WRF-Hydro Model

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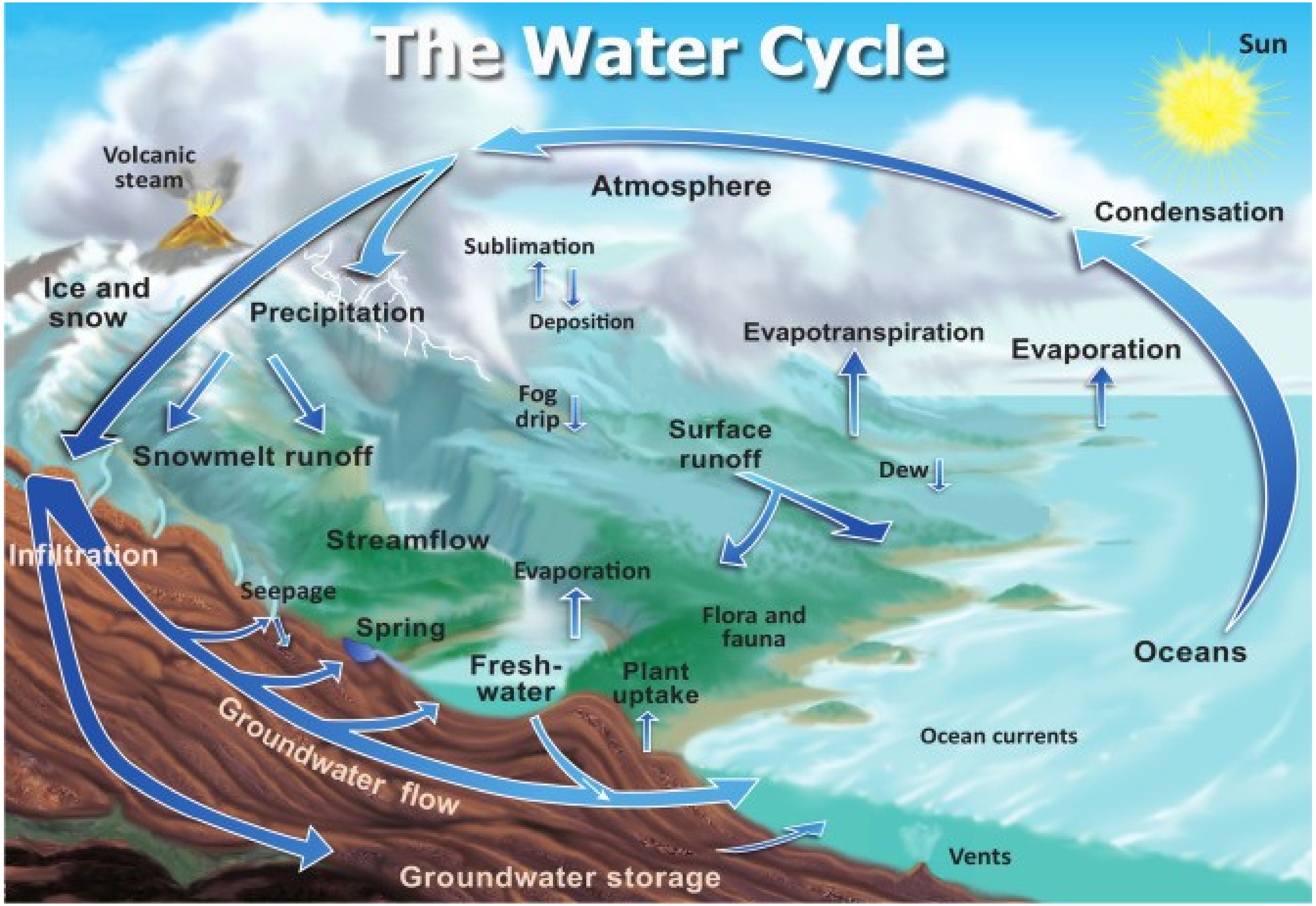
WRF-Hydro modeling system

- Provides a means to couple hydrological model components to atmospheric models and other Earth System modeling architectures.

Hydrologic modeling is used to answer environmental transport questions where water excess, scarcity, or dissolved or solid content is of primary importance (Burges, 1986).

A hydrologic model simulates a flux, flow, or change of water storage with time within one or more components of the natural hydrologic cycle.



US Geological Survey

WRF-Hydro

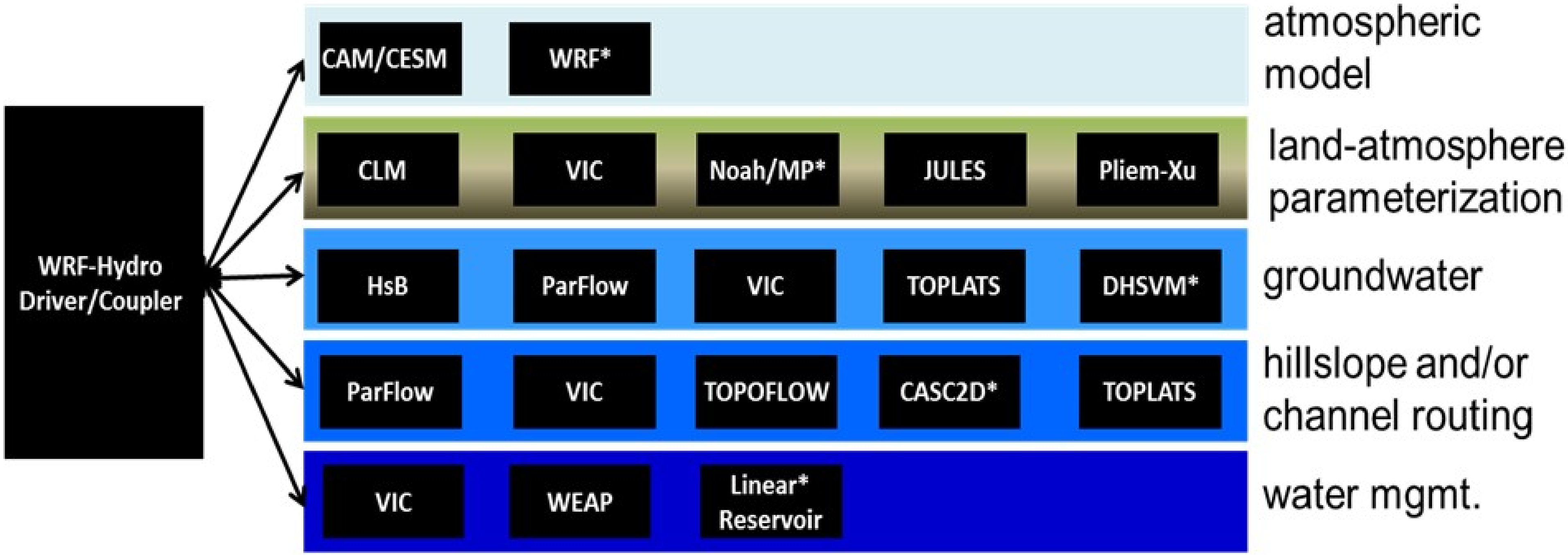
Developed to facilitate improved representations of **terrestrial hydrologic processes** related to

- Spatial redistribution of surface,
- Spatial redistribution of subsurface
- Channel waters across the land surface
- Coupling of hydrologic models with atmospheric models

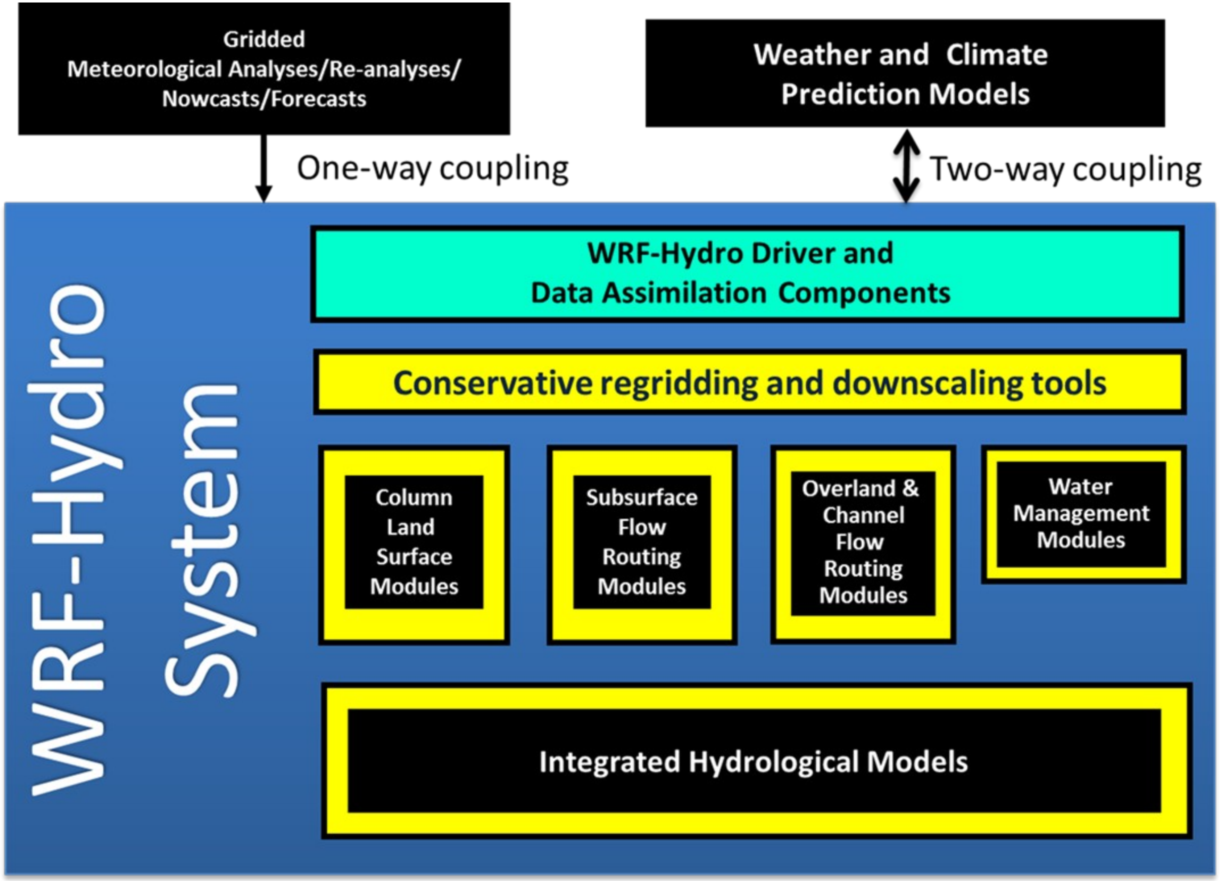
WRF-Hydro

- Is written in a modularized Fortran90 coding structure
- Routing physics modules are switch activated through a model namelist file
- The code has also been parallelized for distributed memory parallel computing applications
- Developed for linux-based operating systems including small local clusters and high performance computing systems
- Utilizes a combination of netCDF and flat ASCII file formats

WRF-Hydro architecture



WRF-Hydro architecture



Generalized conceptual schematic of the WRF-Hydro architecture showing various categories of model components

Uncoupled WRF-Hydro model

- WRF-Hydro uncoupled mode must read in the **meteorological forcing data** necessary to perform land surface model calculations and it contains the necessary routines to do this.
- Uncoupled mode critical for spinup, data assimilation, model calibration and understanding the hydrological processes.

