

Description of the main research directions investigated by the institute

The main mission of CzechGlobe is to provide comprehensive and excellent research, based on acquired knowledge in three basic thematic segments of climate change: atmosphere - ecosystems - human society, and thus significantly contribute to solving one of the main current civilization challenges through adaptation and mitigation measures. Research activities of CzechGlobe cover a large part of the strategic goals set by the Green Deal, and already provide results that are intensively used to meet these goals in various sectors of economy and society. This is achieved mainly thanks to the state-of-the-art research infrastructure integrated into several ESFRIs and the high level of expertise reinforced by intensive international cooperation. More specifically, CzechGlobe provides answers to issues related to climate change impacts, mitigation and adaptation, such as information on:

- Understanding of climate change causes and related processes, for improved modelling of its impacts, strategic planning of adaptation policy, and for active climate change mitigation and adaptation, including the tools for early warning.
- Monitoring of the changing state of ecosystems, landscapes and society, analysis of the real impacts of ongoing climate change on provided ecosystem services, and implications for the sustainability of socio-economic systems.
- Understanding the mechanisms of responses and the resilience of ecosystems to changing environmental conditions and use of this knowledge in the development of specific adaptation measures at different hierarchical levels (from breeding to landscape planning) used by various sectors of economy (food production, agriculture, forestry, energy production) and society (NGOs, cities, regions, government).
- Searching for new ways to involve stakeholders in the development of innovative climate mitigation and adaptation actions in the co-creation process, and development of a system for the education of the decision-making sphere and society in the field of perception of climate change.
- Interconnection of various scientific disciplines and scientific teams at the international level to increase multidisciplinary knowledge about the causes, consequences of climate change and possible complex solutions for its mitigation and adaptation.

For the effective evaluation process three teams have been nominated for the evaluation 2015-2019 reflecting the CzechGlobe structure and the main research directions. Team 1. Climate analysis and modelling, and Team 2. Environmental effects on ecosystems, cover two key scientific approaches to studying all interactions between ecosystems and climate: observational research and modelling, and experimental research, respectively. Although Team 3. Human dimensions of global change impacts, covers only 6% of the total scientific workload within the institute, it represents a key unique extension to the two previous teams and fundamental interface between science and other sectors of society and economy, ensuring full use of the acquired knowledge in strategic decision-making, planning and designing of complex solutions.

The research directions of all teams cover most of the research priority areas defined by the Czech government:

- competitive economy - mainly by the development of the cascade of dynamic crop, water balance and economic models, which are used to investigate climate change and extreme events impacts in a holistic manner, and by provision of adaptation measures and strategies for key economic sectors such as food production, agriculture, forestry, energy production etc.; energy sustainability through research applications in the fields of accurate weather forecasts for the solar/wind/water sectors as well as research on the sustainable use of biomass both for energy production and landscape and soil and function amelioration;
- environment for quality of life - through research of sustainable strategies for providing sufficient and clean water resources; limiting the disruption of the carbon and nutrient cycles; working on ways for reducing agrochemical loads in agriculture and improving soil health, enhanced provision of ecosystem services like biodiversity, cooling and cleaning functions in cities, recreation and aesthetic functions etc.
- security - where research covers both aspects of food security as well as risk associated with extreme events, e.g. drought or wild-fire risks, including real-time forecast and monitoring tools.

Team 1: Climate analysis and modelling

a) Mission

The team mission is based on the development of tools/methods and execution of integrated analysis at the nexus of critical managed ecosystem services which includes the provisioning of food, energy and water sustainably. Team 1 research is linked to activities further studied by teams 2 and 3, and is documented by close collaboration.

b) Uniqueness

Firstly, the team is working across several critical research areas which leads to synergies and innovation development. The interdisciplinarity of the team is underpinned by high individual qualities of leading scientists with median H-index of the top ten scientists being 35 and higher. The team has shown considerable success represented by 385 impact journal papers (WOS) and an additional 306 indexed by Scopus. Several of those papers have been published in the top-rated journals in its own field but also in widely-read interdisciplinary papers in journals as Science, Nature, Nature Geosciences or PNAS. Team 1 combines superb experimental infrastructure with process-based models and model cascades, which allows upscaling of the model results from site to the regional or global levels. At the same time, close exchange of information with policy-makers, farmers/foresters, water and landscape managers and nature conservation institutions, leads to real-world application with high adoption rates. Therefore, team 1 presents its research also to the Czech audience, as has been its comprehensive drought monograph that has been awarded by the prestigious Hlavka price for the best scientific book in inanimate sciences of 2016. The team has been collaborating with top-notch research institutions in Europe (e.g. Cambridge and Cranfield universities, Rothamsted Res., CEH, JRC Ispra, IIASA, ESA, NASA, Technical Univ. Wien or ZALF). The transfer and communication of knowledge is done through direct lecturing, mentoring and workshops that have been attended by almost twenty thousand attendees, through web portals like www.interdrought.cz or www.klimatickazmena.cz with over 1.000.000 visits between 2015-2019 as well as through almost 100 media reports. The work of the team has been acknowledged e.g. by the Minister of Agriculture award in 2019. The uniqueness of team 1 lies in ever-increasing competence of the team and through the development of state-of-the-art infrastructure (e.g. atmospheric tower,

the network of high-tech climate monitoring sites, aircraft and drones, top-notch modelling capability etc). This provides the team with the ability to conduct experiments in the field and at a landscape level that are unapparelled with any other research institution in the Czech Republic in terms of their depth, interdisciplinarity and application potential.

c) *Specific goals*

The key long term goal of team 1 has been the development of sustainable climate change adaptation pathways for the Czech Republic in the face of growing uncertainty. This topic has been defined in early 2015 and then underpinned by core research activities of each scientific group that include:

1) Causes and impacts of climate variability. The aim is to carry out state-of-the-art research of the climate variability in the Czech Republic and Central European region in pre-instrumental and instrumental periods, and research of the frequency and intensity of hydrometeorological extremes and their impacts on natural ecosystems and society in the Czech Lands during the past 500 years. The team uses natural (e.g. tree rings, stable isotopes etc.) and anthropogenic (documentary evidence) archives and also quantitative climate reconstructions and analyses of impacts of past weather and climate, to evaluate the extent and severity of recent climate change in the Central - European context. Out of dozens of collaborative studies, there have been several outstanding papers including a highly referenced *Nature* study into European Floods co-inspired by prof. Brazdil.

2) Hi-precision monitoring of greenhouse gases (GHGs) concentrations and atmospheric chemistry. Work is being supported by the unique super high (250 m) dedicated tower structure; the monitoring is not only in-situ or for country but for a wide region of Central Europe. This provides the team with excellent base data for studies in the field of GHGs emissions.

3) Development of robust and practical climate change scenarios. This activity is based on the best available datasets (e.g. CMIP 5 and 6, EuroCordex, ISIMIP etc.). Formulating climate change scenarios is impossible without proper bias-correction of model outputs and localisation of the outputs to locations. This is needed by follow-up modelling tools used in impact/adaptation and mitigation studies. The team has developed tools that have been proved as leading in this field, in international comparison studies.

4) Estimation of future responses of carbon and water cycles. The combination of strong on the ground expertise in terms of experiments, with the availability of remote sensing platforms and researchers and combined with process-based modelling groups, allows us to truly improve the understanding of changes in water and carbon cycles. For example, the development of in-depth knowledge of drought and its consequences, or early warning provided to stakeholders about the risks of more frequent wild-fires and their implications for the well-being of society but also the carbon cycle and carbon emissions in particular.

5) Development of model ensembles and cascades of dynamic crop, water balance and economic models. This activity encompasses calibration and verification of models, including lab/field experimental programs focused at testing the modelling hypothesis. While sounding simple, an extremely laborious, data and personnel intensive process is at the heart of improved understanding to the complexity of the changing world. These models are central to the Interface and Synthesis Centre (ISC) formed under the ANAEE ESFRI project in collaboration with team 2.

6) Application of innovative methods for dynamic monitoring the processes studied in previous goals from above. The team has been at the forefront in the development of methods of plant trait retrievals from airborne (drones, aircraft) hyperspectral and satellite (Sentinel-2 under Copernicus services) data (in collaboration with ESA, NASA and Team 2) mainly for forest and agroecosystems.

d) *Integration of research into the international context*

As part of a European Centre of Excellence, Team 1 has international collaboration embodied into all its research activities. These activities are supported by direct employment of high-level experienced abroad scientists. Only rarely their research or experiments are done without collaboration with labs across Europe and/or the USA. The top experimental, instrumental and modelling infrastructure makes CzechGlobe an attractive partner which is particularly active in terms of the ESFRI infrastructure projects. The open-access and policy-focused collaborative approach rather than a competitive approach to research questions, enhances new research ideas across disciplines and countries. For example, the team lead an analysis of stable isotopes in oak tree-ring that produced the longest and largest C/O stable isotope-based chronology to this date, that allowed the reconstruction of central European droughts in the past 2000 years in a partnership with Team 2 and the University of Cambridge. Such endeavours are not isolated but rather a rule within the team, that also utilises the infrastructure and capacity to participate in collaborative projects such as COST actions or ERA4CS etc. Team 1 has also developed a number of methods that are being used internationally, including quality control of weather data, protocols for evaluating satellite sensors with ground/aircraft measurements, and assistance in the development of national drought monitoring systems in Slovakia or Austria based on the original national product www.intersucho.cz. Team 1 participates together with Team 2 in ESFRI infrastructures – ICOS ERIC (Integrated Carbon Observation System; <https://www.icos-cp.eu/>), and AnaEE (Analysis and Experimentation on Ecosystems; <https://www.anaee.com/>) and is an active partner in ACTRIS ESFRI project (the European Research Infrastructure for the observation of Aerosol, Clouds and Trace Gases <https://www.actris.eu/>). Team 1 has been involved in the FP7 EUFAR project, contributes every year to ESA-coordinated flight campaigns and supports ESA COPERNICUS services. Team 1 continuously maintains a network of water-balance stations for calibration and verification of both remote sensing methods and process-based models representing gradients from Pannonian and Elbe lowlands to the high Alpine Alm conditions (2100 m a.s.l.). Team 1 continues to run a network of collaborating drought reporters in 8 Central and South Eastern European countries especially in Slovakia, Hungary, Slovenia, Croatia and Serbia.

e) *Weaknesses and opportunities*

The main weaknesses of the team that have been and are being addressed are:

- A significant portion of the infrastructure is being placed outside and is subject to wear and tear over time. The significant cost of renewing infrastructure is difficult to plan within current accounting rules and budget structure, however, the institute strengthens the allocation of funds for insurance and resolution of unexpected damage.
- There exists a relatively slow rate of publication output by some younger team members. This weakness is being systematically targeted by increased efforts in writing skills training and by involving young researchers in wider author groups where these skills are learned.

- The majority of the team budget comes from external project funding (about 90%). This is addressed by efforts by the institution's management to increase the share of institutional funding and also by involving foreign experts in project teams, which increases the quality and thus the success of project applications.
- A large amount of spatiotemporal data from various sources need to be integrated and sometimes suitable tools are missing. Efficient IT solutions and databases are not always in place, but the situation is gradually improving in cooperation with the IT department and external IT experts.

The main opportunities are:

- Main results may be provided to bodies interested in climate change impacts and mitigation – especially through multi-model/method approach;
- There exists a society demand for the prediction of ecosystem service provision and biodiversity loss obtained by modelling under climate change.
- Strengthening the cooperation with the economic modelling community (IIASA)
- GCRI as a platform for much broader and integrated scientific cooperation in environmental studies given the unique experiment – modelling capability of GCRI.

Team 2: Environmental effects on ecosystems

a) Mission

The team addresses globally important issues of climate change impacts on ecosystem functions, including cycles of energy and matters, biodiversity, plant acclimation and consequently the effects on food quality and security. Research activities cover a wide range of processes in the soil–ecosystem–atmosphere continuum from adjustment of metabolome up to changes in biodiversity using theoretical, experimental and monitoring approaches. The team primarily performs excellent basic research tackling huge challenges, challenges closely related to climate change impacts, mitigation and adaptation in ecosystems evaluating different ecosystem potential for global change mitigation/adaptation and having a series of applications addressing pressing societal needs mainly in the fields of agriculture, forestry, food, land use and/or biotechnologies (e.g. wastewater treatment, biofuels, health) and transfers scientific knowledge into practice.

b) Uniqueness

The team contributes to the research of climate change impacts in a complex manner from the molecular level (plant metabolomics) and plant tissues (physiological processes) up to the ecosystem (energy and matter fluxes), at regional (biodiversity, water catchments) and/or global scales. The possibility of research at global scales is particularly due to extensive international cooperation enabling the formation of joint databases and/or realization of joint experiments over wide environmental gradients (geographical, altitudinal). The team is, to a large extent, involved in European research infrastructures (ICOS, AnaEE, eLTER etc.) as a founding member, where it participates in the formulation of new research directions and the ways of future development, but also numerous individual cooperations are continuously developing. The team transfers its expertise into developing countries (Ghana, Vietnam, Panama, Columbia), which has resulted in the construction of CzechGlobe new ecosystem monitoring stations in Vietnam and Ghana under supervision and extensive training provided by the team. Likewise, a new biodiversity research station is now established in Columbia. These activities are the most relevant long-term Czech R&D projects in these countries.

The team is one of the first in the use of metabolomics in ecological research (ecometabolomics) and thus has contributed to a fundamental deepening of the understanding of mechanisms of tolerance and adaptation of ecosystems to climate change factors including particularly elevated atmospheric CO₂ concentration, drought, temperature extremes, mineral supply etc. and their mutual combinations. Developed methodological approaches are successfully used in biotechnological applications searching for the production of valuable compounds in plants/microorganisms, and/or a targeted selection of species and genotypes, breeding, or reducing impact on human nutrition and health risks.

c) *Specific goals*

The main specific goals and research areas of the team are:

- 1) Ecosystem responses to environmental perturbances (heat waves, drought periods, etc.) and climate change and the use of this knowledge for improved modelling predictions and development of mitigation and adaptation measures. The responses are studied using a top-down evaluation of energy and matter (greenhouse gases including trace gases – water vapor, CO₂, CH₄, N₂O) fluxes between different types of ecosystems and the atmosphere supported by bottom-up investigation of key physiological processes associated with carbon and water cycles (photosynthesis, respiration, transpiration etc.),
- 2) Biochemical (key metabolic pathways) and physiological mechanisms of adaptation, acclimation, and resistance of model organisms (plants, microorganisms) to the effects of environmental stimuli (e.g. elevated CO₂ concentration, temperature extremes, drought periods) and transfer of this knowledge into practice (breeding, plant phenotyping, screening of species and natural ecotypes),
- 3) Tree growth strategies in the context of forest functional ecology under global climate change, including the development of new approaches to understand the mechanism of environment-induced effects on biomass allocation and patterns of tree mortality, and associated forest die-offs, and the use of this knowledge in new approaches to forest management.
- 4) Hydrological and biogeochemical responses of soils and waters in small forested catchments and glacier lakes to changes in atmospheric deposition (sulphur, nitrogen), forest management, land use and climate change.
- 5) Evolutionary ecology (in particular the evolution of life strategies), population dynamics (especially predator–prey and plant–pollinator systems), and stability of ecological communities in wide geographical and climatic gradients.
- 6) Development of innovative biotechnological solutions using microalgae provided with metabolic pathways enabling production/secretion of energetically rich substances or substances with attractive bioactivity.

d) *Integration of research into the international context*

The team has developed strong international collaborations, especially at the level of European research infrastructures, COST activities as well as individual cooperations. These activities are supported by direct employment of high-level experienced foreign scientists. The team has a coordinating role in IPBES UN (Global Assessment on Biodiversity and Ecosystem Services of the United Nations; nominated for the 2020 Nobel Peace Prize). The team participates (as a founding member) in two existing ESFRI infrastructures – ICOS ERIC (Integrated Carbon Observation System; <https://www.icos-cp.eu/>), and AnaEE (Analysis and Experimentation on Ecosystems; <https://www.anaee.com/>). The team is also an ESFRI member of DANUBIUS-RI

(<https://www.danubius-ri.eu/>), eLTER RI (<https://www.lter-europe.net/elter-esfri>), and ESFRI ISBE (<https://project.isbe.eu/>).

