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The CaMa-Flood model description

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Concepts of the CaMa-Flood development

CaMa-Flood is designed to achieve the following 3 requirement:

[1] A global-scale model of all rivers, wetlands and lakes on the Earth.

- Simulating floods in all river basins, including ungauged/data-sparse regions.
- Targeting coupling with global climate models or earth system models.
  - ⇒ CaMa-Flood includes global topography data for global simulations.
  - ⇒ Assumed input to CaMa-Flood is runoff from global land models.

[2] Very high computational efficiency.

- Simulation must be fast enough for use in real-time flood forecast.
- Computational cost must be light enough as a sub-model of a complex GCM/ESM.
  - ⇒ 1-D river routine with sub-grid flood scheme. (2-D hydrodynamics is very heavy)

[3] Realistic surface water dynamics.

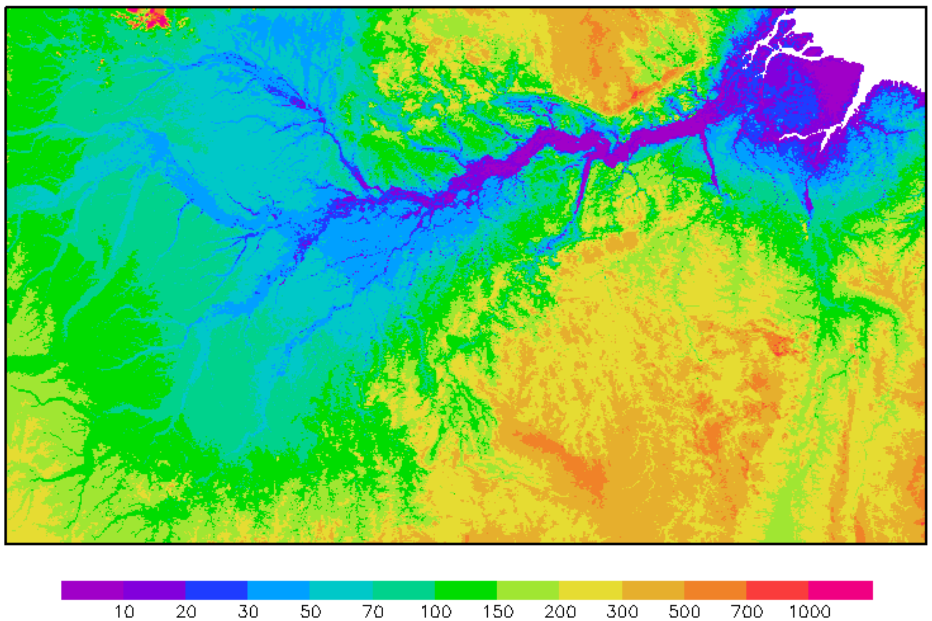
- Water moves from high place to low place. This is the basic of hydrodynamics.
- Simulation of water level & inundated area, in addition to river discharge.
  - ⇒ Hydrodynamic flow equation. (Kinematic wave is not applicable in flat regions)

CaMa-Flood is the only hydrodynamic model which satisfies the 3 requirement.
However, the model became complex to achieve fast and realistic global simulations.
If any of above requirements is not needed, a simpler model may be suitable for your research.