WRF-Hydro compile-time options

Compile time options are choices about the model structure which are determined when the model is compiled.

```
#!/bin/bash

# This is a WRF environment variable. Always set to 1=On for compiling WRF-Hydro.
export WRF_HYDRO=1

# Enhanced diagnostic output for debugging: 0=Off, 1=On.
export HYDRO_D=0

# Spatially distributed parameters for NoahMP: 0=Off, 1=On.
export SPATIAL_SOIL=1  <<-- This allows NoahMP to use spatially distributed parameters for the land surface model rather than parameter based upon soil class and land use category look up tables. S

# RAPID model: 0=Off, 1=On.
export WRF_HYDRO_RAPID=0  <<-- Coupling with the RAPID routing model. This option is not currently supported.

# WCOSS file units: 0=Off, 1=On.
export NCEP_WCOSS=0  <<- Do not use unless working on the WCOSS machines.

# Streamflow nudging: 0=Off, 1=On.
export WRF_HYDRO_NUDGING=0  <<-- Enable the streamflow nudging routines for Muskingum-Cunge Routing.
```

WRF-Hydro run time options

There are two namelist files that users must edit in order to successfully execute the WRF-Hydro system in a standalone mode or “uncoupled” to WRF

- hydro.namelist

    - Used to specify the various settings for operating all of the routing components of the WRF-Hydro system.

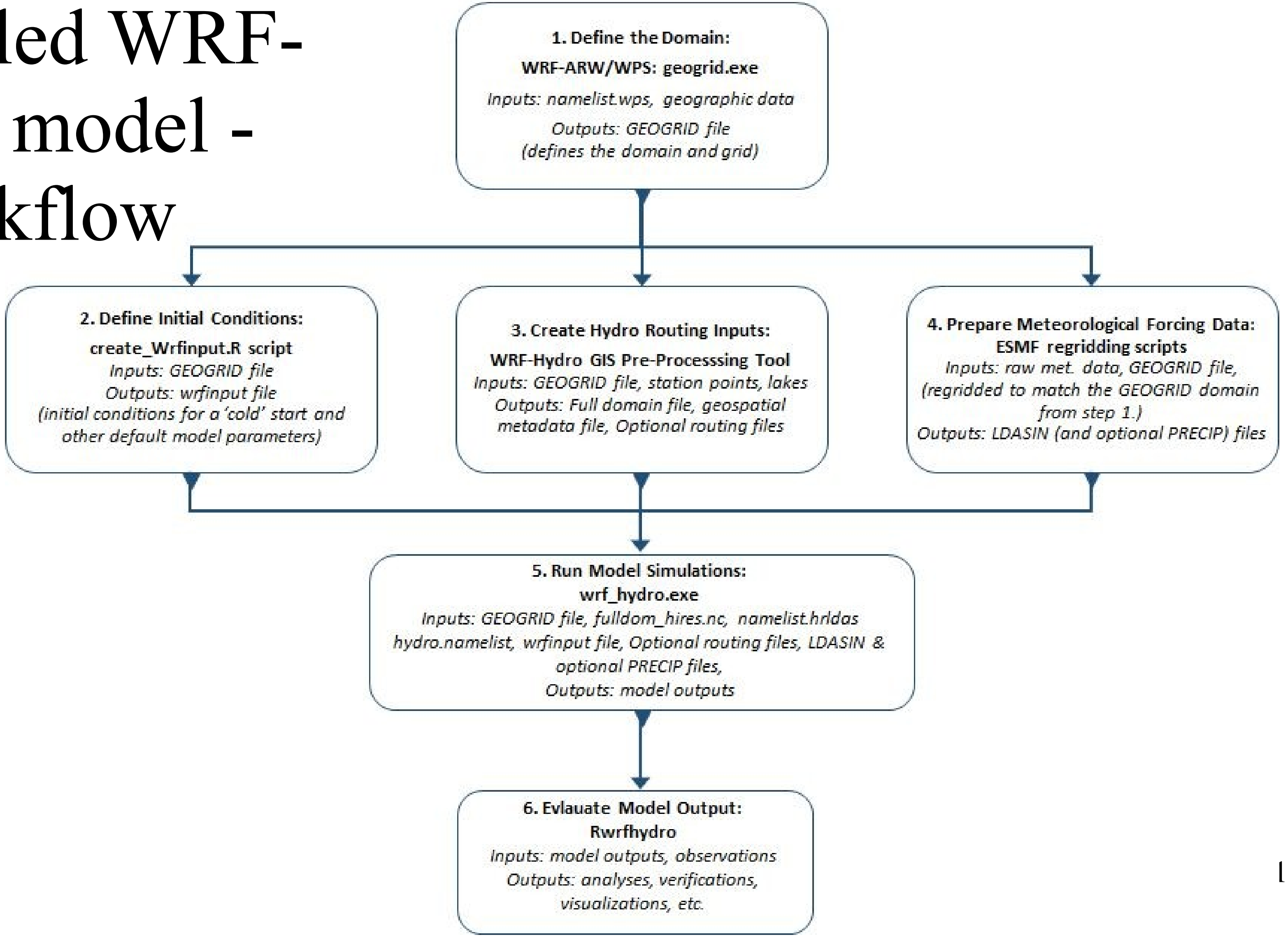
- namelist.hrldas

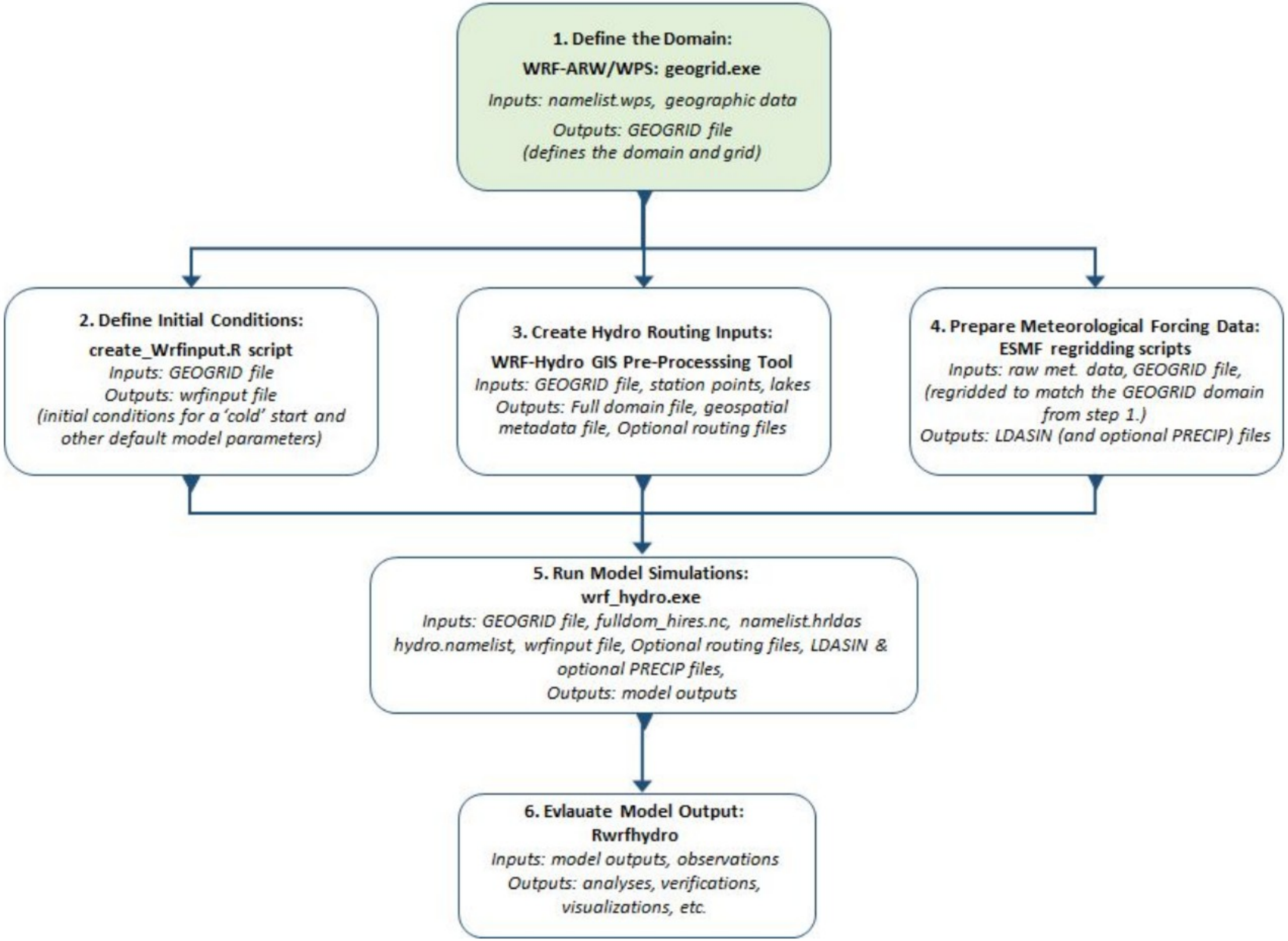
    - Specifies the land surface model options to be used

    - In WRF-Hydro v5.2, Noah and Noah-MP land surface models are the main land surface model options when WRF-Hydro is run in standalone mode

When WRF-Hydro is coupled to the WRF model, the WRF model input file namelist.input becomes the second namelist file instead of namelist.hrldas

Uncoupled WRF-Hydro model - workflow





1. Define the Domain:
WRF-ARW/WPS: geogrid.exe
Inputs: namelist.wps, geographic data
Outputs: GEOGRID file
(defines the domain and grid)
2. Define Initial Conditions:
create_Wrfinput.R script
Inputs: GEOGRID file
Outputs: wrfinput file
(initial conditions for a 'cold' start and other default model parameters)
3. Create Hydro Routing Inputs:
WRF-Hydro GIS Pre-Processsing Tool
Inputs: GEOGRID file, station points, lakes
Outputs: Full domain file, geospatial metadata file, Optional routing files
4. Prepare Meteorological Forcing Data:
ESMF regridding scripts
Inputs: raw met. data, GEOGRID file,
(regridded to match the GEOGRID domain from step 1.)
Outputs: LDASIN (and optional PRECIP) files
5. Run Model Simulations:
wrf_hydro.exe
Inputs: GEOGRID file, fulldom_hires.nc, namelist.hrldas hydro.namelist, wrfinput file, Optional routing files, LDASIN & optional PRECIP files,
Outputs: model outputs
6. Evlauate Model Output:
Rwrfhydro
Inputs: model outputs, observations
Outputs: analyses, verifications, visualizations, etc.

