Numerical Analysis of the Amazon River

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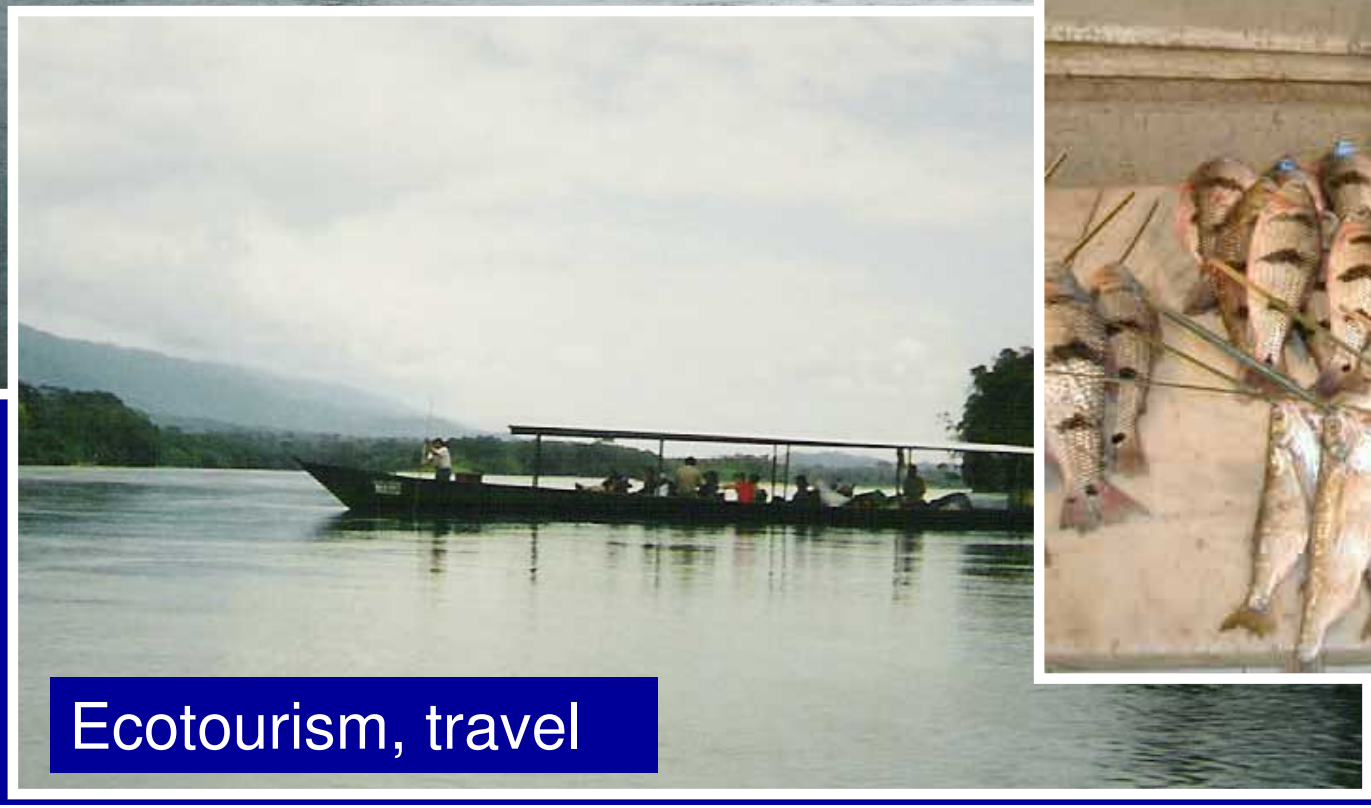
Amazon is central to …

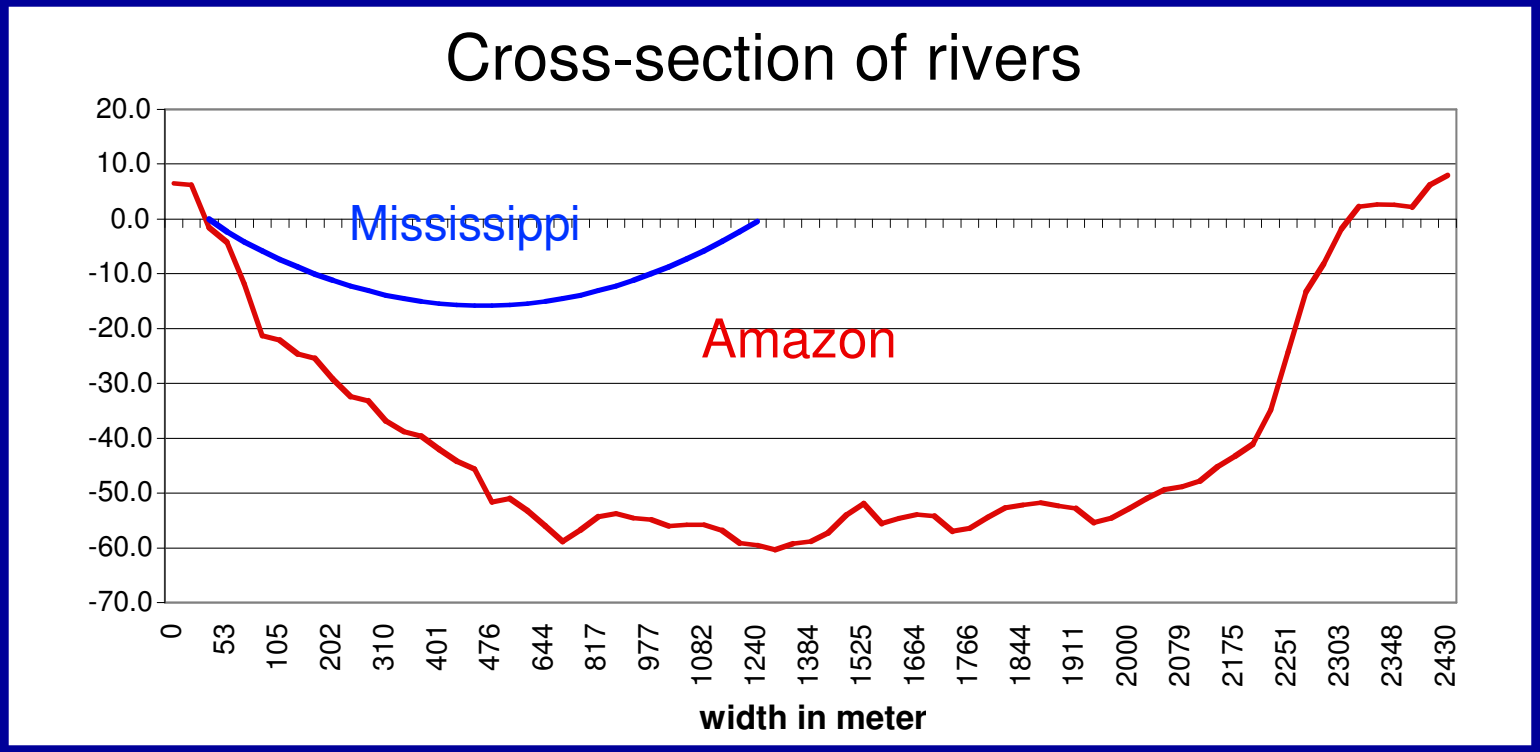


Introduction

It is variable as function of:

- Natural climate variability
- Human changes to land and river
- Global climate change

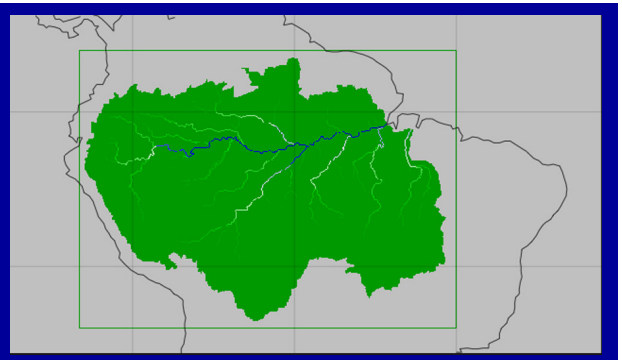
Introduction



It is globally important:

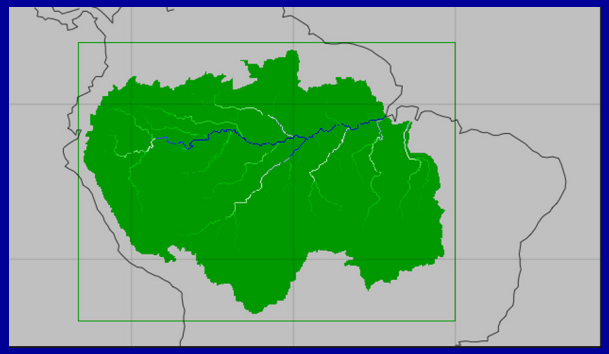
- Scale of the Amazon means variability has global implications

Introduction



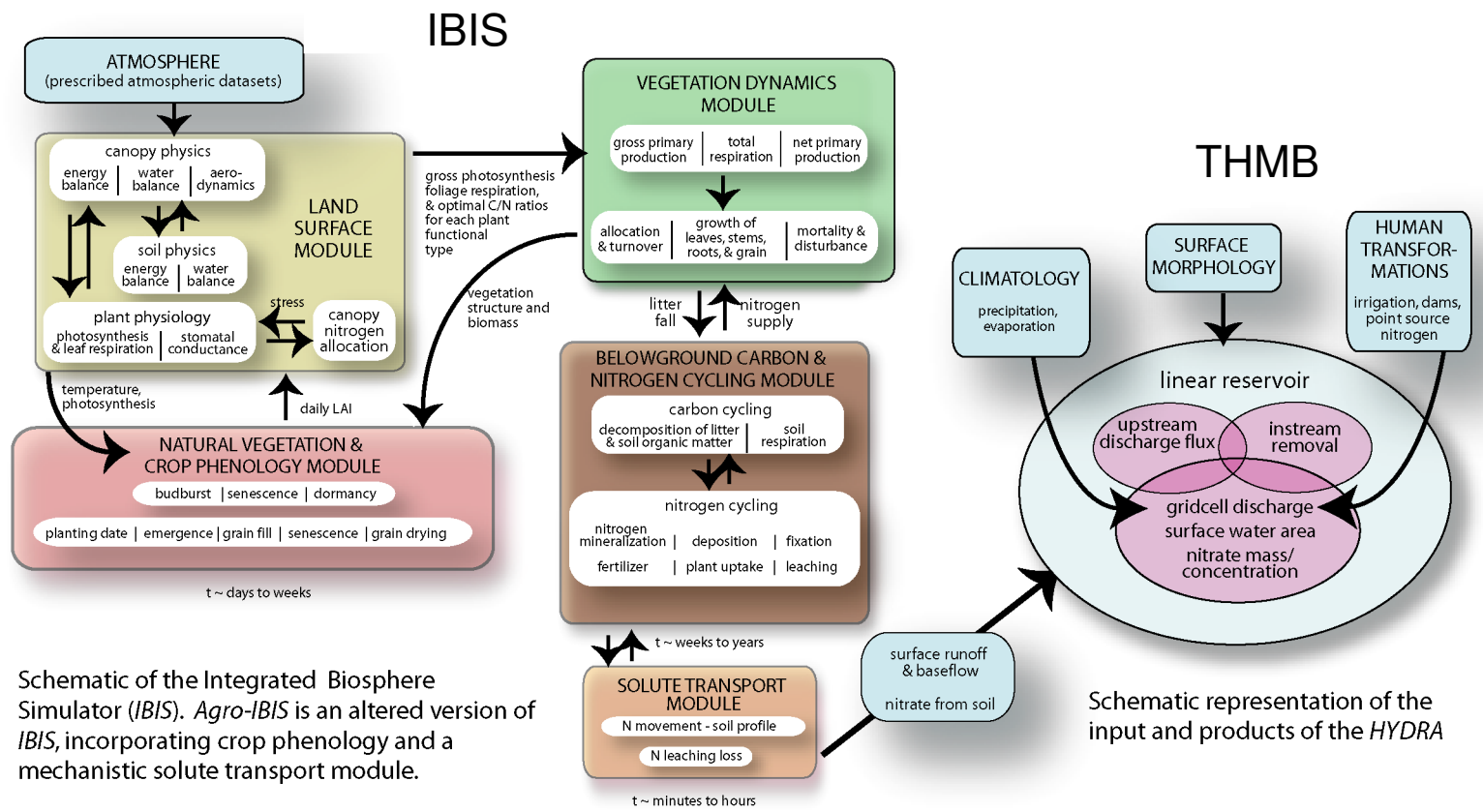
- Would like to address questions about large-scale hydrology of Amazonia such as:
  - How much water, and of what quality, is in the soils, rivers, and floodplains?
  - How variable is it in time and space?
  - How is it linked to atmosphere, vegetation and soil characteristics?
  - How might physical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

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, wetlands, and lakes

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

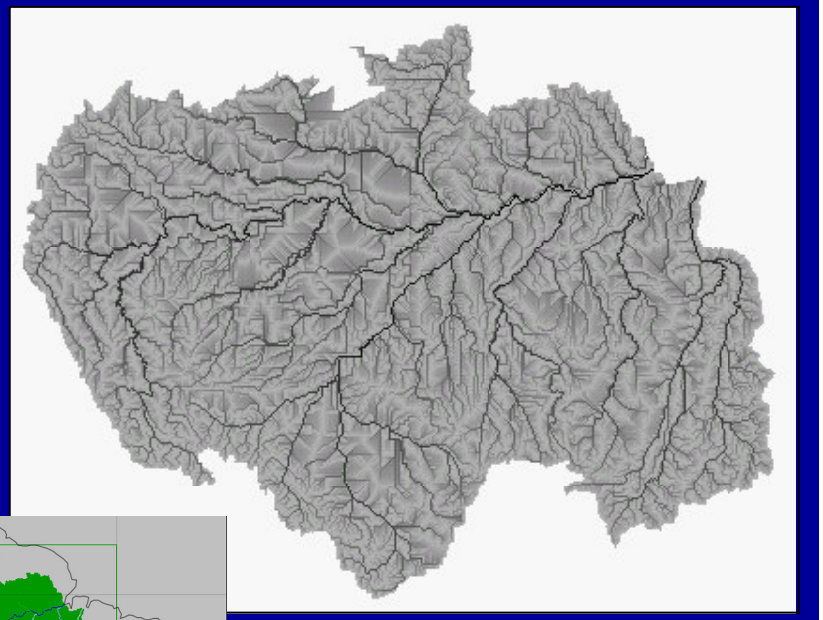
IBIS-THMB models

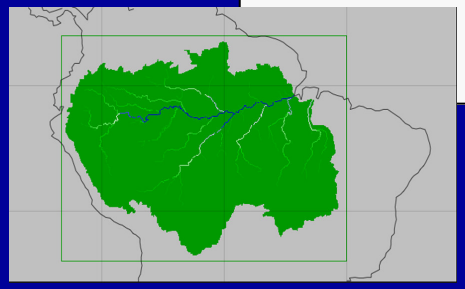
- Use climate (precipitation, temperature, solar radiation, humidity, and wind speed), land cover, and land use data to derive:
  - a temporally and spatially varying representation of aquatic ecosystems.

