3rd July 2024 | Bologna, Italy

Data assimilation developments at ECMWF in support of global emission inversion capacity

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with help from the whole Atmospheric Composition section

ECMWF

Atmosphere Monitoring Service
atmosphere.copernicus.eu

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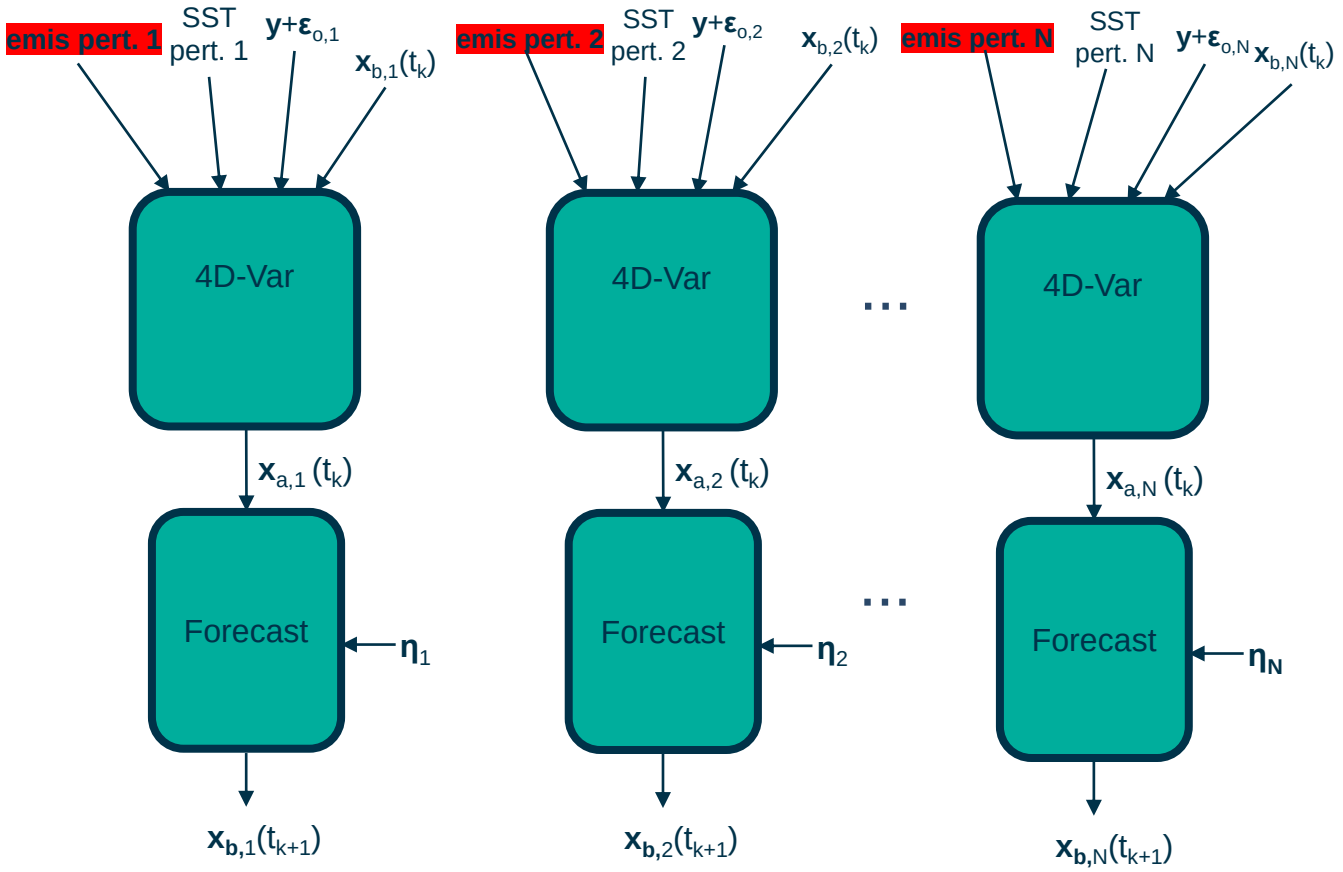
- ECMWF is developing the global component of a new Copernicus service to monitor anthropogenic greenhouse gas emissions (CO2MVS)
- Applications extend to air quality and reactive gases products
- Two major Data Assimilation developments for atmospheric composition species have been implemented:
    - Ensemble of Data Assimilation (**EDA**)
    - Extension of the IFS 4D-Var algorithm to include **emission inversion**
- Examples of applications:

