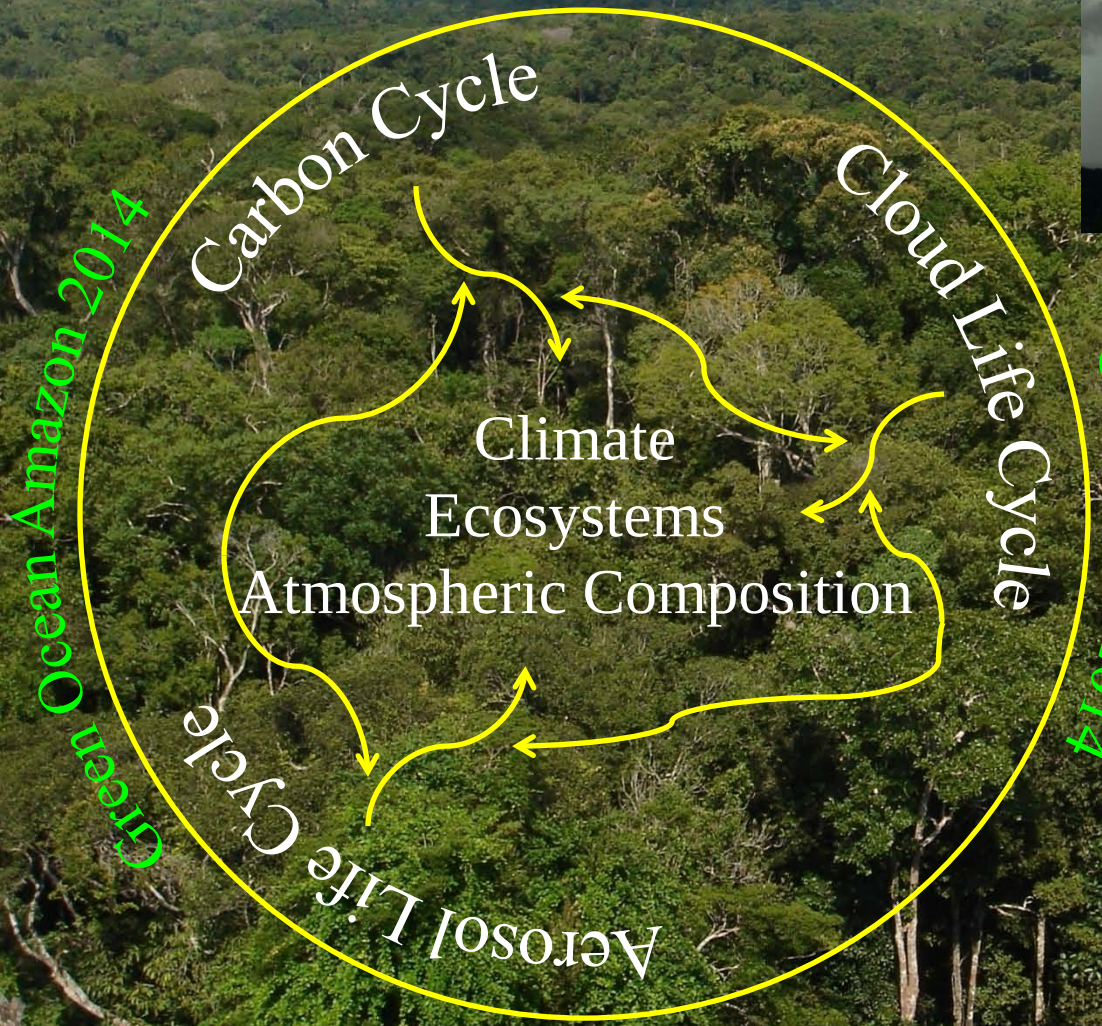
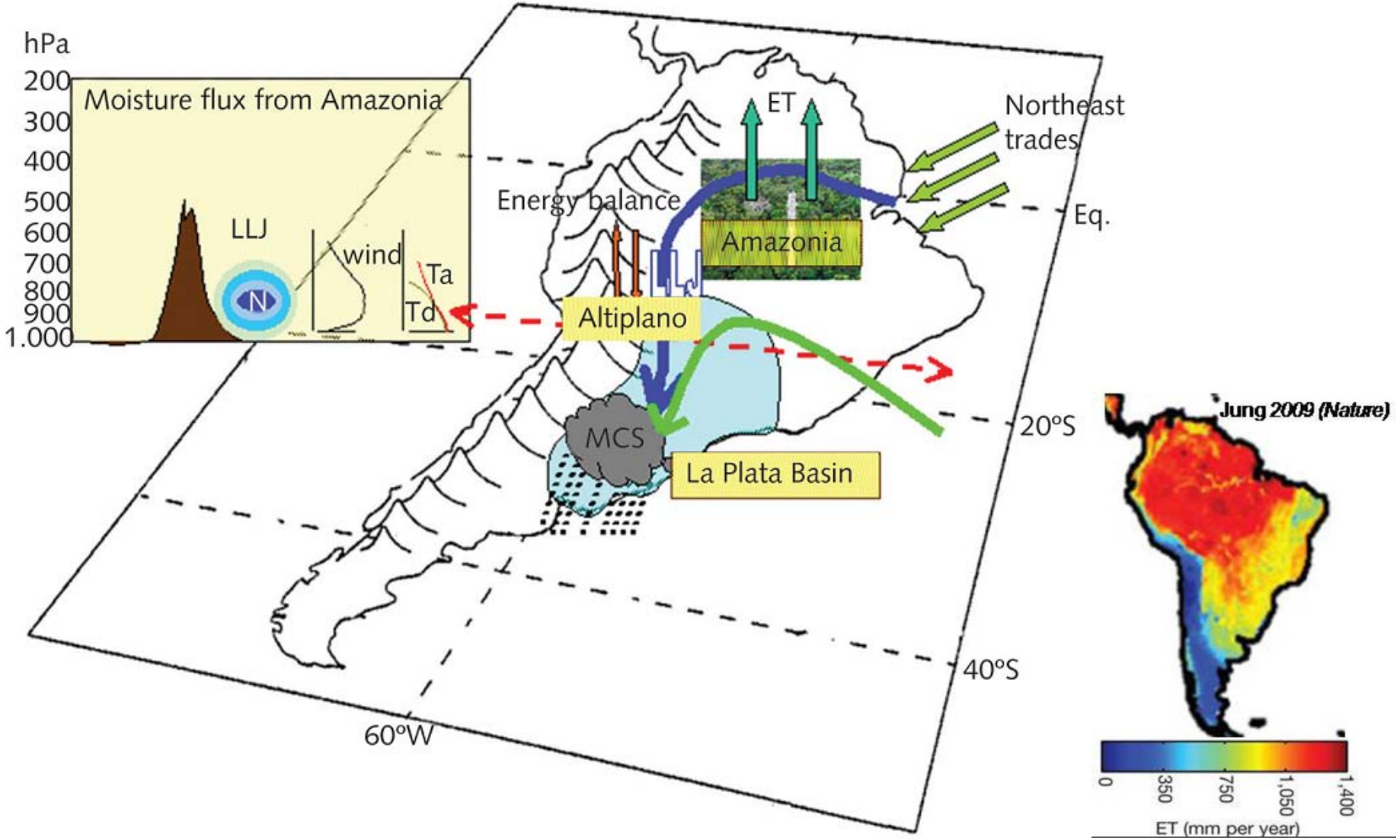
Observations and Modeling of the Green Ocean Amazon



Presented by Scot Martin at USA Interagency Science Meeting, 2 May 2011, Washington, D.C.

A Brief Orientation to Mesoscale Features of the Amazon Basin

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



Amazon forest dieback hypothesis

The future of Amazon forests under climate change?

??

Changes in Net Primary Productivity with Radiation Field
The future of Amazon forests with increased human activities?

Many studies outside of the tropics have found an increase in whole-canopy and shade leaf photosynthesis under conditions that enhance the diffuse fraction of irradiance from clouds or aerosols (Gu et al. 2003; Still et al. 2009).

However, recent work in Amazon forests near Santarem, Brazil, found that photosynthesis in old-growth tropical forests exhibited complex relationships with the quality of solar radiation (Doughty and Goulden 2008; Doughty et al. 2010).

The daily cycle of BVOC emissions between tropical and temperature forests are also very different (i.e., correlation vs. anticorrelation, respeictively, between isopene and terpene emissions).

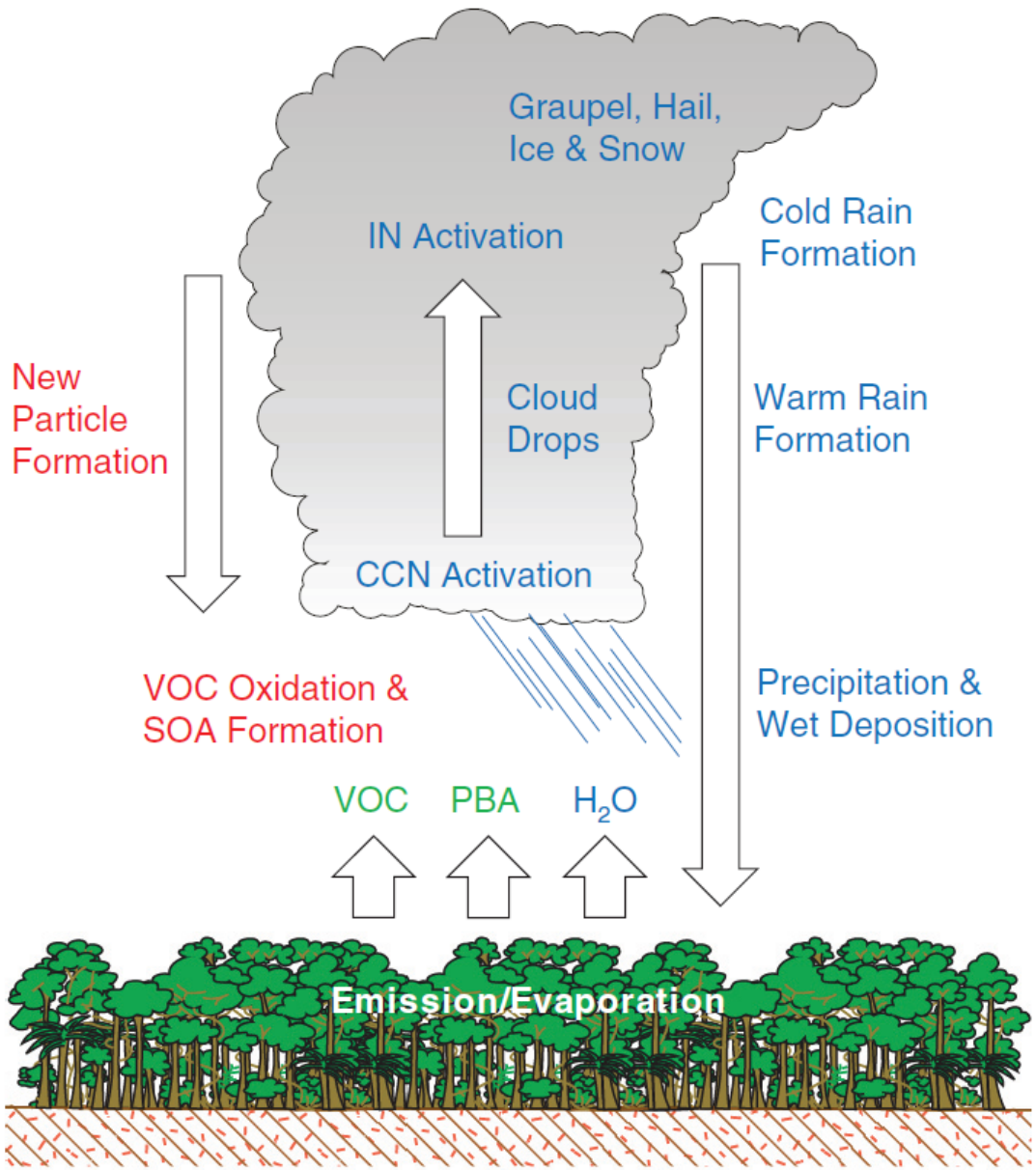
Source: Mercado et al., iLEAPS 2009, Melbourne, 27.08.2009

Aerosol and Water Cycling over the Pristine Rainforest

SOA formed by photo-oxidation of volatile organic compounds (VOC) and PBA emitted from biota in the rainforest (plants and microorganisms) serve as biogenic nuclei for CCN and IN, which induce warm or cold rain formation, precipitation, and wet deposition of gases and particles.

