1. **Research programme**

Top of Form

**Specific aims and objectives of your proposed urgent grant application (maximum 10,000 characters including spaces).\***

Info about Specific aims and objectives of your proposed urgent grant application (maximum 10,000 characters including spaces).

* You should describe and motivate the urgent need to secure data/research material. What is the purpose of securing data/research material? Explain also possible consequences if the data/research material is not secured.
* You should motivate how the project relates to one or more of **Formas areas of responsibility**– environment, agricultural sciences and spatial planning.
* You should describe and motivate the **scientific relevance** of the project (including references).
* **Apply before:**2020-08-31 14:00

**Max length:**10000 characters

Bottom of Form (4 page 1500 words)

**Purpose of the study**

Peatlands comprise 30% of the present-day soil organic carbon pool and are one of the biggest carbon reserves in the terrestrial ecosystem [(Gorham 1991](#_ENREF_6), [(Yu 2012](#_ENREF_33)). They play an important role in the global carbon cycle, as a persistent long-term CO2 sink and a moderate source of methane (CH4) [(MacDonald et al. 2006](#_ENREF_14), [(Yu et al. 2009](#_ENREF_32), [(Loisel et al. 2014](#_ENREF_13)). At present, only a few large-scale dynamic global vegetation models (DGVM) and land surface models (LSM) have incorporated peatland dynamics to hindcast Holocene peat carbon accumulation and applied them to predict responses of these ecosystems in future climate conditions (see Table 1 in Appendix J). To assess how well the models perform and to have a systematic study of the fate of peat carbon under fast future climate change, various established peatland groups (see Methodology section) have come together and initiated a study to intercompare their peatland model outputs. I have been invited in this model intercomparison study to perform hindcast and future experiments with my established state-of-the-art peatland-vegetation model (LPJ-GUESS) [(Chaudhary et al. 2017a](#_ENREF_2), [(Chaudhary et al. 2020](#_ENREF_4)) at contrasting climate-warming scenarios.

The purpose of this study is to minimize the uncertainty surrounding peatland carbon balance at different spatial and temporal scales. The model will be run at 1 to 1-degree resolution across the pan-Arctic area for the last 12000 years. My mechanistic peatland model [(Chaudhary et al. 2017a](#_ENREF_2)), which annually accumulates peat, has shown promising results both at local and regional scales [(Chaudhary et al. 2017b](#_ENREF_3), [(Chaudhary et al. 2020](#_ENREF_4)). However, running the model at this fine-scale requires a significant amount of resources and data storage. Therefore, I am in urgent need of human as well as computing resources to fulfill our objectives and commitment in this community effort study. The main findings of this study will be conveyed to major international authorities working to curb the CO2 emission and mitigate climate change, particularly the Intergovernmental Panel of Climate Change (IPCC). Failing to contribute in this project not only create a knowledge gap but also deprive the policy-makers with the clear and conclusive findings on the peatland dynamics which could enable them to take concrete steps in relation with peatlands and their role in the future. Creating and executing any strategy to reduce carbon emissions can only be feasible when the current numbers are known. Hence, this project will fill the knowledge gaps concerning the fate of peatland carbon dynamics and equip policymakers with the necessary information in order to take effective measures to curb CO2 emissions from the terrestrial ecosystem.

**Background and scientific relevance of the project**

The international community estimated that around one trillion tonnes of Carbon (1000 Petagram carbon - PgC) can be emitted by the end of the century in order to limit the global temperature rise to 2 degree Celsius above pre-industrial level [(IPCC 2013a](#_ENREF_8)). We have already burnt more than 50% of the allocated budget and emitted around 515 PgC since the industrial revolution (1861-1880), leaving 485 PgC in the budget. If we continue to emit the CO2 at this rate, we will consume 1000 PgC by 2045. To limit the emission levels, early and large-scale carbon emission reductions are immediately required to prevent any catastrophic damages [(IPCC 2013b](#_ENREF_9)). The international agencies are contemplating ways to curb CO2 emissions and enhance the capacity of existing sinks using carefully planned adaptive and mitigation measures. Executing any such strategy to limit carbon emissions will only start when the existing numbers are known. Peatlands are an important ecosystem type which not only stores a huge amount of carbon [(Yu 2012](#_ENREF_33)) (i.e. almost twice the size of the world’s forest) but has been playing a significant role in buffering the effects of climate change and have a big role to play in supporting climate adaptation and resilience [(Leifeld and Menichetti 2018](#_ENREF_11)) in coming decades. If they continue to take up carbon in the future, their conservation could be a simple, inexpensive and reliable mitigation option [(Martin and Kirkman 2009](#_ENREF_16)). However, currently, damaged and disturbed peatlands are emitting at least 2 billion tonnes of carbon annually and to reduce these emissions, proper management strategies are required [(Leifeld et al. 2019](#_ENREF_12), [(Goldstein et al. 2020](#_ENREF_5)). There is not enough understanding of how these climate sensitive ecosystems will behave in the future and whether they have the potential to delay the effects of climate change by effectively managing these systems.

