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DEPARTMENT OF ATMOSPHERIC SCIENCES
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PERSONNEL

The following scientific and technical personnel have been employed by the Contract during part or all of the period covered by this report:

DR. SEELYE MARTIN, Co-Principal Investigator

DR. GARY MAYKUT, Co-Principal Investigator

DR. THOMAS GRENFELL, Research Associate

MR. PETER KAUFFMAN, Electronics Technician

MR. DONALD PEROVICH, Predoctoral Associate

MS. JANE BAUER, Predoctoral Associate

INTRODUCTION

During the past year we have organized a large backlog of material and written it up for publication in a series of papers dealing with the ablation of ice walls in seawater, the optical properties of young sea ice, the spectral albedos of snow, the propagation of ocean swell into pack ice, the ice edge in the Bering Sea, the behavior of frazil ice, and the design of a scanning photometer for use under polar conditions. Other work included development of a two dimensional model to describe the growth of grease ice in a wave field, application of the lateral melting in leads concepts to the disintegration of a seasonal ice cover, theoretical studies of how properties of the ice velocity field affect large-scale heat exchange, expansion and generalization of our radiative transfer model, laboratory measurements of spectral absorption in pure ice, observations of parallel crystal growth in a uniform current, and experimental determinations of the stress concentrations which form near the leading edge of floating ice sheets. Construction of a new data acquisition and processing system has substantially enhanced our experimental capabilities. Visits from Peter Wadham and Vernon Squire from the Scott Polar Research Institute were productive and resulted in a technical paper on the flexure of ice in a wave field. S. Martin and G. Maykut participated in initial efforts to develop an overall program for a Marginal Ice Zone Experiment (MIZEX). S. Martin is now taking an active part in organizing a MIZEX-type experiment in the Bering Sea.

DYNAMIC AND THERMODYNAMIC MODELING

Large-Scale Heat Balance Studies. An article on large-scale heat exchange and ice production in areas of perennial ice cover has been prepared for publication in the Journal of Geophysical Research. Large-scale fluxes cannot be measured directly because of large spatial variability in local values which result from the changing ice thickness. Our approach combined observations of the ice motion and incident energy fluxes with theoretical models of ice growth, thickness distribution and heat exchange to obtain area-averaged totals. Results were based on three separate strain histories from regions in the Beaufort Sea and Central Arctic. Despite large differences in the space scales, sampling frequency, velocity field resolution and amount of divergence, large-scale fluxes were found to be remarkably similar in the various cases. The picture which has emerged is quite different from what has been inferred from measurements over multiyear ice. The annual total of net radiation absorbed in a large region is 2.5-3.0 times larger than that received by perennial ice. Most of this extra energy is absorbed in leads, contributing to lateral melting and bottom ablation. Although we still do not understand the details of melting processes in summer leads, these calculations indicate that sufficient solar radiation is deposited in the upper 3 meters of leads to melt away about 10% of the ice cover. Short-wave energy absorbed below the ice appears to be about twice what is needed to maintain the observed ice thickness. What happens to the rest of this energy is unclear. We suspect that it enhances (perhaps indirectly) the decay rate of pressure ridge keels, but more complex interactions involving meltwater and open leads are also possible. In any case, the results support the notion that little, if any, of the heat contained in the Atlantic layer reaches the surface in the Central Arctic.

Regional ice production and salt input to the ocean appear to be controlled by the relatively small areas of thin ice and open water created by ice deformation. Instead of the approximate balance between summer ablation and winter accretion observed in 3 meter ice, net annual ice production varied between 70 and 115 cm/cm^2 in the regions studied. Typically about 2/3 of this ice was advected out of each region, with the rest going to an increase in the amount of deformed ice. While there is no a priori reason to expect an equilibrium to exist, underestimation of ablation rates on pressure ridge keels may be responsible for the apparent thickening of the ice. A better understanding of keel decay would allow improved mass balance estimates. Rates of salt rejection parallel the ice production rates. Total regional salt fluxes were found to be 10-20 kg/m^2 yr, in contrast to the -4 kg/m^2 yr beneath multiyear ice. Much of this salt was injected during the fall and correlates with the deepening of the mixed layer. Unlike the situation over thick ice, turbulent heat exchange between the ice and the atmospheric boundary layer proved to be a major factor in the regional heat balance. Annual totals in all cases were at least an order of magnitude greater than over multiyear ice, being almost as large as the net radiation.

