

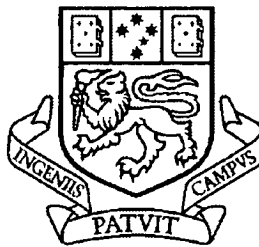
# **Analysis and Visualization Techniques for Integrating Remotely Sensed Sea Ice Data with Plankton Observations**

**by**

**Jun Feng, MComp**

A dissertation submitted to the School of Computing & Information  
Systems in partial fulfillment of the requirements for the degree of

**Master of Computing**



**University of Tasmania**

**November 2008**

## **Declaration**

I, Jun Feng, declare that this thesis contains no material that has been accepted for the award of any other degree or diploma in any tertiary institution, and that, to my knowledge and belief, this thesis contains no material previously published or written by any other person except where due reference is made in the text.

Jun FENG

Jun Feng

## **Abstract**

The study of sea ice dynamics and zooplankton in the Southern Ocean has been undertaken over a long period. Antarctic sea ice is monitored by a number of Special Sensor Microwave Imager (SSM/I) instruments. SSM/I is a passive microwave radiometric system and operated by the Defense Meteorological Satellite Program. Analysed data comprising sea ice concentrations are routinely produced on a 25-km grid and there is a complete collection covering the years from 1987 to 2007. Over many years of zooplankton observations in Southern Ocean a large amount of information has been collected using the Continuous Plankton Recorder. The latest survey aims to study regional, seasonal, inter-annual and long-term variability in zooplankton abundance, species composition, and distribution patterns in the Southern Ocean zooplankton communities (Hosie et al. 2003).

Visualisation techniques are used to display these two important data sets. They can facilitate the observation, analysis and the effective prediction of dynamics of the sea ice and zooplankton. This research utilised data sets provided by the Australian Antarctic Division (AAD) and obtained as part of their recent study of the Southern Ocean in the region of between 50°E and 150°E, and south of 60°S.

The research has demonstrated some of the opportunities provided by the use of scientific visualisation to present satellite images of the sea ice and associated zooplankton information to the researchers. It will assist the researchers to analyse the data characteristics, observing dynamic effects by manipulating user interactive simulations. The research has also confirmed that, compared to the manual approaches currently employed, it is a time saving process achieved by customized computational analysis of large of datasets.

## Acknowledgements

Firstly I would like to thank my supervisor Ray Williams for all the support and guidance throughout the whole year of research and supervisor Ben Raymond for the continual communication and for providing so much valuable information. Thank you to the Australian Antarctic Division (AAD) and the School of Computing & Information Systems for providing this interesting topic and the opportunity to conduct the research. Without these people this project would not have been possible.

I would like to thank Dr Graham Hosie (AAD). Thank you for conducting the SO-CPR survey that is formed the base for undertaking this project and the short presentation and introduction you gave about your research at the beginning of the project. Moreover, I would like to thank you for letting us visit the krill laboratory in AAD.

Thanks go to Jacky Hartnett for the Honours Seminars throughout the year. Those were very useful guides and facilitated the research process. Thank you to David Herbert for installing the MATLAB software and to Klaus Meiners for coming to the last two meetings, helping improve the software and providing evaluation suggestions. Thanks to all office staff of the School of Computing & Information Systems for providing me with help and for lending me other people's theses, which proved to be very useful references.

Thank you to all of my friends on the Internet for the communication and discussion about the solutions of some technique problems. Thanks go to all my friends in and out of TAS for their encouragement. When I was depressed, I would not have been



able to revive so quickly without your regards and your help.

Finally I would like to thank my family, Mum and Dad for supporting me to study abroad. Thank you my dear Mum for your continuous care. When I was sick, I could able to recover quickly because of your love and advice. Thanks also go to my Aunts, Uncles and Grandma for considering me even you were living in a country far from here.

And sorry to everyone for being angry at you, when I was doing my research. I just have been a bit busy, sometimes depressed. But I still love you all and really apologize for that.

*For My Family,*  
*Mum, Dad,*  
*Aunts, Uncles, Grandma*  
*and all My Friends*

# Contents

- 1 Introduction ..... 1
- 2 Literature Review ..... 3
  - 2.1 The Southern Ocean ..... 3
    - 2.1.1 Plankton ..... 4
    - 2.1.2 Sea Ice..... 6
  - 2.2 The Southern Ocean Continuous Plankton Recorder Project ..... 7
    - 2.2.1 The Development of the SO-CPR Survey ..... 8
    - 2.2.2 The Seasonal Succession of Zooplankton in the Southern Ocean south of Australia..... 10
  - 2.3 Remote Sensing for Sea Ice Characterization..... 14
    - 2.3.1 Passive Microwave Systems..... 14
    - 2.3.2 The SSM/I ..... 15
    - 2.3.3 Remote Sensing of Sea Ice ..... 16
  - 2.4 Scientific Visualization..... 18
    - 2.4.1 Geographic Visualization..... 19
    - 2.4.2 Visualization Techniques ..... 20
    - 2.4.3 Development of a Visualization System..... 25
    - 2.4.4 Scientific Visualization for the Ocean Research ..... 27
- 3 Method ..... 30
  - 3.1 System Development ..... 30
    - 3.1.1 Aims and Requirements..... 30
    - 3.1.2 Development Software ..... 31
    - 3.1.3 Development Stages..... 32
  - 3.2 Data Preparation..... 33
    - 3.2.1 Sea Ice Data ..... 34
    - 3.2.2 Penguin Data..... 35
    - 3.2.3 Plankton Data..... 35
  - 3.3 Visualization ..... 38
    - 3.3.1 Data Operation ..... 38
    - 3.3.2 Graphical Interfaces ..... 39
    - 3.3.3 Interaction with Information ..... 46
  - 3.4 Analysis and Evaluation ..... 48
    - 3.4.1 Analysis ..... 48
    - 3.4.2 Evaluation ..... 49
    - 3.4.3 Biologists Evaluation..... 49
- 4 Results and Observations ..... 51
  - 4.1 Results from Development..... 51
    - 4.1.1 Results from Exploring Visualization Techniques..... 51
    - 4.1.2 Results from the Application Development Process..... 52
  - 4.2 Results from Analysis and Evaluation..... 53
    - 4.2.1 Analysis ..... 53
    - 4.2.2 Evaluation ..... 53

**4.2.3 Biologist Evaluation .....53**  
**5 Conclusion and Further Development .....55**  
**6 References .....57**

# Chapter 1

## Introduction

Using the Southern Ocean Continuous Plankton Recorder Survey (SO-CPR) biologists have studied and observed regional, seasonal and inter-annual variability in zooplankton abundance, species composition, and distribution patterns of the Southern Ocean zooplankton communities for a long time and they are pursuing further analysis of the relationship between plankton and sea ice dynamics. This system will become a valuable tool for assisting biologists to undertake relevant analyses systematically.

Remote sensing is a major technique for the study of sea ice changes and to visualize sea ice information it is necessary to further process passive microwave satellite images generated by remote sensing technology. The southern ocean continuous plankton records are obtained from long time monitoring and observation during different voyages by various Antarctic ships. The collections are carried by using the devices called 'Continuous Plankton Recorder' (CPR), which are towed by the ships. This system integrates these two data sets using visualization techniques. The plankton can be accurately located in the sea ice images. Along with sea ice changes during different seasons the monitored plankton information will adapt to the changes and alter the display. Furthermore, the system enables one to provide further plankton tracking information by employing the interaction techniques, thus biologists can focus on particular interested areas.

The processing of such data sets is not simple because of the complexity of the data. Therefore the data analysis is a time-consuming process. In addition it often takes considerable time to discuss and communicate with biologist when designing and

determining the most appropriate ways to visualise these two data sets in order to meet real needs. This project aims to utilise computational data fusion and visualization techniques to integrate sea-ice dynamics data derived from passive microwave satellite images, with zooplankton observational data that is obtained from the Southern Ocean Continuous Plankton Recorder.

## Chapter2

### Literature Review

This project focuses on analyzing and visualizing the relationship between sea ice dynamics data and plankton data. It involves the extraction and effective representation of information from two data sets captured during the survey by Hosie et al. (2003), from research reports (Hunt and Hosie 2005, Hunt and Hosie 2006) and further data from the Southern Ocean Continuous Plankton Recorder provided by the Australian Antarctic Division.

Prior to the development of such a system as an assistant for biologists it is vital for the improvement of current analysis approaches to review the literature as follows. They include the factors in the Southern Ocean such as plankton, sea ice as the research background, the field of remote sensing for sea ice, with particular reference to the SSM/I passive microwave space-borne sensor that provides the sea-ice data to be used by the system. The techniques from the field of Scientific Visualization; in particular geo-spatial visualization, that can benefit the visualization of these two data sets will also be discussed.

#### 2.1 The Southern Ocean

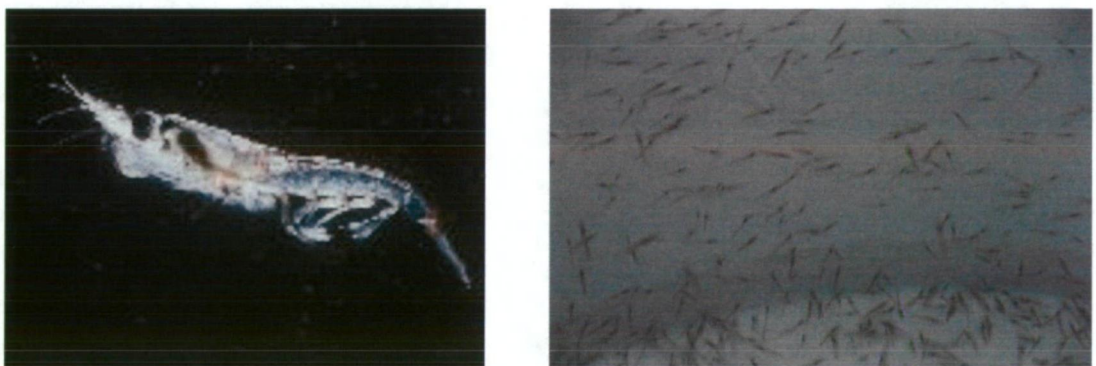
The Southern Ocean is

*“a rich, apparently high productive plankton-pelagic system supporting (at least in the past) great populations of whales and millions of penguins, and seals, and abundant intermediate populations of fish and cephalopods, depending on the near surface productivity.”* (Hedgpeth 1977b)

The Southern Ocean ecosystem, which probably is the largest marine ecosystem on the earth, is semi-enclosed. In particular the overlying water masses and the Polar Front mark an obvious northern boundary (Knox 2007, p. 2). There is a principal variation for most of the major life groups. It is that of productivity which is greater in certain regions than in others. In addition, the distribution of the dominant herbivore and key species of the system, *Euphausia superba* (Antarctic krill), demonstrate the quantitative and qualitative characteristics of the basic processes in the Southern Ocean system which are different from those of other oceanic systems. (Knox 2007, p.3)

### 2.1.1 Plankton

The word 'plankton' is used to describe passively drifting small plants (phytoplankton) and animals (zooplankton) in aquatic systems (Hays et al. 2005). In the mid-1960s there was an increased level of research into Antarctic zooplankton which was stimulated by the possibility of the exploitation of Antarctic krill, shown in Figure 2.1 (Knox 2007, p. 100). Since then a growing number of major coordinated research activities have been carried out by national or international Antarctic programs including the SO-CPR Project (see Section 2.1.3).



**Figure 2.1** *Euphausia superba*, Antarctic krill (Australian Antarctic Division 2007)

The distribution pattern of Southern Ocean zooplankton is influenced by both abiotic and biotic factors. The abiotic factors include the intensity of ocean currents and



variations in the distribution and the nature of the different water masses, as well as variability in the position of the frontal systems (Knox 2007, p. 111). According to relevant observational and modeling studies the advection caused by the annual formation and melting of sea ice disperses phytoplankton and zooplankton away from their main centers of production, therefore extending the regions of enhanced concentrations and distributing these populations over wider geographical ranges (Hofmann et al. 2004, p487).

One of the major biotic factors is that the abundance and composition of the phytoplankton which feed the zooplankton are influenced by climate change. It is considered that Antarctica and the surrounding waters are particularly sensitive and vulnerable to climate change. Therefore, climate may become one of the forces impacting on Antarctic zooplankton (Hoise et al. 2003). Over recent decades it has been shown that there are systematic changes in zooplankton abundance and community structure in many ocean areas. Antarctic krill, which is a major component of the diet of many marine mammals, is an example. They have reduced in abundance by more than an order of magnitude over the past 25 years (Atkinson et al. 2004). This change may be related to a reduction in food availability in the form of phytoplankton blooms in summer and ice algae in winter (Hays et al. 2005). Many commercial fisheries are greatly influenced by the El Niño Southern Oscillation (ENSO). It leads to reduced plankton production and therefore less food for fish (Alheit and Niquen 2004).

Richardson and Schoeman (2004) revealed the importance of the impact of weather on the intensity of ocean mixing (and its reverse, ocean stratification). This intensity, in turn, affects light levels, surface temperatures and the magnitude of nutrient recycling from deep layers, thereby influencing phytoplankton growth and thus driving bottom-up processes throughout the pelagic food chain.

### 2.1.2 Sea Ice

There are several sea-ice zones, the seasonal pack ice zone, the coastal zone, the perennial pack ice, and the marginal ice zone and together these represent a spatial and temporal structuring of Antarctic marine ecosystems by reason of ice-cover seasonality and ice drift (Eicken 1992). Different from open-water pelagic ecosystems sea ice is considered particularly important to the Southern Ocean ecosystem because its growth, deformation, drift, and decay increase the variability of environmental factors impacting on the Antarctic ecosystem and partly changes its structure.

However, sea ice does not simply change the environmental factors and increase the frequency and degree of fluctuation of physico-chemical boundary conditions. When sea ice grows, for example, the depth and rate of mixing of surface waters will increase (Eicken 1992). In addition, the growth, deformation, drift and decay of sea-ice create compartments within the environment, and divides autotrophic communities, which can produce complex organic compounds from simple inorganic molecules, into water-column and ice-resident forms. One of the important factors, affecting the water-column communities is the low average and high variability of irradiative fluxes into ice-covered waters. It seems the latter has a more ideal living environment because of the equable light conditions in a stable and rigid habitat, however it exhibits lower temperatures and higher salinities within the ice cover (Eicken 1992). For instance, in the pack ice zone surface water temperatures are continually low (e.g., in McMurdo Sound they range from  $-1.81^{\circ}\text{C}$  to  $0.08^{\circ}\text{C}$  (Littlepage 1965)), and the ice column temperature may vary by a range of several degrees lower (Kottmeier et al. 1986). Moreover, the salts excluded from ice are concentrated in microscopic ( $<1\text{mm}$ ) brine pockets within the ice column (Knox 2007).

The ice environment provides support and protection for a variety of communities at

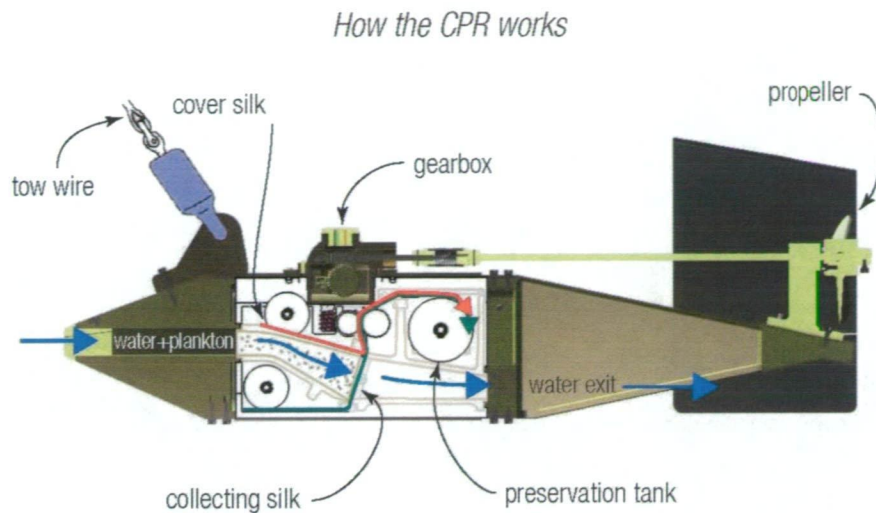
locations which are characterized by distinct micro-climates. Under this environment motile organisms are considered as having an obvious superiority, because they have the ability to retreat to ecologically favourable zones (Eicken 1992).