With this backdrop, the main aim of the study is to review the current state-of-the-art peatland models that can be applied at global/hemispheric scale and to evaluate the contribution of northern peatlands (>30°N) to the global carbon cycle in the historical past (1860-2005) and in the future (2006-2300). The specific objectives of the study are:

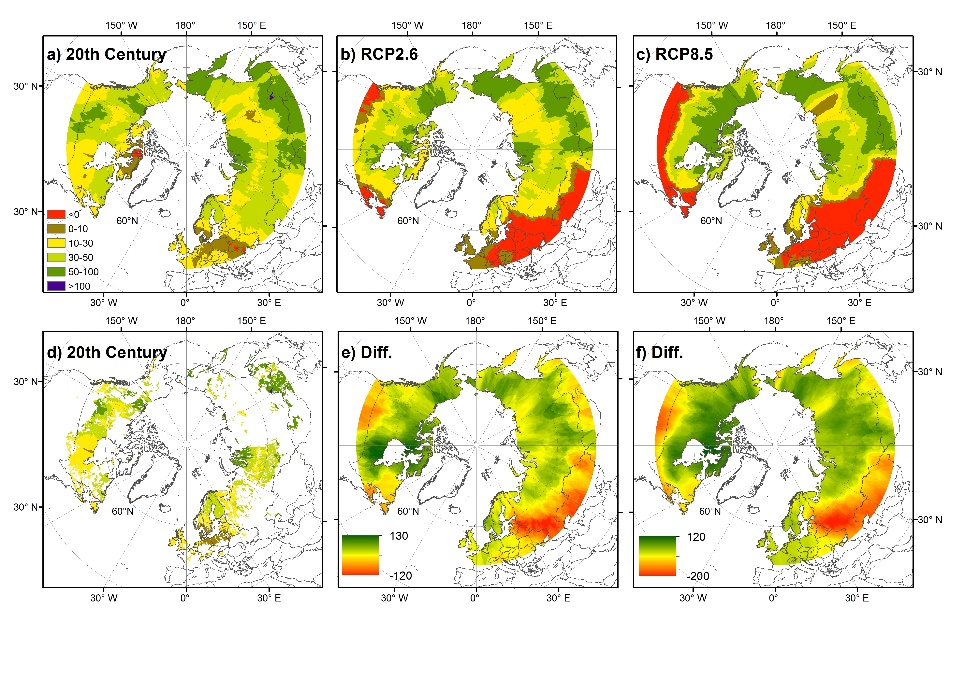
(1) performance of peatland models (an agreement or disagreement);

(2) historical and future CO2 fluxes from northern peatlands at pan-Arctic scale;

(3) identifying the role of peatlands in mitigating climate change under different warming scenarios.

On these lines, we plan a research project (**MODEL-PEAT**) which focuses on running established peatland version of LPJ-GUESS, a dynamic global vegetation model (DGVM; see Table 1) at fine-resolution [(Smith et al. 2001](#_ENREF_21), [(Chaudhary et al. 2017a](#_ENREF_2)). In the first part of the study, the model will be run with two contrasting warming scenarios (RCP2.6 and RCP8.5) and in the next phase, the model will be run with the remaining two mild-warming scenarios (RCP4.5 and RCP6.0). The model simulations will explore the role of peatlands in future climate conditions and will become a part of major scientific reports and policy briefs. The focus of this study will be on the pan-Arctic region above (> 30°N) as the majority of the peatlands (more than >80 percent) are present in this area. The effects of changes in hydrological and structural conditions in future peatland dynamics will also be evaluated. This study will provide the most up-to-date peatland and permafrost extent for the coming century and reduce current uncertainties related to carbon exchanges from the peatlands. The study will also identify the vulnerable regions to high carbon emissions and will evaluate their direct consequences on vegetation and hydrology.

Organizations such as IPCC, Swedish Environmental agencies can benefit from the outputs of this study, as our results will have the potential to influence policy on the importance of peatland protection from a climate change perspective and influence regional planning when thinking about land use and management policy. This work builds on my previous research work on modelling peatland-permafrost dynamics and terrestrial-climate feedbacks. The proposed project has the potential to make step-change progress in the field of peatland and Earth science. Our modelling results will help in government decision making in what level we need to protect our peatlands.

****  **Fig.3** a) Net carbon accumulation rates (in g C m-2 y-1, average 1990–2000), b) following the RCP2.6 scenario (Exp26; average 2091–2100), c) following the RCP8.5 scenario (Exp85; average 2091–2100)

**Formas areas of responsibility**

The project will fulfill two of the **Formas areas of responsibility – environment and spatial planning.** The proposed project mainly comprises the environmental dimension and has major implications on the economy and society. First, this study will provide a better understanding of the fate of peatland carbon balance in future conditions and the role of peatland processes in limiting climate warming. Second, the study results can be used to predict the most probable demarcation of peatland and permafrost extent for the coming century and to reduce current uncertainties regarding CO2 emissions from peatlands. Third, the study will help in identifying the ‘hotspots’ in the pan-Arctic region and other geographical areas that are vulnerable to high carbon emissions and permafrost degradation and will evaluate their direct consequences for plant ecology and hydrology. The project will, therefore, address the United Nations (UN) sustainable development goals 13 (Climate change) and 15 (Biodiversity, forests and desertification).