While this work enabled us to derive a more realistic picture of the ice cover and a quantitative appreciation of the importance of thickness variations, we learned little about the relative importance of different processes, parameters, and assumptions embedded in the models. To address this problem, we carried out a study involving over 40 additional simulations. Initially we concentrated on finding the most suitable values for yield curve and redistribution parameters used in the ice thickness distribution model. We then turned to questions relating to the velocity field and its impact on the regional heat and mass balance: How does the frequency of sampling the ice motion affect the predicted energy fluxes? What is the relative importance of shear in comparison to divergence? Do the uncertainties in our knowledge of ice velocity seriously affect the heat budget results? What is the significance of ice growth relative to strain? To what extent can statistical properties of the velocity field be used to infer large-scale ice characteristics?

Results from the simulations indicate that open water production is directly related to the magnitude of the velocity gradients. Larger velocity gradients decrease the amount of multiyear and deformed ice, while increasing the area covered by first-year ice categories in a way which is inversely proportional to their thickness. The frequency content of the ice motion has a large impact on the amount of young ice, but a relatively small effect on ice thicker than about 50 cm. Although including higher frequency motions does increase the area occupied by thin ice, it appears to be the lower frequency motions which control the total dynamic contribution to the regional heat exchange. Sampling errors due to nonlinearities in the velocity field were found to introduce uncertainties in monthly estimates of ice production and heat exchange of typically less than 20%. Shearing motions tend to produce thin ice and open water, primarily at the expense of the thicker first-year ice. Total ice production is relatively insensitive to the shear. Diverging motions also produce thin ice and open water, and allow for the development of substantial amounts of thicker first-year ice. Without divergence, ice production would decrease by more than 30%. Recent efforts to reproduce the regional results from a knowledge of the velocity variance alone have proven to be quite successful, indicating that it is more the level of deformational activity that is important rather than just the individual details of the strain field. If velocity statistics within particular regions do not undergo significant changes from year to year, it may be possible to drastically decrease the amount of actual data needed to generate large-scale heat and mass balance estimates.

The above calculations have provided us with a much more complete understanding of the coupling between dynamic and thermodynamic processes within the ice cover, and have shown that uncertainties in our large-scale estimates are small in comparison to differences between regional and local values. Nevertheless, understanding the reasons for a particular model response has, in many cases, proven to be difficult. Seasonal variability in the response of the ice, differing sensitivities of the various heat and mass balance components, and interactions between different thickness categories make it hard to unravel details of cause and effect. This has necessitated additional model runs which consumed considerably more time than anticipated. Most of the analysis, however, is now complete. We are presently carrying out supplementary calculations to better understand implications of the statistically generated strain results. We expect to submit this work for publication early in the coming year.

Lateral Melting in Leads. Our regional heat and mass studies have shown that shortwave radiation absorbed in summer leads has a major impact on the mass balance of the ice cover in the Central Arctic. The impact should be even larger in the marginal ice zone where lateral melting is believed to be a major factor in the retreat of the ice edge. Models of the effects of lateral melting on the decay of an ice cover have been formulated by Zubov (1945) and Langleben (1971). Both models are, however, severely limited by the assumption that all the solar energy deposited in a lead is available for lateral melting. In reality some of the energy is absorbed beneath the ice where it contributes to bottom melting, while some part of the remainder is lost to the atmosphere through longwave radiation and turbulent heat exchange.

As the first step in a combined theoretical and experimental study of the problem, we have developed a more realistic model of lateral melting. Solar energy absorbed in the water between the surface and the bottom of the ice goes into lateral melting, warming of the water, and heat input to the atmospheric boundary layer. Part of the energy absorbed below the bottom of the ice is returned to the leads according to their relative area, while the rest is used in the determination of mass changes at the ice bottom. A complete energy balance equation is applied at the surface of the lead to calculate water temperatures, which are then used to determine melt rates on the lead walls. Another energy balance equation is used to calculate surface ablation on the ice surrounding the lead. Using parameterizations developed from our radiative transfer studies, we are able to simulate clear and cloudy conditions, and to treat first-year as well as multiyear ice.