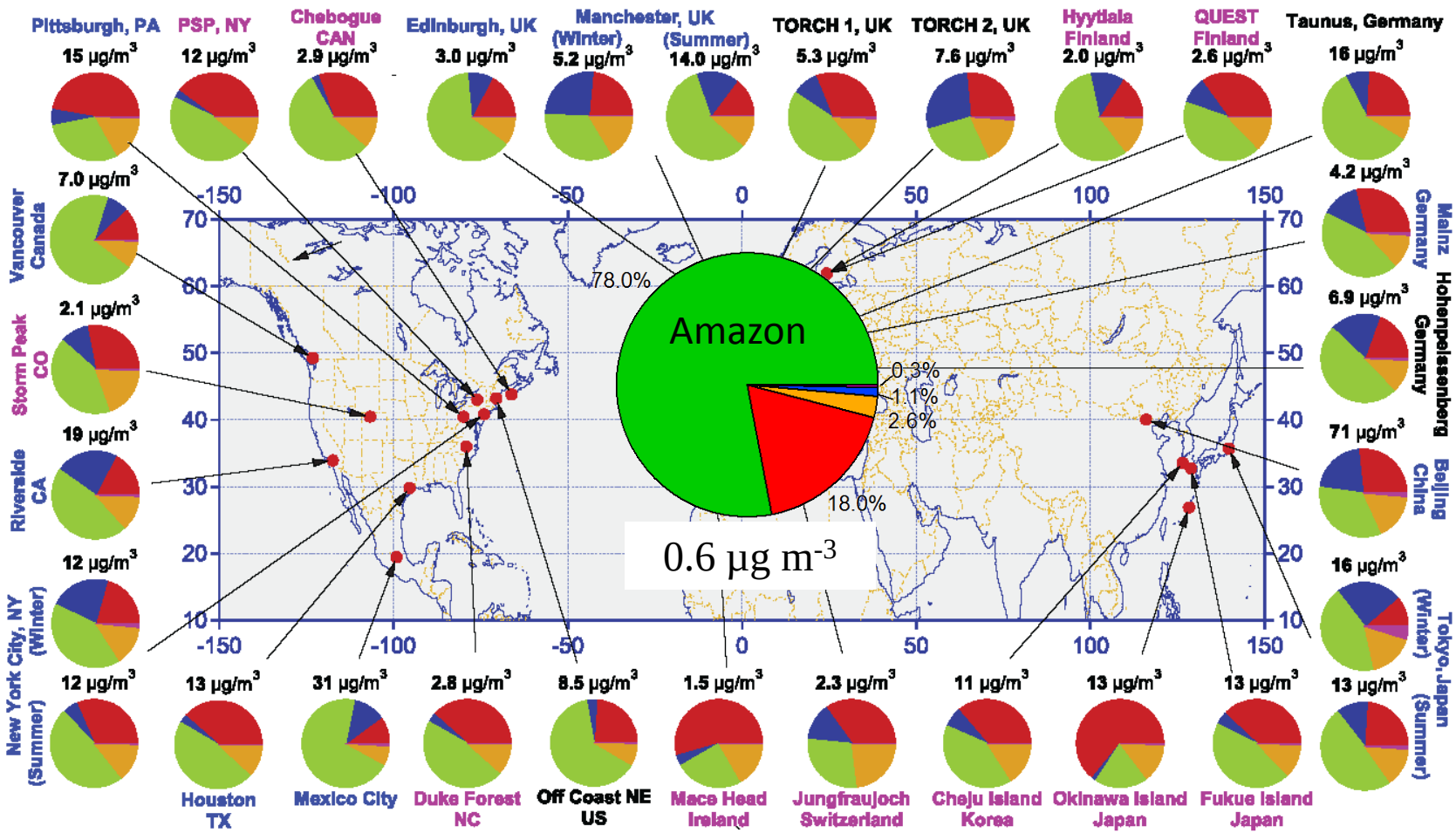
U. Pöschl, S.T. Martin, B. Sinha, Q. Chen, S.S. Gunthe, J.A. Huffman, S. Borrmann, D.K. Farmer, R.M. Garland, G. Helas, J.L. Jimenez, S.M. King, A. Manzi, E. Mikhailov, T. Pauliquevis, M.D. Petters, A.J. Prenni, P. Roldin, D. Rose, J. Schneider, H. Su, S.R. Zorn, P. Artaxo, M. O. Andreae, "Rainforest aerosols as biogenic nuclei of clouds and precipitation in the Amazon," *Science*, 2010, 329, 1513-1516.

S.T. Martin, M.O. Andreae, D. Althausen, P. Artaxo, H. Baars, S. Borrmann, Q. Chen, D.K. Farmer, A. Guenther, S. Gunthe, J.L. Jimenez, T. Karl, K. Longo, A. Manzi, T. Pauliquevis, M. Petters, A. Prenni, U. Pöschl, L.V. Rizzo, J. Schneider, J.N. Smith, E. Swietlicki, J. Tota, J. Wang, A. Wiedensohler, S.R. Zorn, "An Overview of the Amazonian Aerosol Characterization Experiment 2008 (AMAZE-08)," *Atmospheric Chemistry Physics*, 2010, 10, 11415-11438.



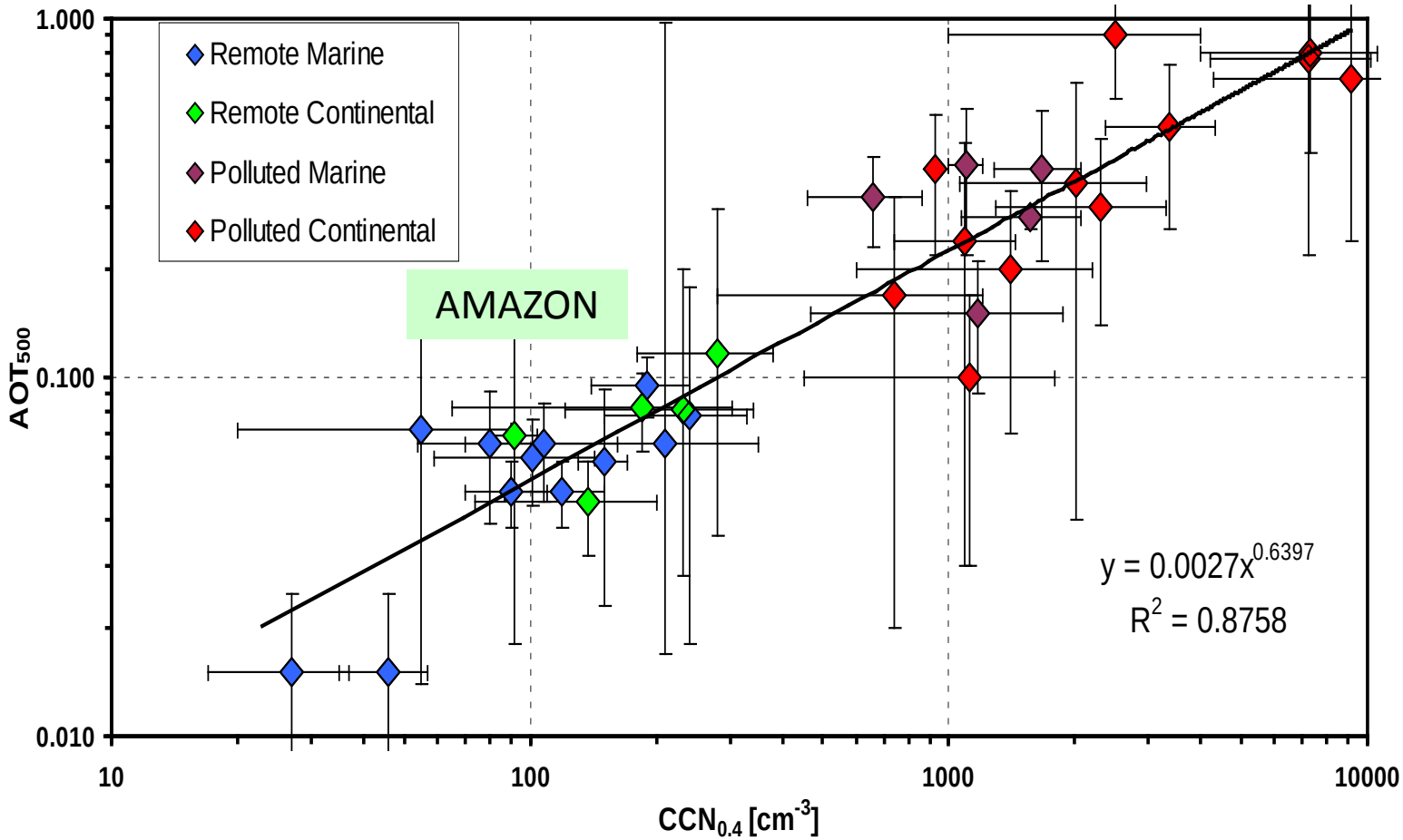
Amazon Particles Dominated by Organic Components

