Development of the ECCC's national carbon flux inversion system

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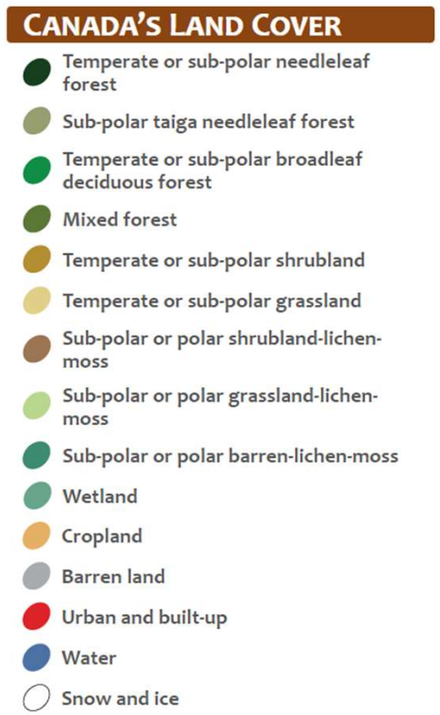
Mathematical approaches of atmospheric constituents data assimilation and inverse modeling, Banff International research Station

Motivation



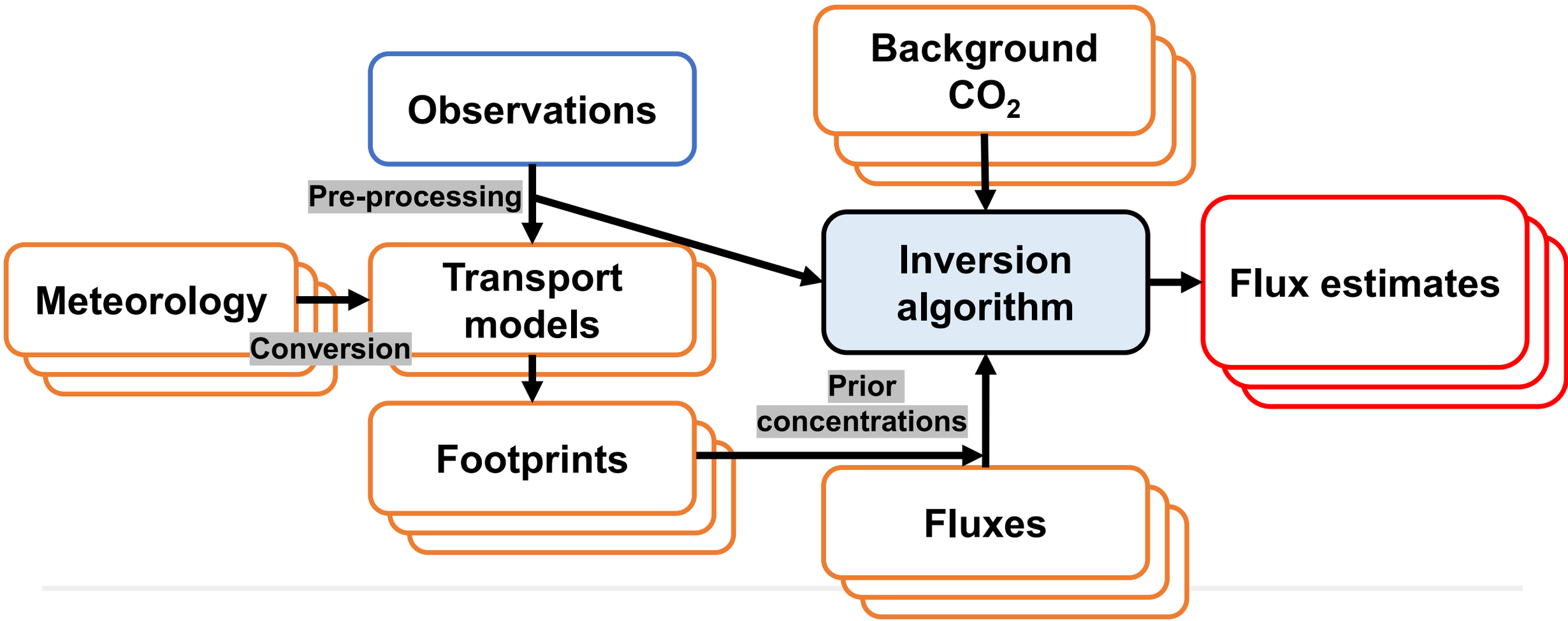
(https://atlas.gc.ca/lcct/en/index.html)

- Large uncertainties in national and finer scales GHG emission estimates.
- The uncertainty of the natural GHG sources/sinks over Canada is large as well.
- The uncertainty is mainly due to insufficient knowledge of model (transport, biosphere, etc.) errors and observation sparsity on regional scales.

ENCIS (ECCC National Carbon flux Inversion System)

- Inverse modelling system based on **LPDM**s (Lagrangian Particle Dispersion Model).
- To obtain **quantitative information** on **GHG fluxes** (natural carbon sources/sinks) over **Canada** from national to provincial scales using atmospheric GHG measurements;
- To address carbon cycle science needs from the **Canadian perspective**;
- To use ECCC operational weather forecasting tools;
- To run routinely, behind real time.

Inversion framework



Inversion algorithm

Analysis equation

$$\lambda = \lambda_p + QK^T(KQK^T + R)^{-1}(z_{bio} - K\lambda_p)$$

1 2 3 4 5

1: Estimated scaling factor
2: Prior scaling factor
3: Prior error covariance
4: Model-data mismatch
5: Observations

