Annual progress report to the Research Council of Norway

Special report for the EMERALD project, project number 294948

Reporting period 1 October 2020 - 30 September 2021

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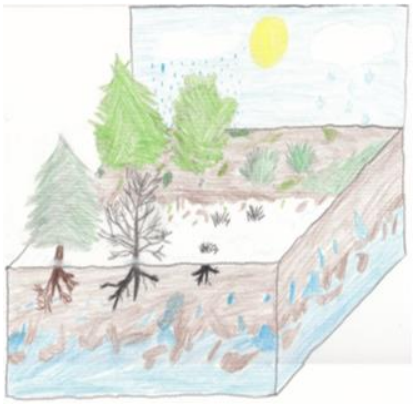

Figure 1: Terrestrial boreal and sub-Arctic ecosystems (left to right): evergreen trees, deciduous trees, shrubs, and mosses, spanning all seasons from summer in the back to winter in front. Illustration by Inger Andrea, 12 years old (illustration from the proposal).

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 (Fig.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 cooperation.

EMERALD applied for a six months extension, until end of June 2023. This extension was granted by the Research Council in January 2021. We have updated the time line of milestones accordingly.

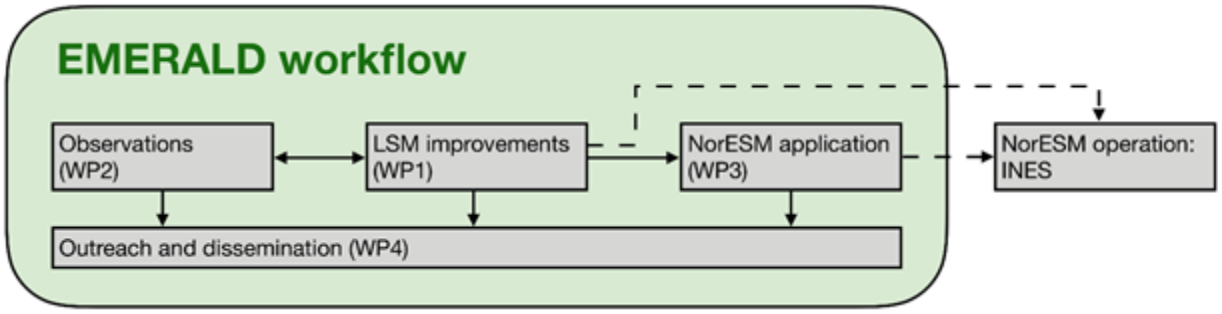

Figure 2: EMERALD activities shown in the green area. EMERALD supports developments of CLM and contributes these to NCAR and INES.

To ensure integration across work packages, four topical cross cutting themes (CCTs) were established at the start of the project, with the short names:

- Albedo
- Hydrology
- Tiling
- New plant functional types (PFTs)

In Section 1 (Scientific progress), progress and results are summarised and concluded 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 provided in Section 2 and a copy provided in Appendix C. The Data management plan (updated) is presented in Section 3, whereas the plan itself is given in Appendix D.

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, CO, 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 opens 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 are used with two different vegetation modules: the default vegetation module with fixed vegetation distribution, BGC, and FATES (Functionally-Assembled Terrestrial Ecosystem Simulator) with prognostic simulation of vegetation distribution.

An important step forward made in the previous year, was the development of the CLM-FATES model platform for site simulations, as described in the EMERALD progress report of 2020. 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 observations (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* and is a point scale version of CLM-FATES. It facilitates validation of ecological and environmental processes and parameterizations against observed local estimates of ecosystem productivity and performance. The modelling platform has undergone developments to make it more accessible for general users, including dockerization and pythonization. The platform provides a set-up to run the CLM5-FATES model on a cluster or in a cloud-computing environment (such as GALAXY used in EMERALD).

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), with mirrored tasks in WP2.

A major contribution of this work package is the establishment of NorESM LandSites Platform (Fig. 3), providing both coding and graphical user interfaces for running the model on a community-developed, open-science and cloud-based server as elaborated above. This work

facilities both formal scientific inquiry in addition to opportunities for educational awareness of land-surface model performance. It is an important tool for ongoing and commencing studies in several tasks (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, and the CHESS Research School course on Integral Projection Models (IPMs) and climate change), 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, one of which is confirmed funded (the FUNDER project).

Three of the tasks (Task 1a, new PFTs on mosses and lichens; Task 1c, plant hydrological processes and Task 1d, albedo) are also covered in cross cutting themes, integrating contributions from WP1 and WP2. Work on vegetation dynamics (Task 1b) and the carbon cycle (Task 1e) has commenced this year, and most of the foundations for the energy balance modelling (Task 1f) are now in place.

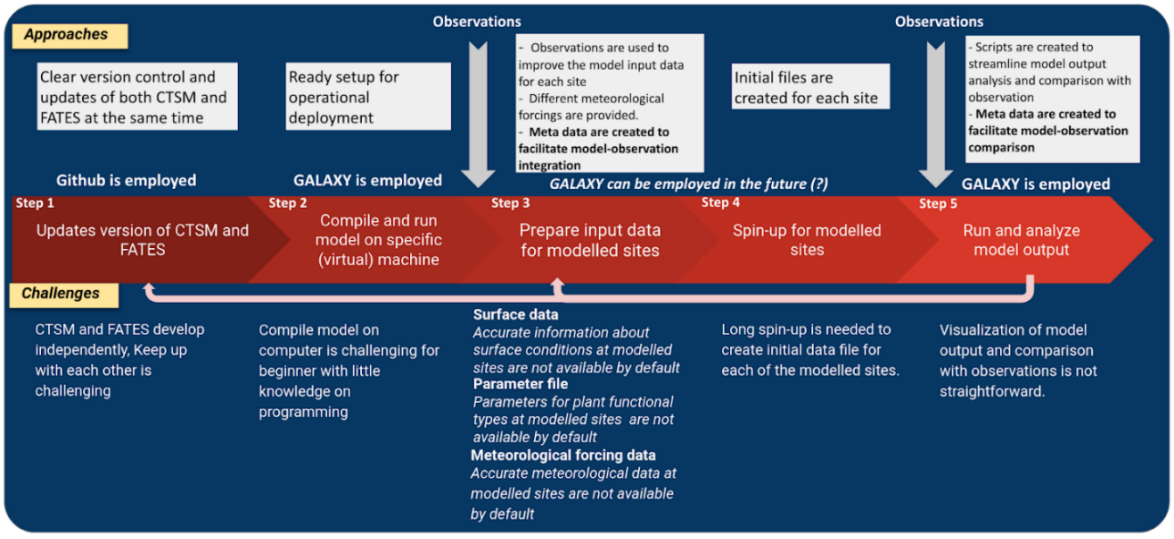

Figure 3: Steps for building the NorESM LandSites Platform*. Figure credit: Hui Tang.*

Three important model developments have reached a state where initial tests can begin:

- 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.
- A first version of the new mosses and lichen PFT has been established and tests are now being performed. 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, and careful testing and further developments are continuing (see CCT New PFTs).

- First tests and comparisons with observations for a new soil organic matter decomposition scheme (to be implemented in NorESM as part of WP3). Fig. 4 shows very preliminary simulation results for two sites in Norway (observations from Strand et al. 2016).

In addition:

- With a new scheme for early growth of new aerosol particles from emissions of BVOCs (ref. WP3), 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., in review, 2021).
- Beyond the work on specific tasks, useful input for modelling has been obtained through collaboration on distribution modelling with LATICE (PhD Lasse Keetz) and the machine-learning environment at the University of Helsinki (Zliobaite et al.).

