The impacts of Amazon forest degradation and fragmentation on energy, water, and carbon cycles

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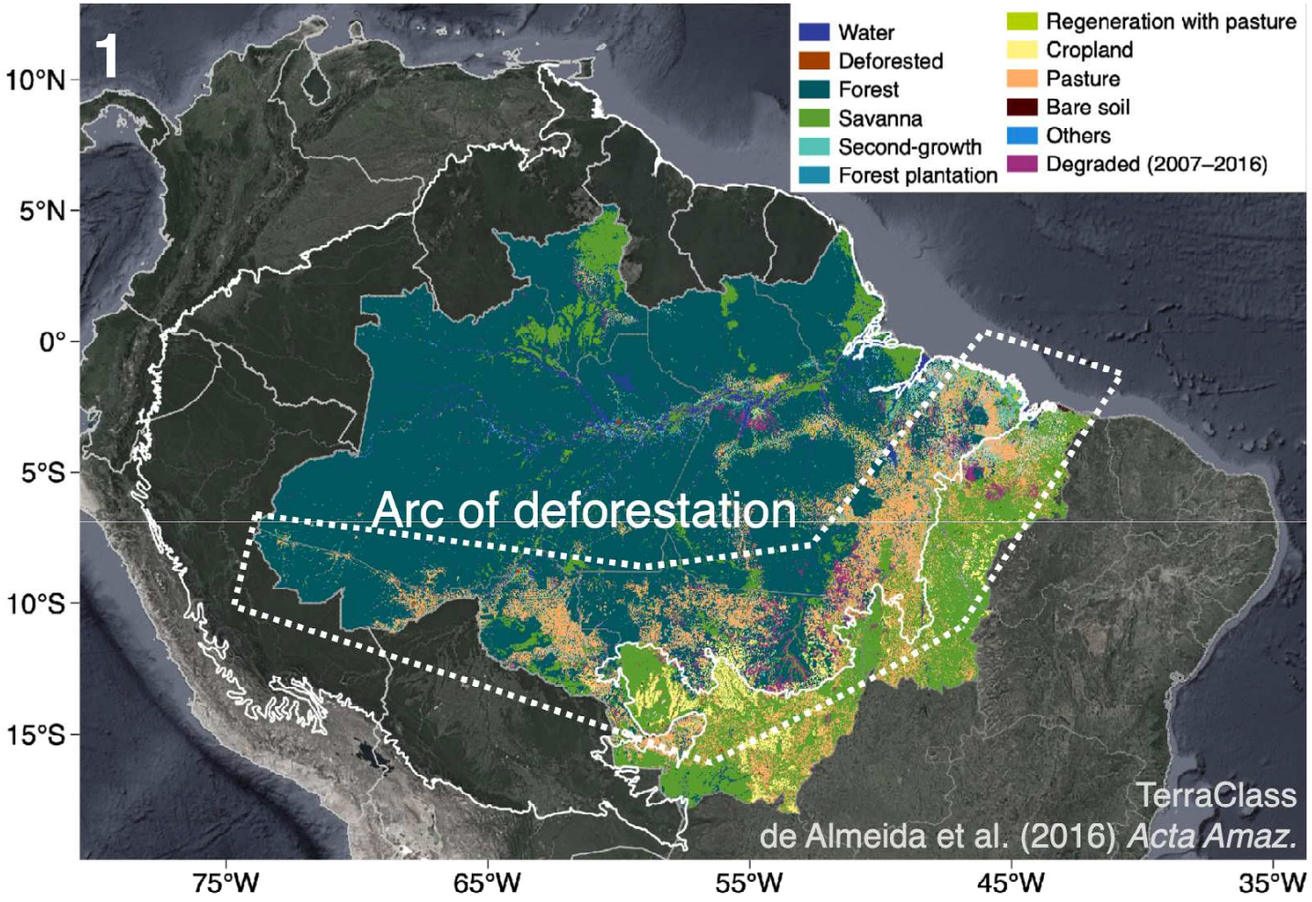
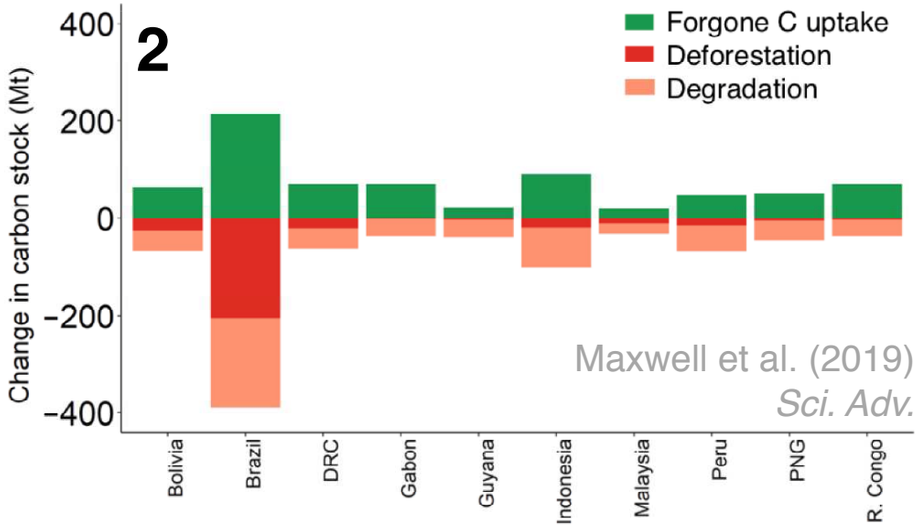
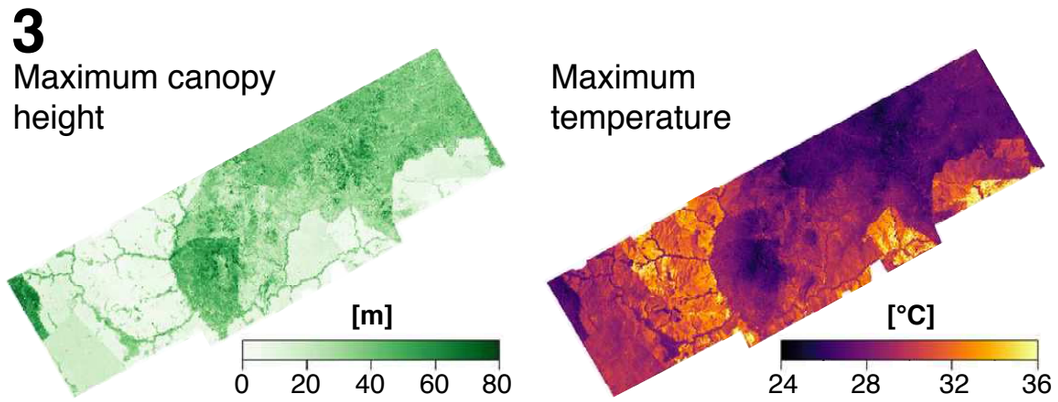
Pervasive deforestation and degradation in the Amazon

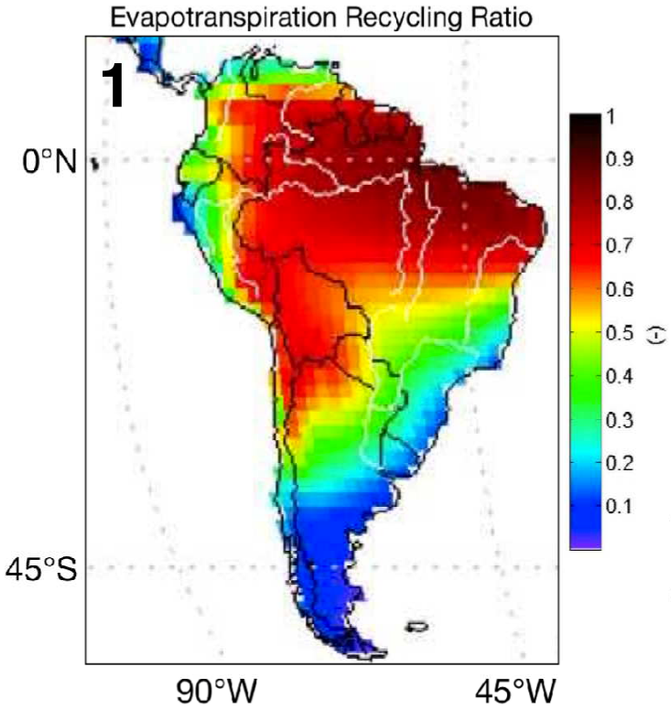




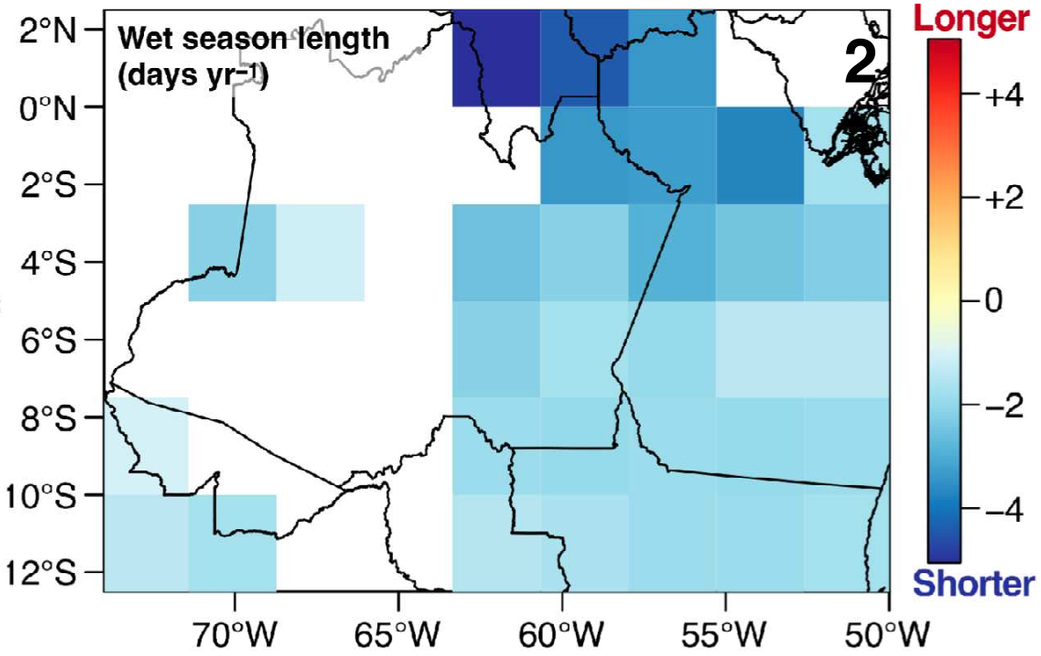


1. Degradation (logging, fires) is as widespread as deforestation in the Amazon arc of deforestation.
2. Degraded forests show substantial biomass depletion, and C emissions comparable to deforestation.
3. Effects of forest degradation on carbon, energy, and water are highly uncertain but likely relevant.

