HESSS2

24th June, 2010 @ IIS U-Tokyo

G5.3

Physically-based representation of floodplain inundation dynamics in a global river routing model

Dai YAMAZAKI[1], Shinjiro KANAE[2], Taikan OKI[1]

[1]The University of Tokyo

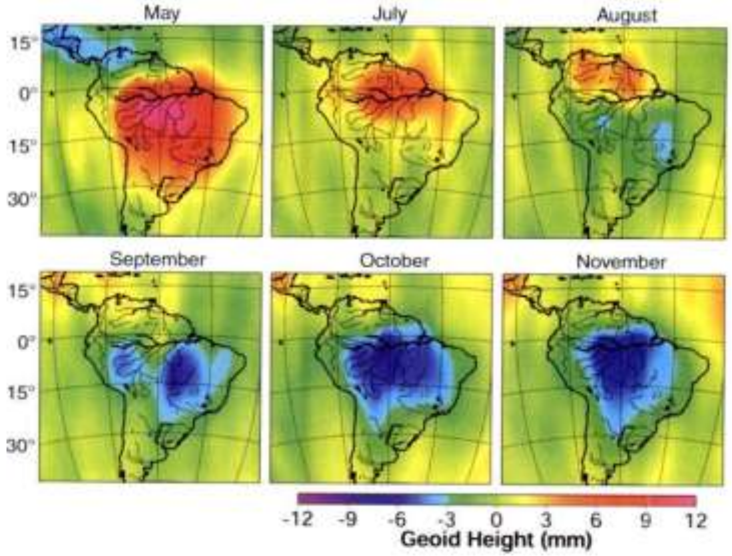
[2]Tokyo Institute of Technology

Yamazaki et al. (2010), A description of floodplain inundation dynamics based on physical evidence in a global river routing model, *J. Geophys. res*, **13**, in prep.

1. Introduction

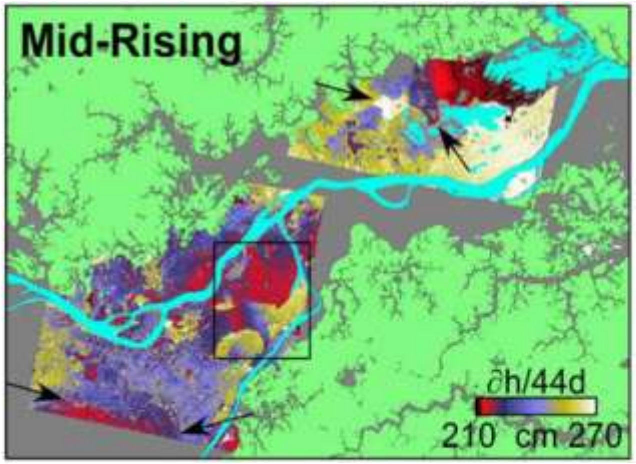
Rivers play an important role as a component of the climate system and as a freshwater supplying system for both human beings and ecosystems.

[Observations] In addition to *in-situ* observation of discharge, advancement of satellite remote sensing reveals various information on surface waters.



GRACE: Water Storage [Tapley, 2004]

InSAR: Surface Water Elevation [Alsdorf, 2007]

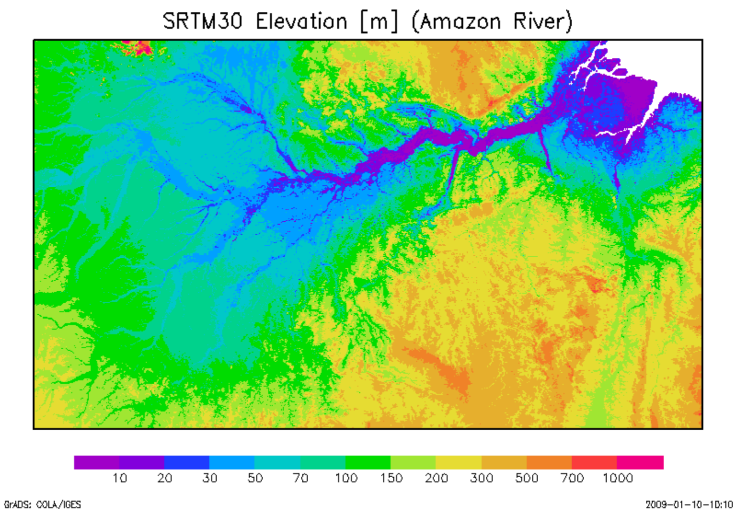


[Modeling] On the other hand, global river routing models have mainly focused on simulation of river discharge. Prediction of water surface elevation or inundated are is not realistically incorporated in global models.

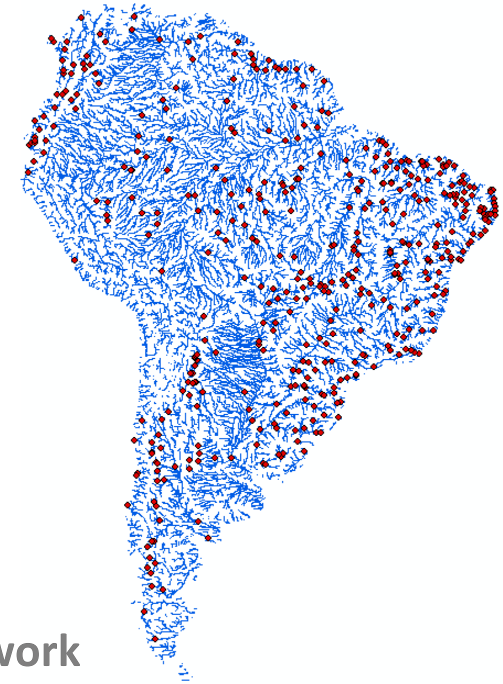
=> *Dynamics of surface waters are regulated by smaller topography than the resolutions of global models*.

1. Introduction

[Dataset] Global hydro-geographical dataset at fine-resolution (<1 km) is already provided based on satellite observations.

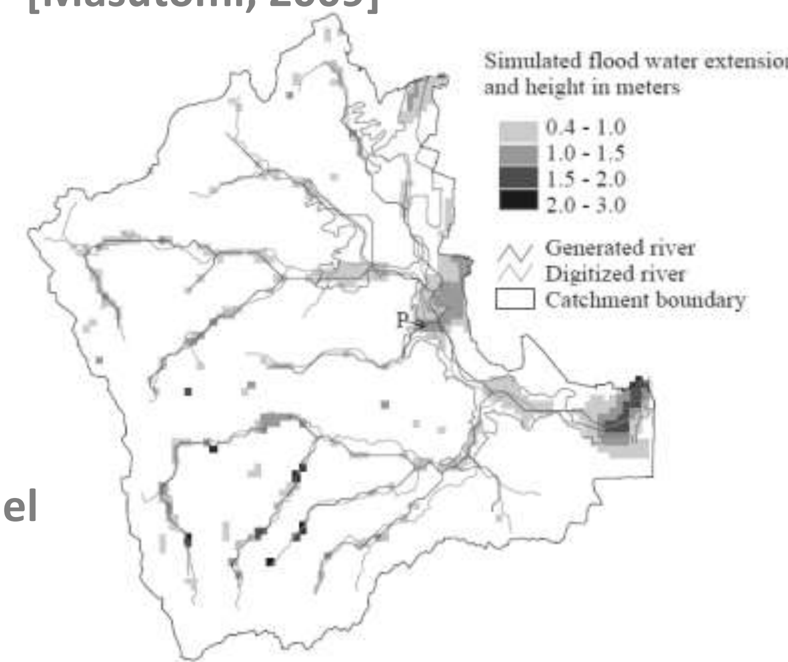


SRTM:
90m elevation
[NASA]



GDBD:
1km river network
[Masutomi, 2009]

[Basin-scale] Models for a small basin represent detailed topography on which 2-D inundation dynamics are simulated.



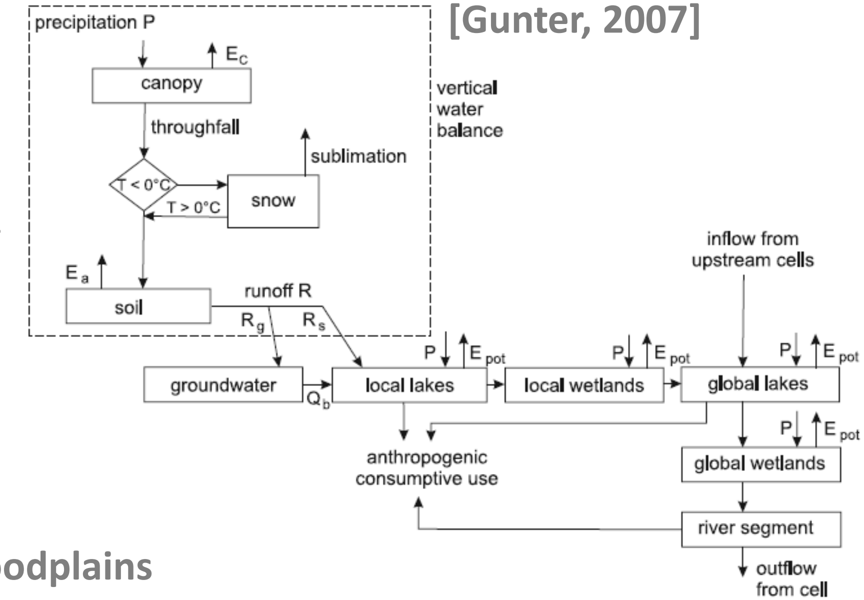
2-D Inundation model
[Dutta, 2000]

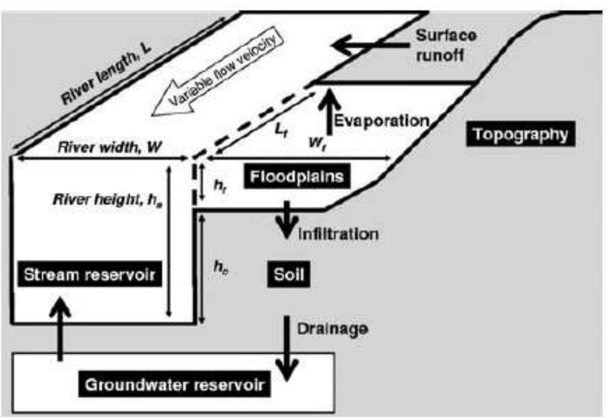
1. Introduction

[Dataset] Global hydro-geographical dataset at fine-resolution (<1 km) is already provided based on satellite observations.

[Global] Global-scale models represents water storage in lakes, wetlands and floodplains ***conceptually or statistically***.

