Annual progress report to the Research Council of Norway

Special report for the EMERALD project, project number 294948

Reporting period 1 October 2021 - 30 November 2022

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Contents

Figure 1: Terrestrial boreal and sub-Arctic ecosystems (left to right): evergreen trees, deciduous trees, shrubs, and mosses, spanning all seasons from summer in the back to winter in front. Illustration by Inger Andrea, 12 years old (illustration from the proposal).

0. Introduction

The EMERALD project aims to improve representation of high latitude ecosystems and their climate interactions in the Norwegian Earth System model (NorESM) by integrating data and knowledge from empirical ecosystem research in model parameterisation, development and testing (Figure 1, 2). Model representations of land surface processes and land-atmosphere fluxes are addressed in a set of topical modelling tasks in work package 1 (WP1) with corresponding observational tasks in WP2, and supporting application in WP3, thereby delivering urgently needed improvements to the land surface scheme in NorESM for application in high latitude environments. Dissemination and communication are addressed in WP4, whereas WP5 concerns Management, organisation and national and international cooperation.

EMERALD lasts until the end of 2023 following a six months extension due to maternity leaves granted in October 2022. We have updated time lines of milestones accordingly.

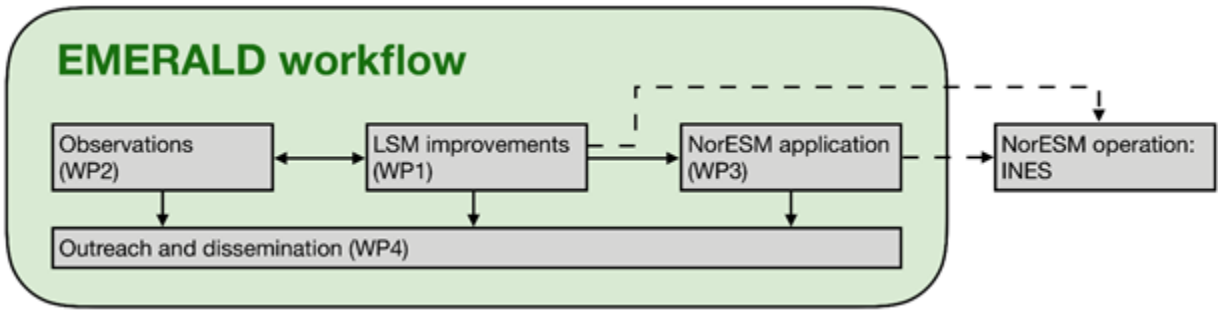

Figure 2: EMERALD activities shown in the green area. EMERALD supports developments of CLM - the land surface model of NorESM - and contributes these to NCAR and INES.

To ensure integration across work packages, four topical cross cutting themes (CCTs) were established at the start of the project, of which two were concluded in 2022:

- Albedo
- Hydrology - Snow and evaporation
- Tiling (concluded in 2022)
- New plant functional types (PFTs) (concluded in 2022)

Section 1 (Scientific progress) summarises progress and results for each WP and CCT (Section 1a) and for EMERALD funded PhD and Postdoc positions (Section 1b), whereas scientific highlights from the project written in a popular science form are given in Section 1c. Project meetings and workshops (Section 1d), challenges (Section 1e) integration with synergy projects (Section 1f), use of national research infrastructure (Section 1g) and further development of NorESM (Section 1h) then follow. An introduction to the Budget status report is given in Section 2 and the report itself provided in Appendix D. The Data management plan (updated) is presented in Section 3, whereas the plan itself is given in Appendix E.

1. Scientific progress

a. Work packages (WP) and Cross Cutting Tasks (CCT)

The Community Land Model (CLM) is the land surface model of both the Norwegian Earth System Model (NorESM) and NCAR's Community Earth System Model (CESM). Scientists at the National Center for Atmospheric Research (NCAR) in Boulder, USA have made an effort to unify CLM with elements of another land surface model (Noah-MP) by creating the Community Terrestrial System Model (CTSM). The flexible structure of CTSM will open the way for the next-generation of land surface models, enabling interdisciplinary synergies between scientific communities working together on climate, weather, water, and ecosystems applications. In this report, both the CTSM and CLM abbreviations refer to the latest version of the land component of NorESM namely CLM5. In EMERALD, CLM is used with two different vegetation modules: (i) the default vegetation module with fixed vegetation distribution (BGC), and (ii) the Functionally-Assembled Terrestrial Ecosystem Simulator (FATES) with prognostic simulation of vegetation distribution.

An important step forward has been the development of the CLM-FATES model platform for site simulations, as also described in the EMERALD progress reports of 2020 and 2021. The platform is now available in the NorESM GitHub repository. It simplifies and streamlines model simulations for selected sites and facilitates interaction between model (WP1) and observation (WP2). The platform has been applied within several tasks in WP1 and WP2, as well as in the preparation of coupled simulations in WP3. The platform is now termed the NorESM LandSites Platform (NorESM-LSP) and is a point scale version of CLM-FATES. It facilitates validation of ecological and environmental processes and parameterisations against observed local estimates of ecosystem productivity and performance. Details of its development and user potential are elaborated in a scientific paper (Keetz, Lieungh et al. submitted). The collaboration with NCAR over platform development is an important step in terms of communication and promotion of new processes representation. Following the EMERALD Data management plan (Appendix E), the NorESM-LSP documentation is published openly available (URL-2).

WP1: Land surface model evaluation and improvement

Leads: Olav Skarpaas, Hanna Lee, Hui Tang

The main objective of WP1 is to target processes and parameters in CLM5-BGC and CLM5-FATES that need improvement for representing boreal, alpine and Arctic terrestrial ecosystems, and to improve their representation by the help of observations and more detailed mechanistic models. The WP consists of six tasks (1a-f) on new plant functional types (PFTs) for mosses and lichens, vegetation dynamics, plant hydrological processes, albedo, carbon cycle and energy balance, with mirrored tasks in WP2. Several of the tasks are also covered in cross cutting themes, and are closely linked to WP3 on implementation in NorESM.

WP1 Milestones[1]

1.1 Parameterize recent CLM improvements	2019.1 - 2019.4
1.2 Build in key missing elements in CLM	2019.1 - 2022.2
1.3 Test adjusted model predictions in WP1 tasks	2019.3 - 2022.2
1.4 Model and observation revisions based on tests	2020.1 - 2022.4
1.5 Prepare models for WP3 applications	2020.3 - 2022.4
1.6 Provide output for WP4 dissemination	2020.1 - 2023.4

[1] Blue background denotes milestones completed prior to the reporting period, grey those completed during the reporting period and white outstanding milestones.

M1.2 Build in key missing elements in CLM

Parameterisation of CLM improvements and incorporation of missing elements have been carried out in parallel with other developments (in the CCTs on hydrology, albedo and new PFTs; see also WP2 and WP3). A new scheme for early growth of new aerosol particles from emissions of Biogenic Volatile Organic Carbon (BVOCs) has been developed and tested (see M1.3 and WP3). In collaboration with NFR partner project WINTERPROOF, PhD student Marius Lambert applied the existing hardening scheme of the demographic vegetation model FATES in order to implement a hardiness-dependent frost mortality into CLM5.0-FATES (Lambert et al., submitted) and upgraded the plant hydraulics in FATES to simulate cold acclimation by high latitude vegetation (Lambert et al 2022). The newly developed scheme is a major step forward in dynamically representing vegetation in ESMs by including a level of frost tolerance that is responding to the environment and incorporating cost and benefit as part of the scheme. This work has brought many improvements, including a range of new model schemes for specific processes related to hardening and physiological impacts (maximum conductance, stomatal conductance, hydraulic failure mortality, pressure volume curve and carbon starvation mortality) as well as technical solutions (new equation solver). Further, a first version of the new mosses and lichen PFT has been established and tested. Due to the very different plant physiology of mosses and lichens compared to plants represented by standard PFTs (e.g. the lack of roots), the inclusion of this new PFT has been challenging (Section 1e), and careful testing and further developments are continuing.

M1.3 Test adjusted model predictions in WP1 tasks

Testing of model predictions has been carried out, yielding interesting results on several aspects of land-atmosphere interactions. For instance, with the new scheme for early growth of new aerosol particles from emissions of BVOCs (reported last year), NorESM has been used to simulate the effective radiative forcing of anthropogenic aerosols, estimated to -1.1 Wm-2 (IPCC, 2021). Using the updated scheme, the effective radiative forcing is reduced by 13% (Blichner et

al. 2021). The inclusion of a new PFT mosses and lichens has been challenging and systematic testing of different representation of mosses in CTSM-FATES has been performed (Tang et al., in prep.). This includes different options (Figure 3) that are distinct in terms of whether (i) the moss can be present and doing photosynthesis under snow or not, (ii) the heat transfer scheme for moss is similar to other vegetation types or not, and (iii) the vegetation part of moss has any impact on heat transfer. Preliminary results show that the adjusted models capture the low photosynthetic activity of moss compared to grassland observed in field data (see also WP2 and WP3, M3.3). Certain (mixed) representations of moss seem to perform better than other combinations (e.g., S1V2). Careful testing and further developments are continuing. We have also run tests and compared with observations for a new soil organic matter decomposition scheme (implemented in NorESM as part of WP3). We tested the new frost mortality (Lambert et al., submitted) and hardening scheme in FATES (Lambert et al. 2022) and evaluated the frost drought from the winter 2013/2014 (Lambert et al., in prep.; see also WP3, M1.3).

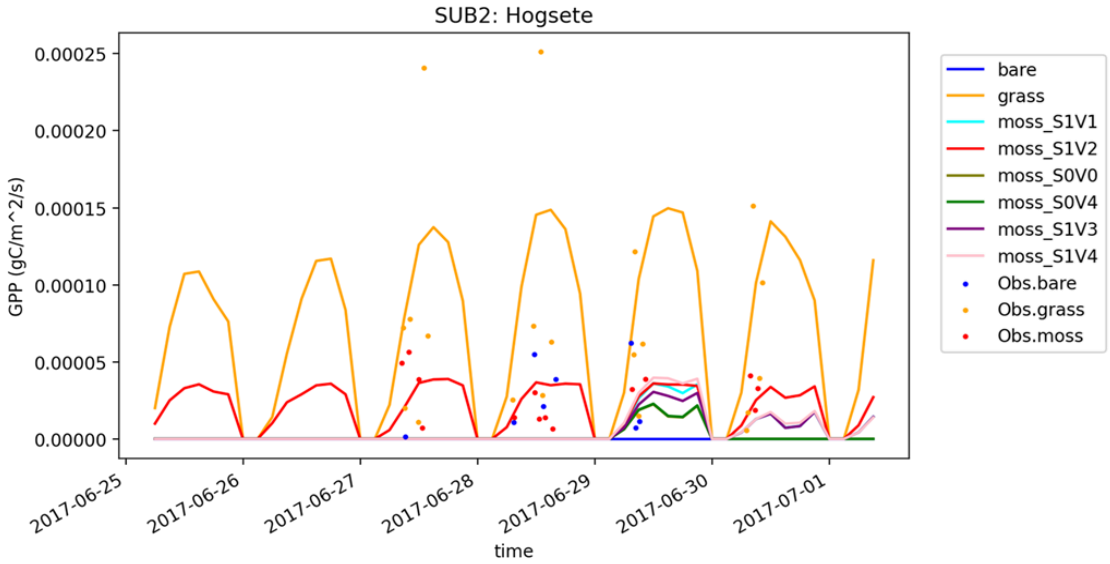

Figure 3: Diurnal gross primary productivity (GPP) predicted by various plant functional types (PFTs) and observed in the field at one of the 12 grassland sites of the Vestland climate grid (Tang et al., in prep); see also illustration of field sites and the various model implementations in WP3 (M3.3).

M1.4 Model and observation revisions based on tests

Model revisions and adjustments are made based on continuous testing of code and model output, and confrontation with observed data (see M1.3). While modelling and empirical work (data collection) are often carried out in isolation, by different people with different scientific backgrounds, a major ambition in EMERALD has been to make the two worlds meet. A key contribution from this project is the NorESM-LSP (Figure 4), providing both coding and graphical user interfaces for running the model with community-developed, open-science software that

works on many operating systems. The platform code is now available on GitHub (URL-1) and a scientific paper presenting the platform is submitted (Keetz, Lieungh et al. submitted). The platform facilitates both formal scientific inquiry to support model and observation revisions and great opportunities for educational awareness of land-surface model performance. It is already an important tool for ongoing studies in WP1 and WP2 (e.g. vegetation dynamics and carbon), and is actively used in advanced university courses at the intersection of bio- and geosciences (e.g. GEO5915 Ecological climatology), training junior scientists within and beyond the EMERALD community. The platform has also been integrated into six new project proposals to the Research Council of Norway in 2021, one of which was funded (the FUNDER project; see also WP2).

