The carbon cycle of southeast Australia during 2019/2020: Drought, fires and subsequent recovery

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Abstract

2019 was both the hottest and driest year on record for Australia, leading to large forest fires in the southeast from November 2019 to January 2020. However, in early 2020, the fires and hot-dry conditions dissipated with above average rainfall and below average temperatures along Australia's southeast coast. In this study, we utilize space-based measurements of trace gases (TROPOMI XCO, OCO-2 XCO2) and vegetation function (OCO-2 SIF, MODIS NDVI) to quantify the carbon cycle anomalies resulting from drought and fire in southeast Australia during the 2019/2020 growing season. During the austral spring, we find anomalous reductions in primary productivity and large biomass burning emissions in excess of bottom-up estimates from GFAS. This is then followed by a remarkable recovery and greening during early 2020, coincident with cooler and wetter conditions. We will further discuss different behaviors of recovery over fire-devasted and non-fire regions. This study showcases the capability of combining observations from multiple satellites to monitor the carbon and ecosystem anomalies resulting from extreme events. Finally, we will discuss the remaining challenges in monitoring the carbon cycle from space.

THE CARBON CYCLE OF SOUTHEAST AUSTRALIA DURING 2019/2020: DROUGHT, FIRES AND SUBSEQUENT RECOVERY

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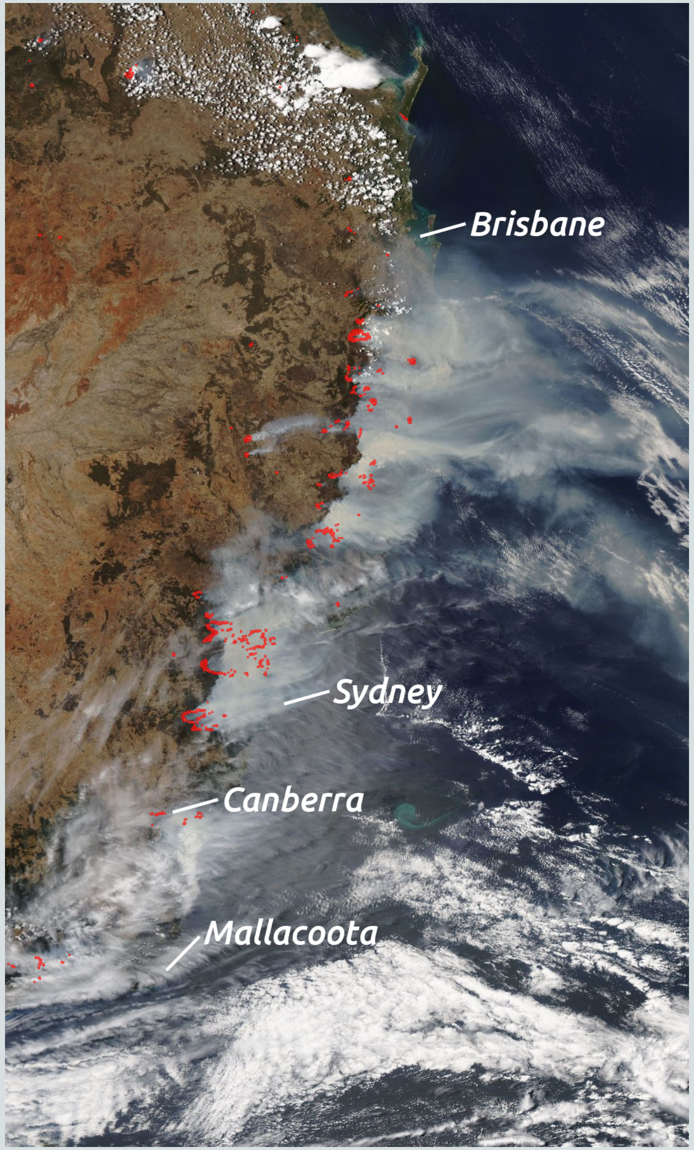
OVERVIEW

- 2019 was the hottest and driest year on recorded history for Australia
- Warm-dry conditions lead to large biomass burning events in southeast Australia during Nov 2019 – Jan 2020.
- We aim to quantify the carbon cycle perturbation over southeast Australia during the summer of 2019/2020 and partial recover in the fall of 2020.

