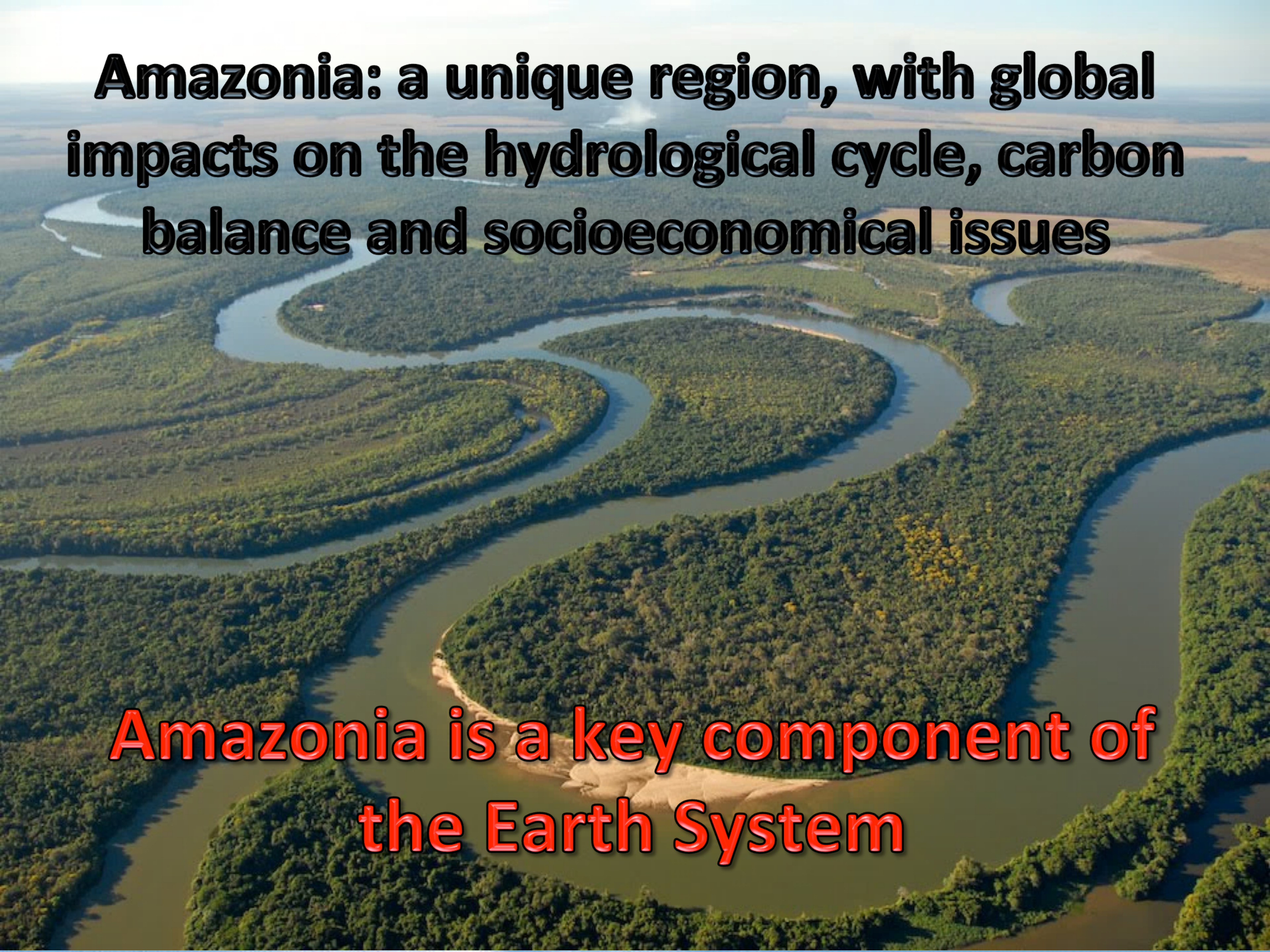
São Paulo School of Advanced Science on Atmospheric Aerosols: properties, measurements, modeling, and effects on climate and health
São Paulo, 26 July 2019

The Close Links Between the Biological Functioning of Amazonia and Climate

Paulo Artaxo
University of São Paulo, Brazil
Artaxo@if.usp.br


Amazonia: a unique region, with global impacts on the hydrological cycle, carbon balance and socioeconomical issues
Amazonia is a key component of the Earth System

AMAZON ECOSYSTEMS AT A GLANCE

Maintenance of global carbon cycle

- 15% of global NPP and a key carbon sink for anthropogenic CO_2
- Stores between 100 to 120 billion ton of carbon in the biomass

Climate stabilization

- Key heat source for the atmosphere
- Annual rainfall = 2400 mm

Powerful hydrology

- 18% of fresh water flow into the global oceans
- Amazon river discharge of 220,000 m^3/s

Helps to maintain cultural and ethnic diversity

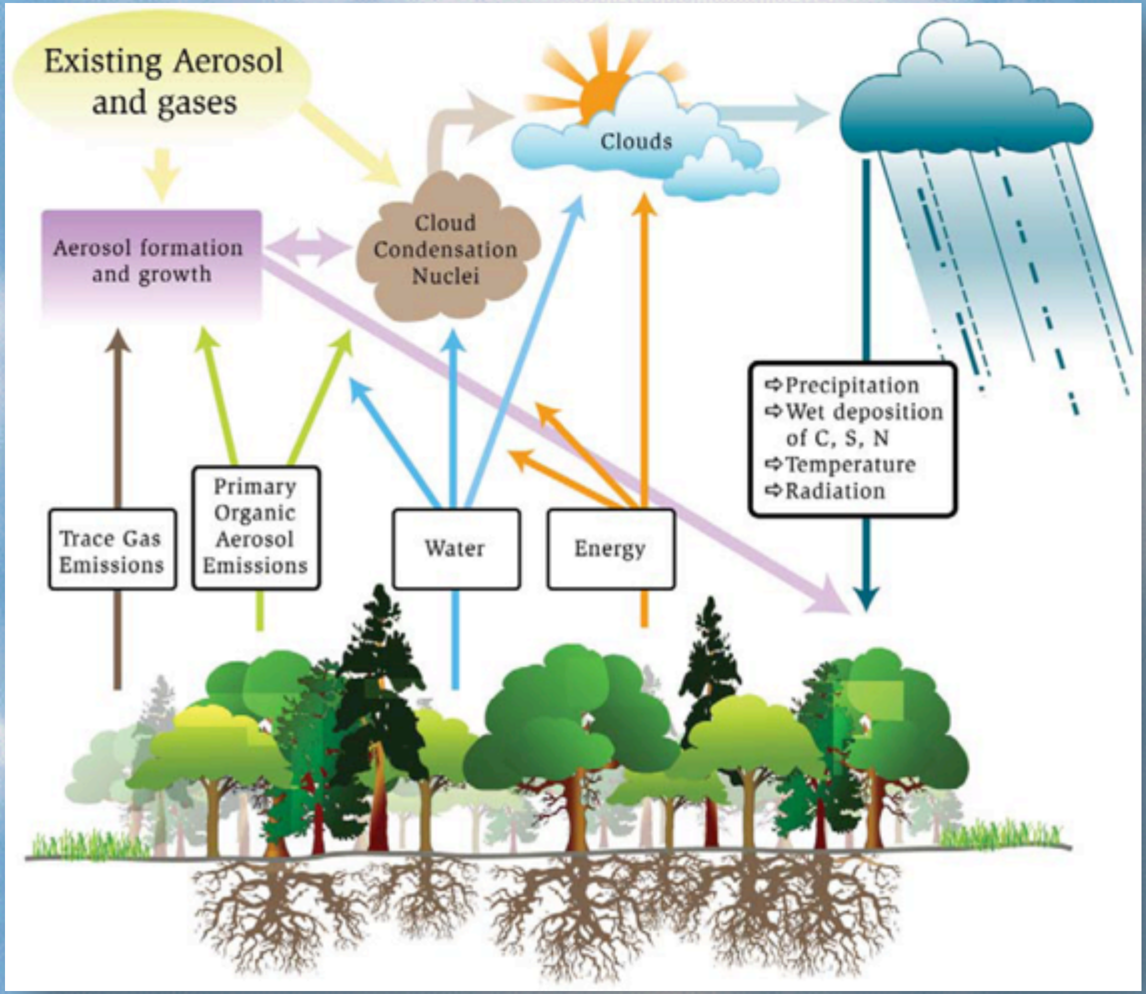
- Over 300 indigenous populations, language diversity

Biodiversity richness

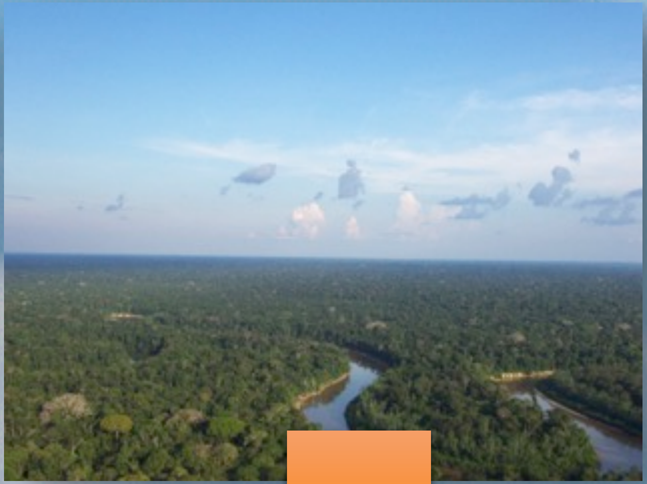
- > 10% of species

There are strong and complex links between the forest biology, and the physics and chemistry of the atmosphere

Natural System



The Transition



Amazonia as a Complex Nonlinear Interactive System

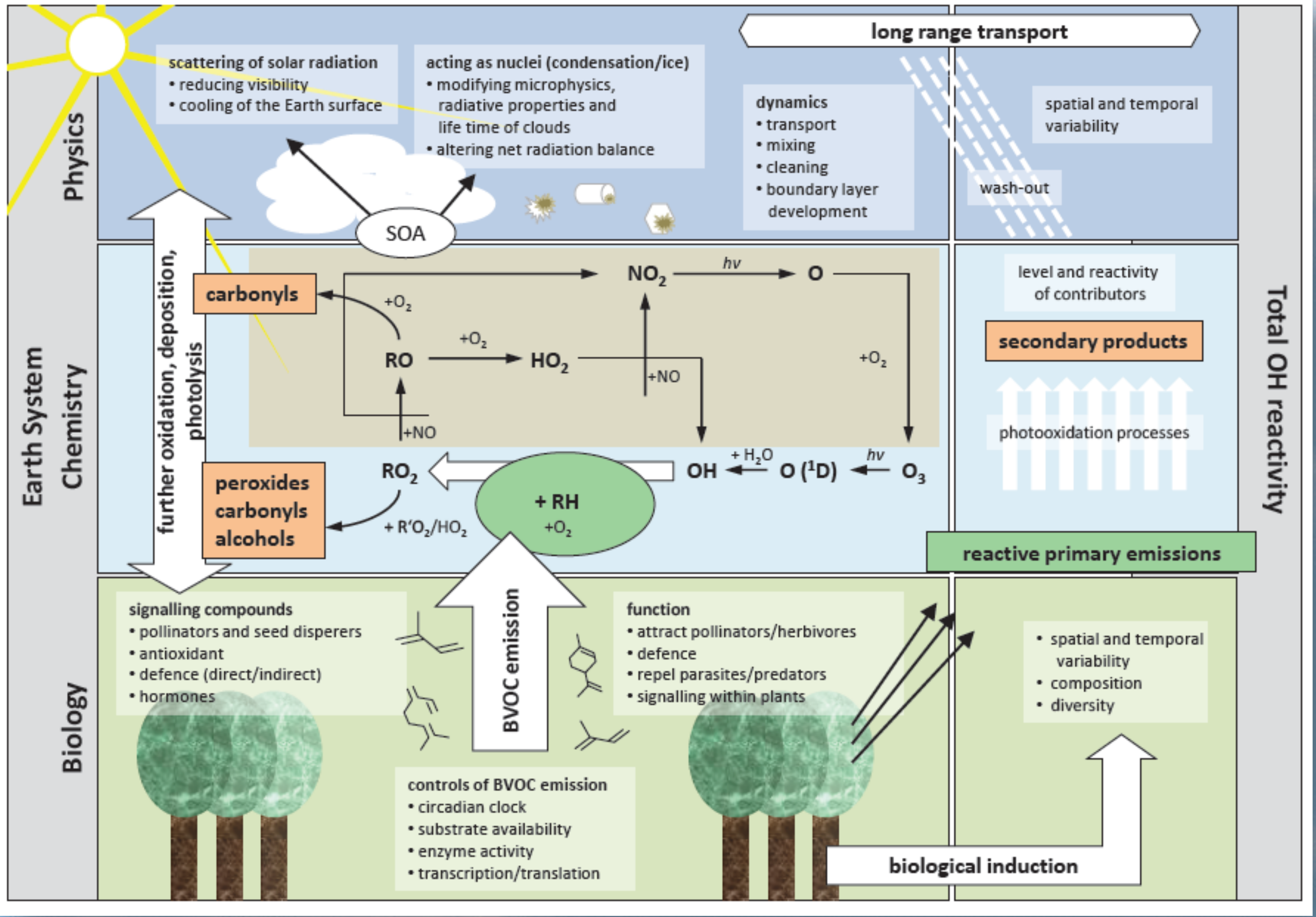
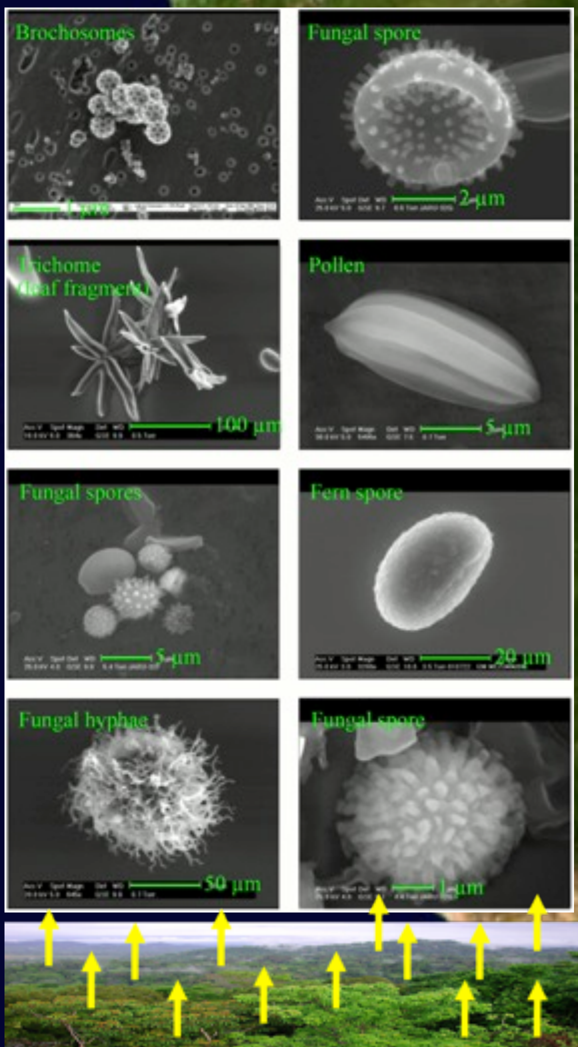
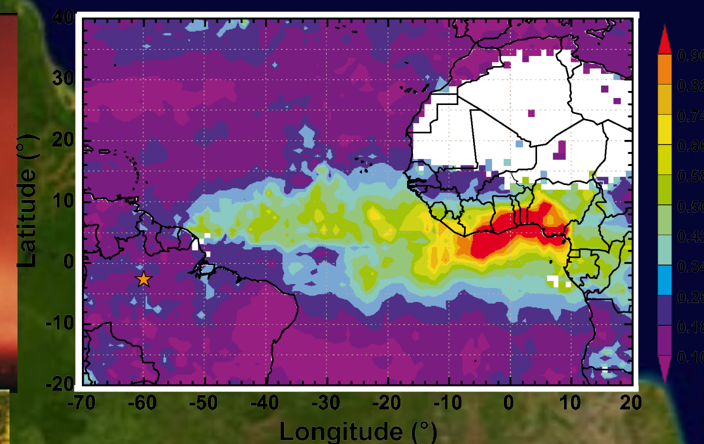


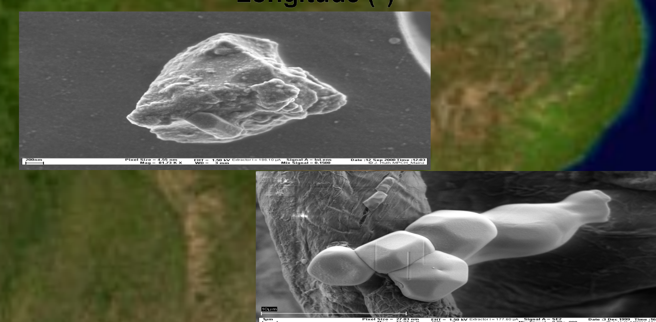
Illustration from Anke Nölscher

Amazonia: 3 different types of aerosols

Biogenic (primary and SOA) | **Biomass Burning** | **Dust from Sahara**







Each with VERY different properties and impacts

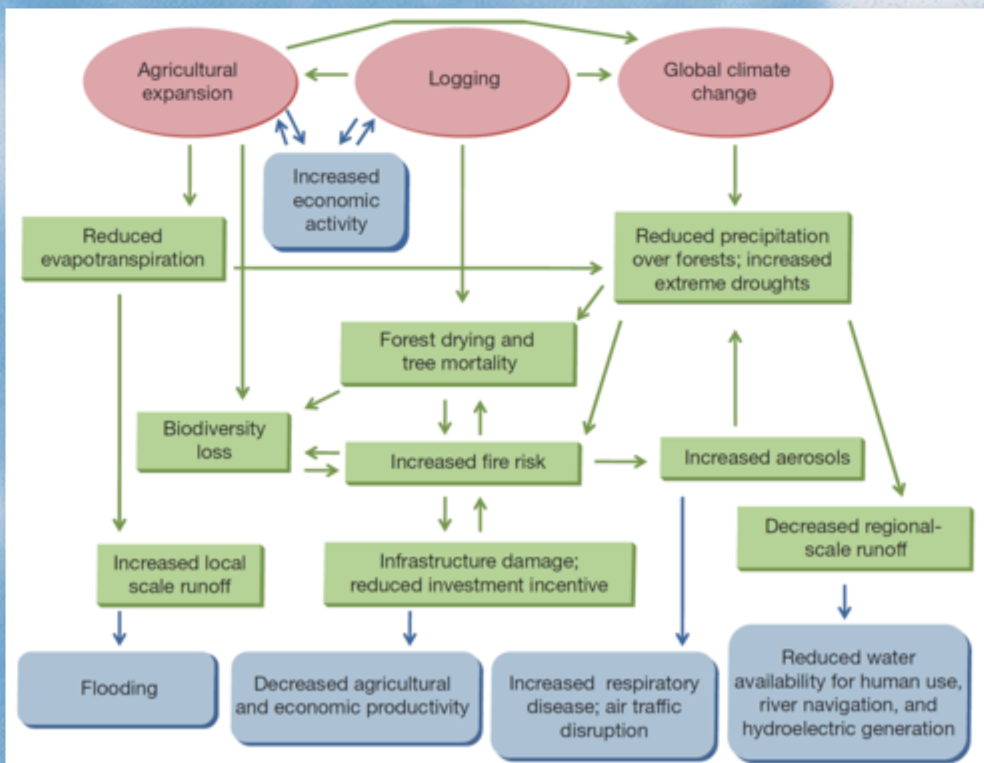
REVIEW

doi:10.1038/nature10717

The Amazon basin in transition

Eric A. Davidson[1], Alessandro C. de Araújo[2,3], Paulo Artaxo[4], Jennifer K. Balch[1,5], I. Foster Brown[1,6], Mercedes M. C. Bustamante[7], Michael T. Coe[1], Ruth S. DeFries[8], Michael Keller[9,10], Marcos Longo[11], J. William Munger[11], Wilfrid Schroeder[12], Britaldo S. Soares-Filho[13], Carlos M. Souza Jr[14] & Steven C. Wofsy[11]

Agriculture expansion and climate variability are critical ingredients on Amazonian transition. Energy balance and hydrological cycles changes are already observed in Amazonia.



Interactions between land use change and climate change are major drivers for changes in Amazonia.


But, the reality of agricultural expansion
in the Amazon is one of fire and forest
destruction


Deforestation

Fire…


Selective
logging…

PROTECTED AREAS

One-third of global protected land is under intense human pressure

Kendall R. Jones,[1,2*] Oscar Venter,[3] Richard A. Fuller,[2,4] James R. Allan,[1,2] Sean L. Maxwell,[1,2] Pablo Jose Negret,[1,2] James E. M. Watson[1,2,5]

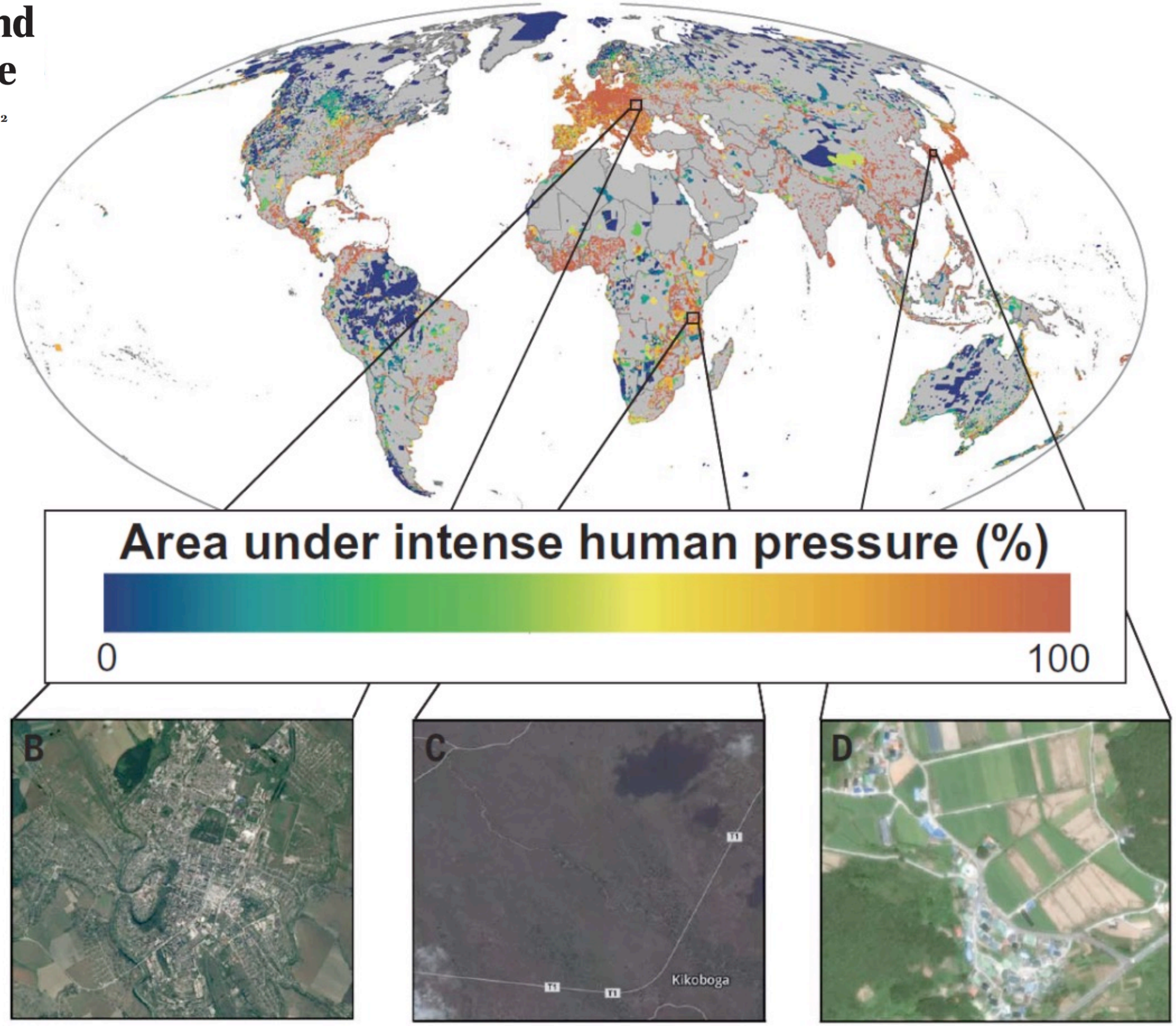


Fig. 1. Human pressure within protected areas. (**A**) Proportion of each protected area that is subject to intense human pressure, spanning from low (blue) to high (orange) levels. (**B**) Kamianets-Podilskyi, a city within Podolskie Tovtry National Park, Ukraine. (**C**) Major roads fragment habitat within Mikumi National Park, Tanzania. (**D**) Agriculture and buildings within Dadohaehaesang National Park, South Korea. [Photo credits: Google Earth]

