Progress in Understanding Natural Carbon Fluxes with Decade-long OCO-2/3 Observations

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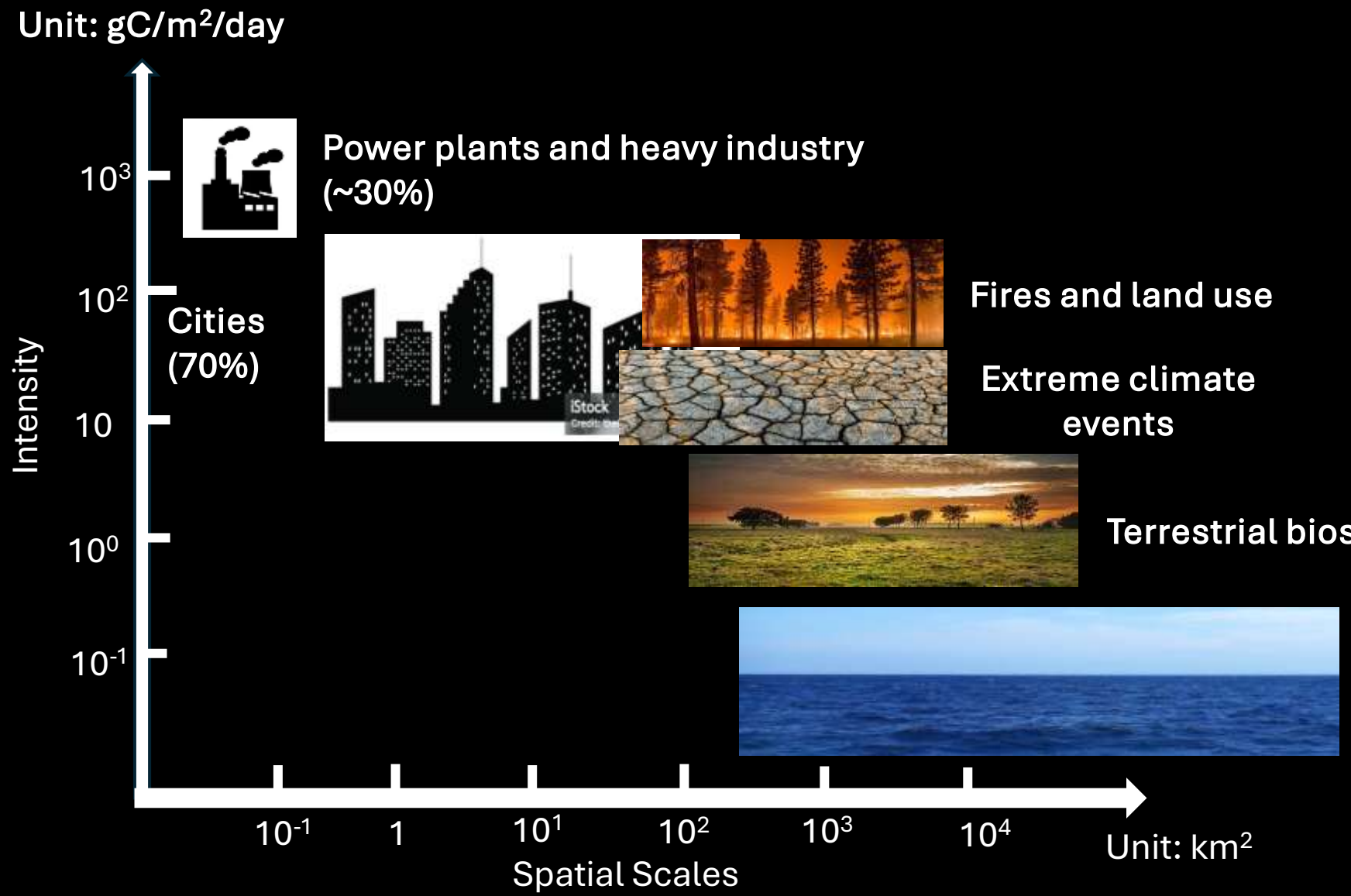
The 21th IWGGMS meeting

June 11th, 2025

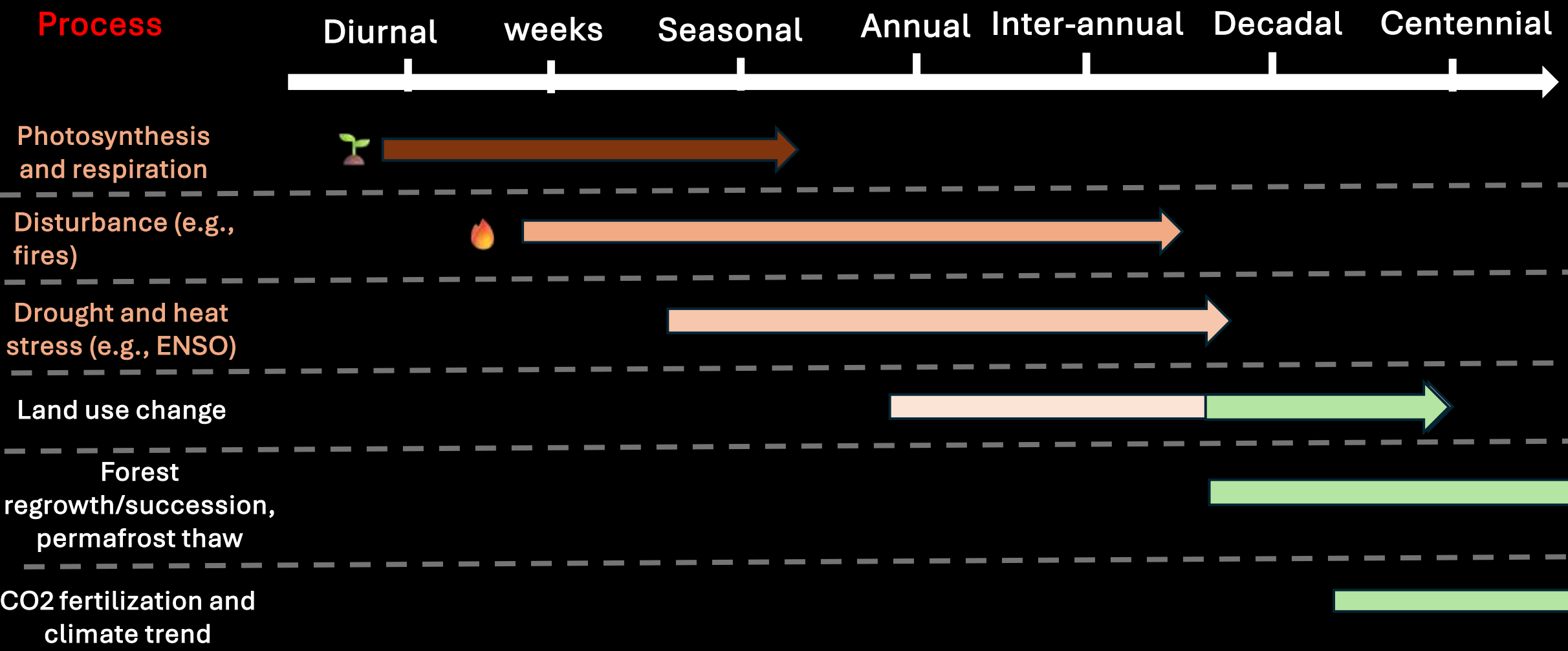
Large Ranges in Spatial Scales and Magnitudes among Major Sources and Sinks of CO_2



Small footprint size allows OCO-2/3 to detect emissions from isolated point sources and urban emissions.

The global coverage and high accuracy and precision allow OCO-2/3 to capture the signals from natural carbon fluxes.

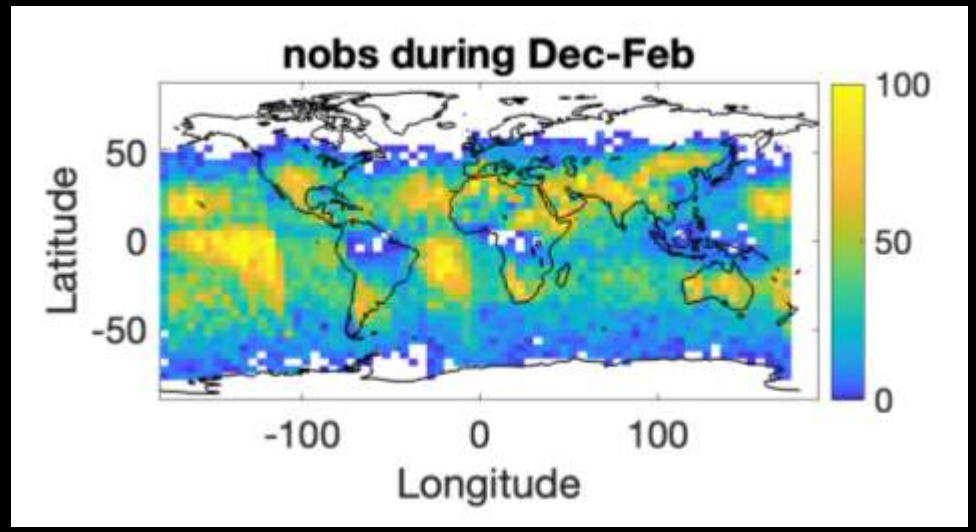
Major Carbon Processes and its Temporal Scales

