Annual report 2021 for Flagship Pilot Study LUCAS

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

Diana Rechid, Edouard Davin, Eleni Katragkou, Martin Leduc & the LUCAS Team

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).

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

The FPS LUCAS started in 2017 for 5 years. In 2021 a 2-year extension to 31.12.2023 was applied for, which was approved by the CORDEX SAT. More than 20 European research institutions are participating in FPS LUCAS. In addition, we started cross-domain collaborations with North America, three groups from Canada and the US have joined the LUCAS community, to apply the LUCAS phase 1 experiment protocol (FOREST-GRASS simulations) in the North American CORDEX domain. The LUCAS-NA activities are coordinated by Martin Leduc from Ouranos in Québec, Canada, who joined the FPS LUCAS coordination team. Nathalie de Noblet-Ducoudré from IPSL in Paris, France changed from active co-coordination to a senior advisor. Edouard Davin continues with co-coordination, now as a professor at Wyss Academy for Nature, University of Bern, Switzerland. Eleni Katragkou from Aristotle University of Thessaloniki, Greece continues with co-coordination, and Diana Rechid from Climate Service Center Germany in Hamburg continues to coordinate FPS LUCAS.

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 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. For LUCAS phase 1 over the North America domain, simulations from three RCM-LSM models are in production phase: CRCM5-CLASS, CRCM6-CLASS and WRF-Noah. Note that CRCM5-CLASS is also used to run FOREST/GRASS simulations over the Europe domain, so an additional RCM-LSM will become available in the phase 1 multi-model database for that domain. 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 internal LUCAS model intercomparison studies. The FPS LUCAS data “terms of use” clearly 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 recently with Geosci. Model Dev. by Sofiadis et al. (2022). It investigates the impact of afforestation on the seasonal cycle of soil temperature over the European continent with the LUCAS ensemble consisting of ten RCMs. The multi-model mean shows a reduction of the annual amplitude of soil temperature over all European regions, although this not a robust feature among the models (Figure 1). On the other hand, all models consistently indicate a widespread decrease of the annual amplitude of ground heat flux and a decline of soil moisture content in summer due to afforestation. In addition, pair FLUXNET sites are investigated in order to compare the simulated results with observations. In line with models, observations indicate a summer ground cooling in forested areas compared to open lands. The vast majority of models agree with the sign of the observed reduction in the annual amplitude of soil temperature, although with a large variation in the magnitude of changes.

Two further studies are publised as discussion papers with Cryoshphere and are currently under review: Both investigate the land-atmosphere interactions in sub-polar and alpine climates in the FPS LUCAS models, with Daloz et al. (2021) doing an evaluation of the snow-albedo effect, and Mooney et al. (2021) investigating the impact of land-use changes on snow albedo effects in the FOREST and GRASS simulations. Further model intercomparison studies are done on "Local and non-local effects induced by maximum deforestation/afforestation" (Strada et al., in prep.) and “Land-atmosphere coupling during compound extreme heat and drought events in the LUCAS experiment: a new coupling metric for climate extremes” presented at vEGU 2021 (Cardoso et al., 2021).

For LUCAS phase 1 in North America, a paper in preparation from preliminary results by Asselin et al. addresses the transferability of the regional response to FOREST/GRASS forcing using CRCM5-CLASS across different domains (Europe and North America), in addition to a detailed multi-model comparison over North America.

