# Cambio climático: balance hídrico y carbono

Pablo Imbach

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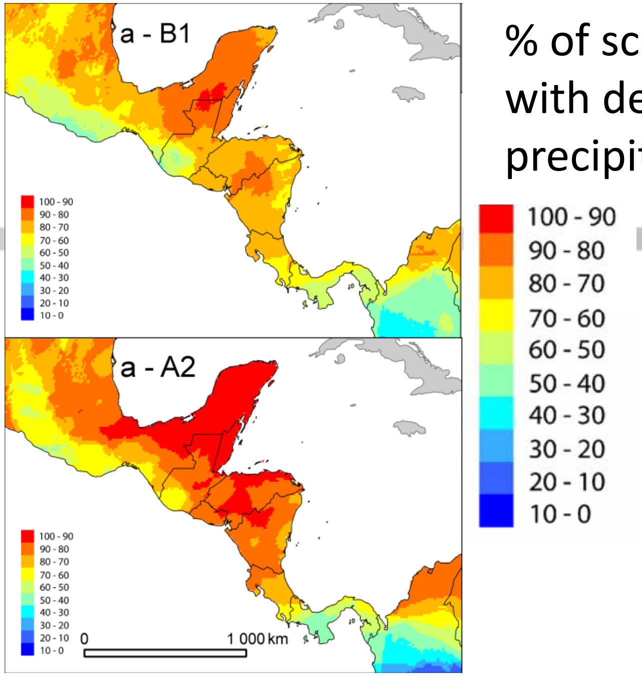
# Contenidos

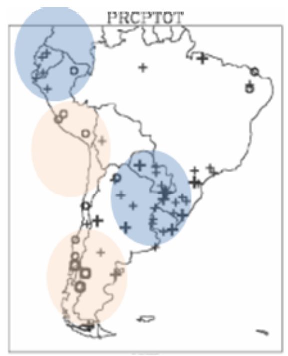
- Parte 1: Impactos del cambio climático:
  - Balance hídrico e impactos en la vegetación
- Parte 2: Flujos de carbono a escalas continentales
  - Cuantificación de sumideros de carbono en Amazonía
  - En progreso…

# Parte 1: Contexto

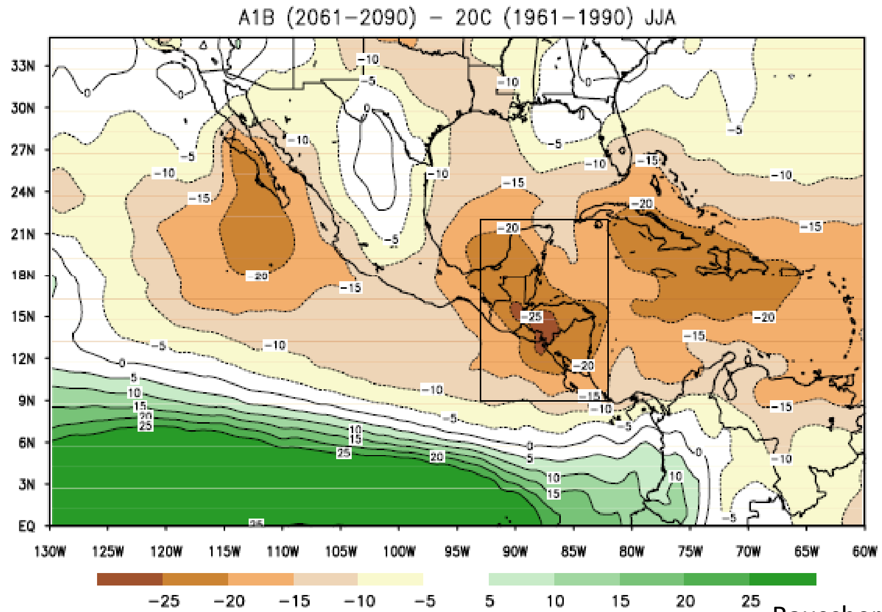
- Observaciones
  - CA: + T, + intensidad de precipitación (Aguilar et al., 2005)
  - AS: Vincent et al. 2005 (- rango diurno de T)
- Proyecciones en CA
  - «Hotspot» en CA (Giorgi 2006)
  - + Temperatura y - precipitación - (Neelin et al. 2006)
  - + Sequías (Scheffield & Wood 2008)
  - Canícula (Rauscher et al. 2008)




Imbach et al., 2011



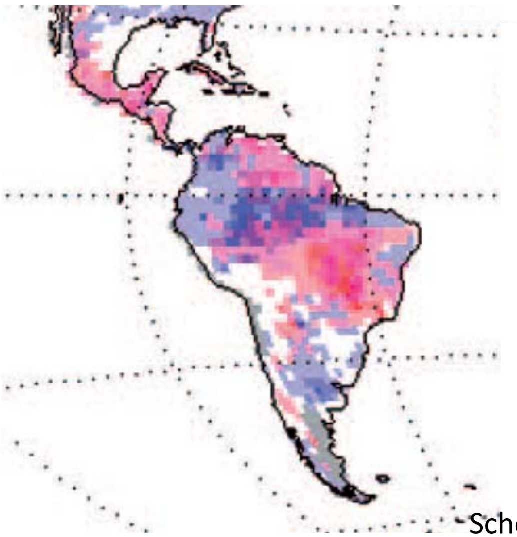

Haylock et al. 2006



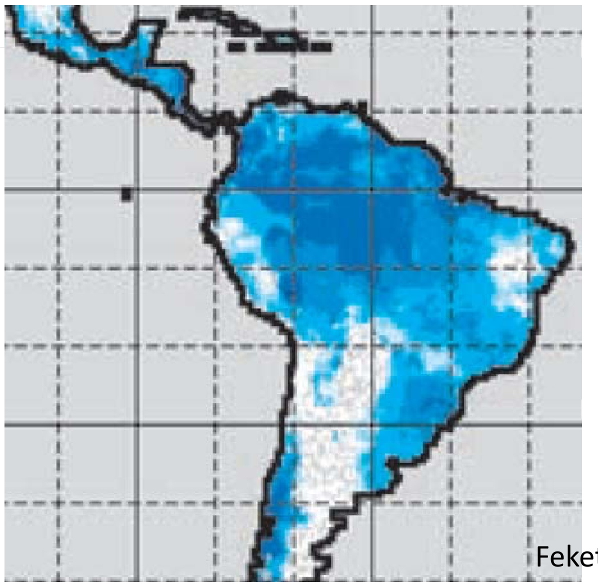

Rauscher et al. 2008

# Impactos en el balance hídrico

- Estudios locales sobre disponibilidad de agua superficial y subterránea
- Simulaciones globales con resolución pobre (0.5°)



Scholze et al. 2006



Fekete et al. 2002

# Preguntas de investigación

- Cuáles serán los impactos del cambio climático en el balance hídrico y la vegetación en Centroamérica?
- Herramienta
  - Modelo para simular el balance hídrico/vegetación a escala regional

# Impacts on water balance and ecosystems

- Mapped Atmosphere Plant Soil System (MAPSS) (Neilson 1995)
  – Static biogeography model for water balance and potential vegetation
  – Vegetation maximizes the Leaf Area Index (LAI) according to available moisture and energy
- Assessment of changes and uncertainties on water balance and vegetation LAI
  – model calibration and validation
  – Simulations for a range of emission scenarios and climate models
- Why MAPSS?

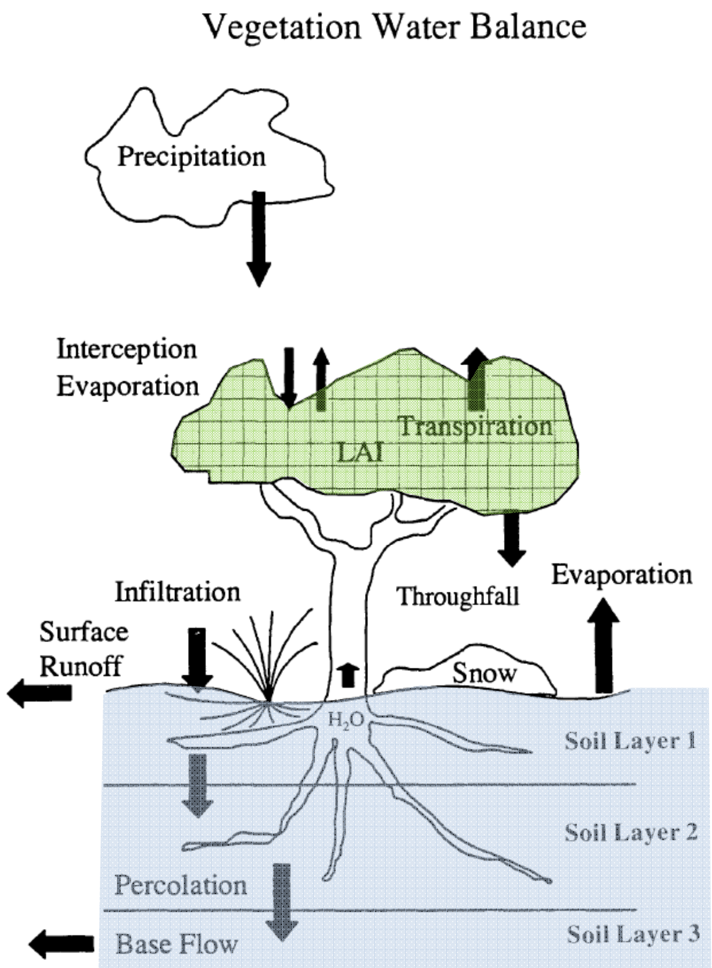



FIG. 1. Conceptual model of the water balance processes incorporated in MAPSS.

Neilson 1995

# Database: soils and precipitation

**Table 1.** Data sources for model input, calibration and validation.

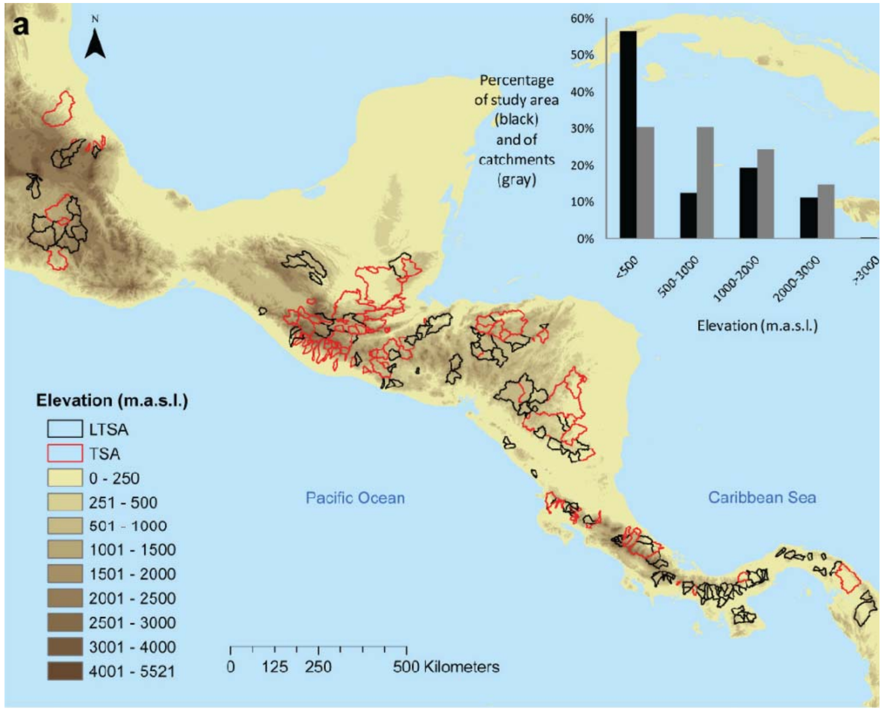
| Name | Variable | Resolution/Averaged time period | Source |
|---|---|---|---|
| | | *Soils and Topography* | |
| NS Soils | Percentage of clay, sand and depth to bedrock | 1:200 000 (Costa Rica)<br>1:250 000 (Guatemala, Mexico)<br>1:500 000 (Honduras)<br>Not reported for Panama | Pérez et al. (1979);<br>Simmons et al. (1959);<br>Simmons (1969);<br>IDIAP (2006); INEGI (1984) |
| World Soils | Percentage of clay and sand, and depth to bedrock | 1:500 0000 | FAO (2003) |
| SRTM | Elevation | 30 arc seconds | Jarvis et al. (2008) |
| | | *Climatology* | |
| CRU CL2.0 | Temperature, precipitation, wind speed, vapour pressure | 10 min/1961–1990 | New et al. (2002) |
| WorldClim[a] | Temperature, precipitation | 30 arc seconds/1950–2000 | Hijmans et al. (2005) |
| FCLIM[a,b] | Precipitation | 5 km/1960–2000 | University of Santa Barbara[c] |
| Wind_PPT[a,b] | Precipitation | 1 km/1997–2006 | Mulligan (2006) |
| TRMM 2b31-Version 1.0[a,b] | Precipitation | 1 km/1997–2006 | Mulligan (2006) |
| | | *Leaf Area Index* | |
| GLOBCARBON--LAI | Leaf area index | 1 km/1998–2007 | http://geofront.vgt.vito.be |
| MODIS-LAI | Leaf area index | 1 km/Mar-2000 to May-2009 | Boston University[d] |
| | | *Vegetation Cover* | |
| Global biomes | Vegetation type | 8 km/2006 | Boston University[d] |
| Global Land Cover 2000 | Vegetation type | 1 km/2000 | EC-JRC (2003) |
| Cloud forests | % of cloud forest | 1 km | Mulligan and Burke (2005) |

