Quantifying the carbon cycle impacts of extreme events with space-based X_{CO2} retrievals

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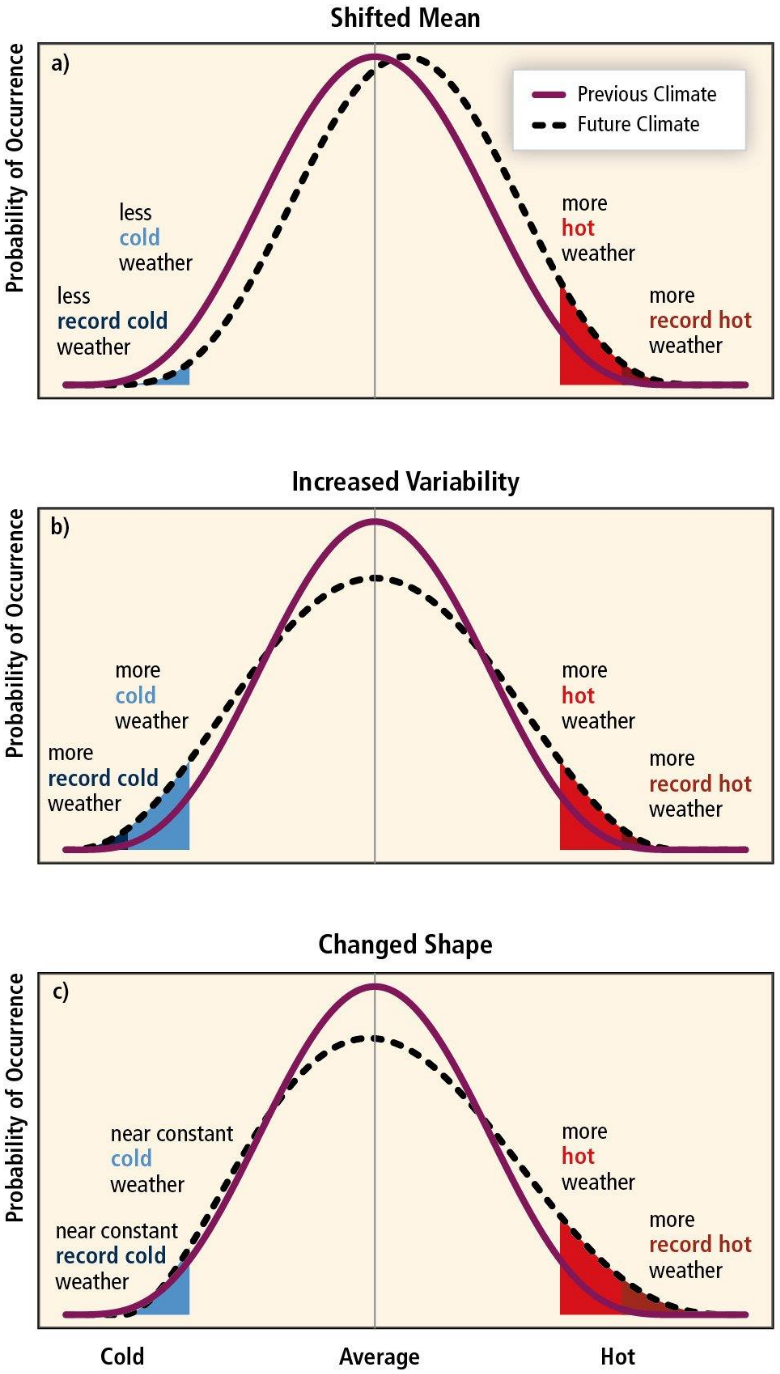


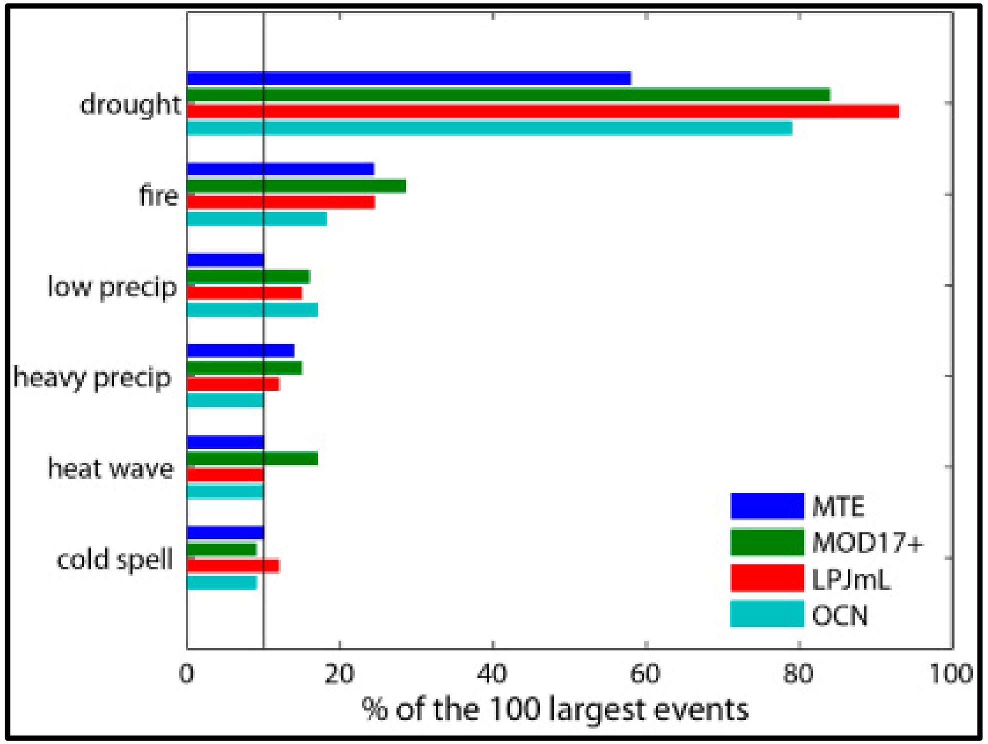
Field *et al* (2012) *IPCC Special Report*

Why we care:

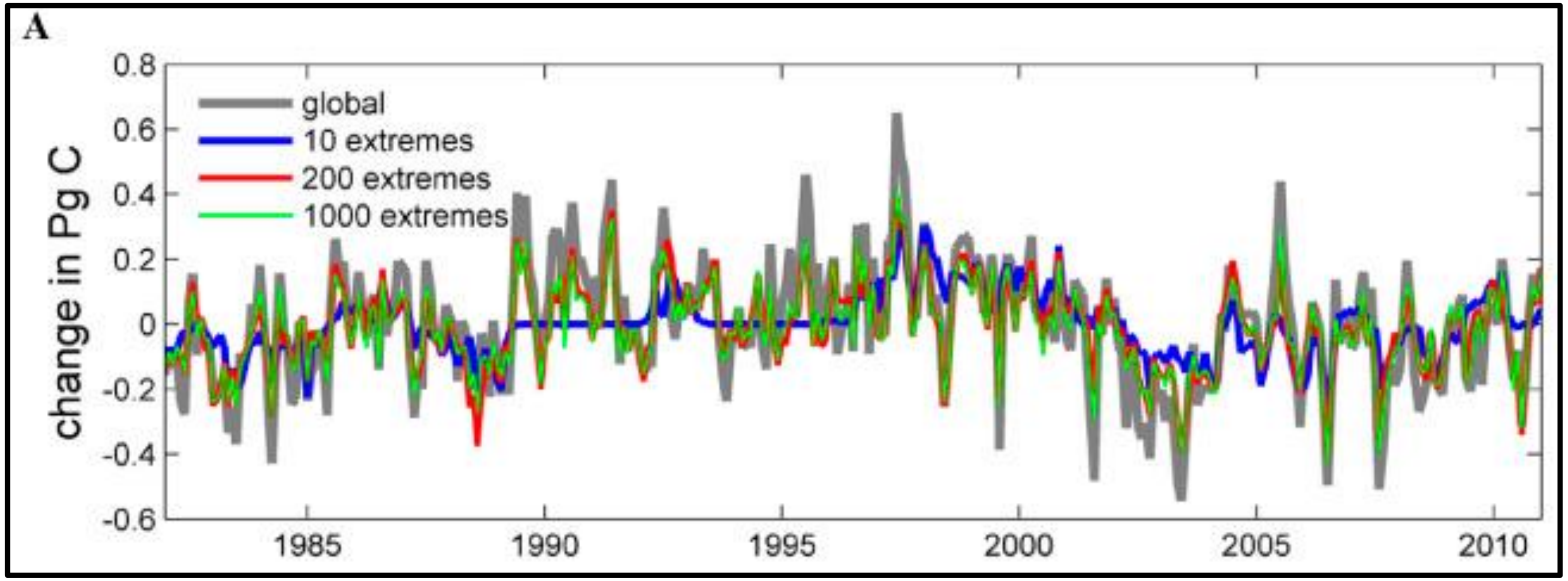
1. Extreme events can become much more common with shift in mean climate

Why we care:

2. Extreme events have an large impact on variability in the carbon cycle.



Zscheischler *et al* 2014 *Environ. Res. Lett.*. Percentages of negative 1%-extreme events in GPP out of the largest 100 that could be associated with extreme drivers



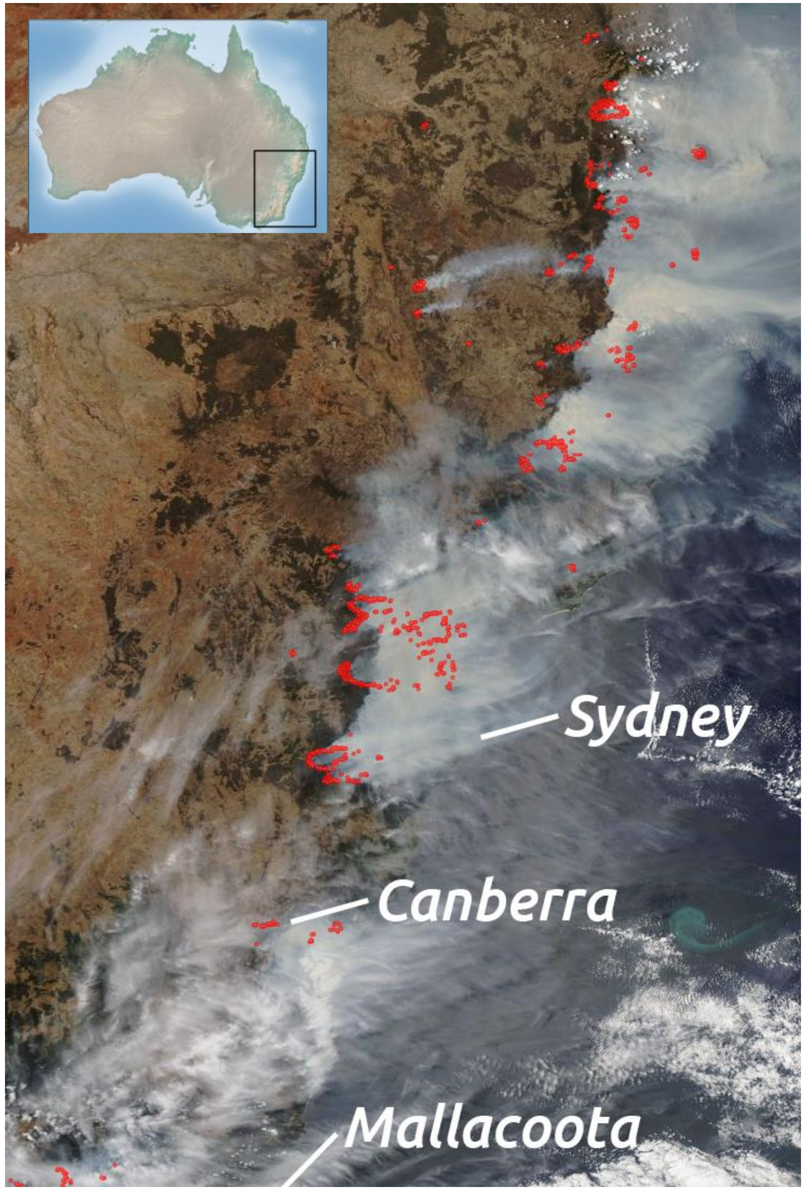
Zscheischler *et al* 2014 *Environ. Res. Lett*. Global GPP anomaly (gray); 10, 200, and 1000 largest positive and negative tenth-percentile extremes in GPP (blue, red, and green lines, respectively), monthly time scale.

Case Study – Current capabilities

Case Study:
Extreme 2019/20 growing season in southeast Australia

- Extreme year:
  - 2019 Hottest and driest year on record
  - Extensive wildfires in southeast Australia during Nov 2019 – Jan 2020.
  - Sudden shift to cool wet conditions in Feb 2020
- What can we say about the CO_2 flux perturbations?

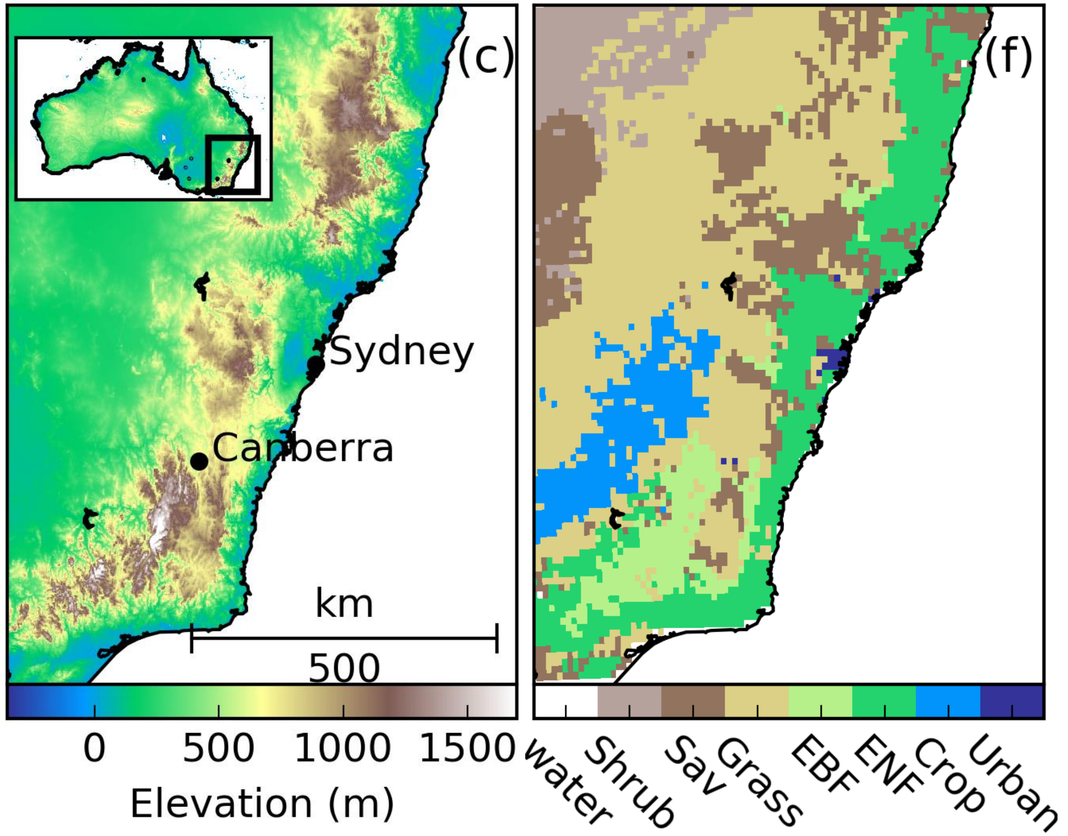
Whittle, L 2020, Analysis of Effects of bushfires and COVID-19 on the forestry and wood processing sectors, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra. CC BY 4.0. DOI:https://doi.org/10.25814/5ef02ef4a3a96