Ensemble of Data Assimilation

Ensemble of Data Assimilation (EDA) for atmospheric composition species



Perturbations added to several system component:

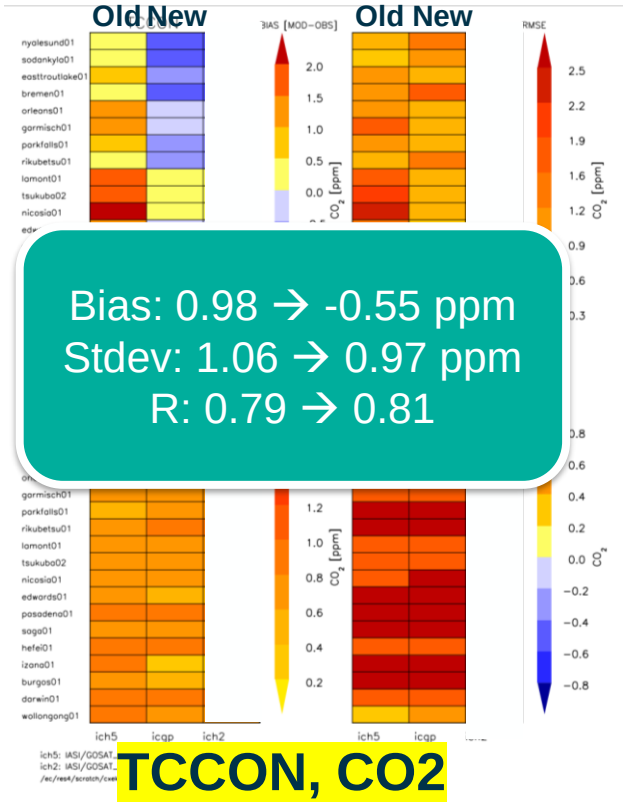
- Model physics tendencies (SPPT)
- Sea Surface Temperature (SST)
- Observations
- Surface emissions

NEW

N.B. not used operationally, but…

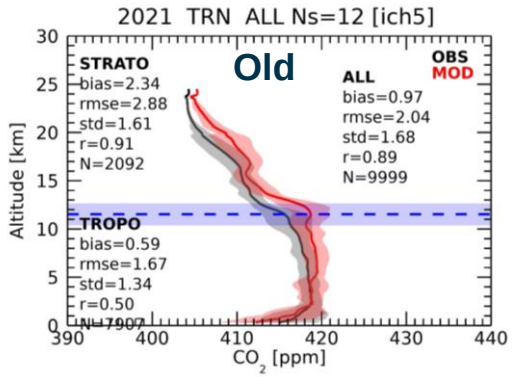
Impact of using (static) EDA-derived covariance matrix in the delayed GHG o-suite

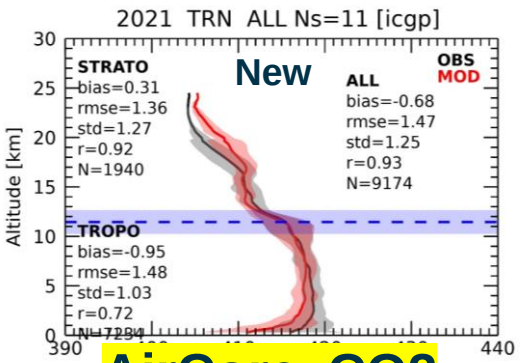
- CAMS produces (deterministic) state analysis of CO_2 and CH_4 at 25km resolution (delayed GHG o-suite)
- We tested a new covariance matrix generated offline using a sample of model states from EDA experiments