Collaboration within ESFRI infrastructures enables an upgrade, being consistent with the requirements of these pan-European consortia, standardization of measuring protocols, and tight international cooperation leading to joint publications and grant applications. The close involvement in pan-European experiments at a large-scale, has resulted in several high impact publications on, among others, adaptation and acclimation processes in plants along environmental gradients.

A very important activity, based on successful international applications, is the team leadership and hosting of (on behalf of CzechGlobe), the Interface and Synthesis Centre (ISC) of ESFRI AnaEE ERIC, to be started in the year 2021. ISC is one of the AnaEE central facilities (apart from Central Hub, there will be another two AnaEE service centres: The Technology Centre and the Data and Modelling Centre) responsible for the overall integration of results obtained thanks to the AnaEE pan-European consortium. It prepares synthesis and opinion papers on behalf of AnaEE, and remains aware of emerging societal needs, thus being able to answer demands from society, economy, and policy makers. It is also responsible for training and outreach activities.

Its technology transfer is also supported by team activities in the European Institute of Innovation and Technology (EIT Climate Knowledge and Innovation Community) especially in the field of smart climate agriculture applications.

e) *Weaknesses and opportunities*

The main weaknesses of the team are:

- Insufficient number of technical staff and PhD students. This problem is solved through the training of new technical staff and by the attraction and selection of potential PhD students already during their MSc study. The situation is thus gradually improving.
- Relatively slow rate of publication output by younger team members (Ph.D. students). This is gradually improving thanks to the organization of training schools on writing, and involving the PhD students in wider teams working on publications, with experts who help PhD students gain improved writing skills.
- Relatively low success with research proposals at the Czech Science Foundation (GACR). This situation is changing slowly, but the shift is evident, mainly due to the involvement of foreign experts in the team, who with their experience and skills improve the quality of grant applications.
- Broad research focus not supported by adequate personal work allocation. To some extent, this is an opportunity that leads to the search for new research directions, but until a new stabilization occurs, it weakens to some extent the team. Here, the management of the institution significantly helps by allocating funds to perspective research groups.
- Majority of the team budget comes from external project funding (about 80%). It represents a heavy burden on submitting new project proposals, but thanks to the effort of institutional management, the ratio gradually improves.

The main opportunities are:

- Society demand for knowledge about climate change impacts on plants and ecosystems.
- “Open-access“ infrastructure and data, co-operation with national/international experts and institutions.

- Establishment of new ecosystem stations in Vietnam (finalization), Ghana (construction phase) and Panama (preparatory phase).

Team 3: Human dimensions of global change impacts

a) Mission

The team is focused on the social aspects of how global change is created, and interacts with, individuals and societies. The team engages with the core global change processes relevant to the Anthropocene: biodiversity loss and climate change and their consequences. The work of the team informs how we understand, and manage the causes, impacts and prevention of such processes of global change. The direct incorporation of the team professional skill into mainly natural science oriented institute is quite unique in the Czech and European research area.

Within the topic of biodiversity loss, the team contributes to understanding how people are impacted by biodiversity loss, through the framework of ecosystem services. Our work on ecosystem services includes the identification and mapping of services, creating understanding of the benefits derived from such services, and understanding how these benefits are valued (financial and non-financial value). In doing so, the team directly contribute to both a basic scientific understanding of how society is part of a broader ecosystem; and an applied evidence-set for making decisions on planning and policy. The results of the team feed into biodiversity policy across all sectors: directly into protected area policy, but also more broadly into agricultural policy, urban and landscape planning, etc.

Within climate change, the team focuses on both adaption and mitigation. It draws on ecosystem service frameworks to understand the impact of climate change on societies, and individuals. We are also able to understand how to enhance key ecosystem services for mitigation and adaptation (e.g. carbon sequestration, runoff reduction) via green infrastructure. The team has particular expertise in cost-benefit analyses of climate change mitigation and adaptation measures, providing strong evidence for decision making. This science feeds into urban planning across the Czech Republic, Europe and the World.

Bridging both these core topics, the team is focusing also on systems transformation for sustainability. We take a critical systems perspective to understanding the root causes of biodiversity loss and climate change, and their unequal impacts. The team engages with empirical research on how systems change to produce more sustainable outcomes. This research feeds into understandings of decision-making and governance processes that are better matched to meeting core sustainability challenges. For example, the role and mechanisms of participation, the need to engage with non-financial values, etc. Therefore, in addition to providing evidence to existing policy systems (as above), we also inform how decisions should be made and what governance infrastructure is needed to address climate change and biodiversity loss. The team closely collaborates with other CzechGlobe teams in cross-disciplinary research projects addressing national (e.g. urban adaptations on climate change in the UrbanAdapt project) and international issues (e.g. H2020 SEACRIFOG project Supporting EU-African Cooperation on Research Infrastructures for Food Security and Greenhouse Gas Observations) based on the use of the CzechGlobe ESFRI infrastructure.

b) Uniqueness

The department is unique in following ways: 1) its highly interdisciplinary approach directly interconnected to the natural science oriented institute, 2) participatory engagement with

policy, and 3) the contribution of a Central-European perspective to the international sustainability community.

1) The team is unique in its sustainability science; the team engages with perspectives from across the social and natural sciences, and works in partnership with societal actors in solution-oriented research. Researchers in the team represent a range of disciplines, including Physical Geography, Environmental Science, Ecology, Political Science, Economics, Sociology, Psychology, and Geography. The team integrates the results of other teams within the Institute to increase awareness and involvement of society in the process of mitigation and adaptation, creation of policy strategies, and also to formulate comprehensive approaches for climate change mitigation and adaptation, involving the wider society in the co-creation process.

2) For example, climate change adaptation and mitigation planning in Czech cities is a rather new practice which requires extensive cooperation between different stakeholders. The department activities boost the cooperation between the actors by running participatory processes focused on future scenarios planning. Based on the outcomes of the process, the scientific knowledge is re-shaped and combined with quantitative models. Such results can be used for policy formulation and planning in the longer-term. This approach runs through our different topic areas.

3) The described co-creation scientific process is innovative and unique in the Czech Republic in general but it also enriches the existing scientific knowledge on the human dimensions of global change from a Central-European perspective, which is often underrepresented within the research community. Through our activities domestically, and in the international community, we ensure this representation.

c) *Specific goals*

The goals of the department are three-fold:

- 1) To ensure that biodiversity is mainstreamed through all policy sectors in Czechia and across Europe, by highlighting the way in which policy outcomes impact ecosystem services, and the subsequent impact to society.
- 2) To ensure that climate change is mainstreamed through all policy sectors in Czechia and across Europe, ensuring that adaptation and mitigation is central to development policy.
- 3) To shape governance processes and systems in order that they can best address goals 1 and 2.

d) *Integration of research into the international context*

The work of the department is strongly integrated into the international context, through publications, teaching, outreach, and engagement in key international panels.

Team members have been actively involved in the international Ecosystem Services Partnership (ESP), a network of scientists for the science, policy and practice of ecosystem services. They have been members of the ESP Steering Committee and co-chairing the ESP Steering Committee since 2019. Team members have been a part of the lead teams of multiple ESP working groups, including the Thematic Working Group on Ecosystem Services in Trade-off analysis & Project evaluation, and the Thematic Working Group on Modelling Ecosystem Services. Consequently, team members have been in the position to influence the direction of the global ecosystem services research community, including co-authoring cross-cutting publications and contributing to conference planning.

Team members have been actively involved in co-authoring assessments of the of the 2020 Nobel-prize-nominated UN Intergovernmental Science-Policy Platform for

Biodiversity and Ecosystem Services (IPBES) and have thus contributed to one of the largest science-policy interfaces related to sustainability and global environmental change. They participated as a Review Editor in Chapter 5 of the IPBES Methodological Assessment on Scenarios and Models and as a Lead Author in the IPBES Thematic Assessment on Land Degradation and Restoration. The other team members have been involved as a Leading Author and a Fellow, respectively, in the IPBES Regional Assessment for Europe and Central Asia and a Leading Author in the currently elaborated IPBES Values Assessment since 2018.

The team member was sought to participate in the revision of the System of Environmental Economic Accounting-SEEA and in particular in the revision of discussion paper 5.1 section 5: Value transfers in ecosystem accounting provided by expert consultation (November 2019).

Researchers in the team are encouraged to participate in professional networks and associations relevant to their field of interest. For example, there were appointed as fellow of the Royal Geographic Society and of the Earth System Governance Project; as an assistant to the president of the International Consortium on Geo-disaster Reduction (ICGR) and they participate in a number of other networks (GAPHAZ - Glacier And Permafrost Hazards in Mountains; ARNEES - Alpine Research NETwork of Early career Scientists; RSESD - Remote Sensing of Earth Surface Dynamics; ICGR; EGU - European Geosciences Union). They are also members of the scientific board of ICP (Environmental Psychology), the Czech Association of Agrarian and Environmental Economists and Sociologists and the YESS network (Young Ecosystem Service Specialists).

Members of the team hold editorships of international journals such as the Journal of Environmental Policy and Governance and Ecosystem Health and Sustainability.

Researchers also retain positions of influence over the research and teaching directions on other academic institutions including lead of department of the Environmental Behaviour Research Unit at Charles University Environment Centre.

e) Weaknesses and opportunities

The main challenge of research in this department is that it does things differently to the status quo of policy-making and research. In terms of research, this inter- and trans-disciplinary approach to research, based around real-world problems, is sometimes criticised by disciplinary thinkers for being too 'un-disciplined'. It certainly requires time and reflexivity for full piecing together a range of disciplinary perspectives. In terms of the policy relevance, a lot of the findings require policy makers to interact differently with information (e.g. through future scenarios, or ecosystem service accounting).

The opportunities to overcome this weakness are now emerging, on an international level. The EU Green Deal, and related research funding, has created more demand for our knowledge to inform policy, and even to find new ways of governing. There is increased emphasis on participation and governing society as part of its broader ecosystem. The research funding emerging to meet this need calls for the inter- and trans-disciplinary approach that we embody, placing social and political sciences as the central focus of the research, rather than the more traditional focus on technical fixes. Furthermore, the prominence and influence of bodies such as IPBES at the international level is growing; IPBES reflects our research and policy approaches and increases their legitimacy.

Research activity and characterisation of the main scientific results

Key research activities

Team 1 combines superb experimental infrastructure with process-based models and model cascades, which allows upscaling of the model results from site to the regional or global level. At the same time, close exchange of information with policy-makers, farmers/foresters, water managers and nature conservation institutions lead to real-world application with high adoption rates. All of this is necessary given the ever-increasing urgency of both climate change adaptation and mitigation. It must be stressed that any successful adaptation and mitigation strategy has to be based on proper assessment of likely impacts, their probability, scale and combined effect. Findings of Team 1 are shared and discussed closely with Teams 2 and 3 but also researchers outside CzechGlobe, with which the solutions could be latter found and tested. Team 1 has been therefore set and is managed as very open and curiosity driven scientific groups that are able to develop intertwining research activities with a vision and will of combining them when the time is right. The team focuses on analyses of climate change, monitoring of causes and consequences, including their modelling, at higher spatial levels from the ecosystem, through the region up to global analyses.

Team 1 deals with solving one of the most important challenges for human society, which is climate change, by addressing the impact on important sectors of the economy (energy, agriculture, forestry), including the searching and development of adaptation and mitigation measures and strategies, and ensuring the sustainable provision of ecosystem services. Team 1 is unique in a way it combines experimental infrastructure to develop process-based model cascades which are verified through monitoring/observational capabilities of remote sensing and observational networks. The complex nature of Team 1 allows to produce solid results withstanding peer-review process which can be measured via scientometric approaches. However, it also provides information relevant and interesting for famers, foresters, energy companies, water managers, policy makers and other stakeholders as well as for media and general public who use the information for their own benefit which could be assessed via number of people who have utilized the information and e.g. changed their behaviour. While such measure is not currently used in evaluating research institutions it is in the view of Team 1 leadership equally relevant as scientific proficiency.

The Team is 1 composed of six collaborating scientific groups and their research has been focused on the nexus of critical ecosystem services which includes provisioning of food, energy and water in a sustainable way and this research is linked to activities further studied by Teams 2 and 3. This includes “liaison” researchers from Team 1 who have been working part-time in two of the remaining Teams.

The key long-term goal of the Team 1 has been development of sustainable climate change adaptation pathways for the Czech Republic in the face of growing uncertainty. This topic has been defined in early 2015 and then underpinned by core research activities of each group that are described below with the key word being marked in bold:

- 1) Dedicated research of the **climate variability** in the Czech Republic in pre-instrumental and instrumental period, frequency and intensity of hydrometeorological extremes and their impacts on natural ecosystems and society in the Czech Lands during the past 500 years. The climate variability has been compiled from various natural (e.g. tree rings) and anthropogenic (documentary evidence) archives. In the same time unique quantitative climate reconstructions and analyses of impacts of past weather and climate are used to evaluate extent and severity of the recent climate change in Central - European context and methodological works with range of approaches and novel statistical methods. This works has led and will lead to a number of research papers but above all also into a more comprehensive understanding of past climate variability, its causes and consequences that will be all used in the further research; During the 2015-2019 period Department of Climate Variability and Climate Change Analysis published several papers in high-quality journals oriented on past and present hydroclimate variability (floods, droughts). These studies were based on a unique database of documentary evidence, which was combined with the natural proxies, mostly tree rings and phenological observations. The most important outcome from the set of these papers is the detailed knowledge of past hydroclimate variability that allows us to put recent climate change into a much broader time-scale context. These include, e.g. the following crucial studies whose authors comprise not only Team 1 members but also top international scientist long-term cooperating with Team through short-term scientific missions.

Brázdil, Rudolf, Andrea Kiss, Jürg Luterbacher, David J. Nash A **Ladislava Řezníčková**. Documentary data and the study of past droughts: a global state of the art. *Climate of the Past*, 2018, roč. 14, č. 12, s. 1915-1960.

Büntgen, Ulf, Myglan, V. S., Ljungqvist, F. C., McCormick, M., Di Cosmo, N., Sigl, M., Jungclauss, J., Wagner, S., Krusic, P. J., Esper, J., Kaplan, J. O., de Vaan, M. A. C., Luterbacher, J., Wacker, L., Tegel, W., Kirilyanov, A. V. Cooling and societal change during the Late Antique Little Ice Age from 536 to around 660 AD. *Nature Geoscience*. 2016, 9(3), 231-236.

