Annual Progress Report Year 1 (3 June 2008- 2 June 2009)

Project Title: **Antarctic sea ice thickness from space: validating estimates from the laser and radar satellite altimeters with ship-based measurements**
(a three year project to The University of Texas at San Antonio funded by the NASA Cryosphere Program from 6/3/2008-6/2/2011)

Investigators: PI: S.F. Ackley (UTSA) CoI's: Hongjie Xie (UTSA), Anthony Worby (Antarctic CRC, Australia), Thorsten Markus (NASA Goddard)

NASA Grant # NNX08AQ87G)

Summary Accomplishments

-Data on several hundred surface elevation and ice thickness profiles from 15 ship-based experiments were recovered from their multiple sources, covering most seasons and regions of circumpolar Antarctic sea ice from 20 years of cruises. This data will allow development of seasonal-regional statistics on the relationship of surface elevation to ice thickness and to compare with IceSAT-based elevation-thickness algorithms and establish errors on ice thickness estimated from surface elevation determined from space.

-Cloud-free IceSAT surface elevation data was obtained over coincident field experiment sites, allowing the first evaluation of *in situ* Antarctic sea ice data with IceSAT profiles obtained at the same time, using helicopter-borne Lidar (SIPEX) or ship-based thickness profiles (SIMBA and SIPEX).

-Publication of six journal articles related to Antarctic Sea Ice processes and IceSAT, AMSR-E and MODIS-based satellite remote sensing in polar or mountainous regions. (The GRL paper: Internal Melting in Antarctic sea ice: investigating 'gap layers', was chosen for the cover figure of GRL, as an Editor's Highlight in GRL, and Selected Publications in EOS)

-Workshop sessions on satellite remote sensing of Antarctic Sea Ice and IceSAT evaluations of Antarctic sea ice thickness during SIMBA and SIPEX were held at the Antarctic Sea Ice: IPY Cruises workshop, Barga Italy 20-22 March 2009 (47 attendees, co-chaired by S.F. Ackley and A. Worby)

-Conference Presentations were made, three at Fall AGU and six at the Gordon Research Conference on Polar Marine Science, related to Antarctic Sea Ice or IceSAT, AMSR-E and MODIS-based satellite remote sensing in polar or mountainous regions.

-ESA Category 1 proposal submitted and approved. This approval allowed access to ESA Envisat and other data from its Rolling Archive, and was used to collect imagery during the *Oden* 2008 and *NB Palmer* 2009 cruises and will be used for joint imagery analyses for upcoming IceSAt missions at the end of 2009

Introduction

The report, in three Parts and one Appendix, relates the activities under the NASA Grant performed in the first year of activity 3 June 2008-2 June 2009. The first section describes the activities of the grant performed at the Univ of Texas San Antonio, under the direction of the Principal Investigator Stephen F. Ackley and Co PI Hongjie Xie. Those activities comprise the main funded efforts of the grant. Sections 2 and 3 are reports on the activities from the two CoI's not at UTSA: Anthony Worby (unfunded CoI) Antarctic CRC, Hobart Tasmania Australia and Thorsten Markus (funded CoI) of NASA GSFC. The Appendix contains the draft summaries of the remote sensing-related sessions held at the Antarctic Sea Ice Workshop: IPY Cruises held in Barga Italy 20-22 March 2009 (S. F. Ackley and A. Worby CoChairs) These sessions were participated in by the PI Ackley and five UTSA graduate students and postdoc, the CoIs Markus and Worby, and Grant Collaborators, Donghui Yi (NASA Goddard), Seymour Laxon, K.Giles and R. Nash (CPOM, Univ College London, UK). A grant meeting of these investigators was also held at the workshop, where coordination activities for the coming year were discussed using radar altimetry, data from cruises and upcoming joint analysis of IceSAT with satellite products on snow depth, radar altimetry and radar backscatter.

Part 1. Activities of the Laboratory for Remote Sensing and Geoinformatics UTSA (S.F. Ackley PI and Hongjie Xie CoI).

Administrative Activities

During this first year of activity, two PhD students, Burcu Ozsoy-Cicek and Michael Lewis, successfully defended their thesis proposals and initiated their principal research activities. B. Ozsoy-Cicek is analyzing profile data from Antarctic sea ice to develop better algorithms for converting IceSAT elevations in sea ice thickness and some preliminary results are given in the *Science Activities*. M. Lewis participated in the SIMBA field experiment in 2007 and is using modeling, field data and satellite data to interpret snow depth, snow-ice interface temperature and the detection of surface flooding, which are related to the correct choice of algorithm for conversion of IceSAT elevation into sea ice thickness, using data derived from space. The implications of not knowing if the surface is flooded or unflooded, for example, in deriving the ice thickness can lead to considerable error in the estimate, as also described in the *Science Activities*. A postdoc, Ahmet Tekeli, with previous experience in using satellite products for snow cover on land, was appointed in Nov 2008 and his initial work has been concentrated on using satellite imagery in conjunction with ground measurements from ships in the Antarctic. These students and postdoc presented posters at the Gordon Research Conference on Polar Marine Science and the Antarctic Sea Ice Workshop (*list of presentations* below) and participated in the workshop discussions on these topics. As well as these meetings in Italy, where the workshop was organized and Co-chaired by S.F. Ackley and A. Worby, H. Xie participated in the AGU Fall meeting (*list of presentations*) and a meeting of the Pacific Arctic Group (PAG) in Bergen Norway 20-21 March 2009. At the PAG, future participation in both Arctic and Antarctic cruises for ground validation of satellite data was discussed. Vessels from China and South Korea as well as US and Australian vessels used (as described below) are possible future venues and initial queries were made for participation in these vessels' cruises. S.F. Ackley will be giving an Invited Presentation at the symposium and workshop marking the launch of the South Korean icebreaker in Incheon Korea on June 10 2009, where these plans will be further developed for future participation with the South Korean vessel. A European Space Agency (ESA) Category 1 proposal was submitted and approved. This acceptance allows access to ESA Envisat and other data from the ESA Rolling Archive, and was used to monitor imagery during Oden 2008 and NB Palmer 2009 cruises and will be used for joint radar altimeter and active microwave imagery for upcoming IceSAT missions at the end of 2009