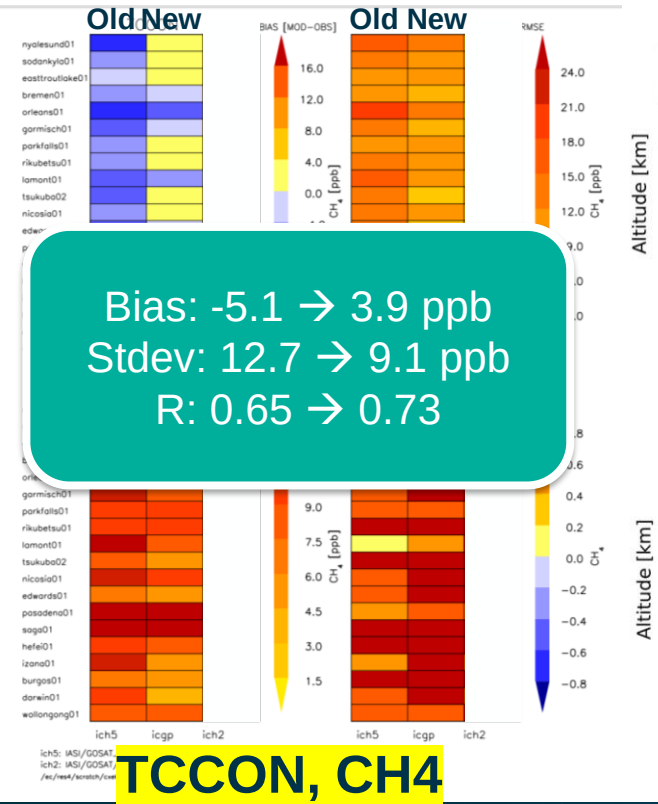
Bias: 0.98 → -0.55 ppm
Stdev: 1.06 → 0.97 ppm
R: 0.79 → 0.81

TCCON, CO2



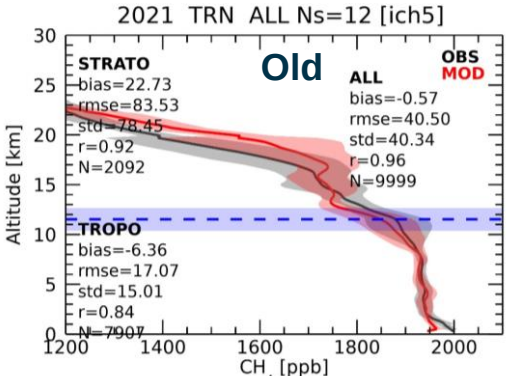


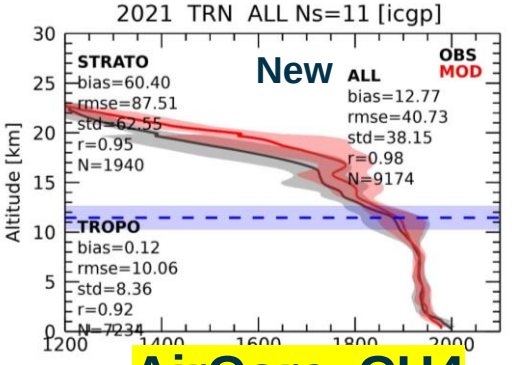
AirCore, CO2



Bias: -5.1 → 3.9 ppb
Stdev: 12.7 → 9.1 ppb
R: 0.65 → 0.73

TCCON, CH4





AirCore, CH4

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- Examples of applications:

Benefit of using EDA-derived covariance matrix in the (delayed) GHG o-suite

Global emission inversion

Extension of the 4D-Var assimilation scheme for emissions inversion

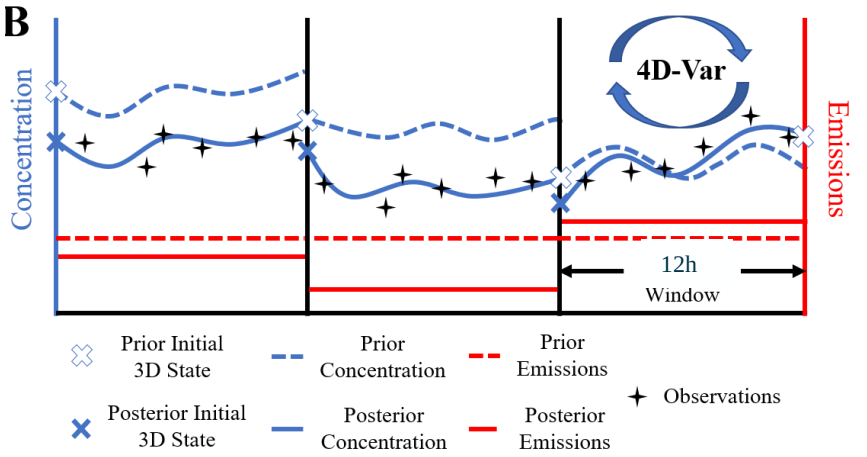
$$J(\mathbf{x},\mathbf{p}) = (\mathbf{x}-\mathbf{x}_b)^T\mathbf{B}_{\mathbf{x}}^{-1}(\mathbf{x}-\mathbf{x}_b) + (\mathbf{y}-h(\mathbf{x},\mathbf{p}))^T\mathbf{R}^{-1}(\mathbf{y}-h(\mathbf{x},\mathbf{p}))$$

state (prognostic)

observations (meteorology, atmospheric composition)

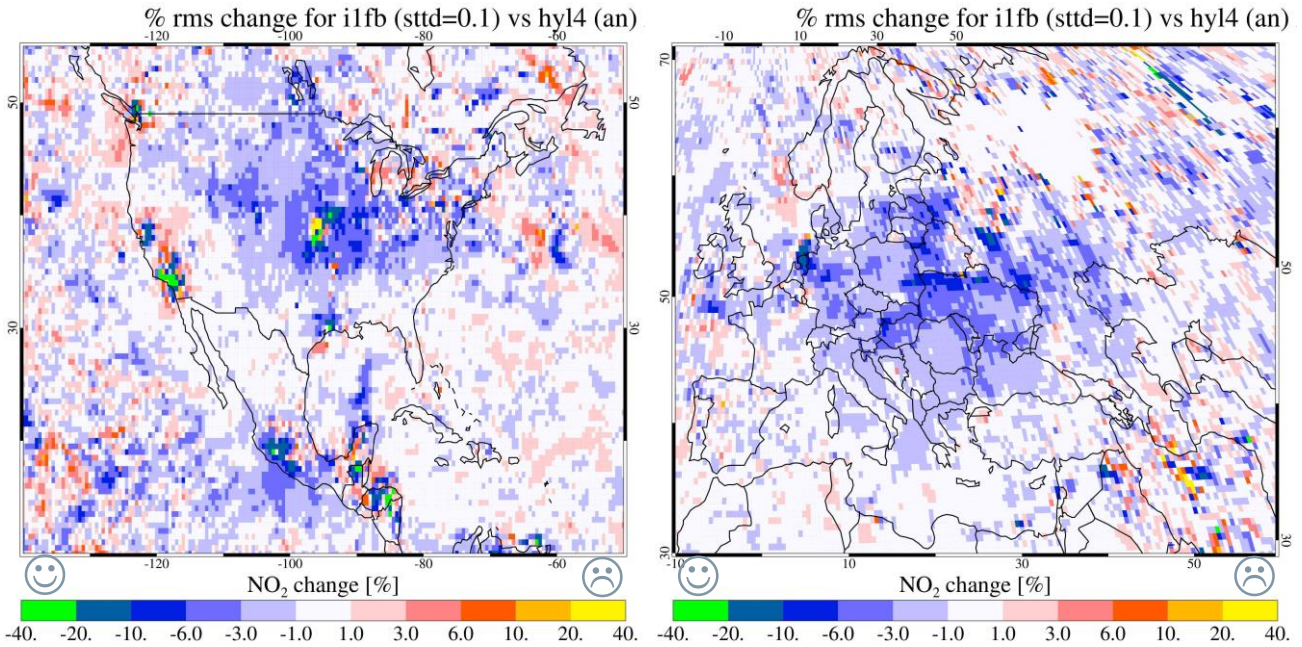
System characteristics:

- 2D species-dependent **scaling factor field** (CO, NOx, CH_4, CO_2) applied to emission inventories
- **Joint optimization** of fluxes, concentrations and meteorology
- Independent optimization within each **12h assimilation window**
- **Static** prior error and correlation length in B_p
- Spatial resolution dependent on last outer loop resolution (here T159)
- Atmospheric Composition observations: **satellite retrievals**

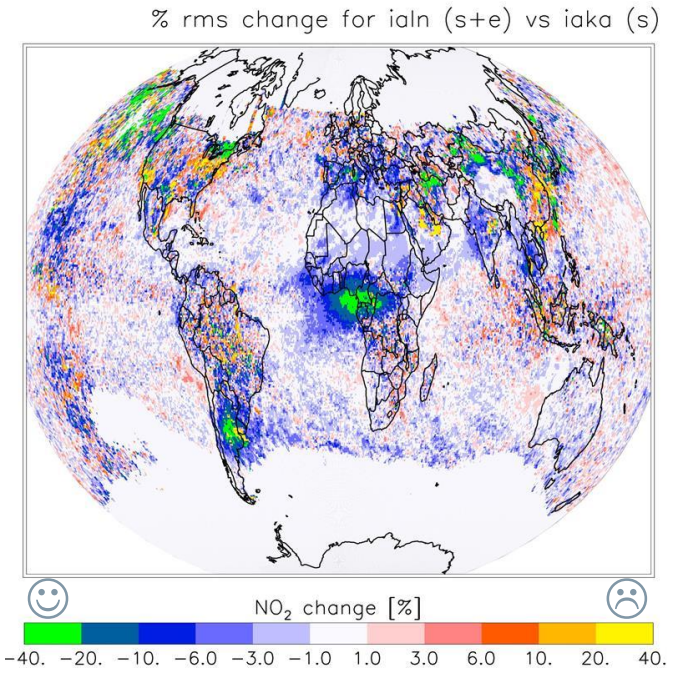


Evaluation: comparison against TROPOMI total column retrievals for NO_2

Impact of including emission inversion w.r.t. 3D state-analysis only (average RMS change for a +24h forecast)



Period: Spring 2020
Lead time: 24h



Period: 1st-25th December 2022
Lead time: 24h

- ECMWF is developing the global component of a new Copernicus service to monitor anthropogenic greenhouse gas emissions (CO2MVS)
- Applications extend to air quality and reactive gases products
- Two major Data Assimilation developments for atmospheric composition species have been implemented:
  - Ensemble of Data Assimilation (**EDA**)
  - Extension of the IFS 4D-Var algorithm to include **emission inversion**
- Focus of this presentation:

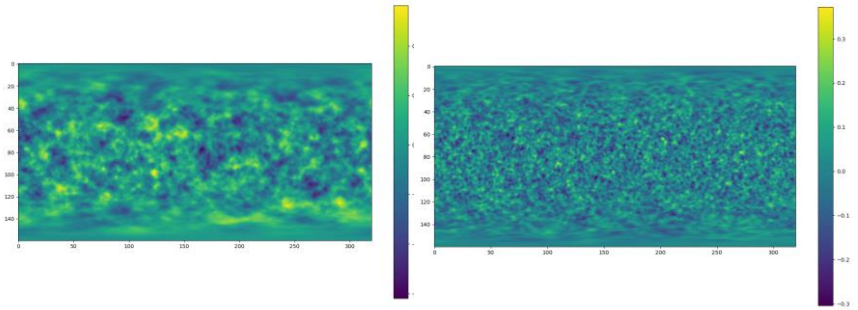
Benefit of using EDA-derived covariance matrix in the (delayed) GHG o-suite

