The hydrological modeling with ORCHIDEE in the Amazon basin

Matthieu Guimberteau

P. Ciais, A. Ducharne, J. Ronchail, B. Sultan

J.-P. Boisier, G. Drapeau, M. De Weirdt, J.-C. Espinoza, J. Polcher, H. Verbeeck...

Introduction

- Severe hydroclimatic (P, ET) and anthropogenic (deforestation, land-use change...) changes are already threatening the Amazon basin

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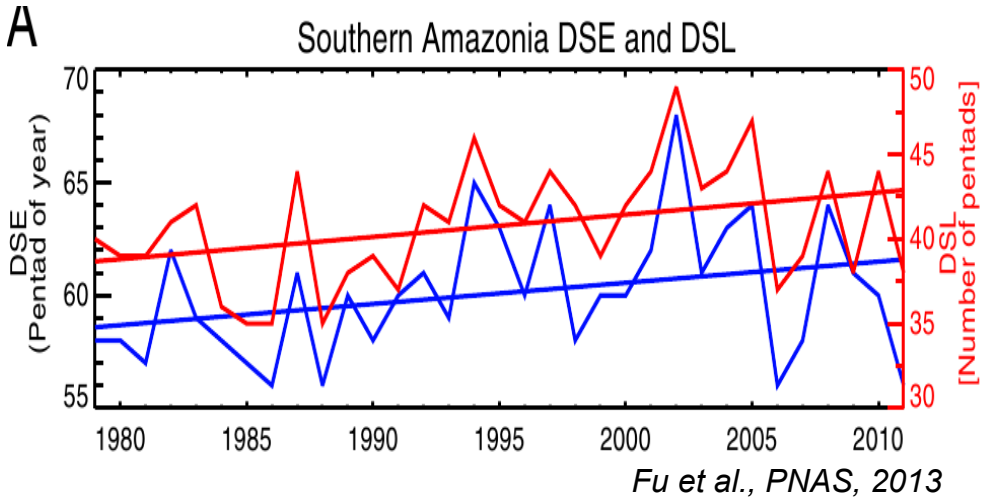
Dry-season length increases in the south since the 80's



Fu et al., PNAS, 2013

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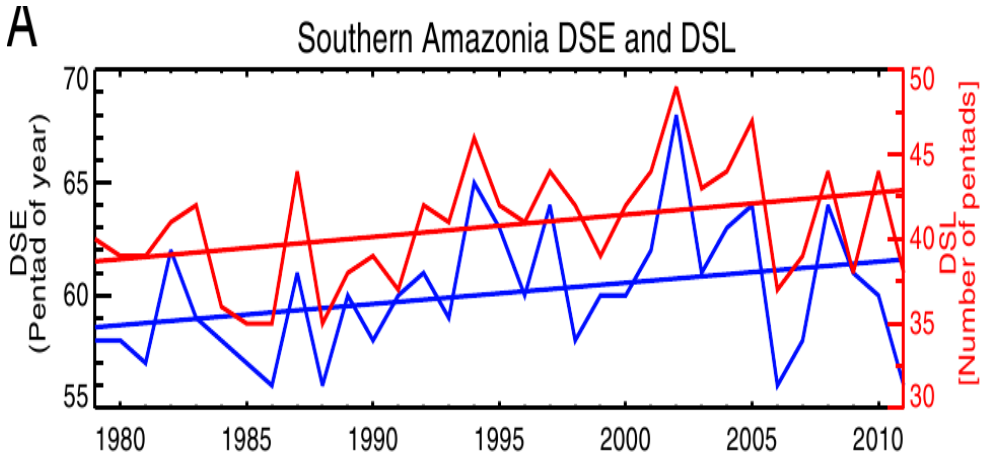

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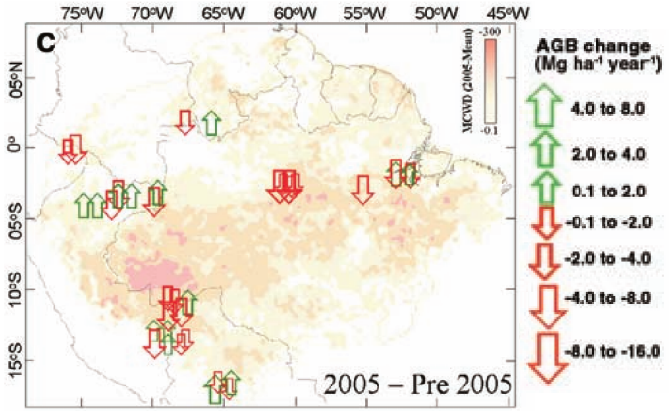
Intense 2005 drought affected aboveground biomass of forest



Phillips et al., Science, 2009

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  - How important is the use of a physically-based soil hydrology model if compared to a simple bucket model to better represent hydrological storages and fluxes?

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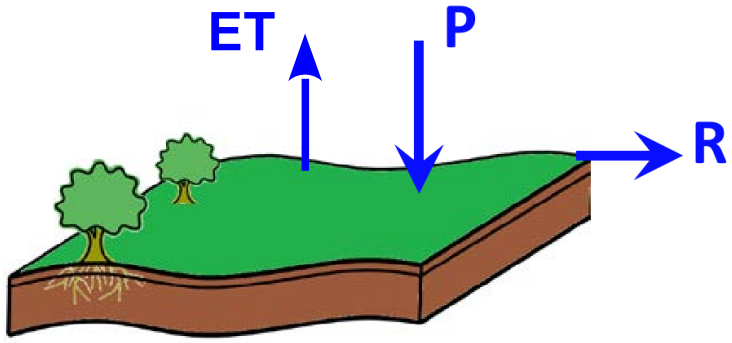
- Severe hydroclimatic (P, ET) and anthropogenic (deforestation, land-use change...) changes are already threatening the Amazon basin
- Land Surface Models (LSMs) have evolved including more physically based approach in soil hydrology representation
  - How important is the use of a physically-based soil hydrology model if compared to a simple bucket model to better represent hydrological storages and fluxes?
  - Will annual extreme flows be more severe during the middle/end of the 21st century than the present ones?

Soil hydrology schemes in ORCHIDEE

2LAY



- Conceptual description of soil moisture storage
- 2 layers for a 2-m soil
- Constant available water holding capacity (wilt. point ↔ field capa.)

- Saturation-excess (Dunne runoff, R)
- Downard flux between the 2 layers

- No drainage

Guimberteau et al.,GMD, 2014

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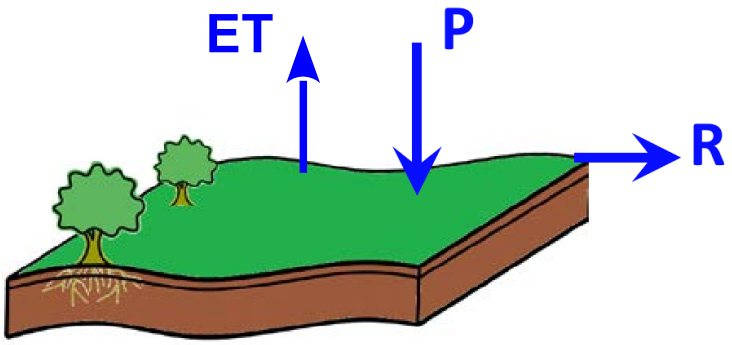

