

# Inter-annual Variability in Large-Scale Flooding of Aquatic Ecosystems in Amazonia: A Modeling Strategy

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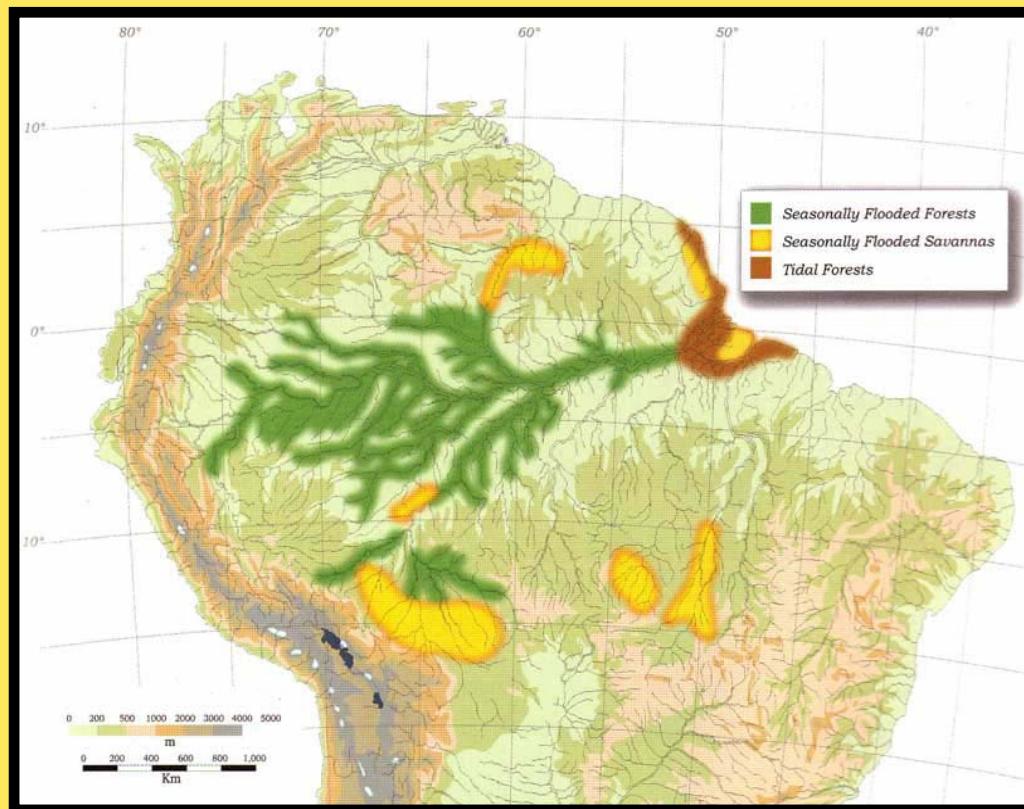
University of Wisconsin – Madison

<sup>2</sup>Woods Hole Research Center, Woods Hole, MA

<sup>3</sup>Universidade Federal de Viçosa

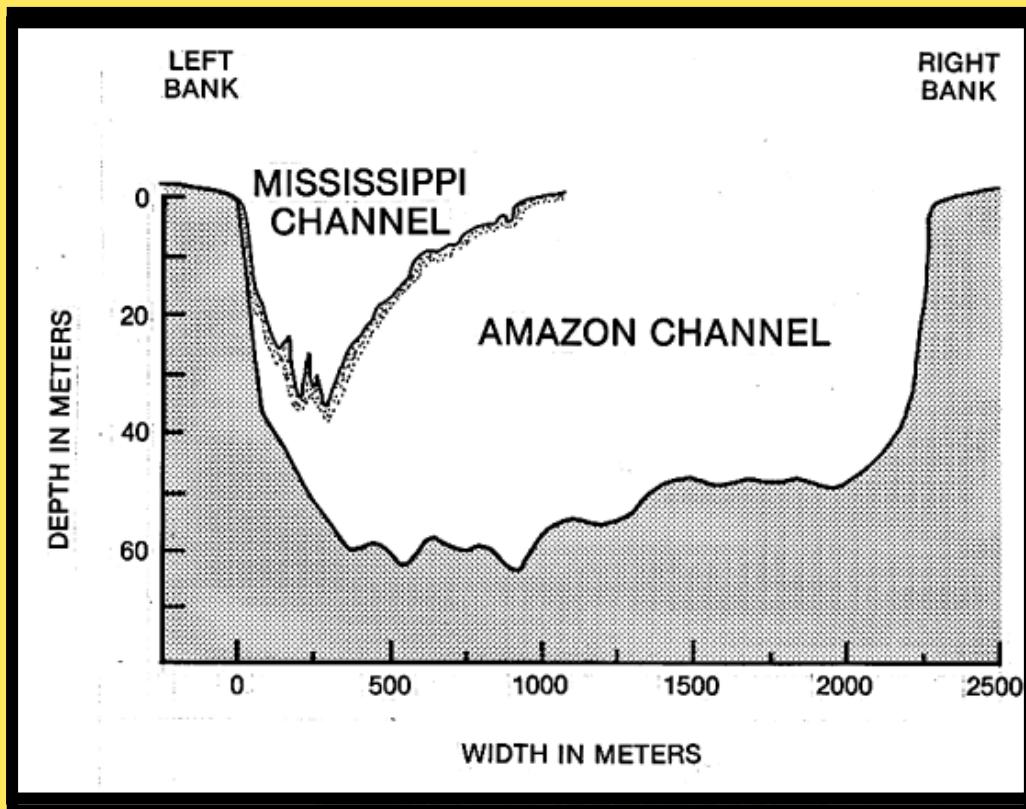
# Outline

- Background
- Previous research
- Driving questions
- Objective 1: Ecosystems
- (Objective 2: Carbon)



# Flooded areas

- Heavy seasonal flooding:
  - 400,000 km<sup>2</sup>,  
*or 6-8% of the Basin*  
~ size of California
- Floodplains of Amazon River and large tributaries only:
  - 350,000 km<sup>2</sup>,  
*or 20% of central Amazonia*



**Background**

**Lowland  
streams**



**Igapó**



**Flooded  
forest  
(várzea)**



**Main channel  
open water**



**Mountain  
streams**



**Floating meadows  
(várzea)**



**Main channel  
levees**



# Amazonians (of all species) are adapted to the flood pulse



*Background*

# Hydrological regulation plays a role in...



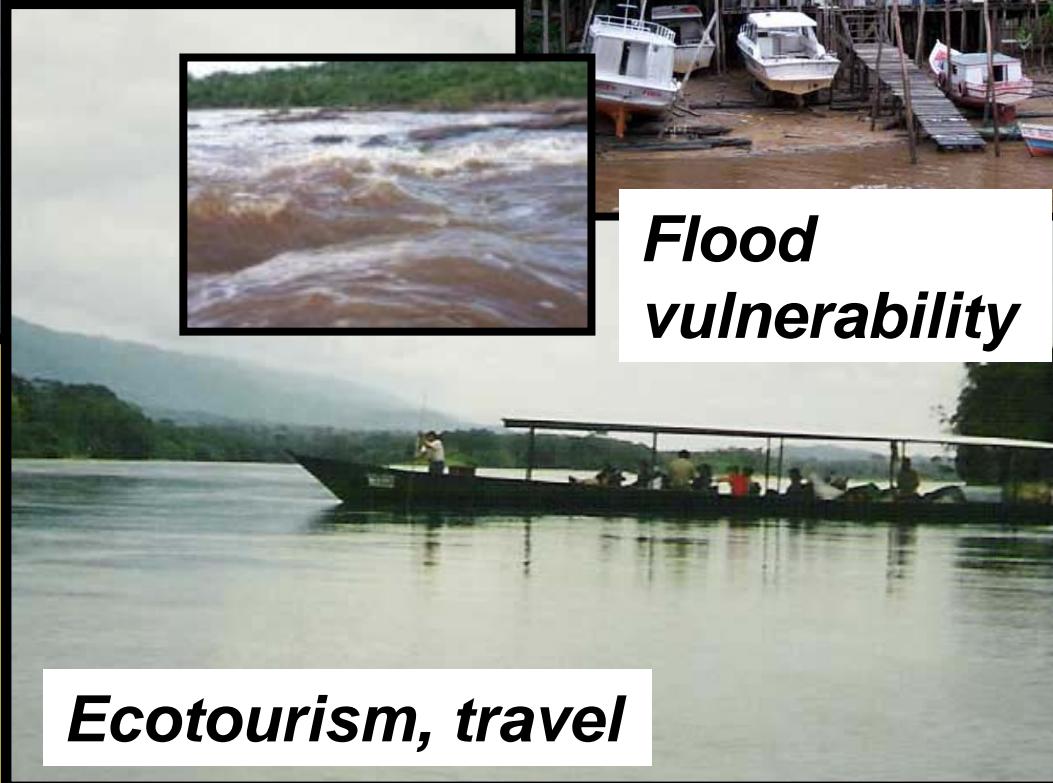
*Commerce*



*Fisheries*



*Flood  
vulnerability*



*Ecotourism, travel*



*Motivation*

# Aquatic carbon cycling questions

What is the relative importance of different aquatic ecosystems for CO<sub>2</sub> emissions?

How sensitive is the flux of carbon dioxide from rivers and the floodplain to interannual climate variability?

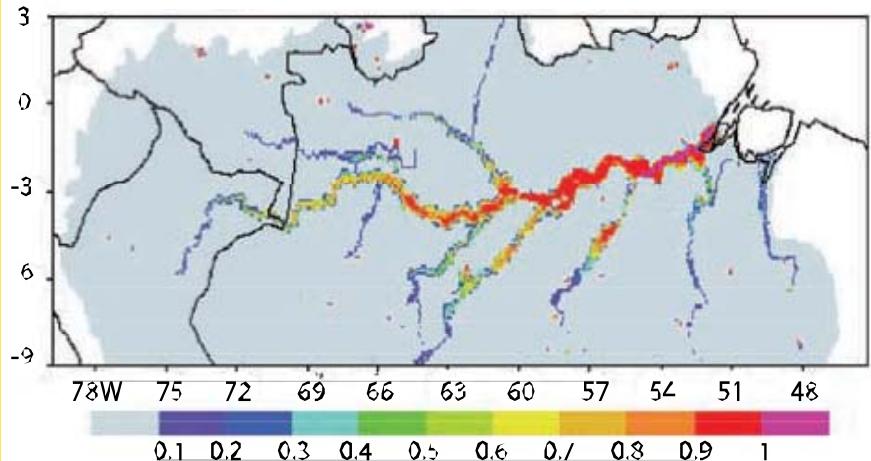
How might the overall contribution of aquatic ecosystems to atmospheric CO<sub>2</sub> emissions change under scenarios of future land cover?



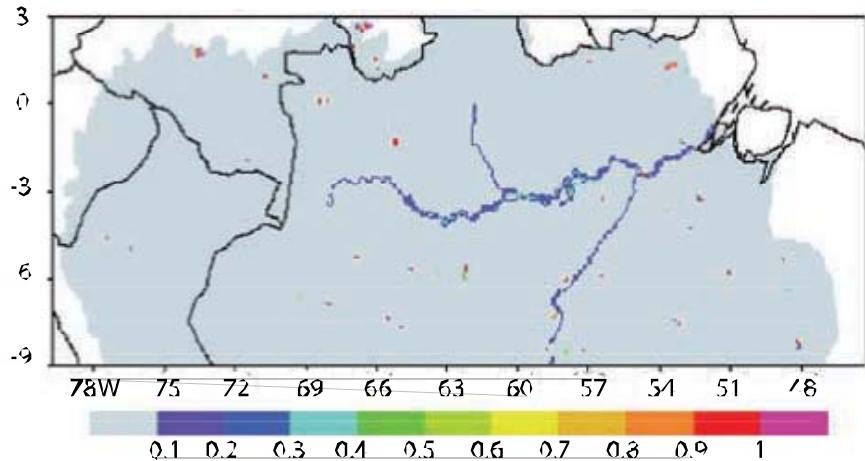
**Motivation**

# Modelling seasonal flooding...

Average years – wet season



Average years – dry season

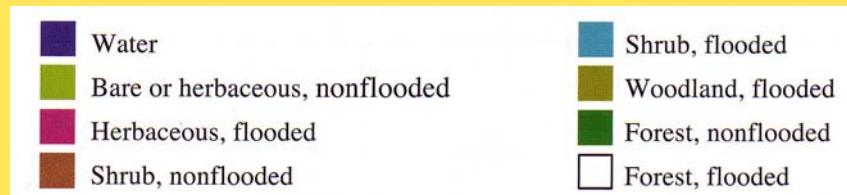
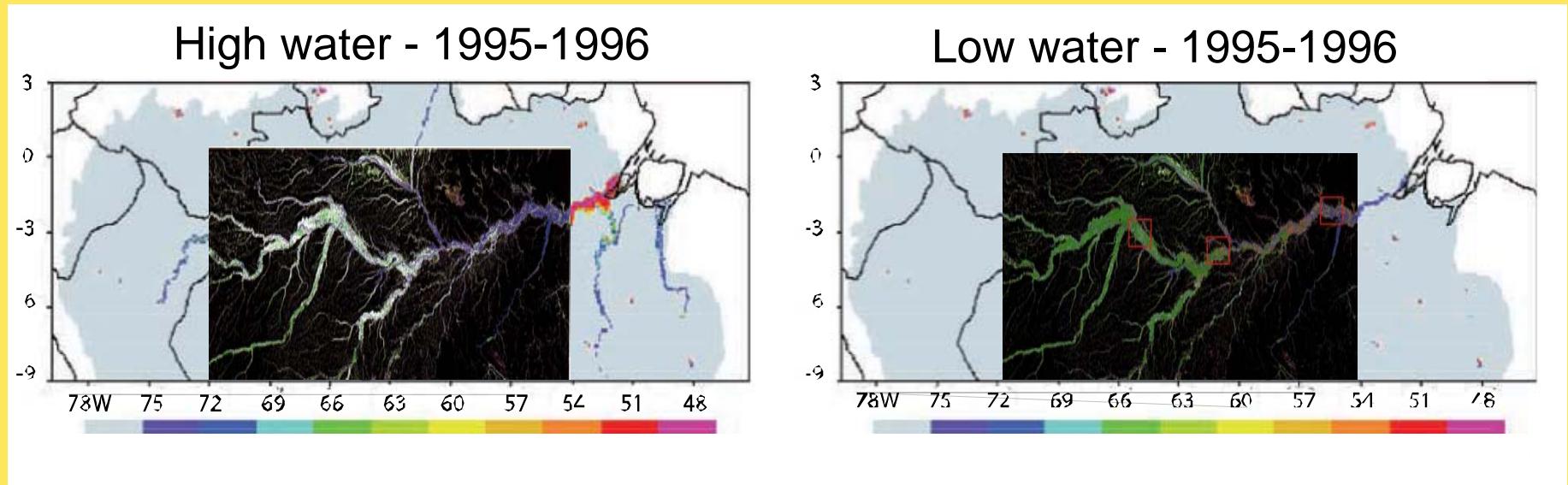


Flooded Area (% of gridcell)

*Climate variability and land cover change affect not only flooding, but also distribution of wetland ecosystems...*

***Previous research***

# Modelling seasonal flooding... ... and remote sensing of wetland habitats



*...but we don't have any information about this across multiple years, across the basin.*

# Driving questions / Objectives

1. How do changes in hydrology affect the distribution of different aquatic ecosystems in the Amazon Basin over space and time?

*Hydrological regulation*

- (2. How is the flow of carbon through these ecosystems affected by changes in hydrology, aquatic ecosystem dynamics, and terrestrial ecosystems?)

*Carbon sequestration*

*Driving questions*

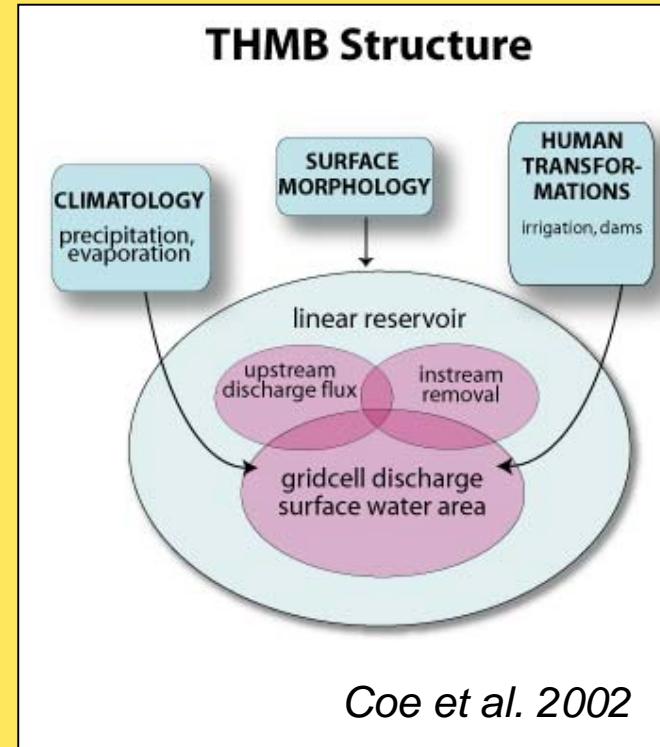
# Terrestrial Hydrology Model with Biogeochemistry (THMB)

## Use:

- Climate data
- Topography at 1-km (SRTM and/or GTOPO30)
- Empirically-derived river directions
- Surface and sub-surface runoff (modeled)

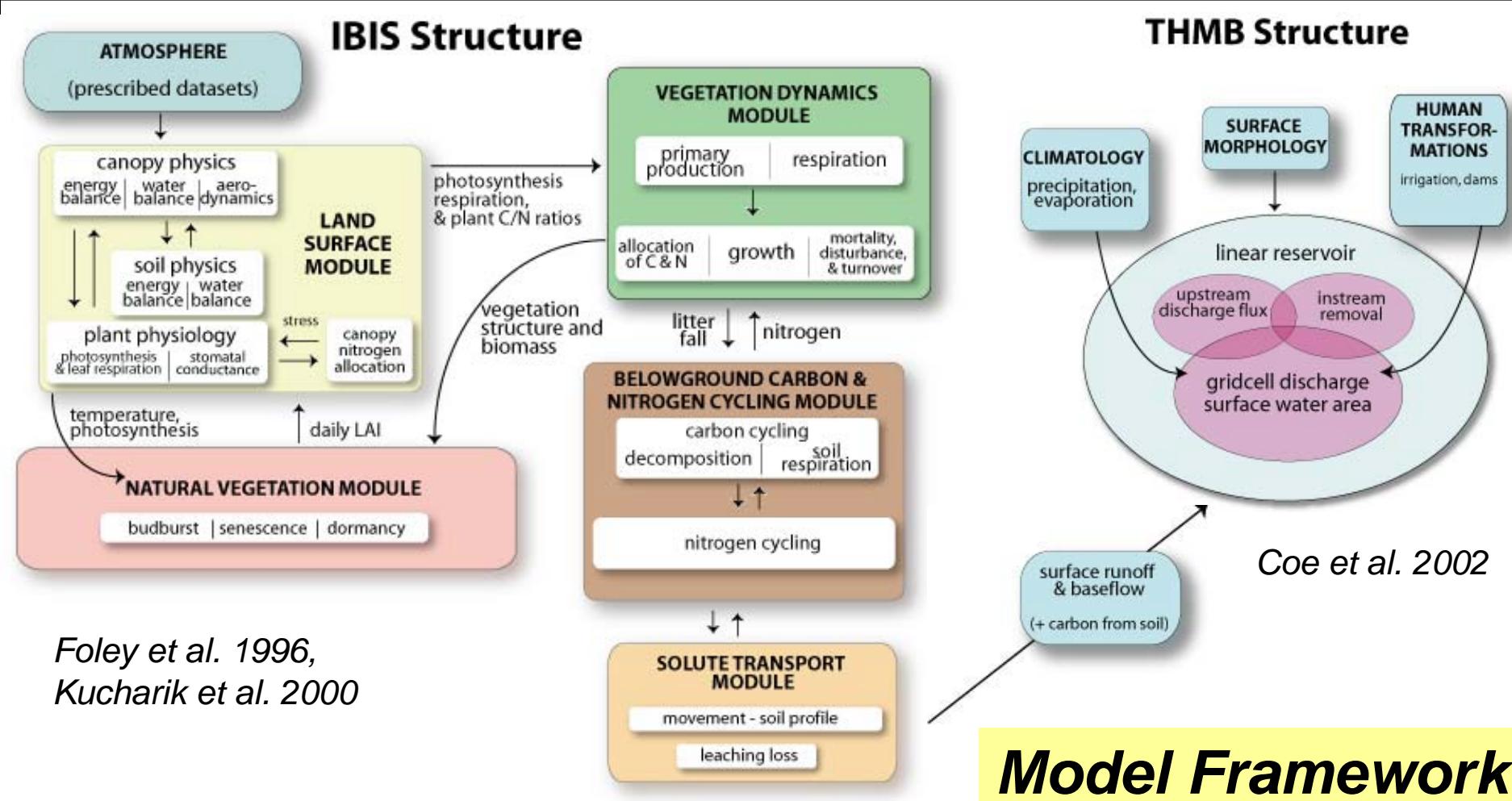
...To simulate land surface hydrology at 5-min spatial resolution (~ 9 km):