By NASA Earth Observing System Data and Information System (EOSDIS) - Data captured from https://worldview.earthdata.nasa.gov, Public Domain, https://commons.wikimedia.org/w/index.php?curid=85664582

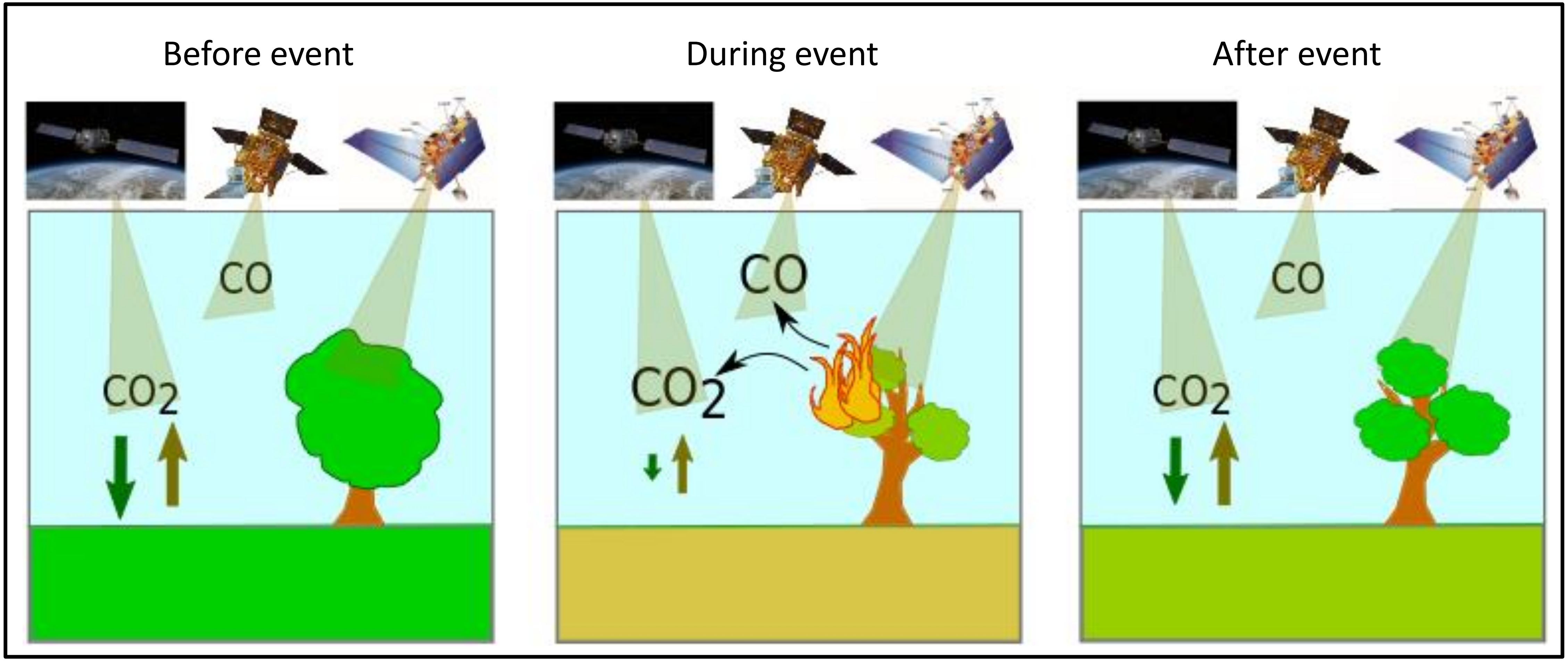
Questions of interest

- How much CO_2 was released to the atmosphere due to drought and biomass burning, respectively?
- Do we see recovery under cool-wet conditions
- How did this event impact forest and non-forest ecosystems differently?
- And what are the differences in carbon cycle perturbations between burned and unburned ecosystems?



Space-based carbon cycle observations

- OCO-2 tracks the atmospheric CO_2 anomalies.
- TROPOMI tracks the CO anomalies
- MODIS tracks the burned area/fire radiative power & vegetation anomalies