Out of dozens of collaborative studies there have been several outstanding papers. One of them published recently on the base of 2015-2020 work has been highly referenced Nature study into European Floods co-inspired by prof. Brazdil:

Blöschl, Günter, Andrea Kiss, Alberto Viglione, Mariano Barriendos, Oliver Böhm, **Rudolf Brázdil**, Denis Coeur, Gaston Demarée, Maria Carmen Llasat, Neil Macdonald, Dag Retsö, Lars Roald, Petra Schmockler-Fackel, Inês Amorim, **Monika Bělinová**, Gerardo Benito, Chiara Bertolin, Dario Camuffo, Daniel Cornel, Radosław Doktor, Libor Elleder, Silvia Enzi, João Carlos Garcia, Rüdiger Glaser, Julia Hall, Klaus Haslinger, Michael Hofstätter, Jürgen Komma, Danuta Limanówka, David Lun, Andrei Panin, Juraj Parajka, Hrvoje Petrić, Fernando S. Rodrigo, Christian Rohr, Johannes Schönbein, Lothar Schulte, Luís Pedro Silva, Willem H. J. Toonen, Peter Valent, Jürgen Waser A Oliver Wetter. *Current*

European flood-rich period exceptional compared with past 500 years. Nature, London: Nature Publishing Group, 2020, roč. 583, č. 7817, s. 560-566.

- 2) Continuous and **hi-precision monitoring of greenhouse gases (GHGs) concentrations**, their vertical distribution in atmosphere and long-distance transport has been second core Team 1 activity. It was combined with collecting critical information about atmosphere as e.g. aerosols physical and chemical properties, ozone and mercury concentrations, meteorological variables. This provides the Team 1 with excellent base data for testing some of the assumptions but above all direct link with teams working at the field of GHGs emission inventory and mitigation measures.

The research work has included researchers across several scientific groups but has been led primarily by SG of Atmospheric Matter Fluxes and Long-range Transport. They focused e.g. on development of elemental carbon (EC) and organic carbon (OC) in fine atmospheric aerosols (PM_{2.5} : aerosol particles with diameter smaller than 2.5 µm). These critical pollutants have newly been measured with a semi-automatic instrument during a 4-year survey at the National Atmospheric Observatory Košetice (NAOK), Czech Republic. Ground based measurements were performed from March 2013 to December 2016 with a field Semi-Continuous OCEC Aerosol Analyzer (Sunset Laboratory Inc., USA). This work then resulted in several studies e.g.

Mbengue, S., Fusek, M., Schwarz, J., Vodička, P., Šmejkalová, A.H., Holoubek, I., 2018. Four years of highly time resolved measurements of elemental and organic carbon at a rural background site in Central Europe. Atmospheric Environment, 182, 335-346.

- 3) Team 1 dedicated significant amount of time and resources into development of **robust and practical set of scenarios of climate change** based on CMIP5 (GCM) and Euro-CORDEX (RCM) simulations for the Globe, Europe and particularly the main area of interest i.e. Central Europe with focus on the Czech Republic. The formulating climate change scenarios is impossible without proper bias- correction of model outputs and localisation of the outputs to locations. This is needed by follow-up modelling tools used in impact/adaptation and mitigation studies. At this field Team 1 has developed some of the tools that have been proved as leading at the field through international comparison studies. Many of the methods developed as basic research tools have been then successfully utilised in practice e.g. in developing tools for accurate prediction of electricity consumption and production from renewable sources (photovoltaic power plants and wind turbines, small hydroelectric power plants). This allows to “close” the circle as the Team 1 activity not only strives to improve our understanding to the climate change and its implications but also directly contributes to the climate change mitigation and adaption efforts.

The work described above can be demonstrated through several papers in Q1 journals which focused on climate change, data processing methodology, climate change projections and circulation conditions in Central Europe and included following key studies:

Štěpánek, P.; Zahradníček, P.; Farda, A.; Skalák, P.; Trnka, M.; Meitner, J.; Rajdl, K. Projection of drought-inducing climate conditions in the Czech Republic according to Euro-CORDEX models. *Climate Research* 70: 179-193, 2016

Zahradníček P, Brázdil R, Štěpánek P, Trnka M. Reflections of global warming in trends of temperature characteristics in the Czech Republic, 1961–2019. *Int J Climatol.* 2020;1–19.

Lhotka, O.; Trnka, M.; Kyselý, J.; Markonis, Y.; Balek, J.; Možný, M. Atmospheric Circulation as a Factor Contributing to Increasing Drought Severity in Central Europe. *Journal of Geophysical Research: Atmospheres* 125(18): 1-17, 2020

The influence of bias correction methods has been compared on the European scale and resulted e.g. in this comparison paper with leading experts of the field.

Squintu, A. A.; van der Schrier, G.; **Štěpánek, P.; Zahradníček, P.** Comparison of homogenization methods for daily temperature series against an observation-based benchmark dataset. *Theoretical and Applied Climatology* 2020(140): 285-301, 2020

Example of utilisation of the robust climate change scenarios could be study focused at Köppen–Geiger climate classification which was calculated using five individual regional climate models (RCM) and the results confirmed that bias corrections have a significant effect on climate classification.

Szabó-Takács B., Farda, A., Skalák, P. and Meitner, J.: Influence of Bias Correction Methods on Simulated Köppen Geiger Climate Zones in Europe, *Climate*, 7, 18, 2019

As mentioned above the work resulted into practical applications as e.g. operational version of solar energy short term, high precision forecast for improved utilisation and management of renewable energy sources:

Verified technology: **Štěpánek, P.; Farda, A.; Zahradníček, P.; Meitner, J.** Poloprovoz korigované předpovědi sluneční radiace pro území ČR. , 2017. https://asep.lib.cas.cz/arl-cav/cs/detail-cav_un_epca-0488442-Poloprovoz-korigovane-predpovedi-slunecni-radiace-pro-uzemi-cR/

- 4) The Team 1 uses the datasets and expertise of the Team 2 which are then as collaborative effort turned into **estimating future responses of carbon and water cycles**. The combination of strong on the ground expertise in terms of experiments, with the availability of remote sensing platforms and researchers and combined with process-based modelling groups allows to truly improve the understanding of changes in water and carbon cycles. As an example could serve the development of in-depth understanding to drought and its consequences or early warning provided to the stakeholders about the risks of wild-fire increase and their consequences on the wellbeing of the society but also the carbon cycle and carbon emission in particular. However, the systematic work in the field of both critical biosphere cycles allowed answering the critical question about the future stability of forest and forest-agricultural landscapes under the climate change and impact of the global change on the role of biodiversity (taxonomic, functional and response diversity) in selected ecosystem function/service (production, evapotranspiration and water and substance retention) provision in the landscape.

Out of many achievements Department of Carbon Storage in the Landscape co-lead the EASAC Environmental Panel and published an article in the journal Global Change Biology Bioenergy, proving that the current predominant use of wood biomass (burning wood pellets from felled trees in power plants) cannot be considered carbon neutral. The article provoked a very heated discussion, especially among the experts forming the European scientific basis for arguments for the transition from fossil fuels to biofuels.

Norton, M., Baldi, A., Buda, V., Carli, B., **Cudlín, P.**, Jones, M.B., Korhola A., Michalski, Novo, F.R., Oszlányi, J., Santos, F.D., Schink, B., Shepherd, J., Vet, L., Walloe, L., Wijkman, A. Serious mismatches continue between science and policy in forest bioenergy. 2019, Global Change Biology Bioenergy,4, 761–772.

A wide international team, led by assoc. prof. Pavel Cudlín, published an article in Climate Research in 2017, examining in 11 European mountains the factors influencing (mostly inhibiting) the shift of the upper forest boundary caused by climate warming.

Cudlín, P., Klopčič, M., Tognetti, R., Máliš, F., Alados, C. L., Bebi, P., Grunewald, K., Zhiyanski, M., Andonowski, V., La Porta, N., Bratanova-Doncheva, S., Kachaunová, E., **Edwards-Jonášová, M.**, Ninot, J. M., Rigling, A., Hofgaard, A., Hlásný, T., Skalák, P., Wielgolaski, F. E. Drivers of treeline shift in different European mountains. Climate Research. 2017, 73(1-2), 135-150.

Almost simultaneously Team 1 has led international survey that aimed at defining key research questions in the drought research that involved dozens leading global drought research institutions.

Trnka, M., Hayes, A., **Jurečka, F.**, **Bartošová, L.**, Anderson, M., Brázdil, R., Brown, J., Camarero, J. J., **Cudlín, P.**, **Dobrovolný, P.**, Eitzinger, J., Feng, S., Finnessey, T., Gregorič, G., Havlík, P., Hain, C., Holman, I., Johnson, D.,

Kersebaum, K. C., Charpentier Ljungvist, F., Luterbacher, J., Micale, F., Hartl-Meier, C., **Možný, M.**, Nejedlík, P., Olesen, J. E., Ruiz-Ramos, M., Rötter, R. P., Senay, G., Vicente-Serrano, S. M., Svoboda, M., Susnik, A., Tadesse, T., **Vizina, A.**, Wardlow, B., **Žalud, Z.**, **Büntgen, U.** Priority questions in multidisciplinary drought research. *Climate Research*. 2018, 75(aug), 241-260.

- 5) As the team has been set at the nexus of experimental and modelling work the development, use and improvement of process-based tools has been at the very heart of the Team 1 work and has been led by SG Climate Change Impacts on Agroecosystems. This has resulted into development of **cascade of dynamic crop, water balance and economic models**, their calibration and verification including lab/field experimental program focused at testing the modelling hypothesis. While sounding simple this extremely laborious, data and personnel intensive process is at the heart of improved understanding to the complexity of the changing World. E.g. defining proper adaptation strategy that would maximise ecosystem services provided by the landscape in the Czech Republic cannot be done without understanding the processes that will likely occur under the climate change globally. Leaving the “island” concept in climate change impact/adaptation/mitigation modelling and replacing it with much more holistic approach has been the major leap done in the Team 1 during 2015-2019.

As examples of Team 1 work (in close collaboration with Team 2 members) have succeeded in demonstrating major risk posed by drought for food security in the near future. The paper published in the *Science Advances* has shown that wheat price and partly wheat yields have been in recent 20 years closely linked to occurrence of drought and that unprecedented levels of droughts are likely in the near future including shifts in major exporting/importing countries. The paper has been relatively well accepted also beyond the research communities and widely discussed.

Trnka, Miroslav, Feng, S., Semenov, **M. A.**, **Olesen, J. E.**, **Kersebaum, K. C.**, **Rötter, R. P.**, **Semerádová, Daniela**, **Klem, Karel**, Huang, W., Ruiz-Ramos, M., **Hlavinka, Petr**, **Meitner, Jan**, **Balek, Jan**, Havlík, P., **Büntgen, Ulf**. Mitigation efforts will not fully alleviate the increase in water scarcity occurrence probability in wheat-producing areas. *Science Advances*. 2019, 5(9), eaau2406.

Almost through entire 2015-2019 period prof. Trnka and Bc. Balek have been leading authors together with prof. Kahiouloto and Dr. Kaseva in a study that focused on the decreasing response diversity of wheat to climate stressors across Europe that is considered as highly risky development in relation to the ongoing climate change. The study has been published in the *PNAS* journal and stirred considerable discussion requiring a follow-up response. Again, the study was led and steered by Czech-Finish partnership where all the co-authors have been at least on one short-term scientific mission to Team 1 facilities.

Decline in climate resilience of European wheat. Kahiulo, H., Kaseva, J., **Balek, Jan**, Olesen, J. E., Ruiz-Ramos, M., Gobin, A., **Kersebaum, K. C.**, Takáč, J., Ruget, F., Ferrise, R., Bezák, P., Capellades, G., Dibari, C., Mäkinen, H., Nendel, C., Ventrella, D., Rodriguez, A., Bindí, M., **Trnka, Miroslav**. Decline in climate resilience of

European wheat. Proceedings of the National Academy of Sciences of the United States of America. 2019, 116(1), 123-128.

Kahiluoto, H.; Kaseva, J.; Olesen, J.E.; **Kersebaum, K.C.**; Ruiz-Ramos, M.; Gobin, A.; Takáč, J.; Ruget, F.; Ferrise, R.; **Balek, J.**; **Trnka M.** Genetic response diversity to provide yield stability of cultivar groups deserves attention. Proc. Natl. Acad. Sci. USA **2019**, 166, 10627–10629

6) The key “advantage” that rapidly developing climate change is providing to the Team 1 is the ability to test many of the hypothesis and models with near real-time data (in terms of years or decades). Therefore, research work on tools that focus **on monitoring the processes from above** is critical. Not only due to the ever-increasing ability of these platforms but also due to the potential to extend the time series back in time when new approaches of data interpretation and fusion are being developed. Therefore Team 1 invested heavily in the development of methods of plant traits retrievals from airborne hyperspectral and satellite (Sentinel-2 under Copernicus services) data (in collaboration with ESA, NASA and Team 2) mainly for forest and agroecosystems. This includes utilisation of the remote sensing data processing chain for airborne sun-induced fluorescence observations (in collaboration with ESA) but also hyperspectral and laser scanning. All these capabilities are seamlessly merged with research described above as many research papers document.

An example of this developmental work can be seen e.g. through ESA FLEX satellite mission and other remote sensing-based method papers have seen quite an extensive contribution from the Team 1 which resulted in several important research papers including e.g.

Siegmann, B.; Alonso, L.; Celesti, M.; Cogliati, S.; Colombo, R.; Damm, A.; Doulas, S.; Guanter, L.; **Hanuš, J.**; Kataja, K.; Kraska, T.; Matveeva, M.; Moreno, J.; Muller, O.; **Piki, M.**; Pinto, F.; Vargas, J. Q.; Rademske, P.; Rodriguez-Moreno, F.; Sabater, N.; Schickling, A.; Schuttemeyer, D.; **Zemek, F.**; Rascher, U. The High-Performance Airborne Imaging Spectrometer HyPlant—From Raw Images to Top-of-Canopy Reflectance and Fluorescence Products: Introduction of an Automatized Processing Chain. Remote Sensing 11(23): Article number 2760, 2019

Rascher, U.; Alonso, A.; Burkart, A.; Cilia, C.; Cogliati, S.; Colombo, R.; Damm, A.; Drusch, M.; Guanter, L.; **Hanuš, J.**; Hyvarinen, T.; Jullita, T.; Jussila, J.; Kataja, K.; Kokkalis, P.; Kraft, S.; Kraska, T.; Matveeva, M.; Moreno, J.; Müller, O.; Panigada, C.; **Piki, M.**; Pinto, F.; Prey, L.; Pude, F.; Rossini, M.; Schickling, A.; Schurr, E.; Schüttemeyer, D.; Verrlest, J.; **Zemek, F.** Sun-induced fluorescence - a new probe of photosynthesis: First maps from the imaging spectrometer HyPlant. Global Change Biology 21(12): 4673-4684, 2015

Novotný, J.; Navrátilová, B.; Janoutová, R.; Oulehle, F.; Homolová, L. Influence of Site-Specific Conditions on Estimation of Forest above Ground Biomass from Airborne Laser Scanning. *Forests* 11(3): Article number 268, 2020

The main scientific results

The above description of the Team 1 work during 2015-2019 was designed as problem oriented. This was because it best captures day-to-day activities of the team and clearly shows that while scientific groups have to lead their individual areas of research, the strong collaboration has existed across scientific groups. However, any assessment of the research results nowadays cannot be done without proper scientometry. While in detail it has been provided through the stage I of the evaluation we would like to shortly summarise and provide some examples of recent work of the Team 1 members. Please note that research studies already included in the descriptions above were not listed again.

