WRF-Hydro Modeling System: Physics Components

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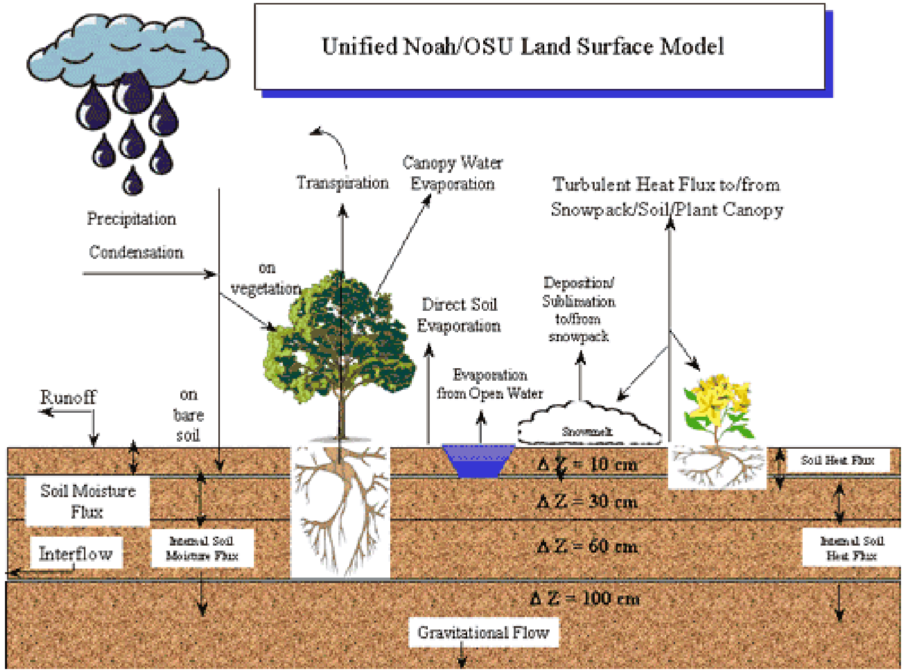
National Center for Atmospheric Research

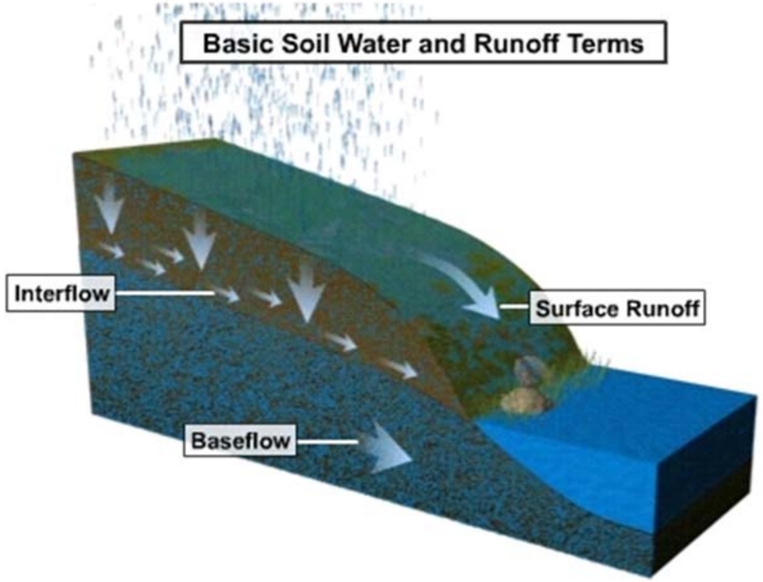
Outline:

- Basic Concepts
- Conceptualization of WRF-Hydro
- Model Architecture & Requirements

Basic Concepts:

- Linking the column structure of land surface models with the ‘distributed’ structure of hydrological models in a flexible, HPC architecture….





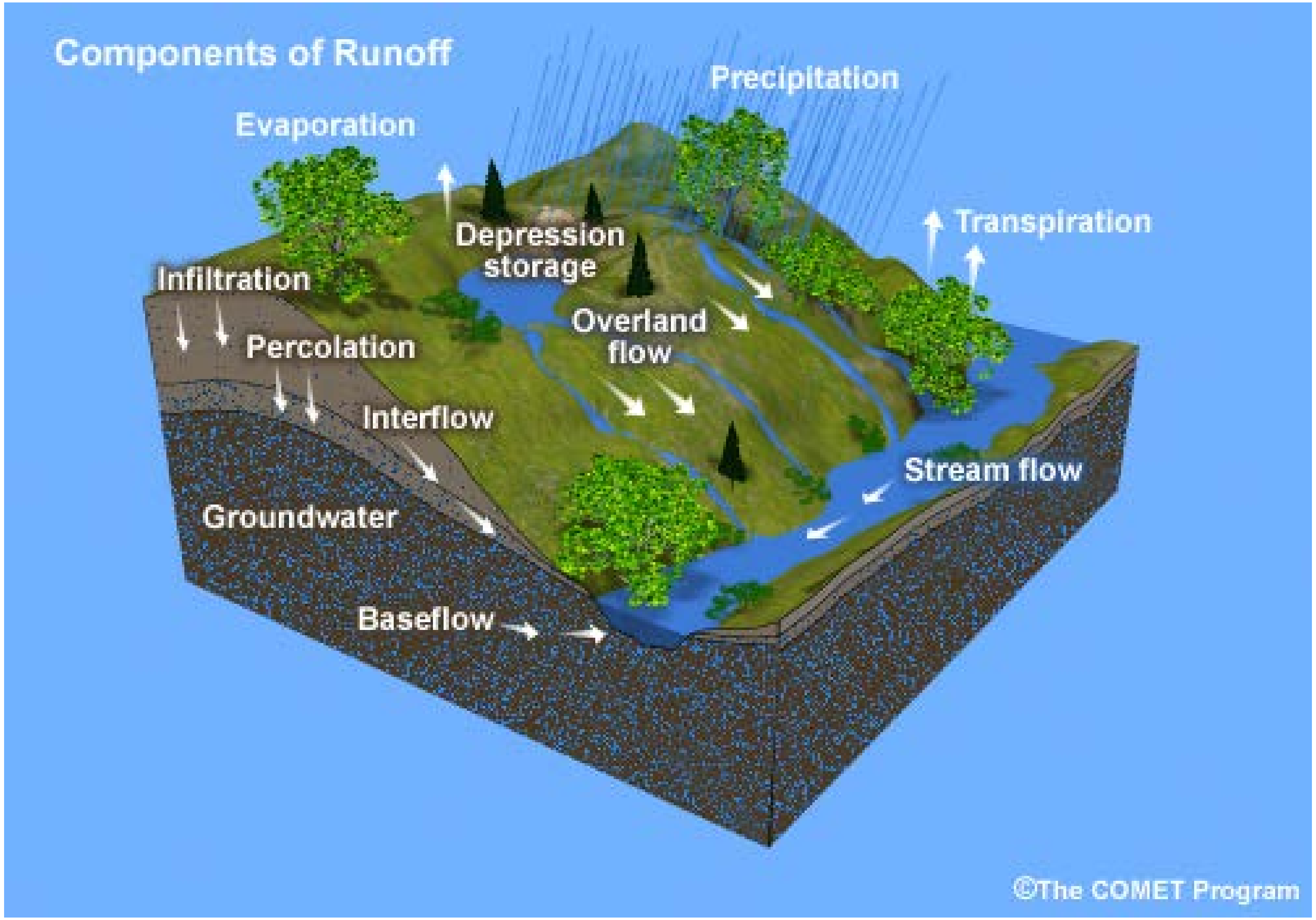
Conceptualization of WRF-Hydro

- Atmospheric coupling perspective and serving the WRF research and forecasting and CESM communities

- Oriented towards existing NCAR-supported community models, but expanding:
  - Not fully genericized coupling which has pros/cons associated…
  - Also aimed at cluster & HPC architectures

WRF-Hydro V5.0 Physics Components

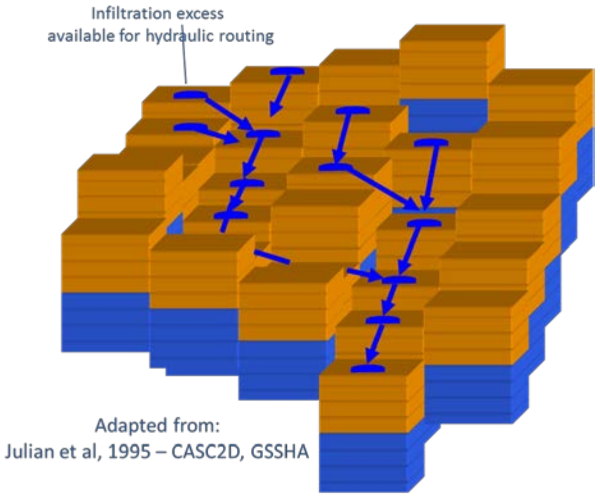
Goal…



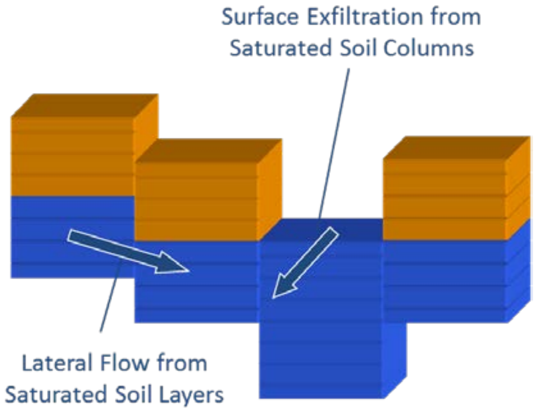
WRF-Hydro V5.0 Physics Components

Runoff and Routing Physics:

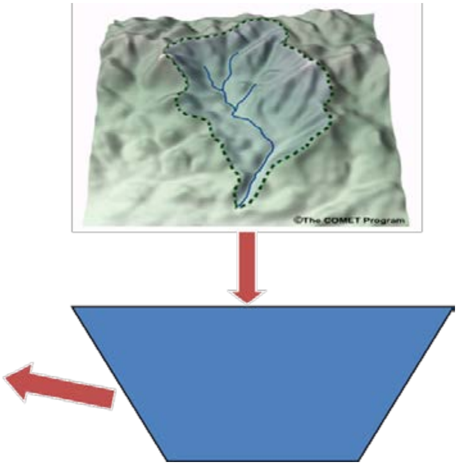
Overland Flow



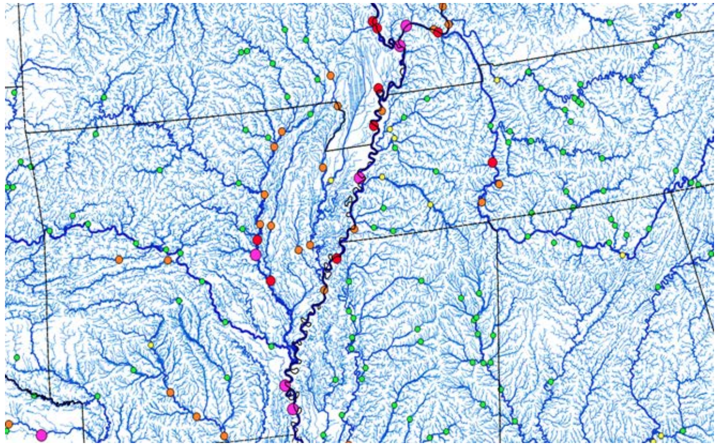
Lateral Subsurface Flow



Simplified Baseflow Parameterization

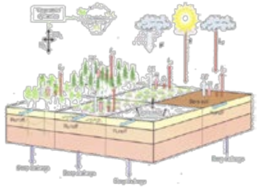
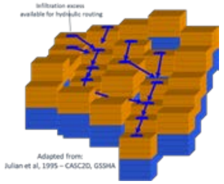
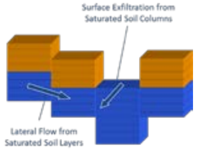
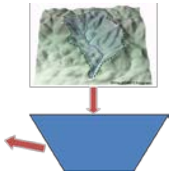
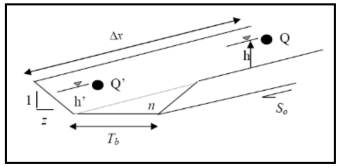
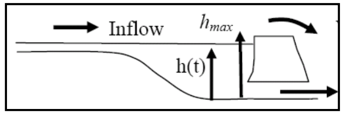


Channel Hydraulics



Simple Water Management

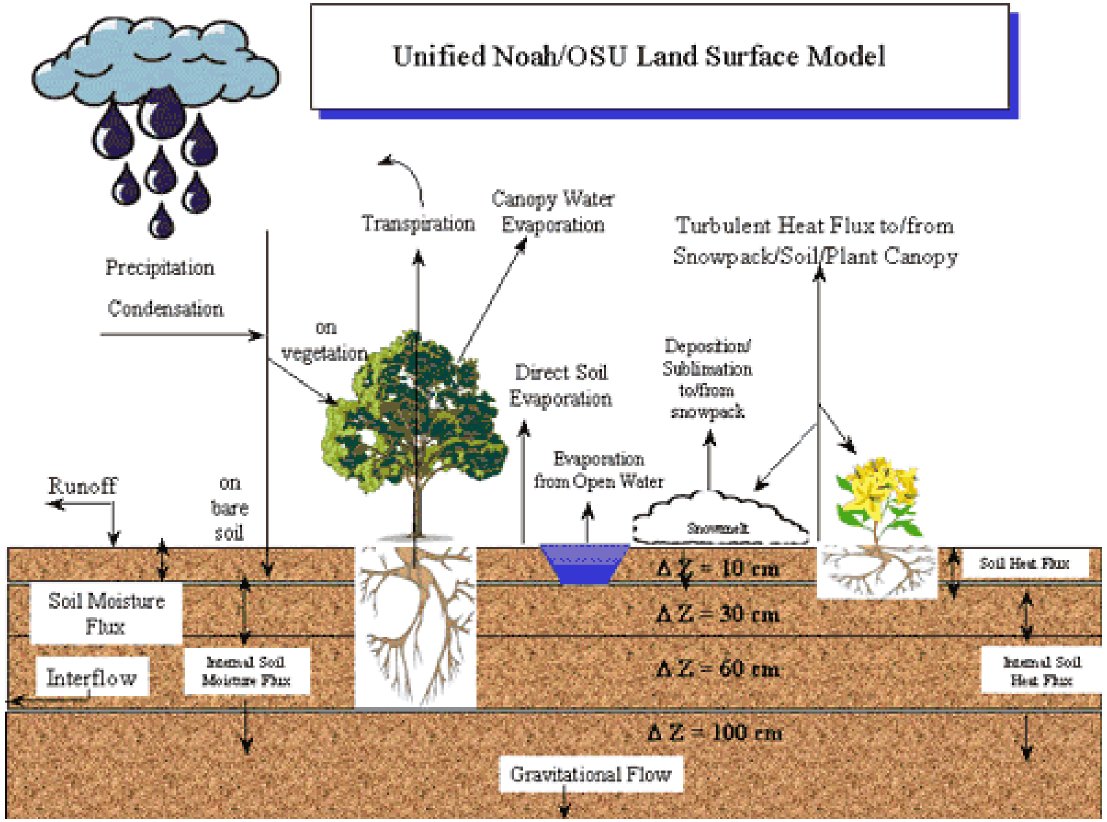
WRF-Hydro Physics Permutations

		WRF-Hydro Options	Current NWM Configuration
Column Land Surface Model		**<u>3 up-to-date column land models</u>:** Noah, NoahMP (w/ built-in multi-physics options), Sac-HTET	NoahMP
Overland Flow Module		**<u>3 surface routing schemes</u>:** diffusive wave, kinematic wave, direct basin aggregation	Diffusive wave
Lateral Subsurface Flow Module		**<u>2 subsurface routing scheme</u>:** Boussinesq shallow saturated flow, 2d aquifer model	Boussinesq shallow saturated flow
Conceptual Baseflow Parameterizations		**<u>2 groundwater schemes</u>:** direct aggregation storage-release: pass-through or exponential model	Exponential model
Channel Routing/ Hydraulics		**<u>5 channel flow schemes</u>:** diffusive wave, kinematic wave, RAPID, custom-network Muskingum or Muskingum-Cunge	Custom-network (NHDPlus) Muskingum-Cunge model
Lake/Reservoir Management		**<u>1 lake routing scheme</u>:** level-pool management	Level-pool management

WRF-Hydro V5.0 Physics Components

Current Land Surface Models:

– Column physics & land-atmosphere exchange



Noah LSM & Noah-MP

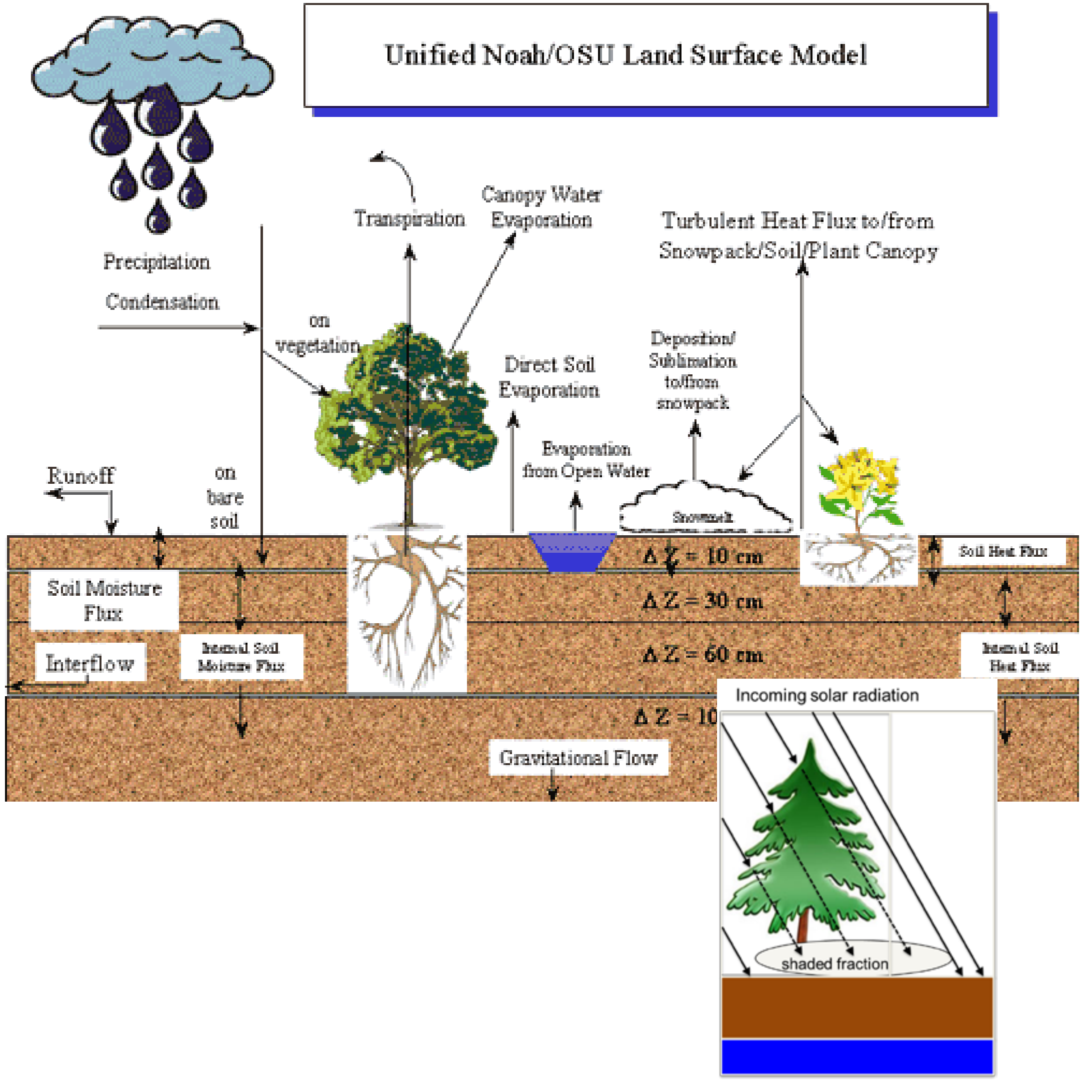
WRF-Hydro V5.0 Physics Components

NoahMP Column Physics:

Noah-MP contains several options for land surface processes:

1. Dynamic vegetation/vegetation coverage (4 options)
2. Canopy stomatal resistance (2 options)
3. Canopy radiation geometry (3 options)
4. Soil moisture factor for stomatal resistance (3 options)
5. Runoff and groundwater (4 options)
6. Surface layer exchange coefficients (4 options)
7. Supercooled soil liquid water/ice fraction (2 options)
8. Frozen soil permeability options (2 options)
9. Snow surface albedo (2 options)
10. Rain/snow partitioning (3 options)
11. Lower soil boundary condition (2 options)
12. Snow/soil diffusion solution (2 options)

Total of ~50,000 permutations can be used as multi-physics ensemble members

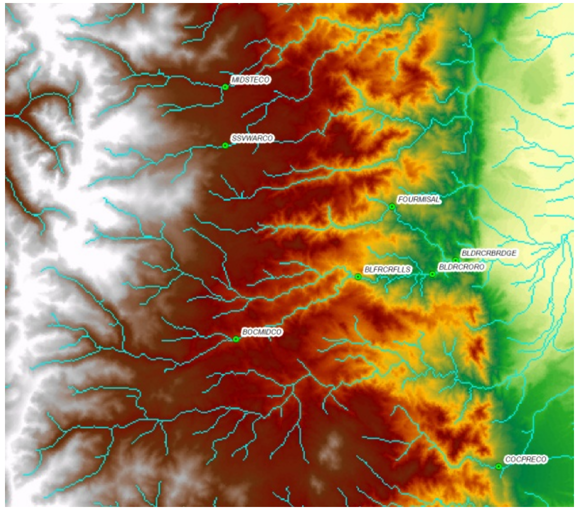


Noah/NoahMP development lead by M. Barlage and F. Chen, NCAR

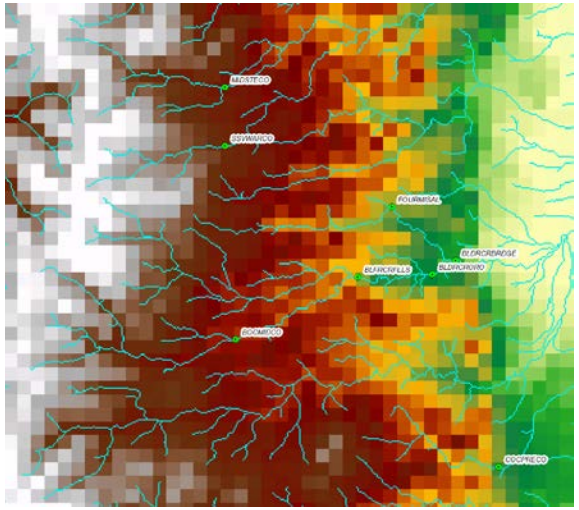
WRF-Hydro V5.0 Physics Components

- Multi-scale aggregation/disaggregation:

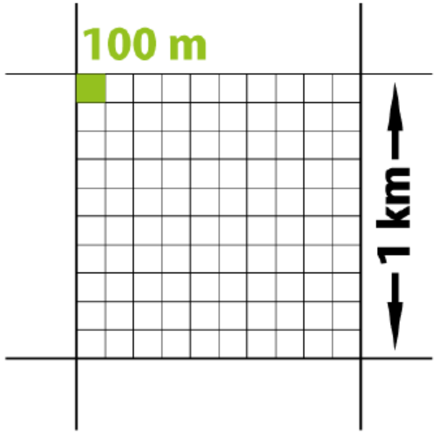
100m Terrain

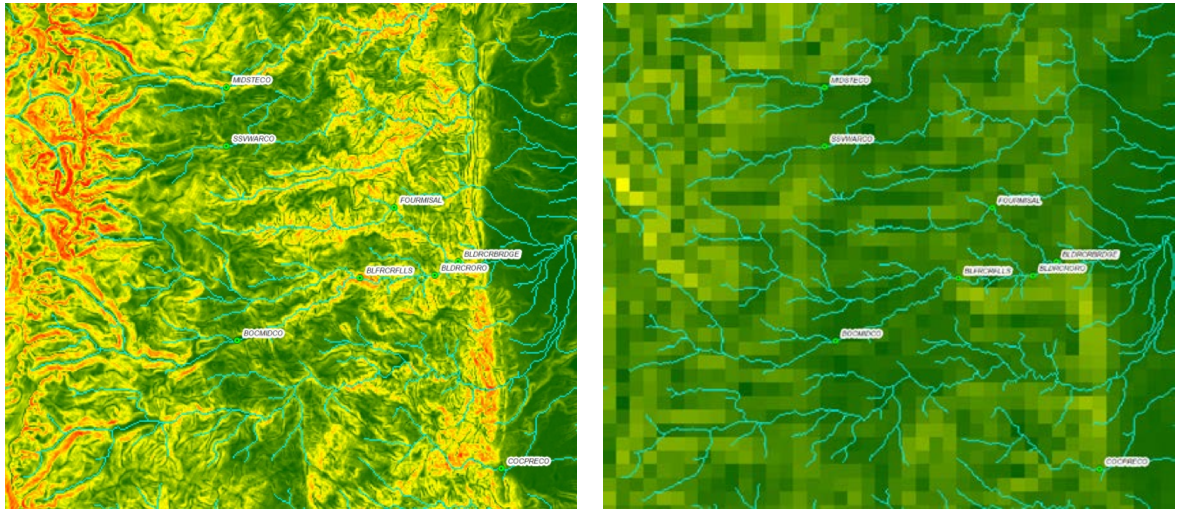


1 km Terrain



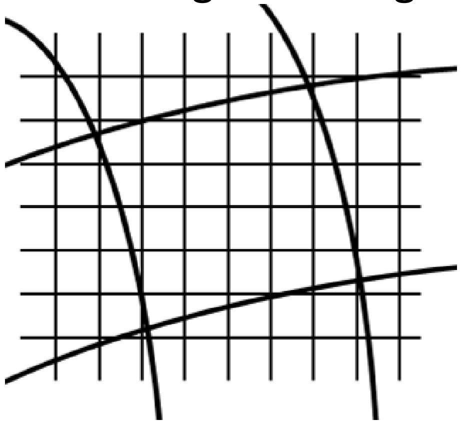
Current ‘Regridding’





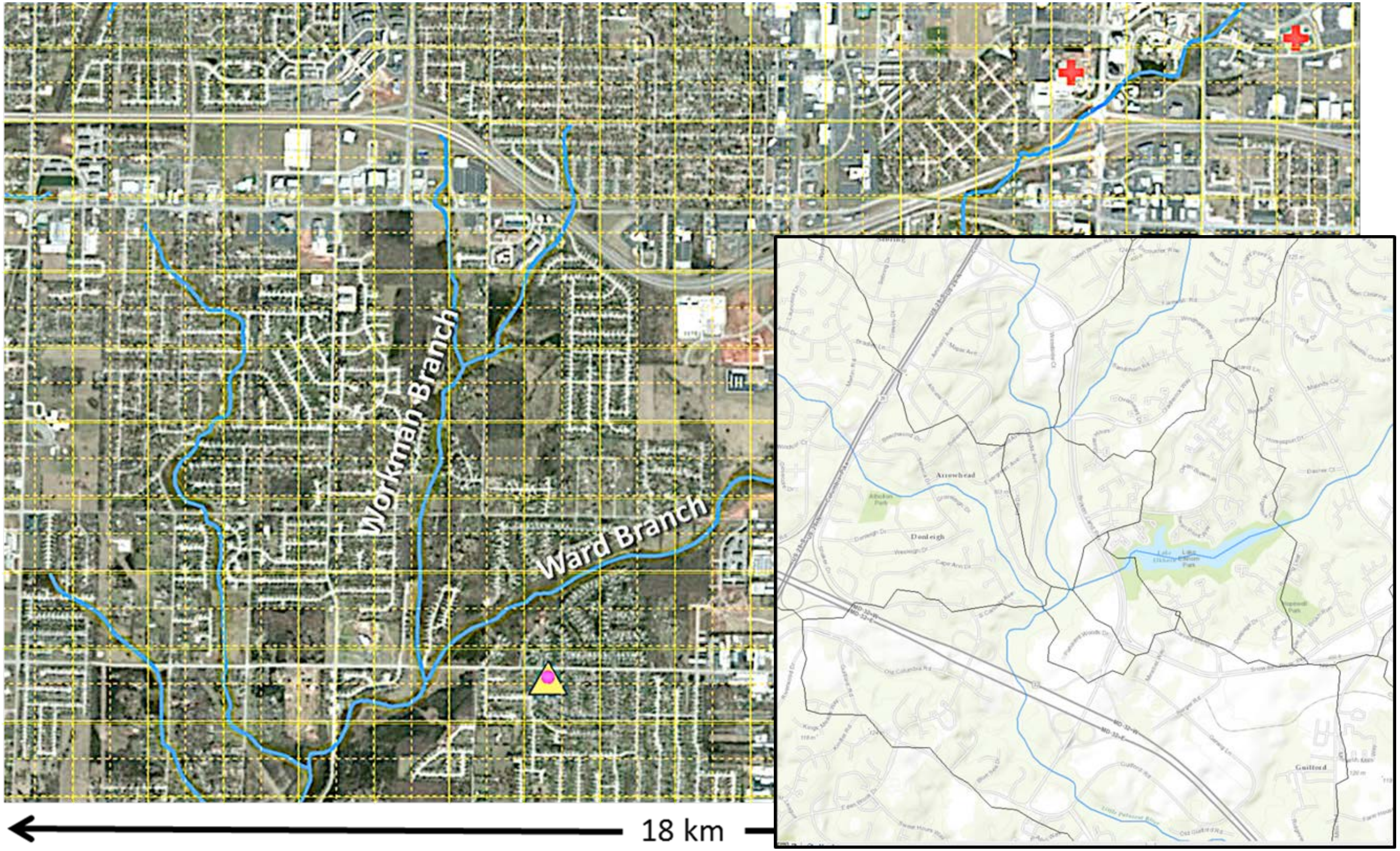
Terrain slope (0-45 deg)

