Annual report 2022 for Flagship Pilot Study LUCAS

"Land Use & Climate Across Scales" - Impact of land use changes on climate in Europe across spatial and temporal scales

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Background

LUCAS (Land Use and Climate Across Scales) is an initiative on coordinated regional climate model experiments for Europe which includes land use change forcing (Rechid et al., 2017). It was initiated jointly by the European branch of the Coordinated Downscaling Experiments EURO-CORDEX and the global intercomparison study "Land-Use and Climate, IDentification of robust impacts" LUCID; and it had been approved by WCRP CORDEX as a Flagship Pilot Study (FPS). In 2021, RCM modelling groups from Northern America joined as "LUCAS-NA".

Land use changes (LUC) are an important human forcing on climate, especially at the regional to local scale. The direct effects of LUC on local to regional climate can potentially exceed those associated with (downscaled) global mean warming. Up to now, LUC forcing is not accounted for in RCM ensemble climate change projections within CORDEX, while it is at those finer regional scales that they have the strongest impacts. In LUCAS, we implement this important human regional climate forcing into RCMs and investigate its direct biophysical effects on the climate in Europe.

Overall objective

The overall objective of LUCAS is to identify robust biophysical impacts of land use changes on climate across regional to local spatial scales and at various time scales from extreme events to seasonal variations and multi-decadal trends. In this context, land use changes (LUC) refer to anthropogenic land cover conversions as well as land management practises. We identified key science questions to be addressed:

- How sensitive are the regional climate models to LUC and how is this interrelated to land-atmosphere coupling in different regions among the suite of models?
- How large is the relative contribution of LUC compared to other forcings in the detection of the past and potential future climate trends?
- How do land use practices modulate climate variability? Can local LUC reduce or amplify extreme climate conditions?
- What is the effect of spatial resolution on the magnitude and robustness of LUC-induced climate changes?
- What errors do we make on the downscaled climate change if we ignore LUC? This is especially important for subsequent impact studies.

LUCAS experiment strategy

The LUCAS experiment strategy is designed in three phases: In **LUCAS phase 1**, idealized experiments are performed for the European continent in order to investigate and inter-compare model sensitivities to extreme land use change (LUC) forcing. In **LUCAS phase 2,** simulations driven by GCMs and dynamic land use changes are performed for past and future, including LUC forcing based on past re-constructions and future projections. The high-resolution experiments in **LUCAS phase 3** shall be conducted over multiple gridded nests to refine the continental simulations down to resolutions below 5 km, in order to investigate feedbacks of local scale land use dynamics on climate.

Status and progress during the year including scientific highlights, end to end perspective and participants engaged in the project

Multi-model simulations from LUCAS phase 1 idealized experiments had been further used to investigate effects of extreme land use changes in Europe. Simulations from more than 10 different RCM-LSM (Regional Climate Model - Land Surface Model) combinations and configurations are available for the Europe domain: CCLM-TERRA, CCLM-VEG3D, CCLM-CLM4.5, CCLM-CLM5.0, RCA, RegCM-CLM4.5, REMO-iMOVE, WRFa-NoahMP, WRFb-NoahMP, WRFb-CLM4.0, WRFc-NoahMP, and CRCM5-CLASS. In 2022, the simulations using CRCM5-CLASS to run FOREST/GRASS experiments over the Europe domain as well as the North America domain could be finalised. Asselin et al. (2022) successfully published a study on the transferability of the regional response to FOREST/GRASS forcing using CRCM5-CLASS across the different domains Europe and North America, in addition to a detailed multi-model comparison over North America. The data from LUCAS RCM simulations is shared within the LUCAS team via the FPS LUCAS data storage at Jülich Supercomputing Centre, kindly coordinated by Klaus Goergen from Research Centre Jülich. The RCM data is used for LUCAS model intercomparison studies. The FPS LUCAS data "terms of use" define conditions of access and use of the data.

The study "Afforestation impact on soil temperature in regional climate model simulations over Europe" has been published with Geosci. Model Dev. by Sofiadis et al. (2022). Two studies are publised with Cryoshphere: Both investigate the land-atmosphere interactions in sub-polar and alpine climates in the FPS LUCAS models, with Daloz et al. (2022) doing an evaluation of the snow-albedo effect, and Mooney et al. (2022) investigating the impact of land-use changes on snow albedo effects in the FOREST and GRASS simulations.