I. Scientific publication in highly impacted journals

During the evaluated period the Team published about 385 papers in scientific journals with impact factor. Out of these, 8 papers have their impact factor above 10 and included also highly influential interdisciplinary papers. Most of these journals belong to the Q1 of the following categories: Meteorological and atmospheric sciences, Atmospheric Chemistry, Plant sciences, Environmental sciences, Forestry, Agronomy, Ecology, Remote sensing and others. The examples of scientific results below were selected according to the first author from the evaluated team criteria and team significant expertise input (exact team share on the results was reported in the 1. evaluation phase). The studies already listed are not included.

1. *European mushroom assemblages are darker in cold climates.* Krah, F.S., **Büntgen, Ulf**, Schaefer, H., Mueller, J., Andrew, C., Boddy, L., Diez, J., Egli, S., Freckleton, R., Gange, A. C., Halvorsen, R., Heegaard, E., Heideroth, A., Heibl, Ch., Heilmann-Clausen, J., Hoiland, K., Kar, R., Kauserud, H., Kirk, P.M., Kuyper, T. W., Krisai-Greilhuber, I., Norden, J., Papastefanou, P., Senn-Irlet, B., Baessler, C. European mushroom assemblages are darker in cold climates. *Nature Communications*. 2019, 10(JUN 28 2019), 1-11), 2890.
2. *Limited capacity of tree growth to mitigate the global greenhouse effect under predicted warming.* **Büntgen, Ulf**, Krusic, P. J., Piermattei, A., Coomes, D. A., Esper, J., Myglan, V. S., Kirdyanov, A. V., Julio Camarero, J., Crivellaro, A., Korner, Ch. Limited capacity of tree growth to mitigate the global greenhouse effect under predicted warming. *Nature Communications*. 2019, 10(may), 2171.

3. *Climate change is predicted to alter the current pest status of Globodera pallida and G. rostochiensis in the United Kingdom.* Jones, L., Koehler, A.-K., **Trnka, Miroslav, Balek, Jan**, Challinor, A. J., Atkinson, H. J., Urwin, P. Climate change is predicted to alter the current pest status of Globodera pallida and G. rostochiensis in the United Kingdom. *Global Change Biology*. 2017, 23(11), 4497-4507.
4. *European warm-season temperature and hydroclimate since 850 CE.* Ljungqvist, F. C., Seim, A., Krusic, P. J., González-Rouco, J. F., Werner, J. P., Cook, E.R., Zorita, E., Luterbacher, J., Xoplaki, E., Destouni, G., Garcia-Bustainante, E., Aguilar, C. A. M., Seftigen, K., Wang, J., Gagen, M. H., Esper, J., Solomina, O., Fleitmann, D., **Büntgen, Ulf**. European warm-season temperature and hydroclimate since 850 CE. *Environmental Research Letters*. 2019, 14(8),
5. *The chemical composition of forest soils and their degree of acidity in Central Europe.* Santrucková, H., **Cienciala, Emil**, Kaňa, Jiří, Kopáček, Jiří. The chemical composition of forest soils and their degree of acidity in Central Europe. *Science of the Total Environment*. 2019, 687(oct), 96-103.
6. *Water footprint of winter wheat under climate change: Trends and uncertainties associated to the ensemble of crop models.* Garofalo, P., Ventrella, D., **Kersebaum, K. C.**, Gobin, A., **Trnka, Miroslav**, Giglio, L., **Dubrovský, Martin**, Castellini, M. Water footprint of winter wheat under climate change: Trends and uncertainties associated to the ensemble of crop models. *Science of the Total Environment*. 2019, 658(march), 1186-1208.
7. *Discerning environmental factors affecting current tree growth in Central Europe.* **Cienciala, E.**, Russ, R., Šantrůčková, H., Altman, Jan, Kopáček, Jiří, Hůnová, I., **Štěpánek, Petr, Oulehle, Filip**, Tumajer, J., Stähl, G. Discerning environmental factors affecting current tree growth in Central Europe. *Science of the Total Environment*. 2016, 573(dec), 541-554.
8. *Increased spruce tree growth in Central Europe since 1960s.* Cienciala, E., Altman, Jan, Doležal, Jiří, Kopáček, Jiří, **Štěpánek, Petr**, Stähl, G., Tumajer, J. Increased spruce tree growth in Central Europe since 1960s. *Science of the Total Environment*. 2018, 619(1 apr), 1637-1647.
9. *Assessment in Central European cities using an urban climate model and observational monitoring data.* Bokwa, A., **Geletič, Jan**, Lehnert, M., Žuvela-Aloise, M., Hollosi, B., Gál, T., Skarbit, N., **Dobrovolný, Petr**, Hajto, M. J., Kielar, R., Walawender, J. P., Šťastný, P., Holec, J., Ostapowicz, K., Burianová, J., Garaj, M. Heat load assessment in Central European cities using an urban climate model and observational monitoring data. *Energy and Buildings*. 2019, 201(53-69).
10. *Diverse growth trends and climate responses across Eurasia's boreal forest.* Hellmann, L., Agafonov, L., Ljungqvist, F. C., Churakova (Sidorova), O., Duethorn, E., Esper, J., Hulsmann, L., Kirdyanov, A. V., Moiseev, P., Myglan, V. S., Nikolaev, A. N., Reinig, F., Schweingruber, F. H., Solomina, O., Tegel, W., **Büntgen, Ulf**.

- Diverse growth trends and climate responses across Eurasia's boreal forest. *Environmental Research Letters*. 2016, 11(7), 074021.
11. *Climatic and environmental aspects of the Mongol withdrawal from Hungary in 1242 CE*. **Büntgen, Ulf**, Di Cosmo, N. Climatic and environmental aspects of the Mongol withdrawal from Hungary in 1242 CE. *Scientific Reports*. 2016, 6(MAY), 25606. (ID 473236)
 12. *Risk factors for European winter oilseed rape production under climate change*. Pullens, J. W. M., Sharif, B., **Trnka, Miroslav, Balek, Jan**, Semenov, M. A., **Olesen, J. E.** Risk factors for European winter oilseed rape production under climate change. *Agricultural and Forest Meteorology*. 2019, 272(jul), 30-39.
 13. *Spatial modelling of summer climate indices based on local climate zones: expected changes in the future climate of Brno, Czech Republic*. **Geletič, Jan**, Lehnert, M., **Dobrovolný, Petr**, Žuvela-Aloise, M. Spatial modelling of summer climate indices based on local climate zones: expected changes in the future climate of Brno, Czech Republic. *Climatic Change*. 2019, 152(3-4), 487-502.

II. The applied outputs/results

Team 1 has been participating in climate change related research which generates number of research questions whose solving is critical for managing this global problem. Key sectors of economy as e.g. agriculture, energy, water provisioning etc. cannot usually apply results of basic research directly. Thus beyond our obligation to conduct basic research, Team 1 has successfully sought the transfer of the newly acquired knowledge into practice as is evident from development of 2 certified demonstrators, 10 certified methodologies as well as 5 software products. These are mainly tools and methodologies used for more efficient renewable energy production, the applied use of remote sensing methods in precision agriculture, reducing the environmental impact of fertilizers and pesticides, use of precise weather forecast to limit impacts of extreme events or the use of growth models for predictions of climate change impacts. Some of these have been widely used and some have been also acknowledged by the stakeholders (e.g. in case of yield forecasting methodology that has received minister of agriculture award in 2019).

Patents, utility models, demonstrators connected with Team activities: 2

1. Procházka, F., Rebok, T., Farda, Aleš. První návrh cílové infrastruktury pro provoz systému IRIS. [First draft of the target infrastructure for the IRIS system operation.] Mycroft Mind, a.s., 2015. Utility model IRIS_infra. <http://www.mycroftmind.cz>
2. Procházka, F., Rebok, T., Farda, Aleš. Prototyp systému IRIS. [IRIS system prototype.] Mycroft Mind, a.s., 2016. IRIS_prototype.

Certified methodologies: 10

1. Lukas, V., Neudert, L., Širůček, P., Kraus, M., Novák, J., Mezera, J., Zemek, F., Píkl, M., Žížala, D. Postupy tvorby aplikačních map se zohledněním variability agrochemických vlastností půdy a výnosové úrovně pozemků. [Creating of variable rate application maps based on the mapping of spatial variability of soil agrochemical properties and crop yield heterogeneity.] Ústav výzkumu globální změny AV ČR, v. v. i., 2019. Certified methodology 091371/2019.
2. Zemek, František, Píkl, Miroslav, Lukas, Vojtěch, Ždímal, V., Kraus, M., Širůček, P. Hodnocení plošné heterogenity vybraných půdních vlastností pozemků na základě obrazové spektroskopie a satelitních dat. [Spatial heterogeneity of selected soil properties assessed from airborne imaging spectroscopy and satellite imagery data.] Ústav výzkumu globální změny AV ČR, v. v. i., 2019. Certified methodology 041650/2019. <http://www.czechglobe.cz/wp-content/uploads/2019/03/>
3. Zemek, František a kol. Metody hodnocení potenciální zranitelnosti podzemních vod reaktivním dusíkem při pěstování polních plodin na orné půdě. [Methods for identification of vulnerable zones for nitrogen leaching in arable land.] Ústav výzkumu globální změny AV ČR, v. v. i. 2016 http://www.czechglobe.cz/wp-content/uploads/2020/05/Certif_met_2016_Zemek_pudy.pdf
4. Lukeš Petr a kol. Hodnocení zdravotního stavu lesních porostů v České republice pomocí satelitních dat Sentinel-2. [Forest health assessment in Czech Republic using Sentinel-2 satellite data.] Ústav pro hospodářskou úpravu lesů. 2019. http://www.uhul.cz/images/aktuality_doc/Metodika_final.pdf
5. Fučík, P., Zemek, F., Hakrová, P., Svobodová, M., Zajíček, A., Šlachta, M., Píkl, M., Duffková, R., Mrkvička, J., Bystřický, V., Procházka, J., Skalický, M., Holubík, O., Moravcová, J., Novotný, J., Skalická, J., Peterková, J., Musil, M., Šantrůček, J., Matoušková, V., Brom, J., Hanuš, J., Novotná, K., Huislová, P. Metodický postup pro hodnocení vlivu pastvy skotu na půdní vlastnosti, množství a jakost vody a biodiverzitu v krajině. [A methodology for assessing the impact of cattle grazing on soil properties, water quality and quantity, plant and invertebrates diversity.] Ústav výzkumu globální změny AV ČR, v. v. i., 2015. Certified methodology 5/2014 MZe
6. Trnka, Miroslav, Hlavinka, Petr, Kudláčková, Lucie, Balek, Jan, Meitner, Jan, Možný, Martin, Štěpánek, Petr, Bartošová, Lenka, Semerádová, Daniela, Bláhová, Monika, Lukas, Vojtěch, Žalud, Zdeněk. Regionální předpověď výnosů plodin pro lepší rozhodování v rostlinné výrobě. [Regional yield forecasting for improved decision making in the plant production.] Ústav výzkumu globální změny AV ČR, v. v. i., 2019. Certified methodology 2/2019-SPU/O. <http://www.vynosy-plodin.cz>
7. Trnka, Miroslav, Štěpánek, Petr, Chuchma, F., Možný, M., Bartošová, Lenka, Hlavinka, Petr, Balek, Jan, Zahradníček, Pavel, Skalák, Petr, Farda, Aleš, Semerádová, Daniela, Meitner, Jan, Bláhová, M., Fiala, R., Žalud, Zdeněk. Využití předpovědi půdní vlhkosti a intenzity sucha pro lepší rozhodování v rostlinné výrobě. [System for monitoring and forecast of impacts of agricultural drought.] Ústav výzkumu globální změny AV ČR, v. v. i., 2018. Certified methodology 2/2018-SPU/O. <http://www.intersucho.cz/cz/o-suchu/vyuziti-predpovedi-sucha/>
8. Hlavinka, Petr, Trnka, Miroslav, Balek, Jan, Dubrovský, Martin, POhanková, Eva, Wimmerová, Markéta, Žalud, Zdeněk. Využití růstových modelů k hodnocení způsobů hospodaření při pěstování polních plodin a vlivu na půdní procesy. [Using growth models to evaluate field crops management practices and influence on soil

- processes.] Ústav výzkumu globální změny AV ČR, v. v. i., 2017. Certified methodology UKZUZ 124987/2017.
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Research activity and characterisation of the main scientific results

The excellence of the team's research activities is given by achieving the best results in an exceptionally comprehensive respect. Research activities are focused on the most important global problem of humanity - global change, and thus to the EU challenges of Green Deal, and on the National Priorities of Oriented Research, Experimental Development and Innovation. The outputs of basic research are very high quality, as evidenced not only by publishing in high quality scientific journals, but also by their evaluation. The Government Council for Research, Development and Innovation evaluates the institution into the best category of research organizations, as well as the Evaluation Commission of the Ministry of Education, Youth and Sports ranks the institution among the best within the evaluated Centers of Excellence. The team devotes considerable attention to the application of knowledge to practice and to address important societal issues related to impacts, adaptation and mitigation of global change. This ensures immediate feedback, the up-to-date focus of research, continuous adjustment of basic research to the needs of the application sphere or societal challenges. The team has built a top research infrastructure, with unique field and in situ experimental facilities. The team is extremely active in international cooperation, especially in pan-European research infrastructures and the export of know-how to Global South countries under UN programs and abroad at global level in the form of education of local scientists and construction of local research infrastructures. Although it is not a university workplace, the team has a rich pedagogical activity at universities, including jointly accredited doctoral programs and including the education of doctoral students for Global South countries. The team also educates the public and responsible staff on important issues - the so-called climate literacy, and perfectly represents the CAS and Czech science in general in public, even at the international level - participation in EXPO 2015 in Milan.

In total, during the evaluated period, the Team published about 378 papers in scientific journals with impact factor. Most of these journals belong to the Q1 of the following categories: Plant Sciences, Environmental Sciences, Forestry, Agronomy, Meteorological and atmospheric sciences, Ecology, Biochemistry and molecular biology, Biodiversity conservation, Soil sciences, Microbiology and others. Some of the results achieved are unique, for example, publishing global studies that are valid worldwide due to cooperation throughout the institute and our extensive international cooperation. For the first time, the Team combined approaches of metabolomics, ecology, ecophysiology and impact (climate manipulation) experiments, resulting in defining of a new field of ecometabolomics, delivering unique results important for the adaptation of different types of ecosystems, targeted selection of species and genotypes, plant breeding, or reducing the impact on human nutrition and health risks. Unique studies have also been conducted by clarifying the sources of emissions of trace greenhouse gases from ecosystems, as important knowledge for mitigating climate change. In addition, Team members are (co)authors of 68 papers in peer-reviewed journals (SCOPUS or other databases), 38 books/book chapters, and 74 contributions in conference proceedings.