- River transport
- Water storage in wetlands and reservoirs
- Seasonal inundation of floodplain



**Model Framework**

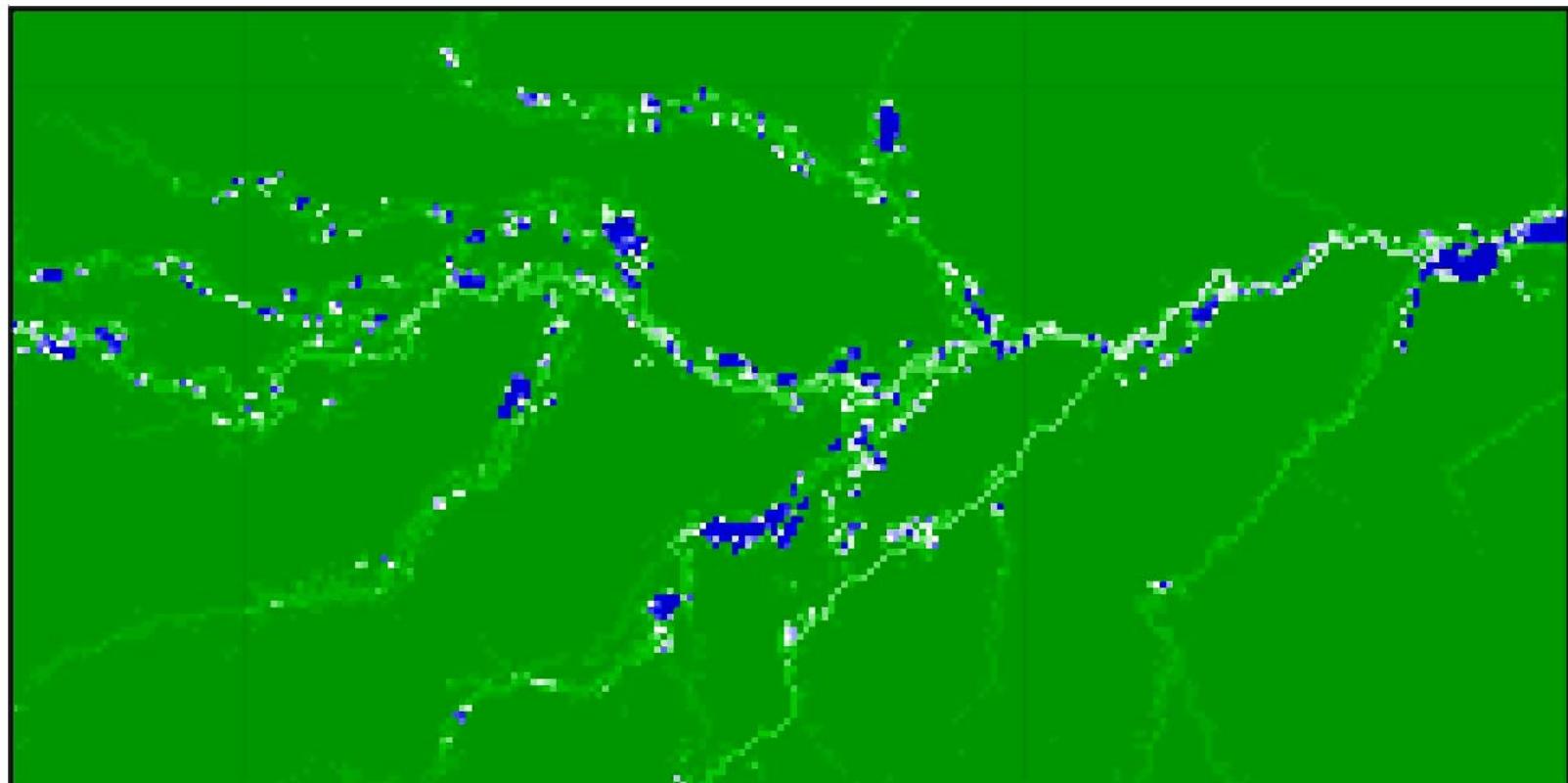
# Surface runoff and baseflow derived from IBIS



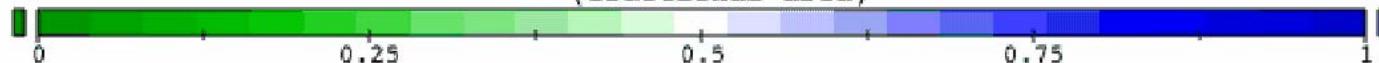
# RESULTS

# Simulation Results

JANUARY / JANEIRO



- (fractional area)

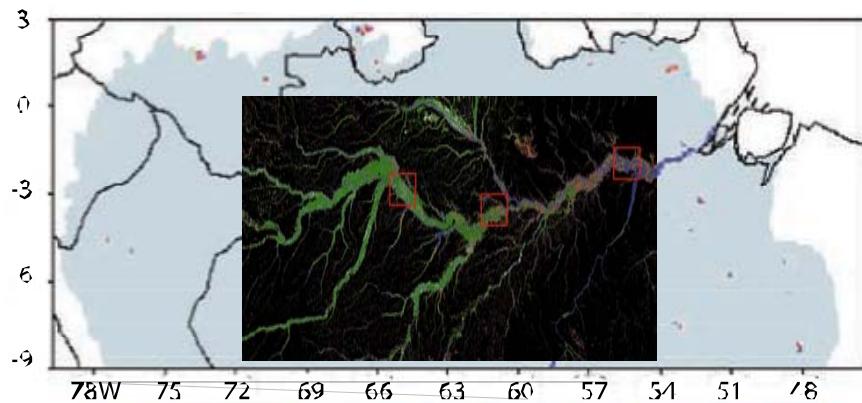


Region bounded by -73.0°E, 1.0°N, -53.0°E, -9.0°N

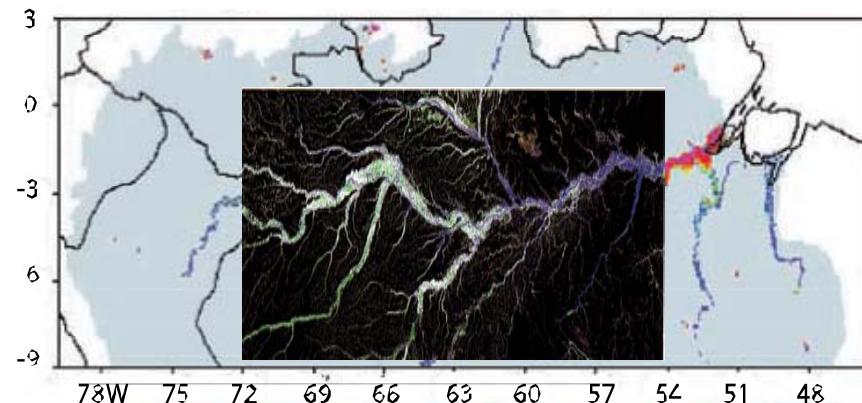
Data Min = 0.00061, Max = 1

# Validation data

Low water - 1995-1996



High water - 1995-1996



- █ Water
- █ Bare or herbaceous, nonflooded
- █ Herbaceous, flooded
- █ Shrub, nonflooded

- █ Shrub, flooded
- █ Woodland, flooded
- █ Forest, nonflooded
- █ Forest, flooded

Hess *et al.* 2003

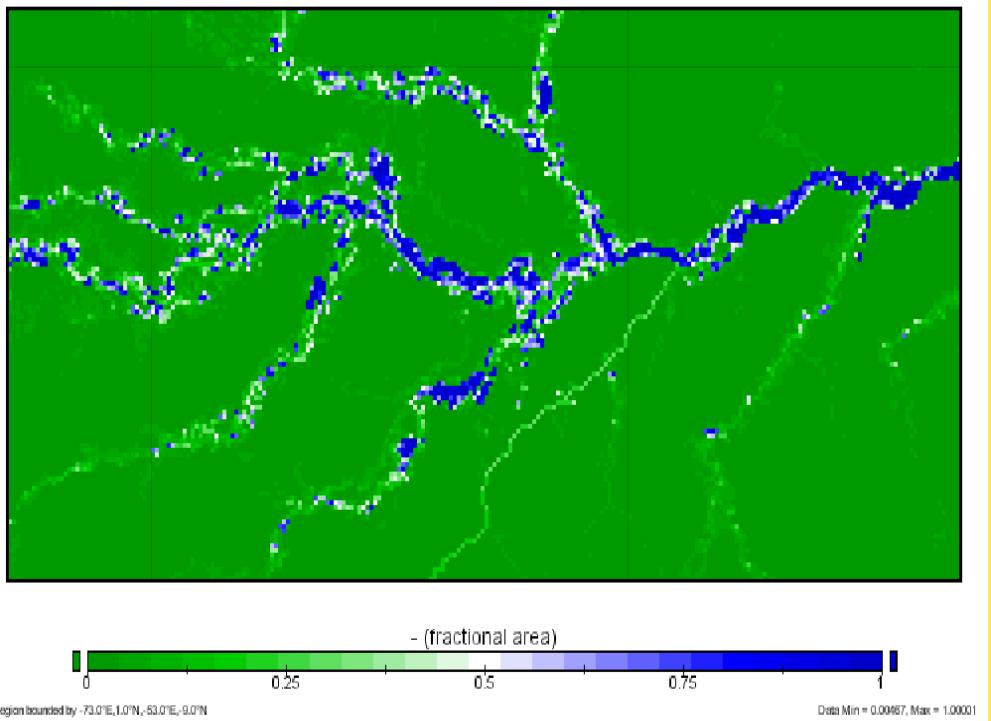
Composite images:

- *Low & high water only*
- *1995 & 1996*
- *Central Amazon only*

Identified wetland pixels:

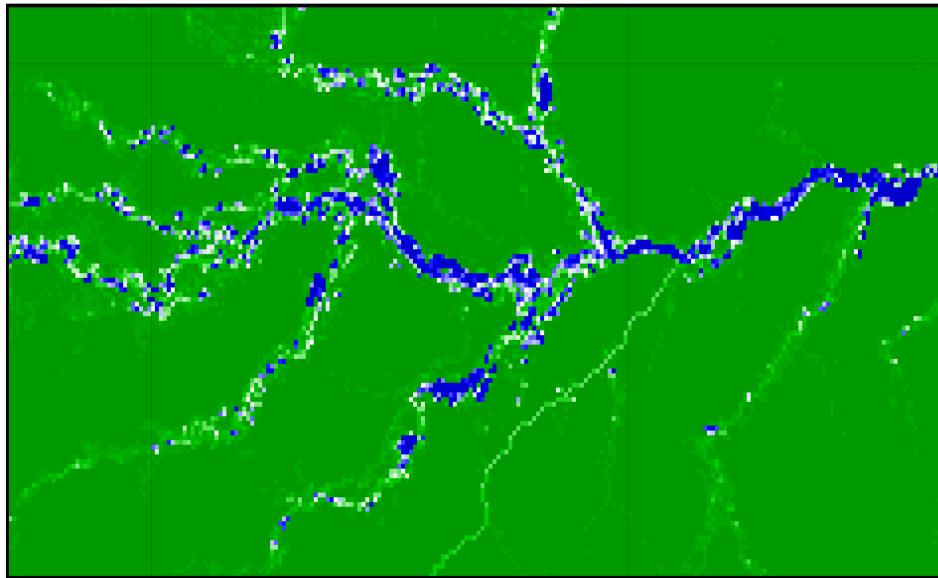
- *Fine scale: 3 arc-sec*
- *Classified by habitat type*
- *Validated against other remote sensing and ground meas'ts*

Simulation of high water flooding (composite)

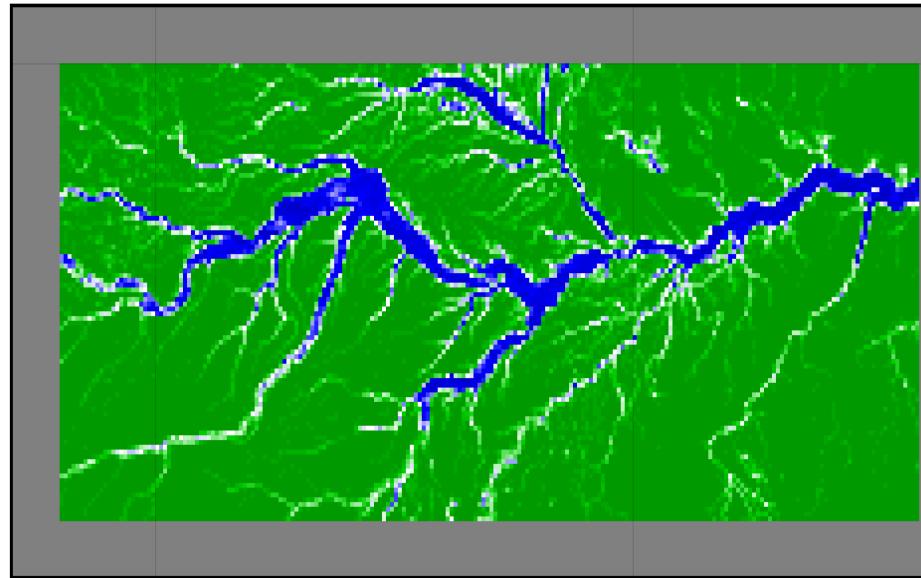


High  
water

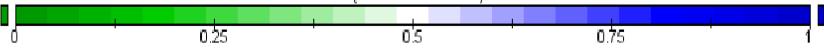
Simulation of high water flooding (composite)



High water composite - All flooded ecosystem types



- (fractional area)



Region bounded by -73.0°E, 1.0°N, 53.0°E, 9.0°N

Data Min = 0.00467, Max =

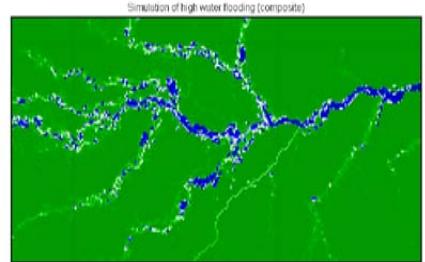
- (fractional\_flooded\_area)



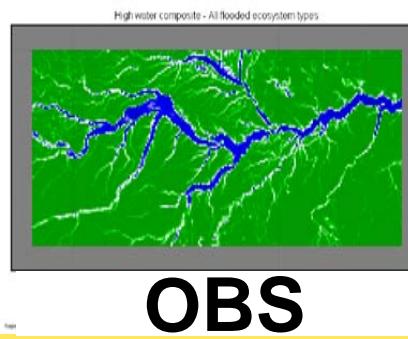
Data Min = 0, Max =

**Correlation in flooding pattern:  $r = 0.54$**   
**% difference in area flooded = -26%**

**High  
water**



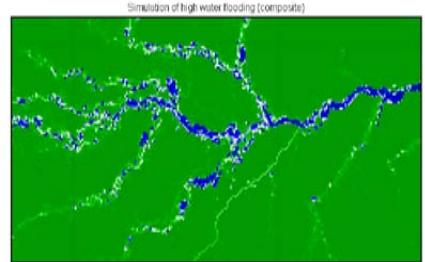
**SIM**



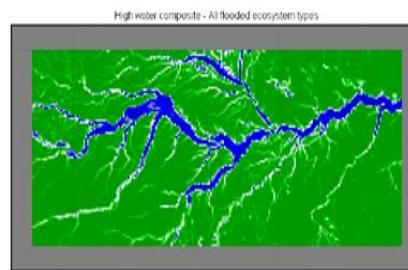
**OBS**

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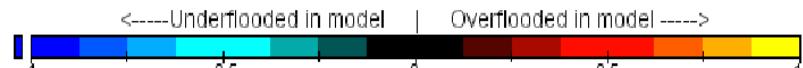
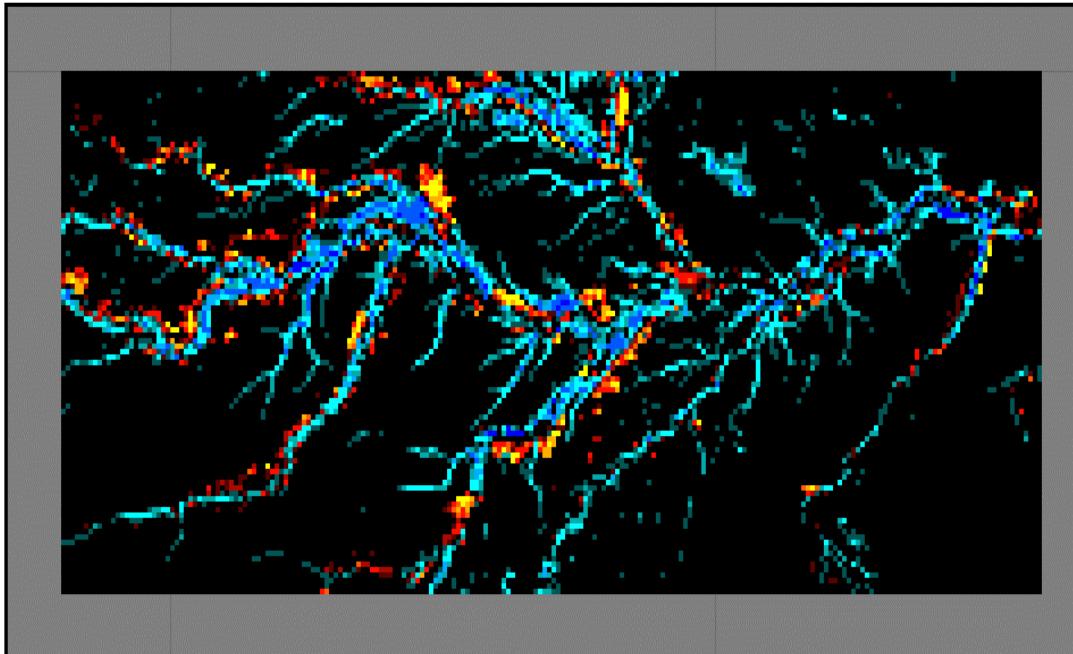
**SIM**



**OBS**

=

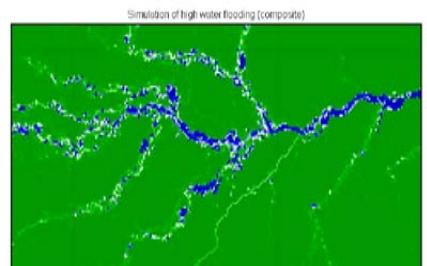
Simulated flooding minus observed flooding (High water)



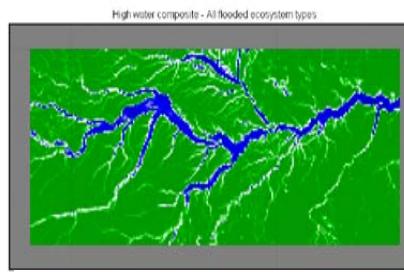
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**High  
water**



