DRI TECHNICAL PROGRAM: Emerging Dynamics Of The Marginal Ice Zone

Ice, Ocean and Atmosphere Interactions in the Arctic Marginal Ice Zone

Year 4 Annual Report

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LONG-TERM GOALS

This DRI TECHNICAL PROGRAM (Emerging Dynamics Of The Marginal Ice Zone) brings together a high-level (global) scientific team in order to better understand the ocean, sea ice and atmosphere interaction within the marginal ice zone (MIZ) north of Alaska. The aim of this multi-disciplinary group is to deliver a step change in our understanding of the processes within the MIZ. This is being achieved through a comprehensive, and continuous observational program of the key physical parameters that influence the development of the MIZ. Our long-term goal is to determine the complex inter-linkages between atmosphere-ice-ocean processes so that, ultimately, parameterisations of MIZ processes can be developed for large-scale models.

OBJECTIVES

Our team's role in this DRI is to better understand the ice-ocean-interactions within the MIZ. This is being achieved through the deployment (2014) an autonomous data acquisition network of ice mass balance buoys (IMBs), wave buoys (WBs), and Automatic Weather Stations (AWS) in the region north of Alaska. The now deployed arrays have a number of roles within our project, with the main priorities being:

(a) the dynamic and thermodynamic evolution of the ice covers,
(b) the development of the wave properties from open-ocean into the ice pack, and
(c) the seasonal evolution of key meteorological parameters and
(d) the continuous measurement of open water fraction and floe size distribution over the network/array region SAR remote sensing programme.

The strategy of using the combination of autonomous platforms and remote sensing ensures the full temporal evolution of the ice cover is monitored continuously from its initial break-up, through to its transformation to a MIZ and then the northward retreat of the ice edge. Through the long-term measurement of the key oceanic, atmospheric, and sea ice processes that shape the MIZ, the links and feedbacks between each can be determined and their importance at different stages in the MIZ cycle established. Our observations link with the corresponding oceanic observations and modelling efforts that the DRI-MIZ community are making.

Annual Objectives

Year 1 objectives:

- Integrate our science into the DRI science plan.
  - Result: COMPLETED
- Begin design of IMB/wave buoy electronics.
  - Result: COMPLETED
- Test first prototype electronics under Arctic conditions:
  - Result: COMPLETED

Year 2 objectives:

- Finalise WaveBuoy (WB) design.
  - Result: COMPLETED
- Build and deploy three prototype WBs in the Arctic
  - Result: COMPLETED
- Begin build of Ice Mass Balance Buoys (IMBs), WBs and automatic weather stations (AWSs)
  - Result: Build started
- Consolidate work with the DRI team
  - Result: COMPLETED

Year 3 objectives:

- Ship and deploy 20 xWBs, 20 x IMBs, 4 x AWSs for Spring campaign.
  - Result: COMPLETED
- Ice Camp planning and participation
  - Result: COMPLETED
- Ship and deploy 5 xWBs, 5 x IMBs, 1 x AWSs for Summer campaign.
  - Result: COMPLETED
- Araon cruise: planning and participation
  - Result: COMPLETED
- Plan and collect remote sensing imagery
  - Result: ON-GOING
- Quality control and analyse both buoy and remotely sensed data
  - Result: ON-GOING
- Consolidate work with the DRI team and begin interpretation of data.
  - Result: ON-GOING

Year 4 objectives:

- Quality control of both buoy and remotely sensed data
  - Result: COMPLETED,
- Analysis of buoy and remotely sensed data and preparation of scientific papers.
  - Result: ON-GOING
- Consolidate work with the DRI team and continue with joint interpretation of data.
  - Result: ON-GOING

APPROACH

Staff Involved:

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WORK COMPLETED

Our fourth year of the ONR-MIZ programme has built on the solid foundation we developed within year 1 and year 2 of the project, as well as the successful field campaign in Year 3. We can summarise this year's achievements into two areas:

1. **Research success:** A key component of the success of the MIZ programme has the been the very effective teamwork/collaborations between Partner organisations and participants, as well as the extensive groundwork that was performed by all Parties. Our team (Hwang, Maksym and Wilkinson) continues to play a proactive role now that we are in the research phase of the project. Highlights during this period include:
    a. Archiving and making easily available over
        i. 6 Gigabytes (>27 GB when unpacked) of continuous wave data
        ii. 176 megabytes of ice mass balance data
        iii. 2.8 megabytes of meteorological data
        iv. Significant numbers of SAR remote sensed imagery
    b. Quality control of the above mentioned data
    c. On-going analysis of buoy and remotely sensed data and preparation of scientific papers (see next sections)
    d. Regular Skype meetings between BAS, SAMS and WHOI, as well external teleconferences and meetings with UW, other MIZ team members, and KOPRI. This tight working relationship is a credit to all involved.

