Project: **bm1400**
Project title: **Integriertes Treibhausgase-Monitoringsystem für Deutschland (ITMS)**
Principal investigator: **Dr. habil. Christoph Gerbig**
Reporting period: **2025-11-01 to 2026-10-31**

1. Achievements during the reporting period

Achievements during the previous HLRE allocation include:

Module M:

- **CSR + STILT (0.25 x 0.25 degrees):** Biogenic CO_2 flux estimates are calculated using CSR with STILT (0.25 x 0.25 degrees) over the domain of Europe for 2006-2025. The spatial distributions of 2025 flux estimates show that the European domain is a weaker sink of CO_2 than suggested by the prior biosphere model FLUXCOM–XVIRRS (Figure 1). The inversion estimates are optimised against atmospheric observations collected from 58 in-situ atmospheric stations (ICOS and non-ICOS) distributed across Europe. In addition, the CSR system has also been used to perform a joint CH_4 and Radon (Rn) inversion for 2020-2024. This dual-tracer inversion exploits the fact that the transport model error between these two gases is correlated. Figure 2 illustrates how the additional Rn information affects the CH_4 flux estimates in Europe.

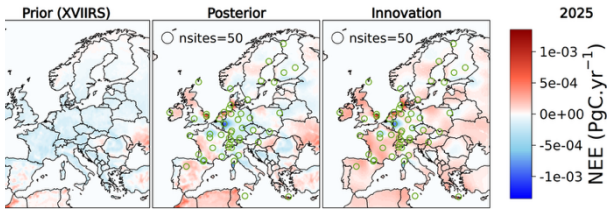


Figure 1. *Prior CO_2 fluxes calculated with the biosphere model FLUXCOM with XVIIRS version (left), posterior fluxes estimated using CSR (middle), Innovation of fluxes (posterior – prior, right).*

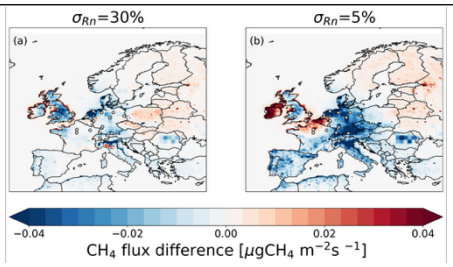


Figure 2. *Impact of the Rn information on the CH_4 flux estimates. Shown is the CH_4 flux difference between the CH_4-Rn and CH_4-only inversions, assuming Rn prior flux uncertainties σRn of (a) 30% and (b) unrealistically low 5% for the annual total flux of Germany. Bluish colours indicate that the Rn information corrects the CH_4 flux estimates*

- **ICON-ART - CTDAS (R3B08, ~6.5 km resolution):** ICON-ART–CTDAS inversions using TROPOMI WFMD XCH4 data have improved through background optimization and frequent re-initializations. Multi-cycle inversions are being developed to mitigate extreme scaling factors.
In parallel, ICON-ART nesting was explored for high-resolution GHG simulations in synergy with the CoMet 2.0 aircraft campaign over Canada. Three nested domains were implemented over the Mackenzie River Delta (Figure 3). D04 remains under development due to computational costs, pending evaluation of D03. This setup will support transport evaluation and future CTDAS assimilation of aircraft measurements alongside satellite data for high-resolution point-source emission estimates.