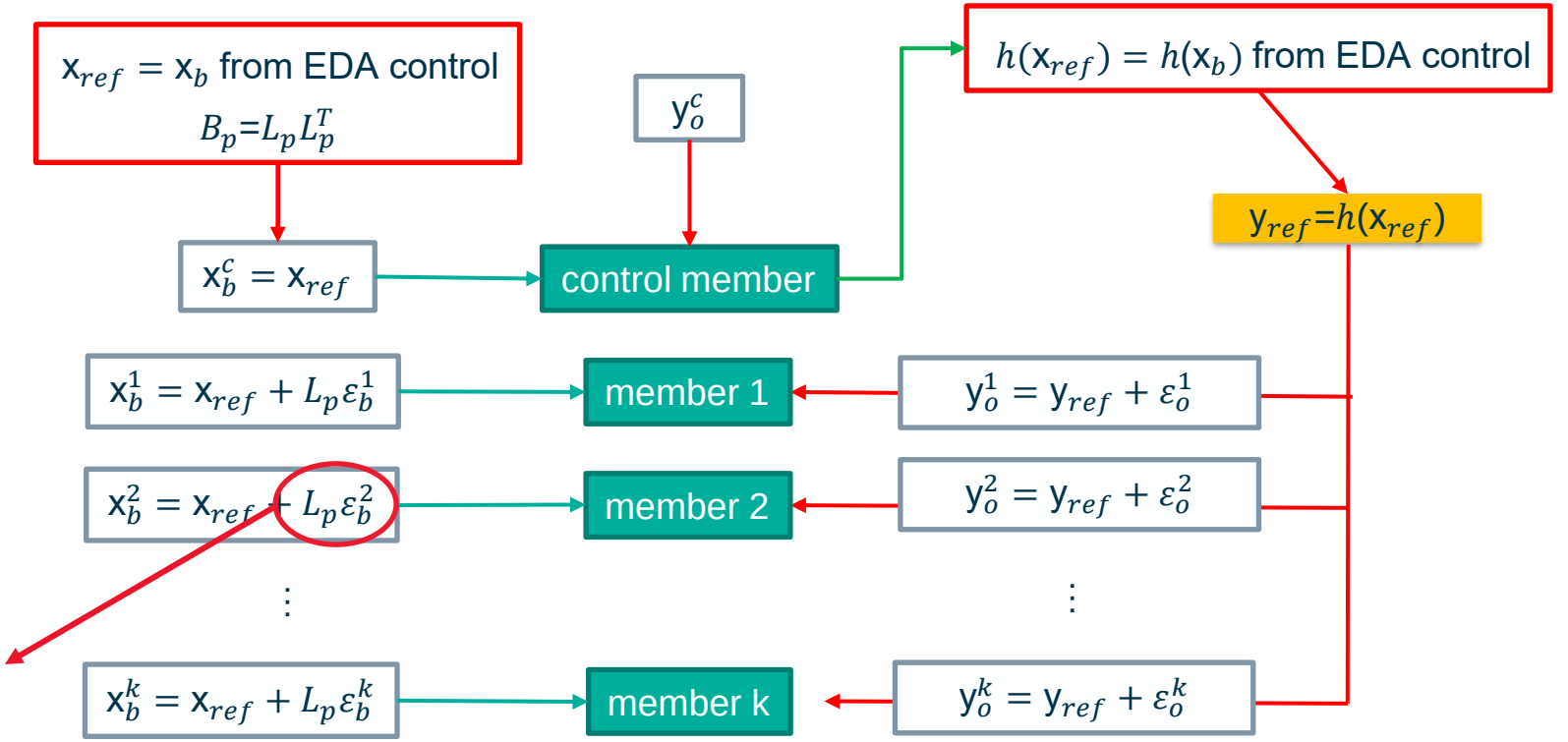
Impact of emissions inversion on state analysis and budgets of NOX

