Numerical Representation of the Amazon River Flood Cycle 1939-1998

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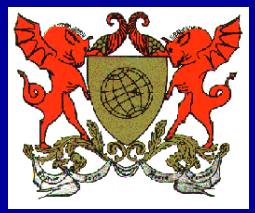


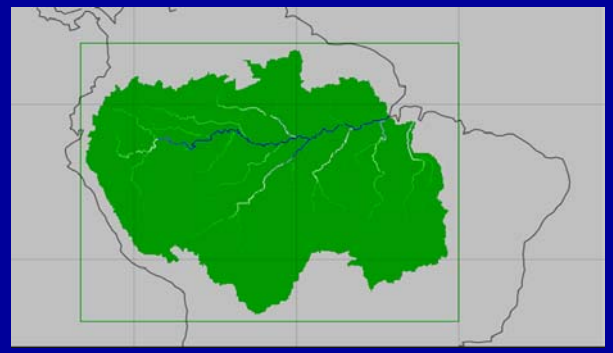
Introduction

Flood pulse is important for all species in Amazonia providing food, habitat, commerce, etc…

Introduction

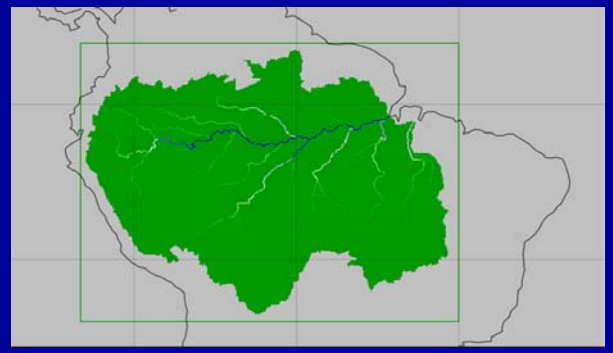
It is also highly variable

Introduction



- Would like to address questions about large-scale hydrology of Amazonia such as:
  - How much water, and of what quality, is in the soils, rivers, and floodplains?
  - How variable is it in time and space?
  - How is it linked to atmosphere, vegetation and soil characteristics?
  - How might physical changes in the basin influence the quantity and quality of the surface waters?
  - What are the roles of the river in biochemical cycling?

Introduction

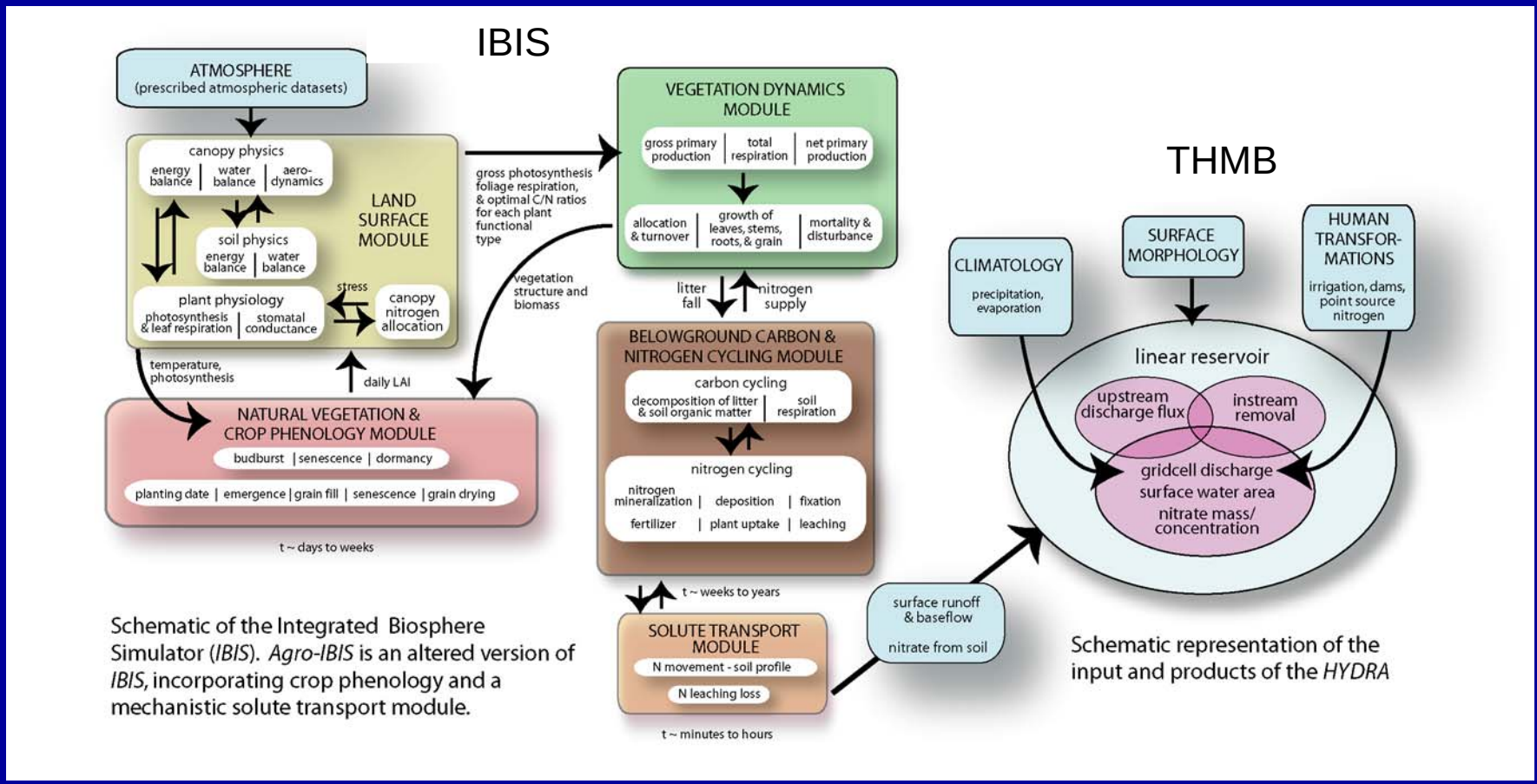


- Scale of basin makes it difficult to answer questions with observations alone.
- These questions can help us understand the regional and global importance of basin
- Numerical models provide spatially and temporally consistent estimates of ecosystem function from simple climatological data

Goal

- Develop mechanistic models to simulate hydrology and biochemistry of Amazon River and floodplain system
  - Simple enough to apply to entire basin, source to sink
  - Complex enough to represent physical processes and sensitivity to change
  - Capable of working at high and low spatial resolution
  - Capable of expansion to model C and nutrients cycling

IBIS-THMB models



Schematic of the Integrated Biosphere Simulator (*IBIS*). *Agro-IBIS* is an altered version of *IBIS*, incorporating crop phenology and a mechanistic solute transport module.

Schematic representation of the input and products of the *HYDRA*

- Mechanistic models of plant and soil functioning
- Partitions incoming precipitation and radiation
- Routes runoff across landscape to simulate rivers, lakes, and wetlands

Kucharik et al., 2000; Coe et al., 2002

IBIS-THMB models

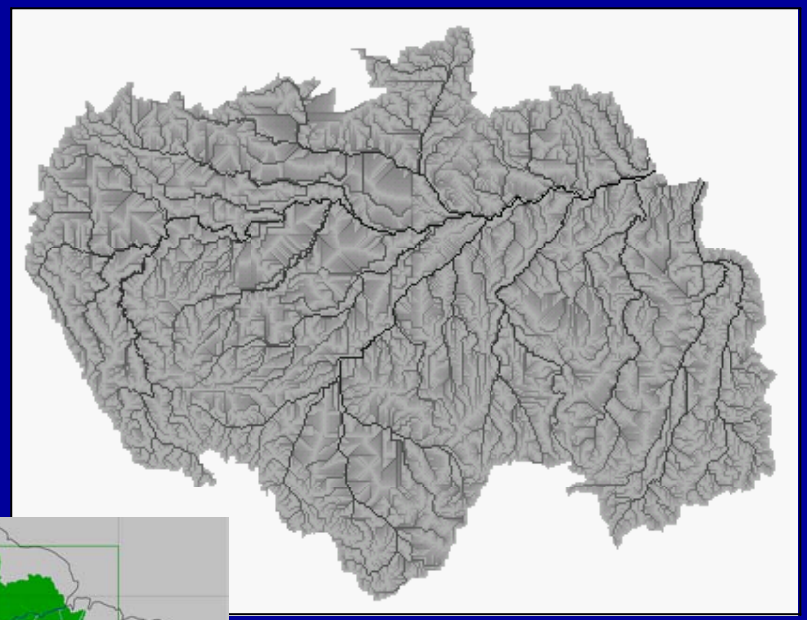
- Use climate (precipitation, temperature, solar radiation, humidity, and wind speed), land cover, and land use data to derive:

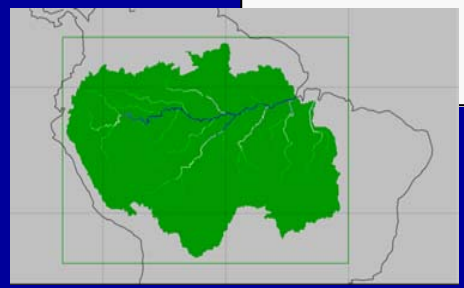
  – a temporally and spatially varying representation of aquatic ecosystems.

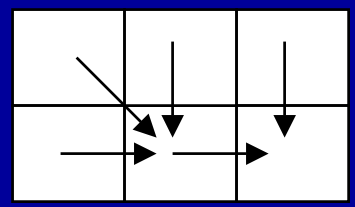
THMB

Model represents the river system as series of boxes connected by prescribed river flow directions

- At 5-minute (9km) resolution entire basin is represented by about 87000 boxes
- 90m and 500m resolution data now available from WWF for all of South America







Costa et al., 2002

THMB

The water volume in each box and the flow from one box to the next in rivers is represented by a simple set of equations

$$\mathbf{dV/dt = R + (\Sigma F_{in} - F_{out})}$$

$$\mathbf{R = R_{surface} + R_{sub\text{-}surface}} \quad \text{(local water)}$$

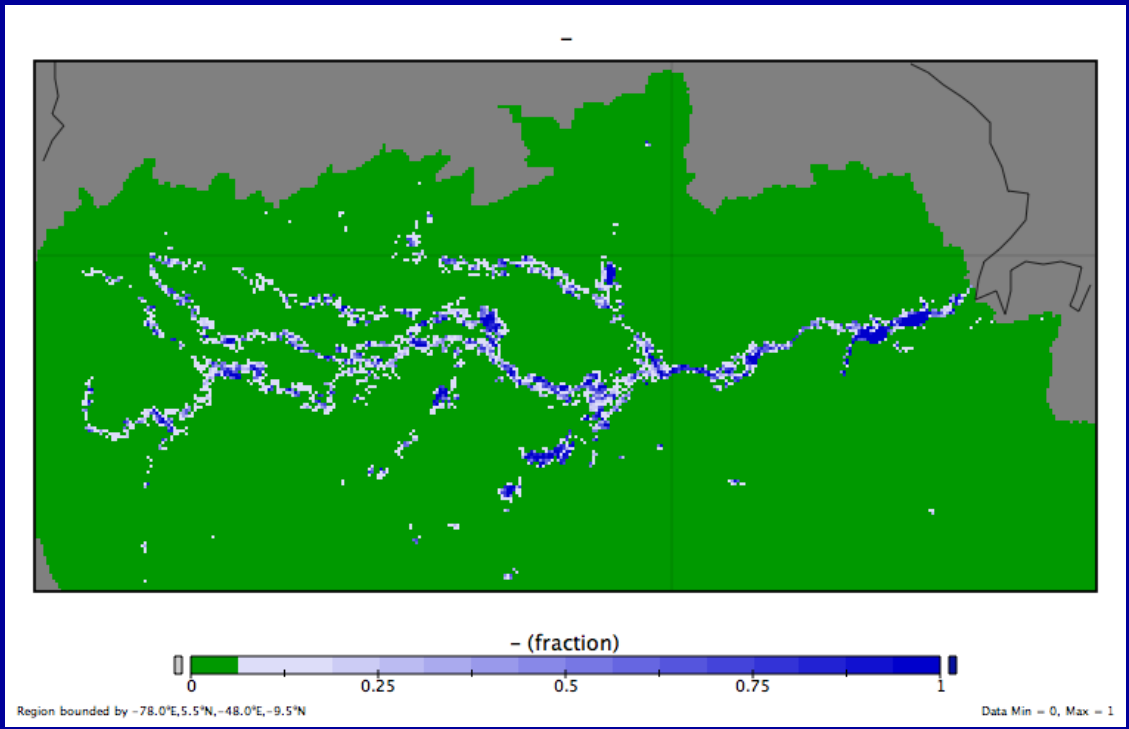
$$\mathbf{\Sigma F_{in} = \Sigma F_{out}} \quad \text{(upstream water)}$$

$$\mathbf{F_{out} = V(u/d)} \quad \text{(discharge)}$$

- Calculates river volume and discharge at all 87000 boxes as a function of local runoff and discharge from upstream at 30 minute timestep
- Conserves mass - all water that enters river either evaporates or is discharged to the ocean