Science May 2018

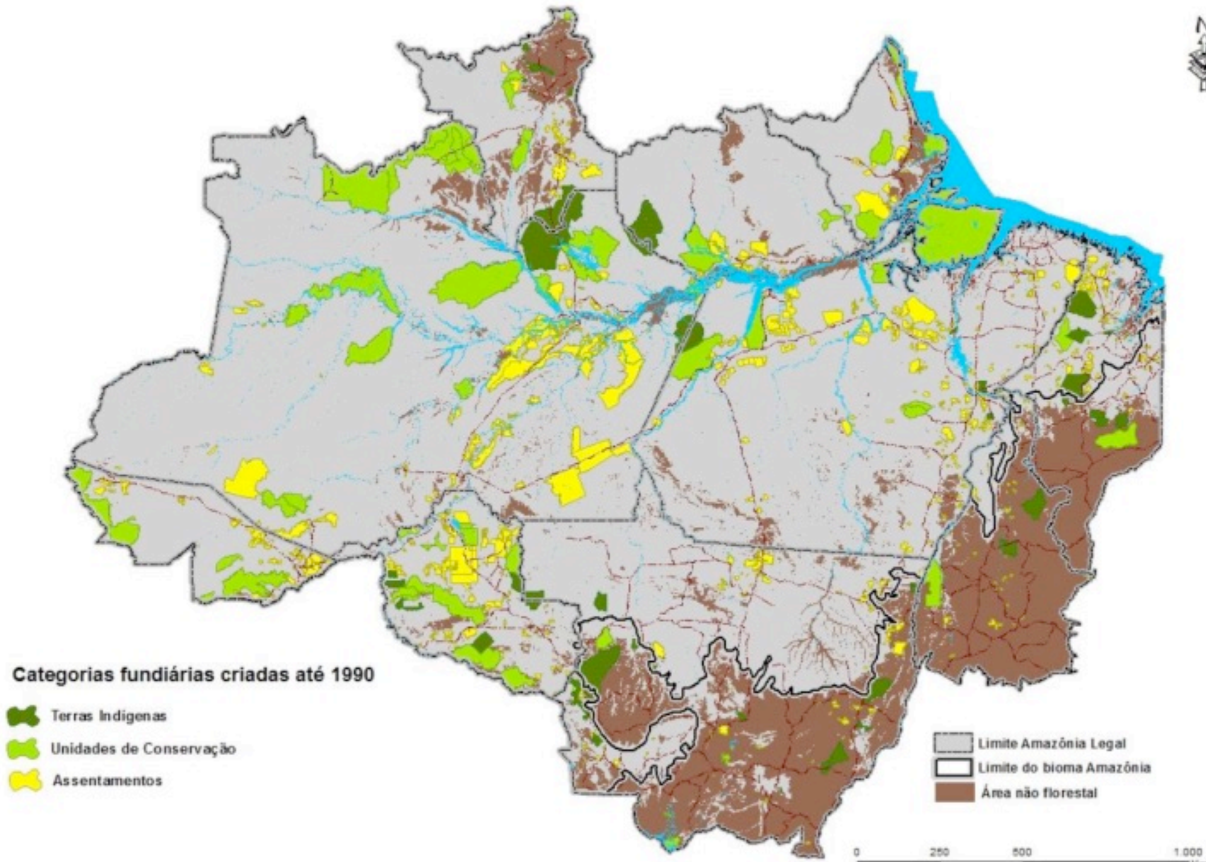
Protected Areas – Brazilian Amazon

IPAM Amazônia

1990

 # Indigenous Lands: 54
Area: 11 million ha

 # Protected Areas: 65
Area: 33 million ha



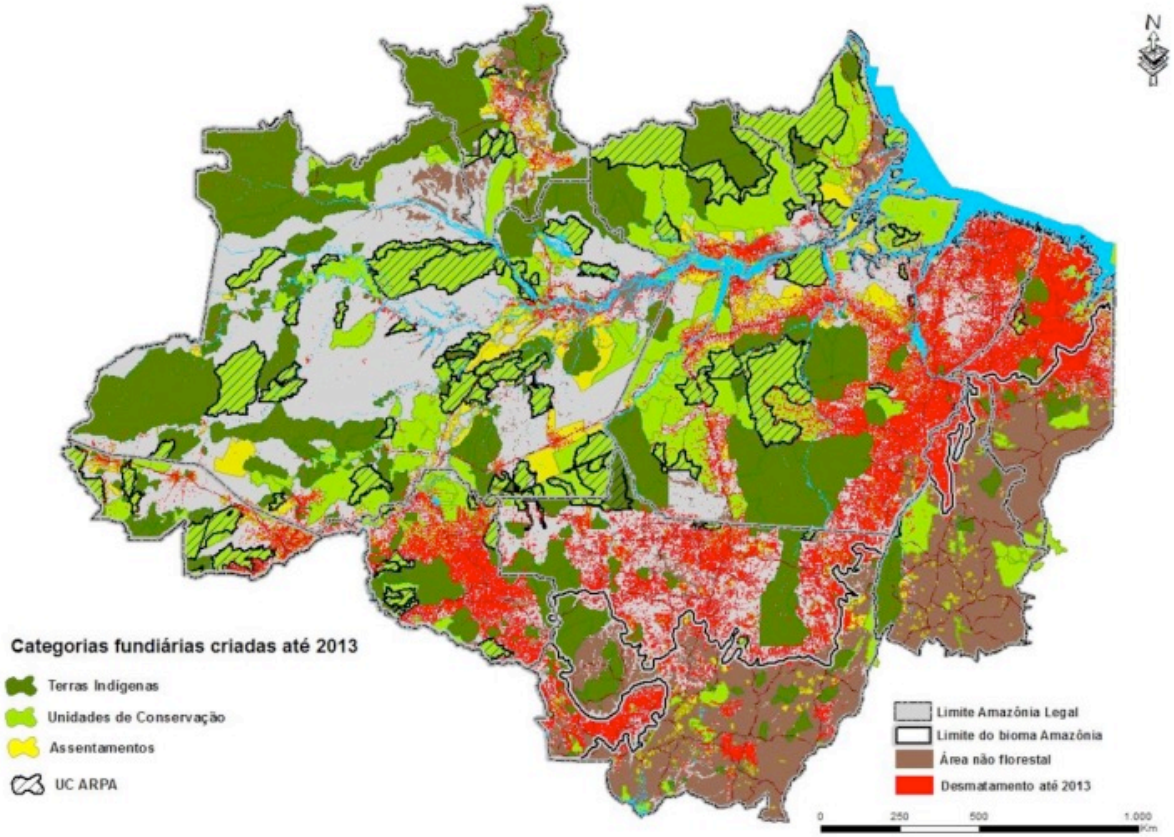
Protected Areas – Brazilian Amazon

Contribuições do INCT-MC

2013

 # Indigenous Lands: 381
Area: 112 million ha

 # Protected Areas: 311
Area: 125 million ha



Amazonia as a Complex Nonlinear Interactive System

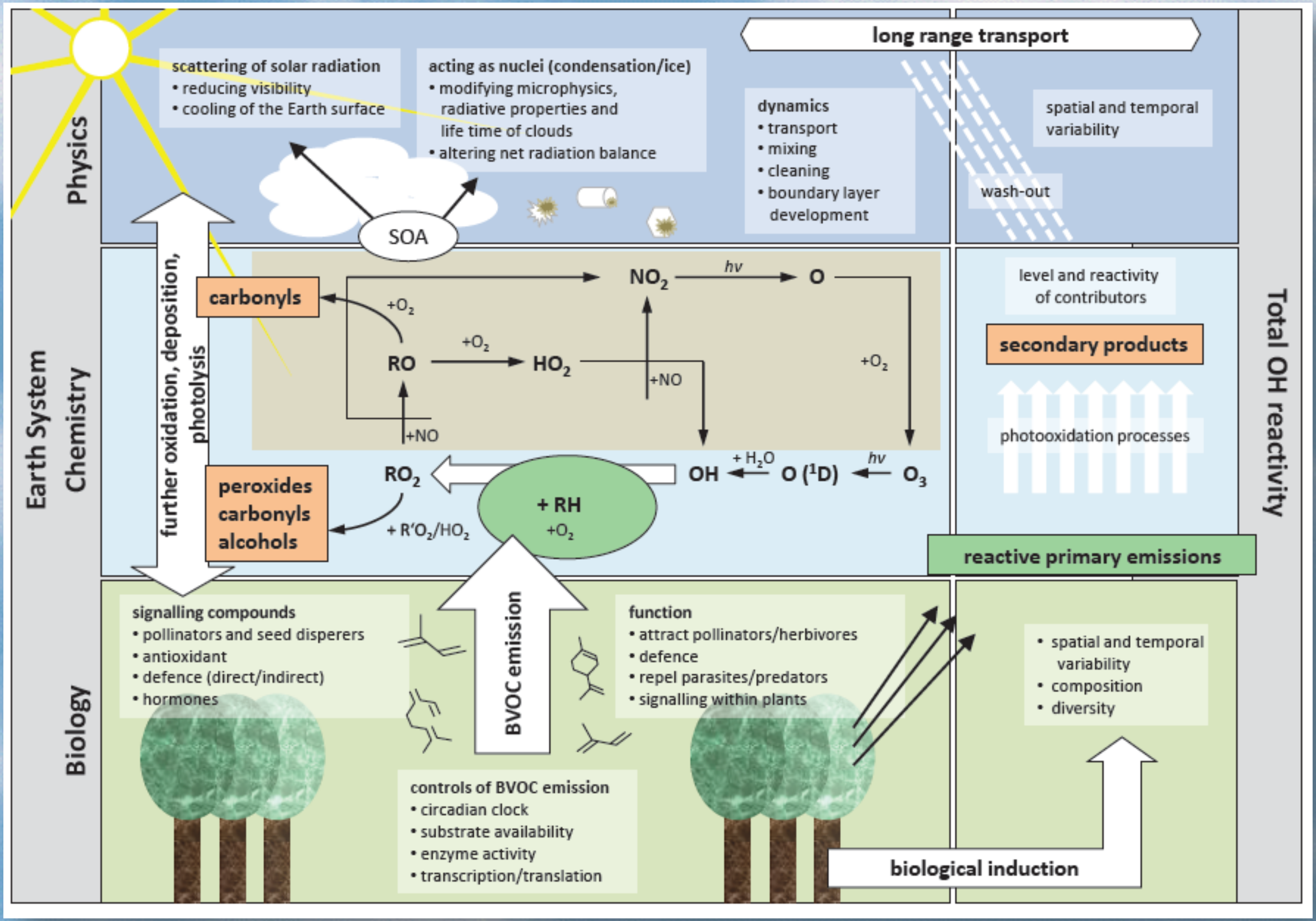
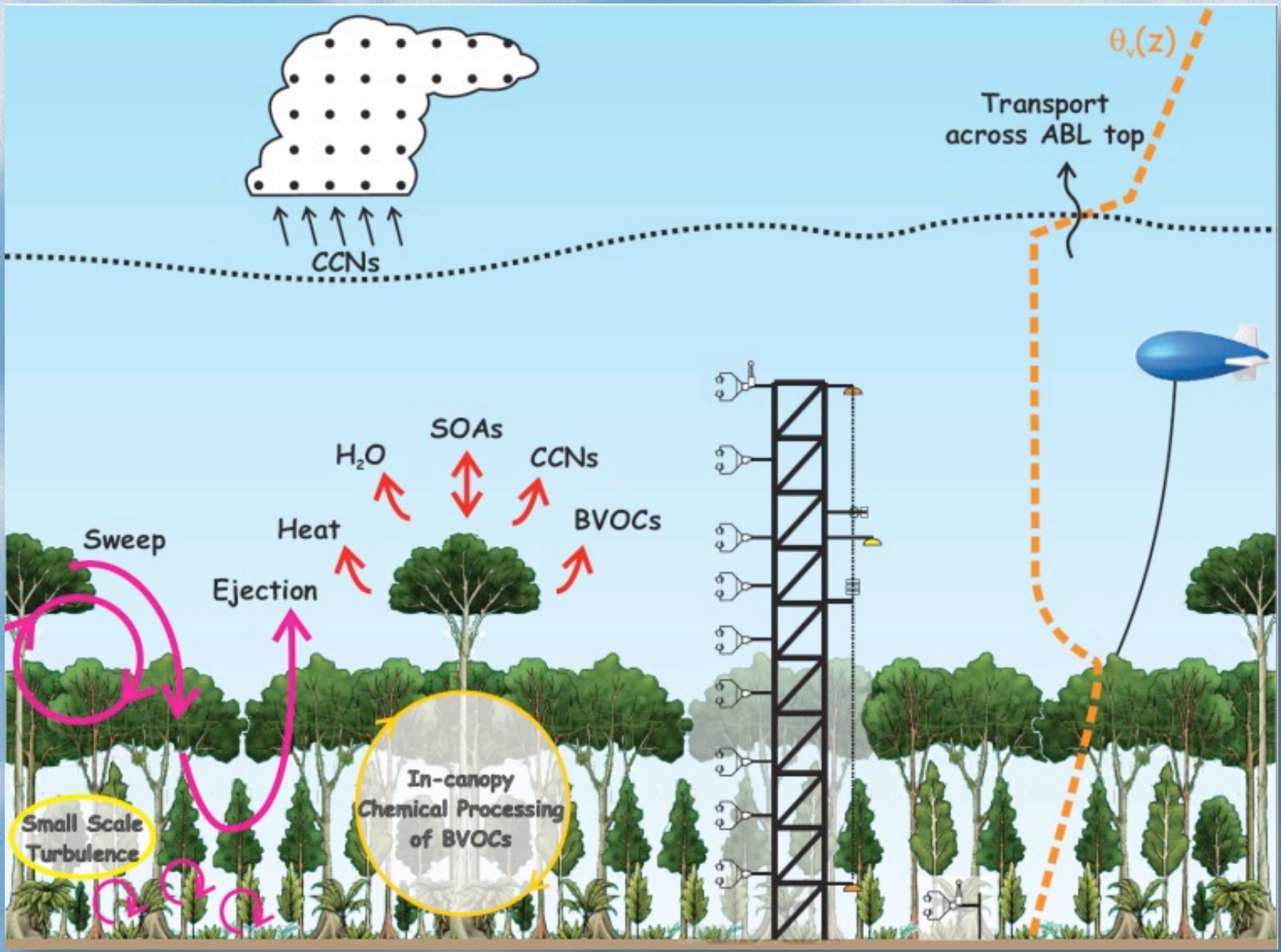


Illustration from Anke Nölscher

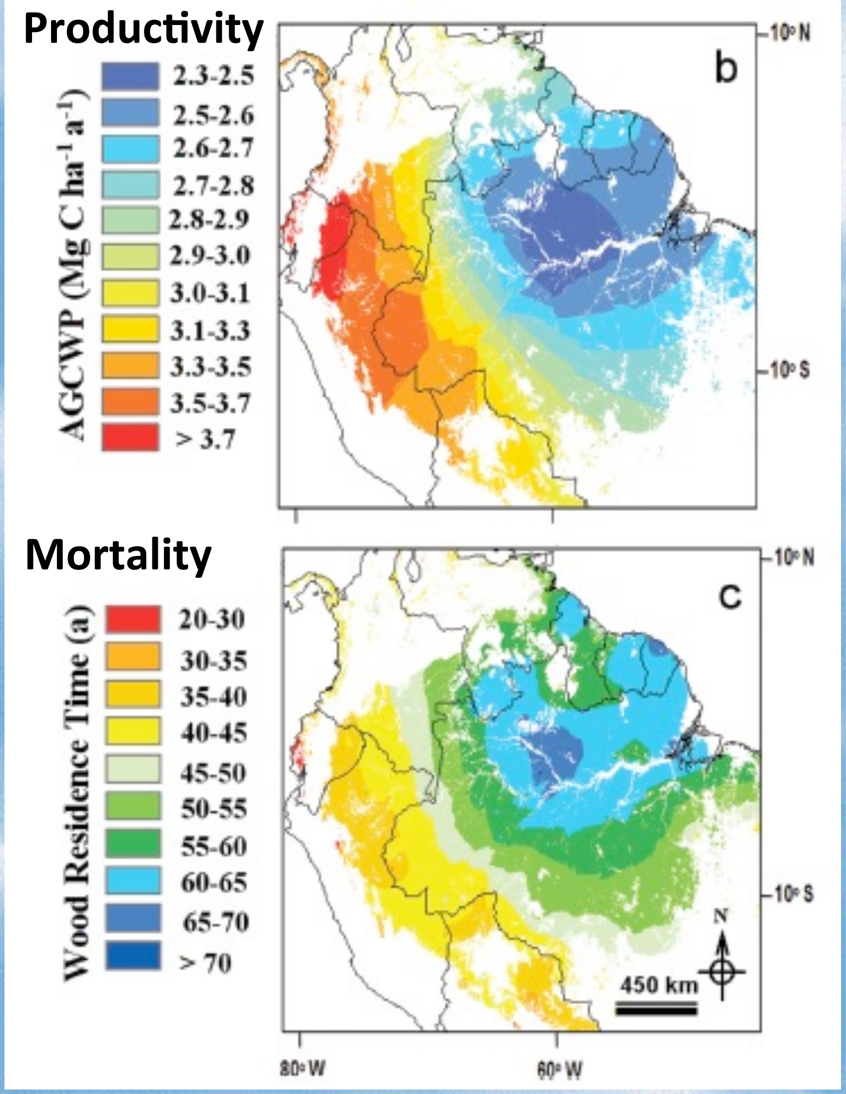
From VOCs, SOA, CCN to the canopy processes in Amazonia



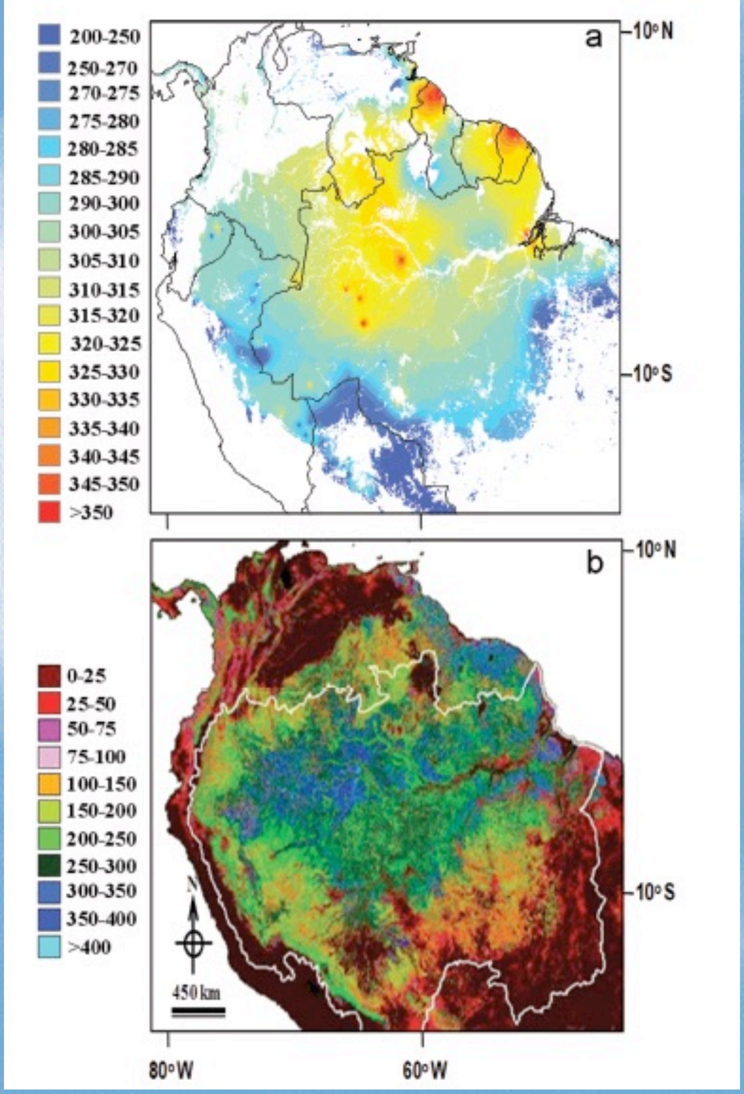
Fuentes et al., BAMS 2016

High spatial variability in productivity, residence time, and biomass in Amazonia

Productivity and Mortality

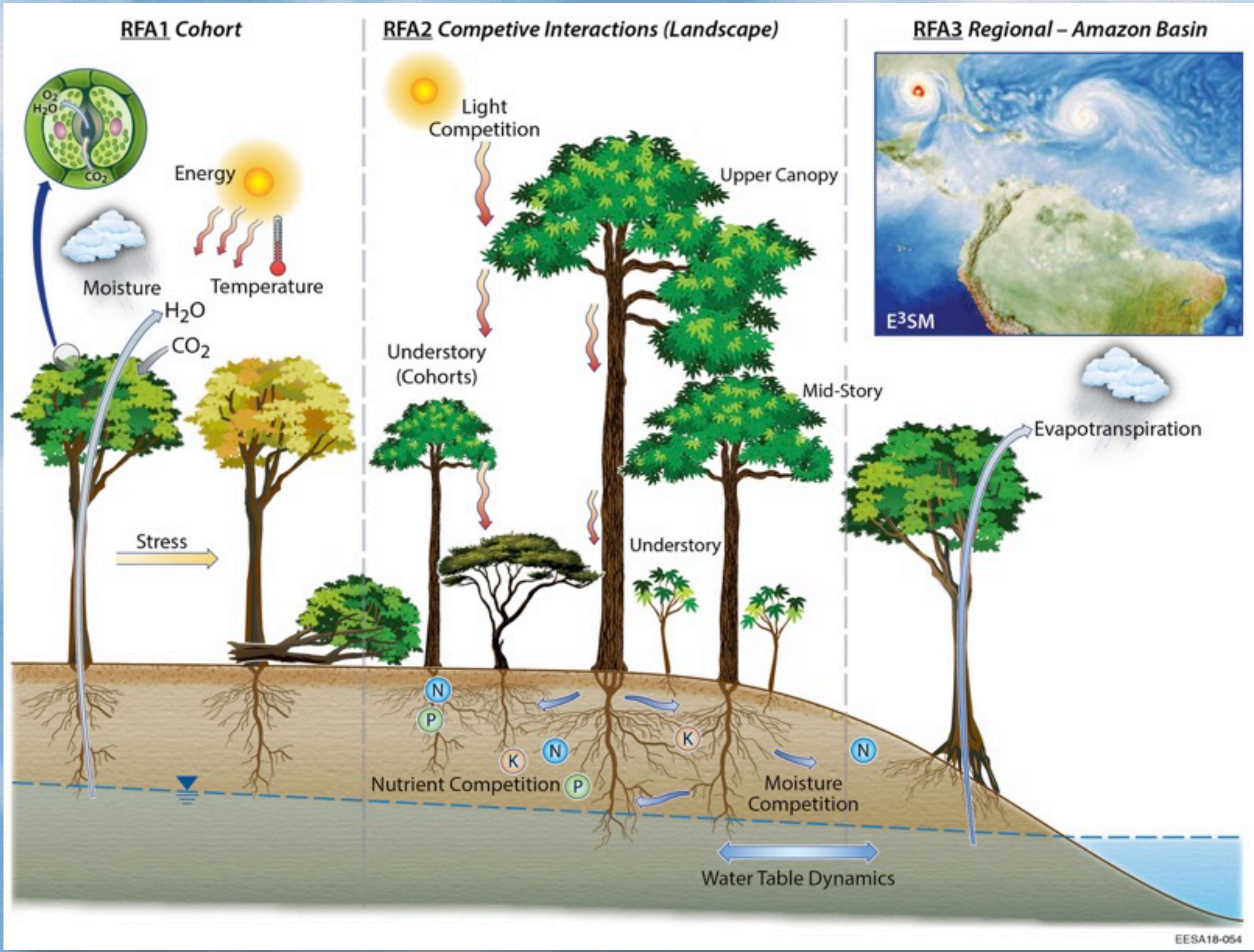


Above Ground Biomass - Units: Mg dry weight ha^{-1} (Malhi, 2006, Saatchi, 2007)

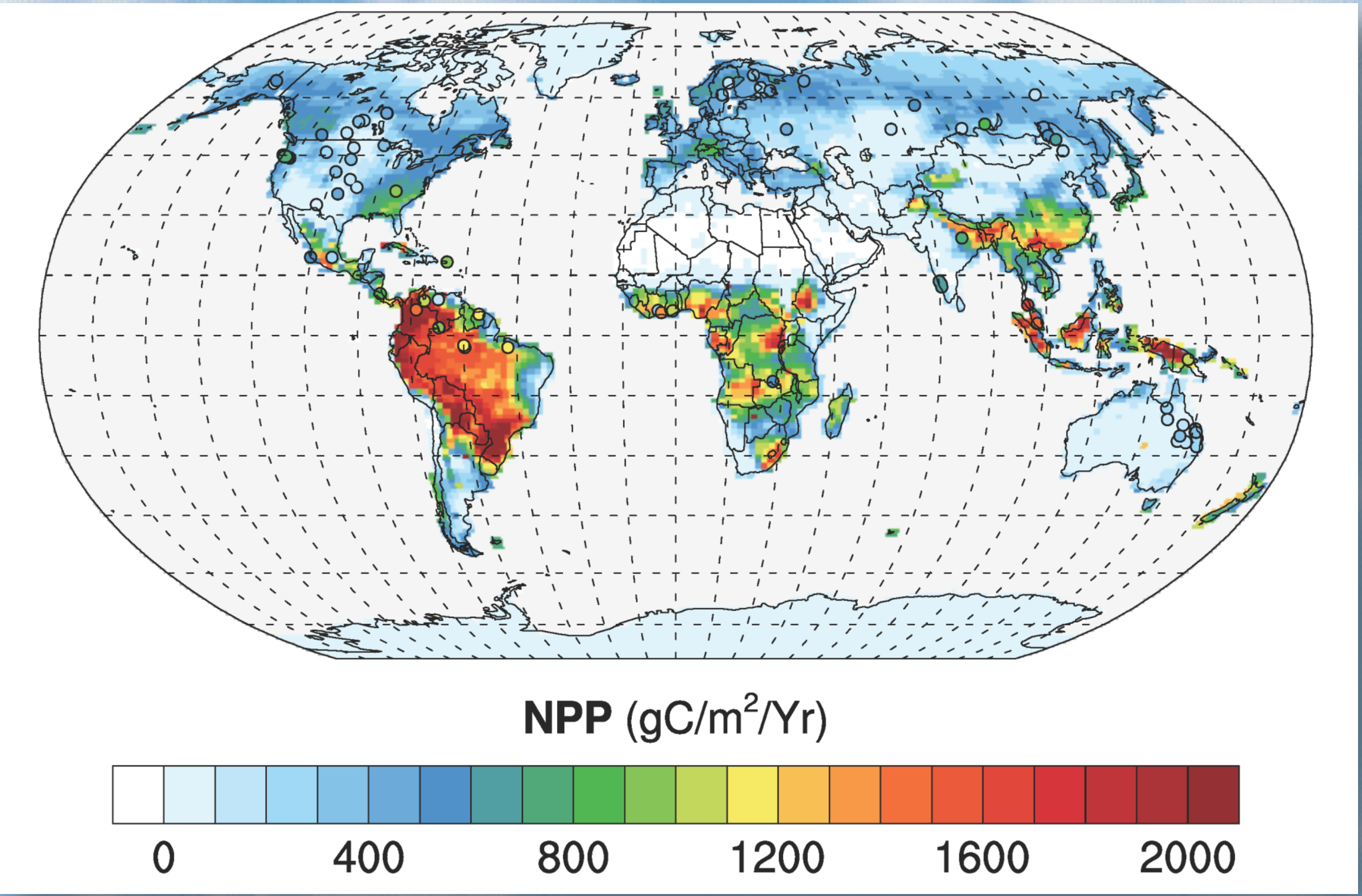


Malhi et al. 2009

Close links between carbon balance and hydrological cycle

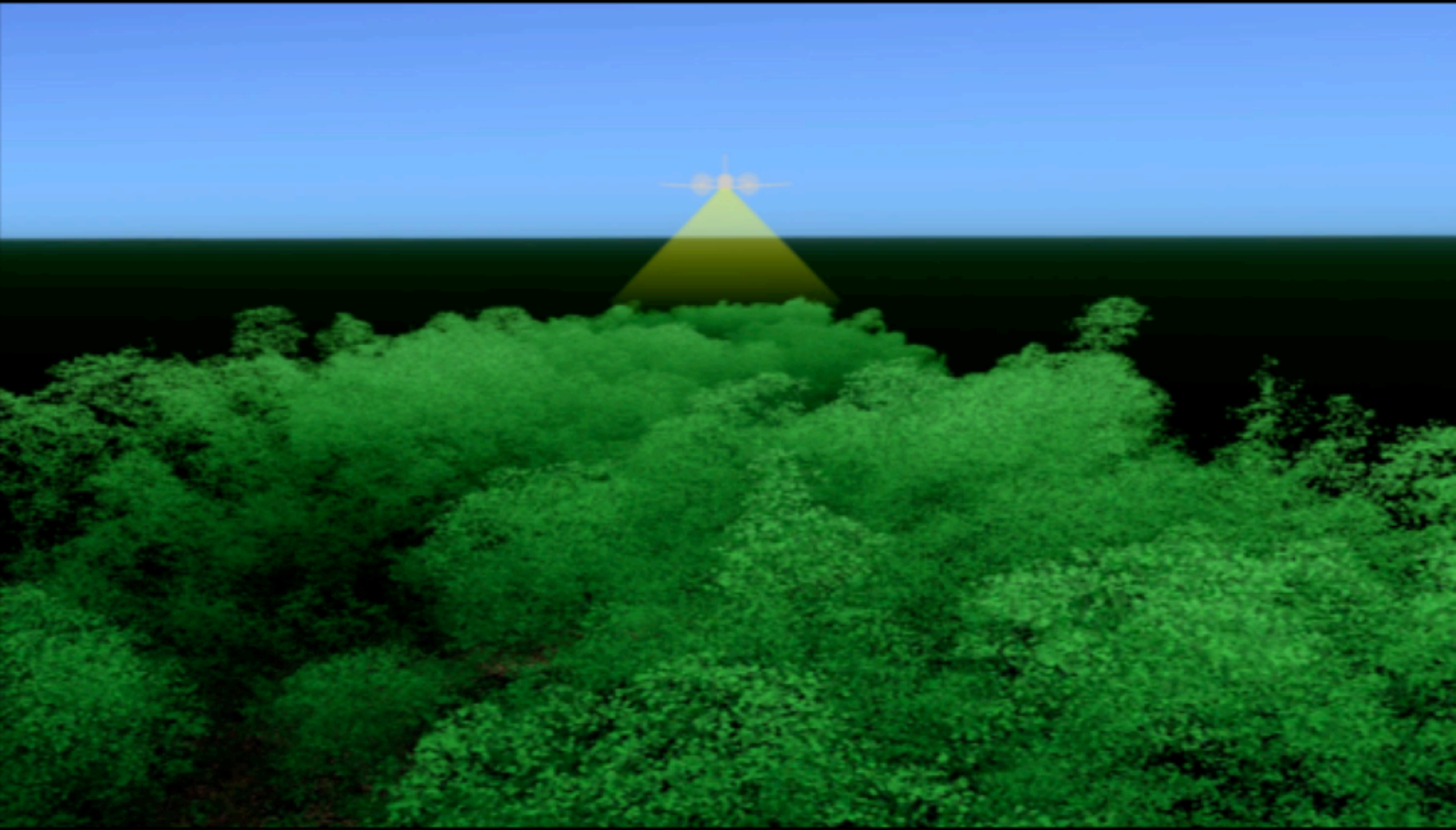


Global Net Primary Productivity NPP: South America is key…

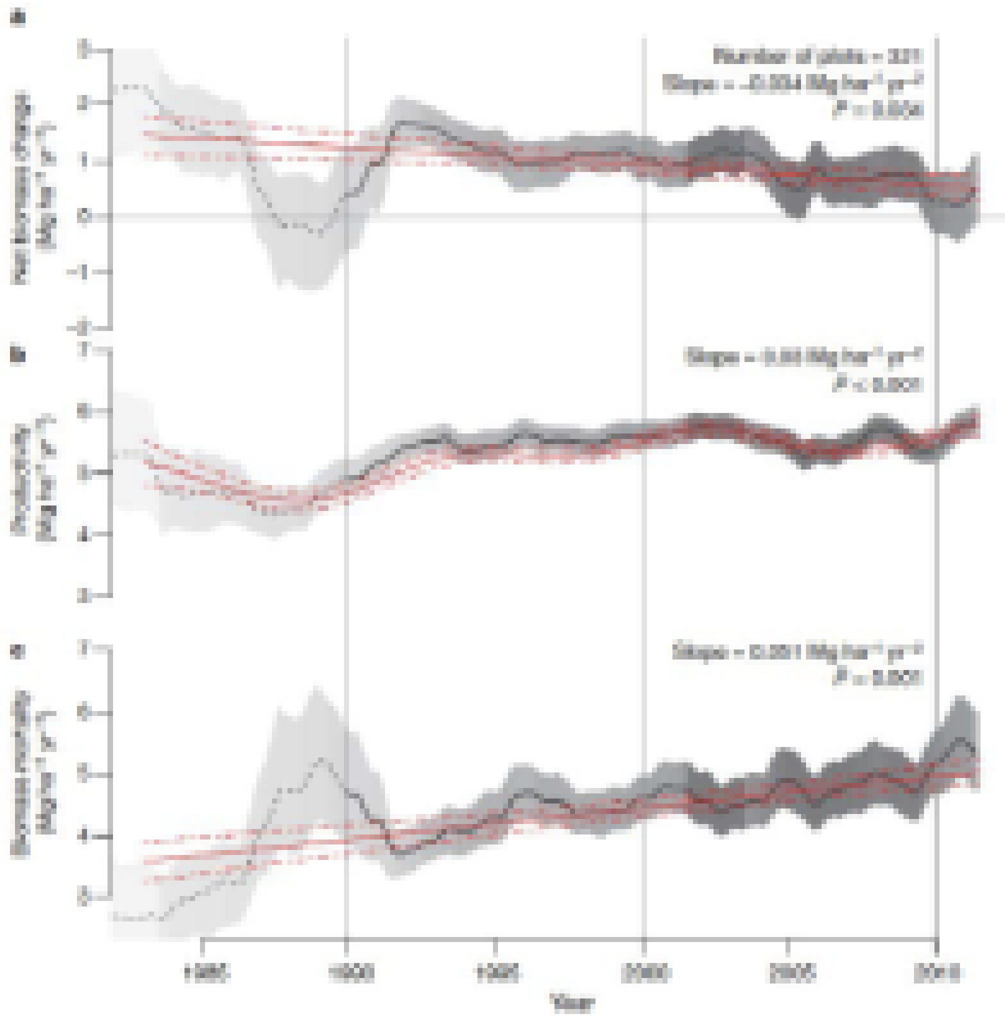


Ecosystem Model Data Model Intercomparison (EMDI) project

Satélites monitorando ciclo do carbono e variáveis acessórias



Carbon cycling: Amazonia stores about 120 Tg C. If only a small fraction goes to or from the atmosphere, large changes in atmospheric CO2 will occurs. How tropical forests processes affects carbon, water and energy fluxes?



(Brienen et al., 2015)

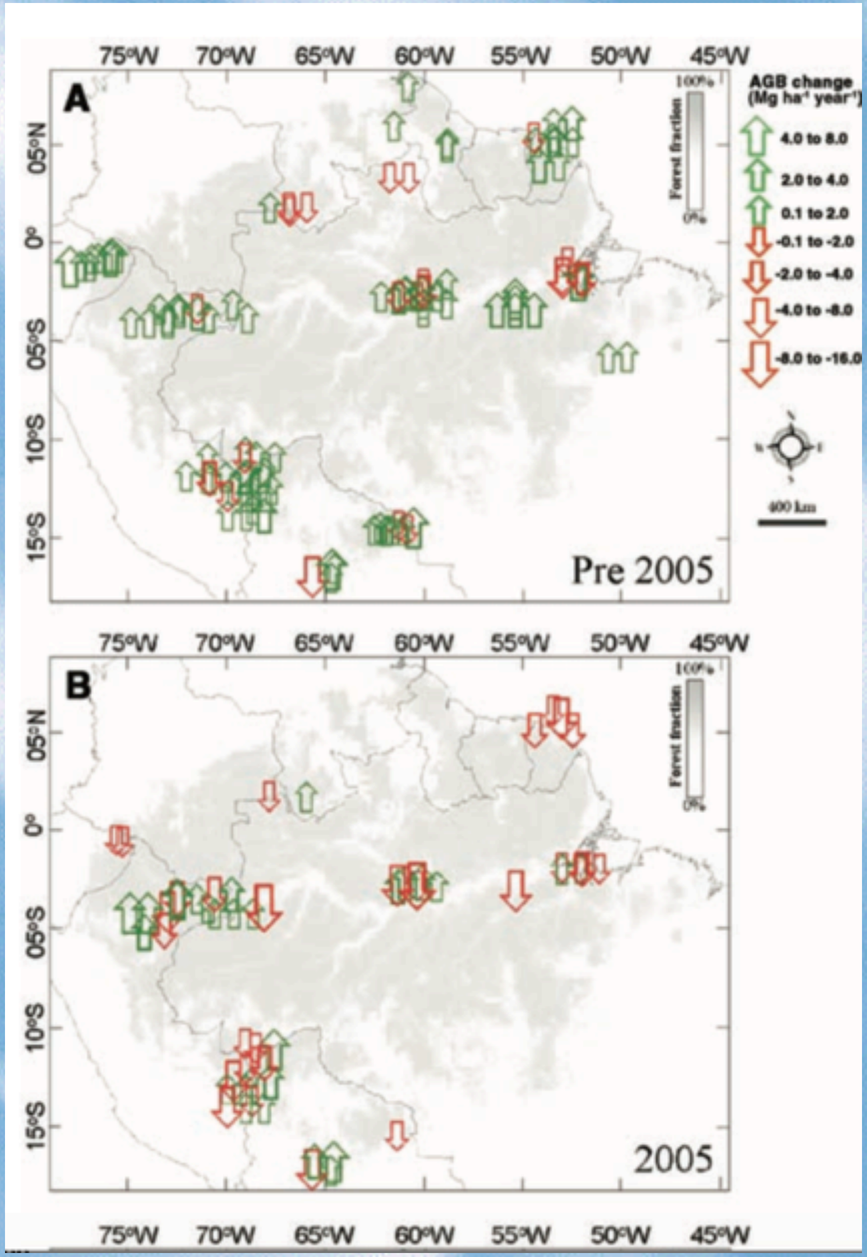
Net carbon flux: Today: ZERO

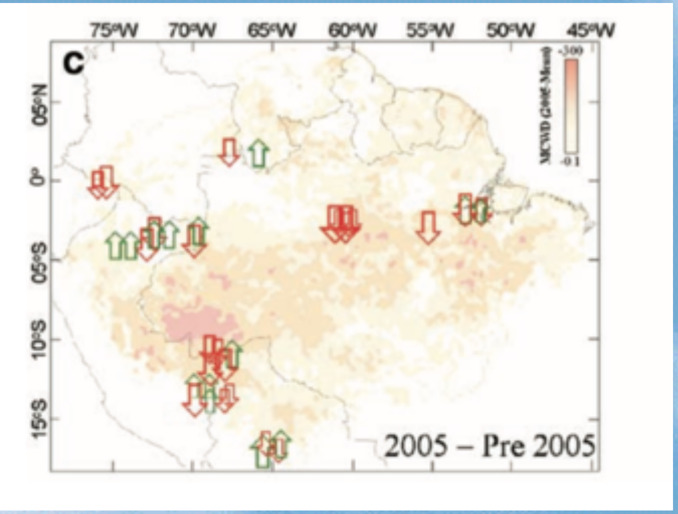
Tree mortality: significant INCREASE

Above ground biomass and drought sensitivity (2005)

ABG Change Pre 2005

ABG Change in 2005

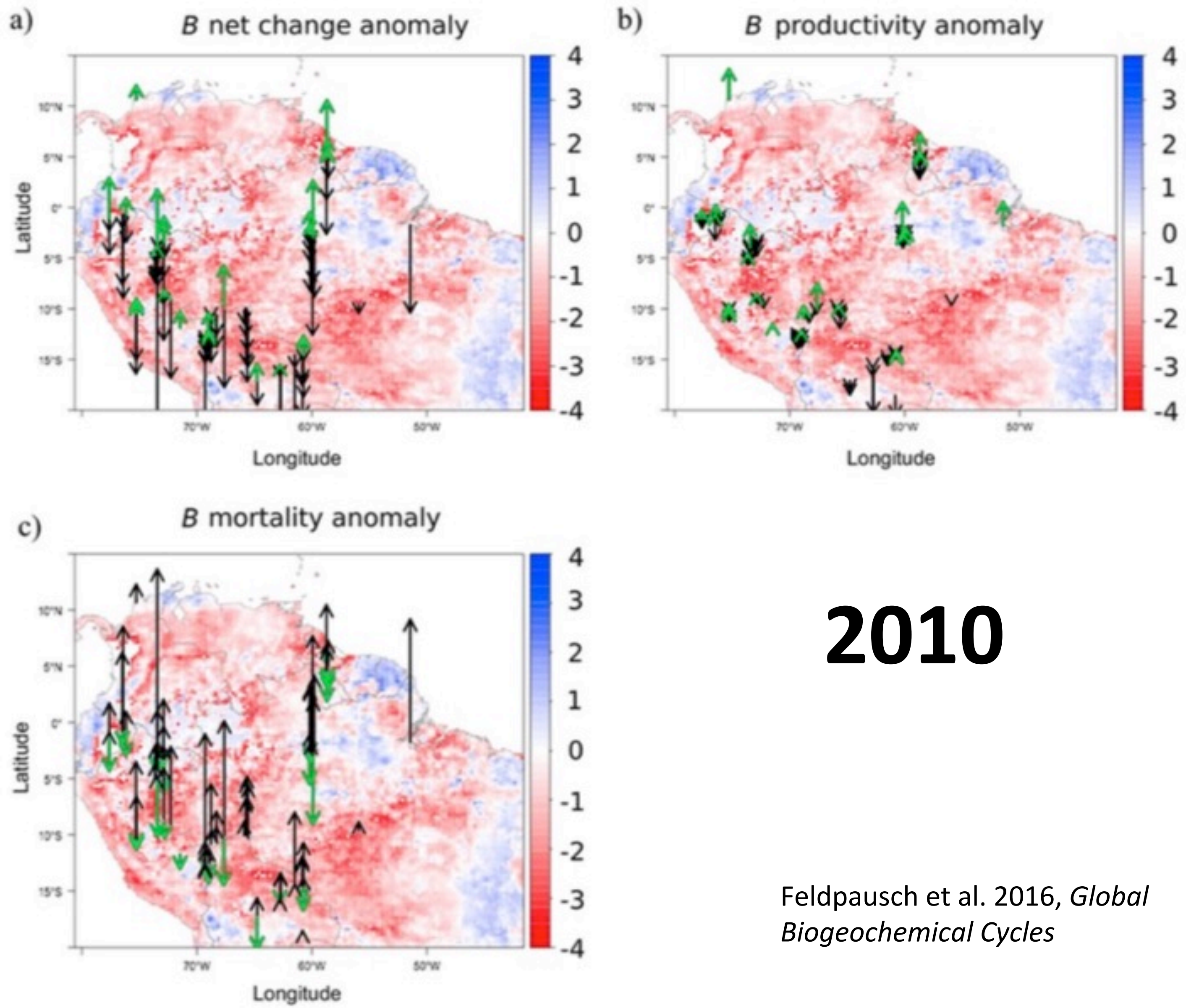




2005 – Pre 2005

Phillips et al., 2009, Science

Above ground biomass and drought sensitivity (2010)