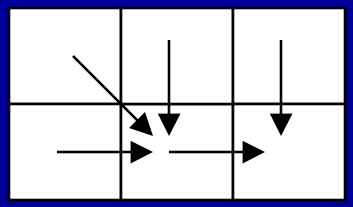
THMB

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

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

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)

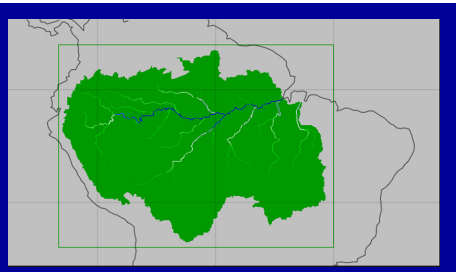
$F_{out} = V(u/d)$ (discharge)

- Calculates river volume, discharge, and flooded area 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

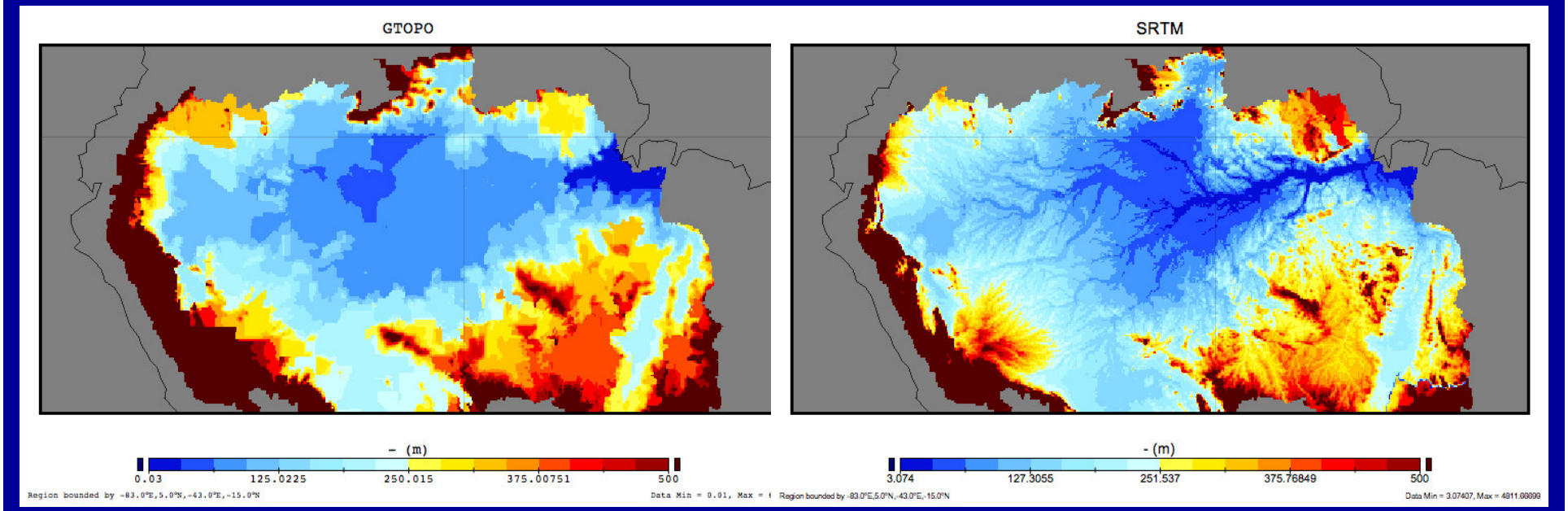
Improvements from Coe et al., 2002

- 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 - use SRTM DEM
- Runoff - add correction to runoff or IBIS to account for poor data in Andes

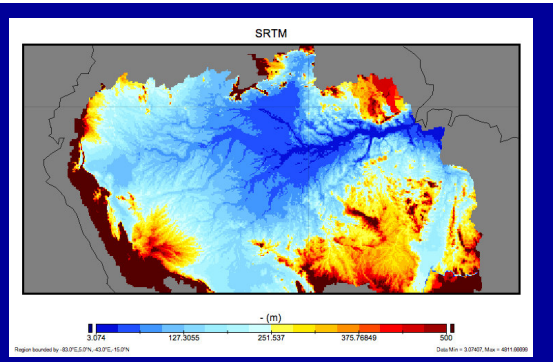
Further Improvements



- SRTM DEM - Remove forest
  - Subtract constant of 23 m where forest is present in 1km Hess et al., 2003 forest delineation
  - Cell elevation average of all 1km cells in 5-minute THMB cell
  - Filled pits using ArcGIS



Further Improvements



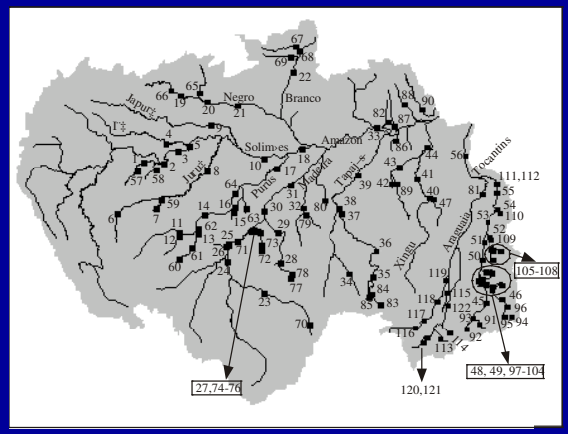
- Flooded area with sub-grid scale topography
  - Create standard normal distribution based on 1km resolution SRTM topography
  - Calculate critical value (z_x) and probability distribution for that z_x.

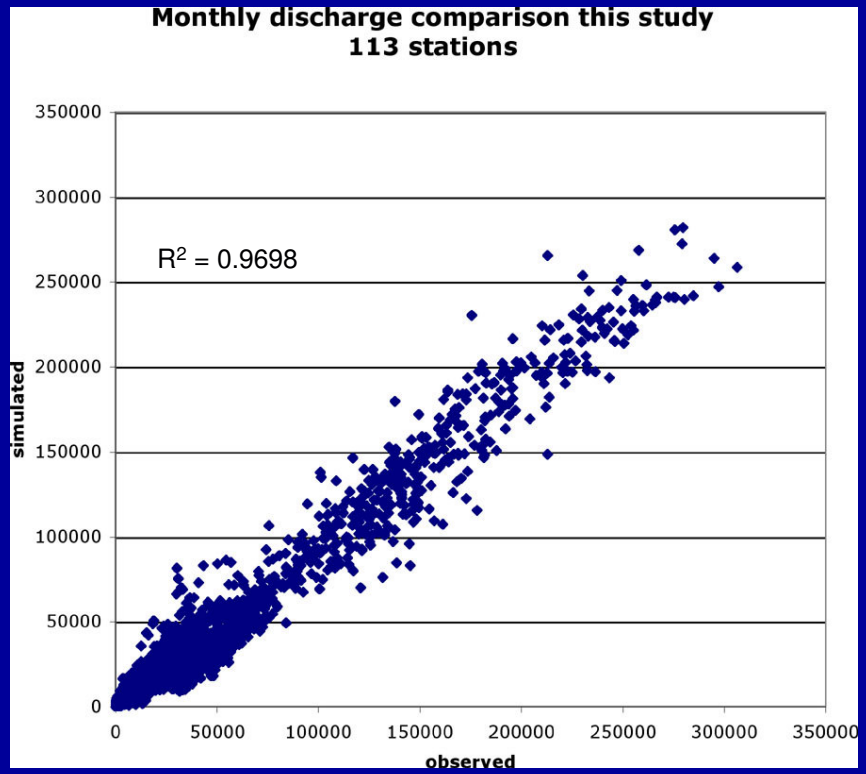
$$z_x = \log(W_f / W_5)$$

$$p(z_x) = [e(-z_x^2/2)]/(2\pi)^{1/2}$$

  - Fraction of flooded area is the cumulative distribution function calculated numerically as the sum of the probability distribution from -4σ to z_x

Analysis -- Discharge





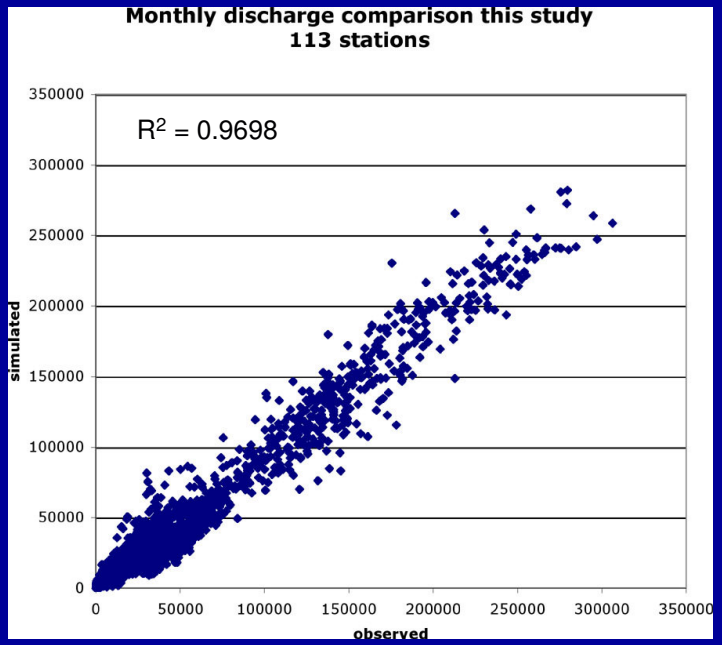
113 stations, ~26,600 months of data not used in calibration

Comparison to Coe et al., 2002

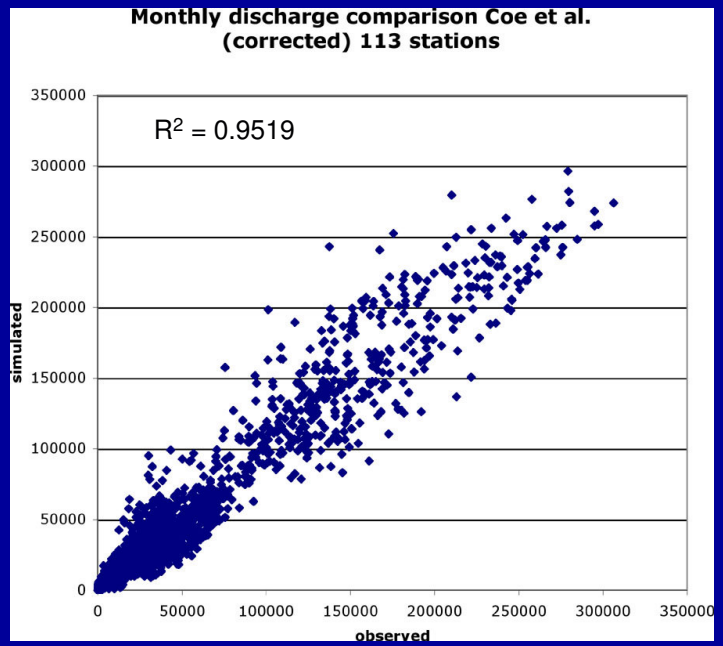
Re-ran Coe et al., 2002 model with identical corrected discharge of this study