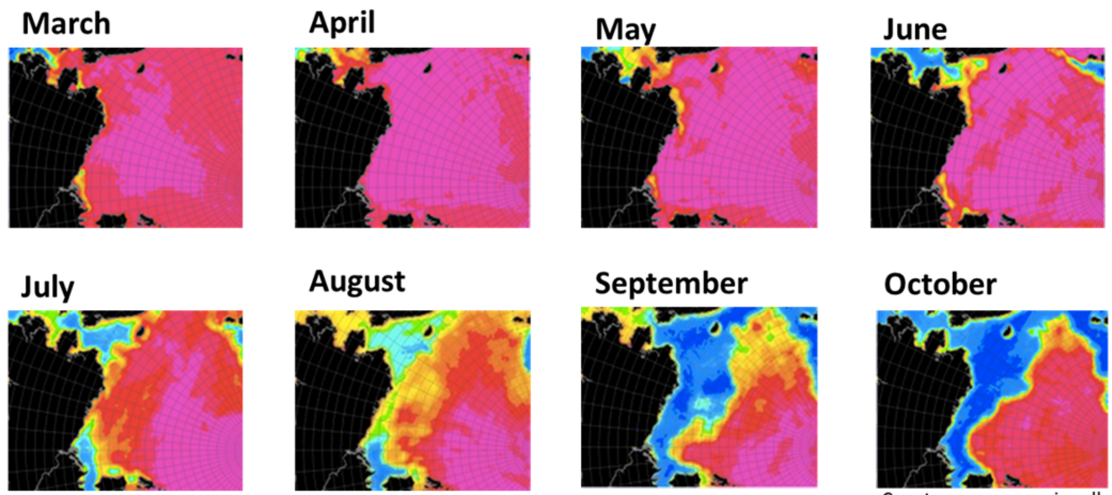
2. Dissemination success: The international impact of the MIZ programme continued to gather momentum in 2014. A selection of some of the major highlights that we were involved in include:
    a. AGU (US): Dedicated session at the Fall AGU meeting on MIZ processes. Wilkinson was one of the co-conveners.
    b. KOPRI (Kr): Hwang and Wilkinson attended a small MIZ workshop that was held at KOPRI. This workshop was aimed at exploring common interests in joint papers and science arising from the MIZ programme.
    c. ASSW (JP): Wilkinson organised a US/Japan/EU workshop on cooperation in Arctic marine science at the Arctic Science Summit Week.

MIZ programme was highlighted as successful example of international cooperation.

d. FSD (UK): Hwang organised a workshop of floe size distribution(FSD) at SAMS in the UK. This workshop highlighted some of the work the MIZ team has been doing in this field.

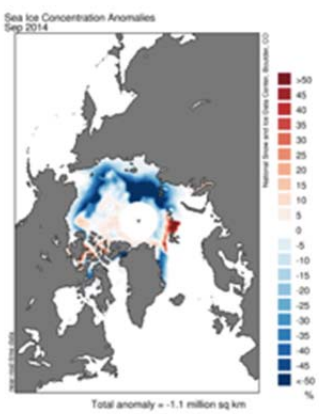
2014 review of the sea ice season.

According to NSIDC the daily minimum in 2014 occurred on September 17th when the sea ice extent occupied 5.02 million square kilometres (after this date the ice extent begins to increase again). This is the 6th lowest ice extent since satellite records began over 30 years ago. From the ice concentration maps below we can see that the region north of Alaska started to open up in July and the ice edge continued to move northward in August and September. In October freeze up well underway and the ice edge began to move southward towards the Alaskan coast.

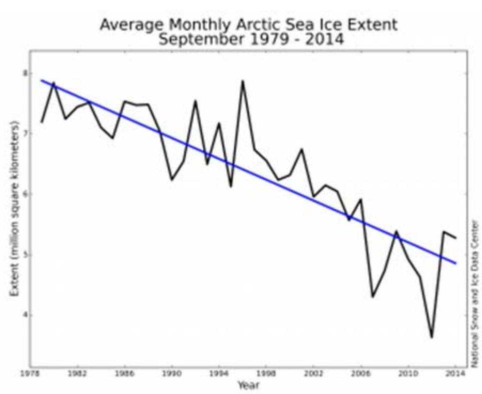


Courtesy: www.seaice.dk

In 2104 the anomalous areas of ice retreat were the region north of Alaska and Siberia. (see figures below). This is not uncommon as these regions have seen the greatest retreat in sea ice. See http://nsidc.org/arcticseaicenews/2014/10/2014-melt-season-in-review/



Arctic sea ice concentration anomalies, September 2014.



Average monthly sea ice extent 1979 - 2014

Images courtesy of NISDC

Results/Analysis

During the spring MIZ deployment we (Maksym/Wilkinson) contributed to the deployment of 20 x WBs, 20 x IMBs, 4 x AWSs. Hwang contributed to the remote sensing part of the programme. These assets were deployed across the four clusters (C1, C2, C3, and C4) in a five-dice array pattern. The distance between the buoys that made up the outside of the array was about 5 km. At the centre of each array was a WB, an AWS, and an IMB, whilst at each corner of the array there was a WB and an IMB installed. Where possible we tried to face the camera of the WB in a southward direction and ensure that any instrumentation deployed on the ice was within the field of view of the camera. A snapshot of where we are at with respect to the analysis form each of these systems is summarised below.

1. Wave Analysis:

A total of 20 Wavebuoys were built for the spring deployment. A summary of their deployment history can be seen in the following table. Of the 20 buoys deployed, 13 continued to transmit data through the summer break up period and into freeze up (October). The metrics from all wave buoys are displayed in the following table.

Wave Buoy identifier	Cluster / asset deployed with	Date of Deployment	Date of last data download	Number of days active
WB201	C2 : IMB02	2014-03-16	2014-11-01	230
WB202	C3 : IMB16	2014-03-18	2014-10-26	222
WB203	C1 : IMB18	2014-03-16	2014-05-11	56
WB204	C4 : IMB14	2014-03-19	2014-10-14	209
WB205	C4 : IMB01	2014-03-19	2014-07-29	132
WB206	C3 : IMB19	2014-03-18	2014-10-25	221
WB207	C1 : IMB12	2014-03-16	2014-10-19	217
WB208	Did not Boot up!	Did not Boot up!	Did not Boot up!	0
WB209	C4 : AWS04	2014-03-19	2014-10-03	198
WB210	C1 : IMB07 AWS01	2014-03-16	2014-09-06	174
WB211	C2 : IMB17 AWS02	2014-03-16	2014-10-31	229
WB212	C2 : IMB06	2014-03-16	2014-11-05	234
WB213	C3 : IMB11	2014-03-18	2014-10-28	224
WB214	C2 : IMB10	2014-03-16	2014-10-21	219
WB215	C2 : IMB03	2014-03-16	2014-10-28	226
WB216	C1 : IMB13	2014-03-16	2014-08-23	160
WB217	C4 : IMB20	2014-03-19	2014-10-25	220
WB218	C3 : IMB08	2014-03-18	2014-07-09	113
WB219	C1 : IMB15	2014-03-16	2014-09-07	115
WB220	C4 : IMB05	2014-03-19	2014-10-26	221

Table: Wavebuoy metrics by identification number.

