6th EC FRAMEWORK PROGRAMME
INTEGRATED INFRASTRUCTURE INITIATIVE HYDRALAB III

Access to major experimental ship hydrodynamics and ice engineering facilities

Please send the completed form by e-mail to the facility provider:

- Hamburg Ship Model Basin (HSVA): Karl-Ulrich Evers, evers@hsva.de
- Canal de Experiencias Hidrodinámicas de El Pardo Madrid, Spain (CEHIPAR): Adolfo Maron adolfo.maron@cehipar.es
- Norwegian University of Science and Technology (NTNU): Alexandra Neyts, alexandra.neyts@bio.ntnu.no

1. Title of the proposal

Understanding the impact of a REduced ice Cover in the ARctic Ocean (RECARO)....................................

2. Requested facility/facilities:

.......Ice tank: . Hamburg Ship Model Basin..

3. Applicant's full name and title (User Group Leader)

Dr Jeremy Wilkinson
Leader: Sea Ice Group, Scottish Association for Marine Science

4. Affiliation

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5. Full name, titles, positions in institution and nationalities and gender of all other persons participating in the project:

	Name, titles and affiliation	Position	Nationality	M/F
1	Dr Jeremy Wilkinson Scottish Association for Marine Science	Scientist	UK	M
2	Dr Antonella Abbà Politecnico di Milano	Scientist	Italy	F
3	Dr Fanny.Ardhuin Institut français de recherche pour l'exploitation de la mer	Scientist	France	F
4	Dr Giacomo De Carolis Istituto di Studi su Sistemi Intelligenti per l'Automazione	Scientist	Italy	M
5	Dr Wolfgang Dierking Alfred Wegener Institute	Scientist	Germany	M
6	Dr Robert Ezraty Institut français de recherche pour l'exploitation de la mer	Scientist	France	M
7	Dr Dan Hayes University of Cyprus	Scientist	Cyprus	M
8	Dr Sebastian Gerland Norwegian Polar Institute	Scientist	Norway	M
9	Nick Hughes Scottish Association for Marine Science	Scientist	UK	M
10	Prof Preben Gudmandsen Denmark Technical University	Scientist	Denmark	M
11	Ingibjorg Jonsdottir University of Iceland	Scientist	Iceland	F
12	Dr Piero Olla Institute of Atmospheric Sciences and Climate	Scientist	Italy	M
13	Dr Flavio Parmiggiani Institute of Atmospheric Sciences and Climate	Scientist	Italy	M
14	Dr Leif Toudal Denmark Technical University	Scientist	Denmark	M
15	Dr Lars Henrik Smedsrud University of Bergen	Scientist	Norway	M
16	Dr Lorenzo Valdettaro Politecnico di Milano	Associate Professor	Italy	M
17	Prof. Peter Wadhams l'Observatoire Océanologique de Villefranche-sur-Mer	Professor	France	M
	Non-EU participants			
i	Prof. Shigeki Sakai Iwate university	Professor	Japan	M
ii	Prof. Hayley Shen Clarkson University	Professor	USA	F
iii	Prof. Stephen Ackley Clarkson University	Professor	USA	M

6. Names and access period of those that made use of the access programme to this facility in previous EC framework programmes:

INTERICE I Peter Wadhams, Lars Henrik Smedsrud.
INTERICE II Sebastian Gerland.
INTERICE III Wolfgang Dierking, Robert Ezraty, Nick Hughes, Leif Toudal, Shigeki Sakai, Peter Wadhams, Jeremy Wilkinson, Hayley Shen, Stephen Ackley.

7. Estimated number of access days requested; *this includes the time needed for building the test setup , testing and calibration when necessary, main experiments, and removal of the test setup:*

Timetable

The project is assumed to begin in April 2007 with a one-day kick off meeting at HSVA involving 2 representatives from each Objective as well as HSVA staff. This meeting will discuss any amendments to the layout of the tank, the placement of equipment and the progression of the experiments. At the end of this meeting HSVA staff will have a clear understanding of the tank design and the timetable of experiments.

The first experiments are scheduled to be preformed in June and will run for 12 days (Monday until week on Friday). After this set of experiments a two-day workshop involving all participants, HSVA personnel and interested parties will be held at HSVA. The aim of this meeting will be for partners to present their research in order for the consortium to evaluate the quality and quantity of the *in situ* data, lessons learnt, the analysis performed and opportunities for the final round of experiments.

In November a final round of experiments, 5 days in duration, will be performed. In order for these follow-on experiments to be beneficial they should be performed at least 6 months after the above mentioned experiments. In this way the consortium has time to analyse the data and will be in a position to tune these experiments to fill the gaps in our knowledge that were not covered by the first round of experiments. We envisage that this programme will deliver a step change in our understanding of new ice formation and its effects on the water column.

The above timetable gives an overview of the needs of our programme, however dates will not be finalised until detailed discussion with the consortium and HSVA staff have been performed.

Testing, calibration and removal

Prior experience has shown that the setup and calibration of equipment should be performed in a methodical way with close liaising with HSVA staff (these points are to be raised at the one day kick off meeting). It is envisaged that all equipment will arrive the week before the start of the experiments. Two members from each objective ((1) sea ice and oceanography, (2) remote sensing and (3) wave attenuation) will then arrive to ensure the equipment is set up at the correct location and that it is calibrated and functioning properly. The rest of the consortium will arrive the day before the start of the experiments.