Any differences are due to model differences alone

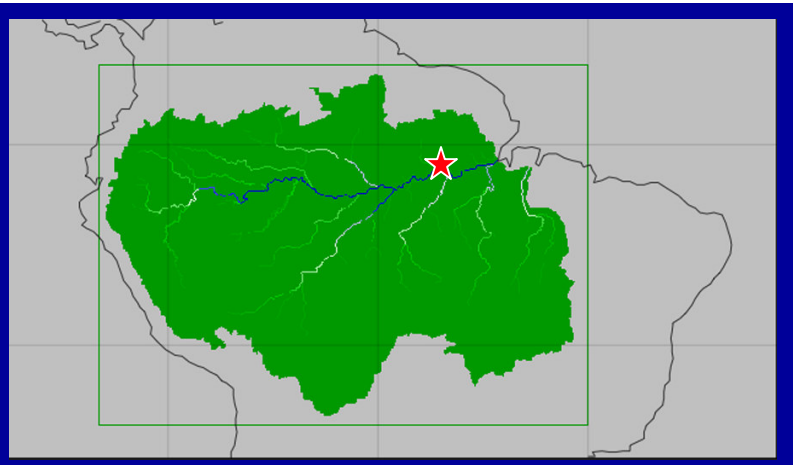
This study

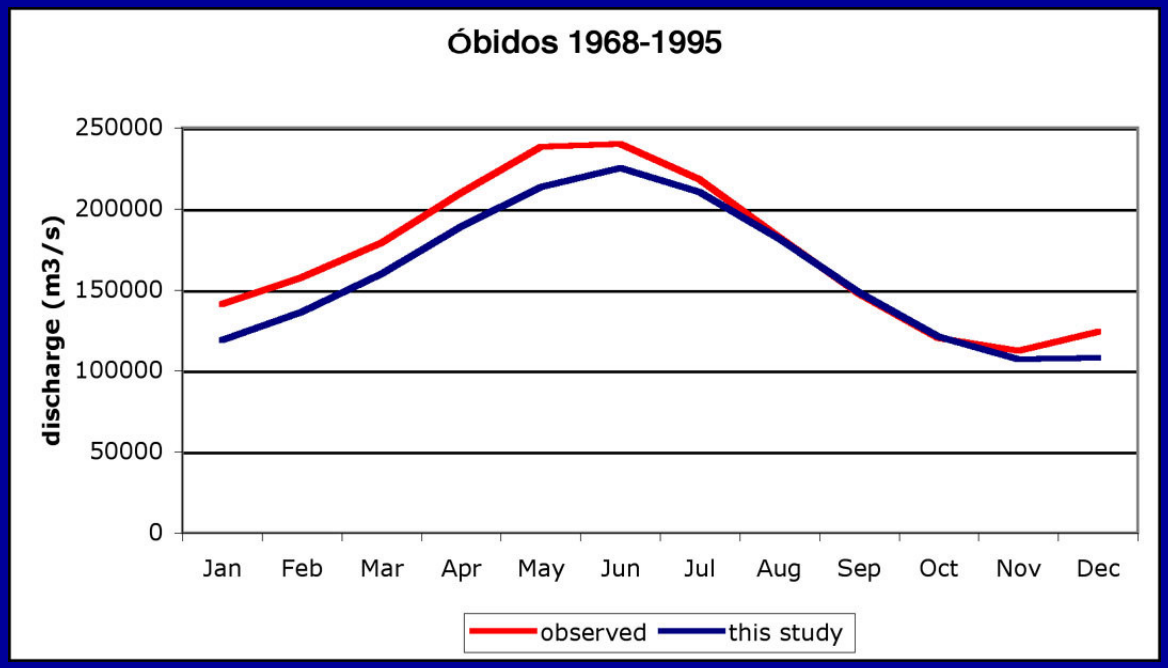


Coe02-C



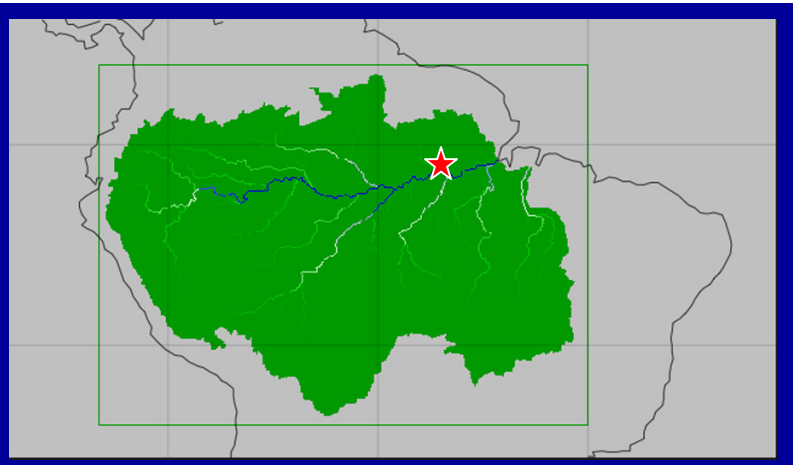
Discharge -- Óbidos

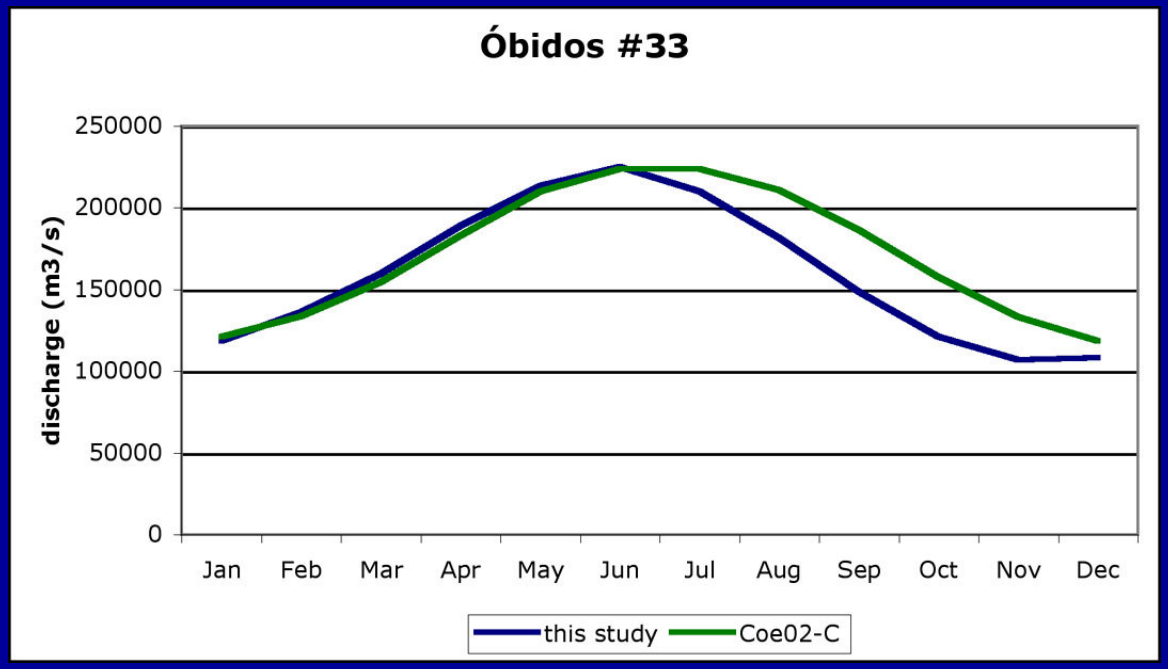




$r^2 = 0.957$

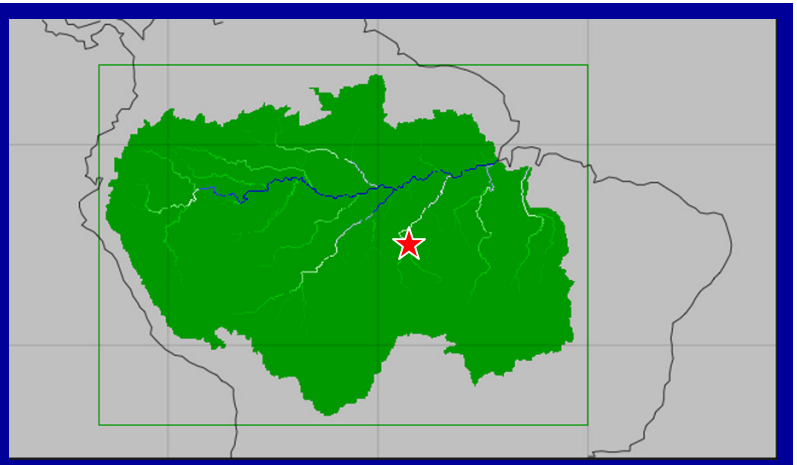
Discharge -- Óbidos

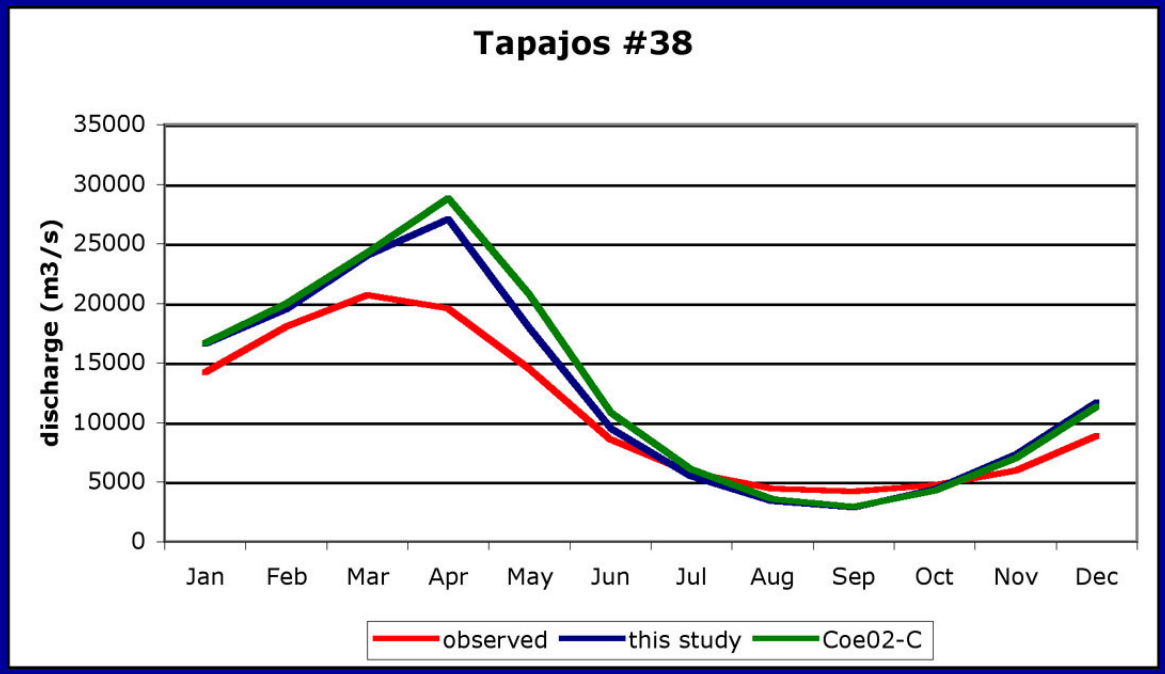




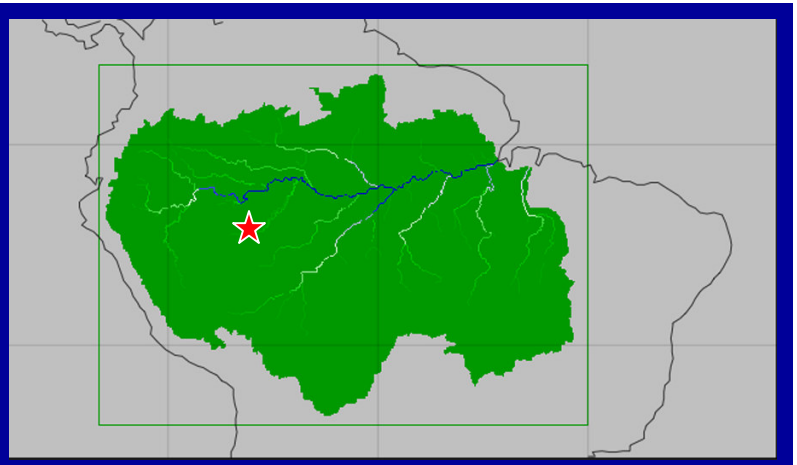
This study r^2 = 0.957, Coe02 r^2 = 0.677