## **2.2 The Southern Ocean Continuous Plankton Recorder Project**

The Southern Ocean Continuous Plankton Recorder (SO-CPR) project is an international research program supported by the Scientific Committee on Antarctic Research (SCAR) (Australian Antarctic Division 2008b). It has provided a dataset of Southern Ocean Continuous Zooplankton Records which contains zooplankton species, abundance data, observation dates and so on.

Contiguous maps of zooplankton over large areas, which are ideal for bio-geographical mapping, have been provided by the SO-CPR project. Also it provides information on the spatio-temporal variation in zooplankton community structure (Australian Antarctic Division 2008b).

The CPR (Figure 2.2) is the most cost-effective method of rapidly and repeatedly surveying plankton species in the Southern Ocean. It is towed 100 m behind the ship at about 10 m depth. In 1926, Alister Hardy collected continuous records of phytoplankton and zooplankton abundance by using a new device and these records dramatically illustrated the patchiness of plankton distribution on the Discovery expedition of the Antarctic (Kemp 1926). He called the new sampling device the 'Continuous Plankton Recorder' (CPR).



**Figure 2.2** CPR (Australian Antarctic Division 2008a)

### 2.2.1 The Development of the SO-CPR Survey

After BIOMASS (Biological Investigations of Marine Antarctic Systems and Stocks) which experiments in the region of the Antarctic Peninsula and Scotia Sea and the Prydz Bay region of eastern Antarctica finished (Pakhomov 1989; Smith & Schnack-Schiel 1990; Hosie 1994; Schnack-Schiel & Mujica 1994), Australia continued surveying eastern Antarctic waters and by 1996 the area surveyed covered a large area between 50 and 150°E, and south of 60°S (Hosie and Stolp, 1989; Hosie, 1994; Hosie and Cochran, 1994; Hosie et al., 1997; Hosie et al. 2000). Based on the previous surveys it aims to study regional, seasonal, interannual and long-term variability in zooplankton abundance, species composition, and distribution patterns of the Southern Ocean zooplankton communities to obtain the information of annual abundance and distribution of krill larvae (Hosie et al. 2003).



**Figure 2.3** CPR Voyages (Australian Antarctic Division 2008b)

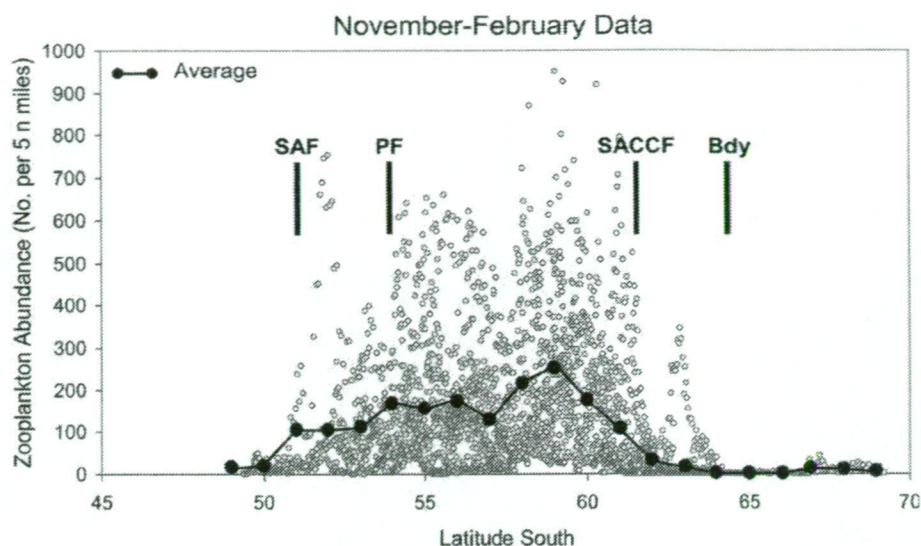
By the end of the 2000–2001 seasons there were over 36,000 nautical miles of records accumulated through the SO-CPR survey, 31,214 miles on *Aurora Australis* over 10 years, 3318 miles on *Shirase* from two seasons and 1915 miles on *Kaiyo Maru* (Hosie et al. 2003). Figure 2.3 represents the voyages of ships *Aurora Australis* (yellow), *Shirase* (purple), *Kaiyo Maru* (green), *Umitaka Maru* (white), *Tangaroa* (orange), R.V. *Polarstern* (black), *Hakuho Maru* (red).

As a result of the most intense sampling during the 1997-1998, 1999-2000 and 2000-2001 seasons it could be concluded that abundances reached a peak through November to February and dropped to low level through the winter months with the lowest values recorded in August.

Abundances are also related to the latitudinal zones. As shown in Figure 2.4 low abundances were recorded in the Sub-Antarctic Zone (SAZ) north of the Sub-Antarctic Front (SAF), and in south of the Southern Antarctic Circumpolar Front (SACCF) that is a sea-ice zone. The highest abundances were recorded in the area between the SACCF and the SAF (i.e. the Polar Frontal Zone (PFZ) between the



SAF and PF, and the Antarctic Zone between the PF and SACCF) (Hosie et al. 2003).



**Figure 2.4** Latitudinal change in total abundance during the peak month of Nov. to Feb.

(Hosie et al. 2003)

## 2.2.2 The Seasonal Succession of Zooplankton in the Southern Ocean south of Australia

Seasonal transitions in sea ice are mainly characterized by the variety of temperature and salinity which influence plankton abundance and communities. Seasonal cycles are an important component of both spatial and temporal variability in zooplankton communities (Atkinson 1998 and Beaugrand et al. 2001).

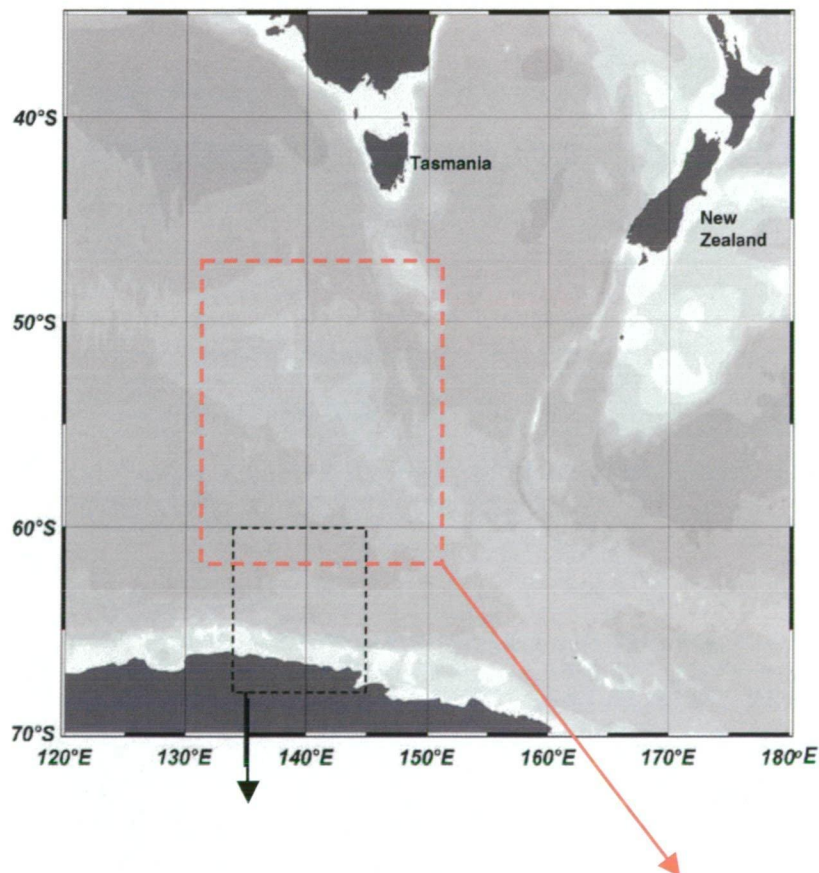
During the 2001-2002 seasons, Australia and Japan contributed to a collaborative study which realised the seasonal data collection from two latitudinal zones the Seasonal Ice Zone (~66– 62°S) and the Sub- Antarctic Zone/Inter Sub-Antarctic Front Zone/ Polar Frontal Zone (~54–47°S). There are six passes of a transect line in the Seasonal-Ice Zone (south of 62°S) along 140°E (Table 2.1; Figure 2.5). Moreover, between October 2001 and March 2002 six transects were realised at monthly intervals in the region from Sub-Antarctic to Polar Frontal Zones. (Table 2.2; Figure 2.5)

Transect	Ship	Net	Sample period	Latitude (°S)	Longitude
A	<i>Aurora Australis</i>	NORPAC	22–28 Nov 2001	62–66.00	140–143
B	<i>Hakuho Maru</i>	CPR	10–15 Jan 2002	62–65.50	140
C	<i>Tangaroa</i>	CPR	11–12 Feb 2002	62–66.24	140
D	<i>Tangaroa</i>	CPR	19–22 Feb 2002	62–64.50	140
E	<i>Tangaroa</i>	CPR	25–26 Feb 2002	62–66.36	140
F	<i>Shirase</i>	CPR	10–11 Mar 2002	62–65.43	140

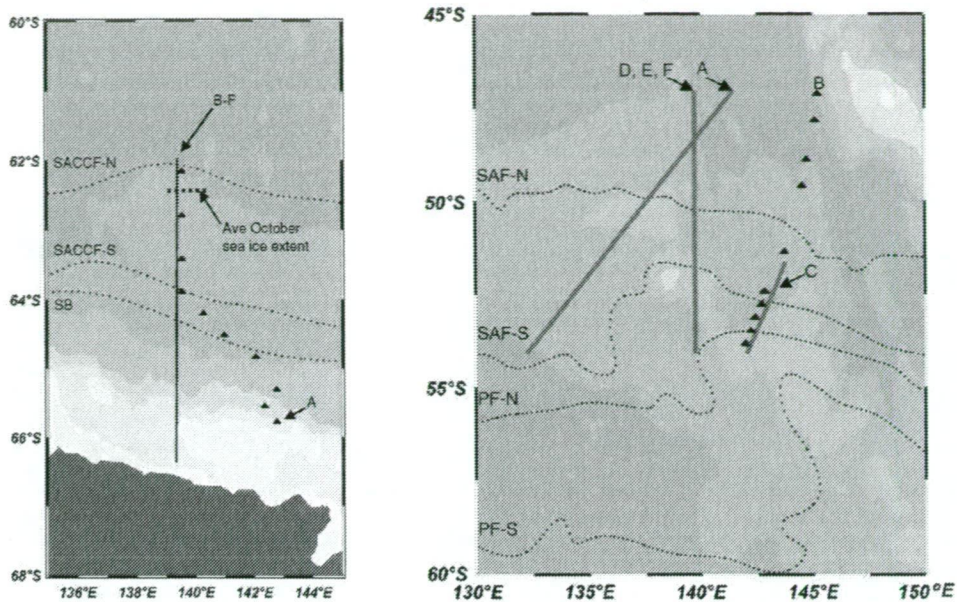
**Table 2.1** Details of zooplankton sampling completed along 140°E between November 2001 and March 2002 (Hunt and Hosie 2006a)

Transect	Ship	Net	Sample period	Latitude	Longitude
A	<i>Aurora Australis</i>	CPR	17–19 October 2001	54.0–47.0°S	132.7–142.6°E
B	<i>Aurora Australis</i>	NORPAC	2–13 November 2001	47.0–54.0°S	144.9–141.9°E
C	<i>Aurora Australis</i>	CPR	11–12 December 2001	53.6–51.3°S	142.0–143.3°E
D	<i>Hakuho Maru</i>	CPR	17–19 January 2002	54.6–47.0°S	140°E
E	<i>Tangaroa</i>	CPR	7–9 February 2002	47.0–54.0°S	140°E
F	<i>Tangaroa</i>	CPR	2–3 March 2002	54.0–47.0°S	140°E

**Table 2.2** Details of monthly transects conducted south of Tasmania between October 2001 and March 2002 (Hunt and Hosie 2006b)



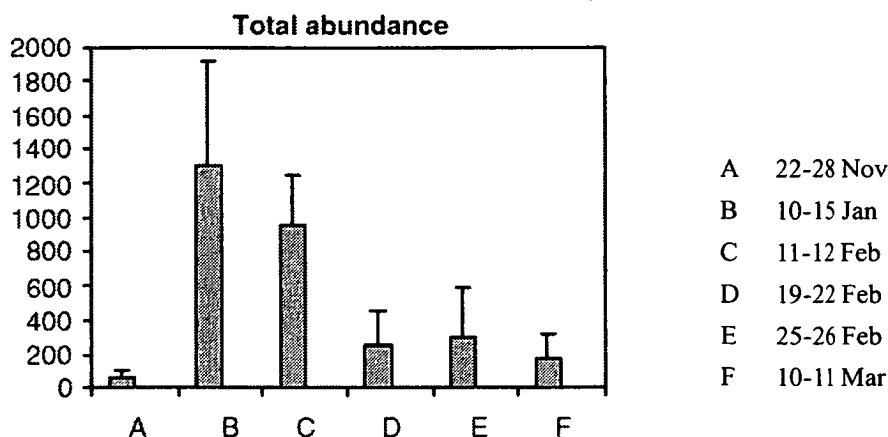




**Figure 2.5** Map of the SIZ study area and Map of the area from the Sub-Antarctic to Polar Frontal Zones (Hunt and Hosie 2006a; Hunt and Hosie 2006b)

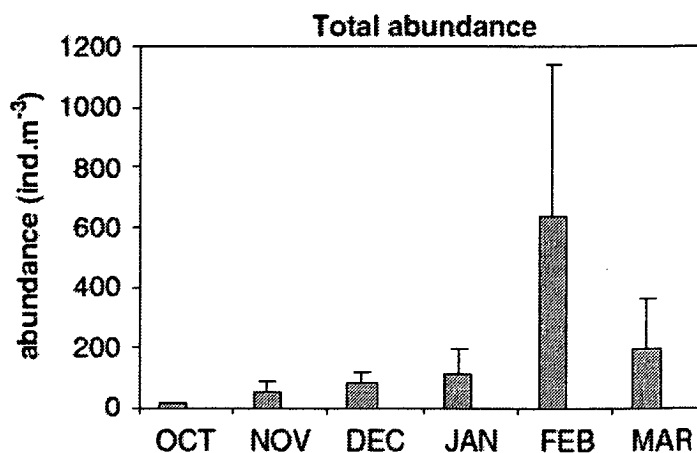
In the Seasonal Ice Zone the average of zooplankton densities that equals 61 individuals (ind)  $\text{m}^{-3}$  was lowest on 22–28 November (Figure 2.6). At that period sea ice almost covered the whole of the transect. By 10–15 January the sea surface temperature across the transect line had risen by  $\sim 2^\circ\text{C}$ , and this area was ice-free. As a result of sampling total zooplankton abundance the average 1301 ind  $\text{m}^{-3}$  was the maximum level for that season. Subsequently total densities started to decline along with each transect, and went down to an average of 169 ind  $\text{m}^{-3}$  on 10–11 March. The seasonal community succession appeared to be impacted by the low sea ice extent and southward projection of the ACC (Antarctic circumpolar current) in this area (Hunt and Hosie 2006a).