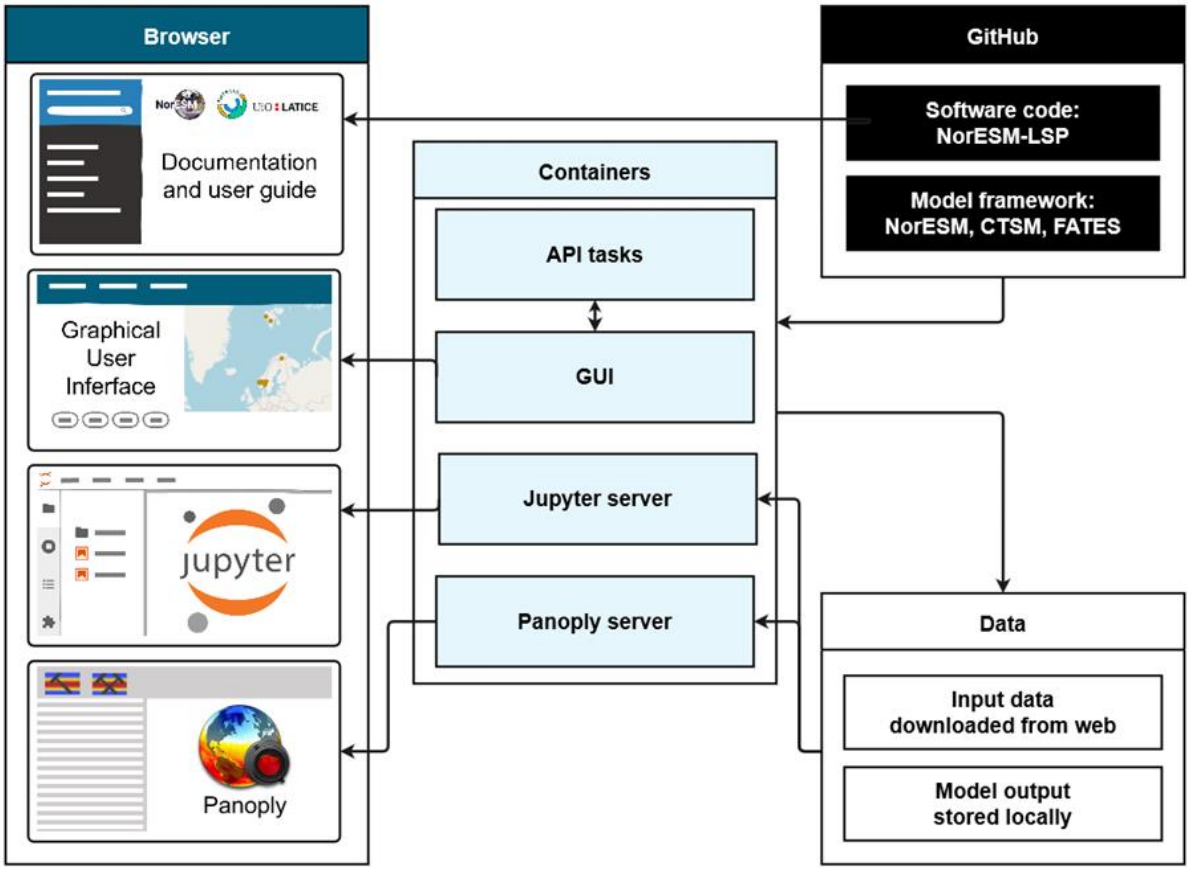

Figure 4: The NorESM LandSites Platform architecture. Users can follow a user guide, customise and run model experiments in a graphical user interface, and easily analyse the results in JupyterLab or Panoply. The software code is developed in GitHub repositories, from which Docker containers are created as virtual computing environments for modelling. The input data (atmospheric forcing, model parameters, etc.) is stored online. Model output is stored locally and is accessible in JupyterLab and Panoply servers for easy data exploration and analysis (URL-2).

M1.5 Prepare models for WP3 applications

There has been close interaction and overlap among scientists working in WP1 and WP3. Different parameterisations of moss and lichen PFTs developed in WP1 are now tested for application in WP3 (see M1.3 and M3.3). Adding separate soil tiles to the individual plant functional types (PFTs) has allowed a better representation of subgrid variability in soil depth and properties. This subgrid variability has significant impacts on soil microclimate, in particular soil moisture, which is an important factor determining the establishment of different PFTs. In the longer term, this is essential when fully dynamical representation of vegetation (i.e. using the FATES model) is included. Further details on the implementation and applications of model developments are provided under WP3 below.

M1.6 Provide output for WP4 dissemination

A major initial contribution from WP1 to dissemination was concretisation of model concepts for public exhibitions (see WP4). Since the beginning of the project until now, WP1 participants have presented their work at project seminar series, university and institute seminars, and national and international conferences. In the last year, we have had a particular focus on preparing scientific papers. Publications are reported in Cristin, and results are communicated to the broader public through various channels (WP4).

WP2: Improved process understanding from observations and experiments

Leads: Vigdis Vandvik, Jarle W. Bjerke, Norbert Pirk

WP2 harnesses research investments already existing in the form of relevant data from past and current synergy research and monitoring projects from across Norway and beyond with their own goals and deliverables. Those results are mentioned under M2.3 (but not reported in full under EMERALD). Additional data are being collected during the project period by EMERALD staff. Overall, field activity (M2.4) during winter, spring and summer of 2022 was productive, and according to plan. Collected data are being handled and analysed by the many researchers involved in WP2. This includes MSc and PhD students, postdoctoral researchers and permanent staff at the involved universities and research institutes, as reported below. WP2 supports WP1, but also contributes stand-alone research in the form of process studies and upscaling by combining observations across methods and parameter space. This includes scientific articles on vegetation dynamics, plant hydrological processes, and climate-mitigating ecosystem services related to carbon cycles and reflection of incoming solar radiation. WP2 consists of seven specific tasks mirroring those in WP1, and fieldwork for task-specific data collection is being conducted at numerous sites in Norway, including Svalbard.

EMERALD WP2 milestones are treated in more detail below. Data from WP2 and synergy projects are collated (M2.3) and transferred to WP1 and CCTs as needed for processing and further use

(M2.5). Output for dissemination (M2.6) include scientific publications and popular science (reported here and under WP4, and under EMERALD and synergy projects in Cristin).

WP 2 Milestones[1]

2.1 Develop data management plan	2019.1 - 2019.1
2.2 Storage space and templates for meta-data files	2019.1 - 2019.1
2.3.Collate existing data	2019.2 - 2019.4
2.4 Field work	2019.2 - 2023.2
2.5 Provide data and knowledge for WP1 and WP2 tasks	2020.2 - 2022.1
2.6 Provide output for WP4 dissemination	2020.1 - 2023.4
2.7 Data arctic testbed	2023.2 - 2023.4

[1] Blue background denotes milestones completed prior to the reporting period, grey those completed during the reporting period and white outstanding milestones.

M2.3 Collate existing data and M2.2 data and meta-data storage

As reported previously, EMERALD is not setting up designated central data storage, but facilitating open data storage and sharing via relevant platforms (see also M2.5). In 2022, a data paper reporting on the vegetation, microclimate and carbon dynamics of the plant functional type removal experiments in the 12 SeedClim sites was published (Vandvik et al., 2022). This data paper reports on methods and data, and is linked to an open OSF data repository (URL-3), which is accessed by the NorESM LandSites platform. More sites and data will be openly published and made accessible in a similar fashion in the future.

M2.4 Field work

The WP2 team has installed and is maintaining four heat field deformation units on four trees at the ICOS Hurdal Ecosystem site. These units enable estimates of whole tree sap flow from which stand-level sap flow can be estimated. This data provision work is carried out under WP2 (Task 2c) and will support planned activities in the last year in WPs 1 and 2.

Lichen-dominated heath and tundra are widespread at northern latitudes and provide services relevant for climate, biodiversity and arctic communities. The team has collected ground observations of albedo characteristics from a range of treeless vegetation types (including lichen-dominated types) under different reindeer grazing regimes in Svalbard and mainland Norway. Emphasis is placed on the contribution from fruticose ground lichen, responsible for some of the highest observed albedo values from snow-free vegetation. The dependence of cloudiness and solar zenith angle on albedo has also been explored in lichen-dominated vegetation. This work,

with EMERALD PhD student Eirik A. Finne as first author, has been submitted and is currently in review.

Experimental field research and modelling approaches have shed new light on winter ecology of northern vegetation. From a 2-year winter warming simulation undertaken at an alpine ridge near Finse High-Alpine Research station, PhD student Finne and co-workers have elucidated that alpine cryptogams (i.e., bryophytes and lichens) are more tolerant than evergreen vascular plants to disturbance of dormancy during winter (see Section 1b for further details).

In the 12 SeedClim sites (Vestland climate grid), destructive harvest of the FunCaB plots for the new FUNDER project is designed to provide data on soil organisms and processes (mesofauna, fungi, bacteria, and carbon and nutrient dynamics) complementing the existing data on plants, vegetation, and ecosystem carbon storage. The 6th plant functional traits course (URL-4) in Aurland Norway, collected data on photosynthesis, ecosystem carbon dynamics, plant functional traits, and multispectral imagery to assess vegetation processes. These data will be written up for publication by the course participants.

Further, the team has collected data for evaluation of transpiration as a component of evapotranspiration at three flux sites, collected photosynthesis and transpiration data three times during the growing season for parameterisation of the dwarf shrub crowberry (*Empetrum nigrum*), collected plants for climate lab experiment on drought and transpiration from dwarf birch (*Betula nana*), and undertaken climate laboratory experiments with the bush *Salix phylicifolia* on effects of ozone exposure on growth, root:shoot partitioning, leaf senescence, root growth, and mycorrhiza development.

M2.5 Provide data and knowledge for WP1 and WP2 tasks

By combining the newly developed metrics and models for albedo and ground lichens (M2.4), the long-term CO_2-equivalent reflectivity properties of ground lichens under variable grazing regimes have been calculated. A manuscript including these new data is in preparation.

A Landsat-based remote sensing model for detection and monitoring of lichen volumes in heath and tundra was developed in close association with another RCN project, VANWHITE, and was recently published in *Remote Sensing of Environment* (Erlandsson et al. 2022). The method relies on artificial intelligence using deep neural networks and has proven to be superior to previously developed remote sensing methods for lichen volume detection. The new method monitors well documented fluctuations in ground lichen volumes, such as in the Finnmark-Finland border region for the period 1984-2020. Additional studies relying on this newly developed method are in preparation. The method is already in use in Norwegian environmental management of grazing ranges of both wild and semi-domestic reindeer herding ranges.

WP2 has developed a stand-alone soil decomposition model designed to capture feedbacks between soil carbon dynamics and vegetation/climate change better than models typically used

in land models such as CLM. Calibration and validation tests of the model are in progress. Additional CLM-BGC development is undertaken, specifically related to forests and their C and N stocks, stand heterogeneity, and drainage.

The NorESM LandSites Platform (NorESM-LSP) enables validation of LSM ecological and environmental processes and parameterisations in conjunction with localised ground-truthing of models against known local estimates of ecosystem productivity and performance. The WP2 team has contributed to the developing of several new initiatives linked to the platform: the new moss and lichen PFT; more reproducible and streamlined pathways for downscaling atmospheric, surface layer, and vegetation inputs; and decision trees and tools for new users with the aim of reducing barriers to initially setting up the model and encouraging model experimentation. Each of these additional elements are in the process of being written up as publications for diverse audiences, including geosciences and ecologists. New initiatives encouraging interdisciplinary collaboration builds on the NorESM-LSP and facilitates both formal scientific inquiry in addition to opportunities for educational awareness of land surface model performance. In support of these initiatives, we have ongoing contributions of data, including soil and surface layer data from test sites for NorESM-LSP; a collated dataset to be set up on the Open Science Framework from the SeedClim project; the establishment of the new project FUNDER – investigating below-ground relationship with vegetation, microorganisms and decomposition; newly established phenology monitoring at the Iškoras site (Finnmark) along with ongoing monitoring of C fluxes, and now vegetation traits; a global thermal tolerance dataset to create a new thermal tolerance mortality function within FATES, amongst others.

M2.6 Provide output for WP4 dissemination

For the NorESM-LSP outreach, presentations have been given at both Norwegian ecological and hydrological conferences and hands-on workshops for scientists and PhD students have been organised, with further interest expressed from research agencies. From the 2021 RCN grants written to expand on the EMERALD remit, two were funded, DURIN and FUNDER (see Section 2f and Appendix A). These are ecological projects that also contain upscaling with LSM model experiments and PFT development informed by the ecological knowledge and data. Publications and other outputs are tagged with EMERALD in Cristin.

In the annually updated report on the state of the tundra, which includes EMERALD partners Bjerke and Tømmervik as co-authors, and which is published both in the Arctic Report Card (every December) and with slight updates in a special issue of the Bulletin of the American Meteorological Society (every August), it is shown that the record-high circumarctic vegetation greenness of 2020 was not beaten in 2021. Still, 2021 has the second-highest circumarctic vegetation greenness ever recorded, as measured by the MODIS satellites, over a time series starting in 2000. The time series shows a clear greening trend, supporting field-based observations of increased vegetation productivity in the Arctic.

WP3: Implementation in NorESM and quantification of feedbacks

Leads: Terje Berntsen, Ryan Bright, Sebastian Westermann

The main objective of WP3 is to harvest the improved process understanding gained in WP1 and WP2, implement it in the process models (CLM, FATES) and eventually into NorESM WP3 taking advantage of recent improvements in the CLM5 version running now in NorESM2.0 (used for CMIP6 simulations). This includes, among other, an improvement in the coupled carbon/nitrogen cycle influencing plant growth and the entire terrestrial carbon cycle. There is not a very clear distinction between the model developments in WP1 and the implementation phase of WP3, and key scientists are very active in both WPs. For EMERALD, the main part of NorESM that is relevant is the terrestrial land surface module CTSM, but also partly the atmospheric module CAM. Developments (done, in progress and planned) are done in close collaboration with the main developers at NCAR and the developers of NorESM, mainly at met.no and UiB. The collaboration is organised through regular zoom meetings and extensive use of GitHub repositories to share code (Appendix C).

WP3 Milestones[1]

3.1 Split vegetated land columns in CLM5	2019.2 - 2021.1
3.2 Quantification of changes in surface feedbacks	2021.1 - 2023.2
3.3 Changes in land-atmosphere feedbacks	2021.1 - 2023.2
3.4 Impacts on C-cycle feedbacks	2021.1 - 2023.4
3.5 New CMIP version of NorESM	2022.2 - 2023.4

[1] Blue background denotes milestones completed prior to the reporting period, grey those completed during the reporting period and white outstanding milestones.

Overall, work is underway in quantifying changes in surface feedbacks through developments of new and revised process representations (jointly with WP1 and in supporting projects) in order to facilitate simulations with NorESM addressing the science questions behind each milestone, as detailed below:

M3.2 Quantification of changes in surface feedbacks

Observations show that Arctic vegetation undergoes both greening and browning. Frost mortality of vegetation during winter-spring transition has been poorly represented in models. A new model scheme has been developed and tested (Lambert et al., 2022) to include the so-called “hardening process” in high-latitude plants in the coupled default CLM-FATES-Hydro land module (Figure 5).

Progress has been made in implementing improved representation of fractional snow cover in CTSM. Also, the ongoing work with updates to FATES will improve the vegetation distribution and

how this responds to climate change in CTSM. Both these processes are important for the land-surface feedbacks. The development of mosses and lichens as new PFTs (WP1, M3.3) will be a major advance in quantifying these feedbacks.

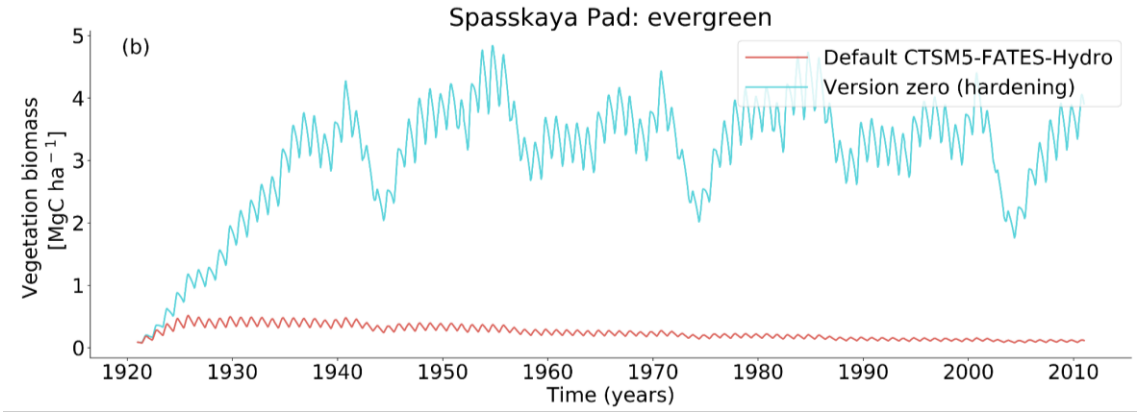

Figure 5: Living biomass for needle leaf evergreen trees at Spasskaya Pad near Yakutsk, Russia (62°N, 129°E), for default CLM-FATES-Hydro simulation (red, no hardening) and with hardening resulting in reduced root water exudation (from Lambert et al., 2022).