Wave buoy metrics by cluster

The marginal ice zone is an extremely difficult region to monitor with autonomous equipment and therefore we were extremely fortunate to have so many wave buoys continuing to transmit data through to freeze up. However, we can see below that Cluster 1 had the most losses, with only one system making it through to October. This may be due to the fact that these were the first systems to break-out, and thus they spent the most time drifting within the ice edge region.

Cluster 1

Wave Buoy identifier	Cluster / asset deployed with	Date of Deployment	Date of last data download	Number of days active
WB203	C1 : IMB18	2014-03-16	2014-05-11	56
WB207	C1 : IMB12	2014-03-16	2014-10-19	217
WB210	C1 : IMB07 AWS01	2014-03-16	2014-09-06	174
WB216	C1 : IMB13	2014-03-16	2014-08-23	160
WB219	C1 : IMB15	2014-03-16	2014-09-07	115

Cluster 2

Wave Buoy identifier	Cluster / asset deployed with	Date of Deployment	Date of last data download	Number of days active
WB201	**C2 : IMB02**	**2014-03-16**	**2014-11-01**	**230**
WB211	**C2 : IMB17 AWS02**	**2014-03-16**	**2014-10-31**	**229**
WB212	**C2 : IMB06**	**2014-03-16**	**2014-11-05**	**234**
WB214	**C2 : IMB10**	**2014-03-16**	**2014-10-21**	**219**
WB215	**C2 : IMB03**	**2014-03-16**	**2014-10-28**	**226**

Cluster 3

Wave Buoy identifier	Cluster / asset deployed with	Date of Deployment	Date of last data download	Number of days active
WB202	**C3 : IMB16**	**2014-03-18**	**2014-10-26**	**222**
WB206	**C3 : IMB19**	**2014-03-18**	**2014-10-25**	**221**
WB208	Did not Boot up!	Did not Boot up!	Did not Boot up!	0
WB213	**C3 : IMB11**	**2014-03-18**	**2014-10-28**	**224**
WB218	**C3 : IMB08**	**2014-03-18**	**2014-07-09**	**113**

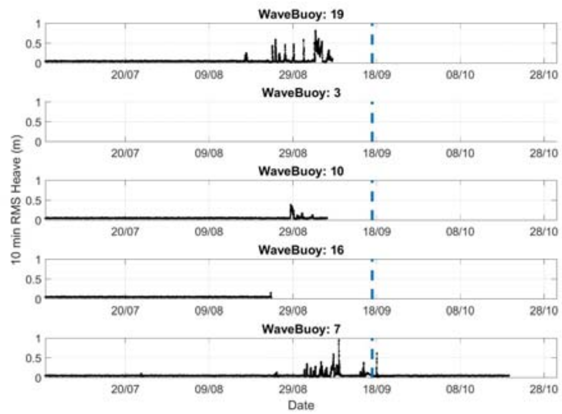
Cluster 4

Wave Buoy identifier	Cluster / asset deployed with	Date of Deployment	Date of last data download	Number of days active
WB204	**C4 : IMB14**	**2014-03-19**	**2014-10-14**	**209**
WB205	**C4 : IMB01**	**2014-03-19**	**2014-07-29**	**132**
WB209	**C4 : AWS04**	**2014-03-19**	**2014-10-03**	**198**
WB217	**C4 : IMB20**	**2014-03-19**	**2014-10-25**	**220**
WB220	**C4 : IMB05**	**2014-03-19**	**2014-10-26**	**221**

Next steps: Waves

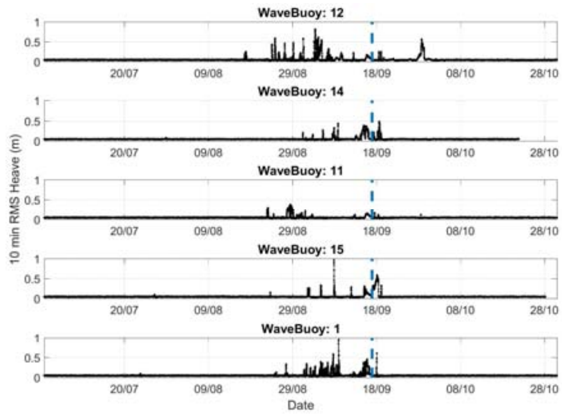
We can see from the figure below that the 2014 season was very quiescent with very little wave activity being seen until near the end of August. This is particularly interesting as by this time the sea ice had already progressed through much of the melt season and the ice-edge was situated quite far north (see ice concentration image on 1 Sept. page 4).

CLUSTER 1



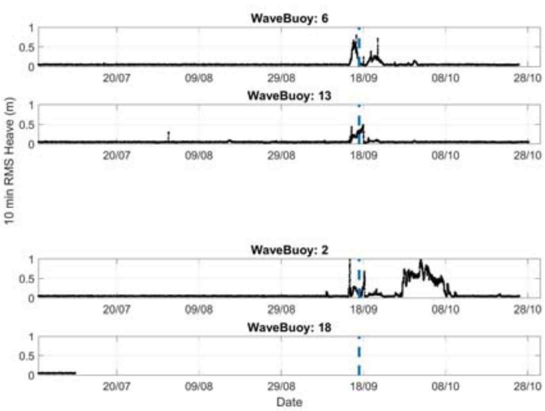
RMS of wave height (heave) for the wavebuoys within Custer 1. Each point in the graph is calculated from a 10 minute window of 1 second heave readings. Blue line indicates the start of freeze up (NSIDC).

