Center for Modeling of Coupled Subsurface Dynamics

ANNUAL REPORT 2021

UNIVERSITY OF BERGEN
Center for Modeling of Coupled Subsurface Dynamics

VISTA

Contents

Director's comments

The year 2021 has marked the start of the VISTA Center for Modeling of Coupled Subsurface Dynamics (CSD). Having recruited four PhDs and two researchers this year, our center has 27 CSD Team Members at the University of Bergen and NORSAR, of which 10 are PhD students. At the University of Bergen, three departments are involved: the Department of Mathematics, which is host for the center, the Department of Earth Science, and the Department of Physics and Technology. Together, we have put in place a solid multidisciplinary foundation for the center, with 12 ongoing research projects and our common VISTA CSD Researcher Training Program.

In our first year, we have launched our website, put in place our own premises at the University of Bergen, held our kick-off and annual meeting at Bekkjarvik, and not least enjoyed common scientific discussions in our weekly seminars. Several of us participated in the VISTA Researcher Day and the International VISTA Seminar at the Norwegian Academy of Science and Letters. For the VISTA Researcher Day, we enjoyed the interaction with team members from our sister center in Trondheim, VISTA Caros, in discussing science advice. You can read more about the VISTA days on page 18 of this report.

The start of two new affiliated projects this year has led to a substantial growth in planned scientific center activities. The MaPSI project, funded by an ERC Consolidator Grant as well as the UiB strategically funded project CCS-ER both started this fall. With these new projects, we have already achieved more than our target of 50% external center funding.

I would like to thank all CSD members for their contributions to the center in 2021. It is a privilege to direct a center with such colleagues! Despite limitations in our possibilities for in-person meetings and collaboration due to the Covid-19 pandemic, we have managed to start our center activities in the best possible manner and provide the basis for continued fruitful collaboration in the years to come.

Inga Berre

Center Director

About the center

In recent years, the surface manifestations of human fluid injection and production have become increasingly apparent. Production of hydrocarbons and geothermal energy, extraction of groundwater, subsurface energy storage, CO_2 sequestration and wastewater disposal all involve massive subsurface extraction and/or injection of fluids (Figure 1). The Center for Modeling of Coupled Subsurface Dynamics (CSD) will develop basic knowledge on how the subsurface deforms because of fluid injection and production.

CSD's primary objective is to develop fundamental knowledge and educate next generation researchers to understand how subsurface fluid injection and extraction results in deformation, fault reactivation and fracturing. The center targets critical and fundamental research questions through mathematical and numerical modeling and data analysis.

