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Towards an ECMWF's CAMS near real-time global surface flux inversion

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Summary

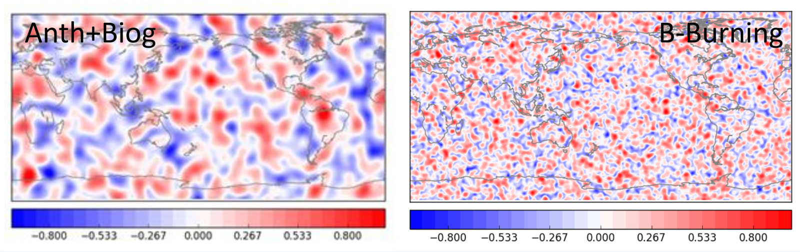
In this work we show the capability of the **ECMWF's Integrated Forecasting System (IFS)** to couple near real-time composition analyses and forecasts with surface flux inversion.
To achieve this, an **Ensemble of Data Assimilations (EDA)** is used, which is an ensemble of perturbed 4DVar independent realizations.
The **methodology** is based on using the ensemble information to compute Jacobians relating a model parameter to another, here concentrations and surface fluxes. The first **results** on carbon monoxide (CO) show realistic and physical constraint patterns on the fluxes and the ensemble inversion spread can provide an evolution of uncertainty on the fluxes. Finally, **evaluation** with surface data is promising, showing improvement on the scores, and it is expected to provide stronger improvement with higher resolution and different species (e.g. NO_2)

Methodology:
Outer-loop ensemble based update in the IFS 4DVar system

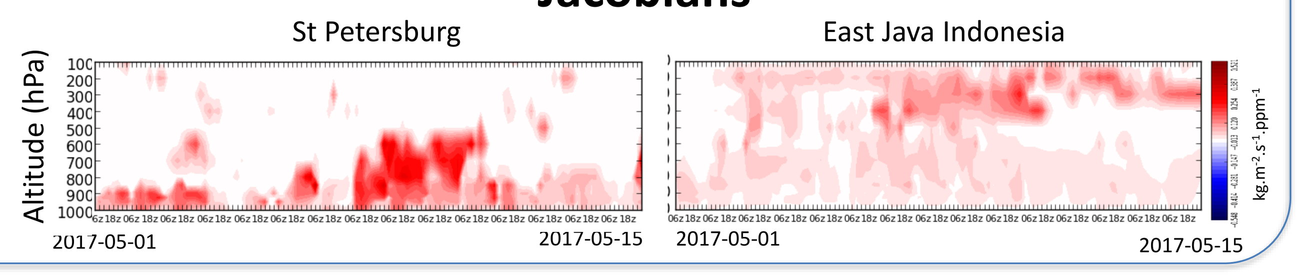
1. Compute and filter vertical Jacobians from ensemble forecasts at analysis time to project concentrations increments ***δc*** to surface flux increments ***δe*** : $\frac{\partial \delta e}{\partial \delta c} = s_{ec} = r_{ec}\frac{\sigma_e}{\sigma_c}$ ***r:*** *correlation* ***σ:*** *st deviation*
2. Compute upper air increments ***δc*** using the inner loop 4DVar minimization per member, using obs
3. At outer-loop *n,* adjust at analysis time, for each member, surface fluxes and upper air fields using ensemble based Jacobians $\delta e^n = S^n_{ec}\delta c^n_{final}$ $\delta c^n_{fi\_adju} = (1-r^2_{ec})\delta c^n_{final}$
4. Inject updated fluxes and concentrations in the next minimization and Repeat 1. - 3. until the last outer-loop is finished and initialize forecasts at higher resolution using updated emissions.

Pre-requisite: The surface fluxes need to be appropriately perturbed. Spatially (and optionally time) correlated to generate meaningful relationship between concentrations fields and surface fluxes.