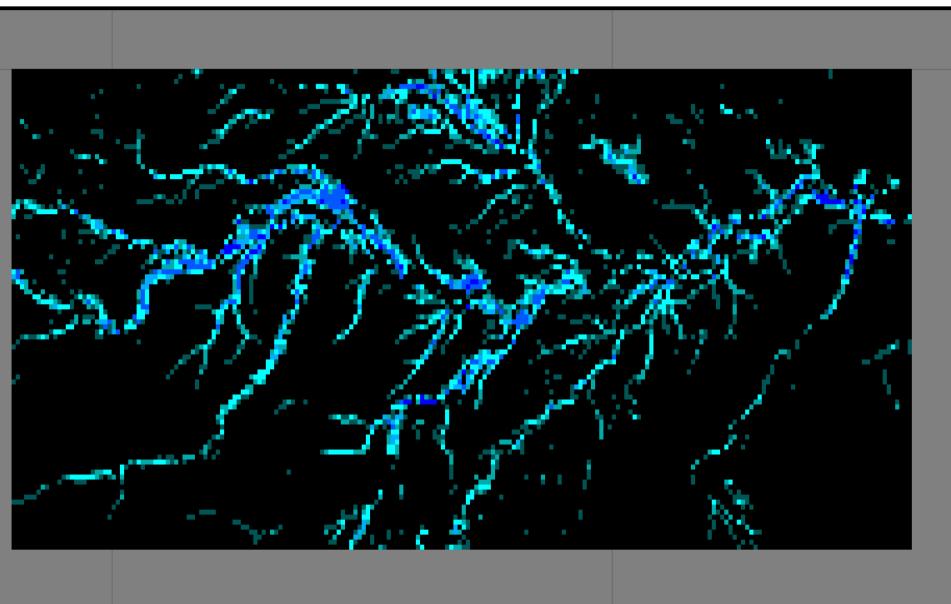
**SIM**



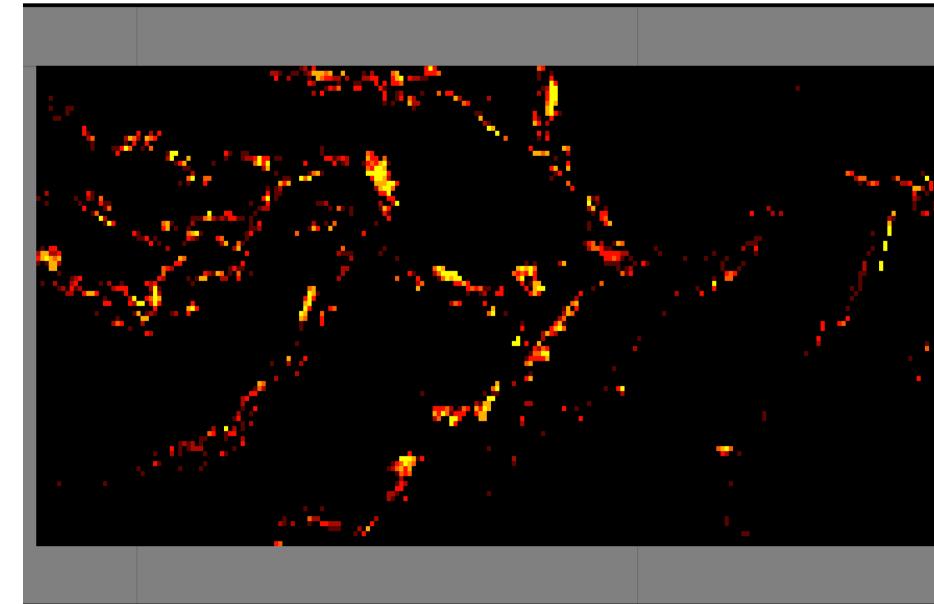
**OBS**

=

Simulated flooding minus observed flooding (High water)



Simulated flooding minus observed flooding (High water)

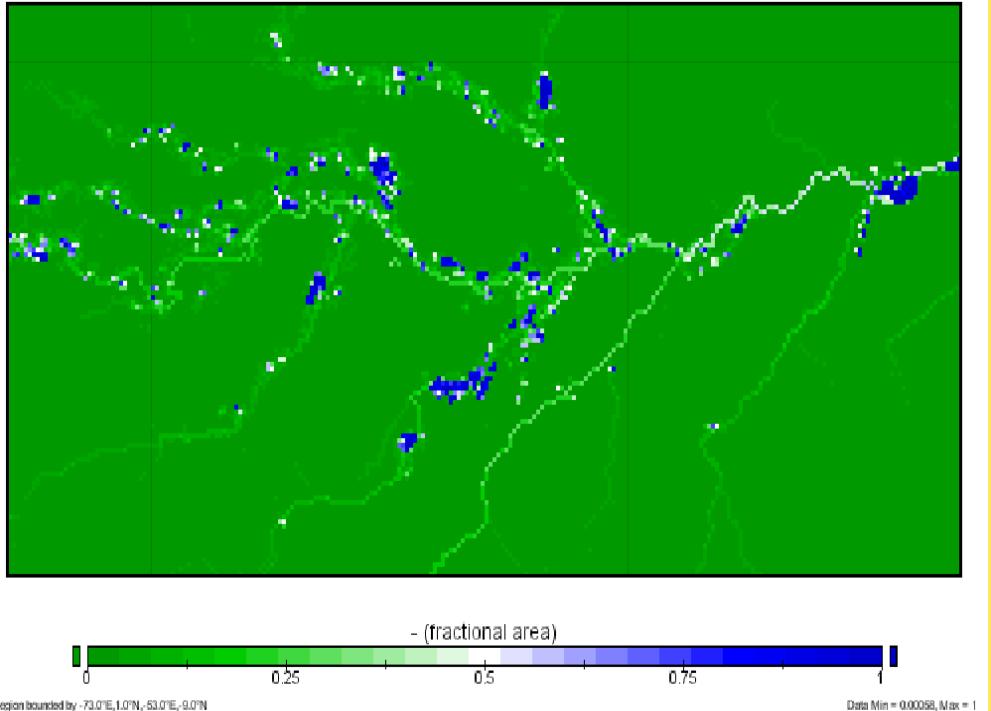


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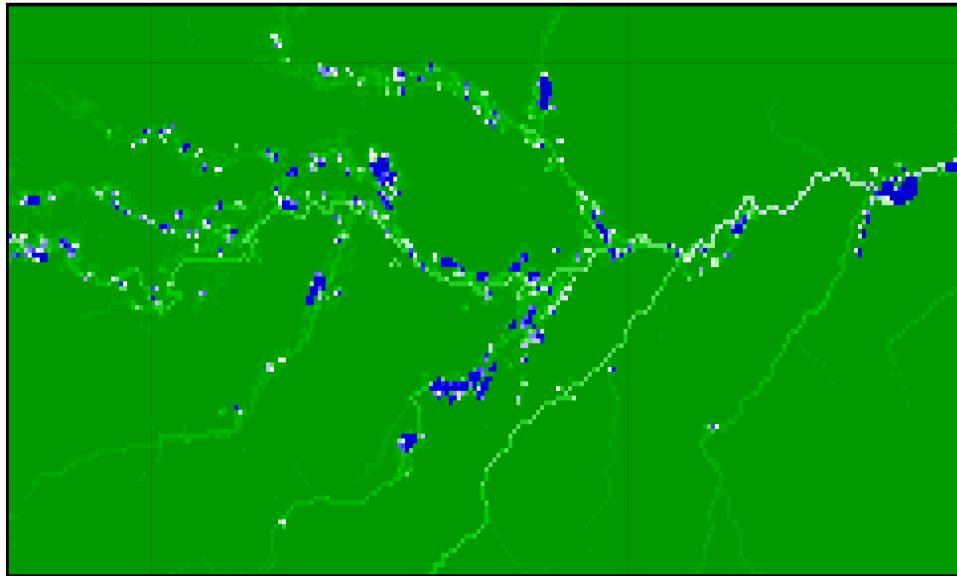
**High  
water**

Simulation of low water flooding (composite)

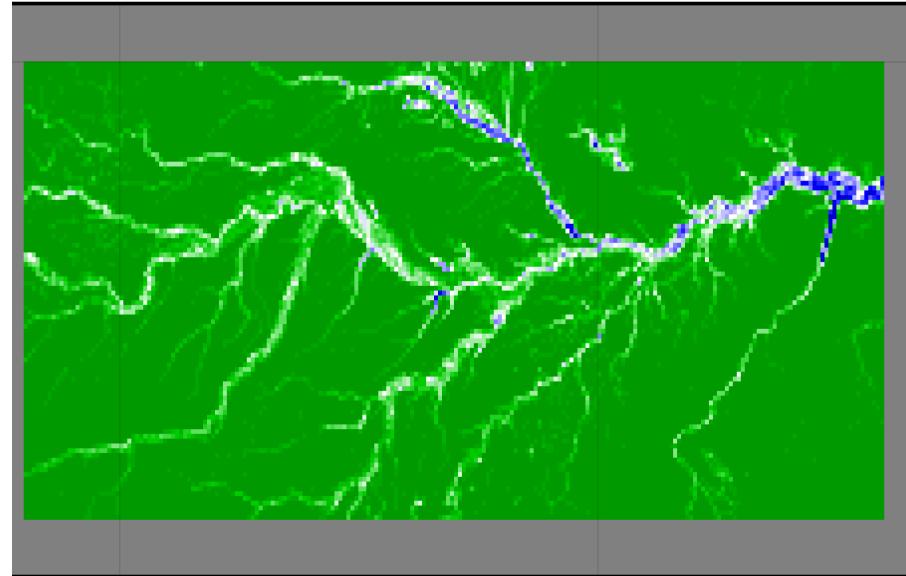


**Low  
water**

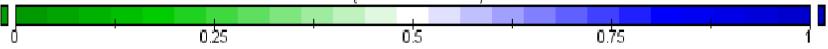
Simulation of low water flooding (composite)



Low water composite - All flooded ecosystem types



- (fractional area)

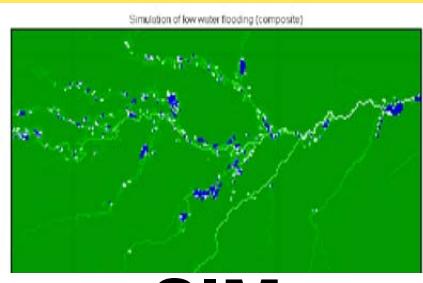


- (fractional\_flooded\_area)

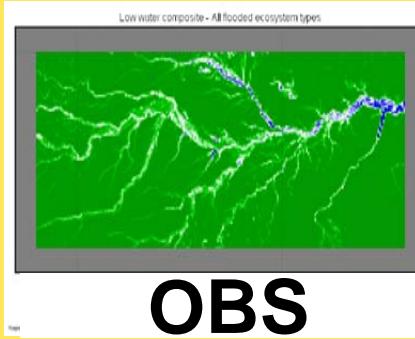


**Correlation in flooding pattern:  $r = 0.35$**   
**% difference in area flooded = -25%**

**Low  
water**



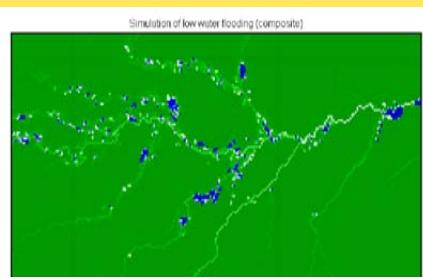
**SIM**



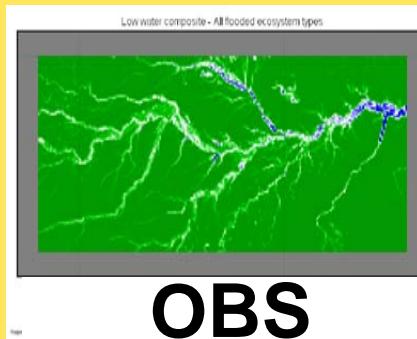
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**Low  
water**



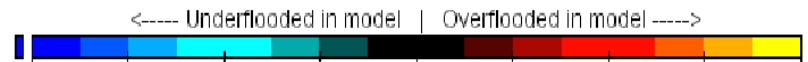
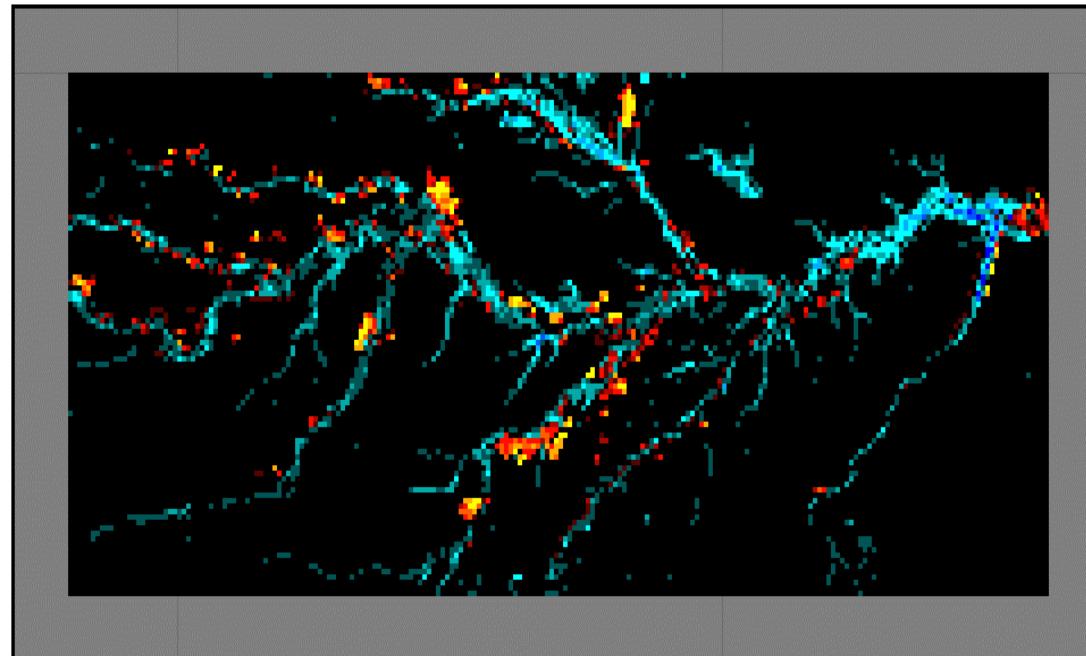
**SIM**



**OBS**

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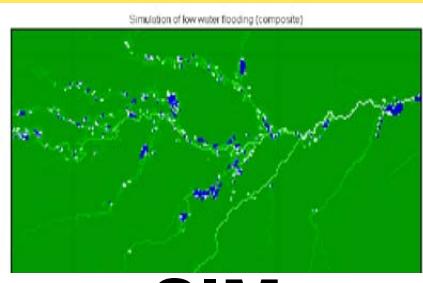
Simulated flooding minus observed flooding (Low water)



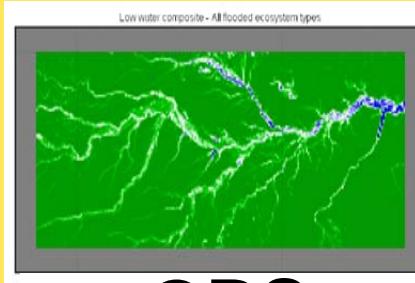
**Correlation in flooding pattern:  $r = 0.35$**

**% difference in area flooded = -25%**

**Low  
water**

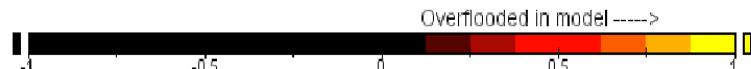
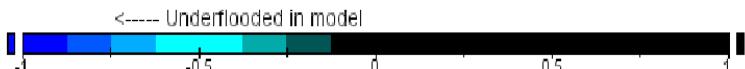
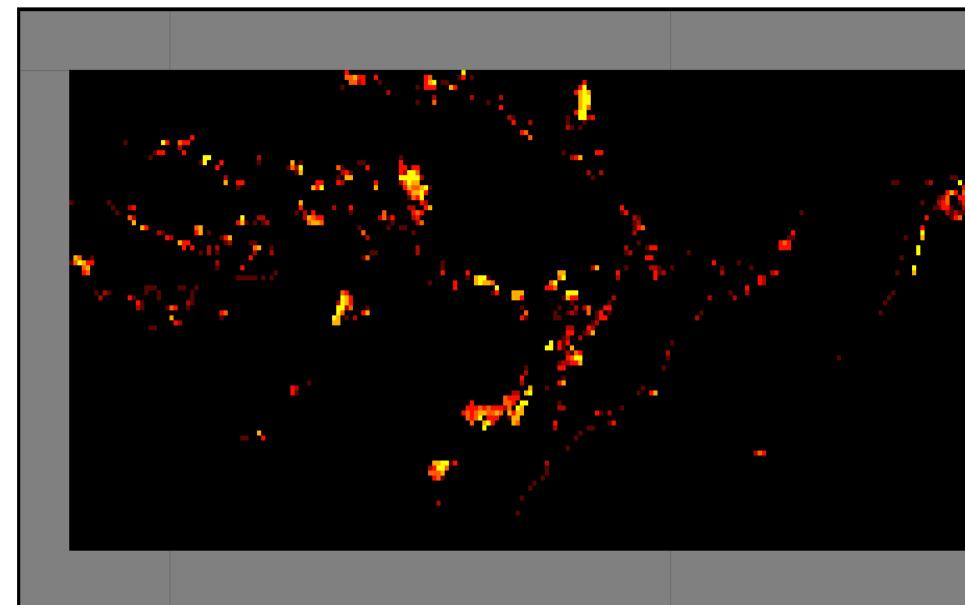
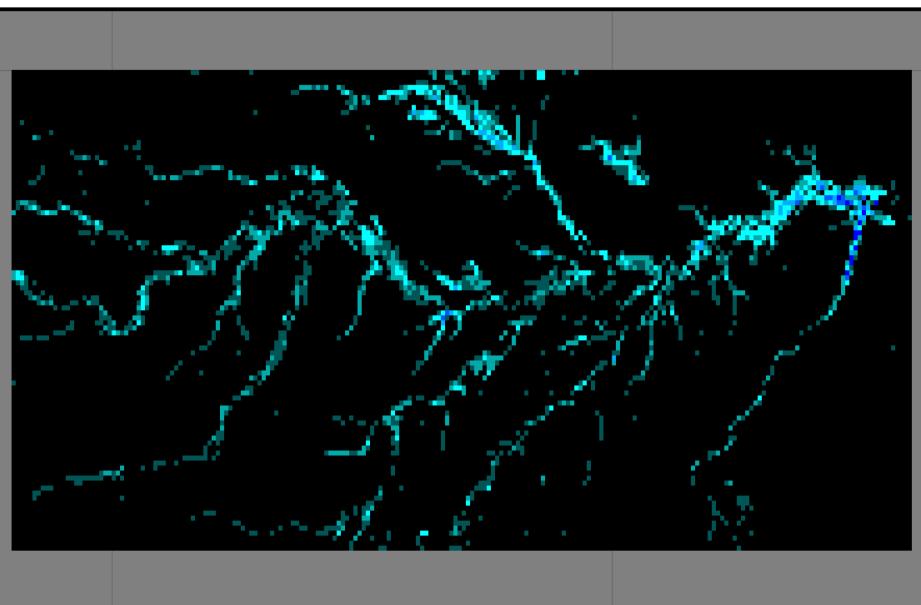


**SIM**



**OBS**

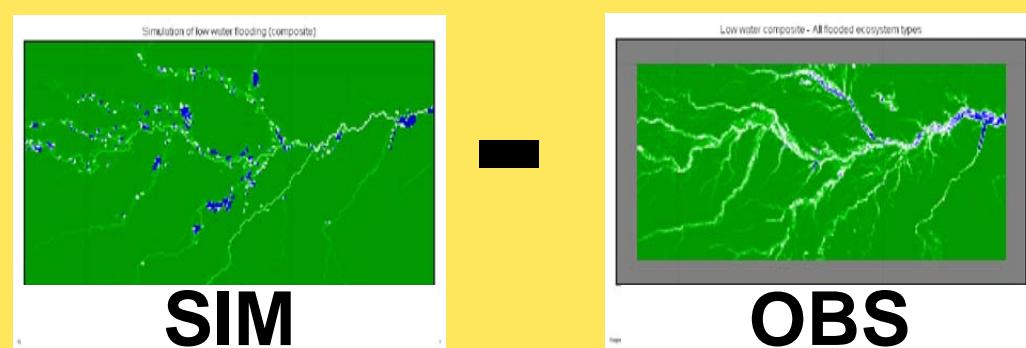
Simulated flooding minus observed flooding (Low water)



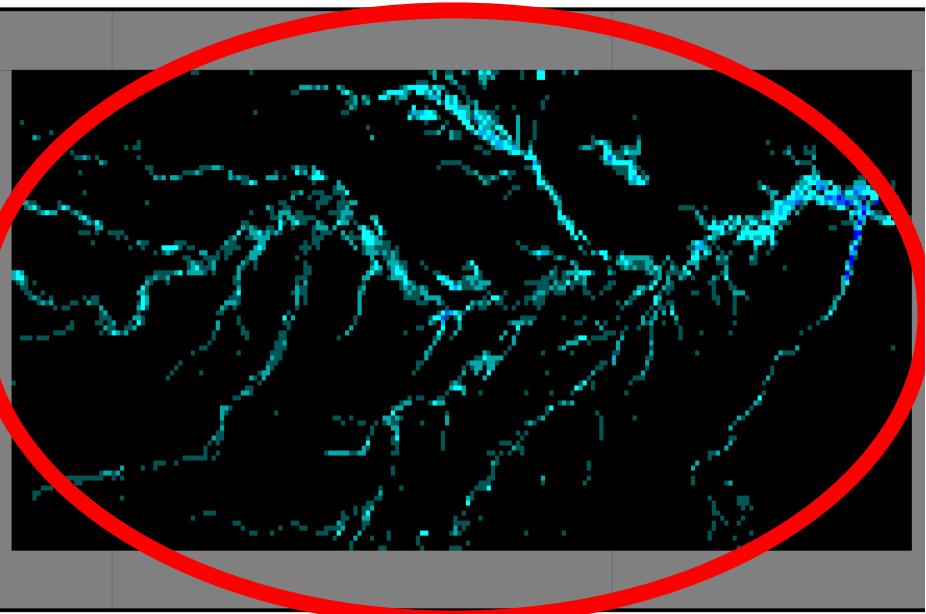
Correlation in flooding pattern:  $r = 0.35$

% difference in area flooded = -25%

**Low  
water**



Simulated flooding minus observed flooding (Low water)



Simulated flooding minus observed flooding (Low water)

Underflooding in model is correlated with prevalence of forested ecosystems.