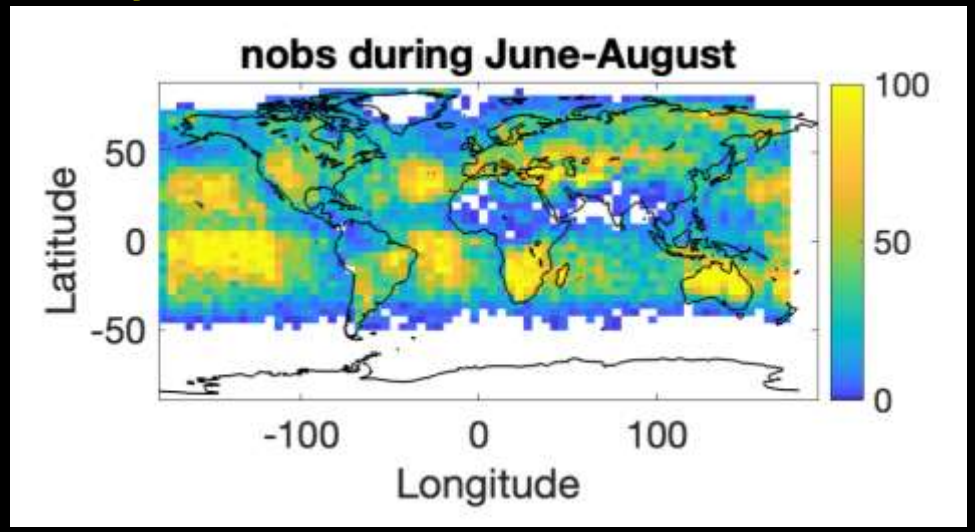


- Longer record of OCO-2/3 enables the community to better understand carbon cycle processes spanning a wide range of temporal scales

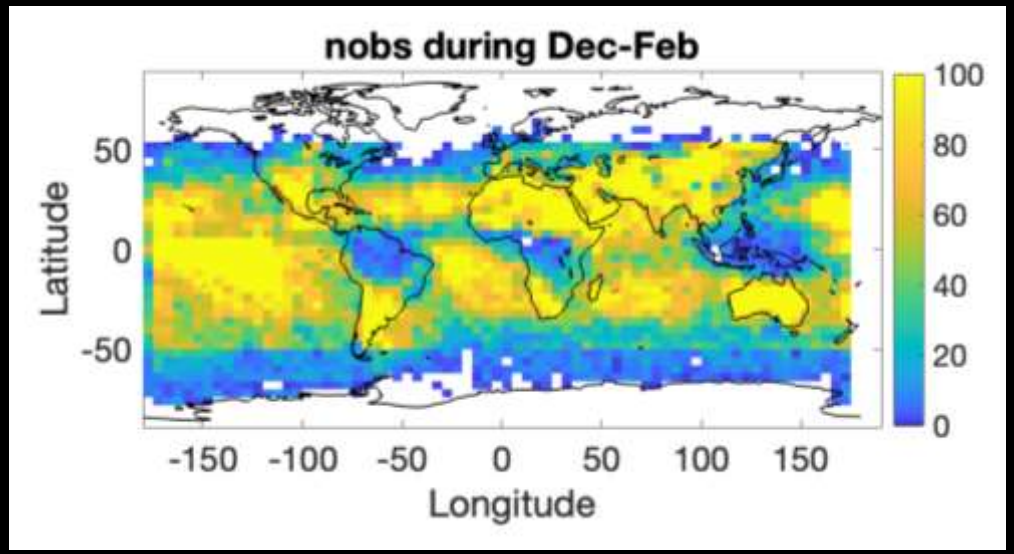
OCO-2/3 Fill Observational Gaps of Surface Observation Network

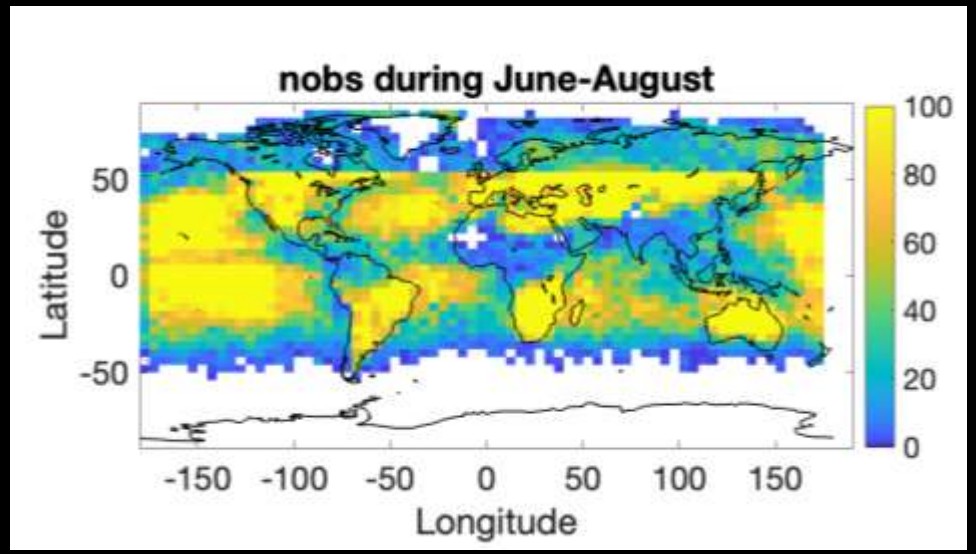
Number of Good Quality 10-sec OCO-2 obs



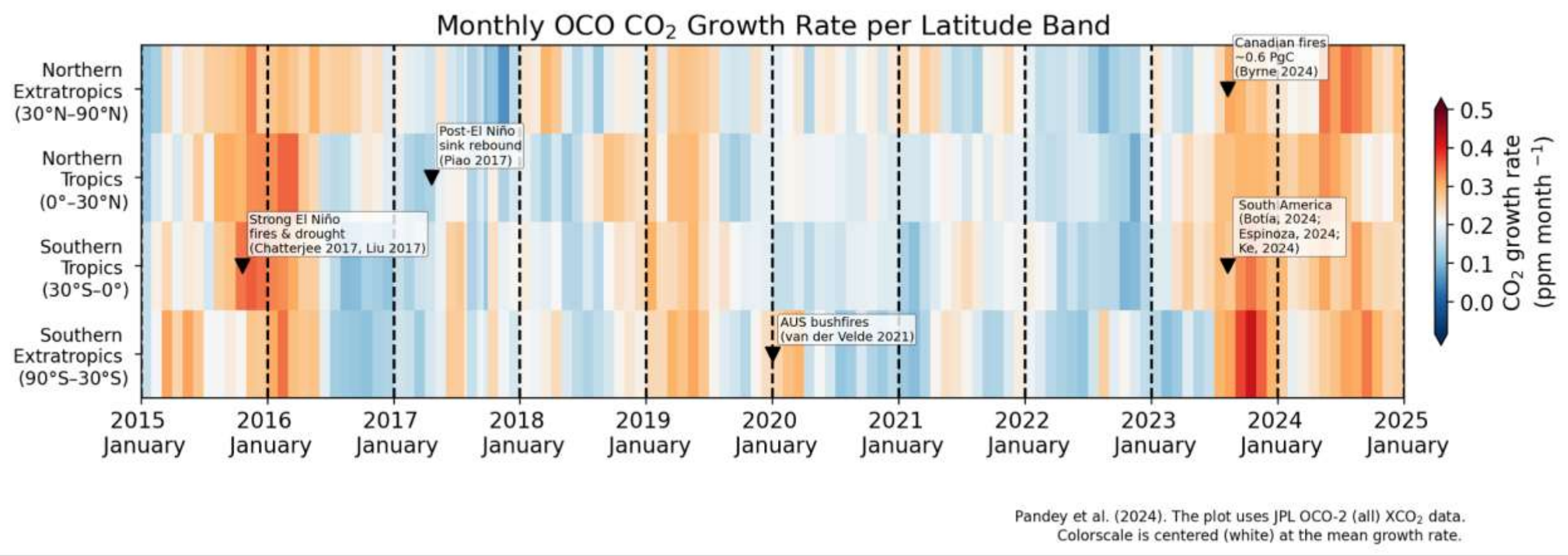


OCO-2 + OCO-3





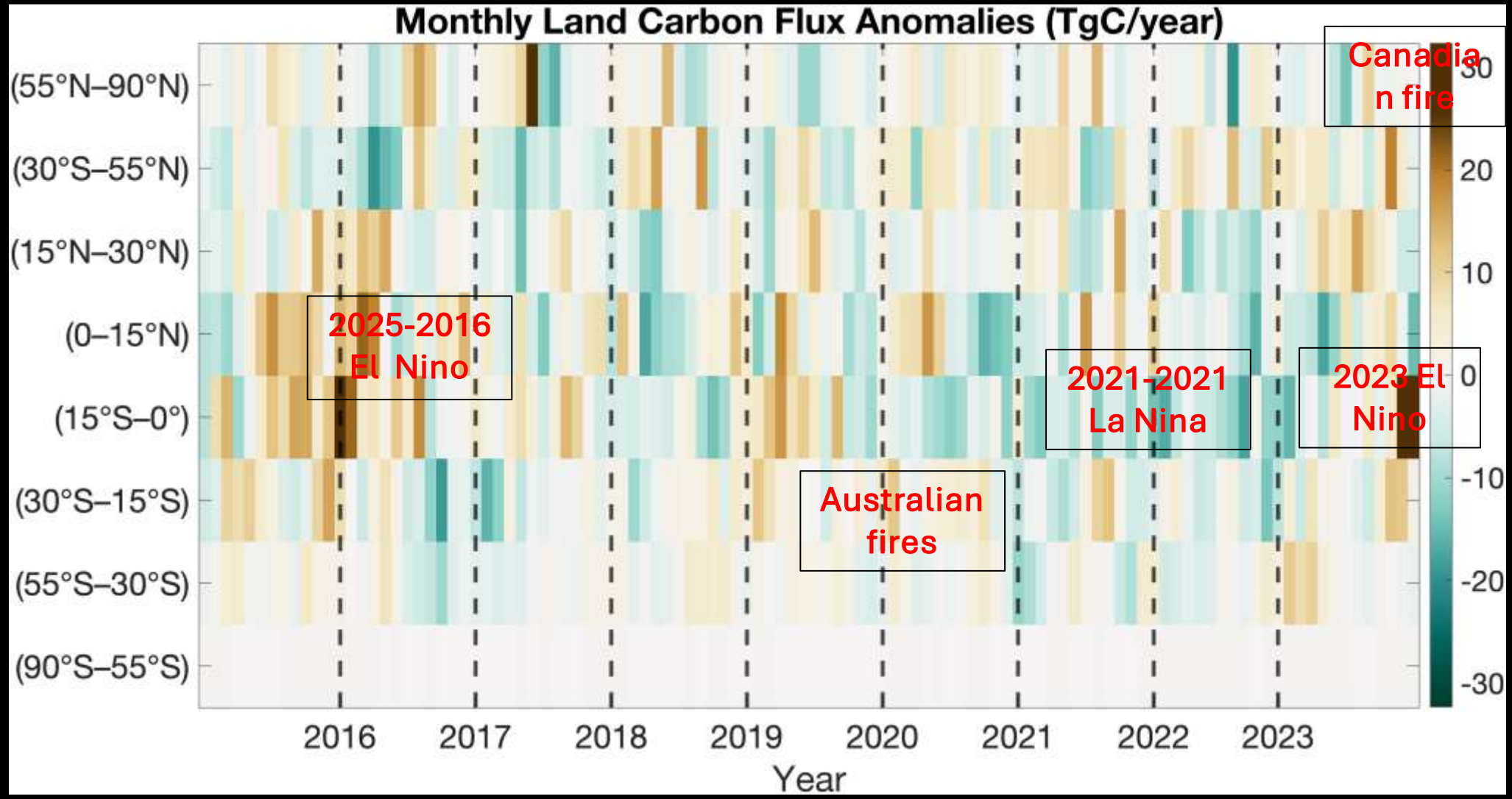
Global OCO-2 Observation Coverage Enables Low-Latency Monthly Latitudinal CO_2 Growth Rate Calculation



- The monthly latitudinal growth rate reveals the impact of several extreme climate events on CO2 growth.