The infrastructure and transportation corridors established over permafrost areas are highly vulnerable to changing climate conditions. My earlier studies [(Chaudhary et al. 2017b](#_ENREF_3), [(Chaudhary et al. 2020](#_ENREF_4)) have highlighted that the total permafrost area will shrink and in many regions it may disappear by the end of the 21st century. This proposed study will further advance my previous research and demarcate areas that is extremely sensitive to excessive warming, which could result in the complete or partial disappearance of permafrost with implications for damage to built infrastructure (roads, buildings, communications). Hence, the results of my study will also address UN SDG 9 and SDG 13 UN (Infrastructure and Climate change).

the CPU hours and data storage area in order to contribute to this proposed study.

Beyond a baseline, a carbon budget needs milestone dates in the future with acceptable emission volumes tagged to those dates. The effort to mitigate emissions is seen as critical today if the nations of our planet intend to achieve the lower or upper limit Paris targets to which all have agreed. Setting an upper limit on CO2 emissions is only one of a total of 6 greenhouse gases that we need to mitigate. Some of the others such as methane (CH4) could be addressed with shorter timelines through changes to industrial practices resulting in more rapid reductions in total emissions. This has a benefit for nations struggling with CO2 which is a much harder greenhouse gas to deal with. **Carbon budget deadlines for CO2 can have longer timelines if other greenhouse gases are reduced sooner.**

Executing a strategy to achieve lower carbon emissions can only start when you know the current numbers. Then the government can set carbon-limits on different greenhouse gas emissions and monitor overall results by measuring amounts in the atmosphere. Less will mean the carbon limit policy is working. If it is not then governments need to get more granular. This can be done by monitoring greenhouse gas emissions at every smokestack and tailpipe, or by determining specific carbon emission content in fuels when combusted at the point of production. Granular would require far greater regulatory oversight.

One way or the other, every nation and its citizens have to make a choice. Do nothing and neither the 1.5 or 2-degree limits will be achievable. At current greenhouse gas emission annual contributions, climatologists see 4 to 4.5-degrees as the rise in global warming by the end of the 21st century. Remember, that is a mean temperature calculation and unevenly distributed over the globe. In places closer to the poles, a mean of 4.5 degrees will turn into an average rise of 15 Celsius or more in places like Alaska, northern Canada, Scandinavia, and Siberia. We have yet to produce models to show us what that will mean to the flora and fauna that live in these areas of the planet. Nor do we know what that will mean to changes in the permafrost and the greenhouse gases we know that are trapped in this no longer permanently frozen ground.

They are able to store the equivalent of around 10 years of the CO2 emissions that come from human activity.

To achieve this objective, the major peatland modelling groups will run their models and submit the model outputs.

their importance to the global climate cycle is known, there are a number of crucial questions surrounding their role that remain a mystery.

For the project, Dr Gallego-Sala will research four key questions - what controls the geographical distribution of peatlands in the tropics; how large is the tropical peatland CO2 sink and what are its main climatic drivers; how large is the methane flux in tropical peatlands; and what is the overall carbon balance of tropical peatlands and how will this change in the future.

The study  will give scientists a comprehensive understanding of the role of tropical peatlands in the global carbon cycle - allowing their inclusion in earth system models - and informing management decisions to optimise provision of multiple ecosystem services.

peatlands are extremely important carbon stores and also methane emitters, and we must focus our efforts in understanding these inaccessible but wonderful ecosystems better”.

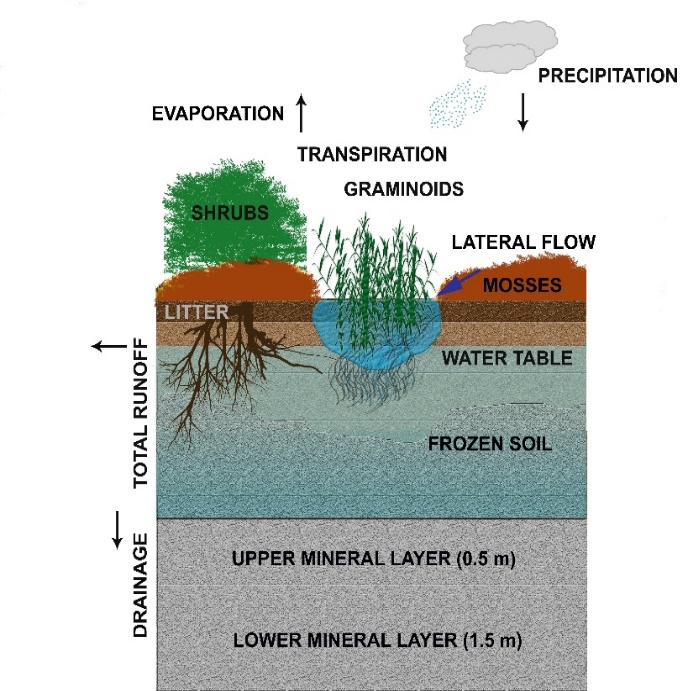
Only by accounting the various factors linked to the changes can the lawmakers craft a policy and ameliorate the problem.

