Naval Oceanographic and Atmospheric Research Laboratory

SP 059:321:90
September 1990

AD-A229 396

Altimeter Sea Ice Workshop

Sponsored by
Naval Oceanographic and Atmospheric Research Laboratory
Remote Sensing Branch
Ocean Sensing and Prediction Division
Ocean Science Directorate

Jeffrey D. Hawkins

Approved for public release; distribution is unlimited. Naval Oceanographic and Atmospheric Research Laboratory, Stennis Space Center, Mississippi 39529-5004.

90 11 26 030

NOARL Remote Sensing Branch

Altimeter Sea Ice Workshop

Who: Scientists actively engaged in altimeter sea ice work

List of attendees attached separately, as is a larger mailing list of interested scientists.

What: Altimeter Sea Ice Workshop

Informal meeting hosted by the Naval Oceanographic and Atmospheric Research Laboratory (NOARL).

When: February 15-16, 1990

Since several participants attended the sea ice and altimeter AGU Ocean Sciences sessions, the workshop met on the afternoon of February 15 and the morning of February 16. This freed Friday afternoon for travel home.

Where: Hyatt Hotel

NOARL reserved the Rosedown Room in the Hyatt Hotel (site of the AGU meeting) in an effort to accommodate AGU meeting attendees.

Why: Information Exchange

To hold a meeting with the select few scientists who are actively investigating sea ice geophysical parameter extraction from altimeter (satellite and aircraft) data to

- exchange information on data sets, findings, problems and likely future research directions;
- identify common goals when possible and foster cooperative efforts, especially since present data sets are inadequate in several ways and future ones are expensive;
- insure best possible products will be available for the next altimeter launched (ERS-1, Geosat Follow-On, etc.).

How: Agenda (complete version on next page)

Past and present work by each organization summarized to bring the participants up to date on the various efforts. Besides the obvious information exchange, the emphasis was on discussing requirements for upgrading parameter extraction for the next altimeter(s) and what cooperative efforts are feasible to meet this goal.

Agenda

NOARL Altimeter Sea Ice Workshop Agenda
(15 February 1990)

Operational Sea Ice Algorithms

1:00–1:10 p.m.	Hawkins	Welcome—overview of workshop
1:10–1:25 p.m.	Hawkins	Present U.S. Navy operational capabilities
1:25–2:05 p.m.	Chase/Fetterer	U.S. Navy ice index upgrades
2:05–2:35 p.m.	Laxon/Rapley	ERS-1 altimeter sea ice products
2:35–2:50 p.m.	Montgomery	ERS-1 data access
2:50–3:05 p.m.	Break	Refreshments and snack available

Altimeter Sea Ice Investigations

3:05–3:30 p.m.	Laxon	Geosat/AVHRR sea ice comparisons
3:30–4:00 p.m.	Ulander	Airborne SAR experiments in support of sea ice altimetry
4:00–4:25 p.m.	Drinkwater	Ku-Band airborne altimetry during MIZEX-84
4:25–4:50 p.m.	Jezek	Ku-band laboratory and field observations of snow-covered ice
4:50–5:15 p.m.	Onstott	Near-surface microwave observations in support of remote sensing using radar altimeters
5:15–5:40 p.m.	Laxon	Variations in Antarctic sea ice extent
6:45 until	Dinner	Informal meal in French Quarter

16 February 1990

8:00–8:30 a.m.	Laxon/Hawkins	Altimeter sensing of tabular icebergs
8:30–9:00 a.m.	All/Hawkins	Existing data sets—Discussion
9:00–9:20 a.m.	All/Hawkins	ERS-1 altimeter validation
9:25–9:40 a.m.	Hawkins/Eppler	Spinsat altimeter (SALT)
9:40–10:05 a.m.	Lagerloef	NASA TOPEX, ERS-1
10:05–10:15 a.m.	Break	Refreshments available
10:15–10:25 a.m.	Luther	CRREL facilities for altimetry research
10:25–11:15 a.m.	All	Unresolved issues—Where are we going?
11:15–Noon	All	Cooperative studies—Discussion
Noon	Adjourn	

NOARL Altimeter Workshop Attendees

Name	Telephone	Address
Nita Chase	601-688-481	NOARL Code 321, SSC, MS 39529-5004
Joey Comiso	301-286-9135	NASA-GSFC Code 671, Greenbelt, MD 20771
Mark Drinkwater	818-354-8189	NASA-JPL MS 300-323 4800 Oak Grove Dr. Pasadena, CA 91109
Duane Eppler	603-646-4175 Fax-4320	NOARL Polar Oceanography Branch C/O CRREL, 72 Lyme Road Hanover, NH 03755-1290
Florence Fetterer	601-688-5456	NOARL Code 321, SSC, MS 39529-5004
Jeff Hawkins	601-688-4864 Fax-4149	NOARL Code 321, SSC, MS 39529-5004
Ron Holyer	601-688-4864	NOARL Code 321, SSC, MS 39529-5004
Ken Jezek	614-292-6531 Fax-4697	Byrd Polar Res Center, 125 S. Oval Mall Columbus, OH 43210
Gary Lagerloef	202-453-1663	NASA Code EEC, Washington, DC 20546
Rob Massom	301-286-2141	NASA GSFC Code 671 Greenbelt, MD 20771
Seymour Laxon	011-44-483-224111 Fax-278312	MSSL, University College London Holmbury St. Mary Dorking Surrey RH56NT
Chuck Luther	202-696-4123 Fax-5383	Office of Naval Research, 800 N. Quincy St. Arlington, VA 22217
Matt Lybanon	601-688-5263	NOARL Code 321, SSC, MS 39529-5004
Vicky Lytle	603-646-4629	Dartmouth College, Thayer Sch. Engineering HB 8000, Hanover, NH 03755

Don Montgomery	703-602-3187 Fax-1535	Space & Naval Warfare Command NCR#1, 2511 Jeff Davis Hwy Washington, DC 20363-5100
Bob Onstott	313-99-1200 Ext 2544	ERIM, P.O. Box 8618 Ann Arbor, MI 48107-8618
Al Pressman	601-688-4864	NOARL Code 321, SSC, MS 39529-5004
Chris Rapley	011-44-483-224111	MSSL, University College London Holmbury St. Mary, Dorking Surrey RH56NT
Lars Ulander	46-31-721843 Fax-164513	Dept. of Radio & Space Science Chalmers University of Technology S-41296 Goteborg, Sweden

Altimeter Sea Ice Workshop

Presentation Summary

Hawkins: Present U.S. Navy Operational Capabilities

NOARL's Remote Sensing Branch successfully carried out a demonstration program aimed at extracting sea ice information from the Geosat altimeter signal. This effort significantly enhanced earlier limited studies done with the GOES-3 altimeter by incorporating the Automated Gain Control (AGC) and the Voltage Proportional to Attitude (VATT) parameters carried in the real-time data stream. These measures of the return pulse were combined in a ratio form to create an "ice index," so that all values less than a cutoff magnitude were characteristic of open water, while all remaining values above were sea ice.

