Report of the International Workshop on Antarctic Sea Ice in IPY

Il Ciocco Hotel and Resort, Lucca (Barga), Italy
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Edited by Anthony Worby

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Antarctica and the Global Climate System (AGCS) program

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Table of Contents

List of Figures **3**
Workshop Conveners **3**
Acknowledgements **3**
Executive Summary **4**
List of Attendees **5**
Workshop Sessions and Schedule **6**
Sunday 22 March 2009 ..... *6*
Monday 23 March 2009 ..... *6*
Tuesday 24 March 2009 ..... *8*
Location and dates of SIMBA voyage **10**
Location and dates of SIPEX voyage **11**
Session 1A: Snow on Sea Ice **10**
1A General Discussion *12*
1A Datasets Acquired *13*
1A Key Questions *13*
1A Recommendations for Future Work *14*
Session 1B: Iron (*Fe*) and EPS **15**
1B General Discussion *15*
1B Datasets Acquired *15*
1B Key Questions *16*
1B Potential Deep Sea Research-II Papers *16*
1B Other Potential Papers *17*
Session 2A: Physics/Biomass **18**
2A General Discussion *18*
2A Recommendations for Future Work *19*
Session 2B: Remote Sensing Altimetry **21**
2B General Discussion *21*
2B Recommendations for Future Work *22*
2B Potential Deep-Sea Research-II Papers *22*
Session 2C: Sea Ice Drift and Deformation **23**
2C General Discussion *23*
2C Key Questions *25*
2C Potential Deep-Sea Research-II Papers *25*
3A General Discussion *26*
Session 3B: Sea Ice Geophysics **29**
3B General Discussion *29*
Session 4A: Remote Sensing General **31**
4A General Discussion *31*
4A Datasets Acquired *32*
4A Key Questions *32*
Session 4B: CO_2/pCO_2 ..... **33**
4B General Discussion *33*

4B Potential Deep Sea Research-II Papers ... *34*
4B Other Potential Papers ... *34*
Session 4C: Bio-Optics ... **35**
4C General Discussion ... *35*
4C Recommendations for Future Work ... *36*
4C Potential Deep Sea Research-II Papers ... *36*
4C Other Potential Papers ... *36*
Session 5A: Modelling Small Scale Sea Ice Processes ... **37**
5A General Discussion ... *37*
5A Potential Deep Sea Research-II Papers ... *37*
Session 5B: Meiofauna and Biodiversity ... **38**
5B General Discussion ... *38*
5B Potential Deep Sea Research-II Papers ... *39*
Session 6A: Modelling Large Scale Sea Ice Processes ... **41**
6A General Discussion ... *41*
6A Potential Deep Sea Research-II Papers ... *43*
Papers for the Deep Sea Research-II Volume ... **44**

List of Figures

Figure 1: Group photograph ... 9
Figure 2: SIMBA Cruise Track. ... 10
Figure 3: SIMBA Ice Station Belgica Layout. ... 10
Figure 4: SIPEX Cruise Track ... 11
Figure 5: SIPEX Buoy Array Deployments. ... 23

Workshop Conveners

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Klaus Meiners (Antarctic Climate & Ecosystems CRC, Australia)
Steve Ackley (University of Texas at San Antonio, USA)

Acknowledgements

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Executive Summary

The International Workshop on Antarctic Sea Ice in IPY was held over 2½ days in Barga, Italy, a small village in Tuscany; about 90 minutes drive from Pisa. It followed the 2009 Gordon Conference on Polar Marine Science "Beyond IPY: Crossing Boundaries", a multi-disciplinary bi-annual meeting that brought together scientists from both polar regions.

The workshop attracted 47 attendees, 30 of whom participated in the 2009 Gordon Conference and 17 of whom travelled to Italy solely to attend the workshop. Many of the attendees were participants in one of the two major sea ice research voyages which took place in the Antarctic sea ice zone in spring 2007. These were the Australian-led "Sea Ice Physics and Ecosystem eXperiment (SIPEX)" program which focused on the region between 110-130ºE, and the US-led "Sea Ice Mass Balance in the Antarctic (SIMBA)" program which took place in the Bellingshausen Sea, close to 90ºW. While many of the in situ measurements conducted on the two programs were similar, the sampling strategies differed in that SIPEX conducted 15 separate ice stations at different locations within the pack ice, while SIMBA focused primarily on one station to conduct long time-series measurements. The goal of the workshop was therefore to explore synergies between the programs in terms of data analysis and to discuss opportunities for preparing joint or complementary publications.

The workshop was structured to ensure that all participants had an opportunity to raise topics for discussion at the first plenary session. These ideas were then massaged into thirteen broad discussion topics, ranging from meiofauna and biodiversity to sea ice physics to large- and small-scale modelling. The discussions took place in 2-3 parallel sessions over 1½ days with a final plenary session that summarised the discussions and developed a list of possible papers for a special volume of Deep Sea Research-II. A Chair and Rapporteur were identified for each session and their reports form the basis of this report.

In addition to the participants of the SIPEX and SIMBA voyages, other members of the sea ice community also attended. They brought expertise in different aspects of Antarctic sea ice processes, modelling and remote sensing measurements, as well as data and insights from other field campaigns. Ground truthing of remotely sensed data was a major emphasis of both voyages and the workshop. Specific RADARSAT (active microwave) and ICESat (laser altimetry) missions coincided with the field programs as well as an archival campaign for Envisat ASAR imagery.

A key output of the workshop was a list of 35 papers confirmed for a special volume of Deep Sea Research-II, which is shown at the end of this report. An editorial committee was identified, including Tony Worby (Chief Editor), Petra Heil, Klaus Meiners, Chris Fritsen, Lisa Miller and Cathy Geiger. A submission deadline of October 31st 2009 was agreed to ensure the volume can be published in late 2010.

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Workshop Sessions and Schedule

Sunday 22 March 2009

1600 – 1900 Plenary 1: Welcome, input to discussion topics, agenda setting (Chair: Tony Worby)

Monday 23 March 2009

Session 1A – Snow on Sea Ice (Chair: Rob Massom)
0900 – 1030
Topics for discussion:

- Snow cover changes caused by low pressure systems (i.e., impacts of meteorological variables on the snow cover characteristics)
- Flooding, changes in depth of snow on ice
- Snow ice formation, changes in satellite signatures
- Contrasts between two SIMBA sites
- Importance of snow processes for snow radar
- Redistribution of snow on the ice
- What is driving the flood/freeze cycle?

Session 1B – Iron (*Fe*) and EPS (Chair: Delphine Lannuzel)
0900 – 1030
Topics for discussion:

- Iron biogeochemistry – sources of Iron as well as spatial and temporal Iron distribution and speciation
- The way EPS is stored, that is biological versus physical processes

Session 2A – Physics/Biomass (Chair: Klaus Meiners)
1100 – 1230
Topics for discussion:

- Compare abundances of sea ice biota and relate them to physical parameters, vertical and horizontal variability, using comparison of cruises and other data
- Smaller scale variability, seasonality?
- Investigate biomass at a large scale in relation to ice and snow thickness distribution

Session 2B – Remote Sensing Altimetry (Chair: Katharine Giles)
1100 – 1230
Topics for discussion:

- ICESat and Envisat data– snow and ice thickness. Algorithms: differences between the Arctic and Antarctic?
- Importance of AMSR-E snow depth and concentration for ICESat
- Discussion of helicopter radar data

- Ensuring consistency between RS and field data sets, the need to look at same geophysical parameters

Session 2C – Sea Ice drift and Deformation (Chair: Petra Heil)
1100 – 1230
Topics for discussion:
- Buoy drift data: Is it possible to look at impacts of swell on thickness and concentration and floe-size distribution?
- Importance for floe-size distribution – pancake ice formation, wave and swell

Session 3A – Ice Physics and Tracers Dynamics (Chair: Jean-Louis Tison)
1430 – 1600
Topics for discussion:
- Physics from the perspective of a gas molecule
- Transfer of tracers
- Different conditions on SIPEX and SIMBA, which is important when comparing data under similar conditions, e.g., transition from winter to spring, changes in temp/sal
- Address questions of large and small scale spatial variability – separate from seasonal progression
- The Oden 2008/09 (summer) voyage data
- Time series of nutrients, biology – strong links with physical processes
- Use biological measurements to constrain the physics

Session 3B – Sea Ice Geophysics (Chair: Tony Worby)
1430 – 1600
Topics for discussion:
- Can we improve EM measurements?
- Buoyancy corrections?
- SIPEX and SIMBA – both underway and ice floe data
- Remotely Operated Vehicle (ROV) data (upward looking sonar)
- Electrical conductivity measurements are closely related to this discussion
- Compare Wenner array measurements from both cruises
- Discussion about cameras for underway observations; corrections for image angle – ice classification from images; quantify ice conditions, possibly real time displays; and SIPEX aerial photography

Session 4A – Remote Sensing General (Chair: Thorsten Markus)
1630 – 1800
Topics for discussion:
- Links between ice and snow geophysical questions and remote sensing data
- Discussion about maximising satellite data for other disciplines
- Interest in detection of snow ice
- Scatterometer data – flooding events

Session 4B – CO_2/pCO_2 (Chair: Tish Yager)
1630 – 1800
Topics for discussion:

- Physical and biological controls, DMS, species variability
- Community structure – micro habitats
- Physical habitat is an important part of discussion
- Seasonal progression
- Links between gas production and abundance/biology

Session 4C – Bio-Optics (Chair: Chris Fristen)
1630 – 1800
Topics for discussion:

- Radiometric data from Remotely Operated Vehicle (ROV) plus some SIMBA data
- Ice Mass Balance buoy
- Snow properties

Tuesday 24 March 2009

Session 5A – Modelling Small Scale Sea Ice Processes (Chair: Ken Golden)
0900 – 1030
Topics for discussion:

- Modelling flood/freeze cycles, thermal, salinity and velocity field profiles and related environmental variables and boundary conditions – implications for biology
- Small scale physics and ice core properties
- Diffusion processes in addition to convective processes, 3D, fluid transport
- Thermistor data

Session 5B – Meiofauna and Biodiversity (Chair: Maike Kramer)
0900 – 1030
Topics for discussion:

- Meiofauna in bio models
- Biocomplexity
- Successional modelling, community structure modelling

Session 6A – Modelling Large Scale Sea Ice Processes (Chairs: Sharon Stammerjohn and Martin Vancoppenolle)
1100 – 1230
Topics for discussion:

- Larger scale ice distribution – links to circulation, ocean heat flux
- Larger scale climate processes
- Ice Mass Balance discussion, tower fluxes, met data etc.
- Expectations of modellers by observational and RS communities, and vice versa. Small, medium and large scales
- Links between scales – impacts of microscale on much larger scales

- Large scale modelling shopping list
- Requirements in terms of accuracy
- Forcing fields
- Discussion about scales and parameterisation

1430 – 1600 Plenary 2: Reports and Discussion (Chair: Steve Ackley)

1630 – 1800 Plenary 3: Deep Sea Research-II Volume (Chair: Tony Worby)

Figure 1: Group photograph by Mitsuo Fukuchi

Location and dates of SIMBA voyage

Range of latitude: 66 – 74ºS
Range of longitude: 110 – 60ºW
Dates in ice: 24 September – 27 October 2007
Chief Scientist: Steve Ackley, University of Texas San Antonio, USA
Voyage Website: http://www.utsa.edu/lrsg/Antarctica/SIMBA
Metadata: Project descriptions are available on the voyage website

