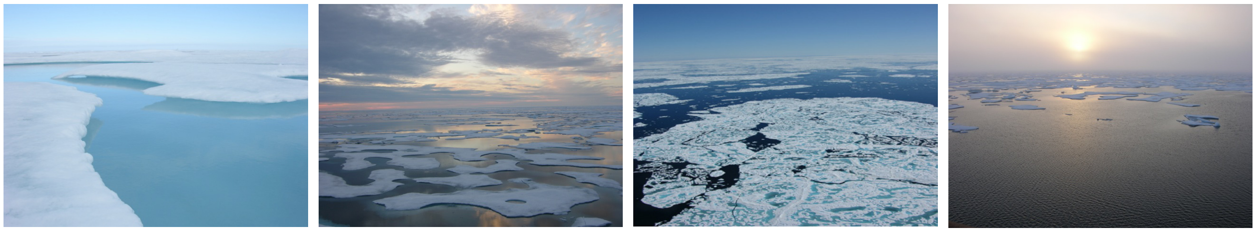

Marginal Ice Zone (MIZ) Program: Science and Experiment Plan

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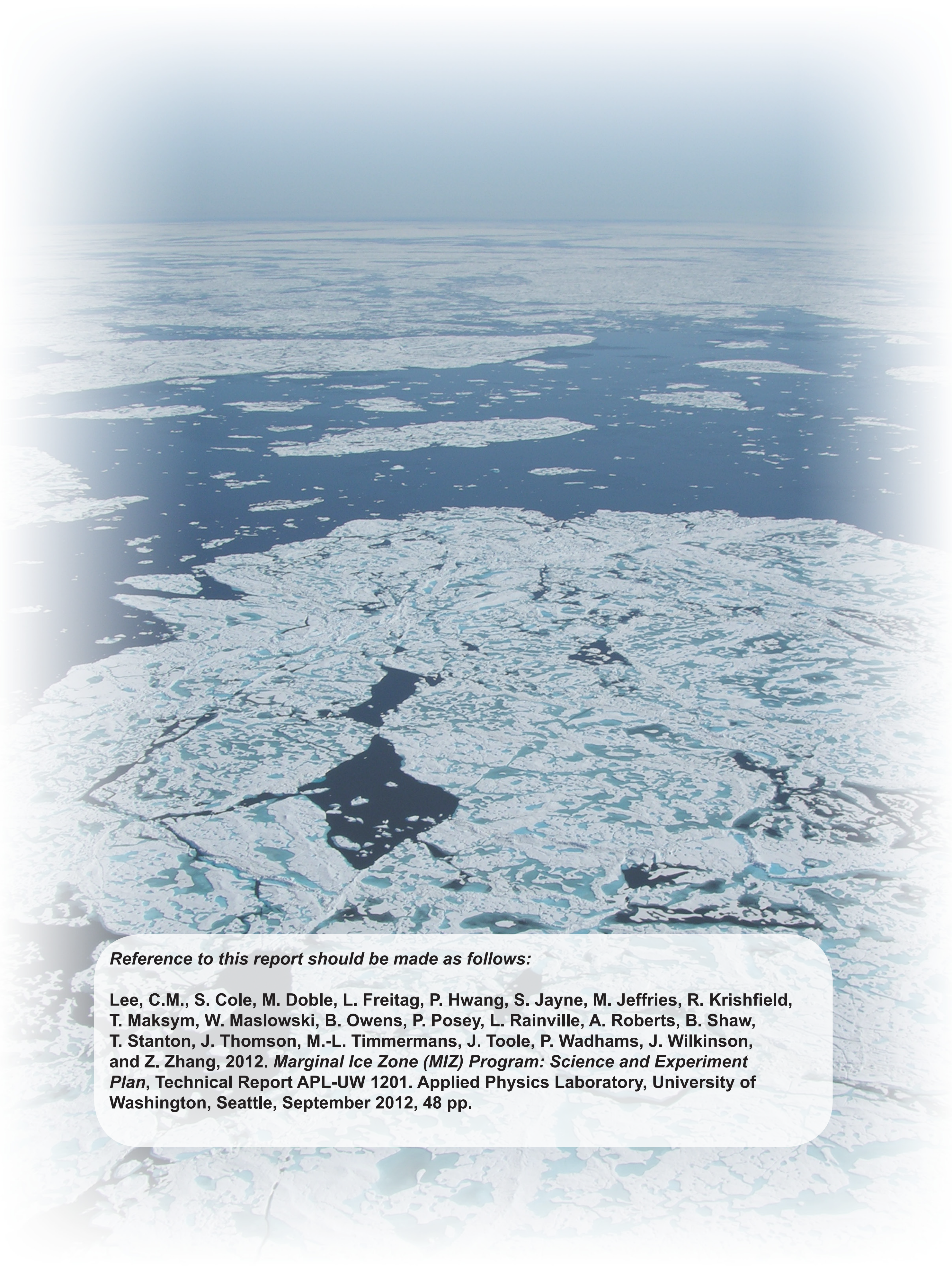
Technical Report

APL-UW 1201
October 2012

Applied Physics Laboratory University of Washington
1013 NE 40th Street Seattle, Washington 98105-6698

Grant numbers: Freitag, N000141210176; Lee, N000141210180; Maksym, N000141210346; Owens, N000141210110; Stanton, N0001412WX20737; Thomson, N000141210113; Toole, N000141210140; Wadhams, N000141210130; Wilkinson, N000141210359; and Zhang, N000141210112



Reference to this report should be made as follows:

Lee, C.M., S. Cole, M. Doble, L. Freitag, P. Hwang, S. Jayne, M. Jeffries, R. Krishfield, T. Maksym, W. Maslowski, B. Owens, P. Posey, L. Rainville, A. Roberts, B. Shaw, T. Stanton, J. Thomson, M.-L. Timmermans, J. Toole, P. Wadhams, J. Wilkinson, and Z. Zhang, 2012. *Marginal Ice Zone (MIZ) Program: Science and Experiment Plan*, Technical Report APL-UW 1201. Applied Physics Laboratory, University of Washington, Seattle, September 2012, 48 pp.

CONTENTS

1. INTRODUCTION

Over recent decades the Arctic has warmed more than any other region (IPCC reports and references therein), accompanied by visible changes to arctic sea ice. Arctic sea ice extent has been in decline since at least 1979, when passive microwave satellite observations began providing the measurements needed to document these quantities (*Perovich et al*., 2012). Arctic sea ice thickness has also been decreasing, leading to significant reduction in sea ice volume (*Kwok et al*., 2009; *Schweiger et al*., 2011). An abrupt change in summer ice extent occurred in September 2007, when a new record minimum was observed. Unexpected at the time, it has since become clear that this event was not an anomaly — the minima of the last six summers (2007–2012) have been the five lowest in the satellite record (1979–2012). In September 2012, arctic sea ice extent reached a new low; dropping to less than 4 million square kilometers for the first time.

Simultaneously, perennial ice has been replaced rapidly by thinner first-year ice (e.g., *Maslanik et al*., 2007) with significant changes in the age distribution (a proxy for thickness distribution) of the ice cover. At the end of summer 2011, the extent of the oldest ice (4 and 5 years) reached a new minimum that was just 19% of the 1982–2005 mean (*Perovich et al*., 2012). As the age/thickness distribution has shifted towards lower values, sea ice drift speed has increased and the ice cover has become more mobile (*Rampal et al*., 2009).

This reduction is set to continue with some coupled models predicting an 'ice-free' arctic summer by 2040 (e.g., *Holland et al*., 2006; *Wang and Overland*, 2009). Even though sea ice will continue to form during the arctic winter, the number of ice-free days in summer will continue to increase in the late 21st century.

A significant feature of the recent (2007–2012) decrease in ice extent has been the retreat of the ice edge away from the coast and continental shelves. At the time of minimum ice extent, the ice edge has been located above the deep ocean, exposing large areas of previously ice-covered waters (Figure 1). The Beaufort Sea and Canada Basin north of Alaska and Yukon have experienced the fastest decline and greatest loss in arctic summer ice (*Shimada et al*., 2006).

The Beaufort Sea lends its name to the Beaufort Gyre, the anti-cyclonic movement of ice and surface waters that occurs in the Canada Basin in response to the large-scale atmospheric circulation. As a consequence of the anticyclonic motion and Ekman transport, the Beaufort Gyre has the distinction of being the largest store of fresh water in the Arctic Ocean (*Proshutinsky et al*., 2011).

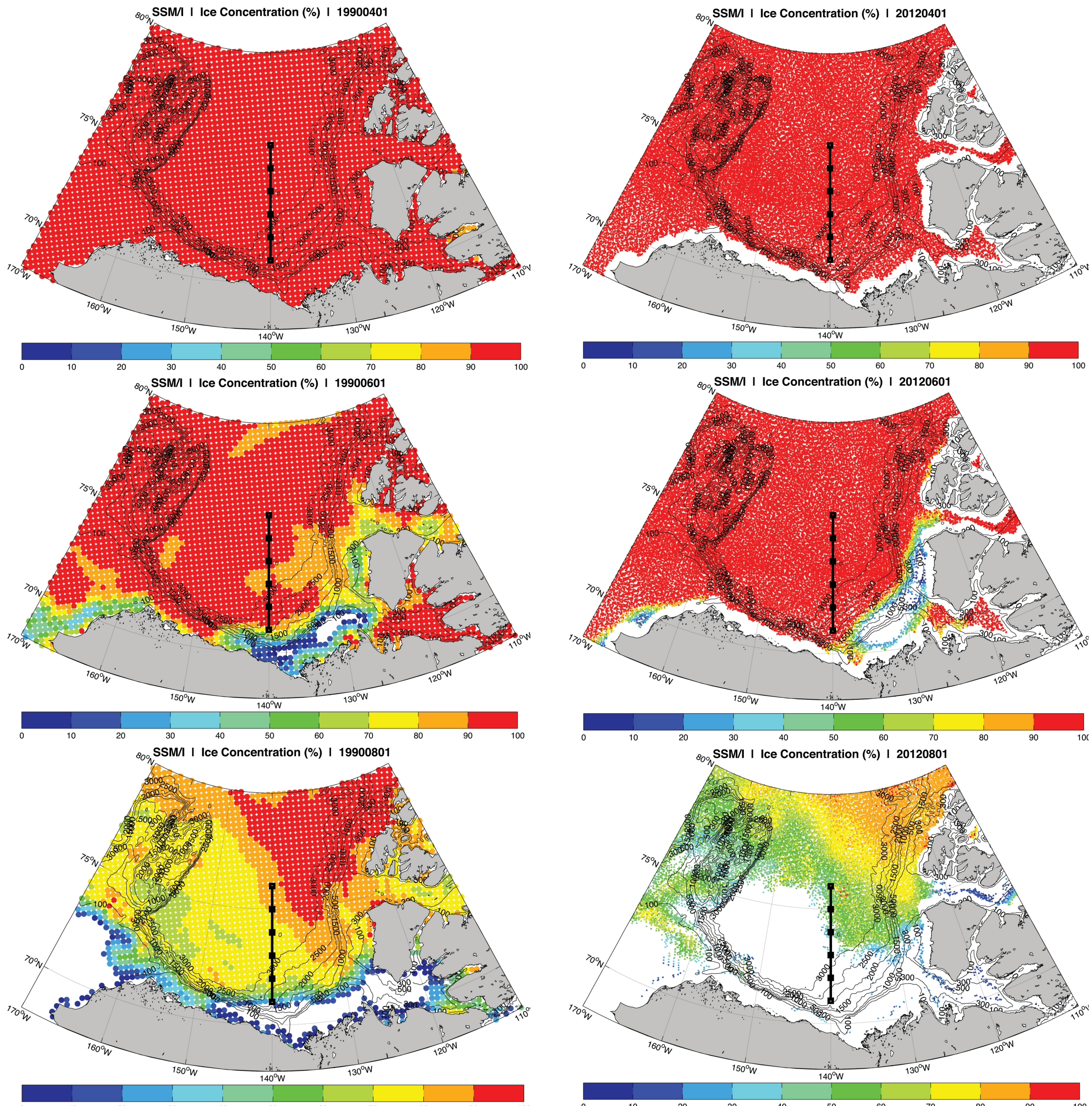


Figure 1. SSM/I ice cover for April, June, and August (top, middle, and bottom) for 1990 (left) and 2012 (right). Prior to the recent period of sea ice decline, the MIZ rarely extended beyond the Alaska slope. More recently, the seasonal MIZ develops in July and retreats rapidly northward, leaving large expanses of open water over the Alaska slope and into the deep Beaufort Sea.

The Beaufort Gyre is also responsible for the generation of most of the thickest and oldest ice in the Arctic Ocean, adjacent to northern Greenland and along the northwestern margin of the Canadian Arctic Archipelago. The Beaufort Gyre carries ice from the northwestern margin of the Canadian Arctic Archipelago southwestward into the Beaufort Sea, immediately north of Yukon and Alaska. There is now evidence for accelerated decay of old ice, possibly amplified by waves and swell, in this region

(*Barber et al*., 2009; *Asplin et al*., 2012), where the ice is melting completely rather than surviving the summer and re-circulating in the Beaufort Gyre. If this is the case, it would contribute to the basin-wide decrease in the age/thickness distribution of the ice cover.

The summer ice retreat and opening of the Beaufort Sea are creating conditions that favor the formation of a marginal ice zone (MIZ). There is no single definition of the MIZ, but according to *Wadhams* (2000) a true MIZ has its features permanently determined by its contact with an ocean in which long-period, large-amplitude waves are frequently present. Those waves are integral to another definition of the MIZ as "… the zone at the edge of the pack ice whose width is the lateral distance over which the penetration of waves can fracture the ice, thereby changing the morphology of the floes." (*Weeks*, 2010).

Waves and swell penetrating into the pack ice can reduce large ice floes into many smaller floes in a matter of hours. The smaller floes are then more susceptible to melting, particularly below the waterline, and dynamic forcing, which together accelerate ice decay. A specific example of this positive feedback is the penetration of a long-period (13.5 s), 200–300-m wavelength swell to distances to as much as 250 km into the ice pack of the eastern Beaufort Sea in September 2009 (*Asplin et al*., 2012). The retreat of the pack ice, and opening of the Beaufort Sea and neighboring areas to the west, are creating fetch conditions that favor the generation of waves and swells, which have the potential to transform the ice cover and create a MIZ where there was none before. Understanding the complex air–ice–ocean–wave interactions contributing to that positive feedback process in the MIZ is vital to improving predictions of ice edge location, and the nature (concentration, floe size, thickness, velocity) of the ice in the vicinity of the ice edge.

