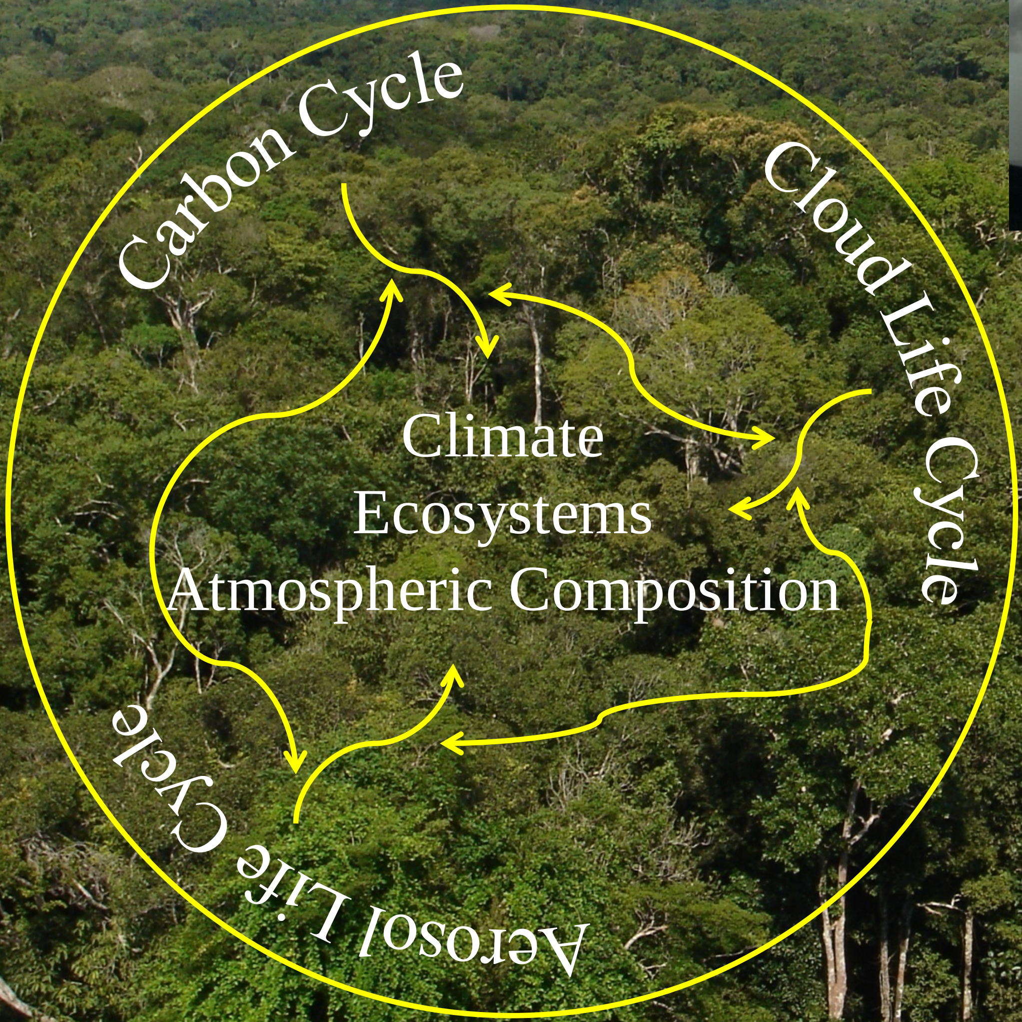
Observations and Modeling of the Green Ocean Amazon (GoAmazon2014/5)

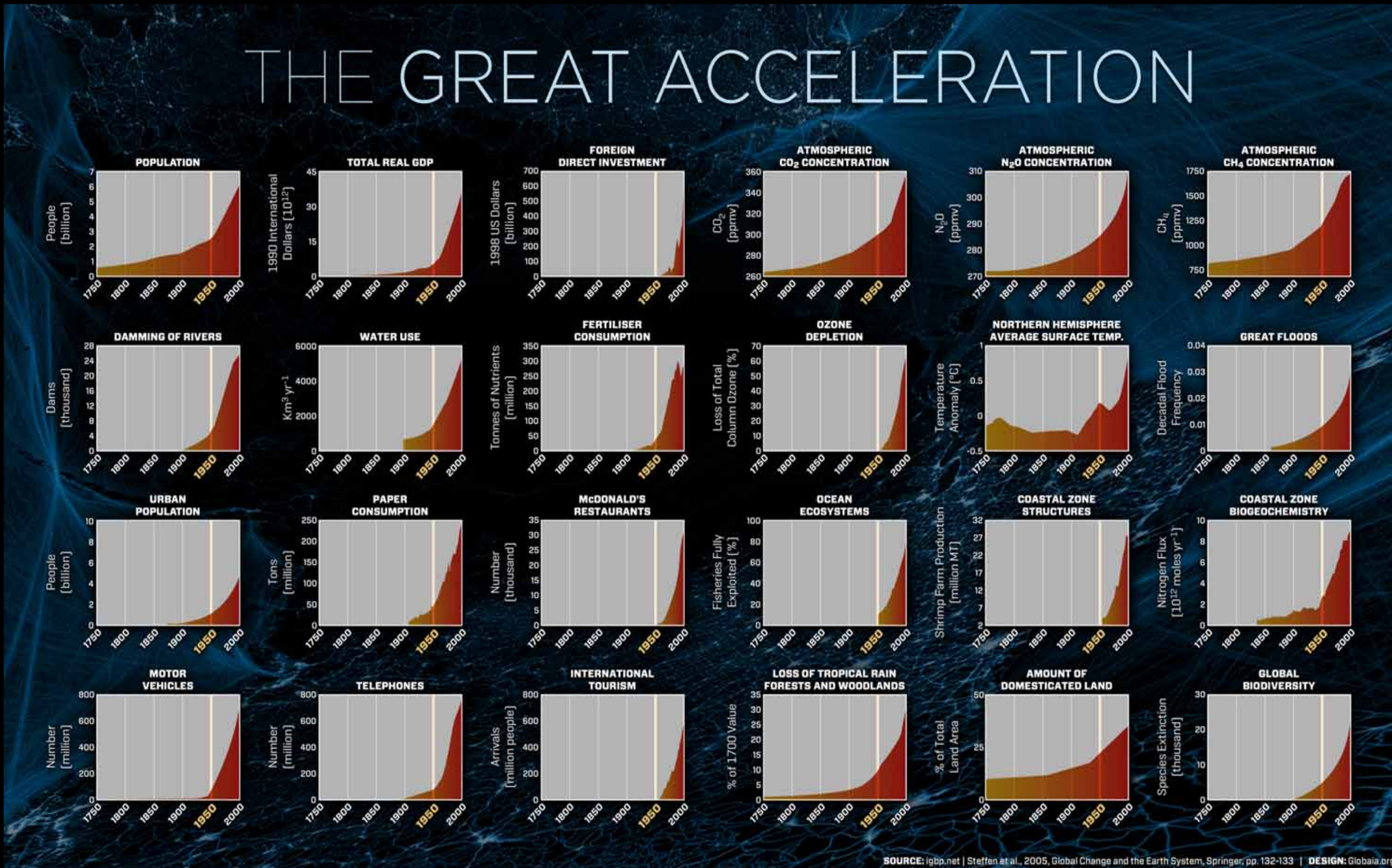


Presented by Scot Martin (Harvard) on behalf of Brazil and USA partners

October 2013

BERAC Meeting, DOE, Washington, D.C.

We are changing Earth rapidly and in many ways



What are the effects of these changes?

Planetary Limits

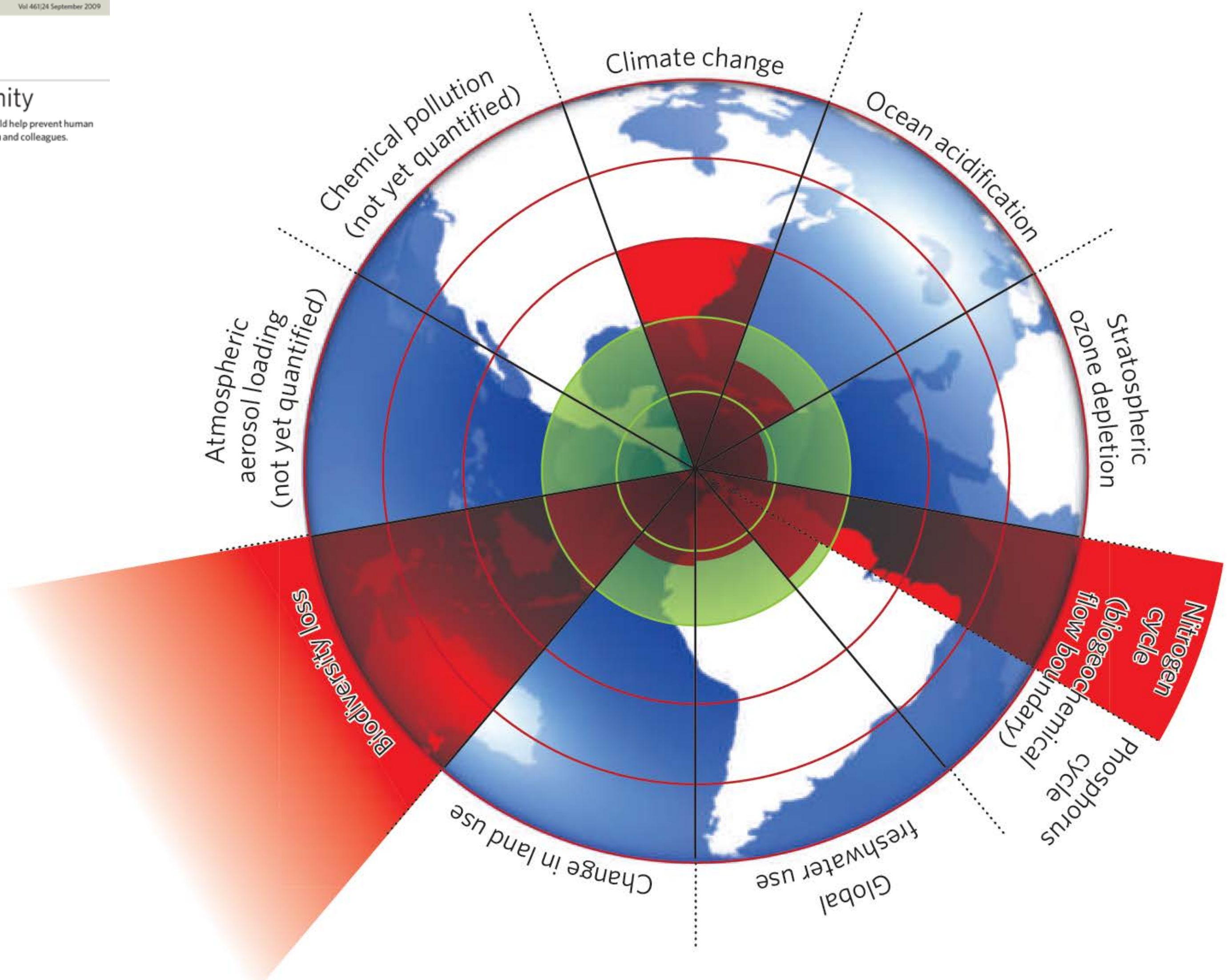

nature Vol 461|24 September 2009

FEATURE

A safe operating space for humanity

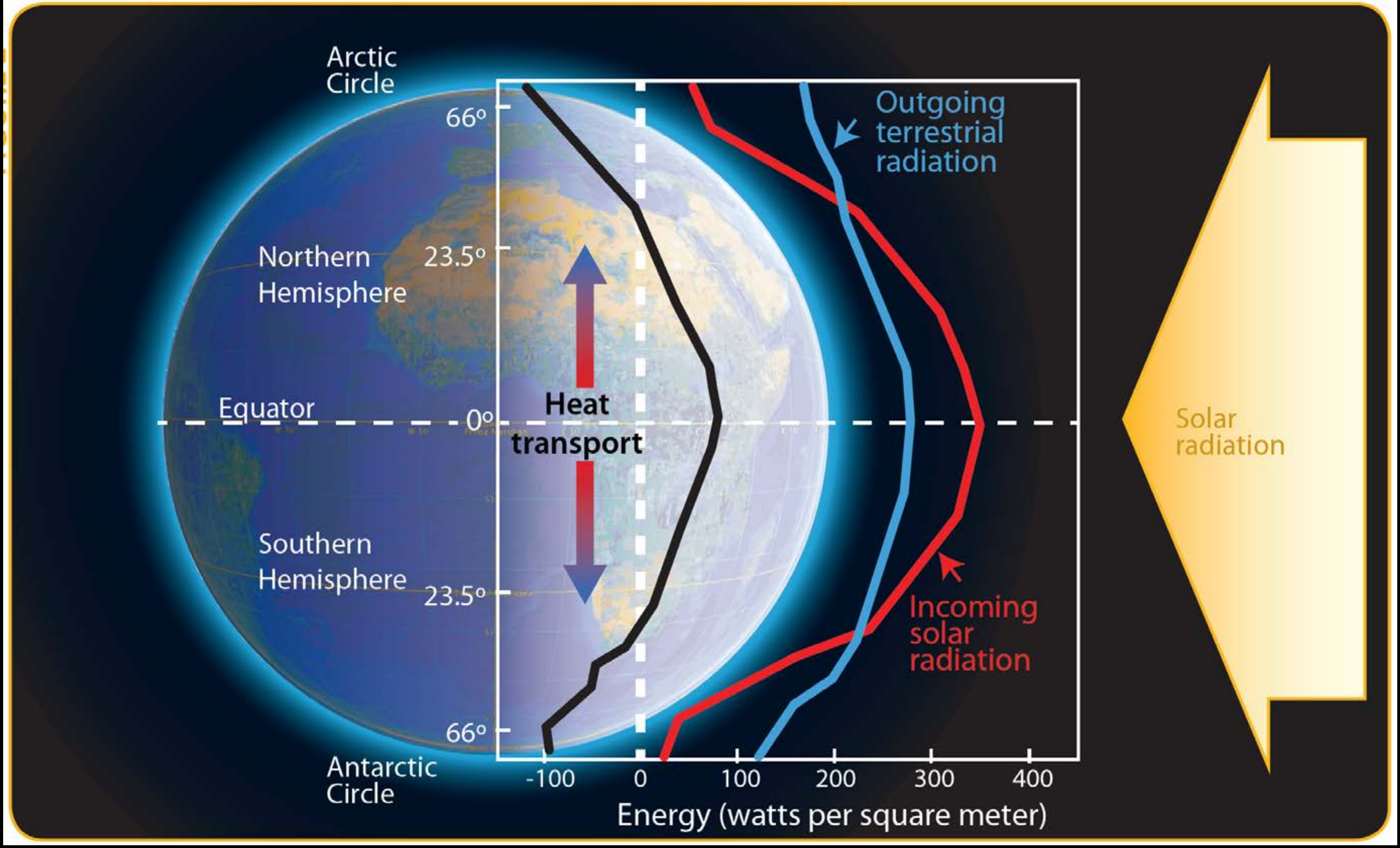
Identifying and quantifying planetary boundaries that must not be transgressed could help prevent human activities from causing unacceptable environmental change, argue **Johan Rockström** and colleagues.

Beyond the boundary. The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference with the nitrogen cycle), have already been exceeded.