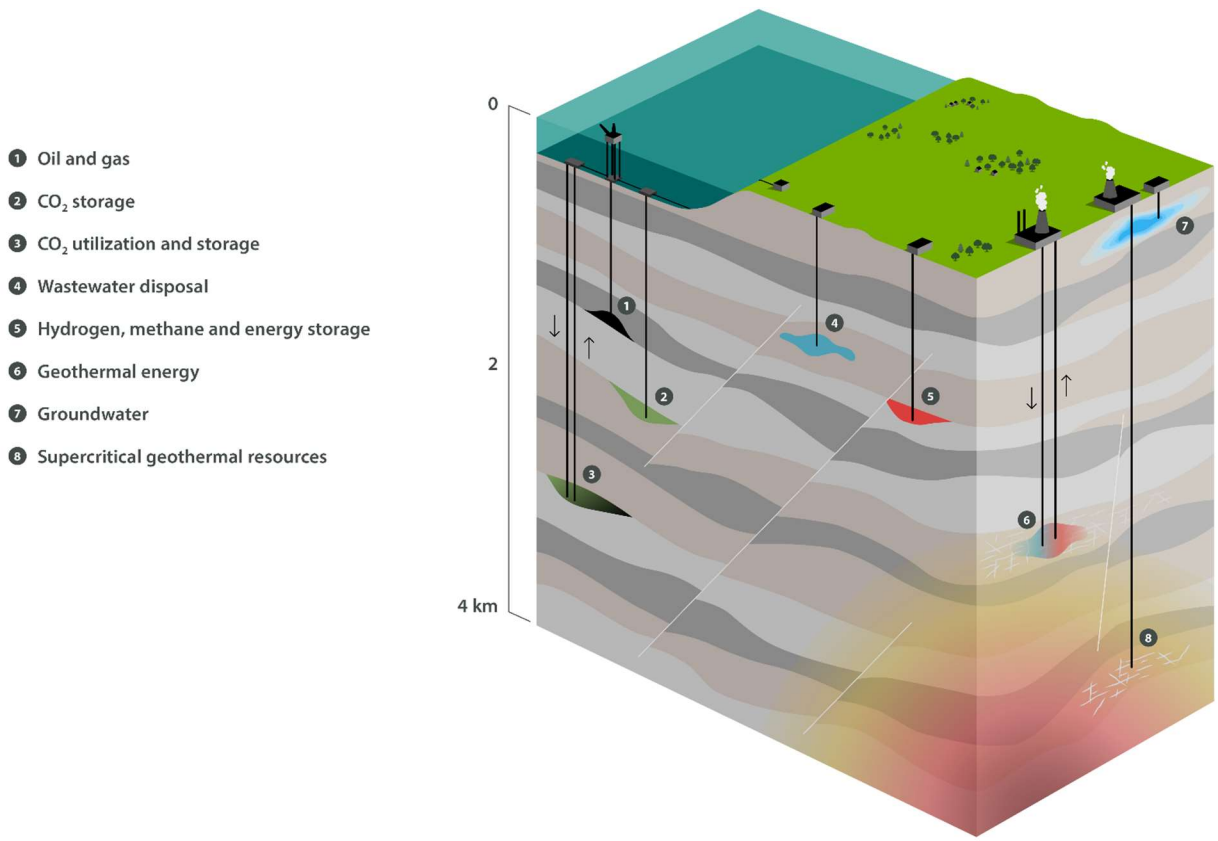


Figure 1. Injection and production of fluid in the subsurface

Organization of the center

The Board is CSD's formal decision body. The Center Director is supported by the Center Management Team (MT) and the Industry Reference Group. The Scientific Advisory Board (SAB) reports to the CSD Board and gives advice to the Center Director. An overview of the organization structure of CSD is provided in the chart below.

The CSD is organized in four pillars, representing the center's main activities. Three pillars (P1-P3) are funded by the VISTA program, two of which focus on research and the third on researcher training to ensure scientific and transferable skills training for PhD, Postdocs and Master students in the center. Affiliated research projects, which are funded through other grants, are structured in a separate pillar (PA).

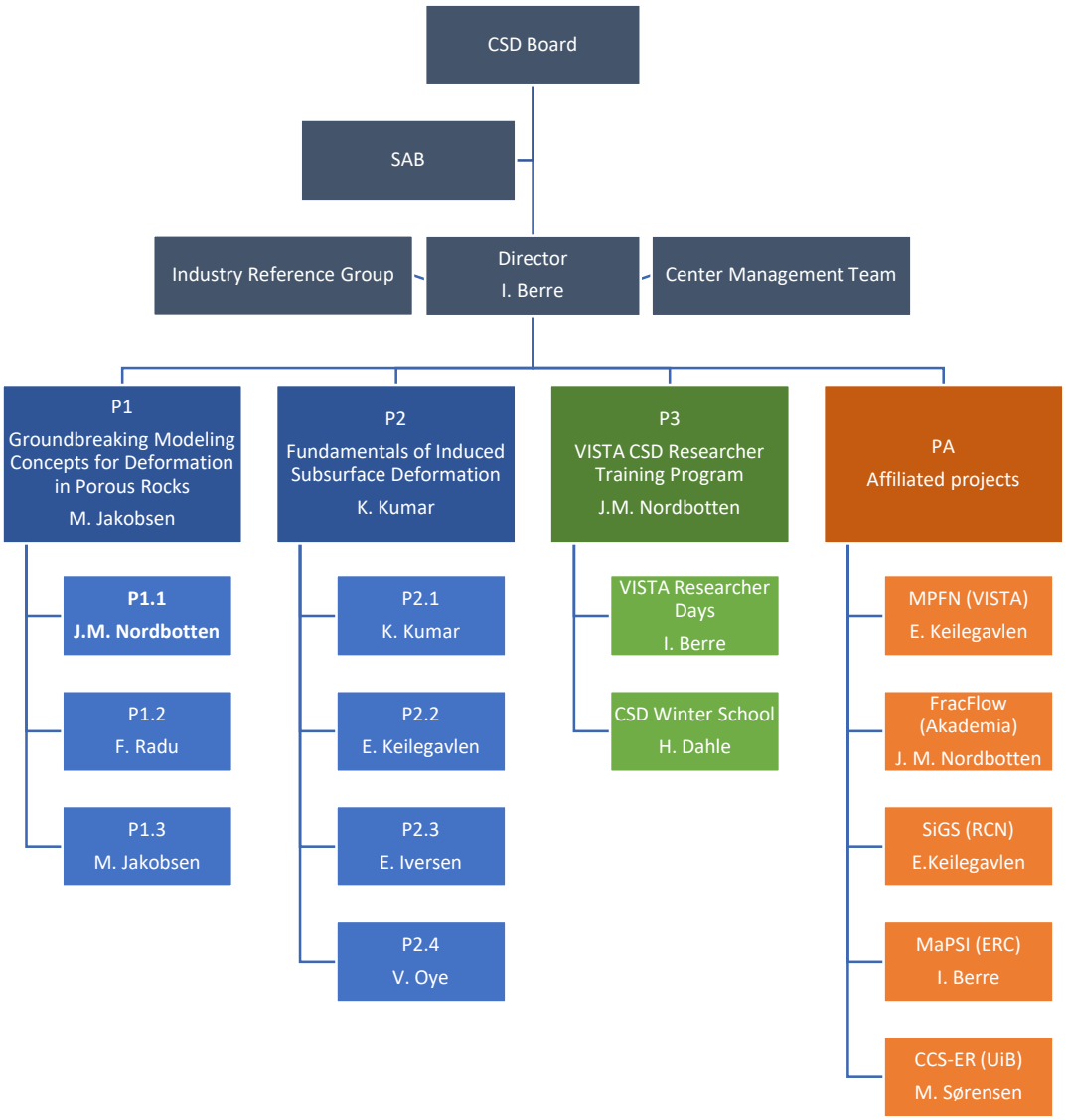


Figure 2. Schematic overview of the center organization structure.