**Figure 2.6** Average densities (individuals m<sup>-3</sup>) of the total abundance for each of the six transects completed between November 2001 and March 2002 (Hunt and Hosie 2006a)

In the region from the Sub-Antarctic to the Polar Frontal Zones the seasonal succession was most obvious as a change in zooplankton densities by the reason of the dominance of the Core and Summer taxa which means taxa are decided in core zone and during summer season. It can be seen from Figure 2.6 that densities in October only averaged < 15 ind m<sup>-3</sup>, rising to 52 ind m<sup>-3</sup> in November, and in the subsequent January there was a slow increase (ave=115 ind m<sup>-3</sup>). In February densities reached the maximum level for the season (ave=634 ind m<sup>-3</sup>), and remained relatively high in March with the average densities of 193 ind m<sup>-3</sup>. Different from the SIZ, the seasonal community succession in this study area strongly responded to species population cycles (Hunt and Hosie 2006b).



**Figure 2.6** Average densities (individuals m<sup>-3</sup>) of the total abundance for each of the six

transects completed between October 2001 and March 2002 (Hunt and Hosie 2006b)

## **2.3 Remote Sensing for Sea Ice Characterization**

Remote sensing is interpreted as an effective way of gathering information about an object without physical contact. It involves airborne or spaceborne observation using electromagnetic radiation that is either naturally occurring, in which case the system employs passive remote sensing such as passive microwave systems (see Section 2.3.1), or is radiated by the remote sensing instrument such as in Imaging Radar (Rees 2006, p. 23).

In recent years, remote sensing approaches are increasingly considered as an important means for obtaining geo-scientific data contributing to both specific site and regional surveys. These approaches are beneficial for basic and applied research covering a wide range of areas, including geo-environmental evaluation (Kuehn et al. 2000, p. 1).

### **2.3.1 Passive Microwave Systems**

Passive microwave systems measure black-body radiation in the microwave range with wavelengths typically from 3mm to 6cm, or equivalently frequencies between 5 and 100GHz (Rees 2006, p.46). They can be employed under any weather conditions, at day or night because of their ability to penetrate most clouds. With thermal infrared systems the aim is to measure the brightness temperature of the emitted radiation. By that way either the physical temperature of the Earth's surface or its emissivity can be deduced (Rees 2006, p.46).

Table 2.3 lists examples of spaceborne passive microwave radiometers. As shown in table the SSM/I (Special Sensor Microwave Imager) carried on board the DMSP (Defense Meteorological Satellite Program) series of satellites and the AMSR/E

(Advanced Microwave Scanning Radiometer) carried on the Aqua satellite are currently operational instruments.

Some Passive Microwave Radiometers with Surface Imaging Capabilities						
Instrument	Satellite	Years	Spatial Res. (km)	Frequency (GHz) and Polarization	Swath Width (km)	Max. Latitude (Degrees)
ESMR	Nimbus 5	1972-1976	25	19.35H	3000	90
SMMR	Nimbus 6	1978-1988	136×89	6.6H, V	780	84.2
			87×57	10.7 H, V		
			54×35	18.0 H, V		
			47×30	21.0 H, V		
SSM/I	DMSP	1987-	28×18	37.0 H, V	1400	87.5
			70×45	19.35 H, V		
			60×40	22.24 H, V		
			38×30	37.0 H, V		
AMSR/E	Aqua	2002-	16×14	85.5 H, V	1445	88.3
			74×43	6.93 H, V		
			51×30	10.65 H, V		
			27×16	18.7 H, V		
			31×18	23.8 H, V		
			14×8	36.5 H, V		
			6×4	89.0 H, V		

**Table 2.3** spaceborne passive microwave radiometers (Rees 2006, p. 49)

### 2.3.2 The SSM/I

This project requires monitoring the sea ice dynamic changes from season to season. The SMMR-SSM/I and the AMSR-E space-borne microwave sensors are the major technologies for supplying crucial sea ice information.

The Special Sensor Microwave/Imager (SSM/I) is a seven-channel, four-frequency, linearly polarized passive microwave radiometric system. The instrument measures ocean surface microwave brightness temperatures (TBs) at 19.35, 22.24, 37.0 and 85.5 GHz (Table 2.3), and intervening atmosphere, from its seven channels. (Gemmill et al. 2008)

Since the early 1970s, polar orbiting satellites have allowed sea ice studies to be conducted using data from visible and infrared imagery. However, sea ice data analysis based on visible and infrared wavelength imagery has limitations caused by obscuring cloud cover and the scarcity of solar illumination during the polar winter. Therefore, these limitations lead to a higher level of reliance on sensors from the microwave part of the electromagnetic spectrum (Tsatsoulis and Kwork 1998, p. 4).

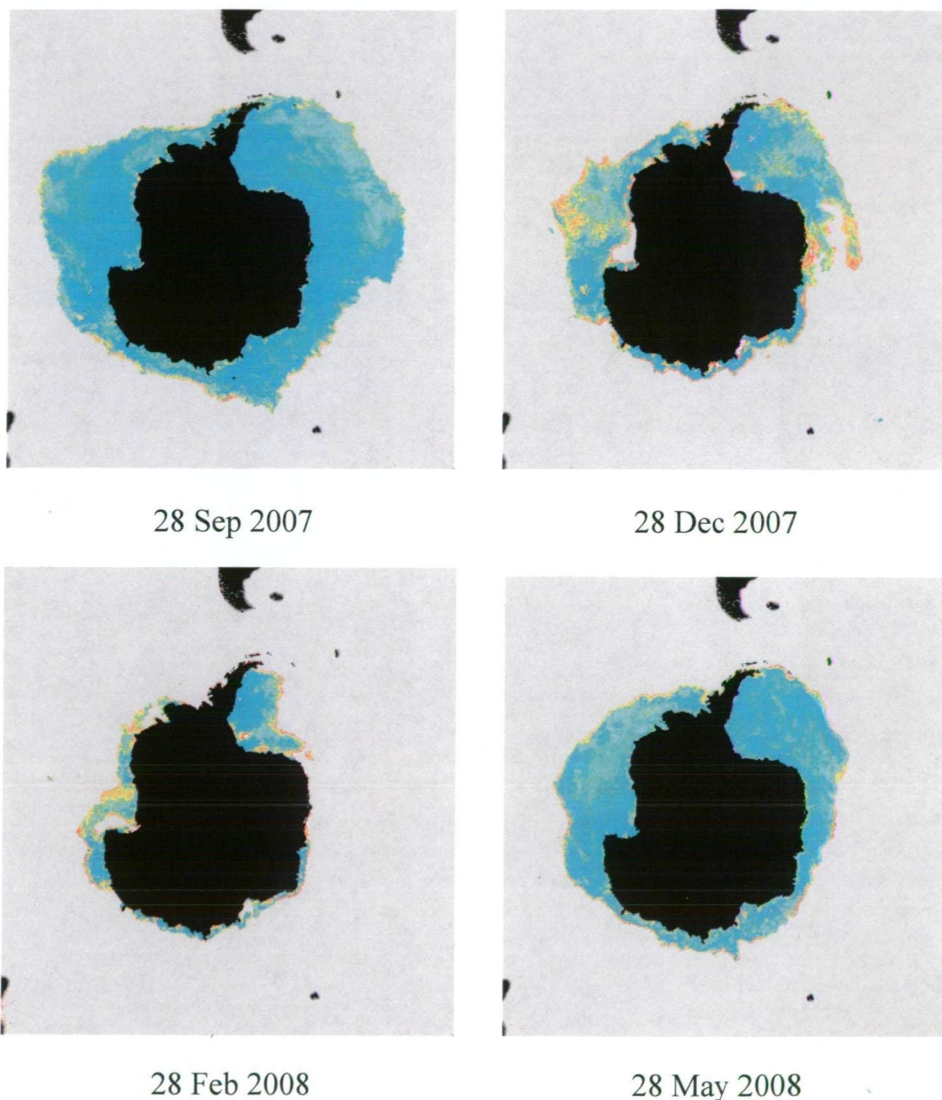
Current passive microwave observations are supported by a series of Special Sensor Microwave Imager (SSM/I) instruments operated by the Defense Meteorological Satellite Program. The DMSP is a Department of Defense (DoD) program carried on by the Air Force Space and Missile Systems Center (SMC). The DMSP designs, builds, launches, and maintains satellites which are responsible for monitoring the meteorological, oceanographic, and solar-terrestrial physics environments (National Geophysical Data Center 2008). Analyzed sea ice data of ice concentration and ice types are routinely produced on a 25-km grid. (Tsatsoulis and Kwork 1998, p. 4)

### **2.3.3 Remote Sensing of Sea Ice**

Like snow on the land sea ice is considered as an easy phenomenon to recognise by remote sensing. The microwave emissivity of sea ice is clearly different from that of open water, so that these two materials are simple to differentiate in passive microwave imagery (Parkinson et al. 2002; Parkinson and Gloersen 1993). Passive microwave radiometry has been used for measuring sea ice from space since early 1970s. It is an effective method to help determine the type of ice, its thickness, its dynamic behaviour, the size distribution of floes and leads, and other physical parameters (Rees 2006).

Sea ice concentration data from passive microwave imagery are archived by the U.S. National Snow and Ice Data Centre. From 1978 to 1987 the datasets were derived from the SMMR instrument. From 1987 till now the datasets are derived from the

SSM/I radiances at a grid cell size of 25 x 25 km. These datasets contain gridded daily (every other day for SMMR data) and monthly averaged sea ice concentrations for both the Arctic and Antarctic Regions (National Snow and Ice Data Centre 2008). Figure 2.7 represents some examples of sea ice concentration in Antarctica calculated from the SSM/I data. In addition, other remote sensing techniques such as synthetic aperture radar (SAR) can be used to deduce sea ice concentration (Burns et al. 1987).



**Figure 2.7** Antarctic sea ice images (SSM/I) (National Weather Service Environmental Modelling Center 2008)

Monitoring ice dynamics is one important aspect of sea ice study. The inference of ice motion requires sequential images over a period of a few days, and this means

that wide-swath VIR (visible and near-infrared region) imagery such as SAR are more suitable (Rees 2006, p.176).

SAR ice kinematics data products are useful to develop a spatial and temporal picture of Antarctic ice drift and opening and closing in response to momentum transfer (Drinkwater MR et al. 1995b). Passive microwave imagery generally is considered too coarse in spatial resolution to be of much use for inferring ice motion, although Liu and Cavalieri (1998) has successfully analysed the SSM/I channel at 85 GHz, which is with a resolution of 12.5 km, by using wavelet transforms. However, it can be used for sea ice concentration. It extends back to 1987, and there is a consistence across that time.

## **2.4 Scientific Visualization**

Scientific visualization, which is an interdisciplinary branch of science, is primarily applied to three dimensional phenomena, such as architectural, meteorological, medical and biological systems. It emphasizes the realistic rendering of volumes, surfaces, illumination sources and so on, perhaps with a dynamic element such as time (Friendly 2008). It aims to help users, normally scientists, get a better understanding, greater insight into the data and form new hypotheses through analysing the statistical images of data characteristics or observing animation effects in an environment or manipulating real-time user interactive simulations. It means users can more easily understand complex, numerical representations of scientific concepts (McCormick 1987; Keim et al. 2002).

Scientific visualization and information visualization are two easily confused concepts. There are subtle differences between scientific visualisation and information visualisation. Scientific visualisation can be considered to relate to visualising “natural” or spatial data, while information visualisation is commonly regarded as visualisation of non-inherently spatial data, for example relational

databases or email traffic flow (Ferreira de Oliveira and Levkowitz 2003).

### **2.4.1 Geographic Visualization**

Geographic visualization based on cartography and scientific graphics is the application of any graphics which are designed to improve a spatial understanding of things, concepts, conditionals, processes or events in the human world (Dodge et al. 2008, p. 2). Geographic visualization provides graphical ideation to render a place, a process or a phenomenon. The advance in computer graphics, user interfaces and computation has facilitated visualization tools to realize interactively data exploratory within multiple representations such as statistical charts, 3D plots, tables, and soon on (Dodge et al. 2008, p. 5).

There are many types of geographical visualizations. Inspired by Lohse et al. (1994), geovisualizations can be divided into seven categories: Maps/Cartograms, Charts/Graphs, Tables, Networks, Symbols, Diagrams and Pictures. Maps and Charts are two of the most important ones.

Maps communicate spatial meaning and there is a direct link between the represented space and realistic space. Geographical maps as one type of maps aims to represent proportions and the geography of realistic human world and can be 2D or 3D. 2D maps as a main reference visualization can be combined with other statistical information that can be layered on top. This information can be referring to agriculture, transportation, boundaries or population density and so on (Dodge et al. 2008, p. 33).

Charts enable to illustrate statistical or mathematical information. The usual categories involve line graphs, histograms, circular histograms, pie charts, surface plots, scatter plots, and parallel coordinate plots (Edsall, 2003). Each of these visualizations addresses specific needs: line graphs and histograms use a 2D plot to

visualize continuous data, surface plots visualize continuous data in 3D, bar charts and pie charts are used for quantitative information and parallel coordinates can visualize multidimensional data, while scatter plots provide the approach to observe clusters (Dodge et al. 2008, p. 33).

## **2.4.2 Visualization Techniques**

Scientific visualization can be thought of as a graphical process equivalent to numerical analysis (William et al. 2006). Understanding of visual perceptive elements such as depth, motion, symmetry, shape, size, colour and visual illusions enables scientists to improve the visibility of details, improve the accuracy of the result, and speed up the process of extracting information (Rosenblum et al. 1994).

Visualization techniques provide an effective way to achieve greater knowledge and insight to a large amount of data by providing for three increasing levels of comprehension: presentation, understanding, and prediction. The starting point is presentation graphics and this is often the ending point as well in the scientific visualization process. Presentation is a very important process, because an effective presentation can aid researchers to extract a deeper understanding of the processed data sets. Furthermore, researchers then are able to predict behavior and form hypotheses based on their enhanced understanding (William et al. 2006).

There are many different techniques that can be used in the field of scientific visualization including digital image processing, data mining and knowledge modelling techniques. The choice of techniques is often based on the dimensionality of the data itself. A data set usually has values, descriptions that can provide auxiliary information and positions that are used to organize all the data values. The dimensionality of the data set is considered to be the number of position variables per measured data value. Obviously one-dimensional data must be represented in a two-dimensional form. Generally for this representation the measured data values



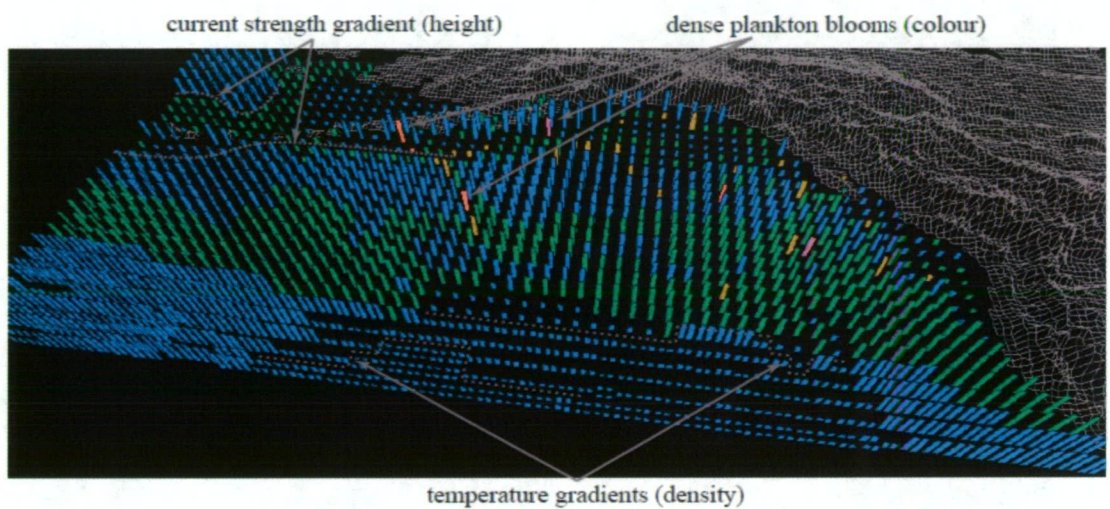
can be mapped to a location along the Y-axis, and the data position is shown by a location along the X-axis, as is done for a standard plot – curve, line graph or bar chart. The common form for representing two-dimensional data is as an image. Both the X and Y axes are used to represent data position and the measured data values are described by some type of symbol located at these positions specified by the X and Y coordinates. Contour plots and vector plots are common examples. Three dimensional data are often referred to as volumetric data and are generally derived from measurements of real three-dimensional objects. The common method for visualizing this type of data is to create realistic looking models. The relevant visualization techniques include wire frame, ribbon, and isosurface representations (William et al. 2006).

