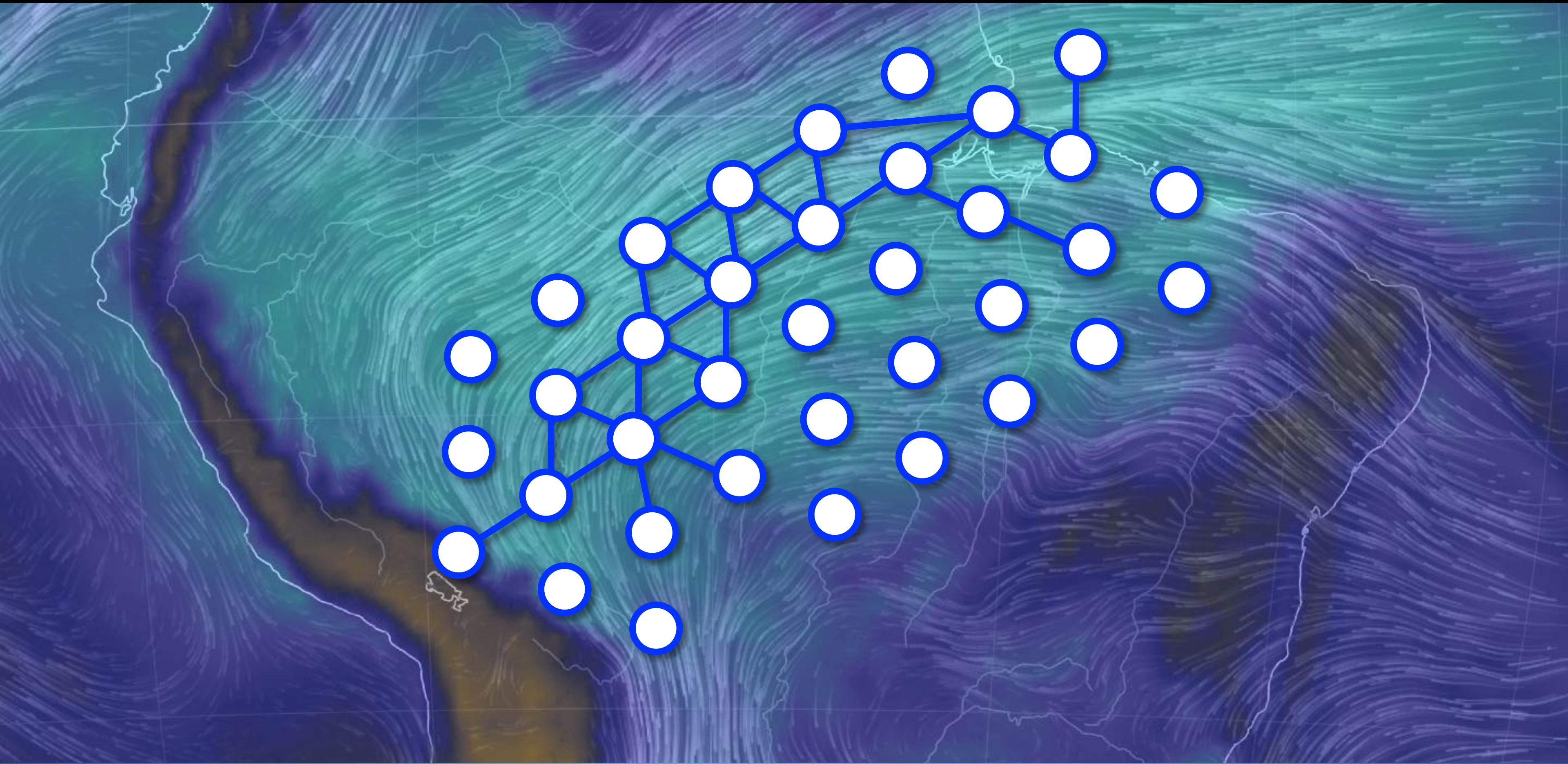
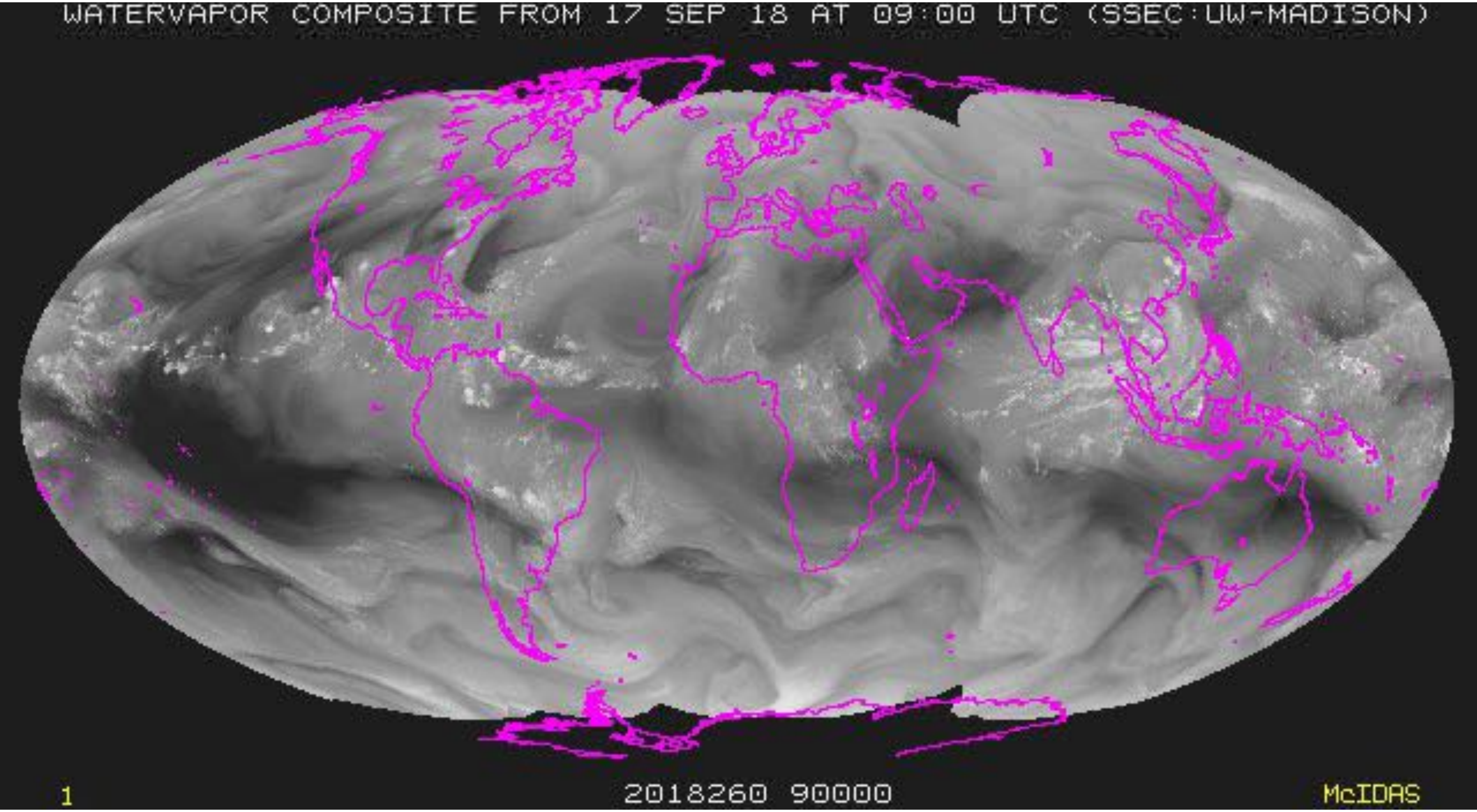
Amazônia, transporte de umidade, e interação biosfera-atmosfera

Henrique M. J. Barbosa

Introducao a Fisica da Atmosfera 2019



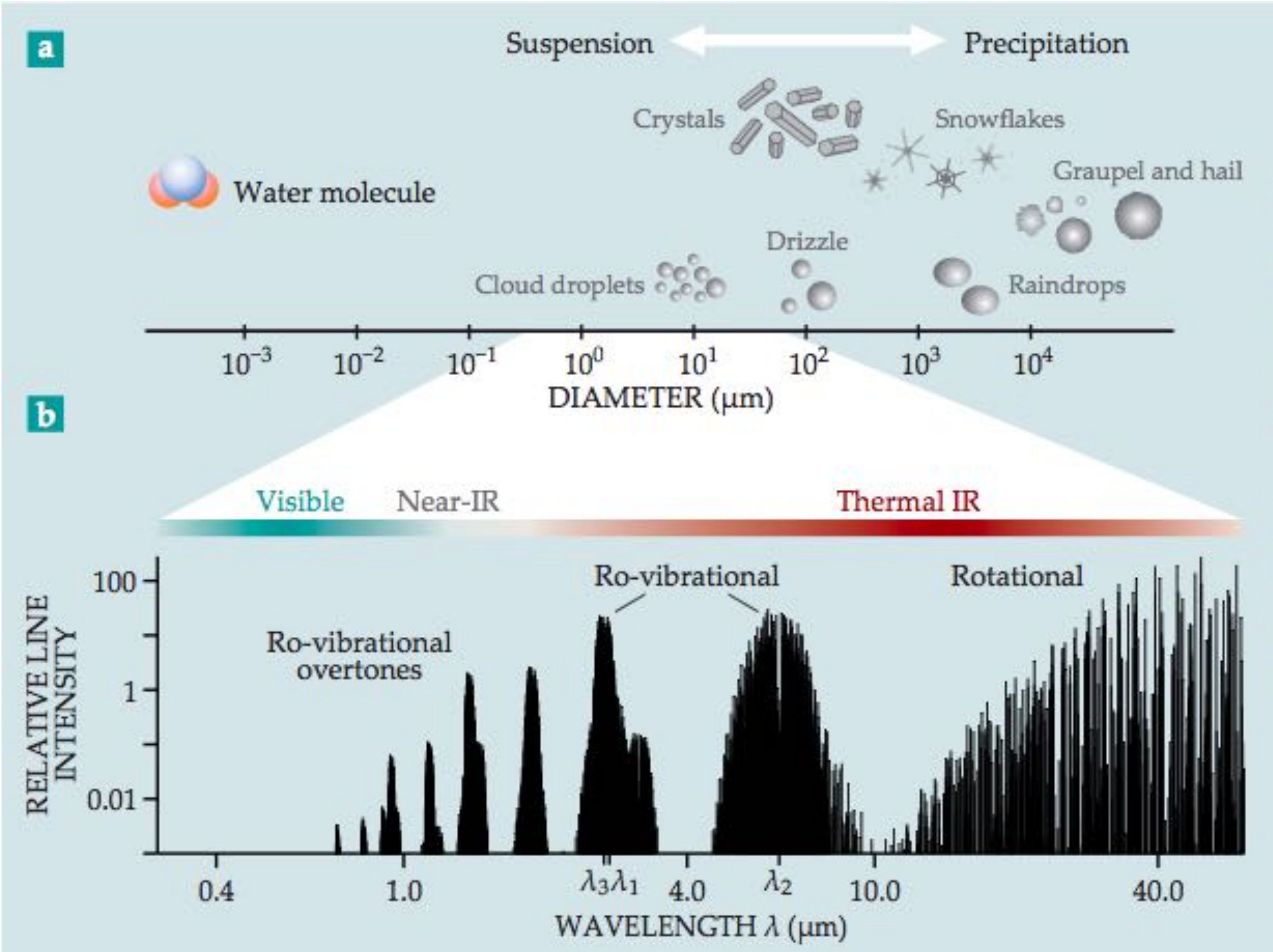
Total column water vapor



GOES, Meteosat, and MTSAT https://www.ssec.wisc.edu/data/comp/wv/wvmoll.mpg

Water in the atmosphere

H_2O	Equivalent in meters
Liquid or solid water in the atmosphere	0.0001 m
Vapor in the atmosphere	0.025 m
Water in soil, lakes, rivers and glaciers	50 to 75 m
Oceans	2800 m



Stevens & Bony, Physics Today 2013

Major greenhouse gases

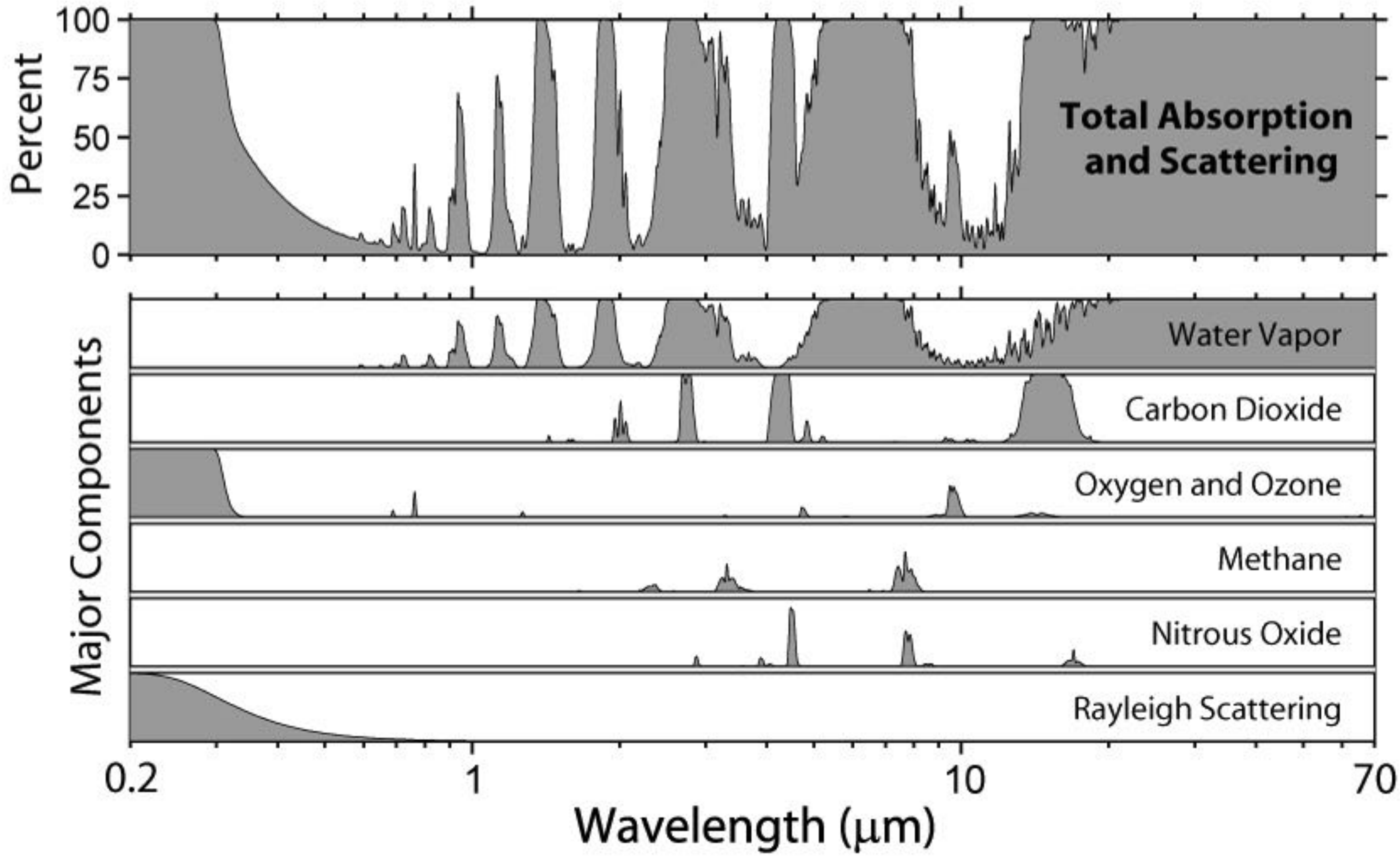
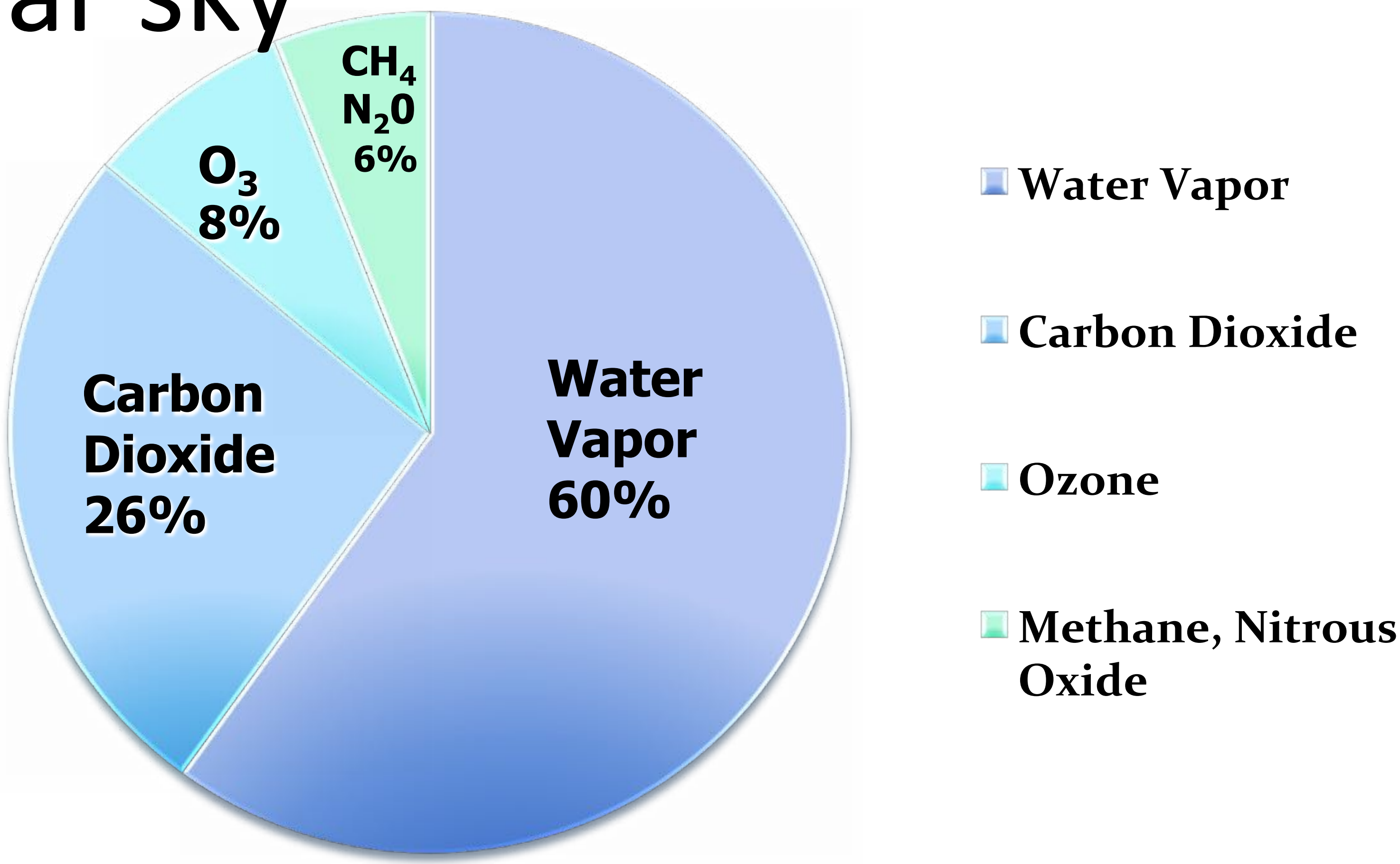


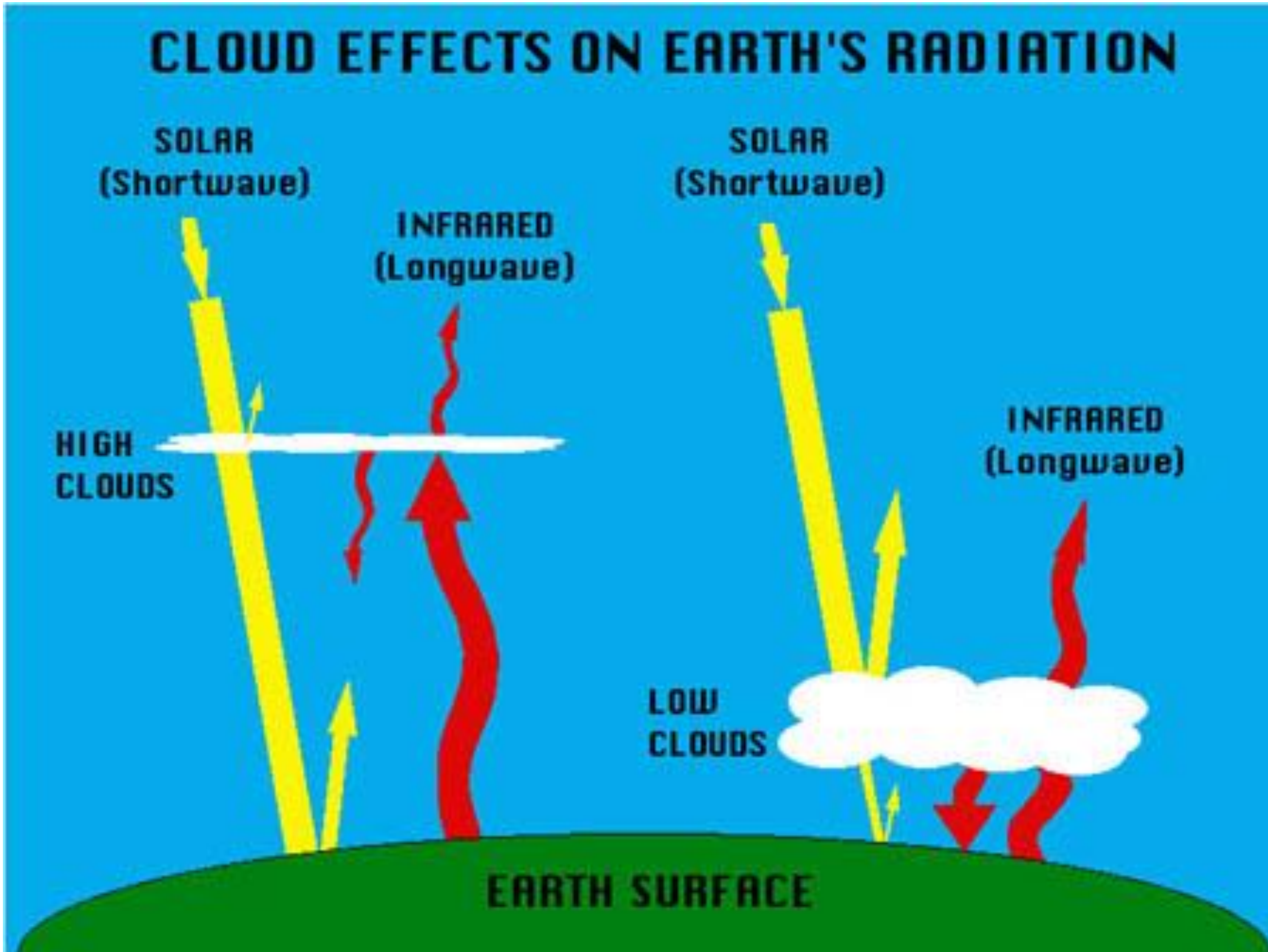
Image by: Robert A. Rohde, Global Warming Art.

