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Horizon 2020 Societal challenge 5:
Climate action, environment, resource
efficiency and raw materials

VERIFY

Observation-based system for monitoring and verification of greenhouse gases

GA number 776810, RIA

Deliverable number (relative in WP)	**D3.11**
Deliverable name:	First Complete NEE inversions
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Changes with respect to the DoA
None.
Dissemination and uptake **(Who will/could use this deliverable, within the project or outside the project?)**
The inversion results are freely available (with password protection, available from the PI). The results include a priori fluxes (used as initial guess) and posterior fluxes (optimized using atmospheric observations) to be used in the synthesis product in WP5. The web-page for data download is listed in section 3.
Short Summary of results (<250 words)
Biosphere-atmosphere exchange of CO_2 and its interaction with climate drivers is an important player in the carbon cycle. To estimate net ecosystem exchange (NEE) fluxes, VERIFY includes both, biospheric models for bottom-up estimation of fluxes, and a regional inversion for a top-down estimation. **The Jena CarboScope-Regional (CSR) inversion system has been deployed for the 2006-2018 period to estimate biosphere-atmosphere exchange fluxes from the top-down perspective, using recent atmospheric observations up to 2018. This deliverable provides details about the inversion. The results include a priori fluxes (used as initial guess) from the diagnostic light use efficiency model VPRM, and posterior fluxes from the CSR inversion.**
Evidence of accomplishment **(report, manuscript, web-link, other)**
All the simulation results are accessible though the dedicated data THREDDS server: **https://verifydb.lsce.ipsl.fr/thredds/catalog/verify/WP3/catalog.html**

Version	Date	Description	Author (Organisation)
V0	11/07/2019	Creation/Writing	Christoph Gerbig (MPI-BGC)
V1	15/07/2019	Writing/Formatting/Delivery	Christoph Gerbig (MPI-BGC) Philippe Peylin (CEA)
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1. Glossary

Abbreviation / Acronym	Description/meaning
CSR	Jena CarboScope-Regional inversion system
IAV	interannual variations
LBC	lateral boundary conditions
NEE	net ecosystem exchange
VPRM	Vegetation Photosynthesis and Respiration Model

2. Introduction

This report describes the NEE inversions for the year 2018 using the Jena CarboScope-Regional (CSR) inversion system. The CSR system uses the combination of the regional transport model STILT (Stochastic Time Inverted Lagrangian Transport) and the global TM3 model. Surface-atmosphere fluxes are estimated from atmospheric observations of CO2 mole fractions using the two-step scheme (Rödenbeck et al., 2009), consisting of a global inversion to provide lateral tracer transport to the regional domain, followed by a regional inversion.

Given that this is the first time that top-down constrained biosphere-atmosphere fluxes have been produced that cover such a recent period (up to the end of last year), many things had to be optimized such that the results can be obtained as soon as the observations become available. This made it impossible to implement at the same time some other features, such as the use of a priori biosphere-atmosphere exchange fluxes from the various bottom-up estimates produced within WP3 (which just became available), or the use of anthropogenic emission data from WP2. These elements will be implemented within the upcoming year.

A further shortcoming is the fact that for 2018 the observations used for the global inversions have not been available in time for this deliverable, such that the regional inversion had to be set up using a different input for lateral tracer transport (in the following referred to as lateral boundary condition or LBC) than that provided in the two-step inversion scheme by TM3. Thus for timely provision of 2018 inversion results the CAMS CO2 forecasts (experiment gqpe) were used. A sensitivity experiment was undertaken to assess the impact of this choice in comparison to the standard CSR inversion.

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3. Setup

3.1. Regional transport model

The regional transport model STILT (Stochastic Time Inverted Lagrangian Transport) driven by ECMWF meteorological fields from short-term forecasts from the IFS at 3-hourly and 0.2°x0.2° spatial resolution was used to pre-compute footprints for every atmospheric observing site at hourly resolution. STILT includes turbulent transport as well as vertical transport through convective clouds. Backward transport was simulated for 10 days, giving ample time for the regional domain to be flushed by advection. The temporal resolution of each footprints was also one hour, sufficient to fully resolve the coupling between transport and fluxes. The spatial resolution of the footprints is at 0.25° x 0.25°.