WaterGAP: "Conceptual" Water Flow [Gunter, 2007]





"Statistical" Floodplains [Decharme, 2008; Coe, 2007]

We propose a new global river routing model, which incorporate ***physically-based representation*** of floodplain inundation dynamics:
Catchment-based Macro-scale Floodplain model (CaMa-Flood)

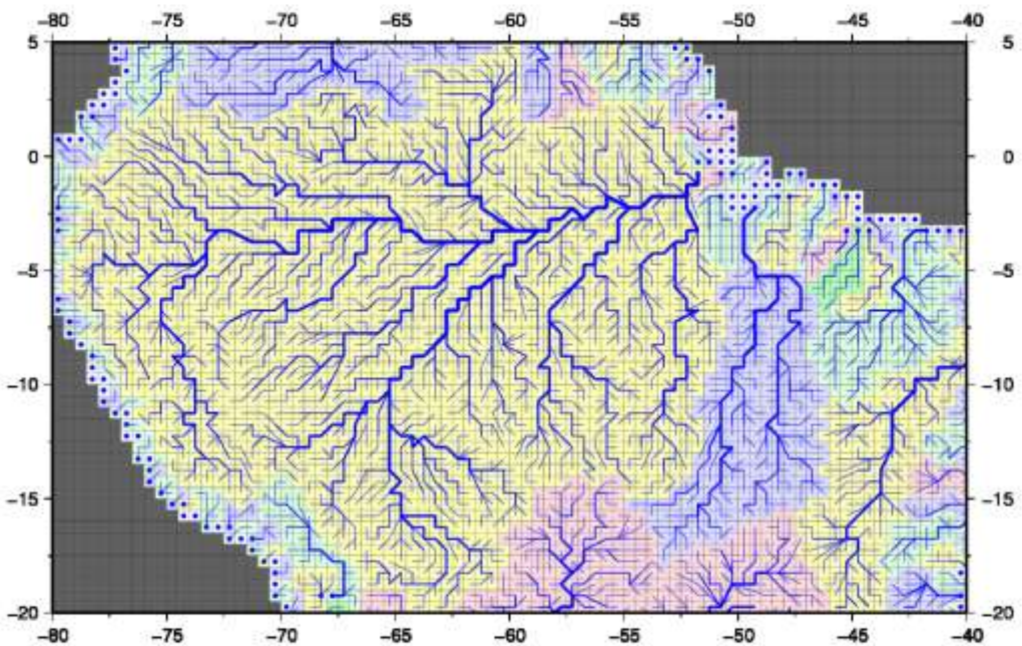
2. Model Framework: CaMa-Flood

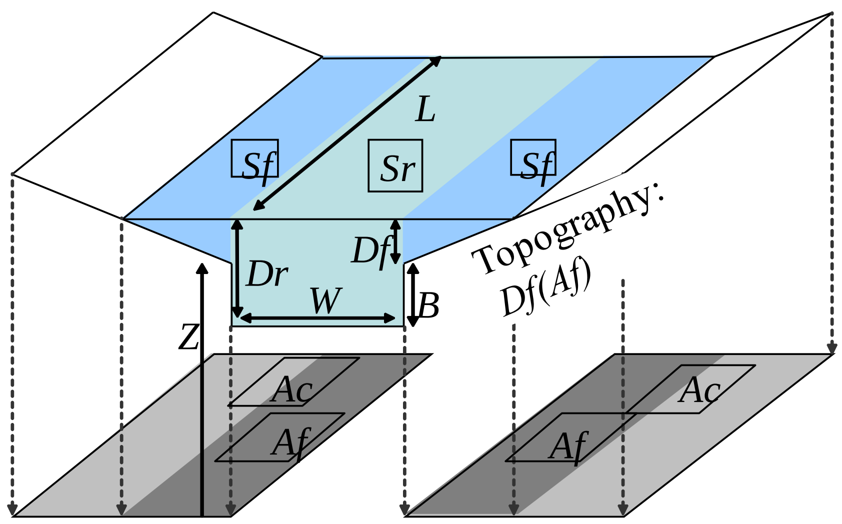
Catchment-based Macro-scale Floodplain model

> A distributed river routing model

> Input: LSM runoff, Boundary Condition: Water level at river mouth
Output : water storage (Prognostic); discharge, water level, Inundated area (Diagnosed)

> River and floodplain storage with sub-grid topographic parameters.





2. Model Framework: CaMa-Flood

Catchment-based Macro-scale Floodplain model

> A distributed river routing model

> Input: LSM runoff, Boundary Condition: Water level at river mouth

Output : water storage (prognostic); discharge, water level, Inundated area (Diagnosed)

> River and floodplain storage, with sub-grid topographic parameters.

> Diffusive wave equation, roughness = Manning, along river network.

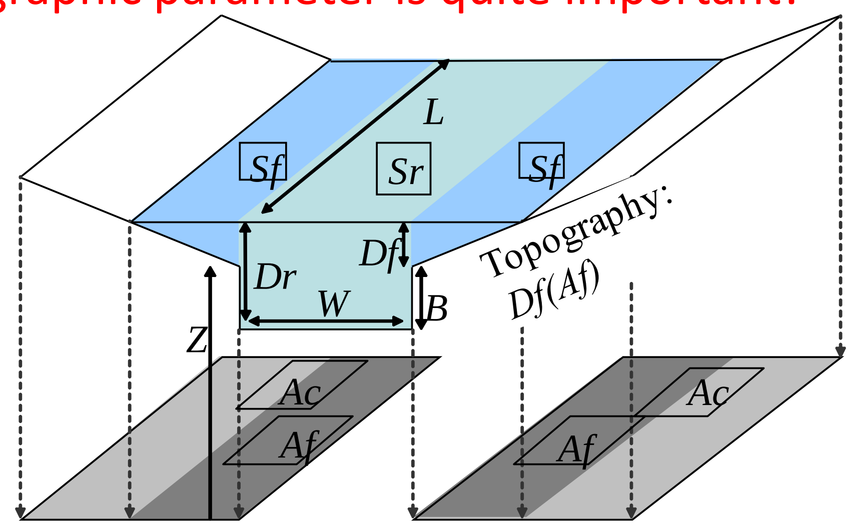
Realistic description of sub-grid topographic parameter is quite important!

Diffusive Wave Eq.

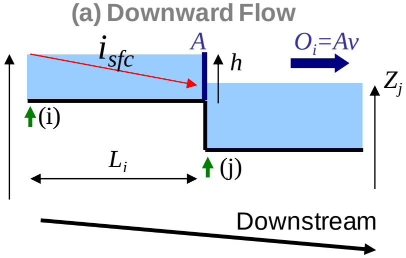
$$\frac{\partial D}{\partial x} + \frac{\partial Z}{\partial x} + i_f = 0$$