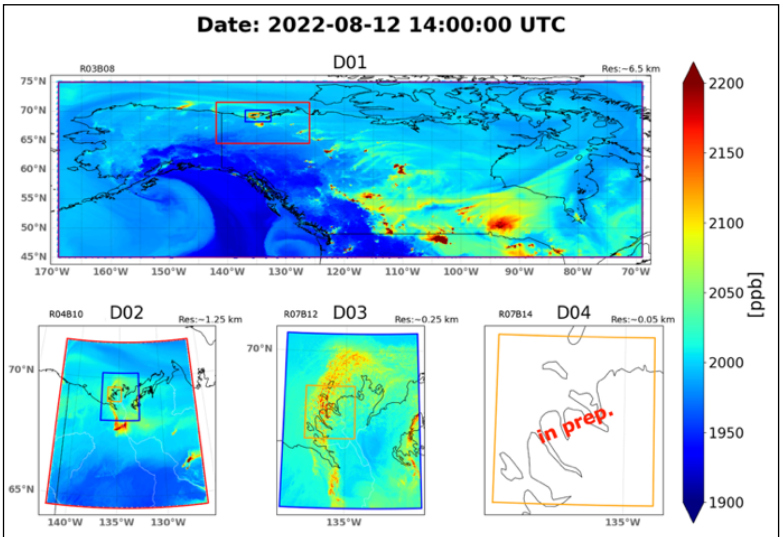


Figure 3. *Snapshot of the CH4 forward simulation on August 12th 2022, at 14UTC using ICON-ART with nesting domains focusing on the Mackenzie River Delta in Canada. From D01 to D04 the spatial resolution ranging from 6.5 km, 1.25 km, 0.25 km and 0.05 km.*

- **ICON-ART OH chemistry and lifetime:** A set of global ICON-ART forward simulations has been carried out in the global R02B06 setup to compare the new super-simplified OH (SSOH) chemistry against the more sophisticated simplified OH chemistry and the much simpler lifetime approach. These show that the SSOH chemistry achieves the same computational performance as the lifetime approach and thus has a massive speed advantage compared to the simplified OH chemistry. At the same time, SSOH provides OH fields and methane depletion rates comparable to more complex simplified OH chemistry and much more sophisticated than the lifetime approach. The LAM simulations will be carried out shortly, still within this allocation period. On top of that, a set of model transport tests (the so-called terminator toy chemistry) has been carried out to estimate intrinsic model transport error. Several transport schemes and parameters have been analyzed and compared in short test runs to find an optimal setup for the ICON forward model.

- **WRF-CHEM (1km resolution):** We have analysed the sensitivity studies of WRF-Chem runs. We showed that the choice of urban canopy and planetary boundary layer schemes has the largest impact on model performance, while station-specific characteristics also strongly influence the outcome. We have additionally identified the best overall configuration of physics schemes for urban areas, which we now use for follow-up studies, e.g. analysing aircraft campaign data over urban areas to quantify the emissions. Pilz et al. 2025.

- **Comparison of inversion results:** Module M produces inversion results from different groups and inversion systems. A centralized storage, comparison, and visualization of these results has been started on Levante, using the fluxy tool and the corresponding data format (Figure 4). The easily accessible comparison has proven highly valuable for the cooperation within the module.

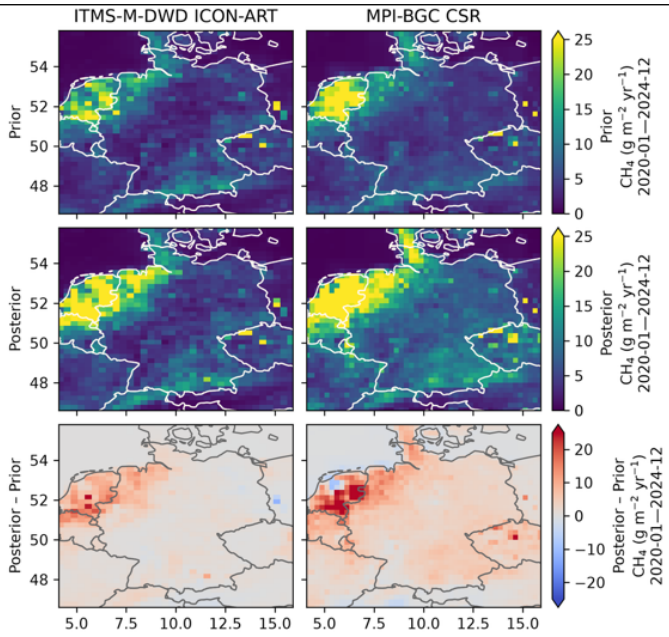


Figure 4. *Comparison of inverse model results for CH_4 from MPI-BGC's CSR (right) and DWD's ICON-ART-based inversion (left) using DKRZ's JupyterHub showing the prior emissions (top), posterior (center row), and innovation (bottom) averaged over five years (2020-2024). This exemplifies how different research groups within ITMS-M collect their results on Levante and visualize the data using the Fluxie tool.*

