# Regional $CO_2$ fluxes and climate-driven anomalies estimated with global high-resolution inverse model using surface and GOSAT data in 2010-2022

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- We present a summary of top-down estimates made with high-resolution global inverse model NTFVAR (NIES-TM-FLEXPART-variational) of the regional carbon dioxide fluxes based on the GOSAT satellite and surface CO2 observations in 2010-2022.
- The transport model achieves high resolution by coupling the global tracer transport model NIES-TM (with 3.75° resolution) and the FLEXPART model operating at 0.1° resolution.
- The prior fossil emissions are provided by ODIAC, and fire emissions by GFAS, while land biosphere and oceanic fluxes are prepared via global upscaling with machine learning based on point observation data. The diurnal cycle of biospheric CO2 exchange is simulated by combining data for the gross ecosystem production and ecosystem respiration.
- We use 2 variants of Obspack dataset a) MIP v10 version used in Byrne et al 2022, and same uncertainties as NIES submission; b) extended set based on GVP 202309 version, using same temporal sampling as MIP dataset, but including all available stations in Europe and Asia
- We completed 6 years 2015-2020 inversions with 2 versions of NIES TM v20 and v21, and 2 sets of inversions for foll period of 2009-2022, with 8 combinations of prior ocean, model version and observation selection
- Results suggest that:
  - interannual flux anomalies are well correlated for regions with dense surface observations, as Europe 2010, 2018 heatwaves
  - Tropical-extratropical-boreal balance is impacted by prior ocean fluxes, data selection, model transport
  - Mean regional fluxes by NIES NTFVAR are comparable with OCO2 MIP and GCB2023 outputs.

| case | NIES-TM version | Obspack mip/gvp | GOSAT | Ocean prior |
|---|---|---|---|---|
| mip-sat-m1-l | 21 | mip | yes | Landschutzer 2020 scaled |
| mip-sat-m0-l | 20 | mip | yes | "" |
| mip-sur-m0-l | 20 | mip | - | "" |
| gvp-sur-m1-l | 21 | gvp | - | "" |
| gvp-sat-m1-l | 21 | gvp | yes | "" |
| gvp-sur-m0-z | 20 | gvp | - | Zeng 2014 |
| gvp-sur-m1-z | 21 | gvp | - | "" |
| gvp-sat-m0-z | 20 | gvp | yes | "" |

Table 1 NIES NTFVAR v20-v21 cases. GVP case includes more stations than MIP
The land flux correlation distance in all cases was reduced to 100 km (from 500 km in NIES MIP submission), and prior flux uncertainty increased 4x to accommodate large flux adjustments to match strong sink signals at LEF and some other continental sites.
NIESTM v20 uses 3rd order van Leer scheme (like Geos-Chem or MIROC), and less cloud convection than v21 in Tiedtke scheme
NIESTM v21 use slopes scheme (like TM3, TM5) and uses cloud convection from ERA5
The version in Maksyutov et al ACP 2021 was based on NIESTM v08.1, with van Leer 2nd order advection and hybrid isentropic grid, while v20-21 use ERA5 data on 42 level hybrid pressure grid.