2010

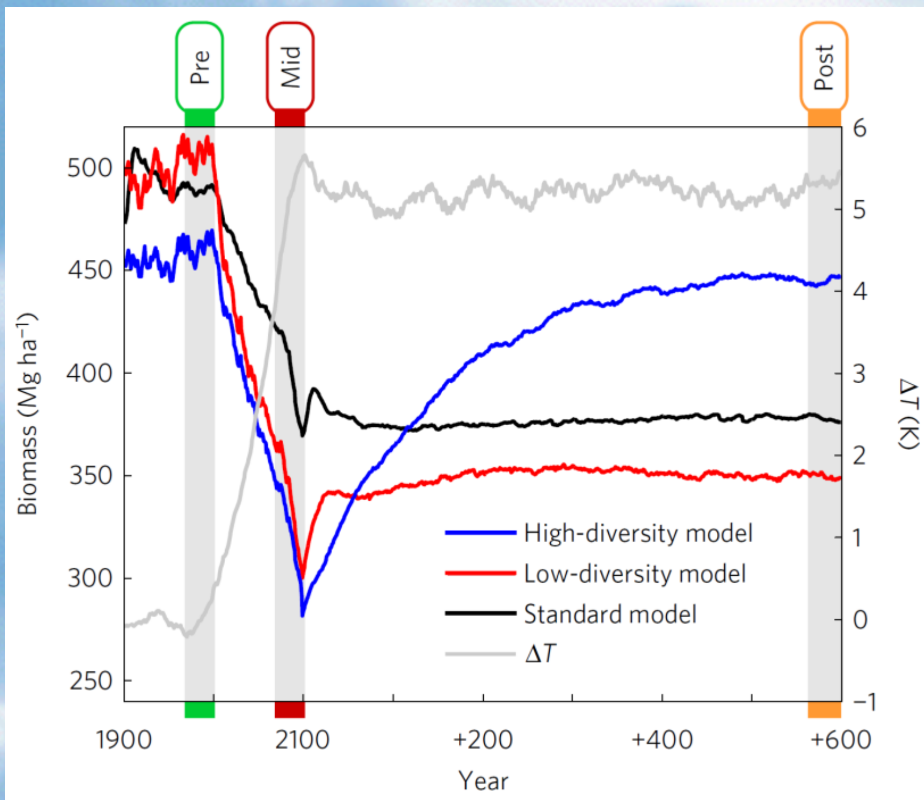
Feldpausch et al. 2016, *Global Biogeochemical Cycles*

Simulated rainforest biomass under climate change and different plant trait diversity

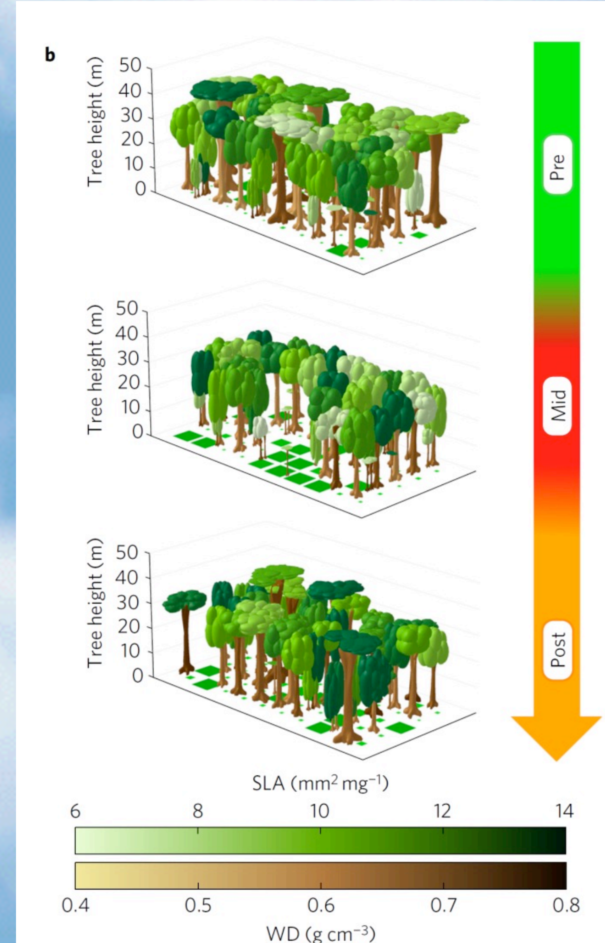
nature climate change
LETTERS
PUBLISHED ONLINE: 29 AUGUST 2016 | DOI: 10.1038/NCLIMATE3109

Resilience of Amazon forests emerges from plant trait diversity

Boris Sakschewski[1,2]*, Werner von Bloh[1,2], Alice Boit[1,2], Lourens Poorter[3], Marielos Peña-Claros[3], Jens Heinke[1,2], Jasmin Joshi[4] and Kirsten Thonicke[1,2]

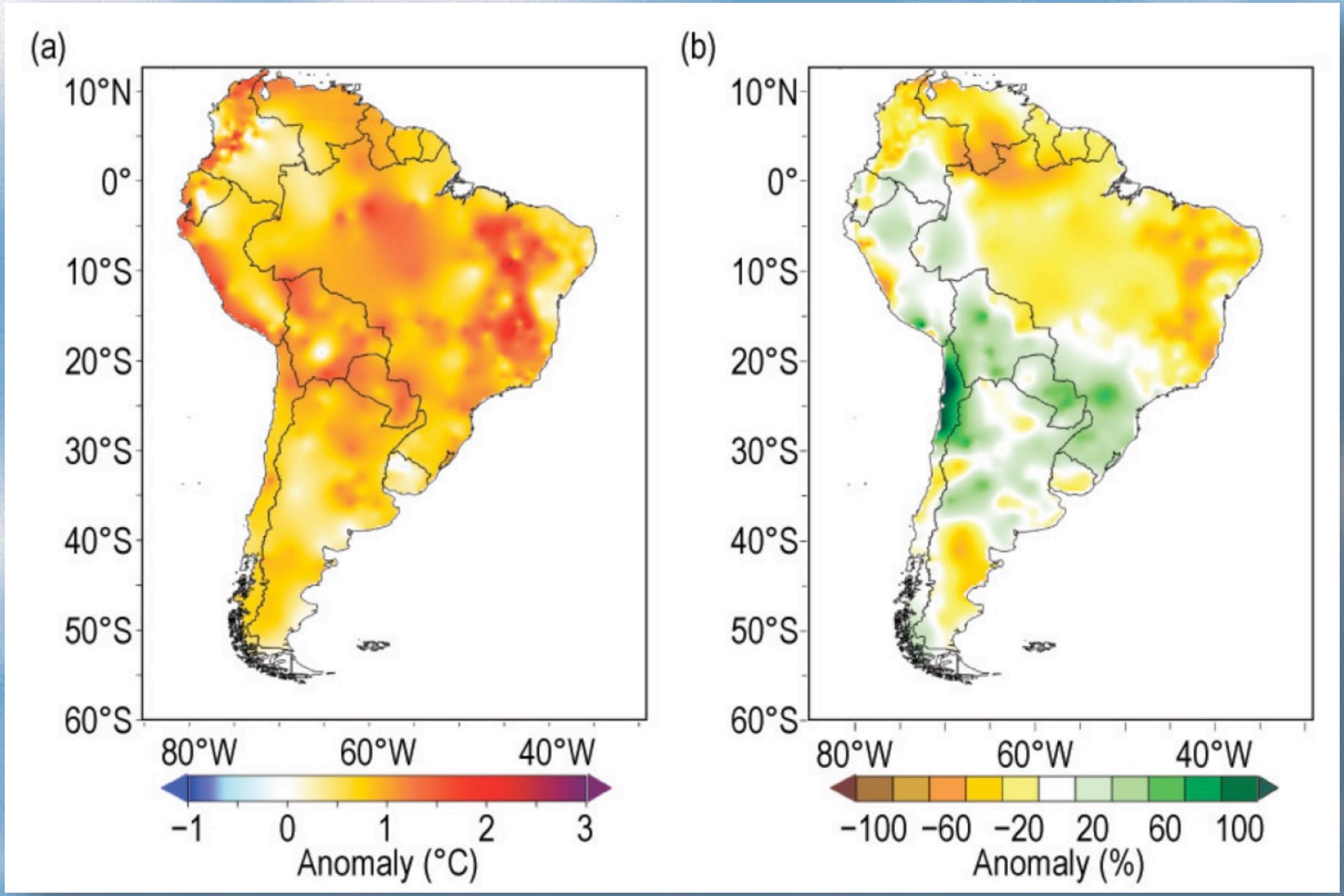


Annual biomass over 800 simulation years for 400 ha of Ecuadorian rainforest from three different versions of the vegetation model LPJmL under a severe climate change scenario (RCP 8.5 HadGEM2). 1*T*: annual temperature difference to the mean temperature of pre-impact time (1971–2000) in K.



Forest height structure recovers with biomass. Visualization of model output showing 0.5 ha of the 400 ha of Ecuadorian rainforest in a selected year during pre-, mid-, and post-impact time, respectively (top to bottom). Different crown (stem) colors denote different SLA (WD) values of individual trees.

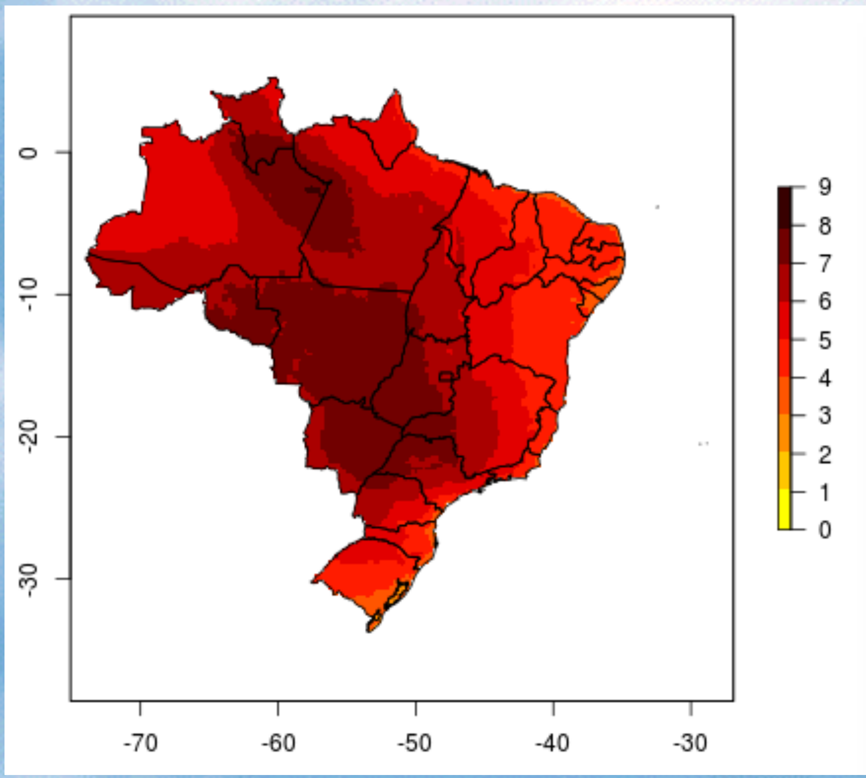
South American (a) temperature anomalies (°C) and (b) precipitation anomalies



base period: 1981–2010.

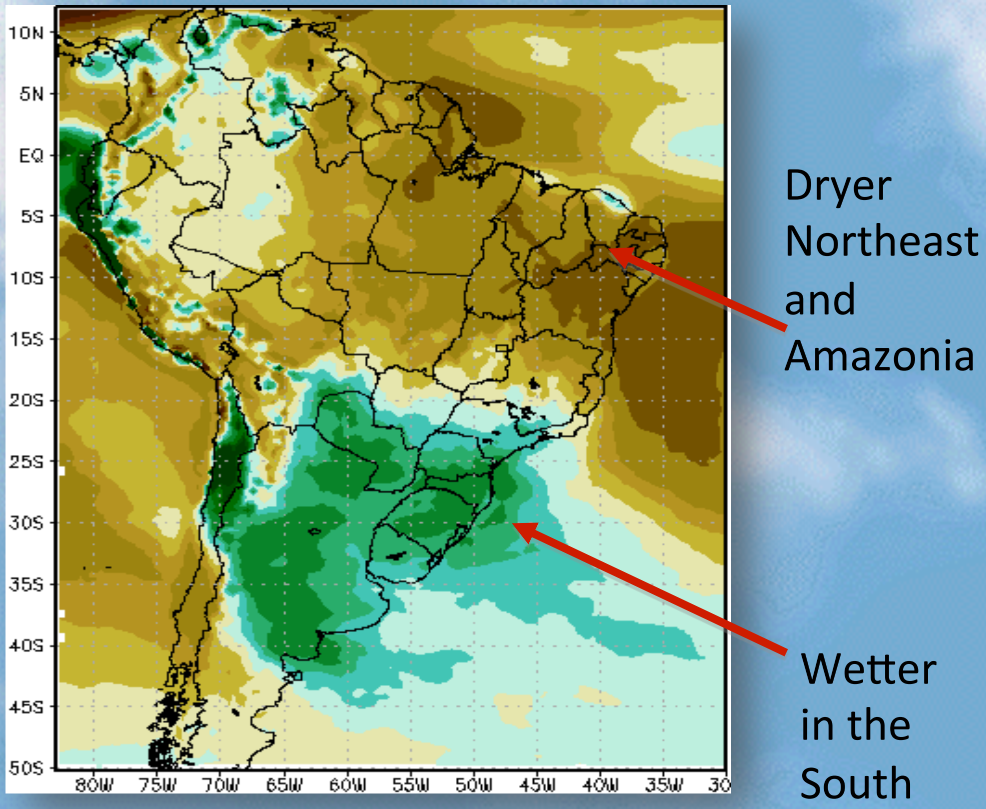
Source 2016: State of the Climate in 2015, Bull. Amer. Meteor. Soc., 97 (8), 2016.

Average increase in temperature expected for Brazil under RCP8.5



2071-2100

Changes in precipitation expected for 2071-2100



INPE, (RCP 8.5)

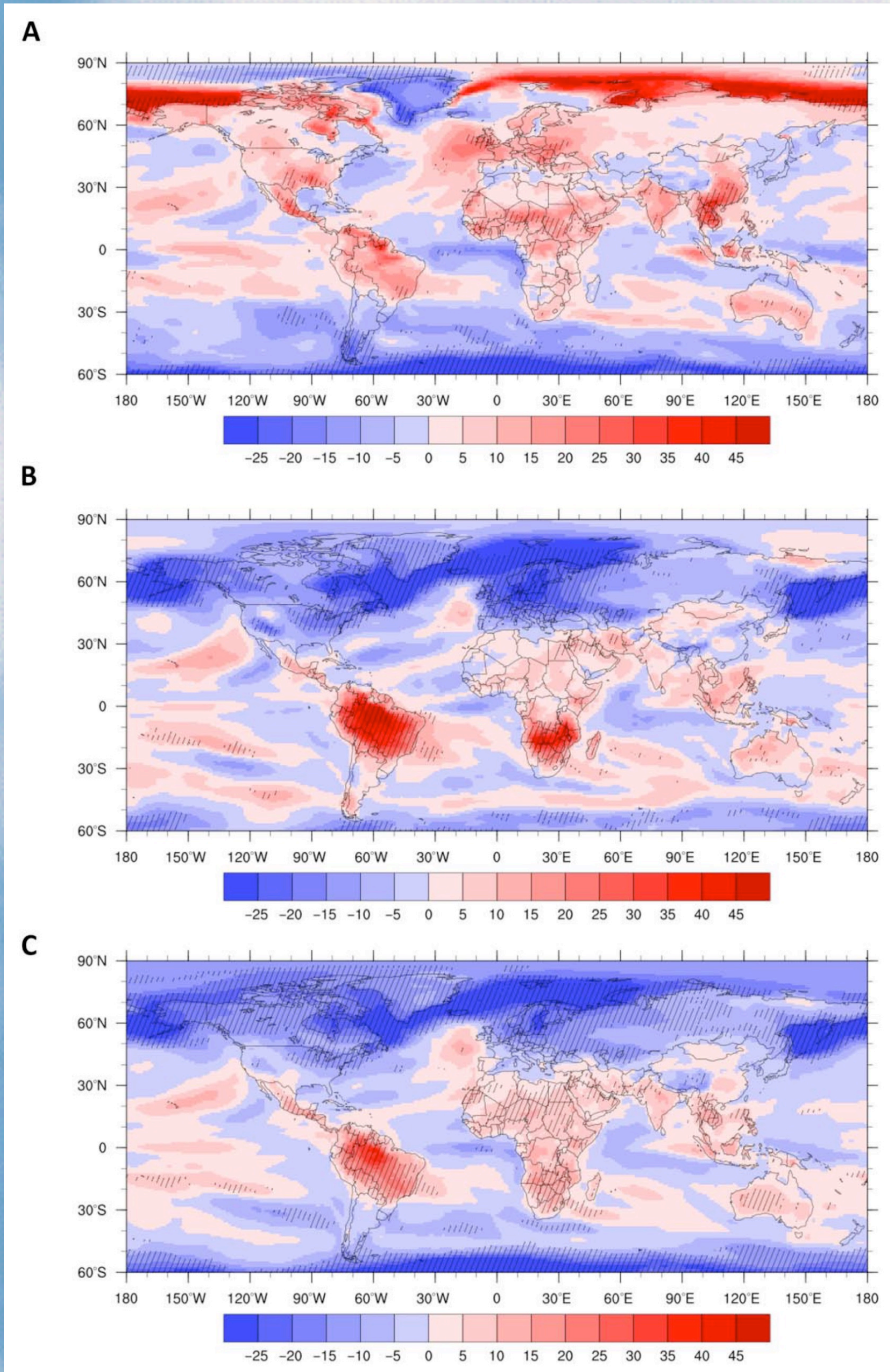
Climate models predict increasing <u>temperature variability</u> in poor countries

A) Boreal summer [JJA]

B) austral summer [DJF]

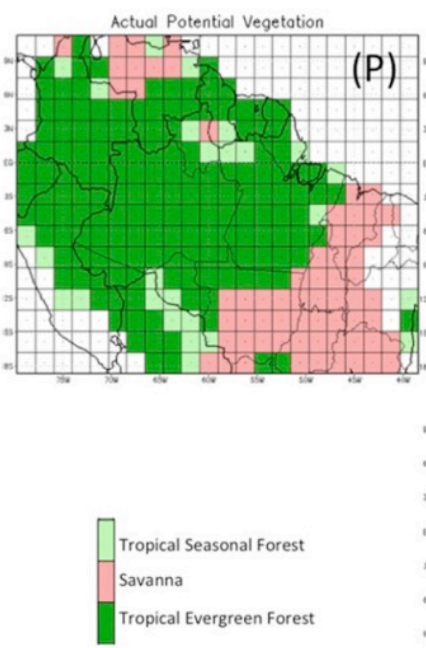
(C) the whole year

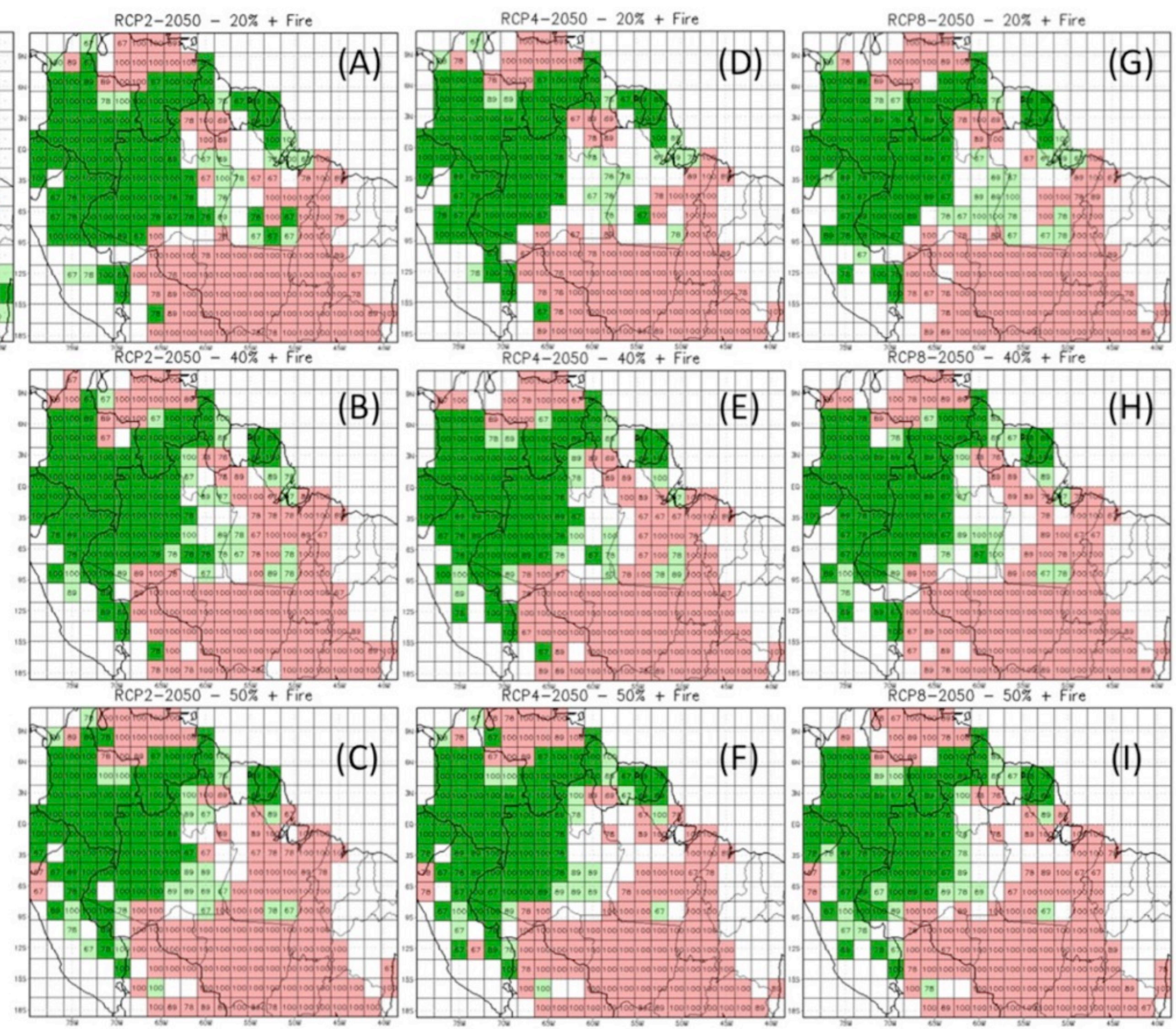
Relative changes of Standard Deviation of monthly temperature anomalies until the end of the 21st century. Averaged over 37 climate models



Bathiany et al., Sci. Adv. 2018;4: May 2018

Projected distribution of natural biomes for RCP 2.4, 4.5 and 8.5. Deforestation scenarios for 20%, 40% and 50% + Fire effect

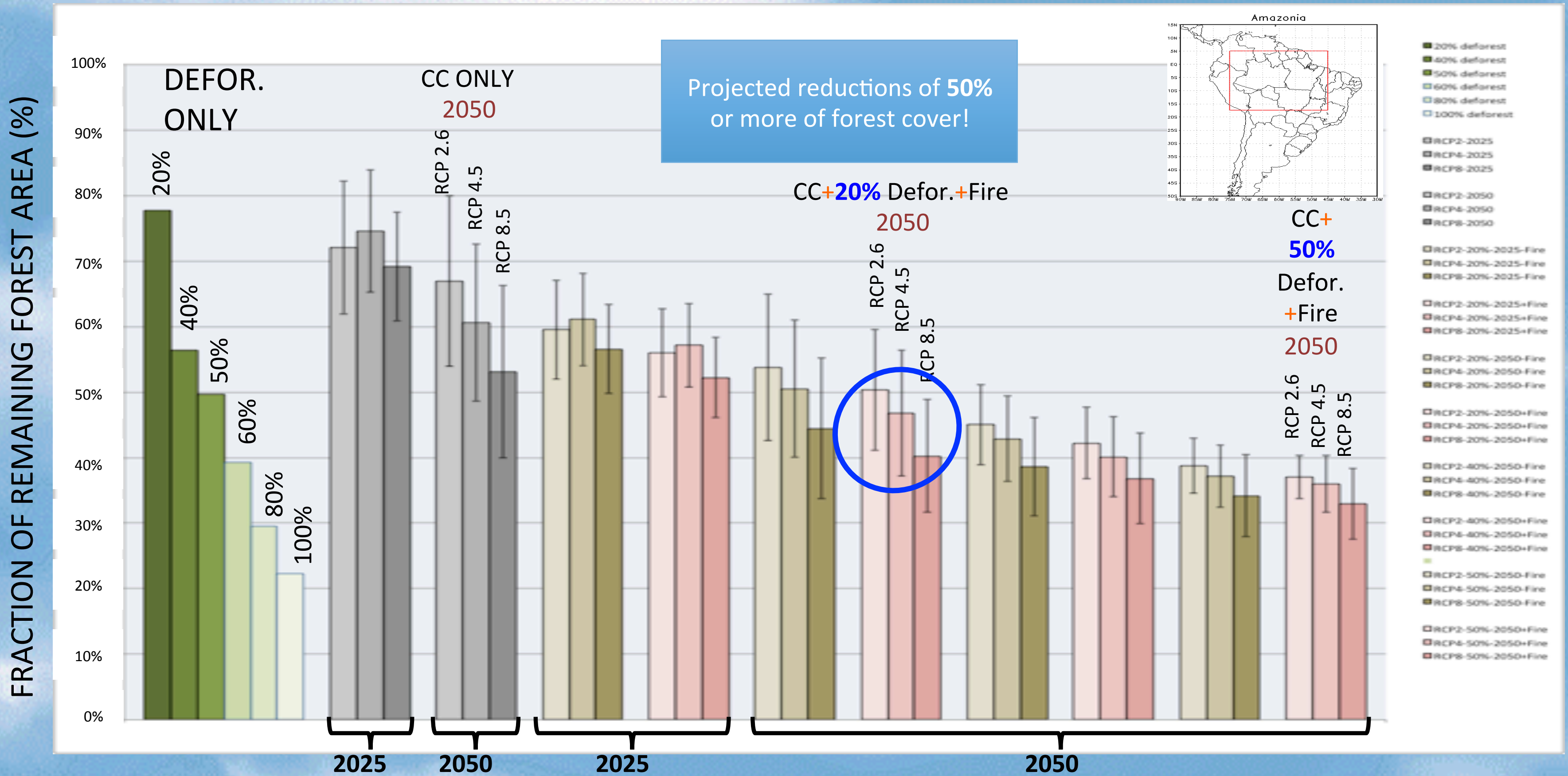




We believe that the sensible course is not only to strictly curb further deforestation, but also to build back a margin of safety against the Amazon tipping point, by reducing the deforested area to less than 20%, for the commonsense reason that there is no point in discovering the precise tipping point by tipping it.

Nobre et al., PNAS, 2016

FRACTION OF THE REMAINING FOREST AREA FOR THE ENTIRE AMAZONIA CLIMATE CHANGE PROJECTIONS – CMIP5 – 9 EARTH SYSTEM MODELS



Nobre et al., 2016 PNAS

'TIPPING POINTS' OF FOREST-CLIMATE EQUILIBRIUM IN THE AMAZON

A) Tropical forest in equilibrium with current climate

One stable equilibrium state

Amazon covered mostly by forests

B) Savanna state triggered by climate change and/or deforestation

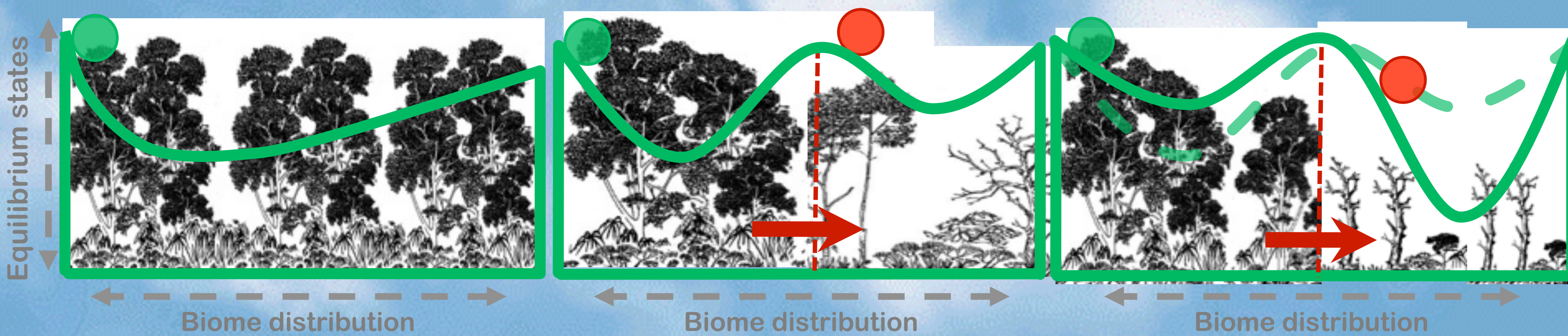
Two stable equilibrium states

Forests in the West

Savannas in the East-Southeast

C) Stability of second equilibrium state

Savanna enhanced by increased /intensity of droughts and forest fires

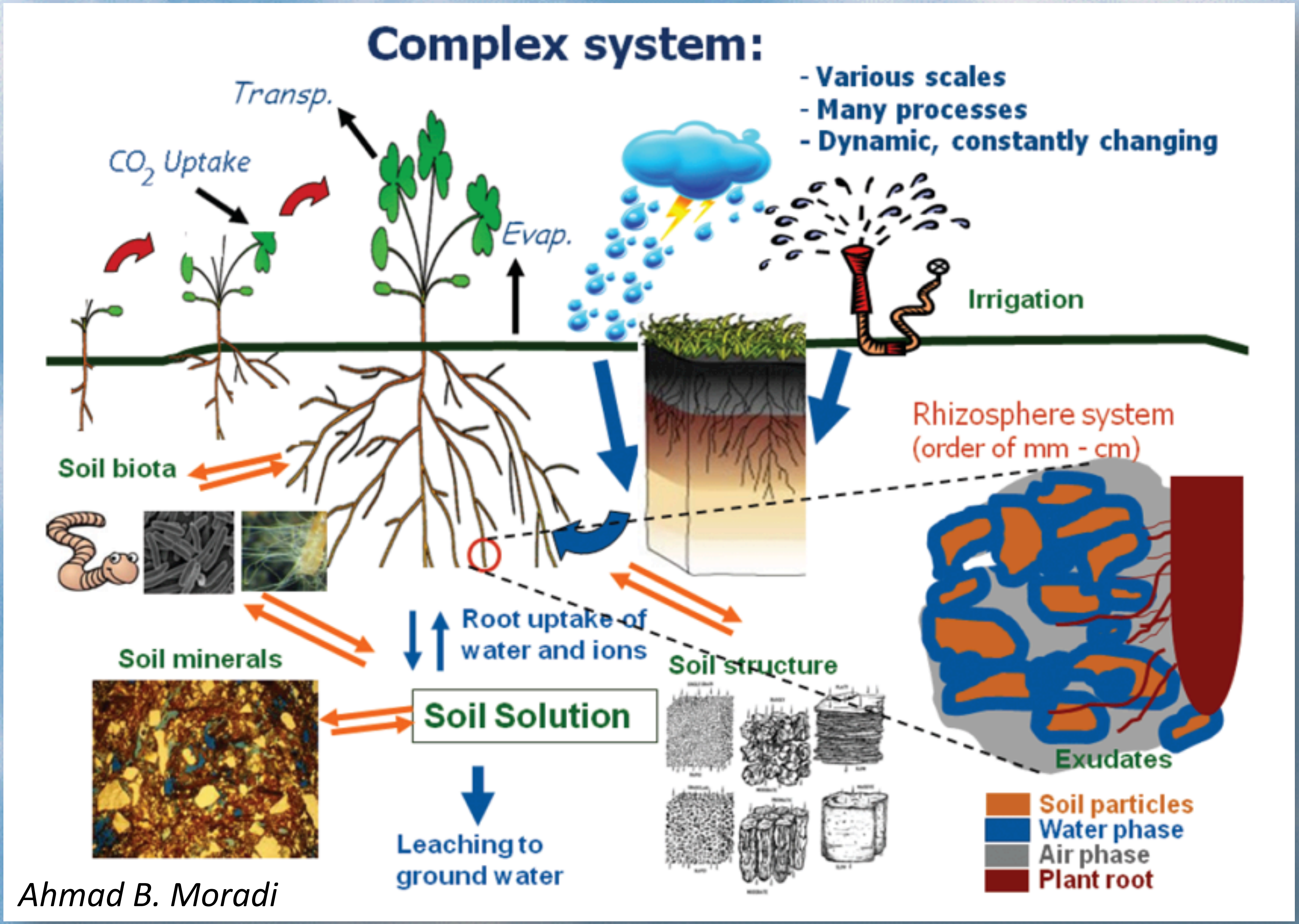


Thresholds for tipping
from state A to state B ≈ 4ºC Amazon warming or
≈ 40% of total deforested area