Summary

- 1-day kick off meeting at HSVA involving 2 representatives from each Objective. They are: (1) Gerland & Wilkinson; (2) Dierking & Toudal, (3) De Carolis & Wadhams as well as representatives from HSVA.
- Experiment 1. 12 days (Monday to week on Friday) + 2 days set up and 1 day removal (15 days total)
- 2-day evaluation workshop at HSVA involving all partners.
- Experiment 2. 5 days + 2 days set up and 1 day removal (8 days total)

TOTAL = 26 days

7. Estimated total number of the visiting person-days

(sum of the days of presence at the installation of all the members of the visiting team);

The integrated programme of multi-disciplinary research (sea ice, oceanography, remote sensing and modelling) we propose to perform at HSVA involves a team of 17 scientists from 8 European countries as well as the USA and Japan. We understand that the cost of such a large inclusive programme such as RECARO would be too expensive for the HYDRALAB-III and therefore a significant contribution to the costs of the programme has been agreed by many of the consortium members, thus bringing considerable added value to this project. The monetary value of this would be several thousand Euros.

We request:

- Full support for **7 scientists**,
- Travel and subsistence support whilst at HSVA (flights will be covered through internal funding provided at no cost to the programme) for **5 scientists**
- 50% support for **2 scientists** (remaining 50% covered through internal funding provided at no cost to the programme)
- Full support for **4 scientists** for 5 days during experiment 1 only (remaining period of the programme will be covered through internal funding provided at no cost to the programme)
- No cost to programme for **2 scientists** (totally self funding from internal sources).

A summary of all contributions and requested funds are included in the Annex: Overview of the Consortium which can be found at the end of this proposal form.

9. Most appropriate period for the experiments? Are there any constraints for the period when you may or may not perform the experiments?

See section 6 for the timetable of the proposed work, however dates will not be finalised until detailed discussion with the consortium and HSVA staff have been performed. There are no constraints for the period of the experiments.

10. Tentative list of instrumentation requested (contact us for information)

A tentative list of equipment that we would like to be supplied by HSVA is as follows:
Wave maker (x2)
Pressure transducers (x6) + recording instrumentation
Moveable platform for CTD and ULS (x3)................................
Underwater camera (x1)...
Apparatus for making thin sections (x1)
Thermistor chains and recording system (x3)
Chain saw (or similar) to remove ice from tank

All other equipment will be supplied by the consortium

11. Description of the proposed work (<u>maximum of four A4 pages in a separate file</u>)

Located on following four pages.

11. Proposed Work: Understanding the impact of a REduced ice Cover in the ARctic Ocean (RECARO)

Jeremy Wilkinson (UK: Co-ordinator): Antonella Abbà (Italy); Fanny Ardhuin (France); Giacomo De Carolis (Italy); Wolfgang Dierking (Germany); Robert Ezraty (France); Dan Hayes (Cyprus); Sebastian Gerland (Norway); Nick Hughes (UK); Preben Gudmandsen (Denmark); Ingibjorg Jonsdottir (Iceland); Piero Olla (Italy); Flavio Parmiggiani (Italy); Lars Henrik Smedsrud (Norway), Leif Toudal (Denmark), Lorenzo Valdettaro (Italy); Peter Wadhams (France).

Non-EU participants: Shigeki Sakai (Japan); Hayley Shen (USA); Stephen Ackley (USA)

The Arctic is warming faster than any other region of the globe and a temperature rise of more than 4°C is predicted over the next 50 years (IPCC 2001; ACIA, 2004). Moreover, accelerated change is expected, including a near-disappearance of summer sea ice in the Arctic Ocean (ACIA, 2004). The near-seasonal disappearance of sea ice will influence ocean stratification and vertical mixing, which in turn will affect primary productivity, ecosystem function and carbon cycling. Furthermore the large expanses of open water that will be present at the end of each summer will lead to an increase in the wind induced turbulence in the upper ocean as well as the wave fetch. This will have a knock-on effect on the evolution process of sea ice, its rate of growth as well as its influence on the density structure of the surrounding water column through the expulsion of brine during ice formation.

Presently a significant portion of the ice formed in the Arctic Ocean forms under calm, non-turbulent conditions. Under the present-day scenario frazil first appears as a smooth oily sheen on the surface of the ocean, this is referred to as grease ice. The smooth appearance results from the dampening of short gravity and capillary waves (high frequency end of the wave spectra) on the water surface. If both the wave and wind effects are limited the agitation of the frazil ceases and the surface layer of frazil can begin to consolidate to form nilas. Further thickening will continue as a unidirectional process by which seawater freezes directly to the underside as heat is conducted through the ice. This is known as congelation growth (Weeks and Ackley, 1986).

However the increase in the upper ocean turbulence under an open Arctic Ocean or near-open Arctic Ocean scenario will promote a different ice development process. The stages of which may be distinguished as: frazil or grease ice formation, flocculation to form pancake ice, pancake rafting, and possibly a continuous ice sheet if the wave energy is dampened enough (Shen et al., 2001; Doble et al. 2003). This is the process that presently occurs in the Antarctic (Wadhams, et. al. 1987). Very limited field measurements of frazil and grease ice are available, but recent results (Smedsrud and Skogseth 2006) indicate that ice concentration in the field are similar to those in laboratory experiments (Martin and Kauffmann 1981, Smedsrud 2001). Once frazil has evolved into pancake ice its vertical growth of pancake ice seems to be controlled by the amount of frazil surrounding the pancake and/or the freezing of sea water spilled on to the top of the cakes, and rafting (Dai et al. 2004), whilst the diameter of pancake ice depends on the high-frequency part of the wave spectrum, and as such pancake ice increases in diameter the further away from the ice edge (Shen et al. 2004). The analysis of the crystal structure of pancake ice, performed by some of the proposers during field campaigns in 1993 and 1997 (Wadhams and Wilkinson, 1999, Wilkinson and Wadhams, 2003), as well as from ice tank experiments performed at HSVA and at CRREL (Haas et al, 1999; Ackley et al. 2002, Evers et al. 2002) during previous experiments revealed that pancake ice consists completely of frazil crystals . No columnar ice growth was seen in any of the pancakes analysed, including field pancakes that were more that 50 cm thick. Columnar growth may only occur when an ice-field becomes consolidated.