Lists of papers and conference presentations are also given below. A website for the project is now housed jointly with one previously established for the Sea Ice Mass Balance in the Antarctic (SIMBA) project sponsored by NSF, (S.F. Ackley, PI), as the ground activities on SIMBA are being joined, as described below, with the spaceborne measurements from IceSAT. The website address is:
http://www.utsa.edu/lrsg/Antarctica/SIMBA/index.html

Science Activities

A major effort to provide IceSAT data over Antarctic sea ice was made prior to the grant initiation during the IPY Antarctic Sea Ice Cruises in 2007. The current NASA grant investigators, S.F. Ackley and A. Worby were Chief Scientists on the cruises of the *NB Palmer* in the Bellingshausen Sea and *Aurora Australis* off East Antarctica, respectively. Arrangements through the NASA IceSAT Mission Planning Team (Jay Zwally and Thorsten Markus et al) resulted in a switching of the mission, usually held for 33 days beginning in November, to instead start in early October of 2007, in order to coincide with the vessels being in the field. Extensive ground measurements on ice thickness, snow depth, ice elevation were held during the *NB Palmer* cruise and airborne measurements (described in Part 2) were conducted from *Aurora Australis*. Figure 1 shows the cloud-free IceSAT measurements of surface elevation that were made in the region and area of the *NB Palmer's* work in the Bellingshausen Sea. As shown, the IceSAT tracks did not generally cross the track of the *Palmer* at the same time, so comparisons of measured elevations and IceSAT elevations must be inferred rather than having a simultaneous measurement. There was a variety of other satellite measurements taken at that time including high-resolution active microwave from RADARSat and EnviSAT. A current effort is to analyze the radar backscatter and relate it to measurements of ship-based properties of sea ice taken from the same site. By relating the backscatter to these measurements, a further comparison of backscatter with IceSAT elevation may then allow the elevation to be "typed" to validation sites and estimates of snow depth, surface elevation, degree of surface flooding, and ice thickness similarly validated to compare with the IceSAT values of elevation. As described below, previous measurements from cruises suggest knowledge of all these parameters is necessary to infer ice thickness from surface elevation measured from space.

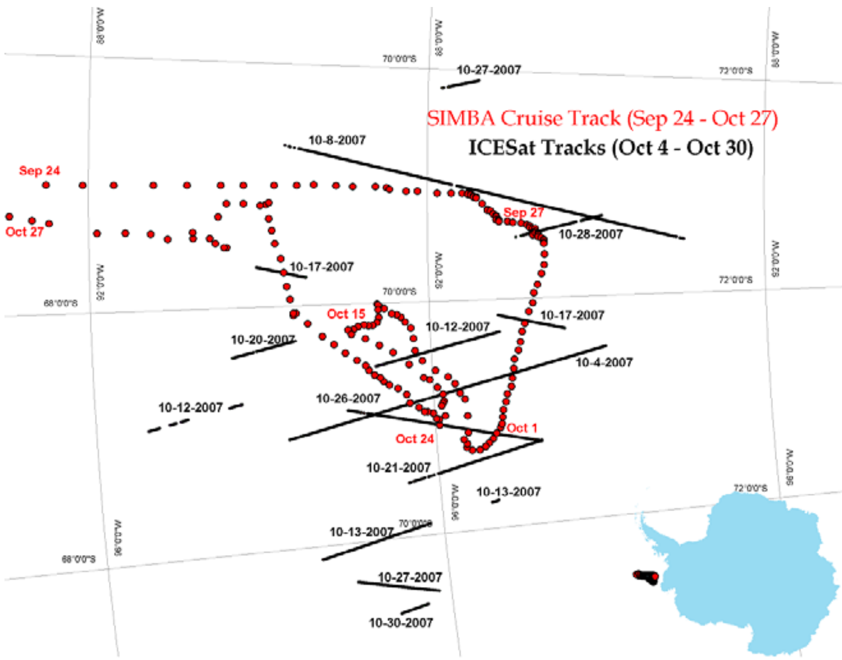


Figure 1. IceSAT Tracks with surface elevation estimates (cloud-free) measured during the Oct 2007 campaign (black lines). The cruise and drift tracks of the *NB Palmer* during the same period (Sept 24 to Oct 27) are shown by the red dots.