3.2. Spatial domain and state space

The CarboScope-Regional inversion system was set up for a European domain covering 33N - 73N in latitude and 15W – 35E in longitude. The full inversion period covers the years 2006 – 2018. The spatial resolution is 0.25° x 0.25°, and the temporal resolution is hourly for the coupling between fluxes and transport.

The state space (or control vector), i.e. the variables optimized within the inversion, are additive flux corrections to prior fluxes at a spatial resolution of 0.5° x 0.5° and a temporal resolution of three hours. A prior error structure was chosen following Kountouris et al. (2018), inversion code "BVR", using a prior uncertainty at annual and domain-wide scale of 0.3 C GtC/yr, and a bias term following the spatial shape of respiration fluxes. Apart from the bias term the prior uncertainty uses spatial correlations with a length-scale of 100 km and temporal correlations with a time scale of 1 month.

3.3. A priori fluxes

3.3.1. Biosphere-atmosphere exchange

CarboScope-Regional uses biogenic prior CO_2 fluxes derived from the Vegetation Photosynthesis and Respiration Model, VPRM (Mahadevan et al., 2008). This diagnostic model uses ECMWF (European Centre for Medium-Range Weather Forecasts) operational meteorological data for radiation (downward shortwave radiative flux) and temperatures (T2m), the SYNMAP land cover classification (Jung et al., 2006), and EVI (enhanced vegetation index) and LSWI (land surface water index) derived from MODIS surface reflectance products. Model parameters were optimized for Europe using eddy covariance measurements made during 2007 from 47 sites

(Kountouris et al., 2015). VPRM NEE fluxes have been produced at a 0.25 degree spatial and hourly temporally resolution.

3.3.2. Fossil fuel emissions

Anthropogenic emissions from fossil fuel combustion are not optimized in the inversion, but are prescribed in the inversion and treated as fixed boundary conditions. They are taken from EDGARv4.3 fuel type and category specific emissions provided by Greet Janssens-Maenhout (EU-JRC), combined with information on national totals from fuel consumption data in recent years as compiled in the BP statistics 2018 (BP 2019), following the COFFEE approach (Steinbach et al., 2011). This way diurnal, day of week, and seasonal variations from TNO as well as interannual variations from BP are included, providing hourly fluxes at the 0.25 degree resolution.

3.3.3. Ocean fluxes

Ocean fluxes in CarboScope-Regional are taken from Mikaloff-Flechter et al. (2007). Since the spatial domain in this project does not contain large areas covered with ocean, ocean fluxes are not adjusted in the inversion but are instead prescribed. This is, apart from the larger domain, the only difference between the CSR setup in this project and that described in Kounouris et al. (2018).

3.4. Atmospheric observations

Atmospheric observations for the 2017-2018 inversion were taken from the dataset collected through the 2018 drought initiative and provided by M. Ramonet (LSCE) on June 6, 2019. This includes ICOS and pre-ICOS data, and data from a total of 46 stations within the CSR domain were used. Of these, 22 are tall towers, nine coastal stations, eight mountain sites, six short towers or near-surface continental sites, and one station classified as in a urban neighborhood. For tall towers, near-surface or coastal stations, 11:00-16:00 UTC observations (referring to the beginning of the observational hour) where used, while for mountain stations the observations from 23:00-04:00 UTC were used.

For the 2006-2017 inversion a set of 41 stations was used. These data were provided through EUROCOM (33 stations), augmented with stations provided from ICOS CP and ICOS-D.

A model-data mismatch was assumed to be 1.5 ppm for tall towers, coastal and mountain sites, 2.0 ppm for ground based continental sites, and 4.0 ppm for stations in an urban neighborhood. These refer to uncertainties for weekly averages; for hourly data an error inflation was applied, for example in the case of tall towers the 1.5 ppm mistmatch was inflated by the square root of the number of observations per week (42), resulting in 9.7 ppm for hourly data.