Module Q&S:

- **LandscapeDNDC (KIT IMK-IFU):**
Agriculture*:* We have run model calibrations of N_2O emissions from German agricultural soils and used this to perform national-scale simulations with a full uncertainty analysis (~2000 node hours). As compared to the year 2025, the calibration procedure has been improved by adding additional calibration sites and improving the algorithm used to compare modelled and observed N_2O emissions. The national-scale simulations have benefited from the improved calibration and also from improved input data (e.g., for fertiliser usage). A preprint has been prepared describing this work. We have also worked on modelling changes in the soil carbon storage, which relates directly to the net CO_2 exchange. This involves both model calibration (~1700 node hours) and national simulations (~2700 node hours), and we have shown that German croplands are a net source of CO_2 emissions, with the highest losses in the North West of Germany. We have also calibrated the crop growth processes based on multi-decade, district-level crop yield data for Germany, especially in relation to heat and drought stress (~1400 node hours). Correctly simulating crop yields is crucial for accurate simulations of the C and N cycle, and therefore a precondition for trustworthy simulations of the greenhouse gas exchange. We have also rerun simulations of soil radon emissions with additional years and taking into account improvements in the national-scale modelling system (~100 node hours).
Forest: A national-scale system for forest modelling that is able to simulate CO_2 exchange with the atmosphere and N_2O emissions has now been fully developed and is ready for deployment on Levante in 2027 (Figure 5).

- **FLUXCOM-X:** Our allocated computing resources were not used because they were insufficient for the full ensemble, which was therefore run on computing resources outside ITMS.

Module B:

- A database of Sentinel-2 surface reflectance data for the years 2018 to 2025 was created for the bands in the near- and shortwave-infrared, which are usually used for greenhouse gas retrievals from satellites. This enables the investigation of a bias, which was theoretically confirmed by Weimer et al., 2026. A first analysis of ACOS v11 OCO-3 data shows that the bias connected to this error can be seen in real satellite data (Figure 6).

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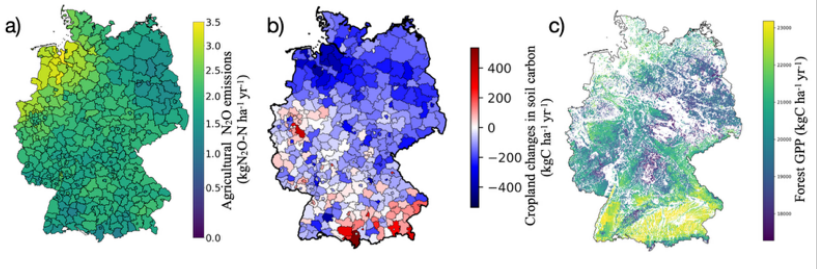


Figure 5. *LandscapeDNDC (LDNDC) estimates of a) N_2O emissions from agricultural soils, b) changes in cropland soil organic carbon and c) gross primary productivity (GPP) of forests.*

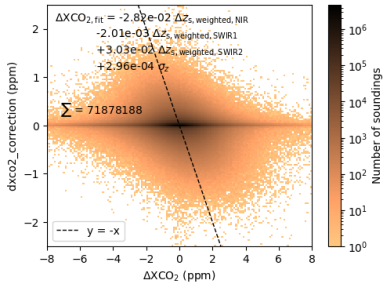


Figure 6. Preliminary analysis of the complete OCO-3 ACOS v11 dataset. An anti-correlation with the albedo-weighted surface altitudes using the albedo database calculated with resources at DKRZ can be seen

2. Justification for 2026 resource underutilization

Due to the character limit, detailed justification for the lower 2026 resource utilisation can be provided upon request.