Much hinges on improving sea ice prediction capability. The unprecedented retreat of the pack ice in recent years has prompted growing interest in access to the Arctic Basin and adjacent high latitude waters. The media is rife with reports of likely increases in tourism, including cruise ship operations; trans-polar and intra-arctic maritime transportation; and natural resource development, including fishing, minerals and oil and gas. These, in turn, have implications for homeland and national security, and thus the U.S. Coast Guard and the U.S. Navy.

Among U.S. Navy responses to the rapid changes being observed in the Arctic, and their implications, was the establishment of Task Force Climate Change (TFCC) and the development of the Arctic Roadmap (*U.S. Navy*, 2009). The Arctic Roadmap identifies understanding arctic change and improving projections, particularly when and to what extent the sea ice will recede and allow increased maritime access, as a desired effect. The objective is to provide Navy leadership and decision-makers with a comprehensive understanding of the current and predicted arctic physical environment on tactical, operational, and strategic time and space scales. To achieve this, the Arctic Roadmap identifies research and development of a next generation environmental prediction capability applicable for the Arctic as a significant action item.

At the Office of Naval Research (ONR), the response to the rapid decline in summer ice extent and the Navy's need to understand and predict the arctic physical environment at a variety of time and space scales was to start a new program: Arctic and Global Prediction. The program has three thrusts: (1) sustained observation of the Arctic Ocean environment; (2) understanding the physical environment and processes; and (3) developing integrated air–ice–ocean–wave models for improved prediction. The MIZ DRI (Departmental Research Initiative) encompasses these thrusts in a 5-year research project that focuses on the air–ice–ocean–wave interactions and feedbacks that current evidence indicates are occurring, perhaps even accelerating (e.g., *Barber et al*., 2009; *Asplin et al*., 2012), in the new summer MIZ of the Beaufort Sea. Understanding the interactions and feedbacks in the summer MIZ will, in turn, contribute to improved models and predictions, and greater understanding of the MIZ processes in the projected further decline in arctic sea ice extent.

2. PREVIOUS INVESTIGATIONS OF THE PERMANENT MIZ

Previous programs advanced understanding of MIZ processes and informed the design of the MIZ DRI. These multi-disciplinary efforts, summarized below, focused primarily on the permanent MIZs of the Greenland Sea and Eastern Arctic. Although the results of these programs form the basis of our current understanding of MIZ processes, previous efforts were limited by the available observational technologies. Moreover, until the last few years the seasonal ice MIZ was not a prominent summer feature of the Chuckchi and Beaufort seas. Significant scientific challenges thus remain.

2.1. MIZEX

The first systematic study of the MIZ was the ONR-sponsored MIZEX Project (Marginal Ice Zone EXperiment), with field operations from 1983 to 1987. The concept was born out of a conference on marginal ice zones called by Warren Denner and held at Naval Postgraduate School (NPS) in 1979; the results were published as volume 2 of "Cold Regions Science and Technology" (*CRST*, 1980). A subsequent meeting at Voss, Norway, in October 1980 initiated planning for an ambitious program, with studies on the mesoscale (MIZ process studies) and large scale (influence of MIZ on hemispheric heat and mass transfer). Peter Wadhams, then the Arctic Chair at the Naval Postgraduate School, was asked to be chief editor of a *MIZEX Science Plan* for process studies (*Wadhams et al*., 1981), and Norbert Untersteiner for large-scale studies (*Untersteiner et al*., 1983). Funding began at the end of 1981, with Leonard Johnson as program manager for the ONR High Latitude Physics Program.

The 1981 plan called for an initial winter field program in the Bering Sea, to be followed by two summer field programs in the Greenland Sea in successive years (1983, 1984), with a winter Greenland Sea field program to follow at a later date.

The winter work in the Bering Sea, the so-called "MIZEX-West" experiment led by Seelye Martin, took place during January–March 1983 and used USCGS *Westwind* and the NOAA ship *Discoverer* (*MIZEX-West Study Group*, 1983). This was followed by the main 1983 summer field program in the Greenland Sea employing M/V *Polarbjørn* and the newly-built R/V *Polarstern*, and an even larger 1984 summer field program with *Kvitbjørn*, *Polarstern*, *Polar Queen*, and *Håkon Mosby*, as well as U.S. (NASA and NOAA) and German research aircraft (*MIZEX Group*, 1986). With its greater complexity, and dependence upon results from 1983, this experiment required a dedicated planning document of its own (*Johannessen et al*., 1983). The final field program was a 1987 winter experiment in the Greenland and Barents seas, carried out during March–April using *Polar Circle*, *Håkon Mosby*, and *Valdivia*.

Initial results were reported in a series of "MIZEX Bulletins," edited by Peter Wadhams and Bill Hibler and published by U.S. Army Cold Regions Research and Engineering Laboratory (CRREL). The bulletins have CRREL Special Report numbers and can be retrievd from the CRREL archival system (*MIZEX*, 1983–1986). Final results were published in a wide variety of journals, but with a focus in three special issues of the *Journal of Geophysical Research – Oceans*, published in 1983 (just before the first experiment), 1987, and 1991 (*JGR* 1983, 1987, and 1991).

The MIZEX field programs consisted of the following elements:

- *Wave–ice interaction*: Measuring wave decay in sea ice, the change in the directional wave spectrum with penetration, and the flexural response of floes to waves; comparison of the floe size distribution with predictions based on scattering theory and fracture mechanics; measurements deeper into the ice interior of flexural-gravity waves and of ice deformation produced by internal waves.

- *Ice and ocean dynamics*: Ice edge kinematics experiments using radar transponders to track arrays of floes, and deployment of buoys equipped with weather stations and current meter strings

- *Polar frontal studies*: CTD shipborne surveys; mini-CTD measurements of the ice–ocean boundary layer under MIZ floes; measurements of floe bottom and sidewall ablation rates and of melt pond occurrence and albedo influence

- *Eddies and bands*: The role of ice edge eddies in mass transport, and in mixing and melting across the polar front (largely undertaken using satellite imagery, but also with drifting buoys, including radar transponder buoys); a special study of the semi-permanent topographically-controlled eddy over the Molloy Deep at 79° 10'N, 3°E; formation and properties of ice edge bands

- *Acoustics*: Sound propagation across ice-covered water masses, including scattering and propagation loss; ambient noise in the marginal ice zone due to wave-induced floe–floe collisions and other mechanisms

A large number of institutions in North America and Europe were involved in MIZEX. Among them (using acronyms) were: NERSC, AWI, MIT, ERIM, USGS, NPS, UWash, CRREL, CNRS, Lamont-Dougherty, McPhee, SAIC, Brookhaven, SPRI, BIO, UMiami. It is interesting to note that MIZEX was the first major field program for two new European institutions that have since attained prominence in Arctic science: Nansen Environmental and Remote Sensing Centre and Alfred Wegener Institute.

2.2. Other MIZ Studies

MIZEX was followed by an ONR project called CEAREX (Co-ordinated Eastern ARctic EXperiment), which did not focus entirely on the MIZ. It began with a drift experiment north of Svalbard using *Polarbjørn* deliberately frozen into the ice (September 1988 – January 1989); this was followed by a Fram Strait ice edge component called SIZEX (Seasonal Ice Zone Experiment) (*Johannessen and Sandven*, 1989) in early spring 1989. The focus was on sea ice validation work for the upcoming ERS-1 satellite, but physical and biological oceanographic work was also done. Two temporary ice camps, one for oceanography (‘O’ camp) and another for acoustics (‘A’ camp), were established north of Svalbard while the ship was at work. A further SIZEX program was fielded in 1992.

Other individual studies of the MIZ have taken place. For example, wave–ice work from Cambridge University started in 1966 and continued with East Greenland helicopter-based field programs in 1978–1979 to measure wave attenuation rates in ice (*Wadhams et al*., 1988) and the change in the directional spectrum with penetration (*Wadhams et al*., 1986). After MIZEX, further work in the Greenland Sea ice margin was subsumed into larger-scale programs covering the Greenland Sea as a whole and sponsored mainly by the European Union (EU), e.g., the Greenland Sea Project of 1987–1990 (GSP Group, 1990), which originated from the Arctic Ocean Sciences Board; and the EU ESOP (European Subpolar Ocean Program) of 1993–1995 (*Wadhams et al*., 1999), which covered the entire Greenland Sea with a focus on the Odden ice tongue region at 72–76°N.

A systematic study of another MIZ, modeled on MIZEX, took place in the Labrador Sea (LIMEX, Labrador Ice Margin EXperiment). It was carried out with a spring pilot study in 1987 (*McNutt et al*., 1988) and a main study in 1989 (*Raney et al*., 1989), largely as a remote sensing experiment designed to anticipate the new types of SAR data that would be available from RADARSAT and ERS-1 and the way in which the MIZ would appear in such data. The field work involved a number of remote sensing aircraft equipped with SAR (e.g. the CCRS Convair 580, the AES Lockheed Electra), while the surface ships in the Labrador MIZ (*Terra Nordica* and *Sir John Franklin*, since renamed *Amundsen*) served largely to provide ground truth data.

By contrast with this continued activity in the Arctic, the world's largest and most important MIZ, that of the circumpolar Antarctic, has been the subject of single-ship experiments but no systematic multi-sensor study on the scale of MIZEX.

The strategy outlined here, focused on the new seasonal MIZ of the summertime Beaufort Sea, builds upon the approaches developed by previous efforts while exploiting modern, autonomous systems and satellite services (remote sensing, GPS, and Iridium communications) to span pack ice-covered, MIZ, and open water conditions, resolve a broader range of spatial and temporal scales, and characterize MIZ evolution through a summer melt season.

A terse summary definition of the MIZ (*McPhee*, 1983) provides an excellent perspective:

> "*From the point of view of air–sea interaction, the MIZ is a very complex system: an interface between ocean and atmosphere with potentially extreme horizontal and vertical temperature gradients and large variations in mechanical properties. The 'joker-in-the-deck' is, of course, sea ice — it modifies momentum transfer from the atmosphere; drastically alters surface albedo; serves as an efficient thermal insulator; damps surface wave motion; and, because it is relatively fresher than sea water, may substantially change both temperature and salinity structure in the upper ocean by melting or freezing. Sea ice is highly mobile in response to surface wind, capable of traveling tens of kilometers per day. It thus represents a negative source of both salt and heat that can be advected long distances across water–mass boundaries by atmospheric systems. It is estimated (e.g.,* Hibler*, 1979) that fresh water exported from the Arctic Basin through Fram Strait as sea ice (about 10^5 m^3 s^{-1}) is roughly comparable to the total continental runoff entering the basin. In this sense, the MIZ of the North Atlantic, despite its limited area, is the terminus of a vast territorial watershed.*"

3. PROCESSES IN THE SEASONAL MIZ

3.1. Atmosphere–Ice–Ocean Coupling in the Evolving MIZ

One of the more obvious impacts of the changes in ocean–ice–atmosphere interaction in the Beaufort and Chukchi seas region has been the expansion of a MIZ; a long-standing feature in the Bering and Chukchi seas, but a relatively new phenomena in the deep Beaufort Sea. The transition from fully pack ice-covered conditions to MIZ and, eventually, open water can lead to dramatic shifts in the processes that govern atmosphere–ice–ocean interactions (Figure 2) with profound impacts on upper ocean structure and sea ice evolution.

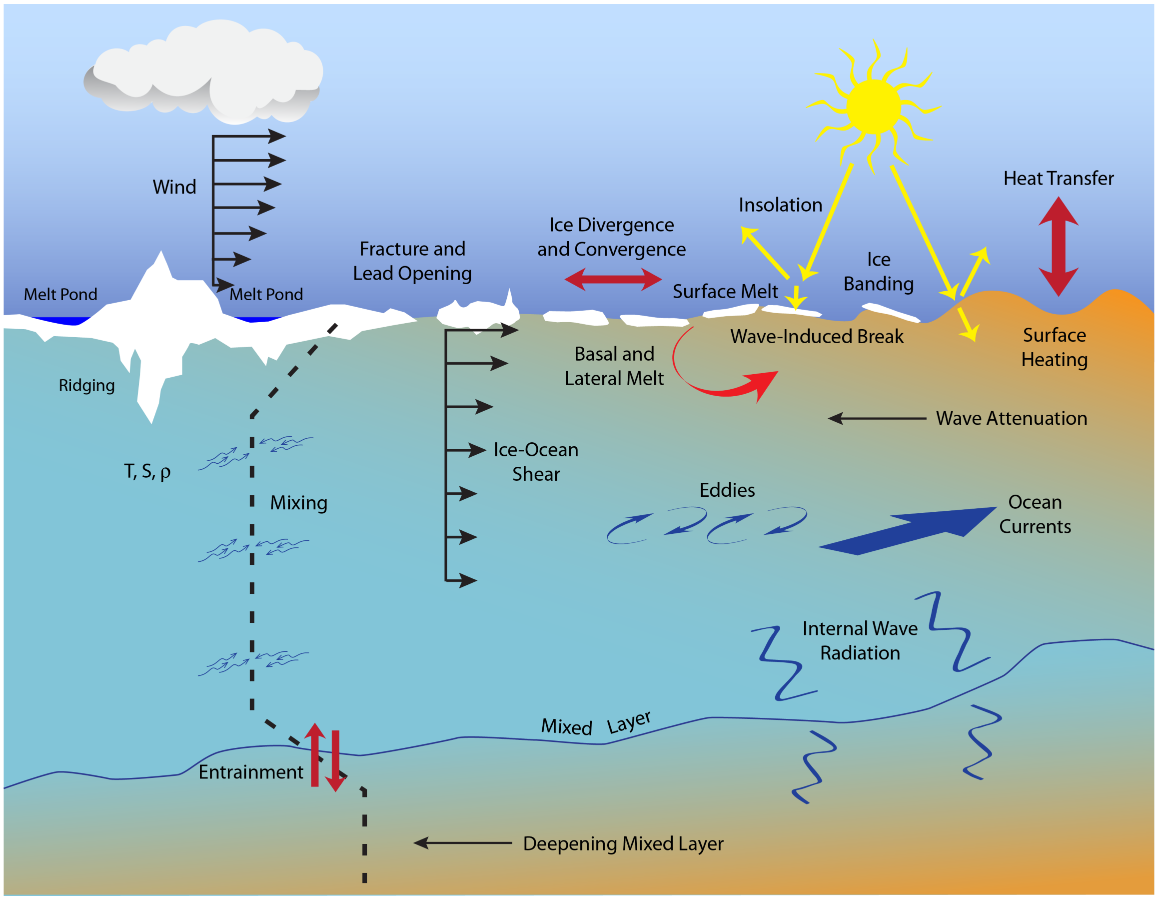


Figure 2. Atmosphere, ice, and upper ocean processes in the MIZ. Ice cover modulates penetration of solar radiation and isolates the upper ocean from direct wind forcing, but increasing open water within the MIZ, and the proximity of large expanses of open water immediately to the south, permits more direct connection with the atmosphere. Strong open water swell and surface wave activity attenuates as it enters the MIZ. Likewise, internal waves, submesoscale eddies, and mixing weaken with increasing ice cover. Small-scale windstress curl associated with ice to open water transitions and variations in ice roughness may induce intense secondary circulations that drive rapid vertical exchange. Enhanced mixing and vertical exchange can entrain heat stored below the mixed layer, increasing basal melting of sea ice within the MIZ. In ice-covered regions, local radiative solar warming leads to direct ablation of sea ice and some bottom melt from the radiation penetrating weakly into the ice-covered upper ocean. Open water regions within and south of the MIZ allow increased radiative upper ocean warming and, through lateral advection, accelerated ice melt. These processes are expected to amplify variance at short spatial and temporal scales across the MIZ.

