Investigating anomalous growth of atmospheric CO_2 in 2023–2024 using GOSAT XCO_2–constrained inverse modeling

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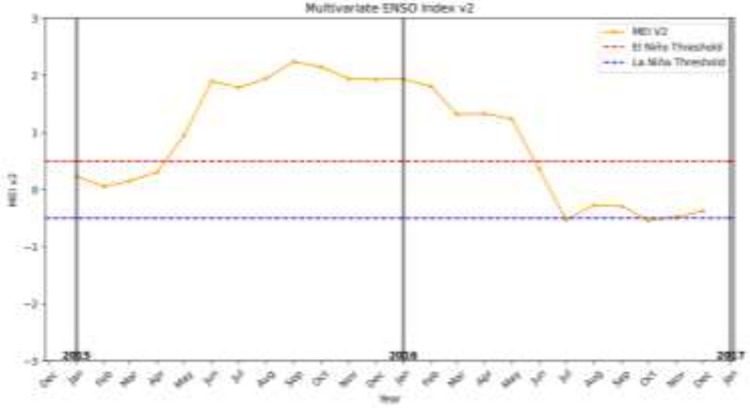
Outline

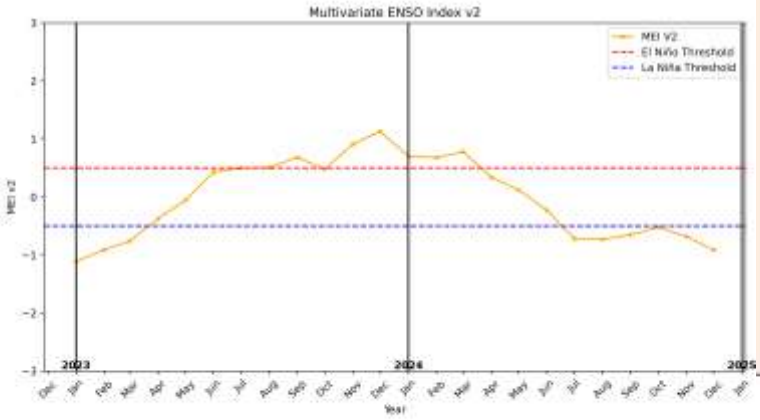
1. Background
2. Scientific Question
3. Model Details
4. Numerical Experiments and Data used
5. Results
6. Summary