Correlation in flooding pattern:  $r = 0.35$

% difference in area flooded = -25%

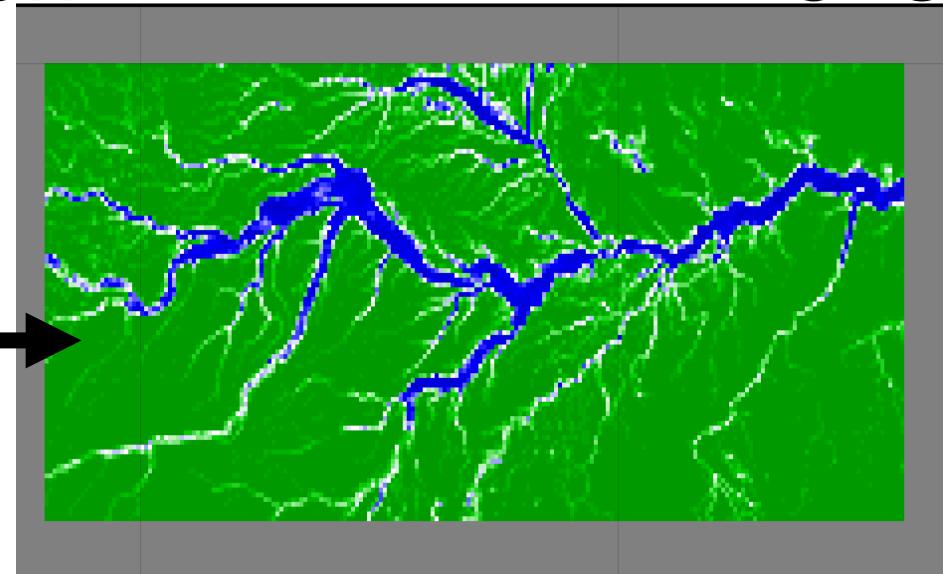
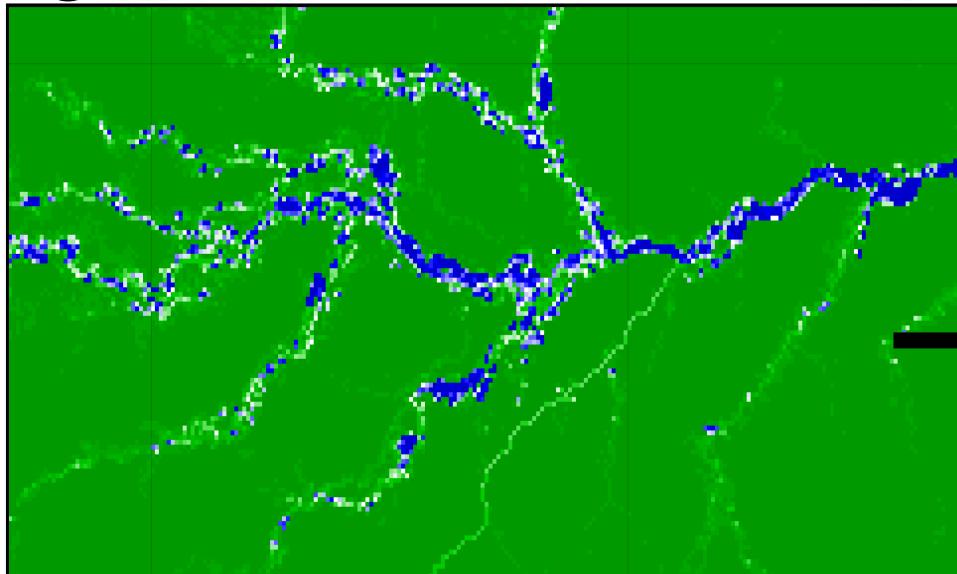
Low  
water

**SIM**

Simulation of high water flooding (composite)

**HIGH**

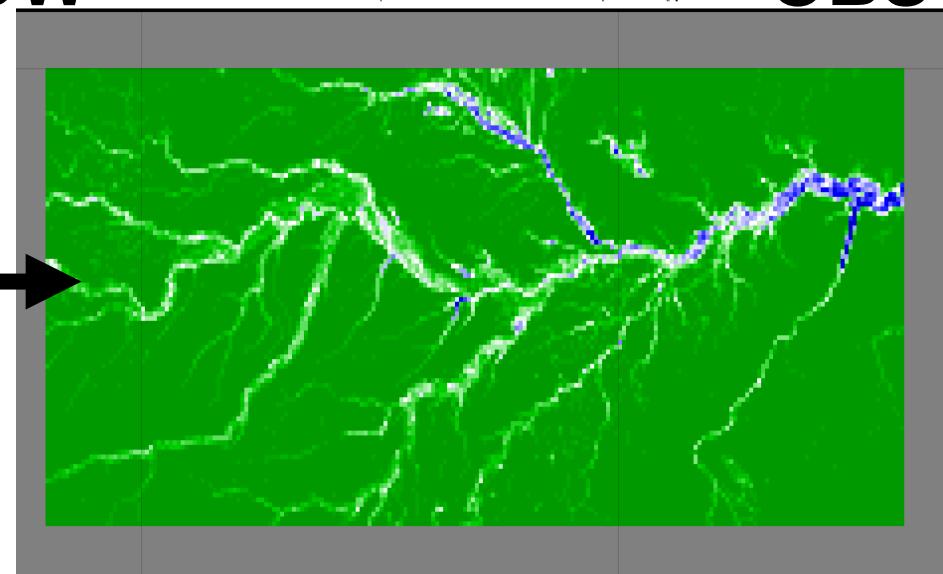
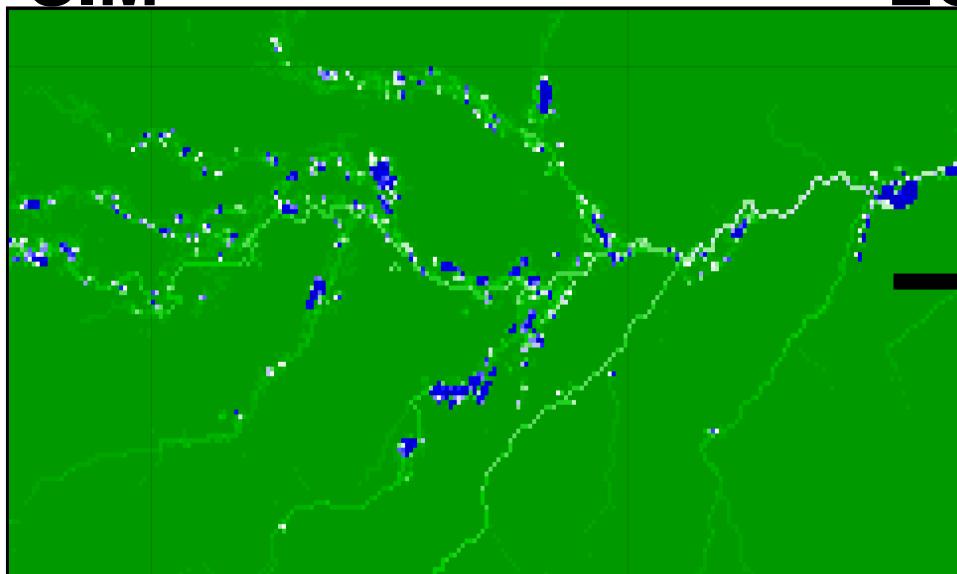
High water composite - All flooded ecosystem types

**OBS****SIM**

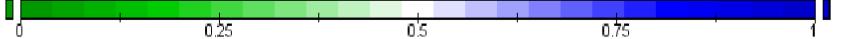
Simulation of low water flooding (composite)

**LOW**

Low water composite - All flooded ecosystem types

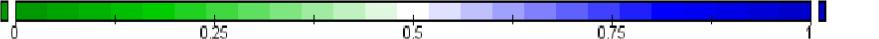
**OBS**

- (fractional area)



Data Min = 0.00058, Max = 1 bounded by -73.01E, 1.07N, 53.01E, 9.07N

- (fractional\_flooded\_area)



Data Min = 0, Max = 1

Region bounded by -73.01E, 1.07N, 53.01E, 9.07N

**SIM**

Simulation of high water flooding (composite)

**OBS**

High water composite - All flooded ecosystem types

## Variability over time

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- (fractional area)



Region bounded by -73.0°E, 1.0°N, -53.0°E, -9.0°N

Fuse this physical hydrology model with remote sensing data to create aquatic biogeography model

Region bounded by -73.0°E, 1.0°N, -53.0°E, -9.0°N

Data Min = 0.00058, Max = 1

- (fractional\_flooded\_area)

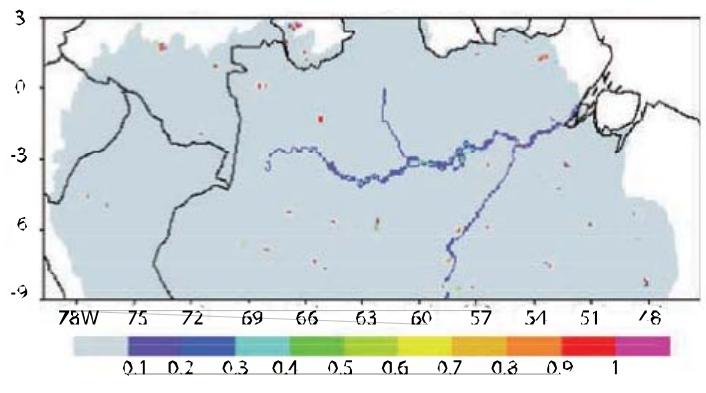
Data Min = 0, Max = 1

Region bounded by -73.0°E, 1.0°N, -53.0°E, -9.0°N

**OBS**

# Aquatic ecosystems biogeography

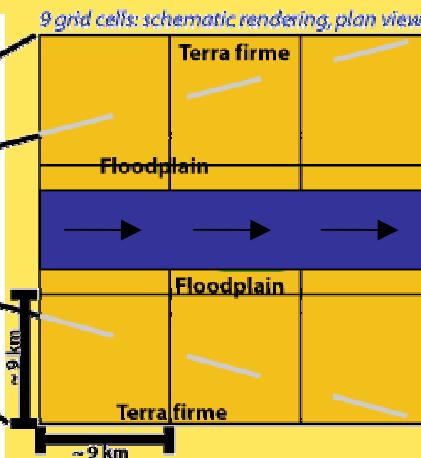
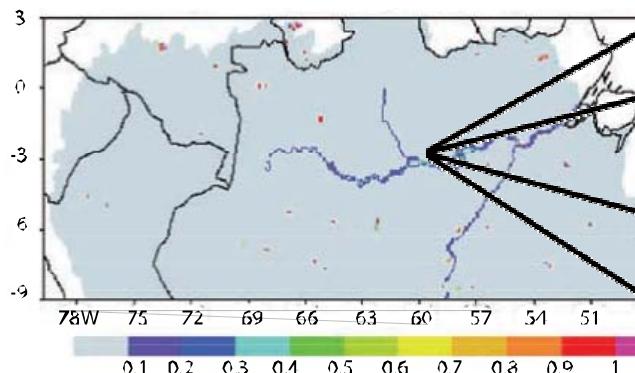
River discharge, low water



*Data/model fusion*

# Aquatic ecosystems biogeography

River discharge, low water

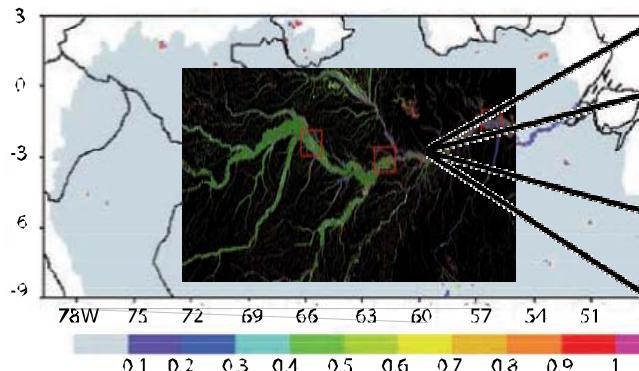


**Now:** Good representation of discharge, reasonable representation of flooded area.

*Data/model fusion*

# Aquatic ecosystems biogeography

River discharge, low water

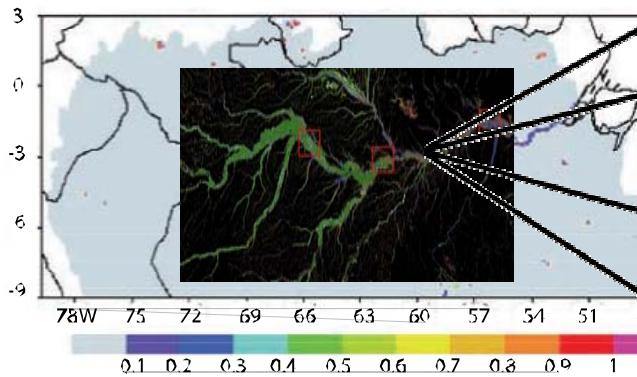


**Now:** Good representation of discharge, reasonable representation of flooded area...

**Next:** Moving towards a better representation of flooded area. We also want to know the distribution of aquatic ecosystems ...*in space and over time*.

# Aquatic ecosystems biogeography

River discharge, low water



**Now:** Good representation of discharge, reasonable representation of flooded area...

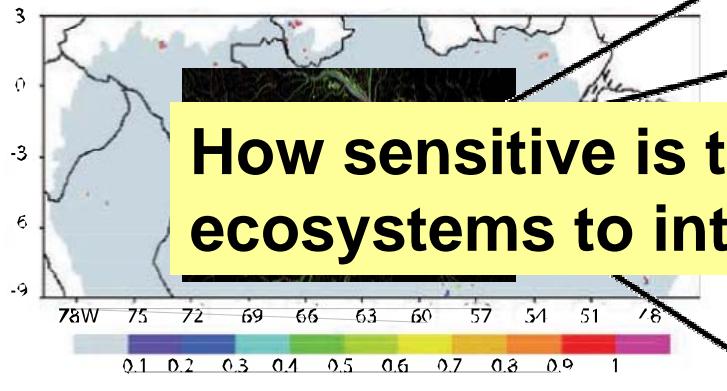
**Next:** Moving towards a better representation of flooded area. We also want to know the distribution of aquatic ecosystems ...in space and over time.

Key ecosystems of interest: *floodable forests, open water and herbaceous ecosystems*

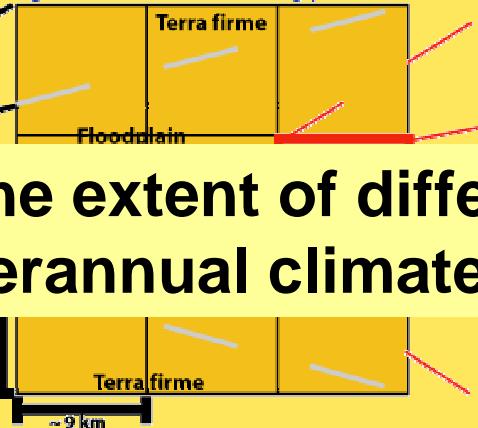
**Data/model fusion**

# Aquatic ecosystems biogeography

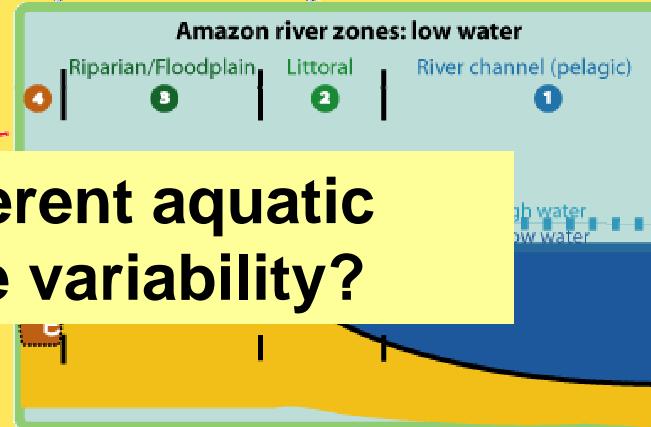
River discharge, low water



9 grid cells: schematic rendering, plan view



1 grid cell: schematic rendering, cross-sectional view



**Now:** Good representation of discharge, reasonable representation of flooded area...

**Next:** Moving towards a better representation of flooded area. We also want to know the distribution of aquatic ecosystems ...in space and over time.

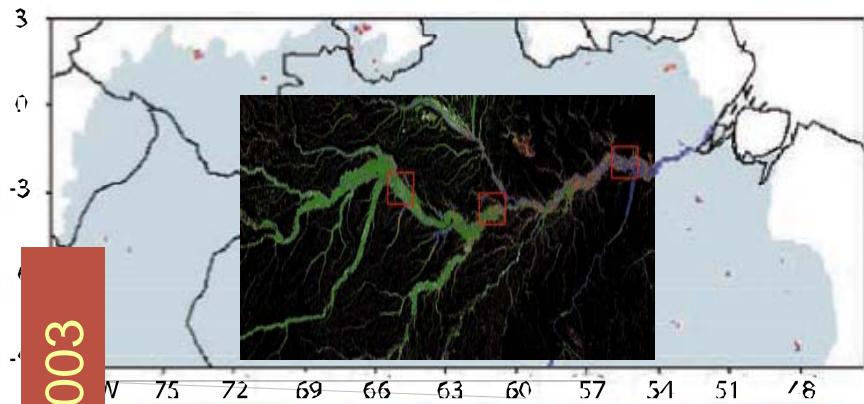
Key ecosystems of interest: *floodable forests, open water and herbaceous ecosystems*

...which will be used to infer info about ecological and biogeochemical characteristics of those grid cells over time.