Since the 1990s interactive three-dimensional computer graphics have become more popular due to the spread of relatively inexpensive graphics display technology, and the development of computer games. However, 3D is not always better than 2D for visualizing data. Which one is employed in a particular application should be according to real needs. Lind, Bingham and Forsell (2003) indicated that 3D may primarily feature providing a general overview of object relationship in a scene, and especially for spatial data.

Colour-mapping is a major tool in digital image processing. Rogowitz and Treinish (1995) mentioned a way of using different colours to communicate different characteristics of the data. The choice of colours is important, because the visualization system must provide an accurate representation of the data. There are many factors influenced by the choice of colour within an image: for example, the perception of isomorphic forms, structure and magnitude of areas of the image (Rogowitz & Treinish 1995).

Healey (1999) revealed the growing importance of the ability to communicate multiple values within a single location. Texture was utilised as a single visual

feature which can be broken up into multiple dimensions instead of multiple individual features such as colour, shape, size and so on (Woods 2004). He named the perceptual texture elements “pexels” (Healey 1999; Healey & Enns 1999; Kosara et al. 2003). Pexels are representations of data elements of which large numbers are displayed across a three-dimensional surface, such as the topographical map displayed in Figure 2.8. In the figure pexel colour represents plankton density, pexel height is used to illustrate the ocean current strength and the density of pexels describes the sea surface temperature (Healey & Enns 1999).



**Figure 2.8** Open Ocean Plankton Density Visualization System (Healey & Enns 1999)

Nowadays analyses and visualization of large complex data sets may be difficult to perform effectively using traditional mode, therefore, they attempt extensive group interactions. To improve scientific analysis, more natural, two or three dimensional, and highly interactive and visual techniques are required.

Visualization should be highly dynamic and interactive. However, many systems essentially perform static presentations and work in batch mode. To support seamless integration of sub-tasks and whole tasks effective dialogs between user (often scientists) and the system are required. It is beneficial to maintain a running task context for realizing such effective dialogs. Such a context would be useful for the

system to infer missing parts of a task specification and improve communication (Rosenblum et al. 1994).

Moreover, a working knowledge of the context has been a requirement when designing systems for performing effective presentation. An important component in the criteria of effectiveness would be a measure of how well the user can relate to the visualization (Rosenblum et al. 1994). It is very important to design a visualization based in part on the user's expected actions.

Increased interactivity often is advised as a principal requirement during the design of visualization systems. It is based on careful consideration of realistic scientific and engineering tasks. Such visualizations are based on many factors including characteristics of the data; information requirements of the user, effectiveness of various techniques such as color, isosurfaces and vectors, effectiveness of various combinations of techniques and characteristics of the display devices (Rosenblum et al. 1994).

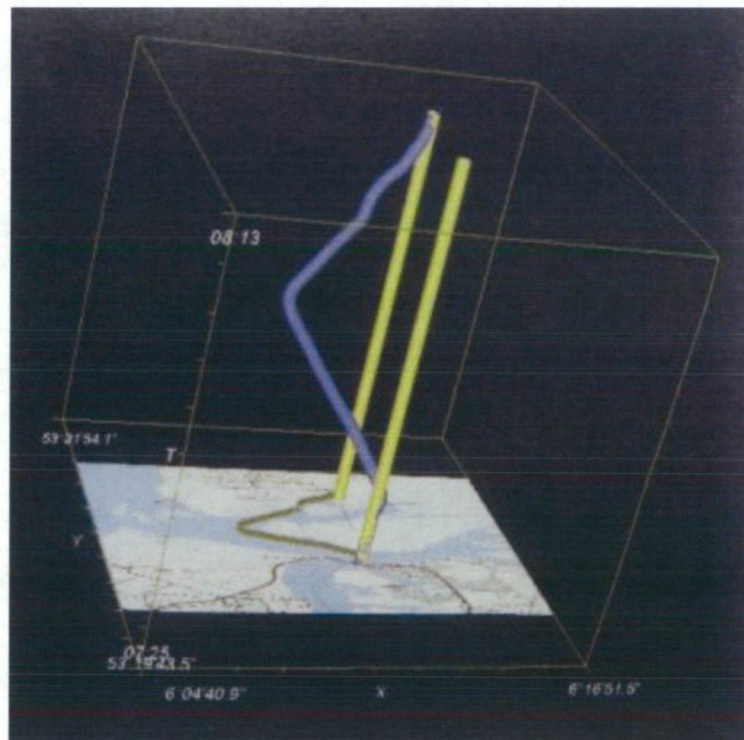
Both developer and the user need make choices not only how to display the data, but how to interact with the information. Usually there are many parameters being changed to alter the visual appearance of the display. In fact, even the simple act of changing the colourmap can have a significant impact on what is hidden or what is emphasized in the display. Interactive filtering and interactively adapting mapping parameters specified by Dodge et al. (2008, p. 36) are two important interaction techniques in visualization.

Not only having a fundamental geographic component but also involving changes over time are considered as important challenges facing science and society, for example when exploring the impact of global environmental change. Maps can provide interesting opportunities to visualize these dynamic phenomena, because the map has extended its traditional definition. Not only the visual representations but

interaction with data can maps offer by the supports from current techniques (Dodge et al. 2008, p. 292).

Dodge et al. (2008, p. 293) indicated that time is a phenomenon that is actually perceived via its consequences and can therefore be displayed through the changes that it induces. These changes can be broadly distinguished as occurring in the spatial domain such as appearance or disappearance, movement, mutation or in the temporal domain such as moment, pace, sequence, duration, and frequency.

Such time-relevant phenomenon can be visualized by spatio-temporal representations and explored further through the interaction with these representations. Hagerstand's time geography observed both space and time as inseparable, and this becomes clear because of the graphic representation, the space –time cube as shown in Figure 2.9.



**Figure 2.9** Space-Time Cube (Dodge et al. 2008, p. 293)

The space-time cube represents longitude and latitude along the x- and y-axes respectively, and time along the z-axis. It displays a base map, a space-time path and

two stations, as well as the footprint of the path. This is an example of a boat trip represented by the path starting at the bottom of the cube (Lauwersoog) and ending at the top (Schiermonnikoog). It can be shown that both harbours appear as stations and the stations stand out as vertical lines from the yellow cube's bottom to its top (Dodge et al. 2008, p. 293)

### **2.4.3 Development of a Visualization System**

A visualization system employs techniques to aid in rapid, accurate and effortless visual exploration (Healey 1999). Visualization systems use visual binding to embody important attributes of the data. This binding can be further subdivided into sets of marks such as points, lines, areas, volumes that represent position or pattern and retinal elements such as colour, shape, size, orientation and texture (Senay and Ignatius 1990).

Visualization systems can be divided into two types: monolithic systems and dataflow systems. Monolithic systems are traditional systems which have a fixed pipeline and are generally designed for a certain application. Dataflow systems employ the scheme that the user builds, constructing their own pipeline by connecting modules. This is generally realised by a direct-manipulation visual programming interface (Rosenblum et al. 1994).

Visualizations can exploit either a two or three-dimensional perspective, the choice of which is based on the technology being used and task being undertaken (Woods 2004). The techniques utilised for particular visualization systems are often specific to the particular scientific field involved. General visualization solutions normally lack focus for specific tasks and can not achieve the goals set by users (Treinish 1999 p.1). Treinish (1999 p.1) defined the following steps for a specific task:

- 1. Defining the application in terms of user needs*
- 2. Composing the design elements and interface actions to implement that*



*definition*

### *3. Establishing different techniques for various user goals*

Kao and Ma (2000) described their adaption of the general life cycle of a task specific visualization system. The important first step which can contribute to success is to provide a clear description of the problem. Then the developer must study the data format, storage and other information. Normally this is a time-consuming process. The choice of visualization techniques should be decided through an agreement which is the result of discussion between the scientist and the developer. Following the agreement the development of a system requires suggestions about improvement from scientists who need to be kept up to date on progress throughout the whole implementation. The process of testing, evaluation and validation is very important. The solution formulation, implementation and testing often require a great deal of iteration.

A key limitation in the use of visualization techniques is the user interaction paradigm. The scientists are often required to think about the visualization according to the computational processes involved instead of relating it to a realistic working environment. It begs the question as to whether the applications and computer science elements are effectively integrated (Rosenblum et al. 1994).

Figure 2.9 describes one typical scenario for the implementation of scientific visualization techniques. It is best situation if such systems embed knowledge about suitable visualization options in an implicit way. However, at worst they risk encouraging ambiguous presentation or obfuscations (Rosenblum et al. 1994). In many cases the data-driven pipeline model is very complex because the user often interacts with more than one system or sets of tools (Felger and Schroder 1992). That means that some data sets need to be translated. However, the data models employed by today's systems and tools are very restrictive in the following three terms:

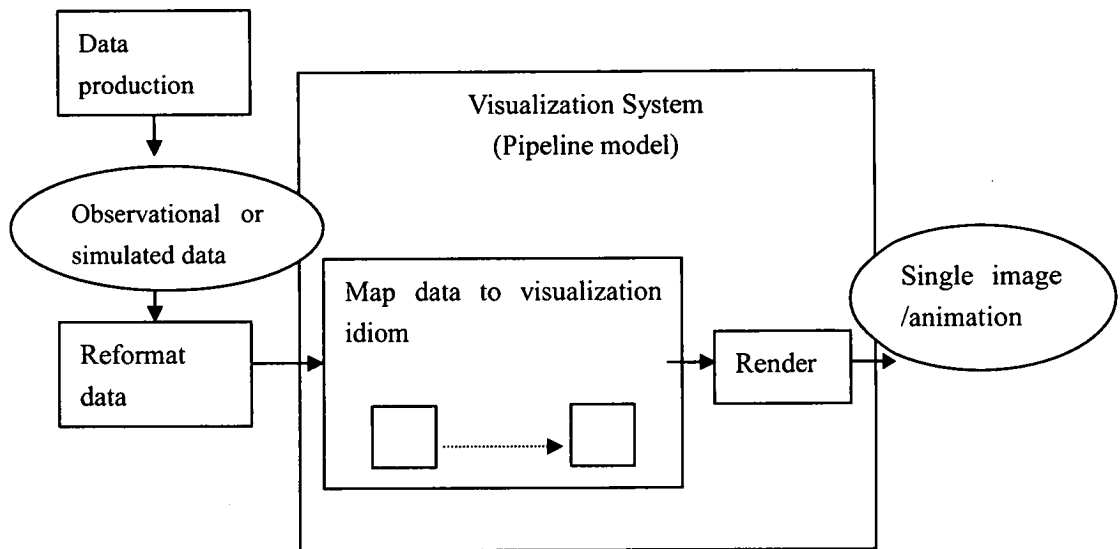
- 1. providing an abstract specification of a data set, its size and dimensionality,*

*domain and range and so forth;*

*2. representing knowledge about the data that can be represented, including relations between data variables;*

*3. allowing multiple data types (Rosenblum et al. 1994).*

Therefore the problem is caused by the conflict between the requirements and the limitations.



**Figure 2.9** Scientific visualization scenario (Rosenblum et al. 1994)

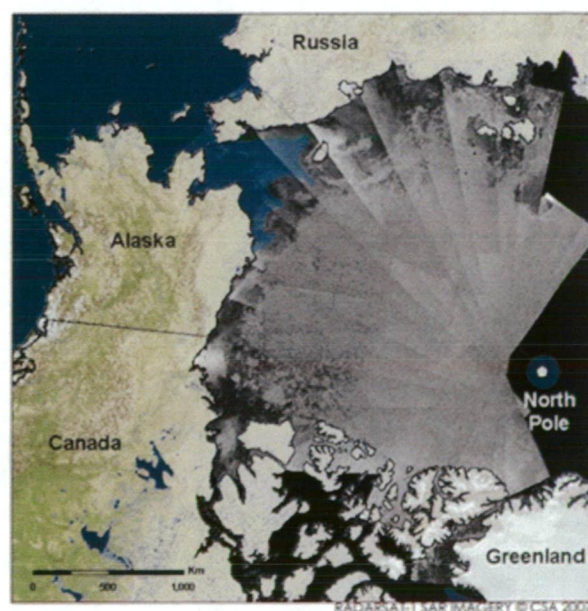
#### **2.4.4 Scientific Visualization for the Ocean Research**

If marine science is to achieve significant progress in studying the biological diversity of ocean plankton, it needs to make effective use of modern technology (Culverhouse et al. 2006). Computer technology can provide the scientific visualization techniques for aiding the analysis of relevant data sets.

Currently there are some useful visualization techniques for ocean studies, including bathymetric mapping, underwater imaging, space oceanography and multi-sensor visualization. Here I focus on space oceanography. Ocean remote sensing techniques are utilised to observe the ocean's surface and obtain measurements which can be used to deduce information about the surface, subsurface and the Ocean bottom,

furthermore, it can attempt to deduce from those information about the surface, the subsurface and bottom, and the physical mechanisms which operate in these environments. The challenge is to understand both the radar imaging mechanisms and the fluid dynamical processes that create the surface effects of the ocean (Mied et al. 1992)

Synthetic aperture radar (SAR), which is an active remote sensing technique, generates a 2D image that contains important ocean information such as sea state, subsurface ocean processes and bathymetry (Figure 2.10). Figure 2.10 is provided by the Alaska Satellite Facility (ASF) at the University of Alaska, Fairbanks. It is a synthetic aperture radar (SAR) image from the Canadian Space Agency RADARSAT-1 satellite. This type of instrument provides a unique view of the ice, and penetrates clouds. In the figure thin and melting ice shows dark, and light gray represents the thickest ice, two or more years old (National Snow and Ice Data Center 2007).



**Figure 2.10** Arctic sea ice animation, summer 2007 (National Snow and Ice Data Center 2007)

However, the reconstruction of images from SAR data requires complicated



processing. Radar signals are able to penetrate clouds and rain, and so produce images which can be processed once to yield a clear surface image under most weather and ground-cover conditions (Rosenblum et al. 1994).

## Chapter 3

### Method

#### 3.1 System Development

This section introduces the aims of the application and its requirements and describes the development process used to create the visualization software. It describes the development of each of the modules of the software package and shows how they contribute to the whole application.

##### 3.1.1 Aims and Requirements

This research aims to test the hypothesis that:

*Computational data fusion techniques can be developed to allow the integration of between sea-ice dynamics data, derived from passive microwave satellite images, and zooplankton observational data, obtained from the Southern Ocean Continuous Plankton Recorder.*

Background sea ice and plankton knowledge is very important, because it is relevant to how to match biologists' needs and how to design the interaction with information in a visualisation system. The essential connection between plankton populations and sea ice dynamics is introduced in Chapter 2. However, there is a lack of any software tools for assisting biologists to analyse the relationship between plankton and sea-ice data to replace the traditional manual approach that is considered tedious and time-consuming. The visualisation techniques developed allow a scientific user to manipulate and interact with this information to undertake further analysis and improve understanding.

The extraction of knowledge from recorded data sets provided by the Australian Antarctic Division was considered as the precondition for representation. One initial requirement of this project was that the sea ice dynamics needed to be characterized from season to season. The main source of this information is passive microwave remote sensing data supplied by the SMMR-SSM/I and the AMSR-E space-borne microwave sensors. In this application the sea ice data is mainly from SSM/I (Special Sensor Microwave Imager) instruments operated by the Defense Meteorological Satellite Program (DMSP).

Another requirement was the visualisation of the track of zooplankton data derived from the Southern Ocean Continuous Plankton Recorder (SO-CPR) project an international research program supported by the Scientific Committee on Antarctic Research (SCAR). The zooplankton data should relate to the sea ice dynamics over some particular period of time.

Not only should the software display these two data sets, but it should readily enable interaction with these data by an expert biologist. Therefore the choice and implementation of appropriate visualization techniques such as customized data filtering techniques and interactive mechanisms for adapting mapping parameters are very important. These techniques are effective methods for developing this system and explore the essential connection between sea ice data and plankton data.

