REQUEST FOR A SPECIAL PROJECT 2026–2028

MEMBER STATE:	……………………Denmark………………………………………………………………
Principal Investigator[1]:	………………Jing Tang……………………………………………………………
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Project Title:	Quantifying biosphere-atmosphere interactions: the impacts from vegetation volatile emissions, plant phenology and lake greenhouse gas emissions

To make changes to an existing project please submit an amended version of the original form.)

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP**dktang………….	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2026	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for project year:		**2026**	**2027**	**2028**
High Performance Computing Facility	[SBU]	60,000,000	67,518,432	55,399,456
Accumulated data storage (total archive volume)[2]	[GB]	115,692	96,182	61,274

EWC resources required for project year:		**2026**	**2027**	**2028**
Number of vCPUs	[#]			
Total memory	[GB]			
Storage	[GB]			

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.
[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.
[3]The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

Number of vGPUs[3] [#]			

Principal Investigator: *Jing Tang*
Project Title: Investigating plant-atmosphere biochemical and biophysical interactions

Principal Investigator:	………Jing Tang…………………………………………………………
Project Title:	… Quantifying biosphere-atmosphere interactions: the impacts from vegetation volatile emissions, plant phenology and lake greenhouse gas emissions………………………………

Extended Abstract

Need for Computer resources:

The computer sources requested will be used to couple the latest dynamic vegetation model LPJ-GUESS into the Earth ecosystem model, EC-Earth, and the main focused features and associated feedback include the extended biogenic volatile organic compounds (BVOCs), new plant phenology in LPJ-GUESS, and newly-coupled lake biogeochemical module. My research group (1) has extended LPJ-GUESS modelled BVOCs from 2 compound groups till a full spectrum of compound species (20 functional groups and approx. 150 compound species) and coupled the LPJ-GUESS modelled BVOCs into the TM5 module in the EC-Earth 3, (2) has developed a new temperature-photoperiod coupled vegetation phenology algorithm into the LPJ-GUESS (Chen et al. 2024), (3) is in the process of coupling the advanced lake biogeochemical model, ALBM (Tan et al. 2015) into the LPJ-GUESS and (4) are planning to test the lastest coupling of WRF-GUESS based on the land surface version of LPJ-GUESS (Martín Belda et al. 2022).

To assess the impacts of a range of BVOC species and lake greenhouse emissions on atmospheric composition and climate, we will need to conduct simulations using offline coupled LPJ-GUESS and TM5 (both are part of EC-Earth modules) as well as full-coupled EC-Earth with new features in it. Further, to quantify the regulation of vegetation phenology on ecosystem water and carbon fluxes and assess associated climatic impacts, we will need to run a few sets of EC-Earth essembles and WRF-GUESS simulations to compare the effects from different phenology modules on regional and global atmospheric variables.

We have good overviews of offline-coupled LPJ-GUESS with TM5 as well as running fully coupled EC-Earth on the ATOS system (see group member's publications based on the EC-Earth simulations on ECMWF severs (Wang et al. 2025)). **The requested SBUs are based on our test on ATOS system and the estimations based on Danish and Swedish supercomputing servers..** The offline testing and site-level evaluations of LPJ-GUESS will be run on our local supercomputing system, and we will only run offline coupled LPJ-GUESS and TM5, as well as fully-coupled EC-Earth on the ATOS system.

Purpose and aims

The purposes of this project are (1) to assess the impacts of full-spectrum BVOCs on atmospheric composition and the climate, (2) to quantify the regulation of plant phenology on seasonal carbon and water fluxes under changing climate, (3) to understand the greenhouse effects (CO_2 and CH_4) from lake processes and (4) to quantify future changes in the Arctic nature volatile emissions and their interactions with anthropogenic sources.

The model simulations are part of four ongoing interdisciplinary projects funded by Danish Villum Fonden, Independent Research Fund Denmark, Swedish STINT and the Department of Biology at the University of Copenhagen.

