The CO2 Human Emissions Project at ECMWF

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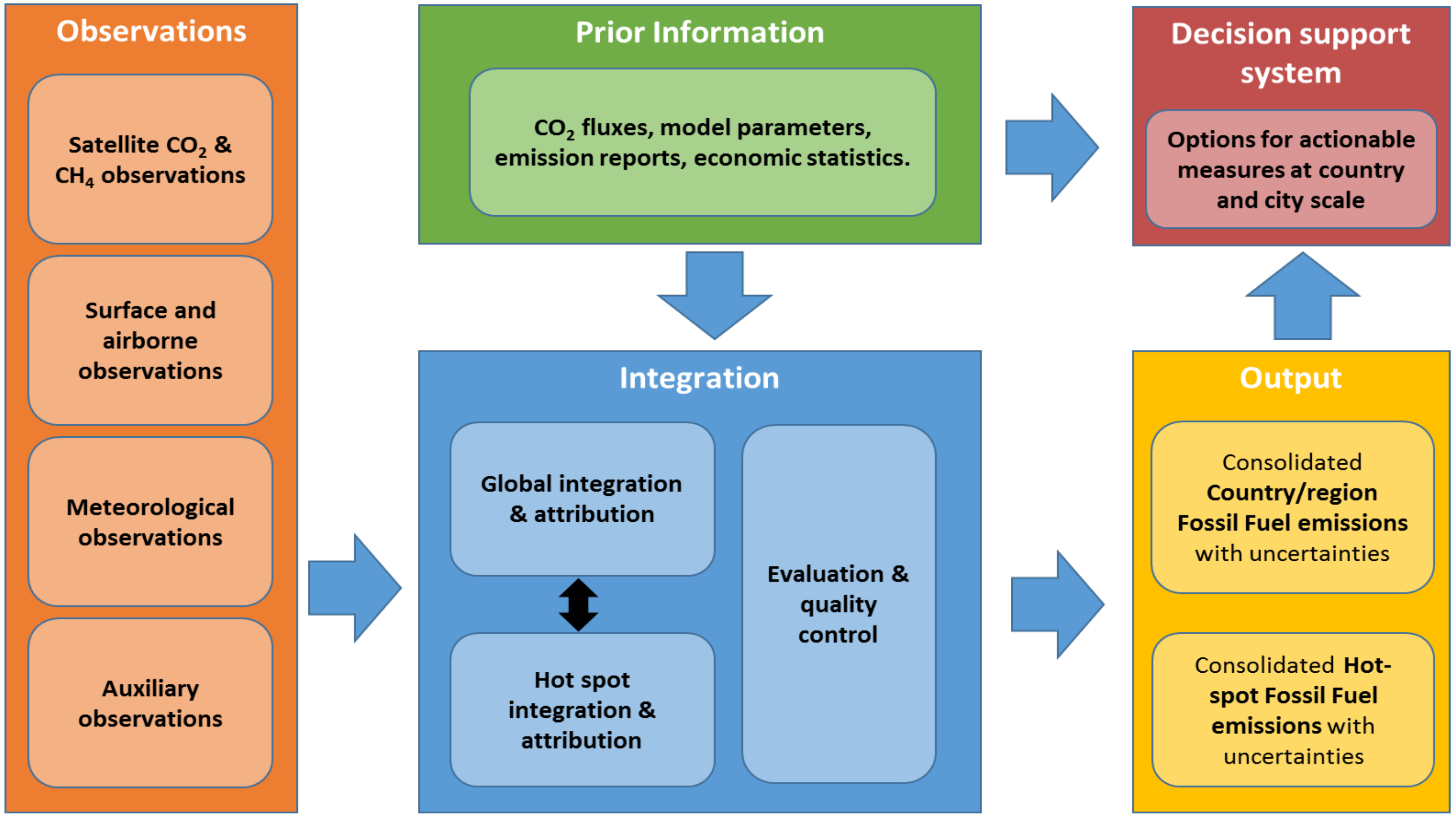
CHE PROJECT OVERVIEW



Project aim:

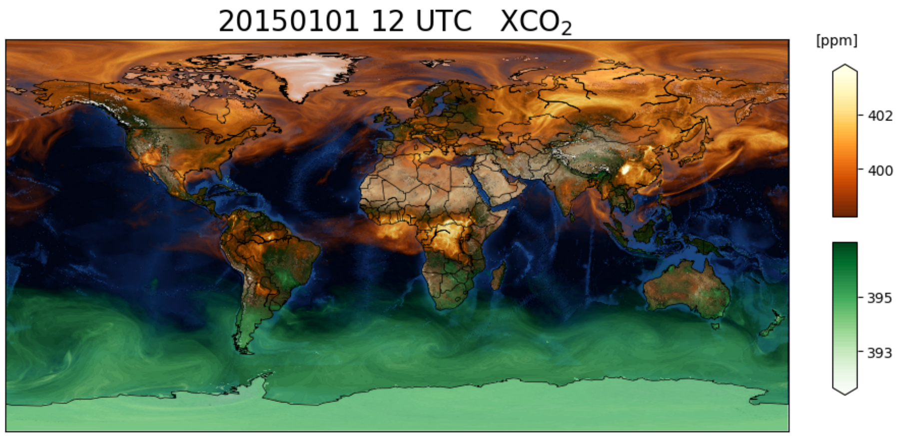
Design a European system to monitor human activity related carbon dioxide (CO2) emissions.

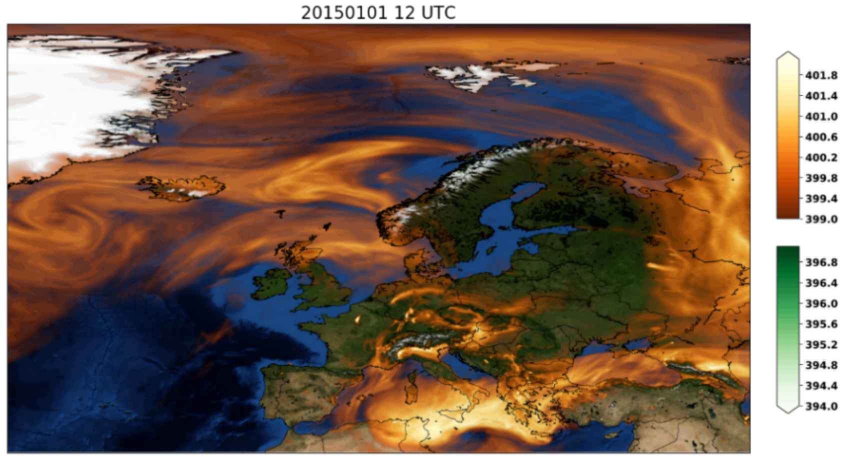
With the following objectives:

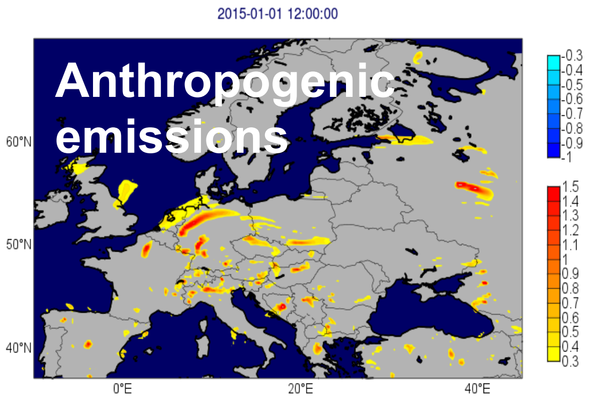
1. Detection of emitting hot spots e.g. megacities or power plants.
2. Assessing emission reductions/ increase of hotspots.
3. Assessing emission changes against local reduction targets to monitor impacts of the NDCs.
4. Assessing the national emissions and changes in 5-year time steps to estimate the global stock take.