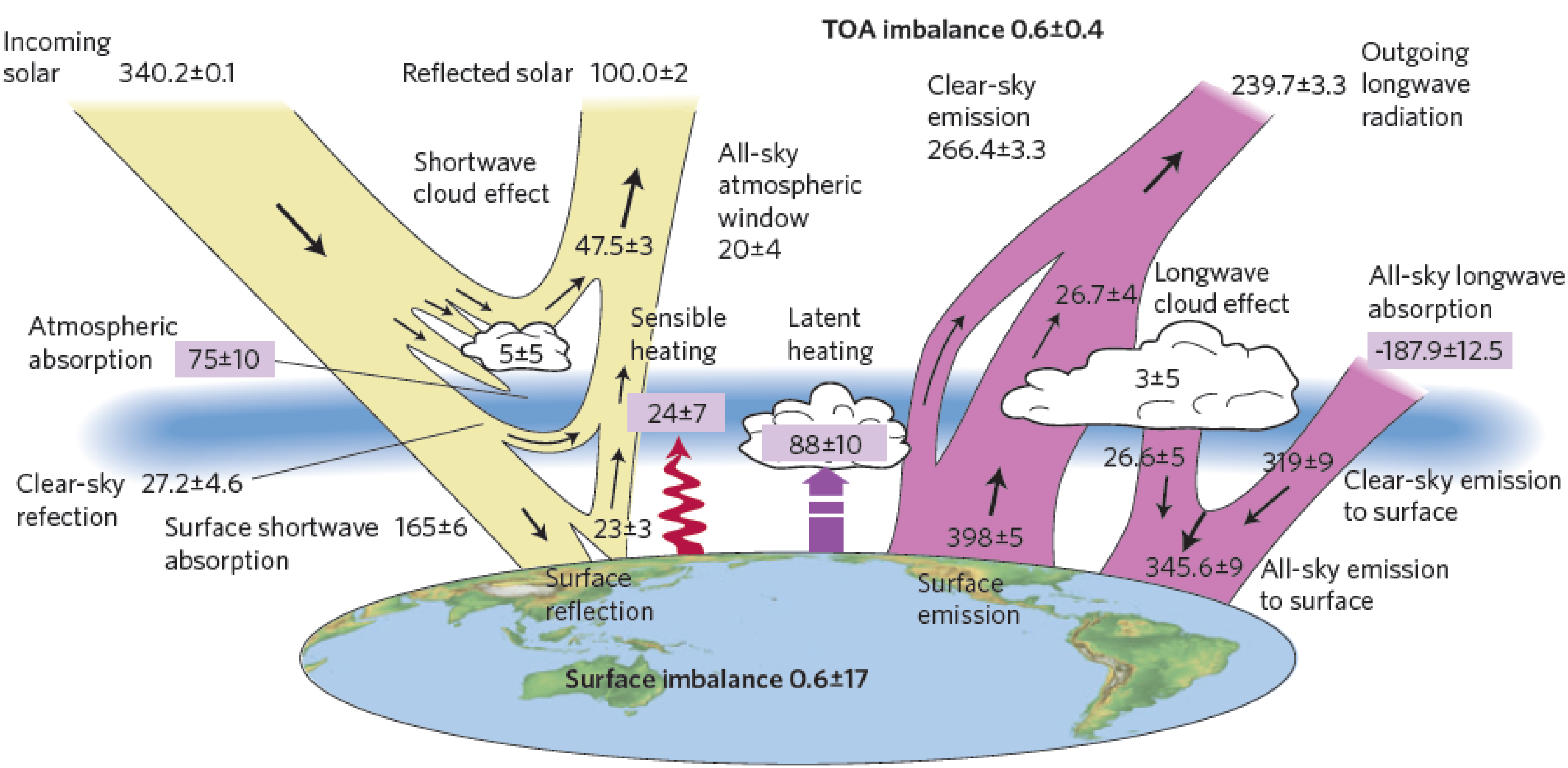


Nature, 2009

Solar Radiation Balance

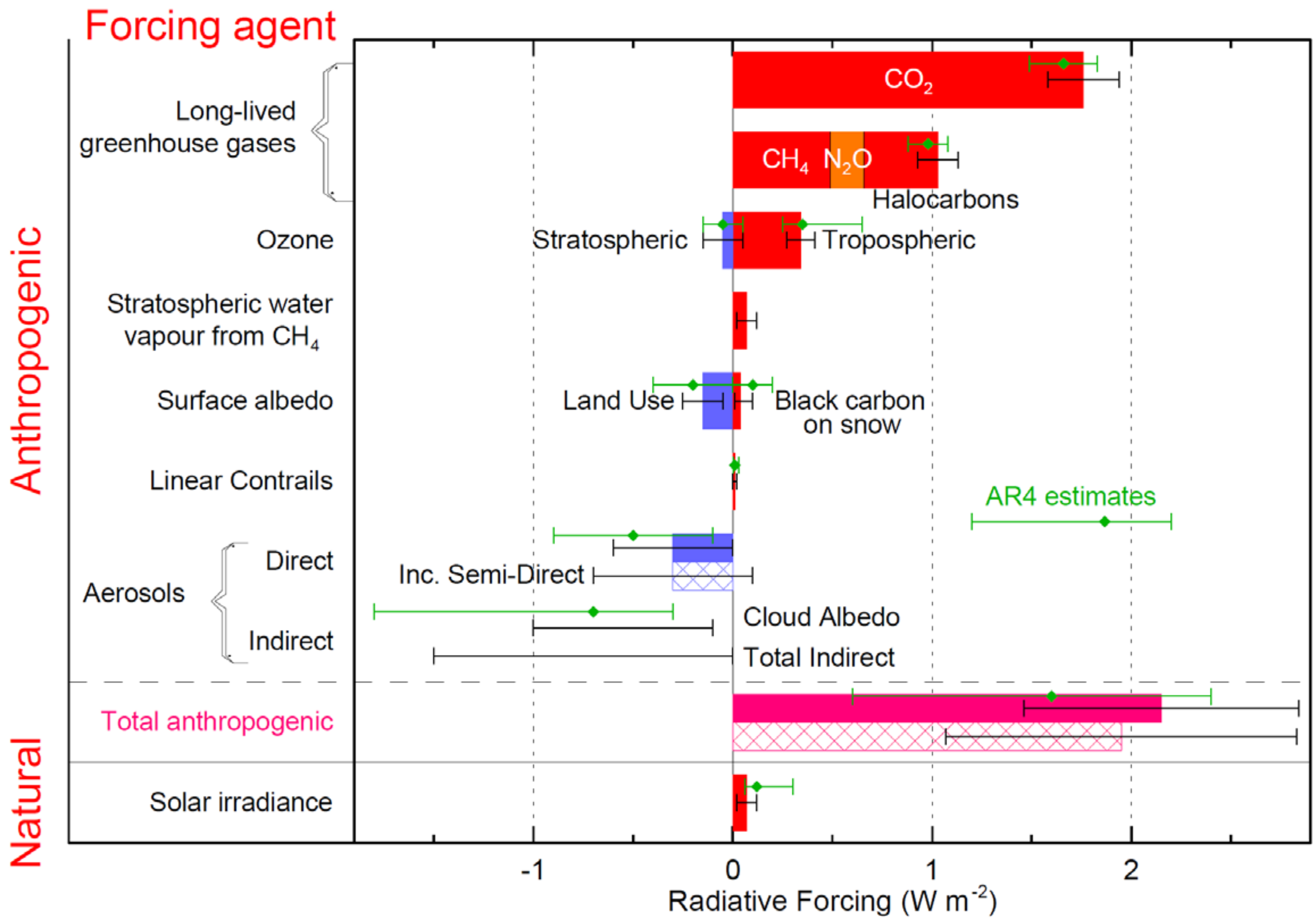


Earth Energy Balance



The global annual mean energy budget of Earth for the approximate period 2000–2010. All fluxes are in Wm^{-2}. Solar fluxes are in yellow and infrared fluxes in pink. The four flux quantities in purple-shaded boxes represent the principal components of the atmospheric energy balance. (Stephens, Nature 2012)

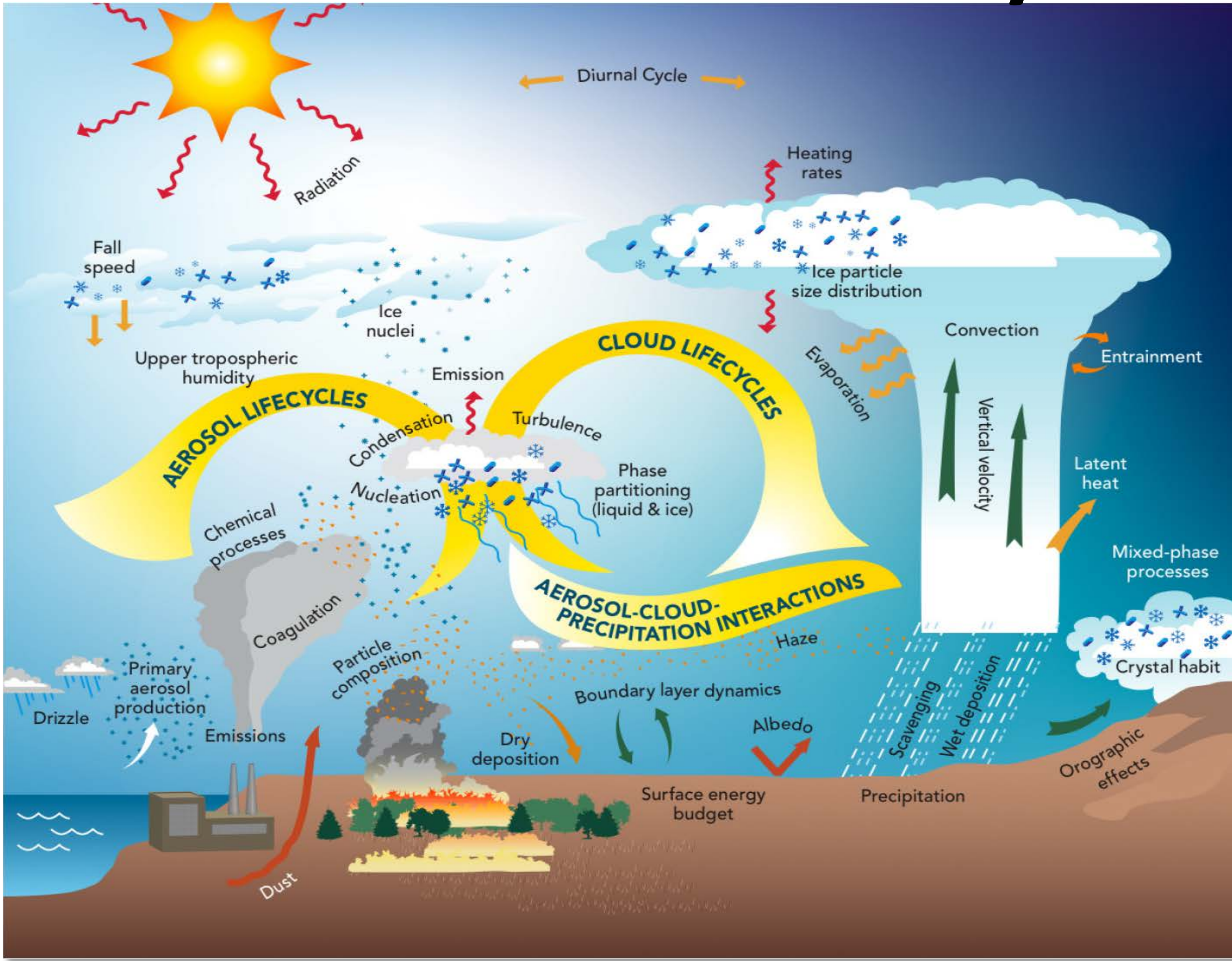
Radiative forcing of climate change 1750-2010



Forcing by component between 1750 and 2010 with associated uncertainty range (solid bars are RF, hatched bars are AF, green diamonds and associated uncertainties are those assessed in AR4).

IPCC 2012

Aerosol and Cloud Lifecycles



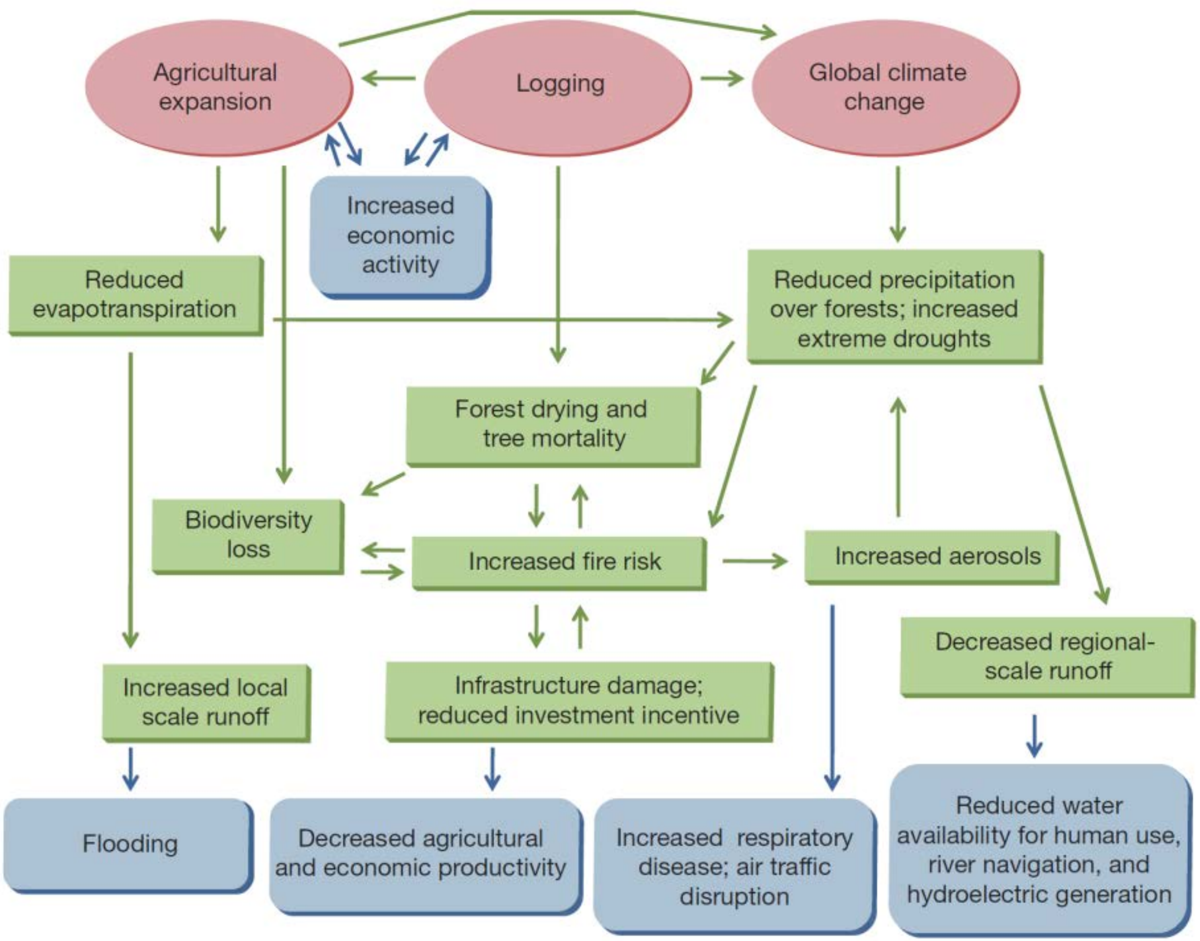
Interactions Between Biosphere and Atmosphere

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]



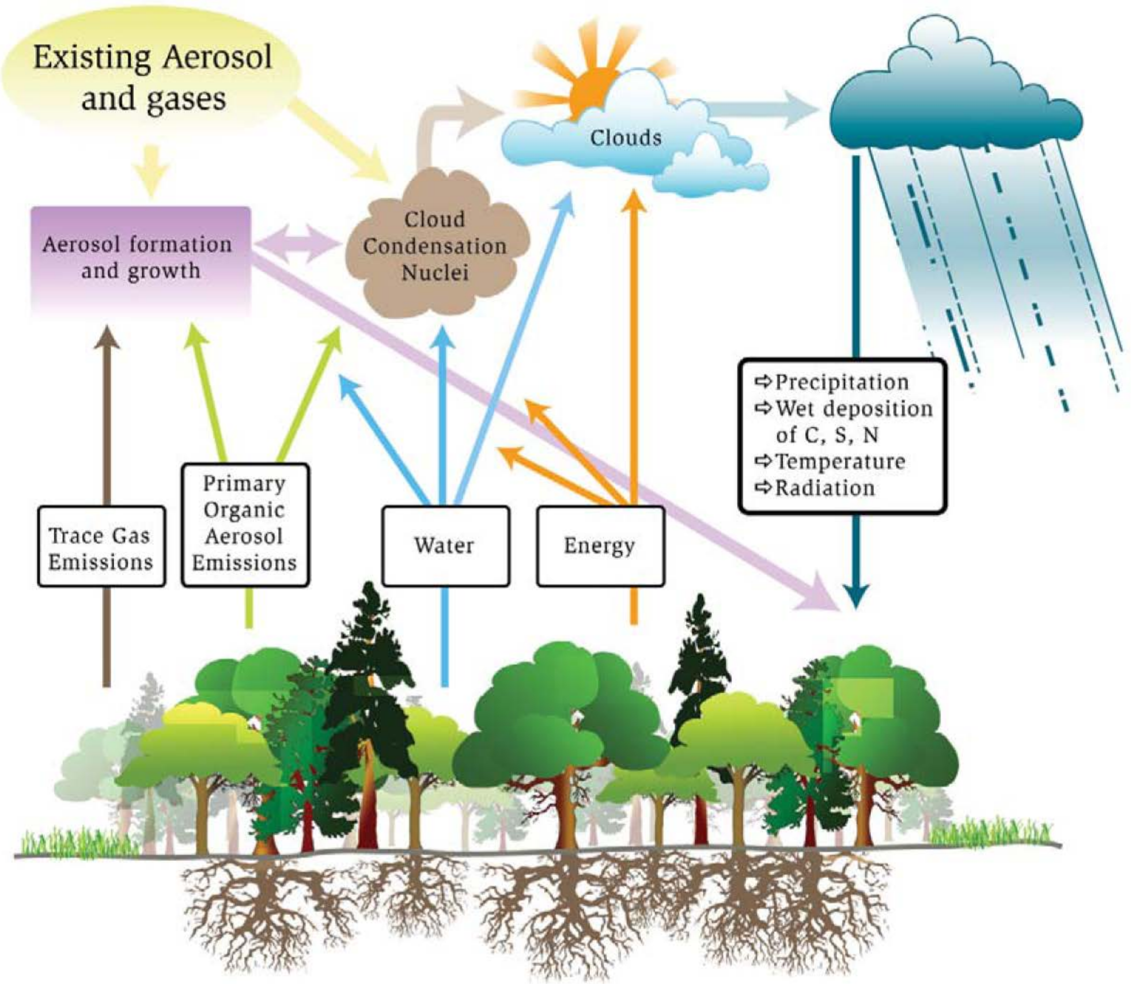
Agricultural expansion and climate variability have become important agents of disturbance in the Amazon basin. There are some signs of a transition to a disturbance-dominated regime. These signs include changing energy and water cycles in the southern and eastern portions of the Amazon basin.

Interactions between global climate, land use, fire, hydrology, ecology and human dimensions.

Forcing factors are indicated with red ovals; processes addressed in this Review are indicated by green boxes and arrows; and consequences for human society are indicated by blue boxes with rounded corners


Amazonia is critical for water vapor transport over South America
What processes controls these fluxes?
Image NASA
Google

Amazon Basin has strong coupling between terrestrial ecosystem and the hydrologic cycle: The linkages among carbon cycle, aerosol life cycle, and cloud life cycle need to be understood and quantified.



Source: Barth et al., "Coupling between Land Ecosystems and the Atmospheric Hydrologic Cycle through Biogenic Aerosol Particles," *BAMS*, *86*, 1738-1742, 2005.

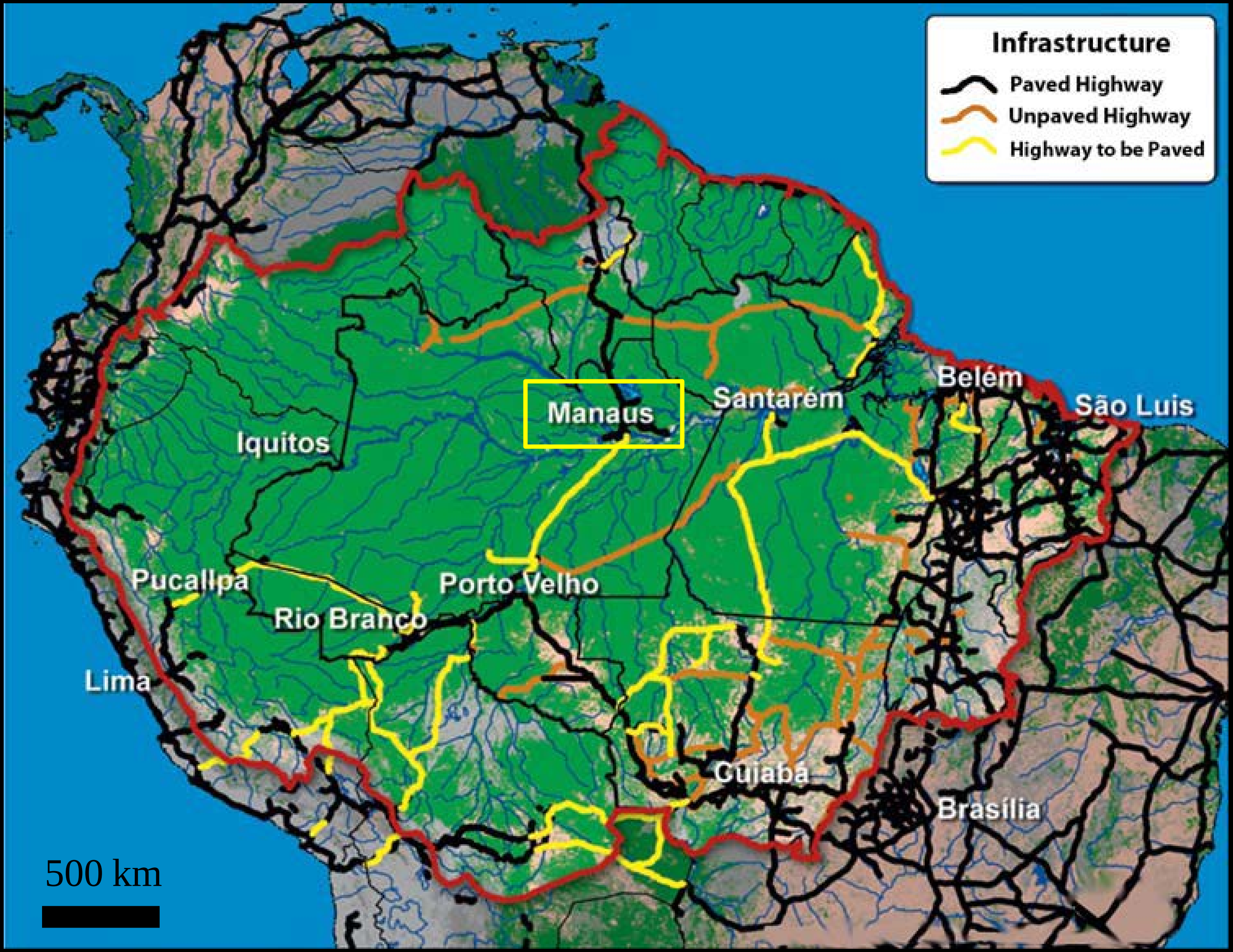
Susceptibility and expected reaction to stresses of global climate change as well as pollution introduced by future regional economic development are not known or quantified at present time.