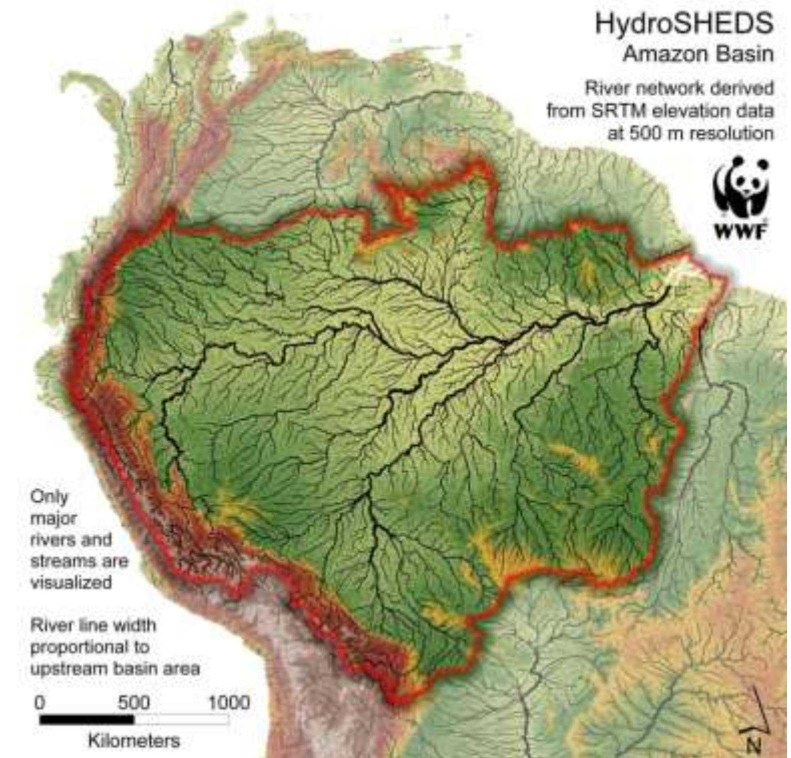
CaMa-Flood (v3.6) development: Model Assumptions

[1] Global topography & hydrography data

- Ground elevation is given by SRTM3 DEM (+SRTM30 above 60N).
- River networks are given by HydroSHEDS flow direction map (+GDBD above 60N).



↑90 m elevation [SRTM3]



Elevation is adjusted to satisfy the condition that downstream is always not higher than upstream along the HydroSHEDS river networks. [Yamazaki et al., 2012]

90 m Flow Direction [HydroSHEDS] →

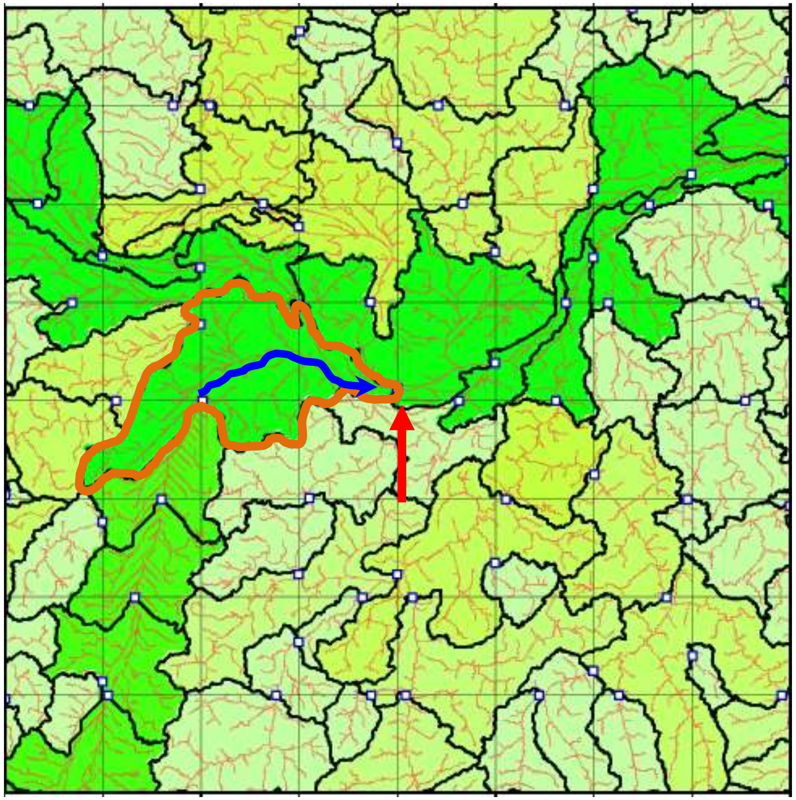
Each pixel is assumed to have one flow direction toward a neighboring pixel to represent river networks.

