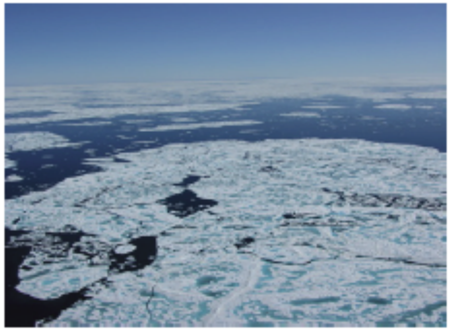
Autonomous Investigations of Marginal Ice Zone Processes- Changing Feedbacks and Observational Challenges

The Marginal Ice Zone Team






Ice Mass Balance Buoys- Wilkinson (BAS), Hwang (SAMS), Maksym (WHOI), Richter-Menge (CRREL)

Wave Buoys- Wadhams (Cambridge), Doble (LOV)

Surface Wave Measurements- Thomson (APL-UW)

Autonomous Ocean Flux Buoys- Stanton, Shaw (NPS)

Autonomous Gliders- Lee, Rainville, Gobat (APL-UW)

Biogechemical Measurements (Perry, U. Maine)

Acoustic Navigation and Wavegliders- Freitag (WHOI)

Profiling Floats- Owens, Jayne (WHOI)

Ice-Tethered Profilers- Toole, Krishfield, Cole, Thwaites (WHOI), Timmermans (Yale)

Remote Sensing- Graber (CSTARS, U. Miami), Hwang (SAMS)

MIZMAS model- Zhang, Schweiger, Steel (APL-UW)

Regional Arctic Climate System Model- Maslowski, Roberts, Cassano, Hughes (NPS)

Arctic Nowcast/Forecast Model- Posey, Allard, Brozena, Gardner (NRL)

Melt Ponds, Biology, Biogeochemistry- Kang, Yang & colleagues (Korean Polar Research Institute)

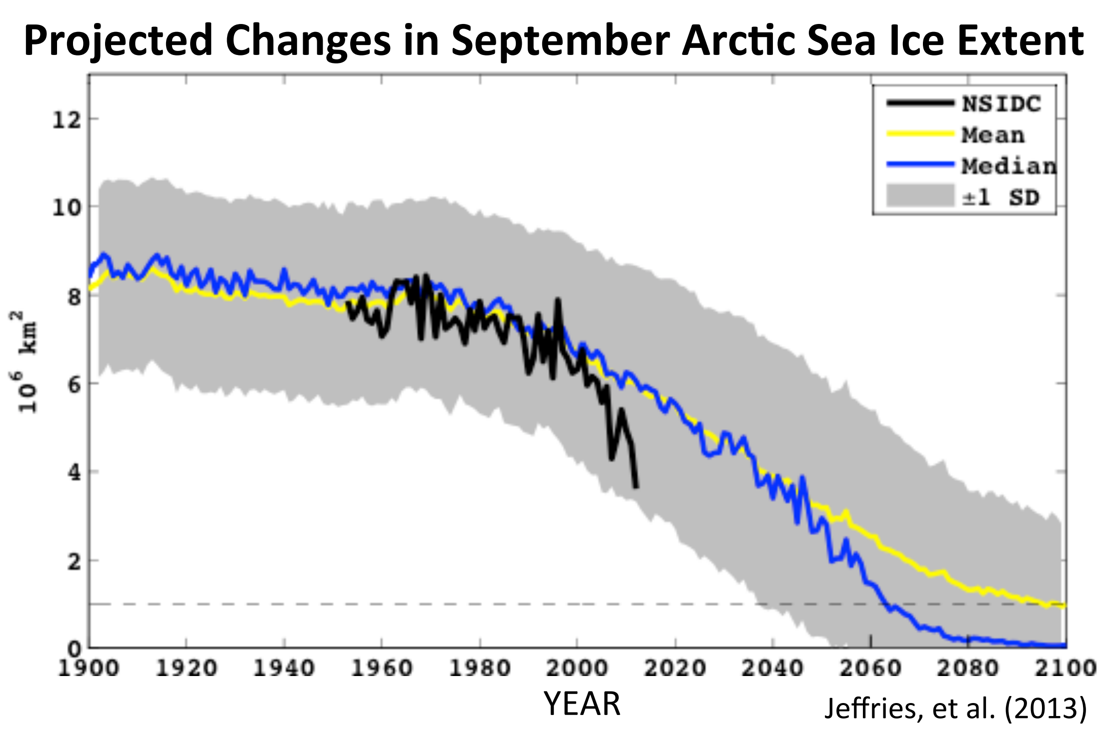
External Collaborations- NRL, NASA, NOAA, ESA

- Tightly integrated program.
- Interdependent elements.
- Exceptional collaboration.
- Strong team effort.

Models Struggle to Reproduce Dramatic Reduction in Summertime Sea Ice Extent

MIZ

- 50% reduction in summer sea ice extent
  - 7 million km^2 in the 1970s
  - 3.4 million km^2 in 2012
- Wintertime sea ice maximum declining.
- Decline primarily thermodynamic, other processes may increase in importance.



Minimum Sea Ice Extent

Improve Predictability – Refine Models

- Process-level investigations
- Improve physics, parameterizations
- Continued testing against sustained observations

Refine physics <u>at the ice edge</u> – between pack ice and open water – <u>Marginal Ice Zone</u>

