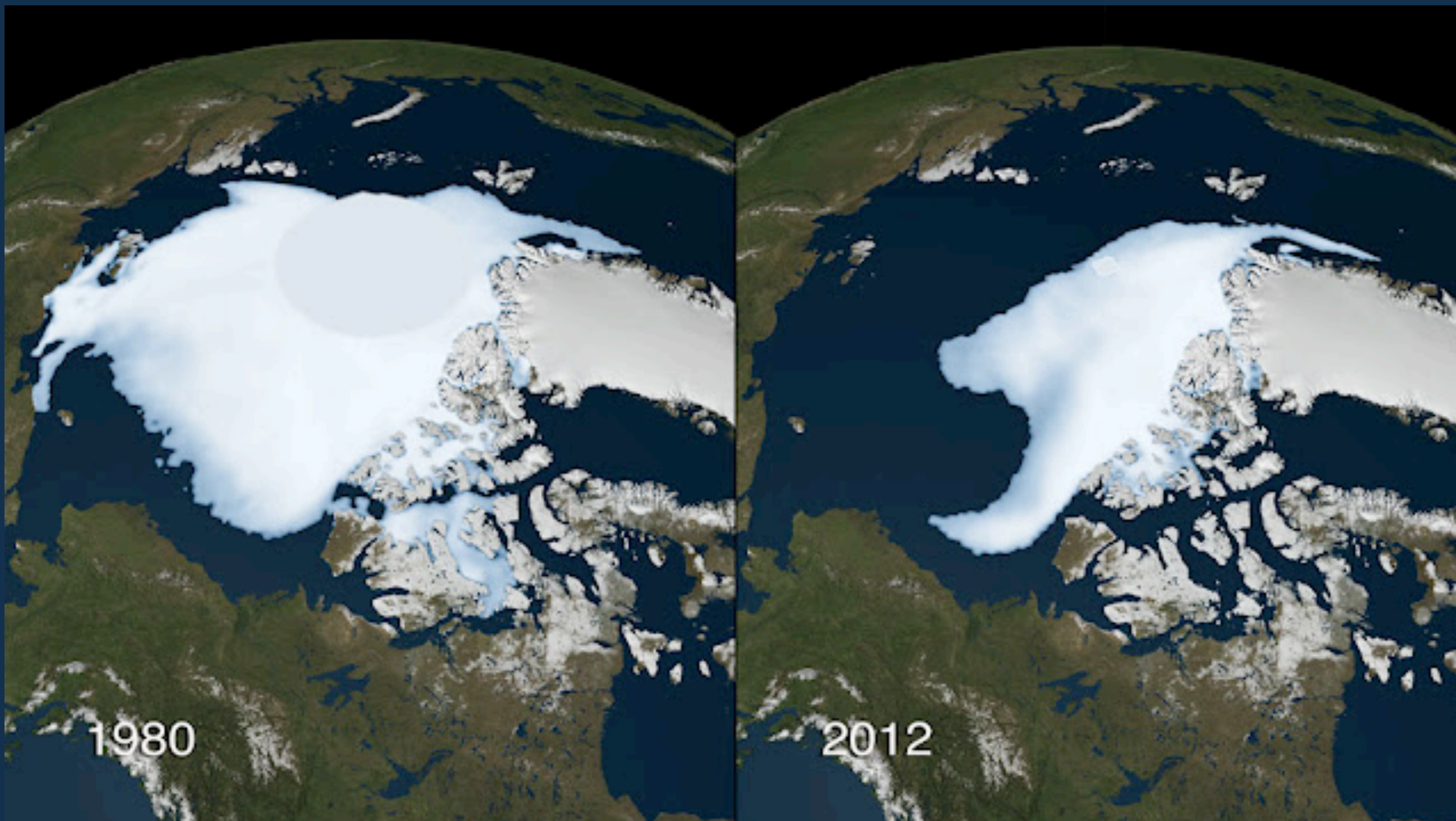
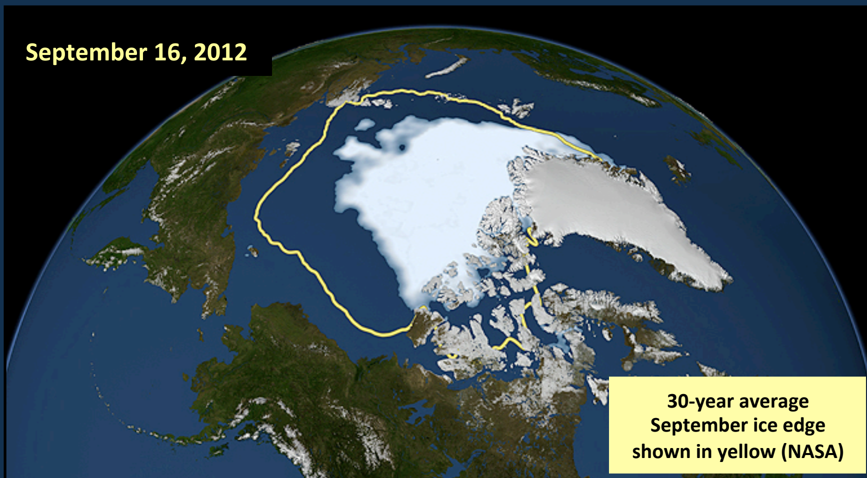
Evolution of Marginal Ice Zone

Craig Lee, Applied Physics Laboratory, Univ. of Washington

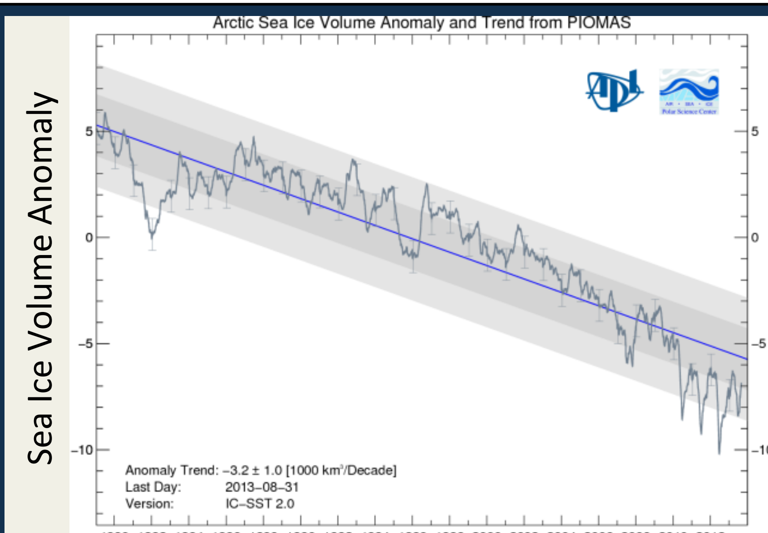


More open water in summer… tighter coupling with atmosphere, different dynamics, changing feedbacks, increased importance of the seasonal and marginal ice zones.

Models Struggle to Reproduce Observations

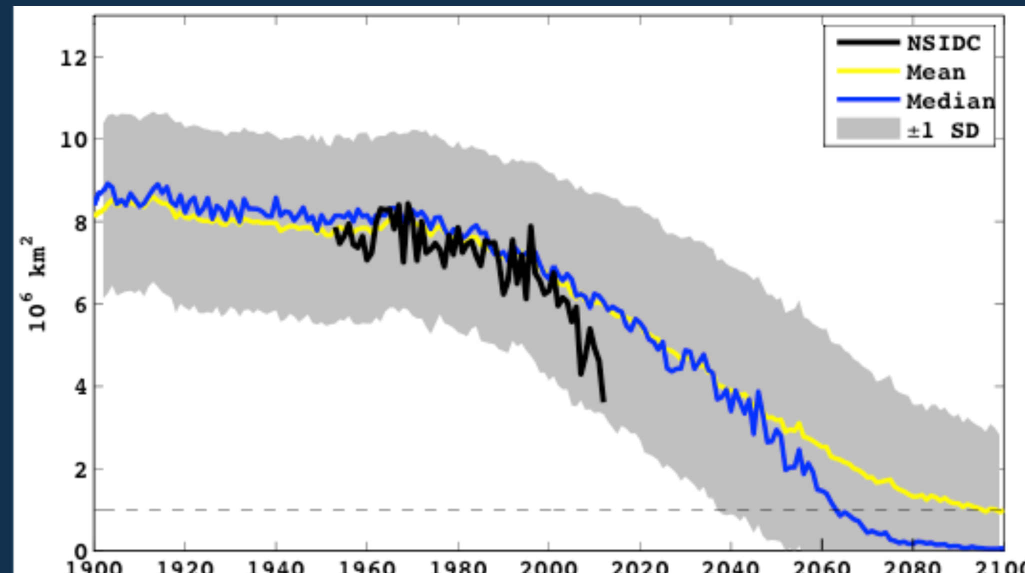


Observed Changes in Arctic Sea Ice



1980 Year 2013

Projected Changes in September Arctic Sea Ice Extent



Year

From Jeffries, et al. (2013)