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



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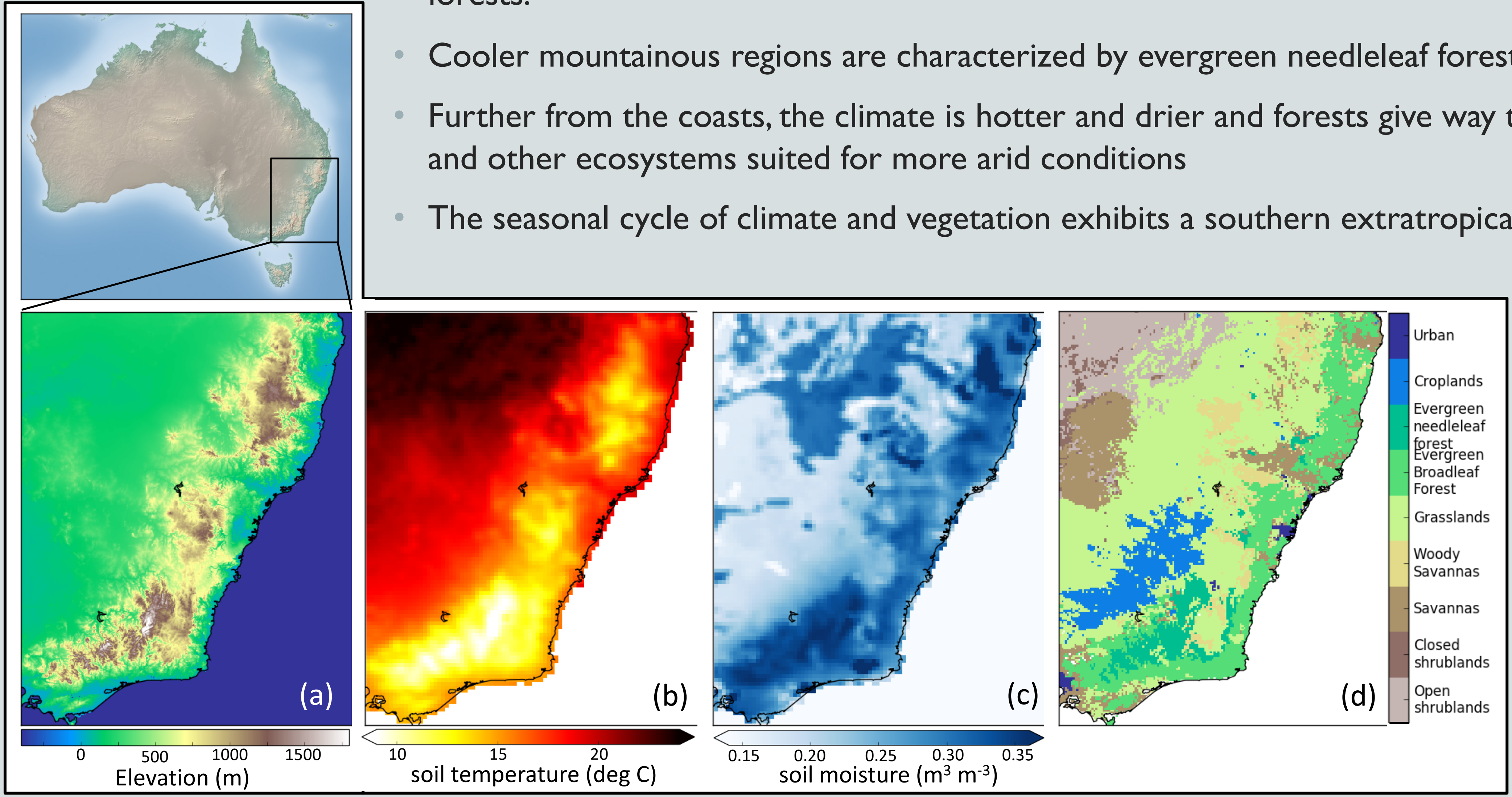
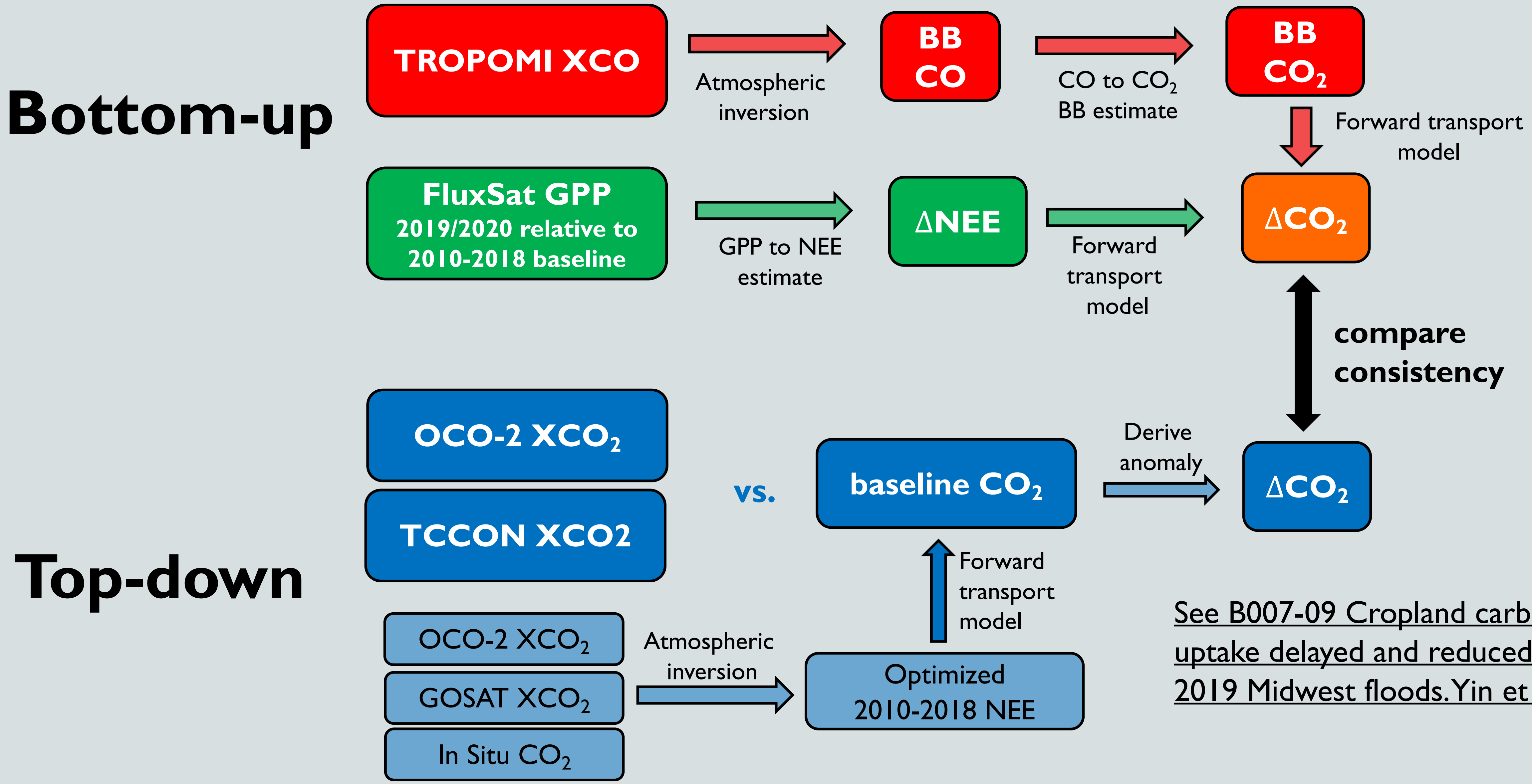
GEOGRAPHICAL CONTEXT

- The climate of southeast Australia is temperate along coastline, supporting evergreen broadleaf forests.
- Cooler mountainous regions are characterized by evergreen needleleaf forests.
- Further from the coasts, the climate is hotter and drier and forests give way to savanna, grasslands and other ecosystems suited for more arid conditions
- The seasonal cycle of climate and vegetation exhibits a southern extratropical pattern.



STUDY APPROACH



See B007-09 Cropland carbon uptake delayed and reduced by 2019 Midwest floods. Yin et al.