Since the inception of the Grant, data from previous cruises, that had measurements of surface elevation (or snow depth), ice surface freeboard (height above or below sea level) and ice thickness were compiled and standardized. Typically these data, gathered from ship cruises (15) from the mid-1980s to the present were taken by using ice augers to measure ice thickness, usually at 1 meter intervals for distances nominally from 50m to 100m. Thousands of ice thickness measurements were obtained from these surface profiles over the fifteen cruises. At the same locations, the snow depth and the ice freeboard (height above or below sea level of the ice surface) was also measured at the same 1m spacing for profiles from tens to greater than one hundred meters in length. From IceSAT, the diameter of the laser altimeter spot on the surface is estimated at 70m so one average elevation is obtained over the diameter of the spot. To compare with the ground-based elevations and thicknesses, we therefore are taking the single mean values for each of the profiles (tens to hundred meters) of ice thickness, elevation and ice freeboard, where the measured elevation is a "synthetic" IceSAT measurement to test various algorithms to derive ice thickness from surface elevation. Results from two of the profile sets, the *NB Palmer* 1993 cruise in the Amundsen-Bellingshausen Sea, and the GLOBEC 2001 cruise (Marguerite Bay, Western Antarctic Peninsula) are shown in Figs 2 and 3. Two comparisons were made, the first used a Normal isostatic relationship with prescribed values for the snow, ice and water densities and used the measured values of mean snow depth and mean ice freeboard (height above or below sea level) to estimate the mean ice thickness. The second computation took into account the increased density of flooded snow, if the ice freeboard was negative (below sea level) to give an estimate of mean ice thickness. The comparison between measured values of mean ice thickness (blue lines) and the Normal isostasy (red line) and Flooded isostasy (green line) predictions are shown on the left side of Figures 2 and 3. The correlation lines between the estimate from the Flooded isostasy(only) and the measured thickness are shown on the right sides of Figs 2 and 3. Since only three profiles from the Palmer data (Figure 2) were flooded, there is generally good comparison with few exceptions between the estimated and measured values using either calculation. The errors shown are principally related to the values prescribed for densities, so some possible adjustment will be investigated to optimize those values. The correlation of 0.97 however indicates that an adjusted isostasy gives quite good estimates for ice thickness from the surface data, principally because of the good agreement for Normal isostasy and better agreement for flooding than without the flooded layer. For the second case, however, where 6 of the 11 profiles measured were flooded, the correlation between estimated and measured thickness drops to only 0.51. On the left side of Figure 3, it is shown nonetheless that the errors in ice thickness estimate are considerably reduced if the flooding depth is known. Analyses of the remaining 13 sets of profiles will yield information on the variability of flooded versus unflooded profiles and whether there are regionally or seasonally (or both) consistent patterns in the frequency of flooded and unflooded profiles. Further testing and adjustments will be made to see if a better predictive algorithm can be derived also. Work on passive and active microwave signatures compared to ground measurements is also continuing in an effort to identify flooded versus unflooded regions of the ice cover, as the results so far have shown that this is the crucial parameter to know in estimating the ice thickness from surface data. This identification, if successful, will then allow us to use coincident microwave and IceSAT data to derive information on flooding and whether the algorithm to derive ice thickness can be switched between Normal and Flooded isostasy for higher accuracy and to provide an adjusted error on the thickness estimate if it is known to be unflooded or flooded. Present comparisons of SIMBA snow data (with different degrees of flooding) with passive microwave models have shown that lower frequency passive microwave (6 and 10GHz) should react to flooding while higher frequencies respond to snow temperature changes only. Studies comparing satellite microwave data with the measured values of the snow temperature and flooding derived from buoys deployed during SIMBA are now ongoing to compare with these modeling results. While we are hopeful of good comparison, expectations are guarded as to whether this comparison will be valid for passive microwave data alone, since the coarse resolution (12.5km pixel size) of the passive microwave could smear over many ice types and not give a clear flooding indication if the sea ice is inhomogeneous in ice types, where some ice types (deep snow) may flood while others may not, and the resulting areal averaged passive microwave signal may be ambiguous as a flooding indicator. Active microwave data with much higher resolution, (100m, comparable to IceSAT altimeter spot diameter) may be useful to resolve the flooding or no flooding issue at sufficient resolution. Studies to relate radar backscatter to ground measurements, particularly the presence of flooding, are also ongoing with data from the *Oden* and

Palmer 2009 cruises as well as the SIMBA cruise to see if changes in backscatter are related to flooding also.

