Annual progress report to the Research Council of Norway

Special report for the EMERALD project, project number 294948

Leader: Lena Merete Tallaksen (Frode Stordal until July 1st 2020)
Reporting period 1 October 2019 - 30 September 2020

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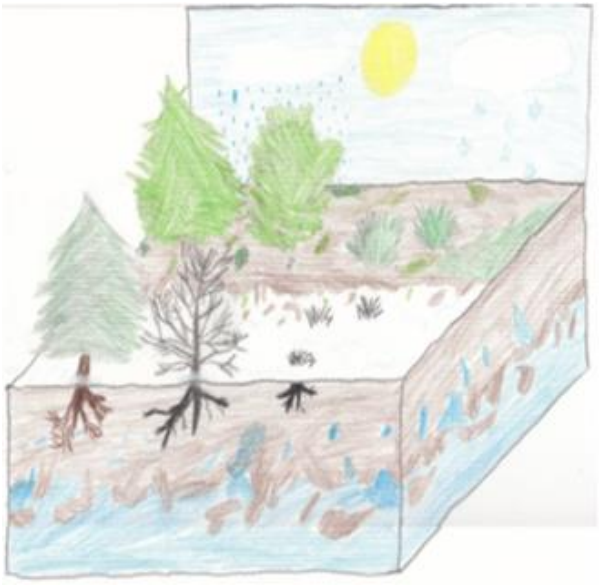

Figure 1: Terrestrial boreal and sub-Arctic ecosystems (left to right): evergreen trees, deciduous trees, shrubs, and mosses, spanning all seasons from summer in the back to winter in front. Illustration by Inger Andrea, 12 years old at the time of drawing. She is the primary target age of the EMERALD exhibitions in the new Climate House at the Natural History Museum (NHM), in place at the opening in 2020.

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. 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 CLM – 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.

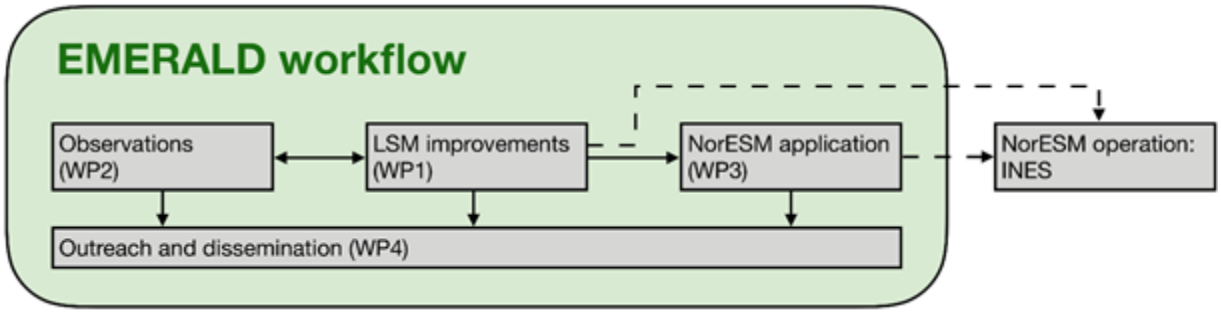

Figure 2: EMERALD activities shown in the green area. EMERALD supports developments of CLM and contributes these to NCAR and INES.

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 PFTs (PFT = plant functional types)

In Section 1 (Scientific progress) below, progress and results for each WP and CCT are summarised and concluded by scientific highlights from the project written in a popular science form. An introduction to the Budget status report is provided in Section 2 (the report itself is submitted separately as an Excel spreadsheet and a copy provided in Appendix C). The Data management plan (update and follow-up) is presented in Section 3, whereas the plan itself in given in Appendix D.

1. Scientific progress

a. Work packages and Cross Cutting Themes

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. Three of the tasks are covered in cross cutting themes (see below).

An important step forward was made this year with the development of the CLM-FATES model platform (Figure 3) for site simulations (https://github.com/NordicESMhub/ctsm/tree/fates_emerald_api). A manuscript (paper) on the platform is in preparation. The platform will facilitate the interaction between model (WP1) and observation (WP2) in EMERALD, and is likely to be important for the progress of several tasks in these WPs, as well as for coupled simulations planned in WP3.

Progress has also been made on more specific points, such as the developing new plant functional types (PFTs) for mosses and lichens (Task 1a, CCT New PFTs). This will improve related phenology, which is closely connected to vegetation dynamics (Task 1b) and albedo (Task 1d, CCT Albedo), and hydrology-related model benchmarking (Task 1c, CCT Hydrology). Further work on vegetation dynamics (Task 1b), hydrology (Task 1c), carbon cycle (Task 1d) and energy balance (Task 1e) will take place within the next year, building on, among other things, the CLM-FATES model platform, and data acquired in WP2.