Validation was carried out using visible and infrared polar orbiter (AVHRR) data in the Greenland Sea and Antarctic and on feedback from ice analysts at the Navy/NOAA Joint Ice Center (JIC). Good agreement was found after the VATT parameter was appropriately redefined and the threshold fine tuned with the help of AVHRR data. However, partial results indicated this "ice edge" index did not approach the ice-/no-ice threshold until the concentration was above 40-60 %. This will be discussed in the next talk.

NOARL provided near-real-time product support for 2 years during which the ice index was plotted perpendicular to the altimeter ground track for each of the 14+ revs per day for each hemisphere. Computer digital files were generated at NOARL, transferred to the Fleet Numerical Oceanography Center (FNOC), and put in graphics format for subsequent transmission to the JIC. Particular care was taken to present the altimeter ice index graphic in the exact same projection and resolution of the JIC working charts. This promoted a user-friendly product, since the data could be simply overlain on all other working charts.

The JIC incorporated the ice index information into their ice analyses, especially in the Antarctic where AVHRR data are less dense. Interest heightened when comparisons with digital AVHRR imagery revealed that variations in the ice index could be crudely aligned with ice characteristics (i.e., a generic term used here to include roughness, type, concentration, etc). This was especially true for a case in the Kara Sea where the change between first year ice and signals from a smooth frozen polynya were accompanied by readily seen ice index gradients. It is envisioned that a similar product will be generated for Geosat Follow On (GFO) altimeters.

After successful demonstration, both hardware and software were transitioned to NAVOCEANO for operational production. NAVOCEANO continued to generate this daily ice information for the remainder of the Geosat mission. One minor change was performed as the index was fine tuned further with additional AVHRR support.

Chase/Holyer: U.S. Navy Ice Index Upgrades

The Geosat altimeter transmits a radar pulse toward earth, then measures earth-reflected energy in a number of discrete time gates. The signal amplitudes in successive gates create a "waveform," the shape of which is determined by the reflectance characteristics of the earth's surface. Until now, the Geosat Ice Index (described in the talk by Hawkins), can be used in two ways: to detect the ocean-ice interface and to give some indication of surface roughness. Thus, this study is aimed at extracting additional information on ice characteristics (i.e., type, concentration, etc.).

The altimeter footprint varies in size, depending on the surface roughness. In extremely smooth cases, the surface area is less than 1 km; in rough examples, it may be 5-7 km in areal extent. So, unless the altimeter footprint is fortuitously sampling a location where only one surface type is present (open water, first-year [FY] ice, multiyear [MY] ice, etc.), the altimeter waveform will be a mixture of returns from two or more surface types.

Linear unmixing theory was chosen as the methodology for analysis of the waveform returns. The mixing model assumes the data samples are linear combinations of a limited number of end members (i.e., FY ice, MY ice, and open water). Thus, unmixing analysis consists of identifying the number and nature of the end members, followed by an interpretation of the data set in terms of end-member combinations.

Estimates of ice type and concentration obtained via linear unmixing were compared with "ground truth" derived from visual interpretation of airborne passive microwave imagery and aerial photography. MIZEX 87 provided the opportunity to use the NOARL K-band Radiometric Mapping System (KRMS), a 33.6-GHz passive microwave imager, on a Navy P-3. Nine Geosat tracks were underflown in the East Greenland Sea within 1 hour of coincident altimeter coverage. The KRMS data were separately analyzed and then compared globally with linear unmixing results.

In general, excellent results were achieved. Sea ice concentrations by ice type over the experiment area agreed with the surface truth to within 5%. When FY and MY ice types were combined to give total ice concentration, the agreement was within 2%. Thus, linear unmixing has been shown to be a useful paradigm for extracting ice information from waveform shapes. However, this approach needs further investigation. In particular, the method of choosing end members (i.e., the mixing polytope) in this effort was subjective.

The present formulization of the ice index was also examined both theoretically and experimentally. The conclusion is that the index is inherently insensitive to changes in ice concentration when the concentration is less than 50%. A new ice index that exhibits sensitivity that is independent of concentration is proposed. Based on statistics using the same "ground truth" as above, it appears the new ice index can be related to ice concen- trations with an rms accuracy near 12%. Further studies are required to determine if these conclusions are valid for areas and seasons other than East Greenland Sea in spring.

Fetterer: Navy Upgrades to Altimeter Sea Ice Index

The Navy/NOAA Joint Ice Center used Geosat altimeter data to obtain ice edge position fixes in near-real time during the Exact Repeat Mission. Previous work (e.g., Ulander, 1988) has suggested that information about ice surface roughness, and by extension ice type, can be inferred through the changing power and shape of altimeter pulse echoes within the ice edge. This talk describes the comparison of a SAR image of East Greenland pack ice with altimeter data. The comparison was made to learn more about the possibility of extracting ice characteristics from altimeter data on an operational basis.

The X-band SAR image was collected during MIZEX-87 within 2 hours of a Geosat over- pass. It covers a 63-km-wide swath across pack ice from the ice edge to the Greenland coast at 72°N. The SAR image shows, from east to west,

- a 150-km-wide, uniformly bright area in the Marginal Ice Zone (MIZ) consists of floes that, for the most part, are smaller than the sensor resolution (5 m by 15 m);
- a broad expanse of FY floes and MY ice in a matrix of FY ice with little or no open water, with a few very large (10-km diameter) MY floes;
- fast ice in Davy Sund.