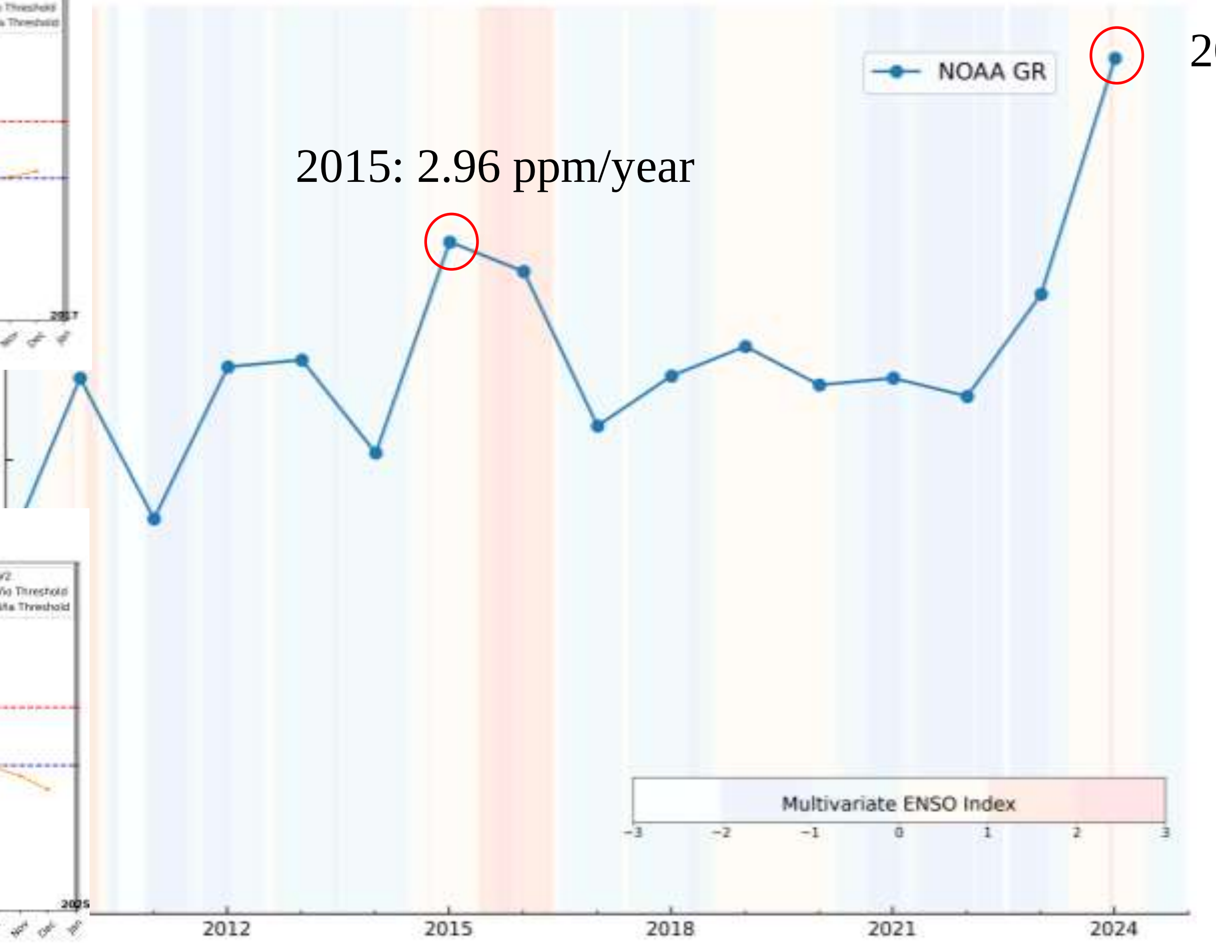
Background

El Niño 1: 2015–16



El Niño 2: 2023–24





2015: 2.96 ppm/year

2024: 3.77 ppm/year

El Niño
affect
CO_2 growth rate?

NOAA GR: Lan et al. (2025)

Courtesy
MEI v2: https://psl.noaa.gov/enso/mei/

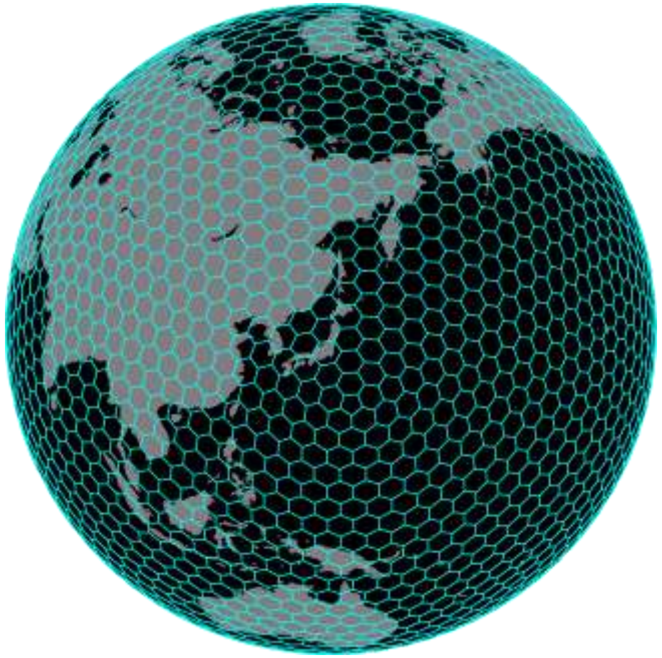
Scientific Questions

- ☞ What are the dominant drivers of this high growth rate?
- ☞ What ways, it (2023–24) differs with the earlier El Niño (2015–16)?
- ☞ What do flux estimate suggest about the regional contribution to this elevated growth rate?

Model details (NISMON-CO_2)

NICAM-based Transport Model (**NICAM-TM**: Niwa et al., 2011)

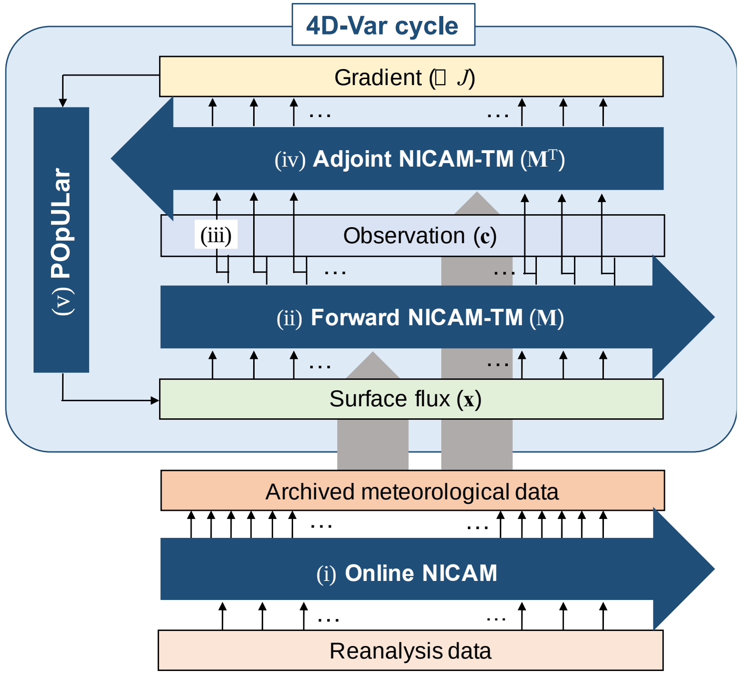
NICAM (Icosahedral) grid



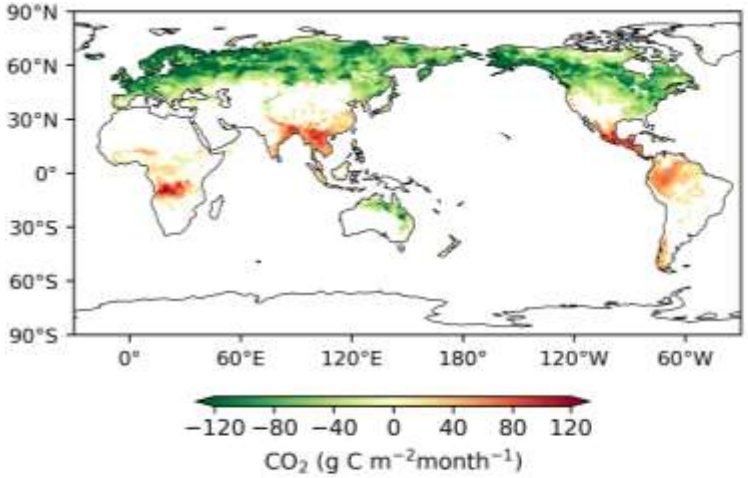
NICAM is a **mass-conserving** icosahedral model (Satoh et al., 2014).

