CTDAS-WRF: Greenhouse gas flux estimation with high-resolution regional transport in an Ensemble Kalman Filter

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What have we done here?

- Goal: monitor anthropogenic greenhouse gas emission changes
- Method: a new greenhouse gas **flux optimization** model for **regional** domains based on **high-resolution** atmospheric transport
- Basis: **CTDAS**
- Key change: transport model TM5 → **WRF-GHG** (variant of WRF-Chem)
- Shown here: Results of a successful **validation test**

Background: CTDAS and WRF-Chem

- Ensemble Kalman Filter: Solves the Bayesian inverse problem
  → State and its uncertainty represented by **random ensemble**
  → **No inverse** of the forward model required!
- CTDAS: modular implementation of CarbonTracker, an EnKF for GHG flux optimization based on atmospheric GHG mixing ratios [1, 2]
- WRF = Weather Research and Forecast model
- WRF-GHG = Variant of WRF with chemical tracer transport [3]

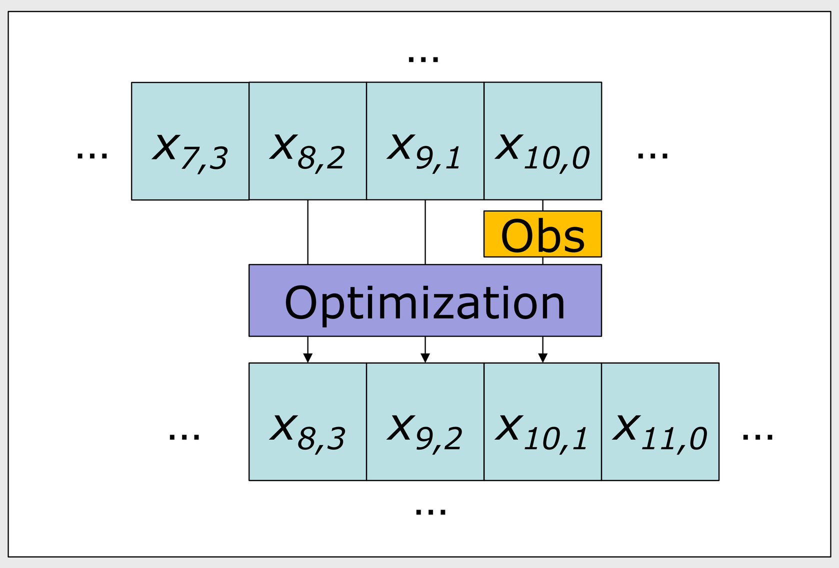

Fig. 1: Schematic of one data assimilation cycle in CTDAS. Here, the state vector element x is optimized at time steps *8–10* based on observations during time step *10*. The second subscript denotes how many times this element has been optimized. x_{10} is optimized for the first time, while x_8 is optimized for the last time in this cycle.

Purpose: Simulate CO_2 monitoring skills of SCARBO and CO2-M

- SCARBO & CO2-M: Proposed satellite CO_2 monitoring missions
- Work embedded in EU-H2020 projects:
  - scarbo-h2020.eu
  - che-project.eu

Test case setup (1): Domain and fluxes

- Period: July 1-6, 2015
- Fluxes and transport resolution: hourly, 36 km
- Initial and boundary conditions: CAMS reanalysis
- Flux model: biosphere (Fig. 2) fixed, anthropogenic (Fig. 3) with 100% uncertainty

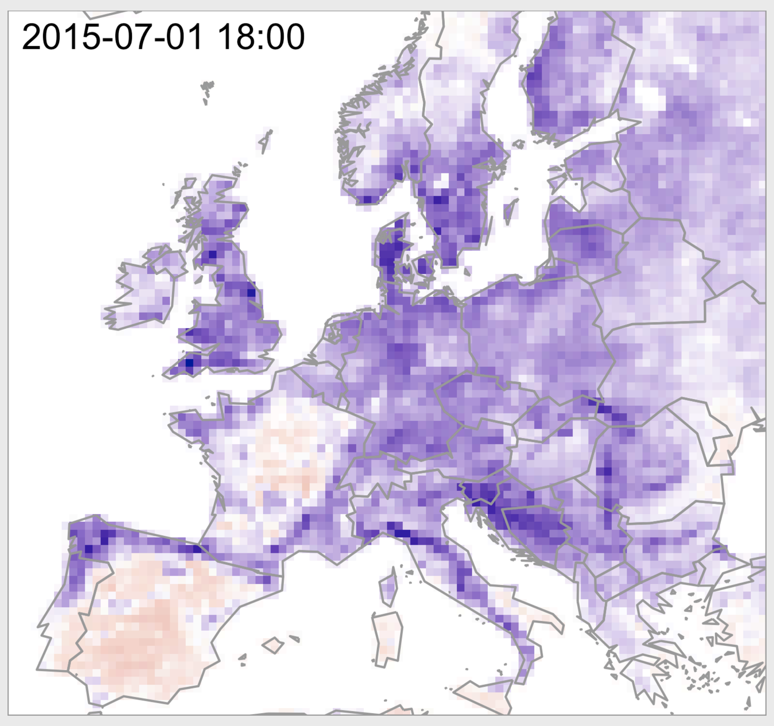

Fig. 2: Example of biosphere CO2 fluxes from WRF-VPRM (courtesy Julia Marshall)