THMB

Water floods surrounding land as river exceeds banks



- Calculates area of each grid cell flooded and the depth of the water

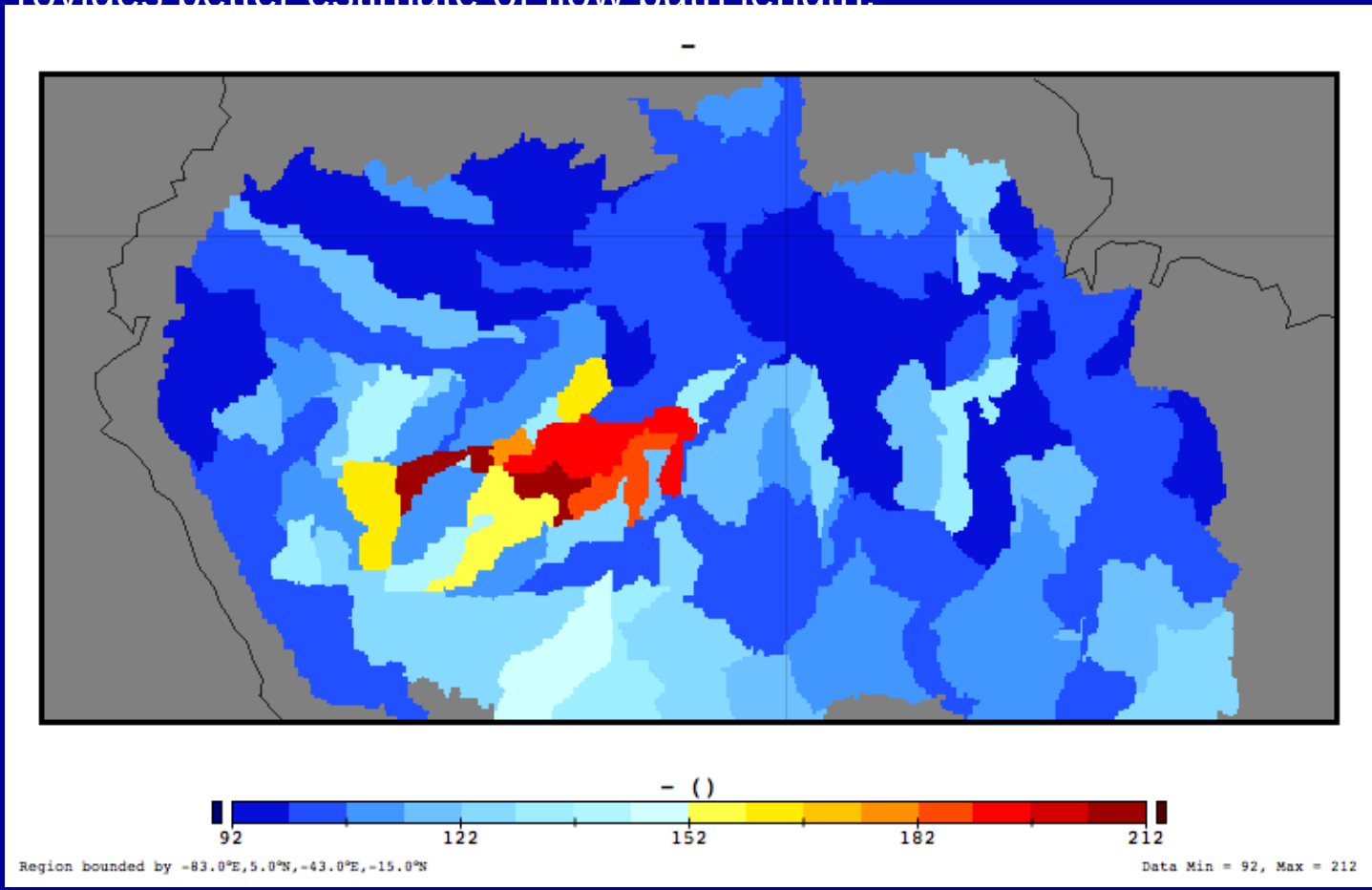
Improvements from Coe et al., 2002

- River length - added representation of river sinuosity to calculation of stream length, from: Costa et al., 2002.
- River velocity - restructured velocity calculation based on the Chezy formula
- Water budget - include precipitation minus evaporation over wetlands and river in water balance
- Flood initiation - use empirical relationships to derive river volume at flood initiation
- Topography - incorporate information from SRTM DEM

Improvements

- River length - Sinuosity of river derived from charts.

Provides better estimate of flow path length.



Costa et al., 2002

Improvements

- River velocity - Velocity now follows Chezy formula. Velocity (u) is a function of the slope of the water surface and its momentum.

$$u = u_{o1} \times (R \times S)^{0.5}$$

S = energy slope of river
R = hydraulic radius

  - Velocity increases with increasing water slope and increasing discharge volume
  - Accounts for increasing velocity of flat downstream sections of river

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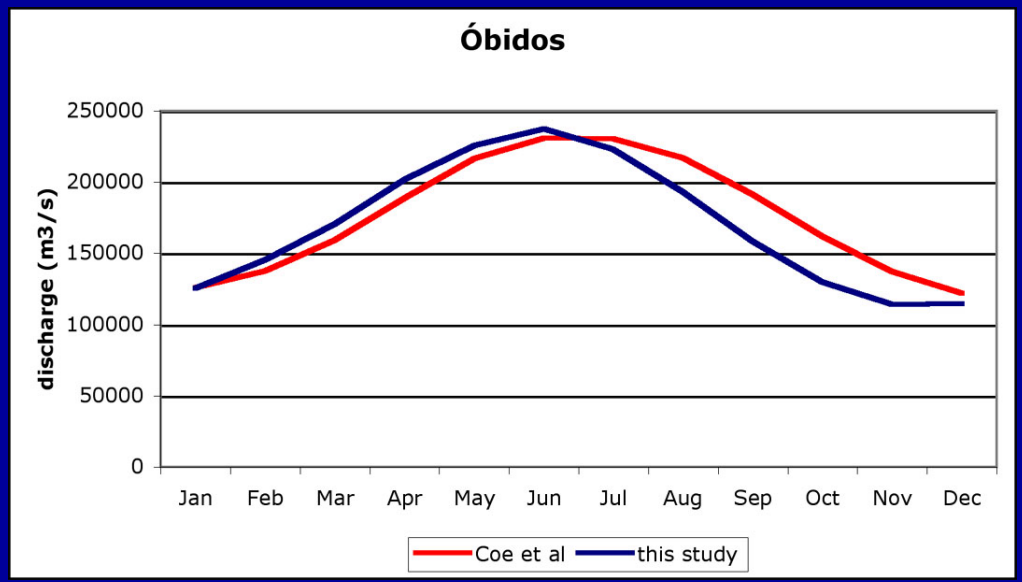

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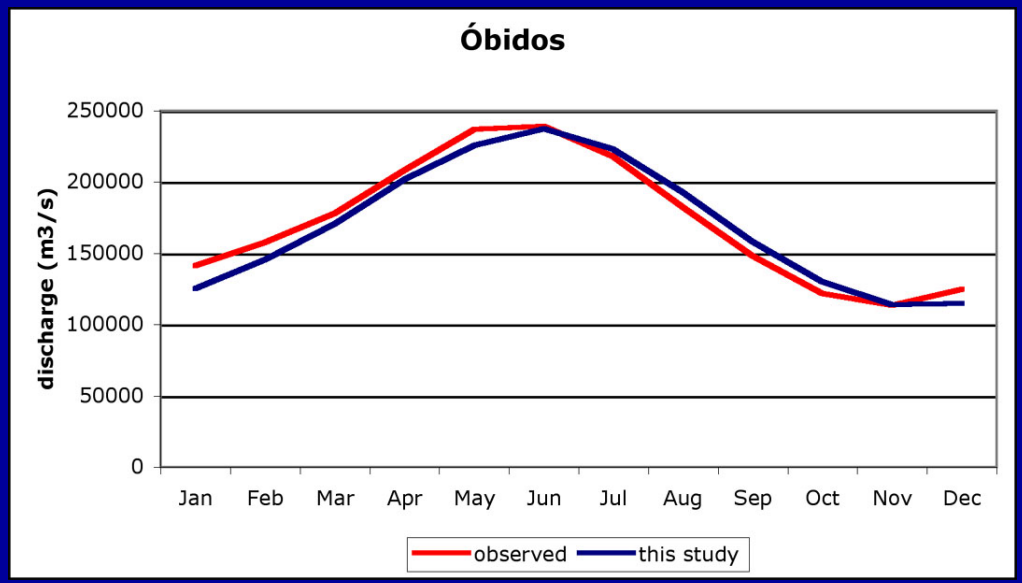
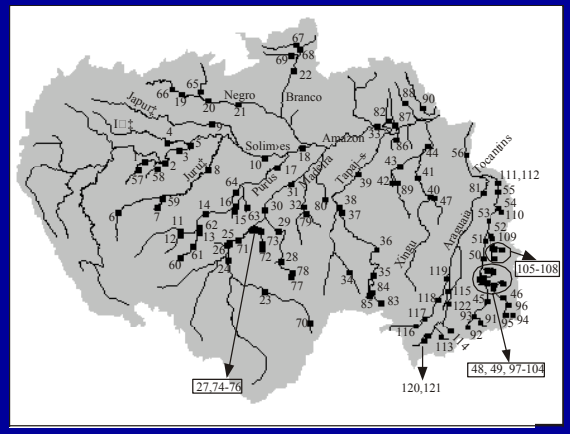
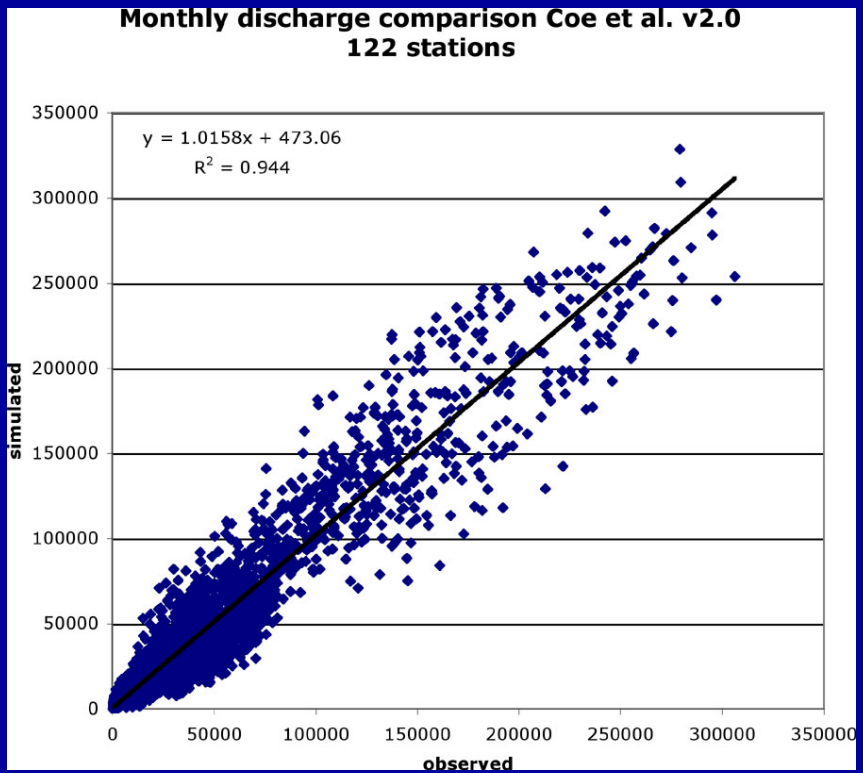
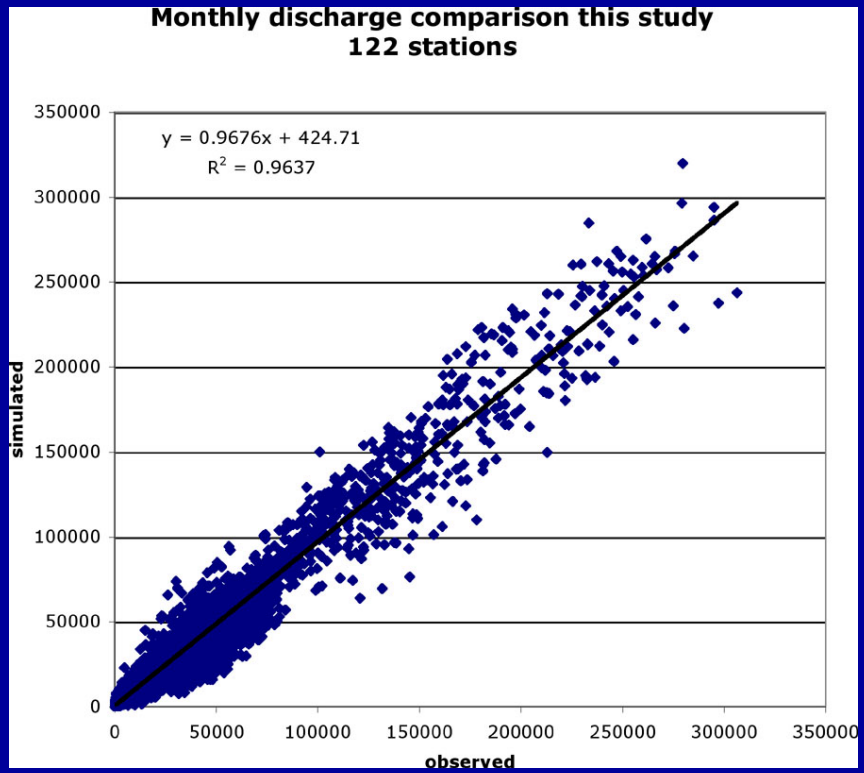