observation

$$z_{bio} = z_{CO_2} - z_{bg} - z_{others}$$

$$K = HP_{\text{bio}}$$

$$Q = (\sigma\sigma^T) \times (D \otimes E) = I_\sigma (D \otimes E) I_\sigma$$

Temporal correlation

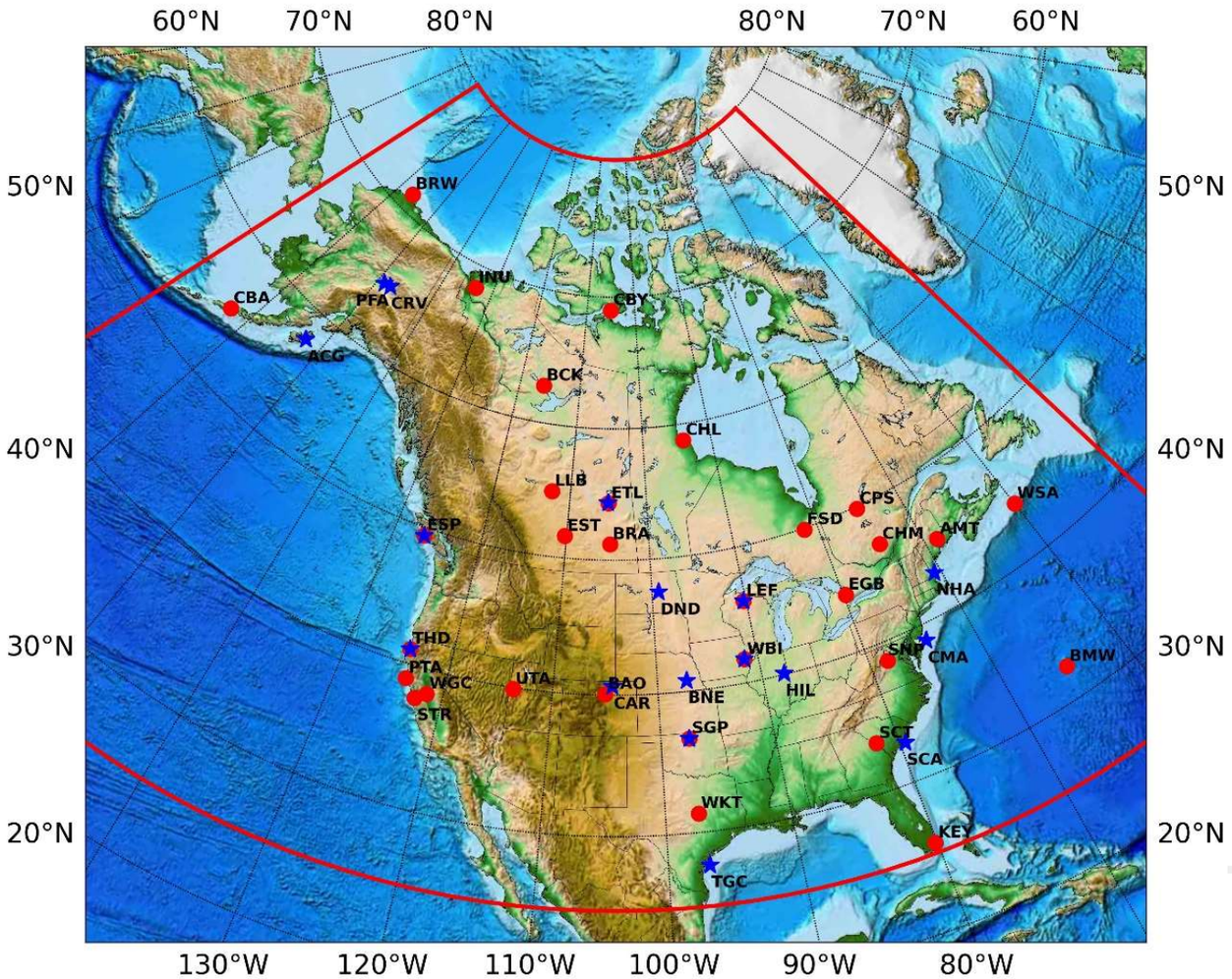
$$D = \left[exp\left(-\frac{X_\tau}{l_\tau}\right)\right]$$

Spatial correlation

$$E = \left[exp\left(-\frac{X_s}{l_s}\right)\right]$$

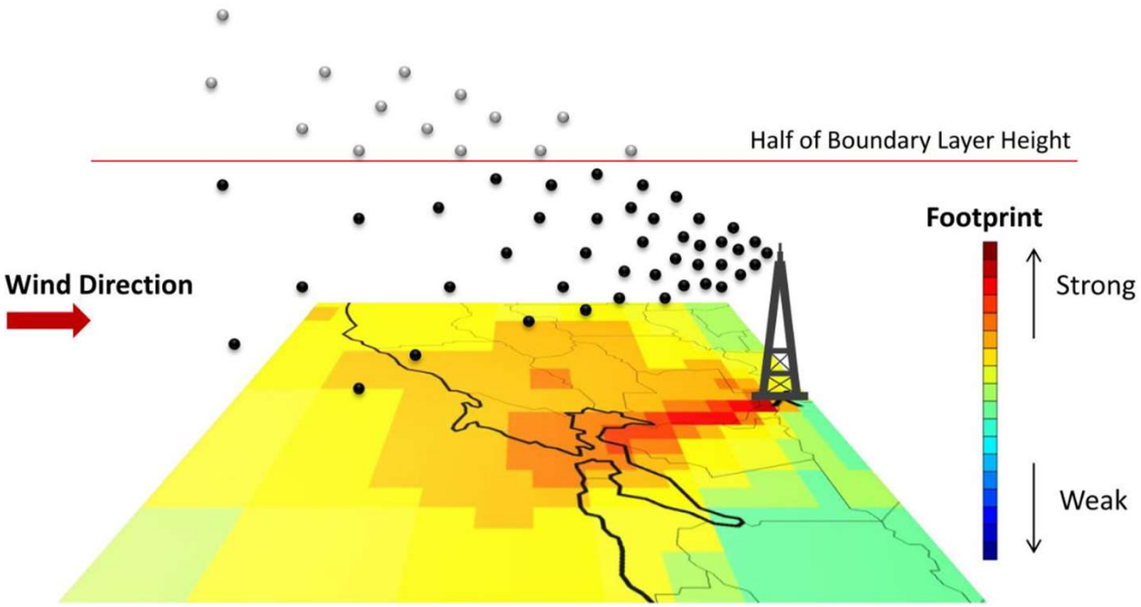
- Adopting the inversion algorithm from CarbonTracker-Lagrange system (Hu et al., 2019).
- Biospheric fluxes (**NEE**) is actually estimated.
- λ: weekly scaling factor (defined on 1°×1° land grid) (1 or 8 per week)
- One analysis for a year by using sparse matrix methods for explicit matrix inversion (Yadav and Michalak, 2013)

Observations



- Atmospheric CO2 measurements from the ObsPack CO2_1_GLOBALVIEWplus_v6.1
- Selected surface sites and aircraft profiles
- Using the variable ‘obs_flag’ in the dataset for data filtering
- Using afternoon time data (12-16 LST for continuous data)
- No averaging for discrete data
- Aircraft profile are available bi-weekly or monthly

Transport models



(Fisher et al., 2015)

- **LPDMs** (Lagrangian Particle Dispersion Model) are used as the transport model to produce hourly footprints on 1°×1° grid spacing.