NICAM-based **I**nverse **S**imulation for **Mon**itoring CO_2 (**NISMON-CO_2**)

Inversion based on the 4D variational method



NICAM-TM runs with **~223km,** but fluxes are optimized on **1°×1°**



Posterior non-fossil flux (July 2024)

Niwa et al., JMSJ (2011); Satoh et al., PEPS (2014); Niwa et al., GMD (2017a,b), PEPS (2022)

Slide prepared by Y. Niwa

Numerical experiments and data used

Numerical experiments is conducted using the following dasets:

Apriori Flux:

- ***Fossil Fuel:*** *Gridded Fossil Emission Dataset (GridFED).*
- ***Ocean:*** *air-sea exchange flux data from Japan Meteorological Agency (JMA).*
- ***Biosphere:****VISIT (Vegetation Integrative SImulator for Trace gases).*
- ***Biomass burning:*** *Global Fire Emissions Database (GFED).*

Meteorological data:

Japanese Reanalysis for Three Quarters of a Century (JRA-3Q) from JMA.

Experiment duration: *January 2009 – December 2024.*

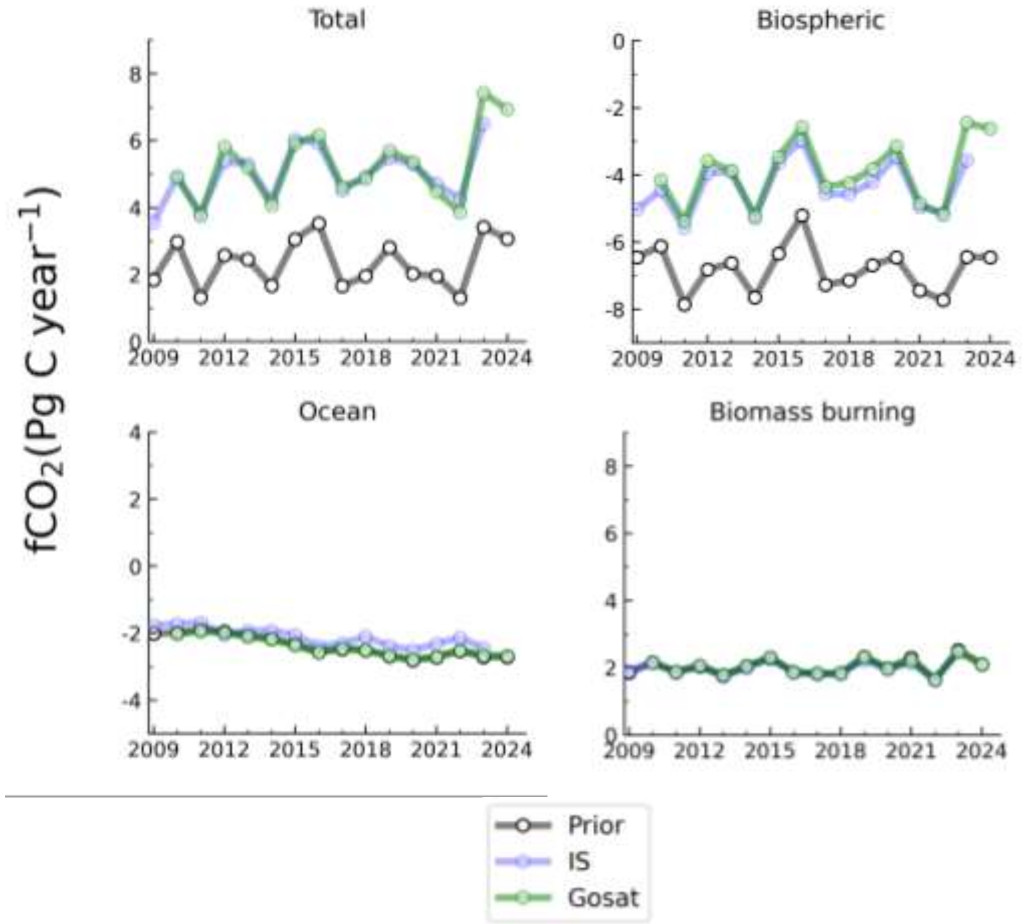
Observation data:

Column-averaged dry air mole fraction of CO_2 (XCO_2) from Greenhouse gases Observing SATellite (GOSAT) measurements (Version – 0305 but excluding SunGlint data) stored in National Institute for Environmental Studies (NIES) Level 2 product.

