Variability in Sea-Ice Coverage and Ice-motion Dynamics in the PAL LTER Study Region West of the Antarctic Peninsula

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Abstract - Sea-ice conditions and kinematics are studied in the Palmer Long-Term Ecological Research (PAL LTER) study region west of the Antarctic Peninsula. Remote sensing data from ERS-1 Synthetic Aperture Radar (SAR) and Scatterometer (EScat) and from DMSP SSM/I, are used to study the influence of synoptic weather systems on sea-ice characteristics during July-August 1992. Weather records from Palmer Station (64° 46'S, 64° 03'W) on Anvers Island show large cyclonic storms moving through the western Antarctic Peninsula (WAP) region on a quasi-weekly basis. Periods of strong north-westerly to north-easterly winds caused above normal air temperatures and in turn a rapid early retreat of the sea-ice cover in the WAP region. Ice motion derived from SSM/I images reveals the large-scale sea-ice kinematics during these periods together with statistical summaries of the impact of each storm upon regional opening/closing.

INTRODUCTION

The PAL LTER is a multidisciplinary program established by NSF to study the polar marine ecosystem in the WAP region (Fig. 1) [1]. The central tenet of the PAL LTER is that the seasonal and interannual variability of sea ice affects all levels of the Antarctic marine ecosystem. The WAP region is a dynamic coastal/continental shelf zone that is annually swept by the advance and retreat of seasonal sea ice. There is largely no perennial sea ice in the PAL LTER region, other than in some small pockets in southern coastal bays.

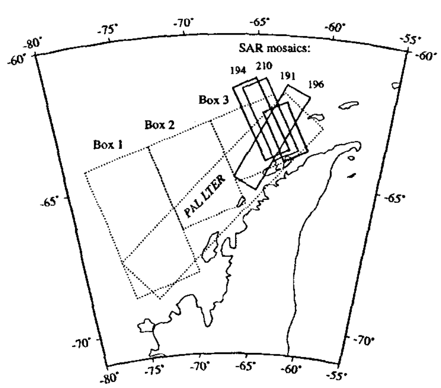

Figure 1. WAP regional map.

PAL LTER field research began in the austral spring of 1991. Since that time there have been annual time-series cruises in the PAL LTER study area every Jan-Feb and a nearshore field program (based at Palmer Station) every austral summer (approx. Nov-Mar). These annual time-series studies, in addition to several seasonal process cruises (e.g. Mar93 and Aug93), are monitoring the marine ecosystem in the WAP region under highly variable seasonal and interannual environmental conditions [2,3,4]. This allows the PAL LTER to study the effects of differing physical forcing on the ecosystem by measuring key parameters and processes before, during and after seasons and/or years of different sea ice coverage. Such a long-term sampling strategy is contributing, for example, to our understanding of how varying winter-spring sea-ice coverage impacts primary production [5].

DATA

The PAL LTER has relied heavily on passive microwave SMMR-SSM/I time-series data (1978 to the present) to characterize the seasonal and interannual variability of sea ice in the WAP region [3]. Data from SMMR-SSM/I, and more recently from EScat (1991 onwards), are the only available data offering a continuous time-series of sea-ice coverage and motion. However, the spatial resolution of these data is coarse (tens of kilometers), and though SMMR-SSM/I sea ice extent information is fairly reliable, the accuracy of derived sea-ice concentration estimates is largely unknown. Also, finer scale features, such as leads and polynyas smaller than about 25 km^2, go undetected. These features mark significant regions of gas and heat exchange between the atmosphere and ocean and are believed to be important feeding grounds, seal pupping or open water access points for the marine wildlife.

High resolution SAR data reveal the finer scale features of the sea-ice cover and offer insight into the accuracy of derived SSM/I and EScat ice information. Although the latter are temporally sparse, due to limited operational times of the ground receiving station, they offer important information on how ephemeral fine-scale features are and to what extent climatic forcing contributes to the frequency or persistence of such features.

SMMR-SSM/I brightness temperature data were provided by the National Snow and Ice Data Center (Boulder, CO). Sea-ice concentrations were calculated with the NASA Team algorithm using regional tie-points from the PELICON study [6]. These tie-points performed better than other

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available hemispheric tie-points in comparisons with coincident SAR data. ERS-1 SAR coverage of the PAL LTER region (which is outside the McMurdo receiving station mask) were downlinked at the German O'Higgins receiving station and made available by the European Space Agency, who also provided the EScat data which is collected whenever the SAR is not operating.