- **Model**

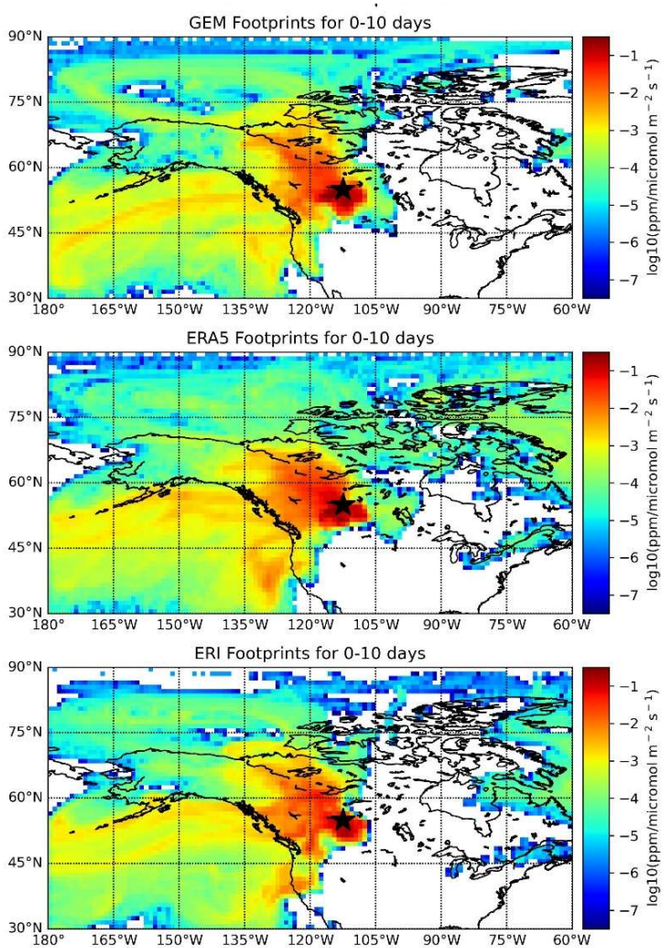
1) FLEXPART
2) STILT

- **Meteorology**

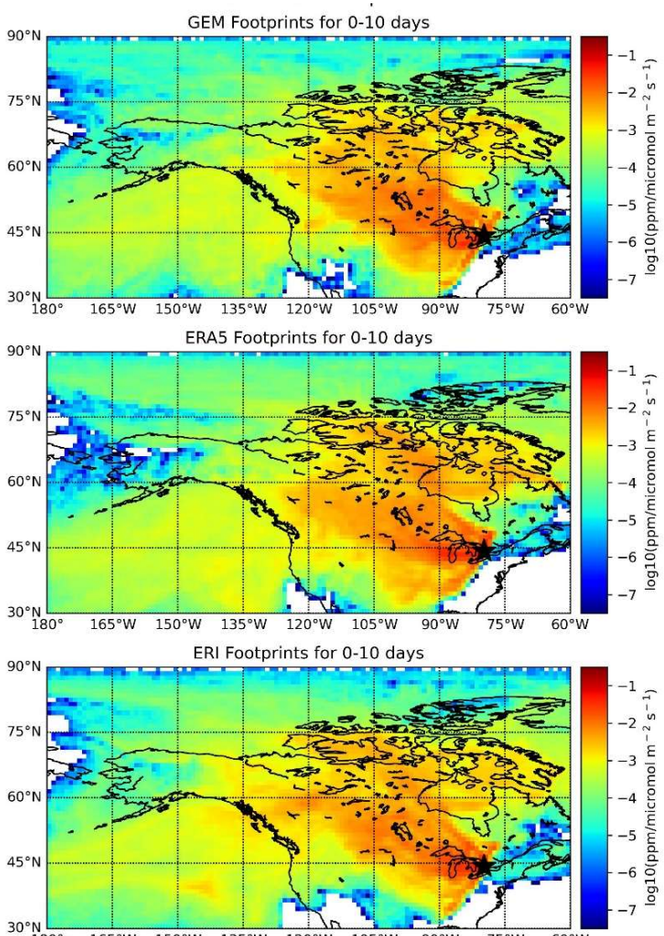
1) GEM-MACH-GHG (global 0.45°, hourly)
2) ECMWF ERA5 reanalysis (global)
3) ECMWF ERA-I reanalysis (global)
4) WRF (only for STILT) (regional)

Footprints

LLB (Lac La Biche, AB)

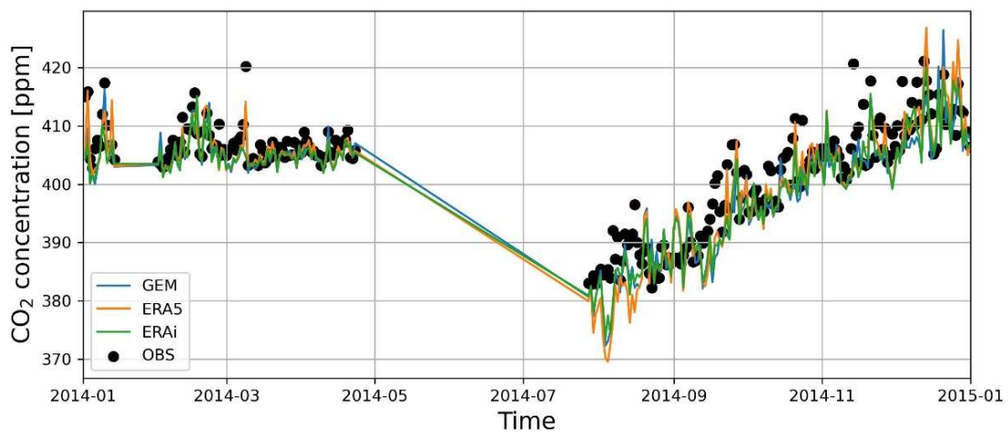


EGB (Egbert, ON)



1-month mean (January 2014)

LLB (Lac La Biche, AB)