Low Number Concentrations, Low Mass Concentrations



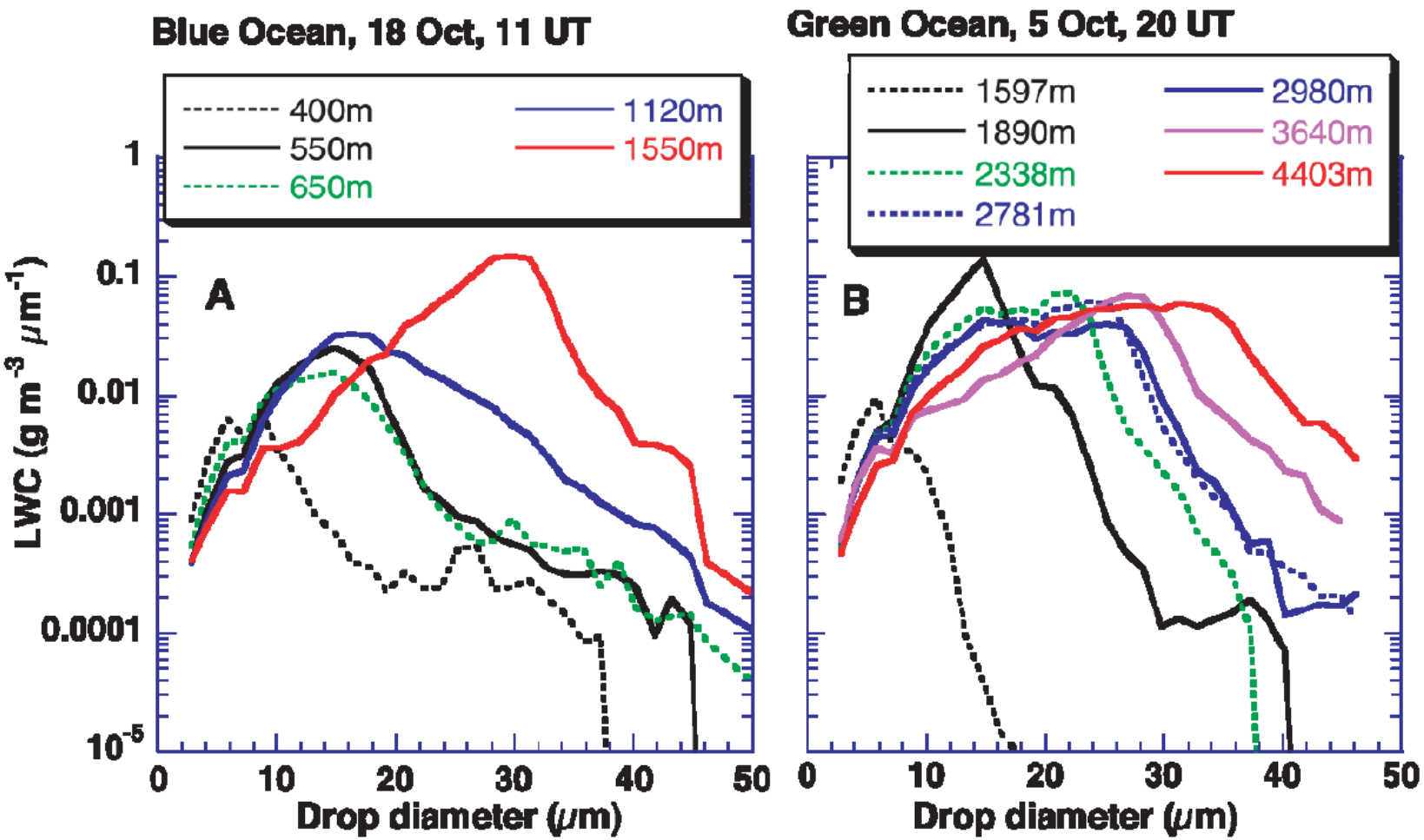
Adapted from Zhang et al., *Geophys. Res. Lett.*, 2007 and Chen et al. *Geophys. Res. Lett.*, **2009**, *36*, L20806.

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.

Aspects of Cloud Development over this Continental Region are Similar to That over Oceans



Adapted from Andreae, M. O.; Rosenfeld, D.; Artaxo, P.; Costa, A. A.; Frank, G. P.; Longo, K. M.; Silva-Dias, M. A. F. *Science* **2004**, *303*, 1337.

Cloud Droplet Numl

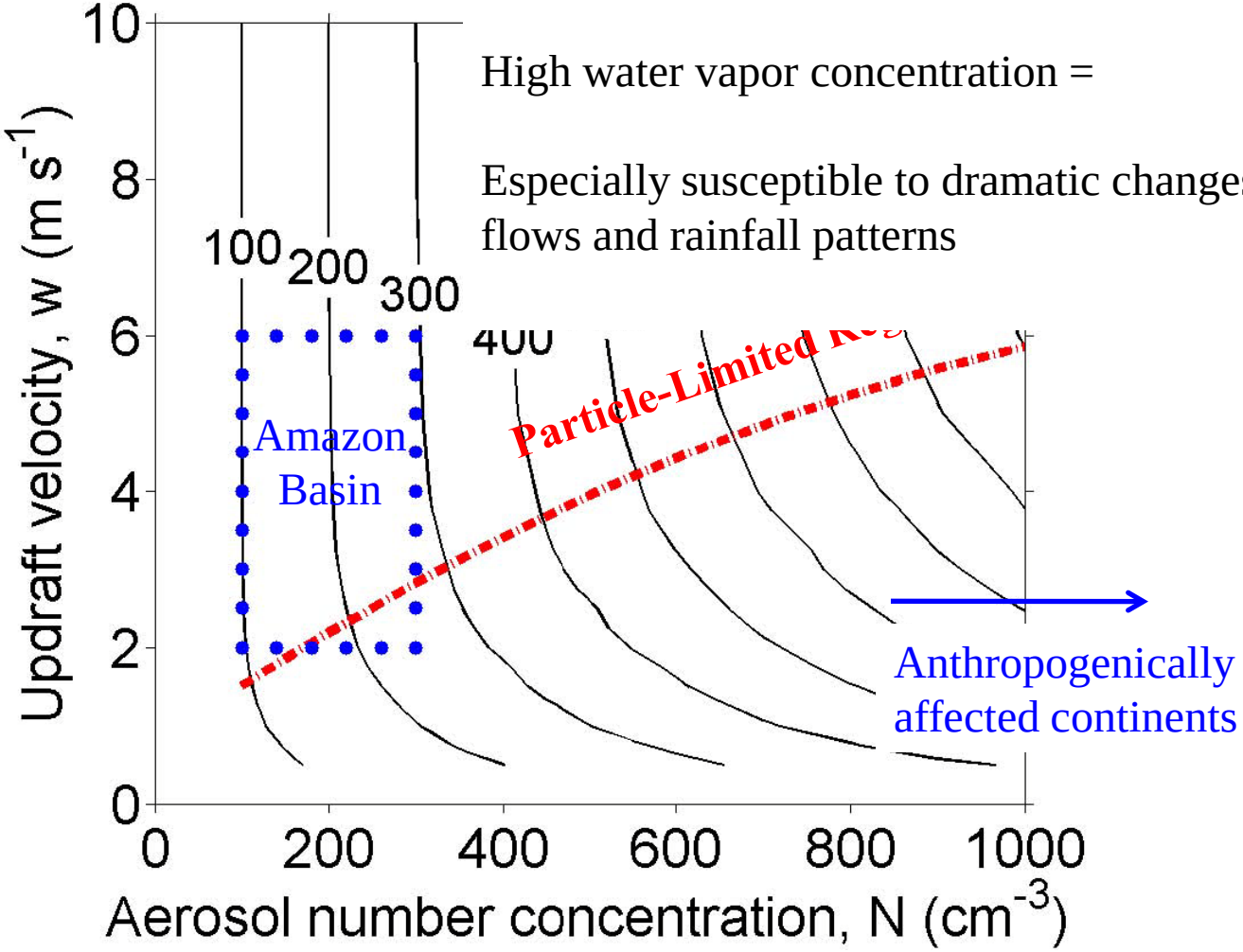
Sensitivity to Pol

Amazon Basin:

High aerosol number concnetrations +

High water vapor concentration =

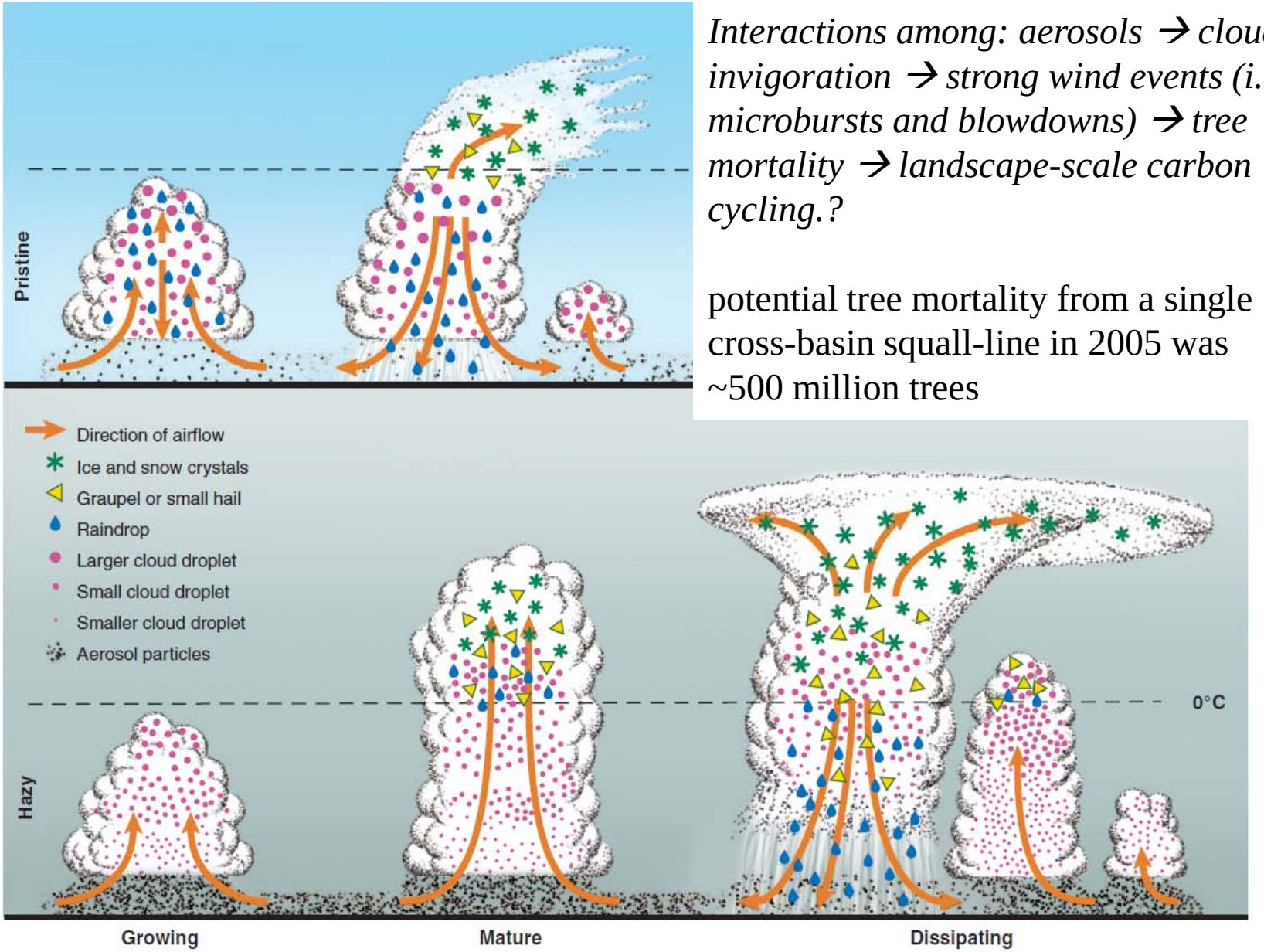
Especially susceptible to dramatic changes in energy flows and rainfall patterns