8:NW	1:N	2:NE
7:W	–	3:E
6:SW	5:S	4:SE

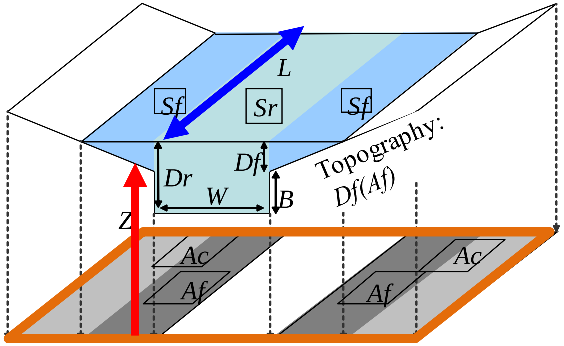
CaMa-Flood (v3.6) development: Model Assumptions

[2] Unit-catchment & sub-grid topography

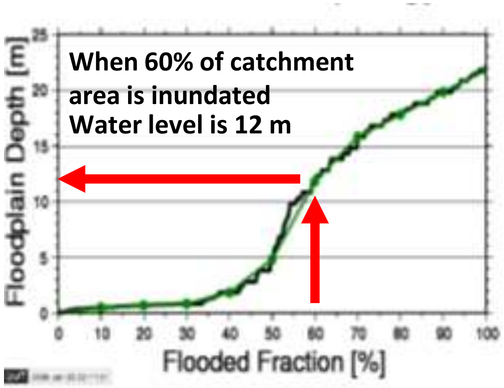
- River basins are divided to unit-catchments in order to reduce computational cost.
- *One unit-catchment is assigned to each lon-lat grid box for easy data handling.
- Water stage (level, area) is diagnosed from water storage using sub-grid topography.
- Uniform water level in a unit-catchment. River and floodplain water levels are same.



Unit-catchments (the Amazon River)



Sub-grid topography



Floodplain Elevation Profile

Sub-grid topography is represented by 6 parameters.
[1] Catchment area, [2] channel length [3-4] channel width + depth,
[5] Floodplain elevation profile, [6] Bank-top elevation

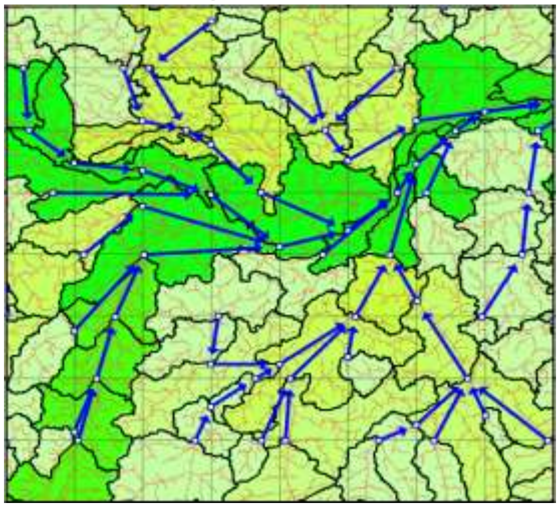
These topography parameters (except channel width + depth) are derived from the high-resolution DEM.

Floodplain profile is given by a non-parametric increasing function of resampled floodplain heights above river channels.
- No levee, no depressions in floodplains

CaMa-Flood (v3.6) development: Model Assumptions

[3] River network map & discharge calculation.

- Water exchange between unit-catchments only occurs along the river network map.
- Only one downstream is assigned to each unit-catchment by the river network map.
- Discharge to downstream is calculated separately for channel and floodplain.



Downstream of each unit-catchment is indicated by the river network map

q: discharge h: depth z: bed elevation
N: roughness R: hydraulic radius i_{sfc}: water slope

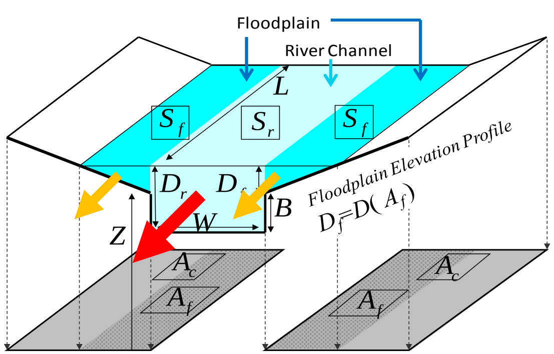
Neglect advection

$$\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + \frac{\partial Q}{\partial t} + gA\frac{\partial h}{\partial x} + gA\frac{\partial z}{\partial x} + \frac{gn^2|Q|Q}{R^{4/3}A} = 0$$

