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A systematic method of obtaining ice concentration measurements from ship-based observations

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Abstract

The distribution and concentration of sea ice plays an important role in the Earth's climate system. Although satellite data are used to observe the distribution and concentration of sea ice, the amount of in situ validation data available is limited. This is because of the hostile climate in the polar regions that limits human activity. This letter presents the first results of ice concentration values obtained from a recording system that has been designed to fit on any ship, with minimal interference to ship operations. The digital image data set presented were obtained from the *R.V. Jan Mayen* scientific cruise to the Greenland Sea, March 2000, which was part of the UK NERC ARCICE scientific programme. The analysis of the digital images using a threshold technique is described, and the results are compared with SSM/I-derived sea ice concentrations along the cruise track.

Keywords: Sea ice; Climate system; IceCam

1. Introduction

Sea ice plays an important role in the global climate system as it reflects solar radiation and regulates the interaction between the ocean and atmosphere (Wadhams, 1994, 1995; Johannessen et al., 1992). The way in which sea ice affects the climate system can be split into two main components. Firstly, the ice extent, and secondly, the concentration of open water within the ice pack (Johannessen et al., 1992), both of which vary seasonally. Due to the size of the polar regions and the hostile environment which minimises human activity, the amount of information recorded from ground-based observations is small in relation to the region of interest (Carsey et al., 1992). As a result satellite observations have been employed to obtain areal coverage of the polar regions. Of particular interest are those satellite observations made in the microwave part of the electromagnetic spectrum due to the ability to obtain data independent of solar luminance and atmospheric conditions. The complex nature of the interaction of microwaves, and in particular microwaves from active systems, can make data interpretation difficult.

Interpretation can be improved if more in situ data can be collected and made available. However, scien-

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tific-based operations in the polar regions are limited, mainly due to the cost of such operations, ship availability and competition from other scientific programmes for ship-time.

The aim of this paper is to present results calculating ice concentration using a cost-effective logging system that can be installed on any ship, with minimal crew maintenance. The results are determined from the permanent record produced by the system.

2. Shipping activity

As stated in the previous section, human activity in polar regions is minimal, although it is increasing for a number of reasons. Firstly, the search for ever-decreasing natural resources in extractable quantities has led to exploration in more hostile climates. In particular, hydrocarbon deposits found in the Kara Sea are attracting interest. Also, the tourism industry, as it continually searches for new exotic locations, has started to expand into the polar regions. There is also an increase in transport shipping, as this is the only way to supply many of the communities found in the polar region, both the scientific bases in Antarctica and local settlements in the Arctic.

In comparison to Antarctica, where all human activity is recorded under the Antarctic Treaty, shipping records in the Arctic are sparse. As an indication to the amount of shipping activity in the Arctic, Canadian Ice Service (CIS) records indicate that during the 2000 summer season 3800 movements by 82 vessels were made in Canadian Arctic waters (John Falkingham, CIS, personal communication). In the Eastern Arctic, Russian ice breakers have been making, on average, two round trips per year to the North Pole for the past 5 years, as part of the expanding tourist industry. This is currently a greater activity than that of publicly accessible submarines that provide the data used in Wadhams and Davis (2000) and Rothrock et al. (1999). If only a fraction of all voyages undertaken supplied data to a central depository, similar to the Comprehensive Ocean Atmosphere Data Set (COADS) or the Environmental Working Group (EWG) Joint US–Russian Atlas of the Arctic Ocean, then our spatial knowledge and understanding of the polar regions would be greatly improved.

3. Traditional ice observations

Traditionally, hourly observations of the sea conditions are made in the ship's log. In regions where sea ice is encountered, this may include a description of the ice (type, concentration, thickness, etc.). Unfortunately, this method, as a means of providing scientific data for satellite image analysis and climate change records, has two main drawbacks. Firstly, and most importantly, there is lack of consistency in the data set, as each observer, without comprehensive training, will have an independent set of reference points to describe the conditions. These reference points will not only differ with each ship but also each observer. Secondly, in areas of rapid change in ice conditions, particularly in the Marginal Ice Zone (MIZ), hourly sampling is too coarse, and a finer resolution is necessary.

4. Automatic ice observations

The use of video data to obtain a permanent record of the ice conditions encountered by a ship has been reported by Korsnes (1994) and Toyota et al. (1999). Toyota et al. (1999) describes a method first developed by Muramoto et al. (1993) that samples continuous video data every second. From each image sample, a line is taken and processed using a threshold algorithm so as to discriminate ice from water. They found that by averaging the data, ice concentration values could be obtained which were in good agreement with the daily operational ice charts.