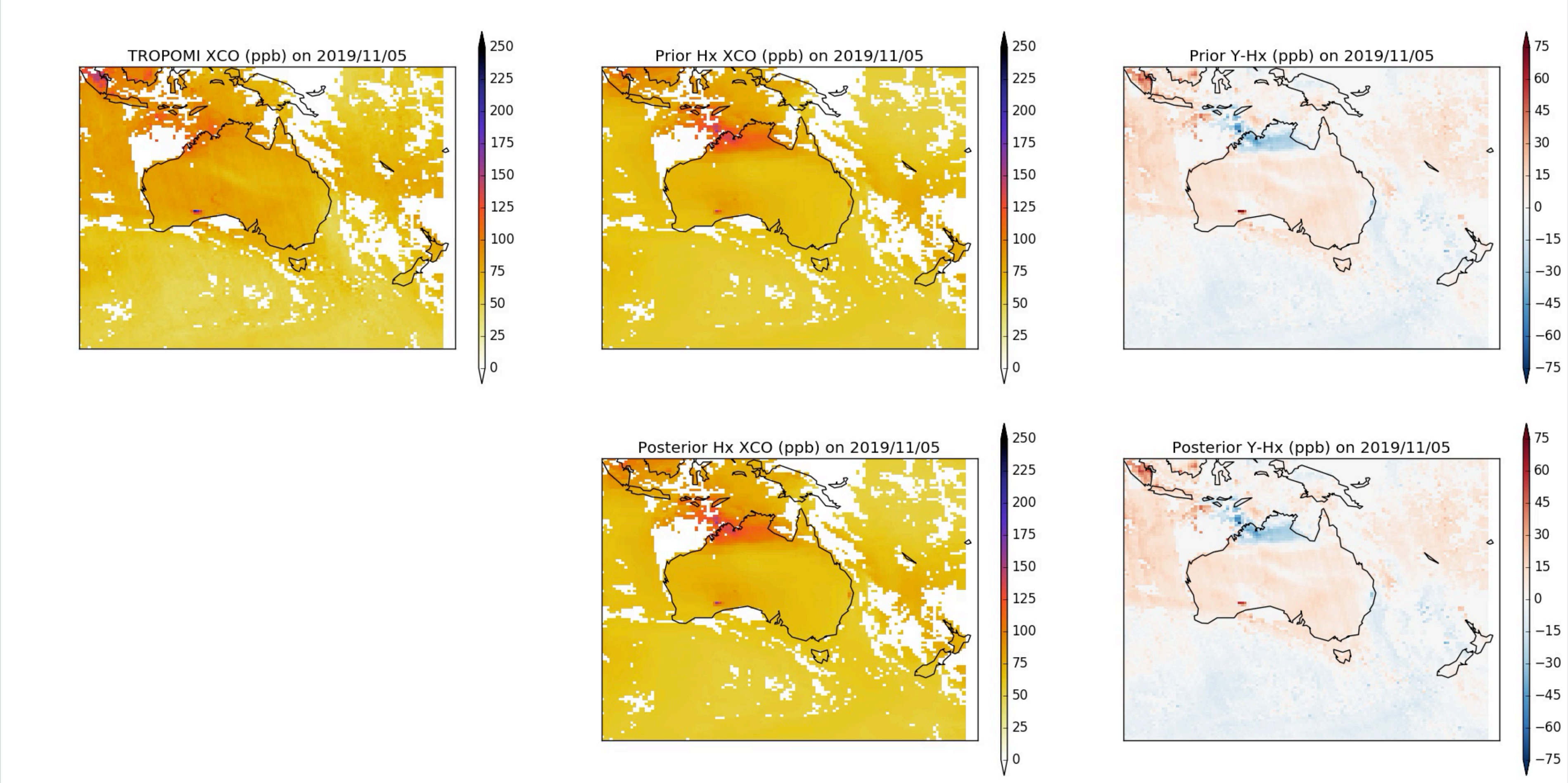
BIOMASS BURNING ESTIMATES

TROPOMI XCO → (Atmospheric inversion) → **BB CO** → (CO to CO_2 BB estimate) → **BB CO_2**

- Perform a one-way nested flux inversions at 0.5 x 0.625 degree resolution over Australia (100-177.5 W, 0-60 S) using GHGF-flux inversion system over Nov 2019 – Jan 2020.
- Generate boundary conditions with global TROPOMI inversion (aggregate obs with Q_a=1 to 4x5 using) then run nested inversion (aggregate with Q_a>= 0.5 to 0.5x0.625)
- Perform inversion using two sets of prior biomass burning emissions:
  - Global Fire Emissions Database (GFED)
  - CAMS Global Fire Assimilation System (GFAS)

