Co-ordinated by ECMWF

CoCO2
Prototype system for a Copernicus CO_2 service

WP3 DEVELOPMENT OF GLOBAL MODELLING AND DATA ASSIMILATION CAPACITY IN AN MVS

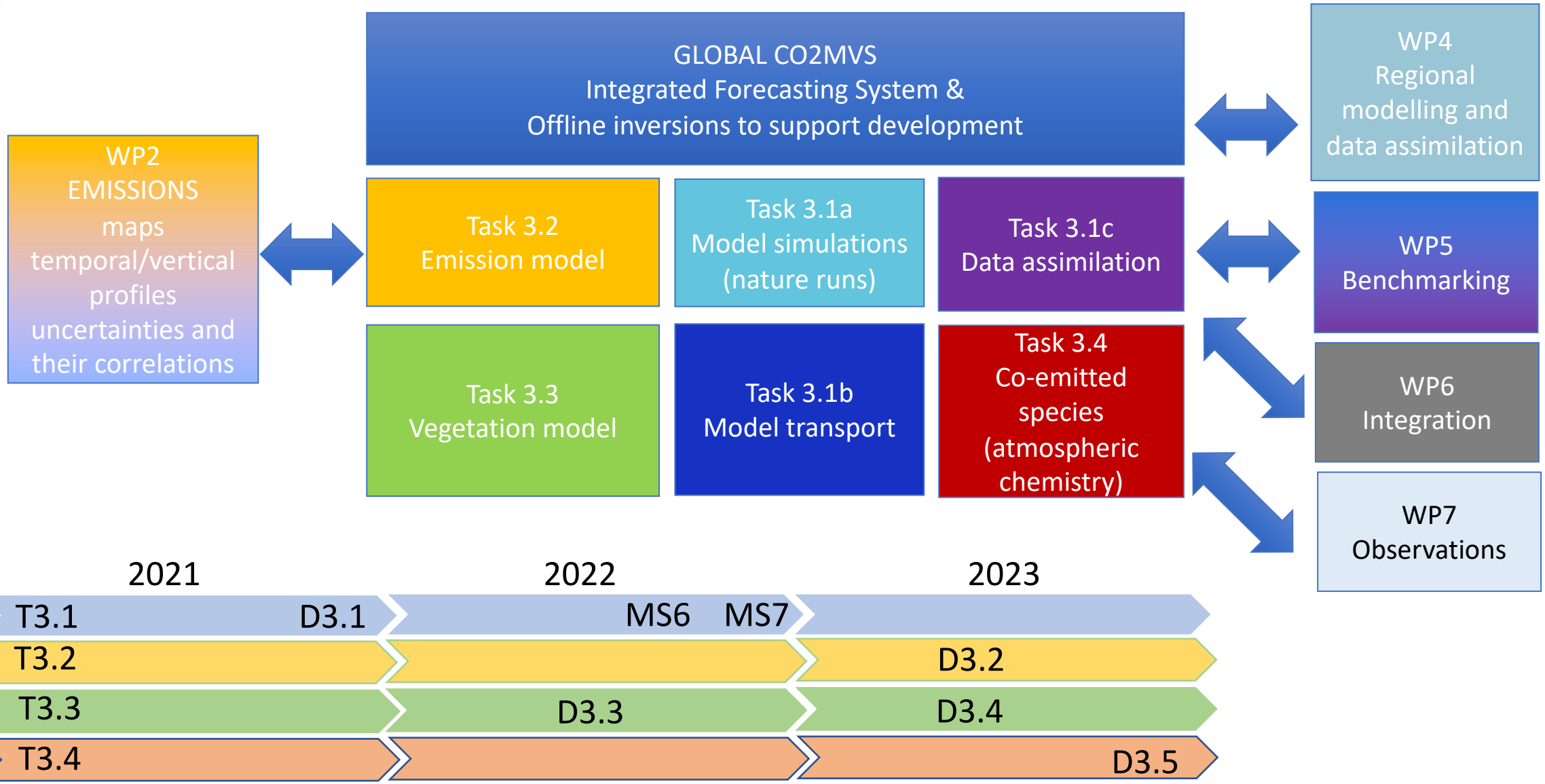
Wouter Peters (WU) and Anna Agusti-Panareda (ECMWF)

With input from WP3 partners

05 December 2022

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958927.

WP3 Development of global modelling and data assimilation capacity in an MVS



T3.2 Fossil fuel emission modelling and parameter estimation (ECMWF, BSC, TNO, iLab/Ulund, FORTH)

Modelling residential CO2 emissions within urban scheme in IFS (McNorton et al., 2022):

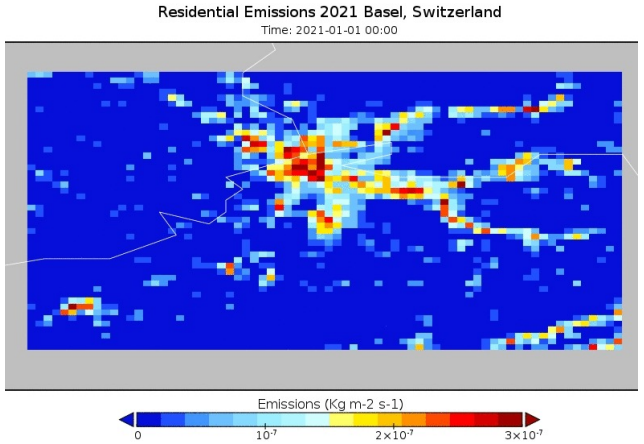
MEHNDI works by taking the annual nationally reported residential sector emissions and spatial and temporally disaggregating those using urban cover used in the IFS. At least 20% of those are assumed constant (cooking etc.) and the remaining up to 80% are derived using the top soil layer temperature in a similar way to the traditional heating degree day. A nationally constant emission factor is calculated to preserve the budget of each country.

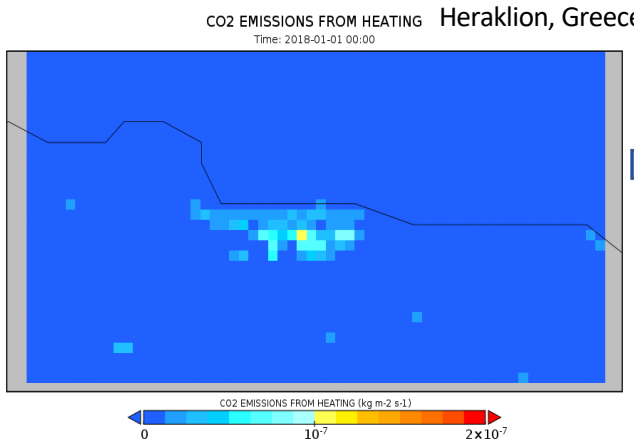
$$\text{Flux} = U_{cover}\, \gamma f(T_{urban})$$

$$f(T_{urban}) = \max(15.5 - Tsoil1, 1)$$

γ, is a national scaling factor based on annual residential heating.
U_{cover} is the urban cover.
$f(T_{urban})$ is the heating degree day function.

Residential emissions at 1km from MEHNDI model

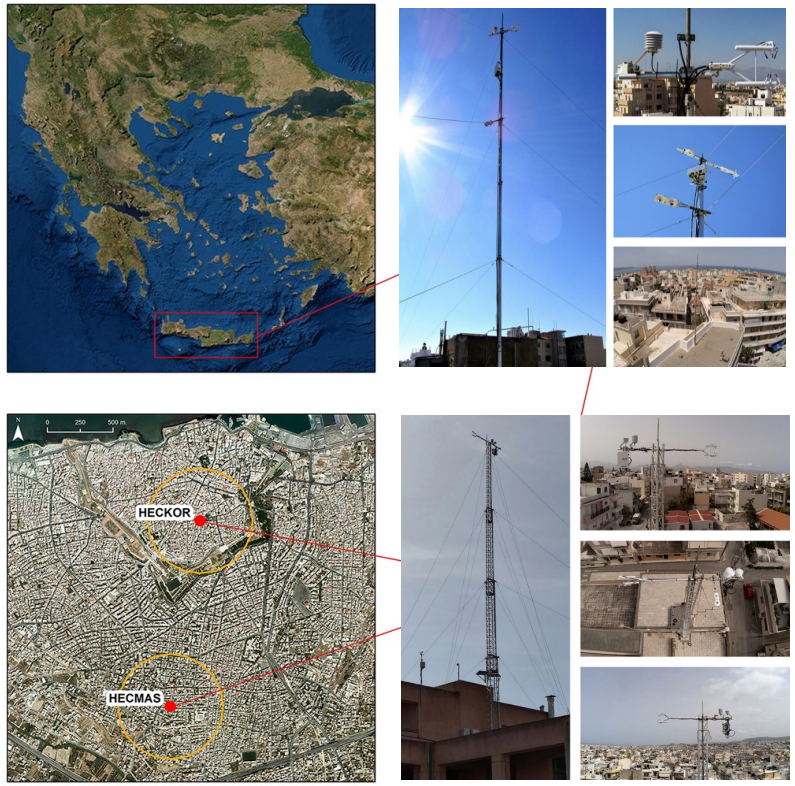




Heraklion, Greece

Joe McNorton, Anna Agusti-Panareda, Marc Guevera, Gabriele Arduini, Gianpaolo Balsamo, Souhail Boussetta, Marco Chericoni, Margarita Choulga and Richard Engelen

