Sea ice extent mapping using the ERS-1 radar altimeter

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ABSTRACT

Satellite radar altimeters are designed primarily for operation over the open ocean. As an altimeter passes from open water to sea ice a dramatic change in return echo strength and shape typically occurs allowing mapping of the ocean-ice boundary and providing other potentially useful information on the sea ice cover. Since satellite radar altimeters provide all weather observations at a relatively low data rate they are well suited to global sea ice mapping. The altimeter on-board ERS-1 provides coverage of latitudes to 82° for the first time. Two parameters contained within the so called Fast Delivery data stream are shown to be sensitive indicators of the presence of sea ice. Such data may be used to generate near real time ice maps for operational applications. Comparisons with infra-red and passive microwave imagery show good agreement on the location of the ice boundary. The altimeter data may also be used to identify areas where weather effects have lead to erroneous identification of sea ice by passive microwave instruments.

1. INTRODUCTION

Sea ice presents a major hazard to both shipping and offshore oil operations in the polar regions. Reliable information on ice conditions is required to maintain safe and economic operations in such areas. Information on sea ice cover is also needed for assimilation into meteorological and climate models, and for long term climate monitoring. It is expected that significant changes in ice extent will occur in response to climate change. Studies have also shown that the extent of polar sea ice may be a sensitive indicator of any changes in global temperature rise (Jacka and Budd, 1990).

Satellite monitoring of sea ice had been carried out for more than twenty years and is the only practical means of monitoring this dynamic medium over wide geographic areas. Although visible and infra-red sensors are used to monitor sea ice their use is limited by cloud cover and darkness, especially during the winter months. Passive microwave sensors, which are virtually unaffected by cloud and light conditions, have been used widely to map the extent and concentration of polar sea ice. Gloersen and Campbell (1988) examined trends in the total ice coverage for the Arctic and Antarctic over a period of more than 15 years to look for any significant changes.

The potential of satellite borne radar altimeters for sea ice mapping has been discussed in several references (Weeks, 1981; Gudmandsen, 1983; Robin, 1983; Robin, 1984; Squire and al, 1984; Thomas, 1984). Although primarily designed for operation over the open ocean, radar altimeter have been shown to provide useful information over sea ice. Dwyer and Godin (1980) were the first workers to quantify the altimeter response over sea ice using data from an instrument flown on the GEOS-3 satellite. They observed that altimeter echo waveforms typically rise to a much greater peak power than over the open ocean. This is followed by a rapid fall in power as the altimeter samples the surface at angles increasingly further away from normal incidence (Laxon, 1989). Figure 1a shows a typical ocean return, where the surface reflectivity is isotropic over the incidence angles that the altimeter samples, compared with a typical return over sea ice, shown in figure 1b, where there is a rapid fall off in reflectivity away from nadir. Laxon (1990) used data from the Geosat radar altimeter to map the total ice extent in the Southern Ocean for comparison with that mapped using SMMR. In this paper we look at early results from the altimeter carried on-board the ERS-1 satellite which provides coverage up to 82° latitude for the first time.

2. ERS-1 ALTIMETRY OVER SEA ICE

The ERS-1 altimeter fast delivery data have several parameters which may be used for sea ice extent map-

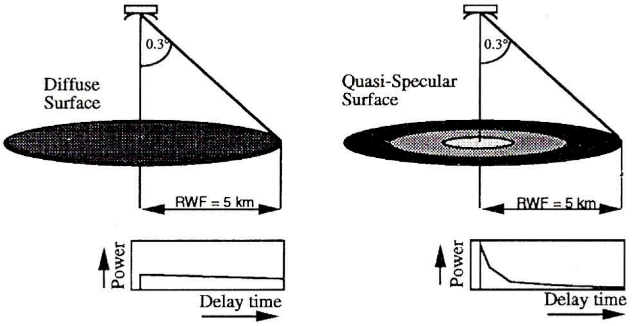


Fig. 1 - Schematic diagram of the altimeter response over (a) Open Ocean and (b) Sea ice cover. The ocean response is isotropic within the altimeter range widow footprint (RWF) whilst sea ice cover typically results in a rapid fall off in return power away from nadir

ping. The Pulse Peakiness (PP) parameter, is included in the data stream to permit filtering of anomalous data over the open ocean, including sea ice. Pulse Peakiness is calculated from the return echo samples using (Francis, 1991):

$$\text{Pulse Peakiness} = \frac{31.5 * P_{max}}{\sum_{i=5}^{64} P_i} \qquad (1)$$

where P_i is the power value in an individual sampler and P_{max} is the maximum sample value in the return echo.

