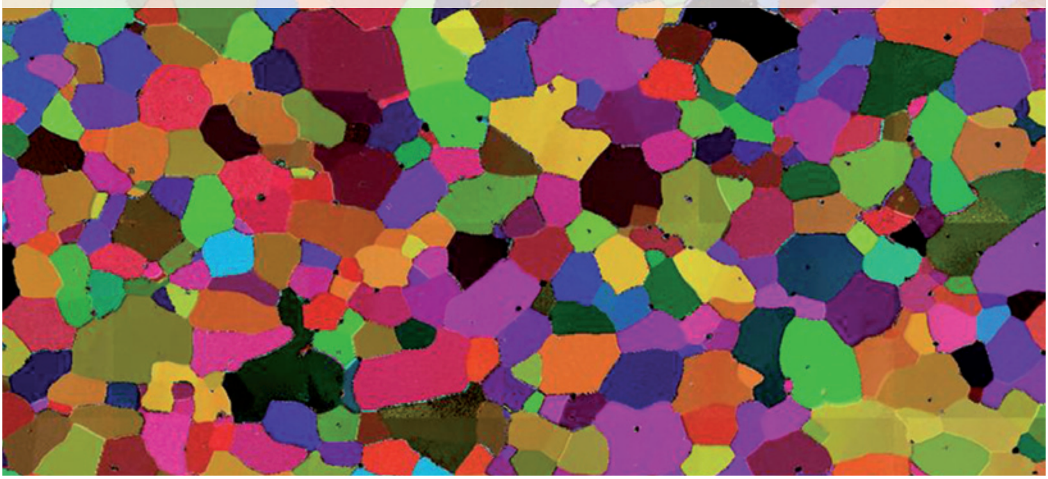
EUROPEAN SCIENCE FOUNDATION

Research Networking Programme

Micro-Dynamics of ICE (Micro-DICE)

Standing Committee for Life, Earth and Environmental Sciences (LESC)



Understanding the dynamic behaviour of ice in glaciers, polar ice caps and sea ice is a major challenge, especially in a time of changing climate. The grain and sub-grain scale microstructure are crucial state variables that link atomic-scale processes to the macroscopic behaviour of ice, including its rheology and transport properties. Improved analysis, modelling and interpretation of ice microstructures are therefore imperative for a better understanding of the flow and evolution of large ice bodies, from polar ice caps, mountain glaciers, sea ice to planetary ice. In addition, linking microstructures to geophysical signals such as radar imaging and seismic profiling will enable mapping of microstructures in 3 and 4 dimensions. This interdisciplinary research network will bring together the main European researchers in the field, as well as those in related fields, such as metallurgy and geology, where ice is now well recognised as a model material. A series of networking activities is planned with the aim of integrating the research efforts of individual groups within Europe and improving the exchange of new ideas and methods.

Improved training and mobility of young researchers will be achieved through a series of workshops, short courses and a summer school, publication of a textbook on ice microstructures, as well as travel grants to visit other research groups and analytical facilities. A research conference at the start of the Programme aims to highlight the major questions and challenges that the research community faces, while a second conference at the end of the funding period will serve to present the achievements of the Programme activities. Web-based initiatives include the Atlas of Ice Microstructures (AIM), which will allow public access to very-high resolution images of ice microstructures from deep ice cores and laboratory experiments. The Micro-DICE website (www.microdice.eu) will be a major resource for research and teaching with a lifetime well beyond that of the Programme.

The running period of the ESF Micro-DICE Research Networking Programme is five years, from May 2010 to May 2015.