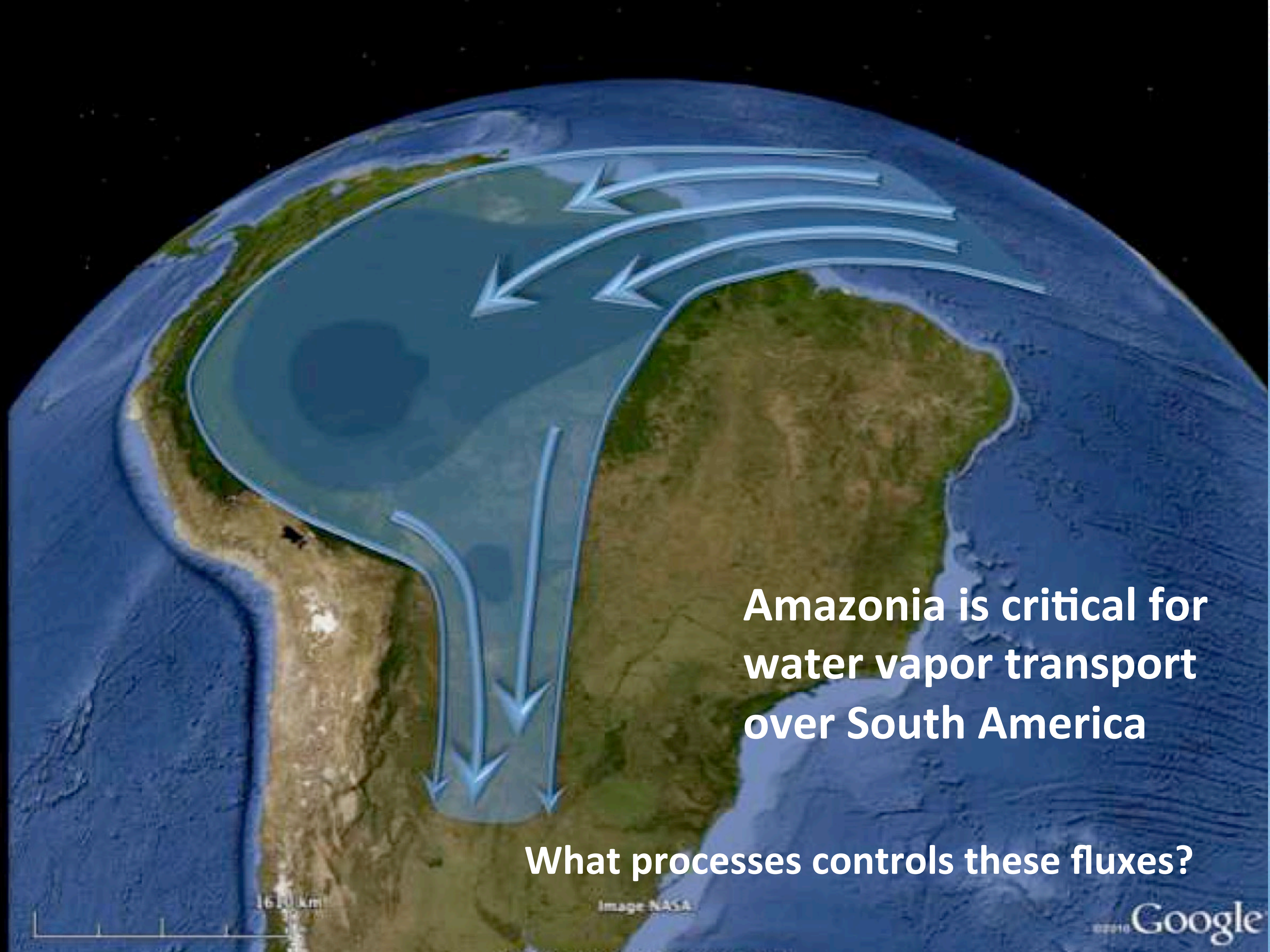
- Observations: ΔT ≈ 1.1 to 1.5ºC
- Deforestation: ≈ 18%
- Forest fire frequency (increasing)
- Lengthening of dry season (increasing)
- Increasing climate extremes

Adapted from Cardoso and Borma, 2010; Borma, Nobre and Cardoso, 2013, Nobre et al., 2015, 2016

O complexo sistema solo-planta-atmosfera



Hydrological cycle critical for Amazonia

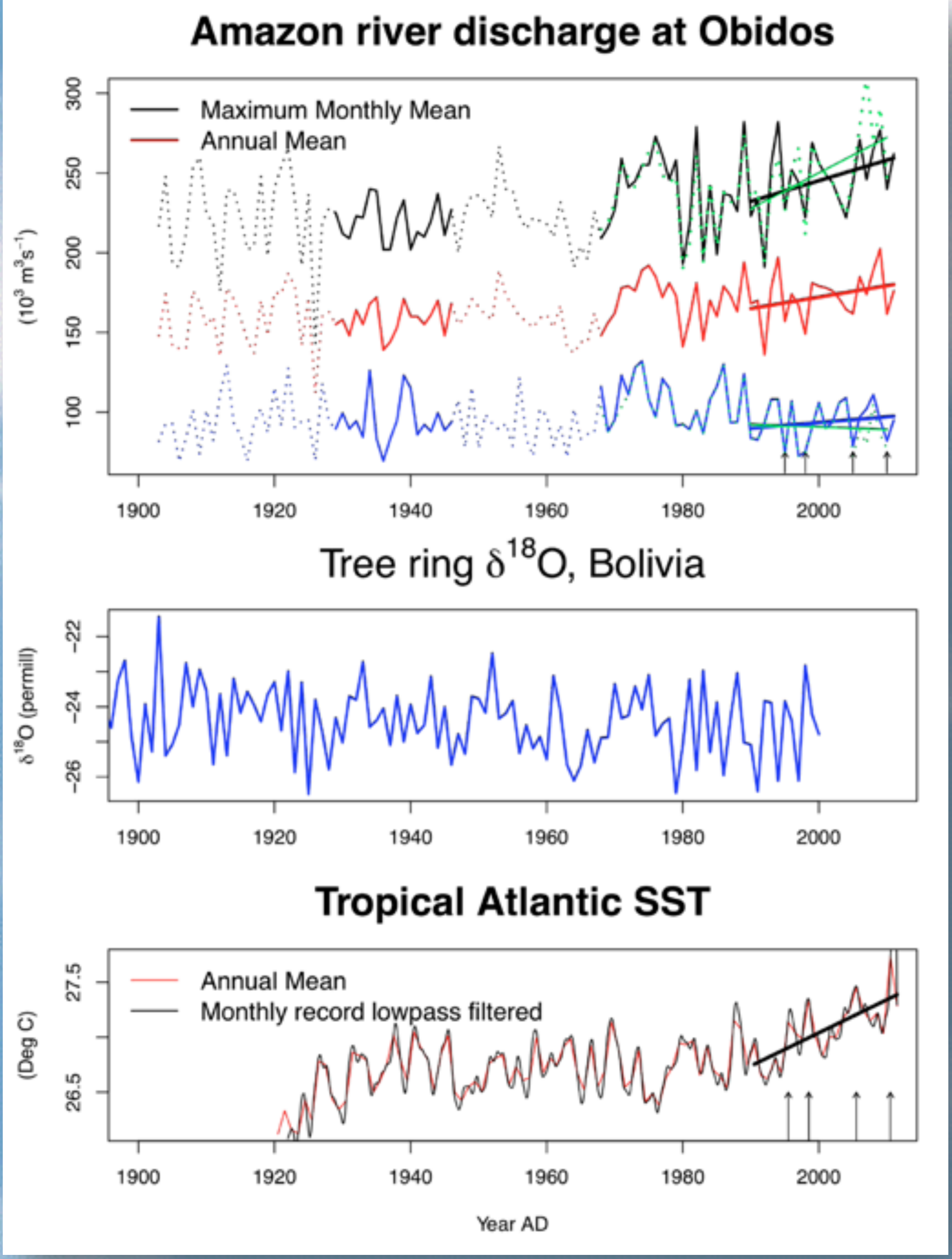


Amazonia is critical for water vapor transport over South America

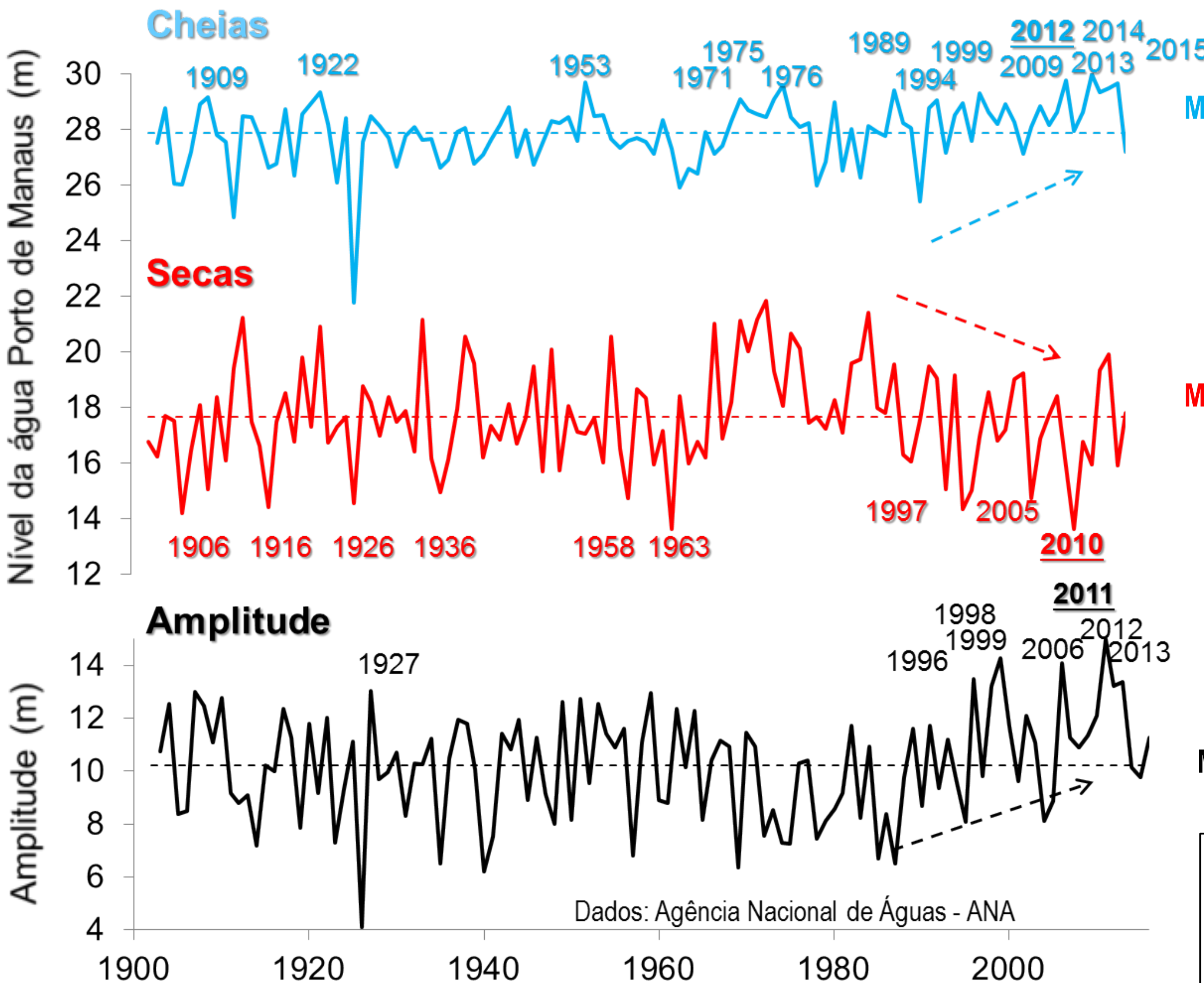
What processes controls these fluxes?

Is the Amazonian hydrological cycle intensifying?

Maximum monthly, annual mean and minimum monthly mean Amazon river discharge at Óbidos and in green maximum and minimum daily mean river discharge, (b) $\delta^{18}O$ in precipitation in Bolivia derived from tree rings (Brienen et al. 2012) and (c) tropical Atlantic sea surface temperature from Extended reconstructed sea surface temperature) (Gloor et al. 2013).



Níveis de água máximos (1903-2016), mínimos (1902-2016) e amplitudes (1903-2016) anuais no Porto de Manaus



Média: 27,87±1,15 m

Média: 17,66±1,83 m

Média: 10,21±2,04 m

Anos calendários indicam cheias extremas (>29 m), secas severas (<15 m) e grandes amplitudes anuais (>13 m), valores máximos em **negrito**

Jochen Schöngart, 2017

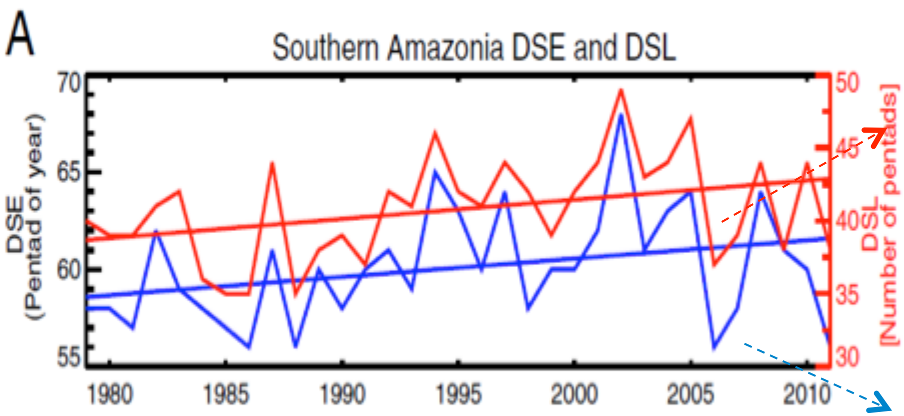
THE AMAZON CLIMATE SYSTEM HAS BEEN OSCILLATING BETWEEN TWO EXTREMES IN THE LAST 13 YEARS

2005
2010
2015/16 (El Niño-related)

2009
2012
2014 (over SW Amazon)

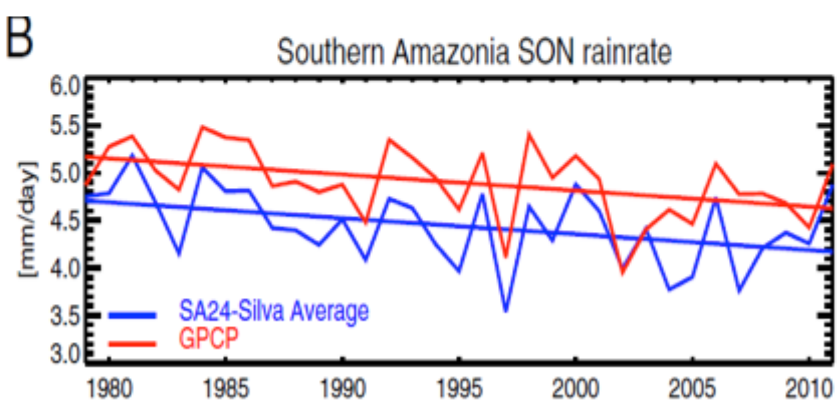
Carlos Nobre, 2018

Dry season length is increasing in Amazonia



Annual time series of **dry season length (DSL)**

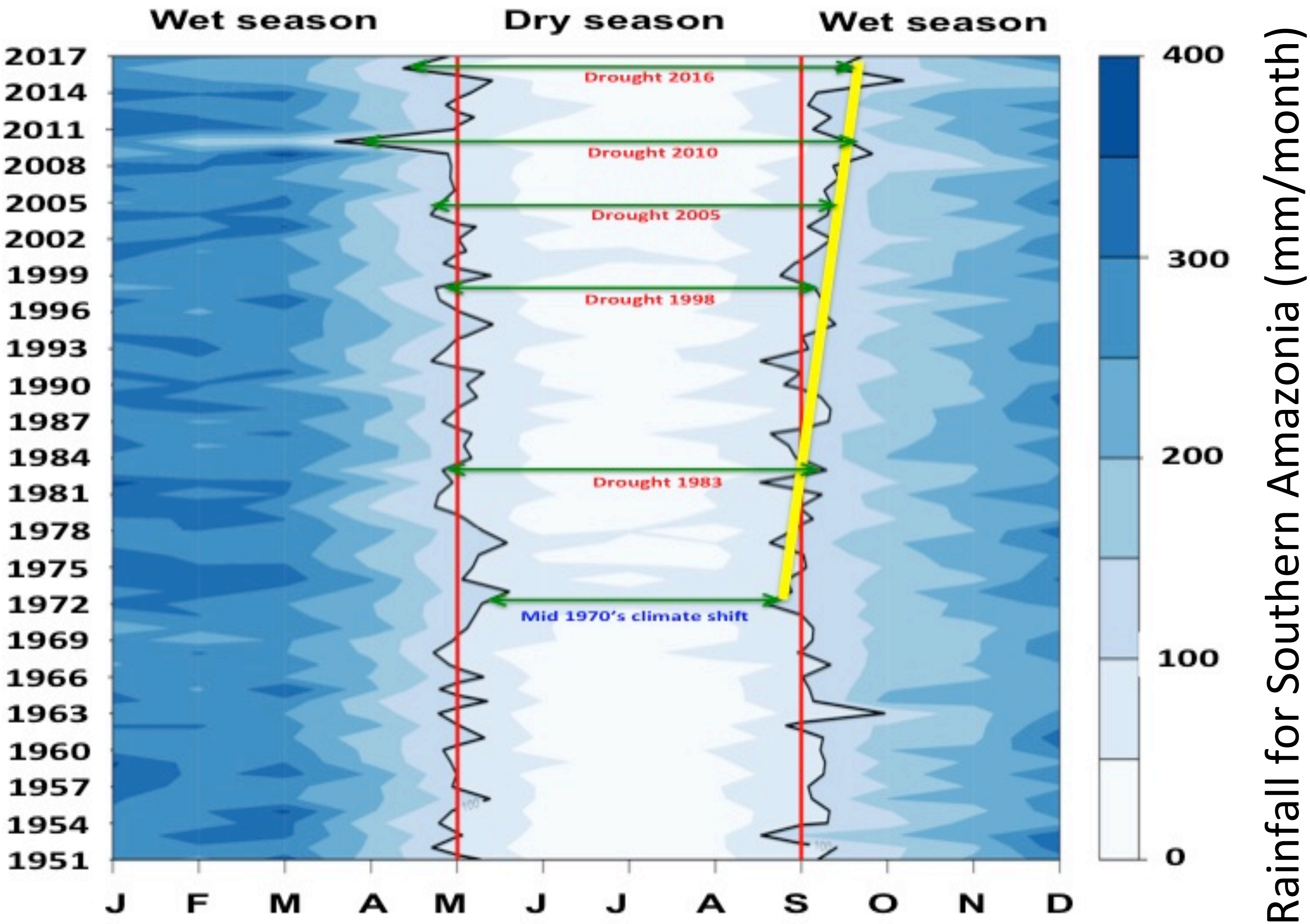
Annual time series of **dry season END (DSE)**



Dry season length has increased by **6.5±2.5** days/decade;

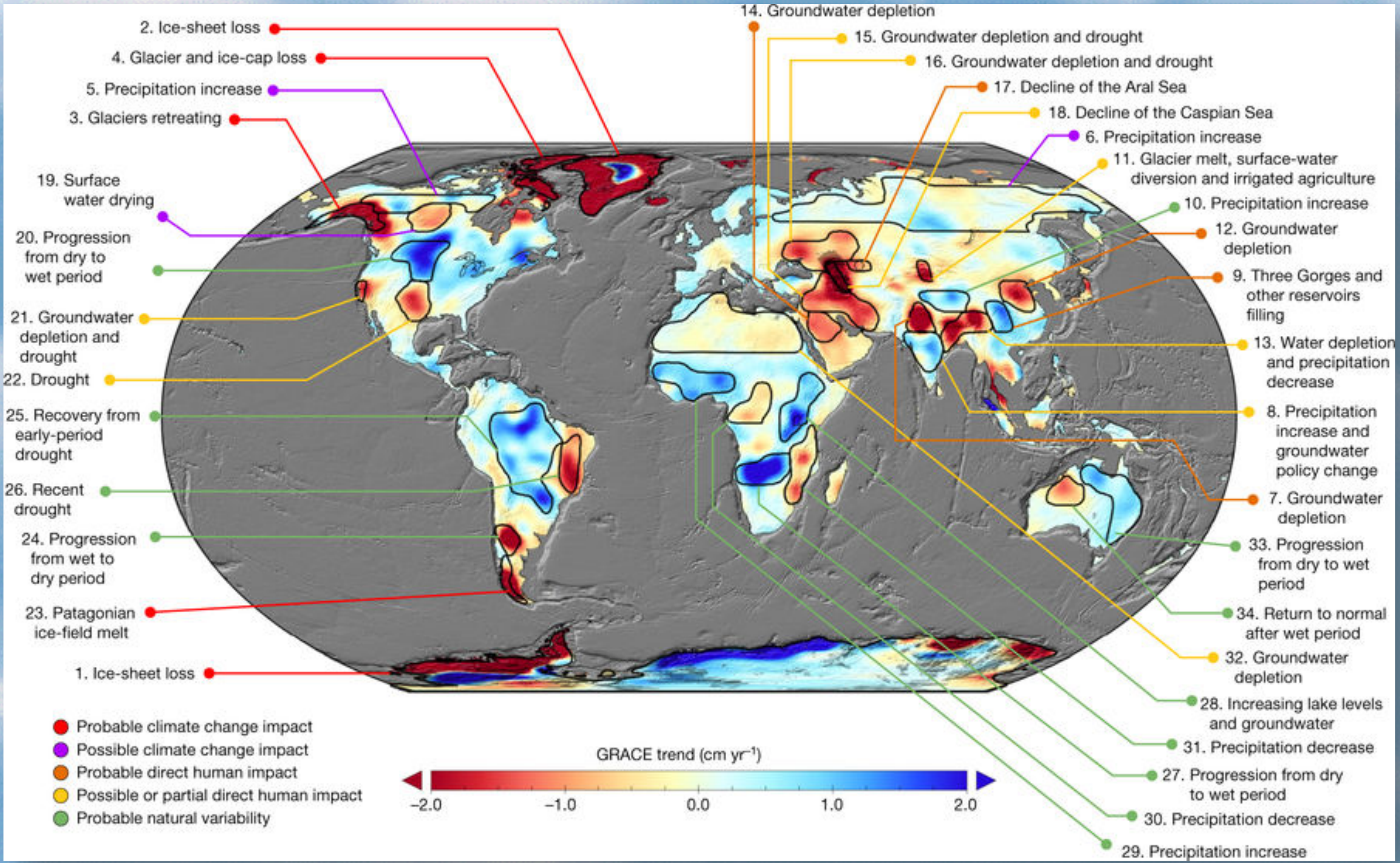
Fu et al. 2013 (PNAS)

A longer dry season in S. Amazonia from 1951 to 2017 (Marengo et al 2018)

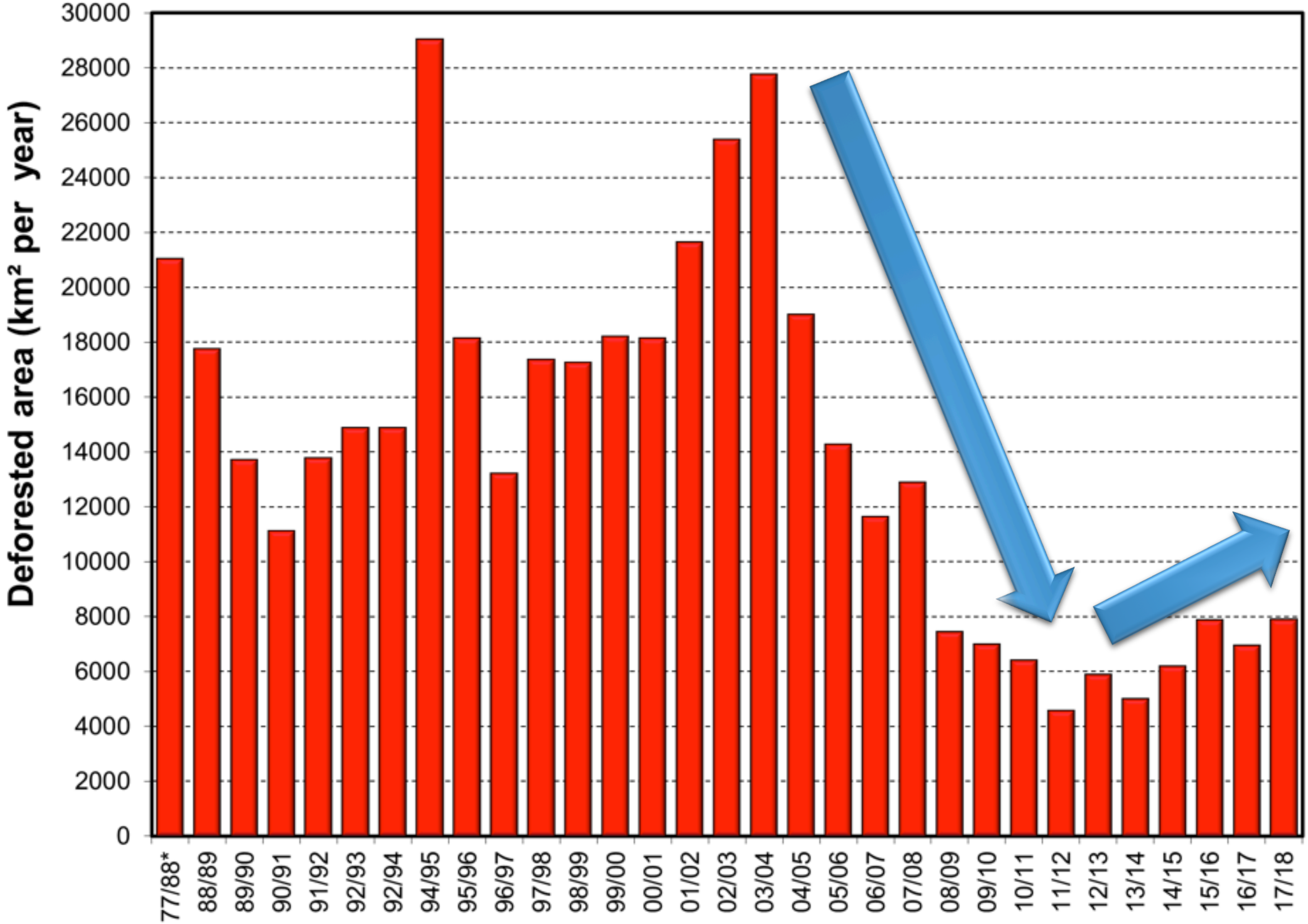


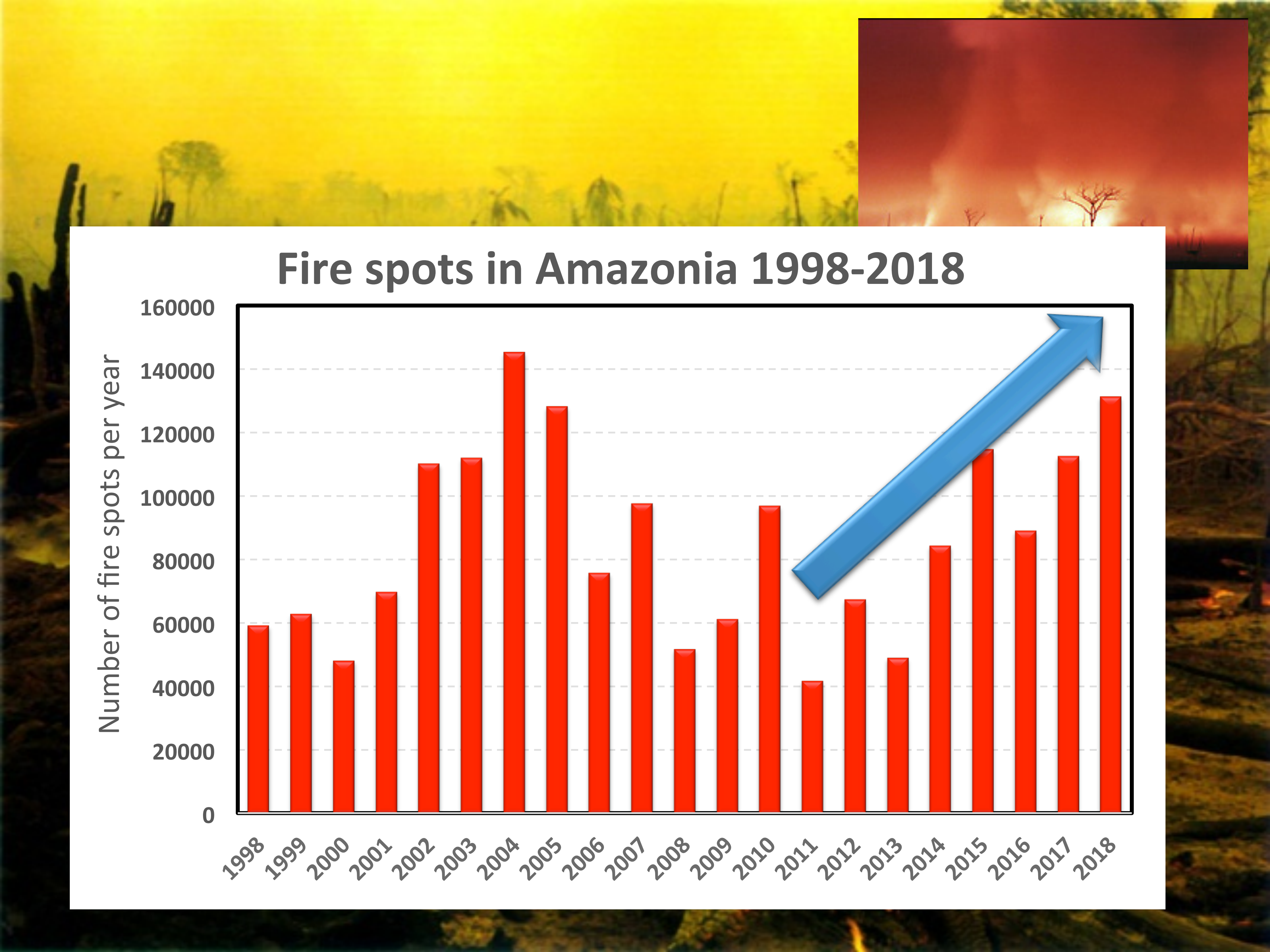
Freshwater availability is changing worldwide

Emerging trends in global freshwater availability GRACE 2002-2016 (terrestrial water storage, Nature May 2018)



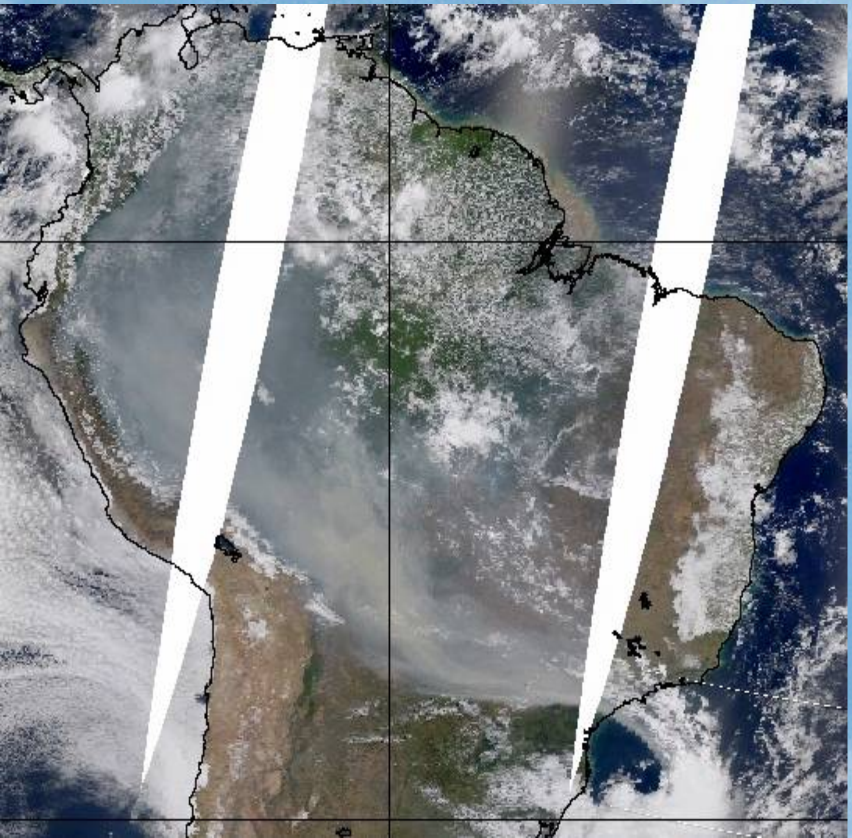
Deforestation in Amazonia 1977-2018 in km² per year