Perturbations



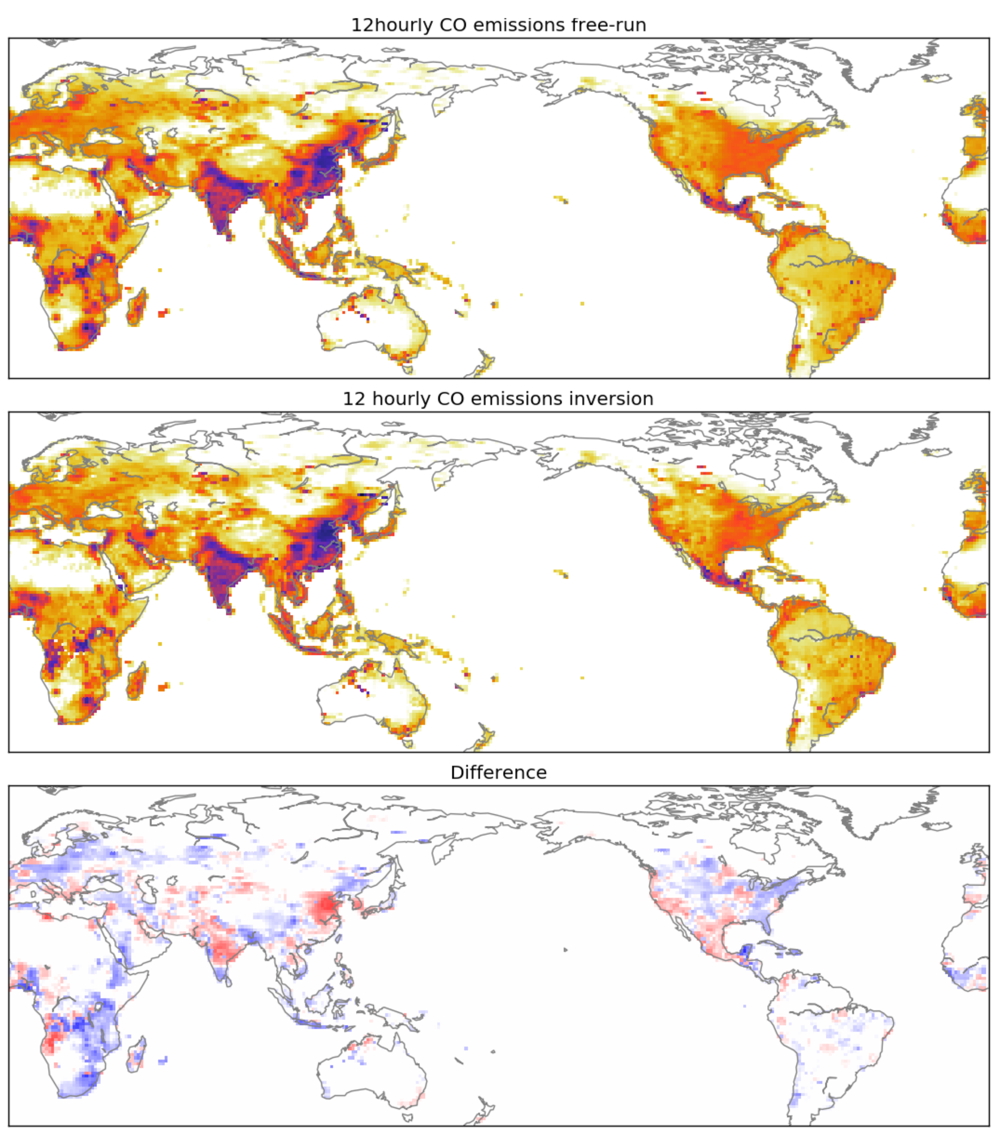
Jacobians



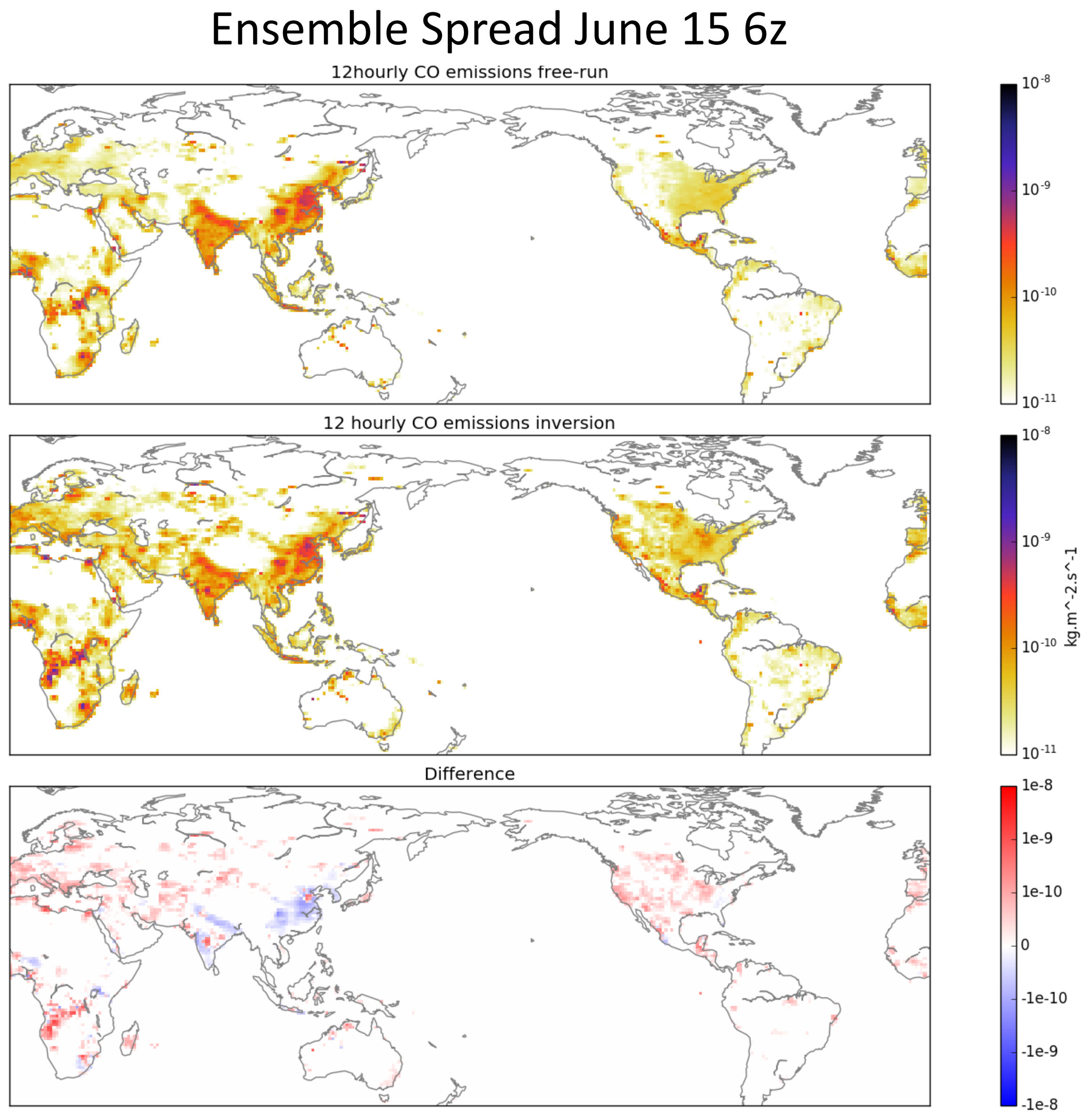
Results

- Experimental setup: EDA with 26 members, 2 outer-loops at T95 and T159, 12 hour assimilation window, linear CO chemical scheme, and forecasts at T159 (approx. 0.8 deg), IASI & MOPITT obs assimilated
- For speed and testing purposes experiments (analyses and forecasts) were carried on CO only at low resolution over May-June-July 2017
- The panels below compares the effects of the method at a given date after 1.5 month of inversion (left) and averaged over the three months (right)