The main challenges and problems addressed by the results of this Team (elaborated in detail below) are the impacts of climate change on ecological balance and biodiversity, especially in areas strongly affected by climate change (i.e. the Arctic), understanding of

trace greenhouse gas emissions of a high radiative-force as significant contributors to climate change and the use of these results to reduce greenhouse gas emissions, ensuring food security under climate change, and adaptation of ecosystems to factors related to climate change, development of perspective adaptation measures, and identification of risks associated with adaptations.

Many of the results of basic research have been transferred into practice in projects that address global, socially very important topics such as food safety, carbon sequestration, the stability of ecosystem functions and services including the biodiversity, ensuring water availability and maintaining its quality, etc. Based on the transfer of know-how, certified methodologies (7 in total), patents (5 in total) and software tools (7 in total) have been accepted by the relevant authorities during the evaluated period (see below for details).

I. Scientific publication in highly impacted journals

During the evaluated period the Team published about 362 papers in scientific journals with impact factor. Most of these journals belong to the Q1 of the following categories: Plant Sciences, Environmental Sciences, Forestry, Agronomy, Meteorological and atmospheric sciences, Ecology, Biochemistry and molecular biology, Biodiversity conservation, Soil sciences, Microbiology and others. Selected main scientific results below were selected according to the first author from the evaluated team criteria and team significant expertise input (the exact team share on the results was reported in the 1st evaluation phase):

1. Impact of climate change on the evolutionary biology processes. The relationships between predators and prey can be significantly changed by climate change and thus have far-reaching impacts on the biodiversity of many ecosystems, because this model study can be used also for other ecological systems including predators and prey relationships to estimate impacts on biodiversity or other ecosystem services. In 2019, dr. Vojtěch Kubelka and his co-workers reaffirmed their results in Science journal that provide clear evidence about a significant increase in the nest predation in shorebirds, especially in the Arctic. They disproved an opposite statement of Bulla et al. (2019) and contested the robustness of their outcomes. This study confirms the effect of climate change. Dr Kubelka is the first and corresponding author.
Kubelka V., Šálek M., Tomkovich P., Végvári Z., Freckleton R.P., Szekely T. (2019) Response to Comment on "Global pattern of nest predation is disrupted by climate change in shorebirds". *Science* 364(6445), 1-5.
2. Understanding the components of trace greenhouse gas fluxes and the potential for mitigation. Trace greenhouse gasses are important players in the Earth's energy balance due to their huge radiative forcing effect and their increasing concentrations over the last decades, and thus the understanding of their fluxes across different ecosystems provide a significant contribution to development of climate change mitigation approaches. Dr Kateřina Macháčová and her co-workers have shown for the first time that main boreal tree species (pine, spruce, birch) are net annual nitrous oxide (N₂O) sources, with spruce being the strongest emitter. They have shown clear seasonality in stem N₂O flux following tree physiological activity peaking during the vegetation season and remain low during winter dormancy. The study was published in Nature Communications journal. Together with other studies on fluxes of trace greenhouse gasses (N₂O and CH₄), including the role of cryptogamic stem covers

(lichens, mosses, algae), these publications represent also a crucial contribution to inventories of greenhouse gasses.

i) Macháčová K., Vainio E., Urban O., Pihlatie M. (2019) Seasonal dynamics of stem N₂O exchange follow the physiological activity of boreal trees. *Nature Communications* 10(1), 4989.

ii) Macháčová K., Bäck J., Vanhatalo A., Halmeenmäki E., Kolari P., Mammarella I., Pumpanen J., Acosta M., Urban O., Pihlatie M. (2016) Pinus sylvestris as a missing source of nitrous oxide and methane in boreal forest. *Scientific Reports* 6, 23410.

iii) Macháčová K., Maier M., Svobodová K., Lang F., Urban O. (2017) Cryptogamic stem covers may contribute to nitrous oxide consumption by mature beech trees. *Scientific Reports* 7, 13243.

3. Understanding the role of UV radiation in the regulation of plant growth and the induction of protective mechanisms. A tight involvement of dr. Otmar Urban and his colleagues in research activities of UV4Plants Association resulted in (a) an organisation of an international workshop on UV effects “Modulation of plant UV-responses by environmental factors” in Brno (2017) followed by a special issue of Plant Physiology and Biochemistry journal (vol. 134, pp. 1-144, January 2019; eds. O. Urban and M.A.K. Jansen), and (b) a series of unique international publications describing the effect of UV radiation on plants along the environmental gradients and showing how UV radiation determines the induction and development of plant defence mechanisms. These results are essential not only for understanding the interactions of UV radiation with other factors of climate change but can also be used for artificial induction of resistance or for searching metabolic pathways and biomarkers relevant for breeding to climate change tolerance:

i) Del-Castillo-Alonso M.Á., Castagna A., Soukupová J., Urban O., ..., and Núñez-Olivera E. (2016) Environmental factors correlated with the metabolite profile of *Vitis vinifera* cv. Pinot Noir berry skins along a European latitudinal gradient. *Journal of Agricultural and Food Chemistry* 64(46), 8722-8734.

ii) Castagna A., Csepregi K., ... Večeřová K., Urban O., Verdaguer D., Jansen M.A.K., Hideg É. (2017) Environmental plasticity of Pinot noir grapevine leaves: A trans-European study of morphological and biochemical changes along a 1,500-km latitudinal climatic gradient. *Plant Cell and Environment* 40(11), 2790-2805.

Among other results, review re-interpreting current knowledge of plant responses to ultraviolet radiation shows that UV-B radiation at ecologically relevant intensities is an important source of information and stimulates numerous protective responses in plants. The paper is highly cited having more than 100 citations during the last five years.

iii) Robson M.T., Klem K., Urban O., Jansen M.A. (2015) Re-interpreting plant morphological responses to UV-B radiation. *Plant Cell and Environment* 38(5), 856-866.

4. Application of non-target plant metabolomics for understanding the acclimation mechanisms to adverse environmental conditions. Using a complex infrastructure of liquid and gas chromatography coupled with mass spectrometry, the Team developed approaches of non-target plants metabolomics. Close collaboration with national and international research teams led to the establishment of the new field of environmental metabolomics and the publication of a series of articles in prestigious journals showing

how the metabolome of plants shifts due to changes in the environment and how these shifts are related to the adaptation of plants. Such results provide key knowledge for exploitation of new molecular mechanisms for tolerance to climate change factors in plant breeding, development of plant stimulating agents applied in very low concentrations or crop management approaches (such as plant nutrition) leading to enhanced accumulation of defence compounds. A new, unique technique for the determination of root exudates was developed. For the first time, the following findings were reported: (i) opposite changes in the metabolome of plant organs (root, shoots) subjected to combined drought and warming, (ii) metabolome of buds, (iii) metabolome of root exudates, etc. were reported. The possible usage of metabolomics in the investigation of trophic webs was also shown (iv).

i) Gargallo-Garriga A., Sardans J., Pérez-Trujillo M., Oravec M., Urban O., Jentsch A., Kreyling J., Beierkuhnlein C., Parella T., Peñuelas J. (2015) Warming differentially influences the effects of drought on stoichiometry and metabolomics in shoots and roots. *New Phytologist* 207(3), 591-603.

ii) Meijon M., Feito I., Oravec M., Delatorre C., Weckwerth W., Majada J., Valledor L. (2016) Exploring natural variation of *Pinus pinaster* using metabolomics: Is it possible to identify the region of origin of a pine from its metabolites? *Molecular Ecology* 25(4), 959-976.

iii) Gargallo-Garriga A., Preece C., Sardans J., Oravec M., Urban O., Peñuelas J. (2018) Root exudate metabolomes change under drought and show limited capacity for recovery. *Scientific Reports* 8, 12696

iv) Rivas-Ubach A., Peñuelas J., Antonio Hodar J., Oravec M., Pasa-Tolic L., Urban O., Sardans J. (2019) We Are What We Eat: A stoichiometric and ecometabolomic study of caterpillars feeding on two pine subspecies of *Pinus sylvestris*. *International Journal of Molecular Sciences* 20(1), 59.

5. Target plant metabolomics for deeper insight into specific protective mechanisms in response to environmental stresses. In parallel, methods of target metabolomics focusing on the main groups of primary and secondary metabolites involved in plant protective mechanisms (osmolytes, antioxidants, UV screening compounds, or growth regulators) against biotic and abiotic stressors were developed together with the approaches for the detection of specific compounds (particularly in plants and soils) including pharmaceuticals or compounds associated with human health and diet. Such studies help to identify until yet unexplained interactions of pollution with other factors of climate change and thus to reveal so far unknown risks to future ecosystems. In particular, changes induced by CdO nanoparticles received great attention in the scientific community (over 55 references to Večeřová et al. 2016). The main results are:

i) Večeřová K., Večeřa Z., Dočekal B., Oravec M., Pompeiano A., Tříška J., Urban O. (2016) Changes of primary and secondary metabolites in barley plants exposed to CdO nanoparticles. *Environmental Pollution* 218, 207-218.

ii) Večeřová K., Večeřa Z., Mikuška P., Coufalík P., Oravec M., Dočekal B., Novotná K., Veselá B., Pompeiano A., Urban O. (2019) Temperature alters the susceptibility of *Picea abies* seedlings to airborne pollutants: The case of CdO nanoparticles. *Environmental Pollution* 253, 646-654.

- iii) Klem K., Gargallo-Garriga A., Rattanapichai W., Oravec M., Holub P., Veselá, B., Sardans J., Peñuelas J., Urban O. (2019) Distinct morphological, physiological and biochemical responses to light quality in barley leaves and roots. *Frontiers in Plant Science* Art.No. 1026.
 - iv) Soral I., Vrchotová N., Tříška J., Balík J. (2019) Changes in the Grape Cane Stilbene Content under Various Conditions of Storage. *Sustainable Chemistry & Engineering* 7(24), 19584-19590.
 - v) Kummerová M., Zezulka Š., Babula P., Tříška J. (2016) Possible ecological risk of two pharmaceuticals diclofenac and paracetamol demonstrated on a model plant *Lemna minor*. *Journal of Hazardous Materials* 302, 351-361.
 - vi) Pexová Kalinová J., Tříška J., Vrchotová N., Novák J. (2016) Uptake of caprolactam and its influence on growth and oxygen production of *Desmodesmus quadricauda* algae. *Environmental Pollution* 213, 518-523.
6. Interconnection of omics techniques to understand the whole cascade of plant responses to environmental stresses. The Team is actively working on the connection of metabolomics with other omics techniques. The changes in plant metabolome mentioned above are often studied in parallel with other omics techniques (genomics, transcriptomics, proteomics, etc.) to understand the mechanisms of plant robustness against environmental stressors and their combinations, adjustment of plant fitness, and/or senescence. Such understanding of cascade of reactions in response to environmental stimuli allows to use different types of markers for breeding process and also help to better understand the heritability of the target traits. The examples of the main results of the research group led by the group of prof. Thomas Roitsch are (i-ii) understanding the regulatory role of glucose in the process of pollination having thus paramount importance for agriculture crops, and/or (iii) explanation of the direct link between drought tolerance and a cell wall invertase having the potential to provide a novel strategy to overcome drought-induced limitations in crops.
- i) Goetz M., Guivarčh A., Hirsche J., Bauerfeind A., Gonzalez M.A., Hyun T.K., Eom S.H., Chriqui D., Engelke T., Grosskinsky D.K., Roitsch T. (2017) Metabolic control of tobacco pollination by sugars and invertases. *Plant Physiology* 173(2), 984-997.
 - ii) Großkinsky D.K., Syaifullah S.J., Roitsch T. (2017) Integration of multi-omics techniques and physiological phenotyping within a holistic phenomics approach to study senescence in model and crop plants. *Journal of Experimental Botany* 99, 1-20.
 - iii) Albacete A., Cantero-Navarro E., Grosskinsky D.K., Arias M.L., Balibrea M.E., Bru R., Fagner L., Ghanem M.E., de la Cruz Gonzalez M., Hernández J.A., Martínez-Andújar C., van der Graaff E., Weckwerth W., Zellnig G., Pérez-Alfocea F., Roitsch T. (2015) Ectopic overexpression of the cell wall invertase gene CIN1 leads to dehydration avoidance in tomato. *Journal of Experimental Botany* 66(3), 863-878.
7. Physiological and morphological adjustments of ecosystem components (plant, soil) to environmental variables. Biochemical processes described above are often studied together with detailed acclimation mechanisms of key physiological processes (photosynthesis, respiration, transpiration, etc.) and plant anatomical and morphological adjustments. Such comprehensive studies of mechanisms of plant acclimation remain rare in the literature. These studies enabled to understand functional properties of the photosynthetic apparatus and its specificity in overwintering coniferous species (i-ii), to understand the interactive role of light and environmental

variables on the formation of photosynthetic apparatus in trees grown along an altitudinal gradient (iii), to understand the links between respiratory processes (CO₂ fluxes and different environmental variables for a consequent modelling (iv-v), to understand the interactive effects of two or more environmental stressors on growth and production of model crop species (vi):

i) Karlický V., Kurasová I., Ptáčková B., Večeřová K., Urban O., Špunda V., (2016) Enhanced thermal stability of the thylakoid membranes from spruce. A comparison with selected angiosperms. *Photosynthesis Research* 130(1-3), 357-371.

ii) Semer J., Navrátil M., Špunda V., Štroch M. (2019) Chlorophyll fluorescence parameters to assess utilization of excitation energy in photosystem II independently of changes in leaf absorption. *Journal of Photochemistry and Photobiology. B - Biology Section* 197, 111535.

iii) Rajsnerová P., Klem K., Holub P., Novotná K., Večeřová K., Kozáčíková M., Rivas-Ubach A., Sardans J., Marek M.V., Peñuelas J., Urban O. (2015) Morphological, biochemical and physiological traits of upper and lower canopy leaves of European. *Tree Physiology* 35(1), 47-60.

iv) Acosta M., Dařenová E., Foltýnová L., Pavelka M. (2018) Seasonal and inter-annual variability of soil CO₂ efflux in a Norway spruce forest over an eight-year study. *Agricultural and Forest Meteorology* 256, 93-103.

v) Urban O., Hlaváčková M., Klem K., Novotná K., Rapantová B., Smutná P., Horáková V., Hlavinka P., Škarpa P., Trnka M. (2018) Combined effects of drought and high temperature on photosynthetic characteristics in four winter wheat genotypes. *Field Crops Research* 223, 137-149.

vi) Šebela D., Quiñones C., Cruz C., Ona I., Olejníčková J., Jagadish K.S.V. (2018) Chlorophyll fluorescence and reflectance-based non-invasive quantification of blast, bacterial blight and drought stresses in rice. *Plant and Cell Physiology* 59(1), 30-43.

8. Understanding the changes in carbon and water cycle at the whole ecosystem level to assess mitigation and adaptation potential of the ecosystem under changing climate.