The Natural Greenhouse Effect: clear sky



Clouds also have a greenhouse effect

Kiehl and Trenberth 1997



https://www.nasa.gov

Latent heat

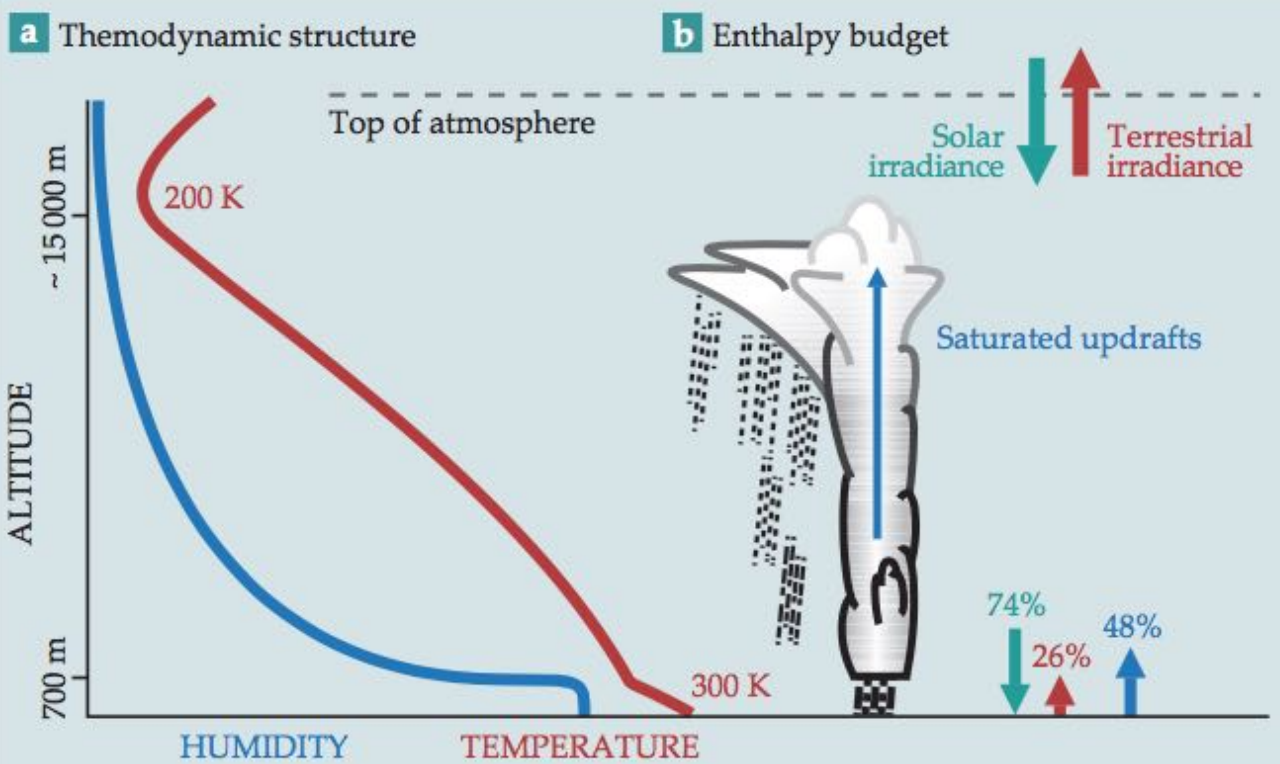


Figure 3. The thermodynamic structure and enthalpy budget of the atmosphere. **(a)** The atmosphere's temperature (red) and its absolute humidity (blue) are closely coupled. **(b)** At the top of the atmosphere solar and terrestrial irradiances balance one another. According to calculations, most (74%) of the incoming solar irradiance reaches the surface, but the net terrestrial irradiance at the surface is only a small fraction (26%) of its value at the top of the atmosphere. The radiative deficit (48%) is balanced by surface turbulent fluxes of enthalpy, arising mostly from evaporation, that transport warm water vapor from the surface to the troposphere, where it cools and condenses.

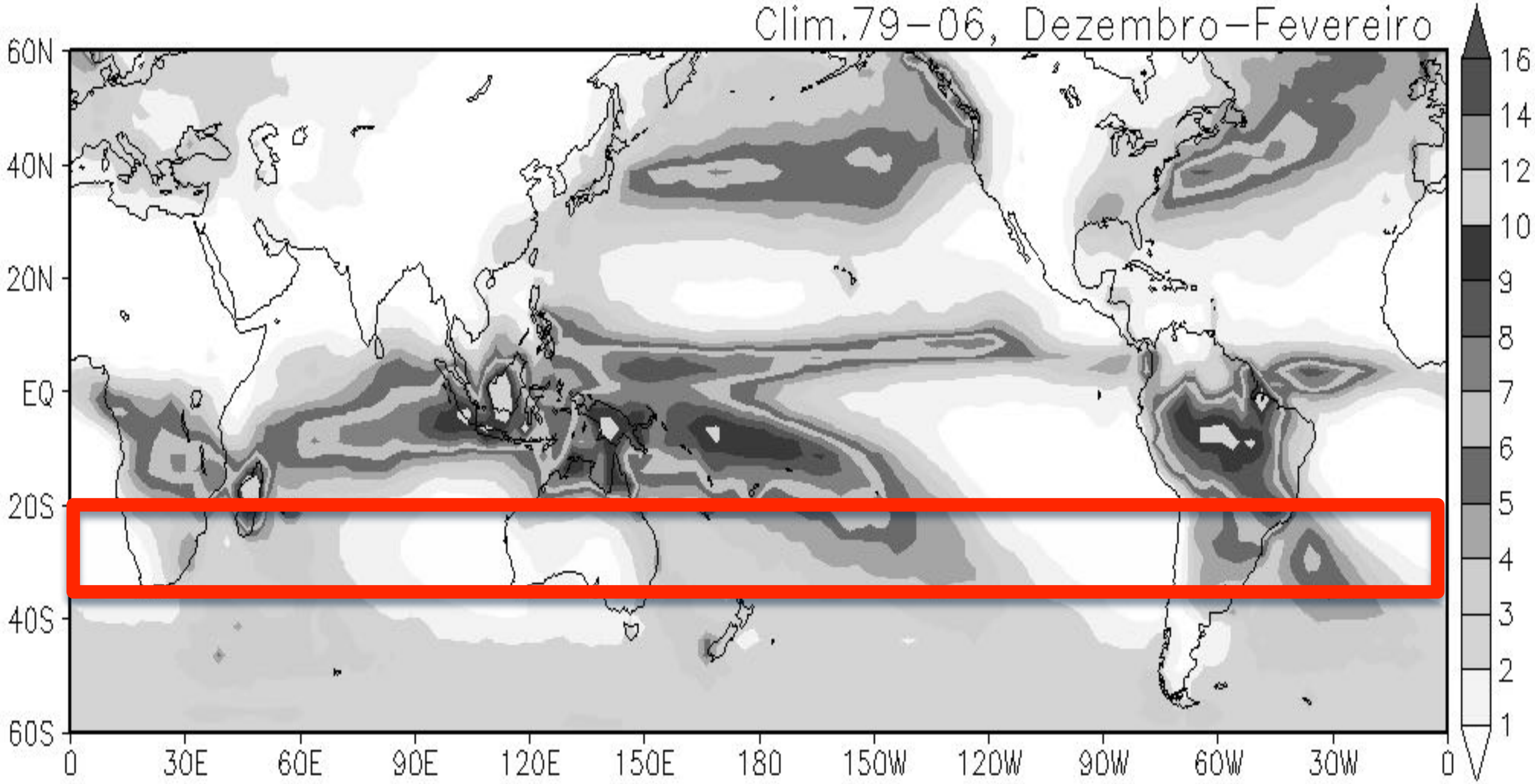
Stevens & Bony, Physics Today 2013

Water in the climate system

Its physical properties determine

- How strong greenhouse effect is;
- Planetary albedo;
- Thermodynamic structure of the troposphere;
- Large scale circulation;
- Hydrological cycle;
- Aerosols hygroscopic growth

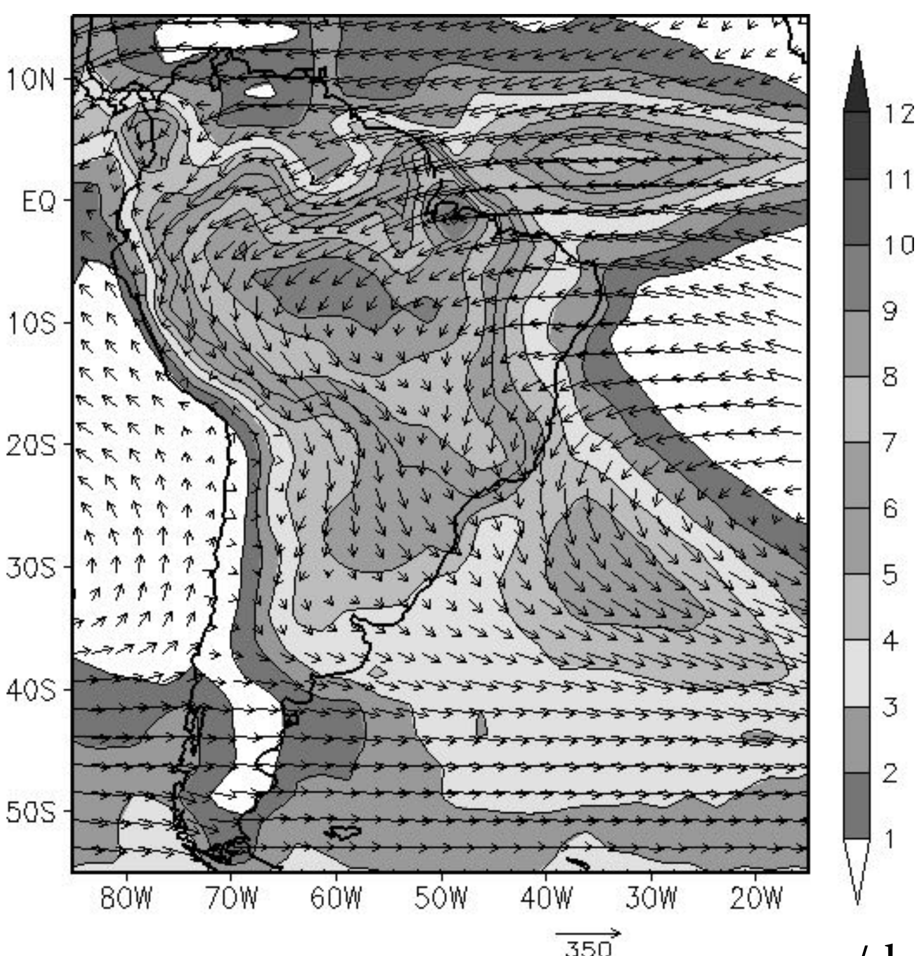
Austral Summer Precipitation 79-06



GPCP, mm/day

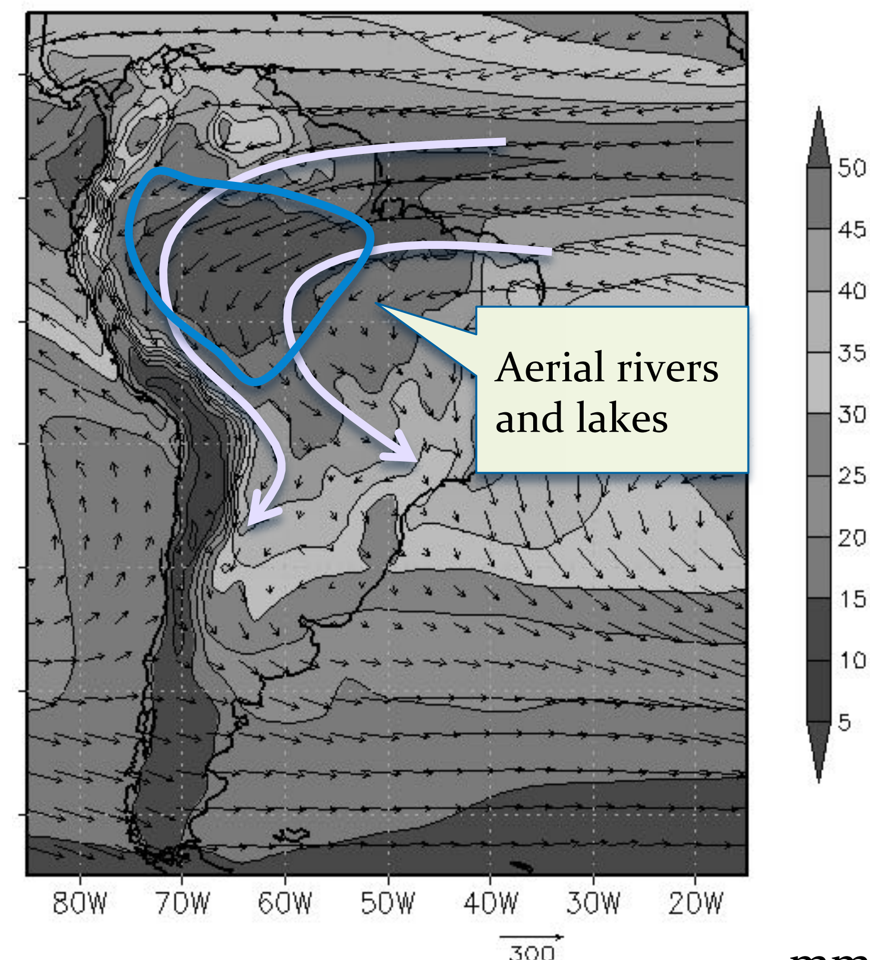
Precipitation, PWV and Vapor transport GPCP + ERA40 1989-2009

Nov-Mar



mm/day

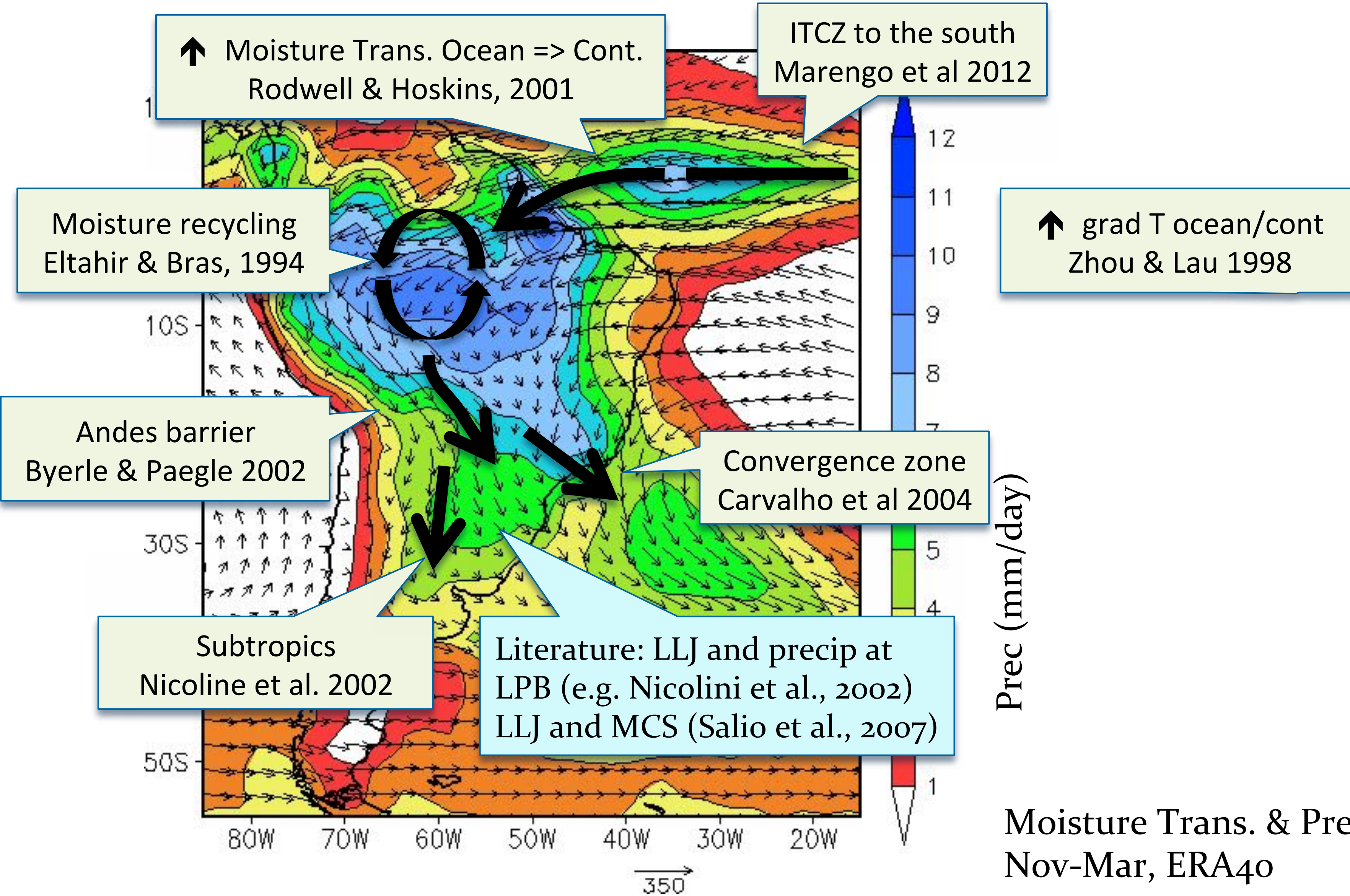
Nov-Mar



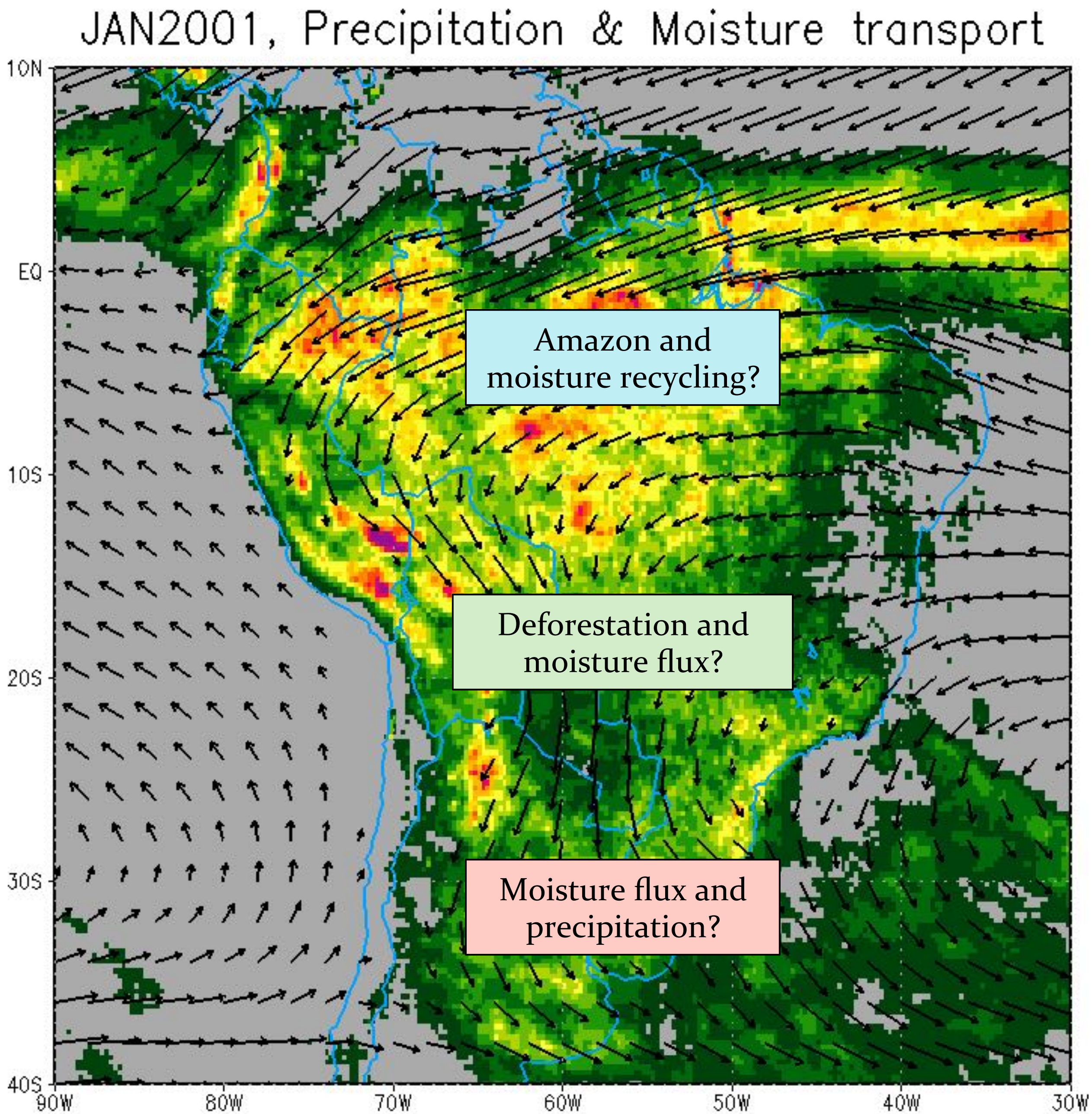
mm

Arraut et al, J. Clim, 2012

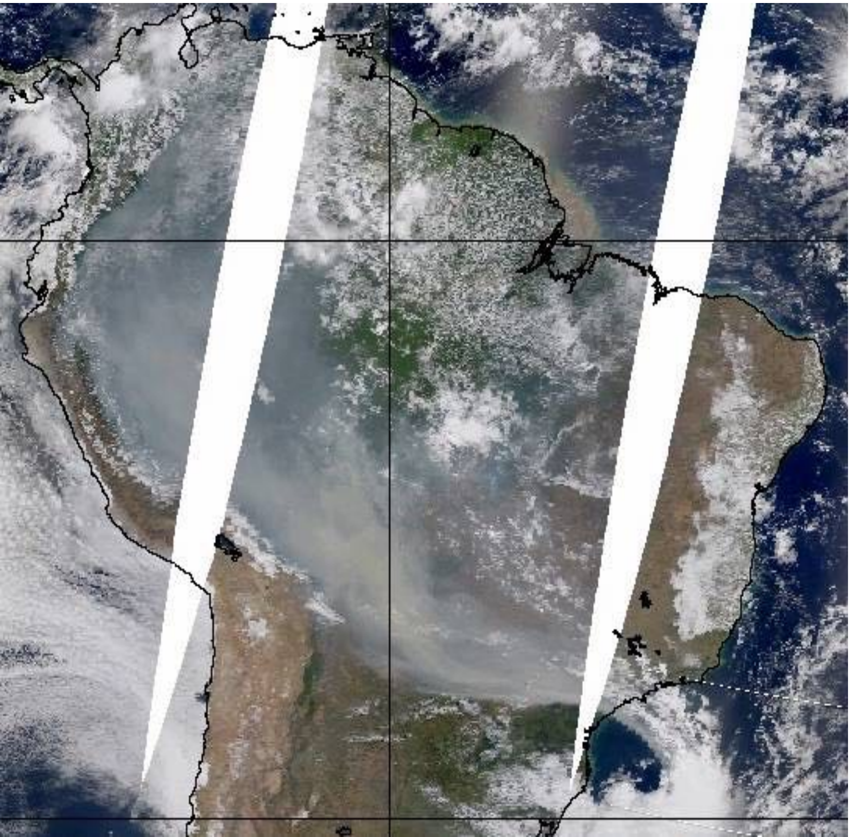
South American Monsoon

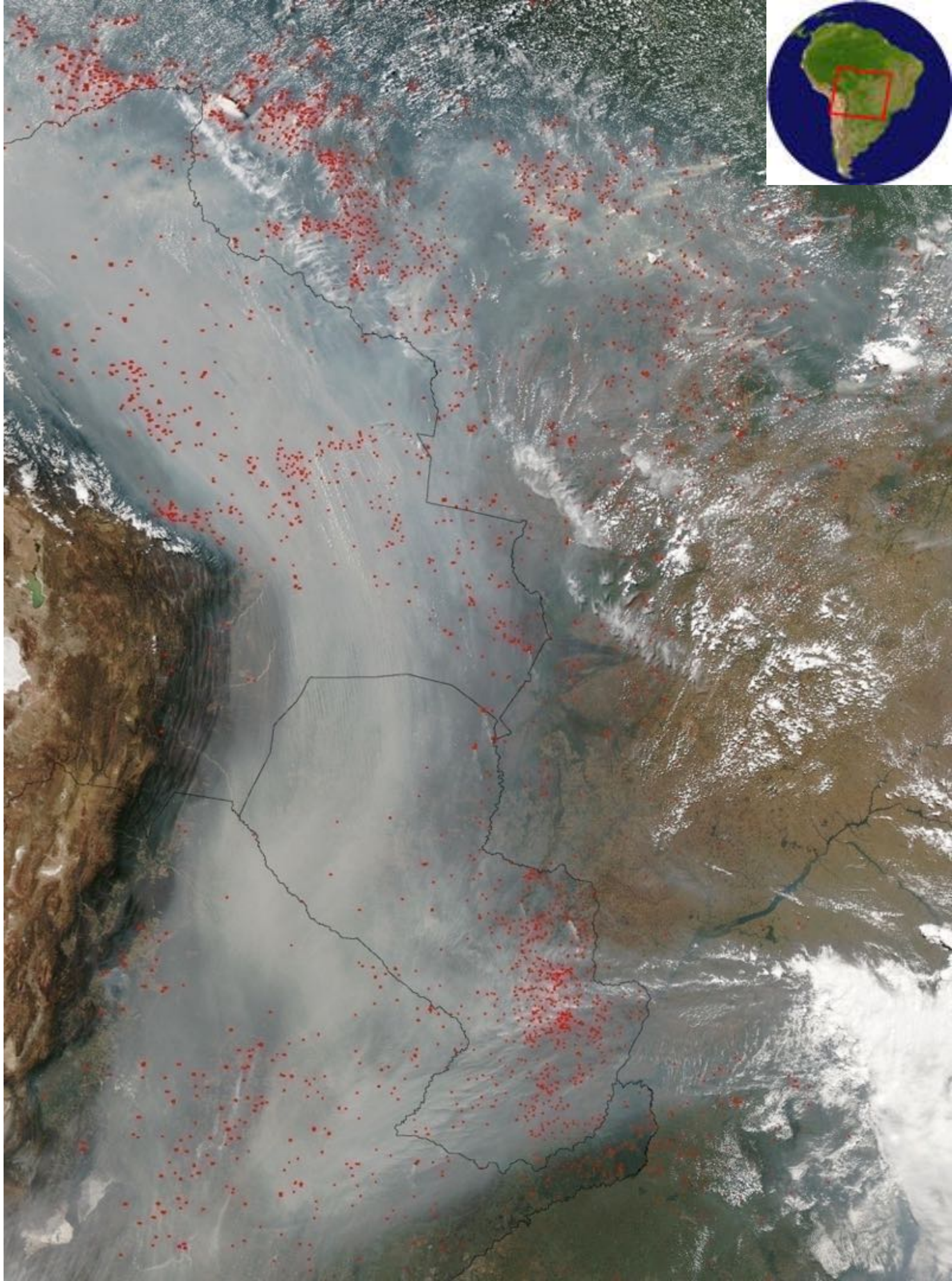


Moisture Trans. & Precip
Nov-Mar, ERA40


JAN2001, Precipitation & Moisture transport
10N
EQ
10S
20S
30S
40S
90W
80W
70W
60W
50W
40W
30W
Amazon and moisture recycling?
Deforestation and moisture flux?
Moisture flux and precipitation?