Relating observations to carbon budget

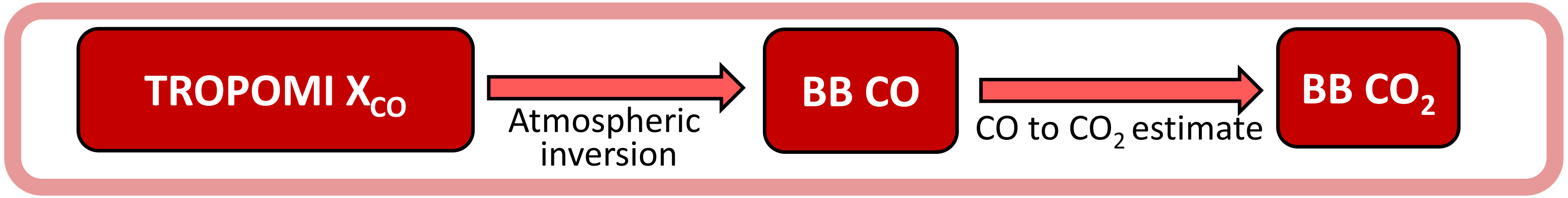
OCO-2 X_{CO2}

TROPOMI X_{CO}

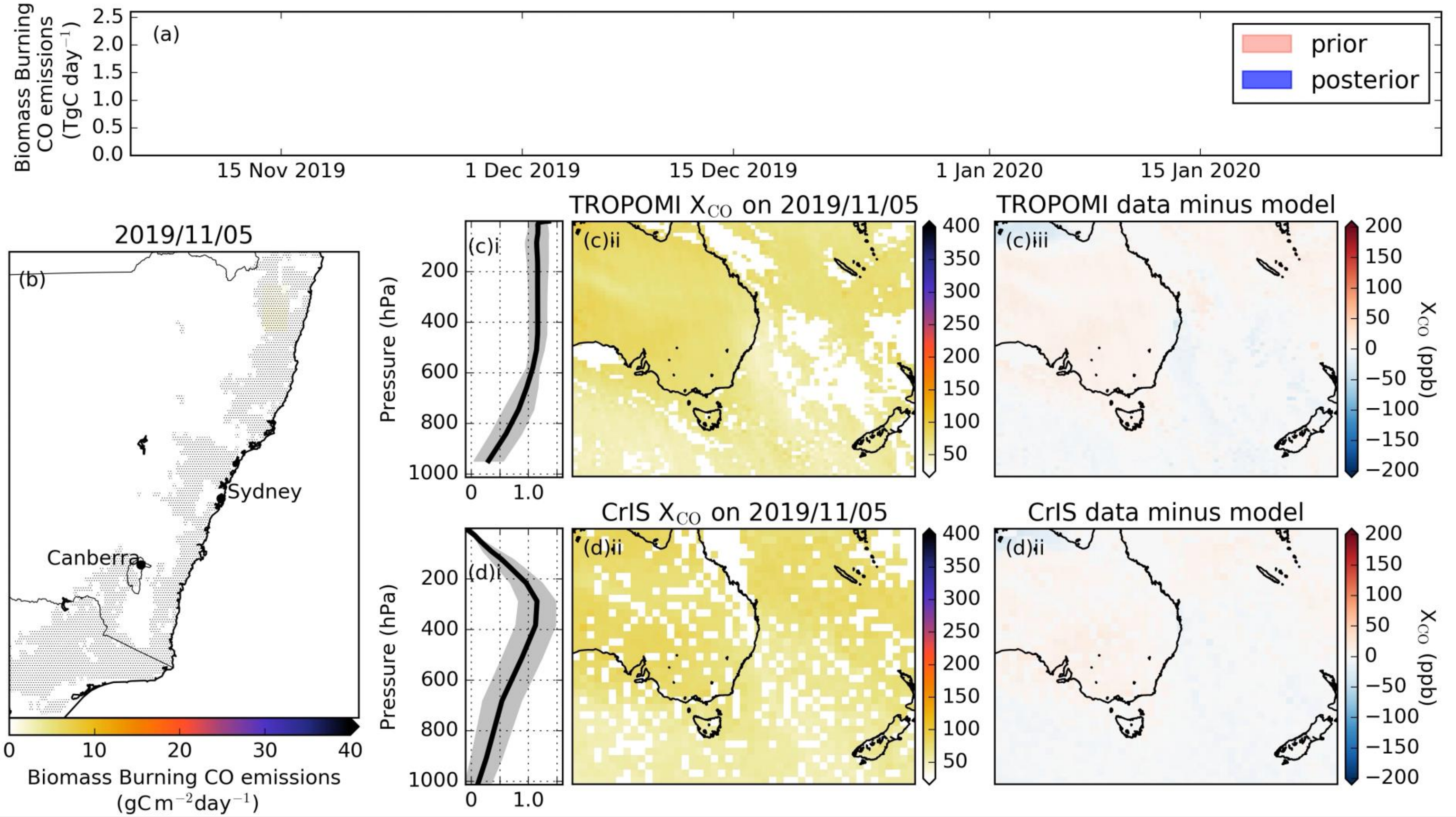
$$\Delta \mathrm{NBE} = \underbrace{\Delta \mathrm{TER} - \Delta \mathrm{GPP}}_{\Delta \mathrm{NEE}} + \mathrm{BB}$$

MODIS-based FluxSat GPP

Biomass burning estimates



- Perform a high resolution carbon monoxide atmospheric inversion over Australia.
- Use prior fire emissions from the GFAS and GFED inventories.
- Infer a scaling on these prior emissions to match the TROPOMI carbon monoxide retrievals
- Estimate CO_2 emissions based of typical CO_2/CO emission ratios for fires.