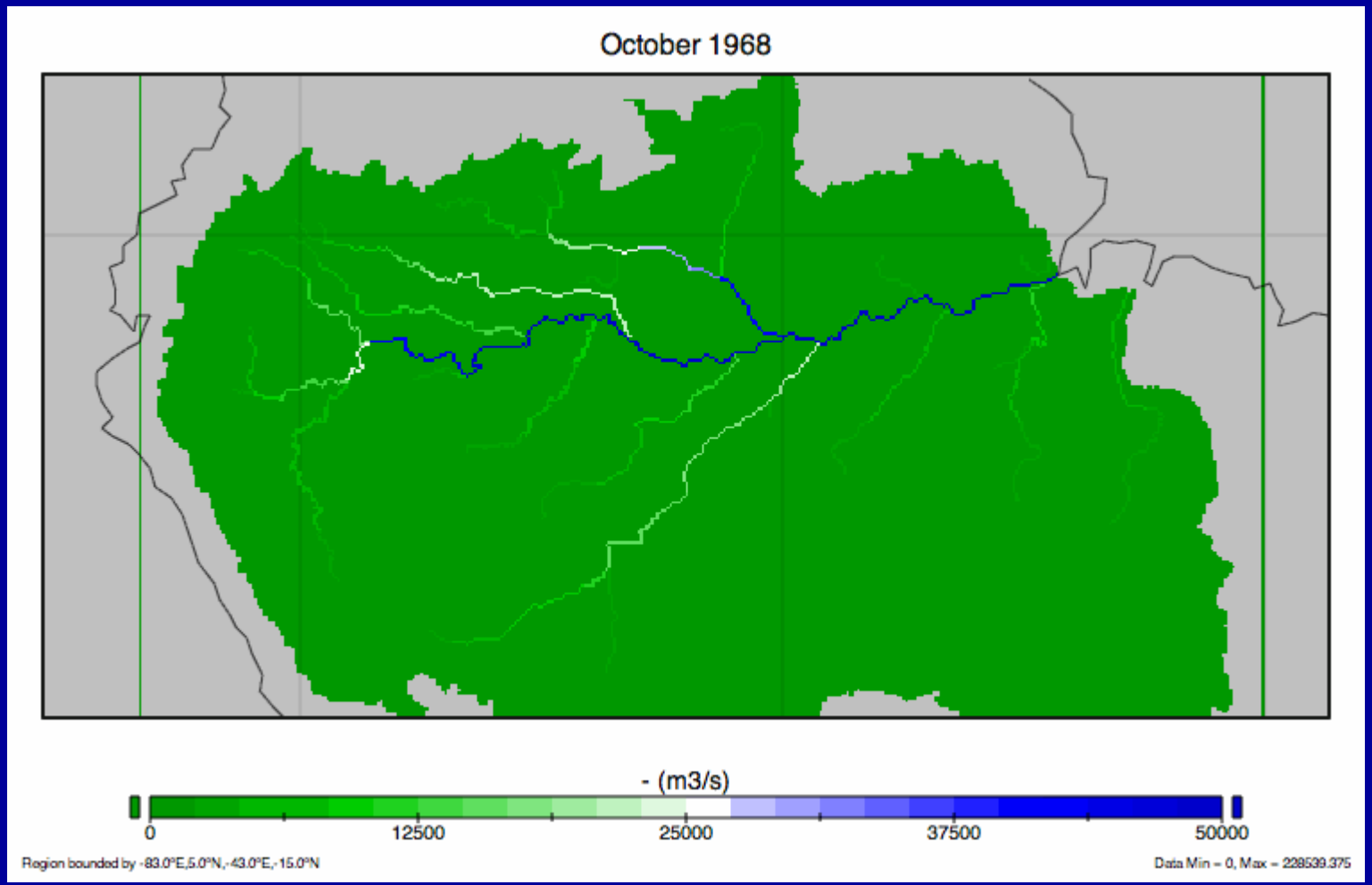
Discharge


Negro
Branco
Solimões
Amazon
Tapajos
Xingu
Araguaia
Tocantins
105-108
48, 49, 97-104
27,74-76
120,121

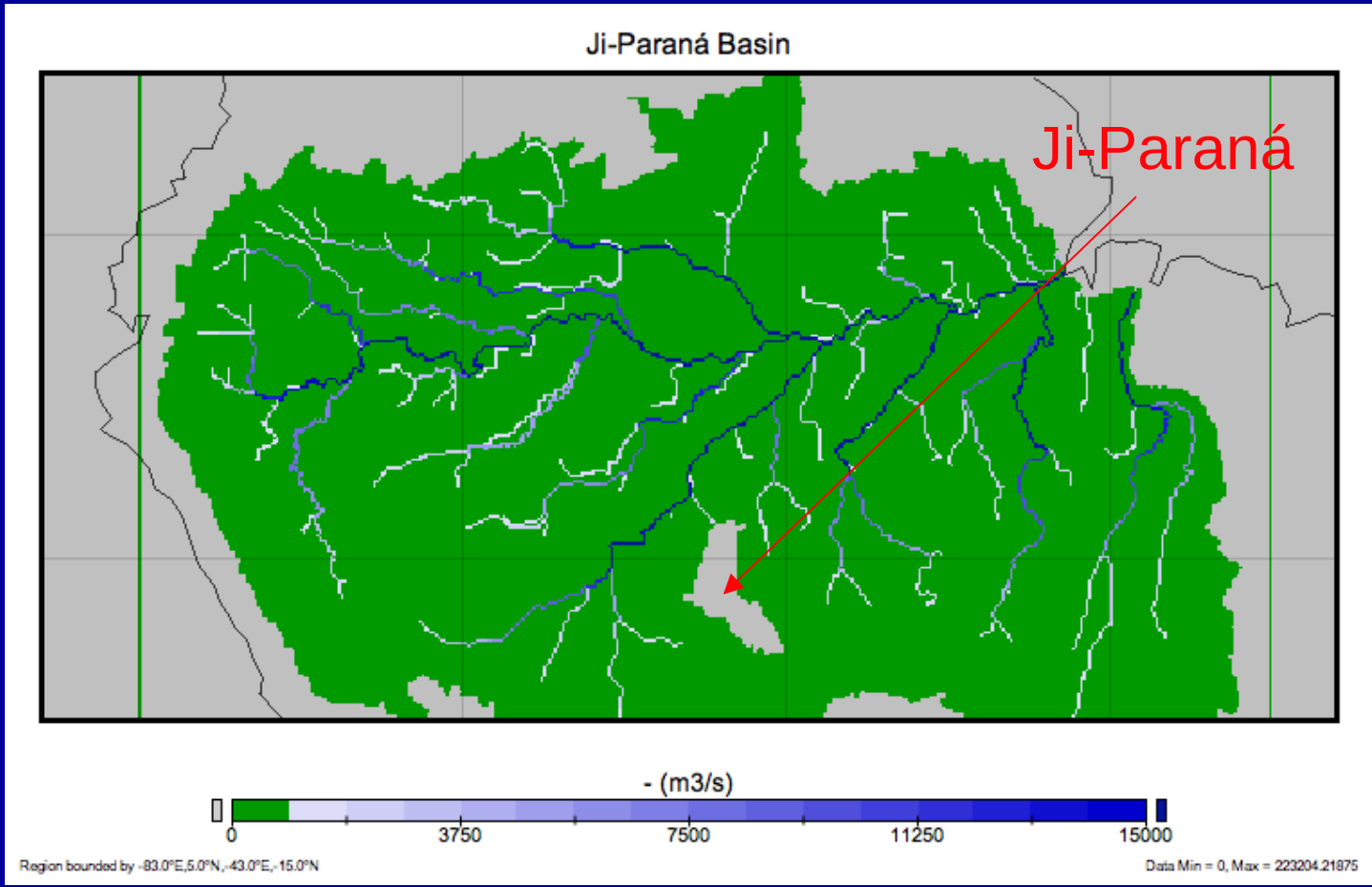

Monthly discharge comparison Coe et al. v2.0
122 stations
y = 1.0158x + 473.06
R2 = 0.944
simulated
observed
0
50000
100000
150000
200000
250000
300000
350000


Monthly discharge comparison this study
122 stations
y = 0.9676x + 424.71
R2 = 0.9637
simulated
observed
0
50000
100000
150000
200000
250000
300000
350000