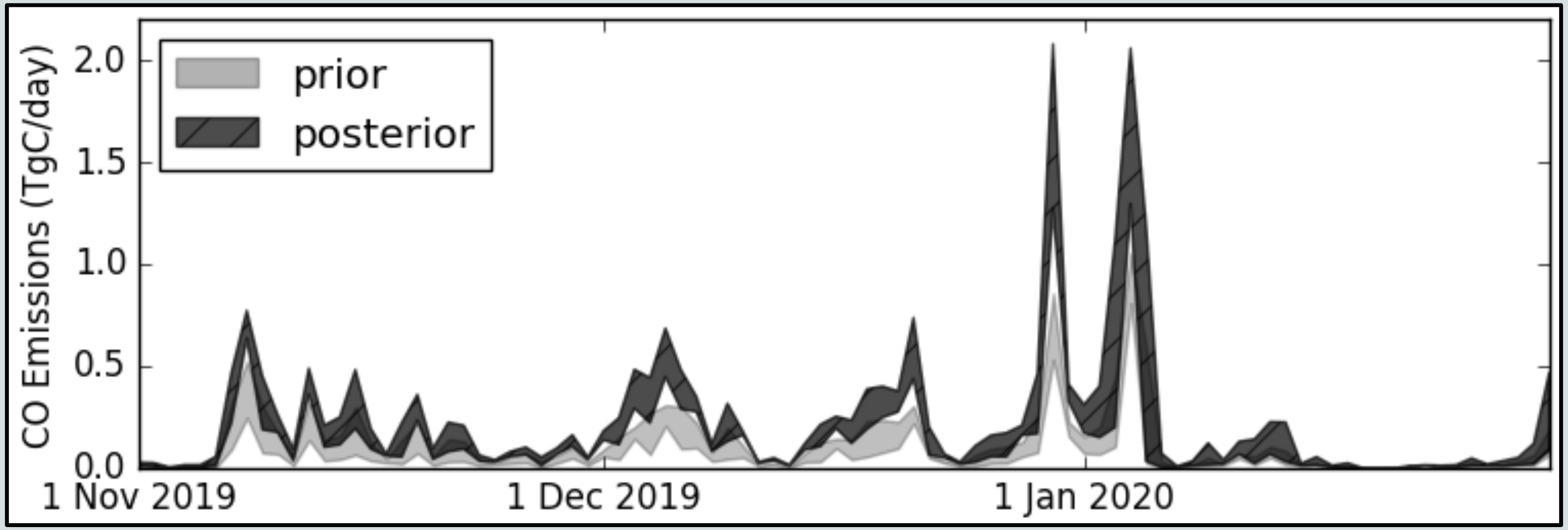
BIOMASS BURNING EMISSIONS

- Capturing Biomass burning plumes with a model is challenging
- Increased CO emissions better match TROPOMI XCO measurements

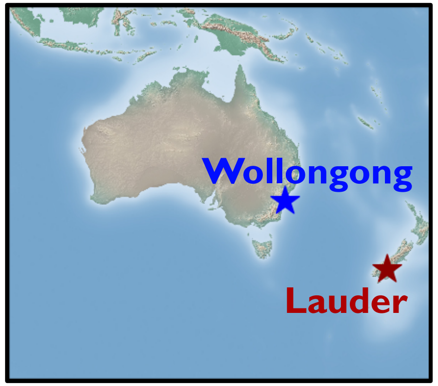


BIOMASS BURNING EMISSIONS

- TROPOMI XCO inversions suggest larger biomass burning emission than GFAS and GFED inventories.



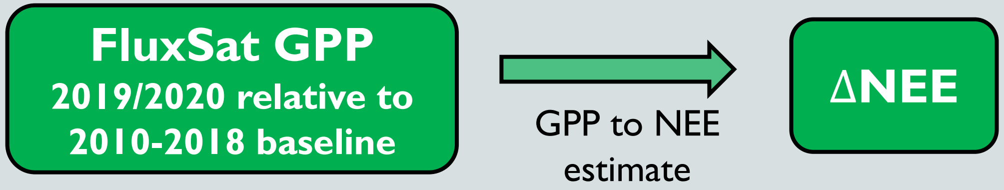
- Posterior estimate of 15 – 29 TgC relative to prior estimate of 6 – 12 TgC
- Posterior XCO fields show improved agreement with TROPOMI, Wollongong TCCON, and Lauder TCCON data.
- Posterior CO emissions are converted to CO2 emissions using GFAS and GFED emission factors



	All observations		BB sensitive obs	
Observations	Prior	Posterior	Prior	Posterior
TROPOMI	11.5 ppb	9.4 ppb	48.3 ppb	30.7 ppb
Wollongong	11.9 ppb	-9.3 ppb	95.5 ppb	18.0 ppb
Lauder	1.5 ppb	-0.1 ppb	9.5 ppb	0.4 ppb

- Downscale posterior CO_2 emissions based on 0.1x0.1 GFAS emissions

FLUXSAT GPP EMISSIONS



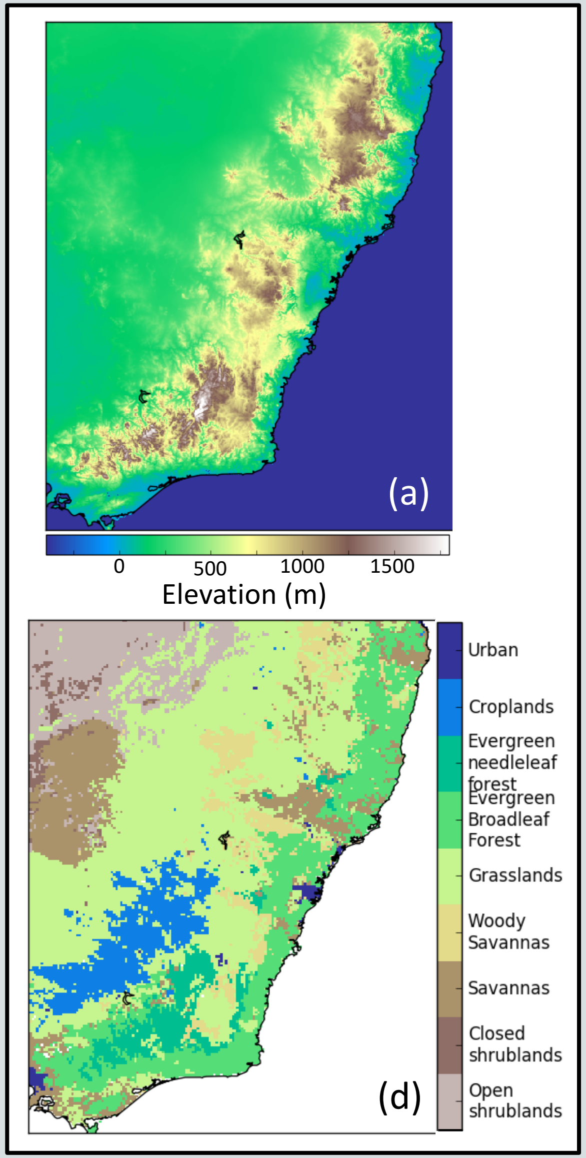
- FluxSat v2 GPP estimates GPP from MODIS reflectance calibrated using FLUXNET GPP estimates (Joiner et al., 2018)
- GPP anomalies (ΔGPP) are estimated as the 2019/2020 anomaly relative to a 2010-2018 baseline
- ΔNEE anomalies are assumed to be a fraction of ΔGPP. Here we assume:

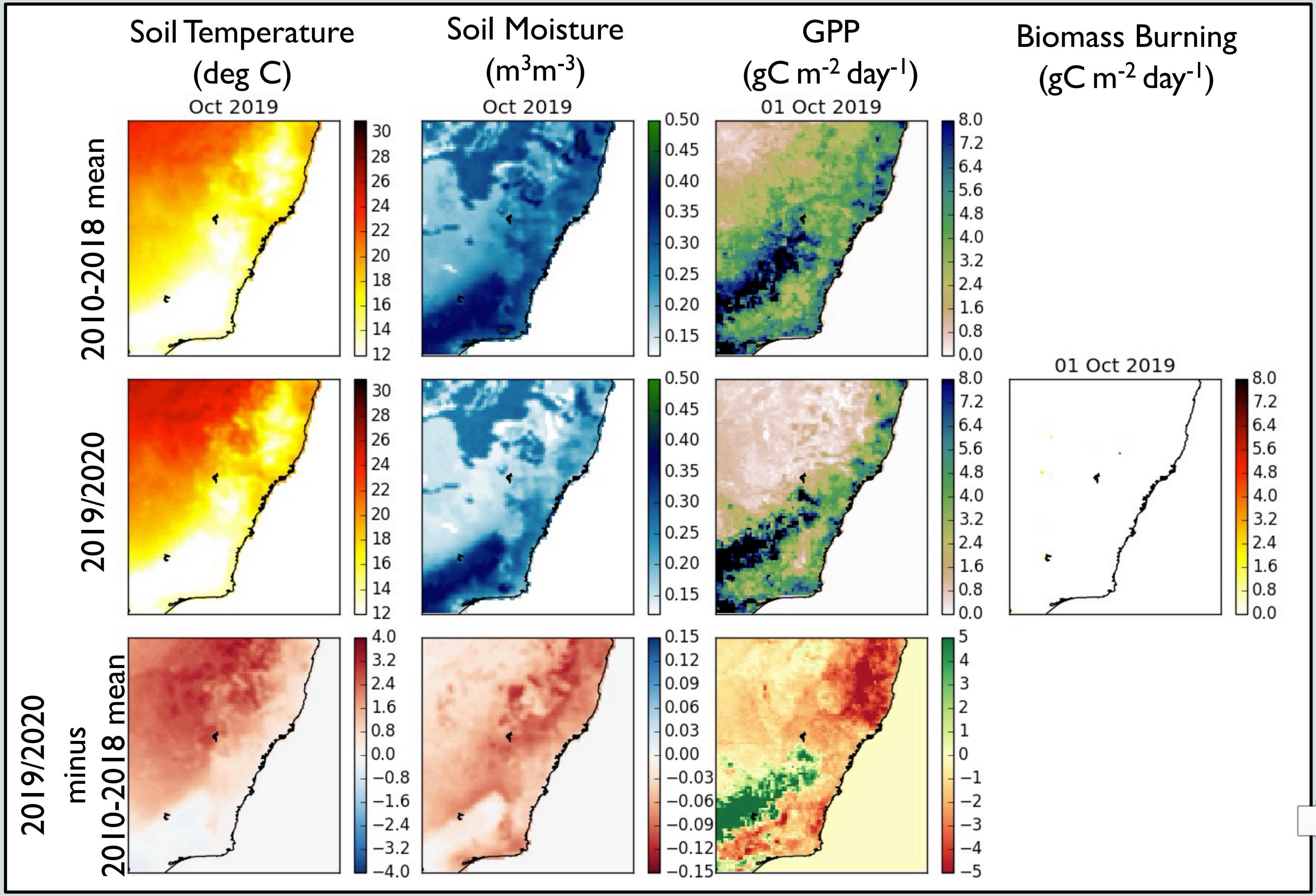
$$\Delta NEE = \Delta RH - \Delta NPP = \Delta RH - 0.5 \times \Delta GPP$$

We assume ΔNEE is in the range $-0.3 \times \Delta GPP$ to $-0.5 \times \Delta GPP$

Joiner, J.; Yoshida, Y.; Zhang, Y.; Duveiller, G.; Jung, M.; Lyapustin, A.; Wang, Y.; Tucker, C.J. Estimation of Terrestrial Global Gross Primary Production (GPP) with Satellite Data-Driven Models and Eddy Covariance Flux Data. *Remote Sens.* **2018**, *10*, 1346.