M3.3 Changes in land-atmosphere feedbacks

A new scheme for simulating early growth of new aerosol particles from emissions of biogenic volatile organic carbon (BVOCs) was reported last year (Blichner et al., 2021). Vegetation in CLM is represented as broad Plant Functional Types (PFTs). In order to be able to simulate feedbacks, the PFTs in the model must include the main vegetation types. Early in the project, it was identified that bryophytes (i.e. mosses) were not represented. Since bryophytes are fundamentally different from vascular plants, it has been a challenge to represent them within the framework of PFTs in CLM. Different parameterisations are now tested, using the SeedClim sites as benchmarks. Figure 6 below shows the different structures that are tested.

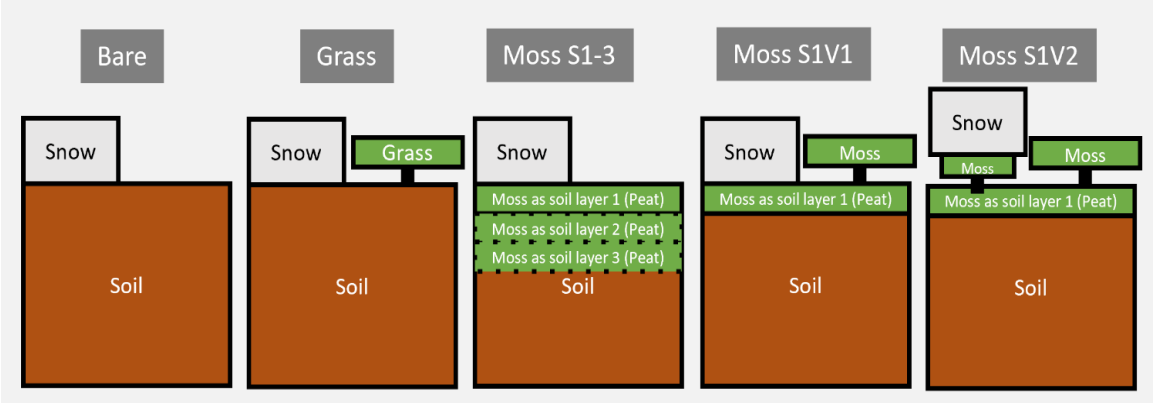

Figure 6: Structure of the various implementations of moss that are tested in CLM.

M3.4 Impacts on C-cycle feedbacks

Changing soil microclimate and vegetation can give significant feedbacks through the soil carbon cycle. A new scheme for explicit representation microbial decomposition of organic carbon in soils (cf. 2021 report) has been developed and is now tested against soil inventories from Norway. The scheme includes explicit representation of soil microbes, mycorrhiza (fungi living in symbiosis with the plants) and nutrient cycling (so far only nitrogen). Figure 7 shows that there is less variability in models as compared to the observations, the models underestimate carbon stocks and overestimate nitrogen stocks. The new decomposition model shows some improvements over the standard CLM5-scheme.

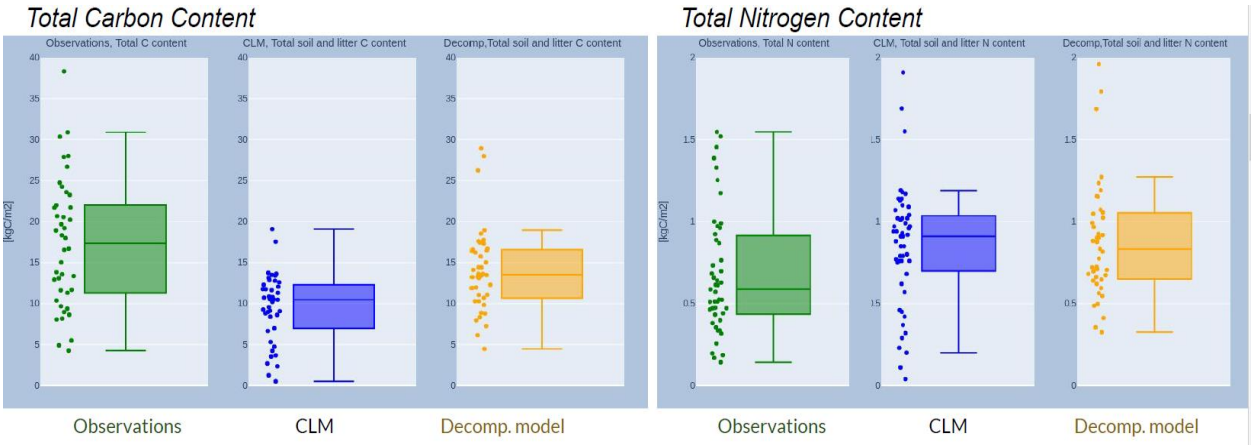

Figure 7: Comparison of observed and simulated soil organic carbon and nitrogen content in podzols for stations across Norway. Simulations include standard CLM-scheme and the new scheme (decomp).

M3.5 New CMIP version of NorESM

The objective of this milestone is to incorporate developments of new parameterisations in CTSM-FATES developed during EMERALD into the official Coupled Model Intercomparison Project CMIP) version of NorESM. The work will run until the end of the project. The main model development for a new CMIP version of NorESM has been funded through a national infrastructure project INES. As INES2 failed to get funded, the future of NorESM for CMIP use is very uncertain. Without the extensive long simulations and tuning required for CMIP acceptable versions (planned within INES2), it remains to be seen how much EMERALD developed code can make it into the main branch of NorESM. Nevertheless, developments in secondary aerosol formation and vegetation hardening, is well documented and ready for NorESM, while the new development of decomposition of soil organic carbon and moss as a new PFT maybe less likely to make it. Anyway, we will structure and document the new code well, so that it is ready for incorporation in NorESM should more funding become available.

WP4: Dissemination and communication

Leads: Irene Brox Nilsen, Anders Bryn and Frans-Jan Parmentier.

A highlight in 2022 was the stakeholders meeting arranged in February 2022, following up the 2019 EMERALD stakeholder meeting. This hybrid meeting assembled 27 participants from research institutions and stakeholders within forestry and agriculture. The meeting was arranged in collaboration with the NFR project IMPRINT (URL-5), and featured input from the NFR project WINTERPROOF. A web-based report was published following the event (Figure 8). For more details see M4.8 below.

Figure 8: Screenshot of the web-based report aimed at stakeholders (URL-6).

Another highlight is the special issue published in journal Naturen in collaboration with the CBA (Section 1f). EMERALD researchers published four articles in this issue (Section 1c).

WP 4 Milestones[1]

4.1 Project web-page	2019.2 - 2023.4
4.2 First stakeholder meeting, NCCS	2019.3 - 2019.3
4.3 Debates, blogs, newsfeeds, media	2019.3 - 2023.4
4.4 EMERALD knowledge in Climate House activities	2019.4 - 2023.4
4.5 Simplified model developed at the Climate house	2020.4 - 2020.4
4.6 Modelling conference at Lillehammer	2022.3 . 2022.3
4.7 Session at EGU	2022.2 - 2022.2
4.8 Second stakeholders meeting	2022.4 - 2022.4
4.9 Updated climate and hydrological projections, NCCS	2023.2 - 2023.2
4.10 Software on GitHub	2022.4 - 2022.4

[1] Blue background denotes milestones completed prior to the reporting period, grey those completed during the reporting period and white outstanding milestones.

M4.1 Project web-page

The project web-page is regularly updated and used for dissemination of activities and results, e.g. highlighting newly published papers and media outreach (M4.3).

M4.3 Debates, blogs, newsfeeds, media

The blog 'Søkelys på skogplanting' (Focus on afforestation) is still a relevant channel for publishing Norwegian popular-scientific blog pieces for the project. Two blog posts have been published since last reporting, and more are in the pipeline. The piece "Snøen smelter tidligere under trærne - hva kan det ha å si for klimamodellene?" was featured on the front page of forskning.no when published (URL-7).

EMERALD researchers continue to publish op-ed pieces in Norwegian mass media. In January, an op-ed in Nationen stressed that increasing photosynthesis through afforestation cannot be taken for granted because forests' ability to take up carbon emissions are altered by various calamities. EMERALD researcher Frans-Jan Parmentier writes op-ed pieces on EMERALD-related topics on a regular basis for Klassekampen. EMERALD researcher Vigdis Vandvik frequently contributes with EMERALD-related opinions, popular science pieces, and public outreach (tagged as EMERALD contribution in Cristin).

M4.4 and 4.5 Temporary exhibition(s) and Climate House activities

The temporary exhibition "Natur i endring" was moved to the Norwegian mountain centre in Lom summer 2021 and has therefore been granted a longer lifetime than initially expected. The simplified wood models of climate model processes that were designed by a professional studio is part of this exhibition.

EMERALD participant Hanne Heiberg (MET Norway) gave a climate talk entitled "Hva slags vær kan vi vente oss?" for the general public at Klimahuset's "Kaffe og klima" series, with contributions from Irene Brox Nilsen (NVE). The event was held on 04.11.2021 with a focus on what kind of weather can we expect in Norway under changing climate, and what does the latest IPCC report say about global precipitation and extreme weather.

M4.6 2021 Modelling conference at Lillehammer

The Lillehammer modelling conference (URL-8) is completed (September 2021, a year earlier than planned) and was summarised in last year's EMERALD report. Since then, it has been reported to the funding institutions RCN, the Norwegian UNESCO Commission and the Nordic hydrological association. A new modelling conference is planned for September 2023, with contributions from e.g. Lena M. Tallaksen (coordinator of EMERALD) in the organising committee.

M4.7 Session at EGU2022

The European Geosciences Union (EGU) General Assembly is a large international conference where several thousands geoscientists meet every year. In 2022, nine presentations were given by EMERALD researchers. These were listed under news at our webpage (URL-9) for promotion before and during the EGU conference. Similar to last year (URL-10), two sessions were co-convened by EMERALD researchers: *BG3.14 Land use and land cover change effects on surface biogeophysics, biogeochemistry and climate* (URL-11) and *BG 3.24: Peatlands Under Pressure* (URL-12). See Section 1c 'Scientific Highlights' for further details.

M4.8 Second Stakeholder meeting

The second stakeholder meeting was organised in February 2022 (half a year earlier than planned). A summary of the two EMERALD stakeholder meetings, held in 2019 and 2022, are published as NVE report 31-2022 (URL-13), in addition to a web-based report aimed at stakeholders (URL-6). The report has also been distributed through the official EMERALD project website (URL-14) and an EMERALD project website on klimaservicesenter.no (URL-15). These reports are written in Norwegian to ease communication with the target group. Input from stakeholders about combining forest fire danger and lightning was forwarded to the weather forecasting services at the Meteorological Institute. Based on this input, a combined version of lightning observations and the forest fire hazard warning is planned (see also highlights).

M4.9 Updated climate and hydrological projections, NCCS

The Norwegian Centre for Climate Services, NCCS, are working on updating national climate and hydrological projections for the end of this century. The project "Climate in Norway 2100" (URL-16) is financed by the Norwegian Environment Agency and in-kind contributions from NCCS' partner institutions. Updated climate and hydrological projections that form the basis for the second "Climate in Norway 2100" report is planned to be issued in 2024, after EMERALD has ended and later than originally planned. Progress on this work was presented by Anita Verpe Dyrrdal at the European Meteorological Society (EMS) Annual Meeting 2022 (URL-17) and by Irene Brox Nilsen at EMERALD-webinar in April 2022. Lena M. Tallaksen presented the EMERALD project at the NCCS Annual Meeting at Geilo, 8-9 November 2022 (see Section 1d).

M4.10 Software on GitHub, including the NorESM-LSP

The NorESM -LSP developed as a community effort within EMERALD enablesnon-expert users, such as ecologists, to run climate simulations on their own. The platform is well documented on GitHub with a user-friendly interface (URL-18) as listed in Appendix C.

WP5: Management, organisation and cooperation

Leads: Lena M Tallaksen, Terje Berntsen and Frode Stordal

EMERALD is managed in two phases; phase I (start 2019 - mid 2020) and phase II (mid 2020 - end 2023). Stordal led phase I whereas Tallaksen (originally co-lead) took over as lead for phase II, 1 July 2020 (Figure 9). At the same time, Berntsen became co-lead of EMERALD, jointly with Stordal (now Prof. Em.). Tallaksen currently leads both EMERALD and the synergy project LATICE (Section 1f), which strengthened the co-leadership of the two initiatives. The management group (Tallaksen, Stordal and Berntsen) meets regularly to discuss management issues.

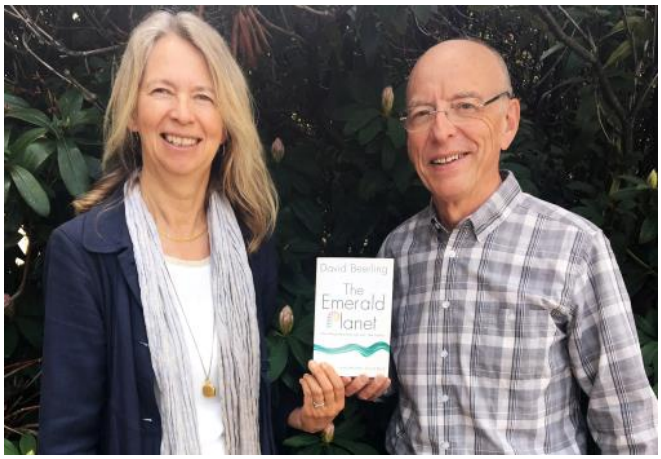

Figure 9. EMERALD leaders Lena M. Tallaksen and Frode Stordal at the start of the project.