The Importance of Microstructure

Ice is one of the most common minerals found on the surface of the Earth. With global warming becoming generally accepted by the general public and governments, research into ice has gained increasing importance. The relevance of ice to society is manifold: changes in the flow behaviour of polar ice caps directly influence sea level and climate; glaciers and ice caps store a large proportion of the global fresh-water budget; polar ice and mountain glaciers contain a unique paleo-climate record, reaching back at least 800 000 years; and traces of extra-terrestrial life, for example on Mars, may potentially be found in ice. Ice research has therefore seen a significant expansion in recent decades. The European community has been strongly involved, with the ESF-supported European Project for Ice Coring in the Antarctica (EPICA) that provided coordination for drilling activities at Concordia and Kohnen Stations. Thanks to these successful deep coring projects, a large amount of data is now available in the field of paleoclimatic studies. The Micro-Dynamics of ICE (Micro-DICE) Research Networking Programme will provide a significantly improved theoretical framework for the analysis and modelling of the microstructure evolution as observed along these drill cores.

The importance of microstructure dynamics

The knowledge of ice crystal properties is central to our understanding of ice dynamics. Natural ice occurs as polycrystalline aggregates in which the bulk behaviour is the result of the behaviour of

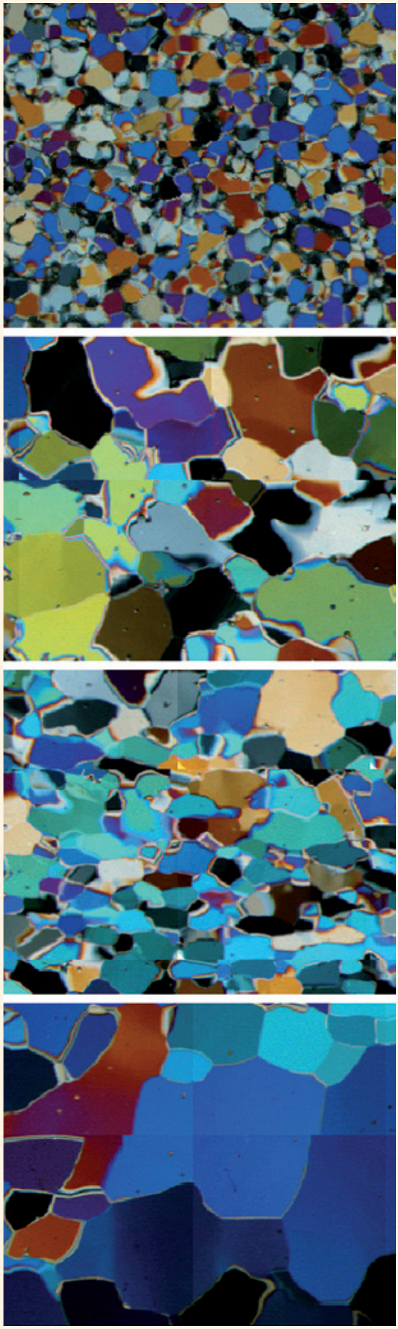


Figure 1. Ice microstructures from the EDML drill core, taken (from top to bottom) at 54.1, 554.4, 1053.1 and 2035.0 m. Width of view 2 mm.
Images by Ilka Weikusat (AWI, Bremerhaven, Germany)