3.5. Lateral boundary condition

Given the late availability of atmospheric CO_2 data needed for the global inversion, a prerequisite for using the two-step scheme, lateral boundary conditions (LBC) were used from CAMS CO_2 forecasts (experiment gqpe) for the year 2018. For the 2006-2017 time period the CSR standard inversion was used, where contributions from outside of the domain are provided through the two-step inversion.
Furthermore for 2017 both CAMS LBC and the CSR standard inversion LBC were used in two inversion runs for a comparison.

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4. Results

4.1. NEE for 2018 in context of the 2006-2017 period

Both posterior NEE (Fig. 4.1.1) and prior NEE (Fig. 4.1.2) fluxes show a larger biospheric sink for 2018 as compared to 2017. Slightly less update in 2018 compared to 2017 is found for southern Sweden, Czech Republic, parts of Germany and France.

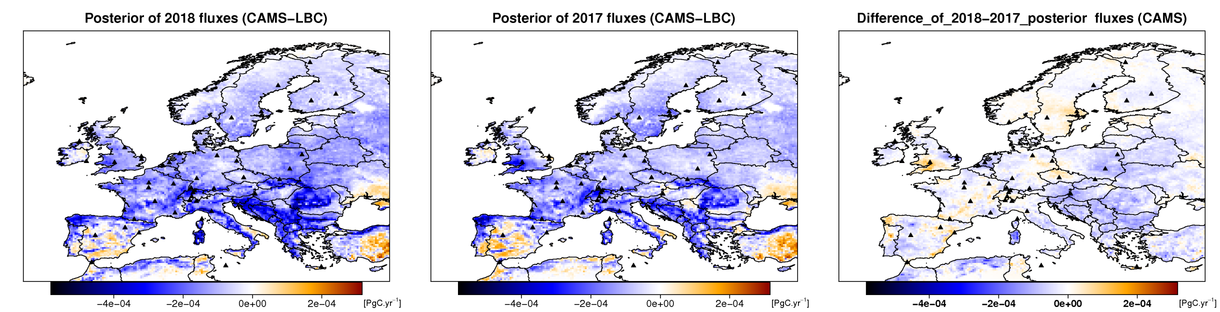

Figure 4.1.1: Annually integrated posterior NEE for 2018 (left) and 2017 (middle) as well as the difference between 2018 and 2017 posterior NEE (right). Black triangles indicate the atmospheric observing stations used in the inversion.

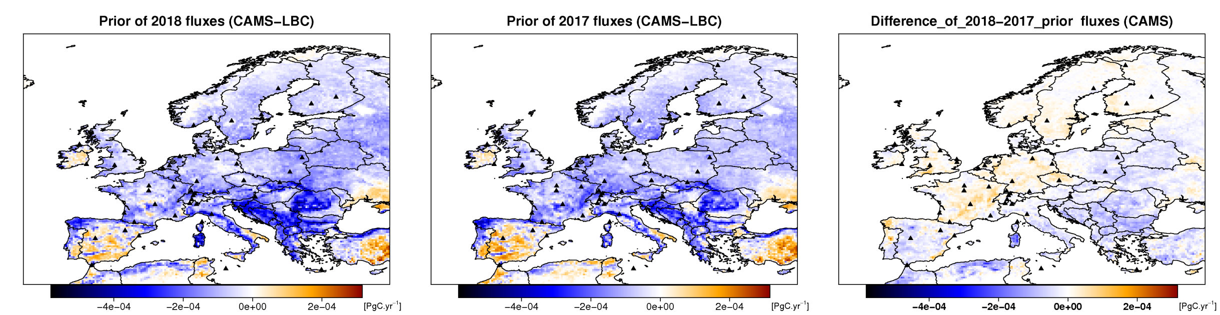

Figure 4.1.2: Same as Fig. 3.1.1 but for a priori NEE

In order to put the year 2018 in context of a longer time period, results from the 2006-2017 CSR inversion using the two-step scheme are also shown. Details for different regions as well as the corresponding prior and posterior uncertainties can be found in Fig. 4.2.3, together with the 2017-2018 inversion results using the CAMS lateral boundary condition. It is obvious that when using CAMS, the inversion estimates a significantly larger biospheric uptake. For the year 2017, for example, annual and domain wide integrated NEE was estimated at -1.11 PgC/yr when using CAMS LBC, while the standard inversion estimates -0.46 PgC/yr. Note that due to the inversion setting BVR the long-term bias component has additional uncertainty, causing the estimated flux for a given year to depend on the time period chosen for the inversion. Therefore additional

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test simulations comparing the inversion with CAMS LBC with the standard inversion for a single year (2017) have been performed and are presented in section 4.2.1.