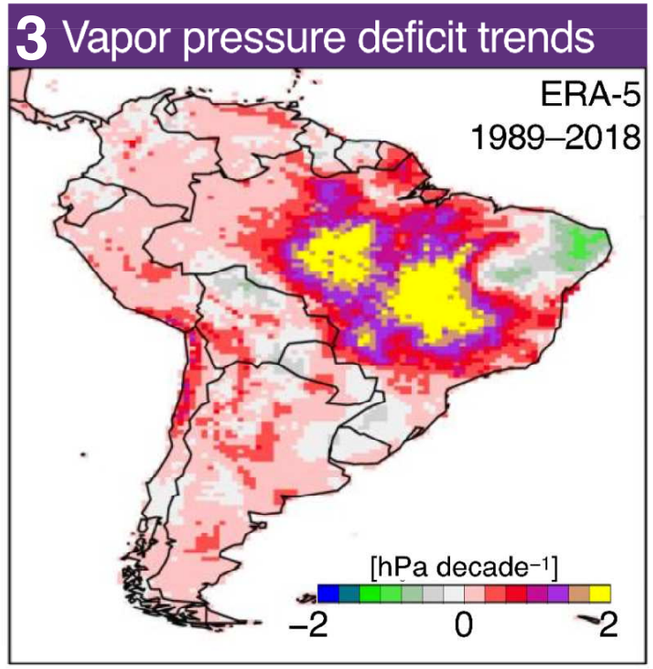
Amazon forest and the water cycle



van der Ent et al. (2010)
Water Resour. Res.



Sena et al. (2018) *J. Clim.*



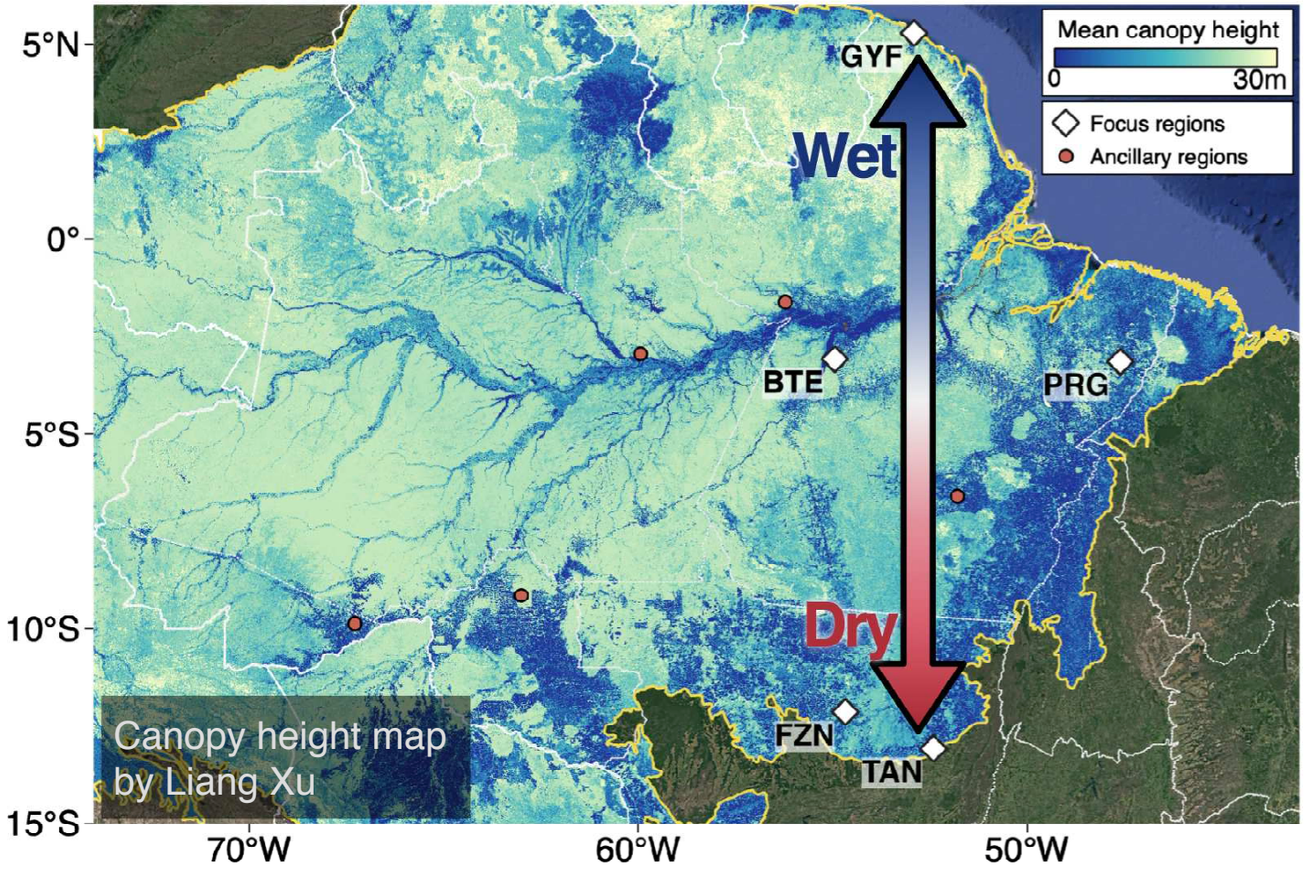
Barkhordarian et al. (2019) *Sci. Rep.*

1. Evapotranspiration → important source of rainfall water in South America.
2. Increasing evidence that wet seasons are becoming shorter in the Amazon.
3. Significant drying trend in the arc of deforestation.

Questions

- Does forest degradation change alter the energy, water and carbon cycles in the Amazon, in particular during extreme droughts?
- What are the main drivers of spatial variation of surface temperature and evapotranspiration across the Amazon during the dry season?

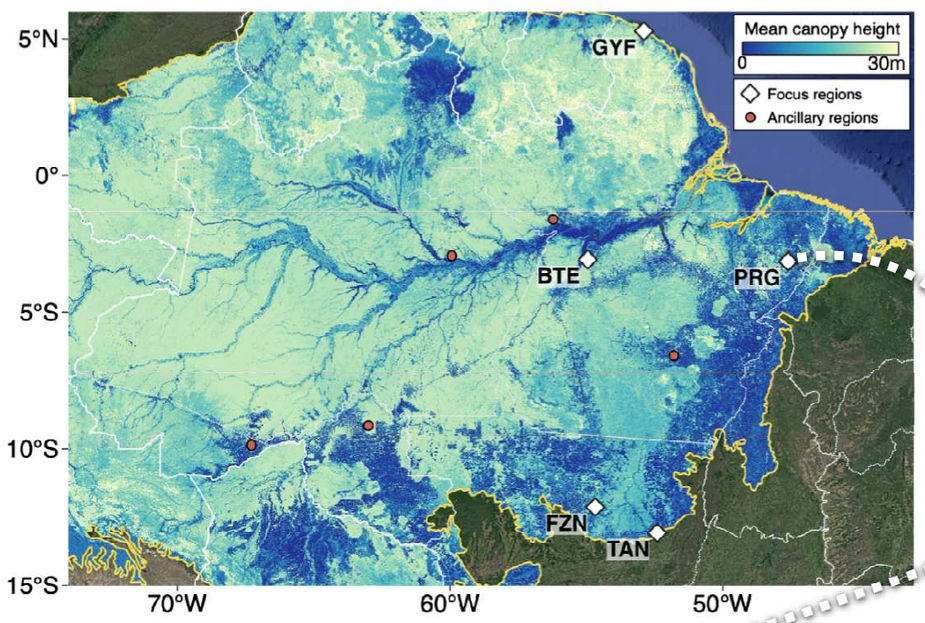
Lidar and forest inventory data sets

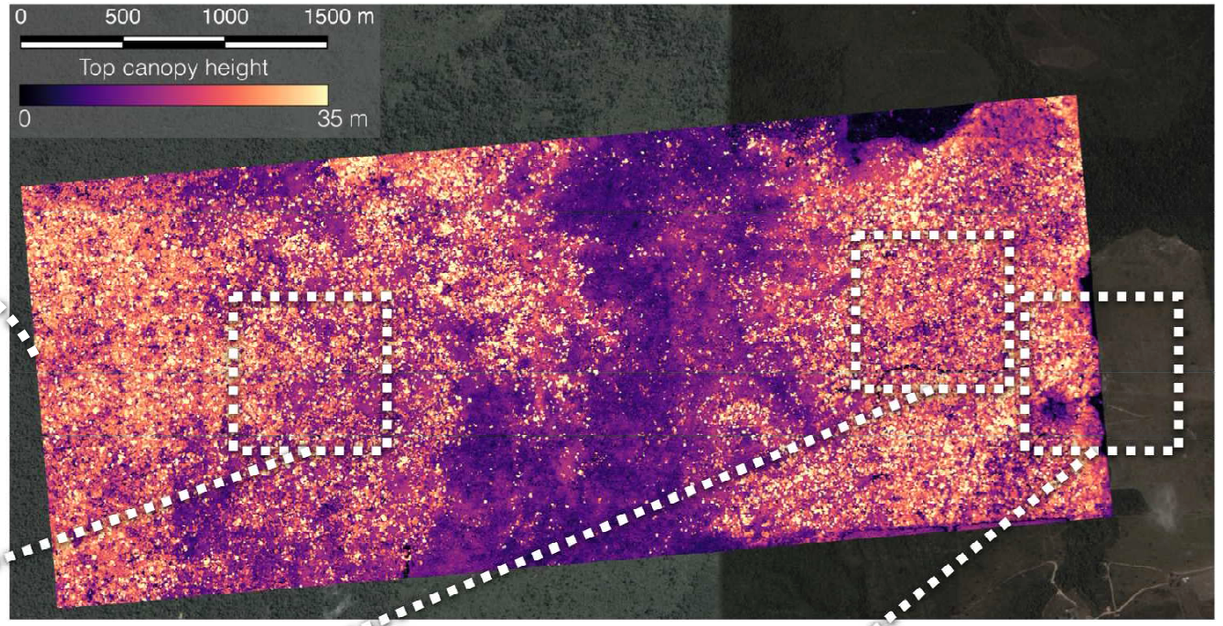


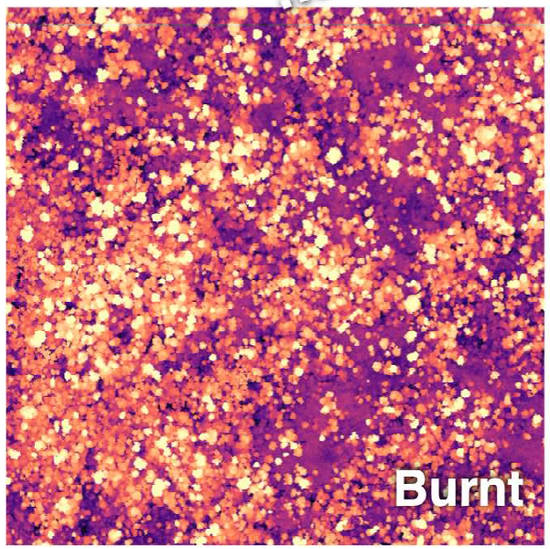
- Site selection:
  - Five regions along rainfall gradient
  - Degradation gradients within each region.
  - Plot, airborne lidar (+3 eddy covariance towers)
- Forest inventory coverage:
  - Focus sites: 173.5 ha
  - Ancillary sites: 28.2 ha
- Airborne lidar survey coverage:
  - Focus sites: 14,419 ha
  - Ancillary sites: 7,541 ha