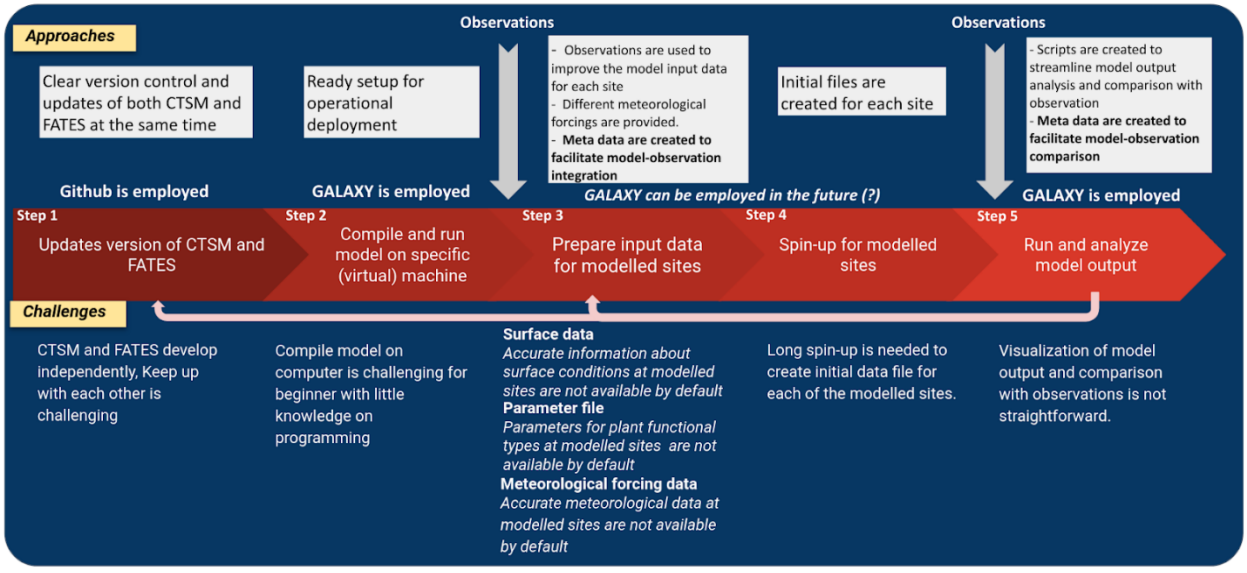

Figure 3: Steps for building the CLM-FATES modelling platform (figure credit: Hui Tang).

WP2: Improved process understanding from observations and experiments

Leads: Vigdis Vandvik, 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 and beyond. Additional data are being collected during the project period by EMERALD staff. 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. WP2 consists of seven specific tasks, and fieldwork for task-specific data collection is being conducted at numerous sites in Norway, including Svalbard (Figure 4). Activity was high and productive during the summer field season of 2020, despite the pandemic restrictions although some delays were reported. Collected data are being handled and analyzed by the many researchers involved in WP2. This include PhD students, postdoctoral researchers and permanent staff at the involved universities and research institutes. Data is transferred to WP1 at regular intervals for further processing there. Results from WP2 will also lead to stand-alone products, in particular scientific articles on vegetation dynamics, plant hydrological processes, and climate-mitigating ecosystem services related to carbon cycles and reflection of incoming solar radiation.

The group contributes to the development of the FATES/CLM platform (Ref. WP1) by improving our understanding of global patterns of photosynthetic thermal tolerance of terrestrial plants. We are conducting a global meta-analysis assessing:

- how different photosynthetic pathways, growth forms and biomes respond to thermal extremes;
- the comparability of thermal tolerance metrics;
- if extreme temperatures are better predictors of global patterns of photosynthetic thermal tolerance than mean temperatures.

As part of the ITEX (International Tundra Experiment) network, we are participating in a paper on delimiting moss functional types, which will feed into the new PFTs (Task 2b and CCT).

Figure 4: Point intercept analysis of graminoid dominated tundra by EMERALD PhD Eirik Aasmo Finne and field assistant François Chauvin in Signehamna, Svalbard - 21.07.2020 (photo credit: Rasmus Erlandsson).

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 CLM5.0 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.

The first task of WP3.1 (Splitting land columns in CLM) is well underway based on previous work by Aas et al. on tiling in the NOAH land surface scheme. 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. The tiling scheme is based on a statistical approach dividing the grid cell in (e.g. five) tiles with different soil properties (i.e. soil depth and texture, hydraulic properties, etc.). This allows the different plant functional types to occupy small-scale environmental niches.

As discussed above, a major effort in WP1 and WP2 is to improve the FATES model for use in CLM in boreal and high latitude regions. WP3 participates in the work, to facilitate that FATES can be used in the coupled simulation planned for WP3. The coupled runs with the updated versions of the model based on the work in WP2 and WP3 are planned for later in EMERALD. However, major changes in parts of an Earth System Model (such as introducing FATES) in general have impacts on the entire modelling system. In WP3, we are collaborating with the other coordinated projects on NorESM development (KeyClim and INES) to make sure that we deliver well-tested modules for the major revision of NorESM for the CMIP7 experiments.