River of Smoke

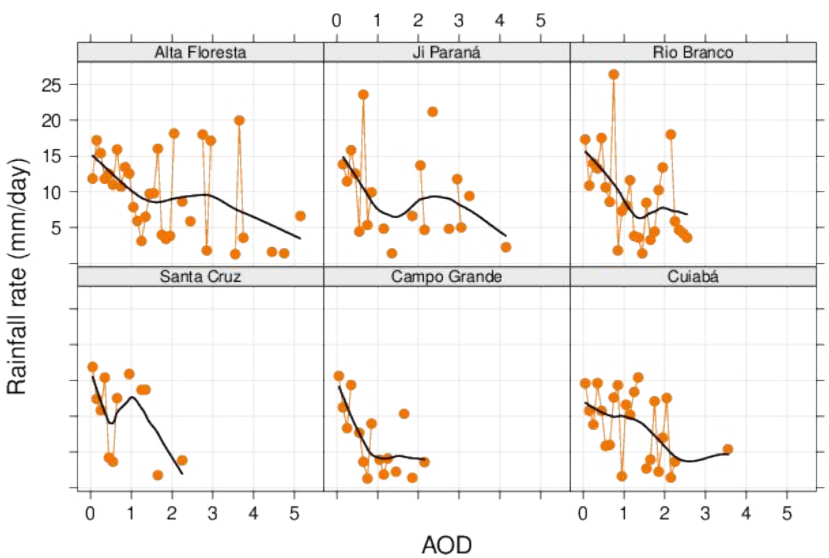




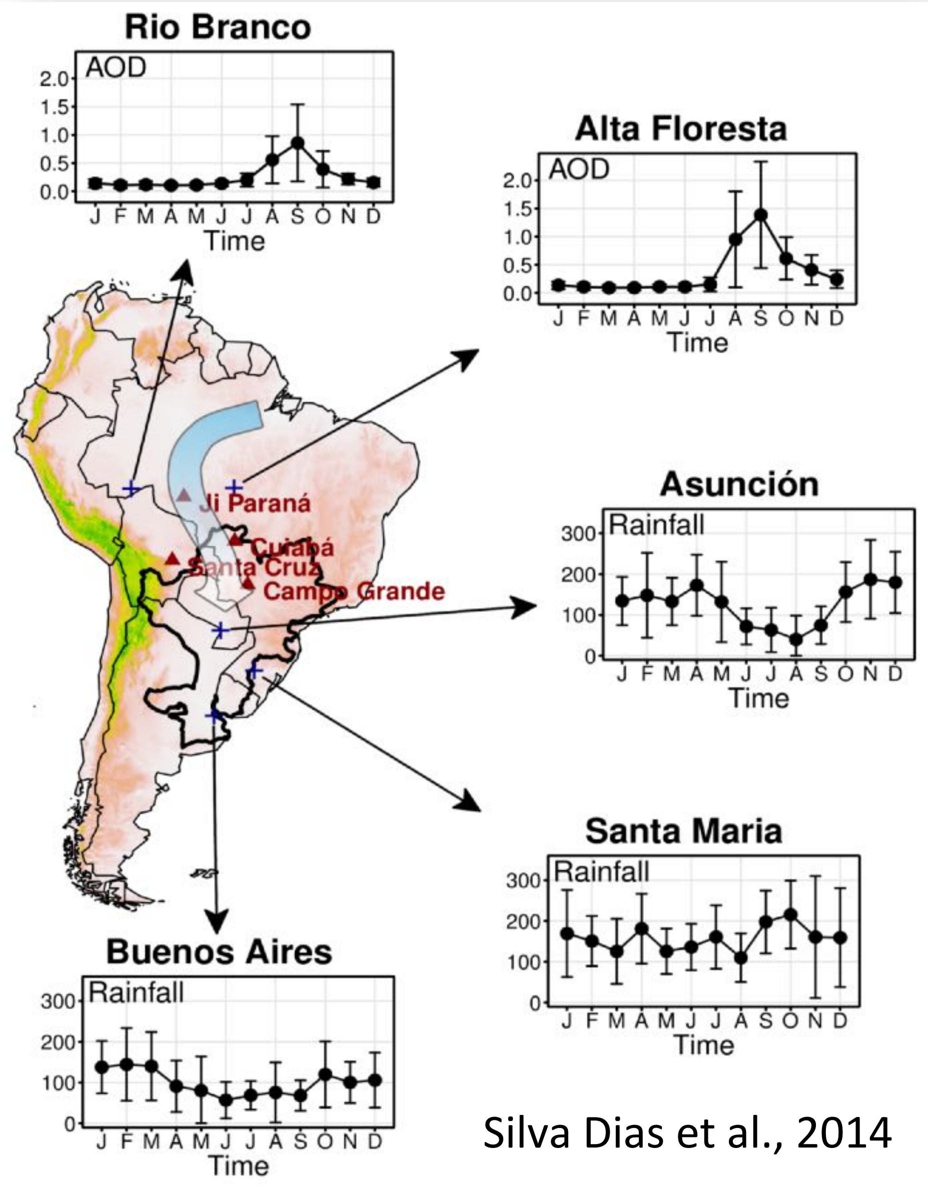
Relationship between aerosols and precipitation in the La Plata Basin

AERONET (Aerossols) + TRMM (Precipitation) + BRAMS (simulations)

Reduction in precipitation with increase in aerosols

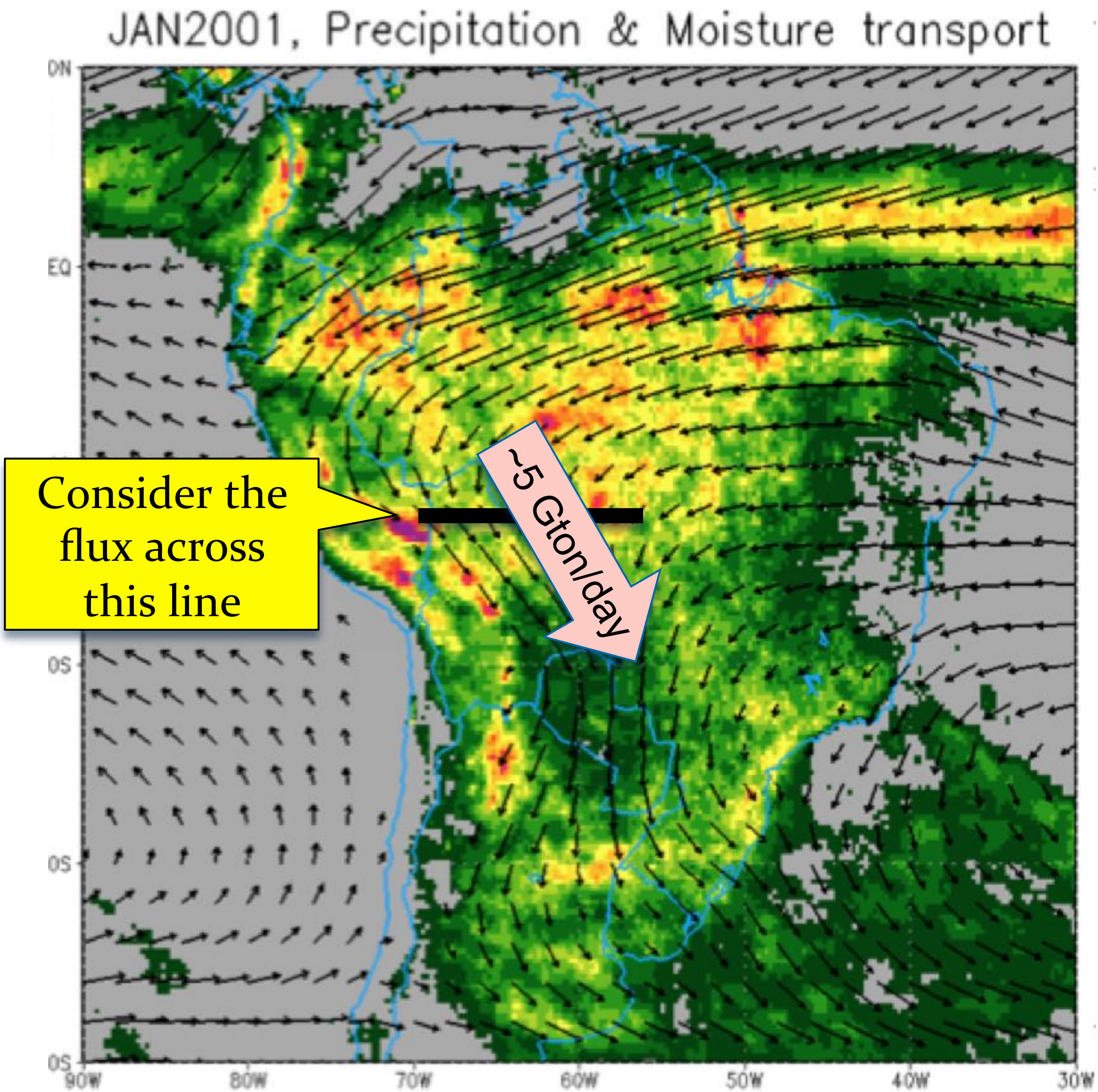


BRAMS: Simulations with cloud microphysics confirm the measurements



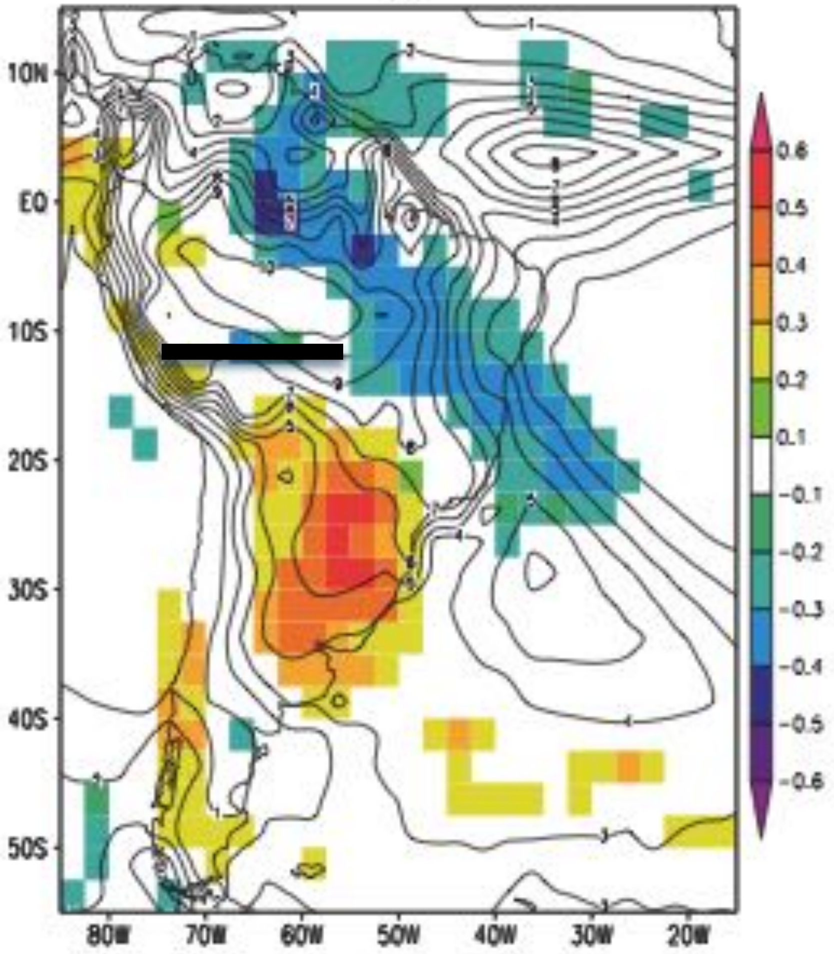
Silva Dias et al., 2014

Correlation maps

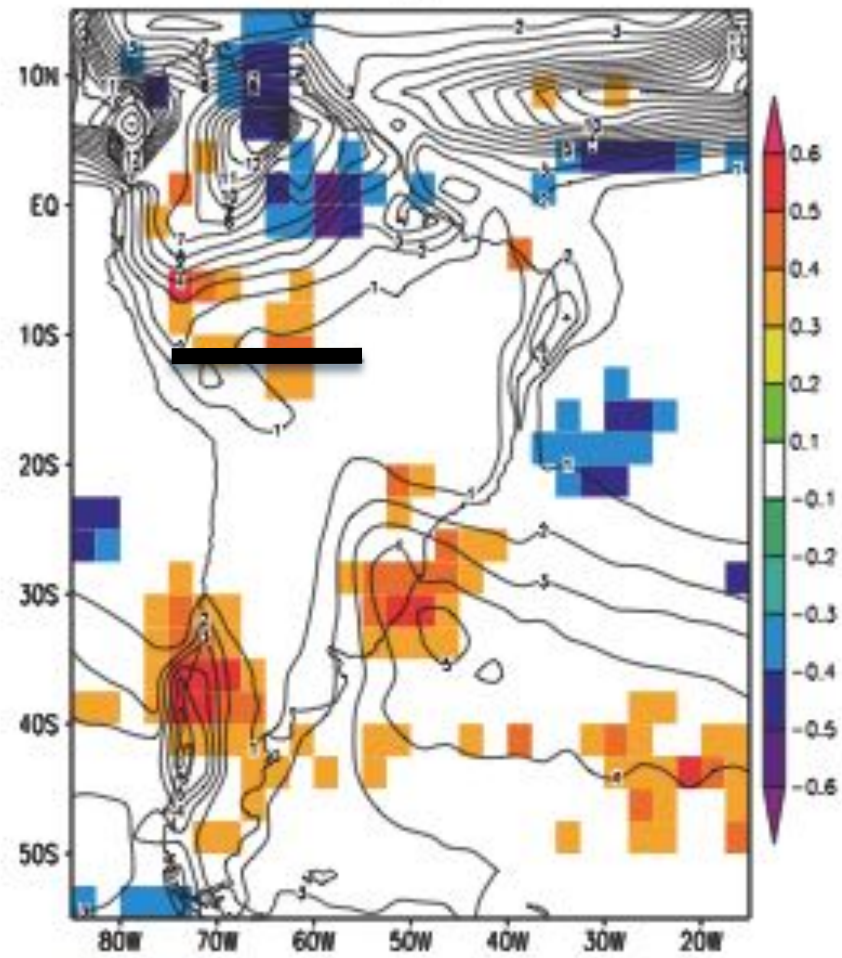


Correlation maps

Nov-Mar



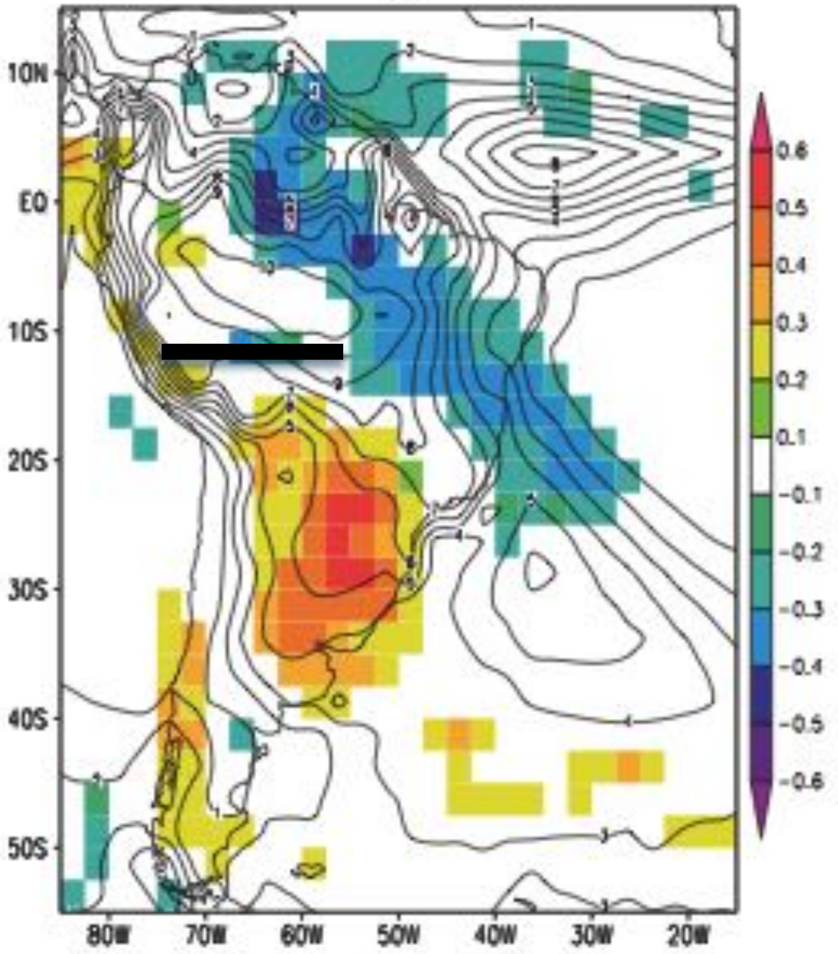
Jul-Aug



Arraut et al, J. Clim, 2012

Correlation maps

Nov-Mar



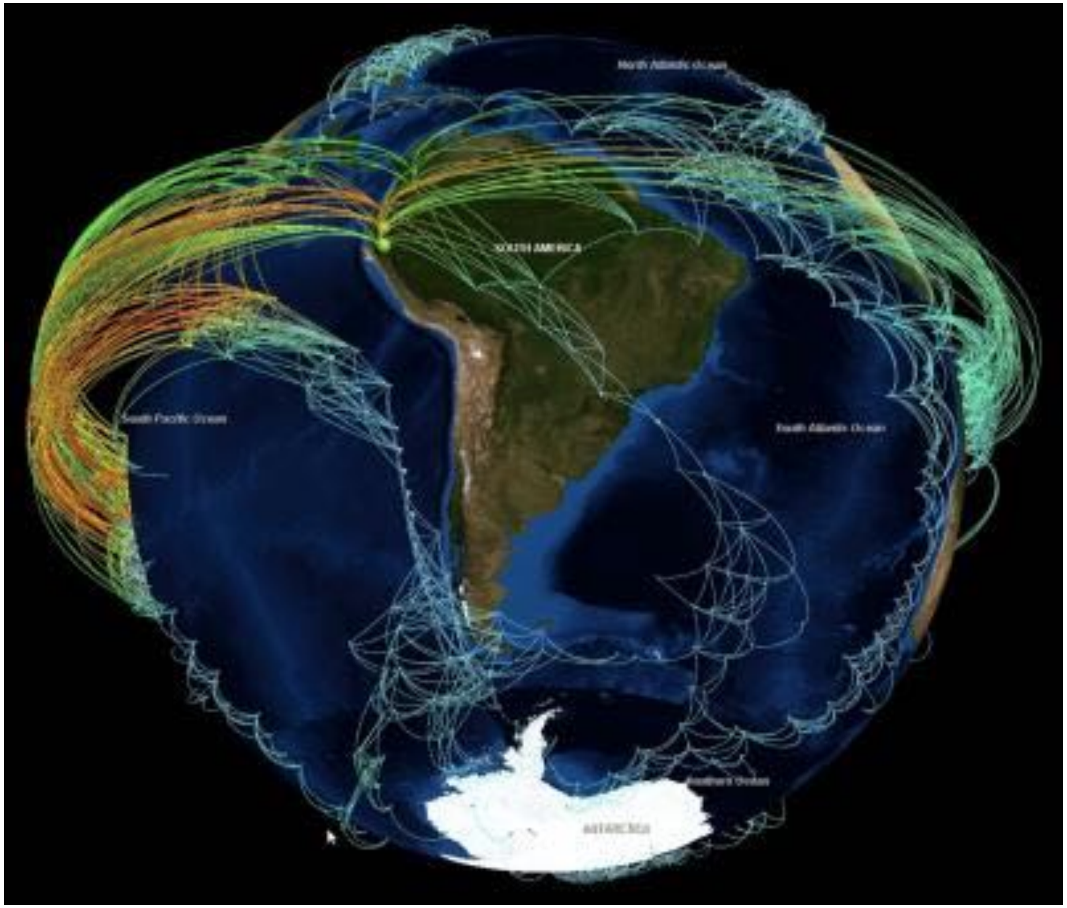
Could we do that for every point?

$$\rho_{i,j,k,l} = \frac{\mathrm{cov}^t(P_{i,j}, MT_{k,l})}{std^t(P_{i,j})std^t(MT_{k,l})}$$

What if both variables are 2D x t ?