Evaluation of CO2 heating model with *in-situ* eddy covariance measurements



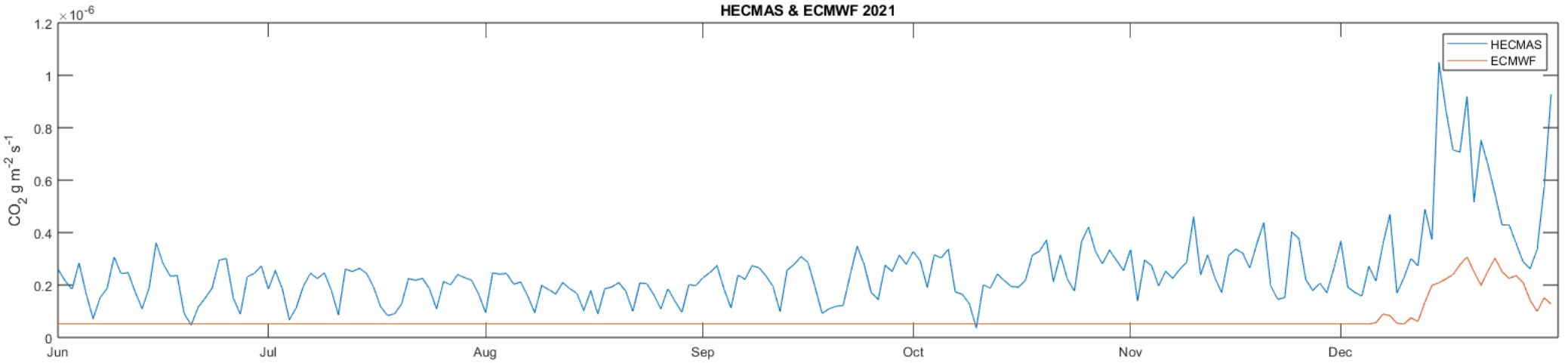
Both flux towers are equipped with IRGASON Integrated CO2/H2O Open-Path Gas Analysers, 3D Sonic Anemometers and Net Radiometers.

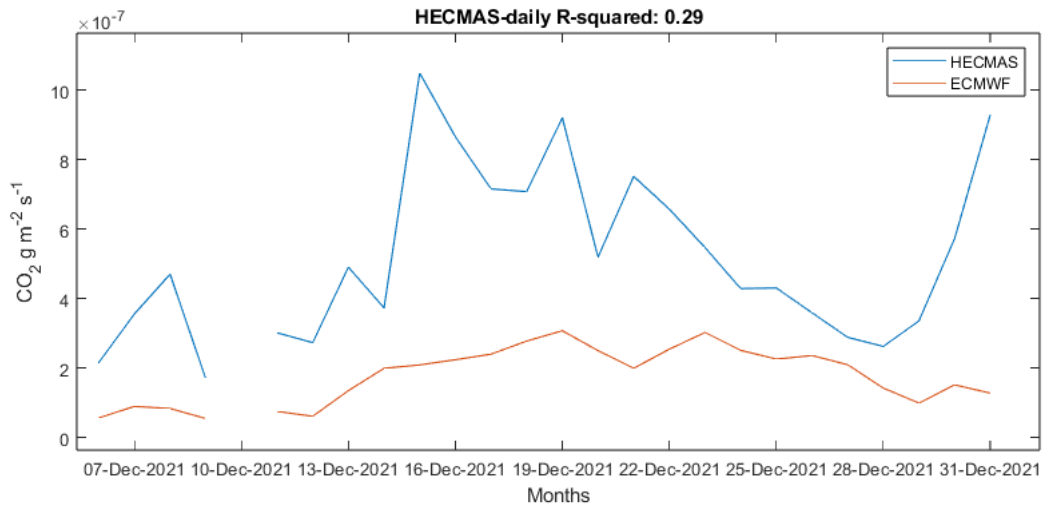
- HECKOR operates since autumn 2016 at the city center.
- HECMAS operates since spring 2021 at a residential area in Heraklion.

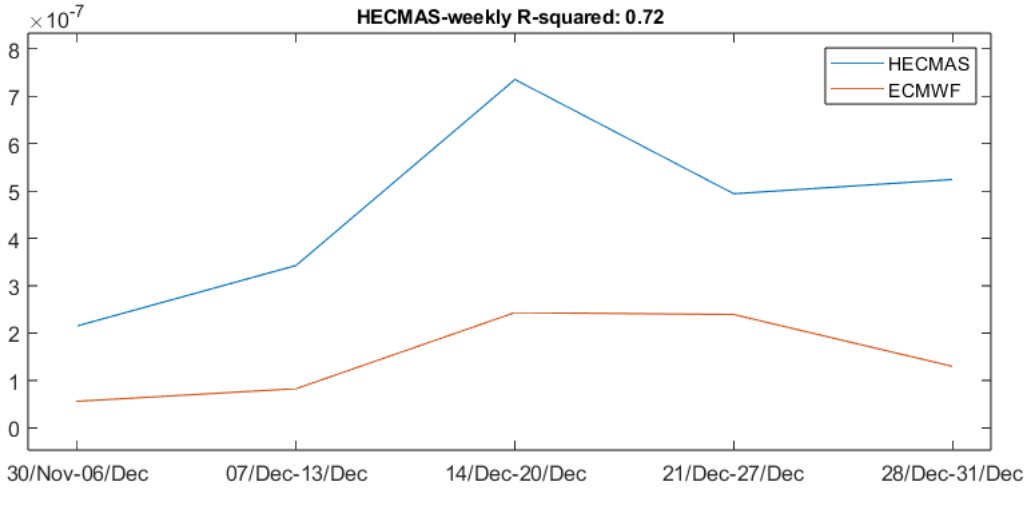
Konstantinos Politakos, Stavros Stagakis, Nektarios Chrysoulakis

T3.2 Heating CO_2 emissions in Heraklion A correlation between models and *in-situ* eddy covariance measurements

Konstantinos Politakos[1,*], Joe MCNorton[3], Stavros Stagakis[1,2], Anna Agusti-Panareda[3], Nektarios Chrysoulakis[1]



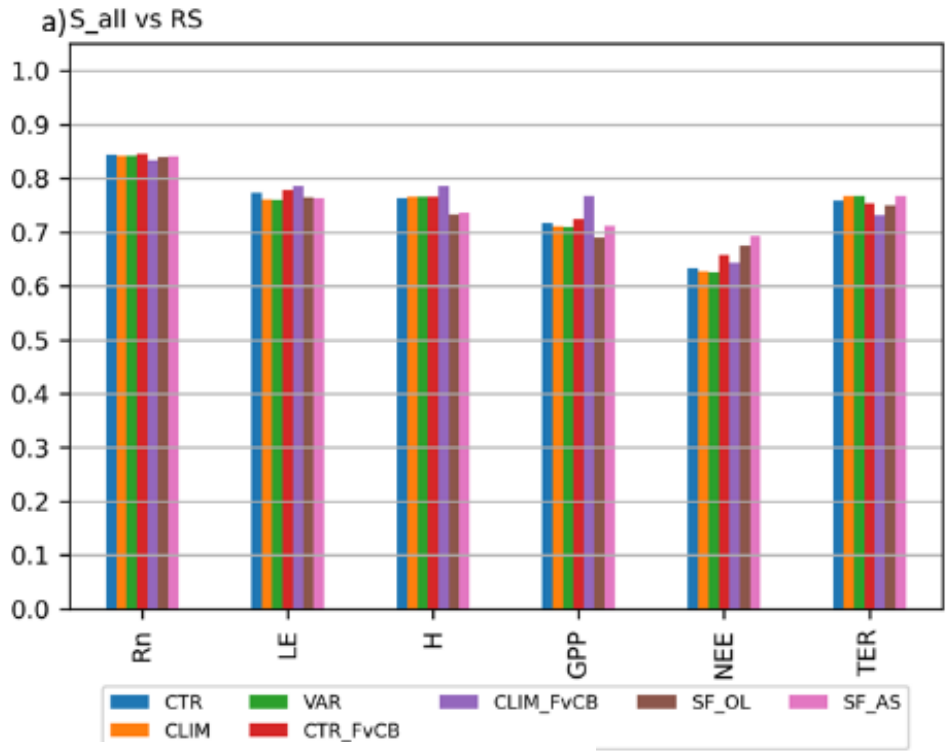




T3.3a Land-surface mapping and modelling (FC.ID/IPMA, ECMWF, Meteo-France, MPI-BGC, LSCE)

D3.3. Dutra and Lopes et al. (2022): Validation of online **global vegetation carbon fluxes in ECLand** for prototype modelling developments FC.ID with contributions from ECMWF, Meteo-France, MPG, LSCE

Main goal: Provide an assessment of the land surface **modelling developments** (land use cover, classification and interactive LAI) and their impact on the **carbon/energy/water fluxes and NWP scores**



	Rn	LE	H	GPP	NEE	TER
β_{bias}	2	1	1	1	0	0
β_{rmse}	1	1	1	1	1	1
β_{phase}	2	2	2	2	2	2
β_{dist}	2	2	2	2	2	2