It is also obvious that the interannual variations seen in the posterior fluxes from the 2006-2017 inversion follows relatively closely those of the prior fluxes. An additional test was done for this, presented in section 4.2.2.

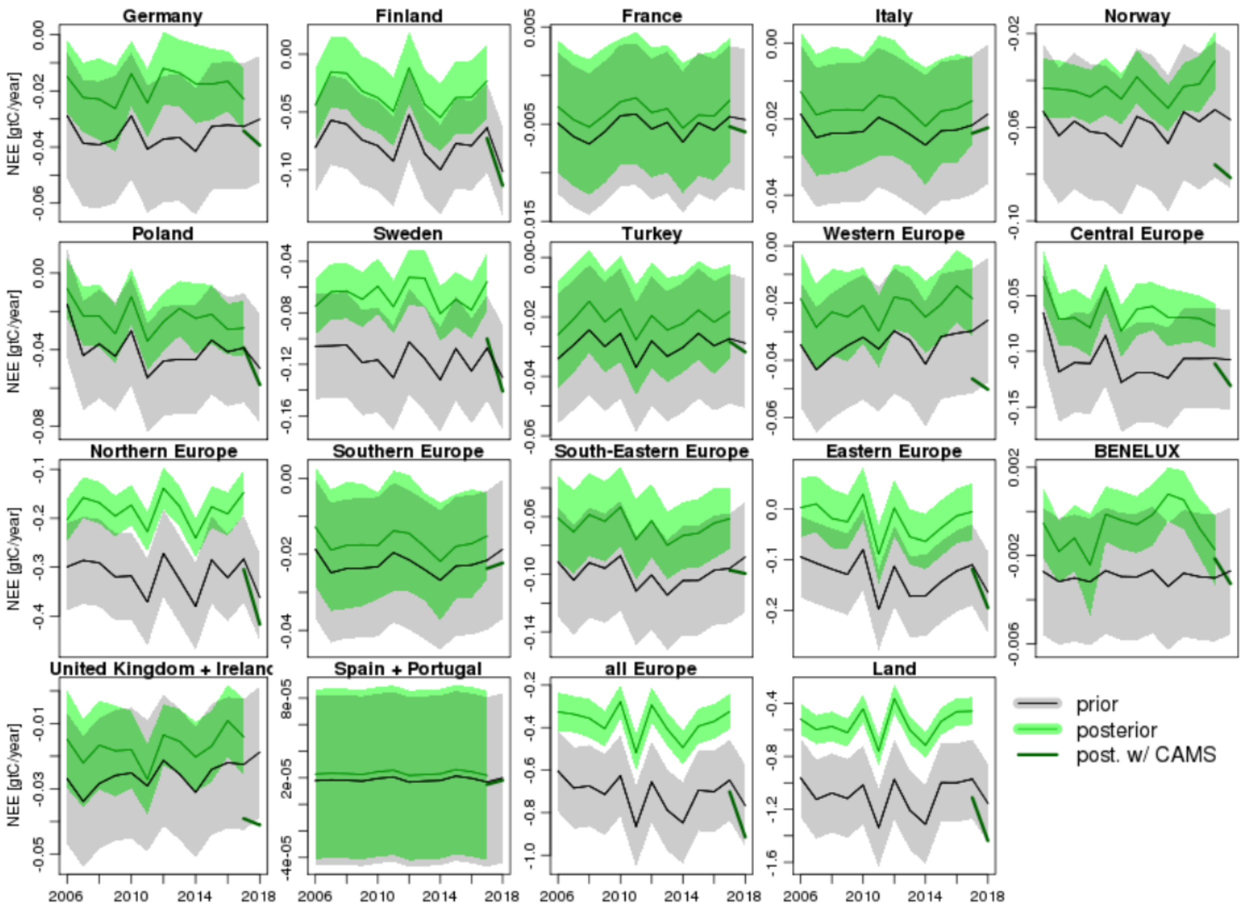

Figure 4.1.3. Annual NEE for the period 2006 – 2018 for different countries and partial domains using the EUROCOM region specifications. Prior fluxes are shown in black, with grey bands showing the prior uncertainty, and posterior fluxes are in green, with light green bands indicating posterior uncertainties. For 2017 and 2018 the posterior fluxes from the inversion using CAMS lateral boundary condition is shown in dark green.