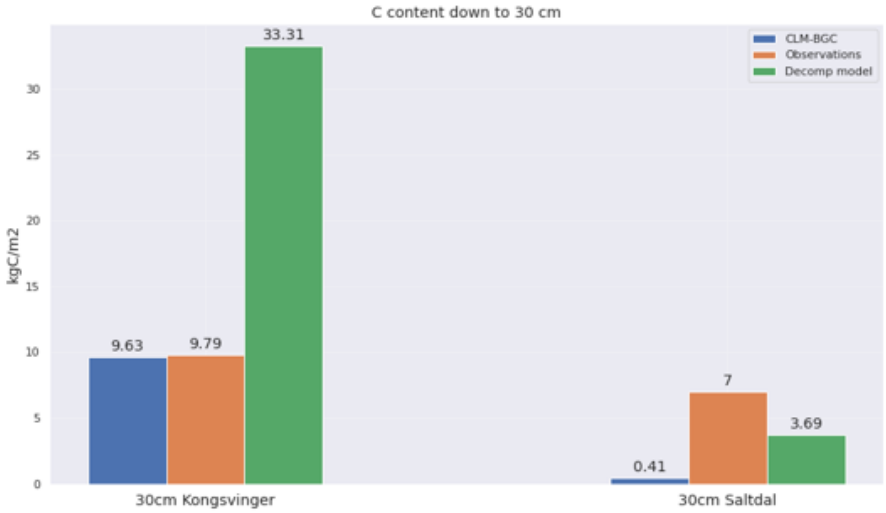

Figure 4: Observed (orange) and simulated soil organic carbon (C) in the upper 30 cm of the soil from two sites in Norway, Kongsvinger (left) and Saltdal (right). Preliminary results from the new decomposition model (green) and from the standard CLM5 model (blue).

WP1 Milestones

1.1 Parameterize recent CLM improvements	(from 2019.01 to 2019.04)
1.2 Build in key missing elements in CLM	(from 2019.01 to 2022.02)
1.3 Test adjusted model predictions in WP1 tasks	(from 2019.03 to 2022.02)
1.4 Model and observation revisions based on tests	(from 2020.01 to 2022.02)
1.5 Prepare models for WP3 applications	(from 2020.03 to 2022.02)
1.6 Provide output for WP4 dissemination	(from 2020.01 to 2023.02)

Parameterization of CLM improvements (M1.1) started according to plan, but is to some extent still going on in parallel with other developments (M1.2-1.5). Key missing elements are being built into CLM (M1.2) and tested (M1.3) in ongoing CCTs (hydrology, albedo and new PFTs) and the commencing work on vegetation dynamics and carbon cycle within WP1. Model revisions (M1.4) and preparation for WP3 applications (M1.5), will be a main focus in the coming year. Output for WP4 dissemination (M1.6) has been provided by WP1 since the beginning of the project, first as concretization of model concepts for exhibitions; now with an increasing focus on scientific results that will be communicated to the broader public through various channels (WP4).

WP2: Improved process understanding from observations and experiments

Leads: Vigdis Vandvik/Sonya Geange, Jarle 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. Additional data are collected during the project period (Fig. 5).

Figure 5: WP2 field site at Veskre, western Norway (photo credit: Sonya Geange).

WP2 supports WP1 with data from various field sites at regular intervals, but also contributes stand-alone research in the form of process studies and upscaling by combining observations across methods and parameter space. Results from WP2 will include publications 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 WP1 tasks), and fieldwork is conducted at numerous sites in Norway, including Svalbard. Field activity during winter, spring and summer of 2021 was productive.

WP 2 Milestones

2.1 Develop data management plan	(from 2019.01 to 2019.01)
2.2 Storage space and templates for meta-data files	(from 2019.01 to 2019.01)
2.3.Collate existing data	(from 2019.02 to 2019.04)
2.4 Field work	(from 2019.02 to 2023.02)
2.5 Provide data and knowledge for WP1 and WP2 tasks	(from 2020.02 to 2022.01)
2.6 Provide output for WP4 dissemination	(from 2020.01 to 2023.02)
2.7 Data arctic testbed	2023.2

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 WP2.5 (2c, i) and will support planned activities in 2022 in WP1 and WP2.

The team has collected data for evaluation of transpiration at the three flux sites operated by LATICE, collected photosynthesis and transpiration data three times during a 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.

Albedo as a topic is a cross-cutting task and is central in WP2. The team has contributed to a completion of an analysis of 1983 – 2018 surface albedo change and snow/ice albedo feedback in all area poleward of 50 °N. This work was carried out under WP2.5 and yielded in a comprehensive dataset of historical surface albedo evolution in polar regions (recently accepted for publication). Moreover, the team has collected ground observations of albedo characteristics from a range of treeless vegetation 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. For more details on the progress, see the albedo CCT.

M2.5 Contribution to WP1: The team has contributed to the development of several new elements linked to the NorESM LandSites Platform: a new mosses and lichens plant functional type; more reproducible and streamlined pathways for downscaling atmospheric surface layer and vegetation inputs; a new soil decomposition model designed to capture feedbacks between soil carbon dynamics and vegetation/climate, as well as further CLM-BGC development specifically related to forests and their C and N stocks, stand heterogeneity and drainage. Finally, WP2 has contributed to the development of decision trees and tools for new users with the aim of reducing barriers to initially setting up the model and encouraging model experimentation.

The establishment of the NorESM LandSites Platform (see WP1) encourage interdisciplinary collaboration with WP2. In support of these modelling initiatives, we have the following on-going data contributions, including soil and surface layer data from the 12 test sites imbedded in the NorESM LandSites Platform: a collated dataset from the SeedClim project to be set up on the Open Science Framework; the establishment of a newly linked project FUNDER – investigating below-ground relationship with vegetation, micro-organisms and decomposition; newly established phenology monitoring at the Iškoras site (Finnmark) along with ongoing monitoring of C fluxes, and now vegetation traits; and a global thermal tolerance dataset to create a new thermal tolerance mortality function within FATES, amongst others.

M2.6 Dissemination: For the NorESM LandSites Platform outreach, presentations have been given at both Norwegian ecological and hydrological conferences and hands-on workshops for scientists and PhD students have been undertaken, with further interest expressed from research agencies. An interdisciplinary perspective on communication and collaboration between ecologists and land surface modellers is under preparation (publication). Several grant applications have been written to expand on the EMERALD remit, including DURIN, BACE, FRAM-CI, and FUNDER.

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 NorESM and perform coupled simulations with the NorESM to quantify biogeophysical and biogeochemical feedbacks in an improved model. WP3 takes advantage of recent improvements in the CLM5 version running now in NorESM2.0 used for the 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 the Norwegian Earth System Model 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 organized through regular zoom meetings and extensive use of GitHub repositories to share code.

WP3 Milestones

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

M3.1 Splitting land columns in CLM5: The work is well underway based on new developments at NCAR. The splitting of land columns (allowing multiple soil columns per grid cell) is necessary to allow for small-scale variability caused by topographic scales much smaller than the grid cell size. Preliminary results (presented at the NHR conference at Lillehammer this year) indicate that the splitting of soil columns to individual PFTs alone does not have a large effect on snow and soil conditions. However, when snow is unevenly distributed between the sub-grid columns (in line with observed snow patterns in high-mountain Norway), the model simulates larger heat loss from the ground to the atmosphere during winter, colder average soil temperatures and changes longer snow melting period, which will be validated against observations in the final part of the EMERALD project.

M3.2 – 3.5 Changes in surface feedbacks: The work is underway 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 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 will be a major advance in quantifying these feedbacks.

M3.3 A new scheme for simulating early growth of new aerosol particles from emissions of biogenic volatile organic carbon (BVOCs) from boreal forests have been implemented in NorESM (Blichner et al., 2021). BVOC emissions are affected by changes in vegetation distribution and in the physiology of the plants. As improvements to FATES are implemented in CTSM, we will apply the new scheme to quantify these feedbacks, including effects on clouds.

M3.4 A new scheme for explicit representation microbial decomposition of organic carbon in soils (Fig. 6) is under development (collaboration with CBA at UiO, ref. Section 1f). See also WP1.

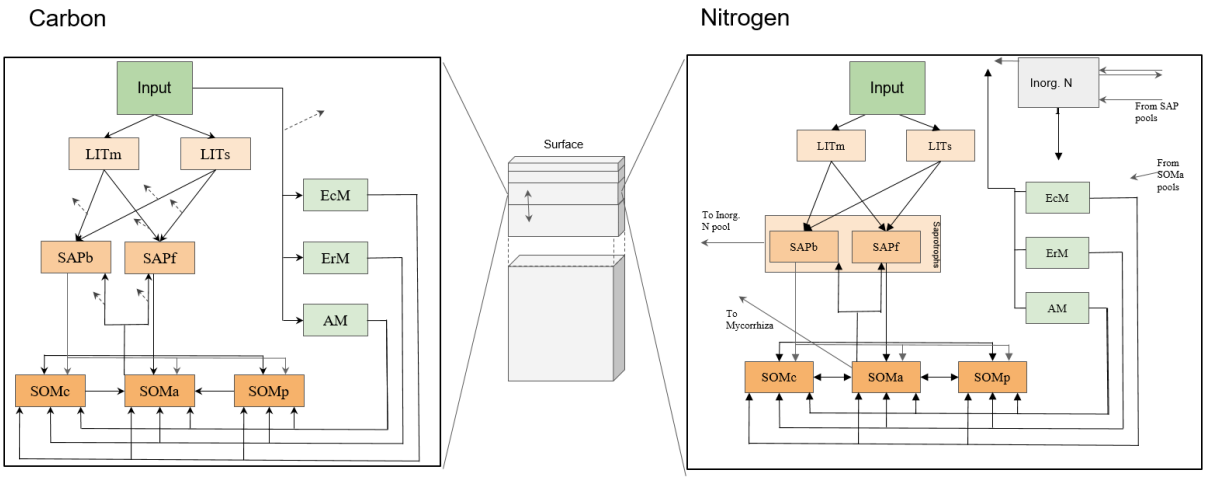

Figure 6: Schematic of the new soil organic matter decomposition scheme under development.