MIZ

Program Objectives

ONR
Revolutionary Research . . . Relevant Results

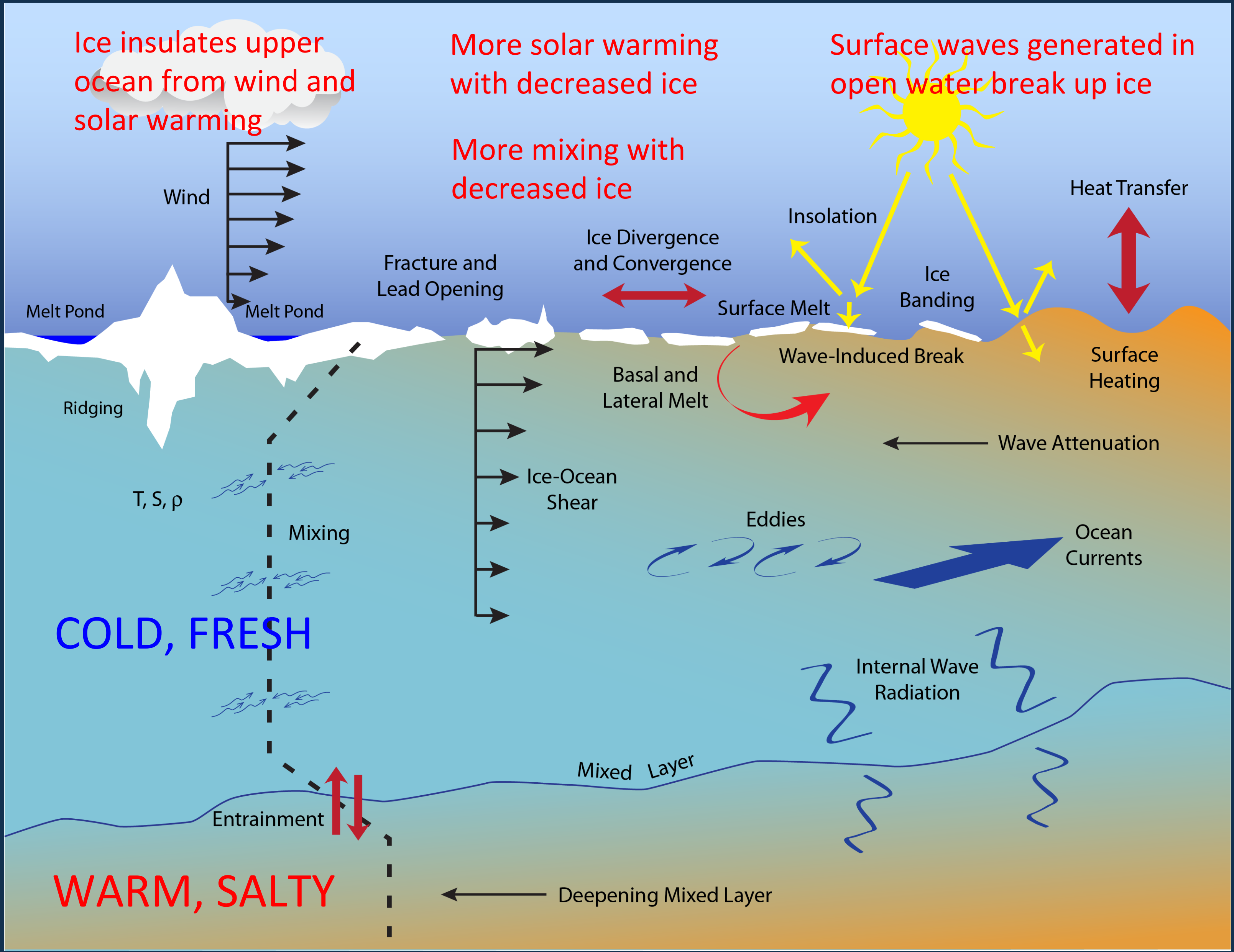
Science

1. Understand the physics that control sea ice breakup and melt in and around the ice edge (Marginal Ice Zone - MIZ).
2. Characterize changes in physics associated with decreasing ice/ increasing open water.
3. Explore feedbacks in the ice-ocean-atmosphere system that might increase/decrease the speed of sea ice decline.
4. Collect a benchmark dataset for refining and testing models.

Technical

1. Develop and demonstrate new robotic networks for collecting observations in, under and around sea ice.
2. Improve interpretation of satellite imagery.
3. Improve numerical models to enhance seasonal forecast capability.

Atmosphere-Ice-Ocean Interaction



Challenges

1. Multiple Domains: Simultaneous measurements of atmosphere, ice and upper ocean.

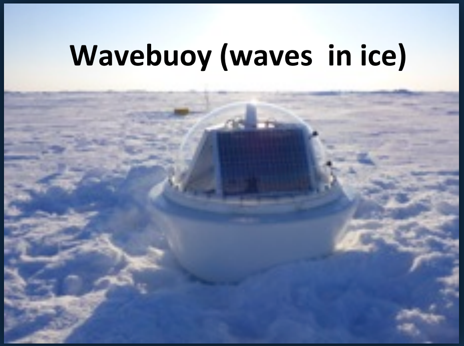
2. Resolution: Resolve temporal evolution and small-scale spatial variability (4-D physics).

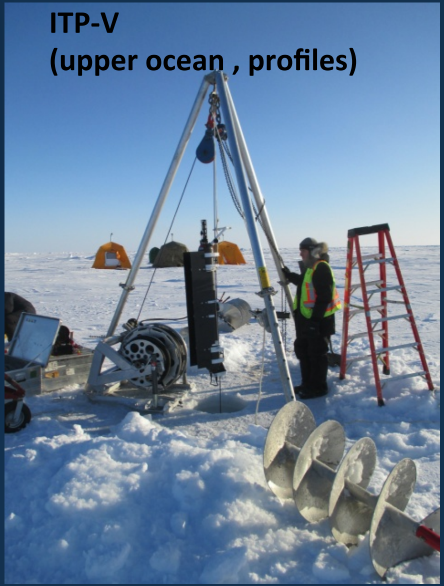
3. Persistence: Sample entire melt season (Jun – Sep). Physics change as a function of open water extent.

4. Access: Measurements in full- and partial- ice cover.

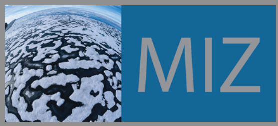
5. Scalability: Large number of platforms provide distributed sampling, mitigate risk.

