Outlook

Application of SAR interferometry to polar research appears to be very promising and can be recommended for the study in detail and for further development for future applications. In particular, it is necessary to identify the geophysical effects involved in the generation of fringes in order to understand the details of the fringe patterns and to interpret them in terms of glaciological parameters. The ERS-1/ERS-2 'tandem mission' would be an excellent opportunity for that purpose. We are convinced that this unique dual mission would signify remarkable progress for polar research. We look forward to close cooperation between the Institut für Navigation, Stuttgart, the Institut für Angewandte Geodäsie, Frankfurt and the British Antarctic Survey, Cambridge, stimulating exciting advances in the interpretation of SAR interferometry of Antarctica.

Enhanced-resolution ERS-1 scatterometer imaging of Antarctic ice

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The ERS-1 AMI scatterometer mode was designed to determine wind speed and direction over the ocean. However, a new method of image reconstruction allows enhanced resolution (~14 km) weekly images to be produced. All-weather day and night C-band microwave images are derived in regions where high-resolution AMI synthetic aperture radar (SAR) image data are unavailable due to the lack of a local receiving station, or during periods when Antarctic receiving stations are closed. These medium-scale resolution images can be used in mapping the dynamics of the Southern Ocean sea-ice cover and snow and ice zones on the Antarctic ice sheet.

Introduction

Low-bit-rate ERS-1 scatterometer (Scatt) data are acquired continuously when the ERS-1 SAR imaging mode is not operating, but they have barely been exploited outside the traditional scope of wind measurement. Applications are limited because of a preference for the 25-m resolution which SAR and other satellite imaging sensors offer. Nevertheless, the contiguous coverage of the Scatt becomes valuable in situations where coverage provided by existing SAR receiving stations is incomplete, such as in Antarctica. A large portion of the South polar region is presently not imaged by SAR. Furthermore, it is not possible to downlink SAR images at times when the Bernardo O'Higgins (German) and Syowa (Japanese) Antarctic SAR receiving stations are unmanned.

An important priority for microwave studies of the polar regions is data acquisition over an extensive area in as short an interval of time as possible, due to the sensitivity of snow and ice conditions to changing meteorological conditions. Logistically, it is impossible to accomplish this with 100 × 100 km SAR images, even in regions with Antarctic stations dedicated to SAR data reception. Significant volumes of data are required to map the Antarctic at frequent intervals, and such a monitoring goal is currently beyond the resources of on-off time allocated to this high-power, high-bit-rate instrument.

Enhanced-resolution scatterometer imaging

The ERS-1 Scatt makes 5.3 GHz (C-band) measurements of linear vertically polarised backscatter (σ^o) on ascending and descending orbits at various azimuth (from mid, fore and aft beams) and incidence angles. Measured pulses are integrated and spatially filtered to yield 50 km resolution measurements on a 25 km grid. During the 35-day repeat (phase C) orbit cycle, orbit precession shifted the 500 km measurement swath meridionally to cover the entire Earth's surface. At high latitudes, a given area is generally observed several times each day with varying azimuth and incidence angle.

An imaging method has been developed using the Scatt mode data from the AMI. The Scatt image reconstruction with filtering (SIRF) approach requires multiple, overlapping gridded measurements of σ^o and post-processing to improve the effective resolution. SIRF takes advantage of spatial overlap in measurements made at different times by different beams. Broadly, a new small-scale rectilinear grid of resolution elements $0.33 \times 0.125°$ is constructed. A weighted average is then calculated from several days of Scatt measurements of σ^o which overlap these resolution elements (as a function of incidence angle, θ). The algorithm produces images of the normalised backscatter coefficient, where each weighted backscatter value fills a pixel in the reconstructed image. At 70° S, the enhanced grid element size corresponds to a pixel resolution of ~14 km.

Figures 1 & 2 show two south polar stereographic image projections of backscatter conditions (south of 60°S) in austral summer and winter. Continental and ice shelf margins are displayed together with the location of the sea-ice margin, charted by the US NOAA/Navy Joint Ice Center.