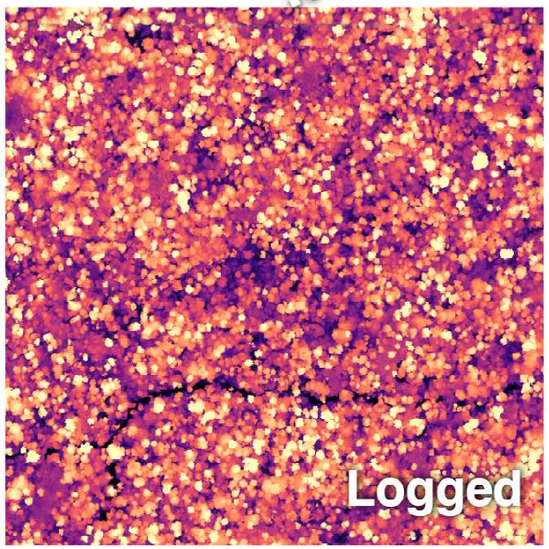
Data over Brazil available at:
https://www.paisagenslidar.cnptia.embrapa.br/webgis/

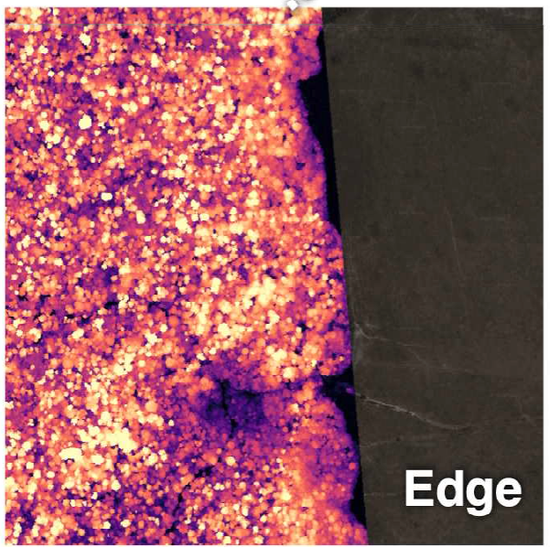
Examples of forest degradation as seen from airborne lidar



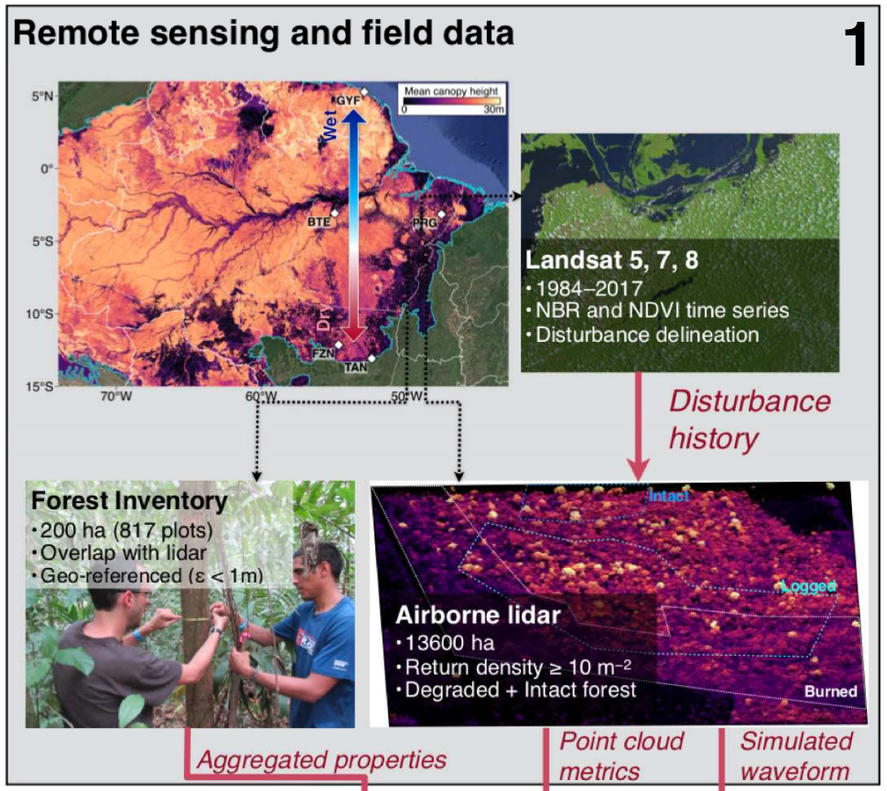


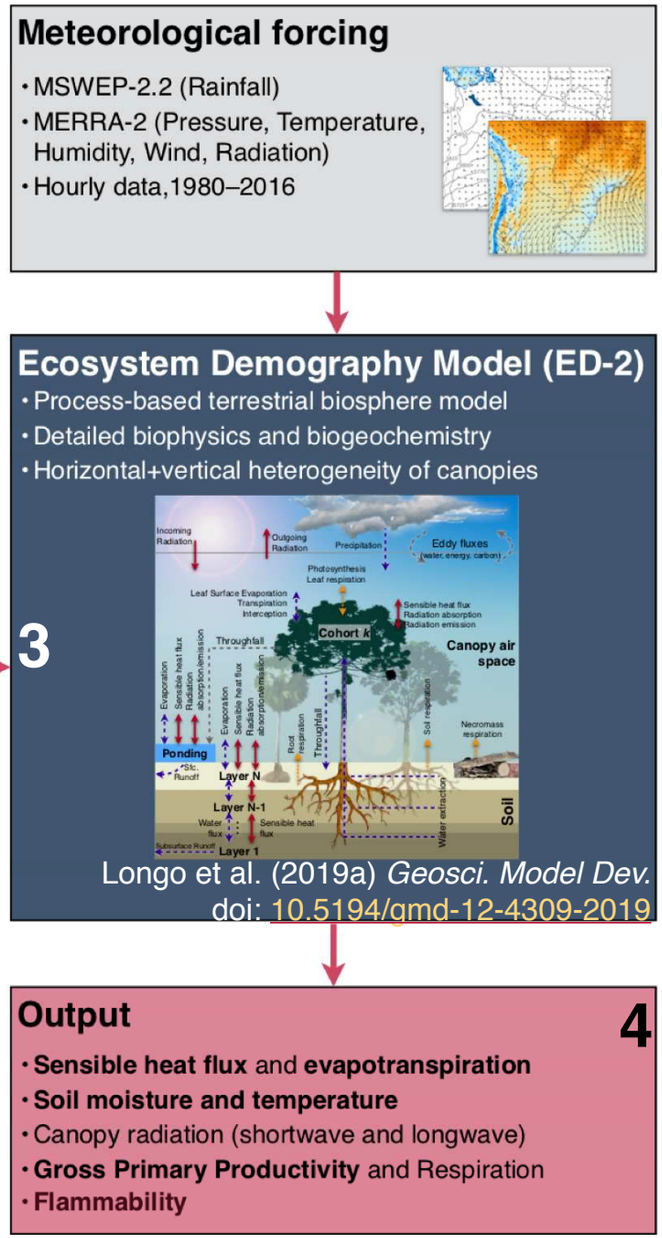






Integration between lidar and the ED-2.2 model





1. Site selection:
   - Degradation history
   - Lidar and inventory data
   - Rainfall gradient

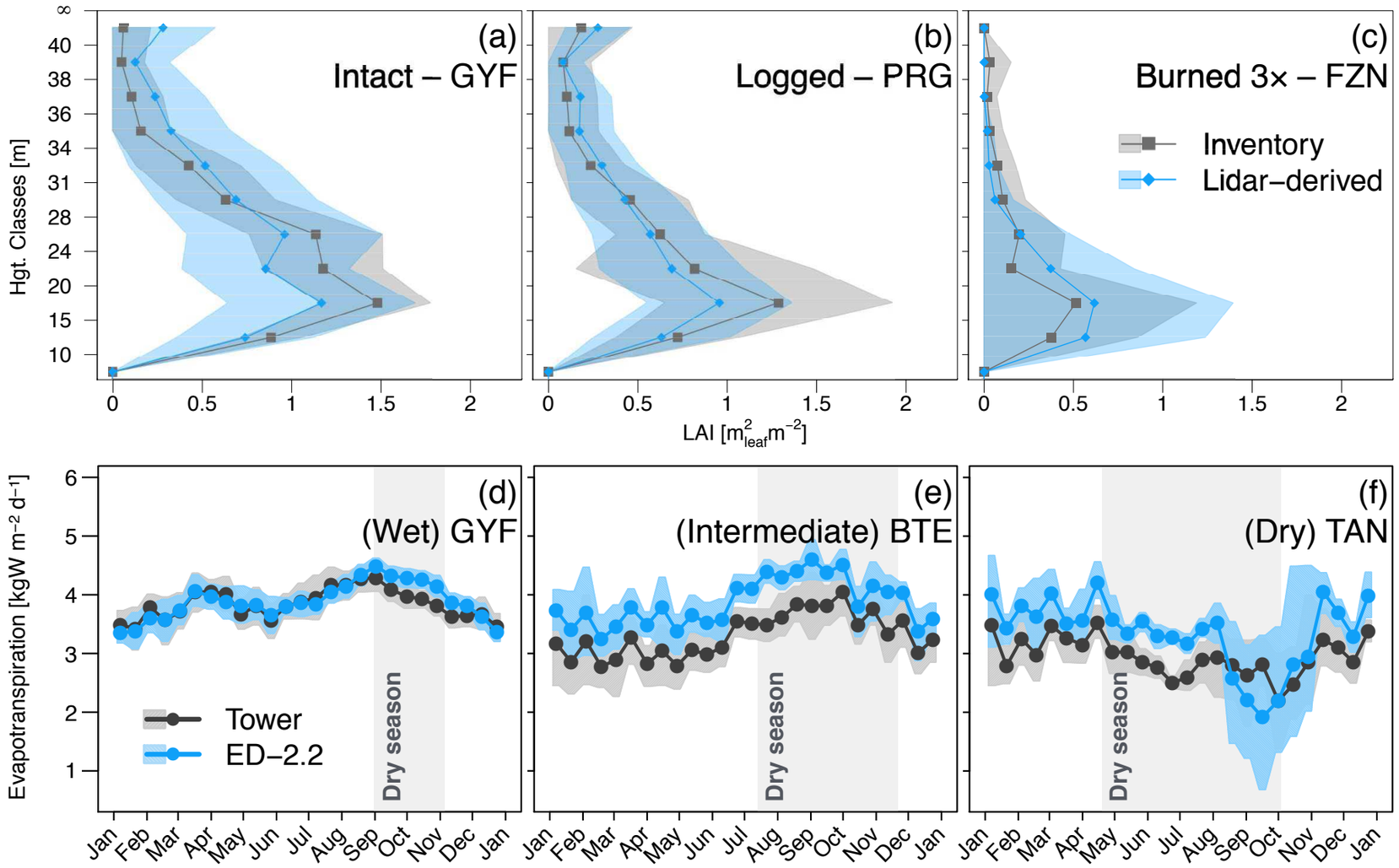
2. Initialization assessment:
   - Regional cross-validation: predicted region excluded from model training stage
   - Assessment across regions and degradation gradients

3. Initialization assessment:
   - Flux evaluation at multiple tower sites
   - Detailed model evaluation:

Longo et al. (2019b) *Geosci. Model Dev.* doi: 10.5194/gmd-12-4347-2019.