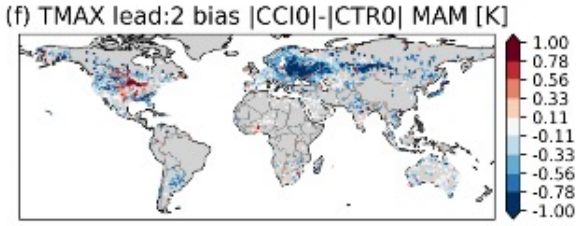
$$S_{all} = \frac{\beta_{bias}S_{bias}+\beta_{rmse}S_{rmse}+\beta_{phase}S_{phase}+\beta_{dist}S\_dist}{\beta_{bias}+\beta_{rmse}+\beta_{phase}+\beta_{dist}},$$ ice

Benchmark with FLUXCOM with offline ECLand and SURFEX simulations. New ESA-CCI land cover and Copernicus LAI :

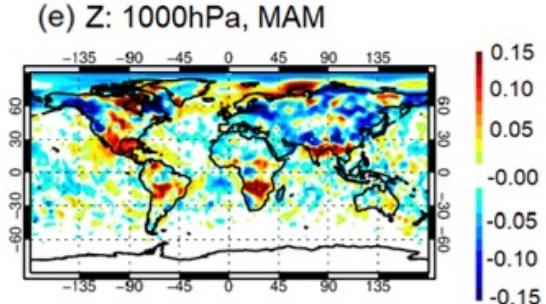
- Neutral impact in ECLand A-gs (CLIM)
- **Positive** impact in LE, H GPP in ECLand neutral impact in ECLand Farquhar (CLIM_FvCB)
- TER needs further attention (requires scaling)

- Technical work and documentation of new land cover and LAI processing ready;
- Mixed meteorological impact : further refinement of model;
- Ongoing developments in IFS/ECland expected to address some of the issues;
- New version of the report D3.3 proposed for mid-2023 to document “final” model version using new FLUXCOM2 data.

Validation of Daily maximum temperature (GHCN)
New land cover / LAI -> Warming : **Positive in regions with cold bias**
(blue == better)



Forecast experiments:
Positive in Spring Northern hemisphere Tropics/sparse vegetation areas with some problems in Spring – worst in summer.
Land cover uncertainties and mapping to the model “world” and parameters;



Meteo-France (Jean-Christophe Calvet and Bertrand Bonan)

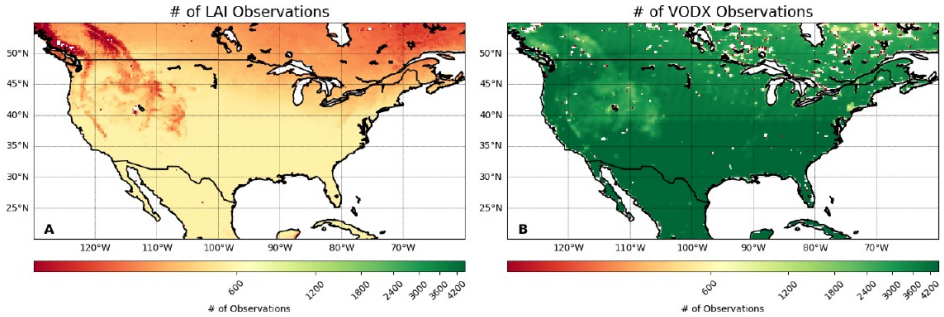
➔ **LDAS-Monde** global run (0.25° spatial resolution) covering 2002 – 2019
- Land surface model: **ISBA NIT option** [Calvet *et al.*, 1998, 2004; Gibelin *et al.*, 2006]
  - Interactive Leaf Area Index (LAI)
  - Carbon fluxes: GPP, Ecosystem respiration (RECO), NEE
  - Post-processing applied to RECO so that RECO = 0.7 GPP on time average. The 0.7 factor was derived from studies of Wang et al. (2008), Peylin et al. (2009) and Yuan et al. (2011)
- Joint assimilation of ESA CCI Soil Moisture v6.1 and CGLS GEOV2 LAI products
- Monthly means of several variables (LAI, GPP, ecosystem respiration) provided to Emanuel Dutra (IPMA) for comparison/evaluation in version 1 of D3.3

➔ Assimilation of **VOD X-band product (VODCA)** performed and validated over the USA
- Seasonal linear rescaling applied to VOD-X to match CGLS GEOV2 LAI
- Work published in Mucia et al. (2022) https://doi.org/10.5194/bg-19-2557-2022
- Over Europe: many regions with data gaps due to RFI (e.g. England, Italy, …)

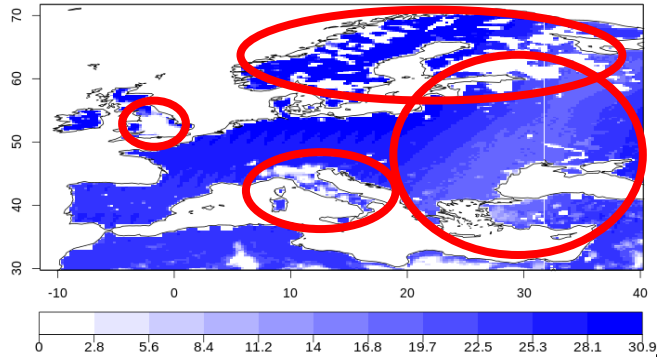
➔ Link to WP5
- Organisation of a WP3.3b – WP5 meeting to prepare the production of D3.4 and of version 2 of D3.3 (to be delivered in June 2023)

Assimilation of microwave VOD (Mucia et al. 2022)

VOD used as a proxy of LAI: much more frequent observations over the USA



… but data gaps in other areas, affected by RFI :

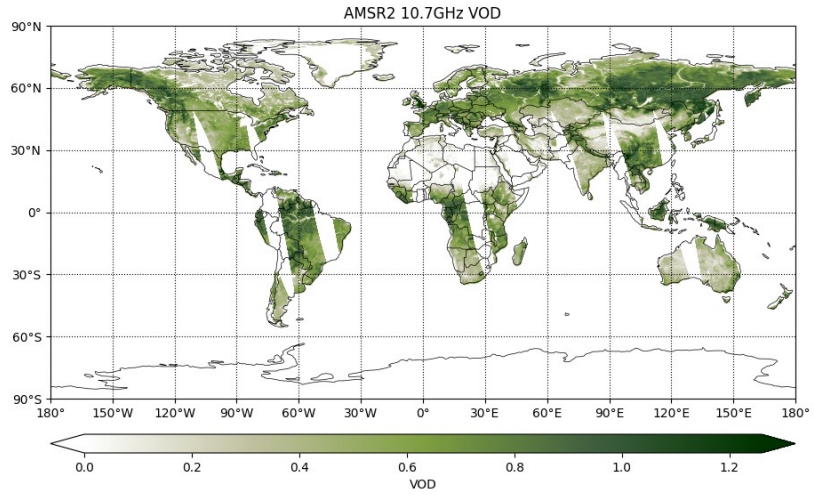


Number of VOD-X obs in July from 2002-2019

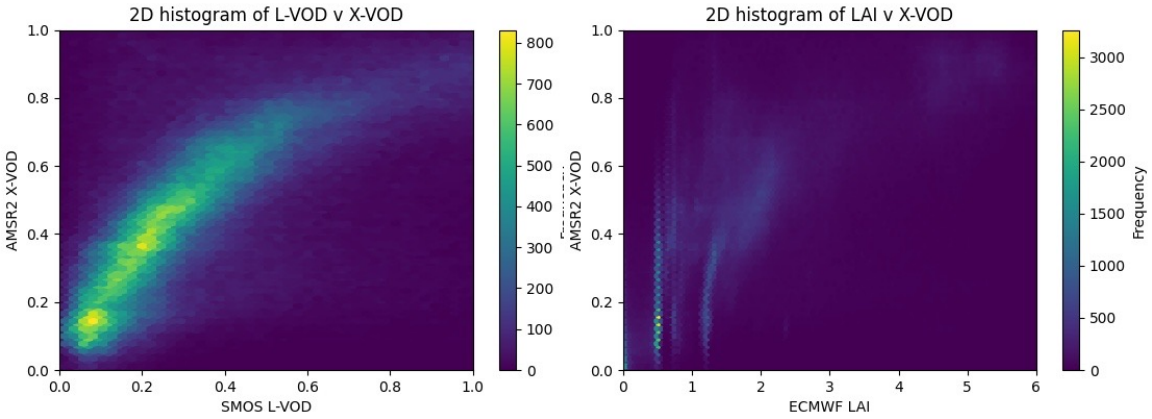
ECMWF (Patricia de Rosnay and Peter Weston)

- Assimilation of VOD data in ECLand to analyse LAI and soil moisture consistently
- Several VOD products being investigated: SMOS L-band (VODL), AMSR2 C-band & X-band (VODC and VODX)
- Ongoing rescaling of the VOD products to the ECLand cycle 49r1 LAI (CGLS/C3S, Boussetta, Balsamo et al.)