Characterize Environmental Change

- Distributed, persistent, long-term observations

Improve Predictability – Refine Models

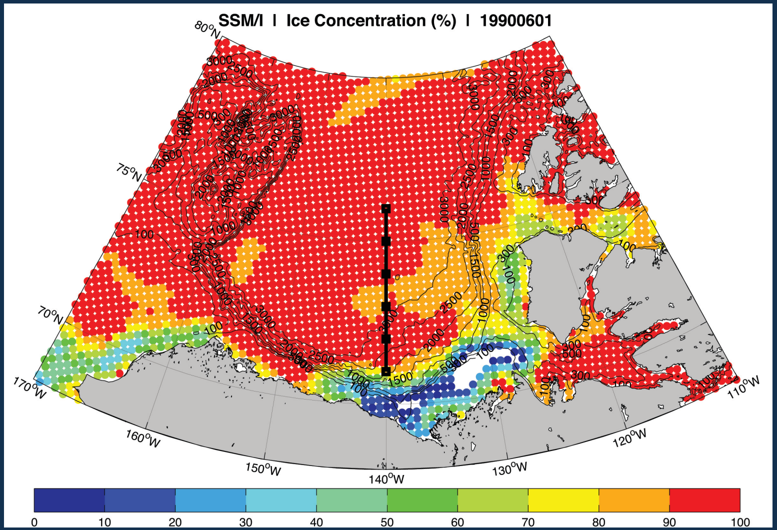
- Process-level investigations
- Improve physics, parameterizations
- Continued testing against sustained observations