4. Experiment design:
   - ED-2 simulations initialized with airborne lidar
   - Forest structure as the only difference in simulations within each region

Assessment of the modeling framework



Lidar initialization (a–c):

- Regional and degradation gradients well represented
- Low bias in the understory of dense, intact forests (a).

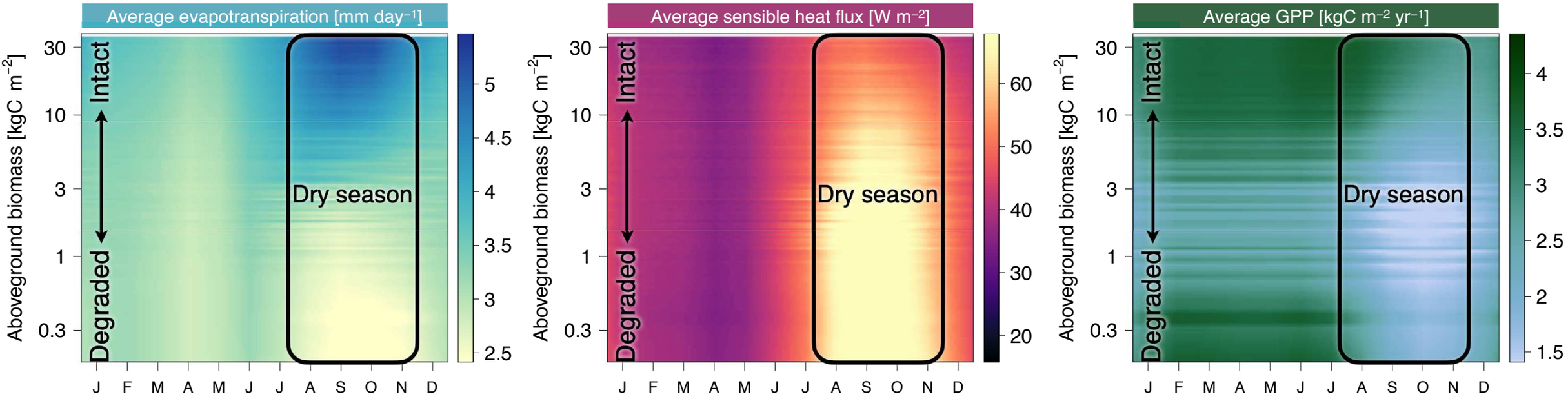
Evapotranspiration (d–f):

- Seasonality and well represented at the wet and intermediate site (d,e)
- Positive biases at the driest sites (e,f)

Additional validation at the pre-print.

Longo et al. *in review*
Pre-print doi:10.1002/essoar.10502287.1

Degradation impacts on ecosystem functioning



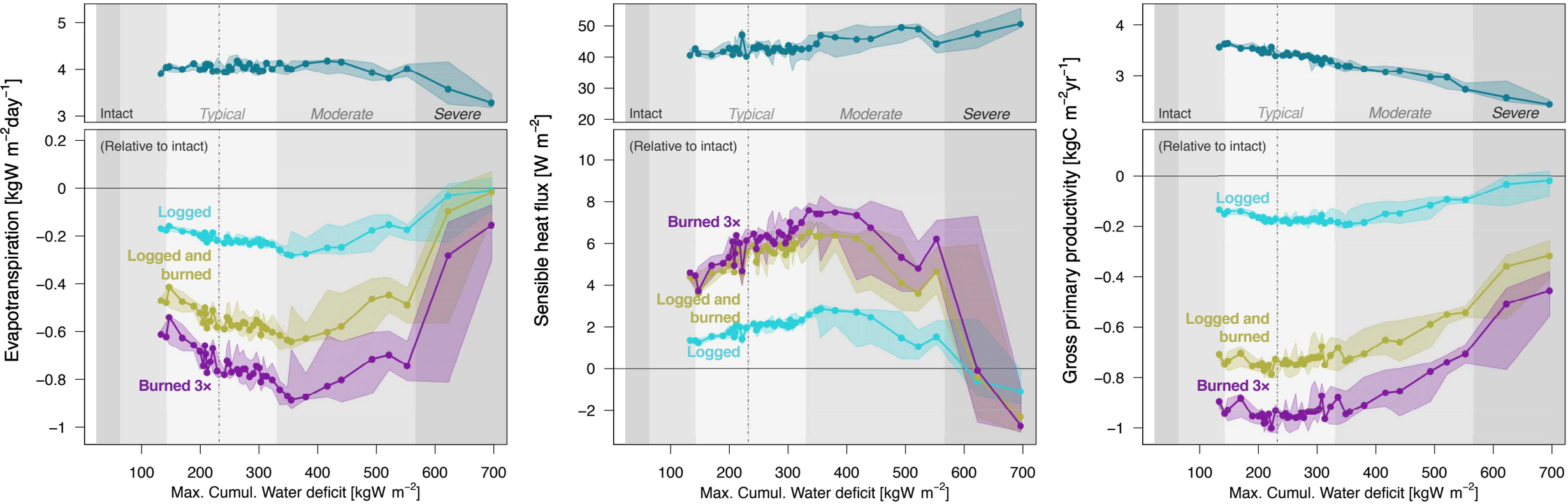
Longo et al. *in review*

Pre-print doi:10.1002/essoar.10502287.1

ED-2 seasonal averages (40-year) as functions of biomass for region PRG (most seasonal):

- Evapotranspiration: dry-season increase in intact forests; dry-season decrease in degraded forests
- Sensible heat: wet-season independent of structure; sharp dry-season increase in degraded forests
- Gross primary productivity: large dry-season reduction in degraded forests. High wet-season GPP in very degraded forests because of C4 grass presence.