The CSD Board

Kenneth Ruud (Chair) is Director General at The Norwegian Defence Research Establishment (FFI). He has held the position as pro-rector for research and development at the University of Tromsø – The Arctic University of Norway. He is Deputy chair of the Board of the Research Council of Norway and Vice President of The Norwegian Academy of Science and Letters. He holds a position as principal investigator at Hylleraas Centre for Quantum Molecular Sciences.

Anne Marit Blokhus is Professor at the Department of Chemistry, University of Bergen. She has been the Vice Dean of the Faculty of Mathematics and Natural Sciences and Head of Department at the Department of Chemistry, University of Bergen. She is a member of the Norwegian Academy of Technological Sciences.

Unni Olsbye is professor at the Department of Chemistry, University of Oslo. She was the Managing Director of the Center for Research-based Innovation inGAP (Innovative Natural Gas Processes and Products) from 2007-2015. Olsbye is member of the Norwegian Academy of Technological Sciences and the Norwegian Academy of Science and Letters.

Antonella Zanna Munthe-Kaas is Professor and Head of Department at the Department of Mathematics, University of Bergen. She is a member of the Norwegian Academy of Technological Sciences.

Ingunn Thorseth is Professor and Head of the Department of Earth Science, University of Bergen.

Roger Sollie is the Academia Program manager at Equinor. He has for 10 years been Adjunct Professor in Applied mathematical physics at NTNU, and on the board of Simula School of Research and Innovation.

Principal Investigators and Project leaders

Inga Berre is Professor at the Department of Mathematics, University of Bergen, and Center Director. Her main research interests are mathematical modeling, partial differential equations, and numerical methods, in particular motivated by simulation of coupled thermal-hydraulic-mechanical processes in fractured geothermal systems. She also has a strong background in inverse modeling.

Morten Jakobsen is Professor at the Department of Earth Science, University of Bergen. His research interests include rock physics as well as full-waveform inversion and nonlinear inverse scattering. His research is often guided by analogies between different physical phenomena and he is very interested in synergies between seismic imaging and medical ultrasound.

Kundan Kumar is Associate Professor at the Department of Mathematics, University of Bergen. His research interests are in developing upscaled models and computational tools for coupled multiphysics processes such as flow, transport, and deformation in porous media. His work involves development and rigorous analysis of novel numerical algorithms for coupled multiphysics processes in subsurface.

Jan M. Nordbotten is Professor at the Department of Mathematics, University of Bergen. His research interests span both pure and applied mathematics, as well as applications as diverse as geophysical processes, biomedicine, and evolutionary ecology. In particular, he is highly recognized for his research on CO_2-storage.

Florin A. Radu is Professor at the Department of Mathematics, University of Bergen. He has a long-term experience with discretization methods and solvers for partial differential equations with applications in flow and reactive transport in deformable porous media. In particular, he has expertise in the design and analysis of robust and efficient solvers for non-linear, coupled equations.

Einar Iversen is Professor at the Department of Earth Science, University of Bergen. His main research interests are seismic ray and wave theory, seismic imaging, and determination of subsurface models. He has specialized in the topics ray theory for anisotropic media and computer representation of subsurface models and wavefields.

Eirik Keilegavlen is a Senior Researcher at the Department of Mathematics, University of Bergen. He works on development of simulation technology for multi-physics processes in fractured porous media. His research expertise includes process couplings, discretization methods and linear and non-linear solvers. Keilegavlen is the initiator and lead developer of the open-source research code 'PorePy', which specifically targets fractured media.