  Use a monthly rescaling approach based on CDF-matching (as in e.g. de Rosnay et al., RSE 2020)



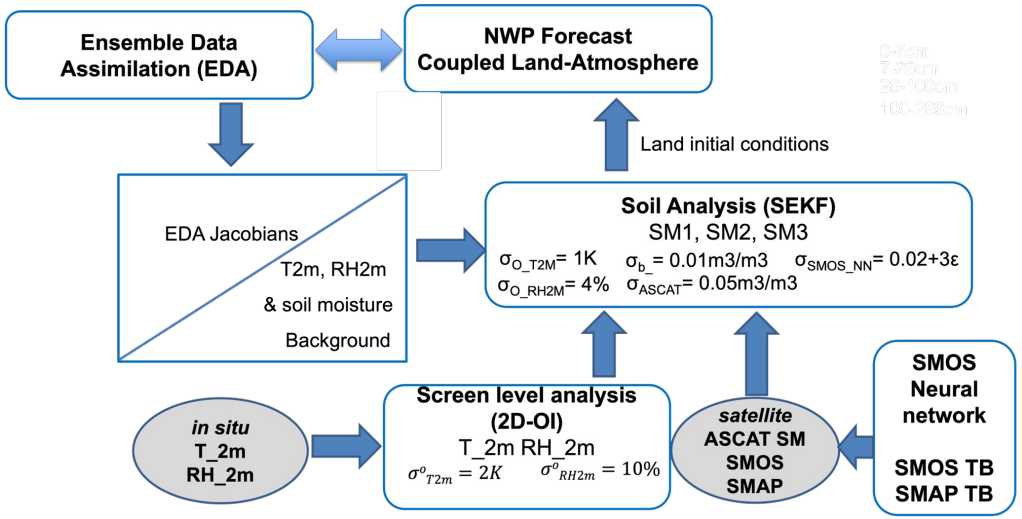
- Ongoing setup control DA experiment using ASCAT soil moisture only, 2016-2021, global 30 km resolution, ERA5 forcing
- Processing SMOS L-VOD and AMSR2 C- & X-VOD products
- C- & X-VOD saturate at lower L-VOD values
- Previous research indicates better correlation of C- & X-VOD with LAI
- Initial focus will be on C- & X-VOD but will also assess L-VOD in our system



ECMWF (Patricia de Rosnay and Peter Weston)

VOD data assimilation developments at Meteo-France in LDAS-Monde (Mucia et al. 2022) used as input for the ECMWF VOD land data assimilation in ECLand

- C-band and X-band VOD products from AMSR2
- Configuration of error specifications
- Rescaling approach to match VOD to the model LAI



ECMWF ECLand data assimilation for CoCO2

- Next step: In December, start series of land DA OSEs, with ASCAT + VOD data assimilation
  - Follow the approach of Kumar et al., (HESS 2020) and Mucia et al. (biogeosci. 2022)
- January-February: Run coupled atmospheric forecast experiments initialised from the land DA OSEs
- February-March: analysis the results, including land surface validation of soil moisture and fluxes and NWP impact

T3.3b **Land-surface data assimilation of remote sensing products (Meteo-France, ECMWF,Ulund/iLab,CEA)**

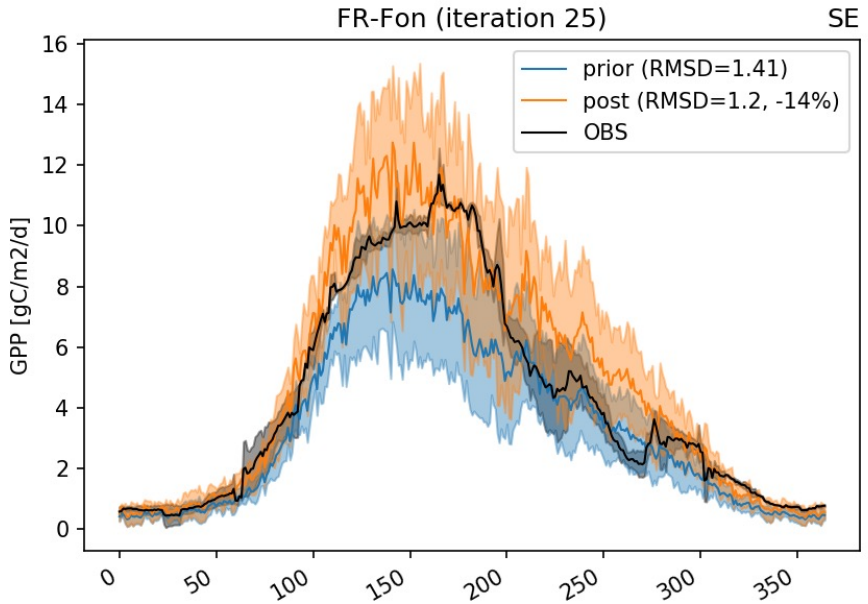
LSCE contribution to land DA of satellite data (Philippe Peylin, Fabienne Maignan, Cedric Bacor, Vlad Bastrikov)

In CTESSEL (with CAMS2-52a project)

- Implementation in ECLand of a SIF observation operator (SCOPE)
- Assimilation of TROPOMI – SIF data at FluxNet sites: 11 param optimised

➔ Large improvement of the GPP !

➔ Next: joint assimilation SIF & GPP



Additional contribution with ORCHIDEE

- Test the assimilation of Atmospheric XCO2 + SIF data from OCO-2; and COS data (Comparison with the assimilation of In-situ data)
- Test new DA approaches: “History Matching” based on Gaussian Emulators !
- Several optimised GPP products will be derived from ORCHIDEE DA experiments

Ulund/iLab contribution to land DA (Marko Scholze, Thomas Kaminski)

- Provide GPP fields inferred by the Simple Diagnostic Biosphere Model (SDBM) from the combination of FAPAR and CO2 observations with meteorological data sets. Work is ongoing, completion planned for 2023.

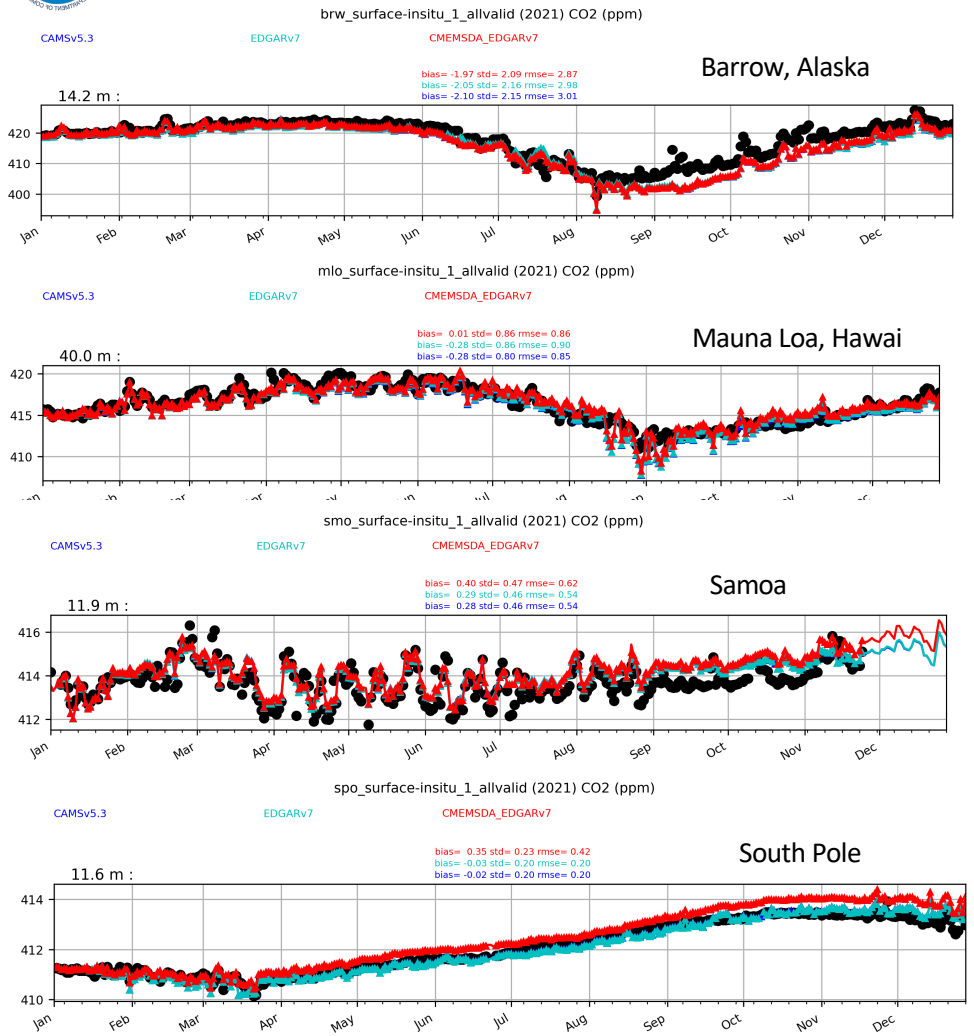
Task 3.1a Testing fluxes from WP2 (preliminary results for 2021)

Ocean CO2 fluxes from PISCES model with assimilation of pCO2 produced by MERCATOR-OCEAN (Julien Lamouroux and Coralie Perruche)

Observations JENA-CS CMEMS PISCES model (pCO2 DA)

