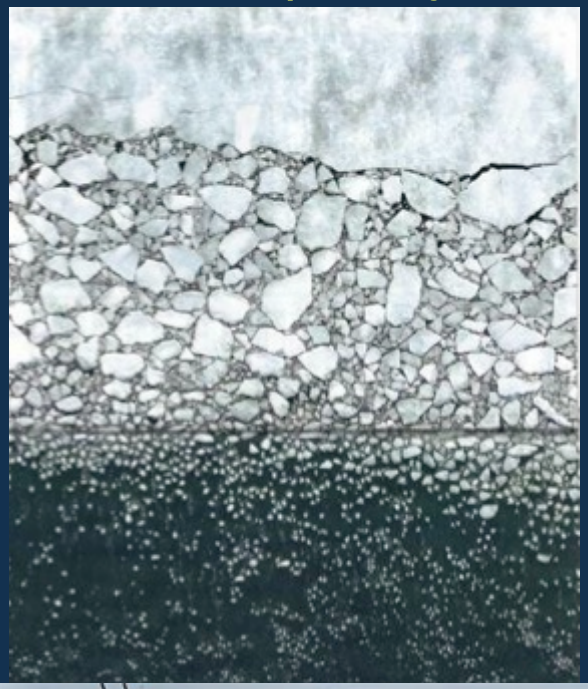
Process Studies in the Changing Arctic- Marginal Ice Zone (early, melt) and Sea State (late, open water)



Craig Lee (Marginal Ice Zone Program)

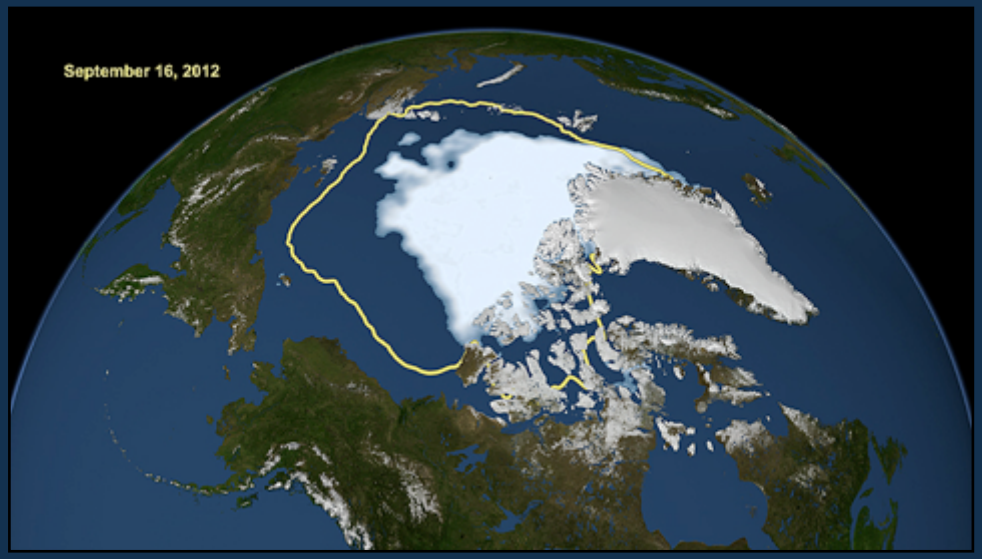
Jim Thomson (Sea State Program)

Applied Physics Laboratory, University of Washington

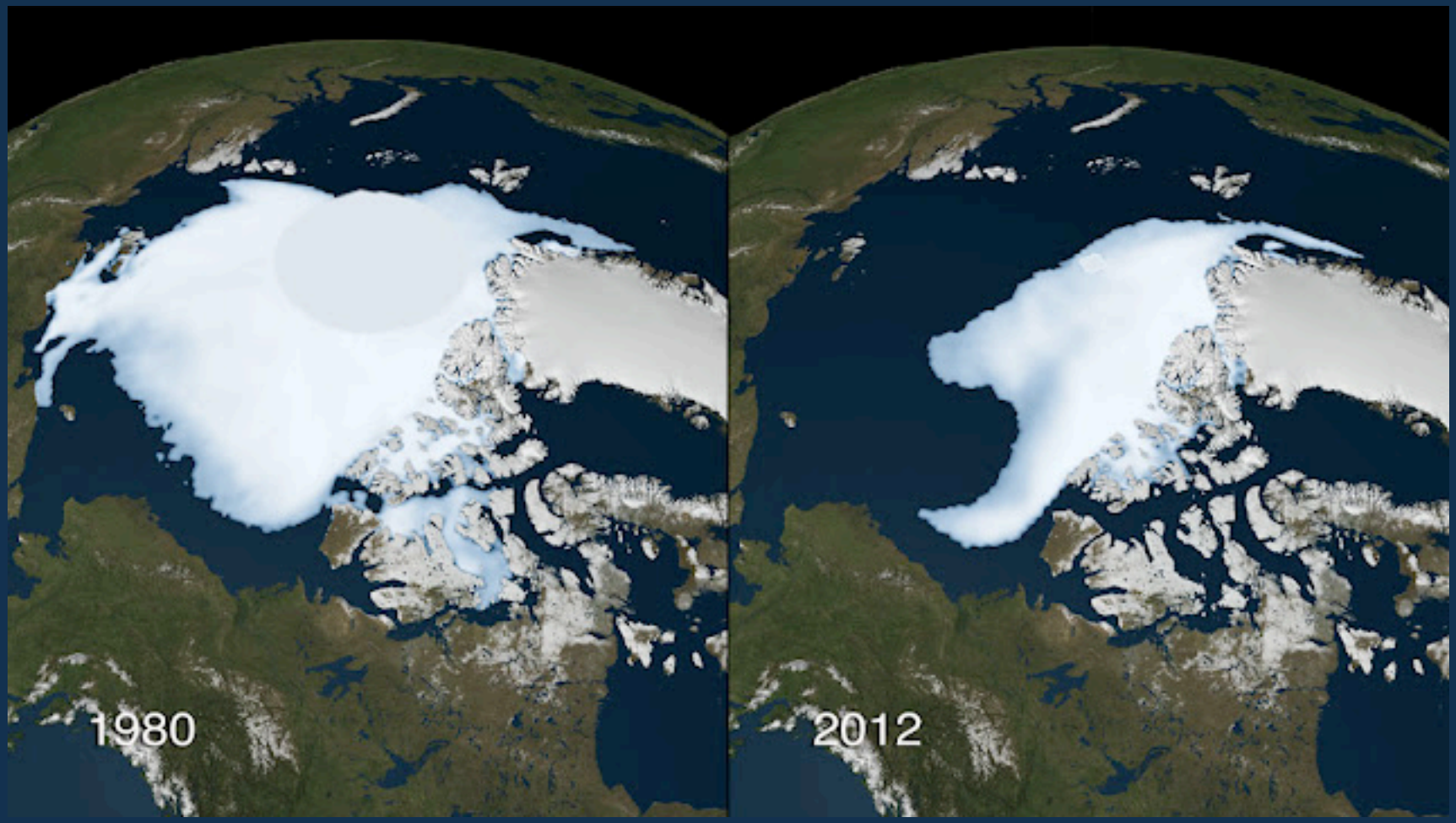
Scott Harper (Program Manager)

Martin Jeffries (Program Manager)

Arctic and Global Prediction, Office of Naval Research

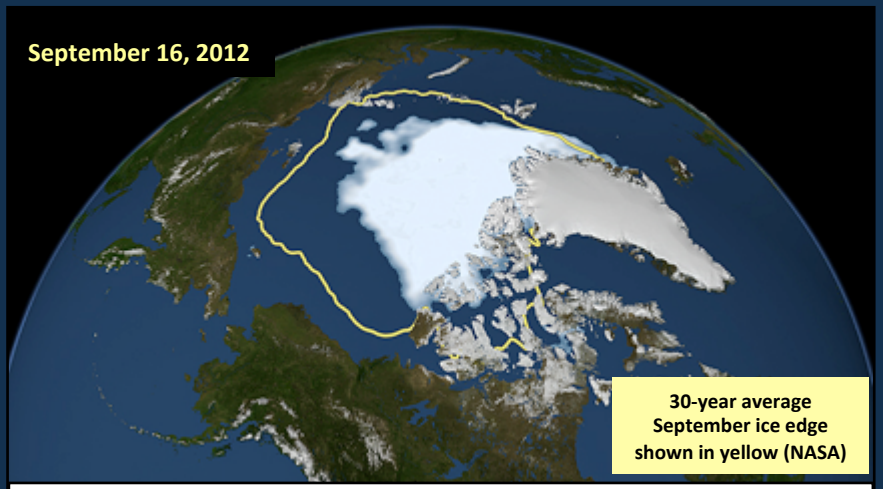


New, Emerging Physical Regime

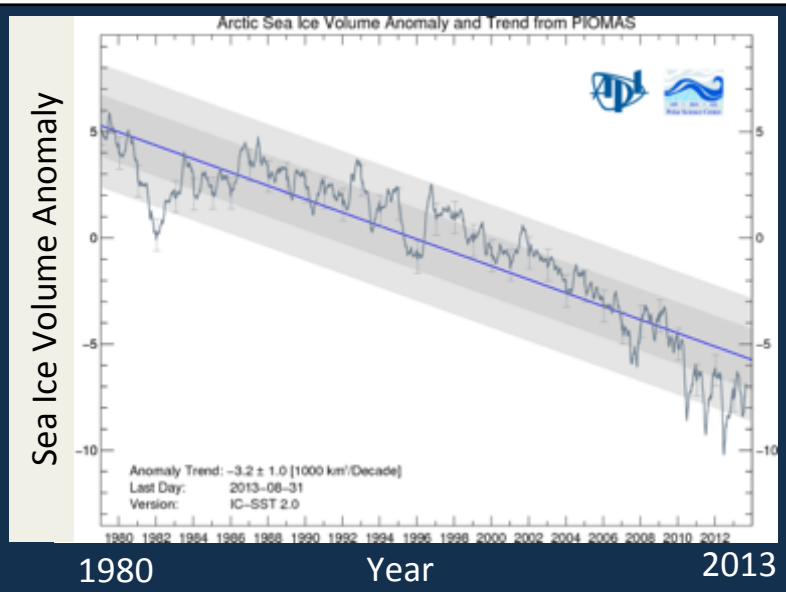


More open water in summer… tighter coupling with atmosphere, different dynamics, changing feedbacks, increased importance of the seasonal and marginal ice zones.