We have carried out a series of simulations to determine the sensitivity of lateral melt rates to air temperature, wind speed, ice thickness and incident radiation. The lateral melting was found to increase fairly linearly with air temperature, with the rate of increase depending on lead width. For example, a 2°C increase in the air temperature above the lead increased melt rates by 50% in narrow leads and by 75% in wide leads. In our standard case, increasing the wind speed decreased the amount of lateral melting because of a larger turbulent heat loss to the atmosphere. However, the response of the ice to a given atmospheric forcing was found to be dependent on assumptions regarding the rate of heat transfer between the water and the lead wall. Two heat transfer parameterizations were tested. One method required the water temperature to remain at the freezing point so that all excess energy contributed to lateral melting. The second method made use of an empirical algorithm determined from Josberger's laboratory experiments. The first method predicted consistently larger melt rates, ranging from a factor of two for a ten meter wide lead to two orders of magnitude for a 1000 meter wide lead. Unlike the first method, calculated water temperatures using the experimental algorithm were consistently higher than the assumed air temperature, reversing the direction of the turbulent heat fluxes. Calculations carried out over periods of several days show a continual increase in water temperature, suggesting either that the laboratory results underestimate the rate of heat transfer to the ice wall or that other processes are removing heat from the lead.

Our treatment predicts that lateral melt rates increase only slightly above a lead width of about 100 meters, in contrast to other models which implicitly assume that melt rates vary directly with lead width. One result of this prediction is a substantial change in the summer decay pattern. Although calculations for a seasonal ice cover yielded disintegration times quite similar to those obtained by Langleben with similar thermal forcing, thinning of the ice played a principal role in the overall decay. In Langleben's calculations it was the decrease in ice concentration which controlled the decay. Thinning of the ice was accelerated by a new positive feedback mechanism: decreasing ice thickness increased the amount of shortwave energy absorbed below the ice, enhancing the oceanic heat flux and rate of bottom ablation. In our simulations, disintegration times were also quite sensitive to the assumed air temperature.

The basic lateral melting model applies only to a single lead. To extend these ideas to the large-scale problem, we must consider an ice cover containing many different leads. The problem is how to represent the complex mosaic of ice floes and open water areas which evolve throughout the melt season. It is clear that ice concentration alone is inadequate for all but the most crude heat and mass balance calculations. We have investigated the effects of various, idealized lead geometries on the disintegration of the ice cover. We found, not surprisingly, that for a given fraction of open water the geometry providing the greatest lead perimeter maximized the amount of lateral melting. Since lateral melt rates appear to be such a weak function of lead width in larger leads, it seems possible that total floe perimeter, in conjunction with ice concentration, may provide a useful representation of the summer ice pack. We plan to analyze remote sensing imagery to better understand geometrical changes accompanying the decay of the ice.

While the simple picture of a well-mixed lead has produced results in general agreement with intuition, there is some evidence that large horizontal temperature gradients can exist in the upper few meters of summer leads. This suggests that the strong stability limits vertical exchange with deeper layers and that horizontal transport of heat across the lead may have a significant influence on lateral melting. The extent to which such transport might affect the previous results is unclear. In light of this we are developing a two dimensional model of heat diffusion in a lead. We also plan to investigate the effects of waves and ice motions on heat transport within the lead.

RADIATIVE TRANSFER STUDIES

A paper containing a detailed description of the operating characteristics of the scanning photometer and some of the spectral albedos from the 1979 spring field experiment at NARL has been accepted for publication by the Journal of Glaciology under the title "A Visible and Near Infrared Scanning Photometer for Observations of Spectral Albedos and Irradiance Over Polar Surfaces".

Laboratory and theoretical experiments have provided us with a good understanding of the optical properties of sea ice, and of the factors which influence them. Since the absorption coefficients of brine and pure ice are essentially independent of temperature, the albedo and transmission properties of young sea ice are governed by the effectiveness of scattering within the ice. Scattering, in turn, is determined primarily by the platelet structure and distribution of brine between the platelets. Enhanced scattering results in higher albedos; it also increases the extinction coefficients because multiple scattering greatly increases the optical path length, resulting in a corresponding increase in the probability that the light will be absorbed within the ice. The amount of scattering is inversely related to the temperature. With increasing temperature, brine pockets and channels open up and the brine/ice interfaces coalesce and become more rounded which lowers the scattering cross sections and decreases the density of the scattering inhomogeneities. If the ice temperature drops below the eutectic point, salt crystals are precipitated out of solution causing a sudden increase in the scattering. The resulting albedos are similar to those of snow. Growth rate was also found to be important because it determines the crystal sizes, platelet spacings, and the initial distribution of brine in the ice.