S. Pandey et al., in preparation

Latitudinal Net Biosphere Exchange Anomalies

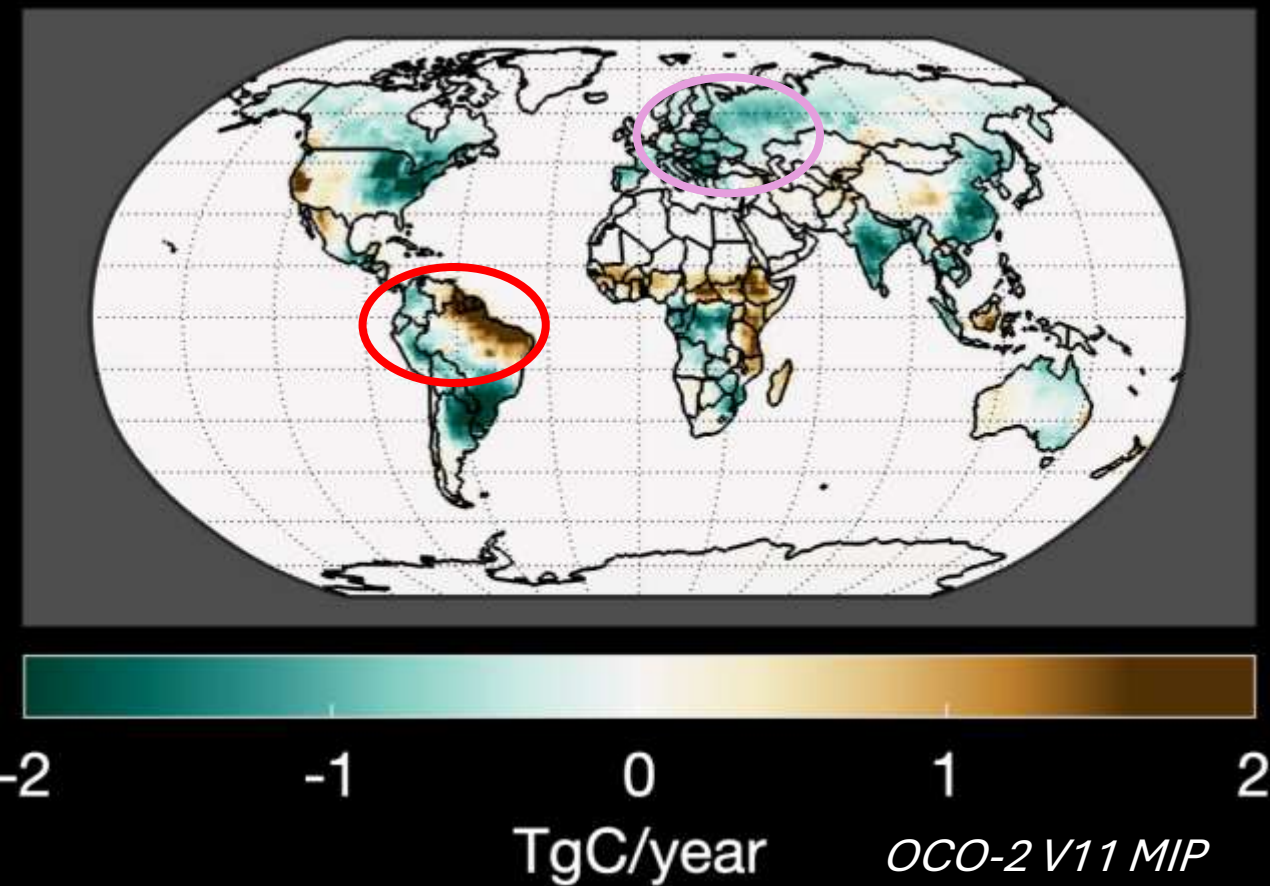


OCO-2 V11 MIP

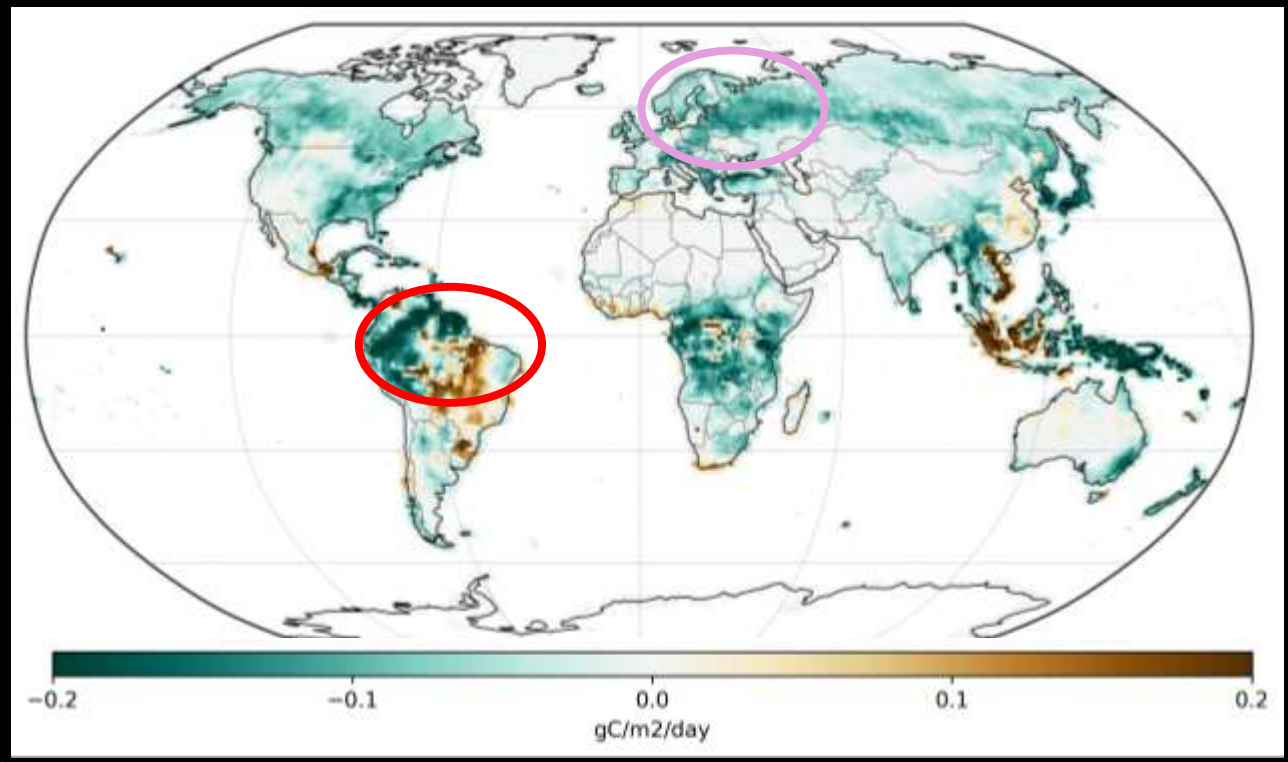
- Top-down inversions attribute the observed CO2 changes to underlying surface fluxes, showing how natural carbon cycle responds to climate anomalies.

Spatial Distributions of Net Biosphere Exchange

Mean Net Biosphere Exchange (2015-2022)

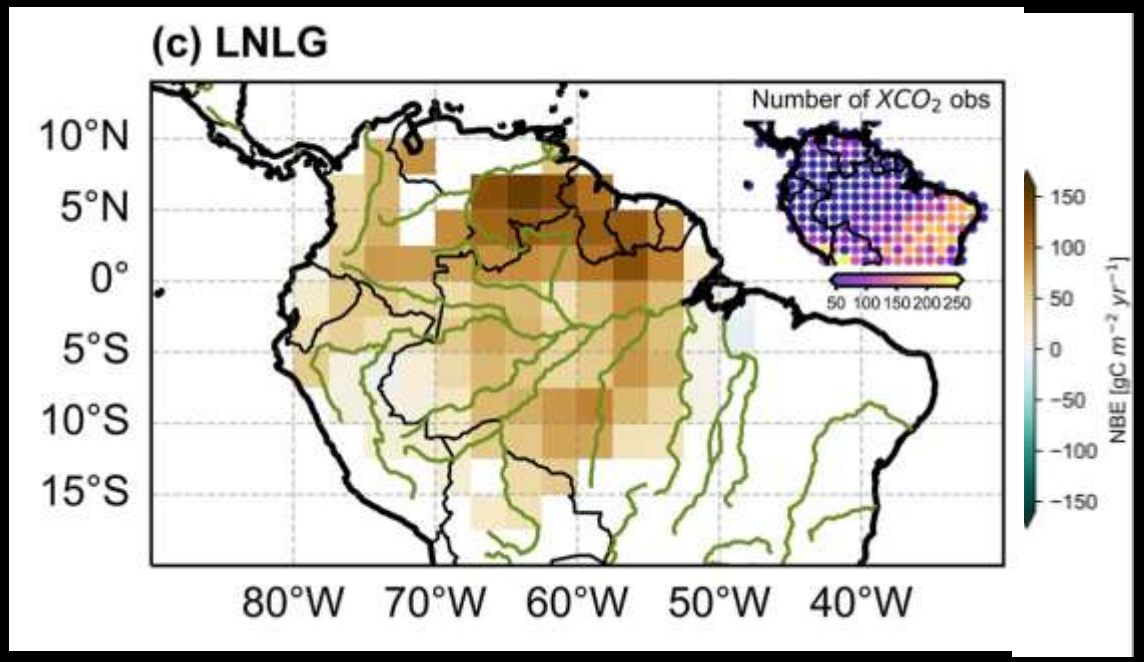


TRENDY (GCP-2023)