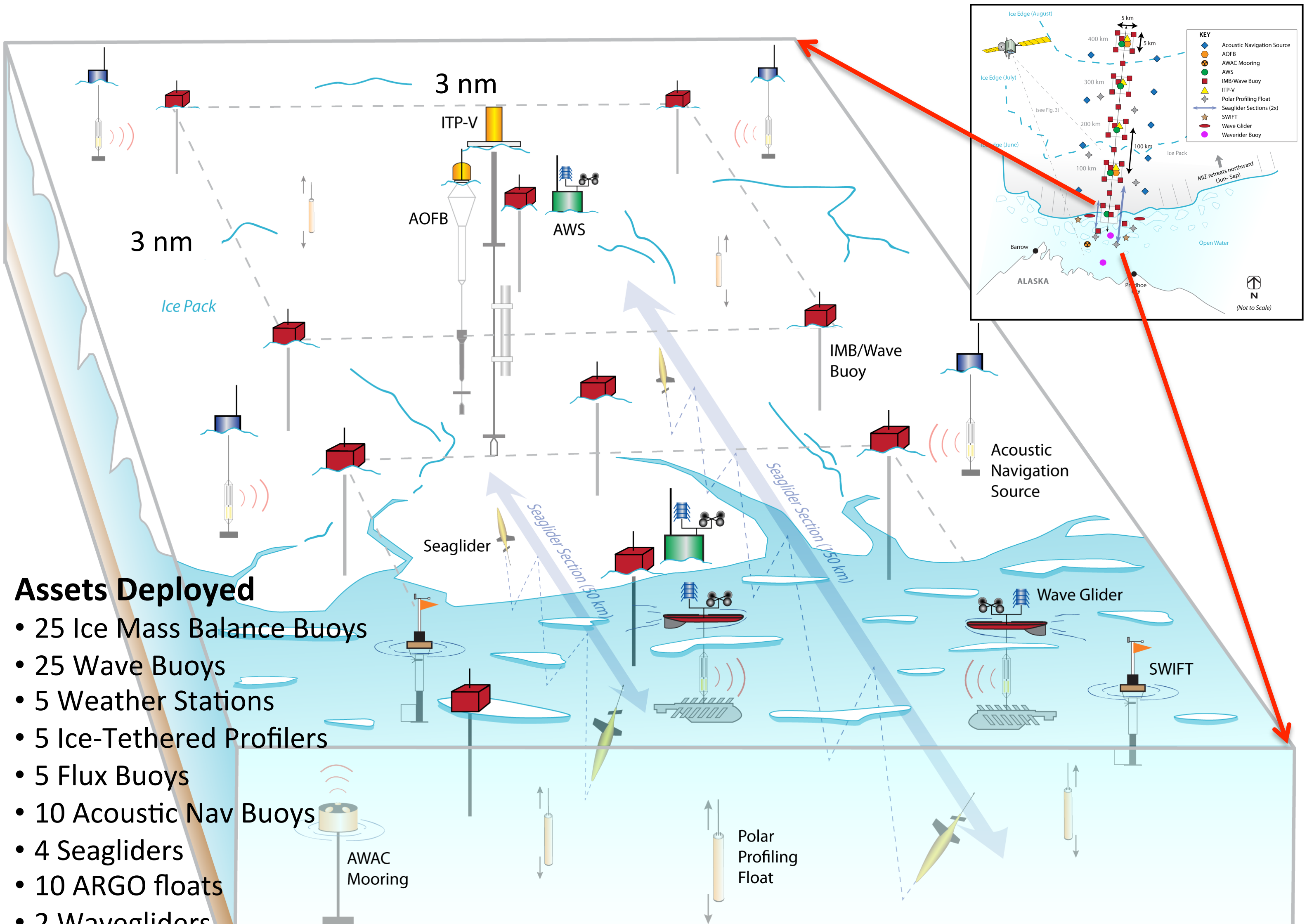
The Revolution in Robotic Observing





Putting the Pieces Together





Assets Deployed

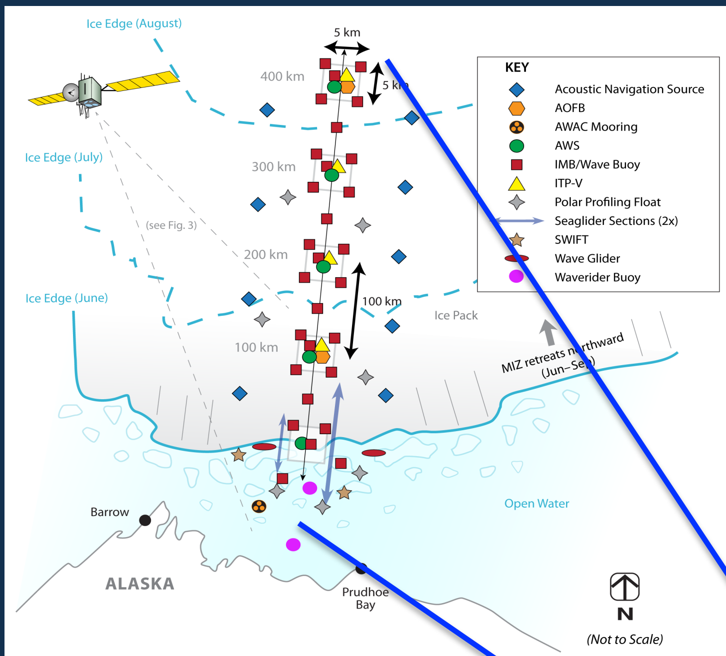
- 25 Ice Mass Balance Buoys
- 25 Wave Buoys
- 5 Weather Stations
- 5 Ice-Tethered Profilers
- 5 Flux Buoys
- 10 Acoustic Nav Buoys
- 4 Seagliders
- 10 ARGO floats
- 2 Wavegliders
- 3 SWIFT floats

90+ Distinct Observing Assets

Autonomous Approach

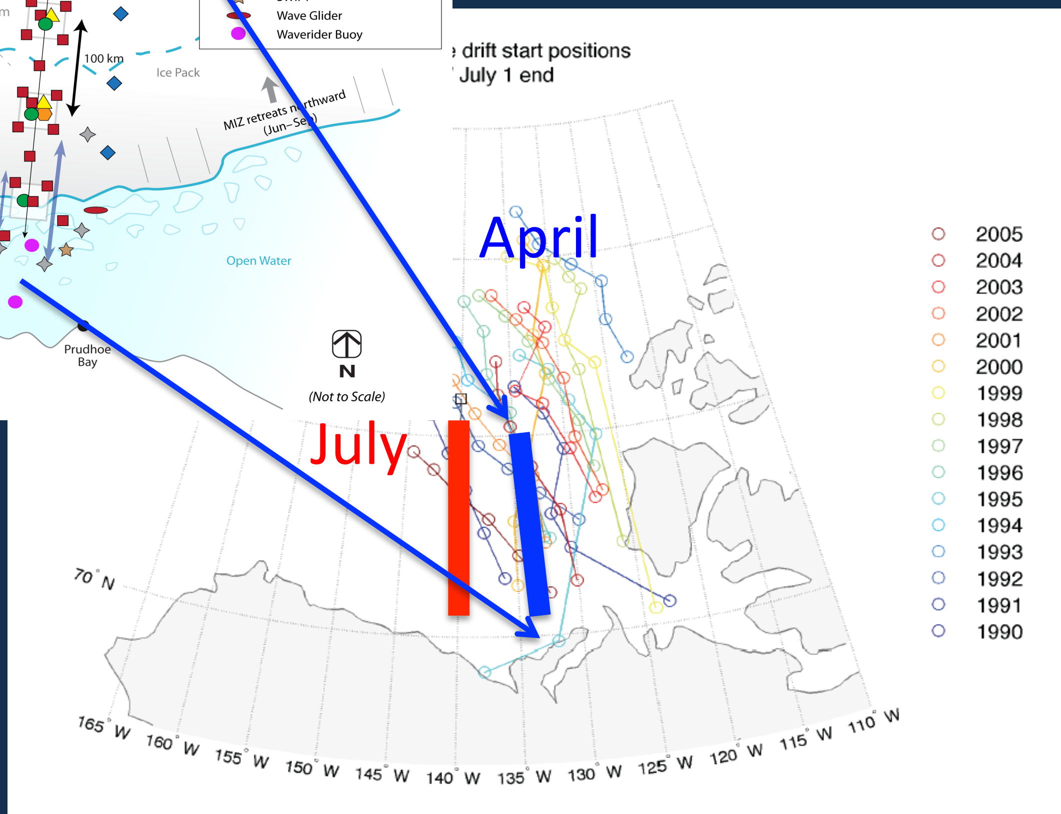
MIZ

ONR — Revolutionary Research . . . Relevant Results



Ice-based array deployed by aircraft in April (full ice cover).

Drifters & gliders deployed in July, immediately after open water forms along the coast.



- Array drifts with ice pack- follow evolution along the line.
- Maintains focus on MIZ by following northward retreat of ice edge.
- Ice-based array samples ice-covered area.
- Drifting platforms in open- and ice-covered water.
- Mobile platforms span ice-free, MIZ and ice-covered regions.
- Follow MIZ retreat northward through September 2014.

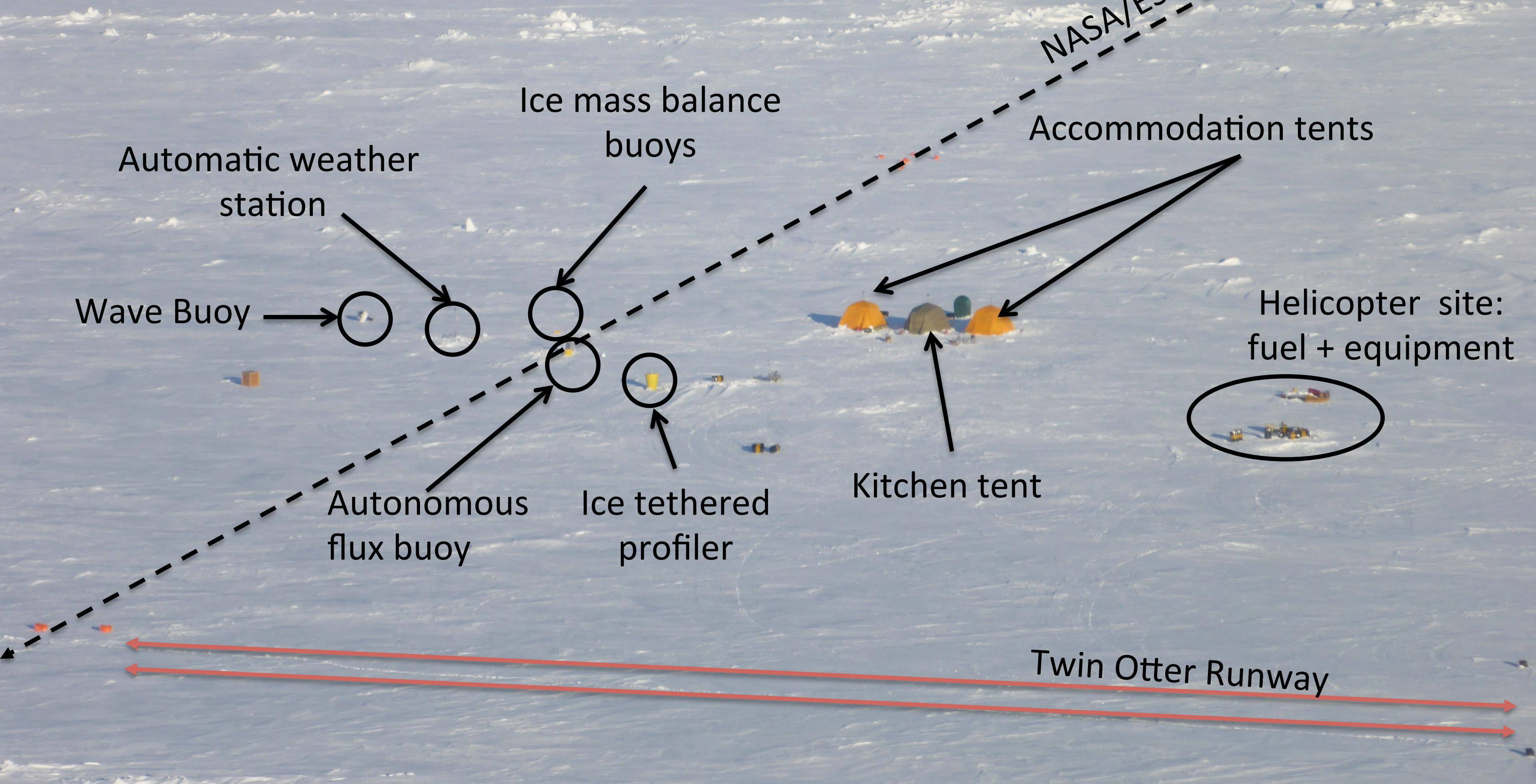
Risk Mitigation: 20% of assets held for deployment in August at northernmost site using Korean icebreaker Araon.