Imbach et al. 2010 HESS

# Database: runoff

- Runoff/Precipitation < 1, water bodies < 1%, record length > 15yr

Selected catchments




Runoff database

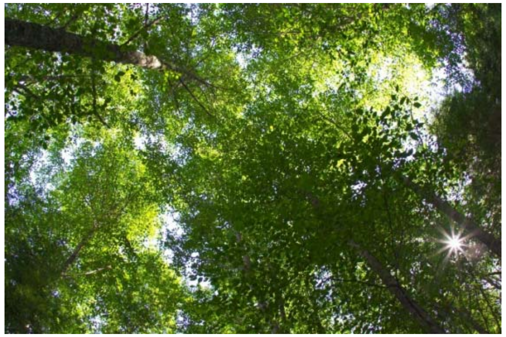
| Country | No. catchments | *Runoff* Time steps (smaller) | Length of the period available[e] | Average |
|---|---|---|---|---|
| Panama | 84 | Monthly | Yes | All years |
| Costa Rica | 128 | Daily | Yes | Year |
| Nicaragua | 33 | Monthly | Yes | Year |
| Honduras | 48 | Monthly | Yes | Year |
| El Salvador | | Monthly | Yes | All years |
| Guatemala | 6 | Monthly | Yes | Year |
| | 31 | Monthly | No | All Years |
| | 73 | Year | No | All Years |
| Mexico (12 southernmost states) | 603 | Daily | Yes | Years |

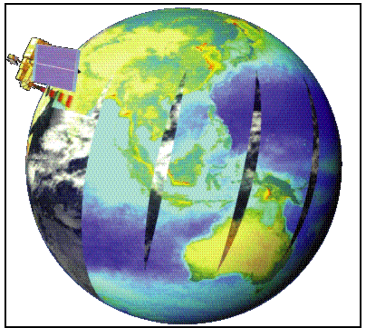
Imbach et al. 2010 HESS

# Steps

- Adjustment of default model parameters
  - Soil thickness
  - Stomatal conductance
  - Wilting point
- Validation
  - Annual and monthly runoff


  - Leaf Area Index (LAI)





# Validation

Annual runoff for each catchment (N=138)

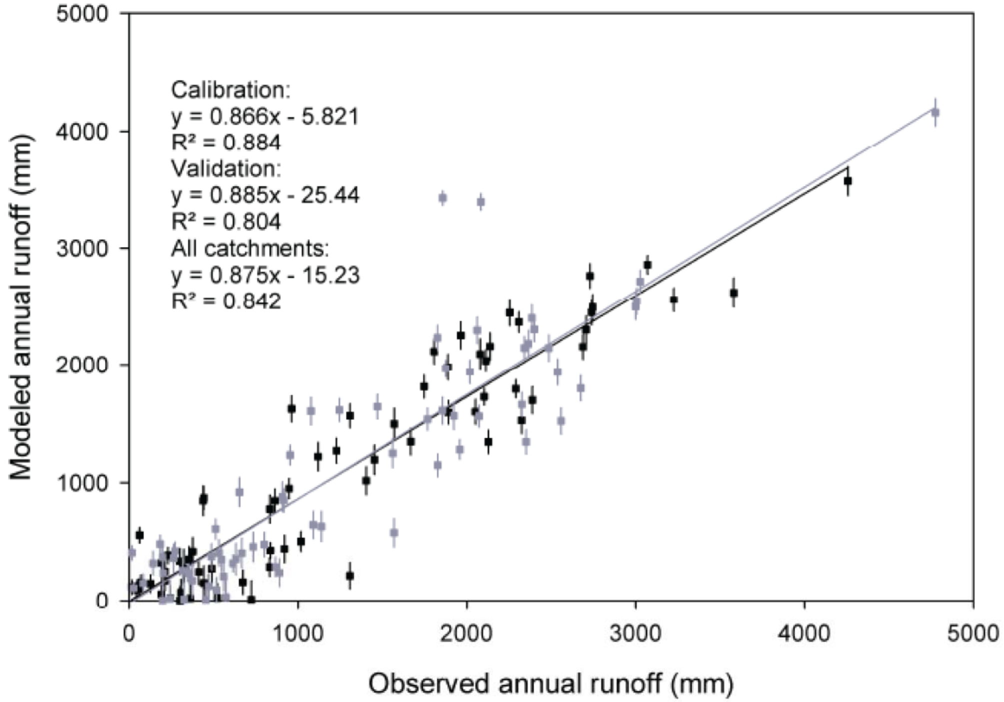
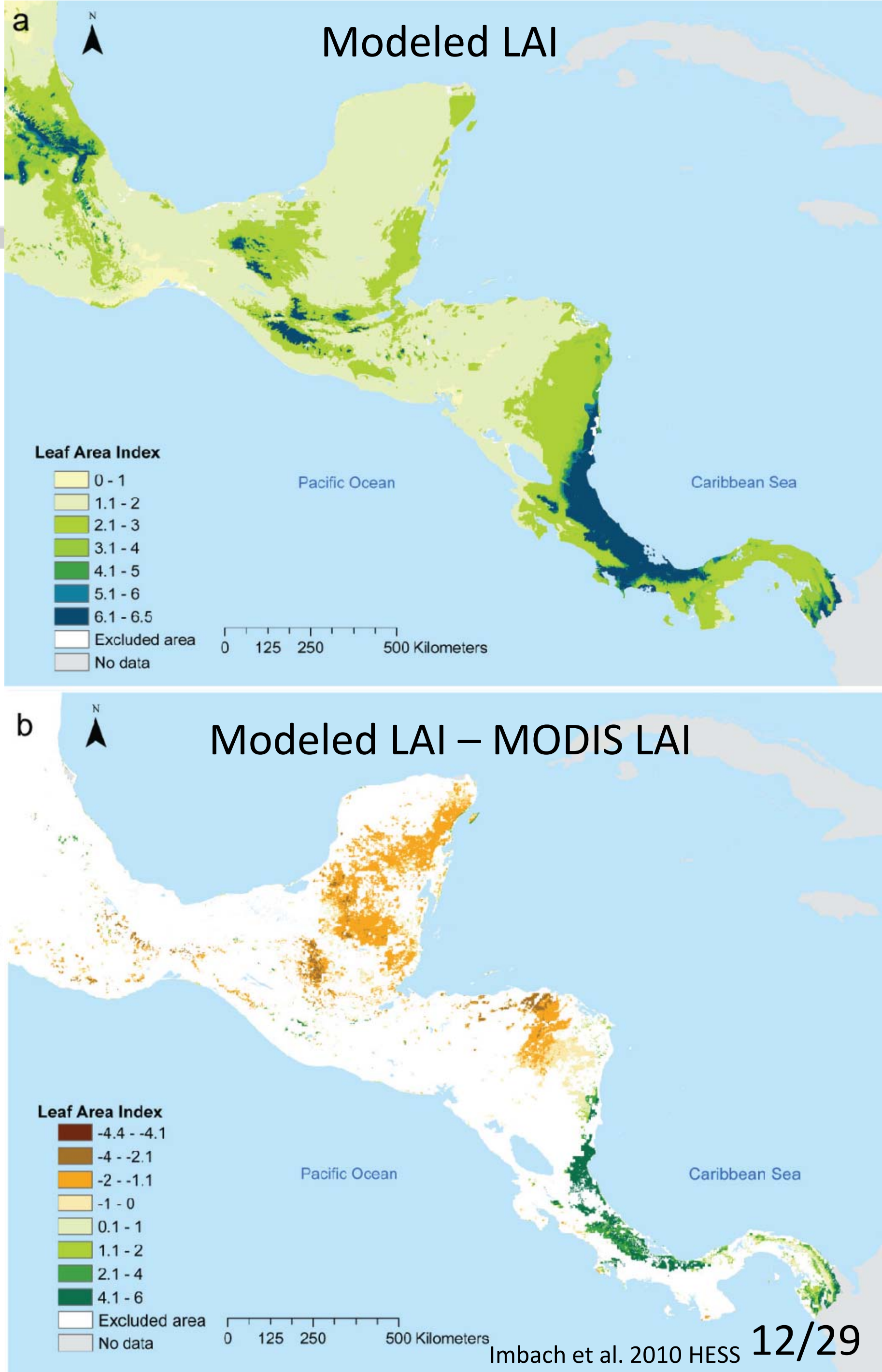



**Table 4.** Modelled runoff qualified by percentage of catchments in each performance category for the LTSA dataset and, in parenthesis, the TSA dataset.

| Performance | NS | $\tau$ | WB |
|---|---|---|---|
| Very Good | 2(2) | 13(11) | 13(10) |
| Good | 19(14) | 22(18) | 6(5) |
| Fair | 25(22) | 43(51) | 29(22) |
| Poor | 54(62) | 22(20) | 52(63) |




Imbach et al. 2010 HESS

# Long term equilibrium…

- Calibrated and validated model for Mesoamerica
  - Annual water balance and LAI
- How would this equilibrium change under a future climate?
- How would increased $CO_2$ affect it?