WP4: Dissemination and communication

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

Communication and dissemination have been a part of the project since the start. In 2021, a blog at forskning.no, a 'new' temporary exhibition and a conference on modelling hydrology, climate and land surface processes are some of the highlights as elaborated below.

WP 4 Milestones

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

M4.3 Blog at forskning.no: The blog "Søkelys på skogplanting" (EN: Spotlight on tree planting), initiated by Hanna Lee (NORCE), currently has 11 blog posts (in Norwegian) written by EMERALD researchers (an overview of blog entries is provided in the list below). An extended version of one of the blog posts on forest planting (by Ryan Bright, NIBIO) was published in Klassekampen March 4, 2021.

Blog entries: Author	Title
Hanna Lee	Et nytt syn på skogplanting
Hanna Lee	Skogens påvirkning på klima
Hanna Lee	Jordsmonnets hemmelighet
Hanna Lee	Ikke bare-bare å plante skog
Ryan Bright	Hva betyr skogplanting i Norge?
Hanna Lee	Noe å tenke over når man skal plante trær
Stefanie Falk	Skogplanting og framtidas by
Olav Skarpaas	Hva er en naturlig skog?

M4.3 Mass media EMERALD researchers have been disseminating their research through various mass media such as the documentary "Norsk hodepine" (Vigdis Vandvik et al., 26 August 2021; see Section 1c Highlights), Dagsrevyen (2 September 2021; Anders Bryn), and social media through the EMERALD twitter account @EmeraldNorway.

M4.4 and 4.5 Temporary exhibition: The temporary exhibition "Natur i endring" established at the Climate House (NHM, Oslo) in June 2020 had about 20 000 visitors during the first year. It was taken down in spring 2021 and moved to the Norwegian Mountain Center in Lom, where it opened in June. Here it was given much more space (expanded from 10 meters to 90) and adjusted accordingly also targeting a somewhat lower age group. In July 2021, the minister of climate and environment, Sveinung Rotevatn, visited Lom and the Mountain Center. The minister was given a guided tour of the exhibition by EMERALD researcher Anders Bryn (NHM) (Fig. 7). The Mountain Centre in Lom is one of the most important sites in Norway for communicating knowledge about mountain areas. The 'new' exhibition is a cooperation between the Mountain Centre and EMERALD, LATICE, CBA and "Natur i endring". At the Mountain Center, Thea Grobstok Dalen and Kjersti Frackmann Strass as well as Bolt design, have worked to make the exhibition a reality. It is supported through grants from Sparebankstiftelsen DNB, the Norwegian Research Council and the Norwegian Environment Agency.

Figure 7: The minister of climate and environment, Sveinung Rotevatn (second left), listening to Anders Bryn (middle) during a guided tour of the EMERALD exhibition at the Norwegian Mountain Centre in Lom, July 15 2021.

M4.6 2021 Lillehammer Modelling conference, 14-16 September 2021: The 6th Conference on Modelling Hydrology, Climate and Land Surface Processes at Lillehammer was the last in a series of biannual event organised by the Norwegian Hydrological Council. The 2021 conference was organised jointly with EMERALD (Fig. 8). Accordingly, a special focus was given to terrestrial ecosystem-climate interactions and their representation in Earth System Models (ESMs). The conference comprised sessions on 1) terrestrial ecology, 2) modelling soil water dynamics 3) climate services and 4) integrating observations into earth system modelling, fostering transfer of knowledge across widely different disciplines.

Figure 8: WP4 Lead Irene Brox Nilsen welcoming the participants at the 6th Modelling conference at Lillehammer, 14 September 2021.

Some key numbers:

- more than 70 participants registered (22 oral and 18 poster presentations)
- seven keynote lectures (four international experts)
- 40 attended in person and approximately 30 digitally on Zoom
- 53% of participants were women
- 14 EMERALD researchers participated

More information can be found at the EMERALD web page: https://www.mn.uio.no/geo/english/research/projects/emerald/news/modelling_conference_2021_1.html

M4.7 vEGU2021: EMERALD was represented with several presentations at the European Geosciences Union (EGU) General Assembly. Further, Ryan Bright (NIBIO) co-convened a session on Land use and land cover change effects on surface biogeophysics, biogeochemistry and climate, and Frans-Jan Parmentier co-convened the session Peatlands under pressure. Both sessions are planned also for 2022. For a full list of presentations, see the EMERALD web page: https://www-adm.mn.uio.no/geo/english/research/projects/emerald/news/egu2021.html?vrtx=admin

M4.8 Second stakeholders meeting: The meeting, planned for the first half of 2022, will be organized in collaboration with the IMPRINT project.

M4.9 Updated projections: The NCCS synergy project "Klima i Norge 2100" has been postponed one year (expected publication: Dec 2024), impacting the planned contribution from EMERALD.

M4.10 NorESM LandSites Platform on GitHub: The platform has been further developed and is now fully integrated into the NorESM framework. It has been publically released in a GitHub repository (https://github.com/NorESMhub/NorESM_LandSites_Platform/). Two tutorials for running the platform on GALAXY have been built and made available for users;

https://training.galaxyproject.org/training-material/topics/climate/tutorials/fates/tutorial.html
https://vimeo.com/439192348

Developments in FATES have also been disseminated through the Bioinformatics Community Conference BCC2020 (July 2020). This work was led by Hui Tang (UiO-Geo and NHM), and Anne Fouilloux (senior engineer at UiO-Geo). Further, EMERALD participants have participated in meetings of the NEON project, a similar NCAR initiative to facilitate the use of CLM-FATES.

WP5: Management, organisation and cooperation

Leads: Lena M Tallaksen, Terje Berntsen, Frode Stordal

EMERALD is managed in two phases; phase I (beginning 2019 - mid 2020) and phase II (mid 2020 - mid 2023). Stordal led phase I whereas Tallaksen (co-lead) took over as lead for phase II, 1 July 2020 (Fig. 9). At the same time, Berntsen became a new co-lead of EMERALD, jointly with Stordal (now Prof. Em.). Tallaksen currently leads both EMERALD and LATICE, which strengthened the co-leadership of the two initiatives.

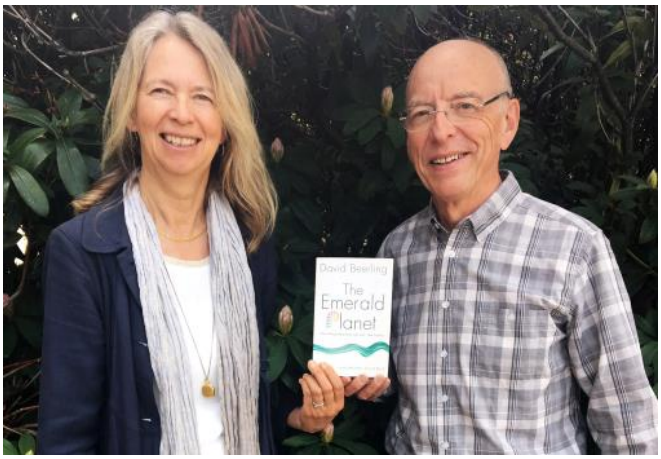

Figure 9: EMERALD leaders Lena M. Tallaksen and Frode Stordal at the start of the project.

The *leader group* consists - since the start of 2020 - of Lena M Tallaksen, Terje Berntsen and Frode Stordal (all UiO-Geo), Hanna Lee (Norce), 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 her change of main position from NORCE to NTNU (still keeps 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. One of the international partners, Paul Miller, took part in the Annual meeting 27-28 September 2021. We envisage a larger engagement with the group once the COVID-19 situation is alleviated.