At the whole ecosystem scale, the fluxes of CO₂ and water vapour are particularly estimated by an eddy-covariance method to reflect the vitality and ability of ecosystems to bound carbon. About seven different ecosystems are currently monitored over the whole year. These ecosystem stations form a part of an ESFRI infrastructure ICOS ERIC and the group led by dr. M. Pavelka substantially contributes to the methodological improvement of measuring techniques and international scientific protocols as well as the own research activities of the consortium. The developed worldwide databases enable comparison of responses to climate perturbations in diverse ecosystems. Primarily, changes in carbon uptake under drought/heatwave periods, spatio-temporal of ecosystem activity at a continental scale, etc. are studied. Such summarizing and integrating studies generate robust findings and are generally highly cited. These studies contribute in particular to global estimates of the impact of climate change on ecosystems, carbon sequestration and, where relevant, on other ecosystem functions. They provide also important data for the development and planning of adaptation and mitigation measures. The examples are:

i) Wu X., Liu H., Li X., Ciais P., Babst F., Guo W., Zhang C., Magliulo V., Pavelka M., Liu S., Huang Y., Wang P., Shi C.D., Ma Y. (2018) Differentiating drought legacy

- effects on vegetation growth over the temperate Northern Hemisphere. *Global Change Biology* 24(1), 504-516.
- ii) Anav A., Friedlingstein P., Beer Ch., Cias P., Harper A., Jones Ch., Murray-Tortarolo G., Papale D., Parazoo N.C., Peylin P., Piao S., Sitch S., Viovy N., Wiltshire A., Zhao M. (2015) Spatiotemporal patterns of terrestrial gross primary production: A review. *Reviews of Geophysics* 53(3), 785-818.
 - iii) Besnard S., Carvalhaisa N., ..., Havránková K., Foltýnová L., ..., Reichstein M. (2018) Quantifying the effect of forest age in annual net forest carbon 2 balance. *Environmental Research Letters* 13(12), 124018.
 - iv) Crabbe R.A., Dash J., Rodriguez-Galiano V.F., Janouš D., Pavelka M., Marek M.V. (2016) Extreme warm temperatures alter forest phenology and productivity in Europe. *Science of the Total Environment* 563-564, 486-495.
 - v) Crabbe R.A., Janouš D., Dařenová E., Pavelka M. (2019) Exploring the potential of LANDSAT-8 for estimation of forest soil CO₂ efflux. *International Journal of Applied Earth Observation and Geoinformation* 77, 42-52.
 - vi) McGloin R., Šigut L., Havránková K., Dušek J., Pavelka M., Sedlák P. (2018) Energy balance closure at a variety of ecosystems in Central Europe with contrasting topographies. *Agricultural and Forest Meteorology* 248, 418-431.
9. Determination of phytotoxic ozone and volatile organic compounds fluxes in ecosystems having the risk potential of biologically driven air pollution. Applications of eddy-covariance method are further expanded. The Team, for the first time in the Czech Republic, realized eddy-covariance measurements of fluxes of volatile organic compounds (i) and ozone (ii) between the forest ecosystems and the atmosphere. For example, parametrization of MEGAN model with seasonal emissions of monoterpenes from sun and shade leaves substantially increased the accuracy of the model. We have also for the first time shown that sky conditions, not only ozone concentration, influence the rate of the uptake of this phytotoxic gas depending on stomata openness and thus modulating the O₃-induced injuries. The fluxes are further calculated on the base of gradient measurements and the data are used to model annual changes in gross primary production and/or changes in atmospheric chemistry. These data significantly improve the accuracy of predictions of potential ozone damages to plants in terms of climate change impacts on ecosystem services (especially biodiversity), and also allow to propose possible measures eliminating this damaging effect.
- i) Juráň S., Pallozi E., Guidolotti G., Fares S., Šigut L., Calfapietra C., Alivernini A., Savi F., Večeřová K., Křůmal K., Večeřa Z., Urban O. (2017) Fluxes of biogenic volatile organic compounds above temperate Norway spruce forest of the Czech Republic. *Agricultural and Forest Meteorology* 232, 500-513.
 - ii) Juráň S., Šigut L., Holub P., Fares S., Klem K., Grace J., Urban O. (2019) Ozone flux and ozone deposition in a mountain spruce forest are modulated by sky conditions. *Science of the Total Environment* 672, 296-304.
10. Development of remote sensing methods/indices for estimation of ecosystem functions. Remote sensing represents a great tool for analysing the ecosystem functions and services on the scale of the region and higher or for the long-term continuous monitoring. The evaluated Team provides also basic data about plant optical properties, changes in spectral-reflectance and/or remotely sensed chlorophyll fluorescence signal from plants under various stress conditions. These findings

consequently enable a series of applications in remote sensing, precision agriculture, and/or early-stress detection. Such studies allow spatially differentiated decision-making at the level of the landscape (strategic landscape planning) or agricultural land (support of site-specific management and using of precision agriculture technologies). Among others, we have shown that passive chlorophyll fluorescence can be used as a tool to monitor the physiological status of plants (i), ability of air-borne sensed fluorescence signal to track changes in carbon uptake at ecosystem level (ii), we suggested an algorithm for the correction of widely used PRI index to better estimate light-use efficiency (iii), and ability of spectral reflectance and infrared thermal imaging to detect interactions between the nitrogen and water availability in field crops (iv).

i) Ač A., Malenovský Z., Olejníčková J., Gallé A., Rascher U., Mohammed G. (2015) Meta-analysis assessing potential of steady-state chlorophyll fluorescence for remote sensing detection of plant water, temperature and nitrogen stress. *Remote Sensing of Environment* 168, 420-436.

ii) Rossini P.M., Nedbal L., Guanter L., Ač A., ..., Hanuš J., Janoutová R., ..., Novotný J., ..., Zemek F., Rascher U. (2015) Red and far-red Sun-induced chlorophyll fluorescence as a measure of plant photosynthesis. *Geophysical Research Letters* 42(6), 1632-1639.

iii) Kováč D., Veselovská P., Klem K., Večeřová K., Ač A., Peñuelas J., Urban O. (2018) Potential of Photochemical Reflectance Index for indicating photochemistry and Light Use Efficiency in leaves of European beech and Norway spruce trees. *Remote Sensing* 10(8), 1202.

iv) Klem K., Záhora J., Zemek F., Trunda P., Tůma I., Novotná K., Hodaňová P., Rapantová B., Hanuš J., Vavříková J., Holub P. (2018) Interactive effects of water deficit and nitrogen nutrition on winter wheat. Remote sensing methods for their detection. *Agricultural Water Management* 210, 171-184.

11. Changes in bio-geochemical cycles under changing environmental conditions. This research addressed investigation how changing climate contributes to biologically driven pollution and vice versa. At the level of landscape/water catchments, a combined effect of past high deposition of sulphur, ongoing deposition of nitrogen and global change on forest soil, soil-water, stream water, forest condition and biodiversity is particularly investigated. The network of forested catchments (GEOMON) is used to measure relevant data allowing, among others, (i) evaluation of effective nitrogen sequestration in forested boreal catchments, (ii) understanding the role of acid deposition and nitrogen enrichment on carbon balance in forest ecosystems, (iii) clarification of links between nitrogen availability and environmental conditions, and/or (iii) description mechanisms of heavy metals accumulations, which all help in identification of measures stabilizing the ecosystems and their functions under ongoing climate change.

i) Moldan F., Jutterstrom S.E.A-K., Hruška J., Wright R. (2018) Experimental addition of nitrogen to a whole forest ecosystem at Gardsjon, Sweden (NITREX): Nitrate leaching during 26 years of treatment. *Environmental Pollution* 242, 367-374.

ii) Oulehle F., Tahovská K., Chuman T., Evans C.D., Hruška J., Růžek M., Bárta J. (2018) Comparison of the impacts of acid and nitrogen additions on carbon fluxes in European conifer and broadleaf forests. *Environmental Pollution* 238, 884-893.

- iii) Cienciala E., Russ R., Šantrůčková H., Altman J., Kopáček J., Hůnová I., Štěpánek P., Oulehle F., Tumajer J., Stáhl G. (2016) Discerning environmental factors affecting current tree growth in Central Europe. *Science of the Total Environment* 573, 541-554.
- iv) Bohdálková L., Bohdálek P., Břízová E., Pacheroová P., Kuběna A.A. (2018) Atmospheric metal pollution records in the Kovářská Bog (Czech Republic) as an indicator of anthropogenic activities over the last three millennia. *Science of the Total Environment* 633, 857-874.
12. Biodiversity risks under changing environmental conditions and natural disturbances. The research group lead by prof. P. Kindlmann discovered more than new 200 orchid species which were used as indicators for effects of climate change on biodiversity. Most of them were found in South America (Bolivia, Peru, Ecuador, Colombia). One of the findings, *Telipogon diabolicus*, was included in the list of the Top 10 New Species (announced in 2017). Except the spreading the information via Washington Post, Discovery Channel and National Geographic, the following key papers on biodiversity conservation were published in scientific journals. The findings can be used as an initial means of identifying and prioritizing areas of conservation concern. The findings also point out missing guidelines for the forest management in the European national parks facing natural disturbances (windstorms, bark beetle).
- i) Traxmandlová I., Ackerman J.D., Tremblay R.L., Roberts D.L., Štípková Z., Kindlmann P. (2018) Determinants of orchid species diversity in world islands. *New Phytologist* 217(1), 12-15
- ii) Finerty G.E., de Bello F., Bílá K., Berg M.P., Dias A.T.C., Pezzatti G.B., Moretti M. (2016) Exotic or not, leaf trait dissimilarity modulates the effect of dominant species on mixed litter decomposition. *Journal of Ecology* 104(5), 1400-1409.
- iii) Kukwa M., Kolanowska M. (2016) Glacial refugia and the prediction of future habitat coverage of the South American lichen species *Ochrolechia austroamericana*. *Scientific Reports* 6, 38779.
- iv) Kolanowska M., Kras M., Lipińska M., Mystkowska K., Szlachetko D.L., Naczek A.M. (2017) Global warming not so harmful for all plants-response of holomycotrophic orchid species for the future climate change. *Scientific Reports* 7(1), 12704.
- v) Zýval V., Křenová Z., Kindlmann P. (2016) Conservation implications of forest changes caused by bark beetle management in the Šumava National Park. *Biological Conservation* 204(part B), 394-402.
- vi) Banasiak L., Pietras M., Wrzosek M., Okrasinska A., Gorczak M., Kolanowska M., Pawlowska H. (2019) *Aureoboletus projectellus* (Fungi, Boletales) An American bolete rapidly spreading in Europe as a new model species for studying expansion of macrofungi. *Fungal Ecology* 39, 94-99.
13. Advances I biotechnological use of photoautotrophic microorganisms. The basic research of the Team is also focused on potential biotechnological applications, especially in the field of the research on photosynthetic microorganisms producing valuable compounds and the development of large-scale bioreactors. The experimental studies are mainly focused on the investigation of key physiological and biochemical parameters (metabolic pathways) regulating the growth of microorganisms and being associated with optimal growth conditions in bioreactors (i). The aspect of maximum production of specific metabolites like ethylene (ii) or nocuolin (iii) having the potential applications in biofuel production or pharmaceutical anti-

cancer research. The new and original method of the usage of the microalgal biofilms for phosphorus removal indicates the great potential in the tertiary treatment of wastewater has been developed (iv).

i) Zavřel T., Faizi M., Loureiro C., Poschmann G., Stuehler K., Sinětova M.A., Zorina A., Steuer R., Červený J. (2019) Quantitative insights into the cyanobacterial cell economy. *eLife* 8, e42508.

ii) Zavřel T., Knoop H., Steuer R., Jones P.R., Červený J., Trtílek M. (2016) A quantitative evaluation of ethylene production in the recombinant cyanobacterium *Synechocystis* sp PCC 6803 harboring the ethylene-forming enzyme by membrane inlet mass spectrometry. *Bioresource Technology* 202, 142-151.

iii) Chmelík D., Hrouzek P., Fedorko J., Vu D.L., Urajová P., Mareš J., Červený J. (2019) Accumulation of cyanobacterial oxadiazine nocuolin A is enhanced by temperature shift during cultivation and is promoted by bacterial co-habitants in the culture. *Algal Research-Biomass Biofuels and Bioproducts* 44, 101673.

iv) Sukačová K., Trtílek M., Rataj T. (2015) Phosphorus removal using a microalgal biofilm in a new biofilm photobioreactor for tertiary wastewater treatment. *Water Research* 2015 75, 55-63

II. The applied outputs/results

Applied results are usually created in parallel with the results of basic research, while also the basic research itself aims to contribute to solving major societal challenges, such as increasing food safety and use the results to improve human health, to reduce environmental pollution, to develop tools for climate change adaptation, for plant breeding and selection, decision support tools for policy-makers and farmers in changing environmental conditions, and/or for the rapid development of microalgae biotechnologies. The applied results represent a number of procedures, methodologies, decision-making tools, software, technologies, etc., which allow direct use of results obtained in basic research to achieve main goals of team, i.e. reduction of climate change impacts on ecosystems and landscape, reduction of environmental burden in connection with management in forests and especially agriculture, the development of mitigation measures (reduction of greenhouse gas emissions and increased carbon sequestration) and the development of adaptation measures for increased security of food production and ecosystem stability in response to climate change (higher water and soil water retention, pesticides and industrial fertilizers, improved resistance to direct and indirect factors of climate change).

Patents, utility models, demonstrators connected with Team activities: 5

1. Patent N. 306700: Híc, P.; Balík, J.; Kulichová, J.; Tříška, J.; Strohalm, J.; Vrchotová, N.; Houška, M. Process for production of lignans for food purposes by extraction from knots of conifers. Food Research Institute Prague - Hostivar, CZ; Mendel University in Brno, Faculty of Horticulture, Lednice, CZ; GCRI, Brno, CZ. 2017. Date of grant of the patent: 05.04.2017. The infrastructure of the analytical laboratory (liquid and gas chromatography) was used to achieve the result.
2. Patent N. 307453: Kulichova, J.; Balík, J.; Hic, P.; Horak, M.; Tříška, J.; Vrchotová, N.; Houška, M.; Strohalm, J.; Novotná, P. Chocolate with increased content of natural

- lignans. Mendel University in Brno, Faculty of Horticulture, Institute of Post-Harvest Technology of Horticultural Products; GCRI; Food Research Institute Prague. 2018. Date of granting the patent: 25.07.2018. The infrastructure of the analytical laboratory (liquid and gas chromatography) was used to achieve the result.
3. Utility model N. 30250: Kulichová, J.; Balík, J.; Híc, P.; Horák, M.; Tříška, J.; Vrchotová, N.; Houška, M.; Strohalm, J.; Novotná, P. Chocolate with increased content of natural lignans. Mendel University in Brno, Faculty of Horticulture, Institute of Post-Harvest Technology of Horticultural Products, Lednice; GCRI; Food Research Institute Prague, 10.01.2017. The infrastructure of the analytical laboratory (liquid and gas chromatography) was used to achieve the result.
 4. Utility Model N. 30654: Balík, J.; Híc, P.; Sural, I.; Kulichová, J.; Tříška, J.; Vrchotová, N. Drink enriched with vine extract. Mendel University in Brno, Faculty of Horticulture, Lednice; GCRI, 11.05.2017. The infrastructure of analytical laboratory (liquid and gas chromatography) was used to achieve the result.
 5. Functional sample: Pavelka M., Trtílek M.: Automatic system for measuring the gas exchange of plant organs (SAMRRO). Brno: GCRI, Photon Systems Instruments s.r.o., 2016. The observatory infrastructure of ecosystem stations where the developed systems were tested was used to achieve the result.

