Drought-induced vegetation change and fire in Amazonian forests: past, present, and future

Michael Palace
Earth System Research Center, Institute for the Study of Earth, Oceans, and Space
Department of Earth Sciences, College of Engineering and Physical Sciecnes
University of New Hampshire

NASA Interdisciplinary Science Program (NNX14AD31G)

Outline

- NASA IDS
- Introduction
- Highlight work from this NASA IDS Project
  - Paleoclimate and Paleoecology
  - Past influencing present
  - Lag in the response of trees to drought
  - Complex remote sensing signals
  - Higher resolution explains complex signals
  - Future of Amazonian forests
- Conclusions

NASA Interdisciplinary Research in Earth Science

Michael Palace, ESRC-University of New Hampshire, michael.palace@unh.edu

Steve Frolking, University of New Hampshire,

Crystal McMichael, University of Amsterdamn

Bobby Braswell, Indigo Ag

Dar Alexander Roberts, UC Santa Barbara

Mark Bush, Florida Institute of Technology

Douglas Morton, NASA GSFC

Michael Keller, USDA Forest Service

Heidi Asbjornsen, University of New Hampshire,

Luiz Aragao, CPTEC

Liana Anderson, CPTEC

Laerte Ferreria, LAPIG-UFG

Matt Vadenboncoeur, University of New Hampshire

Mark Ducey, University of New Hampshire

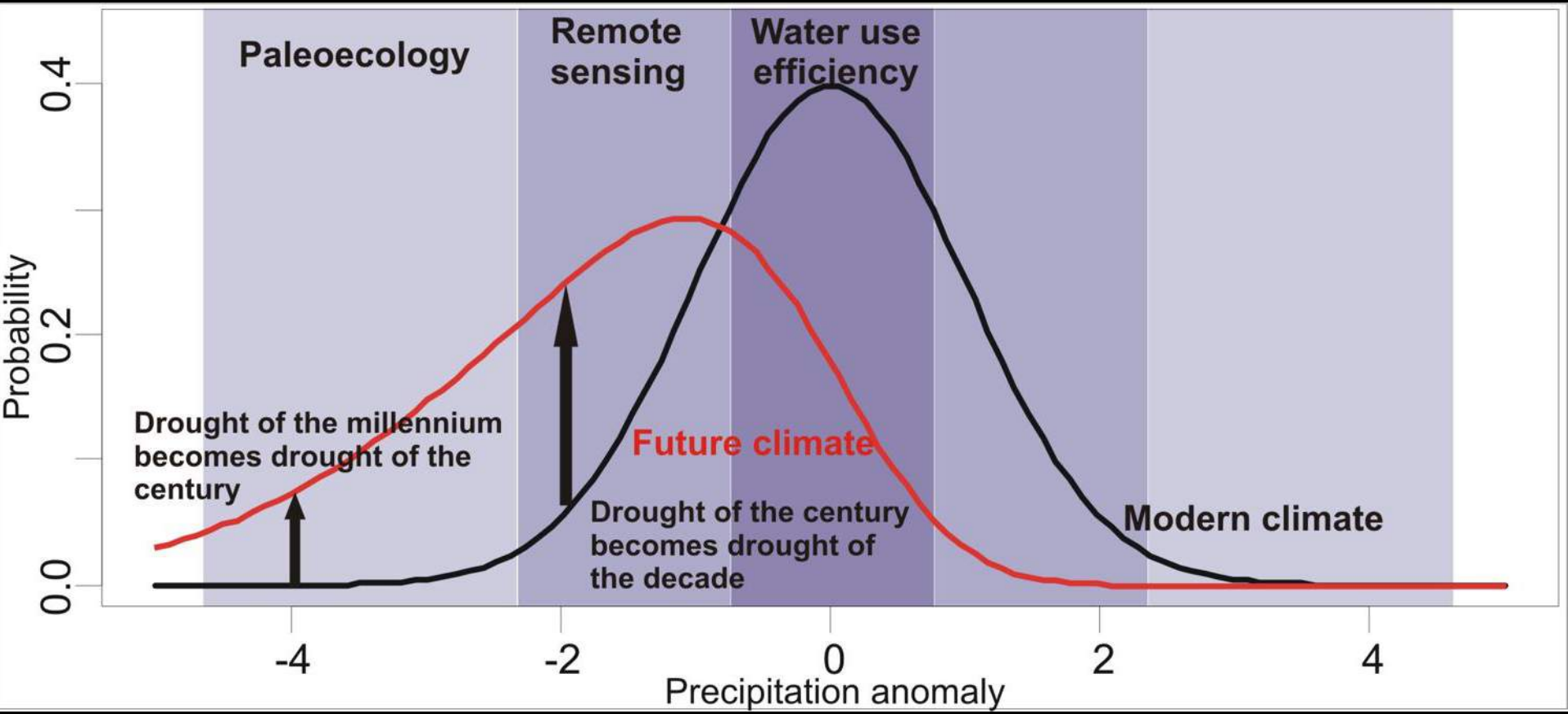
Stephen Hagen, Applied GeoSolutions

Tom Milliman, University of New Hampshire

Christina Herrick, University of New Hampshire

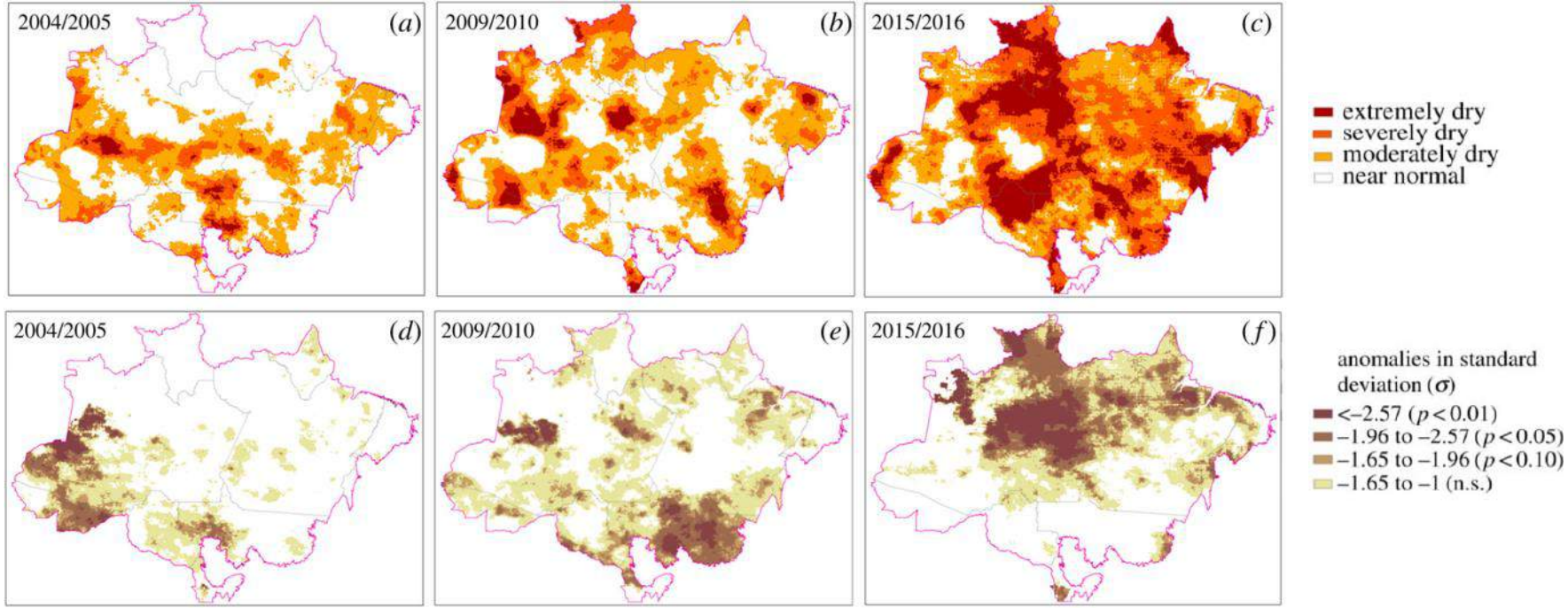
Franklin Sullivan, University of New Hampshire

Seth Peterson, UC Santa Barbara



NASA Interdisciplinary Science Program (NNX14AD31G),

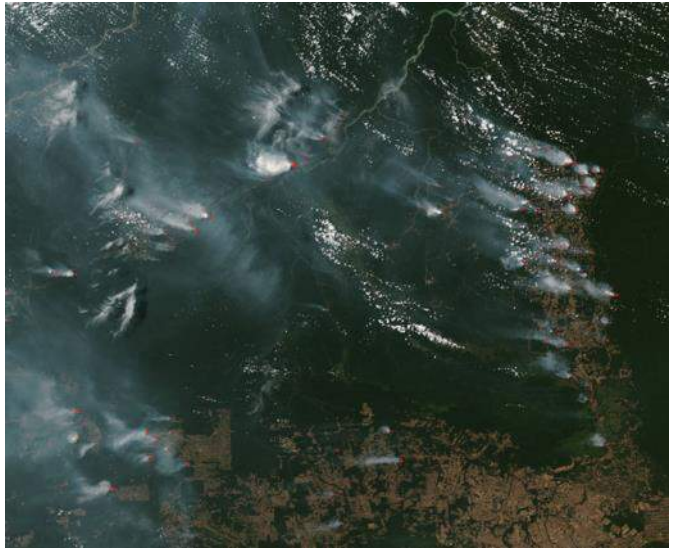
Three 100 year droughts in ten years



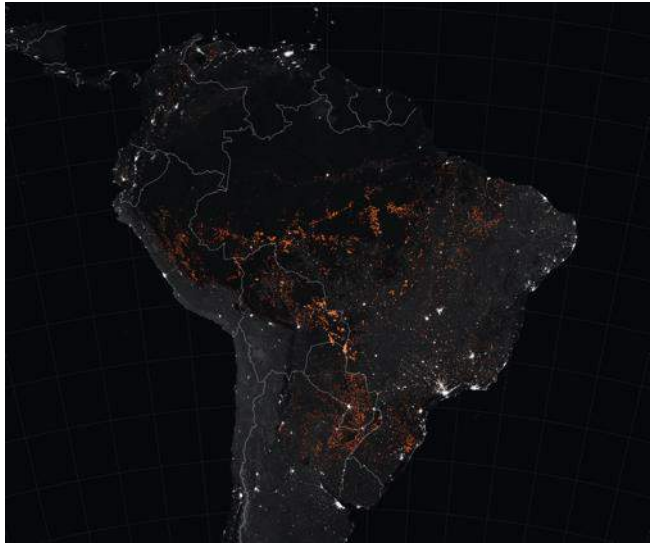
Vulnerability of Amazonian forests to repeated droughts

Liana Oighenstein Anderson, , Germano Ribeiro Neto, , Ana Paula Cunha, , Marisa Gesteira Fonseca, Yhasmin Mendes de Moura, , Ricardo Dalagnol, , Fabien Hubert Wagner and Luiz Eduardo Oliveira e Cruz de Aragão
Published:08 October 2018https://doi.org/10.1098/rstb.2017.0411