The leader group consists since the start of 2020 of Lena M Tallaksen, Terje Berntsen and Frode Stordal (UiO-Geo), Hanna Lee (UiB), Jarle Bjerke (NINA-Tromsø), Ryan Bright (NIBIO) and Anders Bryn (UiO-NHM), ensuring a balanced team in terms of gender and seniority, between geosciences vs biosciences, university vs institute sector, research experience (modelling vs observations), and geographic location. In June 2021, Vigdis Vandvik (UiB) replaced Hanna Lee in the leader group, following Lee's change of main position from NORCE to NTNU (still keeping a 20% position at NORCE).

An international network group with eight members was established at the start of the project, covering the breadth of scientific disciplines in EMERALD. Two of the international partners, Paul Miller and Robert Bjørk, participated in the annual meeting 17-18 October 2022. Others (Katul, Martilla) are engaged in joint publications and new collaborative initiatives.

International network group:

- Robert Björk, University of Gothenburg, alpine and polar ecology;
- Eleanor M. Blyth, Centre for Ecology & Hydrology, land surface and hydrological modelling;
- Torben Christensen, Aarhus University, Arctic environment, nature and ecology;
- Gabriel Katul, Duke University, land-atmosphere exchange physics;

- Hannu Marttila, University of Oulu, catchment hydrology;
- Paul Miller, Lund University, climate and carbon cycle modelling;
- Ranga Myneni, Boston University, vegetation remote sensing;
- Heidrun Matthes, Alfred Wegener Institute, regional climate modelling of the Arctic.

WP 5 Milestones[1]

5.1 Kickoff meeting	2019.1 - 2019.1
5.2 Yearly project seminar	2021.2 - 2021.2
5.3 Yearly project seminar	2022.4 - 2022.4
5.4 Final project meeting	2023.2 - 2023.4

[1] Blue background denotes milestones completed prior to the reporting period, grey those completed during the reporting period and white outstanding milestones.

M5.1-4 Yearly project meetings

The leader group meets regularly by video link, partly in response to the pandemic, but also to reduce travelling (positive experience from the lockdown period is that this works fine). In total three regular (hybrid) meetings took place, 3 February, 3 June and 31 August 2022.

As an integral part of the EMERALD monthly seminars (WP4), Tallaksen has continued to give short updates on the project and provided information of general interest to the members. This to assist a good flow of information internally. Furthermore, the 'EMERALD Teams' site facilitates easy communication and sharing of documents among members. The site is hosted at UiO; however, access is facilitated for outside users. Separate channels are established for each WP and CCT along with channels for sharing photos, collaborating on joint papers, and coordinating fieldwork, amongst other.

Cross Cutting tasks

CCT Albedo: Ryan Bright (Lead)

The albedo team has met regularly to define and prioritise several research tasks/scientific analyses that are now currently in various stages of execution. Parts of the albedo team have contributed to a completion of an analysis of 1983 – 2018 surface albedo change and snow/ice albedo feedback in all areas poleward of 50°C. This work was carried out under WP2 (Task 2d) and yielded a comprehensive dataset of historical surface albedo evolution in Polar Regions. This work was recently published (Bright & Lund 2021). Work will continue in 2023.

CCT Hydrology: Kolbjørn Engeland (Lead)

The Hydrology CCT had seven meetings in the reporting period to progress the model intercomparison (MIP) experiment for evapotranspiration. One of the main motivations for this MIP is the need to improve knowledge about the actual evapotranspiration in Norway, in particular at high altitudes and cold environments. Recent estimates of mean annual evapotranspiration as summarised in Erlandsen et al. (2021) shows that previous estimates vary widely, from 178 – 500 mm/year.

The model intercomparison is performed at three scales: (i) point scale at selected sites with observations of evapotranspiration with eddy correlation (EC) instrumentation, (ii) catchment scale, and ((iii) regional scale covering Norway and Fennoscandia. Different types of models are contributing; two land surface models: CLM (UiO) and SURFEX (Norwegian meteorological institute), three hydrological models: Shyft and LisFlood (UiO) and HBV (NVE), and as a stand-alone algorithm, the Penman-Monteith (NIBIO). The main activity in the reporting period has been to establish basic datasets common for all models and initiate the comparison at the point scale for five eddy covariance sites in Norway. This includes establishing forcing datasets as well as background information about land use and soil types. Preliminary results (first model runs) were presented at EGU in May 2022 (Engeland et al., 2022), see Appendix B-ii. The next step is to finalise the protocol for the MIP, including science questions, data flow, which variables and benchmark indices to compare and a timeline for the work progress. By the end of 2022, a standard forcing dataset that can be accessed by all models will be made available. The MIP will result in one joint scientific paper, with a large potential for additional papers by individual modellers or a specific science focus building on the general outcome of the original comparison.

A separate model intercomparison focusing on snow processes is in preparation. In the ongoing initial phase, representative observational products are being prepared to serve as benchmarks for the models. These snow observations are derived from the long-term satellite observations (MODIS), new high-resolution satellite observations (Sentinel-2, Landsat 8), and reanalyses (ERA5, ERA5-Land, MERRA2) over the Scandinavian region and around some selected observation sites (a manuscript is under preparation). Both MIPs collaborate closely with the LATICE project.

CCT Tiling: Kjetil Aas (Lead)

The CCT on tiling has co-hosted two hackathons together with the newly funded NFR project CN-coESM (PI: Hanna Lee), from 1-5 of August 2022 and from 19-23 of September 2022. Both hackathons were hosted in Oslo, with four participants from UiO, NTNU and NORCE. The aim of both events was to implement laterally coupled tiles in CTSM, building on previous work by EMERALD partners (Aas et al., 2019; Cai et al., 2020). Members of the CCT have contributed to the implementation of permafrost tiles in JULES (Smith et al., 2022). Substantial progress has been made on tiling and the work is considered concluded within the EMERALD project.

However, its members will continue to support the work of implementing tiling in CN-coESM and potentially new projects that will build on these methods.

CCT New PFTs: Terje Berntsen (Lead)

This work is now concluded with new PFTs for mosses and lichen developed (see M3.3).

b. EMERALD PhD and Postdocs

EMERALD PhD - Eirik Aasmo Finne

2022 is the second and final year of the winter warming project at Finse Alpine Research station. The aim is to investigate the effect of extreme winter warming events on vegetation ecophysiology, with emphasis on mosses and lichens. Two experimental treatments were implemented (Figure 10), utilising heating lamps to melt the insulating snow cover and thus exposing the vegetation to fluctuating temperatures as well as pouring water on the snow to form ground ice that encapsulates the vegetation. In February and March this year, we repeated the experiment on six plots established in 2021. In addition to our experimental warming, there was a naturally occurring winter warming event in late December 2021, which melted the snow cover and led to substantial ground icing.

In June and July, summer ecophysiology data was collected from the experimental plots, including photosynthetic efficiency on species and plot level, and plot level NDVI (Normalised Difference Vegetation Index) and frequency of visible damage. With two years of data, patterns emerge. This environmental data collected over a 1,800 km latitudinal transect from a wide variety of arctic and alpine plant cover types, including lichen-dominated types, show that intact lichen cover have very high albedo, in nature only surpassed by the albedo of ice and snow. Photosynthetic capacity varies little between the studied vegetation types. Hence, the role of albedo is considered the most important climate-regulating parameter of these heath and alpine plant cover types. The studied lichen species displayed a rather good resilience against the treatments, while the commonly found moss species *Polytrichum juniperinum* and crowberry (*Empetrum nigrum* subsp*. hermaphroditum*) had reduced summer growth and activity compared with control plots. A seasonal change was observed as well. At the start of the season, when photosynthesis is dominated by the lichens, there was little difference in rates between 2021 and 2022. As the summer proceeded and vascular plants became more active, we observed a tendency of reduced overall activity in 2022 relative to 2021. While summer warming tends to promote a shift from lichen dominated vegetation towards vegetation dominated by vascular plants, this new data suggests that increased frequency and severity of extreme winter warming events may counteract this shift. A preliminary analysis was presented at the EGU conference in May (URL-19) and a manuscript is in preparation.

Figure 10: Field assistant Stian Andreasen collecting data from the experimental winter warming plots at Finse (Photo: Eirik Aasmo Finne).

EMERALD Postdoctoral fellow - Sonya Geange

General Update: In 2022, the focus has been upon developing an enhanced representation of bryophytes as a plant functional type within the NorESM LandSites Platform. As part of this initiative, work included: establishing an open access data repository for some of the feed-in ecological projects, such as FunCAB; testing model representations of bryophytes as soil or vegetation components; and validating modelled bryophyte impacts on ecosystem functioning and environmental conditions using local field-based datasets from southwestern Norway (SeedClim and FunCAB). Work included contributions to the development of the platform and future work will further expand on this, focusing on how to best integrate new data, and set-up ecologically relevant virtual experiments. Lastly, we continued field work on the recently funded FUNDER project (see below), and we were also awarded a new research grant DURIN, which focuses on dwarf-shrub responses and feedbacks under climate change along coastal and continental gradients. DURIN includes a task on integrating field-based insights into new dwarf-shrub plant functional types using the NorESM LandSites Platform.

Field-Based Update: In 2022, fieldwork (Figure 11) has focused on the destructive harvesting of plots within the FUNDER project, which looks to assess and disentangle the direct effects of climate from the indirect effects, mediated through biotic interactions, on the diversity and whole-ecosystem functioning of the plant–soil food web**.** This project builds upon FunCAB, a set of 12 grassland sites distributed across temperature and precipitation gradients in Southwestern Norway, where mosses, grasses and herbs have been removed over the past few years to

understand their interactions and how they affect organisms in the soil. This year, at each of the sites we've collected material enabling us to: assess available soil nutrients; measure root biomass production rate and root traits; measure decomposition rates of both standardised litter and local litter; and assess fungal activity including mycelial production and decomposition. At the end of summer, we destructively harvested the plots, focusing on: above-and-below-ground vegetation biomass and functional group composition; micro-organism and micro-arthropod collections; along with samples of soil composition and structure. The insights from FUNDER will be used to develop new processes within CTSM-FATES, including modification of microclimate by contrasting plant functional types, plant competition for nutrients in the soil, and refining soil decomposition processes. We also conducted some preliminary field-work for the newly funded DURIN project. We conducted test-runs of eco-physiological measures, such as photosynthesis, using high-throughput methodologies.

Figure 11: Activities from the 2022 field season (photo: Camilla Zernichow).

EMERALD Postdoctoral fellow – Inge Althuizen

Inge Althuizen is a postdoc in NORCE, with combined funding from EMERALD, internal NORCE and BCCR funding and the DURIN project. She has contributed to the development of moss as a PFT in CLM-FATES as well as in the NorESM-LSP development. She is an ecosystem ecologist with a focus on terrestrial biogeochemistry, in particular carbon cycling. Her background and strong links with the Between the Fjords research group at UiB, where she obtained her PhD, is very valuable for collaboration in EMERALD. In 2022, she has been on maternity leave from January to September.

c. Scientific Highlights

NorESM-LSP for EMERALD

A paper draft on the development of NorESM-LSP has been submitted to the journal of Global Change Biology (GCB). The paper presents new software that facilitates site-level simulations

with an advanced Dynamic global vegetation model (DGVM) coupled with the land surface model of the Norwegian Earth System model (NorESM). The NorESM-LSP includes a Graphical User Interface and an Application Programming Interface, which improve the user experience and lower the technical thresholds for installing the models and setting up model experiments. The software is distributed via version-controlled containers; researchers and students can run simulations directly on their personal computers or servers, with relatively low hardware requirements and on different operating systems. The first release supports customisable simulations for 20 established geo-ecological observation sites in Norway; sites in the SeedClim grid (Vandvik et al., 2022) and LATICE observational sites. The NorESM-LSP makes simple and educational model experiments easily achievable while retaining the flexibility for pertinent scientific uses. Tools are provided to visualise and interpret the model input and output, including simple examples to relate predictions to local observations. The NorESM-LSP alleviates technical barriers to land surface and DGVM modelling, the first building block of community cyberinfrastructure that may inspire new avenues for mechanistic ecosystem research across disciplines. Several EMERALD participants are co-authors. First authorship is shared between Eva Lieungh and Lasse Keetz, both UiO-PhDs (LATICE and NHM funded).

Course on Ecological climatology for PhD and master students

This interdisciplinary course (GEO 5915/ 9915) was launched within the framework of LATICE and first given in 2018 (URL-20). It has later been slightly modified, and is now a well-established course that specialises on vegetation and its interaction with climate, thus well aligned with the scientific focus of EMERALD. Students learn about relationships between climate and ecology, connections and interactions between land and atmosphere, drivers and roles of fluxes of energy, water and chemical components between plants, soil and atmosphere, climate related feedbacks within boreal, alpine and arctic terrestrial ecosystems, and distribution modelling and dynamic vegetation modelling. The course is given each spring term, and is now part of the curriculum at both the Department of Geosciences and Biosciences. Anders Bryn and Frode Stordal lead and teach the course. In addition, several LATICE and EMERALD researchers teach specific topics within their expertise. Many EMERALD affiliated PhD and master students across Norway as well as international PhD students have taken the course. The EMERALD PhD, Eirik Aasmo Finne, and the LATICE PhDs, Peter Horvath and Lasse Keetz, first took the course themselves, and are now teaching assistants in the course. From 2022, the NorESM-LSP is used in a workshop in the course.

Land Surface Modelling Summit 2022

This summit provided opportunities to have extended discussions on development priorities and challenges and planning on how the international land modelling community can work together to build the next-generation land models needed to address the pressing scientific and societal questions of the 21st century. As the first of its kind, with representation from many international

modelling groups, this summit was open and sharing. The Summit was held in Oxford, United Kingdom, 12-15 September 2022. Kjetil Aas presented an EMERALD poster "Recent high-latitude vegetation developments in CLM-FATES" with several EMERALD participants as co-authors.

Dagens Næringsliv (DN) feature

Two scientific papers with authors from CBA and EMERALD (Wang et al.,2022 and Helbig et al., 2022) were featured in Dagens Nærlingliv August 22nd 2022 (URL-21).

EMERALD@EGU

The European Geosciences Union (EGU) General Assembly brings together geoscientists from all over the world to a yearly conference covering all disciplines of the Earth, planetary and space sciences. In 2022, more than 25 researchers from the EMERALD community took part in Vienna (23 – 27 May), both on-site and online. In total nine presentations were given (Appendix B-ii) and two EMERALD members co-convened a session each. EMERALD PhD candidate Eirik A. Finne gave the talk 'Effects of winter warming events on vegetation ecophysiology on a low-alpine ridge', which contributed to the Outstanding Student and PhD candidate Presentation (OSPP) Award contest. Although not selected for an award, the presentation was ranked amongst the top 20% of the program group. The full list of contributions is published on our website (URL-9).