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

5.1 Kickoff meeting	2019.1
5.2 Yearly project seminar	2021.2
5.3 Yearly project seminar	2022.2
5.4 Final project meeting	2023.2

M5.2 Yearly project meetings: The leader group has met regularly by video link in response to the pandemic, but also to reduce travelling. In total four regular meetings have taken place; 25 November 2020 and 2 March, 22 June and 21 August 2021. In addition, the leader group met with WP and CCT leads for a half-day meeting in April 2021 to ensure a good organisation, communication and planning towards to the field season as well as the annual reporting. This to partly compensate for the reduced interaction among project members during COVID-19. The meeting agenda is provided in Appendix B,i.

As an integral part of the EMERALD monthly seminars (WP4), Tallaksen has given short updates on the project and provided information of general interest to its members. This to facilitate a good flow of information during the pandemic. Furthermore, In April 2021 an 'EMERALD Teams' site was established to facilitate 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, work on joint papers, and coordinate fieldwork, amongst other.

Cross Cutting tasks

CCT Albedo: Ryan Bright (Lead)

In 2019-2020 the albedo CCT met regularly to define and prioritize several research tasks and scientific analyses that are currently in various stages of execution. The following tasks have been carried out in 2021 as an integrating effort across different WPs:

- Began collecting ground observations of albedo characteristics from a range of treeless vegetated ecosystem types - with emphasis on lichens - under different reindeer grazing regimes in Svalbard and mainland Norway (Fig. 10).
- Began developing a routine for including mosses and lichens in CLM-FATES. The albedo observations collected will feed directly into this new routine. Validation experiments are being designed and prepared.
- Began the analysis of comparing estimates of fractional snow-covered area simulated by CLM and remote sensing-based satellite retrievals of fractional snow-covered area over Fennoscandia. A manuscript is under preparation.
- Developed a routine for explicit representation of sub-grid snow heterogeneity in CLM. Quantifying its effect on coarse-grid cell fractional snow covered area and surface albedo is work in progress.
- Began a set of offline CLM simulations at selected ICOS Ecosystem sites in Fennoscandia forced with reanalysis and observed atmospheric input data, with the goal of comparing the observed and simulated surface albedo and identifying error sources related to canopy-snow dynamics and other snow physical processes.
- Carried out a series of offline CLM simulations in the Fennoscandia region designed to quantify and attribute sources of systematic surface albedo bias in the model. A manuscript is under preparation.
- Carried out a large-scale analysis of historical snow-/ice albedo feedbacks in polar regions including terrestrial ecosystems poleward of 50°N. This resulted in a forthcoming publication.

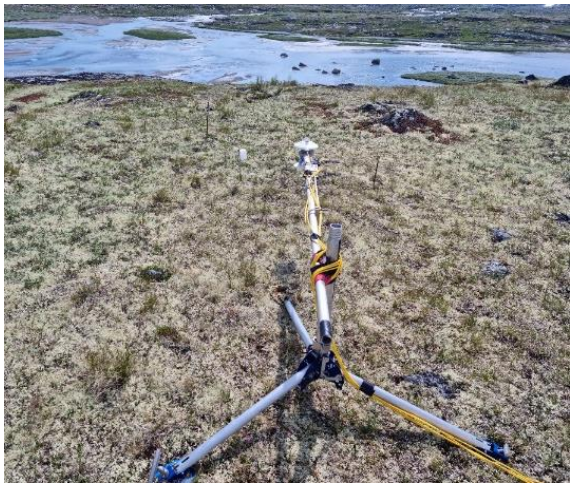

Figure 10: Albedo measurements. Photo credit: Eirik Aasmo Finne.

CCT Hydrology: Kolbjørn Engeland (Lead)

The Hydrology CCT had four meetings in 2021 and decided to establish a Model Intercomparison Project (MIP) experiment with focus on evaporation. One of the main motivation for this MIP is the need to improve knowledge about actual evapotranspiration rates in Norway, in particular at high altitudes and in cold environments. Recent estimates of mean annual evapotranspiration for mainland Norway, summarized in Erlandsen et al (2021), show a high variability, ranging from 178 – 500 mm/year.

The model comparison and evaluation will be performed at three scales: (i) the point scale consisting of three selected (LATICE) sites where evaporation is measured using eddy-correlation (EC) instrumentation; (ii) the catchment scale for which discharge observations exist, and (iii) the regional scale covering all Norway and Fennoscandia. Several models will be involved in this MIP, including two land surface models, CLM5 and SURFEX (used by the Norwegian meteorological institute), two hydrological models, Shyft (used by UiO) and the HBV model (used by NVE), and a stand-alone Penman-Monteith based model (used by NIBIO).

The main activity until so far has been to establish a protocol for the MIP, including formulating key science questions, data flow and sharing, which variables to compare and a timeline for the work planned. Within the end of 2021 a standard forcing dataset that can be accessed by all models will be made available. The MIP is expected to result in one key, joint paper synthesising the main results of the MIP, along with several separate papers on more specific topics.

CCT Tiling: Kjetil Aas (Lead)

The tiling CCT has had a number of meetings (physical and digital) over the last year. A few of these have been exclusively with the EMERALD tiling CCT group, but the majority of the meeting activities have been jointly with other CCTs in EMERALD (particularly albedo and New PFTs), and with external collaborators (notable UK collaborators working with the JULES model).

Through external collaboration, members of the tiling CCT have contributed to two publications (Martin et al., 2021 and Smith et al. submitted), which both build on the concept of explicitly representing sub-grid heterogeneity in land surface models through the use of tiles. In addition, members of the Tiling CCT has developed functionality for explicit representation of sub-grid snow heterogeneity in CLM, building on recent developments from collaborators at NCAR. Testing and validating this functionality is currently work in progress, but preliminary results were presented at the 6th Conference on Modelling Hydrology, Climate and Land Surface Processes, Lillehammer, September 2021 (ref. WP4).

CCT New PFTs: Terje Berntsen (Lead)

The CCT on new Plant Functional Types (PFTs) has made good progress on the work on extending the FATES module to include mosses and lichens as new PFTs. A key step towards this objective has been to establish the NorESM LandSites Platform (see WP1), allowing an efficient framework for testing out model developments. Hui Tang (UiO-Geo and NHM) has been the main responsible

for the development of the new PFT. Regular meetings (on Zoom due to COVID-19 and to involve all partners) have been held to discuss the best strategy and to decide on the key physiological aspects of this new PFT. Mosses and lichens are a very special type of vegetation in that they don't have roots and thus relies on interception of precipitation as their moisture source. This means that the standard structure of PFTs for other plants in CTSM cannot be used directly. Technically this has caused coding challenges as this new PFT have characteristics both as vegetation and a kind of soil. To this end, discussion meetings with NCAR, including their research software engineers, have been held to assure that the new PFT is implemented correctly and in line with best practice for the code structure in CTSM.

Two prototype versions of the new PFTs is now running in CTSM/FATES, one where the PFT is mostly represented as an additional soil layer and one where it more follows the regular PFT structure in FATES. Initial results were presented by Hui Tang at the 6th Conference on Modelling Hydrology, Climate and Land Surface Processes, Lillehammer, September 2021 (see WP4).

b. EMERALD PhD and postdoc positions

EMERALD PhD - Eirik Aasmo Finne

Starting in 2021, we are running a field experiment on Finse investigating the effects of winter warming on vegetation ecophysiology with emphasis on mosses and lichens (Fig. 11). While the impacts of changing winter climate on plants that rely on an insulating snow cover in winter have been well explored during the last ten years, the effects on mosses and lichens are much less known. An extreme winter warming event was simulated in March this year at six plots close to Finse Alpine Research Centre. For each plot, one subplot was heated by infrared lamps. In a second subplot, up to 10 cm layer of ice was formed by adding water and slush. A third subplot was set aside as a control. The effects of these treatments, both on species and on a community level, were investigated during two campaigns in June and July. Observations on species photosynthetic efficiency, ecosystem carbon flux, species composition, and vegetation greenness were collected during this fieldwork. The experiment will be repeated in the coming winter for the additive effect of two subsequent unstable winters.