Further efforts have been put into generating high-resolution Land Use Land Cover Change (LULCC) information for use in RCM experiments for downscaling CMIP6 GCM simulations in Europe. A PFT land cover dataset had been derived from ESA-CCI land cover data, which has been thoroughly evaluated for its use in RCMs (Reinhart et al., 2022a). In 2022, an updated dataset has been generated and published as V1.1 at World Data Center for Climate (WDCC) at DKRZ by Reinhart et al. (2022b), see also figure 1. In this version, the whole time series 1992-2015 is published, at 0.1° (~11km) and 0.018° (~2km) spatial resolution. Minor interpolation issues on coastlines caused by coarse climate data availability are fixed. The quality assessment figures done for LANDMATE PFT V1.0 are not influenced by those minor changes on coastlines.

Starting from the high resolution PFT distribution of 2015, annual land cover maps are generated for the past period 1950-2015 based on Land Use Harmonized Dataset Version 2 LUH2-v2h (Hurtt et al. 2019) land use transitions, and for the future period 2015-2100 based on LUH2-v2f (Hurtt et al. 2019) land use transitions for different SSPs/RCPs, following the LUMIP / CMIP6 protocol. The updated dataset V1.1 has been published at World Data Center for Climate (WDCC) at DKRZ by Hoffmann et al. (2022b,c), and as preprint with Earth Syst. Sci. Data Discuss. (Hoffmann et al., 2022a). The datasets have been evaluated against four available land cover datasets from different sources, and a comprehensive uncertainty analysis was conducted (Hoffmann et al., 2022a). The LUCAS LUC dataset Version 1.1 will be used within the LUCAS FPS as land use change forcing for realistic land use change experiments over Europe, driven by GCM CMIP6 historical simulations 1950-2014 and GCM CMIP6 simulations for SSP126 2015-2100.

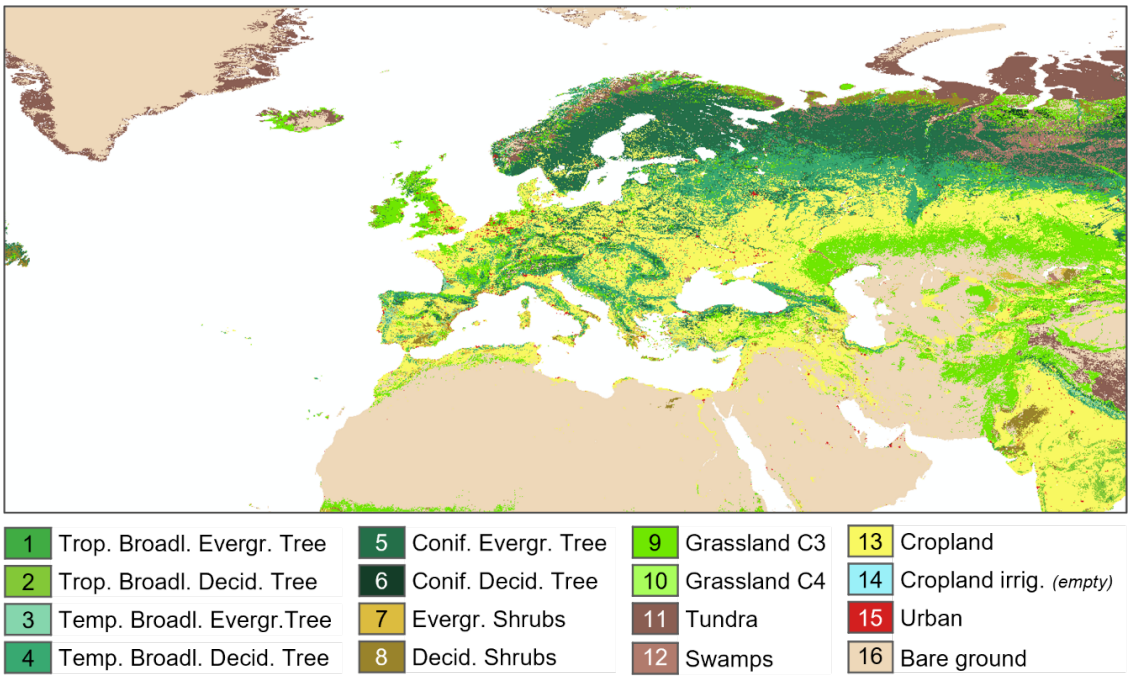

Figure 1: LANDMATE PFT V1.1 for Europe 2015 (Majority PFT per grid cell) *Reinhart, V.; Hoffmann, P.; Rechid, D. (2022). LANDMATE PFT land cover dataset for Europe 1992-2015 (Version 1.1). World Data Center for Climate (WDCC) at DKRZ. https://doi.org/10.26050/WDCC/LM_PFT_EUR_v1.1*