TE Science in the news



One day of fires in the Brazilian Amazon: Aug 10, 2019



One week of VIIRS fires: Aug 15-22nd, 2019

Doug Morton, NBC Nightly News

Most viewed EO page ever: > 2M views

Fire – Used to clear land

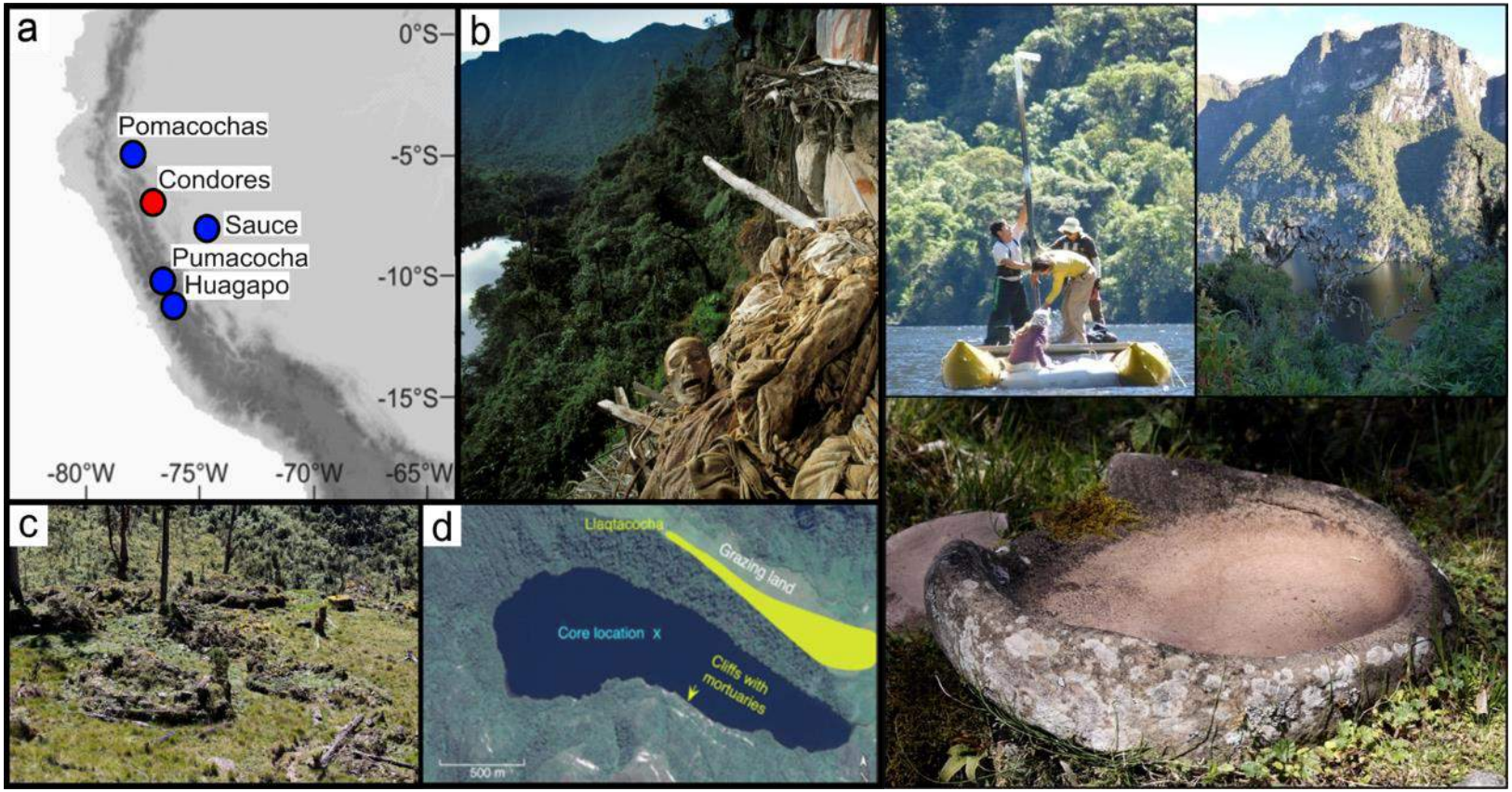
- In Amazonia fire in not natural
- Tied to drought
- Some forest species have adapted to fire, but in savanna systems, not humid tropical forests
- Important in carbon budgets and hydrological cycles
- Health and safety issues
- Spatial component tied to climate, weather, geography, and human activities

Paleoecology

Can the past environment be an analog for future response to changing climatic conditions (i.e. increased warming or aridity)?

Slide from C. McMichael

Laguna de los Condores



From Mark Bush

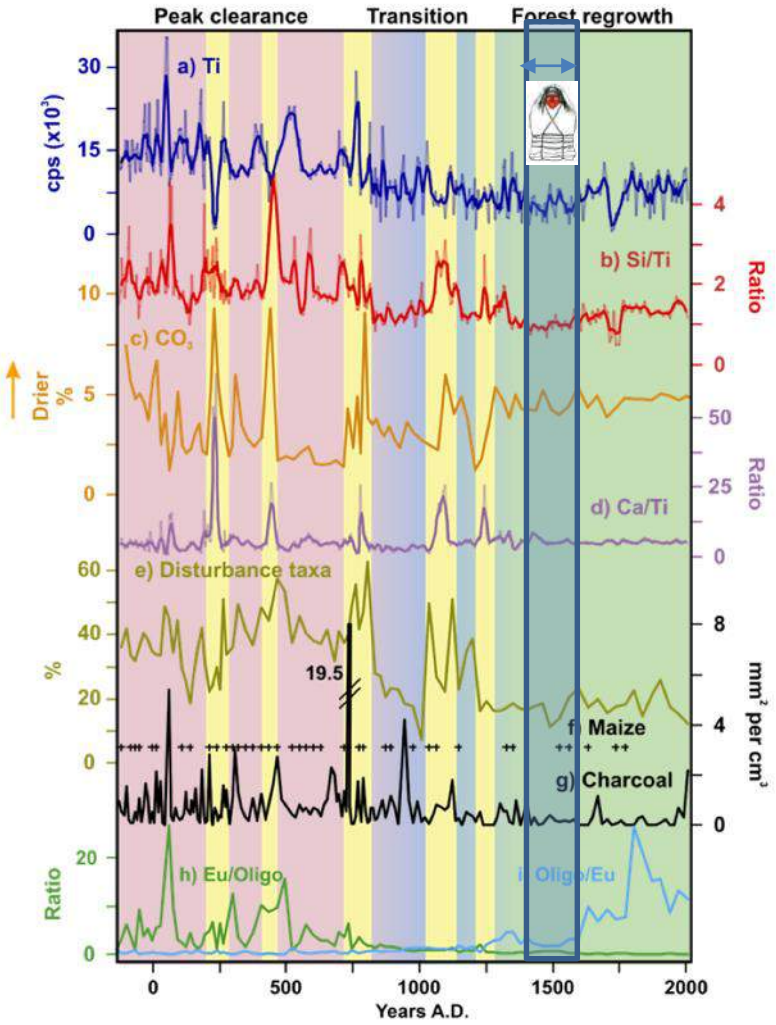
Lake Condores

The last 2000 years of climate change and human occupation.

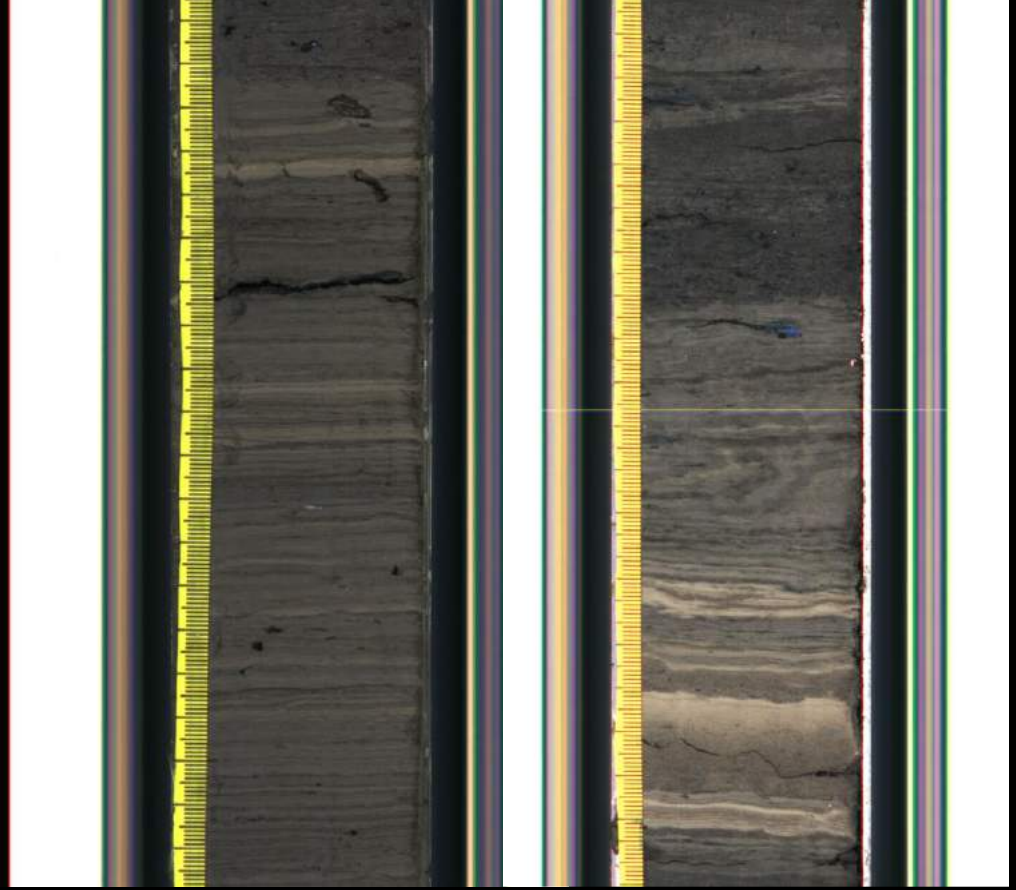
Five major (decadal) droughts…these were good times for agricultural expansion….made the cloud forest more livable.

People started to change landuse from maize agriculture to a sacred site about 1250 when climate became wetter.

Akesson et al. (in review)



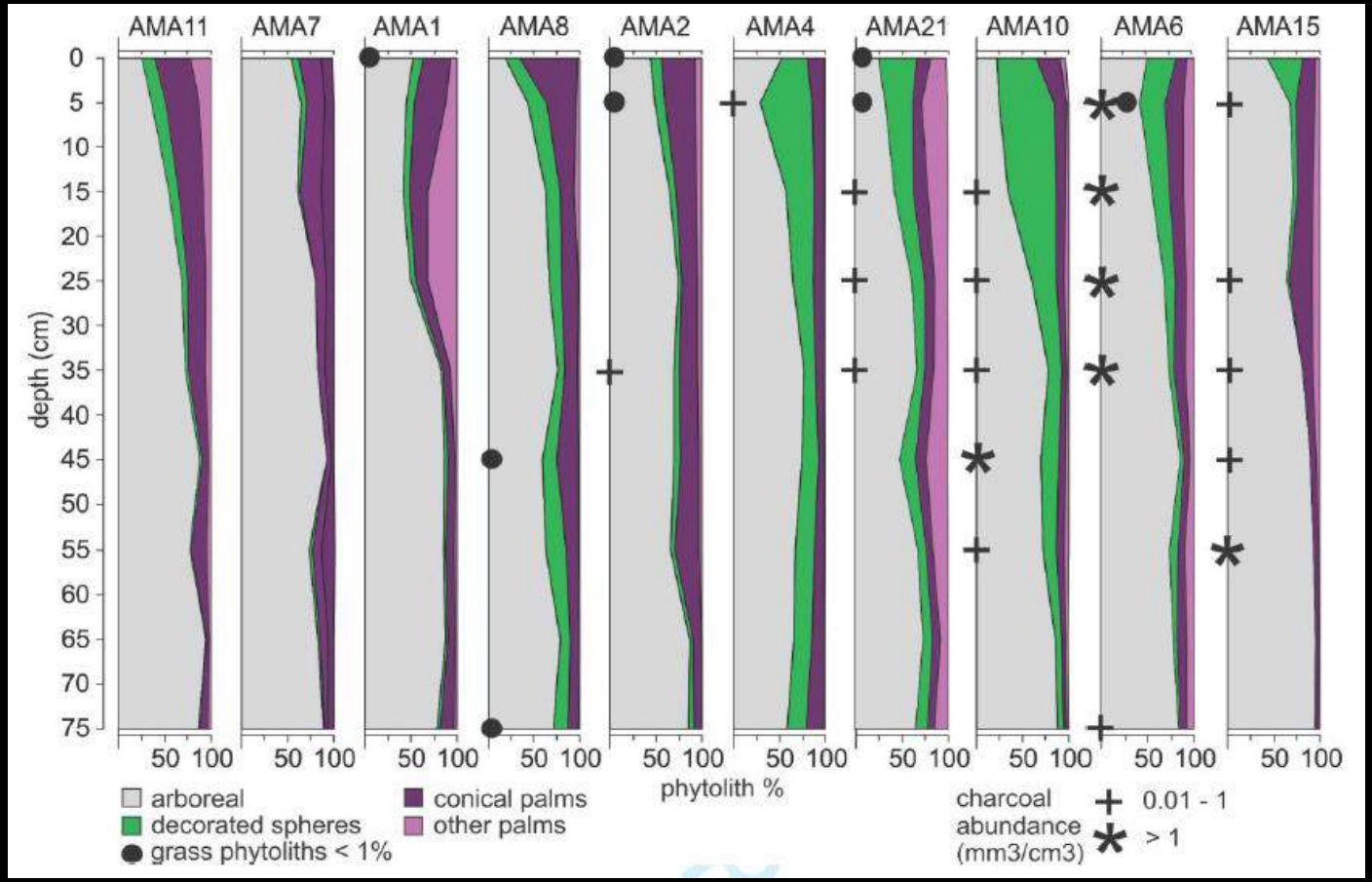
Example image of areal photography taken at Laguna Kumpak, Ecuador. These photographs will be compared with those taken by Paul Colinvaux on June 28, 1983 to detect the change in landcover around the lake as a result of human activity.