Implementing ESMF Regridders



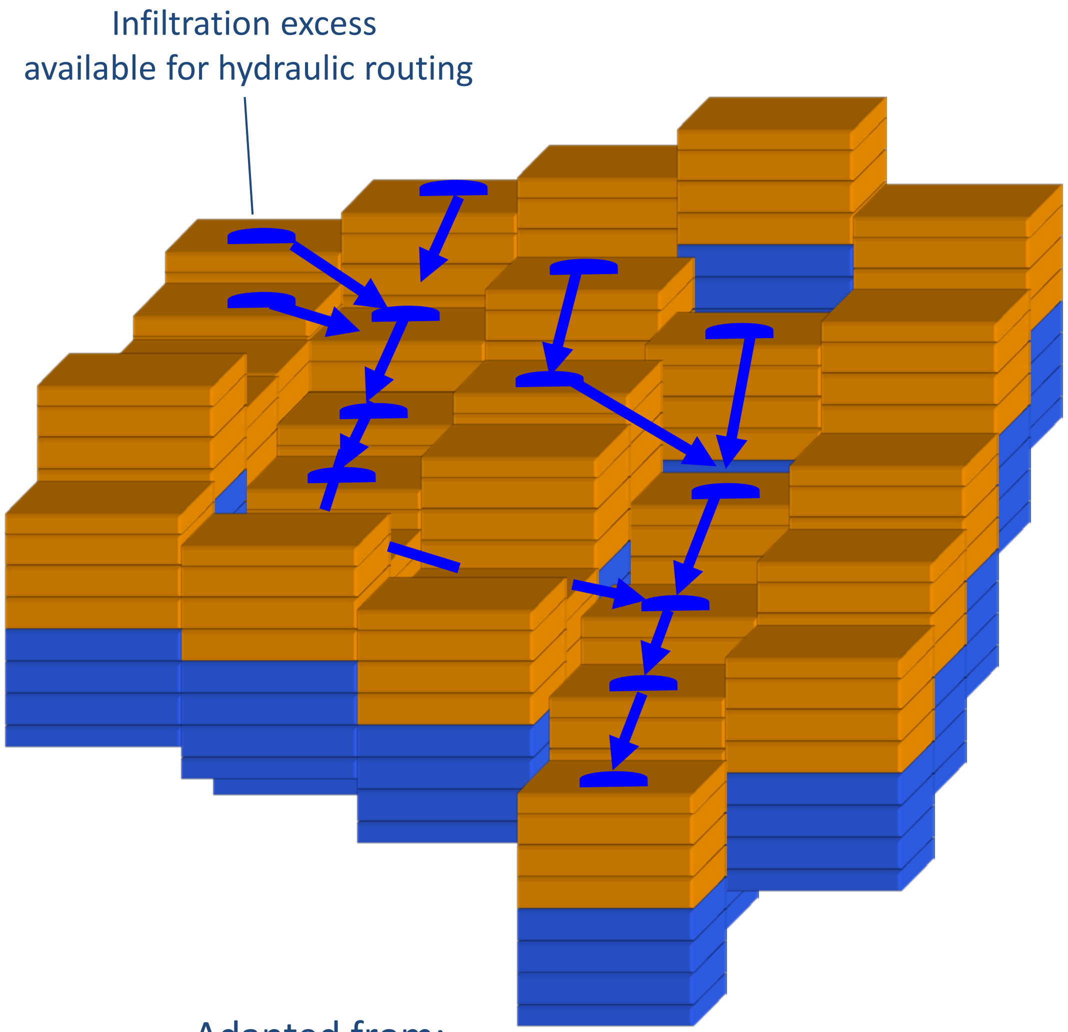
WRF-Hydro V5.0 Physics Components

- Multi-scale aggregation/disaggregation:



Terrain Routing

Surface Routing



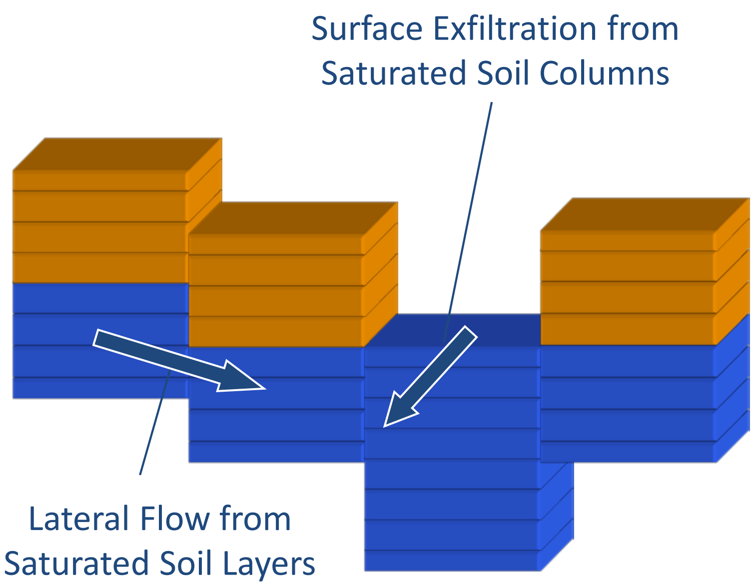
Adapted from:
Julian et al, 1995 – CASC2D, GSSHA

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

Surface Routing: Key Settings and Parameters

Parameter/Setting	Description	Scale/File	Estimate
Runtime Settings			
OVRTSWCRT	Overland routing physics switch (on/off)	hydro.namelist	Landscape/event, compute resources (computationally intensive)
DTRT_TER	Overland routing timestep	hydro.namelist	Based on grid size, landscape/event
Parameters			
TOPOGRAPHY	Land surface elevation; routing based on elevation+head gradient	Routing grid (Fulldom)	Various sources
OV_ROUGH2D	Overland roughness (Manning's n for land)	LSM grid (hydro2dtbl)	Estimated based on land cover type
OVROUGHRTFAC	Multiplier on overland roughness	Routing grid (Fulldom)	Calibrated
RETDEPRTFAC	Multiplier on maximum retention depth on surface before overland flow processes are initiated	Routing grid (Fulldom)	Calibrated (internally scaled based on topographic slope)

Subsurface Routing in v5



Adapted from:
Wigmosta et. al, 1994

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

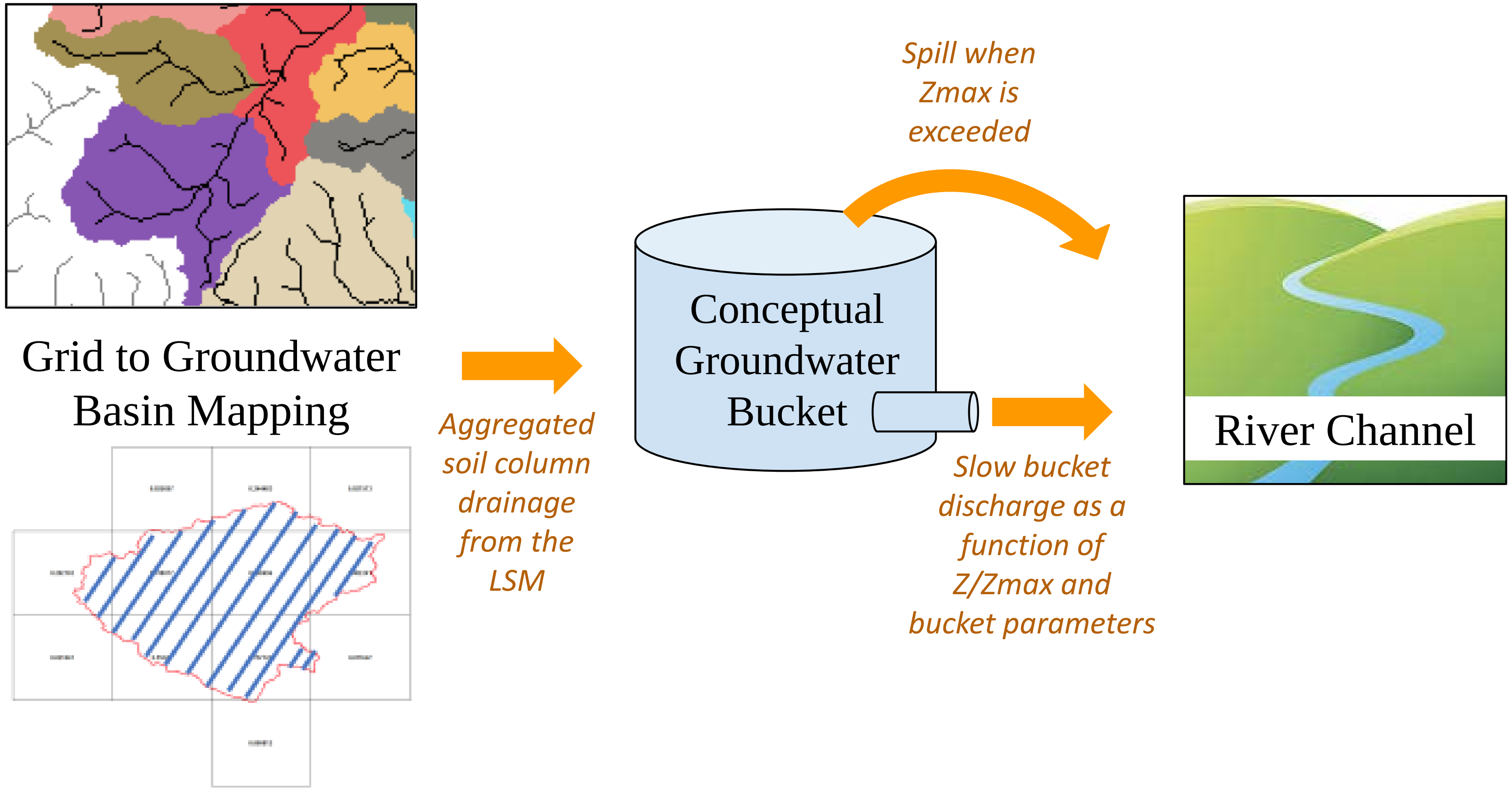
- **Critical initialization value: water table depth**