An experiment set up for short term test simulations in preparation to LUCAS experiments phase 2 had been developed. One main purpose was to translate the LUCAS LUC PFT maps into the individual RCM land surface types and to develop a technical workflow to implement the new annual maps during a model simulation. Reports from all participating modelers about any technical and/or scientific issues were collected, and an implementation protocol for LUCAS phase 2 experiments had been derived. Another purpose was to investigate the influence of the new land use/land cover input data on simulated land surface parameters such as roughness length, leaf area index, forest cover, surface temperature etc. A multi-model evaluation was carried out and presented at several conferences (Hoffmann et al., 2022d,e)n During the virtual LUCAS meetings in 2022, the test experiments for implementing the new LUCAS-LUC land use / land cover maps into RCM evaluation simulations have been discussed. The conclusions have been used to finalise the LUCAS phase 2 experiment design and output variable list, which will be published in its final version at the beginning of 2023.

There is a regular exchange of ongoing research activities and results during bi-annual LUCAS meetings, conference side meetings and individual workshops. Additionally, for continuous internal communication, LUCAS email lists and the LUCAS wiki are used. For external communication, the FPS LUCAS Website is provided (Figure 2). FPS LUCAS results are regularly presented at annual Euro-CORDEX General Assemblies and international conferences, and published in peer-review journals (see meeting and publication list below).

Figure 2. The FPS LUCAS website, maintained by Climate Service Center Germany (GERICS) at Helmholtz Zentrum Hereon: *https://ms.hereon.de/cordex_fps_lucas/*

Summary of each workshop/activity held during the year

Title, date, short description, location, website, links	Responsible person/-s	Funder
FPS LUCAS participation in virtual EURO-CORDEX General Assembly 2022 24th-27th January 2022 Presentation of FPS LUCAS and Session on "Aerosol and land use forcing in CMIP6-CORDEX simulations" at EURO-CORDEX General Assembly	Diana Rechid, Eleni Katragkou	-
FPS LUCAS Spring Workshop 2022 28th May 2022, virtual meeting The focus was on Biophysical impacts of extreme land use change scenarios over Europe and North America and multi-model model results from test experiments in preparation for LUCAS phase 2	Diana Rechid, supported by Peter Hoffmann, Vanessa Reinhart, Christina Asmus	-
FPS LUCAS Annual Meeting 2022 9th – 11th December, virtual conference The focus of the meeting was to share results about ongoing analyses of extreme LUC experiments and new results from LUCAS-NA; and the start of the LUCAS phase 2 simulations.	Diana Rechid, supported by Peter Hoffmann, Vanessa Reinhart, Christina Asmus	-

Related publications during the year

Title, journal and link to publication	Author/-s	Date
Asselin, O.; Leduc, M.; Paquin, D.; Di Luca, A.; Winger, K.; Bukovsky, M.; Music, B.; Giguère, M.: On the Intercontinental Transferability of Regional Climate Model Response to Severe Forestation. Climate	Asselin, O.; Leduc, M.; Paquin, D.; Di Luca, A.; Winger, K.; Bukovsky, M.; Music, B.; Giguère,	2022