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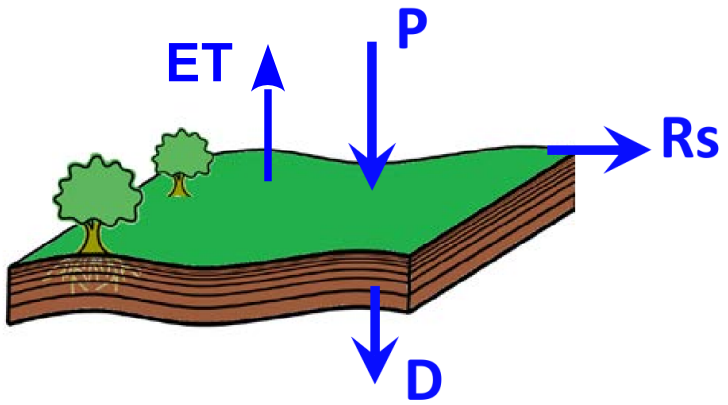
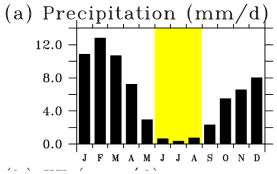


- Physically-based description of soil water fluxes
- 11 layers for a 2-m soil
- Variable water storage capacity (res. wat. content ↔ sat.) depending on soil texture heterogeneity
- Infiltration-excess (Horton runoff, Rs)
- Fluxes between layers following Richards equation & Mualem-Van Genuchten model
- Gravitational drainage, D

Guimberteau et al.,GMD, 2014

Dry-season ET: case study of the Xingu sub-basin



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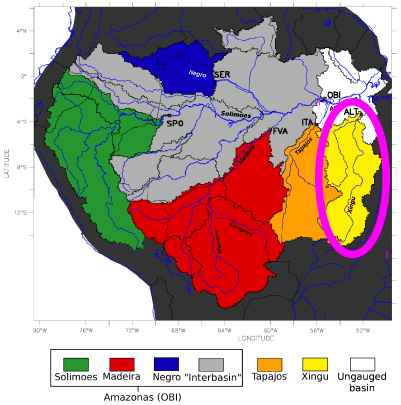

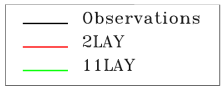

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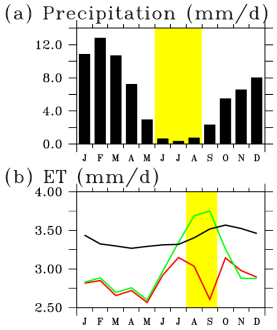

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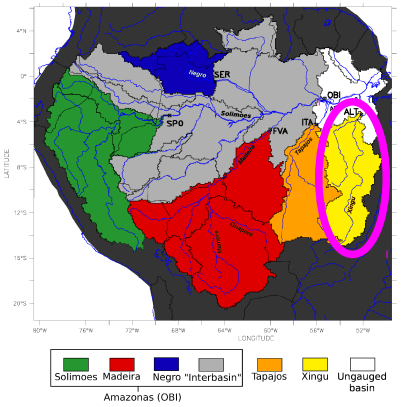

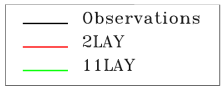

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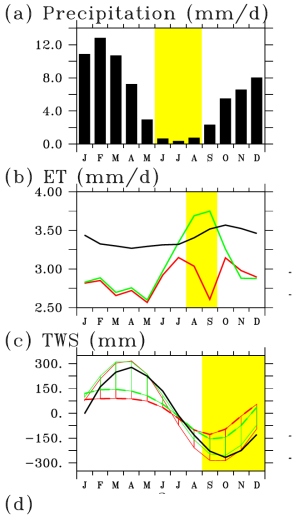

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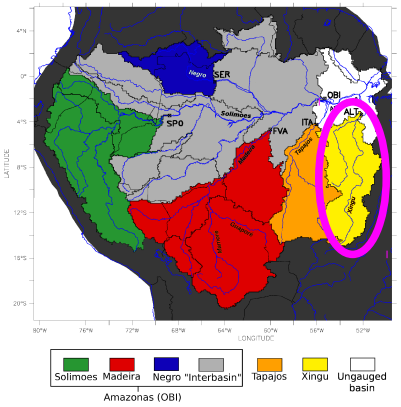

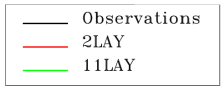

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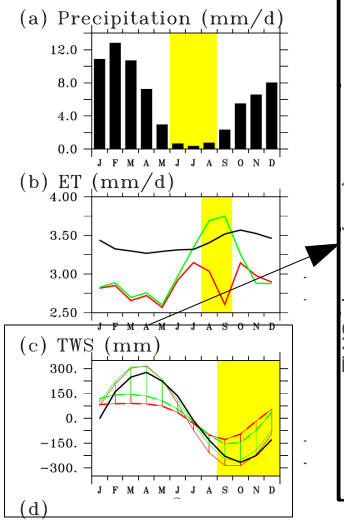

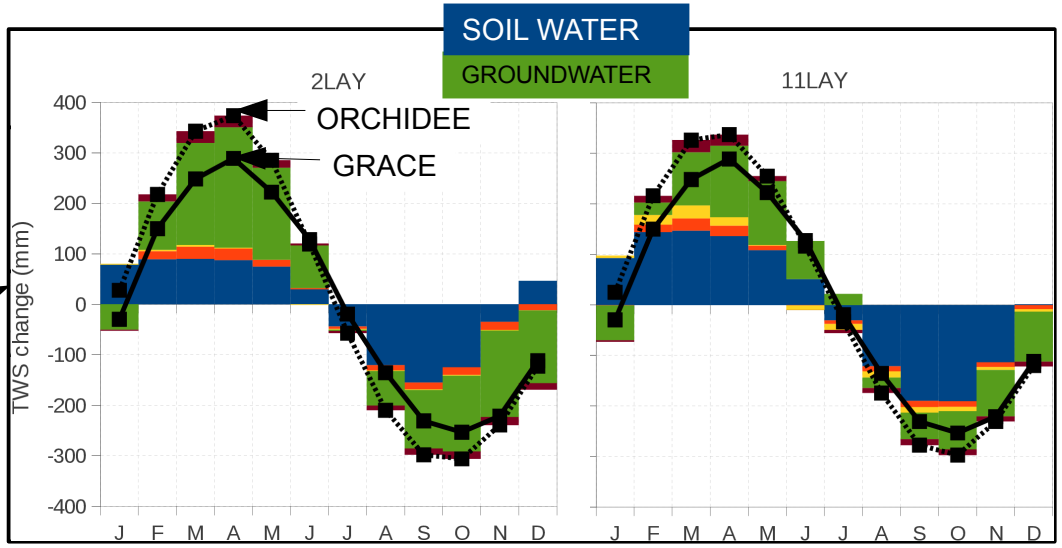

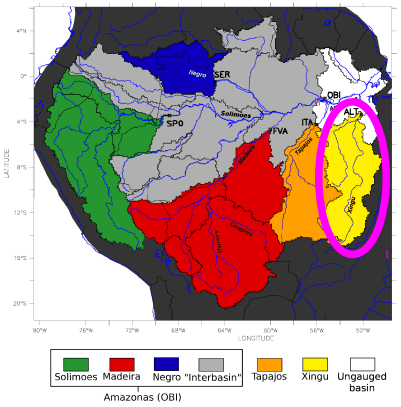

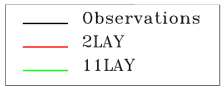

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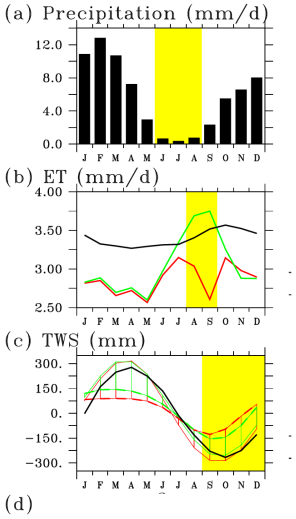

