# Research Project #7

## Exploring trace gas-related climate impacts linked to the agricultural biosphere (ICE-4 & IBG-3)

Biogenic emissions of trace gases have a multitude of environmental impacts, including contributions to climate change, air quality, and stratospheric ozone depletion. At the same time, global change is influencing the scale and variability of such emissions. While the major greenhouse gases (GHGs: $H_2O$, $CO_2$, $CH_4$, $N_2O$) have been studied more intensively in this regard (at least for some plants), many open questions still remain – particularly how GHG fluxes change in a changing climate with more weather extremes (such as longer drought periods, followed by heavy precipitation events (e.g., Zhu et al., 2025). The production of indirect GHGs and ozone-depleting substances (ODSs), the feedback mechanisms they trigger, and their consequential impacts are even less well understood. Gases such as molecular hydrogen ($H_2$) and carbonyl sulfide (COS) are known to be linked to processes that significantly alter the radiative balance of the atmosphere (e.g., Ocko and Hamburg, 2022; Brühl et al., 2012), while biogenic halogenated species such as $CH_3Cl$, $CH_3Br$, or $CHCl_3$ can be transported to the stratosphere where they contribute to the continued depletion of the life-protecting ozone layer (WMO, 2022).

This project aims to combine the expertise of the Institute of Bio- and Geosciences - Agrosphere (IBG-3) and the Institute of Climate and Energy Systems - Stratosphere (ICE-4). IBG-3 has ample expertise in studying plant-soil-atmosphere exchange processes. Of particular relevance here are their measurements of plant, soil and ecosystem fluxes of $H_2O$, $CO_2$, $CH_4$, and $N_2O$. To maximize the process understanding gained from these ongoing measurements, ICE-4 will be developing and carrying out complementary trace gas measurements, with halogenated species, $H_2$, and COS, being the most interesting among the range of gases to be considered. This is an opportunity to obtain valuable extra information on soil processes (e.g., via the $H_2$ soil sink), leaf-based gas exchange (e.g., from COS-$CO_2$ ratio shifts that can be indicative of plant uptake), or potential future ozone layer impacts (e.g., through chloro-/bromocarbon emission changes). Joint measurement activities are planned at IBG-3-maintained long-term field sites (TERENO/ICOS projects) to determine emissions from a range of plants and soil, as well as their spatial and temporal variability. This will be achieved mainly using balloon- and drone-based sensor packages (e.g., Laube et al., 2025) to be developed as part of this project, as well as the concurrent adaptation and optimization of existing measurement systems at both institutes.

In addition, IBG-3 operates the world-class facility AgraSim (https://www.fz-juelich.de/en/ibg/ibg-3/expertise/research-platforms/agrasim) which contains six parallel plant mesocosms that allow to simulate different climate "storylines" under controlled conditions. The project will explore possibilities to use the developed measurement and sampling systems within these mesocosms to determine hitherto unknown potential changes and feedback mechanisms that might impact future climate change and/or agriculture.

The measurements and process understanding generated in this project will ultimately provide valuable information for better quantification of the impact of weather extremes on the trace gas exchange of agricultural ecosystems with the atmosphere.

Key objectives of the proposed PhD project:

- Developing balloon- and drone-based sensor packages primarily focused on the collection of air samples
- Carrying out multiple flights during different seasons with these packages
- Retrieving atmospheric mole fractions, predominantly via lab-based sample analysis techniques, and deriving emission estimates of the trace species
- Quantifying the impact of longer drought periods with subsequent rewetting on soil and ecosystem GHG and other trace gas fluxes
- Extensive comparisons with ongoing long-term measurements of trace species

Tasks to be completed:

- Designing and testing the new airborne packages between late 2026 and late 2027
- Concurrent optimization of the related measurement instrumentation (GC-MS, GC-PDD, optical spectroscopy techniques)
- Flying the new packages predominantly in 2027 and 2028, including subsequent measurements as well as further miniaturization and potential adjustment of the range of target species
- Conducting campaign-based chamber measurements of GHGs and other trace gases during natural drought and rewetting periods
- Comparing the results with those from related previous studies including model-based approaches
- Scientific data interpretation and publication of the findings

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| **Location** of the HITEC Fellow | Forschungszentrum Jülich, Institute of Climate and Energy Systems – Stratosphere (ICE-4), Director: Prof. Dr. Michaela I. Hegglin<br>https://www.fz-juelich.de/en/ice/ice-4 |
| **Partners** of the HITEC Project | Forschungszentrum Jülich, Institute of Bio- and Geosciences - Agrosphere (IBG-3), Directors: Prof. Dr. Jan Vanderborght and Prof. Dr. Wulf Amelung<br>https://www.fz-juelich.de/en/ibg/ibg-3 |
| Specific **requirements** | M.Sc. degree or equivalent in Atmospheric Sciences, Biogeochemistry, Physics, Chemistry or a related field; some experience in meteorology or analytical chemistry would be beneficial |
| For **project specific** questions please **contact** | Dr. Johannes C. Laube, ICE-4, j.laube@fz-juelich.de<br>Prof. Dr. Nicolas Brüggemann, IBG-3, n.brueggemann@fz-juelich.de |


[1] Brühl, C., Lelieveld, J., Crutzen, P. J., and Tost, H.: The role of carbonyl sulphide as a source of stratospheric sulphate aerosol and its impact on climate, Atmos. Chem. Phys., 12, 1239–1253, https://doi.org/10.5194/acp-12-1239-2012, 2012.

[2] Laube, J. C., Schuck, T. J., Baartman, S., Chen, H., Geldenhuys, M., van Heuven, S., Keber, T., Popa, M. E., Tuffnell, E., Voet, F., Vogel, B., Wagenhäuser, T., Zanchetta, A., and Engel, A.: Vertical distribution of halogenated trace gases in the summer Arctic stratosphere based on two independent air sampling methods, Atmos. Meas. Tech., 18, 4087–4102, https://doi.org/10.5194/amt-18-4087-2025, 2025.

[3] Ocko, I. B. and Hamburg, S. P.: Climate consequences of hydrogen emissions, Atmos. Chem. Phys., 22, 9349–9368, https://doi.org/10.5194/acp-22-9349-2022, 2022.

[4] WMO (World Meteorological Organization): Scientific Assessment of Ozone Depletion: 2022, WMO, Geneva, GAW Report No. 278, 509 pp., ISBN 978-9914-733-97-6, 2022.

[5] Zhu, G. et al.: Nitrous oxide sources, mechanisms and mitigation. Nat. Rev. Earth Environ. 6, 574–592, https://doi.org/10.1038/s43017-025-00707-5, 2025.