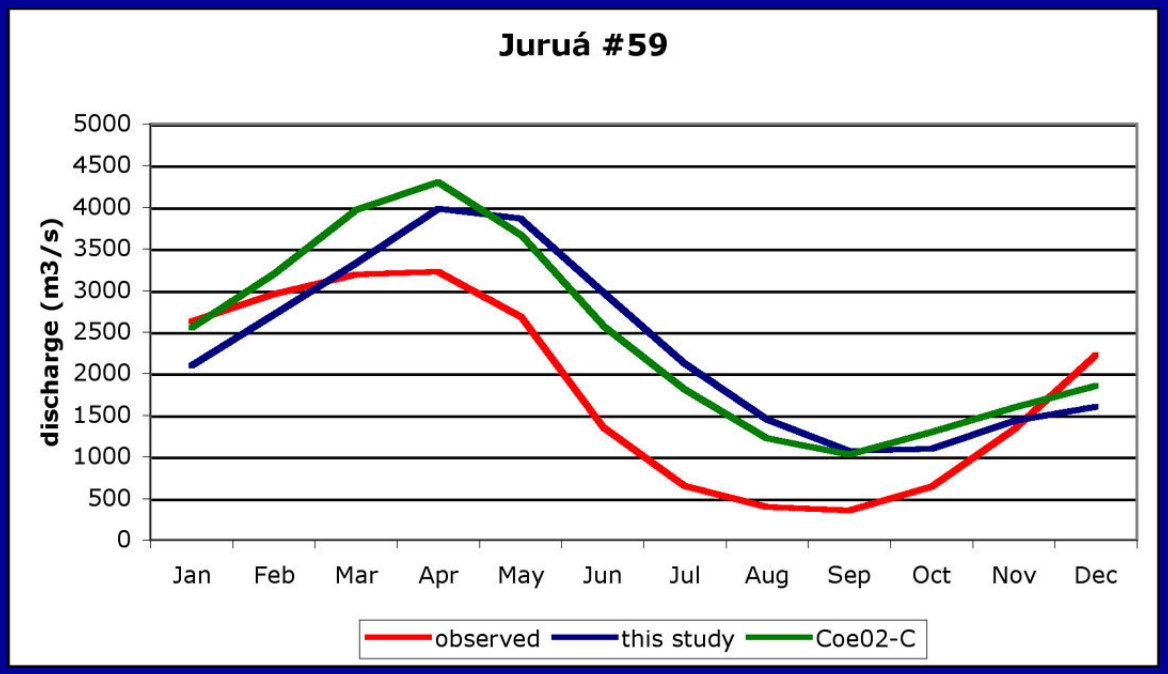
Discharge -- Tapajós



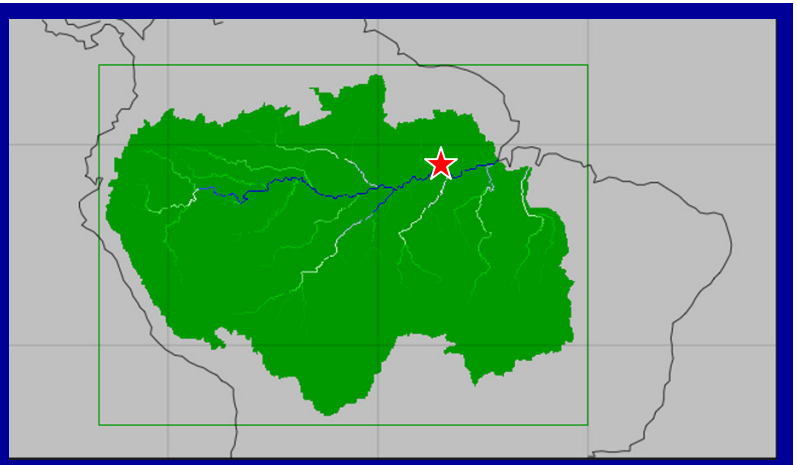


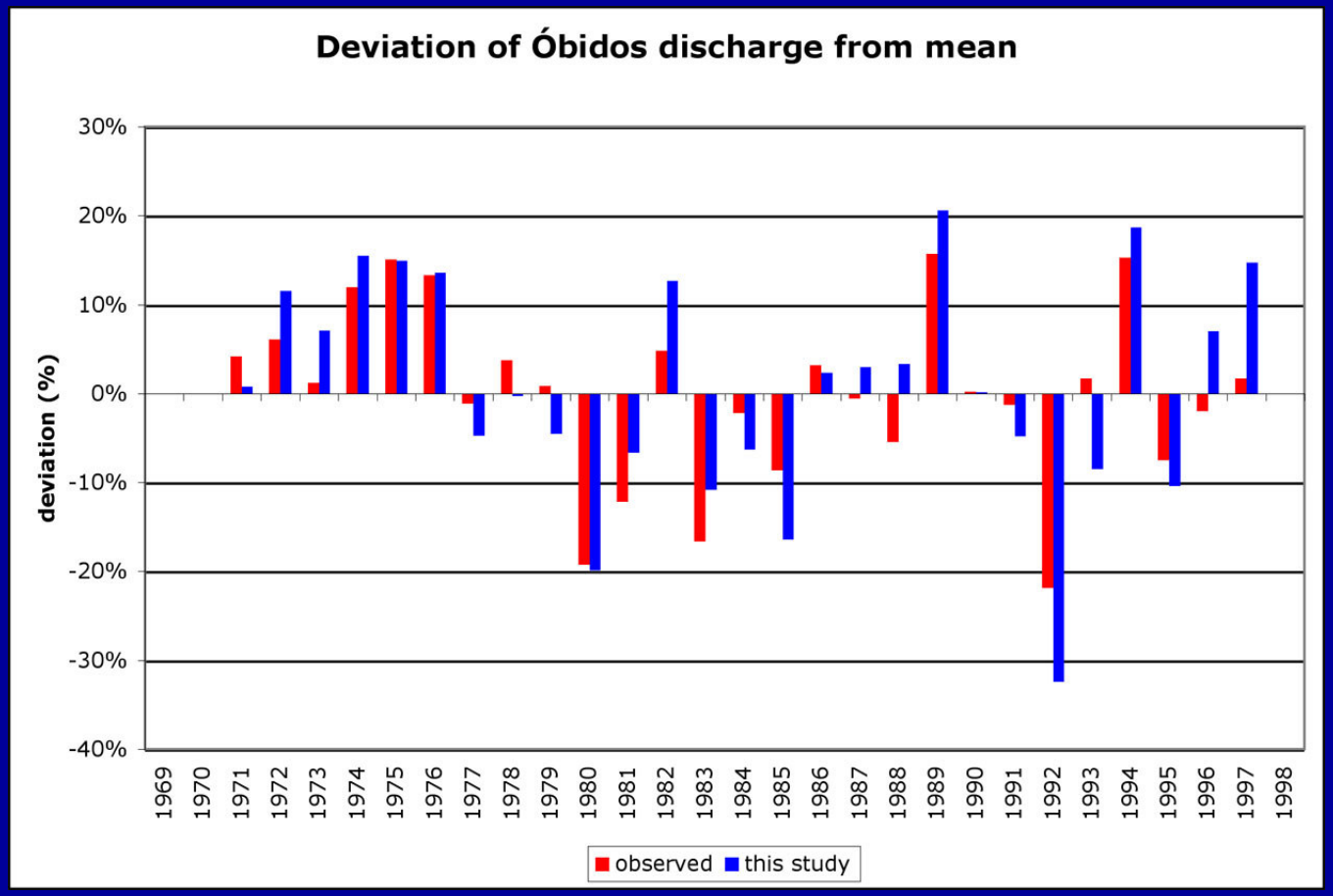
Discharge -- Juruá





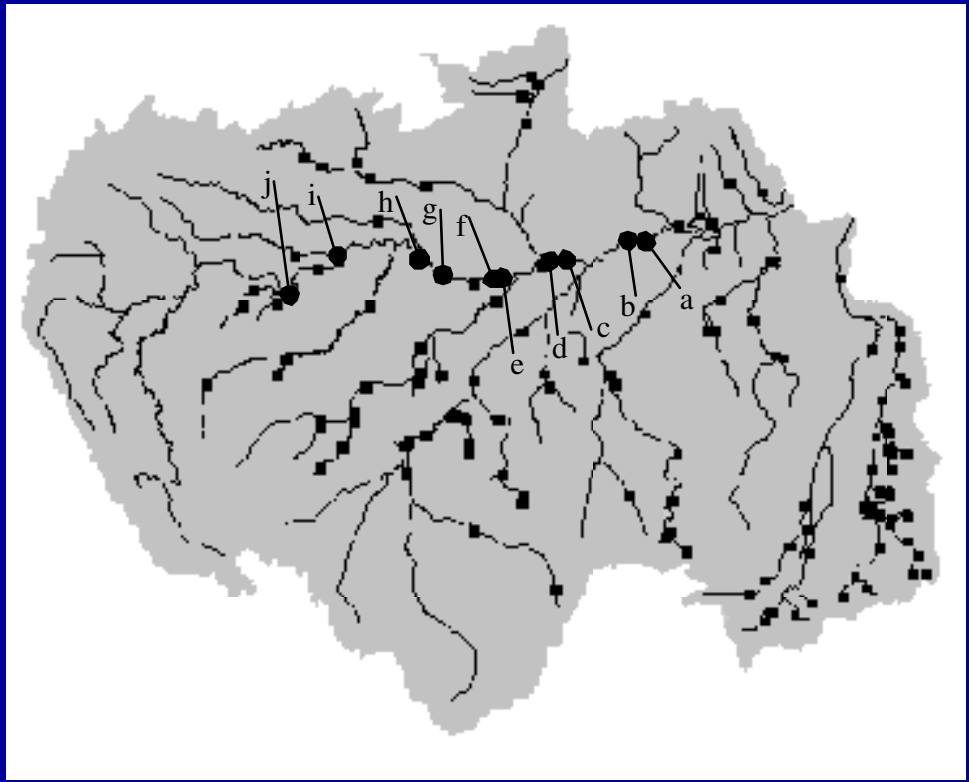
Discharge -- Óbidos, deviation



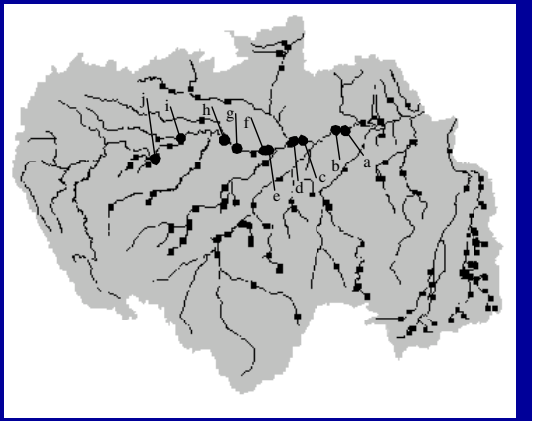


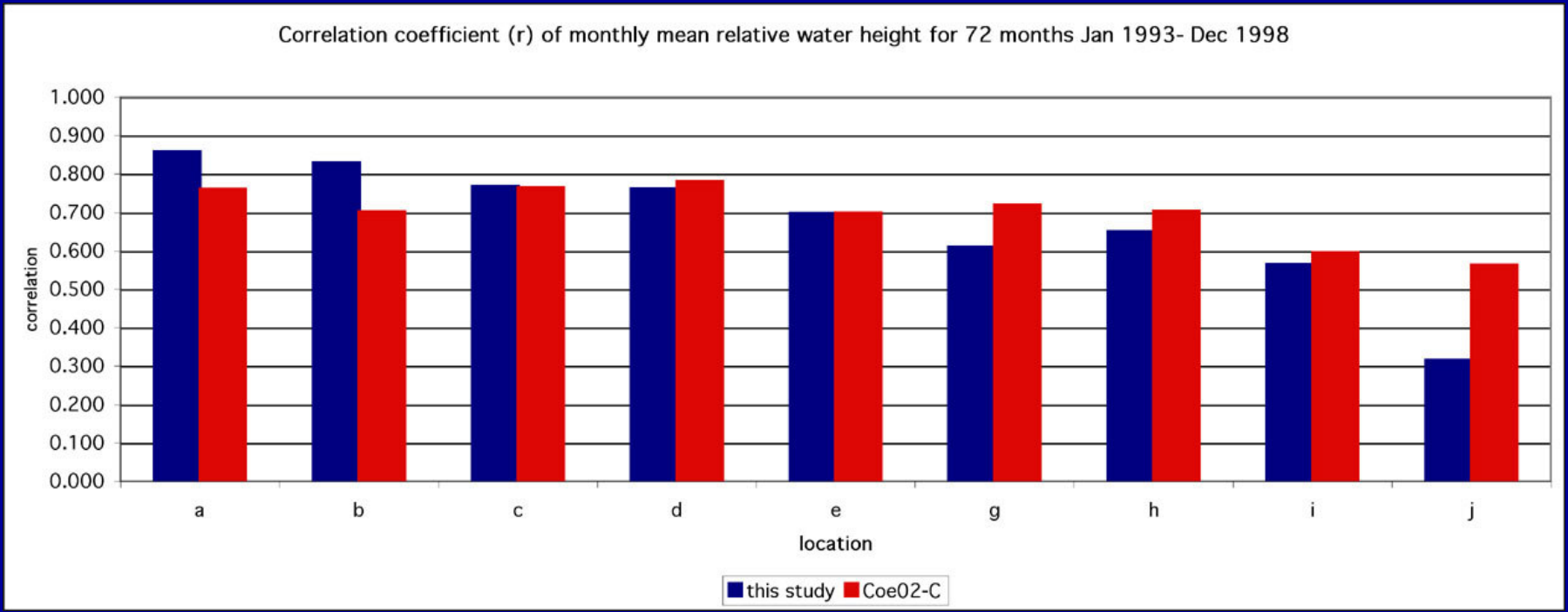
Water height

Comparison to Birkett et al., 2002 -- 9 locations, mean monthly relative water height 1993-1998 TOPEX/POSEIDON radar altimetry

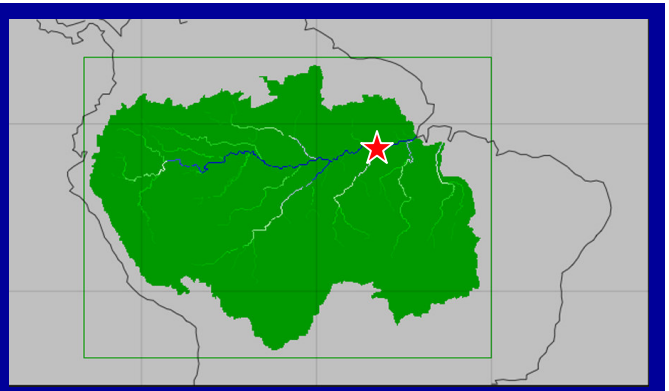


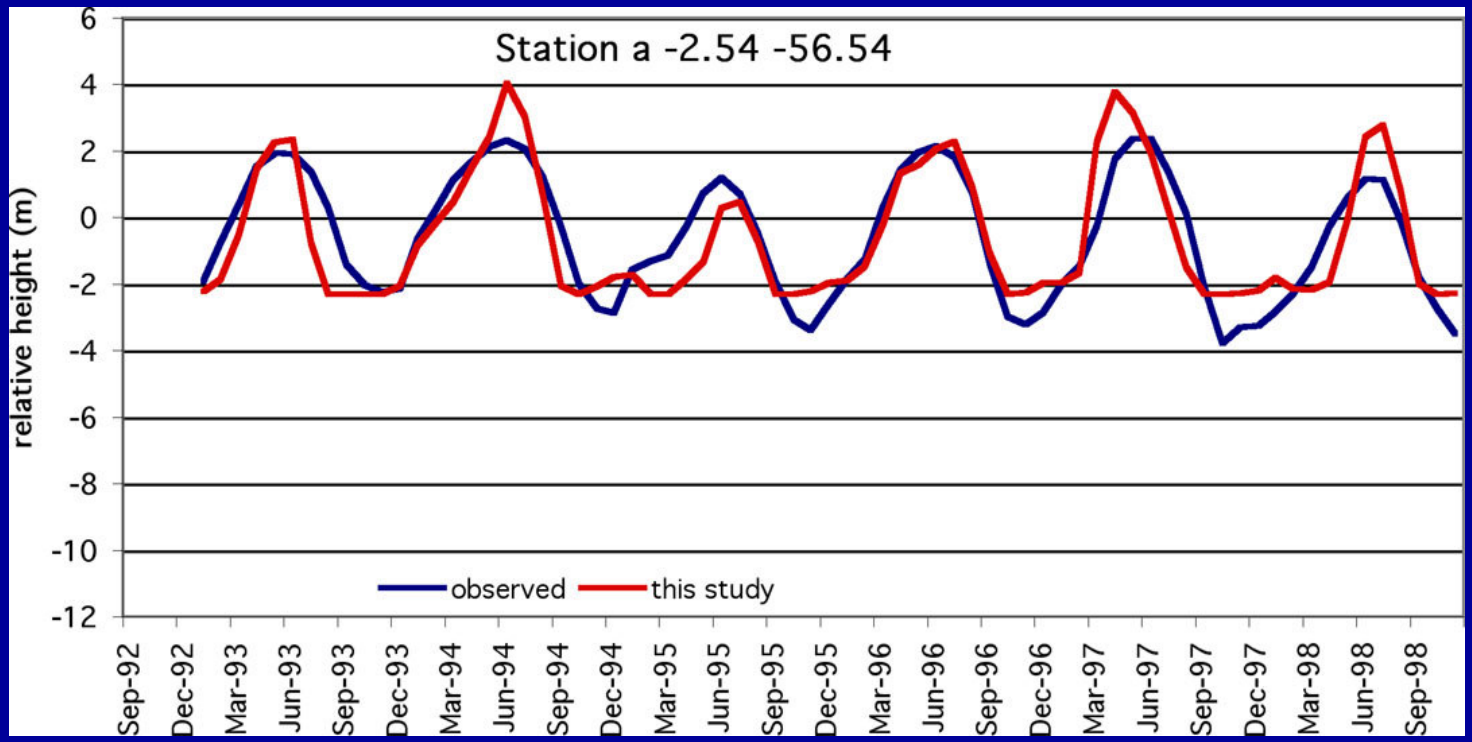
Water height





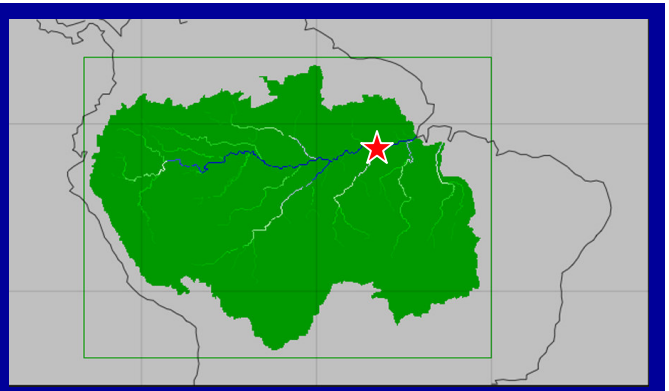
Water height

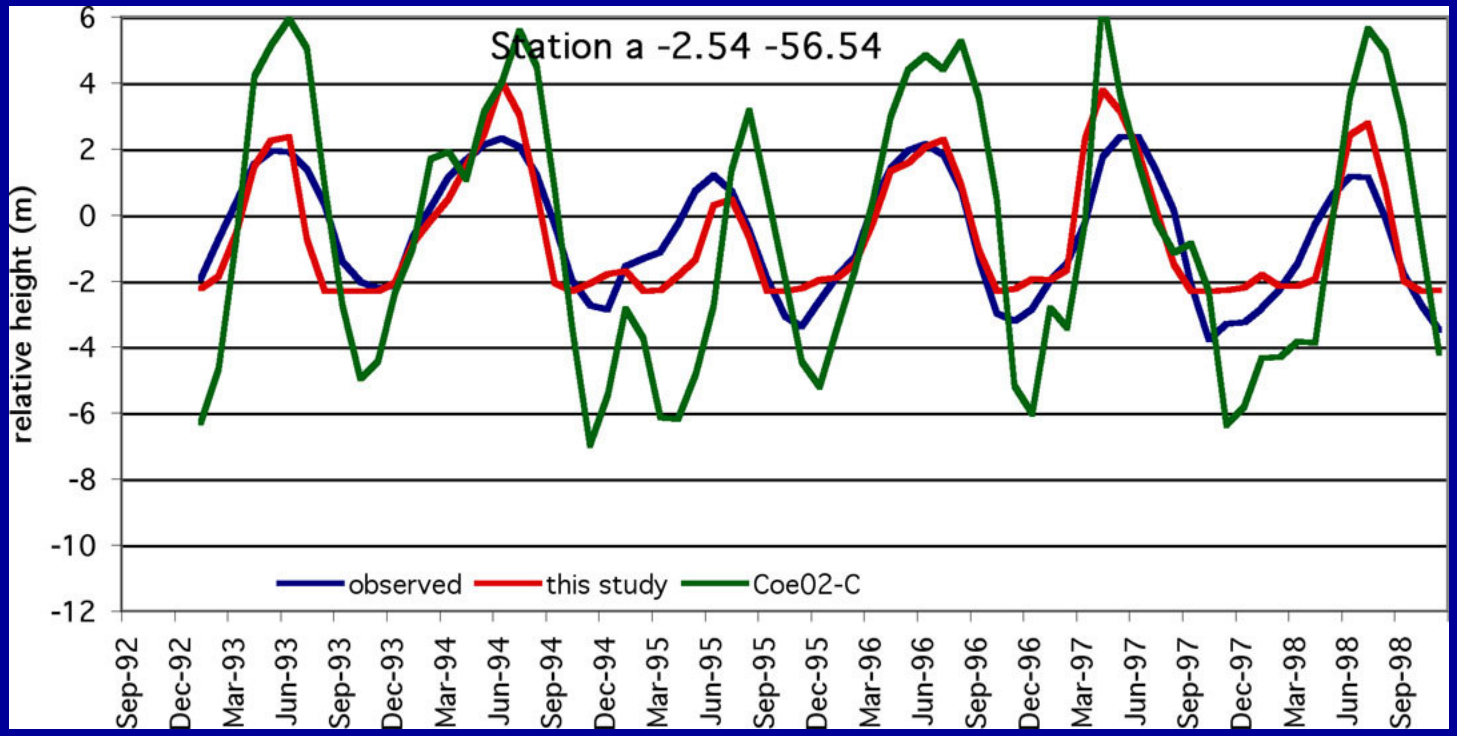




Comparison of relative water height measured by TOPEX/Poseidon radar altimeter and simulated by model. r = 0.858