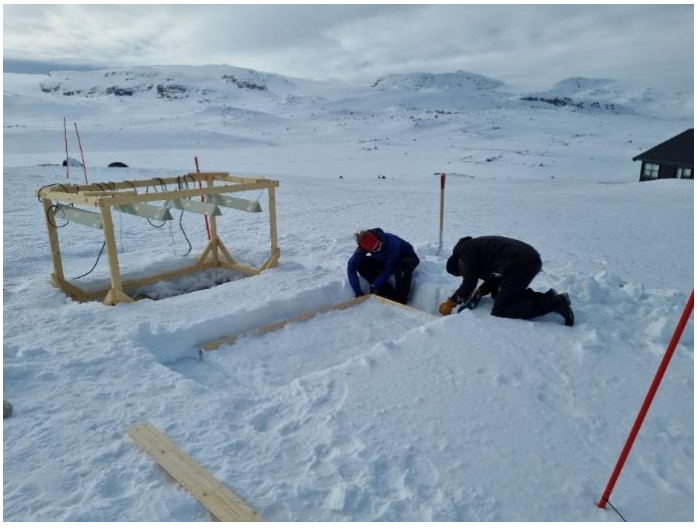

Figure 11: Winter warming experiment at Finse (Photo by Eirik A. Finne).

EMERALD Postdoctoral fellow - Sonya Geange

In 2021, the focus has been upon contributing to the development of the NorESM LandSites Platform. As part of this initiative, ongoing collaborative work includes: establishing open access data repositories for some of the feed-in ecological projects, such as SeedClim; developing decision trees for how we integrate ecological and environmental data into the platform, including addressing issues of data availability, scaling and interpolation; establishing a new plant functional type focusing on mosses and lichens; and establishing ways to reduce the barriers to not only model set up and initialization, but also facilitating inter-disciplinary engagement with land surface models through designing and developing a graphical user interface (GUI) for NorESM LandSites Platform. This GUI has now been used in educational arenas as well. Lastly, there has been a newly established feeder project, FUNDER, which focuses on quantifying plant-soil food webs, and fieldwork for this project has been conducted over the summer, along with collecting new environmental data to inform model set-up.

In 2021, fieldwork has focused on setting up the new 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 (Fig. 12). This project builds upon FunCAB, a set of 12 grassland sites distributed across temperature and precipitation gradients in South Western 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, we've set up the sites to: assess available soil nutrients; measure root biomass production rate and root traits; measure decomposition rates of both standardized litter and local litter; assess fungal activity including mycelial production and decomposition; and prepare the plots for destructive harvesting next year. The insights from this project will be used to develop new processes within CTSM-FATES, including plant competition for nutrients in the soil, and refining soil decomposition processes.

Figure 12: One of the FUNDER plots (Photo by Sonya Geange).

c. Scientific Highlights

The NorESM LandSites Platform for EMERALD

The FATES demographic vegetation model is still a major highlight. It was launched last year and put into use in 2021. The implementation of the NorESM LandSites Platform led by Hui Tang, has been publicly released in a GitHub repository (WP1). The main motivation of this initiative is to increase the interaction between modellers and field ecologists in EMERALD and as such, mitigate the long learning curve of FATES modelling for beginners. The platform provides a set-up to run the CLM5-FATES model on a cluster or in a cloud-computing environment (such as GALAXY for EMERALD). Senior engineer Anne Fouilloux (UiO Geosciences) and Hui Tang prepared a video tutorial to set up CLM-FATES (See M4.10).

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 (https://www.uio.no/studier/emner/matnat/geofag/GEO9915/). It has later been slightly modified, and is now a well-established course that specializes 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, first took the course himself, and is now a teaching assistant in the course.

6th Conference on Modelling Hydrology, Climate and Land Surface Processes

The 2021 modelling conference at Lillehammer was organised jointly with EMERALD and represented by two of its members in the organising committee, i.e. WP4 lead Irene Brox Nilsen and researcher Yeliz Yilmaz. One of its four sessions was specifically devoted to EMERALD: "Terrestrial ecology with links to climate and the hydrological cycle". This session was chaired by the coordinator of EMERALD, Tallaksen. More than 70 participants registered to the hybrid conference, of which 14 EMERALD members. They contributed actively with oral talks and posters and in the discussions, see Appendix B,ii for an overview. For further details see 'Meetings and Workshops' (Section 1d) and the EMERALD web page.

NRK documentary

An NRK documentary on the Norwegian climate court case came out. It is called “Norsk hodepine” (Norwegian headache), and features several EMERALD scientist, i.e. Vigdis Vandvik, Sebastian Westermann, Hanna Lee and Inge Althuizen.

Link: https://tv.nrk.no/program/KOID75006420

International collaboration - Rosie Fisher

Dr. Rosie Fisher's role as an advisor to the EMERALD project helped support her transition from Toulouse and NCAR to Oslo where she will start working at CICERO late 2021. We are pleased to have her closer to us, this move will contribute to even tighter collaborations and open new opportunities.

Exhibition at the Norwegian Mountain Center

The exhibition "Natur i endring" (A changing nature) opened at the Norwegian Mountain Centre in Lom, June 2021. In July 2021, the minister of climate and environment, Sveinung Rotevatn, visited the Center and was given a guided tour by EMERALD researcher Anders Bryn (NHM, UiO).

> *Our lives depend on nature and what it produces. However, nature all around the world is changing at a rapid speed. Which changes are caused by climate change, and what effects do human land use have? What can we do about it?*

The exhibition asks these questions and aims to provide some answers and new knowledge to visitors. The exhibition tells stories about the red fox moving into the mountains, the tree line moving upwards, all while people simultaneously are building more and more cabins and infrastructure. Visitors will learn how climate scientists measure the amount of snow and the soil temperature in alpine areas, and how studies of plant communities are executed. It is based on an exhibition originally made for the Climate House at the Natural History Museum (NHM), but largely expanded and with new activities especially aimed at a younger audience (see also WP4).

ERASMUS Internship

Iris Mužić, who has her MSc degree from Lund University on vegetation albedo, had an internship at the Geosciences department (UiO), with Lena M Tallaksen and Frode Stordal as her supervisors, starting in February 2020. In March 2020 she did field work in Troms with the EMERALD PhD Eirik Finne, with a focus on albedo of various plant covers, and in June 2020 with the LATICE PhD Astrid Vatne at Hedmark, with focus on vegetation mapping and soil moisture measurements. She also made a comparison of various parameters describing vegetation in CLM vs the land surface model LPJ-GUESS. The skills and experience gained within EMERALD and LATICE constituted an important basis for her application for a PhD position at CICERO. She was finally selected for the position and is now working on implementation of the coupled WRF-CTSM model in our geographical region. Terje Berntsen and Yeliz Yilmaz are co-supervisors, strengthening the links between CICERO and EMERALD partners.

d. Meetings and Workshops

EMERALD Writing and Coding Retreat, UiO 28-30 October 2020

After an intense first 1.5 years getting to know each other across research disciplines and research institutions, there is a need to start writing scientific papers together. The purpose with the retreat was to get together to move ongoing coding and modelling efforts forward, and to discuss ideas for joint publications. Several young scientists mainly from UiO, gathered physically at the Geosciences department. Due to the pandemic, only one person took part from outside Oslo (UiB), but several joined via Zoom. Altogether 21 EMERALD students and scientists participated. Kjetil S. Aas, Yeliz Yilmaz and Hui Tang prepared and led the workshop. Each day opened and closed with a plenary session and ample time was devoted to the NorESM LandSites Platform development and associated joint paper. Other issues that were discussed were the inclusion of new PFTs (mosses and lichens) and merging of EMERALD developed codes with NCAR.

EMERALD CLM/FATES Galaxy Workshop, UiO 26-27 October 2020

The workshop was organized by Anne Fouilloux in the framework the European Open Science Cloud projects EOSC-Nordic (Horizon 2020) and EOSC-Life (ESFRI), and the Galaxy Training Network. EMERALD co-hosted the event and the NorESM LandSites Platform was demonstrated and tested by several students and scientists. The majority of the on-line participants (varying between 10 and 20) were from EMERALD. Rosie Fisher gave an opening lecture explaining the need for such a model and how modelling with FATES can be used for reducing climate prediction uncertainties. Most of the workshop consisted of practical sessions that allowed the participants to work at their own pace. By the end of each day, there was a question and answer session. The workshop was well received by the participants as particular useful in their own modelling work.