It has been found that newly formed pancakes have high salinity resembling frazil crystals, but that as they age they lose salt much more rapidly than conventional ice sheets, dropping to 5-7 psu within a few days (Wadhams and Wilkinson, 1999, Wilkinson and Wadhams, 2003). This accelerated salt loss is an important factor in computing the spatial and temporal averaged salt flux from a developing frazil-pancake ice field. It is hypothesised that the frazil-pancake mechanism of ice formation produces sea ice at a faster rate than congelation growth (Evers et al. 2002, Shen et al. 2003), which in turns suggests an increased rate of brine rejection and hence a significant influence on the density structure of the upper ocean. Furthermore the extent of the faster growth of frazil-pancake cycle depends on different physical parameters, such as the frazil collection depth, rise velocity of ice particles, the heat exchange rate between water and ice particles and distribution of size and shape of ice particles. The values of these parameters in actual oceanic conditions are not yet completely known (Abbà et al. 2006), and therefore controlled simulations are needed to elucidate these parameters. For example the frazil collection depth has up to now been parameterized as a function of wind-speed (e.g. Alam and Curry 1998). Field data from Smedsrud and Skogseth (2006) indicate that this parameterisation underestimates this thickness by a factor of 2-5, both at lower and higher wind-speed, further studies are needed to build a better parameterisation.

Europe and other nations are developing complex models to investigate the elaborate processes behind climate change in the polar regions and how it influences the oceans and future climate. However the formation process of frazil crystals and its development into pancake ice and other young ice types is one of the least well documented and understood mechanisms of the whole sea ice formation process and represents a major gap in sea ice research. In order to have confidence in the output from these models they must be driven by the correct physics using realistic data, which in turn requires field measurements to understand the processes involved and to validate and refine the models (IPCC, 2001). Whilst this is conceivable in some locations it is rarely possible in the polar regions due a combination of cost, logistics and lack of control over harsh environmental conditions. To overcome these hurdles we propose an integrated programme of multi-disciplinary research (sea ice, oceanography, remote sensing and modelling) to elucidate the impact of a much reduced summer ice cover on sea ice structure and the underlying oceanography by conducting repeatable, small scale experiments in the temperature controlled laboratory at HSVA. Our bid experiments have three objectives:

1) Quantify the rate of growth of sea ice under both calm and turbulent conditions, the rate of brine drainage under different ice conditions and ages, and the influence different ice formation mechanisms has on the underlying ocean structure and light penetration.
2) Quantify the backscatter and temperature values for different young ice types and thickness in order to obtain improved sea ice type discrimination and detection. This will be applicable to similar satellite mounted sensors.
3) Obtain a wave dispersion relationship for young ice grown at different wave frequencies and relate the relationship to the thickness of the frazil and pancake ice.

The consortium

The proposed team consists of a number of highly ranked scientists whom together possess the competences necessary to handle the challenges associated with this programme. Furthermore international scientists of high esteem augment the consortium. This project involves collaboration between 17 scientists from 8 European countries as well as the USA and Japan. Furthermore the balance between new users and experienced tank users is organised in such a way that the learning curve is small and the facility can be used efficiently, effectively and to its maximum extent. Less experienced personnel will benefit from a close working relationship with experienced scientists and HSVA staff. Their involvement at all levels, preparation, running and analysis of the data, will enhance their qualifications as well as developing opportunities and collaborations for follow-on experiments.

The proposed experiment

In order to successfully perform these experiments we propose to divide the HSVA ice tank into three separate sections with starting salinity of around 34 PSU. The first tank, Tank 1, will be a turbulence free zone which will represent the formation of sea ice in a quiescent environment i.e. as in leads in the Arctic Ocean. The other two tanks, Tank 2 and 3. will represent the future possible ice scenario of the Arctic Ocean, i.e. ice formation under a turbulent environment. These two sections will be identical in size, but each has a separate wave maker (running at different frequencies) and will end in a raised beach so that no wave reflections occur. Frazil and then pancake ice growth will be monitored in these two separate wave tanks as will the growth of the continuous ice cover in the Tank 1. In order to make the most of the limited time we have within this facility all projects are designed in such a way that they can be performed simultaneously with no detrimental impact on any experiment or objective. All data will be time stamped with reference to local time. A schematic of the layout of the tank can be seen below.

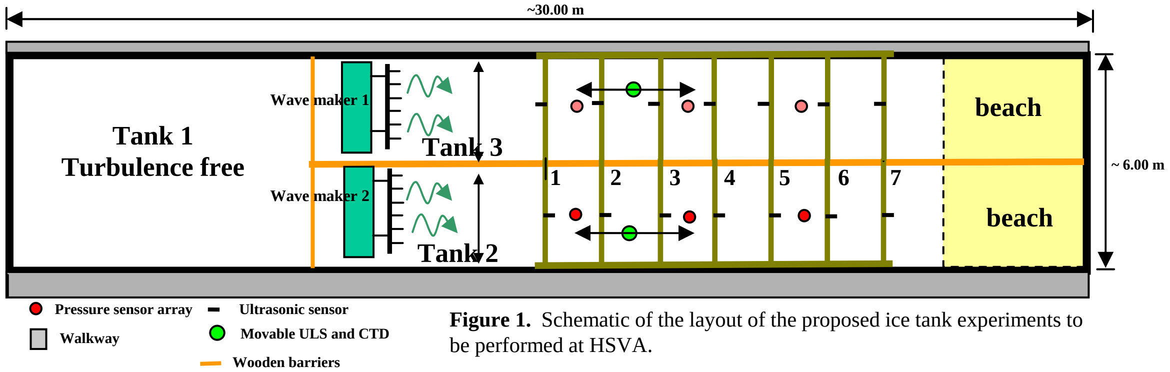

Figure 1. Schematic of the layout of the proposed ice tank experiments to be performed at HSVA.