Manning Low

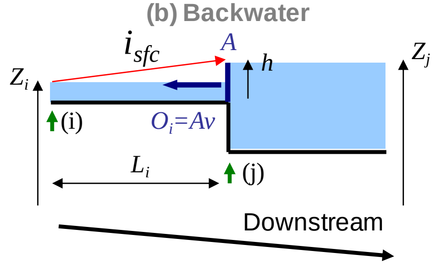
$$i_f = n^2 v^2 D^{-\frac{4}{3}}$$



(a) Downward Flow

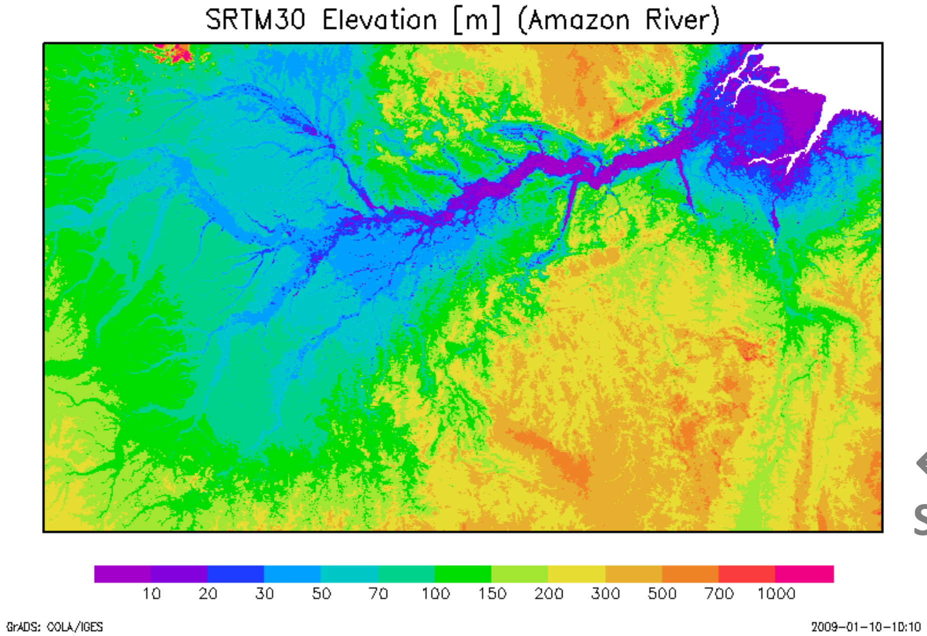


(b) Backwater

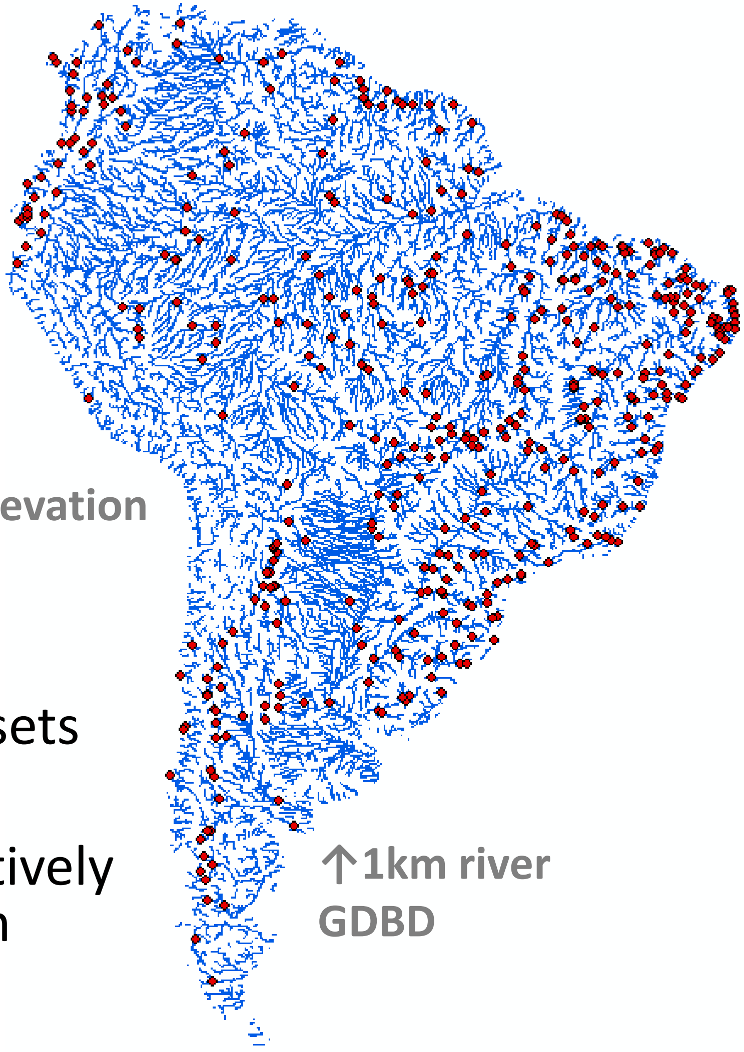


3. Sub-grid topographic parameters: FLOW

Flexible Location of Waterways method



←1km elevation SRTM30



↑1km river GDBD

Fine-resolution (1 km) hydro-topographical datasets

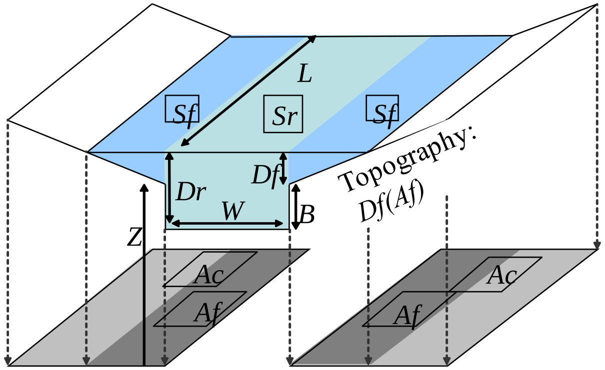
GDBD Flow Direction Map & SRTM30 DEM

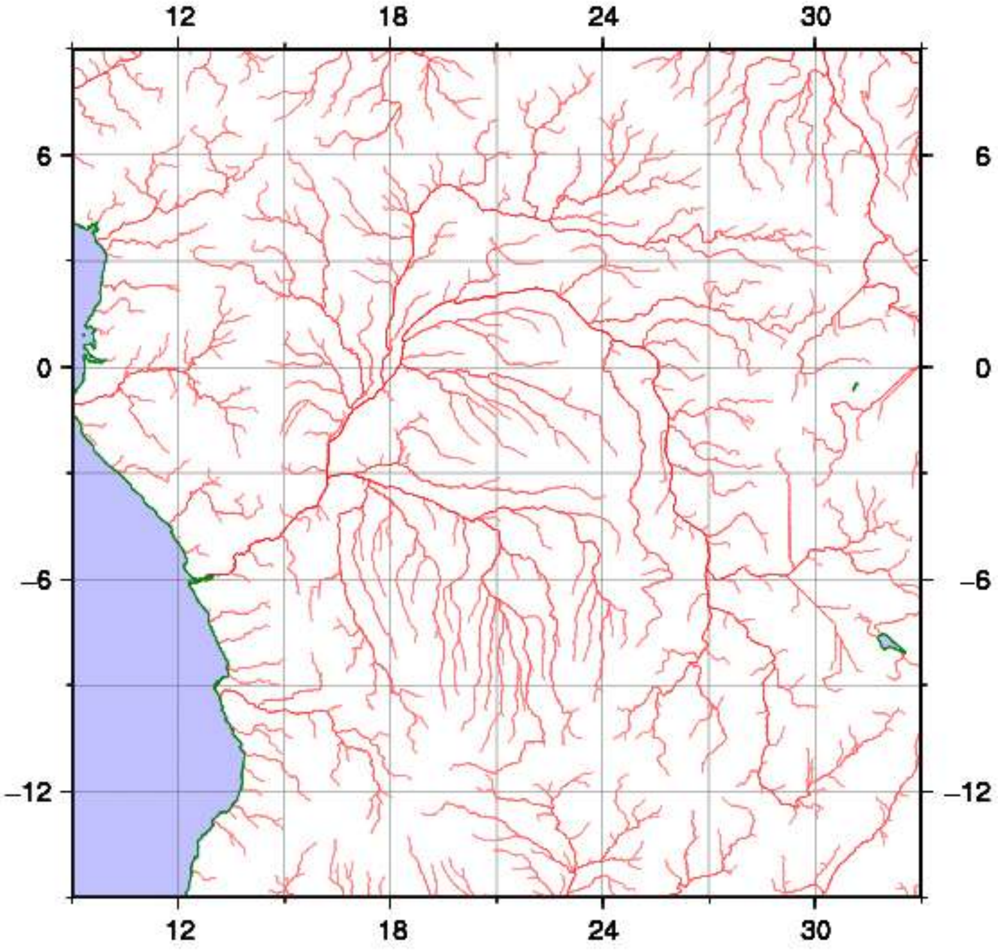
FLOW method [Yamazaki, 2009] is used to objectively decide sub-grid topographic parameters from those hydro-topographical datasets.

Yamazaki et al. (2009), Deriving a global river network map and its sub-grid topographic characteristics from a fine-resolution flow direction map, *HESS*, **13**, 2241–2251.

3. Sub-grid topographic parameters: FLOW

Flexible Location of Waterways method

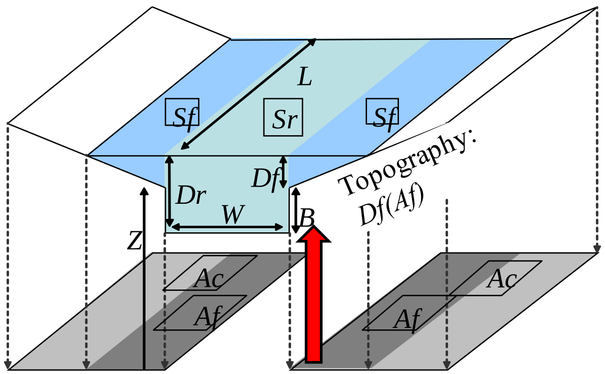


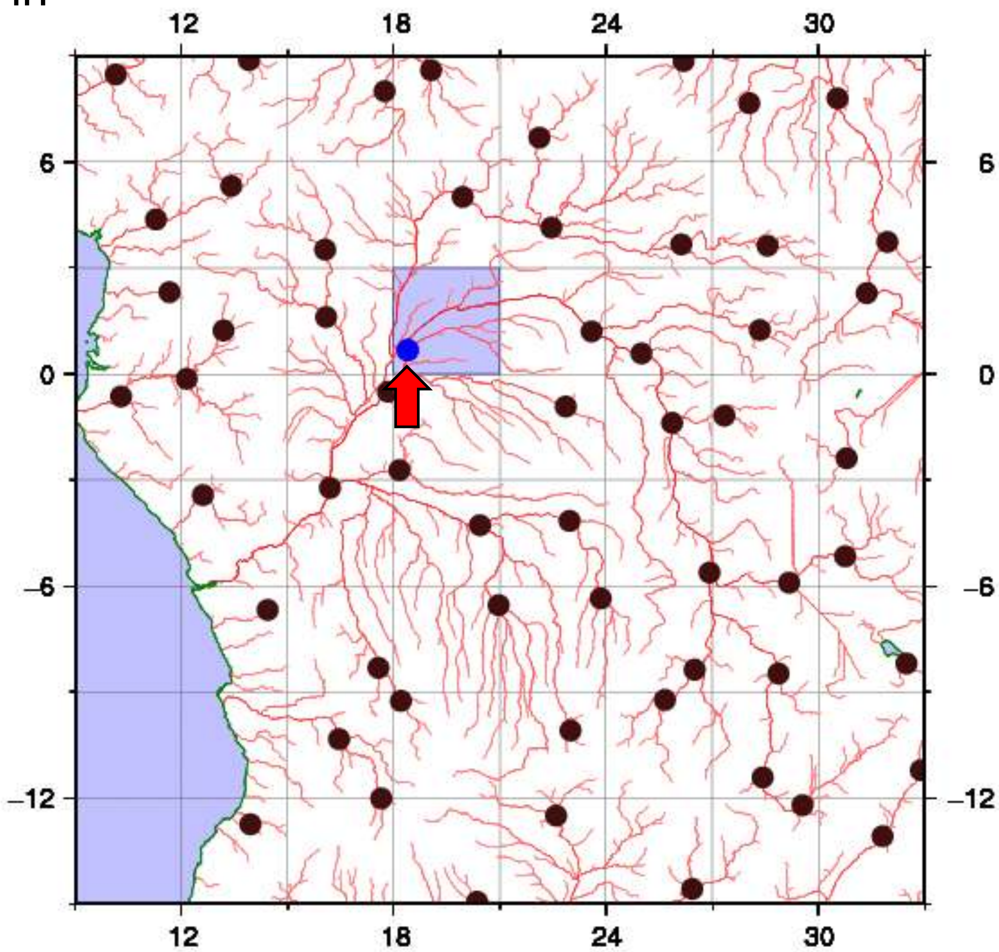


3. Sub-grid topographic parameters: FLOW

Flexible Location of Waterways method

1) Decide "outlet pixel" from GBDB pixels in each CaMa-Flood cell. *>Channel altitude*



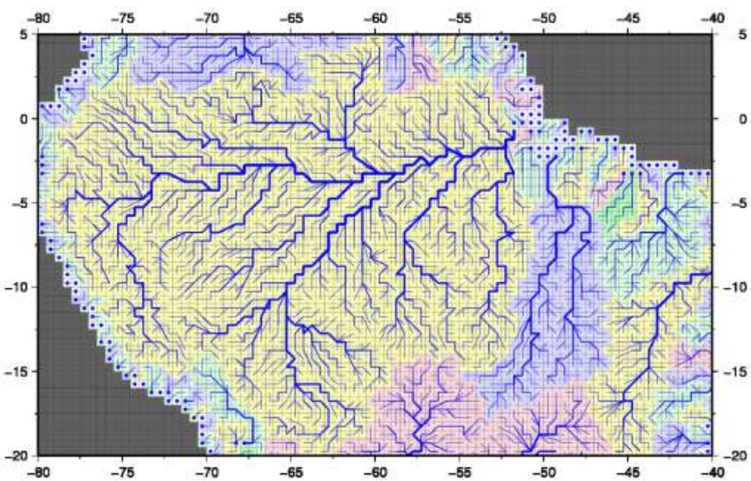


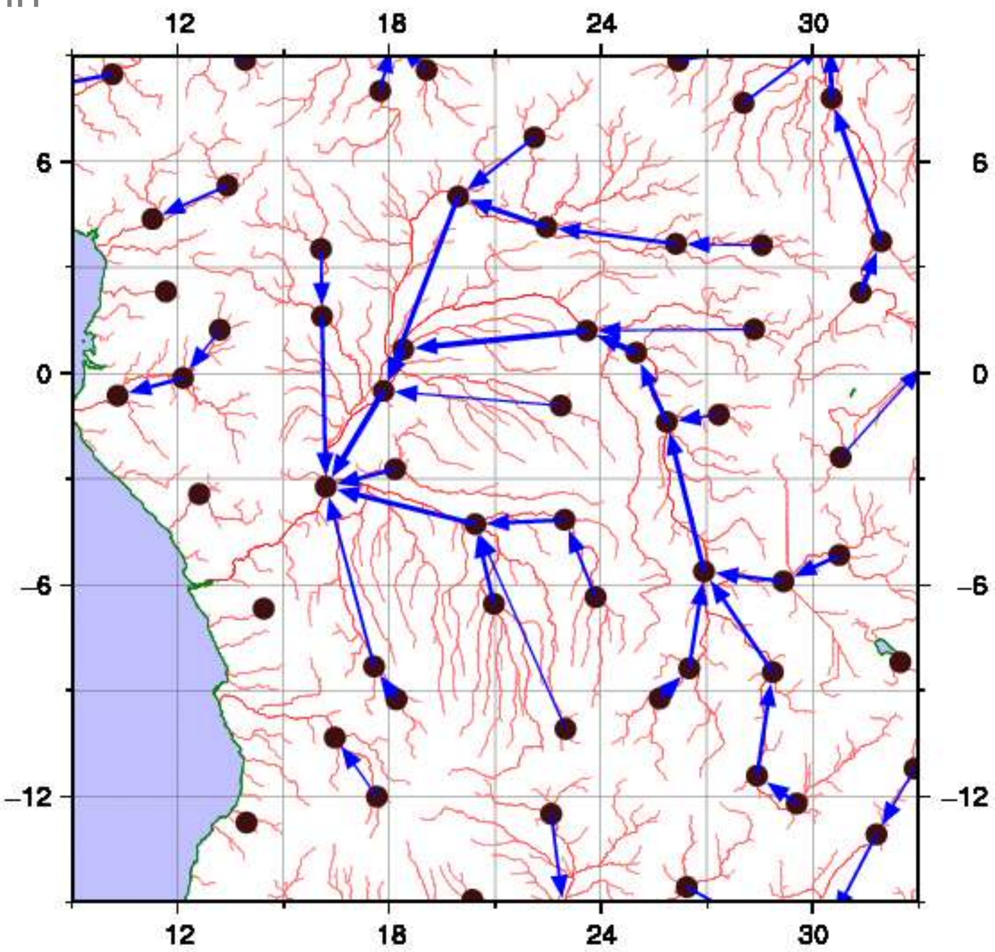
3. Sub-grid topographic parameters: FLOW