Degradation impacts on ecosystem functioning



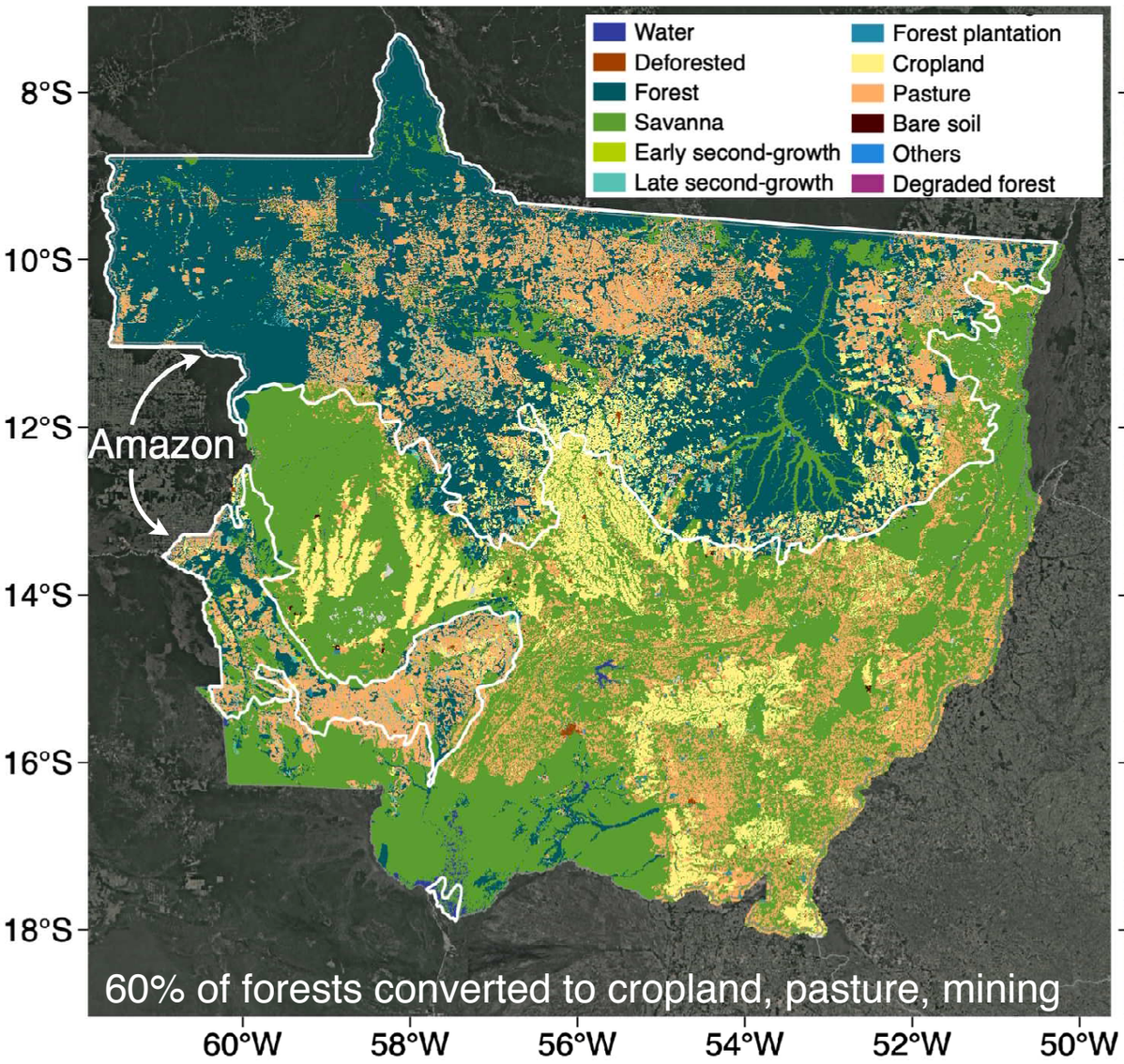
Longo et al. *in review*

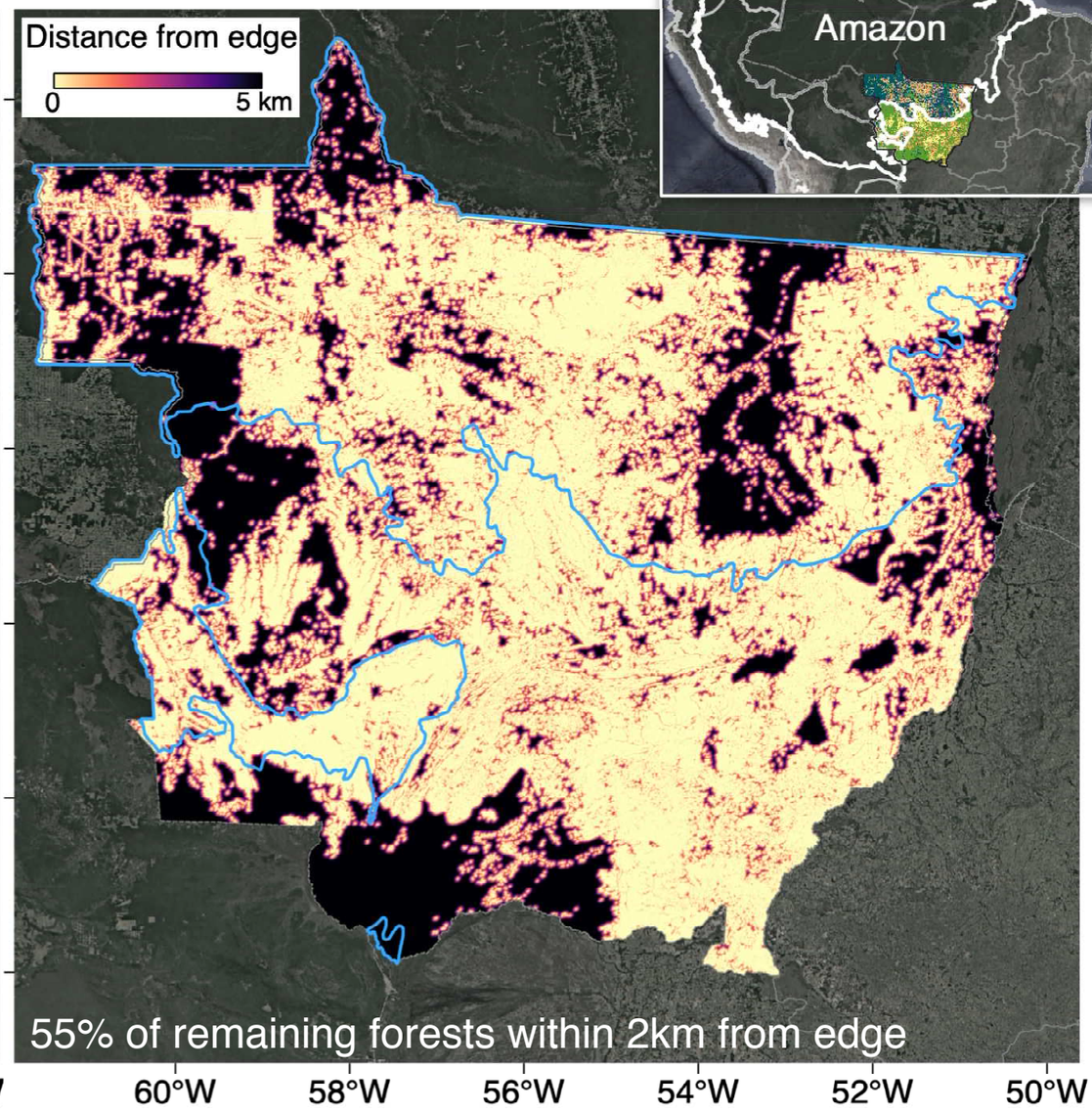
Pre-print doi:10.1002/essoar.10502287.1

1. Degradation effects on fluxes strongest during typical years and moderate droughts.
2. Differences are the greatest for burned forests.
3. Extreme droughts reduce differences between degraded and intact forests.

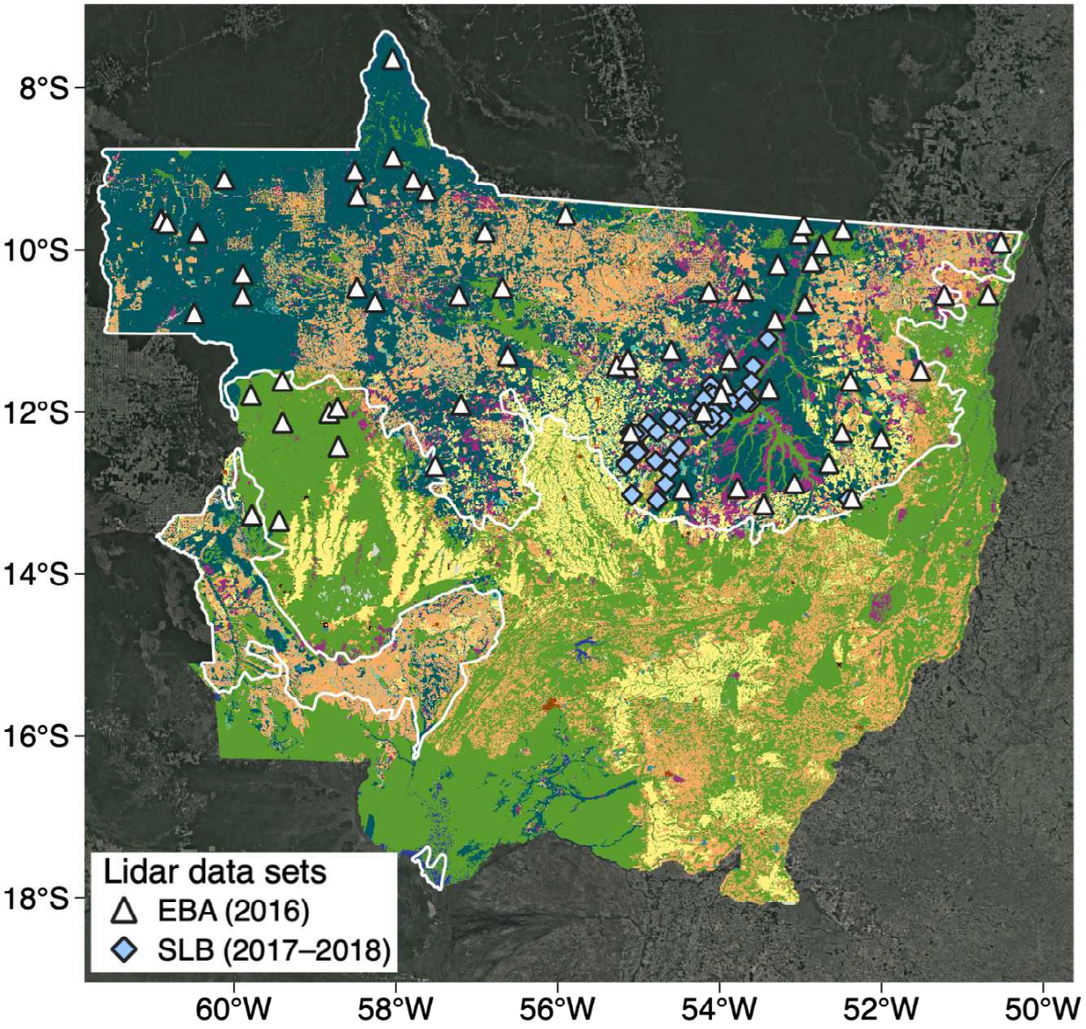
Can we observe some of these effects from space?

Study area – Mato Grosso, Brazil





Airborne lidar data sets



Biomass estimate in the Amazon (EBA)

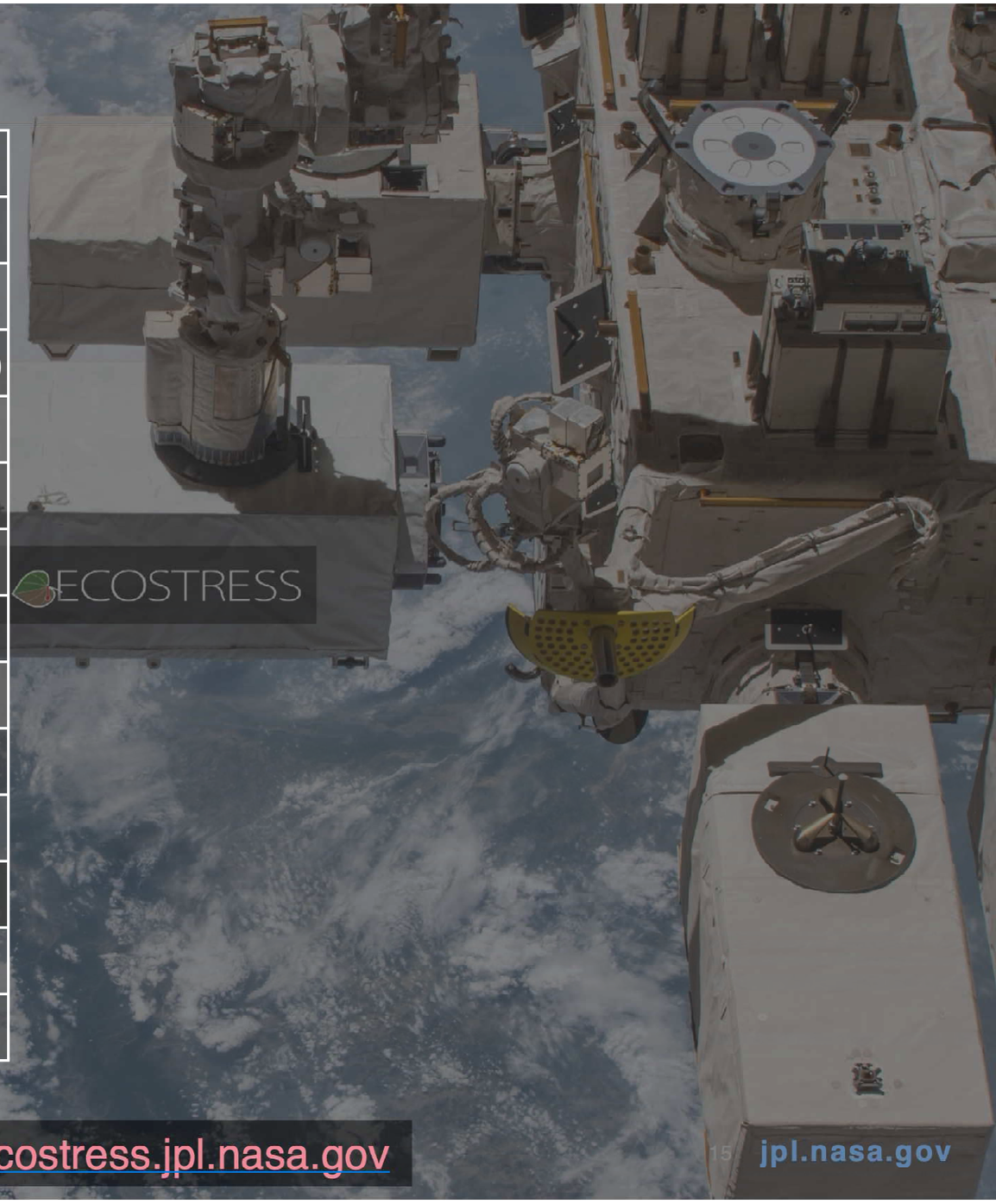
- Total area: 45,000 ha
- (Mostly) Random sampling over forests
- Data acquisition: 2016

Sustainable Landscapes Brazil (SLB)