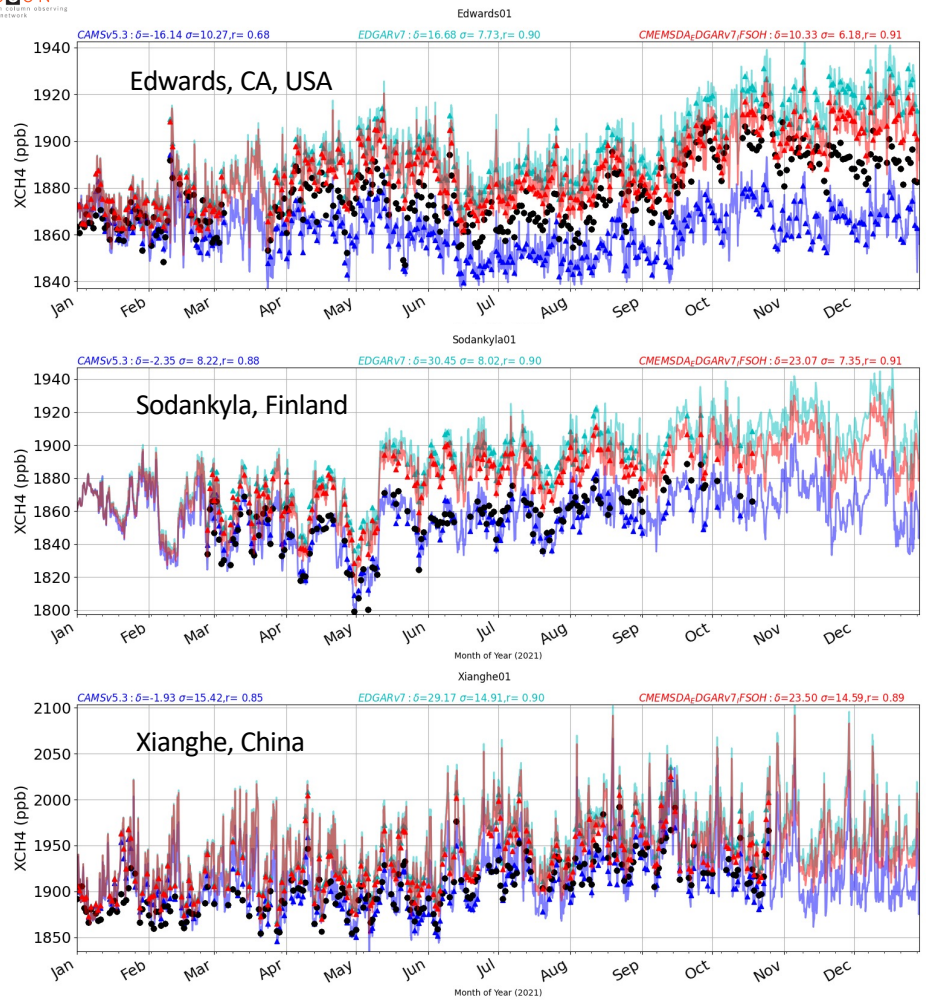
Global budget: -2.64 PgC/year (2019) -1.9PgC/year (2021)

Near surface CO2 [ppm]



EDGARv7_FT2021 (2018, 2021) for CO2 and CH4 and comparing with CAMS-GLOB-ANTv5.3 (EDGARv5) to be used operationally in CAMS in CY48R1 in 2023: small impact on CO2 and large impact on CH4.

Observations CAMS-GLOB-ANTv5.3 (373Tg) EDGARv7 (385Tg) EDGARv7+IFS OH



Task 3.1a CoCO2 nature runs for 2018 and 2021 with IFS (ECMWF)

Ongoing preparation/production of CoCO2 IFS nature runs (schedule affected by move of supercomputer to Bologna and delays in the processing of surface fluxes and prior emissions from WP2):

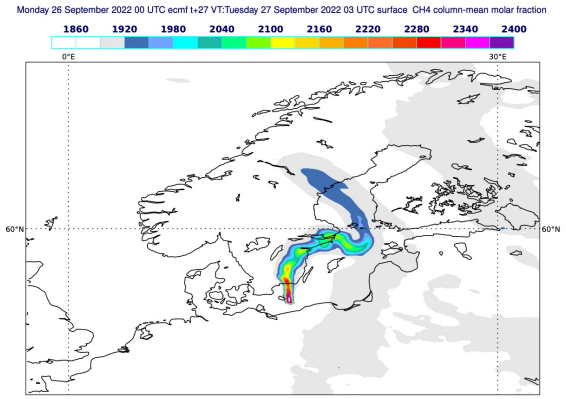
- **Version 1:** CAMS GHG 9-km resolution FC (with CO2, CH4, CO and *Rn222*) using operational configuration of CY48R1 (CAMS-GLOB-ANTv5.3 emissions). Ready by the end of December.
- **Full chemistry** (collaboration with CAMS colleagues) 25km resolution. Ready by end of 2023 Q1.
- **Version 2: CAMS GHG high resolution FC** (with CO2, CH4, CO and Rn222) using operational configuration of CY49R1 (new LAI and land cover, IFS CH4 loss rate and CH4 wetland model) plus emissions from WP2 (ocean fluxes from MERCATOR-OCEAN and EDGARv7.0 emissions). Ready by end of 2023 Q1.
- Configuration and archived fields: https://confluence.ecmwf.int/display/CoCO2/CoCO2+nature+run+preparation

T3.1b Transport development in the IFS

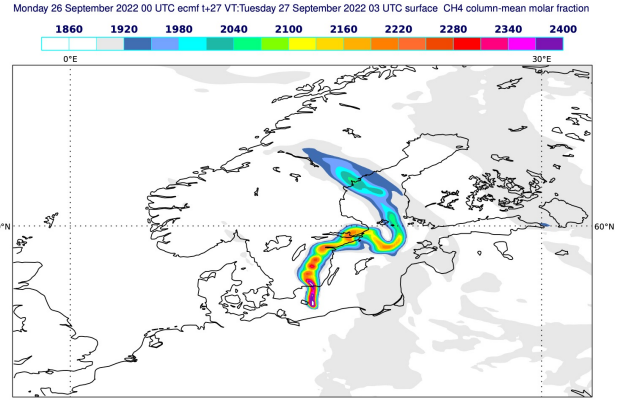
M. Diamantakis, A.Agusti-Panareda (ECMWF)

Mass fixer tuning using MPDATA advection scheme: A CH4 case study of the Nord Stream pipe leaks (Sep 2022)

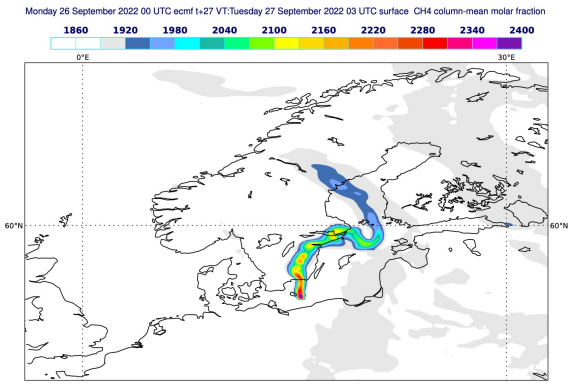
REFERENCE: MPDATA advection scheme



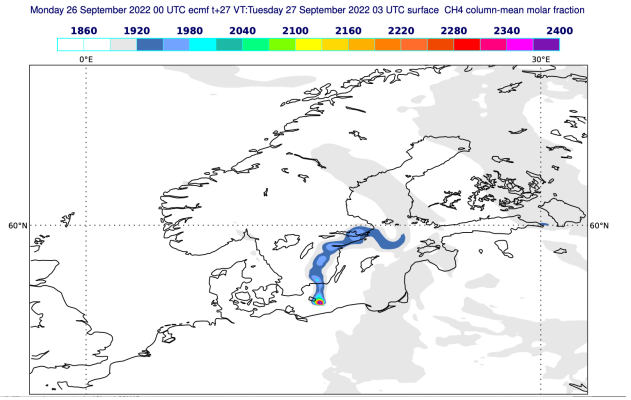
COMADH SL advection scheme



COMADH SL advection scheme with NEW GHG MASS FIXER Bermejo and Conde multiplicative B=1.25

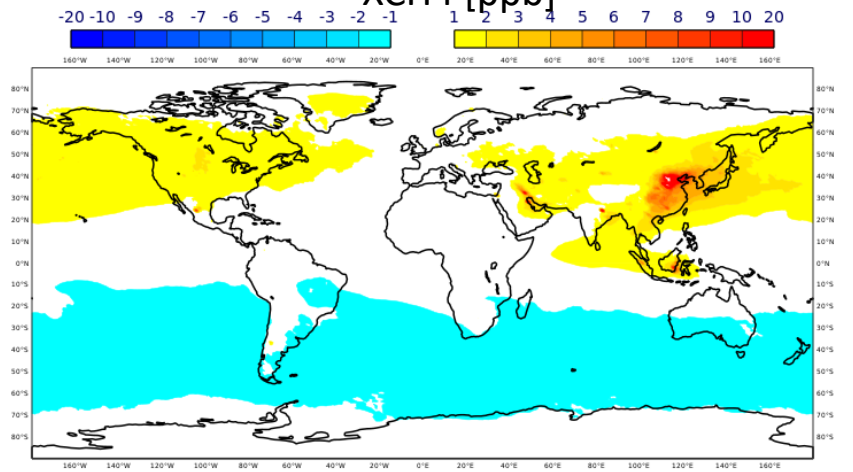


COMADH SL advection scheme with STANDARD GHG MASS FIXER Bermejo and Conde additive B=2