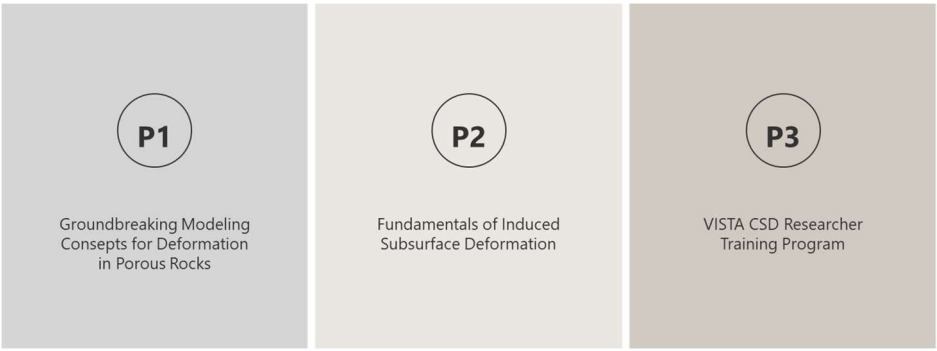
Volker Oye is Head of the Applied Seismology Department at NORSAR and Associate Professor at University of Oslo. Oye has worked with induced seismicity projects within oil and gas (offshore and onshore), CO_2 storage monitoring, mining, tectonic microseismicity, and instable rock slopes. His interests are within seismic source parameters, earthquake scaling relations, earthquake location studies and the discrimination between natural and induced earthquakes.

Mathilde Sørensen is Professor at the Department of Earth Science, University of Bergen. With a background in earthquake seismology, her research interest spans a wide range of geohazards studies. In particular, her work has focused on earthquake studies, seismic and tsunami hazard analyses, as well as studies of earthquake-induced landslides.

Helge K. Dahle is Professor at the Department of Mathematics, University of Bergen. He has his expertise in mathematical and numerical modeling of flow and transport in porous media. He has worked on up-scaling from pore- to continuum scale and further to the field-scale and has made important contributions to the understanding of Lagrangian-type schemes for non-linear advection-dominated transport.

Center Management Team

The center management team consists of Prof. Inga Berre (Center Director), Prof. Morten Jakobsen (P1 Coordinator), Assoc. Prof. Kundan Kumar (P2 Coordinator) and Prof. Jan Martin Nordbotten (P3 Coordinator).



CSD Pillars for Research and Researcher Training

VISTA Projects

P1 Groundbreaking Modeling Concepts for Deformation in Porous Rocks

P1.1: Mathematical framework for handling complex geometries

Duration	2021-2025
PI	Jan M. Nordbotten
Team	Jon Eivind Vatne, Einar Iversen
Description	This project aims at closing the gap between theoretical developments and efficient computational tools by reducing the model and discretization complexity of complex fault and fracture networks. Modern geological descriptions include ever more complex geometric features, as the fidelity of reservoirs, faults, facies and wells increase. This has led to a dramatic increase in numerical complexity, due to the model and grid representations used. The correct mathematical framework for handling complex geometries is that of manifolds. Our recent work on fractured porous media has shown that adopting state-of-the-art knowledge from pure mathematics, including differential forms on manifolds and mixed-dimensional operators, leads to both more robust and more efficient physical models and computational methods.
Activities 2021	The work on the mathematical formulation of the coupling between wells and fractures was initiated.

P1.2: Simulation tool for fully dynamic Biot equations

Duration	2021-2025
PI	Florin A. Radu
Team	Morten Jakobsen, Kundan Kumar
Description	The project's goal is to develop an advanced, energy-preserving numerical model and simulation tool for the fully dynamic Biot equations. Development of efficient solvers for flow in deformable porous media, described by the linear, quasi-static Biot model has received huge attention in the last decade. To include seismicity, the fully dynamic, non-linear Biot-Allard model must be considered, i.e. the acceleration of the porous medium and the process history have to be included. In this activity, higher-order space-time finite element, splitting solvers, which are energy preserving (a very important feature for waves), will be designed, implemented and analyzed based on our previous work. The resulting model will be tested and calibrated based on geophysical methods.
Activities 2021	A study of the convergence of higher order Galerkin schemes (space -time elements) for a simplified version of the dynamic Biot model has been performed.

P1.3: Microseismic imaging using rock physics-based full-waveform inversion

Duration	2021-2025
PI	Morten Jakobsen
Team	Einar Iversen, Inga Berre, Florin A. Radu, Ujjwal Shekhar
Description	Microseismic imaging includes localization of microseismic events and characterization of their source mechanisms. The accuracy of the source localization is highly dependent on the (anisotropic) velocity model. The main goal is to develop accurate methodology for microseismic imaging based on full-waveform inversion. A further aim is to investigate the use of rock physics in this context. Synergies between active and passive seismic FWI approaches based on fast integral equation formulations suitable for large 2D and 3D models will be important.
Activities 2021	The focus in 2021 has been on modeling of the seismic wavefield in acoustic media and inversion for the source parameter using integral equation methods. The fast algorithm for discrete Fourier transform and its inverse has been investigated to accelerate the iterative solution of integral equations.