CLUSTER 2



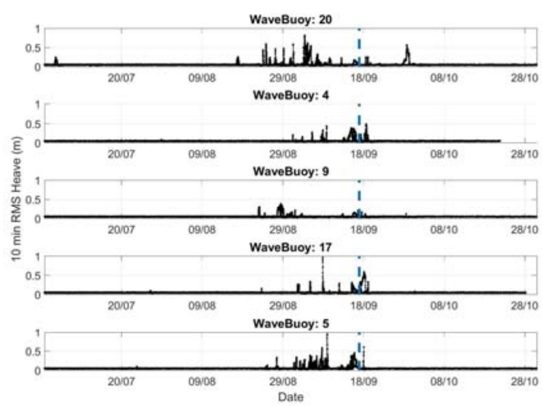
RMS of wave height (heave) for the wavebuoys within Custer 2. Each point in the graph is calculated from a 10 minute window of 1 second heave readings. Blue line indicates the start of freeze up (NSIDC).

CLUSTER 3



RMS of wave height (heave) for the wavebuoys within Custer 3. Each point in the graph is calculated from a 10 minute window of 1 second heave readings. Blue line indicates the start of freeze up (NSIDC).

CLUSTER 4



RMS of wave height (heave) for the wavebuoys within Custer 4. Each point in the graph is calculated from a 10 minute window of 1 second heave readings. Blue line indicates the start of freeze up (NSIDC).

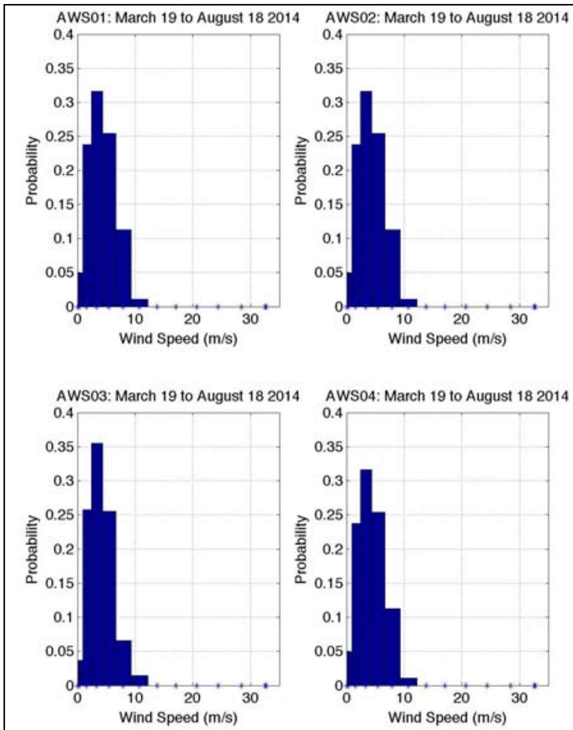
However from the end of August until freeze up, on the September 17th (dotted blue line in graphs), a continuous number of wave events were witnessed. In fact these wave events occurred well into October. An area of interest, and one that we are actively pursuing (Doble, Wadhams, Thompson and Wilkinson), is why despite the wavebuoys being relatively close to each other they do not see the same wave events. This clearly highlights the role sea ice plays in attenuating wave energy.

2. AWS Analysis

A total of 4 AWSs were deployed during the MIZ spring campaign. Each one was located at the centre of a Cluster. These systems monitored wind speed and direction, incoming solar radiation, humidity, air temperature, and air pressure. The metrics from the AWSs are displayed in the following table.

AWS identifier	Cluster / asset deployed with	Date of Deployment	Date of last data download	Number of days active
AWS01	C1: WB210 : IMB07	2014-03-16	2014-08-19	156
AWS02	C2: WB211 : IMB17	2014-03-16	2014-09-20	188
AWS03	C3: WB208 : IMB04	2014-03-18	2014-08-18	153
AWS04	C4: WB209 : IMB09	2014-03-19	2014-09-15	180