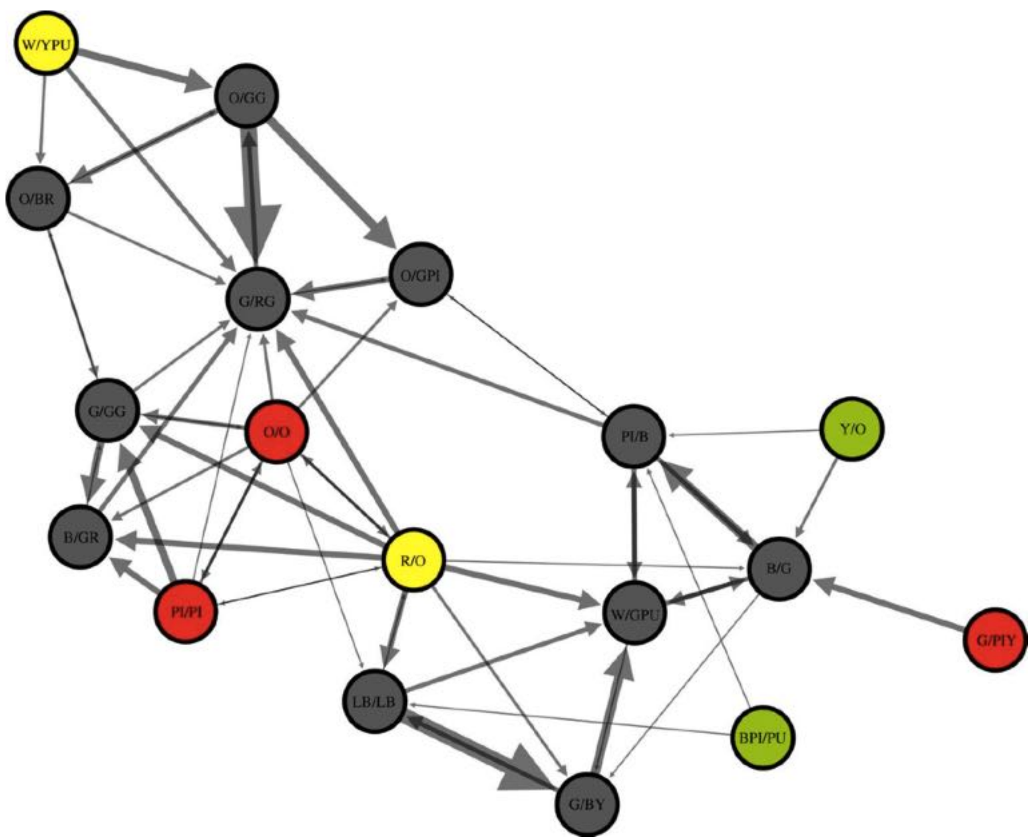
$$\rho_{i,j,k,l} = \frac{\mathrm{cov}^t(P_{i,j}, MT_{k,l})}{std^t(P_{i,j})std^t(MT_{k,l})}$$

Create links only when $\rho_{i,j,k,l}$ > threshold



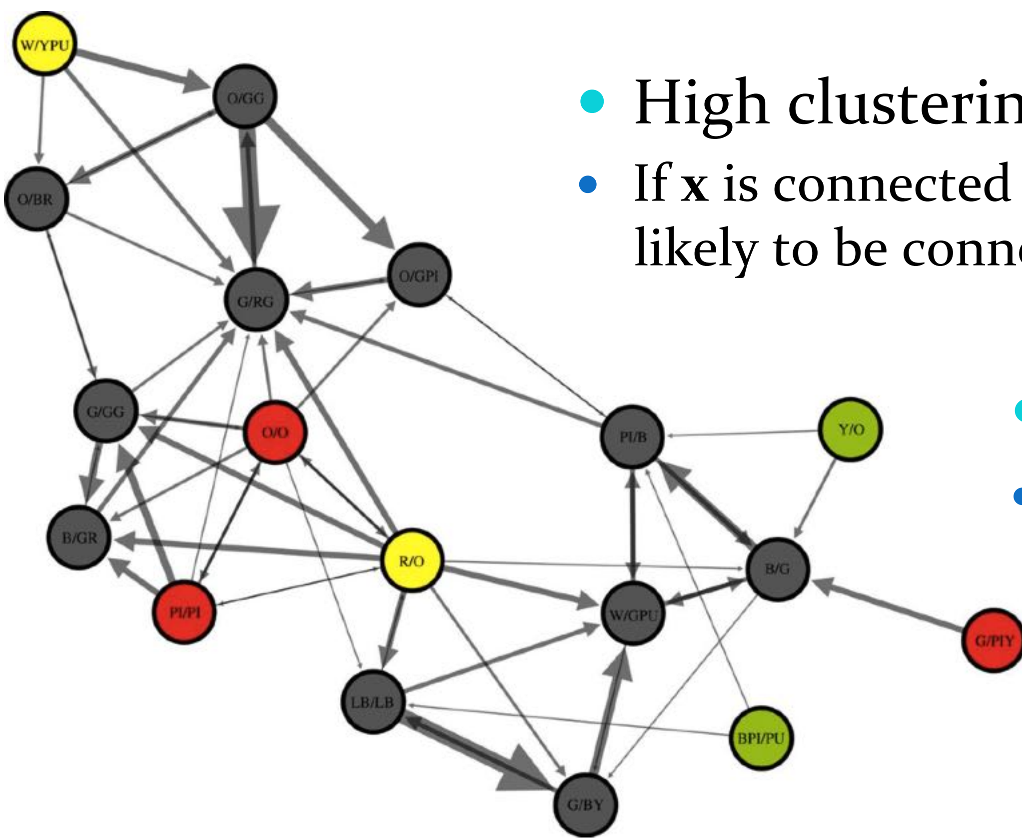
Complex Networks

- *In the context of network theory, a complex network is a graph (network) with non-trivial topological features*



Properties of Real Networks

- Scale-free networks
- Most vertices have few neighbors (degree), but some have very high degree (power-law degree distribution)



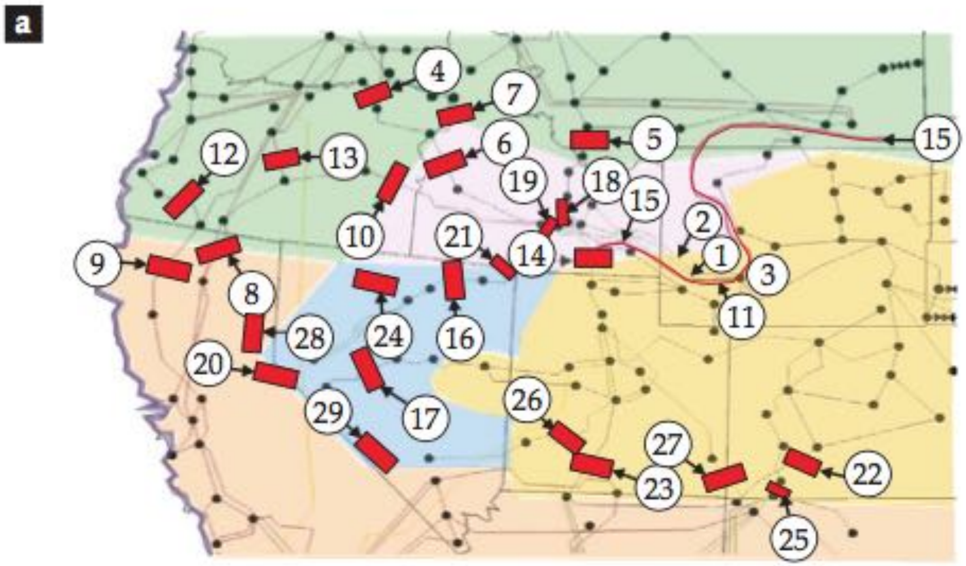
- High clustering coefficient
- If **x** is connected to **y** and **z**, then **y** and **z** are likely to be connected

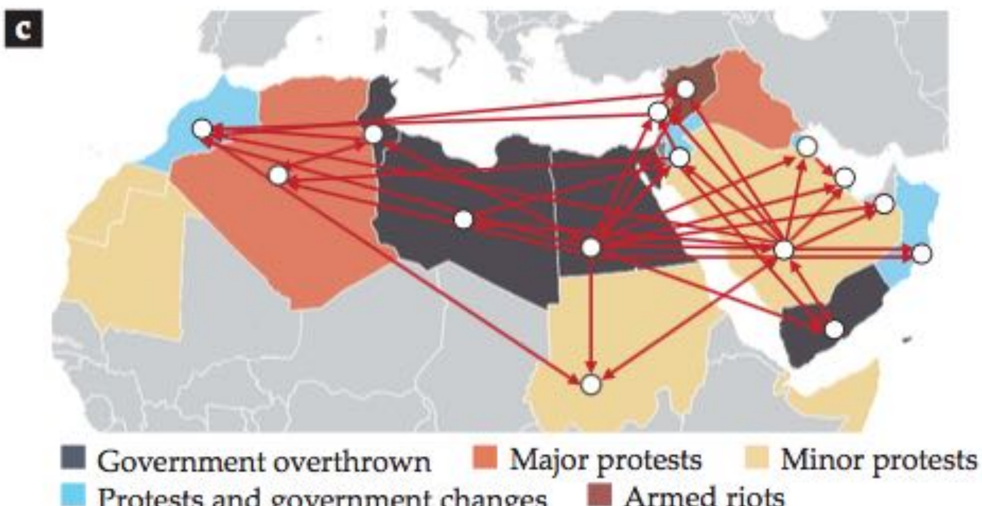
- Small world networks
- Most vertices are just a few edges away on average.

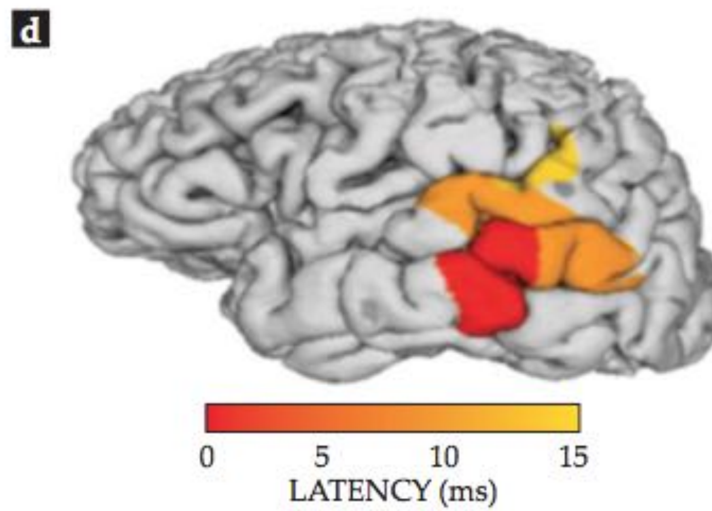
Examples:

- people that are friends on facebook
- computers that are interconnected
- web pages that point to each other
- proteins that interact
- brain cells transmitting information
- phone-call networks
- transportation networks
- transmission grids

The unfolding and control of network cascades







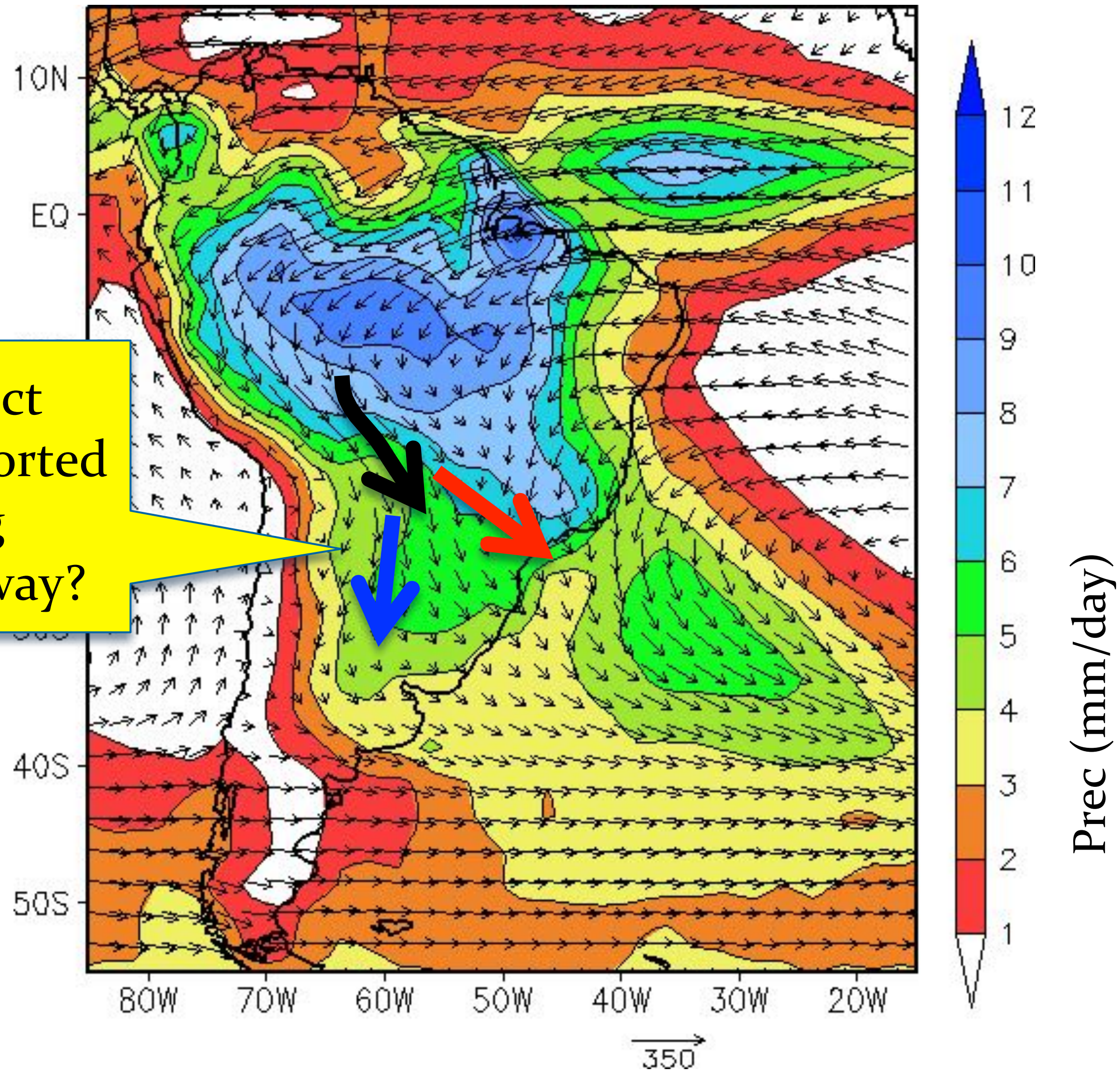
Motter and Yang, Physics Today 70, 1, 32 (2017)

Our intent today is…

Give examples of how we applied Complex Networks for understanding moisture transport over South America

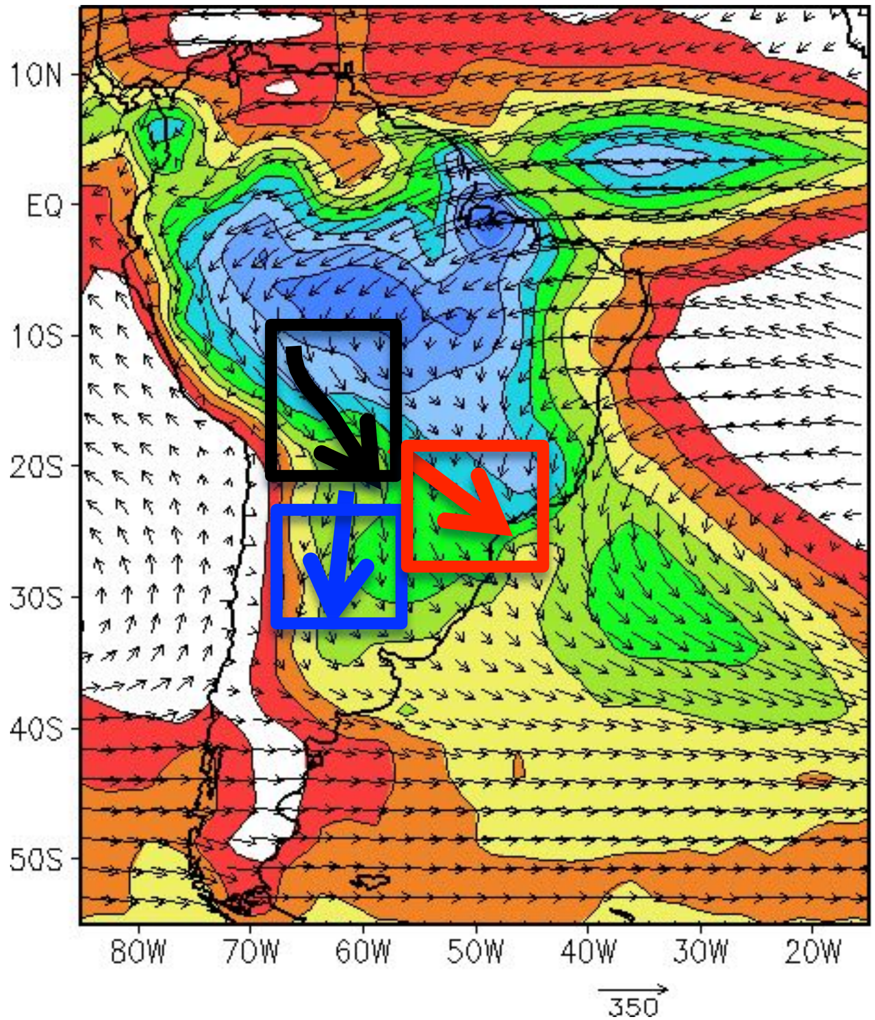
1. Propagation of extreme events
2. Cascading moisture recycling
3. Climate change & Deforestation

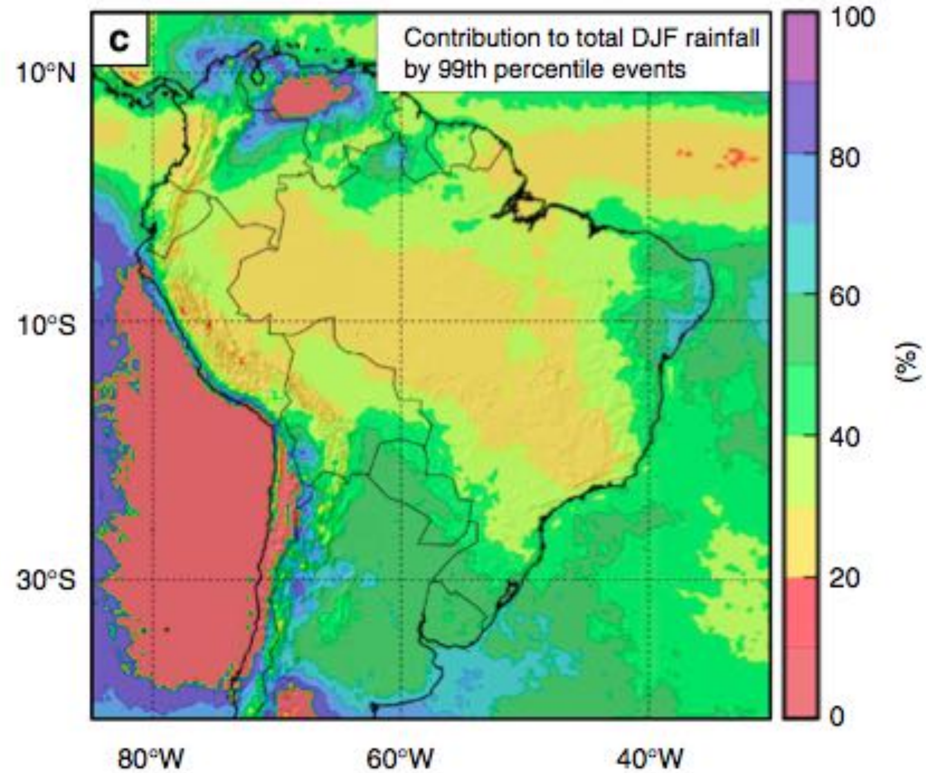
DJF Precip & Moist. Flux



Can **networks** detect moisture being transported south and causing precipitation on the way?

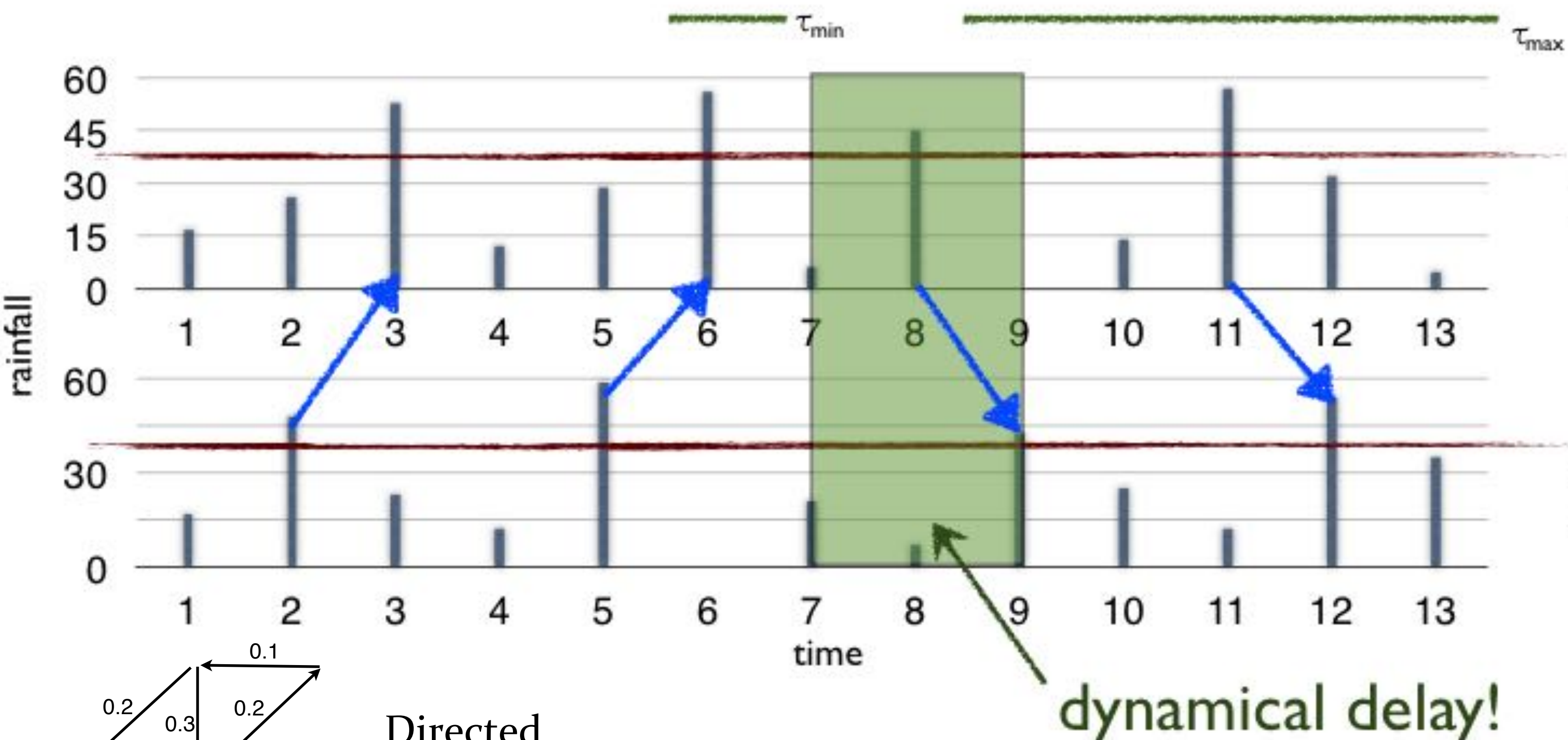
Synchronization of extreme precipitation events

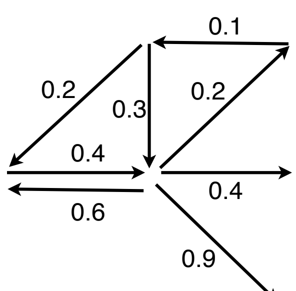




event synchronization

(extreme events: above 99th percentile of all DJF times)