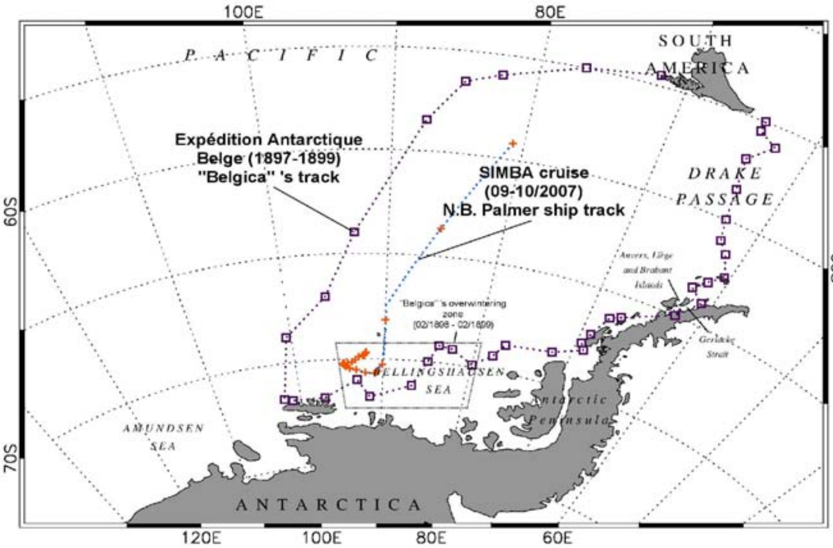

Figure 2: SIMBA Cruise Track. Track of *Nathaniel B. Palmer* during SIMBA, compared with the drift track of the *Belgica* in 1897 – 1899. SIMBA was predominantly a time series study, spending a month at one location "Ice Station Belgica" (see Figure 3), plus four short ice stations while transiting the pack ice.

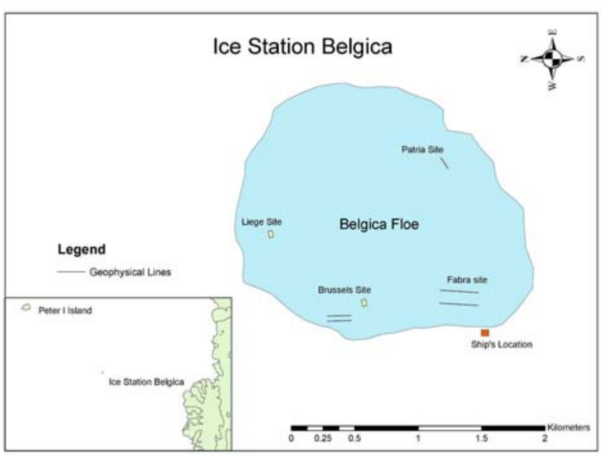

Figure 3: SIMBA Ice Station Belgica Layout. Layout of 'Ice Station Belgica' during SIMBA, showing the location of different experimental sites on the floe. The ship arrived at this location on 27th September and departed on 24th October.

Location and dates of SIPEX voyage

Range of latitude: 63 – 67ºS
Range of longitude: 116 – 130ºE
Dates in ice: 9 September – 11 October 2007
Chief Scientist: Tony Worby, Australian Antarctic Division and ACE CRC, Australia
Voyage website: http://www.sipex.aq
Metadata: Can be viewed in Google Earth by first downloading the sipex.kmz file from the Australian sea ice program home page at: http://seaice.acecrc.org.au

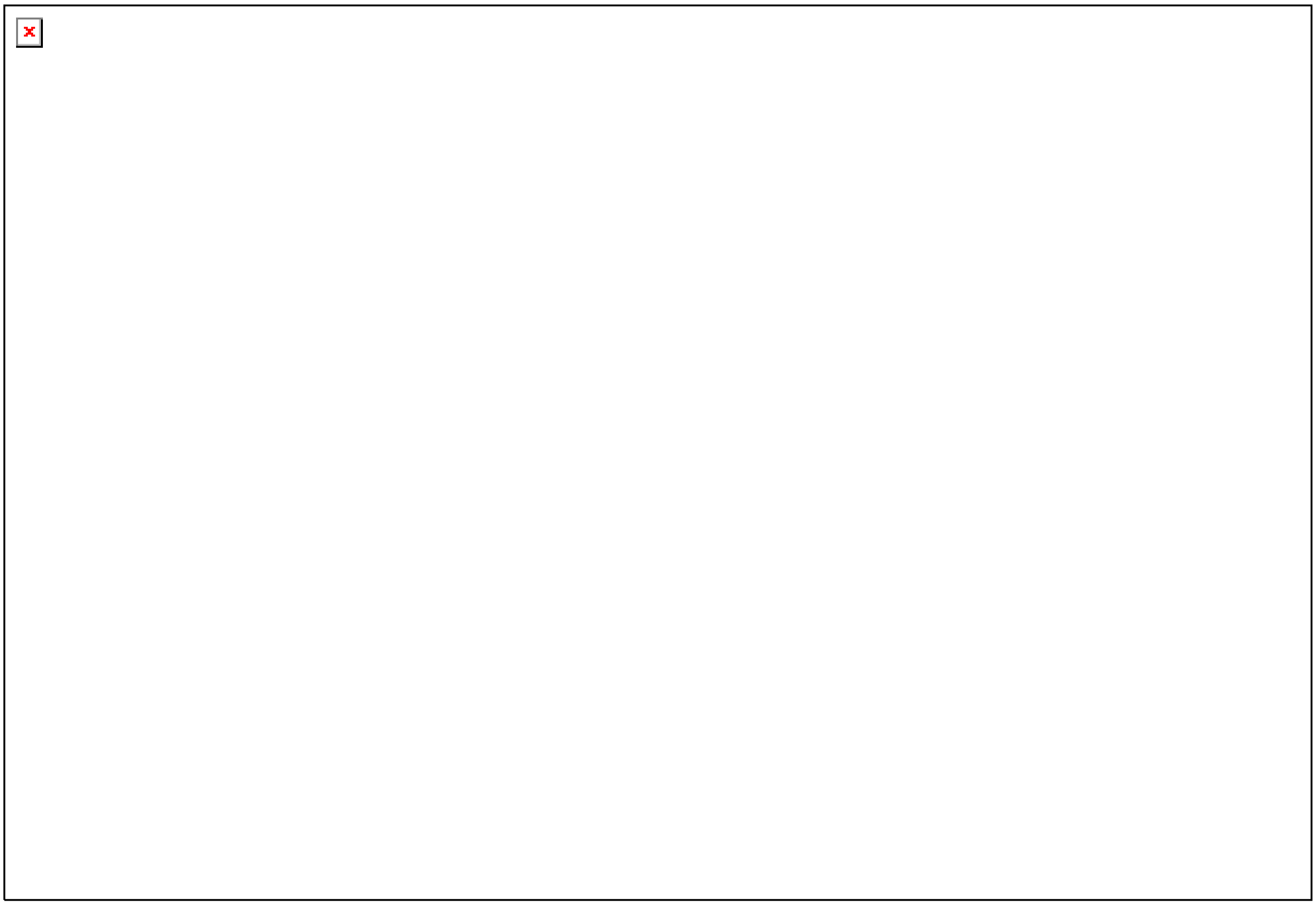

Figure 4: The track of the *Aurora Australis* during SIPEX (solid black line) overlaid on an AMSR-E ice concentration chart from 10th October 2007. The coloured lines show aircraft tracks along which aerial photographs, laser altimeter, snow radar and pyrometer data were collected. The locations of the 15 ice stations are also shown.

Session 1A: Snow on Sea Ice

Chair: Rob Massom
Rapporteur: Sharon Stammerjohn

1A General Discussion

SIMBA and SIPEX provide a unique opportunity to compare contemporary information on the snow cover processes and characteristics from West and East Antarctica, using datasets with different yet complementary attributes. While the SIMBA data set is suited to analysis of the temporal evolution of the snow cover and its coupling to the underlying sea ice response to the passage of storms etc., the SIPEX data set provides the opportunity to analyse spatio-temporal variability over a wider area (also encompassing the shift from a late-winter to early-spring sea ice regime). The SIPEX data set also includes measurements from East Antarctic fast ice.

Snow on sea ice forms a complex, heterogeneous substrate, its properties mirroring conditions (meteorological and sea ice) both during and after deposition. This produces evolving layers with different densities, grain sizes, salinity, and thermal conductivities. By the same token, the snow cover modulates the temperature, porosity and salinity of the underlying sea ice. Snow thickness distribution over local scales is determined not only by the roughness characteristics of the underlying ice but also by wind-blown snow redistribution. The latter was measured on SIMBA (by Katie Leonard), has wide-ranging implications and is a key current unknown. During SIMBA, the sea ice accumulated 1cm water equivalent from a total snowfall of 3 cm water equivalent i.e. ⅔ of snowfall was "lost" to wind-blown events.

The horizontal distribution of snow cover is also intimately associated with flooding and subsequent snow-ice formation. Major current unknowns in this respect are

- Spatio-temporal variability in flooding extent and duration, and the processes responsible i.e. vertical seawater migration up through the ice versus lateral incursion via cracks etc., and
- The forces driving them e.g. the passage of storms etc. Gaining a better understanding of the processes driving flooding and snow-ice formation, and their spatio-temporal variability, is critical to better understand and parameterize:
    i. changes in snow depth;
    ii. physical and thermal characteristics of the sea ice;
    iii. ice mass balance (via snow-ice formation) and response to global warming;
    iv. biological activity and biogeochemical processes within and on the sea ice and fluxes between the ice and atmosphere, e.g., CO_2); and
    v. optical and electromagnetic properties of the snow + sea ice substrate (affecting remote sensing interpretation).

The SIMBA (in particular) and SIPEX datasets provide an opportunity to address the flooding process, by combining observations with modelling (covered by the other groups led by Ken Golden et al.). Snow cover thickness and density information are also being used to derive sea ice thickness from ICESat and helicopter laser altimeter data.

An example from SIPEX illustrates the fact that flooding is not always associated with negative freeboards due to snow loading alone, and that lateral incursions of seawater from the vicinity of pressure ridges (and cracks etc.) may also be important. Improved information on this factor is essential for biogeochemical modelers (e.g. Martin Vancoppenolle), who stressed that it is poorly parameterized at present yet is possibly an important and extensive process.

SIMBA provided the opportunity to study snow (and sea ice) plus flooding evolution along repeat transects, with an intervening storm. Mean snow depth didn't change significantly over the 3-week period, but there were changes in flooding and freezing. In contrast, flooding was less common at the SIPEX stations. Reasons for this are under investigation - in addition to possible changes in snow cover characteristics caused by the passage of storms, the East Antarctic sea ice zone shifted from a late-winter to early-spring regime.

In addition to flooding, the "capillary layer" above the slush is also affected by a significant wetting by seawater. Even in the absence of frost flowers, Antarctic sea ice is generally damp around the snow-ice interface, due to the high salinity in the lower snow layer (incorporation of frost flowers etc.) – again with ramifications for remote sensing.

