Flux towers in the sky

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Flux towers in the sky: global ecology from space

Schimel, Scheider and JPL Carbon and Ecosystems Initiative Participants

Other papers in the Special Issue on Remote Sensing

Tansley insights:	
Terrestrial LiDAR: a three-dimensional revolution in how we look at trees	Disney, Mathias
Tracking seasonal rhythms of plants in diverse ecosystems with digital camera imagery	Richardson, Andrew
Improving plant allometry by fusing forest models and remote sensing	Chave, Jerome
Macro to Micro: Microwave Remote Sensing of Plant Water Content for Physiology and Ecology	Konings, Alexandra
On the role of long-term satellite observations in constraining the vegetation CO2 fertilization effect	Smith, William
Research review:	
Sun-induced chlorophyll fluorescence and its importance for modeling photosynthesis from the side of light reactions	Gu, Lianhong

JPL's Carbon Initiative

- Began 2012
- Funded 2012-2017 (5 years of a three-year program)
- Goals:
  - Ensure scientific leadership and success for JPL's carbon and climate program
  - Establish JPL as a US and NASA Center of Excellence for Carbon Science
  - Exploit OCO-2 and SMAP, prepare for OCO-3, NISAR, GEDI, ECOSTRESS…
  - Develop new mission concepts
  - Explore plant canopy structure and function, functional diversity as an earth system property

JPL's Carbon Initiative

- Results!
  - OCO-3, ECOSTRESS, CARBO, SBG…
  - Science Special Issue
  - ~40 publications
  - Synergism with CARVE, ABoVE
    - Jeong et al, time scales applied to change
  - Key synthesis and concept papers
    - Stavros et al
    - Schimel, Asner and Moorecroft
    - Schimel et al GCB
    - Schimel et al pNAS
    - Schimel et al (Tansley)
    - Fisher et al (review)
    - Long VOD time series
    - 8 postdocs
    - Your many great papers
  - C&E group
  - New hires (5)

Methodology

- Fund synergism between existing projects and missions
- Create "mini-science teams"
- Workshops
- Synthesis and concept papers
- Specific science priorities selected by steering committee, mostly junior (well, they were then) scientists and postdocs…

“Bring me a peer reviewed paper and we’ll fund a program”

Sellers PJ, Schimel DS, Moore B, Liu J, Eldering A. Observing carbon cycle–climate feedbacks from space. Proceedings of the National Academy of Sciences. 2018 Jul 9:201716613.

Muller-Karger FE, Hestir E, Ade C, Turpie K, Roberts DA, Siegel D, Miller RJ, Humm D, Izenberg N, Keller M, Morgan F. Satellite sensor requirements for monitoring essential biodiversity variables of coastal ecosystems. Ecological applications. 2018 Apr;28(3):749-60.

Stavros EN, Coen J, Peterson B, Singh H, Kennedy K, Ramirez C, Schimel D. Use of imaging spectroscopy and LIDAR to characterize fuels for fire behavior prediction. Remote Sensing Applications: Society and Environment. 2018 Aug 1;11:41-50.

Jetz W, Cavender-Bares J, Pavlick R, Schimel D, Davis FW, Asner GP, Guralnick R, Kattge J, Latimer AM, Moorcroft P, Schaepman ME. Monitoring plant functional diversity from space. Nature Plants. 2016 Mar 2;2:16024.

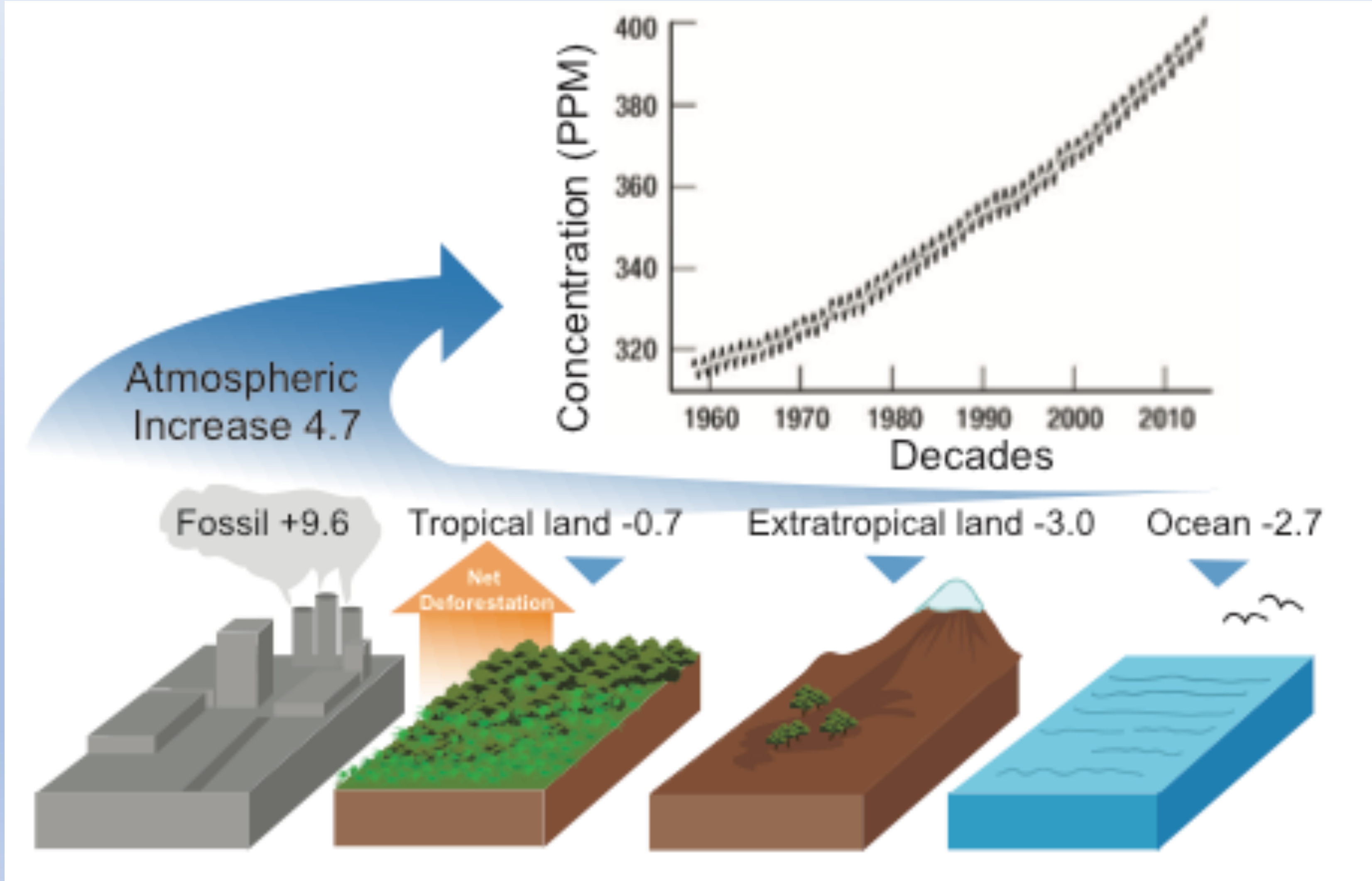
Schimel, D., Pavlick, R., Fisher, J.B., Asner, G.P., Saatchi, S., Townsend, P., Miller, C., Frankenberg, C., Hibbard, K. and Cox, P., 2015. Observing terrestrial ecosystems and the carbon cycle from space. Global change biology, 21(5), pp.1762-1776.

