Status T4.3.4: Very high-resolution inversions

**Dominik Brunner[1], Peter Bergamaschi[2], Arjo Segers[3]
and Jean-Matthieu Haussaire[1]**

[1]Laboratory for Air Pollution/Environmental Technology, Empa, Dübendorf, Switzerland

[2]European Commission Joint Research Centre, Ispra, Italy

[3]TNO, Climate, Air and Sustainability, Utrecht, the Netherlands

Goals of Task 4.3.4

Development and application of a very high resolution inversion system

- Based on atmospheric transport simulations with FLEXPART-COSMO driven by hourly meteorological analysis fields of COSMO at 7 km x 7 km resolution
- Estimation of European CH_4 and N_2O emissions at 0.125° x 0.125° spatial and weekly temporal resolution
- Minimization of cost function with 4D-VAR approach
- Nesting into global TM5-4DVAR system using two-step approach of Rödenbeck et al. 2009
- Comparison with Extended KF and regular VERIFY inversion

Final product: 0.06° x 0.06° spatial & monthly temporal resolution

Deliverable D4.15 (due month 42)
CH_4 flux maps at 0.125°×0.125° for Western/Central Europe for 2010-2015

dominik.brunner@empa.ch

FlexVar 4D-Var application using FLEXPART trajectories

- 4-DVAR: Computation of gradient of cost function $\nabla_x J = B^{-T/2}(x - x_b) + H(x)^T R^{-1}(H(x) - y)$ and minimization using M1QN3 or CONGRAD algorithm
- State transformation (pre-conditioning) for better convergence
- Background from global TM5-4DVAR run following two-step approach of Rödenbeck et al. (2009)

Further design aspects:

- Precise embedding of the non-rectangular domain of FLEXPART-COSMO into TM5-4DVAR
- Precise mapping of a priori fields onto the rotated-pole grid of FLEXPART-COSMO
- Careful consideration of model representation errors (e.g. based on meteorology)
- Optimization of parameters (amplitude, correlation length scales) of prior and observation covariance matrices with a maximum-likelihood approach

Main developers: Arjo Segers (TNO) & Peter Bergamaschi (JRC)

FlexKF Extended Kalman Filter (*Brunner et al. 2012*)

- Sequential assimilation of observations (daily updates)

$$\boldsymbol{x}^+_k = \boldsymbol{x}^-_k + \boldsymbol{K}_k \,.\, (\boldsymbol{y}_k - \boldsymbol{H}_k\, \boldsymbol{x}^-_k),$$

- Optimization of logarithm of emissions, $x = ln(e)$, to ensure positive solution and normally distributed residuals
- Error growth possible due to forecast step

$$\boldsymbol{x}^-_k = \boldsymbol{x}^+_{k-1} + \boldsymbol{\eta}_k$$

- Reduced grid with lower resolution where coverage (sensitivity) of measurement network is lower
- Same background as for FLEXVAR (Rödenbeck two-step approach)

dominik.brunner@empa.ch

FLEXPART-COSMO simulations

- Driven by hourly meteo fields from COSMO at 7 km x 7 km resolution
- Simulations for 54 stations, partly with multiple release heights
- 50’000 particles released every 3 hours and followed backwards over 10 days (results presented here still based on 4 day bkwd simulations)
- Particle residence times (footprints) stored at 7 km x 7 km resolution
- Positions and times of particles stored when they leave domain or are terminated

dominik.brunner@empa.ch

Inversion setup for year 2018

Observations

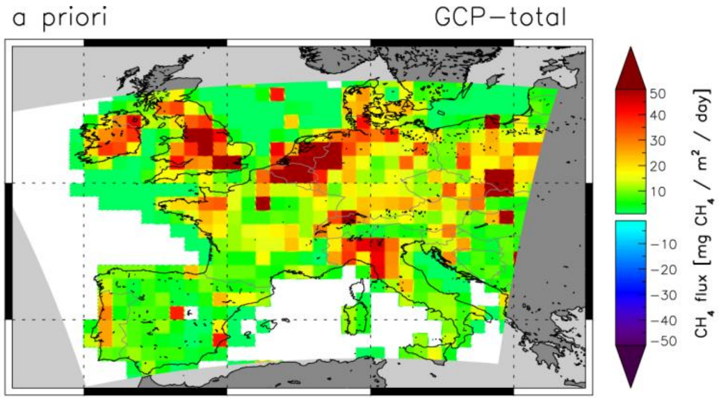
- Core sites: ICOS release 2019-1 (13 sites)+ NOAA flask sampling (5 sites)
- Extended: Core + UK sites (BSD, TAC, RGL, HEA, WAO) + AGAGE (MHD) + TNO (CBW) + LSCE (BIS) + U. Bern/Empa (BRM, LAE) + ??