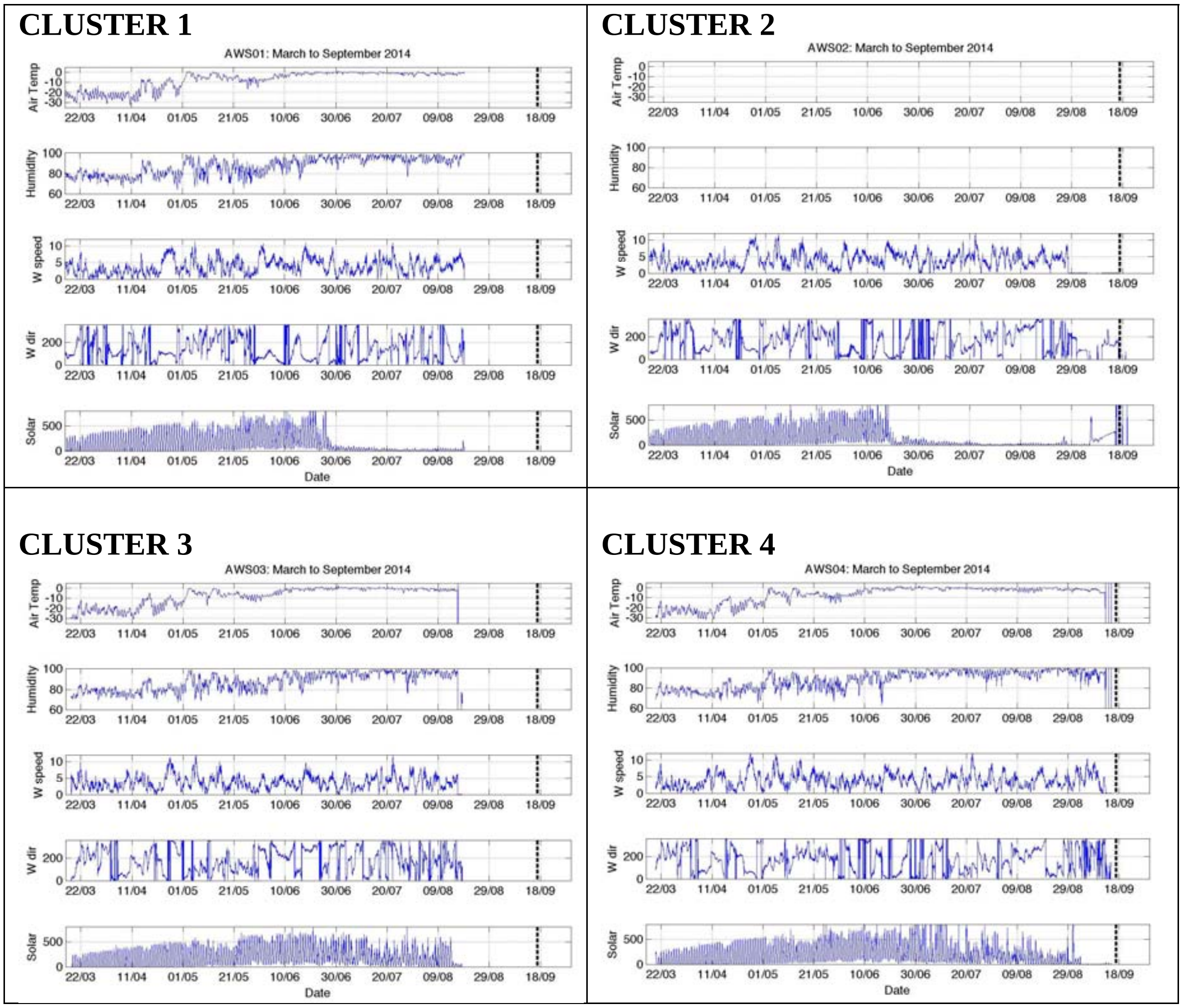
As the systems do not float once the floe they were deployed upon breaks up or melt the system cannot transmit data. Given that the systems remained active until August and September it suggests that all systems continued to work until they sank.



Probability histogram of wind-speed as seen by each AWS between March 19 and August 18 (when all systems were simultaneously active). Despite the separation between the AWS systems (initially 100 km) the winds speeds are very similar. Generally speaking the wind speeds up until mid-August were slight As can be seen very few measurements were above 10 m/s. This is equivalent to a Fresh breeze or less in the in Beaufort Scale.
(note: Bar width are in Beaufort Scale)

AWS04 upon deployment in March 2014 (taken by Wavebuoy WB209)

AWS04 in September 2014. As the system is still upright the meteorological measurements as still valid. At this stage the ice is very weak and the AWS only lasted another two weeks.



A time-series of all parameters that were logged by each AWS can be seen in the figure above. These data are now being used by many MIZ teams. Dotted line highlights when freezing began.

3. IMB Analysis:

Monitoring the mass balance of snow and sea ice is an important part of understanding the processes that drive the formation of a marginal ice zone. We deployed 20 IMBs during the spring campaign. Like the AWSs the IMBs do not float and therefore can only transmit data when the floe they are sitting on remains intact. The metrics from the IMBs are displayed in the following table. As the IMB chain, with its 250 temperature sensors, is frozen into the ice any movement of the electronics pod (yellow pelicase) can sever the chain. When this happens the unit still sends back GPS data, therefore the last two columns of the table below displays information on the date of GPS and chain downloads.

Wave Buoy Identifier	Cluster / asset deployed with	Date of Deployment	Last data download (GPS /Chain data)	Days of activity (GPS /Chain data)
IMB01	C4: WB205	2014-03-16	2014-05-01/ 2014-04-29	46/ 44
IMB02	C2: WB201	2014-03-18	2014-09-21/ 2014-09-20	187/ 186
IMB03	C2: WB215	2014-03-16	2014-09-06/ 2014-07-26	174/ 132
IMB04	C3: WB208:AWS03	2014-03-19	2014-09-27/ 2014-08-18	192/ 152
IMB05	C4: WB220	2014-03-19	2014-09-14/ 2014-06-09	179/ 82
IMB06	C2: WB212	2014-03-18	2014-09-24 / 2014-08-18	190/ 153
IMB07	C1: WB210:AWS01	2014-03-16	2014-08-24/ 2014-08-24	161/ 161
IMB08	C3: WB218	2014-03-19	2014-09-18/ 2014-09-07	183/ 172
IMB09	C4: AWS04	2014-03-19	2015-05-25/ 2014-08-21	432/ 155
IMB10	C2: WB214	2014-03-16	2014-09-12/ 2014-07-29	180/ 135
IMB11	C3: WB213	2014-03-16	2014-07-19/ 2014-06-11	125/ 87
IMB12	C1: WB207	2014-03-16	2014-07-29/ 2014-07-23	135/ 129
IMB13	C1: WB216	2014-03-18	2014-10-24 / 2014-08-24	220/ 159
IMB14	C4: WB204	2014-03-16	2014-11-07/ 2014-08-18	226/ 155
IMB15	C1: WB219	2014-03-16	2014-09-02/ 2014-08-09	170/ 146
IMB16	C3: WB202	2014-03-16	2014-09-27/ 2014-08-17	195/ 154
IMB17	C2: WB211:AWS02	2014-03-19	2014-08-27/ 2014-08-24	161/ 158
IMB18	*Did not boot up!*	*Did not boot up!*	*Did not boot up!*	0
IMB19	C3: WB206	2014-03-16	2014-10-12/ 2014-07-16	210/ 122
IMB20	C4: WB217	2014-03-19	2015-09-23/ 2014-09-07	553/ 172