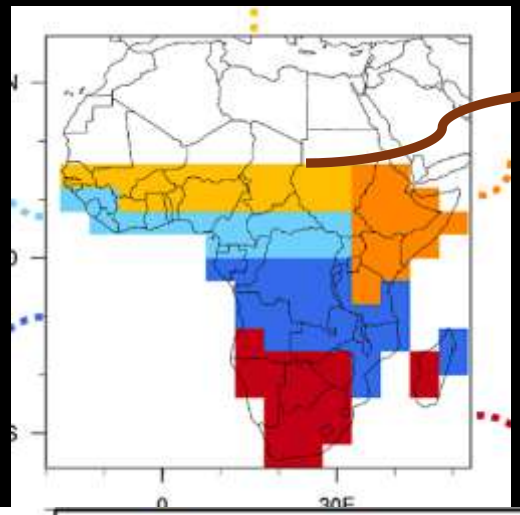
- Large carbon sink over northeast NA, Europe, Asia, Congo Basin, and southern hemisphere mid latitudes;
- Source over N-Africa, northeast Brazil, western US.

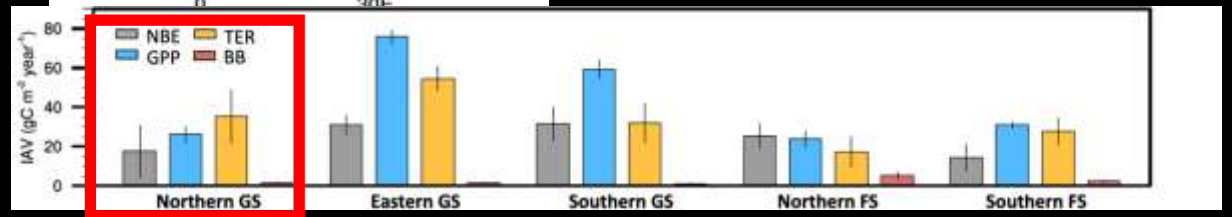
Process Understanding of Tropical Carbon Cycle

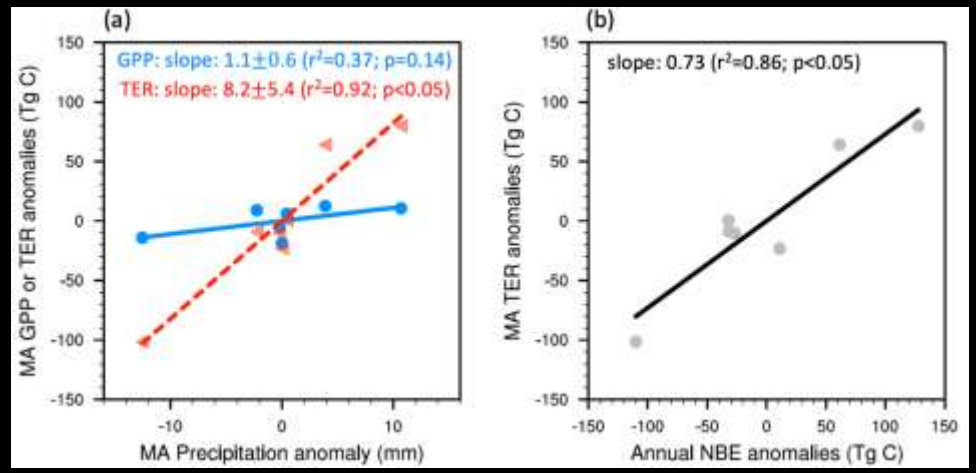


Wang et al., 2023

- Revealed regional difference in the response to 2015-2016 El Nino over tropical South America
- The much stronger sensitivity of respiration to precipitation during late dry season drives the IAV of NBE over northern grassland in Africa.