Certified methodologies: 7

6. Certified methodology: Pokorný, R.: Determination of Leaf Area Index in non-mixed forest canopies, 2015. Canopy analyser and a set of radiation sensors were particularly used to achieve the result.
7. Certified methodology: Zemek, F.; Píkl, M.; Holub, P.; Klem, K.; Záhora, J.; Vavříková, J. Methods of evaluation of the potential vulnerability of groundwater to reactive nitrogen in the cultivation of field crops on arable land, 2017. Infrastructures of manipulation experiments, ecophysiological laboratory, and remote sensing were used to achieve the result.
8. Certified methodology: Zemek, F.; Píkl, M.; Lukas, V.; Ždímal, V.; Kraus, M.; Širůček, P. Evaluation of area heterogeneity of selected soil properties of plots based on image spectroscopy and satellite data, 2018. Infrastructures of manipulation experiments, ecophysiological laboratory, and remote sensing were used to achieve the result.
9. Certified methodology: Lukas, V.; Neudert, L.; Širůček, P.; Kraus, M.; Novák, J.; Mizera, J.; Zemek, F.; Píkl, M.; Žížala, D. Procedures for creating maps taking into account the variability of the agrochemical properties of the soil and the yield level of the land, 2018. The infrastructure of remote sensing was used to achieve the result.
10. Certified methodology: Klem, K.; Veselá, B.; Holub, P.; Urban, O.; Mezera, J. Methods of detection of fungal diseases usable in plant phenotyping and remote sensing, 2018. Infrastructures of manipulation experiments and ecophysiological laboratory were used to achieve the result.
11. Certified methodology: Smutný, V.; Winkler, J.; Klem, K. Integrated Weed Control in Cereals, 2018. Infrastructures of manipulation experiments and ecophysiological laboratory were used to achieve the result.
12. Certified methodology: Krejza, J.; Světlík, J.; Bellan, M.; Horáček, P. Determination of stress responses in Norway spruce forest by direct methods, 2019. Automatic-

dendrometers, plant canopy analyser, and micro-climate sensors and data-loggers were particularly used to achieve the result.

Software Products: 7

13. Software: Klem, K.; Pokrývka, F. OculimaCast - Software for prediction of winter wheat infestation by eyespot (*Oculimacula yallundae* and *Oculimacula acuformis*), 2017. Infrastructures of manipulation experiments and ecophysiological laboratory were used to achieve the result.
14. Software: Klem, K.; Pokrývka, F. GaeumaCast - Software for prediction of winter wheat infestation by take-all (2017 by *Gaeumannomyces graminis*), 2017. Infrastructures of manipulation experiments and ecophysiological laboratory were used to achieve the result.
15. Software: Klem, K.; Pokrývka, F. NitroSpec - software for estimation of nitrogen status in spring barrels using hyperspectral data, 2017. Infrastructures of manipulation experiments and ecophysiological laboratory were used to achieve the result.
16. Software: Klem, K.; Pokrývka, F. WPD Software 0.1 Weed Population Dynamics model - Software for simulating weed population dynamics (number of emerging plants), 2018. Infrastructures of manipulation experiments and ecophysiological laboratory were used to achieve the result.
17. Software: Wutzler, T.; Reichstein, M.; Moffat, A.M.; Menzer, O., Migliavacca, M.; Sickel, K.; Šigut, L. REddyProc 1.1.6. Department of Biogeochemical Integration, MPI-BGC, Jena, Germany; Global Change Research Institute CAS, Brno, CZ, 2018. An observation infrastructure was used to achieve the result.
18. Software: Šigut, L.; Mauder, M.; Sedlák, P.; Wutzler, T., Fischer, M.; Mžourková Macálková, L., McGloin, R.P.; Fratini, G. Openeddy 0.0.0.9004. Global Change Research Institute CAS, Brno; University of Ostrava, 2018. The observation infrastructure was used to achieve the result.
19. Software: Červený, J. Photobioreactor Control Scripts 1.0., 2019. A set of Control Scripts for PSI Bioreactor Client software. These scripts allow you to automate both basic and advanced features that are not available in standard client software distribution. The infrastructures of manipulation experiments and ecophysiological laboratories were used to achieve the result.

Research activity and characterisation of the main scientific results

Within the evaluation period, the team produced an atypically high amount for a relatively small team focused on the social sciences - 29 impact factor journal papers, a further 18 papers in journals without impact factor, 10 book chapters, 5 certified methodologies, and 1 software. Further outputs are being developed from projects that ran during the evaluation period. The team maintains a balanced ratio of basic research and outputs for practice, ensuring immediate feedback, up-to-date focus of research, continuous adjustment of basic research to the needs of the application sphere or societal challenges.

For each research area (outlined above), the outputs are described in terms of their contributions and relevance for solving global challenges. Team authors of the outputs are shown in bold.

1. Hazard and risk adaptation and management

Basic as well as applied research projects addressing natural hazards, risks and adaptation to climate change were successfully completed during the evaluation period 2015-2019 (see table below). These were both national (e.g. TAČR) and international (e.g. LIFE) projects. Additionally, some of the produced scientific outcomes were not directly related to a specific project, but long-term research activities. Scientific results (published papers) generally follow established research directions and geographical scope within this team research area: (i) findings on climate change adaptation in urban areas; (ii) findings on hazardous processes in high mountain regions.

We are one of very few teams in Czechia working on issues with relation to natural hazard science and disaster risk reduction. We are pleased to have been establishing a reputation within this field, both domestically, and internationally. This is demonstrated by an increasing number of publications in high impact-factor journals, particularly on the topics of (i) high mountain geomorphology and earth surface dynamics; (ii) rapid mass movements, lake outburst floods (GLOFs) and hazardous cascading processes; (iii) glacier retreat and geo-environmental changes in deglaciated areas. Our results in this area explicitly link climate change induced physical impacts to risks to society. For example, by quantifying the impact of glacier melt on drinking water supplies, and the risk of landslides and floods. This academic contribution shapes our systemic understanding of the risks of climate change. Practically, it feeds into risk planning. For example, we are working with United Nations Development Programme (UNDP) in Georgia to plan landslide risks in mountainous areas. Our outputs in this topic relate to identifying and documenting hazards (papers 1 to 10); methodological contributions as to how to identify hazards (papers 11 to 13), and critique of disaster risk response approaches (paper 14). The geographical scope of this research is within mountainous areas, but covers much of the world, including the Andes (e.g. paper 1), the Himalayas (paper 6) and the Alps (paper 10).

The outputs produced on this topic are shaping the way in which we understand natural hazards, and the way in which we can respond to them. Results are being picked up for risk response strategies across mountainous areas (e.g. via the UNDP).

1. **Emmer, A.**; Juřicová, A.; Veettil, B. K. Glacier retreat, rock weathering and the growth of lichens in the Churup Valley, Peruvian Tropical Andes. *Journal of Mountain Science* 16(7): 1485-1499, 2019
2. Harrison, S.; Kargel, J.; Huggel, C.; Reynolds, J.; Shugar, D.; Betts, R.; **Emmer, A.**; Glasser, N.; Haritashya, U.; Klimeš, J.; Reinhardt, L.; Schaub, Y.; Wiltshire, A.; Regmi, D.; Vilímek, V. Climate change and the global pattern of moraine-dammed glacial lake outburst floods. *The Cryosphere* 12: 1195-1209, 2018
3. Tacconi Stefanelli, C.; Vilímek, V.; **Emmer, A.**; Catani, F. Morphological analysis and features of the landslide dams in the Cordillera Blanca, Peru. *Landslides* 15(3): 507-521, 2018
4. **Emmer, A.** Geomorphologically effective floods from moraine-dammed lakes in the Cordillera Blanca, Peru. *Quaternary Science Reviews* 177(177): 220-234, 2017
5. Klimeš, J.; Hartvich, F.; Tábořík, P.; Blahůt, J.; Briestenský, M.; Stemberk, J.; **Emmer, A.**; Vargas, R.; Balek, J. Studies on selected landslides and their societal impacts: activity report of the Prague World Centre of Excellence, Czech Republic. *Landslides* 14(4): 1547-1553, 2017
6. Aggarwal, S.; Rai, S.; Thakur, P. K.; **Emmer, A.** Inventory and recently increasing GLOF susceptibility of glacial lakes in Sikkim, Eastern Himalaya. *Geomorphology* 30(295): 39-54, 2017
7. **Emmer, A.**; Kalvoda, J. The origin and evolution of Iskanderkul Lake in the western Tien Shan and related geomorphic hazards. *Geografiska Annaler: Series A, Physical Geography* 99(2): 139-154, 2017
8. Klimeš, J.; Novotný, J.; Novotná, I.; Jordán de Urries, B.; Vilímek, V.; **Emmer, A.**; Strozzi, T.; Kusák, M.; Cochachin, A.; Hartvich, F.; Frey, H. Landslides in moraines as triggers of glacial lake outburst floods: example from Palcacocha Lake (Cordillera Blanca, Peru). *Landslides* 13(6): 1461-1477, 2016
9. **Emmer, A.**; Klimeš, J.; Mergili, M.; Vilímek, V.; Cochachin, A. 882 lakes of the Cordillera Blanca: An inventory, classification, evolution and assessment of susceptibility to outburst floods. *Catena* 43(147): 269-279, 2016
10. **Emmer, A.**; Merkl, S.; Mergili, M. Spatiotemporal patterns of high-mountain lakes and related hazards in western Austria. *Geomorphology* 28(246): 602-616, 2015
11. Mergili, M.; **Emmer, A.**; Juřicová, A.; Cochachin, A.; Fischer, J.; Huggel, C.; Pudasaini, S. How well can we simulate complex hydro-geomorphic process chains? The 2012 multi-lake outburst flood in the Santa Cruz Valley (Cordillera Blanca, Perú). *Earth Surface Processes and Landforms* 43: 1373-1389, 2018
12. **Emmer, A.** GLOFs in the WOS: bibliometrics, geographies and global trends of research on glacial lake outburst floods (Web of Science, 1979–2016). *Natural Hazards and Earth System Sciences* 18: 813-827, 2018

13. **Emmer, A.**; Vilímek, V.; Huggel, C.; Klimeš, J.; Schaub, Y. Limits and challenges to compiling and developing a database of glacial lake outburst floods. *Landslides* 13(6): 1579-1584, 2016
14. **Emmer, A.**; Vilímek, V.; Zapata, M. Hazard mitigation of glacial lake outburst floods in the Cordillera Blanca (Peru): the effectiveness of remedial works. *Journal of Flood Risk Management* 11(1): 489-501, 2018

Our work on urban adaptation to climate change has provided direct input to strategies and planning at multiple levels in the Czech Republic. We had nine separate projects on adaptation to climate change during the project period. Project results have informed the current climate adaptation strategy for Prague, an online decision support tool (<http://www.opatreni-adaptace.cz/>), and a database for information exchange on the impacts, risks, vulnerabilities and adaptation measures (<https://www.klimatickazmena.cz/en/about-us/about-project/>). The outputs for this research topic include methodological contributions on the role of participation in climate change adaptation (papers 1 to 2), and assessments of risk that draw on ecosystem services approaches, and thus link to research area of ecosystem services (papers 3 to 5). We have conducted research in both urban (e.g. paper 1) and rural environments (paper 5), and have contributed to understanding how adaptation needs to occur across different sectors and scales (papers 6 and 7). We have thus generated a broad understanding of how climate changes risks are responded to in different contexts (including e.g. Piloting SEEA-EEA activity in Kyrgyzstan).

The results in this area have expanded our scientific framings of risk, to explicitly include the impacts of climate change with significant activities abroad. We have therefore made explicit the link between the climate mitigation and adaptation research community, and that on more traditional risk management (e.g. earthquakes, landslides, etc.). We are therefore able to create more informed risk responses.

1. **Vačkář, D.**; **Krkoška Lorencová, E.** Aplikace participativní metody World Café v oblasti globálních problémů životního prostředí. *Envigogika* 12(2): 1-25, 2017 (Application of participatory method world café in the area of global environmental problems)
2. Certified methodology: **Pártl, A.**; **Loučková, B.**; Hák, T.; Janoušková, S.; **Krkoška Lorencová, E.**; Rejentová, L.; Stein, Z.; **Vačkář, D.** Metodika hodnocení environmentálního rizika pro poskytování ekosystémových služeb. 2016. (Methodology for the assessment of environmental risk of ecosystem services provision)
3. **Krkoška Lorencová, E.**; **Horáková, C.**; Bašta, P.; **Harmáčková, Z. V.**; Štěpánek, P.; Zahradníček, P.; Farda, A.; **Vačkář, D.** Participatory Climate Change Impact Assessment in Three Czech Cities: The Case of Heatwaves. *Sustainability* 10(6): 1-21, Article number 1906, 2018
4. **Pártl, A.**; **Vačkář, D.**; **Loučková, B.**; **Krkoška Lorencová, E.** A spatial analysis of integrated risk: vulnerability of ecosystem services provisioning to different hazards in the Czech Republic. *Natural Hazards* 2017: 1-20, 2017 (links two themes)

5. **Harmáčková, Z. V.; Krkoška Lorencová, E.; Vačkář, D.** Ecosystem-Based Adaptation and Disaster Risk Reduction: Costs and Benefits of Participatory Ecosystem Services Scenarios for Šumava National Park, Czech Republic. In Renaud, F. G.; Sudmeier-Rieux, K.; Estrella, M.; Nehren, U. (Eds): Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice, p. 99-129. ISBN 978-3-319-43631-9, ISSN 1878-9897, 2016
6. **Krkoška Lorencová, E.; Loučková, B.; Vačkář, D.** Perception of Climate Change Risk and Adaptation in the Czech Republic. *Climate* 7(5): Article number 61, 2019
7. Bouwer, L.; Capriolo, A.; Chiabai, A.; Foudi, S.; Garrote, L.; **Harmáčková, Z. V.**; Iglesias, A.; Jeuken, A. B.; Olazabal, M.; Spadaro, J.; Taylor, T.; Zandersen, M. Upscaling the Impacts of Climate Change in Different Sectors and Adaptation Strategies. In Sanderson, H.; Hildén, M.; Russel, D.; Penha-Lopes, G.; Capriolo, A. (Eds): Adapting to Climate Change in Europe: Exploring Sustainable Pathways - From Local Measures to Wider Policies, p. 173-243. ISBN 9780128498873, ISSN 9780128498750, 2018

2. Ecosystem services

The area of ecosystem services continues to thrive. This is the area around which the team was initially conceived, and the basis for synergistic cooperation with other CzechGlobe teams and for the application of social-economic considerations in the overall research of the CzechGlobe were built. Also the other 2 areas often interact closely with this area, for example drawing on ecosystem services as a framework for analyzing and assessing climate change adaptation. A number of important projects have been funded and run during this assessment period. In particular, the Life Integrated Project (project 16) will establish effective management for Natura 2000 sites across Czechia, drawing on understandings of ecosystem services. We are the coordinating team for this project. Outputs in this area relate to improvements in how we identify and map ecosystem services, and create tools for planning and monitoring (papers to 4). We have also been involved in critical research exploring the challenges to establishing research infrastructure for continued monitoring of ecosystem services (papers 1 and 5). Furthermore, through involvement in the IPBES process, we have contributed to critical debates as to the role and function of the ecosystem services framework (paper 6). The work in this section has global importance for shaping the way in which we understand, value, and make decisions around biodiversity. The team has been at the forefront of advancing analytical frameworks, and valuation approaches to ensure that biodiversity is considered in decision making and planning.