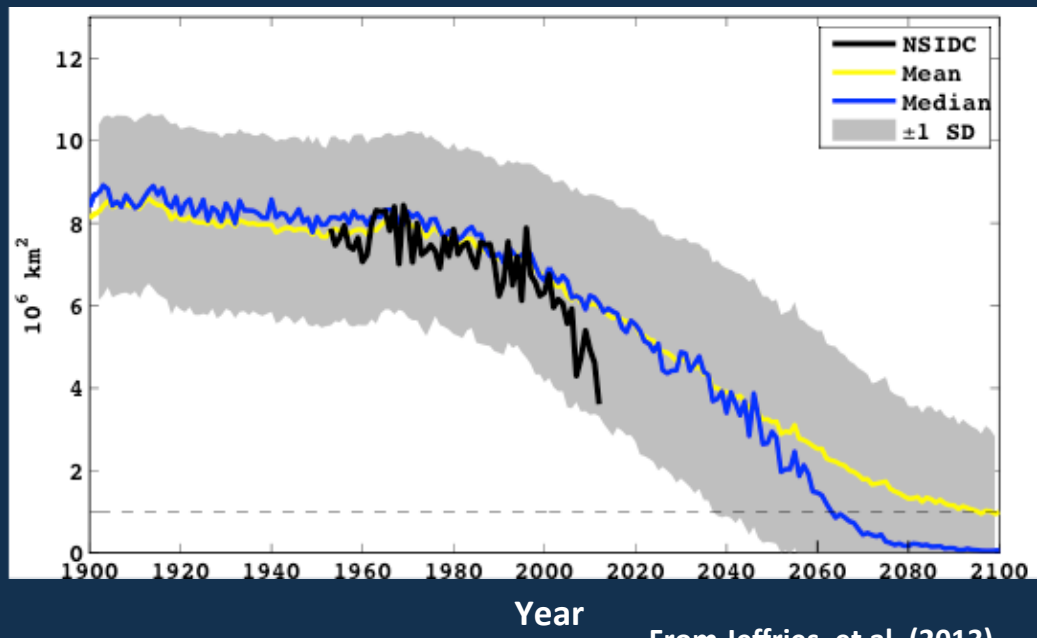
Models Struggle to Reproduce Observations



Observed Changes in Arctic Sea Ice



Projected Changes in September Arctic Sea Ice Extent



From Jeffries, et al. (2013)

Characterize Environmental Change

- Distributed, persistent, long-term observations

Improve Predictability – Refine Models

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

Challenges

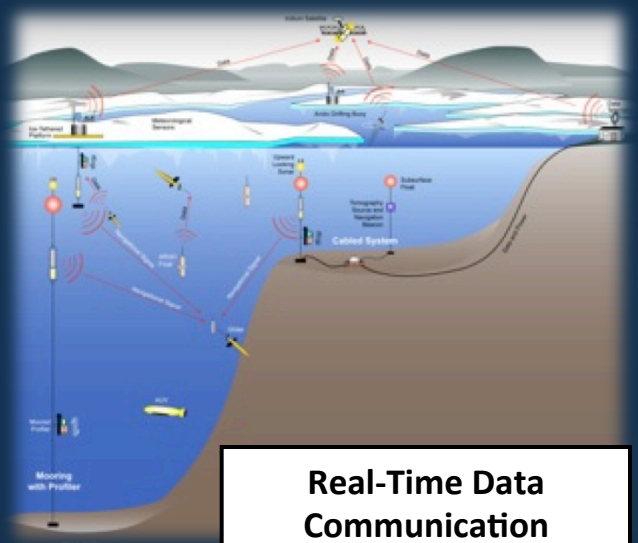
How do we build a sustainable Arctic Observing capability that resolves a broad range of temporal and spatial scales (climate to process) and meets the needs of basic research, policy makers and stakeholders?

- Access- Far from areas of human activity.
  - Poor for ships, good for aircraft (for now…).
  - Exploit ice as measurement platform.
  - Limited access to critical services (GPS, Iridium).
- Risk- Unforgiving operating environment, extended development arc.
- Persistence- Resolve important timescales, transient events.
- Cost/Scalability- Sustain broad, long-term activity.
- Adaptability/Flexibility
  - Sea ice decline- seasonal ice cover, marginal ice zone.
  - Needs evolve with changing environment and understanding.
  - Meet disparate stakeholder needs: climate to tactical.

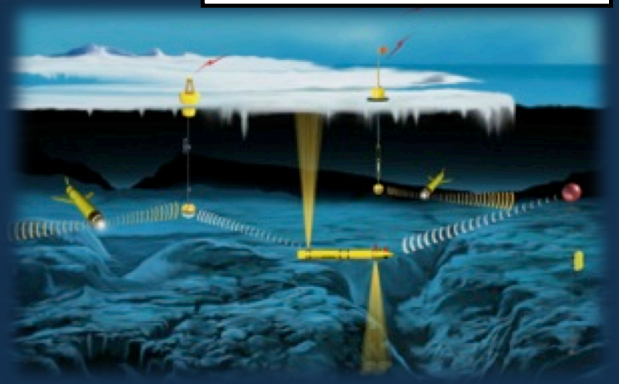
Technology Development for Sustained Arctic Observing

A sensing system must be developed to provide persistent observations that can further scientific understanding, provide long-term monitoring, and constrain the predictive models.

Autonomous platforms – Robust Sensors – Real-time Data Delivery – Key Environmental Variables

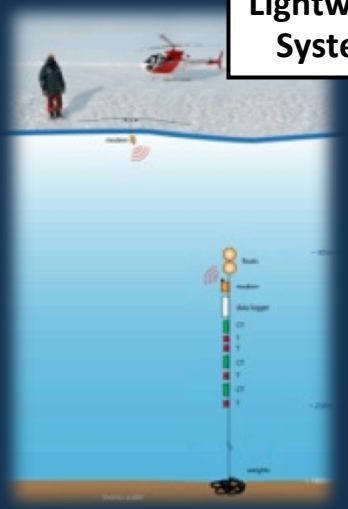


Real-Time Data Communication

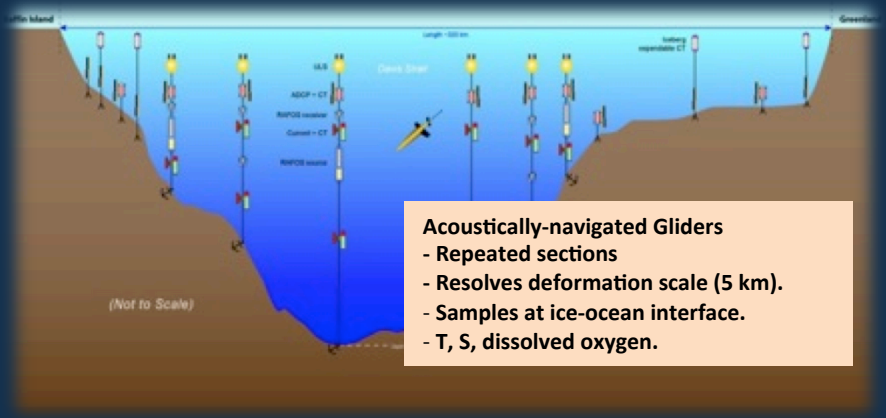


Novel Sensing Systems

Lightweight Systems



Autonomous Platforms and Enabling Technologies



Acoustically-navigated Gliders
- **Repeated sections**
- **Resolves deformation scale (5 km).**
- **Samples at ice-ocean interface.**
- **T, S, dissolved oxygen.**

Dynamics of the Marginal Ice Zone

Ice Mass Balance Buoys- Wilkinson, Hwang (SAMS), Maksym (WHOI)

Wave Buoys- Wadhams (Cambridge), Doble (Laboratoire d'Oceanographie de Villefranche)

Wave Measurements- Thomson (APL-UW)

Acoustic Navigation and Wavegliders- Freitag (WHOI)

Profiling Floats- Owens, Jayne (WHOI)

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

Autonomous Ocean Flux Buoys- Stanton, Shaw (NPS)

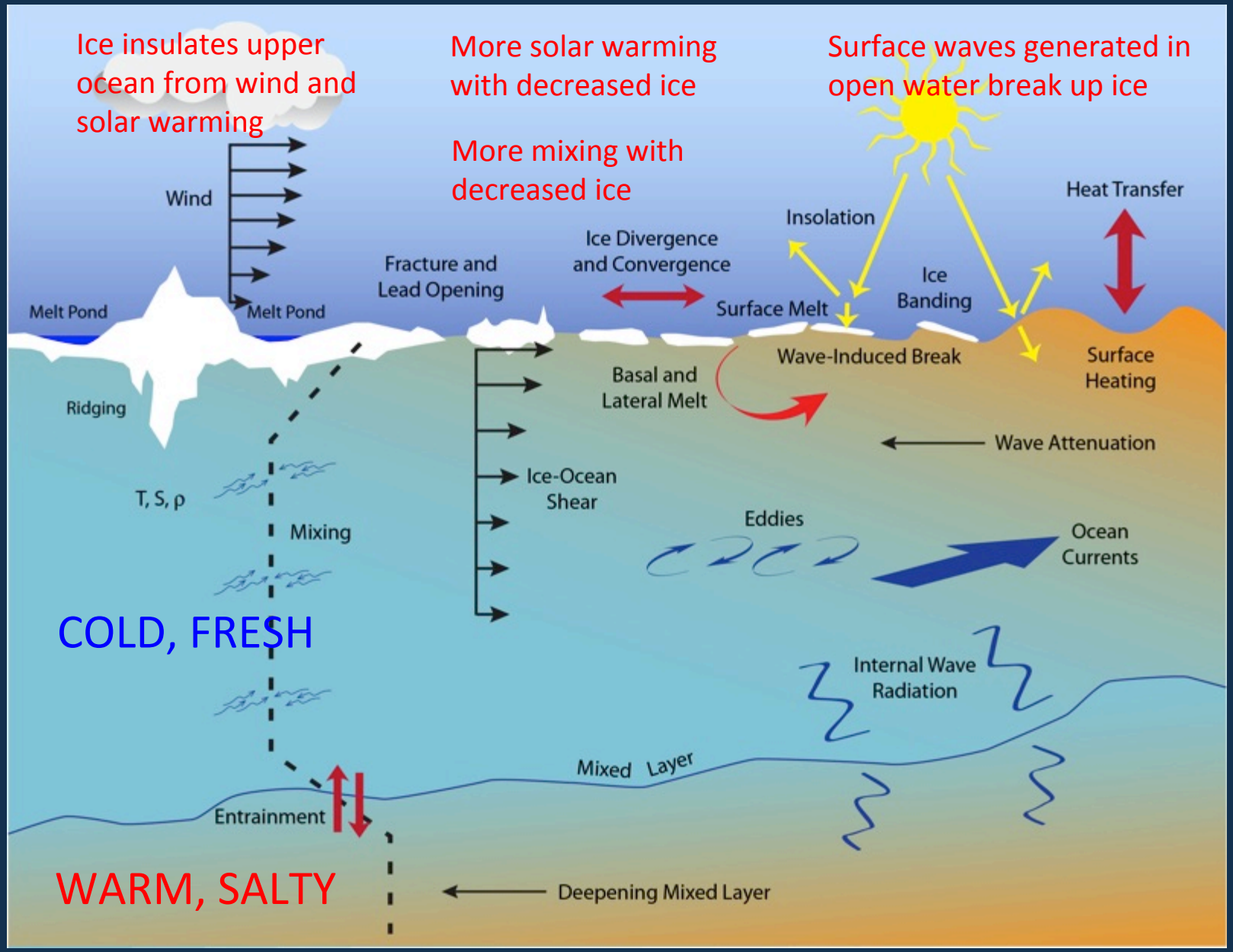
Autonomous Gliders- Lee, Rainville, Gobat (APL-UW)

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)