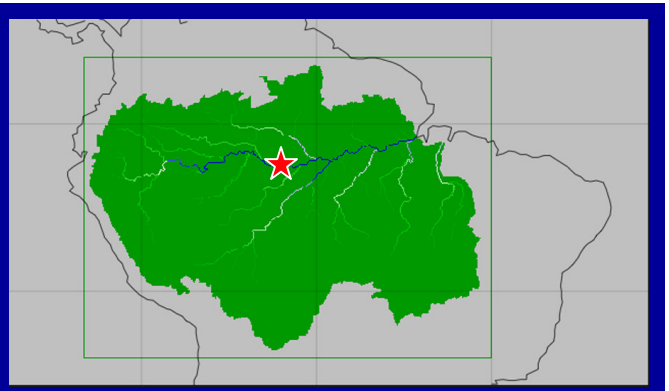
Water height

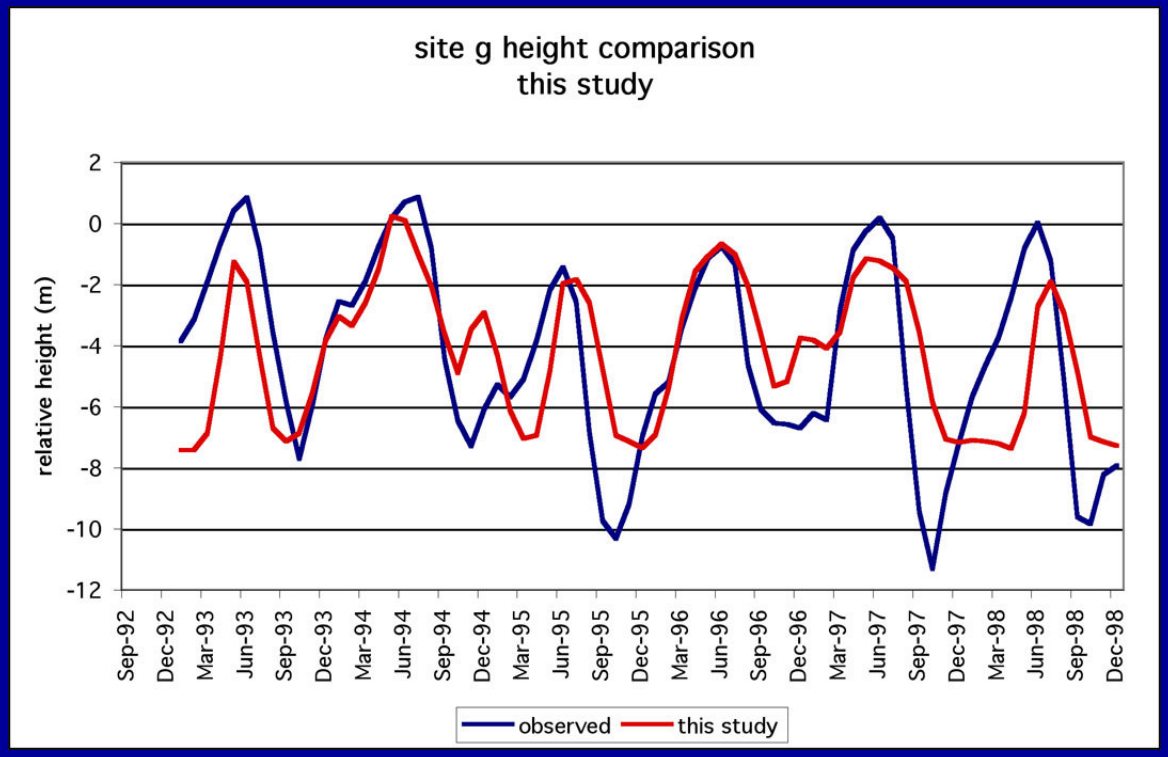




Coe02 r = 0.760, 0.858 this study

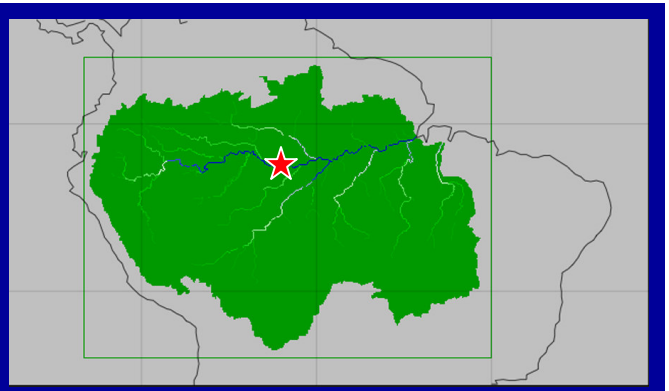
Water height

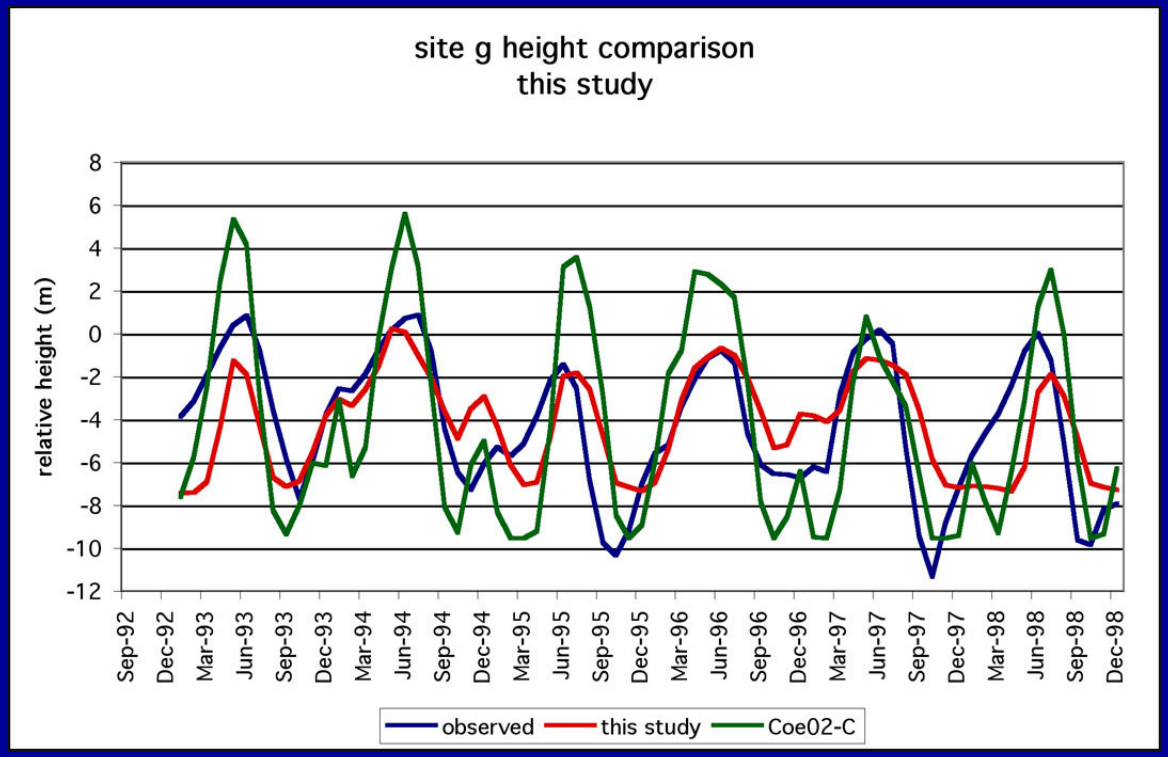




Comparison of relative water height measured by TOPEX/Poseidon radar altimeter and simulated by model. r = 0.609