1A Datasets Acquired

The following snow measurements were acquired on SIMBA:

- 245 snow and ice interface measurements along 30 to 100 metre transects at 3 stations along the inbound track, plus detailed measurements of snow density, stratigraphy, grain size, oxygen isotope and temperature profile from 12 snow pits. Additionally, ice cores were obtained at each station and ice thickness measurements were made at 59 auger holes.
- At a 3-week drift of "Ice Station Belgica" over 2800 snow surface elevation, snow depth, and ice interface measurements were repeated across the same transect lines at 3 site locations, plus detailed information from 27 snow pits. Snow surface elevation and thermal profiles at 2-hour intervals were collected from three Ice Mass Balance buoys operational between 20 to 60 days, and a thermal profile from 1 snow pit was collected at 15-minute intervals over 6 days.
- Snow depth ranged from a few centimetres to over 1 metre, snow density ranged from 208-620 kg/ m³, mean grain size ranged from 0.1 mm to over 4 mm, snow salinity ranged from 0 to 18 psu depending upon location and snow type.

The following snow measurements were acquired on SIPEX:

- 1950 snow thickness and snow-ice interface measurements along 100-200m transects on 12 ice stations, and more detailed measurements of snow density, stratigraphy, grain size and temperature from 50 snow pits (often in association with ice cores); and
- Snow density measured ranged from 180-640 kg/m³, and mean grain size from 0.1-5mm, both depending on snow type.

1A Key Questions

Important central questions that can be addressed using the SIMBA/SIPEX data include:

- Do any large-scale patterns exist in snow cover properties and thickness, & what are the similarities/differences?
- What is the temporal-spatial evolution of the snow cover, and how is this coupled to the underlying sea ice (evolution)?

- What is the impact of storms (warm events) on the snow cover and its coupling to the underlying sea ice?
- What processes and forcing factors are responsible for flooding (i.e., snow loading versus lateral seawater incursion)? Observations towards the fine-scale modelling work by Ken, Ted, Tim, Martin etc.
- How much snow is "lost" by wind-blown snow redistribution, and what role does this play in the snow thickness distribution, flooding, and ice mass balance (via snow-ice formation) etc? In other words, what is the difference between precipitation over the sea ice zone and accumulation on the ice?

1A Recommendations for Future Work

- Continuous deployment of ice mass balance buoys.
- Continued/expanded work on snow redistribution over sea ice – deployment of snow particle flux counters at various sites (including possible fast ice). This work could be tied to information on ice surface roughness and floe-size distribution.

Session 1B: Iron (*Fe*) and EPS

Chair: Delphine Lannuzel
Rapporteur: Andrew Bowie

1B General Discussion

Spatial versus Temporal *Fe* Distribution

Based on first year pack ice data from ARISE (East Antarctic 2003) and ISPOL (Western Weddell 2004-2005), we have observed no clear large-scale spatial forcing of the distribution of dissolved *Fe* (d*Fe*) and TD*Fe*, but rather a seasonal evolution. Physical processes (i.e. ice permeability) strongly control the *Fe* distribution, and therefore the biological activity and species. Seasonal rather than spatial variability appeared to control d*Fe* distribution during SIPEX. The flood/freeze events observed SIMBA may also have driven d*Fe* behaviour both at Liege and Brussels sites, even though small-scale variability was observed.

Fe accumulation pathways in sea ice

No relationship between *Fe* and ice texture has ever been observed (based on data from SIPEX, SIMBA, ARISE and ISPOL). Iron and POC/DOC are accumulated in frazil and columnar ice. Mechanistic entrapment of *Fe* and organic matter occurs via convection, diffusion, wave-field pumping, etc.

Is EPS of allochtonous or autotochtonous origin? *Fe* would rather be accumulated with detrital organic matter.

Iron Sources and Sinks

Sources – Atmospheric iron deposition to Antarctic surface waters is negligible. Upwelling and shelf advection are the main sources of *Fe* to Antarctic surface waters. Therefore, the main source of *Fe* to sea ice is from below. SIMBA has strong *Fe* advection from the continental shelf. On SIPEX, we also observe advection from the continental shelf, mainly of particulate origin at the land-fast ice site. When the ice formed in winter, SIPEX received new *Fe* supply rather than regenerated *Fe*. The differences in *Fe* sources (that is new *Fe* input from upwelling and/or continental shelf plus regenerated *Fe*) will explain the inter-annual/spatial/seasonal variability.

Sinks – 70% of the d*Fe* is released from ice melting in a short-time period while the ice cover is still present and prevents the deepening of the wind mixed layer. The *Fe* and sea ice algae released from sea ice melt induce the large seasonal ice blooms observed from satellites.

1B Datasets Acquired

SIMBA is a seasonal plus spatial (5 stations) study, while SIPEX is a seasonal plus large scale spatial survey (15 stations).

Thermodynamics from the *Fe* sites

- **SIPEX**: At the trace metal sites the sea ice thickness ranged between 35 and 126 cm, mostly newly formed ice. Snow thickness ranged from 2 to 30 cm. Most of the stations had typical frazil underlain by columnar ice. A couple of stations indicated rafting. In situ ice temperatures and calculated brine volume fractions (Vb/V) indicate a transition from the winter (stations 1, 3 and 5 exhibit Vb/V <5%) to the spring season (stations 11 to 14 have Vb/V >5% along the whole cores).

- **SIMBA**: The ice cover was older and thicker than SIPEX. Snow thickness was 10 to 30 cm. The ice texture indicates a complex sequence of events, probably involving rafting. The Liege site was very flooded, mainly granular and rafted, while the Brussels site was mainly columnar (see Figure 3 for site details). The temperature and Vb/V indicate successive flood/freeze processes. There was evidence of brine tubes along entire cores and "rotten" bottom ice.

Biological parameters (i.e. Chla, POC and EPS)

- **SIPEX**: Overall, SIPEX had low Chla, low POC when the ice was cold and Vb/V <5% (first 3 stations). As the ice temperature increased and Vb/V >5% along the whole cores, we observed L shaped profiles with high Chla, high POC and high EPS in the bottom of the ice. This algal development is nevertheless restricted to a thin bio-film about 1cm thick. The maximum Chla value observed is 17µg/litre.
- **SIMBA**: Chla, EPS and POC were higher than on SIPEX, and profiles were reversed when compared to SIPEX. There was higher biomass in the surface of the ice, probably due to macro-nutrients input from flooding events. At the Liege site the large brine tubes probably allowed transfer of POC from the surface towards the lower section. At the Brussels site there was a small C-shaped POC profile.

Iron (*Fe*) and macro-nutrients

- **SIPEX**: Dissolved *Fe* concentrations were, on average, 2.4 nmol/litre and range from 0.23 to 14.4 nmol/litre. d*Fe* concentrations in sea ice were C-shaped and decreased as spring arrived. d*Fe* concentration then averaged 0.52 nmol/litre in the bottom ice at the high Chla sites. Such low d*Fe* levels could limit the growth of large diatoms. Dinoflagellates could therefore be favored. The d*Fe* drawdown coincides with higher Vb/V, Chla, POC and EPS. Therefore, although ice cores were sampled at different locations seasonal forcing (i.e. ice permeability, based on brine volume fraction) drives the *Fe* and biomass distribution in sea ice.
- **SIMBA**: d*Fe* data averaged 6 nmol/litre (> SIPEX) and ranged from 5 to 30 nmol/litre d*Fe*. d*Fe* profiles were C-shaped. This is about 1 to 2 orders of magnitude higher than in the water column below (seawater is around 0.5 nmol/litre d*Fe*). The d*Fe* and organic matter distribution from SIMBA may have been strongly influenced by the flood/freeze cycles.

1B Key Questions

- Is Carbon export from sea ice really negligible compared to the Carbon export of the rest of the Southern Ocean?
- Will changes in the thermohaline circulation lead to changes in equatorial heat fluxes; will this result in more sea ice or less?
- Rather than supplying new iron to Antarctic surface waters, does sea ice act as a storage reservoir that accumulates new and regenerated *Fe* in fall/winter and release it in spring?

1B Potential Deep Sea Research-II Papers

- Masson et al.: Spatial iron distribution from SIMBA

- Masson et al.: Effects of organic ligands on iron bioavailability to pelagic and sympagic communities in the Bellingshausen Sea

- Lannuzel et al.: Iron sources and sinks from the East Antarctic sea ice SIPEX survey

1B Other Potential Papers

- Schoemann et al., The role of organic matter in the accumulation of *Fe* in sea ice

- Van der Merwe et al., Iron-organic matter-EPS coupling in the East Antarctic sea ice sector (to be submitted before June 2009)

- Dumont et al., Distribution, chemical characterization and lability of organic matter in the Antarctic pack ice zone, Bellingshausen Sea.

- De Jong, J.T.M et al., Iron sources in the Western Bellingshausen Sea during SIMBA

Session 2A: Physics/Biomass

Chair: Klaus Meiners
Rapporteur: Delphine Lannuzel

2A General Discussion

Main topics

- Problem of up-scaling in situ data to a larger scale (Martin Vancoppenolle)
- Seasonality: the impact of physics on biology. The variability in temperature, salinity (and Vb/V) and light and their relationship with biomass remain an open field of research
- Physical processes affecting vertical distribution of biota versus integrated values

Presentation: Maike Kramer
Relationships between abundance and biomass of meiofauna (metazoan) to physical parameters. Comparison of two areas with generally different sea ice types:

Winter 2006 (ANT XXIII-7)	Early spring 2007 (SIPEX)
Western Weddell	East Antarctica
Occurrence of MYI around	Only FYI
High (integrated) abundance of copepods and other meiofauna	Low abundance of copepods and other meiofauna
High biological diversity	Low biological diversity

Meiofauna at SIPEX and ANT XXIII-7 (a German cruise) are very different. Ongoing research will determine which physical parameters are driving these differences: e.g. Vb/V (restricted space in the brine pockets/channels may restrict meiofauna colonisation), light or temperature?

Winter 2006 (ANT XXIII-7) – Vertical distribution: Meiofauna was mainly restricted to warm ice.
Early spring 2007 (SIPEX) – Vertical distribution: Heterotrophic organisms did not follow temperature trend while Chlorophyll *a* was mainly restricted to warm ice. Ice temperature does not seem to explain the differences in meiofauna vertical distribution observed in the two study regions. By integrating biomass data, we lose some information on where the meiofauna are sitting. It might be good to just look at the bottom community which actually gives a similar picture for both cruises. Copepods can be living either within the ice or at the ice/water interface depending on species and life-cycle stage. Copepod life-cycle can be linked to the seasonal cycle of the ice. A lot more dinoflagellates were observed on SIPEX as compared to WWOS in the Weddell Sea.

Presentation: Chris Fritsen
SIMBA: Time-integrated PAR can be indicative of inter-annual variability. The SIMBA study showed average nutrient depletion in sea ice samples relative to seawater. Silicate depletion at Liege (SIMBA) results in a high abundance of dinoflagellates. The bottom community was not very well developed at Brussels (SIMBA) and was also silicate depleted. Could dinoflagellates thrive because diatoms are not favoured due to silicate limitation? Also note that dinoflagellates are overwintering species. It is important to decipher between auto- and heterotrophy dinoflagellates in these samples (in progress). Nitrate concentrations were depleted in sea ice samples (throughout the entire ice thickness). Ammonia was enriched in almost all ice samples. Average diatom bio-volume is yet to be determined (in

progress). Liege showed average slush community composition: Dinoflagellates were massively abundant there due to flooding of seawater and input of nutrients. High concentrations of Phaeocystis spec. were coupled to a strong DMSp signal from that surface community.