Subsurface Routing: Key Settings and Parameters

Parameter/Setting	Description	Scale/File	Estimate
Runtime Settings			
SUBRTSWCRT	Subsurface routing physics switch (on/off)	hydro.namelist	Landscape/event
NOAH_TIMESTEP	LSM timestep	namelist.hrldas	Landscape/event
Parameters			
TOPOGRAPHY	Land surface elevation; routing based on elevation+head gradient	Routing grid (Fulldom)	Various sources
LKSAT	Lateral saturated hydraulic conductivity	LSM grid (hydro2dtbl)	Estimated based on soil texture class
LKSATFAC	Multiplier on lateral conductivity	Routing grid (Fulldom)	Calibrated
SMCMAX1	Soil porosity	LSM grid (hydro2dtbl)	Estimated based on soil texture class; calibrated
SMCREF1	Soil field capacity	LSM grid (hydro2dtbl)	Estimated based on soil texture class; calibrated

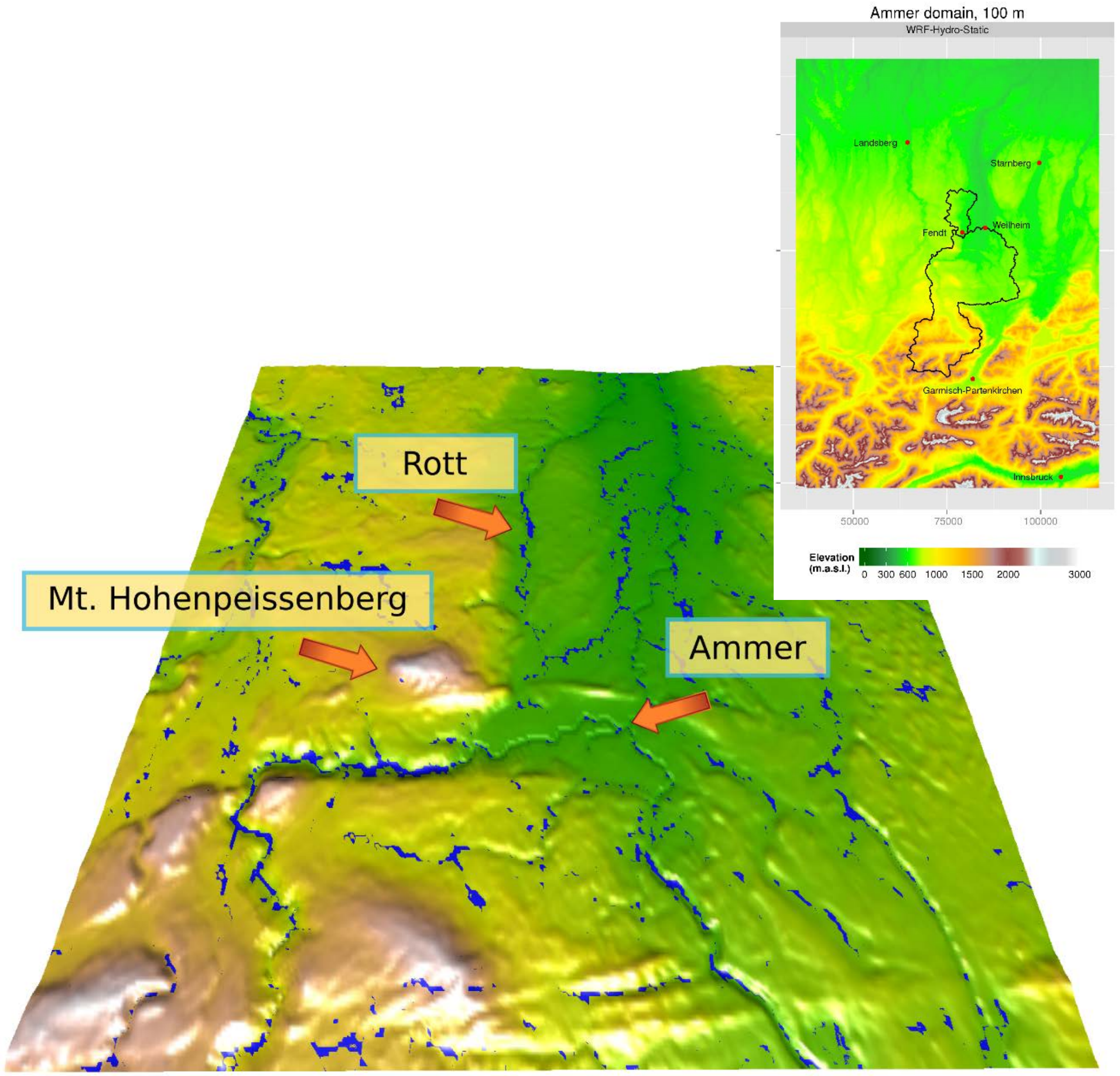
Conceptual groundwater baseflow "bucket" model:

- Simple pass-through or 2-parameter exponential model
- Bucket discharge gets distributed to channel network



Subsurface Routing in v5

- 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

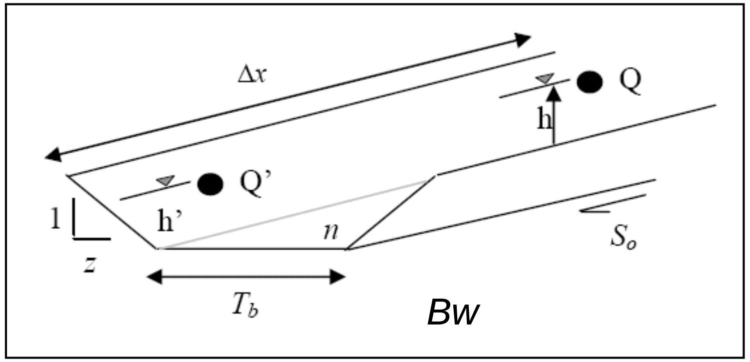
Deep Groundwater: Key Settings and Parameters

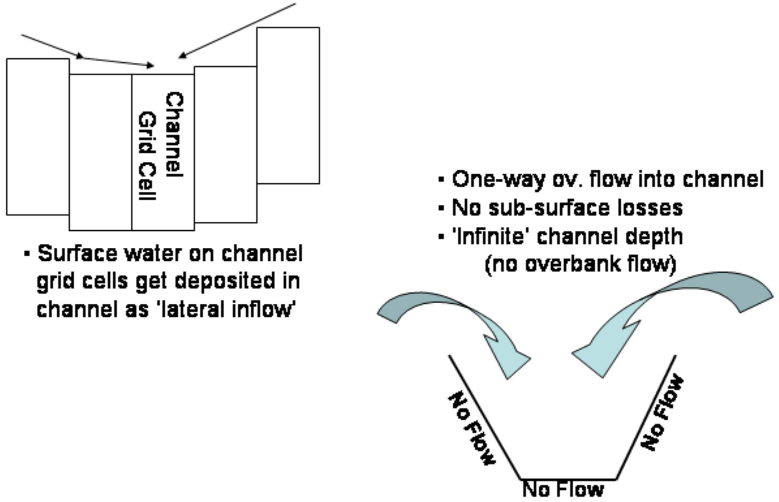
Parameter/Setting	Description	Scale/File	Estimate
Runtime Settings			
GWBASESWCRT	Baseflow bucket model switch (pass-through, exp, off)	hydro.namelist	Landscape/event
NOAH_TIMESTEP	LSM timestep	namelist.hrldas	Landscape/event
Parameters			
GWBASINS/spatialweights	Groundwater “basins”	LSM (GWBASINS) or routing grid (spatialweights)	Landscape
slope	“Openness” of bottom soil column boundary	LSM grid (soil_properties)	Calibrated
Coeff	Coefficient in exponential bucket equation	Bucket objects (GWBUCKPARM)	Calibrated
Expon	Exponent in exponential bucket equation	Bucket objects (GWBUCKPARM)	Estimated based on soil texture class; calibrated
Zmax	Maximum bucket depth	Bucket objects (GWBUCKPARM)	Estimated based on soil texture class; calibrated