During winter and away from coastal margins, ice cover presents a nearly completely closed, moderately rough surface that mediates stress transfer between the atmospheric boundary layer above and the oceanic boundary layer below the ice. Ice ridges and small-scale, mobile, snowdrifts determine the turbulent roughness of the ice surface. At weekly or synoptic timescales, snowdrifts evolve and sea ice deforms (including ridging and lead formation), driving localized changes in the atmospheric boundary layer drag coefficient. At daily timescales, leads enhance air–ocean thermal coupling and drive strong ocean convection arising from salt rejection due to the rapid ice formation, until new ice growth caps this enhanced transfer (*McPhee and Stanton*, 1996).

In the western Arctic, the seasonal MIZ develops during late spring in the Chukchi Sea and along the coastal fringe of the ice pack, and progresses northward during the summer. While oceanic advection of warmer water from the Bering Sea can affect the ice edge position and retreat over the Chukchi shelf, surface gravity waves are a primary source of energy for ice breakup, and therefore have an important role in the formation and evolution of the MIZ. In the western Arctic, the northward retreat of the sea ice edge increases the open water area, allowing direct momentum transfer from the atmosphere to the ocean surface through wind-driven waves. The distance that swell can penetrate into the ice cover sets the lateral scale of the MIZ and is limited by a combination of wave scattering and dissipation by the individual ice floes. From an oceanographic perspective, the MIZ is a relatively narrow zone, with a lateral scale of 25–100 km (e.g., *Dumont et al*., 2011; *Morison et al*., 1987). The amplitude, speed, and period of these waves are a function of the strength and duration of the wind, as well as the distance of open water over which the transfer of energy occurs (i.e., the fetch). Ocean waves have an important role in controlling the floe size distribution within an ice cover through the mechanical flexing and breaking of the pack and increasing floe interaction. As a result of wave action, floe sizes vary from a few meters at the edge of the MIZ to several hundred meters in the interior edge of the MIZ (e.g., *Wadhams*, 1973).

The resulting fragmented ice field has different surface roughness features, and because the smaller floes are significantly more mobile, sea ice can absorb more atmospheric surface stress through deformation and transfer it to the ocean surface. Both of these effects change aerodynamic drag across the MIZ ice field. These changes in ice surface roughness in the atmospheric boundary layer are accompanied by changes in hydraulic roughness of the ice base that affect the oceanic surface boundary layer, in ways that have remained difficult to study with ship-based observations. Concurrent observations of turbulent fluxes in both the atmospheric and oceanic surface boundary layers during the formation of the seasonal MIZ are needed to quantify the changes in drag coefficient and atmospheric and oceanic fluxes of momentum and heat. For example, understanding the fraction of the wind stress that is absorbed by the ice cover compared to the fraction that is transmitted to the upper ocean is critical for predicting the evolution of the MIZ.

More efficient atmosphere–ocean coupling in regions of partial ice cover and open water can amplify upper ocean mixing far beyond levels observed under full ice cover (*Rainville and Woodgate*, 2009). Winds acting on a less concentrated, thus more mobile ice pack, as well as acting directly on larger open-water regions, can generate near-inertial motions that enhance the shear and mixing about the mixed layer base and, by radiating vertically, support increased shear and turbulent mixing throughout the water column. As in the open ocean, strong winds acting on ice-free regions of the Arctic will drive turbulent mixing that deepens the surface mixed layer, entraining waters from below. Depending on the balance between the stratifying effect of increased surface layer freshwater input from ice melt and enhanced wind-driven vertical exchange, the ice–ocean boundary layer might be exposed to the reservoirs of heat contained within the Atlantic Water and Pacific summer water layers. This would further accelerate ice melt and produce more open water in a positive feedback.

The seasonal evolution of the MIZ is a complex interplay between atmospheric, sea ice, and oceanographic processes, with potentially strong feedbacks between them. As sea ice transitions from nearly continuous ice floe during winter conditions, through a wave-influenced MIZ and finally to open water, the changing state of the ice fundamentally changes the coupling of energy and momentum between the atmosphere, ice, and ocean. The influence of wind, waves, and passing storms creates a highly variable distribution of floe sizes near the ice edge, both spatially and temporally. This dynamically-forced breakup can enhance thermodynamic melt through increased solar absorption in newly formed open water, melt of broken ice and brash, and wave-induced melt and upwelling of warmer water from below.

The albedo of sea ice is large compared to open water, and most of the incoming solar radiation incident on sea ice is reflected back to the atmosphere. The thermal conductivity of sea ice is small, so sensible energy transport between ocean and atmosphere is limited in the presence of sea ice. As the MIZ formation progresses, changes toward small, mobile ice floes and a greater open water fraction in the MIZ also modulate the amount of summer shortwave insolation entering the water column. This increased heat uptake in the upper ocean is available both for heating the ocean mixed layer above the freezing point, and increased basal and lateral melting of the floes. This provides a strong ice-albedo feedback within the MIZ, spurring rapid melt of these smaller floes.

The extreme gradients in ice concentration and albedo across the MIZ set up lateral variability and gradients in the upper ocean. The ocean is more readily heated by solar insolation below low-concentration sea ice cover than below high-concentration ice cover, leading to the development of lateral temperature gradients, including sharp fronts, across the MIZ. Furthermore, sea ice is a freshwater reservoir. As this heat is used to melt the ice cover, corresponding upper ocean salinity gradients and fronts develop. There are also momentum gradients associated with contrasts in aerodynamic drag between sea ice and open water (e.g., *Guest et al*., 1987) and the absorption of wind stress by the sea ice cover. Wind stress gradients and ocean divergence at the ice edge can lead to localized upwelling (e.g., *Hakkinen*, 1987) and enhanced vertical exchange.

The ice–ocean boundary layer also exhibits energetic variability on short temporal scales. Large expanses of ice can melt rapidly, causing the ice edge to shift by over 100 km in the span of a single day. Inertial motions, associated with enhanced vertical shear and mixing, have periods of 12–13 hr throughout the Arctic, comparable to the periods of the semidiurnal tides. The high-frequency bound on internal waves, the buoyancy period, ranges from minutes in the highly stratified waters just below the surface mixed layer to several hours in the weakly stratified abyss. Turbulence in the surface mixed layer occurs on time scales of minutes to seconds. Submesoscale circulation associated with localized upwelling and mixed-layer eddies can have timescales of hours to days.

3.2. Processes and Feedbacks Within the Seasonal MIZ

Because the sea ice cover moderates atmosphere–ocean fluxes and the ocean affects the ice cover through fracturing, divergence, and melting, the ice–ocean system is strongly coupled within the MIZ. Highly variable ice and ocean conditions are a source of large perturbations that can trigger feedbacks leading to rapid summertime retreats of the sea ice cover.

Key upper ocean processes that contribute to strong coupling within the MIZ ocean–ice system are:

- Propagation and attenuation of ocean surface waves
- Absorption and storage of incoming solar radiation and its subsequent lateral transport
- Vertical mixing within and at the base of the ocean mixed layer

Surface wave induced deformations are responsible for fracturing the ice cover and reducing the size of floes across the MIZ. Small broken-up ice floes are more mobile than large, compacted floes of the pack interior. This mobility is a significant characteristic of the MIZ. Floes at the seaward edge of the MIZ are vulnerable to being swept out to the open ocean. Small floes within the MIZ readily respond to divergent oceanic or atmospheric forcing compared to the ice pack, decreasing ice concentration inside the MIZ during divergent forcing events.

The heat from solar radiation can manifest in many ways including: direct surface melting/ablation, bottom and/or lateral melting as a result of ocean redistribution of heat absorbed locally through leads and adjacent open water areas, and entrainment into the surface layer of subsurface ocean heat carried into or redistributed within the Arctic by ocean currents. Heat carrying waters in the basin may have traveled long distances, such as from Bering Strait (*Woodgate et al*., 2010) or from the adjacent shelves where extensive radiative warming is experienced due to earlier retreat of sea ice. In the Canada Basin these oceanic heat sources are typically found as near surface temperature maxima (NSTMs) underlying the stratification at the base of the mixed layer (*Jackson et al*., 2010, 2011).

Lateral inhomogeneities resulting from non-uniform heat absorption in the MIZ produce complicated vertical structure in the surface mixed layer, necessitating high vertical resolution thermal structure observations near the ocean–ice interface (e.g., *Stanton et al.*, 2012). In heavily ice-covered conditions, ice melt derives from direct surface melting/ablation and entrainment of warmer waters from below, with local heating through existing leads being less important. Below the central pack ice, entrainment rates of heat contained in the upper pycnocline into the surface mixed layer are thought to be relatively small (*Toole et al*., 2010); under certain conditions, however, these fluxes have been shown to make significant contributions to the ice cover energy budget (*Shaw et al*., 2009). Vertical entrainment depends on the intensity of turbulence about the base of the surface mixed layer, which in turn depends on the forcing of the mixed layer at its upper boundary. Towards the end of winter the surface buoyancy forcing of the ocean tends towards neutral while the extensive sea ice cover inhibits wind forcing of the upper ocean. As ice concentration decreases through spring and into summer, several positive feedbacks can accelerate ice melt. Increased areas of open water allow more heat to enter the ocean from above that is then available for basal and lateral ice melting. In addition, winds acting on a less concentrated, thus more mobile ice pack as well as acting directly on larger open water regions, can generate near-inertial motions that enhance the shear and mixing about the mixed layer base and, by radiating vertically, support increased shear and turbulent mixing throughout the water column increasing vertical fluxes of heat below the mixed layer. Strong lateral temperature gradients, intense solar heating, and temperatures elevated well above the freezing point significantly complicate the vertical heat transport processes in the MIZ.

Recent increased stratification from upper ocean freshening in the western Arctic has likely inhibited entrainment fluxes (*Toole et al*., 2010). In the MIZ, however, the presence of wave-driven circulations such as Langmuir cells and the reduced absorption of wind stress by the mobile ice cover may produce mixed layer turbulence that is energetic enough to overcome the stable stratification and entrain heat into the mixed layer that can contribute to ice melting. Langmuir cells may also contribute to localized sea ice divergence and corresponding areas of localized heating. This is an example of a direct wind stress–ocean wave–thermodynamic forcing.

The classic feedback mechanism operating in ocean–ice systems is the ocean-ice-albedo feedback, which is primarily thermodynamic in nature. In the MIZ, the ocean-ice-albedo feedback is augmented by ocean wave and turbulence dynamics. Divergent openings created by surface waves increase solar radiation absorbed by the surface ocean, acting as triggers for ocean-ice-albedo feedback and accelerated melting of the ice cover.

The thinning, weakening, and retreat of the ice cover during the summer melting season also feeds back to waves and turbulence. The penetration of wave energy into the ice pack sets the initial lateral scale of the MIZ. During summer, it is likely that wave motions penetrate further into the ice pack, creating a wider MIZ. As more open water is created during the summer melt season, the larger fetch allows more energetic waves to be generated. These two effects create secondary positive feedbacks.

Overall, the couplings between seasonal MIZ dynamics and the ocean-ice-albedo feedback are largely unexplored. A concentrated effort to observe wave dynamics and terms in the atmosphere and ocean surface boundary layer energy budgets will quantify these couplings. Such processes and feedbacks, as described above, directly control regional arctic climate variability and indirectly exert control on global climate variability. Their better understanding and realistic simulation is motivating development of computer models with very high spatio-temporal resolution and new parameterizations. This, in turn, is stimulating more robust model evaluation against long-term observations that represent scales that were, until recently, unresolved by even the highest resolution arctic models. However, a system-level understanding of critical arctic processes and feedbacks is still lacking. Fully coupled global climate models (GCMs) have large uncertainties and limited skill in simulating and predicting arctic ice cover (e.g., *Zhang and Walsh*, 2006; *Bitz*, 2008) and related high-latitude climate sensitivity (*Rind*, 2008). The majority of regional arctic models use higher resolution compared to global models, but they do not account for important feedbacks between various system components.

Deficiencies have been identified in how models approximate the surface mass and momentum budget, including: MIZ dynamics; surface albedo parameterizations (*Dorn et al*., 2007); sea ice rheology (*Girard et al*., 2009); fluxes across the atmosphere–ice–ocean boundary layer (*Dorn et al*., 2007; *Hunke*, 2010); and cloud radiative properties. These problems are important, because a reduction of perennial sea ice cover exposes open water to direct interactions with the atmosphere, which in turn influences regional atmospheric circulation patterns and temperature profiles, especially along the seasonal MIZ (*Rinke et al*., 2006). Sea ice thickness variability in space and time modifies the arctic-wide atmospheric circulation and appears to impact the troposphere–stratosphere coupling (*Krinner et al*., 2010; *Gerdes*, 2006). Both for scientific and practical reasons, prediction of sea ice cover is particularly important as it buffers air–sea heat fluxes (*Rind et al*., 1996; *Washington and Meehl*, 1996) and strongly influences Earth's absorption of solar radiation.

Disentangling the relative importance of these sources of uncertainty in modeling arctic sea ice and climate presents a major challenge. Part of the solution rests in improving representation of processes within both regional and global climate models through increased model resolution and improved parameterizations. Another part of the solution lies in increasing the number of arctic processes included in models to explore their non-linear influences on climate evolution. For that reason, there is growing interest in the combined use of atmosphere–ocean general circulation models with regional modeling tools and expertise to help understand uncertainty and improve the quality of probabilistic projections (*Giorgi*, 2005).