MIZ

'Fast & Light' Ice Camp Logistics

- 60+ assets deployed over 300 km km range.
- 2 Twin Otters + 1 Bell 412
- 1 week setup, 1 week ops

Personnel = 6 persons + dog
- 3 x scientists/engineers
- 3 x helicopter personnel



'Fast & Light' Vessel Logistics

R/V Ukpik, July 2014

Deploy:
4 seagliders
3 SWIFT buoys
2 wavegliders

Ice edge measurements
(turbulence wave attenuation)

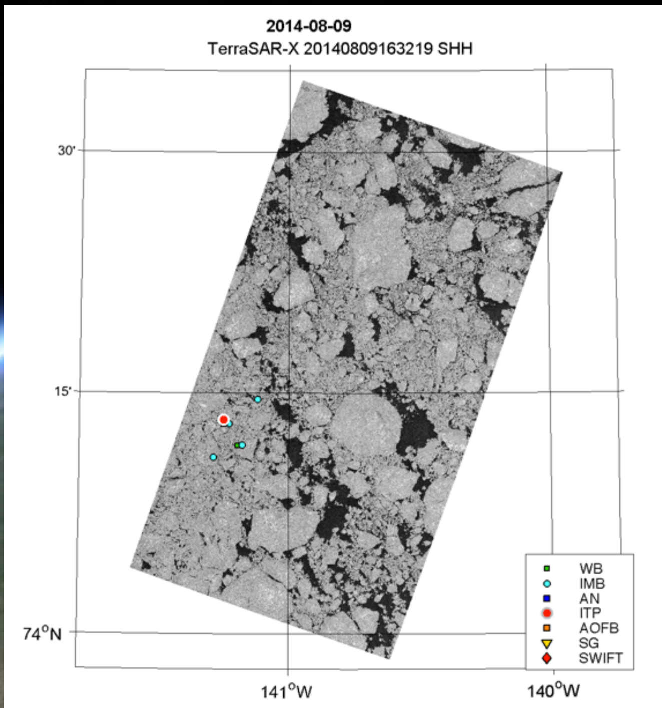
R/V Norseman II, Sept 2014

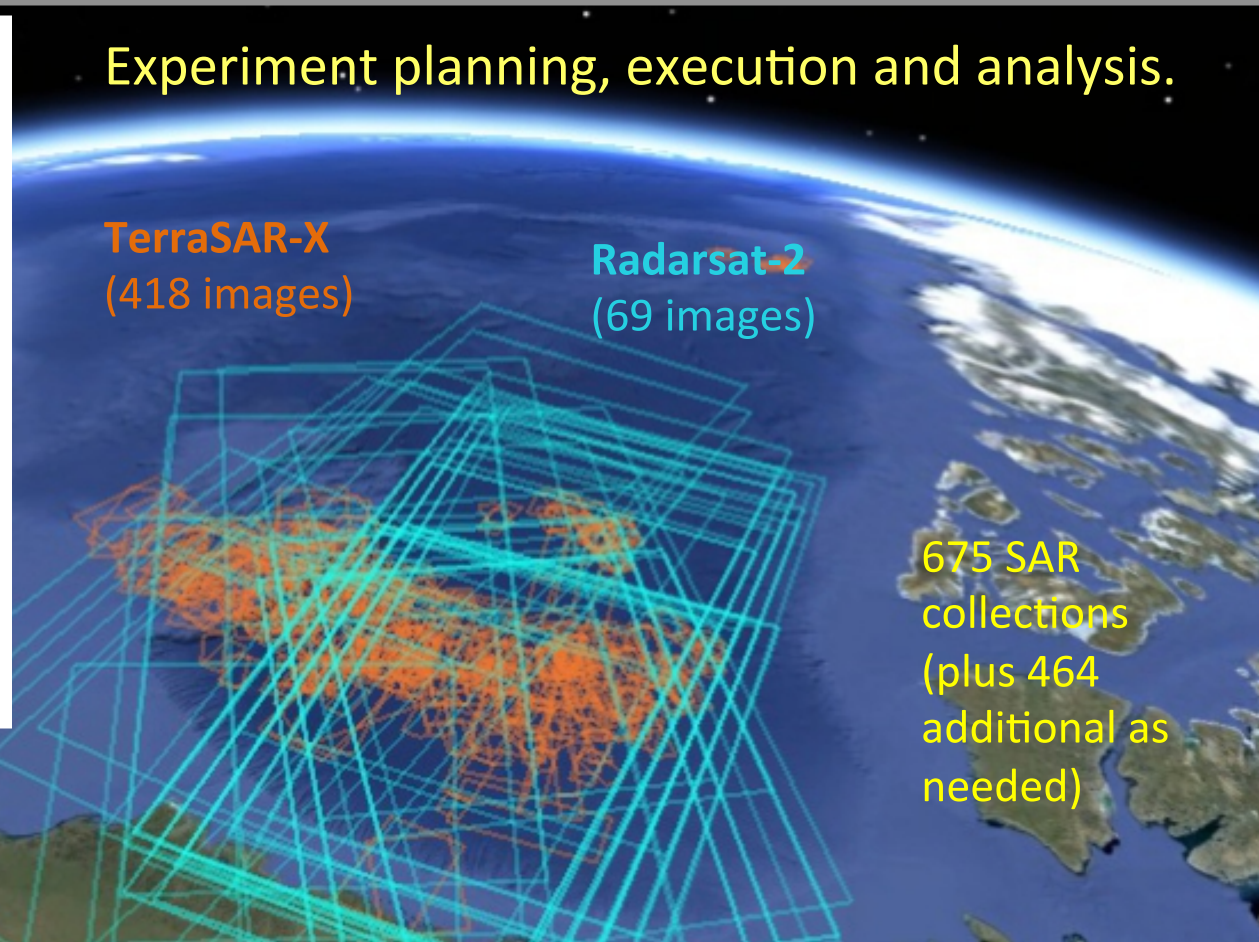
Recover:
4 seagliders
3 SWIFT buoys
1 wavegliders

Ice edge measurements
(CTD and wave attenuation)