**Data/model fusion**

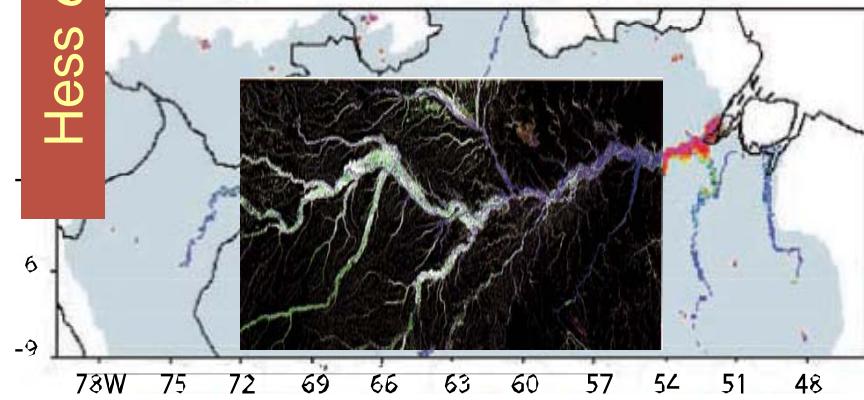
# Aquatic ecosystems biogeography

Low water - 1995-1996



Hess et al. 2003

High water - 1995-1996



Water  
Bare or herbaceous, nonflooded  
Herbaceous, flooded  
Shrub, nonflooded

Shrub, flooded  
Woodland, flooded  
Forest, nonflooded  
Forest, flooded

Use classified remote sensing data to define sub-grid scale potential aquatic ecosystem distribution in THMB

**-scale monthly model results**

**... to maximum and minimum flooded area fractions derived from observations:**

*Sim – Min of Modeled*

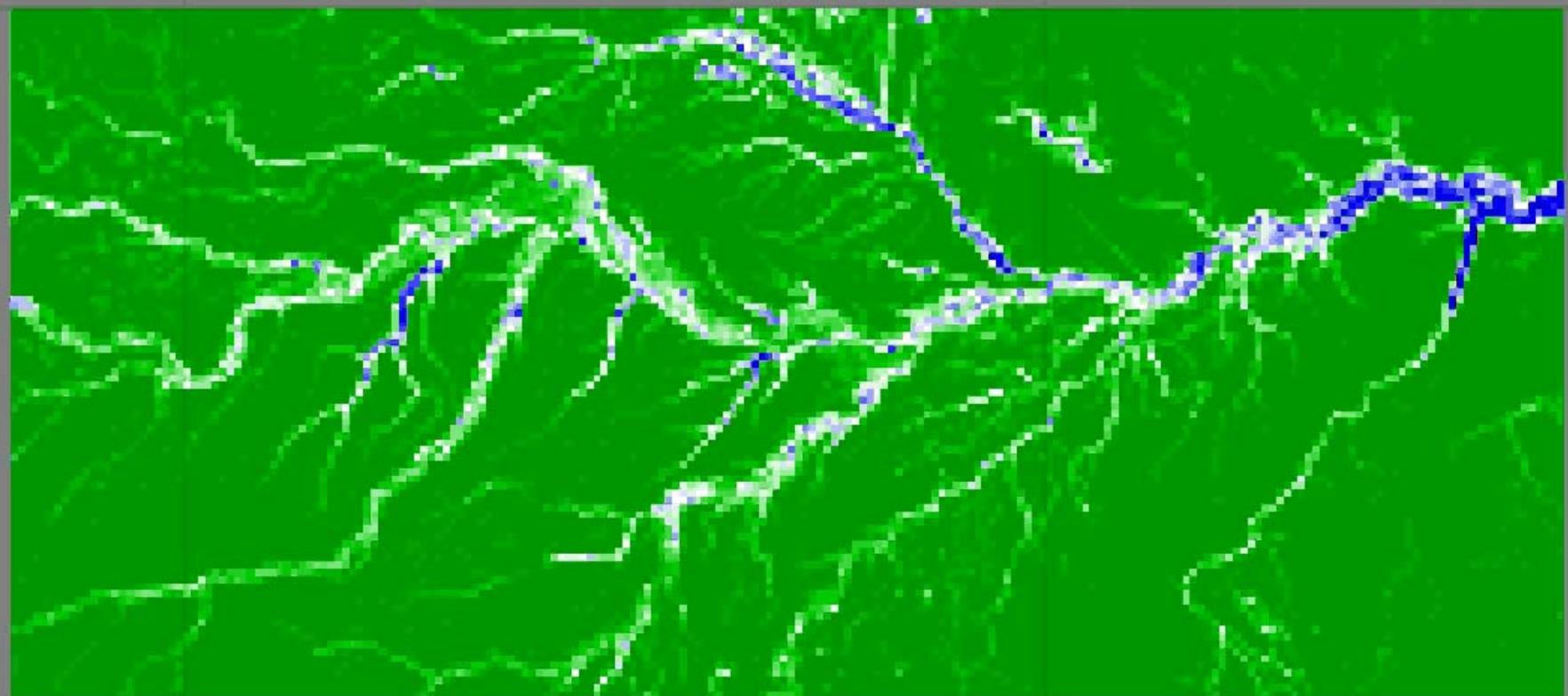
= Y

*(Range of Sim)*

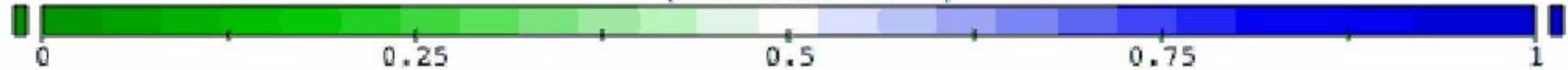
$(Y * (Range of Obs)) + (Min of Obs)$

**Data/model fusion**

JANUARY / JANEIRO



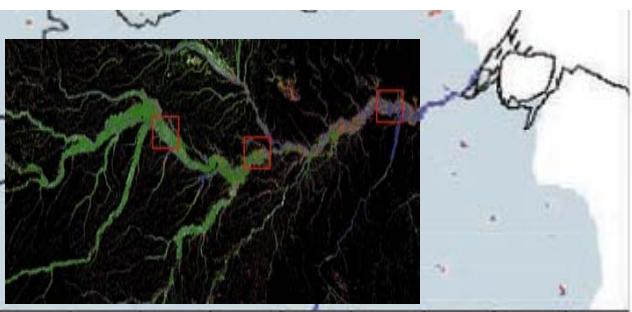
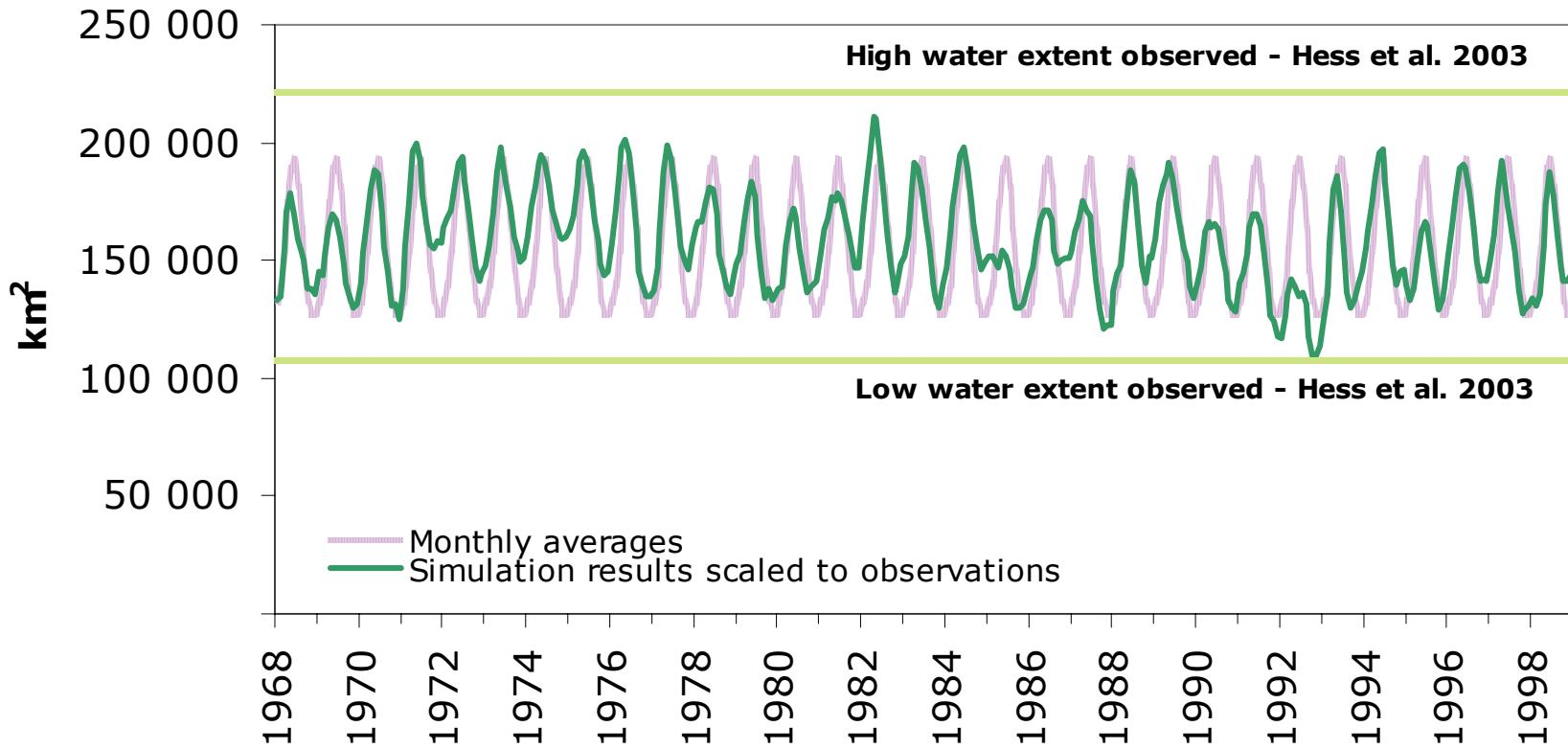
- (fraction of 1)