EMERALD Webinars

Six webinars have been held for EMERALD participants, including also members of synergy projects; for a full overview see:
https://www.mn.uio.no/geo/english/research/projects/emerald/events/webinar/

2021 EMERALD Annual Meeting, NHM 27-28 September 2021

The two-day annual meeting took place at the National History Museum (NHM) at Tøyen, Oslo, 27-28 September. The agenda and list of participants is provided in Appendix B,iii. COVID-19 restrictions meant that only 20 people could physical attend, however, virtual participation was facilitated and 14 members took part through Zoom (Fig. 13). The meeting focused on activities, progress and deliverables for each WP and CCT. By identifying status of each of these activities, we aimed to identify potential gaps, challenges, and as such, lay the ground for structuring the work ahead, through collaborative efforts and well-defined priorities. Accordingly, the program was structured by WP/CCT along with some overarching activities, reporting progress, key results, delays, challenges and future work plans. In addition, a series of short updates were provided

focusing on the EMERALD PhD and PD, joint EMERALD activities, and new affiliated projects. Ample time was reserved for discussions. The new director of the museum, Brit Lisa Skjelkvåle, opened the meeting introducing key activities of the museum and collaboration opportunities. The program also included two invited talks, by Rosie Fisher (Toulouse and NCAR) and Heleen de Wit (NIVA and CBA). For further details see the agenda (Appendix B, iii). A guided tour of the garden and visit to the Climate House was well received by the participants.

Figure 13: Participants at the hybrid 2021 Annual meeting at Zoom/NHM, Tøyen in Oslo.

CESM Land Model & Biogeochemistry Working Group Meeting

Several EMERALD researchers presented their work (on Zoom) at the 2021 CESM Land Model & Biogeochemistry Working Group Meeting organized by NCAR in Boulder, CO, USA on 23-25 February 2021. This annual meeting is regularly held to provide a venue for CLM developers and users to meet and share experiences. The full agenda is available at:

https://www.cesm.ucar.edu/events/wg-meetings/2021/files/2021-Agenda-LMWG.pdf

Presenter	Title
Devaraju Narayanappa	Plan for Modelling Lateral Flow of Dissolved Organic Matter
Yeliz Yilmaz	Benchmarking CLM5 snow cover dynamics with MODIS and reanalyses over Fennoscandia
Stefanie Falk	OzoneLUNA: Ozone damage in CLM revisited
Hui Tang	Implementing moss and lichen and their biophysical impacts in CLM-FATES

e. Project implementation – challenges

- Delays due to COVID-19 are felt in all work packages and activities despite some mitigation actions taken by the leadership. Notable, the pandemic has 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. However, the full impact on the project is overall difficult to quantify.
- WP1 experienced some changes in supporting projects, however, the impact on EMERALD activities are minor. This includes the delay of the NCCS project "Klima I Norge 2100" (see M4.9) and a shift in research focus of one in-kind PhD (Lieungh, NHM). The PhD project stills contributes to model improvement on vegetation dynamics (see below).
- As mentioned earlier, the development of new PFTs (for mosses and lichen) has proven scientifically challenging, as the original structure of how vegetation is represented in CTSM does not directly fit this new PFT. It is something in between a plant and regular soil and we are testing out alternative ways to represent this, including a hybrid solution. Our ambition is to develop the new PFT in such a way that it can be included in the main core of the CTSM model developed at NCAR. This requires that strict coding rules are followed which is needed in the long term, but has proved challenging in the early development phase. We have close contact with NCAR on this; however, the unstable situation with respect to support from research software engineers at the department of Geosciences at UiO has been suboptimal in this respect.
- At NCAR the CTSM model have been coupled to a high-resolution weather forecast model (WRF). This would be 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; however, this is still not working properly.
- 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). There are resources available for this through basic funding at UiO. However, this is currently a temporary position, and the expertise is in great demand in other institutions as well, so it is a 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 University of Oslo, 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 UiO since its start in 2015. 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 parametrization of ecosystem processes in land surface models. Some key synergies between LATICE and EMERALD are listed below:

- Hedmark wetland restoration - EMERALD participants are contributing to an experiment 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 works at the site. The project benefits from the expertise provided by EMERALD and simultaneously contributes with data and field infrastructure to the EMERALD group;
- The LATICE mobile flux station is still located at the Iškoras field site (Fig. 14) and provide useful data for EMERALD;
- Joint LATICE-EMERALD fieldwork and data exchange is part of ongoing work at Finse;
- Experimental test beds within the Cold Climate Container are delayed due to COVID-19;
- Two LATICE PhD students and one Postdoctoral fellow (started fall 2019 and 2020, respectively) collaborate closely with EMERALD focusing on parametrization of high latitude vegetation and estimation of evaporation;
- A LATICE postdoctoral fellow has in the reporting period worked on integrating snow remote sensing products into the evaluation of Earth system models and reanalyses data of value for both LATICE and EMERALD.

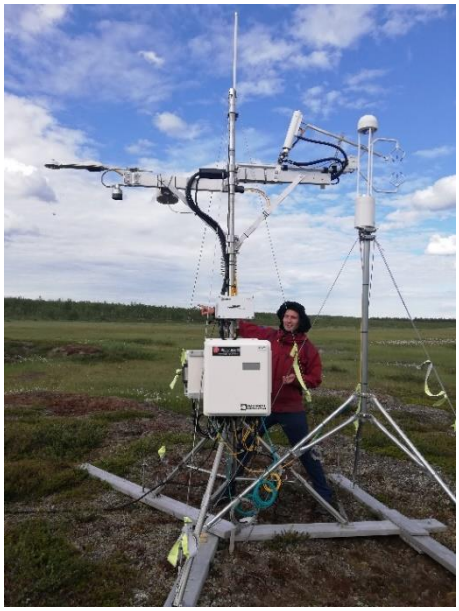

Figure 14: LATICE mobile flux station in Iškoras maintained by Norbert Pirk - 28.07.2020 (photo credit: Yeliz Yilmaz).

CBA: The Centre for Biogeochemistry in the Anthropocene (CBA) is a cooperation between scientists within geosciences, biosciences and chemistry at the University of Oslo established in 2018 and 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 collaboration with EMERALD include the development of a new soil organic matter decomposition scheme (WP2 and 3) and DOC transport in soil and rivers.

During the last year, cooperation between EMERALD and CBA has been extensive:

- Talks at the internal CBA Tuesday talk series from several EMERALD researchers
- Annual meeting for CBA in October where many EMERALD researchers presented their research (Fig. 15)
- The annual report of CBA for 2020 featured EMERALD research
- Regular contact between leaders and administrative staff of EMERALD and CBA.

Figure 15: Participants at the CBA Annual meeting in October 2020.

Synergy projects

BalanC: This project (2016-2021) 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 used together with satellite based surface albedo retrievals to compare to albedo predictions throughout Fennoscandia made by CLM5/FATES in WP1.

COMTESSA: The project deals 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 FINSE site, with the aim to improve the understanding of the energy balance and carbon fluxes.

DroneLab: The UiO DroneLab is a new 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.

dScience: The recently established 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 new Phd position investigating swarm intelligence for observing systems in climate science, which is anticipated to contribute to the EMERALD project.

FUNDER: The project (2021-2025) will 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. 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.

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 (including climate impacts on) amounts of dissolved organic matter in rivers. Linked to Centre for biogeochemistry in the Anthropocene.

ICOS-Hurdal: The establishment of an ICOS “Ecosystem” monitoring site at Hurdal (funded through RCN and ICOS-Norway) will provide a variety of observations useful to the development and/or calibration and/or validation of boreal evergreen needleaf PFT parameterizations in CLM/FATES (soil-surface-atmosphere fluxes of water, CO2, and energy).

IMPRINT: This project (2019-2023) aims to quantify historical and future surface energy and moisture fluxes in Norway using a variety of modelling techniques. As such, the project will produce datasets that may serve as useful benchmarks to predictions made with CLM/FATES in the later stages of EMERALD.

INCLINE / SeedClim / FunCAB: Postdoc Sonya R Geange has made NDVI measurements and collected soil samples for soils structure data (Fig. 16). The NorESM LandSites Platform is parametrized for these sites and ready for model experiments, and several are planned for 2021 (Inge Althuizen on PFTs, Eva Lieungh on dispersal). Geange is translating data and variables between field ecologists and FATES modellers to support parameterisation, assisted by internship students. Discussing if the Oslo team should do vegetation mapping near these sites for 2021.

Figure 16: Open-top chambers warm up some of the alpine vegetation plots in Låvisdalen, Vestland (SeedClim site), 2019, photo credit: Eva Lieungh.

LandPress: Ane V Vollsnes and Sonya R Geange joined fieldwork in 2019, measured photosynthesis and NDVI (greenseeker). The NorESM LandSites Platform is being parametrized for these sites by translating data and variables between field ecologists and FATES modellers. More observational sites (e.g., sites in LATICE MIP) have been included in the platform.