Flexible Location of Waterways method

1) Decide "outlet pixel" from GBDB pixels in each CaMa-Flood cell. >Channel altitude

2) Decide downstream cell by tracking GDBD path from outlet pixel >River map

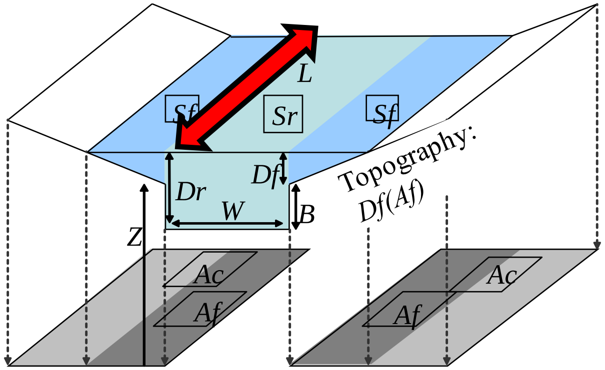


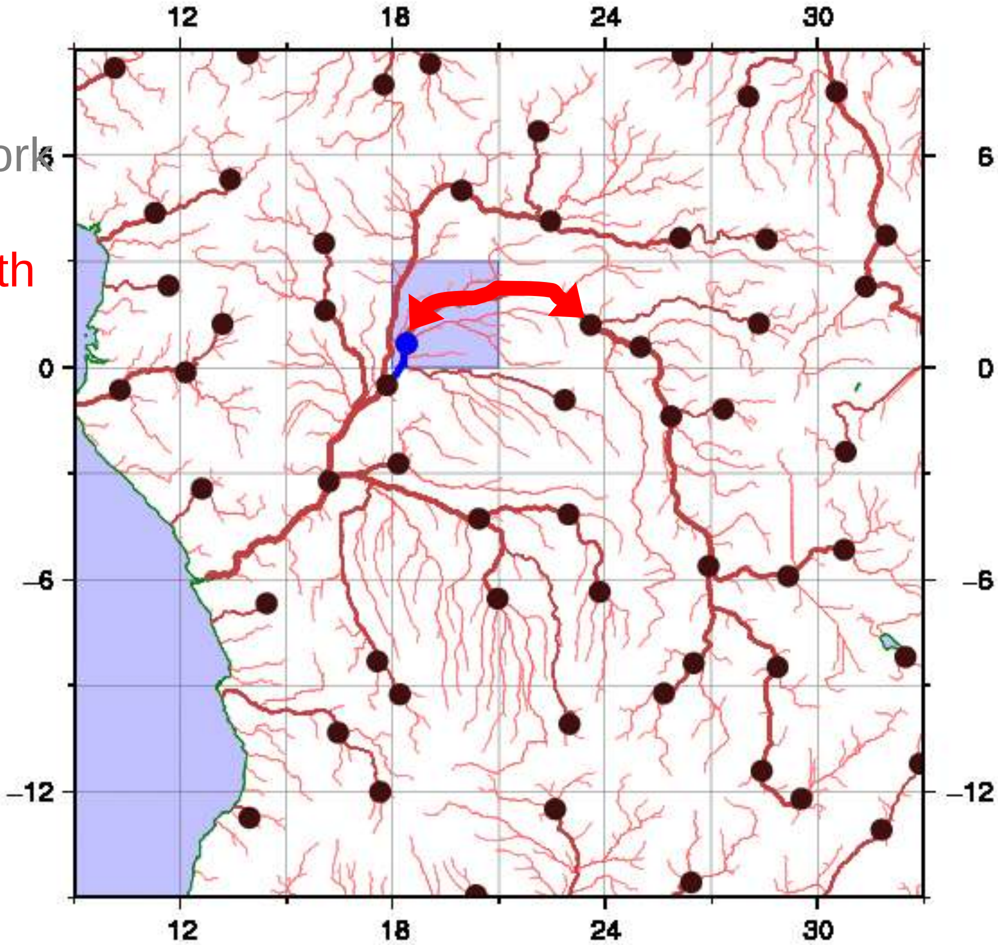


3. Sub-grid topographic parameters: FLOW

Flexible Location of Waterways method

1) Decide "outlet pixel" from GBDB pixels in each CaMa-Flood cell. >Channel altitude
2) Decide downstream cell by tracking GDBD path from outlet pixel >River network
3) Calculate channel length considering meandering in 1-km scale >Channel length





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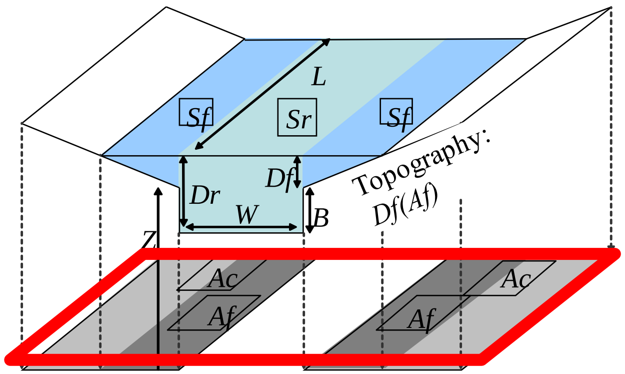
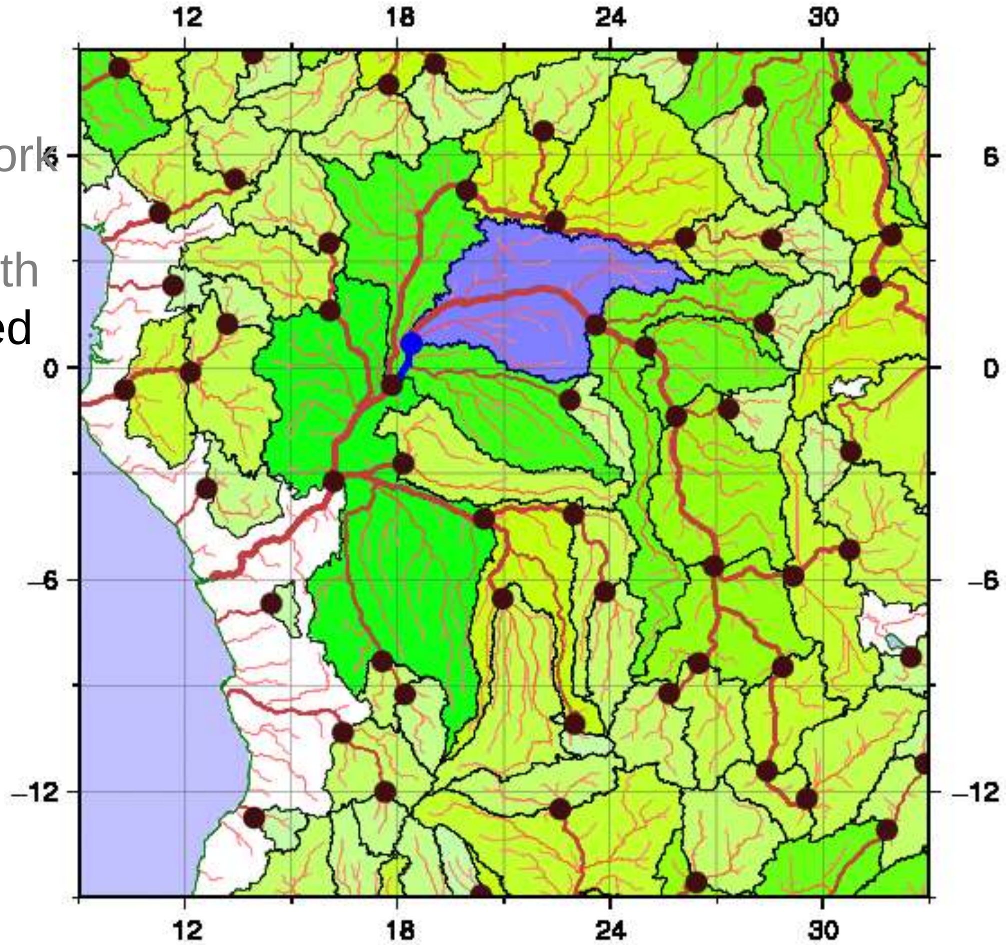
4) Calculate group of GDBD pixels drained to the river channel >Catchment Area





3. Sub-grid topographic parameters: FLOW

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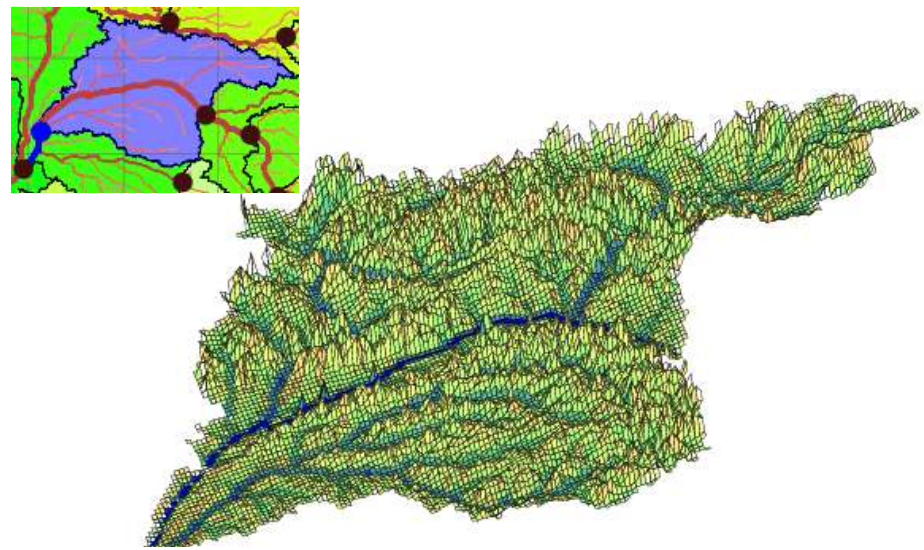
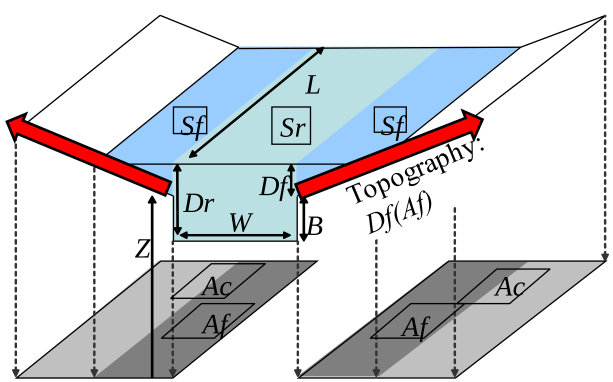
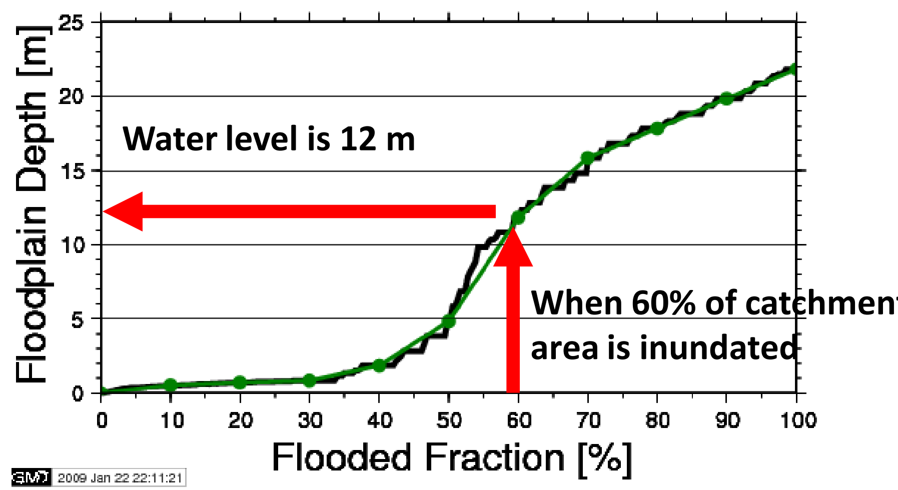
3) Calculate channel length considering meandering in 1-km scale >Channel length
4) Calculate group of GDBD pixels drained to the river channel >Catchment Area
5) CDF of elevation within a catchment is created. >Floodplain Inundation Profile
=> Water level and inundated area is diagnosed from floodplain water storage.





