The development of a portable Earth's field NMR system for the study of Antarctic sea ice

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Abstract

A portable Nuclear Magnetic Resonance (NMR) spectrometer based on digital signal processor (DSP) technology has been developed and applied to the study of the structure of Antarctic sea ice. The portability of this system means that external sources of noise can be minimised and remote sites can be investigated.

A new sea-ice probe has been developed in conjunction with the spectrometer allowing in-situ measurement of water content, relaxation times and self diffusion. The new probe minimises disturbances to the sea ice sample which have been a problem with previous techniques.

The core of the spectrometer consists of a Motorola DSP56303 DSP which controls the NMR experiment under the supervison of a host computer which in this case is a PC laptop. Communication between host and DSP is via either a PCMCIA card or USB interface. DSP software runs the experiment, controls acquisition and performs digital filtering of the NMR data before sending it to the PC for analysis and display.

The flexibility of the DSP based core means that this system could be adapted to other control applications with relative ease.

Acknowledgments

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Contents

1.0 Introduction

To most people the continent of Antarctica has little or no impact on their lives and exists only in their minds as an icy wasteland at the bottom of the globe. However it has captured the attention of a few and has drawn them into its strange and amazing environment. An environment that has unspoiled beauty, yet can be extremely treacherous. Although Antarctica may seem insignificant to some, it plays a very significant role in global ecology and climate due to the vastness of the continent and its surrounding sea ice. It is also considered by some to be the weather engine of the planet, and is sometimes described as the coldest, windiest and driest place on Earth.

Each winter the waters around Antarctica freeze and form a 1 to 2 m thick layer of sea ice over an area of ocean of approximately 20 million square kilometres (figure 1.0). This sea ice behaves as a blanket in that it insulates the cold polar atmosphere from the warmer ocean, thus restricting heat exchange [4]. The exchange of carbon dioxide is also limited by this relatively impermeable covering. The sea ice is usually covered by a layer of snow, which assists it in reflecting over 90% of sunlight in summer. This is much greater than the 5% reflected sunlight from the open ocean and demonstrates the effectiveness of the sea ice as a massive solar reflector. As most of the sunlight is reflected, the amount that is absorbed at the surface, and that is available for photosynthesis in the underlying ocean, is significantly reduced. Furthermore, a layer of algae grows on the underside of the sea ice and further restricts the light available to the ocean. This layer of algae equates to a vast quantity of biomass that is later released into the ocean in summer.

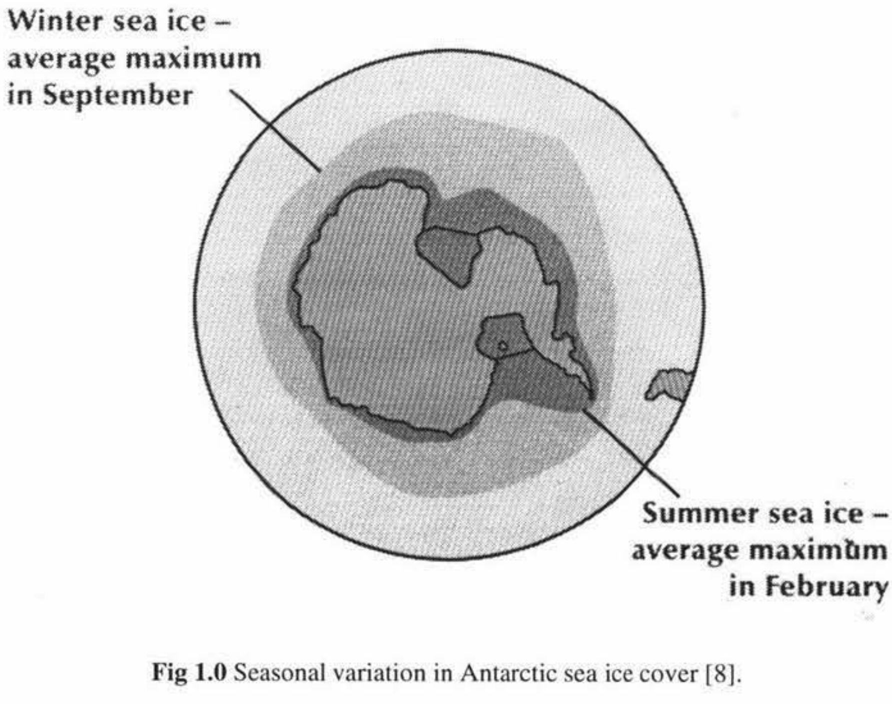

Fig 1.0 Seasonal variation in Antarctic sea ice cover [8].