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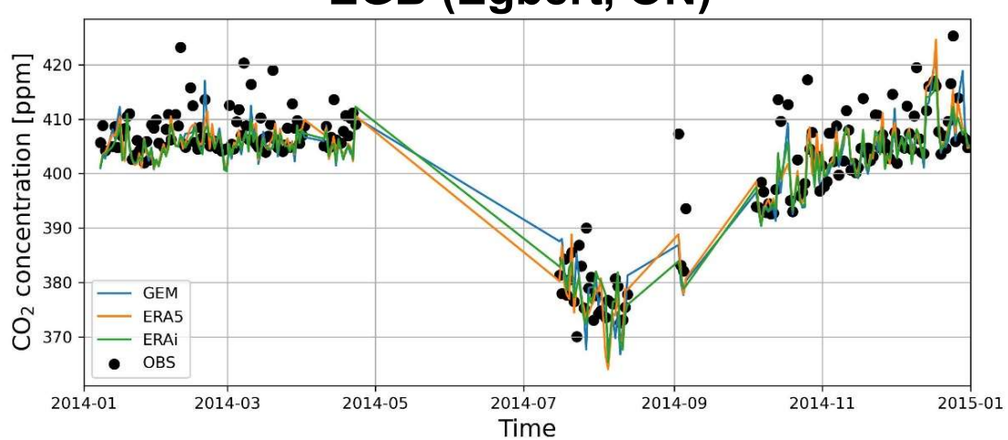
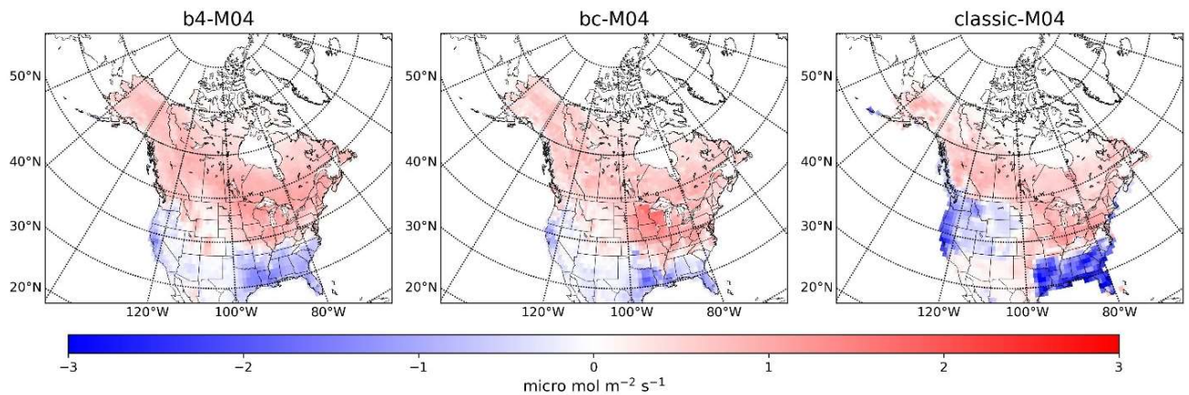
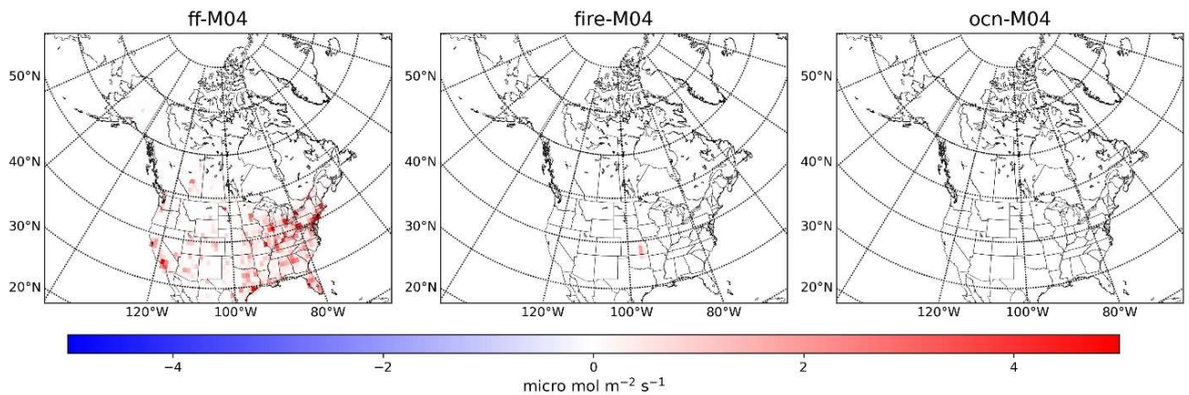


Fluxes

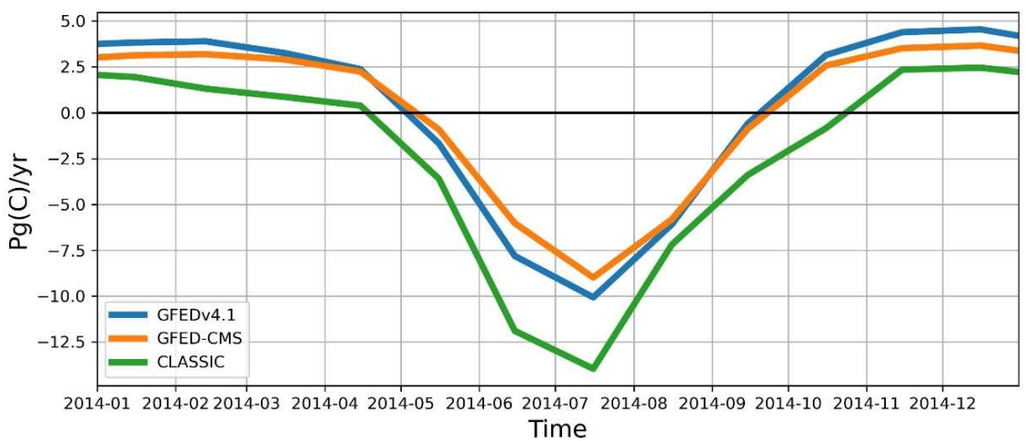
Prior biospheric fluxes (April 2018)



Fossil Fuel, Fire and Ocean (April 2018)



Monthly fluxes (2014)



- CT2019B prior (CASA-GFEDv4.1, CASA-CMS) from CT2019B
- CLASSIC model (ECCC) provides GPP, R
- Other flux components from CT2019B

Experiment design (OSSE)

EXP	Prior flux (NEE)	Footprints	EXP name
1	CT2019B prior GFEDv4.1s (B4)	GEM-FLEXPART (GF)	B4+GF
2		ERA5-FLEXPART (E5)	B4+E5
3		ERAi-FLEXPART (EI)	B4+EI
4		WRF-STILT (WT)	B4+WT
5	CT2019B prior GFED_CMS (BC)	GEM-FLEXPART (GF)	BC+GF
6		ERA5-FLEXPART (E5)	BC+E5
7		ERAi-FLEXPART (EI)	BC+EI
8		WRF-STILT (WT)	B4+WT
9	CLASSIC (CL)	GEM-FLEXPART (GF)	CL+GF
10		ERA5-FLEXPART (E5)	CL+E5
11		ERAi-FLEXPART (EI)	CL+EI
12		WRF-STILT (WT)	CL+WT

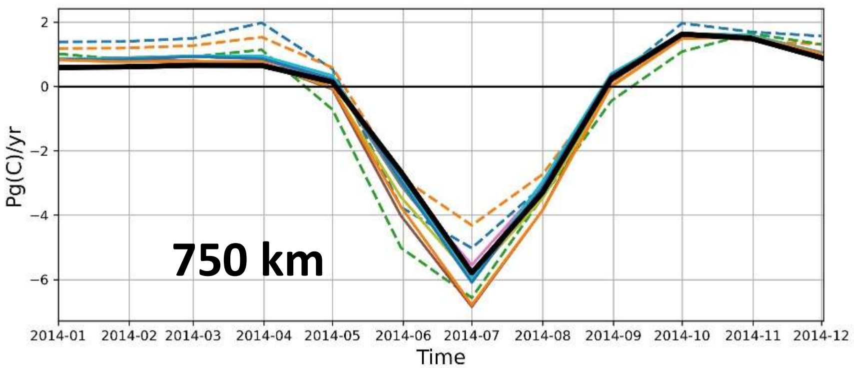
- **Twelve experiments** were conducted with different prior fluxes and footprints in order to consider uncertainties in posterior fluxes.
- **Experiment period**: 2014
- **Truth flux**: CT2019B optimized biospheric fluxes (NEE)
- Adding random noise N(0 ppm, 0.1 ppm) to synthetic observations
- Synthetic observations are sample at the actual location and time as real observations.