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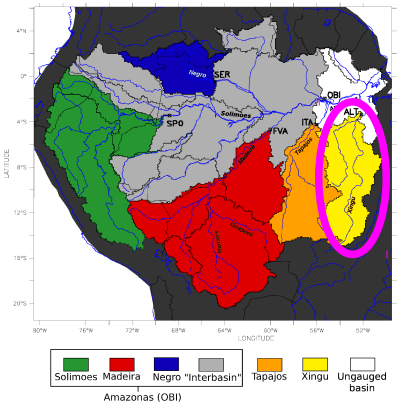

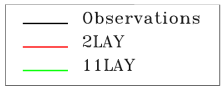

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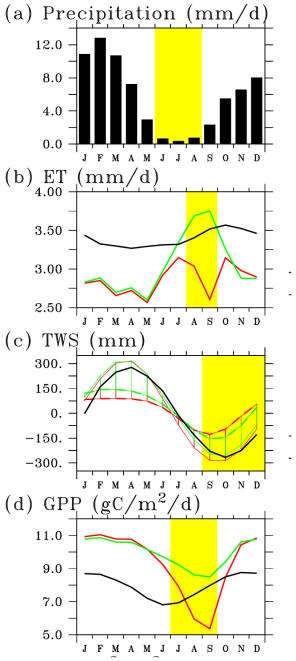

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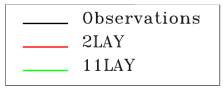

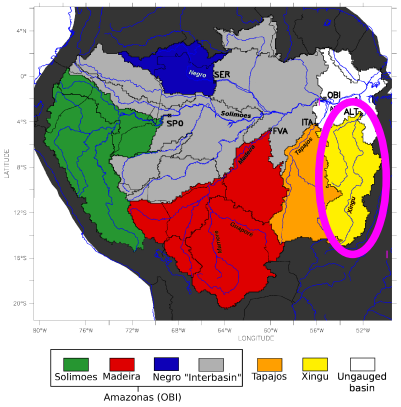

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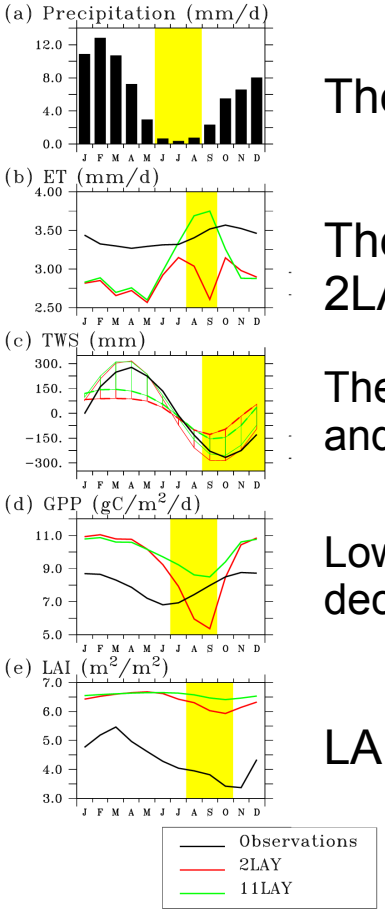

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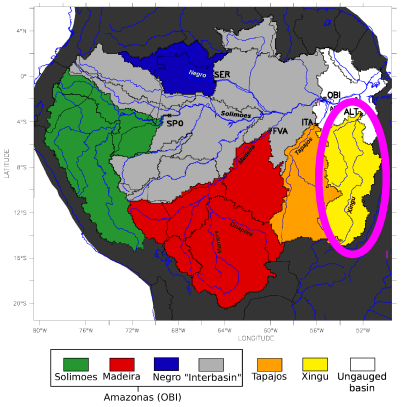
LAI variation is small between the 2 simulations



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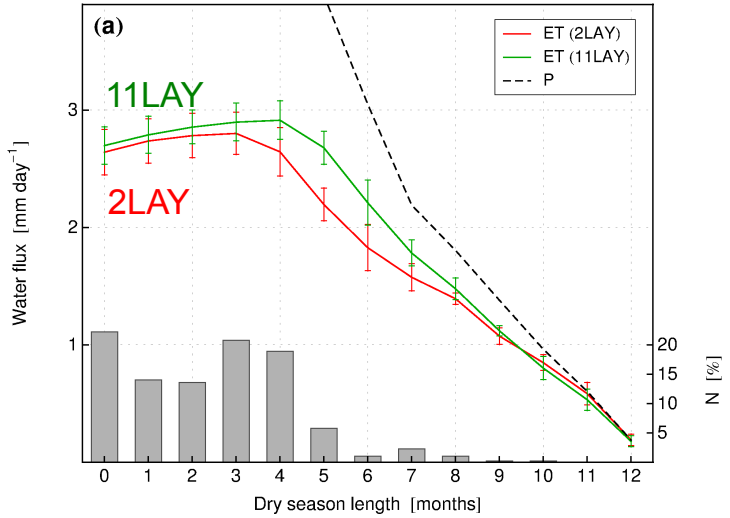
ET sensitivity to dry season length (DSL) over the Amazon basin

ET vs DSL



DSL definition

Mean number of months with P < 2.0 mm/d over the 29-year period

Guimberteau et al.,GMD, 2014

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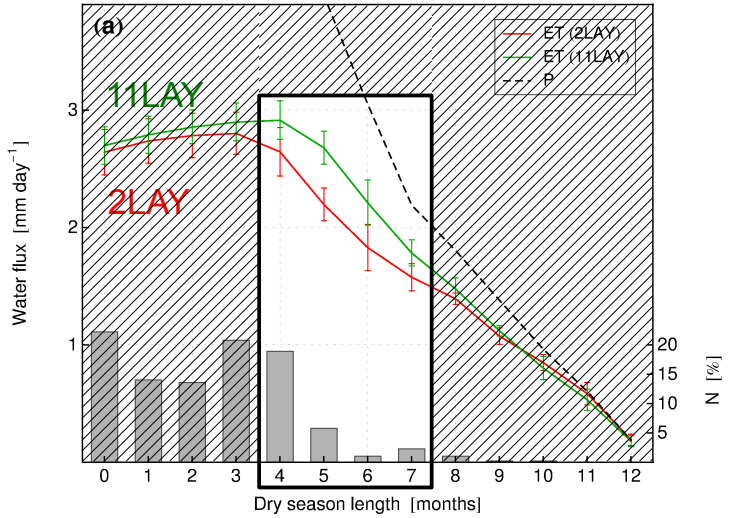

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- The impact of soil hydrology parametrization on simulated ET is high for a DSL of 4 to 7 months (30% of the total grid cells)

Guimberteau et al.,GMD, 2014

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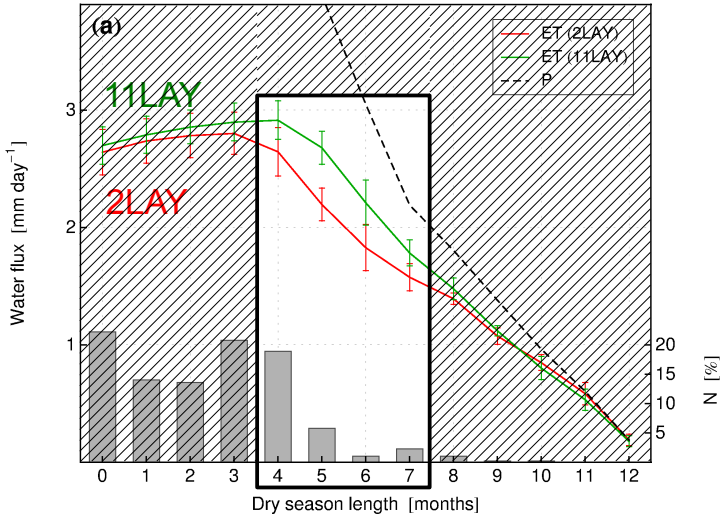
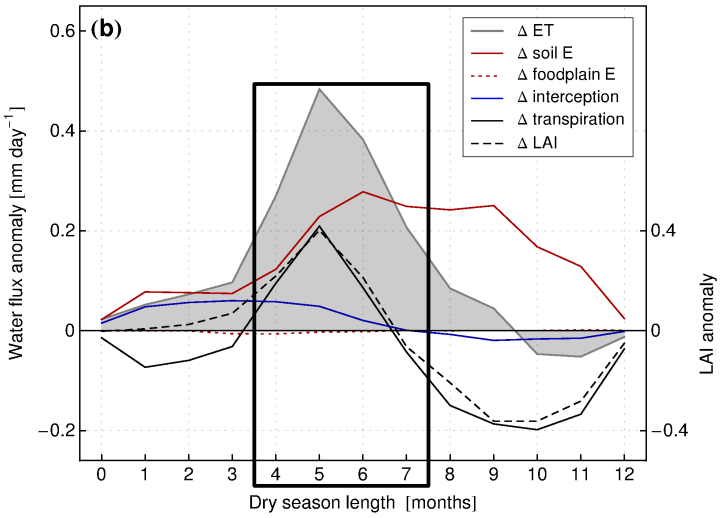