Now with cores from 70 different lakes

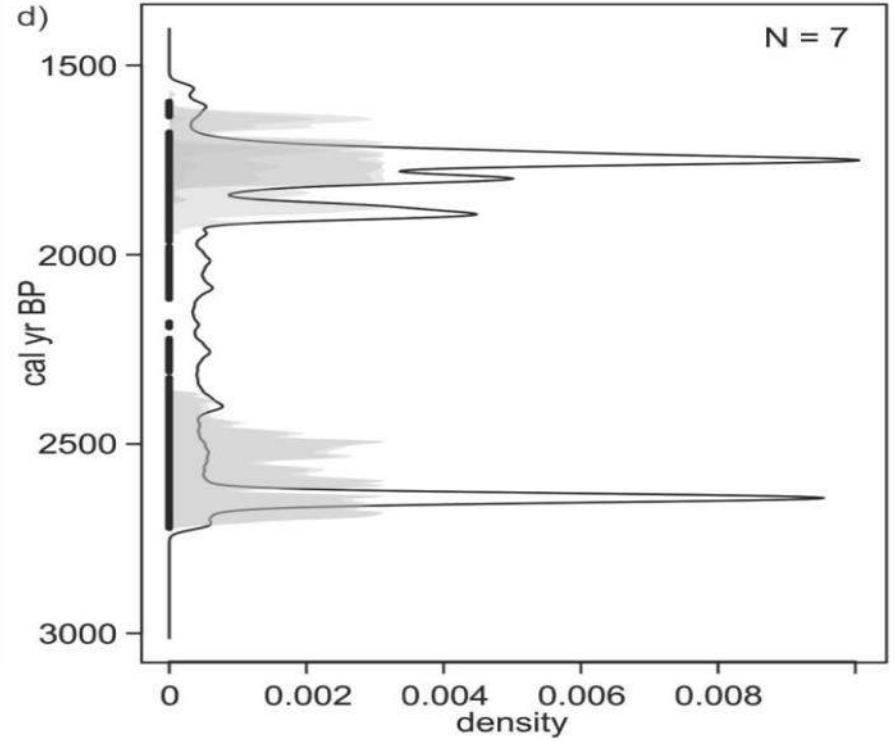
Example of two sections of the Laguna Kumpak sediment core. Both Core A (18m) and Core B (17m) have been photographed in their entirety. Laminations of different colors, such as seen above, are present throughout the entire core. Color analysis and elemental analysis on these laminated sediments can independently identify drought events, and pollen and phytoliths can then be used to reconstruct the response to those events. Left panel: Core A, meter 5; Right panel: Core A, meter 14.

Vegetation changed a lot over the Holocene!



Heijink et al. (in press) *Journal of Biogeography*

No evidence of past fire in over 1600 years!



Heijink et al. (in press) *Journal of Biogeography*

How many people lived in the Amazon pre-contact with Europe and how did they influence the forest?

Lack of archaeological evidence

Bone, wood, tusk, and other organic substances tend to decay easily, especially in the humid tropics

Little stone in Amazonia

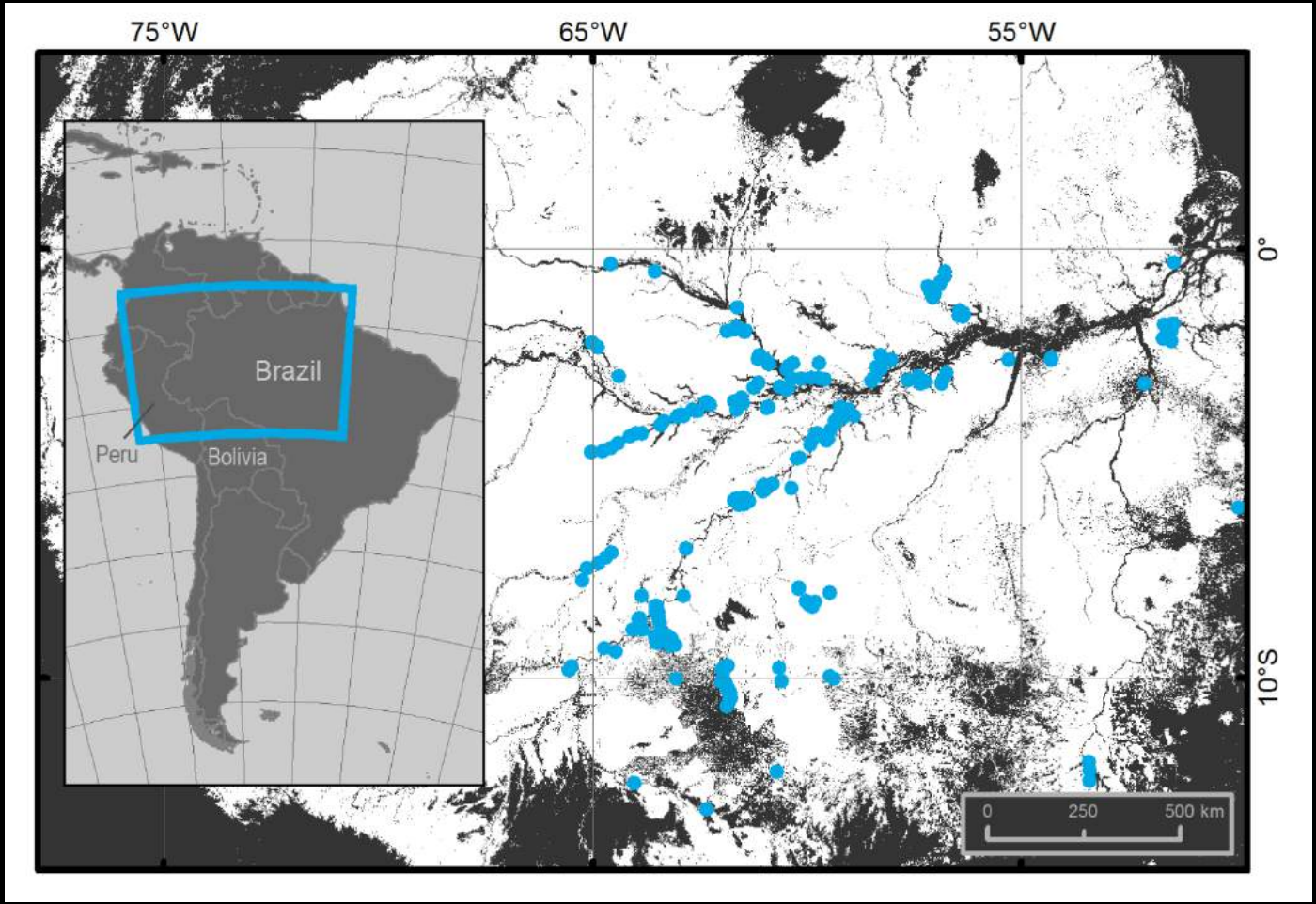
A prime source used in reconstruction of Amazonian societies are Amazonian black earths (ABE) or terra preta.

What is terra preta?

Anthrosols characterized by

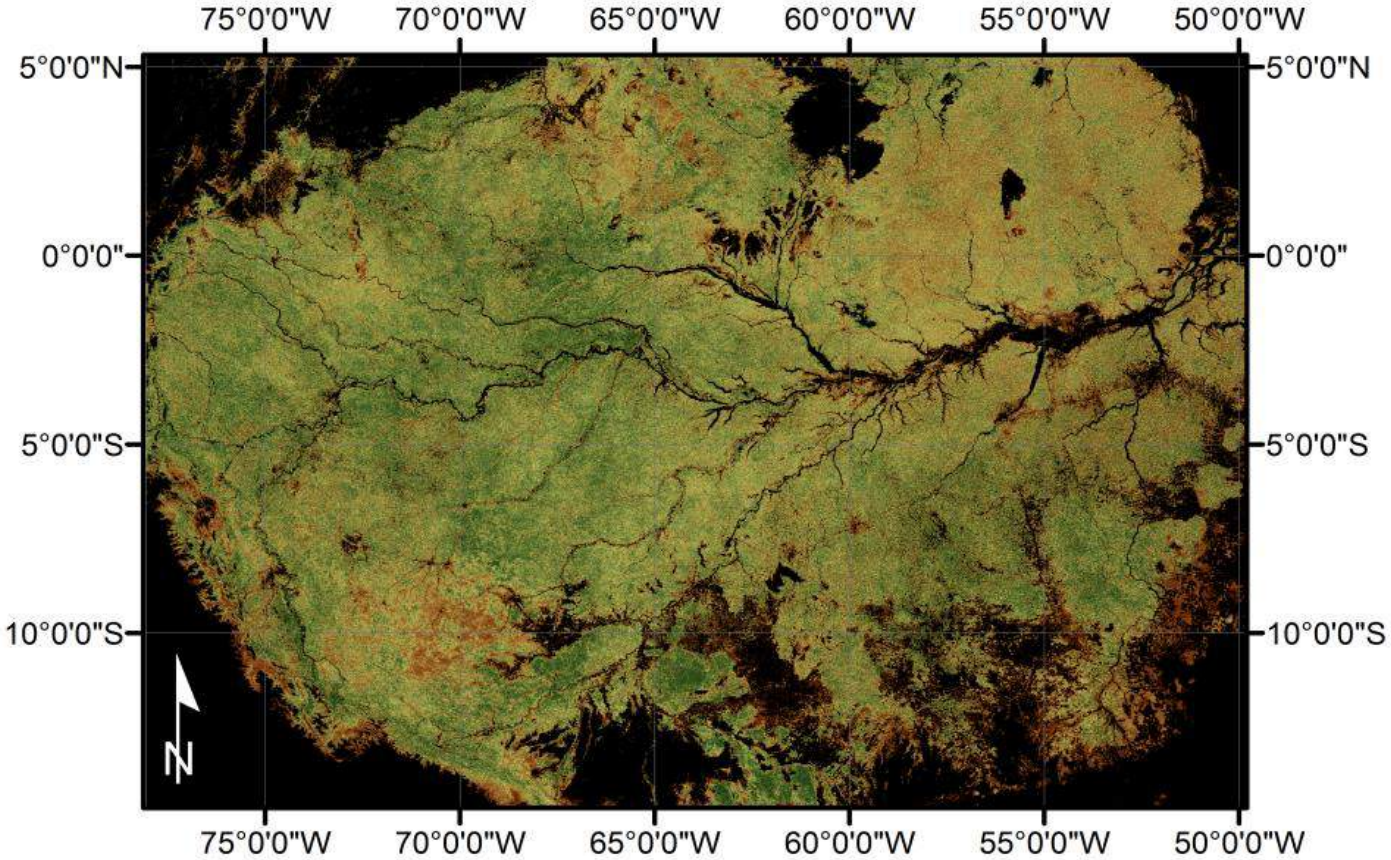
- high levels of organic matter
- charcoal
- nutrient elements
- frequently associated with large accumulations of potsherds and other artifacts of human origin

Archaeological excavation of terra preta sites in Brazil. Courtesy of Eduardo Neves

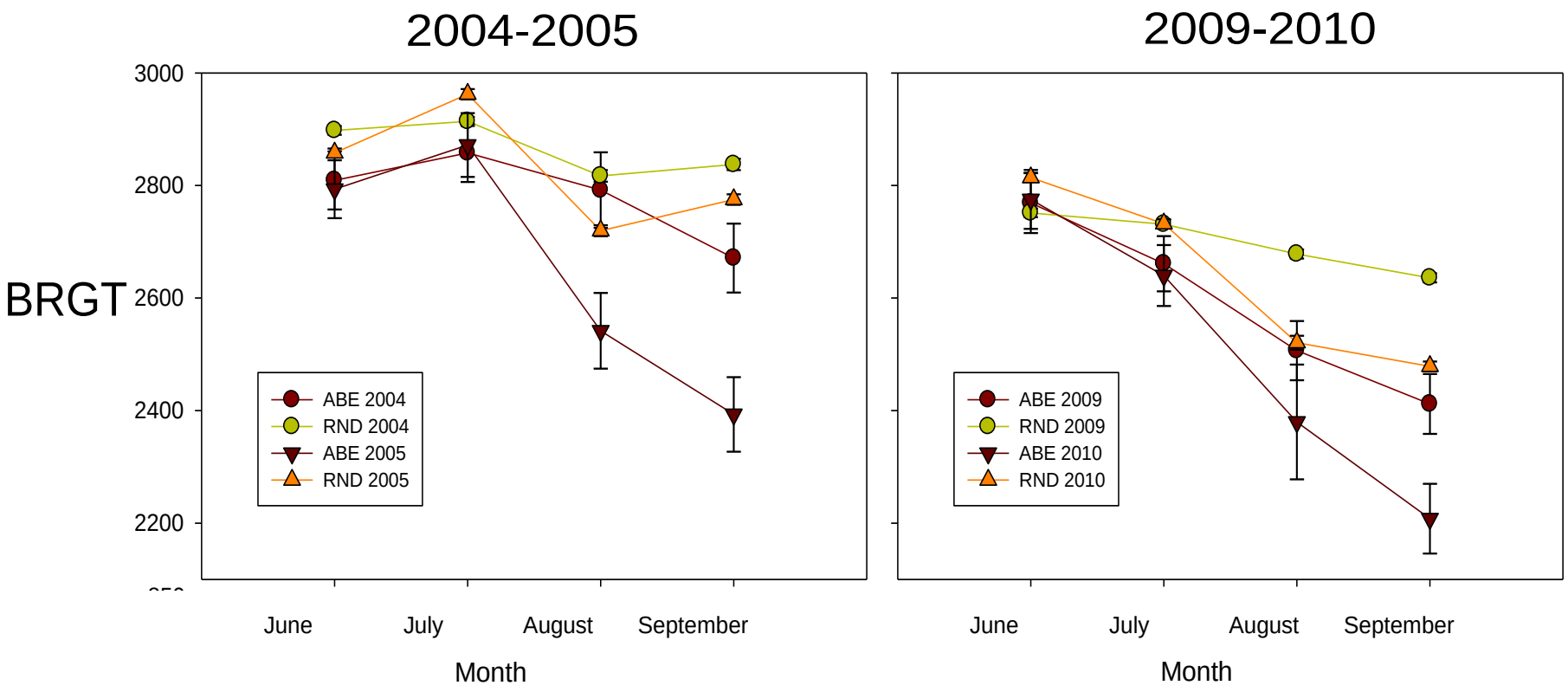


McMichael, C., M. Palace, M.B. Bush, B. Braswell, S.C. Hagen, M. Silman, C. Czarnecki, E. Neves, (*2014*). Terra preta distribution in Amazonia, *Proceedings of the Royal Society B*. doi: 10.1098/rspb.2013.2475.