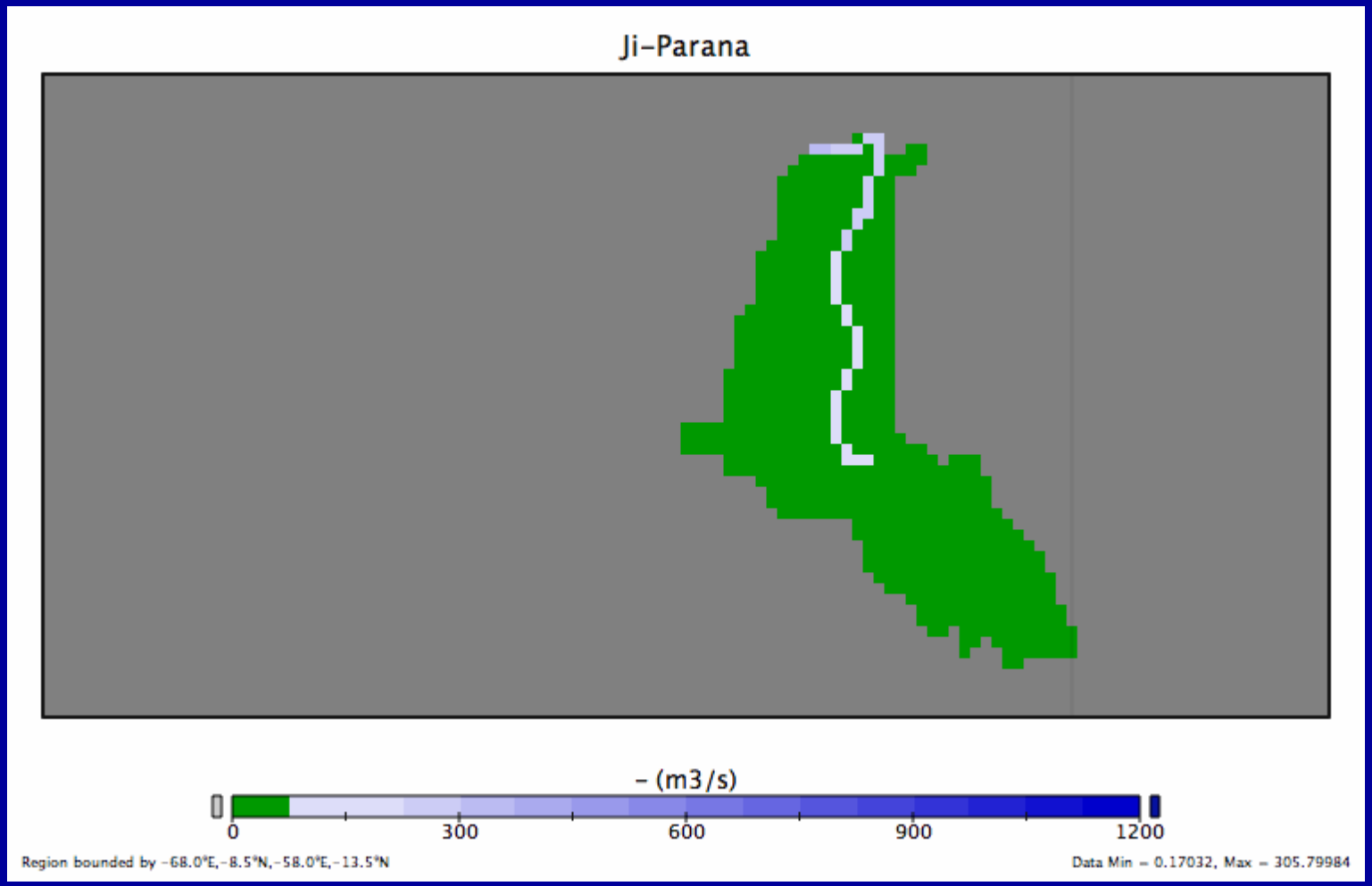
Discharge - inter-annual variability



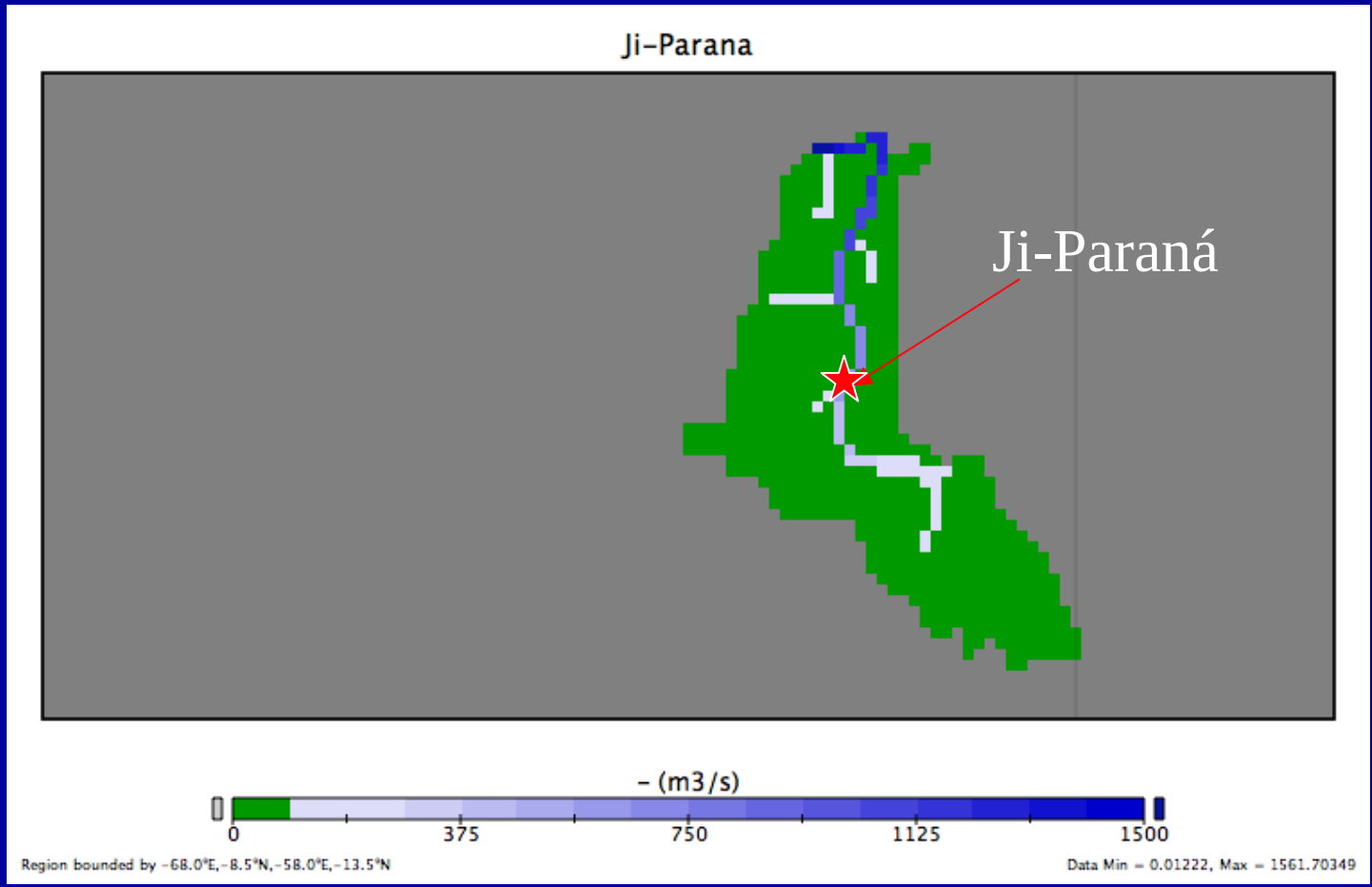
Discharge - inter-annual variability



Discharge - inter-annual variability



Discharge - Ji-Paraná



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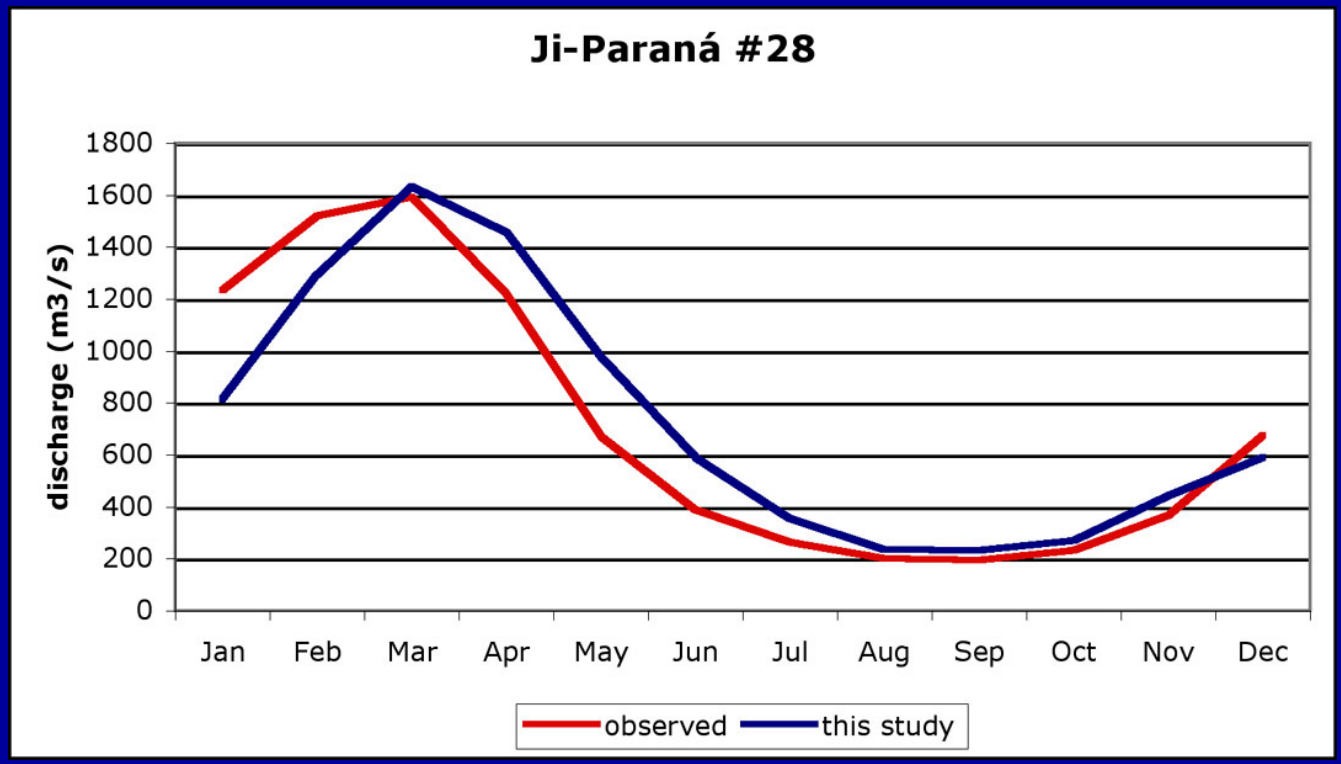


Improvements

- Water budget - explicitly include precipitation and potential evaporation over wetlands and river in the water budget equations

$$dV/dt = R(1-A_w) + (P-E)A_w + (\Sigma F_{in} - F_{out})$$

A_w = flood and river area predicted by model

$R = R_{surface} + R_{sub\text{-}surface}$ (local water)

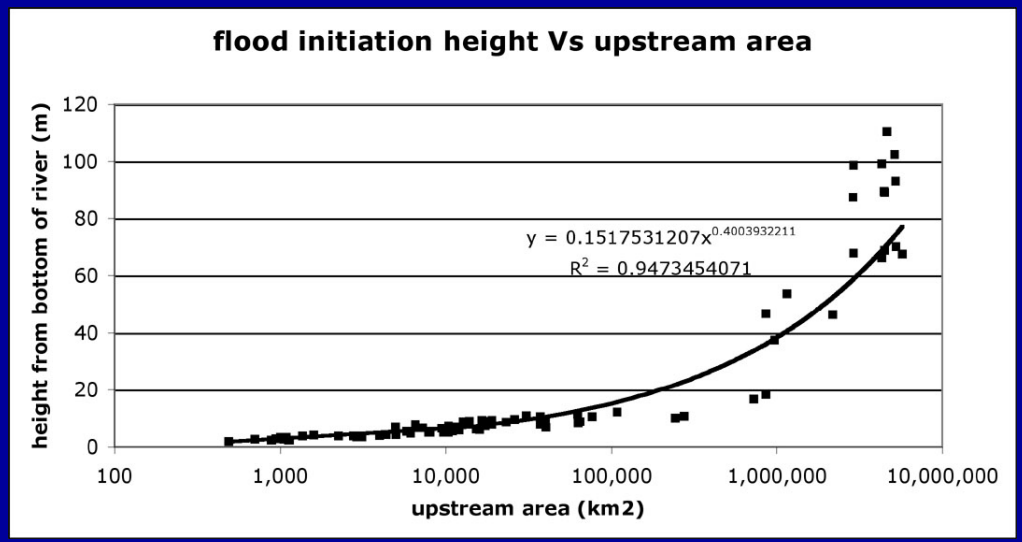
$\Sigma F_{in} = \Sigma F_{out}$ (upstream water)

$F_{out} = V(u/d)$ (discharge)

  - This has relatively small impact on water balance; less than 5% decrease in discharge at Óbidos compared to simulation without P-E over wetlands and river

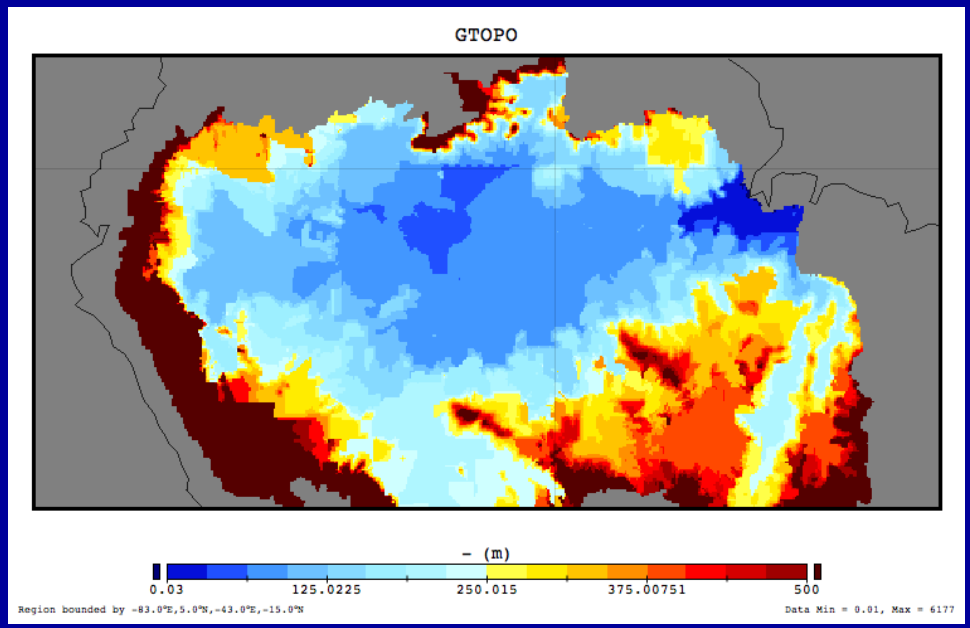
Improvements

- Flood initiation - relationships relating river geometry at bankfull volume were derived from ANA data.
  - Calculate height, width, and length of river at flood initiation (bankfull)
  - Therefore, know volume of river at bankfull (LxWxH)
  - Any volume in river reservoir in excess of bankfull volume is added to floodplain reservoir



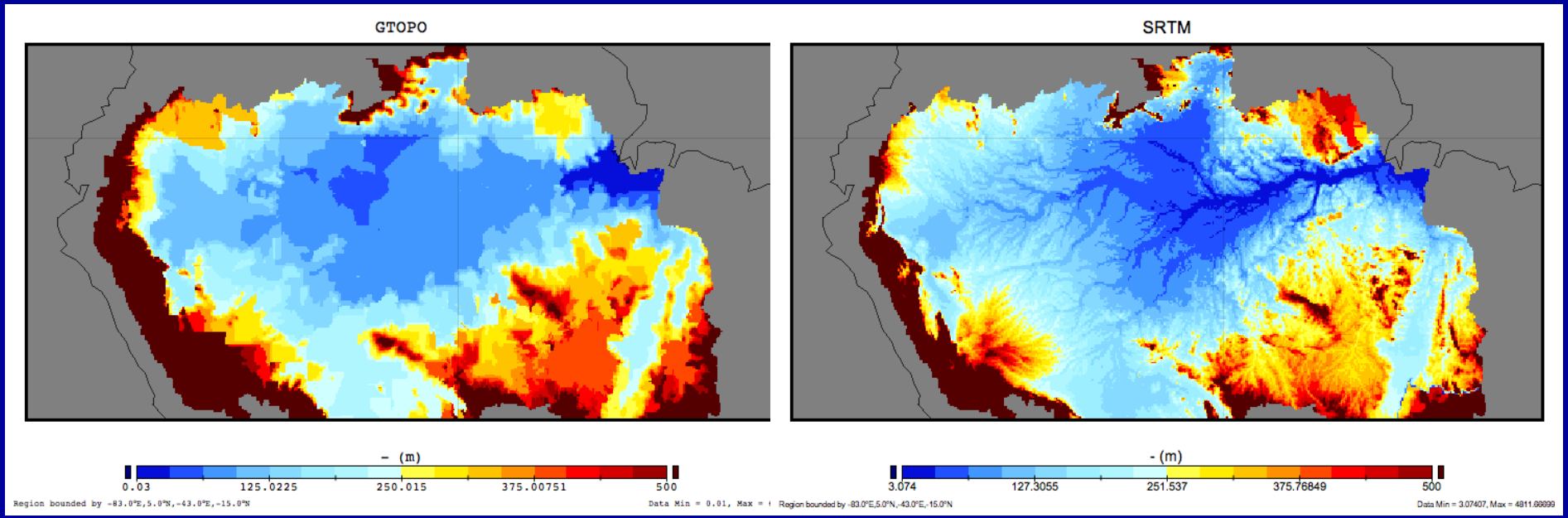
Improvements

- Topography - 5-minute horizontal resolution topography represented by GTOPO30 DEM