Define the domain

- WRF Preprocessing System (**WPS**) is used to define domain
- **WPS** uses Geographical Input Data downloaded from NCAR server. To define the domain's horizontal resolutions
- **WPS** namelist.wps file define:

  - starting and ending time of the simulation

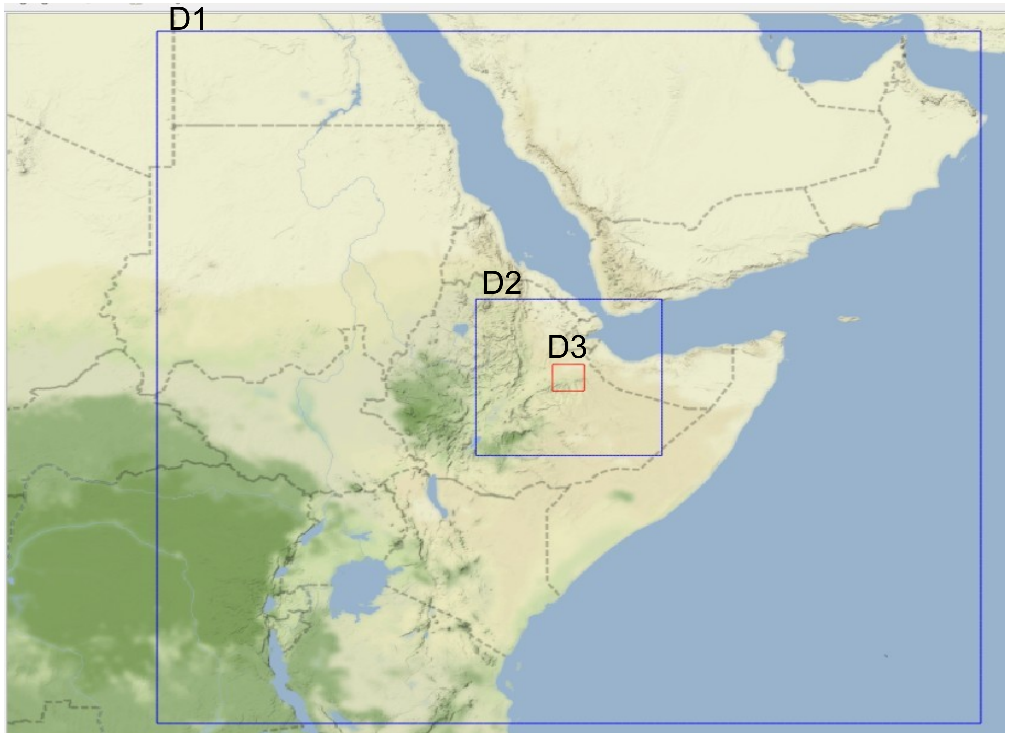
  - land use data resolution

  - the number nested domains

- Once the file is edited the executable **geogrid.exe** will run to create domains

Define the domain

- Once the file is edited the executable **geogrid.exe** will run to create domains
- The executable create netCDF file with the naming convection geo_em.d0x.nc (x refers the number of the specified domains)



Nested domains at 25 (D1), 5 (D2), and 1 km (D3) horizontal resolutions

Define the domain

- The geogrid file contains basic information regarding the domain's coordinate system and static 2D and 3D gridded variables.

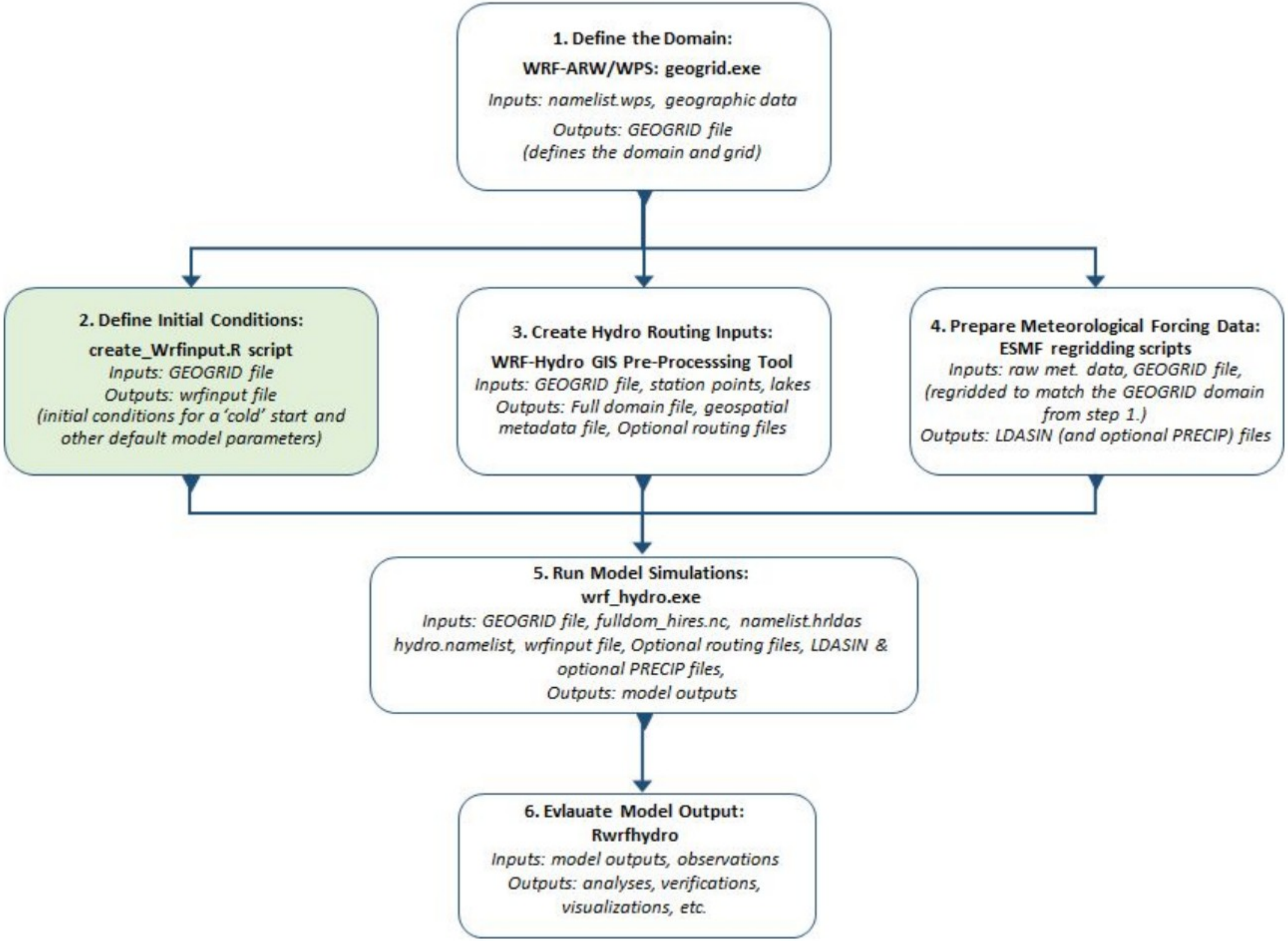
- The projection parameters that define the coordinate system of the domain, the size, spatial location and horizontal resolution of the grid cells are all included in the geogrid file.

```
netcdf geo_em.d03 {
dimensions:
        Time = UNLIMITED ; // (1 currently)
        DateStrLen = 19 ;
        west_east = 150 ;
        south_north = 150 ;
        south_north_stag = 151 ;
        west_east_stag = 151 ;
        land_cat = 21 ;
        soil_cat = 16 ;
        month = 12 ;
variables:
        char Times(Time, DateStrLen) ;
        float XLAT_M(Time, south_north, west_east) ;
                XLAT_M:FieldType = 104 ;
                XLAT_M:MemoryOrder = "XY " ;
                XLAT_M:units = "degrees latitude" ;
                XLAT_M:description = "Latitude on mass grid" ;
                XLAT_M:stagger = "M" ;
                XLAT_M:sr_x = 1 ;
                XLAT_M:sr_y = 1 ;
        float XLONG_M(Time, south_north, west_east) ;
                XLONG_M:FieldType = 104 ;
                XLONG_M:MemoryOrder = "XY " ;
                XLONG_M:units = "degrees longitude" ;
                XLONG_M:description = "Longitude on mass grid" ;
                XLONG_M:stagger = "M" ;
                XLONG_M:sr_x = 1 ;
                XLONG_M:sr_y = 1 ;
        float XLAT_V(Time, south_north_stag, west_east) ;
                XLAT_V:FieldType = 104 ;
                XLAT_V:MemoryOrder = "XY " ;
                XLAT_V:units = "degrees latitude" ;
                XLAT_V:description = "Latitude on V grid" ;
                XLAT_V:stagger = "V" ;
                XLAT_V:sr_x = 1 ;
                XLAT_V:sr_y = 1 ;
        float XLONG_V(Time, south_north_stag, west_east) ;
                XLONG_V:FieldType = 104 ;
                XLONG_V:MemoryOrder = "XY " ;
                XLONG_V:units = "degrees longitude" ;
                XLONG_V:description = "Longitude on V grid" ;
                XLONG_V:stagger = "V" ;
                XLONG_V:sr_x = 1 ;
                XLONG_V:sr_y = 1 ;
        float XLAT_U(Time, south_north, west_east_stag) ;
                XLAT_U:FieldType = 104 ;
                XLAT_U:MemoryOrder = "XY " ;
                XLAT_U:units = "degrees latitude" ;
                XLAT_U:description = "Latitude on U grid" ;
                XLAT_U:stagger = "U" ;
                XLAT_U:sr_x = 1 ;
```