P2 Fundamentals of Induced Subsurface Deformation

P2.1: Solvers for mixed dimensional flow and mechanics on the fracture-matrix interface

Duration	2021-2025
PI	Kundan Kumar
Team	Inga Berre, Ivar Stefansson, Nadia S. Taki, Jan M. Nordbotten
Description	The goal is to develop mathematical model and solution approaches to rupture dynamics including advanced friction laws in the presence of fluids. The project will consider the evolution of spontaneous ruptures embedded in an elastic deforming body, governed by contact mechanics (rate-and-state friction laws). The particularity in the description is accounting for the fluid flow. The resulting model is based on coupled differential equations of different dimensions: Biot-Allard in the matrix coupled to flow (on 3D) on the fracture surface as well as friction laws on the fracture interfaces (2D surface embedded in 3D domain). We will propose a novel scheme that exploits the different time scales for the rate- and state-dependent friction laws, the mechanics and the flow. Numerical schemes based on splitting of multiphysics will be developed and analyzed to ensure convergent and efficient solution schemes.
Activities 2021	The development of a large strain model that includes the contact mechanics has commenced.

P2.2: Simulation technology for injection-related fault and fracture reactivation and induced seismicity

Duration	2021-2025
PI	Eirik Keilegavlen
Team	Inga Berre, Einar Iversen, Volker Oye, Ivar Stefansson
Description	The project aims to develop simulation technology for injection-induced fault reactivation, accounting for seismic and aseismic slips, as well as slip-induced permeability enhancement. The methodology will be based on the open-source simulation tool 'PorePy', which is built on explicit representation of faults, and includes thermo-hydro-mechanical effects. The main research task will be to expand and adapt the framework to account for advanced fracture behavior including permeability increases and friction laws, and to adapt discretizations and linear and non-linear solvers to facilitate efficient simulations. Tests will span from simple cases to problems from the field.
Activities 2021	Work started on a validation study using data from a mesoscale in situ experiment using the existing model. During this work, the model was extended to account for non-linear elastic normal deformation, i.e., fracture volume changes due to variations in normal contact traction.

P2.3: Exploring the subsurface using a generalization of Dix' classic time-to-depth mapping method

Duration	2021-2025
PI	Einar Iversen
Team members	Inga Berre, Morten Jacobsen
Description	The goal of the project is to utilize the generalized Dix method to explore and monitor changes in the subsurface. The generalized Dix method is based on Dix' classic method for velocity estimation and time-to-depth mapping. Whereas the classic approach assumed a one-dimensional subsurface, the generalized Dix method is applicable to variations of velocity in three dimensions. The subsurface structures are assumed to yield weak lateral velocity variations and weak effective anisotropy. The generalized Dix Method has the key advantage that it can be applied locally, in the vicinity of some reference ray. The latter has historically been referred to as the *image ray*, because it provides a connection between seismic images of the subsurface represented in time coordinates and in-depth coordinates. The first task of the project is to develop a new reconstruction approach (relative to the one proposed originally in 2014-2015), where one combines differential geometry with numerical analysis. Second, a Deep Neural Network architecture will be designed to replace this reconstruction, and a generalization estimate will be established. Combining different subsurface locations will be accomplished using a Graph Neural Network, and modeling will provide training data. Third, dynamics in the Dix data will be directly studied using a Recurrent Neural Network architecture.
Activities 2021	In 2021 the project has had internal activities to prepare this subproject for startup in 2022.

P2.4: Interpretation of fluid-induced seismicity patterns

Duration	2021-2025
PI	Volker Oye
Team	Inga Berre, Eirik Keilegavlen, Joern Kaven
Description	The project goal is to understand the spatial and temporal evolution of earthquake clusters as a response to long-term fluid injection in different environments. Full waveform cross-correlation methods will be used to precisely relocate the observed microseismicity and classify and characterize individual events. Investigation of the rupture dimensions and stress drops of the microseismic events will better relate their causality to the injected fluids and their volumes and rates of injection. The work can also be linked to activities within P2.2.
Activities 2021	The research team has identified the most relevant case study and more specific research goals. The study region will be the Coso geothermal site in Southern California, where a significant amount of clustered seismicity is occurring as a response to both geothermal operations and natural processes.

Affiliated Projects

Multi-phase flow in fracture networks

Duration	2019-2022
Funding	VISTA individual fellowship grant
PI	Eirik Keilegavlen
CSD Team	Adrian Florin Radu, Jan M. Nordbotten, Jhabriel Varela
Description	Development of mathematical models and numerical methods for multiphase fracture flow coupled with fracture deformation.
Activities 2021	Modeling work relating to Richards' equation for fractures has started. Separately, work on a posteriori error estimates for approximations to flow in fracture networks was conducted.

FracFlow

Duration	2020-2023
Funding	UiB-Equinor Akademia Grant
PI	Jan Martin Nordbotten
CSD Team	Martin Fernø, Bergit Brattekås, Jakub Wiktor Both, Eirik Keilegavlen
Description	The FracFlow project has the main objective to develop a fundamental understanding for multiphase flow in fractured porous media using interdisciplinary research. Mathematical modeling and complementary lab experiments are utilized to ultimately provide both accurate models and efficient simulation capabilities for multiphase flow in fractured porous media.
Activities 2021	Artificial fracture networks have been constructed by cutting sand-stone samples. These have been subjected to flow experiments in the PET/CT scanners at Haukeland Hospital.