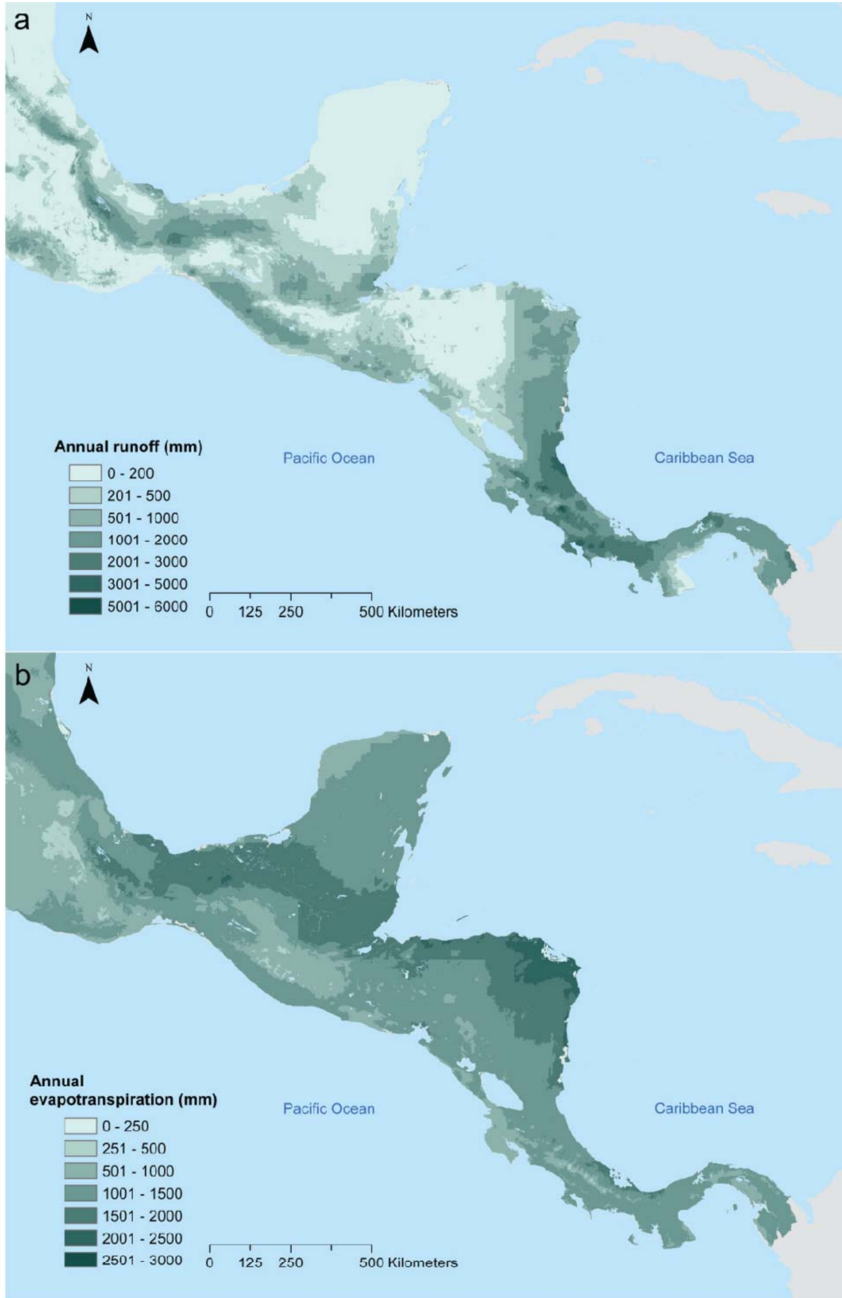
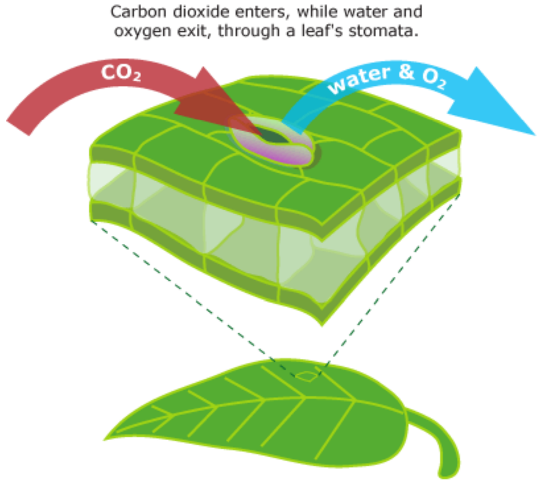



**Fig. 9.** Annual runoff **(a)** and evapotranspiration **(b)** of Mesoamerica modelled by MAPSS.

Imbach et al. 2010 HESS

# Impacts of climate change

- Magnitudes of change and its uncertainties
  - 136 - AR4 future climate scenarios (48/B1, 52/A1B, 36/A2)
  - Spread of variables across scenarios
  - Likelihood of change (i.e. 20%) (IPCC 2005)
  - Effect of $CO_2$ on water use efficiency (WUE)

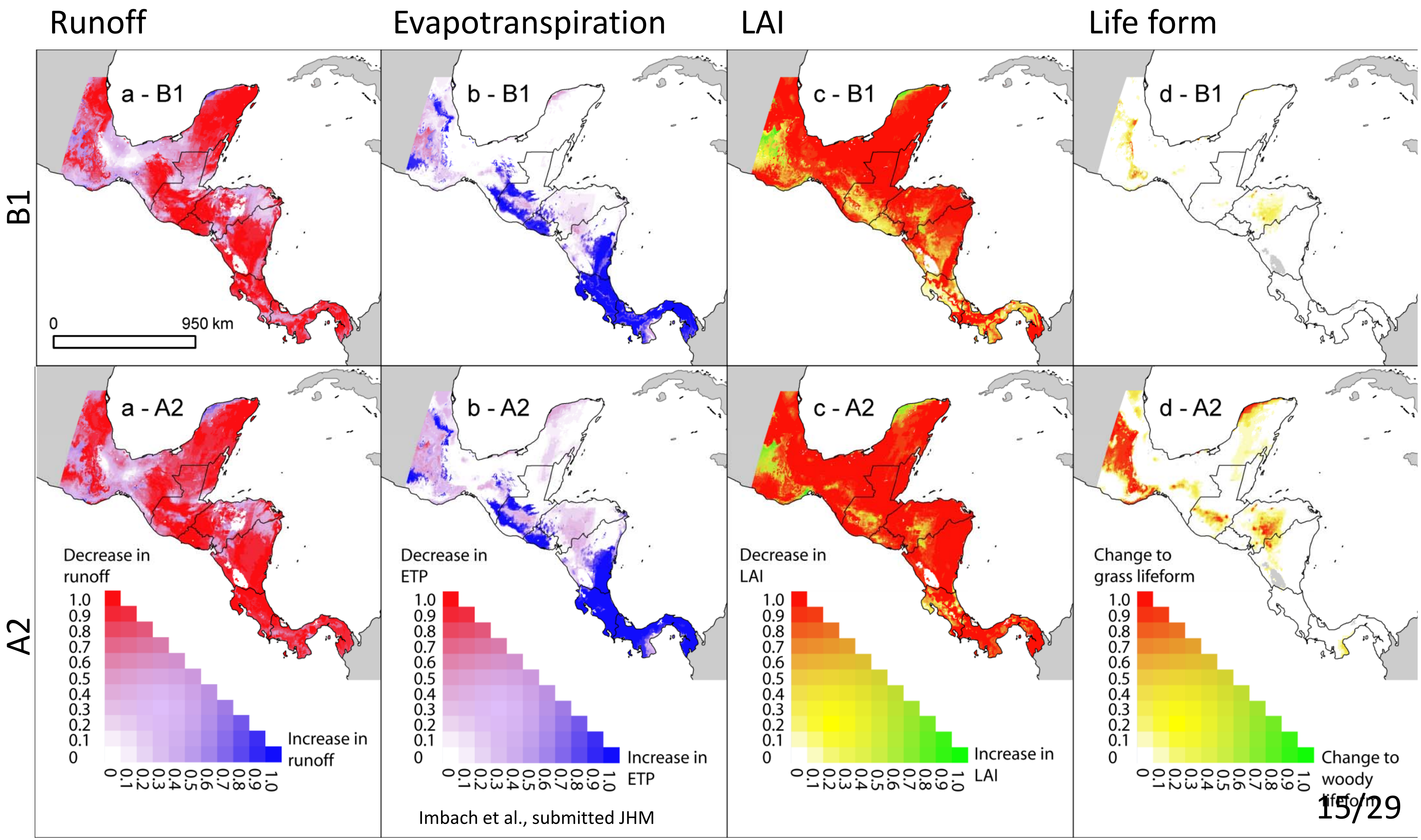


: All scenarios showed a decrease of at least 20%

: All scenarios showed an increase of at least 20%

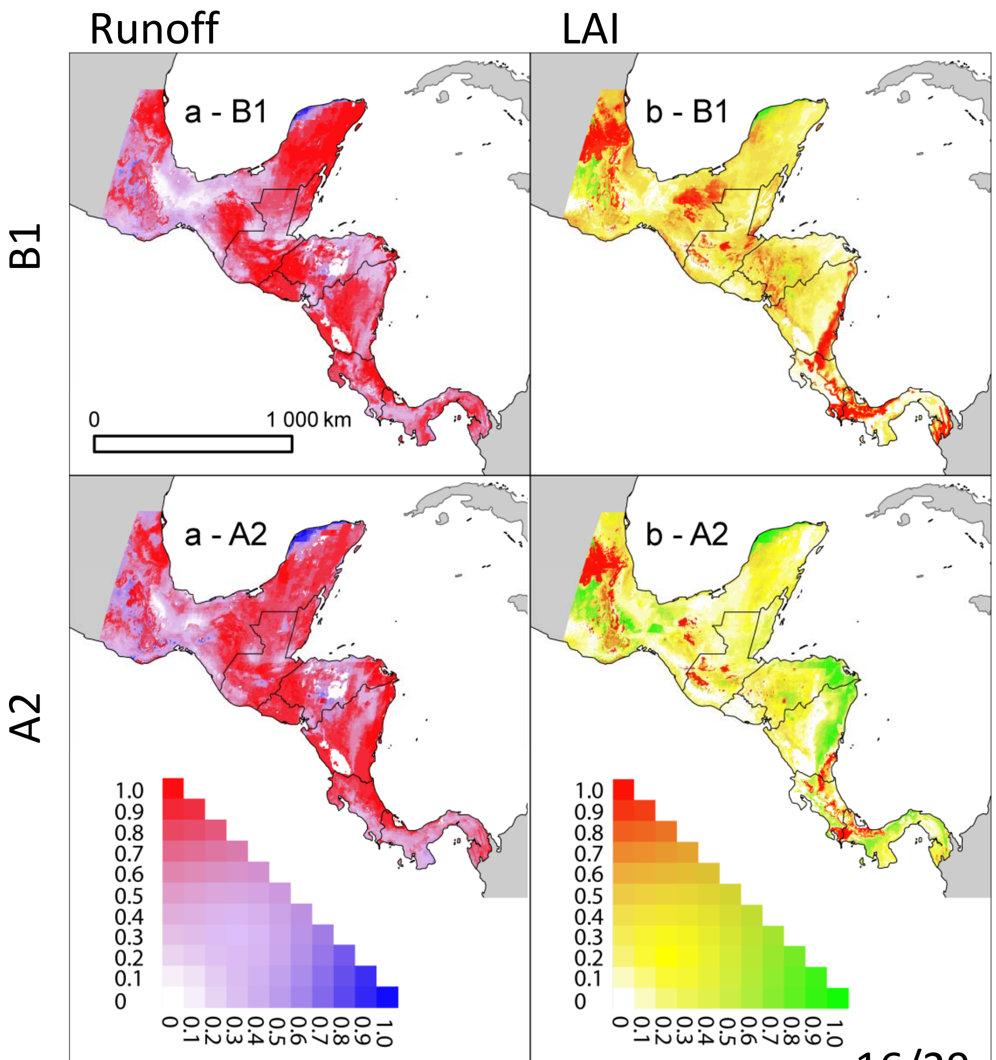
: A fraction of scenarios showed and increase/decrease of at least 20%

: No scenario showed a change larger than 20% (either increase or decrease)