IMB metrics by cluster

CLUSTER1

Wave Buoy Identifier	Cluster / asset deployed with	Date of Deployment	Last data download (GPS /Chain data)	Number of days active (GPS /Chain data)
IMB07	C1: WB210:AWS01	2014-03-16	2014-08-24/ 2014-08-24	161/ 161
IMB12	C1: WB207	2014-03-16	2014-07-29/ 2014-07-23	135/ 129
IMB13	C1: WB216	2014-03-18	2014-10-24 / 2014-08-24	220/ 159
IMB15	C1: WB219	2014-03-16	2014-09-02/ 2014-08-09	170/ 146
IMB18	*Did not boot up!*	*Did not boot up!*	*Did not boot up!*	0

CLUSTER2

Wave Buoy Identifier	Cluster / asset deployed with	Date of Deployment	Last data download (GPS /Chain data)	Number of days active (GPS /Chain data)
IMB02	C2: WB201	2014-03-18	2014-09-21/ 2014-09-20	187/ 186
IMB03	C2: WB215	2014-03-16	2014-09-06/ 2014-07-26	174/ 132
IMB06	C2: WB212	2014-03-18	2014-09-24 / 2014-08-18	190/ 153
IMB10	C2: WB214	2014-03-16	2014-09-12/ 2014-07-29	180/ 135
IMB17	C2: WB211:AWS02	2014-03-19	2014-08-27/ 2014-08-24	161/ 158

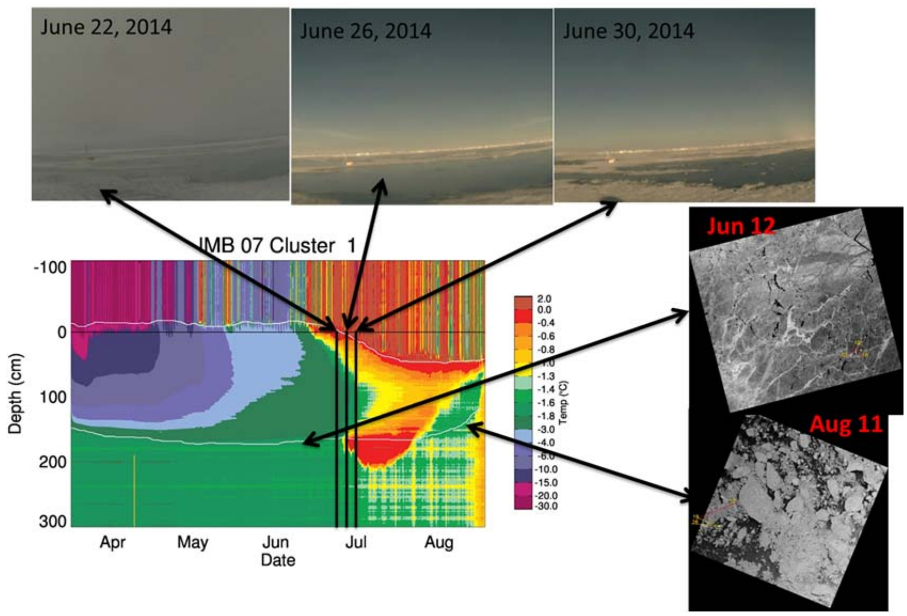
CLUSTER3

Wave Buoy Identifier	Cluster / asset deployed with	Date of Deployment	Last data download (GPS /Chain data)	Number of days active (GPS /Chain data)
IMB04	C3: WB208:AWS03	2014-03-19	2014-09-27/ 2014-08-18	192/ 152
IMB08	C3: WB218	2014-03-19	2014-09-18/ 2014-09-07	183/ 172
IMB11	C3: WB213	2014-03-16	2014-07-19/ 2014-06-11	125/ 87
IMB16	C3: WB202	2014-03-16	2014-09-27/ 2014-08-17	195/ 154
IMB19	C3: WB206	2014-03-16	2014-10-12/ 2014-07-16	210/ 122

CLUSTER4

Wave Buoy Identifier	Cluster / asset deployed with	Date of Deployment	Last data download (GPS /Chain data)	Number of days active (GPS /Chain data)
IMB20	C4: WB205	2014-03-16	2014-05-01/ 2014-04-29	46/ 44
IMB20	C4: WB220	2014-03-19	2014-09-14/ 2014-06-09	179/ 82
IMB20	C4: AWS04	2014-03-19	2015-05-25/ 2014-08-21	432/ 155
IMB20	C4: WB204	2014-03-16	2014-11-07/ 2014-08-18	226/ 155
IMB20	C4: WB217	2014-03-19	2015-09-23/ 2014-09-07	553/ 172

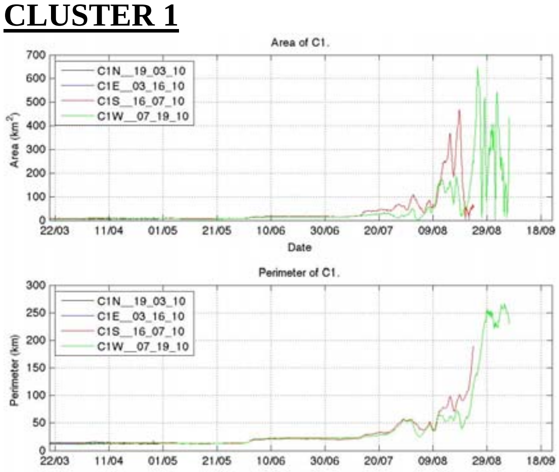
Given the large number of IMBs that were deployed and lasted through to break up we have a direct measure of surface and basal ablation rates. This information is being married to the surface forcing data so that estimates of large-scale melt rates can be achieved. An important part of understanding the results of the IMBs is the 6 hourly photographs, especially in the formation and drainage of meltponds. This can be seen in the images below which show the appearance and drainage of a meltpond and its warm water signature below the ice cover.