Processes Governing Atmosphere-Ice-Ocean Interaction



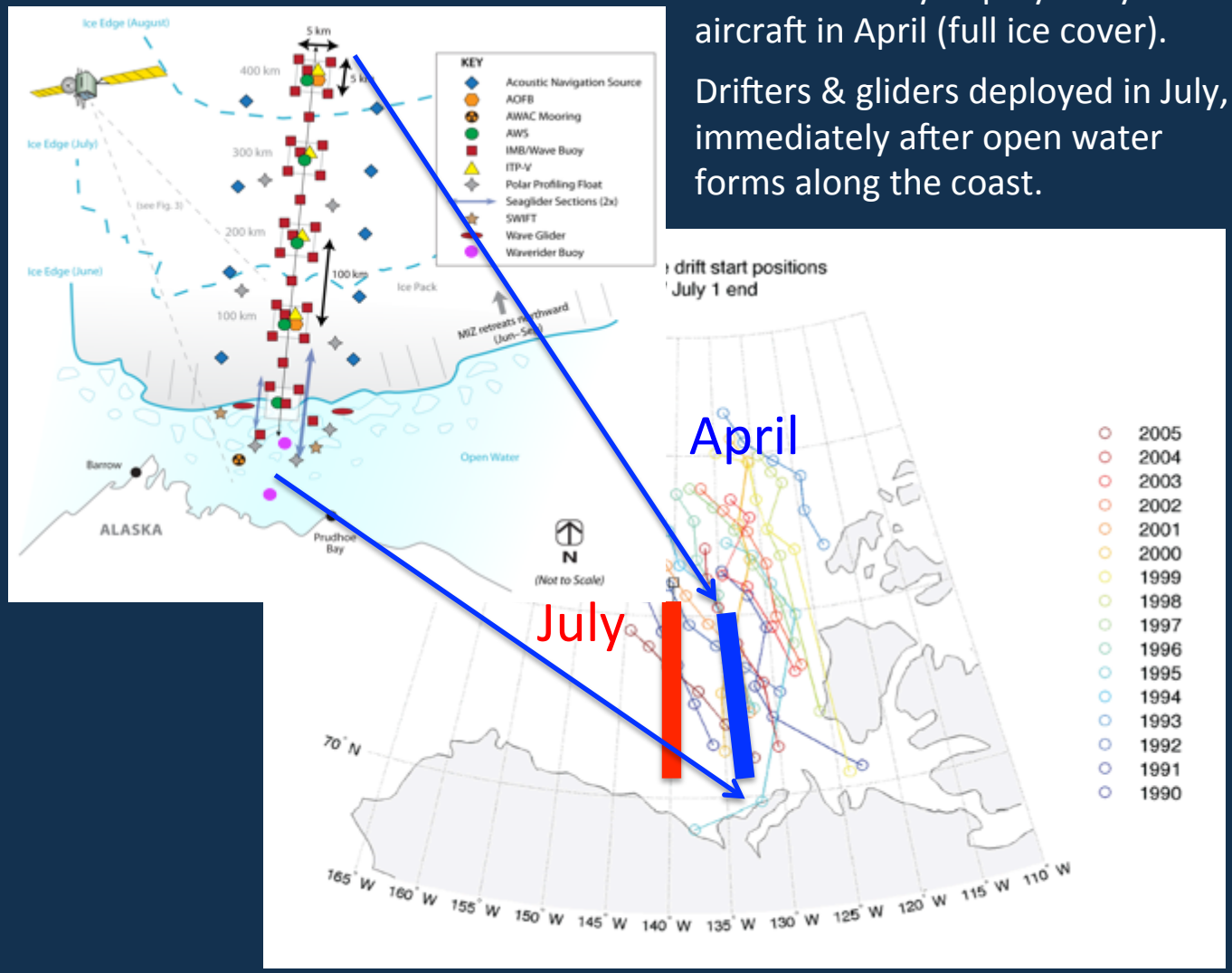
Science Objectives

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 Objectives

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.

MIZ Operational Approach

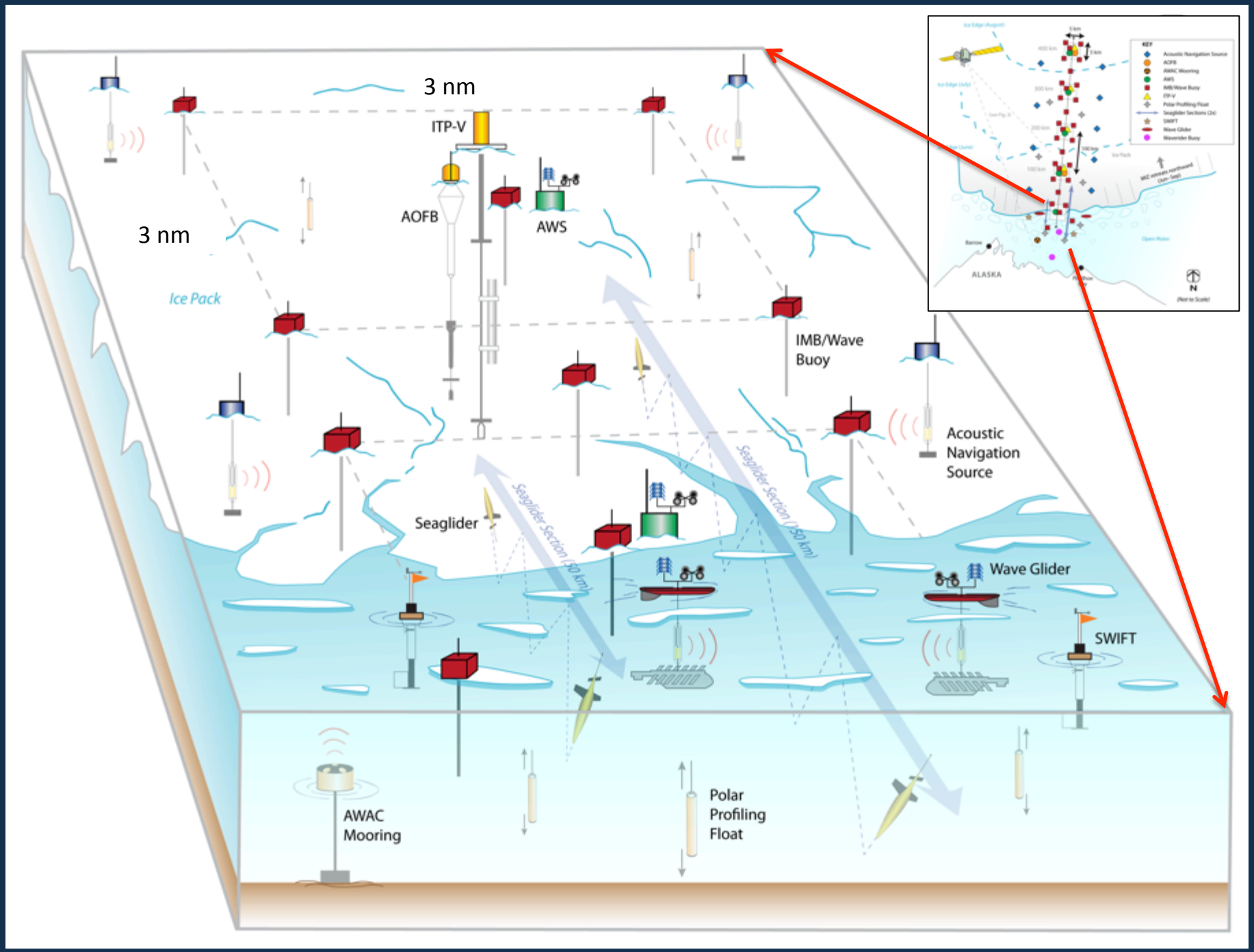


Ice-based array deployed by aircraft in April (full ice cover).

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.


3 nm
ITP-V
AOFB
AWS
3 nm
Ice Pack
IMB/Wave
Buoy
Acoustic
Navigation
Source
Seaglider
Seaglider Section (50 km)
Seaglider Section (150 km)
Wave Glider
SWIFT
AWAC
Mooring
Polar
Profiling
Float
ALASKA
KEY
Acoustic Navigation Source
AOFB
AWAC Mooring
AWS
IMB/Wave Buoy
ITP-V
Polar Profiling Float
Seaglider Sections (2x)
SWIFT
Wave Glider
Waverider Buoy
N
(Not to Scale)

'Fast & Light' Logistics Requirements

Aircraft

Ex Yellowknife

- Hercules and Buffalo aircraft used to bring fuel, supplies and scientific equipment to Sachs Harbour.
- 2 Herc + 1 Buffalo for equipment plus 2 Herc flights for fuel

Ex Sachs Harbour

- Twin Otters x2 (Ken Borek/British Antarctic Survey)
  - Workhorses: Camp equipment, scientific instrumentation, drummed fuel and personnel.
  - 13 flight days with 2 flights per day
- Bell 412 (Great Slave Helicopters)
  - Pinpoint deployment of instrumentation
  - 7 flight days for 40 precision instrument deployments

Camp Infrastructure (2 small camps rather than a large, long-term ice camp)

- Small camps = minimal gear, quick setup/breakdown, flexible site selection
- Multiple camps allowed closer proximity to work sites, leapfrogging to minimize population
- 3 x heated tents, portable generators, food, fuel, comms, etc
- 90 person-days on ice, 69 person-nights overnighting at the 2 camps (including NASA/ESA programs)

Scarcity of large pans of thick ice and rapidly changing conditions make large, long-term camps risky for both personnel and mission. This 'Fast and light' approach offers an alternative for some applications.

Acoustic Navigation

Navigation buoy being deployed at remote site using Twin Otter

Purpose

- Provide navigation for gliders and floats.
- Transmit source positions to allow real-time geo-location by gliders from mobile navigation beacons.
- Transmit simple commands to gliders to alter mission.

Acoustic Parameters

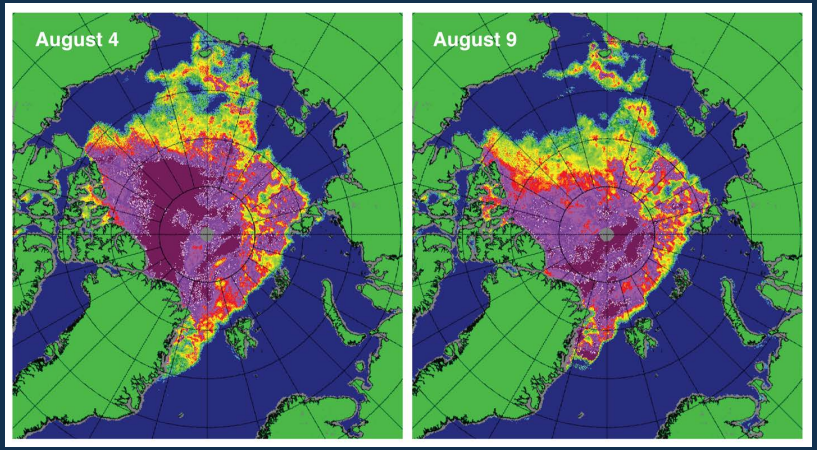
- 900 Hz carrier, 25 Hz bandwidth, 183 dB SPL.
- Data rate is very low, about 1 bit/sec, but could have been faster given results observed to date.

Performance (100 m sound channel)

- 350+ km range, 20 m average range error (100 m max).