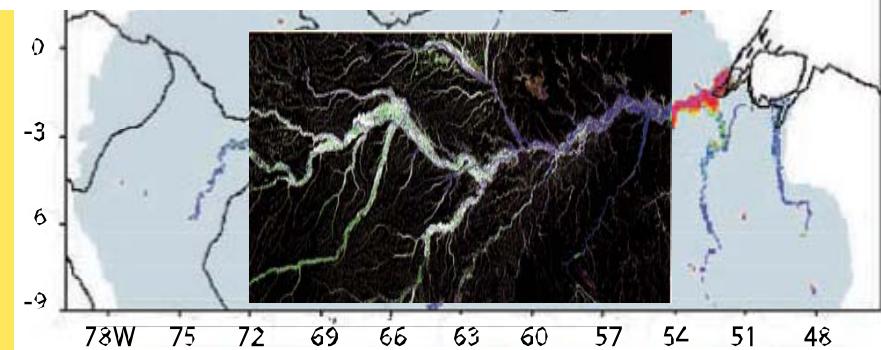
*All flooded ecosystems*

*Data/model fusion*

# Annual flooded area in Central Amazon - model results scaled to observations

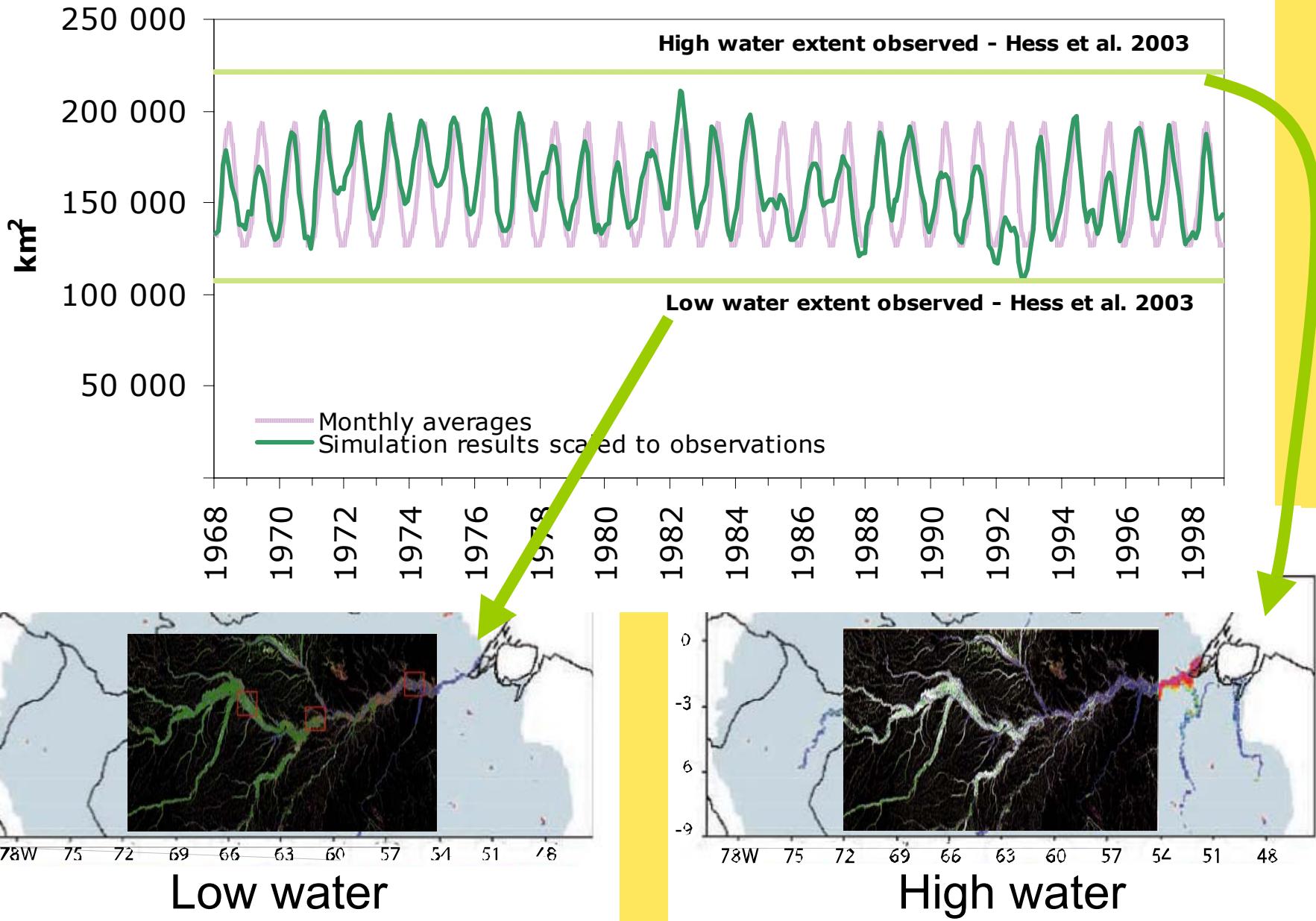


Low water



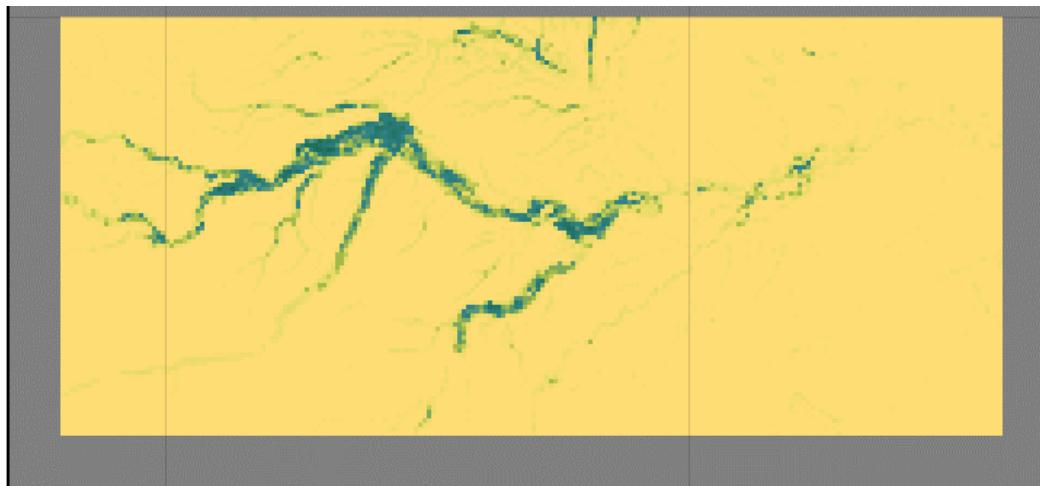
High water

# Annual flooded area in Central Amazon - model results scaled to observations



# Forest flooded at high water only

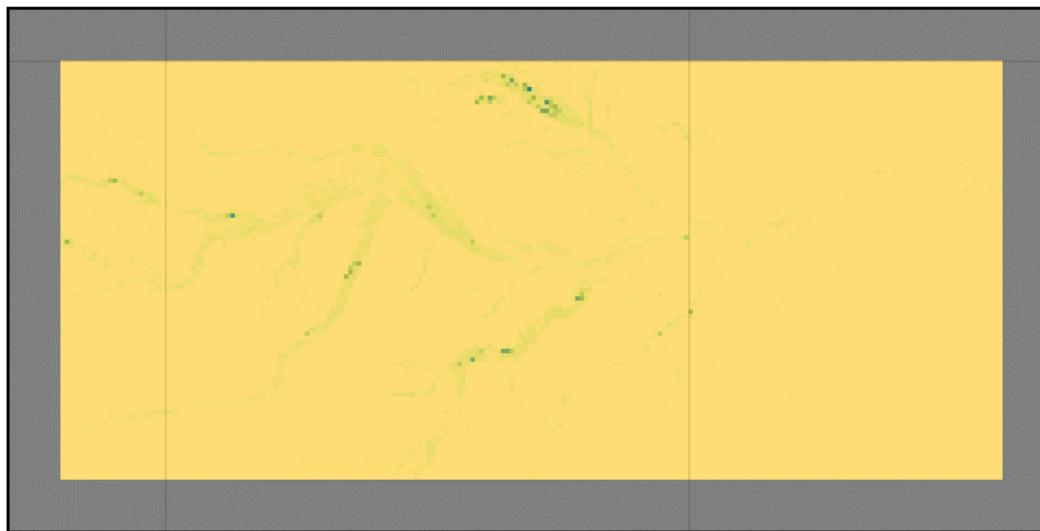
derived from  
Hess et al. 2003



fraction of grid cell containing floodable forests



forest flooded year-round



fraction of grid cell containing flooded forests



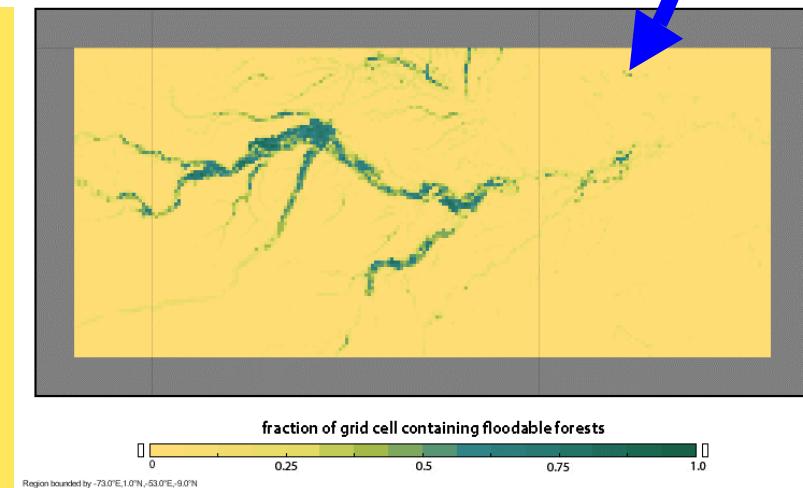
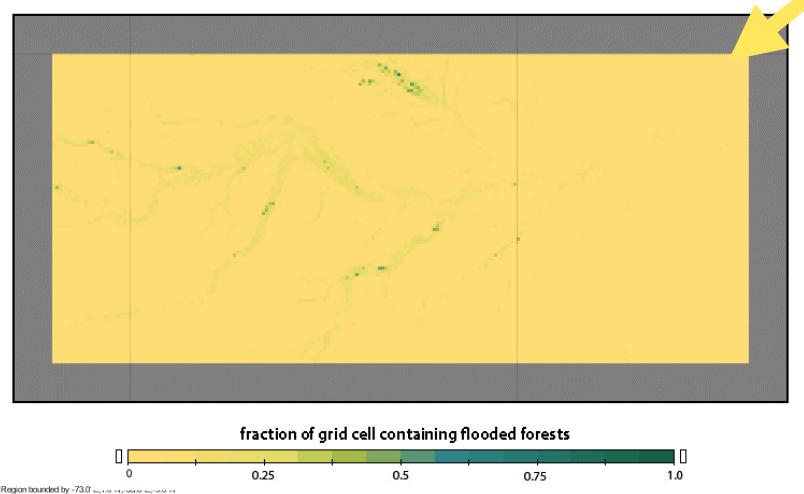
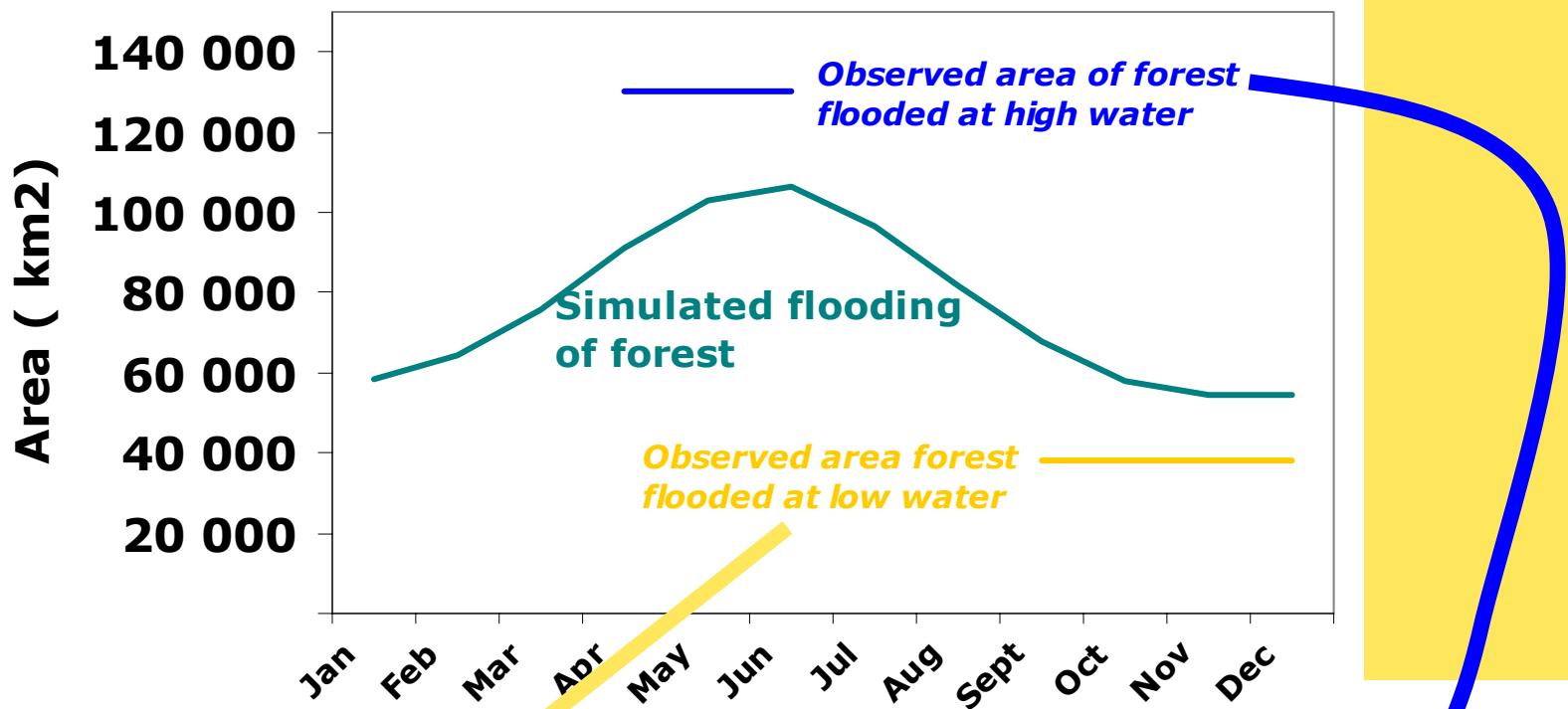
Region bounded by -73.0

**Forests  
only**

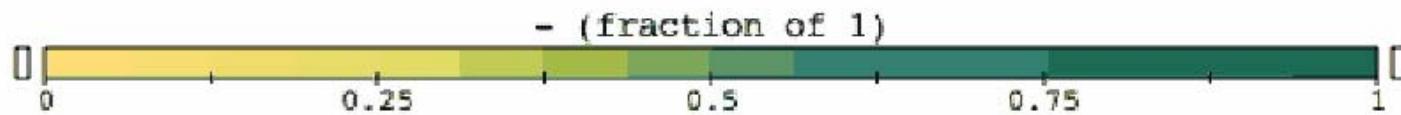
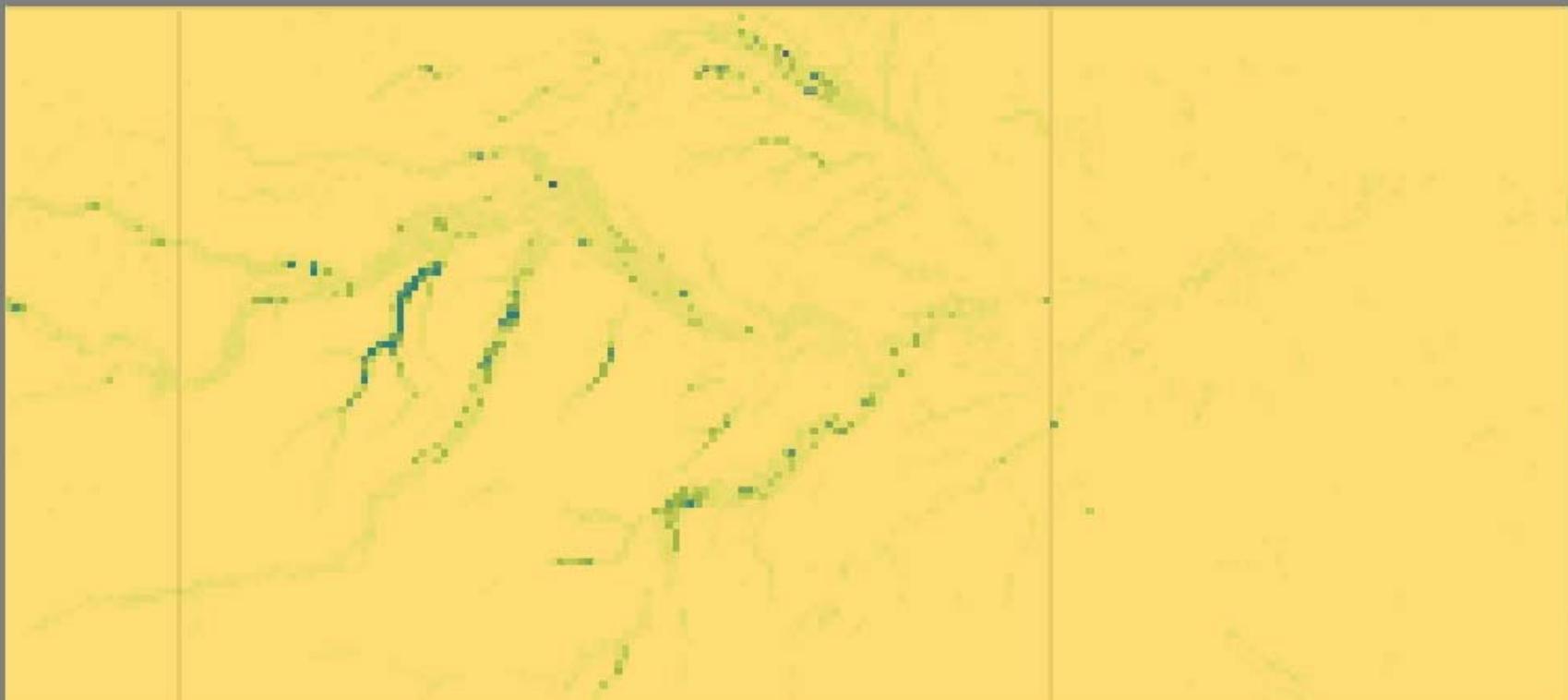
**Data/  
model  
fusion**

# Area of Forests in Flooded State

("average" simulation year, scaled to observations)



## January / Janeiro

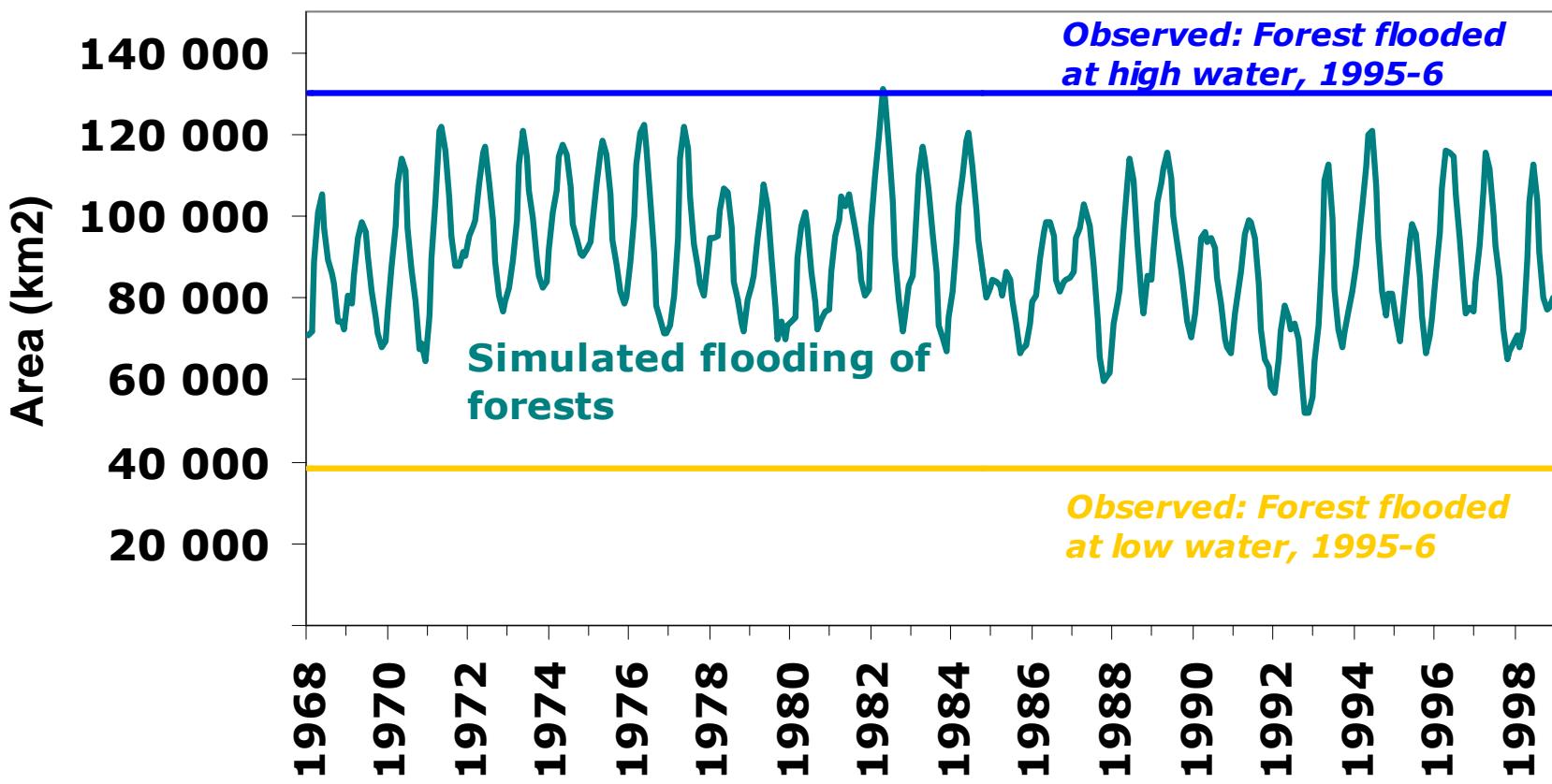


Region bounded by -73.0°E, 1.0°N, -53.0°E, 9.0°N

Data Min = 0, Max = 0.7330

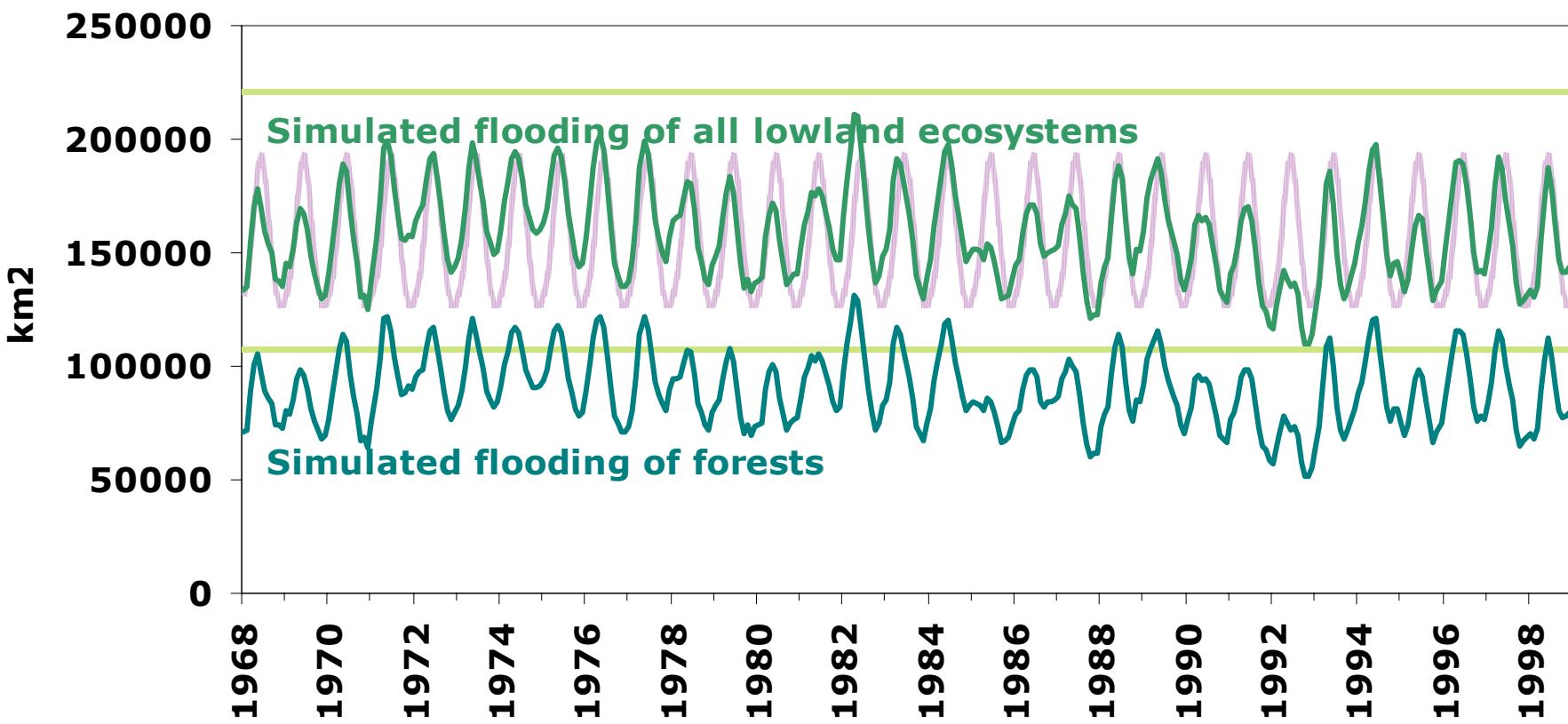
***Data/model fusion***

## Area of Forests in Flooded Condition, Central Amazon Basin (simulation scaled to observations)



Data/model fusion

# Annual flooded area in Central Amazon - model results scaled to observations

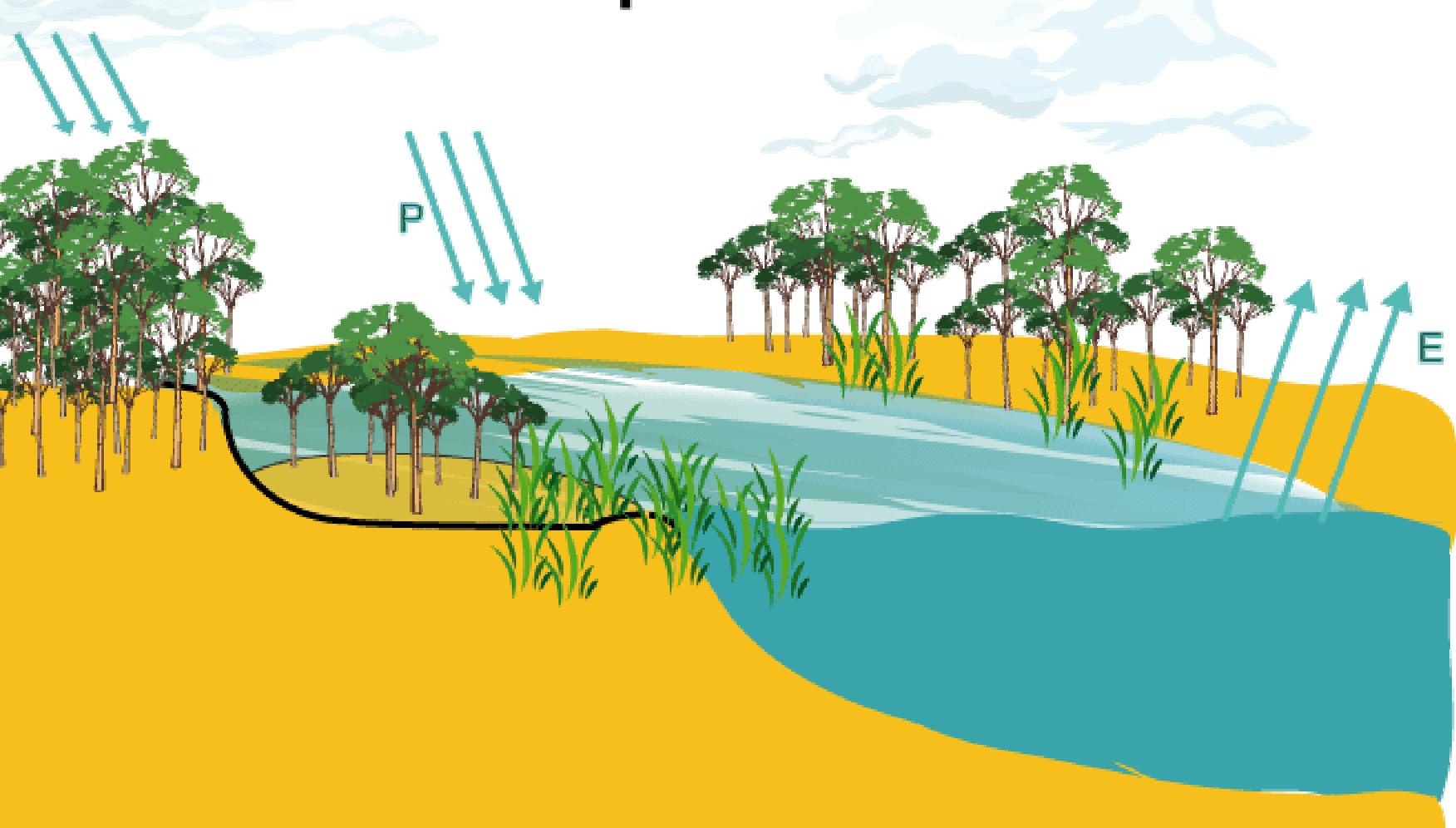


**2. How is the flow of carbon through these ecosystems affected by changes in hydrology, aquatic ecosystem dynamics, and terrestrial ecosystems?**