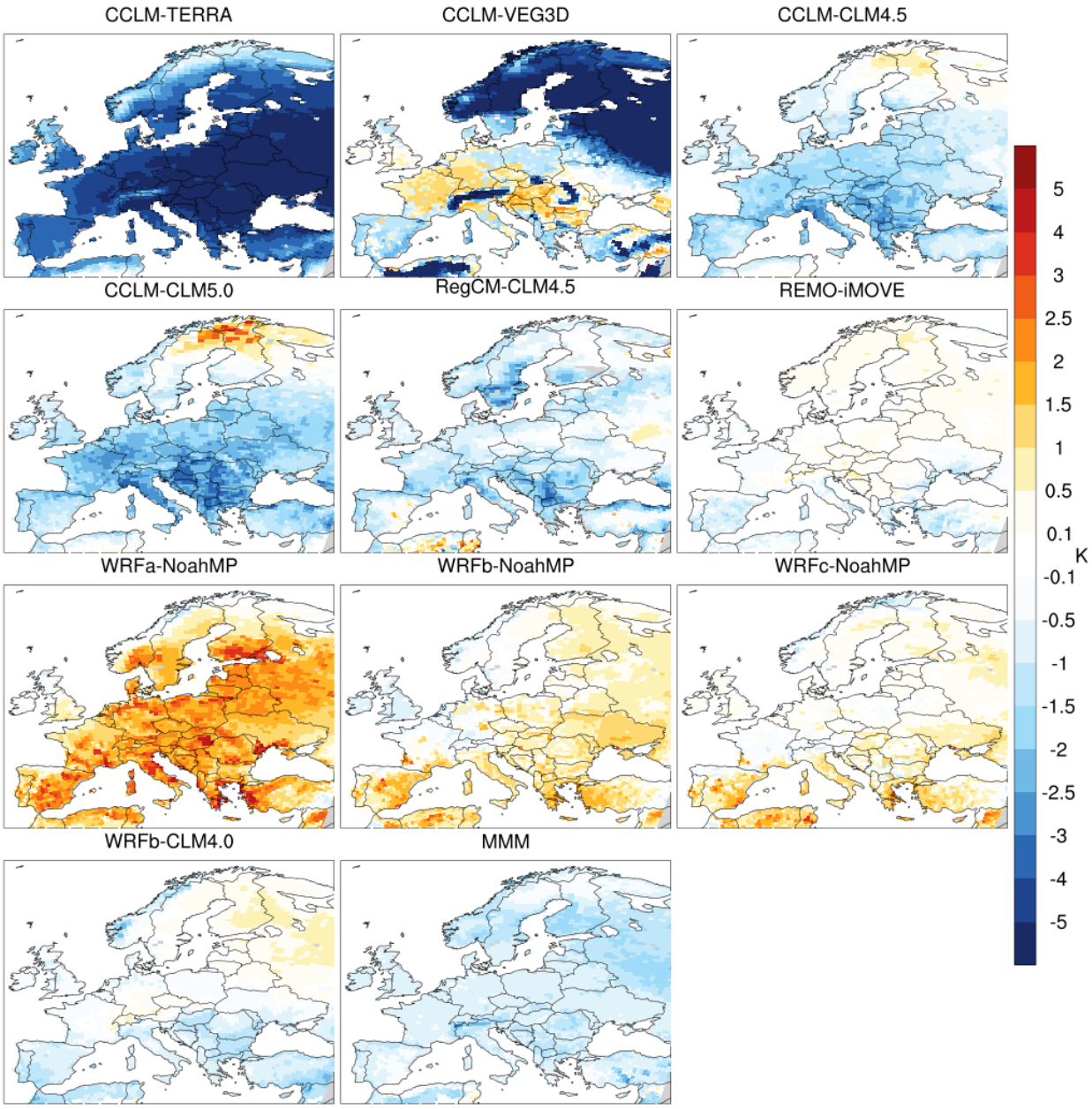

Figure 1. Afforestation impact (FOREST minus GRASS) on the annual amplitude of soil temperature at 1 meter soil depth. MMM: Multi-Model-Mean. (Source: Sofiadis et al., 2022)

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. A basemap PFT land cover dataset had been derived from ESA-CCI land cover data, which has been thoroughly evaluated for its use in RCMs. The dataset has been publised at World Data Center for Climate (WDCC) at DKRZ by Reinhart et al. (2021a), and as preprint with Earth Syst. Sci. Data Discuss. (Reinhart et al., 2021b). Starting from that high resolution present-day PFT distributions, 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 dataset has been publised at World

Data Center for Climate (WDCC) at DKRZ by Hoffmann et al. (2021a), and as preprint with Earth Syst. Sci. Data Discuss. (Hoffmann et al., 2021b). The new datasets will be used as land use change forcing for GCM-driven LUCAS phase 2 experiments from the past to the future with realistic land use changes over Europe.

During several virtual workshops in 2021, the challenges of implementing the new land use / land cover maps into different RCM modelling families had been extensively discussed. General and model specific issues were identified and several workarounds have been developed, which are documented and provided in an implementation guideline to the whole LUCAS and Euro-CORDEX community, in the format of a living document.

There is a regular exchange of ongoing research activities and results during bi-annual LUCAS meetings, conference side meetings and additional 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 session at virtual EURO-CORDEX General Assembly 2021 25th-28th January 2020 Presentation of FPS LUCAS and the LUCAS Land Use / Land Cover Dataset at EURO-CORDEX General Assembly	Diana Rechid, Peter Hoffmann, Eleni Katragkou	-
FPS LUCAS session at EURO-CORDEX Workshop on Aerosols and Land Cover 10th March 2021, virtual meeting Workshop session on how land use changes can be implemented into EURO-CORDEX simulations	Diana Rechid, Peter Hoffmann, Vanessa Reinhart, Eleni Katragkou	-