Channel Routing

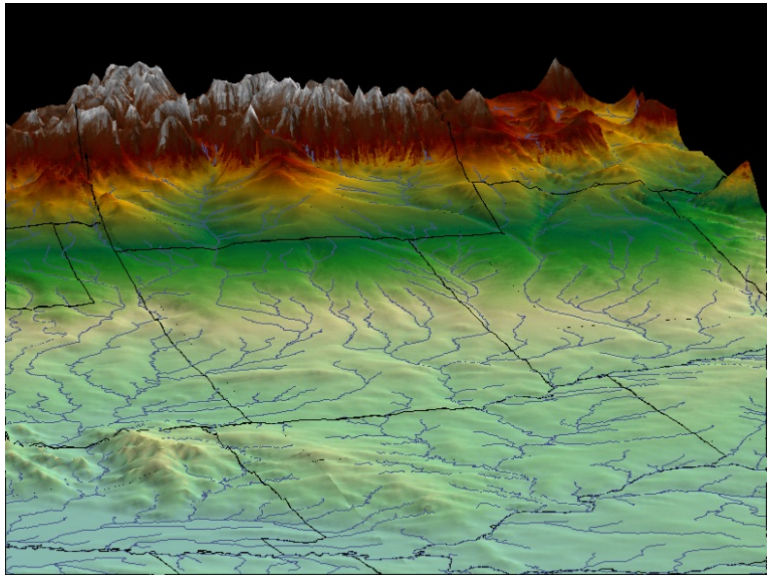
WRF-Hydro V5.0 Physics Components

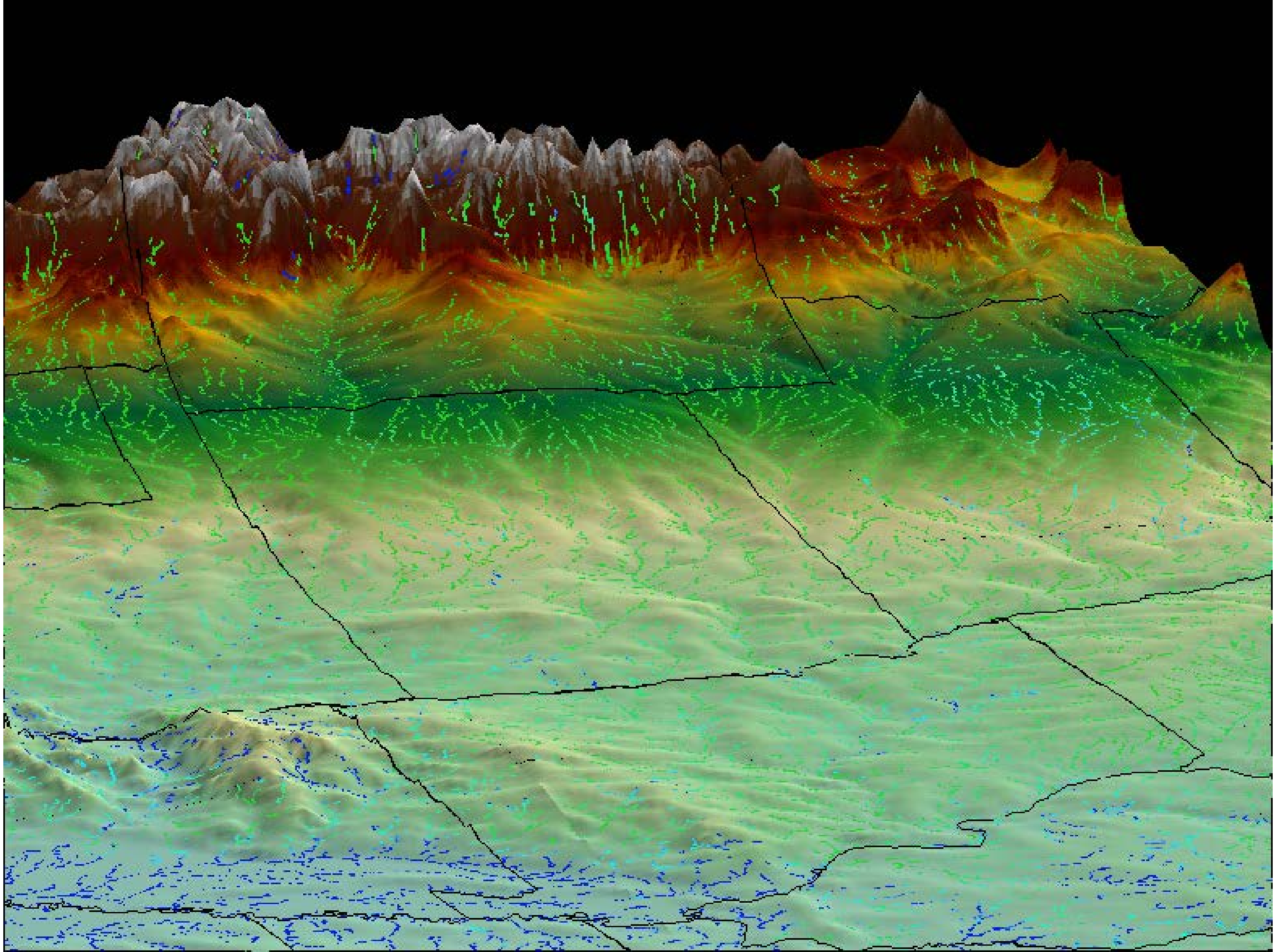
Channel routing: Gridded vs. Reach-based



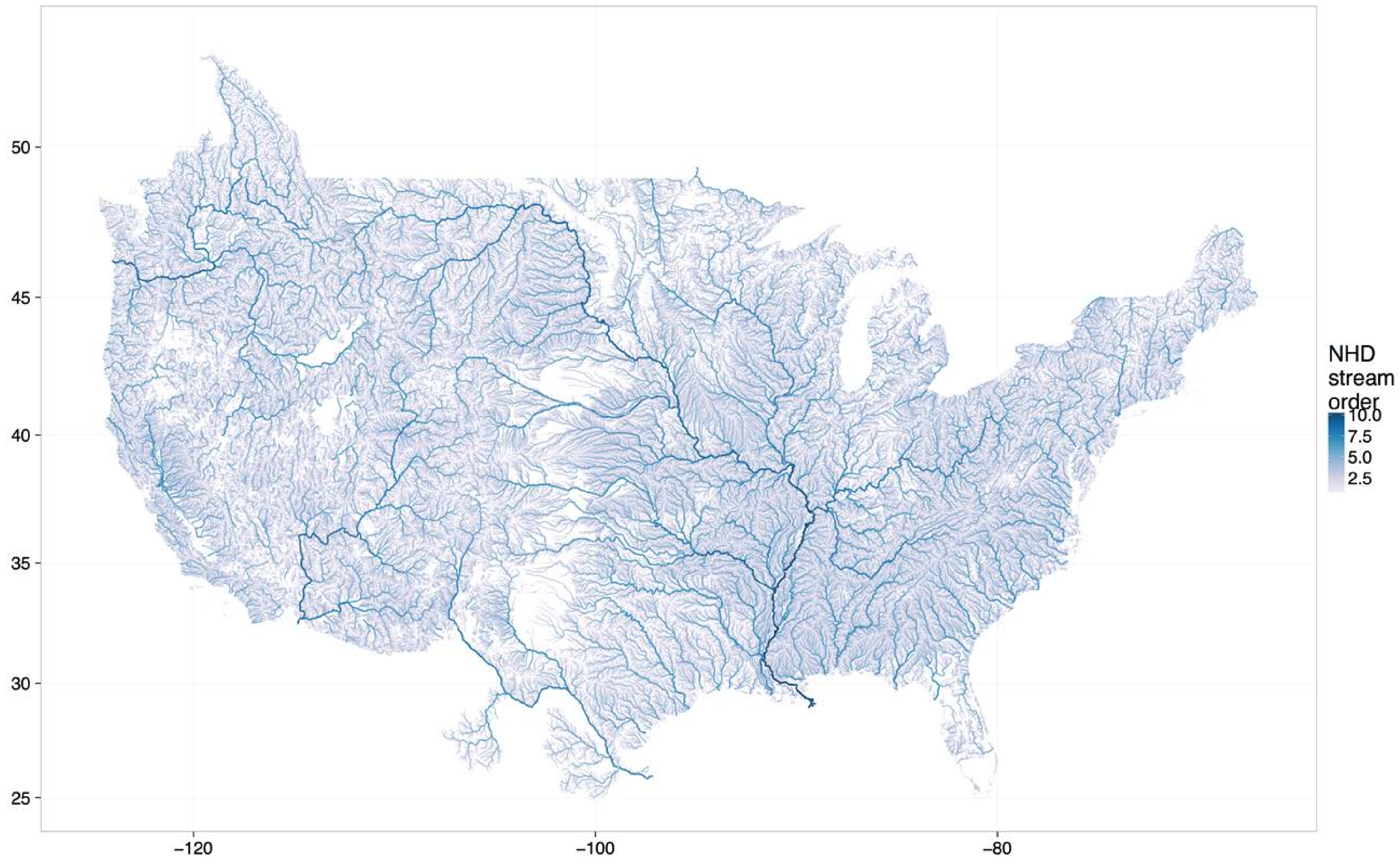


- Solution Methods:
  - Gridded: 1-d diffusive wave: fully-unsteady, explicit, finite-difference
  - Reach: Muskingum, Muskingum-Cunge *(much faster)*
- Parameters:
  - A priori function of Strahler order
  - Trapezoidal channel (bottom width, side slope)