The altimeter ground track is roughly centered on the SAR image. The altimeter param- eter AGC is a measure of the mean power in the altimeter pulse echo and is high (about 20 dB) over the MIZ, lower and more variable over the pack ice, and lowest (about 0 dB) over fast ice. The altimeter parameter VATT is a measure of power in the last eight gates of the waveform, indicates waveform shape, and is low over the MIZ (indicating peaked, specular-type waveforms), variable over the pack, and high over the fast ice.

AGC and VATT, as well as others derived from the altimeter waveforms, were clustered to see if clusters corresponded to ice type or other characteristics. It was concluded that pulse echo power and shape are not certain indicators of ice type in this case, since the surface roughness and dielectric characteristics of the ice are inhomogeneous within the altimeter footprint. However, AGC and VATT can be used in this case to delineate the MIZ, pack, and fast ice. The specular nature of pulse echoes in the MIZ may be due to reflection from small areas of smooth water between floes. Such areas need cover only 0.01% of the surface within the pulse-limited footprint to produce a specular return (Robin et al., 1983).

References

Robin, G. de Q., D.J. Drewry, and V.A. Squire (1983). Satellite observations of polar ice fields. *Philosophical Transactions of the Royal Society of London* A309:447-461.

Ulander, L.M.H. (1988). Observations of ice types in satellite altimeter data. In *Proceedings of IGARSS'88*, Edinburgh, 655-658.

Laxon/Rapley: ERS-1 Altimeter Sea Ice Products

Algorithms for processing sea ice data from the ERS-1 altimeter are already in an advanced state of development at the Mullard Space Science Laboratory (MSSL). Two types of products will be made available.

Quick Delivery (QD) Sea Ice Margin product: This product will consist of a list of transitions detected in the altimeter data from ocean-mixed ocean/sea ice—sea ice surfaces. The algorithm processes a simple sequence of flags indicating an "ocean" or "non-ocean" return and then decides, depending on how consistent the flag is over a predetermined distance, whether the altimeter is in an ocean, mixed, or sea ice regime. It is intended to drive this algorithm using the output from the QD sea ice indices product, although it should be possible to drive it using some parameters from the ERS-1 altimeter Fast Delivery (FD) product if the time delay in obtaining the off-line (waveform) data becomes unacceptable for operational users. However, generating information from the FD product may seriously compromise the quality of the final product.

QD Sea Ice Indices Product: This product consists of a series of six parameters derived from the waveform shape. The parameters are designed to retain information regarding the waveform shapes, which are important in the analysis of altimeter data over sea ice. They are also designed to be semicompatible with previous products (i.e., you can use these indices to generate something that looks very much like the Geosat Ice Index). The product should also be independent of ice/ocean tracking modes employed on ERS-1. Four of the parameters characterize the waveform shape by averaging the power in broad gates and by computing the peak power returned, and two of the parameters characterize the leading edge.

Montgomery: ERS-1 Data Access

U.S. and foreign satellites launched in the 1990-1995 timeframe will provide new sources of ocean measurements. The ERS-1, TOPEX, and RADARSAT satellites will become unique sources of space-based ocean observations that will augment operational NOAA, DMSP, and GOES measurements. Geophysical parameters such as ocean surface winds, ocean wave spectra and high-resolution all-weather sea ice characteristics, which we have only had a taste of in the past, will hopefully become available.

With this in mind, the opportunity now exists to exchange a variety of data sets. This access to future sensors will start with the ERS-1 low bit rate products as they come from Bracknell, U.K. to NESDIS and NMC in Suitland. The data will then be distributed to interested researchers via NOAA specified agreements.

The ERS-1 low bit rate (LBR) real-time products will include global dealiased winds in 500 km x 500 km boxes, wave spectra in 5 km x 5 km boxes and wave height, wind speed and altitude of spacecraft (altimeter). The sigma-nought values from the scatterometer will also be sent. These parameters will be made available to Bracknell within 3 hours of observation and shortly thereafter to NOAA. Of particular interest is the operational demonstration focus of the ERS-1 effort within ESA. This was one of the goals of Seasat, but never really got off the ground. The logistics and time needed to resolve many of the issues that bogged down Seasat have been overcome.

Other sizable efforts are being made to gather ERS-1 SAR data from the Alaska SAR Facility (ASF), Tromso, Norway, and the Canadian Ice Center in Ottawa for sea ice studies. ASF data will be transmitted to the NOAA Ice Center. A separate SAR workstation (utilizing a SUN SPARC) will process and display ice motion and ice-type parameters.

The SAR data is of particular concern for those of us eagerly looking for "ground truth" or coincident data sets to match up with altimeter sea ice parameters. The use of AVHRR or DMSP has been very complementary, but the inherent limitations require the use of an "all-weather" sensor in order to create the necessary data base required to make additional progress. ERS-1 data then holds the promise of filling a portion of this data gap.

Laxon/Hawkins: Geosat/AVHRR Sea Ice Comparisons

The Geosat spacecraft is a single sensor, altimetric, polar platform. As such, testing and validation of geophysical parameters must be done via other sensors (spacecraft), aircraft surveys or field ground truth programs. This task is complicated because the altimeter footprint is relatively small (1-8 km) for space-based instruments. Thus, wide field of view sensors on satellites, which cover the Geosat ground track within agreeable timeframes (several hours), are needed to carry out plausible studies.

NOARL utilized its global AVHRR receiving system to acquire coincident visible and infrared 1-km imagery for altimetric sea ice investigations. The original effort focused on the East Greenland Sea and the Kara Sea, two marginal Arctic Seas that have ice within the 72° limitation of the Geosat satellite. Numerous images with cloud-free scenes were gathered for the East Greenland Sea and several for the Kara Sea.

Comparison of altimetry and AVHHR shows good correlations between features observed in the imagery and zones in the altimeter profiles. In particular, comparisons show that for compact ice edges, a dramatic rise in backscattered power and "peakedness" of the altimeter return occurs. For diffuse ice edges, a more gradual but still significant increase in return power and change in waveform shape occurs. These conditions were found in the East Greenland Sea under a variety of on-ice and off-ice wind conditions.

Comparisons in the Kara Sea were of particular interest, since the images readily revealed the existence of extensive high concentrations of FY ice and smooth, frozen polynyas and leads with young and new ice. The young and new ice areas exhibited much higher back- scatter than over more mature FY ice as expected. This was evident not only in the ice index, but the AGC and VATT signals as well.