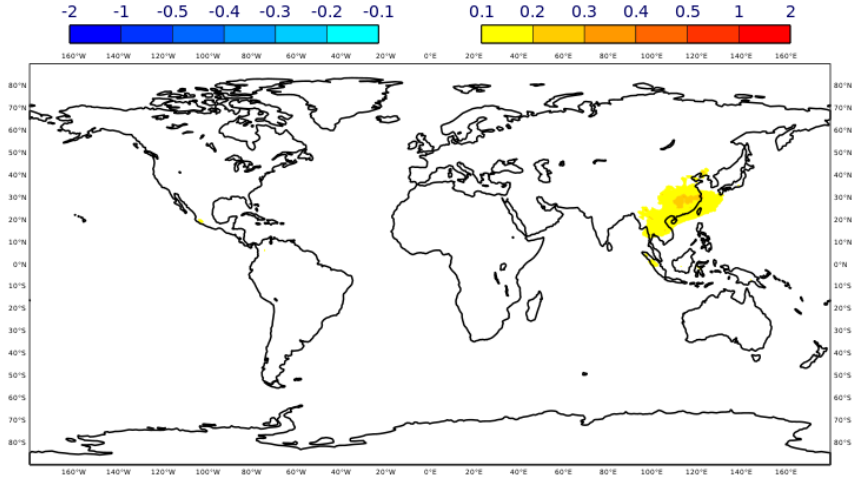


Impact of new mass fixer on CoCO2 nature runs after 3 months

XCH4 [ppb]



XCO2 [ppm]

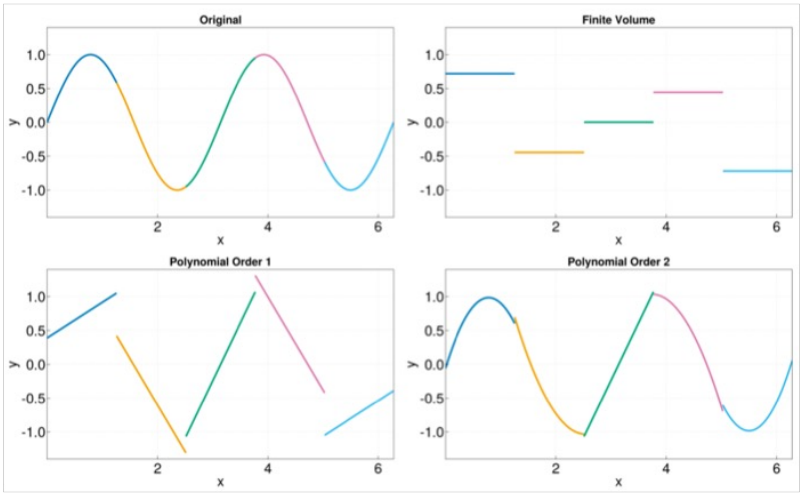


T3.1b Novel semi-Lagrangian discontinuous Galerkin (SL-DG) transport schemes

Giovanni Tumolo, Michail Diamantakis (ECMWF)

WHAT: Transport equation is discretized

- **in space with DG:** DG is a generalization of Finite Volumes with some flavor of spectral methods as it uses a (polynomial) function basis within each control volume
- **in time with SL:** well established time integration technique for transport terms based on fluid parcels trajectories back-tracking (currently in use in grid-point IFS)



Projection of y = sin(x) function (top left) onto spaces of polynomials of different orders

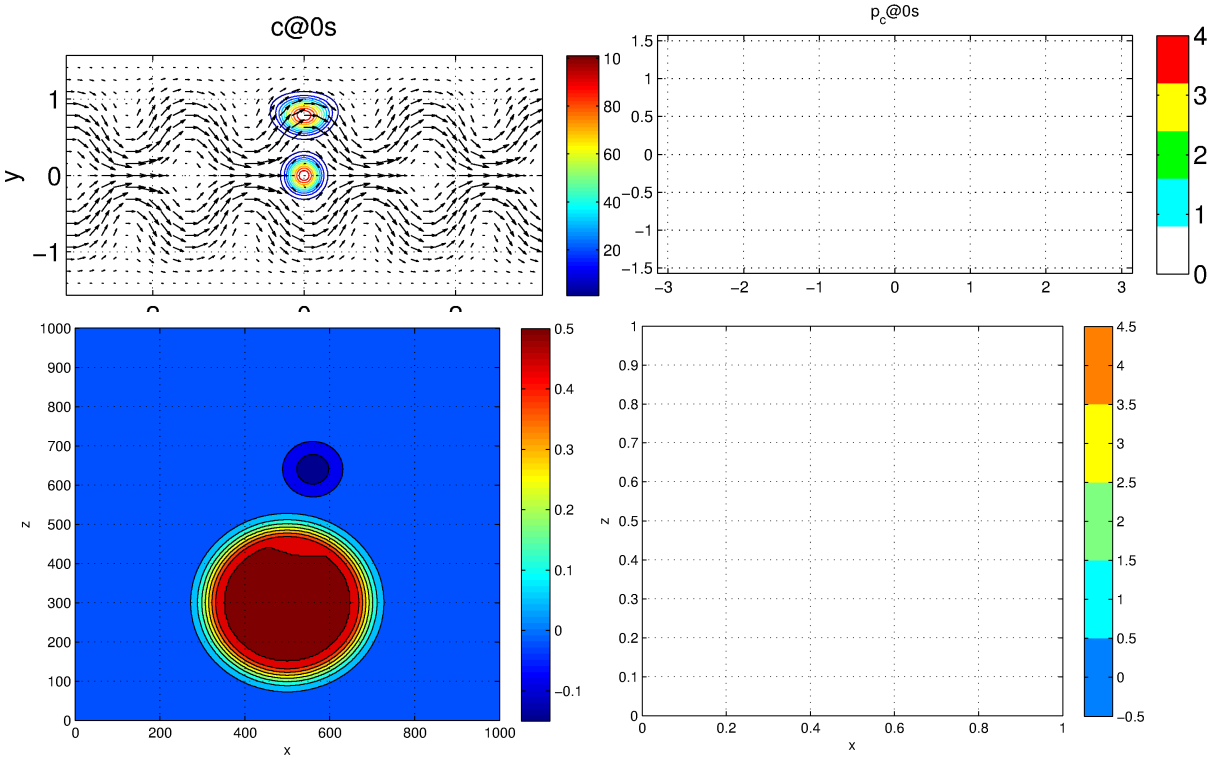
Finite Volume is order 0 DG, need high resolution

Different colors for different control volumes

WHY: SL-DG features are well suited for emission/transport pbs

- **DG** combines *high order accuracy* (small numerical diffusion*)* of spectral methods with *locality* (hence *parallel scalability*) of finite volume methods and it adds extra *flexibility* (e.g. optional adaptive order of accuracy)
- **SL** guarantees *unconditional stability (long time-step)*, *many tracers efficiency*

Example: code prototype tracer transport by RH wave (a,b) and by Robert bubble flow (c,d). Tracer concentration (a,c), local polynomial order (b,d)



WHEN: roadmap

1. SL-DG in advective (non-conserving) form coupled with IFS (via Atlas): **in progress**

2. global and local conservation:
   (i) test Eulerian (expansive) flux-form DG **(2023)**
   (ii) develop more efficient flux-form SL-DG **(post COCO2)**

3. Use of IFS terrain following vertical coordinate **(post COCO2)**
   - improved accuracy and efficiency

T3.1c Global IFS inversion developments

Nicholas Bousserez, Luca Cantarello (ECMWF)

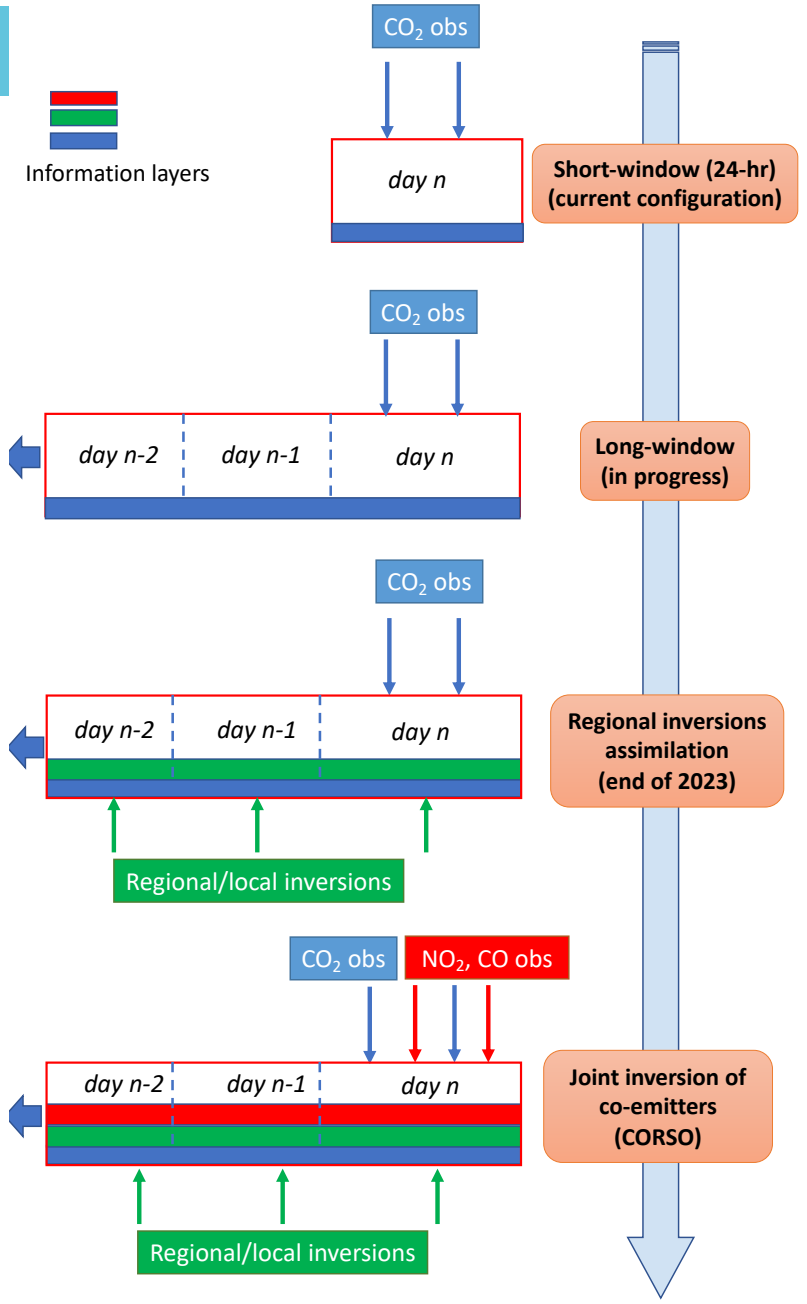
➢ Current status:

- Short-window (24-hr) implemented →inversion of CO_2, CH_4, NO_x, CO fluxes (see WP6)
- Ensemble system for error analysis and OSSE evaluation →CH_4, CO_2 configuration in testing (see WP5)

○ **In progress**: control vector time extension (long-window) with prior temporal correlations

○ **Next steps (2023-):**

- Implementation of cross-windows flux/3D state correlations (long-window) in OOPS system
- Implementation of cross-species (CO_2, NO_X, CO) prior flux correlations for additional observational constraints (**CORSO**)

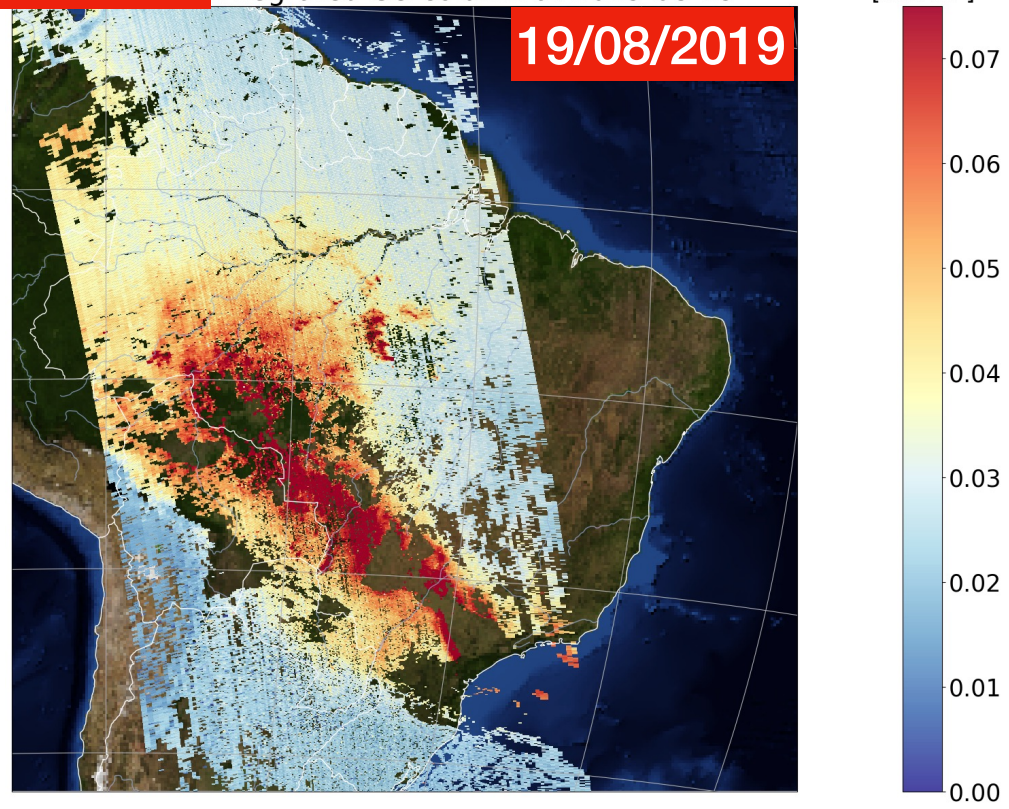


Methods & Goals

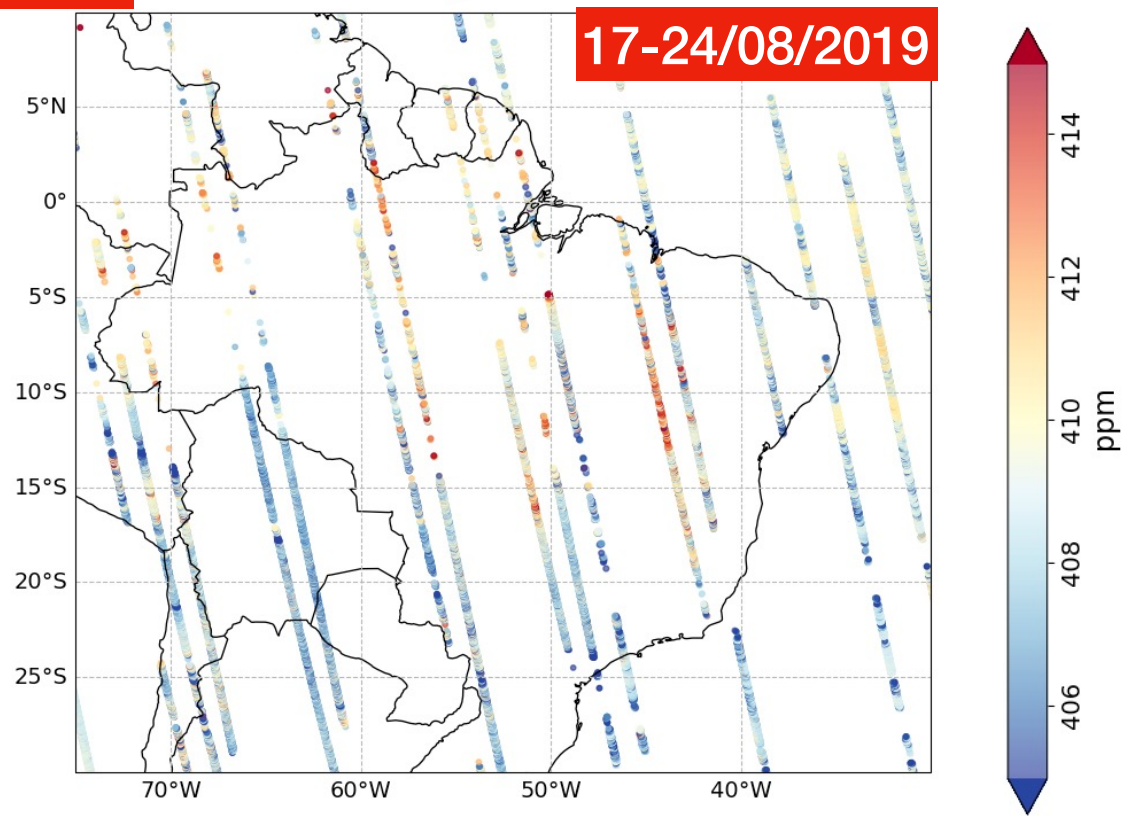
- Select 2 cases suited to test multi-species data assimilation including satellite observations
- Perform a range of assimilation experiments focusing on window-length, covariance structure (T3.4c), linearity/complexity of CO/NO_2 chemistry (T3.4b), and point-source representation (T3.4a)
- Give to IFS prototype of long-window system (T3.1c)
  - (a) ensemble members from experiment with best constraints
  - (b) “best practice” advice for design of statevector + covariance(s)