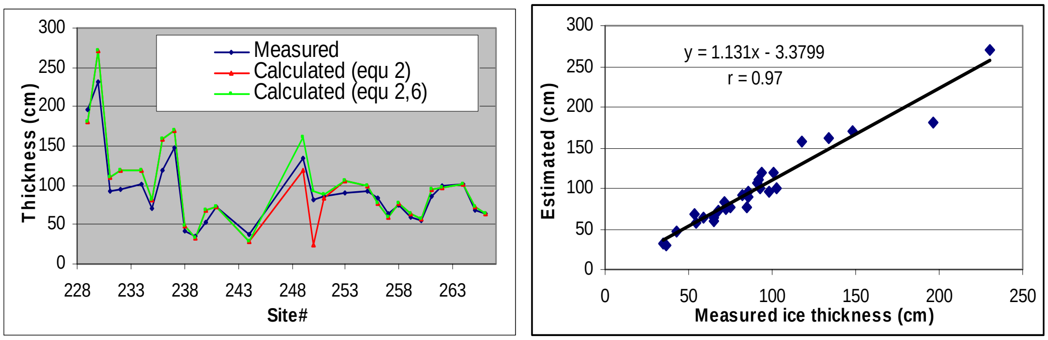


Figure 2. Comparison between measured ice thickness (cm) (blue line) and calculated/predicted ice thickness (cm) (red and green lines) for NB Palmer Cruise 1993. The correlation analysis (right) is based on measured (blue line) and estimated (green line) using normal isostasy for all cases except for the three flooded events.

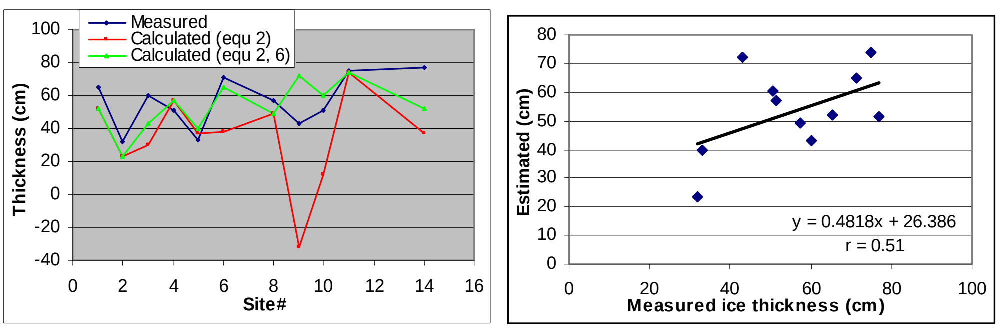
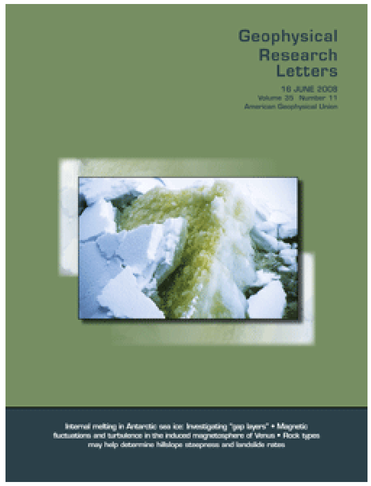


Figure 3. Comparison between measured ice thickness (cm)(blue line and calculated/predicted ice thickness (cm)(red and green lines) for Globec Cruise 2001. The red line estimate using Normal isostasy without flooding gives large errors in the thickness estimate, while a different formulation for the flooded and unflooded events (Flooded isostasy, green line) reduces the error markedly. The correlation analysis (right) is based on measured (blue line) and estimated (green line) using the different isostatic equations for the five unflooded events and the six flooded events.

For Antarctic sea ice, however, work on computing ice thicknesses from satellite algorithms, either laser or radar, are still in a developmental and unvalidated state. Data from ground-based surveys of ice thickness and surface elevation (combined snow depth and ice elevation) have now indicated a more complex relationship between elevation and thickness than predicted by simple isostasy for computing ice thickness, as currently attempted using satellite laser altimetry. Similarly, the presence of significant areas of flooded ice with sea water at the ice surface-snow interface in the Antarctic differs from the Arctic surface case, suggesting radar algorithms based on positive ice elevation may need adjustment for the Antarctic flooded condition with negative ice elevation.

Publications

Ackley, S.F., M.J. Lewis, C.H. Fritsen, and H. Xie, 2008. *Internal melting in Antarctic sea ice: development of "Gap Layers"*. Geophysical Research Letters, 35, L11503, doi:10.1029/2008GL033644   (Cover Photo for GRL selected from the article (below) ; the GRL editor selected it for an Editor's Highlight choice; and was also featured in Selected Publications in EOS)



Ozsoy-Cicek, B., H. Xie, S.F. Ackley, and K. Ye, 2009. *Antarctic summer sea ice concentration and extent: comparison of ODEN 2006 ship observations, satellite passive microwave and NIC sea ice charts.* The Cryosphere, Vol.3 (1):1-9

Weissling, B., S.F. Ackley, P. Wagner, and H. Xie, *2009. EISCAM - Digital image acquisition and processing for sea ice parameters from ships*. Cold Regions Science and Technology, doi:10.1016/j.coldregions.2009.01.001

Wang, X. and H. Xie, 2009. *New methods for studying the spatiotemporal variation of snow cover based on combination products of MOIDS Terra and Aqua.* Journal of Hydrology (accepted).

Huang, X., H. Xie, T. Liang, D. Yi, J. Ren, Estimating vertical error of SRTM and map-based DEMs using ICESat altimetry data in Tibetan Plateau. International J of Remote Sensing. (submitted, under review)

Gao, Y., H. Xie, N. Lu, T. Liang, and C. Xue, Advanced daily cloud-free snow cover and snow water equivalent products from Terra-Aqua MODIS and Aqua AMSR-E measurements. Jl of Hydrology (submitted, under review).