Used Hansen's forest cover and Saatchi's biomass map to filter for undisturbed forests



Examined Monthly Averages of NDVI, EVI, LSWI and BRGT using MCD43A4 Collection 5



Forests on ABE sites were shorter stature, had lower biomass, and were more responsive to drought than random sites located nearby

Maximum Entropy Modeling (MaxEnt)

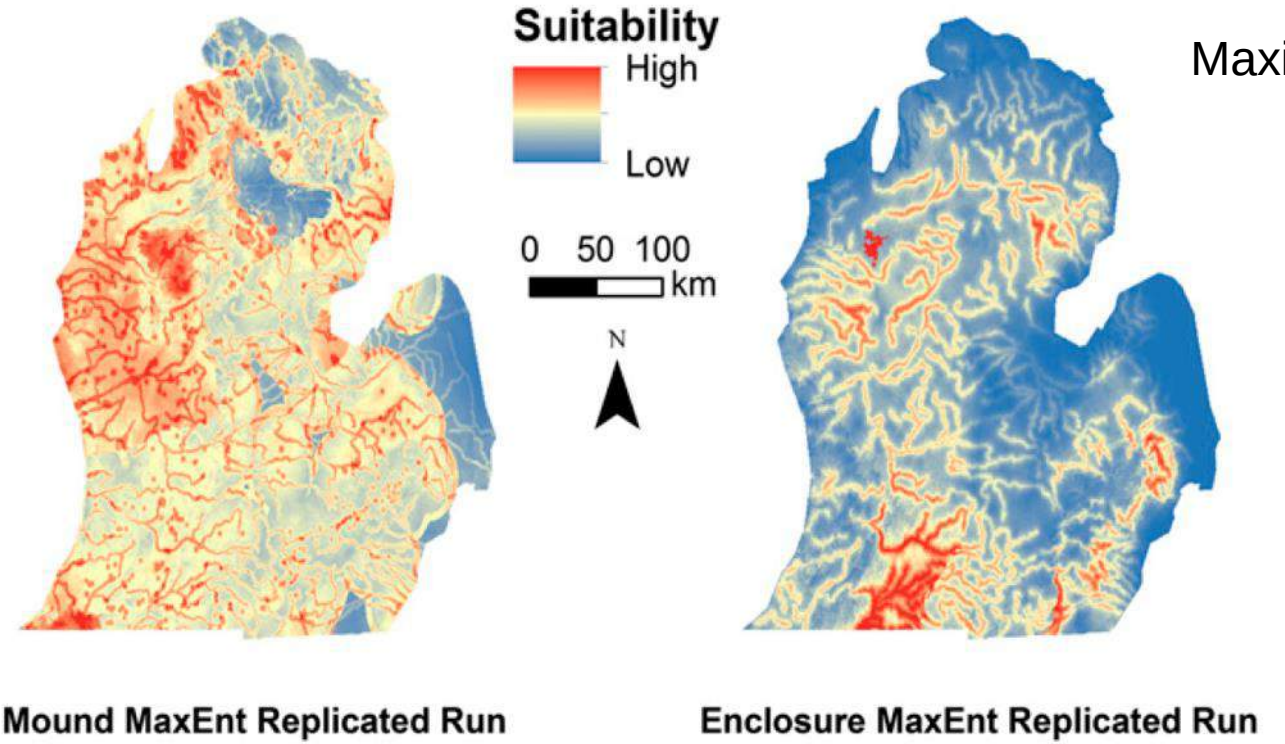
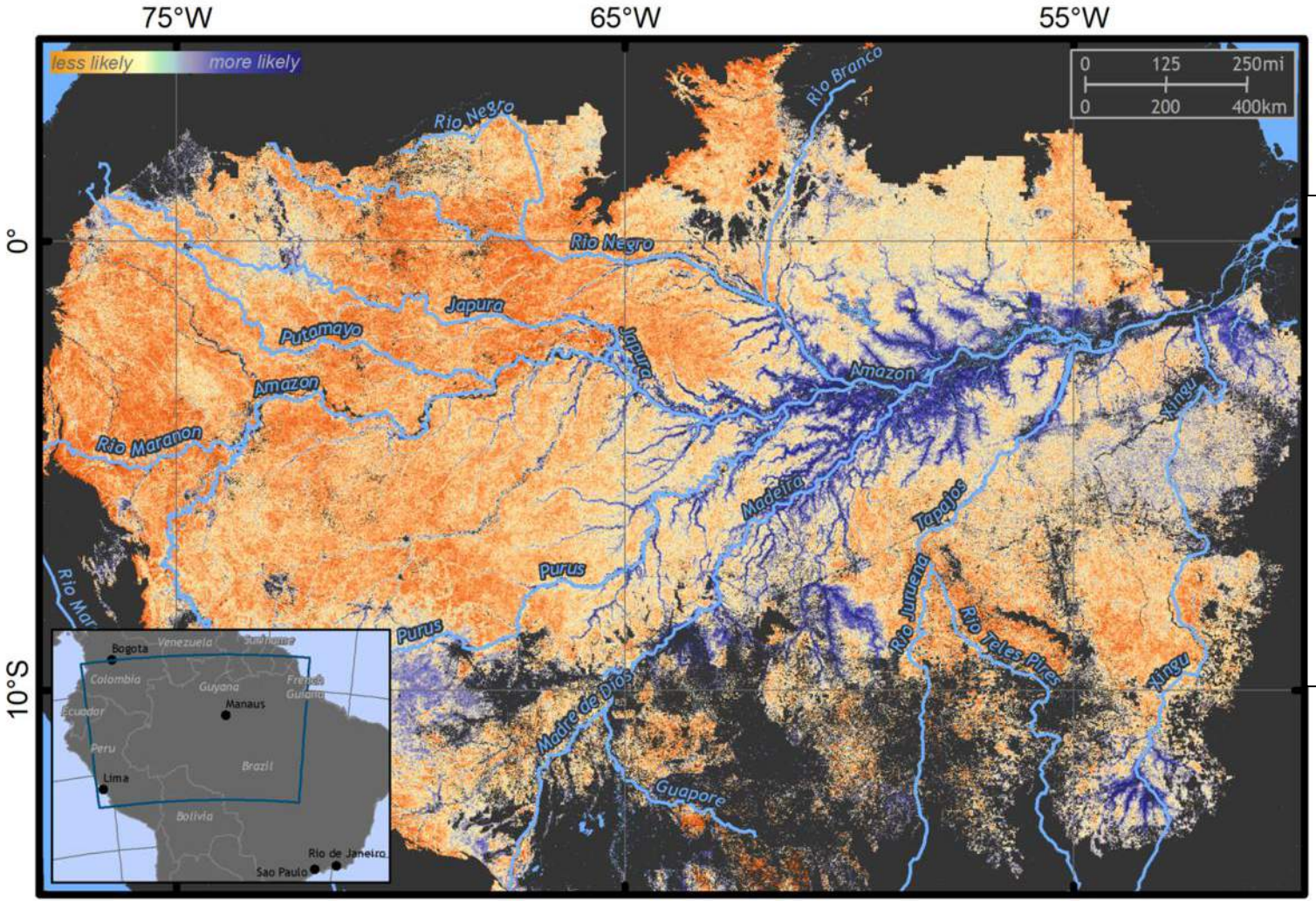


Fig. 2. Replicated MaxEnt model output maps showing predicated mound habitat and enclosure habitat across Michigan.

Howey, M.C.L., Palace, M., and C. McMichael (*2016*). Geospatial Modeling Approach to Monument Construction Using Michigan from AD 1000-1600 as a Case Study. *Proceedings of the National Academy of Scienc*e 113(27): 7443-7448, 2016. doi: 10.1073/pnas.1603450113.



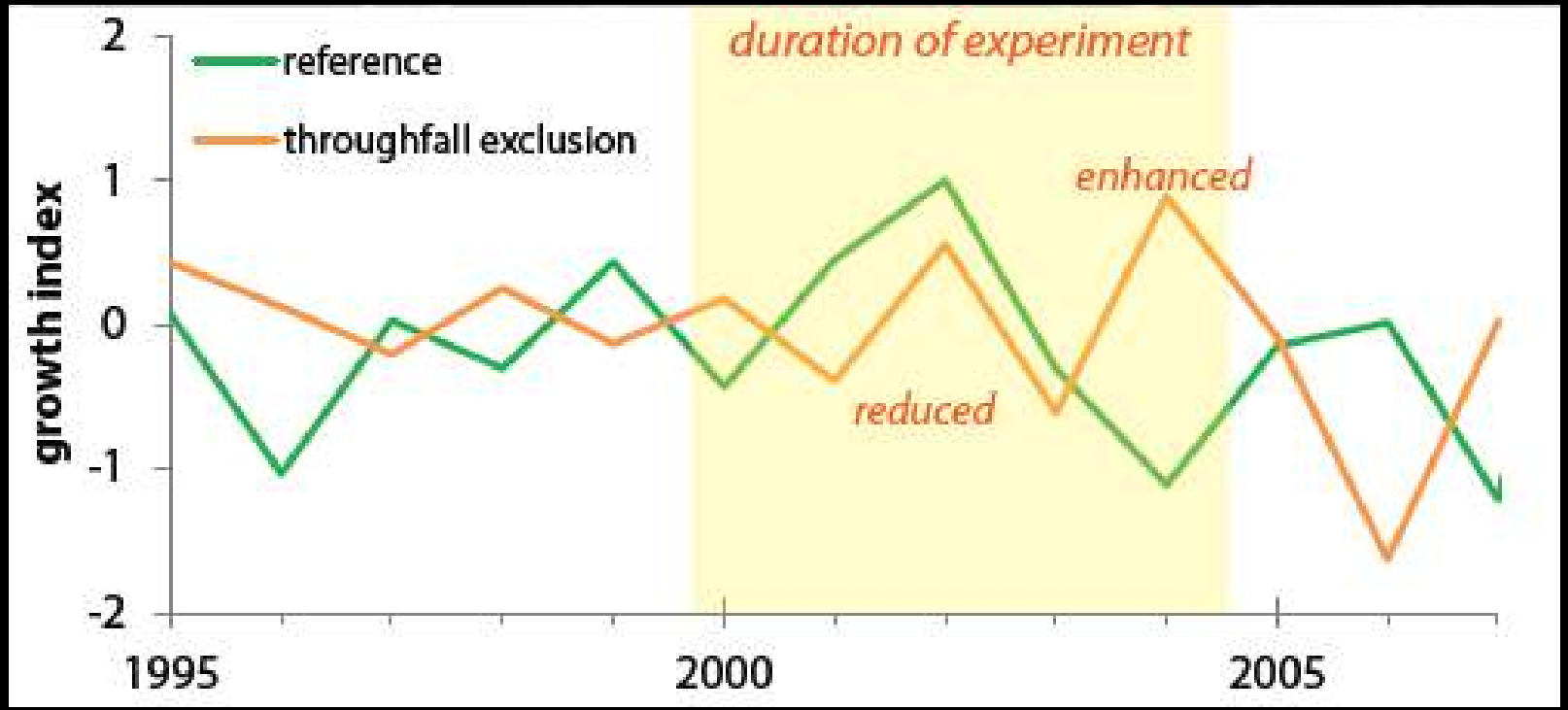
Palace MW, C. N. H. McMichael, B. Braswell, S. Hagen, M. Bush, E. Neves, E. Tamanaha, C. Herrick, S. Frolking (*2017*). Ancient Amazonian populations left lasting impacts on forest structure. *Ecosphere*, 8(12), e02035, doi:10.1002/ecs2.2035