### **3.1.2 Development Software**

In this application MATLAB was chosen as the development environment. MATLAB is a numerical computing environment and programming language. Created by the MathWorks, MATLAB has evolved from “matrix Laboratory” to a mature software package including facilities for easy matrix manipulation, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs in other languages (CleveMoler 2008).

MATLAB features a family of add-on application-specific solution called *toolboxes*. Toolboxes provide specialized technology to most users, so they are considered very important. Each toolbox is a comprehensive collection of MATLAB functions (M-files) which extend the MATLAB environment to provide solutions for particular classes of problems referring to the areas of signal processing, control systems, neural networks, fuzzy logic, wavelets, simulation, and many others (The MathWorks 2007).

During the last few years, MATLAB has been increasingly popular as an effective development environment and tool in the field of earth science. It has been used for finite element modeling, the processing of seismic data and satellite images as well as for generation of digital elevation models from satellite images (Trauth 2006). In this application sea ice dynamics are derived from passive microwave satellite images, and MATLAB is able to provide sufficient support for visualising sea ice dynamics. Moreover, zooplankton observational data involves abundant geographical information which can be represented by MATLAB system effectively.

### **3.1.3 Development Stages**

Because of very tight time constraints the traditional system development life cycle is not suitable as the foundation for guiding the development of this project. Therefore, an alternative way which involves two key stages the experimental (simplified) stage and the specific stage was adopted. Each stage could also be divided into three parts which were the requirements planning phase, the user design phase and the construction phase.

On the experimental stage, the biologist provided the sea ice data and penguin data as a start point. The further extraction of information from these two datasets and representations of sea ice changes every year and penguin population changes at

particular monitoring sites in corresponding years were the initial requirements. It was crucial to communicate with the biologist frequently and clearly understand the requirements for the system. The construction phase followed. The penguin data has been studied for many years. As a result, the accuracy and functionality of the initial program were easy to evaluate.

Based on that program, the following tasks were to analyse the relationship between sea ice data and zooplankton data through modifying the previous constructed program. All of three sub stages of development were altered slightly. Requirements were planned again and design and construction were changed correspondingly. Visualization effects are influenced by the characteristics of the data. There are significantly different characteristics between plankton data and penguin data for example the sampling location for penguins is a fixed geographical site (invariable longitude and latitude), while that for plankton is variable as it is determined by the geographical location of the ship behind which the plankton recorder is being towed.

However, because of the similarity in many respects between these two data sets the modifications required to covert the penguin data analysis package to the plankton analysis package was relatively small. For example, if the site monitored for penguins was represented by a point, the plankton areas sampled were marked by multiple points in the latter application.

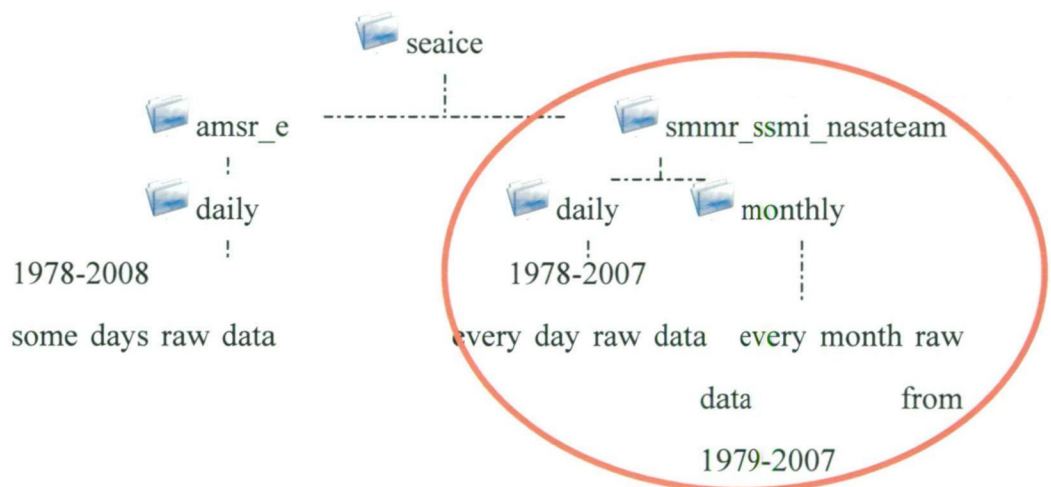
### **3.2 Data Preparation**

Scientists have been carrying out long-term observation programs and have gathered large amounts of data about both sea ice and plankton. From this data they can formulate and test hypotheses, possibly with the assistance of relevant computer techniques, on the forces that have impacted on the ecological region. They can also make predictions about future changes according to the results from the analyses (Trauth 2006).

In this project all relevant data were provided by the Australian Antarctic Division. This section discusses the recorded sea ice data, the penguin data used for initial experimental work and the zooplankton data gathered from biologists' long- term observations and specific data format.

### 3.2.1 Sea Ice Data

Within the context of this project it is very important to understand the files hierarchy for storing the raw data and data's format, because these data would be read into the application, visualized, and manipulated by users to realise interaction. The following is the hierarchy of sea ice files.



In this application the sea ice raw data is from the file named 'smmr\_ssmi\_nasateam'. Both daily and monthly data were used to realise different representation purposes. Monthly data was displayed to compare data over multiple years. Daily data was visualized to observe the changes every day in one particular year. The 'daily' folder includes multiple sub folders named by years from 1978 to 2007. Each folder keeps daily sea ice raw data files gathered every day of that year.

Another folder called 'monthly' contains sea ice raw data every month from 1979 to 2007, except that there is the data in 1979 is incomplete. The following is an

example of the data stored in that file. ...

### 3.2.2 Penguin Data

In this application penguin data was used for initial experiments. The penguin data was recorded in a CSV file called 'adelie\_bechervaise.csv'. The following part lists the different fields represented in the data file.

longitude\_min

longitude\_max

latitude\_min

latitude\_max

observation\_date\_min

observation\_date\_max

chick\_count

### 3.2.3 Plankton Data

Plankton data is recorded in a CSV file called 'cpr\_data.csv'. This data can be divided into three categories.

Part 1:

longitude\_min

longitude\_max

latitude\_min

latitude\_max

observation\_date\_min

observation\_date\_max

tow\_number

Part 2:

sea\_surface\_temperature

normalised\_time\_of\_day

sea\_surface\_salinity

Part3:

total\_abundance

Calanoid copepodites

Calanoid cope & copepodites (small)

Calanoides acutus

Calanus propinquus

Calanus simillimus

Calanus sp.

Chaetognath indet

Clausocalanus brevipes

Clausocalanus laticeps

Clio pyramidata

Clione antarctica

Copepod indet

Copepod Nauplius indet (small)

Copepod Nauplius indet calanoid

Ctenocalanus citer

Cyclopoid nauplii

(etc)

.....

Part1 includes geographical information, observational time and tow number; in part2 the information is about sea environment factors; part3 records total abundance and 61 different types of individual zooplankton species abundance. The geographical information is described by minimum longitude, maximum longitude, minimum latitude and maximum latitude. Therefore, the location monitored can be a geographic point and also an area. The observational time covers two fields: the minimum observation date (observation\_date\_min) and maximum observation date (observation\_date\_max). This part is very similar to penguin data. However, the geographical information of every record in plankton file is variable, while that in



penguin file is fixed. For instance, the location of plankton for observation can be

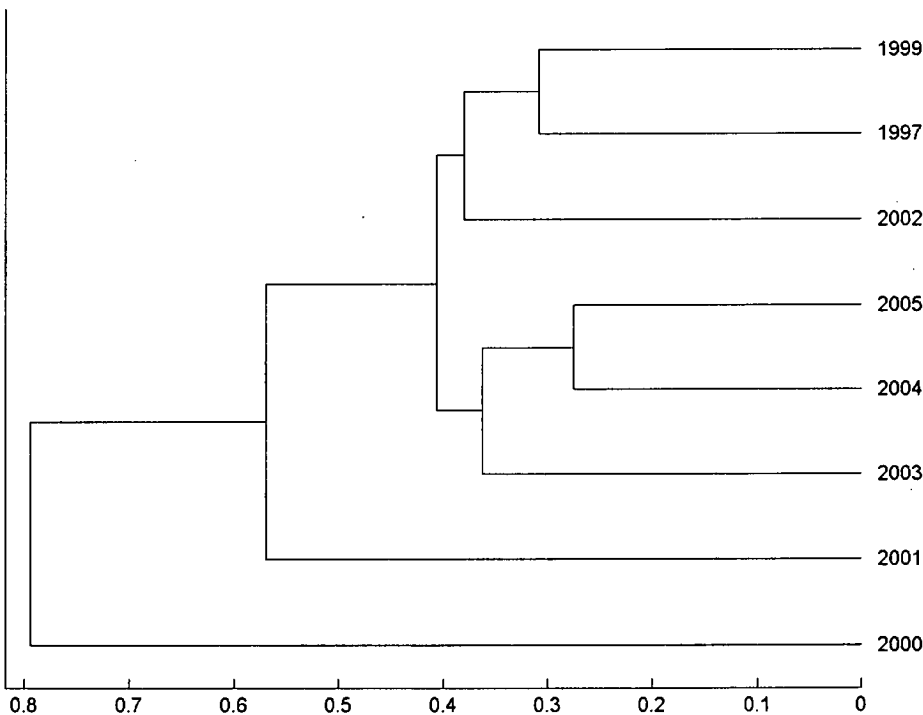
130.8541 130.8541 130.8541 130.8541  
130.6977 130.6977 130.6977 130.6977

or any other places but penguins are always observed at the location.

62.813 62.813 62.813 62.813

Furthermore, the observation time for penguins is specified to the nearest day, but for plankton it is specified to the nearest minute (1997-12-3 23:54).

During long-term observation and analysis, biologists concluded that the similarity between the years from 1997 to 2005 was strong, except for 1998 (Figure 3.1). Plankton records in 2004 and in 2005 were the most similar, with ones in 1997 and in 1999 similar as well. The data in 2000 were very different from other years.



**Table 3.1** similarity in zooplankton records (Australian Antarctic Division 2008)

### **3.3 Visualization**

Implementation of the visualization component covers the extraction of plankton information from the raw data file 'cpr\_data.csv' and the representation of this data is combined with sea ice satellite images which will be displayed by 2-D geographical maps. Maps enable the system to communicate spatial meaning and there is a direct connection between the physical space and the represented space (Dodge et al. 2008). The elements making up the graphical interfaces of the application will be introduced in this section.

The process by which these two data sets are displayed, as well as the process by which the user interacts with them are both important issues in the design of this software. This section also covers the methods that are used to manipulate the data with some information being hidden or emphasized at any particular time. This is a very effective way for biologists to analyse the complex data.

#### **3.3.1 Data Operation**

The folder called 'data' keeps two types of raw data sets the sea ice data stored in 'seaice' folder and plankton data recorded in file 'cpr\_data.csv'.

##### **Display Sea Ice Data**

The display of sea ice data requires ice data, ice longitude and ice latitude returned from the method named `get_ice` (`ice_date`, 'PropertyName', 'PropertyValue'). The parameter `ice_date` decides which specific date to display, and other settings should be property name 'datasource' and property value 'smmr\_ssmi', property name 'timeresolution' and property value 'monthly'. To obtain sea ice data and spatial coordinates we should input data source by `smmr_ssmi` which means data is derived from the `smmr/ssmi` space-borne microwave sensors. There is also another type of data (AMSR-E) kept in the 'amsr\_e' folder, it means this method can be used for obtaining AMSR-E satellite images as well. Another property is time resolution and

its value can be monthly or daily selected according to different requirements.

The area of interest for the display is decided by the two variables called 'lon\_oi' and 'lat\_oi'. They are relevant to the position of plankton observation and are extracted from the raw plankton file with the display range determined flexibly by the user.

The method of finding the elements of the sea ice data matrix that are relevant to the spatial region is very important. The method, known as `meshgrid()`, is to create a longitude and latitude grid at an appropriate spatial resolution. A 0.25 degree grid spacing is used in the application and kept in the variable named 'grid\_cellsize'. However for the AMSR-E data, a finer grid would be better. The application also invokes a method called `griddata()` to interpolate the ice data to the grid and display it by using a method called `pcolor()`.

### **Read Zooplankton Records**

The method named `textscan()` is used to read all plankton observational records in the file. The method called `f_Getfield()` is invoked following the use of the method `textscan()`, because it can help to find the index of particular fields. It is beneficial to search a particular field (column) according to a field name instead by column number.

In addition, the variables named 'sta\_year' and 'end\_year' are used to narrow the range of plankton records. The records selected are limited in a period from start year (sta\_year) to end year (end\_year), both of which are entered by user when the application is launched.

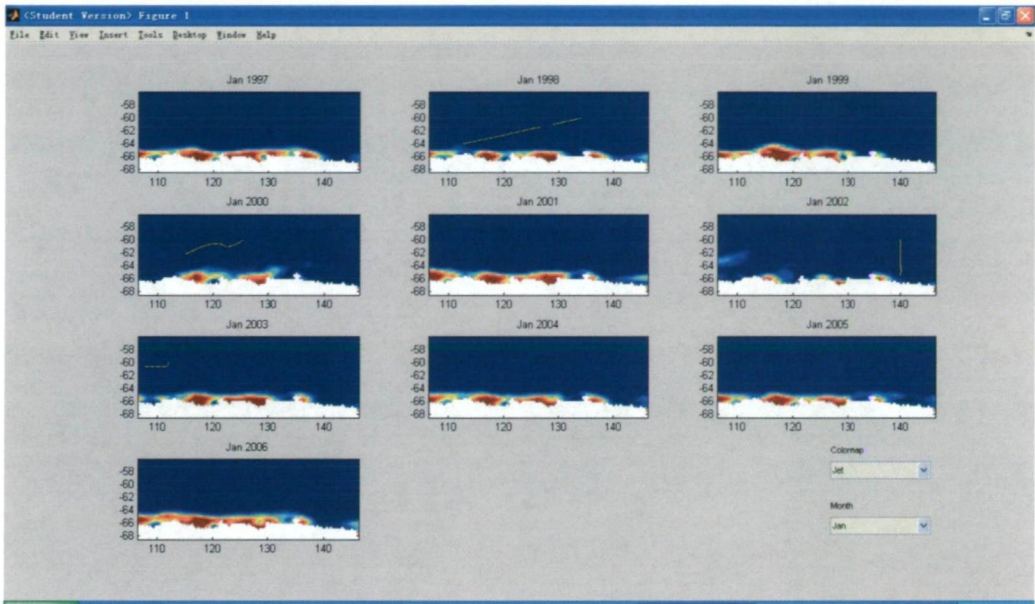
### **3.3.2 Graphical Interfaces**

The graphical interface of this application mainly consists of two parts: the interface for the analysis of multiple years (Figure 3.1, Figure 3.2, and Figure 3.3) and the

interface for every individual year (Figure 3.4).