Scientific Questions for GoAmazon2014

The theme uniting the objectives is the development of a data-driven knowledge base for predicting how the present-day functioning of energy, carbon, and chemical flows in the Basin might change, both due to external forcing on the Basin from global climate change and internal forcing from past and projected demographic changes in the Basin.

The ultimate goal is to estimate future changes in direct and indirect radiative forcing, energy distributions, regional climate, ecosystem functioning, and feedbacks to global climate.

Site Location



Manaus is a Large Source of Pollution

Manaus: Vehicle Fleet 2010

Frota de Veículos -

	Quantidade
Motoneta	8.563
Motocicleta	83.459
Automóvel	252.274
Microônibus	2.334
Ônibus	5.807
Reboque	1.677
Semi-reboque	9.754
Camioneta	18.812
Caminhão	14.631
Caminhão-Trator	2.019
Caminhonete	49.981
Ciclomotor	329
Trator rodas	48
Triciclo	100
Utilitários	2.403
Outros	109
	452.300

Fonte: DETRAN/AM

FUEL MIX:

-tractor, truck and bus: almost 100% diesel

-car and bikes : > 60% gasoline (*)

(*) Ethanol price is very high in Manaus and gasoline is preferred by the consumer.

Acknowledgments: Rodrigo Souza, UEA

Manaus: Power Plant 2009: Fuel Oil

TABELA 1 - CONFIGURAÇÃO DO PARQUE GERADOR DO SISTEMA MANAUS AMAZONAS - AGOSTO DE 2009

Usina		Potência do Sistema (MW)			Tipo de UG	Tipo de óleo
		Nominal	Efetiva	Disponível		
Geração hídrica	**UHE Balbina**	250,0	250,0	250,0	Turbina hidráulica	
Geração Térmica Diesel	Aparecida	198,0	172,0	75,0	Turbina a Gás	PTE
	Mauá	452,4	437,0	259,6	Turbina a Vapor, Gás e Motor	Combustível, PTE e PGE
	Electron	120,0	102,2	0,0	Turbina a Gás	PTE
	UTE*	149,8	120,8	94,2		Óleo
TOTAL GERAÇÃO PRÓPRIA		1.170,6	1.081,3	678,45		
Produtor Independente	Breitener Tambaqui	83,5	60,0	60,0	Turbina a Gás	OCA-1
	Breitener Jaraqui	83,5	60,0	56,7	Turbina a Gás	OCA-1
	Manauara	85,4	60,0	60,0	Turbina a Gás	OCA-1
	Rio Amazonas	85,4	65,0	65,0	Turbina a Gás	OCA-1
	GERA	85,4	60,0	60,0	Turbina a Gás	OCA-1
TOTAL DE COMPRAS		423,1	305,0	301,7		
TOTAL GERAL DO SISTEMA		1.593,7	1.386,3	980,2		

* inclui as UTE-Cidade Nova, UTE-São José e UTE-Flores
Fonte: Adaptado das informações obtidas junto a Eletrobras Amazonas Energia

Hydropower

Oils of different grades

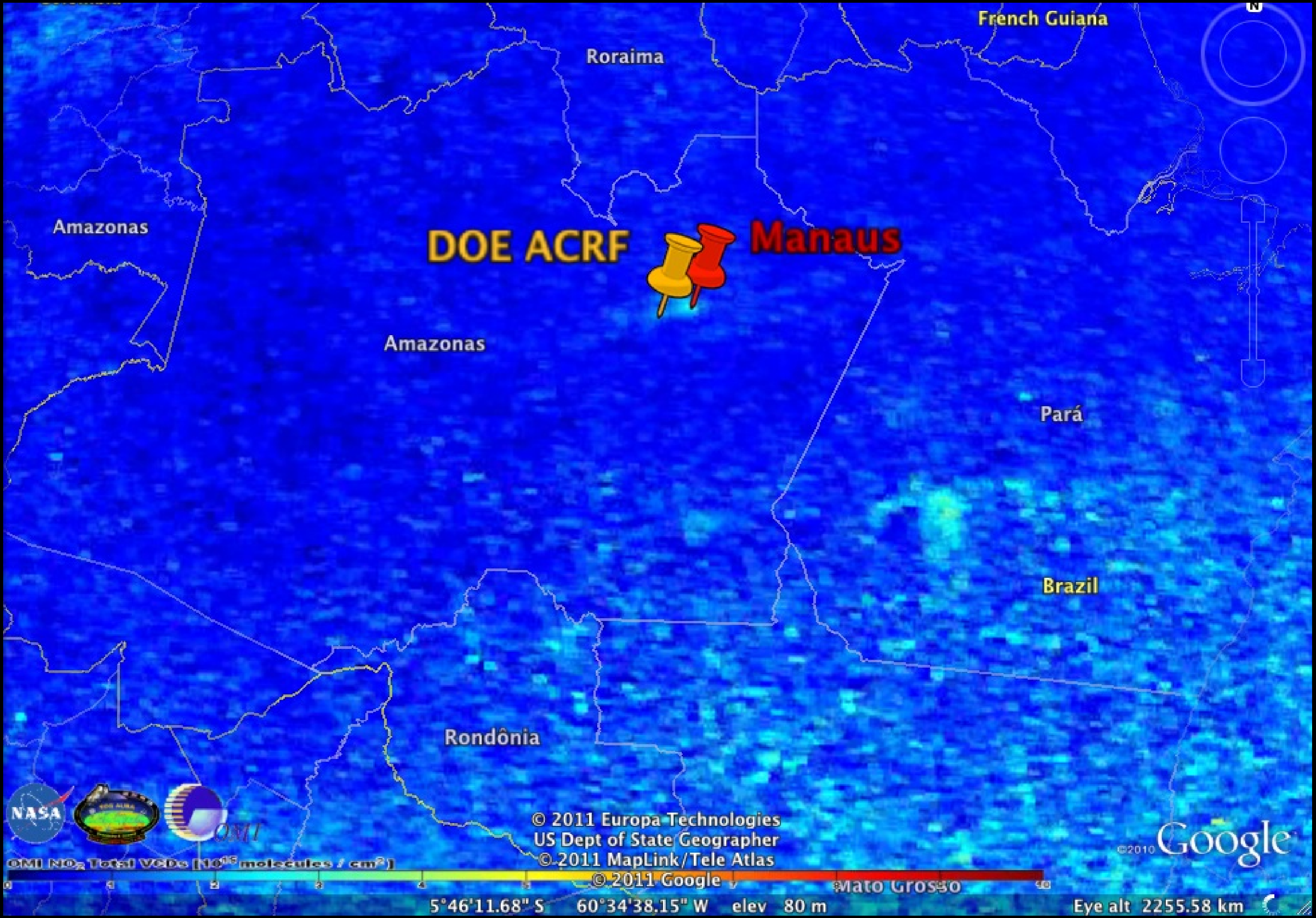
PTE - óleo leve "Para Turbina Elétrica"

PGE - óleo combustível "Para Gerador Elétrico"

OCA-1 = Óleo Combustível com Alto teor de enxofre = Fuel Oil with High Sulfur

Acknowledgments: Rodrigo Souza, UEA

NO_2 Outflow from Manaus in Aug 2010 observed by OMI



Acknowledgments: Jun Wang, Univ. Nebraska

A little bit of information about Manaus: *As Hawaii is to the Blue Ocean so Manaus is to the Green Ocean (within poetic license)*

Population for the metropolitan region of Manaus: 2002/2009

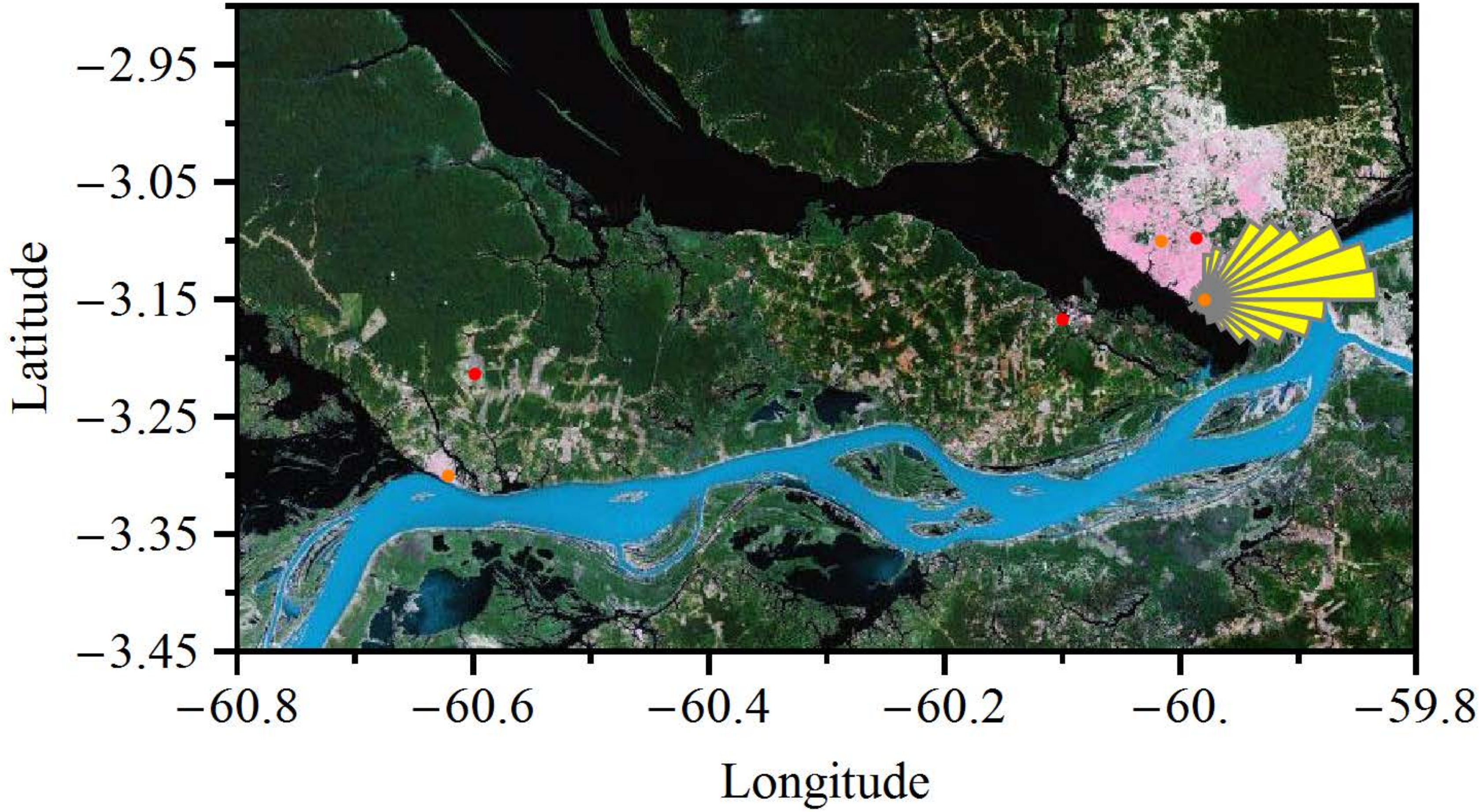
POPULAÇÃO PARA A REGIÃO METROPOLITANA DE MANAUS - 2002 / 2009

Municípios	2002	2003	2004	2005	2006	2007	2008	2009
MANAUS	1.488.805	1.527.314	1.592.555	1.644.690	1.688.524	1.646.602	1.709.010	1.738.641
CAREIRO DA VÁRZEA	17.079	16.992	16.844	16.725	16.626	23.023	24.030	24.704
IRANDUBA	35.128	36.439	38.661	40.436	42.812	32.869	33.834	33.884
ITACOATIARA	74.914	76.217	78.425	80.190	81.674	84.676	87.896	89.440
MANACAPURU	77.171	78.785	81.518	83.703	84.656	82.309	85.279	86.472
NOVO AIRÃO	8.731	8.304	7.580	7.002	6.516	14.630	15.343	15.915
PRESIDENTE FIGUEIREDO	19.562	20.569	22.273	23.636	24.781	24.360	25.474	26.282
RIO PRETO DA EVA	19.910	20.990	22.820	24.283	25.513	24.858	26.004	26.847
REGIÃO METROPOLITANA	**1.741.300**	**1.785.610**	**1.860.676**	**1.920.665**	**1.971.102**	**1.933.327**	**2.006.870**	**2.042.185**