Schimel, D.S., G.P. Asner and P. Moorcroft. 2013. Observing changing biodiversity in the Anthropocene. Frontiers in Ecology and the Environment 11: 129–137

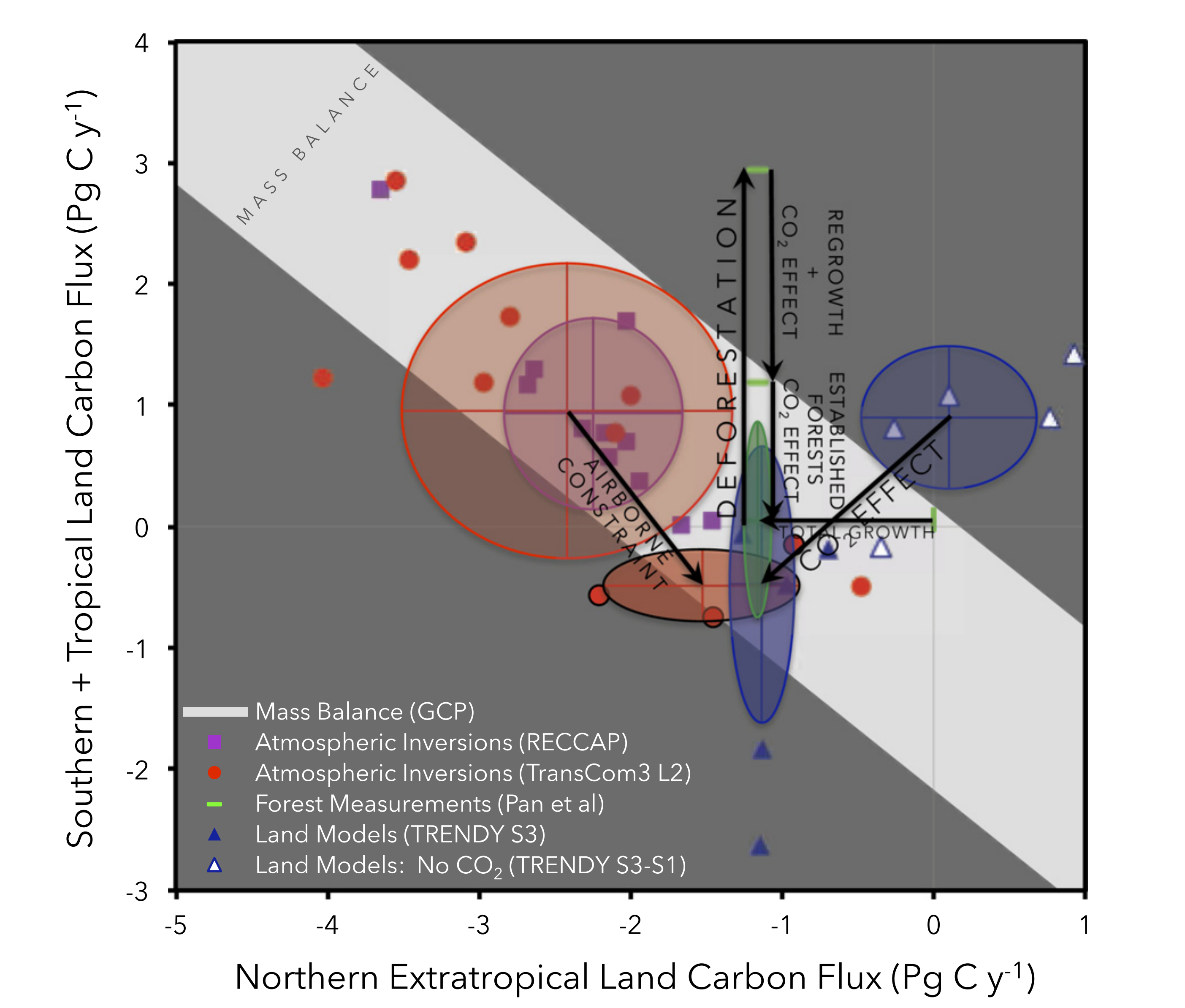
Pretzels, Sloth Bears, Diver Downs and Lat Plots

New visualizations for new data…

The sloth bear: how feedbacks affect the global carbon budget



Diver Down: Merging inverse and forward estimates with data constraint



Schimel D, Stephens BB, Fisher JB. Effect of increasing CO2 on the terrestrial carbon cycle. Proceedings of the National Academy of Sciences. 2015 Jan 13;112(2):436-41.