Pinty et al., (EC CO2 report, 2017)
Janssens-Maenhout et al. (BAMS, 2020)

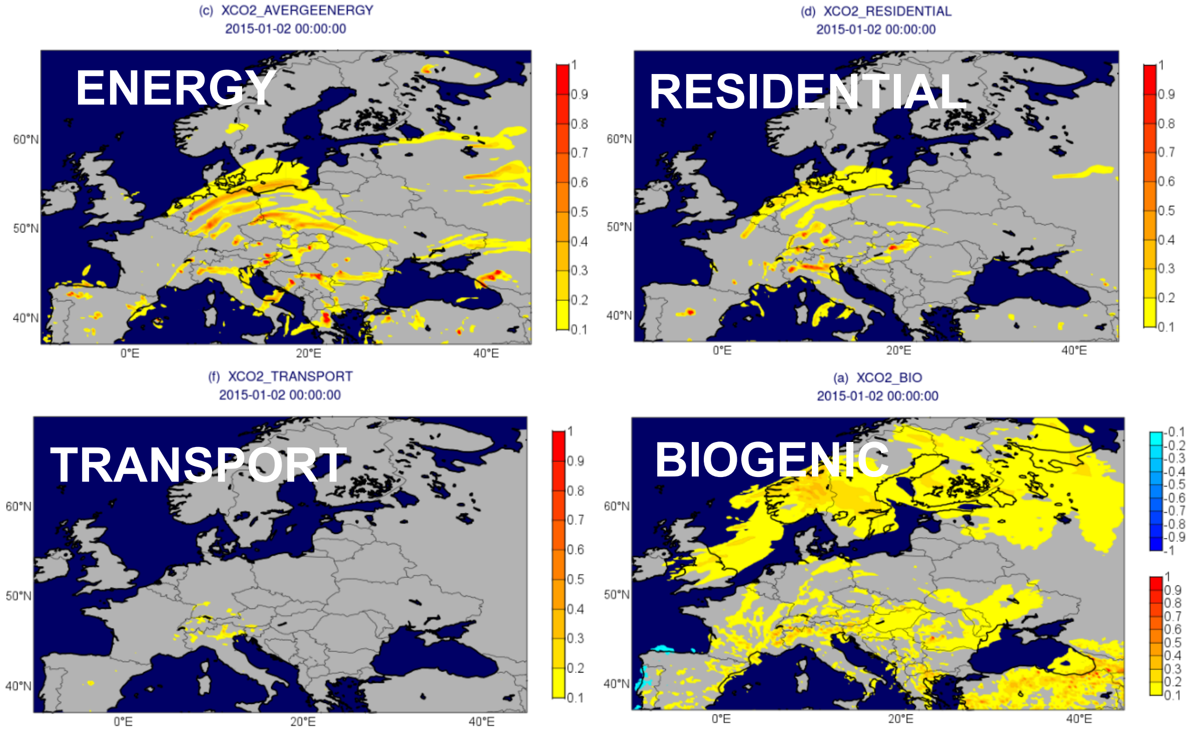
Global nature run: from inter-hemispheric gradient to plumes

