Collaborative Autosub Science in Extreme Environments (CASEE) Travel Bursary for Foreign Researchers.

Oceanographic and sea ice properties beneath the Norske Or Ice Barrier, North-East Greenland with Autosub.

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1 Background

1.1 JR106a: Autosub Under Greenland Sea Ice

In August 2004 I was an observer on board the RSS *James Clark Ross* participating in the JR106a: Autosub Under Greenland Sea Ice experiment. The Autosub-II autonomous underwater vehicle (AUV), operating beneath the Norske Oer Ice Barrier (NOIB) off NE Greenland (Figure 1), obtained the first successful swath sonar measurements under sea ice and showed in unprecedented detail the three-dimensional nature of the under-ice surface (Wadhams et al., 2006). In addition to this, Autosub-II collected a suite of hydrographic measurements including current data from upward and downward looking Acoustic Doppler Current Profilers, and water mass properties from a Conductivity-Temperature-Depth instrument and oxygen sensor.

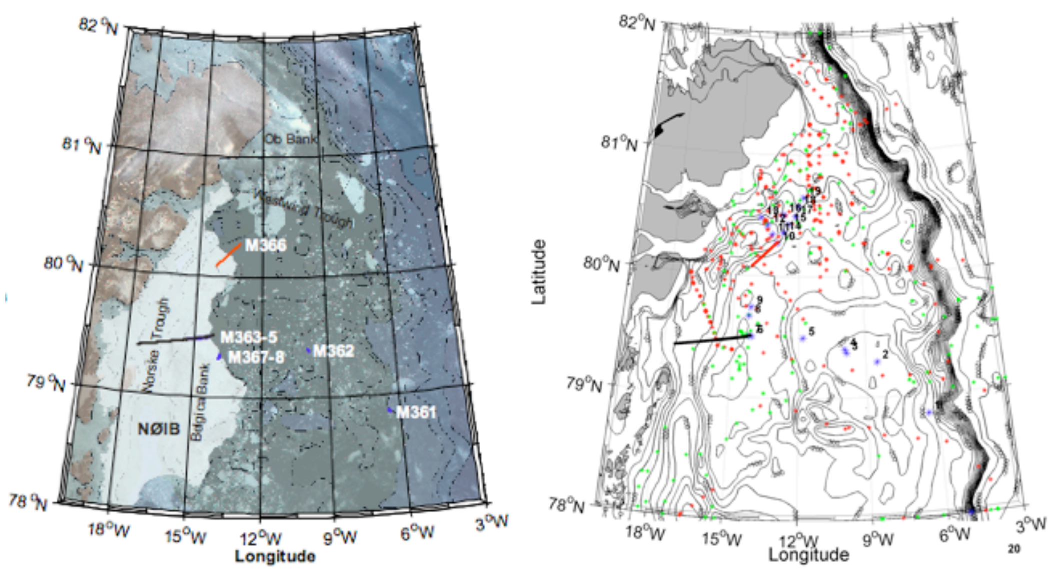

Fig. 1. Study area of JR106a, North-East Greenland. Left panel shows a satellite image of the Norske Oer Ice Barrier and Autosub missions 365 (black line) and 366 (red line) as shown. Right panel shows IBCAO bathymetry and additional shipboard CTDs from JR106 (blue), and historical datasets (green and red).

The AUV collected data from two missions, numbered 365 and 366 (Figure 1). Mission 365 was a 75 km zonal transect across Norske trough beneath the central region of the NOIB. Mission 366 was a 30 km SW/NE transect through the Westwind trough beneath the north-east tip of the NOIB. In addition 19 shipboard CTDs were collected, with a transect across the Westwind trough at the start of Mission 366, and a number of other opportunistic sites over the Belgica Bank including one station near the start of Mission 365.

In May 2005 I visited Dr Jeremy Wilkinson from the Scottish Association of Marine Sciences (SAMS) and we examined the preliminary data from this novel experiment. Our initial results were presented to the Autosub Review Committee from the National Environment Research Council (NERC) at the National Oceanographic Centre (NOC) on the 19th May 2005, and later to the International Glaciological Society in Dunedin, New Zealand on 6th December 2005.