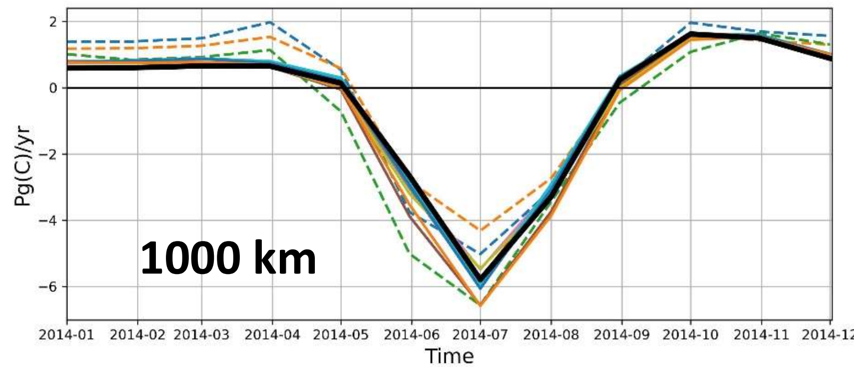
Parameters

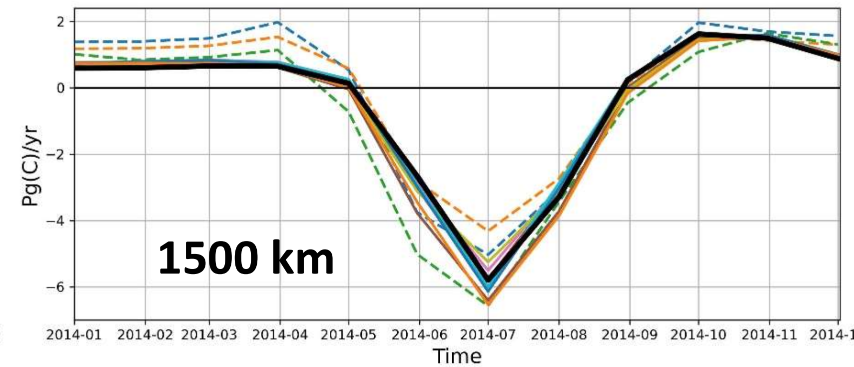
- Q: 100%
- R: 3 ppm (surface), 1 ppm (aircraft)
- SCL: 1000 km
- TCL: 1 week

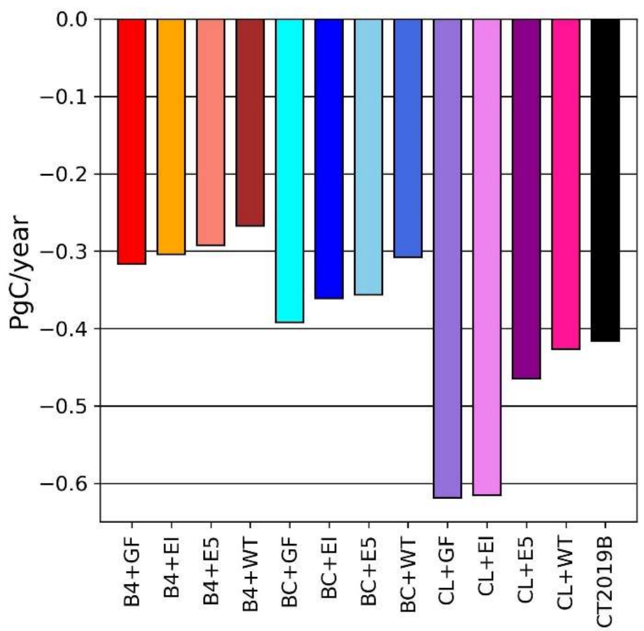
Results - Flux (OSSE)

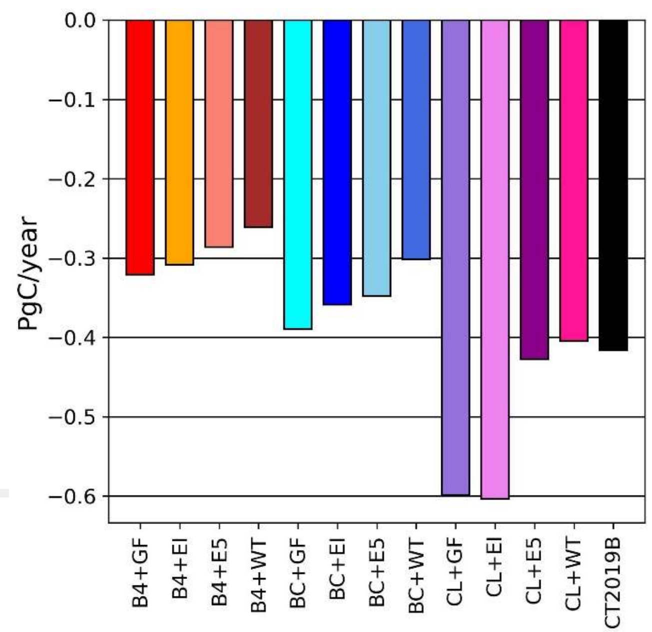
Fluxes over Canada
Dashed: priors
Solid: posteriors
Black: truth