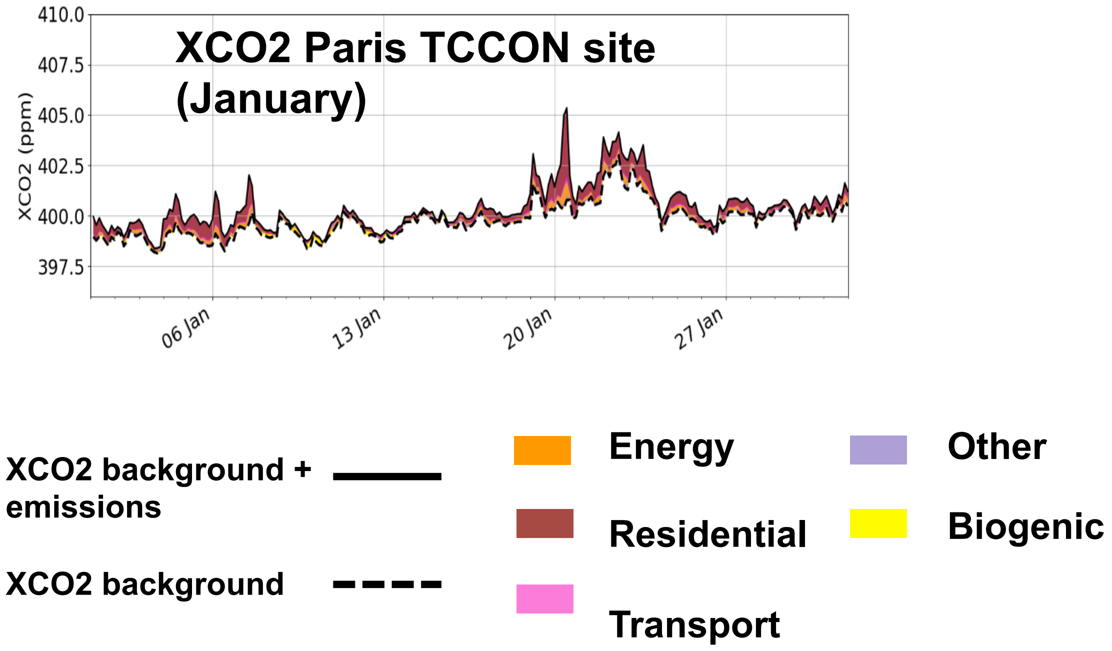




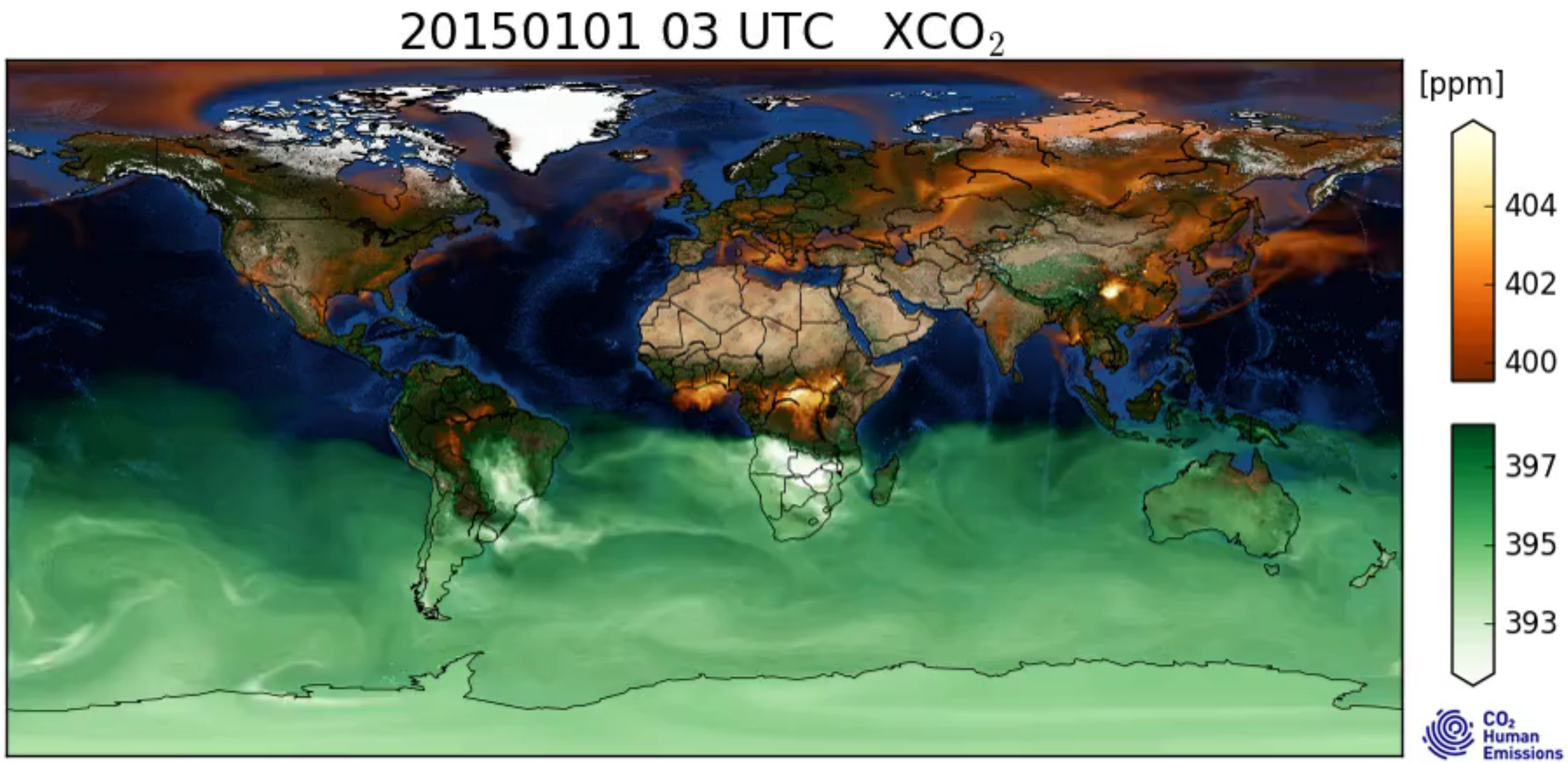


XCO_2 enhancement [ppm] associated with emission sectors and biogenic fluxes during 1-day FC





CHE global nature run based on CAMS CO2 forecasting system



https://www.che-project.eu/news/animation-co2-variability

Agustí-Panareda et al. ACP 2019

CO_2, CH_4, linCO, tagged tracers at Tco1279 (~9km) L137

- CTESSEL NEE (BFAS correction Agusti-Panareda et al. ACP 2016
- EDGARv4.2FT2010
- Takahashi et al. (2009)
- GFAS biomass burning
- IFS transport
- Bermejo & Conde mass fixer (Agusti-Panareda et al. GMD 2017)

Global nature runs in 2015 – Reducing Model Error

Components	CHE Tier 1 nature run	CHE Tier 2 nature run
Surface fluxes	Annual EDGARv4.2FT2010 anthropogenic, Takahashi et al. (2009) ocean, CTESSEL biogenic, GFAS fires	Monthly EDGARv4.3.2FT2015 anthropogenic (WP3) with daily residential heating (CAMS81) Rödenbeck et al (2013) ocean, CTESSEL biogenic, GFAS fires (CAMS)
Meteorological input data	Oper. ECMWF analysis	ERA-5 reanalysis
Initial conditions	CAMS analysis (20150101)	CAMS re-analysis (20141226)
Model version Resolution	IFS CY43R1 9km, 137 model levels	IFS CY46R1 9km and 25km, 137 model levels
Tagged tracers	CO_2 anthropogenic, biogenic, fires, ocean	$+CO_2$ sectorial emissions (power plants, manufacturing, residential heating, transport, other)

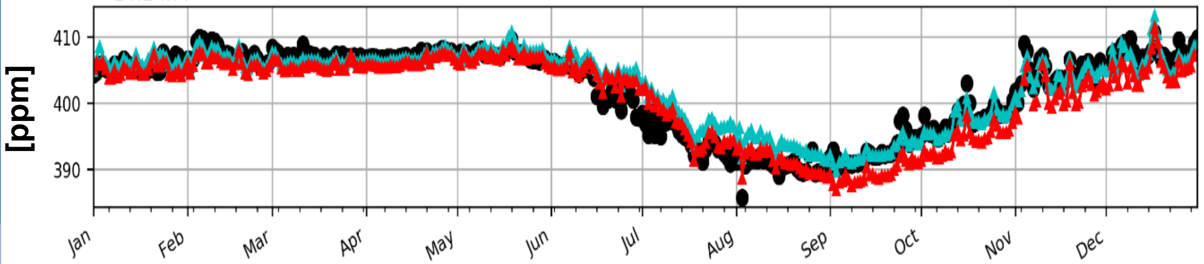
- **Paper on high resolution global nature run in preparation**

Evaluation of global nature runs (2015):

Tier 2 NR
Tier 1 NR
Observations

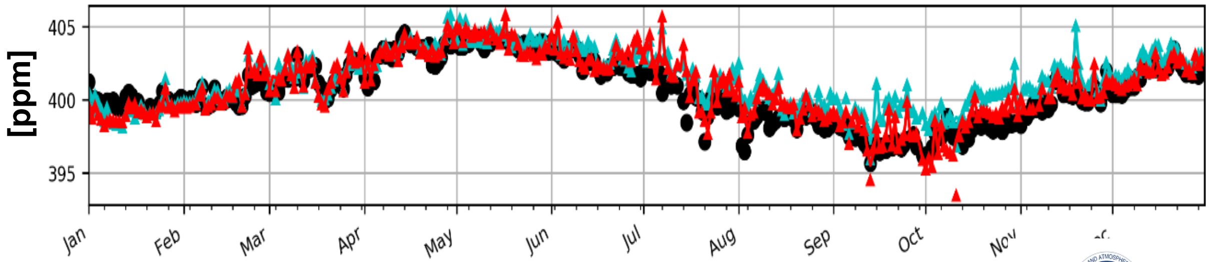
bias= -1.10 std= 1.98 rmse= 2.26
bias= 0.59 std= 1.82 rmse= 1.92

Barrow, Alaska



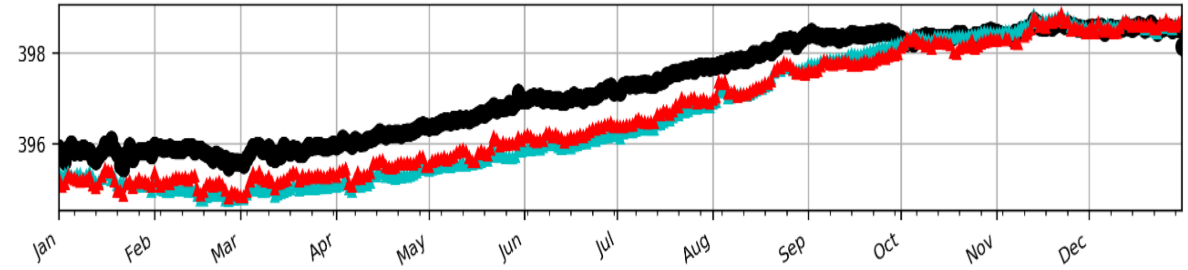
bias= 0.33 std= 0.96 rmse= 1.02
bias= 0.86 std= 1.02 rmse= 1.34