Surface flooding seemed to occur from below rather than from the side (also sampling area located in the middle of the floe). Nutrients are on the dilution curve in the bottom of the ice, but either above or below in the top/inner ice. This is likely due to consecutive warming and freezing processes.

SIPEX: There is a drawdown of nutrients (macro and d*Fe*) as the season evolves (warm stations). Bottom ice nutrients are overall on the dilution curve indicating constant (re)-supply of nutrients due to the proximity to the water column. Cold (winter) stations do not exhibit depletion of nutrients in the inner ice, most probably due to the lack of nutrient uptake by autotrophs.

Thoughts on solar radiation
As PAR accumulates, micro-habitats start being active and get into disequilibria (i.e. nutrient depletion, Vb/V increase, grazing, etc.). We need to look closely at PAR/nutrient relationships. We also need to assess how the variation in light availability, ice thickness, nutrients and other factors influence carbon budgets. So far, no obvious correlation between ice/snow thickness and ice algal biomass has been observed in Antarctic pack ice, which is probably due to high re-distribution of snow on sea ice.

2A Recommendations for Future Work

How to get around the small-scale patchiness problem?
Use of ROVs/AUVs instrumented with upward looking sonars and radiometers will allow determination of integrated biomass along transects.

Do we have enough data to integrate the small-scale data to the large-scale?
There is a strong need to build a data base with parameters such as temperature, salinity, PAR, ice thickness, and integrated (and vertical if available) distribution of biomass (Chlorophyll a concentration). Minimum information should include:

- Time, position, ice thickness, snow depth, chlorophyll a (mg m^2)
- Strong recommendation to report ASPeCt ice class during sampling (future studies)

Data assimilation projects (and key people):

- Pre-1998 data, WWOS, ISPOL (Gerhard Dieckmann, AWI)
- SO-GLOBEC (Chris Fritsen, DRI)
- US - Ross Sea cruises (Kevin Arrigo, Stanford; Michael Lizotte, UW Oshkosh; Dave Garrison, NSF)
- ODEN cruises (Patricia Yager, University of Georgia)
- SIMBA (Jean-Louis Tison, ULB; Chris Fritsen, DRI)
- East Antarctica (Andrew McMinn, UTas; Kerrie Swadling, UTas; Klaus Meiners, ACE CRC)

There is a need to include fast ice data into this database and to extend data mining efforts to Japan, France, Italy, USA, and NZ.

Encourage authors to make data e-available, engage with community (SCAR, APECS) and ask research community to report ASPeCt ice class during sampling.

The summer period might not be the best period to assess biomass in sea ice, due to sampling issues. Most of the biomass (up to 90%, even in warm ice (Becquevort et al., 2009) remain adsorbed to the surface of the brine channels and is therefore underestimated in conventional brine sampling.
Sea ice is seasonally changing and must be considered as an open, as well as a closed system depending on ice temperature.

Session 2B: Remote Sensing Altimetry

Chair: Katharine Giles
Rapporteur: Thorsten Markus

2B General Discussion

Algorithms: Differences between Arctic and Antarctic sea ice? Are the same assumptions valid?
Discussion focused on whether the assumption that the ice freeboard is zero holds for the entire season? Comparison of AMSR-E snow depth and ICESat freeboards indicates that this assumption does not hold. However, there is an argument for the validity of this assumption from observations in the field and comparison of ICESat ice thickness derived using this technique. It was noted that there was a bias towards in situ measurements over thinner ice in the field – with few transects over big ridges. No clear conclusion to this discussion, indicating the need for further field research.

Field data have shown that for buoyancy equation for a two layer model (snow layer and sea ice layer), using a bulk snow density of 300 kg m^3 does not hold for flooded Antarctic sea ice because of the variation in density of the slush layer. It does hold over ice with no slush layer. The presence of slush layer will also alter the bulk density of the overlying snow and this should also be taken into consideration when calculating ice thickness.

Comparison of AMSR-E snow depth and ICESat freeboards: for late winter 20% of the data show a snow depth close to the freeboard. This percentage changes with season (it is smaller at the beginning of winter). Overestimates in AMSR-E snow depth could be a result of wetness/flooding, slush layer. There is also a scaling issue here (i.e. AMSR-E is integrating over a larger area than ICESat); therefore you cannot directly compare them.

Comparisons with in situ and airborne data – Strategies for comparison
Extrapolation of in situ data using ice drift information can be used to expand the data set in time.

Airborne helicopter data will be used for validation of ICESat. There is potential to also use this data to validate Envisat.

What other data sets are needed to derive ice thickness from satellites?

- Snow depth
- Snow characteristics (i.e. wetness)
- Ice concentration
- Ocean surface elevation
- Density (ice, snow, water)

Combining ICESat and Envisat
What can this tell us about the snow properties? Can it tell us if the ice is flooded?

Combination of ICESat with ERS data show some promise in extracting snow depth. However, if the snow is flooded we expect the radar return to originate from the air/snow interface; therefore comparison of elevations derived from the two instruments may be able to identify large areas of flooded snow.

2B Recommendations for Future Work

- Upward looking sonars
- Auto-sub (range several hundred kilometres)
- Bottom pressure data
- Airborne electromagnetic induction
- Make many radar/laser measurements together with measurements of snow characteristics over the same area to monitor temporal evolution
- Drilled ice thicknesses are likely underestimates of the average sea ice thickness because of the avoidance of ridges; similar issues may be true for the ASPeCt data; there is a maximum thickness for the monitoring of tipped floes
- Need to better understand from where within the snow layer the return signal of radar measurements is coming from:
    - Future radar measurements
    - Isolation of snow features
    - Extending frequency range
    - Different geographic locations
    - Address scaling issues
- Snow and ice variability over ICESat footprints? Drilled measurements

2B Potential Deep-Sea Research-II Papers

- Lieser, Worby, Massom and Yi, SIPEX laser altimeter/ICESat paper
- Ozsoy-Cicek: SIMBA ICESat paper

Session 2C: Sea Ice Drift and Deformation

Chair: Petra Heil
Rapporteur: Cathy Geiger

2C General Discussion

2007 Buoy Deployments

Buoy deployments during SIPEX 2007

- 2 deformation arrays were deployed, one near 128ºE, the other near 118ºE (see Figure 5).
- Deployment of the eastern buoy array was on 12th September 2007, and of the western array on 30th September 2007
- The eastern array consisted of 1 MetOcean buoy (with air temperature and pressure), and 4 Clearsat buoys. Four buoys were deployed in a square with 30km sides with the fifth buoy placed in the center of the array. One of the Clearsat buoys did not report good data, despite operating well during calibration at Kingston and testing on the *Aurora Australis*
- The western array consisted of 1 MetOcean buoy (with air pressure and temperature), and 3 Clearsat buoys. The buoys were deployed in an equal sided triangle with 30km sides with the fourth buoy (MetOcean) placed in the center of the array. It was originally intended that a fifth buoy would also be deployed in this array, and that the configuration would be the same as the eastern array, however one battery poor battery cycling behaviour and was not deployed

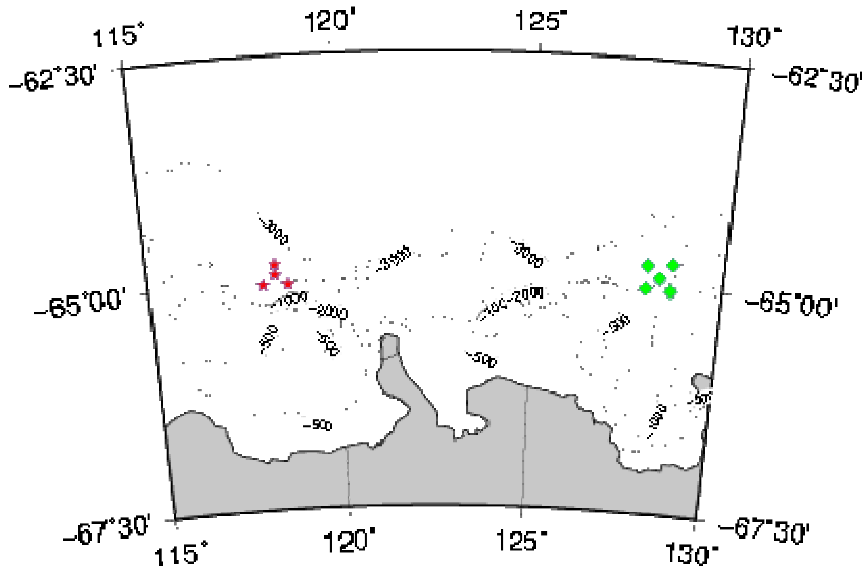

Figure 1: SIPEX 2007 buoy deployment locations, with the eastern array shown by green diamonds (5 buoys) and the western array shown by red stars (4 buoys). By the time the western array was deployed, the eastern array had drifted west of 125°E.

- The first of the SIPEX buoys stopped transmitting in November 2007. The last one stopped in February 2008
- The buoys all moved westward in the coastal current. The eastern array sheared due the strong oceanic jet associated with the shelf break
- 2 stress-gauge buoys were scheduled for deployment on SIPEX but were not completed in time

Data analysis for ice dynamics is underway. Velocity and deformation profiles have been derived. The contact person for SIPEX buoy information is Petra Heil.

Buoy deployments during SIMBA 2007

- 2 mass-balance buoys on the floe of the SIMBA ice station
- 2 IRIDIUM buoys (in about 10nm distance) reported intermittently
- Deployments were carried out at end of September 2007
- Mass-balance buoys ceased transmissions early December 2007
- IRIDIUM buoys ceased transmissions May 2008
- Buoys moved in clockwise circle around Peters Island

Data analysis for ice dynamics has not yet commenced. The contact person for SIMBA buoy information is Steve Ackley.

BAS buoy deployments during March 2007

IRIDIUM buoys were deployed on multi-year ice floes in March 2007 during the 'Forcings from the Ocean, Clouds, Atmosphere and Sea-ice' (ACES-FOCAS) cruise. The buoys moved eastward along the coast, covering about 30º longitude in 22 months

- 1 IRIDIUM buoy ceased transmissions soon after deployment
- 5 IRIDIUM buoys ceased transmissions January 2009

The contact person for BAS buoys is Ted Maksym.

Buoy developments

To address scientific questions regarding sea-ice drift and deformation and the parameterization of sea ice within numerical models, buoy deployments in the Antarctic sea-ice region need to be maintained (at a minimum), or increased. There is also a need to advance our measurement capabilities to capture additional data. This following summarizes relevant developments in drifting sea-ice buoys:

- Scottish Association for Marine Science (SAMS): Mass-balance buoy consisting of a temperature string (hotwire)
- GBP2000 (flatpack "do it yourself"): GPS, IRIDIUM.
- Additional sensors (i.e. for meteorological data) are being developed.
- Jenny Hutchings (IARC): GPS barrels.
- AAD: Stress-gauge buoys, mass-balance stations.

International Arctic Buoy Program (IABP) to expand to Southern Hemisphere

Sharon Stammerjohn reports that Ignatius Rigor enquired about current Southern Hemisphere buoy deployments. There might be a move to push for a Southern Hemisphere expansion of the International Arctic Buoy Program (IABP). The group recommended that Ignatius should contact Christian Haas who is the current coordinator of the International Program for Antarctic Buoys (IPAB). (Post meeting note: Petra Heil, who is a member of the IPAB Committee has done so).