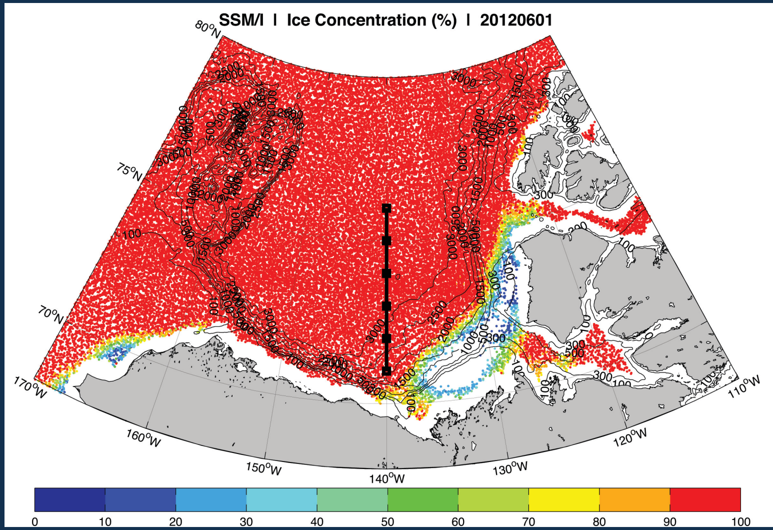
Seasonal MIZ in the Beaufort Sea

1990

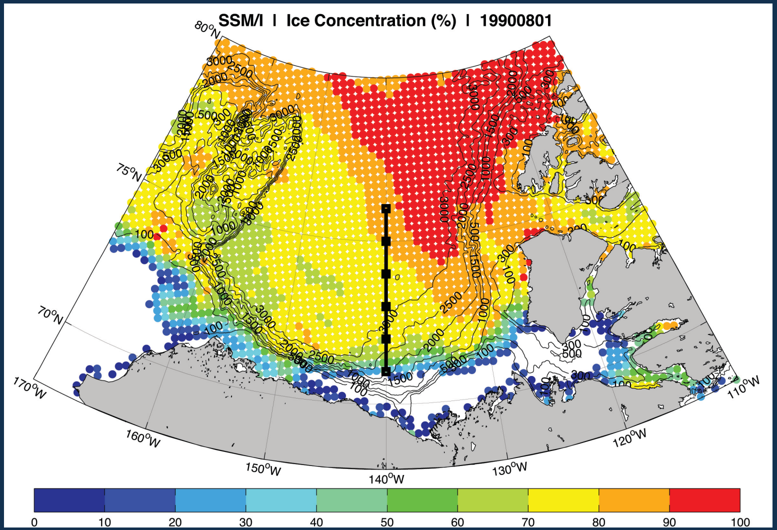
2012

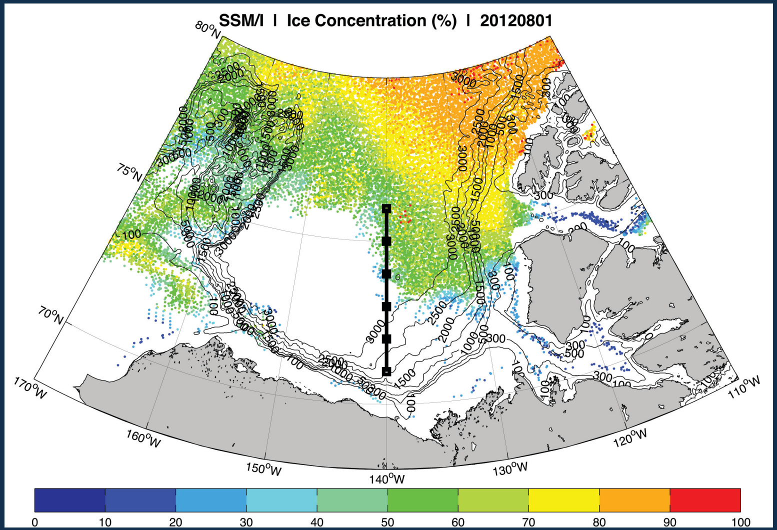
June





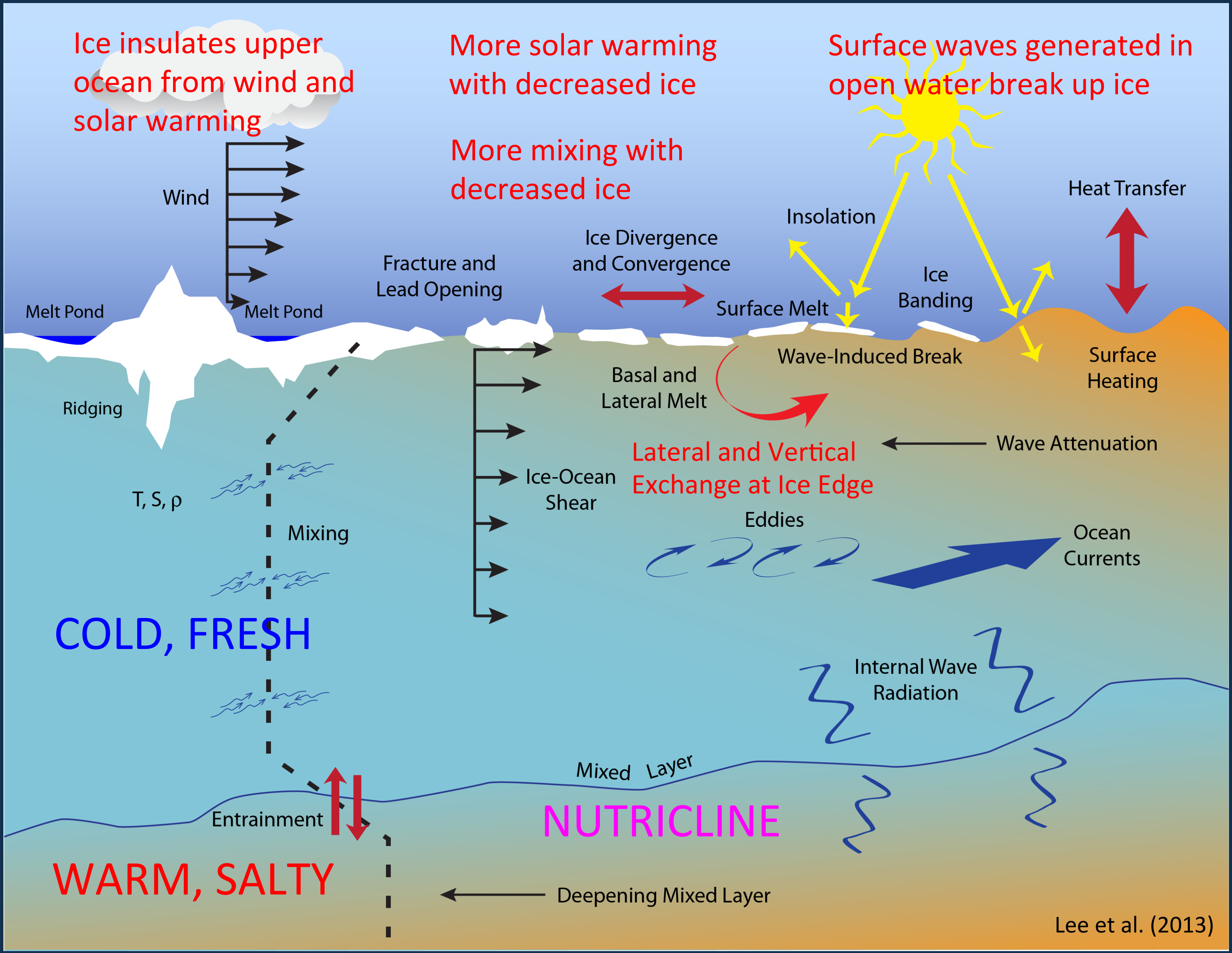
August

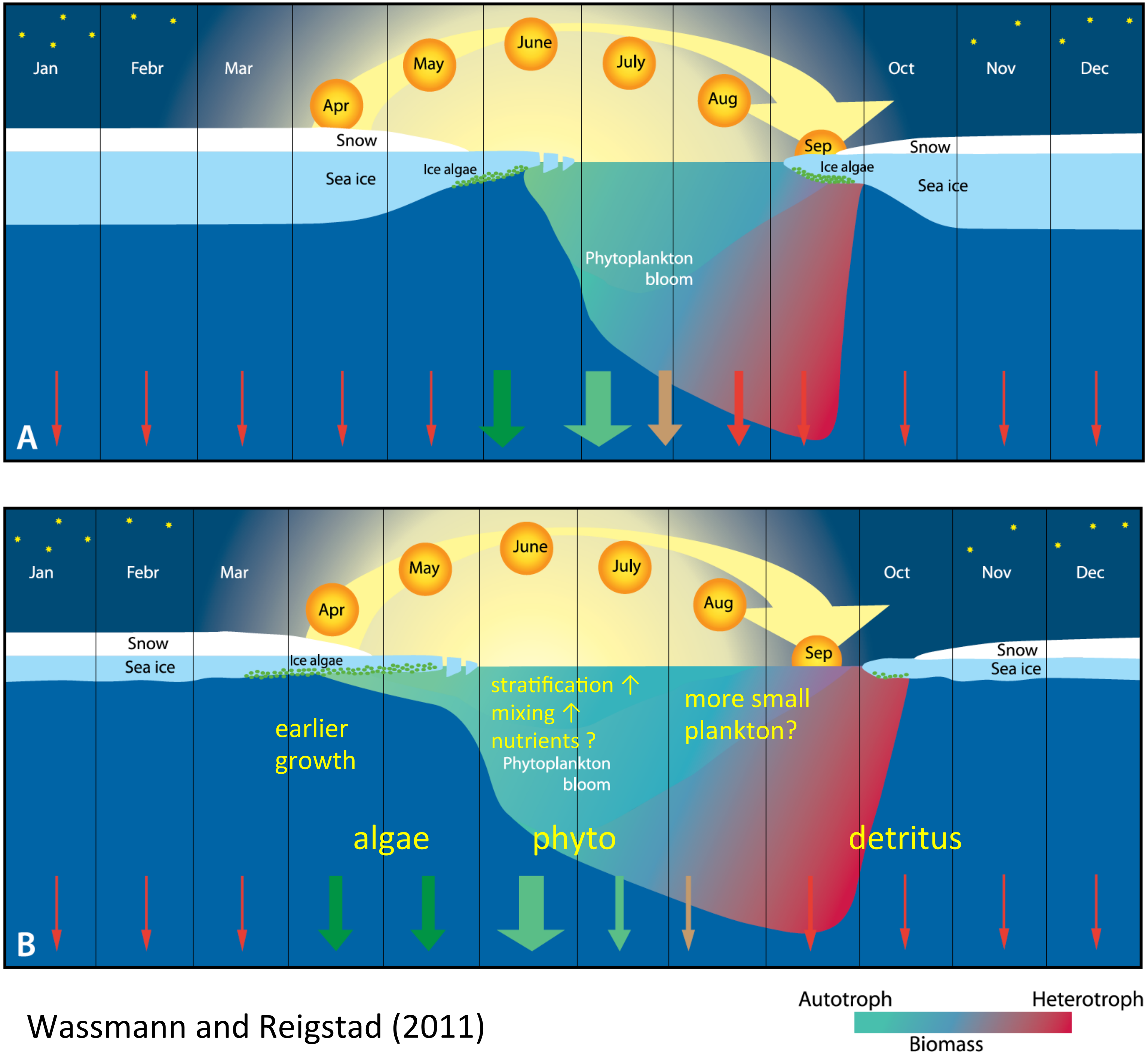




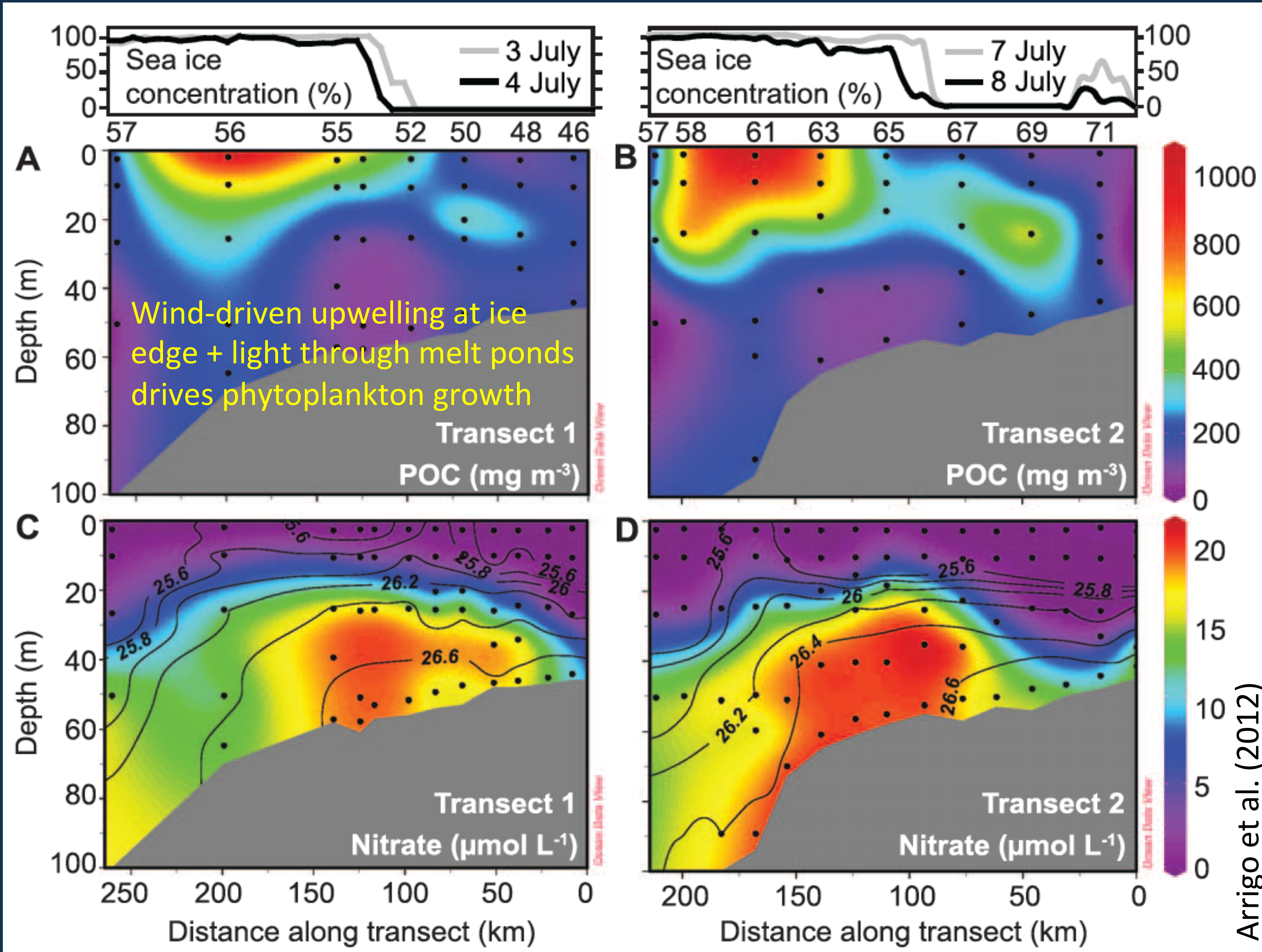
SSM/I - Posey

How do the Atmosphere, Ice & Ocean Interact?