Last year Wadhams et al. (2006) published an overview this data and showed imagery from first- and multiyear ice, including young ridges, old hummocks and undeformed melting ice. In addition, Wadhams et al. (2006) demonstrated how the combination of other on-board sensors enabled the vehicle to obtain detailed information about seabed topography, water structure and current fields within a region that is seldom visited because of difficult year-round ice conditions. The highlight of this multi-sensor dataset was the identification of a new current regime in the Norske Trough, termed the North East Greenland Coastal Current (NEGCC). The NEGCC was shown to be a fast (up to 25 cm s^{-1}) northward flowing current that was distinctly colder and more saline than the southward flowing East Greenland Current (EGC) initially detected under the NOIB.

1.2 This Project

I was awarded this CASEE Travel Bursary to return to the United Kingdom and continue working with Dr Jeremy Wilkinson on the JR106a Autosub dataset. In particular, our goals were to:

- Quantify the hydrographic observations collected beneath the NOIB
- Examine the CTD water mass properties with the 3-D thickness profiles from the Autosub's multibeam instrument
- Examine past satellite imagery to build a conceptual model of the processes that resulting in the observed structure and composition of the NOIB.

2 Preliminary Results

2.1 Hydrographic Observations

Here I present a snapshot of the secondary analysis completed on the JR106a hydrographic dataset during my visit to SAMS. Figure 2 shows the horizontal distribution of water mass properties and current data at 40 dbar and highlights the two current regimes detected by the Autosub on Mission 365, i.e. the colder, saline northward flowing NEGCC close to the coast and the warmer, fresher and southward flowing EGC over the Belgica Bank. Figure 2 also demonstrates how Mission 366 into the Westwind Trough observed the northern extension of the NEGCC becoming fresher and warmer.

$\theta - S$ data for both the shipboard and Autosub Conductivity-Temperature-Depth systems are shown in Figure 3. This is the standard method employed by oceanographers to delineate between water masses and in this case we show conclusively that the two fast opposing currents measured on Mission 365 contain different water masses (magenta and green data points represent the EGC and NEGCC respectively). The data from Mission 366 occupies the same region in $\theta - S$ space and indicates that the NEGCC detected on Mission 365 does flow out of the Westwind trough.

Using 10 cm s^{-1} as the minimum speed defining the EGC (southwards) and NEGCC (northwards), we quantify the properties of both currents in Table 1. The NEGCC was more saline (0.14), colder (0.08 °C) and subsequently denser (0.12 kg m^{-3}) than the EGC. Our data indicates that the NEGCC also had a lower dissolved oxygen content (0.17 ml l^{-1}). This result initially suggests that the EGC had been exposed to greater surface freshening from summer sea-ice melt, atmospheric warming and oxygen transfer than the water mass beneath the ice barrier.

Comparing the two observations of the NEGCC from Mission 365 and 366, we observe that during its northward transport from the centre of the NOIB to the north-east tip over the westwind trough, the NEGCC became fresher (0.09), warmer (0.07 °C) and richer in dissolved oxygen (0.33 ml l^{-1}). There are two possible physical processes beneath NOIB that could be responsible for this change in water mass properties: the melting of sea-ice within the NOIB and the input of meltwater from the Greenland Icesheet (surface) and Glaciers (sub-surface). It should be noted that the CTD sensors aboard the AUV were calibrated *before* the cruise, but not afterwards, and that dissolved oxygen sensors in particular are known to drift and so the absolute values of these water mass transformations may not be robust.