Ecohydrology

Precipitation Removal Experiment

1999-2004

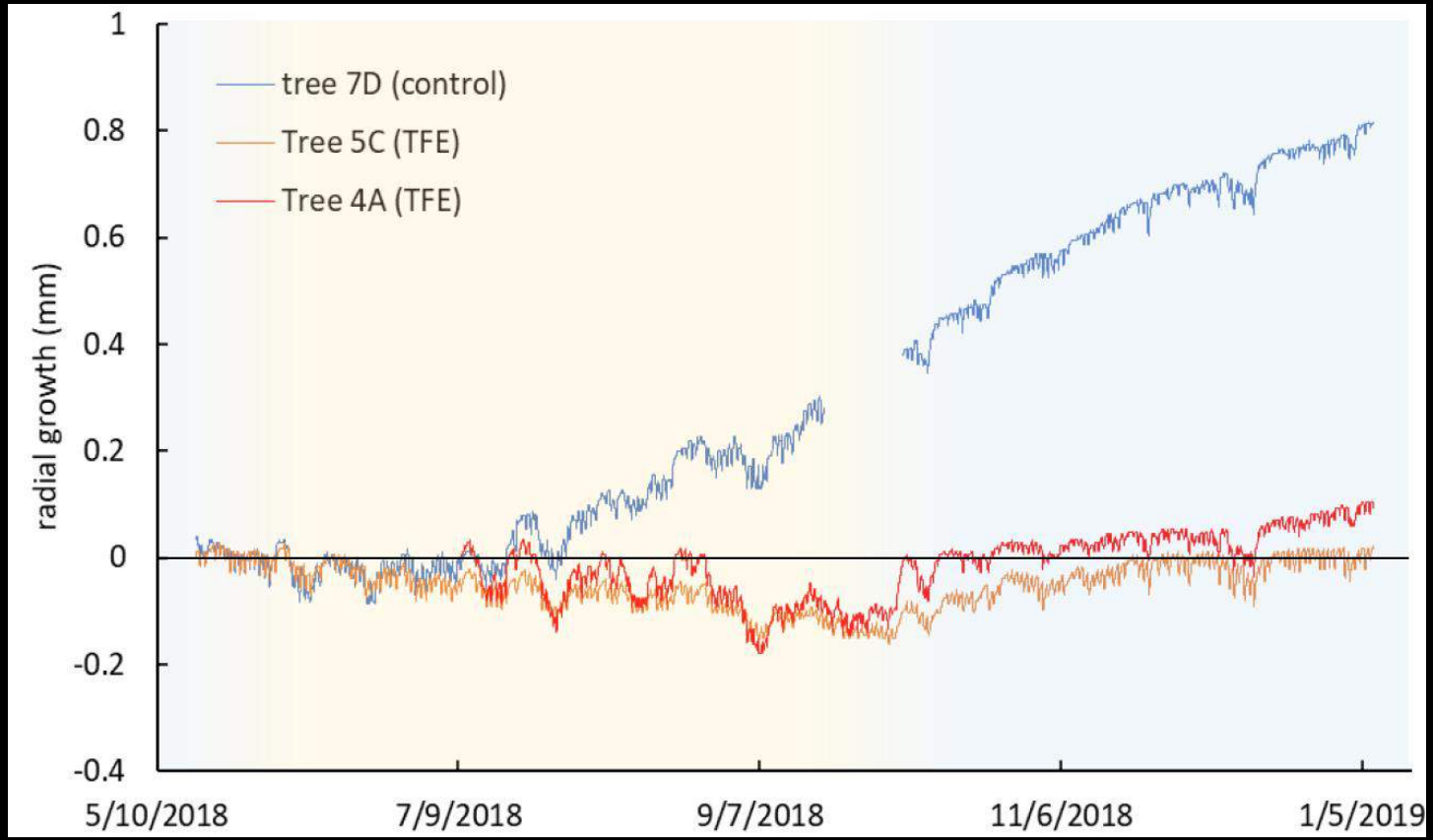
Tapajos National Forest, Para, Brazil



Annual diameter growth estimated from tree rings of *Virola michelli* in the Seca Floresta experiment which ran from 2000-04 at Tapajós km67. Relative to reference trees (green), experimentally droughted *V. michelli* (orange) showed mild but non-significant suppression of growth in years 2-4 of the experiment, but enhanced growth in the final year, possibly triggered by morality of the more dominant trees.

Wayqecha Fog Exclusion Experiment (Peru), 2900m elev.

Wayqecha Rain Exclusion Experiment (Peru), 3000m elev.

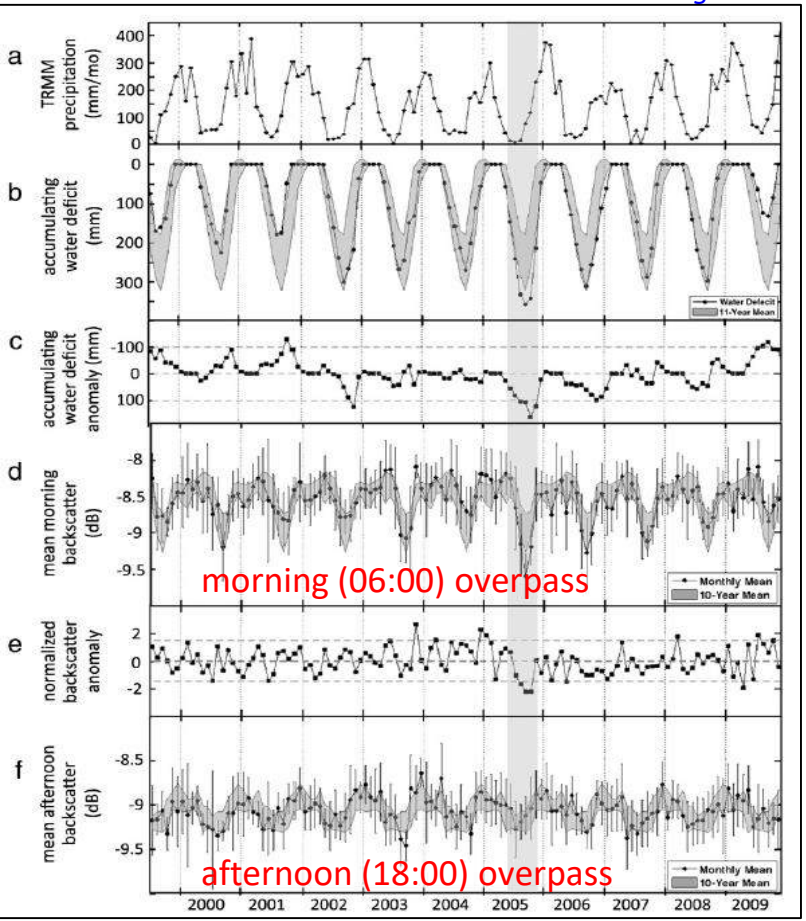


Selected data from point dendrometers in the Wayqecha throughfall exclusion experiment. Background shading indicates the dry season (yellow) and rainy season (blue).

Tropical forest backscatter anomaly evident in SeaWinds scatterometer morning overpass data during 2005 drought in Amazonia

Steve Frolking *, Tom Milliman, Michael Palace, Dominik Wisser, Richard Lammers, Mark Fahnestock

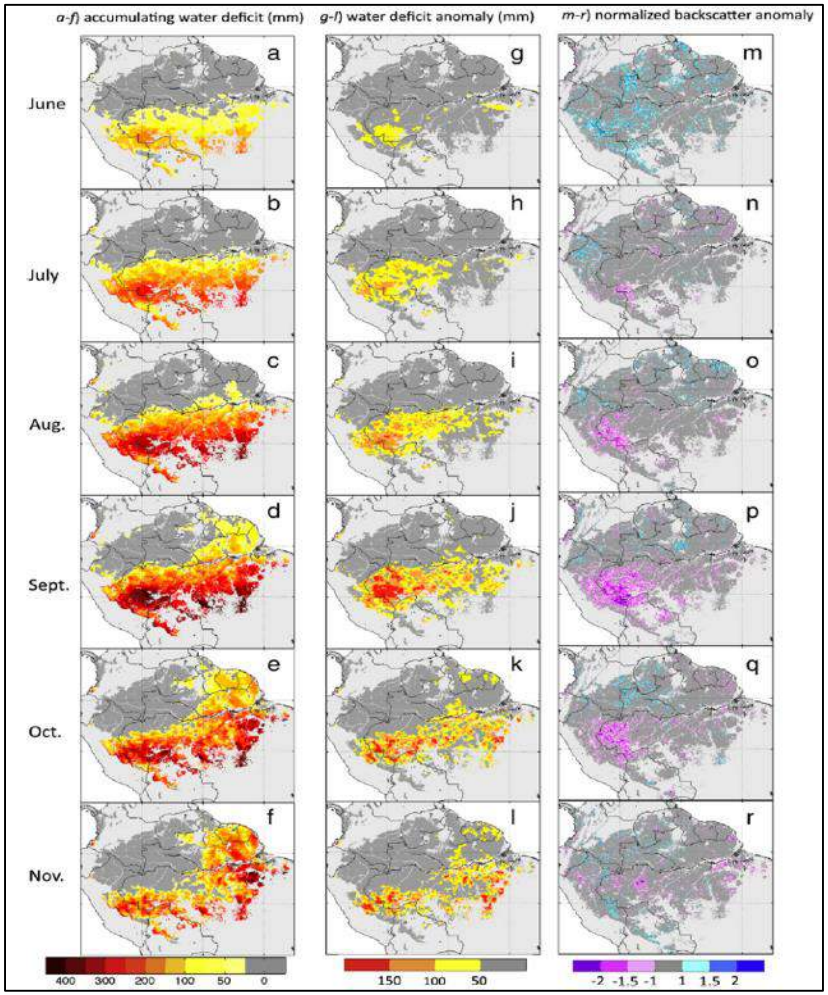
Remote Sensing Environment 2011



Accum. precip deficit

Accum. precip deficit anomaly

Normalized am backscat. anomaly



Detection of Large-Scale Forest Canopy Change in Pan-Tropical Humid Forests 2000–2009 With the SeaWinds Ku-Band Scatterometer

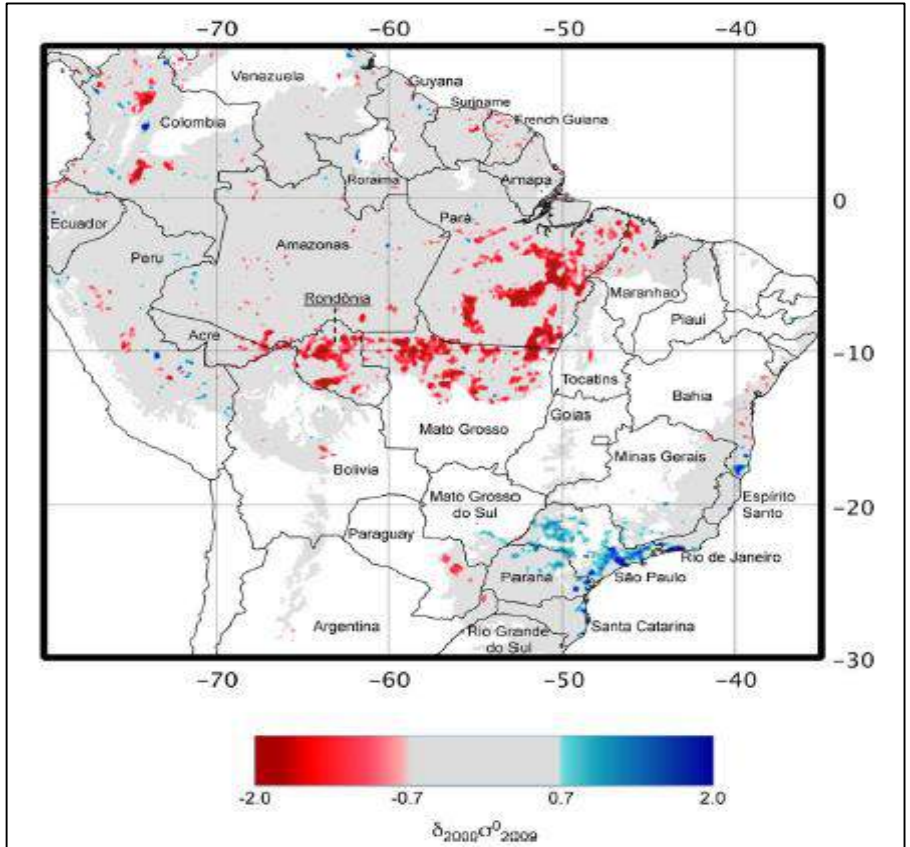
Steve Frolking, Stephen Hagen, Tom Milliman, Michael Palace, Julia Zanin Shimbo, and Mark Fahnestock

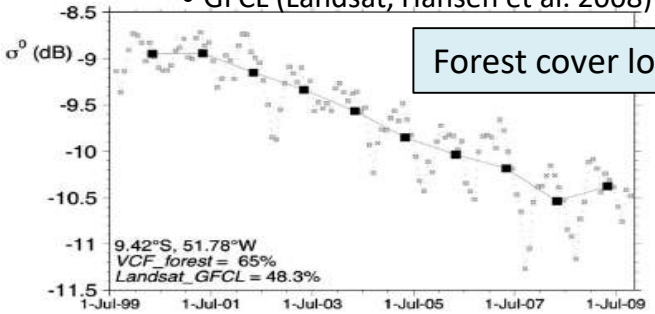
IEEE TGRS 2012

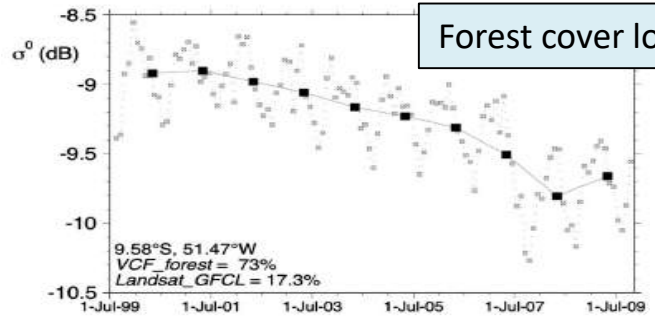
18.5 km Amazon forest blocks

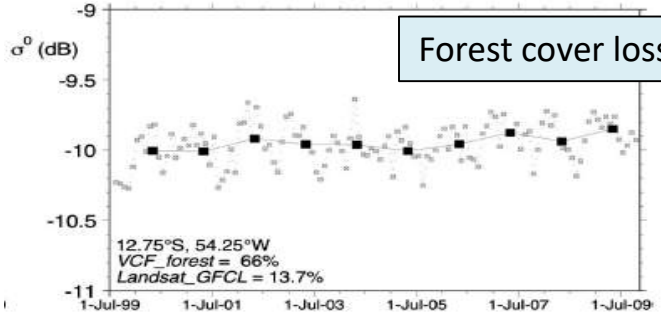
- Trend in backscatter
- GFCL (Landsat, Hansen et al. 2008)