Objective 1: Sea ice and oceanography: Wilkinson (Leader), Abbà, Ackley, Gerland, Hayes, Olla, Smedsrud, Shen, Valdettaro, Wadhams.

The purpose of the sea ice and oceanography programme is to understand and quantify the different sea ice formation and growth processes that occur under both a quiescent and turbulent environment. These are:-

- What is the volume of ice produced in each tank and what is the salinity and porosity of this ice?
- How does the size distribution, aspect ratio and salinity of frazil, pancake ice and ice sheet vary over time?
- How does the frazil collection thickness vary with wave amplitude and frequency?
- How much salt has been released into the water column during ice formation in each tank, and can we quantify the convective brine plumes (length scales, salinity, temperature) that are hypothesized to occur?
- What are the optical properties of the various ice types and stages under different radiative forcing regimes?

Procedure:

The *in situ* temperature and salinity of the water column will be monitored by the use of a Seabird SBE-19 CTD mounted in each tank. It is envisaged that the CTD will be mounted on a movable platform (with wheels) so that it can be pulled horizontally (along the central axis of each tank) through the water column. This will provide insight into the scales of subsurface convective activity from brine rejection, as predicted by the Kämpf and Backhaus (1999) model. The measurement of ice thickness will be obtained from an upward looking sonar mounted on the same platform as the CTD. Additional *in situ* measurements will be obtained at set locations in the three tanks every 30 minutes. This will include, size distribution and aspect ratio of frazil crystals and their salinity; pancake salinity, size, porosity and thickness. The complete air-ice-water temperature profile will be obtained at specific locations by the use of bottom mounted thermistor chains and a meteorological station will record the pressure, wind speed/direction, air temperature, relative humidity, radiation fluxes and turbulence fluxes (including evaporative and sensible fluxes). Laser Döppler velocimeter system will measure the turbulent fluxes above the ice/water surface. Acoustic velocimeters will monitor the horizontal and vertical velocity fluctuations in the water column. These combined measurements will enable total heat flux calculations to be made for comparisons between *in situ* and modelled ice thickness for the different tanks as well as the increase in salinity as seen by each CTD.

The transmissivity of the ice for solar radiation is crucial in determining the amount of heat reaching the ice-water interface. The spectral transmissivity of solar radiation of different ice types will be investigated with a TriOS Ramses ACC VIS radiometer (range 280 – 950 nm). A laboratory lamp with a spectrum similar to the solar spectrum will be mounted above the ice, and the radiometer beneath the ice. Results from all experiments are coupled to Objectives 2 and 3.

Objective 2. Remote sensing: Toudal (Leader), Ardhuin, Ezraty, Dierking, Gudmandsen, Hughes, Jonsdottir.

Satellite radar remote sensing can monitor the sea ice cover on a regular basis because radar sensors are not affected by cloud cover or light conditions. Maps of the sea ice state can be generated from scatterometers which have a wide coverage but a coarse spatial resolution, or from imaging radars (SAR – synthetic aperture radar) which offer a better spatial resolution but acquire the data over smaller swath widths. The radar sensor transmits an electromagnetic pulse which is reflected and/or scattered from the ice. The intensity of the signal which is scattered or reflected back to the radar sensor depends on the radar configuration (frequency, polarization, incidence angle) and on the ice properties (surface and volume structure, dielectric properties). The major goal of this component of the programme is to establish a relationship between the changes of the ice cover properties and the characteristics of the measured radar signal scattered back from the ice. Different ice properties will be quantified: volume structure, temperature, salinity, thickness, and surface and crystal structure in collaboration with Objective 1. Since the frazil and young pancake ice is of high salinity and often has a wet surface, the interaction between the radar waves and the ice is restricted to the surface, whilst volume scattering may be more prevalent in the continuous ice sheet tank (Tank 1). Hence, the surface structure is an important parameter to be related to the measured radar signal. These measurements will help to improve the interpretation of the radar data acquired by means of satellite radar sensors. The mobile scatterometer system, EMISCAT, which was built at the Technical University of Denmark will be used. This radar was used during the Interice III, phase 2 experiments. The EMISCAT data acquired in the tank can be compared with ASCAT data (MetOp satellite). The combination of Ku and C-band data should lead to improved sea ice type discrimination and detection.

Coupled with this programme will be the measurements of surface temperature through the use of time-lapse infrared photography. This will enable us to derive a relationship between backscatter, ice thickness and surface temperature. Through this we hope to have a better understanding of the sources of uncertainty and errors that occur when rolling these measurements out to satellite sensors. These can be used to identify and the same ice types in satellite images and possibly obtain an empirical relationship between the thickness of young ice and its temperature and backscatter value. The IR image will also be used to monitor the growth of pancake diameter.

