ESF funded Micro-DICE Workshop on

Sea and Marine Ice Processes

UCL, 8-9 November 2010

Convenor: Peter Sammonds

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1. Workshop Summary

The ESF Micro-DICE workshop on Sea and Marine Ice Processes was held at UCL from 8-9 November 2010, organized by Professor Peter Sammonds and Alexandra Seymour-Pierce. 23 research scientists from the UK, Norway, Sweden, Finland, France and Belgium attended the 2-day event, 14 of whom were early-career scientists. There were 14 contributed talks, with invited keynote speeches being given by Professor Aleksey Marchenko (UNIS, Norway) and Dr Dan Hatton (Cambridge University, UK).

The aims of the workshop were to improve the training and mobility of early career scientists and researchers and to facilitate the exchange of resources and personnel. This can be achieved by the establishment of a network between countries and institutions with the intention of creating an atmosphere of collaboration. From a research aspect, the workshop aimed to improve analysis and modelling of the evolution of the polar ice caps and sea ice cover through a better understanding of ice physical processes.

The workshop focused on the micromechanics and small-scale transport properties of sea and marine ice, addressing in particular the impact on sea ice models and monitoring, ice shelf stability and ice engineering. Papers were presented under the following themes:

Mechanics of Marine Ice
Freeze Bonds in Sea Ice and Sea Ice Friction
Thermal and Transport Processes
Physical Processes in Large Scale Modelling

There was some overlap between these topics and a broad discussion after each paper pertaining to the implications and issues arising from each presentation. Such research is particularly relevant now, both in terms of environmental models, which are critically influenced by understanding of sea ice processes and with regards to cold regions engineering.

2. Scientific Content

2.1 Mechanics of Marine Ice

The importance of Antarctic ice shelves was discussed; especially with regard to their influence on continental ice dynamics, as the collapsing of ice shelves are a key parameter in the stability of the Western Antarctic Ice Sheet. A little understood component of ice shelves is marine ice, which is formed by accretion beneath the ice shelves. It is agreed that marine ice needs to be better understood for effective modelling of ice shelves as it displays distinct physical and chemical characteristics.

GPR evidence was presented for marine ice in the Larsen C Ice Shelf in the form of mechanically soft 'flow stripes' sandwiched between stiffer units of glacier ice. These represent a governing control on ice shelf stability. . Computations were done using a continuum-mechanical ice shelf model to investigate the impact of the marine flow bands on the stress regime of the Larsen C Ice Shelf. The relatively warm, marine ice rich flow bands in the north and south of Larsen C Ice Shelf promote an acceleration of the central part of the ice shelf in comparison to the standard simulations. An interesting discussion arose as to where and under which conditions the presence of soft flow stripes represents a stabiliser (preventing rift growth) or possible instability of the ice shelf.

Deformation experiments performed on marine ice and were compared with results from freshwater ice. It was found that parameters such as grain size or impurities affect the ice viscosity and hence the crystallography plays a role in the deformation behaviour. The salinity of the marine ice seems to a key factor for the modification of mechanical properties at a given temperature.

2.2 Freeze Bonds in Sea Ice and Sea Ice Friction

Friction is involved in many aspects of Ice deformation. In addition to dry ice friction, hydrodynamic lubrication, asperity sintering and freeze bonding affect the motion of the ice during ridging, rafting and in-plane sliding. Experiments on ice sliding have shown that in general, peak friction did not increase with holding time unless held for prolonged periods in which case bonding occurs between ice blocks, which must be broken before movement can occur. Recent work in sea ice friction has focused on non-steady-state models incorporating memory effects. A critical question for such models is the parameter space over which memory effects persist. Model parameters were chosen to fit experimental data to a rate and state model of friction, which exhibits a dependence on the velocity history of the ice. It is found that friction decreased with slip rate increase but the critical slip displacement is not a constant. The decay occurs over different ranges for different critical slip rates. It was found that a better fit between model and experiment was given when a critical slip time is considered instead. The friction between ice and material in particular has an industrial application and the results were discussed with interest by the workshop.

2.3 Thermal and Transport Processes

The thickness and extent of Arctic sea ice are declining rapidly. Changes in the extent and volume of sea ice can disrupt regional and global temperature, alter ocean circulation, and affect sensitive ecosystems. Therefore, it is important to understand how sea ice grows and ablates at the sheet base.

Theoretical models for the growth/ablation of ice sheets are based on phase equilibrium at the ice-fluid interface, heat balance in ice and water and a corresponding salt balance. A current model was presented which uses a linear temperature profile in the ice, implying thin ice sheets grow in thickness and thick sheets ablate. This gives a small equilibrium thickness, which is approached on a rapid relaxation timescale. A refinement was suggested for consideration whereby the ice depth is not known at the ice base. Modelled results still do not agree with field data and it was speculated that at certain times diffusive transport dominates over turbulent transport in the fluid, which may explain the growth of thick ice.

The reduction in Arctic sea ice is thought to represent in part a switch from multiyear to seasonal sea ice. The thermal properties of first year ice such as the temperature and salinity profiles are not well known. Field observations of sudden salinity anomalies were related to brine convection within the ice and flushing by melt water using a 1D halo-thermodynamic model. Convection is controlled by ice porosity and is driven by the penetration of a cold temperature front within the warm ice. It is suggested that young ice loses a substantial fraction of salt immediately after wintertime growth, a process, which is thought likely to hold at larger spatial scales in the Arctic.