- Total area: 10,500 ha
- Focus on degraded forests
- Data acquisition: 2017–2018
- https://www.paisagenslidar.cnptia.embrapa.br/webgis/

ECOSTRESS

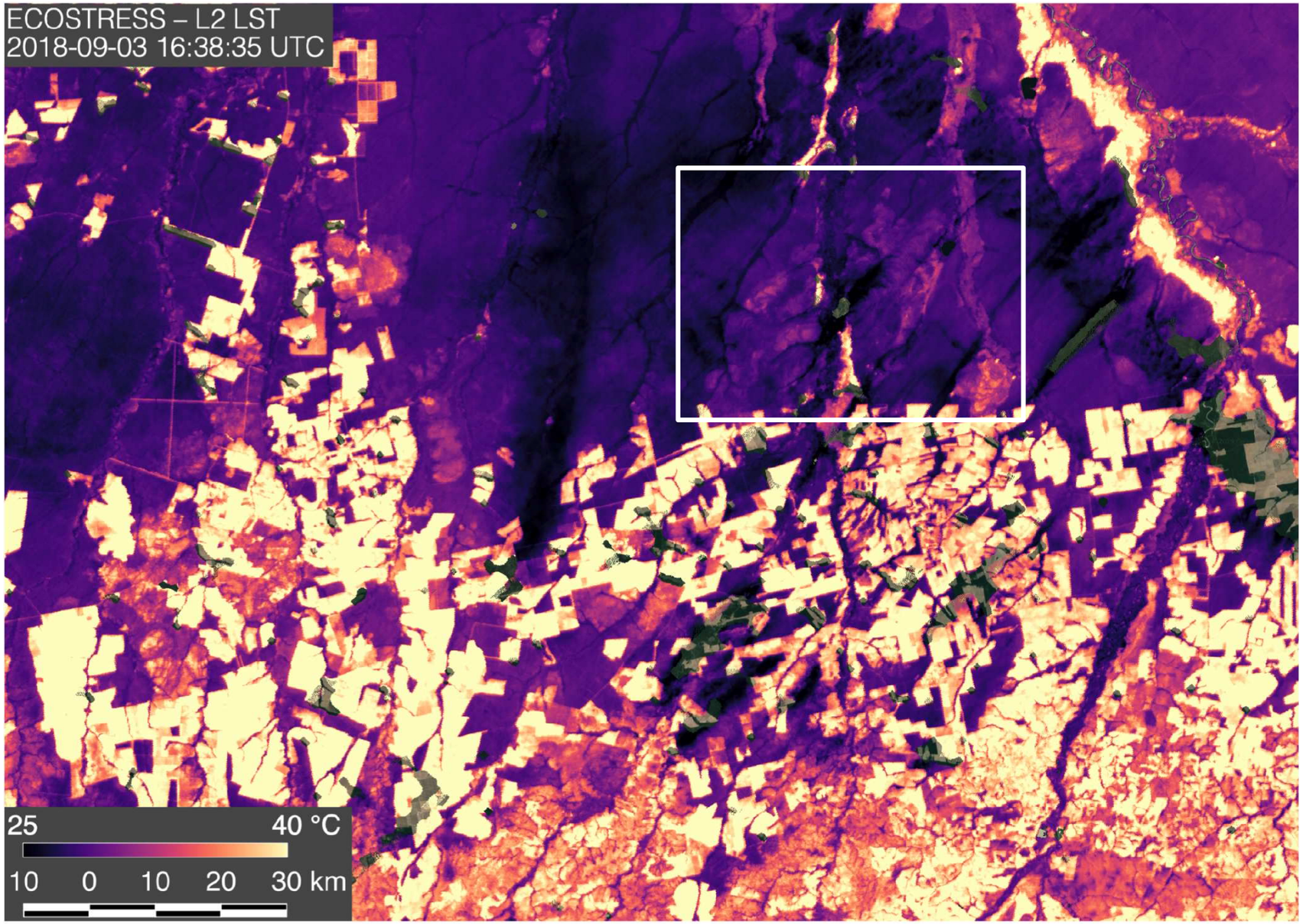
Launch Date		29 June 2018
Spectral bands		1 NIR band: 1.6 µm (geo-location/clouds)
		5 TIR bands: 8.29–12.09 µm
Pixel size at nadir		69×38 m (most science products 70×70 m)
Swath width		384 km
Radiometric precision		0.1–0.29 K (at 300 K)
Temporal resolution		1–7 days over target areas
Products	L1	Radiometric calibrated/geolocated data
	L2	**Land Surface Temperature**
		Emissivity
		Cloud detection
	L3	**Evapotranspiration**
	L4	Water Use Efficiency
		Evaporative Stress



Credit: NASA

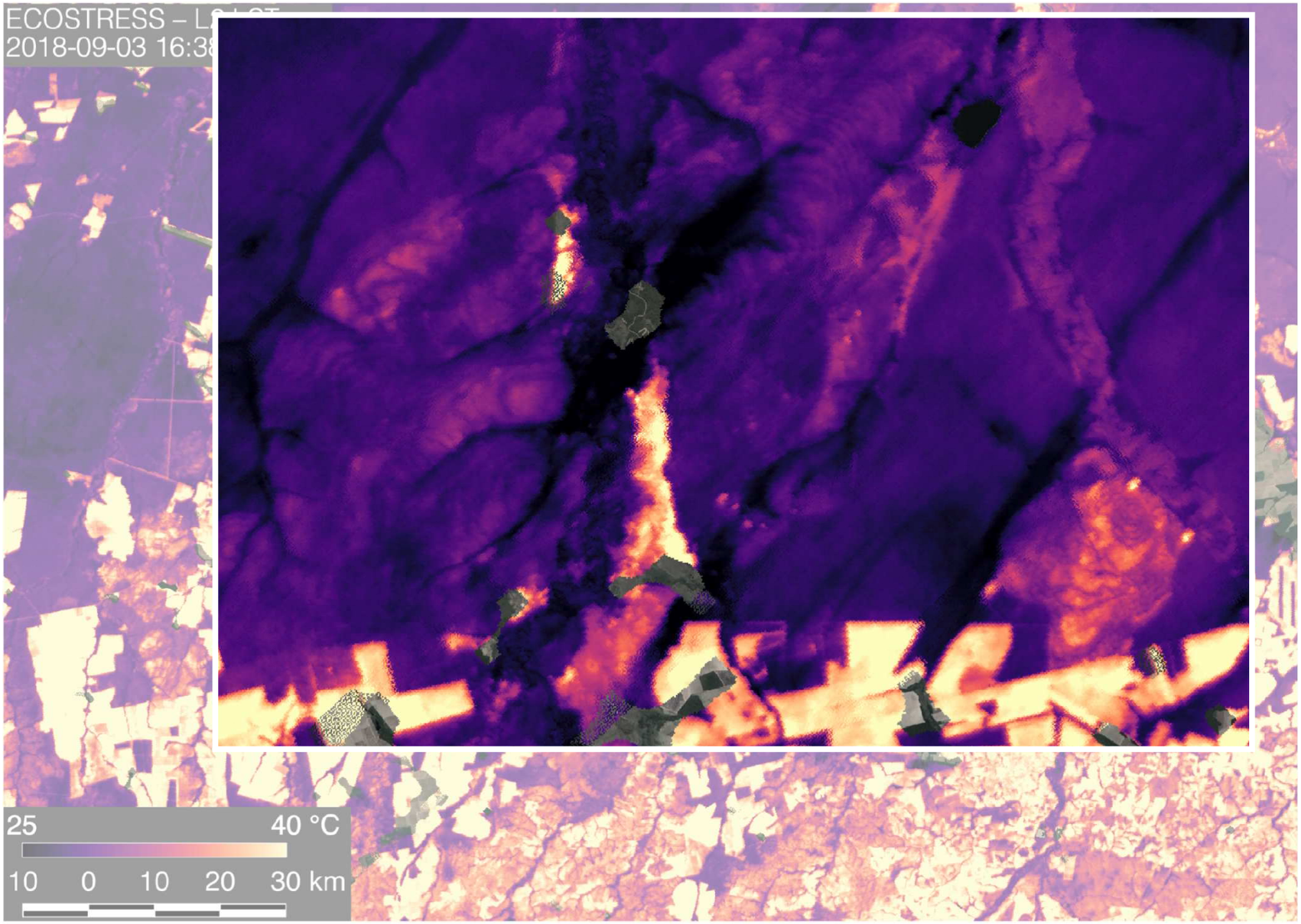
More information at https://ecostress.jpl.nasa.gov

Dry-season, midday temperature



- Land use: dominant spatial feature in surface temperature map
- Deforested areas 10–15°C warmer than forests

Dry-season, midday temperature



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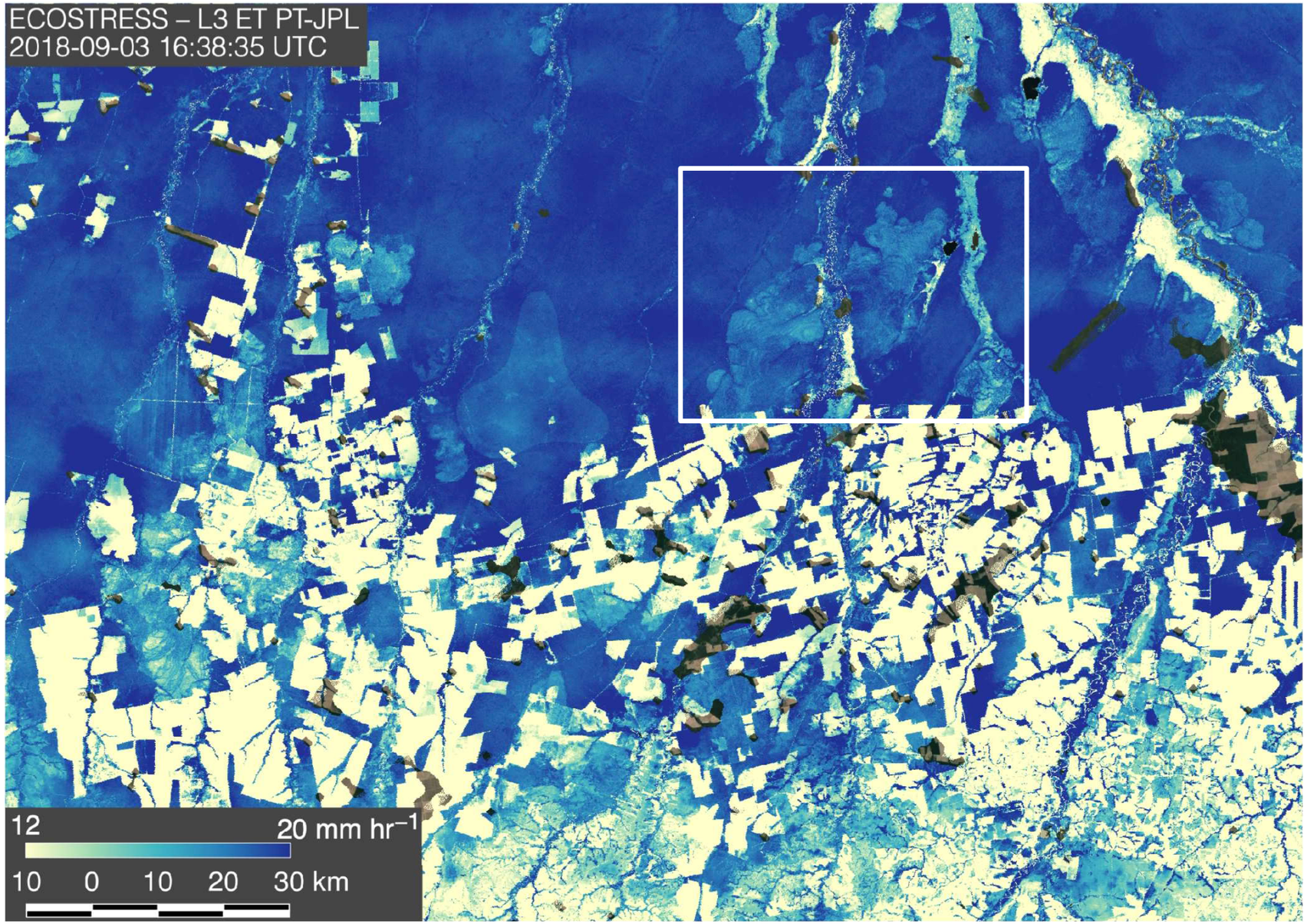
- Degradation patterns in forested areas — fire rings