Period: *April 2009 – December 2024*

***Analysis period:** 2010–2024*

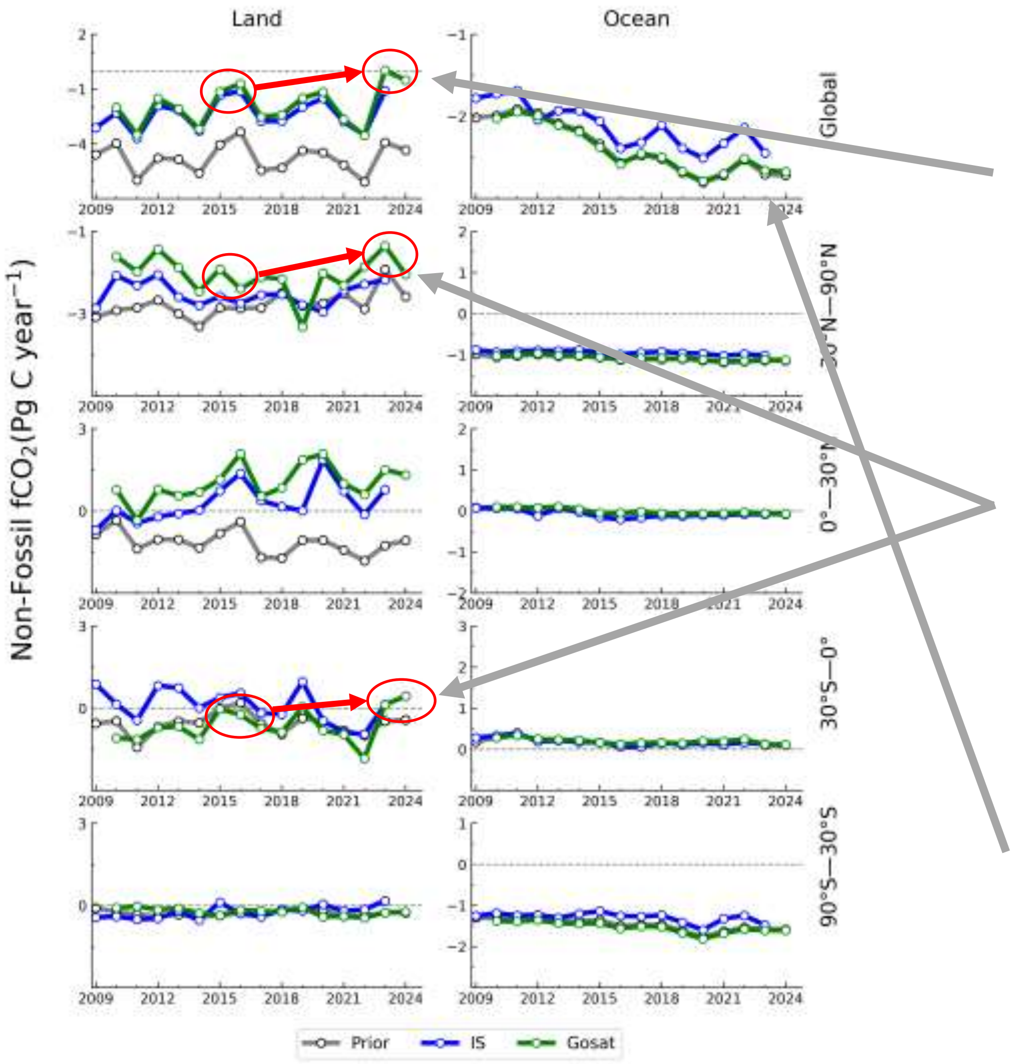
Results: Global Total IAV



- Posterior flux using GOSAT data consistently follows that of using In-Situ observation (IS), indicating robustness of the global flux estimates.
- Inversion flux is observation-independent (GOSAT and IS).

Maity et al., 2025 (in preparation)

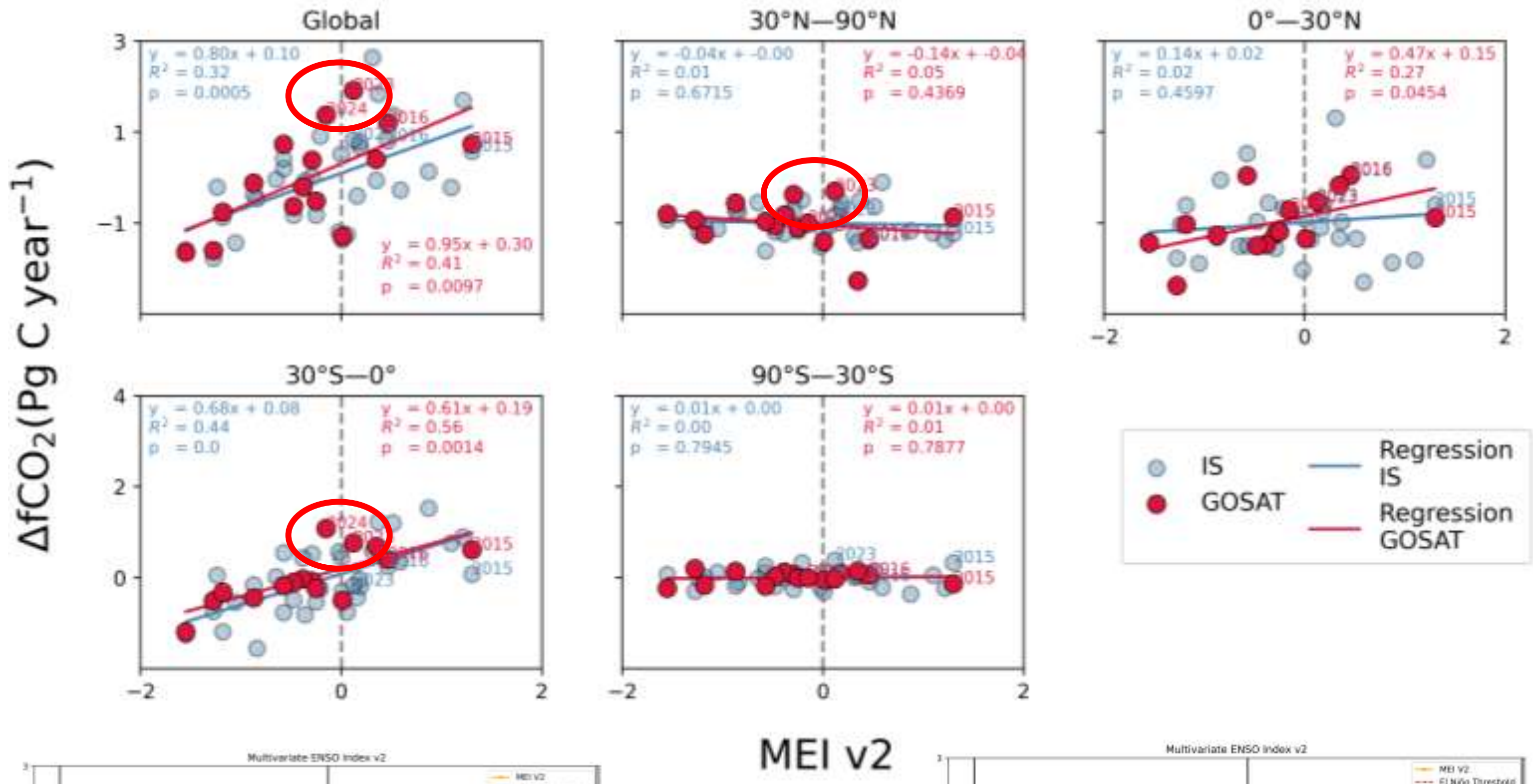
Results: Flux distribution over lat. bands