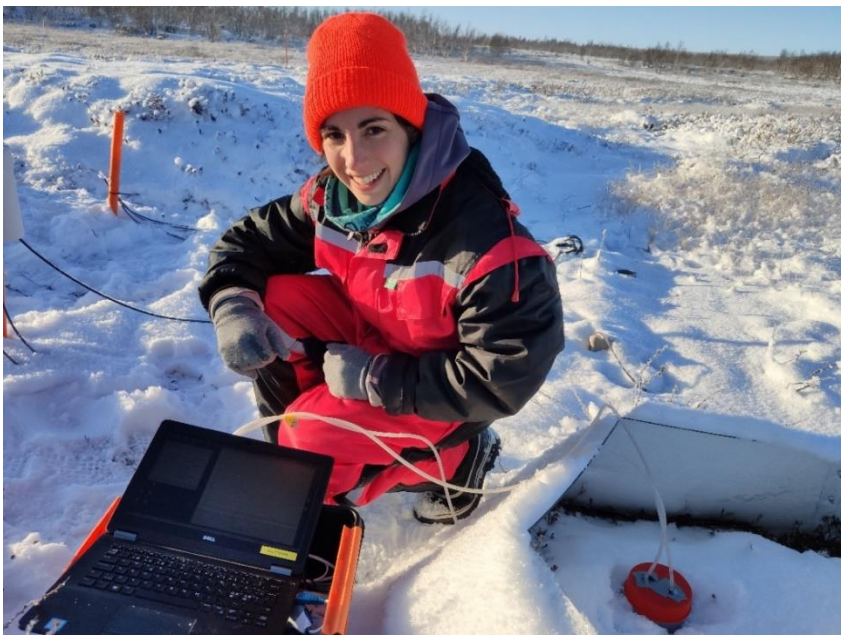

Figure 5. Soil respiration measurement using Li840 infrared gas analyzer by Inge Althuizen in Iškoras - 19.10.2019, photo credit: Casper Tai Christiansen.

WP4: Dissemination and communication

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

WP4 has been active since the beginning of the project, with the first stakeholder meeting and a temporary exhibition in the new Climate House at Natural History Museum in Oslo as highlights.

Stakeholder meeting 26. November 2019, at MET Norway

This meeting was co-arranged with the RCN project PostClim. There were 27 participants for the EMERALD-specific part of the meeting. Presentations covered reindeer herding (UiT and NINA), forestry (Norges skogeierforbund), and vegetation changes (Norges Bonde- og småbrukarlag and NHM). A list of user needs was collected through group discussions (google sheets available upon request).

Temporary exhibition at the Climate house: "Natur i endring", June 2020

EMERALD was invited to populate the temporary exhibition room at the Climate house in NHM at its opening, with an exhibition outlining climate research and vegetation–climate feedback. The work was led by Anders Bryn (NHM) with help from exhibition designers Anita Myhrvold and Runa Klock. The exhibition was created by Thea Grobstok Dalen, Hanne Heiberg, Irene Brox Nilsen, Frans-Jan W. Parmentier, Christine Snekkenes and Frode Stordal, with text contributions from Eirik Aasmo Finne, Kjetil Schanke Aas, Inge Althuizen, Terje Koren Berntsen, Jarle W. Bjerke, Ryan M. Bright, Anita Verpe Dyrrdal, Sonya Rita Geange, Norbert Pirk, Oskar Puschmann, Hui Tang, Michal Torma, Ane Victoria Vollsnes, Sebastian Westermann and Yeliz Yilmaz.

Disseminating developments of the FATES platform

Developments in the module Functionally Assembled Terrestrial Ecosystem Simulator (FATES) have been disseminated through a BCC2020 meeting (July 2020), release of EMERALD FATES platform on GitHub, and a FATES-GALAXY tutorial (e.g. https://vimeo.com/439192348). This work was led by Hui Tang, UiO-NHM and Anne Fouilloux (senior Engineer at UiO Geosciences).

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

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

EMERALD is represented in the Scientific Committee with Yeliz Yilmaz (UiO). One of the sessions is closely related to the topic of EMERALD, more specifically: “Terrestrial ecology with links to climate and the hydrological cycle”.

Social media

A twitter account has been established with the handle @emerald_norway.

WP5: Management, organisation and cooperation

Leads: Frode Stordal and Lena M Tallaksen

As planned, EMERALD is managed in two phases; phase I (2019 - 2020) and phase II (2020 - 2022). Frode Stordal led phase I until 1 July 2020, when Lena M Tallaksen took over (half a year earlier than planned for practical reasons), when Frode Stordal retired. This shift in leadership was estimated to be around the time when LATICE, and her leadership, was meant to terminate. However, in competition with other SRIs in UiO, LATICE has been extended for another four years. Thus, Lena M Tallaksen has the leadership of both EMERALD and LATICE. Accordingly, she has strengthened the co-leadership of both.

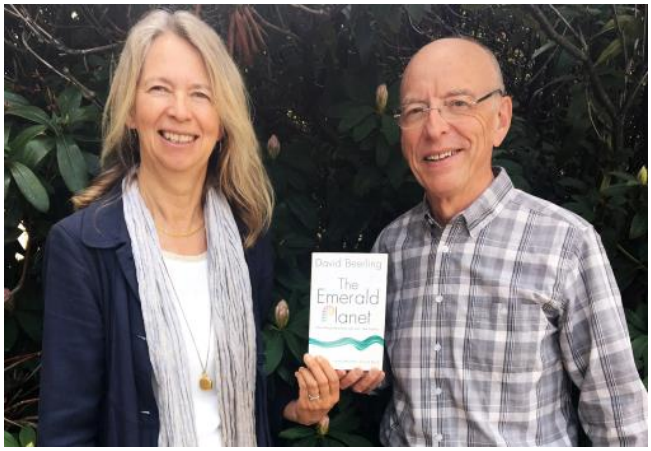

Figure 6. EMERALD leaders Lena M. Tallaksen and Frode Stordal.

The original *leader group* at the start of the project, Frode Stordal, Lena M Tallaksen, Hanna Lee and Jarle Bjerke, ensured 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 (Oslo, Bergen, Tromsø). Following the initiation of the project, the leader group was extended with Ryan Bright (NIBIO, to include Ås), Anders Bryn (UiO-NHM, to include ecological expertise from Oslo), and later Terje Berntsen (co-lead of EMERALD, to replace Frode Stordal). The leader group has met regularly by video link to reduce travelling. In total seven meetings have taken place: three in 2019 (4 April, 30 August and 11 December), and four in 2020 (11 March, 5 May, 8 June and 17 September).