Floe-size distribution from video camera
Results were presented based on data from the Sea of Okhotsk, WWOS (Weddell Sea, 2006) and SIPEX by Takenobu Toyota.

2C Key Questions

- What are the scaling laws for Antarctic sea-ice deformation?
- What is the net freshwater flux due to ice advection?
- Can we use the buoy data to determine the ice strength?

2C Potential Deep-Sea Research-II Papers

- Ted, Sharon and others will work on an overview paper for DSR-II of the regional ice drift derived from ACE-FOCAS and from BeARS buoys.

- SIPEX sea-ice dynamics derived from in situ buoys by Petra and others.

- Modern East Antarctic sea-ice dynamics (from remotely sensed data and buoys) in the context of atmospheric forcing, by Petra, Rob and many others.

- Possibly a manuscript on floe-size distribution by Takenobu.

Session 3A: Ice Physics and Tracers Dynamics

Chair: Jean-Louis Tison
Rapporteur: Patricia Yager

3A General Discussion

The "wish list" established during the introductory plenary session is as follows:

- Discuss the transfer processes of tracers within the sea ice cover and at the various interfaces: ocean-ice-snow-atmosphere
- Discuss the links between tracer distribution and physical processes and forcing (physics from the perspective a gas molecule)
- Compare data obtained under similar conditions of forcing (if these are available for the SIPEX-SIMBA cruise and eventually other cruises: ARISE 2003, ISPOL 2004, ODEN 2008)
- Look at temporal and spatial variability, both small and large scale
- Discuss the potential complexity of up-scaling observed small scale variability to a representative large scale model "grid point"

As an introduction to this session, Jean-Louis Tison attempted to clarify the basics:
What do we mean by tracers?
What are the potential important physical forcings?

Tracers can be present in one of three physical states: dissolved (Nutrients, DOM, O_2, N_2, CO_2, Ar, CH_4, DM(S,O,P), particulate (POM, Iron, $CaCO_3$, DMSP) and gaseous (O_2, N_2, CO_2, Ar, CH_4, DMS), and these will be differently affected by the physical parameters of the sea ice cover. The primary physical variables are temperature, salinity, snow cover, ice texture, and wind. Derived variables include brine salinity (f(temp)), brine volume (f(T,S)), brine stability (f(brine salinity)), and ice permeability (f(brine volume)).

To foster the discussion, Tison presented a list of connected physical forcings and outlined how each changed along a hypothesized time series of data collected from recent ice stations. Early season sites (e.g., SIPEX, ARISE data; with left-leaning temperature profiles) experience warming of a very cold surface (and warmer base) to a near vertical temperature profile (isothermal). This change leads to unstable brine with nutrient concentrations falling along a dilution line and supersaturated pCO_2 potentially trapped by impermeability. Additional warming increases the permeability above the 5% threshold, allowing an initial outward flux of CO_2. The CO_2 flux quickly reverses (to inward) with the initiation of brine dilution, calcium carbonate dissolution, and biological uptake. As the summer season progresses (e.g. ISPOL, Oden08 data), warming proceeds, potentially right-tipping the temperature profile to warmer surface layers, stabilizing the brine, increasing the under-saturation status with respect to pCO_2, and causing diffusion rather than convection to control carbon flux. During this time, nutrients can become depleted relative to the dilution line of the brine, and iron concentration, for example, stabilizes after an initial depletion. Air temperature cycling (e.g. the cooling-warming events observed at SIMBA) can cause flood-freeze events, when the temperature profile can temporarily reverse to left-leaning, destabilizing brine and convecting nutrients so that concentrations fall above or below the dilution curve. Brine pCO_2 cycles with these events, driving an inward pCO_2 flux of variable intensity, partially affected by the replenishment from flooding. DMS(P) cycling also occurs, with DMSP building up in the surface layers, and then being released to the underlying water as brine tubes “eat” their way through the warmer (sometimes isothermal) lower half of the sea ice cover. Upon fall refreeze (or during a new ice formation event on leads such as at the SIMBA Frost Flower site), brine becomes very unstable, with the possibility of zero or outward CO_2 flux and the occasional buildup of excess Ca^{2+} within the sea ice.

Finally, to illustrate both the importance and the complexity of decoupling dissolved, particulate and gaseous compounds in the tracers transfer process, Tison discussed the so-called $CaCO_3$ sea ice pump mechanism and how the efficiency of this carbon pump is related to the potential decoupling of the particulate calcium carbonate from the dissolved/gaseous CO_2.

The discussion part of the session went along three major threads:

- The comparison of small scale chamber vs. large scale tower measurements of carbon dioxide fluxes at SIMBA
- Biotic versus abiotic controls on the ice pCO_2
- What are the nutrients doing in relation to the different physical regimes?

Flux comparisons: A key part of our discussion focused on a comparison between the flux tower data (which integrates CO_2 fluxes over larger spatial scales (~200-400m upwind), smaller scale ice/air interface chamber data, and pCO_2 profiles in the ice cores. Some intercalibration between these methods is going on, but results may take longer than the DSR timeline. Tim Papakyriakou’s flux tower at SIMBA observed an outgassing event (Oct 7) associated with a storm that dropped air temperature and increased windspeed. Two weeks later, another storm led to a temperature rise, increased wind speed, and pCO_2 uptake by the ice. When the atmospheric shear stress peaks, turbulence is the primary transport mechanism that brings about significant non-zero fluxes. Comparing these with the ice/atmosphere chamber data has put the emphasis on totally new perspectives. The chamber fluxes were indeed very moderate throughout the observation period, although they show a very good correlation to the pCO_2 fluctuations within the ice. There was no major degassing event observed, and a large influx was detected by the chamber several days before it was detected in the tower measurements. This, compared with the fact that chamber measurements over snow did not show any fluxes, suggests that the snow cover acts as a capacitor blanket that only releases its information during high wind events, presumably because of wind pumping. CO_2 retention on surfaces of ice crystals and ice powder in crushing techniques is also a documented effect. Also, tower measurements might document episodic pCO_2 outgassing effects during flood-freezing cycles that the chamber measurements do not capture.

Abiotic controls: Temperature directly controls CO_2 fluxes from the ice via permeability, but could also influence indirectly via biology. Key to cycling seems to be the control of the brine volume by changes in temperature, but questions remain as to the relative rates of physico-chemical and biological changes. The relative contributions of convection and diffusion are unknown. It is also unknown whether the gas phase behaves differently from the liquid/dissolved phase. The flood/freeze cycle seems to be a critical driver for transport within and out of the ice.

Nutrient changes in the ice: It was discussed whether we could infer open system behaviour when the nutrients remained on the sea water dilution line (and therefore a closed system when they deviated), but then some questions were raised as to whether the theoretical dilution line itself could be pinned down well enough (what are the seawater and freshwater end members?).

Direct SIPEX-SIMBA-Oden comparisons: The SIPEX cruise didn't measure CO_2. DMSP might however provide some links between the three projects. No information was available at this stage from the SIPEX (or Oden) DMSx measurements and intercomparison may have to occur after the DSR deadline. Another difficulty in comparing SIPEX and Oden to SIMBA's data is the fact that the first two more captured the spatial variability (although they had a temporal signatures too), while the latter was more process oriented at a given location.

Session 3B: Sea Ice Geophysics

Chair: Tony Worby
Rapporteur: Blake Weissling

3B General Discussion

Spatial and Temporal Geophysical Characterization of Early Spring Sea Ice – Bellingshausen Sea 2007

Synopsis
A time-series geophysical characterization of first year and multiyear sea ice along transects at Ice Drift Station Belgica during SIMBA was presented to a sea ice workshop breakout group of approximately 25 people. The discussion of the time series results were presented in the context of four framing questions:

1. Can we effectively interpolate a reasonable ice thickness profile from EMI (electromagnetic induction) ice thickness assessments?
2. Is the snow surface morphology coupled to the underlying ice surface morphology (spatially and temporally)?
3. Is snow loading/redistribution and/or snow ice formation contributing to ice surface self-leveling?
4. Is snow surface elevation a proxy for snow depth?

1. Can we effectively interpolate a reasonable ice thickness profile from EMI (electromagnetic induction) ice thickness assessments?
One transect was drilled at Fabra (see Figure 3 for site details) for ice thickness on a 5 m sampling interval (n=60). This same line was also sampled for EMI thickness on a 2.5 m interval with snow depth and surface elevation sampled at a 1 m interval. A profile of the ice transect was presented to the group depicting snow surface (elevation), top of ice surface (freeboard line), and both EM and augur-derived ice bottom. Though the EM and augured ice thicknesses were in good agreement in thin (<1.0 m thick) level ice, the EM consistently underestimated in thicker (>1.5 m) deformed ice. Two linear equations were fitted to the correlation scatter plot with a breakpoint occurring at approximately 2.3 m (total snow plus ice thickness). A synthetic (modelled) ice thickness was generated and subsequently compared to the EM and augured thicknesses. Discussion centered around the following points.

- Could a physical meaning be ascribed to the apparent shape and trend of the correlation of the EM and augured ice thicknesses?
- Could synthetic modelling tease out the role of the EM footprint averaging effect and ice bottom conductivity changes (high brine volume ice blocks with intervening sea water) in the underestimation problem associated with the ridge keels?

Conclusion was that modelling of the footprint and conductivity physics would probably not lead to any spatially and temporally generalized interpolation equation (considering time and effort) but that empirical results for specific time and place (e.g. Bellingshausen Sea, late winter) might suffice.

2. Is the snow surface morphology coupled to the underlying ice surface morphology (spatially and temporally)?
Correlation scatterplots of snow surface elevation and underlying ice surface elevation were presented of Fabra site Line 1 during time series A, B, and C. Correlations were poor (R^2 <0.10) and suggested an uncoupled snow/ice surface that deteriorated with time (series A to C). The ensuing discussion was

centered around the role of re-distribution of snow from storm and wind events. The point was made that an uncoupled surface is problematic for the use of sea ice thickness interpolation schemes from snow surface morphology and elevation (e.g. ASPeCt buoyancy scheme).

3. Is snow loading/redistribution and/or snow ice formation contributing to ice surface self-leveling?

The redistribution of snow load leading to isostatic readjustment of the ice surface, the formation of sea ice from flooded (negative freeboard) ice surface, and survey error were discussed as potential explanations of an increasingly level and smooth ice surface in the Fabra time series transects. An examination of the variance for the composite of all freeboard measurements for the time series yielded a drop in variance (actually standard deviation) of approximately 40% from series A to C, spanning 21 days. The suggestion that operator error (error in surveying same location) could have contributed to the change in ice freeboard surface was considered unlikely due to the fact that increase in error adds to variance, as opposed to reducing it. Correlation scatter plots were displayed of changes in snow depth vs. freeboard for line 1 from series A to B, and B to C. Both plots yielded linear trend lines with R^2 values of 0.69 to 0.71. The highly significant statistical correlation suggests that snow load redistribution is driving some isostatic movement of ice blocks down into the ice pack. This idea generated some lively discussion as to the physics behind the independent movement of ice blocks back into the pack due to localized snow loading. For some in the group it turned out to be a hard concept to accept, unless the ice comprising the deformed part of the pack was primarily unconsolidated. The contribution of refreezing slush was also discussed as a self-leveling mechanism, although it was unclear how this phenomenon alone could generate the high correlation of delta snow depth to delta freeboard. All agreed that the leveling phenomena is worthy of more analysis.