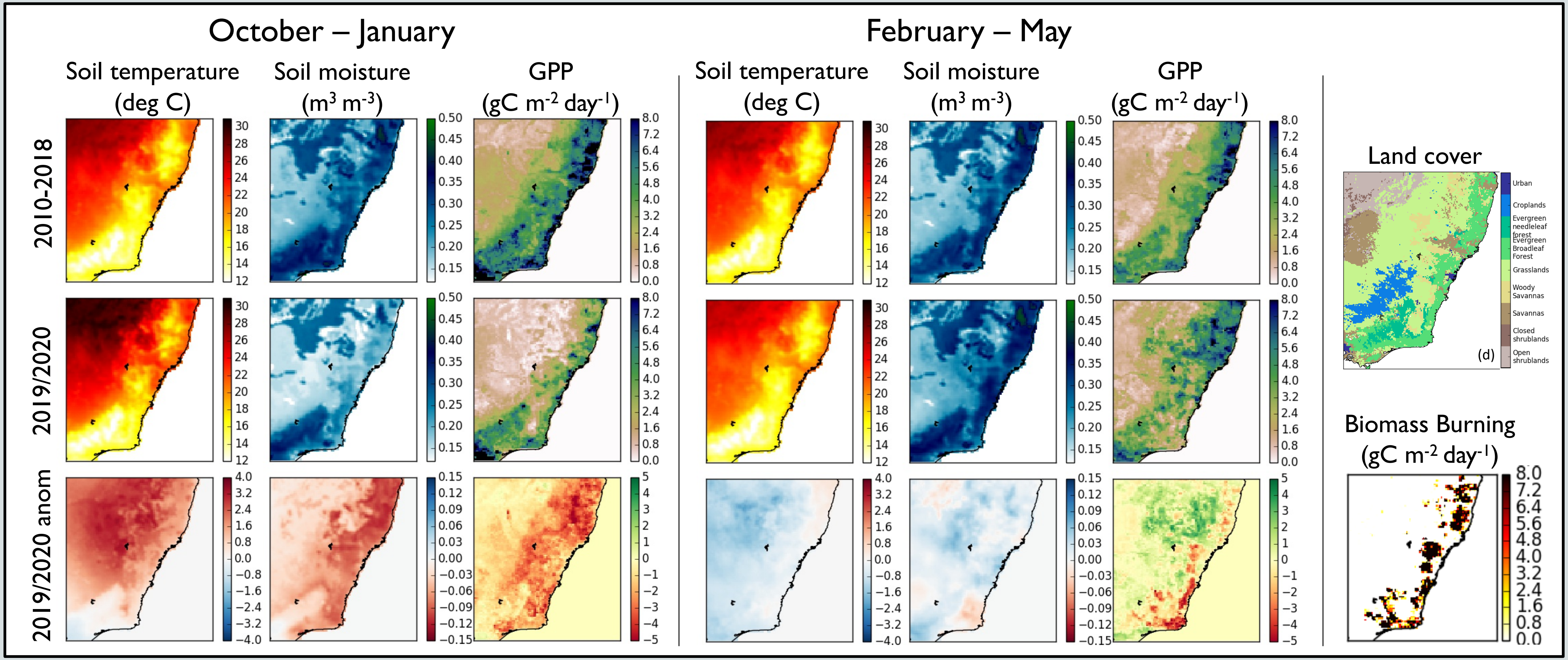
CARBON CYCLE ANOMALIES DURING 2019/2020





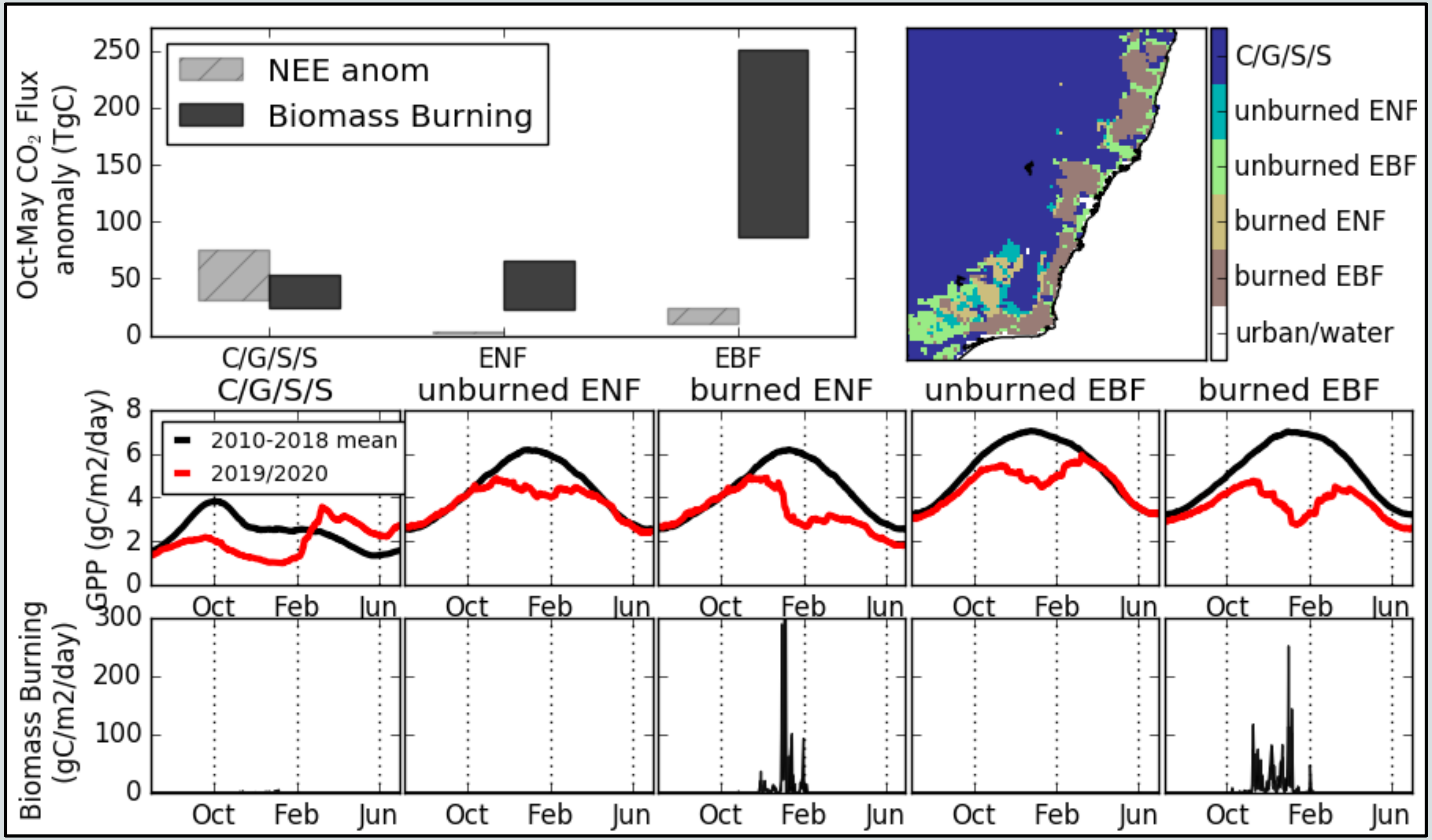
CARBON CYCLE ANOMALIES DURING 2019/2020

- Warm-dry conditions during Oct-Jan lead to reduced GPP and biomass burning
- Cool-wet conditions during lead to increased GPP except where biomass burning occurred.



CO_2 FLUX ANOMALIES OVER 2019/2020

- Oct – May CO_2 biomass burning emissions of 139 – 241 TgC and ΔNEE of 36 – 52 TgC, resulting in a total of 175– 293 TgC.