List of Presentations

Posters: Gordon Research Conference and Antarctic Sea Ice Workshop (15-22 March 2009)

Monitoring sea ice by ASAR and validating with ODEN 2008 cruise field data for Antarctica
Ahmet Emre Tekeli, Stephen Ackley, Burcu Ozsoy Cicek, Hongjie Xie

Intercomparisons of Antarctic Sea Ice Concentration and Properties derived from Ship Observations, Satellite Active and Passive Microwave.
B. Ozsoy-Cicek, P. Wagner, A. Tekeli, S.F. Ackley, H. Xie

ASPeCt Imagery for Ice Thickness in the Bellingshausen-Amundsen Seas SIMBA 2007.
P. Wagner, M. Lewis, S.F. Ackley and H. Xie;

Evaluation of Sea Ice Interface Temperature and the Significance of Sea Ice Flooding Events
M.J. Lewis, H. Xie and S.F.Ackley

Physical and Temporal Characterization of Early spring Sea Ice, Bellingshausen Sea 2007
Weissling, B., M. Lewis and S.F. Ackley (*Winner of Student Poster Award at the GRC*)

Ocean heat flux under sea ice: Antarctica
E. Murphy and S.F. Ackley

AGU Fall Meeting Presentations 2008

Xie, H. and Y. Gao, 2008. Snow cover spatial and temporal variability across three rivers headstream region of Tibetan Plateau based on MODIS and AMSR-E data (2000-2008). AGU Fall meeting, San Francisco, CA, December 15-19. 2008

Huang, X., H. Xie, T. Laing, and D. Yi, 2008. Accuracy estimation of SRTM and map-based DEMs using ICESat elevation data in Tibetan Plateau. AGU Fall meeting, San Francisco, CA, December 15-19. 2008

Gao, Y., H. Xie, N. Lu, T. Liang, C. Xue, 2008. Advanced new daily products of cloud-free snow cover area and snow water equivalent from MODIS/Terra-Aqua & AMSR-E measurements. AGU Fall meeting, San Francisco, CA, December 15-19. 2008

Part 2 Activites of the Antarctic CRC, Hobart Tas, Austalia (A. Worby, CoI)

During the Sea Ice Physics and Ecosystems Experiment (SIPEX) conducted from the Australian research vessel Aurora Australis, an airborne campaign (RAPPLS Helicopter (Radar—Aerial Photography—Pyrometer—Laser Scanner)) was conducted to collect remote sensing data to compare to the IceSAT satellite overpasses which took place at the same time (early October 2007) as the vessel's occupation of the region. Figure 4 shows the region of Antarctic sea ice from 110E to 130E longitude where operations took place.

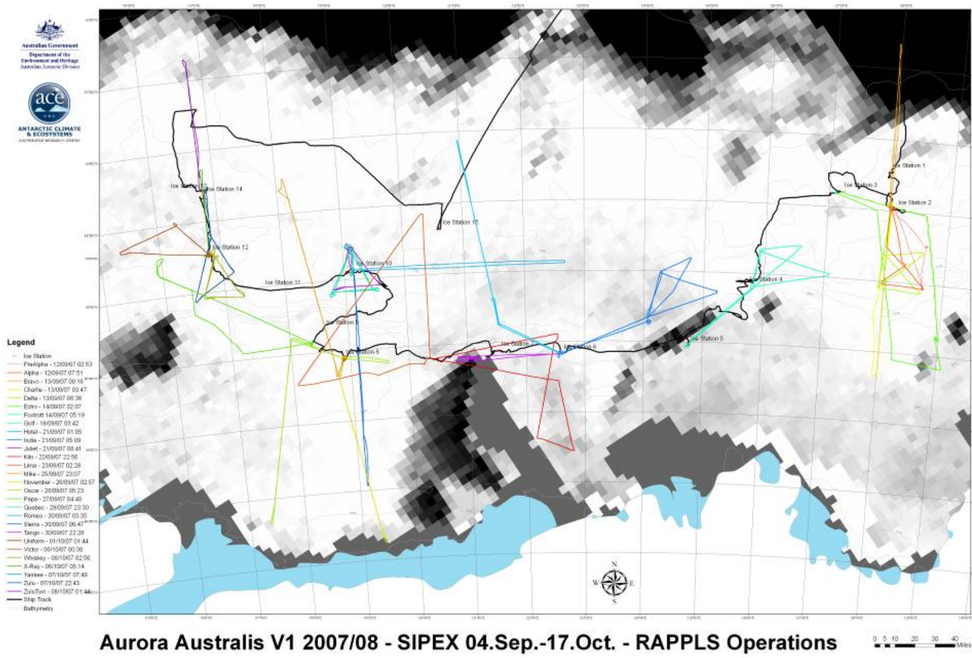


Figure 4. *Aurora Australis* Cruise track (black line) and helicopter survey lines (colored lines) taken during 4 Sept-17 Oct 2007. The background for the map is the passive microwave imagery of ice concentration (black, open water; white 100% ice cover) on or about 1 Oct 2007. (The lower red line is the track of Lidar shown in later figures for analysis.)