MIZ Remote Sensing

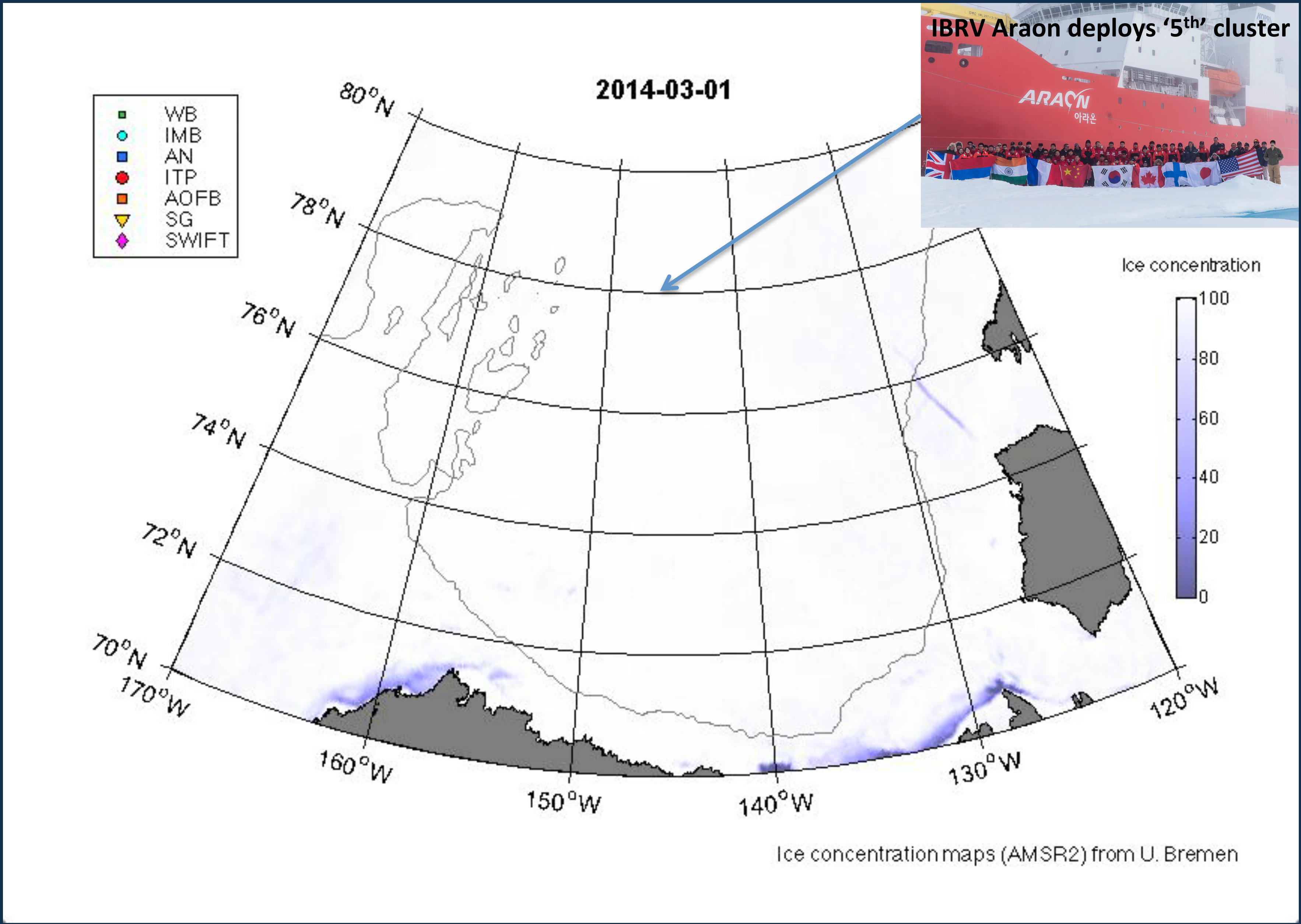
Experiment planning, execution and analysis.





- Dedicated support from National Ice Center, meteorological reports & drift forecasts inform planning & targeting.
- Agile targeting to follow drifting instruments, respond to rapidly-evolving MIZ
- Targeting strategy and protocols developed & tested prior to main program.
- Small targeting team (remote sensing, models, observations) led by Bill Shaw

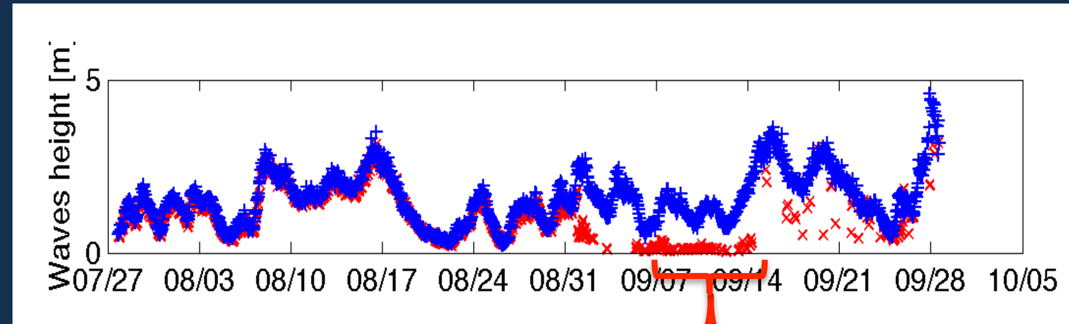
MIZ Autonomous Sampling
(1 Mar – 20 Oct 2014, 8 months)

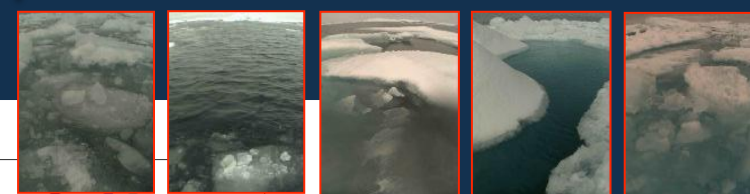


Surface Wave Attenuation in Sea Ice

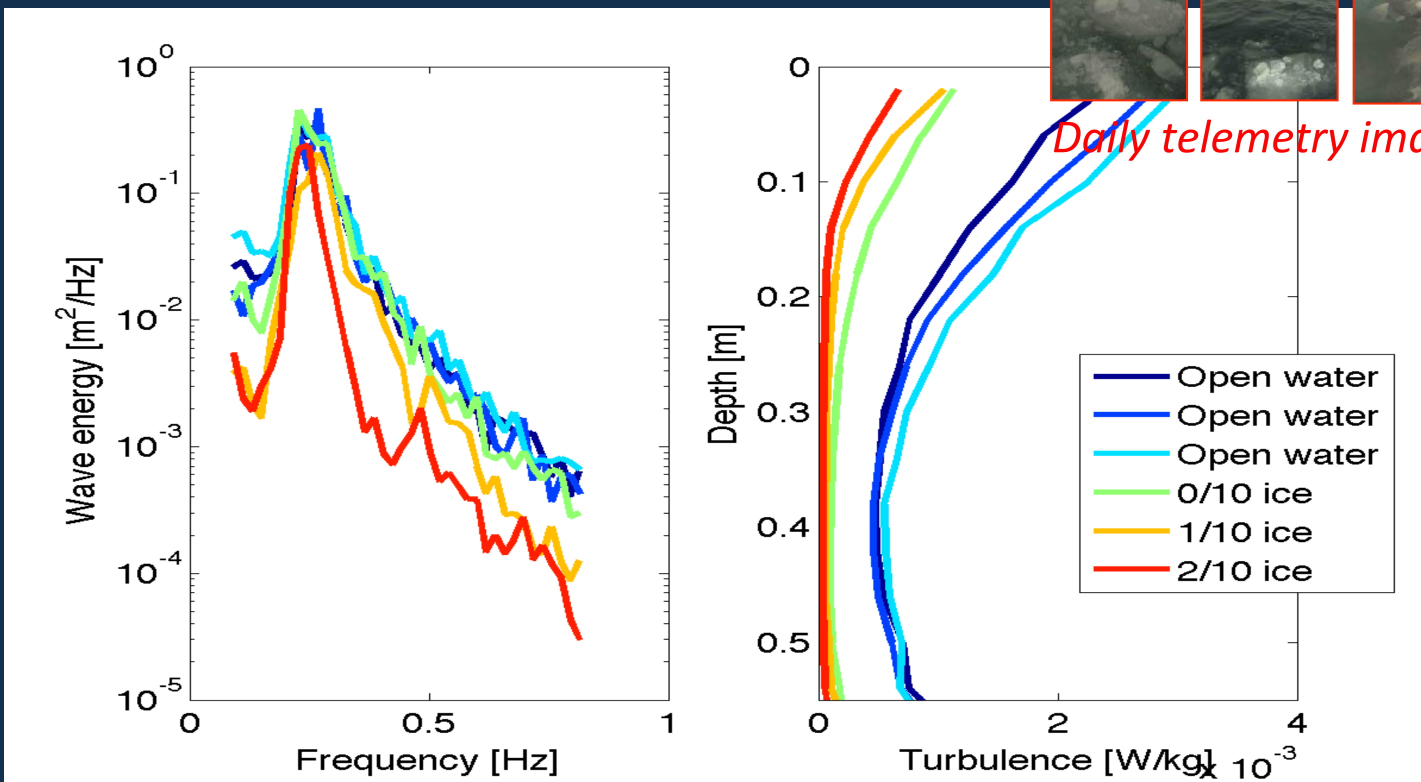
Thomson (APL-UW)