Last, observations over vast (>10 km) ice floes and fast ice in the East Greenland Sea show low power "ocean like" returns. This happens because no smooth areas occur within the altimeter footprint, and the return from MY and Fast ice results in a diffuse return. Additional examples are being studied in the Antarctic within the Weddell and Ross Seas.

Ulander: SAR Experiments in Support of Sea Ice Altimetry

Passive and active microwave sensors are increasingly being used for sea ice monitoring in the polar regions. The spaceborne radar altimeter was primarily designed for oceano- graphic applications, but provides unique measurements over sea ice along the subsatellite track. When it crosses the ocean-ice boundary, the returned pulse echo drastically changes character. Over sea ice, the normal-incidence backscatter coefficient is in the 0- to 50-dB range and may vary considerably with incidence angle; over the open ocean, it is in the 8- to 15-dB range and is essentially independent of incidence angle.

The width of the returned pulse echo is the most sensitive indicator to delineate the ocean-ice boundary. However, the ice type shows a higher correlation with the backscatter coefficient. With this approach, it has been shown that MY ice and new ice can be clas- sified in the Beaufort Sea (Ulander, 1987), and thin FY and young ice in the Baltic Sea (Ulander, 1990). However, ambiguities do exist and the effects of large-scale roughness (rubble/ridges/hummocks) have to be studied in future work. Seasonal effects, such as surface melting (Ulander, 1988), are also important and should be further studied.

During the BEPERS-88 experiment in the Baltic Sea, airborne SAR data and surface truth measurements were taken in support of the Geosat altimeter over sea ice (Ulander, 1990). Subsequent data analysis showed that free-board information could be retrieved from the altimeter data with a vertical resolution of nearly 25 cm. Hence, deformed areas were delineated with this technique. Simulations of altimeter pulse echos over rough and smooth young ice also indicated that the narrow-peaked component, although very high (sigma nought about 30 dB), is nonspecular.

The CCRS airborne SAR acquired data during BEPERS-88 in nadir mode, which includes the nadir echo. The near-nadir data were processed coherently (1 look) to a resolution of 1 and 500 m in azimuth and ground range, respectively. Pulse-to-pulse statistics over sea ice showed that the relative standard deviation of the signal fluctuations were larger at nadir as compared with off-nadir angles. Future work will study the relationship between the fluctuations and geophysical quantities.

References

Ulander, L.M.H. (1987) Interpretation of Seasat radar-altimeter data over sea ice using near-simultaneous SAR imagery. *Int. J. Remote Sensing* 8(11):1679-1686.

Ulander L.M.H. (1988). Observations of ice types in satellite altimeter data. In *Proceedings, IGARSS'88*, Edinburgh, pp. 655-658.

Ulander L.M.H. (1990). Geosat signatures of sea ice during BEPERS-88. In T. Thompson and M. Lepparanta (eds.), *BEPERS-88 Post-experiment Report*, Winter Navigation Research Board.

Drinkwater: Ku-Band Marginal Ice Zone Radar Altimetry

Pulse-limited, airborne radar altimeter data from the Fram Strait were acquired during the MIZEX. The 13.8-GHz Rutherford Appleton Laboratory altimeter was mounted in NASA's CV-990 airborne laboratory and flown over the Greenland Sea MIZ on several occasions during June and July 1984. These data were analyzed with the aid of airborne SAR imagery and simultaneous large format aerial photography. Overlapping data sources clearly illustrate the operation of a wide beam, pulse-limited radar altimeter over mixtures of ice and water.

Variations in the radar return pulse waveforms were quantified and correlated with observed surface ice properties. Quasi-specular or glistening signals are directly attributable to ice floe-damped (reflective) water or new ice surfaces within the first two Fresnel rings (i.e., at nadir). Since the power reflection coefficient of the water, for example, is typically 11 dB higher than snow-covered ice floe surfaces, it is calculated that less then 1% of the surface is required to produce a specular water return for the peaked component of signals to dominate the diffuse component. This results in an effective capability of resolving specular features filling a circular area of only 10-m radius; such features may be open water between ice floes, new ice growth, or leads and polynyas.

Internal or system calibrations performed during flight, and external calibrations undertaken over radar reflector arrays, enable the backscatter coefficient to be calculated. Analysis of the relationship between sigma-nought and ice conditions show the altimeter is an extremely flexible instrument. It is demonstrated that it is possible to (a) locate the ice edge with a high degree of accuracy, (b) estimate the ice concentration, and (c) identify ice types successfully. Empirical relationships, using numerical parameters describing the shape and magnitude of the waveform, are evaluated using coincident SAR imagery and simultaneous aerial photography. Results show that retrievals of ice concentration have an accuracy of 10% ± 3%, while four classes of ice surface appear consistently distinguished using the characteristics of the relationship between sigma-nought and incidence angle.

These results summarize some of the characteristics of altimeter signals over mixtures of ice and water. It is shown that under certain conditions altimeters can have a variety of capabilities. Importantly, such collinear airborne altimetry and photographic or SAR data sets enable a methodology and strategy to be established for geophysical data extraction algorithm development.

Jezek/Gogineni: Laboratory Studies of Microwave Scattering From Saline Ice

The premise of our work is that laboratory experiments on carefully controlled ice types can successfully isolate a specific scattering phenomenon. The most relevant ice types to CRRELX are those that cannot be conveniently studied in the field either because the ice is thin or because other factors in combination will overly complicate the scene. Since the objective is to relate scattering phenomena to naturally occurring ice morphologies, the laboratory ice regimes of most interest are those grown in a fashion closely mimicking natural conditions.

CRRELX 90 experiments by Ohio State University and the University of Kansas concen- trated on indoor studies of sea ice simulants (later measurements will be done on saline ice). Experiment highlights were exploratory observations related to changes in the sea ice scattering signature when snow cover was present. The indoor tank permitted us to characterize ice morphology and Ku-band ice scattering responses carefully as ice grew to about 10 cm thickness. At that point we began applying successive thicknesses of dry snow, measuring snow temperature, density, and snow ice interface wetness. The very interesting results suggest that at Ku-band, only a few centimeters of snow are required to change the signal by over 10 dB at incidence angles greater than 20°. Because we can conveniently and accurately increase "snow cake" thickness, we can produce a semi-empirical model of the relationship between snow thickness and scattering response.