Define the domain

- This file will be used by WRF-Hydro GIS Pre-processing Toolkit, Earth System Modeling Framework (ESMF) regridding scripts and WRFHydro.

```
float HGT_M(Time, south_north, west_east) ;
        HGT_M:FieldType = 104 ;
        HGT_M:MemoryOrder = "XY " ;
        HGT_M:units = "meters MSL" ;
        HGT_M:description = "GMTED2010 30-arc-second topography height" ;
        HGT_M:stagger = "M" ;
        HGT_M:sr_x = 1 ;
        HGT_M:sr_y = 1 ;
float SOILTEMP(Time, south_north, west_east) ;
        SOILTEMP:FieldType = 104 ;
        SOILTEMP:MemoryOrder = "XY " ;
        SOILTEMP:units = "Kelvin" ;
        SOILTEMP:description = "Annual mean deep soil temperature" ;
        SOILTEMP:stagger = "M" ;
        SOILTEMP:sr_x = 1 ;
        SOILTEMP:sr_y = 1 ;
float SOILCTOP(Time, soil_cat, south_north, west_east) ;
        SOILCTOP:FieldType = 104 ;
        SOILCTOP:MemoryOrder = "XYZ" ;
        SOILCTOP:units = "category" ;
        SOILCTOP:description = "16-category top-layer soil type" ;
        SOILCTOP:stagger = "M" ;
        SOILCTOP:sr_x = 1 ;
        SOILCTOP:sr_y = 1 ;
float SCT_DOM(Time, south_north, west_east) ;
        SCT_DOM:FieldType = 104 ;
        SCT_DOM:MemoryOrder = "XY " ;
        SCT_DOM:units = "category" ;
        SCT_DOM:description = "Dominant category" ;
        SCT_DOM:stagger = "M" ;
        SCT_DOM:sr_x = 1 ;
        SCT_DOM:sr_y = 1 ;
float SOILCBOT(Time, soil_cat, south_north, west_east) ;
        SOILCBOT:FieldType = 104 ;
        SOILCBOT:MemoryOrder = "XYZ" ;
        SOILCBOT:units = "category" ;
        SOILCBOT:description = "16-category bottom-layer soil type" ;
        SOILCBOT:stagger = "M" ;
        SOILCBOT:sr_x = 1 ;
        SOILCBOT:sr_y = 1 ;
float SCB_DOM(Time, south_north, west_east) ;
        SCB_DOM:FieldType = 104 ;
        SCB_DOM:MemoryOrder = "XY " ;
        SCB_DOM:units = "category" ;
        SCB_DOM:description = "Dominant category" ;
        SCB_DOM:stagger = "M" ;
        SCB_DOM:sr_x = 1 ;
        SCB_DOM:sr_y = 1 ;
```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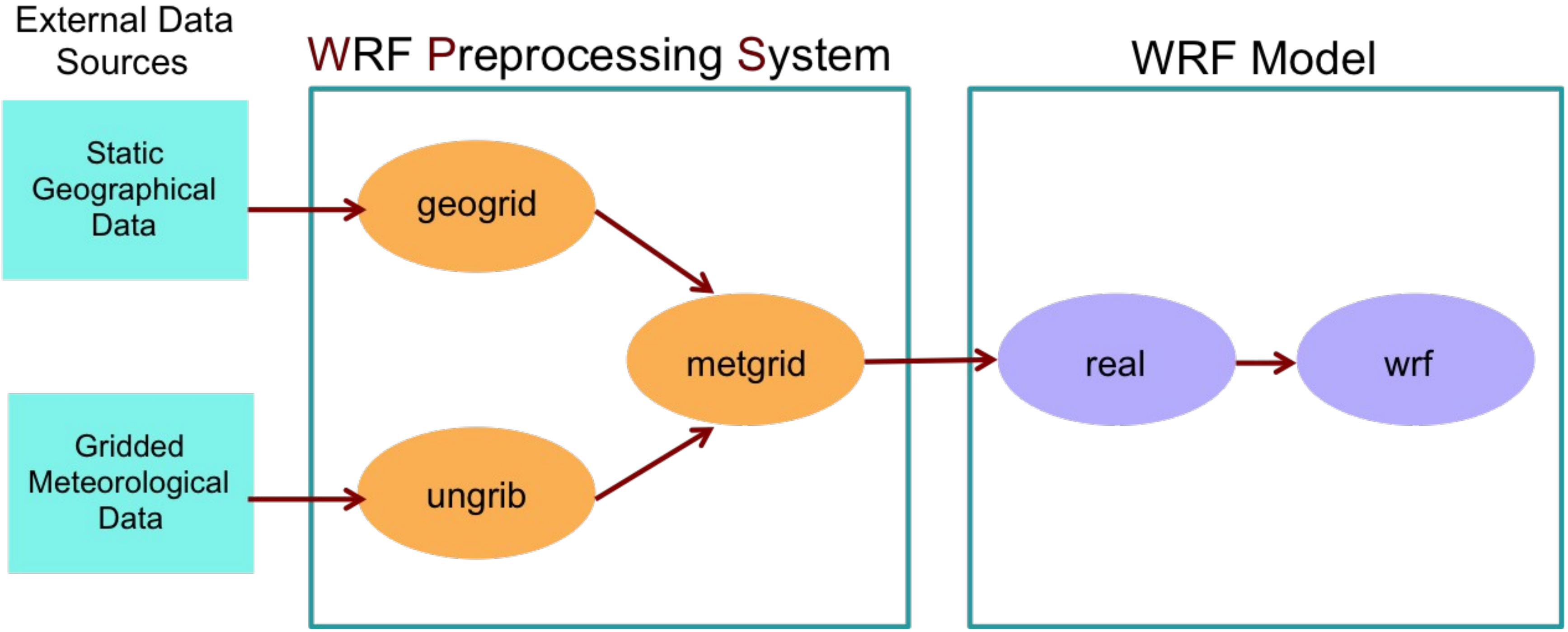
Define initial conditions

WRF program **real.exe** is used to create initial conditions for the domain



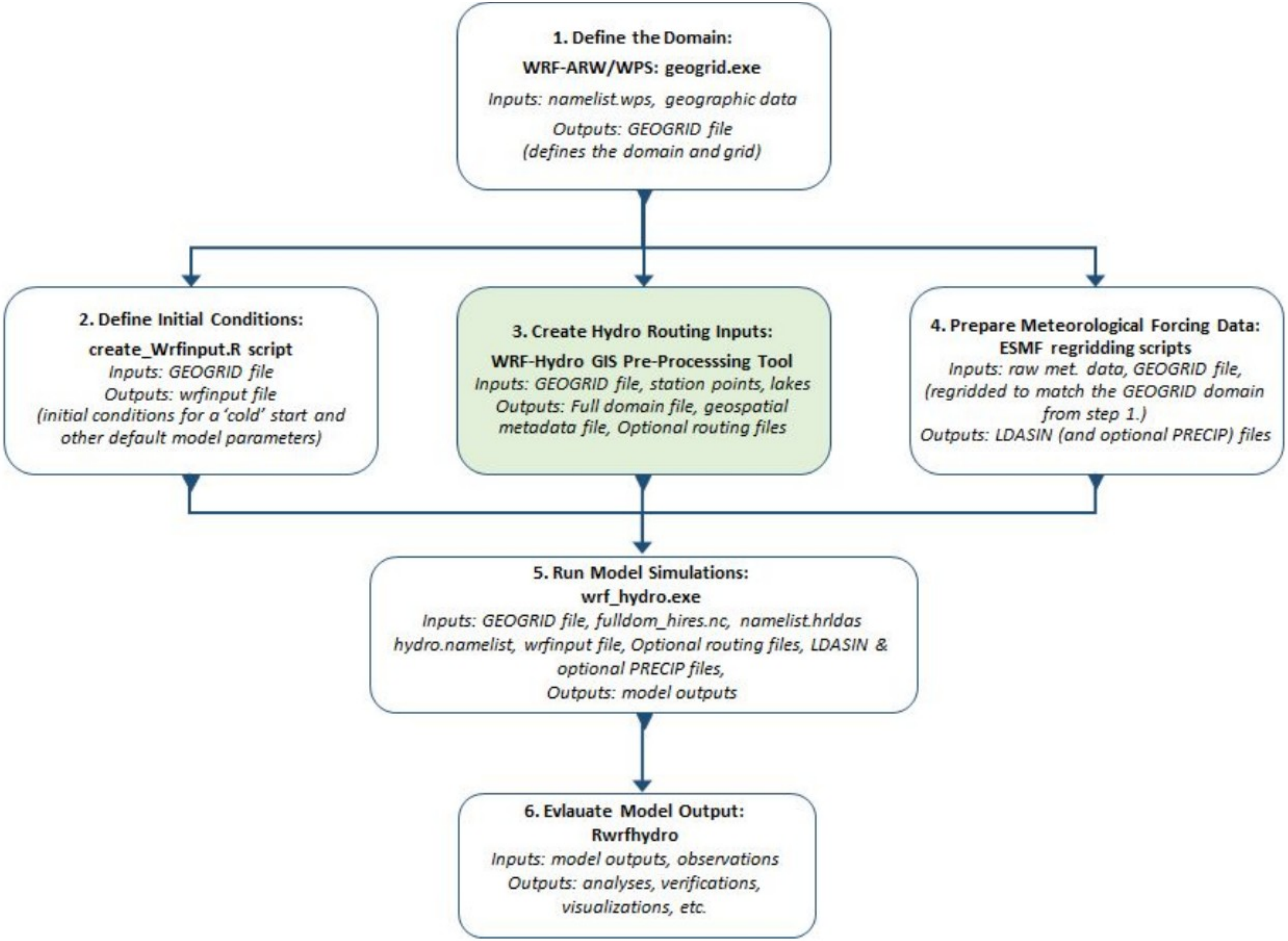
Program flow of a typical WRF model simulation