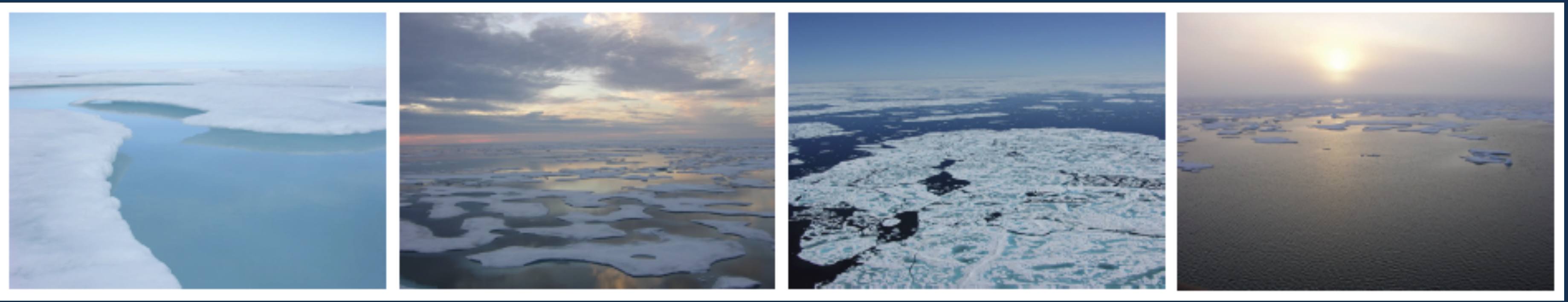
Wassmann and Reigstad (2011)



Sea ice concentration (%)
3 July
4 July
7 July
8 July
A
B
C
D
Depth (m)
Wind-driven upwelling at ice edge + light through melt ponds drives phytoplankton growth
Transect 1
POC (mg m-3)
Transect 2
POC (mg m-3)
Transect 1
Nitrate (μmol L-1)
Transect 2
Nitrate (μmol L-1)
Distance along transect (km)
Arrigo et al. (2012)

ONR Marginal Ice Zone Experiment

March – October 2014



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

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

Wave Measurements- Thomson (APL-UW)

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

Acoustic Navigation and Wavegliders- Freitag (WHOI)

Profiling Floats- Owens, Jayne (WHOI)

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

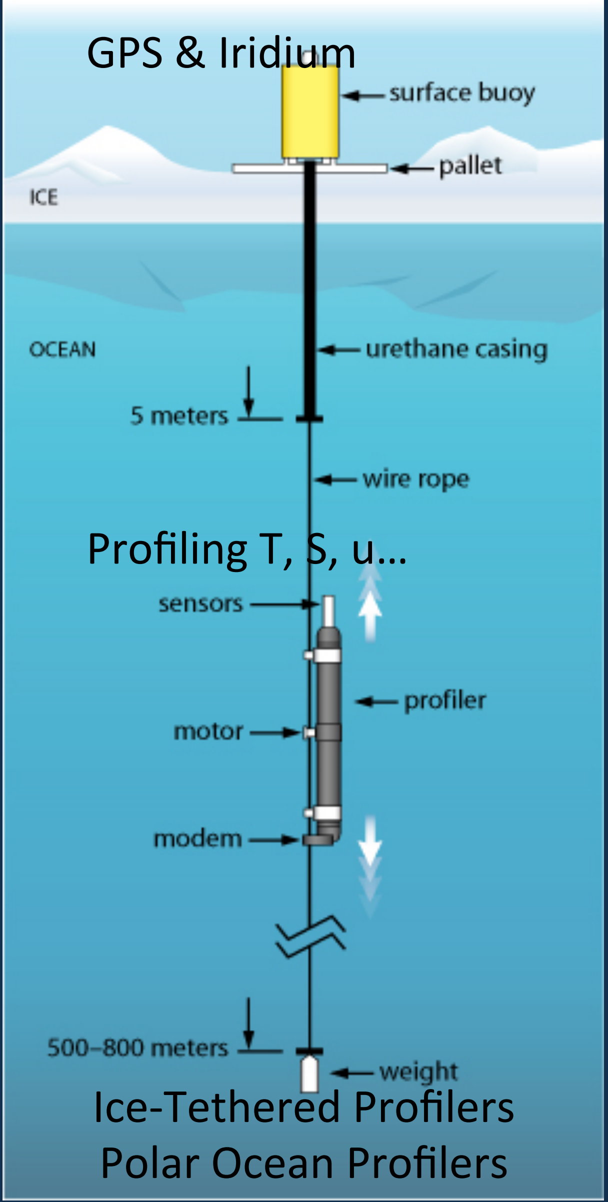
Autonomous Ocean Flux Buoys- Stanton, Shaw (NPS)

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

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

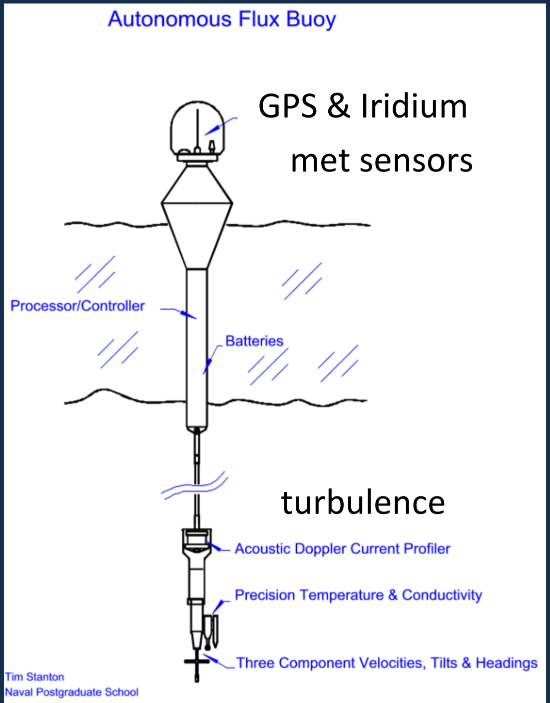
Arctic Nowcast/Forecast Model- Posey, Allard. Brozena, Gardner (NRL)

Profiling from the Ice (ITP, POPS, AOFB)



Stanton, Shaw (NPS) ; Krishfield, Toole, Proshutinsky (WHOI) ;
Kikuchi (JASMTECH) ; Shimada (Tokyo Univ)

- Drift with the ice
- Upper ocean & atmospheric measurements.
- Potential data relay for platforms operating beneath ice.



Access

- Distributed
- Drift pattern may not access all areas of interest.

Risk

- Break-up and refreeze, open water drift.
- Real-time data return mitigates risk.

