



Atmosphere Monitoring

# Considerations for CO<sub>2</sub> AIFS

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## Some questions:

- **Target:** 3D atmospheric CO<sub>2</sub>, 2D CO<sub>2</sub> sources/sinks, specific source/sink sectors? Atmospheric transport, land surface, ocean
- **Reference** for training the ML model: inventory datasets, model simulations/analyses, atmospheric inversions?
- **Input** data: remote sensing data, in situ data, NWP + AC analysis, activity data ?
- **Metrics** to assess the model performance?

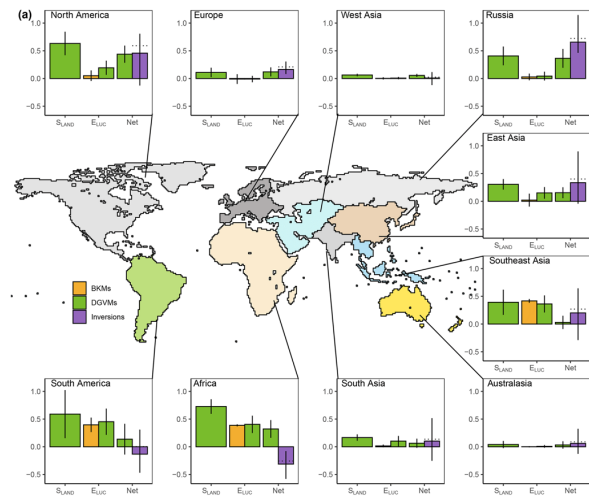
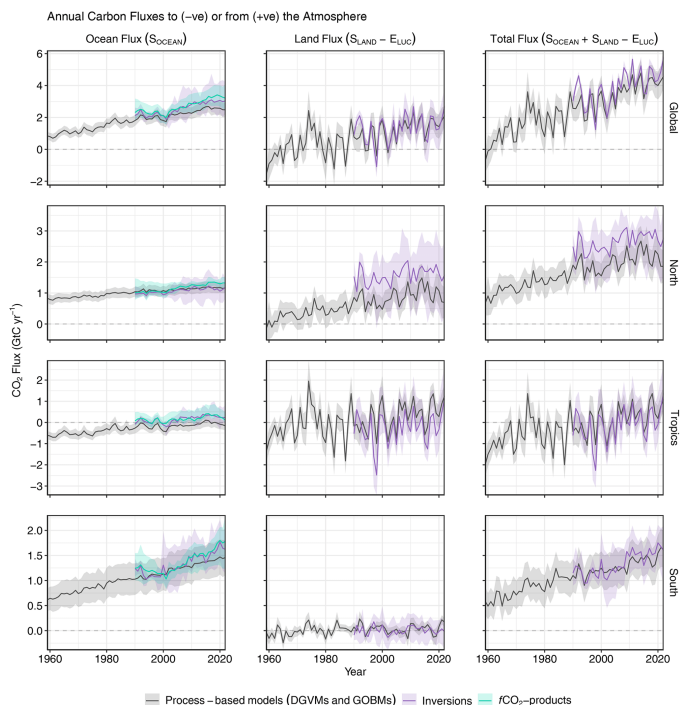
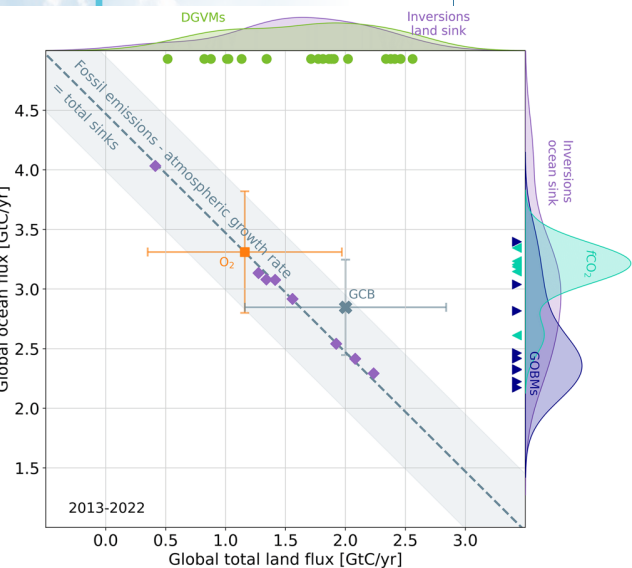
## Some challenges:

- **Reference datasets** for training can have systematic errors (observations/analysis)
- **Atmospheric transport:** Basic requirement of **mass conservation** (changes in atmospheric mass need to be matched with sources/sinks).
- **Representation of sub-gridscale transport (convection and turbulent mixing)**
- **Bias/variance trade-off:** zero global bias in total CO<sub>2</sub> flux while having to represent large/temporal spatial variability associated with emission hotspots and vegetation.
- **Representation of trends** outside training period (NN OCO-2 and IASI CO<sub>2</sub> retrievals, FLUXCOM)