Define initial conditions

- WPS takes gridded meteorological data from external Data sources.
    - NCEP (National Centers for Environmental Prediction) FNL(Final) operational global analysis data is used as the gridded meteorological data
- ungrib.exe unpacks the GRIB meteorological data and packs it into an intermediate file format

Define initial conditions

- metgrid.exe takes the outputs of geogrid.exe and ungrid.exe to interpolate the meteorological data horizontally to the defined domain.
- The the outputs from metgrid.exe serves as input to WRF.
- The real.exe vertically interpolates the data onto the model coordinates to produce wrfinput d0x.nc file that provides the initial conditions for the domain.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Create Hydro Routing Inputs

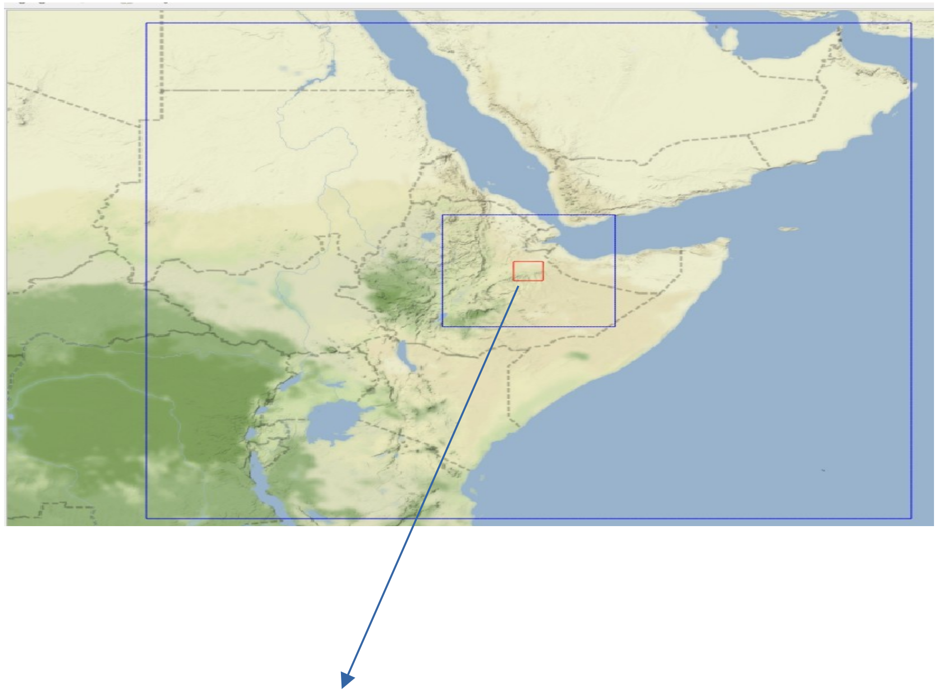
- Hydrologic routing input files are created using the WRF-Hydro GIS Pre-processing Toolkits
    - NCAR Python modules
    - ArcGIS Python application program interface (API), it can be downloaded from the following link:

      https://ral.ucar.edu/projects/wrf_hydro/pre-processing-tools
- Geogrid file and Digital Elevation Model (DEM) data are the main input data for the toolkits

Create Hydro Routing Inputs

Model Domain

- Area of interest
- Defines model domain
    - Size
    - Location
    - Horizontal resolution
- Defined by Geogrid file
    - geo_em.d03.nc



geo_em.d03.nc

Create Hydro Routing Inputs

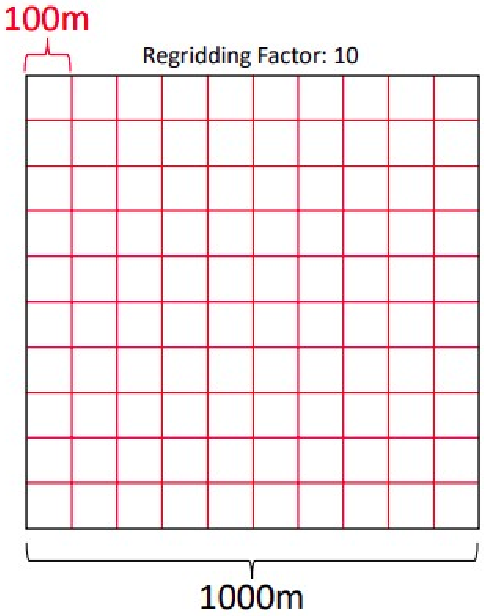
Input Elevation Raster

- Must be an ArcGIS-readable raster format
- Must contain valid coordinate reference system
- Must cover entire extent (and more) of your GEOGRID domain
- Elevation units must be converted to meters (m)

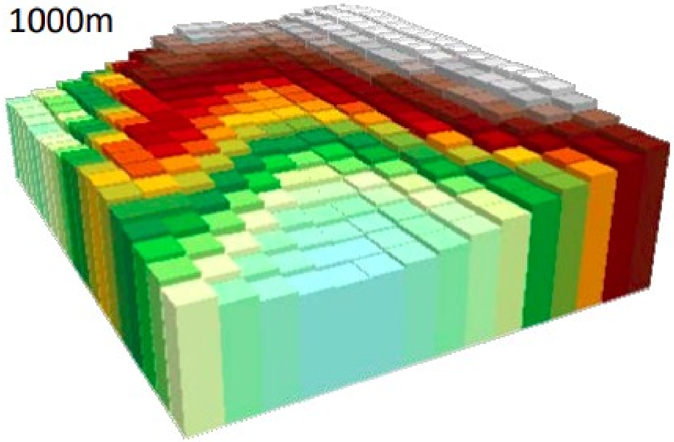
Create Hydro Routing Inputs

Input Regridding Factor

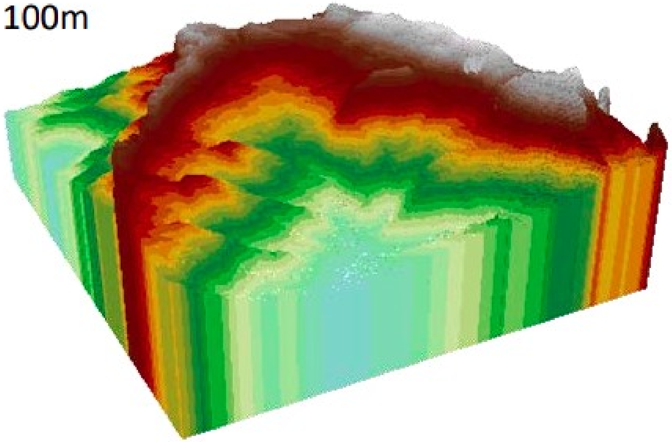
$$\frac{\text{GEOGRID Resolution}}{\text{Regridding Factor}} = \text{Routing Resolution}$$



1000m



100m



Create Hydro Routing Inputs

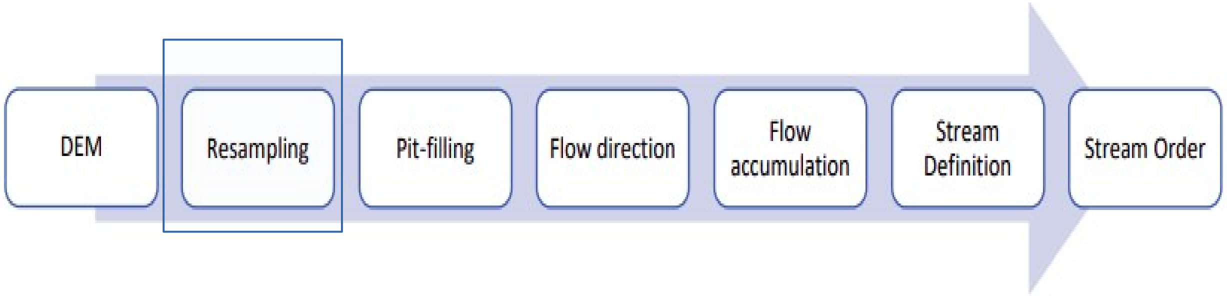
Terrain Pre-processing Workflow

- Resample high-resolution DEM and land use
- Void-fill the resampled DEM
- D8 Flow Direction
- Flow Accumulation
- Derive CHANNELGRID from flow accumulation raster using threshold of minimum basin size
- Derive Strahler stream order from CHANNELGRID

Create Hydro Routing Inputs

Re-project and Re-sample Hydro DEM

- Project input DEM to model projection and domain
- Re-sample to routing grid resolution
  - BILINEAR resampling uses a distance-weighted average of the 4 nearest cell centers.
- Re-projection and re-sampling can 'break' the input HydroDEM.
  - Causing artificial 'pits'.
  - Filling in 'burned in' areas.
- Even though we start with a HydroDEM, we 'break' it, then recondition it.

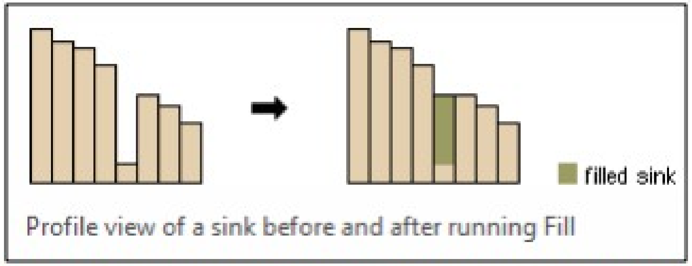


Create Hydro Routing Inputs

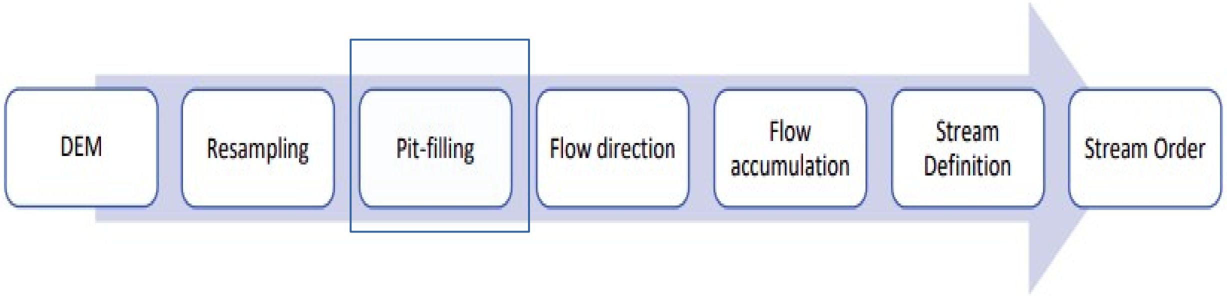
Pit-filling

- Fill depressions so that water can roll downhill only.
- This also creates a smoother DEM than you might find in nature.
- This simple hydro-enforcement method can resolve most flow issues in a DEM.