Simulation of governing processes in superheated and supercritical geothermal systems: mathematical models, numerical methods and field data (SiGS)

Duration	2020-2024
Funding	Research Council of Norway Grant
PI	Eirik Keilegavlen
CSD Team	Shin Irgens Banshoya, Inga Berre, Sæunn Halldorsdottir
Description	The objective of this project is to combine simulation and field data analysis for thermal, hydraulic, mechanical and chemical (THMC) processes in supercritical geothermal reservoirs. SiGS targets improved understanding of processes that are key to unlocking near-magma geothermal resources. The project focuses on two mechanisms that are critical to understand superheated and supercritical geothermal systems: Heat transport from deep heat sources towards the geothermal reservoir and thermal stimulation caused by the introduction of cold fluids during drilling or reinjection. To study the mechanisms, the project combines advanced mathematical modeling and simulation with analysis of data from Icelandic geothermal fields.
Activities 2021	The development continued of simulation tools for coupled flow and geochemistry in fractured porous media. The project also started simulation studies of fracture propagation towards deep roots of geothermal systems.
Publications 2021	Numerical model of convection-driven cooling, deformation and fracturing of thermo-poroelastic media (Stefansson et al., 2021).

Quantifying the relation between Carbon Capture and Storage and earthquake risk (CCS-ER)

Duration	2021-2025
Funding	UiB strategic funds within the focus area “Climate and energy transition”
PI	Mathilde B. Sørensen
CSD Team	Maren K. Karlsen, Lars Ottemöller, Corbett Grainger
Description	The goal is to develop a better model of how CO_2 storage may affect seismic hazard in Norway and vice versa, as well as a better understanding of the environmental and economic implications of such changes. This project aims to quantify the relation between CCS and seismic hazard and risk, the likelihood of earthquakes, and the risk of these earthquakes causing damage. The project will include a field example, evaluating the hazard and risk for a planned storage site at the Horda platform, off the coast of western Norway. A thorough hazard and risk analysis will help inform industry and policy makers when making decisions towards the UN climate goals, as well as the strategic focus of the Norwegian government on CCS as a future industry.
Activities 2021	The project started in October 2021. The work has focused on developing a project plan for the associated PhD project.

Mathematical and Numerical Modelling of Process-Structure Interaction in Fractured Geothermal Systems (MaPSI)

Duration	2021-2026
Funding	ERC Consolidator Grant
PI	Inga Berre
CSD Team	Jan Martin Nordbotten, Adrian Florin Radu, Eirik Keilegavlen, Jakub Wiktor Both, Omar Yesid Duran Triana, Hau Trung Dang, Veljko Lipovac, Ivar Stefansson
Description	MaPSI has as its main objective to provide mathematical models and simulation technology required to assess subsurface process-structure interaction in the context of hydraulic and thermal stimulation in development and production of high-temperature geothermal resources. In the development and production of high-temperature geothermal resources, large, induced gradients in pressure and temperature during injection operations result in complex dynamics. This includes flow and boiling of geothermal fluids combined with deformation of the fractured rock. This coupled process-structure interaction is currently not well understood and provides a core motivation as well as challenging test cases for the mathematical and numerical developments in the MaPSI project.
Activities 2021	The work has focused on developing mathematical and numerical models for multiphase flow of water and steam in geothermal systems as well as fracture deformation and propagation as a consequence of low-pressure stimulation.

International and intersectoral collaboration

Central in CSD research are the center's partners who are all connected through various research projects. With two national and twelve international research partners and seven international industry partners within oil and gas, CO_2-storage, groundwater and geothermal energy the CSD international network extends beyond Norway to the US and Europe.

VISTA CSD Partners

VISTA CSD Research Partners

Prof. Barbara Wohlmuth, TU Munich
Research interests: partial differential equations, discretization methods, multiscale solution methods, coupled multiphysics problems and predictive modeling.

Prof. Hamdi Tchelepi, Stanford University/UiB
Research interests: design of scalable numerical reservoir simulators, modeling unstable fluid flow in heterogeneous porous media, multiscale formulations for coupled multiphase flow and geomechanics, and uncertainty quantification of model predictions of subsurface nonlinear flow dynamics.

Prof. Markus Bause, Helmut Schmidt University
Research interests: applied mathematics, analysis of PDEs.

Prof. Thomas Driesner, ETH Zürich
Research interests: geochemistry, earth systems modeling.

Prof. Rainer Helmig, Prof. Bernd Flemisch, University of Stuttgart
Research interests: hydrology, simulation sciences.

Prof. Maarten V. de Hoop, Rice University
Research interests: theoretical and computational seismology.

Prof. Ruben Juanes, Massachusetts Institute of Technology
Research interests: multiphase flow in porous media, energy resources, CO_2 sequestration.

Dr. Joern Kaven, United States Geological Survey
Research interests: geophysics, microseismicity.