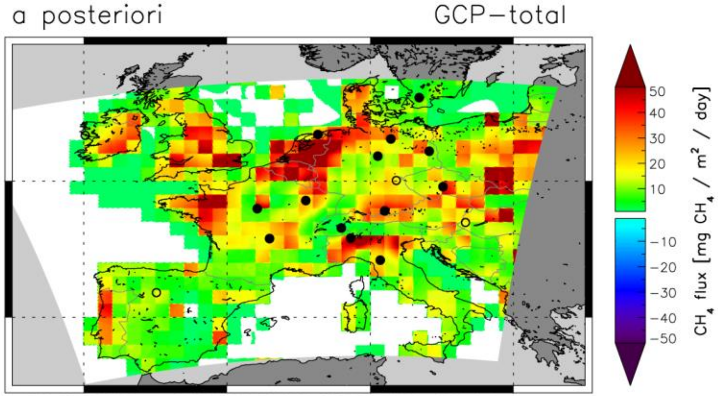
Prior fluxes

Source	Model/Reference	Resolution/coverage
Anthropogenic	GCP-2018, EDGAR-v4.3.2	Global 1°×1°, monthly (2017)
Wetlands	GCP-2018, Poulter et al.	Global 1°x1°, monthly, climatology
Biomass burning	GFEDv4.1s + EDGAR FFF&RCO	Global 1°x1°, monthly
Ocean	GCP-2018, Lambert et al.	Global 1°×1° annual, climatology
Termites	GCP-2018, Castaldi et al.	Global 1°×1° annual, climatology
Geological	GCP-2018, Etiope book	Global 1°×1° monthly

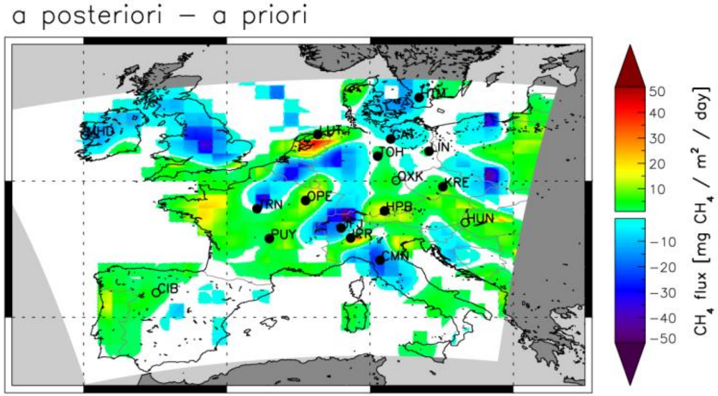
Comparison between FlexVar and FlexKF

FlexVar annual mean 2018





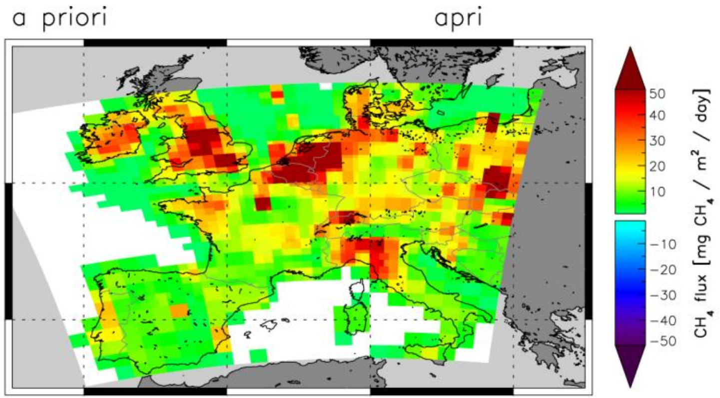
v1.2.10_COSMO−7_GCP−total_R10_20180101_20190101_EU511_FLEX_C100km_DB02_Ct12m

