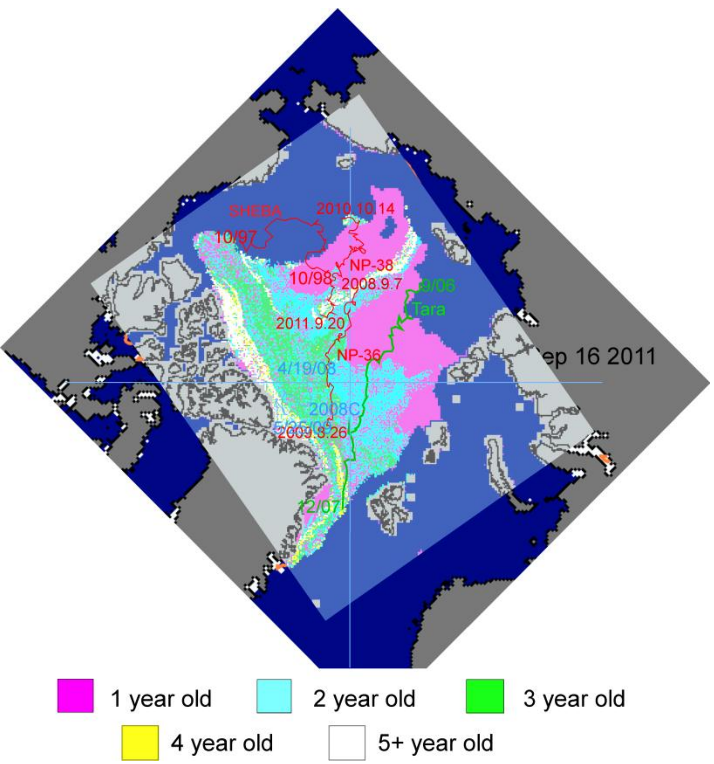
International Arctic Science Committee

The proposed

Multidisciplinary drifting Observatory for Studies of Arctic Climate (MOSAiC)

O. Persson, M. Shupe, M. Tjernström, K. Dethloff, D. Perovich, J. Zhang (& many others)



September 2011 sea ice extent and ice age (courtesy NSIDC and J. Maslanik). Drift tracks of stations installed in autumn of 2006-2010 with at least 1-year longevity are shown to suggest possible observatory put-in locations and tracks

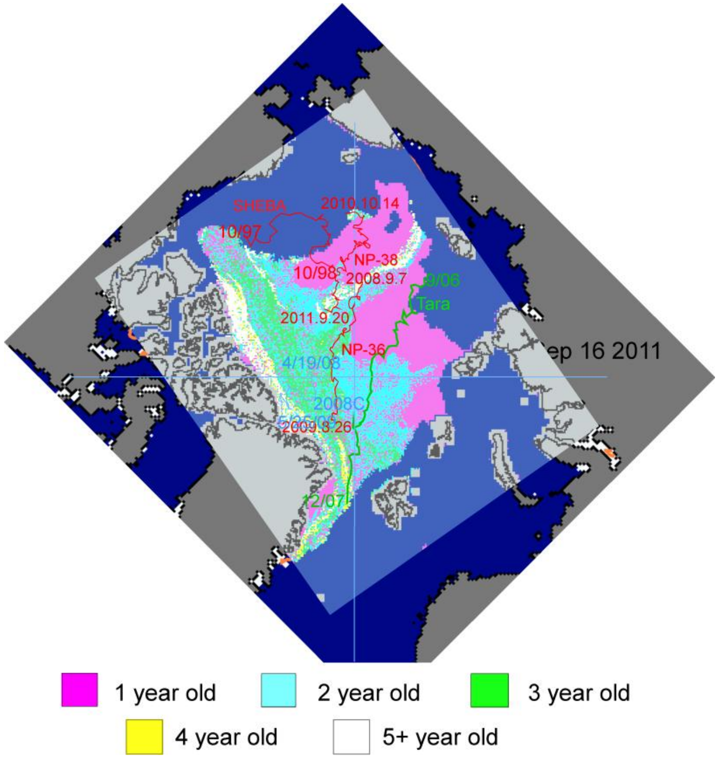
- **What:** Deployment of a heavily instrumented, manned, Arctic Ocean observatory to provide observations addressing key science questions associated with the Arctic atmosphere, cryosphere, and ocean along with their interactions
- **When:** Approximate timeline: start 2016-2017, covering several annual cycles
- **Where:** Central Arctic basin drift will allow measurements in regions with limited instrumentation, include different ice and weather regimes, and provide a multi-year data set
- **Who:** International participation (e.g. US, Germany, Sweden, Finland, United Kingdom, Canada, Japan, China, Russia?…) through IASC coordination, synchronized international funding, and use of international infrastructure
- **Outcomes:** Improved process level understanding of Arctic system components and their interactions; Improved GCM parameterizations; Improved satellite remote sensing techniques; Arctic Ocean observational impact test bed; expand terrestrial climate observations

Why ?

1) ”New Arctic”

- large regions of first-year ice and seasonally open water instead of primarily multi-year ice – regional and global impacts
- commercial interests increasing

2) Lack of <u>understanding</u> of many disciplinary <u>processes</u>
   - Atmosphere
   - Cryosphere
   - Oceans
   - Biosphere



3) Lack of understanding of interdisciplinary interactions/processes

What is meant by process-level understanding?

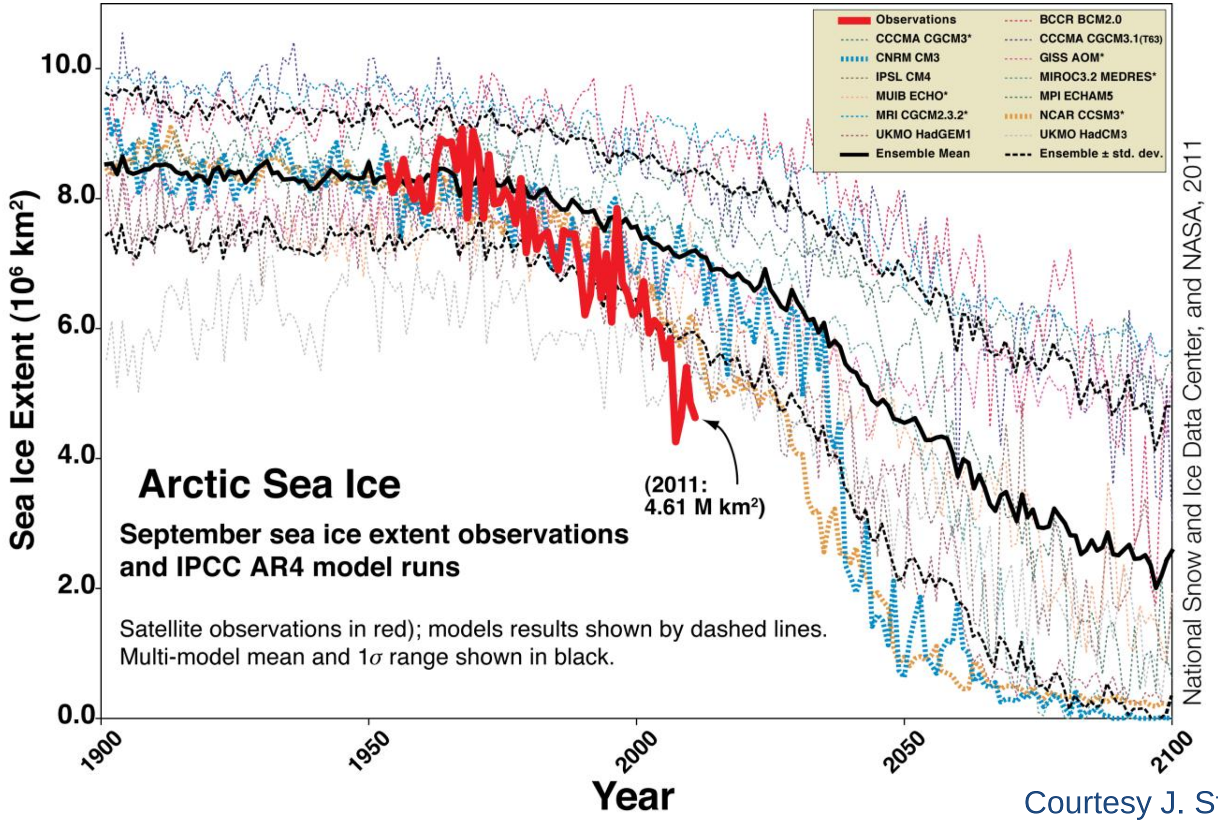
Basic monitoring parameters: Sea-ice extent, global/regional SAT, etc
- indicate what is happening but generally not why

Process-level understanding requires observations of many additional parameters

Acquisition of process-level understanding requirement for significant model improvements

Observed and climate model trends in September Arctic Sea Ice Extent

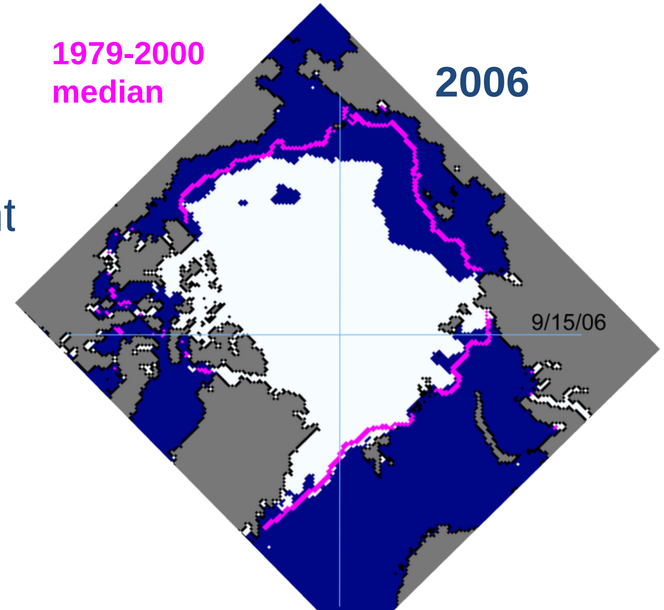
Arctic sea ice extent decreasing more rapidly than climate models predict