These simulations will be used to increase our current understanding of the factors responsible for carbon sequestration and

**Project description (maximum 10,000 characters including spaces).\***

Info about Project description (maximum 10,000 characters including spaces).

* You should describe the project performance, including work packages and time plan
* You should explain the research methods and the collection of the data/research material.

The main aim of **MODEL-PEAT** is to determine the fate of peatland carbon stock in the warming world. First, the project will identify how large the northern peatland CO2 sink is and then it will explore the important drivers that are responsible for modulating carbon fluxes at peatland sites. In addition, this community project will also evaluate the influences of different warming scenarios on peatland carbon fluxes. **MODEL-PEAT** focuses on running an established peatland version of the dynamic vegetation model, LPJ-GUESS at different warming scenarios. The current model has been employed in a number of global change impact and feedback studies at regional and global scale. In this research project, I will update and run the LPJ-GUESS model based on the simulation protocol which is included in the appendix (A1):

**Fig. 1. A schematic diagram showing the LPJ-GUESS peatland structure and functioning**

**Key Model - LPJ-GUESS** is a second-generation DGVM [(Smith et al. 2001](#_ENREF_21)), which simulates vegetation structure and composition in response to a changing climate from local to global scales. It is a process-based model of vegetation dynamics which includes physiological and biogeochemistry processes of terrestrial ecosystems. LPJ-GUESS will be used as a modelling tool for the proposed project. This model has been applied in more than 200 published studies and evaluated against datasets across many ecosystem types including the pan-Arctic region. Recently, the multi-layer peat accumulation and permafrost functionalities have been included [(Chaudhary et al. 2017a](#_ENREF_2)) (see Fig. 2 in A1) and the current version of the model has been developed to include microbial CH4 biogeochemistry and advanced hydrological schemes. The new model minimize the recent uncertainties related to anoxic carbon exchanges and peatland management practices.

Other models which are taking part in this study are: **ORCHIDEE, LPJ-MPI and LPX-Bern**

**ORCHIDEE**

Organising Carbon and Hydrology In Dynamic Ecosystems (ORCHIDEE) is a land surface model which simulate hydrology, surface energy balance, and CO2 fluxes of peatlands at different timescales [(Qiu et al. 2018](#_ENREF_17)). The model comprises distinct soil tile in each grid cell which is constrained using a global peatland map. Within a grid cell, the water is transferred as runoff from adjacent area composed of non-peat vegetation to the peat soil tile. The water table position separates oxic from anoxic decomposition. The model considers different plant functional types (PFTs): trees (8), grasses (2), crops (2), and bare-soil type. The model has been evaluated against eddy-covariance (EC) observations from 30 northern peatland sites and the maximum rate of carboxylation (Vcmax) being optimized at each site. The model has been employed in a number of studies and assessed the impact of change in climate properties on peatland carbon balance.

**LPJ-MPI**

LPJ-MPI has been developed from the dynamic vegetation model LPJ [(Sitch et al. 2003](#_ENREF_20)) and it is further improved to include wetland modules and peat specific routines. The wetland module is based on the TOPMODEL approach [(Stocker et al. 2014](#_ENREF_25)) which dynamically calculates the waterlogged regions and water table position using climate signals. Only the permanently inundated area where the water table remains stable for a long time accumulate peat. The peat module describes oxic and anoxic decomposition processes. The model has been described in detail in [(Kleinen et al. 2012](#_ENREF_10)).

**LPX-Bern**

The dynamic vegetation and land surface process model (“Land surface Processes and eXchanges” model of the University of Bern, version 1.0) [(Spahni et al. 2013](#_ENREF_22), [(Stocker et al. 2013](#_ENREF_24)) is also a based on LPJ [(Sitch et al. 2003](#_ENREF_20)). The model describes changes in vegetation and biogeochmical processes. Later, it was further developed to integrate the peatlands processes [(Wania et al. 2009a](#_ENREF_28), [b](#_ENREF_29), [(Spahni et al. 2013](#_ENREF_22)) and their carbon and nitrogen dynamics. The model also takes into account the release and uptake of the trace gases such as CO2, N2O and CH4 [(Wania et al. 2010](#_ENREF_30), [(Spahni et al. 2011](#_ENREF_23), [(Zürcher et al. 2013](#_ENREF_36), [(Stocker et al. 2014](#_ENREF_25)). It comprises various plant functional types which compete for resources (water, light and nitrogen) on each grid cell. In the model, carbon and water cycles are coupled through photosynthesis and evapotranspiration. It also comprises soil hydrology, heat diffusion and thawing-freezing schemes [(Wania et al. 2009a](#_ENREF_28)).