Sea State & Boundary Layer Physics of the Emerging Arctic Ocean

Less ice, more storms…



… and waves

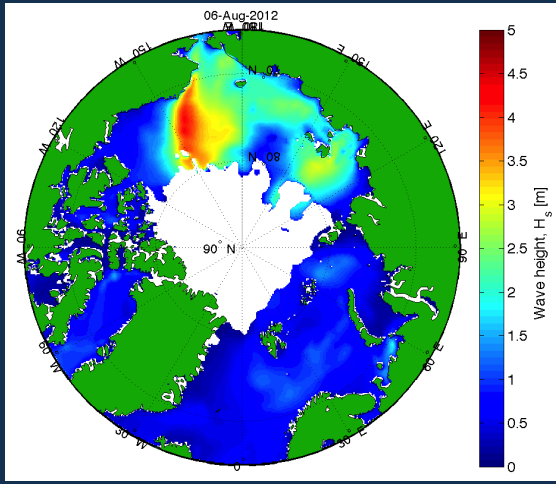


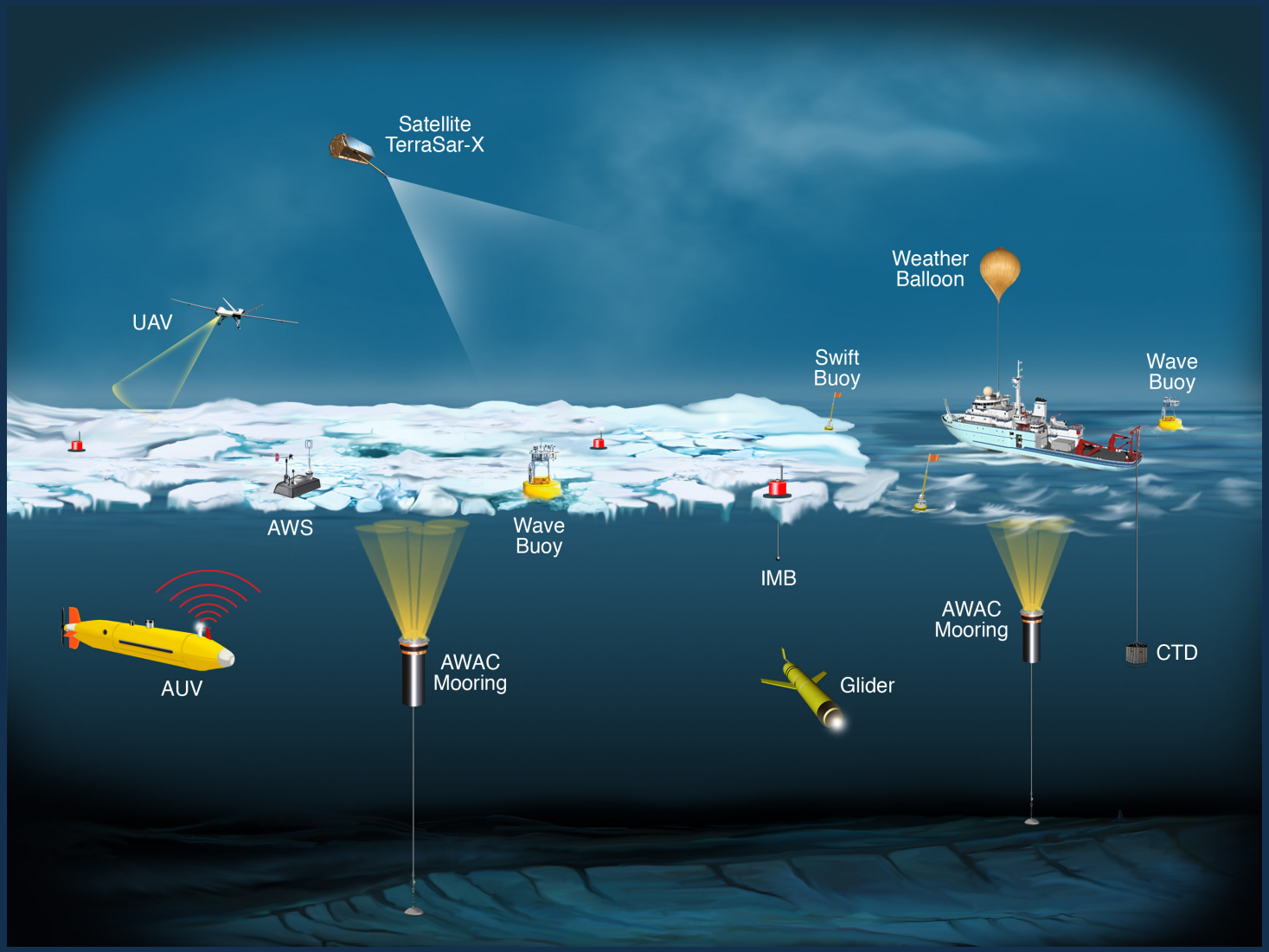
Table 1: Processes, key variables, and related elements of the Sea State DRI.

Process	Key Variables	SeaState DRI Plan (by PI)
Wave reflection	Directionality	Wave buoy array (Doble/Wadhams), scattering models (Squire/Williams), viscoelastic models (Shen/Squire/Rogers), laboratory experiment (Shen/Ackley/Babanin/Squire)
Wave attenuation and dispersion	Ice distribution, ice thickness, wave spectra	Ship and AUV transects (Maksym/Ackley), wave buoy array (Doble/Wadhams), satellite observations (Lehner/Gemmrich/Holt), scattering models (Squire/Williams/Meylan/Bidlot), viscoelastic models (Shen/Squire), phase-averaged spectral models (Rogers/Babanin), laboratory experiments (Meylan/Shen/Ackley)
Wave generation	Ice cover, fetch, winds, boundary layer turbulence	SWIFT buoys and wave video (Thomson), Meteorological fluxes and LIDAR (Guest/Fairall), Marine Radar (Graber), Satellite observations (Lehner/Gemmrich/Holt), phase-averaged spectral models (Rogers/Babanin)
Ice formation	Ice distribution, heat loss, wave spectra	AUV and ship surveys (Ackley/Maksym), wave spectra (Doble/Wadhams)
Ice growth	Ice distribution, heat loss, wave spectra	AUV and ship surveys (Ackley/Maksym), UAV photography (Maksym/Doble), wave spectra (Doble/Wadhams), satellite observations (Lehner/Gemmrich/Holt)
Ice evolution	Transition to quiet growth, wave attenuation	AUV and ship surveys (Ackley/Maksym), wave spectra (Doble/Wadhams)
Heat and momentum flux	Radiative fluxes, turbulent fluxes, surface drag	Covariance observations (Guest/Fairall), AUV ice transects (Ackley/Maksym), SWIFT buoys (Thomson)
Heat storage	Temperature profiles, ice cover	Glider transects (Maksym/Stammerjohn), Acrobat and CTD (Stammerjohn), UpTempo buoys (Stammerjohn/Steele), Ice Mass Balance Buoys (Maksym)
Storm formation	Ice cover, clouds, winds	Meteorological observations and ceilometer (Guest/Fairall), SWIFT buoys (Thomson), satellite observations (Lehner/Gemmrich/Holt)
Wave climate	Wave height, period, direction	Satellite observations (Babanin, Lehner/Gemmrich), moorings (Thomson), phase-averaged spectral models (Rogers/Babanin)

Objectives

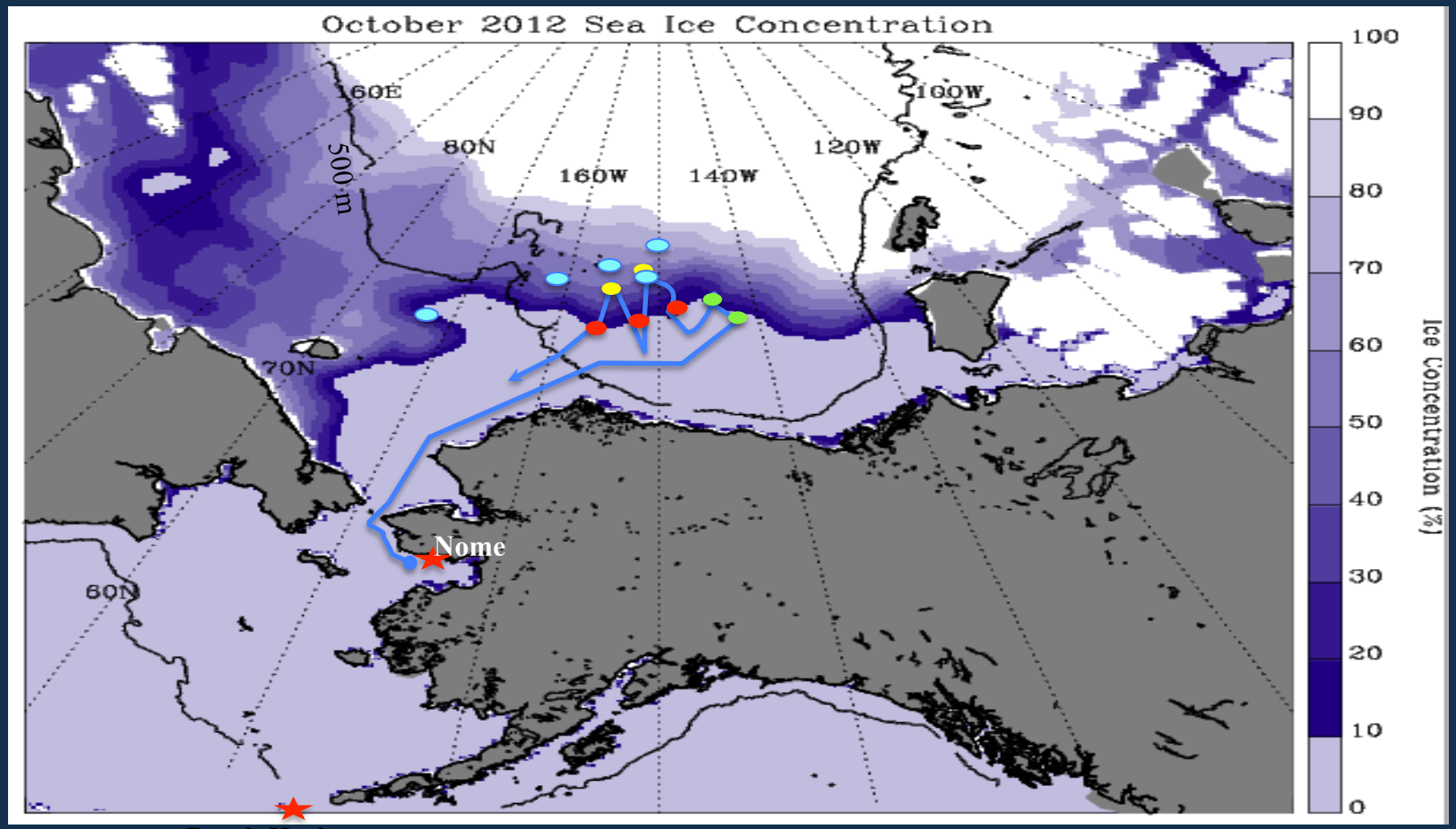
1. Develop a sea state climatology for the Arctic Ocean
2. Improve wave forecasting in the presence of sea ice
3. Improve theory of wave attenuation/scattering in the sea ice cover
4. Apply wave–ice interactions directly in integrated arctic system models
5. Understand heat and mass fluxes in the air–sea–ice system

In situ observations



Sea State DRI Cruise Plan: R/V Sikuliaq, 25 Sep - 4 Nov, 2015

- Boundary layer fluxes (underway meteorology, wave radar, temperature, salinity)
- Open water, sea state / flux study (SWIFTs, wave buoys, CTDs, glider)
- Solid ice edge, wave reflection study (wave buoys, CTDs, SWIFTs)
- Advancing ice study (AUV under-ice transects, LiDAR, EMI, CTDs, UpTempOs)
- Ice pack/transect study (IMBs, AUV, LiDAR, EMI, CTDs)



Collaborations with Other Programs (MIZ & Sea State)

- Seasonal Ice Zone Reconnaissance Surveys (ONR)
- Marginal Ice Zone Observations and Process Experiment (NASA, NOAA)
- Determining the Impact of Sea Ice Thickness on the Arctic's Naturally Changing Environment (Naval Research Laboratory)
- ICEBridge (NASA)
- Korean Polar Research Institute