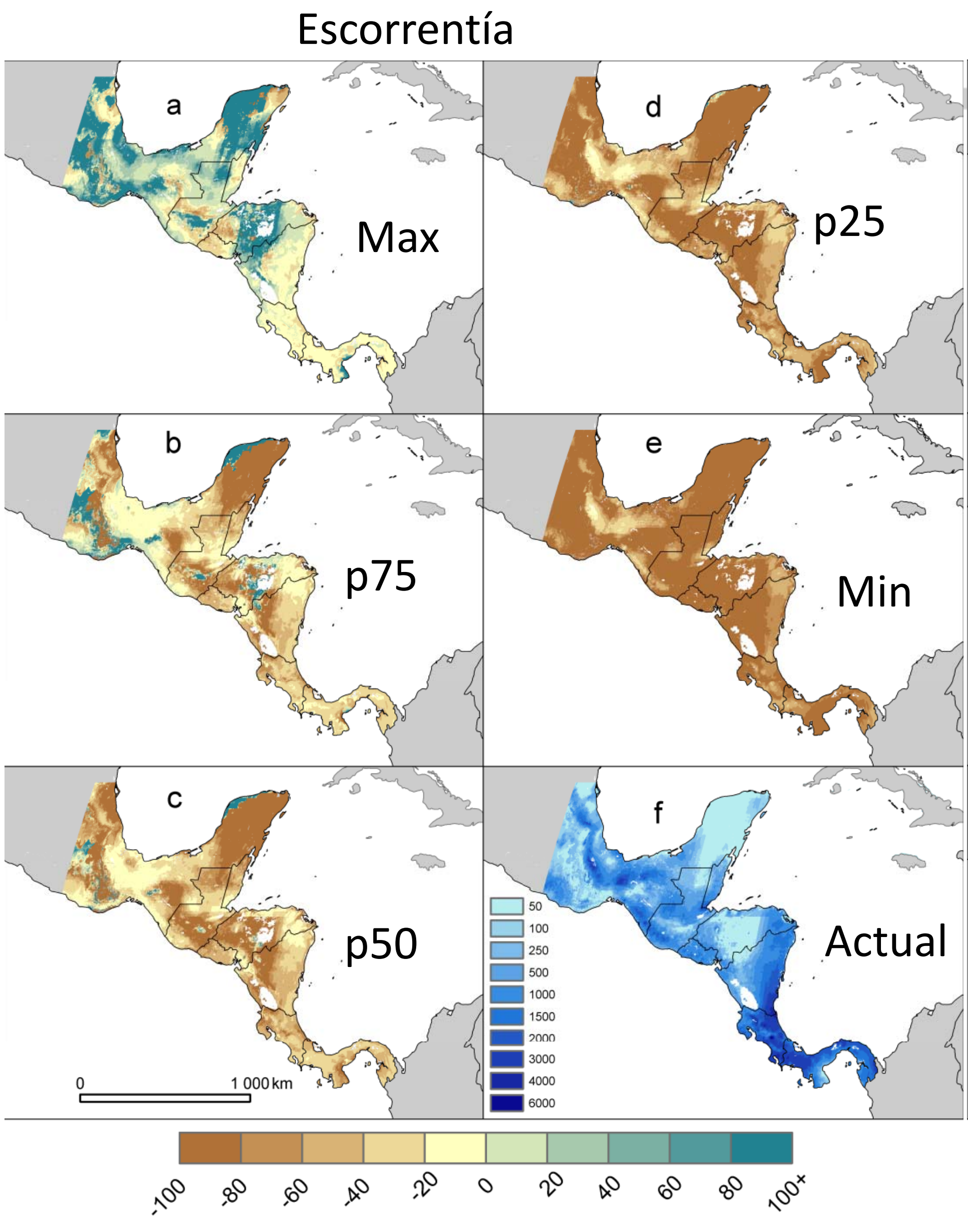
# $CO_2$ and water use efficiency (WUE)

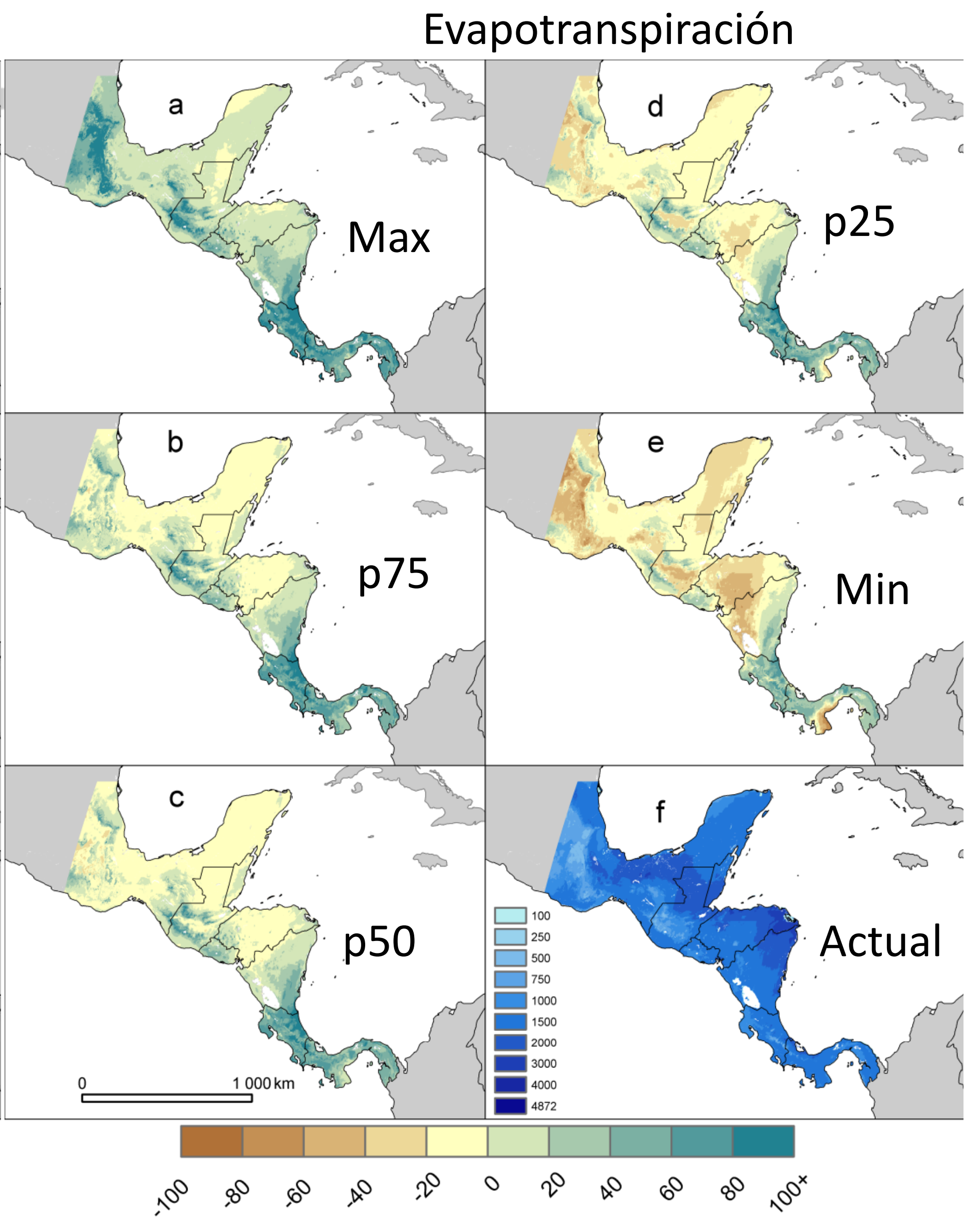
- Evidence of WUE increase for plant or plot experiments
- Uncertain effects at ecosystem scale for tropical areas
- Hypothesis: 35% decrease in stomatal conductance for $2xCO_2$



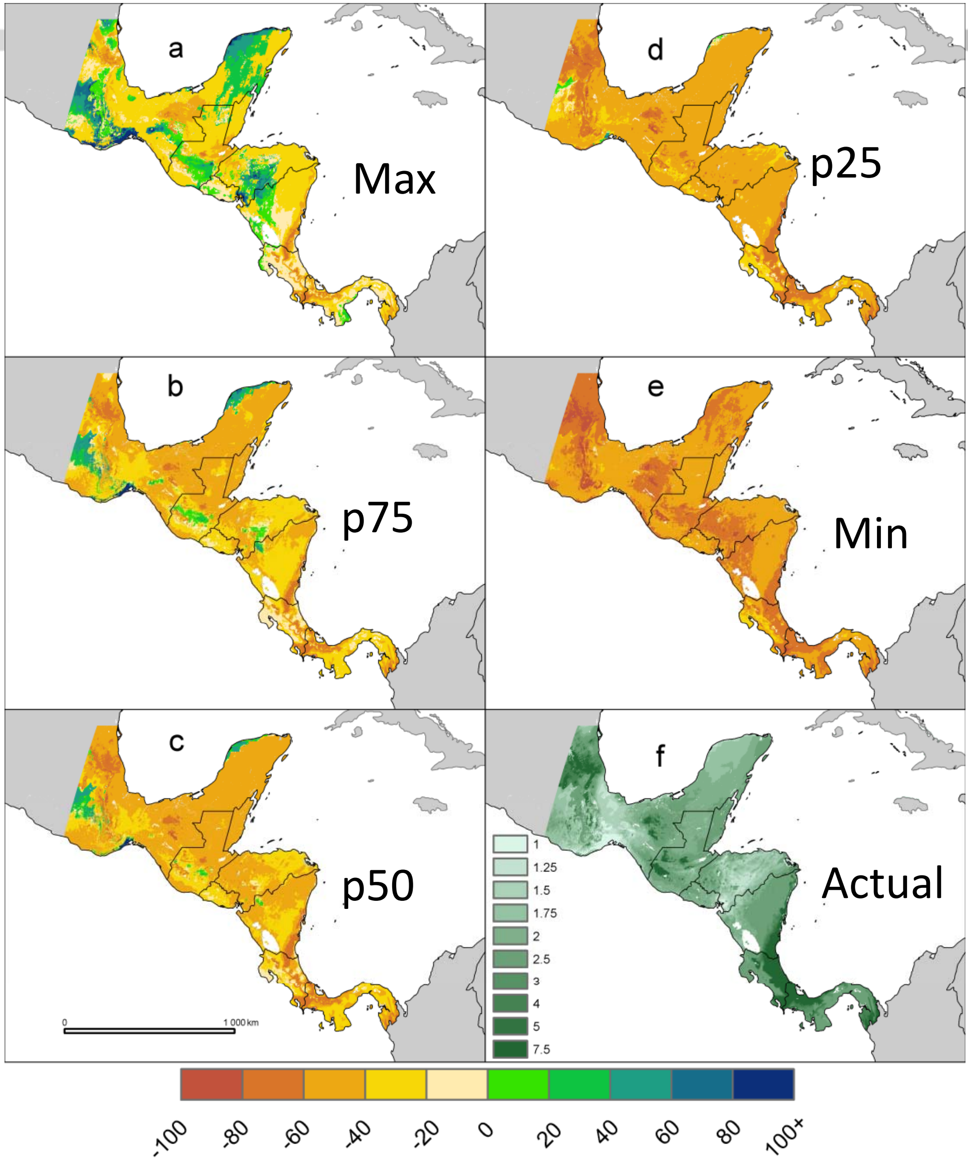

Imbach et al., submitted JHM

# Water balance: projections spread



# LAI: projections spread



# Summary of results

- Under a general drying trend in future climate scenarios we found mixed sensitivities from ecosystems and their water balance
- Importance of accounting for vegetation changes to simulate the impacts of changing climate conditions on water balance
- Increased water use efficiency due to $CO_2$ fertilization can reduce the impact on LAI but not (as much) on runoff

# Parte 2: flujos de Carbono

- Ecosistemas son un componente importante en el balance global de carbono
- “Missing sink”: desbalance entre emisiones (combustibles y CUT), remoción por los océanos y las concentraciones atmosféricas. 1.8±0.8 $PgCyr^{-1}$ (Houghton et al. 1998, McGuire et al. 2001)
- Regiones tropicales son importantes: ecosistemas fueron sumideros durante los 90s contrarrestando emisiones por deforestación (Schimel et al. 2001)

# Amazonía: justificación

- 8 mill. km$^2$, mayor reservorio global de C-orgánico
- Stock de biomasa y variaciones estacionales e inter-anuales resultan del balance entre fotosíntesis, respiración, descomposición y quema de biomasa (Ometto et al. 2005)
- Enfoques para cuantificar flujos:
  - Biométricos
  - Torres de flujo (eddy-flux covariance)
  - Inversión atmosférica
- Amazonía: desacuerdo entre los métodos
  - Variaciones interanuales y estacionales (fuente o sumidero)
  - Respuestas a disturbios recientes (sequías 2005/10) o de largo plazo (+CO2)