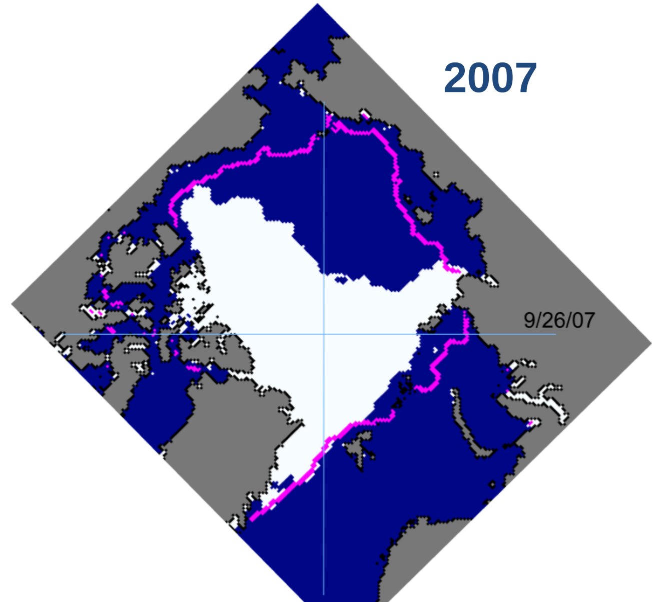


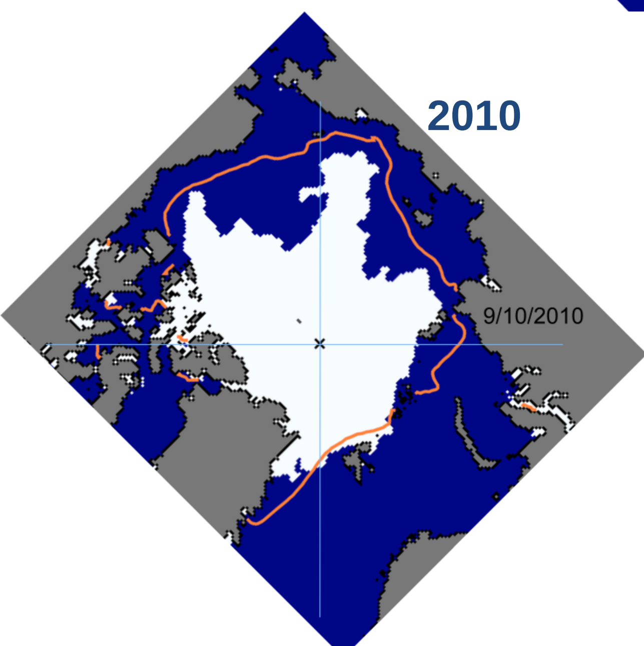
Courtesy J. Stroeve

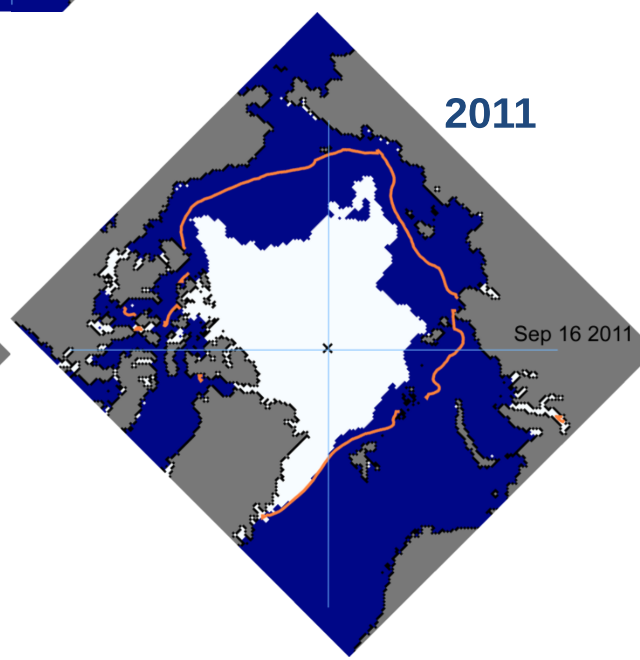
Spatial changes in sea-ice distribution

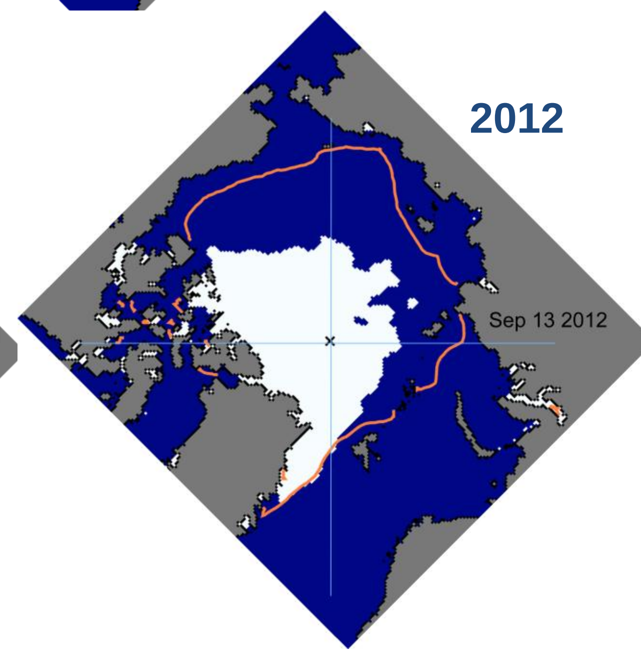
September
sea ice extent



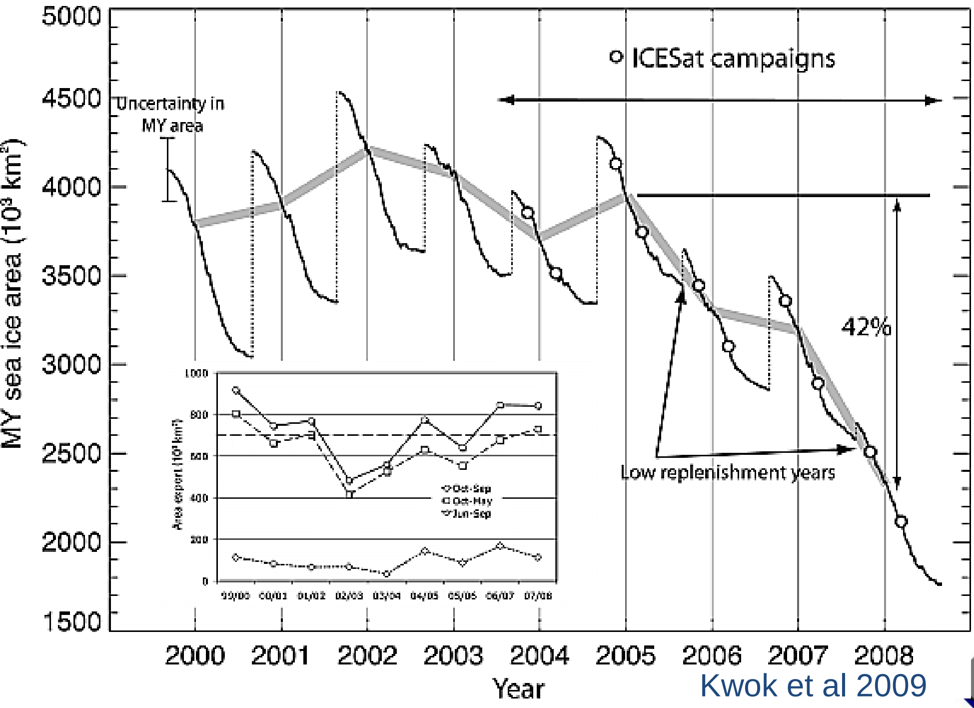






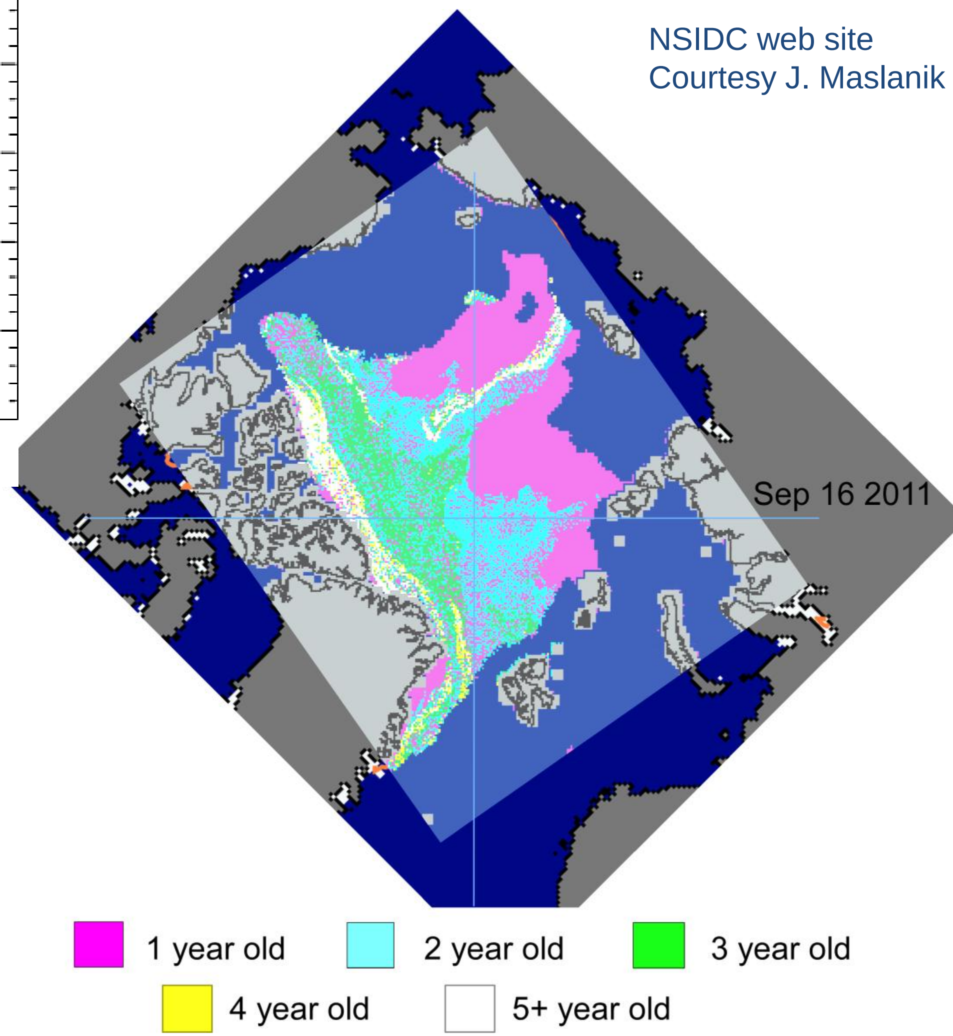


Changes in MYI percentage & sea-ice age

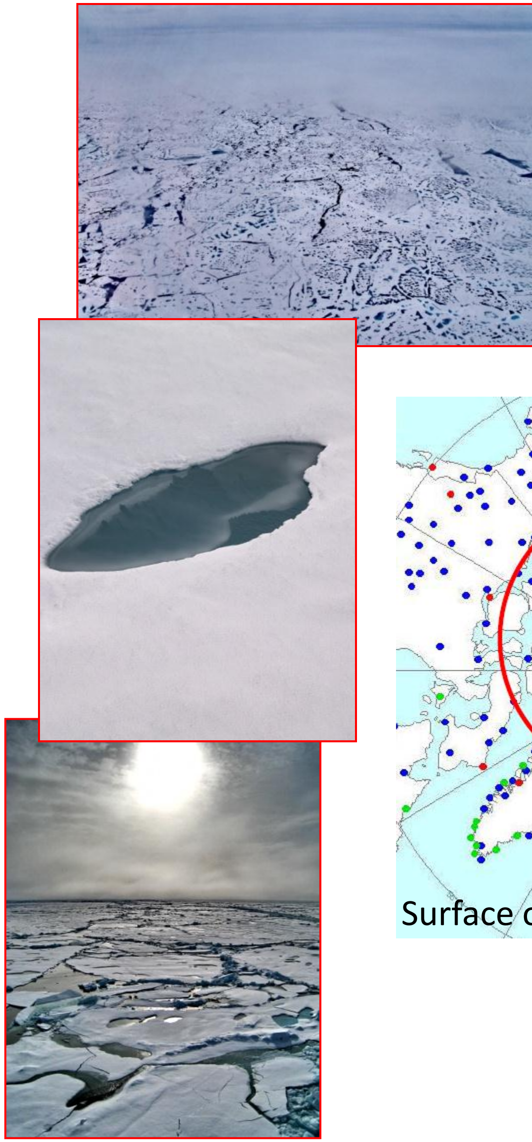


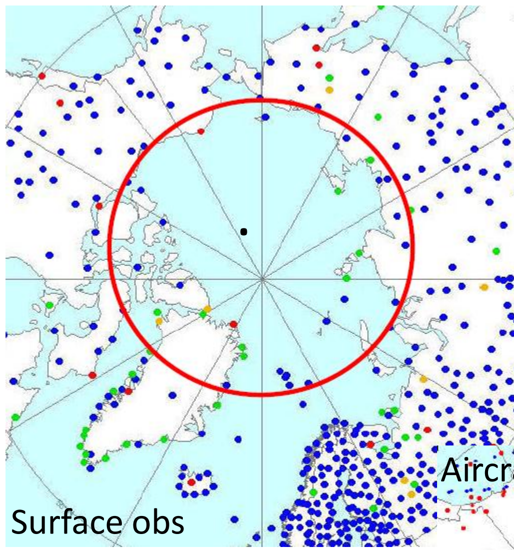
Kwok et al 2009

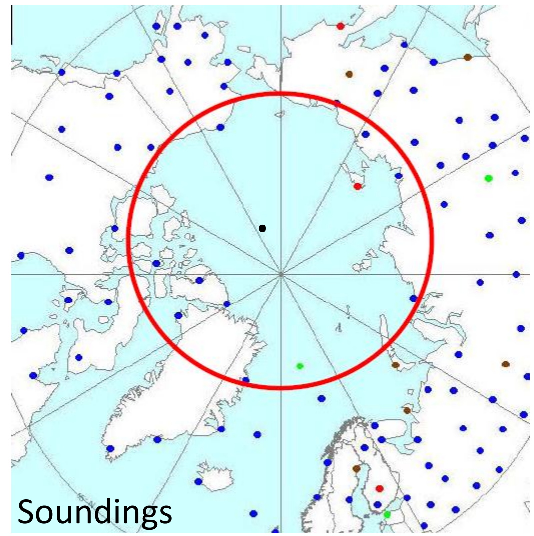
NSIDC web site
Courtesy J. Maslanik

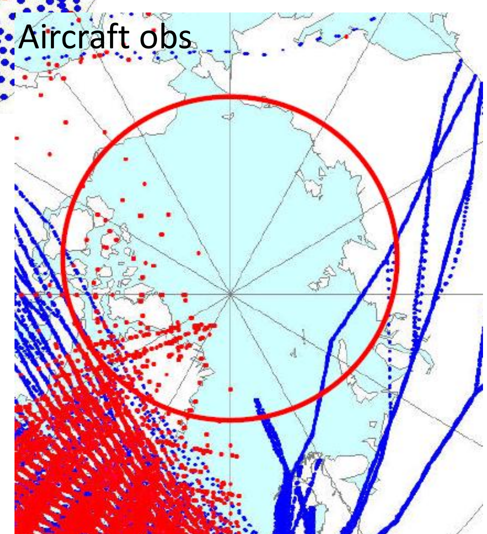


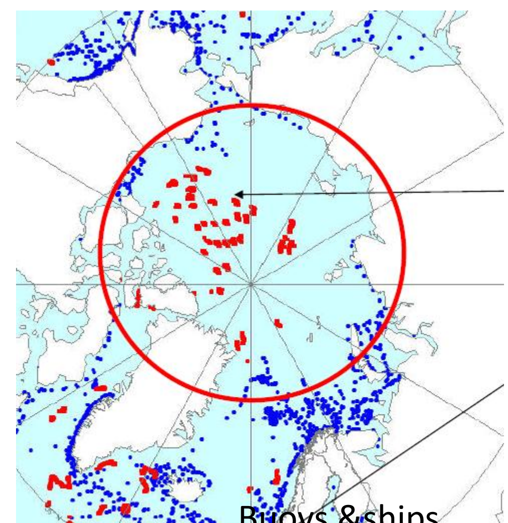
General lack of atmospheric data over Arctic Ocean (process level or other)











Overarching Science Question

"What are the causes and consequences of an evolving and diminished sea ice cover?"

Broad Sub-questions

- How do ongoing changes in the Arctic ice-ocean-atmosphere system drive heat and mass transfers of importance to climate and ecosystems?

- What are the processes and feedbacks affecting sea-ice cover, atmosphere-ocean stratification and energy budgets in the Arctic?

- Will an ice-reduced Arctic become more biologically productive and what are the consequences of this to other components of the system?

- How do the different scales of spatial and temporal heterogeneity within the atmosphere, ice and ocean interact to impact the linkages or feedbacks within the system?

- How do interfacial exchange rates, biology and chemistry couple to regulate the major elemental cycles?

Key Science Questions

• What are the processes and feedbacks producing the recent loss of sea-ice cover?

a) enhanced energy fluxes from ocean or atmosphere? If so, what is the relative contribution from atmosphere and ocean? Which processes are changing? Why? Where are these process changes occurring? What are the primary energy fluxes, and what is their spatial and temporal variability?

b) advective ice losses from changes in atmospheric circulation/ocean currents? If so, what changes? Where? When? Are these circulation changes linked to changes at lower latitudes?

c) combination of above: imbalance between formation, melt, advective export? If so, all processes need to be quantified and above questions addressed.