An *international network group* with eight members has been be established, covering the breadth of scientific disciplines in EMERALD. Four network partners took part in the kick-off meeting in Oslo, providing valuable feedback to the way forward.

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.

Cross Cutting Themes

CCT Albedo: Lead Ryan Bright

The albedo CCT has carried out two teleconference meetings in the past year to define and scope cross cutting research activities, as well as to allocate tasks and responsibilities among participants. The scoped activities are in various stages of execution, with some still in the early planning phases and others in the later phases of manuscript preparation. Progress in this CCT over the past year has been slow, owed to a paternity leave by the leader as well as reduced working capacity of all members due to COVID-19 mitigation measures (i.e., closed schools/day-cares). Nevertheless, the following activities have been completed:

i) downloading and processing of remotely sensed snow cover data (MOD10A1/MYD10A1) from Aqua and Terra satellites and reanalysis data (ERA5-Land) for the entire Fennoscandian region;
ii) several regional offline model simulations with CLM5 and CLM4.5;
iii) in-situ data collection of surface albedo on Svalbard;
iv) development of a new "satellite phenology" model for CLM-FATES.

These initial activities essentially lay the groundwork for addressing the scoped scientific research questions within the CCT in late autumn 2020 and beyond.

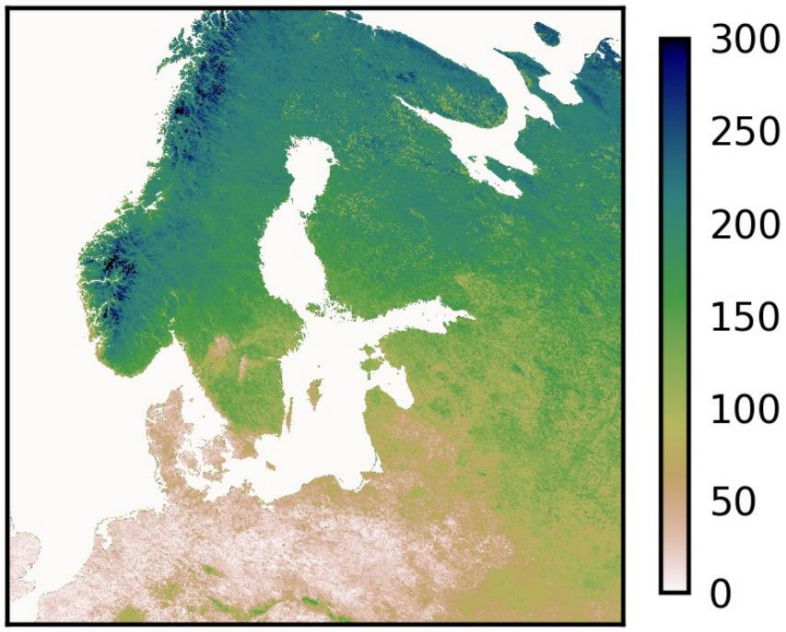

Figure 7. The 2018 snow cover duration (days) over Fennoscandia obtained from MODIS (Aqua and Terra satellites), figure credit: Yeliz Yilmaz.

CCT New PFTs: Lead Terje Berntsen

The CCT on new Plant Functional Types (PFTs) has started the work on extending the FATES module to include mosses and lichens as new PFTs. A key step towards this objective has been to develop the

CLM/FATES platform (see WP1 above), which allows an efficient framework for testing out model developments. Both mosses and lichens are large groups of different species, so a decision has been made to concentrate on two main types, sphagnum mosses growing mainly in humid soils and cladonia lichens (Reindeer lichens) growing drier exposed ridges. For this work, the platform allows simple and efficient testing for different soil and humidity conditions. Initial work is ongoing to identify and quantify the parameters needed to describe these new PFTs in the FATES framework. The work is also closely related to development of the tiling scheme in CLM (ref. WP3 above), which is needed to represent the sub-grid scale conditions that favour mosses and lichens.

CCT Tiling: Lead Kjetil Aas

Tiling CCT has had one physical meeting (fall 2019) and participated in meetings and discussions with the other three CCTs (hydrology, albedo and PFT). Based on the work of Cai et al. (2020), this CCT has worked on demonstrating the importance of lateral heat, snow and soil water fluxes to represent carbon fluxes in a permafrost landscape (Aas et al., in prep). Future work aims to investigate the importance of sub-grid heterogeneity of snow and soil properties in boreal and Arctic regions, in collaboration with the other CCTs.

CCT Hydrology: Lead Kolbjørn Engeland

The Hydrology CCT had one physical meeting (15 November 2019) to share different approaches to understand and model evapotranspiration from actual transport processes within plants and how evapotranspiration is parametrized in hydrological models versus a land surface model (here CLM). Progress in this CCT the past year has been somewhat slower than anticipated, among other due to the COVID-19 lockdown (reduced working capacity of all members). Future work within this CCT will be to apply and compare evapotranspiration modelling using both hydrological models (Shyft) and CCT. This work will be closely related to the CCT on new PFTs.