3.3. A New Look at Processes in the Seasonal MIZ

Observational and numerical investigations of the MIZ face numerous challenges. The ocean, ice, and atmosphere interact through a complex web of feedbacks that likely vary as a function of ice concentration, with significant variability at short spatial and temporal scales. Both full and partial ice cover greatly complicate observational efforts, while the seasonal, northward retreat of the MIZ demands mobile approaches for studying MIZ evolution. Although many of the relevant processes have received attention through several dedicated MIZ field programs (see *Previous Investigations of the Permanent MIZ,* section 2), the evolving MIZ in the western Arctic provides a natural laboratory for studying how the ice–ocean–atmosphere system varies with changing ice conditions. Coincident and continuous measurements of the atmosphere, sea ice, and ocean are required to resolve the complex processes and feedbacks affecting the large-scale MIZ evolution and seasonal ice retreat. Improved process-level understanding can then be applied to constrain model representation of sea ice thickness distribution and prediction of its future seasonal trajectory (*Zhang et al*., 2008; *Maslowski et al*., 2012). The challenges posed by rapid ice drift, the unpredictable nature of MIZ evolution, the broad range of spatial and temporal scales and the difficult, costly logistics of polar research motivate development of a novel autonomous observational approach capable of: (i) sampling from full ice cover, though the MIZ and into open water, (ii) following the MIZ as it retreats northward, and (iii) resolving processes that occur at short spatial and temporal scales.

4. MIZ PROGRAM OBJECTIVES AND SCIENCE QUESTIONS

The ONR Marginal Ice Zone (MIZ) program focuses on the emergent, seasonal MIZ in the Beaufort Sea in an effort to:

1. Collect and analyze a benchmark dataset that resolves the key processes controlling MIZ evolution, with sufficient spatial and temporal scope to capture a broad, representative range of environmental conditions
2. Understand the processes that govern the evolution of the MIZ, identify key interactions and feedbacks in the ice–ocean–atmosphere system, and investigate how these might change with the predicted increased seasonality in arctic sea ice cover
3. Evaluate the ability of existing models to predict MIZ seasonal evolution, and improve parameterization of key processes with the goal of enhancing seasonal forecast capability

Specific science questions include:

1. What processes govern the temporal and spatial evolution of the MIZ in the Beaufort Sea?
2. How do the vertical structure of temperature and salinity, internal wave variability, turbulent mixing, and radiative warming vary as a function of ice cover, extending from open water, though the MIZ, and deep into the fully ice-covered ocean?
3. What are the respective roles of surface wave driven mechanical forcing, solar

radiation driven thermodynamic forcing, and the delivery of heat through advection and diapycnal mixing (driven by direct wind forcing, internal waves and small-scale, wind stress curl driven vertical exchange) in governing MIZ evolution? How do these processes couple?

4. How do surface waves evolve within the MIZ as a function of fetch and season? What is the input–dissipation balance of waves in a mixed fetch of open water and ice floes? How do surface waves attenuate/collimate across the MIZ?

5. What is the ice floe response to surface waves? What are the short-scale flexural variations across a floe?

6. How does the upper ocean response to wind forcing vary as a function of ice cover? How do wind stress and ice–ocean stress vary across the MIZ, and how do they relate to mixed layer currents and internal wave intensity? What influence do extreme events (i.e., storms) have on the evolution of the MIZ?

7. Do these processes, combined with the increasing areas of open water, act to amplify the seasonality of Arctic Ocean ice cover?

8. Can the historical evolution of Beaufort–Chukchi ice–ocean variability (ice thickness, floe size distribution, seasonality) be quantified and understood in the context of these processes?

9. What feedback mechanisms become important in the emerging Beaufort Sea MIZ?

6. EXPERIMENT STRATEGY

The MIZ intensive field program will employ an array of cutting-edge autonomous platforms to characterize the processes that govern Beaufort Sea MIZ evolution from initial breakup and MIZ formation though the course of the summertime sea ice retreat. Instruments will be deployed on and under the ice prior to initial formation of the MIZ along the Alaska coast, and will continue sampling from open water, across the MIZ, and into full ice cover, as the ice edge retreats northward through the summer. A project timeline (Figure 3) provides an overview of field operations. The flexible nature of ice-mounted and mobile, autonomous oceanographic platforms (e.g., gliders and floats) facilitates access to regions of both full ice cover and riskier MIZ regions. This approach exploits the extended endurance of modern autonomous platforms to maintain a persistent presence throughout the entire northward retreat. It also takes advantage of the inherent scalability of these instruments to sample over a broad range of spatial and temporal scales.

6.1. Observational Approach

The sampling goal is to achieve a deployment of ice-based platforms arrayed around a line that stretches northward approximately 400 km from the Alaska slope (roughly 70°–76°N at 140°W) on 1 July (Figure 4 and Table 1). Ice-based instruments include arrays of Ice Mass Balance and Wave Buoys (IMB/WB), Autonomous Weather Stations (AWS), Ice-Tethered Profilers (ITP), and Autonomous Ocean Flux Buoys (AOFB). This array will quantify ice and snow thickness, surface wave properties within the MIZ, sea ice deformation, upper ocean water properties, currents and turbulence, and meteorological variables as a function of distance from the ice edge. Ice-based elements will deform as the system is carried westward with the drifting sea ice, and will melt out from the south over the course of the northward sea ice retreat, but the 400-km-long array will ensure continuous measurements from the MIZ northward throughout the melt season. A single bottom-anchored Acoustic Wave and Current (AWAC) mooring will be deployed over the slope to characterize evolution of the surface wave field under increasingly large regions of open water. Additionally, and array of Acoustic Navigation Sources (ANS) will ensonify the region around the ice-based platforms to provide geolocation (‘underwater GPS’) for mobile platforms working beneath the ice.

An array of drifting and mobile autonomous platforms will operate within the matrix of ice-based instruments (Figure 5 and Table 1). Polar Profiling Floats (PPF) will be deployed at locations spanning the entire line to provide daily profiles of temperature and salinity. Surface Wave Instrument Floats with Tracking (SWIFT) drifters and Waverider Buoys will be deployed in open water, near the MIZ, shortly after its formation, and may be recovered and relocated during the melt season. These free-drifting instruments will provide wave observations in the MIZ and open water regions and allow evaluation of the input–dissipation balance for waves in a fetch that consists of both open water and ice.

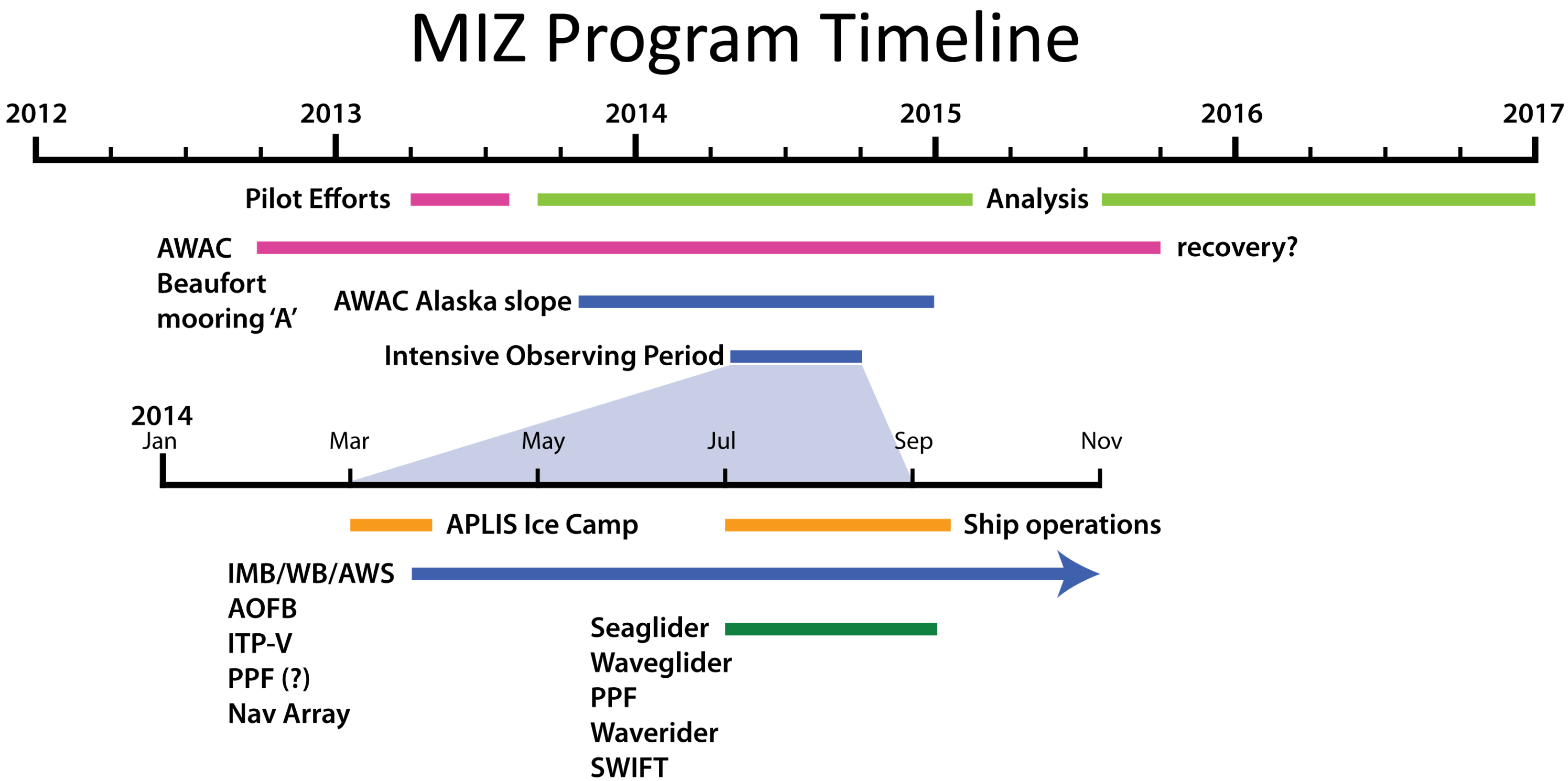


Figure 3. Timeline of the five-year MIZ Program. Magenta and blue bars in the upper timeline (2012–2017) mark two extended deployments of subsurface AWAC moorings. The lower (expanded) timeline describes the 2014 intensive observing period, with orange bars marking the ice camp and ship operations intervals, the blue bar indicating the (open-ended) sampling by ice-based platforms and the green bar delineating sampling by mobile and drifting platforms.

Table 1. MIZ DRI autonomous platforms. 'Domain' indicates data collection in full ice cover (Ice), MIZ, and open water. 'NR' indicates no recovery planned.

Instrument	No.	Deploy	Recover	Logistics	Domain	Measurements
IMB/WB	24	April 2014	NR	APLIS Ice Camp Aircraft	Ice	Air–ice–upper ocean T at 2-cm resolution (~1 m above ice, ~3 m below; snow and ice thickness, thermal structure), wave properties, barometric pressure
AWS	5	April 2014	NR	APLIS Ice Camp Aircraft	Ice	Wind speed and direction, humidity, air temperature, pressure, solar radiation, and floe rotation
AOFB	2	April 2014	NR	APLIS Ice Camp Aircraft	Ice	*Subsurface*: T, S, **u** from 5 m depth into ice *Surface*: Thermal structure of ice, shortwave radiation, tiltmeters
ITP-V	4	April 2014	NR	APLIS Ice Camp Aircraft	Ice	T, S, **u** over upper 250 m. Profiles at 2-hr intervals with 1-m resolution.
Seaglider	4	July 2014	September 2014	Ship	Open water MIZ Ice	T, S, temperature microstructure, dissolved oxygen, downwelling irradiance, depth average **u** Profiles from ice bottom to as deep as 1000 m at intervals of 1–8 hr.
Polar Profiling Float	10	April 2014 July 2014	NR	APLIS Ice Camp Aircraft Ship	Open water MIZ Ice	T, S Profiles from ice bottom to 1000 m once per day.
Navigation Mooring	8	April 2014	NR	APLIS Ice Camp Aircraft	Ice	Acoustic navigation beacon
Waveglider	2		September 2014	Ship	Open water	Acoustic navigation beacon, meteorological sensors
AWAC Mooring	2	September 2013 (BG) Summer 2013 (AK)	Summer 2015 (?) September 2014	Ship	Open water MIZ Ice	Waves (height, period, direction, spectra), ice (draft), currents (mixed layer profiles)
Waverider Buoy	2	July 2014	September 2014	Ship	Open water MIZ	Waves (height, period, direction, spectra), temperature (sea surface)
SWIFT floats	4	Juyl 2014	September 2014	Ship	Open water MIZ	Turbulent dissipation (from wave breaking), waves (height, period, direction, spectra), winds (speed, direction, stress), currents (surface drift), temperature (air and sea surface)

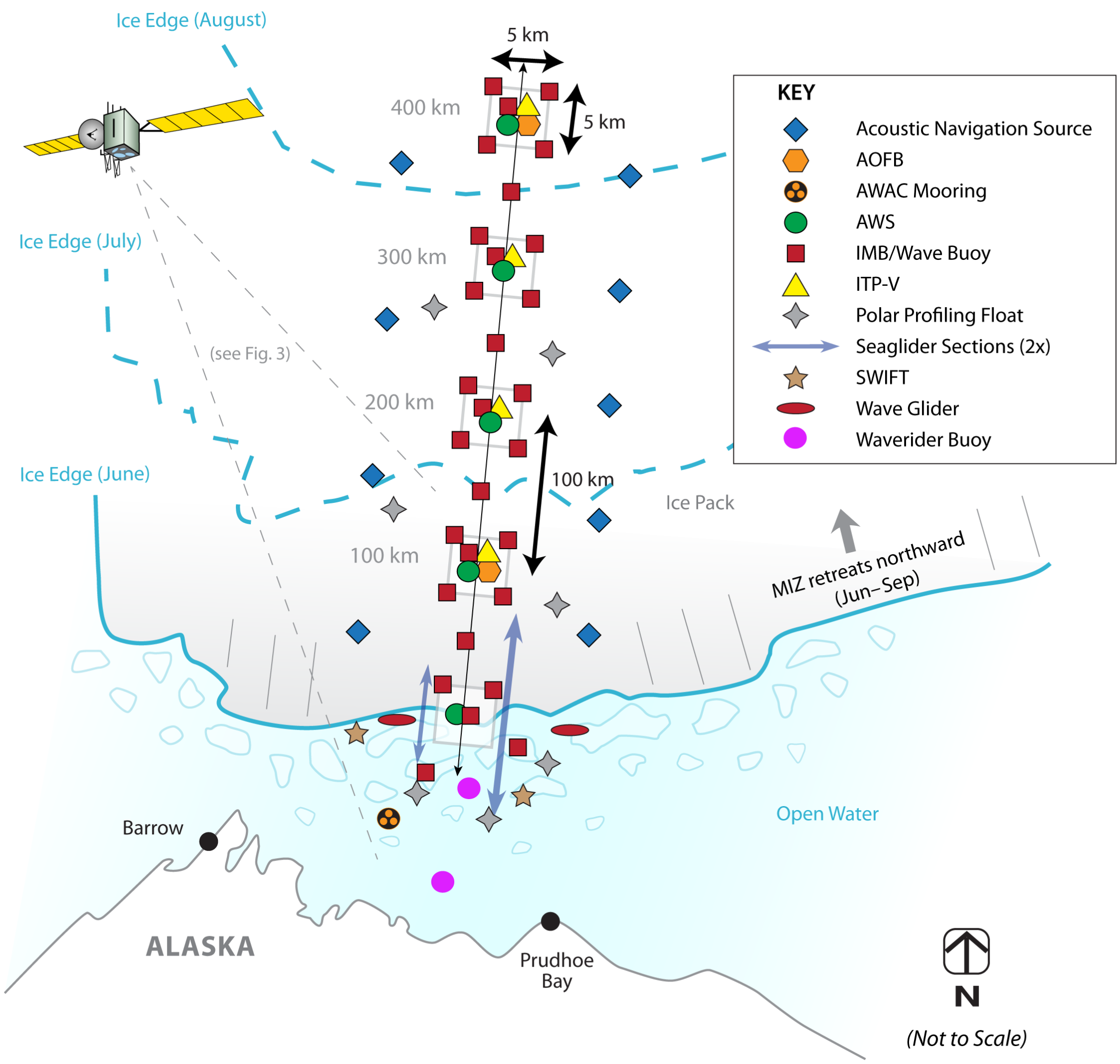


Figure 4. Idealized (target) configuration of the MIZ DRI observing array. The actual array will deform as it drifts westward through the region. Note the markers indicating various instrument separations (drawing is not to scale). Ice-based instruments will melt out from the south as the MIZ retreats northward. Blue, double-ended arrows mark glider sections that will follow the northward retreat of the sea ice to remain centered on the MIZ. The satellite 'footprint' marks the area depicted in Figure 5. Solid (dashed) light blue lines mark notional positions of the ice edge in June, (July, and August) relative to the observing array. By August, the MIZ is far to the north and much of the ice-based instrumentation has melted out.