FTCS Differentiation

$$q_{i+1/2}^{n+1/2} = \frac{q_{i+1/2}^{n-1/2} + gh_{flow} i_s \Delta t}{(1 + gh_{flow} n^2 \Delta t |q_{i+1/2}^{n-1/2}| h_{flow}^{-10/3})}$$

The shallow water momentum equation is approximated to a local inertial form.
[Bates et al., 2010; Yamazaki, Tanaka & Bates, 2015]



River and floodplain discharge

$$S_i^{t+\Delta t} = S_i^t + \sum_k^{Upstream} Q_k^t \Delta t - Q_i^t \Delta t + Ac_i R_i^t \Delta t$$

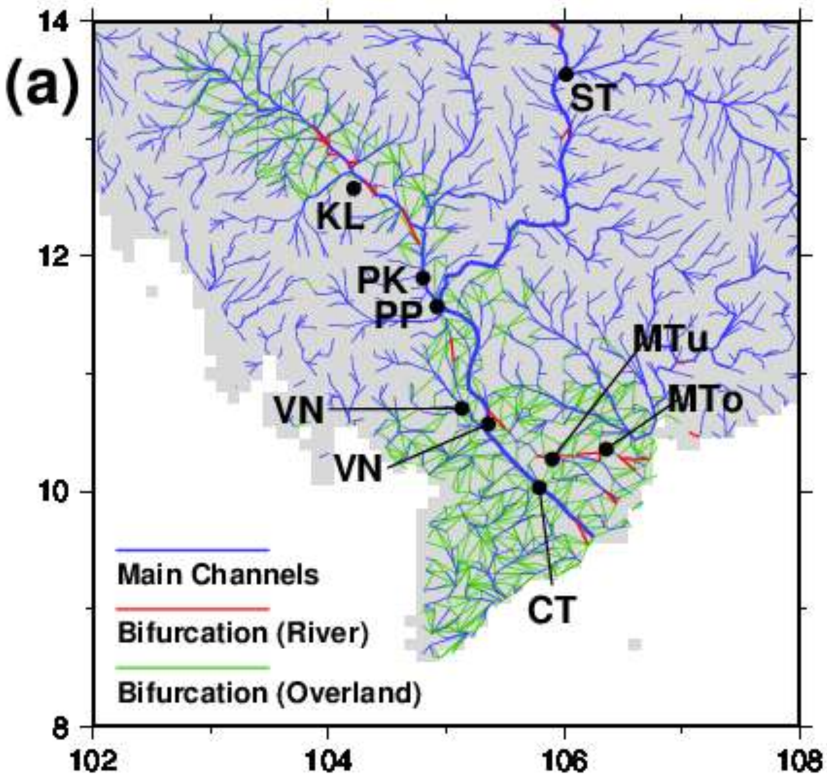
S: storage Q: discharge (channel + floodplain)
Ac: catchment area R: Input runoff

Water storage in next time step is updated using mass-balance equation.