Scientific highlights

The CLM-FATES modelling platform for EMERALD

The implementation of the CLM-FATES modelling platform (WP1 and Figure 3) led by Hui Tang, has been publicly released in a GitHub repository. The main motivation of this initiative is to increase the interaction between modellers and field ecologists in EMERALD. The aim is to help with 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). Senior engineer Anne Fouilloux (UiO Geosciences) and Hui Tang prepared a video tutorial to set up CLM-FATES with Galaxy Climate JupyterLab.

https://github.com/NordicESMhub/ctsm/tree/fates_emerald_api
https://vimeo.com/439192348

The temporary exhibition at the Climate House

In spring 2020, the Natural History Museum of the University in Oslo, opened the Climate House. EMERALD contributed with a temporary exhibition for the opening (Figure 8) focusing on key research topics of the project. We are proud to have EMERALD represented as the first temporary exhibition in the Climate House. The exhibition will be moved to The Norwegian Mountain Center next year. Presently, we are working on an exhibition catalogue, including tasks for school classes. About the opening: https://www.nhm.uio.no/english/about/news/20 20-06-16-crownprice-opens-climate-house.html

Figure 8. EMERALD exhibition, Climate house museum at NHM Tøyen, Oslo - 11.06.2020, photo: Irene Brox Nilsen and Anders Bryn.

Nature Climate Change perspective paper

The paper, published 31 January 2020 with six co-authors from EMERALD: JW Bjerke, A Bryn, CT Christiansen, F-JW Parmentier, F Stordal, and H Tømmervik, has the title "Complexity revealed in the greening of the Arctic". It shows that over the past 40 years, satellite-derived vegetation indices have indicated widespread change at high latitudes. Satellite records allow the quantification of change in places that are otherwise unevenly sampled by in-situ ecological observations. In recent years, slowing or reversal of apparent greening from satellite studies has been reported in some regions (sometimes termed Arctic browning). This slowdown is seemingly at odds with earlier responses to long-term warming trends. Research now indicates substantial heterogeneity in vegetation responses to climate change in the Arctic. However, the mechanistic links between satellite records and in-situ observations remain unclear, owing to conceptual and technical barriers in their analysis and combined interpretation. Paper: https://www.nature.com/articles/s41558-019-0688-1

Award - Hjernekraftprisen 2019

The project "Natur i endring" (Nature in change) was one of two research contributions that were awarded Hjernekraftprisen (the Brain Power Prize) for 2019, issued by Forskerforbundet (the Norwegian Association of Researchers). The project leader Anders Bryn from the UiO-NHM received the prize at the Researchers' Association's yearly seminar in Oslo together with key contributors in the project; Peter Horvath, Inger Kristine Volden, Michal Torma and Frode Stordal (Figure 9).

https://www.forskerforbundet.no/om-oss/hjernekraftprisen/vinnere/2019-vinnerbidragene/
https://www.forskerforbundet.no/PageFiles/24019/Hjernekraftprisen-2019_Naturiendring_AndersBryn.pdf

Figure 9. EMERALD/LATICE participants awarded Hjernekraftprisen 2019 (from left): Bryn, Stordal, Volden, Horvath and Torma. Right: Guro Lind (leader of Forskerforbundet).

Internal EMERALD workshop highlights

Iškoras workshop (7 November 2019)

The topic of the meeting was data analysis and sharing, and how to secure a good flow of information about modelling and measurements at Iškoras site. Two international participants (Sarah E. Chadburn and Noah Smith, University of Exeter, UK) from the synergy projects FEEDBACK and PERMANOR took part. There were nine additional participants from UiO and NORCE (please see Appendix B1 for the workshop agenda).

CLM-FATES Workshop (11-12 February 2020)

The CLM group at UiO and collaborating institutes in Norway (mostly PhDs and PostDocs) has been working together by using and developing CLM5 and FATES models since the EMERALD project kicked-off. To make a real contribution to a model of this complexity, a high level of expertise in terms of technical skills is

required, as well as scientific understanding and knowledge about the status and ongoing developments of the model. Therefore, we organized a CLM-FATES workshop where two of the NCAR partners in EMERALD were invited to discuss future plans, exchange ideas, and learn about the ongoing model development at NCAR. David Lawrence, leader of the CLM developers at NCAR, and Rosie Fisher, one of the main developers of FATES, participated. There were 20-30 participants (please see Appendix B2 for the workshop agenda).

EMERALD Annual Meeting (13-14 May 2020)

A two-day physical event was originally planned for, however, due to the COVID-19 lock-down, the meeting was organised over Zoom, still over two days. In total, around 30-40 participants, including International Expert Group members and all EMERALD partners, took actively part (please see Appendix B3 for the workshop agenda).

b. Project implementation – challenges

Challenges with respect to EMERALD implementation (scientific challenges, management and progress} are listed below:

- Nationally-mandated COVID-19 mitigation measures enacted in March resulted in reduced working hours for most researchers within EMERALD (for some due to closed schools/day-cares). This has delayed the implementation of research activities in almost all WPs as well as the installation of new scientific equipment at some of the project's field sites.
- Uncertainties related to the COVID-19 pandemic restrictions, had impacts on fieldwork planning. A planned expedition to Svalbard was in the end undertaken nearly as planned, but required short-noticed planning, decision, and reorganization as the permission came late.
- Due to COVID-19, the May Annual Meeting was held in a virtual format over two days.
- Planned international collaboration, including an exchange visit with the University of Sheffield (ACCE) and a field trip to Tibet with Chinese collaborators (VANWHITE) had to be cancelled (or postponed).
- A delayed hiring of a PostDoc at UiB (6 months delay).

Overall, the delay due to COVID-19 is estimated to be in the order of 3-6 months.

c. Integration with synergy projects

An updated overview of EMERALD synergy projects is provided in Appendix A. The original list (dated February 2019) was provided as an attachment to the original Data Sharing and Management Agreement. Here we present a short description of how EMERALD has integrated relevant scientific contributions and expertise from these projects, and how this has provided added value, synergy and cooperation.