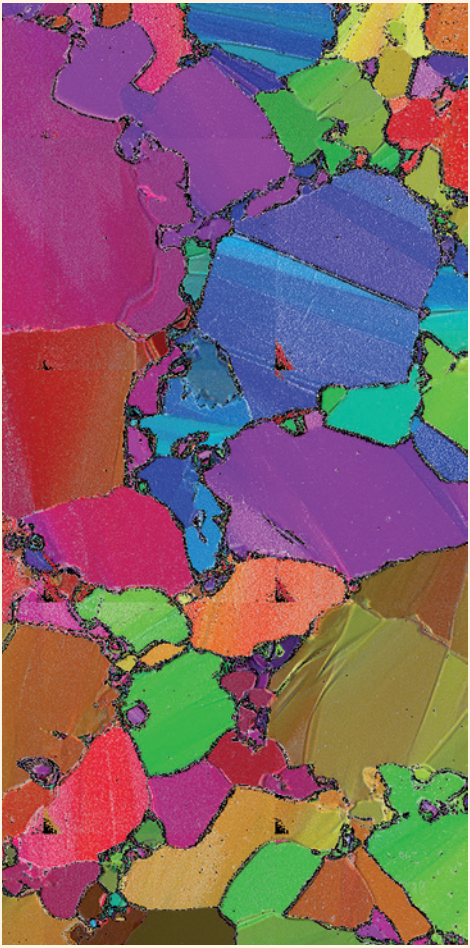


Figure 2. Ice microstructure after creep test in the laboratory.
Image by Maurine Montagnat (LGGE, Grenoble, France)

the ensemble of individual grains. It is thus dependent on the microstructure, here used to describe the whole arrangement of grains (size, shape, shape- and lattice orientations, also referred to as fabrics), their internal substructure (dislocation density, sub-grains), impurities and second phases (bubbles in firn, clathrates, dissolved impurities). The microstructure is a constantly changing and evolving, *dynamic* entity. Important processes that change the microstructure are deformation, grain growth (driven by surface-energy reduction) and (discontinuous) dynamic or post-dynamic recrystallisation (driven by strain energy).

Recrystallisation is of particular interest to materials engineers since recrystallisation dramatically changes the properties of a material, notably the mechanical properties such as strength, ductility and anisotropy. Recrystallisation is therefore intentionally used in engineering to optimise materials properties of steels and non-ferrous alloys. The interplay of forming strain, temperature and time generates a wide spectrum of different microstructures that are associated with different mechanical properties. Metals, rocks and ice – all polycrystalline aggregates – show remarkable similarities in their recrystallisation behaviour. In this respect, hot rolling of a steel sheet, the formation of a mountain belt and the flow of a glacier are therefore highly comparable processes, despite the differences in length and time scale, and the material-specific properties of the individual polycrystals. Ice-specific complications arise, for example in sea ice, where a second, saline, phase may interact with the polycrystal and significantly modify its microstructure, and hence mechanical behaviour.

Despite much research (*e.g.* analyses of drill cores, lab experiments, numerical modelling) into the evolution of microstructure and its effect on the behaviour of ice, much remains unknown. Although computing resources now allow a much better consideration of ice rheology and strain-induced anisotropy within flow laws of 2D and 3D ice sheet modelling, efforts are still necessary to understand the exact impact of microstructure

Aim

(in terms of fabrics and grain size) and its evolution on flow behaviour.

Considering that the microstructure is one of the primary state variables in determining the bulk behaviour of a material, investigations into ice are being undertaken by various groups across Europe. However, significant advances could be gained thanks to improved European-wide interaction between the different research groups working on materials microstructures, and between these groups and other scientific communities (geophysics, climatology, etc.).

The aim of Micro-DICE is to advance our knowledge of the dynamic behaviour of ice, based on the idea that:

- The predictive value of small- and large-scale models of ice behaviour under changing conditions relies on a correct description of ice properties and their evolution;
- Grain-scale processes (microstructure) strongly influence the properties of ice; and
- hence, better understanding of dynamic grain-scale processes in ice is needed.

For this, it is necessary to bundle and open up resources and expertise across Europe.

Bundle expertise beyond the 'ice community'

Many research communities struggle with the same problems and questions: improving the material for high performance turbine blades, predicting the flow of

Figure 3. Drilling in an ice waterfall to study the link between the microstructural evolution and the mechanical stability of these ephemeral structures.
Image courtesy of D. Richalet (France)

perovskite in the lower mantle of the Earth, or forecasting the future flow rate of polar ice caps all hinge on one question: *what is the role of the microstructure?* This Micro-DICE Research Networking Programme responds to the urgent need to bring together researchers from different communities to bundle and exchange the expertise they can offer each other.