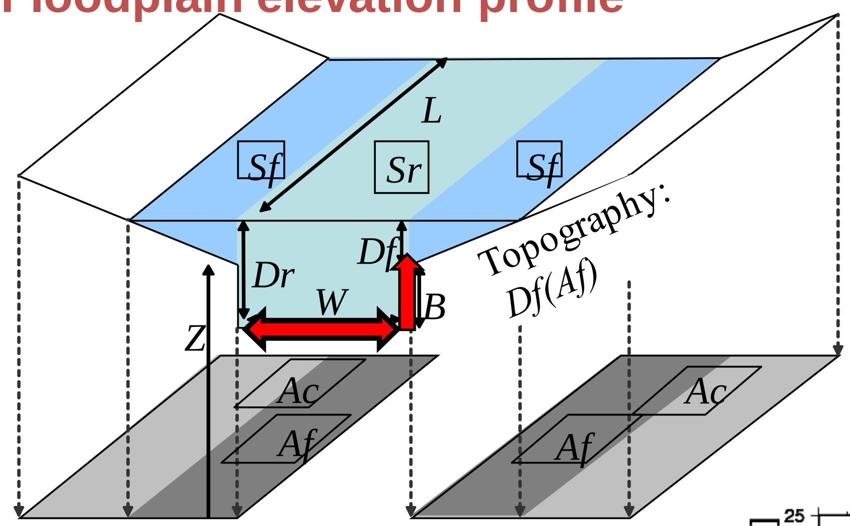


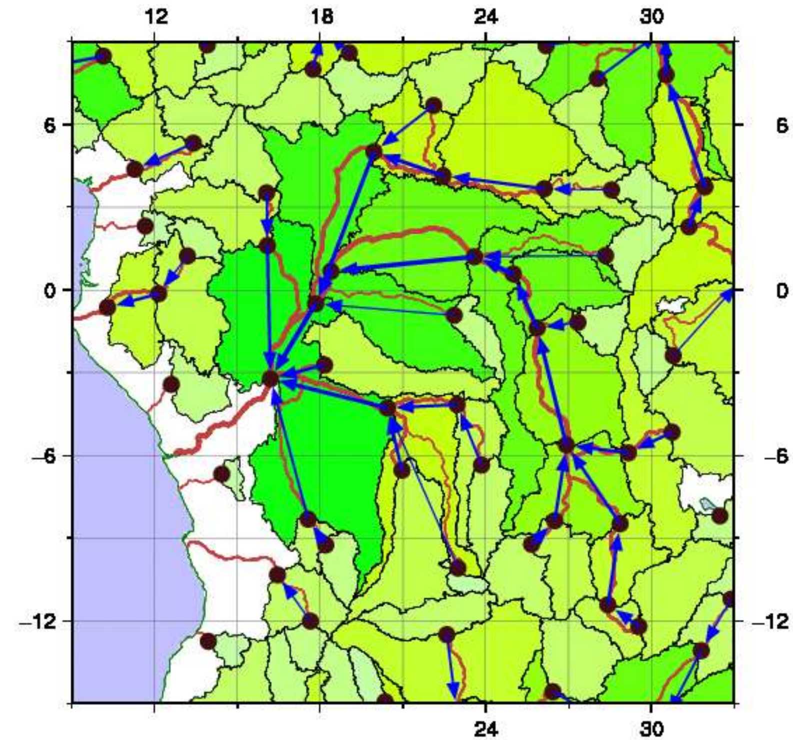
3. Sub-grid topographic parameters: FLOW

Flexible Location of Waterways method

> Derived from 1-km topographic data

Channel elevation･Downstream cell･
Channel length･Catchment area･
Floodplain elevation profile



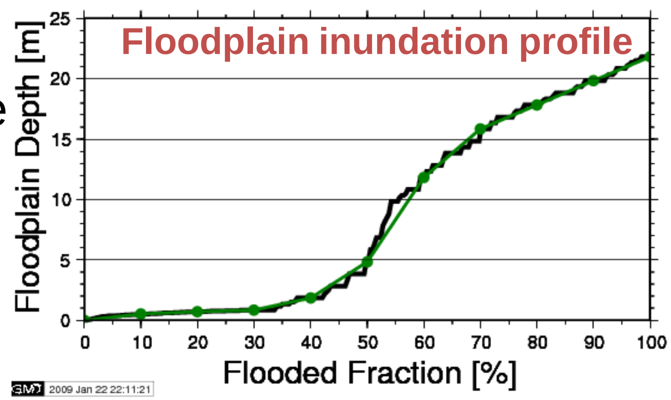


> Estimated from annual discharge

River width･Bank height

$$W = Max[10.0 \times \overline{Q}^{0.5}, 10.0]$$

$$B = Max[1.0 \times \overline{Q}^{0.4}, 1.0]$$



Channel elevation
Downstream cell
Channel length
Catchment area

4. Floodplain inundation simulation in the Amazon

Impact of introducing *1)* ***floodplain reservoir*** and *2)* ***diffusive wave equation*** is discussed

> Experimental setting

Experiment	Storage	Flow Routing
NoFLD	River Channle Only	Kinematic Wave
FLD+Kine	River Channel + Floodplain	Kinematic Wave
FLD+Diff	River Channel + Floodplain	Diffusive Wave

> Special Resolution = 15 arc-min (25 km),   Time step = 15 min

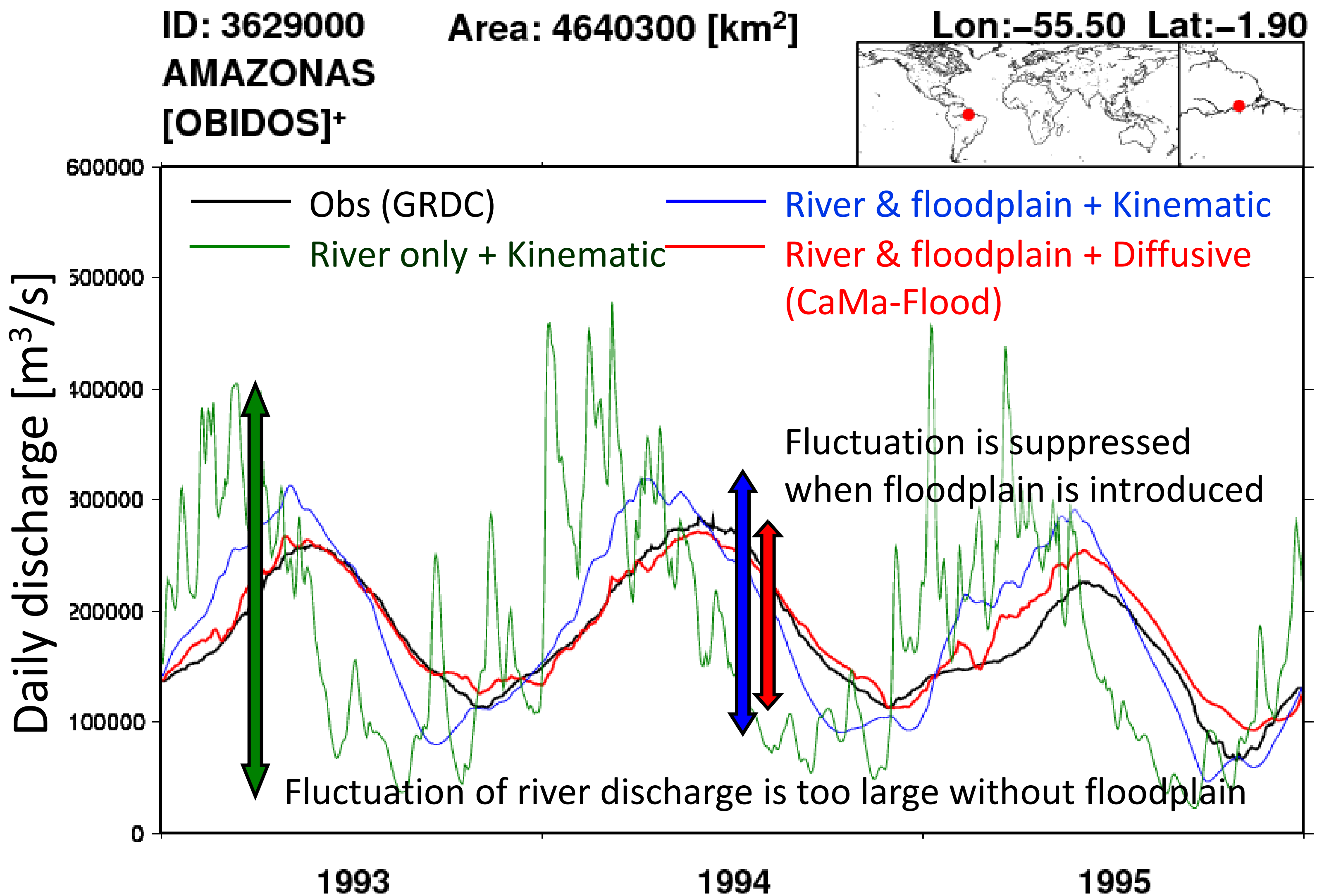
> LSM runoff [Kim, 2009]: Spatial = 1 deg, Time step = 1 day (Linear interpolation)

Climate Forcing (JRA25) + Precipitation (GPCP) ⇒ LSM (MATSIRO) ⇒ Runoff

> Boundary condition at river mouth: Constant sea elevation.