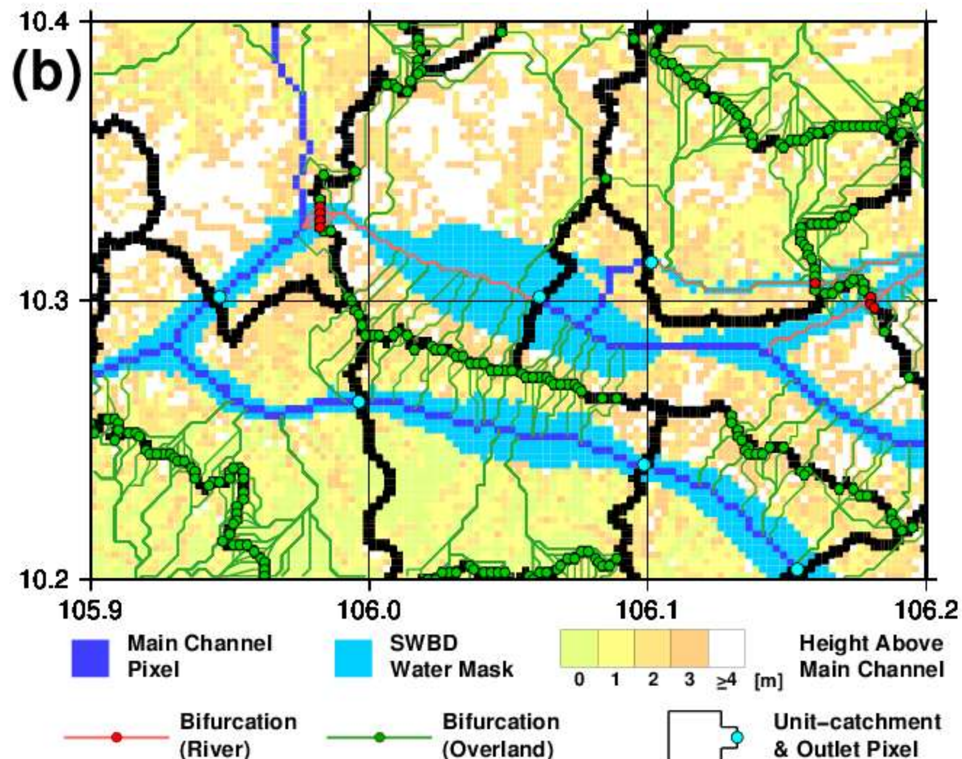
CaMa-Flood (v3.6) development: Model Assumptions

[4] Multi-downstream connectivity scheme

- Additional downstream directions can be added to the river network map to represent bifurcation channels and 2-D floodplain flow. [Yamazaki et al., GRL 2014]



River Network with Multi-downstream



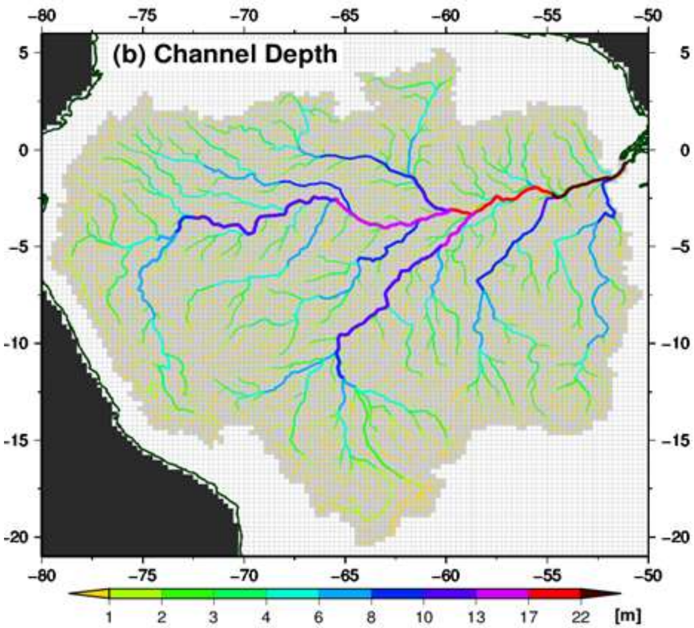
Delineation of bifurcation pathways

High-resolution DEM is analyzed to find potential flow pathways which connect two unit-catchments without upstream-downstream relationship on the original river network map.
Flow pathways are divided to channel bifurcation and overland connections using the SWBD water mask.
Discharge calculation for these sub-channels is same as main channels (i.e. local inertial equation).