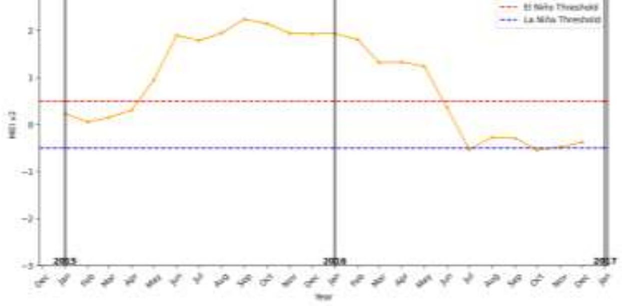


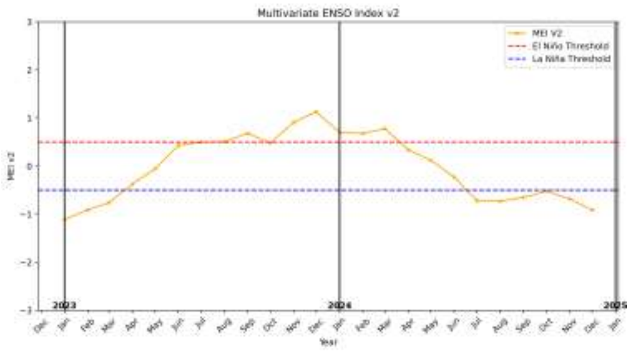
- Weaker global land sink in El Niño 2 (more in GOSAT fluxes), contributing this high atmospheric growth rate.
- It is predominantly because of reduced land uptake over northern hemisphere and southern tropics.
- Ocean sink remained relatively stable/slightly strengthened.

Maity et al., 2025 (in preparation)