4. Is snow surface elevation a proxy for snow depth?

Time remaining in the session did not allow discussion of the last question in the context of the Fabra geophysics. It is possible that snow ice formation in many areas of the Antarctic pack mean that this relation may be valid at times, but this is complicated by areas of deformation, which are ubiquitous in Antarctica. However, it was agreed this is a very important topic for future research.

Session 4A: Remote Sensing General

Chair: Thorsten Markus
Rapporteur: Katharine Giles

4A General Discussion

What remotely sensed data is required by the SIMBA and SIPEX participants?

Data

- Albedo (MODIS, aerial photography)
- Surface temperature (MODIS)
- Sea ice concentration (MODIS, AMSR)
- Snow depth (AMSR)
- Sea ice elevation, freeboard (ICESat, Envisat)
- Sea ice drift (AMSR)
- Thin ice thickness (MODIS)
- Surface roughness (ICESat, aerial photography)
- Ice roughness (QuikSCAT)
- Ice type (QuikSCAT, MODIS, AMSR)

Future data sets

Lagrangian ice motion data

Seymour Laxon could probably get ESA to process the Antarctic ASAR data through their Arctic processor. However, he would need to get the buoy drifts in Antarctic to validate it. The GLOBICE project has proved the concept with ESA, and it has been verified using Arctic buoys. He may be able to run it on the prototype system at UCL. A publication of this verification would be good, but won't meet 31st October deadline (daily resolution is required).

Flooded areas from space

There is potential for a pre-study for retrieving flooded ice areas from space (a first look paper in DSR) and comparing in situ and remote data. Lytle and Golden have already done this in the Weddell Sea, so this work could be compared to the SIMBA and SIPEX areas. Tony Worby published a paper on backscatter changes with regards to retrieving flooded areas in 2008.

It is not clear who would take the lead on this. Could this question be folded into one of the other papers i.e. in the introduction in one of the papers – could be useful in terms of future proposals.

For example: Is ice concentration biased by ice flooding? These questions could be addressed in DSR. Mike Lewis noted that flooding affects brightness data (AMSR-E data). But in the first look in the SIMBA data he did not see this drop. He thinks this has something to do with the 12.5km averaging.

Location of data

- **SIMBA**: 66ºS, 74ºS, 110ºW, 60ºW, September – December 2007
- **SIPEX**: 58ºS, 68ºS, 110ºE, 140ºE, September – October 2007

Where the data could be stored: possibly the SIPEX website (www.sipex.aq) or the ASPeCt website (www.aspect.aq).

Documentation
It is important to have comments on the uncertainties of the data, how to use it, caveats, etc. NSIDC does this for its data, so some of this documentation can be copied. It is also important to attach a lead publication and/or reference.

Format
Ascii text: lat, lon, variable, or for ice motion lat_start, lon_start, lat_end, lon_end.

4A Datasets Acquired

What data are available from SIPEX and SIMBA?

Meta-Data

- SIPEX meta-data: Google Earth has all the meta-data (see details on page 7). Individual data sets can be requested from Tony Worby or any other member of the Australian sea ice group
- SIMBA meta-data: Go to http://www.utsa.edu/lrsg/Antarctica/SIMBA. Project descriptions and an event log are available, with meta data to follow

Value Added Data
There is a plan to do this. The ACE CRC website has a products link so they already have the facility and would be able to host products.

Sea ice data set at AADC (Australian Antarctic Data Centre) – this is now up and running and people can contribute data directly online. What is the process for corrections to or additions to data?
The data should be submitted first time straight to the data centre. If updating there may be more human interaction but Tony Worby will look into this. There are some teething problems with the data centre i.e. file names not bearing a relation to the ice station.

4A Key Questions

- If there is coherency for the issue then it will make it better, i.e., if there are numerous papers centered on some key issues it makes it more appealing.
- What are the key similarities and differences between the remote sensing products and field observations? (how many papers would come out of those questions?)
- What is the relative importance of dynamic vs. thermodynamic thickening?
- SIPEX field experiments have resulted in lots of airborne laser altimetry data that is not coincident with satellite data. Consequently there is a need to look at the scales on which we should be comparing the field and satellite data. Over what temporal and spatial scales is it reasonable to average the data? The drifting buoy data might be useful for correcting the location of in situ data with respect to the satellite data.

Session 4B: CO_2/pCO_2

Chair: Tish Yager
Rapporteur: Lisa Miller

4B General Discussion

Key words: physical and biological controls, species variability, community structure, micro-environments, physical habitats, seasonality, rates versus biomass

This session ended up being a continuation of the larger physics/tracers session, but focused entirely on CO_2.

We discussed CO_2 fluxes measured by eddy-flux towers (which integrate over a larger (200-400m) scale) versus chamber (small (<1m) scale) fluxes.

- *Outcome*: Spring/summer transition in the Arctic (seen by flux tower) is very similar to what is seen in the Antarctic spring/summer at SIMBA. Fluxes appear to be sensitive to temperature/salinity and brine fraction. A spring/summer pCO_2 sink in the sea ice is probably linked to net autotrophy.

We discussed the capacitor role of the snow cover (i.e., how it can modulate the CO_2 flux by damping strong CO_2 gradients in the ice unless the winds/turbulence is very strong). This is a recent revelation. We also discussed the importance of the saline snow found in the Antarctic (snow ice) and how this alters the possibilities for CO_2 flux mechanisms. Note that this is still a hypothesis, and no actual data are available.

We discussed possibilities for the annual CO_2 flux balance, primarily when and how CO_2 can come out of the ice and how this compares to the drawdown in the spring/summer.

- *Outcome*: Preliminary estimates suggest that there may be a net annual balance between uptake and outgassing, but we probably don't have enough data for this conclusion yet (no fall data, and the rest of the year is patched together from different experiments in different years and in different places). Any net drawdown would have to involve carbon export from the ice in the form of DIC, solid $CaCO_3$, or organic carbon to the surface waters below. Freeze/flooding cycles may offer a means for exporting carbon to the underlying waters.
- *Outcome*: The frost flower situation on SIMBA may offer our first look at the processes involved with fall freeze up.

We discussed the role of biology on top of the physical signal and whether we can tease them apart. Main controls include temperature, wind, light, photosynthesis and respiration, and flooding events. Since the physical processes in ice are not entirely understood, differentiating will depend on our ability to measure biological rates in the ice, and there is concern that melting of the ice (in order to apply oceanographic methods) could be problematic. Still, rate measurements are rare and may be a key contribution of the Oden '08 expedition.

With the above understanding, we got back to discussing physical drivers over the winter. Is there any efflux in winter? Arctic winter data suggest that it may be possible, but we have no Antarctic data. Early spring data suggests that something has already been happening since winter.

Based on some methods comparisons done at CFL and SIMBA, there will be an inter-calibration between pCO_2 in the ice measured by peepers and using a flow-through system in sack holes.

We briefly discussed the role of particulate inorganic carbon in the process, specifically how $CaCO_3$ precipitation and dissolution in the ice or in the seawater below could influence the pCO_2 flux. It seems that $CaCO_3$ forms, as ikaite, at high temperatures (> -5ºC) in newly forming sea ice. We also briefly discussed Gerhard Dieckmann and Stathys Papadimitriou's hypothesis that ikaite can form particularly in surface ice under conditions of active biological drawdown. Its export to the ocean is uncertain. It is also uncertain how readily ikaite re-dissolves in melting sea ice.

4B Potential Deep Sea Research-II Papers

- One CO_2 flux paper (the title is already submitted to Tony) will be written by a student of Bruno DeLille (Nix).

- Other papers are unlikely to be ready before the October deadline, although there is a possibility that a paper comparing Oden data to other sea ice fieldwork may come together in time. The Oden workshop in September will likely determine that.

4B Other Potential Papers

- There is interest in a synthesis paper that uses existing field programs to hypothesize the seasonal cycle of CO_2 fluxes. The lack of CO_2 data from SIPEX makes comparisons between SIMBA and SIPEX difficult; however the Oden data may provide some insights.

Session 4C: Bio-Optics

Chair: Chris Fritsen
Rapporteur: Chris Fritsen

4C General Discussion

Both SIMBA and SIPEX had very similar and thus comparable sea ice optics activities. Both included a suite of measures aimed at the assessment of the spectral transmission and absorption of solar radiation in sea ice and how this is affected by sea ice particulate material (including ice algae). As a result of this work an additional aim was to use the spectral transmission information to make some assessments of the spatial distribution of ice algae at select locations as well as the potential tracking of the development of ice algal biomass over time (at SIMBA ice mass balance buoys: IMBs).

Specific measures that were made included the following:

- Incident PAR time series (both ship-based sensors)
- Incident spectral irradiance (UV-PAR), upwelling spectral irradiance (UV-PAR), & Transmitted Spectral radiation (UV-PAR) using radiometers deployed on under ice articulated arms. These combined measures allow calculations of spectral albedos and attenuation coefficients to be derived for both ice and snow
- Particulate absorption spectra (ap(λ)) on particulates collected from ice cores were taken from where transmitted irradiances were measured. These were also treated to derive the absorption by detritus and microalgae. In addition to Chla and microscopy based biomass samples being collected/determined on cores from both cruises algal pigments (via HPLC) were also determined on SIPEX particulate material
- The spectral absorption characteristics of the Chromophoric dissolved organic matter (CDOM) was also evaluated on SIPEX
- The spatial variability of the under ice spectral irradiances were evaluated on both SIMBA and SIPEX. On SIPEX irradiances were measured by deploying the radiometer close to ice and snow thickness lines (100+ meters) using an ROV. On SIMBA, the small-scale variability (within ~3m) was assessed by rotating the articulated arm over a 180ºarc. These optical measures were conducted at three sites at SIMBA corresponding to the Brussels and Liege sites as well as near the ship
- An under-ice radiometer with four spectral bands was deployed on the IMB buoy near the Brussels location on the SIMBA cruise and provides a time series of under ice irradiances at this location. Data from ARGOS still need to be processed to make this time-series complete

Highlights of the discussion included the analysis of the spectral ratios approach and the significant correlations gained (~0.7) between these under-ice irradiances ratios and Chla measured in ice cores (SIPEX analysis). The ratios analysis on the SIMBA IMB radiometer time series was discussed. The radiometer clearly shows reductions in under-ice irradiances- that are primarily associated with snow deposition/accumulation. It remains unclear if the time series may indicate or detect any changes in sea ice algal biomass (recall that the time series was relatively short, on the scale of several weeks). Preliminary analysis does show the rationing change on a daily cycle- (likely due to the changes in the surface solar radiation spectra, diffuse, versus direct radiation etc.). It is anticipated that the remainder of the time series will be useful for assessing changes that may have been due to changes in the biota.

Analysis of ap(λ) spectra from SIMBA sites do show the UV-absorbing compounds in the upper portions of the ice yet low or absent deeper in the ice. Thus, demonstrating the capacity of the sea ice biota to make screening compounds and thus alter the transmission of the UV into the ice/ocean environment. ACDOM spectra from SIPEX also were indicative of UV absorption. More work to be completed included microscopy analysis, analysis of the spatial and time series measures from both cruises, analysis of ratios to get snow depths, synthesis of the combined measures, etc.