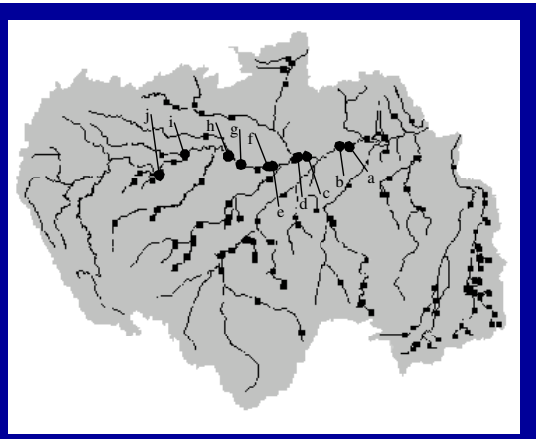
Water height

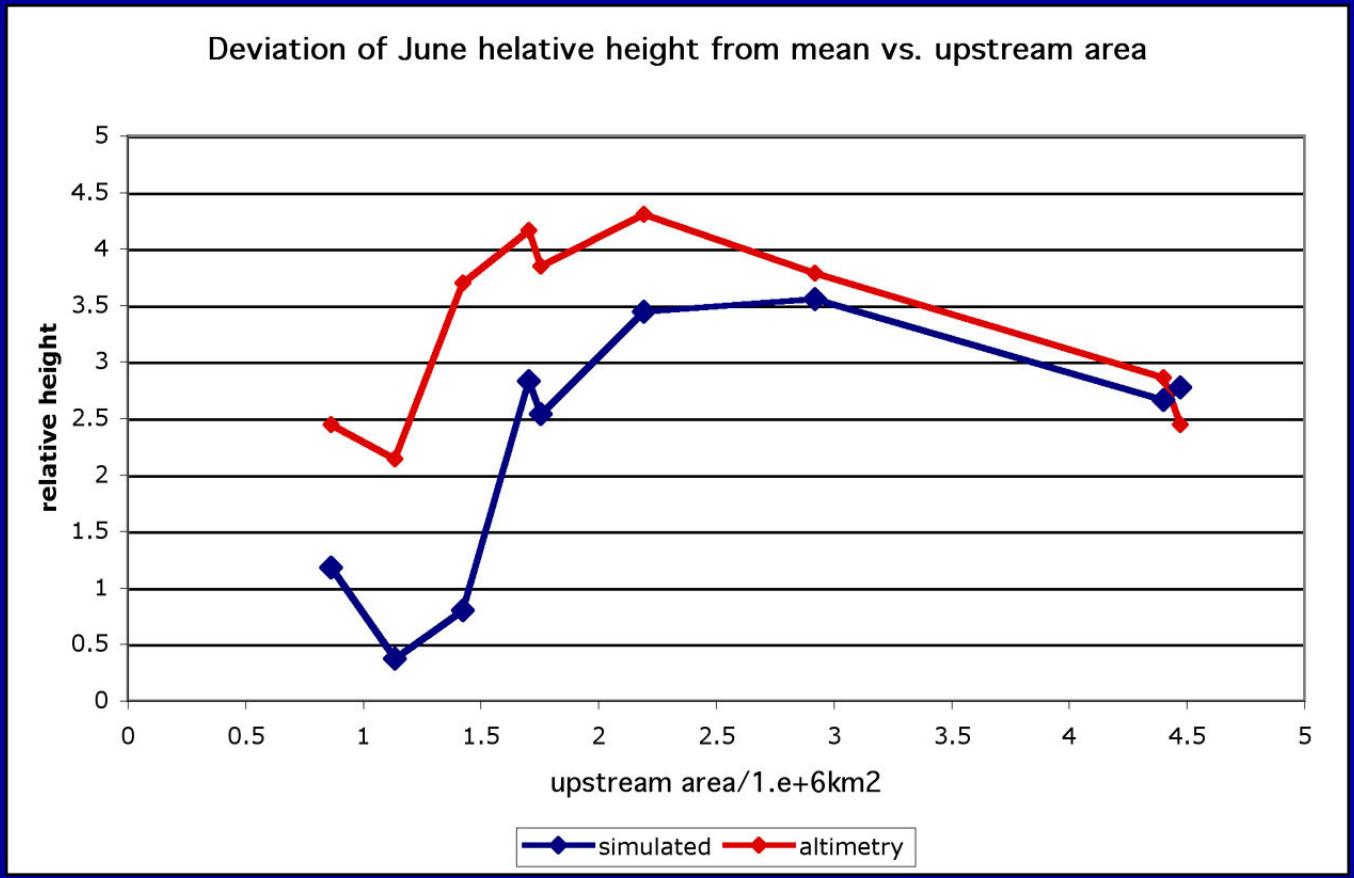




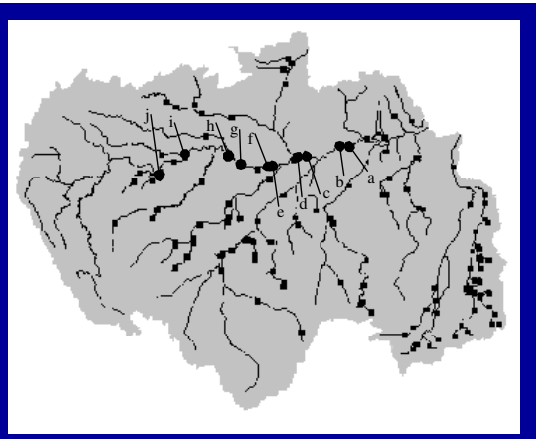
Coe02 r = 0.719, 0.609 this study

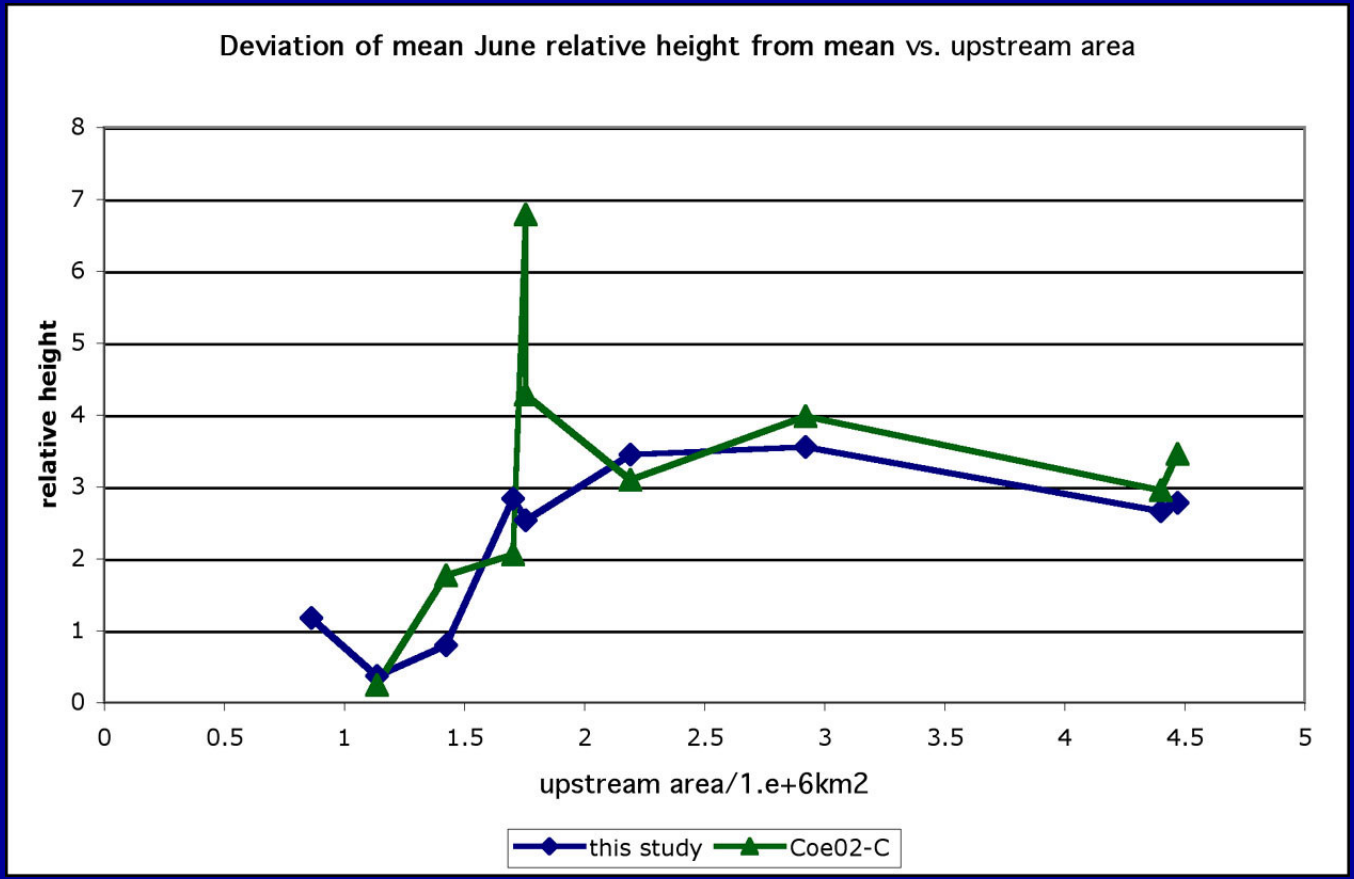
Water height





Water height



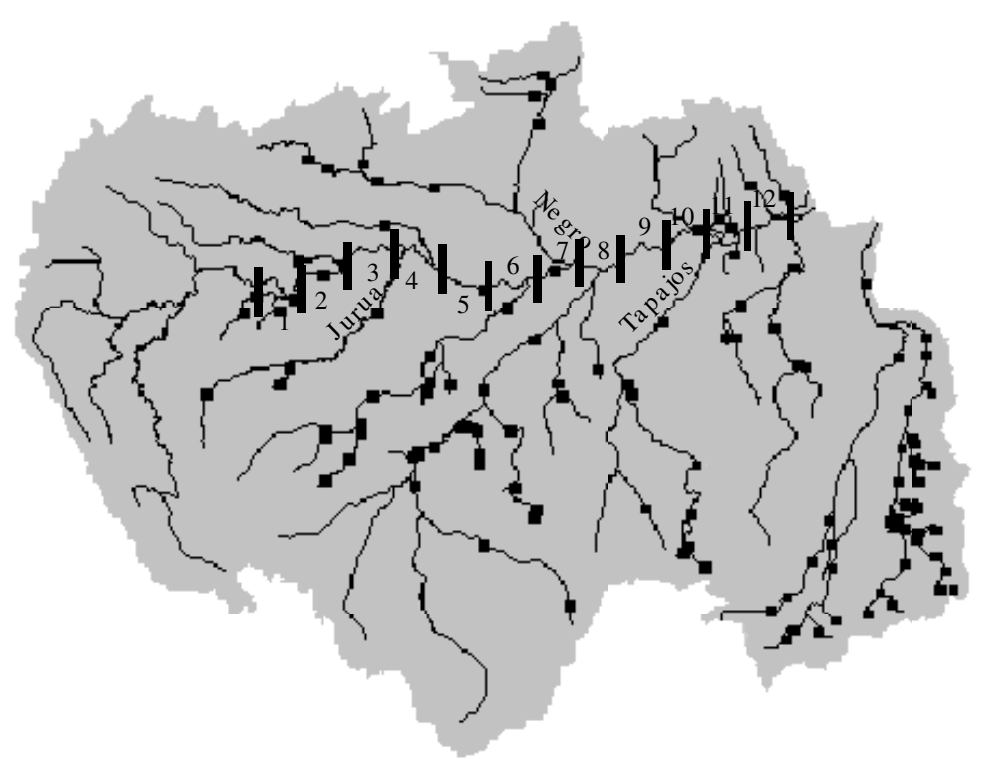


Water area

QuickTime™ and a
GIF decompressor
are needed to see this picture.

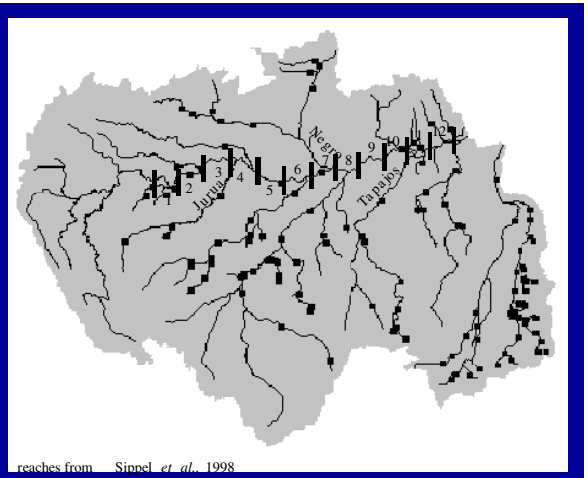
Water area

Comparison to Sippel et al., 1998 -- 12 reaches, mean monthly water area 1983-1987, SMMR/empirical model