As shown before for the SIMBA data, the incidence of cloud-free IceSAT passes, also coincident with a vessel or helicopter working the area is very low. To overcome this problem, the track (red line) shown in the lower portion of Figure 4 was flown with laser scanner over landfast sea ice, within a few days of the IceSAT pass. With the reasonable assumptions of no ice motion(fast ice) and that only small changes in elevation (e.g. drifting snow) will take place in this short period of time, this pass provides a regional scale track that is comparable with the IceSAT data obtained.

Figure 5 shows in three strips, the continuous track (~N-S) obtained from the Lidar, with color coding corresponding to the ice thickness distribution. The surface elevations were converted to ice thickness using snow depth and isostatic relationships developed from measurements taken on similar ice cover from the vessel north of the region.

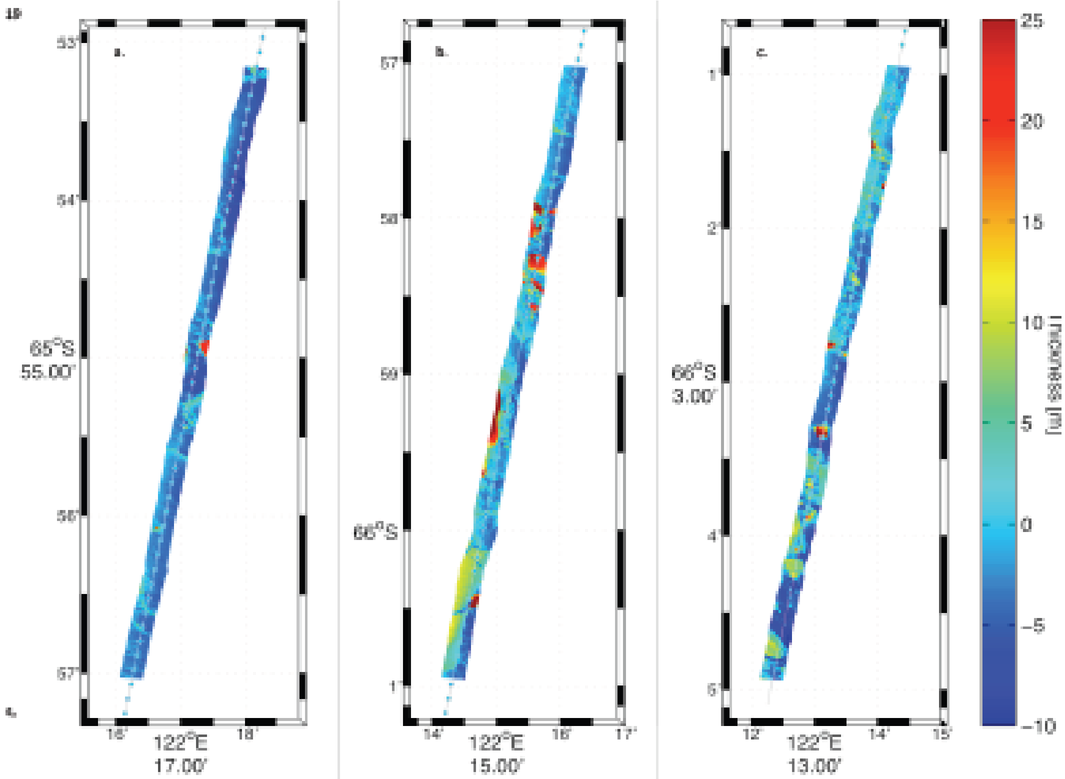


Figure 4. Lidar scans of landfast ice area nearly coincident with IceSat pass, Oct 2007, E. Antarctica. Color Scale is Ice thickness derived from Lidar measured ice elevation using isostasy and measured values of snow depth and ice thickness to determine the isostatic relationship from nearby stations. (after Lieser et al, GRC Poster, March 2009)

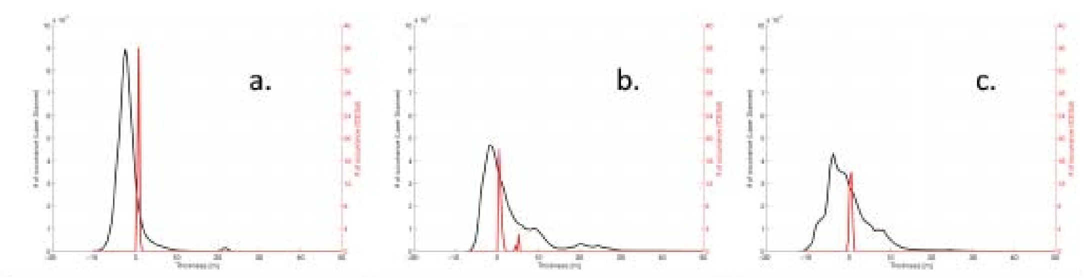


Figure 4: PDFs of ice thickness derived from surface elevation estimates from laser scanner (black) and ICESat (red) for the three legs shown in figure 3.