Procedure:

Ice formation measurements will be acquired from high-resolution digital cameras, the EMISCAT mobile scatterometer and the infrared camera system. A log of the conditions in the turbulence-free and front turbulence tank will be maintained between intervals of scatterometer measurements (Objective 1). The differences of backscatter between calm conditions and a wind roughened sea surface will be studied. Significant interest is the change of backscatterer intensity as a function of ice thickness (ice growth under calm conditions (Tank 1) and ice surface roughness (in case of developing pancake ice: Tank 2 or 3). The combined photogrammetry will be validated by *in situ* measurements conducted in conjunction with Objectives 1 and 3. Another emphasis is laid on technical tests of the EMISCAT (operated at C- and Ku-band), which will be equipped with a new amplifier for the Ku-band channel. Validated measurements and observations will be used to construct a model of microwave backscatter response to ice growth, considering changing temperature fluxes. This will be useful in assessing satellite sensor data from the Arctic held by the project partners. In particular the Ku-band channel is of interest, since the dynamic range of backscatter variations during ice growth is expected to be larger compared to C-band. A Ku-band SAR system was proposed as an ESA (European Space Agency) Explorer Mission, which is undergoing further studies.

Objective 3. Wave attenuation: Wadhams (Leader), Ackley, De Carolis, Olla, Parmiggiani, Sakai, Shen, Wilkinson.

When ocean waves enter frazil-pancake icefields the open water dispersion relation changes. It was found in early experiments by Wadhams and Holt (1991) that it was possible to derive the wave number of the dominant wave component in open water and in ice by analysing the change in wavelength and direction of these components as detected by the two-dimensional Fourier analysis of SAR imagery. Later refinements of this procedure including the use of a full inversion (e.g. Wadhams et al., 1999) led to a culminating paper (Wadhams et al., 2002) in which the change in wave number was measured with much higher resolution by using a cross-spectral technique. It was found that the wave number of typical ocean waves (period 8-14 s) decreases on entering frazil-pancake ice. Using the simplest form of theory, that of mass loading, they concluded that the method could in principle be used to measure the thickness of the icefield, but that values derived from mass loading usually appeared unrealistically large. At the same time, experiments in a cold room using very short period waves (Newyear and Martin, 1999) showed a wave number increase in ice, and a dispersion and attenuation relation that was a better match to viscous theories such as that later offered by Keller (1998). Most recently, these problems appear to have been resolved when the Keller theory, of which a further refinement has been given by De Carolis and Desiderio (2002), was applied to an Antarctic SAR image of winter pancake ice, giving an inferred ice thickness which exactly matched that measured *in situ* by the icebreaker “Polarstern” (Wadhams et al., 2004). The free parameter in the Keller theory is the kinematic viscosity of the viscous surface layer, which was best fitted in the field experiments by 5×10^{-2} m^2 s^{-1} and in the lab experiments by ($3 \pm 0.25 \times 10^{-2}$ m^2 s^{-1}). The theory predicts, as observed, a wavelength increase at short periods and decrease at long periods. A further theoretical result was achieved by studying the nature of frazil ice viscosity (De Carolis et al., 2005). It was found that the bulk viscosity of frazil particles moving in a periodic wave field may depend on the wave frequency, amplitude and on the aspect ratio of frazil particles modelled as disks. However, many questions remain to be answered, for which a fresh series of laboratory experiments within a controlled tank environment are needed. These include (1) is the kinematic viscosity a function of the physical state of the frazil-pancake icefield? If so, what determines it? (2) How does the frazil-pancake transition take place and is the propagation mode in frazil ice different from that in pancake ice? (3) What determines the initial and final diameters achieved by pancakes? (4) Does the De Carolis theory give a better or worse description of the propagation than the Keller theory? (5) Do waves decay exponentially in frazil-pancake through viscous loss (Newyear and Martin, 1997) or in a more complex power law way though energy loss from mutual collisions (Shen and Squire, 1998) (6) Is the kinematic ice viscosity a function of the wave field strength and frequency along with the size distribution of ice particles?

Procedure:

The wave frequency and height will be obtained using the standard technique of placing pressure transducers within Tanks 1 and 2. Additional measurements will be obtained by positioning of ultrasonic sensors above these tanks. The wave makers in Tank 1 and 2 will be operated independent of each other and at different frequencies. This will enable not only the wave dispersion relationship to be determined at set frequencies, but as the atmospheric conditions are identical the effect of frequency with respect to frazil volume, pancake size etc can also be determined. The thickness of frazil and pancake ice will be measured through *in situ* sampling as well as the upward looking sonar mounted on the CTD platform as described in Objective 1. During each two week campaign a series of sub-experiments will be run. Each sub-experiment will continue until the pancake ice begins to consolidate into a continuous sheet after which the ice will be removed from the tanks and the experiment will be repeated but at a different frequency. It is envisaged that the removal of the ice will require down-time of 24 hours. Ideally this would coincide with the weekend. During this time experimental results will begin to be analysed.

The IR images are grey-scaled according to temperature. A threshold set at the temperature of the water under the forming ice cover can be used to distinguish areas occupied by pancake ice and the surrounding frazil/water mixture. Standard image analysis packages based on pixel values will be used to determine the average pancake ice diameter and the total pancake coverage versus the frazil/water fraction. Time series of these images provide the evolution of pancake ice (Shen et al. 2004).

Dissemination

A report containing the experimental set-up and procedure as well as a summary of the data collected will be available within two weeks of the end of each campaign. This will enable problems to be flagged, successes to be highlighted, and the progress of the project to be evaluated. Communication through email and by phone will be encouraged to ensure the engagement and involvement of all parties. The smooth transition of data (in agreed format) between partners will occur rapidly through the password protected website, located at the coordinator's home institution. This website will have a public area dedicated to this programme. After the two year transition period the password will be removed and the data will be made available to all.