RESULTS

The location of the PAL LTER study region in relation to the SAR passes is given in Fig.1. Boxes 1-3 were used in extracting sea-ice concentrations and the ice kinematics. For the present study, the focus will be on box 3 which also includes most of the SAR swath area.

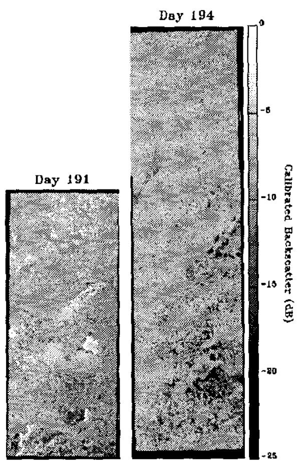

Figure 2. ERS-1 SAR mosaics from days 191 and 194 in 1992.

The two SAR mosaics shown in Fig. 3 illustrate the variety of sea-ice conditions found near the marginal ice zone in the northern part of the PAL LTER study area. The majority of pixels in both images are of snow-covered sea ice (medium gray in appearance). Since there is very little perennial sea ice in this region, the radar backscatter originates from highly deformed first-year sea ice with a fairly damp snow-cover [7]. In contrast, undeformed first-year ice typically has a uniform darker appearance [7]. In addition to the medium-gray pixels, day 191 has several bright patches indicating areas of wind-roughened open water. Small patches at the northermost extent of the day 191 image contain strings of small floes in Langmuir cells aligned with the easterly wind direction. Extensive open-water areas also formed in the lee of islands during the preceding period of south-westerly ice drift. In contrast, day 194 has many dark patches signifying areas of new ice growth in recent fractures. Day 191 also has some darker patches to the south, where air temperatures were perhaps more conducive to new-ice growth. Palmer Station met observations indicate that on day 191 winds were from the N/NE, averaging at 4.6 ms^{-1}, peaking at 10.8 ms^{-1}. On day 194 winds were from the W/NW, averaging 2.6 ms^{-1} and peaking at 4.1 ms^{-1}. Daily mean air temperatures were -13.7° C and -15.4° C, respectively.

Not shown are the SAR mosaics for days 196 and 210. Day 196 shows nearly complete coverage of mostly rough first-year ice with numerous small dark leads between floes. In contrast, day 210 shows the ice margin crossing the middle of the mosaic with wind-roughened open water to the north and marginal ice zone to the south. The different sea-ice conditions present in each SAR mosaic are illustrated by the probability distribution functions (pdf) shown in Fig. 3. Note that all of the SAR mosaics, except day 194, contain some land and/or large bodies of wind-roughened open water, which enhances the number of bright returns (*i.e.*, the upper or right

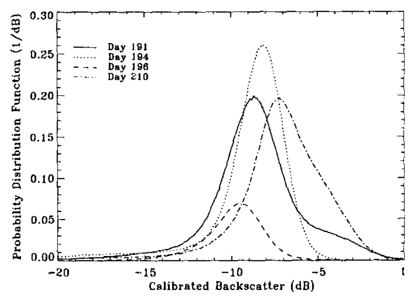

Figure 3. Normalized SAR histograms

tail of the pdf). In that sense, the pdf for day 194 which contains no land and little open water serves as a good reference for the uni-modal backscatter distribution of sea ice common to this region during winter. Day 194 was the coolest and calmest of the four days with environmental conditions conducive to the smooth new-ice growth reflected in the long lower tail of the pdf (and in Fig 2). In contrast to day 194 is day 210 which shows a pdf shifted significantly to the right due to the majority of wind-roughened open water pixels in that image.

SSM/I-derived ice concentrations determined for box 3 for the 4 days of SAR coverage show similar distributions of relative sea-ice coverage. The SSM/I daily mean sea-ice concentrations were 71%, 81%, 87% and 53% for days 191, 194, 196 and 210, respectively. As has been shown by many other studies, it appears from these comparisons that the NASA Team algorithm underestimates sea-ice concentrations greater than about 90% but is fairly reliable in capturing relative, day to day variability. It is noted, however, that we achieved better agreement when using local, instead of hemispheric, tie-points. Most likely results would be further improved if seasonally adjusted regional tie-points were used, as has been suggested by others. Nonetheless, we feel that the relative changes in the SSM/I derived daily sea ice concentration estimates do reflect the broad scale changes in the sea ice coverage, at least for the July-August time-period.