EMERALD research in the Naturen Special Issue

In collaboration with CBA, four scientific articles by EMERALD researchers were published (in Norwegian) in a special issue in the Naturen journal (Vol. 145, Issue 5), see table below. One of these (by Parmentier) was awarded the Fægriprisen for 2021 for good research dissemination (URL-23).The complete list of articles in this issue is given at URL-22.

Author(s)	Title
Marius Lambert	Grønt eller brunt? Uforutsigbar fremtid i Arktis
Frans-Jan Parmentier	Permafrost: den sovende klimakjempen
Terje Berntsen	Modellering av biogeokjemiske prosesser i den norske klimamodellen NorESM
Ane V. Vollsnes, Stefanie Falk, Aud B. Eriksen, Frode Stordal, Håvard Kauserud, and Terje K. Berntsen	Luftforurensning og klimaendringer gir dobbelt stress for vegetasjonen

Stakeholder meeting

A meeting with ten stakeholders within forestry and agriculture (NVE, MET, NIBIO, UiO, NHM, Landbruksdirektoratet, Fylkesmannen i Vestfold og Telemark, Norsk fjellsenter, og Mat- og

landbruksdepartementet) was arranged 8 February 2022, in collaboration with the project IMPRINT and the Norwegian Centre for Climate Services (M4.8). This was the second of two stakeholder meetings in the project (see Appendix B-iii for the agenda). A summary of both stakeholder meetings, held in 2019 and 2022, has been published as NVE report 31-2022 (URL-13) and is available on the EMERALD project website (URL-15). In addition, a web-based report (Figure 8) aimed at stakeholders (URL-6) has been prepared.

d. Meetings and Workshops

EMERALD Webinars

Seven webinars were organised for EMERALD participants, including also members of synergy projects; for a full overview see Appendix B-iv.

2022 EMERALD Annual Meeting, NHM, 17-18 October 2022

The two-day annual meeting took place at the National History Museum (NHM) at Tøyen, Oslo, 17-18 October 2022 (Figure 12). The Director of NHM, Brit Lisa Skjelkvåle opened the meeting and gave a welcome address. She also participated in the dinner the first day. This year our RCN scientific officer, Tarjei Nødtvedt Malme, joined the meeting on the first day and gave a valuable overview of upcoming research funding options. The meeting focused on activities, progress, and deliverables for each WP and CCT.

Figure 12: Group photo from the 2022 EMERALD Annual Meeting in NHM.

The program was structured by WP/CCT along with some overarching activities, reporting progress with a specific focus on milestones, key results, delays/challenges and future work plans. By identifying the status of each of these activities, potential gaps and challenges could be identified, and as such, lay the ground for structuring the work in the final year. In addition, short updates from the EMERALD PhD and PD, and key activities were given. Ample time was reserved for discussions. In total 29 people took part in the meeting of which three were on Zoom. The opportunity to meet physically again was motivating and stimulated the discussion. Details of the event, including the agenda and list of participants, can be found in Appendix B-v.

CESM Land Model & Biogeochemistry Working Group Meeting 2022

Several EMERALD researchers presented their work (on Zoom) at the 2022 CESM Land Model & Biogeochemistry Working Group Meeting organised by NCAR in Boulder, CO, USA on 31 January-4 February 2022. This annual meeting is held regularly to provide a venue for CLM developers and users to meet and share experiences. The full agenda is available at URL-24.

Presenter	**Title**
Devaraju Narayanappa	DOC implementation in CLM progress
Elin Ristorp Aas	MIMICS+ Extending the MIMICS decomposition model with additional functional groups
Marius Lambert	Towards realistic plant hydraulics in the Arctic-Boreal Zone by modelling cold acclimation in CTSM5-Fates hydro
Kjetil Aas	Simulating the effect of moss on soil temperature and carbon fluxes over Alpine tundra - A study using CLM-FATES with large structural uncertainties

Norwegian Centre for Climate Services (NCCS), Geilo, 8-9 November 2022

EMERALD is recognised as a NCCS project and Lena M Tallaksen was invited to present its research and activities at the NCCS annual meeting at Geilo.

e. Project implementation – challenges

- The COVID-19 pandemic continued to impact the project during the first half of the reporting period, although significantly less than earlier. Notable, the pandemic led to less opportunity for informal interactions as well as fewer formal meeting places – both important for any research project in order to foster new ideas, inspiration and collaboration. Although this was alleviated in the second half of the reporting period, the accumulated impact of the pandemic during the first years of the project has led to less interaction and collaboration than foreseen at the start. This being said, new partnerships have emerged and promising new initiatives and proposals are under discussion.

- The development of new PFTs (for mosses and lichen) has proven scientifically challenging as reported earlier. At high-latitudes bryophytes can dominate vegetation cover, and thus play an important role in *biogeochemical cycles* regulating fluxes of carbon, water and energy, and may thus have ranging impacts on *ecosystem processes* such as primary productivity, nutrient cycling, soil decomposition, and permafrost stability. Bryophytes, such as mosses, act as an *insulating* layer of vegetation, dampening soil temperature fluctuations by intercepting solar radiation, keeping cloudy day soils warmer, sunny day soils cooler, and reducing incidence of freezing events. Bryophytes may play a substantial role in *hydrological regulation* in high-latitude ecosystems, intercepting precipitation and moderating run-off rates. A paper, including and discussing these *very diverse effects*, is underway, where different structural approaches to implement moss in CLM-FATES are discussed. Results are compared with data from several SeedClim sites.
- At NCAR the CTSM model has been coupled to a high-resolution weather forecast model (WRF). This is an ideal testbed for our developments as it allows high resolution two-way coupling between the surface and the atmosphere by quantifying fluxes and energy, moisture and carbon. Considerable effort has been put into setting up this system on our local HPC computers; and finally a version is ready for use and further testing as part of the thesis work of EMERALD associated PhD student Iris Mužić (CICERO), who is co-supervised by EMERALD members T.K. Berntsen and Yeliz Yilmaz.
- The ambition for model development and implementation in NorESM is to provide best-practice code that follows the structure recommended by NCAR. This is expertise beyond what can be expected by PhDs and researchers, and as such requires support from coding experts (i.e. research software engineers). This year, we benefited substantially when setting up the NorESM LSP from the temporary software engineer at the Department of Geosciences. In addition, there are some limited resources available for this through basic funding at UiO. However, this expertise is in great demand internally as well as in other institutions, thus it is a major challenge to build long-term expertise and support for a specific need as in our case.

f. Integration with synergy projects and other initiatives

An updated overview of EMERALD synergy projects is provided in Appendix A. Here we present a short update of how EMERALD has integrated relevant scientific contributions and expertise from these projects, and how this has provided added value, synergy and cooperation. In addition, there are important synergies with several strategic initiatives, including LATICE and CBA at UiO, a series of projects focusing on ecology and climate at UiB and the FRAM Centre in Tromsø.

Synergy initiatives

LATICE: The EMERALD project builds on the LATICE project (www.mn.uio.no/latice), which is an interdisciplinary Strategic Research Initiative (SRI) supported by the Faculty of Mathematics and Natural Sciences at the University of Oslo. LATICE stands for Land-ATmosphere Interactions in Cold Environments and brings a focus on cold regions exchange processes. It aims to advance the knowledge base on land-atmosphere interactions and their role in controlling climate variability and climate change at high northern latitudes. EMERALD adds to this by focusing specifically on ecosystem-climate interactions at these latitudes and the parametrisation of ecosystem processes in land surface models. The LATICE mobile flux station is still located at the Iškoras field site (Figure 13) and provide useful data for EMERALD researchers.

Figure 13 : LATICE mobile flux station in Iškoras - 20.09.2022 (photo credit: Norbert Pirk).

Other key synergies between LATICE and EMERALD are listed below:

- Hedmark wetland restoration - EMERALD participants are contributing to an experiment funded by the Norwegian Environment Agency, where previously drained peatlands are restored while their greenhouse gas emissions are monitored. The restoration started September 2021 and one master student collected water chemistry data prior to the restoration. A LATICE Fulbright scholar starting in August 2022, has engaged in the project, continuing the water chemistry sampling with the aim to assess the total carbon budget prior to and after restoration. The project benefits from the expertise provided by EMERALD and simultaneously contributes with data and field infrastructure to the EMERALD group;
- Joint LATICE-EMERALD fieldwork and data exchange is part of ongoing work at Finse;
- The LATICE Cold Climate Container has been used in support of an EMERALD/LATICE collaboration vegetation experiment;

- Two LATICE PhD students and one Postdoctoral fellow (started fall 2019 and 2020, respectively) collaborate closely with EMERALD with focus on parametrisation of high latitude vegetation and estimation of evapotranspiration (see CCT on Hydrology);
- The research by a previous LATICE postdoctoral fellow - now EMERALD researcher - on integrating snow remote sensing products and reanalyses data into the evaluation of Earth system models is ongoing. This work also contributes to the CCT on Albedo and to the model intercomparison efforts on snow in CCT on Hydrology.

CBA: The Centre for Biogeochemistry in the Anthropocene (CBA) is a cooperation between scientists within the departments of Geosciences, Biosciences, and Chemistry at the University of Oslo established in 2018. Dag Hessen (UiO-Bio) is the centre leader, and Terje K. Berntsen is a member of the leader group. Yeliz Yilmaz also worked as the CBA centre administrative coordinator from March to September 2022. CBA is a major collaboration partner for EMERALD. The goal is to assess and predict changes in global carbon cycling, a crucial requirement to develop strategies to counter anthropogenic climate change. CBA integrates research at various scales from the molecular level to organisms, catchments, and up to regions. Ongoing collaborations with EMERALD include the development of a new soil organic matter decomposition scheme and DOC transport in soil and rivers. Similar to the last year, cooperation between EMERALD and CBA has been extensive:

- Presentations at the internal CBA Tuesday talk series from several EMERALD researchers
- Many EMERALD researchers (Appendix B-i) presented their research at the CBA annual meeting (Figure 14)
- The CBA annual report 2021 included contributions from several EMERALD researchers
- Dagens Næringsliv (DN) published two scientific articles by CBA and EMERALD researchers
- Four articles were published by the EMERALD researchers in the Naturen special issue which was coordinated by CBA
- Regular contact between leaders and administrative staff of EMERALD and CBA.

Figure 14: Participants at the CBA Annual meeting in September 2022.

Between The Fjords Lab: This lab at UiB - using macroecological experiments - replicating field experiments across broad geographical and climatic extents within Norway and across the globe - to disentangle and understand patterns and processes underlying generalities as well as context-dependencies in global change effects and responses. The research is both methodological and conceptual, and most often conducted in alpine, grassland, or heathland systems. The Vestland Climate Grid is the main experimental playground. NorESM-LSP is parametrised for these sites and ready for model experiments. SeedClim, FunCAB, FUNDER and DURIN (see Appendix A) are projects in the Between the Fjords suite. A data paper on PFT removals is published, various other data papers in progress. The new FUNDER project assesses and disentangles the direct effects of climate from the indirect effects, mediated through biotic interactions, on the diversity and whole-ecosystem functioning of the plant–soil food web. To achieve this, we use a powerful macroecological experimental approach to quantify the impacts of vegetation diversity on interactions and ecosystem functioning across factorial broad-scale temperature and precipitation gradients. The research provides added value, through exploiting an existing Norwegian experimental infrastructure. Of particular relevance for EMERALD is:

- new data collection on soil organisms and processes via the FUNDER project in 2022
- Several collaborative EMERALD publications in preparation (Hui Tang on parameterising moss PFT, Inge Althuizen on C flux and PFTs, Eva Lieungh on dispersal).
- Geange is translating data and variables between field ecologists and FATES modellers to support parameterisation, assisted by internship students.

FRAM: High North Research Centre for Climate and the Environment (The Fram Centre) is a collaboration between several research institutions with head office or departments in Tromsø. This includes the EMERALD partners NINA, NIBIO, Norce and NILU. The centre carries out interdisciplinary research which is important for the management of the northern areas. FRAM contributes with research that addresses the challenges in the northern areas, both with regard to the environment and societal consequences. The research is directed towards the increasingly complex challenges within climate and environment where management decisions must be made under uncertainty. FRAM has provided funding which offers synergy with EMERALD, through grants to R. Bright (FRAM-EMERALD) and J.W. Bjerke (FRAM-VANWHITE) (see below).

Synergy projects - past

BalanC: This project quantified differences in stand carbon cycling and surface albedo between deciduous-dominant and spruce-dominant stands at five sites located throughout western Norway. It resulted in the production of a PFT-dependent surface albedo database for Norway, which is now being used together with satellite based surface albedo retrievals to compare to albedo predictions throughout Fennoscandia made by CLM5/FATES in WP1.

COMTESSA: The project dealt with measurements of the atmospheric surface layer turbulence and turbulent dispersion of tracers and the modelling of these physical processes by means of Large-Eddy Simulation and Lagrangian Stochastic models. The relevant synergies for the EMERALD project in the reporting period are mainly in the development of the modelling tools that are used in simulating surface fluxes of momentum, energy, and chemical species at the LATICE sites (including Finse), to improve the understanding of the energy balance and carbon fluxes.

FEEDBACK: The project aimed to link observations and modelling to understand and quantify how permafrost thawing and subsequent hydrological changes in permafrost-affected landscape alter CO_2 and CH_4 balance. The field site established under the FEEDBACK project, Iškoras site in Finnmark, Norway, is now recognised as part of the EMERALD core observation sites.

HiddenCosts: The project combines different disciplines, namely regional climate modelling, Earth System Modeling, biodiversity, above and belowground C storage, public perception, and ecosystem services, to better understand the cost effectiveness of afforestation in Norway to mitigate climate change. The results from the HiddenCosts project have inspired better understanding of biogeochemical and biogeophysical effects of climate change under afforestation and fostered new initiatives for dissemination.

LandPress: Ane V Vollsnes and Sonya R Geange joined fieldwork in 2019, measured photosynthesis and NDVI (greenseeker). Data paper in preparation. The NorESM Land Sites Platform is being parametrized for the LandPress sites by translating data and variables between field ecologists and FATES modellers.

OzoNorClim (Double Punch): Joint fieldwork with EMERALD took place in 2020 and 2021, including transpiration measurements and seed and plant collection for experiments under controlled conditions. A method for optimising plant functional type parameterisation to subarctic climate was developed in a study modelling the uptake of ozone in vegetation in current and future climate.

Permafrost_CCI: The objective of Permafrost_CCI is to develop and deliver permafrost primarily derived from satellite measurements. Validation and evaluation efforts comprise comparison to in-situ measurements of subsurface properties (active layer depth, active layer and permafrost temperatures, organic layer thickness, liquid water content in the active layer and permafrost) and surface properties (vegetation cover, snow depth, surface and air temperatures).