CaMa-Flood (v3.6) development: Model Assumptions

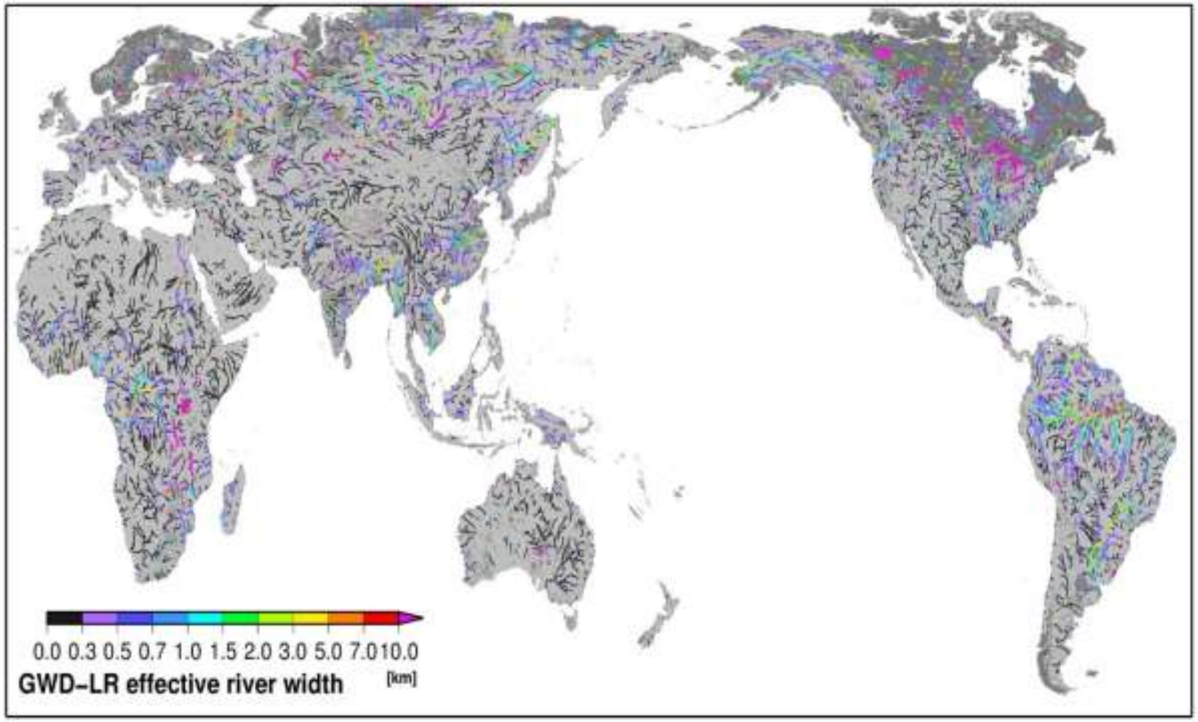
[5] Channel cross-section parameters

- Channel depth + width are given by a power-low function of mean flow.
- Channel width can be given from a satellite water body map (optional).



$$B = \max\left[0.14 \times R_{up}^{0.40}, 1.00\right]$$

Channel depth estimated by power-low



Global Width Database for Large Rivers

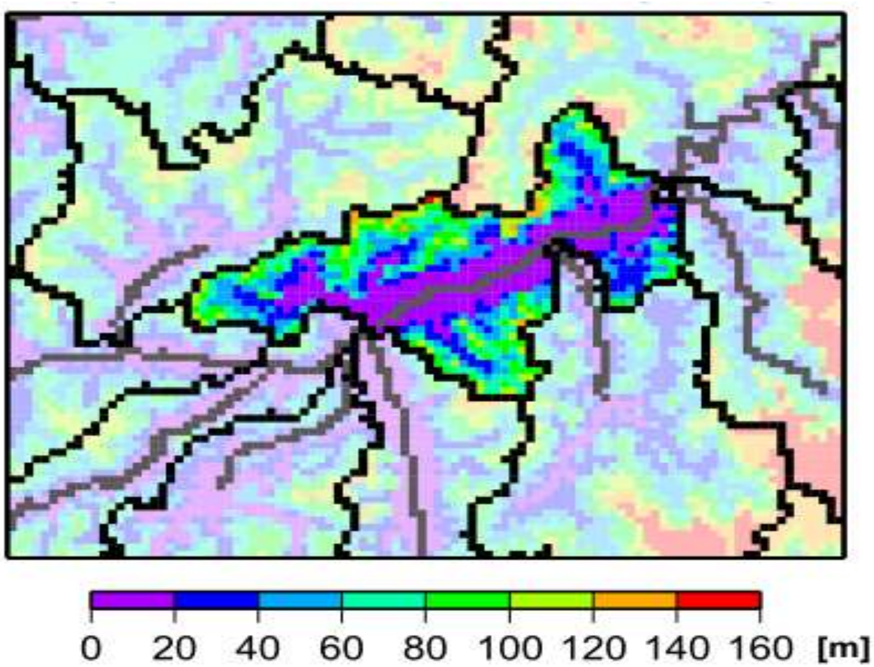
There is no global measurement of river channel depth, thus is estimated by a power-low equation.