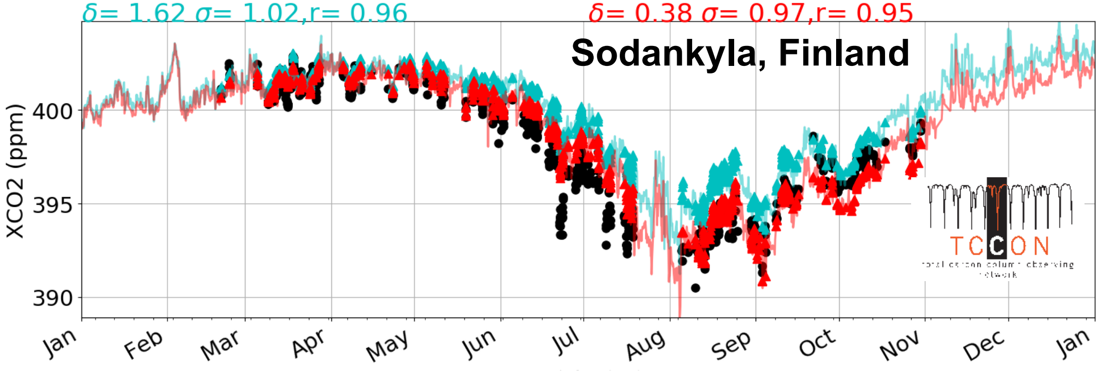
Mauna Loa, Hawaii

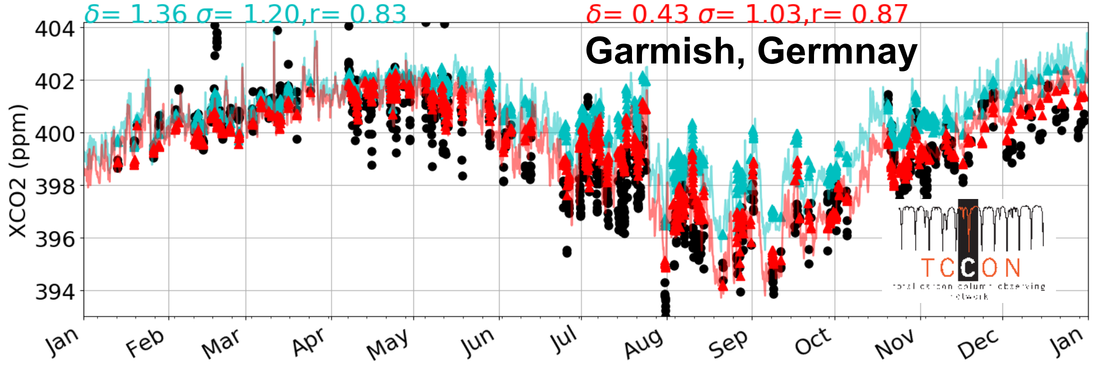


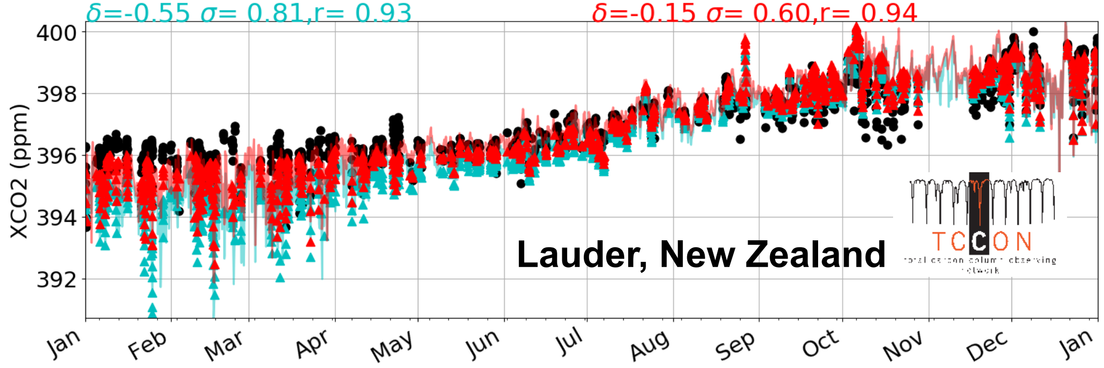
bias= -0.55 std= 0.31 rmse= 0.63
bias= -0.62 std= 0.42 rmse= 0.75

South Pole









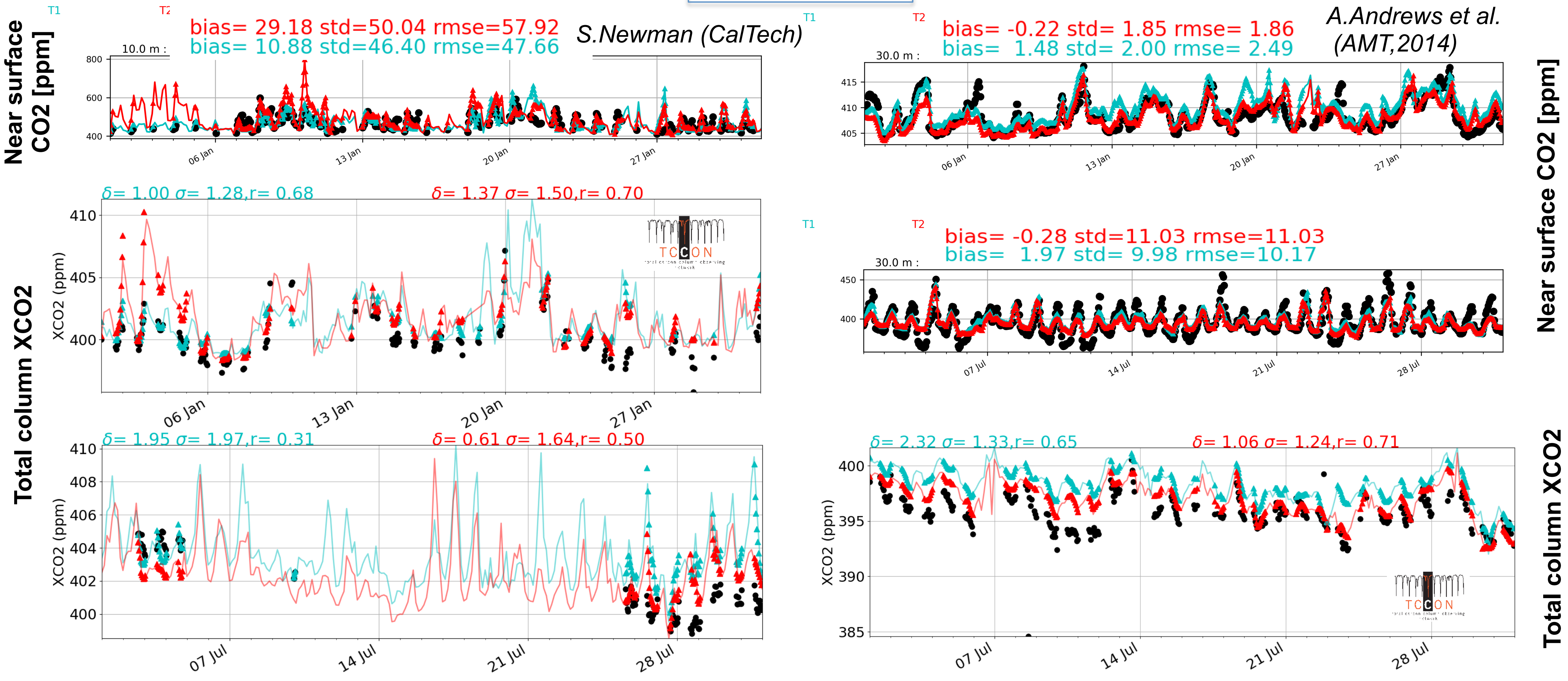
obspack_co2_1_GLOBALVIEWplus_v5.0_2019-08-12

Evaluation of global nature runs: synoptic to diurnal variability

Tier 2 NR
Tier 1 NR
Observations

Pasadena, California

Park Falls, Wisconsin



Uncertainty Overview – Requirements for anthropogenic CO_2 inversion system

- Prior biogenic flux estimates or LSM process parameters.

  Multi-model spread or literature assessment (e.g. trait database) but no meteorological uncertainty.