Spatial Analyst “Fill“ Tool



© Esri: http://desktop.arcgis.com/en/arcmap/latest/tools/spatial-analyst-toolbox/how-fill-works.htm



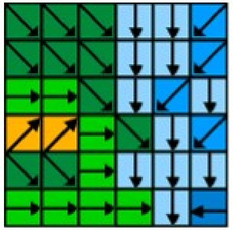
Create Hydro Routing Inputs

Flow Direction and Flow Accumulation

- D8 Flow Direction

32	64	128
16		1
8	4	2

- Flow Accumulation

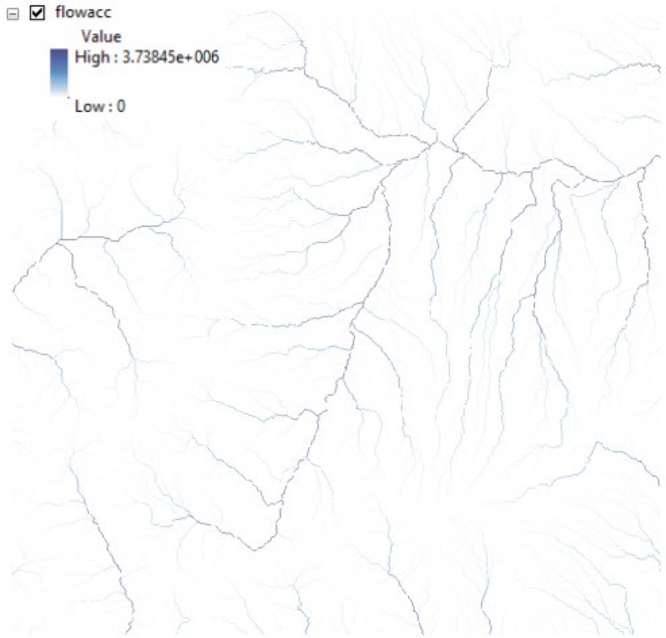


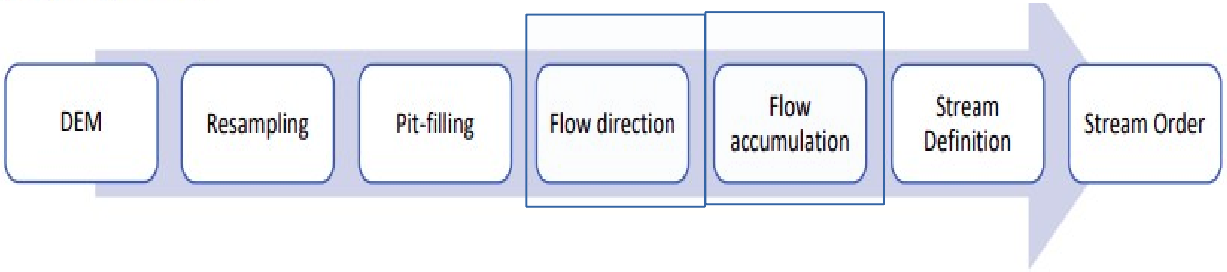
Flow direction

0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	20	0	1
0	0	0	1	24	0
0	2	4	7	35	1

Flow accumulation

© Esri: http://desktop.arcgis.com/en/arcmap/latest/tools/spatial-analyst-toolbox/how-flow-accumulation-works.htm



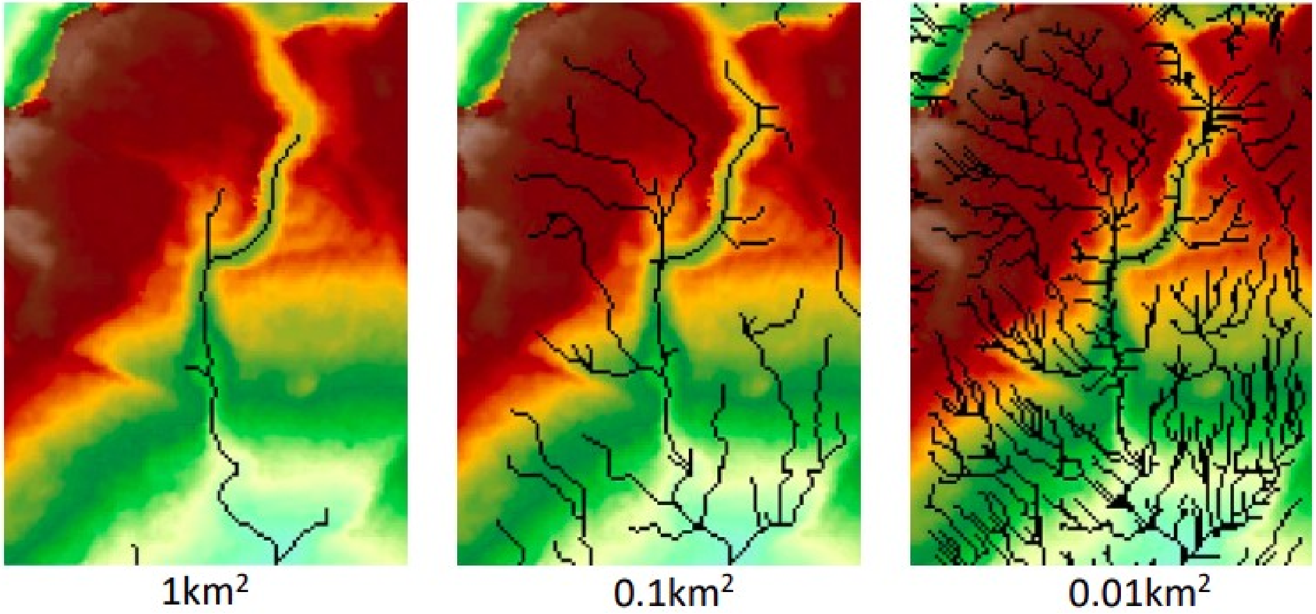


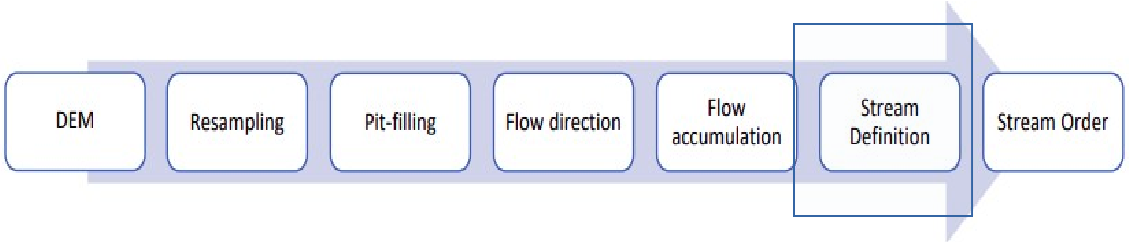
Create Hydro Routing Inputs

Stream Definition

Input Parameter: Number of pixels to define stream

- Yields a minimum ‘basin’ size
- Given in pixels, on the routing gri
- Affects density of generated channel network





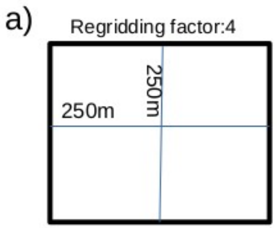
Create Hydro Routing Inputs

Stream Definition

a) Nesting of WRF-Hydro routing grid cells (blue boxes) within a WRF grid cell (black box).

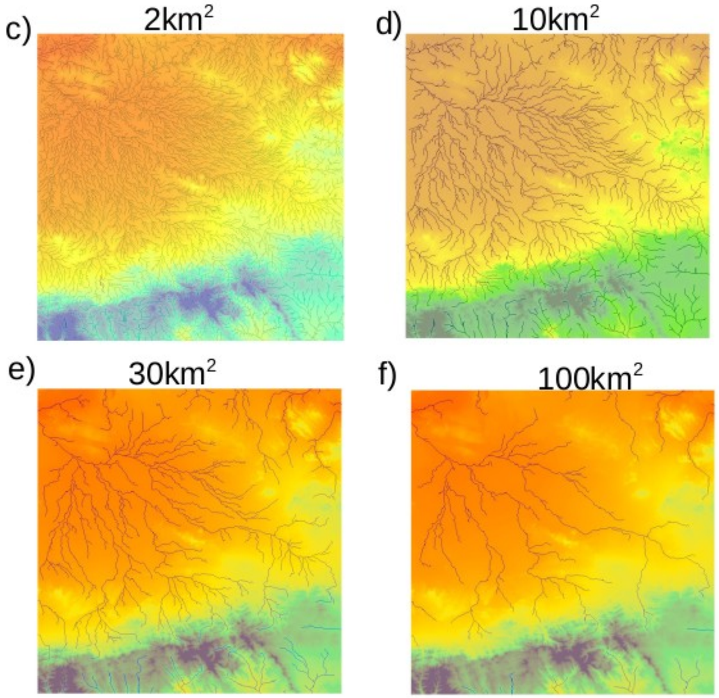
b) contributing cells effect on routing grid cell size.

