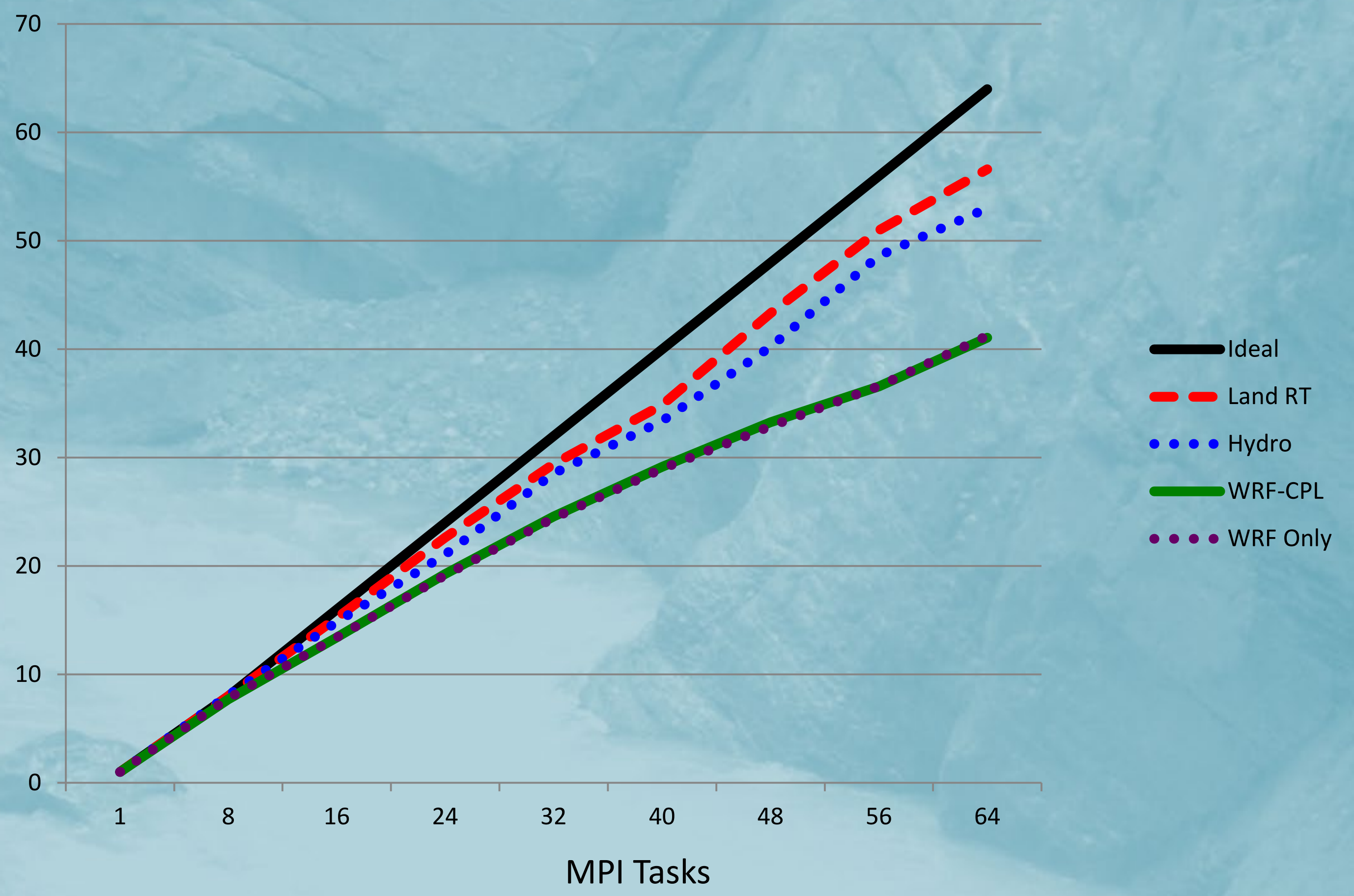
- Suite of data processing and analysis tools to provide:

- Standard verification scores comparing *gridded model data to point-based observations*
- Standard verification scores comparing *gridded model data to gridded observations*
- *Spatial verification methods* comparing gridded model data to gridded observations using neighborhood, object-based, and intensity-scale decomposition approaches
- *Ensemble and probabilistic verification* methods comparing gridded model data to point-based or gridded observations

WRF-Hydro Performance Speedup

Time of Sequential Run

Time of Parallel Run



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

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