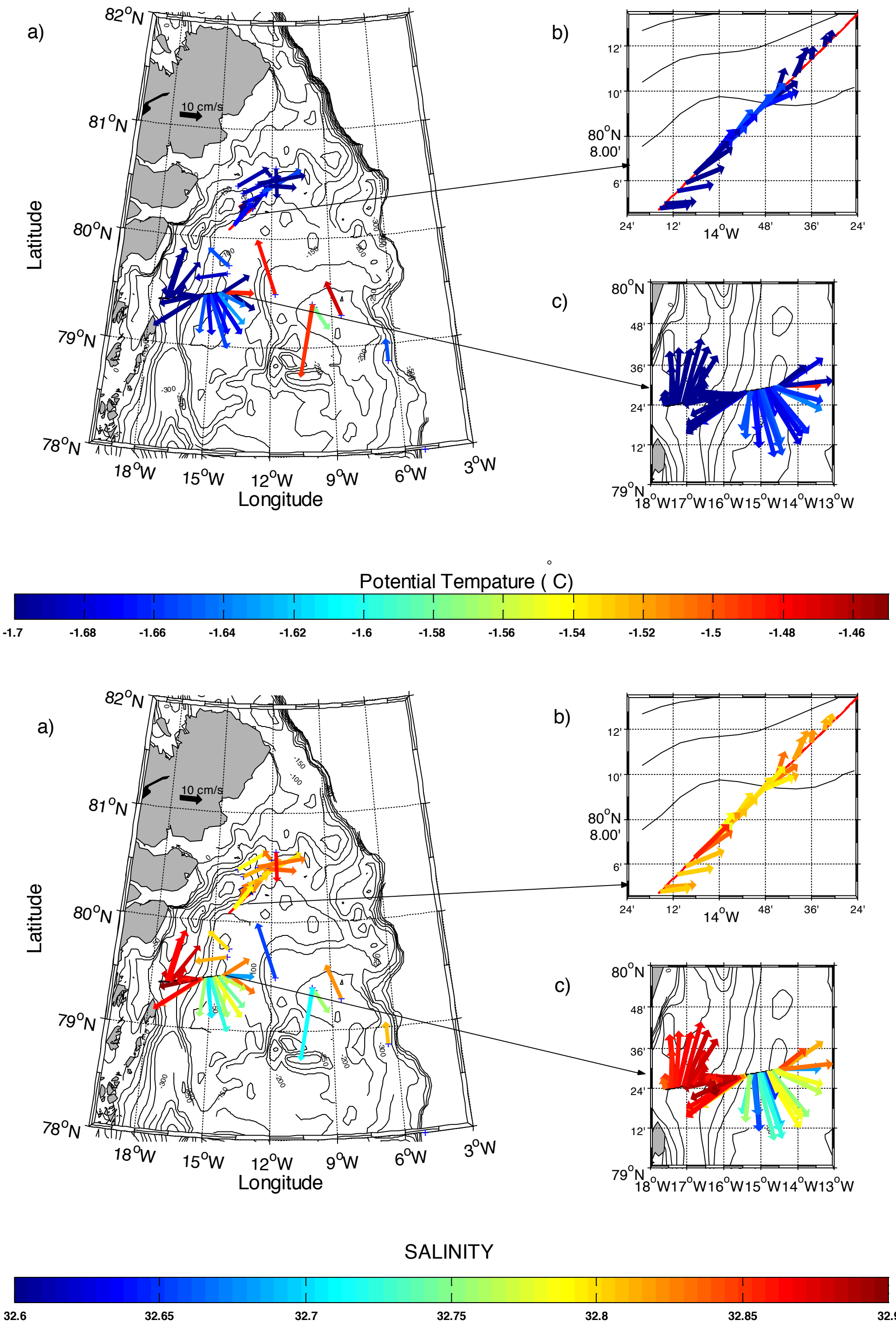

Fig. 2. CTD Water mass properties and ADCP currents at 40 dbar collected by the Autosub and JR106a. Top panel is potential temperature ($^{\circ}C$) and bottom panel is salinity. Current speeds indicated by 10 cm s^{-1} legend.