Data Policy Highlights

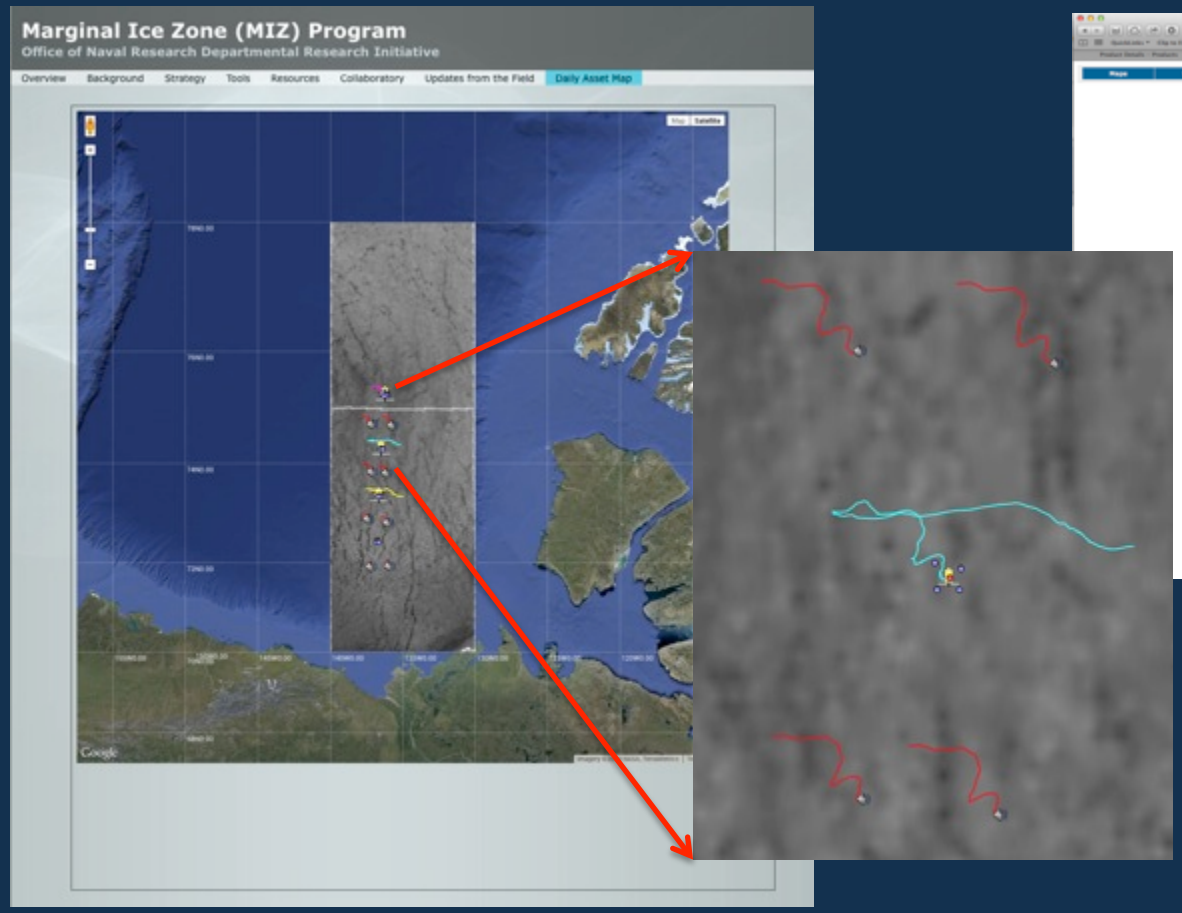
See the MIZ and Sea State science plans for complete data policies.

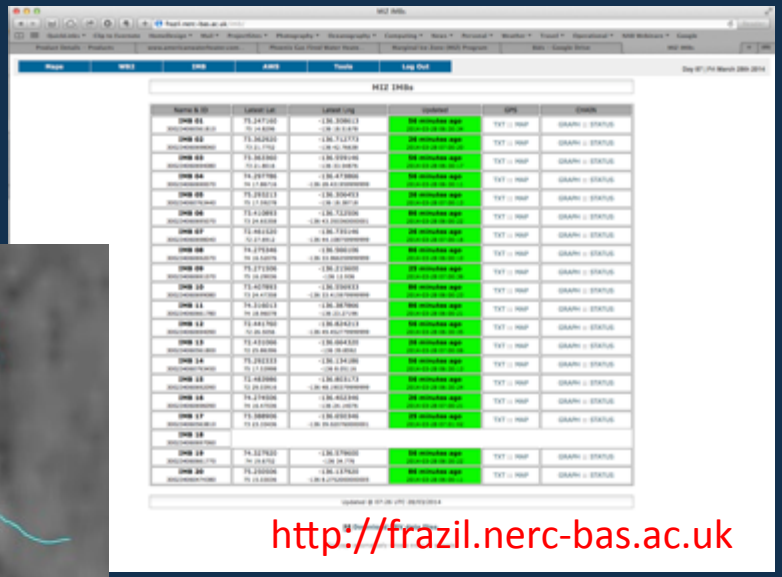
- Integrated nature of program requires high degree of trust among team members.
- Full, open data sharing among MIZ team with strict requirements for collaboration, co-authorship and attribution.
- Protection for students and postdocs.
- Immediate release of 'operational' data (e.g. Ice Tethered Profiler data, glider data to the GTS).
- During active (funded) phase of programs, data sharing outside the program team only by consensus within the team.
- Submission of data to Arctic Observing Network data facility (full public access) required immediately after program end.

More Information & Data Access

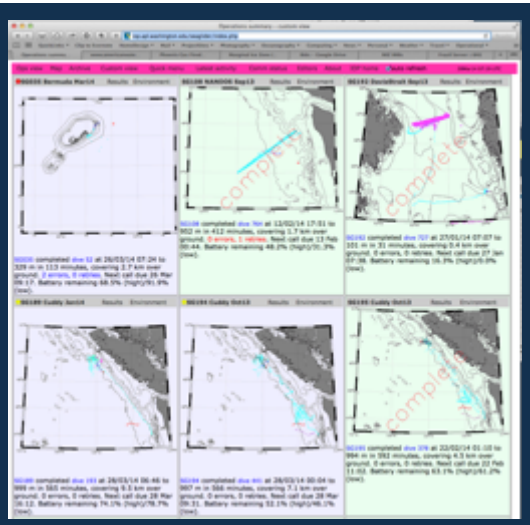
http://apl.washington.edu/miz

http://www.apl.washington.edu/project/project.php?id=arctic_sea_state





http://frazil.nerc-bas.ac.uk



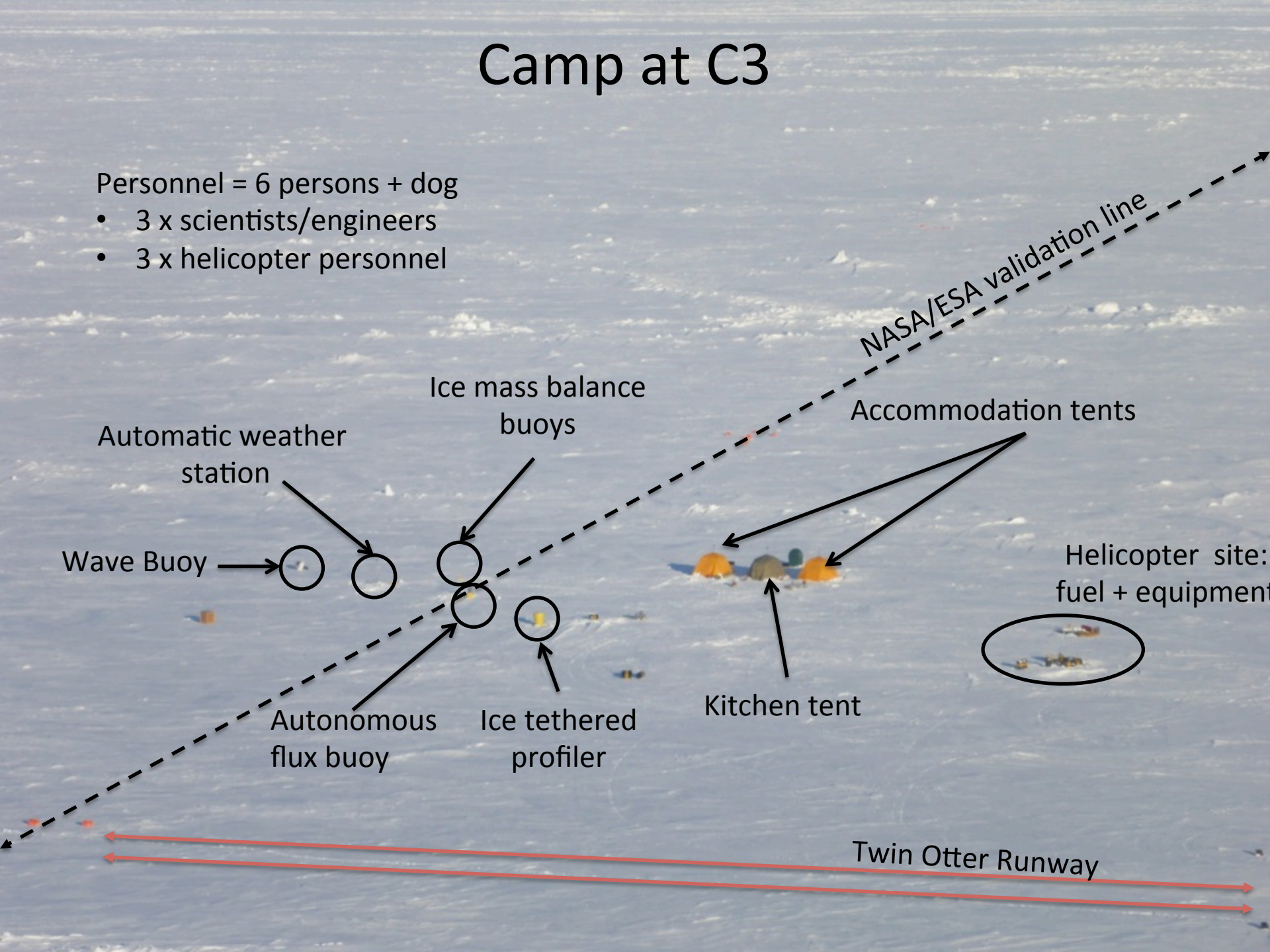
http://iop.apl.washington.edu/seaglider

- Science plans for both programs available.
- Scott Harper (Program Manager) - Scott.L.Harper@navy.mil
- Martin Jeffries (Program Manager) - martin.jeffries@navy.mil
- Craig Lee - craig@apl.washington.edu
- Jim Thomson – jthomson@apl.washington.edu