# Inversión atmosférica: observaciones y flujos

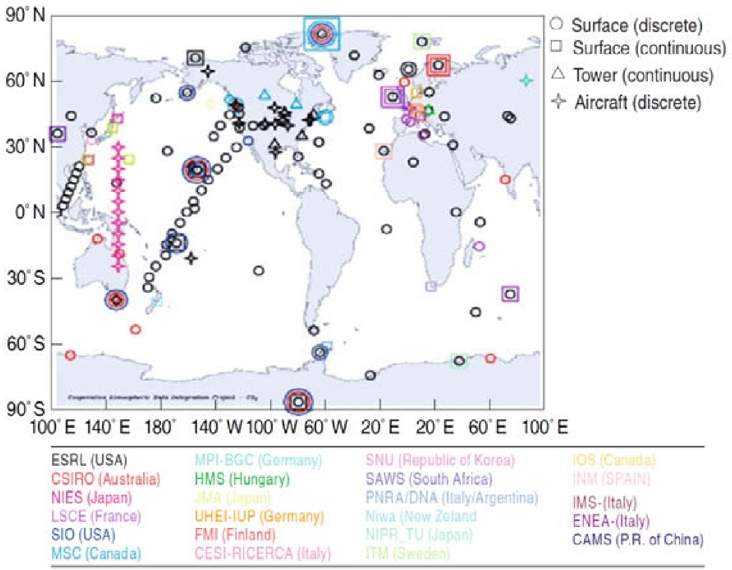



**Fig. 3** Map of atmospheric stations where $CO_2$ observations are made routinely by means of flask sampling and continuous measurements. Each *color* corresponds to a different laboratory contributing measurements (courtesy of K. Masarie at NOAA-ESRL)

- Modelos de vegetación (p.e. ORCHIDEE, Krineer et al. 2005)
- Océanos (Takahashi et al. 2001)
- Combustibles, incendios (p.e. EDGAR4)

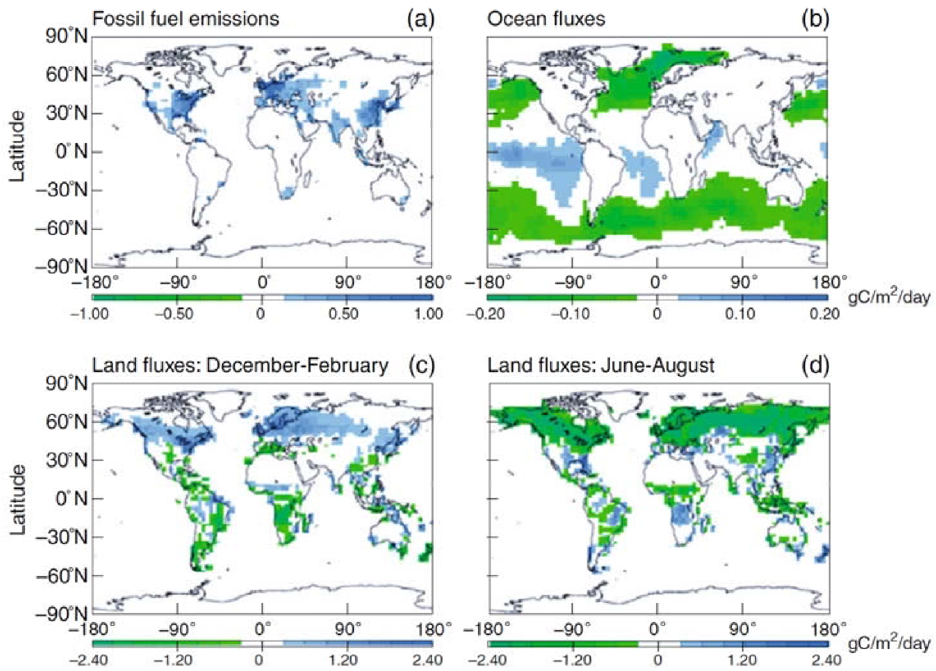
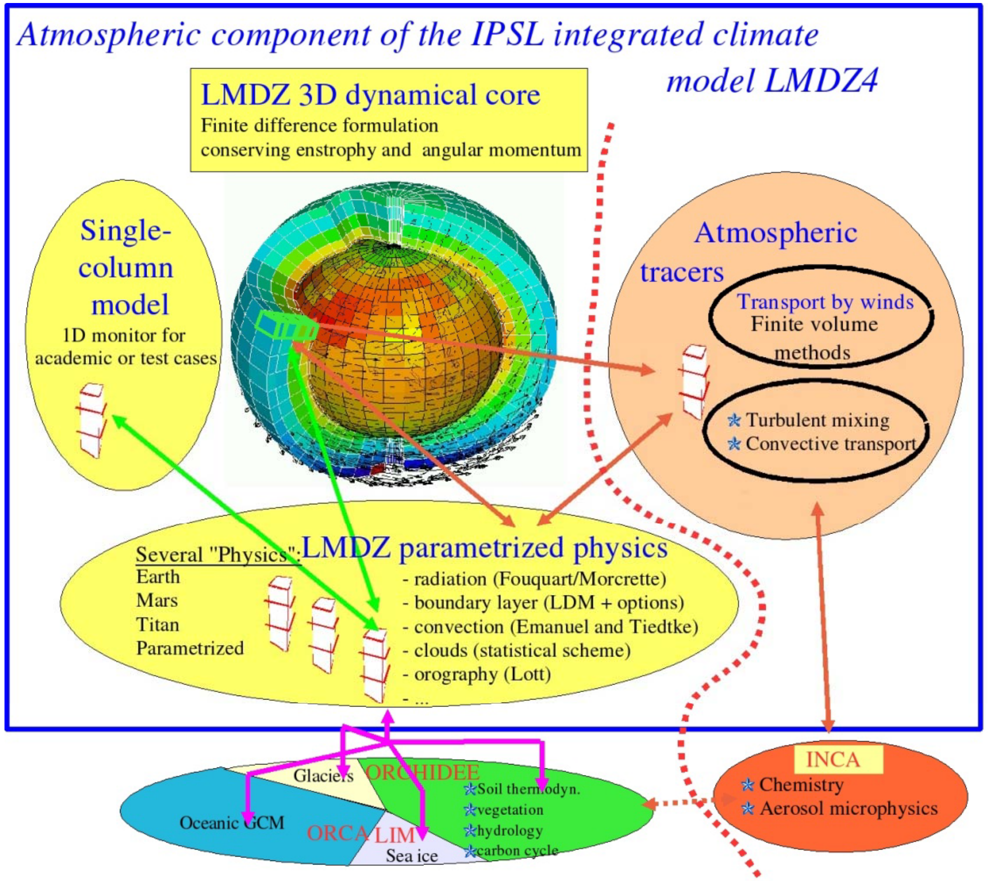



**Fig. 2** **a** Distribution of mean annual fossil fuel $CO_2$ emissions obtained from statistics on energy consumption and spatial information on population density and anthropogenic activities (after EDGAR FT2000 database). **b** Air–sea flux (after Takahashi et al. 1997). **c** Land–atmosphere flux of $CO_2$ in the peak of the northern hemisphere growing season during June–August (after Krinner et al. 2005). **d** Same during the non-vegetative season in January–March

- Aerotransportadas (Gatti et al. 2010)
- Satélite (Chevallier et al. 2005)
- Torres y «flasks»

# Modelo atmosférico: LMDz

- Hourdin y Armengaud 1999
- 76x92x19
- 3 hr
- AR5



# Estudio

ORCHIDEE: Emisiones de los ecosistemas

LMDz: transporte en la atmósfera

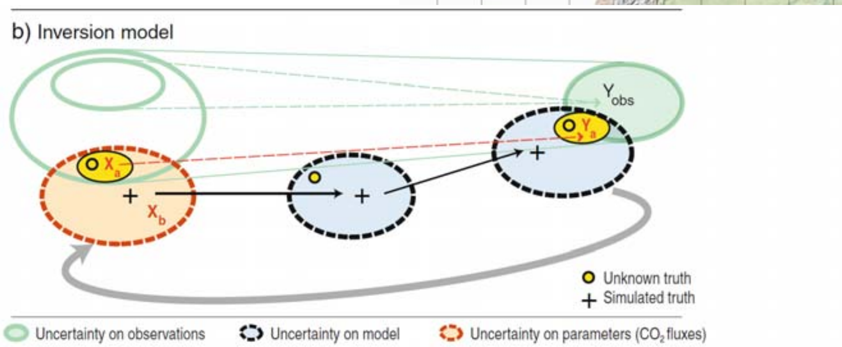
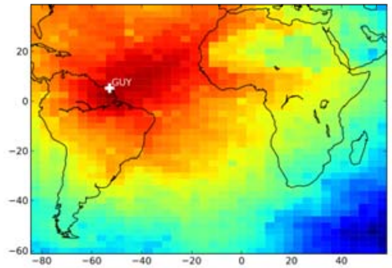




**Fig. 1** **a** Information flow in a forward atmospheric transport model with errors compared with the available $CO_2$ concentration observations, **b** Same for an atmospheric inversion model where an optimal set of parameters (surface $CO_2$ fluxes, x) is determined from the available concentration observations within their errors. *H* represents the transport model used to simulate concentrations everywhere in the atmosphere. *O* is observation operator in which the modeled $CO_2$ distribution is sampled at the time and location of the actual observations

# Avances

- «footprint» de las observaciones
- «monitoreo»



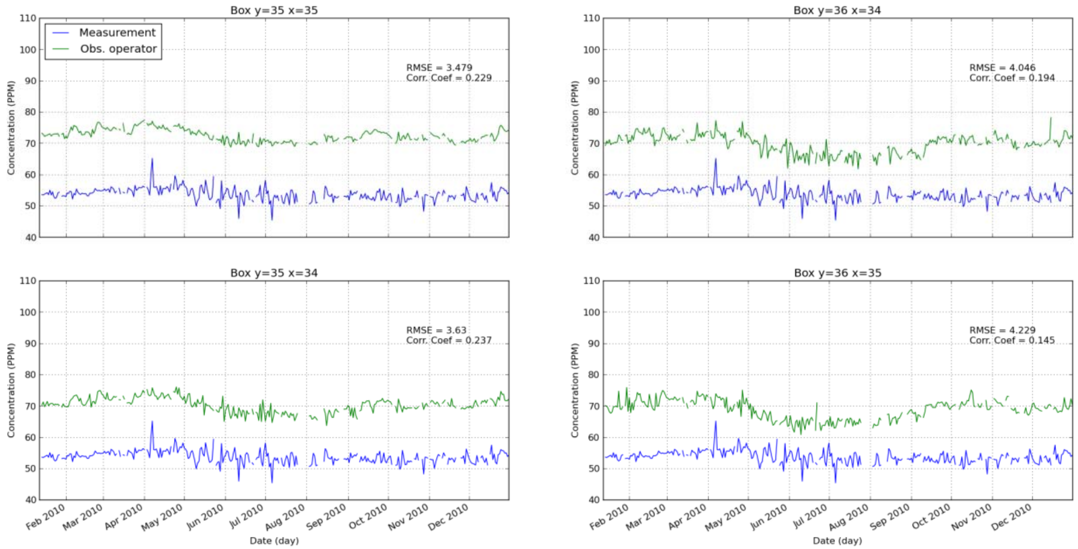




Fig XX. Guyaflux monitoring to test for the original and adjacent-inland LMDz buckets. Observations were selected between 12 and 15 hr and wind speeds > 2m/s.