FONTE: IBGE

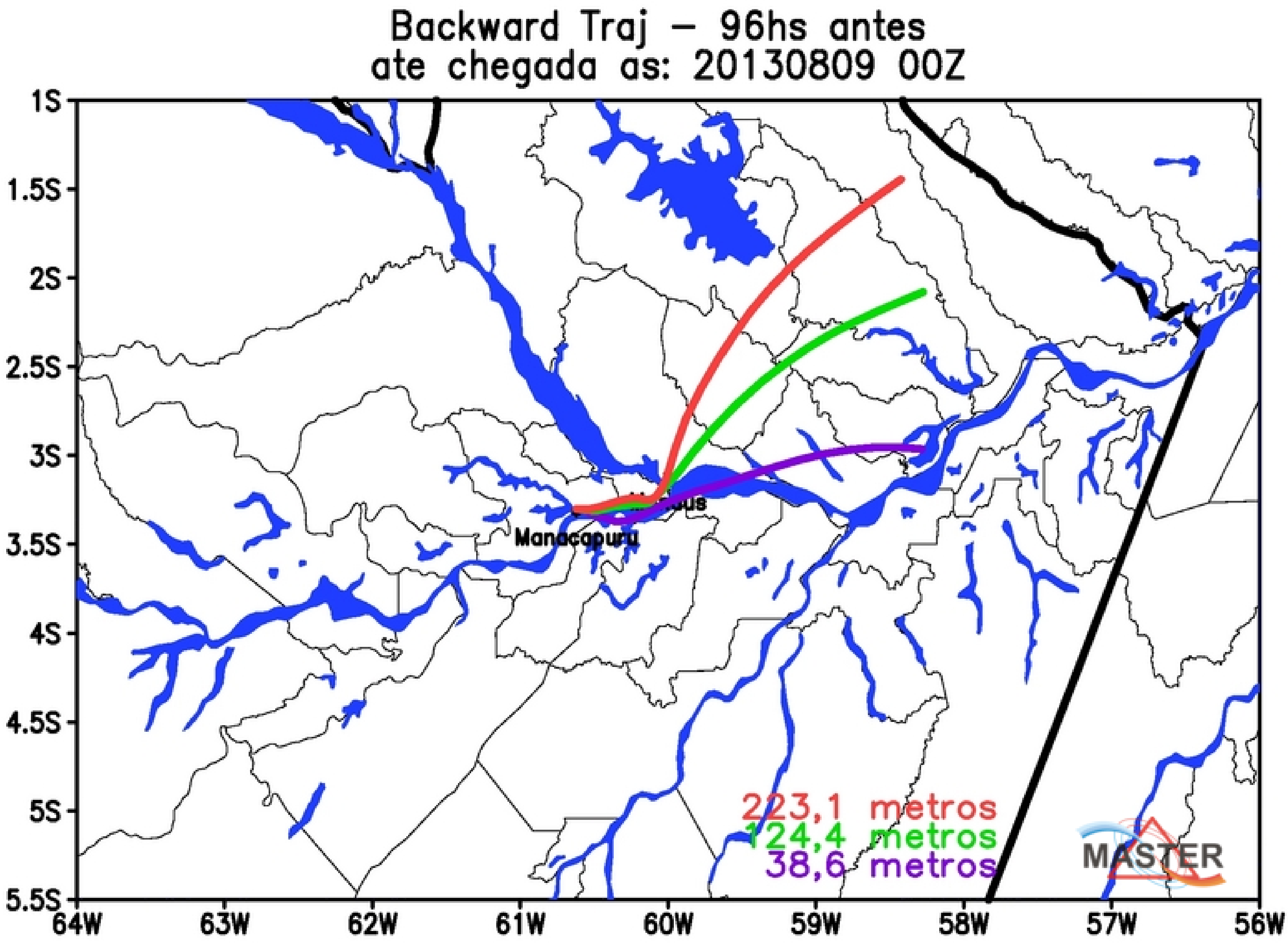
Acknowledgments: Rodrigo Souza, UEA

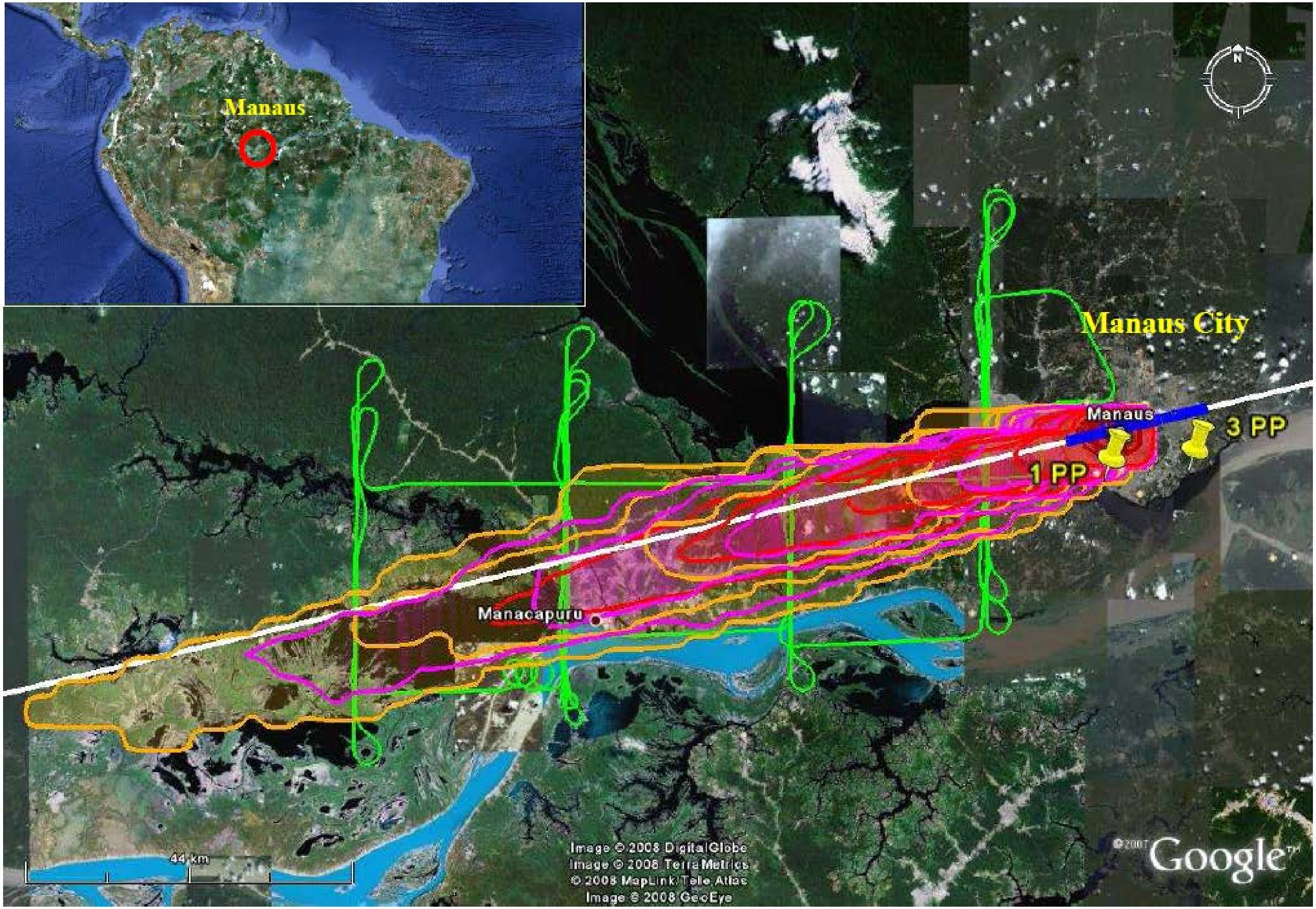
Downwind of Manaus



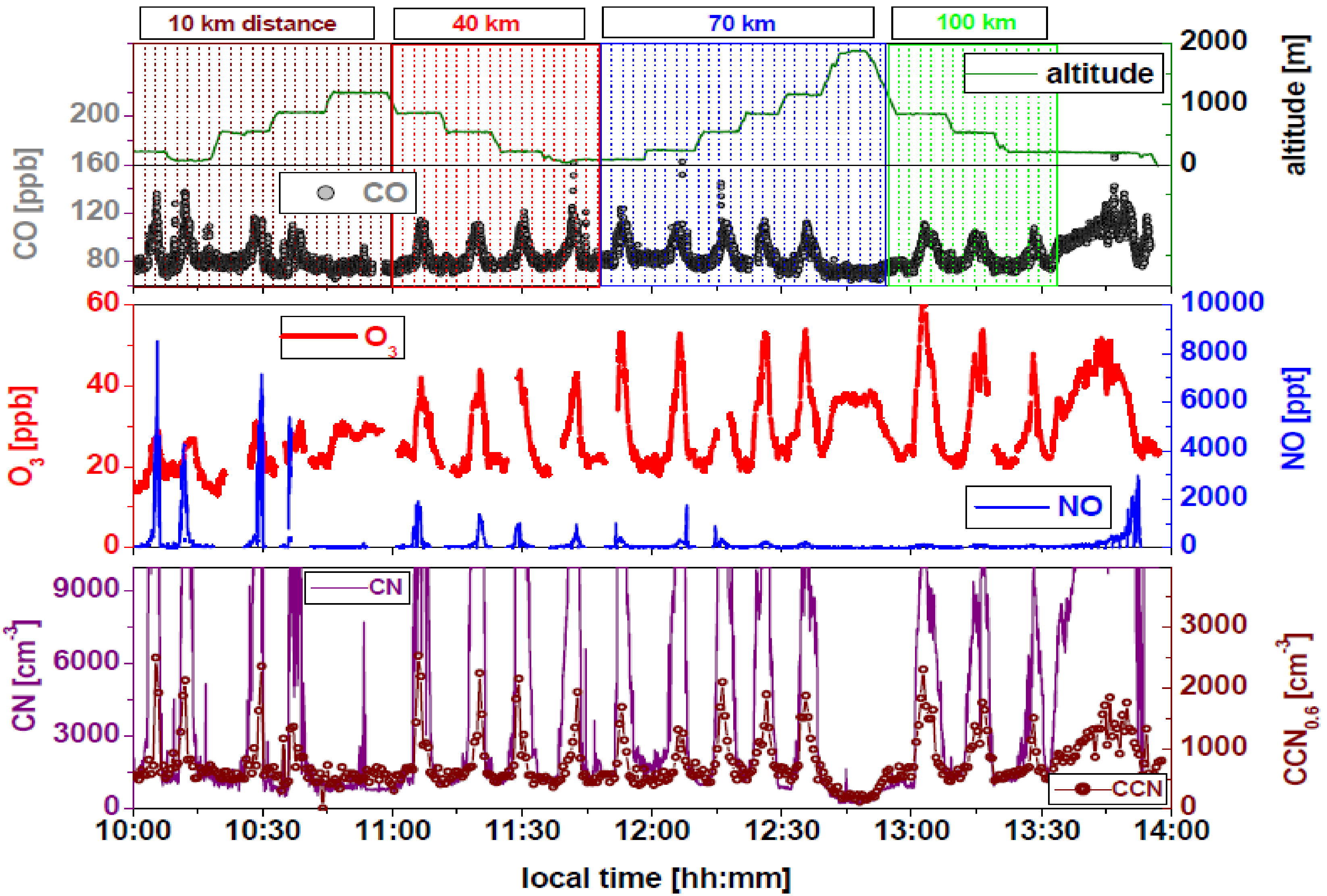
(−3.21328 ,	−60.5987)	DOE ARM ACRF	T3
(−3.16667 ,	−60.1)	TBD	T2
(−3.09722 ,	−59.9867)	INPA/UEA	T1
(−2.14663 ,	−59.005)	ATTO	T0
(−2.60908 ,	−60.2093)	K34	K34
(−2.59458 ,	−60.2093)	AMAZE08	TT34

- 111 by 60.8 km represented by this box.
- Wind speeds at 1 km altitude are typically 10 to 30 kph.
- T2→T3 transit time of 2 to 6 hr.


Backward Traj – 96hs antes
ate chegada as: 20130809 00Z
1S
1.5S
2S
2.5S
3S
3.5S
4S
4.5S
5S
5.5S
64W
63W
62W
61W
60W
59W
58W
57W
56W
Manacapuru
223,1 metros
124,4 metros
38,6 metros
MASTER



Reference: Kuhn, U.; Ganzeveld, L.; Thielmann, A.; Dindorf, T.; Welling, M.; Sciare, J.; Roberts, G.; Meixner, F. X.; Kesselmeier, J.; Lelieveld, J.; Ciccioli, P.; Kolle, O.; Lloyd, J.; Trentmann, J.; Artaxo, P.; Andreae, M. O., "Impact of Manaus City on the Amazon Green Ocean atmosphere: Ozone production, precursor sensitivity, and aerosol load," *Atmos. Chem. Phys.* **2010**, *10*, 9251-9282.



Reference: Kuhn, U.; Ganzeveld, L.; Thielmann, A.; Dindorf, T.; Welling, M.; Sciare, J.; Roberts, G.; Meixner, F. X.; Kesselmeier, J.; Lelieveld, J.; Ciccioli, P.; Kolle, O.; Lloyd, J.; Trentmann, J.; Artaxo, P.; Andreae, M. O., "Impact of Manaus City on the Amazon Green Ocean atmosphere: Ozone production, precursor sensitivity, and aerosol load," *Atmos. Chem. Phys.* **2010**, *10*, 9251-9282.

Downwind of Manaus: A Natural Laboratory

The deployment site is situated in the steady trade winds such that it experiences the extremes of:

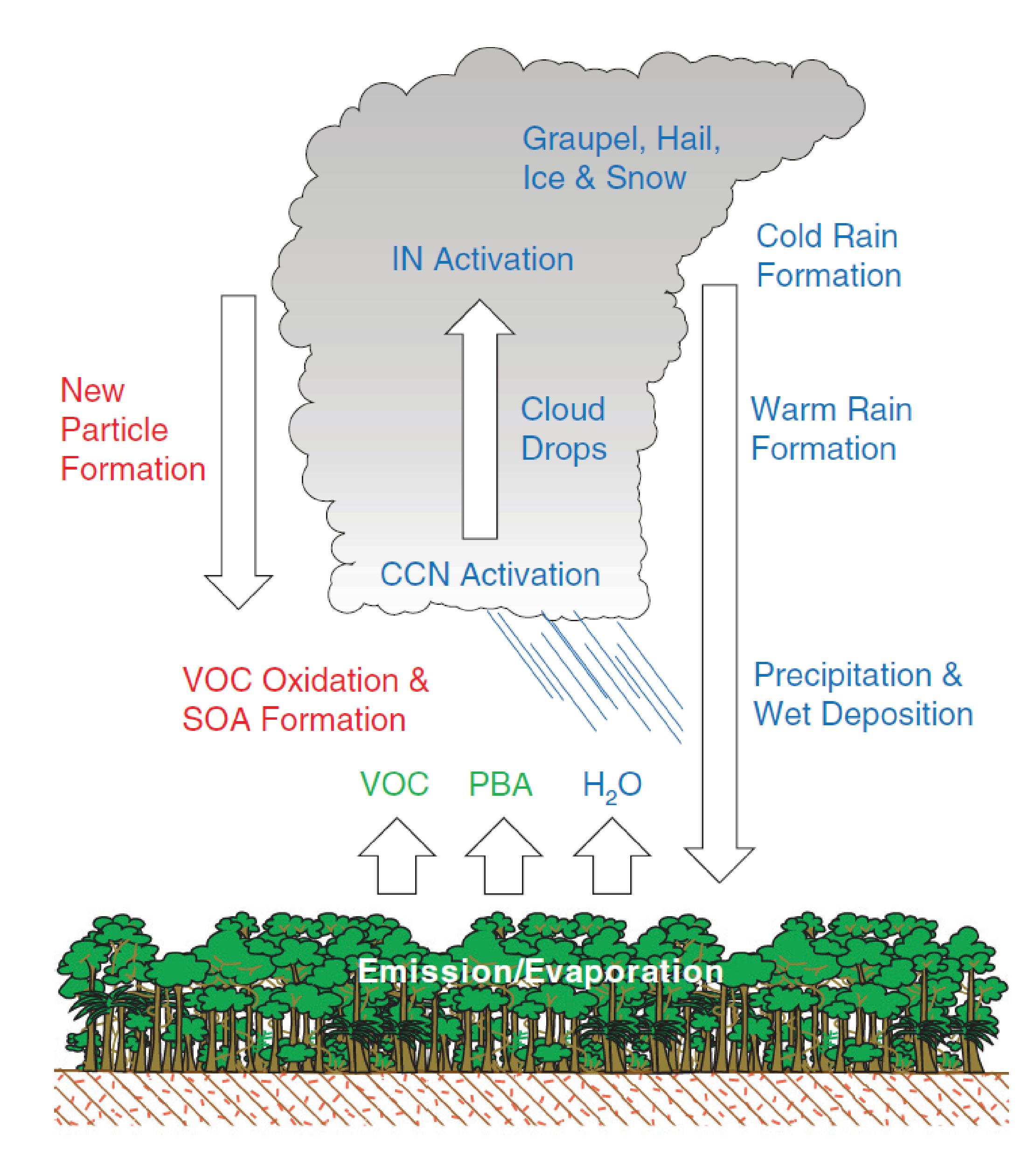
(i) a pristine atmosphere when the Manaus pollution plume meanders; and

(ii) heavy pollution and the interactions of that pollution with the natural environment when the plume regularly intersects the site.

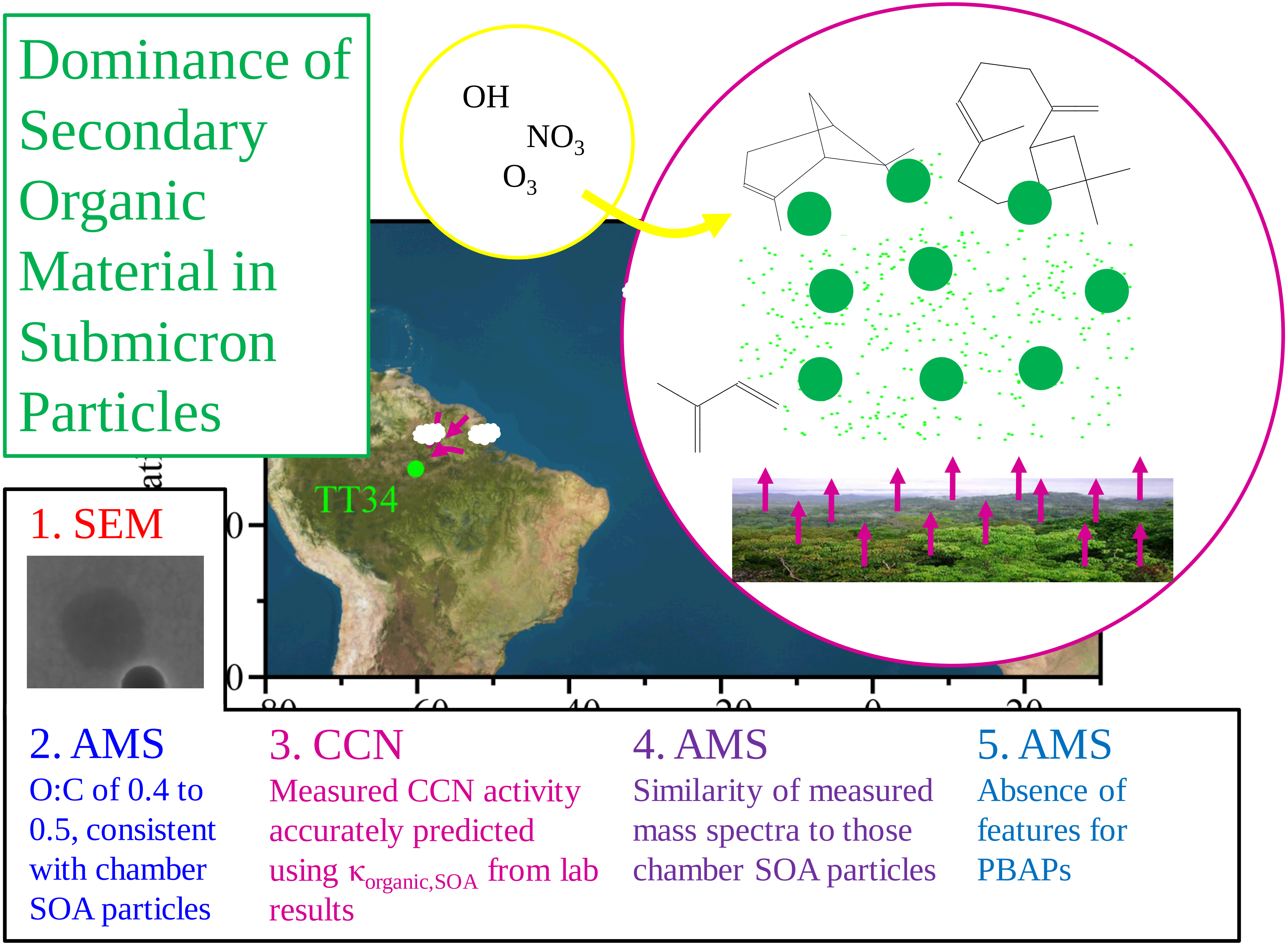
Reminder: GoAmazon2014/5 Theme: What is the effect of pollution on… these cycles and the coupling among them?

Cloud Life Cycle, Aerosol Life Cycle, Aerosol-Cloud-Precipitation Interactions, Carbon Cycle are all represented in this schematic.

GoAmazon2014: *What is the effect of pollution on…* these cycles and the coupling among them?

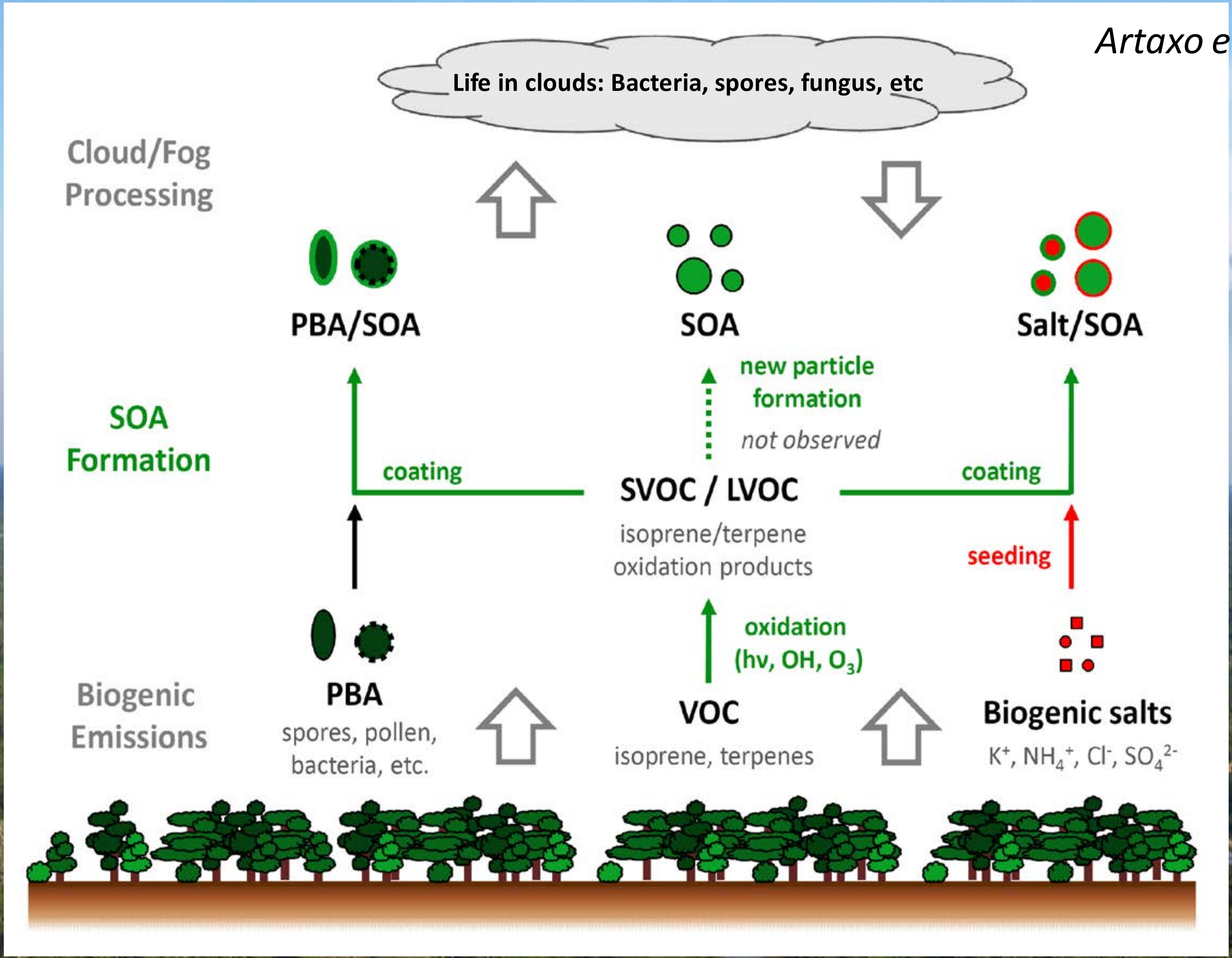


Source: Pöschl, Martin, et al., "Rainforest aerosols as biogenic nuclei of clouds and precipitation in the Amazon," *Science*, 2010, 329, 1513-1516.