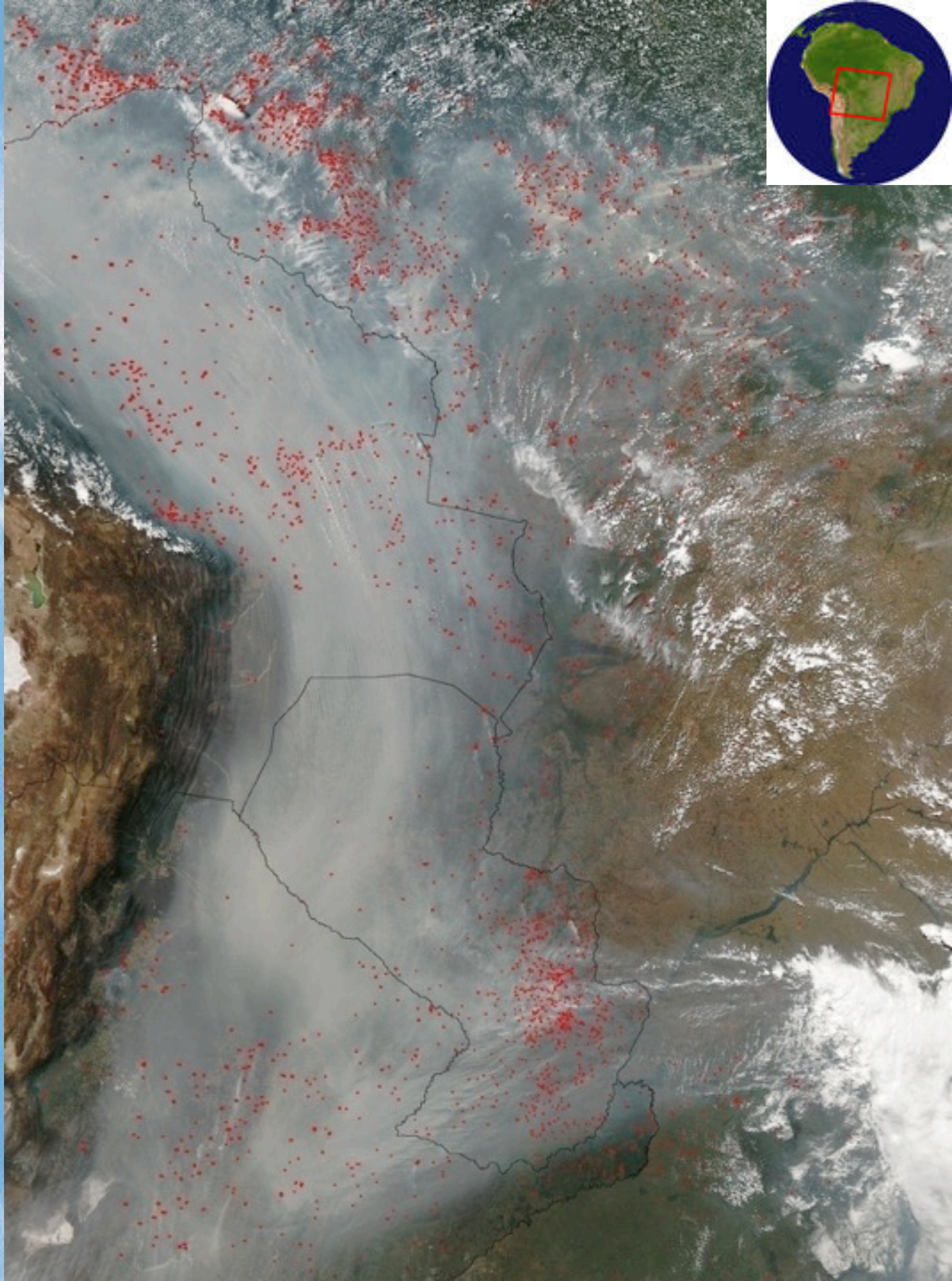



Fire spots in Amazonia 1998-2018
Number of fire spots per year
0
20000
40000
60000
80000
100000
120000
140000
160000
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018

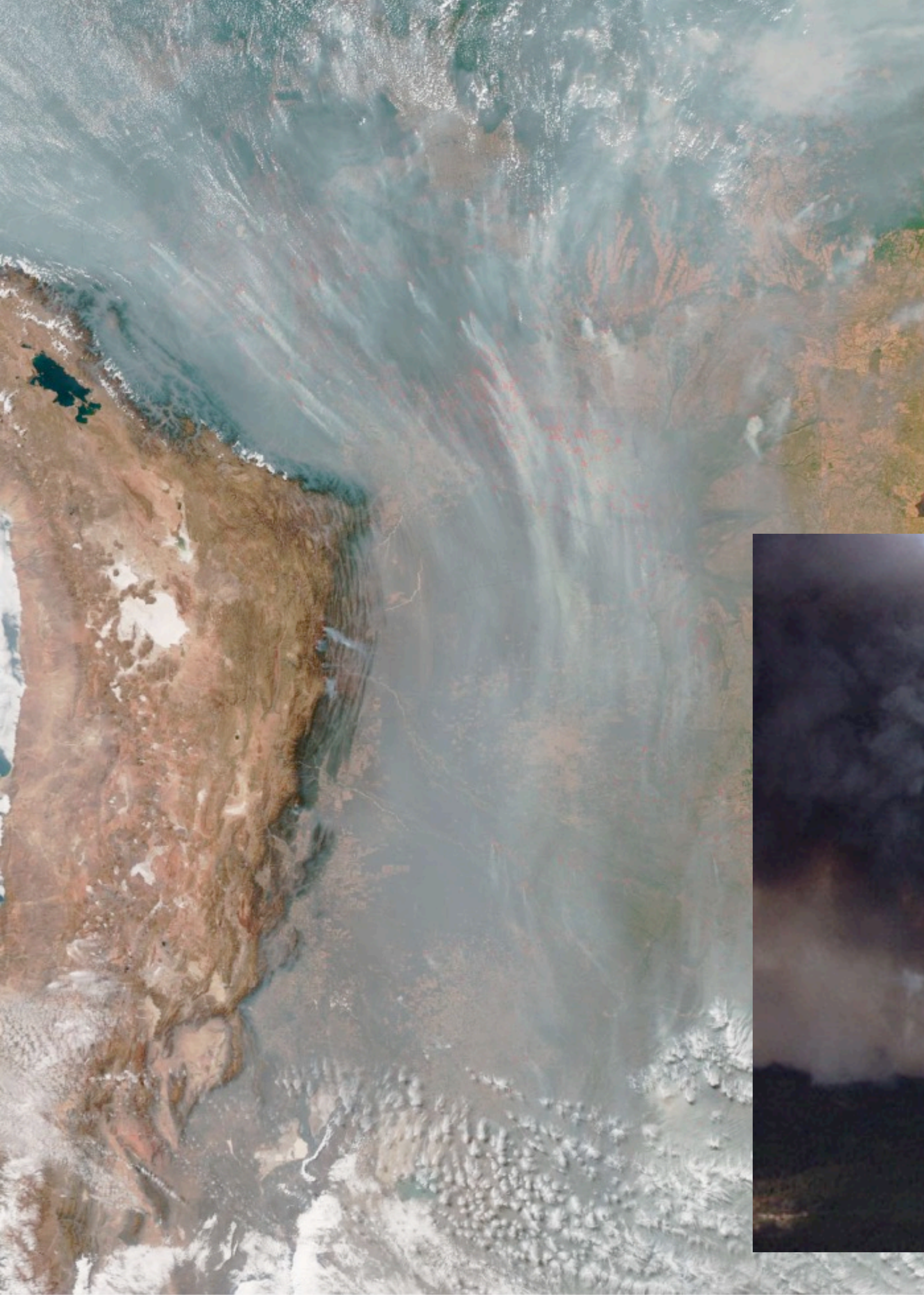
Large scale aerosol distribution in Amazonia

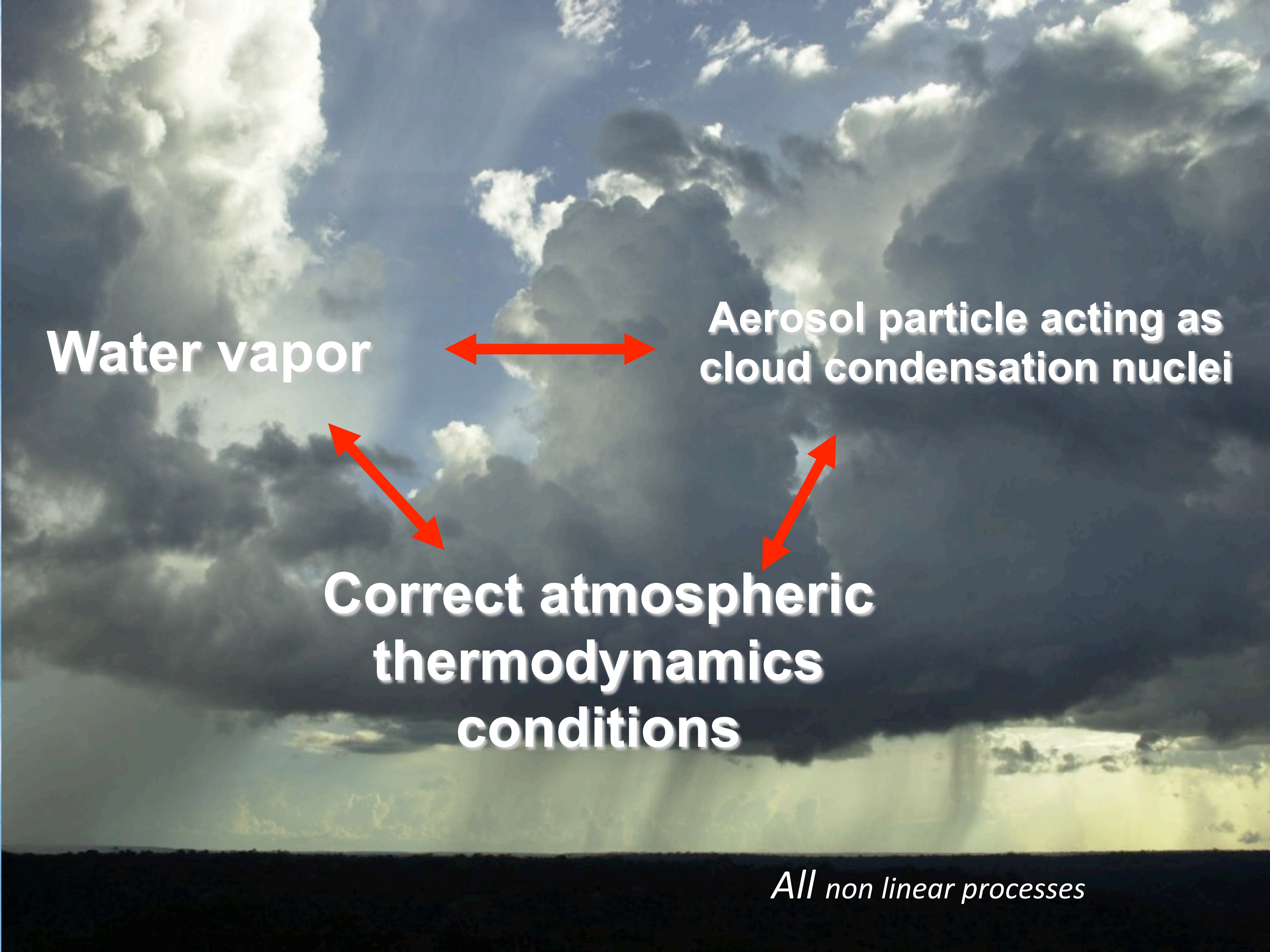
- Severe health effects on the Amazonian population (about 20 million people)
- Climatic effects, with strong effects on cloud physics and radiation balance.
- Changes in carbon uptake and ecosystem functioning





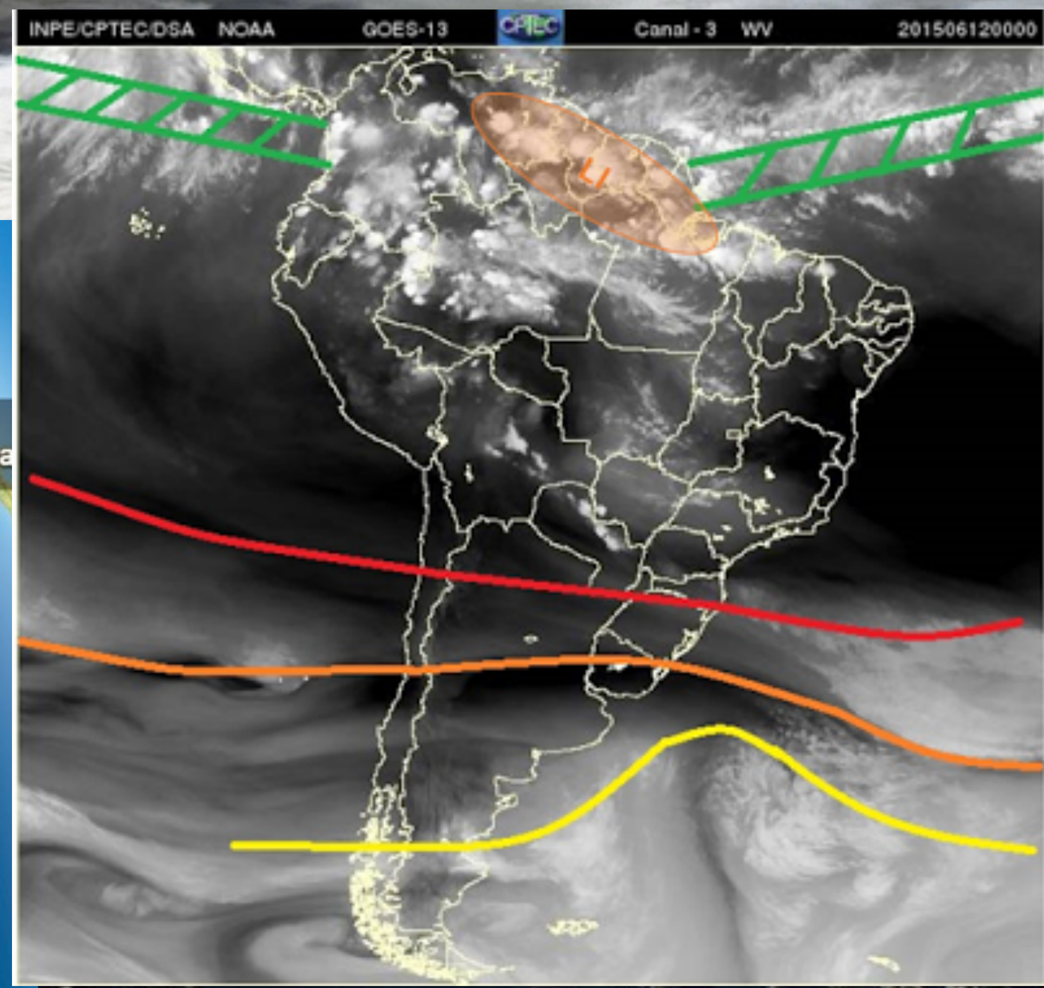
Aerosol emissions make the high variability visible – it also applies to aerosol composition and the trace gases!



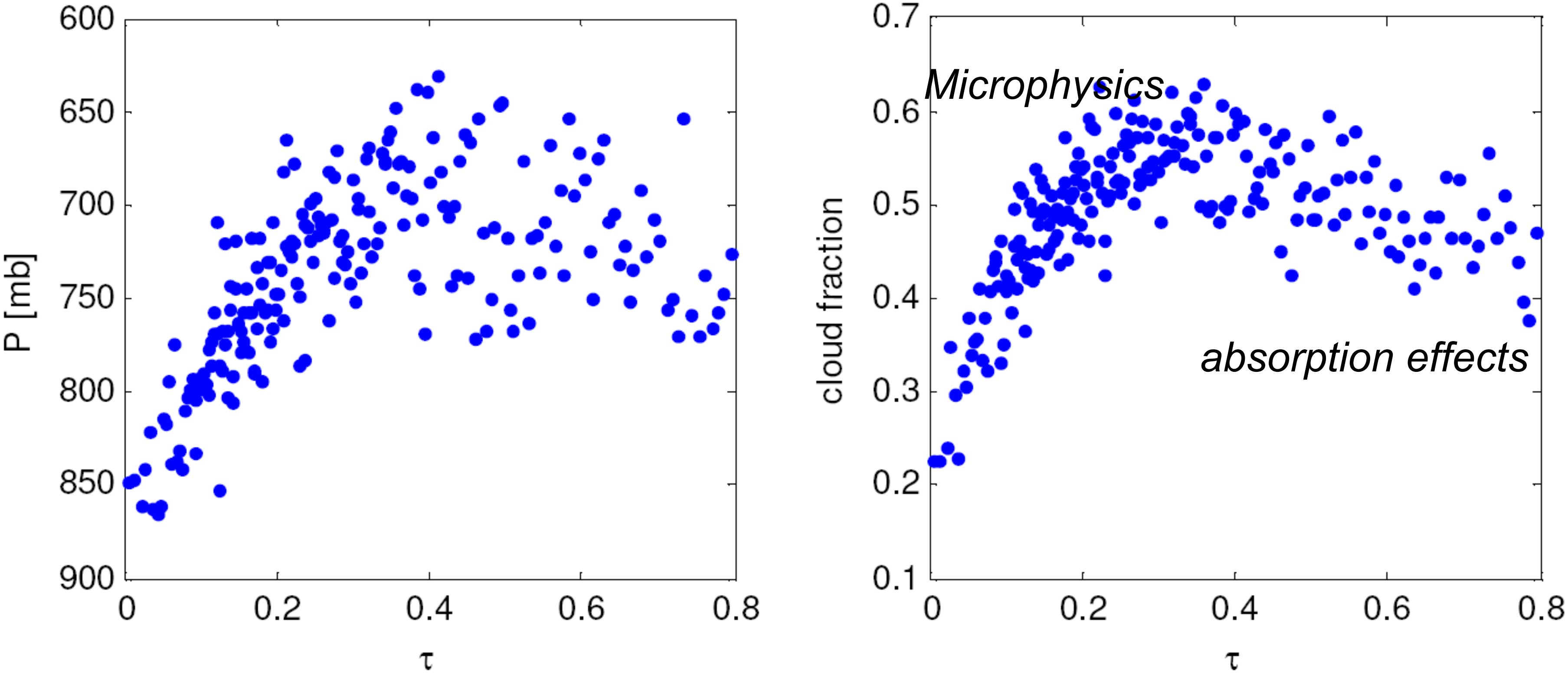


Water vapor
Aerosol particle acting as
cloud condensation nuclei
Correct atmospheric
thermodynamics
conditions
All non linear processes

Convective clouds: Key for radiation balance and precipitation



Cloud fraction and height as a function of aerosols in Amazonia



Cloud top pressure (P) vs. AOD

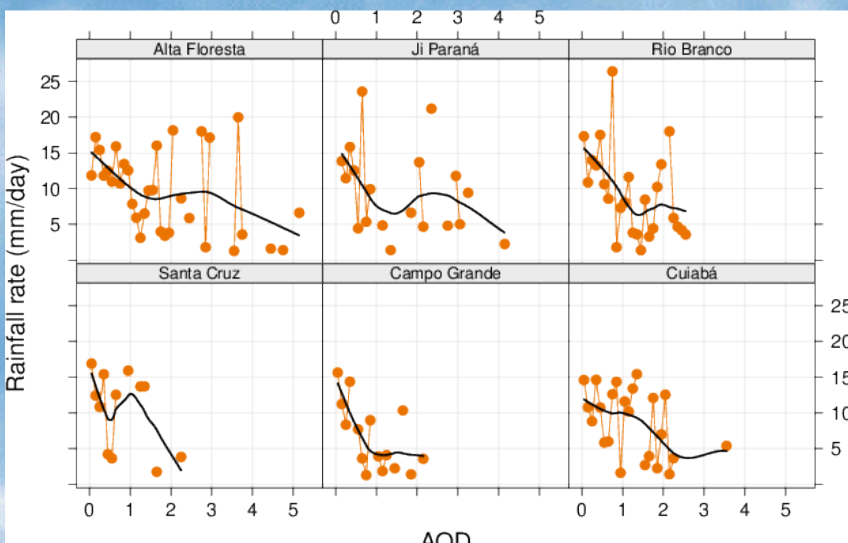
Cloud fraction vs. AOD.

Ilan Koren et al., Science 2008

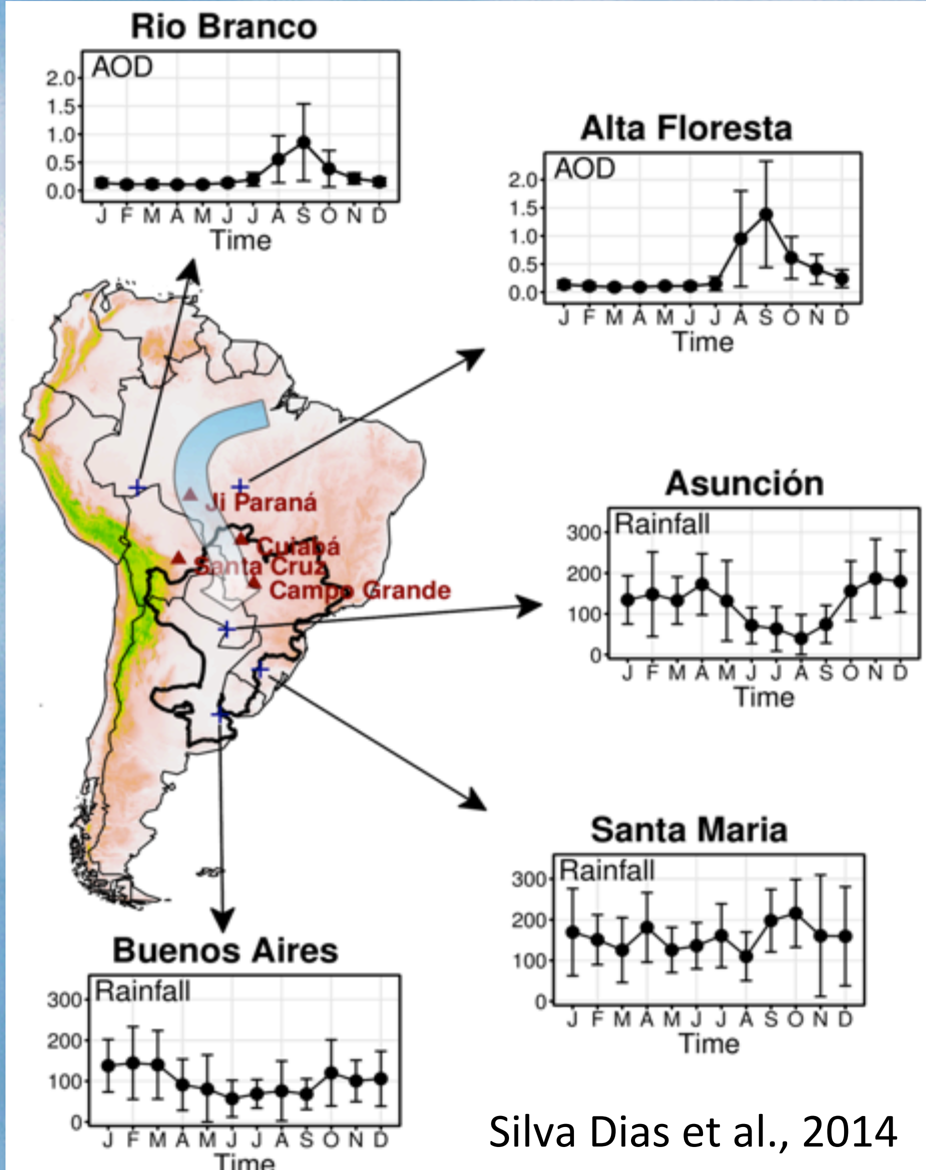
Relationship between aerosols and precipitation in the La Plata Basin

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

Reduction in precipitation with increase in aerosols

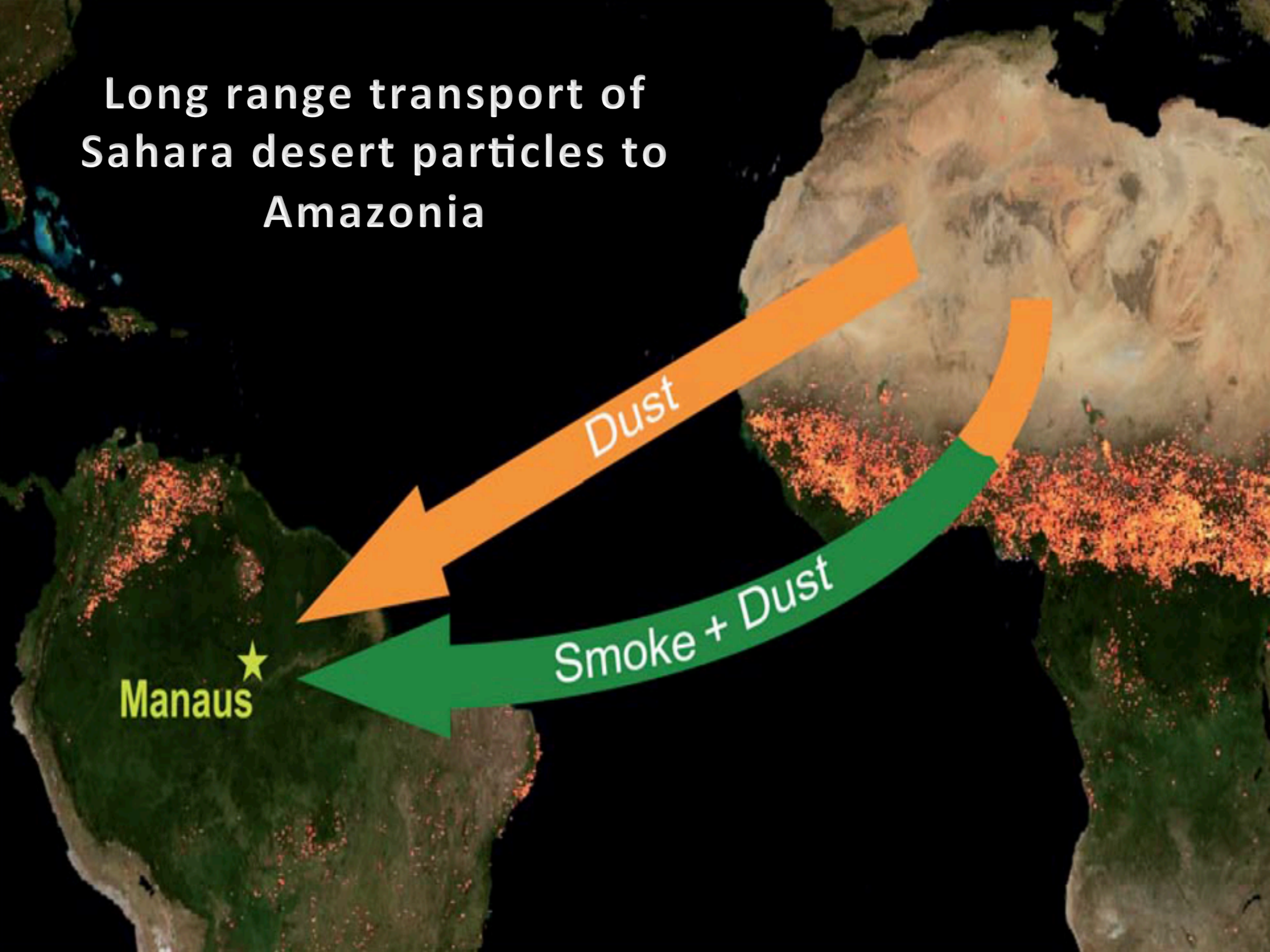


BRAMS: Simulations with cloud microphysics confirm the measurements

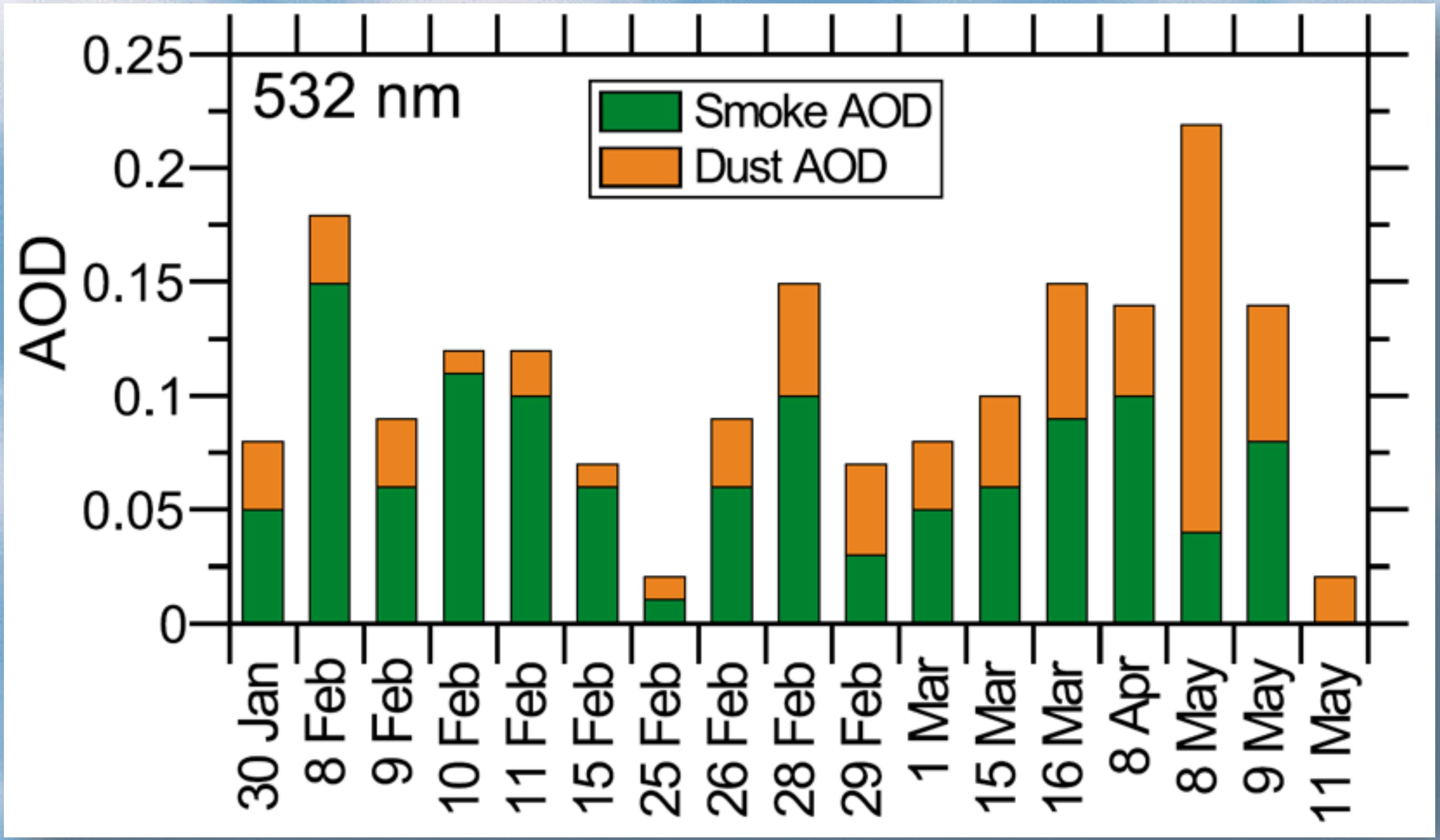


Silva Dias et al., 2014

Long range transport of Sahara desert particles to Amazonia

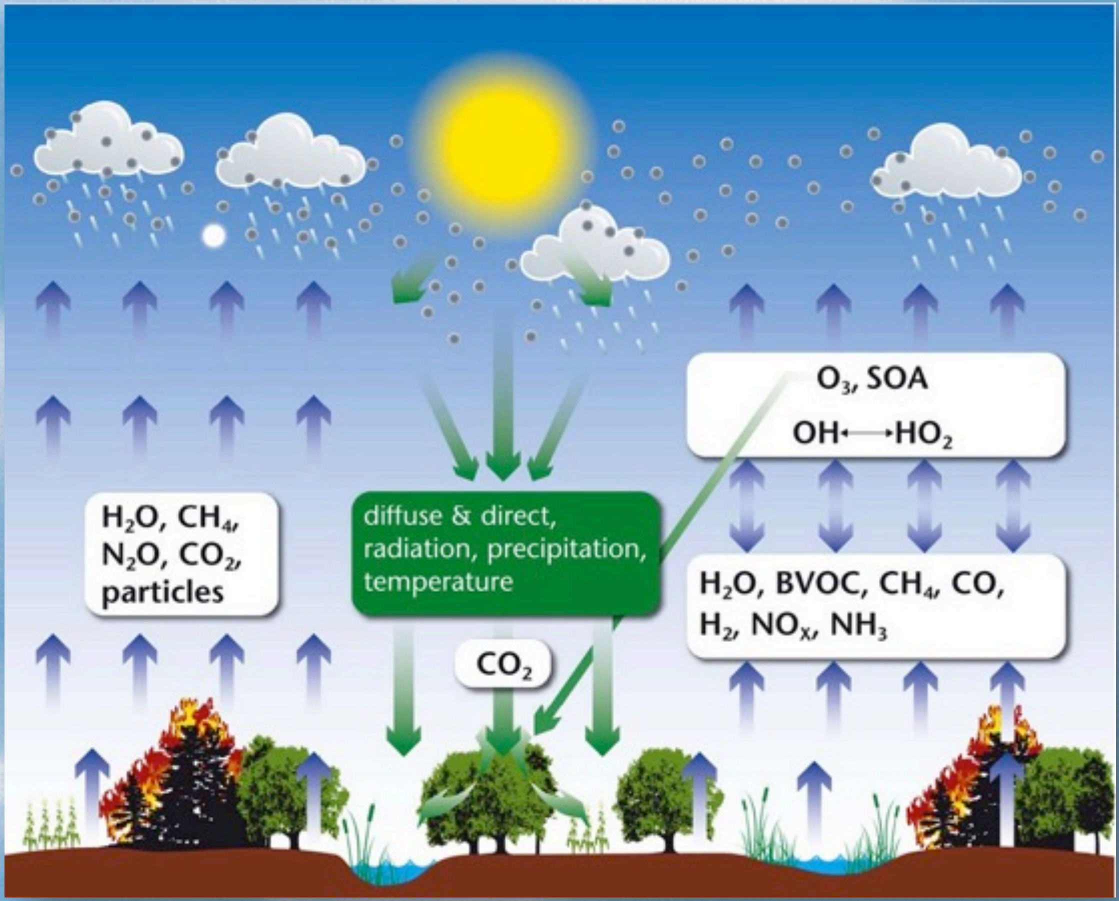


African aerosol in central Amazonia

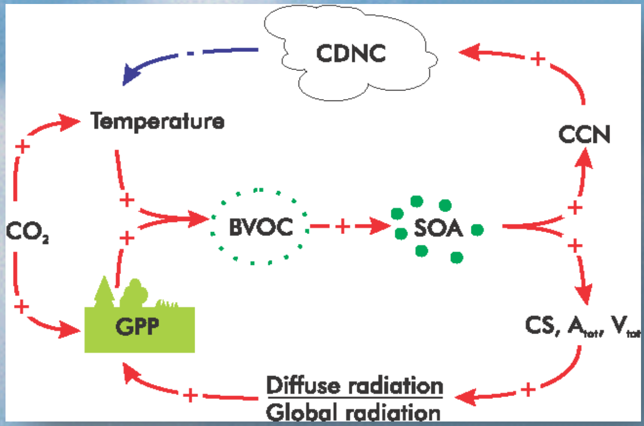


Smoke and dust AOD indicating the advection of African aerosol toward Amazonia (Baars, 2011).