• What are key consequences of recent sea-ice loss?

a) how does sea-ice loss produce local, regional, and/or global atmospheric circulation changes
b) what processes produce changes in the oceanographic structure and circulation
c) what processes produce changes in the biosphere

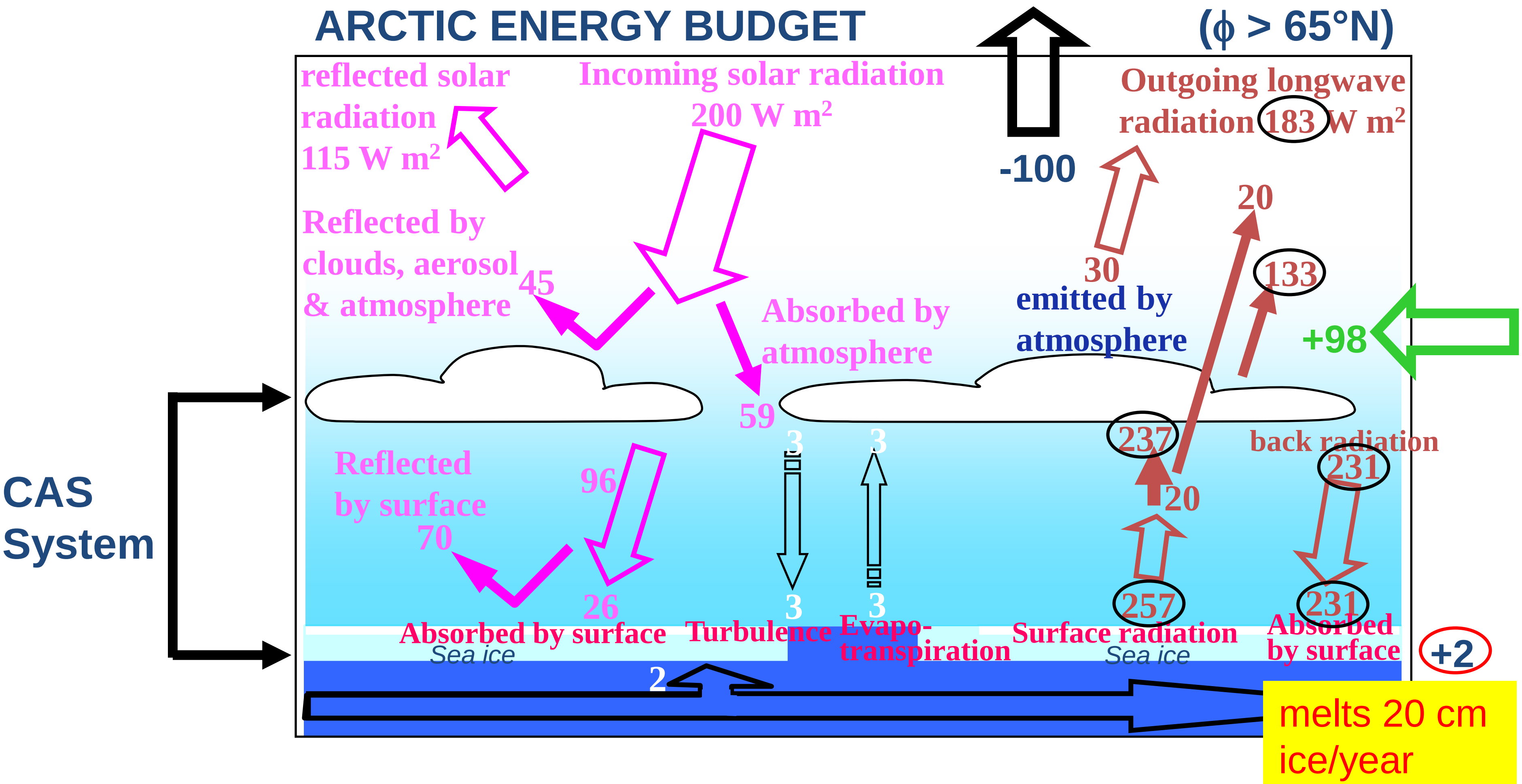
Arctic Cloud-Atmospheric Boundary Layer-Surface (CAS) System

Motive

Surface energy fluxes are key for understanding observed changes in Arctic sea ice and permafrost

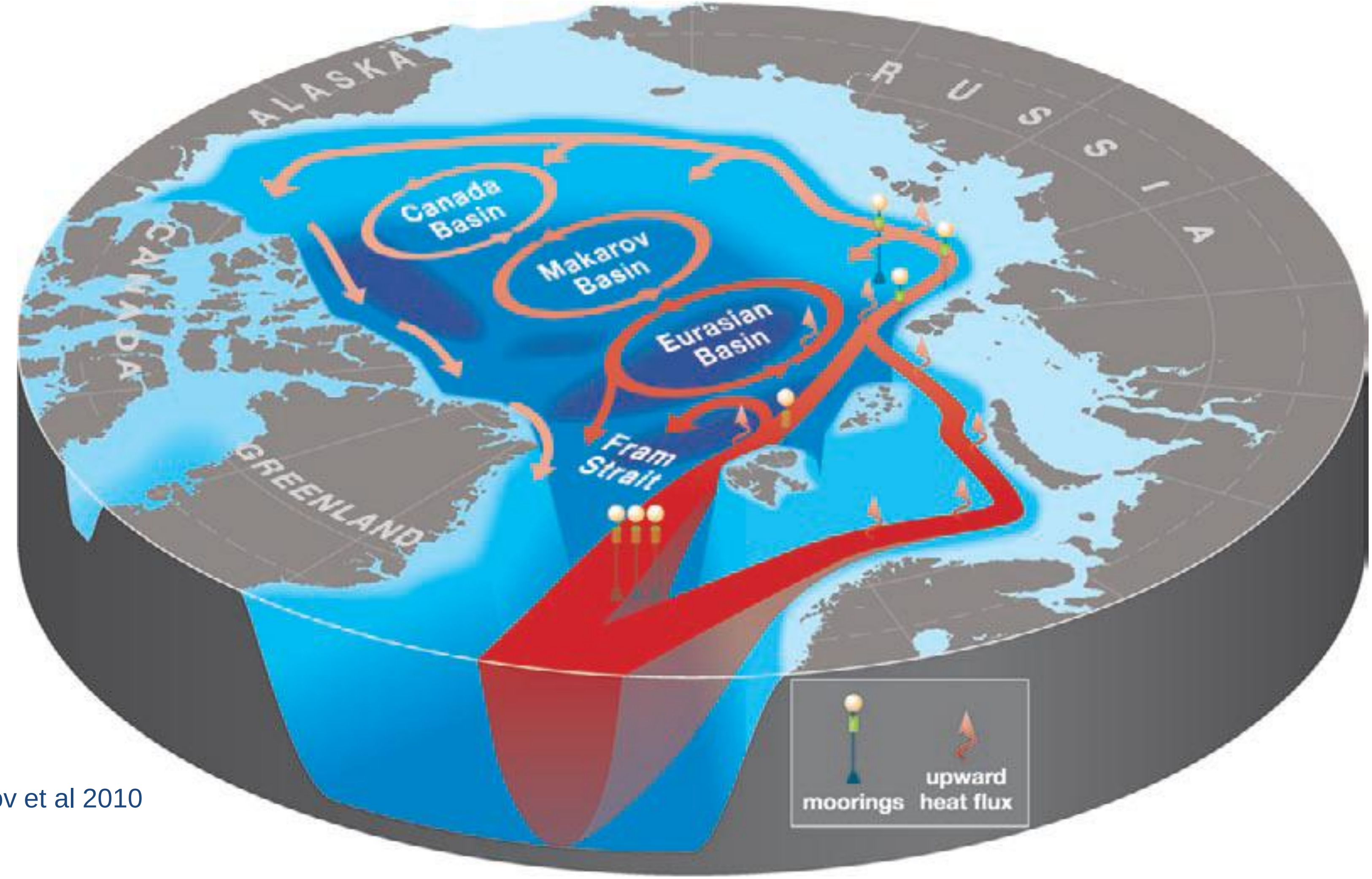
Objective

Determine key atmospheric processes in CAS system controlling Arctic surface energy fluxes