Permanor: The Permanor project developed the concept of laterally coupled tiling, which strongly improves the representation of small-scale water and energy exchange processes in models. The concept is explored further in EMERALD. Furthermore, EMERALD fieldwork in Finnmark relies on the outcomes of fieldwork undertaken in Permanor, e.g., high-resolution orthophotos compiled in the project.

QUIFFiN: By combining environmental systems analysis and detailed ecosystem modelling with high-resolution climate modelling, QUIFFiN will provide detailed data for vegetation changes under various future strategies for management of the Norwegian forest, quantify climate impacts from the regional to global scale following vegetation changes in a Norway, and identify possible win-win solutions of forest management practices for simultaneous provision of bio-resources and mitigation of climate change.

Terra-BGP: This project assesses the sensitivity of surface properties (i.e., albedo) and fluxes (i.e., water and energy) to changes in forest structure and composition within the Fennoscandian region. The project generated several empirical datasets, including a high spatial resolution dataset of land/forest cover, forest tree species composition, and forest structure, which will be applied in EMERALD to initialise surface data in regional climate modelling experiments, improve parameterisations and/or benchmark predictions with in CLM5-BGC and CLM-FATES in WP1.

Synergy projects - ongoing

4C: The 4C project is bringing together leading European groups on climate modelling and carbon cycle research. Together, they will develop knowledge that will support the Paris Agreement by providing robust estimates of the remaining carbon budgets and available near-term carbon dioxide emission pathways consistent with the agreement's goal of limiting global warming to "well below 2°C".

BioGov. BioGov will provide inputs to state-of-the art Land Surface Models (LSM) and Earth System Models (ESM), to understand and predict changes in production and uptake of CO_2 and CH_4 (methane) in boreal areas under different climatic scenarios, and to generate data for improved performance of climate models at regional and global scale. By using field studies, lab experiments and models, BioGov will achieve a strongly improved understanding of transport of carbon compounds between ecosystem components.

CN-coESM: The project aims to advance our understanding of the interactions and the feedback cycles between key Arctic-Boreal ecosystem processes and the climate system. It will investigate the impacts of 1) emissions driven climate feedbacks and 2) physically driven feedbacks from albedo associated with abrupt permafrost thaw and wildfire. This goal will be achieved by collaboratively improving ESMs that are developed and maintained in China and Norway.

DroneLab: The UiO DroneLab is a core facility at the Faculty of Mathematics and Natural Sciences, aiming at providing support for research projects using drones. This includes providing hardware (drones and sensors), know-how for the operations, and guidance for following airspace rules and regulations. This will contribute to efforts in EMERALD to map the vegetation biomass, land cover changes, and gas fluxes at our sites.

DURIN: DURIN will study context-dependencies in plant-mycorrhizal interaction, and ecosystem climate responses. The project will offer one of the first parameterisations and test-beds of dwarf-shrubs in large scale earth system modelling.

dScience: The Center for Computational and Data Science at UiO aims at developing and supporting new and important interdisciplinary research within computational science and data science across UiO and together with partners. The Center provided funding for a Phd position investigating swarm intelligence for observing systems in climate science, which is contributing to the EMERALD project.

ESM2025: ESM2025's aim is to develop a next generation of European 'mitigation-oriented' ESMs that can meet these objectives and improve the consistency of carbon budgeting throughout the modelling chain from economic models to ESMs to impact models. ESM2025 brings together a world-leading team of experts in Earth system modelling, model evaluation and feedback analysis, Integrated Assessment Models, reduced complexity carbon-cycle climate models, climate education and science-policy communication, all working towards a common goal of developing and assessing robust pathways for realising the Paris Agreement.

FRAM-EMERALD: The project provides internal funding to EMERALD partners in the Fram Centre, i.e. NIBIO and NINA, strengthening work and contributions from the two institutions.

FRAM-VANWHITE: The project provides internal funding to VANWHITE partners in the Fram Centre, i.e. NINA, strengthening work and contributions from the two institutes in VANWHITE, and thus EMERALD.

GreenBlue: Developing code for using CTSM to quantify the amounts of dissolved organic matter in rivers and their climate impacts. Linked to CBA.

HEATLAND is a PhD project for Iris Mužić who has an internship in the LATICE group before starting at CICERO. By using the coupled WRF-CTSM model, her key objectives are to understand the role of land surface properties to near-surface air temperature and amplification of heatwaves, and to evaluate different coupled land-atmosphere model configurations in simulating biogeophysical fluxes.

ICOS-Hurdal: The establishment of an ICOS "Ecosystem" monitoring site at Hurdal provides a variety of observations useful to the development and/or calibration and/or validation of boreal evergreen needle leaf PFT parameterisations in CLM/FATES, such as soil-surface-atmosphere fluxes of water, CO2, and energy.

IMPRINT: This project aims to quantify historical and future surface energy and moisture fluxes in Norway using a variety of modelling techniques. As such, the project produces datasets that serve as useful benchmarks to predictions made with CLM/FATES in EMERALD.

KiN2100: The Norwegian Environment Agency regularly updates information on expected climate changes in Norway. EMERALD researchers in MET and NVE contribute with knowhow and EMERALD outcomes.

MoSMoT: In this project a field deployable cable prototype for measuring soil temperature and moisture content is prepared for measurements in the Iškoras permafrost monitoring site in Finnmark. Measurements will be compared with satellite data.

NUNATARYUK: This is an international permafrost research project aiming to understand how thawing permafrost on land, along the coast and below the sea changes the global climate and life for people in the Arctic. NUNATARYUK combines permafrost research with modelling and socio-economic analysis and includes stakeholders from all over the Arctic, including Svalbard. The findings will be used to develop targeted adaptation and mitigation strategies both for the local communities and for our global society.

PathFinder: The project aims to develop a coherent European forest monitoring framework that ensures updated and consistent information about the state of European forests, and consistent and reliable reporting of their GHGs. PATHFINDER also aims to develop modelling tools for the prediction of future forest states to further our understanding of how European forests can contribute to climate change mitigation and adaptation policy objectives in light of additional objectives to protect biodiversity and ensure a sustainable timber supply.

PROVIDE: The project will provide climate services and support decision-making. The project will assess risks of high-end global warming for sectoral impacts and potential irreversible impacts of overshoots including for sea level rise, permafrost loss, glacier loss and terrestrial and marine species. PROVIDE will produce global multi-scenario, multi-sectoral climate information; co-develop a generalisable Overshoot Proofing Methodology; and identify and prioritise adaptation needs in four Iconic Regions. One of these regions is Arctic Fennoscandia, with focus on Bodø, Nordland County.

RECAP: The project assesses the contribution and long-term compensation capacity of different plant functional groups in terms of ecosystem carbon flux. Further, RECAP links data on ecosystem carbon flux with other parameters measured within the larger FUNDER project, including above and belowground C stock, above and below-ground plant functional traits, plant-soil food web interactions, decomposition and nutrient cycling. Finally, RECAP uses the collected data to improve the representation of high latitude plant functional groups in NorESM-FATES.

SNOWDEPTH: This project will combine various satellite-based datasets with statistical methods to get currently lacking global snow depth maps. In the second part of the project, the novel maps are applied to advance our knowledge in the fields of global climate reanalyses, high-mountain precipitation and permafrost.

Spot-ON: The project uses drone observations in a data assimilation framework for inverse modelling of surface fluxes of sensible heat, latent heat, CO2 and CH4. This new method is validated at the eddy covariance sites supported by EMERALD. Its results are directly usable to assess the representability of the eddy flux measurements, which is of key interest for data-model comparisons within EMERALD. Successful technical test flights with drones have been undertaken at UiO test-sites as well as at key EMERALD field sites. These data are valuable for assessing surface fluxes to advance development of CLM in WP1.

VANWHITE: This research project studies the role in the climate system of various alpine and arctic vegetation types. Both ground-based and remotely sensed methods are applied to investigate these roles through the variable biogeochemical and biophysical properties of the various vegetation types.

WinterGrazing: This is a long-running monitoring project financed by The Norwegian Agriculture Agency and led by NINA to understand how vegetation in the interior parts of Finnmark vary in time and space with climate and reindeer grazing variability. The 20-year long dataset contributes as input data in several EMERALD analyses.

WinterProof: This project focuses on the impact of extreme winter events on arctic vegetation, and the release of carbon from permafrost soils during winter. The aim of the project is to include these processes in LPJ-GUESS and CLM-FATES. The developments in WINTERPROOF lead to many synergies with EMERALD, primarily on plant hydraulics and vegetation dynamics, which will help to narrow uncertainties in model projections of carbon cycle feedbacks.

g. Use of national research infrastructure

EMERALD has made use of the following national research infrastructures:

- Biophysical time series collected through the SIOS programme will be analysed to understand intra-seasonal and year-to-year variation in photosynthesis and physiological activity and health of Arctic tundra.
- CTSM, FATES and NorESM model development, testing and simulations have been conducted using the Norwegian e-infrastructure for Research & Education. More specifically, the supercomputers run by Sigma2 have been used for running the model, and NIRD (National e-Infrastructure for Research Data) has been used for data storage.
- In collaboration with EOSC-Nordic led by NeIC (Nordic e-Infrastructure Services), EMERALD has taken advantage of the GALAXY platform (URL-25) for developing an accessible NorESM LandSites Platform. Norwegian e-Infrastructure for Life Sciences (NeLS) is currently a contributor to the GALAXY platform.
- Norwegian Research and Education Cloud (NREC) resources are being used for the development of the NorESM LandSites Platform.

- The CTSM model is part of the Norwegian Earth System Model (NorESM), which is defined as national infrastructure through the INES project. Scientists from EMERALD are actively participating in the management meetings for NorESM as the main responsible for the development of the terrestrial part (CTSM).

The Research Council encouraged partners in EMERALD to develop a proposal for funding of infrastructure within its research field, to strengthen EMERALD and future national activities within the field of vegetation-climate interactions. Accordingly, John F Burkhart, EMERALD participant and previous LATICE co-lead, lead a proposal to the infrastructure program in 2021, namely "The Norwegian Flux-enabled Real-time Autonomous Modeling Cyber Infrastructure (FRAM-CI)". In response to the significant challenges of conducting such critical interdisciplinary research, the EMERALD consortium highlighted the need for a dedicated platform to procure critically required in-situ parameters in order to characterise interactions and feedback between land surface processes, terrestrial ecosystems, and the climate system. FRAM-CI addresses specifically this gap in Norwegian infrastructure by establishing a cost effective resource providing the capability to collect in-situ observations and in near real-time, generate results and inform models. Unfortunately, the proposal was not funded, but is kept on the road map of prioritised future initiatives on infrastructure at the Department of Geosciences, UiO.

h. Use and further development of NorESM

WP1 contributes to NorESM by providing land surface model developments that are taken further in WP3. In the short term, the implementation of new arctic PFTs (mosses and lichens) will lead to improved representation of biogeophysical processes (e.g. albedo). In the longer term, a number of improvements and contributions to CLM-FATES (see overview of WP1 tasks) will benefit NorESM when FATES will be implemented as the standard land model.

All developments of the CTSM described for WP3 above will be fed into the NorESM model. The longer-term goal is that these improvements will be part of a future version of NorESM that is ready for the next iteration of CMIP/IPCC (timeframe not yet set).

The Community Land Model (CLM version 5.0) is an integral part of the NorESM model. Extensive work has been done within the INES and KeyClim projects to set-up and calibrate NorESM2 model for the CMIP6 simulations that form the basis for the IPCC AR6 report. The main development of CLM within EMERALD is related to the FATES module for dynamic vegetation. EMERALD researchers are actively participating in the international consortium developing FATES. The first NCAR version using FATES with simplified fixed satellite phenology (FATES-SP) is run in EMERALD, e.g. in the NorESM-LSP, which has been fully integrated into NorESM framework, so that the use and further development of the platform can more directly benefit NorESM development.

2. Budget status report

The budget report (provided as a separate file) includes budget information on personnel working on the project, both financed through the Research Council of Norway and through own financing or other external financing.

In the call, we were asked to "integrate existing activities among partners and provide added value through critical mass and more effective cooperation. Parts of existing and new project portfolios can constitute internal funding efforts, and making these activities visible in the proposals will be seen as positive." Thus, in the application we listed several projects in EMERALD partners' project portfolios where mutual benefits between such projects and EMERALD were anticipated, terming them synergy projects. Links to the original synergy projects, as well as new projects funded later, are successfully established, as described in Section 1f. In the EMERALD budget personnel file (Appendix D) we provide a list of personnel involved in EMERALD (with both RCN and in-kind funding) and synergy projects. Data are in some cases more easily available in terms of person years, in other cases in terms of NOK. We have provided a simplified conversion between the two, using the RCN rates for PhD and postdocs, which, however, introduces some slight inaccuracies for professor and researcher positions.

As stated in the proposal, EMERALD takes research in Norway on terrestrial ecosystems-climate interactions a big leap ahead. First, the 30 MNOK funding from RCN released 21 MNOK in-kind contributions. Next, through synergy and efficient cooperation, 38 MNOK was available in projects that were ongoing at the time of the start of EMERALD; 28 MNOK for personnel and 10 MNOK for running costs. These synergy projects were mainly from two ERC grants and ongoing RCN funded projects. Thus, at the start of EMERALD in total 89 MNOK was available for research collaboration within terrestrial ecosystems-climate interactions in Norway. Since then, several new synergy projects have been funded and included in the EMERALD sphere. We have registered EMERALD relevant funding from such projects, in this case for simplicity only for personnel, the by far largest budget item for most projects. Counting these allocations adds another 41 MNOK, now totaling 130 MNOK. As seen in the budget table for personnel, allocations for personnel for EMERALD and its synergy projects amount to 116 MNOK or 102 person years.

3. Data management plan

Only minor revisions have been made to the original EMERALD Data Sharing and Management Agreement (the updated plan is provided in Appendix E). This includes the option to use alternative repositories for data storage i.e. Zenodo and OFS. The plan has been distributed to all project partners and specific elements, such as how to acknowledge EMERALD, co-authorship (Vancouver rules), open science policy (FAIR) and data sharing, are regularly followed-up when relevant through communication with the EMERALD community. The plan is available on Teams.