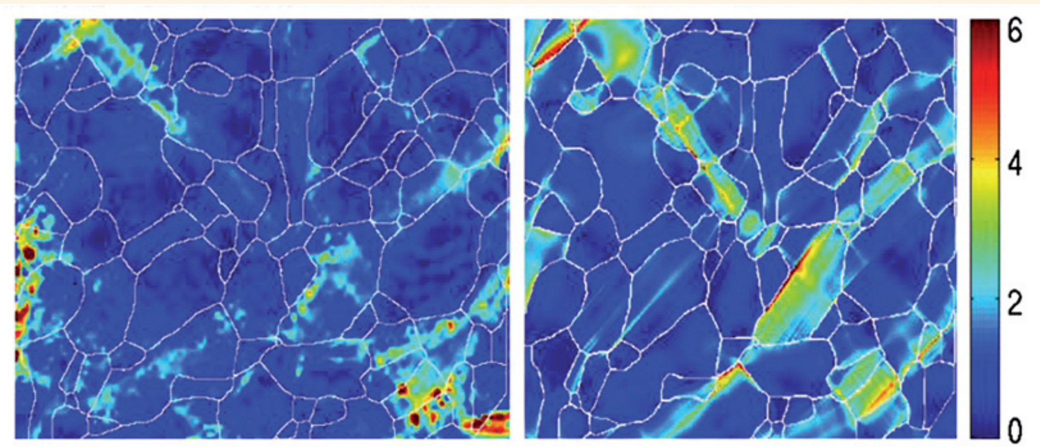
Bundle resources

Recent progress in this research field strongly relies on new experimental and analysis techniques (electron backscatter diffraction, synchrotron, microstructure mapping, digital image correlation) and improved numerical models (from dislocation dynamics to 3D ice sheet modelling). The increasing complexity (and cost) of these methods often outstretch the capability of individual research groups. Micro-DICE intends to bring together research groups to bundle resources and methods and develop new ones.

Open up resources

International and national research agencies have funded a vast range of new experimental and analytical facilities. Although some are available to all researchers (*e.g.* ESRF), access to facilities is all too often hampered by a lack of knowledge of the rapidly increasing number and complexity of techniques. Through short or exchange visits, training workshops and a summer school, Micro-DICE will increase the awareness of young researchers in particular, to the possibilities available to them.

Figure 4. Comparison between strain field measured by Digital Image Correlation technique on 2D ice creep test (left), with simulated strain-rate field obtained by a full-field micro-macro approach (FFT, Ricardo Lebensohn, LANL, Los Alamos, USA, right). This work was performed by F. Grennerat, LGGE, Grenoble, France



Activities

To achieve its aims, Micro-DICE will undertake the following activities:

Conferences and special sessions

- Two research conferences are scheduled for 2011 and 2014. The first will take place in Grenoble (France) in honour of Paul Duval.
- Micro-DICE will support up to three special sessions at major international conferences, such as the EGU, PCI or other meetings.

Calls for grants

They will be announced on the Micro-Dice websites (www.microdice.eu and www.esf.org/microdice) for:

- One summer school aimed at young researchers to be held in 2012.
- Workshops/short courses to bring together small groups of senior specialists and young researchers.
- Travel grants for short and exchange visits will foster the exchange between students and scientists within Europe.

Publications

- A special issue resulting from the 2011 Paul Duval Conference will document the state of the art in microstructural research on ice.
- The special issue will form the base for a textbook aimed at graduate-student level.
- The Micro-DICE website is intended to become a central communication platform for the wider community, providing links to activities, facilities.
- The Dictionary of Glaciology (DoG) will be a Wikipedia-inspired website where all members of the community can provide content.
- The Atlas of Ice Microstructures (AIM) will provide a comprehensive digital atlas of microstructures from drill cores, experiments, numerical simulations, etc.

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For the latest information on this Research Networking Programme consult the Micro-DICE websites:
www.esf.org/microdice or
www.microdice.eu

Cover picture:
Ice thin section from Talos Dome ice core, Antarctica.
Image by Maurine Montagnat (LGGE, Grenoble, France)

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