Byrne et al., 2021, *AGU Advances*

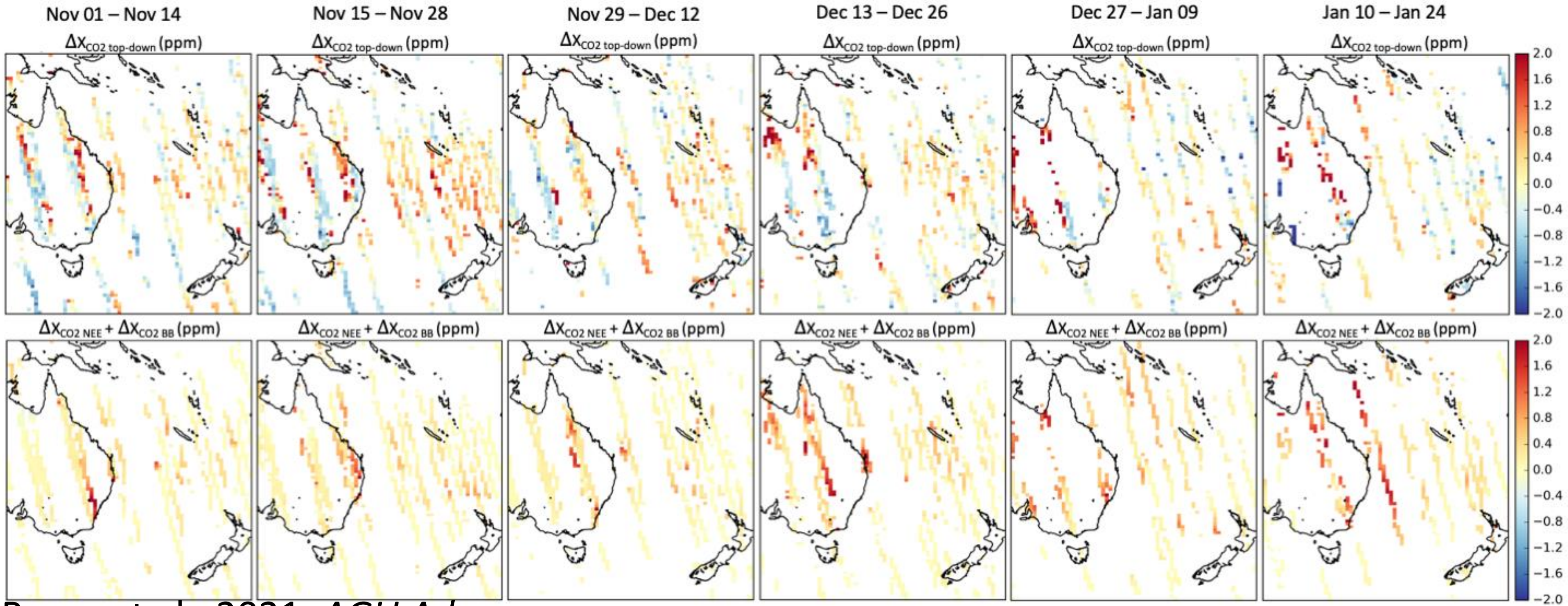
GPP/NEE anomalies during 2019/2020

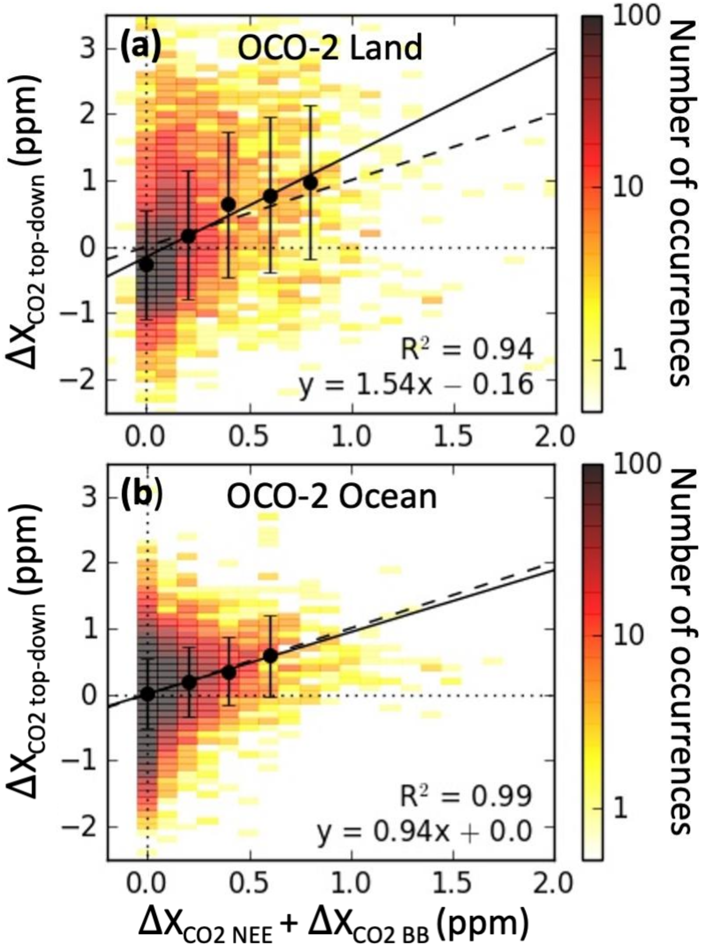
FluxSat ΔGPP → ΔNEE ← ΔX_{CO2} due to ΔNEE

GPP determines spatiotemporal structure

ΔX_{CO2} determines the magnitude

- Calculate ΔGPP from FluxSat remote-sensing-based estimate
- Assume $\Delta NEE \propto \Delta GPP$ [Li et al., 2017]
- Scale ΔNEE to be consistent with OCO-2 X_{CO2} anomalies



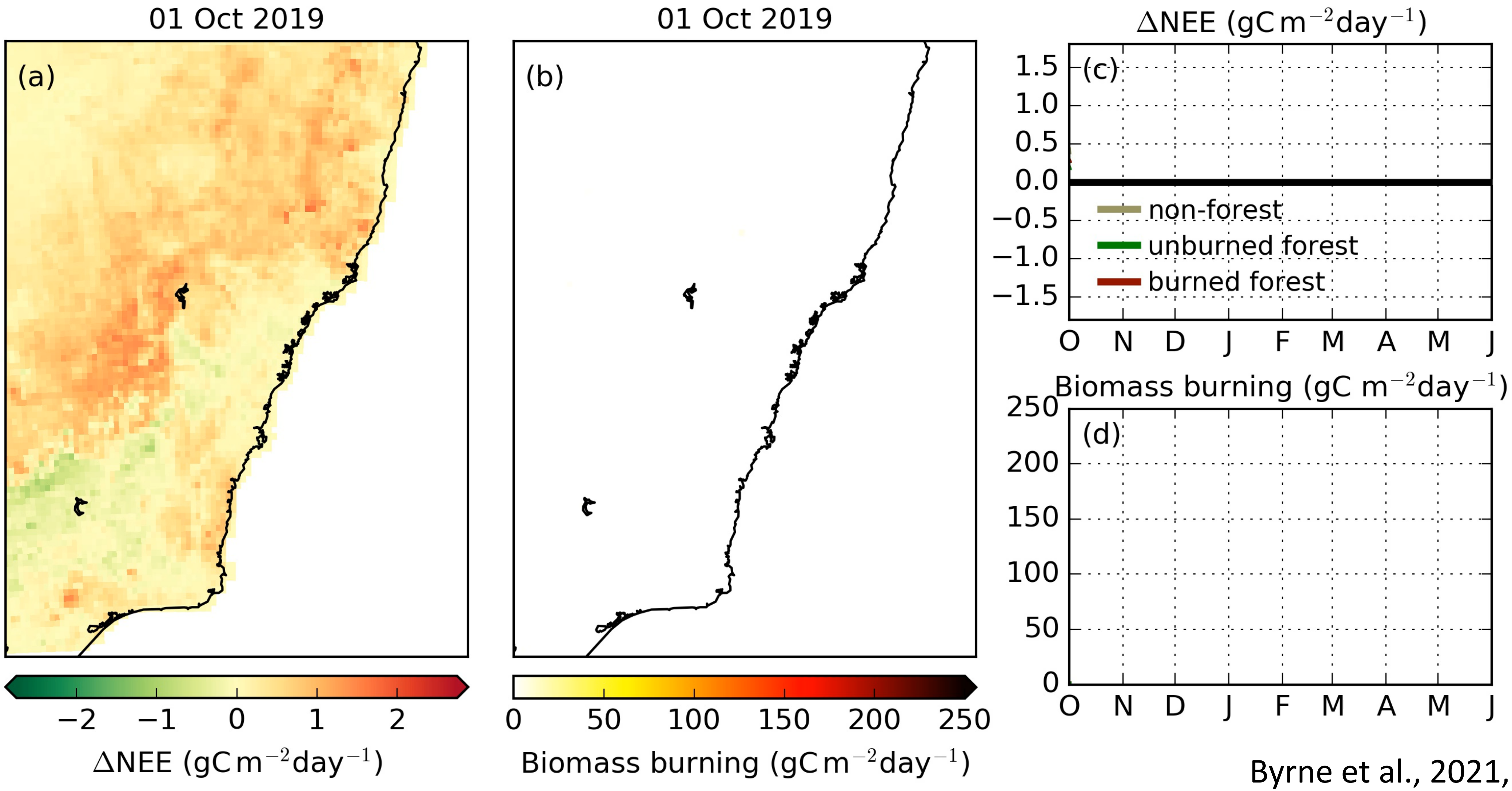


Byrne et al., 2021, *AGU Advances*

Li et al. (2017). Responses of LAI to rainfall explain contrasting sensitivities to carbon uptake between forest and non-forest ecosystems in Australia. Scientific Reports, 7(1), 1–9. https://doi.org/10.1038/s41598-017-11063-w