ACCE: The pandemic prevented the planned visit by the ACCE-PhD student from the University of Sheffield, UK, for fieldwork in Norway and Svalbard (postponed to 2021). Still, two scientific papers were published this year as a result of joint work with the previous ACCE-PhD student.

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 coastal Western Norway. It resulted in the production of a PFT-dependent surface albedo database for Norway, which will serve as an empirical benchmark for PFT-level albedo predictions by CLM5/FATES in WP1. Data collected in the project can be used to assess fidelity of predictions made with FATES for similar forest ecosystem types and climate regimes.

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 e.g., the FINSE site, with the aim to improve the understanding of the energy balance and carbon fluxes.

FEEDBACK: The project (2016-2020) 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.

GreenBlue: This project involves a study of changes in transport of Dissolved Organic Matter (DOM) through catchments, rivers and lakes to the ocean due to climate change. Evolution of vegetation cover, cycling of carbon and nitrogen, and leakage of dissolved organic carbon and nitrogen to rivers and lakes will all be estimated using the CLM model. Focus is on the past history as well as the future, assuming two different climate scenarios.

HiddenCosts: The HiddenCosts project (2017-2020) combines different disciplines (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.

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). The sites is not yet up and running due to various reasons, but will provide important data for EMERALD when in operation (next year).

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. The FATES 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 10. 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 FATES platform is being parametrized for these sites by translating data and variables between field ecologists and FATES modellers.

LATICE: EMERALD collaborates closely with LATICE, as demonstrated by the following joint activities:

i) 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. This project benefits from the expertise provided by EMERALD and simultaneously contributes with data and field infrastructure to the EMERALD group;

ii) The LATICE mobile flux station is currently located at the Iškoras field site (Figure 11);

iii) Joint fieldwork and data exchange is part of ongoing work at the Finse research station;

iv) Two recent LATICE PhD students (Keetz and Vatne) both collaborate closely with EMERALD partners, with focus on parametrization of high latitude vegetation and estimation of evapotranspiration;

v) One postdoctoral fellow is currently working on integrating snow remote sensing products into the evaluation of Earth system models and reanalyses data of value for both LATICE and EMERALD.

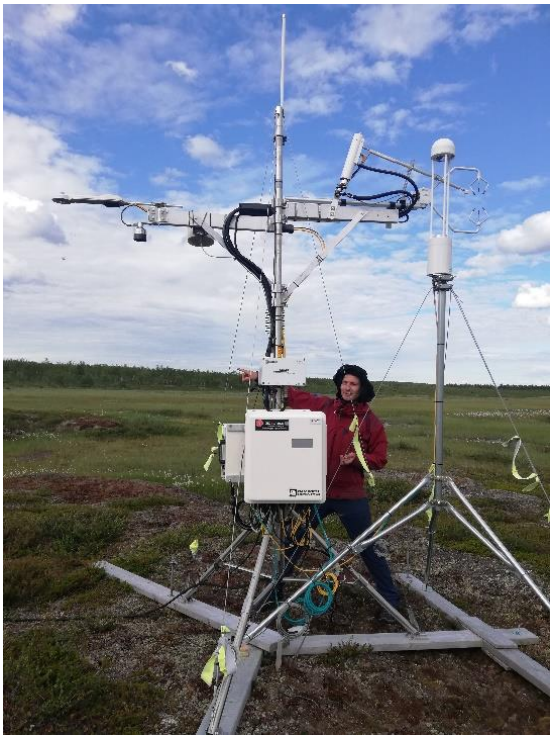

Figure 11. LATICE mobile flux station in Iškoras maintained by Norbert Pirk - 28.07.2020, photo credit: Yeliz Yilmaz.

OzonNorClim (Double Punch): Joint fieldwork with EMERALD took place in both 2019 and 2020 in Finnmark, including photosynthesis and albedo measurements. The project deals with changes in vegetation due to climate change as well as ozone exposure.

Permanor: The Permanor project (finished spring 2020) 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.

Spot-ON: 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.

Terra-BGP: This project (2016-2020) assessed the sensitivity of surface properties (i.e., albedo) and fluxes (i.e., water and energy) to changes in forest structure and composition within the Fennoscandic 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 initialize surface data in regional climate modelling experiments, improve parameterizations and/or benchmark predictions with in CLM5-BGC and CLM-FATES in WP1.

VANWHITE: The project studies the role in the climate system of various alpine and Arctic vegetation types in collaboration with Chinese partners. Both ground-based and remotely sensed methods are applied to investigate these roles through the variable biogeochemical and biophysical properties of various vegetation types – of great value also for EMERALD.

WICLAP: WICLAP is the acronym of a project funded over the EEA Norway grants. A gradient of vegetation plots established on Svalbard was studied over several consecutive years, demonstrating drastic year-to-year variation in plant health, shown to correspond to degree of winter stress. This gradient turned into an environmental monitoring system, which is followed up by NINA, partly through EMERALD. This contributes to our understanding of the impacts of rapid climate change on Arctic lands and how these changes affect the climate-mitigating properties of Arctic vegetation.