Dominance of Secondary Organic Material in Submicron Particles
OH
NO3
O3
TT34
1. SEM
2. AMS
O:C of 0.4 to 0.5, consistent with chamber SOA particles
3. CCN
Measured CCN activity accurately predicted using κorganic,SOA from lab results
4. AMS
Similarity of measured mass spectra to those chamber SOA particles
5. AMS
Absence of features for PBAPs

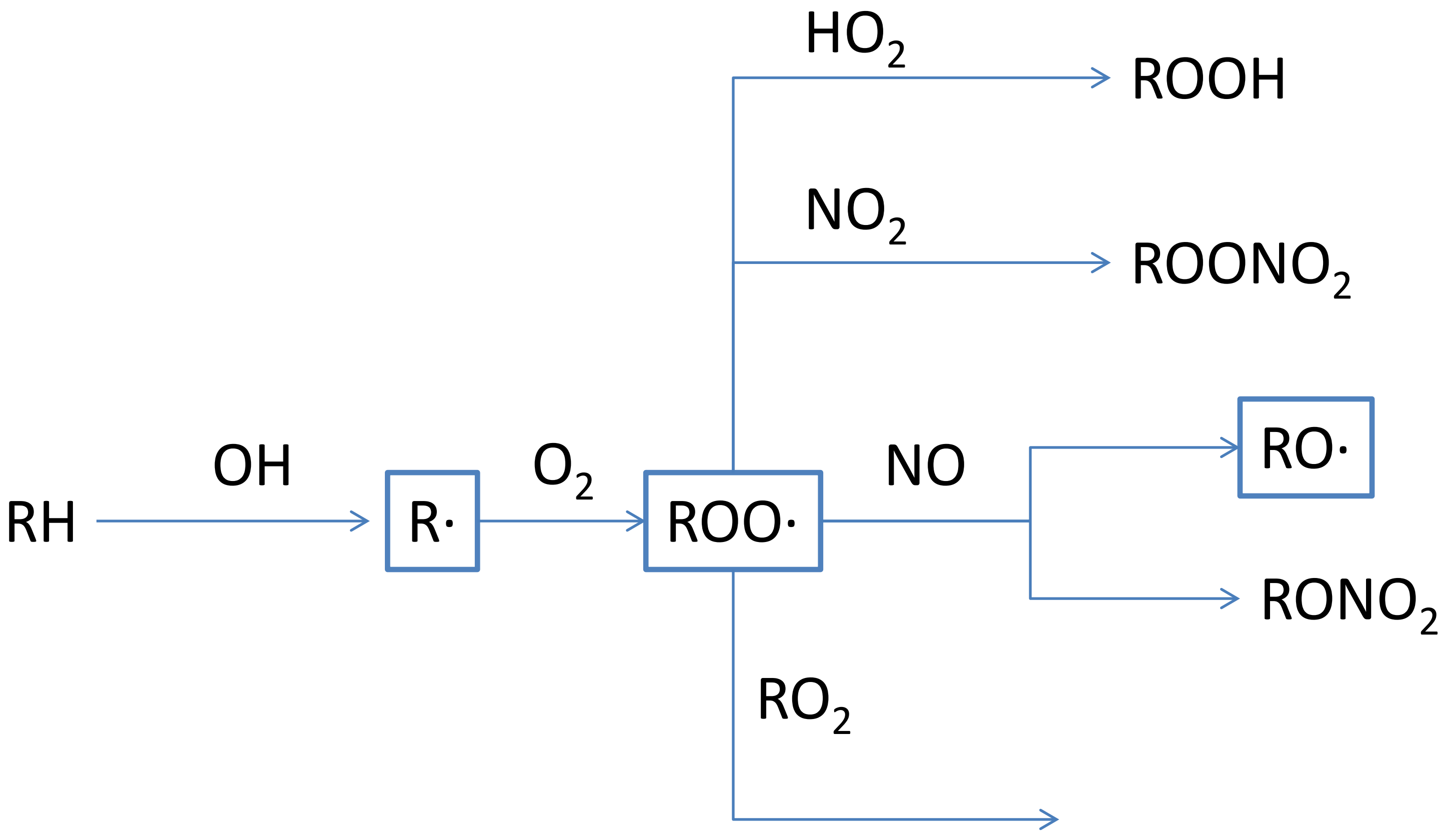
The biology of the forest partially controls the chemistry and physics of the atmosphere in Amazonia

Artaxo et al., 2013

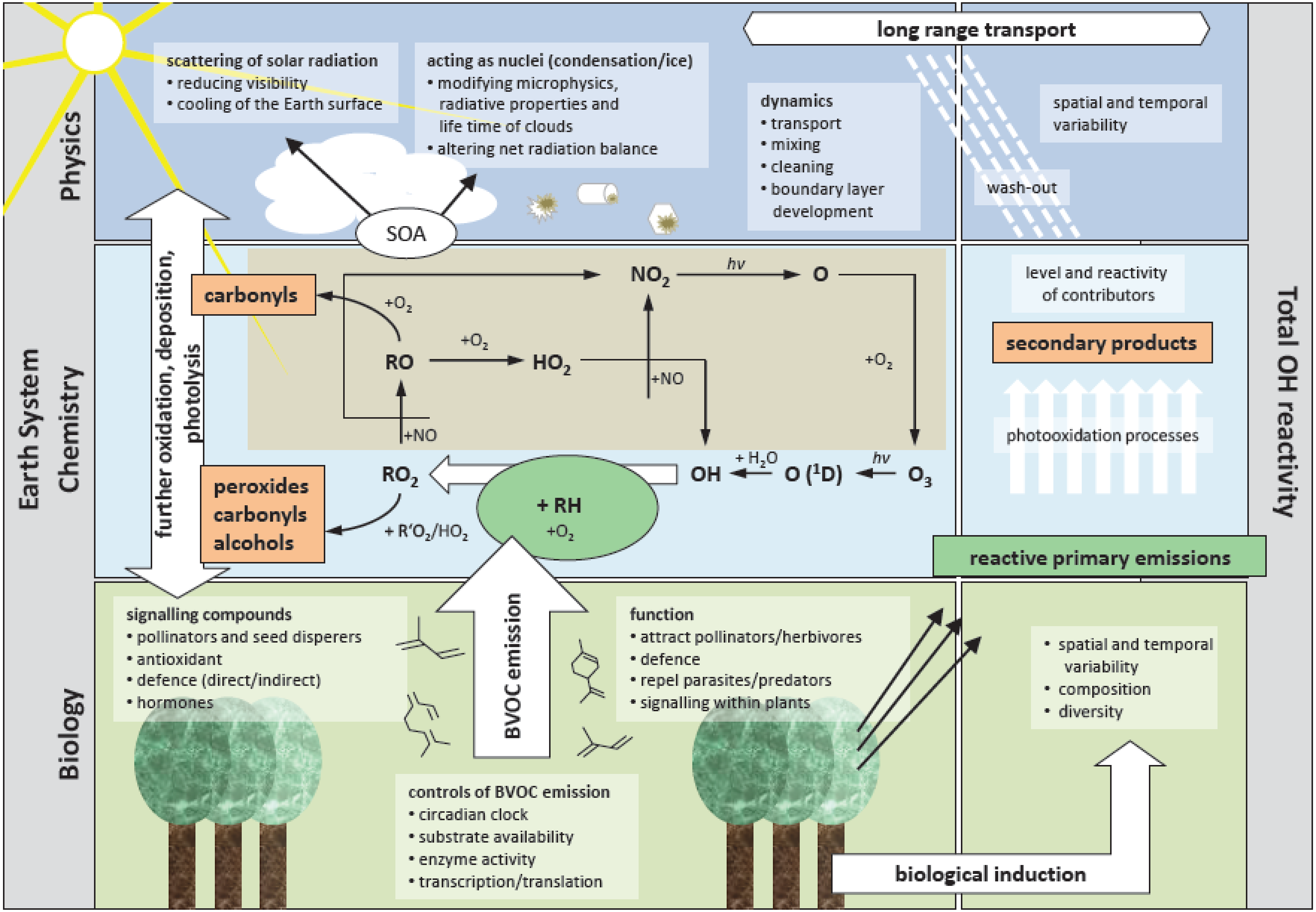


Strong interactions between forest biology, physics and chemistry of the atmosphere

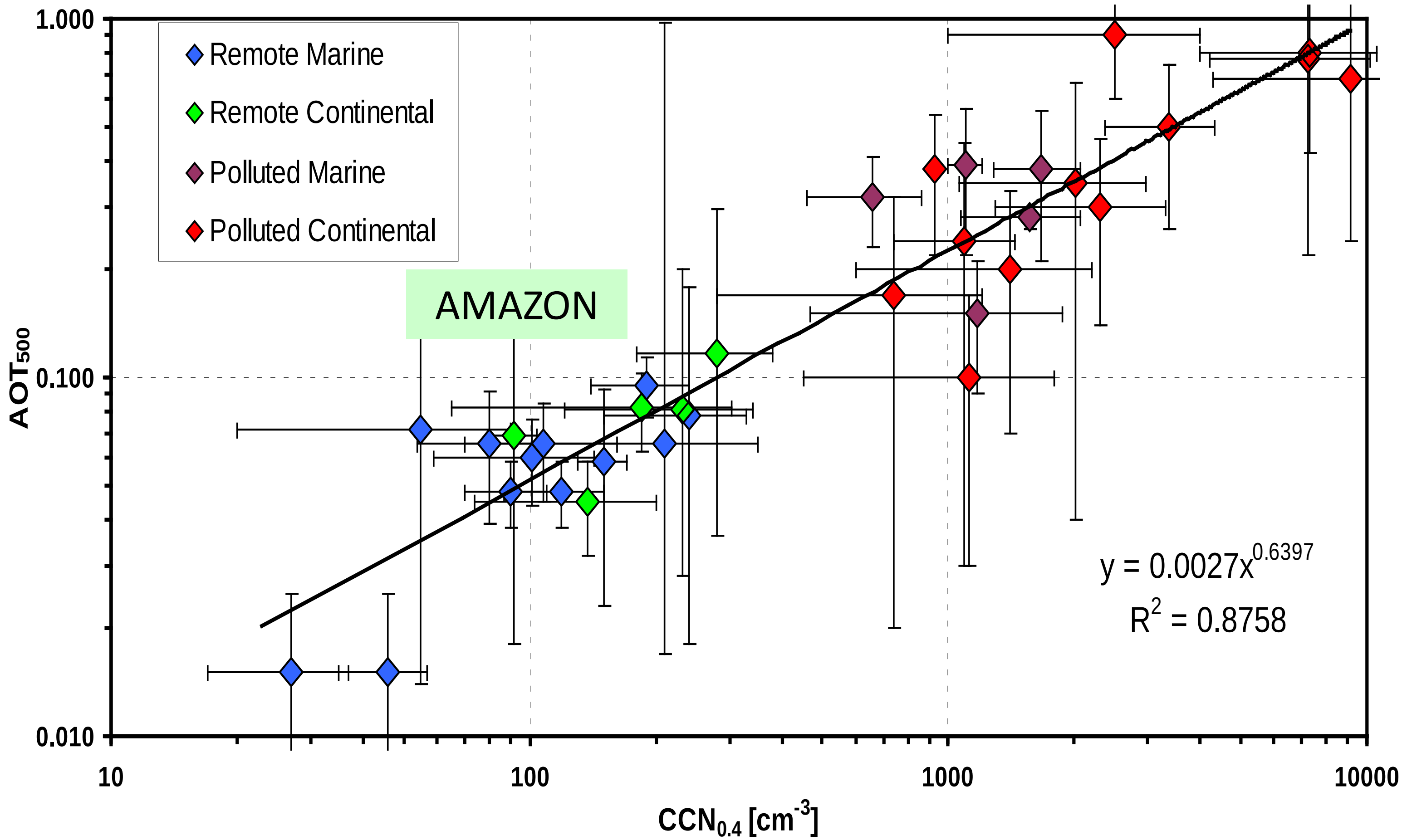
The chemistry can be completely shifted under anthropogenic influences… NO_x concentration, SO_2/H_2SO_4 particles



Processos químicos atmosféricos são fundamentais

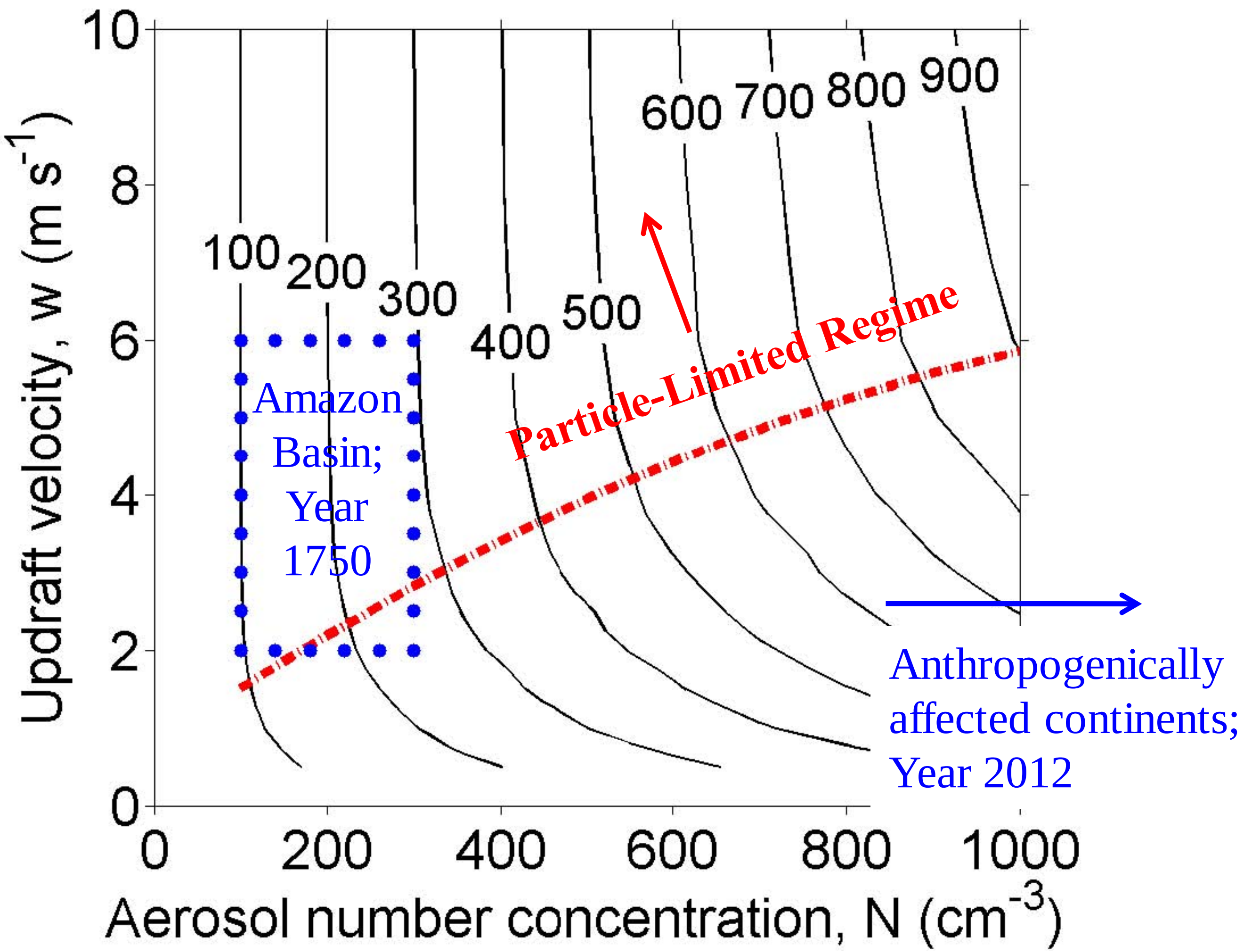


Particle Chemistry & Physics, Circa 1750



Adapted from Andreae, "Correlation between cloud condensation nuclei concentration and aerosol optical thickness in remote and polluted regions," *Atmos. Chem. Phys.*, **2009**, *9*, 543–556.