Conceptual overview of terrestrial carbon cycle – chemistry – climate interactions



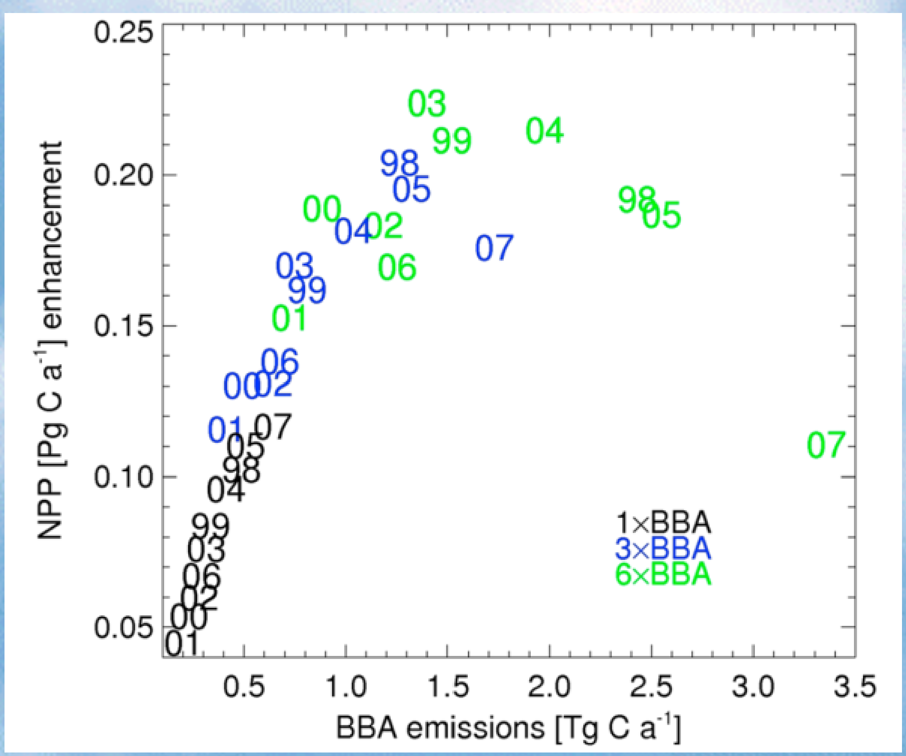
Arneth et al., 2011



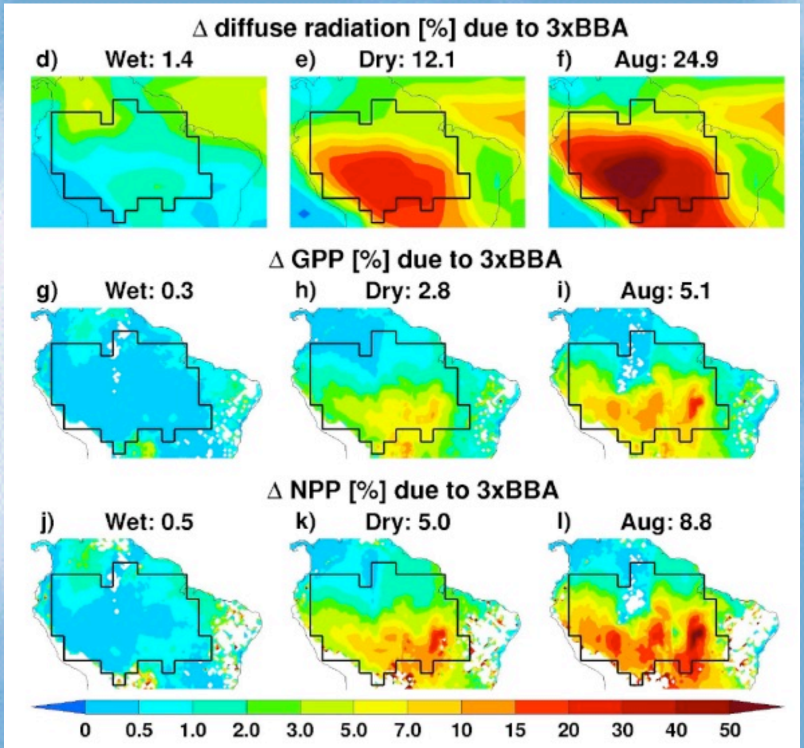
Kulmala et al, 2013

Fires increase Amazon forest productivity through increases in diffuse radiation

Rap et al., 2015



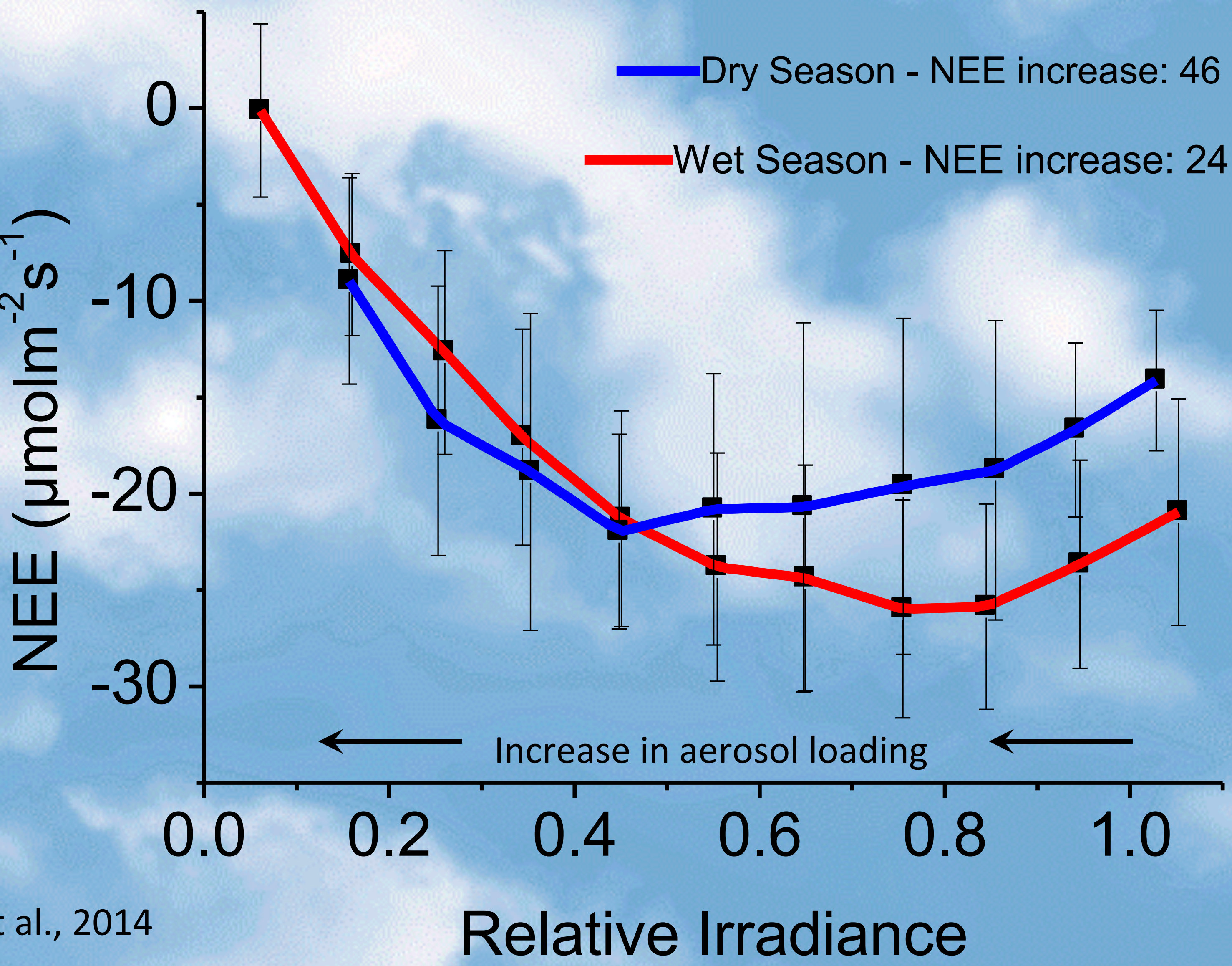
Amazon basin annual mean NPP enhancement caused by BBA as a function of BBA emissions (black: standard BBA emissions; blue: 3 × BBA emissions; and green: 6 × BBA emissions), for each year during



Modeled 1998–2007 mean percentage changes in (a–c) diffuse radiation, (g–i) GPP, and (j–l) NPP during the wet (defined here as December to May) season, dry (June to November) season, and August due to BBA emissions.

Strong effects of aerosols on carbon uptake in Amazonia

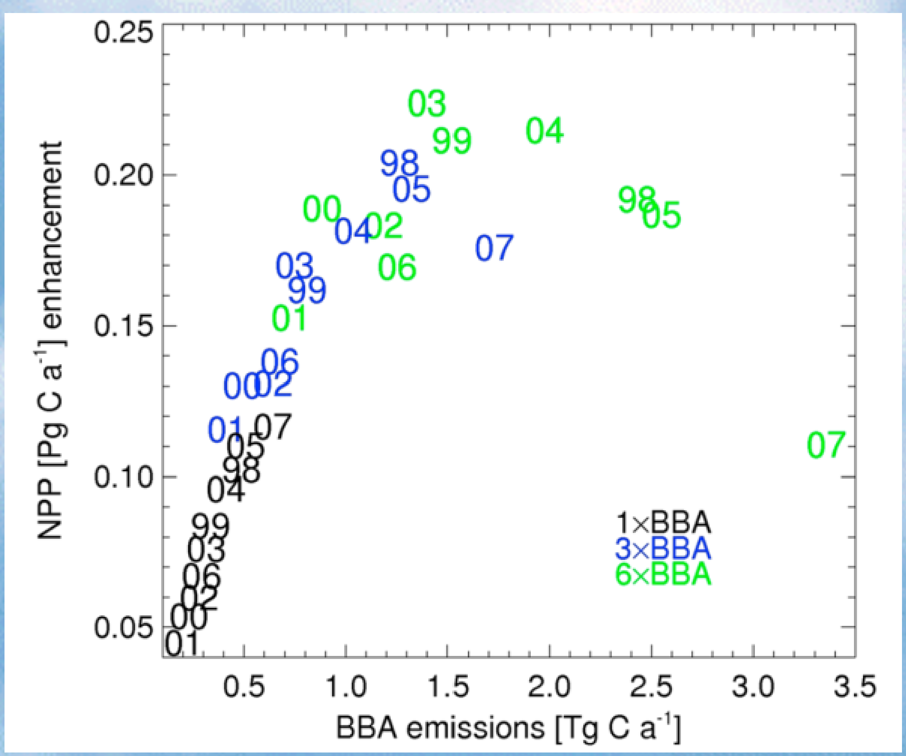
Amazonia Rondonia Forest site 2000-2001



Cirino et al., 2014

Fires increase Amazon forest productivity through increases in diffuse radiation

Rap et al., 2015



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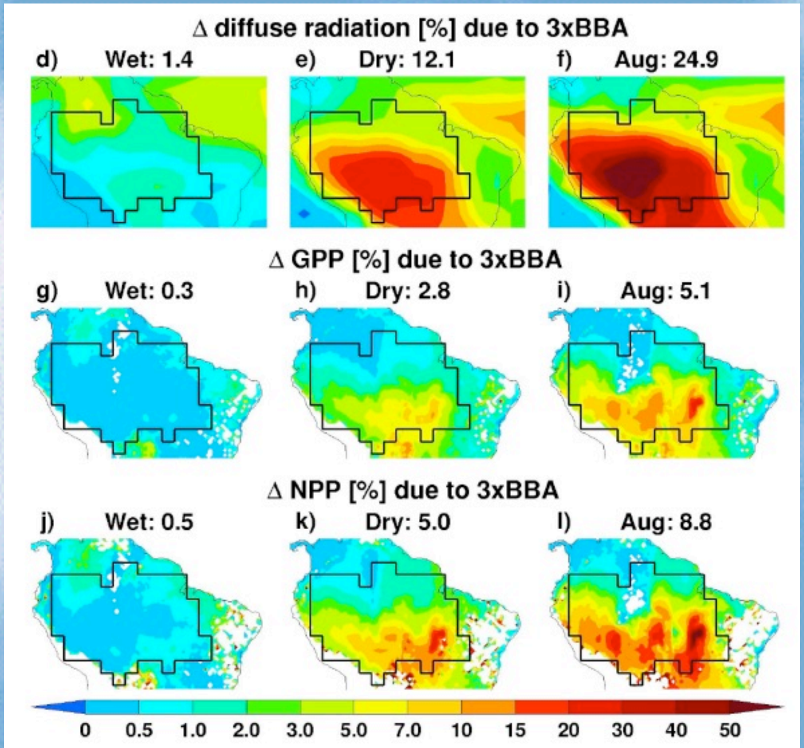

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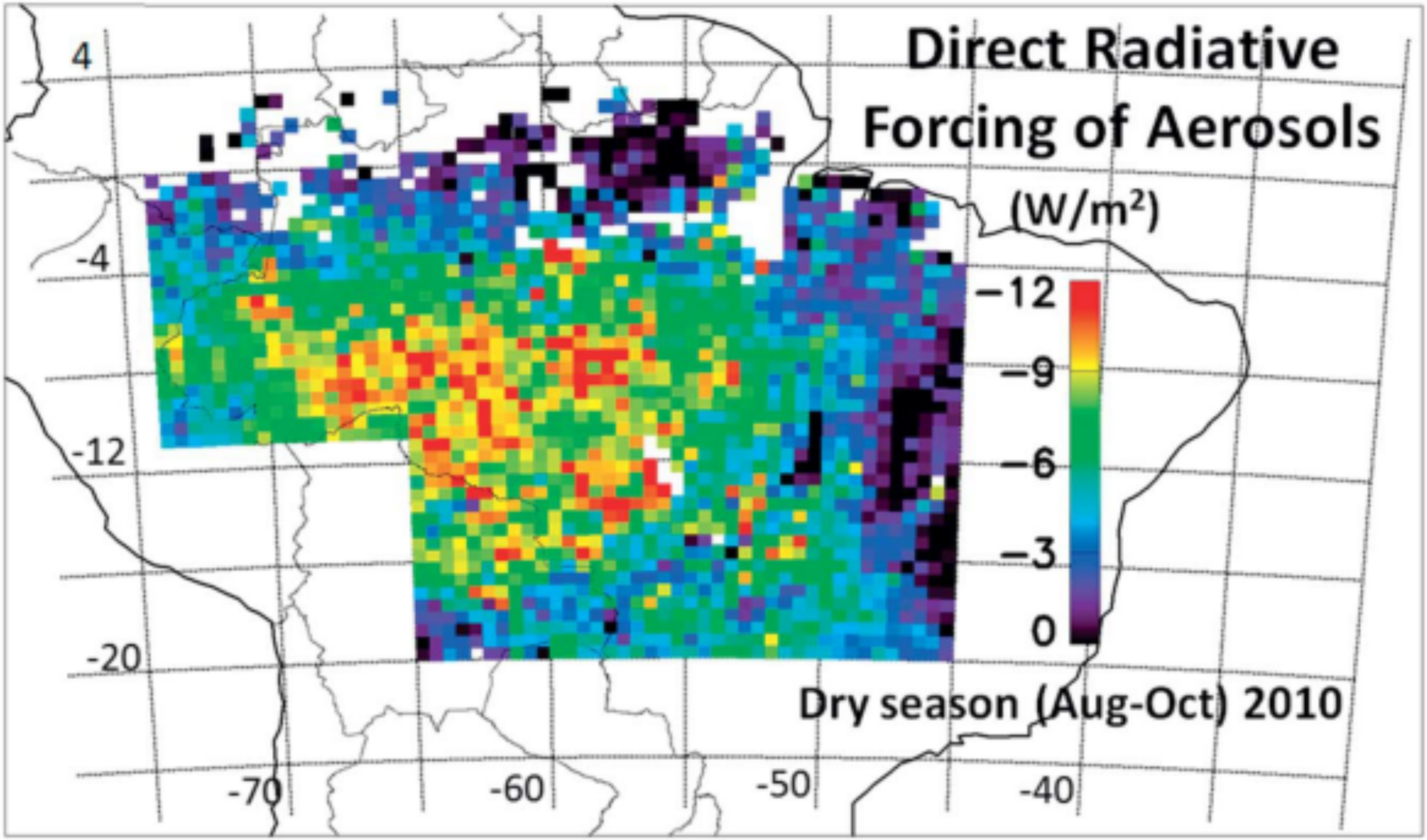

Fig. 18 Average spatial distribution of the direct radiative forcing (DRF) of biomass burning aerosols in Amazonia during the dry season (August to October) of 2010. Forcing derived from calculations using a combination of MODIS and CERES sensors data. During this three-month period, the daily-average radiative forcing of aerosols for the whole area was on average -5.3 ± 0.1 W m^{-2}.

LETTERS
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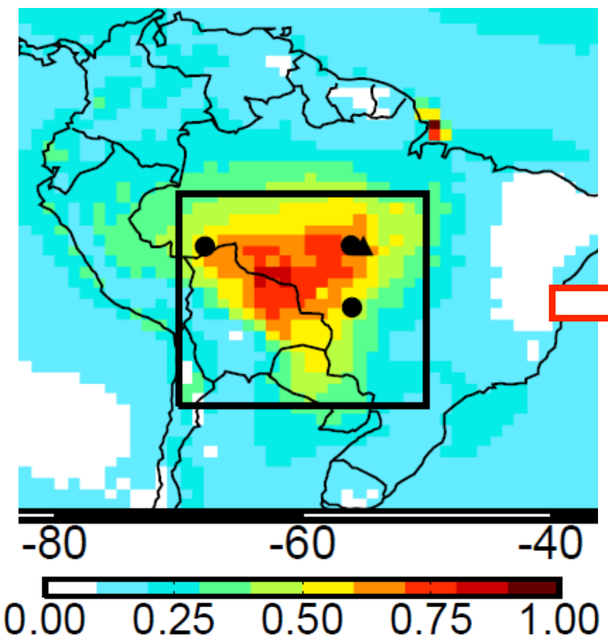
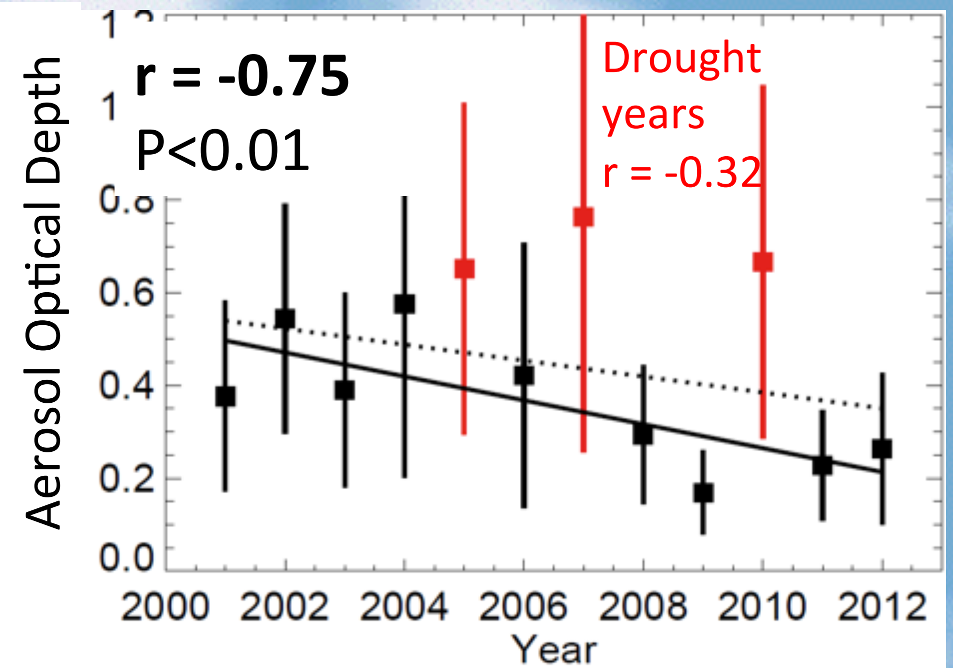
nature geoscience

Air quality and human health improvements from reductions in deforestation-related fire in Brazil

C. L. Reddington[1], E. W. Butt[1], D. A. Ridley[2], P. Artaxo[3], W. T. Morgan[4], H. Coe[4] and D. V. Spracklen[1]*



Dry season mean AOD retrieved by MODIS



⇒Reduction in PM2.5 may be preventing roughly 1,700 premature adult deaths annually across South America.

Ozone and carbon uptake in Amazonia in the dry season

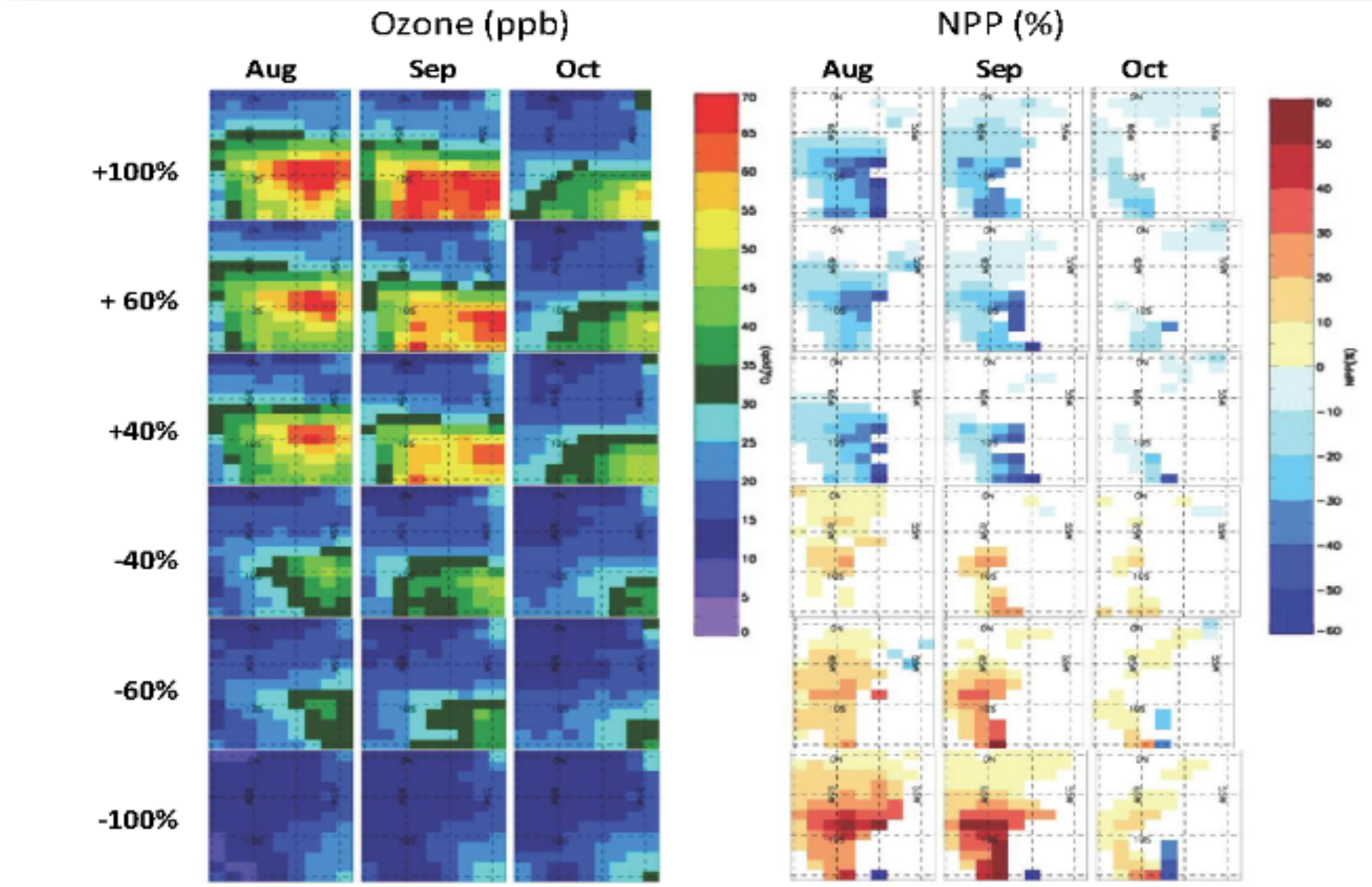
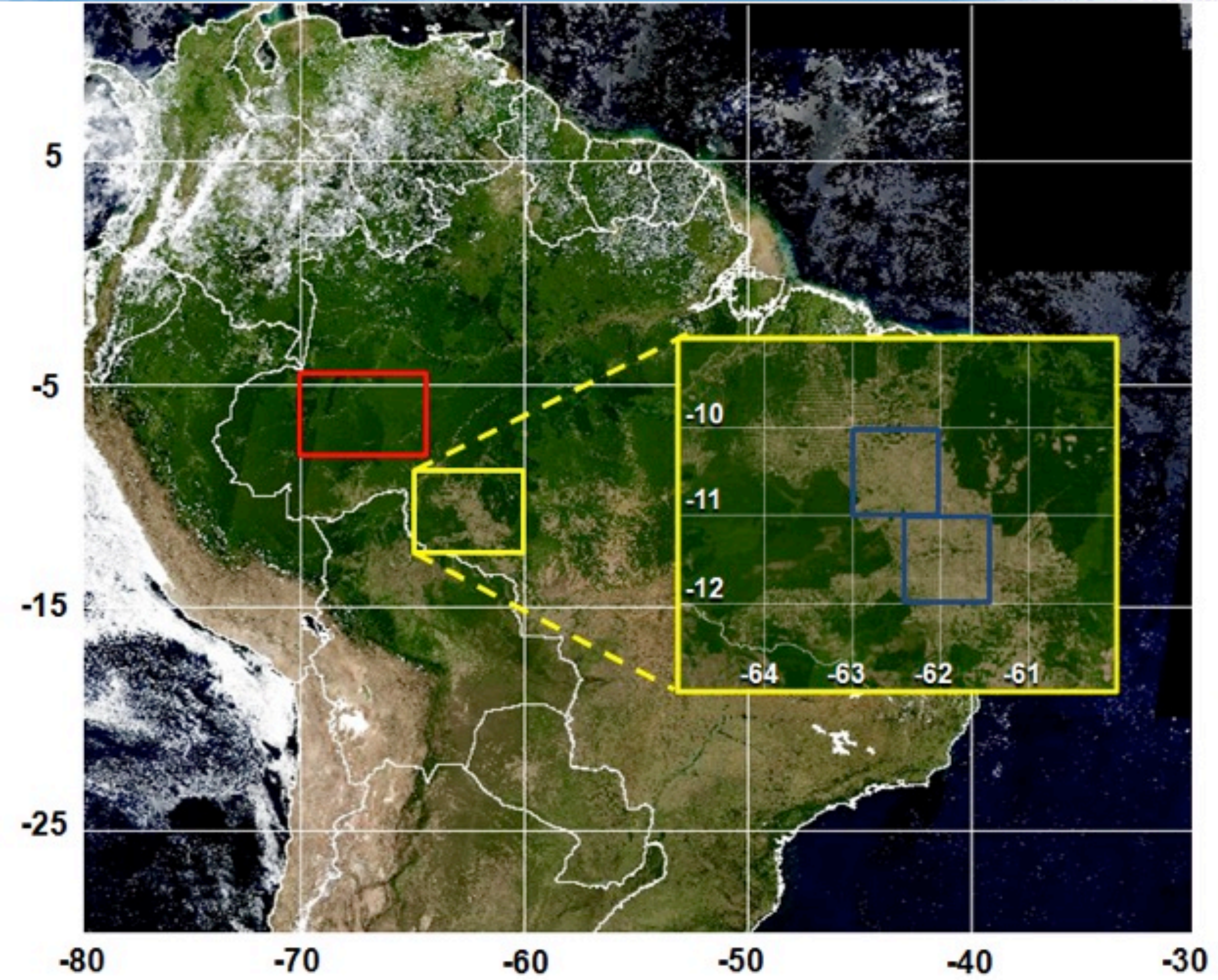


Figure 6. From the left: simulated variation in surface O_3 mixing ratios and NPP over the region of analysis for the months of Aug September and October.

Ozone exposure reduces carbon uptake at the same order of magnitude as emissions from deforestation. Potentially doubling the impact of biomass burning on the carbon cycle



Mean Diurnal Radiative Forcing due to change in surface albedo: -8.0 $\pm$ 0.9 W/m^2

Mean Diurnal Aerosol Forcing Efficiency:

Forest: -22.5 + 1.4 W/m^2

Cerrado: -16.6 $\pm$ 1.7 W/m^2

Land-use change radiative forcing. Forested areas are selected in red and deforested areas are selected in blue.

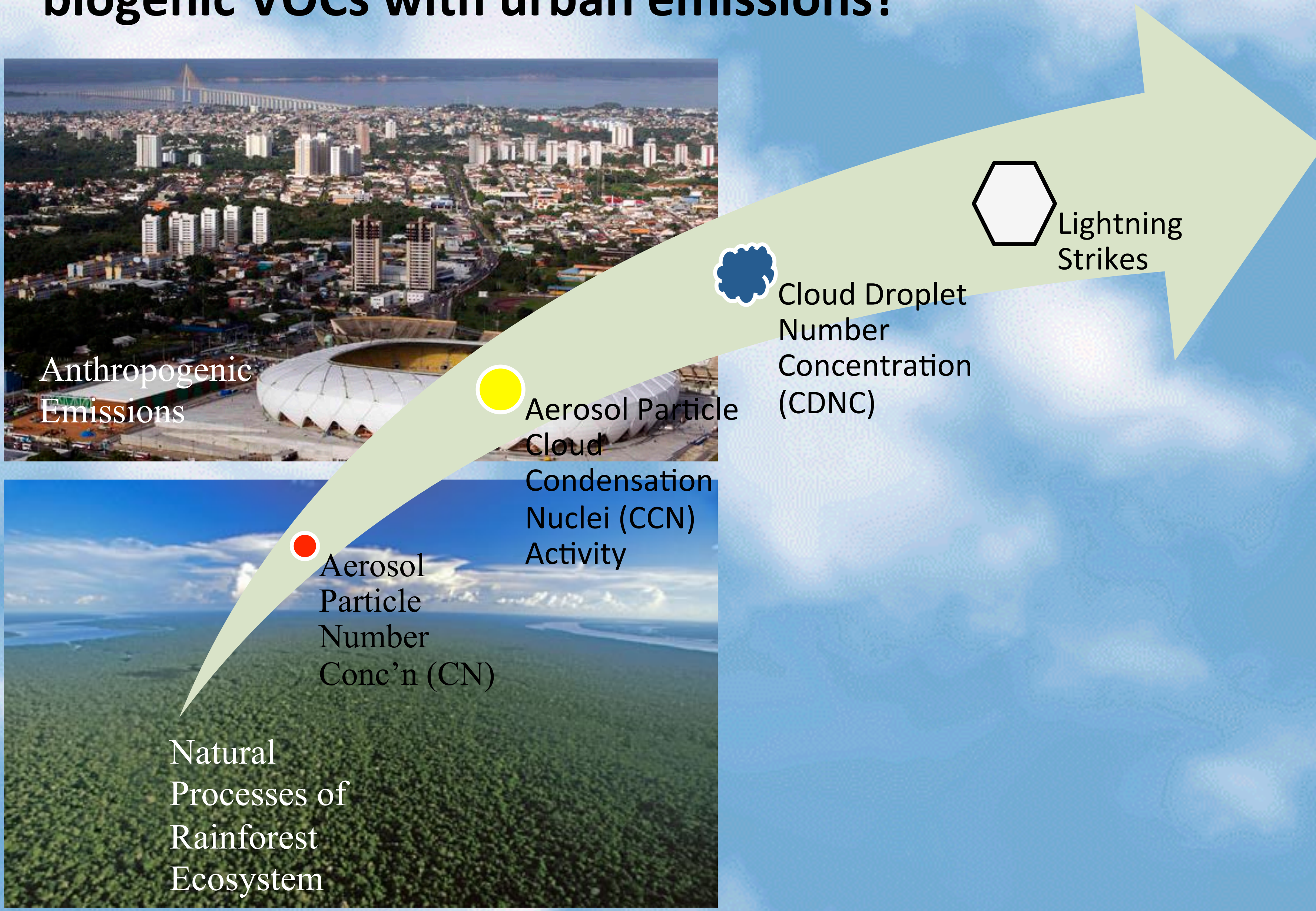
Elisa Sena results, 2011

GoAmazon2014/15 Experiment
The central idea...

Manaus is a city of 2 million people surrounded by just forest in a radius of 1.500 Km. UNIQUE situation.