Possible mechanisms

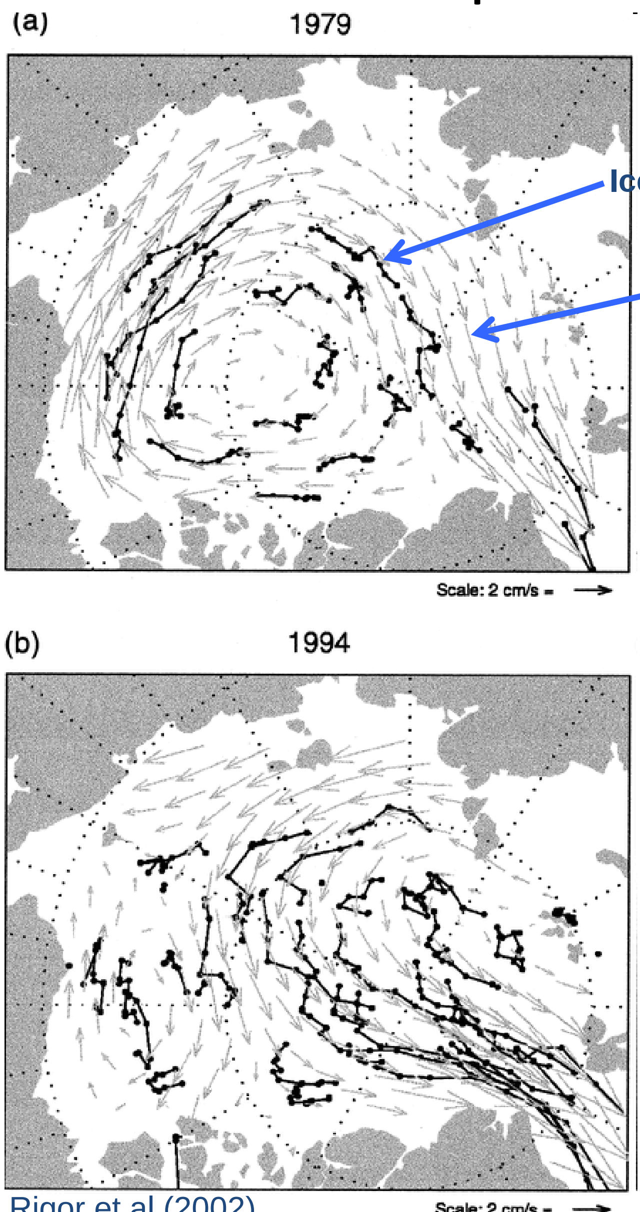
- Oceanographic heating



Polyakov et al 2010

Possible mechanisms

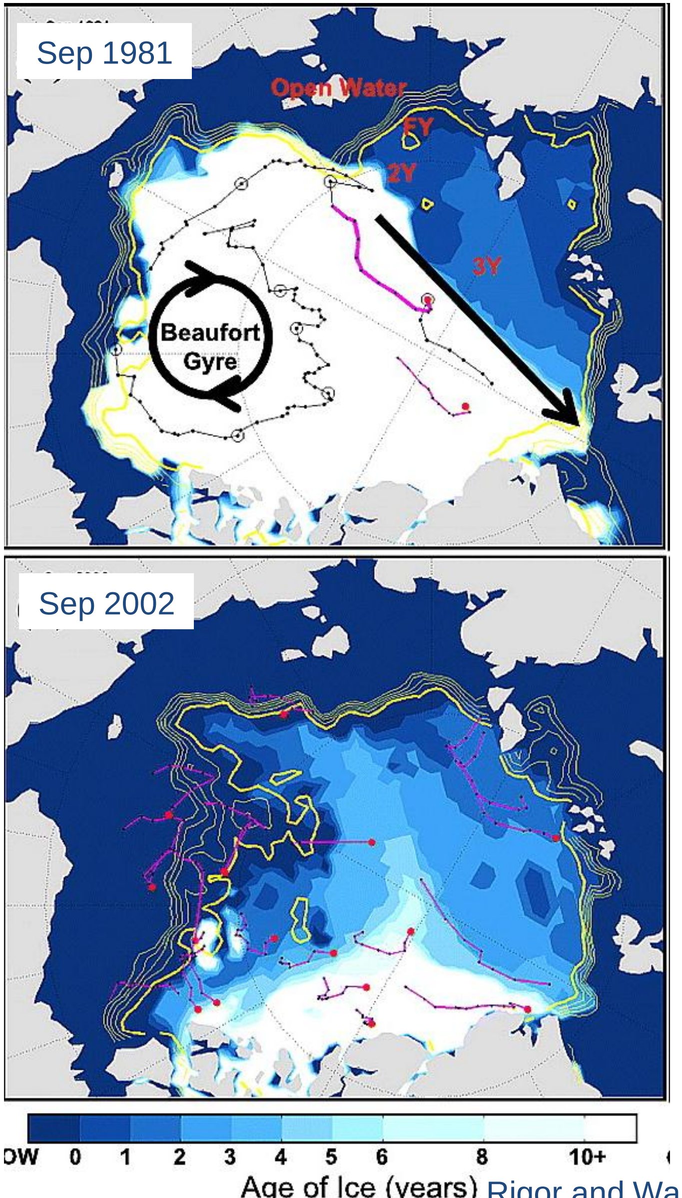
- atmospheric winds/ sea ice circulation



Ice buoy tracks

Sea ice motion vectors

Rigor et al (2002)



Rigor and Wallace (2004)

Needed atmospheric science study areas over Arctic Ocean

1) Water Budget

a) **Precipitation** (formation mechanisms, rates, spatial and temporal distribution, accumulation, surface albedo impacts, aerosol wet deposition)
b) **Cloud evolution and phase** (mixed-phase cloud formation and maintenance, liquid and ice nucleation)
c) **Arctic water vapor** (sources and sinks, long-range transport vs local sources, bubble bursting and sea spray)

2) Boundary Layer

a) **energy budget** (radiative and turbulent fluxes)
b) **vertical structure, transport, mixing**
c) **momentum budget** (impacts by/on cyclones; ice/ocean surface impacts)
d) **aerosol budget and processes** (local vs remote sources; influence on surface albedo; impacts on cloud optical properties)
d) **surface layer processes**
e) **stable boundary layer processes**
f) **ozone depletion** (influence of increased bromine from more leads & polynyas; impact on surface exchange processes)

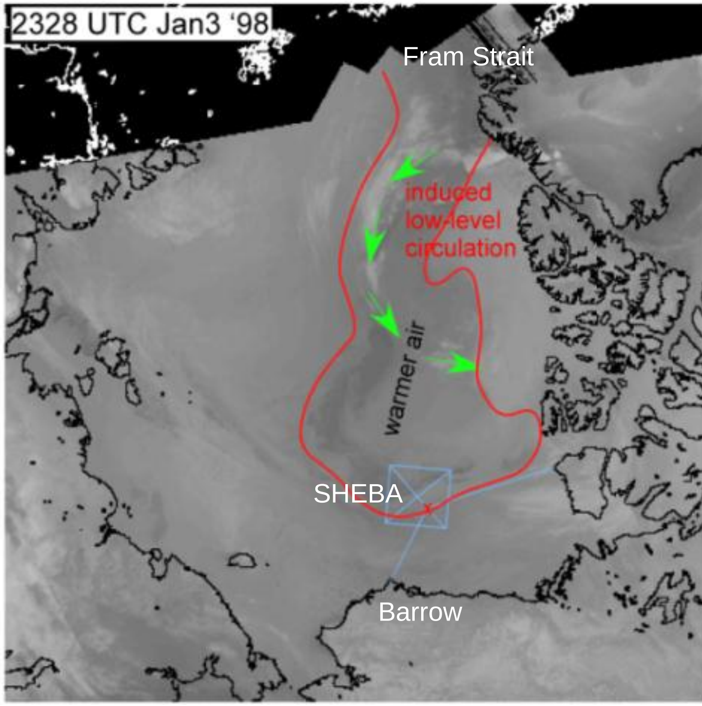
3) Interactions with Weather Systems

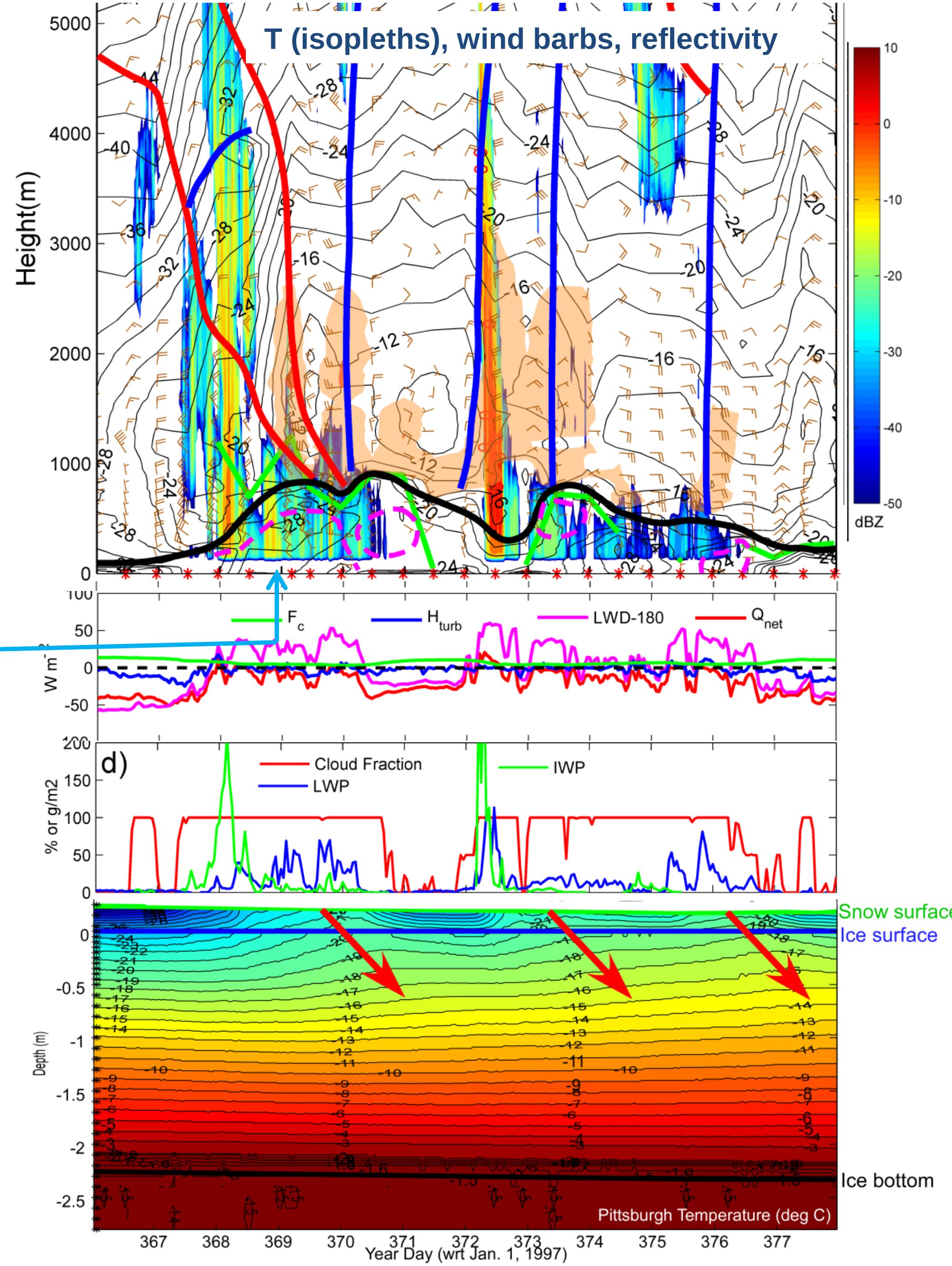
a) **impact of large-scale systems on local processes** (boundary-layer structure; cloud/precipitation properties; water vapor and aerosol transport)
b) **influence of ”New Arctic” on weather systems** (increased heat and/or moisture fluxes; polar low development)
c) **influence of Arctic measurements for improving reanalyses** (location, assimilation frequency, impacts of Arctic data)

4) Stratospheric Processes

a) **stratosphere-troposphere interactions during Arctic Oscillation events** (investigate ”system memory”)
b) **long-range teleconnections**
c) **ozone hole** (characterization of Arctic ozone hole; effect of tropospheric coupling on ozone depletion)