URL Reference List

URL-1 : https://github.com/NorESMhub/noresm-land-sites-platform

URL-2 : https://noresmhub.github.io/noresm-land-sites-platform/user_guide

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URL-4 : https://plantfunctionaltraitscourses.w.uib.no

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URL-8 : https://www.mn.uio.no/geo/english/research/projects/emerald/news/modelling_conference_2021_1.html

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URL-25 : https://galaxyproject.org

Appendix A: EMERALD synergy projects - an updated overview

Synergy initiative

LATICE: 2015-2024. Land–Atmosphere Interactions in Cold Environments, Strategic Research Initiative in the Faculty of Mathematics and Natural Sciences, University of Oslo. PI: L.M. Tallaksen, N. Pirk, A. Bryn, F. Stordal. mn.uio.no/latice

Synergy projects - past

BalanC: 2016-2021. Quantifying impacts to carbon cycling and albedo to spruce aff-/reforestation in southern coastal Norway. PIs: O.J. Kjønaas, R. Bright. https://www.nibio.no/en/projects/balanc-the-impact-of-increasing-spruce-plantation-area-on-the-carbon-balance-of-forests-in-western-norway

COMTESSA: 2017-2021. Camera Observation and Modelling of 4D Tracer Dispersion in the Atmosphere. European Research Council under the European Union's Horizon 2020 research and innovation program, grant agreement No 670462. PI: Dr. A. Stohl, University of Vienna. The scientist involved in EMERALD is M. Cassiani who led the meteorological measurements and simulations activity in the project. http://comtessa-turbulence.net

FEEDBACK: 2016-2020. Feedback: Advancing permafrost carbon climate feedback improvements and evaluations of the Norwegian Earth System Model with observations. RCN FRINATEK program. PI: H. Lee.

https://prosjektbanken.forskningsradet.no/project/FORISS/250740?Kilde=FORISS&distribution=Ar&chart=bar&calcType=funding&Sprak=no&sortBy=score&sortOrder=desc&resultCount=30&offset=0&Fritekst=Advancing+permafrost+carbon+climate+feedback+improvements

FunCaB: 2015-2018. The role of Functional group interactions in mediating climate change impacts on the Carbon dynamics and Biodiversity of alpine ecosystems. RCN KLIMAFORSK project 244525. PI: V. Vandvik. http://uni.no/en/uni-climate/biogeochemistry/funcab-the-role-of-functional-group-interactions-in-mediating-climate-change-impacts-on-the-carbon/

HiddenCosts: 2017-2020. Hidden costs of implementing afforestation as a climate mitigation strategy: A comprehensive assessment of direct and indirect impacts. RCN KLIMAFORSK project 268243. PI: H. Lee.

http://uni.no/en/uni-climate/climate-impacts-on-nature-and-society/hidden-costs-of-implementing-afforestation-as-a-climate-mitigation-strategy-a-comprehensive-assessm/

INCLINE: 2018-2021. Indirect climate change impacts on alpine plant communities. RCN FRIMEDBIO project 274712. PI: V. Vandvik, J. Töpper. http://www.uib.no/en/rg/EECRG/114810/incline

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Permafrost_CCI: 2018-2021. European Space Agency. PI UiO: S. Westermann.

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Permanor: 2016-2020. RCN KLIMAFORSK project number 255331. PI: S. Westermann.

http://www.mn.uio.no/geo/english/research/projects/permanor

SeedClim: 2008-2015. The role of seeds in a changing climate - linking germination ecophysiology to population and community ecology. RCN NORKLIMA project 184912. PI: V. Vandvik.

http://www.uib.no/en/rg/EECRG/55395/seedclim

QUIFFiN: 2016-2022. Quantifying climate Impacts of Future Forest management strategies in Norway. RCN KLIMAFORSK.PI: M.T. Lund. https://prosjektbanken.forskningsradet.no/project/FORISS/254966

TerraBGP: 2016- 2020. Quantifying the impact of Fennoscandian forest management on surface energy and water budgets. RCN FRINATEK. PI: R. Bright.

Synergy projects - ongoing

4C: 2019-2023. Climate-Carbon Interactions in the Current Century. EU Horizon 2020. PI: G. Peters. https://cicero.oslo.no/en/projects/4c

BioGov: 2022-2027. Biogeochemical processes governing boreal carbon cycling. RCN FRIPRO and UiO. PIs: D. Hessen, T.K. Berntsen. https://www.mn.uio.no/cba/english/news-and-events/news/cba-starts-the-large-rcn-project-biogov.html

CN-coESM: 2022-2025. Permafrost, wildfire, climate change processes, interactions, and feedbacks: co-development of Earth System Models between China and Norway. RCN Polar/China. PI: H. Lee. https://cicero.oslo.no/en/projects/cn-coesm

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ESM2025: 2021-2025. Earth system models for the future. EU Horizon 2020. PI: B. Sanderson. https://cicero.oslo.no/en/projects/esm2025-copy

FRAM-EMERALD: 2020-2023. Terrestrial ecosystem-climate interactions of our EMERALD planet. The Fram Centre Flagship project. PI: R. Bright.

FRAM-VANWHITE: 2021-2023 The vanishing white: management of stressors causing reduction of pale vegetation surfaces in the Arctic and the Qinghai-Tibetan Plateau. The Fram Centre Flagship project. PI: J. Bjerke.

FUNDER: 2021-2025 Direct and indirect climate impacts on the biodiversity and Functioning of the UNDERground ecosystem. RCN KLIMAFORSK, project 315249. PI: V. Vandvik.

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GreenBlue: 2019-2022. A green-blue link made browner: How terrestrial climate change affects marine ecology. RCNy MILJØFORSK, project: 287490. PIs: A.F. Opdal, UiB, D.O. Hessen, UiO.

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HEATLAND: 2021-2024. The role of land-atmosphere interactions on temperature variability in Fennoscandia. CICERO internal funding. PI: I. Mužić and Ø. Hodnebrog.

ICOS-Norway (Hurdal): 2019-2023.Measuring and monitoring of land-atmosphere mass and energy exchange in a mature conifer forest. PI: H. Lange, R. Bright.EU Research Infrastructure project., funded through RCN and ICOS-Norway. http://no.icos-cp.eu

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KiN2100: 2021-2024. Klima i Norge 2100. Norwegian Environment Agency. PI: A.V. Dyrrdal, MET. https://klimaservicesenter.no/kss/om-oss/nye-framskr

MoSMoT: 2022-2023. Wide area Monitoring of Soil Moisture and Temperature for climate research. Internal NORCE funding. PI: I. Althuizen.

NUNATARYUK 2019-2023. European Union Horizon 2020 framework programme. 26 partners from 12 countries participate. Pi UiO: S. Westermann.

https://www.nunataryuk.org/about-us

PathFinder: 2022-2026. Towards an Integrated Consistent European LULUCF Monitoring and Policy Pathway Assessment Framework. EU, Horizon Europe, CL5 Climate, energy and mobility. PIs J. Breidenbach, M.T. Lund, R. Bright.

https://www.nibio.no/en/projects/pathfinder

PROVIDE: 2021-2024. Paris Agreement Overshooting – Reversibility, Climate Impacts and Adaptation Needs. EU Horizon 2020. PI: B. Sanderson. https://cicero.oslo.no/en/projects/provide

RECAP: 2022-2023. Representation of Ecosystem C flux of Alpine Plant functional groups under climate change. Internal BCCR funding. PI: I. Althuizen.

SNOWDEPTH: 2021-2026. Global snow depths from spaceborne remote sensing for permafrost, high-elevation precipitation, and climate reanalyses, RCN ROMFORSK Young Research Talents, project 325519, PI: D. Treichler. https://www.mn.uio.no/geo/english/research/projects/snowdepth/index.html

Spot-ON: 2020-2024. Upscaling hotspots - understanding the variability of critical land-atmosphere fluxes to strengthen climate models, RCN FRIPRO Young Research Talents, project 301552, PI: N. Pirk.

https://www.mn.uio.no/geo/english/research/projects/upscaling-hotspots/index.html

VANWHITE: 2019-2022. The vanishing white: management of stressors causing reduction of pale vegetation surfaces in the Arctic and the Qinghai-Tibetan Plateau. RCN POLARPROG, project 287402. PI: J. Bjerke. https://prosjektbanken.forskningsradet.no/#/project/NFR/287402

WinterGrazing: Monitoring programme. Last round of monitoring undertaken in 2018. Data going back to 1999. Financed by Landbruksdirektoratet. NINA Tromsø.

WinterProof: 2018-2022. Quantifying the role of cold season processes in vegetation-permafrost feedbacks, RCN FRIPRO Young Research Talents, project 274711. PI: F.-J. Parmentier. http://www.mn.uio.no/geo/english/research/projects/winterproof/index.html

Appendix B: Agenda of EMERALD meetings, workshops and contributions to national and International events

i) EMERALD at the CBA 2022 annual meeting

Several EMERALD researchers presented their work at the CBA 2022 annual meeting in September 2022 in Hurdal and an overview is given in the table below.

Presenter(s)	**Talk title**
Frans-Jan Parmentier	Plant hydraulics and frost damage in FATES
Anders Bryn	Tree- and forest line dynamics in Norway: causes and consequences
Sebastian Westermann	Overview over BioGov study sites in Finnmark
Terje Berntsen	Climate modelling
Lena M. Tallaksen	LATICE and EMERALD from a hydrological perspective
Astrid Vatne and Ane Vollsnes	Drought through increased air VPD or lowered soil water content have different effects on Betula nana leaves
Michael A. Bekken and Astrid Vatne	Characterizing the water chemistry, soil properties, and carbon balance of the Hisåsen site
Yeliz Yilmaz	Evaluating modeled snow cover dynamics over Fennoscandia using Earth observations and reanalyses
Elin Ristorp Aas	Nitrogen limitations in a soil decomposition model

ii) EMERALD at EGU2022

List of presentations (EMERALD members in bold)

https://www.mn.uio.no/geo/english/research/projects/emerald/news/egu2022.html

- Junbin Zhao, Holger Lange, Helge Meissner, and **Ryan Bright**. Heat Field Deformation (HFD) vs Linear Heat Balance (LHB): A critical comparison of two sap flow methods based on the same instrumentation. https://meetingorganizer.copernicus.org/EGU22/EGU22-4370.html
- **Eirik Aasmo Finne, Lena M. Tallaksen, Frode Stordal**, and **Jarle W. Bjerke**. Effects of winter warming events on vegetation ecophysiology on a low-alpine ridge, https://doi.org/10.5194/egusphere-egu22-12571

- **Yılmaz, Y. A., Aalstad, K.,** Filhol, S**.,** Gascoin, S., **Pirk, N.,** Remmers, J., **Stordal, F.,** and **Tallaksen, L. M.**: Evaluating modeled snow cover dynamics over Fennoscandia using Earth observations, https://meetingorganizer.copernicus.org/EGU22/EGU22-6092.html
- **Engeland, K., Aas, K. S.,** Erlandsen, H. B.**, Gelati, E.,** Huang, S.**, Narayanappa, D., Pirk, N.,** Silantyeva, O.**, Tallaksen, L. M., Vatne, A.,** and **Yilmaz, Y.**: LATICE MIP evapotranspiration – A model intercomparison project for evapotranspiration estimates at high latitudes, https://meetingorganizer.copernicus.org/EGU22/EGU22-12034.html
- **Hanna Lee, Casper Christiansen, Inge Althuizen**, Anders Michelsen, Peter Dörsch, **Sebastian Westermann**, and David Risk. Long lasting greenhouse gas emissions beyond abrupt permafrost thaw event in permafrost peatlands. https://meetingorganizer.copernicus.org/EGU22/EGU22-4211.html
- Yuan Zhang, **Devaraju Narayanappa**, Ciais Philippe, Wei Li, Daniel Goll, Nicolas Vuichard, Martin G. De Kauwe, and Laurent Li : Evaluating the vegetation-atmosphere coupling strength of ORCHIDEE land surface model. https://meetingorganizer.copernicus.org/EGU22/EGU22-6626.html
- **Ristorp Aas, E., Koren Berntsen, T**., Eiler, A., and de Wit, H.: Representing microbial activity in a soil decomposition model, https://doi.org/10.5194/egusphere-egu22-10985
- **Vatne, A., Vollsnes, A. V., Pirk, N.,** and **Tallaksen, L. M**.: Parameterization of Stomatal Conductance in a Subarctic Deciduous Shrub, https://doi.org/10.5194/egusphere-egu22-11346
- **Lambert, Marius S. A.; Tang, Hui; Aas, Kjetil Schanke; Stordal, Frode; Fisher, Rosie; Bjerke, Jarle W.; Parmentier, Frans-Jan W.**:Towards realistic plant hydraulics and frost damage in the Arctic-Boreal Zone by modelling cold acclimation in CTSM5-Fates (hydro). EGU General Assembly 2022 https://meetingorganizer.copernicus.org/EGU22/EGU22-4068.html

Co-convened sessions related to the EMERALD research group:

- BG3.14 «Land use and land cover change effects on surface biogeophysics, biogeochemistry and climate».