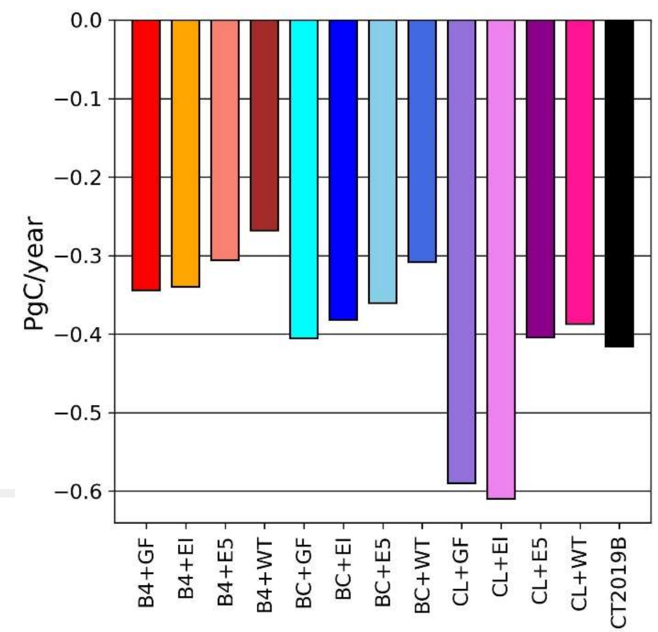




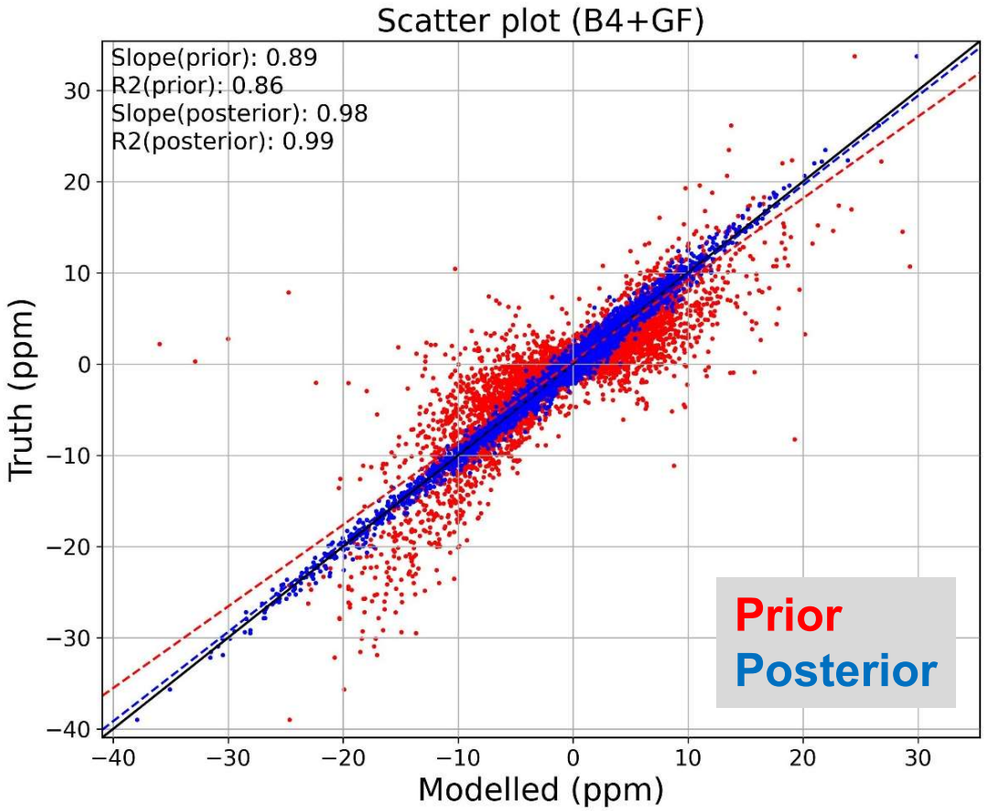








Results - Modelled CO_2 (OSSE)



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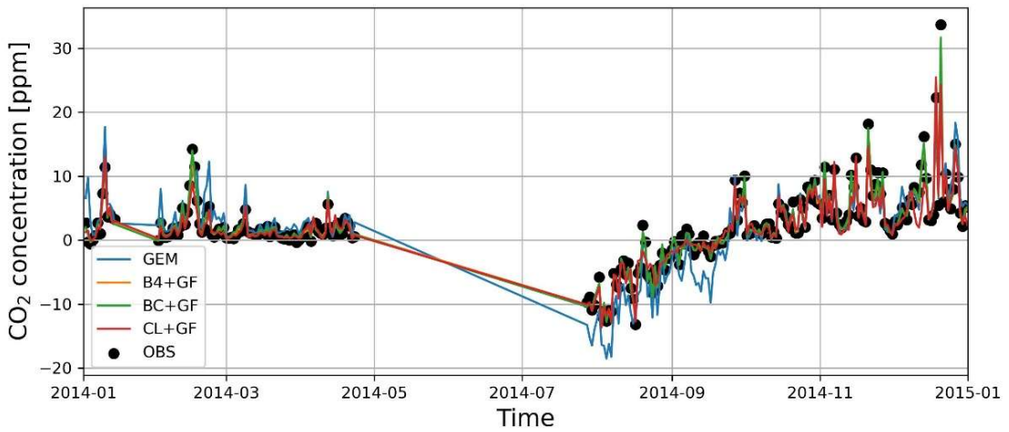

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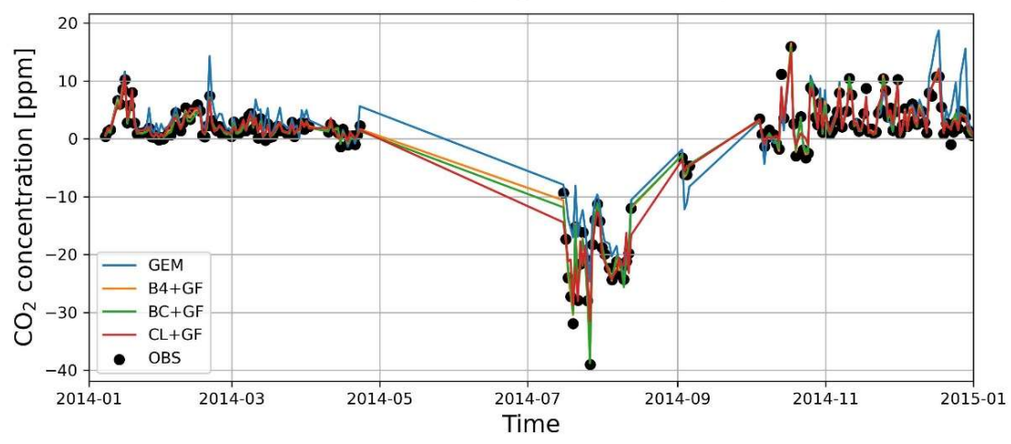


Experiment design (with real-data)