- Prior anthropogenic flux estimates or FF process parameters.

  Rough estimates with little/no sector/country consideration.

- Observations.

  Reasonable knowledge of observation accuracy.

- Initial atmospheric 3D CO_2 field.

  Typically not considered.

- Meteorological conditions.

  Typically not considered (with exceptions, see later).

- Model physics.

  Typically not considered or inflation of observation.

- Representation Error.

  Typically not considered or inflation of observation.

EMISSION UNCERTAINTY – Dataset

Zenodo: CHE_EDGAR-ECMWF_2015, [doi:10.5281/zenodo.3712339](https://doi.org/10.5281/zenodo.3712339);

Global gridded (0.1°×0.1° resolution) **anthropogenic** CO_2 **2015** emission uncertainties.

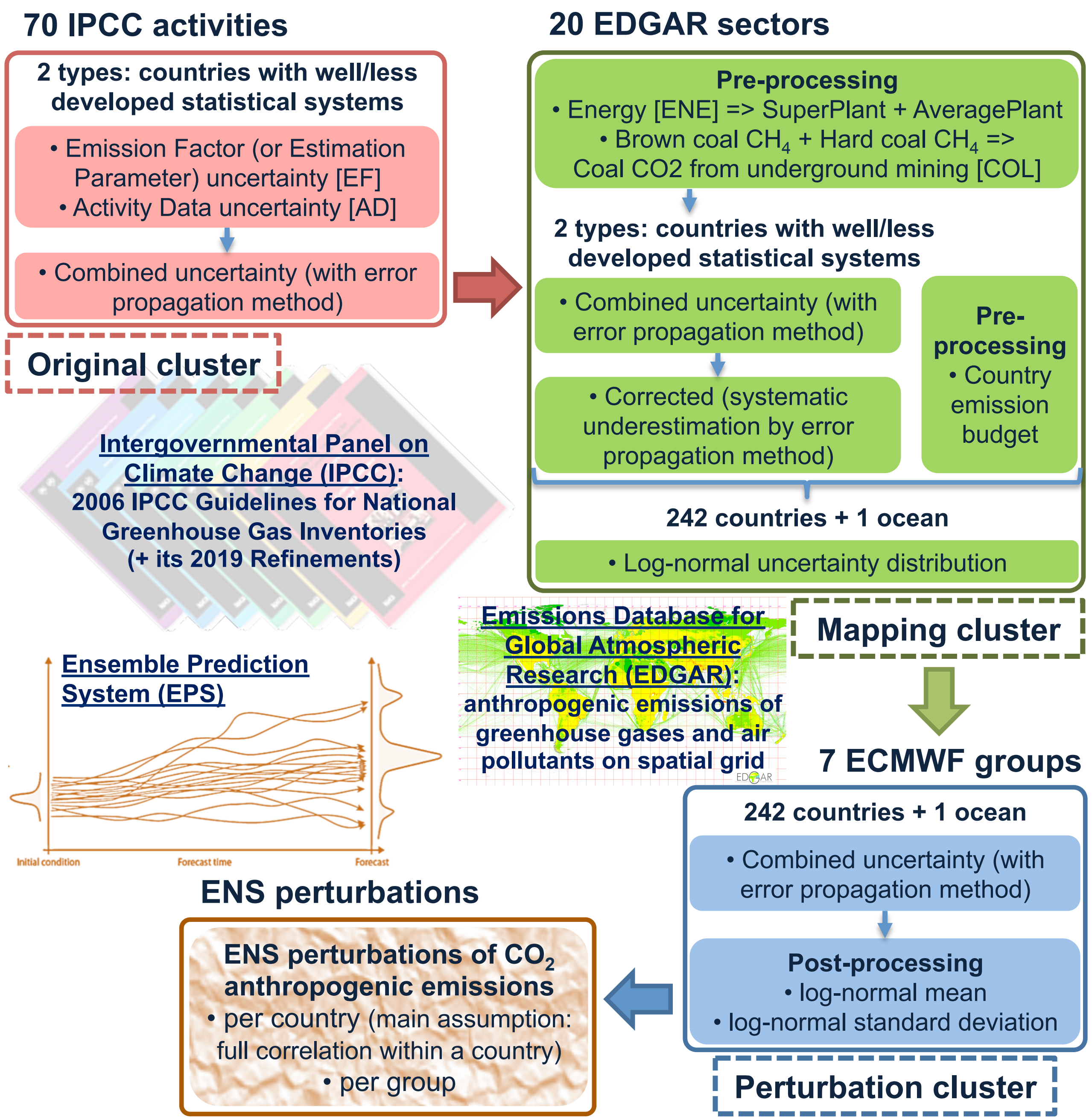
Aggregated in **7 main groups**:

1) Super Power Stations
2) Energy Sector
3) Manufacturing
4) Settlements
5) Aviation
6) Non-Air Transport
7) Other

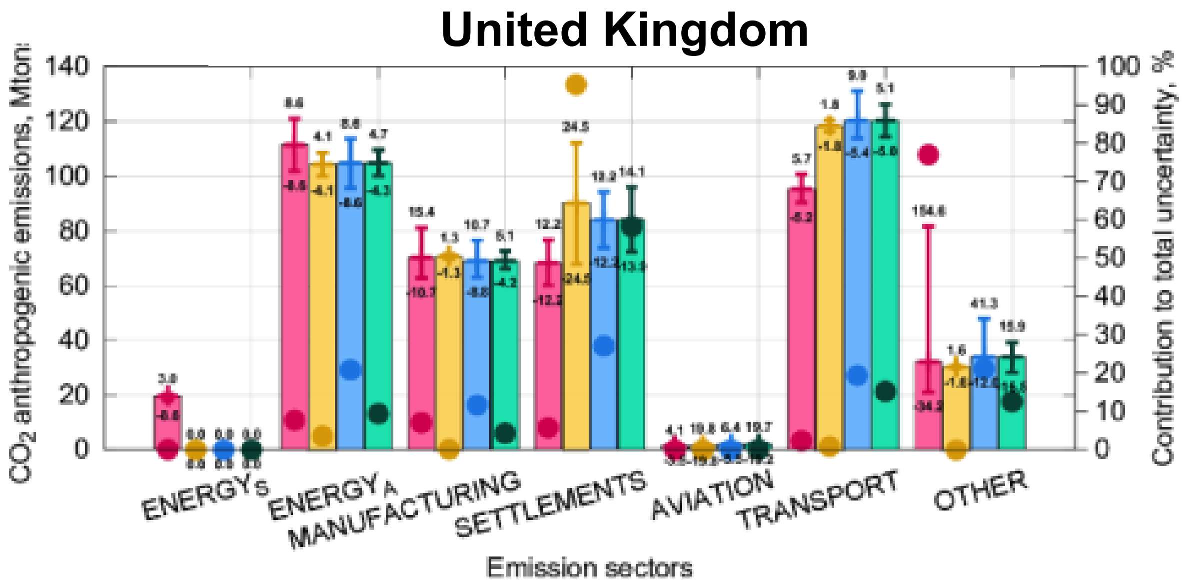
Based on **IPCC (2006) and IPCC-TFI (2019)** EF and AD uncertainty values. (Uncertainty in proxy data not included).