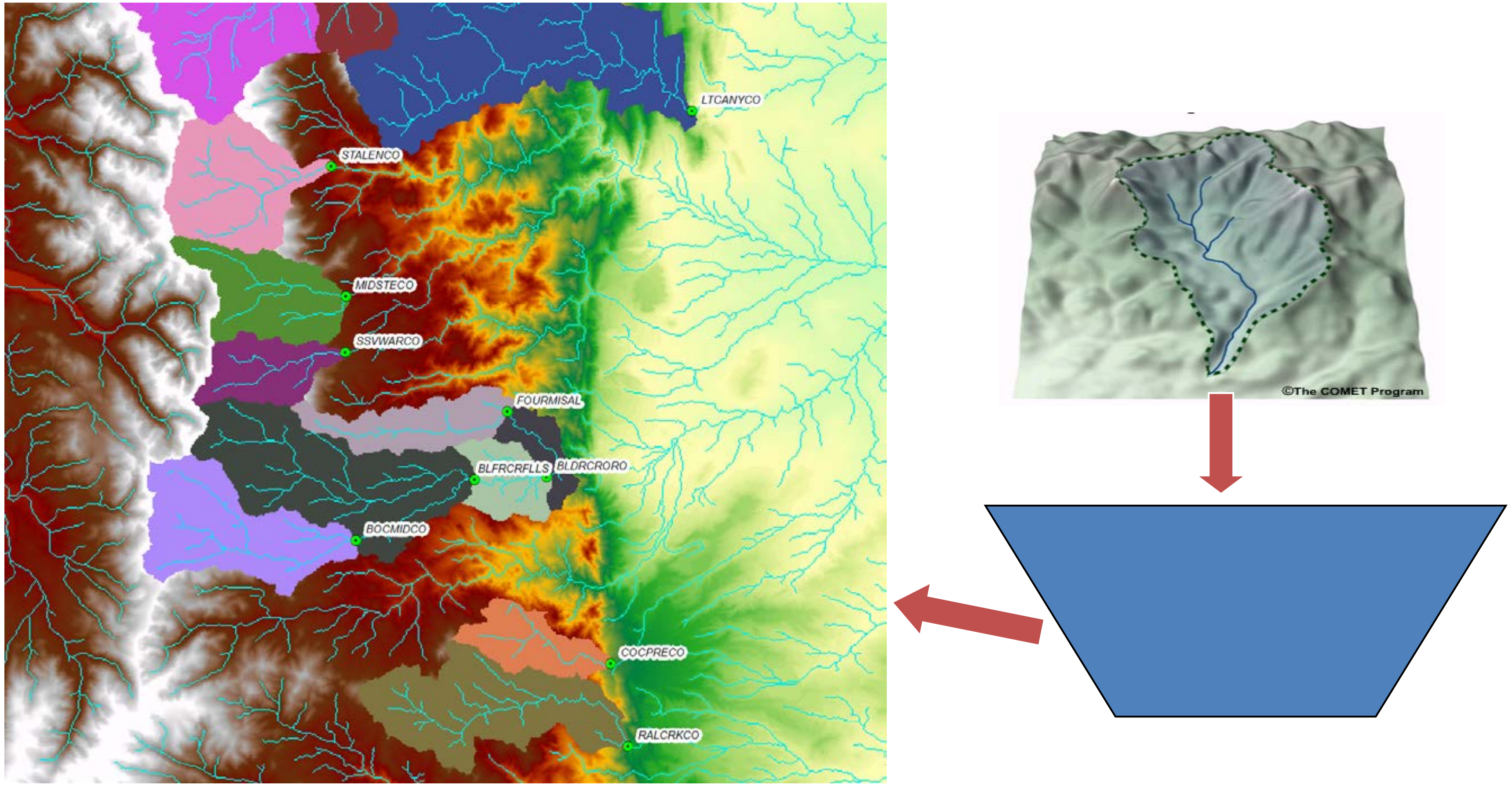
NHDPlus Reach Channel Network



WRF-Hydro V5.0 Physics Components

Optional conceptual ‘Bucket’ models:

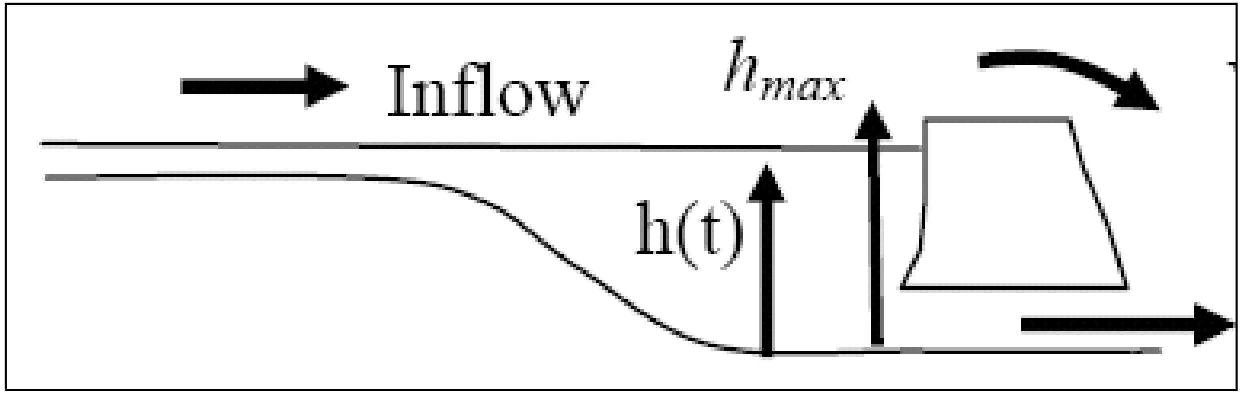
- Used for continuous (vs. event) prediction
- Simple pass-through or 2-parameter exponential model
- Bucket discharge gets distributed to channel network



WRF-Hydro V5.0 Physics Components

Optional lake/reservoir model:

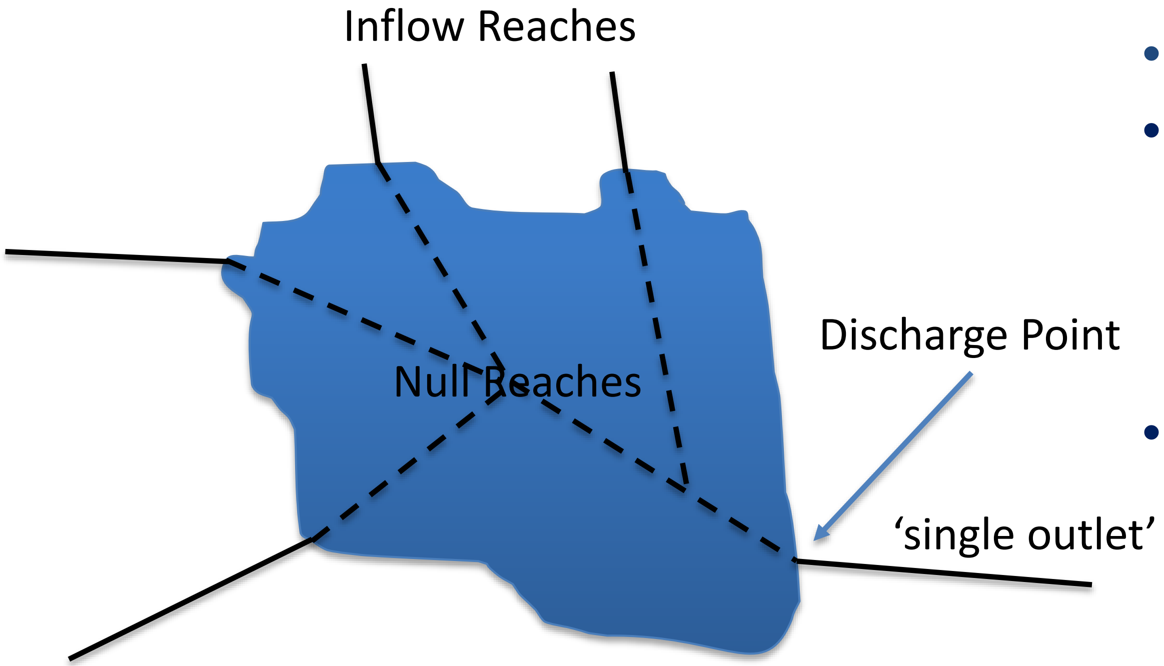
- Level-pool routing (i.e. no lagging of wave or gradient in pool elevation)
- Inflows via channel and overland flow
- Discharge via orifice and spillway to channel network
- Parameters: lake and orifice elevations, max. pool elevation, spillway and orifice characteristics; specified via parameter table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



Lakes & Reservoirs

WRF-Hydro V5.0 Physics Components : Lake/Reservoir Represenation

- Defined in GIS Pre-processing, integrated with channel hydrograph
- Specified spillway characteristics (length, height)



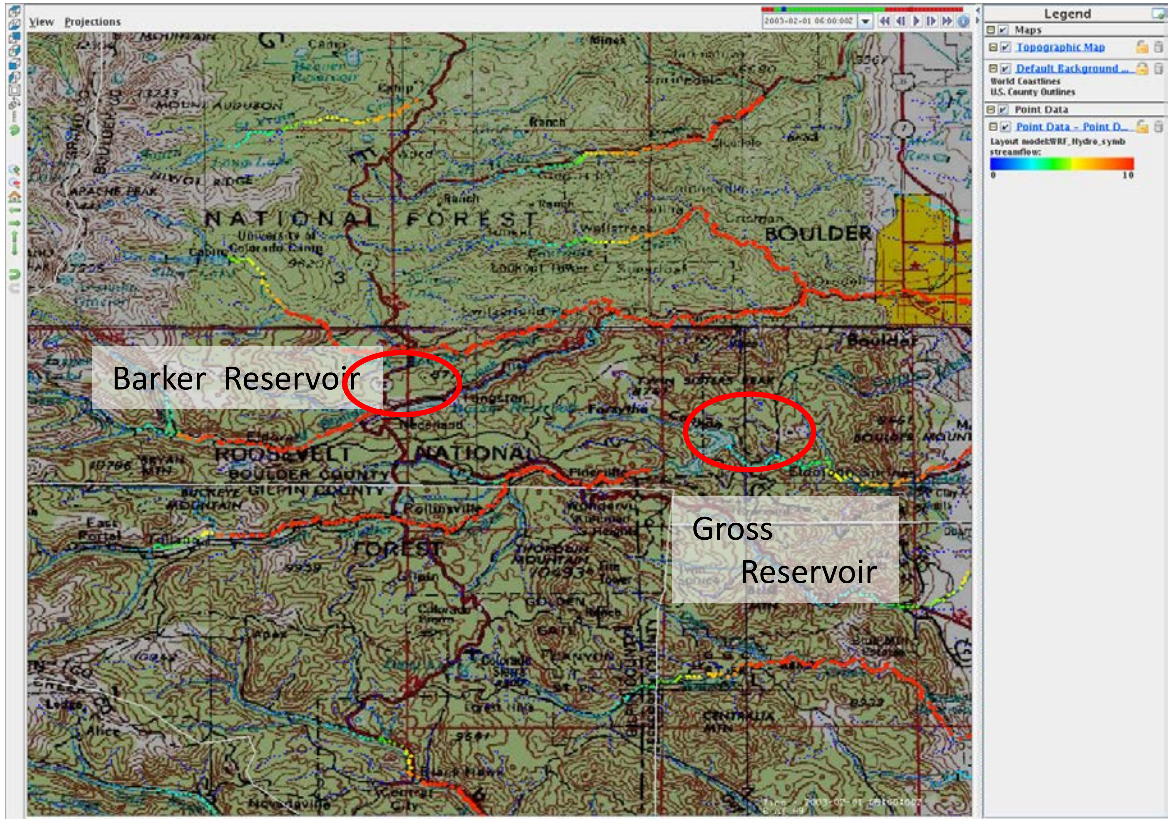
- Level Pool Scheme:
- 3 'passive' discharge mechanisms:
  - Orifice flow
  - Spillway flow
  - Direct Pass-through