EDA + global emission inversion

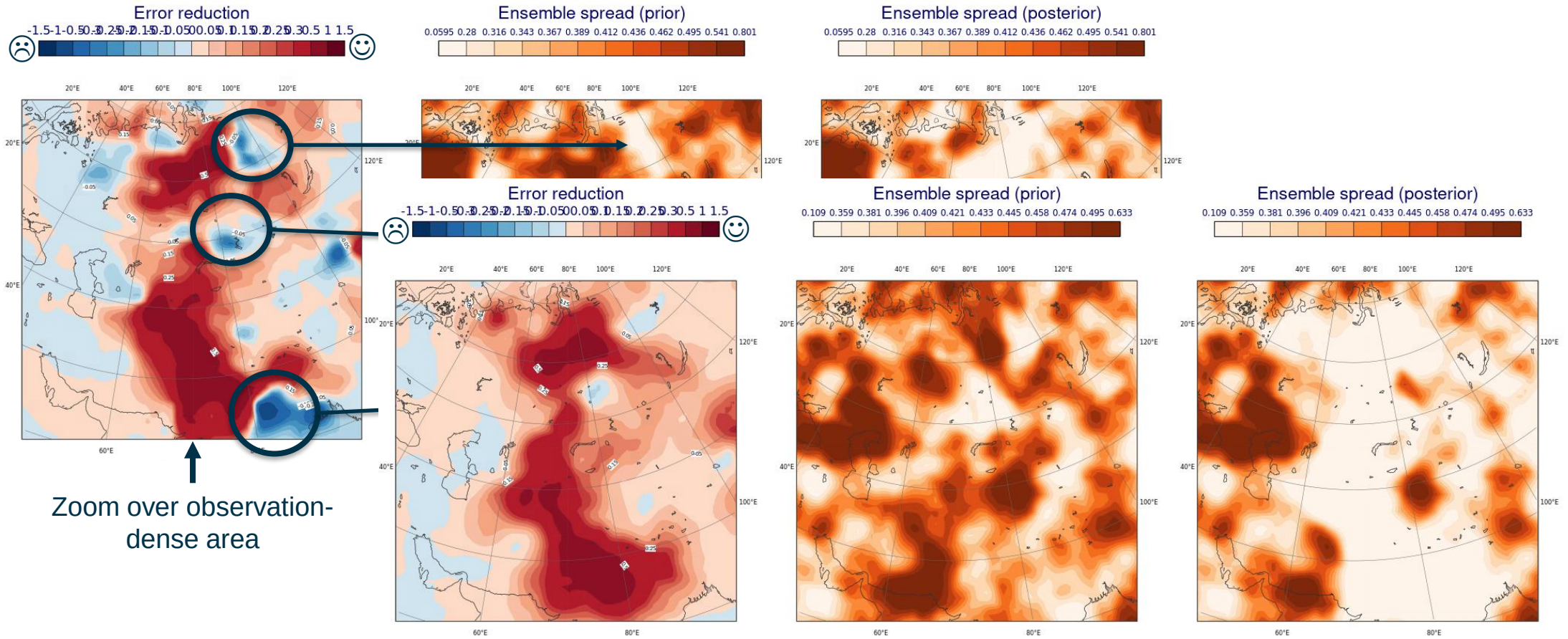
An EDA-based Observing System Simulation Experiment (OSSE) configuration

- Control = truth
- Synthetic observations = interpolated first guess at real obs. location
- Scaling factors perturbations generated with randomized approach, consistently with covariance matrix B_p
- **Expectation is members are drawn towards the truth (control)**





OSSE EDA error reduction (CH4): sampling issues?



Zoom over observation-dense area

40 members

Conclusions

- ECMWF is developing the global component of a future Copernicus service to monitor anthropogenic emissions of greenhouse gases (CO2MVS);
- The IFS 4D-Var assimilation scheme has been extended to include inversion of surface emissions of multiple atmospheric composition species;
- The Ensemble of Data Assimilation (EDA) method has been extended to atmospheric composition taking also into account prior emission perturbations;
- The use of the EDA to generate (offline) a new covariance matrix for the delayed GHG o-suite has shown a positive impact on both total column estimates and vertical profiles;
- The validation of the new global inversion system has started: both the comparison against TROPOMI retrievals and the first budget estimates for NOX look promising;
- An Observing System Simulation Experiment (OSSE) configuration leveraging on the EDA has been developed for validation and testing. Early results suggest challenges with sampling error due to ensemble size