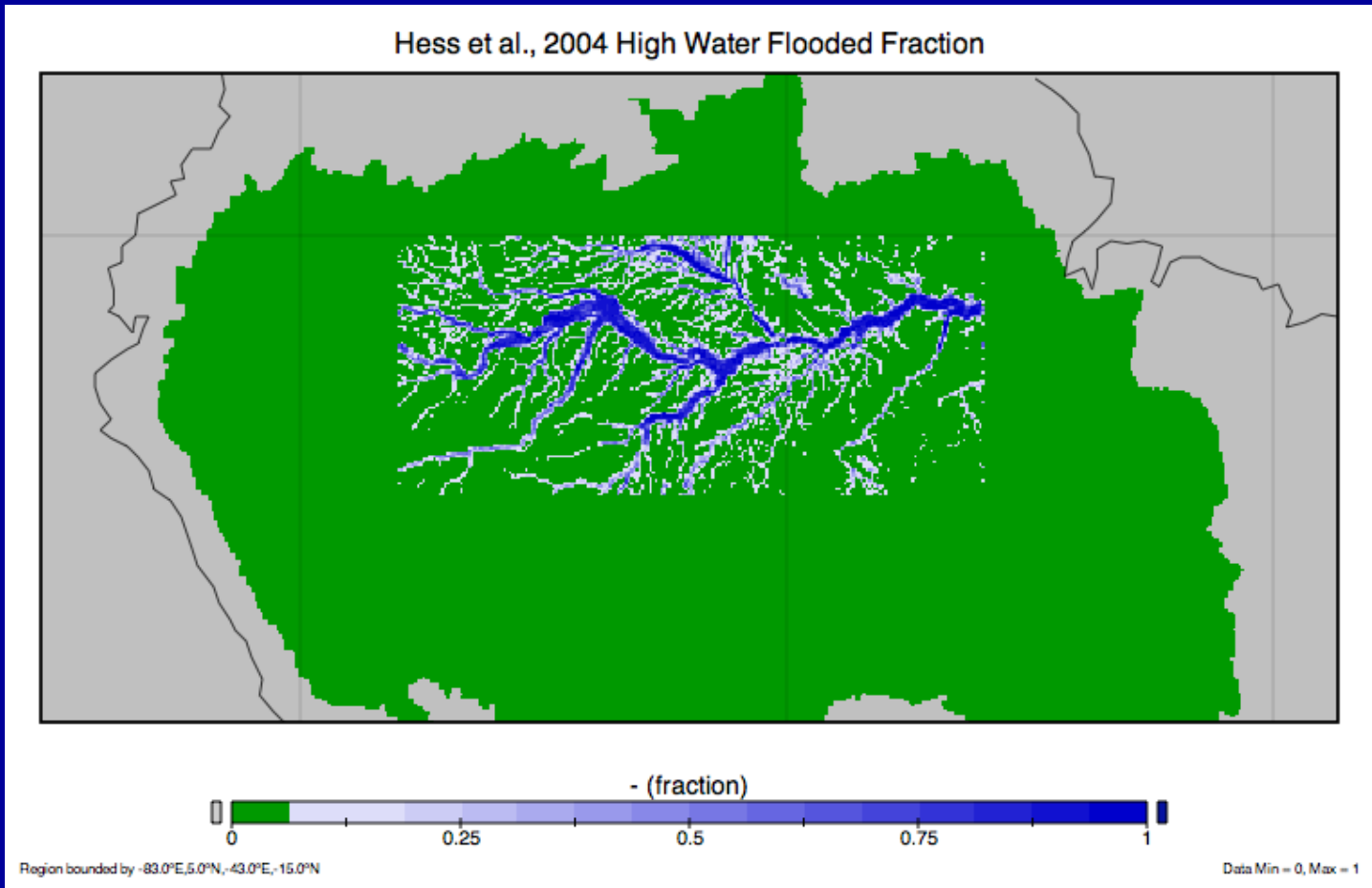
Improvements

- Topography - Shuttle RADAR Topography Mission (SRTM) data averaged to 5 minute horizontal resolution clearly provides more information



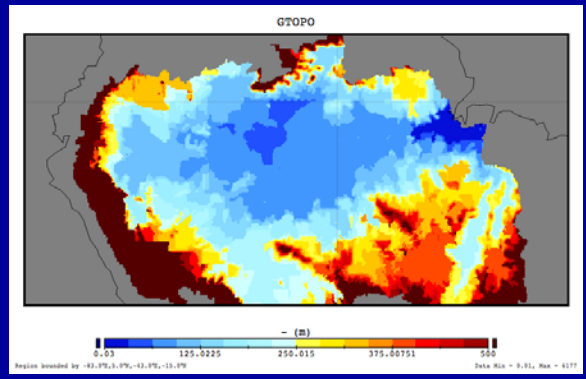
Improvements

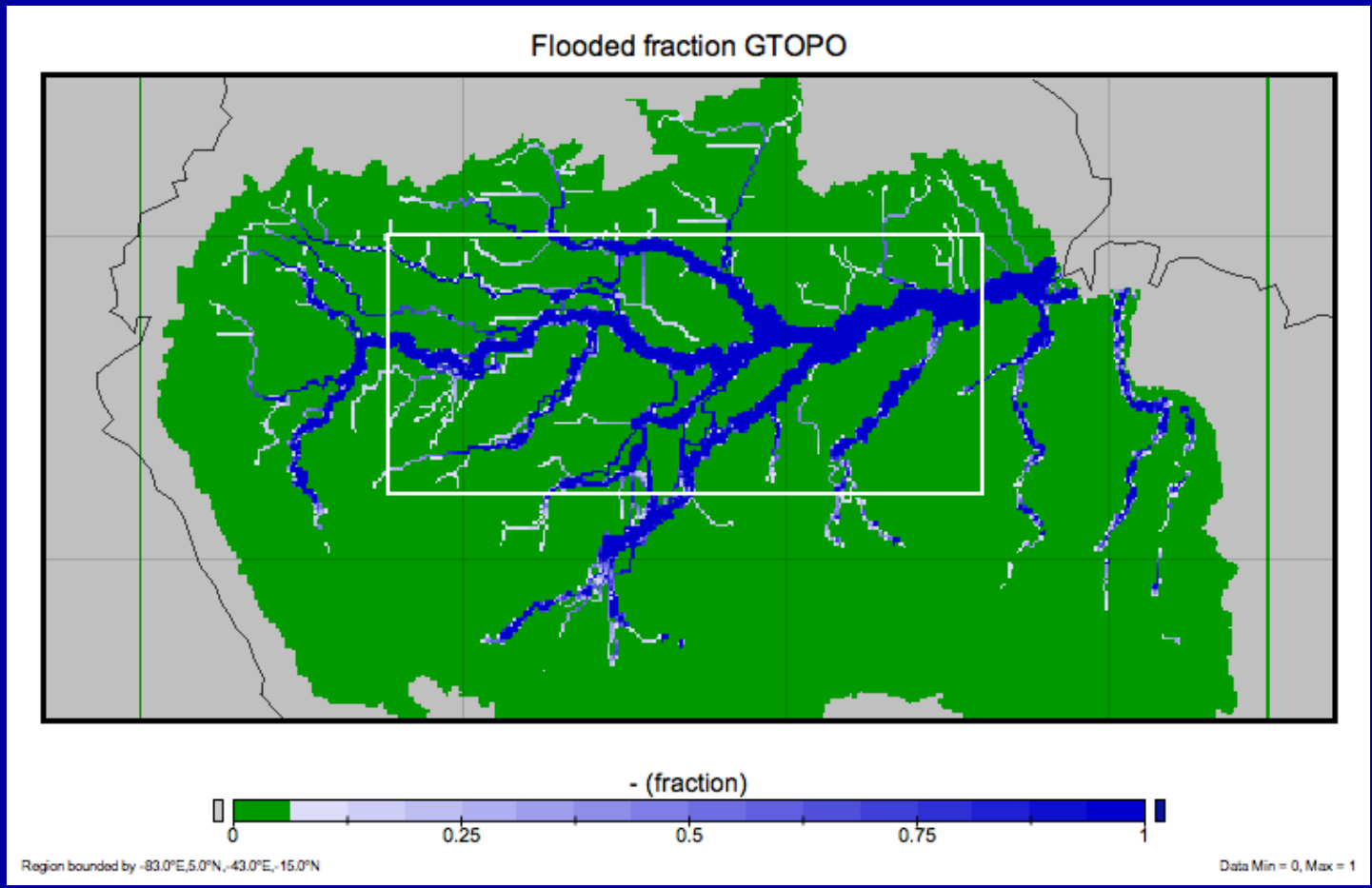
- Topography - in part determines the flooded area