ΔET and ΔLAI vs DSL



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Conclusion

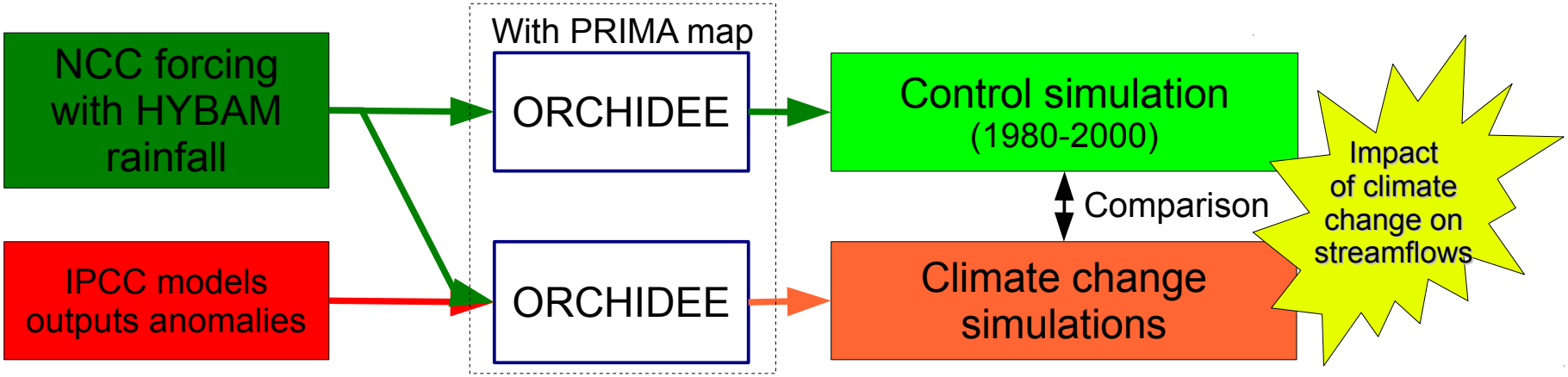
(1) Compared to the bucket scheme, the physically-based multilayer soil hydrology scheme:

- slightly improves the simulated water budget
- simulates better TWS anomalies
- sustains ET during the dry season in the south-east thanks to its higher soil water holding capacity => better representation of GPP

(2) A dry season length between 4 to 7 months in the Amazon basin is critical in distinguishing differences in water budget components and carbon flux dynamics simulated by the 2 soil hydrology schemes

Future changes in precipitation and impacts on extreme streamflow

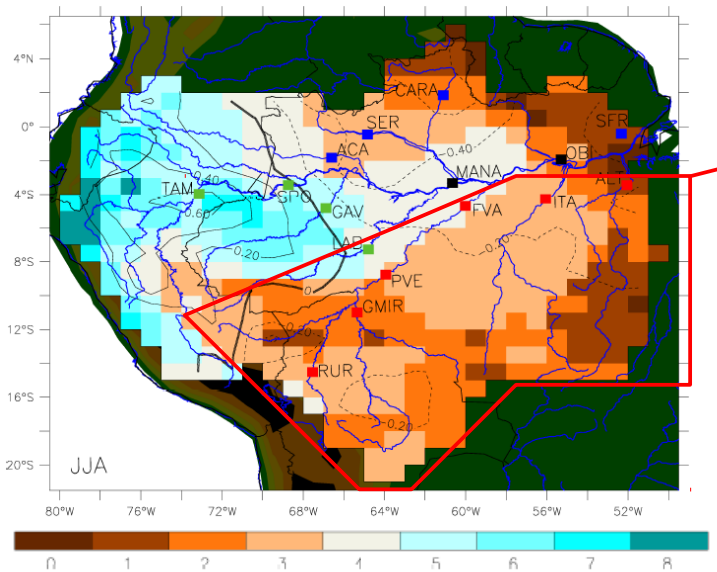
- **Delta downscaling method** approach to produce climate change forcing based on GCMs results from AR4
  - 3 scenarios: B1, A1B and A2
  - 2 periods: 2046-2065 and 2079-2098
- Climatology of future anomalies added to the NCC forcing including ORE HYBAM precipitation
  - delta method incorporates more realistic spatio-temporal patterns in precipitation
- ORCHIDEE forced by the different future climate forcings => climate change simulations



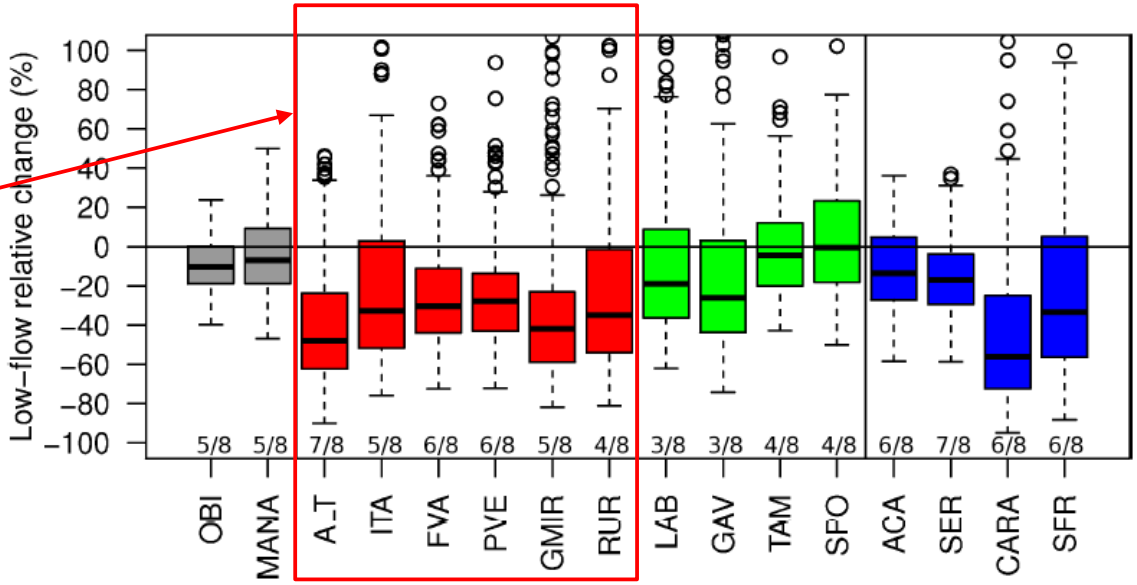
Guimberteau et al., ERL, 2013

Future changes in precipitation and impacts on extreme streamflow

Result for 2046-2065 under SRESA1B scenario



Number of GCMs out of eight that project a JJA precipitation increase



Mean relative change (%) of the **low flows** for 16 stations

- Southern sub-basins (with low runoff coefficients (R/P)) will become more responsive to precipitation change than the western sub-basins (with high runoff coefficients)
- Western and north-western sub-basins: more responsive to evaporation change