Figure 1 is an image constructed near minimum sea-ice extent, during the first week of February 1992 (Julian days 32-39). Figure 2 shows the contrasting situation near maximum ice extent at the end of September (Julian days 272-278). Each map shows radar backscatter values normalised to 40°, with smoothly varying isotropic returns from sea ice which contrast variable, anisotropic returns in the open ocean. The sea-ice boundary can be successfully mapped using azimuthal isotropy measures described by Lecomte *et al.* (*EOQ*, N° 40, p. 8), but an independent source is indicated here for validation.

C-band backscatter values at 40° incidence largely reflect the density, wetness, salinity and roughness of the snow or ice. The sea-ice around Antarctica contains features related to ice growth, circulation and deformation patterns. Figure 1 indicates the largest summer extent to occur in the Weddell Sea, with two distinctively low backscatter polynya areas in the relatively high backscatter summer ice cover.

Figure 2 shows a dramatic reduction in the mean backscatter of the winter first-year ice cover which extends north of 60°S near the prime meridian. Backscatter from the continental ice and floating ice shelves is equally distinctive with a fringe of high backscatter around the steep and mountainous margins of the ice sheet. Variations of backscatter in the interior of the ice sheet appear related to topography and zones of melting and accumulation.

Time-series images

Time-series imaging of the Southern Ocean is a key application of the SIRF imaging technique as 100 km wide SAR images retrieve limited spatial and temporal coverage of dynamic phenomena responding to ocean and atmosphere forcing.

A regional time-series is shown in Figure 3 for the Weddell Sea. Weekly backscatter images are generated at 21-day intervals from the first week in

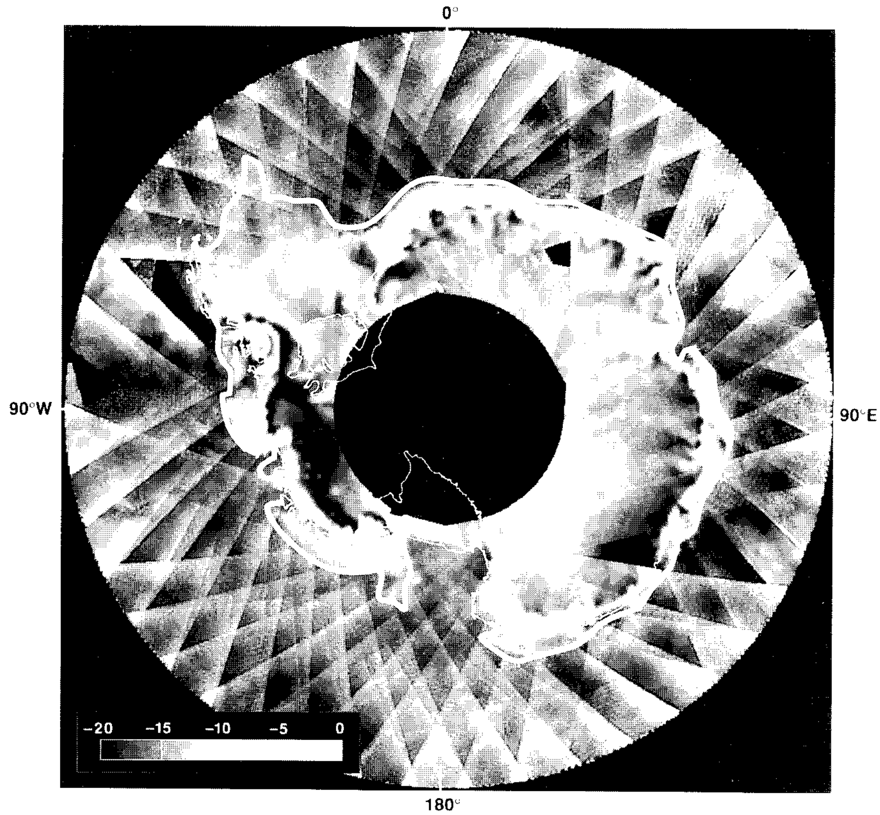

Figure 1. Antarctic ERS-1 scatterometer image (south of 60°S) of the normalised backscatter coefficient (at 40° incidence) for 1 – 7 February 1992