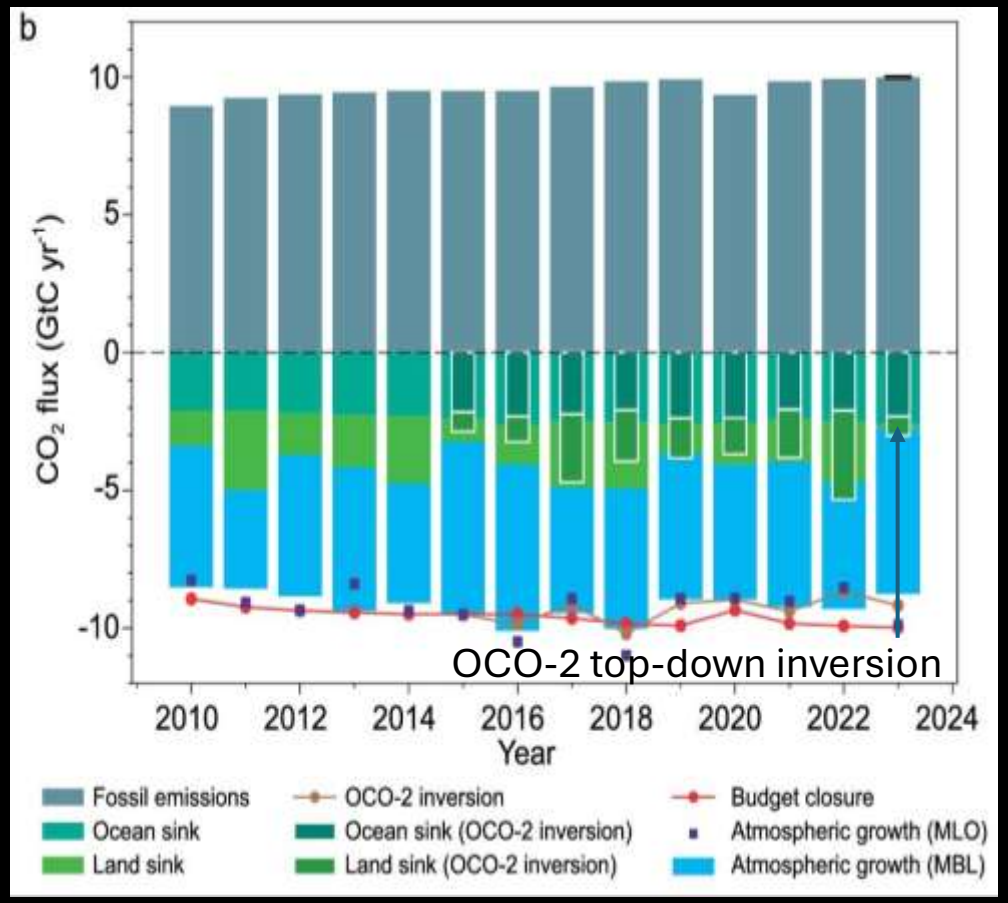




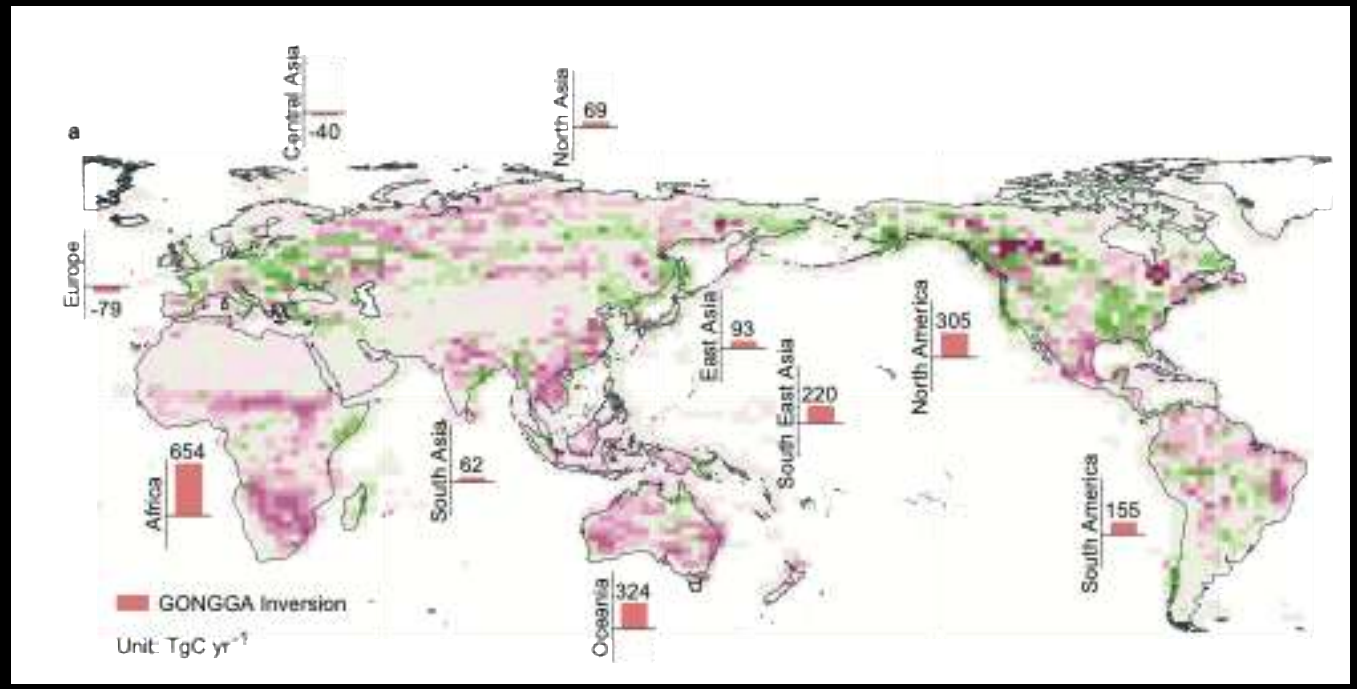


Yun et al., 2025, minor revision

OCO-2 Data Allows Low Latency Carbon Budget Calculation



2023 flux anomalies inferred from OCO-2 based top-down inversion

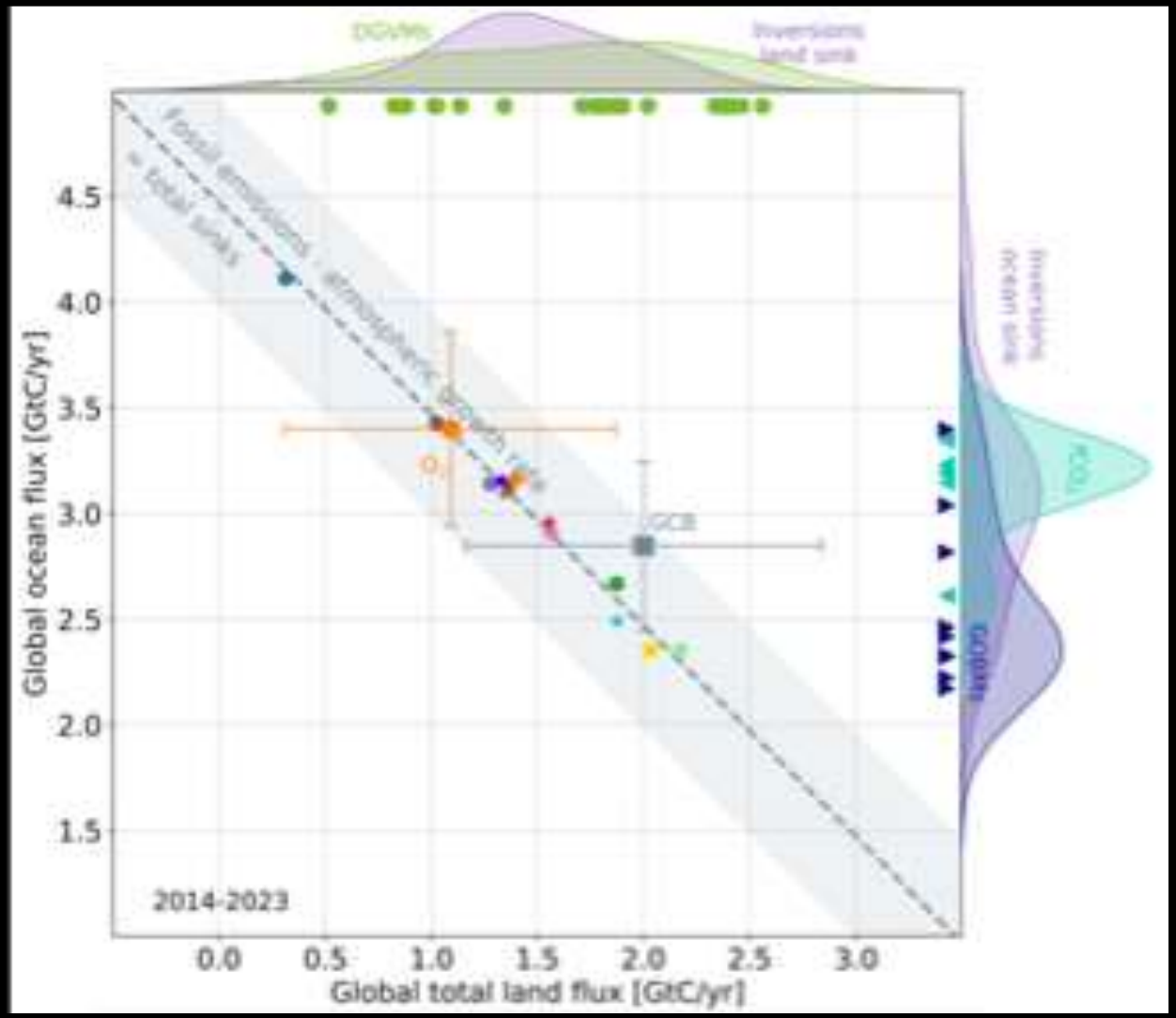


- Retrospective OCO-2 is available in about a month.
- The preprint on 2023 carbon budget based on OCO-2 XCO2 was published in June 2024, and the final publication in Oct 2024.

Ke et al., 2024, Gui et al., 2024

Contributions to Global Carbon Project Annual Carbon Budget Report

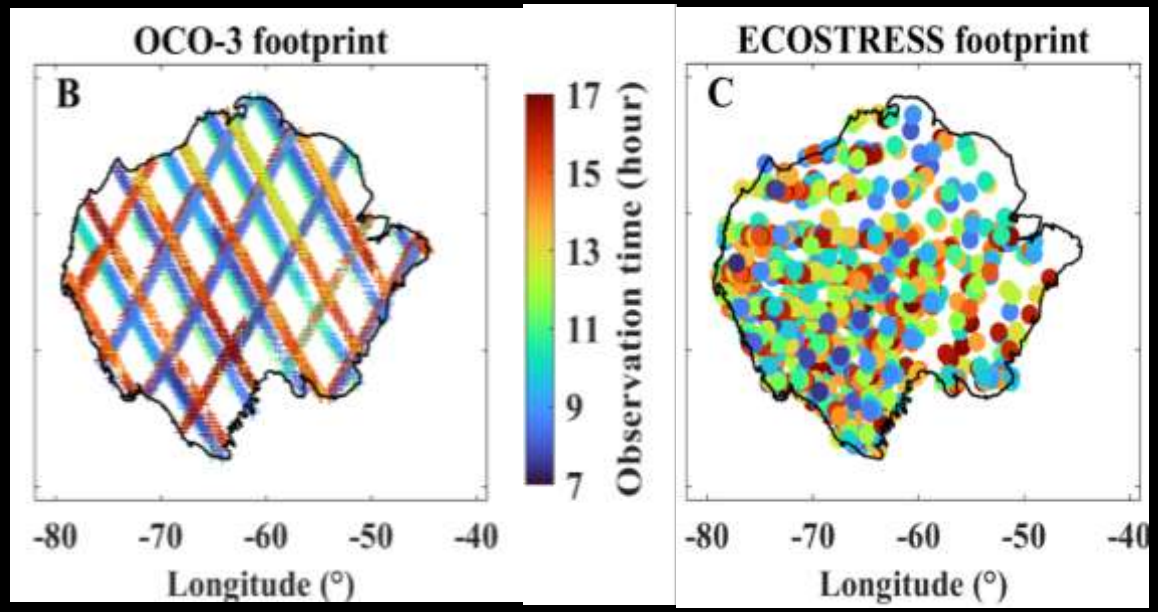
2014-2023



- The annual carbon budget report by GCP is widely used by scientific community and policy makers.
- Five out of 14 models assimilated OCO-2 observations in the most recent GCP atmospheric inversions
- The OCO-2 based inversion results will be included in the main figure this year, as the OCO-2 record reaches 10-year milestone.

OCO-3 SIF and ECOSTRESS ET Enables Quantification of Diurnal Changes of Photosynthesis, ET, and WUE