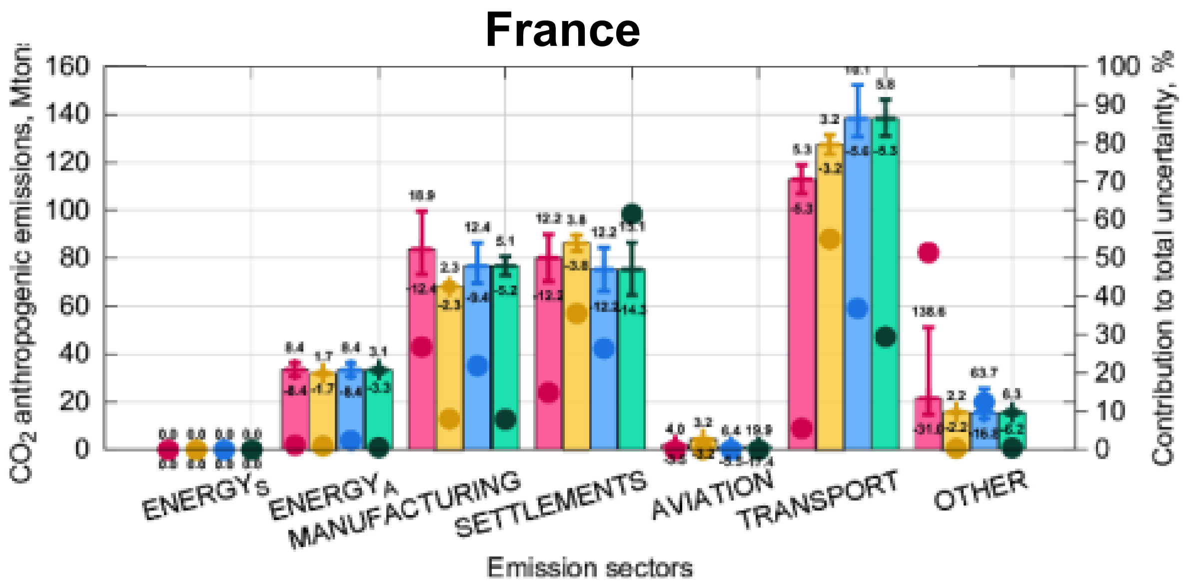
Uncertainties assumed perfect correlation within a country and no correlation between sectors and across borders.

Can be easily adapted for other years and datasets.



EMISSIONS - Comparisons





Our estimates (CHE)

UNFCCC

TNO v1.1 Tier 1

TNO v1.1 Tier 2

- Good agreement in emission budgets and uncertainties from different sources of emission data.

TRANSPORT UNCERTAINTY – Experimental Setup

Global ensemble simulations performed to investigate the following atmospheric CO_2 uncertainties:

- Initial Meteorological Conditions
- Biogenic Feedback to Transport Uncertainty
- Atmospheric Model Physics
- Emission Uncertainties

Initial Concentration

Informed from high resolution (~9km) IFS simulation

Prior Emissions

Perturbed inventory estimates based on uncertainties

Meteorology

Introduce tracers to current IFS-EPS framework

Perturbed Ensemble

- TCO399 (~25km)
- Hourly output
- January and July 2015
- Several experimental setups

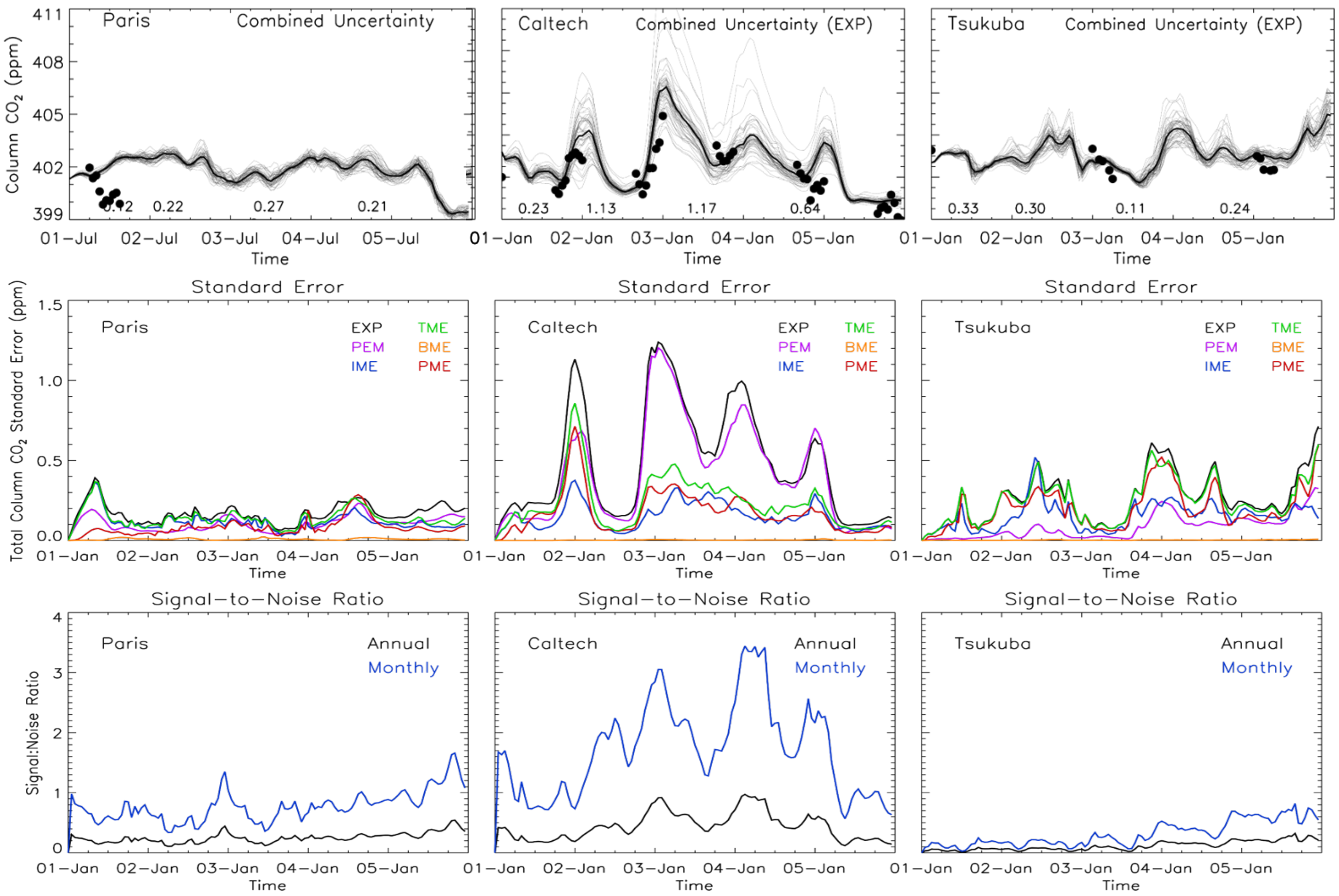
Ensemble-based Inversion System

Test multiple inversion systems to estimate sector/ national posterior fluxes

TRANSPORT – Model Configurations

Name	Initial Conditions	Physics	Biogenic Emissions	Anthropogenic Emissions	Error Information
FME	EDA	SPPT on	Online	Fixed	Model (noise)
TME	EDA	SPPT on	Offline	Fixed	Transport
IME	EDA	SPPT off	Offline	Fixed	Initial meteorological
PME	Control	SPPT on	Offline	Fixed	Model physics
BME	Control	SPPT off	Offline-FME	Fixed	Biogenic feedback
PEM	Control	SPPT off	Online	Perturbed	Emission (signal)
PEA	Control	SPPT off	Online	Perturbed Annual Error	Anthropogenic emission (signal)
EXP	EDA	SPPT on	Online	Perturbed	Full PDF (signal & noise)

TRANSPORT – Do We Accurately Represent Uncertainty?