Assoc. Prof. Eric Verschuur, TU Delft, Program Director Delphi research consortium
Research interests: geophysics, seismics.

Dr. Ivan Psencik, Czech Academy of Sciences and SW3D consortium
Research interests: geophysics.

Dr. Gunnar Thorgillsson, Icelandic GeoSurvey (ISOR)
Research interests: reservoir physics, geothermal engineering.

Assoc. Prof. Denis Voskov, Assoc. Prof Hadi Hajibeygi, TU Delft
Research interests: reservoir simulation/code development.

Assoc. Prof. Xiaozhe Hu, Tufts University
Research interests: scientific computing.

Prof. Mary Wheeler, University of Texas at Austin
Research interests: numerical analysis, reservoir engineering.

Assoc. Prof. Jon Eivind Vatne, Western Norway University of Applied Sciences
Research interests: geometry, algebra.

Industrial partners

Equinor funds the VISTA program and is involved in a range of operations where fundamental understanding of how subsurface fluid injection and extraction is connected to deformation, fault reactivation and fracturing is important. Equinor has active collaboration with CSD on the SiGS project.

Wintershall Dea is an international petroleum company sponsoring the UiB Prof. II professorship of R. Helmig.

Zweckverband Landeswasserversorgung is a bulk water supply company for 3 million inhabitants in the German state Baden-Wurttemberg.

Seismik is a privately held company providing seismic services for oil and gas, geothermal, nuclear and CO_2 sequestration industry with focus on passive seismicity.

HS Orka operates two high-temperature geothermal plants in SW Iceland and has drilled the IDDP2, a 4650 m deep supercritical well. HS Orka has active collaboration with CSD on the SiGS project.

Landsvirkjun operates two high-temperature geothermal plants in NE Iceland, where electricity is generated. Landsvirkjun drilled the IDDP1 well, reaching magma at 2100 m depth, in Krafla 2009.

Reykjavik Energy operates two co-generative high-temperature geothermal plants at Hengill and will provide the center with important scientific insight on the nature of hydrogeological resources and provide valuable datasets.

VISTA CSD Researcher Training Program

The VISTA CSD Researcher Training Program[1] includes all PhD students affiliated with the center, also those who are employed based on other external and internal funding. The program is focused on transversal skills as well as interdisciplinary technical skills. In 2021, the VISTA Researcher Day has been a central activity of the training program (organized in collaboration with VISTA DNVA, VISTA CSD and VISTA CAROS) as well as the CSD Annual Meeting and Kick-off. The weekly CSD seminar has also been central to the training program.

VISTA Days 2021

By VELJKO LIPOVAC, 3 December 2021,
https://www.uib.no/en/vista-csd

At the 2021 VISTA Researcher Day, the VISTA centers CSD and CAROS (NTNU) were hosted by The Norwegian Academy of Science and Letters to discuss scientific advice as a response to crisis and critical events, but also as a strategic component for policy in preparation for the future. The current pandemic situation served as a model problem on how science-policy advice not only has to be composed, but also communicated. Young researchers and PhD students who participated got the opportunity to reflect on the many-faceted situation and the consequences of advice given under uncertainty of data, guided by the directors of both research centres, Prof. Inga Berre (CSD) and Prof. Asgeir J. Sørensen (CAROS). The topic cumulated into a talk by Director-General of the Norwegian Institute of Public Health Dr. Camilla Stoltenberg, the keynote speaker for this event. She shared her experiences and strategies on how the institute acquired, analysed and formed data into advice for policy makers under the aspect of uncertainty.

The participants were also confronted with the topic of subsea floor utilization. Mining efforts to feed the world's need for rare earth metals and minerals, as well as carbon storage are the main drivers for these considerations, which are going to pose major challenges for the international society in the near future. To limit human impact on the environment, the aforementioned aspirations have to be carried out under equivalent ecological and moral standards. Under the guidance of the CSD and CAROS directors, as well as VISTA board chair Dr. Ole Sejersted and DNVA representative Prof. Anders Elverhøi, the participants drew parallels and presented critical questions.

On November 17th, the International VISTA Seminar took place, for which The Norwegian Academy of Science and Letters gathered a round of European experts involved with subsea research, including disciplines ranging from climate research over microbiology to geodetic mapping. The broad audience and group of talks enabled the participants to illuminate the topic of subsea floor processes and a sustainable ocean from multiple angles, discuss the options of immediate industrial exploitation, research prioritization or a moratorium on subsea mining, and to get an overview on opinions of different stakeholders and parties involved.

Left: Camilla Stoltenberg. Right: Asgeir Sørensen (CAROS) and Inga Berre (CSD) instructing one of the working groups. Photo: Ola Gamst Sæther / DNVA

[1]CSD Training Program, https://www.uib.no/en/vista-csd/145109/researcher-training-program

CSD Annual Meeting

19-20 October 2021, 20 VISTA CSD team members assembled in Bekkjarvik to discuss the research plans and progress of research activities under CSD. This included an interactive session with presentation for each project. Emphasis was given to discussion of project plans for new PhDs in the center. Apart from scientific discussions, there were socializing events allowing the participants to become acquainted with each other.