Dry-season, midday evapotranspiration (PT-JPL)



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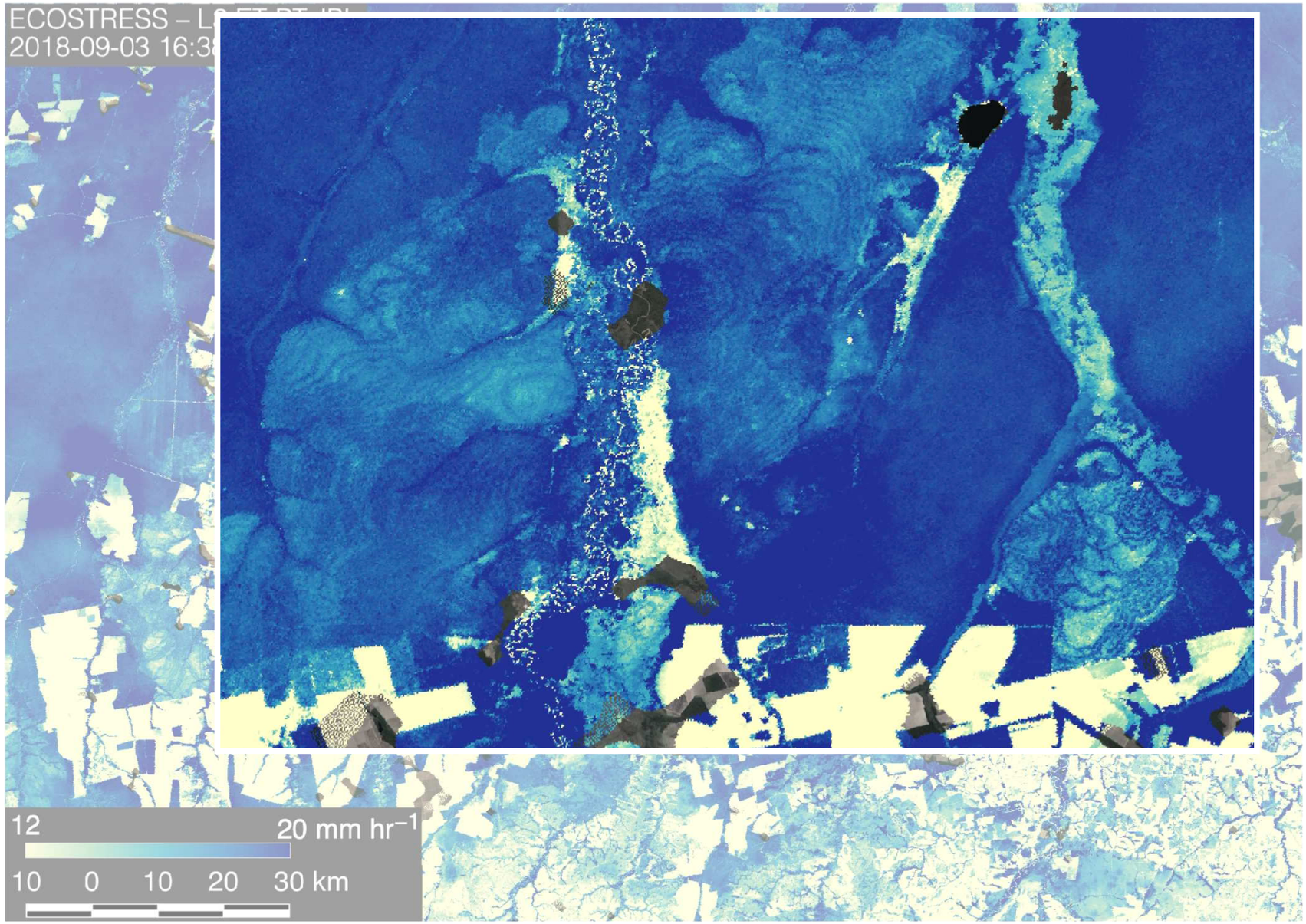
- Similar patterns in the evapotranspiration product

Dry-season, midday evapotranspiration (PT-JPL)



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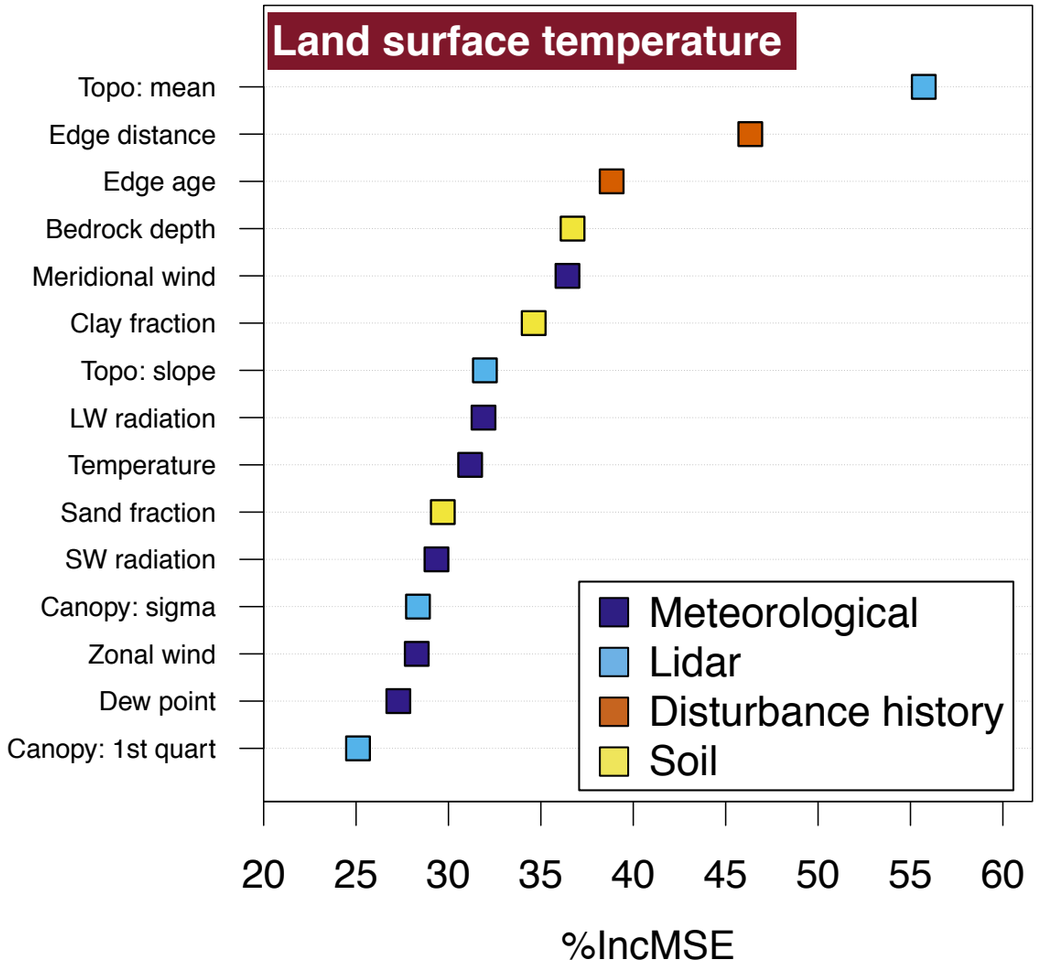
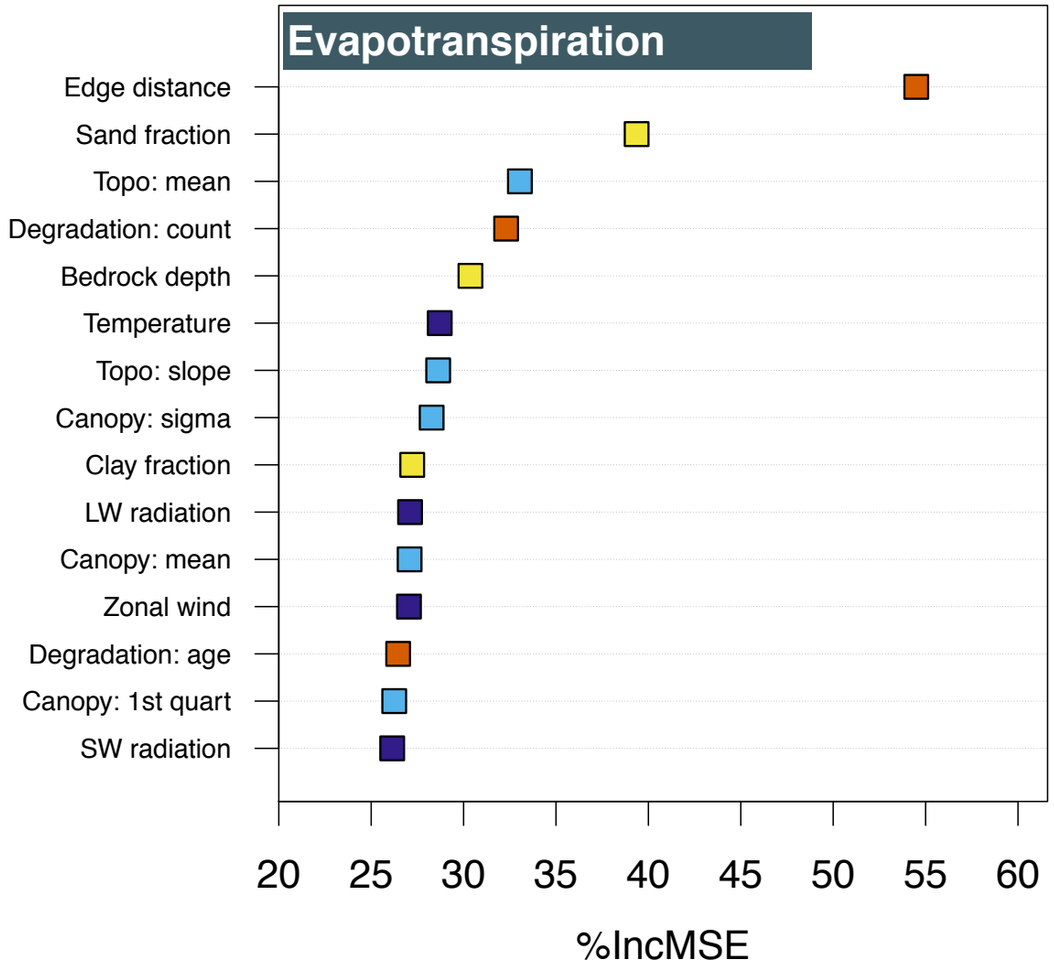
Identifying key drivers of surface temperature and evapotranspiration