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.

Spot-ON: The project (2020-2024) 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 will be validated at the eddy covariance sites supported by EMERALD. Its results will be directly useable 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 is a research project funded by the Research Council of Norway (2019-2021, project no. 287402, granted one extra year to 2022). It 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 (2018-2022) 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 supercomputer SAGA and FRAM 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 (https://galaxyproject.org/) 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-clime interactions. Accordingly, John F Burkhart, EMERALD participant and LATICE co-lead, prepared and submitted a proposal to the infrastructure program, 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 characterize 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.

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 WP1 and CCT New PFTs) will benefit NorESM when FATES will be implemented as the standard land model.

All developments of the CTSM described for WP3 will feed into the NorESM model. The longer-term goal is that these improvements will be part of 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 project 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. From NCAR the first version using FATES with simplified fixed satellite phenology (FATES-SP) is now available for testing. The NorESM LandSites platform has been fully integrated into NorESM framework, so that the development of the platform and the land model 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 C) 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 releases 21 MNOK in-kind contributions. Next, through synergy and efficient cooperation, 38 MNOK is available in projects that were ongoing at the time of the start of EMERALD. These synergy projects are 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 the field of terrestrial ecosystems-climate interactions in Norway. Since then, several new synergy projects have been funded and included in the EMERALD sphere, adding another 27 MNOK, now totaling 116 MNOK. As seen in the budget table for personnel, allocations for personnel for EMERALD and its synergy projects amount to 103 MNOK or 90 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 D). This includes the option to use alternative repositories for data storage, than NIRD, when appropriate. 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.

Appendix A: EMERALD synergy projects - an updated overview

BalanC: Quantifying impacts to carbon cycling and albedo to spruce afforestation and reforestation in southern coastal Norway. PI: Kjønaas, Bright.

COMTESSA: 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. Andreas Stohl, University of Vienna. The scientist involved in EMERALD is Massimo Cassiani who leads the meteorological measurements and simulations activity in the project. http://comtessa-turbulence.net

ExperTS: Experiments, Traits, Synthesis: Using knowledge from global ecological experiments to validate, assess, and improve trait-based theory. The Research Council of Norway INTPART project 287784. kNOK 5.960. 2019 – 2021. PI: Vandvik, Enquist.

DroneLab: Drone laboratory. Funding by UiO: 3 MNOK investment, with running costs covered by individual research projects. PI: Pirk.

dScience: Center for Computational and Data Science at UiO provided funding for a new Phd position, ~5.000 kNOK. PI: Pirk.

FEEDBACK: The Research Council of Norway. 2016-2020. PI: Lee.

http://uni.no/en/uni-climate/climate-impacts-on-nature-and-society/feedback-advancing-permafrost-carbon-climate-feedback-improvements-and-evaluations-of-the-norweg/

FunCaB: 2015-2018. The role of Functional group interactions in mediating climate change impacts on the Carbon dynamics and Biodiversity of alpine ecosystems. The Research Council of Norway KLIMAFORSK project 244525. kNOK 7.900. PI: Vandvik.

http://uni.no/en/uni-climate/biogeochemistry/funcab-the-role-of-functional-group-interactions-in-mediating-climate-change-impacts-on-the-carbon/

FRAM-EMERALD: Terrestrial ecosystem-climate interactions of our EMERALD planet. The Fram Centre. kNOK 880. 2020-2021. PI: Ryan Bright.

FRAM-VANWHITE: The vanishing white: management of stressors causing reduction of pale vegetation surfaces in the Arctic and the Qinghai-Tibetan Plateau. The Fram Centre. kNOK 880. 2020-2021. PI: Jarle Bjerke.

FUNDER: Direct and indirect climate impacts on the biodiversity and Functioning of the UNDERground ecosystem. Research Council of Norway KLIMAFORSK, project 315249. kNOK 12.000. 2021 – 2025. PI: Vandvik. FUNDER - Direct and indirect climate impacts on the biodiversity and Functioning of the UNDERground ecosystem - Prosjektbanken (forskningsradet.no)

GreenBlue: A green-blue link made browner: how terrestrial climate change affects marine ecology. The Research Council of Norway MILJØFORSK, project: 287490, 18.8 mNOK. 2019-2022. PI: Anders F. Opdal, UiB.

HiddenCosts: 2017-2020. Hidden costs of implementing afforestation as a climate mitigation strategy: A comprehensive assessment of direct and indirect impacts. The Research Council of Norway KLIMAFORSK project 268243. kNOK 10.936. PI: 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/

ICOS-Norway (Hurdal): Measuring and monitoring of land-atmosphere mass and energy exchange in a mature conifer forest. PI: Lange, Bright. http://no.icos-cp.eu

IMPRINT: Quantifying historical and future impacts of land use/management on surface energy and water budgets in Norway. PI: Eisner, Bright.

INCLINE: Indirect climate change impacts on alpine plant communities. The Research Council of Norway FRIMEDBIO project 274712. kNOK 11.009. 2018 – 2021. PI: Vandvik, Töpper. http://www.uib.no/en/rg/EECRG/114810/incline

KiN2100: Klima i Norge 2100. Norwegian Environment Agency. kNOK 25.000. 2021-2024. PI: Anita Verpe Dyrrdal, MET.

LandPress: 2016-2019. Land use management to ensure ecosystem service delivery under new societal and environmental pressures in heathlands. The Research Council of Norway MILJØFORSK project 255090. kNOK 12.983. PI: Vandvik, Velle. http://www.uib.no/fg/eecrg/95158/landpress

LATICE: Land–Atmosphere Interactions in Cold Environments, Strategic Research Initiative in the Faculty of Mathematics and Natural Sciences, University of Oslo. PI: Tallaksen, Stordal. mn.uio.no/latice

OzoNorClim: "The double punch: ozone and climate stresses on vegetation" The Research Council of Norway MILJØFORSK. PI: Vollsnes.

Permanor: The Research Council of Norway. Finished spring 2020. PI: Westermann. http://www.mn.uio.no/geo/english/research/projects/permanor/

RECITE: Research and Education Partnership in Climate Change Impacts on Terrestrial Ecosystems. The Research Council of Norway INTPART project 274831. kNOK 5.787. 2018 – 2021. PI: Vandvik. http://app.cristin.no/projects/show.jsf?id=616372

SEEDCLIM: 2008-2015. The role of seeds in a changing climate - linking germination ecophysiology to population and community ecology. The Research Council of Norway NORKLIMA project 184912. kNOK 9.566. PI: Vandvik. http://www.uib.no/en/rg/EECRG/55395/seedclim

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

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

Three-D: Integrated assessment to aid mitigation of negative impacts by THREE global change Drivers on alpine biodiversity and ecosystem function. The Research Council of Norway MILJØFORSK project 287801. kNOK 6.220. 2019 – 2022. PI: Halbritter, Vandvik.

VANWHITE: The Research Council of Norway 2019-2022. NINA Tromsø.

WICLAP: Financed by the EEA Poland-Norway grant (2013-2016). Monitoring activity financed by Svalbards miljøvernfond (2017-2019) and SIOS. NINA Tromsø.
http://www.nina.no/english/tabid/5394/language/en-GB/Default.aspx

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

WINTERPROOF: Quantifying the role of cold season processes in vegetation-permafrost feedbacks, The Research Council of Norway, FRIPRO Young Research Talents, project 274711, kNOK 8000, 2018-2022. PI: Parmentier.
http://www.mn.uio.no/geo/english/research/projects/winterproof/index.html