# Resultados?

- Inversión en unas semanas…

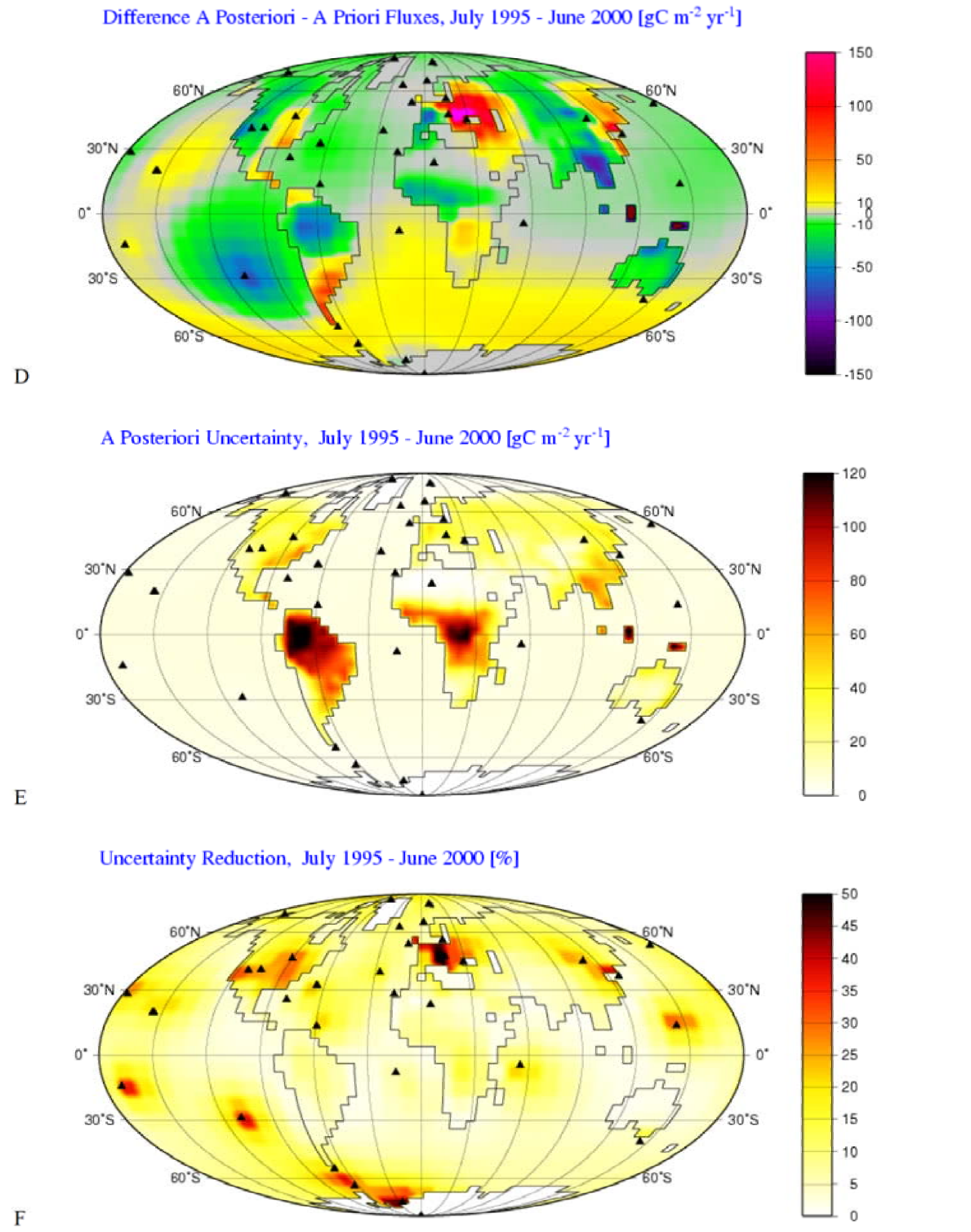



**Fig. 9. (D)** "Inversion update" (deviation of the a-posteriori flux from the a-priori flux). **(E)** A-posteriori uncertainty $\sigma_{post}$. **(F)** Reduction in uncertainty $(1 - \sigma_{post}/\sigma_{pri})$.

Rodenbeck et al. 2003

Muchas gracias!

pimbach@catie.ac.cr

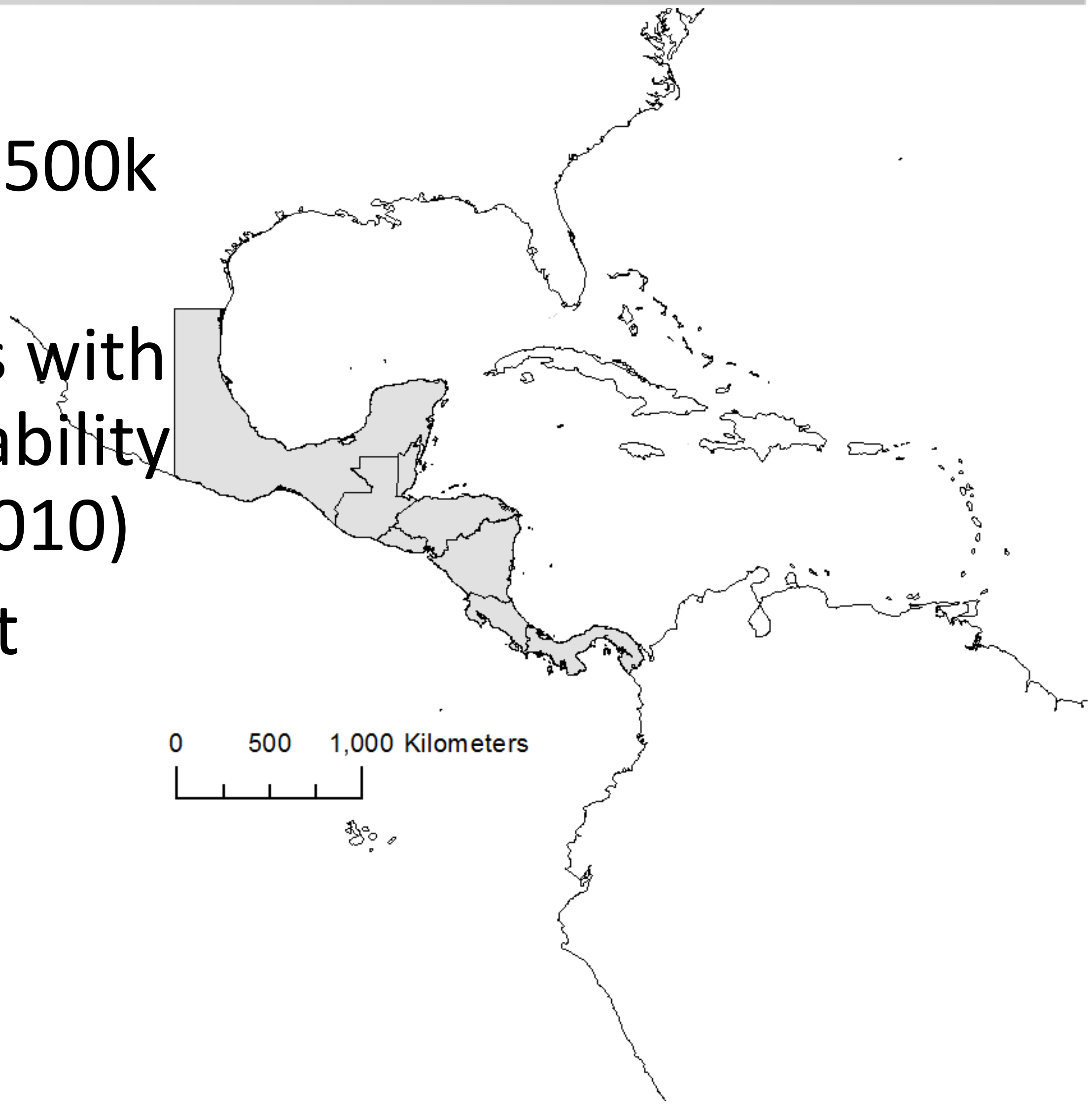
imbachpablo@gmail.com

# Future perspectives

- Downscaled climate scenarios
- Validation of remotely sensed datasets with global coverage in Mesoamerica
- Evaluate transient trends by means of DGVMs (i.e ORCHIDEE)
- Historical runoff trends (Aguilar et al. 2005)
- Land use/change combined with climate change impacts
- Number of species by dispersal rate per ecosystem
- Vulnerability assessments and adaptation measures

# Background – Mesoamerica

- 8 countries
- 60 million persons, 500k $km^2$, HDI (48 – 118)
- Water access issues with high resource availability (FAO 2003; UNEP 2010)
- Biodiversity hotspot (Myers et al. 2005)
- Integration efforts



# Validation (2/2)

- Model bias
- Parameter uncertainty

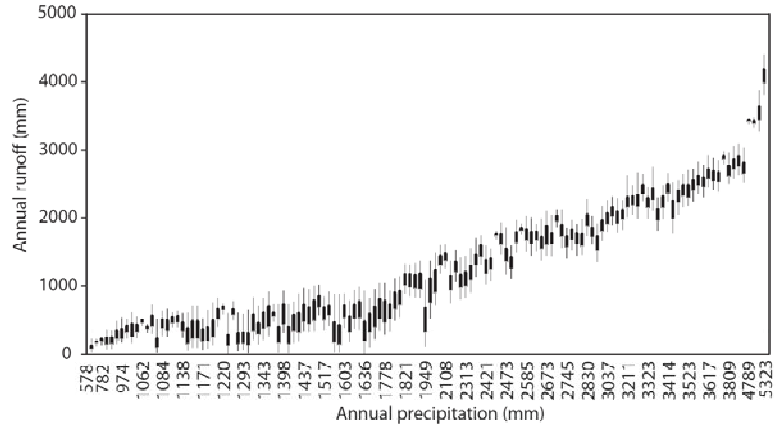



**Fig. 6.** MAPSS model runoff uncertainty obtained by a Monte Carlo-type approach (Latin Hypercube Sampling). For each catchment, the black line shows the whole range of predicted values and the box ranges within one standard deviation from the mean. Catchments were ordered according to annual precipitation. (Horizontal axis does not show all catchment values).

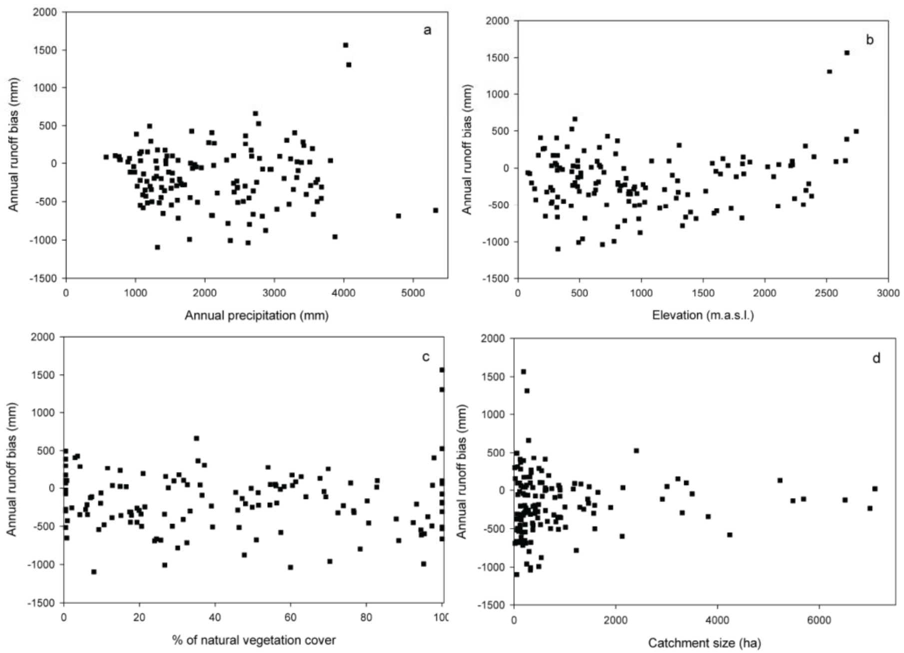



**Fig. 5.** Residual distributions of annual runoff according to catchment annual precipitation **(a)**, average elevation **(b)**, percentage of natural vegetation cover **(c)**, and size **(d)**. Each dot corresponds to the difference between MAPSS-modelled and observed annual runoff for each catchment.