Assuming the waveform is roughly centred in the altimeter range window the Pulse Peakiness parameter is effectively a measure of the ratio of the peak and average power in the return. Over the open ocean this value is approximately 1 although noise, resulting from the speckle in the altimeter return, will result in a value closer to 1.5 (Laxon and Rapley, 1987). Over sea ice, where more peaked returns are typically observed, higher values will be seen. Knudsen et al. (1992) excluded peakiness values greater than 1.7 to eliminate sea ice cover in the Norwegian-Greenland Sea.

Another parameter, the standard deviation of surface height (SDALT), also indicates the presence of sea ice. As the altimeter return becomes distorted this leads to a highly non-linear response by the on-board tracker, significantly increasing the height noise.

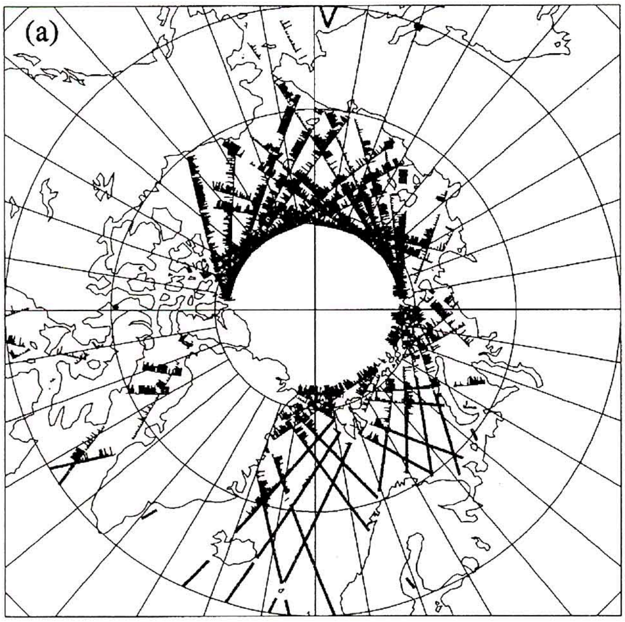
The SDALT parameter is calculated once per second from the 20Hz range values using:

$$\text{SDALT} = \sqrt{\sum_{n=1}^{N} \frac{(H(n)-<H(n)>)^2}{(N-1)}} \qquad (2)$$

where N is the number of valid samples (normally N = 20) and <H(n)> is the mean range to the surface during a one second period.

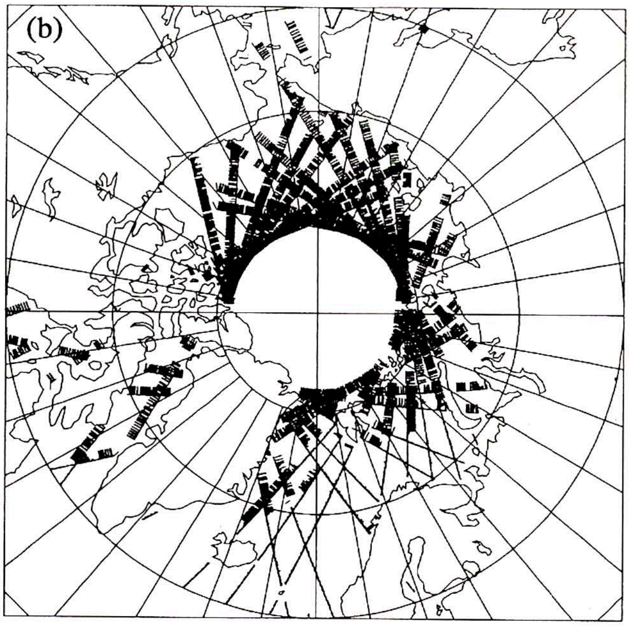
Figure 2a shows the PP parameter over a three day period in the Arctic. High values are observed over areas where sea ice is expected to be present during February. Except for some coastal crossings values of PP are reasonable constant over the open ocean and show no evidence of contamination by other effects. In most cases a gradual increase in PP values is observed as the altimeter moves further into the ice pack, suggesting a correlation with ice concentration near the boundary. Although this may be useful in determining the compactness of ice it will also be subject to the prevailing wind and wave conditions.