Daily biomass burning and NEE anomalies during 2019/20

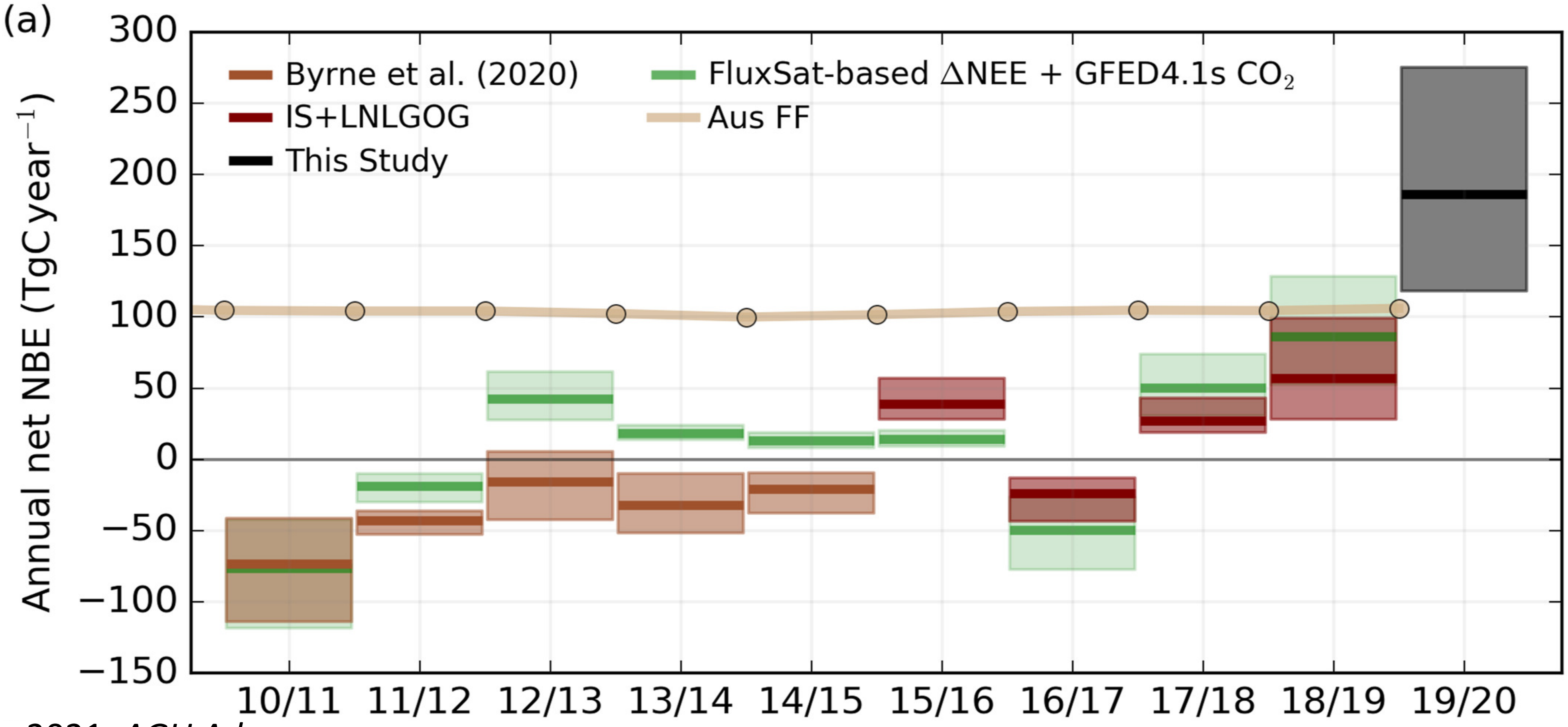
- Carbon loss primarily due to biomass burning (83% fires, 17% ΔNEE).
- Carbon losses were concentrated in burned forests, including from ΔNEE. (~82% loss was in burned forests, ~16% non-forest, ~2% unburned forest).



Byrne et al., 2021, *AGU Advances*

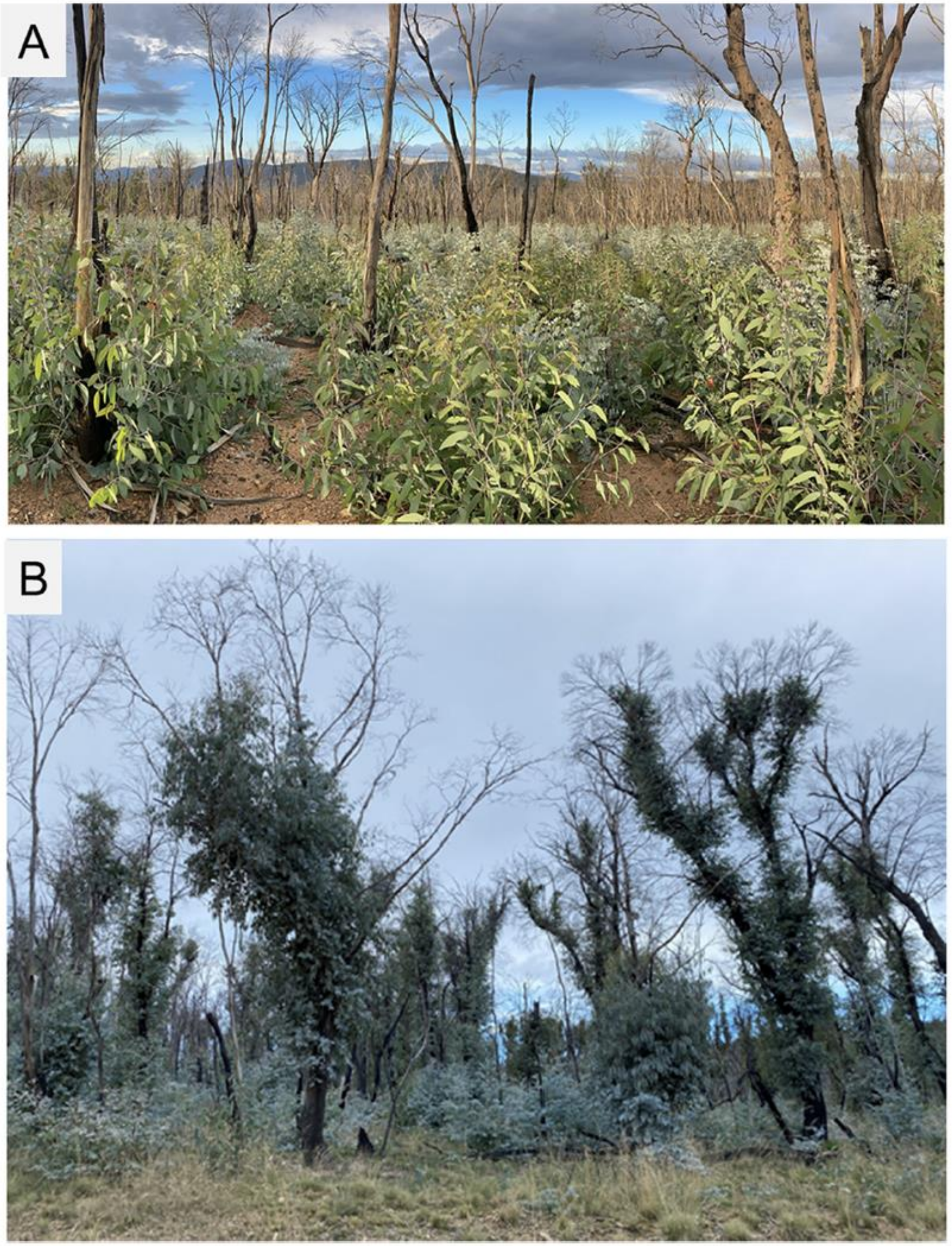
Carbon loss for 2019/20 is large relative to previous years

- 2019/2020 stands out for the large carbon loss, and exceeds the annual net fossil fuel emissions!
- Large impact of this event demonstrate importance of tracking these events for monitoring the carbon budget.