FPS LUCAS Spring Workshop 2021 27th May 2021, virtual meeting The focus was on the implementation of the new LUCAS Land Use / Land Cover Dataset into RCM land surface schemes	Diana Rechid, supported by Peter Hoffmann, Vanessa Reinhart, Christina Asmus	-
FPS LUCAS Interim Meeting 2021 23th-24th June 2021, virtual meeting The focus of the meeting was to share LUCAS results about ongoing analyses of extreme LUC experiments and the setup of new test experiments in preparation to LUCAS phase 2.	Diana Rechid, supported by Peter Hoffmann, Vanessa Reinhart, Christina Asmus	
FPS LUCAS Annual Meeting 2021 9th – 11th December, virtual conference The focus of the meeting was to share futher results about ongoing analyses of extreme LUC experiments, exchange experiences and first results of the short-term test experiments and further develop the LUCAS phase 2 experiment protocol. https://www.hicss-hamburg.de/projects/landmate/LandmateDetail/104203/index.php.en	Diana Rechid, supported by Martin Leduc, Eleni Katragkou, Edouard Davin, Peter Hoffmann, Vanessa Reinhart, Christina Asmus	-

Related publications during the year

Title, journal and link to publication	Author/-s	Date
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. (2021): Land-atmosphere interactions in sub-polar and alpine climates in the CORDEX FPS LUCAS models: I. Evaluation of the snow-albedo effect, The Cryosphere Discuss. [preprint], https://doi.org/10.5194/tc-2021-290	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.	2021
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.,	Mooney, P. A., Rechid, D., Davin, E. L., Katragkou, E., de	2021

Meier, R., Soares, P. M. M., Sofiadis, G., Strada, S., Strandberg, G., Toelle, M. H., and Lund, M. T.(2021): Land-atmosphere interactions in sub-polar and alpine climates in the CORDEX FPS LUCAS models: Part II. The role of changing vegetation, The Cryosphere Discuss. [preprint], https://doi.org/10.5194/tc-2021-291	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	
Reinhart, V., Hoffmann, P., Rechid, D., Böhner, J., and Bechtel, B.(2021): High-resolution land-use land-cover change data for regional climate modelling applications over Europe – Part 1: The plant functional type basemap for 2015, Earth Syst. Sci. Data Discuss. [preprint], https://doi.org/10.5194/essd-2021-251	Reinhart, V., Hoffmann, P., Rechid, D., Böhner, J., and Bechtel, B	2021
Hoffmann, P., Reinhart, V., Rechid, D., de Noblet-Ducoudré, N., Davin, E. L., Asmus, C., Bechtel, B., Böhner, J., Katragkou, E., and Luyssaert, S.(2021): High-resolution land-use land-cover change data for regional climate modelling applications over Europe – Part 2: Historical and future changes, Earth Syst. Sci. Data Discuss. [preprint], https://doi.org/10.5194/essd-2021-252	Hoffmann, P., Reinhart, V., Rechid, D., de Noblet-Ducoudré, N., Davin, E. L., Asmus, C., Bechtel, B., Böhner, J., Katragkou, E., and Luyssaert, S.	2021
Reinhart, Vanessa; Hoffmann, Peter; Rechid, Diana (2021). LANDMATE PFT land cover dataset for Europe 2015 (Version 1.0). World Data Center for Climate (WDCC) at DKRZ. https://doi.org/10.26050/WDCC/LM_PFT_LandCov_EUR2015_v1.0	Reinhart, Vanessa; Hoffmann, Peter; Rechid, Diana	2021
Hoffmann, Peter; Reinhart, Vanessa; Rechid, Diana (2021). LUCAS LUC historical land use and land cover change dataset (Version 1.0). World Data Center for Climate (WDCC) at DKRZ. https://doi.org/10.26050/WDCC/LUC_hist_landCovChange_v1.0	Reinhart, Vanessa; Hoffmann, Peter; Rechid, Diana	2021
Hoffmann, Peter; Reinhart, Vanessa; Rechid, Diana (2021). LUCAS LUC future land use and land cover change dataset (Version 1.0). World Data Center for Climate (WDCC) at DKRZ. https://doi.org/10.26050/WDCC/LUC_future_landCovChange_v1.0	Reinhart, Vanessa; Hoffmann, Peter; Rechid, Diana	2021
Breil, M., Davin, E. L., and Rechid, D.(2021): What determines the sign of the evapotranspiration response to afforestation in European summer?, Biogeosciences, 18, 1499–1510, https://doi.org/10.5194/bg-18-1499-2021	Breil, M., Davin, E. L., and Rechid, D	2021
Meier, R., Schwaab, J., Seneviratne, S.I., Sprenger M., Lewis, E., Davin, E.: Empirical estimate of forestation-induced precipitation changes in Europe. *Nat. Geosci.* **14,** 473–478 (2021). https://doi.org/10.1038/s41561-021-00773-6	Meier, R., Schwaab, J., Seneviratne, S.I., Sprenger M., Lewis, E., Davin, E	2021
Reinhart, V., C.C. Fonte, P. Hoffmann, B. Bechtel, D. Rechid, J. Boehner (2021) Comparison of ESA climate change initiative land cover to CORINE land cover over Eastern Europe and the Baltic States from a regional climate modeling perspective, International Journal of Applied Earth Observation and Geoinformation, Volume 94, 2021,102221,ISSN 0303-2434, https://doi.org/10.1016/j.jag.2020.102221.	Reinhart, V., C.C. Fonte, P. Hoffmann, B. Bechtel, D. Rechid, J. Boehner	2021
Tölle, M. H. and E. Churiulin 2021: Sensitivity of convection-permitting regional climate simulations to changes in land cover input data: role of land	Tölle, M. H. and E. Churiulin	2021