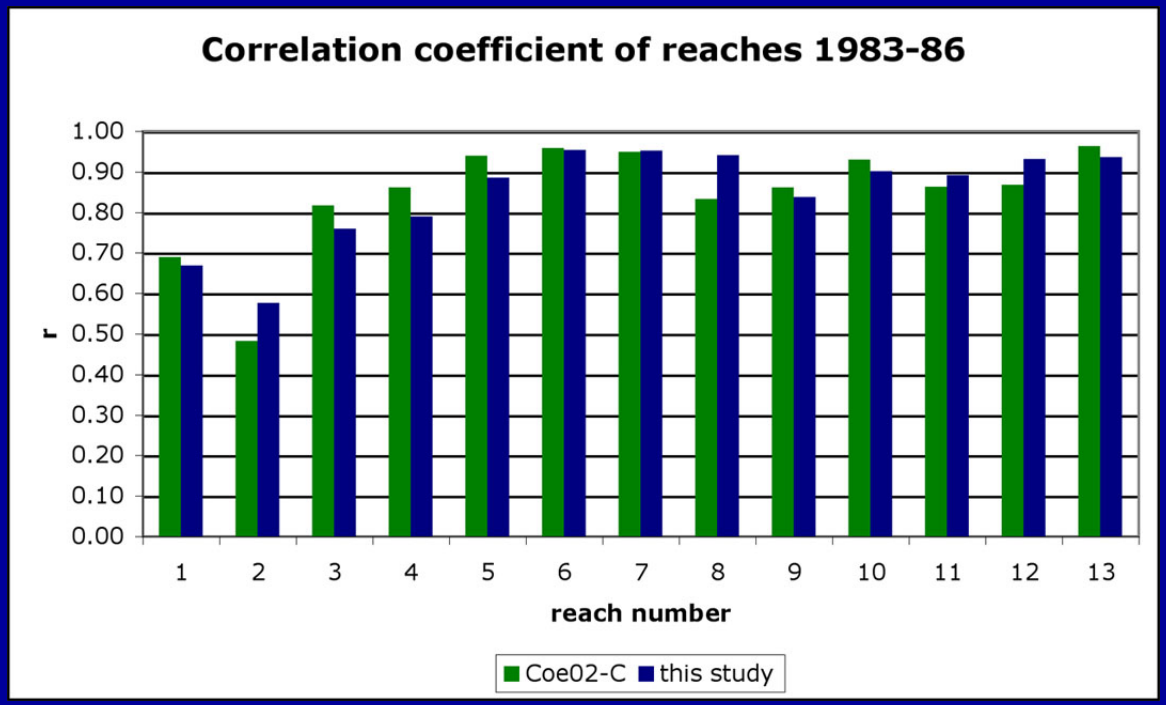


reaches from Sippel *et al.*, 1998

Water area

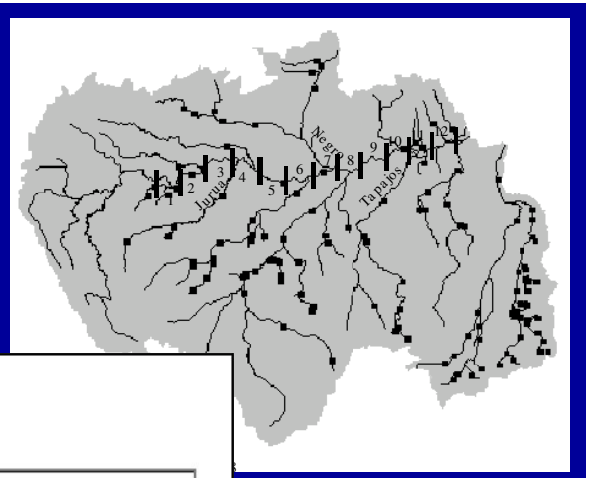


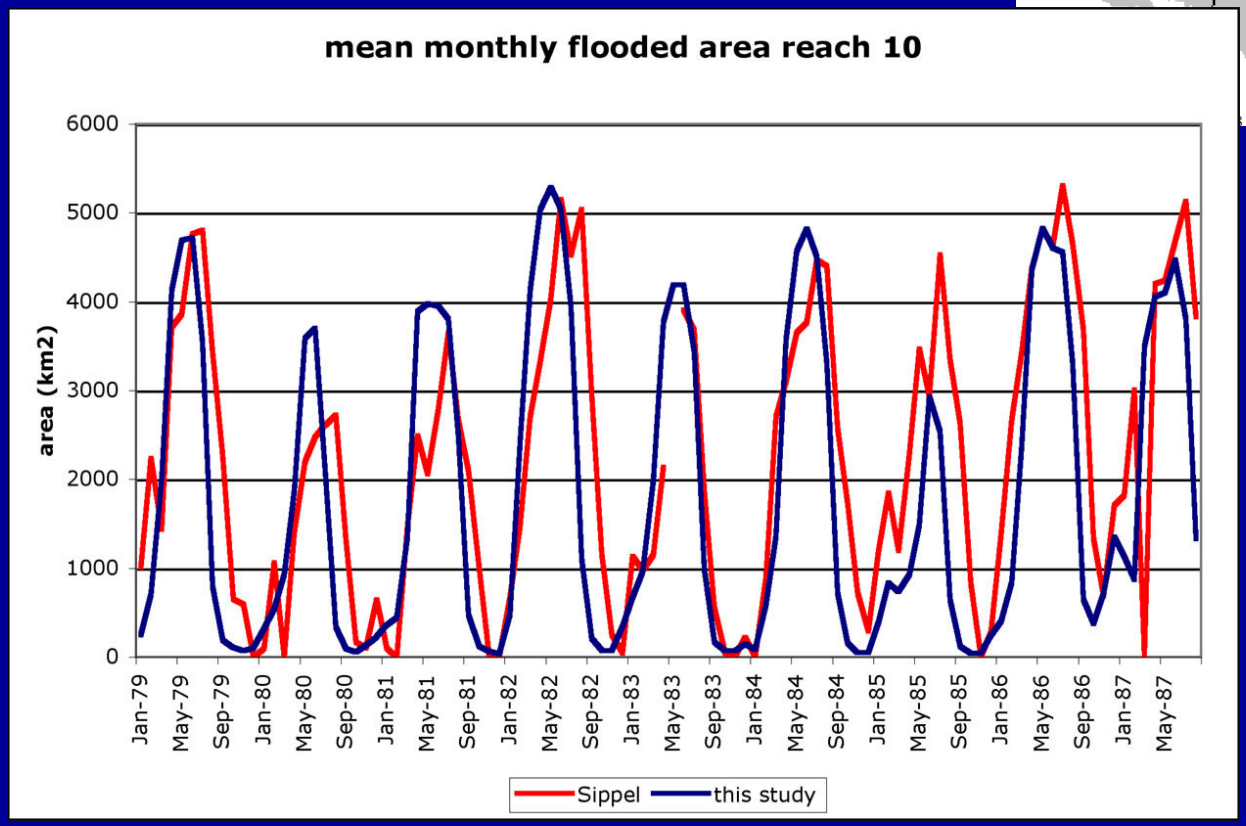
reaches from Sippel *et al.*, 1998



Similar agreement with Sippel for mean monthly area on all reaches

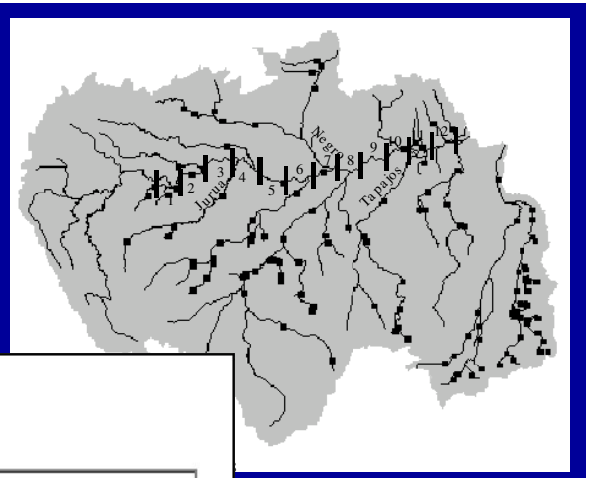
Water area

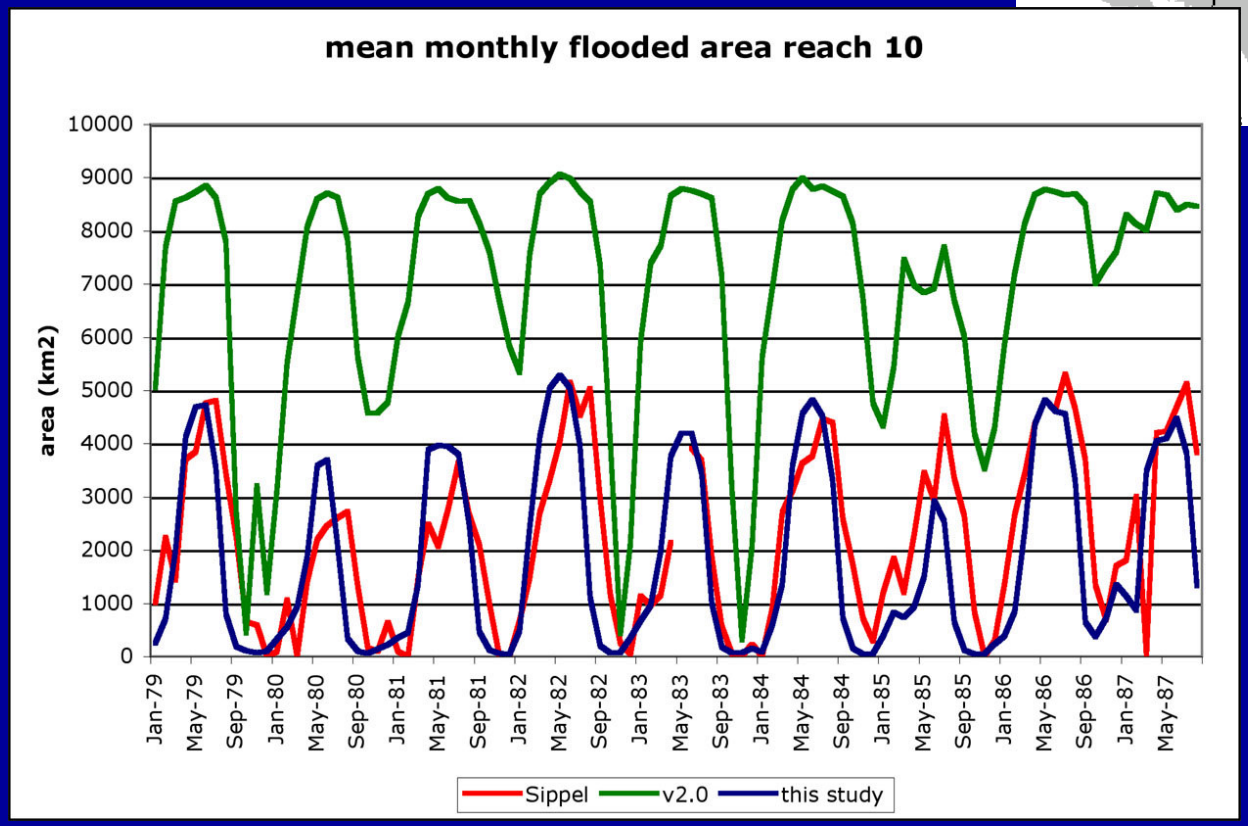




Reach 10

Water area

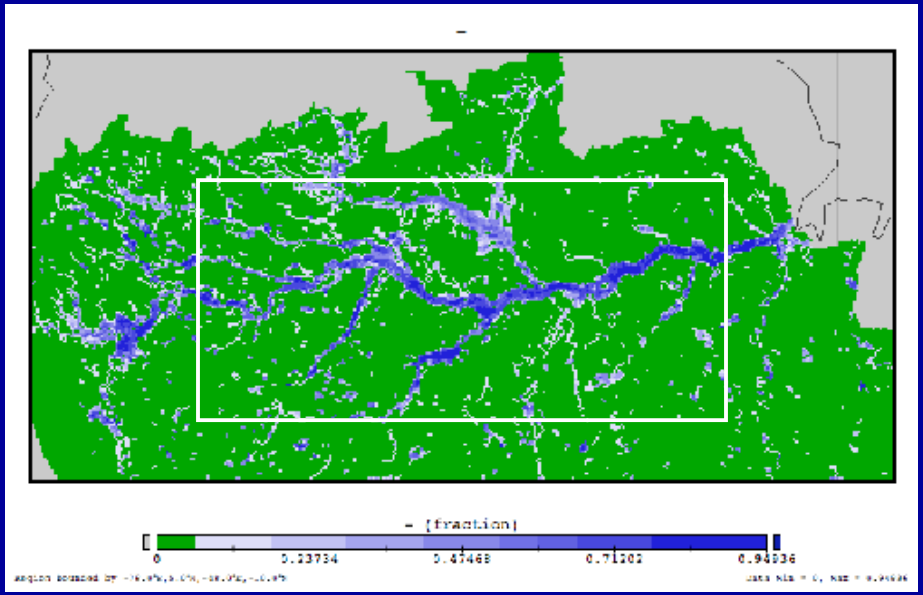




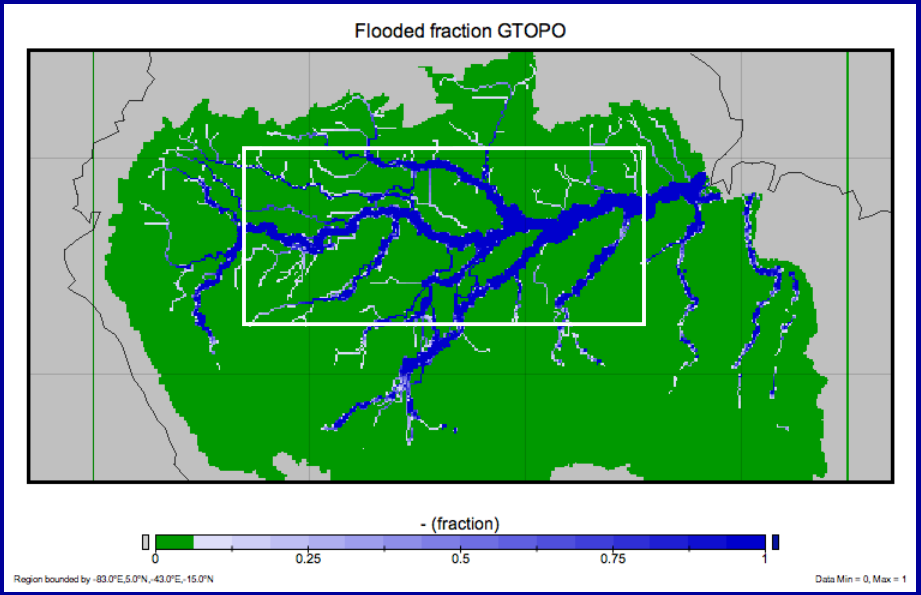
Reach 10

Water area

Simulated this study

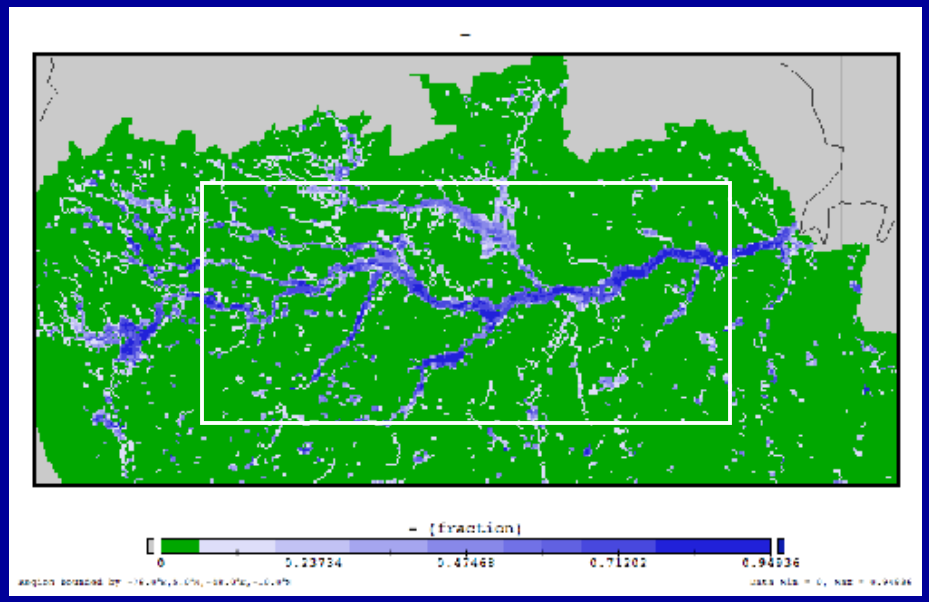


Simulated Coe02

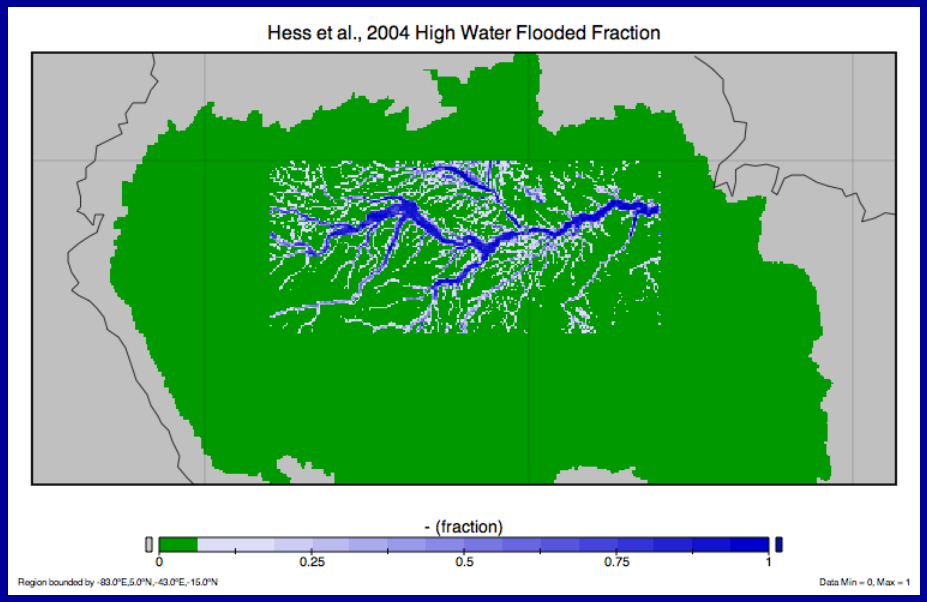


Water area

Simulated this study
247,079 km^2



Observed Hess et al.
220,222 km^2



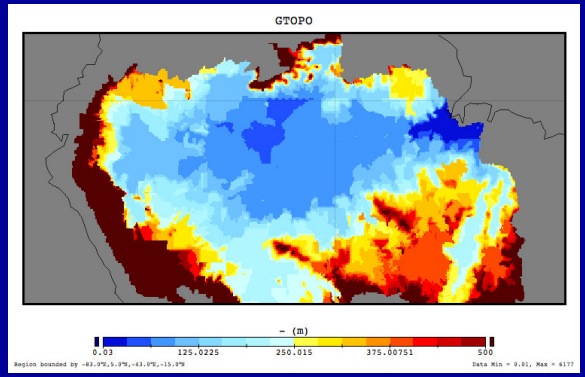
Conclusions

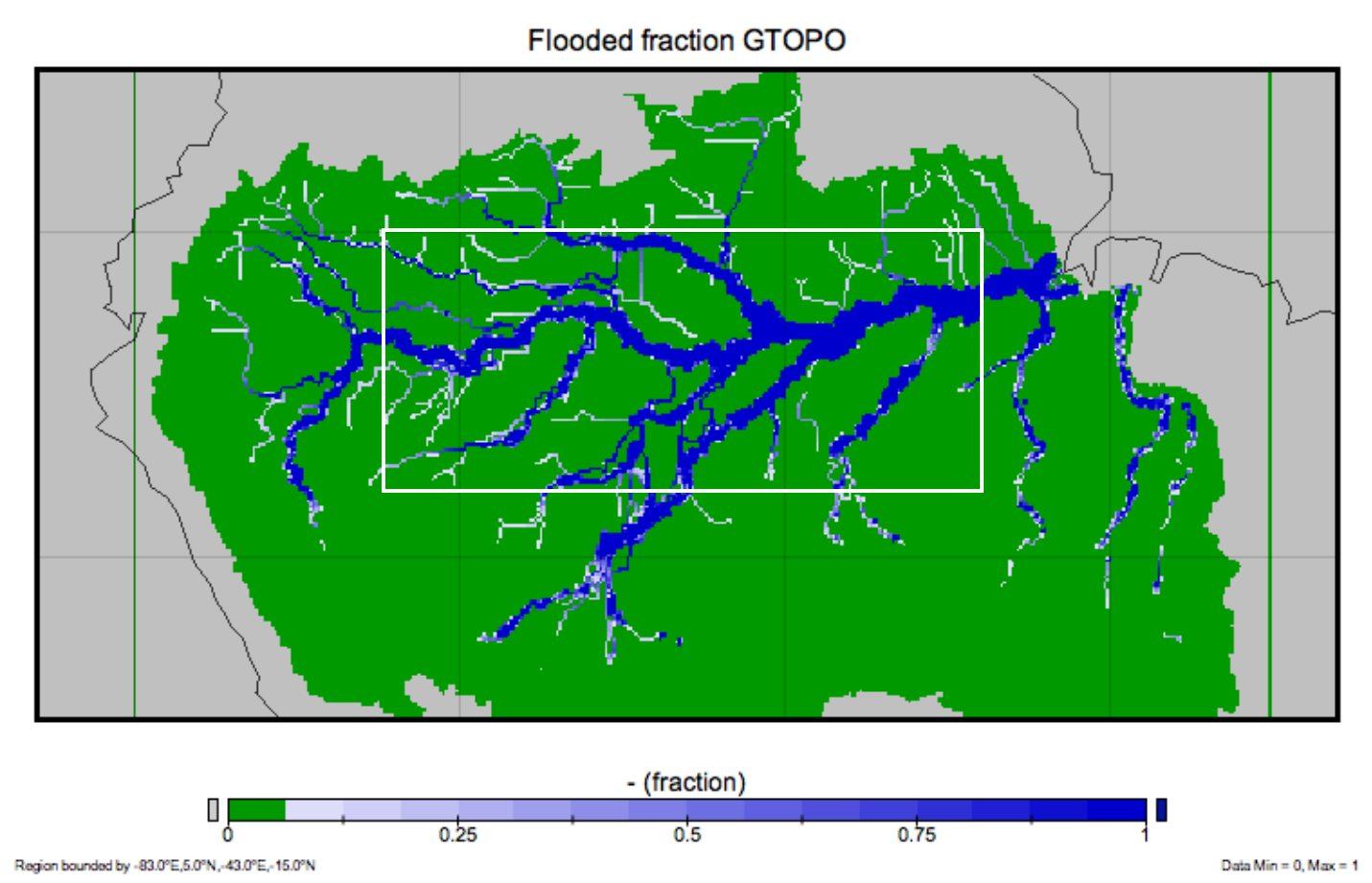
- Improvements to model provide better representation of seasonal and inter-annual behavior of the River system
- Work remains to be done on the surface topography data but physical characteristics of floodplain are improved.
- Can incorporate C and nutrient cycling within model structure
- With new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