Results: Regression with MEI







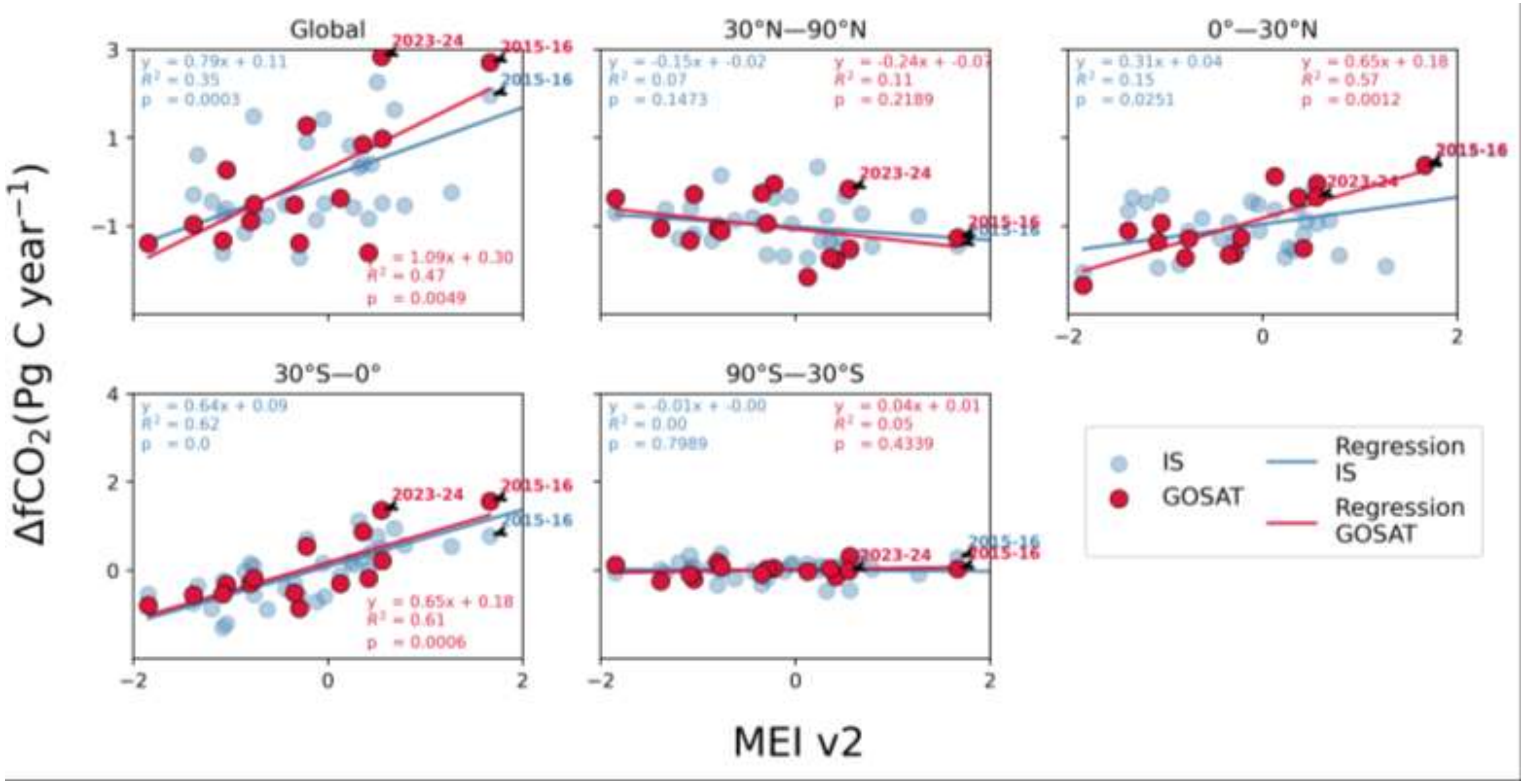
△fCO2: Annual anomaly

2023 and 2024 MEI V2 values are neutral??

The MEI v2 time series for El Niño 1 is skewed while El Niño 2 is mostly flat; as a result, annual averaging in El Niño 2 suppress the anomalous signal, yielding a near-neutral value.

Maity et al., 2025 (in preparation)

Results: Regression with MEI



☞ Globally, the ENSO2 induced larger fluxes compared to the regression line.

☞ ENSO-driven CO_2 flux anomalies is much stronger in the tropics.

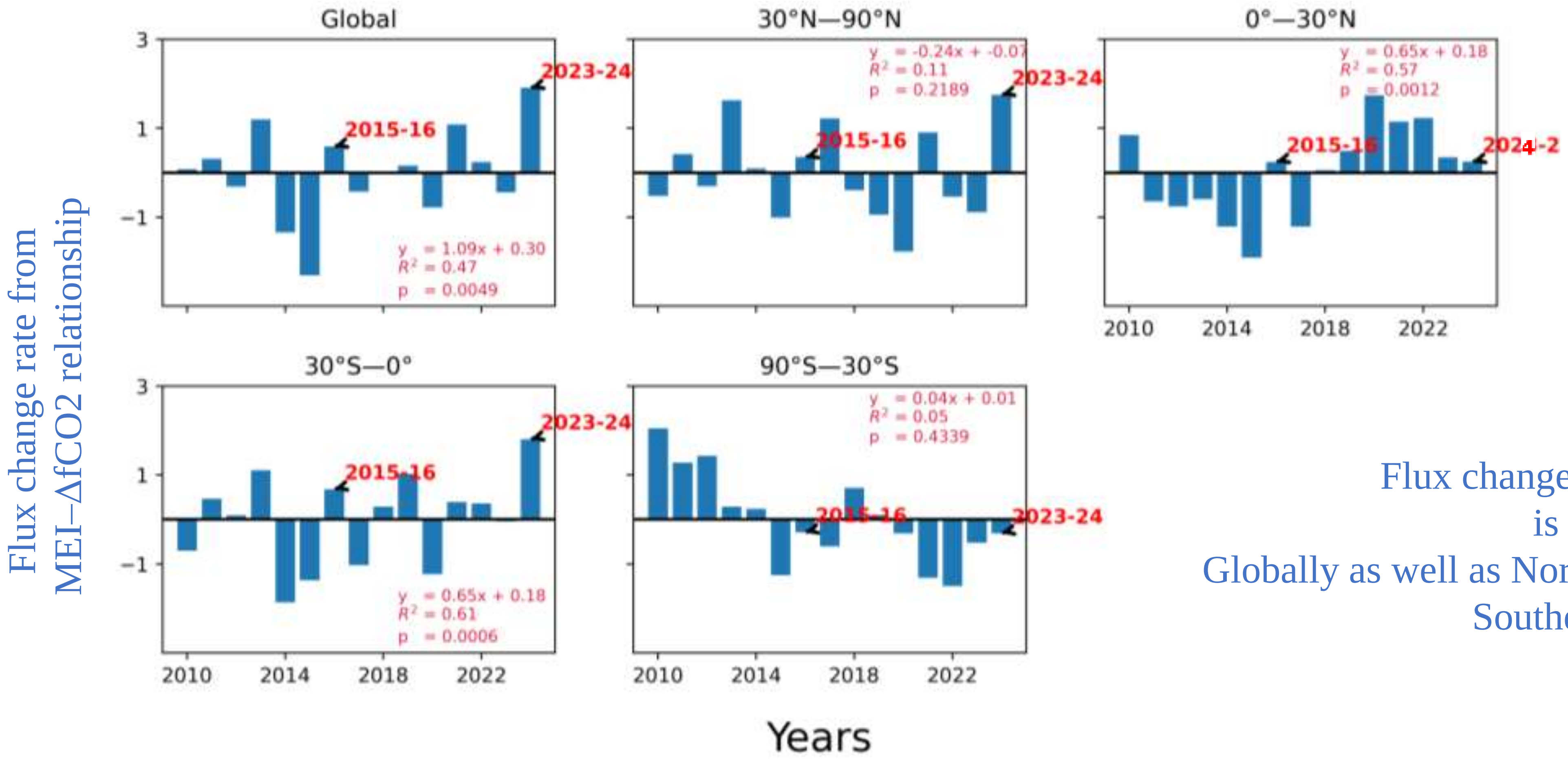
☞ In ENSO2, southern tropical land released more carbon than expected from the historical MEI–ΔfCO2 relationship (lying above the regression line), unlike ENSO1 which aligned closely with the expected response.