SHEBA Jan. 1-12, 1998; Beaufort Sea





1) Long-distance free tropospheric advection of heat and moisture significant

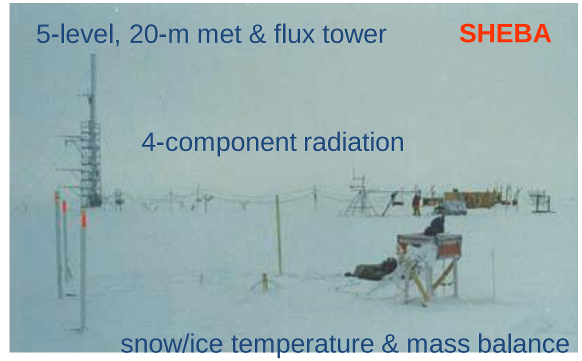
2) Associated clouds (esp. with liquid) have strong impact on LW_d, F_{net}, and T_s

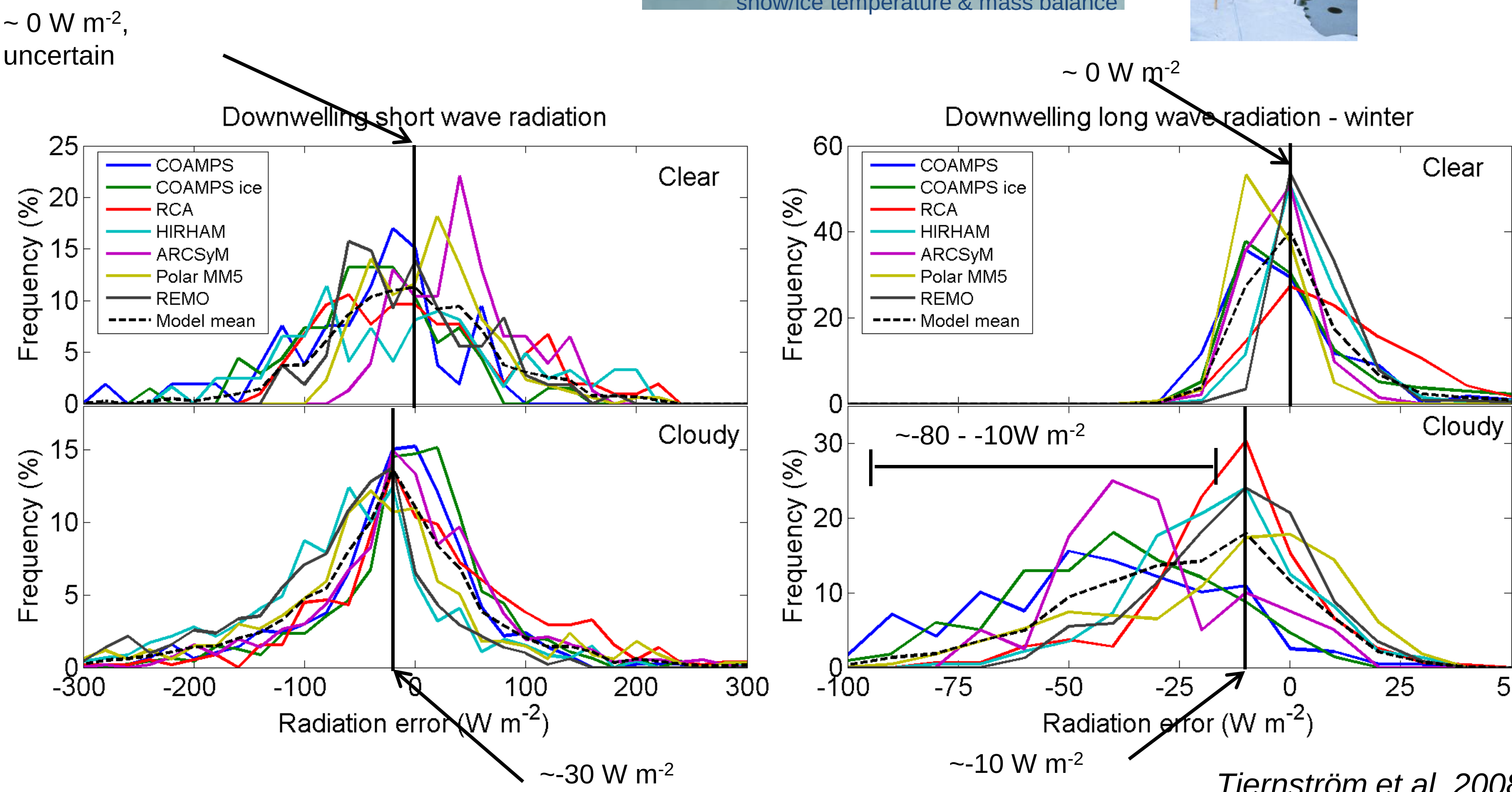
3) Thermal structure in snow and ice respond strongly to synoptic/mesoscale atmospheric events and presence of liquid water in clouds

Previous observations illustrating current atmospheric science issues

SHEBA Data

- only year-round, comprehensive, atmospheric data set over sea ice
- extensively used; e.g., validation of regional climate models





Tjernström et al. 2008

Validation of Energy Fluxes over Sea Ice in Reanalyses (“best” representation of Arctic)

Table 1: Annual biases of the individual surface energy fluxes for the four reanalysis data sets using SHEBA observations as validation. The bottom row shows the root-mean-square (RMS) biases of the flux terms for each reanalysis, while the right-most column shows the RMS bias of the reanalyses for each flux term.

SEB Term	Main processes represented	ERA-40 bias	ERA-Interim bias	NCEP/DOE bias	JRA-25 bias	RMS bias
H_s	turbulence transfer coefficient	-3.0	-0.9	-22.2	-8.8	**12.0**
H_l	turbulence transfer coefficient	3.1	2.1	1.2	2.6	**2.4**
SW_d	SW cloud properties	-8.2	-7.6	23.0	6.8	**13.2**
SW_u	SW_d, surface albedo	-12.3	-9.9	28.0	-11.0	**17.0**
LW_d	LW cloud properties	-4.4	-4.3	-30.8	-28.9	**21.3**
LW_u	surface temperature	6.7	5.6	-3.8	5.0	**5.4**
SEB		-7.1	-8.8	-11.0	-9.3	
RMS bias		7.1	5.9	21.5	13.6	

Persson, Wheeler, and Cassano (in preparation)

Observed at SHEBA

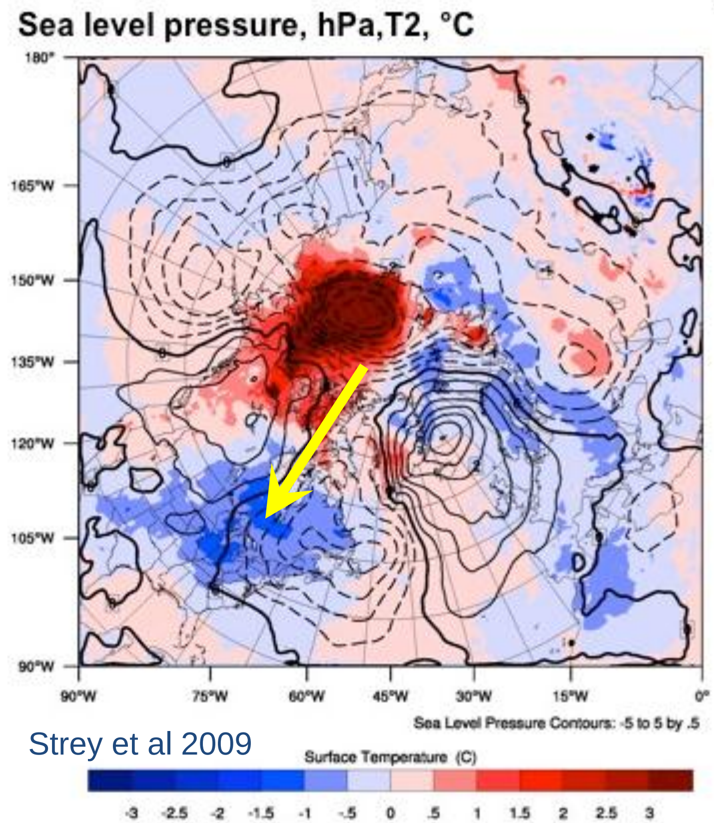
Annual F_{net}: +7.1 - 8.2 W m^{-2}
Surface ice mass loss 0.88 m (+8.4 W m^{-2})

Questionable whether reanalysis fluxes should be used to force sea-ice or ocean models

Mid-latitude Impacts of Regional Sea-Ice Loss

- winter 2009-2010

- enhanced T_s and heights in Arctic ice-free regions in autumn
- enhanced meridional flow
- poorly understood interaction with mid-latitude circulation – great interannual variation
- see also Francis and Vavrus (2012; GRL)



Strey et al 2009

Needed cryospheric science study areas over Arctic Ocean

”Big Questions”

● What are the quantitative contributions of various processes to ice mass balance over the annual cycle?

● What positive and negative feedbacks may change significantly in a future Arctic?

● What are the linkages of sea ice changes with other systems, including ecosystems, mid-latitudes, carbon cycling, etc.?

Specific sea-ice issues to be addressed and needed observations

1) Measurements of Heterogeneity

a) **snow/ice thickness distribution** (airborne radar and EM, RS assets, UAVs)
b) **ice surface/bottom roughness** (LiDAR; multibeam on ROV)
c) **snow redistribution** (LiDAR)
d) **internal melt** (micro CT)
e) **under-ice radiation field** (logging spectroradiometers)

2) Observations of ”New Arctic” (open ocean – ice transition states)

a) **thin ice upper-ocean cooling**
b) **measurement logistics challenges – must be met**

3) Biological Impacts

a) **EPS ice structure/strength interactions** (molecular techniques)
b) **light transmission** (time series; logging spectroradiometers; ROVs)
c) **porosity/permeability – nutrient cycling relations** (Micro CT; analytical techniques)
d) **DMS production/release**
e) **bacterial/algae linkages** (molecular techniques)

4) Biogeochemical Cycling

a) **DIC pump to deep ocean**
b) **brine movement**

5) Spatial/temporal Extensions

a) **cal/val of remote sensing**
b) **development of autonomous platforms**

Needed ocean science study areas over Arctic Ocean

”Big Questions”

● Will an ice-reduced Arctic become more stratified, and what are the consequences of this to other components of the system?