Local Observing Time

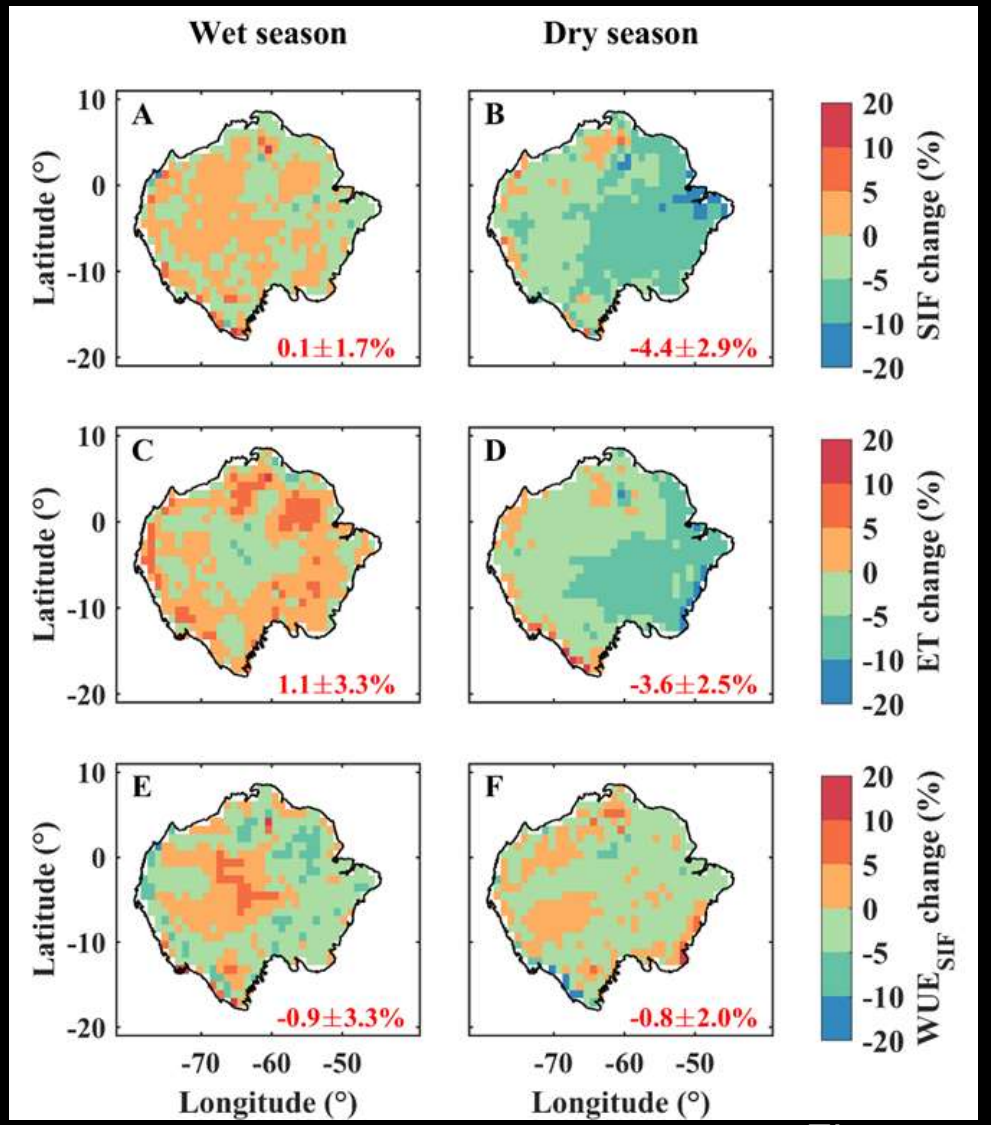


OCO-3 Footprint： Jan – Feb, 2020

ECOSTRESS Footprint ： July 2018 – Sept. 2020

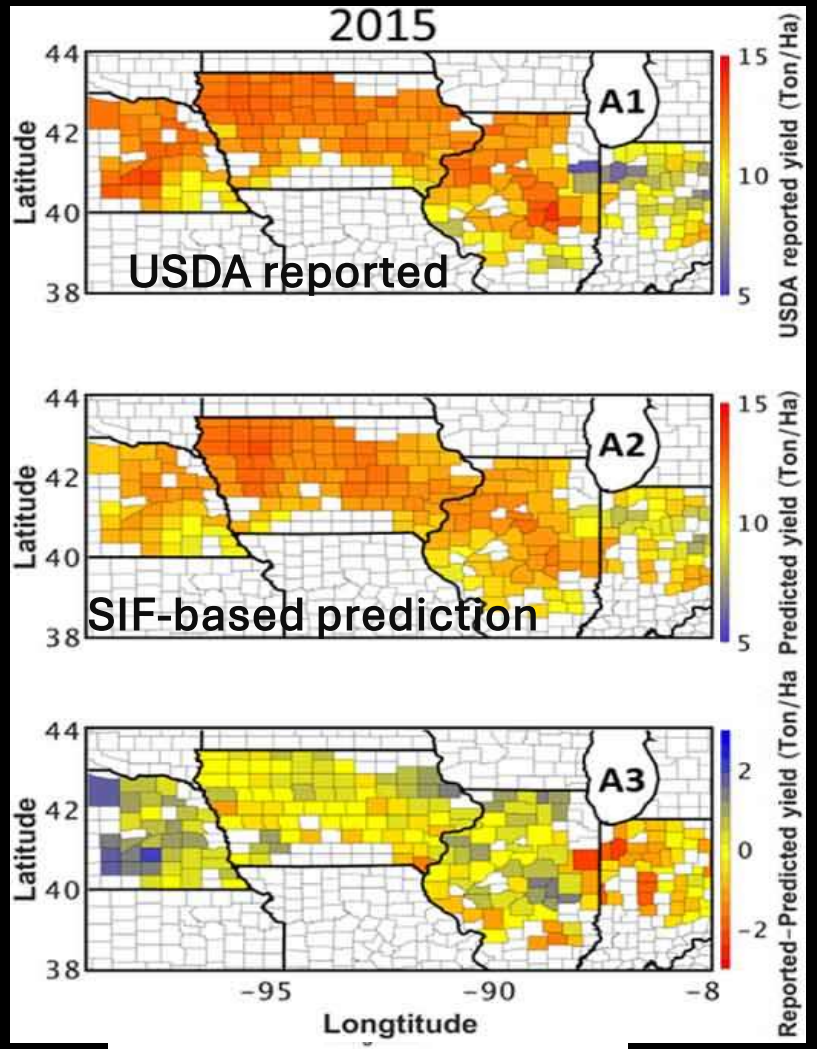
- **Wet season**: no significant difference between morning and afternoon photosynthesis. ET increase
- **Dry season**: SIF and ET decrease in the afternoon.

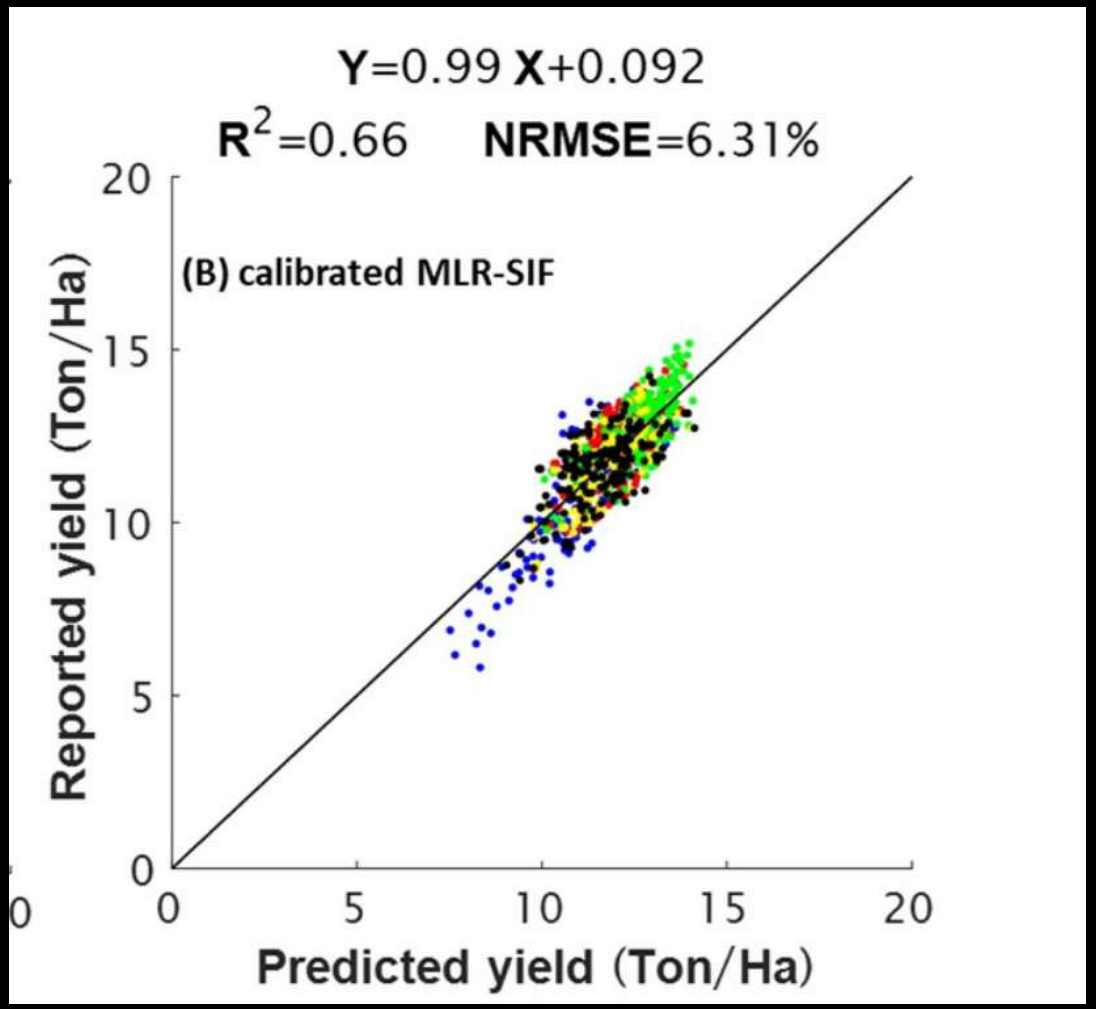
Afternoon-Morning



Zhang et al., 2023

Crop Yield Prediction



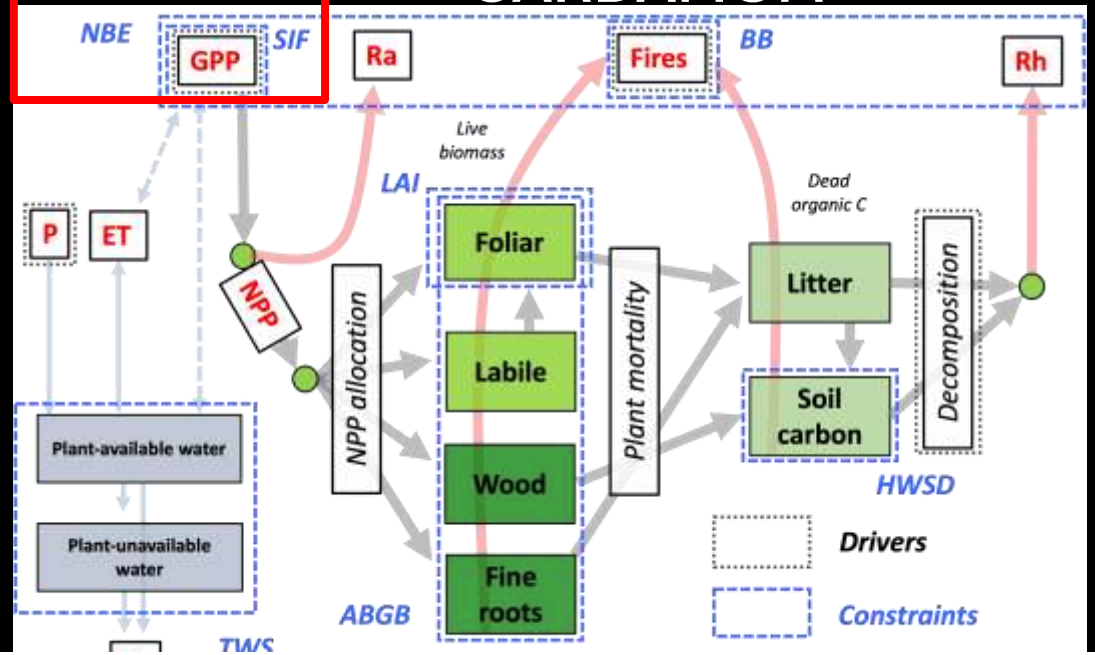


- OCO-2 SIF-based crop yield prediction reproduces both spatial gradient and temporal variability.
- Accurate low-latency crop yield prediction is critical to help forecast disruptions in food supply.