Figure 2b shows the SDALT parameter over the same period. The response of this parameter is much clearer than PP in defining the ice boundary but the response is highly non-linear and therefore more difficult to relate to surface properties. SDALT exhibits a higher sensitivity to sea ice than PP as seen in the East Greenland pack ice and may pick up frazil or grease ice.



PP 0-5

Fig. 2a



SDALT 0^{-1}

Fig. 2b

Fig. 2 - This figure shows vertical lines plotted for each ERS-1 altimeter observation with a length proportional to the values of (a) Pulse Peakiness (PP) and (b) Standard deviation of altitude (SDALT) between the 6th and 8th of February 1992.

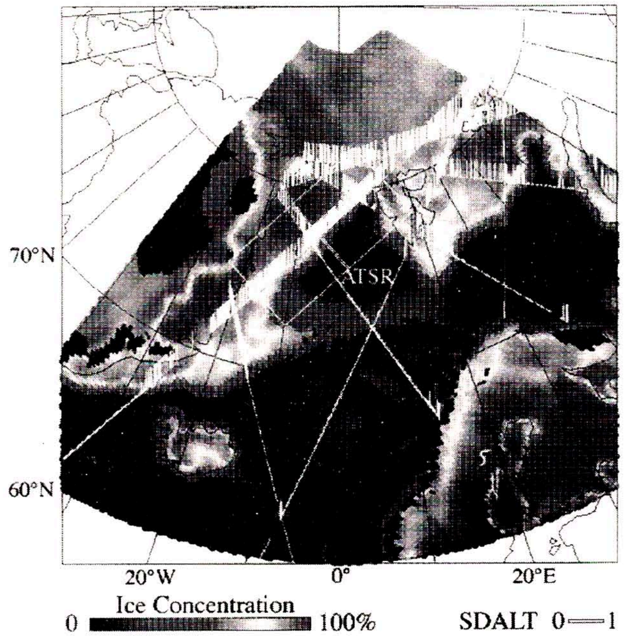


Fig. 3 - ERS-1 altimeter observations of SDALT from the 7th of February 1992 overlayed on ice concentration derived using the NASA teams algorithm applied to data from SSM/I for the same day. The locations of two ATSR frames shown in figure 4 are also shown.

3. COMPARISONS WITH INFRA-RED AND PASSIVE MICROWAVE IMAGERY

A key application of radar altimeter observations of sea ice is to validate observations of ice extent made using passive microwave imagery. Although the spatial coverage of the altimeter is poor it is the only instrument that can currently provide global synoptic data on sea ice extent to compare with the widely used passive microwave observations. Figure 3 shows altimeter data from the 7/2/92 overlaid on a map of ice concentration derived by processing SSM/I swath data using the NASA team algorithm. The ice concentration algorithm uses the latest recommended tie points (Cavalieri, 1992). In addition an experimental weather filter recently developed at the Goddard Space Flight Centre was applied to the data (Cavalieri, personal communication). The SDALT parameter, derived from ERS-1 fast delivery data, shows a clear increase on crossing the Ocean-Ice boundaries in the East Greenland Sea and around Svalbard. Within the ice pack zero values of SDALT are observed resulting from altimeter tracking problems ERS-1 has over dense ice cover (Scott et al., 1994). Over the open ocean there are several areas where the SSM/I data clearly show erroneous non-zero ice concentration values, particularly around 0E, 67N and 5W, 72N. The ERS-1 altimeter SDALT values show no deviation from open ocean values demonstrating that they are insensitive to the weather effects that cause the anomalous concentrations to be derived from the SSM/I data. In such cases the altimeter has a clear application in confirming SSM/I observations of the ice boundary and in identifying anomalies due to weather effects.