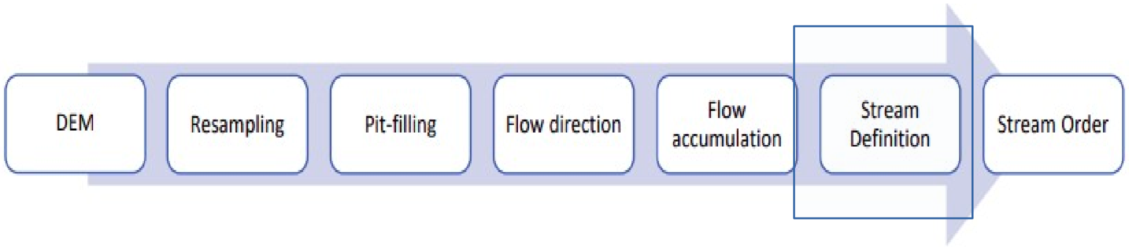
c-f) effect of contributing area threshold on stream density overlaid on elevation .



b)

Routing resolution	Contributing cells	Contributing area
250m	32	$2km^2$
250m	160	$10km^2$
250m	480	$30km^2$
250m	1600	$100km^2$

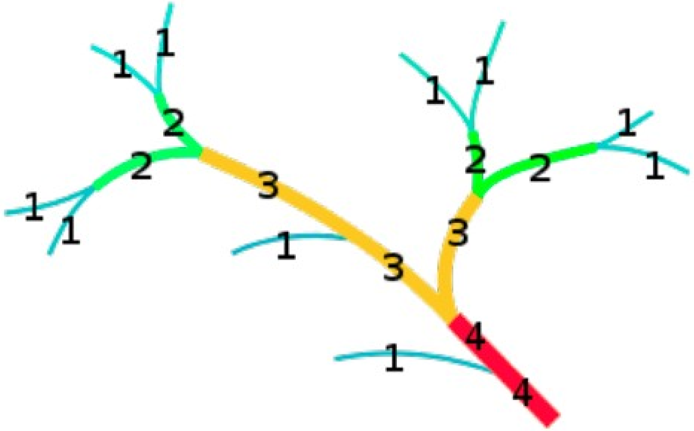


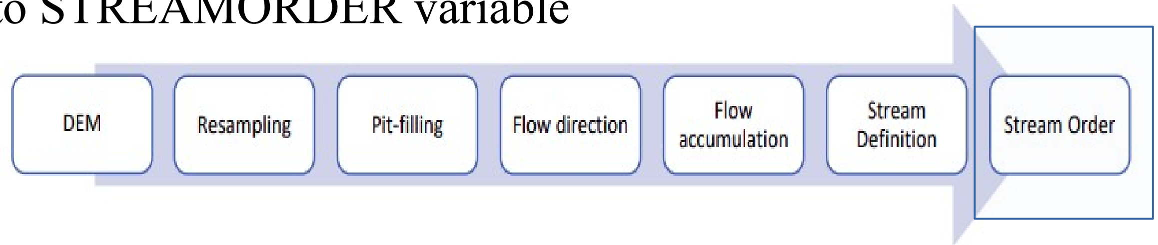


Create Hydro Routing Inputs

Stream Order

- Strahler number – measure branching complexity
  - If the node has no children, its Strahler number is one.
  - If the node has one child with Strahler number ***i***, and all other children have Strahler numbers less than ***i***, then the Strahler number of the node is ***i*** again.
  - If the node has two or more children with Strahler number ***i***, and no children with greater number, then the Strahler number of the node is ***i + 1***.
- Writes output file to STREAMORDER variable





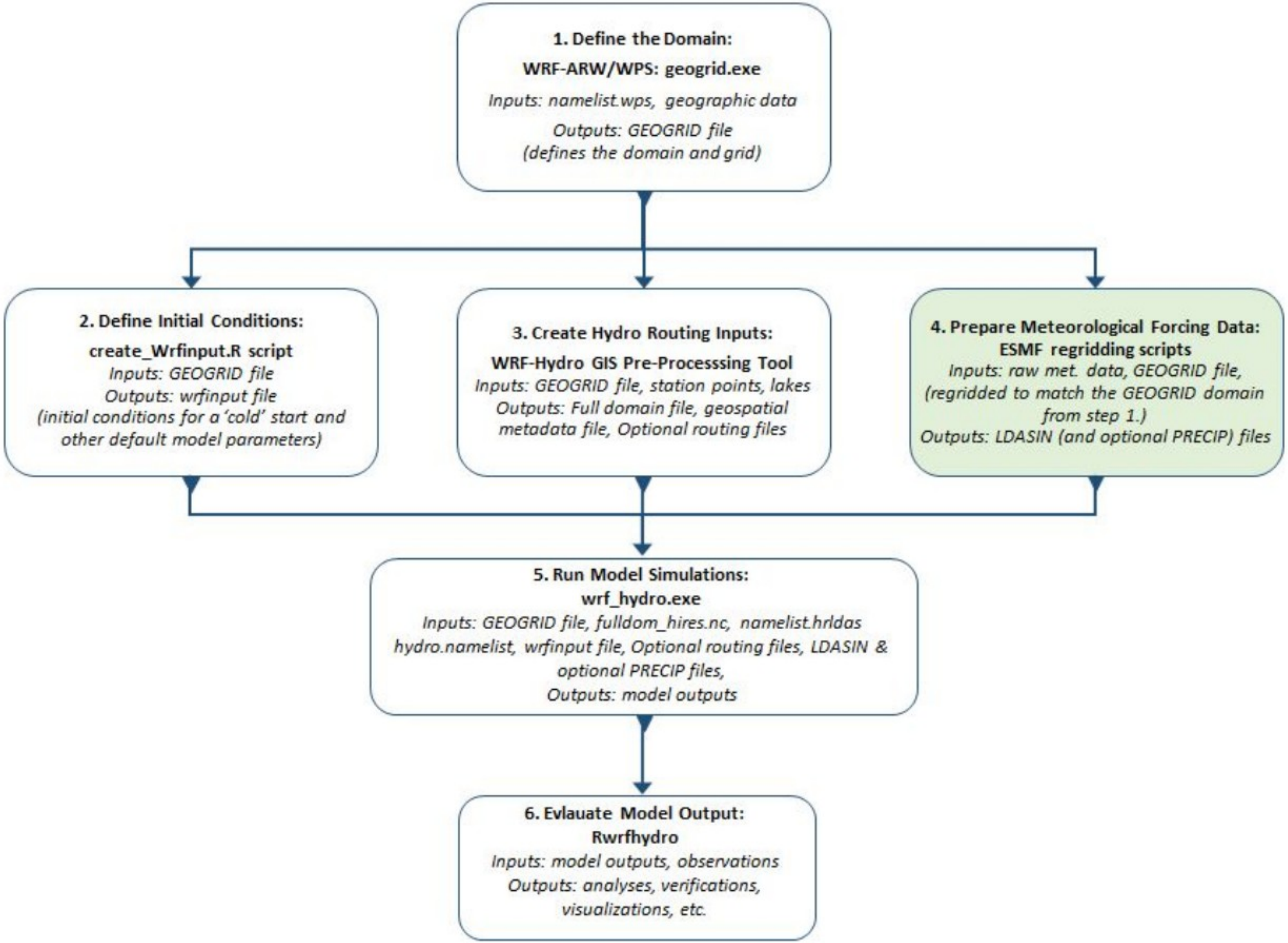
Create Hydro Routing Inputs – four output files

1. Fulldom hires.nc

- CHANNELGRID - The channel grid. Channel pixels = 0, non-channel pixels = -9999.
- FLOWACC - Flow accumulation grid. This grid gives the number of contributing cells for each cell in the domain.
- FLOWDIRECTION – Flow direction grid. This grid gives the direction of flow using the D8 algorithm between each cell and the steepest down-slope neighbor. The result is an integer grid with values ranging from 1 to 128.
- STREAMORDER – Stream order grid, calculated using the Strahler method. No Data cells have values of '-15'.
- TOPOGRAPHY – Elevation grid. The units of elevation are the same as the 'Input Elevation Raster' dataset, which should be in meters (m).
- Landuse – This is the same data as the 'LU INDEX' variable in the GEOGRID file, but resampled using Nearest Neighbor assignment to the resolution of the routing grid.

Create Hydro Routing Inputs – four output files

2. GEOGRID LDASOUT Spatial Metadata.nc - This is a CF-netCDF format file that provides the metadata associated with the GEOGRID variables. By default, no 2 dimensional grids are written to the file. This file is used for appending geospatial metadata to the land surface model output, if necessary.
3. GWBASINS.nc - This is a 2D netCDF of the 'basn msk' grid, but re-gridded to the GEOGRID file resolution. No Data cells are given a value of '-9999'.
4. GWBUCKPARM.nc - Groundwater Bucket Parameter which contains a groundwater parameter table and contains no spatial referencing information


1. Define the Domain:
WRF-ARW/WPS: geogrid.exe
Inputs: namelist.wps, geographic data
Outputs: GEOGRID file
(defines the domain and grid)
2. Define Initial Conditions:
create_Wrfinput.R script
Inputs: GEOGRID file
Outputs: wrfinput file
(initial conditions for a 'cold' start and
other default model parameters)
3. Create Hydro Routing Inputs:
WRF-Hydro GIS Pre-Processsing Tool
Inputs: GEOGRID file, station points, lakes
Outputs: Full domain file, geospatial
metadata file, Optional routing files
4. Prepare Meteorological Forcing Data:
ESMF regridding scripts
Inputs: raw met. data, GEOGRID file,
(regridded to match the GEOGRID domain
from step 1.)
Outputs: LDASIN (and optional PRECIP) files
5. Run Model Simulations:
wrf_hydro.exe
Inputs: GEOGRID file, fulldom_hires.nc, namelist.hrldas
hydro.namelist, wrfinput file, Optional routing files, LDASIN &
optional PRECIP files,
Outputs: model outputs
6. Evlauate Model Output:
Rwrfhydro
Inputs: model outputs, observations
Outputs: analyses, verifications,
visualizations, etc.

Gather and regrid forcing data

- There are several options to obtain forcing data for the WRF-Hydro model
- The commonly used data sources include:
  - NLDAS(North American Land Data Assimilation System),
  - GFS (Global Forecast System)
  - WRF
- WRF-Hydro model accepts hourly or minute time step data.