Kira et al., 2024

Improve Process Representations and Predictions with OCO-2 Inferred Fluxes

CARDAMOM



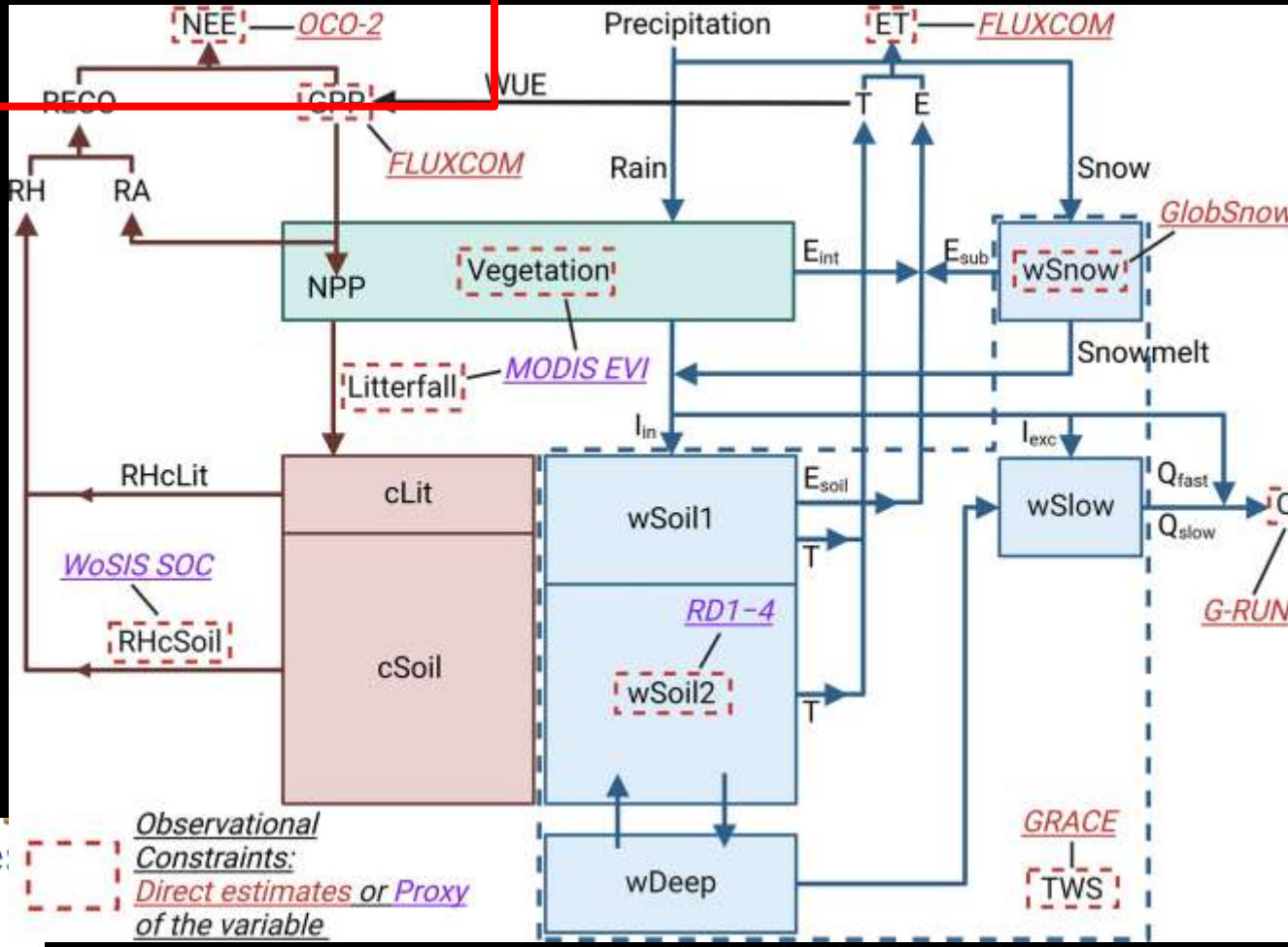
Water Stress Dominates 21st-Century Tropical Land Carbon Uptake

Paul A. Levine[1], A. Anthony Bloom[1], Kevin W. Bowman[1], John T. Reager[1], John R. Worden[1], Junjie Liu[1], Nicholas C. Parazoo[1], Victoria Meyer[1], Alexandra G. Konings[2] and Marcos Longo[1,3]

Respiration Response to CO_2 Fertilization Shifts Regional Distribution of the Carbon Sink

Gregory R. Quetin[1,2], Caroline A. Famiglietti[1], Nathan C. Dadap[1], A. Anthony Bloom[3], Kevin W. Bowman[3,4], Noah S. Diffenbaugh[1,5], Junjie Liu[3,6], Anna T. Trugman[2], and Alexandra G. Konings[1,5]

SINDBAD



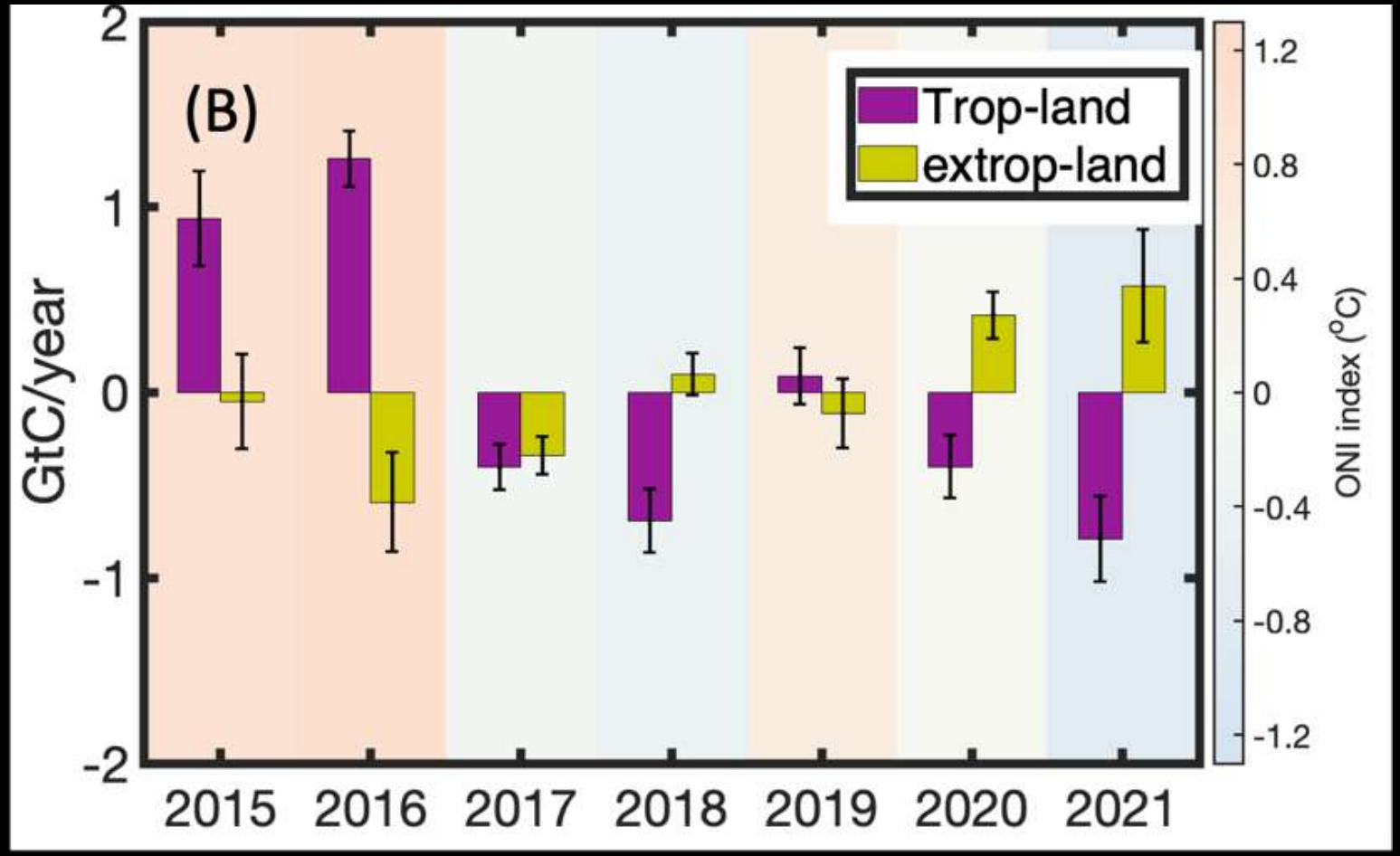
Bloom et al., 2019; Lee et al., 2025

Concluding Remarks

- **The scientific value of OCO-2/3 data is increasing with a longer record:**
  - **Global OCO-2 observational coverage allows low-latency monthly latitudinal CO_2 growth rate calculation.**
  - **New insights on the spatial and temporal variability of natural carbon sinks.**
  - **Increasing use in GCB and low latency estimates of the response of natural carbon cycle to climate anomalies.**
  - **SIF-related applications: low-latency SIF-based crop-yield predictions , drought monitoring, recovery from fires.**
  - **Constraining biogeochemical models.**