Meteorological conditions (ERA5)	• Temperature • Dew point temperature • Incoming radiation (SW and LW) • Wind components
Structural (lidar) Top canopy height statistics	• Mean • Roughness • Skewness • 1st quartile • 3rd quartile • Interquartile range • Maximum • Gap fraction
Topographic (lidar)	• Mean • Roughness • Slope • Topographic position index
Soils • SoilGrids 250m: Hengl et al. (2017) *Plos One*	• Clay fraction • Sand fraction • Depth to bedrock
Disturbance history • INPE: PRODES and DEGRAD • TerraClass: de Almeida et al. (2016) *Acta Amaz.*	• Land use class • Distance to edge • Edge age • Degradation count • Age since last degradation

Edge effect and degradation effects on temperature and evapotranspiration





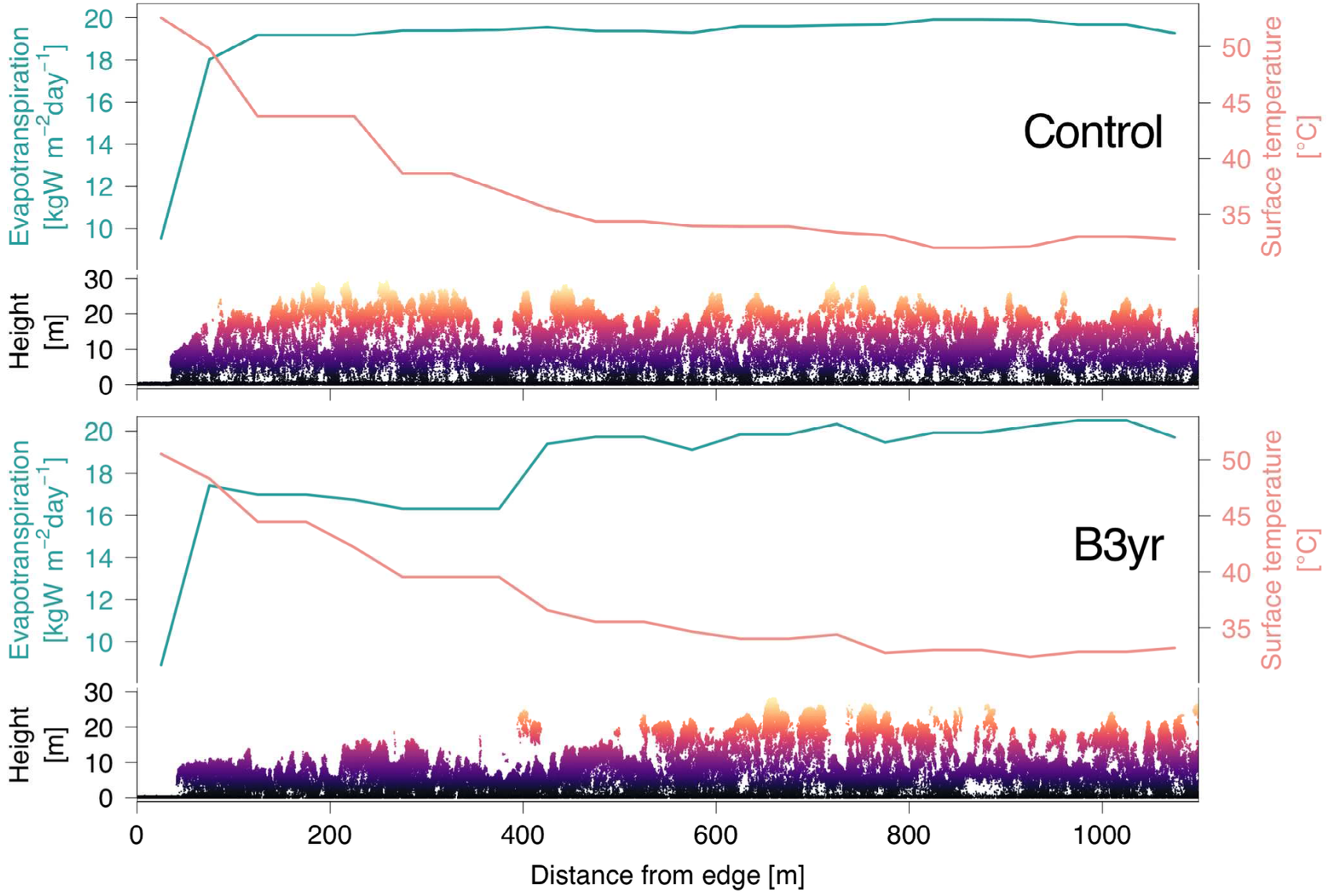
Distance from edge and degradation history → strong predictors of temperature and ET

Canopy metrics → similar to lower relevance than meteorological, edaphic, and topographic variables

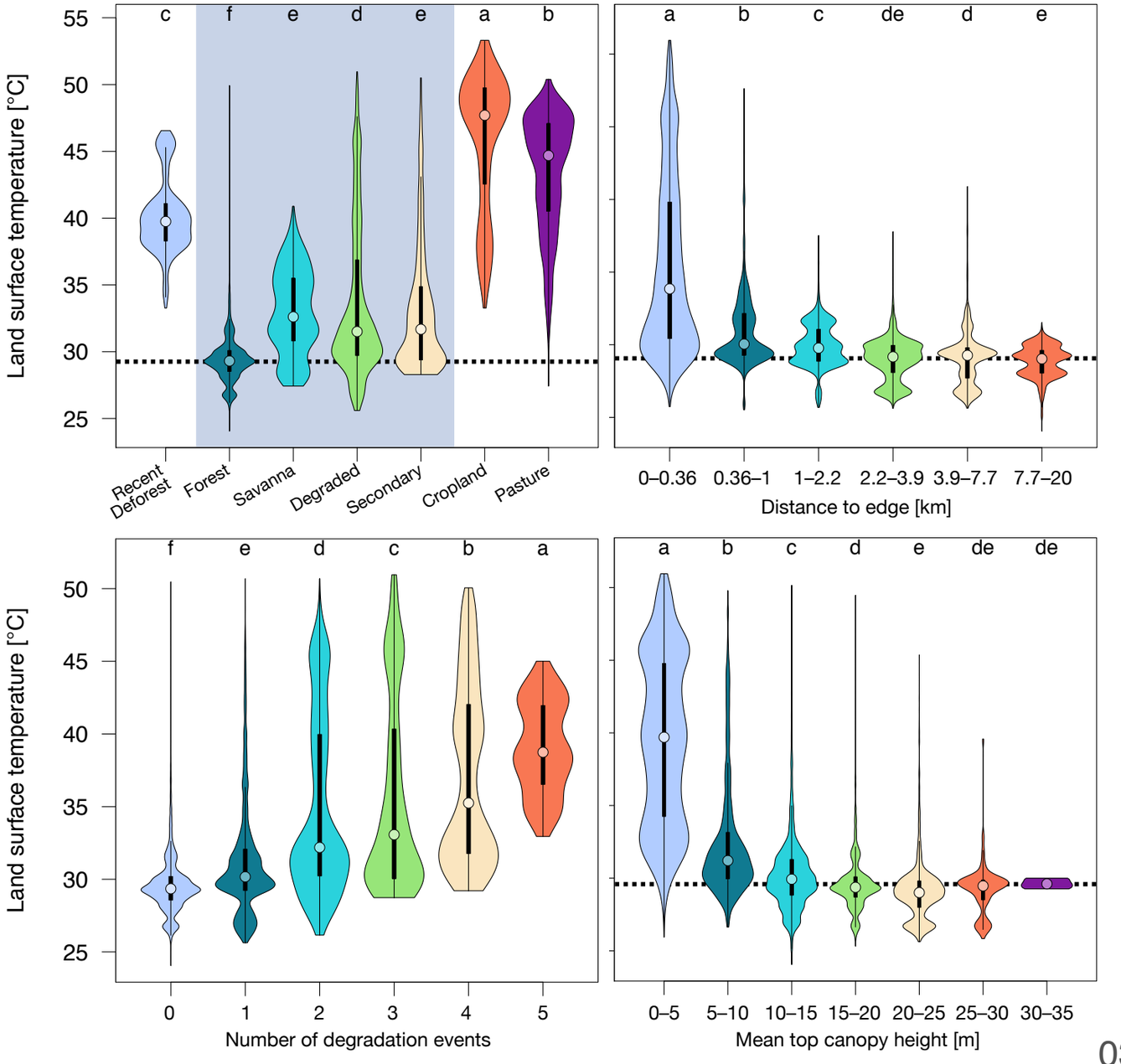
Caveat: Disturbance history not independent from canopy structure change

Distance to deforestation matters – Example from Tanguro fire experiment

Photos: Balch et al. (2015) *BioScience*



Land use history and forest structure impacts on land surface temperature



Degraded and second-growth forests significantly different from intact forests

Edge effect statistically significant up to 2 km

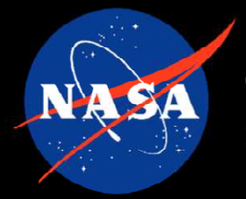
Cumulative effect of forest degradation on temperature

Forest structure effects significant for canopies shorter than 15 m.

03 Sep 2018 13LT

Conclusions

- Quantification of tropical forest degradation impacts in the energy, water, and carbon cycles can leverage advances in remote sensing and ecosystem models.
- Strongest effects of tropical forest degradation on energy, water and carbon fluxes:
  - Dry season and in drier forests
  - Burned forests
  - Near forest edges (also supported by ECOSTRESS data).
- Degradation effects on ecosystem functioning:
  - Typical years show the largest differences between degraded and intact forests
  - Extreme drought stress reduces differences between degraded and intact forests
- ECOSTRESS data support impacts of degradation on energy and water cycles:
  - Mid-afternoon temperatures ~ 4°C warmer in degraded forests
  - Mid-afternoon ET ~ 10% lower in degraded forests
- Extensive edge effects on temperature and evapotranspiration:
  - Temperature: significant differences up to 2 km from edge
  - Evapotranspiration: noticeable edge effects 100–250 m.



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