Improvements

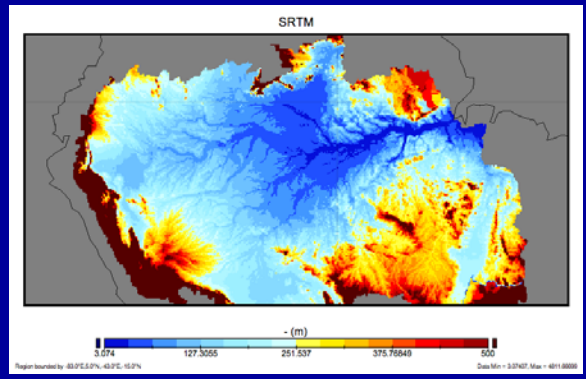
- Topography - GTOPO30 alone

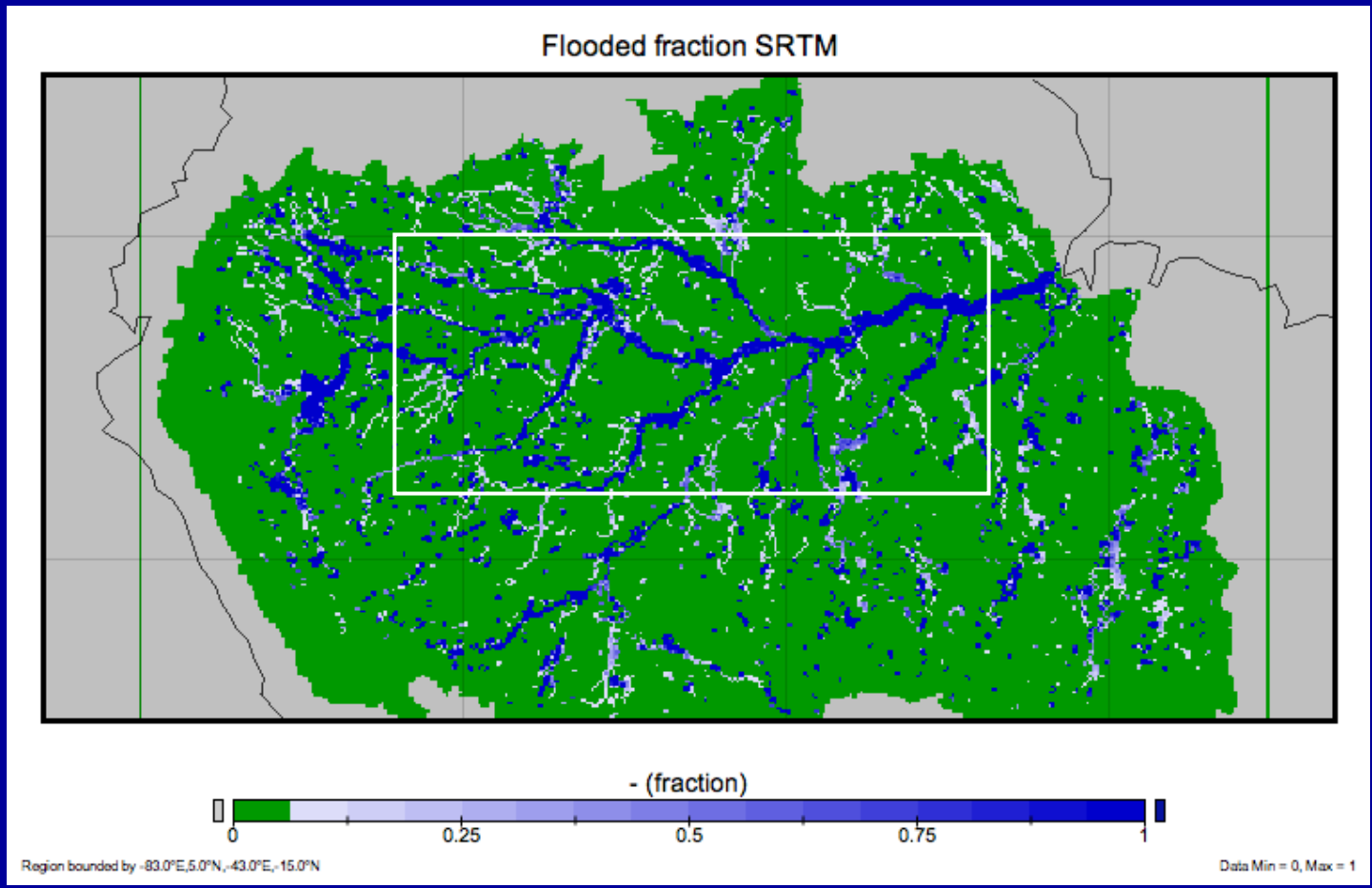




Improvements

- Topography - SRTM alone

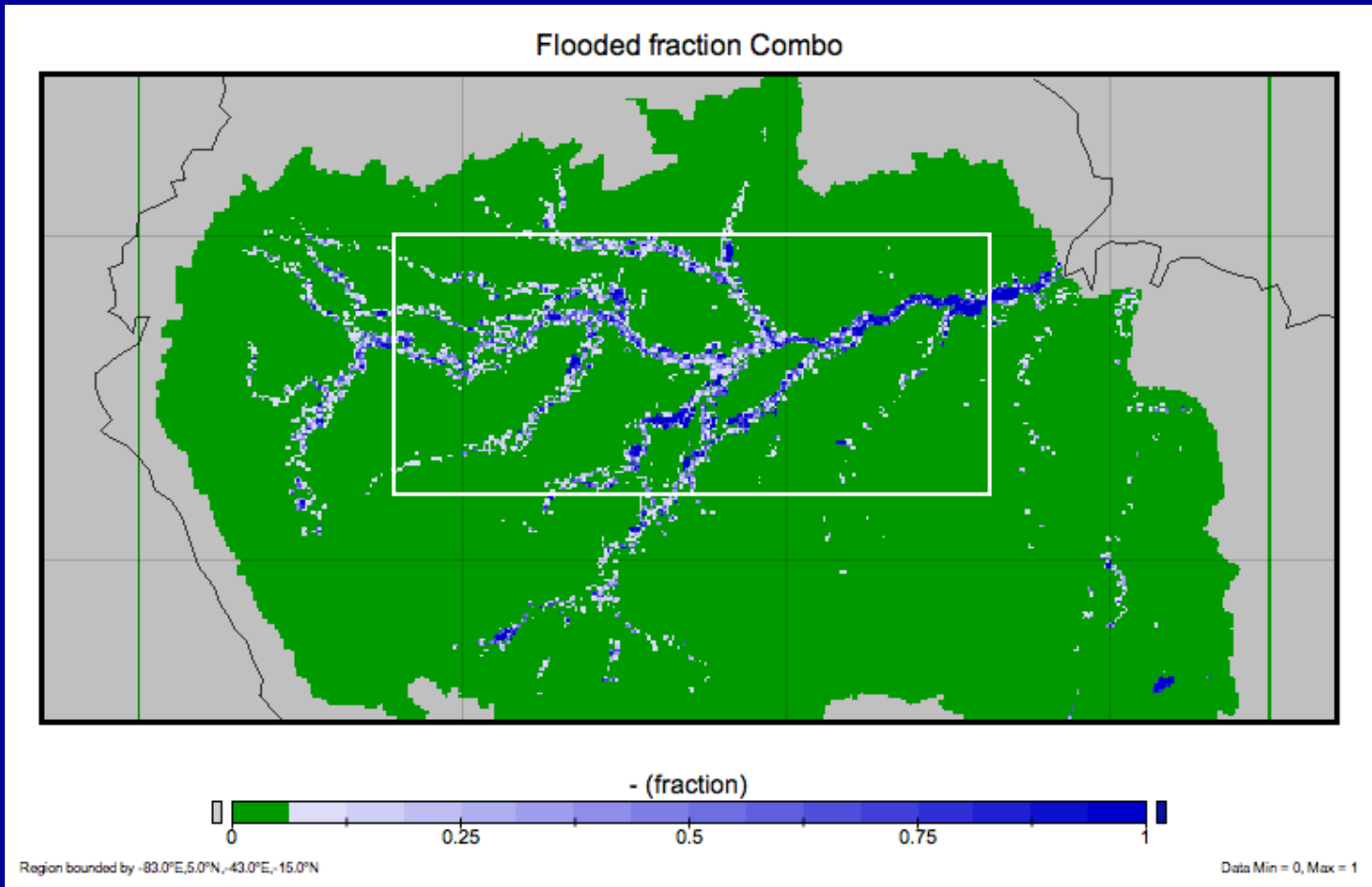




r = 0.50

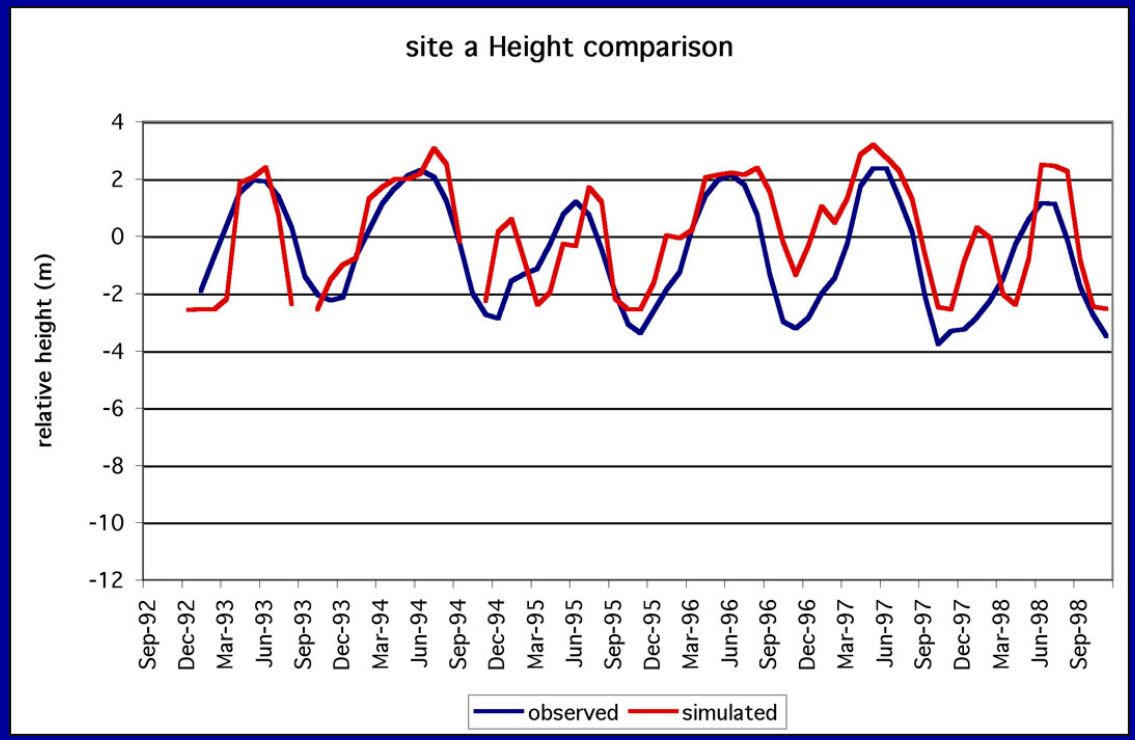
Improvements

- Topography - GTOPO30 with probability distribution of SRTM



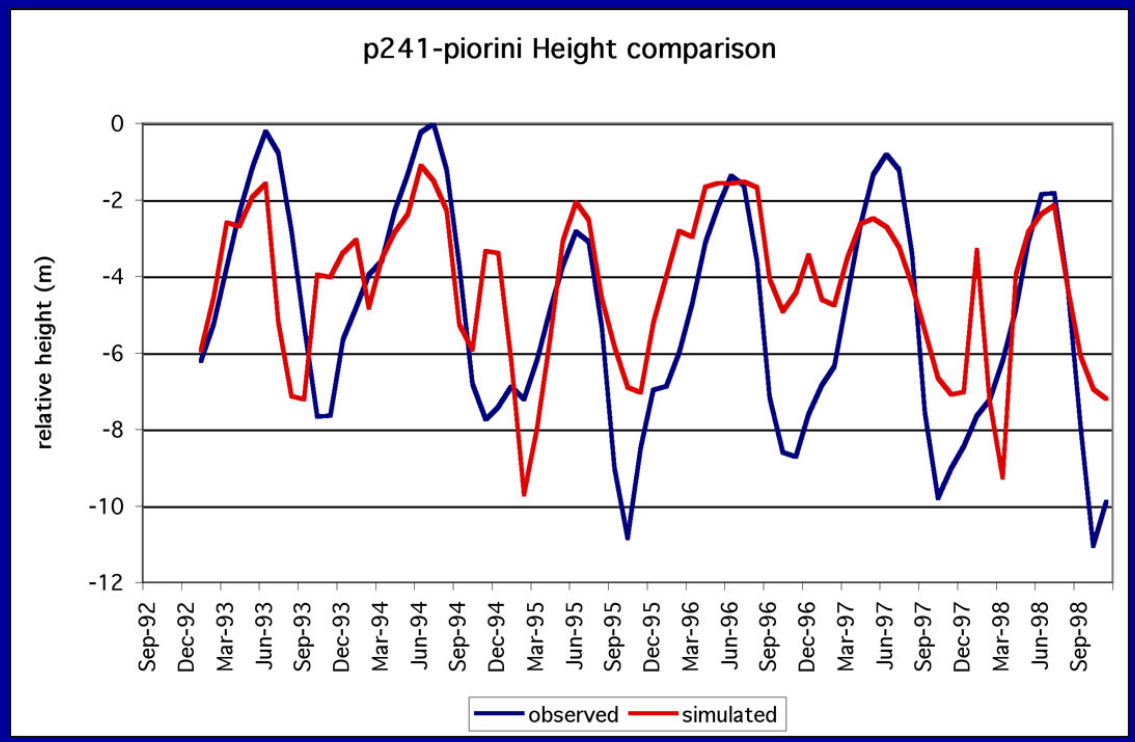
r = 0.54

Water height



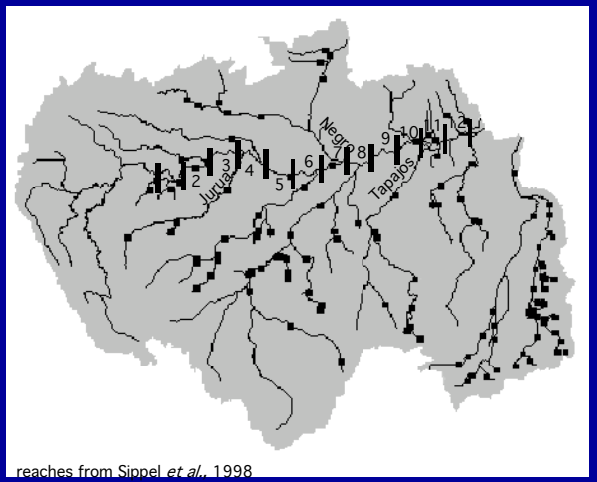
Comparison of relative water height measured by TOPEX/Poseidon radar altimeter and simulated by model. r = 0.75

Water height

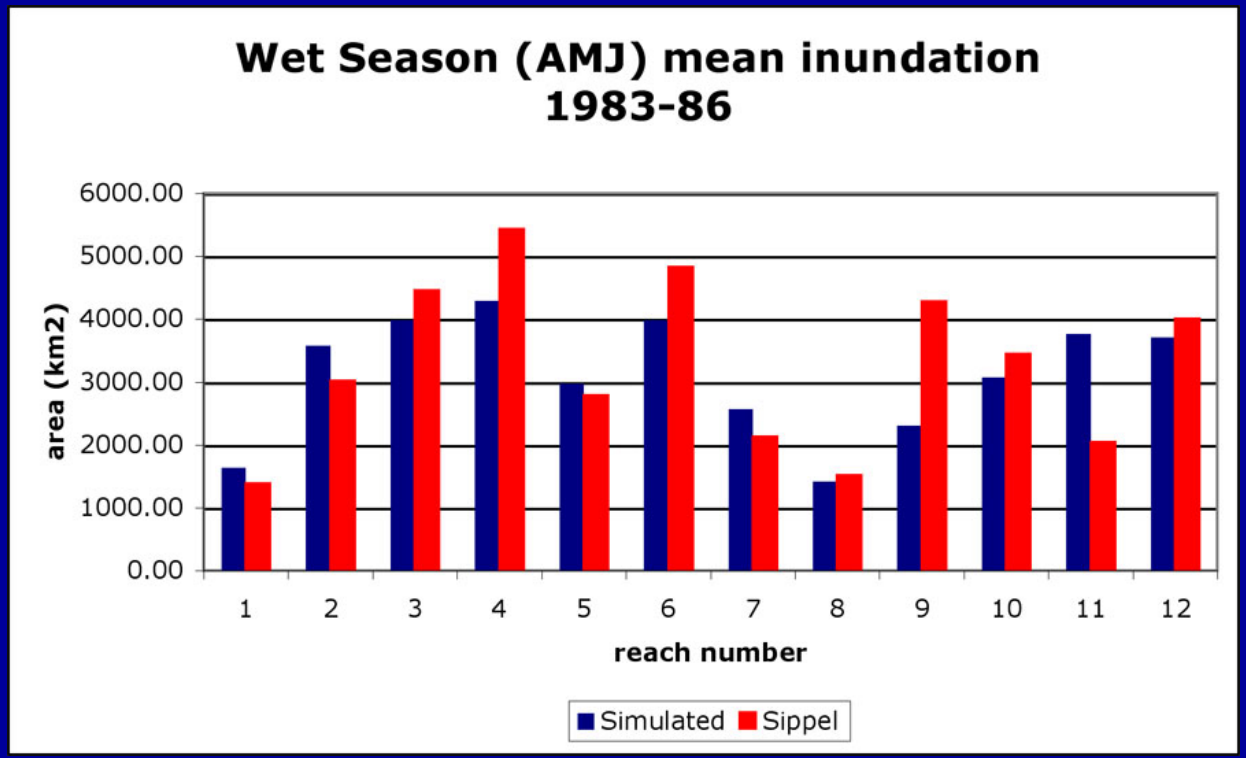


Comparison of relative water height measured by TOPEX/Poseidon radar altimeter and simulated by model. r = 0.67