Attenuation in the uppermost layers and spectral albedos are also influenced by changes in surface conditions. Flooding of the surface due to melting or to expulsion of brine upon cooling gives a smooth surface and lowers the albedo. Formation of salt flowers or melting followed by brine drainage leaves an uneven crumbly surface with a higher albedo. A complete description of these results is now available as a scientific report. A condensed version which concentrates on the dependence of albedo and light transmission in young sea ice on temperature, brine volume, and surface conditions has also been accepted for publication by the Journal of Glaciology.

A theoretical analysis using a four stream discrete ordinates model was carried out to relate variations in albedo and transmittance to changes in such model parameters as single scattering albedo, the angular distribution of scattering by small elements of ice (the phase function), and surface scattering. One and two layer models were compared to experimental results using absorption coefficients derived from the work of Sauberer (1950), and a representative phase function derived from the results of our scattering experiments. The scattering efficiency was treated as an adjustable parameter to fit the observed spectral albedos at 650 nm. Calculated transmissivities at 650 nm were then compared with observations. The difference between theory and observation varied from 0.6% to 55%, where the best agreement was obtained for warm homogeneous ice. The differences increased for colder more rapidly grown ice. The poor agreement for cold ice suggests that vertical variations in the ice structure resulting from temperature and brine volume gradients are sufficiently important that a precise treatment of the problem will require a model containing more than two layers.

To further test the model, spectral albedos (α_λ) and transmissivities (T_λ) were calculated for the homogeneous ice. The scattering cross sections were taken to be independent of wavelength. Agreement with observations for both α_λ and T_λ were quite good, however, small systematic deviations up to about 10% were present for T_λ. We suspect that since the wavelength dependence of the transmittance is determined primarily by the spectral absorption coefficients, the observed deviations indicate that inaccuracies may be present in the absorption coefficients obtained by Sauberer. A paper describing in detail the theoretical analysis of the observations has been submitted to the Journal of Glaciology.

The magnitudes of the spectral absorption coefficients for pure ice (k_λ) at visible wavelengths, although quite small, are very important in radiative transfer modeling of sea ice, snow, and terrestrial ice clouds. They are also needed in a number of extraterrestrial applications. The only data available between 400 and 900 nm have been those of Sauberer. He reported values at 100 nm intervals, but because of the relative thinness of the pure ice samples available to him, his data are reliable only to one or two significant figures. In view of inconsistencies which have appeared in our comparisons of observational and theoretical results and because of similar difficulties encountered by other investigators in modeling albedos of snow, we felt that it was important to improve our knowledge of k_λ at visible and near-infrared wavelengths.

Accordingly, we carried out a series of measurements using the new scanning photometer obtaining substantially better spectral resolution. To improve the accuracy of the k_λ determinations, it was necessary to grow thick samples of bubble-free ice. For this purpose, we employed the stirring technique developed several years ago in our laboratory. We produced a single ice block 2.8 m long which allowed us to obtain a sufficiently large beam attenuation to achieve three figure accuracy in k_λ. At wavelengths greater than about 1000 nm the resulting values agree very well with previous data, but differences increase gradually at shorter wavelengths and are greatest between 400 and 600 nm. Because of the higher spectral resolution and the much greater optical path length through the ice, the present values are at least an order of magnitude more accurate than the data of Sauberer. We now see new spectral features which are consistent with those for k_λ (water) and an absorption minimum at 470 nm instead of 400 nm, again in better agreement with the results for water. Although we have not yet checked quantitatively, it also appears that the new results will improve the accuracy of the theoretical predictions for ice and snow albedos. A paper describing the experiment has been submitted for publication to Journal of Geophysical Research, and the results were also described in a presentation at the latest meeting of the Northwest Glaciological Society.

Reduction of the data from the 1979 spring field experiment at Pt. Barrow is still in progress. Spectral albedos have been obtained from all 40 observation sites. The incident spectral irradiances recorded on magnetic tape have also been retrieved. We now have a complete record for first-year ice from late winter through the onset of the melt season. Because of the improved spectral resolution in the infrared and the extended wavelength range, we have spectral albedos over essentially the entire solar spectrum together with the incident spectral irradiance for clear and cloudy conditions. Consequently, we will be able to carry out precise radiative energy balance calculations without resorting to extrapolation to longer wavelengths. The present results are consistent with concurrently measured bulk albedos and total irradiances. Good agreement is also found with our previous results for melting first-year ice at visible wavelengths, where the spectral resolution is comparable. Beyond 800 nm, however, the new data appear to be much more accurate. In addition, we find that although clouds do absorb much of the infrared radiation, a good deal more infrared energy reaches the surface than we previously suspected.