Consortium members publish in premier journals and would aim to get the outputs from this project into high impact journals. Reporting of results at major international conferences and publication of articles in popular science journals such as "New Scientist" will be pursued. We will encourage presentations at national and international conferences. Furthermore results of this project will be of direct relevance to the EU funded DAMOCLES programme, a basin wide evaluation of the changing sea ice and oceanographic properties of the Arctic Ocean, as well as other International Polar Year (IPY) Programmes. If funded we would pursue recognition of this programme from the IPY committee. Furthermore considerable added value is brought to this project via a significant contribution to the costs by many of the consortium members. The monetary value of this would be several thousand Euros. A summary of the contributions are included in the Annex: Overview of the Consortium.

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ANNEX: Overview of the Consortium

Jeremy Wilkinson (Co-ordinator)
Scientist at the The Scottish Association for Marine Science, UK.

Jeremy Wilkinson has studied climate related processes in the polar oceans such as deep convection and water mass modification in the polar seas, sea ice dynamics and thermodynamics and remote sensing of sea ice for over a decade. He has participated in 13 polar field expeditions and his observational work has been performed on many different platforms, including, ship, helicopter, aeroplane, ice camps and tank experiments. His experience in sea ice and polar oceanography has been gained through his work on a number of national and major EU and international programmes (ESOP-1, ESOP-2, CONVECTION, SITHOS, and DAMOCLES). Wilkinson is head of the Sea Ice Group at SAMS. His scientific and management expertise combined with field/tank experience ensures the necessary partnership for both the managerial and scientific aspects of the project.

Antonella Abbà
Assistant Professor at the Department of Mathematics - Politecnico di Milano, Italy.

Antonella Abba's research activity deals with turbulence modelling and Large Eddy Simulation of turbulent flows. Applications include Benard convection, reactive flows and flows in complex geometries. Recently she numerically studied the first steps of ice production in freezing conditions for free turbulent convection.

Fanny Ardhuin
Scientist at Laboratoire d'Océanographie Spatiale, Ifremer /Centre de Brest, France.

Fanny Ardhuin received her Ph. D. in radar meteorology at the Laboratoire d'Aérologie (Toulouse, France) in 2001. Her thesis deals with atmospheric boundary layer studies, using wind profiler radar with radio acoustic sounding system. Research fellow at ENST Bretagne (Brest, France), she analyzed Synthetic Aperture Radar (SAR) data in the framework of the E.U. project MARSAIS, especially for oil spill detection. She joined BOOST Technologies (Brest, France) to implement and test oil slick detection algorithms applied on SAR images. Currently a post-doctoral research associate at IFREMER (Brest, France), she is involved in sea ice monitoring from active and passive sensors.

Giacomo De Carolis
Scientist at CNR-ISSIA, Bari, Italy

Giacomo De Carolis. Researcher at CNR-ISSIA, Bari (Italy) since 1994. His research activity is mainly devoted to the extraction of physical parameters from remotely sensed imagery of the marine environment. He contributed to the EU project CONVECTION by developing an inversion scheme of SAR imagery to estimate frazil/pancake ice thickness through the inversion of SAR image spectra inversion combined to the use of a two-layer wave propagation model.

Wolfgang Dierking
Scientist at Alfred Wegener Institute for Polar and Marine Research, Germany

Wolfgang Dierking has 20 years experience in the field of microwave remote sensing of polar oceans. He has participated in several land-based, ship-based, and airborne field campaigns in the Arctic, Antarctic, and Baltic Sea. He is a member of the ESA SAR Advisory Group and Cat-1 Advisory Group, and a PI for ENVISAT Cat-1, TerraSAR-X, and ALOS projects.

Robert Ezraty
Senior Scientist at Laboratoire d'Océanographie Spatiale, Ifremer, France

Robert Ezraty is in charge of the Sea Ice project at Ifremer. He graduated from Ecole d'Ingénieur de Marseille (1968) and holds a Docteur Ingénieur degree in fluid mechanics from Institut de Mécanique Statistique de la Turbulence, Université d'Aix-Marseille (1971). He participated to several scatterometer based sea ice project: Co-PI Sea ice applications of the ESA/ERS-AMI/wind , Co-PI in the NSCAT sea ice /validation activities. Invited participant to the NASA QuikSCAT sea-ice validation activities. Principal Investigation of a NASDA/NASA-approved sea ice scatterometer project. He was also co-PI in European Supported Projects (IMSI, 1994-1998 ; CONVECTION, 1998-2002; INTERICE III, (2001) ; ICEMON , 2003-2004. He is presently involved in the MERSEA fp6 project (2004-2007), co-PI in the EU project DAMOCLES (2005-2008). He is a partner in the PolarView project (2005-2008) supported by ESA in the framework of the GMES initiative. He is a member of the ESA/EUMETSAT ASCAT Science Advisory Group.

Daniel R. Hayes

Researcher: University of Cyprus, Cyprus

Daniel R. Hayes received his Ph.D. in physical oceanography from the University of Washington in Seattle in 2003. For part of his dissertation, he studied the summertime Arctic mixed layer processes in the frame of the SHEBA project, both with measurements he helped collect (AUV, CTD, and turbulence masts) and with numerical models he developed. He has also performed lab experiments on wintertime lead convection with rotation. During his post-doctoral work at the British Antarctic Survey in Cambridge, he described the interaction of surface gravity waves and sea ice in the Antarctic by analyzing AUV-based measurements. Currently, he is a researcher at the Oceanography Centre at the University of Cyprus developing a coastal-scale near real time observation and forecasting system.