This indicates that video data could be used to firstly provide a permanent record of ice conditions, and secondly measure ice concentration. From work carried out by the authors, it has been determined that it is important that the recording system not only captures an image but also records the time of capture, the position of the ship (latitude, longitude), and camera attitude (pitch and roll of the camera platform). This reduces the errors when the data are geo-located with satellite images, and other corresponding data sets.

5. IceCam

The IceCam is an integrated visual monitoring and environmental data logging system designed for deployment on any ship. As well as providing valuable data on the extent and state of sea ice in the polar regions for the assessment of global climate change, it also has potential as a shipboard navigation and safety aid.

The IceCam provides a solution to the problem of temporal and spatial referencing that had been identified in previous experiments, and can also be the centre of a complete oceanographic sensing suite. The system is intended to be completely autonomous, requiring just the connection of a power supply to initiate a logging session. The aim is to provide a general purpose, cost-effective, simple and automated system for use on Ships-Of-Opportunity (SOO). Widespread use of the system will increase data coverage of sea ice conditions in the vicinity of vessels in the Arctic and Antarctic making ground truthing of satellite data possible over a wider area than at present. Timing and frequency of images along a ship's cruise track can be adjusted for covering times of satellite overpasses or regions of interest.

During 1999, two IceCam prototypes were constructed for use on RESEARCH cruises. These cost approximately $3000 each in off-the-shelf components and instrumentation and are housed in a large, waterproof (to IP67) enclosure. The heart of IceCam is a digital camera. Technology developments in digital camera technology allow a reduction in power requirements and equipment size through the use of Charge Coupled Device (CCD) sensors. In the prototypes the camera is a 3Com/US Robotics "BigPicture" which is marketed for use as a PC video conferencing aid. Although it has a low pixel resolution of 384×288 the camera has still provided pictures suitable for quantitative analysis. We are currently looking into the use of cameras with a higher pixel resolution and infrared sensing capability. This will correct one of the prototype system's biggest flaws — the lack of night-time operating capability.

IceCam currently carries two temperature probes for measuring the external and internal air temperatures, respectively. The system electronics allow the connection of industrial data logging modules through an RS-485 network interface. Additional sensors for meteorology and oceanography can therefore be added to the system as required allowing the IceCam to gather data from various locations around a ship as the controller of a Distributed Digitisation Architecture (DDA).

Good spatial positioning information is vital on a moving platform such as a ship where there are often no land features visible to help locate an image. In the IceCam, this is provided by a Motorola Encore XT GPS board which is a standard low power, 8-channel receiver capable of providing timing as well as positional information. In addition, the attitude of the camera, i.e. the angle the camera is positioned at, needs to be determined and this information is provided by two Schaevitz Accustar clinometers. These are mounted within the IceCam so as to provide a measure of the pitch and roll of the ship. This is important when it comes to producing data products that rely on geometric correction of images.

The system is controlled and data logged by a standard Personal Computer (PC) motherboard and hard disk. This allows the system to run standard PC operating software and to be connected to other computers for data download. The computer allows the operator greater flexibility in data logging; timing of image capture and sensor sampling intervals when required. The computer itself runs the Linux operating

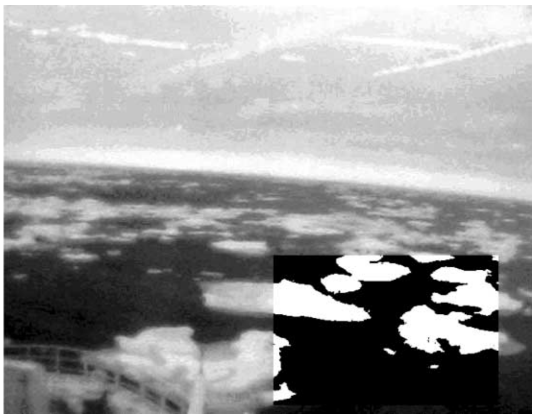

Fig. 1. IceCam image acquired at 11:10, 26 February 2000. The ship's bow is visible in the bottom-left-hand corner. In the bottom-right-hand corner, a threshold has been applied to the study sub-scene, and this is used to determine the sea ice concentration.

system. This is a free, non-commercial version of Unix for PCs that allows the development of bespoke software to control IceCam.