Channel width is calculated based on the SWBD water map [Yamazaki et al., 2014].

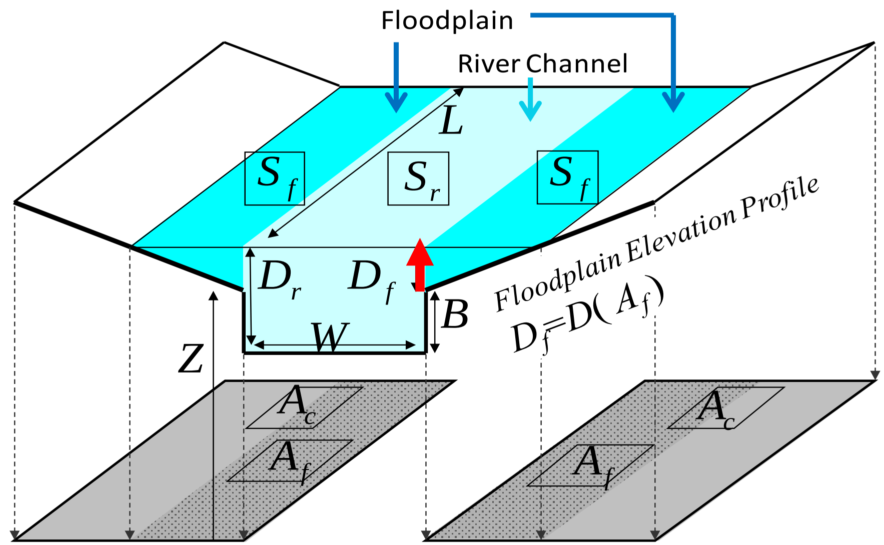
CaMa-Flood (v3.6) development: Model Assumptions

[6] Diagnostic downscaling of flood depth

- Flood depth can be diagnostically downscaled to the high-resolution DEM by post processing after the hydrodynamic simulation.



DEM's height above river channel (FLDDIF)



Water depth above river channel (FLDDPH)

"High-resolution DEM's height above river channel" and "simulated water depth above river channel" are compared to calculate water depth of each high-resolution pixel.

CaMa-Flood (v3.6) development: Model Assumptions

[7] Other assumptions (or limitations)

- Evaporation from water surface and infiltration to soil are not considered.

- Lake/water fall schemes are not yet developed.
  These are solved by same equations as rivers.

- No river bank/levee is represented.
  This is partly due to depression is not assumed in floodplains.