Sebastian Gerland;

Senior Scientist at The Norwegian Polar Institute, Norway

The geophysicist Sebastian Gerland received his PhD (Dr. rer. nat.) on marine sediment physics at the University of Bremen (Germany) in 1993. He has 18 years experience in polar sciences, and started with sea ice-related work in 1991. Gerland has worked before in gaciology groups at the Alfred Wegener Institute (Germany), at the University College of London (UK), at the Norwegian Radiation Protection Authority, and from 1997-2000 and since 2002 at the NPI in Norway (sea ice and climate). Gerland was and is involved in international and national funded research projects (e.g. in the ice tank experiment INTERICE II (1998), and currently as the leader of WP1.4 sea ice thermodynamics in EU DAMOCLES). His main research topics include the sea ice mass and energy balance in the Arctic, with focus on the Fram Strait and Svalbard. He authored or co-authored so far 35 peer-reviewed scientific publications. Gerland has participated in 22 Arctic and 2 Antarctic scientific expeditions.

Nick Hughes

Scientist at The Scottish Association for Marine Science, UK

Nick Hughes has been a research scientist since 1994. He has been involved in development of remote sensing algorithms to determine sea ice parameters for the IRIS and EUROCLIM EC 5th Framework projects and leads the Cryospheric Variables Group within EUROCLIM. In April 2004 he participated in the Royal Navy's ICEX-04 on board the submarine *HMS Tireless* as a sea ice advisor. He has also been involved in numerous field campaigns in the Arctic.

Preben Gudmandsen

Professor emeritus at Technical University of Denmark, Denmark

Employments in the fields of microwave technology and microwave radio propagation in Denmark and the Netherlands.

- Employed at TUD since 1961, teaching microwave technology, radio wave propagation, radio communications and remote sensing.
- Initiated in 1967 remote sensing in Denmark by a programme of airborne radio sounding of the Greenland ice cap, including development of equipment.
- Since 1971 engaged in airborne and satellite remote sensing with emphasis on the cryosphere. Danish representative in European Space Agency until 1994.
- In 1977 co-founder and first chairman of the European Association of Remote Sensing Laboratories (EARSeL).
- Retired in 1994 but still active in application of passive and active remote sensing for sea-ice studies.

Ingibjorg Jonsdottir;

Associate Professor at the Institute of Earth Sciences, University of Iceland

Ingibjörg Jónsdóttir has studied sea ice, remote sensing and climate impact in Iceland. She has been on three cruises to the Greenland Sea to study polar oceanography and deep convection, as well as on numerous ice reconnaissance flight to study remote sensing in the Iceland Sea. She has participated in a number of EU programmes: ESOP-1, ESOP-2, CONVECTION, IWICOS, as well as a few NSF programmes. Ingibjörg is a member of the International Ice Charting Working Group.

Piero Olla;

Researcher at ISAC-CNR, Sez. Cagliari, Italy

Piero Olla received his Ph.D. in physics at UCSC in 1992. From 1992 to 1995, he was a postdoc at the Physics Department of the University of Chicago, then, for a short period in 1995, at CRS4 in Cagliari. From 1996 he holds a research position (permanent from 2000) at CNR. His formationis that of a theorectical physicist, with interests in both fluid dynamics and stochastic processes. His main research topic is turbulence theory, but he has carried on also research on the dynamics of particle suspensions, with application to biofluid mechanics. Recently, he has been studying frazil particle dynamics from the point of view of suspension theory.

Flavio Parmiggiani;

Senior scientist at ISAC-CNR-Bologna, Italy

Date and place of birth: 19 July 1945 - Campagnola E., Reggio E., Italy 'Laurea' degree in Physics, University of Milan, Academic Year 1969-70. He begun his collaboration with the Italian Antarctic Program in 1989, being responsible of the remote sensing activities at the Antarctic Base. In the academic year 1992-93 he was visiting scholar at the Scott Polar Res. Institute, University of Cambridge, U.K. In the last 12 years he participated to three EU Projects regarding the Arctic Ocean; in these projects he was in charge of the analysis of sea-ice by SAR. Since 2005 he is partner of the GMES Project 'Polar View', funded by ESA.

Lars H. Smedsrud

Researcher at Bjerknes Centre for Climate Research, Norway

Dr.scient. (2000) in physical oceanography on how frazil ice crystals forming in polar waters may entrain sediments into sea ice. Presently Smedsrud works on sea ice formation in Svalbard Polynyas in the ProClim project, conducting both field measurements and numerical modelling. Recently he studied effects and causes of warming deep waters in the Weddell Sea, Antarctica, and did a model study at the British Antarctic Survey (Cambridge, UK, 2001-2002) as a Marie Curie fellow of ice-ocean processes below floating Antarctic ice shelves. Smedsrud participated in the "Transport and effects" project coordinated by the Norwegian Polar Institute on pollution transport from the Kara Sea to the Barents Sea (Tromsø 1999-2000), and has worked with laboratory experiments of ice formation in the InterIce (Hamburg, Germany, 1996-1998) and Cosmos (Bergen, 2000) projects. He has been the editor of the Forum for Research into Ice Shelf Processes (FRISP) web pages and reports since 2003.

Leif Toudal,

Professor at Technical University of Denmark, Denmark

Leif Toudal Pedersen holds a PhD degree in passive microwave radiometer techniques and has 25 years of experience in remote sensing and modelling of sea ice. He as acted as co-investigator in the Greenland Sea Project, ESOP, IMSI, IWICOS, PELICON, SEALION, GreenICE and IOMASA projects. He runs the data distribution system www.seaice.dk.

Lorenzo Valdettaro

Associate Professor at Politecnico di Milano, Italy.

His research activity deals with the analytical and numerical treatment of fluid dynamics problems. A relevant part of his activity is devoted to the Large Eddy Simulation of turbulent flows. Applications of his work have included the numerical simulation of turbulent Benard convection. Recently he studied the formation of frazil ice in polar ocean by numerical simulation.

