Overview of CAS Snow and Ice Measurements Techniques.

This overview is a summary of the methodology used to collect the data in the associated spread sheet. It is intended as accompanying notes for scientists using the data provided by CAS and also as general information for layman followers of the survey.

The spreadsheet shows the manual measurement collected by the Catlin Arctic Survey. At the time of writing data collection is ongoing. Scientific research programs can obtain the latest updates by contacting CAS directly. (www.catlinarcticsurvey.com)

On most days Pen Hadow, the lead observer, was able to take a range of measurements over a 3-5 hour session, although severe weather conditions hampered data gathering throughout the survey but especially in the earlier days.

Modal Ice Thickness Measurement

Each evening using the time and tools available (Mora hand operated Ice drill, Kovacs Ice Gauge), Pen drilled up to 10 holes through ice pans near camp that best reflected the characteristics (snow cover, deformity e.t.c.) of the pans the team had encountered while trekking that day. To this extent the ice thickness measured is deemed to be representative of the ice transited for that day. Subjectivity was reduced by the experience Pen has in recognising pan characteristics and by the limited variability within the daily distances covered. Related satellite imagery, radar imagery and weather maps are available for each day to scientific researchers using this data.

It's important to stress that this methodology gives a measure of un-deformed ice thickness, which is the *modal* average ice thickness of the total ice covering, and is not a measure of *mean* average ice thickness.

Modal average ice thickness is used to accurately determine ice age, and investigating the rate of development of First Year Ice which is hugely significant in identifying the mechanisms of long term sea ice decay and formation.

Mean average ice thickness is one of the statistical characteristics used to compare observed results with ice modeller's data.

The modal results will be converted into an inferred mean average ice thickness using 3 methods.

1. **Mode to Mean coefficient**. Using known and comparable relationships of mean and mode average ice thickness found from submarine data in comparable locations at comparable times of previous years, modal thickness data can be converted into a mean thickness.

   This methodology has been developed by Prof Wadhams Professor of Ocean Physics, and Head of the Polar Ocean Physics Group in the Department of Applied Mathematics and Theoretical Physics, University of Cambridge, and the analysis is being carried out by his department.
2. **Ridge Observation data**. While trekking, the team make detailed notes of the number of rubble fields and pans over which they pass as well as the number and height of ridges.

From this data, the ice thickness of the ridges (ignored by the undeformed sampling technique) can be estimated thanks to the predictable shape and characteristics ridges are known to form. The thickness of undeformed ice (measured) can be combined to the thickness and frequency of deformed ice (inferred), and the mean ice thickness can be calculated.

This analysis will be performed by Prof Wadhams' Team after the expedition, when all the data cards can be transcribed by their author.

3. **Mean Thickness Measurements**. For 4 days, between the 16th and the 22nd of April, Pen collected data using a randomised method of sample selection. Drilling positions were selected at regularly spaced intervals along a 400m straight line transit running N-S through the camp. This is designed to act as a small sample for use as a 3rd corroborating method for comparing mean to mode average thicknesses.

It was decided early on in the project that measuring mean ice thickness by drilling randomly selected sample positions posed a risk of damage to equipment which could only be replaced at resupply, and therefore a risk to the amount of data that could effectively be gathered. Drilling through ridges is also physically very demanding and only usually attempted with a powered auger and not a hand auger. The fatigue caused and time required to drill through ridges by hand would result in less data being gathered. Many ridges are deeper than the length of the drill (5.2m) so the ridge thickness data would be incomplete with an unquantifiable bias.

Given the constraints on the team, it was decided in collaboration with our science partners that the most valuable results would come from using time and human effort to collect data using this selective sampling technique with a known and quantifiable bias, to give modal thickness.

These methodologies were developed in ongoing discussions with Prof Wadhams, of Cambridge University, and Prof Christian Haas of the University of Alberta, world leaders in field techniques for data gathering on sea ice.

Freeboard

Pen also measured Freeboard (more specifically Ice Freeboard) as the height between the water level in the drilled hole and the top of the ice.

Because this was taken from sample holes away from pan edges, it is less impacted by dynamic forces of ice movement, and a better reflection of ice flotation. This can therefore be used to measure the ice density (based on how low the ice sits in the water).

Ice density is important as this will affect the longevity of the ice over the summer. Denser ice requires more heat energy to achieve the same volumetric melting.

Snow Thickness and Density

As part of the same routine, Pen also took up to 46 snow depth readings using a rule and logged these on the same chart.

On some occasions the team have been able to measure snow column weight. This is done using a tube of a known diameter (79mm). Snow is collected from a vertical column. The height of the column is measured within the tube so the volume can be calculated. Using a bag (measured at 85g) and a spring balance the snow is weighed to give density. The data shown includes the bag weight. Snow thickness and density is important for a number of science partners, as it impacts on measurements and observations made by satellite altimetry and radar backscatter energy. Snow thickness is used as an initiation condition by some ice modellers.

Snow Temperature

Snow temperatures, taken 5 cm below the surface, help to correlate findings with atmospheric conditions.

Finding instrumentation which was accurate, able to operate extreme cold and was robust enough proved very difficult, resulting in irregular measurements in between resupplies.

Atmospheric Conditions

Data on atmospheric conditions was also collected up to 3 times per day, and corroborating weather charts/satellite imagery are also available from CAS on request.

Data Presentation

On the summary sheets the results are averaged on a daily basis, with standard deviation plotted on the bar charts. The 3rd bar chart shows averages for snow and ice added together. Zero readings represent where no data was collected.