## Mean land fluxes for Transcom-3 regions – balance of sources and sinks

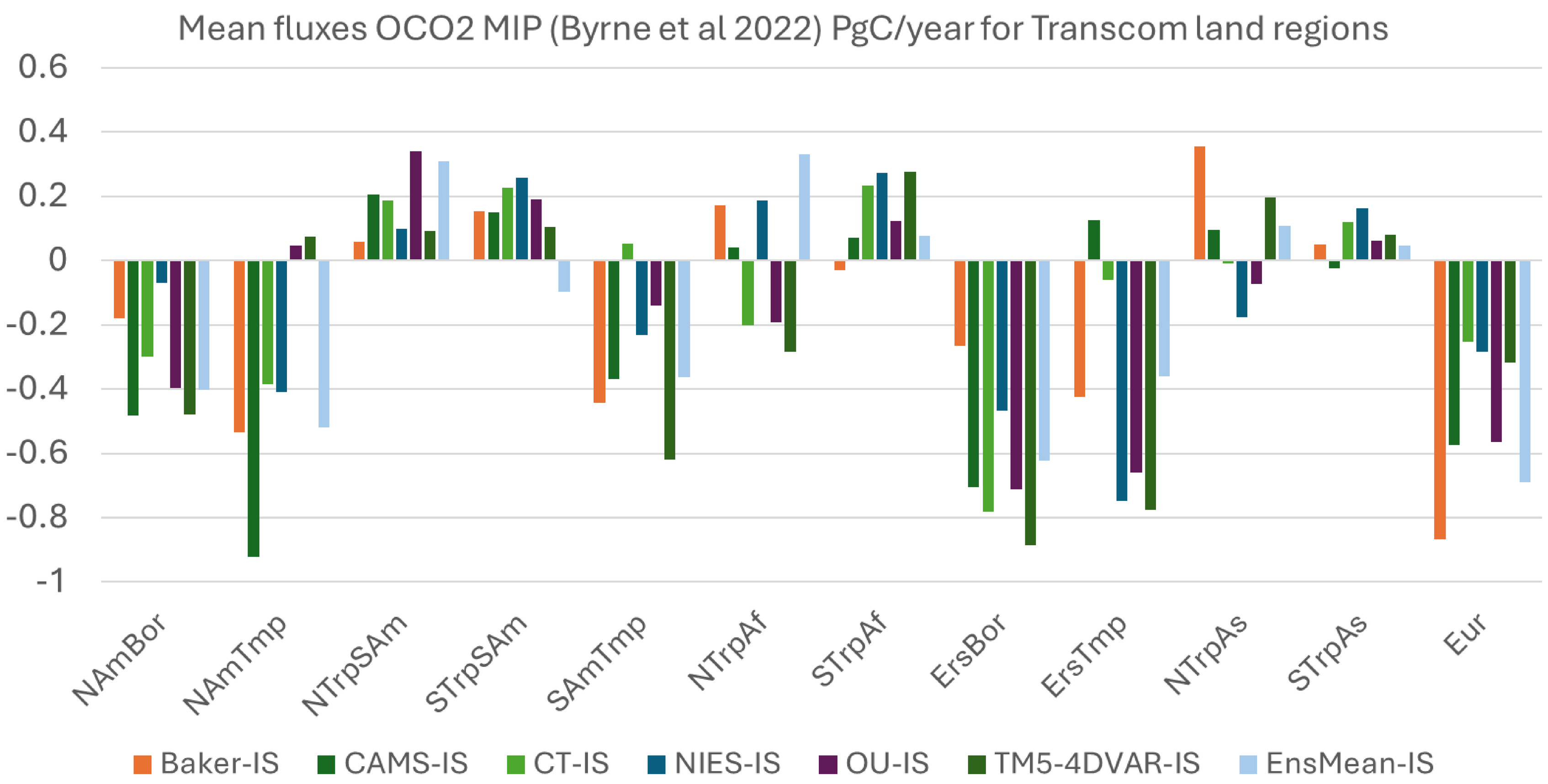


Fig 1. Mean regional land fluxes for Transcom regions by MIP models and NIES NTFVAR v21, NIES model show less sink in boreal regions, and temperate S. America, likely due to strong ocean prior. NIES Landschutzer 2020 ocean fluxes are scaled to produce global 3 PgC/y sink in 2010s. (IS–in situ case). MIP paper Byrne et al ESSD 2022