Accounting for uncertainties in:

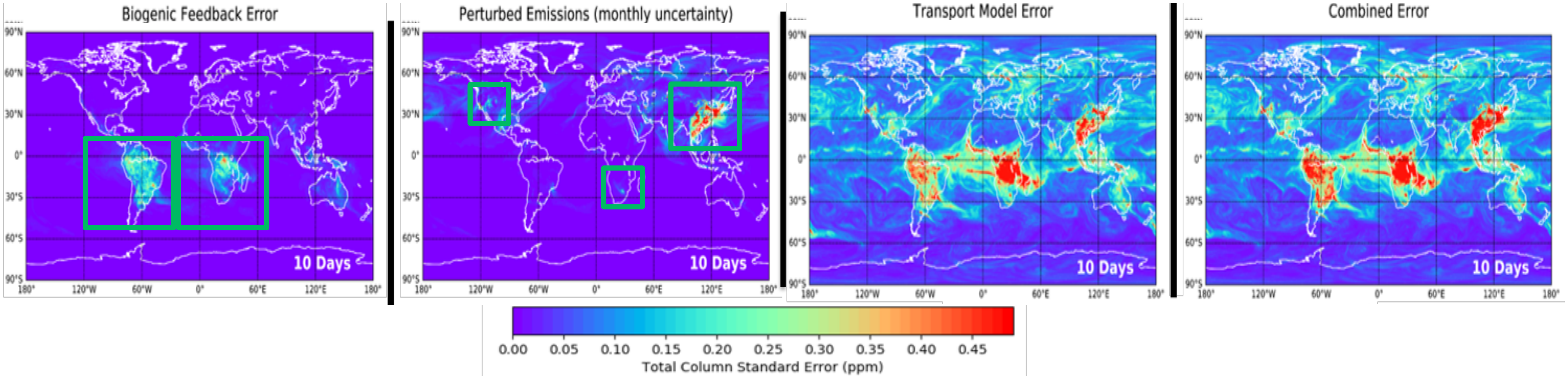
- Initial meteorology.
- Model physics.
- Biogenic feedback to meteorological uncertainty.
- Anthropogenic flux.

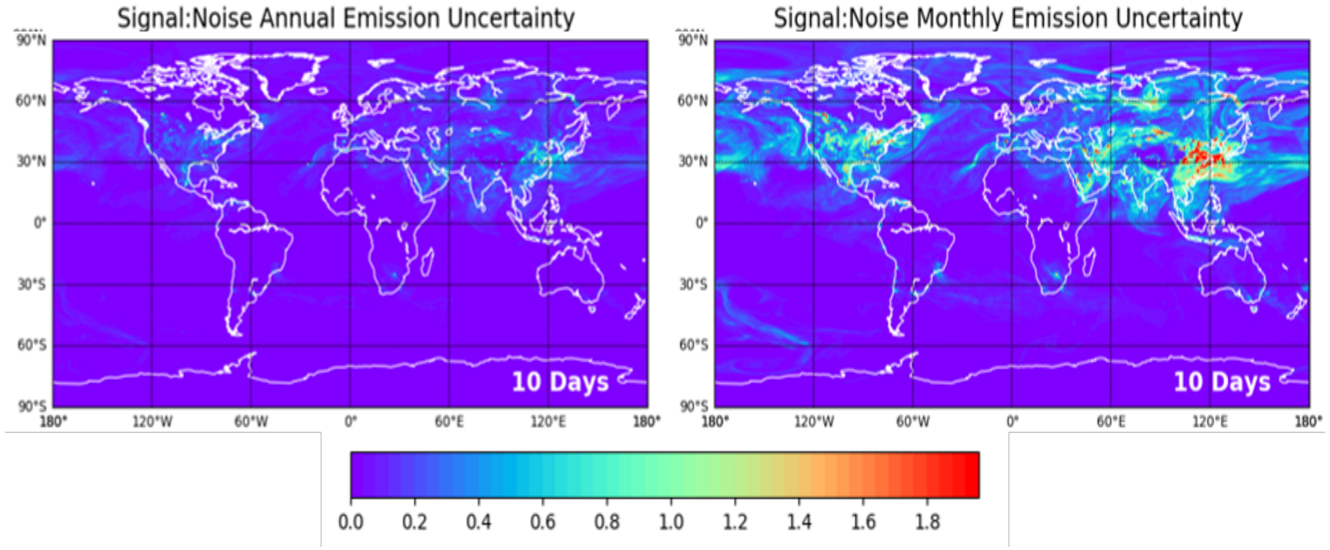
Over TCCON sites accounts for **21-65% of total error**.

The remaining error:

- Prior biogenic uncertainty.
- Observations.
- Initial 3D CO_2 field.
- Representation Error.

TRANSPORT - What Does Model XCO2 Uncertainty Look Like?





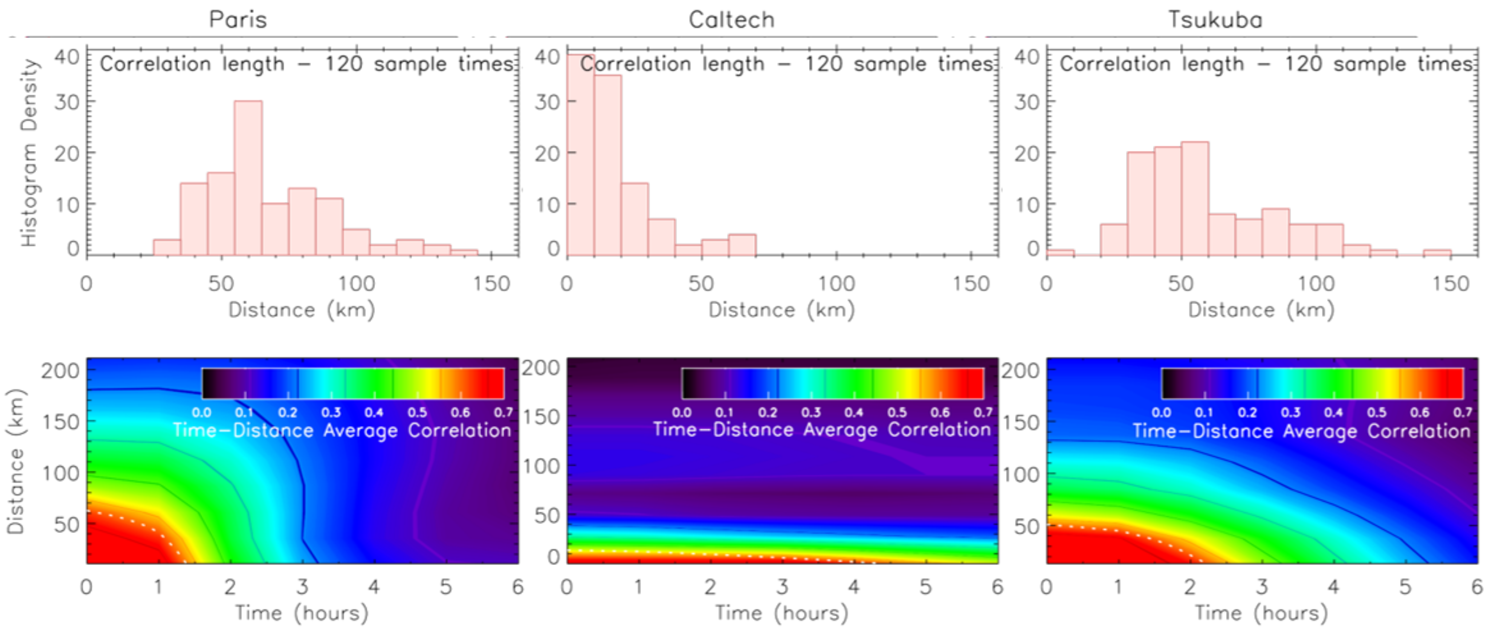
Signal: Prior emission spread

Noise: Remaining model uncertainty

High uncertainty (monthly emissions) provides **reasonable ratio over emission hotspots**.