# Uncertainty in analysis reference datasets

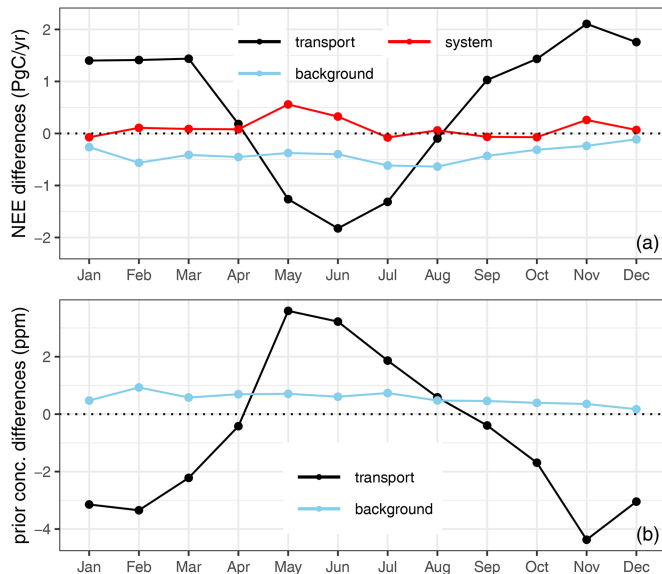
- IFS CAMS GHG NRT analysis, IFS CAMS GHG HR FC, IFS CAMS GHG re-analysis (Agusti-Panareda et al., 2023), IFS CAMS inversion in development (CoCO2 and CORSO HE projects)
- CAMS inversion dataset (Chevallier et al., 2010, 2019, available from ADS)
- GCP inversion products (Friedlingstein et al., 2023)



# Why do inverse models disagree?

Munassar et al., 2023

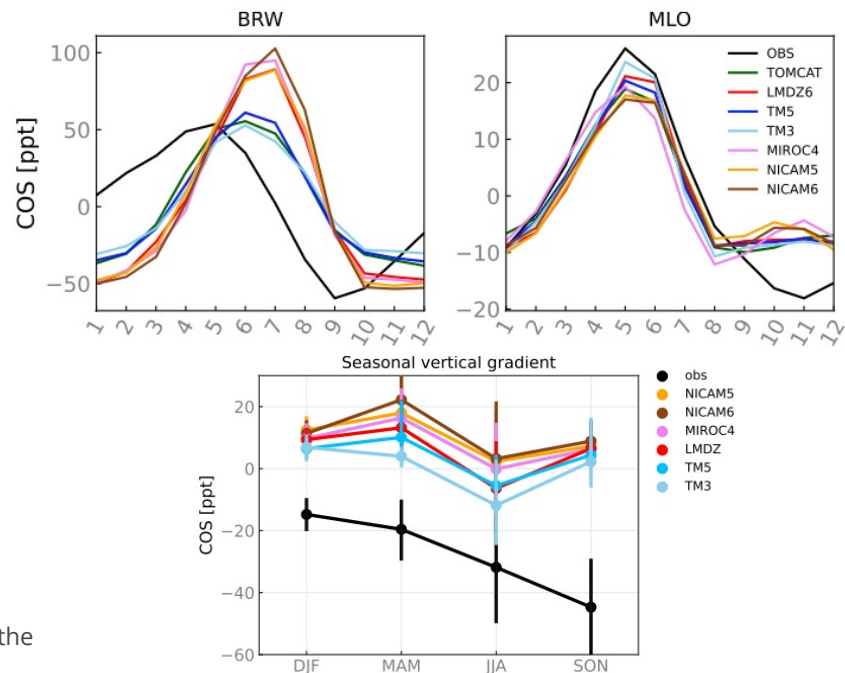
Intercomparison of two European inversions



Differences in optimized fluxes **(a)** and prior concentrations **(b)** calculated with the regional transport models STILT and FLEXPART (CS3-CF3) and background provided through TM3 and TM5 (CS3-CS5). "system" refers to the differences between CSR and LUMIA inversion for optimized fluxes (CS5-LS5).