2.4 Physical Processes in Large Scale Modelling

Sea ice motion is driven by winds and currents and the response of ice to this forcing is determined by ice inertia, Coriolis acceleration, ice advection and internal friction. Frequency spectra of ice drift were examined using mathematical models and drift data. It is found that the response to forcing is nonlinear with amplitude modification and phase change but with no change in the frequency. This property is due to an asymmetry of sea ice rheology, which gives strong resistance to compression but weak resistance to tension; the convergence and divergence of ice was shown to follow the forcing and consequently the internal friction does so also.

Ice floes are modelled using a discrete element model (DEM), which has been modified to include shear failure as well as failure lines due to tension and compression. The Mohr Coulomb failure criterion is translated into ice floe displacements and models the aggregation of individual ice floes. Results suggest that the thicker the ice between floes, the larger the resultant floe aggregate. Other modifications to DEM models have been to incorporate an anisotropic sea ice model into CICE whereby the stress is dependent on lead orientation. This agrees better with observations of localised ice deformation and hence improves the accuracy of sea ice models.

3. Assessment and Impact of the Results

The main outcome of the workshop was to provide an overview of current research into different aspects of physical processes in sea and marine ice and to demonstrate the interconnectivity of the various areas in which work is being undertaken. For the individual participant, there was the opportunity to meet other researchers within the specialist discipline and general discussions were undertaken both during and after talks between the interested parties. Questions and opinions from the group allowed for useful discussions of the validity and applications of research currently being conducted, allowing new interpretations of results and conclusions, as well as informing other areas of exploration.

All the work presented is particularly relevant now, with concerns about accurate modelling and predictions of the response of the cryosphere to temperature and atmospheric changes. By understanding the micro-scale controls on ice dynamics and thermodynamics, a better view of ice shelves and the sea ice cover can be put forward. The workshop also allowed early career scientists to meet, which should allow the formation of collaborative groups of institutions and researchers in the future. The opportunities arising from Micro-DICE network were explained by the Convenor and members of the workshop urged to take these up.

4. Programme of the Workshop (including speakers)

	Monday 8th November	
11.00	Registration - *tea and coffee*	
11.15	Welcome - Peter Sammonds	
11.30-	**Invited Keynote Lectures**	
	Aleksey Marchenko	Sea ice processes
	Dan Hatton	Micromechanics of sea ice friction
13.00-14.00	*Buffet Lunch*	
14.00-	**Mechanics of Marine Ice**	
16.00	Peter Sammonds	Fracture toughness of marine ice
	Denis Samyn	Combining rheological & mapping analysis of marine ice
	Marie Diercx	Marine ice rheology in compression: driving parameter
	Daniela Jansen	Marine ice within the Larsen C Ice Shelf: evidence from geophysical field data
16.00	*Tea and coffee*	
16.30 -	**Freeze bonds in sea ice and sea ice friction**	
18.00	Ben Lishman	Critical slip in sea ice
	Sergiy Sukhorukov	Field and lab experiments on ice friction
19.30	*Dinner at Da Paolo*	
	Tuesday 9th November	
9.00	**Thermal and transport processes**	
11.00	Knut Hoyland	Thermal aspects of model basin ridges
	Fernanda Jardon	Full-depth desalination of Arctic sea ice after the growth season
	Aleksey Shestov	Consolidation of ice ridges
	Dan Hatton	Ablation and growth at the base of floating ice sheets
11.00	*Tea and coffee*	
11.30 -	**Physical processes in large scale modelling**	
13.00	Matti Lepparanta	Frequency spectrum of drift ice velocity
	Daniel Feltham	The effect of shear failure on aggregate scale formation in sea ice
	Michel Tsamados	Implementation of anisotropic rheology for the arctic cover in a global climate model
	Aleksey Marchenko	Solutions decribing cyclonic and anticyclonic wind drift of elastic-plastic ice cover
13.00-14.00	*Buffet Lunch*	
14.00-	**General Discussion**	
16.00	Rock & Ice Physics Lab Tour	
17.00	Close	

Participants

Peter Sammonds*	UCL	UK
Daniel Feltham*	NCEO-CPOM	UK
Eleanor Bailey	CPOM, UCL	UK
Alexandra Seymour-Pierce	UCL	UK
Michel Tsamados*	CPOM, UCL	UK
Daniela Flocco	CPOM, UCL	UK
Harry Heorton	CPOM, UCL	UK
Ceri Middleton	UCL	UK
Daniela Jansen*	Swansea University	UK
Dan Hatton*	Cambridge	UK
Ben Lishman*	Bristol University	UK
Knut Hoyland*	NTNU	Norway
Sergiy Sukhorukov*	NTNU	Norway
Aleksey Marchenko*	UNIS	Norway
Aleksey Shestov*	UNIS	Norway
Matti Lepparanta*	Helsinki University	Finland
Mika Makela	Helsinki University	Finland
Annu Oikkonen	Helsinki University	Finland
Fernanda Jardon*	Université Pierre et Marie Curie	France
Frederic Vivier	Université Pierre et Marie Curie	France
Jean-Louis Tison*	Université Libre de Bruxelles	Belgium
Marie Dierckx*	Université Libre de Bruxelles	Belgium
Denis Samyn*	University of Uppsala	Sweden

* Speaker