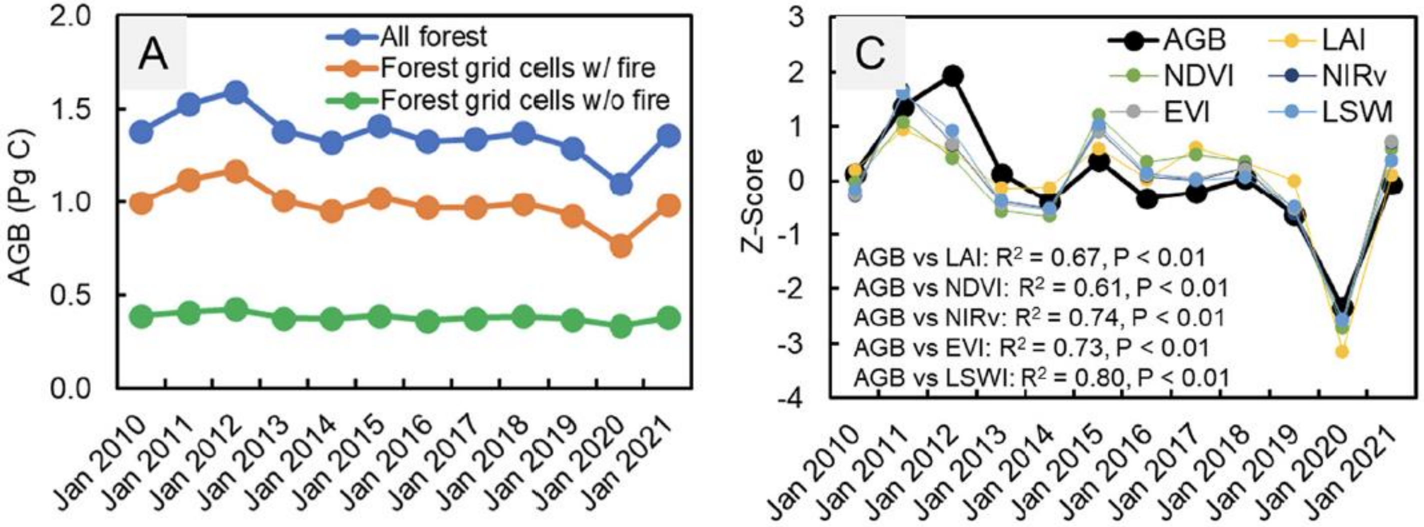


Byrne et al., 2021, *AGU Advances*

Similar story for aboveground biomass



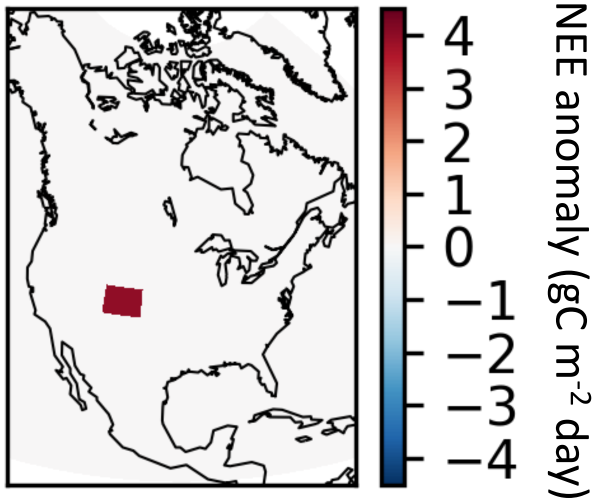
Qin et al., 2022, Remote Sensing of Environment,
https://doi.org/10.1016/j.rse.2022.113087



- Large biomass loss in 2019 but large gains in 2020 (~15% variation in AGB).
- Fire-adapted Eucalyptus forests and above-average annual precipitation drove the recovery of vegetation cover
  - Note the forests don’t look the same, though.