Case 1: Deforestation emissions in Amazonia

TropOMI S5P integrated CO column at 2019-08-19

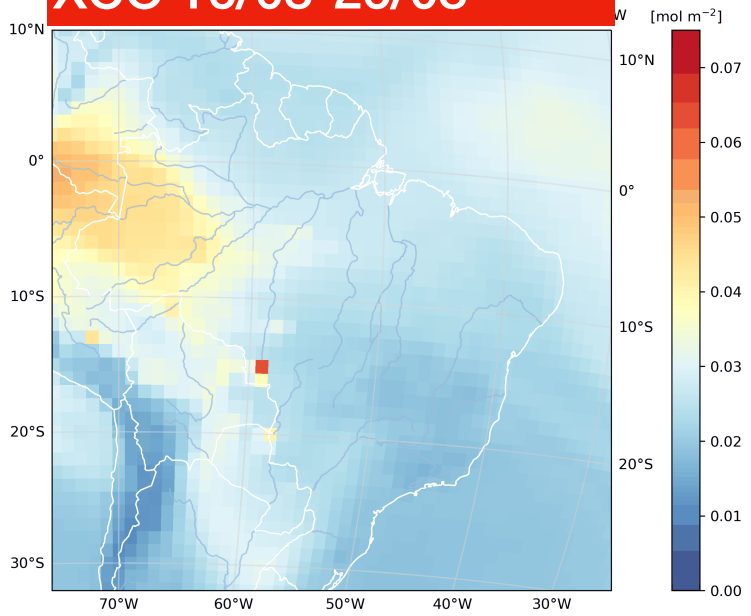


OCO-2

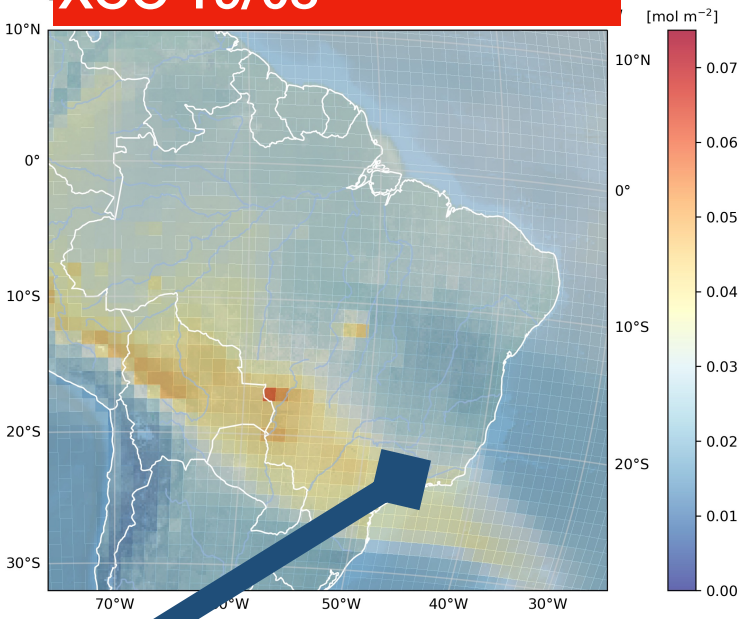


Case 1: Deforestation emissions in Amazonia

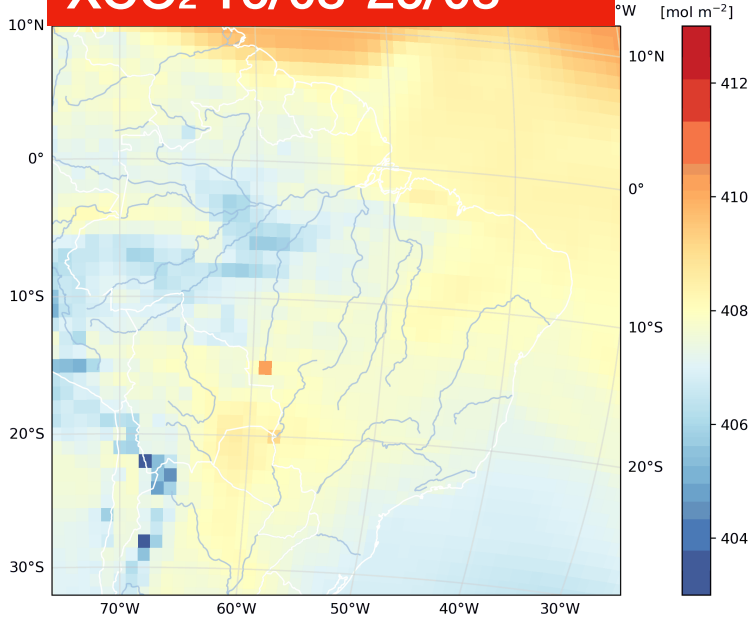
XCO 16/08-26/08



XCO 19/08

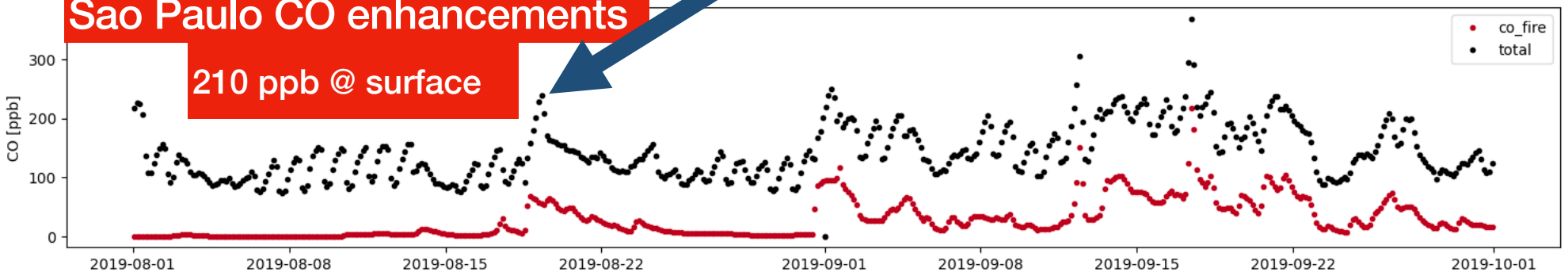


XCO_2 16/08-26/08



Sao Paulo CO enhancements

210 ppb @ surface



Anne-Wil van den Berg

Work Package 3

Progress and *Challenges*

WP3 has a large number of tasks, some very complex, and multiple of them requiring input from other WPs or exchange across tasks. This causes accumulation of delays especially for the year-3 “integration” goals

Delays have occurred nearly everywhere, from late starts, shortage of personnel, supercomputer changes, move of ECMWF, over-optimistic planning, technical issues, etc. Our assessment:

- Task 3.1 (global DA design) shows much innovations but also is complex and needs iterations. *How will we benchmark the system or measure progress on anthropogenic emission estimation?*
- Task 3.2 (fossil fuel model) has slowed/stopped after initial nice work on the residential heating T-model. *How will we now move to FFDAS and how will we build forecasting capacity?*
- Task 3.3 is progressing nicely but its (logical) GPP focus makes bridge to atmosphere long (GPP != NEE != NEP). *How will the 30-50% non-respiratory CO_2 fluxes be incorporated? Will we need carbon pools?*
- Task 3.4 (multi-species) is behind planning and lags behind T3.1c. *How will the variability of emission factors be handled once multiple species are coupled?*

The next year will be busy and lots of decisions to be made on the prototype design. Community input needed, through much interaction

Summary

- Delays due to move of ECMWF supercomputer to Bologna, recruitment delays and staff leaving.
- Heating degree day model (MEHNDI) will work on urban tile of the IFS model in near-real time. Preliminary evaluation with TCCON data and eddy covariance data shows positive impact. Model needs to be implemented in the IFS so that it can run online.
- New LAI and land cover mapping first evaluation completed (D3.3) . Evaluation will be re-done with FLUXCOM2. Ongoing work to assimilate VOD to estimate LAI and soil moisture is ongoing. The impact on GPP will be evaluated using FLUXCOM2. Other independent GPP products based on PAR, atmospheric CO2 inversion and SIF will also be provided for intercomparison.
- A first version of the CoCO2 nature runs using the CAMS CY48R1 configuration for 2018 and 2021 is under production. Estimated to finish end of December 2022. A second version using WP2 fluxes is being tested (expected end of 2023 Q1).
- Transport model developments in the iFS are ongoing with revision of mass fixer and work towards mass conserving advection schemes using Discontinuous Galerkin methods.
- Inversion system has been implemented in the IFS to work for CO2, CH4, co-emitted and other reactive species with a 24-hour assimilation window. Work to extend the DA long-window is ongoing.

Progress on deliverables and milestones

T3.1 Forward modelling and data assimilation developments for operational global prototype (Lead: ECMWF, M1-M36)

- D3.1 Progress on developing the global transport model, data assimilation, and preliminary demonstration of MVS capacity (Lead: ECMWF, M12 R, PU)
- MS6 Evaluation of fossil fuel emissions provided by WP2 (Lead: ECMWF/FORTH, M20) **Delay to M24 ->** DHS Bologna move, issues with sectors in the global CAMS+DACCIWA emissions and new plan to use EDGARv7 for 2018 and 2021.
- MS7 Completion of first global nature runs ~~and global ensemble runs~~ for OSSEs (Lead: ECMWF, **M24**, R, PU) -> Plan to work on low resolution tests in November and start production of high-resolution simulations in December.

T3.2 Fossil fuel emission modelling and parameter estimation (Lead: ECMWF, M1-M36)

- D3.2 Recommendations on anthropogenic CO_2 emission modelling, evaluation, and optimization (Lead: ECMWF, M33, R, PU)

Progress with evaluation of residential heating model using urban EC observations (FORTH, ECMWF) and preliminary discussion with Marko Scholze and Marc Guevara (WP2, T2.4) on the improvement of point sources representation in the IFS.

T3.3 Community land-surface modelling for vegetation carbon exchange fluxes: "ecland" (Lead: ECMWF/ULUND, M1-M36)

- M3.1: Workshop on ecland model and planned developments (Lead: ECMWF, M9-12, @ECMWF, All T2.3 partners)
- D3.3: Validation of online global vegetation carbon fluxes in ecland for prototype modelling developments (Lead: FC.ID, M18, R, PU).
- D3.4 Demonstrator systems for using remote sensing data (LAI, VOD, SIF) in online global prior fluxes for the MVS prototype (Lead: Meteo France, M30, P , PU). Meeting arrange on 8 Nov to discuss progress.

T3.4 Multi-species global modelling and data assimilation (Lead: WU, M1-M36)

- D3.5 Demonstration of multi-tracer capability for 2021 (Lead: WU, M36, P, PU)