ISS Suite Initiative

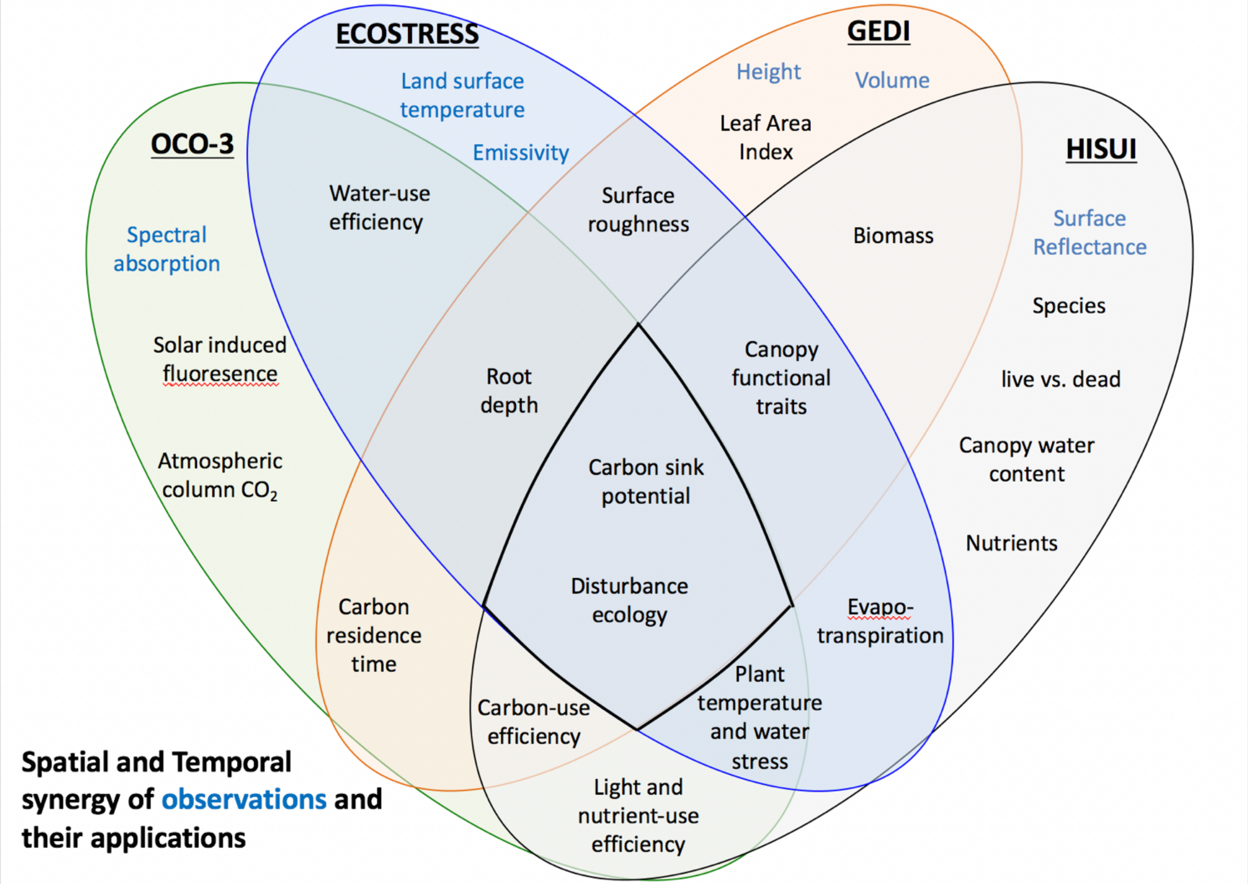
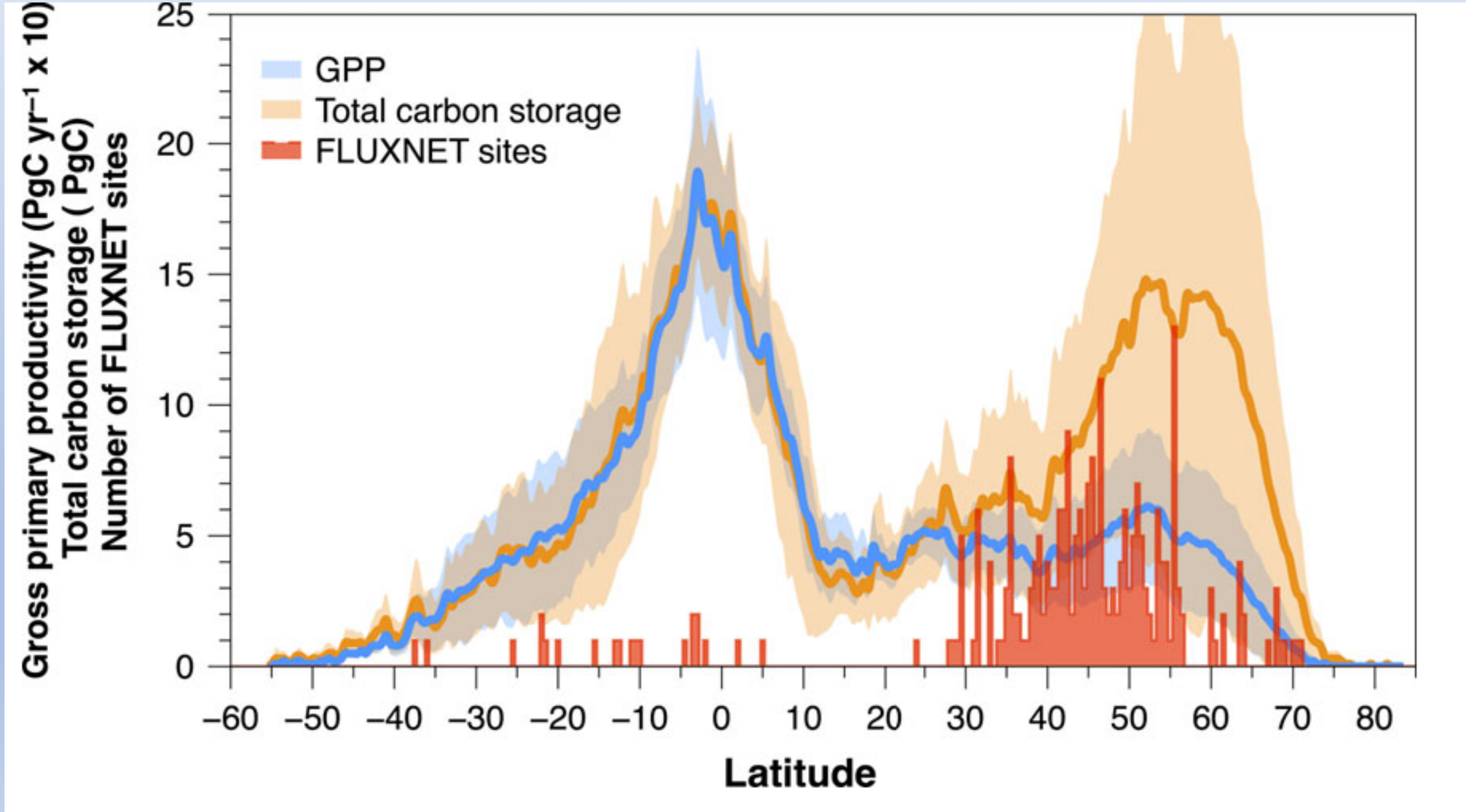


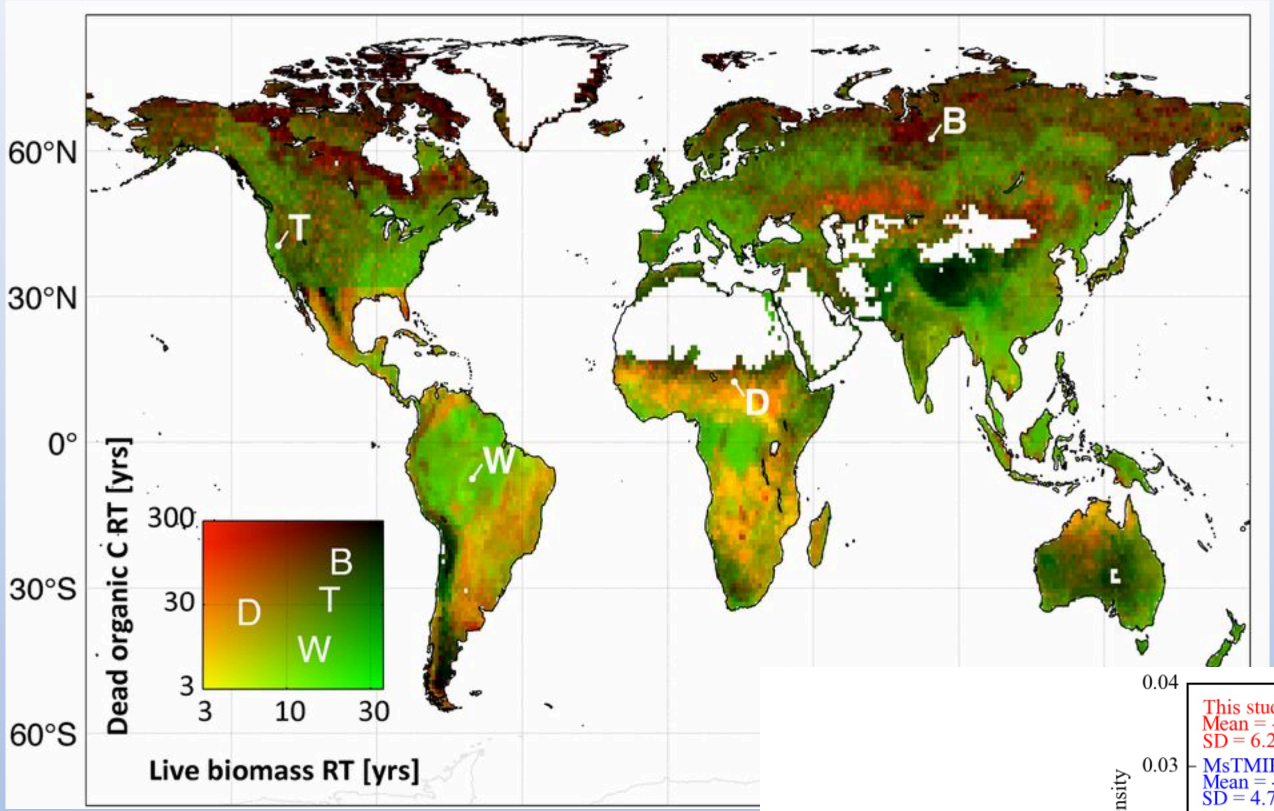
Figure 1. A pretzel diagram of observations (blue) from each instrument and the synergistic physical parameters that can be derived (black) when observations are taken at synchronous and complementary spatial and temporal resolutions.