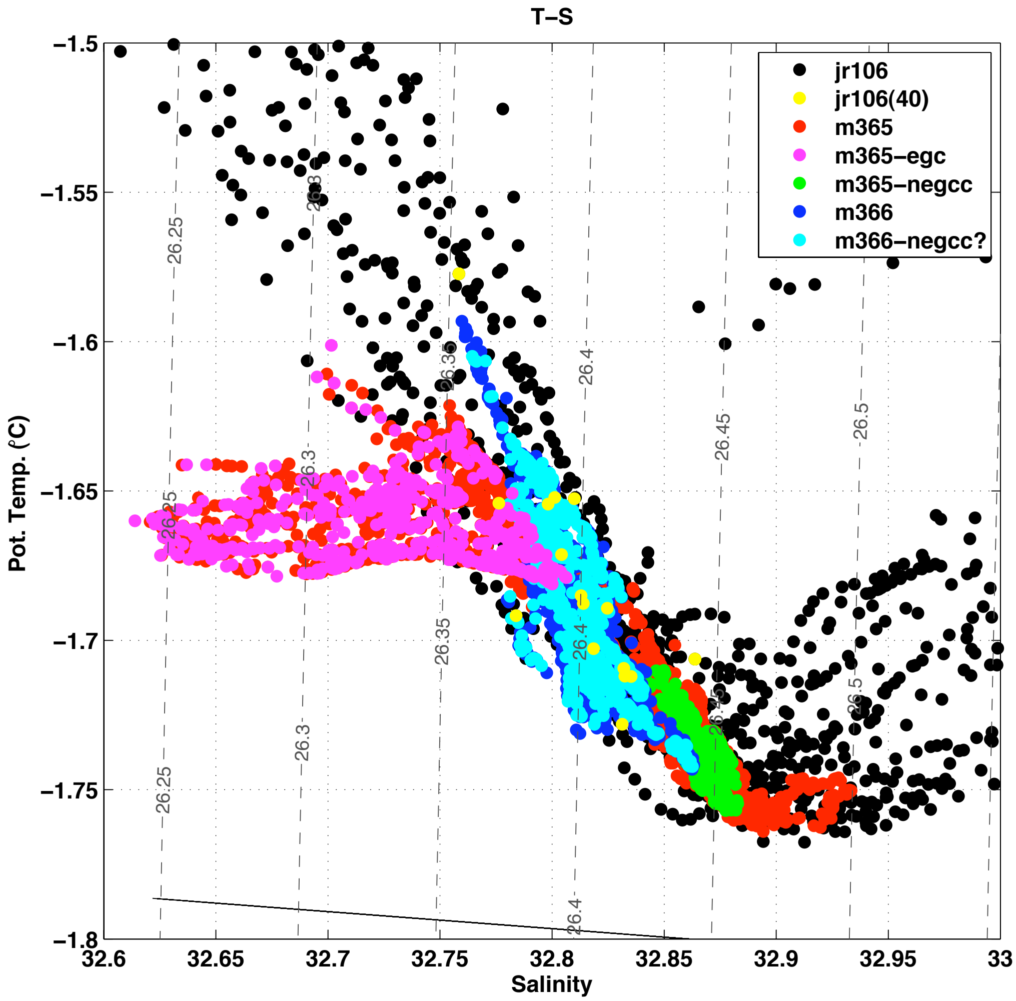

Fig. 3. Potential Temperature (°C) vs Salinity diagram for JR106a CTD and AUV data (mission 365 and 366). Data points are: JR106a CTD (black); JR106a CTD at 40 dbar (grey); AUV m365 (red); AUV m365 - EGC (magenta); AUV m365 - NEGCC (green); AUV m366 (blue); and AUV m366 - NEGCC (cyan). Grey dashed lines of constant potential density (σ_θ kg m^{-3}) and thick black line surface freezing line as shown.

2.2 Combined Ice thickness and Hydrography Analysis

Together with the hydrographic measurements, Autosub collected ice thickness data with a EM-2000 multibeam instrument. Integrating these data (see Figure 4) represents a major advance in our ability to further our understanding of the relationships between ice and ocean. Wadhams et al. (2006) showed several examples of the different ice classes observed in Missions 365 and 366 and presented probability density functions of the ice thickness distribution of the NOIB. We combined all the data types and examined the sensitivity to change between the properties. Figure 4 is a good example of the challenges this involves. This section of Mission 365 contained an embedded multi-year

Table 1
Mean water mass properties for the East Greenland Current and the North East Greenland Coastal Current.

