Numerical Analysis of the Amazon River

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Amazon is central to ...

- **Commerce**
- **Fisheries**
- **Ecotourism, travel**
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

- 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 87,000 boxes
- 90m and 500m resolution data now available from WWF for all of South America

Costa et al., 2002
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

\[ \frac{dV}{dt} = R(1-A_w) + (P-E)A_w + (\sum F_{in} - F_{out}) \]

\( A_w \) = flood and river area predicted by model
\( R = R_{surface} + R_{sub-surface} \) (local water)
\( \sum F_{in} = \sum F_{out} \) (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 $-4\sigma$ to $z_x$. 

[Image of SRTM topography with color scale]
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

\[ r^2 = 0.957 \]
This study $r^2 = 0.957$, Coe02 $r^2 = 0.677$
Discharge -- Tapajós

![Discharge Graph]

**Tapajos #38**

- **Observed**
- **This Study**
- **Coe02-C**

Discharge (m³/s) over the months from January to December.
Discharge -- Juruá

![Map of Juruá basin with discharge graph](image)
Discharge -- Óbidos, deviation

Deviation of Óbidos discharge from mean

-40% -30% -20% -10% 0% 10% 20% 30%


- observed
- this study
Water height

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

Correlation coefficient ($r$) of monthly mean relative water height for 72 months Jan 1993 - Dec 1998

- a, b, c, d, e, g, h, i, j

- Correlation

- Location

- Blue: this study
- Red: Cee02-C
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

Deviation of June relative height from mean vs. upstream area

- simulated
- altimetry
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
Water area

Similar agreement with Sippel for mean monthly area on all reaches
Water area

Reach 10

mean monthly flooded area reach 10

Sippel  this study

Reaches from Sippel et al., 1998
Water area

Reach 10

Mean monthly flooded area reach 10

area (km²)

Jan-79 Jan-80 Jan-81 Jan-82 Jan-83 Jan-84 Jan-85 Jan-86
May-79 May-80 May-81 May-82 May-83 May-84 May-85 May-86
Sep-79 Sep-80 Sep-81 Sep-82 Sep-83 Sep-84 Sep-85 Sep-86

Sippel v2.0 this study

reaches from Sippel et al., 1998
Water area

Simulated this study

Simulated Coe02
Water area

Simulated this study
247,079 km²

Observed Hess et al.
220,222 km²
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

Wet Season mean inundation
1983-86

[Chart showing wet season mean inundation for 1983-86 with reach numbers 1 to 12, comparing 'this study' and 'Sippel' with area in km².]
Water area

Wet Season mean inundation 1983-86

reach number

area (km²)

this study Sippel Coe02-C

reaches from Sippel et al. 1998
Water area