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 CLM/FATES. The parallel development of the same models in EMERALD leads to many synergies between the two projects, which will help to narrow uncertainties in model projections of carbon cycle feedbacks.

d. 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.
- CLM and FATES model development and testing 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. Moreover, 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 FATES model platform. Norwegian e-Infrastructure for Life Sciences (NeLS) is currently a contributor to the GALAXY platform.

e. Use and further development of NorESM

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 upcoming IPCC AR6 report. EMERALD researchers have participated in this work, in particular with fixing a bug related to accumulation of snow covering wetlands. Within the LATICE project at UiO, a new parameterization for formation and growth of aerosols has been implemented in NorESM (Sara Blichner's PhD work). New particle formation is strongly influenced by the availability of low volatile organic gases that are formed from organics emitted by vegetation, thus linking the dynamics of the vegetation to atmospheric processes such as cloud formation.

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 aim at NCAR is to have FATES ready and tested to be officially available in CLM from the summer of 2021. The CLM-FATES platform (ref. WP1) is actively used to include new plant functional types (PFTs), such as mosses and lichens, in FATES. To achieve this a better representation of the sub-grid scale variation in soil depth and properties is needed. This is currently facilitated for CLM (and thus NorESM) within EMERALD.

2. Budget status report

The budget report (provided as a separate Excel-spreadsheet and as a copy in Appendix C) includes budget information on personnel working on the project, both financed through the RCN 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 since the EMERALD proposal was submitted, are successfully established, as described in Section 1c. 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 inaccuracies for professor and researcher positions.

3. Data Management Plan

Only minor revisions have been made to the 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

ACCE: Doctoral training partnership. Natural Environment Research Council, UK. 2019-2021. J. Bjerke, NINA Tromsø. http://acce.shef.ac.uk/

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

COMTESSA: Camera Observation and Modelling of 4D Tracer Dispersion in the Atmosphere, European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program, grant agreement No 670462. The scientist involved in EMRALD is Cassiani, who leads the meteorological measurements and simulations activity in the project. PI: Andreas Stohl (University of Vienna, Austria). http://comtessa-turbulence.net

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

FEEDBACK: Advancing permafrost carbon climate feedback – improvements and evaluations of the Norwegian Earth System Model with observations. Research Council of Norway FRINATEK project. 2016-2019. 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: The role of Functional group interactions in mediating climate change impacts on the Carbon dynamics and Biodiversity of alpine ecosystems. Research Council of Norway KLIMAFORSK, project 244525. kNOK 7.900. 2015 – 2018. PI: Vandvik.
http://uni.no/en/uni-climate/biogeochemistry/funcab-the-role-of-functional-group-interactions-in-mediating-climate-change-impacts-on-the-carbon/

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

HiddenCosts: Hidden costs of implementing afforestation as a climate mitigation strategy: A comprehensive assessment of direct and indirect impacts. Research Council of Norway KLIMAFORSK, project 268243. kNOK 10.936. 2017 – 2020. 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. Research Council of Norway FRIMEDBIO project 274712. kNOK 11.009 .2018 – 2021. PI: Vandvik, Töpper.
http://www.uib.no/en/rg/EECRG/114810/incline

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

LATICE: Land–Atmosphere Interactions in Cold Environments, Strategic Research Initiative at 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". Research Council of Norway MILJØFORSK project. PI: Vollsnes.
Permanor: Permafrost landscapes in transformation - from local-scale processes to the global model NorESM. Research Council of Norway project. 2016 – 2019. PI: Westermann.
http://www.mn.uio.no/geo/english/research/projects/permanor/
RECITE: Research and Education Partnership in Climate Change Impacts on Terrestrial Ecosystems. Research Council of Norway INTPART project 274831. kNOK 5.787. 2018 – 2021. PI: Vandvik.
http://app.cristin.no/projects/show.jsf?id=616372
SEEDCLIM: The role of seeds in a changing climate - linking germination ecophysiology to population and community ecology. Research Council of Norway NORKLIMA project 184912. kNOK 9.566. 2008 – 2015. 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: 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. Research Council of Norway MILJØFORSK, project 287801. kNOK 6.220. 2019 – 2022. PI: Halbritter, Vandvik.
VANWHITE: The vanishing white: management of stressors causing reduction of pale vegetation surfaces in the Arctic and the Qinghai-Tibetan Plateau. Research Council of Norway POLARPROG, project 287402. 2019-2021. PI: Bjerke (NINA Tromsø). https://prosjektbanken.forskningsradet.no/#/project/NFR/287402
WICLAP: first 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, 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 EMERALD internal workshops

Appendix B1. Iškoras workshop

Oslo, November 7, 2019
Venue: Room 3213, Kristine Bonnevies Hus, University of Oslo, Blindern
https://www.uio.no/om/finn-fram/omrader/blindern/bl18/index.html

10:00	*Frode Stordal and Lena Tallaksen*	Welcome, background, aims, practicalities
10:15 - 10:30	*Hanna Lee and Sebastian Westermann*	Why study Iškoras? Iškoras in the context of Permanor and Feedback. Overview of available data
10:30	*Bernd*	Climate and permafrost data
10:45	*Casper*	Carbon fluxes
11:00		Coffee break
11:15	*Norbert Pirk*	Eddy covariance fluxes at Iškoras
11:30	*Lei, Kjetil*	Modelling Iškoras: opportunities and challenges
11:45	*Sarah Blichner, Noah*	Data-model comparisons including Iškoras
12:00		Lunch
13:00	*Hanna Lee, Sebastian Westermann, all*	Summary of the morning and open discussions: Possible papers and next steps
14:00	*All*	Hands-on group work
15:00 15:30	*Frode Stordal and Lena Tallaksen*	Iškoras within EMERALD: Possibilities and plans