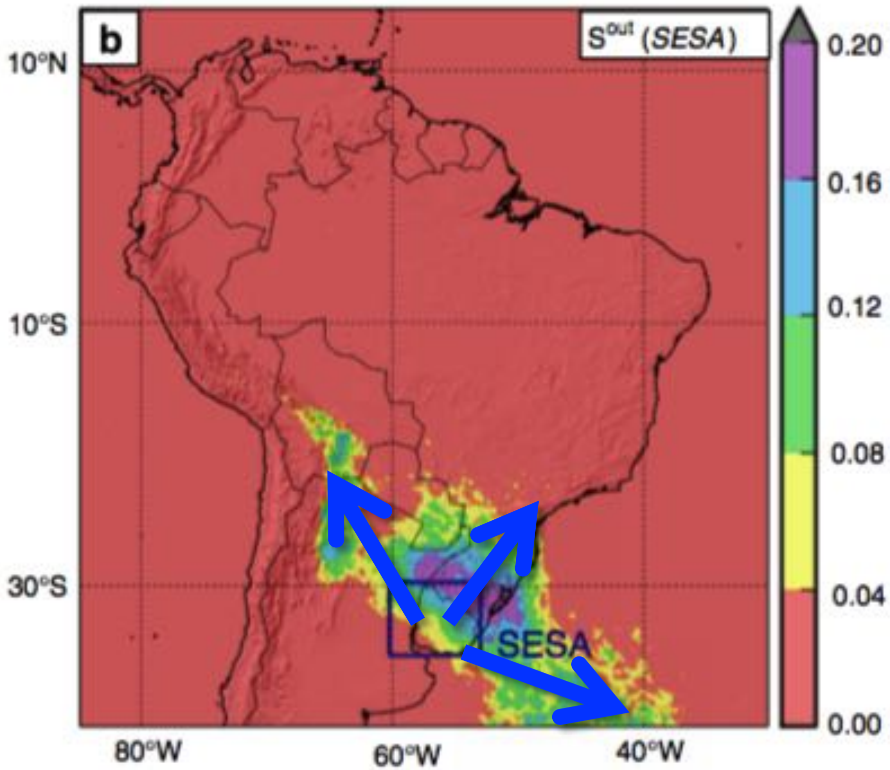


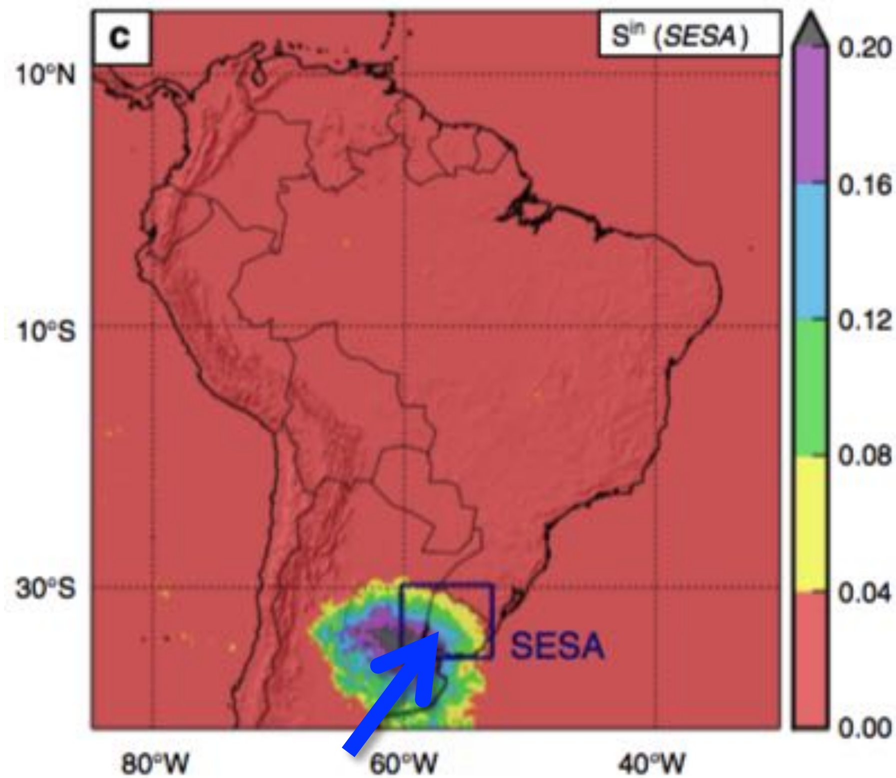
Directed weighted network

Boers et al, Nature Comm. 2014

OUT strengh

IN strengh



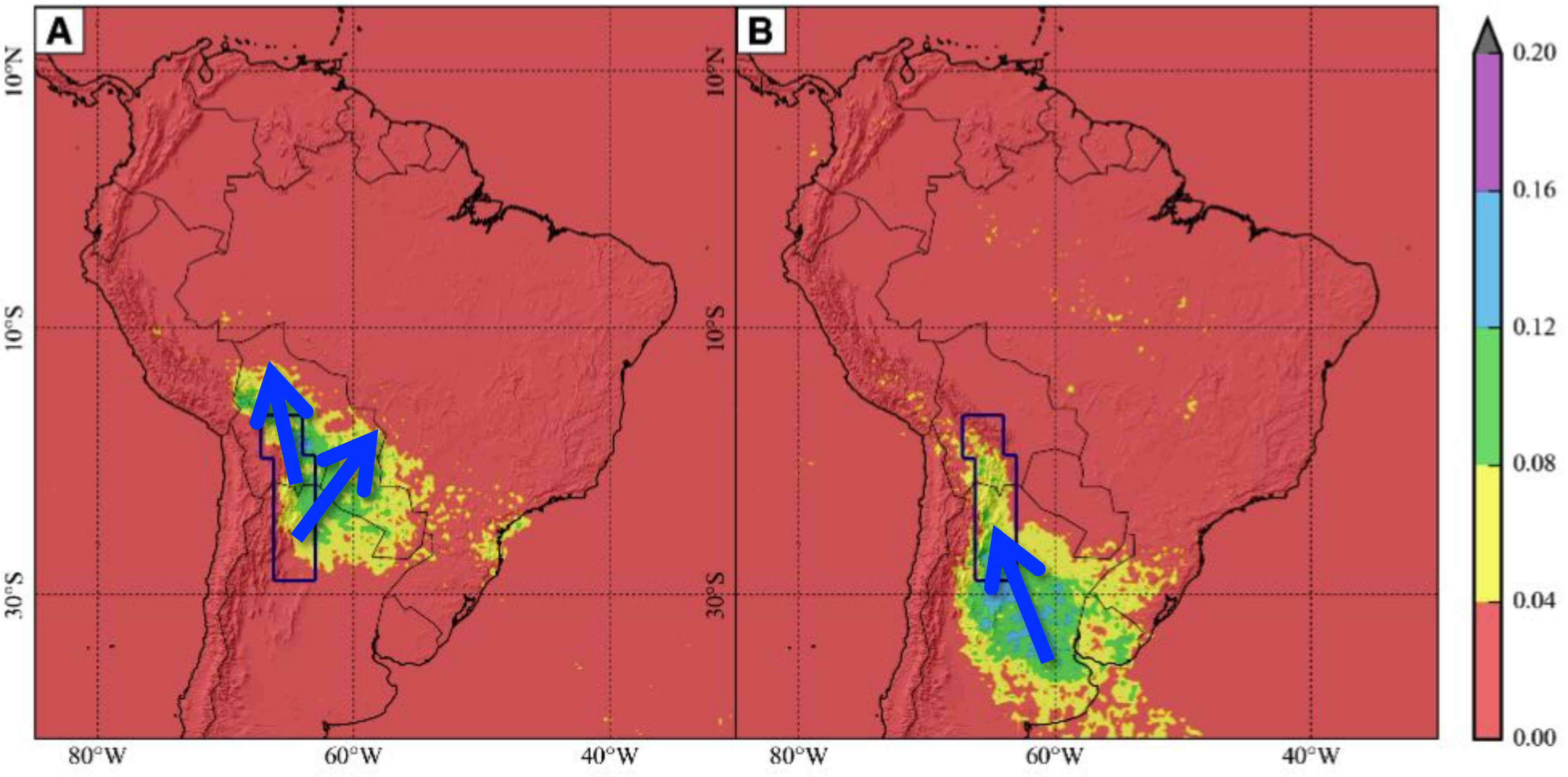


$$In(i) = \sum_{j=1}^{N} A(ij)$$

$$Out(i) = \sum_{j=1}^{N} A(ji)$$

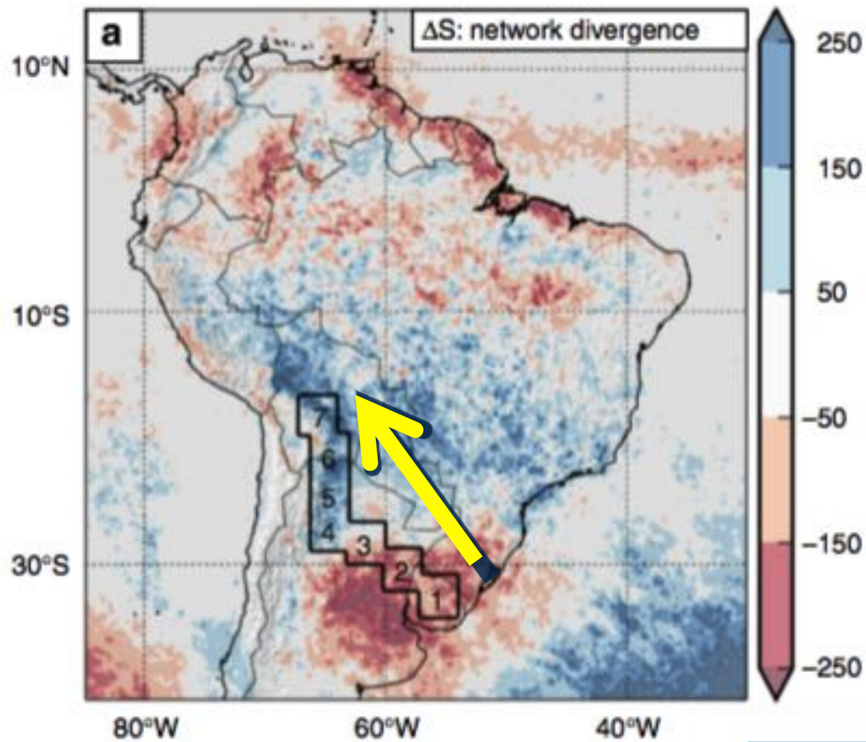
Boers et al, Nature Comm. 2014

OUT strengh IN strengh

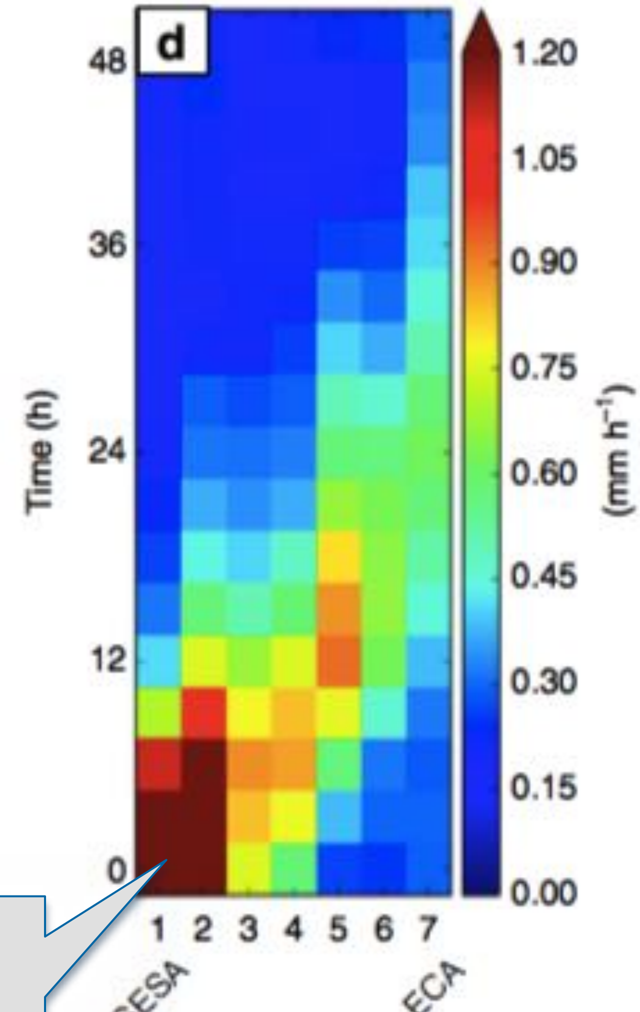


Boers et al, Nature Comm. 2014

Network Divergence

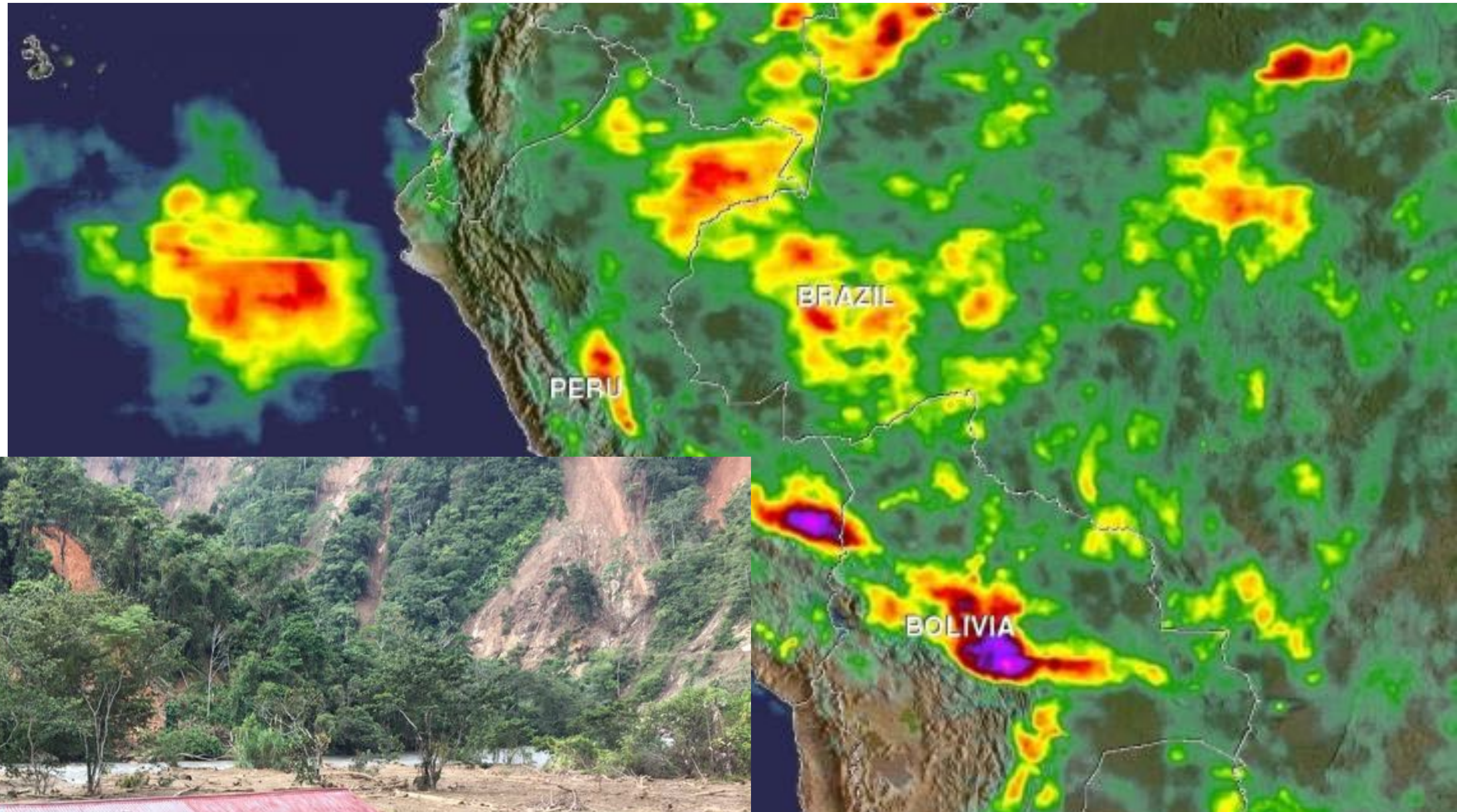


$$\Delta S(i) = In(i) - Out(i)$$



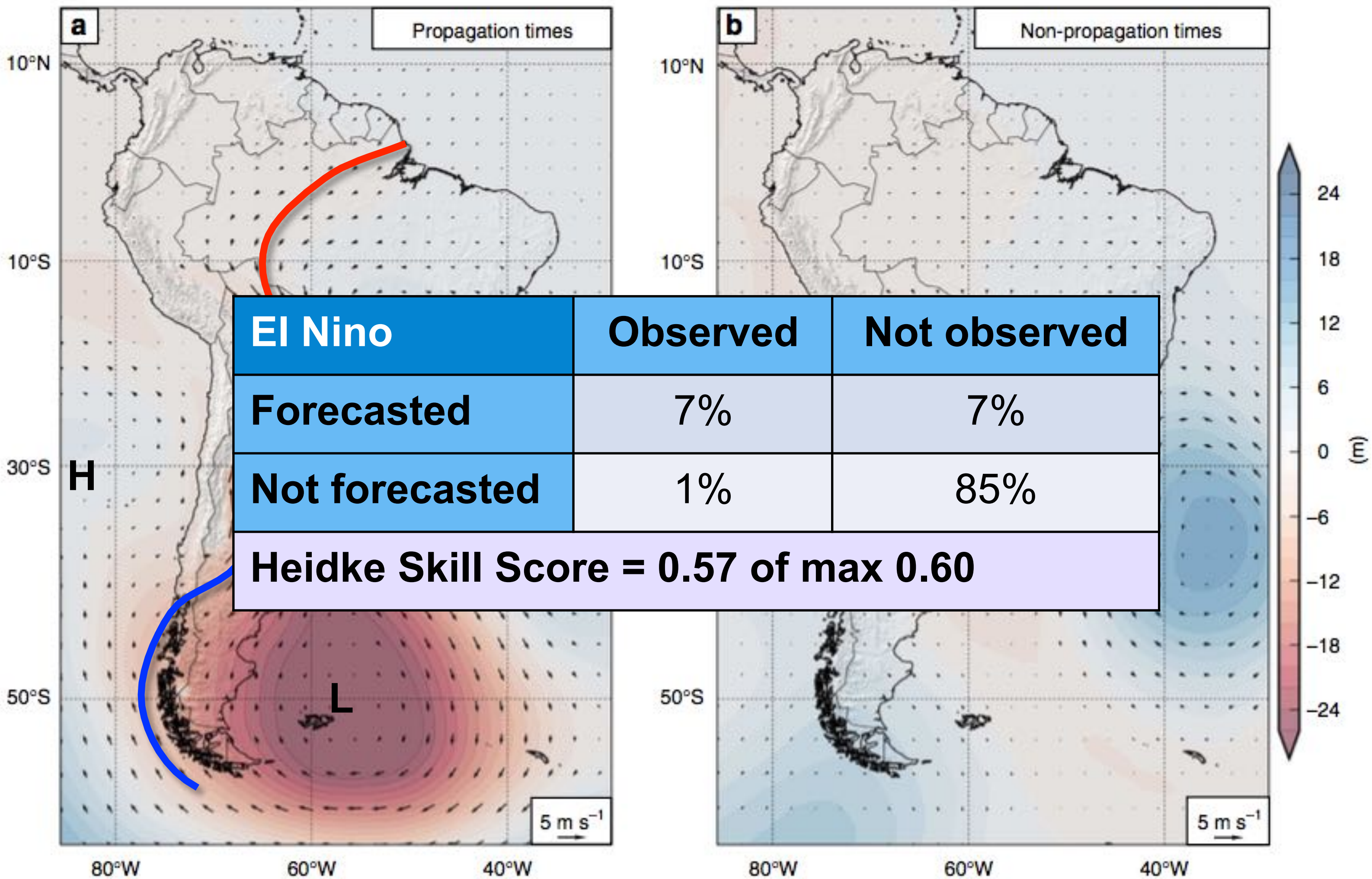
~ 80 km /h contrary to moisture flux!

Boers et al, Nature Comm. 2014



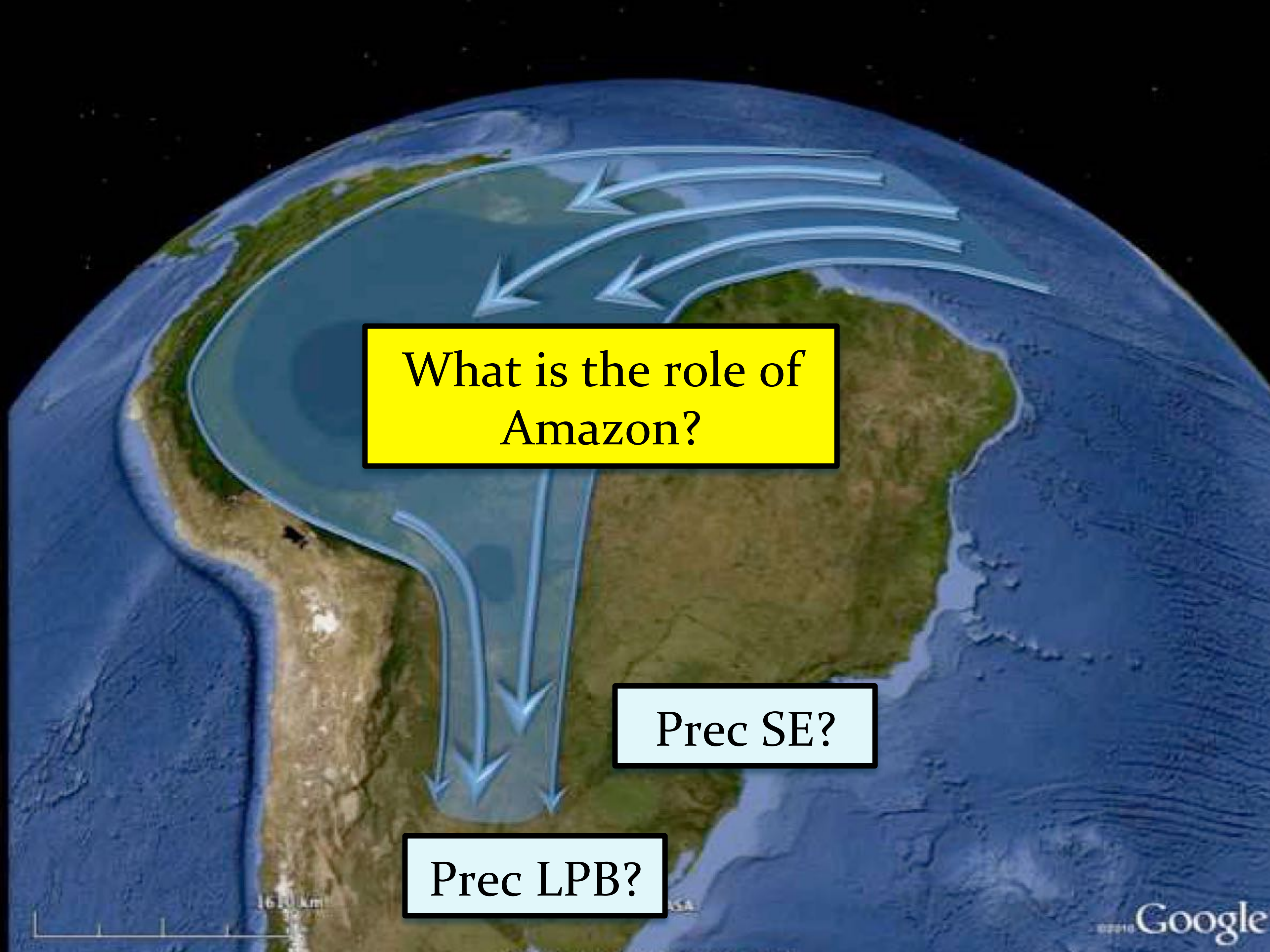
http://floodlist.com/america/nasa-satellites-measure-flooding-rain-in-peru-and-bolivia

Can we predict?