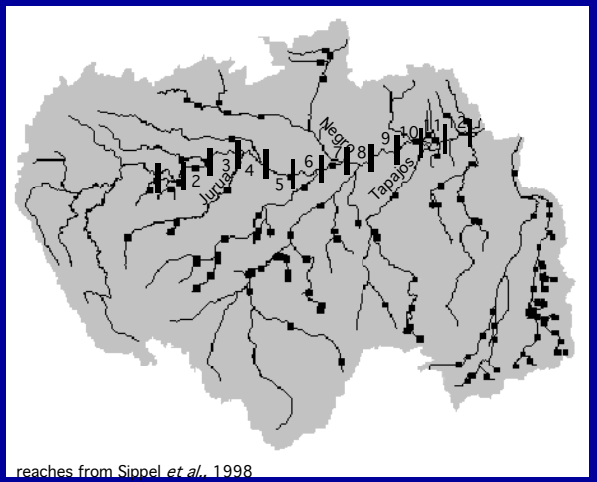
Water area



reaches from Sippel *et al.*, 1998



Water area



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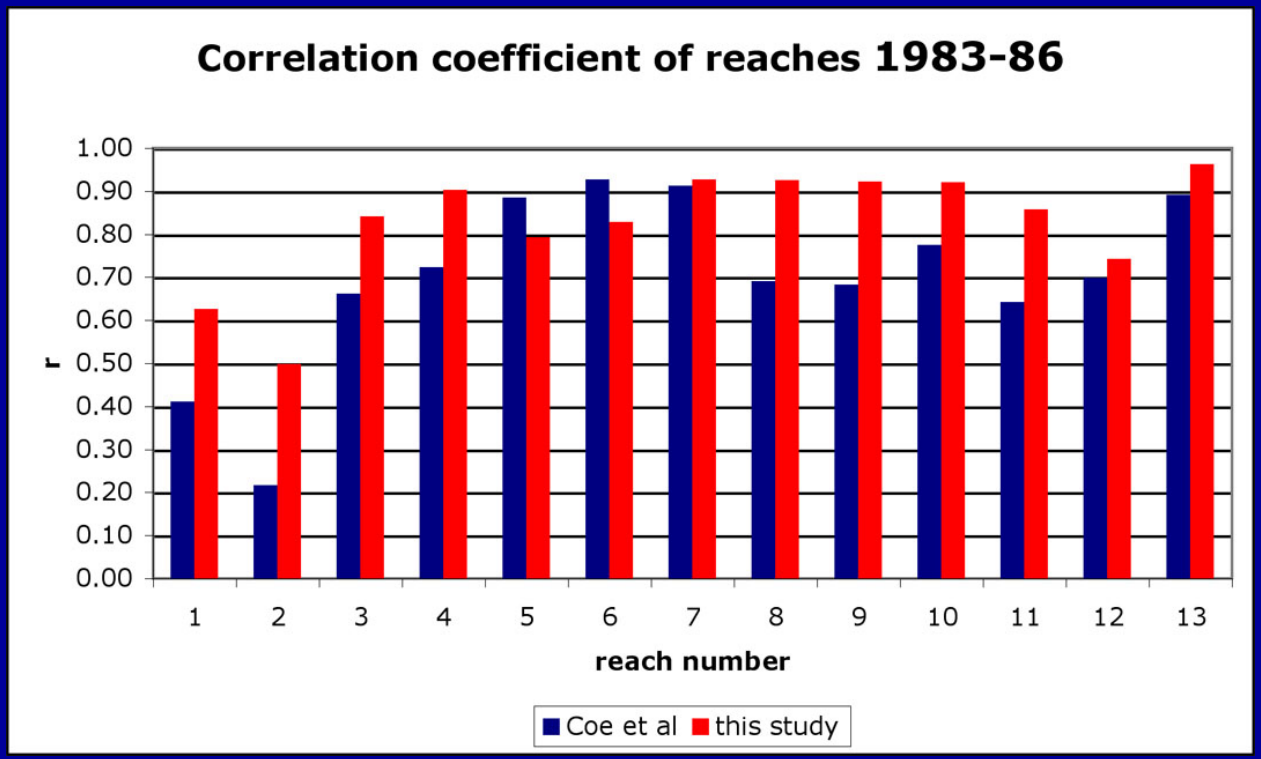
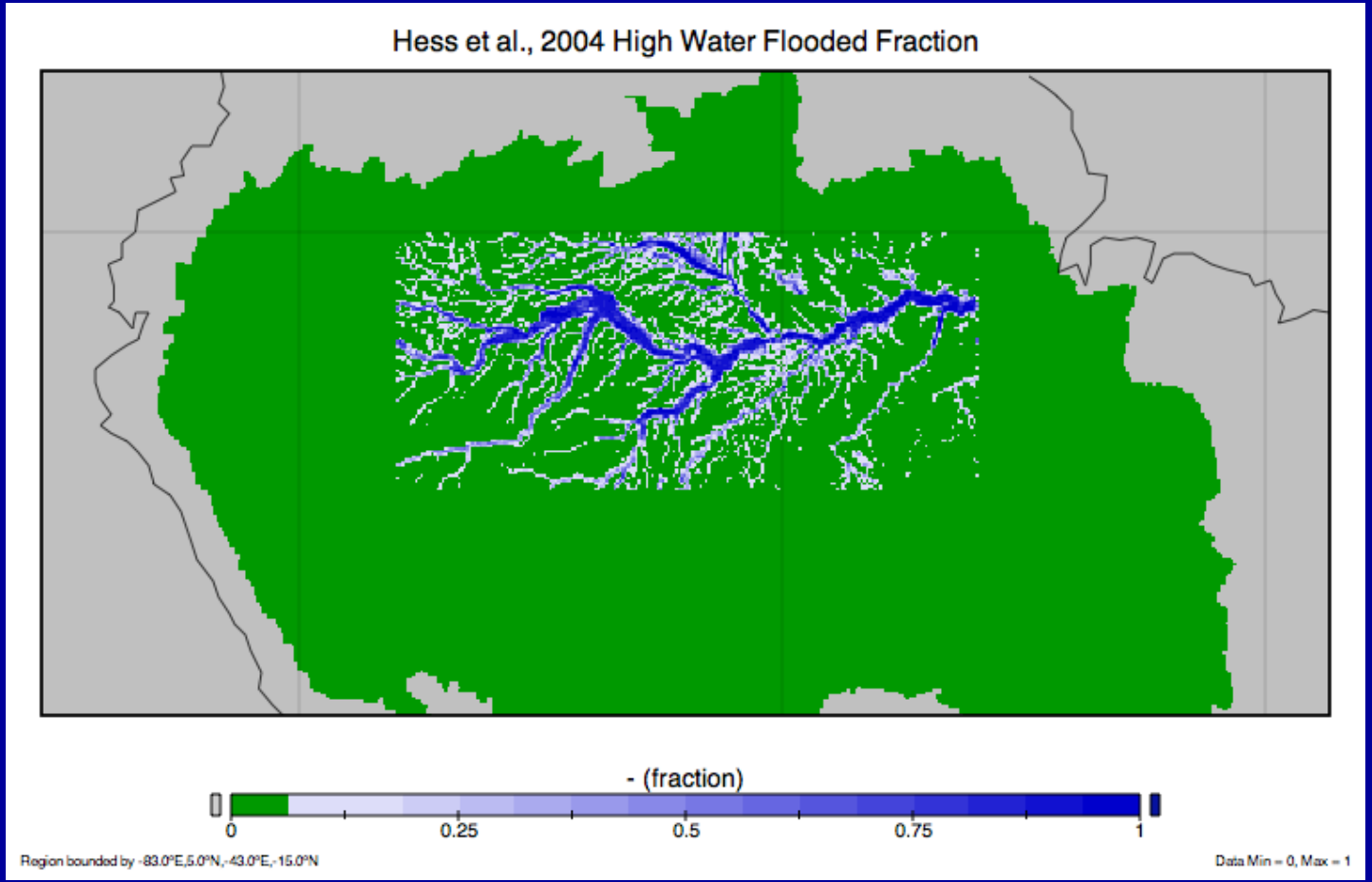
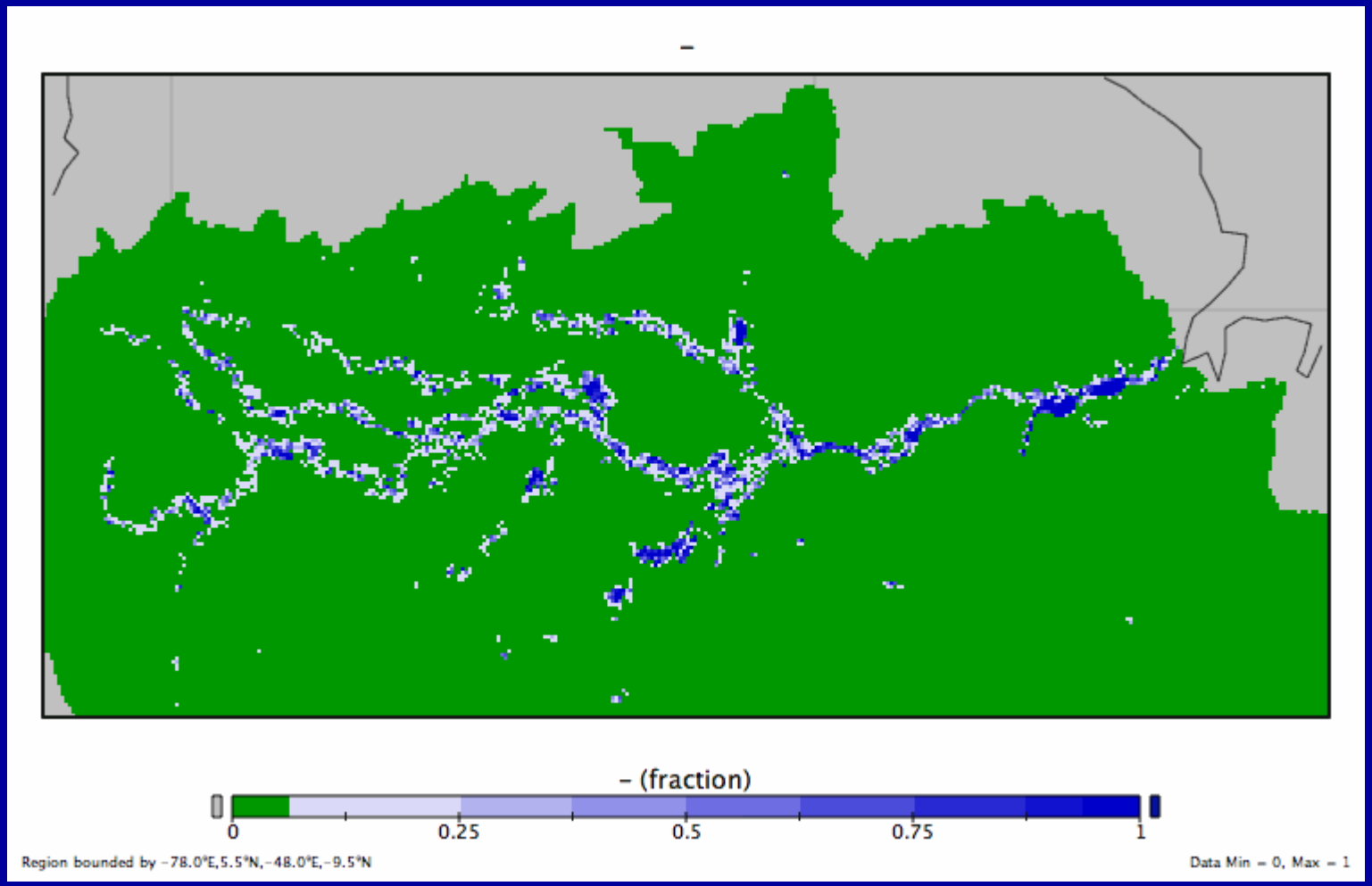


Water area


Hess et al., 2004 High Water Flooded Fraction
- (fraction)
0
0.25
0.5
0.75
1
Region bounded by -83.0°E,5.0°N,-43.0°E,-15.0°N
Data Min = 0, Max = 1

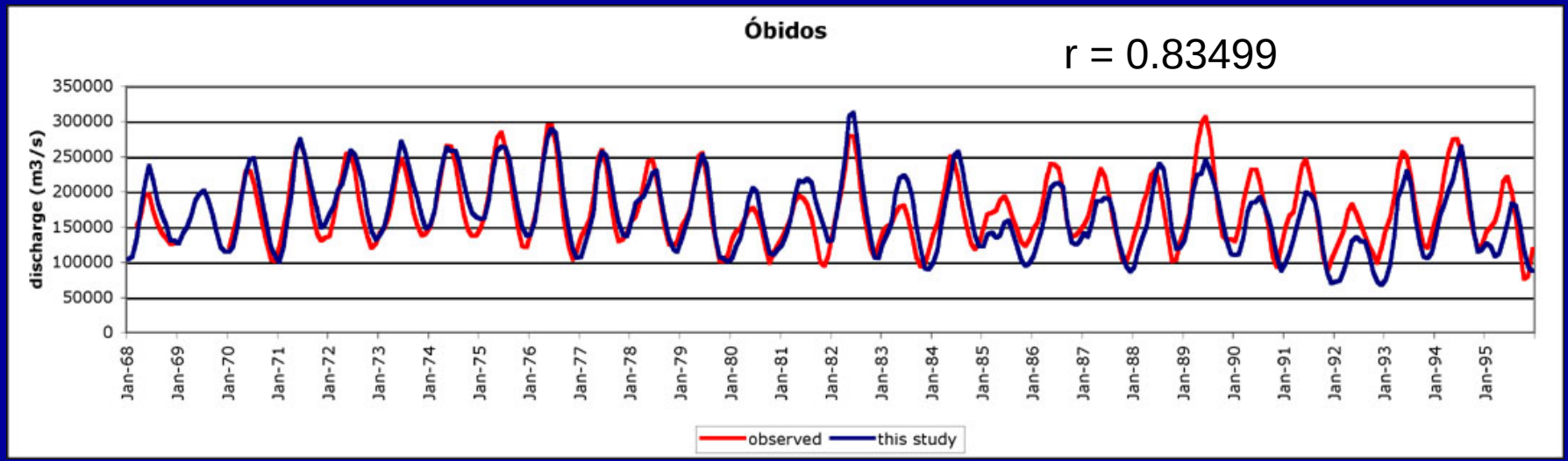
Flooding


– (fraction)
0
0.25
0.5
0.75
1
Region bounded by -78.0°E,5.5°N,-48.0°E,-9.5°N
Data Min = 0, Max = 1