4. Floodplain inundation simulation in the Amazon

Validation of daily river discharge:



4. Floodplain inundation simulation in the Amazon

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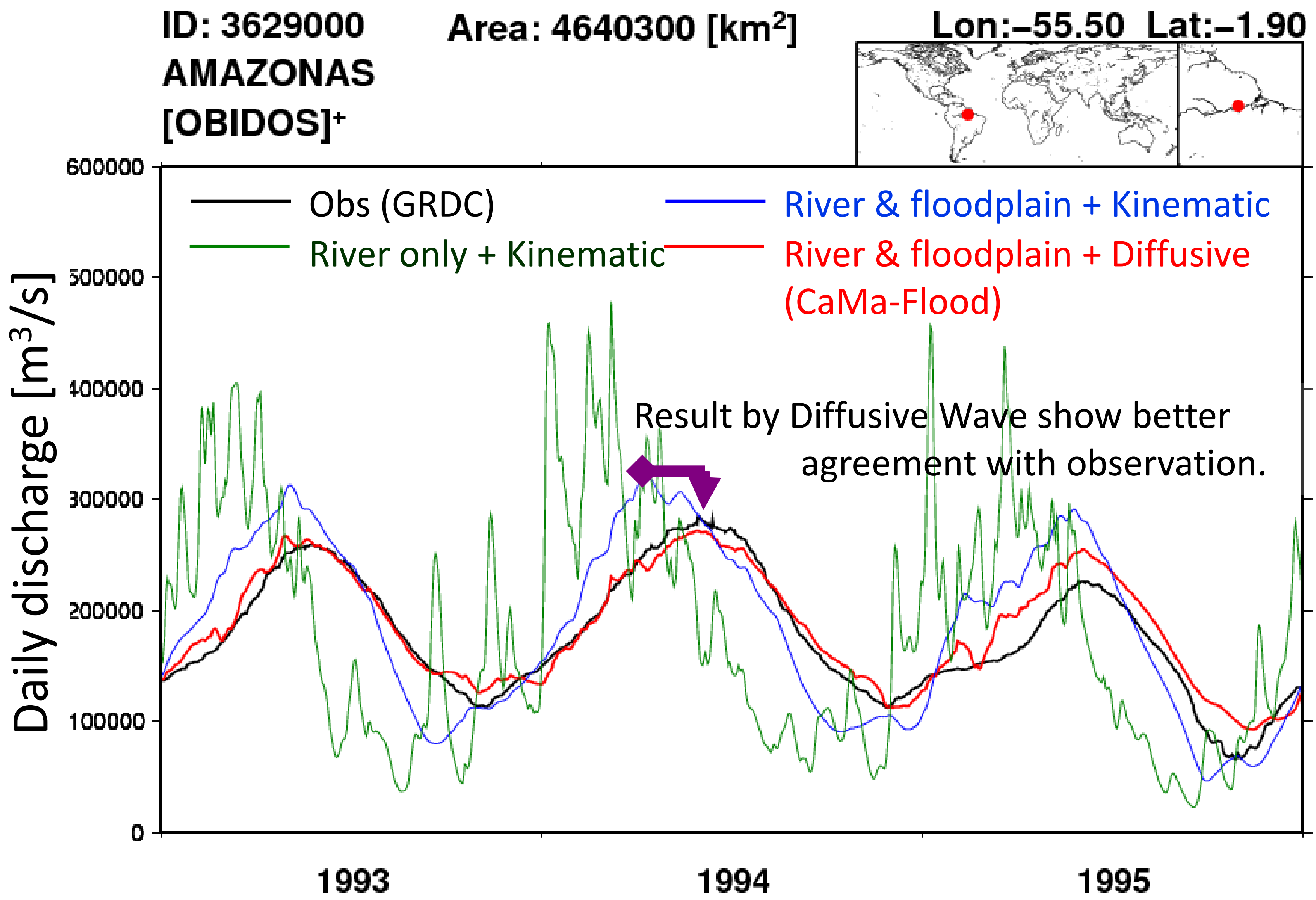
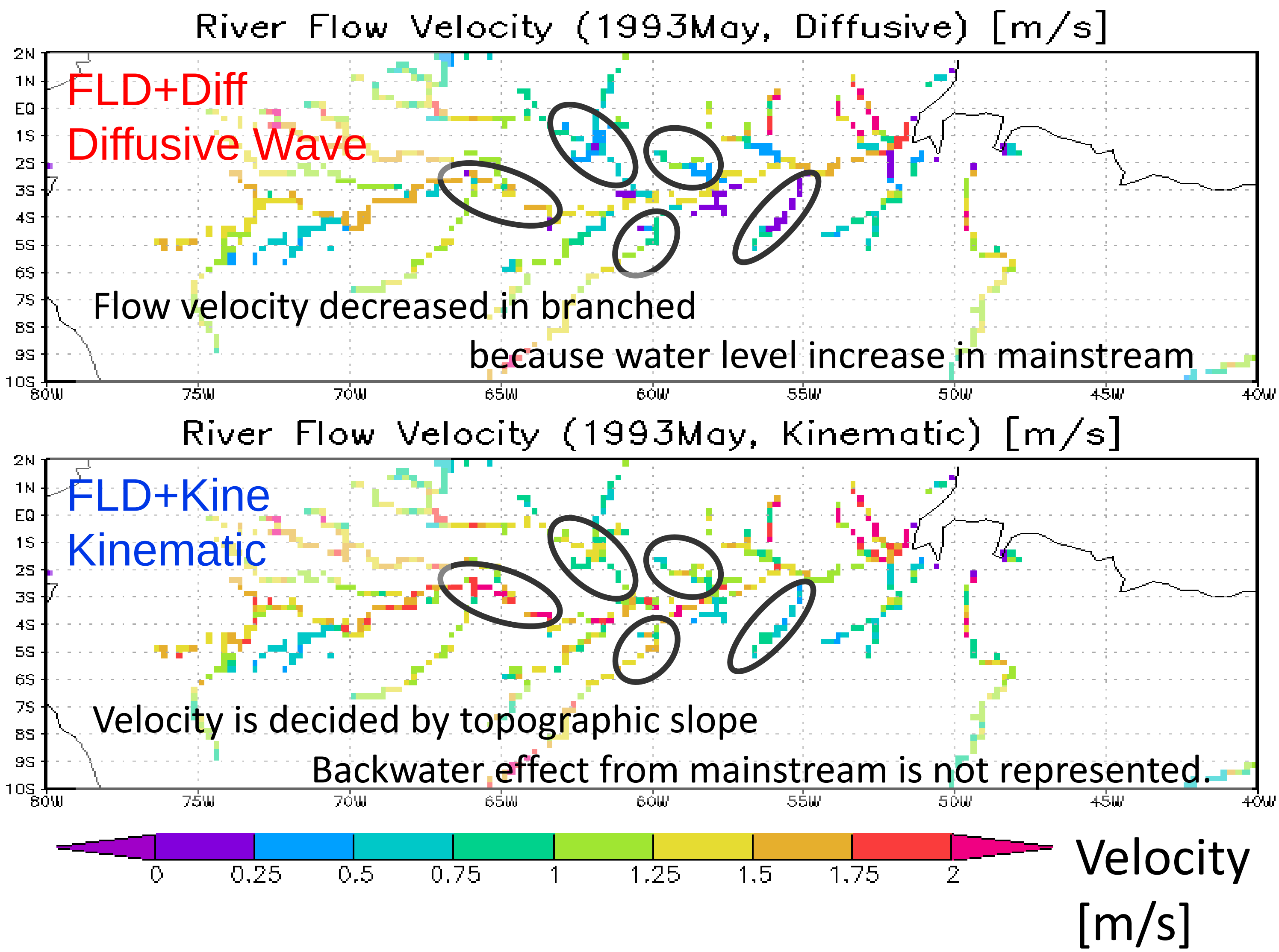


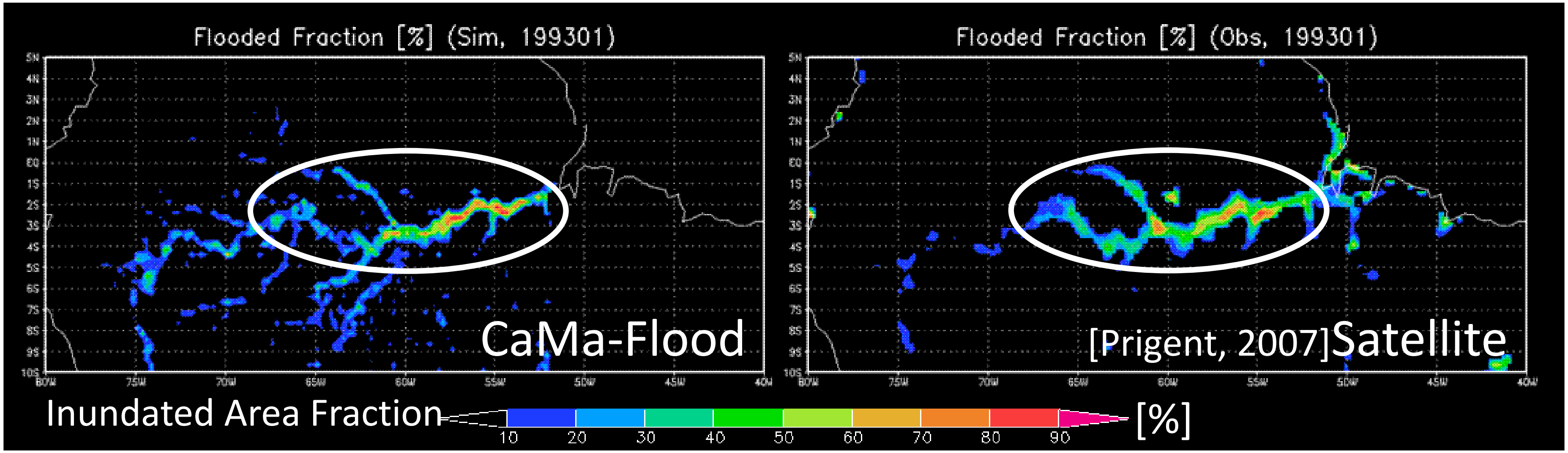
4. Floodplain inundation simulation in the Amazon

Flow velocity in May 1993: [Kinematic .vs. Diffusive]



4. Floodplain inundation simulation in the Amazon

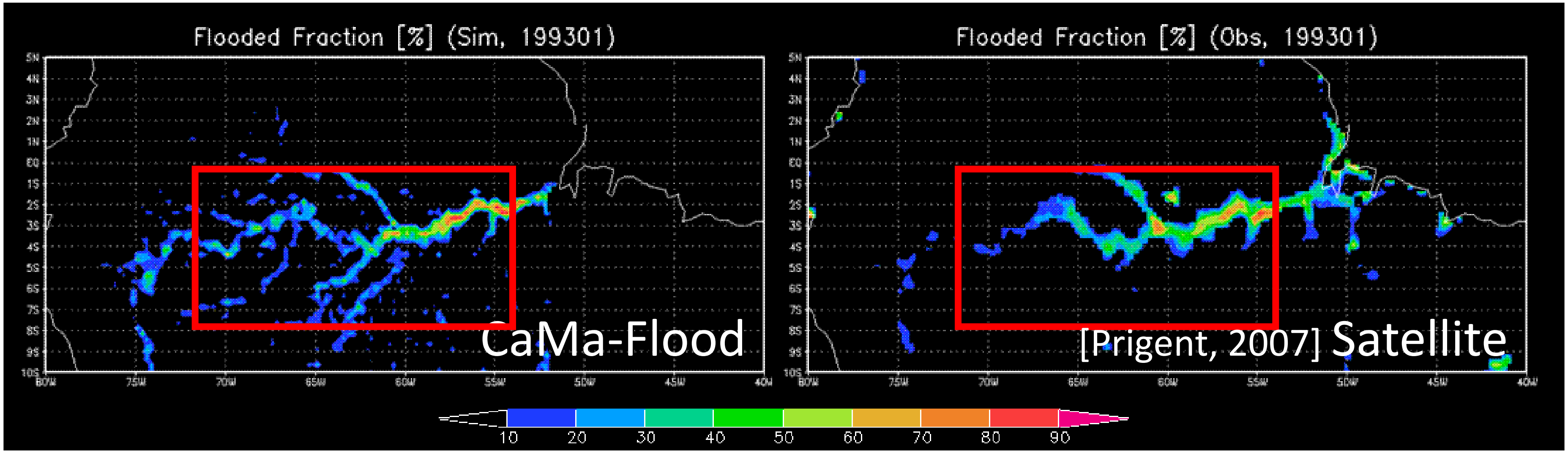
Comparison of inundated area against satellite obs. [Prigent, 2007]