Guimberteau et al., ERL, 2013

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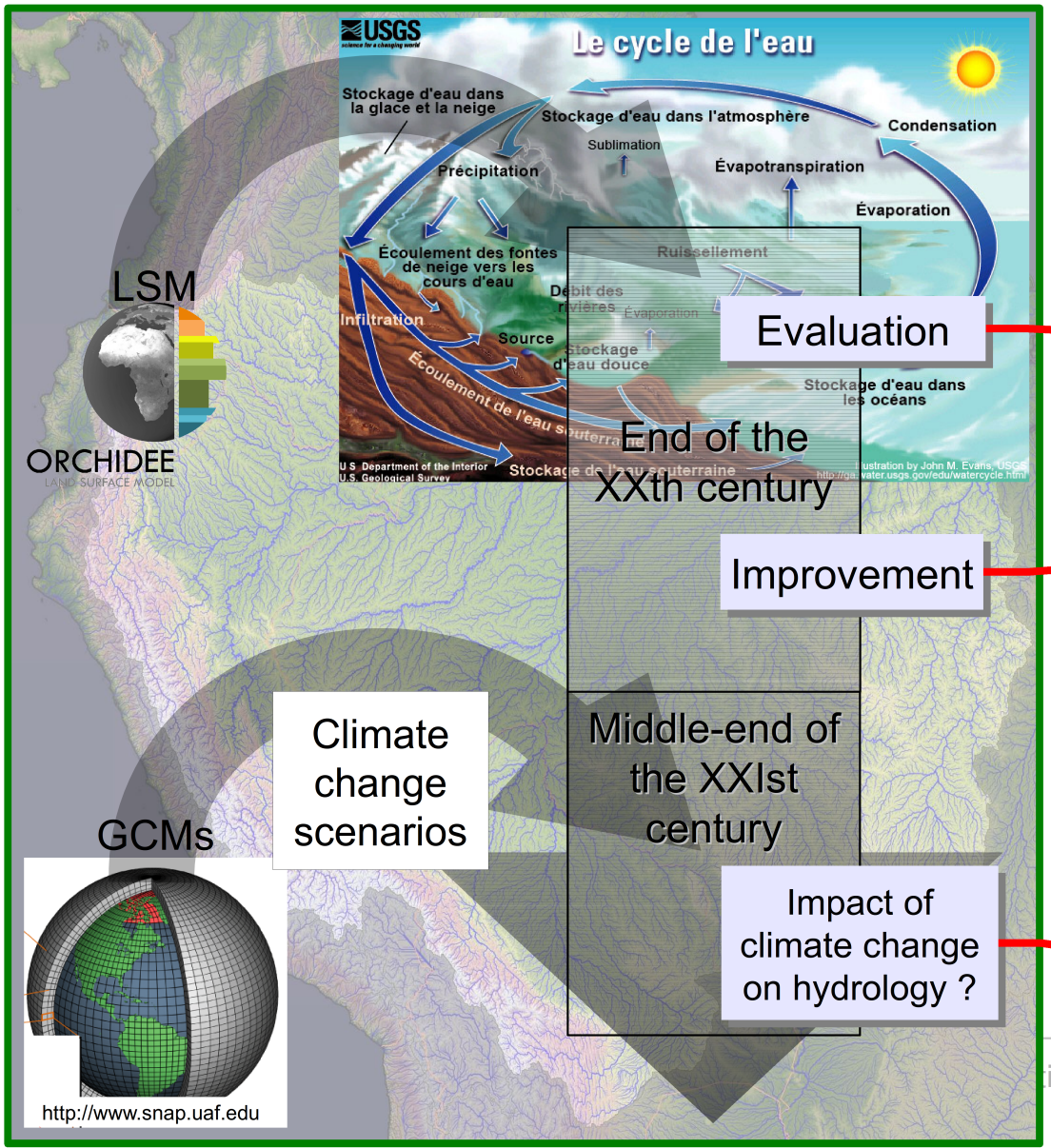
(3) ORCHIDEE projects more severe low flows in the southern part of the basin for the middle of the century

Perspectives

- Influence of the sub-daily frequency of precipitation on surface hydrology and vegetation in Mato Grosso (in prep.)
- Effect of LUC (historical and future scenarios) on the hydrology over the Amazon basin

ORCHIDEE and the Amazon basin: evaluation of the model for future hydrology simulation



Evaluation

1

- In-situ river gauging data
- Floodplains water height from satellite products
- ET (and GPP) data products
- Total water storage variations from GRACE dataset
- Soil water profiles measurements
- FLUXNET dataset

Improvement

2

- ORE HYBAM precipitation product
- Spatial distribution of flooded areas from satellite products

Impact of climate change on hydrology ?

3

- Future change of river discharge ?
- LUC impact on hydrology ?

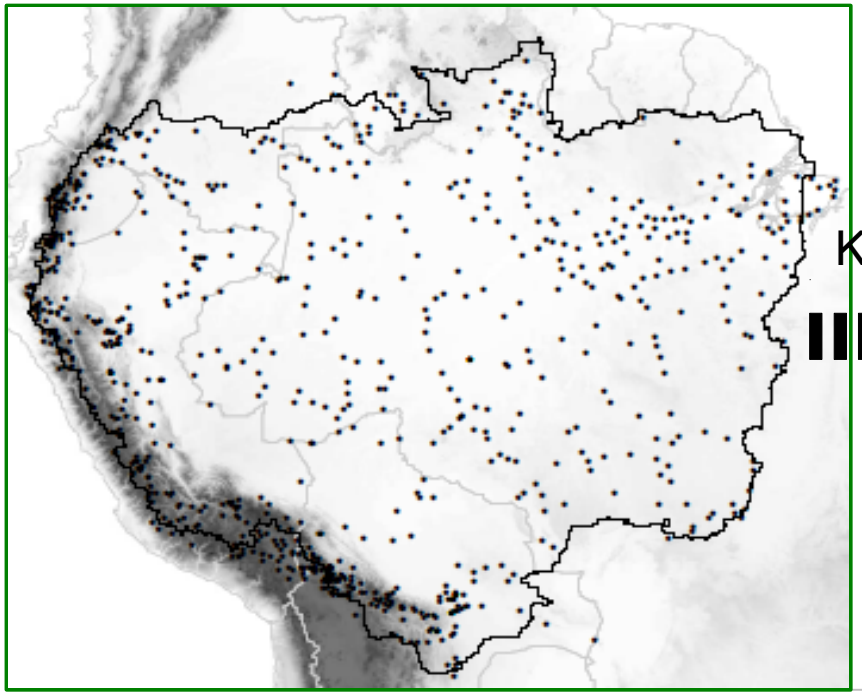
New precipitation dataset for the Amazon River basin

- ~1500 pluviometric stations from the meteorological services of Amazonian countries. 50% are selected after quality control.
- Daily data (1980-2009) interpolated over the basin (1°x1°)
- Temporal distribution of the data according to the diurnal variation of NCEP in NCC forcing (daily value spread over the 6h time-step of the forcing)

ORE HYBAM: Observatoire de Recherche en Environnement Hydrogéodynamique du Bassin Amazonien