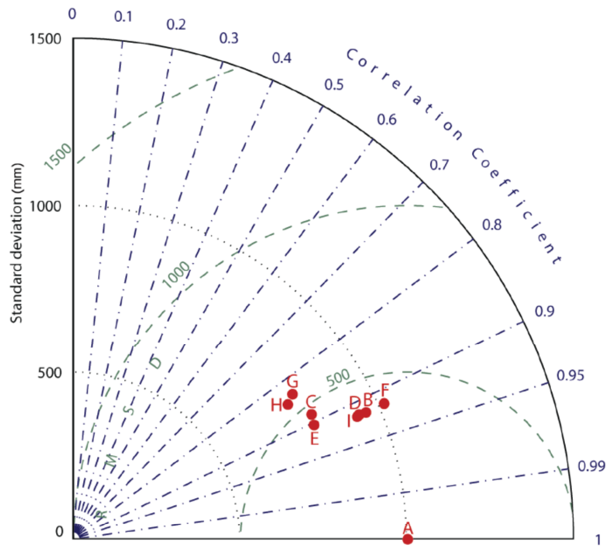



**Fig. 8.** Taylor plot with observed runoff (A) and modelled values using FCLIM (B), CRUCL 2.0 (C), original MAPSS parameterization (D), WorldClim (E), TCMF (F), TRMM (G), WindPPT (H), and NS (I) datasets.

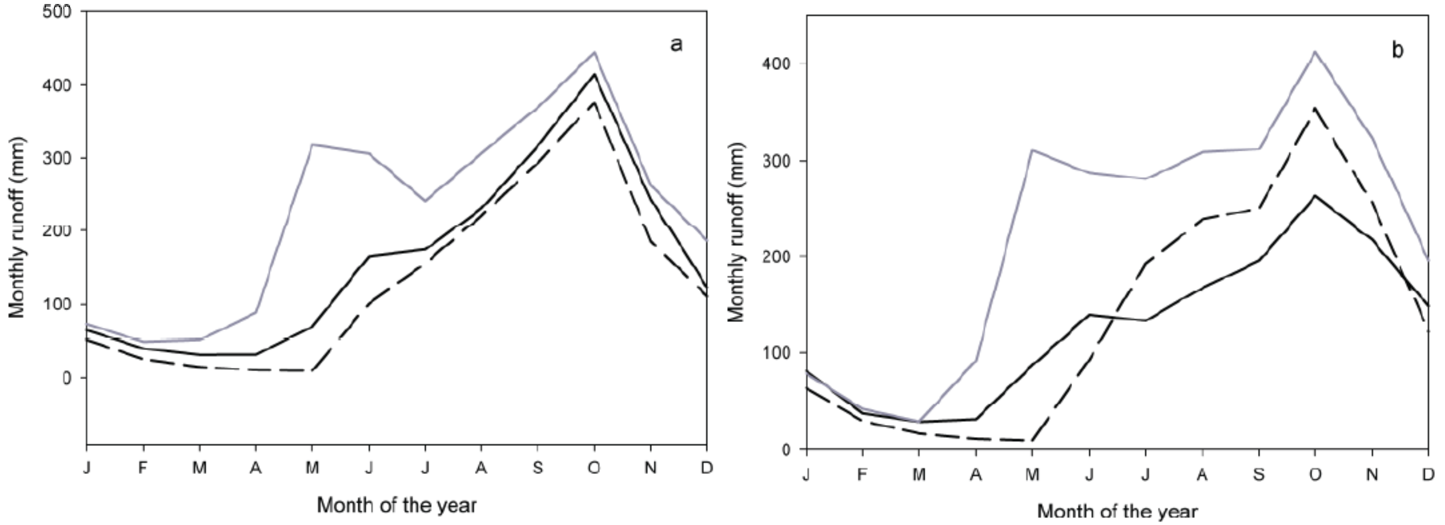



**Fig. 7.** Two examples of contrasting seasonal catchment behaviour, according to the water storage term from Eq. (14): **(a)** a catchment without significant storage term (San Juan, Panama), and **(b)** a catchment (Los Cañones, Panama) with recharge during the rainy season (July to November) and discharge later on. Rainfall (gray straight line), observed (black straight line) and modelled (black dashed line) monthly runoff.

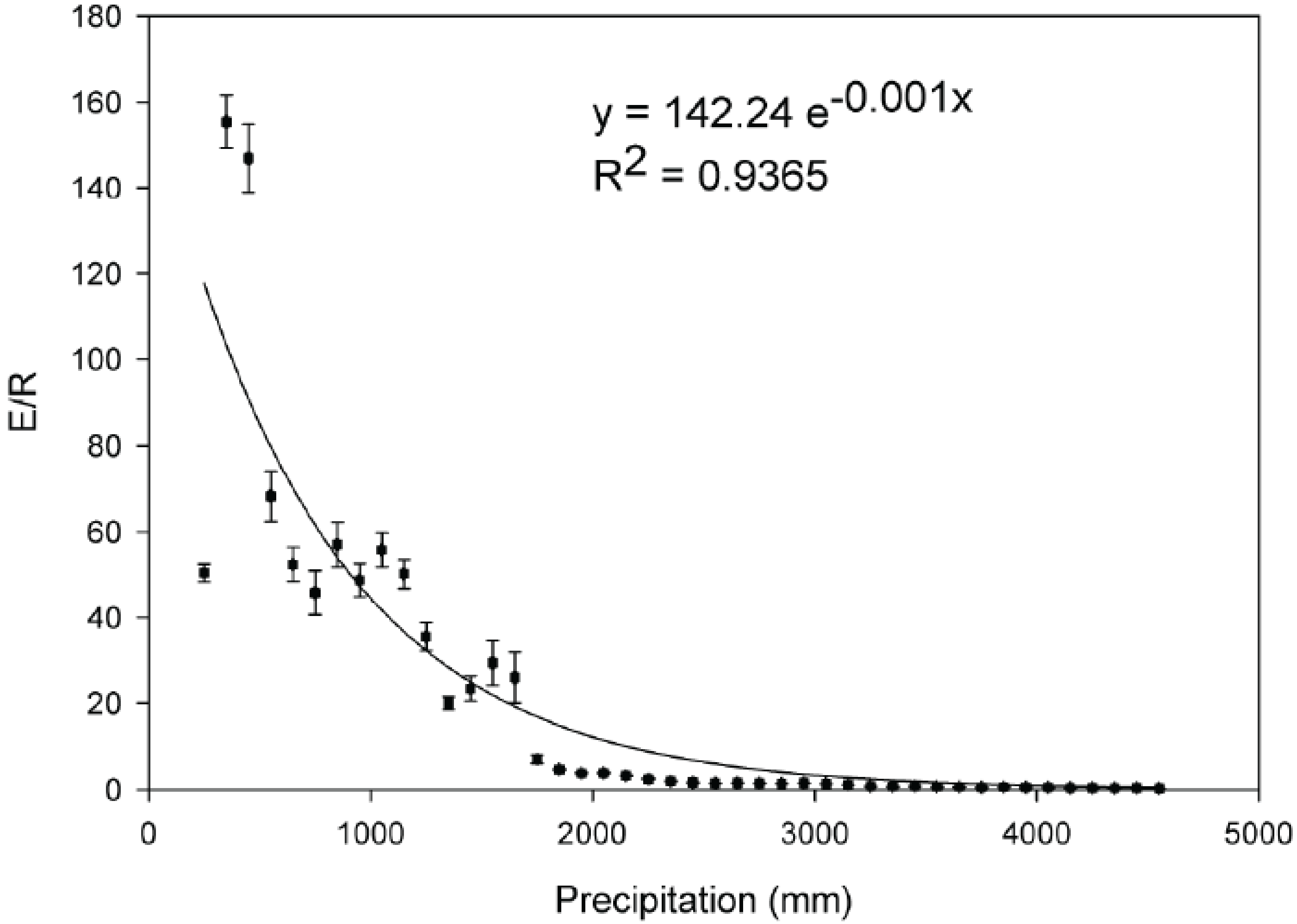



**Fig. 10.** Modelled evapotranspiration-runoff ratio (*E/R*) along the annual precipitation gradient across the Mesoamerican region. Each point represents a 100 mm annual precipitation class. Bars show standard error of each class.

# MAPSS workings

- LAI is related to canopy transpiration rates that determine available soil water
- Transpiration is a function of stomatal conductance and LAI
- Stomatal conductance decreases with soil water potential and with increasing PET
- LAI equilibrium is estimated through successive iterations in which grass and woody vegetation compete for water and light until a point is found where most of the soil water is consumed

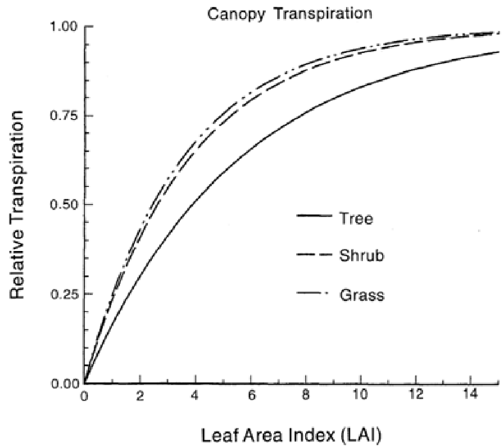



FIG. 2. Actual transpiration is plotted relative to potential evapotranspiration (PET) as a function of increasing all-sided LAI for each of the three life-forms (Appendix 1, Eq. 1.9). PET is normalized to 1 and incorporates the roughness length of the three life-forms.

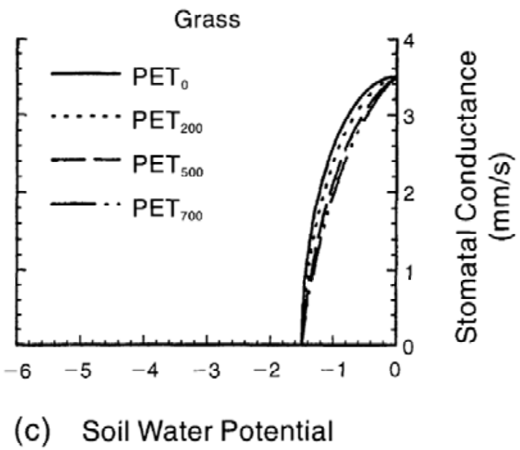
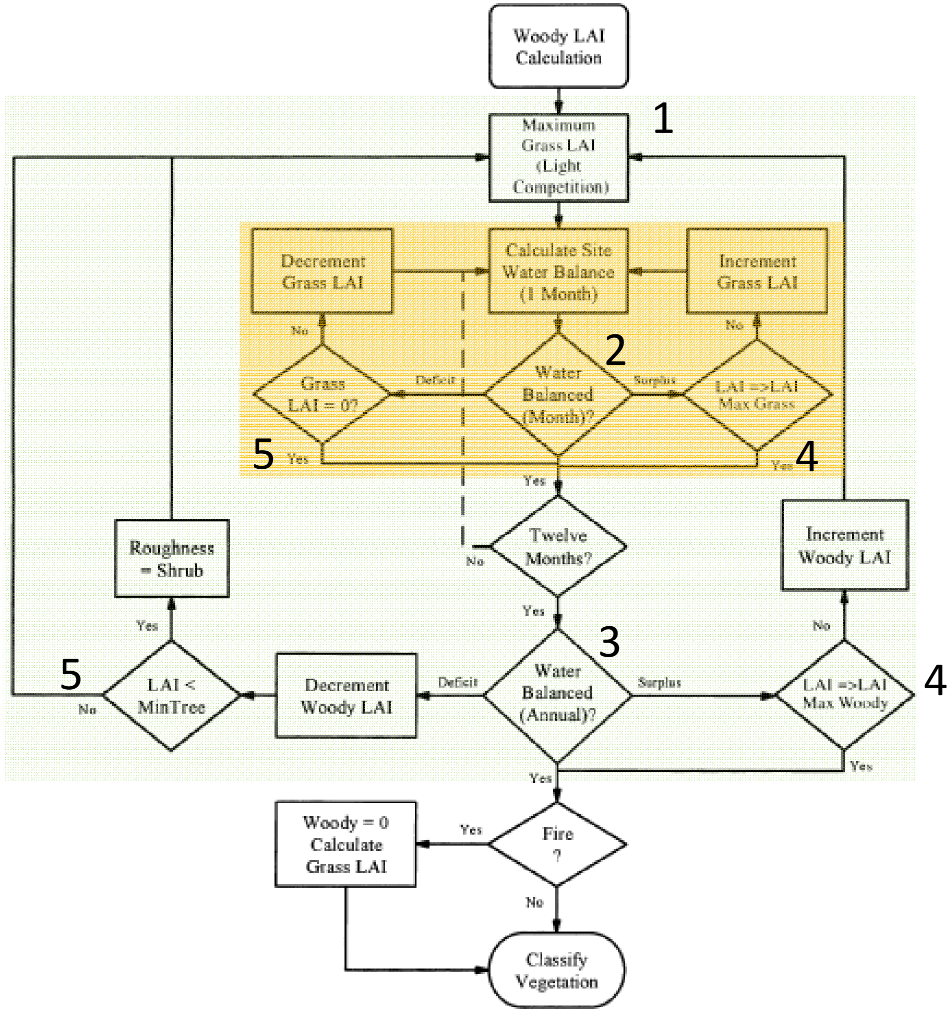



FIG. 3. Stomatal response functions for the three different life-forms as a function of soil water potential and potential evapotranspiration (PET). The response to PET is continuous, but discrete levels are shown to indicate the unique sensitivities defined for each life-form. PET subscripts refer to monthly PET in millimetres. The levels shown for each life-form are representative of the range of PET values most frequently experienced by each life-form. Soil water potential is expressed in megapascals.