Sensitivity of Cloud Droplet Number Concentration and Rainfall Patterns and Intensity to Pollution (aka "Aerosol Indirect Effects")



Amazon Basin:

Low aerosol number concentrations +

High water vapor concentration =

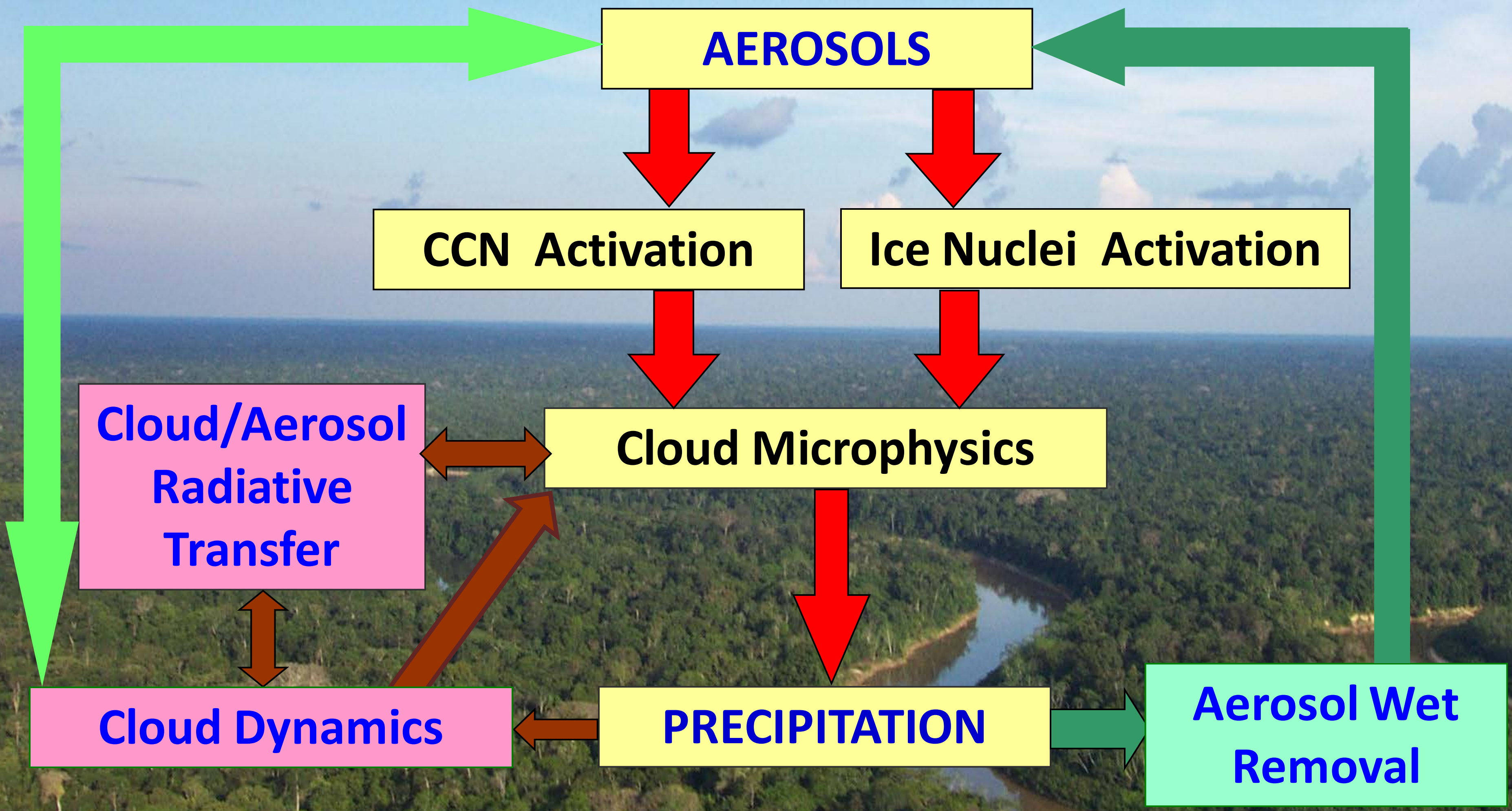
Especially susceptible.

Possibility of dramatic changes in energy flows and rainfall patterns

Reference: Pöschl, Martin, et al., "Rainforest aerosols as biogenic nuclei of clouds and precipitation in the Amazon," *Science*, **2010**, *329*, 1513-1516.

Aerosol-cloud-precipitation feedbacks

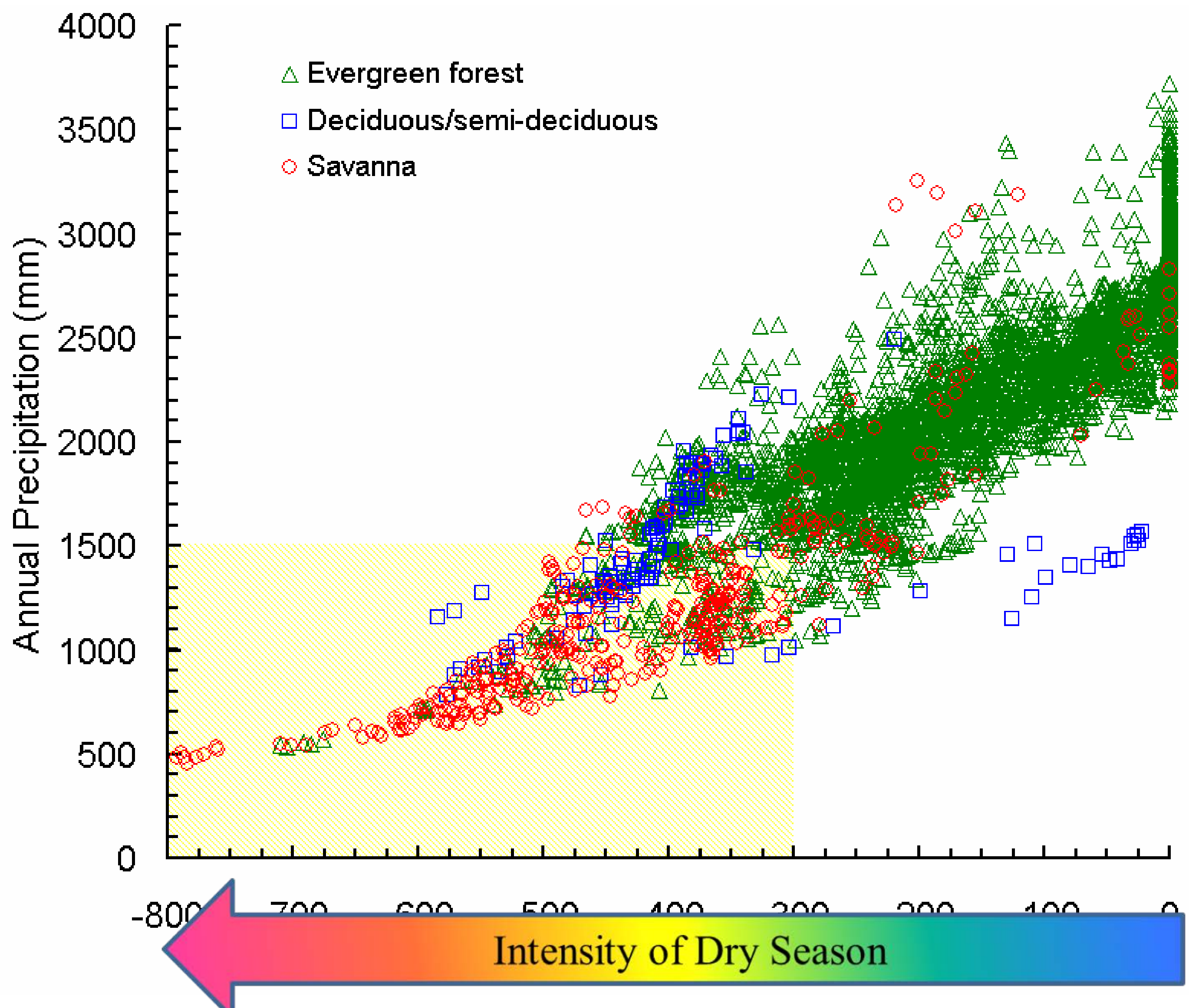
CCN = cloud condensation nuclei and IN = ice nuclei.



Amazon forest dieback hypothesis

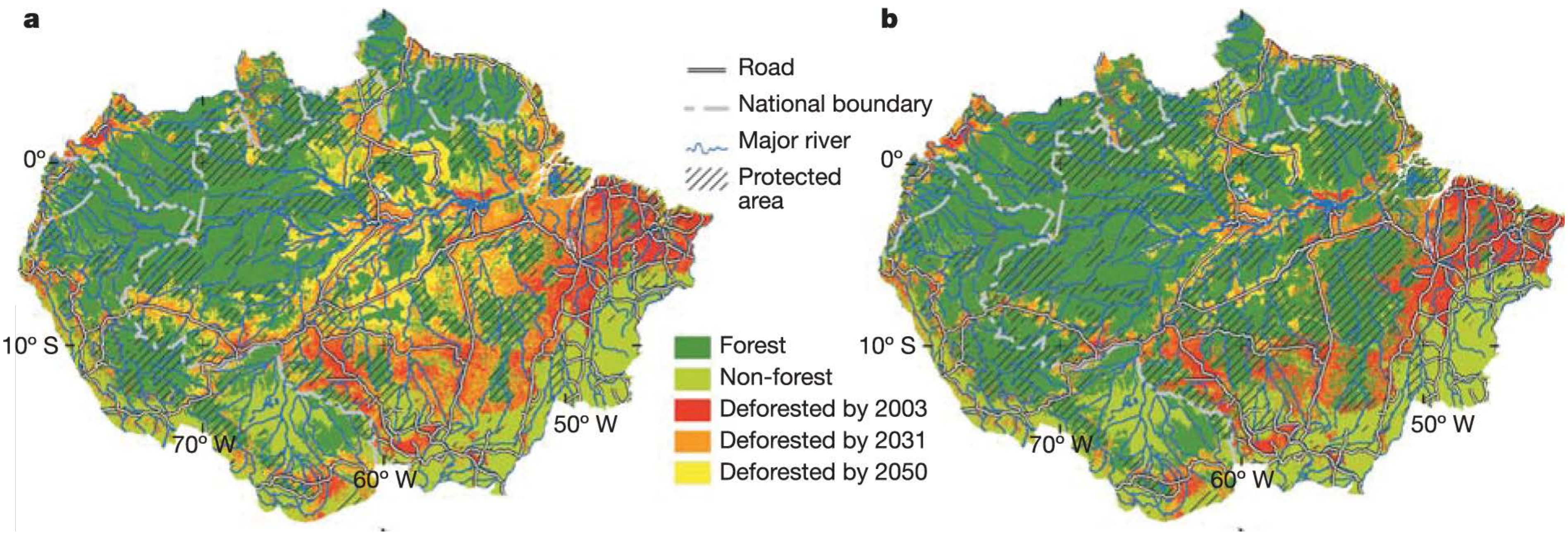
The future of Amazon forests under climate change?

A Rainfall Biogeography of Amazonia



Source: Malhi *et al.*, **Exploring the likelihood and mechanism of a climate-change induced dieback of the Amazon rainforest,** *Proceedings of the National Academy of Sciences*, submitted

Simulations of Forest Cover for Year 2050



Business As Usual

Good Governance

Soares-Filho, B. S., D. C. Nepstad, L. M. Curran, G. C. Cerqueira, R. A. Garcia, C. A. Ramos, E. Voll, A. McDonald, P. Lefebvre, and P. Schlesinger (2006), Modelling conservation in the Amazon Basin, *Nature*, **440**, 520–523, doi:10.1038/nature04389.

Dates of GoAmazon2014/5

AMF Operations (T3 ground site)

- 1 January 2014 until 31 December 2015

AAF Operations (aircraft)

- 15 February until 26 March 2014 (wet season) (75 hrs)
- 1 September until 10 October 2014 (dry season) (75 hrs)

Aircraft operations correspond to the two *intensive operating periods* planned for the experiment.

Large Point Source of Pollution in Manaus:
High-Sulfur Diesel for Electricity

Manaus Outflow Continues Across 60 km Forest

Principal Research Site "T3": *Fazenda Agropecuária Exata S/A*

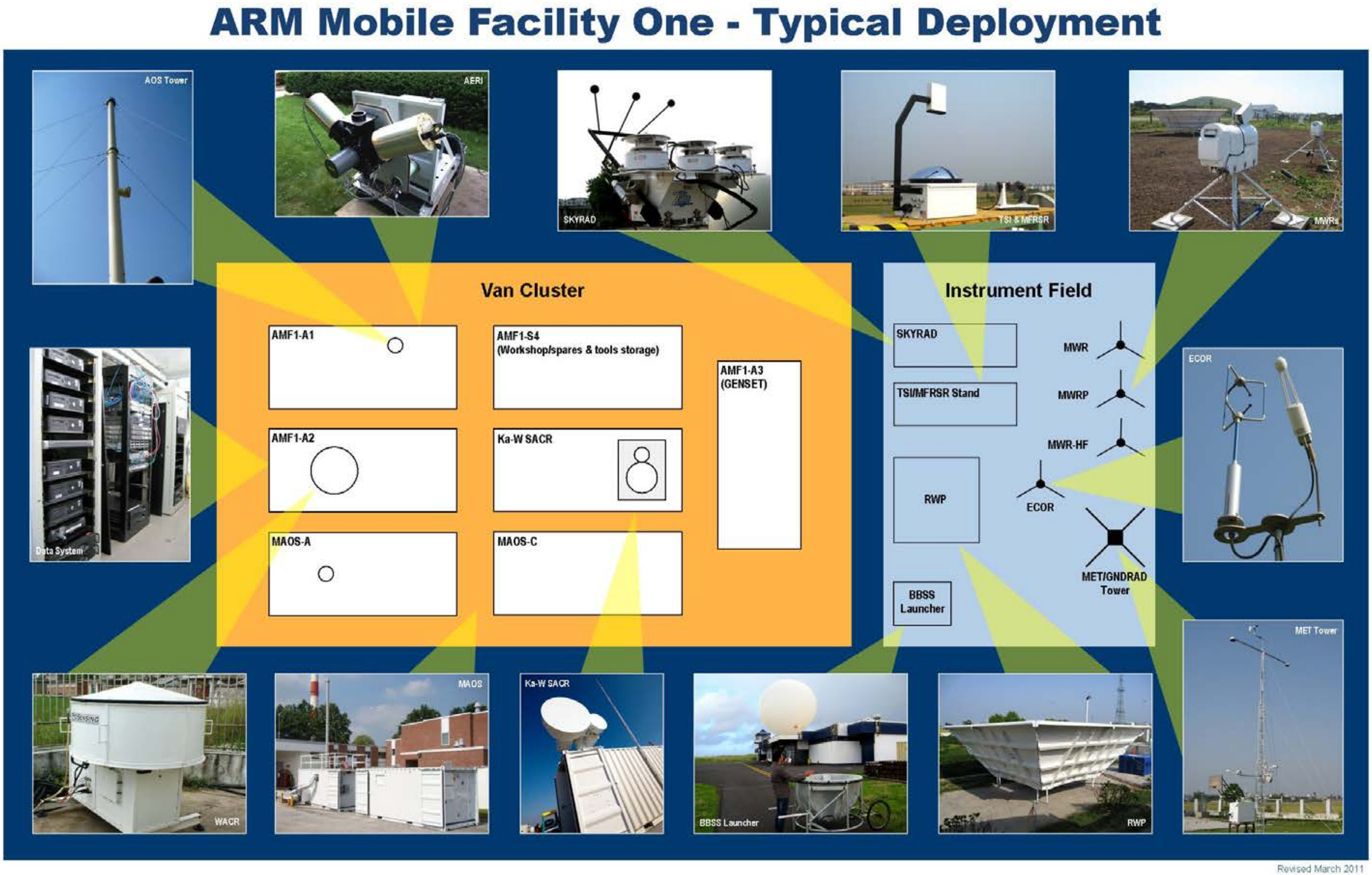
Fence and Weather Station

December 2011, T3

18 March 2013, T3

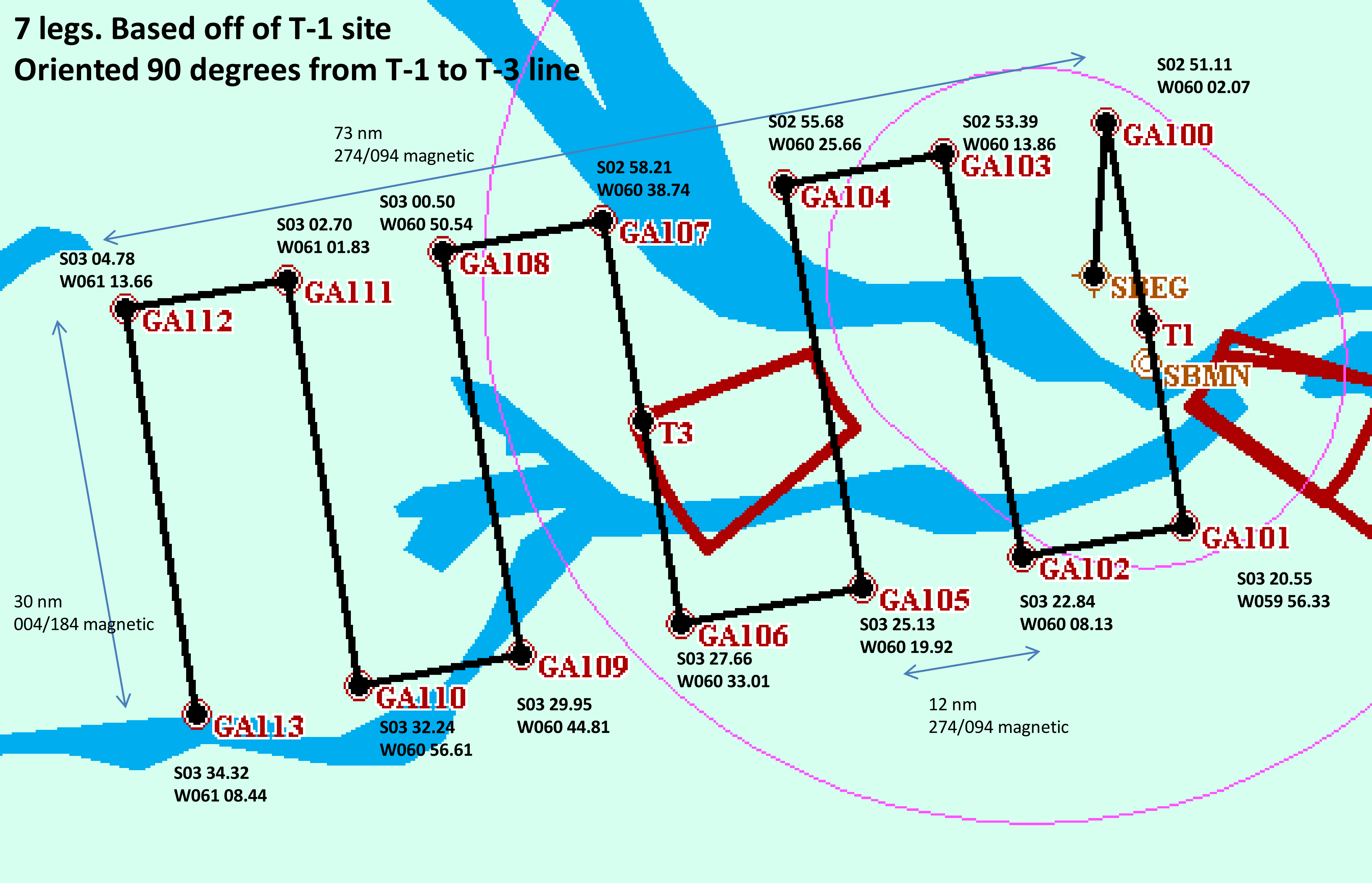
October 2013, T3

ARM Mobile Facility in Amazônia (AMFA) (Jan 2014)



“Intensive Airborne Research in Amazonia 2014” (IARA-2014)

The ARM Aerial Facility (AAF) in Brazil



IARA – Intensive Airborne Research in Amazonia

Flight Plan #7

1:35 to complete one pattern.