Persistence/Cost/Scalability

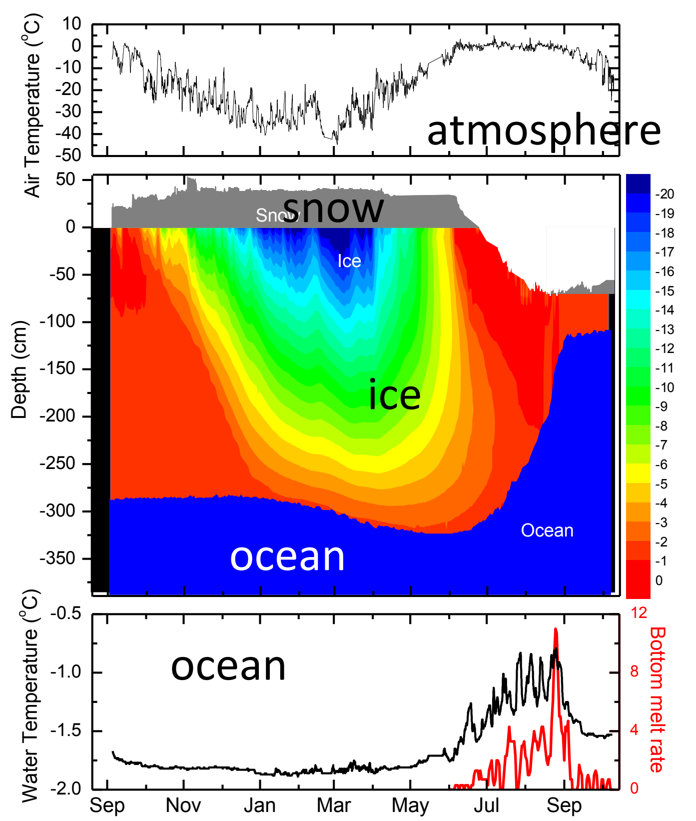
- Persistent presence, long endurance.
- Moderate cost and deployment logistics.

Adaptability/Flexibility

- Adapt for use in marginal ice zone.

Autonomous Ice Mass Balance (IMB)

Wilkinson (BAS), Hwang (SAMS), Maksym (WHOI)
Perovich, Richter-Menge (CRREL)



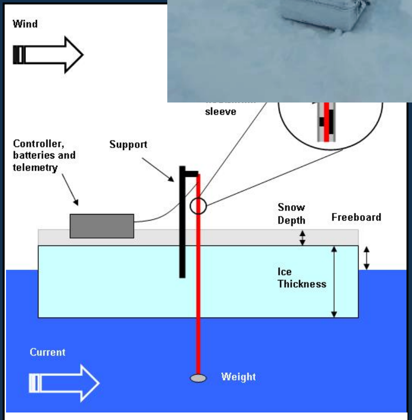


Diagram of chain set up,.

Access

- Distributed
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Risk

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Persistence/Cost/Scalability

- Persistent presence, long endurance.
- Inexpensive, light logistics.

Adaptability/Flexibility

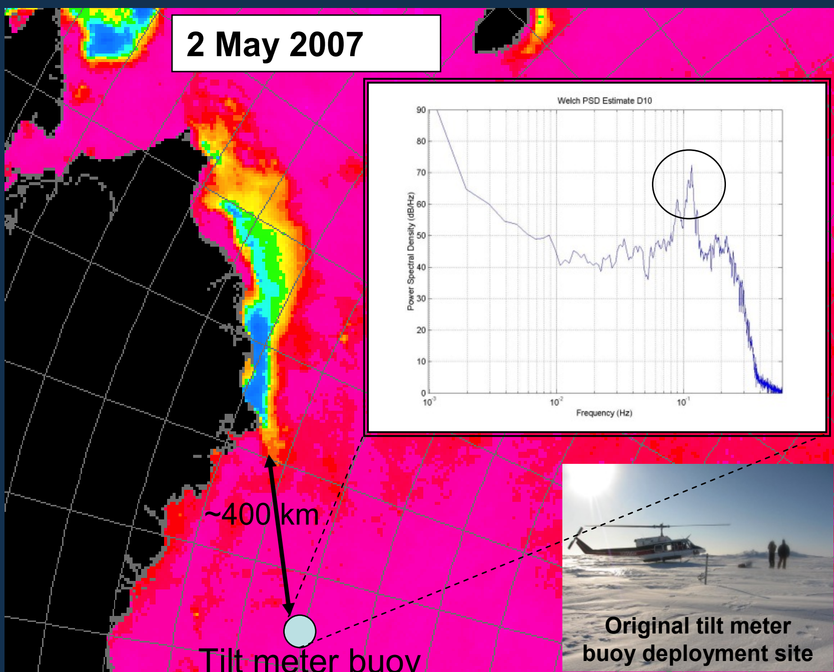
- Easy to reconfigure.

- Attribute changes in ice cover
- Quantify:
  - Snow accumulation & melt
  - Ice growth
  - Ice surface & bottom ablation
  - Air, ice, ocean temperature
  - Net surface heat budget
  - Ocean heat flux

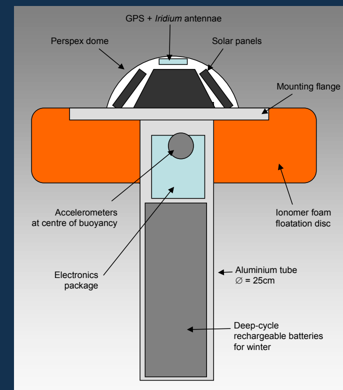
Autonomous Wave Measurements: Ice & Water

Wadhams (Cambridge), Dobble (LOV), Wilkinson (BAS), Hwang (SAMS), Maksym (WHOI)

Waves in Sea Ice



Ice conditions and power spectral density of swell waves seen by a wave buoy from the first trans-Arctic wave experiment: Beaufort Sea to Fram Strait (Wilkinson et al., 2008). The circled region shows a ~15 second peak originating from ocean waves within the polynya.



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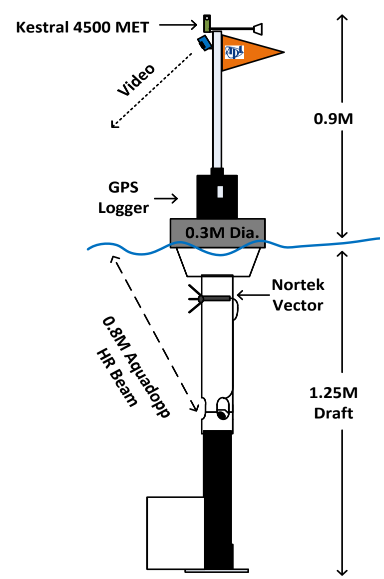
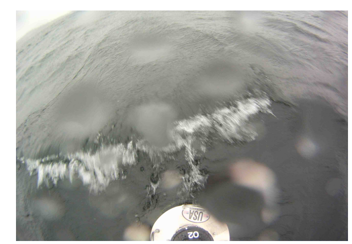
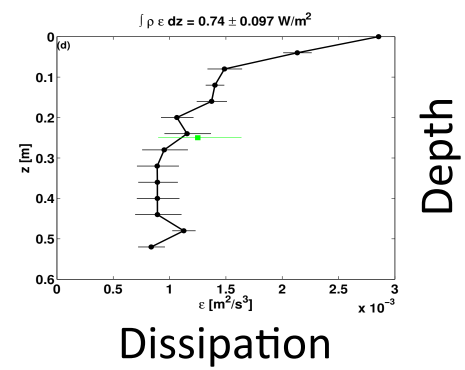
Surface Waves in Open Water