Low uncertainty (annual emissions) shows low ratio, suggesting **small posterior error reduction**.

TRANSPORT – How Well Correlated are The Errors?

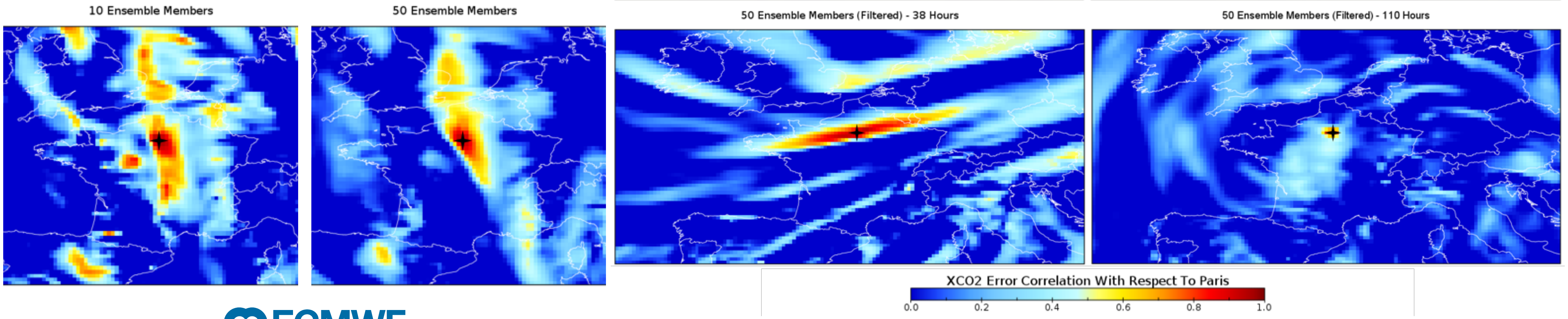


Average correlation length is variable with time.

Correlations variable dependant on location in time and distance.

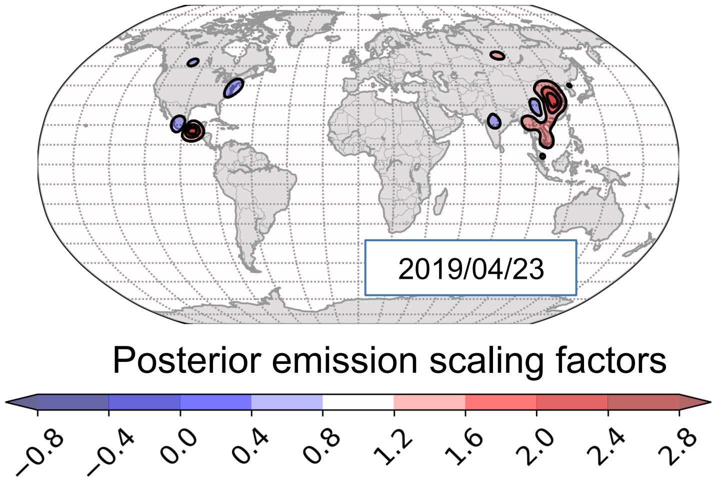
Correlations show spurious noise for low ensemble sizes.

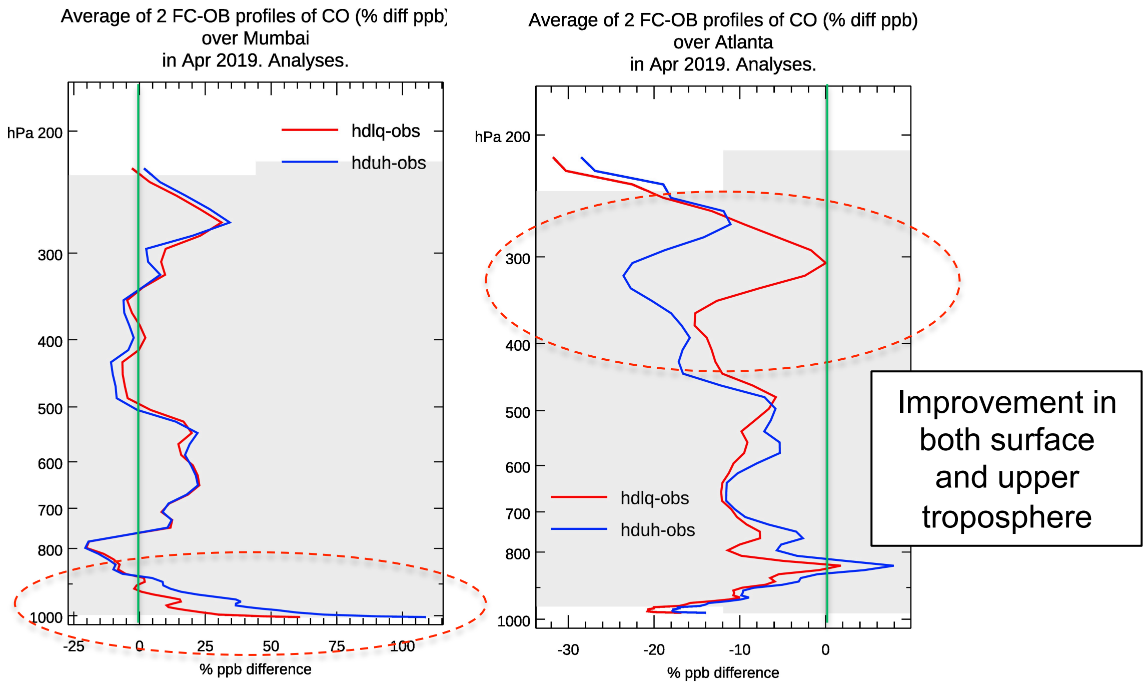
Correlations are flow-dependent.



CoCO2: Prototype system for a Copernicus CO2 service

IFS 4D-Var inversion of CO emissions





- **Multi-scale**: from global to local (high resolution capability)
- **Multi-species**: CO2, CH4, CO, NOx (use of satellite observations)
- **Multi-stream**: NRT monitoring with coupled NWP-atmospheric composition and re-analysis product with multi-model ensemble.

Integrated Forecasting System (IFS) at ECMWF:

- **Prior anthropogenic emissions**: modelling emissions residential heating with urban model, use of temporal and vertical profiles.
- **Prior biogenic fluxes**: new photosynthesis model, new land use cover and assimilation of observations (NRT LAI, SIF, VOD)
- **Transport model**: Testing new advection scheme and evaluation of plume dispersion
- **Hybrid data assimilation system**: optimal combination of adjoint-based and ensemble-based error covariance propagation.

SUMMARY

- CHE nature runs can provide a useful data set to explore observing system configuration requirements and modelling capabilities, as well as provide boundary conditions to regional models.
- New CoCO2 nature runs to be performed for 2016 and 2021.
- Plans for evaluation of CHE nature runs: use of aircraft data and OCO-2 XCO2.
- CHE nature runs will be made available in **Copernicus Atmosphere Data Store (ADS)** by end of 2020.
- Anthropogenic annual and monthly uncertainties have been derived for 7 sectors for 2015 for each country, with data available via Zenodo repository.
- A representation of model uncertainty and a “modest” prior anthropogenic uncertainty suggests the IFS-ENS can account for 21-65% of the total error. (also available via Zenodo).
- For monthly uncertainties signal-to-noise ratios are consistently above 1 over hotspots, but drop below 1 elsewhere.
- Work is on-going to reduce model error by improving priors and transport, and develop the multi-species inversion capability in the IFS within the CHE and **CoCO2** project in cooperation with the Copernicus Atmosphere Service at ECMWF.