Project description

Below, I will describe the backgrounds and aims for these four projects individually.

Project 1: 5-yr Villum Young Investigator project titled with "**Plant temperature-regulated Arctic responses and feedbacks to the changing climate**" (2023-2028)

Background:

The Arctic experiences warming at twice the global rate, and this amplified warming is expected to largely increase the frequency of heatwaves in this region. In a warmer climate, arctic plants adjust leaf phenological development and adapt photosynthetic rates to influence the fluxes of CO_2 and biogenic volatile organic compounds (BVOCs) to the atmosphere. Under heatwaves, we expect a reduced plant uptake of CO2, but a large burst of stress BVOCs as a plant defence mechanism. Highly reactive BVOCs contribute to lengthening methane lifetime, form aerosols and clouds, and change ozone concentration in the atmosphere, so studying the fluxes of CO_2 and BVOC is highly important for understanding climate changes within and beyond the Arctic. Importantly, all the abovementioned processes are regulated by plant temperature (influenced by plant traits and leaf energy balance) instead of routinely-measured air temperature. The observed differences between plant and air temperatures for arctic plants can be even larger than the projected changes in air temperature by the end of this century. We still tend to use air temperature for understanding plant processes due to its easy availability, which can, however, cause errors in the understood plant responses to changing environments and in estimated impacts of arctic ecosystems on the climate.

Furthermore, to account for the impacts of BVOC on the changing climate, we need to link BVOC emissions with plant physiology, account for stress-induced BVOC emissions and run fully-coupled earth system model, such as EC-Earth. The current limitation in EC-Earth is that plant-emitted BVOCs (simulated LPJ-GUESS) are not coupled with the atmospheric chemistry part in EC-Earth. Instead, a global dataset, disconnected from the dynamic vegetation, was read in to quantify potential impacts from BVOCs, meaning large uncertainties in quantified BVOC impacts on our climate system.

Aims:

This project will study how plant temperature varies across different arctic ecosystems and improve the model accuracy of plant temperature. We then experimentally determine the dependences of physiological processes on different temperatures and apply the quantified relationships into models to assess the feedbacks of these modified processes on regional and global climate systems.

This project will also fully couple LPJ-GUESS modelled plant BVOC emissions with atmospheric processes in the upcoming version of EC-Earth 4. More specifically, the major aims are to: (1) extend LPJ-GUESS modelled volatile compounds till full spectrum of compound species (20 functional groups and approx. 150 compound species); (2) develop a flexible framework where the compound species can be easily mapped to different aerosol schemes; (3) assess BVOC impacts modelled aerosol and cloud radiative forcing after explicitly linked to vegetation dynamics and plant photosynthesis.

Project 2: a 3-yr STINT project funded by The Swedish Foundation for International cooperation in Research and Higher Education, and titled "**Assessment of plant phenology impacts on**

terrestrial carbon and water cycles in northern ecosystems – combing climate change manipulation experiments and LPJ-GUESS modelling”

Background:

Global warming has profoundly affected the structure and function of terrestrial ecosystems. Vegetation phenology is very sensitive to climate warming and is the most sensitive biological indicator of climate change (Peñuelas et al. 2009) . It was found that climate warming would significantly advance the spring phenology and delay the autumn phenology of vegetation in the middle and high latitudes of the northern Hemisphere, significantly extend the length of the vegetation growing season, and thus affect the carbon and water cycle of terrestrial ecosystems (Keenan et al. 2014; Piao et al. 2020). However, the mechanism by which vegetation phenology responds to climate change remains unclear (Fu et al. 2019; Körner and Basler 2010), resulting in greater uncertainty in the simulation results of phenological models, which in turn leads to inaccuracy in the simulation results of the carbon cycle of global dynamic vegetation models (Richardson et al. 2012; Tang et al. 2015). Therefore, accurate understanding of phenological response mechanisms to climate change, construction of phenological models coupled with global dynamic vegetation models, and identification of future phenological changes under climate change and their impacts on ecosystem carbon and water cycles are urgent research topics in global change ecology.