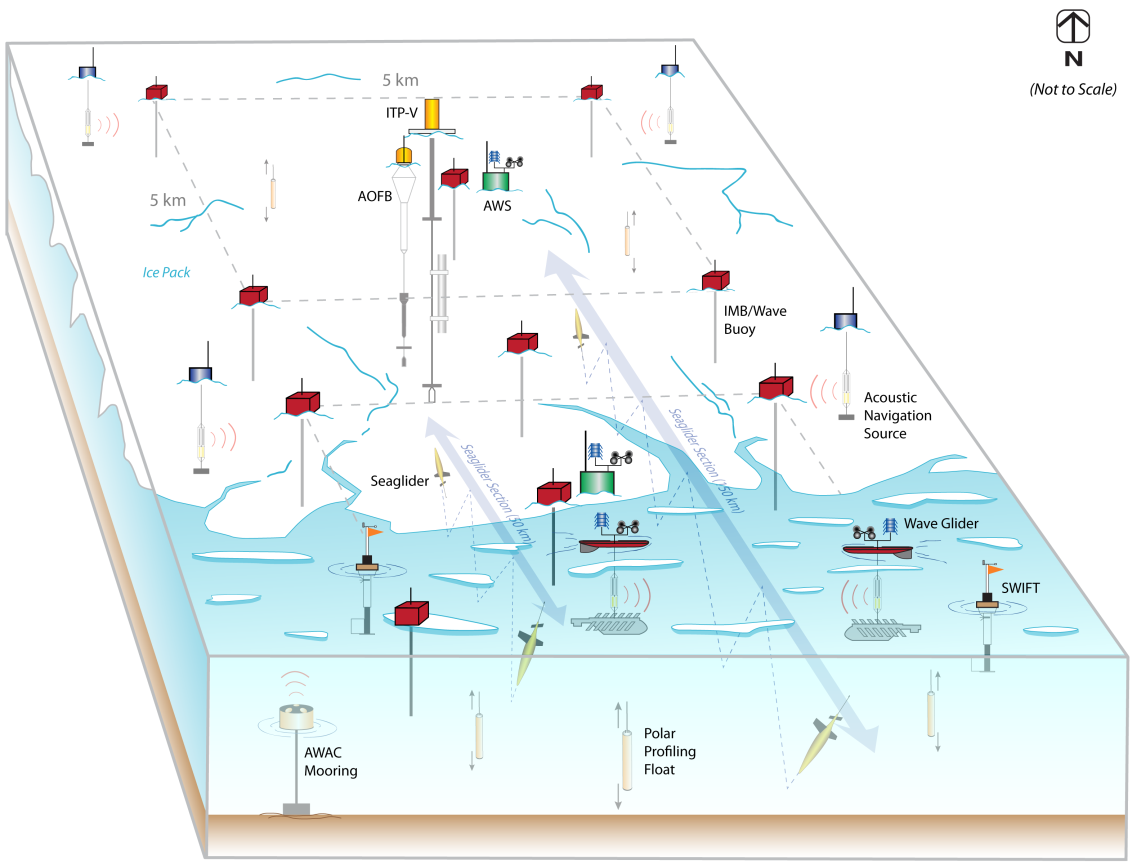


Figure 5. Ice-edge and '5-dice' IMB/WB sub-array configuration, depicting oceanographic sampling by floats and gliders beneath the ice and by various ice-based instruments that penetrate through the ice. Gliders conduct sections that extend from full ice cover, through the MIZ, and into open water. Wavegliders and SWIFT drifters sample within the MIZ and the open water to the south.

Two Liquid Robotics Wavegliders will follow the northward sea ice retreat, maintaining position close to the ice-based instruments nearest the ice edge, to provide additional acoustic navigation signals, open water measurements, and boundary layer meteorological measurements within the open water south of the MIZ. Lastly, autonomous Seagliders will follow the retreating ice edge, occupying sections that span open water, the MIZ, and full ice cover to document upper ocean evolution as a function of distance from the ice edge throughout the entire northward retreat. These high-resolution sections will bridge the regions between observations collected by the ice-based and drifting platforms, provide spatial context, and bind the array together.

6.2. Timing and Logistics

Ice-based instruments will be deployed using aircraft support, which dictates that all assets be placed prior to the time when thinning sea ice makes for unsafe landing conditions, typically no later than mid-April. This means that all ice-based elements must be deployed approximately three months prior to initial MIZ formation over the Alaska shelf and slope. The ice-based array will thus undergo three months of drift and deformation before it begins collecting observations in and around the MIZ. To maximize the chance that something approximating the desired array configuration — ice-based platforms arrayed around a line that stretches northward approximately 400 km from the Alaska slope, roughly 70°–76°N at 140°W (Figure 4) — is in place around 1 July to capture the formation and evolution of the MIZ, initial deployments of ice-based instruments must be sited 'upstream', to account for westward advection and deformation prior to arrival at the target site.

Sixteen years (1990–2005) of simulated trajectories derived from analysis of the Naval Postgraduate School's fully coupled Regional Arctic Climate Model (RACM) illustrate the challenges associated with this 'drift-in' deployment approach. Back-calculating trajectories from the target 70°–76°N, 140°W line from 1 July to 1 April yields deployment sites consistently to the northeast, with only modest rotation and distortion, but significant variability in drift distance (Figure 6, left column). Projecting forward from 1 July to 1 September, reveals increased rotation and distortion, and an even larger spread in potential drift speeds, with most tracks turning with the shelf edge, but some following paths that cross onto the shallow waters of the Alaska shelf (Figure 6, right column). Actual April 2014 deployment locations for ice-based assets will be determined from an analysis of observed and simulated drifts, but the RACM results illustrate the issues that impact these decisions.

To maximize co-location of platforms and focus sampling on MIZ dynamics, gliders, SWIFTs, Waverider buoys, and some of the PPFs will be deployed in July, shortly after the MIZ forms and moves offshore to provide open-water access over the Alaska shelf and slope. These assets will be deployed at the southern end of the array of ice-based platforms, at whatever location they have drifted to over the course of the April–July period. Deployments will take place from a chartered vessel, which may also be employed to reposition assets that have drifted away from the main observing array.

Although all autonomous assets are potentially expendable, the MIZ intensive measurement program will end in September, with a chartered vessel attempting to recover AWACs moorings, Waverider buoys, SWIFTs, and gliders. Surviving ice-based instruments, many of which might now be adrift, will be recovered if convenient, or left to continue their valuable sampling regime through the upcoming freeze-up.

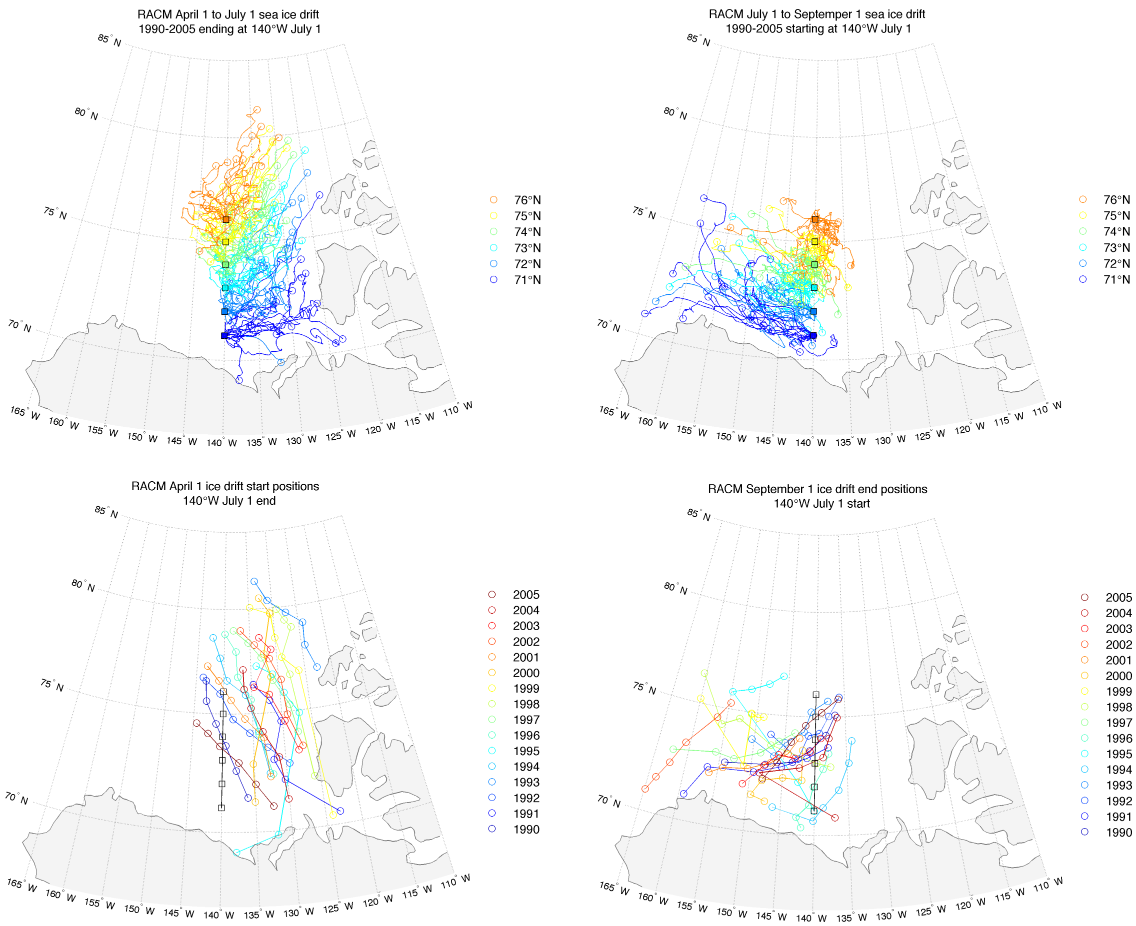


Figure 6. Simulated trajectories (1990–2005) derived from analysis of the Naval Postgraduate School's fully coupled Regional Arctic Climate Model (RACM). Back-calculated trajectories (upper left) and starting positions (lower left) from the target 70°–76°N, 140°W line from 1 July to 1 April and forward trajectories (upper right) and end positions (lower right) from the target line on 1 July to an endpoint on 1 September.

Aircraft operations for deployment of ice-based instruments will likely take place from the 2014 APLIS ice camp, utilizing the helicopters already positioned for the camp, augmented by a fixed wing aircraft brought in specifically for the MIZ program. Science operations will begin late March or early April, after the conclusion of the main camp, with a slight possibility of an early start, concurrent with the final week or two of the main camp. There is a small possibility of land-based aircraft operations, but flight distances, identification of suitable facilities, and costs make this unlikely. Ship-based operations may stage from Seward and/or Prudhoe, though the specifics depend on the ship. Due to the complex and fluid nature of logistics planning, specifics are provided in a separate document (available upon request).

6.3. Modeling Approach

High-resolution modeling of the MIZ in the Chukchi and Beaufort seas will be conducted using three distinctive models targeting various key MIZ processes. The Marginal Ice Zone Modeling and Assimilation System (MIZMAS) model will be used to simulate the evolution of ice thickness and floe size distributions jointly in the MIZ. New model development includes the implementation of floe size distribution and the related improvement of model physics such as sea ice rheology and lateral melting. The MIZMAS model will be used for hindcast, seasonal ensemble forecast, and future projection of the MIZ.

The Arctic Cap Nowcast/Forecast System (ACNFS), developed at the NRL, will be used for nowcasts and 5-day forecasts of ice thickness, ice drift, ocean currents, salinity, and temperature fields. The NRL effort will include new algorithms from satellite and aircraft measurements to determine arctic-wide satellite-derived ice and snow thickness and incorporation of wave dynamics.

The Eddy-resolving Regional Arctic Climate System Model (E-RASM) is a fully coupled model including atmosphere, land hydrology, ocean, and sea ice components. Currently under development is the incorporation of ice sheets, glaciers and ice caps, and dynamic vegetation. The model will be used to examine the critical physical processes and atmosphere–ocean–ice feedbacks that affect sea ice thickness and area distribution using a combination of forward modeling and state estimation techniques.

The development of these models in simulating MIZ processes will be based on systematic model parameterization, calibration, and validation, and data assimilation, taking advantage of the integrated observational and modeling efforts planned by the ONR MIZ program. Satellite and in situ observations will be used, particularly those from the upcoming field campaign. Model–data synthesis will be performed via synergistic analysis of model simulations and field data. The modeling efforts will also support fieldwork identifying key processes and possibly optimal sampling sites and providing weather and seasonal forecasts of sea ice conditions in the western Arctic.