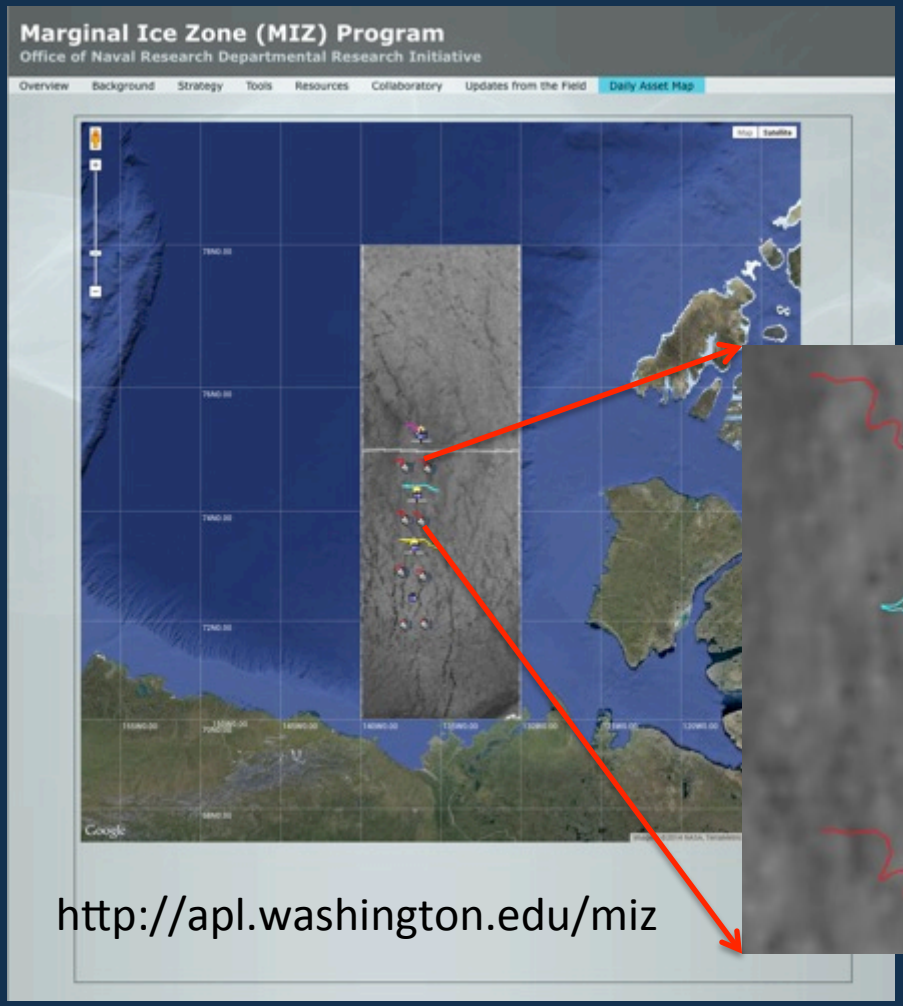
Camp at C3

Personnel = 6 persons + dog

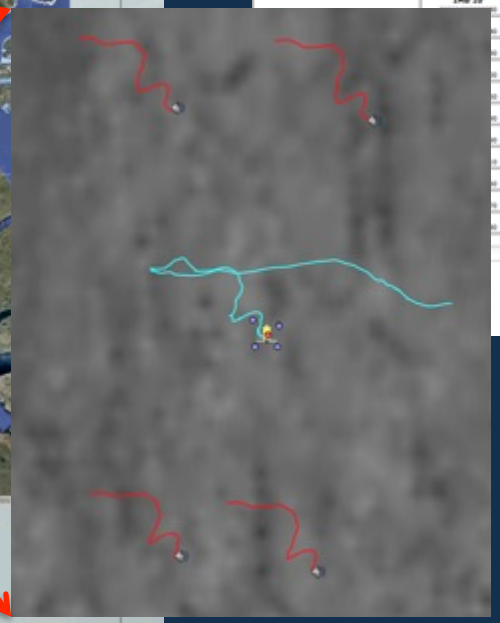
- 3 x scientists/engineers
- 3 x helicopter personnel

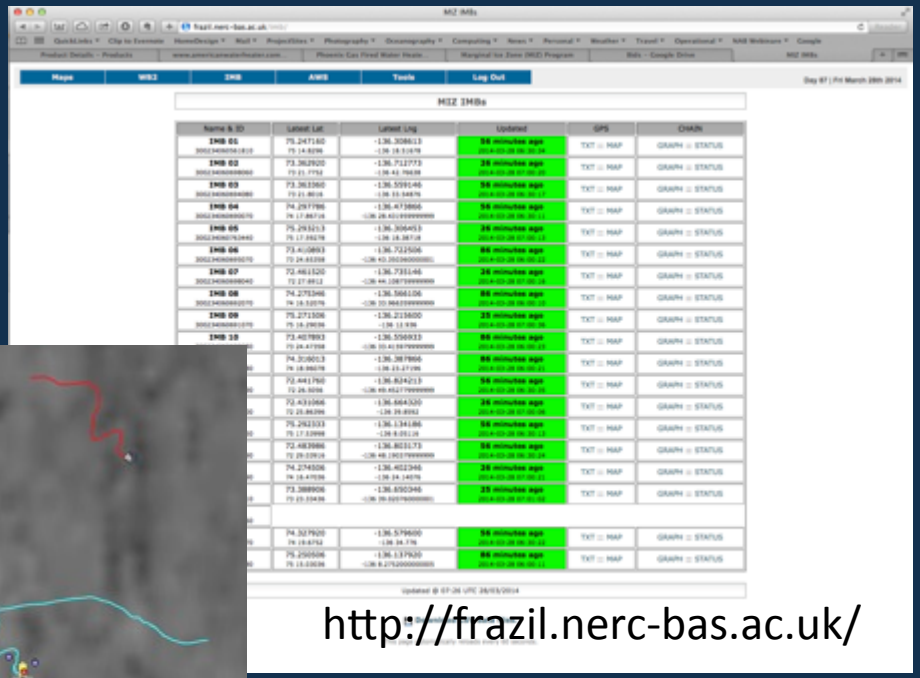


Real-time Asset Maps and Data

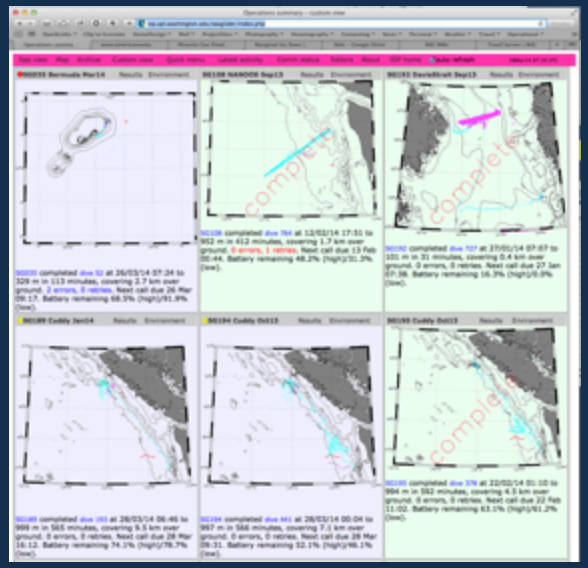


http://apl.washington.edu/miz





http://frazil.nerc-bas.ac.uk/



http://iop.apl.washington.edu/seaglider

http://www.whoi.edu/itp/data/

More Information & Data Access

Marginal Ice Zone

- Program Website: http://apl.uw.edu/miz
- Science Plan: available on web site under 'Resources'

Sea State

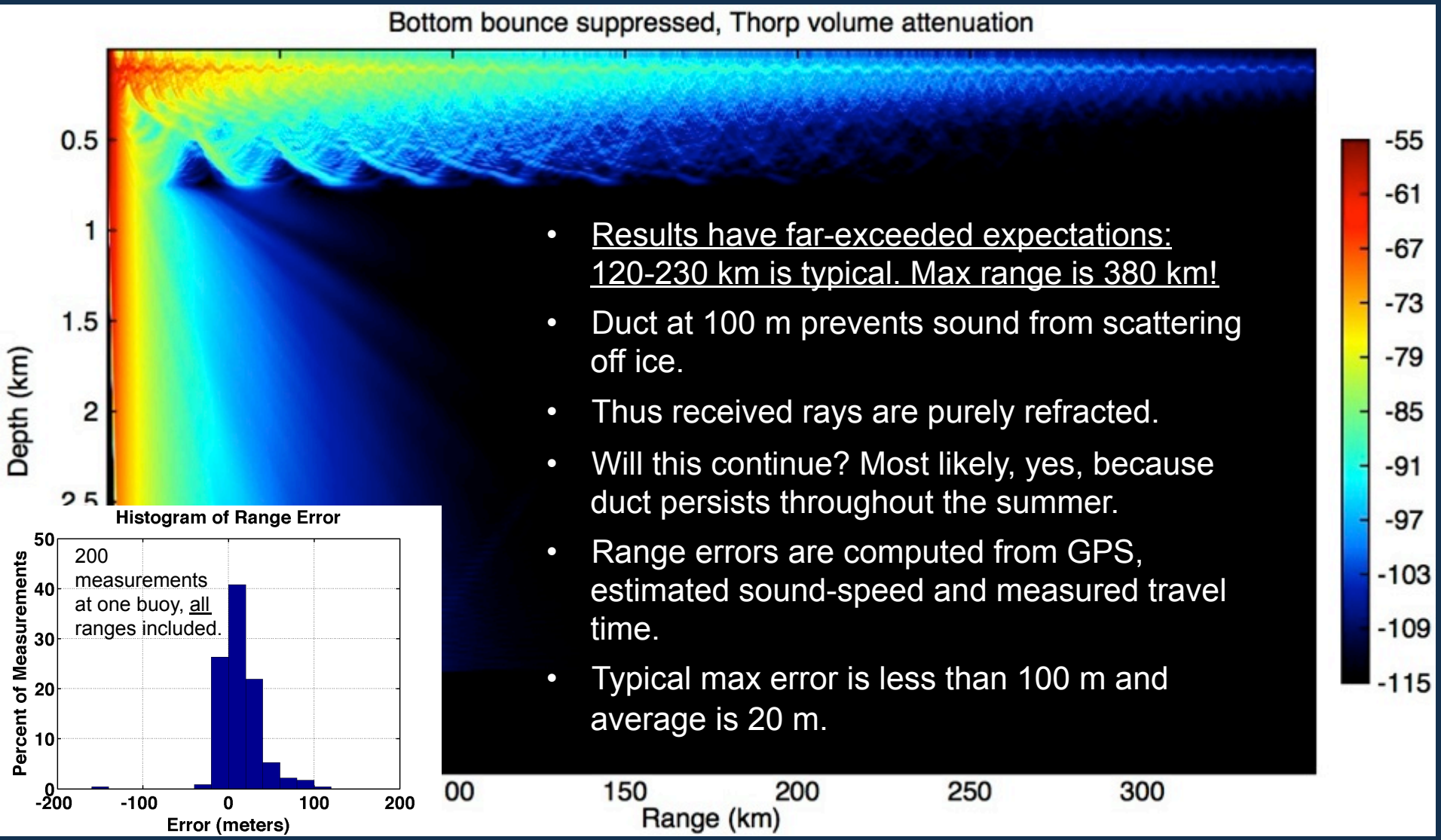
- Program Website: under development
- Science Plan: available through Jim Thomson or ONR

Web sites feature:

- Real-time displays of instrument locations and data
- Satellite remote sensing imagery
- Model results

Contacts:
Scott Harper (Program Manager) - Scott.L.Harper@navy.mil
Martin Jeffries (Program Manager) - martin.jeffries@navy.mil
Craig Lee - craig@apl.washington.edu
Jim Thomson – jthomson@apl.washington.edu