- Fetch-limited waves in the Beaufort sea are rapidly attenuated at ice edge, because wavelengths are short
- Ice effectively protects itself from the waves, like a beach protects the coast… and thus interior of ice pack is likely controlled by thermodynamics



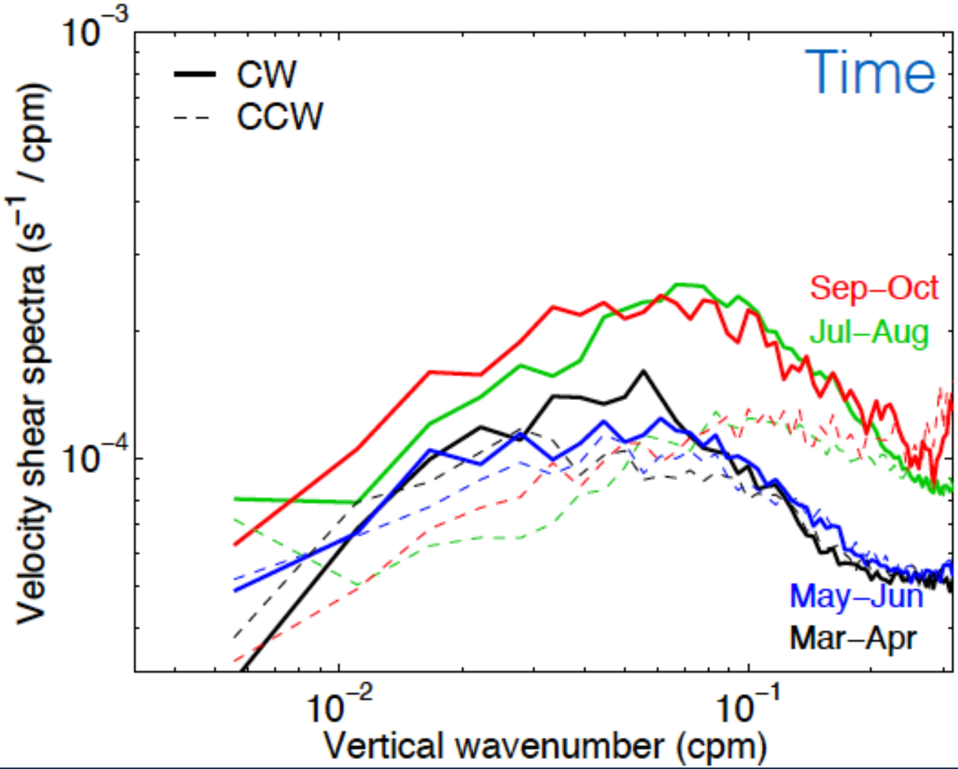


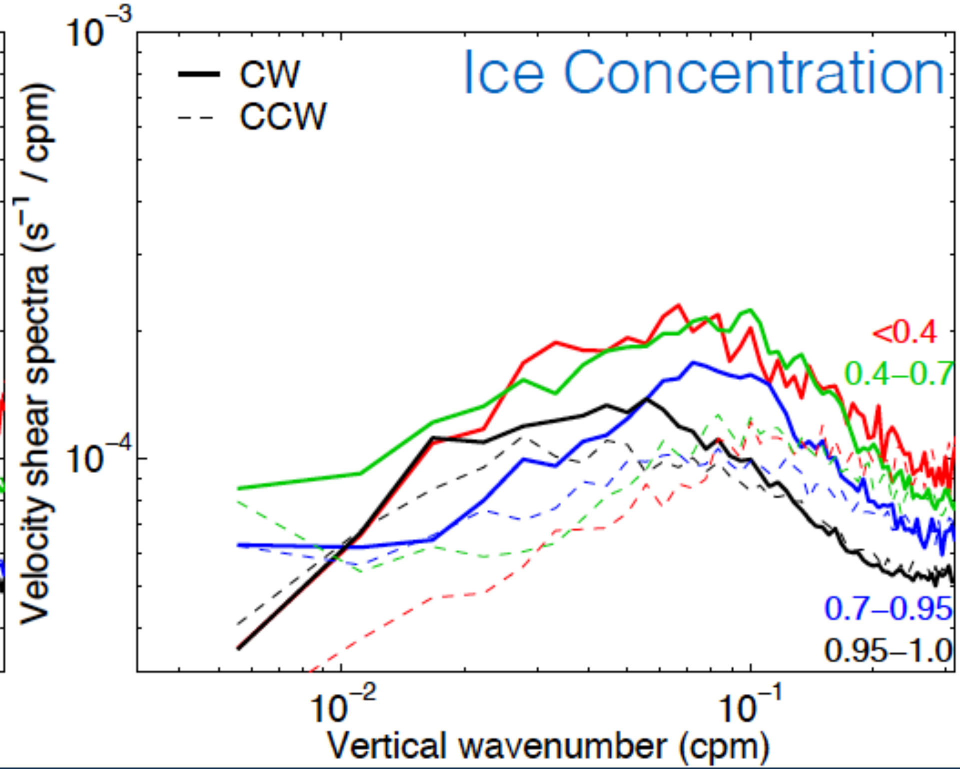
Daily telemetry images from SWIFT 10



Internal Wave Energy Changes with Ice Cover

Cole, Toole, Timmermans, Krishfield

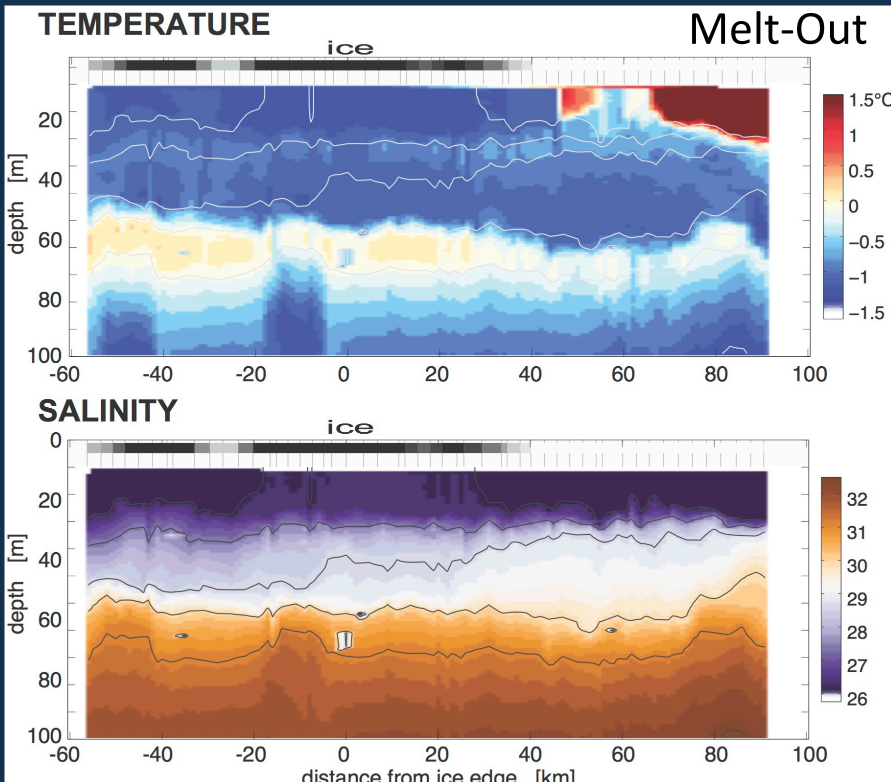


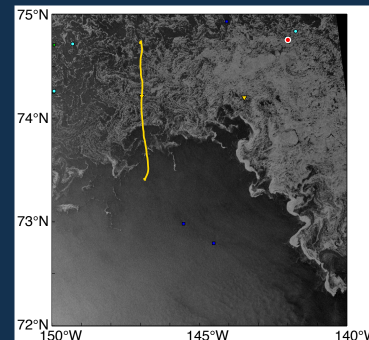


- Ice-Tethered Profilers at C2 and C4
- 70-250 m depth
- IW energy increases from spring into summer
- IW energy appears to increase with increasing open water fraction.