Change in normalized ann. mean qdev backscatter, 2000-09









Persistent effects of a severe drought on Amazonian forest canopy

Sassan Saatchi[a,b,1], Salvi Asefi-Najafabady[b], Yadvinder Malhi[c], Luiz E. O. C. Aragão[d], Liana O. Anderson[c,e], Ranga B. Myneni[f], and Ramakrishna Nemani[g]

Proc. Nat. Acad. Sci. 2013

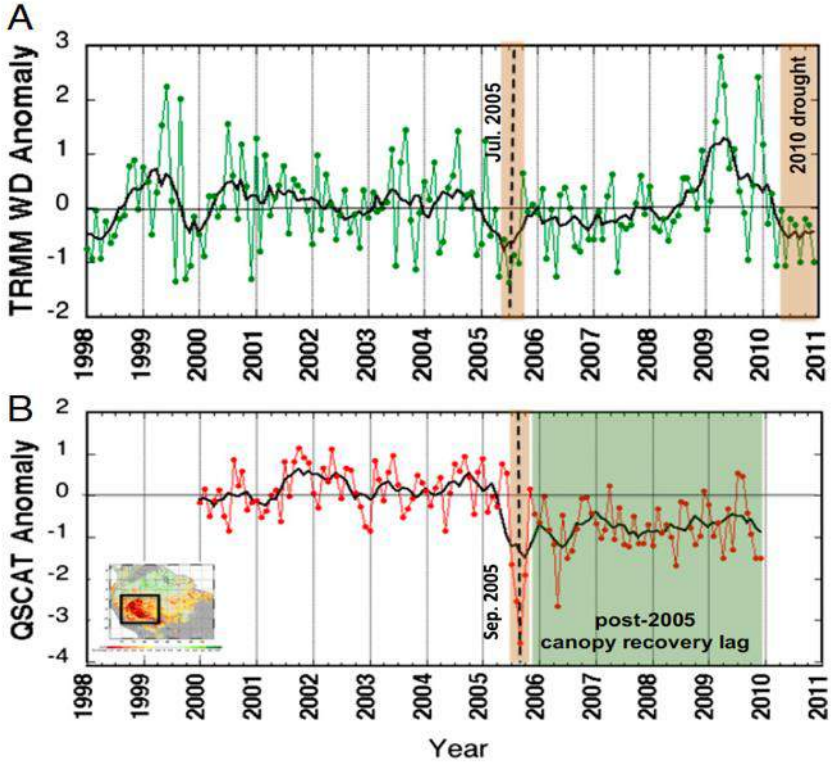
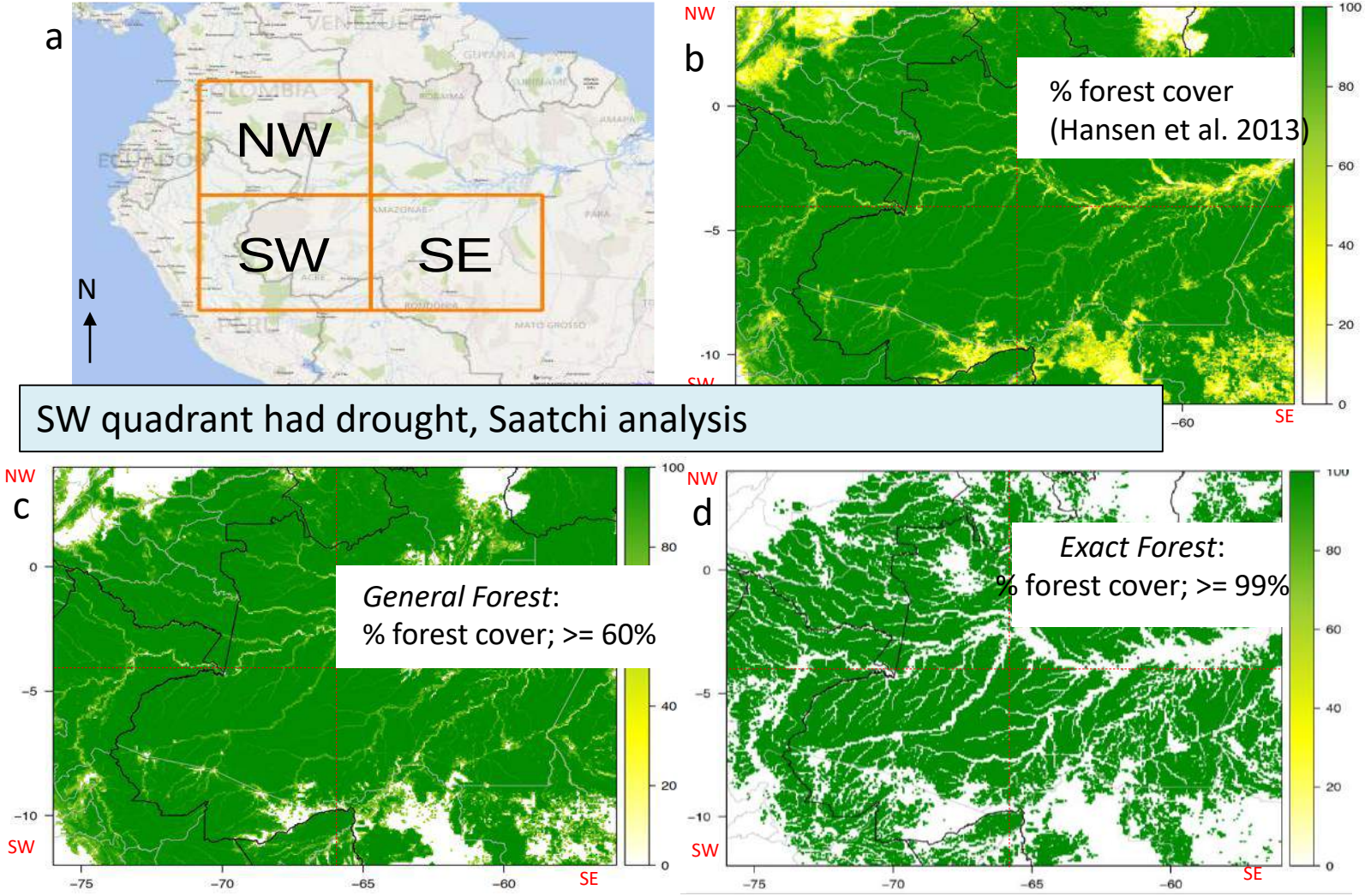


Fig. 2. Time series of (*A*) TRMM and (*B*) QSCAT monthly anomaly over western Amazonia (window: 4°S–12°S, 76°W–66°W). Solid lines show the result of the ARMA of the order of 6 mo.

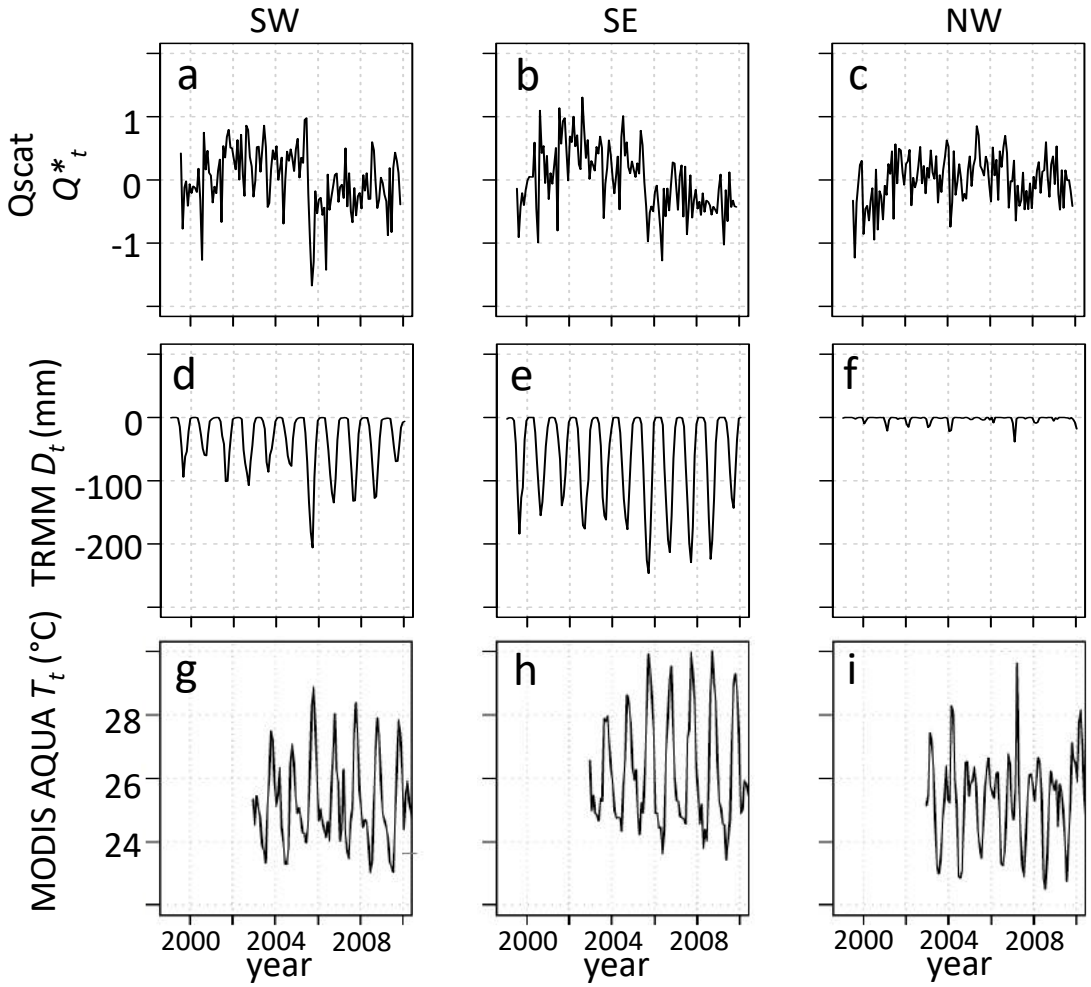
Saatchi et al. interpretation:

- Strong *regional* relationship between drought and Qscat persistent drop.
- Implication that Qscat persistent drop follows Qscat drought anomaly, and is indication of **increased forest vulnerability to next drought.**
- No role for land-cover change.
- No post-drought change in weather.



SW quadrant had drought, Saatchi analysis

8°x10° regional mean monthly time series 1999-2009



QScat Microwave backscatter

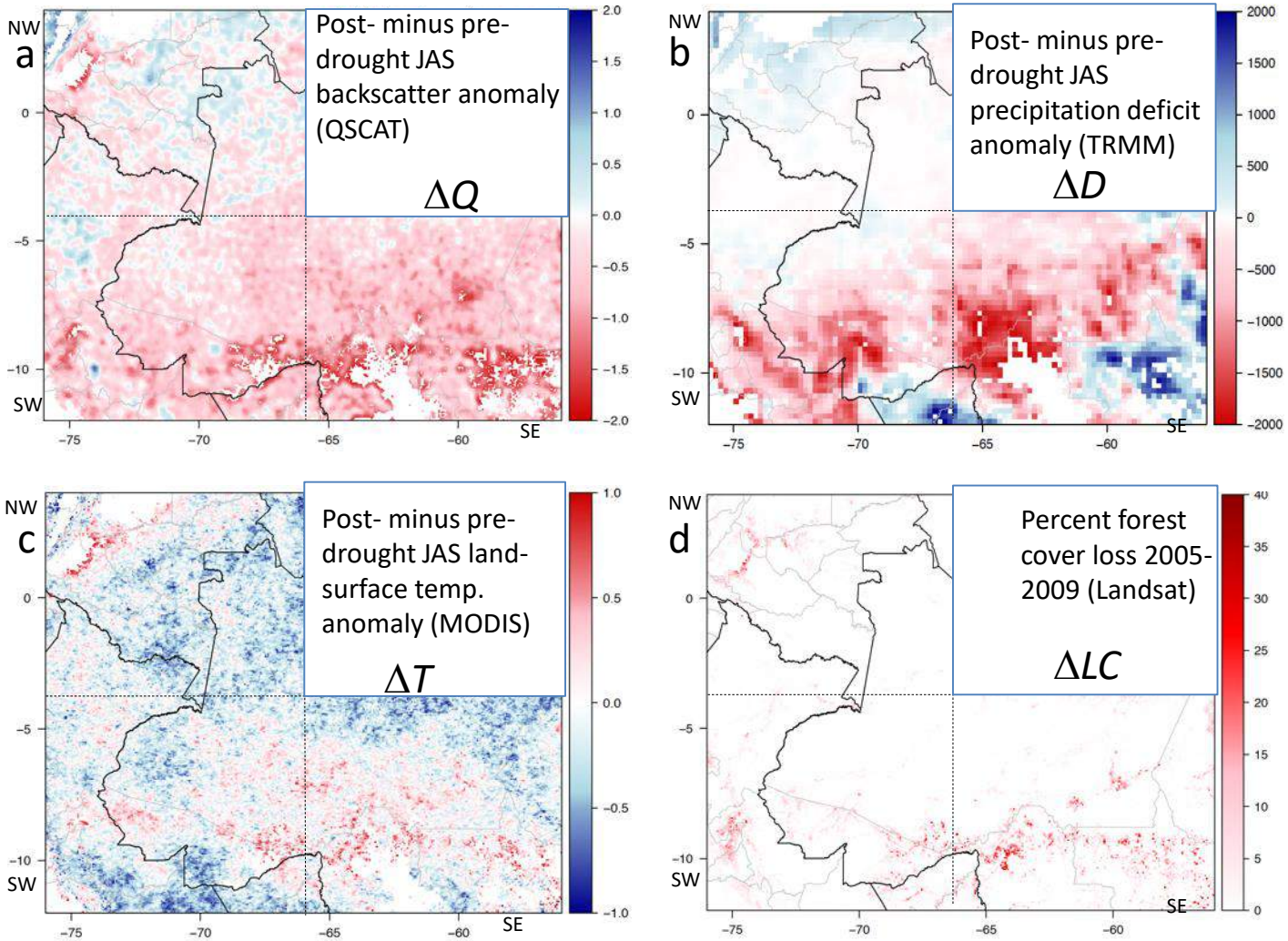
SW & SE: lower post-drought

TRMM Precipitation deficit

SW & SE: stronger post-drought

MODIS 13:30 land-surface temp.