A July-August 1992 time-series of Palmer Station weather observations and ice concentration and motion statistics from box 3 are illustrated in Fig. 4. Vertical dotted lines indicate days of SAR coverage. Examination of the weather data, demonstrates a strong association between air temperature and wind with relation to sea-level pressure.

During periods when daily sea-level pressure climbs from a low to a high, air temperatures drop and reach a minimum just as the pressure peaks. During this time daily average wind speeds are typically low. Day 194 is an example of this transition, the result of which is undisturbed new-ice growth and increased sea ice coverage. After sea-level pressure peaks and begins to descend to the next low, air temperatures dramatically increase to near 0° C and some of the strongest winds occur. These associations are strongest in July (days 183 to 213) but also remain evident in August. The strongest peak winds are mostly northeasterlies, with some occasional northwesterlies. Both advect warm air from lower latitudes and bring sustained mild temperatures. Climatologically, it appears that the winter of 1992 experienced a situation where a quasi-stationary low was located just west of the peninsula, which advected warm air from lower latitudes, and which caused the air temperatures in these two months to be above normal. The end result is that winter sea ice in the WAP region reached a maximum one month earlier (July) than the climatological mean. The early sea ice maximum was then followed by an early rapid retreat, causing the spring sea ice extent to be well below normal.

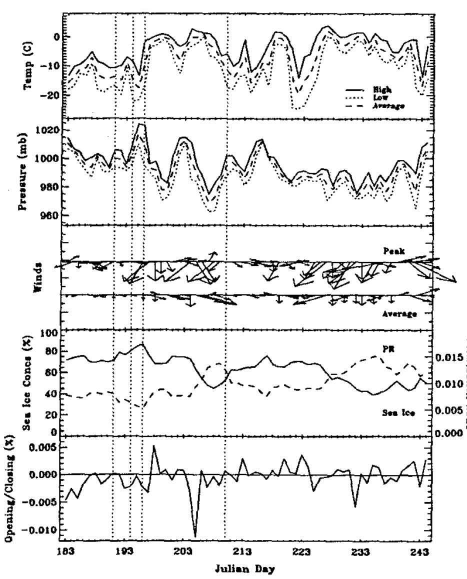

Figure 4. Time-series of Palmer Station weather and box 3 sea-ice characteristics.

The combined effect of wind speed/direction, air temperature and present sea-ice concentrations determine the effect these synoptic systems have on sea-ice characteristics and ice drift. For example, sea-ice concentrations reach a maximum on day 196 after a long period of cool air temperatures. The SAR images on days 194 and 196 indicate high ice concentrations and new ice growth in the leads. According to the percent openings and closings derived from tracked ice-drift data, these two days experienced net closing or convergence implying ridging of the thin ice component. Since most of box 3 was covered by sea ice, these closing events are marked by an increase in SSM/I-derived sea-ice concentration. Day 196 marks a turning point in the weather. Air temperatures rise and remain near 0° C for the next 12 days and sea ice concentrations steadily decrease. During the beginning of this warm period there is an opening event on day 198 which because of the high temperatures and strong northerly winds facilitates ice advection and melt instead of new ice growth. The closing event on day 205 is accompanied by strong winds from the northwest, compacting the sea ice up against the peninsula, and leaving a large portion of box 3 north of the sea-ice margin. A few cold days between day 211 and 226 along with net opening of the pack ice contribute to new ice growth and increasing sea ice concentrations. However, this is reversed again in the next warm windy period between days 226 and 242, which also appears to finalize the trend towards an early rapid sea ice retreat.

CONCLUSIONS

SAR, Escat and SSM/I satellite data of the PAL LTER study region from July-August 1992 reveal a large degree of variability in local sea-ice conditions. The frequency of storms such as those illustrated in this study are responsible for the high degree of seasonal and interannual variability in kinematics and resulting sea-ice production in this region. The dynamic response is highly ephemeral and storms play a dominant role in forcing ecosystem and mixed layer conditions.

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