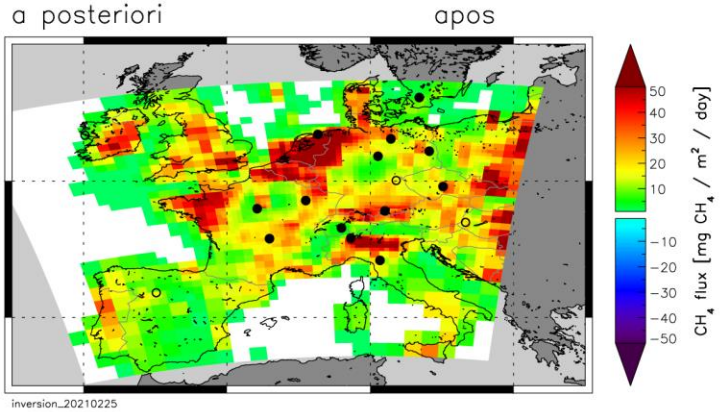


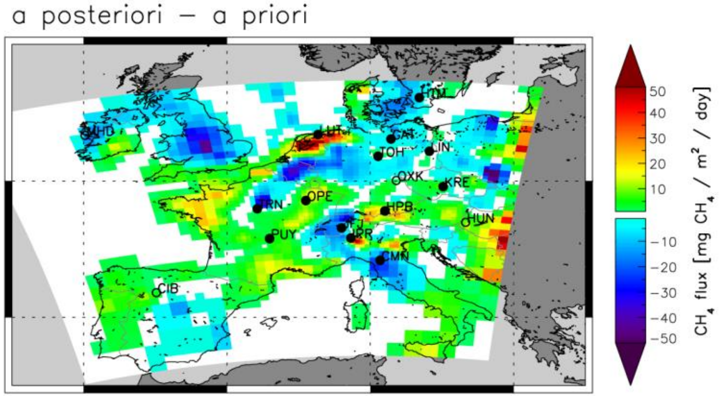
dominik.brunner@empa.ch

Comparison between FlexVar and FlexKF

FlexKF annual mean 2018





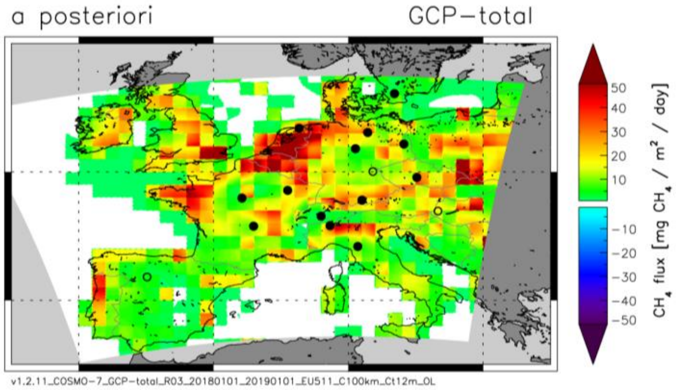


Influence of baseline and station release heights

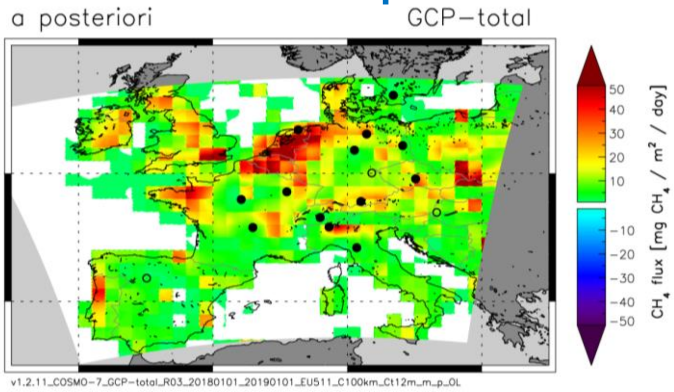
Baseline treatment

Example for FLEXVAR

Rödenbeck scheme



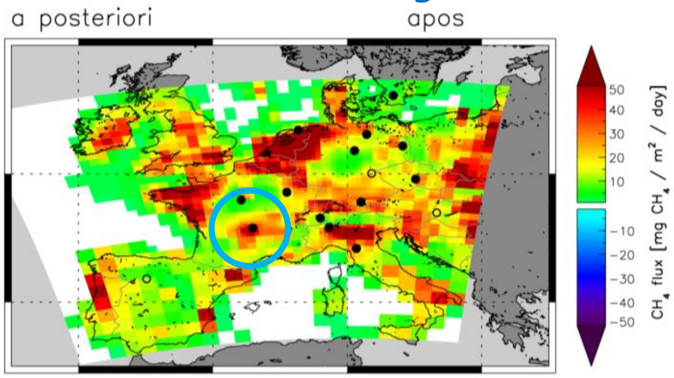
Particle dumps



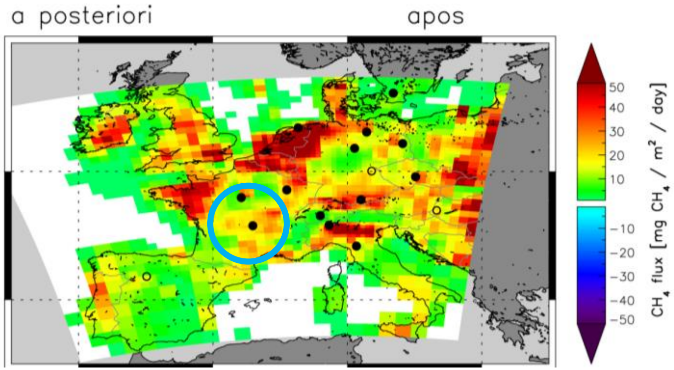
Release height

Example for FlexKF

True station height

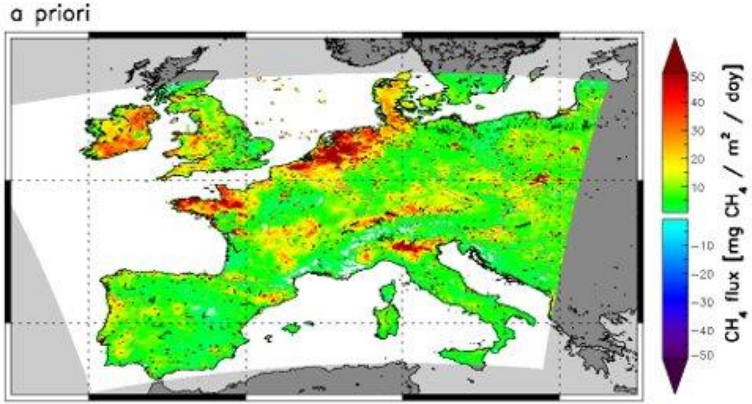


Optimal height

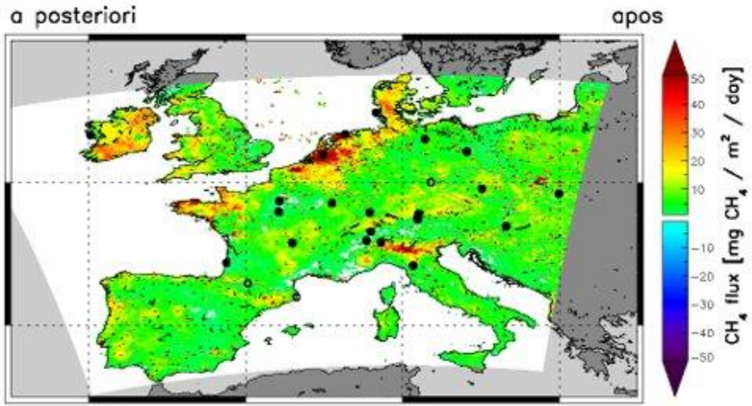


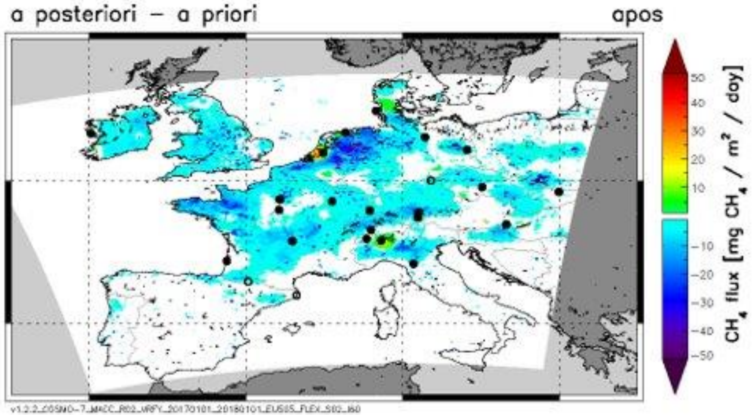
dominik.brunner@empa.ch

Example of high-resolution inversion for 2017



A priori:
EDGAR 5.0, 0.1° x 0.1° resolution
(no natural sources)





dominik.brunner@empa.ch

Conclusions

- FLEXVAR system fully functional: sophisticated, flexible and well-documented 4D-VAR inversion tool
- Coupled global (TM5-4DVAR) – regional (FLEXPART-COSMO) inversion implemented using two-step Rödenbeck approach
- First inversions performed for 2018 with ICOS + NOAA flask sites only and with coarse a priori (for consistency with global TM5-4DVAR)
- FLEXVAR allows optimizing state vector with $O(10^5)$ elements
- Comparison with FlexKF shows largely consistent results, except for domain boundaries where FlexKF shows stronger adjustments
- 4-day backward simulations not enough for Rödenbeck scheme -> new 10 days
- Choice of particle release height for mountain sites has strong impact on results