The location of two images from the ERS-1 Along Track Scanning Radiometer, also acquired on the 7th of February, are shown in figure 2. The images themselves are shown in figure 4 with the ERS-1 altimeter derived values of Pulse Peakiness overlaid. The increase in PP is more gradual than SDALT and some variation in signal is also seen over the ice itself. The images show cloud streak formed by an off-ice wind and both the altimeter and SSM/I show ice to be present to the east of the visible ice edge. As before some zero values of PP occur due to the inclusion of data where the altimeter is no longer tracking the surface. In other places valués of PP are observed within the pack that are characteristic of open ocean values. It is know that ocean like returns can occur where a large floe or consolidated rough ice fills the altimeter footprint.

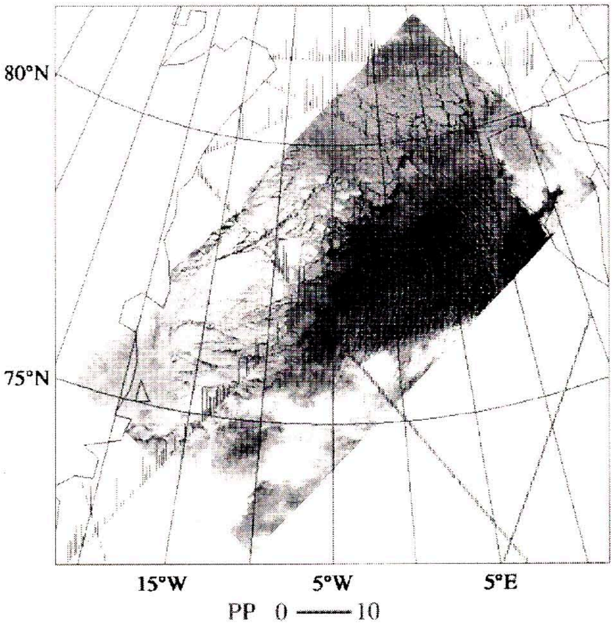


Fig. 4 - ERS-1 altimeter observations of PP from the 7th of February 1992 overlayed on two brightness temperature images from the 12nm channel of ATSR from the same day.

4. APPLICATIONS OF ERS-1 RA SEA ICE MAPPING

Routine operational sea ice products from radar altimeter data were first produced by the US Navy using data from the Geosat satellite (Hawkins and Lybanon, 1989). The fast delivery data from ERS-1 are normally available within three hours of observation. During it's multi-disciplinary stage ERS-1 completes an orbit cycle once every 35 days with a three day sub cycle. Data is therefore selected from the previous three days to generate an operational map of the sea ice boundary similar to those shown in figure 2. Although the spatial sampling is poor compared with other sensors, the accuracy and simple processing required make the altimeter a useful addition to other sources of operational data. Maps were generated by MSSL and faxed via the James Rennell Centre to ships during two research cruises in the Southern Ocean.

In a study funded by the British National Space Centre and carried out by European Systems Ltd and MSSL several operational users, including the UK Meteorological Office, the Norwegian Meteorological office, expressed and interest in receiving such data. In addition research institutes, such as the Hadley Climate research centre, Scott Polar Research Institute and British Antarctic Survey expressed an interest in longer term observations of ice extent derived from the ERS-1, and other, radar altimeters.

5. CONCLUSIONS

In this paper we have demonstrated how data from the ERS-1 radar altimeter can be used to map the extent of polar sea ice both for research and operational applications. The altimeter provides a global synoptic data set and is a highly sensitive detector of sea ice. Comparisons with passive microwave imagery show that it is much less sensitive to contamination by weather effects over the open ocean. By using infra-red imagery the accuracy of the altimeter observations can be assessed and signals within the ice further interpreted. Altimeter data from ERS-1 has clear applications in both operational and long term climate monitoring of global sea ice cover.

ACKNOWLEDGEMENTS

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