→ Add aquatic carbon cycling to THMB

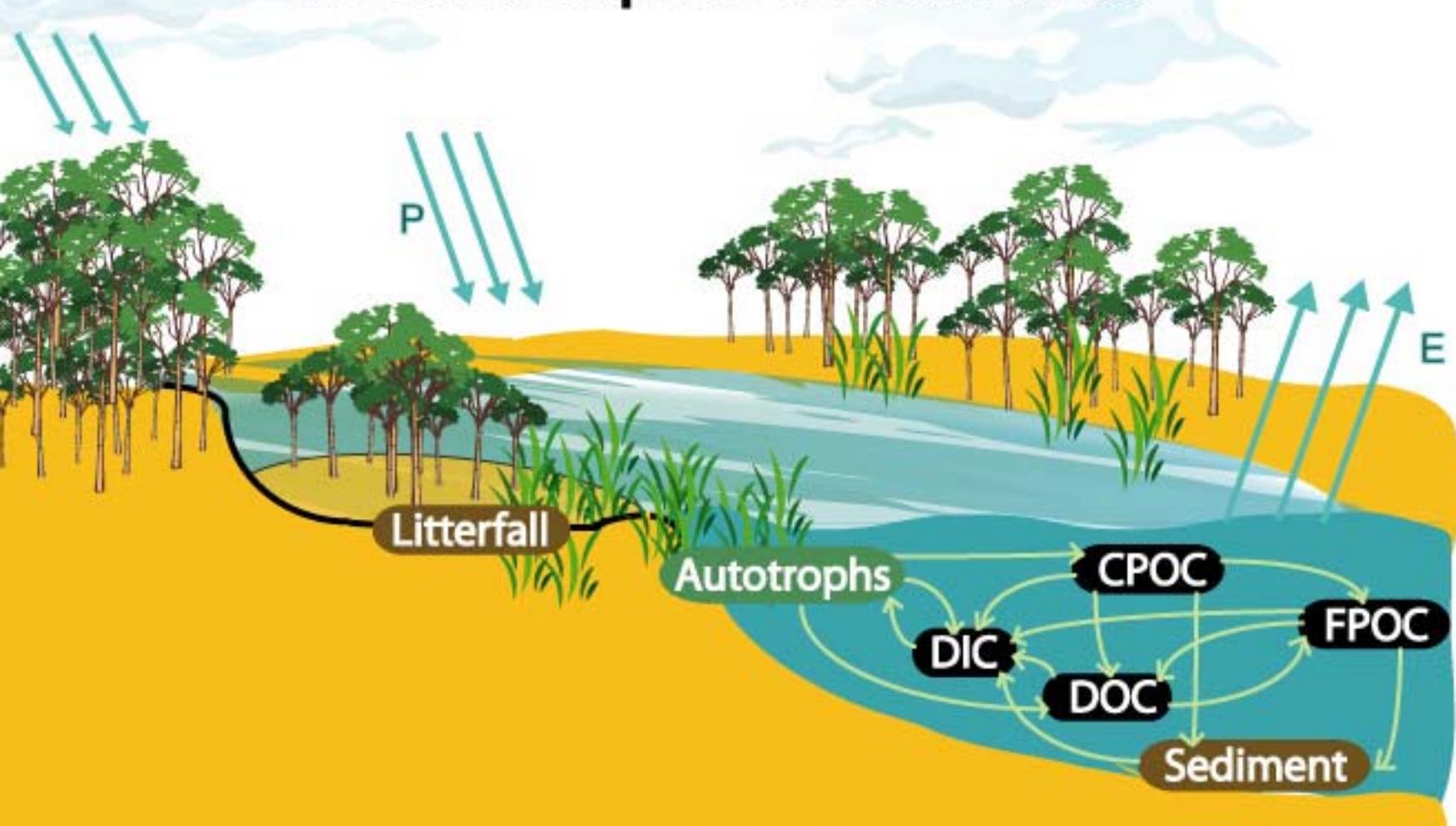
*Future applications*

# Terrestrial-Aquatic Carbon Fluxes



**Carbon**

# Terrestrial-Aquatic Carbon Fluxes



CPOC, FPOC: Coarse & Fine Particulate Organic C

Q: River flow

DOC: Dissolved Org. C

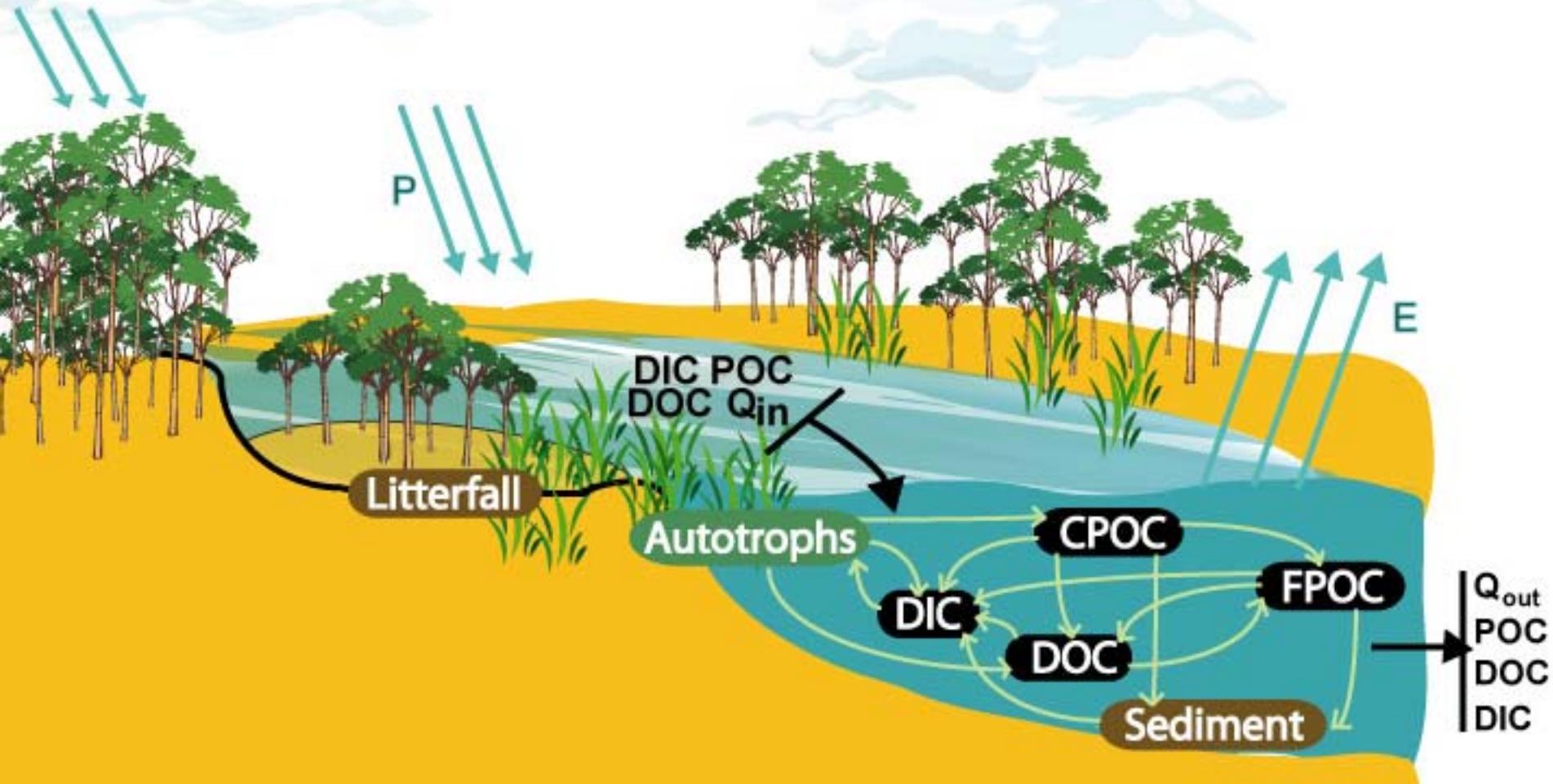
S: Runoff from land surface

DIC: Dissolved Inorg. C ( $\text{CO}_2 + \text{H}_2\text{CO}_3 + \text{HCO}_3 + \text{CO}_3$ )

G: Groundwater

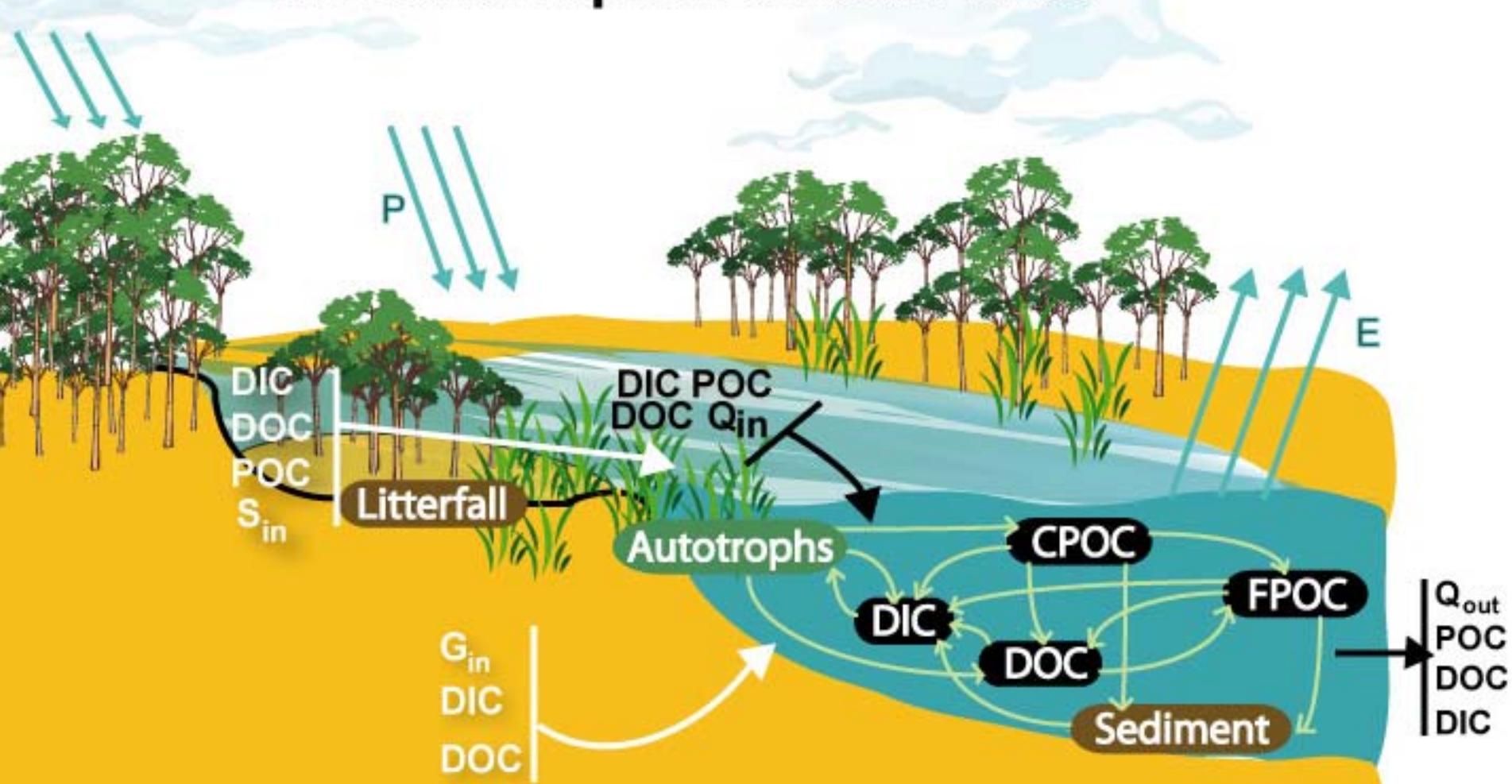
**Carbon**

# Terrestrial-Aquatic Carbon Fluxes



**Carbon**

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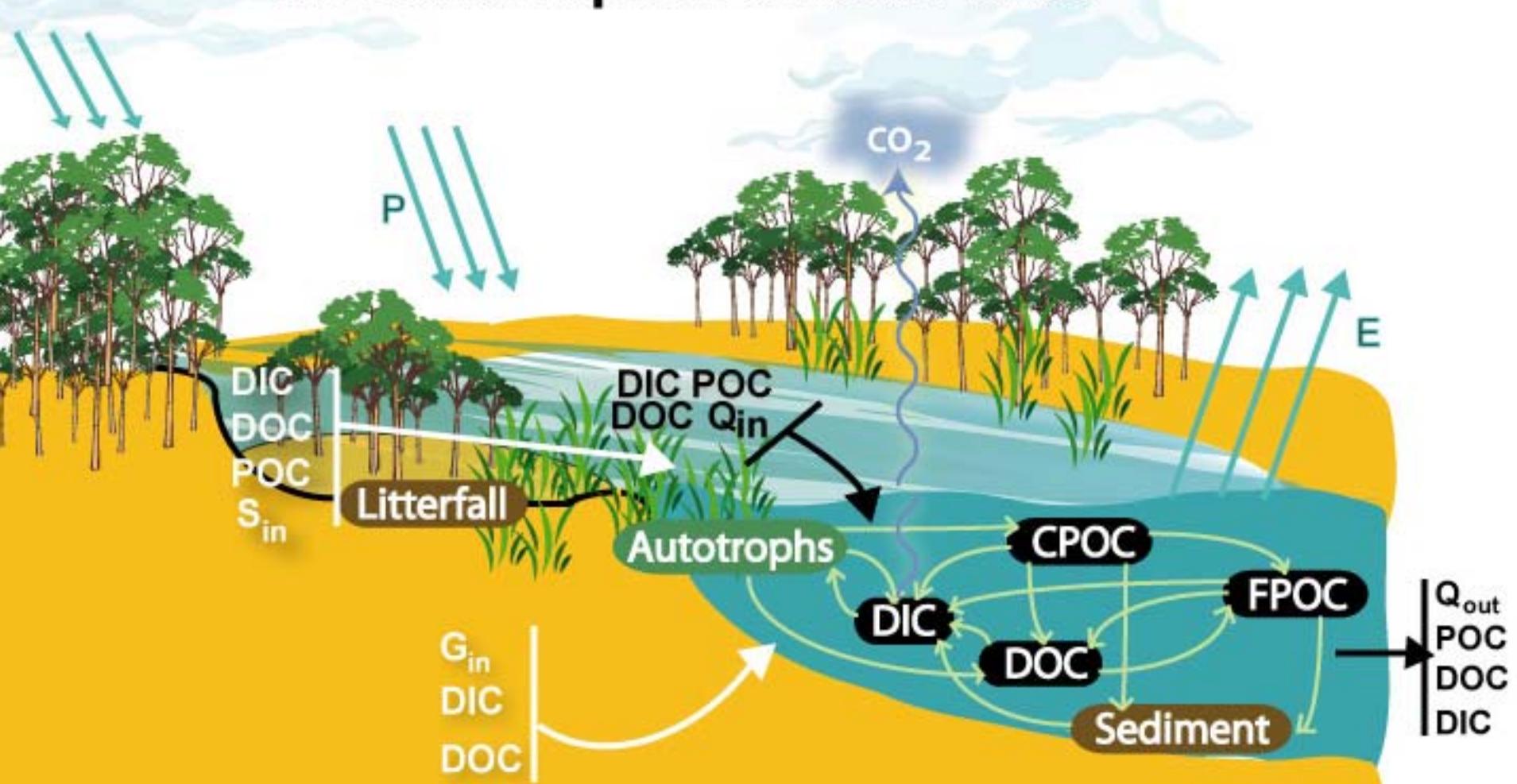
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**Carbon**

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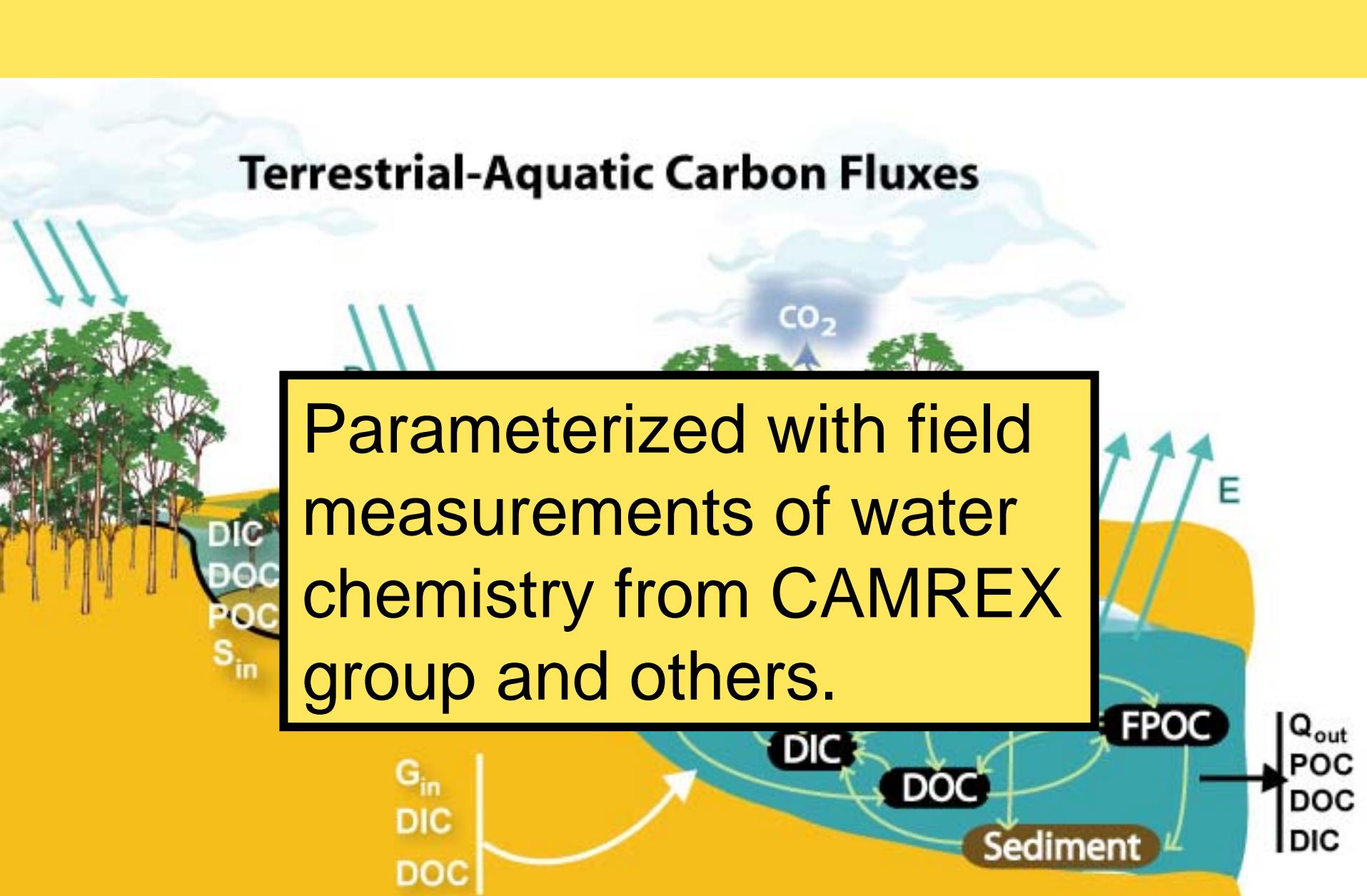
DIC: Dissolved Inorg. C ( $\text{CO}_2 + \text{H}_2\text{CO}_3 + \text{HCO}_3 + \text{CO}_3$ )

G: Groundwater

**Carbon**

# Terrestrial-Aquatic Carbon Fluxes

Parameterized with field measurements of water chemistry from CAMREX group and others.