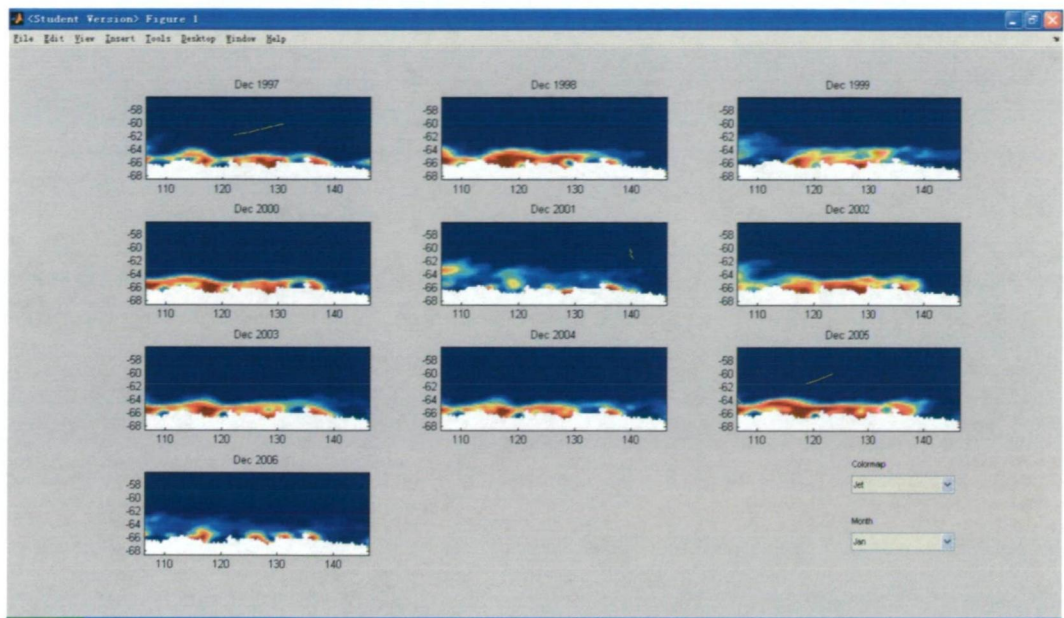
**Multiple Years**

The application can display multiple sea ice satellite images during a specific period together, for example from 1997 to 2006 (Figure 3.1) and track the plankton which is marked by yellow dots in the sea ice images. If no yellow dots can be found in the image, then there are no relevant plankton records in that month of some year.



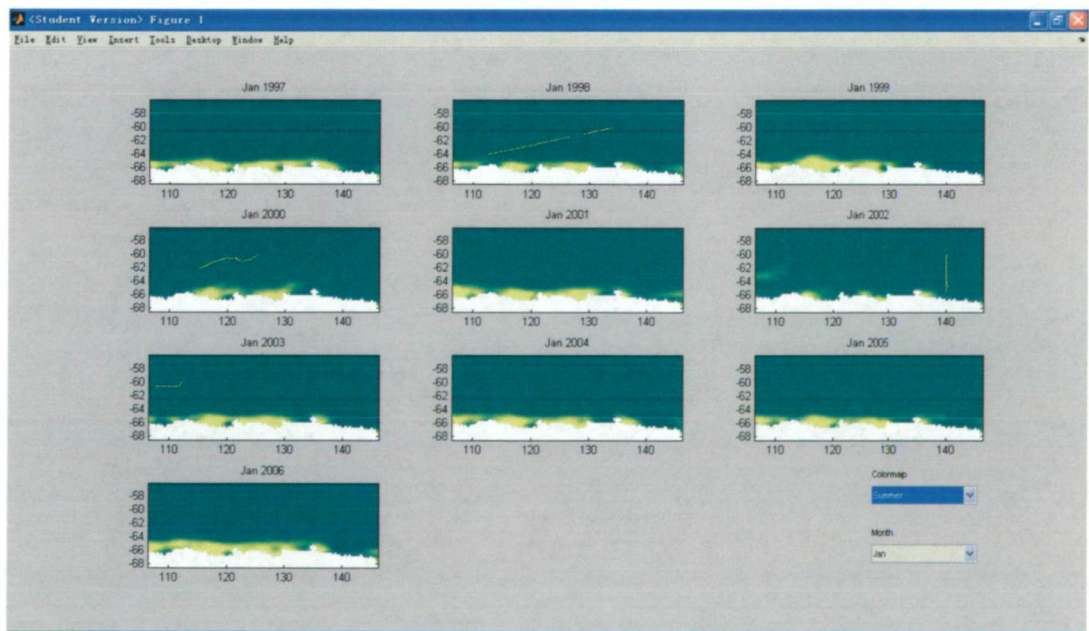
**Figure 3.1** sea ice and plankton in Jan from 1997 to 2006

There are two popup lists at the right bottom of the window labeled ‘month’ and ‘colormap’ (Figure 3.1). The options in the month list can let the user decide the particular month of the year to be displayed. For example, when the user selects the month Dec, the images in December of each year will be shown on the screen (Figure 3.2).



**Figure 3.2** sea ice and plankton in Dec from 1997 to 2006

The options in the colormap list let the user decide which particular color map to be used. If the user chooses the summer color map, the window will display all images by employing that color map (Figure 3.3). As mentioned in the previous chapter this technique allows a user to hide or emphasize some information to facilitate the analysis.

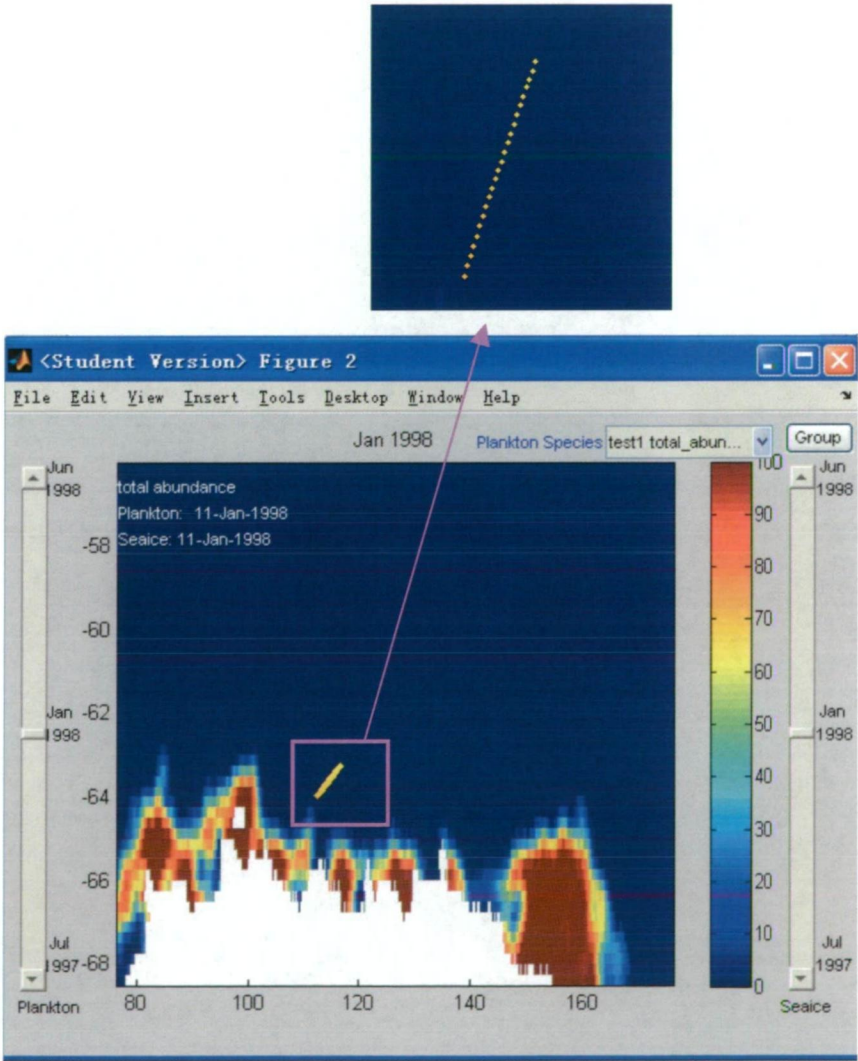


**Figure 3.3** sea ice and plankton in Jan from 1997 to 2006 within summer colormap



**Individual Year**

If the user moves the mouse to a particular image and right clicks the mouse, a new window for displaying the data in that particular year will be created. The information on sea ice and plankton visualized in the figure is clearer and is focused on one particular year starting from July and ending by June the next year. The plankton records are displayed by different coloured dots placed over a background on which the sea-ice concentration data is displayed. The brightness of the colour (Figure 3.4) represents the observational time track. The direction is from darker dots to lighter dots.



**Figure 3.4** sea ice and plankton in Jan 1998

The slider on the left side of the window controls the display of the plankton data. Each scale represents a particular observational period. When a user drags the slider, the visualized plankton signs will change following the dragging (Figure 3.5). The marks made by previous actions are gray and the new marks illustrate the latest action. Moreover, the text on the left top corner shows the specific observational period for plankton.

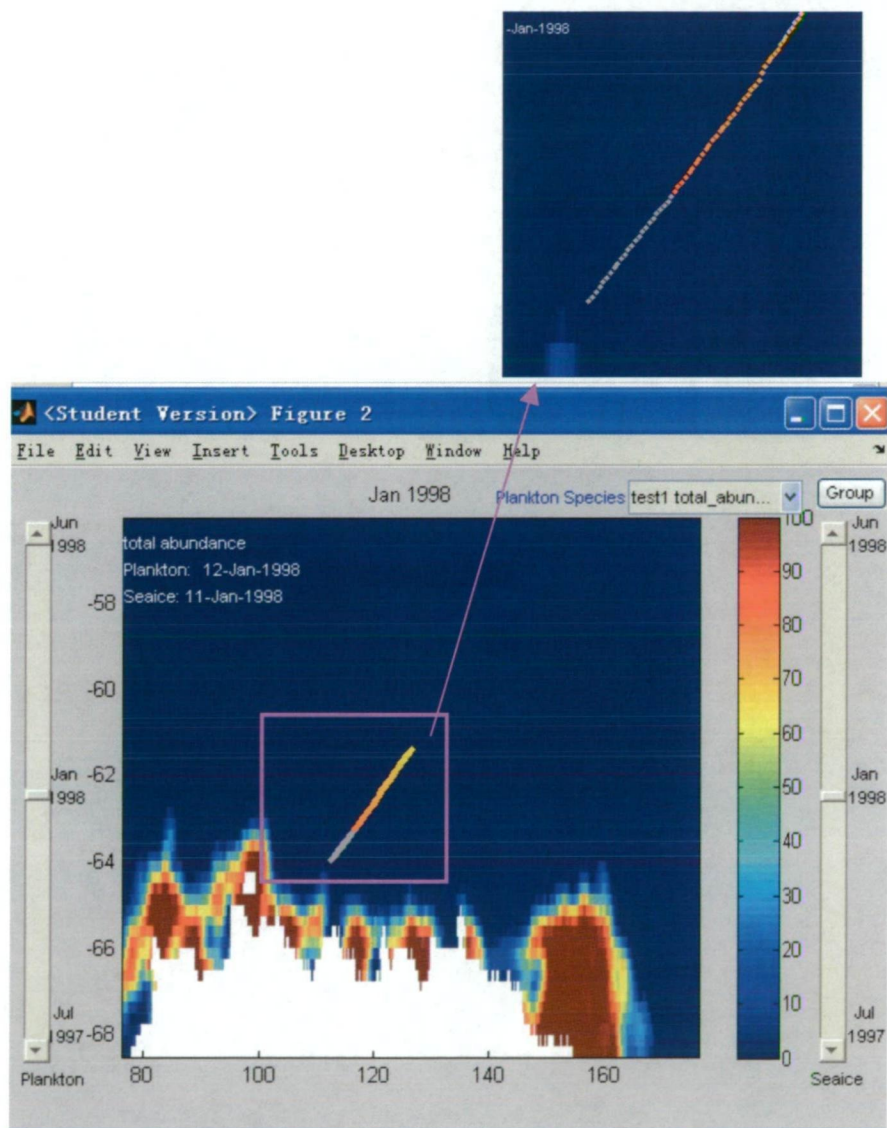


Figure 3.5 changing period of plankton observation

Another slider on the right side of the window controls the display of the sea ice. Each scale represents a particular day. When the user drags the slider, the visualized



sea ice as background will change (Figure 3.6 and Figure 3.7). The text on the left top corner also shows the specific day for current visualized sea ice data.