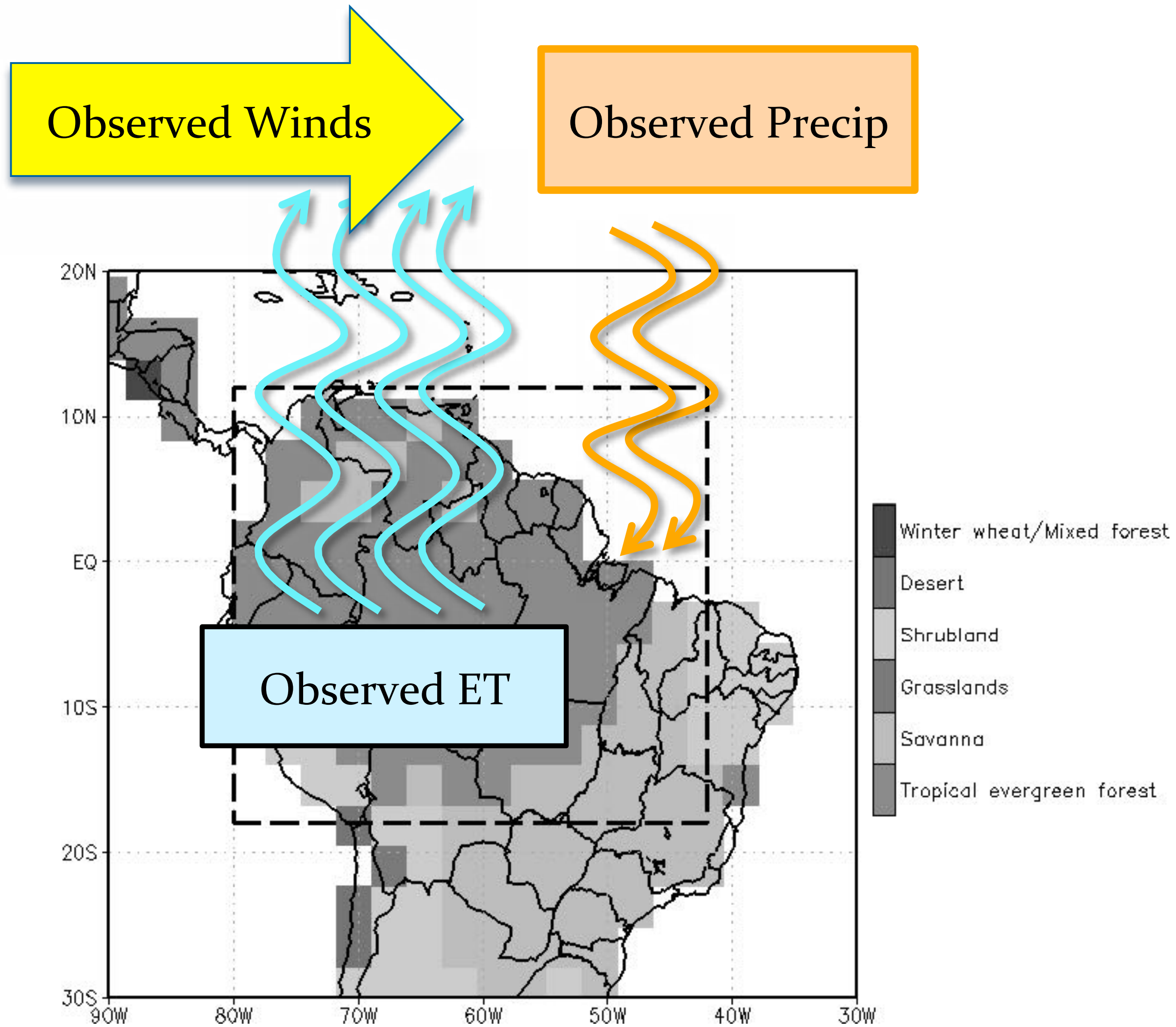


El Nino	Observed	Not observed
Forecasted	7%	7%
Not forecasted	1%	85%
Heidke Skill Score = 0.57 of max 0.60		

Boers et al, Nature Comm. 2014


What is the role of Amazon?
Prec SE?
Prec LPB?
Google

2-Layer Moisture Transport Model

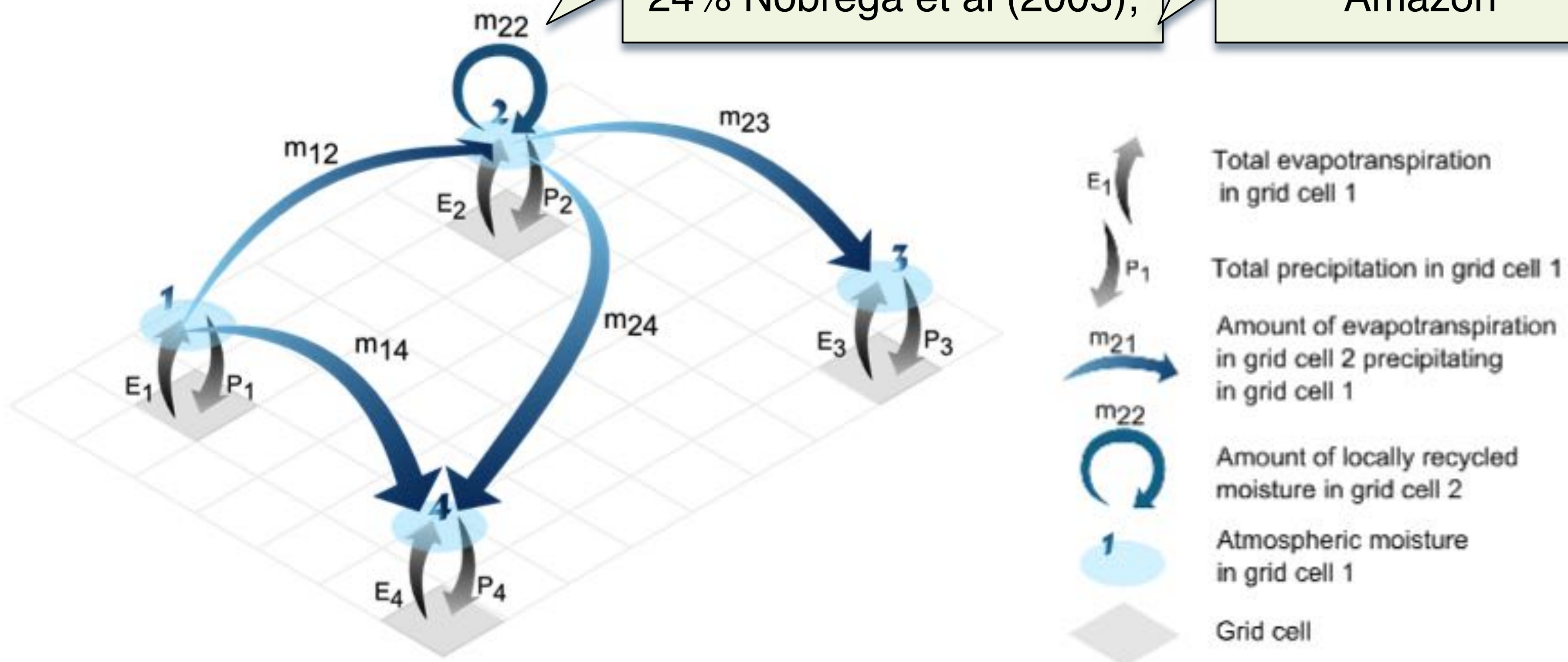


Moisture (complex) network

56% Molion (1975);
Recent (20-35%):
23% Brubaker (1993);
30% Eltahir & Bras (1994);
34% Trenberth (1999);
24% Nobrega et al (2005);

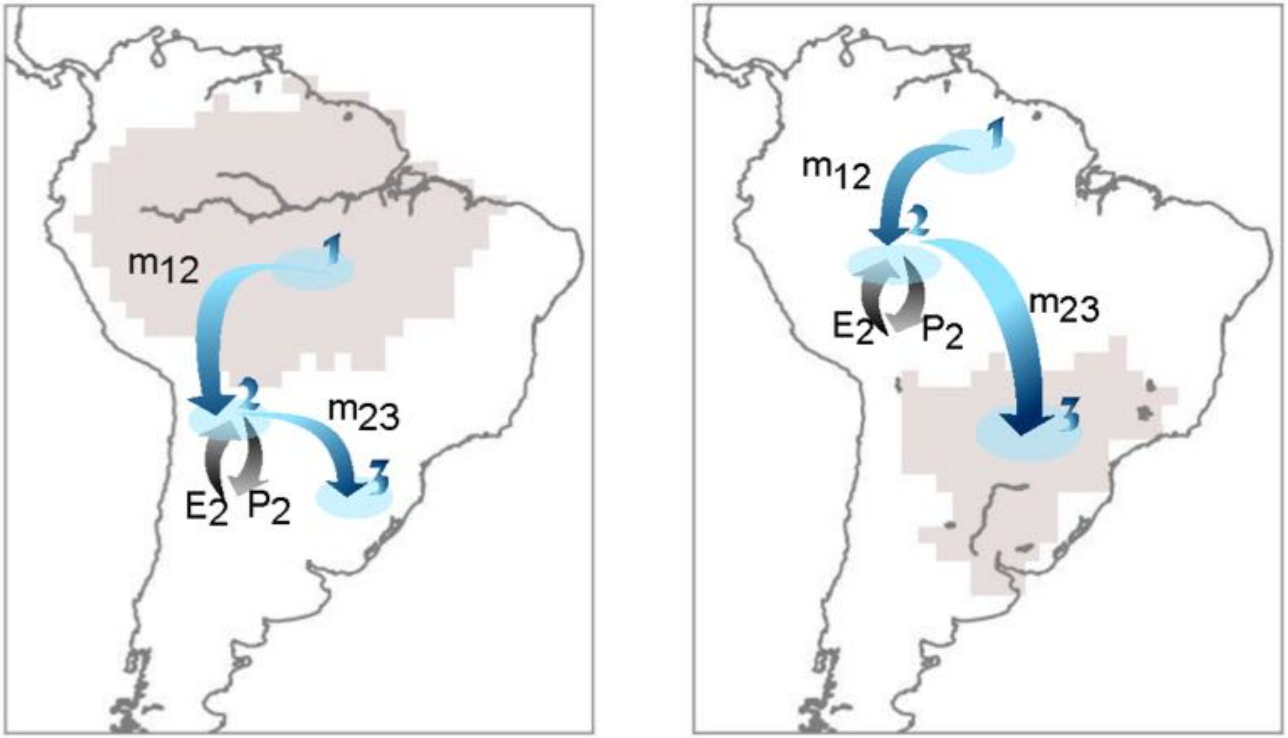
Van der Ent (2010)

Scale effect:
4% for one grid-box
28% for entire Amazon



Zemp et al, Atmos. Chem. Phys. 2014

Cascading



Different paths for water, and possible cascading before getting to "final" destination!

Zemp et al, ACP 2014

Cascading

- For 45% of the **walks**, the direct transport the most important
- For 55%, a **walk** with at least one stop is more efficient!

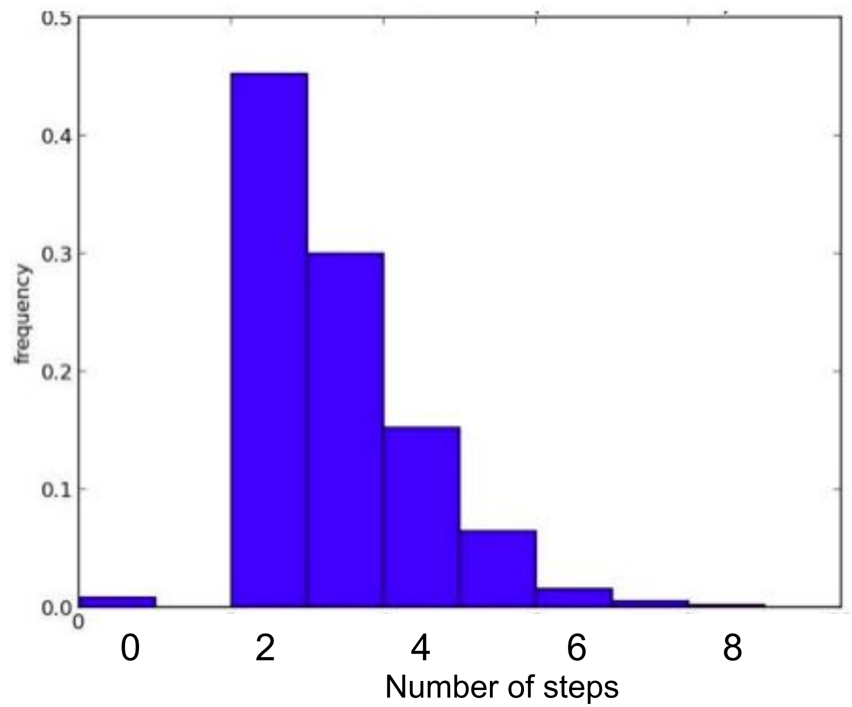
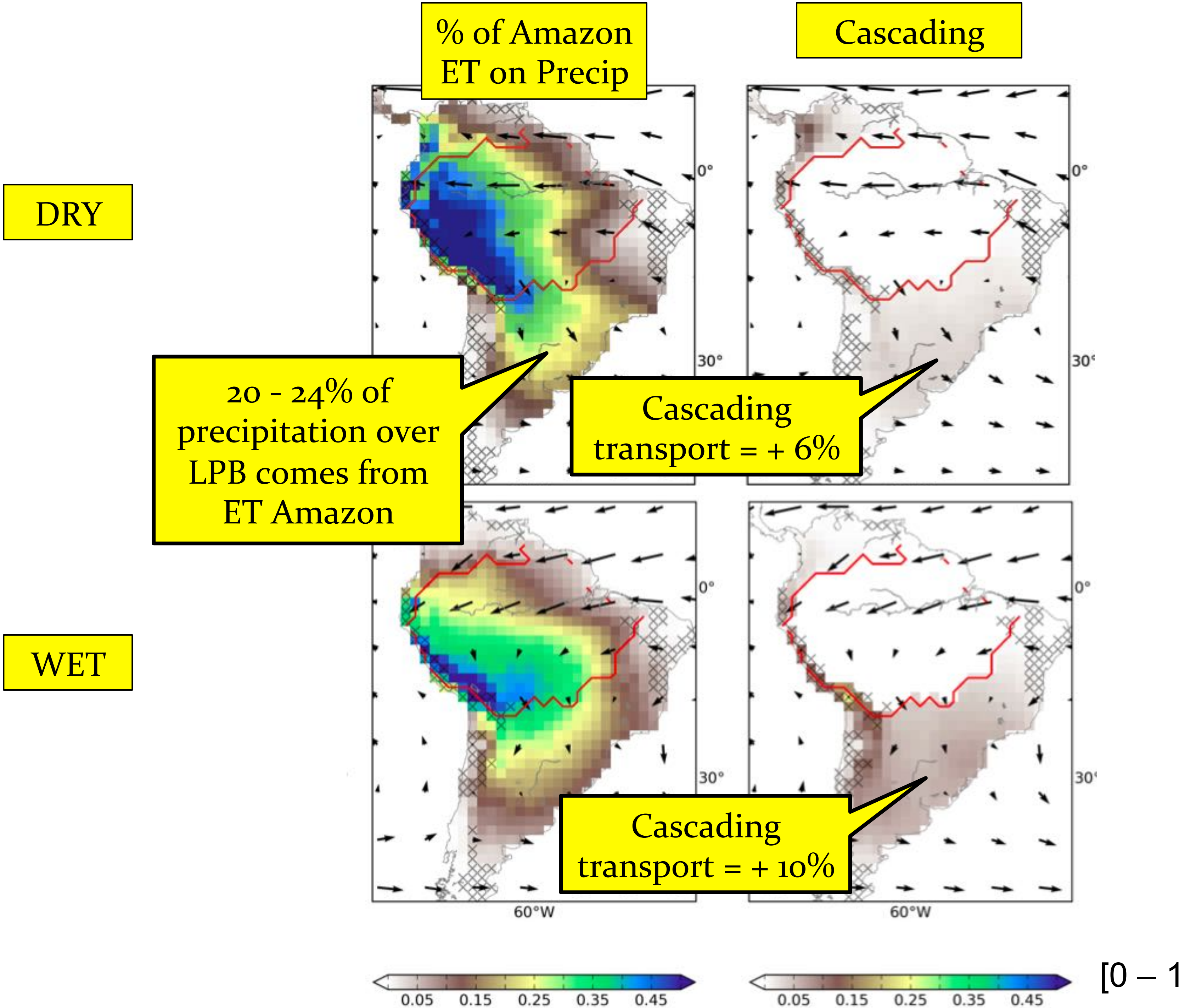
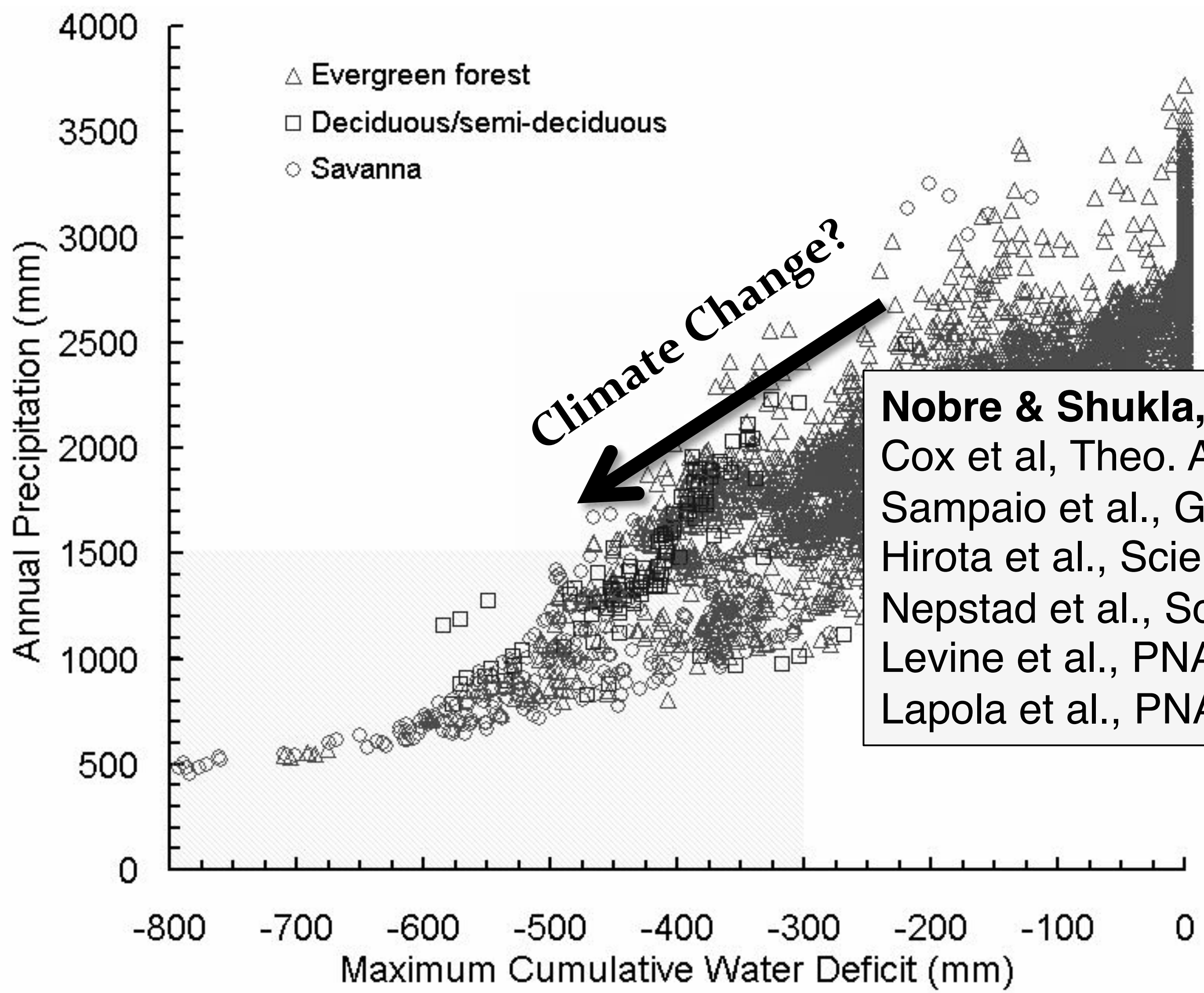


Fig. - Distribution of optimal paths
For 0 steps, local recycling
For 2 steps, direct transport
For 3 or more steps, path with cascading

Zemp et al, ACP 2014


% of Amazon ET on Precip
Cascading
DRY
WET
20 - 24% of precipitation over LPB comes from ET Amazon
Cascading transport = + 6%
Cascading transport = + 10%
0°
30°
60°W
0.05
0.15
0.25
0.35
0.45
[0 – 1]

Effects of water defining the transition forest-Savanna



Nobre & Shukla, J Climate 1991
Cox et al, Theo. App. Clim. 2004
Sampaio et al., Geo. Res. Let. 2007
Hirota et al., Science 2011
Nepstad et al., Science 2014
Levine et al., PNAS 2016
Lapola et al., PNAS 2018

Malhi *et al.*, PNAS 2010

Probability of finding forest

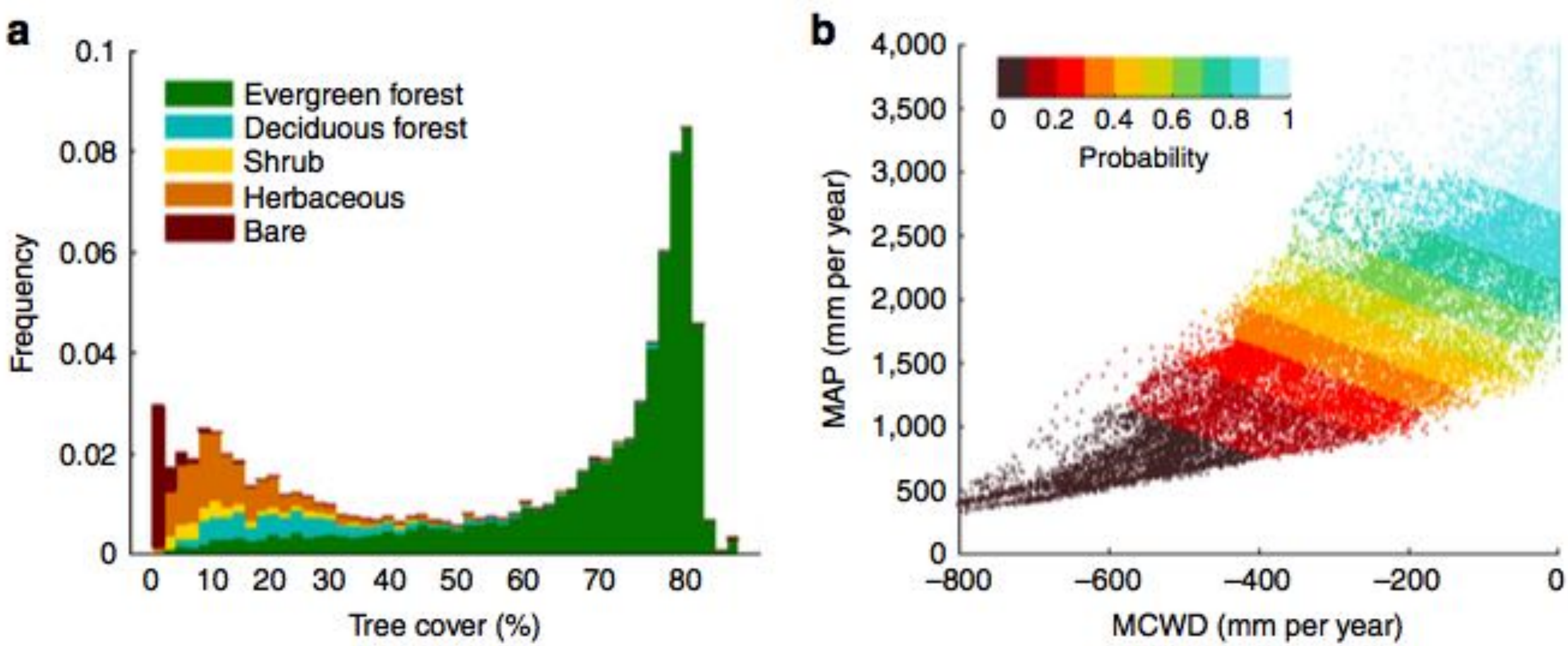
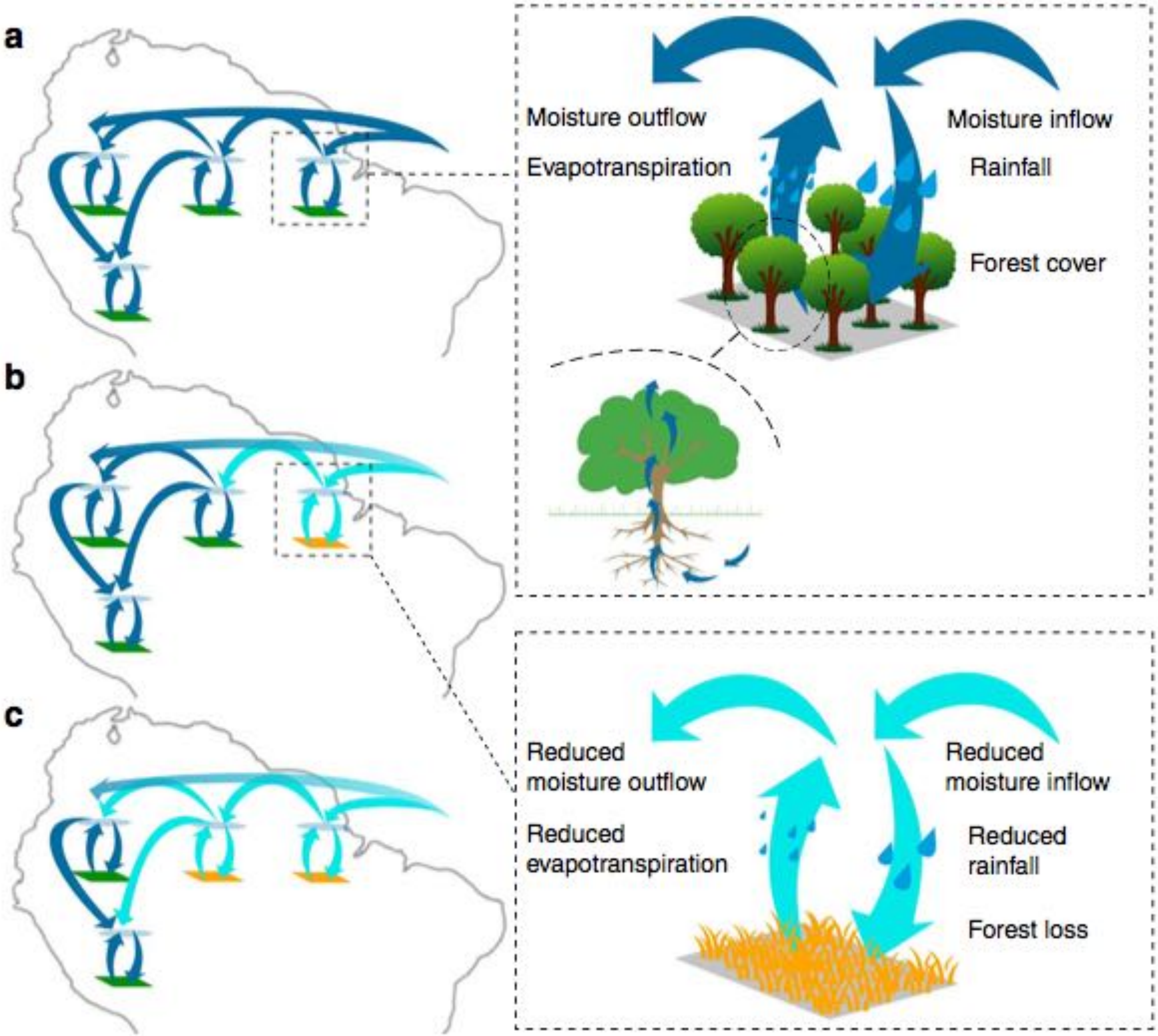
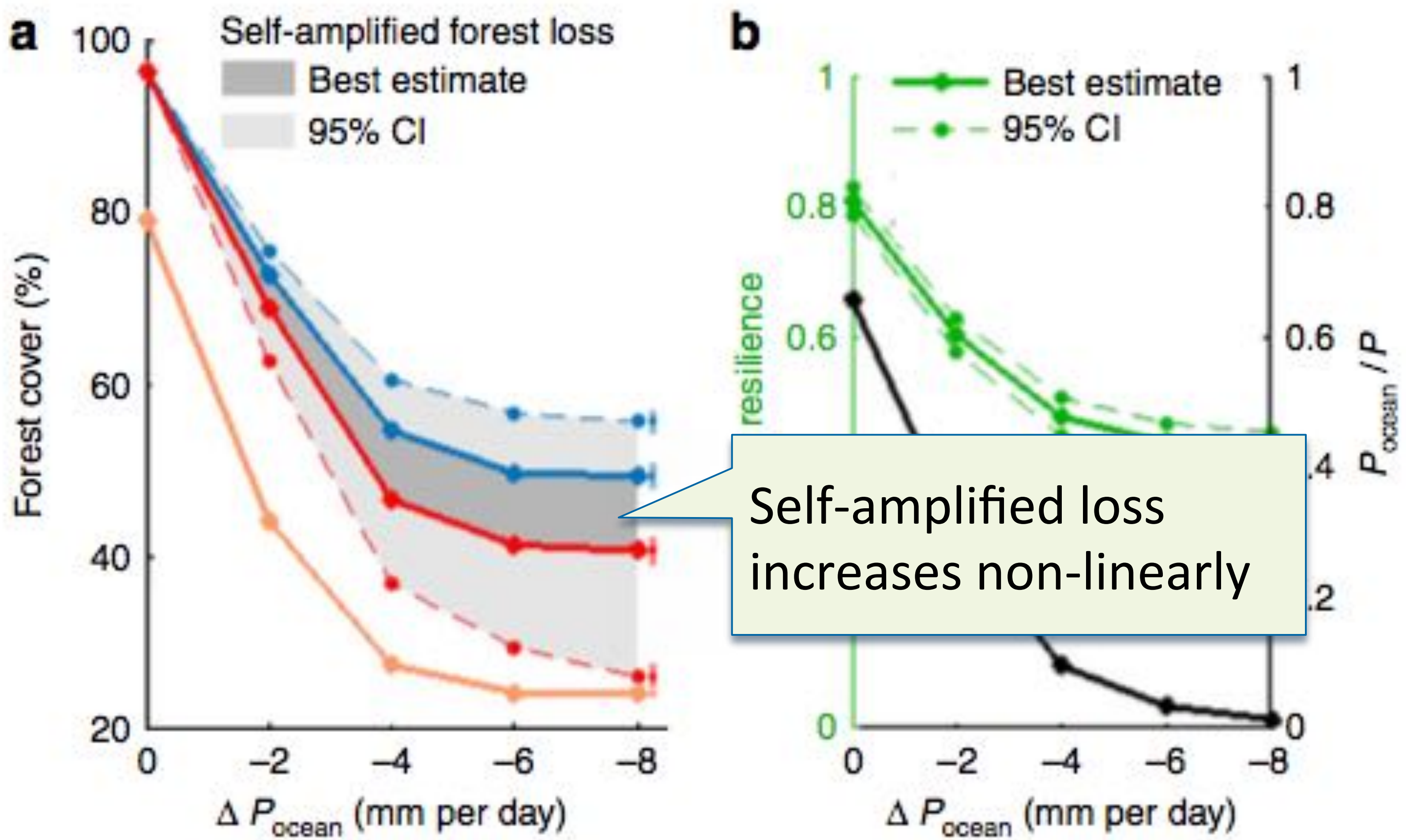