Figure 5. Probability Density Functions (pdf's) of derived ice thicknesses from airborne laser scannet (black lines) and IceSAT elevations (red curves). (after Lieser et al, GRC Poster, March 2009)

However, pdfs of ice thickness and mean values for the IceSat and Lidar data, for the leg (3 parts) (Figure 5) when compared show some differences. Mean values of 0.89m for

IceSAT thickness and 0.48m for airborne Lidar thickness were derived from these pdf's.. So, this first comparison indicates an approximate 80% overestimate of mean thickness from the IceSAT elevation measurements, compared to the Lidar-derived values. Along with Geoid and sea level estimates for the IceSAT as possible error sources, the source of snow depth information used for the IceSAT computation is presently unknown. Work continues to determine possible discrepancies between the assumptions used in the conversion of elevation to thickness in the two sets of measurements.

Part 3 Comparison of in-situ freeboard measurements with estimates from ICESat (T. Markus, Goddard Space Flight Center, Greenbelt MD)

In October 2003 a campaign onboard the Australian icebreaker Aurora Australis had the objective to validate standard Aqua Advanced Microwave Scanning Radiometer (AMSR-E) sea ice products. Additionally, the satellite laser altimeter on Ice, Cloud, land Elevation Satellite (ICESat) was in operation. To capture large-scale information of the sea ice conditions as necessary for satellite validation, the measurement strategy, therefore, was to obtain large-scale sea ice statistics using extensive sea ice measurements in a Lagrangian approach. A drifting buoy array spanning, initially 50 km by 100 km, was extensively surveyed using 50 m to 500 m transects as well as performing random sampling within the buoy array using helicopters. Extrapolation using buoy drift information was utilized to enhance the data volume in time.

During ARISE the snow and ice measurements were collected in three different ways:

a) Hourly ice and snow thickness measurements from the ship (ice observations). Ice and snow thickness is estimated from ice floes tipping over along icebreaker. Furthermore, the sea ice conditions (concentration and thickness of various ice types) are estimated visually for a radius of approximately 500 m following the ASPeCt protocol.

b) On twelve ice stations detailed snow and ice properties along transects of between 50 m and 500 m length were collected. Snow and ice thickness as well as ice freeboard measurements were taken every meter. Additionally, every 50 m snow pits yielded information on snow stratigraphy and snow physical properties.

c) Random sampling, referred to as mini stations, using helicopters on floes within the buoy were used to create representative statistics. Each of these mini stations consisted of 20 snow depth and ice temperature measurements over smooth and 20 measurements of rough sea ice. A total of 97 mini stations were carried out. The positions of these boxes also gives us information on sea ice drift and ice convergence/divergence.

Figure 6 shows the locations of the various data sets. AMSR-E and QuikSCAT data are available daily in a 12.5 and 25 km grid, respectively. All other data are only available for a specific day. The figure shows that for ICESat there is not good overlap with the in-situ data. Especially since either of the two data sets have values for certain days only. In order to increase the number of coincident data we used grid spaced 0.5 degrees in latitude and 1 degree in longitude. For this latitude this corresponds to a grid size of roughly 55.5 km by 47 km.

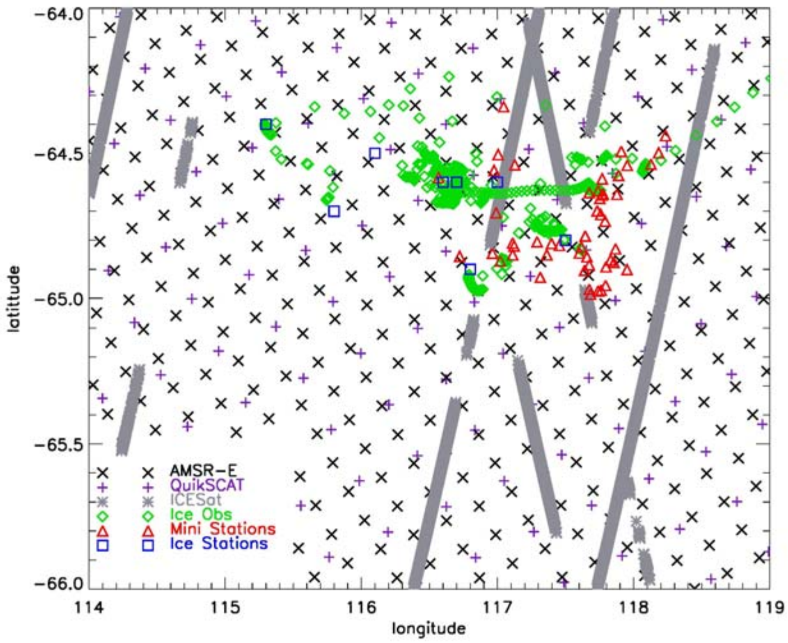


Figure 6: Overview of measurements taken during the ARISE cruise. AMSR-E and QuikSCAT data are available daily in a 12.5 and 25 km grid, respectively. All other data are available for a specific day only.

Additionally, we are using ice drift information obtained from the beacons to extrapolate ICESat and in-situ observations to other days. For example, using drift information we can locate an ice station on October 5 also an October 6 etc. Analysis of the beacon locations has shown that the ice in the area drifted about 0.1 degrees to the west with negligible meridional drift. The assumption is that snow and freeboard conditions for those ice floes measured do not change significantly over the campaign period. The only change is in the fraction of thin ice for each grid cell caused by ice divergence. This is accounted for by the calculation of thin ice fraction from microwave data.