7. RESOURCES AND PROGRAM COMPONENTS

Measurement assets employed for the MIZ program include:

- 25 IMB/Wave Buoys (IMB/WB)
- 5 Automated Weather Stations (AMS)
- 2 Autonomous Ocean Flux Buoys (AFOB)
- 4 Ice Tethered Profilers with velocity sensors (ITP-V)

- 4 ice-capable autonomous gliders
- 10 Polar Profiling Floats (PPF)
- ice-tethered acoustic navigation sources (ANS)
- 2 Liquid Robotics Wavegliders
- 2 subsurface Acoustic Wave And Current (AWAC) moorings
- 2 Waverider surface moorings
- 4 Surface Wave Instrument Float with Tracking (SWIFT) drifters
- remote sensing

Numerical efforts include:

- The coupled ice–ocean Marginal Ice Zone Modeling and Assimilation System (MIZMAS)
- Arctic Cap Nowcast/Forecast System
- Naval Postgraduate School Regional Arctic Climate Model

7.1. Ice Mass Balance Buoys, Wave Buoys, Tiltmeters, and Automated Weather Stations (Wilkinson, Maksym, Hwang, Wadhams, and Doble)

Marginal ice zone evolution and seasonal ice edge retreat is a complex interplay between a number of dynamic and thermodynamic processes, with potentially strong feedbacks between them. The influence of wind, waves, and passing storms creates a highly variable distribution of floe sizes near the ice edge, both spatially and temporally. This dynamically forced breakup can enhance thermodynamic melt through increased solar absorption in newly formed open water, melt of broken ice and brash, and wave-induced melt and upwelling of warmer water from below. To elucidate some of the key processes governing the evolution of ice conditions in the MIZ, autonomous instrumentation must continuously monitor four parameters:

1. Ice mass balance
2. Open ocean and in-ice wave characteristics
3. Ocean–atmosphere heat flux
4. Floe size distribution

These measurements can then be combined with others in the ONR MIZ program to better understand MIZ development. We will deploy a number of combined IMB/WBs and automatic weather stations, and use high-resolution remote sensing images. Each is explained below:

Ice mass balance (IMB) + wave buoy (WB): Inference of ice growth or melt at the surface and bottom of the sea ice depends on accurate localization of the ice–ocean interface, which in the case of our IMB buoys, relies on measurement of both the ambient temperature and the thermal response of the immediate surroundings of the heater/sensor pairs to short periods of heating, i.e., the temperature elevation above ambient. The thermal response of air, snow, ice, and water to this heating cycle is different, and thus the medium the sensor is embedded in can be recognized. Once the interfaces have been identified the rate of change in the position of the interface along the chain is interpreted as the melt rate. Generally an IMB chain is 5 m long with temperature sensors spaced at 2 cm along its length. This allows a portion of the chain to sample the ambient air, snow, ice, and upper water column temperature. The IMB system also includes a compass for floe rotation, GPS, and a barometer.

Wave characteristics will be obtained through the incorporation of a vertical accelerometer (heave) and tiltmeters to give surface slope. For waves in ice (as opposed to open ocean waves), this configuration is more sensitive than a three-dimensional accelerometer, because the relatively constrained ice cover is not able to respond to orbital motion in the x/y plane. The sensors will collect data at 1-s intervals, transmitting full timeseries data on demand (e.g., during the most interesting breakup period, where the evolution of wave energy and period can be better tracked), as already done for our tiltmeter wavebuoys (*Doble*, 2010; *Wadhams and Doble*, 2009; *Wilkinson et al*., 2008). Otherwise, spectra and metadata (e.g., significant waveheight, mean and peak period) will be transmitted routinely, allowing the full timeseries to be requested over the two-way Iridium link when required.

On-chip solutions (e.g., the three-dimensional accelerometers used in smart phones; *Wilkinson et al*., 2011) are being investigated for wave property measurements. Power requirements and component costs for the buoys could be reduced significantly, making this a potentially attractive option.

The IMB/WB will be a float, and thus will continue to obtain important data on the evolution of the upper ocean heat and the ocean wave spectra. The background open ocean spectra will be used in conjunction with buoys that are still in the ice to quantify wave attenuation rate. The open water spectra are an important part of the process and therefore Wavegliders should also be deployed in the open water near the ice edge.

Automated Weather Station (AWS): AWS installations measure GPS location, wind speed and direction, humidity, air temperature, pressure, solar radiation, and floe rotation. This is a standard, field-tested design and requires no development. It is based around a Campbell CR1000 logger and Iridium SBD messaging.

Iridium: All platforms take advantage of solar power and the two-way communication offered by Iridium. This allows batteries to be recharged and users to alter, when required, the sampling rate remotely. In-house software displays the transmitted data on the web in real time and automatically backs up data in a web-accessible database.

GTS: All transmitted data will be piped directly to the Global Telecommunications System (GTS). These data will then be available to numerical weather prediction centers in near-real time.

Floe size distribution: High-resolution satellite imagery will be acquired to obtain co-incident information on the open water fraction and floe size distribution within the area of the buoy arrays and from the ice edge northwards along the buoy deployment line. Analysis of these images will enable us to quantify the continuous evolution of sea ice conditions (open water fraction, floe size distribution, and MIZ width) with respect to the in situ parameters that are measured by the buoys. The principle satellite sensor will be the SAR TanDEM-X (TDX), successor of TerraSAR-X, as it can provide all-weather, high-resolution images (3–18-m pixel size) at reasonable cost. More importantly the system has the flexibility to obtain scenes with only 3–4 days notice. This facility was used successfully during recent cruises, and will be utilized in the upcoming *Aaron* cruise to the Chukchi Sea (August–September 2012).

7.2. Autonomous Ocean Flux Buoys and Manual Turbulence Measurements (Stanton and Shaw)

Autonomous Ocean Flux Buoys (Figure 7) will quantify vertical turbulent fluxes in the centers of two of the '5-dice' IMB/WB arrays (Figure 4, orange hexagons) from the spring formation of the MIZ through the summertime sea ice retreat. Each buoy measures thermal structure from 5-m depth up into the ice, and measures the vertical fluxes of heat, salt, and momentum near the top of the ocean mixed layer to determine entrainment fluxes and summertime solar heating fluxes over month–year time scales. These enhanced flux buoys have a surface buoy that sits on the ice, a bulk meteorology and shortwave solar radiation sensor attached to the buoy housing 1.5 m above the ice, and precision tilt and inertial motion sensors within the buoy hull to detect both distant and near wave effects on the local ice floe. An instrument frame hangs from the housing by a series of torsionally rigid poles to support the ocean flux package, and a 16-element thermistor string spanning the upper 4 m of the water column into the ice. The flux package instrument frame is equipped with a downward looking 300-kHz Acoustic Doppler Current Profiler (ADCP, RDI Workhorse) to measure current structure down into the pycnocline every 2 m. The surface housing also contains processing and control electronics, Global Positioning System (GPS) electronics, an Iridium satellite modem, GPS and Iridium antennae, and primary lithium cell batteries. After field installation, AOFBs maintain twice-daily, two-way communications with a computer running at the NPS allowing transmission of the full data timeseries and routine updates of sampling parameters. The buoy system has a hull and floatation system capable of surviving multiple melt-out and refreeze events.

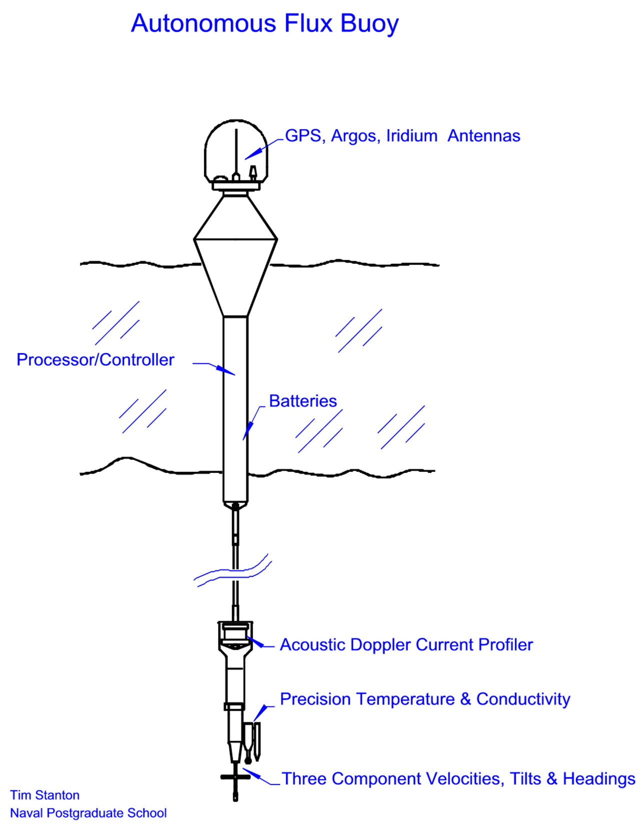


Figure 7. The Naval Postgraduate School (NPS) Autonomous Ocean Flux Buoy (AOFB). A surface buoy sits on the ice supporting an instrument package suspended into the upper ocean by a series of poles from the bottom of the surface buoy. The surface buoy contains processing electronics, GPS and Iridium antennae, and batteries. The instrument package is outfitted with a downward looking 300-kHz Acoustic Doppler Current Profiler (ADCP, RDI Workhorse) and a custom-built flux package. Additionally, the buoys have GPS receivers for measuring position and calculating ice velocity. After installation in the field on selected ice floes, AOFBs maintain twice-daily, two-way communications with a computer running at the NPS.

In addition to the two AOFBs, a 6-m-long instrumented frame equipped with two eddy correlation flux sensors, a 16-element temperature string, and an ADCP may be deployed from an ice floe to measure fluxes at the mixed layer base or weaker density jumps within the remnant mixed layer. These measurements would be collected from the ice camp used to support deployment of the ice-based assets.

7.3. Ice-Tethered Profilers (Toole, Krishfield, Timmermans, Cole, and Thwaites)

An array of four autonomous Ice-Tethered Profilers with velocity (ITP-Vs, Figure 8) will quantify the seasonally varying upper ocean stratification and velocity field, and the turbulent ice–ocean exchanges of heat and momentum in the Arctic MIZ. ITP-Vs will be deployed in spring 2014 along a meridional swath with approximately 100-km separation. ITP-Vs will sit at the center of four of the five IMB/WB clusters. The ITP-Vs will sample through the melt season to follow mechanical displacements of the ice as the ice edge sweeps north. High spatial (1 m) and temporal (2 hr) resolution profile observations of upper ocean temperature, salinity, and velocity will be provided in near-real time from the ice–ocean interface to 250 m depth. This high temporal resolution will allow the characteristics and intensity of near-inertial motions and higher-frequency internal waves and their associated shears and strains to be quantified. In addition, direct estimates of the turbulent vertical fluxes of heat, salt, and momentum just below the ice–ocean interface will be made every four hours. The ITP-V array will document the changes in internal wave properties, turbulent fluxes, and entrainment of subsurface heat into the mixed layer as the sea ice concentration evolves during the melt season. The array will also provide initialization or validation data for numerical models, and will capture many of the processes important to the seasonal evolution of the sea ice cover.

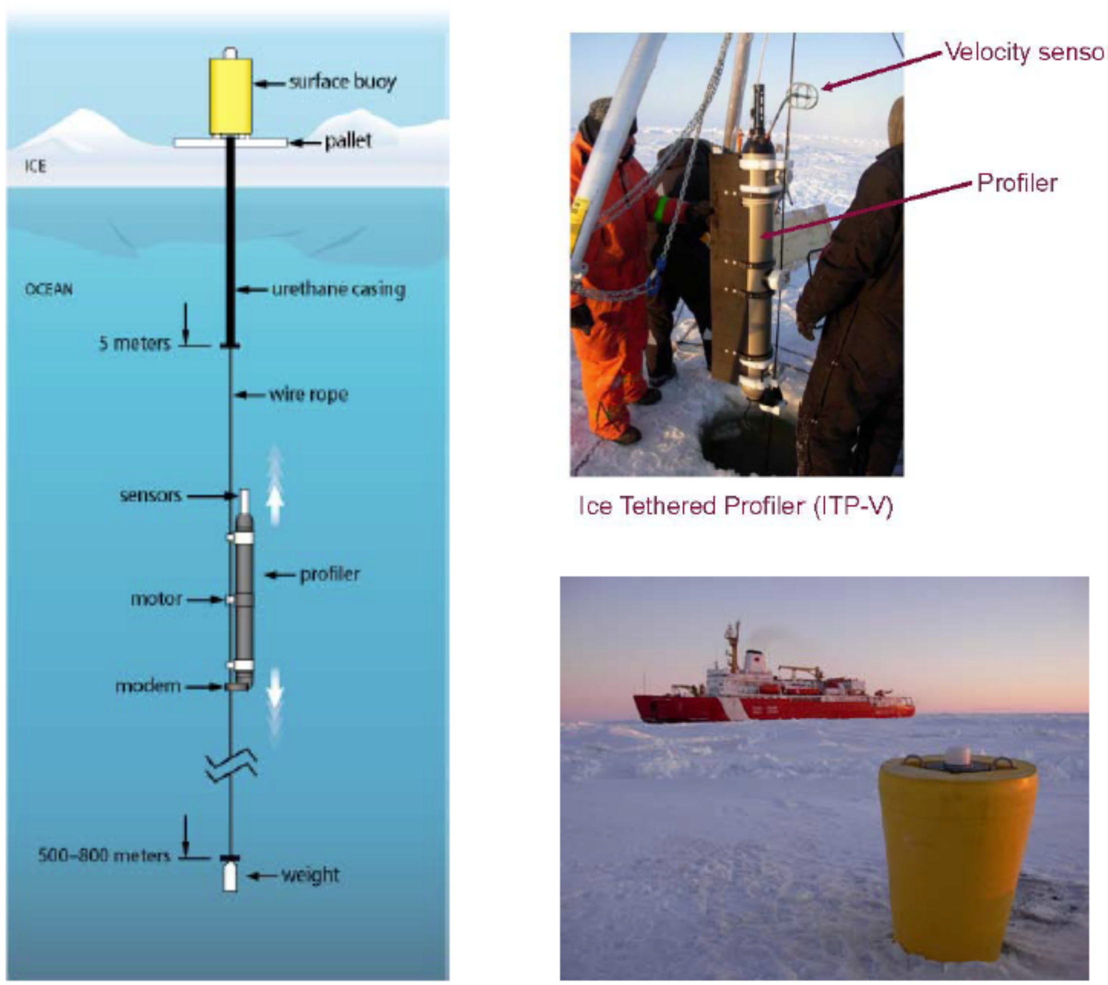


Figure 8. Schematic of the WHOI Ice-Tethered Profiler system (left), the profiler with velocity sensor (ITP-V) prior to deployment (upper right), and the surface expression (lower right).

