CliC Arctic Sea Ice Working Group; Consensus Document

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A note on the accuracy and reliability of satellite-derived passive microwave estimates of sea-ice extent

Since the 1970s, total sea-ice extent both in the Arctic and in the Antarctic can be estimated from satellite-borne passive microwave sensors. These sensors are able to provide near-complete coverage of the sea ice-covered regions under all sky conditions at daily intervals. The satellite-derived time series of global sea-ice cover, now spanning more than 30 years, has been invaluable in our understanding of the processes responsible for seasonal and interannual fluctuations of the Earth's sea ice cover.

Nevertheless, passive microwave sensors have several limitations that can yield considerable uncertainties in sea ice concentration and total sea ice extent (total areal coverage, usually above a concentration threshold criterion). Even under optimal conditions, such as mid-winter in the middle of the ice pack, passive microwave sensors can only provide concentration estimates to within about ±5% accuracy. In less optimal conditions during summer melt, near the ice edge, and over thin ice regions, the uncertainty might reach values of more than ±20%. This significantly complicates comparison with or assimilation into models as well as other applications.

The uncertainties result from the limitations of the sensors and the ambiguities in the microwave emission from the surface and atmosphere. In the microwave spectrum of these instruments (18-37 GHz), sea ice typically emits much more energy than open water. However, because the overall emitted energy is low, a large sensor field of view (footprint) is required. Historically, passive microwave sensors had footprint sizes on the order of 50 km yielding gridded fields of 25 x 25 km, though newer sensors have smaller footprints. This limits the precision of the ice edge location to 25-50 km. Over the entire perimeter of the sea ice, this can result in an absolute ice extent uncertainty of several hundred thousand square kilometers.

It also means that within the ice pack, a single grid cell contains a conglomeration of many different ice types. At various times of year and locations there may a mixture of many of the following: bare ice, ice covered by snow of different characteristics, thin ice, ice with surface melt, ponded ice, ice with flooded snow, ridged ice, ice of different salinities. While there are five passive microwave channels (three frequencies, two with dual-polarization) on past and current sensors suitable for sea ice detection, the channels are not completely independent. So generally only three surface types can be distinguished (open water, and two sea ice types). Thus there can be considerable ambiguity in the signal that sea ice concentration algorithms cannot resolve. Surface melt and meltponds during summer generally cause the largest errors, resulting in possible underestimation of concentration of 20% or more. Regions of thin ice, low concentration ice, or ice in an extreme state of decay may not be detected at all. For this reason and the limited spatial resolution, passive microwave sea ice data is not suitable for operational support of vessels in ice-infested waters. This underestimation can also potentially impact climate applications because if melt/decay is occurring over a wider area, the underestimation may become larger with time, imparting an error into trend/variabililty estimates. The error would be more notable in concentration and total area estimates than in total extent estimates because the low concentration threshold used by extent should capture most ice, even where the concentration is underestimated. However, this issue has not been investigated in any detail, so the degree of impact is not known.

Atmospheric emission, though generally small in the microwave frequencies used by sea ice, can result in errors. Also, wind roughening of the ocean surface can raise the emission so that the surface is mistaken for ice. Near-coastal areas can also be misclassified as ice because the mixture of land and ocean within the sensor footprint may have an emissive signature similar to sea ice.

Several algorithms have been developed using various combinations of the available passive microwave frequencies and polarizations. Studies that compare different algorithms have repeatedly found that differences between algorithms are largest in summer, with differences of more than ± 20 %. In winter, differences between the different algorithms are usually less than ± 10 %. No single algorithm has been found to be clearly superior under all conditions. The differences between satellite-derived estimates of sea-ice extent and so-called ground-truth observations are of similar magnitude. Nevertheless, while the absolute differences between algorithms and between with non-passive-microwave data sets are relatively large, they are generally constant over time. Hence, trends in sea-ice extent that are estimated from different algorithms agree much more closely than do the absolute values of extent. Consequently, trend estimates provide a rather high level of confidence in estimates of sea ice change and variability. In terms of absolute values, estimates of total sea-ice extent are more reliable than estimates of sea-ice area. For the former, a certain concentration threshold (often 15% ice cover) is defined, and the size of any grid cell covered by more ice than this threshold contributes fully to total sea-ice extent. For ice area, however, only the truly ice-covered fraction of each grid cell contributes, giving rise to higher uncertainty.

In conclusion, scientists using passive microwave sea ice products need to understand the limitations and uncertainty characteristics of the data, particularly during summer when concentration values are prone to large underestimations. Nevertheless, the downward trend in sea-ice extent that is displayed by all satellite algorithms is an extremely robust feature, and its magnitude is consistent between the different algorithms. Thus the sea ice record available from the series of passive microwave sensors, processed consistently through over three decades of data, provides one of the longest, most complete, and most reliable indicators of long-term climate change.

Further Reading

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