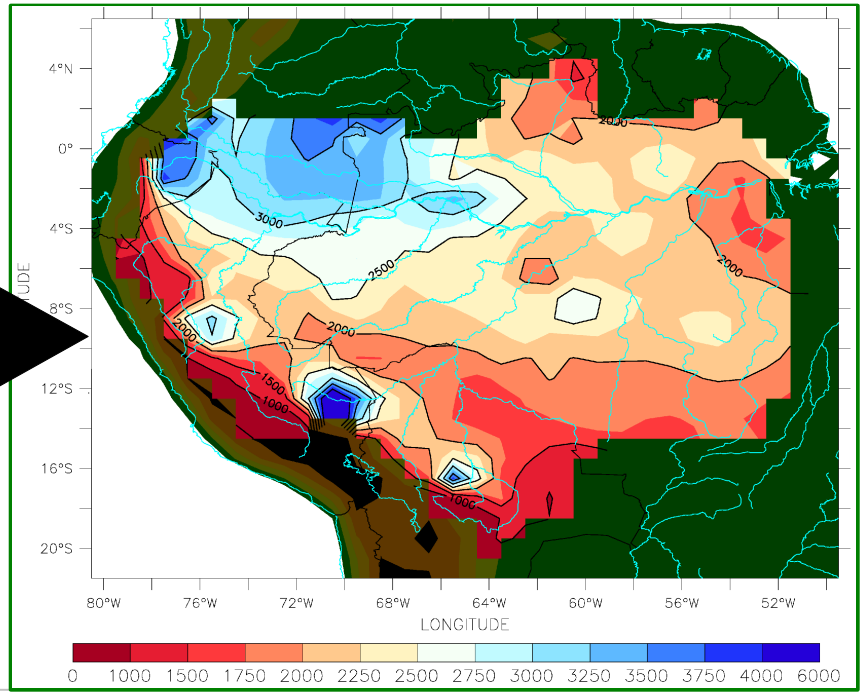
NCC: NCEP/NCAR Corrected by CRU (Ngo-Duc, 2005)

~750 pluviometric stations



Kriging

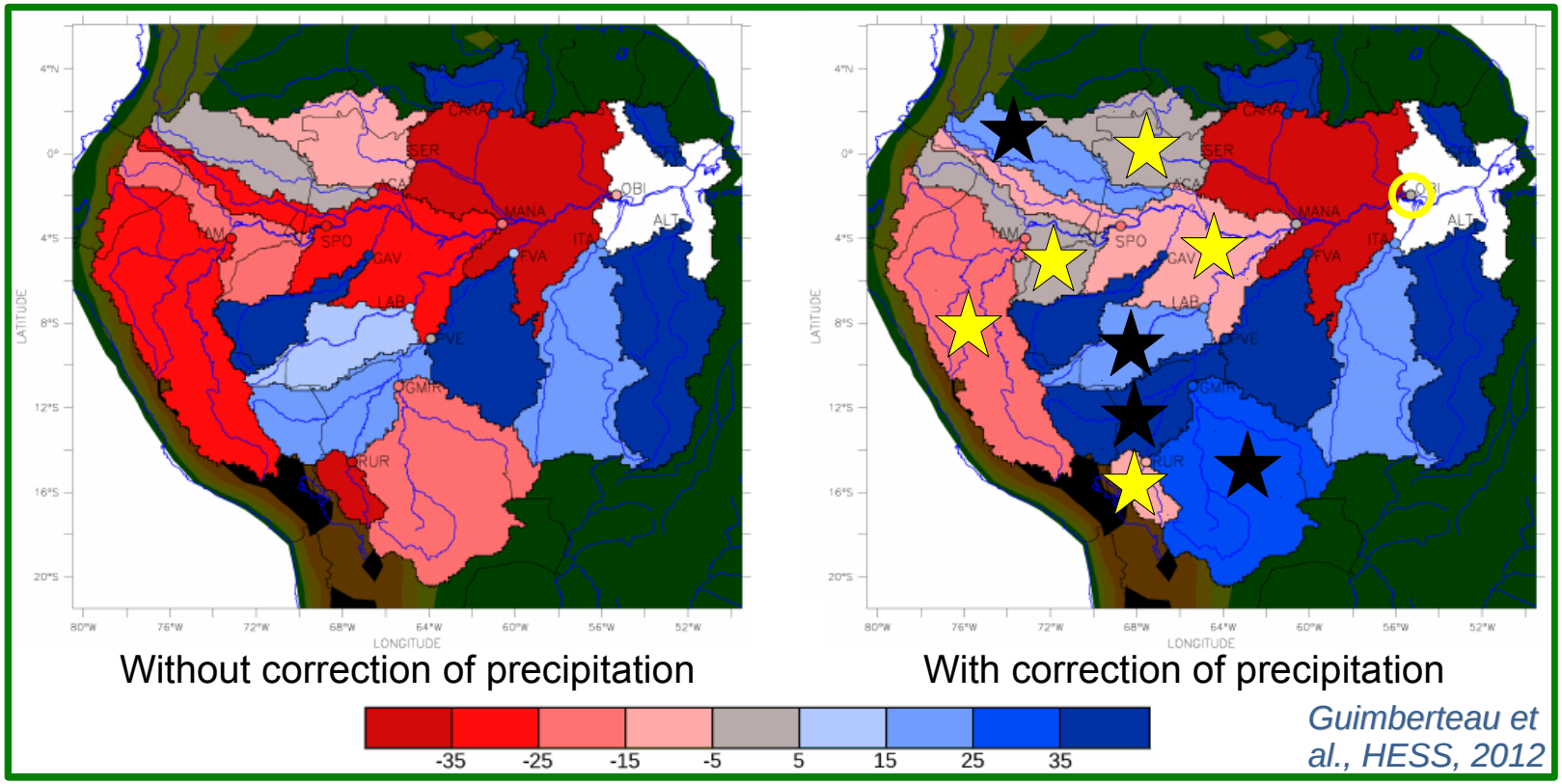
Interpolation at 1°x1°



Guimberteau et al., HESS, 2012

Simulated river discharge with ORE HYBAM precipitation

Mean annual relative bias of **runoff** (%)



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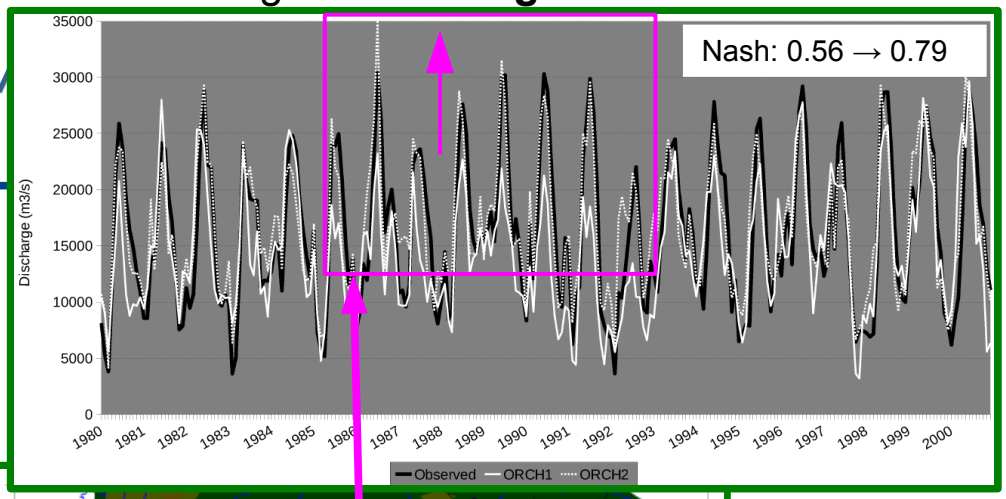
Simulated river discharge w