The indoor work enabled us to investigate the phenomenon of flo ıg. The magnitude of this effect in the Arctic is contested, but investigators have witnessed flooding on several kilometer-scale floes in the Greenland Sea away from the MIZ and on snow/thin-ice-covered leads in the same area. The effect is also very important in the Weddell Sea. In the lab experiment we simply cut the snow-covered ice free from the pit walls and allowed the ice to depress under the added snow weight. The flooding process was dramatically quick, and we soon had a fully saturated volume of snow that nevertheless retained sufficient structural integrity to preserve its shape. We monitored backscatter signatures throughout the flooding process and after the saturated snow began to refreeze.

The success of our indoor work suggests several classes of experiments can now be meaningfully attacked. For example, temperature cycling can be used to study the effect of changing brine pocket size and concentration on backscattering. The effect of snow thickness can be studied, as well as snow wetness. By parameterizing the observed radar data against such factors as roughness, wetness, snow thickness, snow density, snow crystal size, brine pocket concentration, pocket size, etc., semi-empirical models can be efficiently developed. It is worth emphasizing that this kind of model is not a simple regression analysis. Rather than observing a scene composed of a very limited number of variables, it should be possible to develop meaningful scattering relationships based on very simple scattering concepts—essentially an approach that Ulaby has used very effectively. These relationships in turn may better serve to advance a more sophisticated theory, if in fact one is needed.

Onstott: Near-surface Microwave Observations in Support of Remote Sensing using Radar Altimeters

Near-surface microwave observations were made to characterize the reflectivity of bare and snow-covered sea ice surfaces, and sea ice during fall freeze-up, winter, spring, and summer melt conditions. These have been made with the purpose of describing scattering properties, to document the seasonal evolution of the microwave signature of Arctic sea ice and to describe signature variations statistically. Observations were made as a function of ice type, deformation conditions, and season and are supported by physical property information.

Measurements at vertical have been a regular component of the active microwave meas- urement program. Vertical measurements complete the angular response characterization of the radar scattering coefficients, provide a measurement of reflectivity (angle = 0° incidence), and, when combined with the middle angle data provide a measure of surface roughness. They also were obtained to support altimeter studies (i.e., MIZEX-84, coordinated flights made with the Rutherford Appleton Lab Ku-Band Altimeter).

A wide range of conditions including bare ice, heavy snowpack, snow in rubble, ridge lines, rafting, brash, meltpools, open ocean, polynyas, etc., were sampled. This list is given with the purpose of indicating the variations in the make-up of the scene, which may cause a perturbation in the expected microwave response. The scattering property measurement instrumentation includes a helicopter-borne scatterometer which operates at frequencies from 1 to 10 GHz, sled-based scatterometers operating from 0.5 to 94 GHz, and a polarimetric (coherent/quad-pol) scatterometer operating at 1 to 35 GHz.

A number of viewgraphs were presented to show the microwave response of ice in the MIZ during MIZEX'84 and CEAREX. Synthetic aperture radar mosaics were used to describe the construction of the MIZ. As an example, an ice interpretation example for 5 July 84 was presented, revealing open water, various sea ice concentrations and floe sizes, as well as large individual floes of 2-20 km and polynyas. A corresponding set of transects were made by the HELOSCAT on 5 July due west from a ship stationed 20 nmi from the ice edge in the open ocean. These transects illustrate the range in variation of the microwave response at 0° and 25° incidence. A significant decrease in sigma-nought is seen when crossing from open water to the MIZ and the variability within the ice is considerably larger than that offshore. These variations have been associated with air-sea stability, changes in ice concentration, floe size, and deformation.

Results based on the MIZ data suggest that there are up to three identifiable liquid ocean signatures (open ocean, ocean immediately adjacent to the ice edge, and MIZ interior ocean). Also, variation in the reflectivities of the three major ice types (MY, thick FY, and medium FY) is minor (about 3 dB) during midsummer, and that mean radar scattering cross sections (i.e., averaged in decibels over many resolution cells) are linearly related to ice concentration for the case when resolution cells are small (meters).

Laxon: Variations in Antarctic Sea Ice Extent

Previous Antarctic work has focused on the use of passive microwave data, first NIMBUS-7 SMMR and more recently DMSP SSM/I, to map the extent of sea ice on regional scales. The total areal coverage has then been calculated over the last 10 years to examine whether trends can be detected in the growth or decay of Antarctic sea ice. These passive microwave efforts have provided interesting data sets, which for the first time permit us to derive this type of product, and is especially timely in light of the growing concern for climatic changes.

However, all passive microwave mapping efforts to date generically suffer from several disadvantages: (1) summer melt and (2) coarse spatial resolution, although this is less of a problem for this particular application. Thus, part of the question has always focused on the accuracy of passive microwave observations during the summer melt season when ponding causes considerable problems and on a search for other means to supplement this data base.

In partial response to this problem, a simple sea ice detection algorithm has been used to process 28 months of data from the Geosat altimeter to compute the total Antarctic sea ice extent every 17 days. Interpolation is necessary due to the ground track spacing, but the Geosat limitation of 72° is not as critical in the Antarctic as in the Arctic. Comparisons of the total extent with that mapped by Gloerson and Campbell shows excellent agreement during most of the year except the late melt period, where differences of up to 20% are observed. Some of this difference may be due to the limit of the altimeter coverage up to 72°. Current work aims to further understand these differences by directly comparing Geosat and SSM/I data.

Laxon/Hawkins: Altimeter Sensing of Tabular Icebergs

Giant Antarctic tabular icebergs measuring anywhere from 25 to 80 km in length and width have recently calved from the ice shelves in both the Weddell and Ross Seas. Once loose from the shelf, their progress depends greatly on the time of year (amount of pack ice or open water in region), bathymetry, ocean currents and wind-induced movement.

Problem: How do we track these icebergs continuously over their lifetimes—which may last several years or more? The only operational answer to date has been the use of visible and infrared imagery from polar-orbiting satellites. Both NOAA AVHRR and DMSP OLS data are used routinely by the Navy/NOAA JIC to try and keep tabs on them. However, even though their size is huge, cloud cover often obscures them from view, sometimes for periods of weeks or more than a month.