2022, 10, 138. https://doi.org/10.3390/cli10100138	M.:	
Sofiadis, G., Katragkou, E., Davin, E. L., Rechid, D., de Noblet-Ducoudre, N., Breil, M., Cardoso, R. M., Hoffmann, P., Jach, L., Meier, R., Mooney, P. A., Soares, P. M. M., Strada, S., Tölle, M. H., and Warrach Sagi, K.: Afforestation impact on soil temperature in regional climate model simulations over Europe, Geosci. Model Dev., 15, 595–616, https://doi.org/10.5194/gmd-15-595-2022	Sofiadis, G., Katragkou, E., Davin, E. L., Rechid, D., de Noblet-Ducoudre, N., Breil, M., Cardoso, R. M., Hoffmann, P., Jach, L., Meier, R., Mooney, P. A., Soares, P. M. M., Strada, S., Tölle, M. H., and Warrach Sagi, K	2022
Daloz, A. S., Schwingshackl, C., Mooney, P., Strada, S., Rechid, D., Davin, E. L., Katragkou, E., de Noblet-Ducoudré, N., Belda, M., Halenka, T., Breil, M., Cardoso, R. M., Hoffmann, P., Lima, D. C. A., Meier, R., Soares, P. M. M., Sofiadis, G., Strandberg, G., Toelle, M. H., and Lund, M. T.: Land–atmosphere interactions in sub-polar and alpine climates in the CORDEX flagship pilot study Land Use and Climate Across Scales (LUCAS) models – Part 1: Evaluation of the snow-albedo effect , The Cryosphere, 16, 2403–2419, https://doi.org/10.5194/tc-16-2403-2022, 2022.	Daloz, A. S., Schwingshackl, C., Mooney, P., Strada, S., Rechid, D., Davin, E. L., Katragkou, E., de Noblet-Ducoudré, N., Belda, M., Halenka, T., Breil, M., Cardoso, R. M., Hoffmann, P., Lima, D. C. A., Meier, R., Soares, P. M. M., Sofiadis, G., Strandberg, G., Toelle, M. H., and Lund, M. T.	2022
Mooney, P. A., Rechid, D., Davin, E. L., Katragkou, E., de Noblet-Ducoudré, N., Breil, M., Cardoso, R. M., Daloz, A. S., Hoffmann, P., Lima, D. C. A., Meier, R., Soares, P. M. M., Sofiadis, G., Strada, S., Strandberg, G., Toelle, M. H., and Lund, M. T.: Land–atmosphere interactions in sub-polar and alpine climates in the CORDEX Flagship Pilot Study Land Use and Climate Across Scales (LUCAS) models – Part 2: The role of changing vegetation, The Cryosphere, 16, 1383–1397, https://doi.org/10.5194/tc-16-1383-2022, 2022.	Mooney, P. A., Rechid, D., Davin, E. L., Katragkou, E., de Noblet-Ducoudré, N., Breil, M., Cardoso, R. M., Daloz, A. S., Hoffmann, P., Lima, D. C. A., Meier, R., Soares, P. M. M., Sofiadis, G., Strada, S., Strandberg, G., Toelle, M. H., and Lund, M. T	2022
Reinhart, V., Hoffmann, P., Rechid, D., Böhner, J., and Bechtel, B.: High-resolution land use and land cover dataset for regional climate modelling: a plant functional type map for Europe 2015, Earth Syst. Sci. Data, 14, 1735–1794, https://doi.org/10.5194/essd-14-1735-2022, 2022.	Reinhart, V., Hoffmann, P., Rechid, D., Böhner, J., and Bechtel, B	2022a
Hoffmann, P., Reinhart, V., Rechid, D., de Noblet-Ducoudré, N., Davin, E. L., Asmus, C., Bechtel, B., Böhner, J., Katragkou, E., and Luyssaert, S.: High-resolution land use and land cover dataset for regional climate modelling: Historical and future changes in Europe, Earth Syst. Sci. Data Discuss. [preprint], https://doi.org/10.5194/essd-2022-431, in review, 2022.	Hoffmann, P., Reinhart, V., Rechid, D., de Noblet-Ducoudré, N., Davin, E. L., Asmus, C., Bechtel, B., Böhner, J., Katragkou, E., and Luyssaert, S.	2022a
Reinhart V., Hoffmann P., Rechid D. (2022): LANDMATE PFT land cover dataset for Europe 1992-2015 (Version 1.1). World Data Center for Climate (WDCC) at DKRZ. https://doi.org/10.26050/WDCC/LM_PFT_EUR_v1.1	Reinhart, Vanessa; Hoffmann, Peter; Rechid, Diana	2022b
Hoffmann P., Reinhart V., Rechid D. (2022): LUCAS LUC historical land use and land cover change dataset for Europe (Version 1.1). World Data Center for Climate (WDCC) at DKRZ. https://doi.org/10.26050/WDCC/LUC_hist_EU_v1.1	Reinhart, Vanessa; Hoffmann, Peter; Rechid, Diana	2022b