- Development:
  - Basic thermodynamics (CLM/WRF lake model)
  - Full lake accounting
    - Evaporation
    - Ice formation
    - Inflows/outflows
    - Simple management
  - Coupling to FVCOM (GLERL)

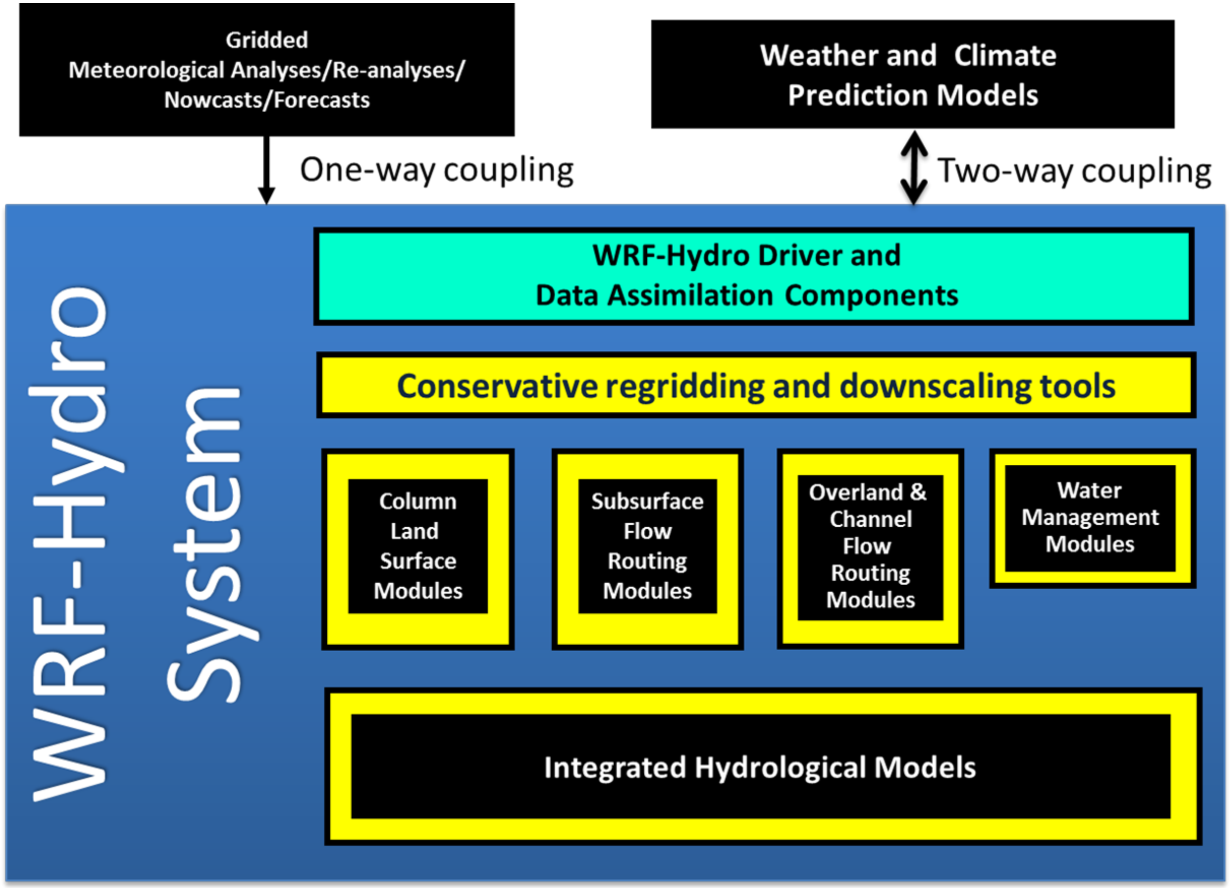
WRF-Hydro V5.0 Physics Components

Implementing lakes and reservoirs in WRF-Hydro

Visualization of lake impacts

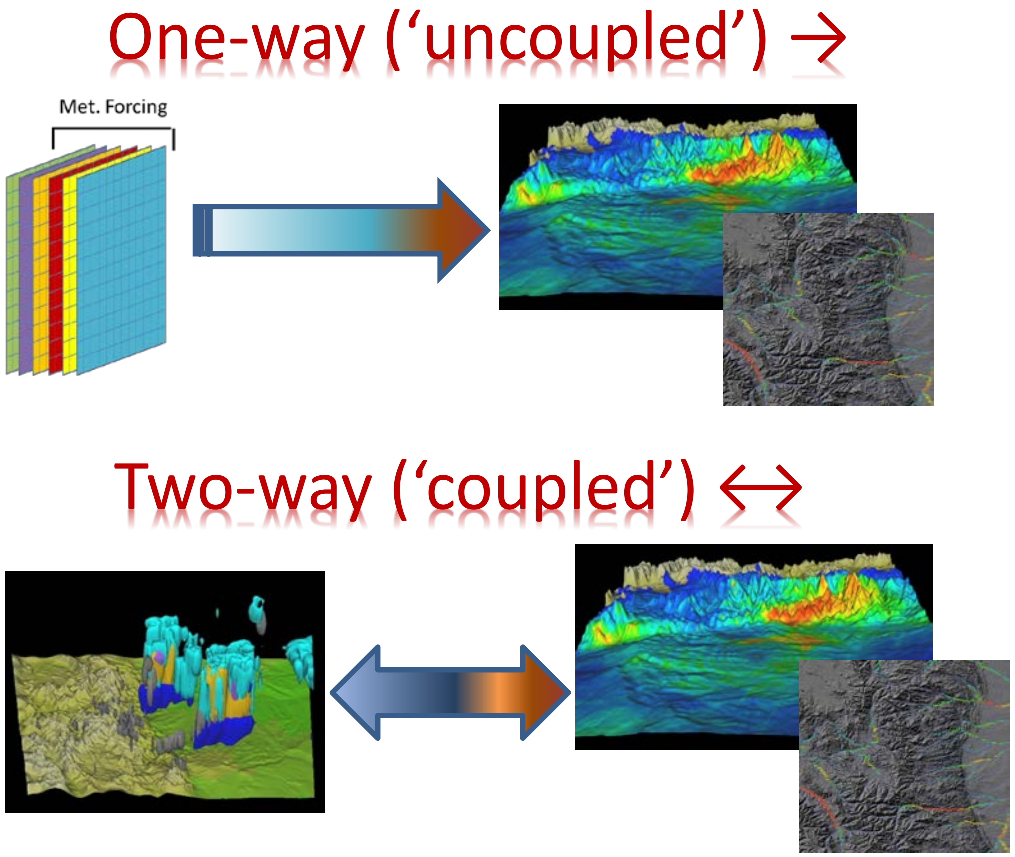


WRF-Hydro Model Architecture



- Model physics components….
- Multi-scale components….
  - Rectilinear regridding
  - ESMF regridding
  - Downscaling

WRF-Hydro Model Architecture



- Modes of operation..1-way vs. 2-way
- Model forcing and feedback components:
  - Forcings: T, Press, Precip., wind, radiation, humidity, BGC-scalars
  - Feedbacks: Sensible, latent, momentum, radiation, BGC-scalars

Routing Options

Type	When/Why To Use	Benefits	Drawbacks
Subsurface Routing			
SUBRTSWCRT	When local topography is important to flow processes or your fluxes/states of interest	Allows lateral water movement between cells, better representing convergence/divergence patterns (e.g., water converging into a valley) and residence times	More computationally expensive
Overland Flow Routing			
OVRTSWCRT	When fast surface flow processes are of interest/importance (e.g., flood forecasting vs. water supply forecasting)	Better represents local ponding and re-infiltration; required to capture land runoff directly to channels and lakes	More computationally expensive
Channel Routing			
CHANRTSWCRT	When you want streamflow in the channel		
Muskingham- **Reach** channel_option = 1	When you want an approximate solution as efficiently as possible (e.g., over a large domain or with limited compute resources)	Computationally cheap and fast	Limited to uniform fluxes/states per reach (not ideal if reaches are long); no backwater effects
Muskingham-Cunge-**Reach** channel_option = 2	When you want an approximate solution as efficiently as possible (e.g., over a large domain or with limited compute resources)	Computationally cheap and fast; more “stable” in terms of propagating flow one-way down the channel	Limited to uniform fluxes/states per reach (not ideal if reaches are long); no backwater effects
Diffusive Wave- **Gridded** channel_option = 3	When you need a more precise/accurate local solution and have sufficient compute resources (e.g., small or high-resolution domains, conditions where hydraulic processes are important)	Captures backwater flow; provides higher spatial detail on channel flow (e.g., every channel grid cell); only option that allows (limited) water fluxes from land to lake	More computationally expensive, can be sensitive to parameters and internal time steps

WRF-Hydro®

MODELING SYSTEM

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