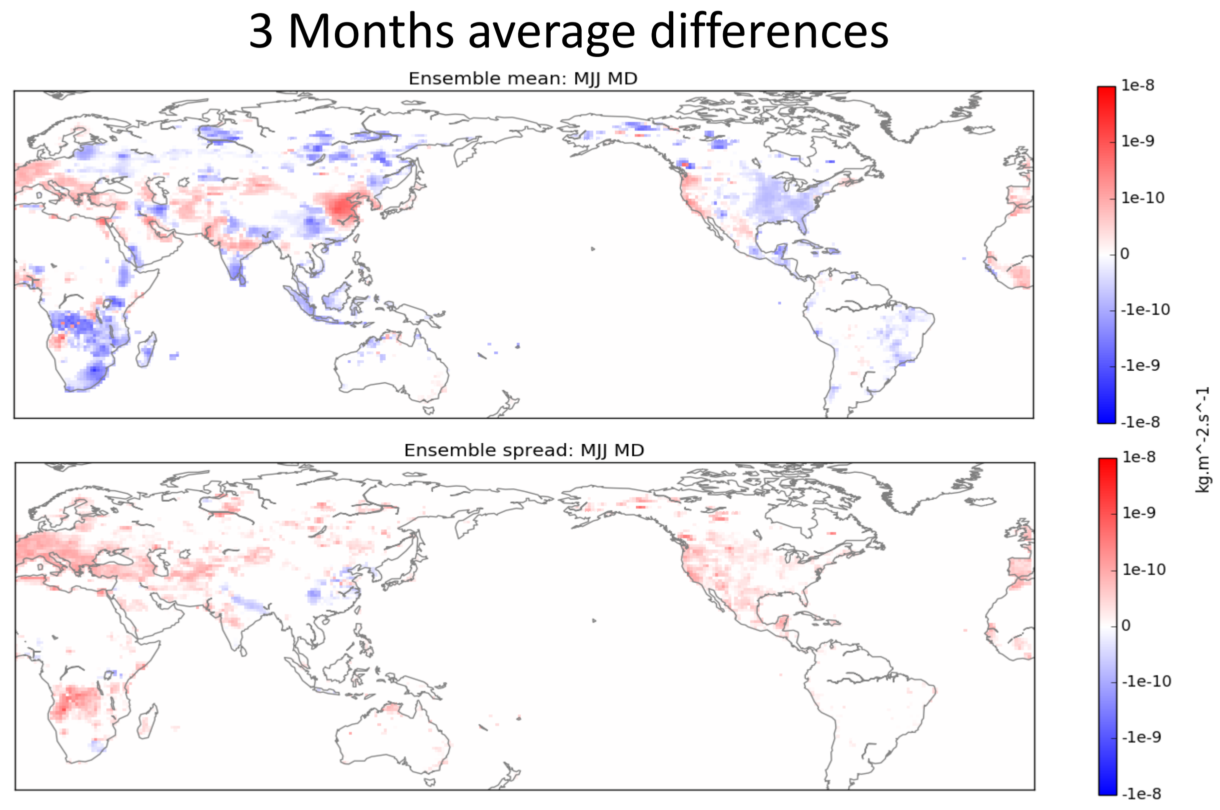
Ensemble Mean June 15 6z



Ensemble Spread June 15 6z



3 Months average differences



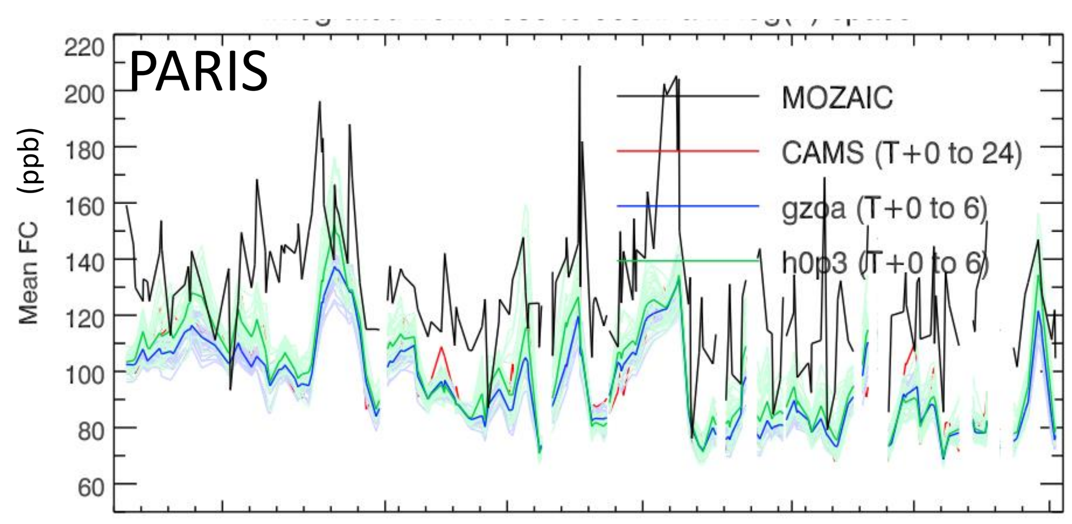
- The EDA based Jacobians allow to constrain on fluxes within a 4DVar system without the TL/AD
- The ensemble approach allows also estimation and evolution of the uncertainty (ensemble spread) on the emissions but needs filtering

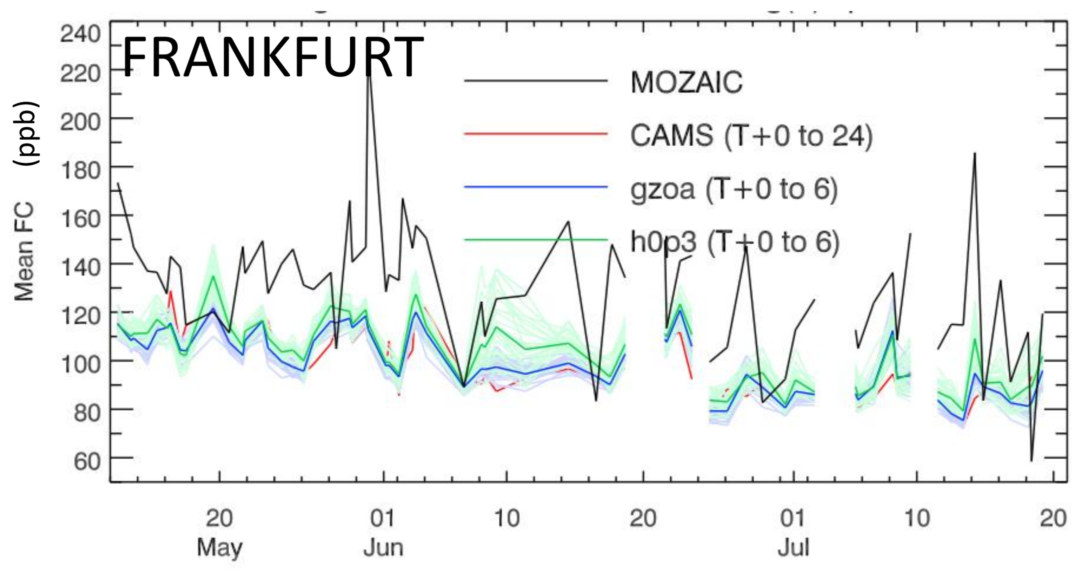
Evaluation and further work

- Overall, the evaluation with independent data near or at the surface shows little improvement. In some short periods of time the improvement can be significant.
- The improvement regarding the IAGOS data is expected to be better with higher resolution runs.
- The improvement with GAW sites is sporadic and show the impact on medium to long range transport. The sites are remote and the background levels of CO are already good with no inversions.

- To **conclude** the results are promising and running an EDA based forecasting system is beneficial for atmospheric composition and allow easy computation of surface fluxes inversions.
- The present methodology requires good obs coverage. **Sentinel-5p** L2 is coming = good news!
- Higher resolution runs and other species: NO_2, CH_4

Evaluation against IAGOS Surface-900hPa





Colors: OBS, CAMS oper, EDA Control, EDA Inversion

Examples of remote surface sites.