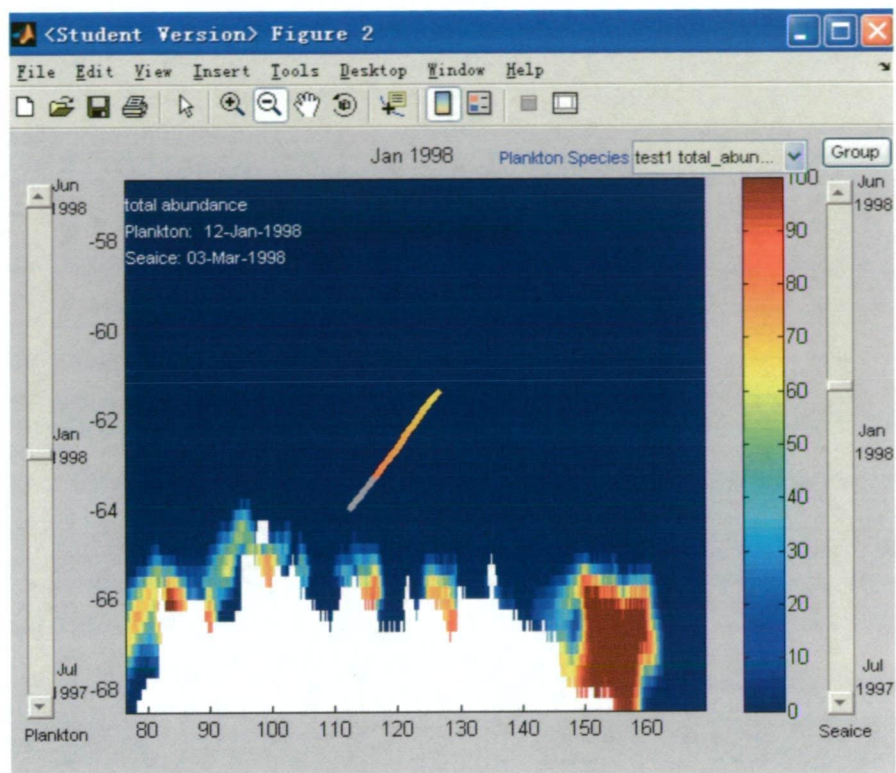


Figure 3.6 sea ice on 03-Mar-1998

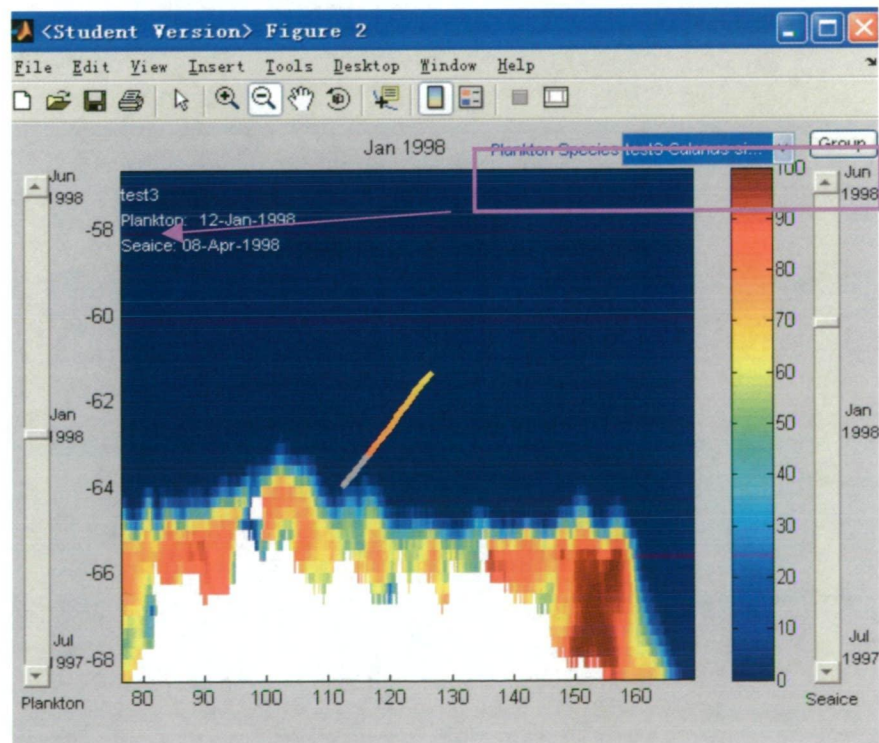
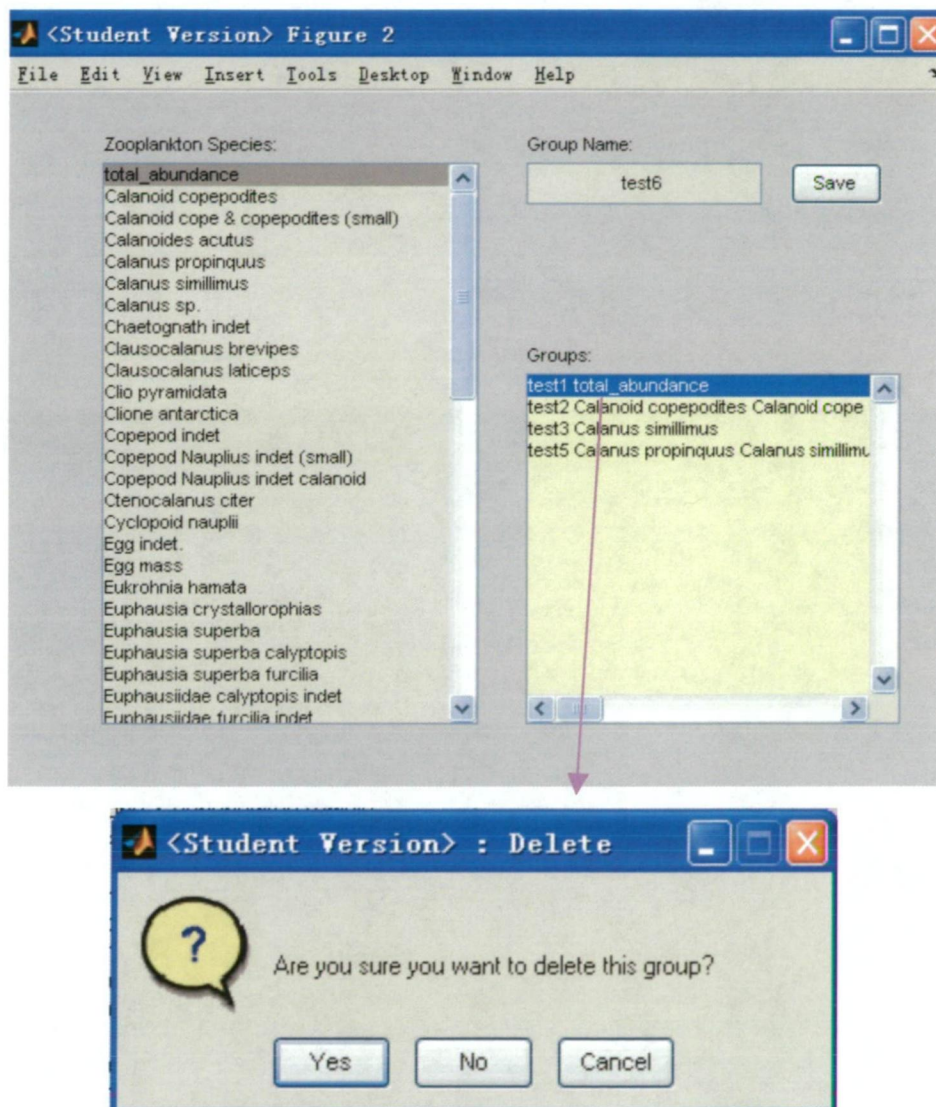


Figure 3.7 sea ice on 08-Apr-1998



Near the title there is a list called 'zooplankton species'. The user can choose the zooplankton species they wish to analyse (Figure 3.7). The user can also regroup the zooplankton species according to real needs (Figure 3.8). When the group name is input and some species are selected, then click 'Save', a new group can be created. If the user clicks an item in the 'Groups' list, a delete dialog will open. When the user chooses 'yes' to confirm, the selected group will be deleted.



**Figure 3.8** zooplankton species regrouping

If the user right clicks the figure (Figure 3.7) and chooses 'Abundance by 3D', the new window will be open (Figure 3.9). By using the tool button 'Rotate' the

abundance information can be viewed from different angles (Figure 3.10, Figure 3.11 and Figure 12).

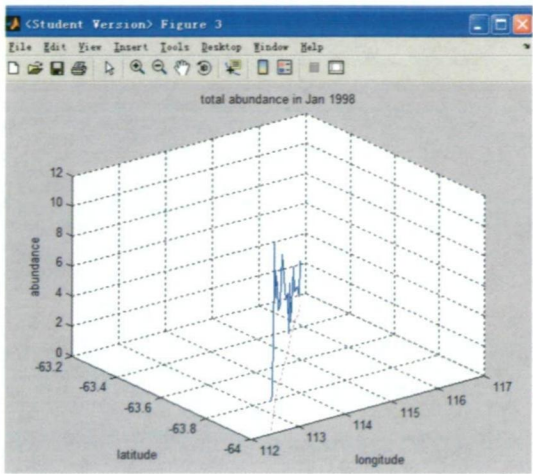


Figure 3.9 abundance of zooplankton species

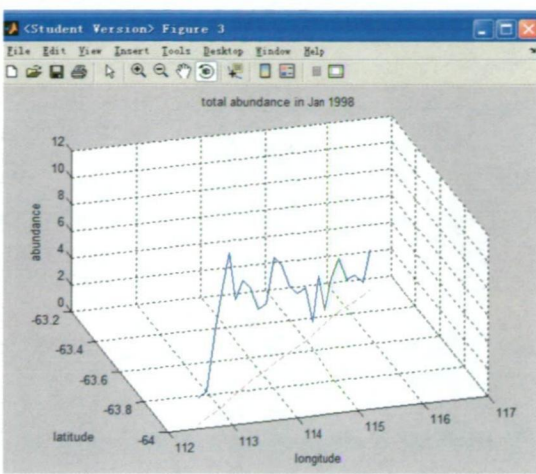


Figure 3.10 abundance viewed by angle 1

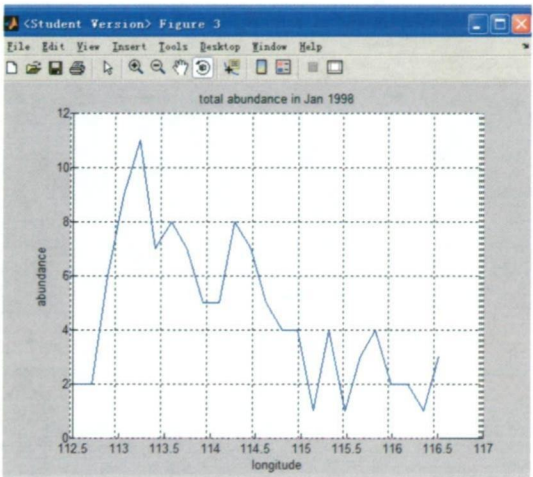


Figure 3.11 abundance viewed by angle 2

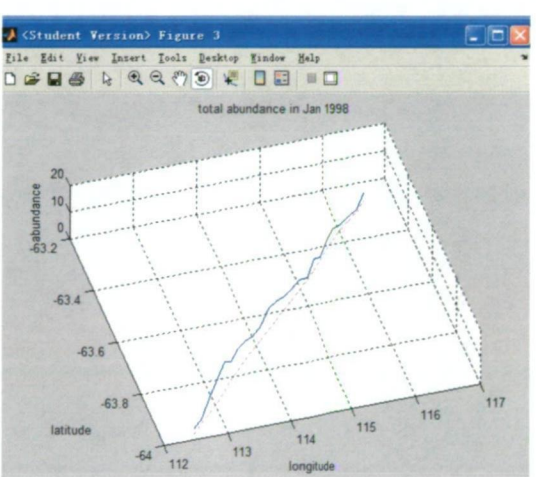


Figure 3.12 abundance viewed by angle 3

### 3.3.3 Interaction with Information

Interactive filtering is an important exploratory technique and it is widely employed in this application. The user can reduce the quantity of information that is being displayed by changing a parameter, or the range of values. One important feature of this interaction is that the query immediately alters the display (Dodge et al. 2008).

The user can interact with information by controlling the range of years for the

display and determining the range of the monitored spatial region. Multiple images in interesting years can be compared with each other. Moreover, the regional range entered expands the observational area according to different foci. For example, if the user only wants to track the plankton dynamics, the observational region can be located in the area nearby the plankton. If it is necessary to explore the sea ice environment around the plankton, the visualized observational range should be adjusted so that it is wider. The Figure 3.13 describes the operations at the start of this application.

```
EDU>> main
Enter the start year (e.g 1997):
1997
Enter the end year (e.g 2006):
2006
Enter the logitude range (e.g. 50):
50
Enter the latitude range (e.g. 5):
5
```

**Figure 3.13** user input when application is launched

Users can select different months and color maps for the display. There are different plankton data sets in each month. Furthermore, it is well known that color is important in geographical visualization. Changing how colour is mapped to the display can considerably influence how the information is perceived. The importance is that some elements can be hidden or emphasized through different colour mappings; colour can be used to delimitate boundaries and areas, at the same time allowing the user to perceive relationships more clearly (Dodge et al. 2008).

The interaction with the plankton data is achieved by controlling the plankton observational time using the slider and the zooplankton species using the pop list. For example, users can select to observe the plankton data during the period from 1<sup>st</sup>

Dec 1998 to 12<sup>th</sup> Jan 1999 or from 2<sup>nd</sup> Jan 1999 to 23<sup>rd</sup> Jan 1999. Moreover, the length of that period can be altered by the user; it means that the observational period can be one day, one month or a longer time. The zooplankton species observed is decided by the selected option on the pop list 'Plankton Species' and the options can be created by regrouping the species. In addition the abundance of a particular species in a particular period can be observed through 3D visualization.

The interactions with the sea ice data are similar to those with the plankton data. The user can change the date of sea ice data and, in response to that action the sea ice satellite image will be updated.

### **3.4 Analysis and Evaluation**

Following development of the visualization program, evaluation was undertaken by the developer and two biologists. The analyses were mainly focused on the benefits which can be derived from this application and the interaction with relevant information. Evaluation is related to how efficient and usable this application is perceived to be by the biologists and undertaken by means of three domain expert feedback meetings.

#### **3.4.1 Analysis**

Sea ice data and plankton data were visualized together in different layers. Analyses were realized by comparing these data sets in the same month (season) during different years. The similarities and differences which could be concluded through observation are valuable because they enable the biologist to clearly understand and deeply explore the process by which the Antarctic marine ecosystem is regulated. The operations in that part of each individual year represented in the application by the period starting from 1<sup>st</sup> July some year and ending by 30<sup>th</sup> June next year assisted biologists to observe the plankton data dynamically and compare it with sea ice

changes. This type of interaction contributed to a biologist's ability to explore the relationship between plankton and sea ice dynamics.

### **3.4.2 Evaluation**

Evaluation was the last but necessary step in developing this application. Following the development of the system both users and the developer have undertaken an effective evaluation process covering several crucial aspects as follows.

**Functionality** The features of the application determine how well the application meets a real need and so determine whether the application can satisfy the requirements from biologists.

**Performance** This aspect usually relates to the run-time speed of the application to perform different functions. In this project it is related to how efficiently the visualization can facilitate the biologists, and whether the information displayed is valuable and sufficient.

**Usability / Ease of use** It is normal that every system takes some time to for a user to learn. However system use should be as intuitive as possible in order to minimize the time needed to learn how to operate the system. In this project the point is to evaluate how easy it is for a user to undertake appropriate interaction with information.

**Stability** This aspect refers to the errors or bugs in applications and applications vary in the number of times they fail. If a system can be well designed and have been tested adequately before it is first introduced, a reasonable level of stability can be achieved (Chaffey and Wood 2005).

### **3.4.3 Biologists Evaluation**

After the first and basic evaluation, there were two domain expert feedback meetings

following. They respectively were focused on the improvement directions and the final demonstration and conclusion.

The improvements were mainly considered three aspects as follows.

1. Building a 3D module for visualising the abundance of plankton species.
2. Regrouping the plankton species into broader groups prior to visualization.
3. Thresholding the sea-ice concentration values. This would enable the user to specify a sea ice concentration value, and the system will then display the sea-ice map, coloured white wherever the concentration is above that specified value and coloured dark-blue wherever the concentration is below that specified value.

In the final evaluation, the application was demonstrated. The biologist Klaus Meiners mainly focused on some improvements which were based on the above suggestions. After using the visualization system he provided a written feedback as an evaluation of the system.



## **Chapter 4**

### **Results and Observations**

The process of development this project involved the requirement to first understand the topic and the context within which the system would be applied, to explore effective visualization techniques, to develop the application itself, and finally to undertake the evaluation. This chapter discusses the results obtained as a result of implementing and evaluating this system.

#### **4.1 Results from Development**

##### **4.1.1 Results from Exploring Visualization Techniques**

Remote sensing techniques, visualization techniques and the application were explored deeply in the early preparation. As a result, useful visualization techniques and visualization effects were found to incorporate into the development of this application.

The interaction and manipulation mechanisms needed with those two data sets were investigated by both the developer and the biologists during frequent discussion and communication. The ways to visualise the data sets were decided upon and also the methods by which the biologists can interact with the information being displayed. The parameters needed to be changed to alter the visual appearance of the display were carefully considered.

Consequently, interactive filtering as an important exploratory technique was used in this application. The users can change a parameter, or the range of values, to reduce the quantity of information that is being displayed. Moreover, interactively adapting



mapping parameters was another technique that was implemented. Colour is important in geographical visualization, because it can have a strong impact on how the information is perceived. In addition to the colour map whose colours can permit the user to perceive depth and could be used to delimit areas and borders, there are many other methods that can utilize colour to provide the user with more information.

#### **4.1.2 Results from the Application Development Process**

The graphical interfaces for this application consisted of two parts: the interface for the analyses of multiple years and the interface for each individual year. The application can display multiple sea ice satellite images during a specific period together, for example from 1997 to 2006, entered by the user when the application was launched. User can also change color map and the month for observation. Furthermore, biologists can observe the plankton track by searching for a yellow line on the images and selected that particular season for further tracking.

An individual window can be opened to display the data in a particular year. The information of sea ice and plankton visualized in the figure were clearer and were focused on one particular year within a period that started from July and ended by June the next year. The location of each plankton record was displayed by a dot on the screen with different colors assigned to the dots. The brightness of color represented the observational time track. The direction of the track proceeded from darker dots, for the earlier observations, to lighter dots, for the later observations. The two sliders on the window controlled the period for observing the plankton and the sea ice. For the plankton observations, the biologists could easily find the previously displayed information marked by gray dots and the current information colored according to different species. The application could also display the total abundance of zooplankton on different observational days by 3D and the user could regroup different zooplankton species.

## **4.2 Results from Analysis and Evaluation**

### **4.2.1 Analysis**

With the visualization system, the biologists can easily observe sea ice changes during different years and compare the similarities and differences. Moreover, the system helped them to explore the relationship between sea ice and plankton through the interaction of altering observational periods of both.

### **4.2.2 Evaluation**

Evaluation was undertaken as the last phase in the completion of this application. It mainly referred to several aspects as follows.

**Functionality** This application realised the requirements specified by the biologists initially and met the biologists' needs.

**Performance** This application it appeared to have a well organized graphical interface for visualization. By interacting with the information using the graphical user interface it could change the appearance of the display and it provided biologists differently focused information. In addition, the speed of the application to perform different functions was considered acceptable.

**Usability / Ease of Use** The functions and operations were intuitive and easy to manipulate.

**Stability** The system was well designed and has been tested before it was first introduced. The application was run multiple times and during the running the application no errors or bugs could be found.

### **4.2.3 Biologist Evaluation**

There were another two domain expert feedback meetings to follow. The former was focused on the improvement and mainly considered three aspects as follows.

1. Building a 3D module for visualising the abundance of plankton species.
2. Regrouping the plankton species into broader groups prior to visualization.
3. Thresholding the sea-ice concentration values. This would enable the user to specify a sea ice concentration value, and the system will then display the sea-ice map, coloured white wherever the concentration is above that specified value and coloured dark-blue wherever the concentration is below that specified value.

In the final evaluation, the application was demonstrated and some improvements based on the above suggestions have been implemented. The biologist Klaus Meiners after using the visualization system provided the following written feedback as an evaluation of the system.