Other USA-sponsored contributions:
DOE EMSL: HR-TOF-AMS
DOE ARM: DMA-CCN
DOE TES: GECO
DOE-FAPESP-FAPEAM (ASR, RGCM, TES): 6 projects
NSF Atmospheric Chemistry: 2 projects
PNNL and BNL SFA's

Other Brazil-sponsored contributions:
CHUVA
Aeroclima
CsF
LBA

Other international contributions:
ACRIDICON
ATTO

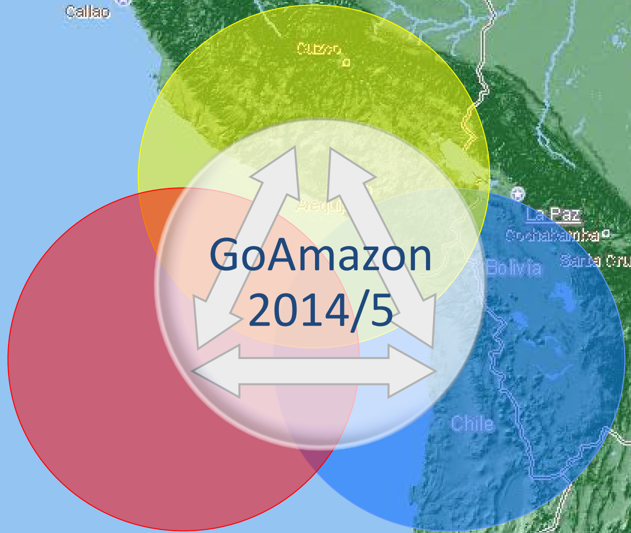
LBA: A Program of the Ministry of Science and Technology (MCT)

Main research foci:

- The changing environment of Amazonia
- Environmental sustainability and the sustainability of current terrestrial and aquatic production systems
- Variability and changes in climatic and hydrologic systems – feedback, adaptation and mitigation

Integrated and interdisciplinary investigations:

Yellow: multi-scale physico-chemical interactions at biosphere-atmosphere interface;
Red: physico-chemico-biological processes in aquatic and terrestrial ecosystems and their interactions;
Blue: the social dimensions of environmental change and the dynamics of land cover change

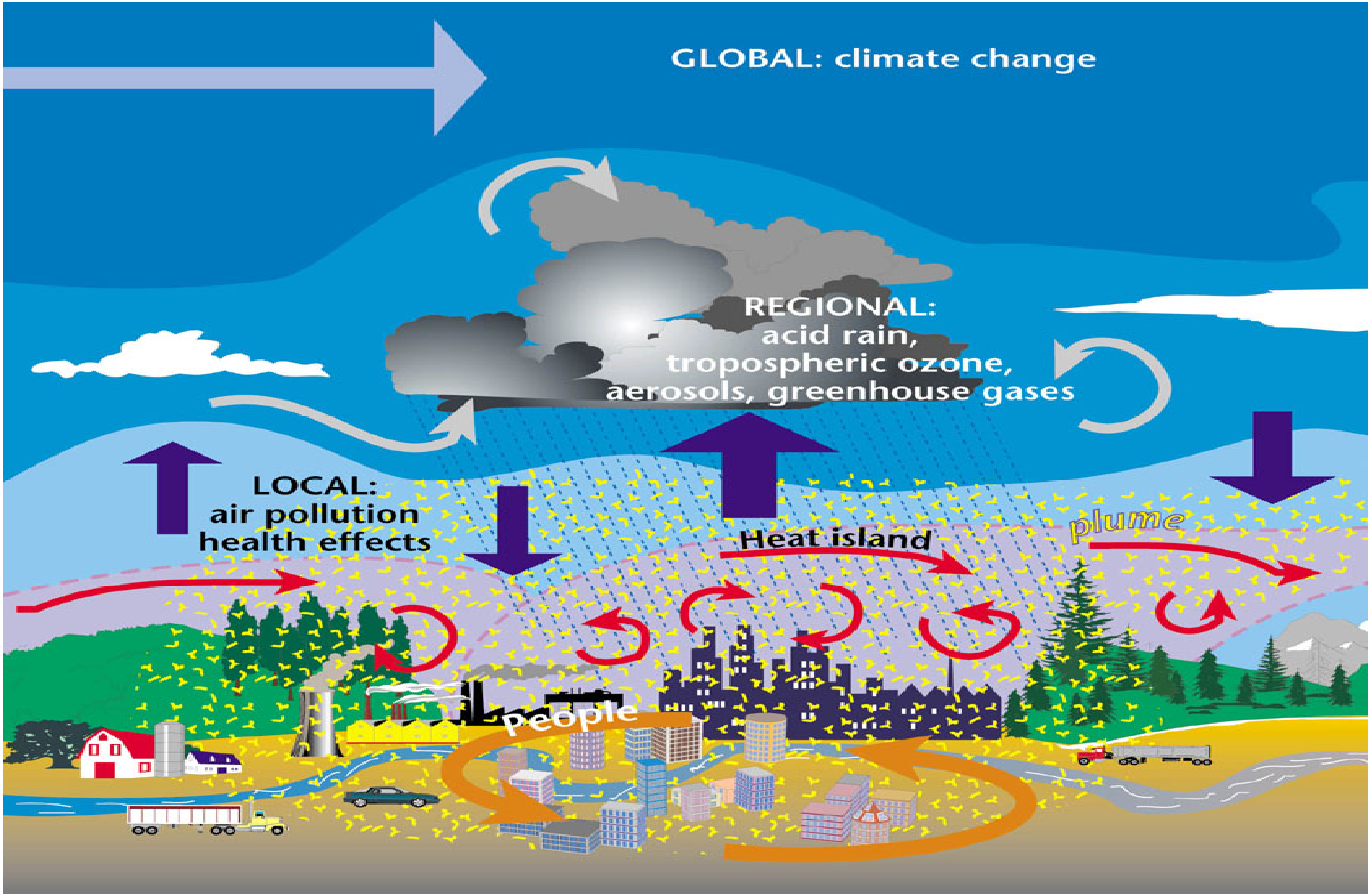


Acknowledgments: Laszlo Nagy, INPA/LBA

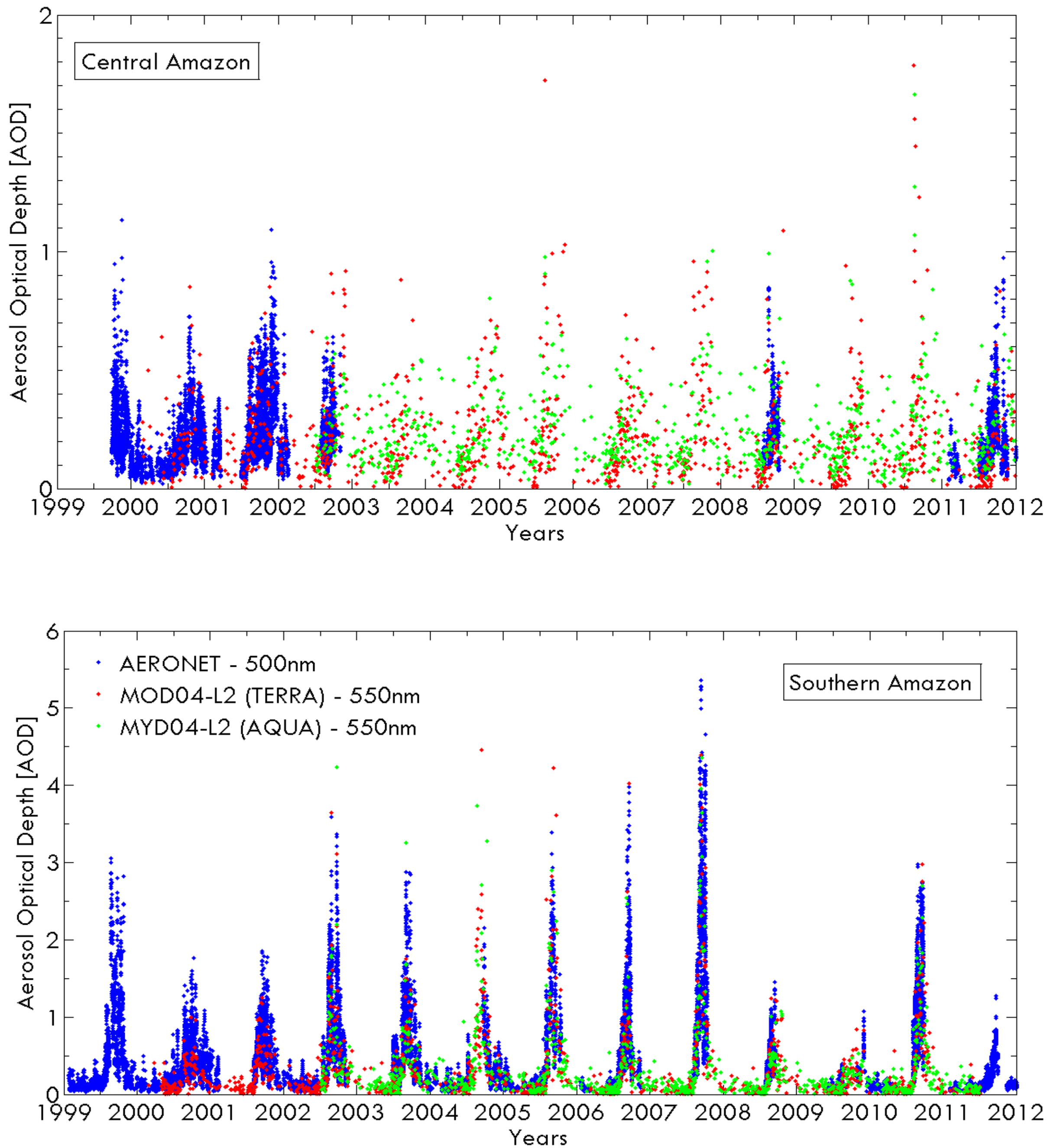
Brazil-Side Organizations

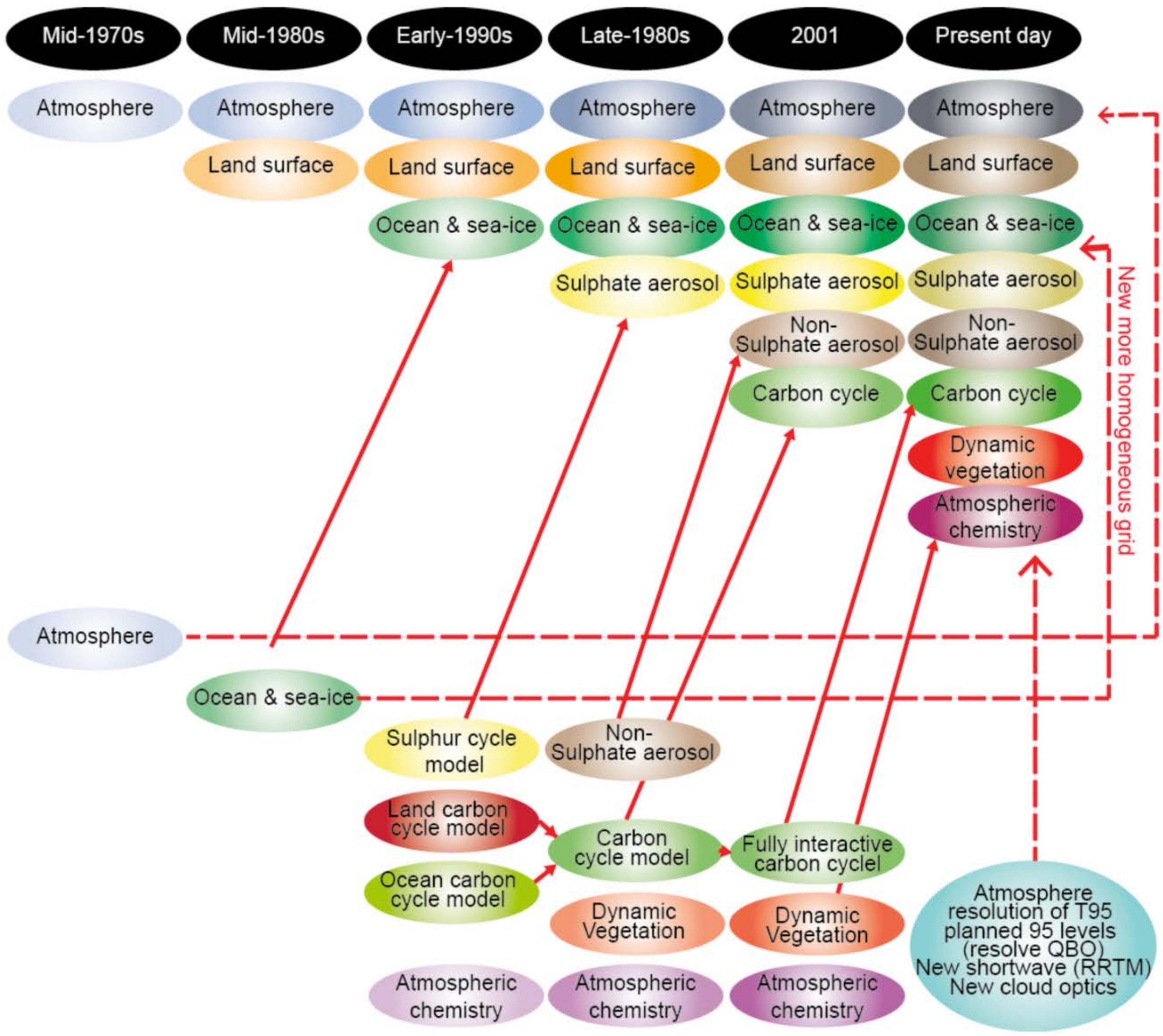
- LBA - Large-Scale Biosphere Atmosphere Experiment, http://lba.inpa.gov.br/lba/
- INPA - National Institute for Amazonian Research, http://www.inpa.gov.br/
- INPE - National Institute for Space Research, http://www.inpe.br/ingles/index.php
- CTA - Department of Science and Aerospace Technology, http://www.cta.br/
- UEA - University of the State of Amazonas, http://www1.uea.edu.br/
- USP - University of São Paulo, http://www.thefullwiki.org/University_of_Sao_Paulo, http://web.if.usp.br/ifusp/, http://www.master.iag.usp.br/index.php?pi=N
- GPM-CHUVA (http://chuvaproject.cptec.inpe.br/portal/en/index.html)
- CsF - Ciencias Sem Fronteiras (http://www.cienciasemfronteiras.gov.br/)
- FAPEAM - Fundação de Amparo à Pesquisa do Estado do Amazonas (www.fapeam.am.gov.br)
- FAPESP - Fundação de Apoio à Pesquisa do Estado do São Paulo (www.fapesp.br)

Upscaling is Fundamental: Time and Distance



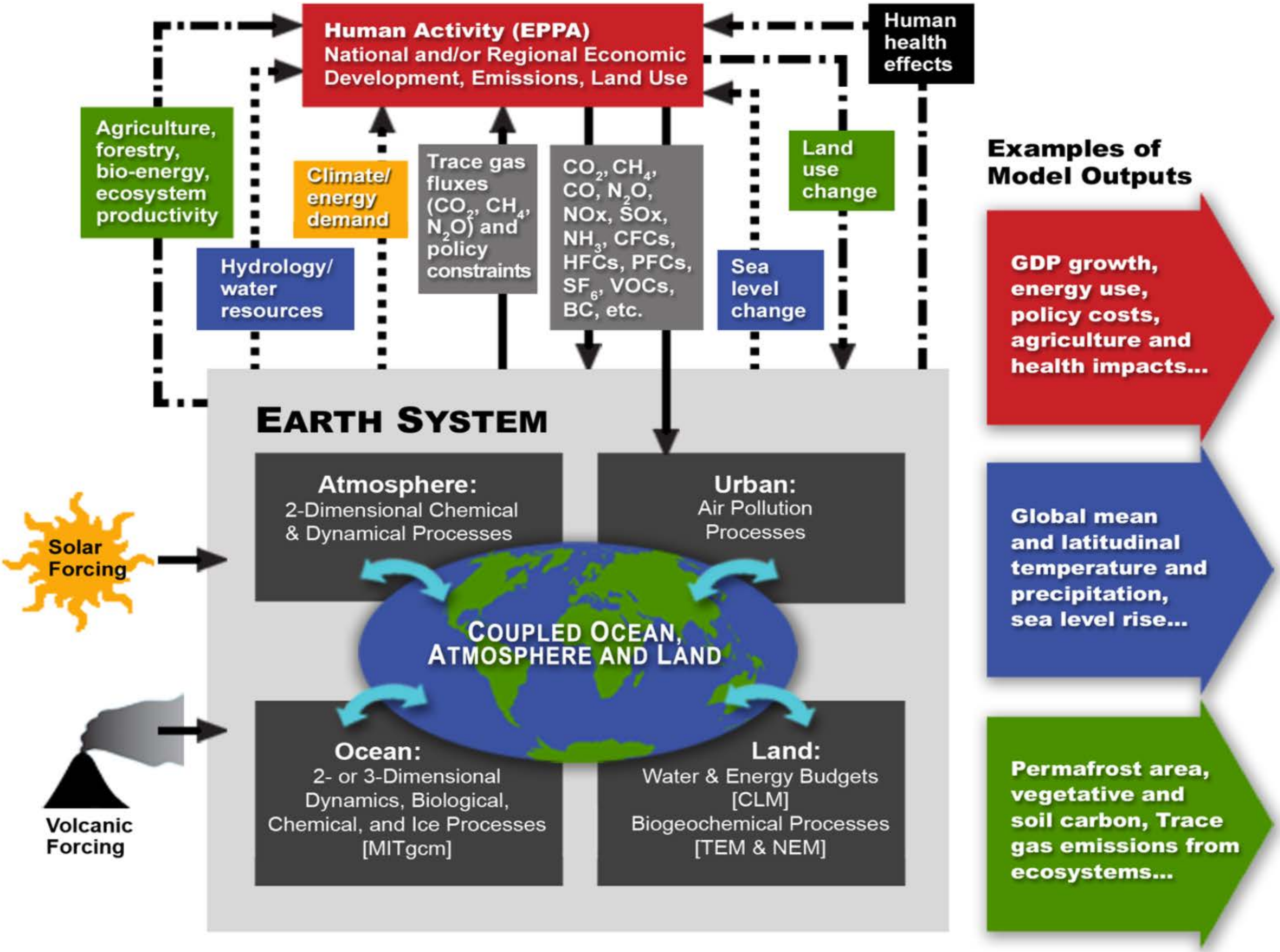
Time series of aerosol optical depth at the Central and Southern Amazonia with MODIS (550 nm) and AERONET (500 nm) retrievals from 1999 to 2012.