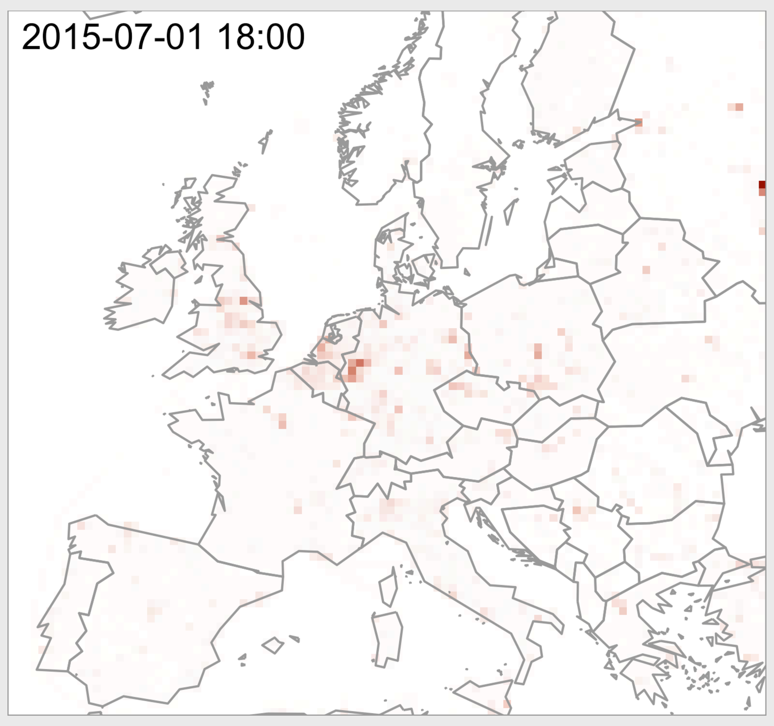

Fig. 3: Example of anthropogenic fluxes from EDGAR v4.2 FT2010

Test case setup (2): Kalman smoother setup

- Ensemble size: 150
- Optimization timestep: 1 day
- Assimilation window: 3 days
- Cycles: 6
- Localization: 95% probability threshold that observation and state vector element correlate

Test case setup (3): State vector and observations

- State vector: **4 scaling factors** for anthropogenic fluxes (Fig. 4)
- Synthetic atmospheric data (Fig. 5): total column CO_2
  - Locations: SCARBO orbital simulation (courtesy LMD and NOVELTIS)
  - Assigned uncertainties: 1 ppm
  - Values: WRF-Chem run with **50% of prior ant. emissions**