Glider sections across the MIZ

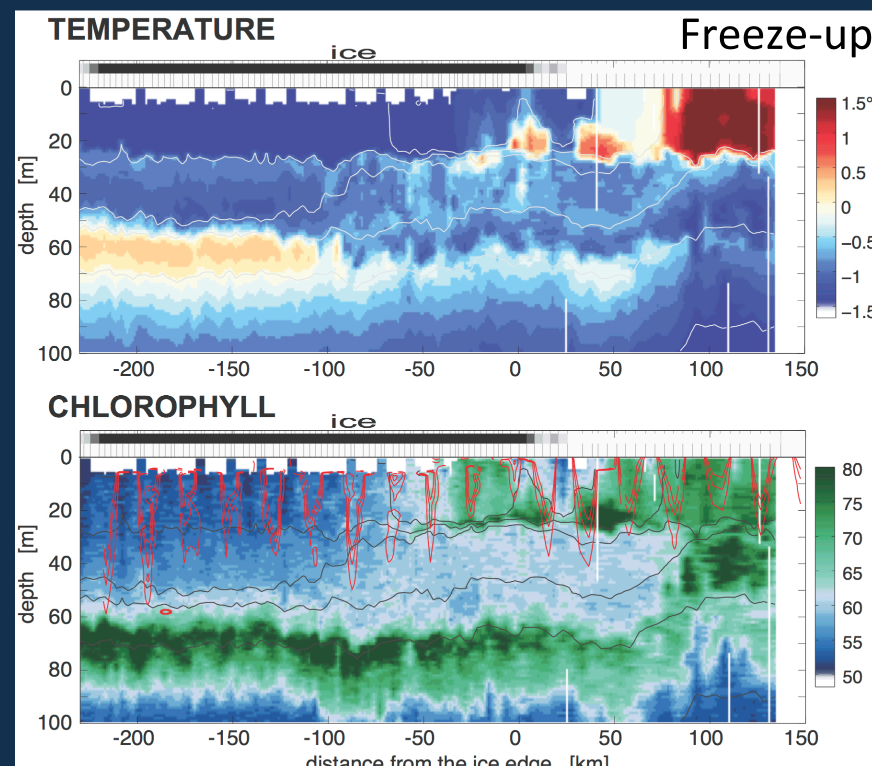
Lee, Rainville, Gobat, Webster, Freitag





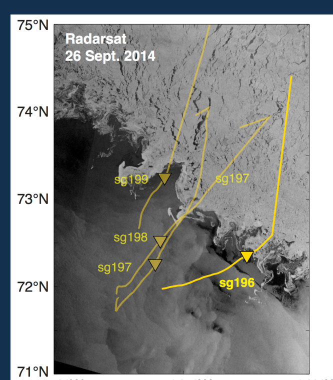
Melt-Out (5 Sep 2014)

- Warmer, fresher out of the ice.
- Thickening isopycnal layer at ice edge.
- Ice-edge upwelling?
- Ice-edge mixing?



Freeze-up (26 Sep 2014)

- Deeper mixed layers.
- Elevated lateral variability.
- Near-surface temperature maxima formation?
- Sharp contrast in chl fluorescence across MIZ.



Early Results

Science

1. In this year, waves do not appear to have played a large role in breakup of the pack- thermodynamics dominate.
2. Surface waves attenuate rapidly upon encountering ice, even in fractional cover.
3. Signatures of lateral mixing and vertical exchange driven by small-scale front and eddies near the ice 'edge'.
4. Clear contrasts in chlorophyll distribution associated with ice 'edge'.
5. Secondary bloom during freeze-up, associated with elevated mixing.

Technical

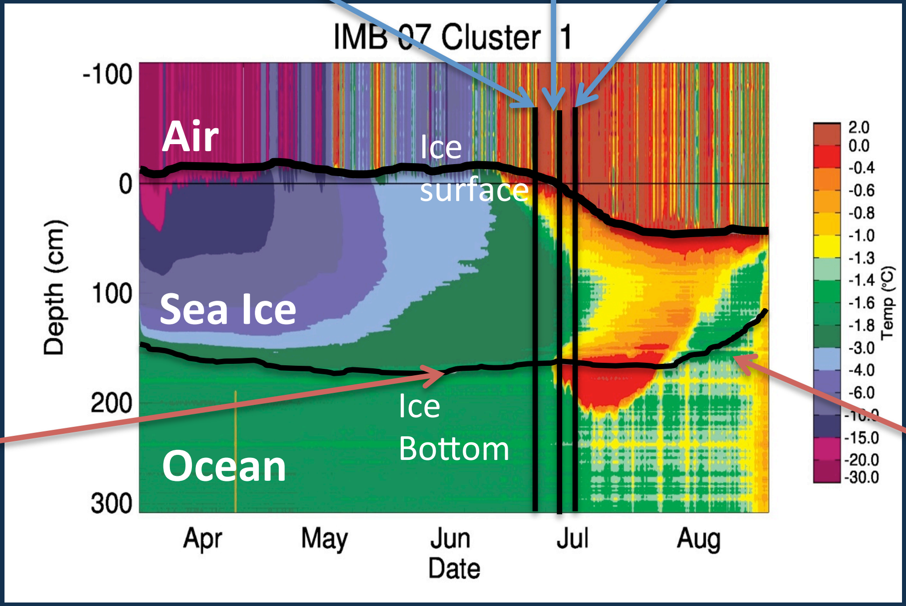
1. Autonomous observing from pack ice, though the MIZ and into open water spanning an entire melt season (March – October 2014).
2. Under-ice glider operations using new, drifting broadband sources.
3. Acoustic receptions at 400+ km due to shallow sound channel associated with Beaufort Sea near-surface temperature maximum.