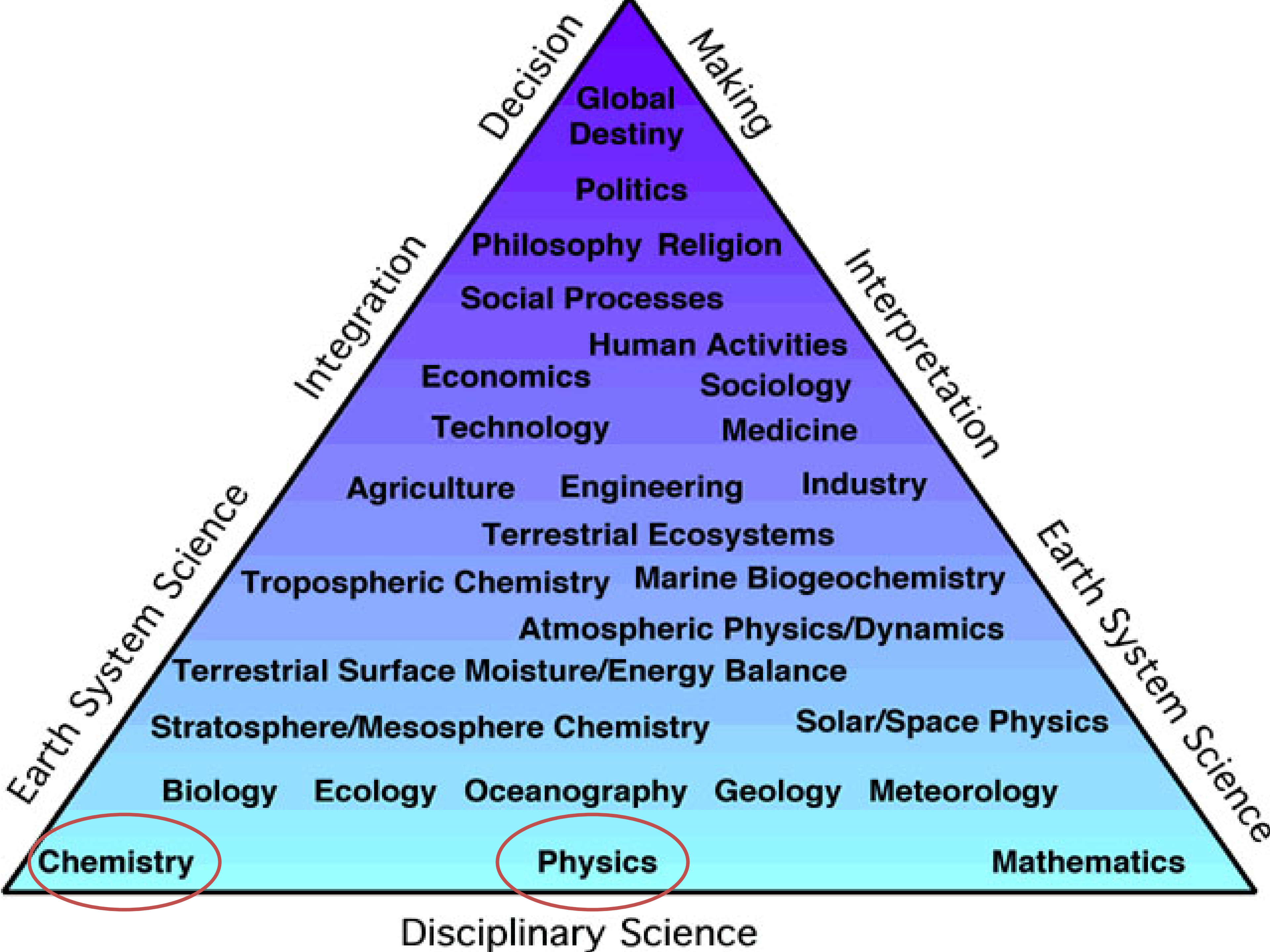


Clouds and aerosols are VERY poorly implemented

The development of climate models showing how the different components are first developed separately and later coupled into comprehensive climate models.



Human Activity (EPPA)
National and/or Regional Economic Development, Emissions, Land Use
Human health effects
Agriculture, forestry, bio-energy, ecosystem productivity
Climate/ energy demand
Trace gas fluxes (CO_2, CH_4, N_2O) and policy constraints
CO_2, CH_4, CO, N_2O, NOx, SOx, NH_3, CFCs, HFCs, PFCs, SF_6, VOCs, BC, etc.
Land use change
Hydrology/ water resources
Sea level change
Examples of Model Outputs
GDP growth, energy use, policy costs, agriculture and health impacts...
Global mean and latitudinal temperature and precipitation, sea level rise...
Permafrost area, vegetative and soil carbon, Trace gas emissions from ecosystems...
Earth System
Atmosphere:
2-Dimensional Chemical & Dynamical Processes
Urban:
Air Pollution Processes
Coupled Ocean, Atmosphere and Land
Ocean:
2- or 3-Dimensional Dynamics, Biological, Chemical, and Ice Processes [MITgcm]
Land:
Water & Energy Budgets [CLM]
Biogeochemical Processes [TEM & NEM]
Solar Forcing
Volcanic Forcing


Decision
Making
Global Destiny
Politics
Philosophy
Religion
Integration
Interpretation
Social Processes
Human Activities
Economics
Sociology
Technology
Medicine
Agriculture
Engineering
Industry
Terrestrial Ecosystems
Tropospheric Chemistry
Marine Biogeochemistry
Atmospheric Physics/Dynamics
Terrestrial Surface Moisture/Energy Balance
Stratosphere/Mesosphere Chemistry
Solar/Space Physics
Earth System Science
Earth System Science
Biology
Ecology
Oceanography
Geology
Meteorology
Chemistry
Physics
Mathematics
Disciplinary Science


If we want to avoid a warming of 3 to 4 K this century, we must utilize the natural resources of our planet in a more intelligent way.

Join this Google group to receive email from PI:

http://groups.google.com/group/GoAmazon2014

Websites:

DOE maintained: http://campaign.arm.gov/goamazon2014/. See there a workshop report of July 2011.

PI maintained: http://www.seas.harvard.edu/environmental-chemistry/GoAmazon2014/

AMF1

AMF1 – 7 x 20' sea containers
1 full-time on-site technician

- Precision Spectral Pyranometer (PSP) x 2
- Precision Infrared Radiometer (PIR) x 2
- Shaded Black & White Pyranometer (B/W)
- Shaded Precision Infrared Pyrgeometer (PIR)
- Normal Incidence Pyrhiliometer (NIP)
- Infrared Thermometer (IRT) x 2
- Multi-Filter Rotating Shadowband Radiometer (MFRSR)
- Narrow Field of View Zenith Radiometer (NFOV)
- Optical Rain Gauge (ORG)
- Anemometers (WND)
- Temperature/Relative Humidity Sensor (T/RH)
- Barometer (BAR)
- Present Weather Detector (PWD)
- Eddy Correlation Flux Measurement System (ECOR)
- Shortwave Array Spectrometer (SAS-He, SAS-Ze)
- Microwave Radiometer (MWR)
- Microwave Radiometer Profiler (MWRP)
- Microwave Radiometer 90/150 (MWR-HF)
- Doppler Lidar (DL)
- Ceilometer (CEIL)
- Balloon Borne Sounding System (BBSS)
- W-band ARM Cloud Radar - 95GHz (WACR)
- Ka-W Scanning ARM Cloud Radar (SACR)
- Atmospheric Emitted Radiance Interferometer (AERI)
- Total Sky Imager (TSI)
- Aerosol Observation System (AOS)
  - CCNC
  - PSAP
  - Nephelometers X 2
- Radar Wind Profiler – 1290MHz (RWP)
- Cimel Sunphotometer (CSPHOT)

LANL Solar Fourier Transform Spectrophotometer (FTS) (Dubey) (OCO-2 validation)

MAOS

Mobile Aerosol Observing System (MAOS) – 2 x 20' sea containers (MAOS-A & MAOS-C); technician + 2 x full time post-docs (supplied by ARM) ; Guest operational personnel (up to 5)

- SOnic Detection And Ranging (SODAR) System (1000 to 4000 Hz)
- Ultra-High Sensitivity Aerosol Spectrometer (enhanced) - Senum
- Dual Column Cloud Condensation Nuclei Counter (CCN) - Senum
- Single Particle Soot Photometer (SP2) - Sedlacek
- Scanning Mobility Particle Sizer (SMPS) - Kuang
- Photo-Acoustic Soot Spectrometer (PASS), 3 Wavelength –Dubey and Aiken
- Trace Gas Instrument System (Research-Grade) (CO, NO, NO_2, NO_y, O_3, SO_2) - Springston
- Particle Into Liquid Sampler-Ion Chromatography-Water Soluble Organic Carbon (PILS-IC-WSOC) - Watson and Lee
- Particle Soot Absorption Photometer (PSAP), 3 Wavelength – Springston
- Condensation Particle Counter (CPC), 10 nm to >3000 nm particle size range - Kuang
- Condensation Particle Counter (CPC), 2.5 nm to >3000 nm particle size range - Kuang
- Hygroscopic Tandem Differential Mobility Analyzer (HTDMA) - Senum
- Proton Transfer Mass Spectrometer (PTRMS) - Watson
- 7-Wavelength Aethelometer - Sedlacek
- Weather Transmitter (WXT-520) - Springston
- Aerosol Chemistry Speciation Monitor (ACSM) - Watson
- Ambient Nephelometer (3 wavelength) – Senum
- Controlled RH Nephelometer (3 wavelength) - Senum
- DMA-CCN – Wang
- HR-ToF-AMS – Alexander

IARA-2014: AAF G1 Payload

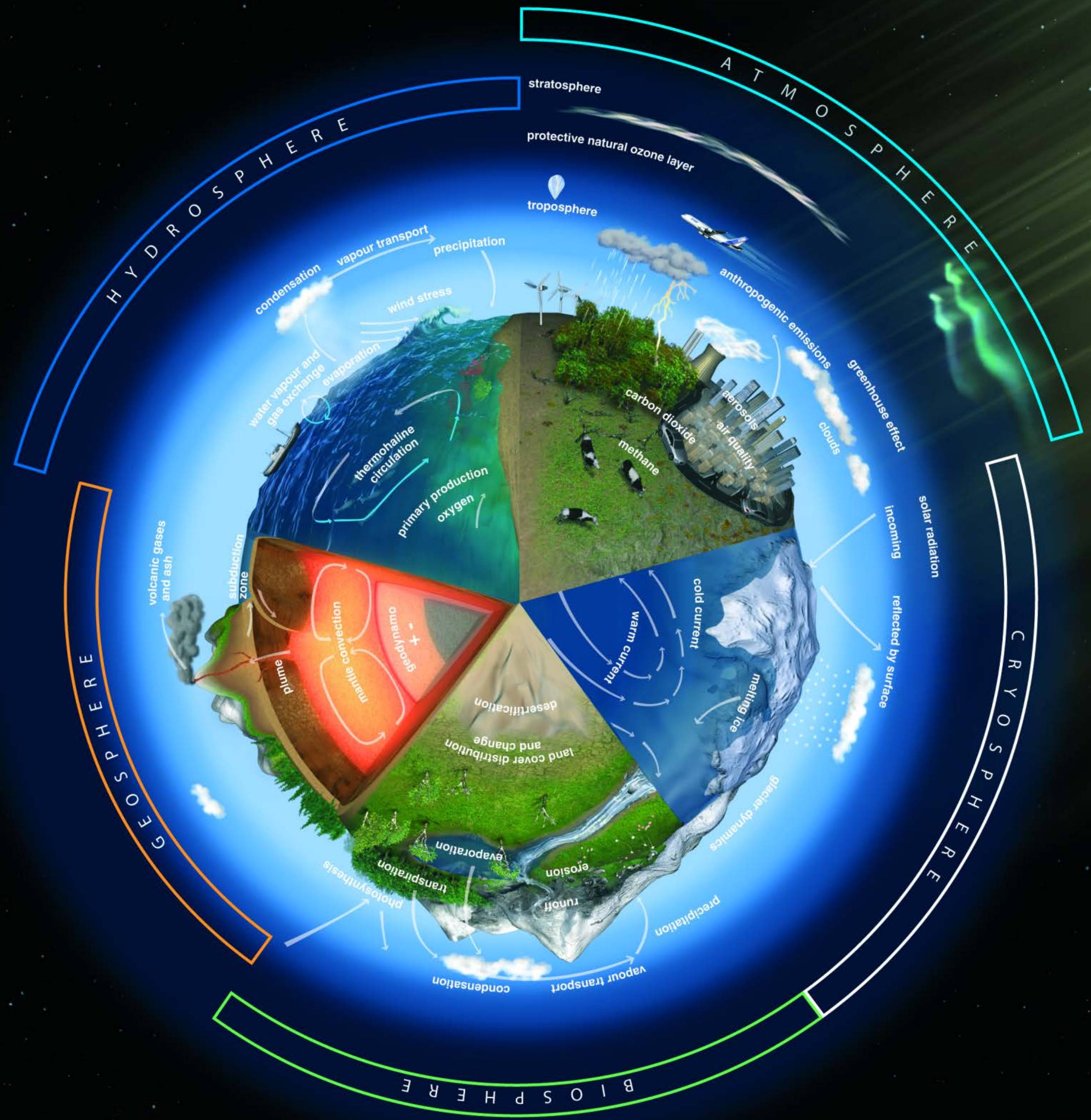
Platform Position/Velocity/Altitude			
Instrument	**Trimble DSM**	**Trimble TANS 10 Hz**	
Measurement	position/velocity at 10 Hz	pitch/roll/azimuth	
Atmospheric State			
Instrument	**Rosemont 102 probe**	**Rosemount 1201F1**	**Rosemont 1221F2 (3)**
Measurement	temperature	static pressure	differential pressure (dynamic, alpha, beta)
Instrument	**GE-1011B chilled-mirror hygrometer**	**AIMMS-20**	
Measurement	dew-point temperature	5-port air motion sensing: true air speed, altitude, angle-of-attack, side-slip, temperature, relative humidity	
Aerosol Measurements			
Instrument	**TSI 3025 ultrafine condensation particle counter (UCPC)**	**TSI 3010 condensation particle counter (CPC)**	**fast integrated mobility spectrometer (FIMS)**
Measurement	total particle concentration (>3 nm)	total particle concentration (>10 nm)	aerosol particle size distribution (30 to 100 nm)
Instrument	**passive cavity aerosol spectrometer probe (PCASP)**	**particle/soot absorption photometer (PSAP)**	**TSI Nephelometer**
Measurement	aerosol particle size distribution (100 to 3000 nm)	aerosol particle light absorption at 3 wavelengths	aerosol particle light scattering at 3 wavelengths
Instrument	**Aerodyne HR-ToF-AMS**	**DMT Dual Cloud Condensation Nuclei Counter (CCNC)**	**isokinetic inlet (heated)**
Measurement	size-resolved particle composition	CCN concentrations at two supersaturations	sample stream of dry aerosol, sizes < 2.5 µm
Gas Measurements			
Instrument	**Ionicon Quadrupole PTR-MS**	**carbon monoxide analyzer**	**oxides of nitrogen instrument**
Measurement	real-time VOCs	CO	NO, NO_2, NO_y
Instrument	**Thermo environmental model 49i**	**Picarro cavity ringdown spectrometer**	
Measurement	O_3	CO_2, CH_4, H_2O	

IARA-2014: AAF G1 Payload

Cloud Measurements			
Instrument	**HVPS-3**	**2DS**	**Fast-CDP**
Measurement	cloud droplet size distribution (400 to 50000 μm)	cloud droplet size distribution (10 to 3000 μm)	cloud droplet size distribution (2 to 50 μm)
Instrument	**CIP**	**SEA WCM-2000**	
Measurement	images of cloud particles (2 to 1000 μm)	liquid water content and total water content	
Radiation			
Instrument	**SPN-1 unshaded**	**SPN-1 unshaded**	
Measurement	downwelling shortwave radiation	Upwelling shortwave radiation	
Other Measurements			
Instrument	**SEA M300**	**weather radar**	**TCAS**
Measurement	central data acquisition/ display system	cockpit display of precipitation returns	traffic collision and avoidance system
Instrument	**TAWS**		
Measurement	terrain awareness and warning system		

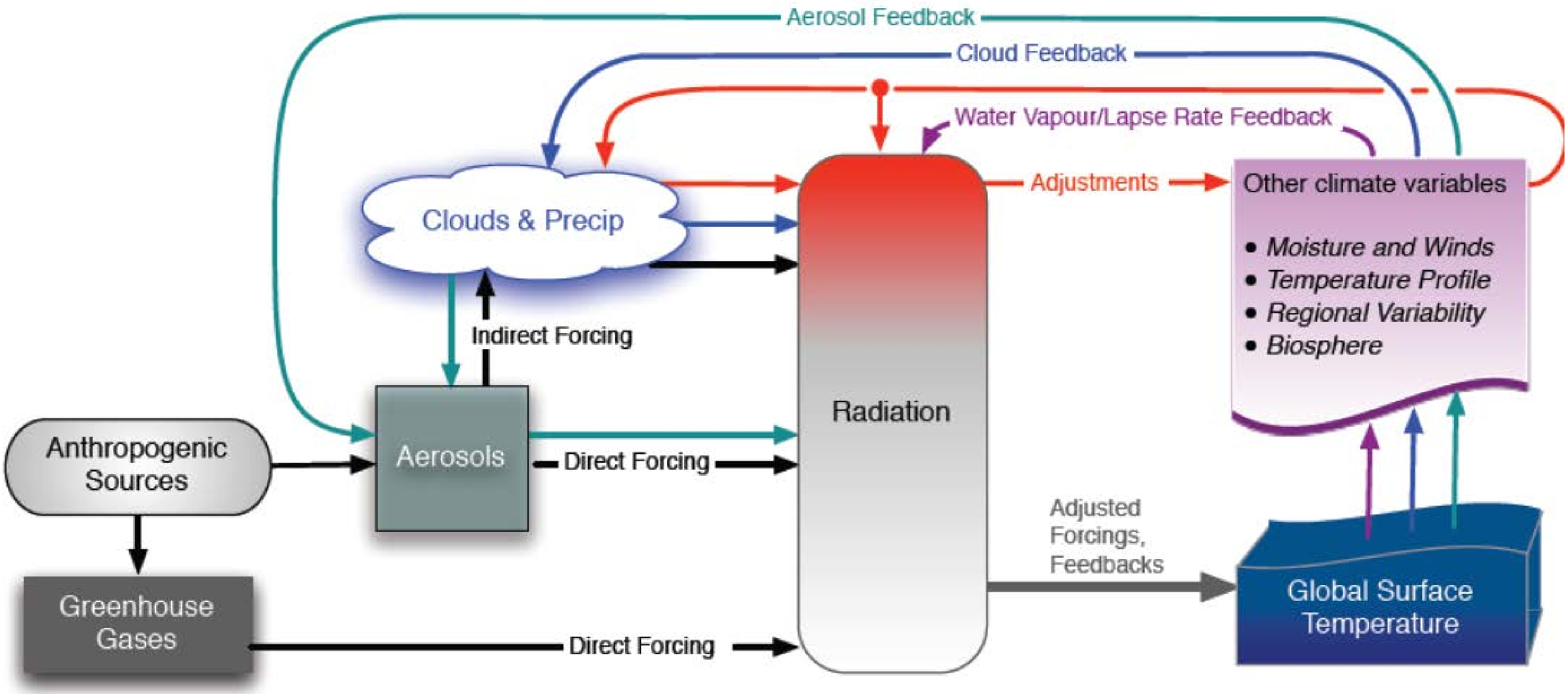
Earth under change:

Atmosphere
Cryosphere
Biosphere
Geosphere
Hydrosphere



Aerosols, radiation, clouds, and greenhouse gases in the global climate system

The major uncertainties in the climate system



Prevailing Patterns of Wind, Water, and Energy Flows in the Amazon Basin