4.2. Sensitivity runs

4.2.1. LBC test

A test run was set up to assess if using CAMS as lateral boundary condition (LBC) results in different posterior fluxes compared to those from the standard inversion using the two-step scheme with a global inversion providing the CO_2 contribution from outside of the domain. In this test inversions for the year 2017 were made, as that is the most recent year with global inversion data available.

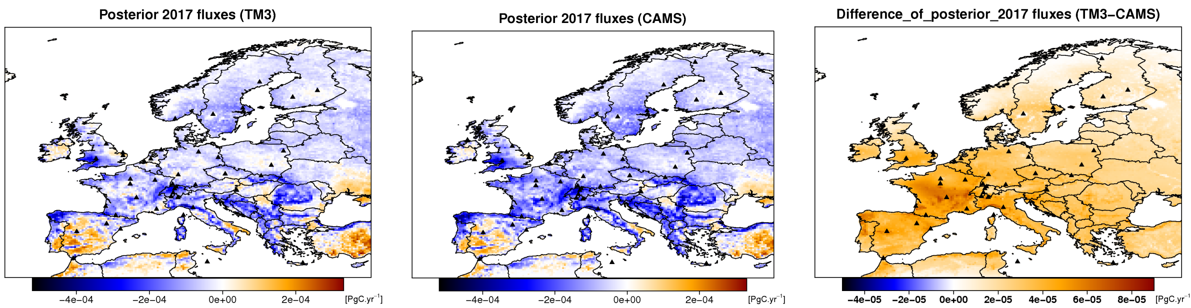

Figure 4.2.1.1: Posterior biosphere-atmosphere exchange fluxes for 2017 from the standard inversion (left), from an inversion using CAMS lateral boundary conditions (middle), and the difference of the two (right). Note the different color scale for the plot on the right.

It is obvious that the inversion using CAMS results in much stronger biospheric uptake fluxes as can be seen from Fig. 4.2.1.1. The annually and domain integrated NEE for 2017 in this case was estimated to be -0.97 PgC/yr, while the standard inversion results in -0.61 PgC/yr for the same year. The difference between the two inversions (Fig. 4.2.1.1, right) shows a gradient from west to east, indicating a too high CO_2 lateral boundary condition in the CAMS case.

4.2.2. IAV test

To assess if interannual variations in posterior fluxes are dominated by interannual variations (IAV) in prior fluxes, an inversion was setup to use specifically filtered prior fluxes without IAV for the time period 2011 - 2014. Results in Fig. 4.2.1.1 show that posterior fluxes exhibit IAV that show a similar behavior as those from the standard inversion, however the magnitude of those variations is reduced by about a factor 2, and the mean flux averaged over the full time period is higher by about 0.3 PgC/yr. This confirms that the top-down constraint on interannual flux variations from the atmosphere is certainly present and in line with interannual variations in prior fluxes, albeit with lower amplitude.

This observed domination of posterior IAV by the a-priori IAV is related to the inversion setup (BVR in Kountouris 2018), which uses a bias term to increase prior uncertainty. This additional flexibility in the inversion causes a lot of the mismatch between a-priori modeled atmospheric CO_2 and observed CO_2 to be put into this bias term.