**Work Package 1- Model simulations at pan-Arctic scale (Month 1–6)**

In the first part of this study, the established peatland version of LPJ-GUESS will be run at fine-resolution (1-1 degree resolution) [(Smith et al. 2001](#_ENREF_21), [(Chaudhary et al. 2017a](#_ENREF_2)). The implications of climate warming on peatland carbon balance under two contrasting Representative Concentration Pathway (RCP) scenarios (RCP2.6 and RCP8.5) will be investigated. The focus will be on the period 2080-2100 (recent future) and 2280-2300 (future) which will be compared with the period 1991-2010 (recent past). Climate change signals will be determined by subtracting the future from recent past simulations. These findings will set a stage for the already ongoing project where the peatland-mediated feedbacks will be calculated as a difference between the future and present with and without feedback simulations. The results of **MODEL-PEAT** will identify the regions where the model does not sufficiently capture the observed patterns and provide useful insights into new areas to investigate. We will also analyze the influence of historical climate change on peatland carbon balance, carbon accumulation rates and permafrost distribution at the regional scale, and compare these values with their development under climate change scenarios spanning the range of modelled climate (RCP2.6 and RCP8.5).

Permafrost has an intricate relationship with peatland vegetation, hydrology and biogeochemical processes [(Vardy et al. 2000](#_ENREF_26)). Peat deposits on the frozen surface soil create different landforms such as palsa, peat plateaus and polygonal peat plateaus  [(Malmer et al. 2005](#_ENREF_15)). This leads to a strong interaction between peat soil and permafrost and any changes in the current state of permafrost dynamics affects the overall peatland carbon balance [(Robinson and Moore 2000](#_ENREF_18)). In this work package, we will determine the permafrost initiation period in these climate-sensitive ecosystems. We will also investigate how these ecosystems have been evolved over time and how did permafrost influence their carbon accumulation rates. The main focus of this study will be on the effects of future warming on permafrost distribution across the pan-Arctic region.

Under this work pakcage, one unique study is planned where we will compare the outputs of other community models with the LPJ-GUESS peatland. There will be a model comparison study (see Table 2) addressing all the three aims of this study.

**Work Package 2 – Model evaluation and additional experiments (Month 6–12)**

In this work package, I will perform the remaining two simulations which are not covered in the simulation protocol and will extend the scope of this study. In the first work package, the model will be derived into the future using the ultra-low emissions, RCP2.6; and, high-emissions RCP8.5 scenarios due to the time-constraint. It is quite common to focus on these two extremes so as to provide end-member estimates in future modelling studies. However, to provide a complete picture it is always better to run the model with all RCP scenarios and deliver a complete picture. These scenarios are developed as a suite of complementary possibilities, and the IPCC recommends that modelling studies should consider all four together. Additionally, RCP8.5 has recently been discredited because the amount of coal that the scenario requires India and China to use in coming decades likely exceeds estimates of readily available fossil resources (see [Wang et al. (2017)](#_ENREF_27)). RCP4.5 and RCP6.0 are the most realistic of the four scenarios yet these scenarios are often omitted. For these reasons, I will perform the analysis with the remaining two scenarios and extend the scope of the study.

Model simulations will be evaluated with observations, reanalysis and satellite-based, and gauge-based datasets. Modelled near-surface temperature, precipitation, and Leaf Area Index (LAI) will be compared with observations within the 1991–2010 time period. Annual and seasonal surface temperature and precipitation will also be compared with the gridded observations from the CRU TS3.23 [(Harris et al. 2014](#_ENREF_7)). The rain gauge data are upscaled in the Global Precipitation Project that can provide additional information to evaluate the model. GIMMS-AVHRR and MODIS-based LAI3g [(Zhu et al. 2013](#_ENREF_35)) will be used to evaluate LAI simulations. ERA-interim is a reanalysis dataset [(Berrisford et al. 2009](#_ENREF_1)) that gives the information on the state of the atmosphere, and land conditions from 1989 to 2013. The dataset contains multiple types of data such as temperature, precipitation, evapotranspiration, global radiation, water balance, and water vapour. Peatland locations and extent will be evaluated with PEATMAP developed by [Xu et al. (2018)](#_ENREF_31), global CH4 simulations will be compared with global CH4 budget [(Saunois et al. 2016](#_ENREF_19)) from 2000–2012 and observations of carbon accumulation rates for the pan-Arctic region will be extracted from [Loisel et al. (2014)](#_ENREF_13) and [Chaudhary et al. (2017b)](#_ENREF_3) (see Table 3 in that paper).