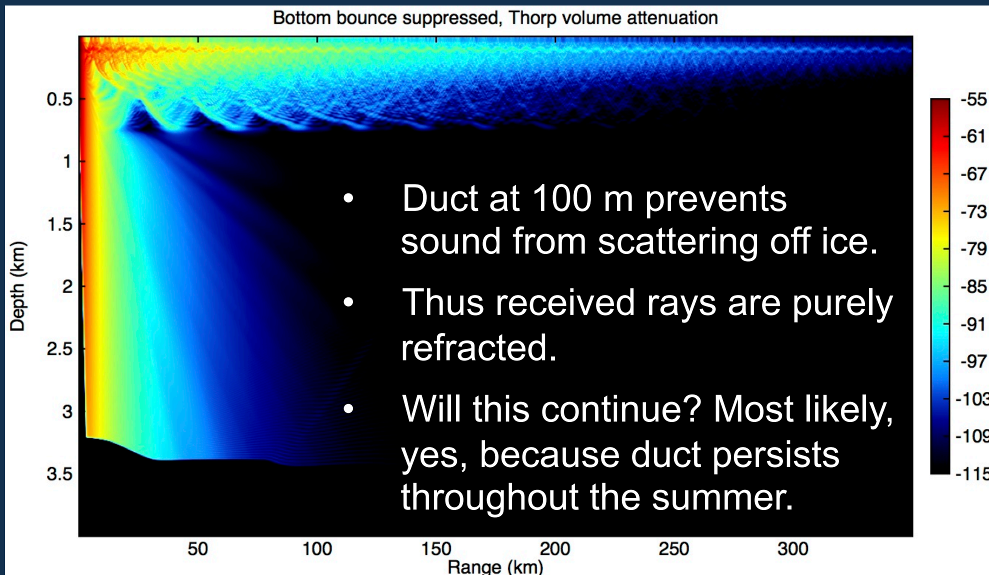


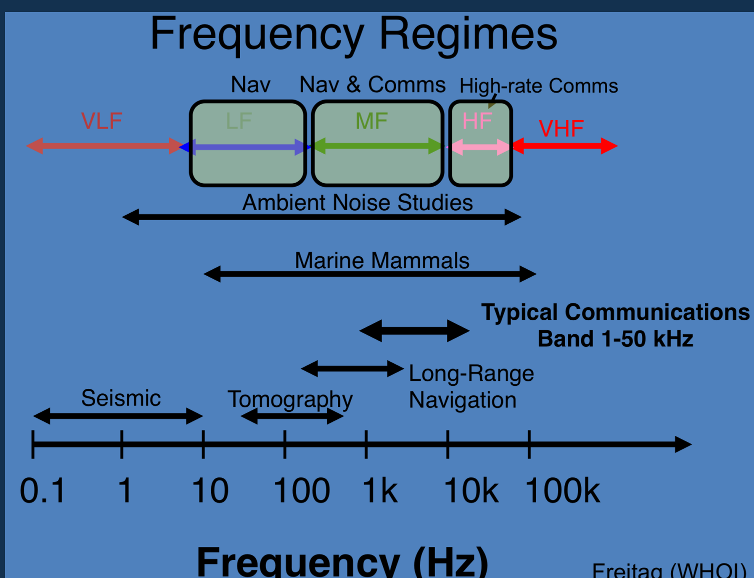




Acoustic Navigation

Freitag (WHOI)





Purpose

- Provide real-time navigation for gliders and floats from drifting beacons.
- Transmit simple commands to gliders to alter mission.

Acoustic Parameters

- 900 Hz carrier, 25 Hz bandwidth, 183 dB SPL.
- Very low data rate(1 bit/sec), but could have been faster given conditions.

Results

- Range far-exceeded expectations: 120-230 km typical, Max is 380 km!
- Duct at 100 m prevents sound from scattering off ice.
- Typical max error is less than 100 m and average is 20 m.

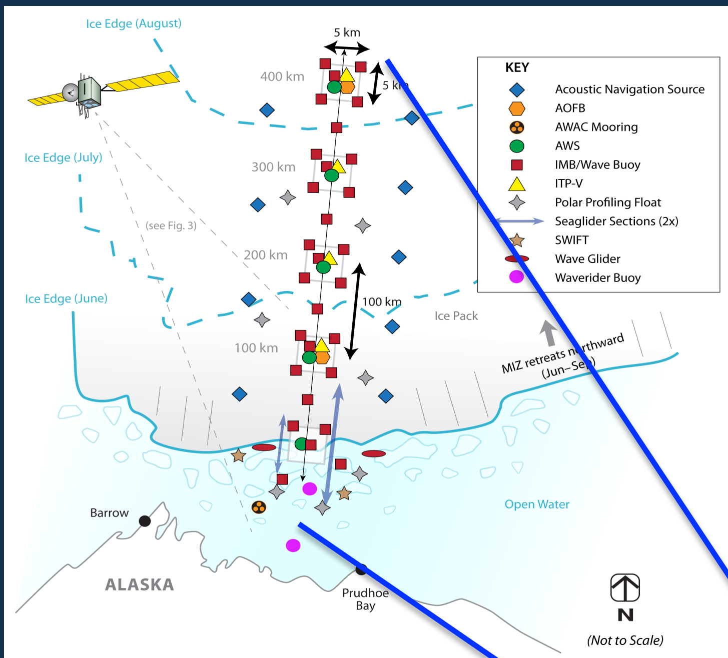
Science Objectives

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

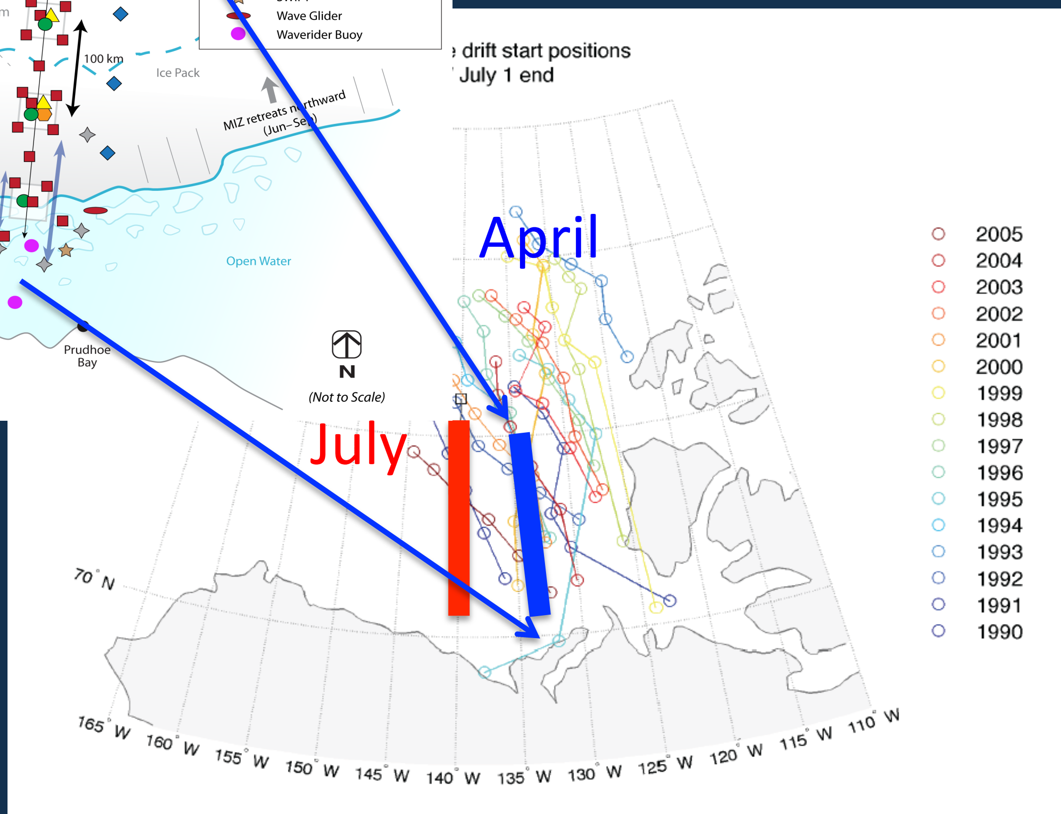
1. Develop and demonstrate new robotic networks for collecting observations in, under and around sea ice.
2. Improve interpretation of satellite imagery.
3. Improve numerical models to enhance seasonal forecast capability.