Convener: Gregory Duveiller | Co-conveners: **Ryan Bright**, Taraka Davies-Barnard, Alan Di Vittorio, Julia Pongratz. https://meetingorganizer.copernicus.org/EGU22/session/42313

- BG3.15 «Peatlands under Pressure»

Convener: Annalea Lohila | Co-conveners: Jorge Hoyos-Santillan, Claudio Zaccone, Angela Gallego-Sala, Julien Arsenault, Gareth Clay, Maxim Dorodnikov, **Frans-Jan W. Parmentier**
https://meetingorganizer.copernicus.org/EGU22/session/42356

iii) Stakeholder meeting agenda

Interessegruppemøte i EMERALD og IMPRINT, 8. februar 2022, Oslo

	Før lunsj		**Møteleder: Hanne Heiberg**
09:30	Velkommen og introduksjon til prosjektene EMERALD og IMPRINT	25 min	Anders Bryn, UiO Stephanie Eisner, NIBIO

09:55	Nye nasjonale klimaframskrivninger kommer i 2024: Hva kan landbrukssektoren vente seg?	15 min	Inger Hanssen-Bauer, MET
10:10	Mapping and modelling snow damage in forests (foredrag på engelsk)	15 min	Morgane Merlin, NIBIO
10:25	Pause	15 min	
10:40	Hvordan påvirker klimainformasjon forvaltningen?	15 min	Torleif Terum, Landbruksdirektoratet
10:55	Hvordan bruker skogeierne klimainformasjon?	15 min	Ida Aarø, Norges skogeierforbund
11:10	Skogsbeiter i tørkeperioder	15 min	Anders Bryn, NHM
11:25	Lunsj	60 min	
	Etter lunsj		**Møteleder: Irene Brox Nilsen**
12:25	Vinterskader: Hvordan påvirkes naturen av ekstremt vintervær og vintertørke?	15 min	Frans-Jan Parmentier, UiO
12:40	Oppsummering av første interessegruppemøte i EMERALD, skjæringspunkter med prosjektet Klima i Norge 2100.	15 min	Irene Brox Nilsen, NVE og KSS
12:55	5 min pause - flytte til møterom	5 min	
13:00	Diskusjon: Gruppearbeid i parallell Parallelle grupper tørke og frost/snø.	60 min	
13:55	Pause	15 min	
14:10	Oppsummering av gruppearbeid	20 min	Referat sendes på epost til arrangør
14:30	Utstilling Natur i Endring	15 min	Thea Dalen, Norsk fjellsenter
14:45	Buffer og vel hjem	15 min	Irene
15:00	Slutt på det faglige programmet		
17:00	Middag		Alle/Irene

iv) EMERALD webinars

https://www.mn.uio.no/geo/english/research/projects/emerald/events/webinar/

Speaker	Title	Time and place
Han Wang, Tsinghua University	Understanding and predicting plant traits and carbon processes with Eco-Evolutionary Optimality principle	27.10.2021, 12:00, Zoom
Ragnhild Gya, UiB and participants at a joint IPM/Galaxy FATES workshop	Opportunities for integrating insights from population ecologists into FATES	08.12.2021, 12:00, Zoom
Rasmus Erlandsson, NINA	An artificial intelligence approach to remotely assess pale lichen biomass	23.02.2022, 12:00, Zoom
Magni Olsen Kyrkjeeide, NINA	A joint climate and nature cure: A transformative change perspective	30.03.2022, 12:00, Zoom
Speaker 1 : Sil Schuuring, PhD student at UNIS Speaker 2 : Irene Brox Nilsen, NVE and the Norwegian Centre for Climate Services	Title 1: A Green Blanket: How vegetation insulates the Arctic soil. Title 2: New climate projections for Norway: Climate in Norway 2100.	27.04.2022, 12:00, Zoom
Ken Tape, Research associate professor at University of Alaska Fairbanks	The Changing Arctic Landscape of Alaska: Beaver Colonization of the Tundra	18.05.2022, 12:00, Zoom and the Climate House
Frode Stordal, UiO	Evaluating global and regional land warming trends in the past decades with both MODIS and ERA5-Land land surface temperature data	12.10.2022, 12:00, Zoom

v) 2022 EMERALD Annual meeting; NHM, Tøyen, 17-18 October 2022

Agenda

Monday 17 October

Time	Topic	Responsible
09:30 – 10:00	Signing in (physically or on Zoom) - Coffee & Tea	NHM, Tøyen hovedgård
10:00 – 11:00	**Introduction session**	**Chair: Lena M Tallaksen**
10:00 – 10:15	Welcome address; the Museum and collaboration opportunities	Brit Lisa Skjelkvåle Director NHM

10:15 – 10:30	Participants – short introduction	
10:30 – 10:50	EMERALD – status	Lena M Tallaksen, UiO
10:50 – 11:00	Discussion	
11:00 – 13:00	**WP progress; key results, progress towards milestones, challenges and future plans**	**Chair: Terje Berntsen**
11:00 – 11:30	WP1 - LSM evaluation and improvement	Olav Skarpaas, NHM
11:30 – 11:40	Short break; coffee/tea & cake	
11:40 – 12:10	WP2 – Improved process understanding from observations and experiments	Vigdis Vandvik, UiB
12:10 – 12:30	Hurdal ICOS site – one year of experience	Holger Lange, NIBIO
12:30 – 12:50	Research council – feedback and opportunities	Tarjei Nødtvedt Malme, Research Council
12:50 – 13:00	Discussion	
13:00 – 14:00	**Lunch**	
		Chair: Frode Stordal
14:00 – 14:30	**Invited talk**: Recent developments in the LPJ-GUESS model show the importance of arctic ecosystems for regional and global climate	Paul Miller Lund University
14:30 – 16:00	**WP progress; key results, progress towards milestones, challenges and future plans, cont.**	
14:30 – 15:00	WP3 – Implementation in NorESM and quantification of feedbacks	Terje Berntsen, UiO
15:00 – 15:30	WP4 – Dissemination and Communication	Irene Brox Nilsen, NVE
15:30 – 15:40	WP5 – Management, organisation and cooperation	Lena M Tallaksen, UiO Frode Stordal, UiO
15:40 – 15:50	Discussion	
15:50 – 16:00	Short break; coffee/tea & fruit	
16:00 – 17:00	**Guided tour in the garden**	Anders Bryn, NHM
16:00 – 16:15	Introduction to the garden	
16:15 – 17:00	Guided walk	
17:00 – 18:00	**CCT progress; results, challenges and future plans**	**Chair: Jarle W. Bjerke**
17:00 – 17:15	Hydrology	Kolbjørn Engeland, NVE
17:15 – 17:30	Albedo	Ryan Bright, NIBIO

17:30 – 17:45	Model platform and platform paper	Eva Lieungh & Lasse Keetz, NHM
17:45 – 18:00	Discussion	
18:00	**Close of Day 1**	
18:30 –	Dinner at a close by restaurant	

Tuesday 18 October

Time	**Topic**	**Responsible**
08:30 – 09:00	Signing in (physically or on Zoom) - Coffee & Tea	NHM
09:00 – 10:00	**Short 10 min updates**	**Chair: Irene Brox Nilsen**
09:00 – 09:10	EMERALD PhD	Eirik Finne, NINA Tromsø
09:10 – 09:20	EMERALD Postdoc	Sonya Geange, UiB
09:20 – 09:30	EMERALD Postdoc	Inge Althuizen, Norce
09:30 – 09:40	Spot-On update	Norbert Pirk, UiO
09:40 – 09:50	CBA update	Terje Berntsen, UiO
09:50 – 10:10	Discussion	
10:10 – 11:00	**Short 5 min updates**	
10:00 – 10:05	Getting the winter into FATES	Frans-Jan Parmentier, UiO
10:05 – 10:10	An update on FUNDER	Sonya Geange, UiB
10:15 – 10:20	Experimental plant physiology	Ane V Vollsnes, UiO
10:20 – 10:25	Large Eddy Simulation of the Finse alpine site	Massimo Cassiani, NILU
10:25 – 10:35	Characterizing the water chemistry, soil properties, and carbon balance of the Hisåsen site	Astrid Vatne & Michael Bekken, UiO
11:35 – 11:00	Discussion	
11:00 – 11:30	**Break**	
		Chair: Anders Bryn
11:30 – 12:00	**Invited talk**: Impact of climate warming on Arctic plant diversity: phylogenetic diversity unravels opposing shrub responses in a warming tundra	Robert Björk University of Gothenburg
12:00 – 12:30	**Annual reporting to RCN**	

12:00 – 12:20	Status and remaining issues	Lena M Tallaksen & Yeliz Yilmaz
12:20 – 12:30	Budget update	Frode Stordal
12:30 – 13:15	**Lunch**	
13:15 – 14:00	**Walk & Talk in the Garden (team of 2-3 persons)**	
14:00 – 15:30	**Group discussions**	**Chair: Olav Skarpaas**
14:00 – 14:30	By WP: What remains according to plan and how to resolve these remaining tasks (ref. Milestones)	WP Leads
14:30 – 15:00	Way forward beyond EMERALD (groups to be defined)	
15:00 – 15:30	Plenary reporting from Group discussions	
15:30 – 16:00	**Concluding remarks**	
15:30 – 15:50	Participant feedback	All
15:50 – 16:00	**Closure**	Lena M Tallaksen

List of participants

1. Inge Althuizen, NORCE, ialt@norceresearch.no (online)
2. Michael Bekken, GEO/UiO, mabekken@uio.no
3. Terje Berntsen, GEO/UiO, t.k.berntsen@geo.uio.no
4. Jarle Bjerke, NINA, jarle.bjerke@nina.no
5. Ryan Bright, NIBIO, ryan.bright@nibio.no
6. Anders Bryn, NHM/UiO, anders.bryn@nhm.uio.no
7. Massimo Cassiani, NILU, mc@nilu.no
8. Kolbjørn Engeland, NVE, kolbjorn@engeland.no
9. Eirik Aasmo Finne, GEO/UiO & NINA, e.a.finne@geo.uio.no
10. Sonya Geange, University of Bergen, Sonya.Geange@uib.no
11. Emiliano Gelati, GEO/UiO, gelati@uio.no
12. Hanne Heiberg, MET Norway, hanne.heiberg@met.no
13. Lasse Keetz, GEO/UiO, l.t.keetz@geo.uio.no
14. Holger Lange, NIBIO, holger.lange@nibio.no
15. Eva Lieungh, NHM/UiO, eva.lieungh@nhm.uio.no
16. Irene Brox Nilsen, NVE, ibni@nve.no
17. Frans-Jan Parmentier, GEO/UiO, f.j.parmentier@geo.uio.no
18. Norbert Pirk, GEO/UiO, norbert.pirk@geo.uio.no
19. Olav Skarpaas, NHM/UiO, olav.skarpaas@nhm.uio.no
20. Frode Stordal, GEO/UiO, frode.stordal@geo.uio.no

21. Lena M. Tallaksen, GEO/UiO, lena.tallaksen@geo.uio.no
22. Vigdis Vandvik, University of Bergen, vigdis.vandvik@uib.no (online)
23. Astrid Vatne, GEO/UiO, astrid.vatne@geo.uio.no
24. Ane Vollsnes, IBV/UiO, a.v.vollsnes@ibv.uio.no
25. Yeliz Yilmaz, GEO/UiO, yeliz.yilmaz@geo.uio.no

Invited speakers

26. Robert Björk, University of Gothenburg, robert.bjork@gu.se
27. Tarjei Nødtvedt Malme, Research Council of Norway, tnm@forskningsradet.no
28. Paul Miller, Lund University, paul.miller@nateko.lu.se (online)
29. Brit Lisa Skjelkvåle, NHM/UiO, b.l.skjelkvale@nhm.uio.no

Appendix C: Software on GitHub

EMERALD researchers contribute to open code practices by publishing their code on GitHub. This includes:

1) Software to make CLM (FATES) modelling easy, made by EMERALD, such as the NorESM-LSP and its documentation:
   https://github.com/NorESMhub/noresm-land-sites-platform
   https://noresmhub.github.io/noresm-land-sites-platform/
2) Models made by other institutions and projects, such as fates, repository for the Functionally Assembled Terrestrial Ecosystem Simulator (FATES)
   https://github.com/peterhor/fates
   and the Norwegian Earth System Model (NorESM) https://github.com/kjetilaas/NorESM
3) Data for publications, such as Horvath et al., 2020:
   https://github.com/huitang-earth/Horvath_etal_BG2020
   and Vandvik et al., 2022 : https://github.com/Between-the-Fjords/funcab_data
4) Scripts, such as R scripts for making maps
   https://github.com/evalieungh/map_scripts
5) Training material, such as galaxy material for the NorESM LandSites Platform:
   https://github.com/huitang-earth/galaxy-training-material

Appendix D: Budget personnel

{removed prior to circulation as it contains internal institutional information}

Appendix E: EMERALD Data Sharing and Management Agreement (updated)

This Data Sharing and Management Agreement regulates data management, availability, usage and ownership of data within the EMERALD group, led by Lena M Tallaksen at the University of Oslo. The agreement is updated yearly during the project period.

The EMERALD group is responsible for running field and experimental measurements, collecting remote sensing data and performing model experiments, as described in the EMERALD Project Description document. Within these activities, there are a number of externally funded research projects, each with a designated Principal Investigator (PI), a number of researchers and students, and various collaborators and smaller and larger synergy projects. The aim of this data sharing and management agreement is to facilitate collection and use of high-quality research data while pre-empting data quality problems and misunderstandings or disputes about data ownership and rights. All researchers, technicians and students collecting or using EMERALD data must adhere to this agreement.

I. Data storage

1. A database will be established on the open EMERALD web page at University of Oslo containing metadata information on field and model experiments in the project and how to obtain the data.
2. Selected datasets from EMERALD field and model experiments will be made available to the research communities on the data storage system NIRD Research Data Archive https://archive.sigma2.no or a similar open repository (Zenodo and OSF).

II. Data collection and management agreement

1. All staff and students involved in collecting data in EMERALD and associated projects agree to follow the data gathering protocols agreed for each (sub)project, and to collect, record and report high-quality research data.
2. To avoid loss of data all staff and students commit to comprehensive data and metadata documentation by following agreed protocols.
3. High-quality and well documented research data is key to ensure scientific reproducibility. It requires all data to be correctly and fully recorded and documented; including full openness and transparency about any data errors, data loss, uncertainties, data cleaning procedures, outlier treatment, etc.

III. Data documentation, ownership, usage, and sharing agreement

1. Unless otherwise specified, the raw data and accompanying data documentation belong to the individual research projects and the institution of the PI of each specific research project.

2. All subprojects, data collection, data storage and data usage should be described in project documentation files for each main project.
3. Project PIs are responsible for collecting and safely storing project data and metadata.
4. All data and code from the collaborating projects will be shared with the EMERALD group, and will be made available to the group members as needed and agreed.

IV. Authorship rights to reports and downstream publications

1. All research project participants' authorship rights to reports and downstream publications based fully or in part from the project data, are regulated by international research ethics standards (cf. the Vancouver Protocol, and the Norwegian National Research Ethics Committees, https://www.etikkom.no/en/).
2. Authorship credit should be based on;
    . substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data;
    a. drafting the article or revising it critically for important intellectual content; and
    b. final approval of the version to be published.
2. Authors should meet conditions 2 a, b, and c. In addition to being accountable for the parts of the work they have done, an author should be able to identify which co-authors are responsible for specific other parts of the work. In addition, authors should have confidence in the integrity of the contributions of their co-authors.
3. EMERALD practice an open and inclusive authorships policy, this means that potential co-authors (anyone that has contributed to a) above), should be offered the opportunity to earn co-authorship by contributing to b) and c) above.
4. These rules apply to all project participants, from students to PIs.
5. The PI regulates the usage of data in downstream research publications for each project.

V. Data sharing outside of the EMERALD group

1. Unpublished project data can be used, shared or presented outside the projects, but this should be explicitly agreed (on a case-by case basis with the relevant project PI).
2. The data ownerships and authorship rights follow the data when shared outside of the EMERALD group, and any potential issues should be discussed before data sharing.
3. Any publications using the EMERALD data must follow current international research ethics standards (cf. the Vancouver Protocol, and the Norwegian National Research Ethics Committees, https://www.etikkom.no/en/).
4. EMERALD have an open science policy, adopting the FAIR Guiding Principles for data management and stewardship, https://www.go-fair.org/fair-principles. We will share and

make data and code publicly available, either as a standalone dataset or when appropriate in databases. We expect that the original publication is appropriately cited when data is used in downstream publications.

VI. Reference to projects in acknowledgement

1. All papers based on or using EMERALD project sites, data, or metadata shall refer to the project short name (EMERALD), funding source (Research Council of Norway) and project code (NFR project no 294948) in the acknowledgements.