When the seawater freezes, small cavities of concentrated brine form inside pure ice. Some of the brine drains out through vertical channels as the sea ice grows in thickness, but some of it remains trapped. As the ocean and atmosphere are at different temperatures, a temperature gradient exists within the sea ice, which then causes convection processes to occur within the cavities. The cavities slowly migrate downwards due to the melting that occurs at the bottom of the cavity and the subsequent refreezing at the top. Over time these cavities migrate towards the ocean and eventually drain out, releasing the brine into the ocean. In summer the sea ice slowly breaks up and moves north releasing vast quantities of fresh water and algal spores into the ocean, again influencing the climate and ecology. The enormous seasonal variation in the surface area of the sea ice is a large annual event that is much intertwined with the global climate, and therefore any effective climate modelling depends upon an understanding of the optical, thermal and mechanical properties of this complex and unusual material.

For a number of years now the Physics department at Massey University has been using Nuclear Magnetic Resonance (NMR) techniques to study the microstructure of Antarctic sea ice. This is part of a larger Antarctic sea ice research program in which the study of the structure and mechanical properties of sea ice has been undertaken, allowing predictions to be made about the strength of sea ice, how it formed and how it breaks up under wave action. Our involvement is at the microscopic end of the scale where we are studying the behaviour of the brine cavities.

There are two types of experiments that we perform on sea ice:

1. The first is the determination of the brine content within the ice. This information is used to make predictions about the age of the ice and how it formed. The concentrated brine has a very low freezing point and significant free water can still be found in sea ice at temperatures below -20 ^{0}C.
2. The second is the measurement of the brine diffusivity. Here we get information about the diffusion and convection occurring within the cavities which will help in making predictions about the thermal behaviour of the sea ice. It can also give information about the brine pocket dimensions.

This thesis describes some work that I have been doing part time over a period of about three years, during which time a portable Earth's field NMR system designed primarily for Antarctic research, but with other applications in mind, was developed. This work is an extension to previous work done within the Physics department, where a system for studying sea ice was initially put together using a number of commercial units and some homebuilt electronics [3]. This early system itself grew out of a laboratory experiment [1] that was developed a number of years ago within the department.

My task was to design and construct a totally in-house system. The project could be divided into four parts:

1. Probe design and construction.
2. Antarctic Earth's Field NMR System design and construction.
3. The design and construction of a general purpose NMR system "core".
4. Experimental work in Antarctica.

This work started in the latter part of 1997 when I designed and built a new probe for the Antarctic visit at the end of the year. Some improvements and modifications were also made to the existing NMR system electronics that were used with the new probe. In 1999 another visit was planned, so I then put together a totally new portable system that would allow us to make remote measurements. Some improvements were also carried out on the probe that I built for the previous season. Since returning from the last Antarctic visit, I have continued with the development of the system, in order to optimise it for any future visits, and to lay the foundation for some future work where systems will be developed for other NMR and non-NMR applications.

The following chapter presents a brief introduction to NMR, with some further information regarding the areas concerning my project. The third chapter describes the design and construction of the new portable Earth's field NMR system and the new probe, and concludes with an evaluation of the system and probe's performance. Chapter four gives the details of the design and construction of the "system core" component mentioned in chapter 3. Included is a description of the digital signal processing techniques used. The end of the chapter describes some work that has been done to improve and extend the capabilities of the system core. An overview of some of the work done in Antarctica is given in chapter 5, while the final chapter presents some conclusions.