4C Recommendations for Future Work

The potential for future work was briefly discussed and included prospects and approaches for deploying hyperspectral radiometers on AUVs, buoys, and moorings for larger scale (time and space) assessments of biomass in ice (which is a continuation of ongoing dialog in the community). Specific approaches for dealing with navigation, variations in cloud cover, instrument packages (e.g. radiometers, transmissometers) and bio-fouling issues were further discussed.

4C Potential Deep Sea Research-II Papers

- SIMBA: Chris, Eric, Elisabeth, Martin and Steve (Bio-optical properties of sea ice in the Winter-Spring)

4C Other Potential Papers

- Polarstern and SIPEX papers by Meiners et al. Title: Determination of ice algae biomass with under-ice irradiance measurements

- Comparative papers were discussed briefly. It may be that the second of the Meiners et al. papers would take the information from the SIPEX, SIMBA and Polarstern results and provide the overall synthesis paper. The specifics are still to be determined.

Session 5A: Modelling Small Scale Sea Ice Processes

Chair: Ken Golden
Rapporteur: Ken Golden

5A General Discussion

Our session focused on identifying and modelling sea ice processes at the scale of individual floes and smaller, yet which are important in regional and global scale ice, ocean, and climate models. We considered the transport of brine, heat, nutrients and gases through the porous microstructure of the ice, and processes which are mediated by such transport and are particularly important in the Antarctic. The transport of fluid, dissolved gasses and tracers is controlled by the microstructural characteristics of the brine phase, particularly its connectedness properties. Brine connectedness undergoes a transition at a critical brine volume fraction or porosity of around 5% in columnar sea ice, which corresponds to a critical temperature of -5 degrees C for bulk salinity of 5 ppt, known as the *rule of fives*. Below a porosity of 5%, the ice is effectively impermeable to fluid flow, and above 5% it is increasingly permeable with porosity. This on/off switch for fluid flow affects many of the processes we considered. We considered a number of processes which are constrained or controlled by the microstructure, including: surface flooding and snow-ice formation, brine drainage and convective overturning, the evolution of salinity profiles and thermal, nutrient, and gas fluxes, and the diffusion of tracers, enzymes and dissolved gasses. A key issue which was discussed at length was the 3D structure of the brine velocity field within the ice, which is of critical importance to many of the processes considered, but about which not much is really known. Various suggestions were made concerning the use of tracers, imaging, and numerical modelling to address this key question.

Given its importance in the Antarctic marine environment, and the types of data available, particularly from time series obtained during SIMBA and previous experiments such as ANZFLUX and HIHO, we focused on flood-freeze cycles and snow-ice formation. This process accounts for significant proportions of total Antarctic sea ice production, and plays an important role in microbial biology. In this regard, we would like to model the co-evolution of the temperature, salinity, and brine velocity fields in sea ice subject to atmospheric and oceanic thermal forcing, snow-loading and bottom melting. We briefly discussed a key partial differential equation describing the temperature and salinity evolution in the presence of a flow field, namely the advection-diffusion equation. We reviewed previously developed models (by Zhu and Golden, Maksym, and Vancoppenolle) where this equation was solved along with other coupled equations for system parameters in various settings closely related to the flood-freeze cycling observed during SIMBA. We plan a joint effort to take existing one dimensional models and adapt them to quantitatively describe thermal, salinity and snow-ice evolutions observed during SIMBA. We anticipate that this work, which will be covered in the proposed paper below, will be a first step toward more comprehensive two and three dimensional models of this key, small-scale sea ice process.

5A Potential Deep Sea Research-II Papers

- Golden, K. M., T. Maksym, M. Vancopponelle, A. Gully, S. F. Ackley, and J. L. Tison, Modelling flood-freeze cycling and snow-ice formation in Antarctic sea ice during the SIMBA experiment.

Session 5B: Meiofauna and Biodiversity

Chair: Maike Kramer
Rapporteur: Rainer Kiko

5B General Discussion

Motivation

Compositions of nutrients, gases and organic substances in sea ice are influenced by:

- chemical processes
- physical forcing (exchange processes with water and atmosphere, sea ice cycle)
- biological processes (including e.g. nutrient uptake by algae, exudation of EPS by algae, contribution of algae and meiofauna to POM)

However, biogeochemical models of sea ice include meiofauna only marginally, and algae are also only little represented.

Meiofauna in sea ice food webs

Meiofauna has commonly been assumed to feed mainly or even exclusively on algae, and only allometric equations have been used for calculation of the grazing impact. A carbon budget model for Arctic sea ice (Michel et al.) includes meiofauna as one group grazing on algae. However, experiments during ANT-XXIII/7 (Weddell Sea, winter 2006) have shown that omnivores (feeding on algae and ciliates) and carnivores (feeding on ciliates and other meiofauna) are present in sea ice. The sea-ice food web is thus more complex than generally assumed. The idea is therefore to construct a simple conceptual model with 4 compartments (algae, ciliates, omnivores, carnivores). This model can then be used to test the impact of the more complex food web structure on the dynamics of sea ice communities. On the long term, this simple model should be incorporated into a broader model, including:

- bacteria
- nutrients and organic substances
- physical forcing (light, temperature, sea ice cycle, exchange processes)

Discussion of grazing experiments

Grazing and predation experiments have been done to assess ingestion rates. We discussed the design of the experiments. Chris Fritsen pointed out the importance of food concentration and assessment of saturation. These have been measured to some extent, as far as possible. Klaus Meiners points out the possible influence of brine channel geometry on feeding activity, referring to papers by Krembs et al. and Deming et al. He described an unpublished experiment performed by Weissenberger, who did serial dilution experiments with melted and refrozen ice cores, information of which might be available in the cruise report. Klaus Meiners asked how the experimentally derived ingestion rates compared to those from allometric equations; however, the experimental rates still need to be converted to biomasses.

Discussion of life histories

Chris Fritsen asked whether the food-web model is supposed to include life histories, and how growth rates will be constrained. Maike explains that some data do exist for sympagic copepods, but not for acoels. Mitsuo Fukuchi presented studies from 1982 done by himself and Tanimura, concerning the life cycles of sympagic copepods, highlighting the importance of including seasonality of sea ice and life cycle strategies in later stages of a sympagic food-web model.

Discussion of physical forcing and model validation
Klaus Meiners asked whether physical forcing will be included in the model and whether time series data are available for validation of the model. Maike explained that physical forcing is not going to be included at this point (just the four compartments mentioned above). The model is thought to be purely conceptual for the moment, based on abundance data and rates (feeding, growth, mortality) from own observations or literature. Rainer Kiko suggested to use ISPOL meiofauna and ice-algae data (available from Sigi Schiel, Henrike Mütze and Harri Kuosa) for validation at a later point.

Succession modelling
Discussion how to study succession
Chris Fritsen suggested that data on sea ice biota from the SIPEX and SIMBA cruises might be used to study seasonal succession of sea ice communities, if a critical amount of data are available for this. Klaus Meiners mentioned that Martin had the idea to use data from ARISE and SIPEX for time series studies, however it is important to bear in mind the change of positions; ice thickness can be used in this context as a proxy for ice age. Klaus Meiners pointed out that one also needs to bear in mind inter-annual variability. Some long-term studies have been performed in the Canadian Arctic (CASES, CFL). Maike suggested that experiments with new-ice formation should be combined with field data from new or young ice. We discussed possible set-ups of experiments (e.g. power field, hole in the ice).

Discussion of what succession of sea ice communities might look like
Chris Fritsen raised the question of whether terrestrial succession models apply to sea-ice communities? Maike Kramer mentioned that from the few studies on algae succession it seems that sea ice is colonised first by nanoflagellates, followed by diatoms. Klaus Meiners pointed out that incorporation processes and selection are probably the two main factors. The meeting discussed the possible role of multi-year ice for colonisation of first-year ice.

Sea ice biota in different ice types and regions
Differences have been observed in both algae and meiofauna taxonomical composition in fast as compared to pack ice. As for pack ice, meiofauna composition seems to be fairly similar in first- and multi-year ice within one region. First-year ice regions seem to have lower meiofauna abundances and diversities as compared to regions with multi-year ice.

We discuss the possibility of comparing algae and meiofauna data from one expedition. As for SIPEX, meiofauna has been analysed with respect to vertical distribution in the ice; for ice algae, only analyses of bottom-ice sections are planned for the near future. We also discuss possibilities of cross-comparison of algae or meiofauna data from different regions.

We further discussed problems of patchiness, the need of randomised sampling and the difficulty of analysing sufficient numbers of samples in biological sea ice studies. We also discuss the opportunities of and difficulties with using molecular biology to assess biodiversity in the ice.

5B Potential Deep Sea Research-II Papers

- Maike is working on a paper comparing sea ice meiofauna from SIPEX and ANT-XXIII/7, together with Klaus Meiners, Rainer Kiko, Kerrie Swadling, Iris Werner and Annette Scheltz. A similar paper could be planned comparing ice algae in bottom-ice sections from SIPEX and

SIMBA. Some algae data from SIMBA are already available (Brussels and Liege), further samples may be provided by Jean-Louis; SIPEX algae data will be available soon. Rainer Kiko suggests the use of similar statistical methods in both papers. Maike offers to do the statistics for the ice-algae paper.

- We also discussed the alternative opportunity to publish the SIPEX ice-algae data in conjunction with ANT-XXIII/7 data (probably available from Andreas Krell), such as to complement the meiofauna paper. Klaus Meiners and Chris Fritsen mentioned earlier studies on ice algae performed in the Weddell Sea in winter (Garrison, Buck, Close); the published data, as well as available samples from the respective expeditions are not analysed as yet but will be included in a paper on ice algae in the Weddell Sea.

Session 6A: Modelling Large Scale Sea Ice Processes

Chairs: Sharon Stammerjohn and Martin Vancoppenolle
Rapporteur: Cathy Geiger

6A General Discussion

Presentation Highlights

Presentation: Sharon Stammerjohn

- 2007 Large Scale Distributions/Anomalies. Setting the physical context for SIPEX/SIMBA. Overall Themes included: I. Atmospheric circulation anomalies, II. Regional Sea ice Anomalies, III. Regional Ocean surface anomalies
- Similar anomaly patterns seen in both SIMBA and SIPEX regions. This includes late advance and early retreat. These are the strongest of all regions around Antarctica and therefore the most sensitive to warming responses at least for 2007
- Low annual precipitation in SIMBA and high precipitation in SIPEX

Presentation: Martin Vancoppenolle

- Assessing model forcing data – very important to understand in terms of quality
- Some important biases in the forcing data, including shortwave radiation
- What data was assimilated into NCEP and ECMWF?
- SIMBA data may have been assimilated into NCEP and ECMWF but it is not clear how much of it was included? Buoy data was not.
- Model comparisons relative to capabilities in northern and southern hemispheres (synthesis slide for different variables was shown)
- In general Antarctic modelling is doing very poorly compared to Arctic.