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

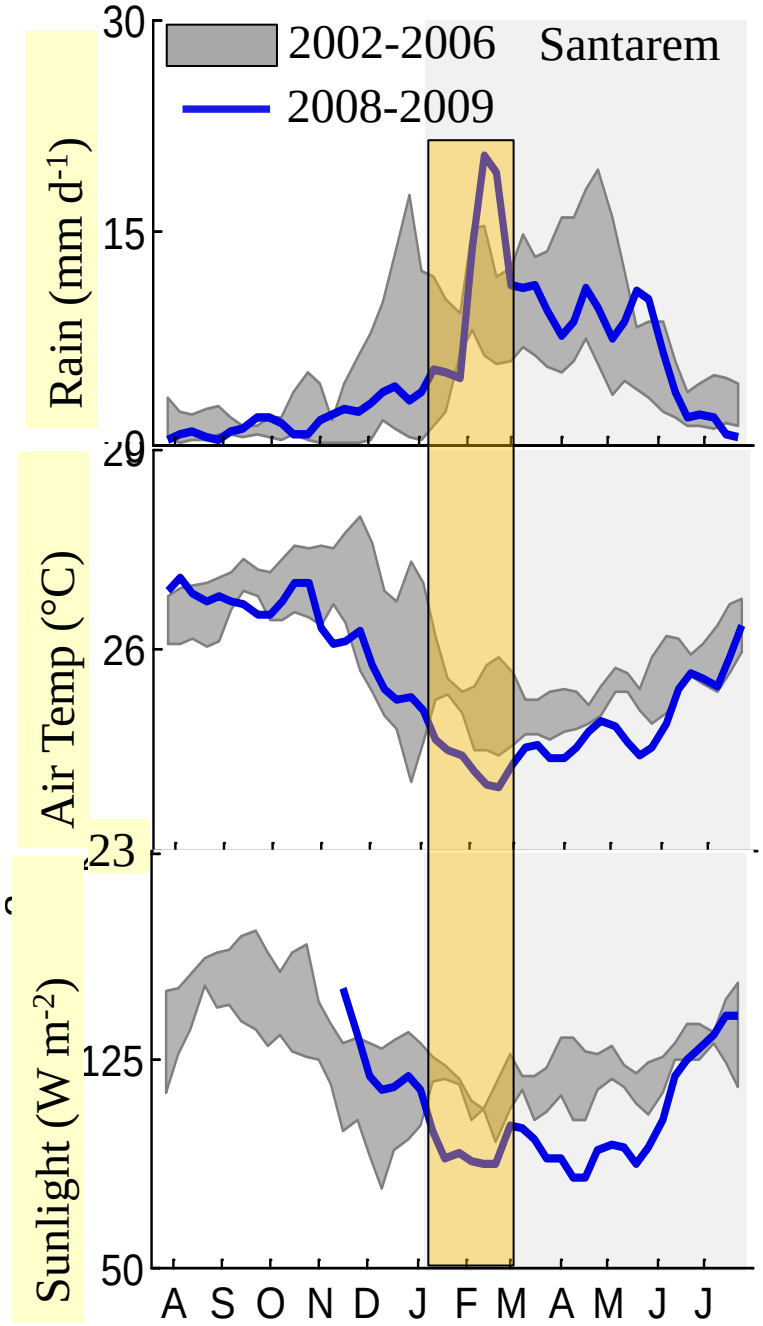
Interactions among: aerosols → cloud invigoration → strong wind events (i.e., microbursts and blowdowns) → tree mortality → landscape-scale carbon cycling.?

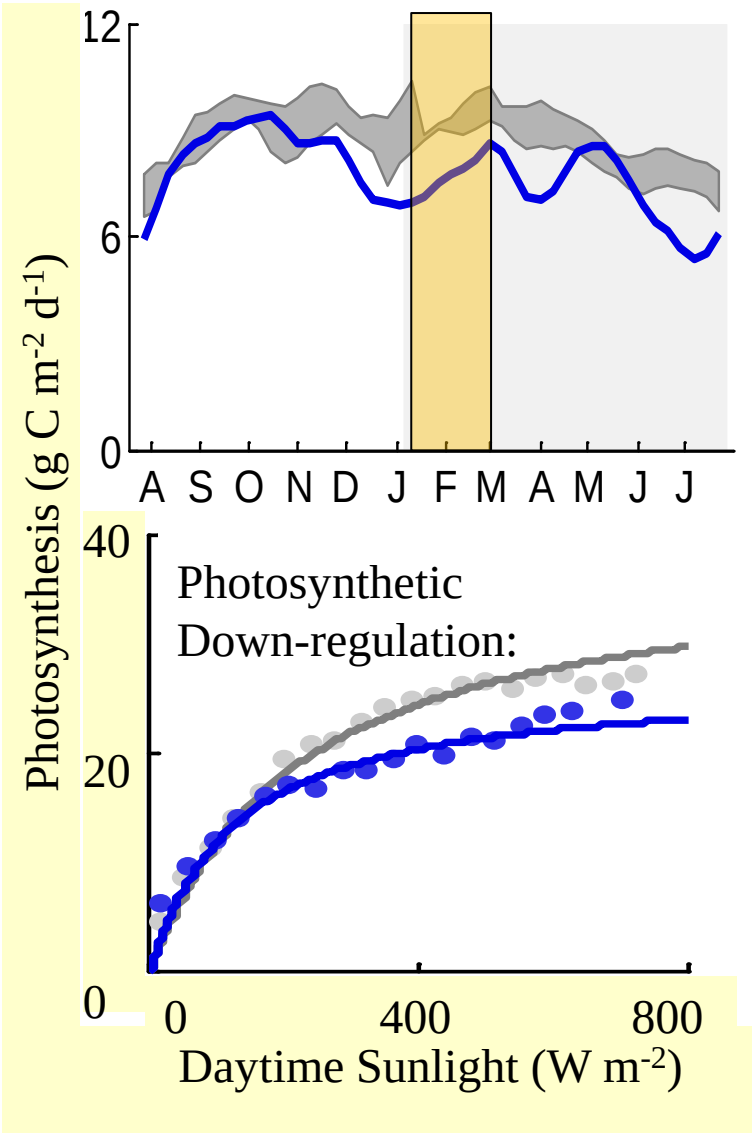
potential tree mortality from a single cross-basin squall-line in 2005 was ~500 million trees



Source: Rosenfeld, D., U. Lohmann, G. B. Raga, C. D. O'Dowd, M. Kulmala, S. Fuzzi, A. Reissell, and M. O. Andreae (2008), Flood or drought: How do aerosols affect precipitation?, *Science, 321, 1309-1313.*

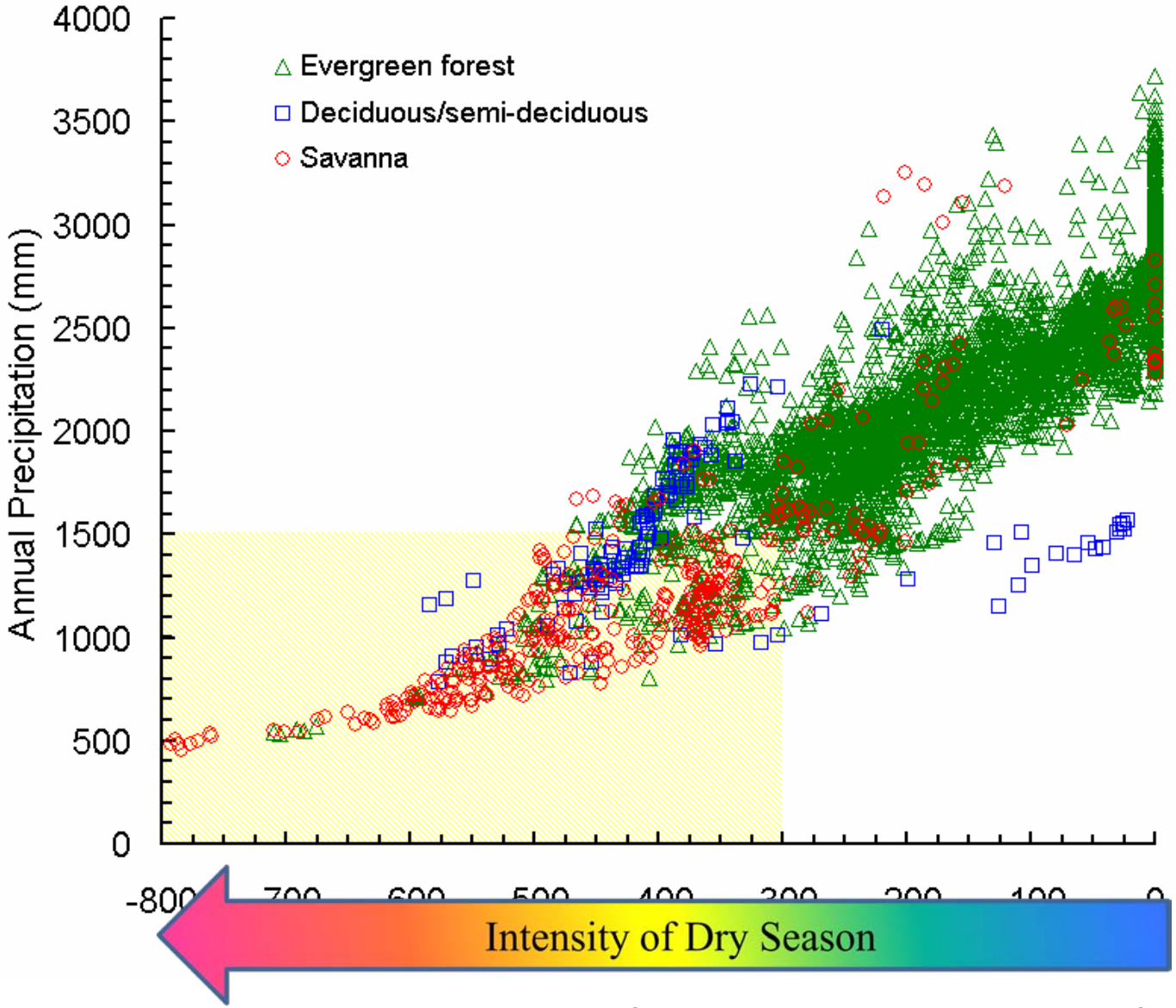
Water Stress: Links to Carbon Cycle: *Feedback to Hydrol. Cycle (?)*





Source: Saleska, Wofsy, et al. (personal communication)

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

Statement of Motivation

Scientific Questions for GoAmazon2014

Note: Non-exhaustive selected list. Further development anticipated.

Carbon Cycle - improve Community Earth System Model (CESM) for land-atmosphere processes in the Amazon Basin, including aerosol-cloud-precipitation connections

- Objective - Reduce uncertainties in our knowledge of feedbacks between vegetation-hydrology that underlie the Amazon forest dieback hypothesis. The uncertain range of feedbacks at present leads to large differences in ESM predictions.
- Objective - Response of photosynthesis and transpiration, including BVOC emissions, to changes in the direct and diffuse components of incoming solar radiation, i.e., in the context of current and future scenarios of aerosols and clouds in the Amazon Basin.

Aerosol Life Cycle - accurate modeling of aerosol sources/sinks and aerosol optical, CCN, and IN properties, as affected by pollution of pristine tropical environments

- Objective - The interaction of the tropical urban pollution plume with biogenic emissions of volatile organic compounds, especially the impact on the production of secondary organic aerosol, the formation of new particles, and biogenic releases of aerosols and their precursors.
- Objective - Influence of anthropogenic activities on aerosol microphysical, optical, cloud condensation nuclei (CCN), and ice nuclei (IN) properties in the tropics.