The interaction of multiple environmental factors should be considered in response to climate change. It was found that the coupling of chilling in winter, growing degree days (GDDs) and photoperiod in spring determines the spring phenology of vegetation in the middle and high latitudes of the Northern Hemisphere (Fu et al. 2019; Zohner et al. 2016). However, the coupling relationship between the three is still unclear, especially how photoperiod regulates accumulated temperature and cold shock needs further study. Therefore, based on climate change control experiments, it is of great significance to study the difference in response of plant phenology to surface temperature and air temperature, as well as the coupling relationship between photoperiod, cold shock and accumulated temperature, and then build plant phenology models, coupled with global dynamic vegetation models, and study the carbon-water cycle process of terrestrial ecosystems for accurate understanding of ecosystem response to climate change.

Aims:

Following the recent development in the LPJ-GUESS phenology module for the tundra and boreal vegetation functional types (Chen et al. 2024), we will continue building phenology equations for summergreen vegetation types for the rest of the globe. We will further assess the impacts of the new phenology module on carbon and water cycling. To assess the atmospheric impacts, we will couple LPJ-GUESS with new phenology features into the current version of EC-Earth 3 and the upcoming version of EC-Earth 4. The project will provide Earth system models with a set of plant functional type-trained phenology algorithms that can potentially improve the representation of vegetation phenology in different regions.

Project 3: a 3-yr PhD project funded by the University of Copenhagen, 2024-2027, titled with “Warming-induced vegetation growth and permafrost-thaw feedback to lake greenhouse gas production”

Background:

Warming is likely to accelerate permafrost thawing further and enhance plant growth in high latitudes, which can potentially release a large amount of organic matter into lake ecosystems. Permafrost thaw can subsequently form thermokarst lakes, increasing lake area in the Arctic. Terrestrial ecosystem models (such as LPJ-GUESS) account for warming-induced vegetation changes and permafrost thaw as well as their impacts on leached carbon and nutrients from soils, but do not simulate the land cover changes caused by thermokarst dynamics. The Arctic Lake Biogeochemistry Model (ALBM), developed by my collaborator (Tan and Zhuang 2015), simulates detailed thermal and biogeochemical cycles in arctic lakes and accounts for the landscape development of thermokarst. The ALBM, however, assumes constant carbon and nutrient discharges from land. These missing spatial connections between land and lake models might result in large uncertainties in estimated regional fluxes of CO_2 and CH_4.

Aims:

Through coupling the dynamic vegetation model LPJ-GUESS with the arctic-specific lake model ALBM, this project aims to investigate missing-counted CO_2 and CH_4 emissions from the high latitudes. The coupled model will provide a powerful tool to explicitly quantify the feedbacks from the warming-induced changes in land processes to lake biogeochemical processes. This project will also develop a high-resolution chlorophyll-a dataset across the high latitude lakes based on satellite data (see the retrieving algorithm in my co-authored paper (Guan et al. 2020)) and the dataset will be used for lake model evaluation.

Project 4: a 3-yr project funded by the Independent Research Fund Denmark, 2025-2028, titled with “Arctic Cooling from Anthropogenic and Natural Emissions (ARCANE)”

Background:

The Arctic is currently warming at a rate almost four times the global average, and we expect to see a practically ice-free Arctic for the first time before 2050. As the Arctic continues to warm, we expect more trees and shrubs to grow (Tang et al. 2023), permafrost thawing and opening sea ice, which will accelerate biogeochemical processes and likely elevate the emissions of aerosol-precursors reactive gases: volatile organic compounds (VOCs). Less ice will increase human activities, such as new shipping routes and pipelines, increasing releases of greenhouse gas (GHG), particulate matter components (such as black carbon, sulfur) and VOCs, which interact with natural VOCs and also affect radiative balance in a manner that is currently poorly quantified.