Navigation Performance

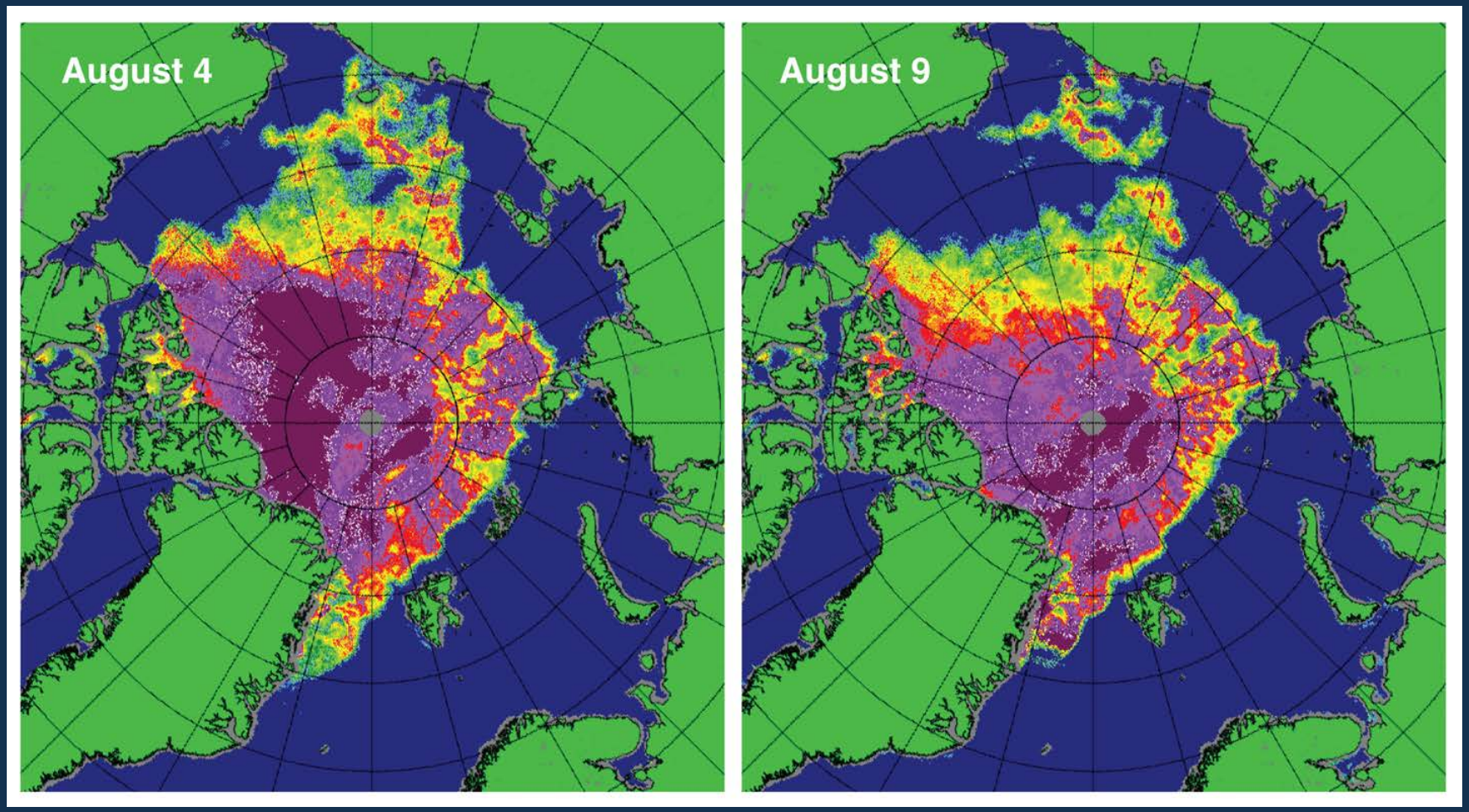


- Results have far-exceeded expectations: 120-230 km is typical. Max range is 380 km!
- Duct at 100 m prevents sound from scattering off ice.
- Thus received rays are purely refracted.
- Will this continue? Most likely, yes, because duct persists throughout the summer.
- Range errors are computed from GPS, estimated sound-speed and measured travel time.
- Typical max error is less than 100 m and average is 20 m.

Transmission loss modeling by K. Heaney, OASIS

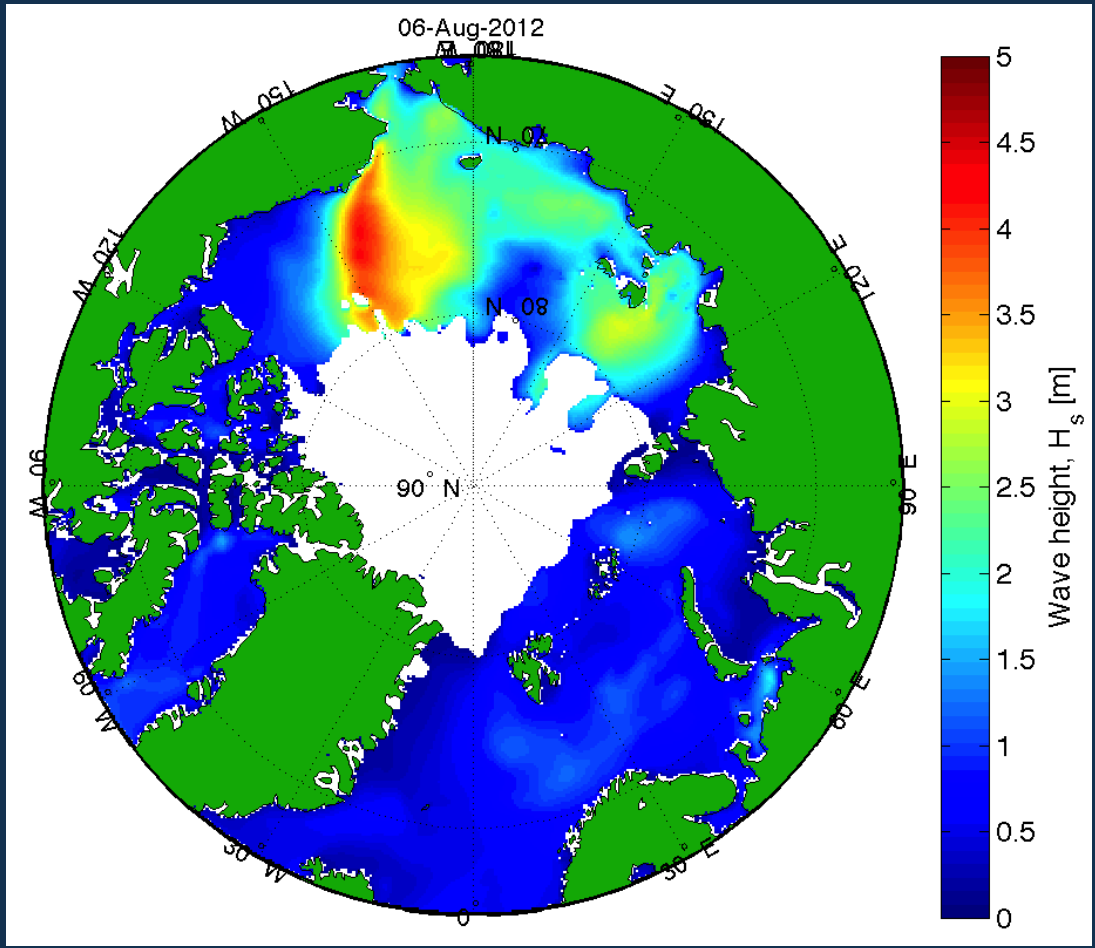
The Emerging Arctic:
Less ice, more storms…

Aug 2012



… and waves

Aug 2012

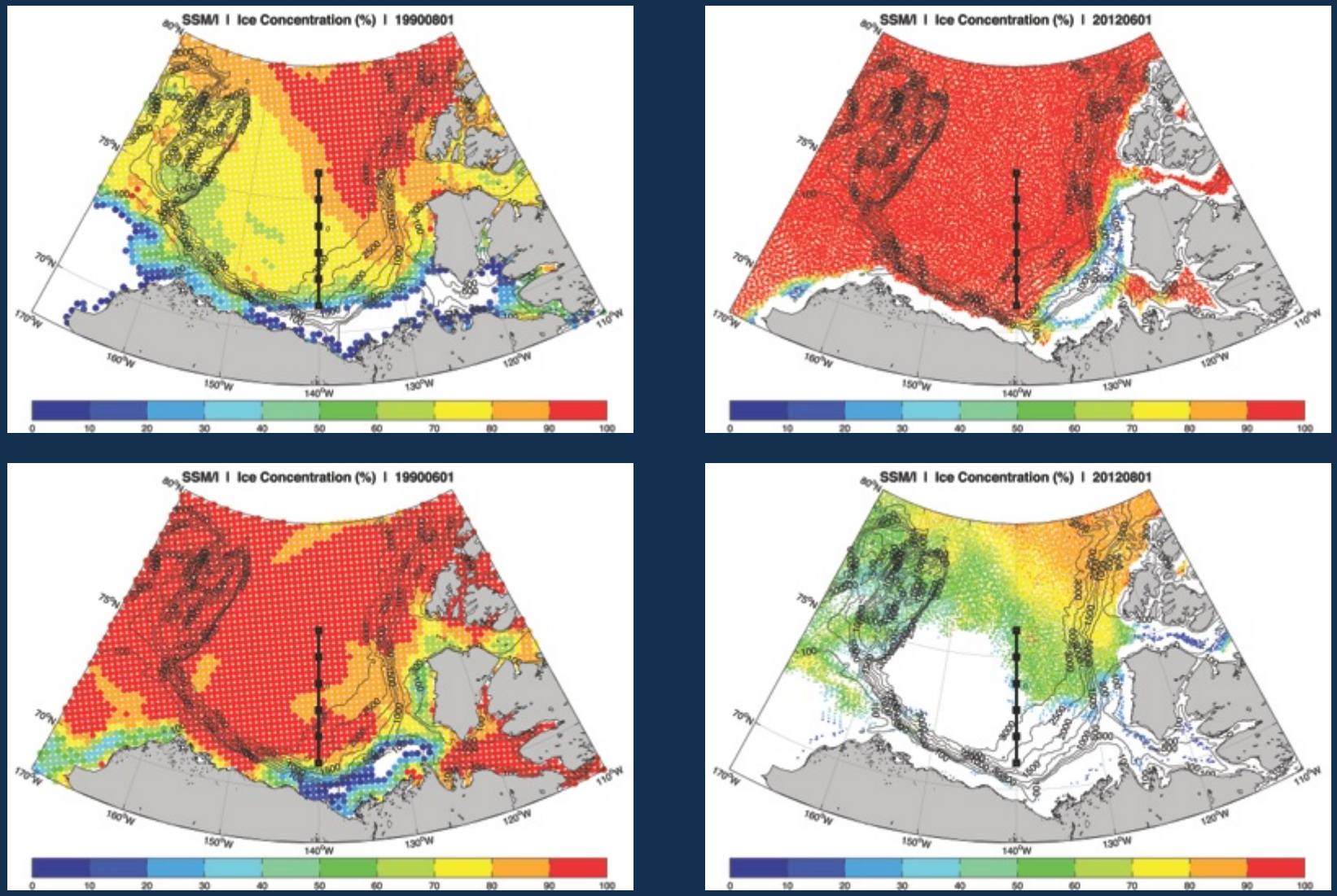


Seasonal MIZ in the Beaufort Sea

1990 2012

June

August



SSM/I - Posey

Flexibility Through Nested Observing Activities

Policy- 'science' (climate) driven

- Focus: Characterize environmental change, planning.
- Time scale: Decades, value placed on long records.
- Spatial scale: Distributed, may be far from population centers.
- Data: Real-time data return not necessary.
- Long, consistent records. Committed observing.