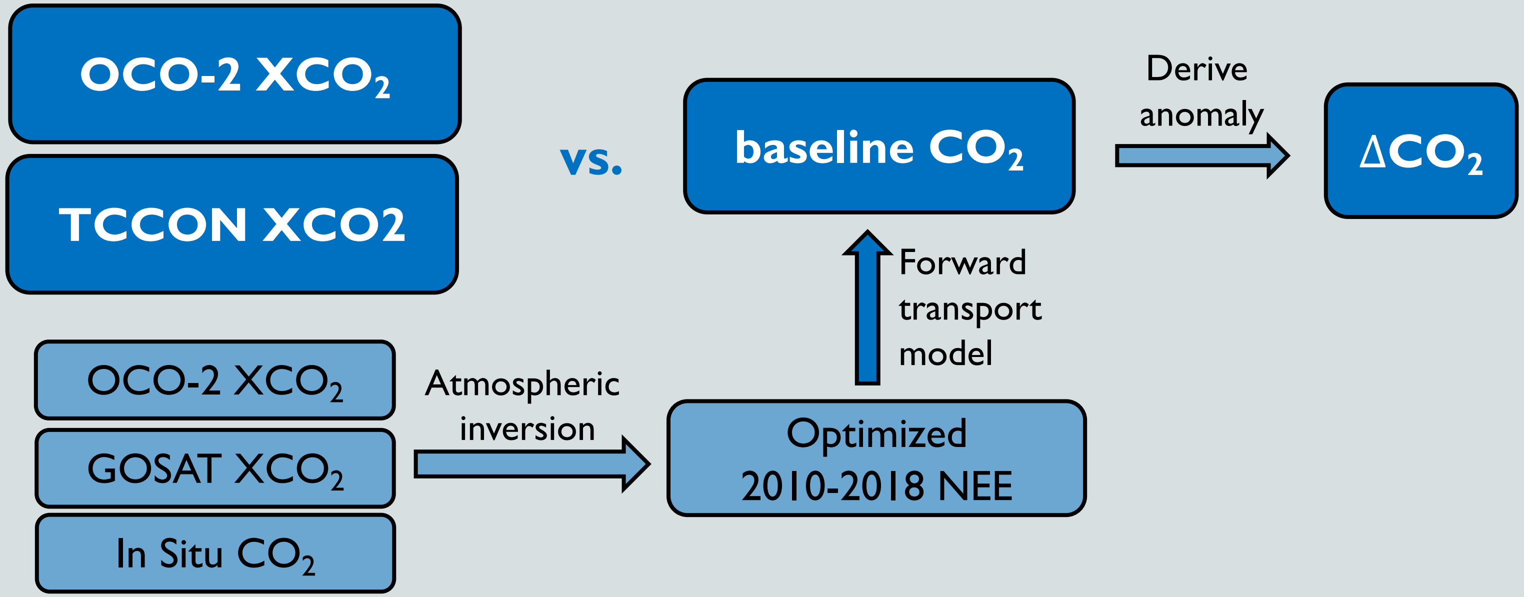


- Carbon loss is particularly pronounced in forested regions.
- Burned forests experience both large carbon loss from biomass burning and reduced recovery during Feb-May.
- C/G/S/S NEE anomalies are partially compensated for by a strong drought recovery during Feb-May.

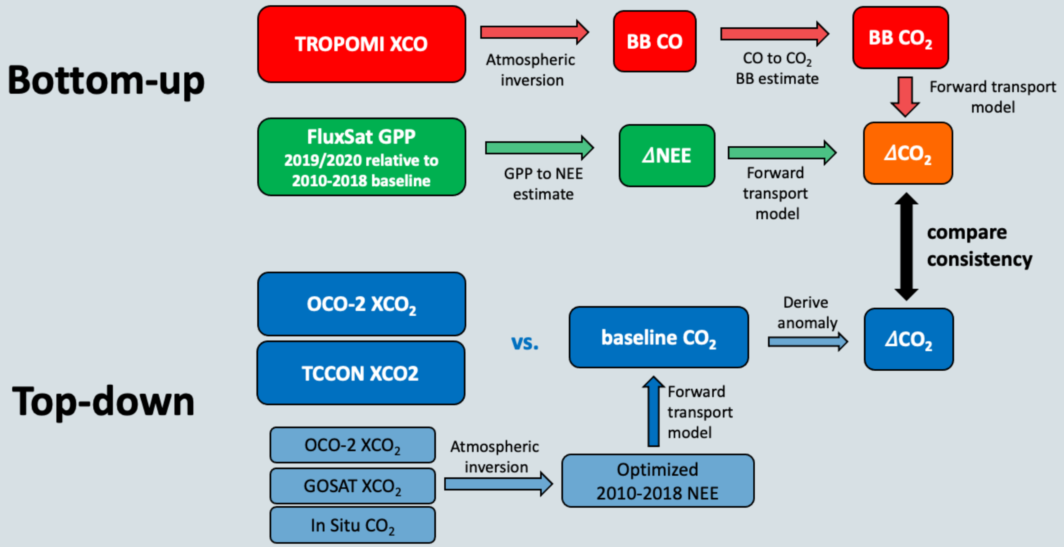
COMPARISON WITH CO_2 MEASUREMENTS

- Want to compare "bottom-up" estimates of CO_2 flux anomalies with constraints from atmospheric CO_2
- To do this, we simulate CO_2 fields using 2010-2018 climatological NEE fluxes with year specific fossil emissions.
- We then look at the difference between simulated expected climatological CO_2 and measurements of atmospheric CO_2 from OCO-2 and TCCON sites.