Peter Wadhams

l'Observatoire Océanologique de Villefranche-sur-Mer, France

Peter Wadhams has 35 years of experience in research into sea ice and ocean processes in the Arctic and the Antarctic. He is one of the worlds most experienced sea ice researcher. He has led 40 research expeditions to all parts of the polar seas, working on the dynamics and thermodynamics of sea ice; sea ice thickness; waves in ice; icebergs; ocean convection and kindred topics. He is was Co-ordinator of the EU FP5 GreenICE project, partner in two other current EU Arctic projects (SITHOS, IRIS) and on the Steering Committee of the FP6 DAMOCLES Integrated Project to monitor the Arctic Ocean. He was Director of the Scott Polar Research Institute in Cambridge from 1987-92 and has been honoured by an ScD from Cambridge University and a Polar medal from the Queen as well as being winner of the 1990 Italgas Prize for Environmental Sciences. He is currently on the Scientific Committee of the European Environment Agency.

<u>Non-EU participants</u>

Shigeki SAKAI
Professor, Department of Civil & Environmental Engineering
Iwate University,
Japan.

Prof. Shigeki Sakai began his sea ice study from 1990. In his early studies, wave-ice interaction was discussed based on his experimental results and numerical simulations. He proposed an empirical formulation of dispersion relation of waves propagating in a field of ice floes with various sizes. From 1989, he has been developing a numerical simulation model of oil spreading under the ice cover. His recent studies include pancake ice formation in the wave field.

Hayley Shen
Professor, Department of Civil & Environmental Engineering
Clarkson University
USA

Prof. Hayley Shen began her sea ice study from 1983. After her early studies of the ice rheology in the marginal ice zone, she began research in wave-ice interactions from 1986. The studies have included wave induced drift of ice, pancake ice formation in the wave field, limiting pancake ice size and equilibrium rafting thickness. Her work utilized theoretical formulation, computer simulations, and laboratory measurements. She has had field experience in the Greenland Sea, McMurdo Sound, and Bohai Bay of China. She and Steve Ackley participated in Interice III in 1997. They also designed and conducted an EU/US National Science Foundation jointly funded pancake ice study using a twin tank facility at HSVA in 2001.

Stephen F. Ackley
Professor, Civil and Environmental Engineering Department
Clarkson University
USA

Prof. Stephen F. Ackley has been recipient of peer-reviewed research grants from National Science Foundation since 1976 for research on Antarctic sea ice. This research has been conducted during twelve research cruises on several nations' icebreakers into the sea ice zone surrounding Antarctica and on the first Antarctic sea ice drifting station, Ice Station Weddell (1992). Research was also funded by Dept of the Army, NASA, Office of Naval Research, and FAA for work on various snow and ice problems requiring laboratory experiments, fieldwork in the Arctic and on Mt. Washington, NH, analysis of remote sensing data from aircraft and satellites, and computer modelling. He has published over 150 articles, book chapters, technical reports on sea ice. The US Board on Geographic Names recently approved of the Antarctic Geographic name Ackley Point to recognize his sea ice work.

Breakdown of requested costs associated with RECARO, including contributions from partners

Partner number	Partner	Kick off meeting (Support needed)	Experiment 1 (Support needed)	Workshop (Support needed)	Experiment 2 (Support needed)	Comment
1	Dr Jeremy Wilkinson	100%	T&S only	T&S only	T&S only	Will cover costs of travel to/from experiments
2	Dr Antonella Abbà	N/A	0%	0%	0%	Totally self funding from internal sources
3	Dr Fanny Ardhuin	N/A	100%	100%	100%	Full support requested from HYDRALAB III
4	Dr Giacomo De Carolis	100%	100%	100%	100%	Full support requested from HYDRALAB III
5	Dr Wolfgang Dierking	N/A	T&S only	T&S only	T&S only	Will cover costs of travel to/from experiments
6	Dr Robert Ezraty	N/A	ticket + 5 days T & S	0%	0%	Air ticket + 5 days T & S
7	Dr Dan Hayes	N/A	100%	100%	100%	Full support requested from HYDRALAB III
8	Dr Sebastian Gerland	100%	100%	100%	0%	Full support requested from HYDRALAB III
9	Nick Hughes	N/A	100%	100%	100%	Full support requested from HYDRALAB III
10	Prof Preben Gudmandsen	N/A	0%	0%	0%	Totally self funding from internal sources
11	Ingibjorg Jonsdottir	N/A	ticket + 5 days T & S	0%	0%	Air ticket + 5 days T & S
12	Dr Piero Olla	N/A	ticket + 5 days T & S	100%	0%	Air ticket + 5 days T & S
13	Dr Flavio Parmiggiani	N/A	0%	100%	0%	Will cover costs of travel to/from experiments
14	Dr Leif Toudal	100%	T&S only	T&S only	T&S only	Will cover costs of travel to/from experiments
15	Dr Lars Henrik Smedsrud	100%	100%	100%	100%	Full support requested from HYDRALAB III
16	Dr Lorenzo Valdettaro	N/A	ticket + 5 days T & S	0%	0%	Air ticket + 5 days T & S
17	Prof. Peter Wadhams	100%	T&S only	T&S only	T&S only	Will cover costs of travel to/from experiments
	Non-EU participants					
18	Prof. Shigeki Sakai	N/A	100%	0%	100%	Full support requested from HYDRALAB III
19	Prof. Hayley Shen	N/A	50% of cost	0%	50% of cost	Will cover 50% of all costs from internal sources
20	Prof. Steve Ackley	N/A	50% of cost	0%	50% of cost	Will cover 50% of all costs from internal sources

N/A = Not Applicable.
xx% = Percentage of support needed through the INTEGRATED INFRASTRUCTURE INITIATIVE HYDRALAB III programme
T & S = Only travel and subsistence support requested whilst at HSVA. Flights will be covered through internal funding provided at no cost to the programme