CPOC, FPOC: Coarse & Fine Particulate Organic C

Q: River flow

DOC: Dissolved Org. C

S: Runoff from land surface

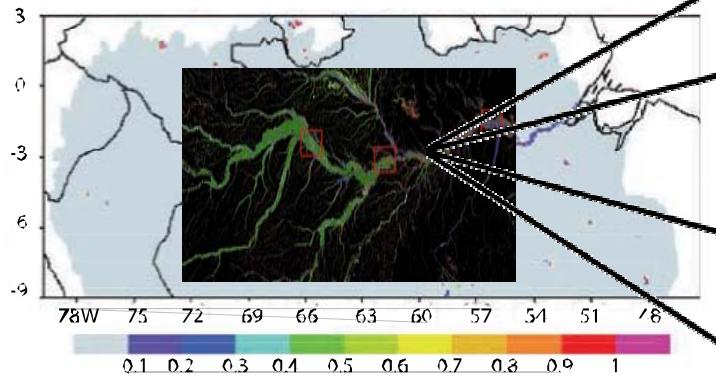
DIC: Dissolved Inorg. C ( $\text{CO}_2 + \text{H}_2\text{CO}_3 + \text{HCO}_3 + \text{CO}_3$ )

G: Groundwater

**Carbon**

# Aquatic carbon cycling

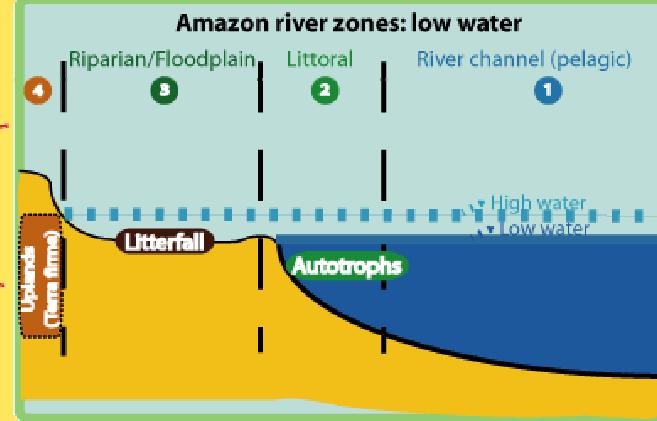
River discharge, low water



9 grid cells: schematic rendering, plan view



1 grid cell: schematic rendering, cross-sectional view

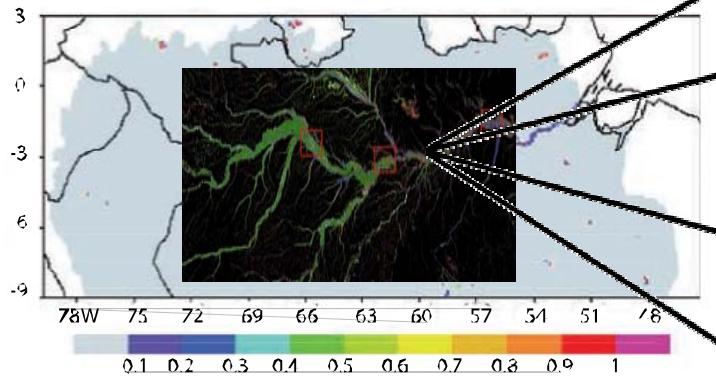


From hydrology and  
aquatic ecosystem  
biogeography...

Carbon

# Aquatic carbon cycling

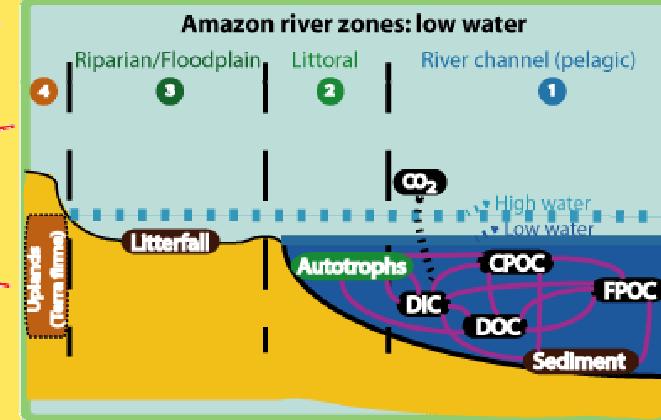
River discharge, low water



9 grid cells: schematic rendering, plan view



1 grid cell: schematic rendering, cross-sectional view



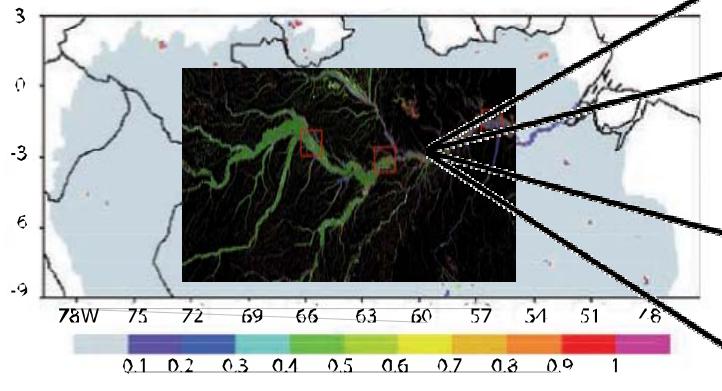
From hydrology and  
aquatic ecosystem  
biogeography...

...to simulation of  
carbon cycling in  
these different  
aquatic  
environments  
over time.

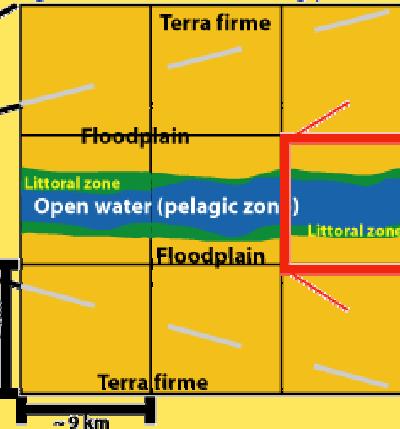
Carbon

# Aquatic carbon cycling

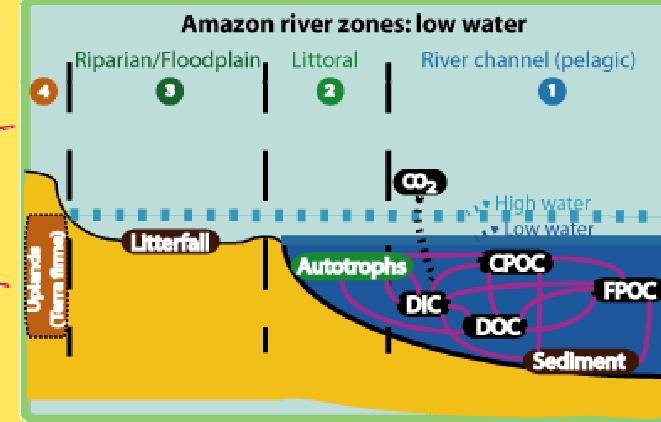
River discharge, low water



9 grid cells: schematic rendering, plan view



1 grid cell: schematic rendering, cross-sectional view



From hydrology and  
aquatic ecosystem  
biogeography...

...to simulation of  
carbon cycling in  
these different  
aquatic  
environments  
over time.

We know that different environments  
will emit CO<sub>2</sub> at different rates (learning  
more about this all the time!) ...

Carbon

# Aquatic carbon cycling questions

What is the relative importance of different aquatic ecosystems for CO<sub>2</sub> emissions?

How sensitive is the flux of carbon dioxide from rivers and the floodplain to interannual climate variability?

How might the overall contribution of aquatic ecosystems to atmospheric CO<sub>2</sub> emissions change under scenarios of future land cover?



Carbon

## Other future applications ...

- *Fisheries*
- *Endangered species habitat*
- *Effects of dams*
- *River transportation planning*
- *Floodplain agriculture*

# *Thanks!*

*Work is funded through  
the NASA LBA-ECO  
project*

*[eahoward@wisc.edu](mailto:eahoward@wisc.edu)*



*On the Rio Tapajos, an Amazon tributary*

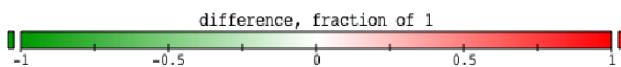
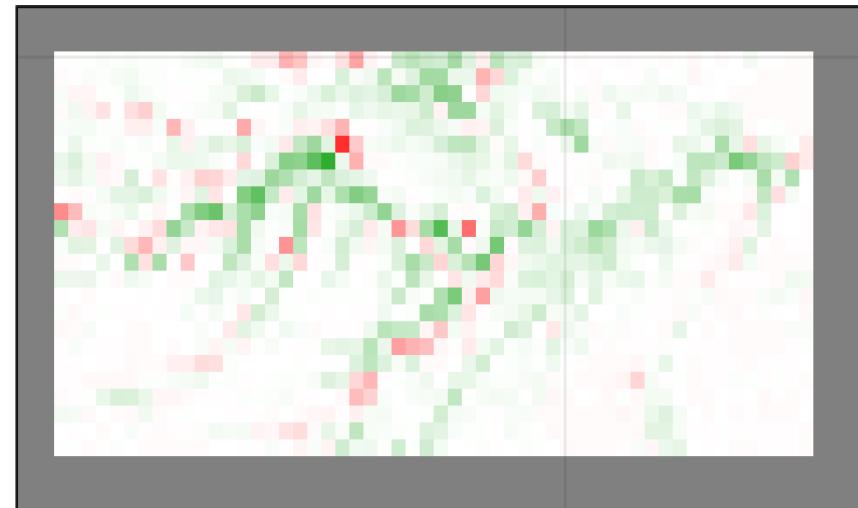
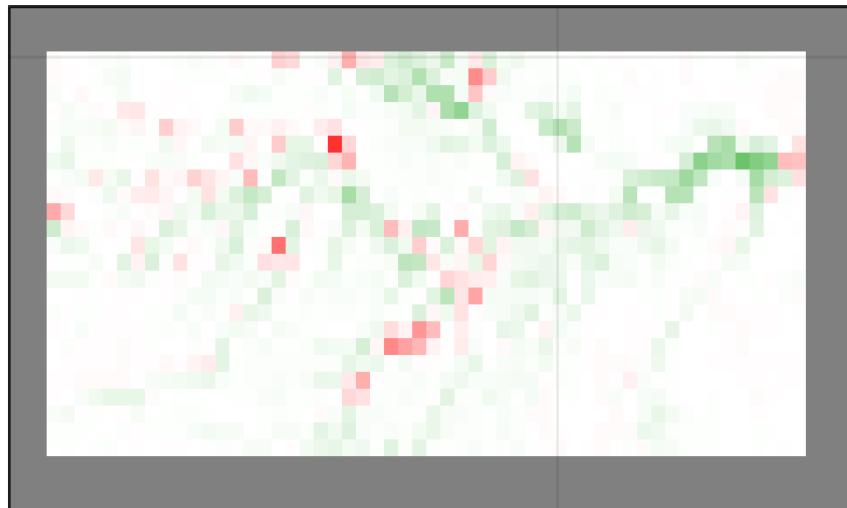
Region bounded by -73.0°E, 1.0°N, -53.0°E, -9.0°N

Data Min = -0.79664, Max = 0.926 Region bounded by -73.0°E, 1.0°N, -53.0°E, -9.0°N

Data Min = 0.66854, Max = 0.52461

#77: Min sim flooding minus low water obs, 1995; 20 min res; r=.54

#77: Max sim flooding minus high water obs, 1996; 20 min res; r=.76



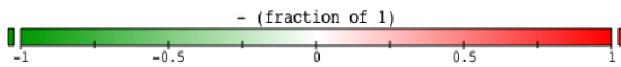
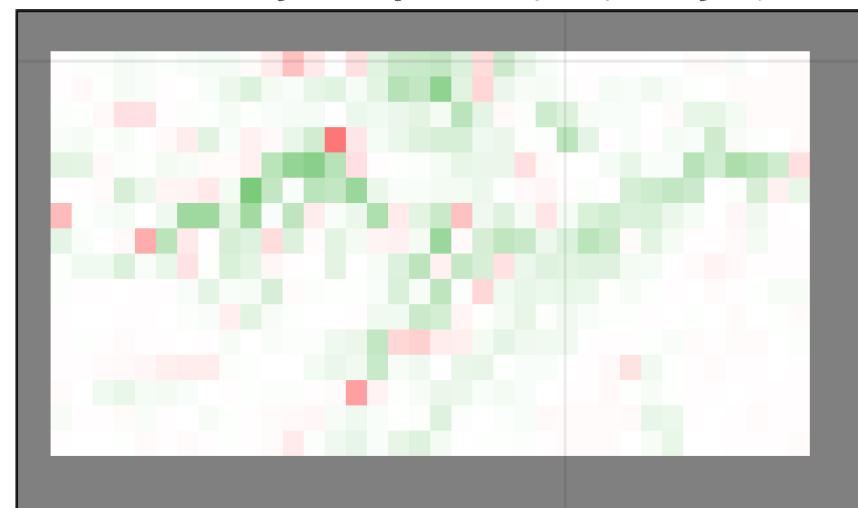
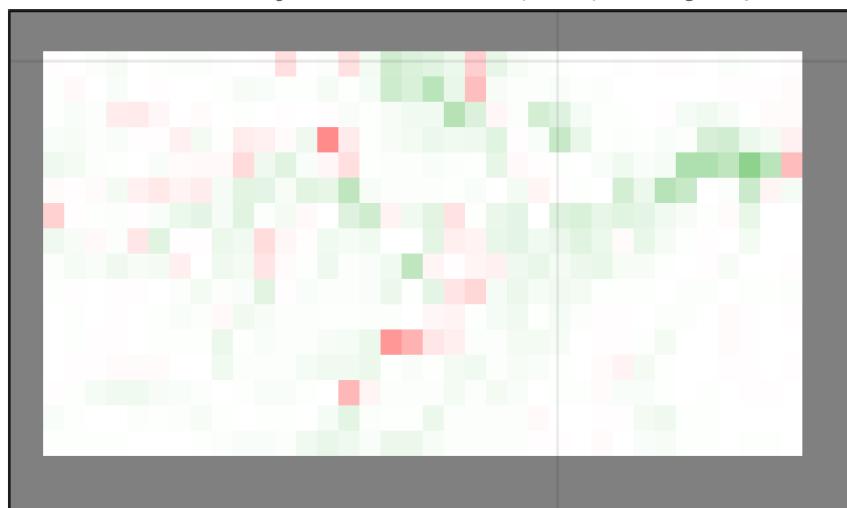
Region bounded by -73.0°E, 1.0°N, -53.0°E, -9.0°N

Data Min = -0.57591, Max = 0.8028 Region bounded by -73.0°E, 1.0°N, -53.0°E, -9.0°N

Data Min = -0.80894, Max = 0.81171

#77: Min sim flooding minus low water obs, 1995; 0.5 deg res; r=.62

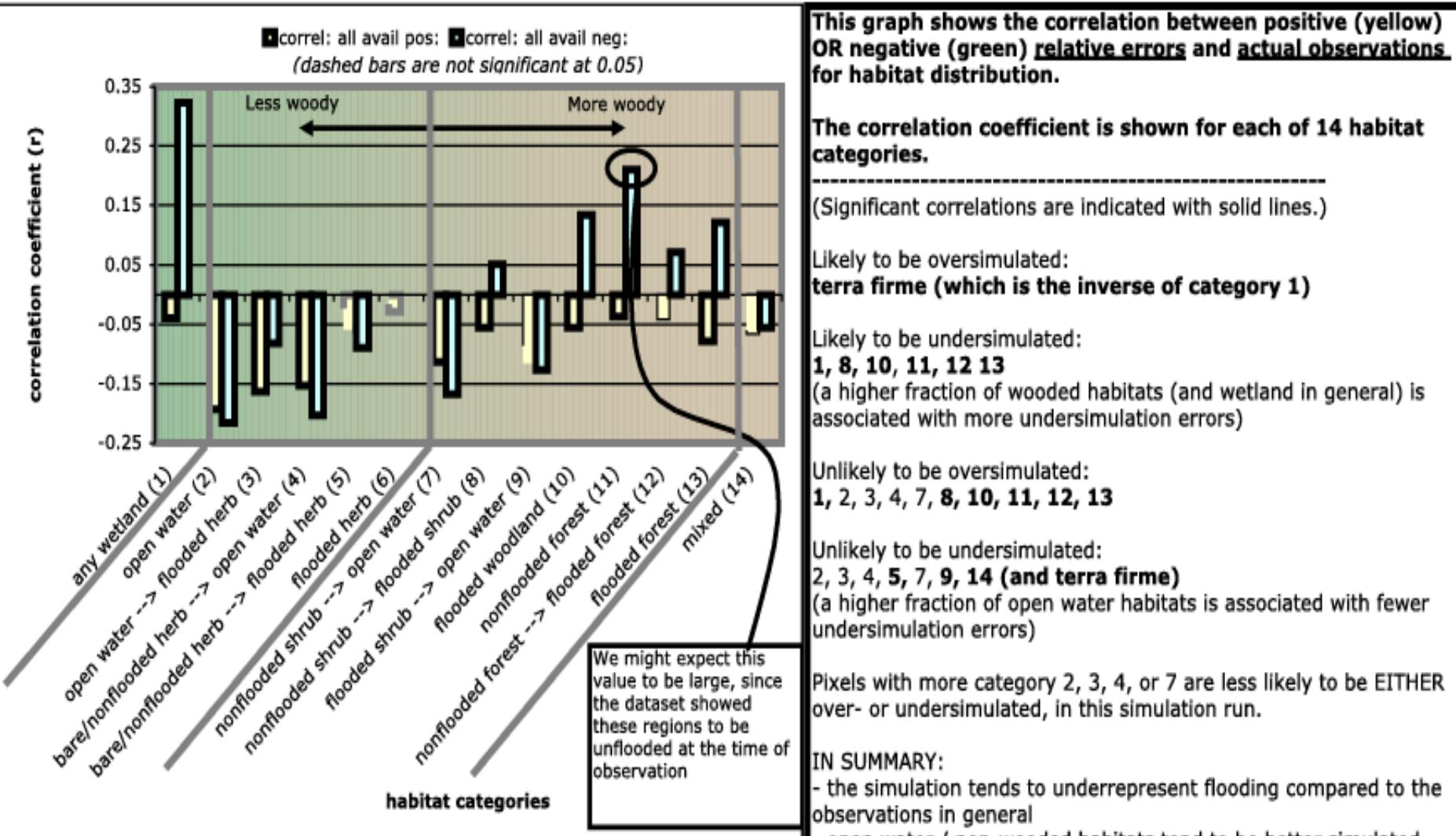
#77: Max sim flooding minus high water obs, 1996; 0.5 deg res; r=.81



Region bounded by -73.0°E, 1.0°N, -53.0°E, -9.0°N

Data Min = -0.43695, Max = 0.4578 Region bounded by -73.0°E, 1.0°N, -53.0°E, -9.0°N

Data Min = -0.51128, Max = 0.53231



#### IN SUMMARY:

- the simulation tends to underrepresent flooding compared to the observations in general
- open water / non-wooded habitats tend to be better simulated
- flooded woodlands and forests and some shrublands are more likely to be undersimulated

Run 77; 23 Oct 05; EAH