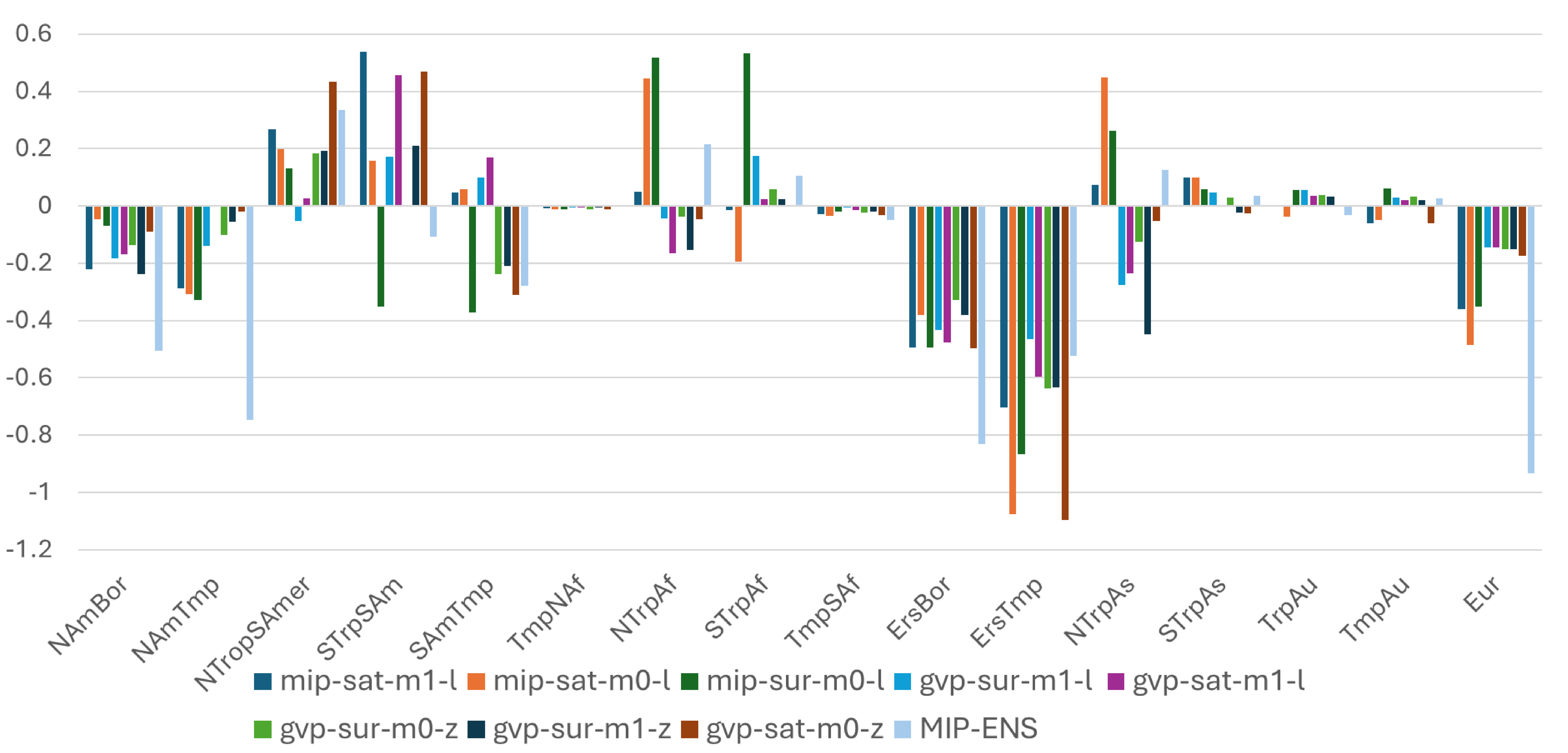


Fig 2. Mean regional land fluxes for Transcom regions by NIES NTFVAR v20-21,
V20 model show less sink in boreal regions than v21, but more sink in East Asia/Eurasia Temperate