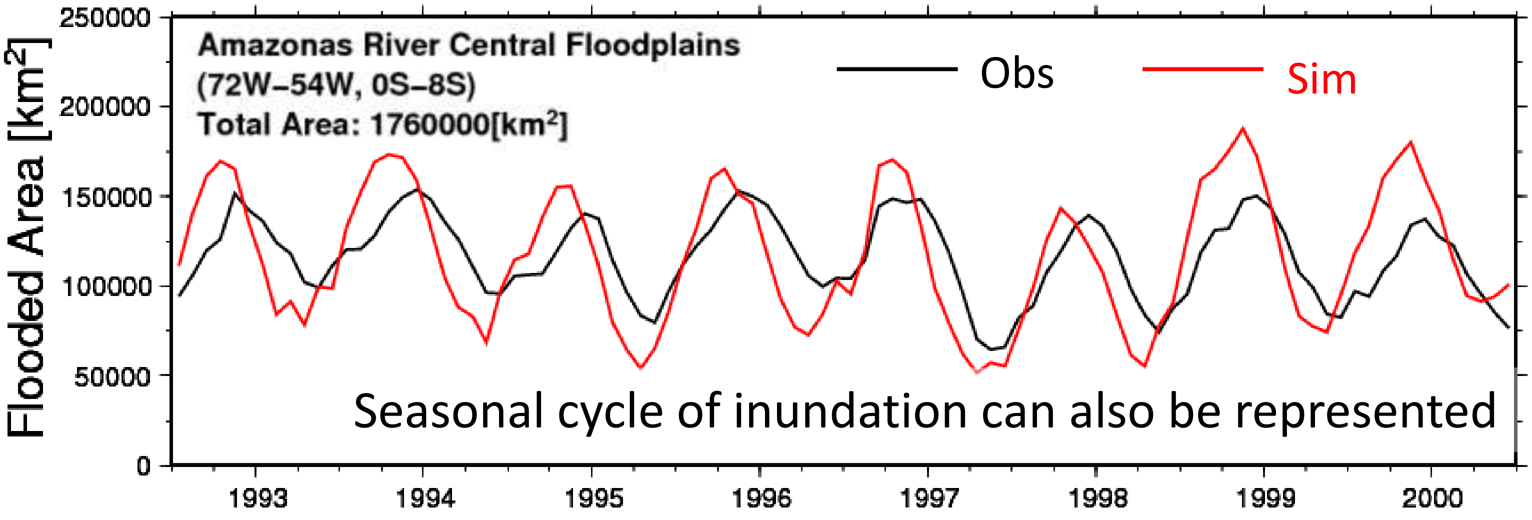


General pattern of inundated area is reproduced.

4. Floodplain inundation simulation in the Amazon

Comparison of inundated area against satellite obs. [Prigent, 2007]





5. Hydrological simulation in Tonle-Sap, Cambodia

Can CaMa-Flood reproduce unique characteristics of Tonle-Sap?

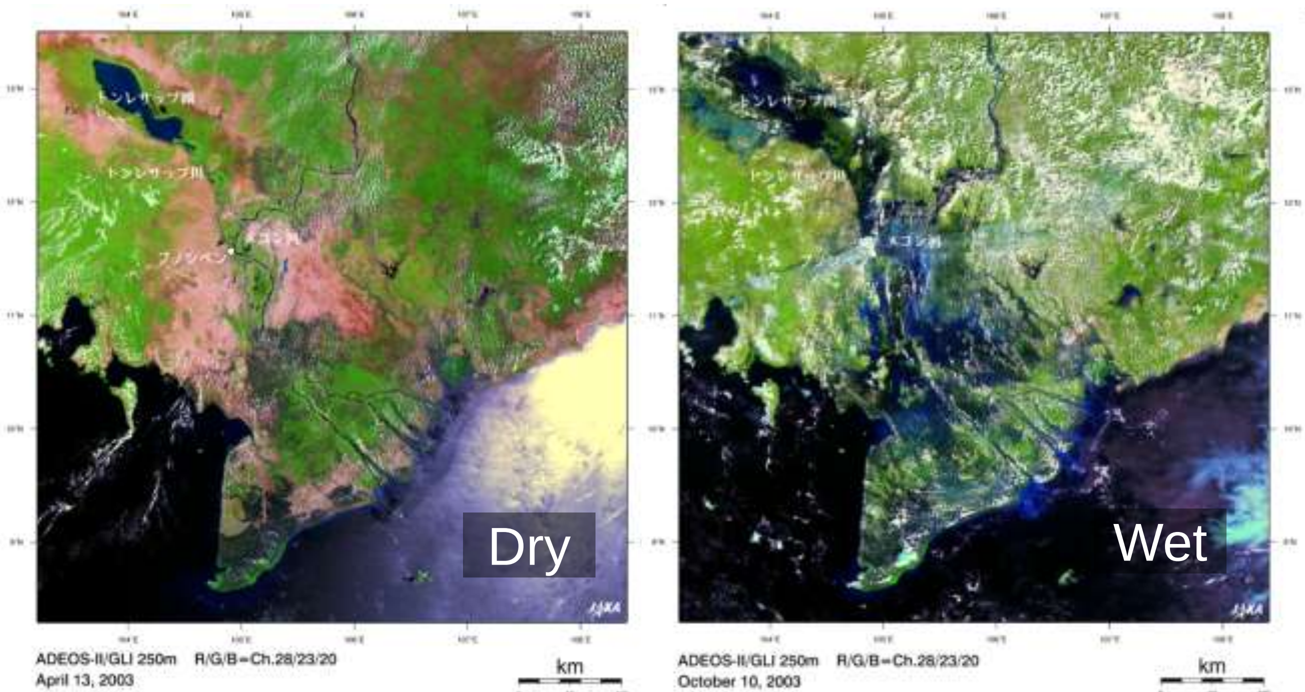
> Experiment setting: River + Floodplain reservoir + Diffusive Wave Equation

> Spatial resolution = 5 arc-min (8 km);   Time step : 5 min

> LSM runoff [Kim, 2009]: Spatial = 1 deg; Time step = 1 day (Linear Interpolation)

Climate Forcing (JRA25) + Precipitation (GPCP) ⇒ LSM (MATSIRO) ⇒ Runoff

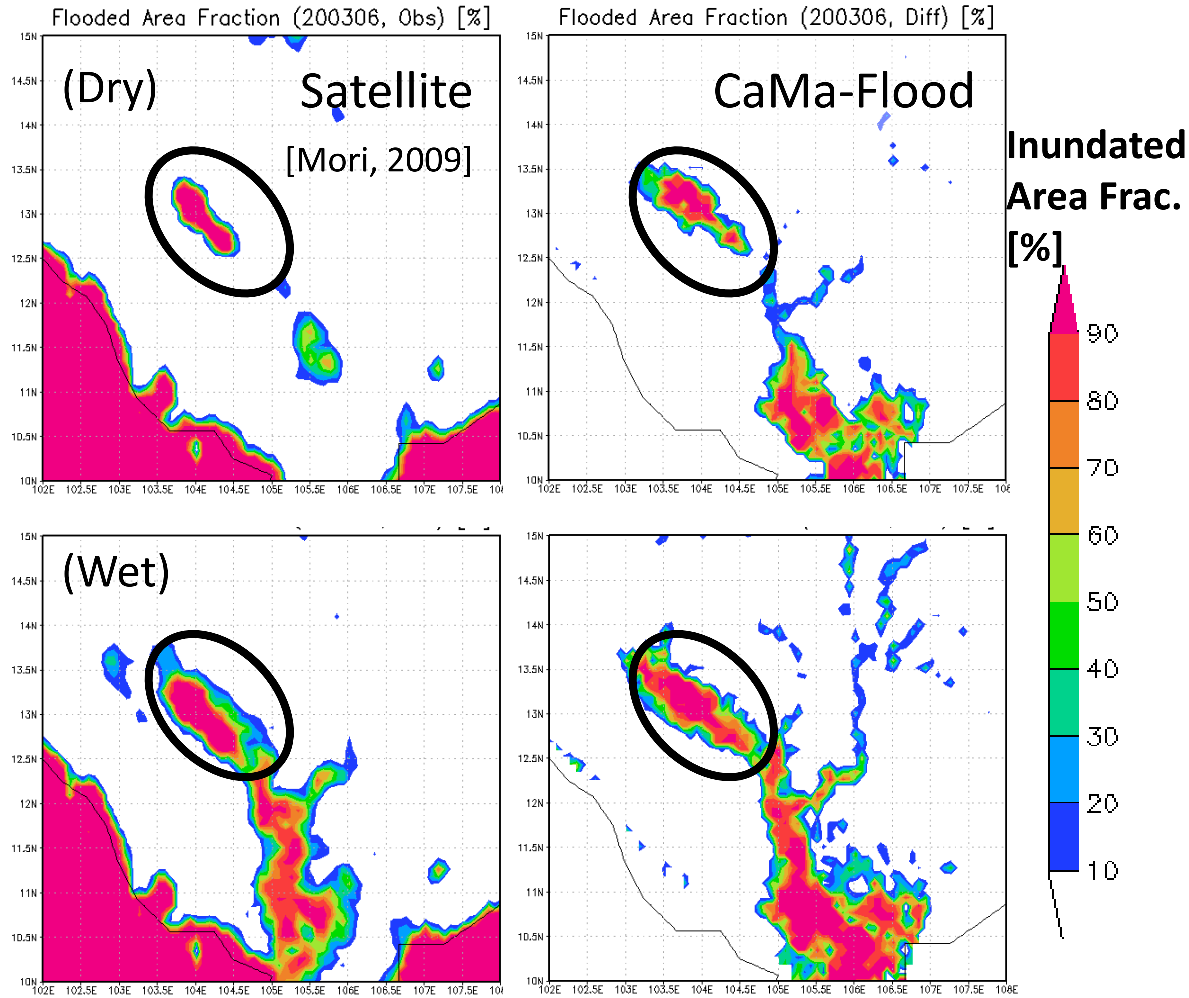
> Boundary condition at mouth: Constant sea level



ADEOS-II Visible [JAXA, 2004]

5. Hydrological simulation in Tonle-Sap, Cambodia

Inundated area compared to MODIS+AMSR observation [Mori, 2009]