Prior flux
CT2019B prior CASA-GFEDv4.1
CT2019B prior CASA-CMS
CLASSIC

✖

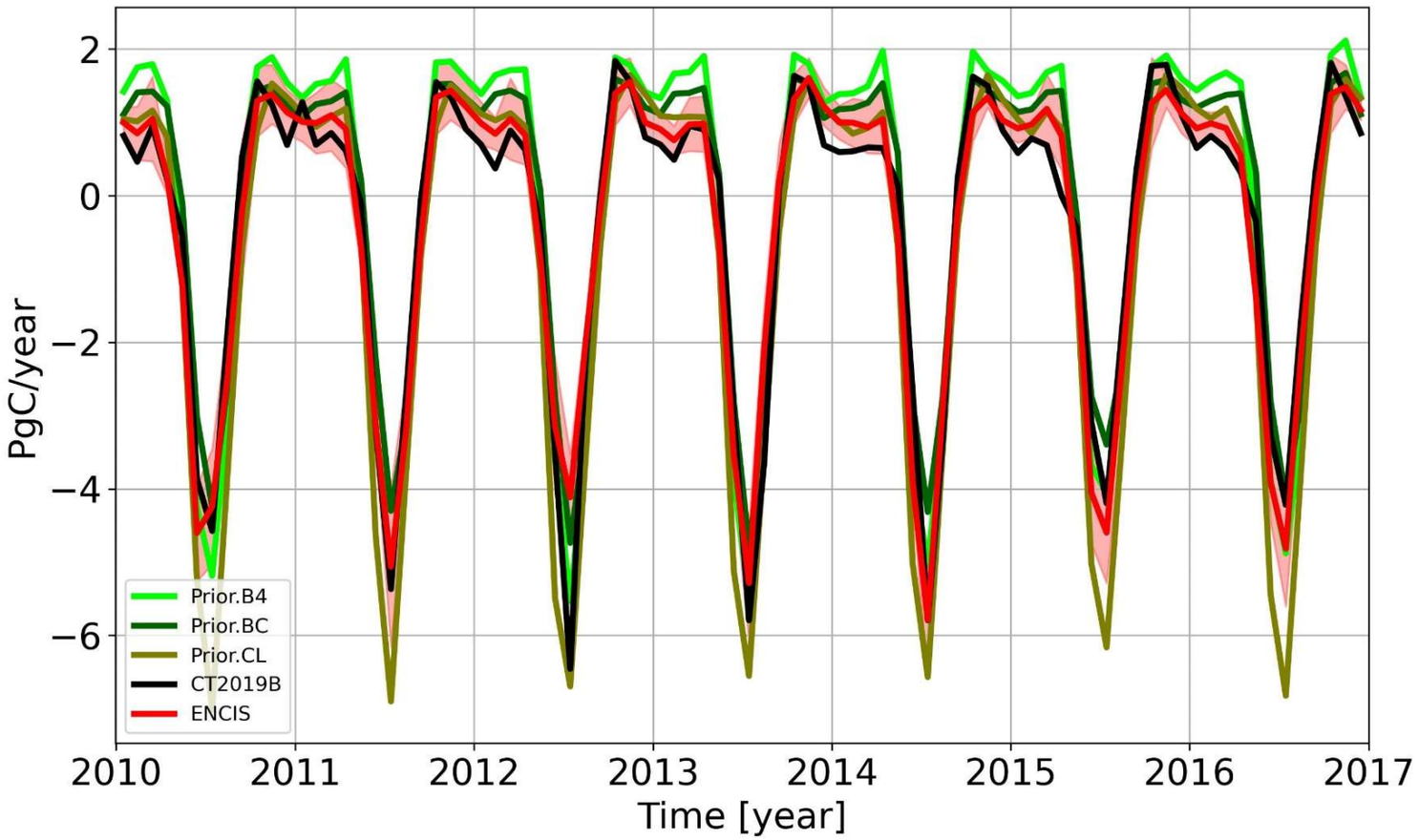
Transport
FLEXPART-GEM
FLEXPAR-ERA5
FLEXPART-ERI
WRF-STILT
Others

✖

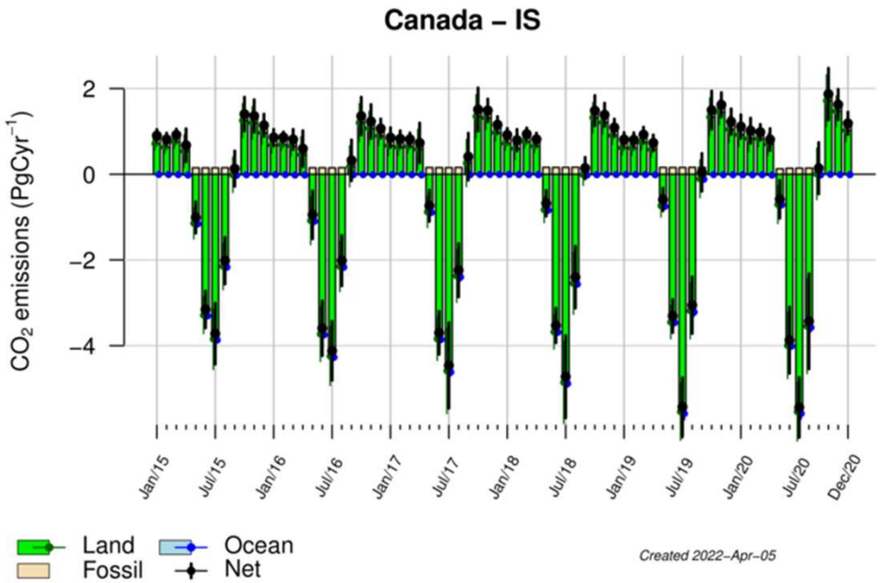
Background CO_2
CT2019B
GEM-MACH-GHG global
ECMWF CAMS

- **Experiment**: 12 experiments for now (3 Transport * 4 Priors * 1 background)
- **Period**: 2010-2016
- **Parameters**: Similar to OSSE configuration (for now).

Results - Flux (real-data)