We agree with the reviewer that the missing RCPs are important to provide a complete picture of possible future pathways, but our intention in choosing the high and low-end RCP scenarios was to examine the peatland dynamics and CAR in the most extreme scenarios available. It is correct that our model is easy to run but it is quite computationally intensive. We accumulate peat in the form of individual layers (with many variables) annually and keep track of these individual layers throughout the simulations. We cannot yet run the last 100 years (i.e. 2000-2100) separately, but instead we have to run all the simulation points again from the start and running 2\*1000 points on a cluster will take more than 2\*60,000 CPU hours (at least two-three months). We believe spending this much time and resources on running the missing scenarios will add very little to the study.  However, this issue will be addressed in our upcoming model intercomparison study where we will perform model simulations with one of the missing RCP scenarios (RCP 6.0). However, we have revised the text for more clarity

Methodology

All simulations should be performed at 1°x1° spatial resolution, for regions above 30°N. Find attached a flowchart demonstrating the simulation protocol in the appendix. All models will do the S1 simulations (use fixed peatland extent of Xu et al., 2018), S2 simulations are for models that can simulate peatland extent dynamically.  
  
We have been invited to submit our simulation for this proposed study. However, we lack resources to run our model at such fine scale. Running more than 4000 points requires

Natural disturbance, i.e, fires, should be disabled from simulations. Anthropogenic land-use change should be kept fixed or disabled.

Peatlands are important C reserves in terrestrial ecosystem and cover 3% of the terrestrial globe (4 × 106 km2) [(Gorham 1991](#_ENREF_6)). Since the Holocene, they have stored around 350-500 Petagrams [109] of C (PgC), comprising around 30% of present-day soil organic C pool [(Yu et al. 2010](#_ENREF_34)). They have the potential to

If we continue to emit the CO2 at this rate, we will burn out 1000 PgC by 2045. To achieve this goal, early and large-scale carbon emission reductions are immediately required to prevent any catastrophic damages.

Work Package 1

Peatlands comprise 30% of the present day soil organic carbon pool and are one of the biggest carbon reserves in the terrestrial ecosystem5. They play an important role in the global carbon cycle, as a persistent long-term CO2 sink and a moderate source of methane (CH4). At present, only a few large-scale Dynamic Global Vegetation Models (DGVM) and land surface models (LSM) have incorporated peatland dynamics to hindcast Holocene peat carbon accumulation and apply them to predict responses of these ecosystems to future climate change (see Table 1). To assess how well the models perform and to have a systematic study of the fate of peat carbon under fast future climate change, various established peatland groups come together and have initiated a study to intercompare their peatland models. We have been invited in this model intercomparision study in which we will perform hindcast and future experiments with our established state-of-the-art peatland-vegetation model (LPJ-GUESS) at contrasting climate-warming scenarios.

 The purpose of this study is to minimize the uncertainty surrounding peatland carbon balance at different time scales. We will run the model at 1 to 1-degree resolution across the pan-Arctic area for the last 12000 years. Our mechanistic peatland model, which annually accumulates peat, has showed promising results both at local and regional scales. However, running this model at this fine-scale requires significant amount of resources and data storage. Therefore, we are in urgent need of human as well as computing resources to fulfill above objectives and our commitment in this community effort. The main findings of this study will be conveyed to major international authorities working to curb the CO2 emission and mitigate climate change, particularly Intergovernmental Panel of Climate Change (IPCC). Failing to contribute in this project not only create a knowledge gap but also deprive the policy-makers with the clear and conclusive findings of the peatland dynamics which could enable them to take concrete steps in relation with peatlands role in the future. Creating and executing any strategy to reduce carbon emissions can only be feasible when the current numbers are known.

* 1. **Potential Impact of the proposed research**

The three main pillars of sustainability are economy, society, and environment. Alteration in any one of these pillars directly affects the others. The proposed project mainly comprises the environmental dimension, and has major implications for the economy and society. First, this study will provide a better understanding of the role of peatland-centric feedbacks and peatland processes at regional and global scales by including their representations in regional and global ESMs. Second, the study results can be used to predict the most probable demarcation of peatland and permafrost extent for the coming century and to reduce current uncertainties regarding CH4 emissions from the peatlands. Third, the study will help in identifying the ‘hotspots’ in the pan-Arctic region and other geographical areas that are vulnerable to high C emissions and permafrost degradation and will evaluate their direct consequences to plant ecology and hydrology. The project will, therefore, address United Nations (UN) sustainable development goals 13th (Climate change) and 15th (Biodiversity, forests and desertification).

The infrastructure and transportation corridors established over permafrost areas are highly vulnerable to changing climate conditions. My earlier study (Chaudhary et al. 2017)[32](https://prisma.research.se/Application/Details/b9ecbad8-22b3-442e-b18b-a8b90181de28?pageIndex=1#_ENREF_30) have highlighted that the total permafrost area will shrink and in many regions it may disappear by the end of the 21st century. This proposed study will further advance my previous research and demarcate areas that are extremely sensitive to excessive warming, which could result in the complete or partial disappearance of permafrost. Hence, the results of my study will also address the 9th and 13th UN goals (Infrastructure and Climate change).