Hoffmann P., Reinhart V., Rechid D. (2022): LUCAS LUC future land use and land cover change dataset for Europe (Version 1.1). World Data Center for Climate (WDCC) at DKRZ. https://doi.org/10.26050/WDCC/LUC_future_EU_v1.1	Reinhart, Vanessa; Hoffmann, Peter; Rechid, Diana	2022c
Reinhart V. (2021). The improvement of land use and land cover representation in regional climate models (Doctoral dissertation, Staats-und Universitätsbibliothek Hamburg Carl von Ossietzky). https://ediss.sub.uni-hamburg.de/handle/ediss/9702 (Dissertation, *published July 2022*)	Reinhart, Vanessa;	2022
Jach, L., Schwitalla, T., Branch, O., Warrach-Sagi, K., and Wulfmeyer, V.: Sensitivity of land–atmosphere coupling strength to changing atmospheric temperature and moisture over Europe, Earth Syst. Dynam., 13, 109–132, https://doi.org/10.5194/esd-13-109-2022. 2022	Jach, L., Schwitalla, T., Branch, O., Warrach-Sagi, K., and Wulfmeyer, V	2022
Asmus C., Hoffmann P., Pietikäinen J.-P., Böhner J., Rechid D. (2022): Analyzing the influence of irrigation on convection – Case study for Northern Italy using convection-permitting simulations, EMS Annual Meeting 2022, Bonn, Germany, 5–9 Sep 2022, EMS2022-275, https://doi.org/10.5194/ems2022-275.	Asmus C., Hoffmann P., Pietikäinen J.-P., Böhner J., Rechid D.	2022
Hoffmann P., Rechid D., Reinhart V., Asmus C., Davin E., Katragkou E., Adinolfi M., Böhner J., Breil M., García-Bustamante E., Cardoso R., González-Rouco J., Lima D., Luu L., Mooney P., Navarro J., de Noblet-Ducoudré N., Raffa M., Soares P., Sofiadis G., Strada S., Tölle M. (2022): Implementing a high-resolution land use and land over change dataset derived from ESA-CCI LC and LUH2 into a regional climate model ensemble. ESA Living Planet Symposium 23.-27. May, Bonn, Germany	Hoffmann P., Rechid D., Reinhart V., Asmus C., Davin E., Katragkou E., Adinolfi M., Böhner J., Breil M., García-Bustamante E., Cardoso R., González-Rouco J., Lima D., Luu L., Mooney P., Navarro J., de Noblet-Ducoudré N., Raffa M., Soares P., Sofiadis G., Strada S., Tölle M.	2022d
Hoffmann P., Rechid D., Reinhart V., Asmus C., Böhner J., Breil M., Cardoso R.M., Davin E. L., Katragkou E., Lima D.C.A., Sofiadis G., Strada S., Tölle M.H. (2022): Implementierung von Landnutzungsänderungsdaten in ein Ensemble von regionalen Klimamodellen, DACH2022, Leipzig, Germany, 21–25 Mar 2022, DACH2022-204, https://doi.org/10.5194/dach2022-204	Hoffmann P., Rechid D., Reinhart V., Asmus C., Böhner J., Breil M., Cardoso R.M., Davin E. L., Katragkou E., Lima D.C.A., Sofiadis G., Strada S., Tölle M.H.	2022e

Planned activities for next year

Outlook 2023

There are further ongoing model intercomparison studies based on extreme land use change scenarios for Europe, e. g. regarding 3-d wind analyses and drought assessment. RCM experiments with realistic land use changes for downscaling GCM simulations from CMIP6 over Europe will be started. A virtual LUCAS Spring Meeting 2023 is planned in May, the final FPS LUCAS meeting is planned in winter 2023.

Contact person/-s

FPS LUCAS Team

Around 20 European institutions are involved in LUCAS. In 2021, additional groups from Canada and the United States joined as LUCAS-NA. It is coordinated jointly by:

- Diana Rechid, Climate Service Center Germany (GERICS)/Helmholtz-Zentrum Hereon;
- Nathalie de Noblet-Ducoudré, Laboratoire des Sciences du Climat et de l'Environment, Institute Pierre Simon Laplace, France *(until 2021)*
- Edouard Davin, Wyss Academy for Nature, University of Bern, Switzerland
- Eleni Katragkou, Department of Meteorology and Climatology, School of Geology, Aristotle University of Thessaloniki, Greece
- Martin Leduc, Ouranos and Université du Québec à Montréal (UQAM), Canada *(since 2021)*

If you are interested in this initiative, **please contact: *diana.rechid@hereon.de***