Negro's **discharge** at Serrinha



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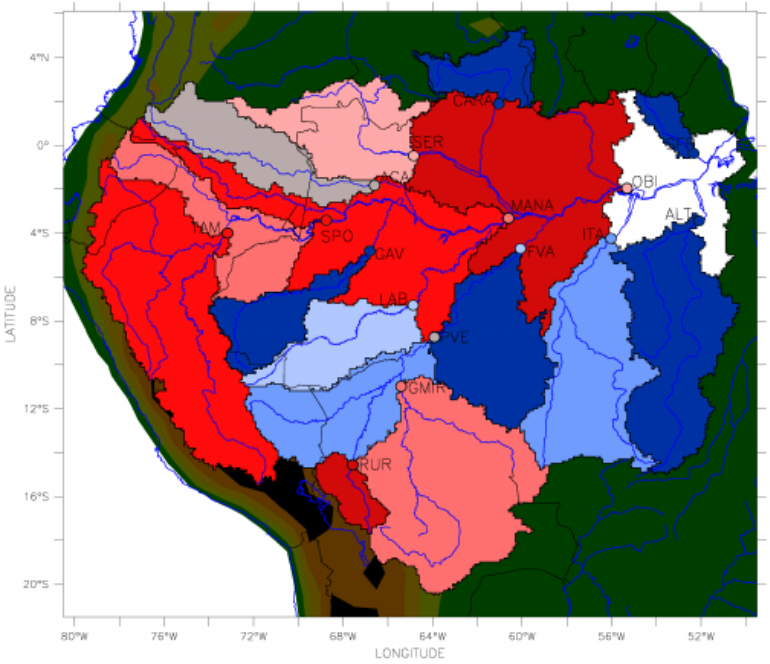
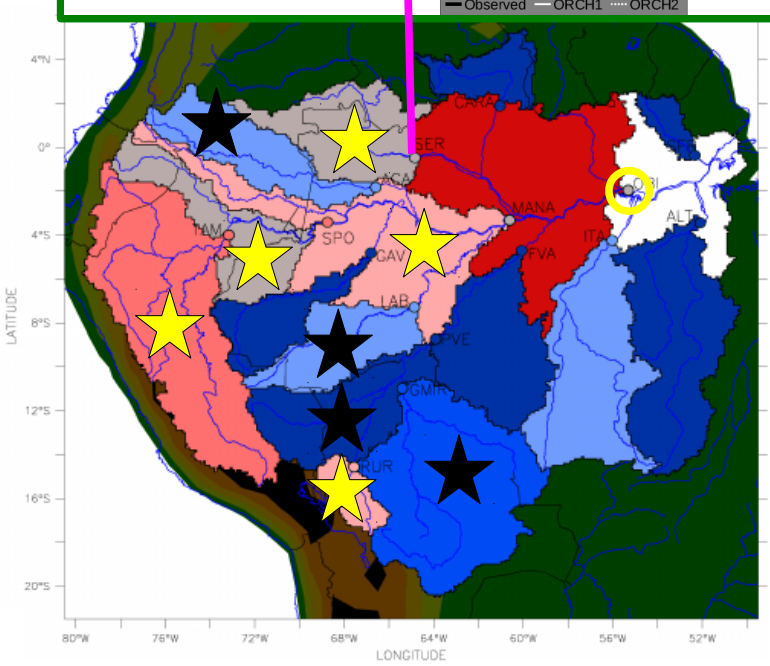


Without correction of precipitation



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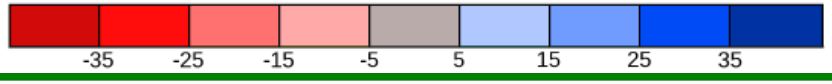

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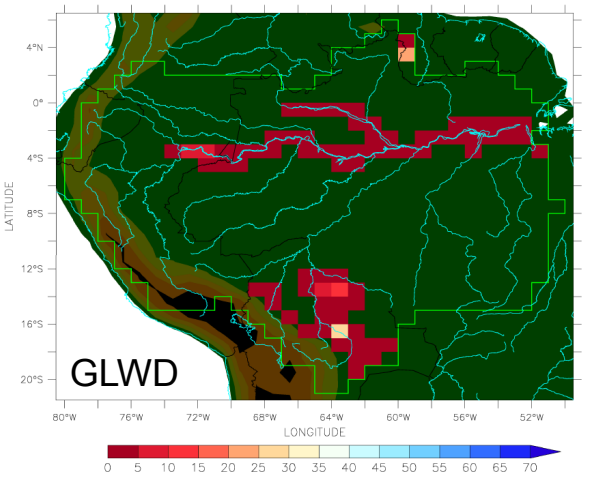
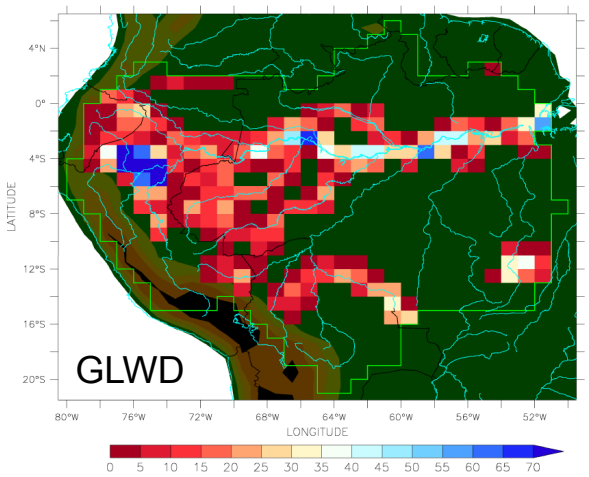
A new satellite-derived map of maximal fraction of floodplains and swamps

Floodplains



Swamps



Maximal fraction within the mesh (%)

Initially for ORCHIDEE:
GLWD (Lehner & Döll, 2004)
+ d'Orgeval & al. (2008)

Guimberteau et al., HESS, 2012

A new satellite-derived map of maximal fraction of floodplains and swamps

- Multisatellite method (Prigent & al., 2007)

  => Inundated fraction (0.25°x0.25°) at global scale (1993-2000)

- No distinction between floodplains and swamps

- Multi-temporal SAR data (Martinez & Le Toan, 2007)

  => Inundated fraction estimated for the highest water level during the 1995–96 hydrological cycle

- Distinction between floodplains and swamps

- Computation of maximal fractions of inundated areas within the mesh (1993-2000)

- For each mesh, computation of a ratio of the maximal distribution of floodplains and swamps