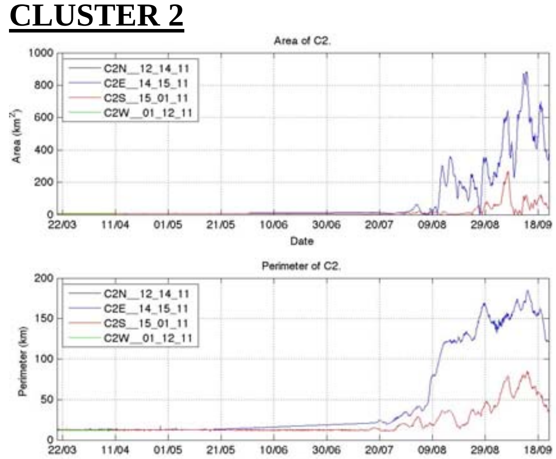
4. Sea ice dynamics

With so many GPS enables devices in each array it is possible to investigate the deformation the each array undergoes. That is the differential kinetic parameters (DKPs) that describe the deformation of the array – divergence/area, vorticity, and shear and deformation. The figures below show the changing area within a set of three wavebuoys (northern, eastern, southern and western set of three) for each Cluster. This indicates when break-up in the region began i.e. near the end of July.

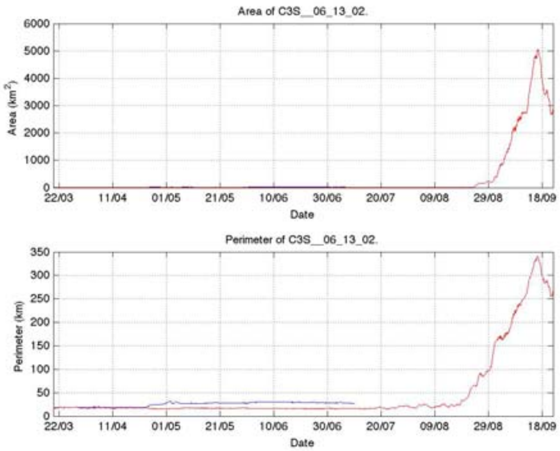
CLUSTER 1



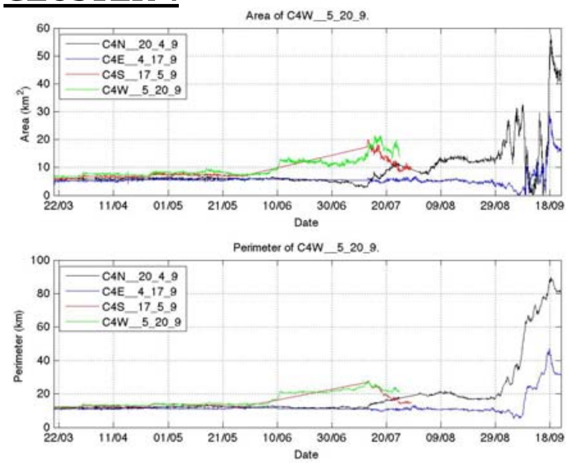
CLUSTER 2



CLUSTER 3



CLUSTER 4

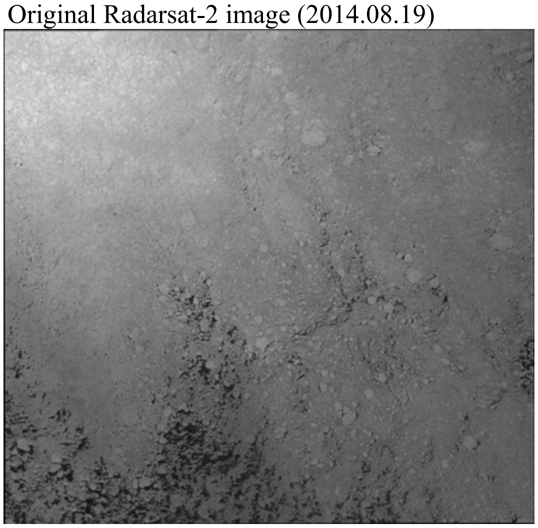


5. Remote sensing Analysis:

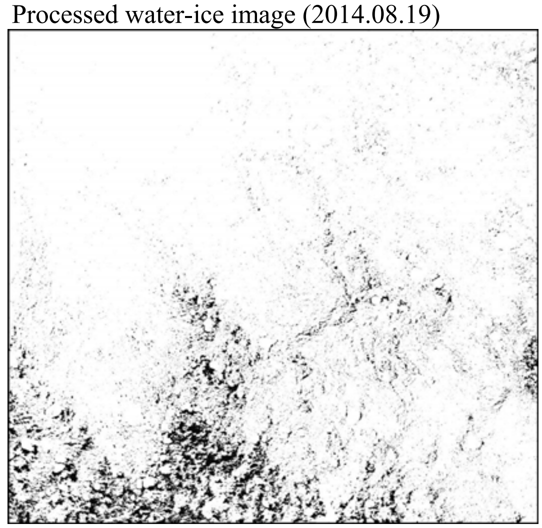
The 4 MIZ buoy clusters as well as the summer cluster (Cluster 5) were well captured by satellite imagery. The SAR images acquired by CSTARS (Graber) are 63 x Radarsat-2 images and 378 x TerraSAR-X images. Hwang acquired an additional 30 TerraSAR-X images.