6. Method and results

The IceCam was programmed to obtain still images every 5 min of the ice conditions encountered by the *R.V. Jan Mayen*. The images were obtained from the ship's observation tower, providing an oblique view of the ice conditions, an example of which is shown in Fig. 1.

To reduce the effects of geometric distortion, an uncorrected sub-scene of the image was selected (Fig. 1). The sub-scene boundaries are defined so as not to contain any part of the ship, and to minimise geometric distortion, which increases with distance from the ship towards the horizon. The boundaries of the sub-scene also minimise the horizon, and therefore sky, appearing in the sub-scene, despite the pitching of the ship.

For each sub-scene, a two-band threshold filter is applied to a grey-scale version of the sub-scene (Fig. 1). The threshold limit, which is set to 100 DN (Digital Number), is previously determined by manual observation of randomly selected images from the complete data set. The percentage ice cover is calculated from the threshold image. For each day the ship operates in ice-infested waters, a daily ice concentration file is produced, starting at 08:00 and finishing at 18:30. This covers the daylight hours encountered in the geographical study area. The daily ice concentration graph is shown in Fig. 2, along with images produced by the IceCam.

A moving average, with a window of 20 data points, is applied to the raw data set. By averaging the data, the effect of erroneous measurements is reduced. For example, a single floe in open water can potentially fill the entire sub-scene, returning 100% rather than the true concentration. In reality, this is unlikely to happen, as a ship would normally avoid single floes, especially when the fastest route is desired. By averaging the data, it also reduces the spatial resolution of the IceCam data, and, therefore, the data are more comparable to satellite-derived sea ice concentrations from SSM/I data that has been

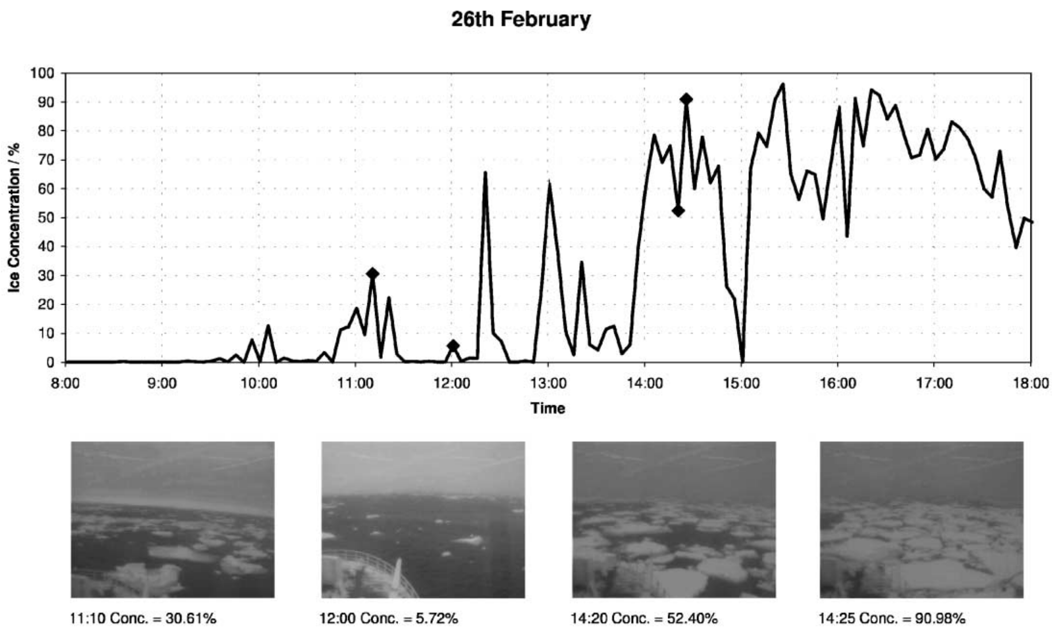

Fig. 2. IceCam-derived sea ice concentrations along the cruise track of *R.V. Jan Mayen* on 26 February 2000. With examples of IceCam images, labelled with the time of acquisition and sea ice concentration.