Scientific Questions for GoAmazon2014

Note: Non-exhaustive selected list. Further development anticipated.

Cloud Life Cycle - development of a knowledge base to improve tropical cloud parameterizations in GCMs

- Objective - The transition from shallow to deep cumulus convection during the daily cycle of the Amazon Basin, with comparison and understanding to other environments.
- Objective - The role of landscape heterogeneity—the Manaus urban area as well as the 10-km-scale of river width—on the dynamics of convection and clouds (+carbon cycle)
- Objective - The evolution of convective intensity from severe storms in the dry season to moderate storms in the wet season.

Cloud-Aerosol-Precipitation Interactions - improvement of parameterizations of aerosol-cloud interactions in climate models

- Objective - Aerosol effects on deep convective clouds, precipitation, and lightning under different aerosol and synoptic regimes, including the roles of aerosols in changing regional climate and atmospheric circulation.
- Objective - Aerosol effects on scattered cumulus clouds, especially the aerosol radiative effect.

Scientific Questions for GoAmazon2014

Note: Non-exhaustive selected list. Further development anticipated.

The theme uniting these 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.

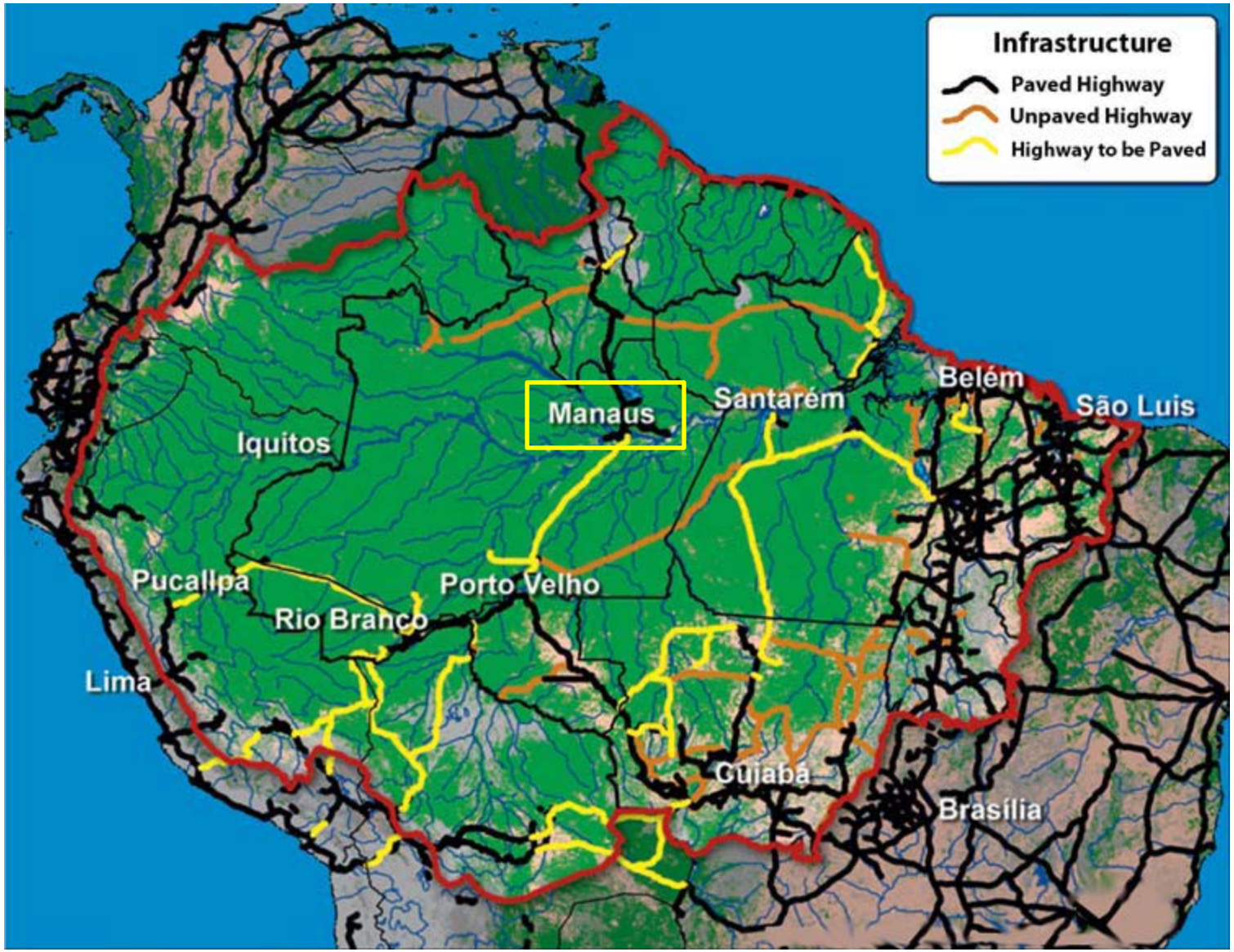
The ultimate goal is to estimate future changes in direct and indirect radiative forcing, energy distributions, regional climate, ecosystem functioning, and feedbacks to global climate.

In this regard, the presented objectives are representative, and further definition and broadening can be expected as the science team spins up prior to deployment.