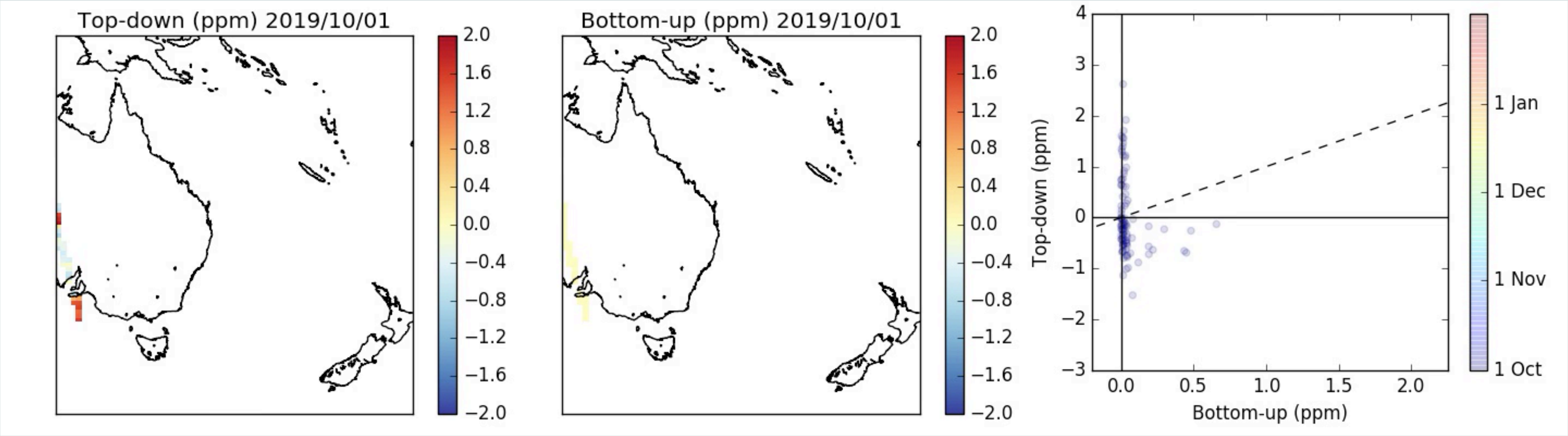
Top-down



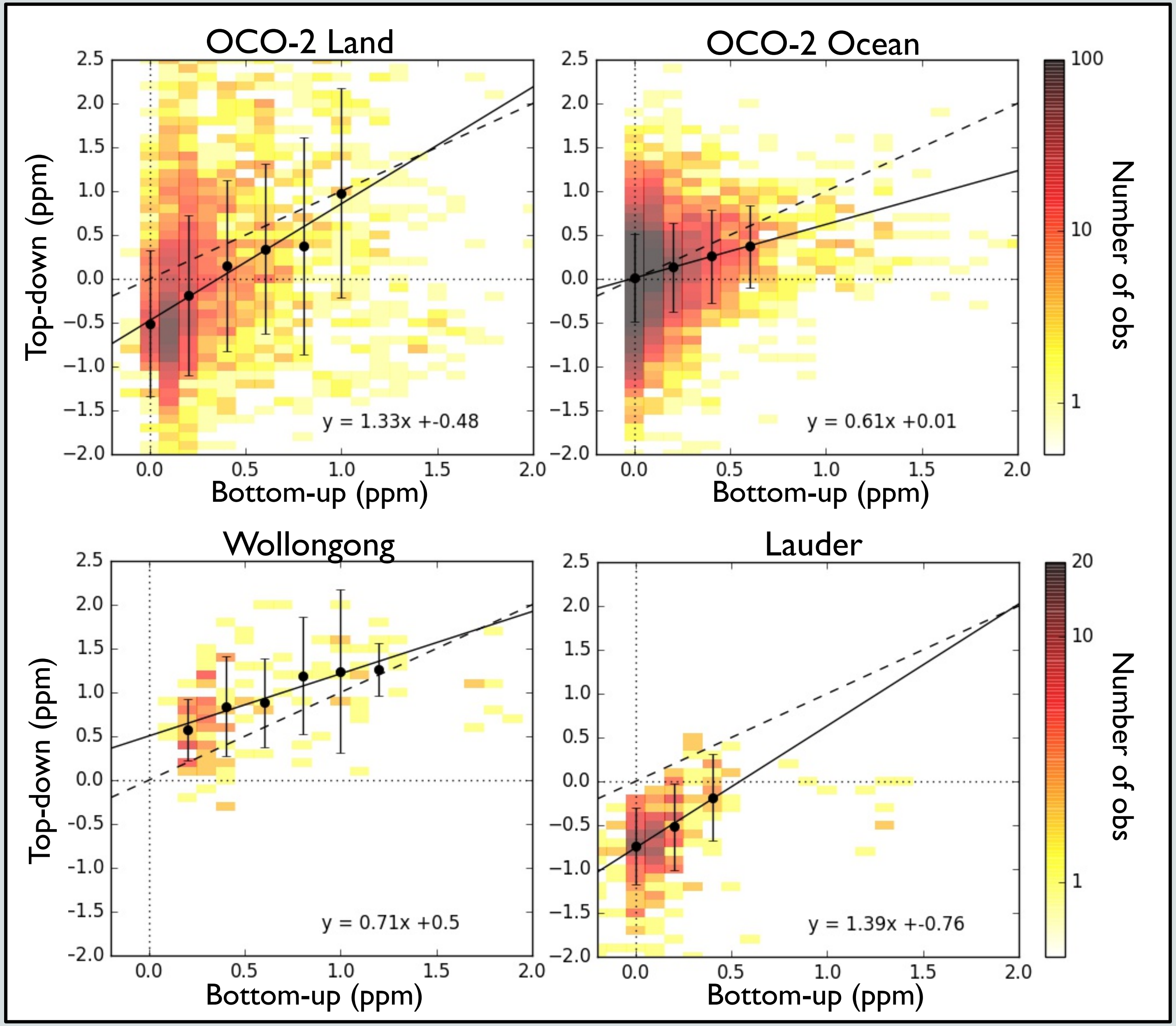
TOP-DOWN VERSUS BOTTOM-UP



- Top-down ΔCO_2 shows deviations in atmospheric CO_2 due to anomalies in the surface fluxes.
- Bottom-up ΔCO_2 shows the expected anomaly in CO_2 due to anomalies in surface fluxes.
- Agreement between the bottom-up and top-down ΔCO_2 (e.g., fall along a 1:1 line) shows that the bottom-up anomalies can explain observed anomalies in atmospheric CO_2



CONSISTENT SIGNAL IN TOP-DOWN AND BOTTOM-UP



- For all atmospheric CO_2 observing systems, the bottom-up estimates are consistent with the estimated anomalies in CO_2.
- Provides support for our bottom-up estimates of CO_2 flux anomalies.

CONCLUSIONS

- Observations from multiple observing systems provide consistent information on the carbon cycle anomalies during the 2019/2020 austral growing season.

- Oct – May biomass burning emissions of 139 – 241 TgC and ΔNEE of 36 – 52 TgC, resulting in a total of 175– 293 TgC. For comparison Australia's annual FF emissions are ~115 TgC.

- C/G/S/S showed rapid recovery to above average productivity during Feb-May with cooler-wetter conditions, while unburned forests recovered to average productivity.

- Burned forests continued to have below average productivity throughout the 2019/2020 growing season, suggesting a slow recovery.

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