MIZ Operational Approach



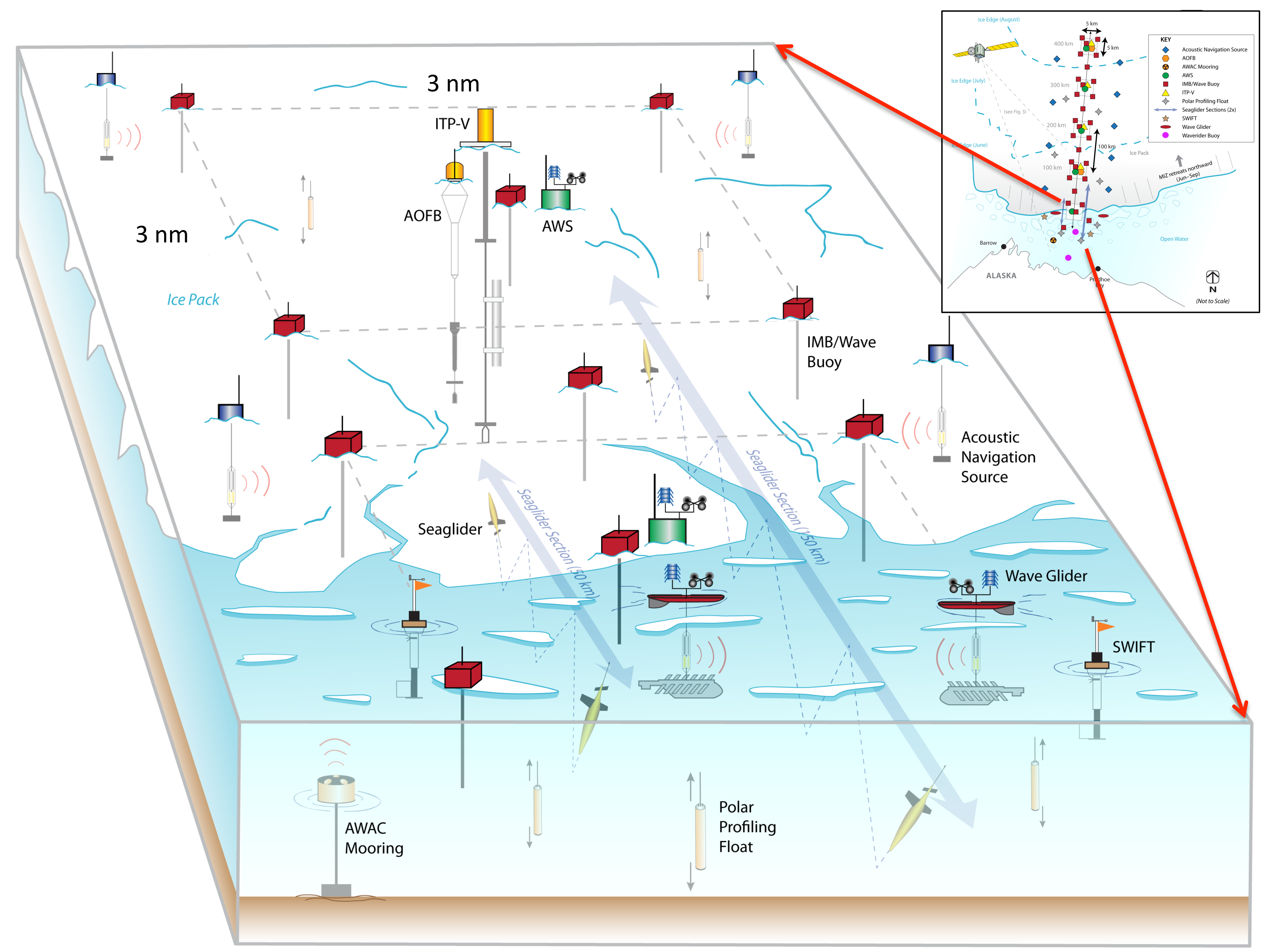
Ice-based array deployed by aircraft in April (full ice cover).

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



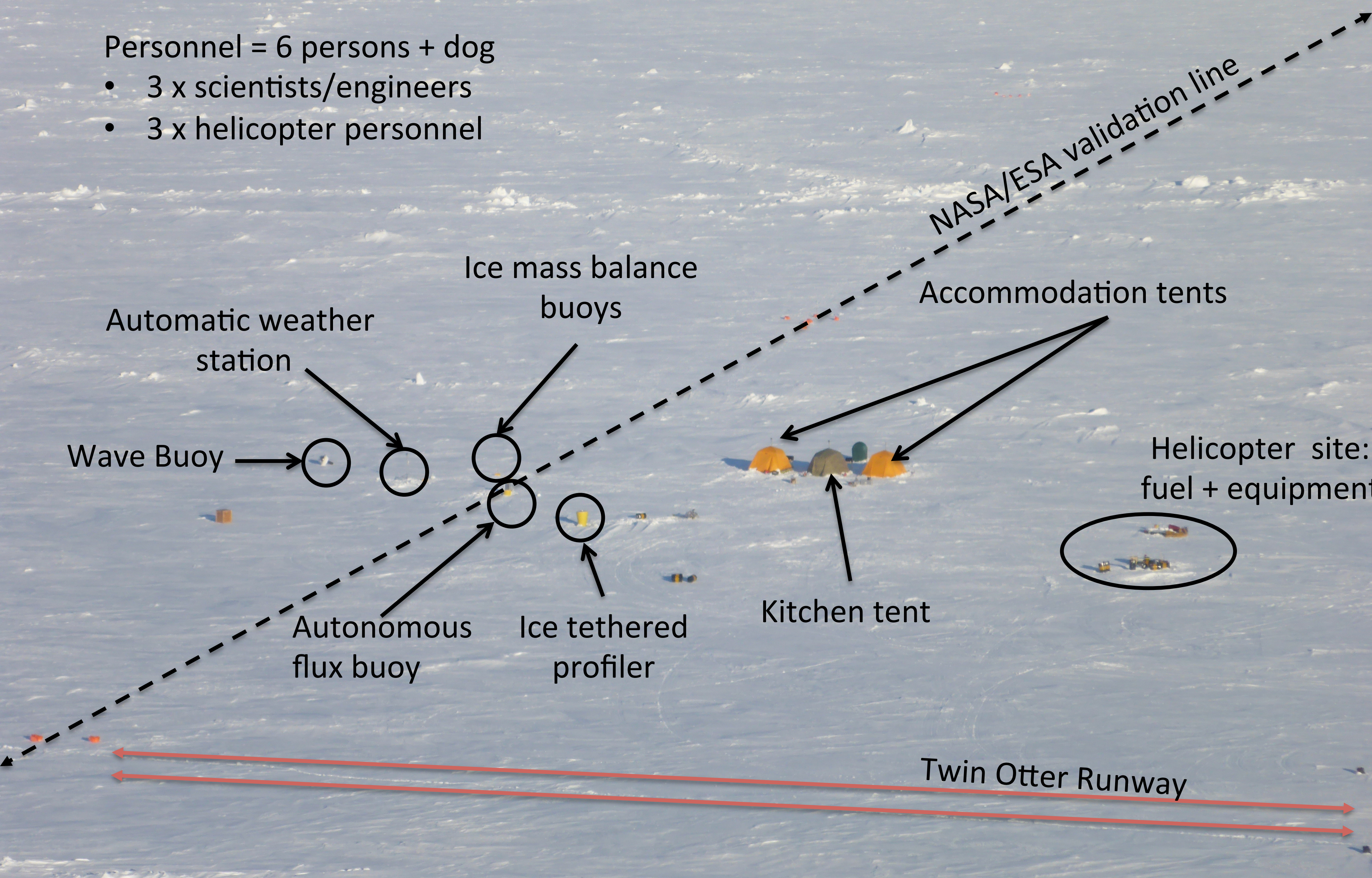
Risk Mitigation: 20% of assets held for deployment in August at northernmost site using Korean icebreaker Araon.

- 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.