Remaud et al. (2023)

Intercomparison of Carbonyl Sulfide (TransCom-COS)



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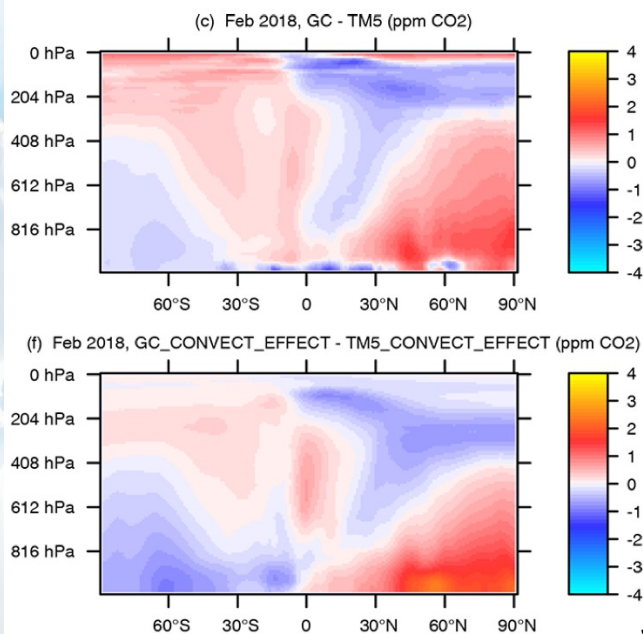
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# Systematic errors in tracer transport

- **Advection scheme and resolution:** mass conservation and numerical diffusion (Agusti-Panareda et al., 2017, Eastham & Jacob, 2017)
- **Convective transport** (Schuh and Jacobson, 2023)
- **Turbulent mixing** (Kretschmer et al., 2012)
- **Winds from NWP analyses** (largest in boundary layer and stratosphere) (Yu et al., 2018, Zhang et al., 2021)



Schuh et al. (2019):

“inverse model flux estimates for large zonal bands can have systematic biases of up to 1.7 PgC/year due to large-scale transport uncertainty.”

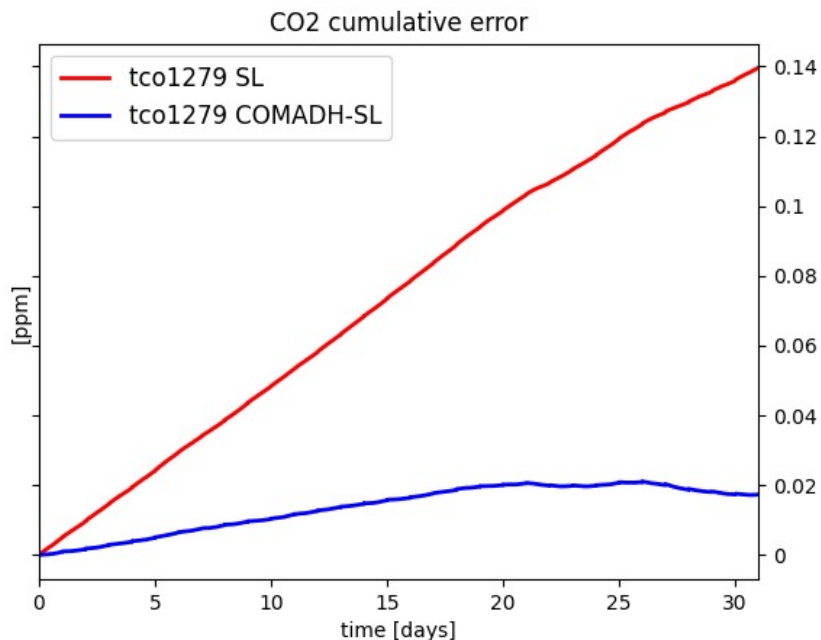
“The research suggests that variability among transport models remains the largest source of uncertainty across global flux inversion systems and highlights the importance both of using model ensembles and of using independent constraints to evaluate simulated transport.”





# Systematic errors in tracer transport

**IFS limitations:** atmospheric transport is not mass conserving and **mass fixer** could be responsible for artificially transferring CO<sub>2</sub> horizontally and vertically. The problem becomes more acute close to emission hotspots. The **HE CATRINE project** will be looking at the evaluation of the mass conservation error in more detail and improve numerical schemes to reduce its impact.



- Large improvement in mass conservation with COMADH SL advection (Malardel and Ricard, 2015).
- Bermejo-Conde mass fixer (Diamantakis and Agusti-Panareda, 2017) still required for climate runs and cyclic forecasts, but not for the analysis and flux inversion.







## Land surface fluxes from ECLand

- Marieke Wesselkamp (University of Freiburg)
- Sebastien Garrigues, Patricia de Rosnay (ECMWF)
- Joe McNorton, Francesca di Giuseppe (ECMWF)

## CO<sub>2</sub> retrievals

- XCO<sub>2</sub> from OCO-2 L1 data using neural-network-based approach (David et al., 2021, Breon et al. 2022, CAMS2-52b)
- CO<sub>2</sub> from IAISI L1 data (Crevoisier et al., 2009, CAMS2-52b)

## Bias corrections in IFS

- Bermejo and Conde mass fixer (Diamantakis and Flemming, 2014, Agusti-Panareda et al., 2017, Diamantakis and Agusti-Panareda, 2017).
- Biogenic Flux Adjustment Scheme (BFAS) (Agusti-Panareda et al., 2016)