The photometer was used this spring to measure the evolution in the albedo of an alpine snowpack. The goal of this study was to provide a standard of comparison for snow measurements at high latitudes, and to test existing theories of the optical properties of snow. Data were obtained from initial snowfall until the final melting stage and concurrent measurements were taken of snow grain geometry, density, and impurity content (dust and graphitic carbon) to permit an accurate comparison with theory. Bulk albedos were also obtained using Kipp and Zonen radiometers as a check for the spectral values. Subsequent integration of the spectral albedos showed close agreement with the bulk albedos. In the visible, the albedos are influenced most strongly by the impurity content while at infrared wavelengths, the snow grain size is the controlling parameter. Beyond 900 nm the effect of impurities is negligible for the amounts of impurities encountered in the field. Comparison with recent theoretical calculations indicated that predicted albedos are still a bit too large in the visible suggesting that further sophistication is needed in the theory. The results of this study have been accepted for publication by Cold Regions Science and Technology and a talk was presented at the last meeting of the Northwest Glaciological Society.

We are presently adapting the 16-stream radiative transfer model to carry out a parameter study of how the albedo and transmission of the ice are affected by variations in the brine volume and distribution, crystal structure, and the concentration and size distribution of vapor bubbles. We have adapted to the UW computer an efficient Mie scattering program developed at NCAR which is two to three times faster than our previous program. This will be used to calculate scattering and absorption by spherical brine inclusions and by bubbles. We have also acquired a computer program for scattering by long cylinders which will be used for brine channels. The code has been adapted to work on the UW computer. It has been checked for accuracy, and has been speeded up by a factor of 50 to operate efficiently for the very large size parameters necessary. When this code has been incorporated into the model, we will begin to construct a consistent theoretical framework to compare with the optical properties of different ice types for which we have observational data. Once this is completed, we plan to extend the results to cases for which data are not yet available. We will also use the data from the scattering experiments together with the model to determine how varying the concentrations of the different scattering inhomogeneities affects the optical properties of the ice. Finally, we plan to generalize the program to make simultaneous calculations at microwave wavelengths (3 mm to 3 cm) in order to take advantage of aircraft and satellite data obtained for the same ice types we have studied at visible and near infrared wavelengths.

Measurements of the light scattering properties of sea ice and glacier ice have been completed. Fifty-eight different cases were studied including bubble-free ice, fresh bubbly ice (glacier ice), young sea ice grown at various air temperatures, and grease ice. The scattering coefficients of sea ice depend on the initial freezing rate, the current sample temperature, and the bubble density. However, the phase function, which describes the angular distribution of the scattered radiation, does not depend strongly on wavelength or sample orientation. For a given temperature, grease ice shows more side and backscattering because it consists of small randomly oriented crystals as opposed to the larger columnar crystals characteristic of sea ice grown in calm water. Publication of the results has been delayed because the observed phase functions are not well approximated by Mie scattering for spheres. Since long circular cylinders better approximate the shape of the brine inclusions in our samples, we plan to use the new scattering code to see if agreement with observations can be improved.

FLUID MECHANICS AND SEA ICE

During the past year we have organized a large backlog of material and written it up for publication in a series of eight papers and reports. The subjects of these papers include the ablation of vertical ice walls in warm seawater, the propagation of ocean swell into pack ice, the nature of the Bering Sea ice edge, and the behavior of oceanic frazil ice.

Our results include the following, where the names in parentheses refer to particular papers:

1. An experimental demonstration of the nonlinear viscosity of grease and frazil ice (Martin and Kauffman);
2. A theoretical and experimental study of how vertical ice walls melt in seawater and the presentation of a simple formula for the prediction of this melt rate (Josberger and Martin);
3. Observations on the environment of the Marginal Ice Zone (MIZ), the role of ocean swell in maintaining the MIZ, and the formation of the 1 km wide by 10 km long bands of ice which form and decay at the edge (Bauer and Martin, Squire and Moore, Squire and Martin).