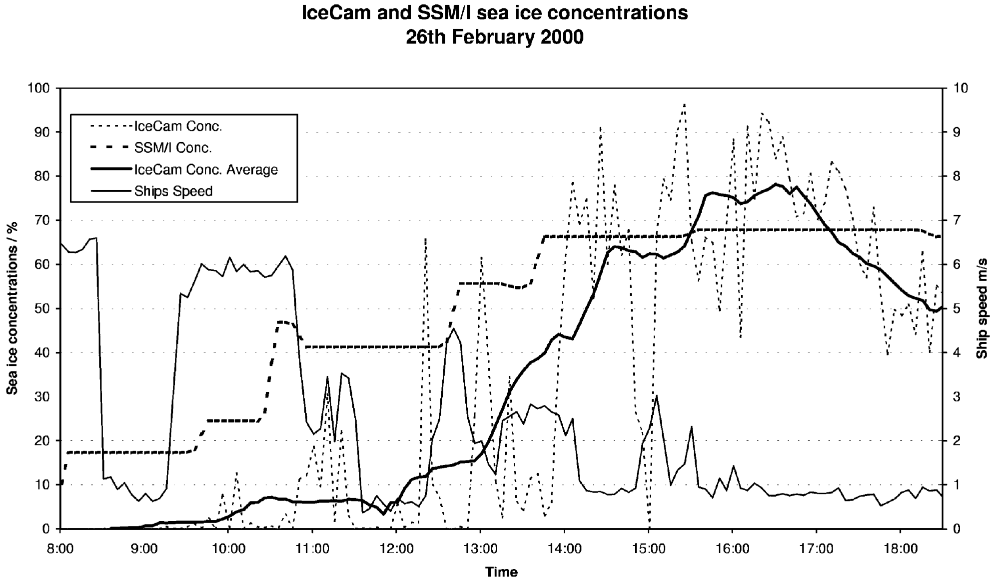

Fig. 3. IceCam-derived sea ice concentrations and SSM/I-derived sea ice concentrations along the cruise track of *R.V. Jan Mayen* on 26 February 2000 against time. Also plotted is the ship's speed against time.

provided by Leif Toudal following the method described in Toudal (1999).

This is illustrated in Fig. 3 where it can be seen that the raw IceCam data, the averaged data, and the SSM/I sea ice concentration data from along the cruise track are plotted against time. The trend in the averaged IceCam data set and the SSM/I data follow very similar trends over time. The ship's speed is also plotted against time, and it can be seen that, as expected, there is an inverse relationship between sea ice concentration and ship speed.

The differences between the IceCam-derived ice concentration plot and the SSM/I-derived ice concentration can be due to a number of reasons. Firstly, the two systems have very different spatial coverage. This is exemplified if we consider an open lead surrounded by very high sea ice concentrations. The lead will not show up in the SSM/I data, instead the value reported will reflect the whole 25 km^2 covered by the pixel, of which the lead may only make up a small percentage. In comparison, the IceCam data may over-emphasise the lead, and the value may not reflect the high concentration of sea ice on either side of the open lead. Satellite data with a higher spatial resolution than SSM/I, for example ERS-2 SAR and Radarsat, will reveal leads and, therefore, the comparison between ship- and satellite-derived sea ice concentrations would be expected to be more similar. Secondly, as can be seen in Fig. 3 and reported by Gloersen et al. (1992), SSM/I data overestimate sea ice concentrations less than 15%. Finally, the third reason why there are differences between the two data sets is that there is no record of an extensive validation exercise in determining the accuracy of the sea ice concentrations derived from SSM/I data.

7. Conclusions

The results obtained from 26 February 2000 clearly indicate the ease of obtaining systematic sea ice and open water concentrations from a ship-borne camera system. The results also compare favourably with sea ice concentrations derived from SSM/I data, despite the large difference in spatial coverage and resolution of the two systems.

A more extensive in situ data set may provide evidence to enhance the current algorithms used to derive sea ice concentrations from SSM/I data. It will also provide a unique data set to interpret and validate other satellite-borne data sets. This can be done either quantitatively by following the methodology described here, or qualitatively. Images obtained by the IceCam can be interpreted to describe the ice type present and then geo-located. From this, a supervised classification may be performed on the corresponding satellite data, which would not only include existing ERS and Radarsat programmes, but also future satellite programmes, including Envisat, Radarsat and Cryosat.

The results also demonstrate the ease with which basic observations of sea ice conditions can be made consistently over time with minimal maintenance. The potential for such a system is that if every ship had an IceCam installed and if that data were stored in a central depository, then a large data base would be created. In addition, all the data would be collected in the same consistent manner that would remove any ambiguity between different sets. The benefits of such a database have already been highlighted by the COADS and EWG programmes, and a similar data base for the polar regions could improve our understanding of their role in the Earth's climate system.

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