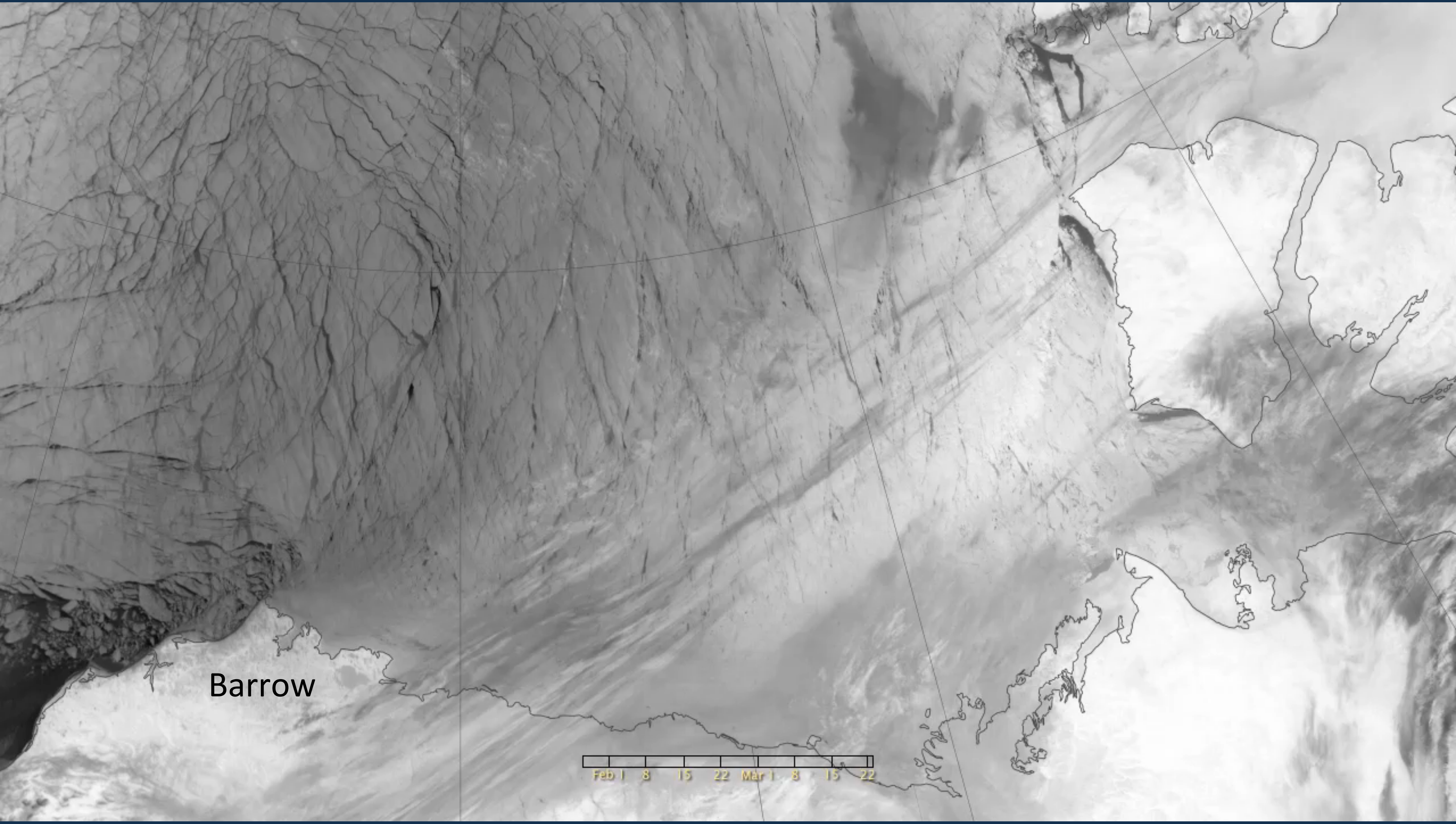

3 nm
3 nm
ITP-V
AOFB
AWS
Ice Pack
IMB/Wave Buoy
Acoustic Navigation Source
Seaglider
Seaglider Section (50 km)
Seaglider Section (150 km)
Wave Glider
SWIFT
AWAC Mooring
Polar Profiling Float
Ice Edge (August)
Ice Edge (July)
Ice Edge (June)
5 km
5 km
400 km
300 km
200 km
100 km
100 km
(see Fig. 3)
Ice Pack
MIZ retreats northward (Jun–Sep)
Open Water
Barrow
ALASKA
N
(Not to Scale)
KEY
Acoustic Navigation Source
AOFB
AWAC Mooring
AWS
IMB/Wave Buoy
ITP-V
Polar Profiling Float
Seaglider Sections (2x)
SWIFT
Wave Glider
Waverider Buoy

Camp at C3

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

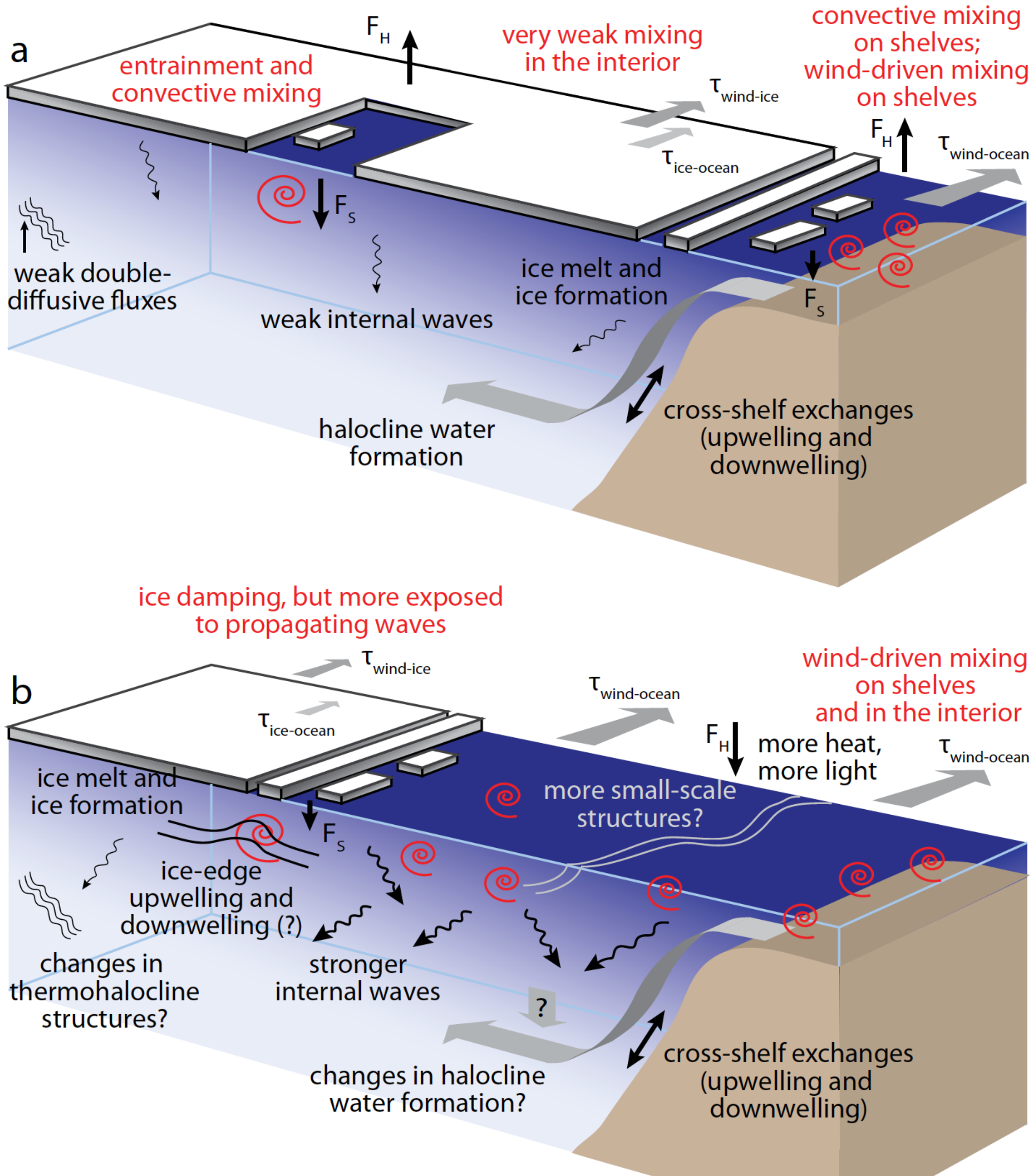


Sea Ice February-March 2013



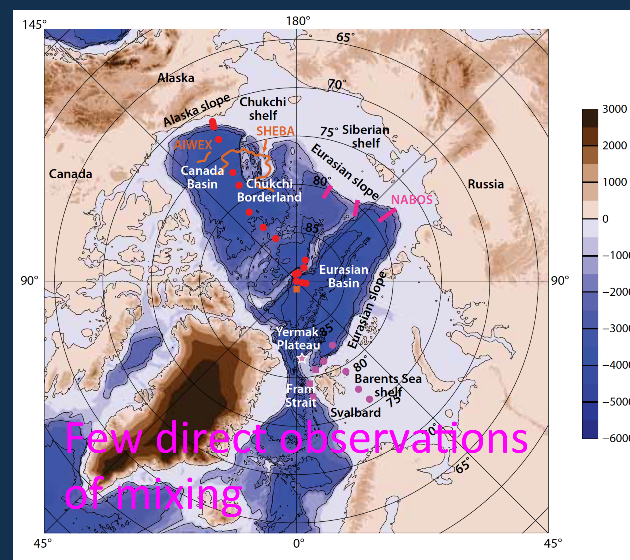
NASA VIRS (http://http://visibleearth.nasa.gov

Mixing and Exchange



Rainville, Lee and Woodgate (2011)

- Internal waves, mixing weak in ice-covered Arctic
- Increased open water-wind-mixing, internal wave generation, solar warming, ice-edge upwelling/ downwelling, fog/clouds
- Impacts stratification, nutrient flux, light availability



'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.