Group Discussion

Marilyn Raphael: Climate models are quite poor. She compared with Marika Holland 6 IPCC models to try and reproduce the dipole modes. The main point is that sea ice is not the passive feature it is often thought of by the climate community. Because of this, the models are having a very hard time getting the large scale circulation correct and consequently the global impacts. Both the sea ice thickness and the distribution of thickness are needed. Currently at 1x1 degree resolution, keeping in mind that this is much too large relative to the natural variability of sea ice. Ted Maksym is running into the same problem at BAS, due to parameterization of sea ice models large errors are associated with atmospheric forcing errors. But Marilyn runs stand alone models and still runs into problems. Martin finds that you need an interactive ocean to get things correct – as a minimum you need ocean mixed layer depth and ocean heat flux – you cannot just force the ocean but the ocean must interact as it is more reactive to the ice behaviour. There are problems with the forcing and in the model physics with no understanding of the proportion of the errors.

Steve Ackley commented that a good test of models is their ability to reproduce the Weddell Polynya as a process over long climate time scales. Martin commented that this is not ever reproduced – not a chance. Big break through when this happens.

Cathy Geiger commented that SSM/I ice extent is bad in summer. Steve says based on Burcu's poster that you get half a million square km^2 in extent errors of SSM/I versus ship observations in summer. QuikSCAT looks a bit better with a 10 year record showing a more promising result. But this makes it very tricky for modelers as the results are being compared to observations which themselves are still evolving with regard to quality. Ted did a quick look at QuikSCAT and found that it has the opposite effect of overestimating the ice edge. Rob Massom said it gets back to the fundamental question of what is an ice edge. Steve Ackley says that bands and strips concentrated or diffuse makes a big question of defining the ice edge for climatological purposes. Rob – each sensor has its own pros and cons that make this issue very complex. Steve – Ice Station Weddell – Cathy Geiger's thesis shows the ice in the western Weddell Sea is tidal driven. Petra shows inertial oscillations are a big issue everywhere around Antarctica (Cathy's DSR paper in Margarite Bay also shows this).

Rob Massom said wave-ice interaction is also very, very big especially given the huge pancake ice field of the Antarctic. In general the ice responds very quickly to wind and can 'take off' very quickly in strong wind conditions. Steve said buoy advection can go in completely different direction of pancake development by hundreds of kilometres. Rob also commented that wave interaction can break up the ice floes and change the albedo, but Martin said there is no way to put this into the larger models because there is no representation of waves yet in ocean models. Rob emphasized that the action of waves can be observed up to 700km from the ice edge into the pack.

Seymour Laxon - Melt pond dynamics implemented in the Arctic by Danny Feltham. Steve emphasised the importance of surface processes and coastal polynyas. Martin said sometimes these processes are modeled, but coastal polynyas are not always in the correct time or place. There are no katabatic winds in the models yet either. Rob – polynyas are ice production and ice destruction systems so these are very important. Martin says this can be looked at as case studies.

Marilyn Raphael provided a large scale modelling shopping list. Thorsten Markus provided a list of available remote sensing products in an earlier session (Session 4A) and this is very useful. But we also need sea ice elevation and thickness distribution at the large scale. Natalia Galin asked about the requirements in terms of accuracy. Tony Worby asked whether temporal or spatial measurements are most important. Marilyn said both and especially the coupling between them. Data on the seasonal cycle of ice thickness would be very nice and important according to Martin.

Thorsten Markus said that more information on the upper ocean salinity is important. It could be sufficient to resolve the mixed layer seasonally to monthly. Basically it is a very difficult task to get ocean variables beneath the ice on a large scale. At the station level we can do this for case studies. ARGO deployments and instruments on elephant seals are starting to provide some data under the ice.

Martin Vancoppenolle would like to see more large scale deformation arrays with buoys. Petra Heil commented that the scale of these is important. Tower-based measurements are available for 15 days on SIMBA with some noise due to blowing snow and precipitation. Two deformation arrays were deployed on SIPEX, with buoy life averaging approx. 3 months.

Tony Worby suggested the establishment of a working group or panel to focus on Southern Hemisphere issues and provide dialogue between the modelling, in situ observations and remote sensing communities. There is potential support for this from WRCP/CliC and SCAR. Marilyn Raphael and others agreed this would be a good idea and would provide a valuable mechanism for modellers to find out what data are available. Meta-data is particularly important. Tony Worby and Marilyn Raphael agreed to follow this up (post-meeting note: discussions have begun on forming a panel within CliC).

6A Potential Deep Sea Research-II Papers

- We are looking at processes and cycles so how does this play into the larger role in the context of the DSR special issue? It was noted that 2007 had huge anomalies relative to climatology that should be tied together in this larger context to round off the more integrated picture.

- Vancoppenolle, Ackley, Tison, Papakyriakou, Leonard, Lieser et al. Assessment of model forcing data sets for Antarctic pack ice.

- Stammerjohn et al., large scale sea ice circulation context for SIMBA, SIPEX and Oden spring cruises around the Antarctic continent.

Papers for the Deep Sea Research-II Volume

The following papers are likely submissions to the special volume of Deep Sea Research-II on Antarctic Sea Ice in IPY; however paper titles and authorship may change on some papers. This list has been revised since the final session of the workshop to more accurately reflect the papers that will be ready for the 31st October 2009 submission deadline.

Brabant, F., G. Carnat, S. F. Ackley, S. El Amri and J.-L. Tison, DMS and DMSP dynamics in Antarctic early spring sea ice in the Bellingshausen Sea.

DeLiberty, T., C. A. Geiger, S. F. Ackley, A. P. Worby and M. van Woert, Sea ice thickness and mass balance derived from ice charts.

Delille, B., J.-L. Tison, G. Carnat, A. V. Borges, S. F. Ackley and N. Geilfus, Sea ice pCO_2 dynamics and related air-ice CO_2 fluxes during a flood-freeze cycle.

Dumont, I., F. Masson, J.-L. Tison and S. Becquevort, Distribution and chemical characterisation of organic matter in the Antarctic pack ice zone, Bellingshausen Sea.

Fritsen, C., Memmott, Wirthlin, M. Vancoppenolle, E. Murphy, S. Stammerjohn, J.-L. Tison, and S. F. Ackley, Bio-optical properties of Antarctic pack ice during early spring.

Galin, N. R. Willatt, and A. P. Worby, Development of wide-band Frequency Modulated Continuous Wave (FMCW) radar for measuring snow thickness over Antarctic sea ice.

Geiger, C., B. Ozsoy-Cicek and S. F. Ackley, Gyre dynamics of sea ice in the Amundsen/ Bellingshausen Seas during IPY.

Golden, K. M, A. Gully, C. Sampson, A. P. Worby and J. Reid, Fluid and electrical transport in first year Antarctic sea ice.

Golden, K., T. Maksym, M. Vancoppenolle, A. Gully and S. F. Ackley, Modelling of flood-freeze cycling and snow ice formation in Antarctic sea ice during the SIMBA experiment.

Heil, P., I. Allison, A. Steer, R. A. Massom and A. P. Worby, East Antarctic sea-ice drift and deformation during Spring and Summer 2007.

Jones, G., R. Kelley, et al., Dimethylsulphide and Dimethylsulphoniopropionate in sea ice: relationship with ice thickness, sea ice extent and the radiative climate.

Kawaguchi, S., P. Virtue and K. Swadling, Krill physiology and growth off East Antarctica during early spring.

Kramer, M., K. Swadling, K. Meiners, R. Kiko, A. Scheltz, M. Nicolaus and I. Werner, Antarctic sympagic meiofauna in winter: comparing diversity, abundance and biomass between the western Weddell Sea and the Southern Indian Ocean.

Lewis, M., J.-L. Tison, B. Weissling, B. Delille and S. F. Ackley, Sea ice and snow cover characteristics during the winter-spring transition in the Bellingshausen Sea: an overview of SIMBA 2007.

Leonard, K. and T. Maksym, The importance of wind-blown snow redistribution to snow accumulation on Bellingshausen Sea ice.

Lieser, J., A. P. Worby, D. Yi and R. A. Massom, Antarctic sea ice freeboard from airborne laser altimetry and comparison with ICESat measurements.

Maksym, T., et al., Summer sea ice properties in the Amundsen and Bellingshausen Seas.

Masson, F., J. de Jong, I. Dumont, J.-L. Tison, S. Becquevort and V. Schoemann, Spatial distribution of iron in the Antarctic pack ice in spring.

Meiners, K., M. Granskog, A. Krell, P. Heil, L. Norman and D. Thomas, Bio-geochemistry and ecology of East Antarctic pack-ice during the winter-spring transition.

Michael K. J. and J. Higgins, Transmission of sea ice and snow at ultraviolet and visible wavelengths.

Murphy, E., S. F. Ackley and C. A. Geiger, Ocean heat flux measurements in the pack ice of the Bellingshausen Sea, Antarctica.

Norman, L., M. Granskog, C. Stedmon, S. Papadimitriou, K. Meiners, G. Dieckmann and D. Thomas, Absorbance Characteristics of Chromophoric Dissolved Organic Matter (CDOM) in Antarctic Sea Ice.

O'Brien, C., P. Virtue, S. Kawaguchi and P. D. Nichols, Aspects of krill growth and condition during late winter-early spring off East Antarctica between 110°E and 130°E during the SIPEX expedition (Sea Ice Physics & Ecosystem eXperiment, September-October 2007)

Ozsoy-Cicek, B., A. Tekeli, P. Wagner, S. F. Ackley and H. Xie, Intercomparison of Antarctic sea ice concentration and properties derived from ship observations, active and passive microwave satellite during SIMBA.

Stammerjohn, S., R. A. Massom, P. Heil, R. Cullather, K. Leonard, T. Maksym, S. Jacobs, S. F. Ackley and A. P. Worby, Anomalous Antarctic sea ice and atmospheric conditions during IPY 2007.

Stewart, B., Marine mammals and sea birds in spring Antarctic pack ice, Bellingshausen Sea, Antarctica.

Tekeli, A., S. F. Ackley, H. Xie and B. Ozsoy-Cicek, Amundsen Sea summer ice cover characteristics derived from ENVISAT ASAR satellite and ship-based surface data.

Tison, J.-L., S. F. Ackley, K. Golden, F. Brabant, C. Fritsen, N. Geilfus and B. Delille, Physico-chemical properties and CO_2 fluxes at a frost flower station in the Bellingshausen Sea.

Toyota, T., C. Haas and T. Tamura, Floe size distribution of relatively small sea ice from digital video images in the Antarctic marginal ice zones.

Toyota, T., R. Massom, K. Tateyama, T. Tamura and A. Fraser, Snow on sea ice – results from SIPEX and SIMBA.

Vancoppenolle, M., S. F. Ackley, J.-L. Tison, T. Papakyriakou, K. Leonard and J. Lieser, Assessment of model forcing data sets for large-scale sea ice models in the Southern Ocean.

Wagner, P., B. Oszoy-Cicek, M. J. Lewis, C. Geiger, S. F. Ackley and B. Weissling, The sea ice thickness distribution at 90W Bellingshausen Sea during austral winter.

Weissling, B., M. Lewis and S. F. Ackley, Sea ice mass characterization derived from in situ geophysical assessment at Ice Station Belgica, Antarctica.

Williams, G., A. Poole, A. Meijers, P. Mathiot and A. Klocker, Late winter hydrography beneath East Antarctic sea ice.

Worby, A. P., K. Meiners, A. Steer, et al., The Sea Ice Physics and Ecosystem eXperiment (SIPEX): regional characterisation of the physics and biology of the Antarctic sea ice zone in spring.