Figure 2 | Probability of finding forest in tropical South America depending on rainfall regime. (**a**) Frequency distribution of tree-cover (TC) data (MOD44B v5 for the period 2001–2010) and associated land-cover types (from GLC2000 classification). (**b**) Probability of finding forest (TC ≥ 55%) as a function of mean annual precipitation (MAP) and maximum cumulative water deficit (MCWD) calculated from a logistic regression model (equation (4 and 5)) using monthly rainfall data (TRMM 3B42 for the period 2000–2012).



a
b
c
Moisture outflow
Moisture inflow
Evapotranspiration
Rainfall
Forest cover
Reduced moisture outflow
Reduced moisture inflow
Reduced evapotranspiration
Reduced rainfall
Forest loss

Non-linear response



One-way coupling P➔Veg
Fully coupled system P⟷Veg

Zemp et al., Nature Comm. (2017)

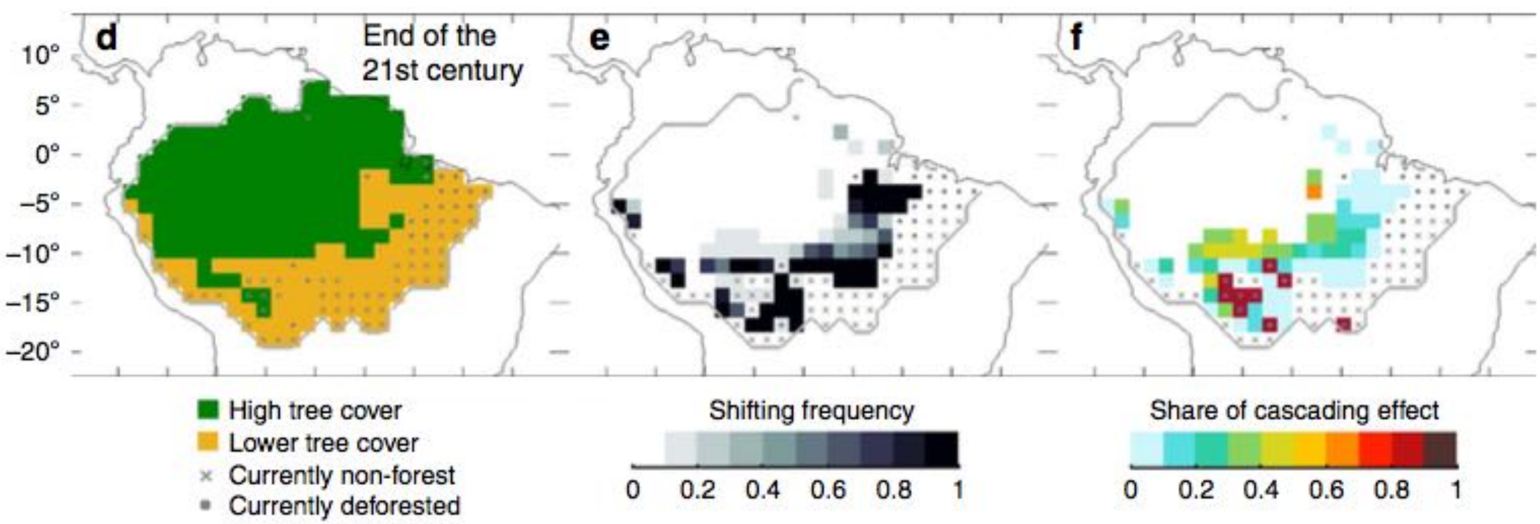
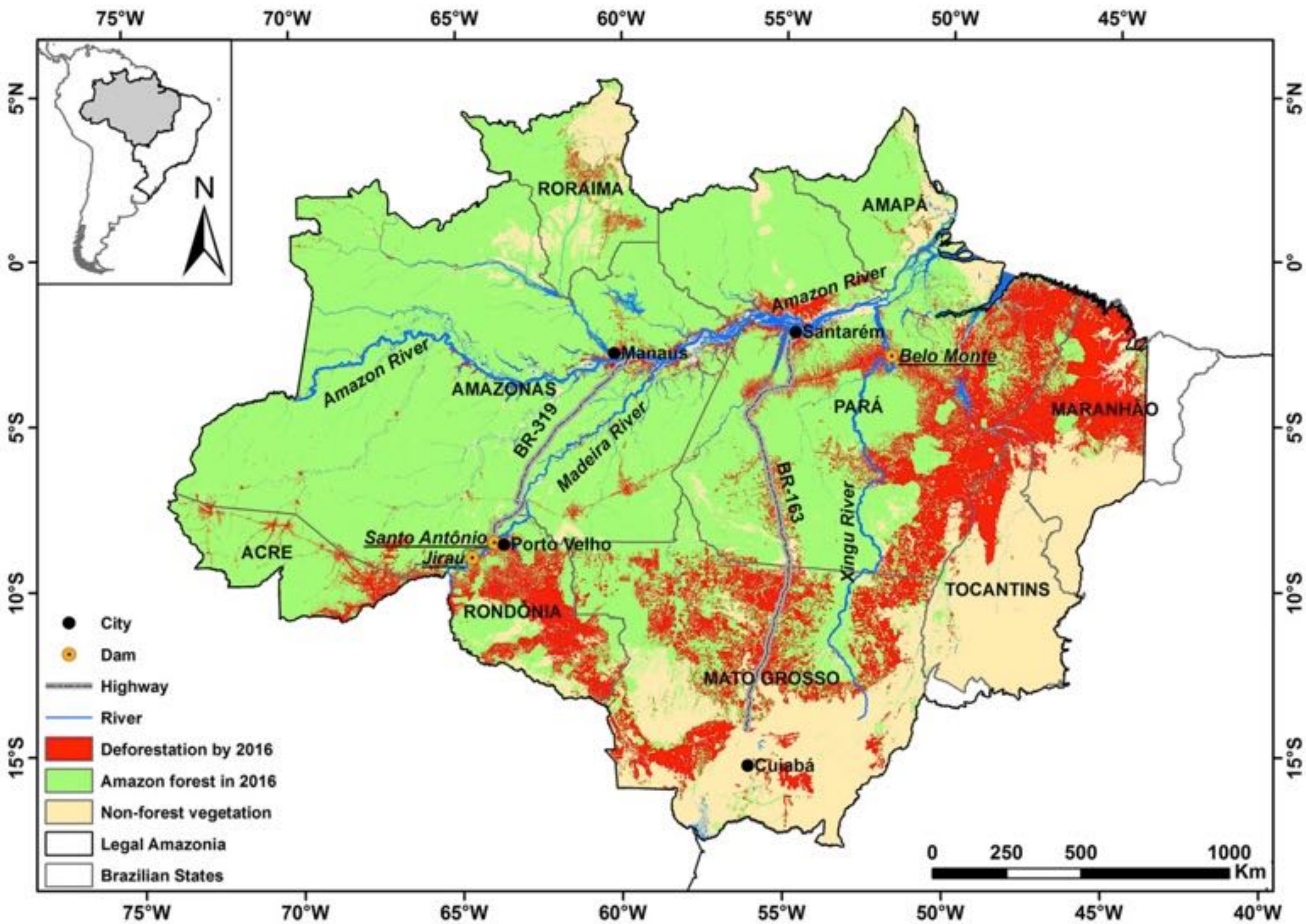


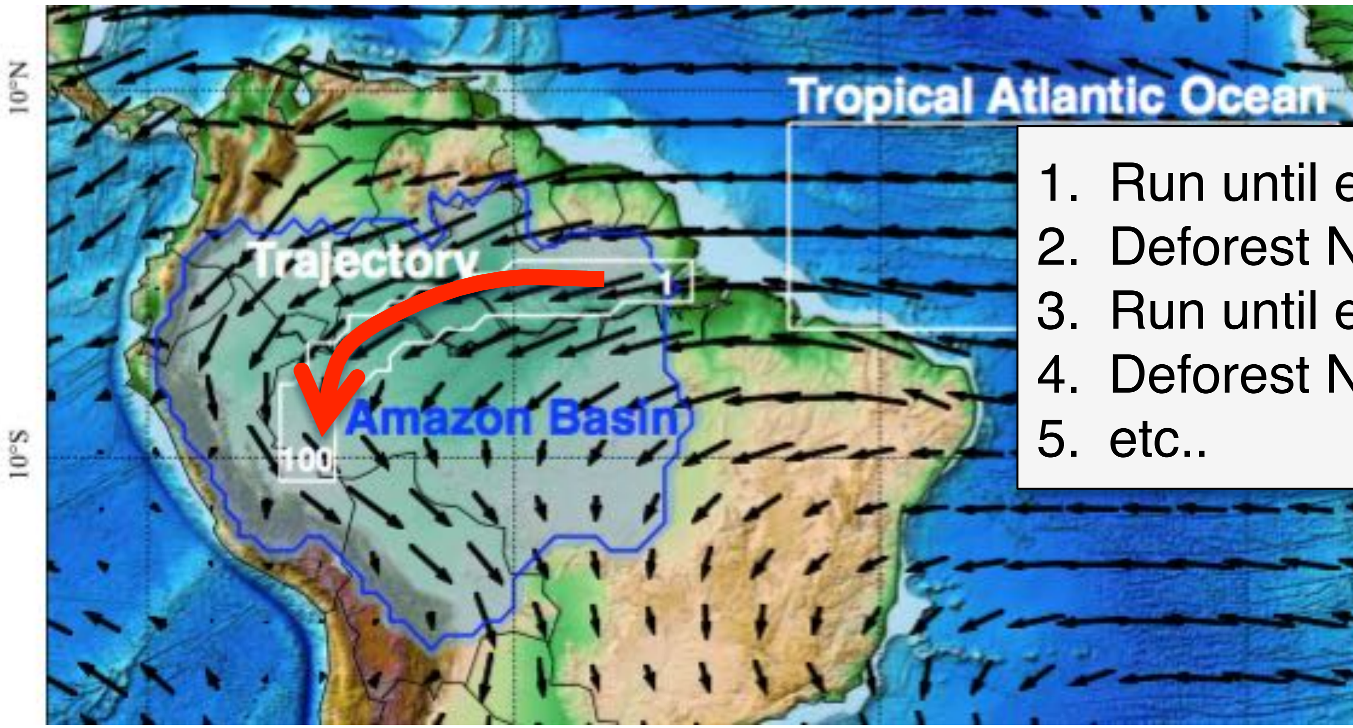
Figure 5 | Self-amplified forest loss for the Last Glacial Maximum (LGM) and for the end of the twenty-first century. (**a**,**d**) Most frequent vegetation cover for 1,000 realizations of the cascade model. (**b**,**e**) Shifting frequency of Amazon forest. (**c**,**f**) Share of cascading effects in causing forest shifts (see Methods). Results are shown (**a**–**c**) for the 'LGM' scenario and (**d**–**f**) for the 'end of twenty-first century' scenario (see Methods).

Zemp et al., Nature Comm. (2017)

Deforestation ↑ => ↓ evapotranspiration
↓ moisture transport
↓ precipitation
Forest => Cerrado



1d dynamical system



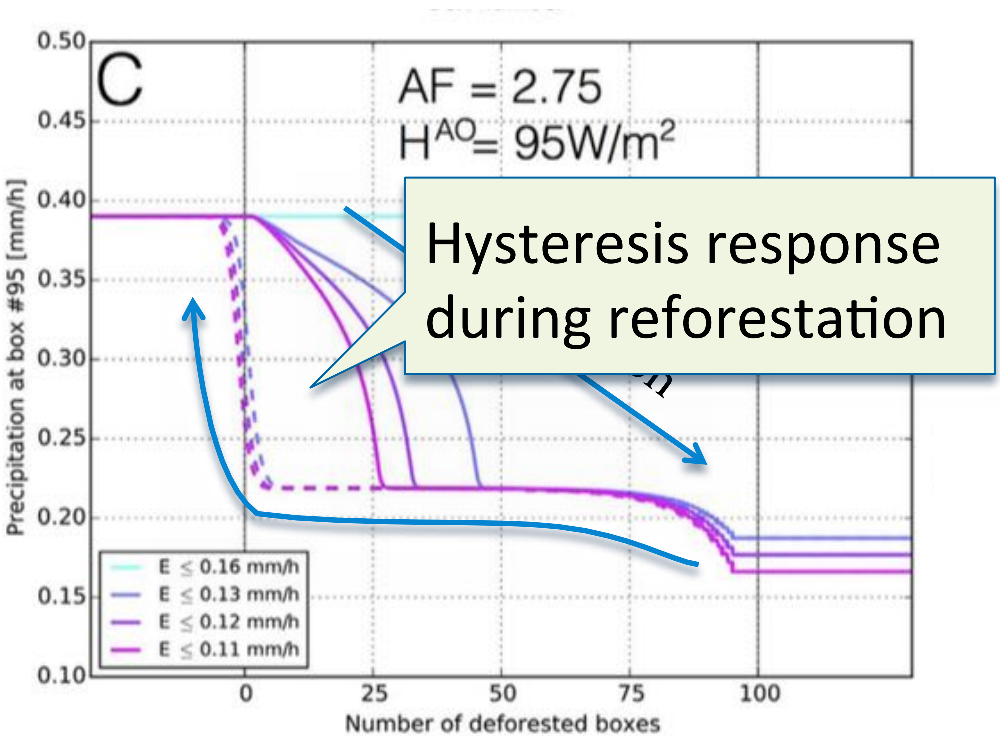
1. Run until equilibrium
2. Deforest N-th box
3. Run until equilibrium
4. Deforest N+1 box
5. etc..

atmos: $$A_i(t+1) = A_i(t) + E_i(t) - P_i(t) - \frac{W_i(t)A_i(t) - W_{i-1}(t)A_{i-1}(t)}{l}$$

soil: $$S_i(t+1) = S_i(t) + P_i(t) - E_i(t) - R_i(t)\ ,$$

$$W_i^{trade} = (w_0 - w_c)\left(1 + \frac{1}{1+e^{w_1 * i - w_2}}\right) \qquad W_i^H(t) = w_c L\pi(t)\left(1 + \frac{1}{1+e^{w_1 * i - w_2}}\right)$$

Deforestation shows hysteresis

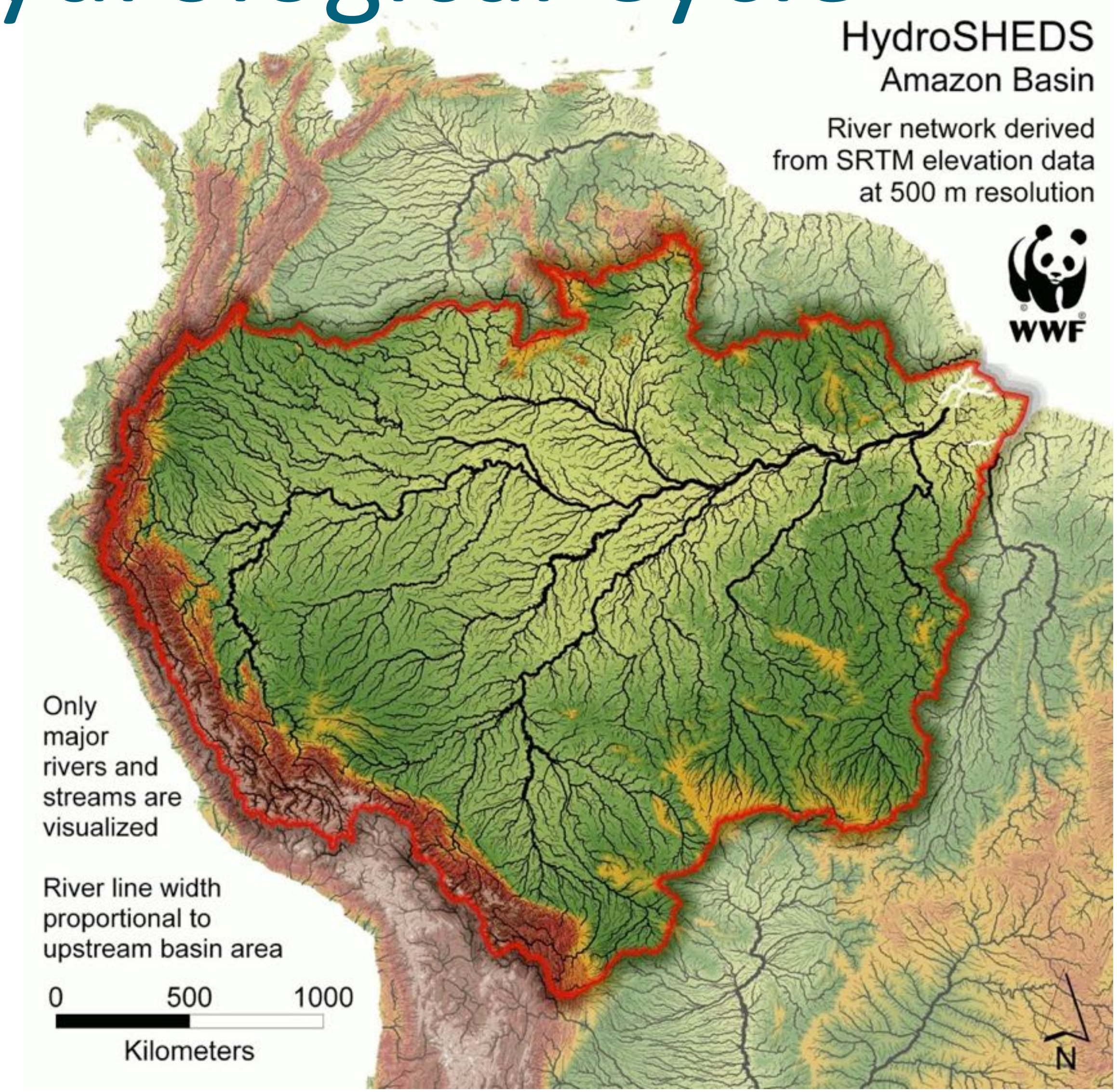


Or it never come back, if coupling is very strong

Boers et al., Nature Scientific Reports (2017)