● Will an ice-reduced Arctic become more biologiclly productive, and what are the consequences of this to other components of the system?

Specific ocean issues to be addressed

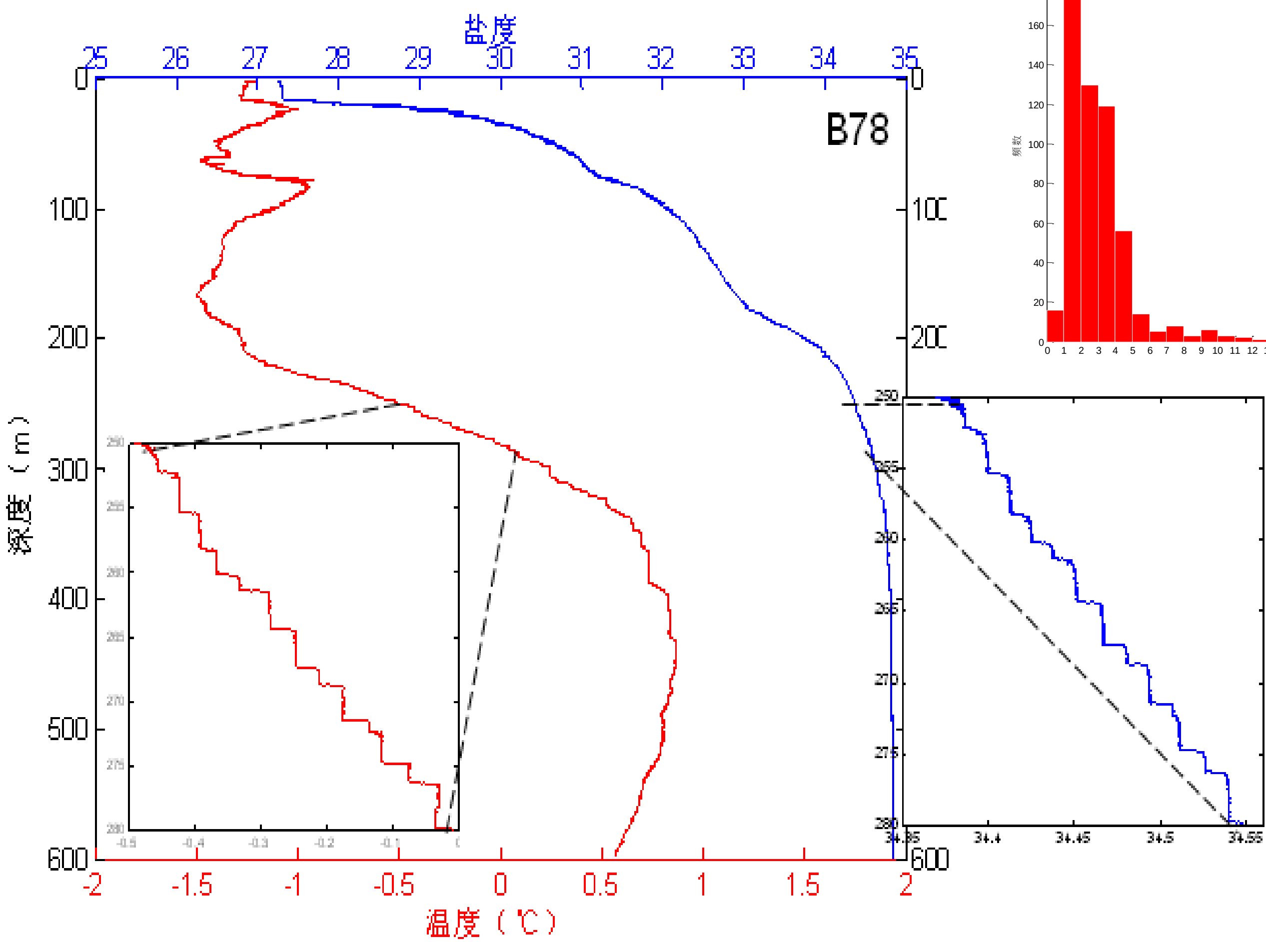
1) Questions and measurements of stratification and vertical structure

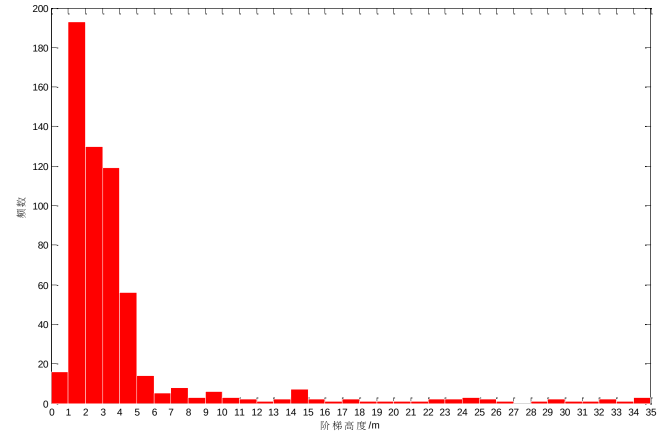
a) **What changes will be observed in the mixed layer under reduced sea ice?**
b) **What will be the net effect of the competition between changing stress and changing buoyancy?**
c) **Will small scale physical processes become more important?**
d) **How will changes in stratification and ice cover impact air-sea-ice heat flux and the formation of vertical hydrographic structure (e.g., near-surface temperature maximum)?**
e) **How will these physical processes change under the ”new Arctic” ice conditions?**

2) Biological questions

a) **Is production limited by light or nutrients?**
b) **How do physical processes, such as stratification, wind mixing, ice cover, and ice topography, interact with biological processes to determine the magnitude, timing, and type of primary production?**
c) What are the consequences of changing production timing and magnitude to the other trophic levels and to ecosystem structure and function?
d) How will these changes in primary production impact gas fluxes, aerosol formation, etc.?

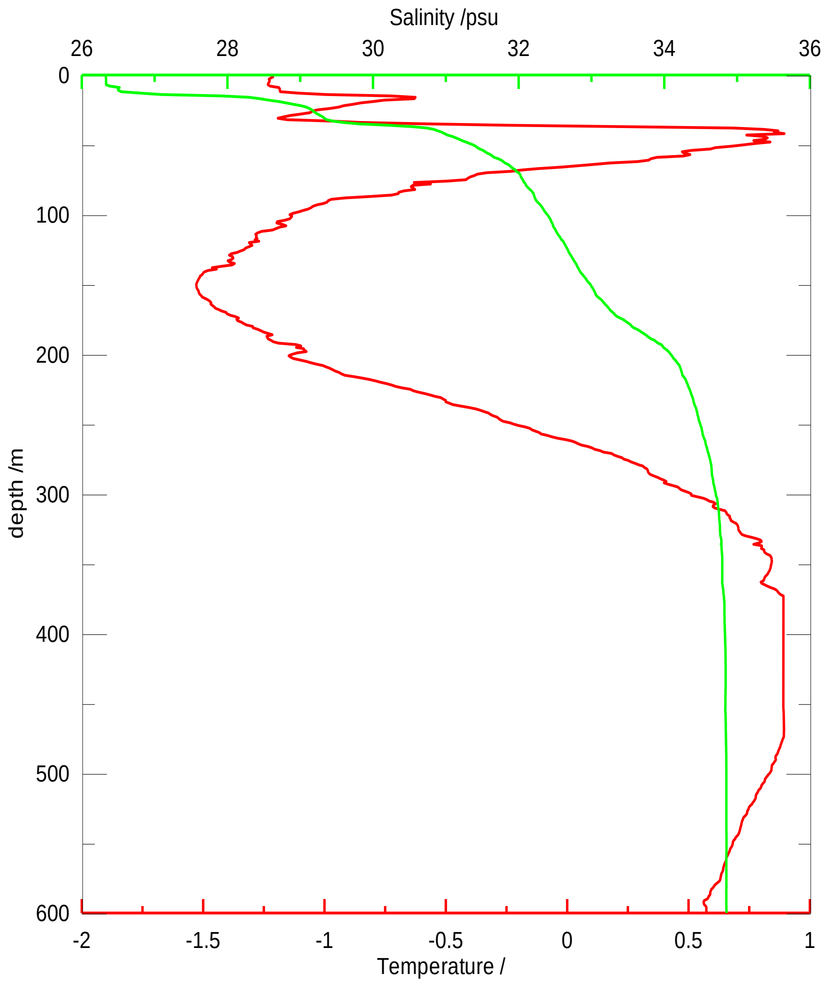
Double diffusion appeared in the main halocline





Courtesy J. Zhao

4. Vertical temperature and salinity structure in Canada Basin (Near surface temperature maximum)



Maykut and McPhee (1995)

McPhee et al. (1998)

Guay and Falkner (1997)

Shimada et al. (2001)

Kadko (2000).