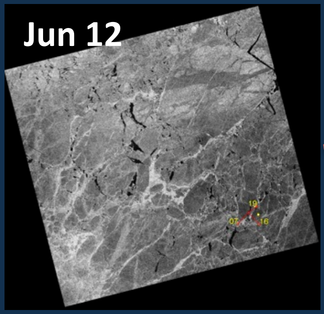
Sea ice mass balance

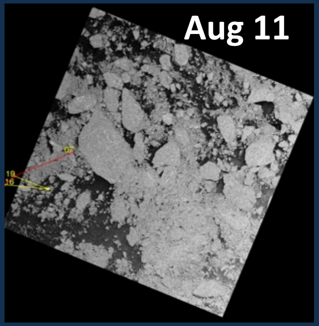
Wilkinson, Maksym and Hwang

Cannot directly measure ice thickness from space
Need autonomous platforms

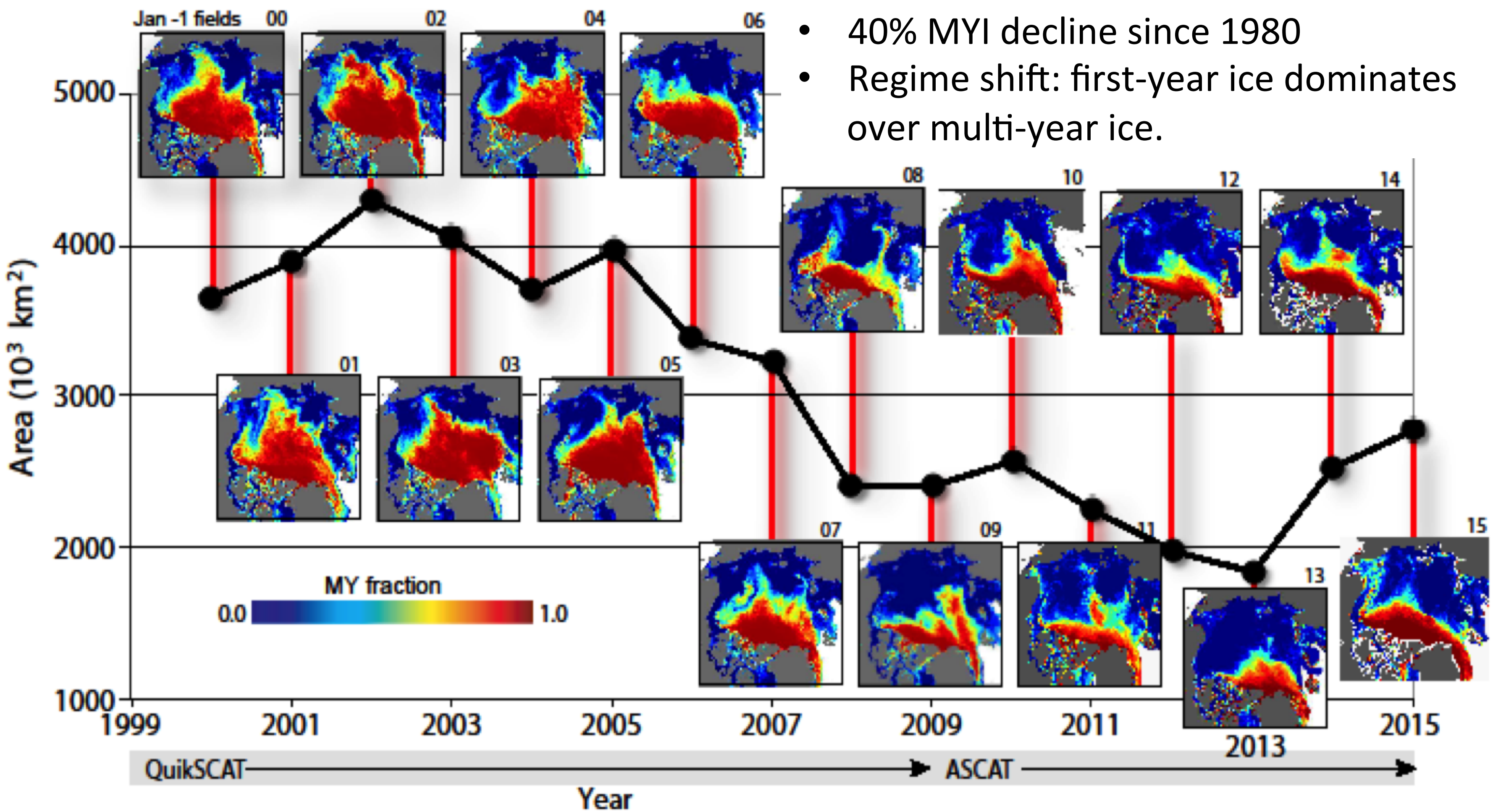
20 x ICE MASS BALANCE BUOYS







MIZ Declining Extent & Multi-Year Fraction



- 40% MYI decline since 1980
- Regime shift: first-year ice dominates over multi-year ice.

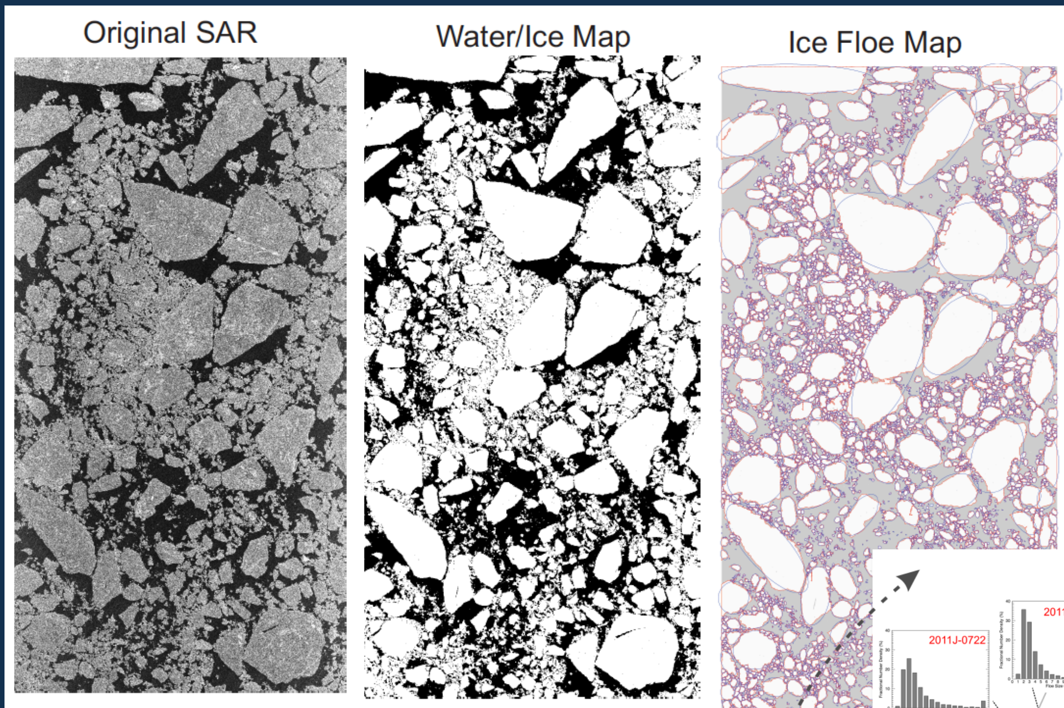
Kwok, JPL

⇓ Extent + ⇓ Thickness = ⇓ sea ice volume

Quantity *and* quality of sea ice impact processes and feedbacks.

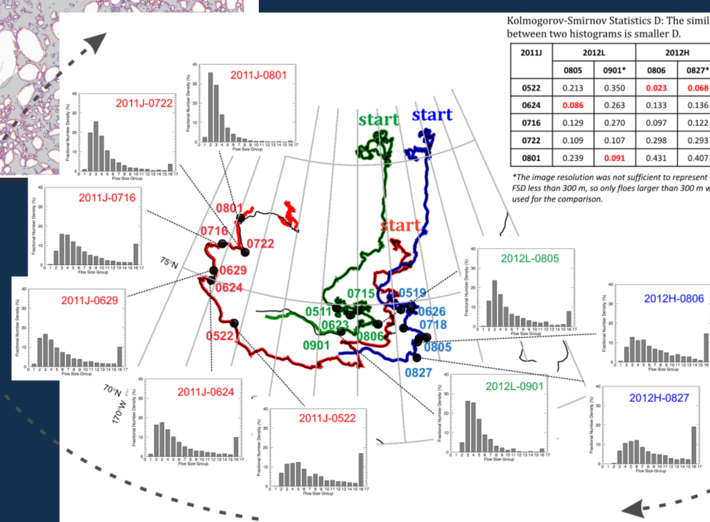
Open Water Fraction & Floe Size Distribution

Wilkinson, Maksym and Hwang



- Complex algorithms needed to separate floes.
- Not fully automated
- Floe size distribution
- Fraction of open water

Can be applied to both high resolution radar and visible satellite imagery.



Kolmogorov-Smirnov Statistics D: The similar between two histograms is smaller D.

2011J	2012L		2012H	
	0805	0901*	0806	0827*
0522	0.213	0.350	0.023	0.068
0624	0.086	0.263	0.133	0.136
0716	0.129	0.270	0.097	0.122
0722	0.109	0.107	0.298	0.293
0801	0.239	0.091	0.431	0.407

**The image resolution was not sufficient to represent FSD less than 300 m, so only floes larger than 300 m was used for the comparison.*