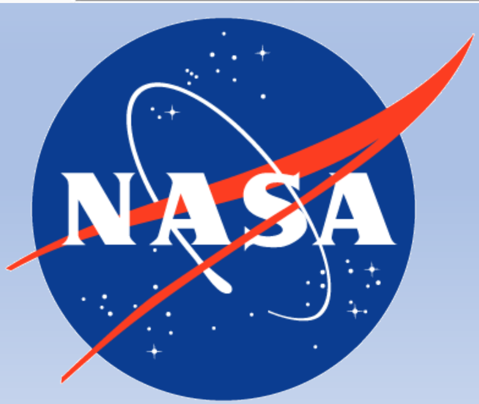
Stavros EN, Schimel D, Pavlick R, Serbin S, Swann A, Duncanson L, Fisher JB, Fassnacht F, Ustin S, Dubayah R, Schweiger A. ISS observations offer insights into plant function. Nat. Ecol. Evol. 2017 Jun 22;1:0194.

Global sampling: space versus in situ "The two poles of the carbon cycle"



Residence time: Model development and application to Arctic





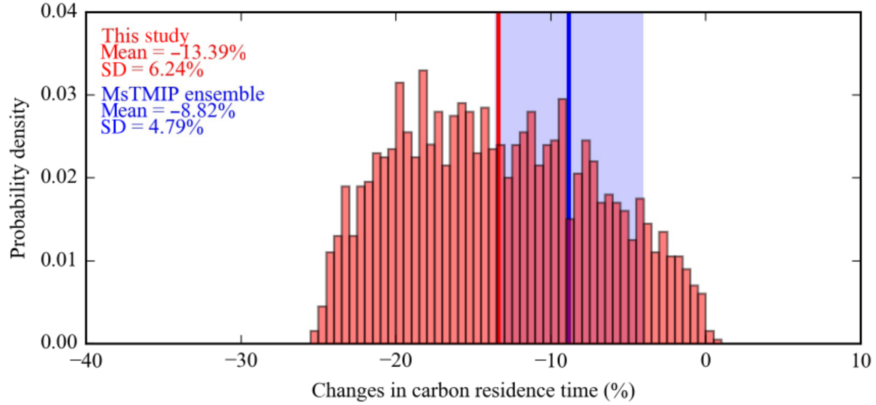


Fig. 2. Retrieved changes in carbon residence time based on the difference between 1979 1988 and 2004 2013 10-year periods. The vertical red line indicates the average of retrieved changes in carbon residence time. The blue line indicates mean (solid line) and range (shading) in the equivalent residence time change estimates from the MsTMIP model ensemble.

Fire and the Carbon Cycle: airborne studies

AGU Journal of Geophysical Research: Biogeosciences 10.1002/2015JG003315

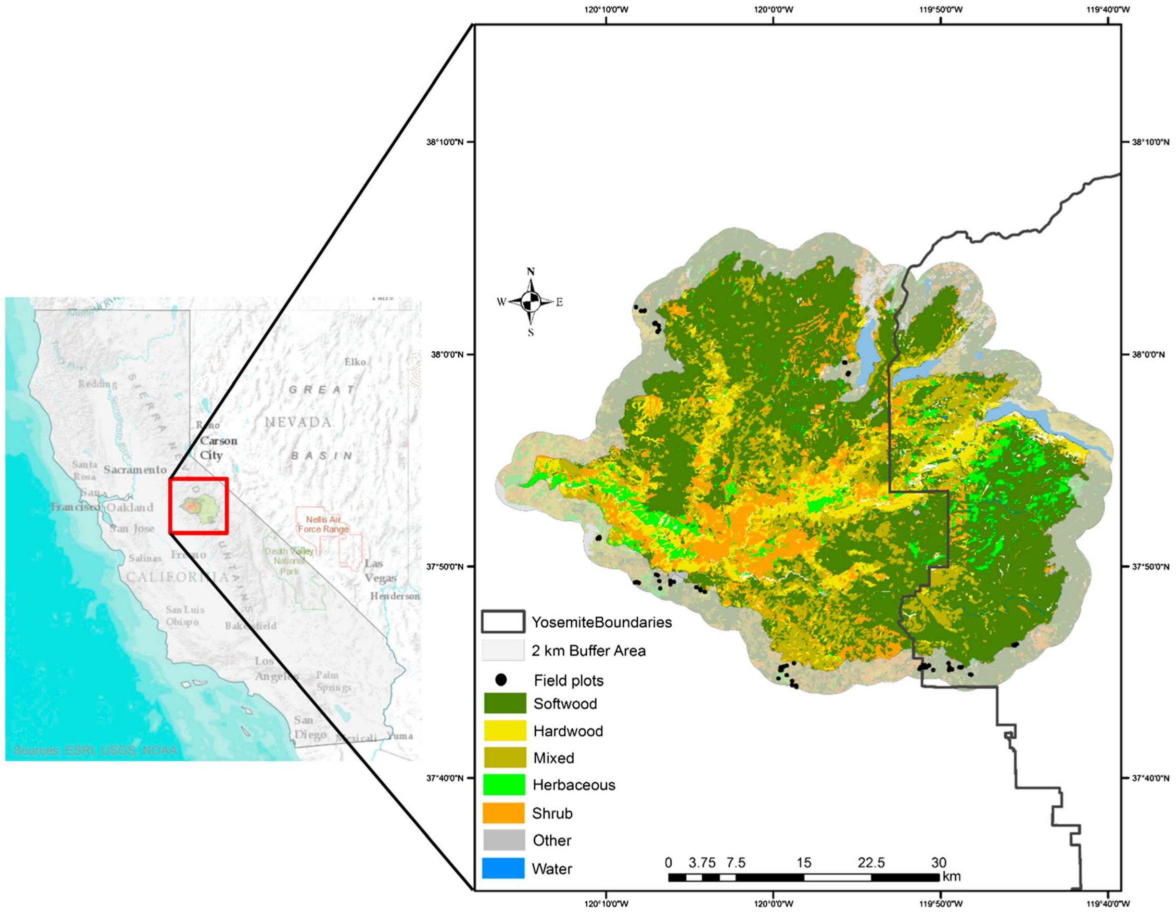


Figure 1. Study area comprising the footprint of the Rim re, in the Sierra Nevada Mountains, California, USA.

Flights arranged with NSF and JPL assets to characterize forest structure and biomass over California “megafires”

Garcia M, Saatchi S, Casas A, Koltunov A, Ustin S, Ramirez C, Garcia-Gutierrez J, Balzter H. Quantifying biomass consumption and carbon release from the California Rim fire by integrating airborne LiDAR and Landsat OLI data. Journal of Geophysical Research: Biogeosciences. 2017 Feb 1;122(2):340-53.