Current⇒	EGC (m365)		NEGCC (m365)		NEGCC (m366)	
⇓Property	mean	st. dev.	mean	st. dev.	mean	st. dev.
Salinity	32.73	0.05	32.87	0.01	32.81	0.02
θ (°C)	-1.66	0.01	-1.74	0.01	-1.67	0.03
σ_θ (kg m^{-3})	26.33	0.04	26.45	0.01	26.40	0.02
dO_2 (ml l^{-1})	7.48	0.09	7.31	0.02	7.64	0.06
East/West (m s^{-1})	0.07	0.06	0.05	0.04	0.08	0.05
North/South (m s^{-1})	-0.19	0.04	0.19	0.05	0.10	0.02
Speed (m s^{-1})	0.21	0.04	0.20	0.04	0.14	0.03

floe with a ridge-like feature over 30 m deep. This feature alone is estimated to contain over 200,000 tonnes of ice. Here we see a general trend of freshening, warming and increased oxygen content as the AUV passes under this ridge. However care must be taken given that the AUV itself dived an extra 10 m whilst going underneath. To overcome this analysis we sub-sampled the CTD at a fixed depth of 40 dbar before re-examining the variability.

Overall we determined that the AUV was too far from the ice (40 dbar) to detect any thermodynamic influence but nonetheless we did observe freshening, cooling and oxygen increases in conjunction with increases in the thickness of the sea ice above. We attribute these changes to the dynamic influence of ridges and embedded floes. That is, the likely impact that thick ice has of forcing cooler, fresher and more oxygen-rich water at a given depth deeper into the water column. Future missions of the AUV need to consider flying much closer to the ice surface, though we understand this is not a trivial request.

2.2.1 Further work

After examining the small-scale variability, we began extending our comparison of two current regions and completed the PDFs of ice thickness distribution for the NEGCC ice and EGC ice (not shown). It was perhaps surprising to find that EGC section had first-year ice approximately 35 cm thicker than the region over the centre of the NOIB where the NEGCC flowed beneath and in the area to the north-east over the Westwind trough. Given the same atmospheric forcing (air temperatures, snow regimes etc), it is not obvious why the eastern/outer section of the NOIB would have produced thicker ice.