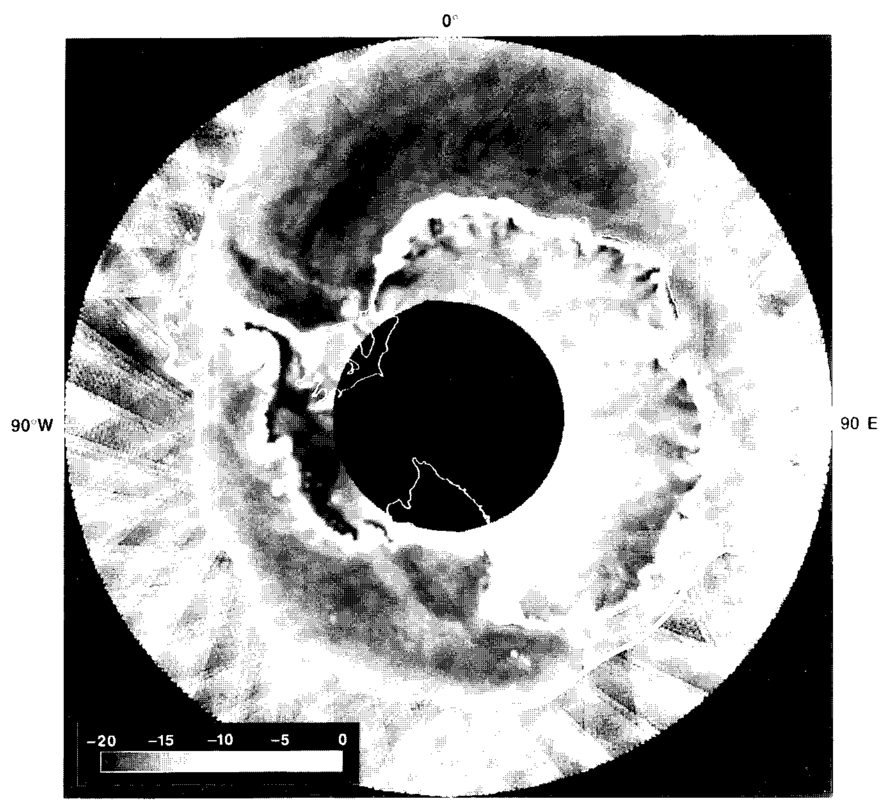

Figure 2. Antarctic ERS-1 scatterometer image (south of 60°S [illegible] backscatter coefficient (at 40° incidence) for 28 Sept. – 4 Oc[illegible]