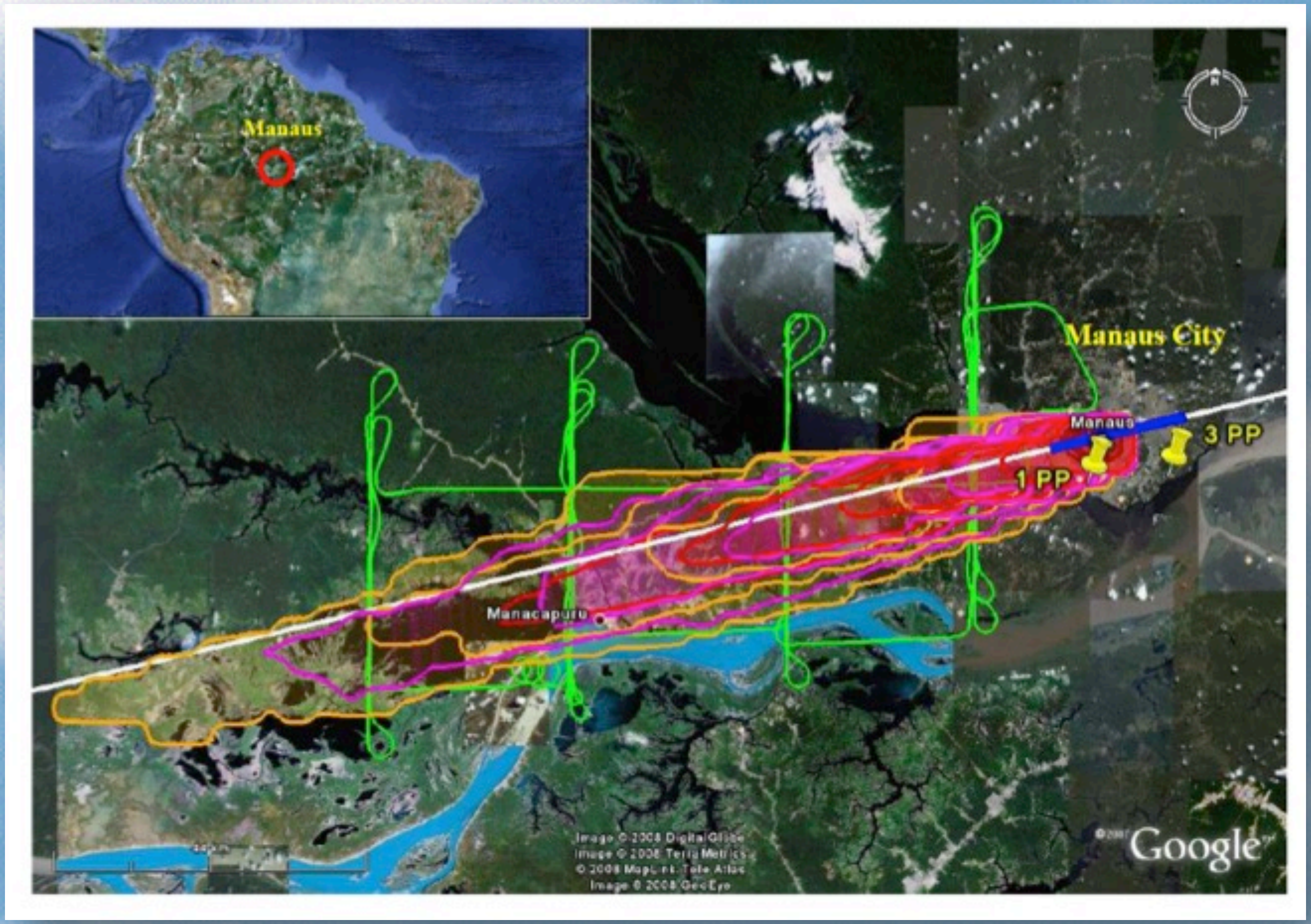
The aim of the GoAmazon 2014/15 experiment is to analyze how the emissions of pollutants of the city of Manaus interacts with the Amazonian natural biogenic emissions from the forest and how are the impacts on the climate over the forest and ecosystem functioning.

How particles are formed from the interactions of forest biogenic VOCs with urban emissions?



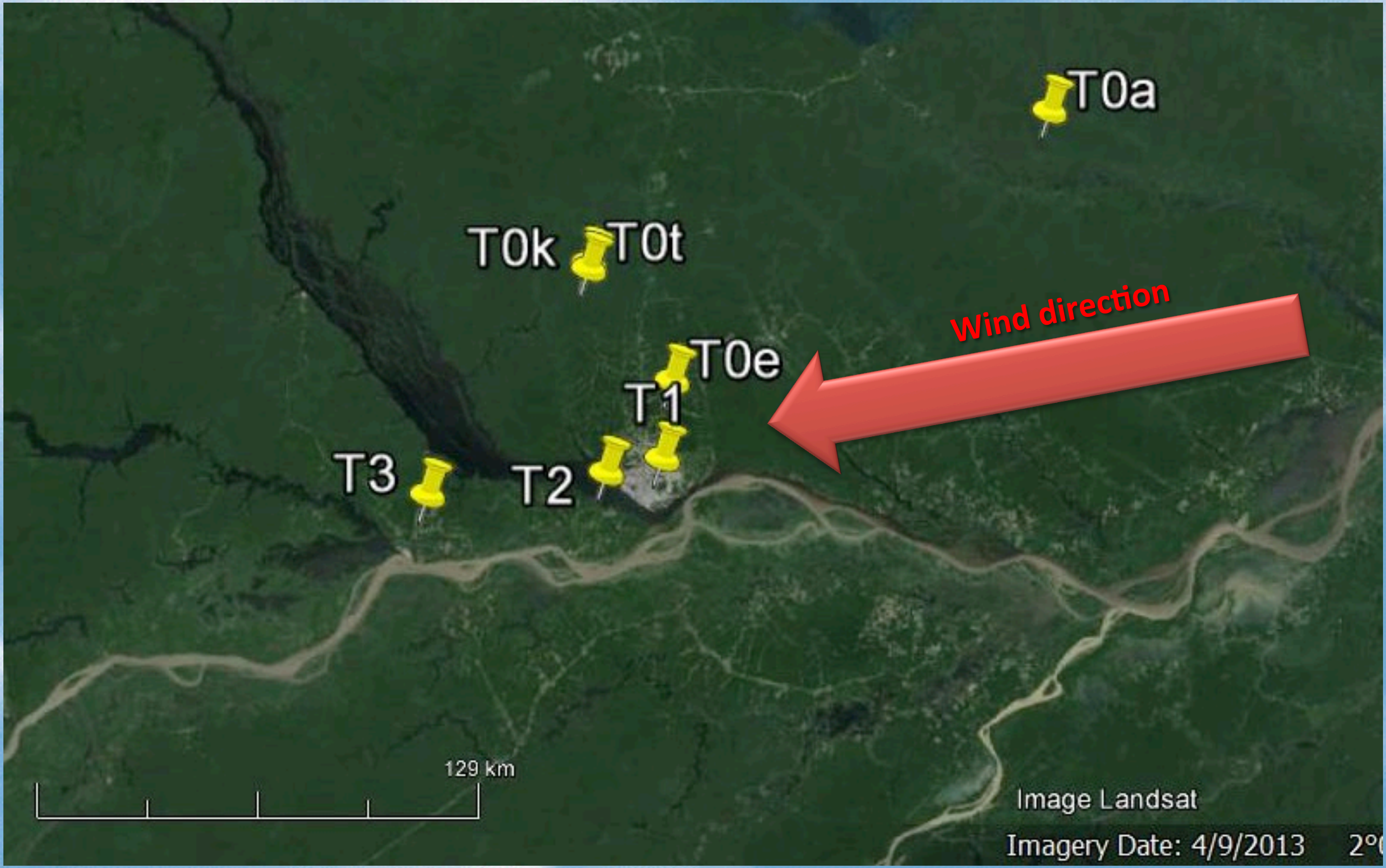
GoAmazon Experiment 2014/15

7 ground sites (before at and after Manaus plume)
DoE G1 plane and the German G5 HALO plane for large scale

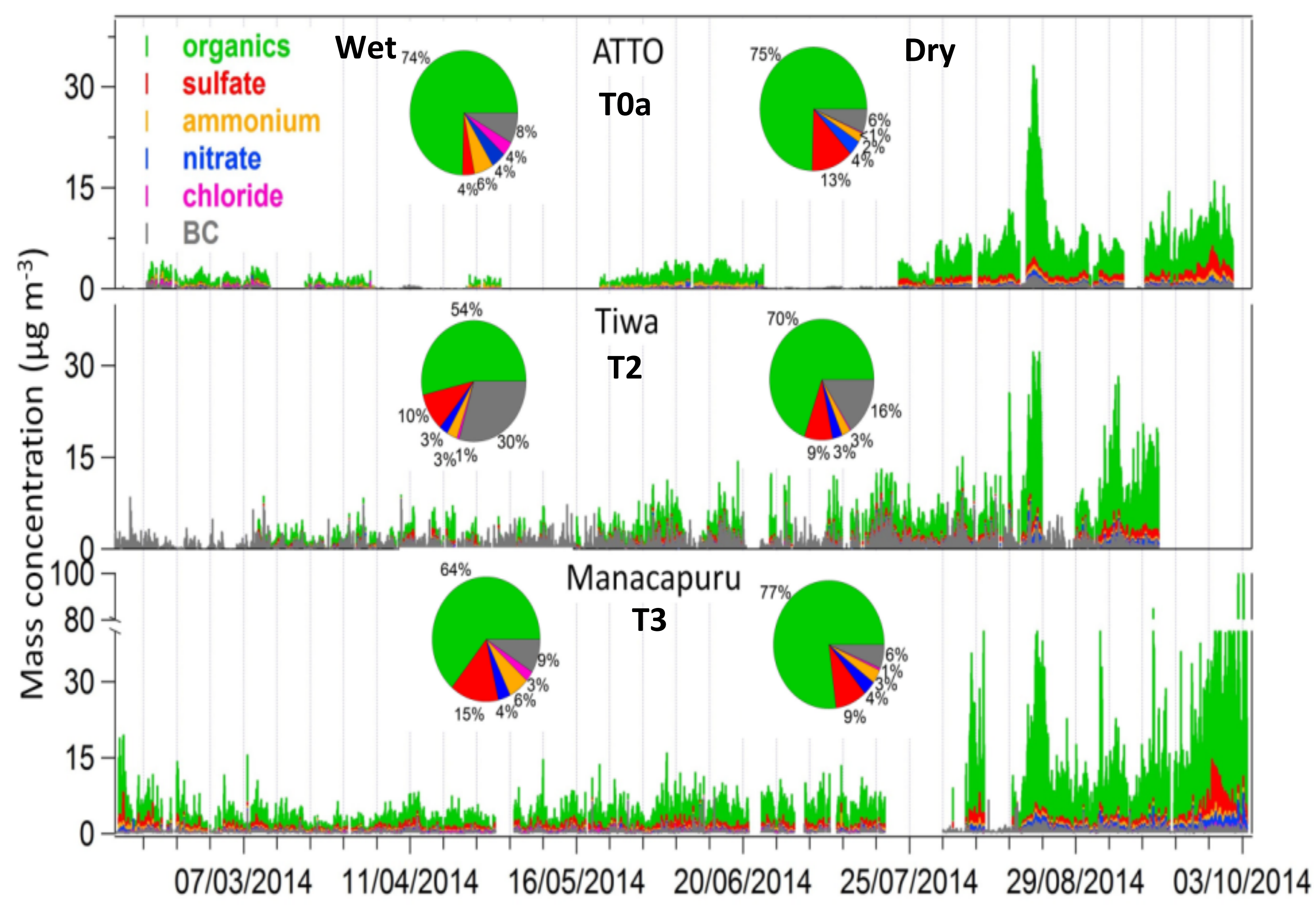


Study of the interactions of the urban plume of Manaus with the forest, producing secondary organic aerosols, ozone and others

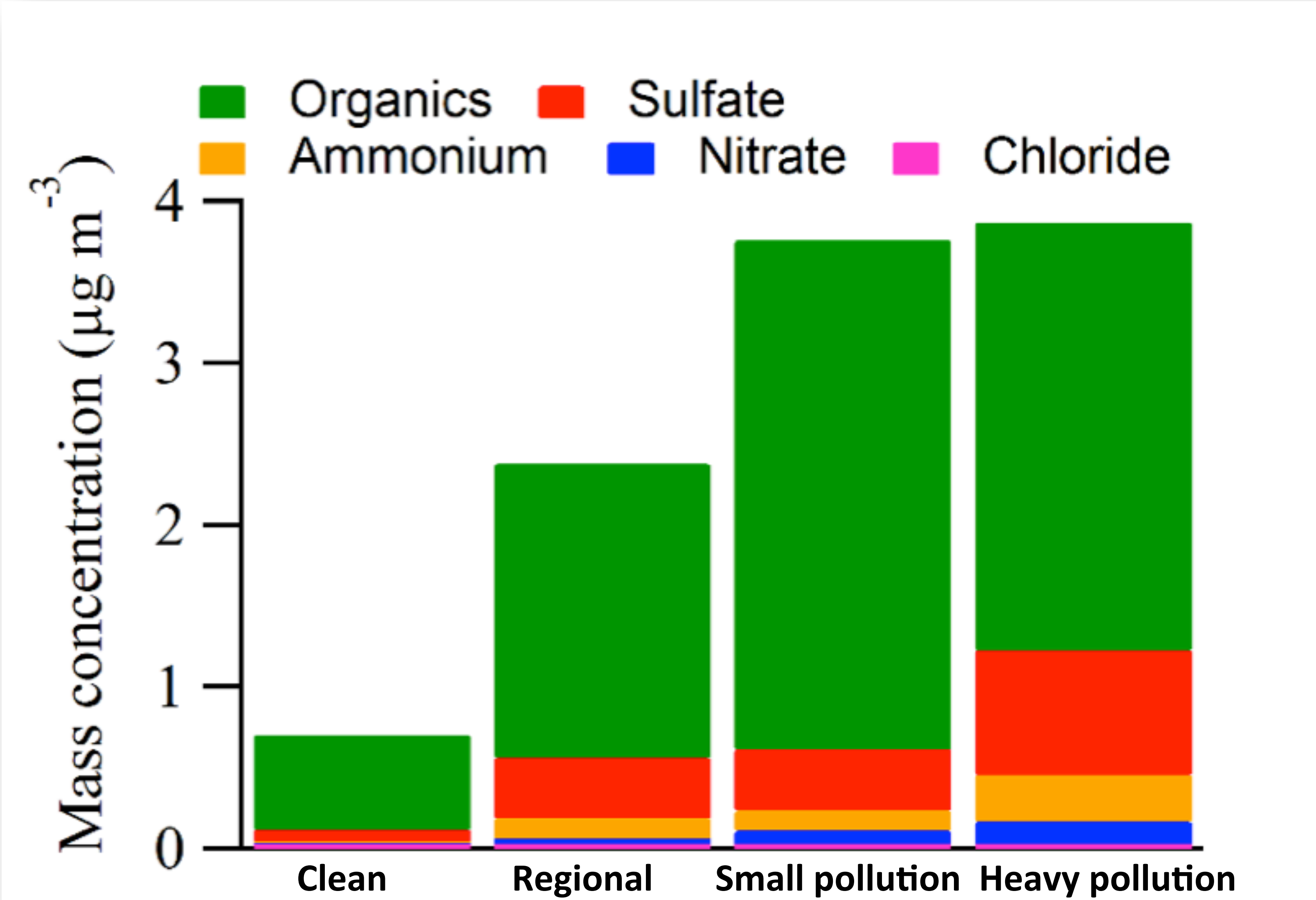
Simple question: How do atmospheric composition looks like at **T3** compared to **T0a**, **T0z** and **T2**?



Organic aerosols from ATTO to Tiwa and Manacapuru (with BC)



Shifts in aerosols with anthrop. influences



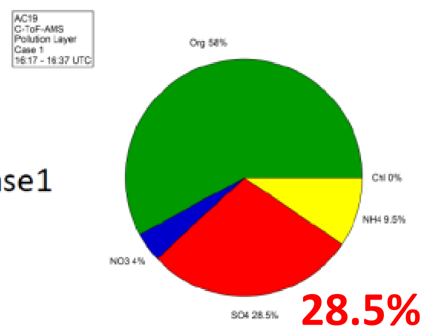
Increase in organic aerosols from 0.7 to 4 ug/m³

Transport of Biomass Burning from Africa with 30% of sulfate in Amazonia?

AC19 Pollution Layer, 2 cases

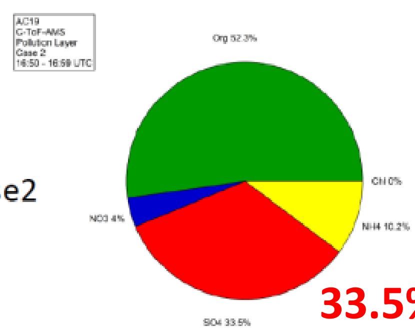
Composition Plot:
- Main fraction again organic aerosol
- **Enriched sulfate fraction**

Case1



28.5% SO4

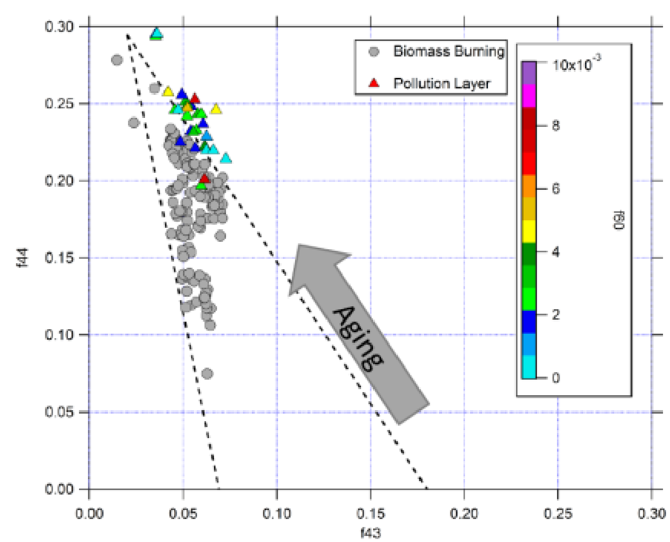
Case2

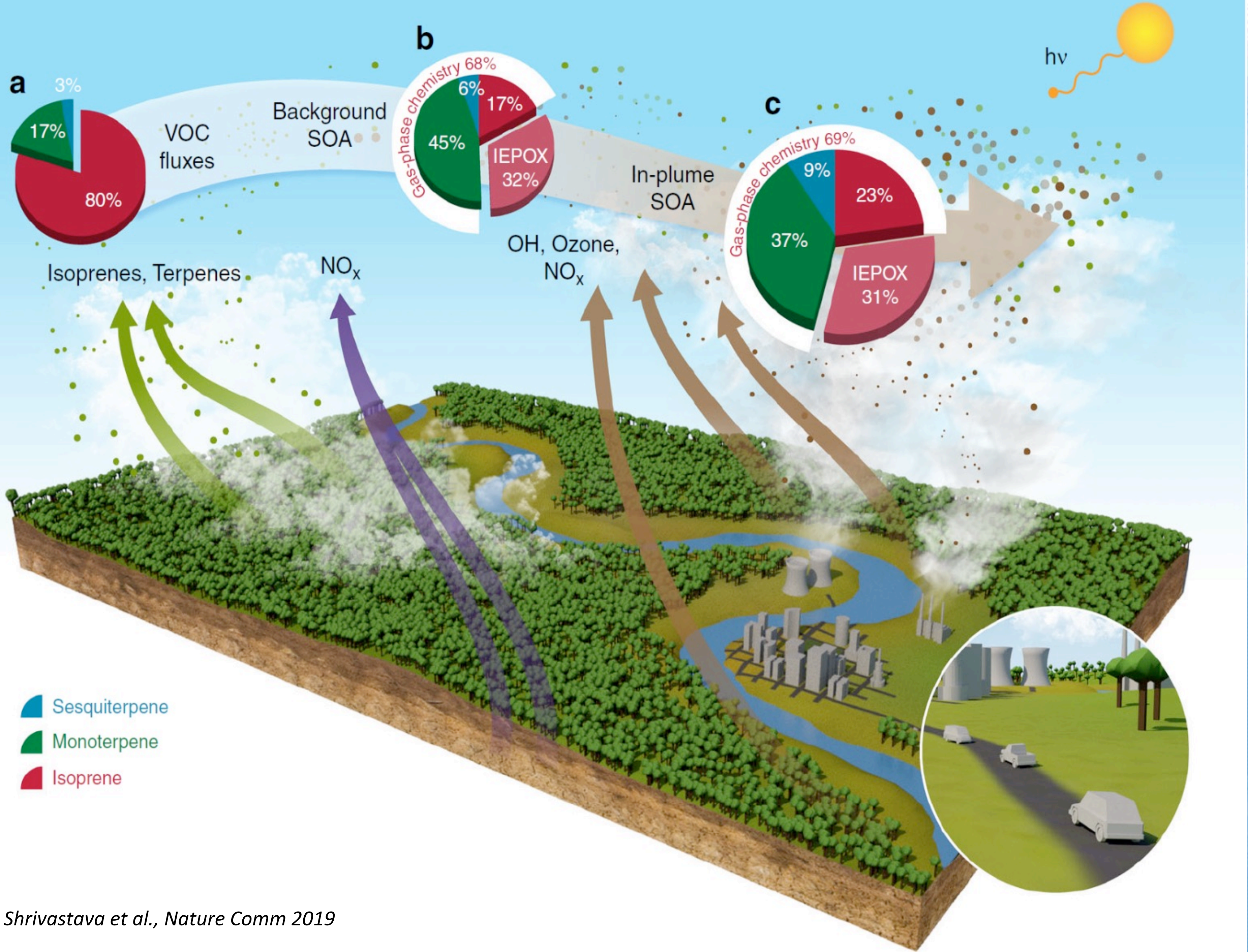


33.5% SO4

Fossil fuel
or
Biomass
burning?

f43/f44 Plot:
- Oxidized organic aerosol, **more oxidized than BB organic aerosol**
- Some indications for f60 (=BB), but mostly this marker does not appear

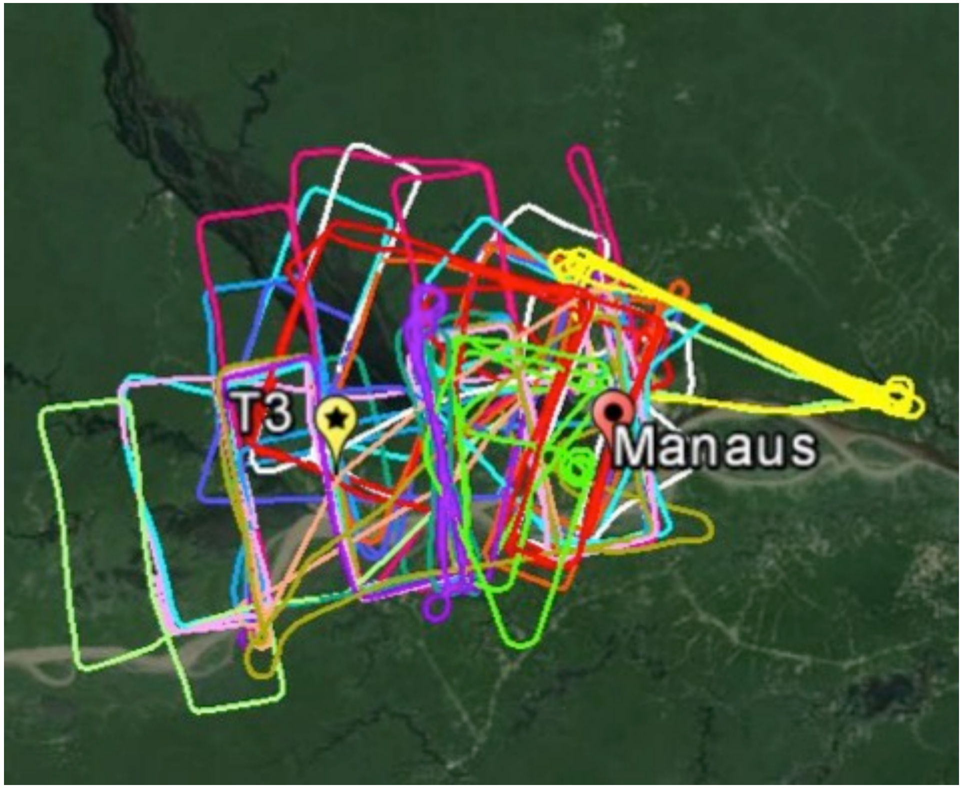




Shrivastava et al., Nature Comm 2019

G-1 Flight Paths during GoAmazon

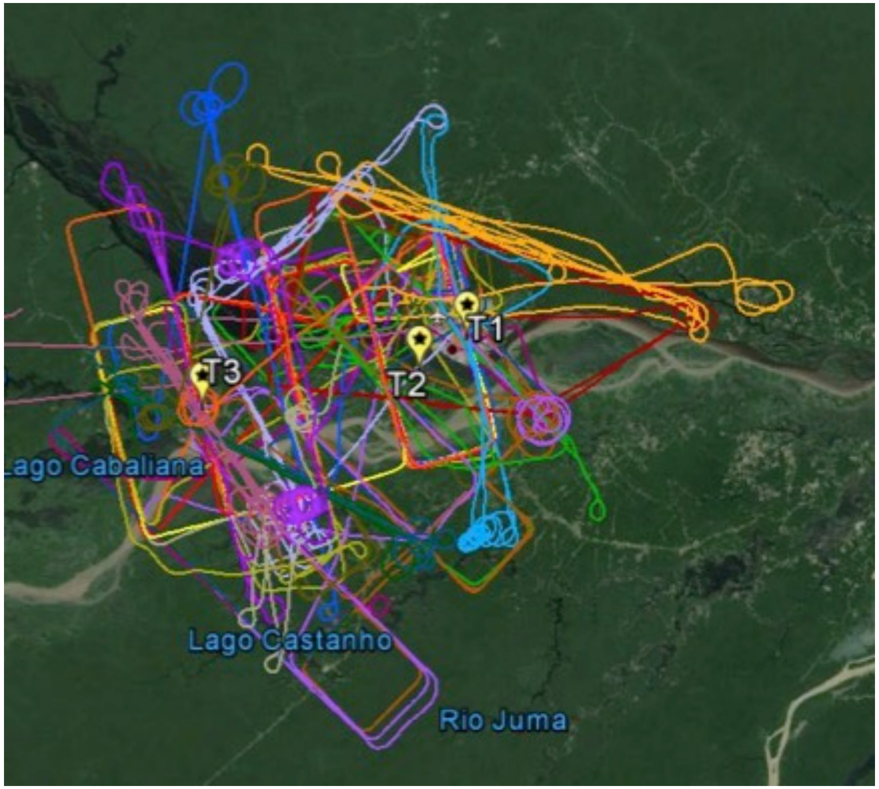
Phase 1 (Wet season)



16 flights – 42.8 hours

Feb 15th - March 26st , 2014

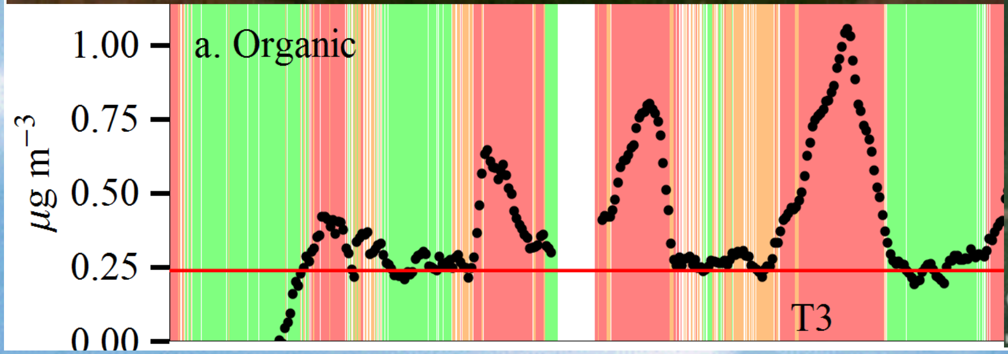
Phase 2 (dry season)