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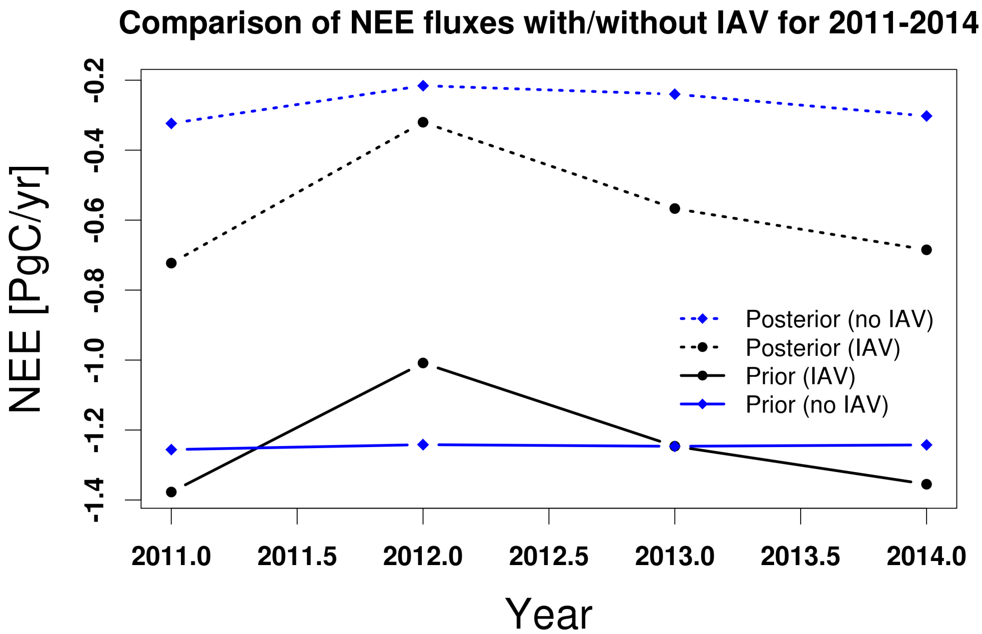

Figure 4.2.2.1: Annual and domain-wide integrated NEE for 2011-2014 from a-priori VPRM (black solid line), from a-priori filtered to remove interannual variations (blue solid line, “no IAV”), from posterior fluxes (black dotted line), and from posterior fluxes using prior fluxes without interannual variations (blue dotted line, “no IAV”).

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5. Conclusions

Inversion results for 2018 NEE fluxes for the European domain have been obtained using the Jena CarboScope-Regional inversion framework, and put into the context of NEE in the 2006-2011 time frame. Due to the required early provision of inversion results for 2018, the lateral boundary condition for CO_2 could not be taken from the global TM3 inversion as done in the standard CSR setup, but had to be taken from CAMS CO_2 forecasts. This led to a large difference in posterior NEE fluxes, with much larger uptake especially in the western part of the domain. The reason is that the CAMS CO_2 forecasts are biased, which is obvious from Figure 3.3.1.

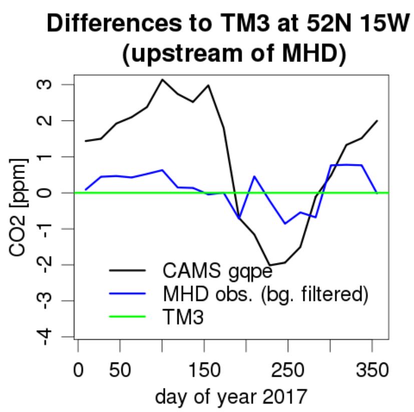

Fig 3.2.2.1. Differences of CO2 mole fractions extracted from CAMS (experiment gqpe) to CO2 extracted from TM3 analyzed fields at a location directly west of Mace Head (MHD) at the domain boundary. Also shown are CO2 mole fractions observed at MHD during background conditions. All data are averaged over 18.25 days (1/20 of a year).

Therefore an update of the inversion is lined up as soon as the global inversion with the Jena CarboScope system is available. A further reason for an update is related to the weakness in the inversion capturing interannual variations (section 3.2.2). For this the inversion setup “nBVH” from Kountouris et al. (2018) will be implemented. This setup uses hyperbolic rather than exponentially decaying spatial correlation for prior uncertainties, which makes the use of additional flexibility in a long-term bias term unnecessary. This also means that inversion results for a specific year do not depend on the inversion time period.

The update will likely be available by mid August 2019, and will cover the 2006-2018 period with a single consistent setup.

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