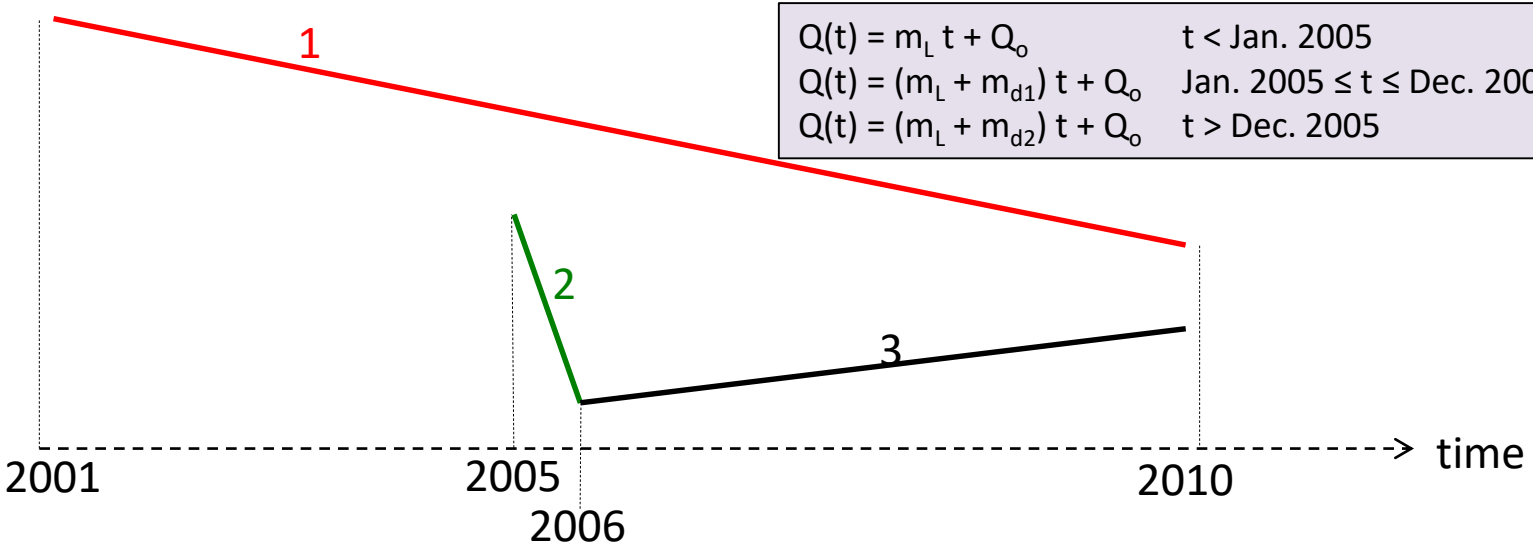
SW & SE: warmer post-drought



Pre- to post-drought changes; 0.05° gridded remote sensing data

Our hypothesis: backscatter time series is super-position of 3 trends:

1. General linear decline due to forest cover loss (Frolking et al. 2012)
2. Abrupt, short-term decline due to 2005 drought (Frolking et al. 2011)
3. Slow recovery from drought (Saatchi et al. 2013)



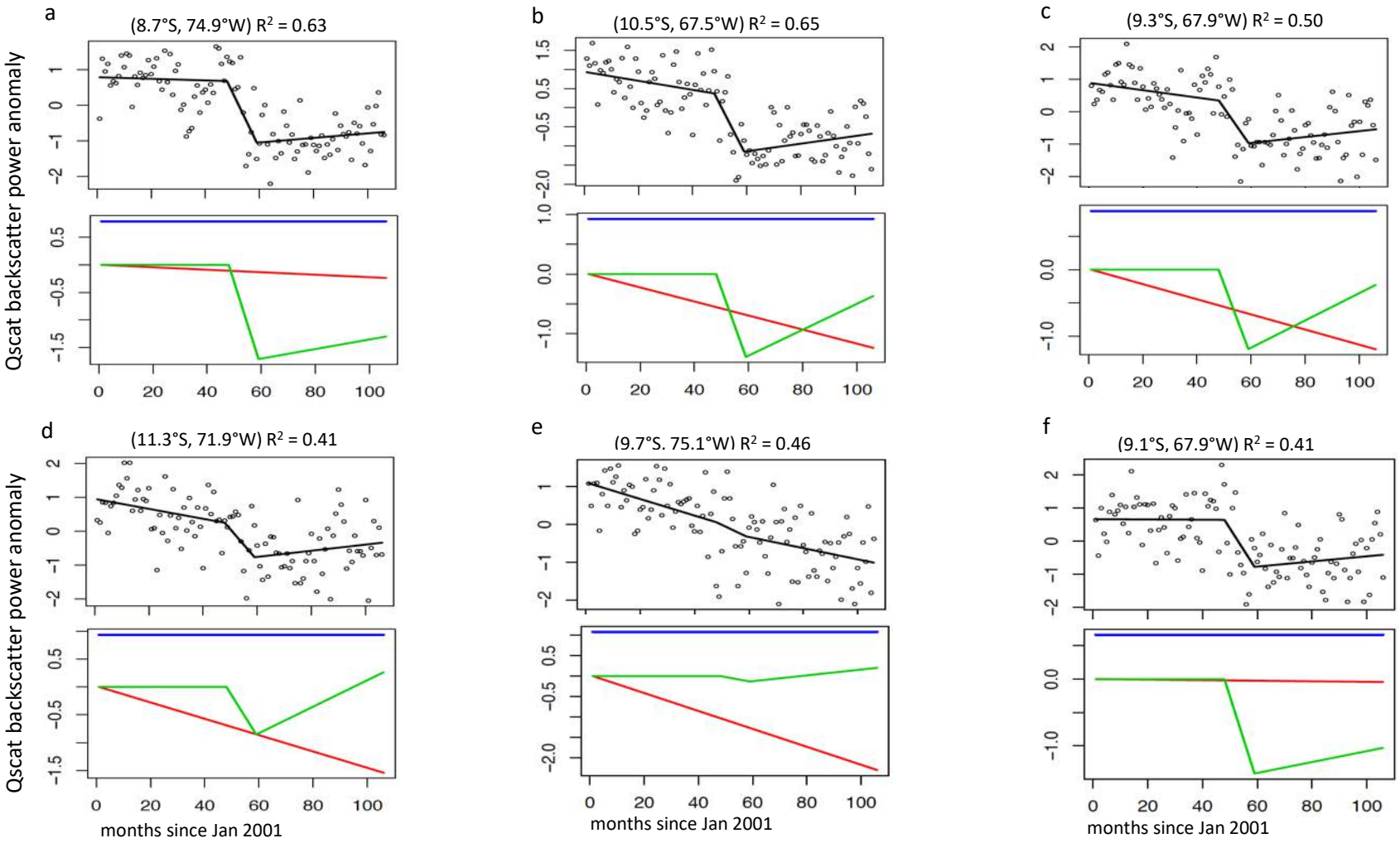
$Q(t) = m_L\, t + Q_o$ $\quad t < \text{Jan. } 2005$

$Q(t) = (m_L + m_{d1})\, t + Q_o$ $\quad \text{Jan. } 2005 \le t \le \text{Dec. } 2005$

$Q(t) = (m_L + m_{d2})\, t + Q_o$ $\quad t > \text{Dec. } 2005$

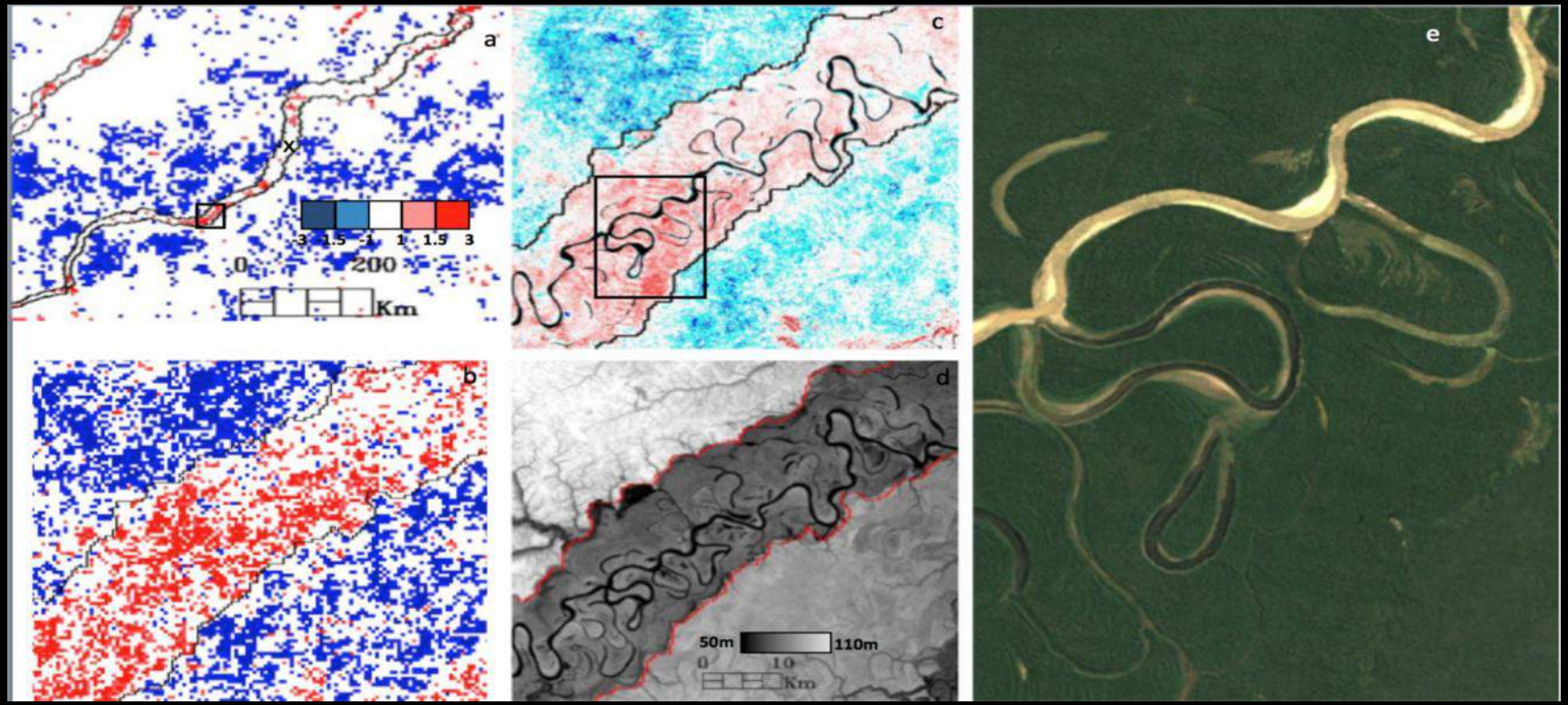
Look at *General Forest* in SW Quadrant, using data aggregated to 0.2° (~1800 grid cells).

Look at time series for Feb 2001-Nov 2009 (n=106 months).