**Session Description:** Smart monitoring and observation systems for natural hazards, including satellites, seismometers, global networks, unmanned vehicles, and other linked devices, have become increasingly abundant. With these data, we observe the restless nature of our Earth and work towards improving our understanding of natural hazard processes such as landslides, debris flows, earthquakes, floods, storms, and tsunamis. The abundance of diverse measurements that we have now accumulated presents an opportunity to employ statistically driven approaches that speed up data processing, improve model forecasts, and give insights into the underlying physical processes. Such big-data approaches are supported by the wider scientific, computational, and statistical research communities who are constantly developing data science and machine learning techniques and software. Hence, data science and machine learning methods are rapidly impacting the fields of natural hazards. In this session, we will see research from natural hazards for processes over a broad range of time and spatial scales.

Reference:

Berrisford, P., D. P. Dee, K. Fielding, M. Fuentes, P. W. Kållberg, S. Kobayashi, and S. Uppala. 2009. The ERA-Interim archive. Page 16 ERA Report Series. ECMWF, Shinfield Park, Reading.

Chaudhary, N., P. A. Miller, and B. Smith. *Biogeosciences* 14, 2571-2596, (2017a).

Chaudhary, N., P. A. Miller, and B. Smith. *Biogeosciences* 14, 4023-4044, (2017b).

Chaudhary, N., S. Westermann, S. Lamba, N. Shurpali, B. K. Sannel, G. Schurgers, P. A. Miller, and B. Smith. *Global Change Biology* n/a, (2020).

Goldstein, A., W. R. Turner, S. A. Spawn, K. J. Anderson-Teixeira, S. Cook-Patton, J. Fargione, H. K. Gibbs, B. Griscom, J. H. Hewson, J. F. Howard, J. C. Ledezma, S. Page, L. P. Koh, J. Rockström, J. Sanderman, and D. G. Hole. *Nature Climate Change* 10, 287-295, (2020).

Gorham, E. *Ecological Applications* 1, 182-195, (1991).

Harris, I., P. D. Jones, T. J. Osborn, and D. H. Lister. *International Journal of Climatology* 34, 623-642, (2014).

IPCC. 2013a. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC. 2013b. Summary for Policymakers. Pages 1–30 *in* T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P. M. Midgley, editors. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Kleinen, T., V. Brovkin, and R. J. Schuldt. *Biogeosciences* 9, 235-248, (2012).

Leifeld, J., and L. Menichetti. *Nature Communications* 9, (2018).

Leifeld, J., C. Wüst-Galley, and S. Page. *Nature Climate Change* 9, 945-947, (2019).

Loisel, J., Z. C. Yu, D. W. Beilman, P. Camill, J. Alm, M. J. Amesbury, D. Anderson, S. Andersson, C. Bochicchio, K. Barber, L. R. Belyea, J. Bunbury, F. M. Chambers, D. J. Charman, F. De Vleeschouwer, B. Fialkiewicz-Koziel, S. A. Finkelstein, M. Galka, M. Garneau, D. Hammarlund, W. Hinchcliffe, J. Holmquist, P. Hughes, M. C. Jones, E. S. Klein, U. Kokfelt, A. Korhola, P. Kuhry, A. Lamarre, M. Lamentowicz, D. Large, M. Lavoie, G. MacDonald, G. Magnan, M. Makila, G. Mallon, P. Mathijssen, D. Mauquoy, J. McCarroll, T. R. Moore, J. Nichols, B. O'Reilly, P. Oksanen, M. Packalen, D. Peteet, P. J. H. Richard, S. Robinson, T. Ronkainen, M. Rundgren, A. B. K. Sannel, C. Tarnocai, T. Thom, E. S. Tuittila, M. Turetsky, M. Valiranta, M. van der Linden, B. van Geel, S. van Bellen, D. Vitt, Y. Zhao, and W. J. Zhou. *Holocene* 24, 1028-1042, (2014).

MacDonald, G. M., D. W. Beilman, K. V. Kremenetski, Y. Sheng, L. C. Smith, and A. A. Velichko. *Science* 314, 285-288, (2006).

Malmer, N., T. Johansson, M. Olsrud, and T. R. Christensen. *Global Change Biology* 11, 1895-1909, (2005).

Martin, K. L., and L. K. Kirkman. *Journal of Applied Ecology* 46, 906-914, (2009).

Qiu, C., D. Zhu, P. Ciais, B. Guenet, G. Krinner, S. Peng, M. Aurela, C. Bernhofer, C. Brümmer, S. Bret-Harte, H. Chu, J. Chen, A. R. Desai, J. Dušek, E. S. Euskirchen, K. Fortuniak, L. B. Flanagan, T. Friborg, M. Grygoruk, S. Gogo, T. Grünwald, B. U. Hansen, D. Holl, E. Humphreys, M. Hurkuck, G. Kiely, J. Klatt, L. Kutzbach, C. Largeron, F. Laggoun-Défarge, M. Lund, P. M. Lafleur, X. Li, I. Mammarella, L. Merbold, M. B. Nilsson, J. Olejnik, M. Ottosson-Löfvenius, W. Oechel, F. J. W. Parmentier, M. Peichl, N. Pirk, O. Peltola, W. Pawlak, D. Rasse, J. Rinne, G. Shaver, H. P. Schmid, M. Sottocornola, R. Steinbrecher, T. Sachs, M. Urbaniak, D. Zona, and K. Ziemblinska. *Geosci. Model Dev.* 11, 497-519, (2018).