## North – South gradient of the estimated land fluxes

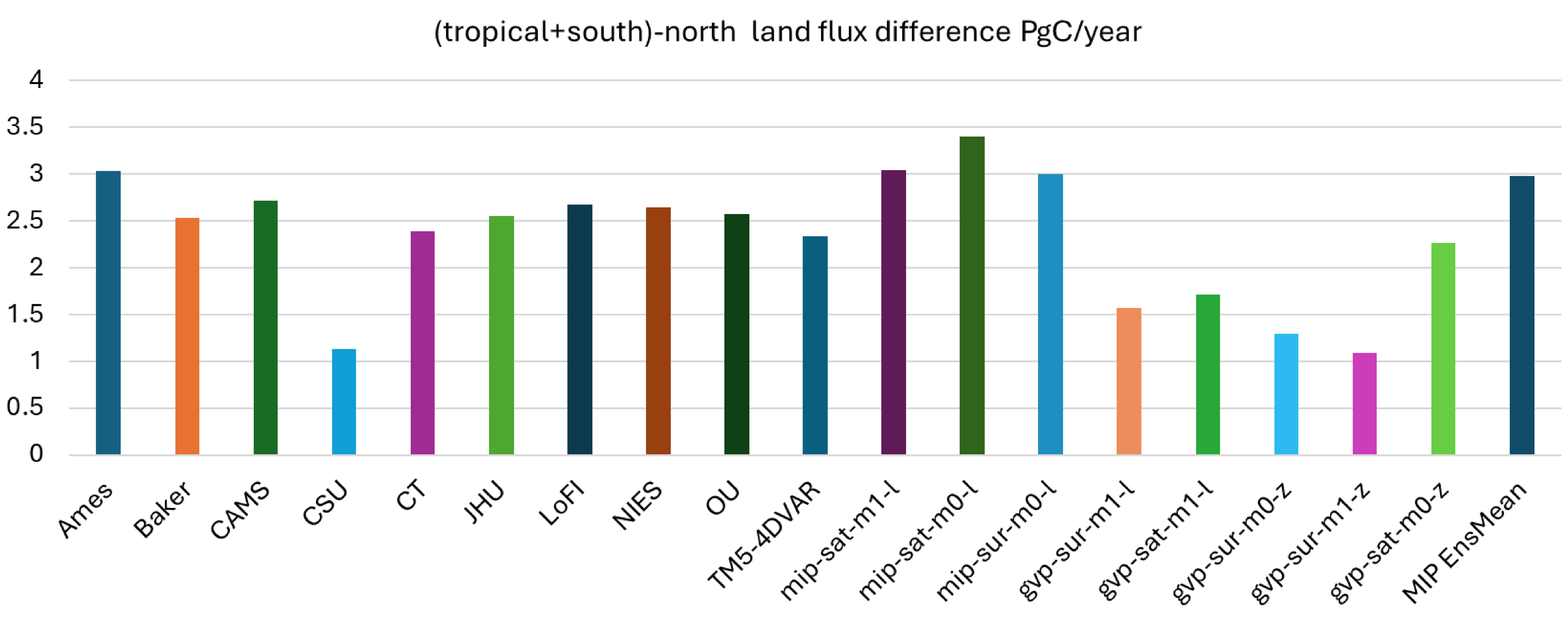


Fig 3 Mean regional land flux Nort South gradient by MIP models and NIES NTFVAR v20-v21 cases Changing data and flux uncertainty (gvp case) reduces the northern sink with both ocean priors.