It Takes More Than a Village…

The Flux Anomalies over the Tropics and Extra-tropical Land

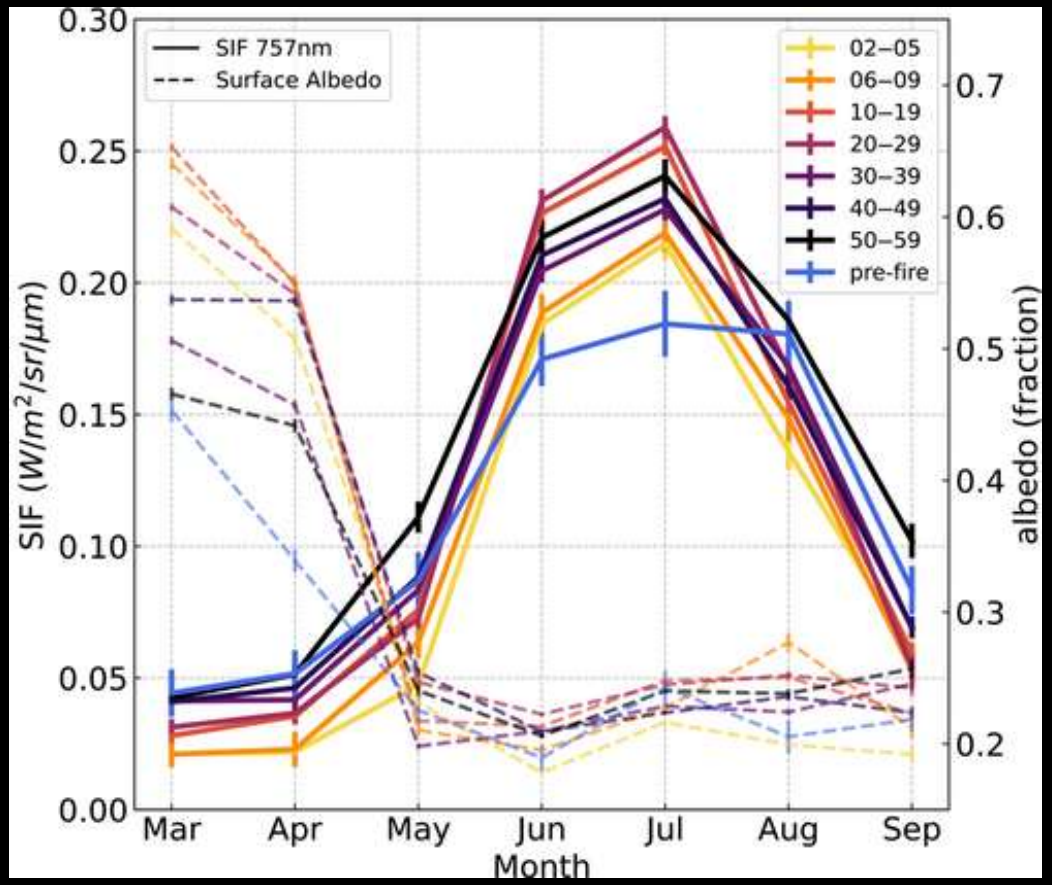


- Extra-tropics shows weaker carbon sink in recent years.
- Requires longer record to detect trends

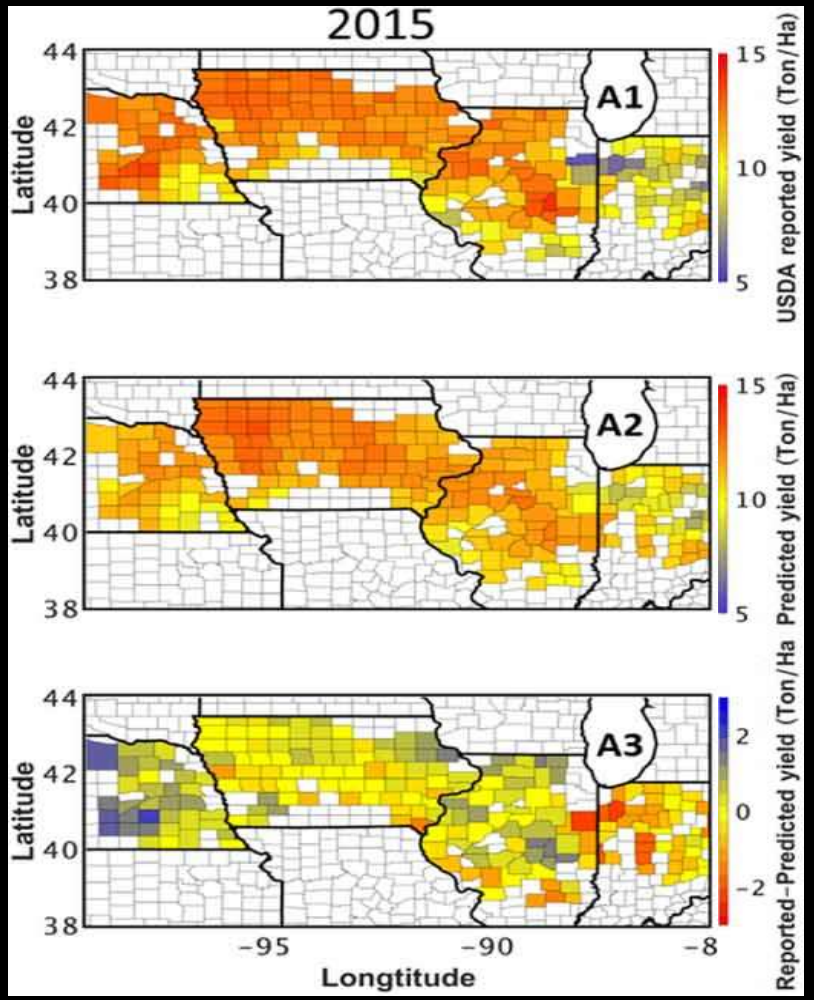
Liu et al, 2024

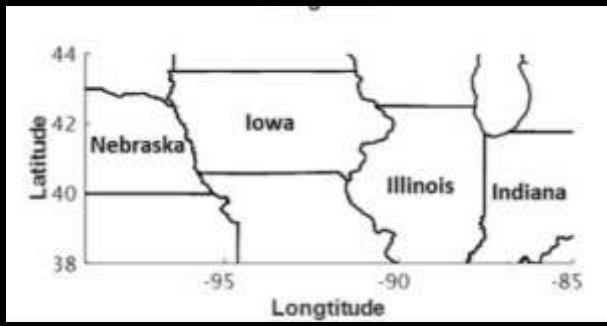
Recovery from Wildfire over Boreal Region and Crop Yield Prediction

The annual cycle of OCO-2 SIF and albedo as a function of post-fire stand age in western boreal North America.



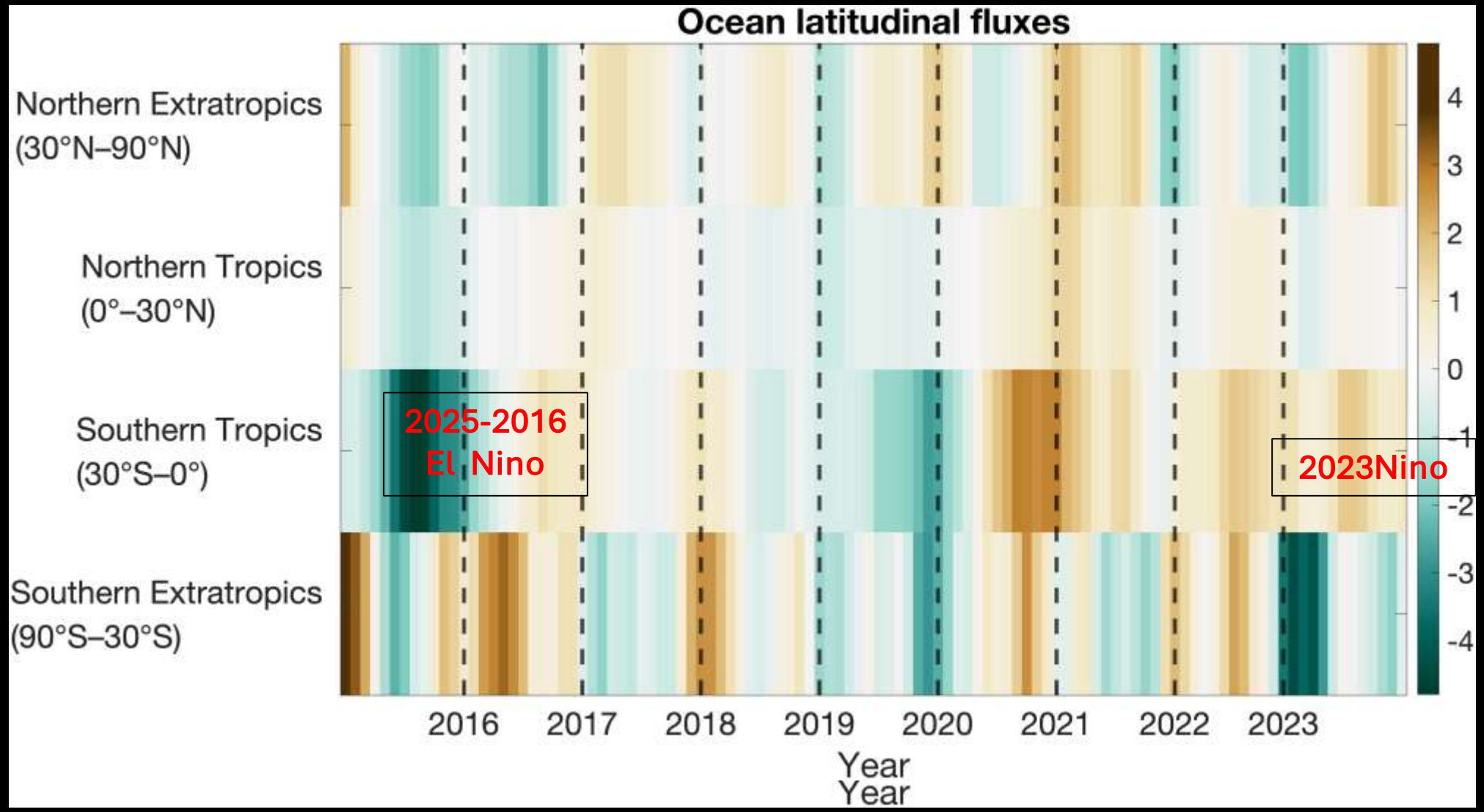
- SIF increases considerably in 2-59 year post fire stand classes in mid-summer, with greater enhancements in the 20-40 year stands.





Kim et al., 2024;
Kira et al., 2024

Monthly Air-Sea Net Carbon Flux Anomalies



- About an order of magnitude smaller than land carbon flux IAV