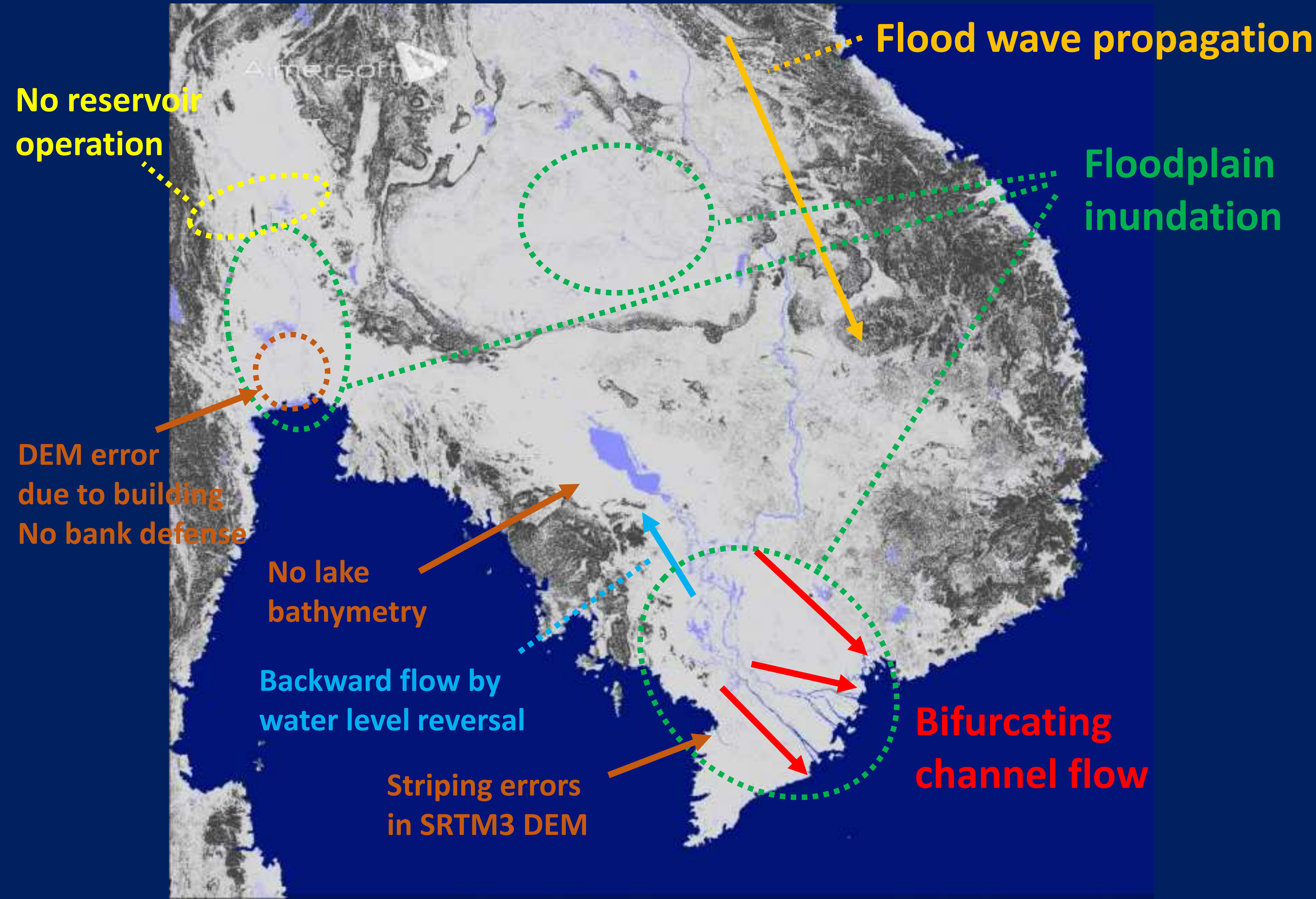
- No human activities (e.g. dam regulation, irrigation, canals, weirs).

- Water "disappears" at river mouth. No water balance calculation at inland seas.

- Topography does not change in time. No sedimentation or geomorphology process.

- Runoff is given from external land models. No surface-ground waters interaction.

What can('t) CaMa-Flood simulate?



Summary: CaMa-Flood model development

[1] Concepts: Fast but realistic global hydrodynamic simulation

- Global 2D hydrodynamic models (e.g. LISFLOOD-FP) is best for accurate simulations because of explicit flow calculation on high-res pixels without sub-grid assumptions.
- But 2D hydrodynamic models are computationally heavy. We need faster simulations.

- CaMa-Flood overcomes this difficulty by adopting following assumptions:
  <1> Sub-grid flood inundation scheme
  <2> 1D river network + multi-downstream connectivity
  <3> Diagnostic downscaling by post-processing simulated water level
- The dynamics of CaMa-Flood is now mostly similar to 2D hydrodynamic models.

[2] Limitations (both in CaMa-Flood and 2D hydrodynamic models)

- Global topography dataset (DEM, Hydrography) still has large errors.
- Channel bathymetry (width + depth) are not well represented.
- Large uncertainty in input runoff forcing.
- Only river & floodplain flow are solved. No lake, human activity, sediment, etc.