Thus, use of "all-weather" sensors is required. SMMR data were typically too coarse for such work, but recent SSM/I data is proving to be beneficial. However, it has cloud water restrictions as well, especially when using the 12-km resolution, 85-GHz channels. Therefore, more than 2 years of Geosat altimeter data were searched to see if icebergs could be readily detected due to the abrupt height gradient and change in the backscattered waveform. This study revealed that the altimeter had obtained good data over two large icebergs (A20A and A20B), which originated from the Larsen ice shelf and moved northward, out into the South Atlantic over a period of about 2 years.

Six iceberg "hits" were found for each berg during their journey in the Weddell Sea and the South Atlantic. The positions match quite well with the available satellite imagery positions and nicely fill in some of the cloud gaps. Measurements of the freeboard of A20A carried out using the altimeter data, showed a significant decrease over a period of about 12 months. Future work will aim at a more thorough search of the data for iceberg "hits" and will attempt to match this data set with coincident SSM/I imagery.

Existing Data Sets

Spacecraft Observations

Satellite	Time	Location	Laboratory
AVHRR	Intermittent	E. Greenland Baffin Bay Beaufort, Bering, Kara, Chukchi Sea	NOARL
SSM/I	Intermittent	Arctic Antarctic	NOARL
AVHRR & SSM/I	Intermittent	Chukchi E. Greenland	NOARL
Landsat	?	Baffin Bay Beaufort	CIRES

Airborne

KRMS	Mar 87 Mar 88 Mar 87	E. Greenland Chukchi/Bering Limex	NOARL-N
SAR Interra	Apr 87	E. Greenland	NOARL-S
ERIM SAR	Mar 88 Mar-Apr 89	Beaufort, Chukchi Greenland Seas	ERIM ERIM
JPL SAR	Mar 88	Beaufort, Chukchi, Bering Seas	JPL
AES HOLTR SLAR	Operational	Canadian Arctic	AES (Rene)
CCRS SAR	Mar 87, 89 Mar 88 Feb 89	Limex Baltic Barents Sea	CCRS Sweden ERIM
French SAR	Apr 87	Baltic	Sweden
RAL Alt	Jun 84	Greenland Sea	JPL

Shipborne Observations

Ship/Sensor	Time	Location	Laboratory
Polarstern Ku-Band	Sep-Oct 89	Weddell Sea	OSU/KU
CEAREX	Mar 89	E. Greenland	ERIM
ERIM SAR		Odden 70°N, 0°W	
Scatterometer KU-C Band	May 89	E. Greenland Sea	Rene Ramseier Mike Collins
Polarstern L-C-X-Ku-band Scatt	Jun-Jul 84	E. Greenland	ERIM
Polar Circle L-C-X-Band Scatt	Mar 87	E. Greenland	ERIM
Polarbjorn L-C-X-Ku-Ku Ka-W-band Scatt	Sep-88-Mar 89	E. Greenland Barents Sea	ERIM

Ground Observations

Instrument	Time	Location	Ice Types	Laboratory
Ku-band	CRRELX	CRREL	Bare and snow covered saline ice	OSU/KU
Ku-band	CRRELX	CRREL	Frost flower covered fresh ice	
Ku-band	CRRELX	CRREL	Bare, snow covered and flooded area ice	

Hawkins/Eppler: Spinsat Altimeter (SALT)

The Navy and the scientific community at large have received a wealth of new oceanographic information from the Geosat altimeter during its healthy life from March 1985 to late 1989. This was largely due to the decisions to place the satellite into a 17-day exact repeat orbit. Data so obtained are unclassified, since Geosat flew along Seasat tracks. Early efforts to put another altimeter in space (NROSS) failed in 1988, but the altimeter was already well on its way to completion. Thus, the Navy has been searching for a viable platform to put this sensor on board.

Early planning focused on the NOAA and DMSP polar orbiters, but this proved to cause too much change in both systems on the short notice needed. The options then took a new tack as the Navy considered launching the altimeter as a small, inexpensive free flyer using one of the old Scout launch vehicles. Weight restrictions were severe, but preliminary studies indicated the job could be done, and the overall cost would be substantially lower than "comparable" projects using Delta or Titan vehicles.

This helped define in part a new Navy program called the Special Purpose INexpensive Satellite (SPINSAT) project. The idea, simply put, is to launch small, free-flying satellites with sorely needed sensors, which were too costly to launch as part of a larger integrated package. Thus, Spinsat ALTimeter (SALT) was designed as a cost-effective method of orbiting the NROSS altimeter.

The SALT Program was recently terminated. Instead, the Navy will focus on the Geosat GFO Program. GFO will be an operational system that will provide altimetric data from the year 1994 until the Defense Meteorological Satellite Program Block VI upgrade is operational in the year 2003. An important addition to the altimeter on board GFO will be a radiometer for water vapor correction. All existing SALT hardware, including the space-qualified altimeter, will be transferred to the GFO Program. The altimeter, as well as interface design requirements and SALT spacecraft hardware, will provide the opportunity to accelerate the GFO Program. GFO data will be available to the public. This news is bleak in the short term, but represents a long-term commitment that has been lacking up till now. Hopefully, the GFO will come to fruition and mesh with other altimetric missions. At this point, it appears the GFO will fly in Geosat ERM tracks, since the data will be open to the public. This simplifies many aspects of the program, but limits polar applications as outlined in this workshop.

Some glimmer of hope is fast approaching. Instead of using the Scout vehicle and its limited 400-lb payload capability, the new airlaunch Pegasus platform would provide several advantages over the Scout for launch of an altimeter: the weight restriction would be lifted to 600 lb; the ability to launch from a plane at high altitude would remove many of the problems associated with ground launches (i.e., weather, expensive ground support, etc.); and launch flexibility would be enabled for polar orbits not available for the Scout.

At this point, the Pegasus launcher appears to be the way to go, but time is needed to get the system operational, and then a new effort to integrate the altimeter would have to come on line. This involves a lot of "ifs," but is the best chance to date. It would be highly frustrating to miss the opportunity coming in 1992-1993, when ERS-1 (now a spring 1991 launch) and TOPEX will both be in orbits other than Geosat. Although TOPEX tracks will have little sea ice utilization, the ability for precise tracking could help tie down other satellite orbits at cross-over points. Cost-effective ground truth efforts could then be convened to serve multiple satellites.