f^{max}

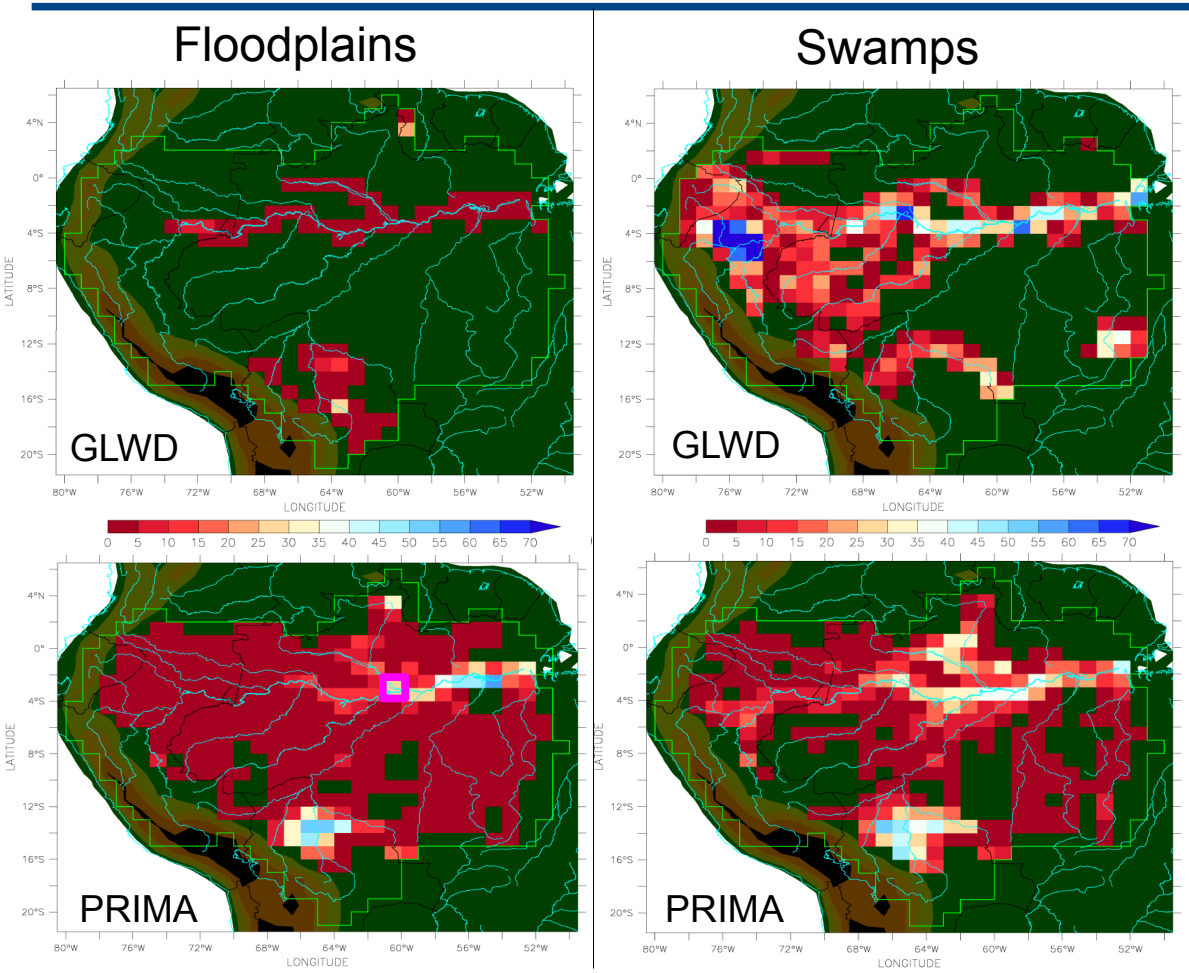
$ratio_{(FP)}$ $ratio_{(SWP)}$

$$f_{FP}^{max} = ratio_{(FP)} * f^{max}$$
$$f_{SWP}^{max} = ratio_{(SWP)} * f^{max}$$

PRIMA map

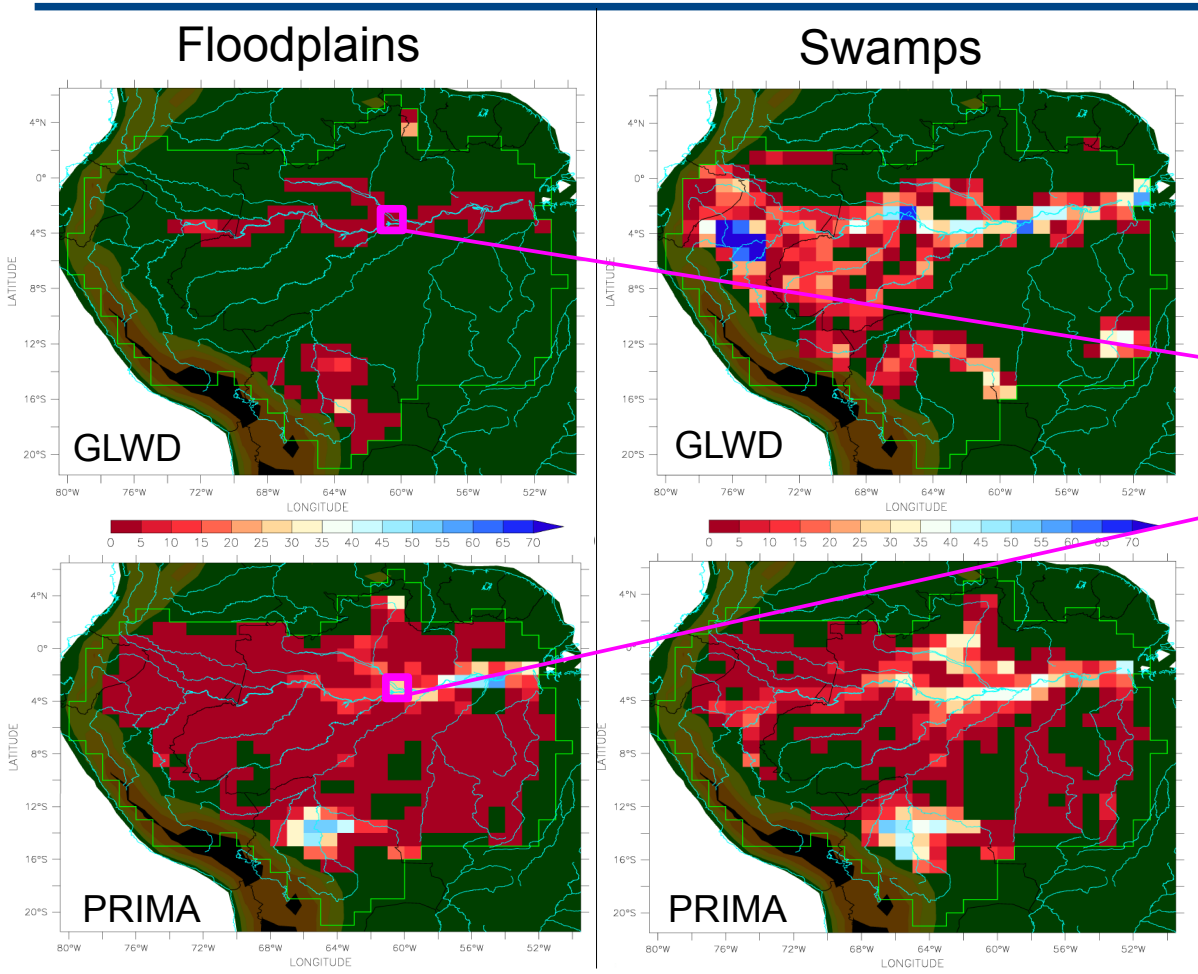
Guimberteau et al., HESS, 2012

A new satellite-derived map of maximal fraction of floodplains and swamps

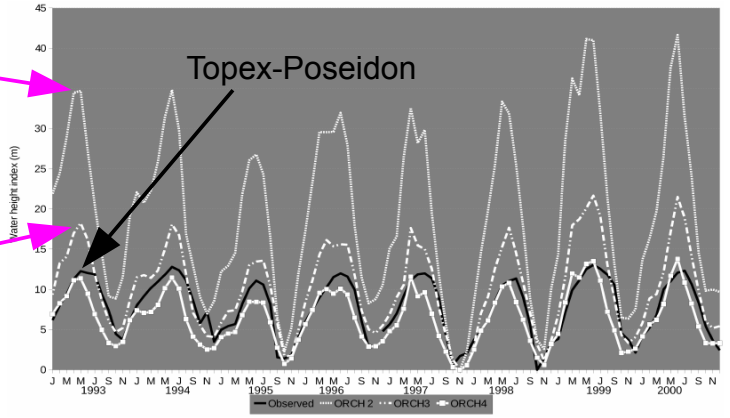


Guimberteau et al., HESS, 2012

A new satellite-derived map of maximal fraction of floodplains and swamps



Maximal fraction within the mesh (%)



Interannual variation of **monthly water height** index (m) on the Negro

Guimberteau et al., HESS, 2012

Conclusion

(1) Compared to the bucket scheme, the physically-based multilayer soil hydrology scheme:

- slightly improves the simulated water budget
- simulates better TWS anomalies
- sustains ET during the dry season in the south-east thanks to its higher soil water holding capacity => better representation of GPP

(2) A dry season length between 4 to 7 months in the Amazon basin is critical in distinguishing differences in water budget components and carbon flux dynamics simulated by the 2 soil hydrology schemes

(3) ORCHIDEE projects more severe low flows in the southern part of the basin for the middle of the century

(4) The use of the ORE HYBAM precipitation dataset and the new spatial distribution of flooded areas improve the simulated hydrology