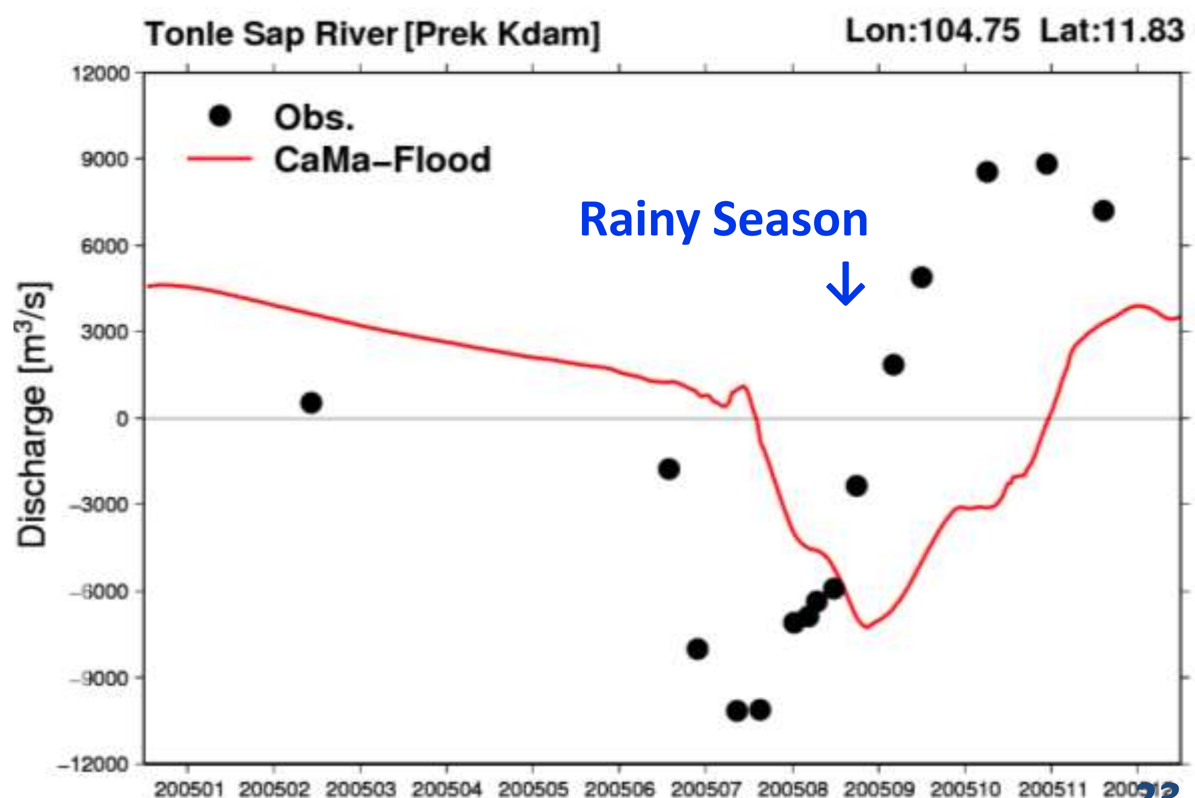


Seasonal lake area change is reproduced.

5. Hydrological simulation in Tonle-Sap, Cambodia

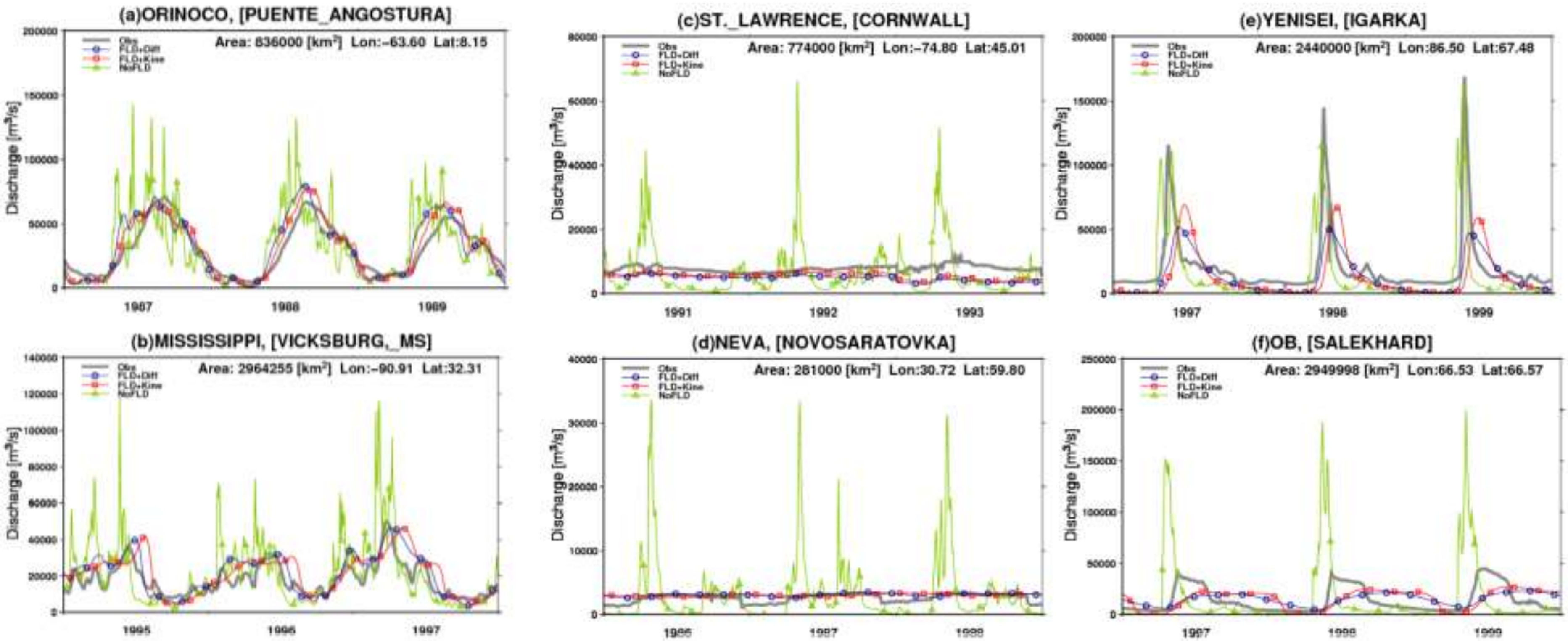
Discharge at Tonle-Sap River, which connects Tonle-Sap Lake and Mekong River.

During its flooding phase, the Tonle Sap receives more than 51,000 millionm^3 of water from the Mekong River via the Tonle Sap River. [Penny, 2006]



Large-scale backflow of Tonle-Sap River is reproduced.

6. Results in major rivers in the world.



Tropics & Extra tropics | River with lakes | Boreal Cold

Obs (GRDC)

River & floodplain + Kinematic

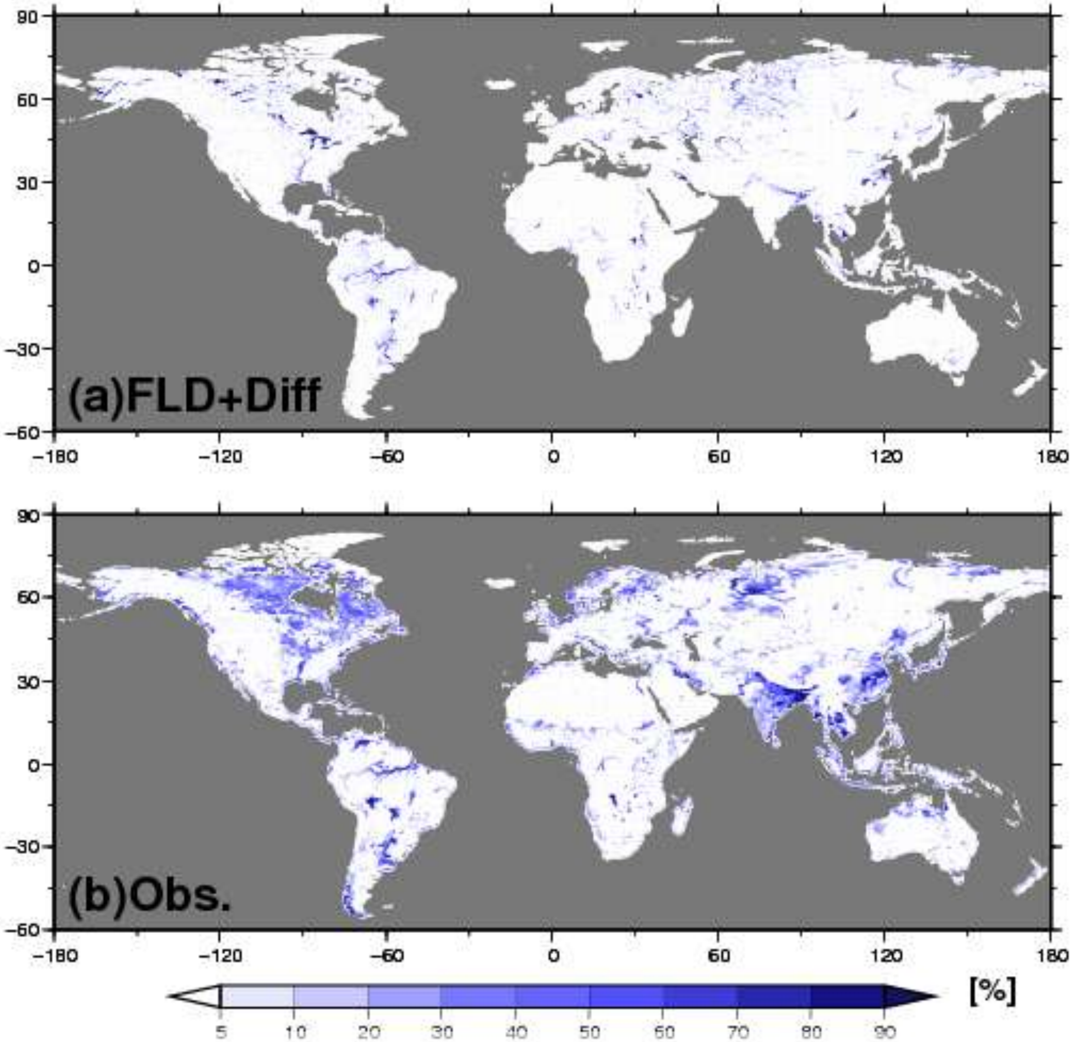
River only + Kinematic

River & floodplain + Diffusive (CaMa-Flood)

Simulated discharge by CaMa-Flood shows good agreement with observation, except for boreal rivers in cold region.

6. Results in major rivers in the world.

Validation of inundated area against satellite observation [Prigent, 2007]



Inundated area fraction at annual maximum (1993)

Inundation in floodplains along mainstream of major rivers is reproduced.

While, inundated area is generally underestimated in the global-scale:

> Inundation in small pools due to local depression is not considered.

> Irrigated paddy fields are also not negligible.

7. Summary

- Physically-based description of inundated area dynamics is achieved in the global river routing model, CaMa-Flood.
  - River networks and topographic parameters are automatically derived from 1-km DEM and flow direction map.
  - Relationship between water storage, water level, inundated area is objectively described.
  - Flow computation by diffusive wave equation is realized.

- Simulation by CaMa-Flood
  - Daily river discharge is well reproduced. Consideration of floodplains reduces overestimation of flood peak discharge.
  - Diffusive wave equation is effective to simulate flow velocity variability in a flat river basins like the Amazon.
  - Inundation in floodplains along mainstreams of major rivers are reproduced.
  - Large-scale backflow in Tonle-Sap River is reproduced by realistic representation of water surface elevation.

Thank You!

Tonle-Sap Lake, Cambodia
3rd Oct 2009