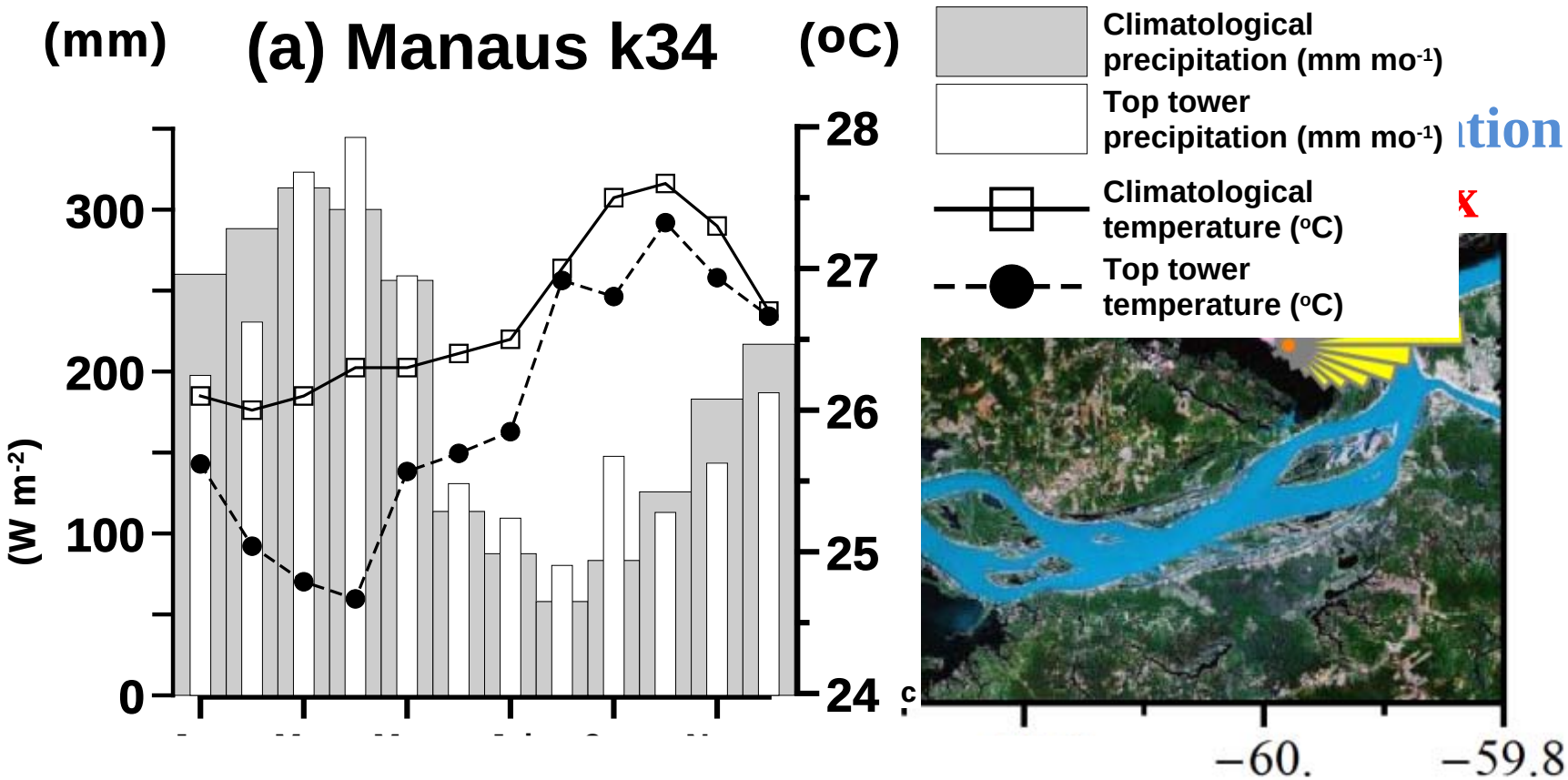
ACRF Site Location

MegaCity Outflow in the Tropics: Manaus, Brazil

Site Location

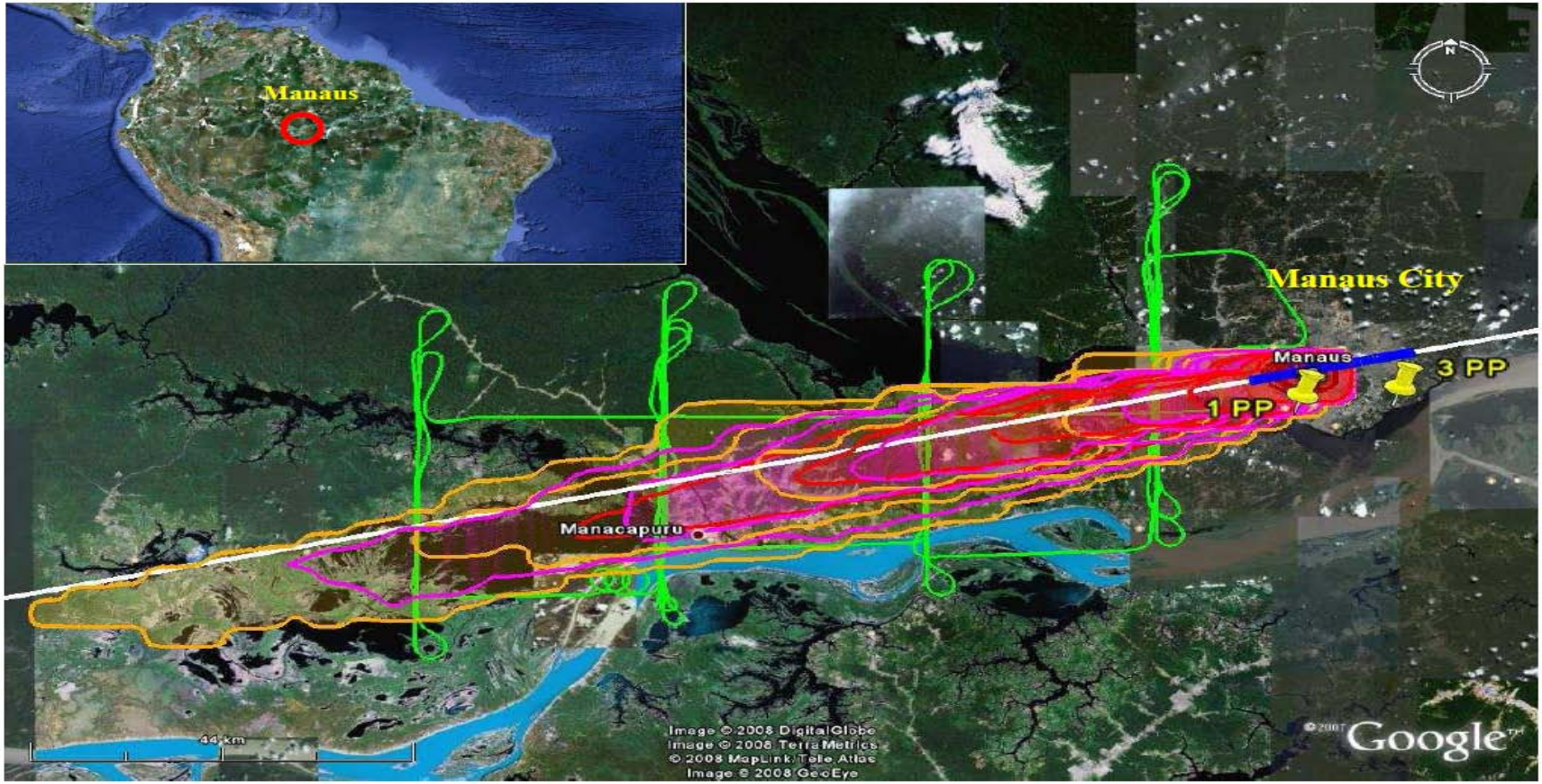


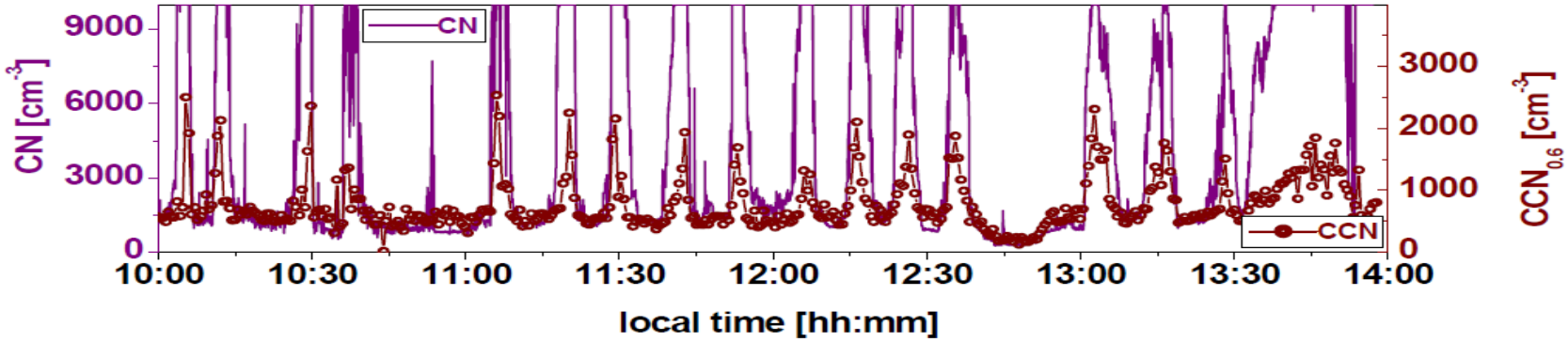
Site Location: AAA Site Near Manacapuru
Large Pasture Site (LPS)



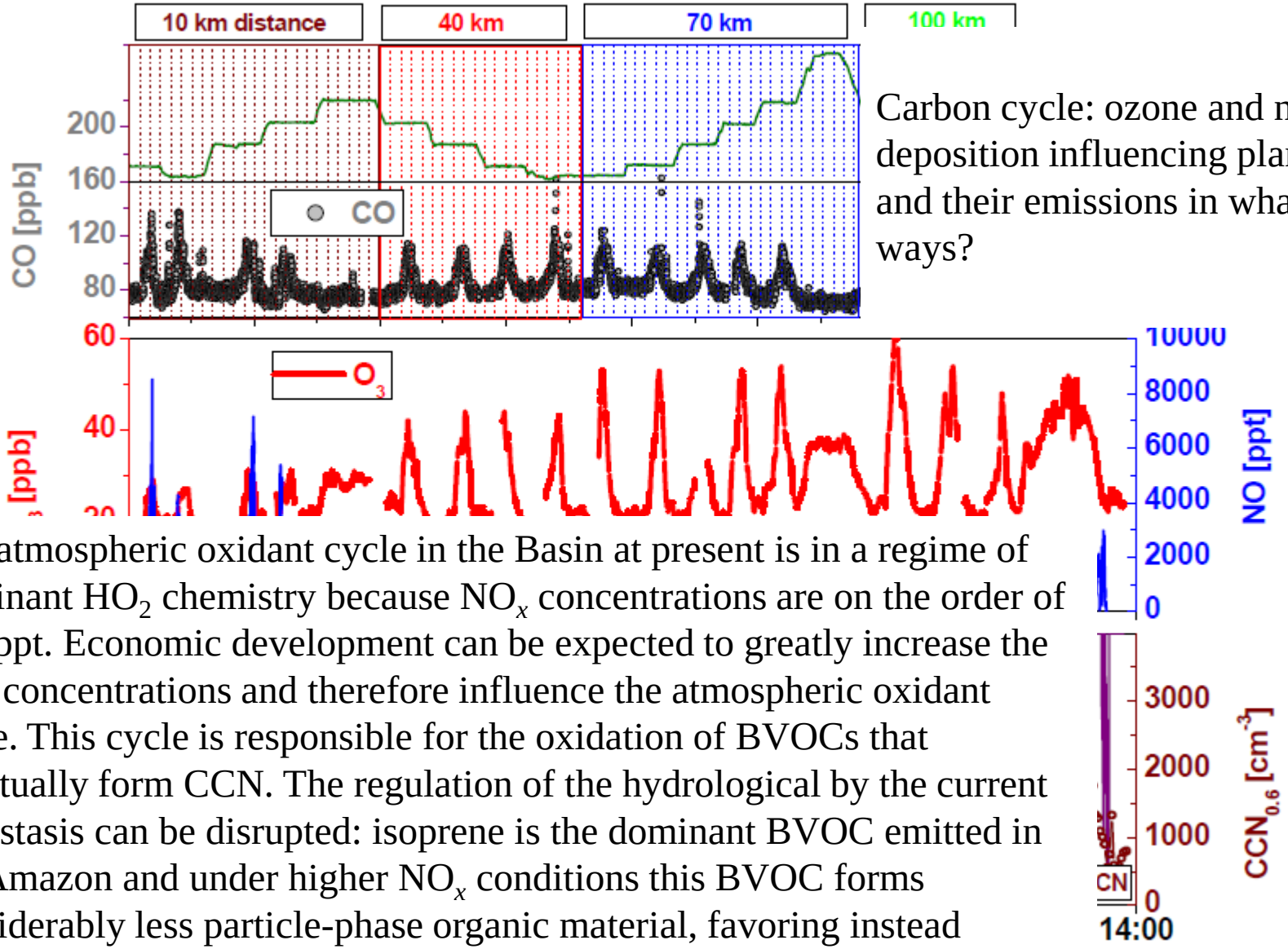
Source: Rocha et al. 2009 (JGR), 2010 (LBA book)

111 by 60.8 km represented by this box. Wind speeds at 1 km altitude are typically 10 to 30 kph.





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.



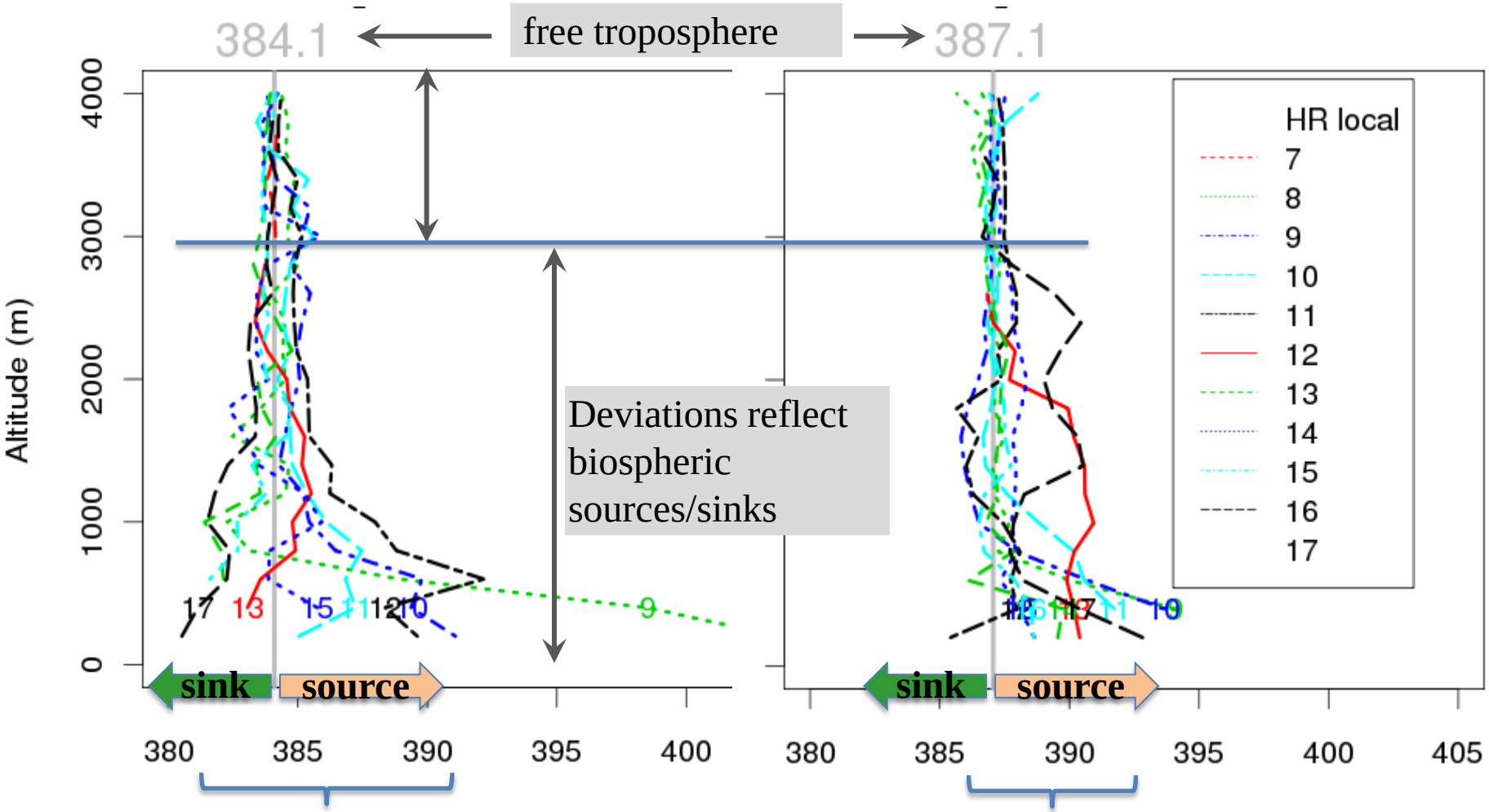
Carbon cycle: ozone and nitrate deposition influencing plants and their emissions in what ways?