1. Certified methodology: **Harmáčková, Z. V.**; Rynda, I.; **Vačkář, D.** Metodika rozvoje dlouhodobého sociálně-ekologického monitoringu (LTSER) v biosférických rezervacích České republiky, 2015. (Methodology for developing long-term social-ecological monitoring (LTSER) in biosphere reserves in the Czech Republic.)
2. Certified methodology: **Vačkář, D.**; **Frélichová, J.**; **Krkoška Lorencová, E.**; **Pártl, A.**; **Harmáčková, Z. V.**; Loučková, B. Metodologický rámec

- integrovaného hodnocení ekosystémových služeb v České republice, 2015. (Methodological framework for integrated assessment of ecosystem services in the Czech Republic.)
3. Certified methodology: **Frélichová, J.; Harmáčková, Z. V.; Pártl, A.; Vačkář, D.** Metodika hodnocení ekosystémových služeb v sídlech v České republice, 2017. (Methodology for assessment of urban ecosystem services in the Czech Republic)
 4. Burkhard, B.; Maes, J.; Potschin-Young, M.; Santos-Martín, F.; Geneletti, D.; Stoev, P.; Kopperoinen, L.; Adamescu, C.; Adem Esmail, B.; Arany, I.; Arnell, A.; Balzan, M.; Barton, D.; van Beukering, P.; Bicking, S.; Borges, P.; Borisova, B.; Braat, L.; Brander, L.; Bratanova-Doncheva, S.; Broekx, S.; Brown, C.; Cazacu, C.; Crossman, N.; Czúcz, B.; **Daněk, J.; Frélichová, J.; Vačkář, D.**; Groot, R.; Depellegrin, D. Mapping and assessing ecosystem services in the EU - Lessons learned from the ESERALDA approach of integration. *One Ecosystem* 2018, roč 3: 1-20, 2018
 5. López-Ballesteros, A.; Beck, J.; Bombelli, A.; Grieco, E.; **Krkoška Lorencová, E.**; Merbold, L.; Brümmer, C.; Hugo, W.; Scholes, W.; **Vačkář, D.**; Vermeulen, A.; Acosta, M.; Butterbach-Bahl, K.; Helmschrot, J.; Kim, D. G.; Jones, M. J.; Jorch, V.; Pavelka, M.; Skjelvan, I.; Saunders, M. Towards a feasible and representative pan-African research infrastructure network for GHG observations. *Environmental Research Letters* 13(8): Article number 85003, 2018
 6. Kadykalo, A. N.; Lopez-Rodriguez, M. D.; Ainscough, J.; Droste, N.; Ryu, H.; Avila-Flores, G.; Le Clec'h, S.; Munoz, M. C.; Nilsson, L.; Rana, S.; Sarkar, P.; Sevecke, K. J.; **Harmáčková, Z. V.** Disentangling 'ecosystem services' and 'nature's contributions to people'. *Ecosystems and People* 2019(15): 269-289, 2019

In particular, we are developing a niche within the field of cultural ecosystem services. Cultural ES are flagged as being of key importance in the preservation and management of biodiversity. Under the Life IP project (project 16), and CultES (project 20), we are creating methodologies for the identification and (non-monetary) valuation of cultural ecosystem services (papers I and II). In addition, we are exploring the disaggregated benefits derived from such ecosystem services, and understanding the trade-offs and synergies in their management. Linking into such trade-offs, we have focused on potential future ecosystem services provision under changing social and environmental conditions (papers 3 to 8). Such work is essential in ensuring that biodiversity is preserved for its non-monetary importance, and feeds into cutting edge global research on the trade-offs in biodiversity decision making.

1. **Daněk, J.; Zelený, J.; Pecka, S.; Vačkář, D.** Exploring and Visualizing Stakeholder Value Regimes in the Context of Peri-Urban Park Planning. *Society & Natural Resources* 33: 1-14, 2019

2. Luo, Y.; Zhang, L.; Zeng, Y.; Fu, B.; **Horáková, C.**; Liu, S.; Wu, B. Representation of critical natural capital in China. *Conservation Biology* 31(4): 894-902, 2017
3. Weinzettel, J.; **Vačkář, D.**; Medková, H. Potential net primary production footprint of agriculture: A global trade analysis. *Journal of Industrial Ecology* 23(5): 1133-1142, 2019
4. **Harmáčková, Z. V.**; **Vačkář, D.** Future uncertainty in scenarios of ecosystem services provision: Linking differences among narratives and outcomes. *Ecosystem services* 33: 134-145, 2018
5. **Vačkář, D.**; **Harmáčková, Z. V.**; Kaňková, H.; Stupková, K. Human transformation of ecosystems: Comparing protected and unprotected areas with natural baselines. *Ecological Indicators* 66: 321-328, 2016
6. **Harmáčková, Z. V.**; **Vačkář, D.** Modelling regulating ecosystem services trade-offs across landscape scenarios in Trebonsko Wetlands Biosphere Reserve, Czech Republic. *Ecological Modelling* 2015(295): 207-215, 2015
7. **Krkoška Lorencová, E.**; **Harmáčková, Z. V.**; Landová, L.; **Pártl, A.**; **Vačkář, D.** Assessing impact of land use and climate change on regulating ecosystem services in the Czech Republic. *Ecosystem Health and Sustainability* 2(3): 1-12, 2016
8. **Frélichová, J.**; Fanta, J. Ecosystem service availability in view of long-term land-use changes: a regional case study in the Czech Republic. *Ecosystem Health and Sustainability* 1(9): 31, 2015

We are shaping methodologies and knowledge around the financial valuation of ecosystem services. For example, under the H2020 MAIA project (project 19), we are valuing ecosystem services, and developing understandings of ecosystem service accounting, and cost-benefit analysis. Contributions in this area are both methodological, in terms of how to elicit value (papers 1 to 3), and applied (papers 4 to 6). This is a strong contribution to environmental economics, and researchers in this area were quickly gaining international reputations in this regard.

1. Certified methodology: **Vačkář, D.**; **Grammatikopoulou, I.**; **Harmáčková, Z. V.** Metodika tvorby ekosystémových účtů na národní úrovni, 2018. (Methodology for ecosystem accounting at the national level)
2. **Bad'ura, T.**; Ferrini, S.; Michael, B.; Binner, A.; Bateman, I. J. Using Individualised Choice Maps to Capture the Spatial Dimensions of Value Within Choice Experiments. *Environmental and Resource Economics* 2019: 1-26, 2019
3. **Vačkář, D.**; **Grammatikopoulou, I.**; **Daněk, J.**; **Krkoška Lorencová, E.** Methodological aspects of ecosystem service valuation at the national level. *One Ecosystem* 2018, roč 3: 1-21, 2018
4. Turner, K.; **Bad'ura, T.**; Ferrini, S. Natural capital accounting perspectives: a pragmatic way forward. *Ecosystem Health and Sustainability* 2019: Article number 1, 2019

5. Torres-Miralles, M.; **Grammatikopoulou, I.**; Rescia, A. Employing contingent and inferred valuation methods to evaluate the conservation of olive groves and associated ecosystem services in Andalusia (Spain). *Ecosystem services* 26: 258-269, 2017
6. **Vačkářů, D.**; **Grammatikopoulou, I.** Toward development of ecosystem asset accounts at the national level. *Ecosystem Health and Sustainability* 5(1): 36-46, 2019

3. Systems changes and transformation

Foundations of a new research area have been laid during this reporting period, for example by the submission of research proposals, and the establishment of an institutional project on carbon governance in Ghana. This new research area is now fully developing in the team. We focus on critical social ecological systems research, and contribute to expert discussions as to how we can create fundamental systems change for sustainable futures. We are thus intensifying international cooperation and cooperation within CzechGlobe. Due to early stage of these research activities we do not have much as results for this reporting period. Emerging results relate to critical consideration of the way in which ecological systems are nested within broader social, economic and political systems, and seek ways to envision alternative systems (e.g. scenario planning). Papers 1 and 2 here are outcomes from involvement in the influential Intergovernmental United Nations' Panel on Biodiversity and Ecosystem Services (IPBES) – see section "Participation of team members in activities of scientific community".

This research area is leading the scientific focus on how we transition to a more sustainable society. There is an increasing level of interest globally in alternative futures, for example towards the European Green Deal, Donut Economics and Degrowth. However, despite having models of future economies and societies, the question remains as to how we transform our existing systems. Our outputs in this area provide insight as to pathways towards these alternative models, and the barriers and opportunities for following them. The outputs are shaping the global political response to sustainability challenges, by being direct inputs to e.g. the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), and by contributing to the Green Deal.

1. Harrison, P. A.; **Harmáčková, Z. V.**; Aloe Karabulut, A.; Brotons, L.; Cantele, M.; Claudet, J.; Dunford, R.; Guisan, A.; Holman, I. P.; Jacobs, S.; Kok, K.; Lobanova, A.; Moran-Ordóñez, A.; Pedde, S.; Rixen, C.; Santos-Martín, F.; Schlaepfer, M.; Solidoro, C.; Sonrel, A.; Hauck, J. Synthesizing plausible futures for biodiversity and ecosystem services in Europe and Central Asia using scenario archetypes. *Ecology and Society* 2019(24): Article number 27, 2019
2. Sitas, N.; **Harmáčková, Z. V.**; Anticamara, J. A.; Arneth, A.; Badola, R.; Reinette, B.; Blanchard, R.; Brotons, L.; Cantele, M.; Coetzer, K.; DasGupta, R.; den Belder, E.; Ghosh, S.; Guisan, A.; Gundimeda, H.; Hamann, M.; Harrison, P. A.; Hashimoto, S.; Hauck, J.; Klatt, B. J.; Kok, K.; Krug, R. M.; Niamir, A.; O'Farrell, P.; Okayasu, S.; Palomo, I.; Pereira, L. M.; Riordan, P.; Santos-Martín, F.; Selomane, O. Exploring the usefulness of scenario

archetypes in science-policy processes: experience across IPBES assessments. *Ecology and Society* 2019(24): Article number 35, 2019

3. Hartwell, C. A.; Horváth, R.; **Horváthová, E.**; Popova, O. Democratic Institutions, Natural Resources, and Income Inequality. *Comparative Economic Studies* 61(4): 531-550, 2019

We have further results emerging in 2020 and beyond (including already-published papers); for example, Leventon is editing a special issue of the journal *Sustainability Science* on Leverage Points for Sustainability Transformations, and Harmáčková will launch a Solstice-funded project on landscape transformations.

These outputs are the result of 25 research projects that the team was a part of during the evaluation period.

Project title	Project number	Lead institution	Funding	Start	End	Research Area
Supporting development of adaptation measures and strategies in cities	1	CzechGlobe	TA ČR Omega	1/1/2016	12/31/2017	2
Adaptation of settlements to climate change - practical solutions and knowledge sharing	2	Civitas per Populi, o. p. s.	EEA and Norway Grants	1/16/2015	4/30/2016	2
Bottom-Up Climate Adaptation Strategies Towards a Sustainable Europe (BASE)	3	Aarhus University (coordinator)	EU FP7	10/1/2012	9/30/2016	2
CzechAdapt - A system for the exchange of information on climate change impacts, vulnerability and adaptation measures in the CR	4	CzechGlobe (Department of Climate Change Impacts on Agroecosystems)	EEA and Norway Grants	1/1/2015	11/30/2016	2
Integrated assessment of the global change	5	CzechGlobe	Ministry of Interior	1/1/2012	8/31/2015	2

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impacts on the environmental security of the CR						
Sharing of Czech Experience: Piloting SEEA-EEA in Kyrgyzstan	6	CzechGlobe	UNDP Czech Trust Fund	1/1/2016	12/31/2016	2
Analysing the Services of Urban Ecosystems and their Impact on Resident Well-being in the Czech Republic	7	CzechGlobe	TA ČR Omega	1/1/2014	12/31/2015	3
Development of urban adaptation strategies using ecosystem-based approaches to adaptation	8	CzechGlobe	EEA and Norway Grants	2/1/2015	12/31/2016	2, 3
Enhancing ecoSystem sERVICES mApping for poLicy and Decision mAKing	9	CHRISTIAN-ALBRECHTS-UNIVERSITAET ZU KIEL, Germany (CAU)	EU H2020	2/2/2015	7/31/2018	3
Climate Change and Migration as Adaptation	10	CzechGlobe	LD - COST CZ (MŠMT)	3/1/2013	10/31/2015	2
Developing and testing experimental ecosystem accounting in the CR	11	CzechGlobe	TA ČR Omega	1/1/2016	12/31/2017	3
Is the occurrence of slope movements in the Cordillera Blanca, Peru, influenced by the El Niño Southern Oscillation?	12	CzechGlobe	8J (MŠMT)	1/1/2018	12/31/2019	2
Restoration of biodiversity and ecosystem services in the through	13	CzechGlobe (Coordinated by P Skalák from the Dptm of	EU Interreg V-A SK CZ	7/1/2018	6/30/2020	1,3

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climate change endangered forests in Beskydy region		Climate Modelling)				
Participatory modelling of ecosystem services values in protected areas	14	CzechGlobe	TA ČR ÉTA	3/1/2018	6/30/2021	3
Urban Adaptation Challenges: Promoting Sustainable Planning Using Integrated Vulnerability Analysis	15	CzechGlobe	TA ČR ÉTA	3/1/2018	2/28/2022	1
Integrated LIFE project for the Natura 2000 network in the Czech Republic	16	MoE (MŽP)	LIFE	1/1/2019	12/31/2026	1,3
LIFE TreeCheck: Green Infrastructure Minimising the Urban Heat Island Effect	17	Nadace Partnerství	LIFE	9/1/2018	8/31/2022	2
LIFE LOCAL ADAPT: Integration of climate change adaptation into the work of local authorities	18	Technische Universitaet Dresden	LIFE	7/1/2016	6/30/2021	2
Mapping and Assessment for Integrated ecosystem Accounting (MAIA)	19	Wageningen University	EU H2020	10/1/2018	9/30/2022	3
Assessment and mapping of cultural ecosystem services in landscape	20	CzechGlobe	TA ČR ÉTA	2/1/2019	7/31/2022	3
Tools for planning and evaluation of the ecological benefit of urban vegetation	21	CzechGlobe (Department of Remote Sensing)	TA ČR EPSILON	1/1/2019	12/31/2021	3
Thermal comfort in urban areas: human perception, physics	22	CzechGlobe (Department of Remote Sensing)	TA ČR ÉTA	1/1/2019	12/31/2021	3

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based reality, role of greenery						
Supporting EU-African Cooperation on Research Infrastructures for Food Security and Greenhouse Gas Observations	23	Thünen-Institute of Climate-Smart Agriculture	EU H2020	3/1/2017	2/28/2020	3
The value of ecosystem services provided by the peatlands in Southern Finland	24	Natural Resource Institute in Finland (LUKE)	Nessling Foundation, Finland	1/1/2017	12/31/2020	3
Dynamics and spatiotemporal patterns of evolution of glacial lakes and implications for risk management and adaptation in recently deglaciated areas	25	CzechGlobe	CAS	1/7/2018	30/6/2020	2