Aims:

Through conducting offline coupled LPJ-GUESS and TM5, this project aims to quantify future changes in Arctic nature VOC emissions and their interactions with local and long range-transported anthropogenic sources and further explore potential geoengineering strategies focusing on aerosol feedback to slow down the Arctic against further warming.

<u>Benefits from the project</u>

In addition to the scientific purposes of these four ongoing projects, the proposed project will provide many new features for the next generation of EC-Earth4, which uses the ECMWF’s OpenIFS system. The added new processes and assessed feedback from these new features will be beneficial for other ecosystem modelling groups as well.

<u>Workplan</u>

The planned activities in the period 2026-2028 are listed below:

2026: Continuation of testing EC-Earth 3 with coupled BVOC and CO_2 between LPJ-GUESS and TM5. Twan van Noije, Zhenqian Wang, Philippe Ie Sager, and Jing Tang are currently coupling LPJ-GUESS modelled BVOC into the TM5 in EC-Earth3-AerChem, and there is a coupled version ready in February 2025. My team will then further test the coupled models and compare the outputs from the coupled runs with the run outputs from the prescribed MEGAN inputs.

A recently hired 3-year postdoc Wim will work on the Project 4, which will conduct offline simulations of LPJ-GUESS and TM5 for historical and future biogenic and anthropogenic

emissions. The simulations will include different combinations of natural and anthropogenic emissions from 45°N north and 45°N south.
The team member Shouzhi Chen is currently parameterising global and regional (China) phenological module in LPJ-GUESS. He plans to couple LPJ-GUESS with the latest phenology module in the coupled EC-Earth and conduct a series of simulations to assess the biophysical feedbacks in 2026. He will also bring in experimental datasets from Project 1.
2027:
My group will further couple CH_4, N-gas and CO into the atmosphere component, which will be built based on the existing BVOC and CO2 coupling framework.
Once the lake module ALBM is coupled to the LPJ-GUESS, the plan is to update the new version into the EC-Earth3/4 and add released CO_2 and CH4 into LPJ-GUESS land emissions to be further coupled to TM5/OpenIFS.
My group will also test to add ocean volatile and DMS emissions from ocean and potentially start with developing processes in the high latitude regions first due to current knowledge of data availability.
2028:
This year, the focus will be on continuing to assess the atmospheric impacts of different sources of volatile and greenhouse gases.
For Project 4, we will establish scenarios for Arctic shipping traffic and integrate anthropogenic emissions from local Arctic shipping routes and from southern regions. Furthermore, the impacts of deliberately altered vegetation types and associated BVOC emissions will be quantified. We will supply different emission data to TM5 to asssess spatial changes in atmospheric variables caused by these future emissions.

Justification of resources

Computing and storage resources
The table below gives an overview of the core hours per simulated model year (CHPSY) of the different models and the conversion factor of 17.06 has been used to convert CHPSY to SBU. We currently did our estimation based on EC-Earth3 and it might vary if some of the arctivities planned in 2026 will test in EC-Earth4.

Configuration	Core-hours / model year	SBU/year	Storage / model year
LPJ-GUESS offline simulation	9.6 CHPSY	168 SBU/year	1.5 GB / y
TM5 offline simulation	90 CHPSY	1584 SBU/year	1.5 GB / y
EC-Earth3-Veg	871 CHPSY	14870 SBU/year	40 GB / y
EC-Earth3-Veg-TM5	2075 CHPSY	35407 SBU/year	41 GB / y
EC-Earth3-CC	2075 CHPSY	35407 SBU/year	42 GB / y
EC-Earth3-PISCES	871 CHPSY	14870 SBU/year	41 GB / y
EC-Earth3-CC-PISCES	2075 CHPSY	35407 SBU/year	43 GB / y

According to the abovementioned work plan, we estimate the following needs for 2026-2028.