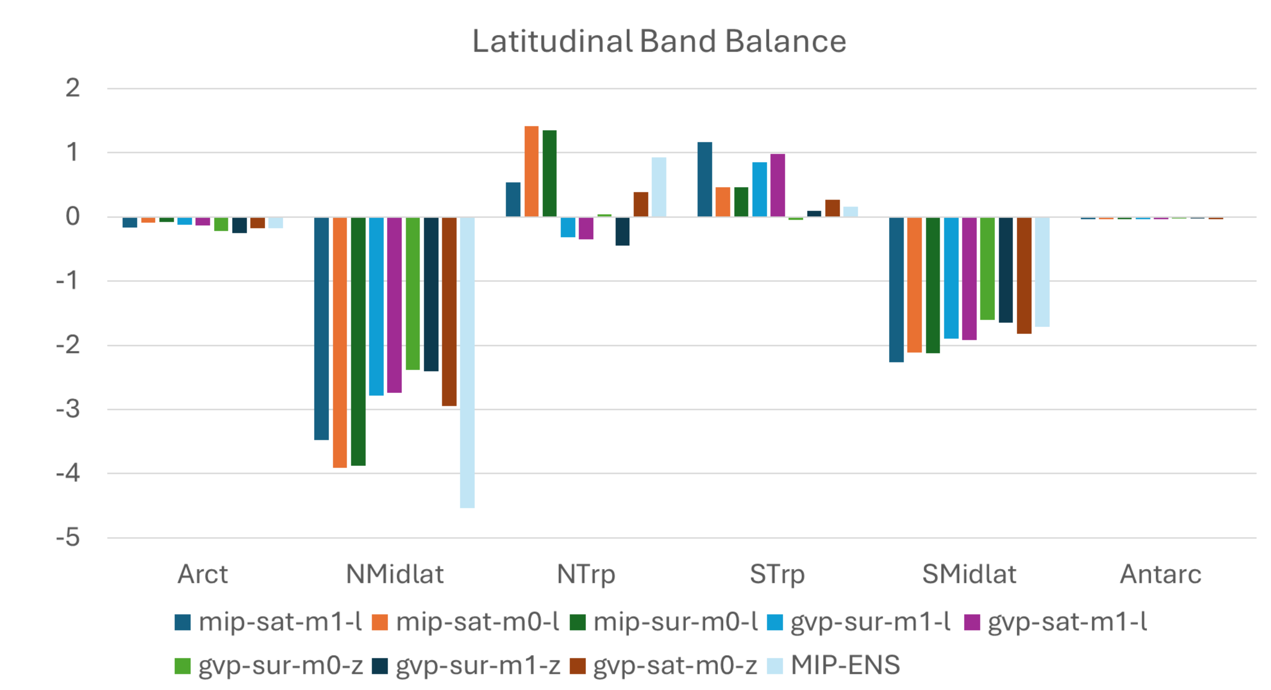


Fig 4 Mean regional band fluxes by NIES NTFVAR v20-v21 cases PgC/yr. Lower ocean prior in SH by Zeng 2014 fluxes reduces the southern midlatitude sink and south tropical source.

## Monthly flux anomalies driven by interannual climate variability

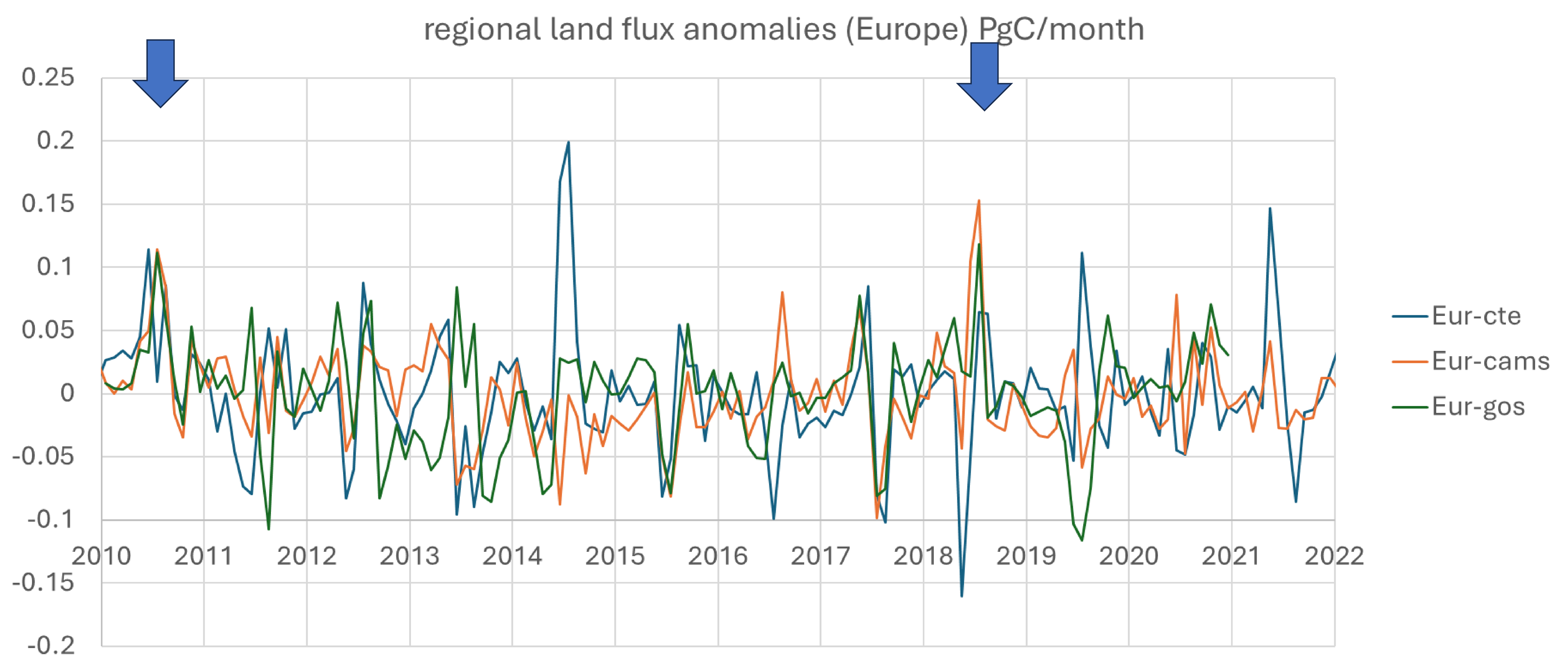


Fig 5 Monthly flux anomalies for Europe. Comparison with GCP2023 fluxes by CAMS and CTE. Amplitudes and phase very similar to CAMS for 2010 heatwave, 2018 drought. gos - case mip-sat-m1-l.( GCB data on ICOS citation Luijkx etal , 2024. https://doi.org/10.18160/4M52-VCRU)