☞ Mid-high latitude regions remained largely insensitive to ENSO in both periods. However, northern mid-high latitude acted as a larger source in ENSO2 despite a weak MEI–ΔfCO2 relationship, whereas they were nearly neutral in 2015–2016.

Definition of the year:
2023-24 : July, 2023-June, 2024
2015-16: July, 2015-June, 2016 and so on…

Maity et al., 2025 (in preparation)

Results: Flux change rate

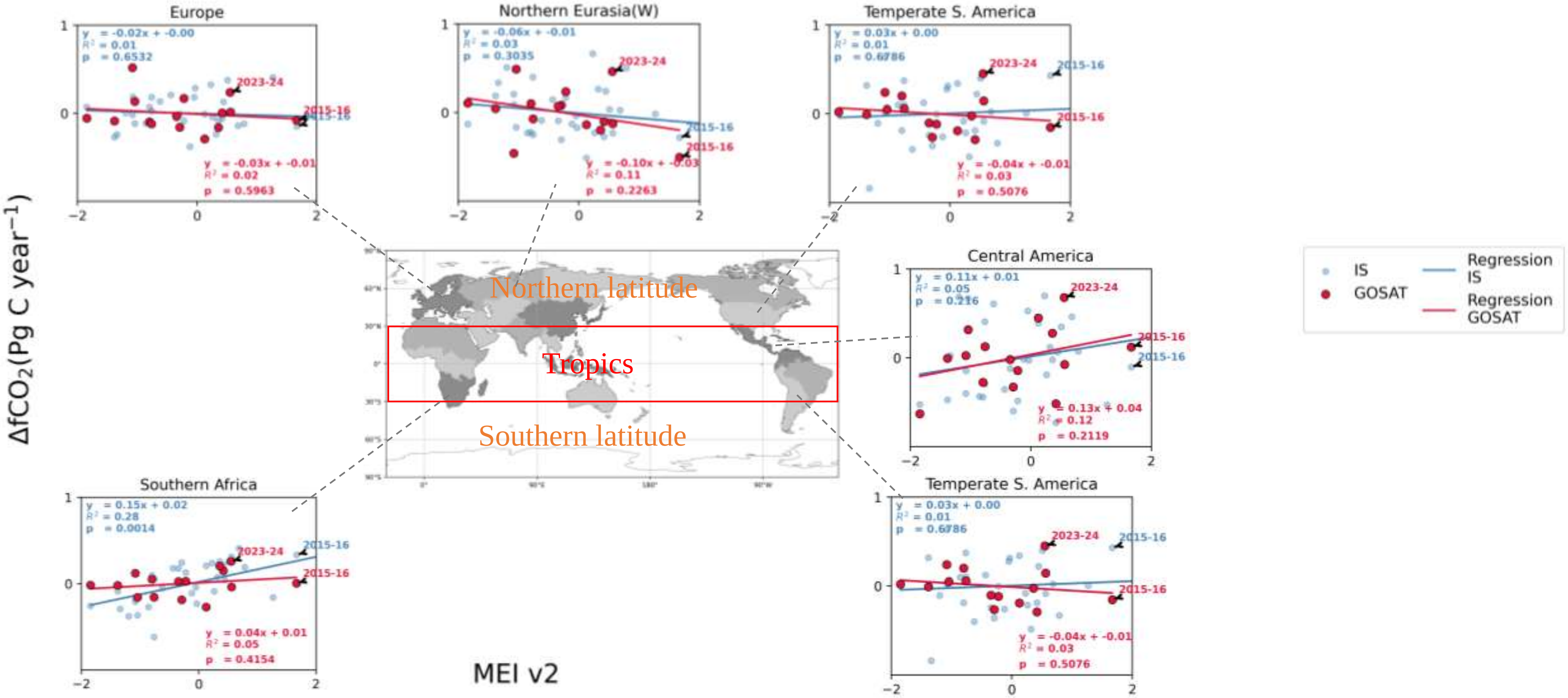


Flux change rate in 2023-24
is higher
Globally as well as Northern mid-high latitude and
Southern tropics

Standard residual = residual/std(residual)

Maity et al., 2025 (in preparation)