Thank You

Improvements

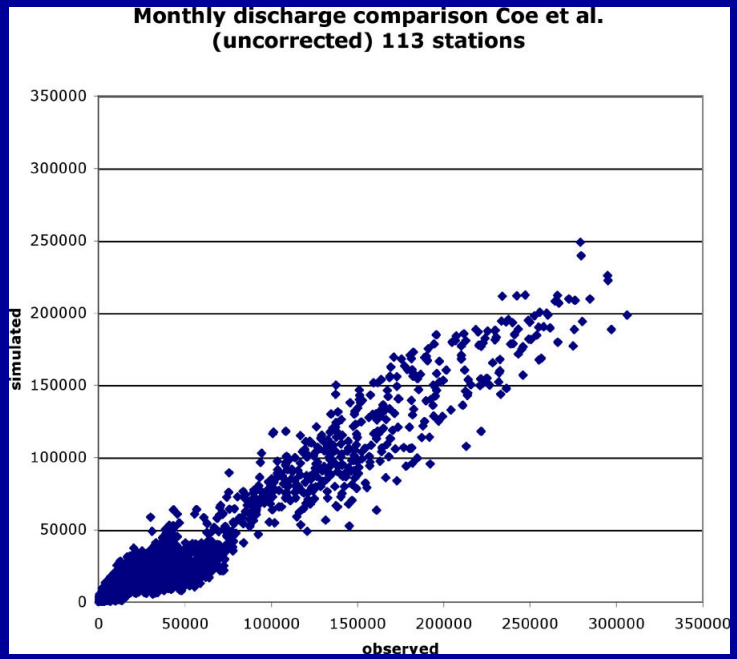
- Topography - GTOPO30 alone

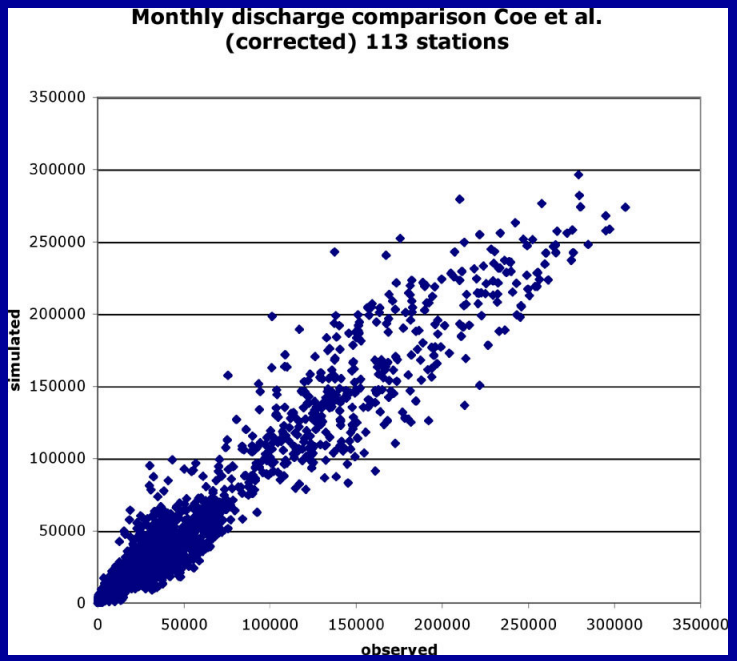




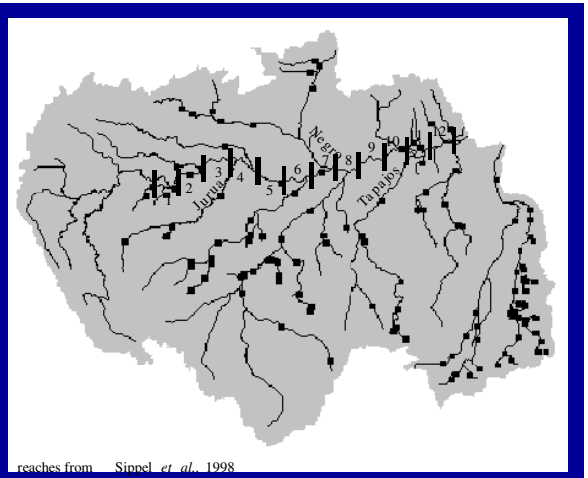
Comparison to Coe et al., 2002

- Re-ran Coe et al., 2002 model with identical corrected discharge of this study
- Any differences are due to model differences alone

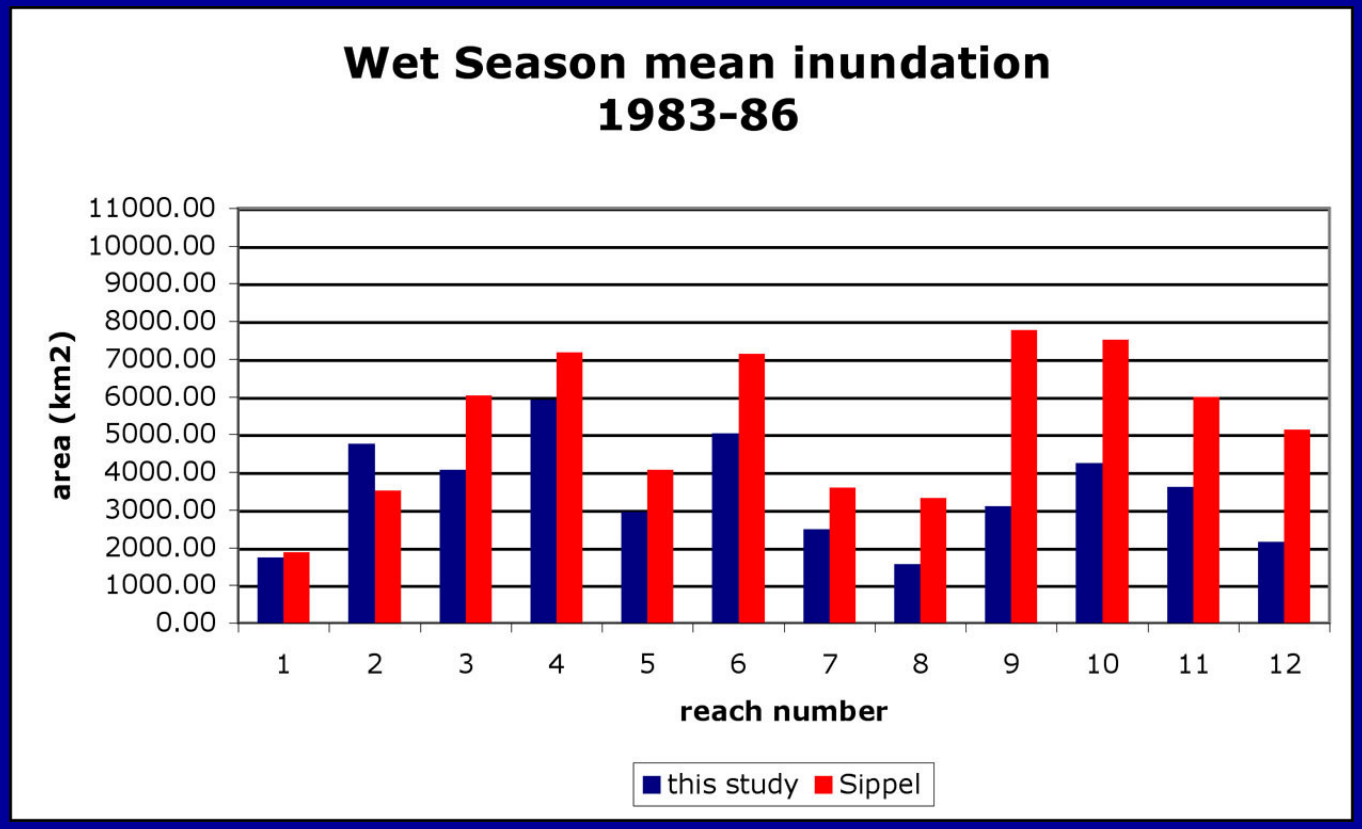




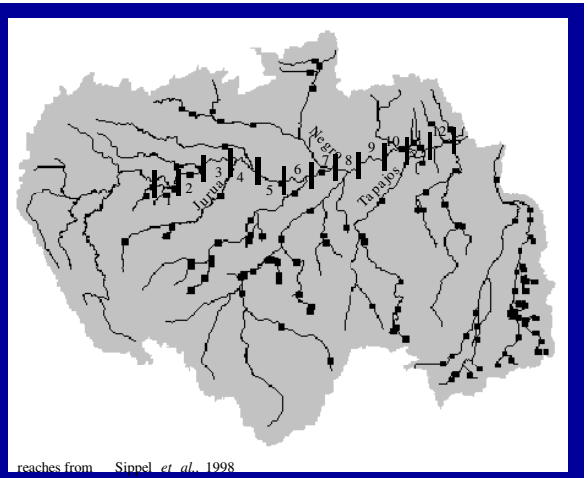
Water area



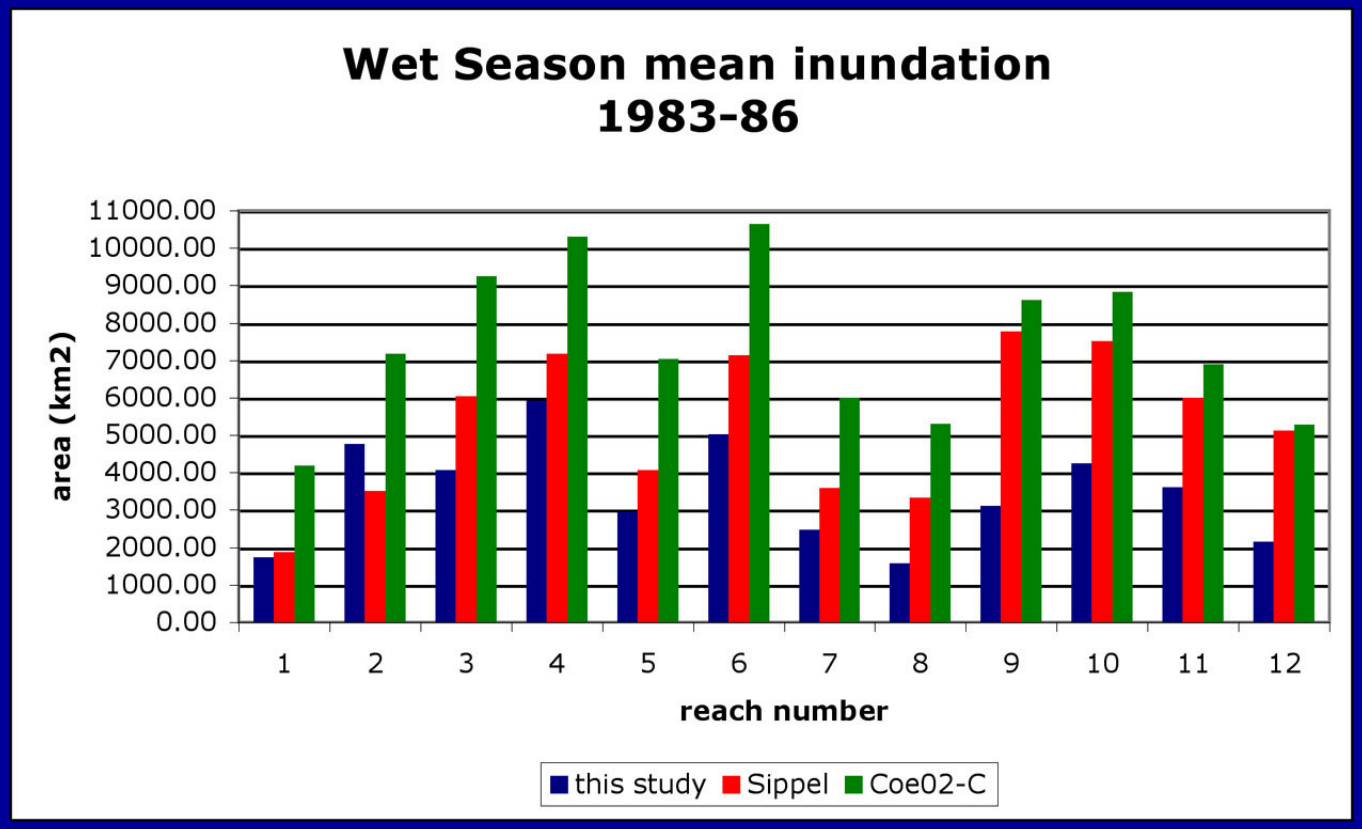
reaches from Sippel *et al.*, 1998



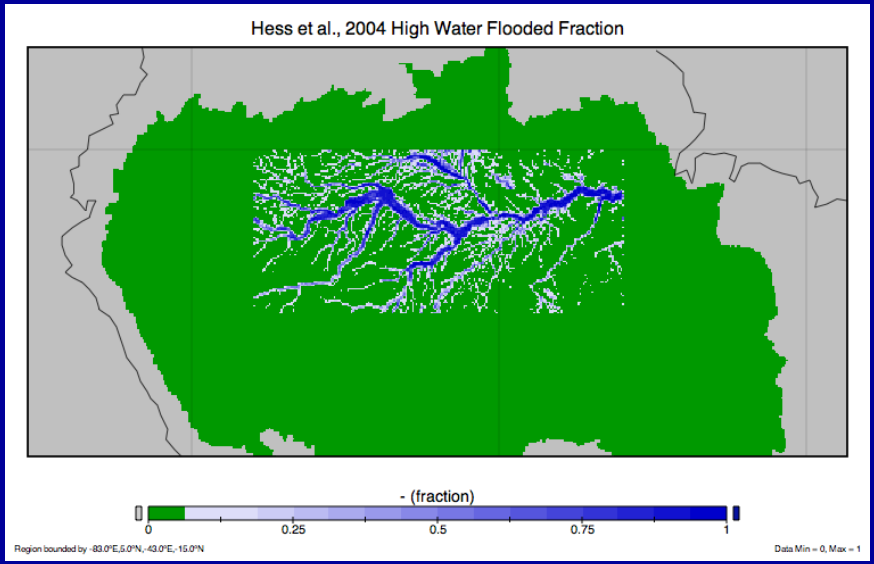
Water area

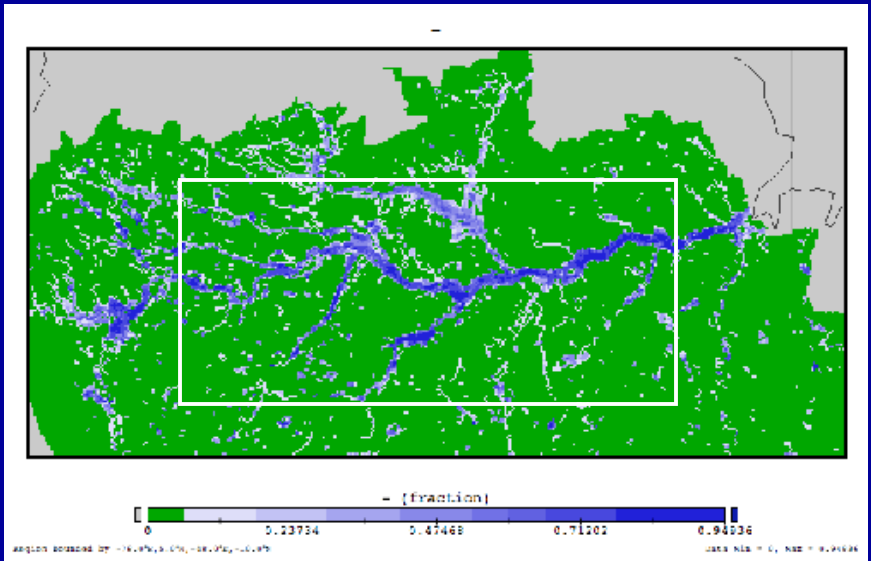


reaches from Sippel *et al.*, 1998



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


- (fraction)
0
0.23734
0.47468
0.71202
0.94936