Appendix B: Agenda of the EMERALD meetings and workshops

i) EMERALD WP & CCT leads meeting 16 April, 13:00 - 16:30

Agenda

Time	Topic	Responsible
13:00 – 13:15	**Introduction and Welcome**	Lena M Tallaksen
13:15 – 15:00	**WP progress; key results, progress towards milestones, possible delays/challenges and future plans (incl. field work 2021)**	
13:15 – 13:30	WP1 - LSM evaluation and improvement	Olav Skarpaas
13:30 – 13:45	WP2 – Improved process understanding from observations and experiments	Vigdis Vandvik
13:45 – 14:00	WP3 – Implementation in NorESM and quantification of feedbacks	Terje Berntsen
14:00 – 14:15	WP4 – Dissemination and Communication	Irene Brox Nilsen
14:15 – 14:25	WP5 – Management, organisation and cooperation	Tallaksen and Stordal
14:25 – 14:45	Discussion	All
14:45 – 15:00	Break	
15:00 – 15:10	**CCT progress, including key results, challenges and future plans (continue or not?)**	
15:00 – 15:10	Albedo	Ryan Bright
15:10 – 15:20	Hydrology	Kolbjørn Engeland
15:20 – 15:30	Tiling	Kjetil Aas
15:30 – 15:40	New PFTs	Terje Berntsen
15:40 – 15:55	Discussion	All
15:55 – 16:10	Budget update	Frode Stordal
16:10 – 16:30	**Concluding session and way forward**, incl. planning for the Annual meeting, fall 2021.	Lena M Tallaksen

ii) 6th Conference on Modelling Hydrology, Climate and Land Surface Processes

Scandic Lillehammer hotel, 14.–16. September 2021

Talks below are those given by EMERALD researchers. Full agenda available at: http://www.hydrologiraadet.no/wp-content/uploads/2021/09/modelling2021_abstracts.pdf

Session 1: Terrestrial ecology with links to climate and the hydrological cycle (chair : Lena M. Tallaksen)		
Rosie Fisher, CNRS	Keynote 1.2 A hierarchical complexity framework for managing the complexity of land surface models	talk
Kjetil Schanke Aas, UiO	Explicit representation of sub-grid snow and vegetation heterogeneity in a land surface model	talk
Astrid Vatne, UiO	Sensitivity of evapotranspiration and surface conductance to vapour pressure deficit across high latitude climatic gradients	talk
Yeliz Yılmaz, UiO	Probing Fennoscandian snow cover dynamics in the community land model and climate reanalyses during the satellite era	talk
Hui Tang, UiO	The impact of moss and lichen on hydrological cycle at surface: a study using CLM-FATES	talk
Eirik Aasmo Finne, NINA	Effect of winter warming events on vegetation ecophysiology on a low-alpine ridge	poster
Emiliano Gelati, UiO	Community land model v5 runoff evaluation in small near-natural catchments in fennoscandia	poster
Rebekka Gullvåg, UiO	Effects of high-latitude light conditions on stomatal conductance and photosynthesis in white clover (trifolium repens)	poster
Marius Lambert, UiO	Causes of plant mortality from extreme winter events: model insights into desiccation processes during frost droughts	poster
Devaraju Narayanappa, UiO	Simulated runoff and river discharge in CLM-evaluation over Scandinavia	poster
Session 2: Modelling soil water dynamics: from observations to prediction		
Terje Berntsen, UiO	Keynote 2.2 Representing soil dynamics in Earth System Models	talk
Session 3: Improved knowledge-base for decision-making (Co-chair: Kolbjørn Engeland)		

Irene Brox Nilsen, NVE	Parallel discussions 2: Young hydrologists, needs and directions	moderation
Kolbjørn Engeland, NVE	Design flood estimation at locations with no data or short records in a Bayesian framework	poster
Kolbjørn Engeland, NVE	Estimating long term mean annual runoff by combining outputs from a gridded precipitation runoff model with observations from both short and long records	poster
Session 4: Integrating observations into earth system modelling, including non-conventional observations		
Sonya Geange, UiB	Bridging earth system modelling and ecological insights: a model platform for the functionally assembled terrestrial ecosystem simulator with community land model (CLM-FATES)	talk

iii) 2021 EMERALD Annual meeting, Tøyen 27-28 September 2021

AGENDA

Monday 27 September

Time	Topic	Responsible
09:30 – 10:00	Signing in (physically or on Zoom) - Coffee & Tea	NHM
10:00 – 11:00	**Introduction session**	**Chair: L.M Tallaksen**
10:00 – 10:20	Welcome address; the Museum and collaboration opportunities	Brit Lisa Skjelkvåle
10:20 – 10:30	Participants – short introduction	
10:30 – 10:50	EMERALD – status	Lena M Tallaksen
10:50 – 11:00	Discussion	

11:00 – 15:30	**WP progress; key results, progress towards milestones, challenges and future plans**	
11:00 – 11:30	WP1 - LSM evaluation and improvement	Olav Skarpaas
11:30 – 12:00	WP2 – Improved process understanding from observations and experiments	Sonya Geange, Jarle Bjerke og Norbert Pirk
12:00 – 12:15	Discussion	
12:15 – 13:30	**Lunch**	
		Chair: F. Stordal
13:30 – 14:00	**Invited talk**: Controls of long-term DOC change in surface waters: evidence from large-scale lake surveys in Europe and North America	Heleen de Wit
14:00 – 14:30	WP3 – Implementation in NorESM and quantification of feedbacks	Terje Berntsen
14:30 – 15:00	WP4 – Dissemination and Communication	Irene Brox Nilsen
15:00 – 15:10	WP5 – Management, organisation and cooperation	Lena M Tallaksen Frode Stordal
15:10 – 15:30	Discussion	
15:30 – 15:50	Break	
15:50 – 17:30	**CCT progress; results, challenges and future plans**	**Chair: J. Bjerke**
15:50 – 16:10	Hydrology	Kolbjørn Engeland
16:10 – 16:30	Albedo	Ryan Bright
16:30 – 16:50	Tiling	Kjetil Aas
16:50 – 17:10	New PFTs	Terje Berntsen
17:10 – 17:20	Discussion	
17:20 – 17:30	**Close of Day 1**	Lena M Tallaksen
17:30 – 19:30	Short social event for those present, including a walk in the botanical garden and a visit to the Climate House, followed by a small treat ☺	

Tuesday 28 September

Time	Topic	Responsible
08:30 – 09:00	Signing in (physically or on Zoom) - Coffee & Tea	NHM
		Chair: T. Berntsen
09:00 – 09:30	**Invited talk**: Modeling the biosphere from the bottom up: impacts of ecological process representation in FATES	Rosie Fisher
09:30 – 11:00	**Short 10 min updates**	
09:30 – 09:40	EMERALD PhD	Eirik Finne
09:40 – 09:50	EMERALD postdoc, incl. the FUNDER project	Sonya Geange
09:50 – 10:00	Field and lab Experiments	Ane V Vollsnes
10:00 – 10:10	Spot-On, dScience and DroneLAB	Norbert Pirk
10:10 – 10:20	Winterproof	Frans-Jan Parmentier
10:20 – 10:30	Model platform	Hui Tang
10:30 – 10:40	Coupled veg./climate models: Runaway feedbacks	Frode Stordal
10:40 – 10:50	CBA	Terje Berntsen
10:50 – 11:00	Discussion	
11:00 – 11:30	**Break**	
11:30 – 12:30	**Group discussions**	**Chair: LM Tallaksen**
11:30 – 12:00	WP1 and WP3	O. Skarpaas, T. Berntsen
12:00 – 12:30	WP2 and WP4	S. Geange, I.B. Nilsen
12:30 – 13:30	**Lunch**	
13:30 – 15:00	**Group discussions, cont.**	
	Topic I – Research proposals (Ideas)	N. Pirk, T. Berntsen
	Topic II – Field 2021 Evaluation and 2022 Planning	J. Bjerke, A. Bryn
14:30 – 15:00	Plenary reporting from Group discussions	

15:00 – 16:00	**Annual reporting to RCN**	**Chair: A. Bryn**
15:00 – 15:20	Status and outstanding issues	Lena M Tallaksen
15:20 – 15:30	Budget update	Frode Stordal
15:30 – 16:00	**Concluding remarks**	
15:30 – 15:50	Participant feedback	All
15:50 – 16:00	**Closure**	Lena M Tallaksen

EMERALD annual meeting – participant list

Last name	*First name*	*Institution*	*E-mail*
Physical attendance			
Berntsen	Terje	UiO/Geo	t.k.berntsen@geo.uio.no
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de Wit	Heleen	NIVA/ UiO (CBA)	hwi@niva.no
Engeland	Kolbjørn	NVE	koe@nve.no
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Nilsen	Irene Brox	NVE	ibni@nve.no
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Stordal	Frode	UIO/Geo	frode.stordal@geo.uio.no
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Online attendance

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Appendix C: Budget personnel (only included in the version to RCN)

Appendix D: 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 dispute 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 meta data information on field and model experiment 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.

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;
    a. substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data;
    b. drafting the article or revising it critically for important intellectual content; and
    c. final approval of the version to be published.
3. 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.
4. 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.
5. These rules apply to all project participants, from students to PIs.
6. 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, . 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.