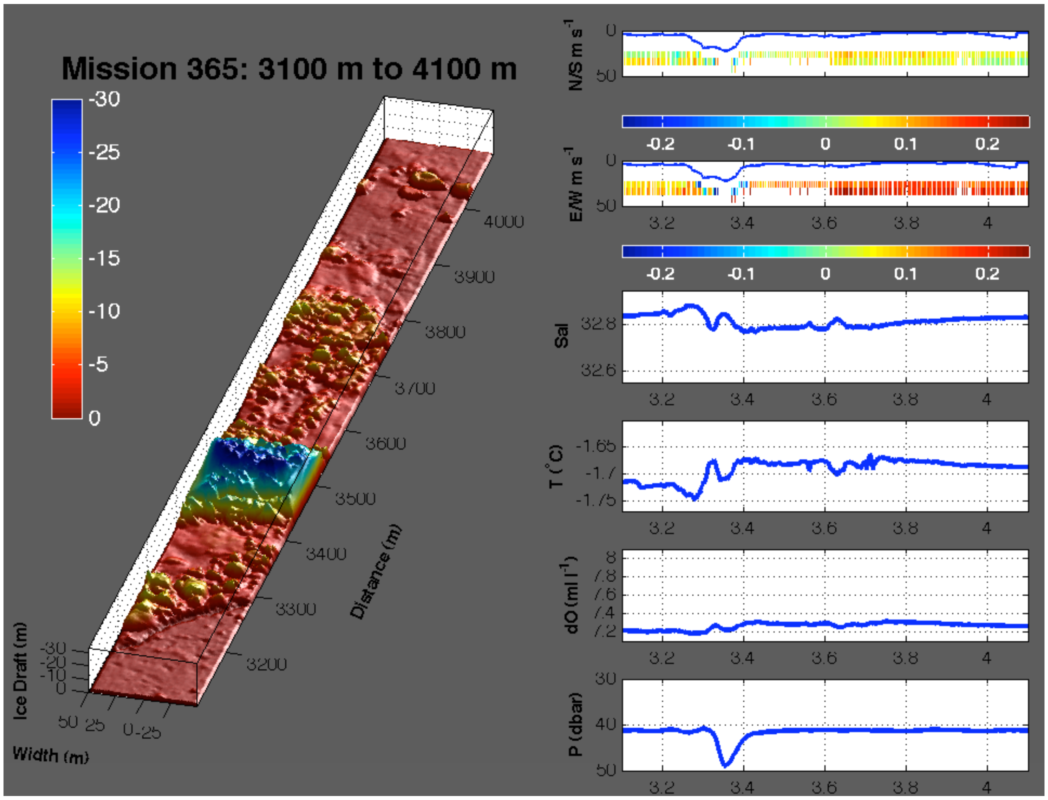

Fig. 4. A snapshot of Autosub II multibeam, ADCP and CTD data crossing a multi-year floe with a very large ridge.

Further work is required to explain this and will involve a closer examination of the vertical structure of the water column, both at the time of sampling and during the previous ice growth season. This is a challenge due to the lack of historical hydrographic measurements for this region in the winter. We plan to incorporate AMSR-E sea-concentration and MODIS sea-surface temperature analyses to assist in building a conceptual model of the NOIB formation. This will be invaluable as more research is planned in this unique region of the Arctic fringe that represents such a wonderful case-study for the predicted impacts of Arctic climate change.

Although my CASEE visit has now ended the work will continue. We have an accepted abstract for an upcoming special volume of *Limnology and Oceanography* focusing on Scientific Results from Autonomous and Lagrangian Platforms and Sensors. Work completed during this CASEE Travel Bursary will directly contribute to this publication (manuscript submission September 2007).

3 Miscellaneous Outcomes of the CASEE Travel Bursary

In addition to the completed work outlined in the report above, I was able to use my CASEE Travel Bursary to attend the following scientific meetings.

3.1 AUV Science in Extreme Environments workshop. Scott Polar Research Institute, Cambridge 11–13th April 2007.

Between 13–15th April I attended the 2nd CASEE Autonomous Underwater Vehicle Masterclass Workshop at the Scott Polar Research Institute, Cambridge. The 1st Masterclass Workshop from the previous year focused on AUV technologies. This workshop represented the next step and was primarily concerned with the scientific applications of AUVs in both the present and future. The workshop attendees represented a wide range of commercial, academic and military users of AUV technologies. It was a wonderful opportunity to meet with those in and out or my field of expertise.

3.2 General Assembly & Congress European Geoscience Union 2007 (EGU) in Vienna 16–20th April.

After the AUV workshop in Cambridge I travelled to Vienna, Austria and attended the General Assembly & Congress European Geoscience Union meeting. I gave an oral presentation titled 'Under-ice oceanography of the NEW polynya region with an Autonomous Underwater Vehicle' at the '*Instrumentation related to polar regions and the IPY*' session held under the '*Geosciences Instrumentation and Data Systems*' programme. This was another fantastic experience that gave me valuable exposure to a wide-range of European scientists in the fields of oceanography, data acquisition and autonomous lagrangian platforms.

In conclusion I am very grateful for the opportunities afforded to me by this bursary and would like to thank CASEE, NERC, Dr Ken Collins and in particular Dr Jeremy Wilkinson for their support in this.

References

Wadhams, P., Wilkinson, J. P., McPhail, S. D., 2006. A New View of the Underside of Arctic Sea Ice. Geophysical Research Letters 99, 20,417–20,426.