2026					
Model resolution	**Models**	**Activity**	**Planned Model years**	**Computing cost (SBU)**	**Storage cost**
0.1 and 0.5 degree	LPJ-GUESS	LPJ-GUESS coupled with new phenological module runs, tuning and Validation	2000 (tuning) 500 (validation)	756,000	6750

			2000(new version and standard version		
3 by 2 degree	TM5	TM5 runs with different natural and anthoropogenic emissions	36 spinup years and 36 simulations year	114048	108
T255	EC-Earth3-Veg	EC-Earth3-Veg with modefied LPJ-GUESS (testing with 100 simulation years; 2 historical: 1982-2014; 4 future scenarios: 2015-2100 with 5 simulations in each ensemble),	100 (tuning and testing) 2*33*5(historical) 4*86*5 (model experiments)	31972622	81200
T255	EC-Earth3-Veg-TM5	Testing&Tuning for 100 simulations years Simulation on 2 historical 33 year with 5 simulations in each ensemble and 86 future years with 4 senarios.	100 (tuning and testing) 2*33*5(historical) 86*4 (future)	27405104	27634
Sum				59,377,726	115,692

2027					
Model resolution	**Models**	**Activity**	**Planned Model years**	**Computing cost (SBU)**	**Storage cost**
T255	EC-Earth3-Veg-TM5	Testing&Tuning for 100 simulations years Simulation on 2 historical 33 year with 5 simulations in each ensemble and 86 future years with 4 senarios.	100 (tuning and testing) 2*33*5(historical) 86*4 (future)	27405104	27634
0.1 and 0.5 degree	LPJ-GUESS	LPJ-GUESS with coupled lake module	2000 tunning and testing 4000 simulation	1008000	9000
3 by 2 degree	TM5	TM5 runs with lake greenhouse emissions	20 spinup years and 100 simulations year	190080	180
T255	EC-Earth3-CC	Test and tuning for 100 years EC-Earth3-CC including lake greenhouse emissions sent through LPJ-GUESS (2 historical scenarios: 1982-2014; 4 future scenarios: 2015-2100), with 5 simulations in each ensemble	100 testing and tuning 2*33*5 (historical) 4*86 (model experiments)	27405104	31734
T255	EC-Earth3-PISCES	Test and tuning for 100 years EC-Earth3-PISCES including ocean emissions (2 historical scenarios: 1982-2014; 4 future scenarios: 2015-2100), with 5 simulations in each ensemble	100 testing and tuning 2*33*5 (historical) 4*86 (model experiments)	11510144	27634
Sum				67,518,432	96,182

2028					
Model resolution	**Models**	**Activity**	**Planned Model years**	**Computing cost (SBU)**	**Storage cost**
3 by 2 degree	TM5	TM5 runs with lake greenhouse emissions	20 spinup years and 100 simulations year	190080	180
3 by 2 degree	TM5	TM5 runs with different natural and anthoropogenic emissions	36 spinup years and 216 simulations year	399168	378

T255	EC-Earth3-Veg-TM5	Test and tuning for 100 years adding calculated CH4, N-gas and CO, 2 historical (1982-2014) with 5 simulations in each ensemble and 4 future senarios (2015-2100)	100 years for testing and tuning 2*33*5 (historical) 4*86 (future scenarios)	27405104	31734
T255	EC-Earth3-CC-PISCES	Test and tuning for 100 years EC-Earth3-CC-PISCES including lake and Ocean emissions and adding calculated CH4, N-gas and CO (2 historical scenarios: 1982-2014; 4 future scenarios: 2015-2100), with 5 simulations in each ensemble	100 testing and tuning 2*33*5 (historical) 4*86* (model experiments)	27405104	28982
Sum				55,399,456	61,274

Reference list

The Data Portal serving the FLUXNET community

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