A good check to assess the validity of these steps is the agreement between Ice Station and Mini Station data (Figure 7). The dotted line indicates the 5 cm differences. While some data show good agreement others differ widely. We conclude that large differences are an indication that our assumptions do not hold for those values, and in the following we use only those values where the difference between Ice Stations and Mini Stations is less than 5 cm. This number is arbitrary but 5 cm was also the noise level in the AMSR-E snow depth retrievals.

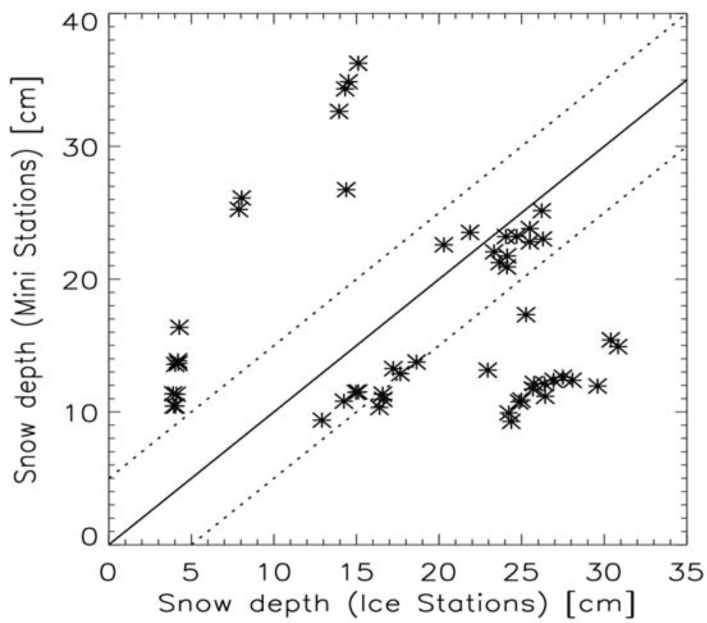


Figure 7: Mini Station snow depth versus Ice Station snow depth. Dotted lines indicate 5 cm differences.

The average ICESat retrieved freeboard in a grid cell for each individual ICESat overpass (taken between September 25 to October 17, 2003) is used for comparison with the results shown in Figure 8. The data have a correlation of 0.6 with some of the scatter likely due to spatial variability of the ice freeboard and snow depth within the grid cell. The mean difference between the data sets is small, with ICESat having an average freeboard 1.8 cm higher than the ARISE data set. The small mean difference is particularly important as it suggests that the method to retrieve the sea surface tiepoints is not significantly biased and that the large-scale retrieved freeboard values compare well with observations.

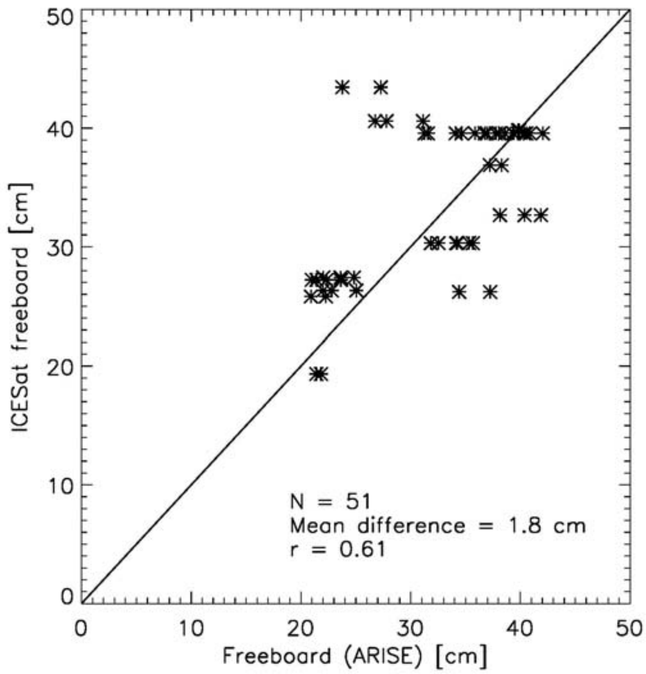


Figure 8: Comparison between the ICESat derived freeboard and mini station freeboard from the ARISE data set. Freeboard is taken to be the height of the ice and snow layer above the water level.

APPENDIX Draft reports from the Antarctic Sea Ice Workshop Remote Sensing Sections, 20-22 March 2009, Barga Italy (S.F. Ackley and A. Worby, Co Chairs)

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 2B: Remote Sensing Altimetry

Chair: Katharine Giles

2B General Discussion

Algorithms: Differences between Arctic and Antarctic? Are the same assumptions valid?

Discussion whether the assumption that the ice freeboard is zero hold for the entire season?
Comparison of AMSR 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 and ASPeCt data (the bias towards thinner ice thickness' in the field data was also noted). No clear conclusion.

Cruise 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 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 snow depth could be a result of wetness/flooding, slush layer. There is also a scaling issue here (i.e. AMSR 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? 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 kilometers)

- Bottom pressure data
- Airborne EM-31
- 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

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 4A: Remote Sensing General

Chair: Thorsten Markus

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. N.B. 1 year before the system will be built. 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). Comparing in situ and remote data. Lytle and Golden have already been 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.