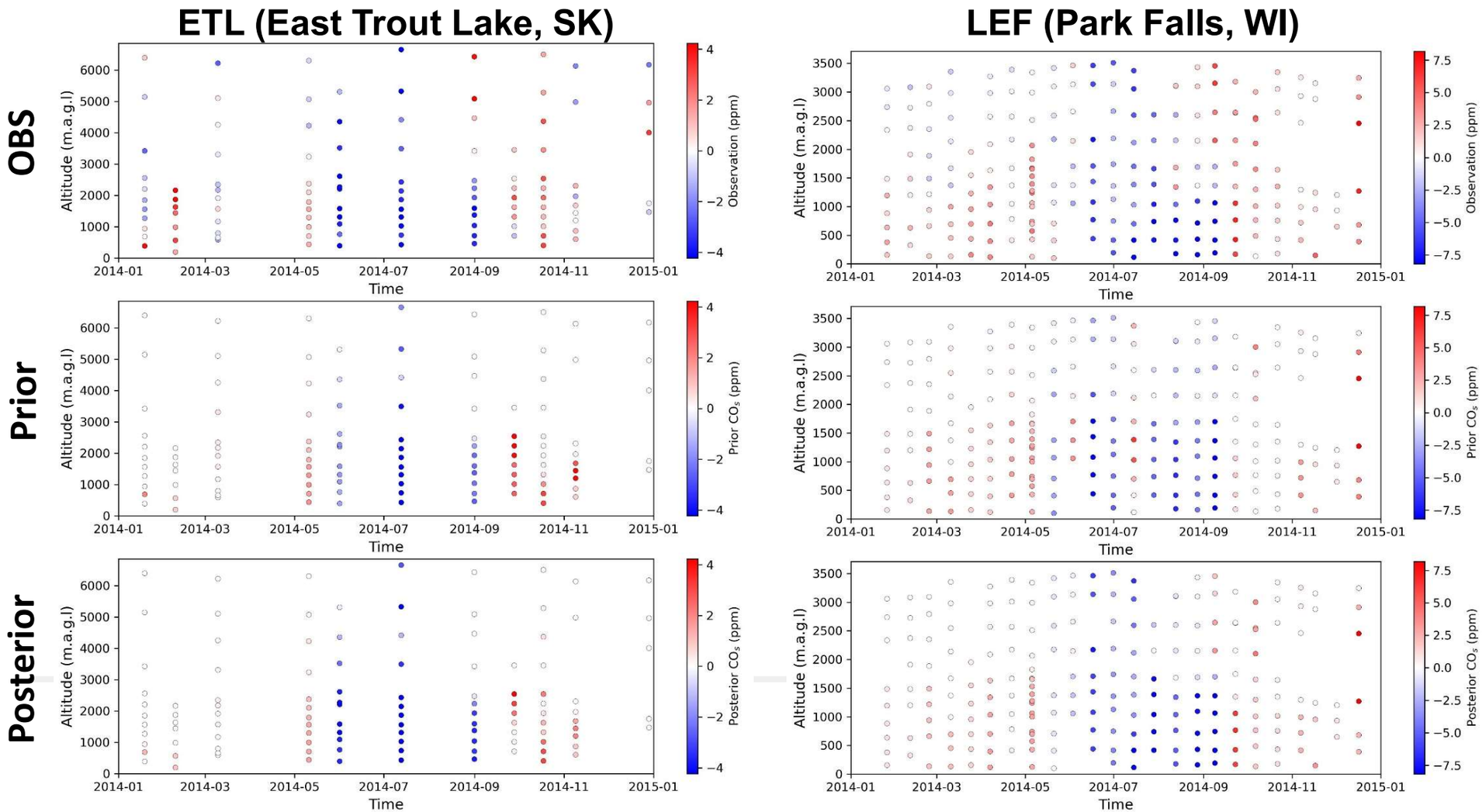


- Flux estimates over **Canada (Preliminary)** with the real-data.

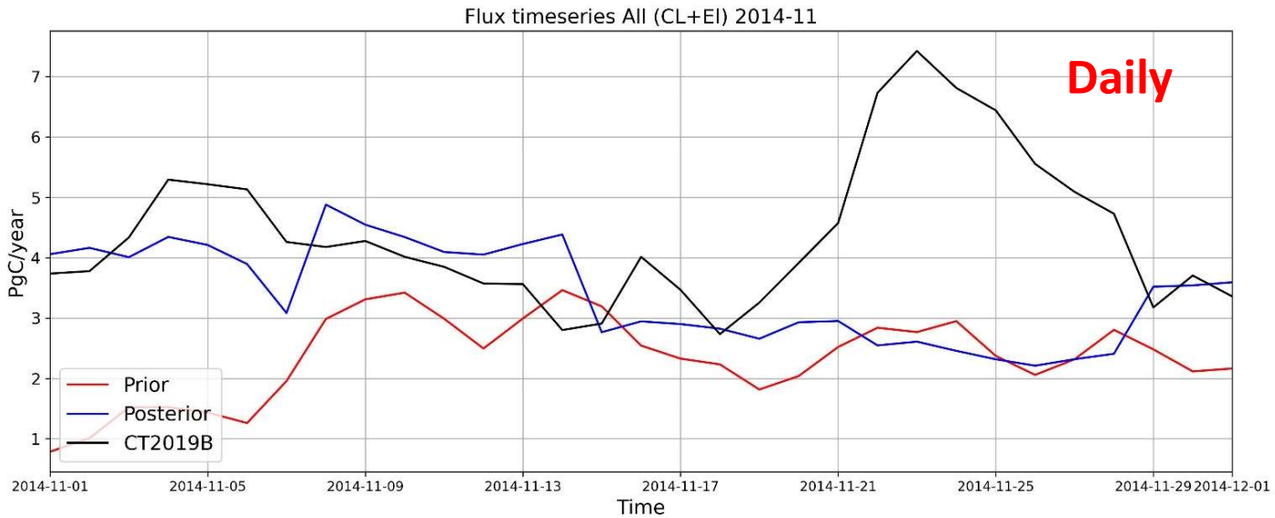


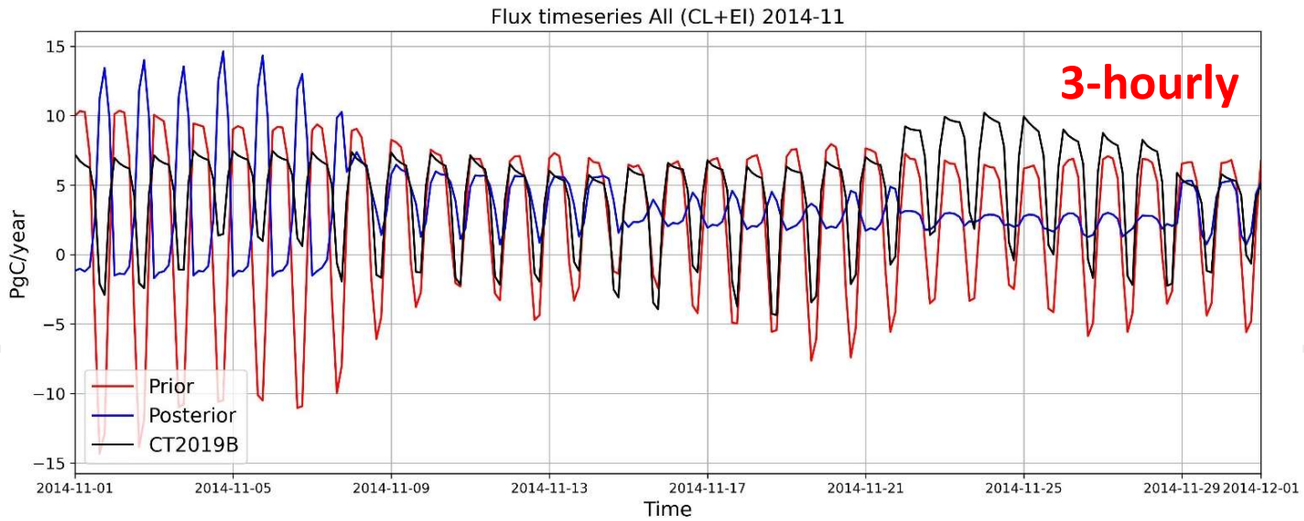
(https://www.gml.noaa.gov/ccgg/OCO2_v10mip/index.php)

Results - Modelled CO_2 (aircraft profile)



What happens with improper settings





- It necessary to ensure that the flux estimates are physically making sense.

Summary

- ENCIS is a regional-scale flux inversion system for inferring source and sinks of CO_2 using atmospheric CO_2 measurements.
- The system well estimates NEE over Canada (OSSE).
- Some issues remain in using real-data.
- We are working on utilizing more observations, transports and etc.

Thank you