We also carried out the following work in the laboratory. First, in September 1979, Peter Kauffman completed construction of our new wave tank measuring 4.5 m long, 1 m deep, and 1 m wide, which we are presently using to study grease ice growth and wave damping by ice floes. He then assembled a microprocessor based, data-acquisition and processing system, with which we record laboratory data on discs, then carry out Discrete-Fourier Transforms (DFT's) on the data. For our study of wave propagation in ice sheets and floes, he also built wave amplitude probes out of commercial accelerometers. Using this system, we carried out a series of experiments between March and June 1980 in cooperation with Vernon Squire of the Scott Polar Research Institute (SPRI) on wave propagation from open water into thin ice sheets.

The purpose of these experiments was to search for theoretically-predicted stress concentrations near the leading edge which cause large ice sheets to fracture in nature, and for which Squire has developed a theoretical solution. We carried out these experiments by growing an ice sheet of thickness 10-40 mm, then cleaning out a 1 m long open water space between the paddle and the leading ice edge before generating waves with our paddle. We then placed our accelerometers at 50 mm intervals down the centerline of the ice, recorded the wave amplitudes over the 2.5 m ice sheet length, then ran the DFT on the signals. The data shows the presence of a stress concentration near the leading edge as expected, but the location of the stress concentration was altered by the presence of waves reflected from the trailing edge of the sheet for the cases both with and without the presence of a beach in the water. For some cases when the propagating wavelength corresponded to the length of the sheet, we also observed strong resonances.

Also in June we carried out two experiments on the problem of parallel crystal growth in a uniform current with a graduate student at SPRI, Ms. Patricia Langhorne. We did these experiments in the wave tank, where we took advantage of the fact that in the boundary layer between a flexible ice sheet and a propagating wave, there is a mean current in the direction of wave propagation. In our experiments we grew a thin sheet of ice without waves, then turned on the waves while keeping the room cold so that the ice continued to grow. Our preliminary results suggest that parallel crystals grew in the wave field with c-axes at right angles to the wave-generated current. Because long ocean waves incident on a coast propagate with their crests parallel to the coast, these experiments suggest yet another mechanism besides mean currents for the generation of ice crystals with c-axes parallel to the coastline. Because of the importance of these observations, we plan a possible repeat of this experiment during Fall-Winter 1980-81. Finally, we are just beginning in the same tank a series of experiments on wave damping by ice floes.

In work outside the laboratory, a graduate student Jane Bauer is using the results of our laboratory and field grease ice data to assemble a model of ice growth in a one-dimensional polynya with a cold wind blowing over it. For this case, our observations show that grease ice forms over the entire polynya, then wind and waves herd this ice to the downwind end, where the thickness to which the grease ice piles up is a function of the wave properties and wind speed. We hope that this model will predict the ice cover growth as a function of fetch, windspeed, and wave properties. We plan to compare this model with existing satellite observations in the Bering Sea to see if our assumption that the polynyas are important ice generation regions is correct. We then plan to extend the model to the case of Langmuir circulations in two-dimensional polynyas in an attempt to model observed ice growth in wind rows.

REPORTS PUBLISHED AND IN PRESS

1. Martin, S., A field study of brine drainage and oil entrainment in first-year sea ice. Journal of Glaciology, 22 (88), 473-502, 1979.

From field observations this paper describes the growth and development of first-year sea ice and its interaction with petroleum. In particular, when sea ice initially forms, there is an upward salt transport so that the ice surface has a highly saline layer, regardless of whether the initial ice is frazil, columnar, or slush ice. When the ice warms in the spring, because of the eutectic condition, the surface salt liquifies and drains through the ice, leading to the formation of top-to-bottom brine channels and void spaces in the upper part of the ice. If oil is released beneath winter ice, then the oil becomes entrained in thin lenses within the ice. In the spring, this oil flows up to the surface through the newly-opened brine channels and distributes itself within the brine-channel feeder systems, on the ice surface, and in horizontal layers in the upper part of the ice. The paper shows that these layers probably form from the interaction of the brine drainage with the percolation of melt water from surface snow down into the ice and the rise of the oil from below. Finally in the summer, the oil on the surface leads to melt-pond formation. The solar energy absorbed by the oil on the surface of these melt ponds eventually causes the melt pond to melt through the ice, and the oil is again released into the ocean.

2. Josberger, E. G., The effect of bubbles released from a melting ice wall on the melt-driven convection in salt water. Journal of Physical Oceanography, 10 (3), 474-77, 1980.