Radarsat-2 images, ScanSAR Wide (SCW), offer pixel spacing of 50 m and swath size of 500 by 500 km. At the MIZ meeting the processing of Rardarsat-2 images was set as a high priority. Our team (Hwang) processed the Radarasat-2 images by using adjusted Kernel Graph Cut algorithm (so far 23 data processed and uploaded into the CSTARS ftp site). The same water-ice analysis was done for TerraSAR-X images as well.

Original Radarsat-2 image (2014.08.19)



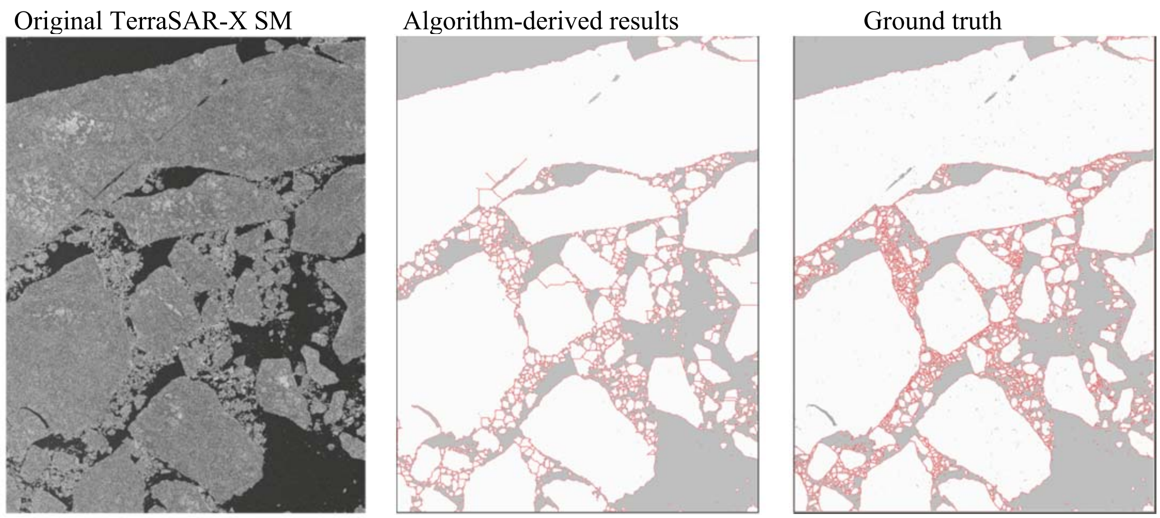
Processed water-ice image (2014.08.19)



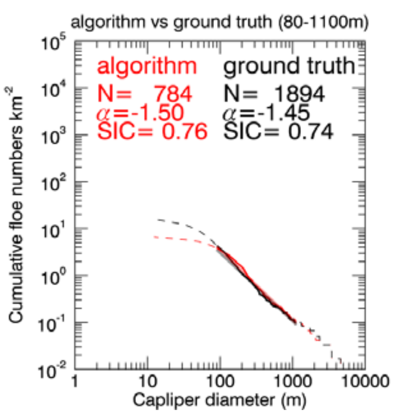
An example of Radarsat-2 image (left) acquired August 19, 2014, and the processed water-ice image (right). White is ice and black is water.

The algorithm for the retrieval of sea ice floe size distribution (FSD) was developed and validated against the ground truth data. The validation shows promising results, and journal manuscript is in preparation to be submitted.

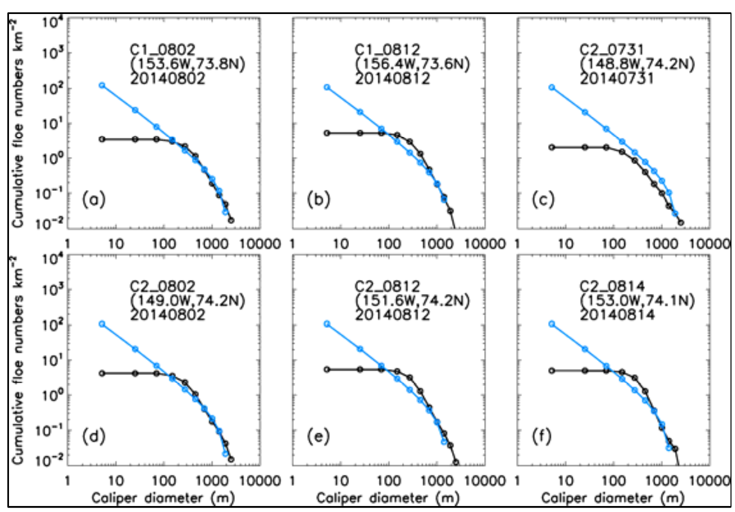
FSD data have been produced from TerraSAR-X images (acquired by CSTARS) by using the developed algorithm. These FSD data have been shared among the members of the ONR MIZ DRI team for the comparison with Zhang's MIZMAS model (see example below) as well as Schweiger's MODIS-derived FSD. Collaborative papers are in preparation for the submission. Further FSD analysis on remaining TerraSAR-X images is on-going.



Original TerraSAR-X SM image is shown above, along with algorithm-derived results and ground truth data in which the red lines indicate floe boundary (above). Ground truth data was manually constructed with aid of high-resolution visible image from the USGS GFL.



Validation results of FSD between algorithm and ground truth in terms of cumulative floe size distribution (left).In the plot N is the number of identified floes, α is the exponent of power law, and SIC is sea ice concentration (left).



Comparison between TerraSAR-X and MIZMAS FSD results. TerraSAR-X FSDs are shown in black, and MIZMAS in blue.

IMPACT/APPLICATIONS
[Potential future impact for science and/or systems applications]
N/A at present.

TRANSITIONS
N/A at present.

RELATED PROJECTS
- ICE-ARC EU FP7 funded programme
- DRI-Sea State

REFERENCES
N/A

PUBLICATIONS
N/A

PATENTS
N/A

HONORS/AWARDS/PRIZES
N/A