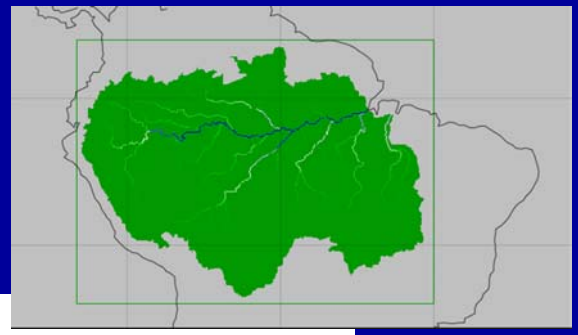
Conclusions

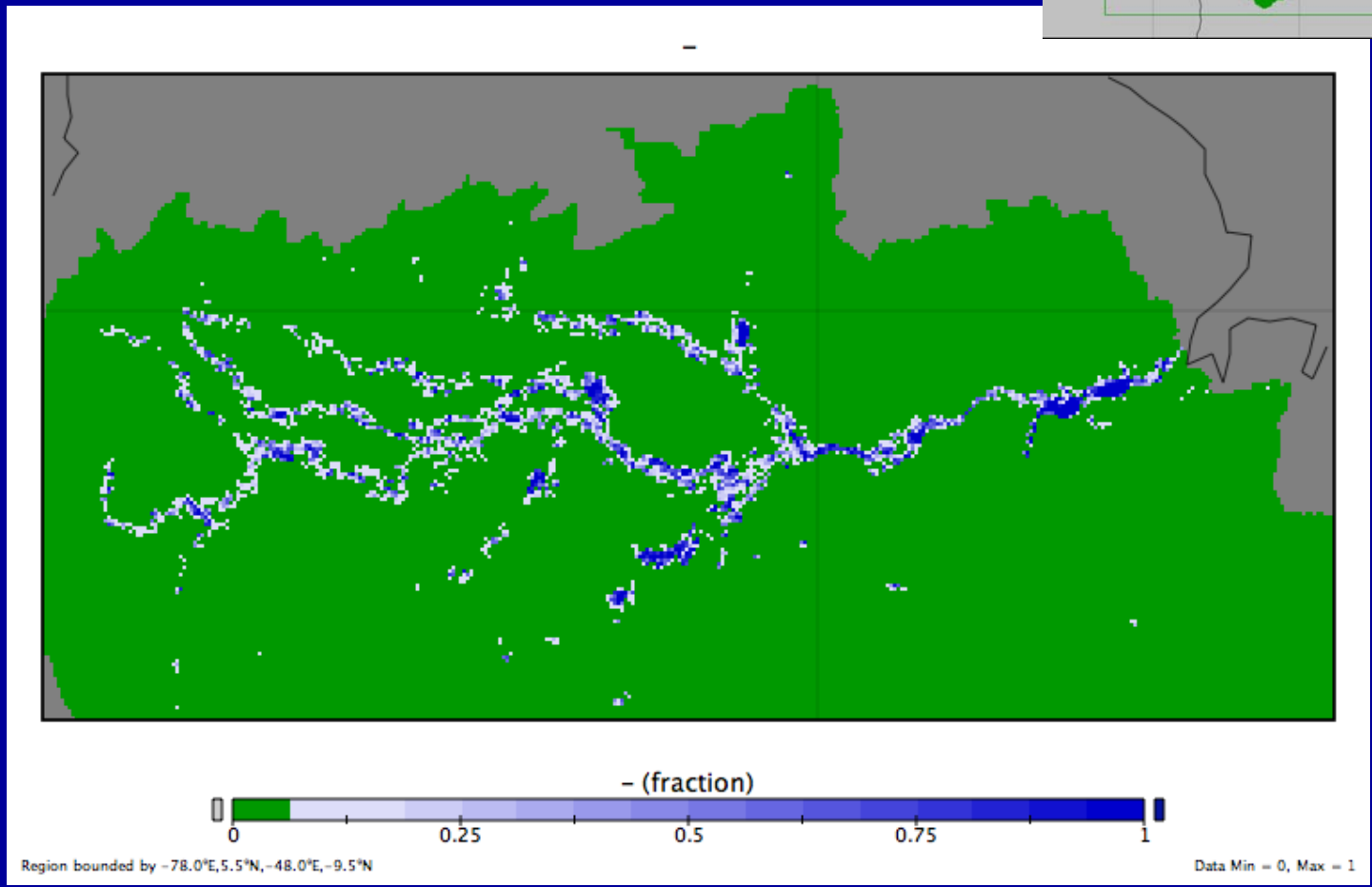
- Improvements to model provide better representation of seasonal and inter-annual behavior of the River system
- Work remains to be done on the surface topography data but physical characteristics of floodplain are improved.
- Model is being used to analyze hydrologic variability and sensitivity to change within the basin
- Can incorporate C and nutrient cycling within model structure
- With new high resolution river products can be run at numerous resolutions (90m, 500m, and 5-minute).

Discharge - inter-annual variability



Flooding

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– (fraction)
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0.25
0.5
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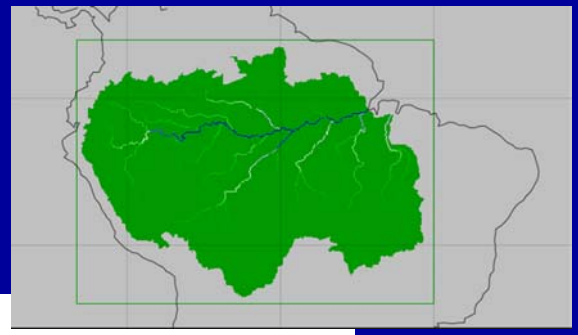
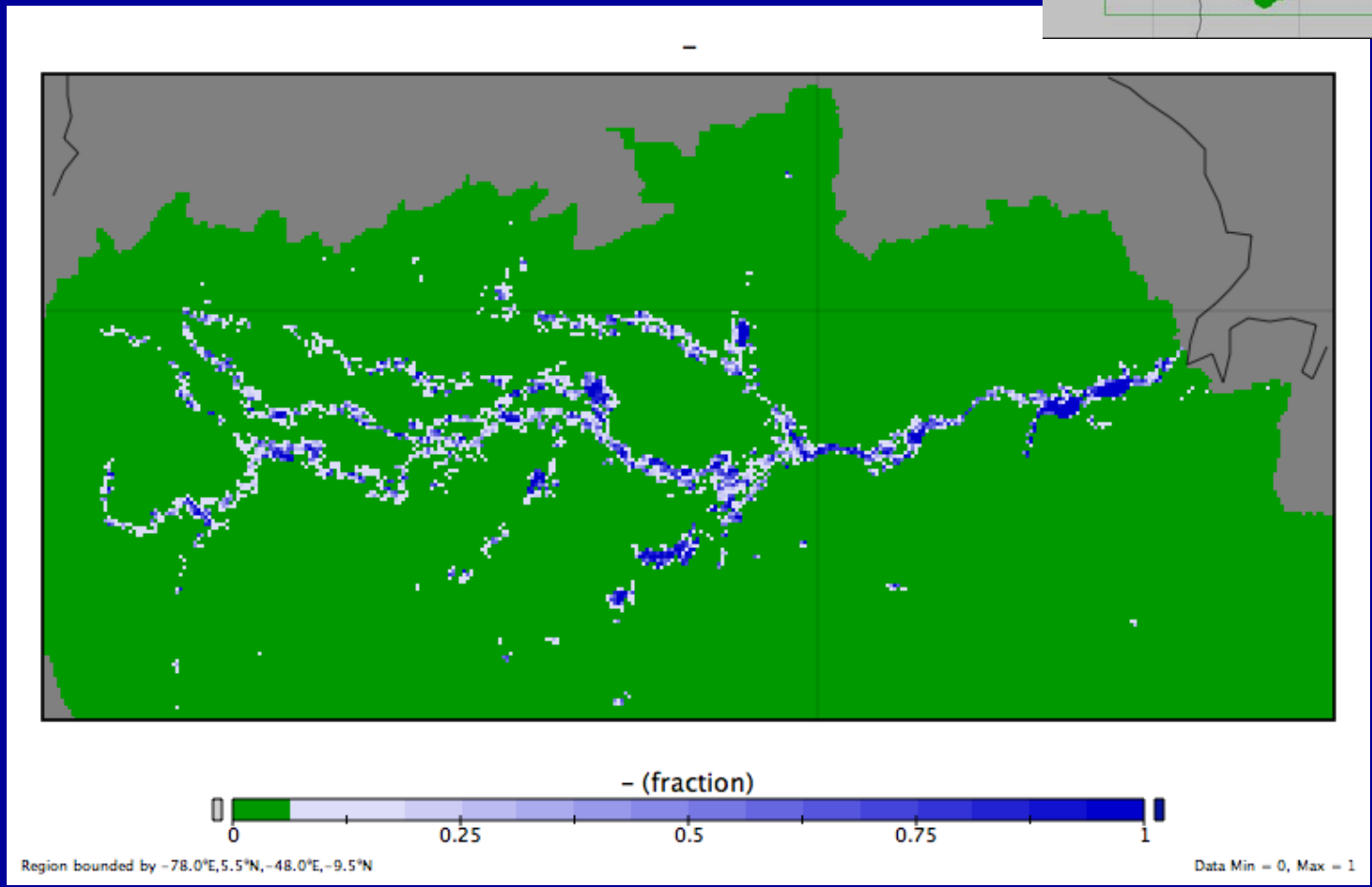
1
Region bounded by -78.0°E,5.5°N,-48.0°E,-9.5°N
Data Min = 0, Max = 1

Flooding

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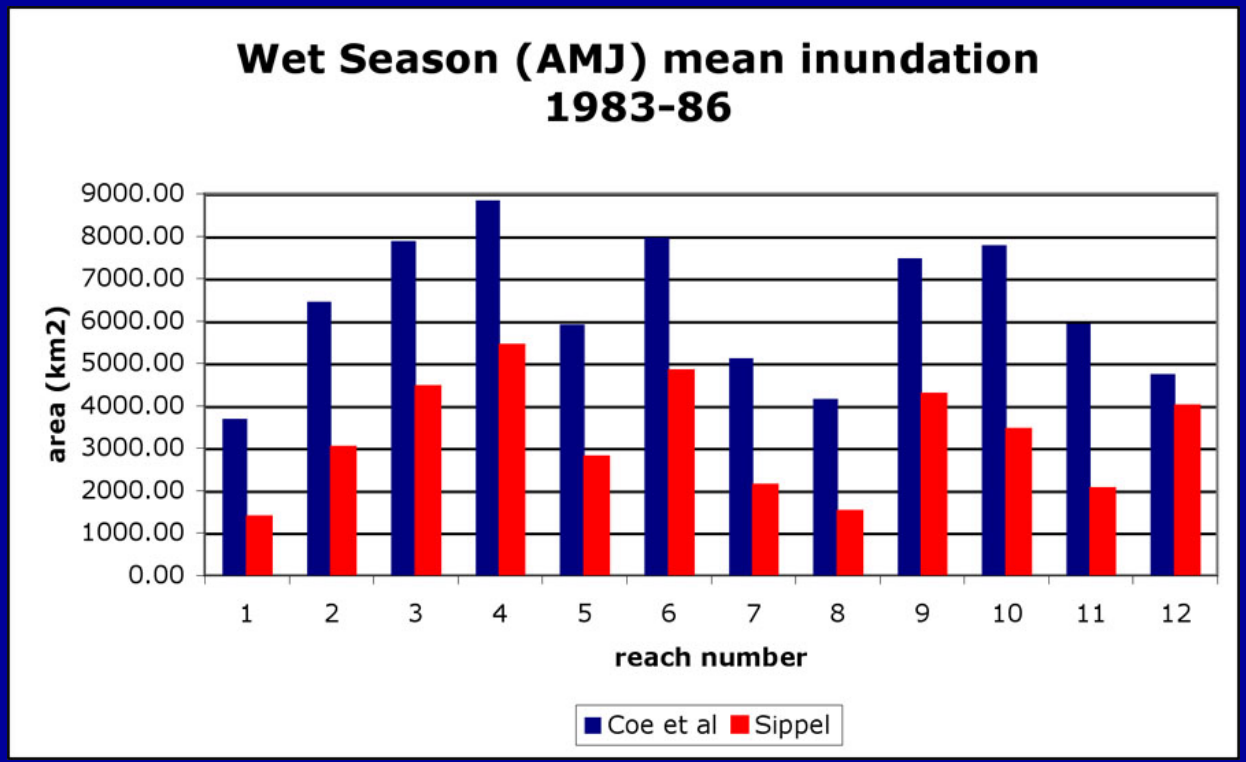
– (fraction)
0
0.25
0.5
0.75
1
Region bounded by -78.0°E,5.5°N,-48.0°E,-9.5°N
Data Min = 0, Max = 1

Water area


Wet Season (AMJ) mean inundation
1983-86
9000.00
8000.00
7000.00
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
area (km2)
1
2
3
4
5
6
7
8
9
10
11
12
reach number
Coe et al
Sippel