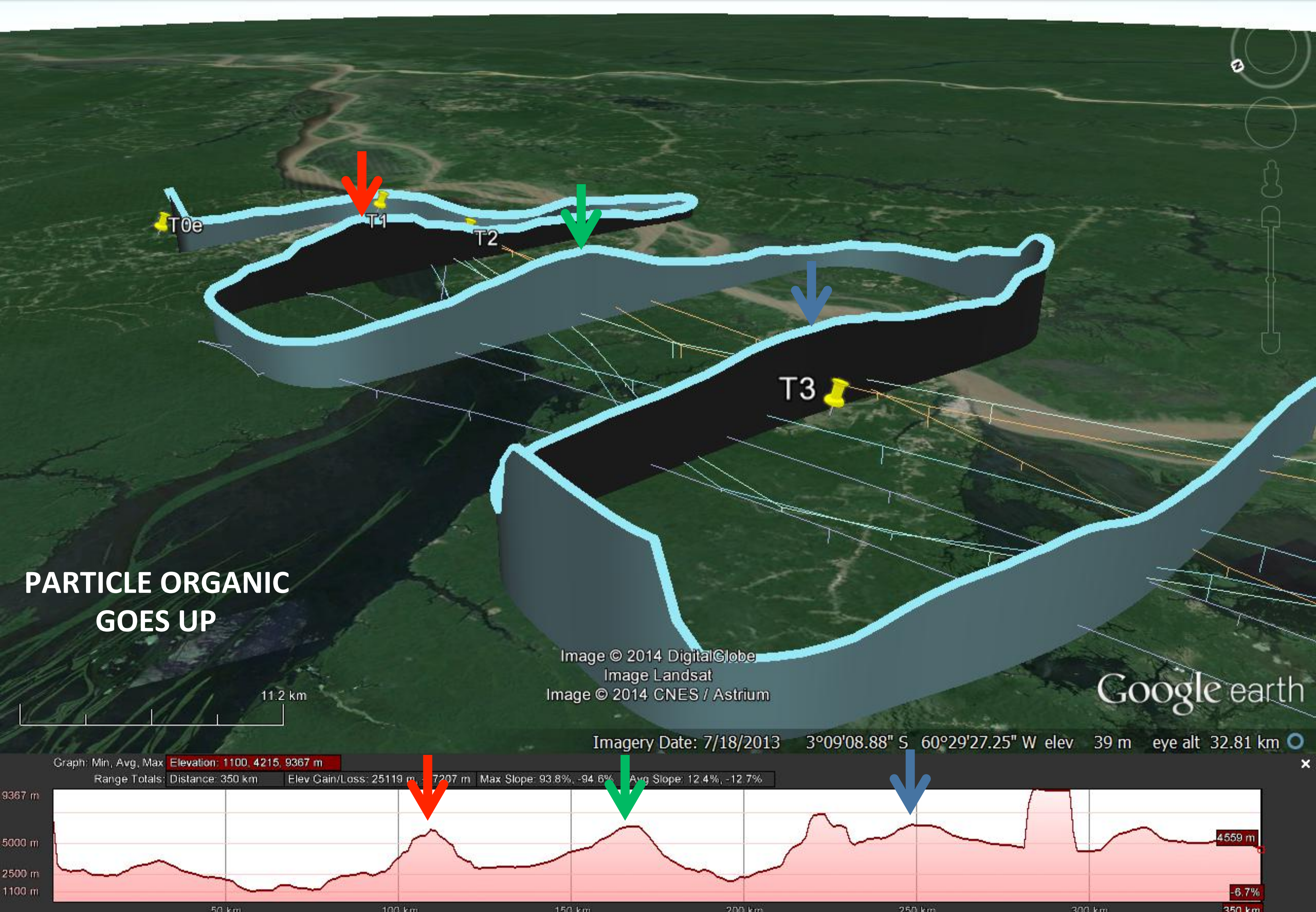
19 flights – 53.7 hours

Sep 1st - Oct 10th , 2014

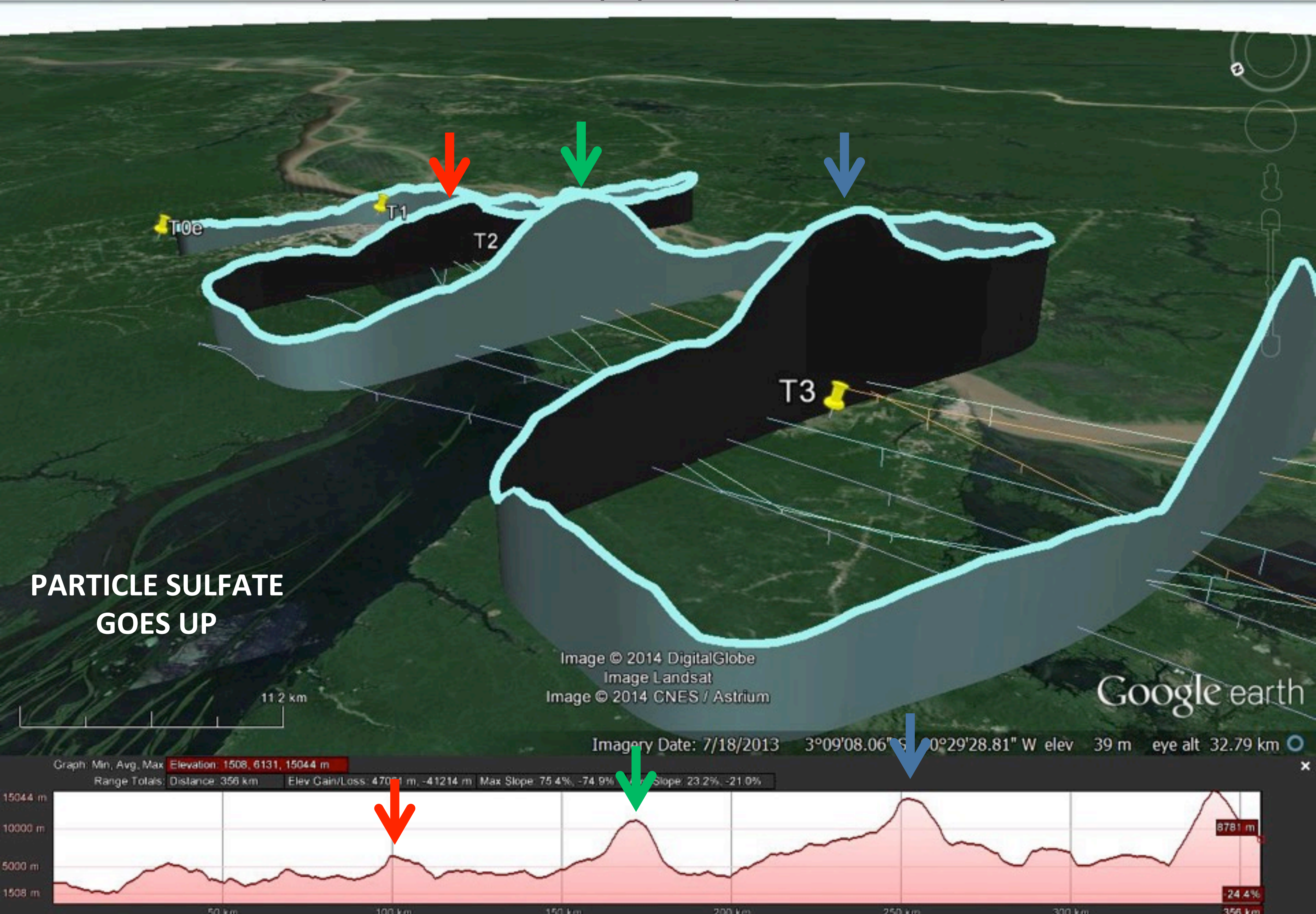
G-1 Flight Paths during GoAmazon



PARTICLE ORGANIC, GoAmazon2014/5, IOP1, 17 March 2014, 16:24 to 17:31



PARTICLE SULFATE, GoAmazon2014/5, IOP1, 17 March 2014, 16:24 to 17:31

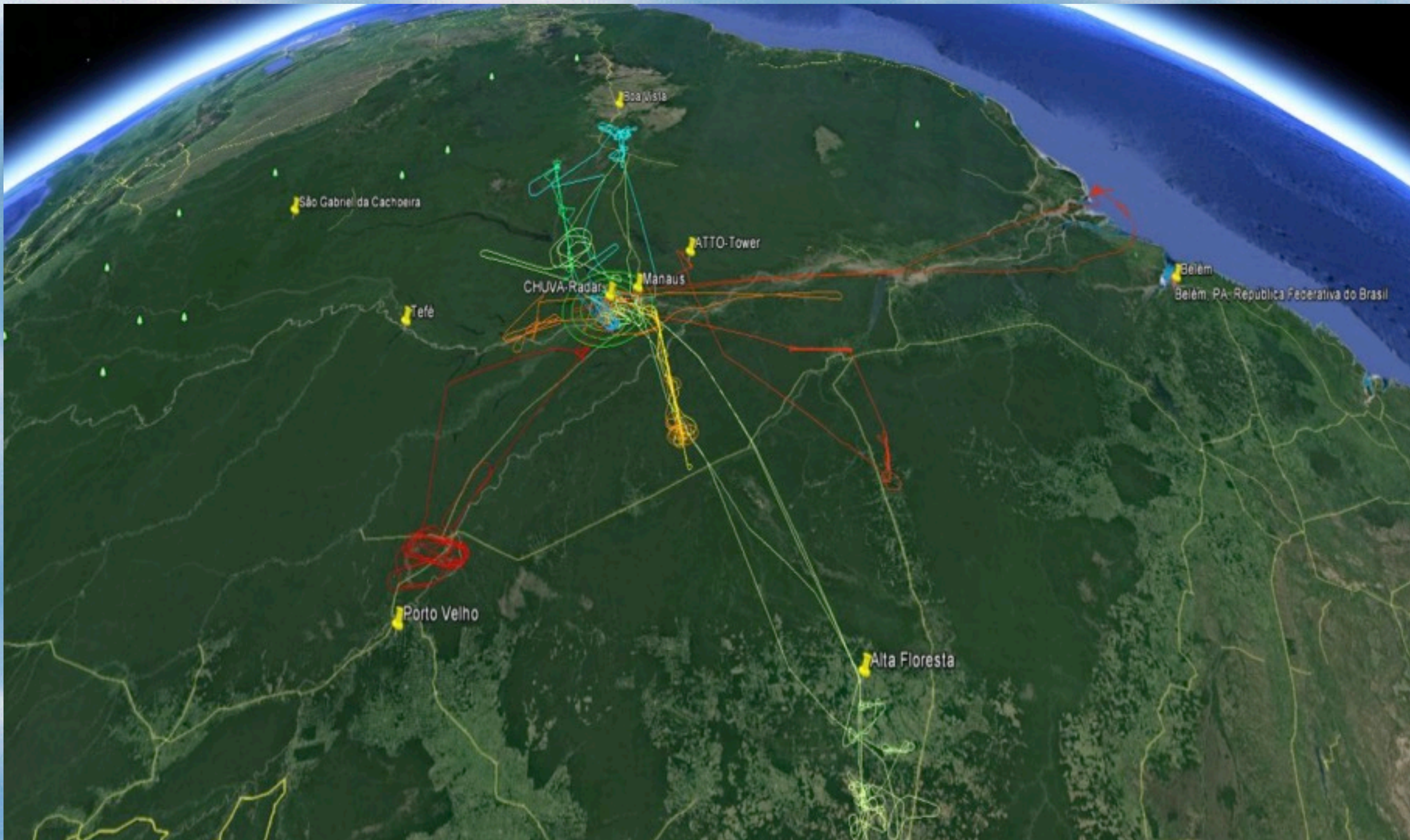


GoAmazon Large scale measurements

G5 HALO plane - “High Altitude and Long Range Research Aircraft”.

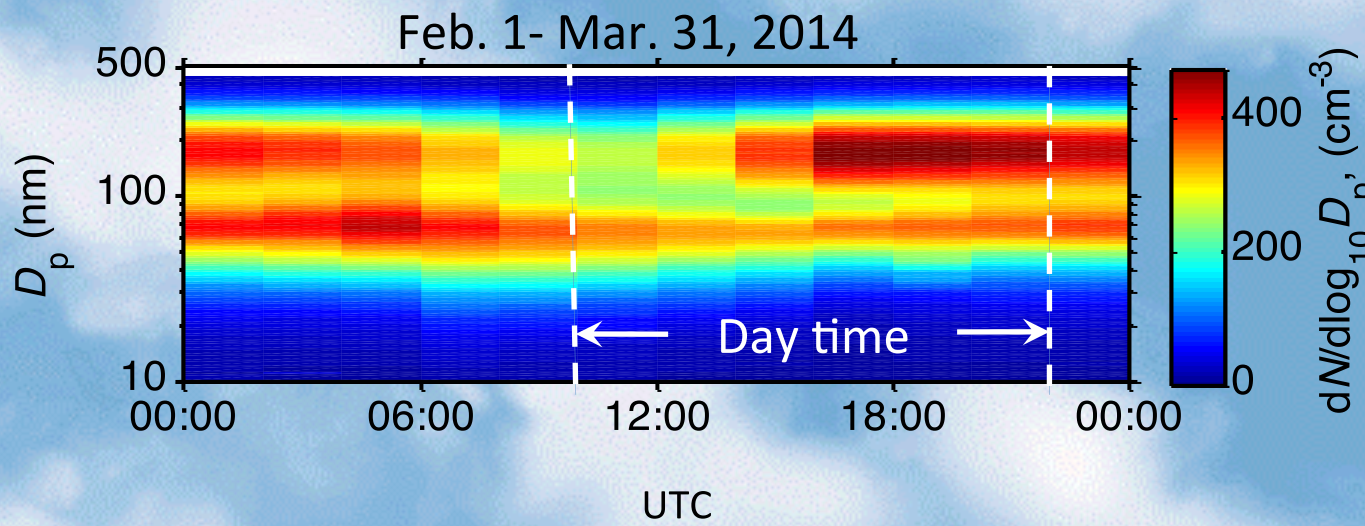
DoE G1 plane in two campaigns at wet and dry seasons

ACRIDICON Flights G5-HALO plane dry season 2014

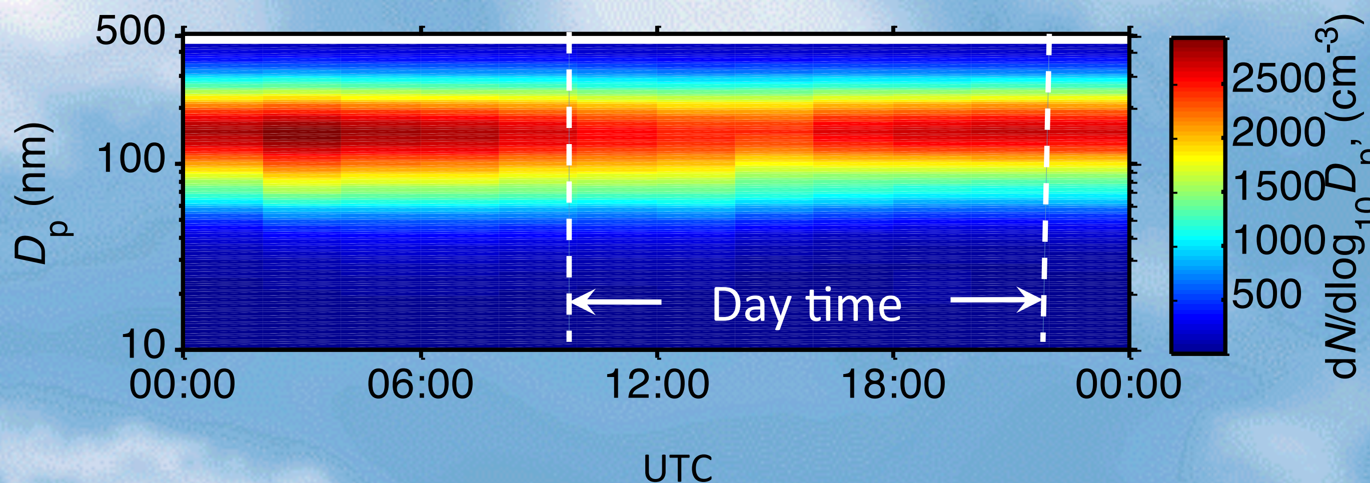


How particles are produced in Amazonia?

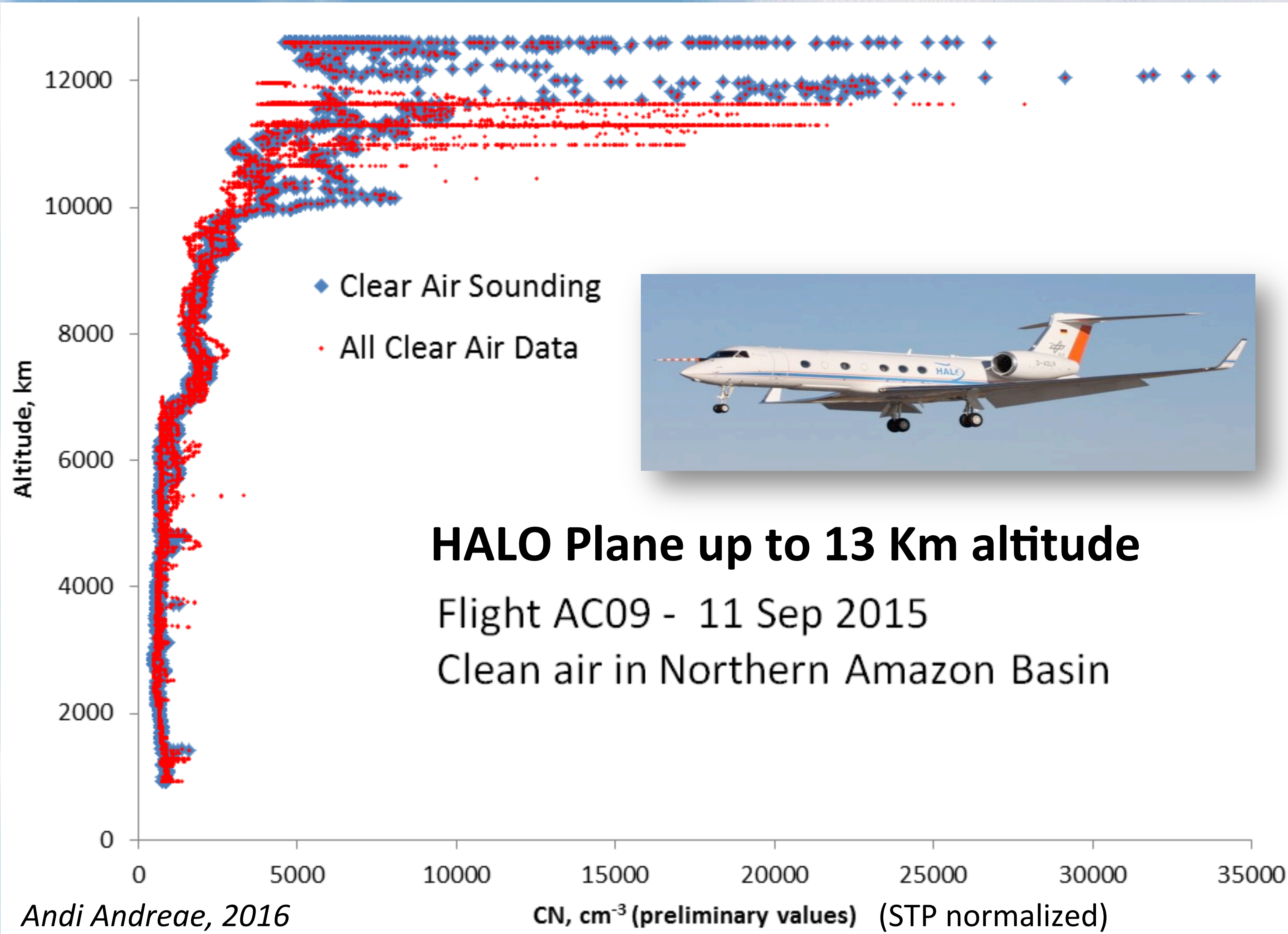
T0 site (ATTO)
(All data)
N: ~320 cm^{-3}



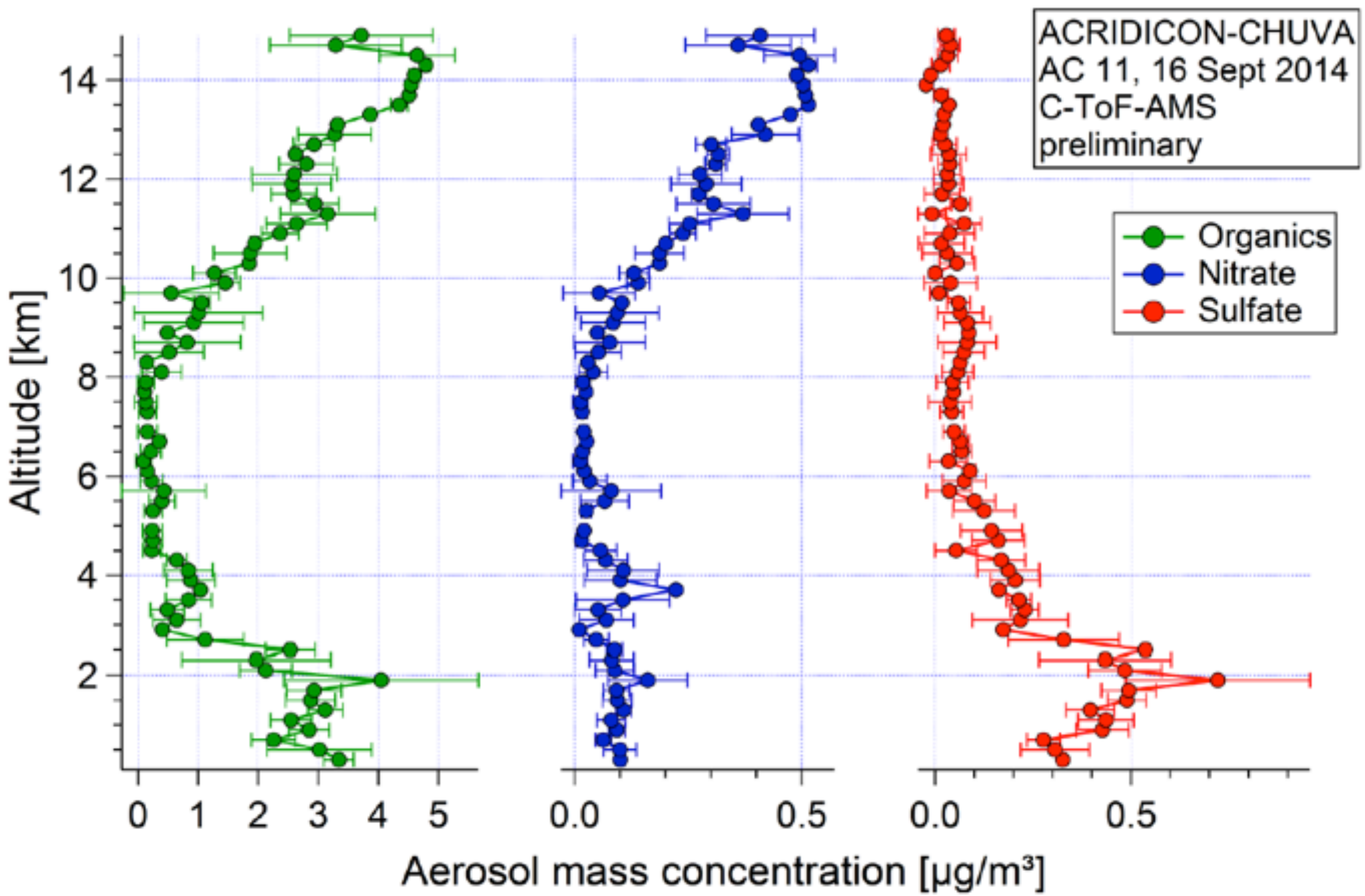
T0 site (ATTO)
(dry season)
N: ~3100 cm^{-3}



It rains a lot. Removal very high. How the particles are formed?

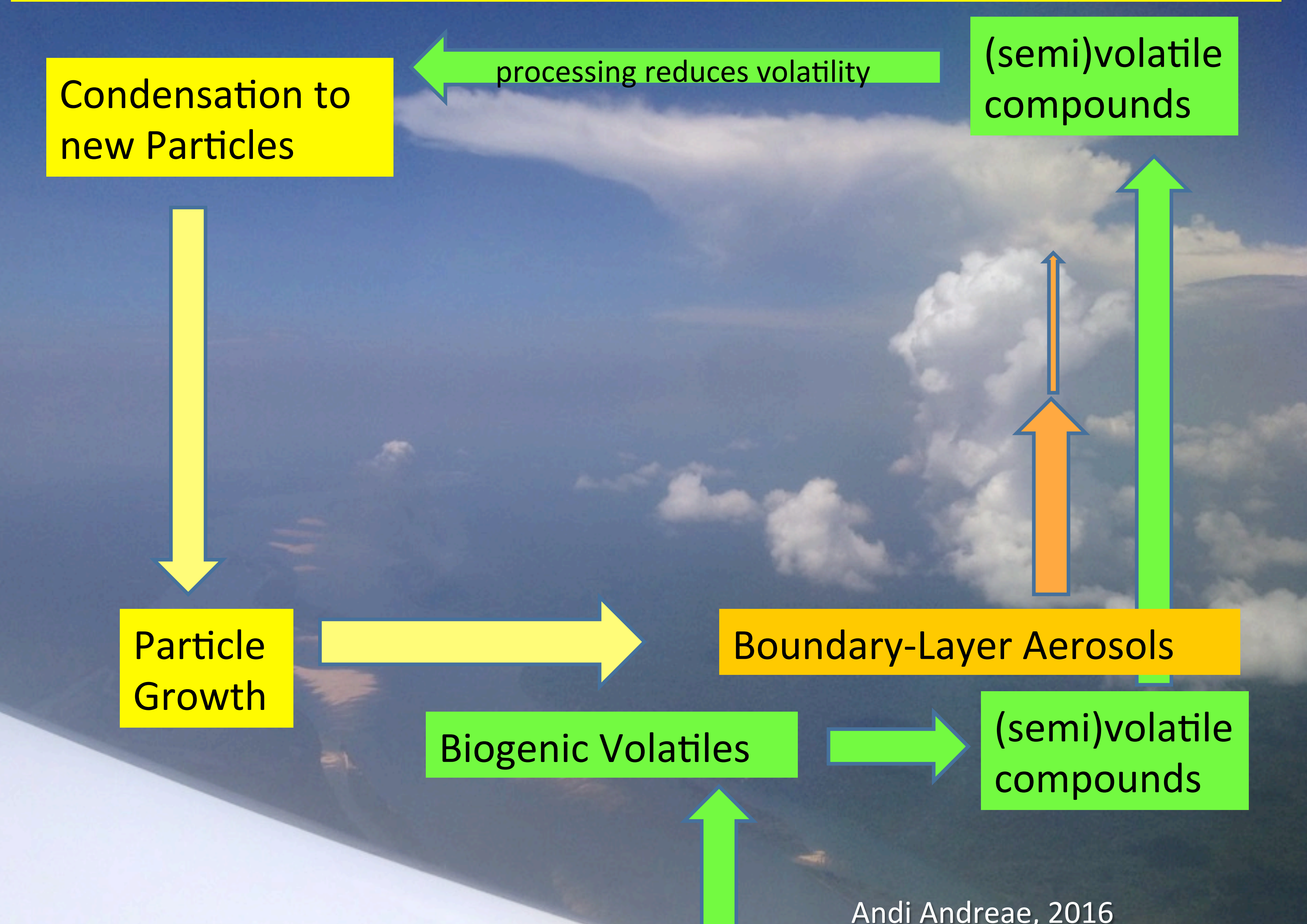

HALO Plane up to 13 Km altitude
Flight AC09 - 11 Sep 2015
Clean air in Northern Amazon Basin
Clear Air Sounding
All Clear Air Data
Altitude, km
0
2000
4000
6000
8000
10000
12000
0
5000
10000
15000
20000
25000
30000
35000
CN, cm-3 (preliminary values) (STP normalized)
Andi Andreae, 2016

AMS Aerosol composition: Organics and nitrates. No sulfates

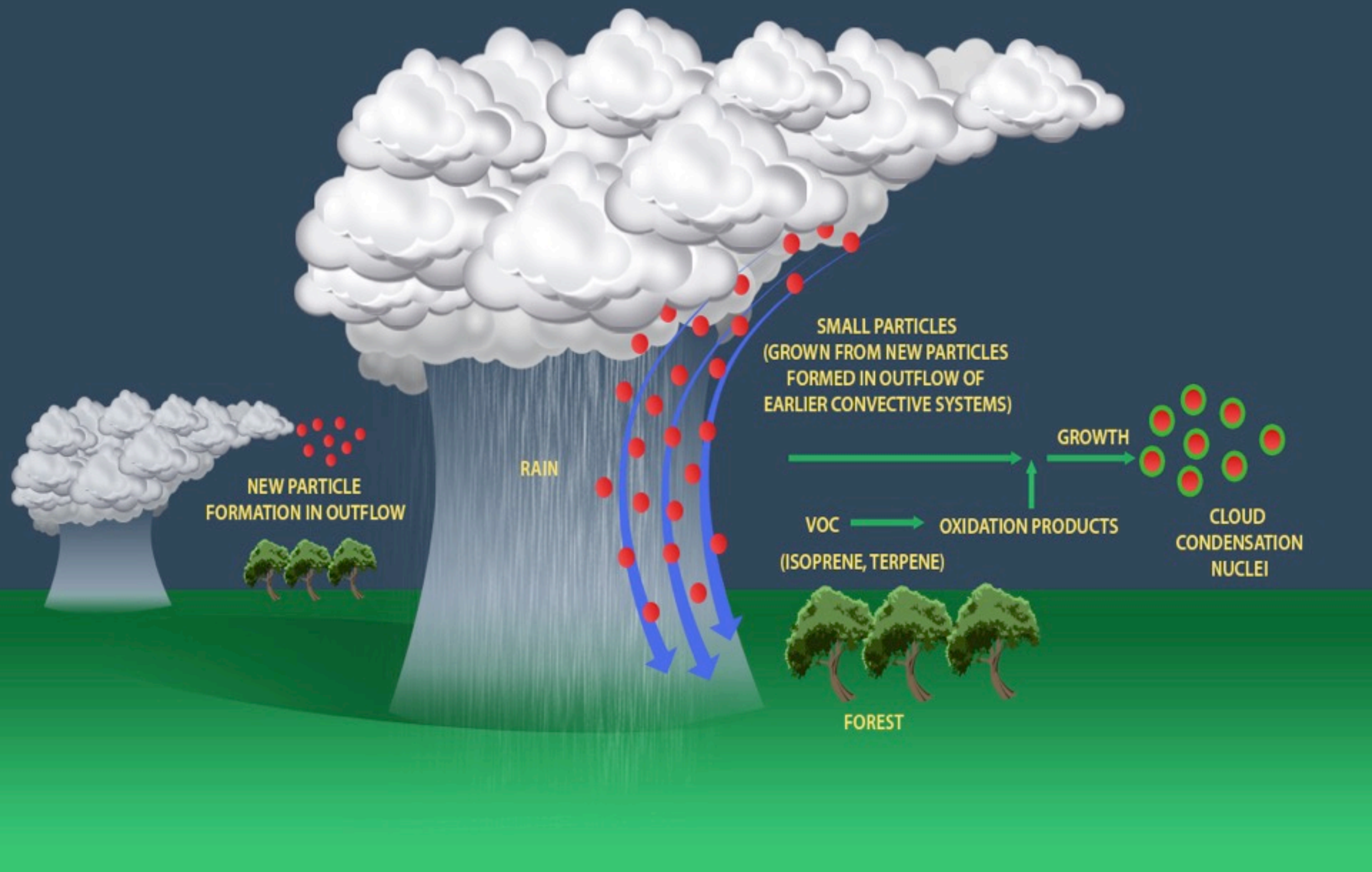


Andreae et al., 2017

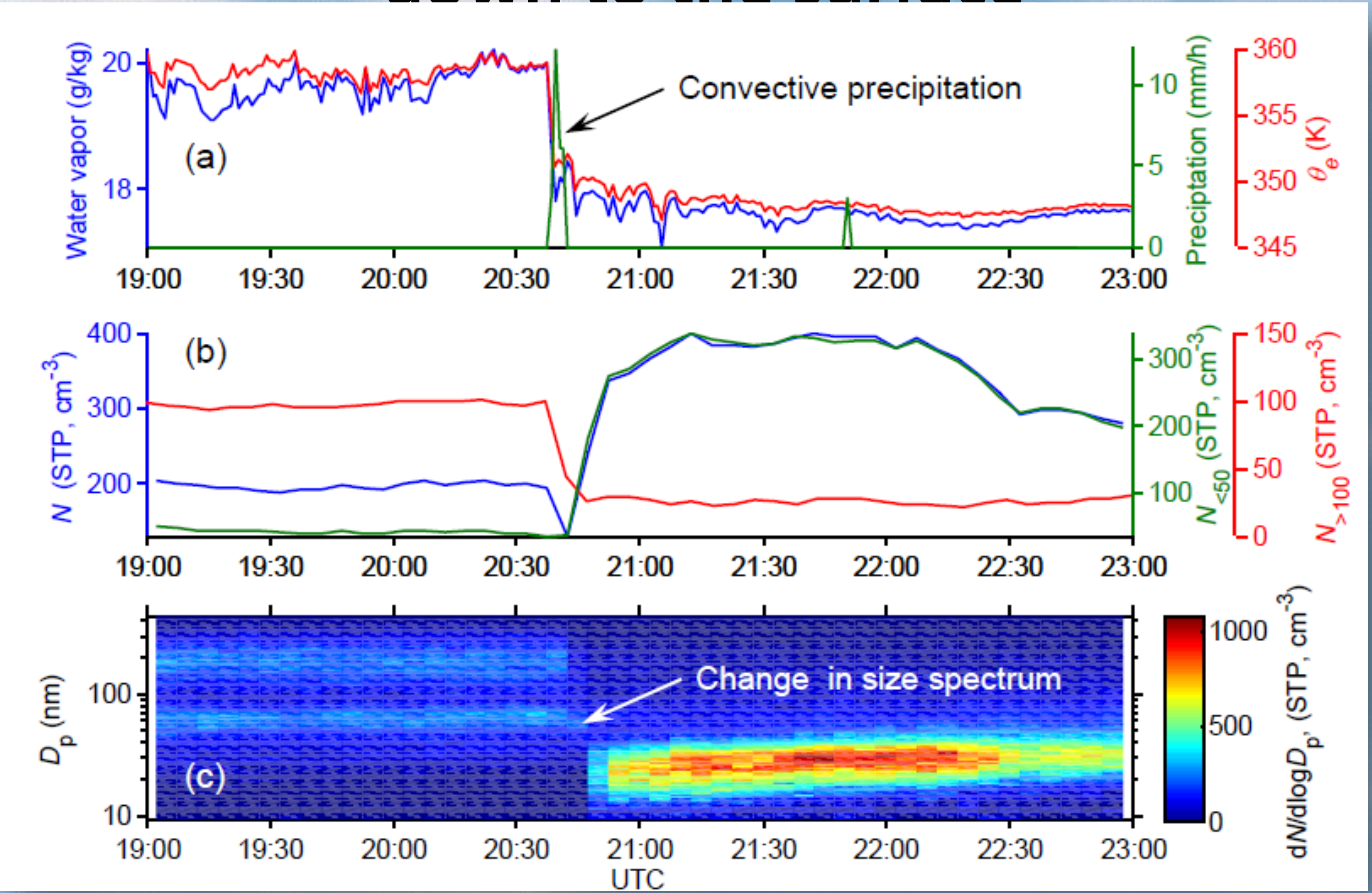
Biogenic organic aerosol formation at low H_2SO_4 happens in UT!



Clouds as active aerosol processors in the atmosphere



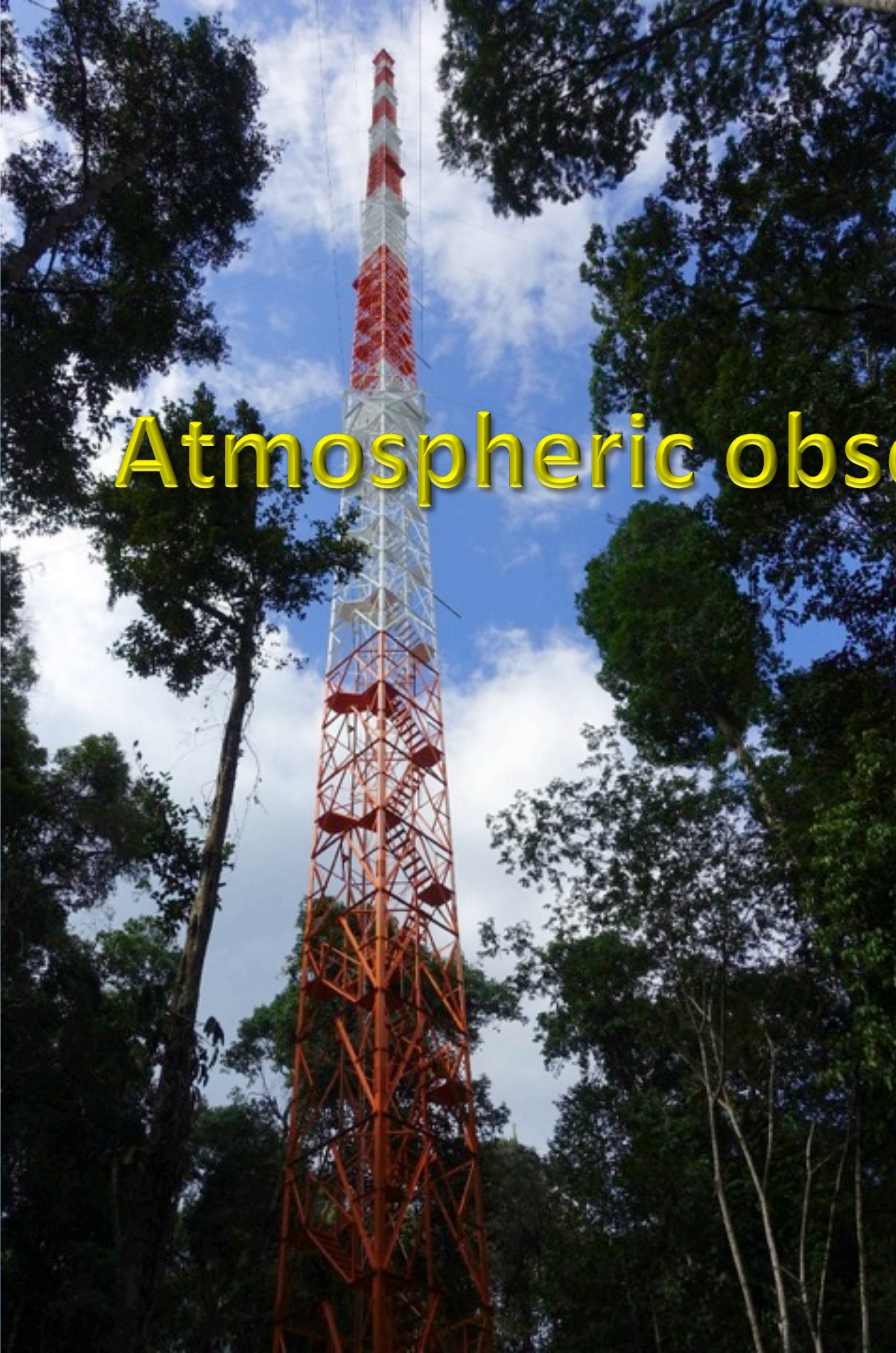
Convective precipitation brings these particles down to the surface



Wang et al. (2016, in press)

ATTO Tower: Permanent observatory at 325 meters height

Atmospheric observations at ATTO




Amazonia is key to global sustainability
Thanks!!!