Amazonia is a key component
of the Earth System

Hydrological Cycle

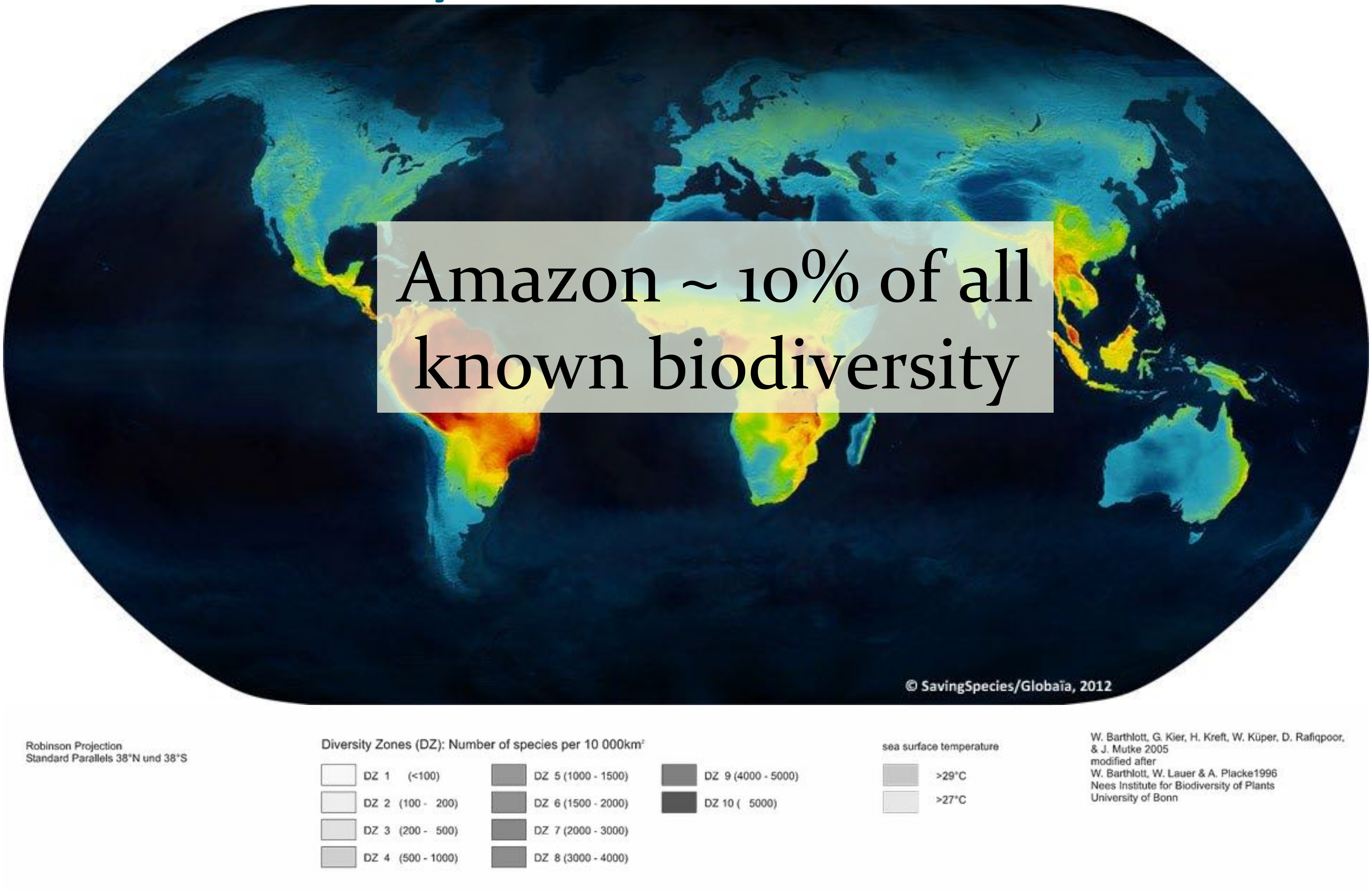


Rainfall 1.5 m to 3 m

Average discharge of 219,000 m3/sec of water

1/6 of all fresh water that drains into the world's oceans

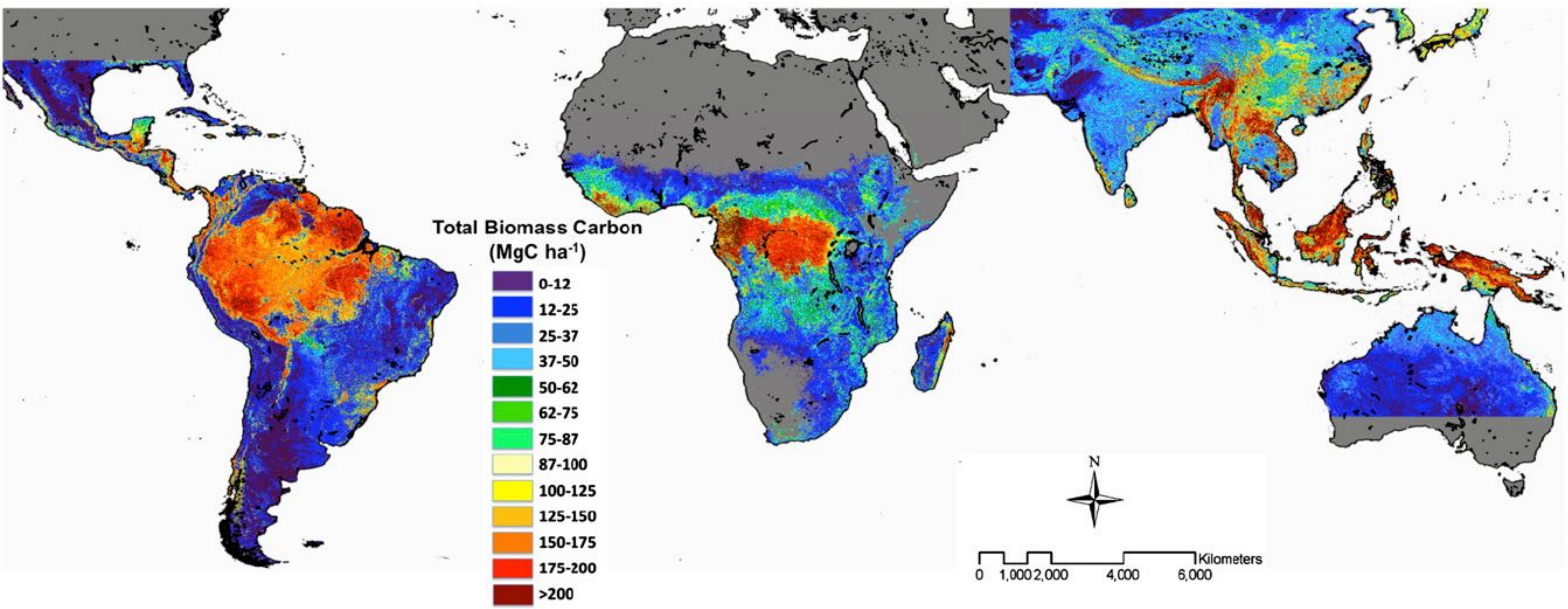
Biodiversity



Amazon ~ 10% of all known biodiversity

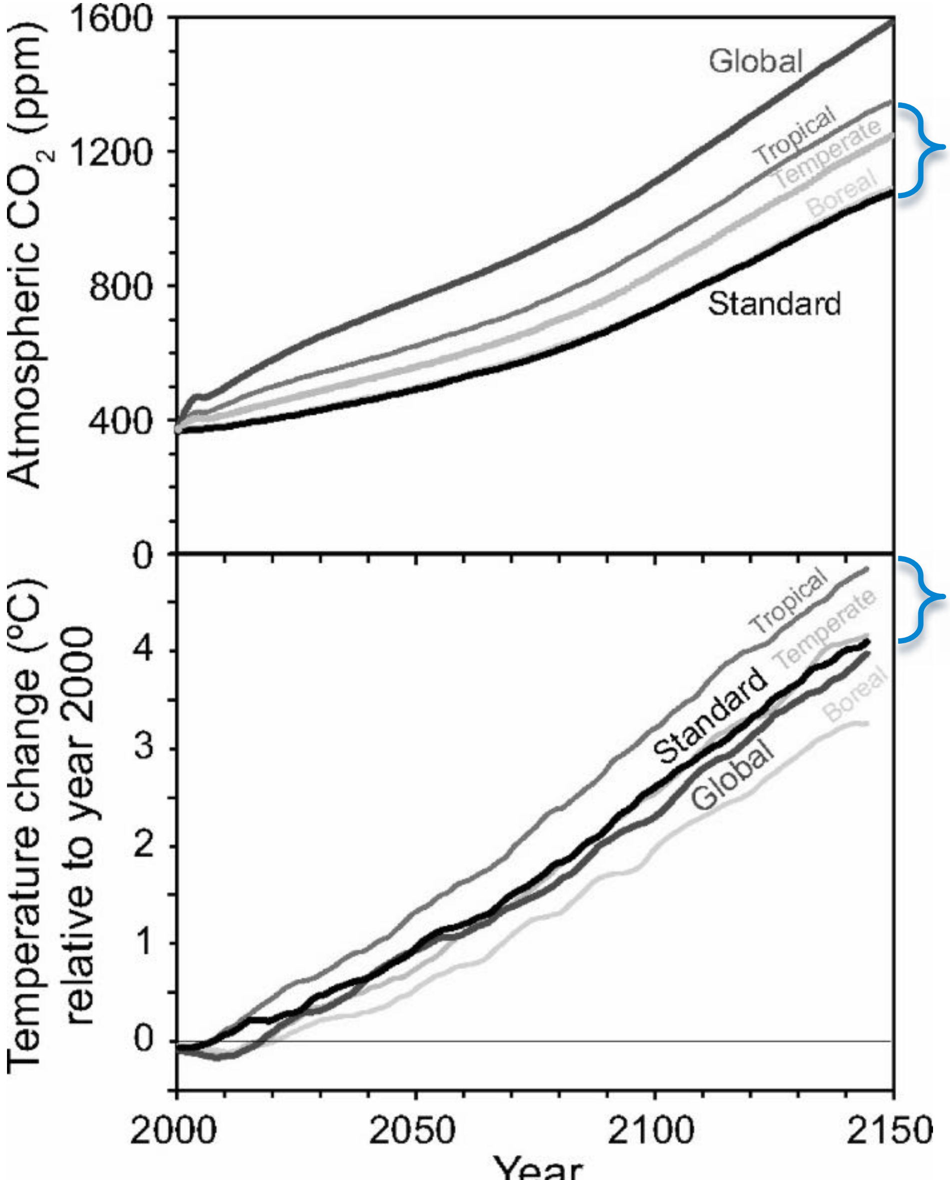
https://www.nees.uni-bonn.de/research-/systematics-evolution-ecology/biogeography-and-macroecology-biomaps/worldmaps/worldmaps-of-plant-diversity

Biomass => Carbon storage



Saatchi et al., PNAS 2011

CO_2 in a world without forests



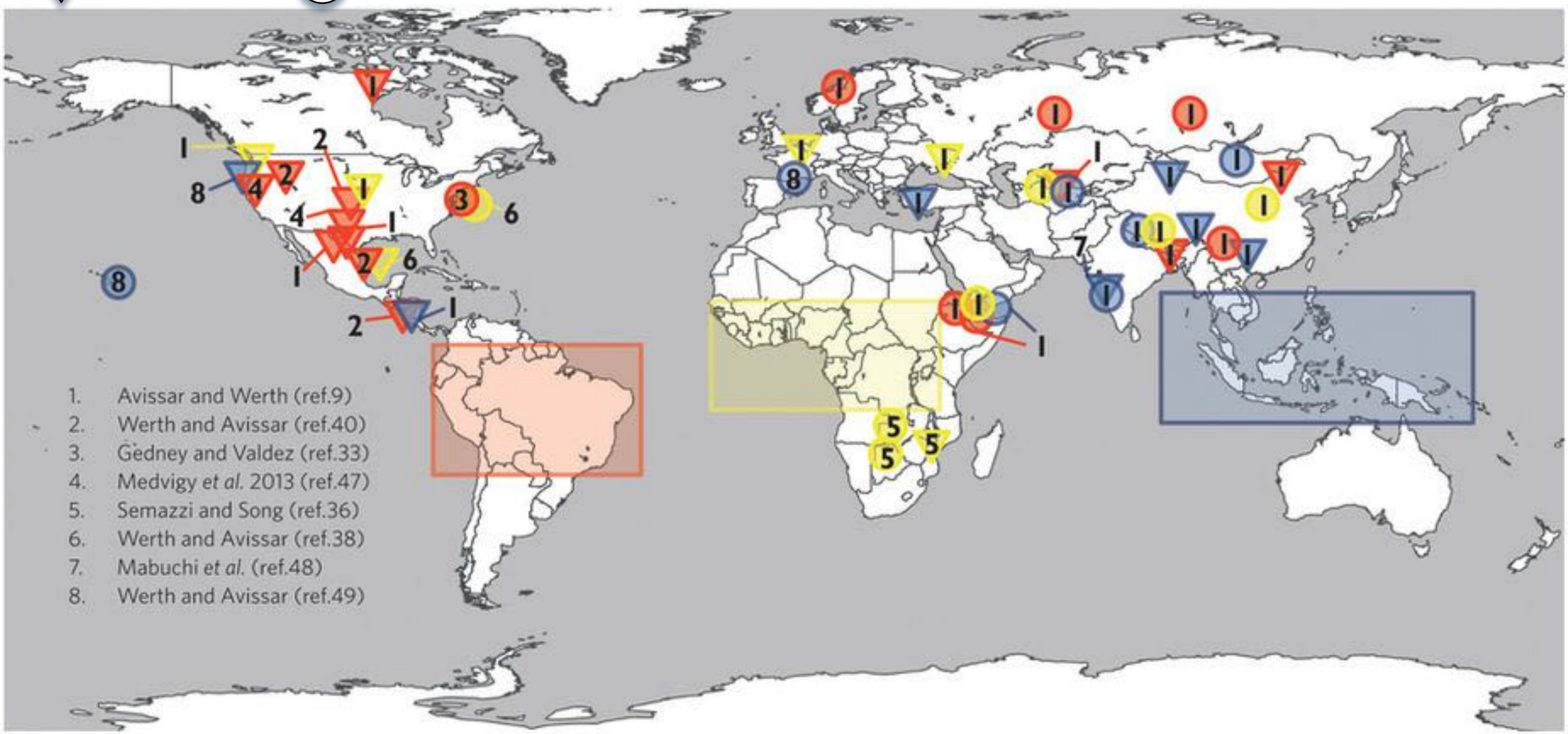
About +200 ppm

Global temperature <u>additional</u> increase of +0.7 °C with removal of all tropical forests

Bala et al., PNAS 2007

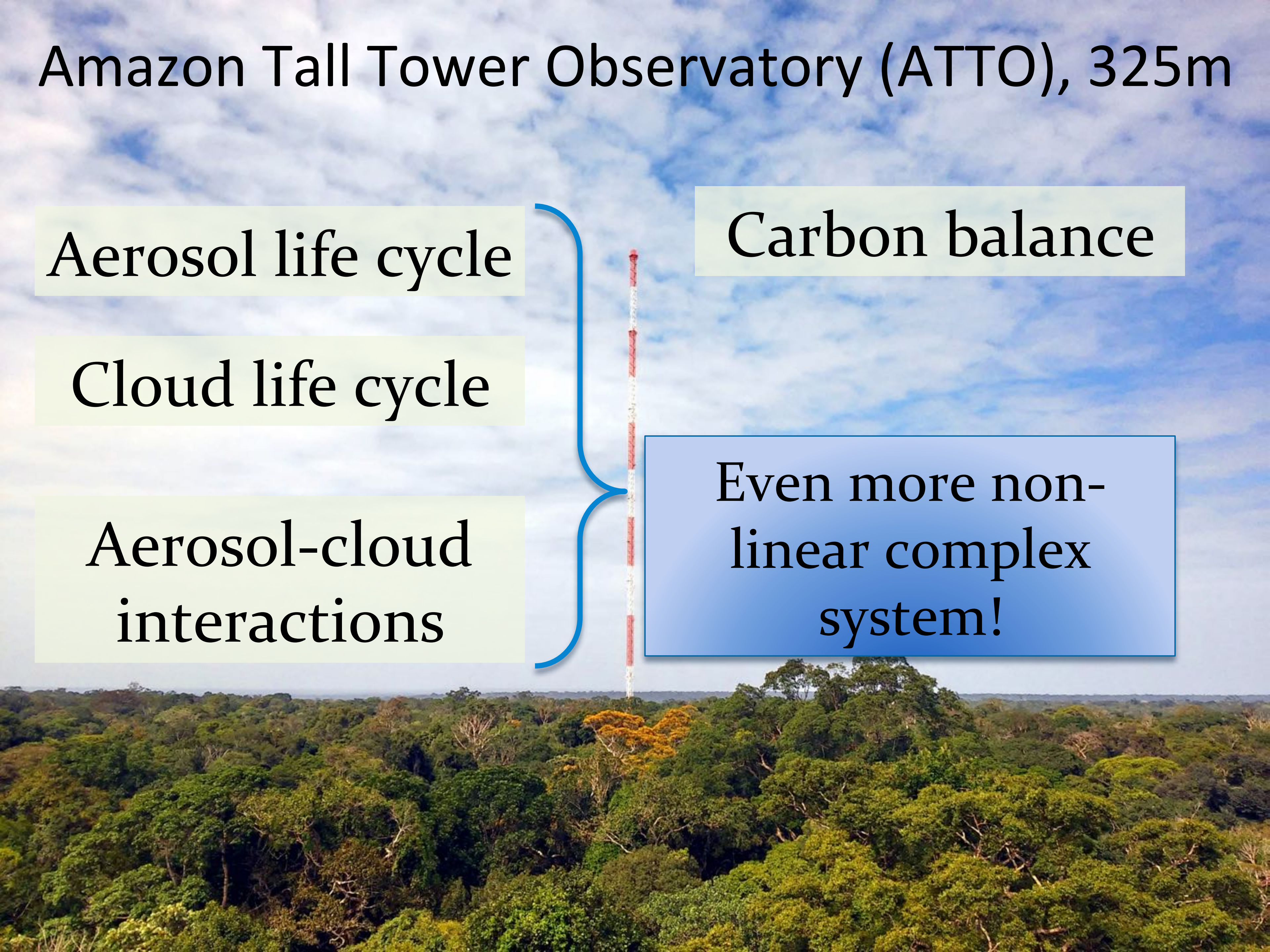
World without tropical rainforests

Decrease Increase

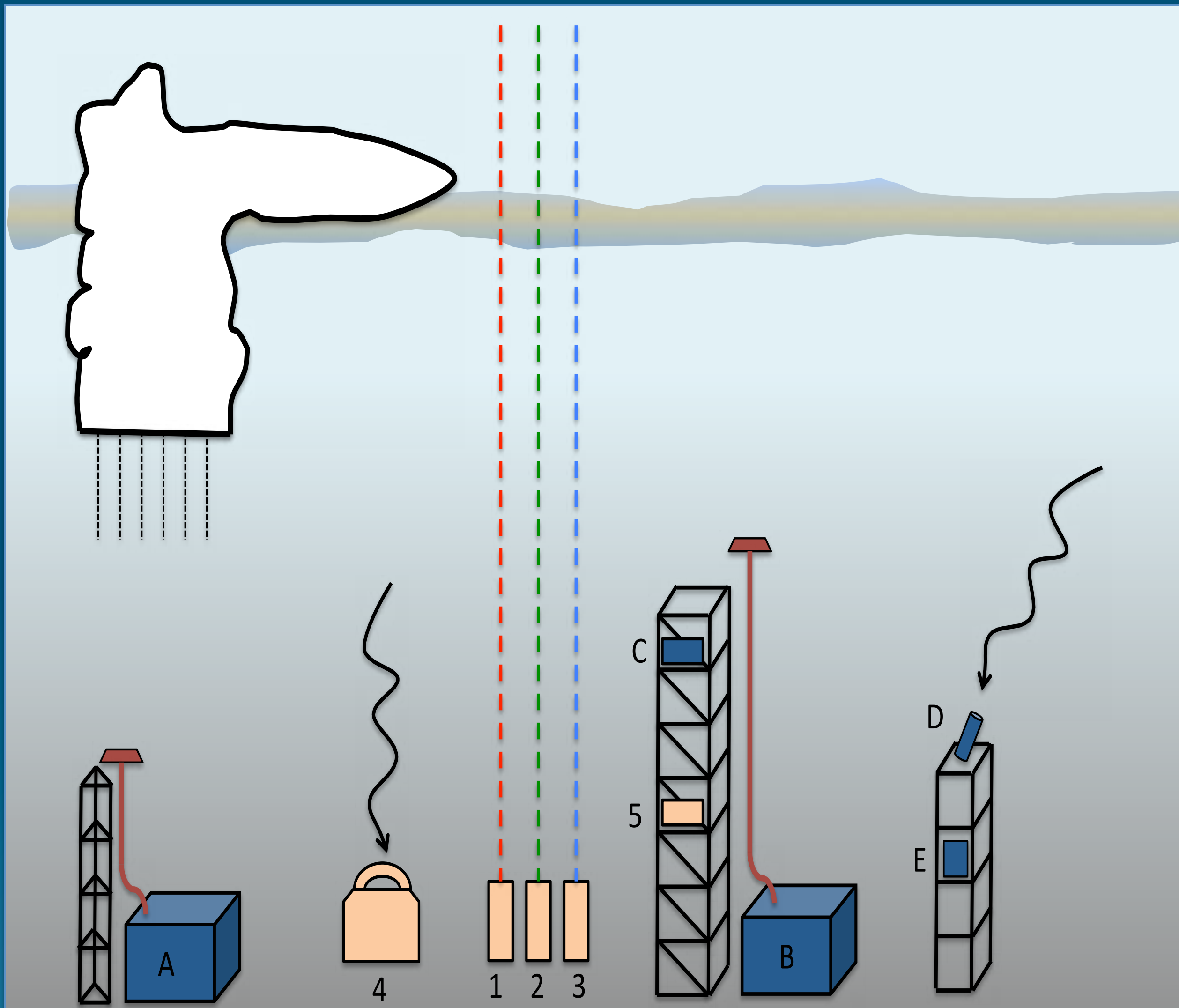


D. Lawrence & K. Vandecar, Nature Climate Change (2015)

Amazonia: a unique region, with global impacts on the hydrological cycle, carbon balance and socioeconomical issues


Amazon Tall Tower Observatory (ATTO), 325m
Aerosol life cycle
Cloud life cycle
Aerosol-cloud interactions
Carbon balance
Even more non-linear complex system!

Aerosol measurements at ATTO

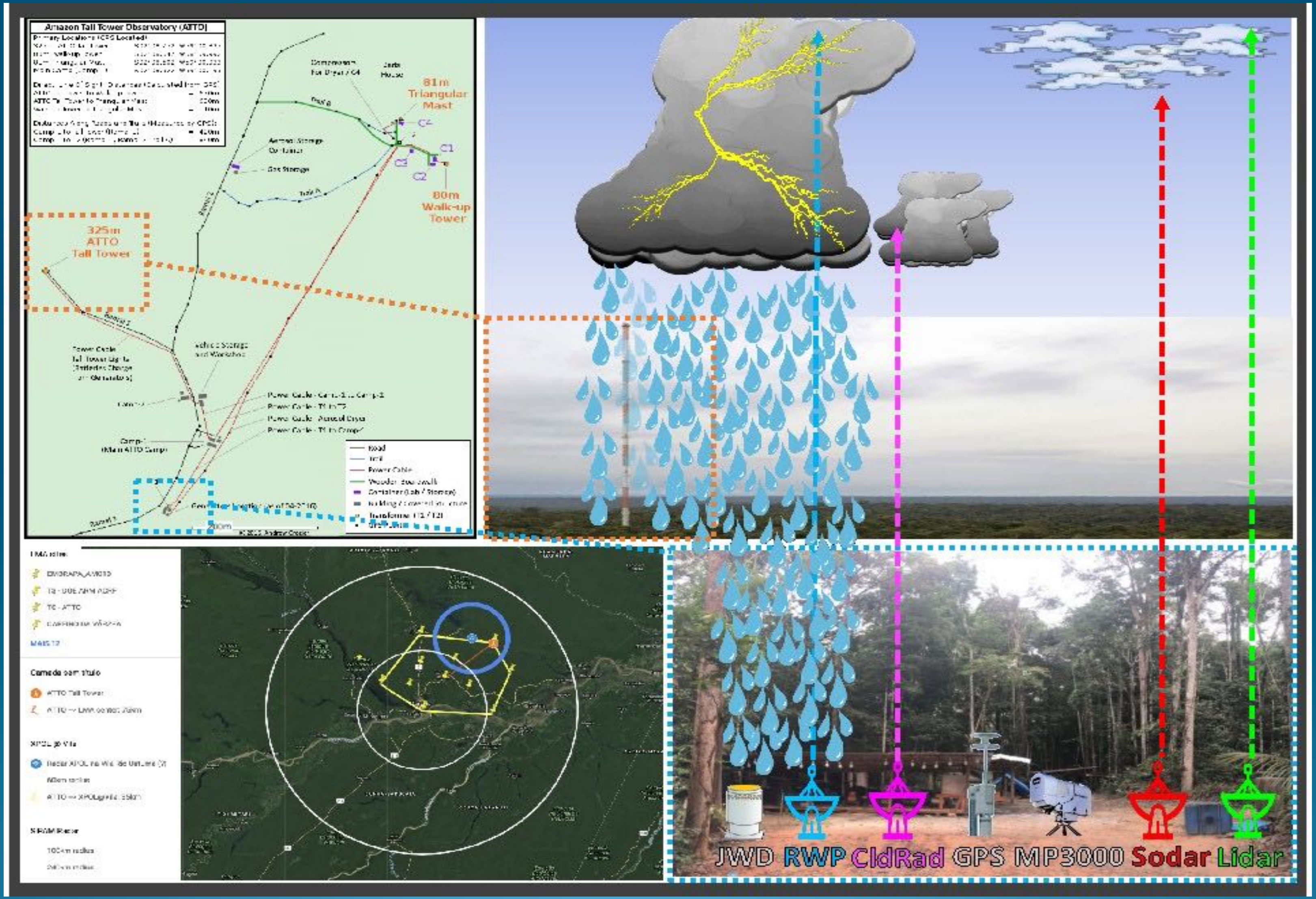


	Existing
A	Aerosol Microphysics • Scattering • Absorption • Concentration • Particle size and mass • Chemical composition • CCN spectra
B	Aerosol Microphysics
C	Bioaerosol sampler
D	Sun photometer
E	Filter collection

	New
1	Ceilometer (IR)
2	Micro-pulsed lidar (VIS)
3	Raman lidar (UV)
4	All-sky IR camera
5	Fog sampler

Schematic view of the aerosol measurements at the ATTO site. Detailed aerosol particle microphysics measurements are already in operation at the 60 m triangular tower (A), and the tall tower (B). Filter collection for elemental chemical composition, and organic and elemental carbon concentration (E) takes place at the walkup tower, and for analysis of fungi and spores (C), at the tall tower. New instruments will allow measuring the vertical profile of aerosol and cloud properties, and collecting in-cloud water for chemical and biological analysis.

Aerosol-Cloud Physics instrumentation site



Aerosol-Cloud Physics instrumentation site, containing: Joss-Waldvogel disdrometer (JWD), Radar Wind Profiler (RWP), W-band Cloud Radar (CldRad), GPS for water vapor column, MP3000, Sodar and dual-polarization Lidar. This system will allow an innovative view of precipitation formation over Central Amazonia


Obrigado