The atmospheric oxidant cycle in the Basin at present is in a regime of dominant HO_2 chemistry because NO_x concentrations are on the order of 100 ppt. Economic development can be expected to greatly increase the NO_x concentrations and therefore influence the atmospheric oxidant cycle. This cycle is responsible for the oxidation of BVOCs that eventually form CCN. The regulation of the hydrological by the current gaia stasis can be disrupted: isoprene is the dominant BVOC emitted in the Amazon and under higher NO_x conditions this BVOC forms considerably less particle-phase organic material, favoring instead higher-vapor pressure products.

CO_2 Profiles in Manaus Region (BARCA)

A. Dry-season (16-22 November 2008)

B. Wet-season (15-27 May 2009)



Deviations show biosphere to be neutral or a weak CO_2 source (dry season)

Deviations show biosphere to be a strong CO_2 source (wet season)

Source: Saleska, Wofsy, et al. (personal communication)

Organizational Modes

Umbrella: GoAmazon2014

Jan-Dec 2014

GPM-CHUVA project

Jan-Apr 2014

Leader: Luiz Machado

Aerosol Life Cycle Project

T0 → T3 IOP periods (2)

Feb/Mar 2014, Sept/Oct 2014, coincident with G1 aircraft

T0: ATTO, T1: UEA-Manaus, T2: USP-UEA-ACRF-30min, T3: ACRF-2-6hr

Jian Wang, Scot Martin, Paulo Artaxo, Rodrigo Souza, + 4-8 other groups

Santarem Carbon Cycle

Steven Wofsy, Scot Martin, Paulo Artaxo

3 year project, 1000 km east of Manaus

More focus groups expected:

Cloud Life Cycle, Aerosol-Cloud-Interaction Precipitation, Carbon Cycle, Satellite Retrievals, international partners, …

Manaus Campaign

Main Target Study: Organized and Local Convection from Warm and Ice Clouds

From 6 January to 4 April 2014.

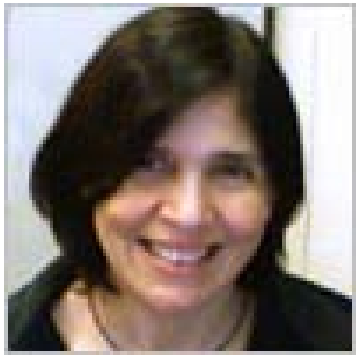
Additional Data: The ARM Climate Research Facility in the Amazon Basin (Scot Martin – Havard University and several partners)
S Band Radar (SIPAM)

http://chuvaproject.cptec.inpe.br/portal/en/index.html

Final Thoughts

Brazil-Side Scientific Steering Committee

Gilberto Fisch (CTA)
Boundary Layer Studies
http://buscatextual.cnpq.br/buscatextual/visualizacv.jsp?id=K4780139T4

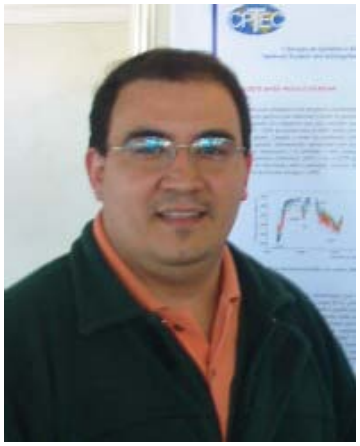


Karla Longo (INPE)
Atmos. Modeling: Chemistry
http://meioambiente.cptec.inpe.br/gmai/index.php

Luiz Machado (INPE)
Convection/Cloud Dynamics
http://buscatextual.cnpq.br/buscatextual/visualizacv.jsp?id=K4789453E1

M.A. Silva Dias (USP)
Atmos.Models: Energy Flows
http://www.proficiencia.org.br/article.php3?id_article=88

Paulo Artaxo (USP)
Aerosol Life Cycle & Climate
http://www.csixxxvii.org/index.php?pag=invited



Rodrigo Souza (UEA)
Satellite Observations
http://buscatextual.cnpq.br/buscatextual/visualizacv.jsp?id=K4768578Y1

Interests for ACRF

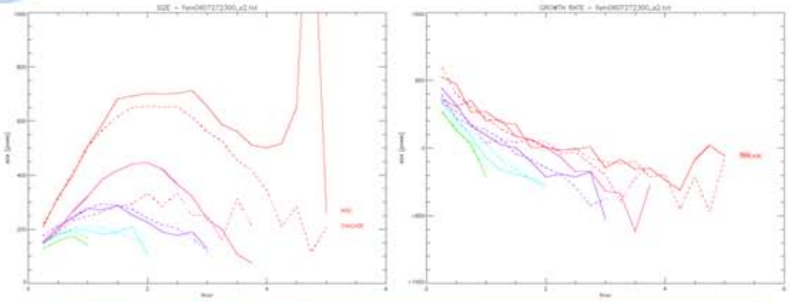
Study the impacts of aerosol indirect effects on the IWV, VIL, IWC, cloud droplets spectrum, cloud fraction and storm dynamics

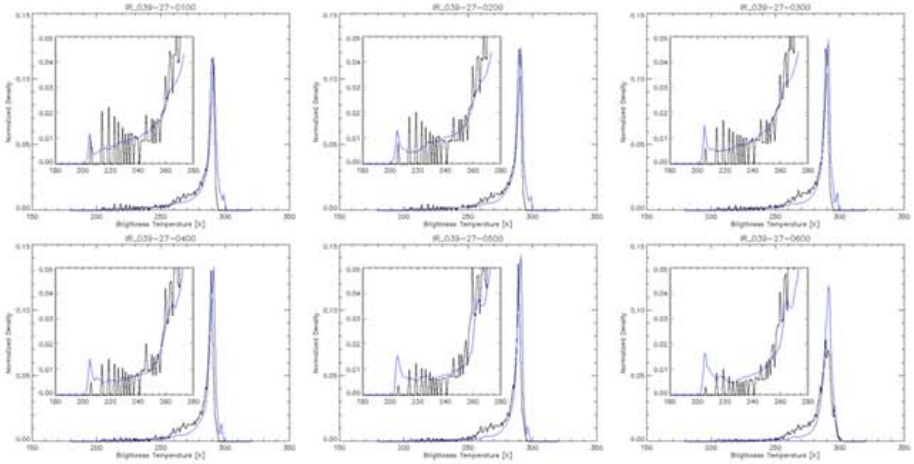
Study cloud-precipitation processes: the relative importance of the various cloud processes for warm rain and ice phase processes

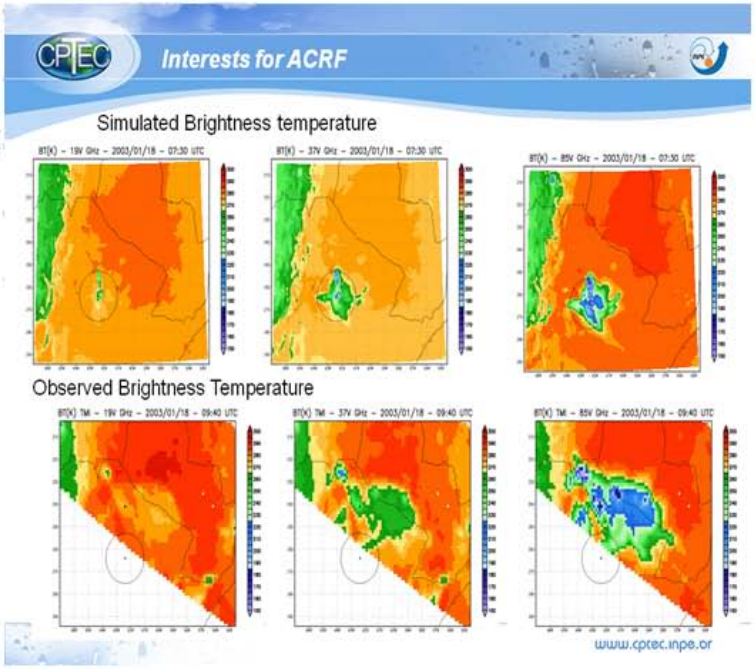
Precipitation estimation techniques over land still need significant improvement. For example, warm clouds that can contribute significantly to the total rainfall in tropical regions, are poorly retrieved. Knowledge of the cloud life cycle can significantly enhance precipitation estimation techniques.

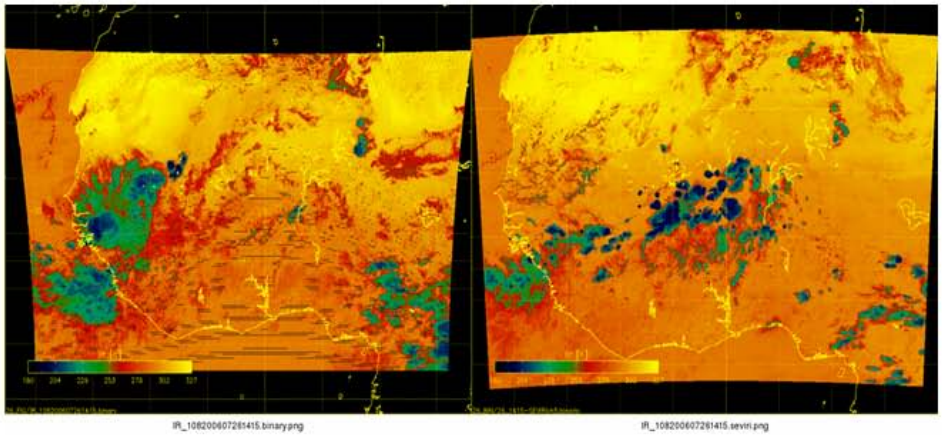
In order to enhance our knowledge of radiative feedbacks is necessary a description of the water-mixed-phase - ice profile.

Interests for ACRF: Combine Cloud Resolving Model with Satellite – radar and radiative transfer Model









ACRF Linkage to GPM

1) The core satellite will be up- so, obviously high resolution network measurements of radiation and precip would be of interest for direct validation.

2) Physical validation- Aerosol “regimes” impact the resultant physical characteristics of the precipitation. Precipitation estimation depends on cloud water vs. rain water threshold; impacts of aerosol loading/variability on rain water Droplet Size distribution and ice Partical size distribution – the first is critical for precipitation estimation by radar and the latter being critical to how the ice scattering is used to estimate precipitation by satellite

The key will be ACRF to interact early with the PMM Science Team and GPM Science management. There are many really solid field efforts out there, but really nothing close to the resources to do them all. There is a pathways designed to enable productive interaction between the communities.