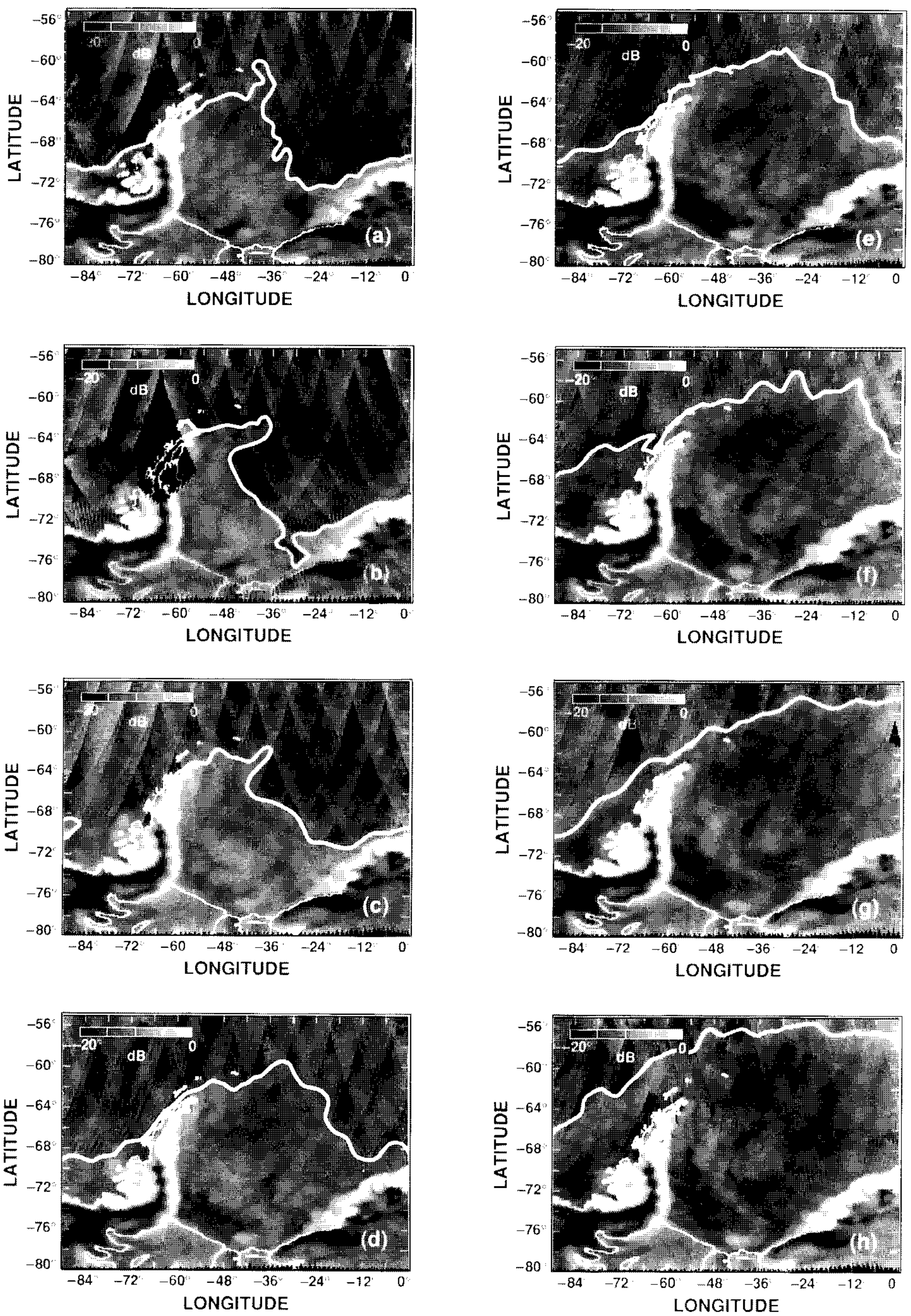

Figure 3. Time-series of weekly images illustrating evolving backscatter characteristics of the Weddell Sea ice cover in 1992. Julian-day periods illustrated are : (a) *32-38;* (b) *53-59;* (c) *74-80;* (d) *104-110;* (e) *125-131;* (f) *146-152;* (g) *167-173;* (h) *188-194. Coastlines and ice shelves are indicated by a thin white line while the sea-ice margin is identified by a thick line.*

February (3a) through the first week in July (3h). Figure 3 indicates how ice growth causes rapid ice edge advance during the onset of austral winter. As the Weddell Sea becomes ice-bound, wind- and current-driven ice motion carries large units of older relatively high backscatter sea-ice floes northwards leaving low backscatter thinner ice to form along the coastal and ice shelf margins. Measurements of mean sea-ice floe drift rates of 10 $\pm$7 km/day in the western Weddell Sea (by Argos buoys and a drifting ice station) indicate mean drift speeds which correspond closely with the rate of northward evacuation of older ice from the basin.

Conclusions

The ERS-1 Scatt provides extensive medium-resolution coverage which complements high-resolution SAR images. Weekly averaged C-band backscatter maps of the entire Antarctic region have applications in a wide variety of geophysical studies. For instance, large-scale feature tracking within the sea-ice cover enables the study of Southern-Ocean wide ice dynamics and sea-ice mass flux and time-series images clarify the processes of ice formation and decay in response to climatic and oceanographic forcing. Similarly, frequent mapping of the Antarctic ice sheet enables the extent of surface melting and snow accumulation to be quantified. When coupled with radar altimeter measurements, ice sheet images will provide valuable indications of changes in regional ice-sheet mass balance in response to climate

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