Neilson 1995

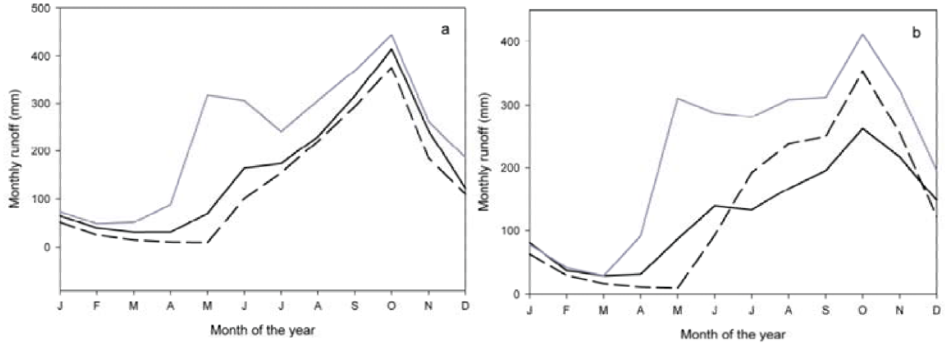
# MAPSS iterations




Neilson 1995

# Strengths and weaknesses

- Annual water balance outputs and LAI
- Limitation for monthly assessment due to groundwater recharge/discharge

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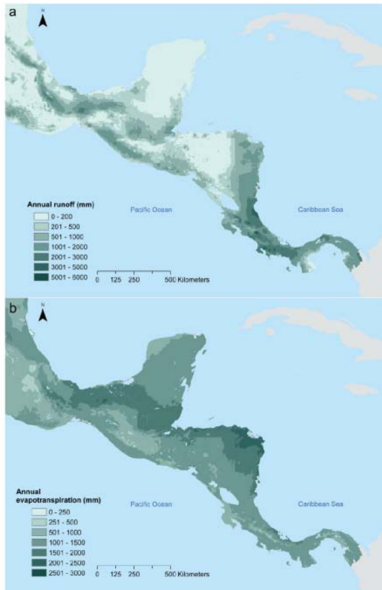
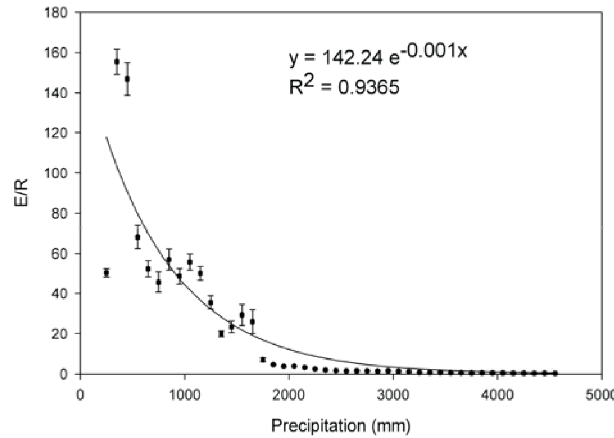


Fig. 9. Annual runoff (a) and evapotranspiration (b) of Mesoamerica modelled by MAPSS.

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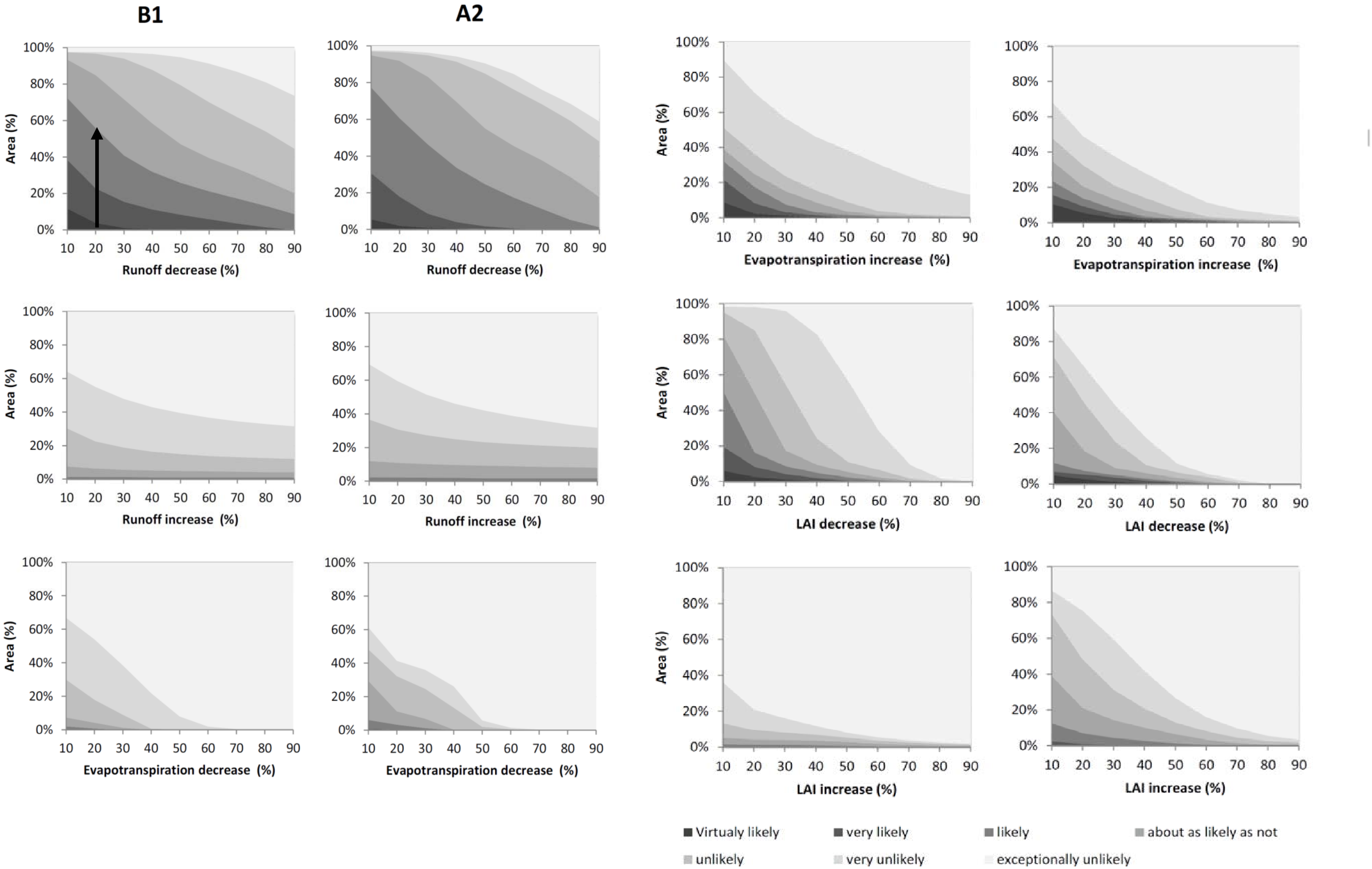



Imbach et al., submitted JHM

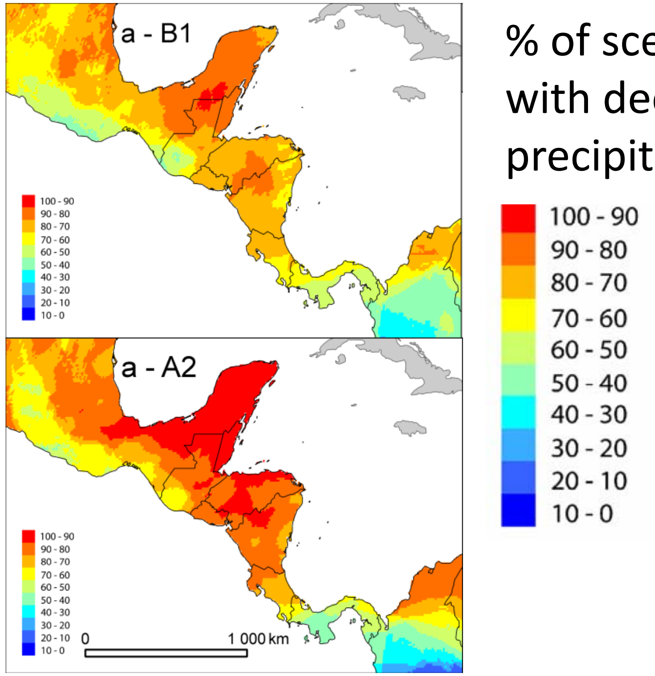
Figure 8. Percentage of area under different likelihoods of change in runoff and leaf area index (LAI) in Mesoamerica in 2070-2099, depending on the threshold above which changes are observed on simulations accounting for $CO_2$ effect on water use efficiency. Low (B1) (left hand column a, b, c, d, e, and f) and high (A2) (right-hand column g, h, i, j, k, and l) emissions scenarios are presented. Area for each likelihood category is presented

**Table 2.** Modified parameter values from the original MAPSS configuration for calibration.

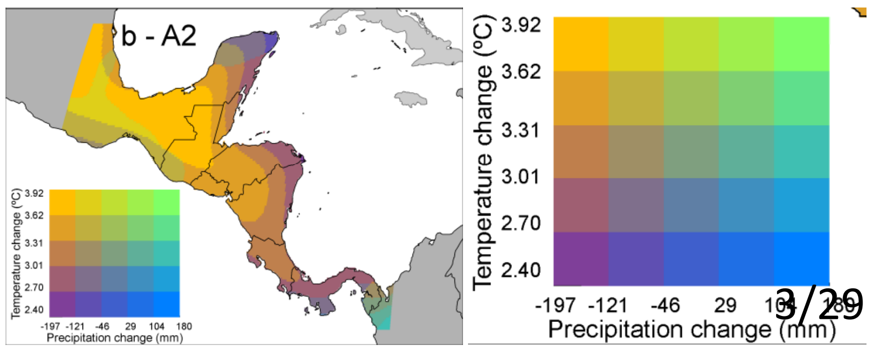
| Parameter | Original | Calibrated |
|---|---|---|
| Intermediate layer thickness (soil) (mm) | 1000 | 3000 |
| Deep layer thickness (soil) (mm) | 1500 | 4600 |
| Maximum conductance (tropical grass) (mm/s) | 5.5 | 6.5 |
| Wilting point (tropical grass and tree) (MPa) | −1.5 | −2.2 |
| Transpiration constant (tropical grass, needleleaf) | 4.25 | 6.25 |
| Transpiration constant (tropical grass, broadleaf) | 3.35 | 5.35 |

# Context: climate change

- Climate change hotspot (Giorgi 2006)
- General drying trends (Neelin et al. 2006, Scheffield & Wood 2008, Rauscher et al. 2008)
  - Temperature increase
  - Precipitation signal uncertain




% of scenarios with decrease in precipitation




Average changes in precipitation and temperature

Imbach et al., submitted JHM