*The annual advance and retreat of sea ice around the Antarctic continent is a key factor of Antarctic marine ecosystem function and plays a pivotal role in the biogeochemical cycles of the Southern Ocean. The sea ice cover greatly affects the exchange of energy and mass between the atmosphere and the sea. It also strongly affects pelagic production due to its effect on the under-ice light regime and coupled physical-biological processes at retreating ice edges during spring, including water column stratification, release of nutrients and seeding of the water column with ice algae. Computational tools for the visualization of biological distributions (e.g. zooplankton data) in relation to sea ice extent/concentrations are needed to help ecologist to understand the interactions between sea ice and biological ecosystem components. The MATLAB tool developed by Ms. Jun Feng allows the user to overlay satellite data on sea ice concentrations and ice edge location with data on zooplankton distributions from Continuous Plankton Recorder (CPR) deployments. The code is a very useful tool for the visualization of these data sets and allows marine scientists to explore the distributions of individual zooplankton species and groups in relation to the physical environment.*

*(Dr Klaus Meiners, Antarctic ecologist, private communication, 2008)*

## **Chapter 5**

### **Conclusion and Further Development**

This research has confirmed the hypothesis by utilising computational data fusion techniques to integrate sea-ice dynamics data, derived from passive microwave satellite images, with zooplankton observational data, obtained from the Southern Ocean Continuous Plankton Recorder. The development of this system facilitates the exploration of the relationship between sea ice and plankton by utilizing advances in visualization techniques and implementing the interaction with relevant data sets.

The benefits of the utilisation of scientific visualization and the increasing development and integration of visualization techniques to realise it are one major area that must be explored, as it is directly connected with the development of this system. From the review of literature of this field of scientific visualization, especially geographical visualization, the relevant knowledge which is adapted to the requirements and specifications of this system has been studied and understood. It has greatly facilitated the development of this new system.

A successful implementation of computational techniques for both the analysis and the visualization of sea ice data, integrating with plankton data, have been completed. However, further development could significantly enhance the functionality by utilizing more advanced visualization techniques to explore the information and assist in the prediction of new phenomena deduced from the information currently at hand.

Further developments of the visualization system can now follow in four main directions. (1) Improving the visualization of zooplankton with sea ice by extensive use of 3D graphics with appropriate interaction within a 3D environment. (2)

Providing a facility for thresholding the sea ice concentration values so that the user can specify the concentration values and observe the particular regions in which the sea-ice concentration falls below, or exceeds these values. (3) Visualising other environmental data, such as sea surface temperature and salinity, since there is much information available about other environmental factors and their impacts on both sea ice formation and zooplankton populations, and (4) improving the function for visualising the data combined with different zooplankton species and optimizing the algorithm to improve computational performance. Currently, functions were mainly focused on visualising the information about the total abundance of zooplankton.

## References

- Alheit, J. and Niquen, M. 2004, *Regime shifts in the Humboldt Current ecosystem*, Prog. Oceanogr. 60, 201–222
- Atkinson, A. 1998, *Life cycle strategies of epipelagic copepods in the Southern Ocean*, Journal of Marine Systems 15, 289–311
- Atkinson, A. et al. 2004, *Long-term decline in krill stock and increase in salps within the Southern Ocean*, Nature 432, 100–103
- Australian Antarctic Division 2007, *Life in the Southern Ocean*, viewed 29/09/2008, <<http://www.aad.gov.au/default.asp?casid=221> >
- Australian Antarctic Division 2008a, *How the CPR works*, viewed 29/09/2008, <[http://data.aad.gov.au/aadc/cpr/cpr\\_works.cfm](http://data.aad.gov.au/aadc/cpr/cpr_works.cfm)>
- Australian Antarctic Division 2008b, *Southern Ocean Continuous Plankton Recorder Survey*, site viewed 30/03/2008, <<http://data.aad.gov.au/aadc/cpr/>>
- Beaugrand, G., Ibanez, F., Lindley, J.A. 2001, *Geographical distribution and seasonal and diel changes in the diversity of calanoid copepods in the North Atlantic and North Sea*, Marine Ecology Progress Series 219, 189–203
- Burns, B.A., Cavalieri, D.J., Keller, M.R., Campbell, W.J., Grenfell, T.C., Maykut, G.A., and Gloersen, P. 1987, *Multisensor comparison of sea ice concentration estimates in the marginal ice zone*, Journal of Geophysical Research 92 (C7):6843-6856
- Chaffey, D., and Wood, S. 2005, *Business Information Management: Improving Performance Using Information Systems*, Prentice Hall
- CleveMoler, 2008, *Parallel MATLAB®: Multiple Processors and Multiple Cores*, site view 02/04/2008, <[http://www.mathworks.com/matlabcentral/files/16033/42682\\_91467v00\\_NNR\\_Cleve\\_US.p](http://www.mathworks.com/matlabcentral/files/16033/42682_91467v00_NNR_Cleve_US.p)



df>

Culverhouse, P.F., Williams, R., Benfield, M., Flood, P.R., Sell, A.F., Mazzocchi, M.G., Buttino, I., & Sieracki, M. 2006, *Automatic image analysis of plankton: future perspectives*, Mar Ecol Prog Ser Vol. 312: 297-309, Inter-Research 2006, April 24 2006

Drinkwater, M.R., Hosseinmostafa, R., Gogineni, S.P. 1995a, *C-band backscatter measurements of winter sea ice in the Weddell Sea, Antarctica*, Int J Remote Sensing 16, no 17:3365-3389

Drinkwater, M.R., Kreyscher, M., Fischer, H., Harder, M. 1995b, *Comparison of seasonal sea-ice model results with satellite microwave data in the Weddell Sea*, Proc Int Geosci Remote Sens Symp IGARSS 95, July 10-14, Florence, Italy, pp 357-359

Dodge Martin, McDerby Mary, Turner Martin 2008, *Geographic Visualization*, JohnWiley&Sons, Ltd England

Edsall, R.M. 2003, *The parallel coordinate plot in action: design and use for geographic visualization*, Computes and Statistical Data Analysis 43 (4): 605-619

Eicken, H. 1992, *The role of sea ice in structuring Antarctic ecosystems*, Polar Biology, Springer-Verlag, 1992

Friendly, M. 2008, *Milestones in the history of thematic cartography, statistical graphics, and data visualization*, viewed 30/09/2008, <  
<http://www.math.yorku.ca/SCS/Gallery/milestone/milestone.pdf>>

Gemmill, W.H., Burroughs, L.D., and Gerald, V.M. 2008, *OCEAN SURFACE WIND SPEEDS RETRIEVED FROM DSMP SATELLITES*, site viewed 02/04/2008, <  
<http://forecasts.weather.gov/om/tpb/467text.htm>>

Hays, G.C., Richardson, A.J. & Robinson, C. 2005, *Climate change and marine plankton*, Elsevier

Healey, C.G 1999, *Perceptual Techniques for Scientific Visualization*, paper presented to Issues of Visual Perception for Effective Image Generation, Los Angeles, California, pp.1-42

Healey, C.G. and Enns, J.T. 1999, *Large datasets at a glance: Combining textures and colors in scientific visualization*, IEEE Transactions on Visualization and Computer Graphics, vol.5, no.2, pp.145-67

Hedgpeth, J.W. 1977, *The Antarctic marine ecosystem*, in *Adaptations within Antarctic Ecosystems*, Llano, G.A., Ed., Smithsonian Institution, Washington, DC. 1977, 3-10

Hofmann, E.E. and Murphy, E.J. 2004, p487-p499, *Advection, krill, and Antarctic marine ecosystems*, Antarctic Science

Hosie, G.W. 1994, The macrozooplankton communities in the Prydz Bay region, Antarctica. In S. Z. El-Sayed (Ed.), *Southern Ocean Ecology: The BIOMASS Perspective* (pp. 93–123). Cambridge: Cambridge University Press.

Hosie, G.W. and Cochran, T.G. 1994, Mesoscale distribution patterns of macrozooplankton communities in Prydz Bay, Antarctica — January to February 1991, *Marine Ecology Progress Series*, 106, 21–39

Hosie, G.W. and Stolp, M. 1989, *Krill and zooplankton in the western, Prydz Bay region, September–November 1985*, Proceedings of the NIPR Symposium on Polar Biology, 2, 34–45.

Hosie, G.W., Cochran, T. G., Pauly, T., Beaumont, K. L., Wright, S. W., and Kitchener, J. A. 1997, The zooplankton community structure of Prydz Bay, January–February 1993, *Proceedings of the NIPR Symposium on Polar Biology*, 10, 90–133

Hosie, G.W., Fukuchi, M., Kawaguchi, S. 2003, *Development of the Southern Ocean Continuous Plankton Recorder survey*, Progress in Oceanography 58 (2003) 263–283

Hunt, B. P.V. and Hosie, G.W. 2005, *Zonal Structure of Zooplankton Communities in the Southern Ocean south of Australia: results from a 2150 kilometer Continuous Plankton Recorder transect*, Deep-Sea Research I 52, 1241–1271

Hunt, B.P.V. and Hosie, G.W. 2006a, *The seasonal succession of zooplankton in the Southern Ocean south of Australia, part I: The seasonal ice zone*, Deep-Sea Research I 53, 1182–1202, ELSEVIER

- Hunt, B.P.V. and Hosie, G.W. 2006b, *The seasonal succession of zooplankton in the Southern Ocean south of Australia, part II: The Sub-Antarctic to Polar Frontal Zones*, Deep-Sea Research I 53, 1203-1223, ELSEVIER
- Kao, D.L. and Ma, K.L. 2000, *The life cycle of a visualization case study*, IEEE Computer Graphics and Applications, vol.20, no.5, pp. 29-31
- Keim, D.A., Member IEEE Computer Society 2002, *Information Visualization and Visual Data Mining*, IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS, VOL. 8, NO. 1, JANUARY-MARCH 2002
- Kemp, D. 1926, *The Discovery expedition*, Nature, 118: 628–629
- Knox, G.A. 2007, *Biology of the Southern Ocean*, second edition, CRC Press Taylor & Francis Group the United States of America 2007
- Kosara, R., Healey, C.G., Interrante, V., Laidlaw, D.H. and Ware, C. 2003, *User studies: Why, how, and When?* IEEE Computer Graphics and Applications, vol.23, no.4, pp.20-5
- Kottmeier, S.T., Miller, M.A., Lizotte, M.P., Craft, L.L., Sullivan, C.W. 1986, *Ecology of sea ice microbial communities during the 1984 winter-summer transition in McMurdo Sound, Antarctica*, Antarct, J.U.S., 20, 128-130, 1986
- Kuehn, F., King, T., Hoerig, B., Peters, D. 2000, *Remote Sensing for Site Characterization, Methods in Environmental Geology*, Springer, Germany
- Lind, M., Bingham, G.P. and Forsell, C. 2003, *Metric 3D structure in visualization*, Information Visualization, 2:51-57
- Littlepage, J.R. 1965, *Oceanographic investigations in McMurdo Sound, Antarct*, Res. Ser.,5, 1-37, 1965
- Liu, A.K. and Cavalieri, D.J. 1998, *On the sea ice drift from the wavelet analysis of the Defense Meteorological Satellite Program (DMSP Special Sensor Microwave Imager (SSM/I) data)*, International Journal of Remote Sensing 19(7):1415-1423
- Lohse, G.L., Biolsi, K., Walker, N. and Rueter, H.H. 1994, *A classification of visual representations*, Communications of the ACM 37 (12): 36-49

Mann, K.H. and Lazier, J.R.N., 2006, *Dynamics of Marine Ecosystems: Biological-physical Interactions in Oceans*, Blackwell

MathWorks 2007, *MATLAB&SIMULINK student version R2007a*, Getting Started with MATLAB, The MathWorks, Inc., the United States of America

McCormick, B.H. et al. 1987, *Visualization in Scientific Computing*, Computer Graphics 21,6 November 1987, ACM SIGGRAPH, New York

Meid, R.P., Askari, F., Marmorino, G.O., Valenzuela, G.R. and Trizna, D.B. 1992, *High resolution remote sensing*, In 1992 Naval Research Laboratory Review, NRL Publication 202-4830, May pp.181-183

National Geophysical Data Center 2008, *Earth Observation Group (EOG) Defense Meteorological Satellite Program (DMSP) Data Archive, Research, and Products*, viewed 29/09/2008, < <http://www.ngdc.noaa.gov/dmsp/index.html>>

National Snow and Ice Data Center 2008, Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I Passive Microwave Data, viewed 29/09/2008, [http://nsidc.org/data/docs/daac/nsidc0051\\_gsfc\\_seaice.qd.html](http://nsidc.org/data/docs/daac/nsidc0051_gsfc_seaice.qd.html)

National Snow and Ice Data Center 2007, Arctic Sea Ice News & Analysis, viewed 02/10/2008, < <http://nsidc.org/arcticseaicenews/2007.html> >

National Weather Service Environmental Modeling Centre 2008, viewed 30/05/2008, <<http://polar.ncep.noaa.gov/seaice/analysis/sh/?C=N;O=D>>

Pakhomov, E.A. 1989, *Raspredeleniye makroplanktona v tsentral'noy chasti Indiiskogo Sektora Yuzhnogo Okeana v letniye seson'i 1984-86*, Antarktika, 28, 145-157

Parkinson, C.L. and Cavalieri, D.J. 2002, *A21 year record of Arctic sea-ice extents and their regional, seasonal and monthly variability trends*, Annals of Glaciology 34:441-446

Parkinson, C.L. and Gloersen, P. 1993, *Global sea ice coverage*, In *Atlas of Satellite Observation Related to Global Change*, edited by R.J. Gurney, J.L. Foster, and C.L. Parkinson, Cambridge: Cambridge University Press

Rees, W.G. 2005, Remote sensing of snow and ice, Taylor & Francis Group, 2005

Richardson, A.J. and Schoeman, D.S. 2004, *Climate impact of plankton ecosystems in the Northeast Atlantic*, Science 305, 1609–1612

Rogowitz, B.E. and Treinish, L.A. 1995, *How Not to Lie with Visualizaiton*, IBM Research, <<http://www.research.ibm.com/dx/proceedings/pravda/truevis.htm>>

Rosenblum, L., Earnshaw, R.A., Encarnacao, J., Hagen, H., Kaufman, A., Klimenko, S., Nielson, G., Post, F., Thalmann, D., 1994, *Scientific Visualization Advances and Challenges*, Academic Press, Published in association with IEEE Computer Society Press

Schnack-Schiel, S.B., and Mujica, A. 1994, The zooplankton of the Antarctic Peninsula region. In S.Z. El-Sayed (Ed.), *Southern ocean ecology: The BIOMASS perspective* (pp. 79-92), Cambridge University Press

Senay, H. and Ignatius, E. 1990, *Rules and Principles of Scientific Data Visualization*, Technical Report: GWU-IIST-90-13, The George Washington University, Washington, DC, May. (Also in State of the Art in Scientific Visualization, SIGGRAPH'90 tutorial notes, August.)

Smith, S.L. and Schnack-Schiel, S.B. 1990, Polar zooplankton, In W. O. Smith Jr. (Ed.), *Polar Oceanography, Part B Chemistry, Biology and Geology* (pp. 527-598), San Diego: Academic Press

Suvanaphen, S. and Roberts, J.C. 2004, *Textual difference visualization of multiple search results utilizing detail in context*, In Theory and Practice of Computer Graphics, Lever, P.G. (ed.), Bournemouth, June 2004, EGUK, IEEE Computer Society Press, pp.2-8

Trauth, M.H. 2006, *MATLAB Recipes for Earth Sciences*, Springer, the United States of America

Treinish, L.A. 1999, *Task-specific visualization design*, Ieee Computer Graphics and Applications, vol.19, no.5, pp.72-7

Tsatsoulis, C and Kwok, R. 1998, *Analysis of SAR Data of the Polar Oceans Recent Advances*, Springer

William, A. and Yang W. 2006, *Scientific Visualization Today*, Consortium for Computing Sciences in Colleges, USA

Woods, M.R. 2004, *Computational Techniques for the Analysis and Visualization of Marine Animal Movement Data*, University of Tasmania, School of Computing, Nov 2004