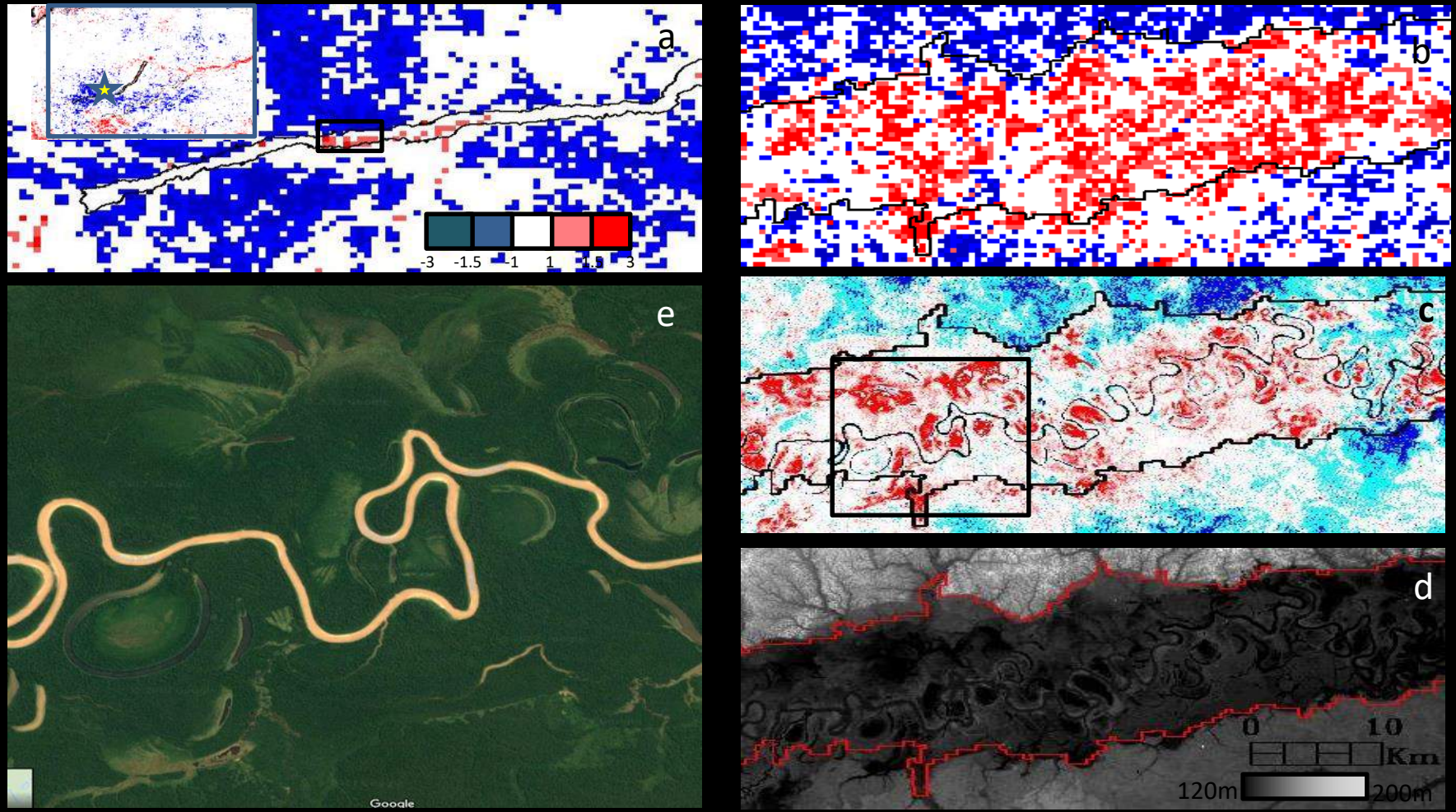

a
(8.7°S, 74.9°W) R² = 0.63
b
(10.5°S, 67.5°W) R² = 0.65
c
(9.3°S, 67.9°W) R² = 0.50
d
(11.3°S, 71.9°W) R² = 0.41
e
(9.7°S. 75.1°W) R² = 0.46
f
(9.1°S, 67.9°W) R² = 0.41
Qscat backscatter power anomaly
Qscat backscatter power anomaly
months since Jan 2001
months since Jan 2001
months since Jan 2001

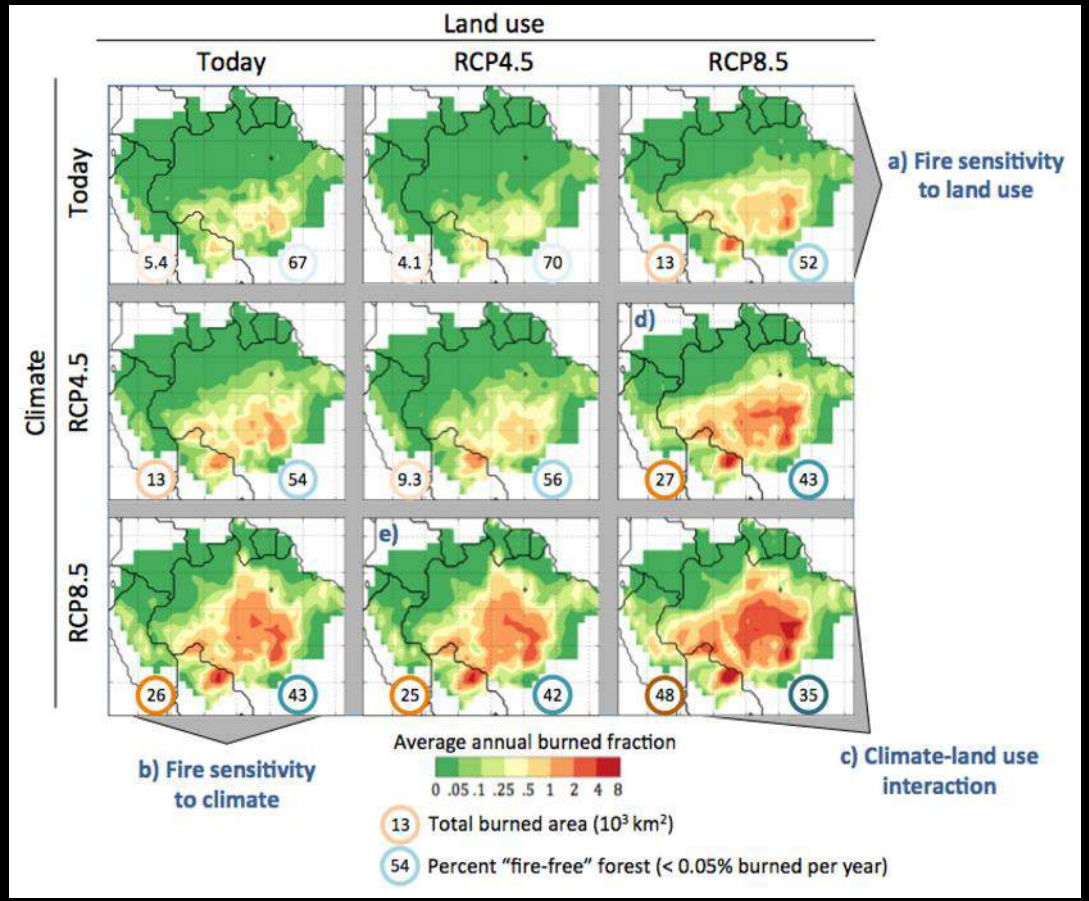
Conclusions

- Quikscat signals (drought anomaly, persistent low post-drought) are real.
- Fragmented forest cover loss (up to 35%) occurred during 2005-09 in 0.05° grid cells which would still be classified as forest in 2010.
- TRMM precipitation data have drier post-drought dry seasons in SW & SE quadrants.
- The persistently low dry-season backscatter post-drought could have had several causes – (i) drought impact and slow recovery, (ii) forest cover loss, and/or (iii) drier weather.
- The data are noisy, and generally none of these alone or in combination with others, seem to be able to explain most of the variance in the data.



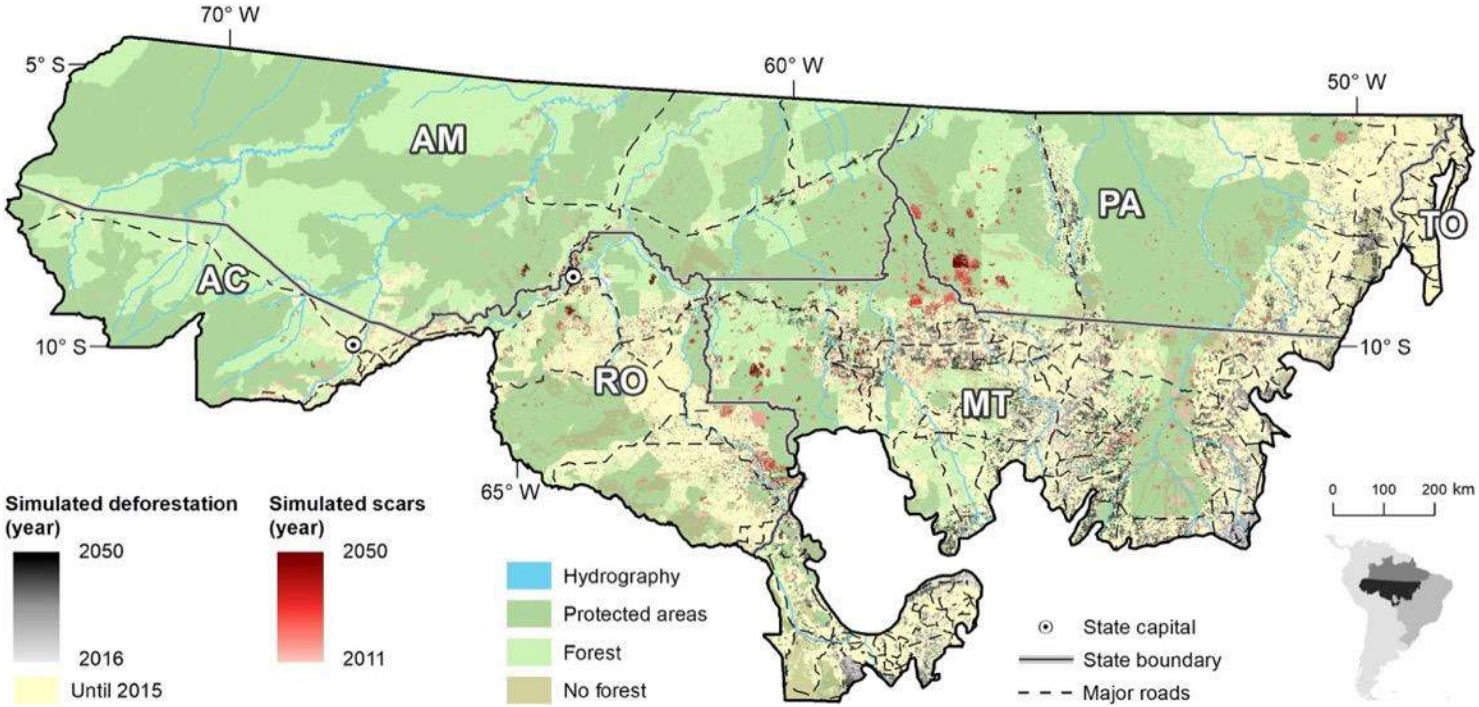
MODIS JAS 2005 non-photosynthetic vegetation pixel fraction anomalies aggregated to 0.05^0 along the Purus River, a tributary to the Amazon in the southwestern portion of the Amazon Basin, near 6° 47’ 53”S, 70° 23’ 8”W; black rectangle is region zoomed to in panels b-d. (b) MODIS JAS 2005 NPV anomalies at 500m, (c) Landsat JAS 2005 NPV anomalies aggregated to 120m (black square is location of Landsat imagery in panel (e), and (d) elevation from ALOS DEM. (e) Landsat true color imagery from Google Earth. Anomalies are presented as z-scores or standard deviations about the mean. Peterson et al. (in revision).

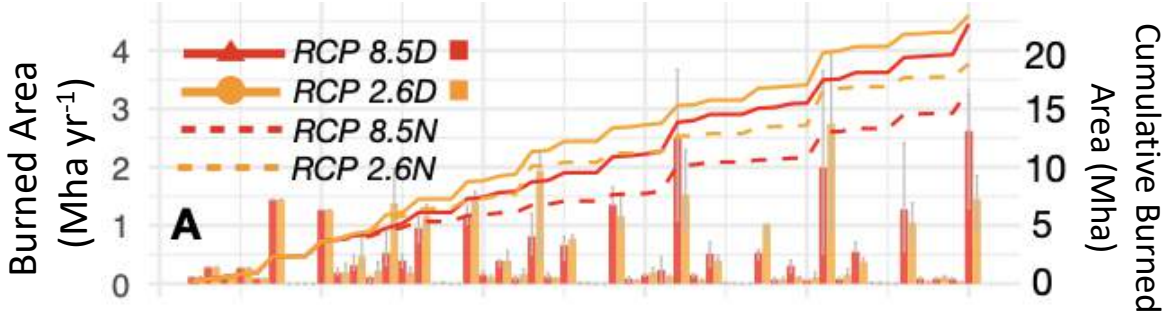

a
-3
-1.5
-1
1
1.5
3
b
c
d
0
10
Km
120m
200m
e
Google



A fire model to estimate that fire activity could increase by an order of magnitude without climate mitigation. Our results show that avoiding further agricultural expansion can limit fire ignitions, but that tackling climate change is essential to insulate the interior Amazon through the 21st century.

Annual burned fraction projected in HESFIRE for 2080-2100 varies across models and climate scenarios. The 10th, 50th and 90th percentile values indicate variability from 8 climate models.





Brando et al., in press

Conclusions

- Past is important in understanding both the present and future
- Often there are lags, both at the plot level and the continental level
- Remote sensing signatures can be complex and higher resolution data or data from multiple sensors aid in clarification of some ecosystem level responses
- Assumptions in one area of Amazonia are not always relevant across the region