Brazil-Side Organizations

- LBA - Large-Scale Biosphere Atmosphere Experiment, http://lba.cptec.inpe.br/
- INPA - National Institute for Research in the Amazon, 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
- Links to GPM-CHUVA (http://chuvaproject.cptec.inpe.br/portal/en/index.html), SAMBBA (http://www.ncas.ac.uk/fgam/index.php?option=com_content&task=view&id=194&Itemid=1), Andes-Amazon Initiative (http://www.moore.org/andes-amazon.aspx), Amazon-PIRE (http://www.amazonpire.org/)

Scientific information on energy, carbon, and chemical flows in the Amazon Basin is limited in 2011, in part because of a sparse observational data set

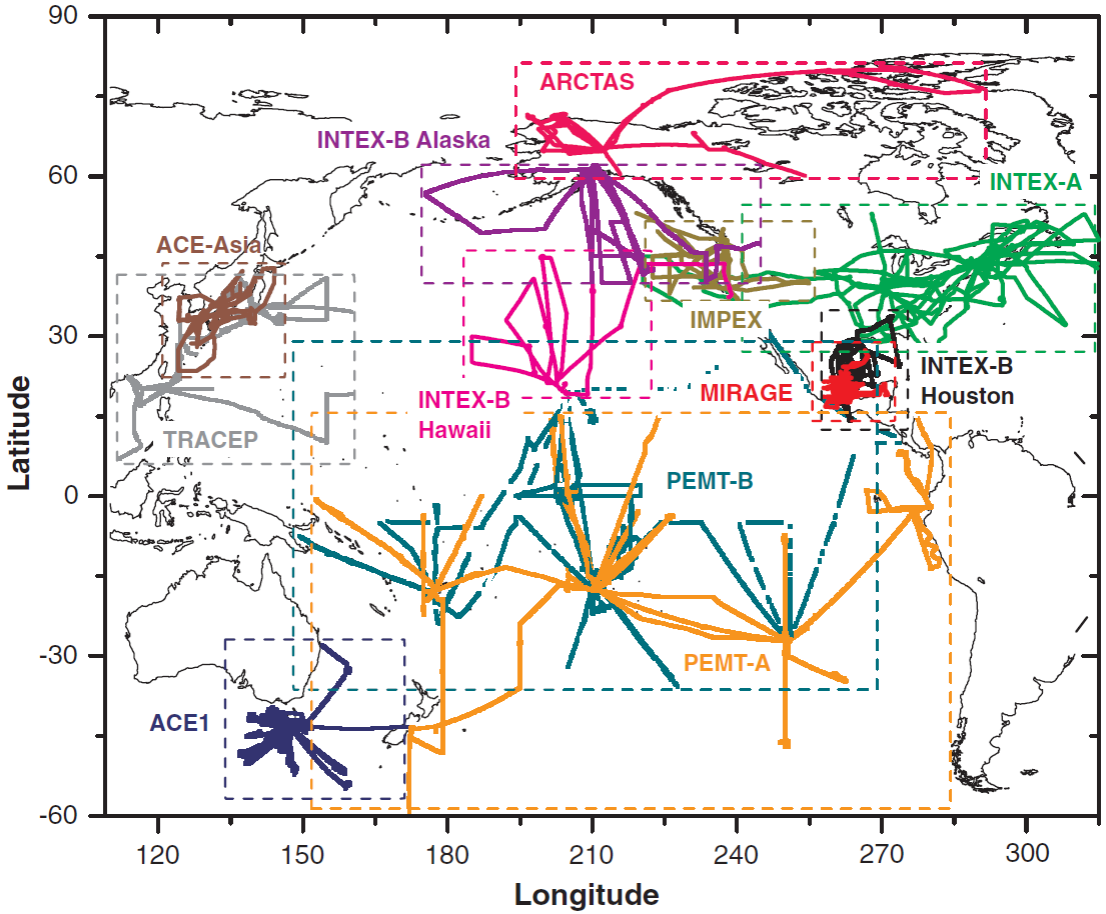


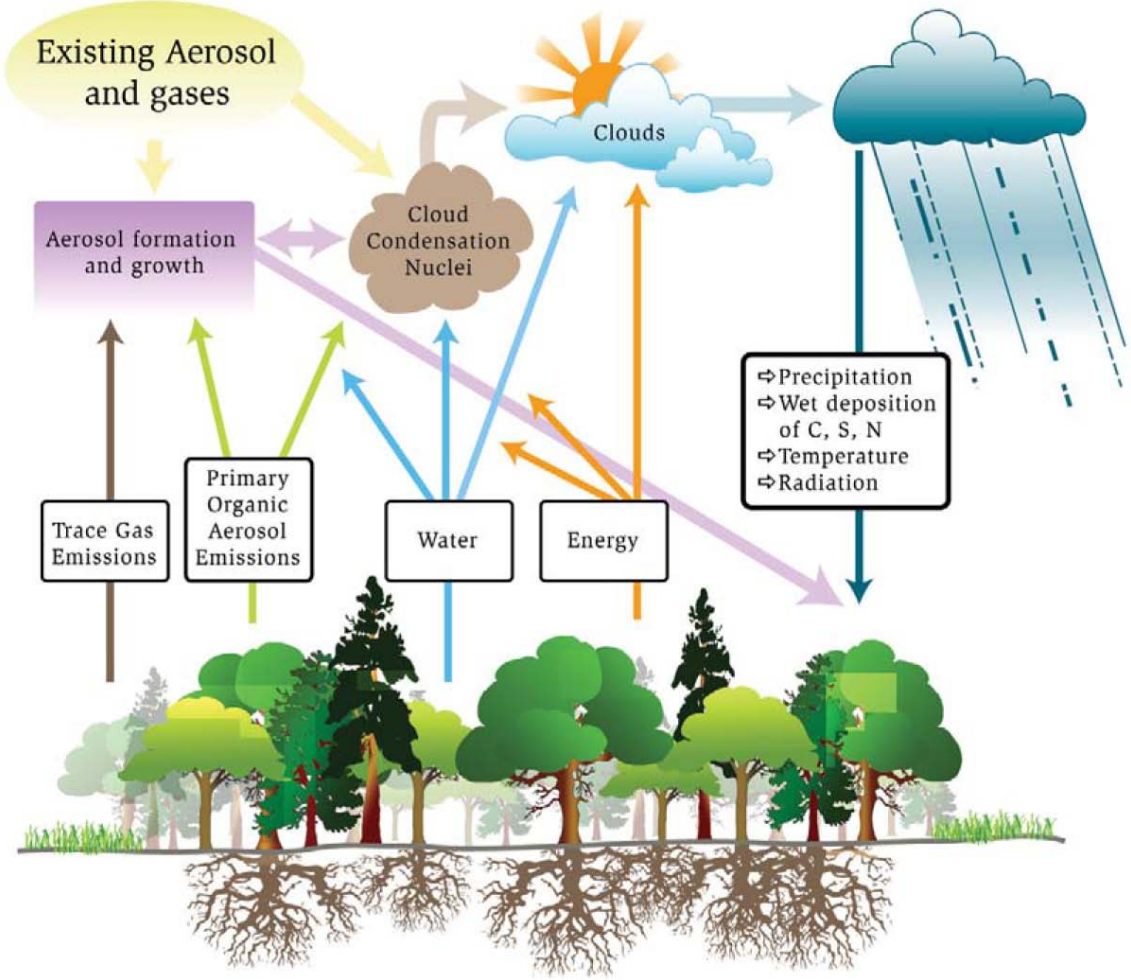
Fig. 1. Flight tracks for all experiments, as identified in Table 1 and included in the SOM (*40*).

Source: Clarke, A., and V. Kapustin, Hemispheric Aerosol Vertical Profiles: Anthropogenic Impacts on Optical Depth and Cloud Nuclei, *Science*, **2010**, *329*, 1488-1492.

AMF Ground Site Operations: Jan-Dec 2014 (Manacapuru)

AAF Aircraft Operations: Feb/Mar & Sep/Oct 2014 (Manaus)

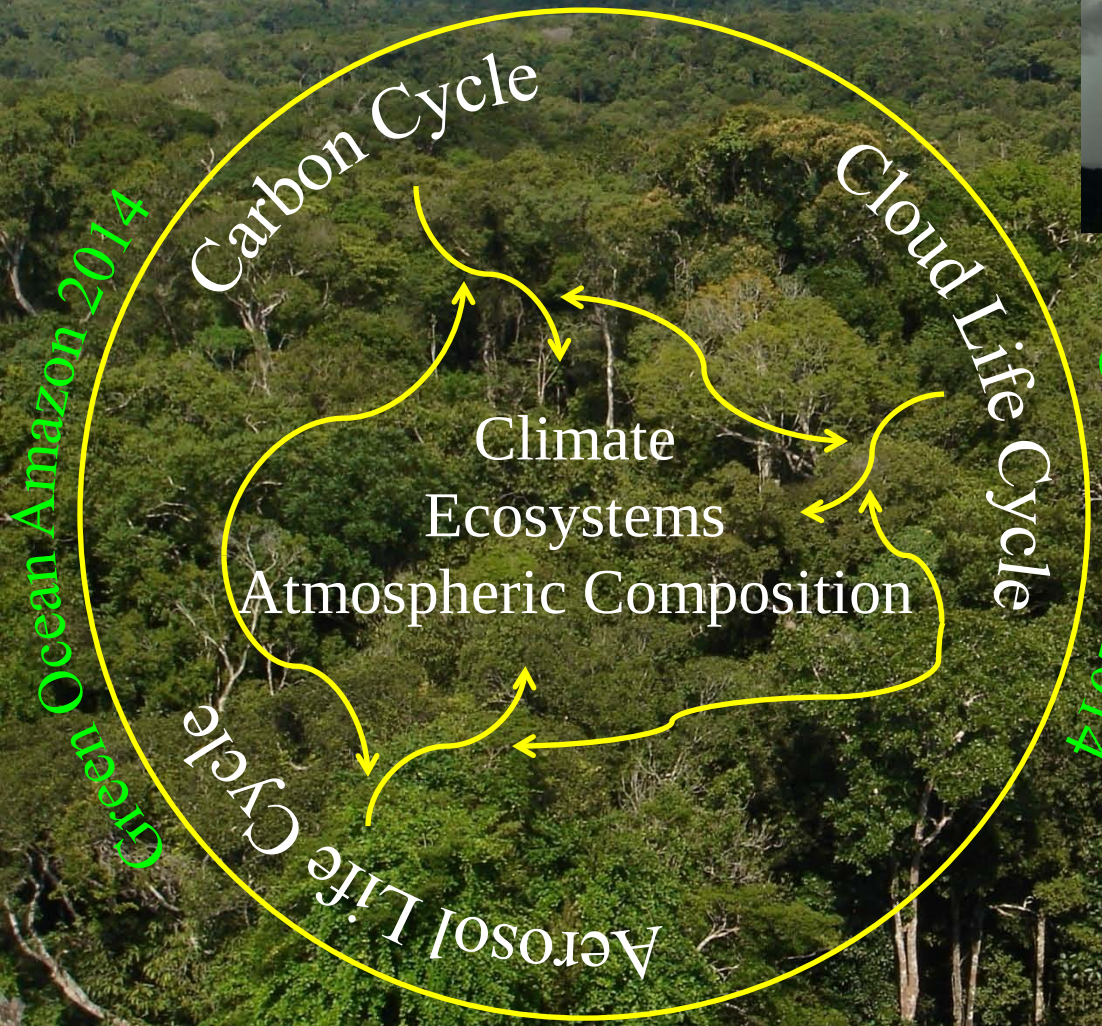
Amazon Basin has strong coupling between terrestrial ecosystem and the hydrologic cycle: The linkages among carbon cycle, aerosol life cycle, and cloud life cycle need to be understood and quantified.



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.

Observations and Modeling of the Green Ocean Amazon



Presented by Scot Martin at USA Interagency Science Meeting, 2 May 2011, Washington, D.C.