Luther: ONR CRRELX Experiments using the CRREL Facilities

Since 1984 the Office of Naval Research has supported basic research at CRREL aimed at understanding the scatter and emission characteristics of various types and thicknesses of sea ice. The requirement for such research is driven (a) by the inability to correct interpret the several ice types in remotely sensed imagery provided primarily by high-resolution active and passive microwave imagers and (b) by the need for information with which to construct theoretical models of these scatter and emission characteristics, as well as models and algorithms for use in the automatic classification of sea ice from remotely sensed imagery.

This research is conducted through a series of annual experiments called CRRELX, which feature growth of a series of artificial sea ice types in a quasi-controlled laboratory setting to duplicate their natural growth in the polar environment. Coincident measurement of the physical and electrical properties and the related scatter and emission characteristics are obtained for each ice type. The primary advantage of the CRREL type experiments is that the various types of sea ice and surface cover can be duplicated and studied much more cheaply and effectively than they can be found and studied in the polar environment. More importantly, in the truly controlled environment, temperature cycling experiments can be conducted, while the effects of temperature, which have the single most significant impact on the physical/electrical properties of the ice, can be measured in terms of dominant seasonal conditions (freeze-up, freeze-thaw cycles; spring melt, summer melt, melt ponding, etc.).

A multidisciplinary team of modelers, ice physicists, remote sensoring scientists with interest in both active and passive radiometry has been carefully selected to grow the artificial ice types, to measure their physical/electrical properties and scatter/emission characteristics, and to incorporate the results in the form of predictive theoretical models. Until this year two outside ice "tanks" or ponds, known as the upper and lower ponds, were used for the CRRELX experiments.

Upper Pond

The upper pond is approximately 4 feet deep, 20 feet wide and 40 feet long. The bottom is lined with rubber sealant to prevent the saline solution from leaking into the ground. A large tent slides over the top of the pond for solar shading and inclement weather protection.

A mobile gantry, which spans the width of the pond, is used to mount the various sensors. The gantry has an adjustable height and is able to traverse the pond so that several spatially independent samples can be obtained. A separate bar is used to adjust incidence angle. The pond is also fitted with a motorized paddle for making waves, which is needed for developing frazil and pancake ice types. A heated tent is used as a control center for operating the radars and data acquisition subsystems.

Lower Pond

The lower pond (used primarily for snow measurement) is approximately 4 feet deep and 40 feet along the sides. A roof on tracks can covering the pond to protect the growing ice from weather when necessary. A walkway mounted on the tracks serves as a mobile base on which the antenna mount is placed. A permanent shed adjacent to the pond houses the control and data acquisition systems.

Commencing this year (1990) an indoor, fully controlled ice tank called the indoor pit, was made available, and measurements in this controlled environment are now possible. The indoor pit is approximately 20 feet on the sides, and can accommodate ice growth in excess of 3 feet. The pit is a refrigerated room capable of maintaining temperatures less than −15°C. Thus, the freezing rate (growth rate) can be controlled. Temperature cycling experiments can also be conveniently conducted. This facility also permits experimentation with various types of surface cover (snow, snow/ice mixtures, flooded surfaces, etc.).

The CRRELX type experiments and the CRREL facilities mentioned above are very well suited for examining the effects of various classes of ice on the altimeter waveform, and should therefore be exploited.

All: ERS-1 Validation Efforts

A wide variety of efforts are being mounted to validate the sensor suite on ERS-1, tentatively set for launch in spring 1991. The list below is a draft of those programs related to sea ice activities that may be of interest to altimeter sea ice investigators looking to establish potential cooperative ventures.

NAME/GROUP	AREA/EFFORT OF STUDY
ONR LEADEX (Curtin)	Beaufort Sea (92-93): Lead statistics
Livingstone	Newfoundland (92): SAR flights
SIZEX (Johannessen)	Barents Sea (92-93): Aircraft, ships, field truth
Sweden, Germany, USSR	Central Arctic: Three ice vessels to North Pole
NOARL (Eppler/Hawkins)	Arctic (92-93): Aircraft underflights of ERS-1
Young/Allison	Prydz Bay, Antarctica: ?
Thompson	Baltic (92): Aircraft SAR
ERIM	Arctic: Aircraft SAR
Gunther Weller	North of Alaska: ?
Goodmanson	?: Aircraft SAR
Germany	Weddell Sea: ?
Norway	Filcher Ice Shelf: Ships
Mark Drinkwater	Weddell Sea (92): Anzone Exp (A/C, ships, surface)
Arnold Gordon	Antarctic Circumpolar Current (Anzone Exp): ?

Future Needs: Altimeter Sea Ice Research

Extraction of additional sea ice parameters from altimeter data over ice and the refinement of present techniques to define ocean-ice boundaries requires future research efforts that fall within three broad categories:

Understanding what it is that the altimeter is actually sensing

- Where in the snow-ice boundary is the signal originating?
- Where is the centroid of the backscatter return?
- How does snow depth, ice type, roughness, etc., affect the backscattered power?

This is just a partial list of the unsolved items that remain to be answered. Progress in these basic research areas must be made in order to apply the correct theory to the data being collected and analyzed. Until this occurs, the empirical methods now used will be limited in success.

A number of the workshop presentations highlighted the facilities at CRREL that can facilitate experiments aimed at understanding fundamental physical concerns about active microwave sensing of ice surfaces. The controlled environment of the indoor tanks permit cost-effective means of examining ice growth, ice type, and temperature cycling studies with sensors utilizing a variety of spectral channels, polarizations, and incidence angles. These microstructure projects will hopefully allow us to refine present algorithms and create new ones that do not rely on simple regression analysis or empirical relationships.

Intercomparison of altimeter sea ice data/products with "ground truth"

Some limited studies have been carried out collecting on-ice data with coincident altimeter overflights. However, the inability to cover sufficient area on the ground has been a major drawback. Thus, on-ice work has been focused on documenting conditions more on the microscale level using sensors based from ships, helicopters, and sleds. These data have readily exhibited dramatic shifts in backscatter returns when ice characteristics such as snow content, roughness, age, salinity, etc., change.

Conclusions from this type of data suggest that we cannot successfully extract meaningful sea ice information from altimeter instruments. However, the mismatch in scales between the on-ice data and satellite sensors helps diffuse some of these concerns, but also raises others as well. One of the larger points of interest is the fact that only a very small percentage of open water (on order 2%) can completely dominate the backscattered return. This presents a number of problems for investigations in the MIZ and in the central pack whenever the altimeter footprint overlaps ice floes and surrounding open water.