7.4. Autonomous Gliders (Lee, Rainville, and Gobat)

An array of Seagliders will follow the retreating ice edge to document upper ocean structure and quantify the relative importance of processes that impact the ice–ocean boundary layer in and around the MIZ. The glider program is designed to:

- Collect observations that span open water, the MIZ, and full ice cover
- Resolve the short temporal and spatial scales associated with key upper ocean processes
- Quantify how the relative importance of these processes varies as a function of location relative to the MIZ
- Measure turbulent mixing rates (via micro-temperature) and multi-spectral downwelling irradiance in the upper water column
- Provide high-resolution spatial context for other components of the DRI

Beginning in late spring or early summer and extending though the time of minimum sea ice extent (September), four Seagliders will repeatedly occupy sections centered on the MIZ, following its northward retreat. Two gliders will occupy short lines (~50 km) designed to resolve short time scale variability about the MIZ itself, while the other two will conduct longer surveys (>150 km) that extend beyond the influence of the MIZ in both the open ocean and ice-covered directions (Figure 9). At a typical speed of 0.25 m/s (23 km/day) gliders will require ~2 days to transit the short sections and ~7 days to occupy the long sections. The gliders will provide many realizations of the sections, providing insight into the processes controlling stratification in open ocean, MIZ, and ice-covered waters. Rapid data delivery (near-real time in open water, with latency of days for under-ice excursions) will inform other measurement efforts and contribute to making this a dynamic and adaptive program.

Long-endurance, autonomous Seagliders (Figure 10), previously adapted for extended missions in ice-covered waters, will repeatedly occupy sections that extend from open water, across the MIZ and into full ice cover, with surveys following the retreating ice edge through 4 months of the summer melt season. Multi-month endurance will provide the persistence needed to build up robust statistics while flexibility provided by near-real time control will allow gliders to follow the ice edge and adapt sampling strategies to meet changing conditions. When operating in ice-covered waters, gliders navigate by trilateration from moored acoustic sound sources (or dead reckoning should navigation signals be unavailable) and incorporate enhanced autonomy to perform functions such as sensing overhead ice, determining when to attempt to surface, and decision making in the event of lost navigation or instrument malfunction. Gliders will measure temperature, salinity, dissolved oxygen, rates of dissipation of temperature variance (and vertical turbulent diffusivity), and multi-spectral downwelling irradiance.

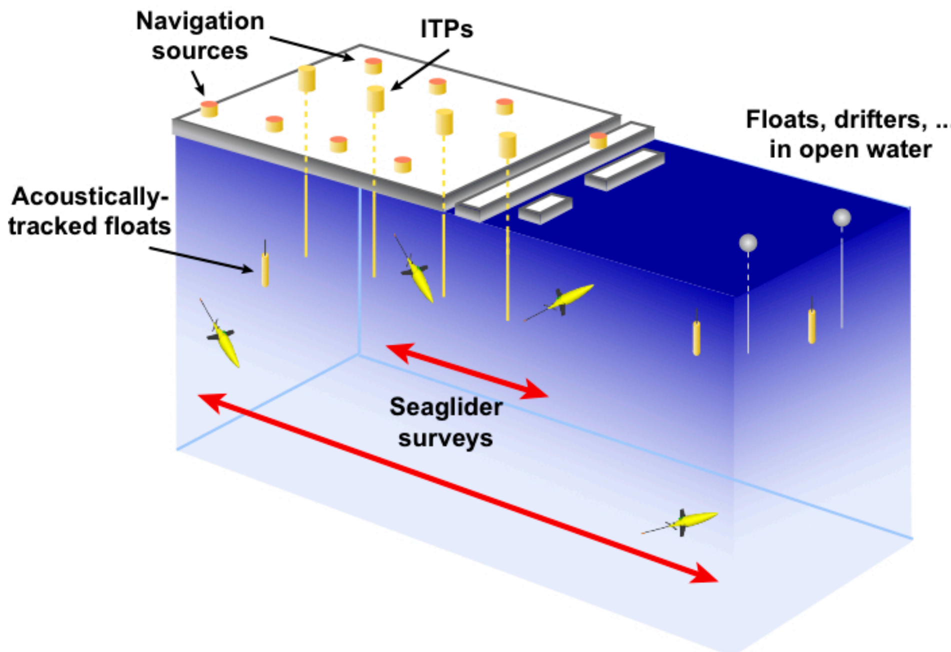


Figure 9. The Mobile MIZ Observing Network. Ice-Tethered Profilers, ice-capable Seagliders, and profiling floats, with an acoustic array providing under-ice geolocation and navigation, provide high spatial and/or temporal resolution ocean measurements in the MIZ. The array follows ice drift and retreat though the melt season. Gliders sample from open water, through the MIZ, and into full ice cover, profiling from the ice–ocean interface to 1000 m depth.

Figure 10. APL-UW ice-capable Seagliders. Gliders are small (50 kg, 1.5 m), long-endurance (multi-month), buoyancy-driven vehicles capable of navigating survey patterns while diving from the surface/ice–ocean interface to depths up to 1000 m. Iridium satellite modems provide two-way communications for command and data upload. Payload includes Seabird T & C, dissolved oxygen, downwelling irradiance, and temperature microstructure.

In collaboration with Lee Freitag (WHOI), a new acoustic navigation system will be implemented that allows encoding of small quantities of data onto the navigation signal. These sources will hang below ITP-like surface buoys and Wavegliders, recording GPS position from the surface unit and encoding instantaneous source position onto each navigation signal. Because broadcast position is included with every signal, gliders and floats can range from sources whose position changes with time. Extensive experience in Davis Strait, coupled with initial modeling efforts (Freitag) indicate source ranges of at least 100 km when signaling under ice.

7.5. Polar Profiling Floats (Owens, Jayne)

Twelve WHOI polar profiling floats will be deployed as part of the MIZ observing system. These floats will carry a WHOI micro-modem capable of receiving the signals from the mid-frequency, 780-Hz sound sources that will allow geopositioning during the initial part of the observational period, when the floats profile entirely in ice-covered waters. During the later stages of the experiment, when the region is relatively ice-free, floats will use GPS for positioning. A two-phase ice detection scheme will be developed, using a modified version of a scheme based on mixed-layer temperature and salinity for the initial part of the experiment and a multiple surface approach when the probability of open ocean is high. The floats will provide 1-m bin-averaged temperature and salinity profiles from the bottom of the ice or 1 m from the sea surface to 1000 m depth on a daily schedule during the intensive observational period. At the end of the experiment, the floats will change to a 10-day repeat and report their data through the Argo float program.

7.6. Acoustic Navigation Array and Wavegliders (Freitag)

An array of at least eight ice-tethered acoustic navigation sources will be deployed in two meridional lines running parallel to the main IMB/WB/ITP array, with separations to be determined based on a careful characterization of the effective under-ice working range of the new source and signal design. An additional pair of sources will be carried by two Liquid Robotics Wavegliders. The mobility afforded by Wavegliders will be used to keep these two sources positioned in the open water, as close to the northward-retreating ice edge as possible, to provide a reliable set of navigation signals to platforms operating within the MIZ itself. The two Wavegliders will also be instrumented with meteorological sensors to characterize atmospheric forcing over the open water south of the MIZ. The array of sources provides a drifting acoustic navigation network for gliders and floats operating beneath the ice. The new source design will allow encoding of information onto the navigation signal. This will be used to broadcast source position (which allows mobile assets to navigate from drifting, rather than fixed, beacons) and to transmit a small number of commands to alter the behavior of floats and gliders during under-ice operations, when they have no access to satellite communications.

7.7. SWIFT, AWACS, and Waveriders (Thomson)

In the MIZ, wave evolution is confounded by sequences of open water and ice floes, which create a mixed, or 'broken', fetch. Despite significant theoretical progress (e.g., *Squire*, 2007), fundamental understanding of waves and sea ice is lacking (or at least untested). A combination of moored and drifting observations in the MIZ and the open water to the south will focus on improving understanding of ocean surface waves in the presence of sea ice, especially under conditions of retreating ice and increasing fetch. Specific objectives include:

- Observe waves in the evolving MIZ as a function of fetch and season
- Evaluate the input–dissipation balance of waves in a mixed fetch of open water and ice floes
- Provide wave observations for testing ice–wave models and validating global wave models

Three instruments will capture the temporal evolution and spatial variation of waves in the MIZ. Two sub-surface moorings equipped with Nortek Acoustic Wave and Current (AWAC) meters (Figure 11) will be deployed, one on the Beaufort Gyre Experiment mooring A at 75°N, 152°W and the other over the Alaska slope in the target region for the primary MIZ array. These instruments will capture the onset of waves and progression to open water at the southern end of the MIZ array. Two surface Waverider buoys (Figure 11) will be deployed in open water at the southern edge of the MIZ to provide a boundary condition for wave measurements collected by drifters deployed within the MIZ. Six Surface Wave Instrument Float with Tracking (SWIFT) drifters (Figure 12) will be deployed into the MIZ as part of ship-supported operations in July, after initial formation and northward retreat of the MIZ. SWIFTs measure wind speed, wave height, wave directional spectra, air temperature, sea surface temperature, surface currents, and dissipation by turbulence. Depending on the availability of vessel support, SWIFTs and Waveriders may be relocated one or more times during the course of the experiment, to help them follow the MIZ northward retreat.

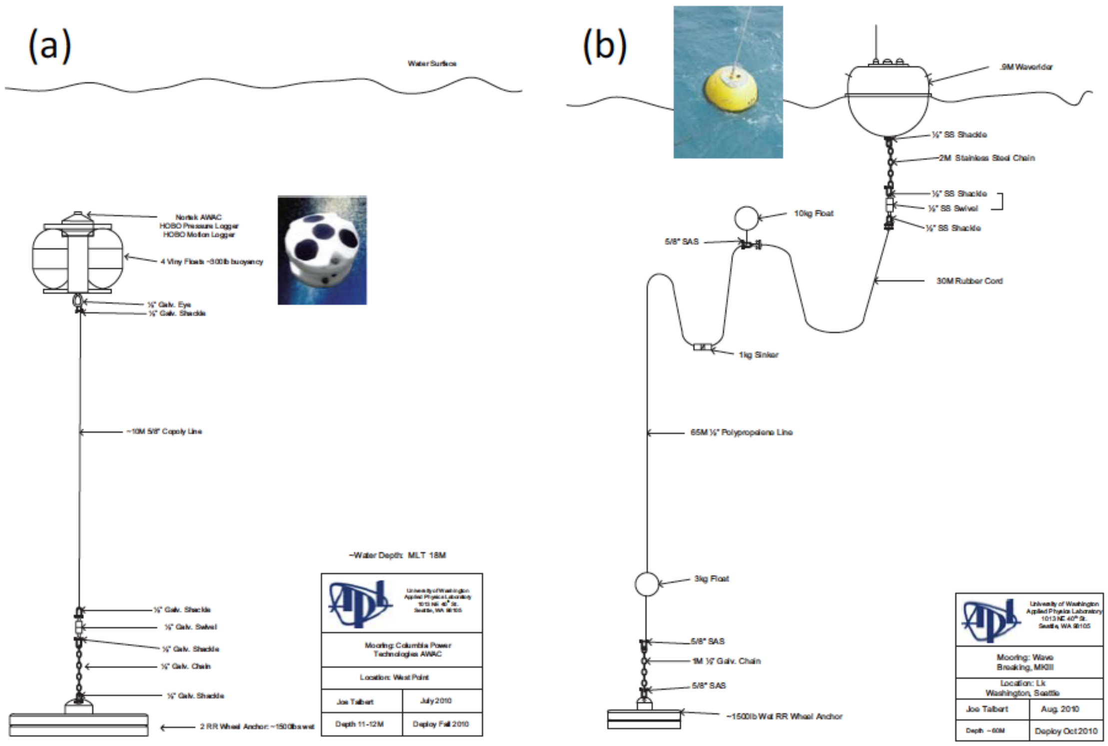


Figure 11. (a) Nortek Acoustic Wave and Current (AWAC) and (b) Waverider moorings. Waveriders may also be deployed in a drifting configuration.

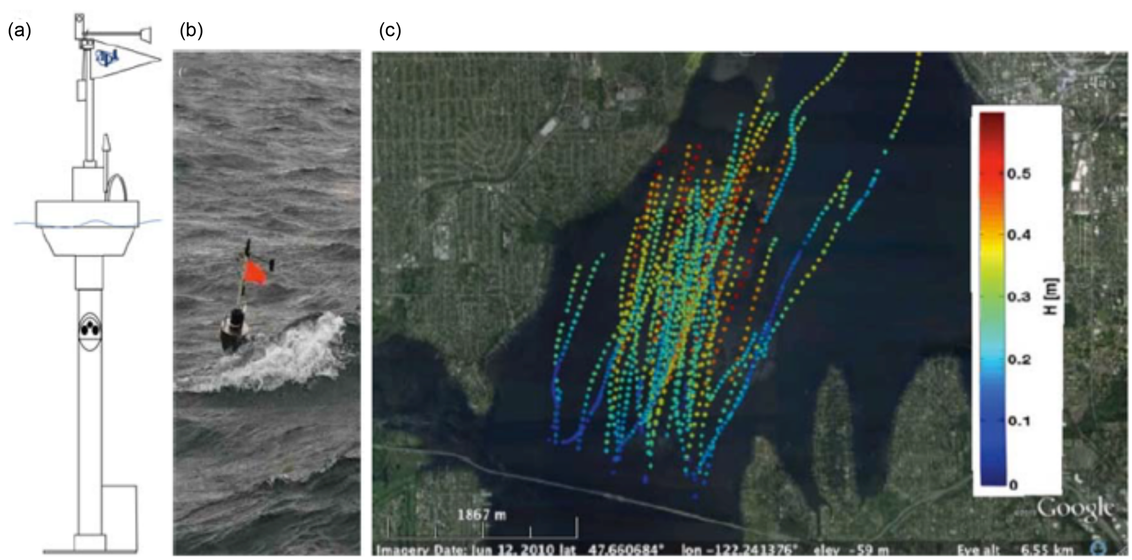


Figure 12. Surface Wave Instrument Float with Tracking (SWIFT) drifter: (a) schematic, and (b) deployed. SWIFTs measure wind speed, wave height [(c) Lake Washington, Seattle], wave directional spectra, air temperature, sea surface temperature, surface currents, and dissipation by turbulence.

7.8. Remote Sensing

Several remote sensing efforts will contribute to MIZ science objectives:

1. TerraSAR-X images will be acquired as part of the Scottish Association of Marine Science effort (Wilkinson, Maksym, and Hwang). Orders require a 4-day lead time.
2. COSMO SKyMed SAR may be acquired. Orders require a 2-week lead time. Rapidly repeated swaths are possible.
3. The Center for Southeastern Tropical Advanced Remote Sensing (CSTARS, Hans Graber) will supply remote sensing products for the MIZ DRI, particularly SAR.
4. NASA IceBridge will coordinate missions to sample in conjunction with the 2014 field program. Focused airborne surveys will include measurements of sea ice thickness, surface elevation, and snow cover. NASA IceBridge may also coordinate with 2013 pilot activities.
5. Data will be available from over-flights by the SIZRS (Seasonal Ice Zone Reconnaissance Surveys) project (J. Morison, APL-UW, and colleagues).