Flux towers in the sky: global ecology from space

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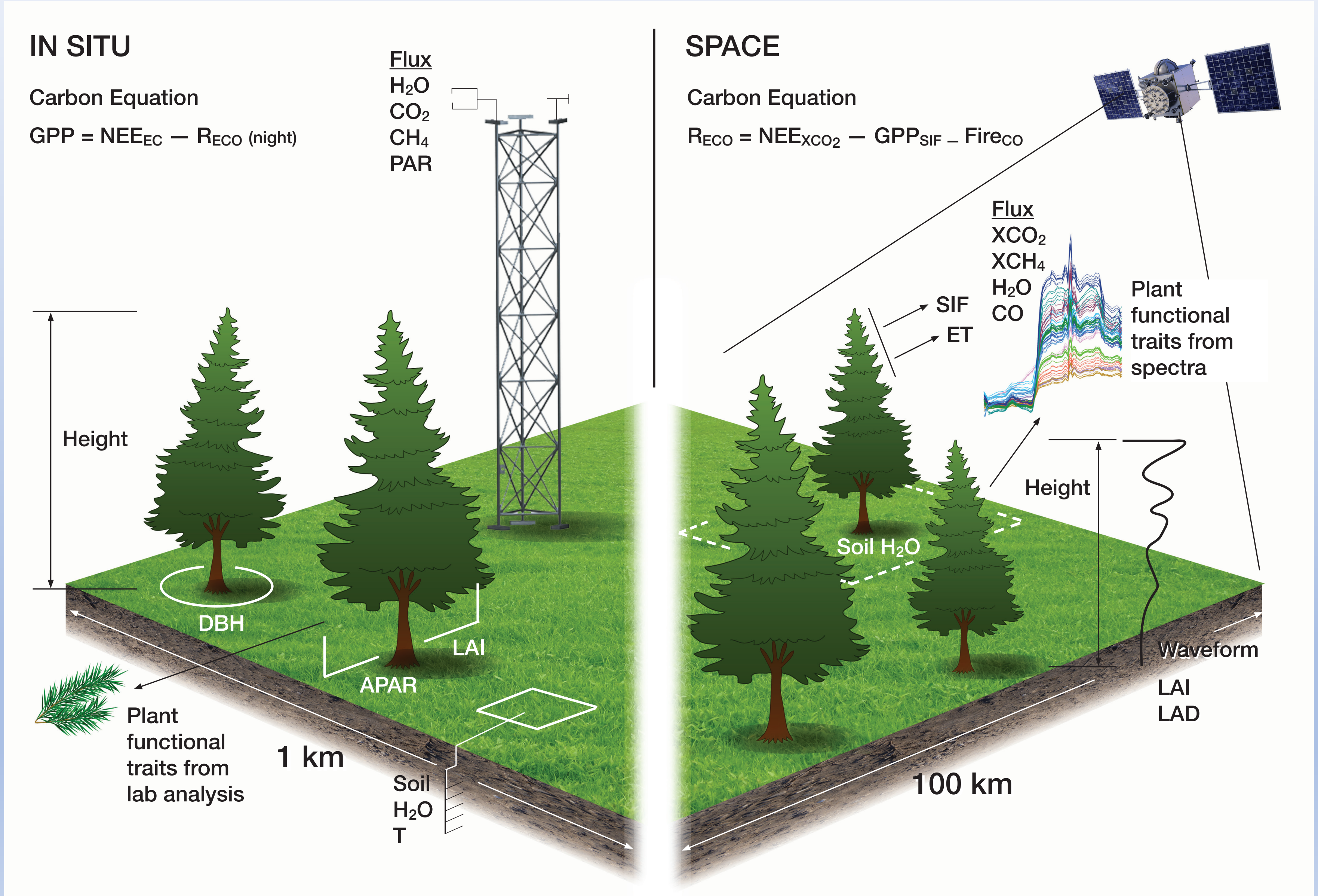
Grand Challenges for Global Ecology

- What is the primary productivity of the globe and what controls it?
- How much carbon does the biosphere store and how could it change?
- How does direct human exploitation of the biosphere affect productivity and carbon storage?
- What is the biological diversity of the world and how does it affect the function and stability of ecosystems?
- **Can we predict the future of terrestrial carbon storage and the role of ecosystems in the Earth System:**

New tools for Global Ecology

- In situ networks, big data compilations, genomics, citizen science…
- New remote sensing technologies for ecology since greenness…
  - GHGs
  - SIF
  - VOD
  - Lidar and radar
  - Spectroscopy
  - TIR
  - GPS/bistatic radar

Flux towers in the sky



The carbon equations are more different than at first look…

$$NEE = GPP + R_{eco} \text{ versus } NECB = GPP + SIF + Fire$$

- 1 km^2 versus ~100 km^2.
- NEE versus NECB, disturbance included
- GPP from day-night contrast difference versus from SIF
- Space measurement sees emissions
- Totally different error sources and uncertainty models
- Similar but differently sampled and differently measured covariates

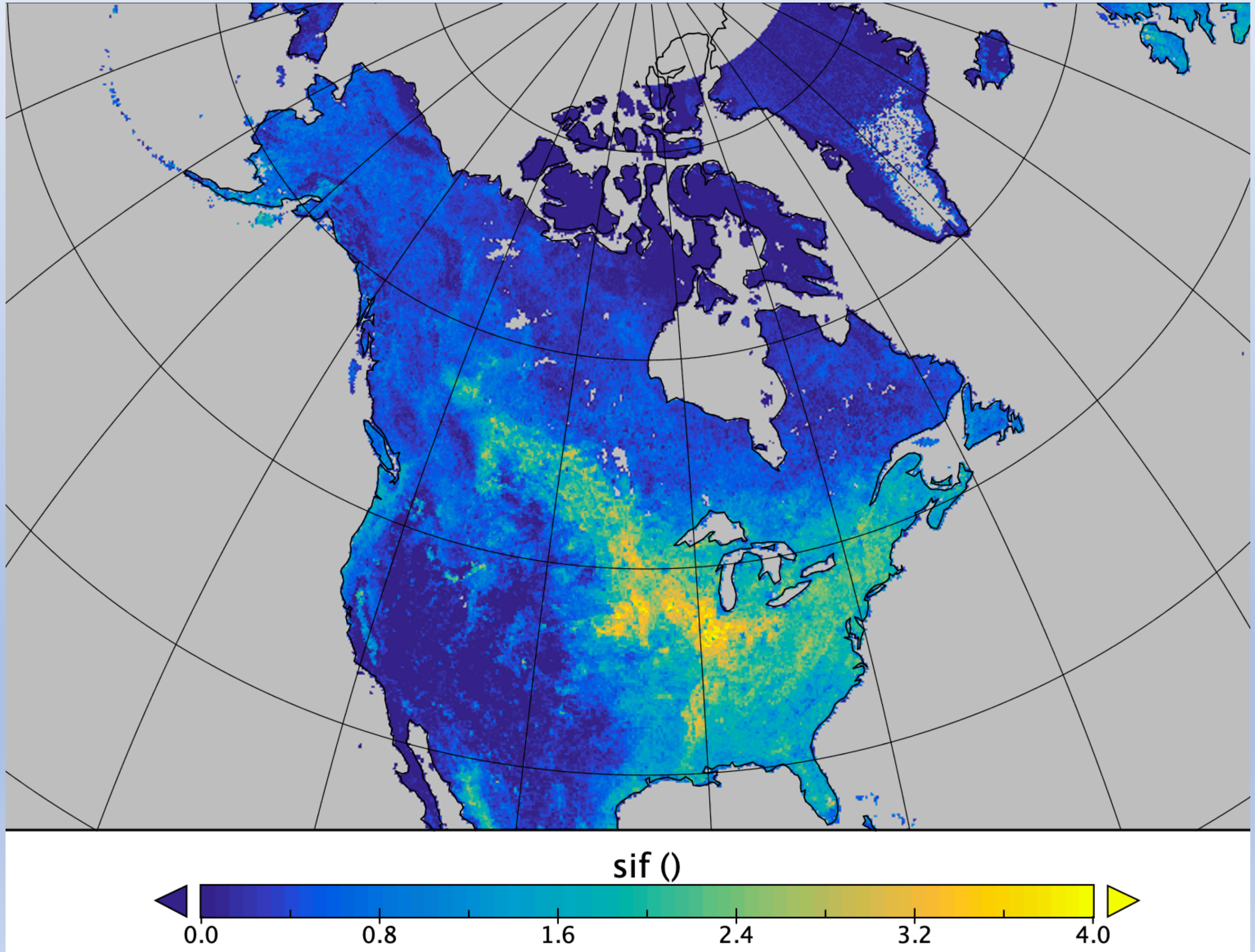
Water cycle

The editors asked for this, too:

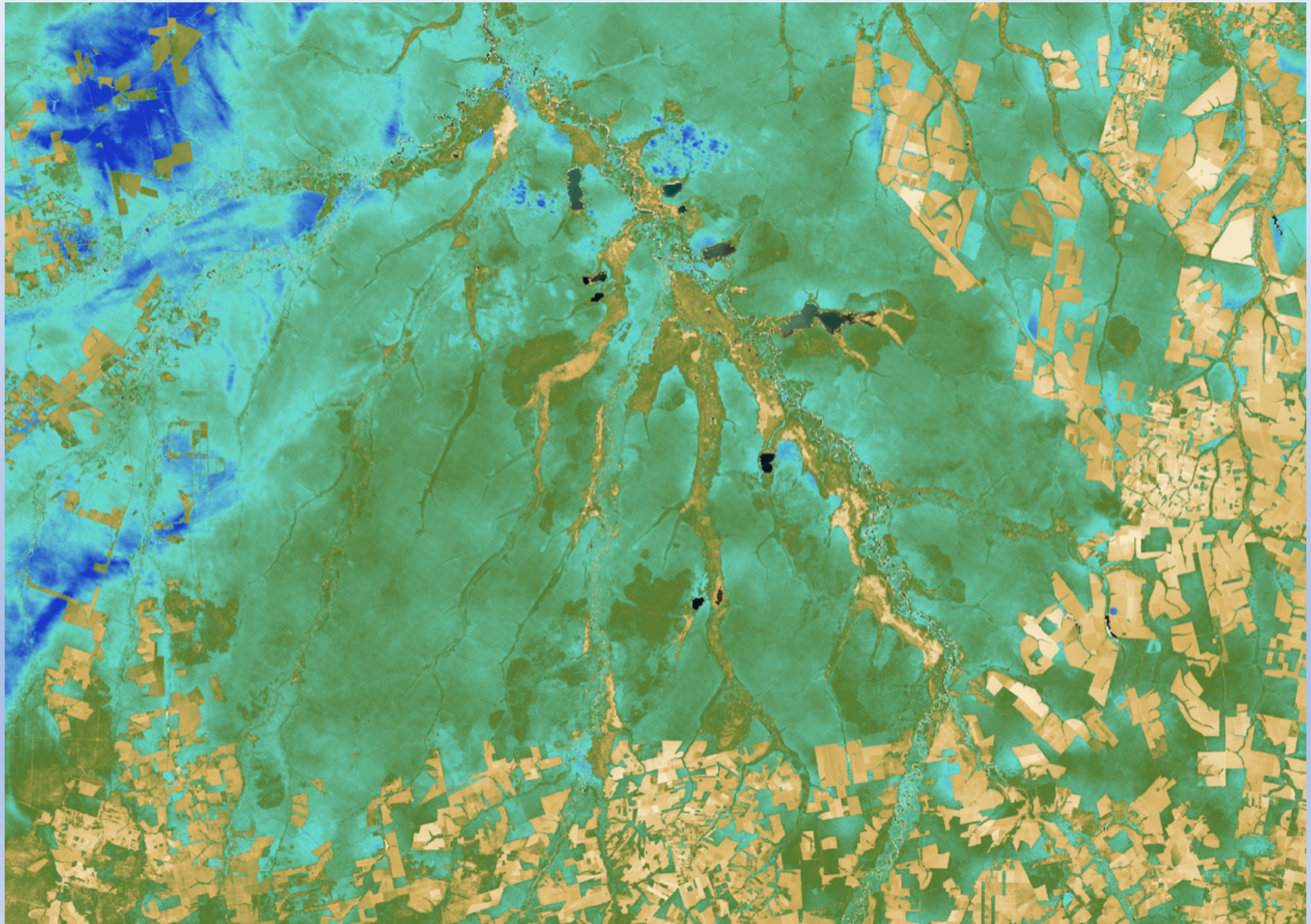
Acronym Dictionary

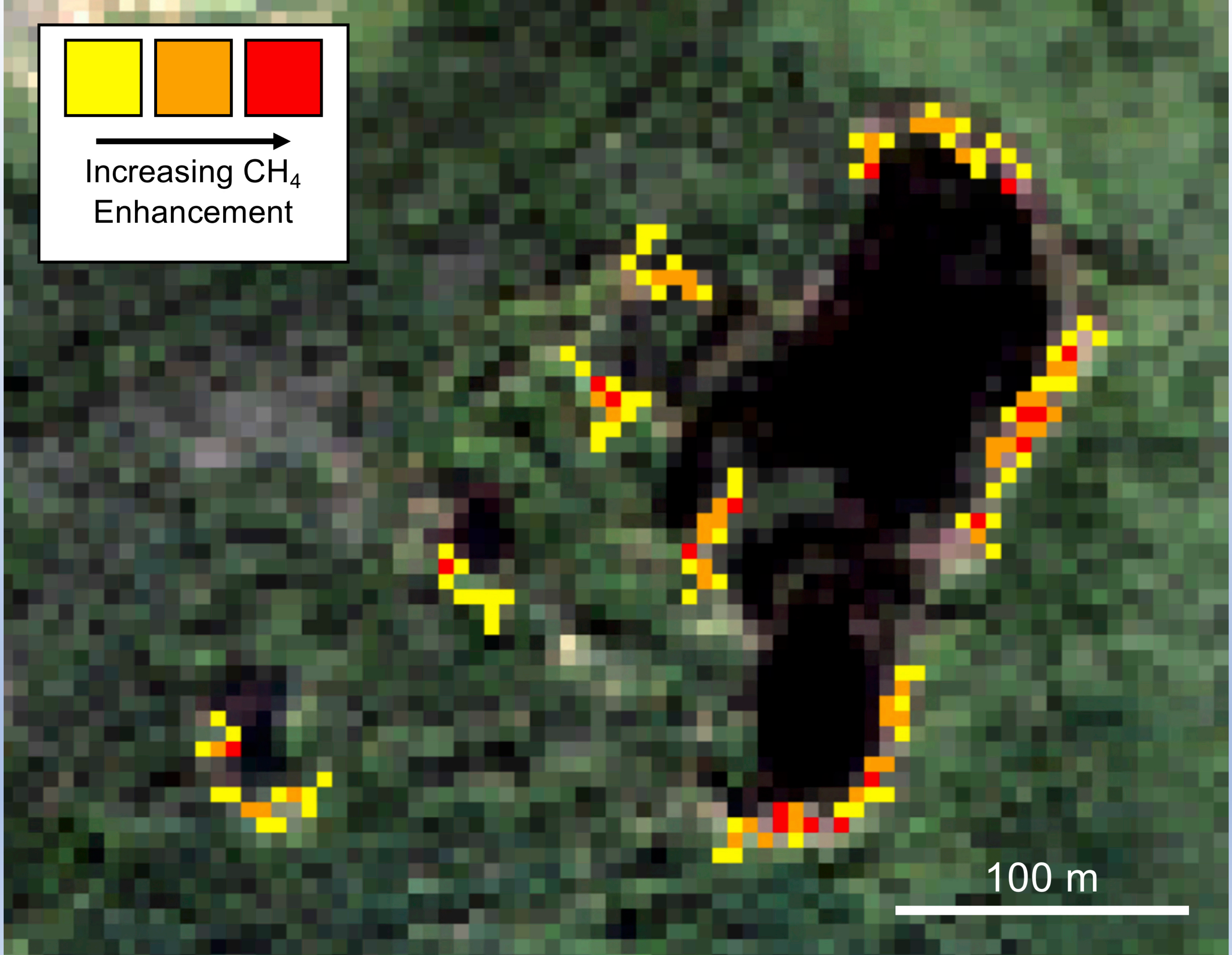
ABoVE – Arctic Boreal Vulnerability Experiment
APAR – Absorbed Photosynthetically Active Radiation
AVIRIS – Airborne Visible/Infrared Imaging Spectrometer
BIOMASS – European Space Agency mission
CO – Carbon Monoxide
DBH – Diameter Breast Height
DLR – Deutsches Zentrum für Luft- und Raumfahrt, Germany
ECOSTRESS – ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
EMIT – Earth Surface Mineral Dust Source Investigation
ESA – European Space Agency
ET – EvapoTranspiration
GEDI – Global Ecosystem Dynamics Investigation Lidar
GLAS – Geoscience Laser Altimeter System
GPP – Gross Primary Productivity
GRACE – Gravity Recovery and Climate Experiment
HISUI – HyperSpectral Imager Suite
ISRO – Indian Space Research Agency
LAI – Leaf Area Index
LAD – Leaf Area Distribution
LST – Land Surface Temperature
LUE – Light Use Efficiency
MODIS – MoDerate Resolution Imaging Spectroradiometer
NECB – Net Ecosystem Carbon Balance
NEE – Net Ecosystem Exchange
NISAR – NASA-ISRO Synthetic Aperture Radar
NPP – Net Primary Productivity
PAR – Photosynthetically Active Radiation
R_{eco} – Ecosystem Respiration
SIF – Solar (or Sun)-Induced Fluorescence
SBG – Surface Biology and Geology
TIR – Thermal InfraRed
TROPOMI – TROPOspheric Monitoring Instrument
VSIR – Visible and Shortwave InfraRed
VOD – Vegetation Optical Depth
XCH_4 – Column mole fraction of methane
XCO_2 – Column mole fraction of carbon dioxide