Figure 5. Participants at the CSD annual meeting 2021

Day 1 – 19th of October, Research pillar P2: Fundamentals of Induced Subsurface Deformation

Time	Activity/Topic	Speaker	Chair
09:30-10:00	Introduction	Inga Berre	
10:00-10:45	Fracturing of Porous Media in the presence of multiphase flow	Jhabriel Varela	Inga Berre
10:45-11:15	Coffee break and Snack		
11:15-12:00	Simulation of governing processes in superheated and supercritical geothermal systems: mathematical models, numerical methods and field data (SiGS)	Eirik Keilegavlen	Veljko Lipovac
12:00-13:00	Lunch		
13:00-14:00	Walk & Talk		
14:00-14:45	Simulation technology for injection-related fault and fracture reactivation and induced seismicity	Ivar Stefansson	Ujjwal Shekhar
14:45-15:30	Solvers for mixed dimensional flow and mechanics on the fracture-matrix interface	Nadia Skoglund Taki	Ujjwal Shekhar
15:30-16:00	Coffee break & Snacks		
16:00-16:45	Monitoring subsurface processes using the generalized Dix' method	Einar Iversen	Veljko Lipovac
16:45-19:00	Leisure time		
19:00-20:00	Dinner		
20:00-	Board Games		

Day 2 – 20th of October, Research pillar P1: Groundbreaking Modelling Concepts for Deformation in Porous Rocks

Time	**Activity/Topic**	**Speaker**	**Chair**
07:30-08:30	Breakfast		
08:30-09:15	FracFlow, PoroTwin, FluidFlower	Jakub Both	Kundan Kumar
09:15-10:15	Training program discussion	Jan Martin Nordbotten	Kundan Kumar
10:15-10:40	Coffee break & Snacks		
10:40-11:20	Microseismic imaging using rock physics-based full-waveform inversion	Ujjwal Shekhar	Morten Jakobsen
11:20-12:00	Simulation tool for fully dynamics Biot equations	Florin Adrian Radu	Morten Jakobsen
12:00-13:00	Lunch		
13:00-14:00	Walk & Talk		
14:00-14:45	Mathematical and Numerical Modelling of Process-Structure Interaction in Fractured Geothermal Systems (MaPSI)	Veljko Lipovac	Nadia Skoglund Taki
14:45-15:15	Coffee break & Snacks		
15:15-16:00	Mathematical framework for handling complex geometries	Jan Martin Nordbotten	Maren Kjos Karlsen
16:00-16:10	Concluding words	Inga Berre	
16:10-17:30	Packing, Dinner and Departure		

CSD Seminar

To promote the sharing of scientific knowledge and research results, CSD organizes weekly seminars. Lectures were given at UiB and via Zoom, on Fridays at 1PM (CET). During 2021, 30 seminars were held, 14 of which were given by external collaborators or visitors.

Honors and awards

At the 2020+1 ECCOMAS Virtual Congress and 14th WCCM, 11-15 January 2021, CSD researcher Jakub Both was one of 18 theses selected for the finals in the ECCOMAS PhD award for the best PhD thesis in 2019. His thesis “Mathematical and Numerical Analysis of Flow in Deformable Porous Media" was nominated by the Nordic Association for Computational Mechanics. He eventually won the ECCOMAS PhD Olympiad at the WCCM-ECCOMAS 2020 congress for the best presentation amongst the finalists.

Center director Inga Berre was this year featured as the 10,000th ERC grantee[2]. Over 1,000 participants watched the live ceremony in May with European Commission President Ursula von der Leyen and European Parliament President David Sassoli. Many more watched the recording[3], with grantees and host institutions sharing their stories on social media around the world. Berre was announced as the 10 000th grantee by European Commissioner for Innovation, Research, Culture, Education and Youth Mariya Gabriel.

Outreach

The CSD webpages[4] were launched at the start of the year and provides general information on the center as well as regular news updates. CSD also has an active Twitter account @csd_uib with more than 100 followers.

Related to the celebration of Inga Berre as the 10,000th ERC grantee, several news articles on the MaPSI project were published in national and international media.

Journal Publications 2021

Stefansson, I., Keilegavlen, E., Halldórsdóttir, S. and Berre, I. (2021). Numerical Modelling of Convection-Driven Cooling, Deformation and Fracturing of Thermo-Poroelastic Media. Transp Porous Med 140, 371–394. https://doi.org/10.1007/s11242-021-01676-1

[2]European Research Council Funds 10 000th Researcher; https://erc.europa.eu/news/10000grantees
[3]Celebrating 10 000 Grantees, https://www.youtube.com/watch?v=iszgm08JQdo&t=2509s
[4]Center for Modeling of Coupled Subsurface Dynamics; https://www.uib.no/en/vista-csd