7.9. MIZMAS: Modeling Evolution of Ice Thickness and Floe Size Distributions (Zhang, Schweiger, and Steele)

The MIZ is generally defined as a transition region from open water to pack ice with changing concentration, thickness, and ice floe sizes and shapes. The state of sea ice in the MIZ is currently modeled by an ice thickness distribution (ITD) that provides no information on the geometry of the ice pack, i.e., no description of the floe size distribution (FSD). This is not optimal, given that the FSD impacts ice strength and roughness, ice melt and growth, air–sea fluxes, and surface wave propagation. The FSD is in turn influenced by many of these processes.

At present, most ITD-based modeling of Arctic Ocean sea ice has focused on the large-scale climate response to changing winds and thermodynamic forcing, with relatively little attention paid to the special physics found in the MIZ. At the same time, there is a body of literature on floe dynamics that is largely theoretical or applied only to simple models. What is needed now is to combine the results of these two fields into a full model of the arctic sea ice pack including the MIZ that includes both ITD and FSD, validated with new MIZ observations. This will be especially exciting when applied to the Chukchi and Beaufort MIZ (CBSMIZ), where rapid transformation has occurred in recent years in response to arctic warming and changing atmospheric and oceanic circulation.

Numerical investigations of the historical and contemporary changes in the sea ice and upper ocean of the CBSMIZ will enhance understanding of MIZ processes and interactions, and strengthen predictive capability of future climate change, particularly the changes in both the ITD and the FSD. Work will focus on the development, implementation, and validation of a new coupled ice–ocean Marginal Ice Zone Modeling and Assimilation System (MIZMAS) that will enhance the representation of the unique MIZ processes by incorporating a FSD and corresponding model improvements.

MIZMAS development will be based on systematic model parameterization, calibration, and validation, and data assimilation, taking advantage of the integrated observational and modeling efforts of other MIZ program components. Scientific objectives include:

- Examine the historical evolution of the CBSMIZ ice–ocean system and its ITD and FSD from 1978 to the present to quantify and understand the large-scale changes that have occurred in the system
- Identify key linkages and interactions among the atmosphere, sea ice, and ocean, to enhance our understanding of mechanisms affecting the CBSMIZ dynamic and thermodynamic processes
- Explore the predictability of the seasonal evolution of the MIZ and the summer location of the ice edge in the CBS through seasonal ensemble forecast
- Explore the impacts of future anthropogenic global climate change (including a summer arctic ice-free regime) on the CBSMIZ processes through downscaling future projection simulations

7.10. Arctic Cap Nowcast/Forecast System (ACNFS) (Posey, Allard, Brozena, and Gardner)

The NRL has developed a 1/12° Arctic Cap Nowcast/Forecast System (ACNFS). The system is a coupled ice–ocean model and consists of the Los Alamos Community Ice CodE (CICE) and the HYbrid Coordinate Ocean Model (HYCOM) and uses the Navy Coupled Ocean Data Assimilation (NCODA) system. The grid resolution for ACNFS is approximately 3.5 km near the North Pole and 6.5 km near 40°N. ACNFS assimilates satellite measurements (altimeter data, SST, and sea ice concentration) as well as in situ SST and temperature and salinity profiles using a 3DVAR assimilation scheme. Currently, ACNFS assimilates DMSP ice concentration (25-km resolution) along the MIZ. ACNFS produces a nowcast and 5-day forecast each day of ice concentration, ice thickness, ice drift, ocean currents, salinity, and temperature fields.

NRL is now providing to the MIZ DRI a zoomed area of the Beaufort/Chukchi region of daily ACNFS plots (analysis and out to a 5-day forecast) of ice thickness and ice concentration (both with ice drift overlaid). Fields are available through the NRL anonftp area. Along with CRREL, NRL is currently planning fieldwork off Barrow (March 2013) to study ice surface roughness. In 2012 NRL started a new 5-year effort called "Determining the Impact of Sea Ice Thickness on the Arctic Naturally Changing Environment – DISTANCE." This 6.1 effort will develop new algorithms from satellite and aircraft measurements to determine arctic-wide satellite derived ice and snow thickness. This program will also evaluate ocean processes that now have a larger role in the prediction of the reduced volume ice–ocean system (e.g., wave dynamics). As part of the DISTANCE project, NRL (along with CRREL) is also planning to participate in ONR's 2014 fieldwork in the Beaufort area. Our focus will be to collect high-resolution data with aircraft and in situ measurements to help validate satellite derived ice thickness and snow depth data. These new datasets will be used to validate the ACNFS model forecasts and for possible future model assimilation.

7.11. E-RASM: Eddy-resolving Regional Arctic Climate System Model (Maslowski, Roberts, Cassano, and Hughes)

The overall science goal of this ONR Arctic and Global Prediction (AGP) project is to address the short to long-term U.S. Navy / DOD and national requirements to understand and predict arctic climate change. The main working hypothesis is that the oceanic heat flux convergence in the upper Arctic Ocean is one of the main, yet overlooked and long-term driving forces acting to reduce the sea ice cover. Realistic model representation of mesoscale ocean dynamics and air–sea feedback processes under diminishing sea ice cover are critical to test this hypothesis.

This projects builds on successful research by the PIs, which has resulted in the development of a fully coupled Regional Arctic Climate Model (RACM) consisting of atmosphere (Weather Research and Forecasting – WRF), land-hydrology (Variable Infiltration Capacity –VIC), ocean (Parallel Ocean Program – POP) and sea ice (CICE) model components. An expanded RACM, a Regional Arctic Climate System Model (RASM), is now being developed to include ice sheets (Community Ice Sheet Model – CSIM), glaciers and ice caps (GIC), and dynamic vegetation to allow investigation of coupled physical processes responsible for decadal-scale climate change and variability in the Arctic. In addition, a pending complementary project will include a marine biogeochemical (mBGC) model in RASM to investigate the marine carbon cycle response to changing climate and to predict future changes and responses.

A fully coupled eddy-resolving regional Arctic climate system model (E-RASM) with an improved ocean–ice–atmosphere boundary layer through data assimilation will be used to address Earth System Model limitations, synthesize the historically available and new expected remotely sensed and in situ data to advance understanding and prediction of arctic sea ice and climate change at hourly to decadal time scales. All model components will be configured at sufficient resolution and include improved physics to realistically represent sea ice kinematics, oceanic mesoscale eddies and currents, and atmosphere–ice–ocean interactions. The assimilation strategy we are adopting for E-RASM differs substantially from conventional ice–ocean prediction systems. Rather than focusing on assimilating sea ice velocity, concentration, and oceanic variables, we are focusing on assimilating the RASM atmosphere, and 'satellite-equivalent' variables in RASM's sea ice model.

Three main science objectives are to:

1. Advance understanding and model representation of critical physical processes and feedbacks of importance to sea ice thickness and area distribution using a combination of forward modeling and state estimation techniques
2. Investigate the relation between the upper ocean heat content and sea ice volume change and its potential feedback in amplifying ice melt
3. Upgrade the current version of RASM with data assimilation in WRF/CICE to estimate a physically consistent state of arctic climate for operational and tactical prediction of arctic climate using a single model

7. DATA DISSEMINATION

The MIZ program will employ a lightweight data distribution structure consisting of a password-protected, central repository for storing and distributing project data and model output, along with associated documentation. To promote broad use of the data, and to encourage active collaboration, open access, governed by the MIZ program data policy (section 8), will be provided to all MIZ investigators.

To facilitate use in numerical efforts, to inform ongoing MIZ program activities, and to assist collaborating programs, data will be posted as rapidly as possible. Specific data and product needs for MIZ numerical efforts include:

- Atmosphere

  Validation of atmospheric forcing used in ice ocean models, air drag as a function of ice floe size, experimental/statistical relationship between air drag and floe size

  Prediction of SAT, winds, shortwave down, long-wave down, surface heat flux, clouds/moisture/aerosol

- Sea ice

  Thickness distribution, concentration/extent, drift/deformation, temperature/salinity profiles, regional ice floe size distribution, ridges/ridging, stress, melt ponds/albedo/radiative fluxes, ice–wave interaction

- Ocean

  SST/SSS, mixed layer depth, seasonal pycnocline, upper halocline depth, waves, upper ocean (0–150 m), 3D currents at different seasons, ice ocean momentum and heat fluxes, heat entrainment into the mixed layer, mixing/diffusion (turbulence, double diffusion), upper ocean heat/freshwater content

Each observational component will plan for a hierarchy of data release that should include:

1. Quick-release products that incorporate minimal quality control and processing in order to allow for rapid release.
2. Delayed-mode products, delivered in time for use in the analysis phase, that incorporate full quality control, processing, and correction. These products will be versioned to accommodate updates as additional issues are identified and corrected.

Delayed-mode data should be accompanied by full documentation describing platform, instrument, sensors (including precision and accuracy), quality control, calibration, and correction procedures.

A Data Coordination Working Group will be formed from the MIZ PIs. This team will be responsible for working with the various program components to establish mutually agreed upon data formats and to coordinate delivery, distribution, and archiving of observational data and model output.

8. DATA POLICY

The following data policy derives from experience in multiple ONR DRIs. Successful ONR DRIs share a distinguishing characteristic: tightly integrated experimental and numerical efforts followed by highly collaborative analysis efforts. This is essentially the difference between a single, large, coordinated experiment and a large collection of independent projects working in parallel. The single, large, coordinated experiment requires open data sharing to function. Moreover, rapid, open data release is becoming standard for large programs. The MIZ data policy recognizes this and attempts to strike a balance with rapid, full release within the MIZ team followed by public release at the conclusion of the program.

The ONR MIZ program consists of all investigators participating in the integrated efforts associated with the MIZ DRI. This includes the core team of ONR-supported investigators funded directly by the MIZ DRI and investigators funded though other mechanisms, but coordinated as part of the MIZ program. MIZ DRI data will include observations from field programs, remote sensing data, and model results, all of which will be treated equally for the purposes of the program data policy. All data are collected for basic research, and will be unclassified. As the MIZ DRI also represents an ONR contribution to the U.S. interagency Study of Environmental Arctic Change (SEARCH) and the U.S. interagency Arctic Observing Network (AON), data will also be released to the official data management facility of the US AON for archiving, dissemination, and curation.

Given the complex nature of the science questions and challenges associated with collecting the necessary observations, the success of the MIZ program depends on open, effective data sharing and collaboration. To facilitate sharing of data and collaboration between MIZ scientists, the MIZ DRI will establish a program data archive. To further promote and support sharing and collaboration, the MIZ DRI specifies the following policies to govern the use of data collected under the program.

8.1. Data Use

It is not ethical to publish data without proper attribution or co-authorship. The data are the intellectual property of the collecting investigator(s).

The intellectual investment and time committed to the collection of a data set entitles the investigator to the fundamental benefits of the data set. Publication of descriptive or interpretive results derived immediately and directly from the data is the privilege and responsibility of the investigators who collect the data.

There are two possible actions for any person making substantial use of MIZ data sets, both of which require discussion with and permission from the data collector:

1. ***Expectation of co-authorship***
   This is the usual condition. Scientists making use of the data should anticipate that the data collectors would be active participators and require co-authorship of published results.

2. ***Citation and acknowledgment***
   In cases where the data collector acknowledges the importance of the application but expects to make no time investment or intellectual contribution to the published work, the data collector may agree to provide the data to another scientist providing data reports are properly cited and the contribution is recognized in the text and acknowledgments.

Authors must share and discuss manuscripts with all MIZ investigators who contributed data prior to submission anywhere.

Agreements about publication, authorship, or citation should be documented at a minimum by email between the investigators.

8.2. Roles and Responsibilities

Principal Investigators who are responsible for the collection of observational data or generation of model data during the MIZ DRI are considered participating MIZ DRI scientists and may request data from and provide data to other participating scientists.

Participating scientists have primary responsibility for quality control of their own data and making it available to the rest of the MIZ participating scientists on a timely basis.

Data should be released as soon as possible, through the MIZ data archive, along with documentation that can be used by other researchers to judge data quality and potential usefulness.

The data contained in the archive are made available even though they may not be "final" (i.e., error free) data so it is the responsibility of the user to verify the status of the data and to be aware of its potential limitations.

Participating scientists who wish to use others' data sets are responsible for notifying those Principal Investigators of their intent and inviting collaboration and/or co-authorship of published results.

Participating scientists must consider the interests of graduate students and postdocs before publishing data. Plans for graduate student and postdoc projects must be discussed openly and effort made by all MIZ DRI investigators to facilitate and protect these efforts.

For the duration of the MIZ DRI (2012–2016), program data will be restricted to MIZ DRI investigators. Dissemination beyond program investigators will require the agreement of MIZ DRI investigators and the cognizant ONR program managers. After this time, MIZ DRI participating investigators are required to submit their data to the official data management facility of the U.S. AON for public dissemination and long-term curation.

The MIZ DRI prohibits third party data dissemination; participants are not allowed to redistribute data taken by other MIZ investigators.

All potential users who access the data will be reminded of the MIZ DRI commitment to the principle that data are the intellectual property of the collecting scientists.

Program sponsors of participating scientists may arbitrate and reach agreement on data sharing questions when they arise.

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*
09-10-2012

2. REPORT TYPE
Technical Report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Marginal Ice Zone (MIZ) Program: Science and Experiment Plan

5a. CONTRACT NUMBER

5b. GRANT NUMBER
N000141210176, N000141210180, N000141210346,
N000141210110, N0001412WX20737, N000141210113,
[illegible]

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

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8. PERFORMING ORGANIZATION REPORT NUMBER
APL-UW TR 1201

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Science Foundation
4201 Wilson Boulevard
Arlington, VA 22230

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The Marginal Ice Zone (MIZ) intensive field program will employ an array of cutting-edge autonomous platforms to characterize the processes that govern Beaufort Sea MIZ evolution from initial breakup and MIZ formation though the course of the summertime sea ice retreat. Instruments will be deployed on and under the ice prior to initial formation of the MIZ along the Alaska coast, and will continue sampling from open water, across the MIZ, and into full ice cover, as the ice edge retreats northward through the summer. The flexible nature of ice-mounted and mobile, autonomous oceanographic platforms (e.g., gliders and floats) facilitates access to regions of both full ice cover and riskier MIZ regions. This approach exploits the extended endurance of modern autonomous platforms to maintain a persistent presence throughout the entire northward retreat. It also takes advantage of the inherent scalability of these instruments to sample over a broad range of spatial and temporal scales.

15. SUBJECT TERMS
physical oceanography, observational oceanography, sea ice, polar science, autonomous underwater vehicles, air-sea interaction, remote sensing

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(Include area code)*
				48	

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18