The buoyancy created by the release of air bubbles from melting glacial ice walls results from both the upward drag of the bubbles and the density defect caused by the steady-state distribution of bubbles in the water. Calculations using typical antarctic ice bubble concentrations and Southern Ocean temperatures and salinities show that the bubble buoyancy is comparable to the dilution for vertical ice length scales greater than 100 m. A comparison of laboratory experiments using 0.6 m long sheets of both bubbly and bubble-free ice shows two additional bubble effects. First, the bubbly ice melts in an irregular fashion that produces indentations in the ice which measure 20 mm long, 25 mm wide and 5 mm deep, while the bubble-free ice melts smoothly. Second, the ice-water interface salinity in the bubbly case is higher than in the bubble-free case. Finally, the observed melt rates lie within 10% of the observed melt rates from the bubble free experiments.

3. Squire, V. A. and S. Martin, A field study of the physical properties, response to swell, and subsequent fracture of a single ice floe in the winter bering sea. Scientific Report No. 18, Office of Naval Research, Contract N00014-76-C-0234, Department of Atmospheric Sciences, University of Washington, Seattle, Washington, 56 pp., 1980.

Surface strain and vertical heave response experiments were conducted for a single floe within the marginal ice zone of the winter Bering Sea. The strain was measured using an array of three strainmeters placed in a 120° rosette configuration, and the heave was computed from simultaneous records of vertical acceleration on the floe and in the water around the floe. Physical properties studies and underwater traverses by divers were also carried out for the floe. The data are presented and interpreted in the light of the subsequent floe fracture; the mean fracture strain amplitude ε is found to lie between 44 and 85 μstrain. A discussion of the directionality of the wave energy during the experiment is also given.

4. Squire, V. A. and S. C. Moore, Direct measurement of the attenuation of ocean waves by pack ice. Nature, 283 (5745), 365-68, 1980.

Early experimental work in the Antarctic using a ship-borne wave recorder has shown that pack ice can significantly attenuate incoming ocean waves, particularly those of shorter period. Wadhams has subsequently reported similar wave decay through arctic ice in data obtained remotely by means of airborne laser profiling and inverted echo sounding from a submarine. The two predominant mechanisms by which the decay can occur - scattering by individual ice floes and energy loss by creep within each flexing floe - have been studied theoretically by Wadhams, Squire, and Squire and Allan. We present here the results of further experiments to measure wave decay which took place in the Bering Sea during spring 1979 from the research ship Surveyor of the National Oceanic and Atmospheric Administration. During the cruise, oceanographic, meteorological and remote sensing data were also collected. The results show the energy decay of waves in pack ice to be exponential with an attenuation coefficient which increases with decreasing wave period.

5. Bauer, J. and S. Martin, Field observations of the Bering Sea ice edge properties during March 1979. Monthly Weather Review (in press).

6. Grenfell, T. C., A visible and near infrared scanning photometer for field measurements of spectral albedo and irradiance under polar conditions. Journal of Glaciology (in press).

7. Grenfell, T. C., D. K. Perovich, and J. A. Ogren, Spectral albedos of an alpine snow pack. Cold Regions Science and Technology (in press).

8. Josberger, E. and S. Martin, A laboratory and theoretical study of the boundary layer adjacent to a vertical melting ice wall in salt water. Journal of Fluid Mechanics (in press).

9. Martin, S., Frazil ice in rivers and oceans. Annual Reviews of Fluid Mechanics (in press).

10. Martin, S. and P. Kauffman, A field and laboratory study of wave damping by grease ice. Journal of Glaciology (in press).

11. Perovich, D. K. and T. C. Grenfell, Laboratory studies of the optical properties of young sea ice. Journal of Glaciology (in press).

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The report summarizes research performed under Contract N00014-76-C-0234, NR 307-252, during the year 1 October 1979-30 September 1980. Research topics include: (i) growth of ice in a wave field, (ii) large-scale heat exchange and ice production, (iii) interaction of solar radiation with the ice and upper ocean, (iv) optical properties of ice and snow, (v) generalized radiative transfer modeling, (vi) wave propagation and other ice edge phenomena.		

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NATIONAL SCIENCE FOUNDATION
WASHINGTON, DC 20550

DR NORBERT UNTERSTEINER
DIRECTOR OF OCEAN AFFAIRS
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