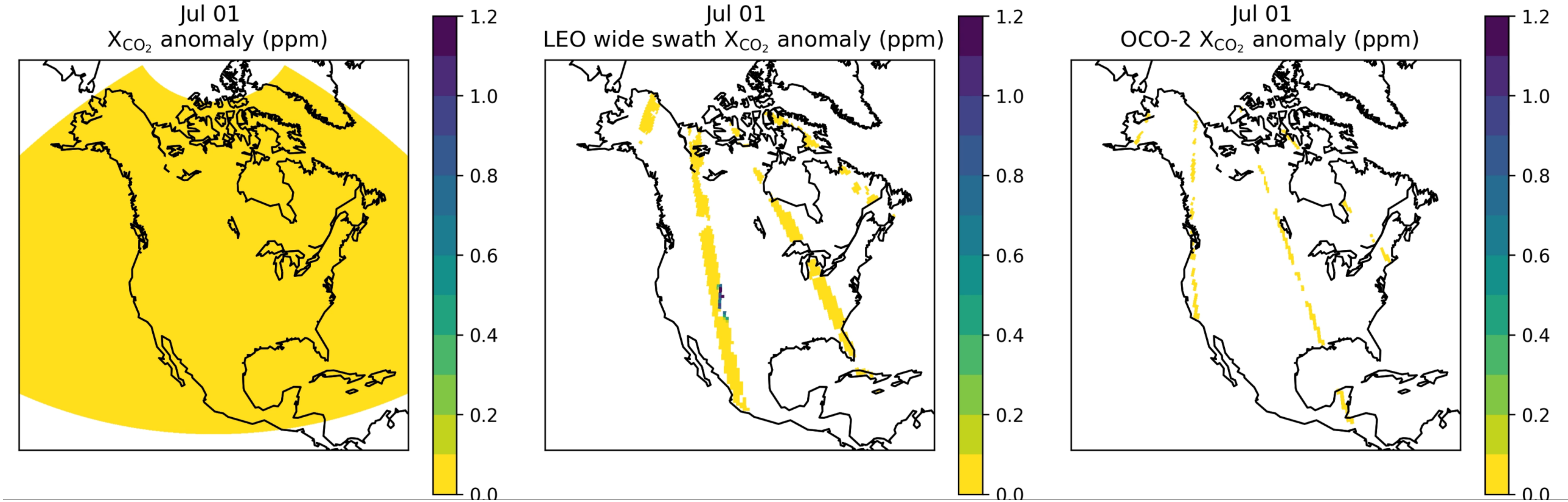
Looking to the Future

Anomaly detection with 200 km wide-swath LEO sampling

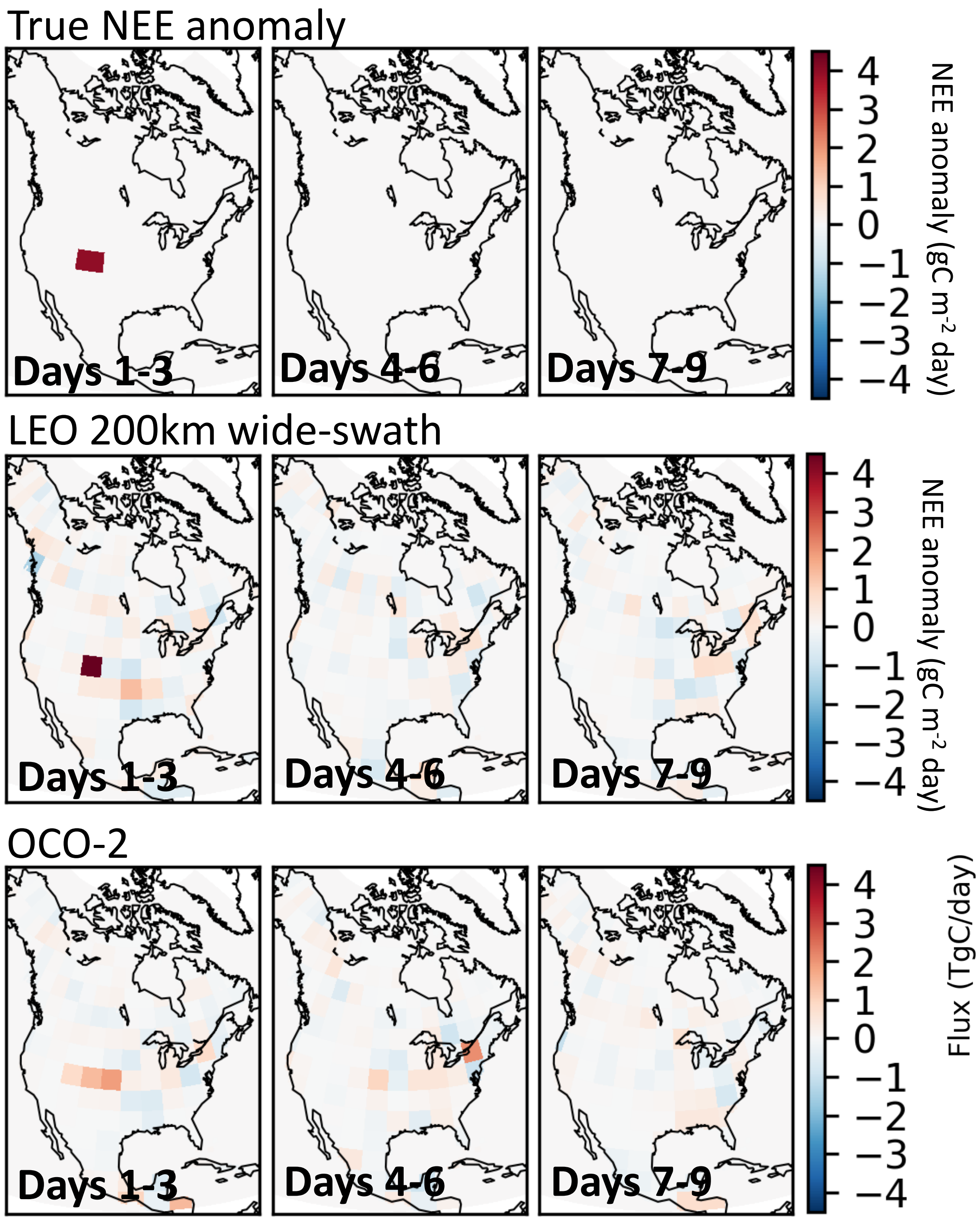


- Test how well a 200 km wide-swath LEO CO2 mission can detect an extreme event:
  - Release CO2 pulse over Colorado for three days (~1 TgC/day)

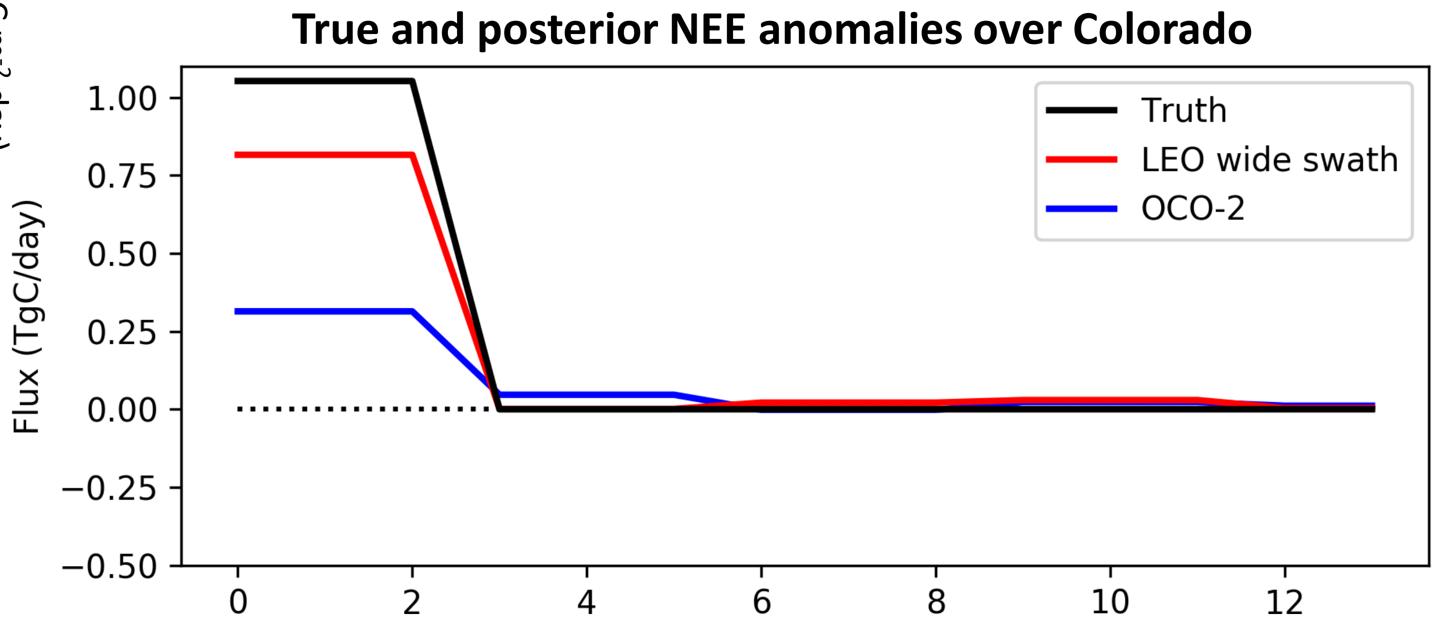
- Atmospheric CO2 signal is more evident with this sampling relative to OCO-2.



Increase sampling improves quantification & localization of extreme NEE anomalies



- A 200 km wide-swath LEO mission is able to isolate the NEE anomaly to Colorado, while OCO-2 is not.
- Similarly, the wide-swath LEO mission better captures the magnitude of the event.



Recommendations / Thoughts

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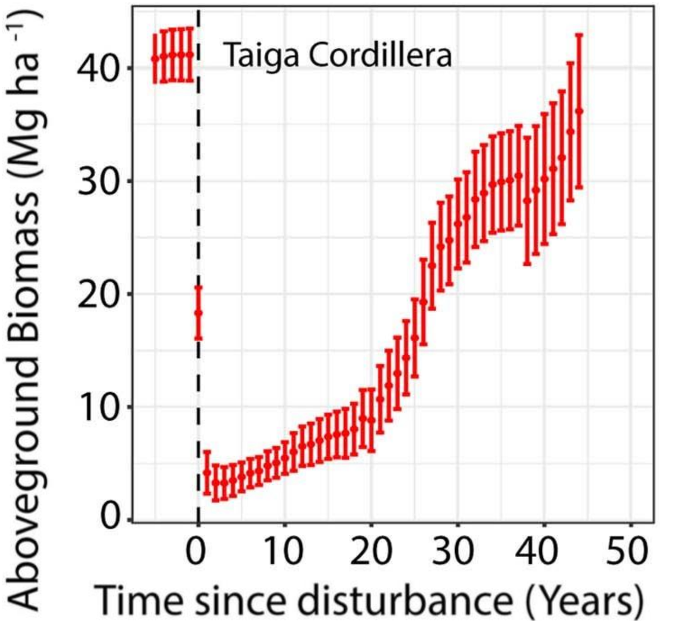
- **Dense satellite data are allowing us to track carbon cycle responses to extreme events with unprecedented detail.**

- <u>**Recommendation:**</u> **Launch CO_2 missions with dense sampling**, this will improve our ability to track carbon cycle responses to extreme events from space.
    - Complementary datasets (e.g., CO & VIs/SIF) are also important for understanding component fluxes.
    - These events have a large impact on national carbon budgets.

- <u>**Challenge**</u>**: Extreme events are unique**, what generalizations can we take away from the 2019/20 SE Australia carbon cycle anomaly? And what are implications of DGVMs ability/inability to capture this event?



Wang et al (2021) Nat. Clim. Change
Aboveground biomass for 45 years after fire

Mountain Ash Pine
https://en.wikipedia.org/wiki/Eucalyptus_regnans#/media/File:Sherbrooke_forest_Victoria_220rs.jpg