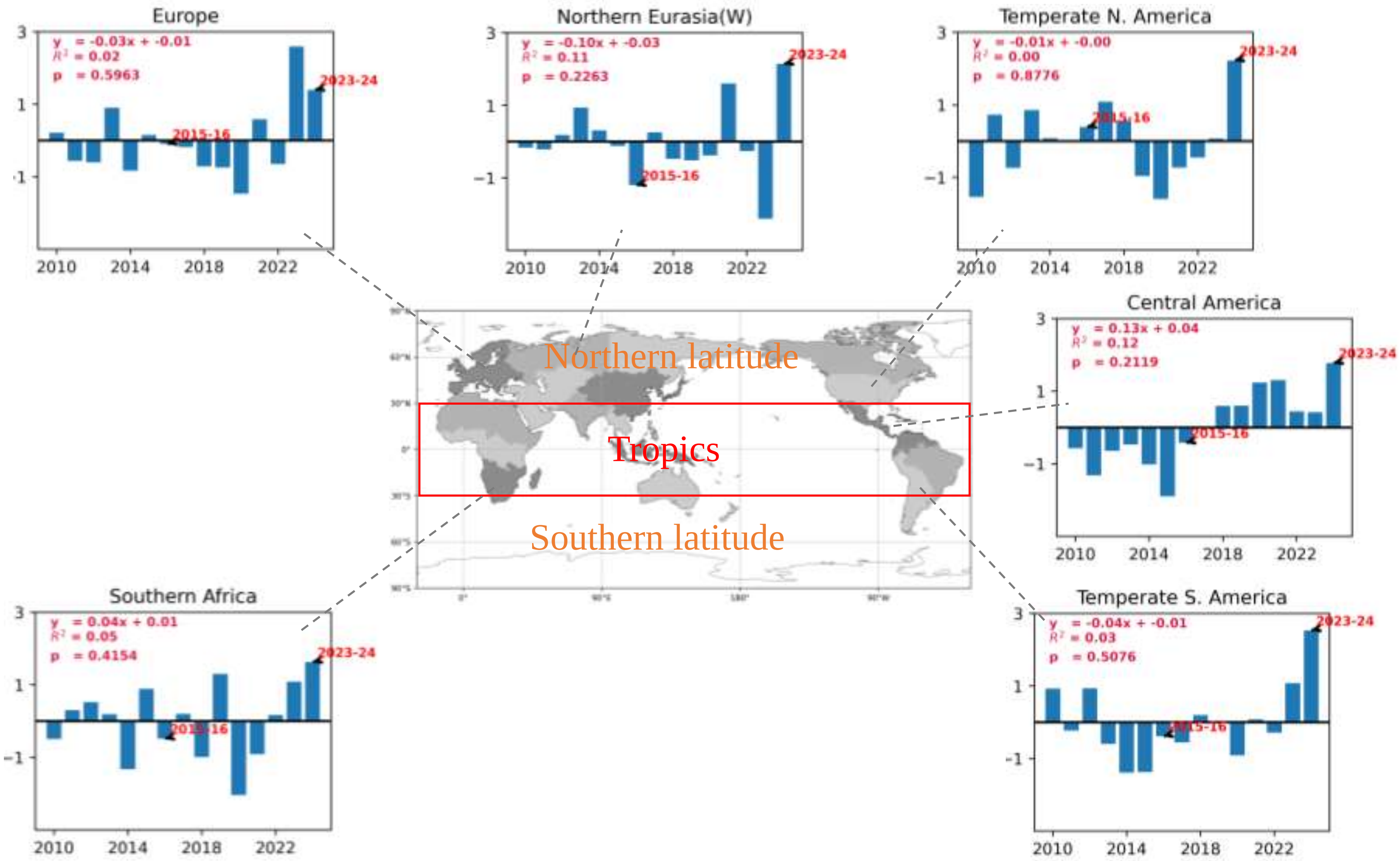
Results: Regression Over RECCAP2 regions



Maity et al., 2025 (in preparation)

Results: Flux change rate

Flux change rate from MEI–ΔfCO2 relationship



Maity et al., 2025 (in preparation)

Summary

- This anomalous GR in 2023–24 is primarily driven by reduced land sinks or increased land sources, likely enhanced by El Niño. Ocean uptake slightly strengthened, contributing less to this anomaly.
- Compared to 2015–16 El Niño, the 2023–24 event induced stronger net land flux anomalies in global, particularly evident in GOSAT estimate. Specifically, those in the northern latitude and the tropics are predominant.
- Globally, the 2023-24 flux increase is stronger than that expected by the ENSO-flux anomaly relationship (the MEI–ΔfCO_2 regression line). They are also true for the northern latitude and the southern tropics. The flux increase in the northern tropics well align with the ENSO-expected response. Meanwhile, the 2015-16 flux increase is well consistent with the ENSO-expected response for all the latitudinal areas.
- Southern Africa, Temperate South America, Central America (tropics), Europe, Northwestern Eurasia, temperate North America (northern latitude) contributed most to those flux anomalies. It is also noteworthy that Boreal North America showed strong prior fluxes due to fires, but this did not appear in posterior estimates, implying minimal net impact on global CO_2 growth.

Maity et al., 2025 (in preparation)

Acknowledgements

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- ☞ This study is partly supported by the Environment Research and Technology Development Fund of the Environmental Restoration and Conservation Agency (JPMEERF24S12200), provided by Ministry of the Environment of Japan.