Robinson, S. D., and T. R. Moore. *Arctic Antarctic and Alpine Research* 32, 155-166, (2000).

Saunois, M., P. Bousquet, B. Poulter, A. Peregon, P. Ciais, J. G. Canadell, E. J. Dlugokencky, G. Etiope, D. Bastviken, S. Houweling, G. Janssens-Maenhout, F. N. Tubiello, S. Castaldi, R. B. Jackson, M. Alexe, V. K. Arora, D. J. Beerling, P. Bergamaschi, D. R. Blake, G. Brailsford, V. Brovkin, L. Bruhwiler, C. Crevoisier, P. Crill, K. Covey, C. Curry, C. Frankenberg, N. Gedney, L. Höglund-Isaksson, M. Ishizawa, A. Ito, F. Joos, H. S. Kim, T. Kleinen, P. Krummel, J. F. Lamarque, R. Langenfelds, R. Locatelli, T. Machida, S. Maksyutov, K. C. McDonald, J. Marshall, J. R. Melton, I. Morino, V. Naik, S. O'Doherty, F. J. W. Parmentier, P. K. Patra, C. Peng, S. Peng, G. P. Peters, I. Pison, C. Prigent, R. Prinn, M. Ramonet, W. J. Riley, M. Saito, M. Santini, R. Schroeder, I. J. Simpson, R. Spahni, P. Steele, A. Takizawa, B. F. Thornton, H. Tian, Y. Tohjima, N. Viovy, A. Voulgarakis, M. van Weele, G. R. van der Werf, R. Weiss, C. Wiedinmyer, D. J. Wilton, A. Wiltshire, D. Worthy, D. Wunch, X. Xu, Y. Yoshida, B. Zhang, Z. Zhang, and Q. Zhu. *Earth Syst. Sci. Data* 8, 697-751, (2016).

Sitch, S., B. Smith, I. C. Prentice, A. Arneth, A. Bondeau, W. Cramer, J. O. Kaplan, S. Levis, W. Lucht, M. T. Sykes, K. Thonicke, and S. Venevsky. *Global Change Biology* 9, 161-185, (2003).

Smith, B., I. C. Prentice, and M. T. Sykes. *Global Ecology and Biogeography* 10, 621-637, (2001).

Spahni, R., F. Joos, B. D. Stocker, M. Steinacher, and Z. C. Yu. *Clim. Past* 9, 1287-1308, (2013).

Spahni, R., R. Wania, L. Neef, M. van Weele, I. Pison, P. Bousquet, C. Frankenberg, P. N. Foster, F. Joos, I. C. Prentice, and P. van Velthoven. *Biogeosciences* 8, 1643-1665, (2011).

Stocker, B. D., R. Roth, F. Joos, R. Spahni, M. Steinacher, S. Zaehle, L. Bouwman, R. Xu, and I. C. Prentice. *Nature Climate Change* 3, 666-672, (2013).

Stocker, B. D., R. Spahni, and F. Joos. *Geosci. Model Dev.* 7, 3089-3110, (2014).

Vardy, S. R., B. G. Warner, J. Turunen, and R. Aravena. *Holocene* 10, 273-280, (2000).

Wang, J., L. Feng, X. Tang, Y. Bentley, and M. Höök. *Futures* 86, 58-72, (2017).

Wania, R., I. Ross, and I. C. Prentice. *Global Biogeochemical Cycles* 23, (2009a).

Wania, R., I. Ross, and I. C. Prentice. *Global Biogeochemical Cycles* 23, (2009b).

Wania, R., I. Ross, and I. C. Prentice. *Geoscientific Model Development* 3, 565-584, (2010).

Xu, J. R., P. J. Morris, J. G. Liu, and J. Holden. *Catena* 160, 134-140, (2018).

Yu, Z., D. W. Beilman, and M. C. Jones. 2009. Sensitivity of Northern Peatland Carbon Dynamics to Holocene Climate Change. Carbon Cycling in Northern Peatlands.

Yu, Z. C. *Biogeosciences* 9, 4071-4085, (2012).

Yu, Z. C., J. Loisel, D. P. Brosseau, D. W. Beilman, and S. J. Hunt. *Geophysical Research Letters* 37, 5, (2010).

Zhu, Z. C., J. Bi, Y. Z. Pan, S. Ganguly, A. Anav, L. Xu, A. Samanta, S. L. Piao, R. R. Nemani, and R. B. Myneni. *Remote Sensing* 5, 927-948, (2013).

Zürcher, S., R. Spahni, F. Joos, M. Steinacher, and H. Fischer. *Biogeosciences* 10, 1963-1981, (2013).