A gallery of new measurements



ECOSTRESS ET over the Amazon

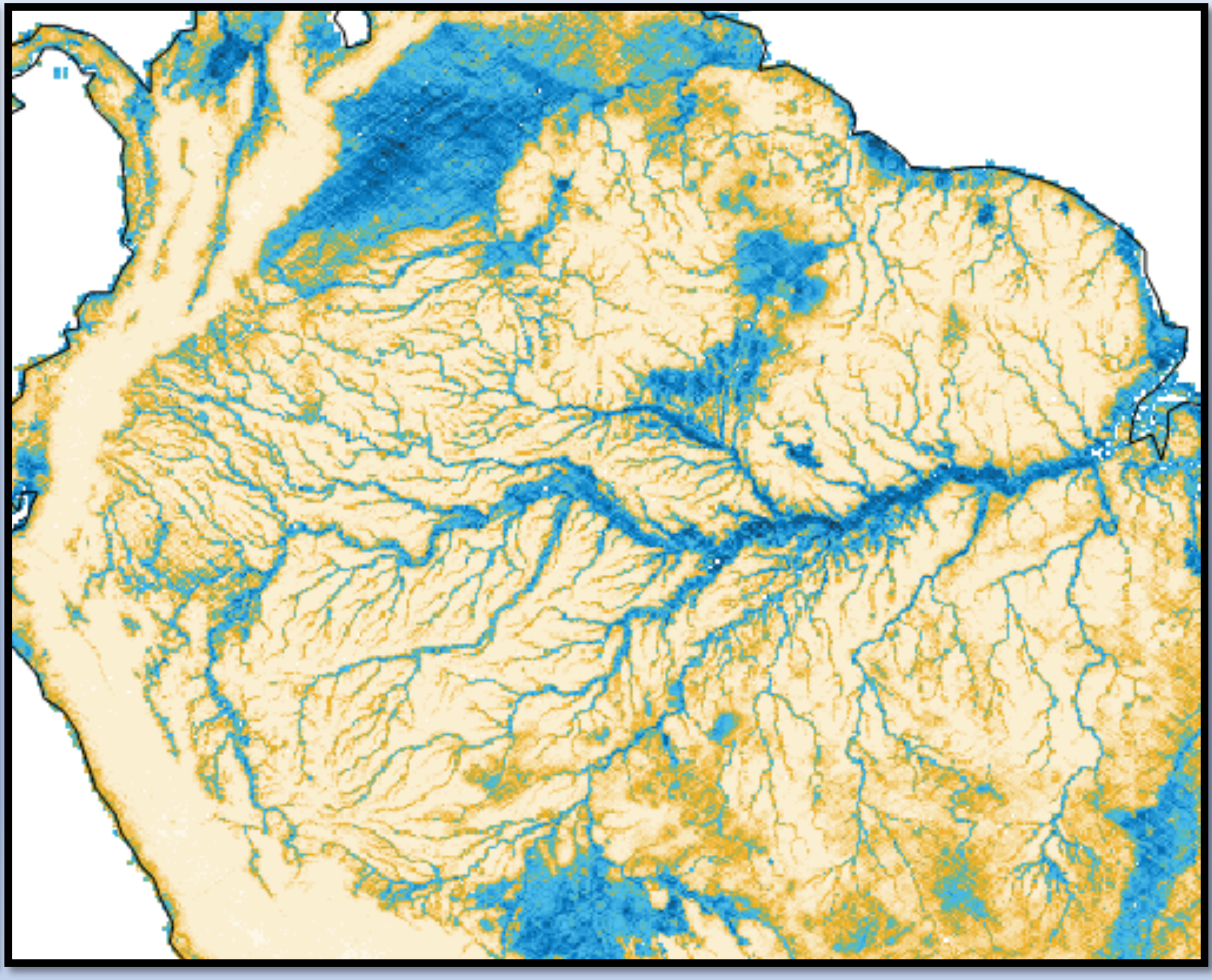


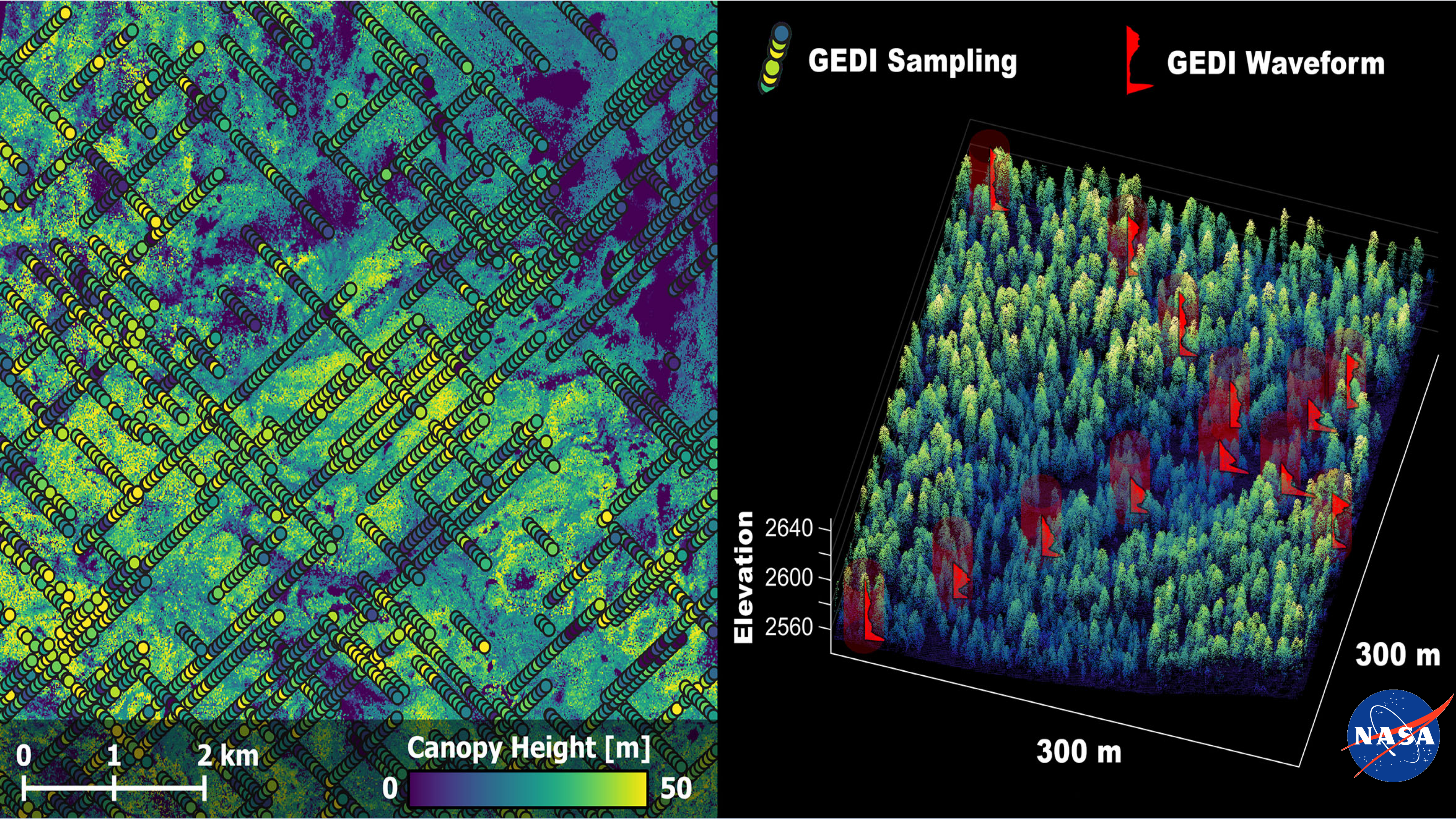


Increasing CH_4 Enhancement
100 m

USGS data base versus Cygnss reflections

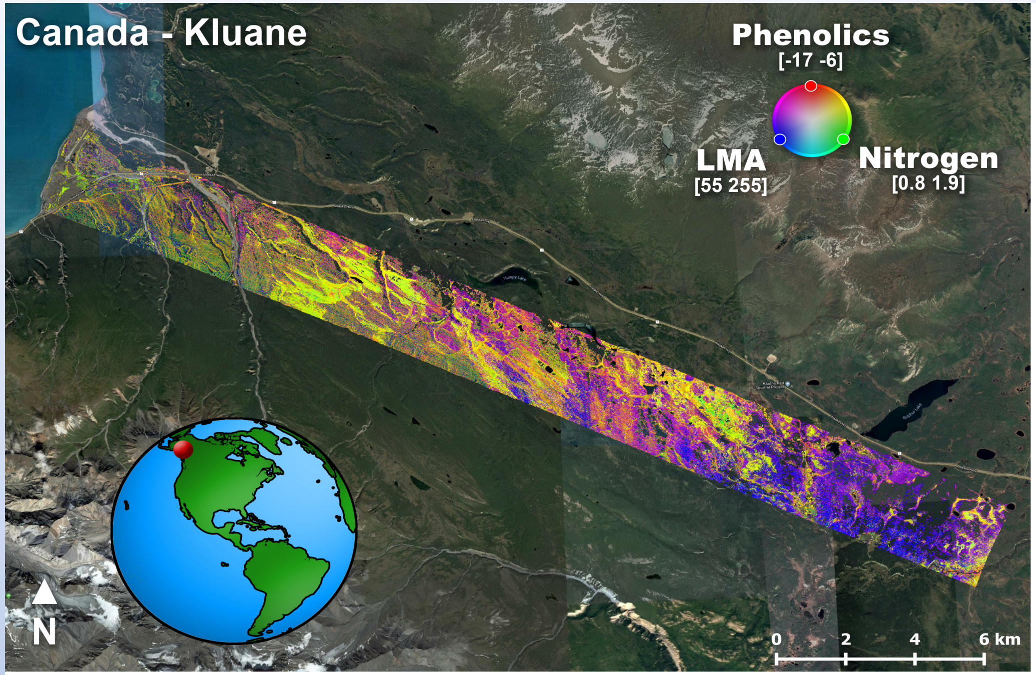
Potential for GPS reflectometry

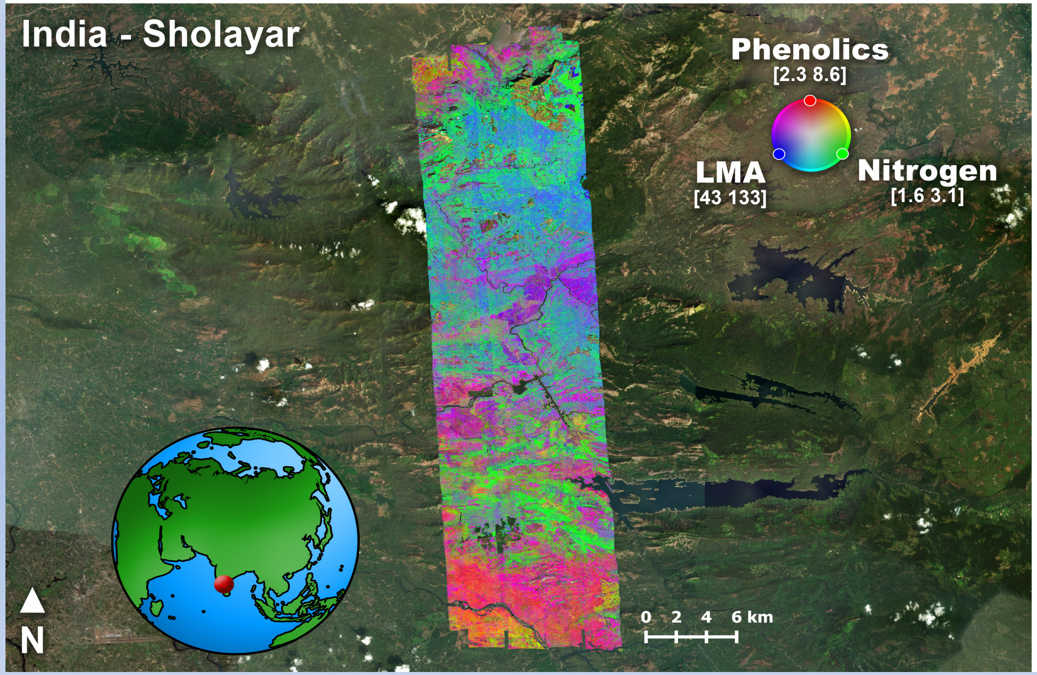



GEDI Sampling
GEDI Waveform
Elevation
2640
2600
2560
300 m
300 m
0
1
2 km
Canopy Height [m]
0
50
NASA

Imaging spectroscopy for plant canopy functional traits

Functional Trait	Units	Normalized Uncertainty, Retrieved (Singh et al 2015)
LMA	g/m^2	11%
Nitrogen	% dry mass	16%
Chlorphyll	ng/mg	8%
Lignin	% dry mass	12%
Phosphorus	% dry mass	16%





Technical challenges

Uncertainty quantification: To distinguish real phenomena, and combine observations from multiple sources in model statistical and data assimilation models, the uncertainty of each observation must be well-quantified, so as to balance its influence against other sources of information.

Algorithm development: Algorithms for new satellite observables can be extraordinarily complex, and their development constitutes a field in itself. In many cases, the usability of satellite data products depends directly on how the data were processed.

Modeling and Data integration: The seamless fusion of new global satellite observations, in situ measurements and modeling of biology is key to the success of global ecology, combining observations of different processes and at different scales.

Prediction: Policy and management depend on forecasting of global and regional change, to inform carbon management and to ensure skillful simulation of Earth System feedbacks.

Watersheds in the sky

Storage = Precipitation – Evapotranspiration – Runoff

All now measurable at some scales from space

And storage includes

Storage = Plant water + Soil water + Groundwater + Surface Inundation + Snow and ice

All now measurable at some scales from space