A number of small, diverse programs have been carried out to underfly the Geosat altimeter with airborne sensors with the purpose of characterizing the sea ice conditions within the altimeter's narrow swath. Most of these field projects were discussed within the workshop and have shed some light on the prospects for extracting sea ice information from altimeter data. Unfortunately, this has only been done in a piecemeal fashion with a little SAR data here, some passive microwave there, and some optical data elsewhere. Thus, a coordinated effort is sorely needed to bring the full calibrated sensor suite together, which is necessary to describe the sea ice environment.

Other projects have taken the broader perspective of using near-coincident satellite sensors to help validate/calibrate altimeter ice algorithms. The ability to use infrared and visible satellite imagery from the NOAA polar orbiters enables huge altimeter transects to be viewed synoptically, provided cloud conditions are favorable. This is especially helpful for ice edge match-ups and to a lesser degree ice concentrations comparisons. Efforts to identify leads with altimetry have been shown possible, due in part to validating AVHRR data. The presence of coincident visible/infrared data on ERS-1 with altimetry will be a big plus for altimeter sea ice studies.

A partial reason for this lack of data is the 72° limitation for Geosat. Much of the ice work has been done at higher latitudes in MIZEX and CEAREX and some in the Central Arctic. Thus, the prospects increase measurably with ERS-1 due to its high orbit (81°). This will enable long tracks to be flown at a single time and will cover, in many instances, the transition from ocean-ice, pack ice and the high Arctic with variations in concentration of FY and MY ice.

Thus, one of the items to conclude from this workshop is the fact that a cooperative effort is needed for ERS-1 underflights that will permit us to sample numerous ice regimes not seen with the Geosat altimeter data set. These projects should be interwoven with the ongoing PIPOR efforts that are more focused on SAR investigations. The possibilities of joint efforts with expensive long lead time assets from a number of institutions should be enthusiastically pursued.

Standard data sets

Typical validation/calibration activities collect "standardized data sets," on which all interconnected groups work. This ensures that a high-quality data set is used by all parties and that apparent algorithm differences are not due to a host of environmental factors. The lack of such a data set is a distinct drawback to this community and should be a priority goal. As noted in discussions, NOARL will be able to collect and process the following satellite digital data by the time the next altimeter is launched: AVHRR, OLS, SSM/I and ERS-1 SAR. This represents a significant start to a "satellite" data set for comparison with altimeter results, but needs airborne and field data to attack some of the problem areas noted above.

Comments are welcome as to how a standard data set could be achieved, from the point of view of the science required and what is feasible.

Distribution List

Name	Address
Dave Benner	Naval Polar Oceanography Center
Tony Busalacchi	NASA-GSFC Code 671
Don Cavalieri	NASA-GSFC Code 671
Nita Chase	NOARL Code 321
Pim Chavasant	Fleet Numerical Oceanography Center
Bill Cook	Space and Naval Warfare Command
Joey Comiso	NASA-GSFC Code 671
Jim Cornelius	FNOC Code 43
John Curtis	Commander, Naval Oceanography Command
Mark Drinkwater	NASA-JPL
Herb Eppert	NOARL Code 300
Duane Eppler	NOARL Code 322
Len Fedor	NOAA Wave Propagation Lab
Florence Fetterer	NOARL Code 321
Kathy Garcia	Naval Polar Oceanography Center
Prasad Gogineni	Kansas Univ Center for Remote Sensing
Claire Hanson	National Snow and Ice Data Center
Jeff Hawkins	NOARL Code 321
Ron Holyer	NOARL Code 321
Ken Jezek	Byrd Polar Res Center
Ola Johannessen	Nansen Ocean and Remote Sensing Center
Gary Lagerloef	NASA Code EEC
Seymour Laxon	Mullard Space Science Lab
Chuck Luther	Office of Naval Research
Matt Lybanon	NOARL Code 321
Vicky Lytle	Dartmouth College
Rob Massom	NASA Code 671
Joe McCaffrey	NOARL Code 320
Richard Moore	Kansas Univ Center for Remote Sensing
Don Montgomery	Space & Naval Warfare Command
Paul Moersdorf	Commander, Naval Oceanography Command
Bob Onstott	Environmental Research Institute of Michigan
Al Pressman	NOARL Code 321
Rene Ramseier	Institute for Space and Terrestrial Science
Chris Rapley	Mullard Space Science Lab
Jim Rigney	Naval Oceanography Command
Irene Rubenstein	Institute for Space and Terrestrial Science
Bob Shuchman	Environmental Research Institute of Michigan
Cal Swift	Univ. Massachusetts Microwave Remote Sensing Lab
Bob Thomas	NASA Headquarters
Lars Ulander	Canadian Center for Remote Sensing
Gary Wohl	NOAA Joint Ice Center
Jay Zwally	NASA-GSFC Code 671
Code 125P (6)	Naval Oceanographic & Atmospheric Research Lab

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. Agency Use Only *(Leave blank).*

2. Report Date. September 1990

3. Report Type and Dates Covered.

4. Title and Subtitle.

Altimeter Sea Ice Workshop

5. Funding Numbers.

Program Element No	63704N
Project No	0101
Task No	100
WUIS	93210H
Accession No	DN 294462

6. Author(s).

Jeffrey D. Hawkins

7. Performing Organization Name(s) and Address(es).

Naval Oceanographic and Atmospheric Research Laboratory
Remote Sensing Branch, Ocean Sensing and Prediction Division
Stennis Space Center, MS 39529—5004

8. Performing Organization Report Number.

SP 059:321:90

9. Sponsoring/Monitoring Agency Name(s) and Address(es).

Space and Naval Warfare Systems Command
Washington, DC

10. Sponsoring/Monitoring Agency Report Number.

11. Supplementary Notes.

12a. Distribution/Availability Statement.

Approved for public release; distribution is unlimited.

12b. Distribution Code.

13. Abstract *(Maximum 200 words).*

Workshop agenda and dialogue.

14. Subject Terms.

remote sensing, altimeter, satellites, automated techniques

15. Number of Pages. 27

16. Price Code.

17. Security Classification of Report.	18. Security Classification of This Page.	19. Security Classification of Abstract.	20. Limitation of Abstract.
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	None