Appendix B2. CLM-FATES workshop

11-12 Feb. 2020 - Agenda

Location: Sognsveien 77B, Ullevål Stadion, Oslo

February 11th		
10:00-12:00	Update on CLM and FATES developments. Room: Main lecture room ("Danskebåten")	
	David Lawrence	Update and status on CLM/CTSM development and LSM developments in general
	Rosie Fisher	The nitrogen cycle and the status of the FATES vegetation model
12:00-13:00	Lunch	
13:00-15:00	Short presentations with discussions: Soil and snow processes. Room: Fruen fra havet	
	Frode Stordal/Lena Tallaksen	Short overview of current CLM-related projects
	Lei Cai/Hanna Lee	Sub-grid representation of excess ground ice in CLM
	Kjetil Aas	Simulation of polygonal tundra at Samylov with tiles, and plans for future tiling scheme in CLM.
	Yeliz Yilmaz	Regional CLM simulations over Scandinavia
	Break	
15:00-17:00	Short presentations with discussions: Soil and snow processes cont. Room: Fruen fra havet	
	Norbert Pirk	Current observations in Norway and its relevance for CLM validation
	Frans-Jan Parmentier	WinterProof project activities relevant for CLM
	Elin Aas	Development of a microbial soil model for CLM
	Hui Tang	Evaluation of surface albedo prediction in high latitude forest environments using CLM5 and CLM5-FATES
Evening	Dinner	
February 12th		
10:00-12:00	Short presentations with discussions: Vegetation. Room: Fruen fra havet	
	Peter Horvath	Advancing land surface model representations of high latitude vegetation - a case study for Norway
	Marius Lambert	Representing frost droughts in CLM
	Ane Vollsnes/Stefanie Falk	Introduction of a new plant functional type in CLM/FATES: Arctic Evergreen (dwarf-)shrub
	Eva Lieungh	"Fates_emerald_api" - a FATES modelling platform for ecologists
12:00-13:00	Lunch	
13:00-16:00	Meeting for project leaders. Room: Fruen fra havet	Future developments in CLM at NCAR and in NorESM - Current projects and future possibilities

Appendix B3. EMERALD Annual Meeting 2020 (online)

May 13th		
		Introduction Day 1
10:00	*Frode Stordal*	Welcome and introduction
		Cooperation projects: Achievements, plans and relation to EMERALD
10:20	*Vigdis Vandvik*	Three-D, ExpertTS, INCLINE, RECITE
10:30	*Ryan Bright*	Terra-BGB, IMPRINT, ICOS-Norway
10:38	*Jarle Bjerke*	VANWHITE, ACCE
10:45	*Ane Vollsnes*	Double Punch
10:50	*Frans-Jan Parmentier*	WINTERPROOF
10:55	*Hanna Lee*	HiddenCosts
11:00	*Sebastian Westermann*	Permafrost4Life
11:05	*Casper Christiansen*	Two new projects
11:10	*Norbert Pirk*	Upscaling hotspots
11:15	*Janne Kjønaas*	BalanC
11:20	*Massimo Cassiani*	COMTESSA
11:25	*Lena Tallaksen*	LATICE
		Work Package presentations
11:30	*Olav Skarpaas*	WP1: Status and plans
11:45	*Vigdis Vandvik*	WP2: Status and plans
12:00		Break
13:00	*Hui Tang*	Bridging WP1 and 2: Model platform
13:10	*Terje Berntsen*	WP3: Status and plans
13:20	*Irene Brox Nilsen*	WP4: Status and plans
		Work Package discussions
13:30	*Olav Skarpaas, Vigdis Vandvik, Terje Berntsen, Irene Brox Nilsen*	WP Break out groups
14:00	*Terje Berntsen*	WP3: Report from break out groups, plenary chat discussion
14:15	*Irene Brox Nilsen*	WP4: Report from break out groups, plenary chat discussion
14:30	*Olav Skarpaas*	WP1: Report from break out groups, plenary chat discussion
14:45	*Vigdis Vandvik*	WP2: Report from break out groups, plenary chat discussion
15:00		End Day 1
May 14th		

		Introduction Day 2
10:00	*Frode Stordal*	Introduction
		Cross Cutting Themes (CCTs) presentations
10:10	*Kolbjørn Engeland*	CCT Hydrology: Short presentation of status and plans followed by plenary chat discussion
11:00	*Kjetil Aas*	CCT Tiling: Short presentation of status and plans followed by plenary chat discussion
12:00		Break
13:00	*Ryan Bright*	CCT Albedo: Short presentation of organization of the work
13:10	*Terje Berntsen*	CCT New PFTs: Short presentation of status and plans followed by plenary chat discussion
		Field activities 2020 orientations and questions
14:00	*Vigdis Vandvik*	Planned field activities
14:05	*Jarle Bjerke*	Planned field activities
14:10	*Anders Bryn and Olav Skarpaas*	Planned field activities
14:15	*Hanna Lee and Sebastian Westermann*	Planned field activities
14:20	*Norbert Pirk*	Planned field activities
14:25	*Ane Vollsnes*	Planned field activities
14:30	*Other groups*	Planned field activities
14:40	*All*	Questions for clarification regarding reported field activities
		Closing remarks
14:55	*Frode Stordal*	Closing remarks
15:00		End Day 2

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 Frode Stordal and Lena M Tallaksen at the University of Oslo. The agreement will be updated 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

3. 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.
4. To avoid loss of data all staff and students commit to comprehensive data and metadata documentation by following agreed protocols.
5. 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;
    1. substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data;
    2. drafting the article or revising it critically for important intellectual content; and
    3. final approval of the version to be published.
3. Authors should meet conditions 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.