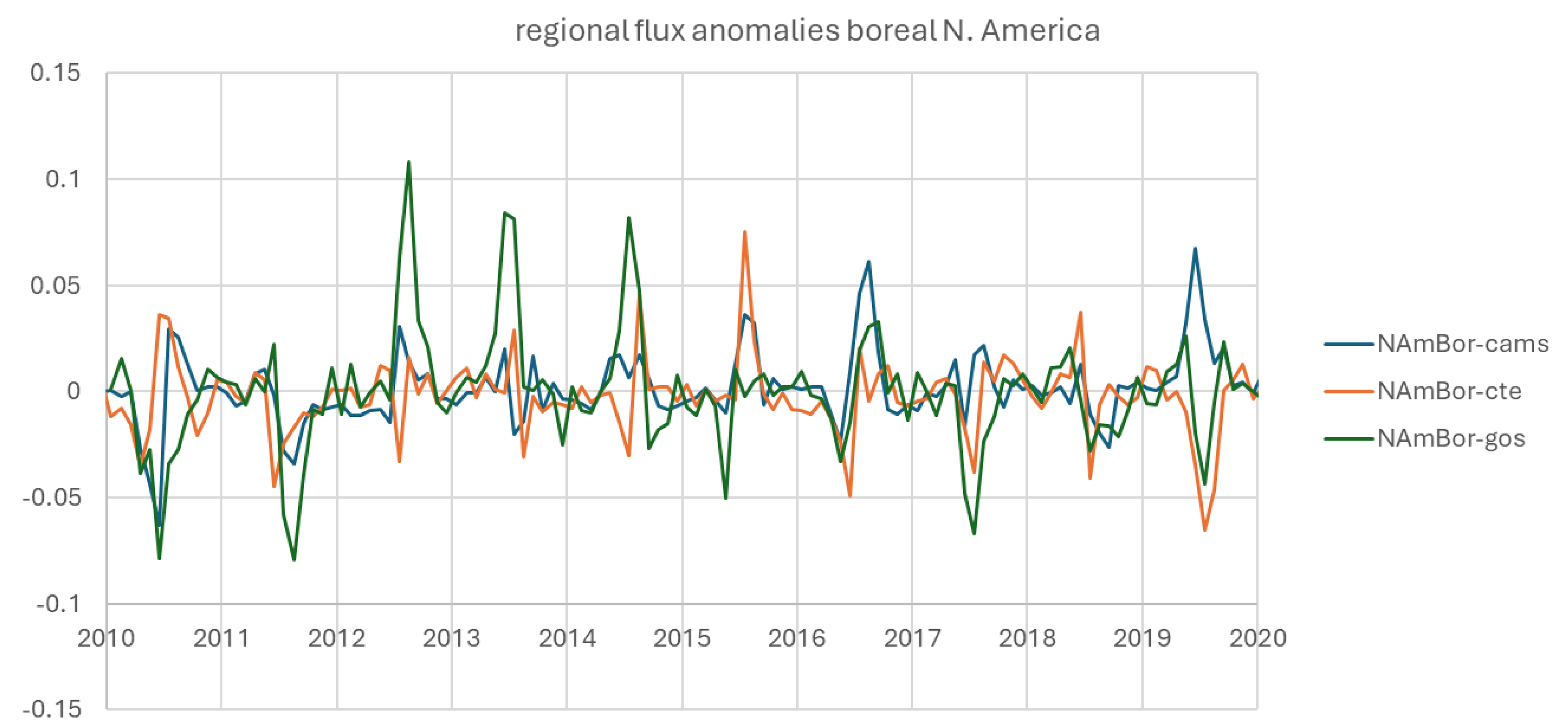


Fig 6 Monthly flux anomalies as in Fig 5. but for boreal N. America. Differences could be due to fire prior fluxes and impact of GOSAT. Models agree on stronger uptake in 2010, 2011, 2017, 2019 summer, disagree on 2012-2015 summer.