surface characteristics for temperature and climate extremes, Front. Earth Sci. - Atmospheric Science, https://doi.org/10.3389/feart.2021.722244		
Zhang, M., M. H. Tölle, E. Hartmann, E. Xoplaki and J. Luterbacher 2021: Sensitivity study of COSMO-CLM to different land cover maps in convection-permitting climate simulations over Europe. Atmosphere, 12, 1595, https://doi.org/10.3390/atmos12121595	Zhang, M., M. H. Tölle, E. Hartmann, E. Xoplaki and J. Luterbacher	2021
Cardoso, R. M., Lima, D. D. C. A., Soares, P. M. M., Rechid, D., Breil, M., Coppola, E., Davin, E., Hoffmann, P., Jach, L., Katragkou, E. K., Meier, R., Mooney, P. A., de Noblet-Ducoudré, N., Panitz, H.-J., Sofiadis, I., Strada, S., Strandberg, G., Tölle, M., and Warrach-Sagi, K.: Land-atmosphere coupling during compound extreme heat and drought events in the LUCAS experiment: a new coupling metric for climate extremes, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-15797, https://doi.org/10.5194/egusphere-egu21-15797	Cardoso, R. M., Lima, D. D. C. A., Soares, P. M. M., Rechid, D., Breil, M., Coppola, E., Davin, E., Hoffmann, P., Jach, L., Katragkou, E. K., Meier, R., Mooney, P. A., de Noblet-Ducoudré, N., Panitz, H.-J., Sofiadis, I., Strada, S., Strandberg, G., Tölle, M., and Warrach-Sagi, K	2021
Daloz, A. S., Schwingshackl, C., Mooney, P., Strada, S., T. Lund, M., Breil, M., M. Cardoso, R., Davin, E., Hoffmann, P., Katragkou, E., C.A. Lima, D., Meier, R., de Noblet-Ducoudre, N., Rechid, D., M. M. Soares, P., Sofiadis, G., Strandberg, G., and H. Toelle, M.: Climate forcing due to the snow albedo effect in the regional climate models from the CORDEX Flagship Pilot study LUCAS., EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-2120, https://doi.org/10.5194/egusphere-egu21-2120, 2021.	Daloz, A. S., Schwingshackl, C., Mooney, P., Strada, S., T. Lund, M., Breil, M., M. Cardoso, R., Davin, E., Hoffmann, P., Katragkou, E., C.A. Lima, D., Meier, R., de Noblet-Ducoudre, N., Rechid, D., M. M. Soares, P., Sofiadis, G., Strandberg, G., and H. Toelle, M	2021
Hoffmann, P., Rechid, D., Reinhart, V., Asmus, C., Davin, E. L., Katragkou, E., de Noblet-Ducoudré, N., Böhner, J., and Bechtel, B.: Generating long-term high-resolution land-use change datasets for regional climate modeling in CORDEX domains, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-14967, https://doi.org/10.5194/egusphere-egu21-14967, 2021.	Hoffmann, P., Rechid, D., Reinhart, V., Asmus, C., Davin, E. L., Katragkou, E., de Noblet-Ducoudré, N., Böhner, J., and Bechtel, B	2021
Asmus, C., Hoffmann, P., Pietikäinen, J.-P., Böhner, J., and Rechid, D.: Modeling irrigation effects on the regional climate in the "Greater Alpine Region" using a newly developed parameterization, EMS Annual Meeting 2021, online, 6–10 Sep 2021, EMS2021-176, https://doi.org/10.5194/ems2021-176, 2021.	Asmus, C., Hoffmann, P., Pietikäinen, J.-P., Böhner, J., and Rechid, D	2021

Planned activities for next year

Outlook 2022

There are further ongoing model intercomparison studies based on extreme land use scenarios for Europe. New results of first FOREST-GRASS experiments over North America are expected. The new high-resolution LUCAS LUC annual land use land cover maps based on LUH2 are going to be tested with further RCM modelling groups, and recommendations for implementing land use changes into regional climate change projections will be derived. RCM experiments with realistic land use changes for downscaling GCM simulations from CMIP6 over Europe will be started. A virtual LUCAS Interim Meeting 2022 is planned in Spring, the annual FPS LUCAS meeting is planned in winter 2022.

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***