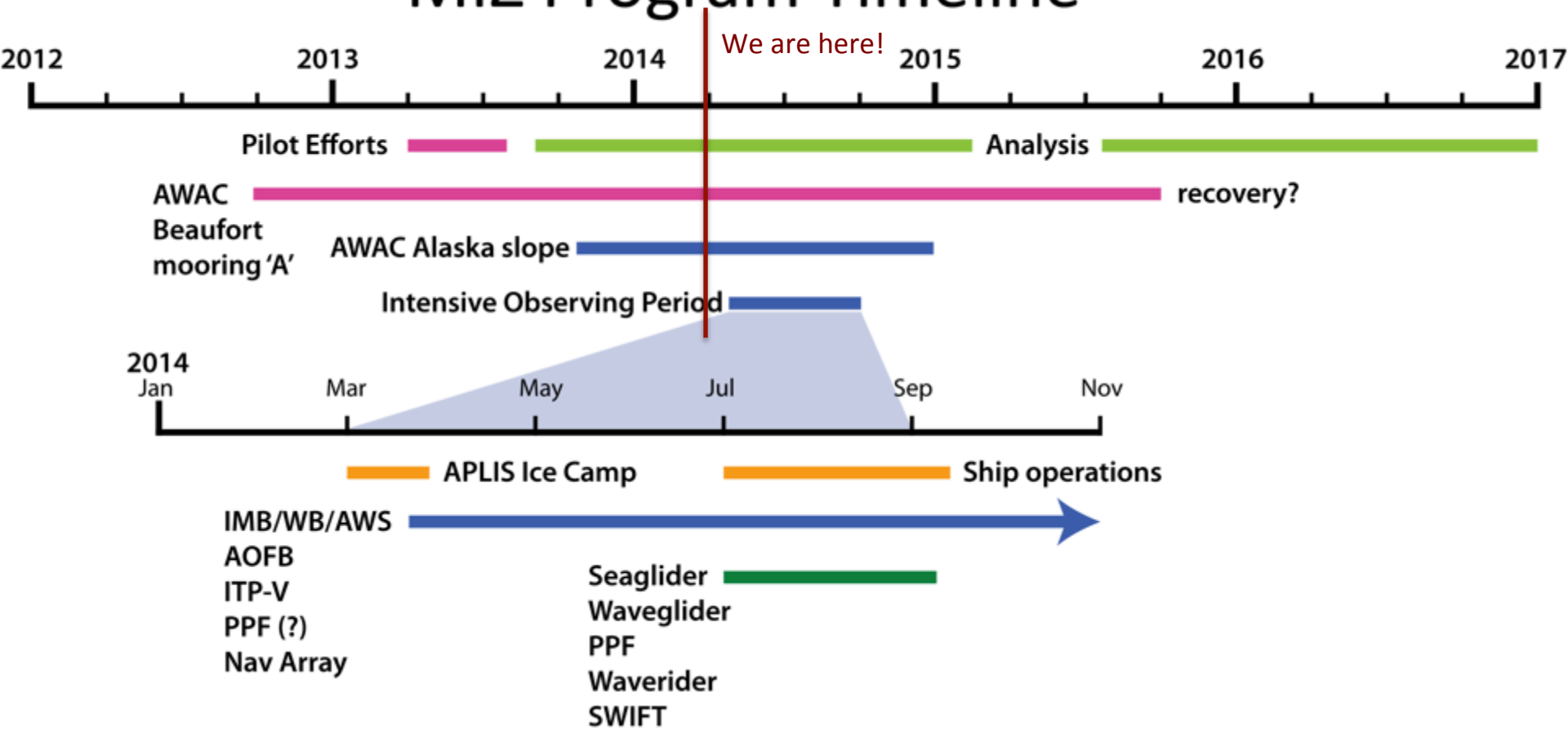
Strategy- process studies, planning support

- Focus: Planning for high-risk activities (extraction, navigation).
- Time scale: Seasons to decades, long records valued.
- Spatial scale: Limited geographic scope, perhaps near population centers.
- Data: Rapid data access (near real time) may be required.

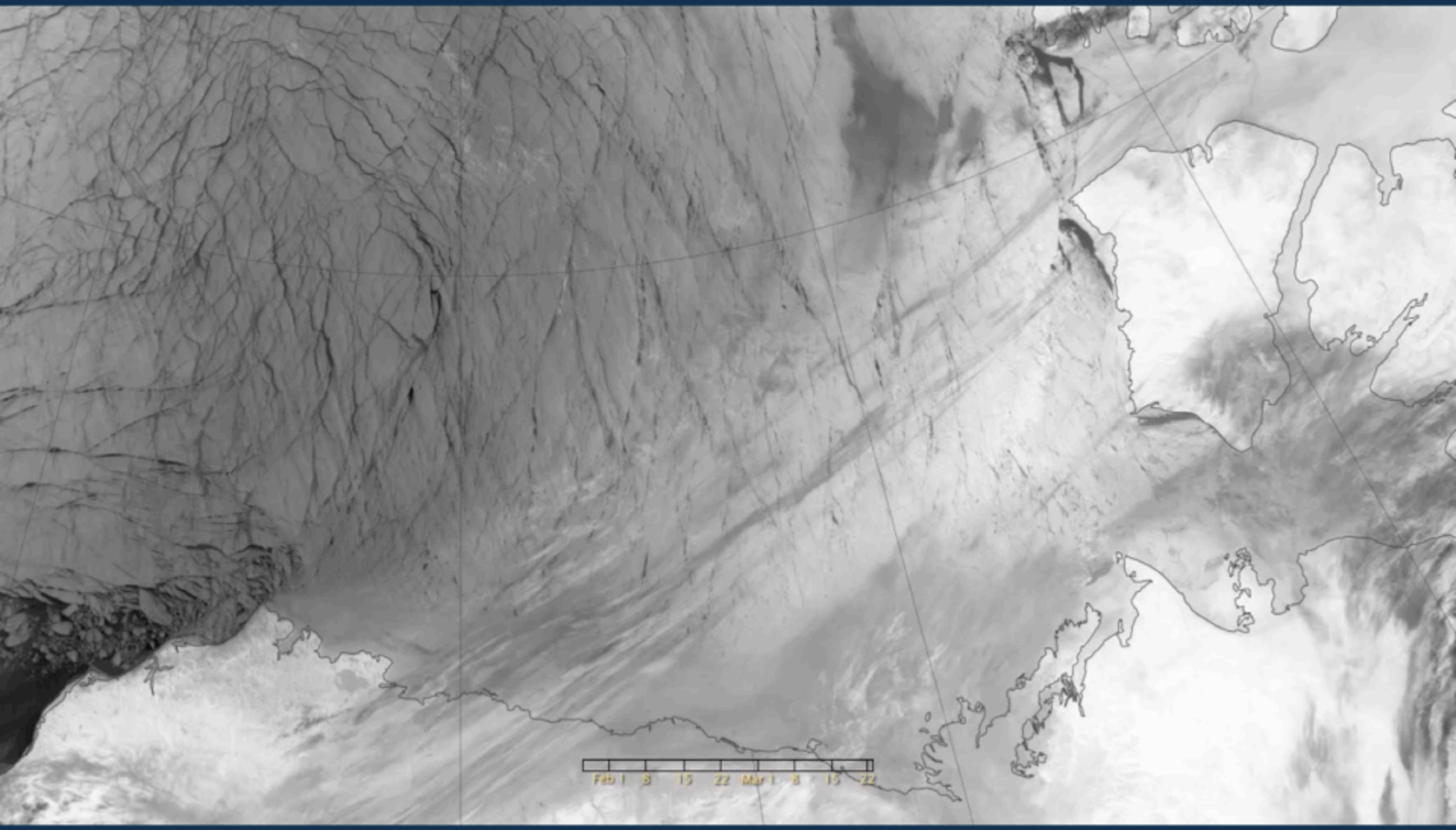
Tactical- 'stakeholder' driven collection

- Focus: Support for specific activities.
- Time scale: Rapid spin-up, spin-down. Flexible design,.
- Spatial scale: Tightly focused, often near regions of human activity.
- Data: Useful products delivered in real time. Data have little shelf life.

MIZ Program Timeline

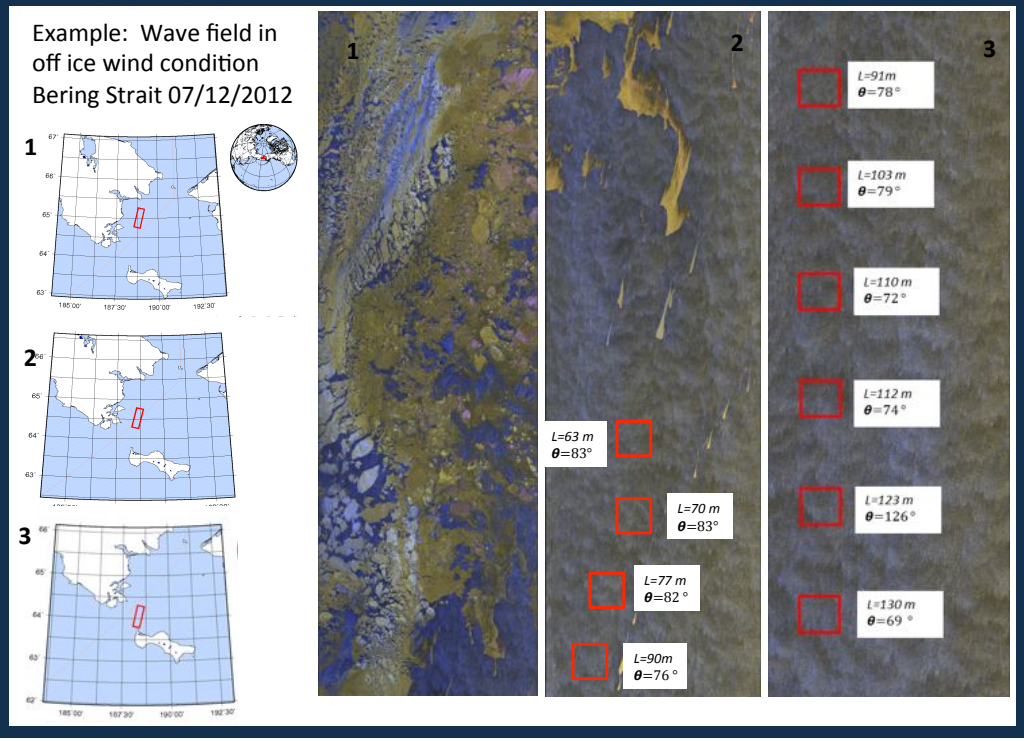


Sea Ice February-March 2013



NASA VIRS (http://http://visibleearth.nasa.gov

Remote sensing



Data	Products	Scales
SAR (Lehner/Gemmrich, Holt)	Wave direction and wavelength, wave propagation, ice cover and floe size distribution	1 m - 100 km
Altimeter (Babanin)	Wave height	1 km - 10 km
ASTER and declassified high-resolution imagery (Holt)	Ice cover and floe size distribution	10 m - 1 km

Modeling

- Spectral developed in parallel with phase-resolving (fundamental physics) models
  - spectral: $S_{ice} \rightarrow S_{id} + S_{is}$
  - phase-resolving: viscoelastic vs. scattering
- Coupling, modifying the floe size distribution