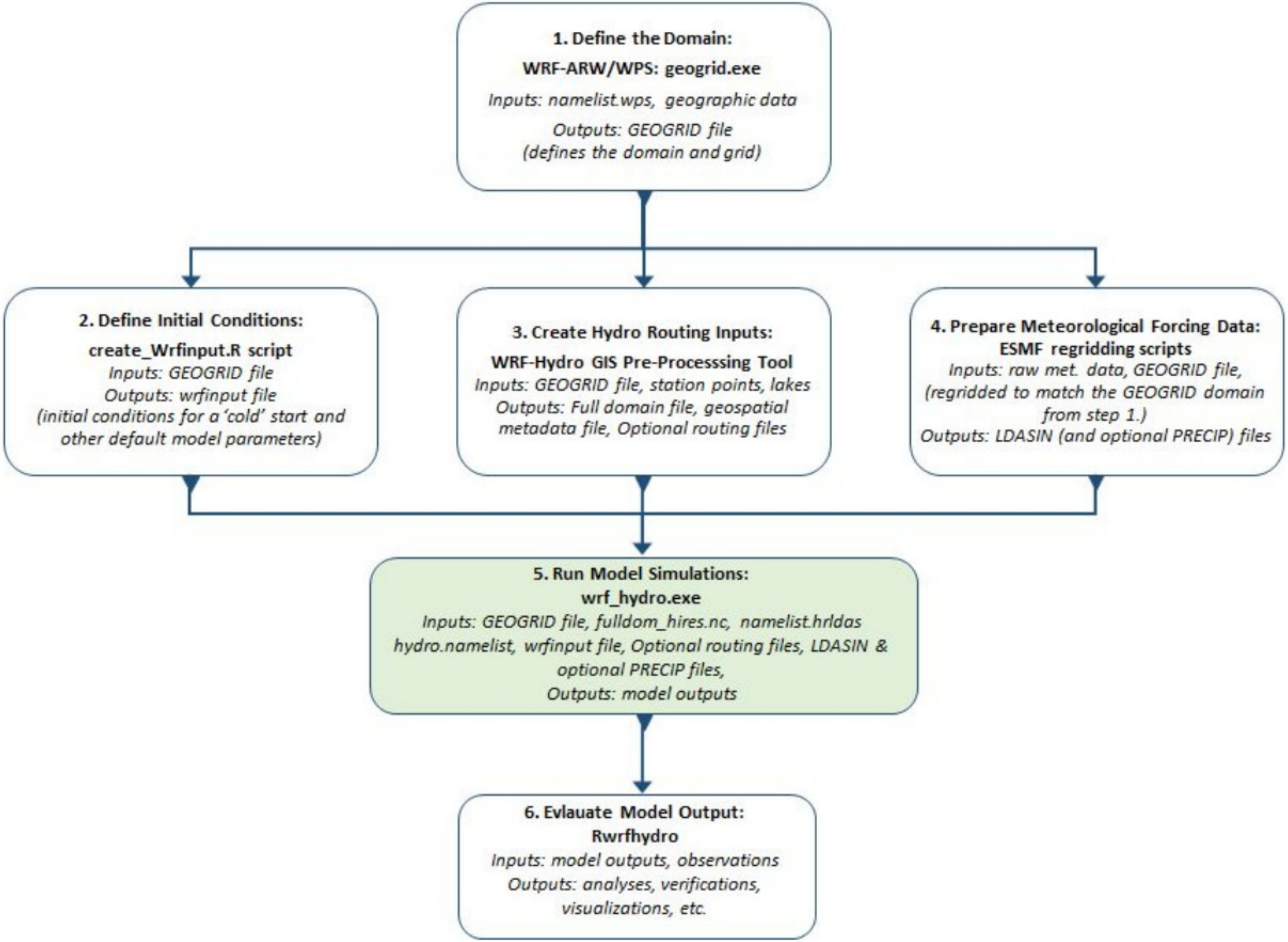
Gather and regrid forcing data

The offline WRF-Hydro model requires the following eight variables as a forcing input data:

1. SWDOWN - Incoming shortwave radiation (W/m^2)
2. LWDOWN - Incoming shortwave radiation (W/m^2)
3. Q2D - Specific humidity at 2m above the surface (kg/kg)
4. T2D - Air temperature at 2m above the surface (K)
5. PSFC - Surface pressure (Pa)
6. U2D - Near surface (2m above the surface) wind in the u-component (m/s)
7. V2D - Near surface (2m above the surface) wind in the v-component (m/s)
8. RAINRATE - Precipitation rate (mm/s or kg/m^2 /s)

Gather and regrid forcing data

- ESMF regridding NCL script is used to regrid the forcing data to match the WRF-Hydro geogrid domain grid
- The script produce a netCDF file with the following file naming convection: YYYYMMDDHH.LDASIN DOMAINx.nc
  - YYYY= Year
  - MM = Month
  - DD = Day
  - HH = Hour
  - LDASIN DOMAIN = Input file naming convention for the land surface model
  - X = Domain number.
- These files should be placed in the FORCING directory of the WRF-Hydro model.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Outputs: Full domain file, geospatial
metadata file, Optional routing files
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from step 1.)
Outputs: LDASIN (and optional PRECIP) files
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Inputs: GEOGRID file, fulldom_hires.nc, namelist.hrldas
hydro.namelist, wrfinput file, Optional routing files, LDASIN &
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Rwrfhydro
Inputs: model outputs, observations
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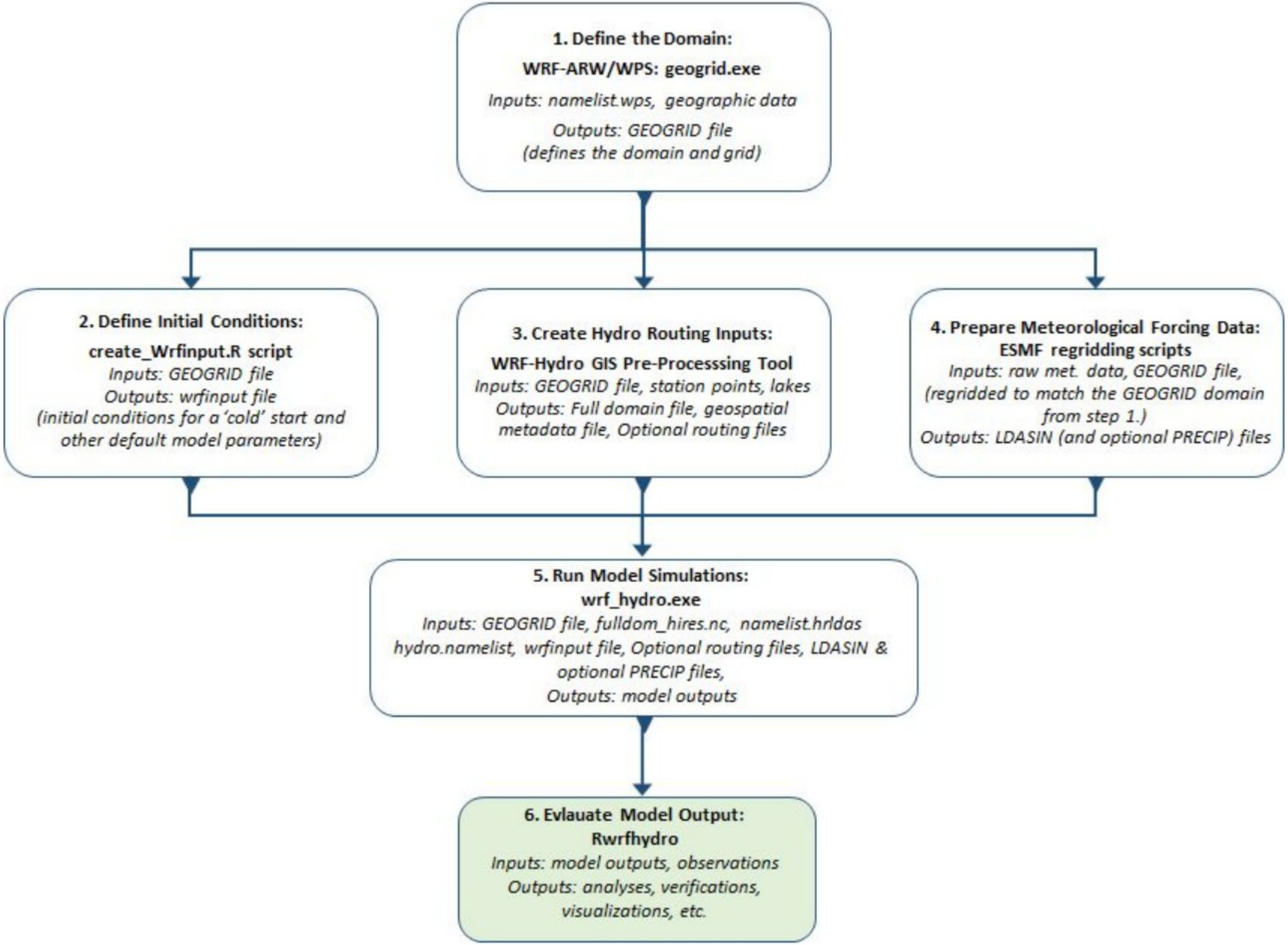
Run Model Simulation

After successful compilation of the code we will have the following files and directories in the Run directory

- DOMAIN and FORCING directory with all the needed input files
- wrf_hydro.exe
- hydro.namelist and namelist.hrldas
- Parameter files such as: SOILPARM.TBL, MPTABLE.TBL, GENPARM.TBL, HYDRO.TBL and CHANPARM.TBL

Run Model Simulation – output files

1. Land surface model output (YYYYMMDDHHMM.LDASOUT DOMAINX)
2. Land surface diagnostic output (YYYYMMDDHHMM.LSMOUT DOMAINX)
3. Land surface diagnostic output (YYYYMMDDHHMM.LSMOUT DOMAINX)
4. Land surface diagnostic output (YYYYMMDDHHMM.LSMOUT DOMAINX)
5. Streamflow on the 2D high resolution routing grid (YYYYMMDDHHMM.CHRTOUT GRIDX)
6. Terrain routing variables on the 2D high resolution routing grid (YYYYMMDDHHMM.RTOUT DOMAINX)
7. Lake output variables (YYYYMMDDHHMM.LAKEOUT DOMAINX)
8. Ground water output variables (YYYYMMDDHHMM.GWOUT DOMAINX)
9. 'frxst pts out.txt' – output at forecast point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6. Evlauate Model Output:
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Evaluate model outputs

- ’rwrfhydro’ is R tool for the WRF Hydro Model, detail can be found: https://ral.ucar.edu/sites/default/files/public/projects/wrf_hydro/v3_0/rwrfhydro/rwrfhydro-manual.pdf
- Wrfhydropy provides an end-to-end python interface to support reproducible research and construction of workflows involving the WRF-Hydro model.
- We can also build our Python script

Thank you!

Questions?