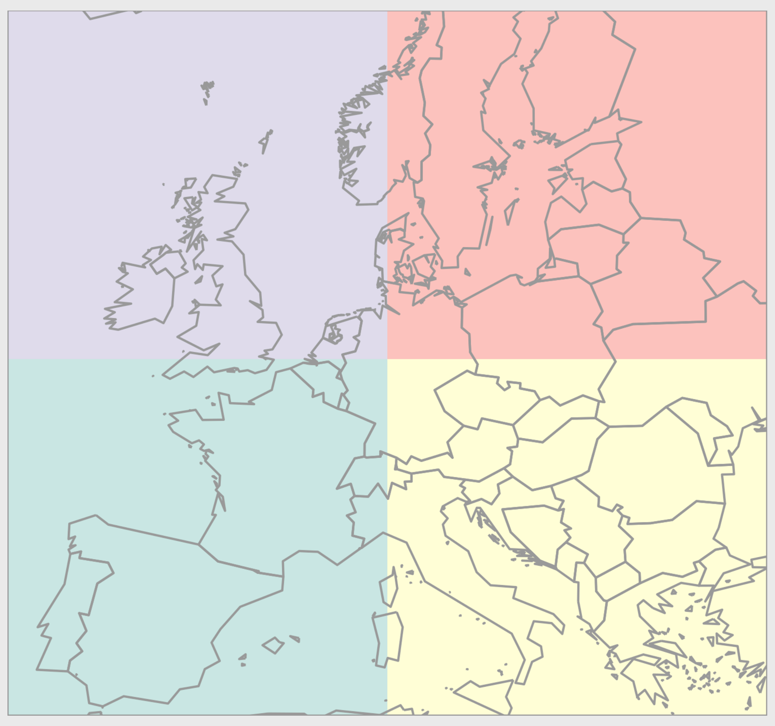

Fig. 4: Scaling factor map

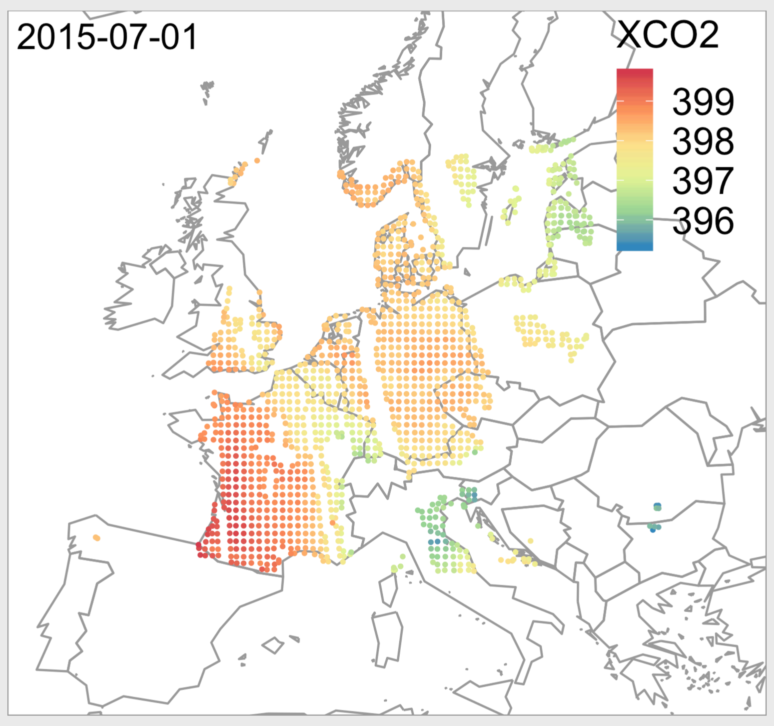

Fig. 5: Simulated observation coordinates, binned to WRF grid

Test case results

- CO_2 fluxes **successfully retrieved** (Fig. 6): mean=53±5%, truth=50%
- Flux **uncertainty reduced** (Fig. 7): prior=100%, optimized=55%
- Performance: 64 CPU-hours on 48 CPUs

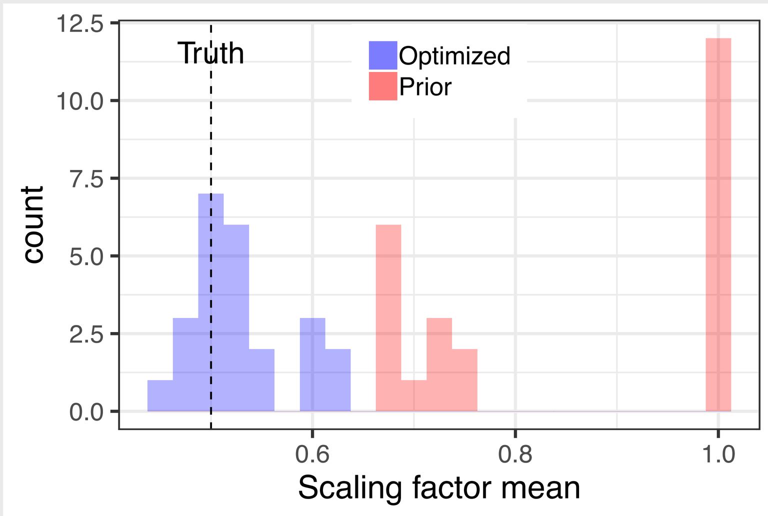

Fig. 6: All prior and optimized scaling factors (4 values x 6 days = 24 values)

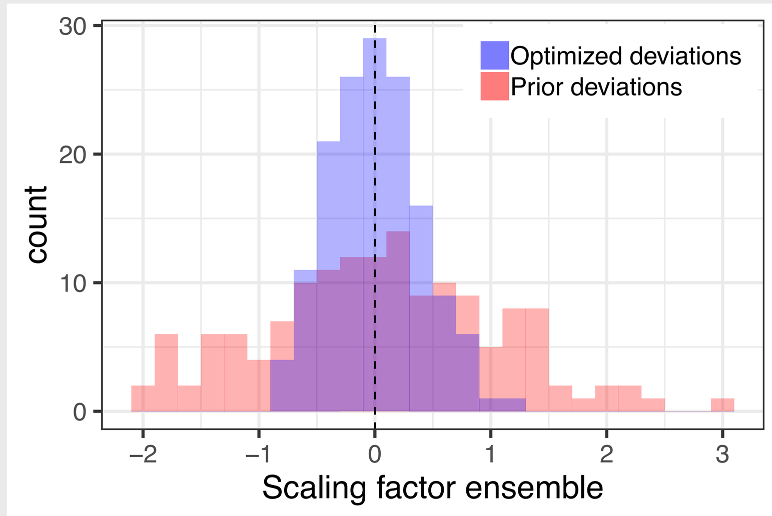

Fig. 7: Example of one prior and optimized ensemble (deviations from respective mean)

Conclusions

- CTDAS-WRF-Chem enables regional, high-resolution emission transport modeling for optimizing fluxes with CTDAS
- Tests with synthetic data confirm the system works
- Performance improvement planned by parallelizing WRF over ensemble

Code availability

- This code will be added to CTDAS, which can be obtained by contacting its main developers: **carbontracker.eu/ctdas/**
- WRF-Chem is available at: **github.com/wrf-model**

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References

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