Zhao et al. (2003)

Wang and Zhao (2004)

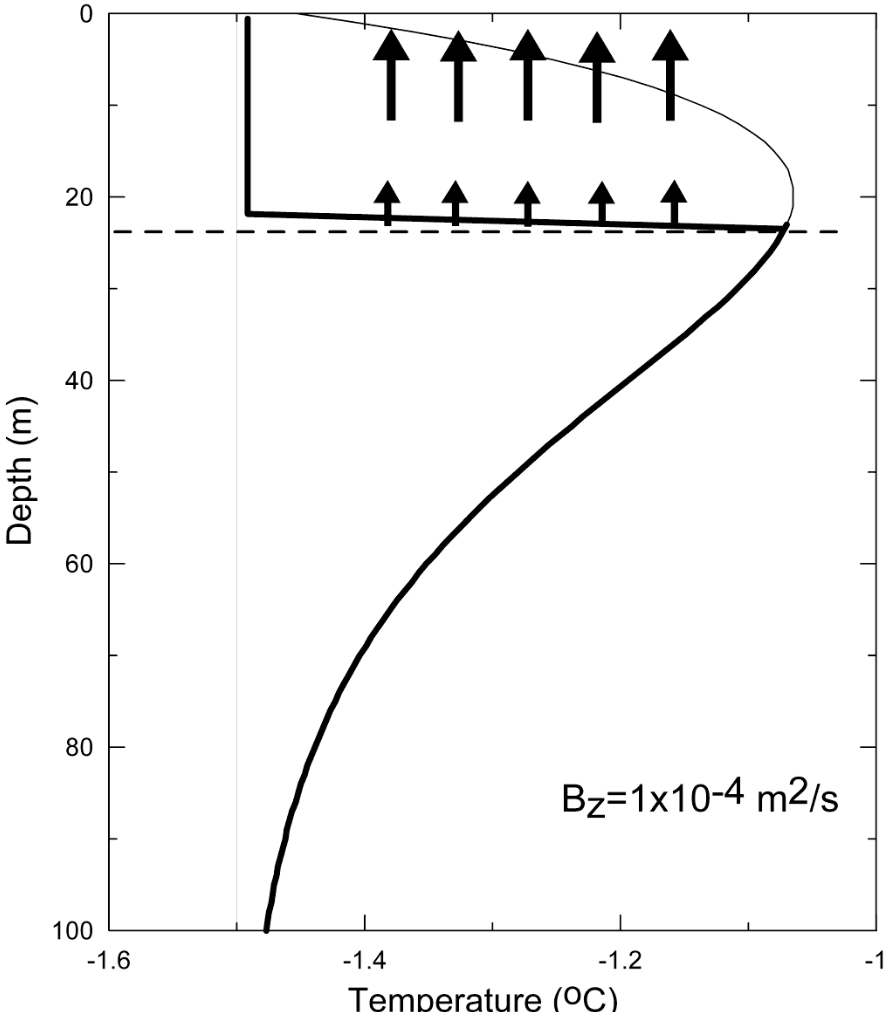
Jackson et al. (2010)

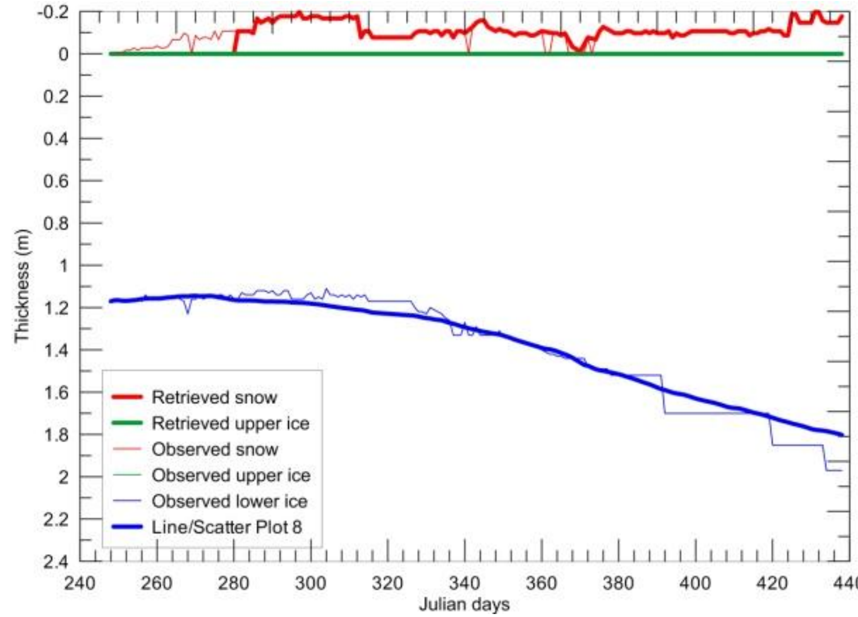
Chen and Zhao (2010)

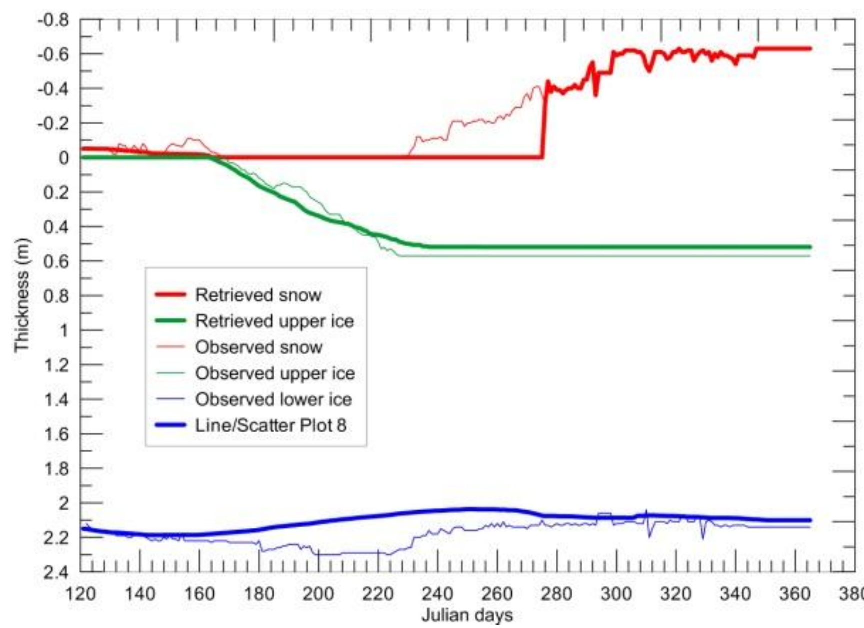
Zhao et al. (2011)

Courtesy J. Zhao

Heat storage?
Heat remain?

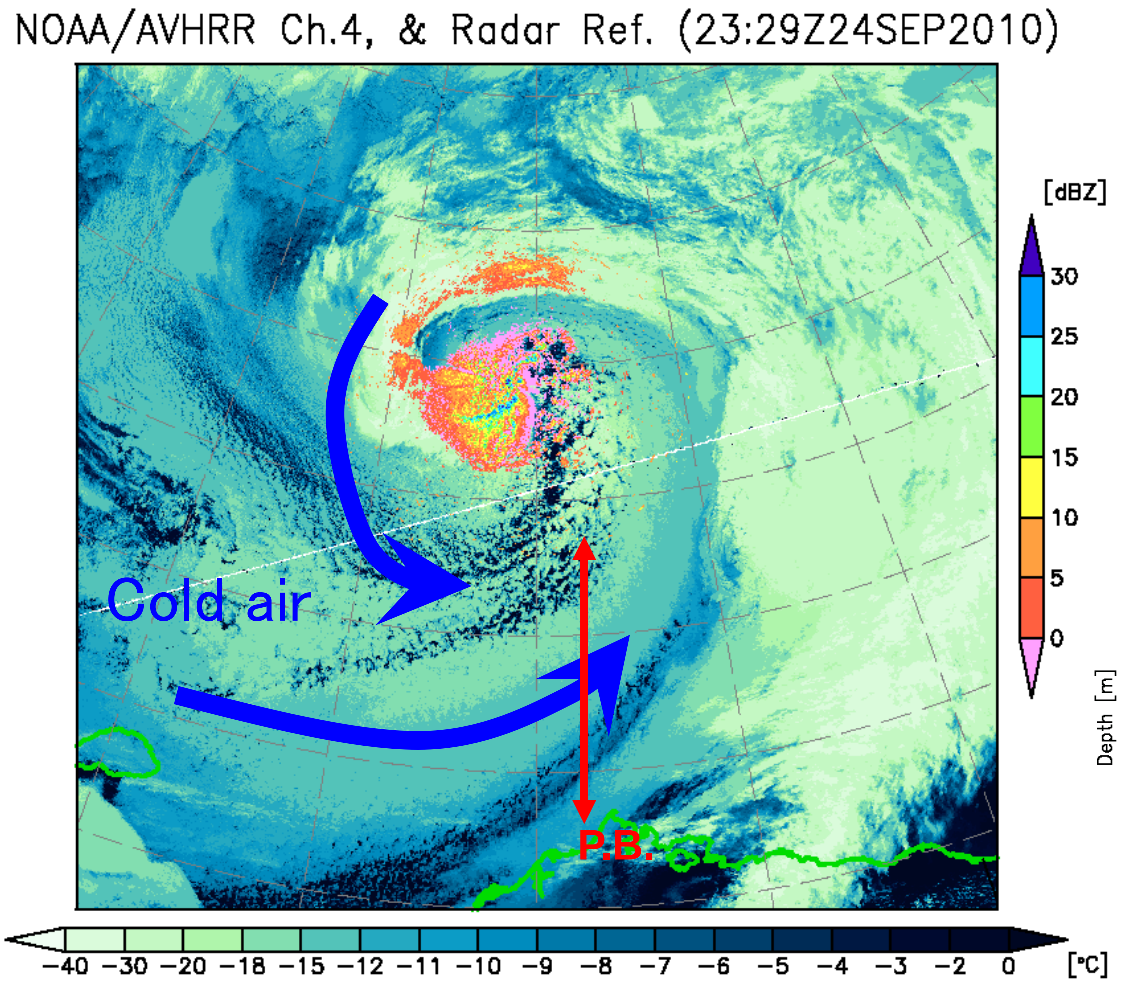


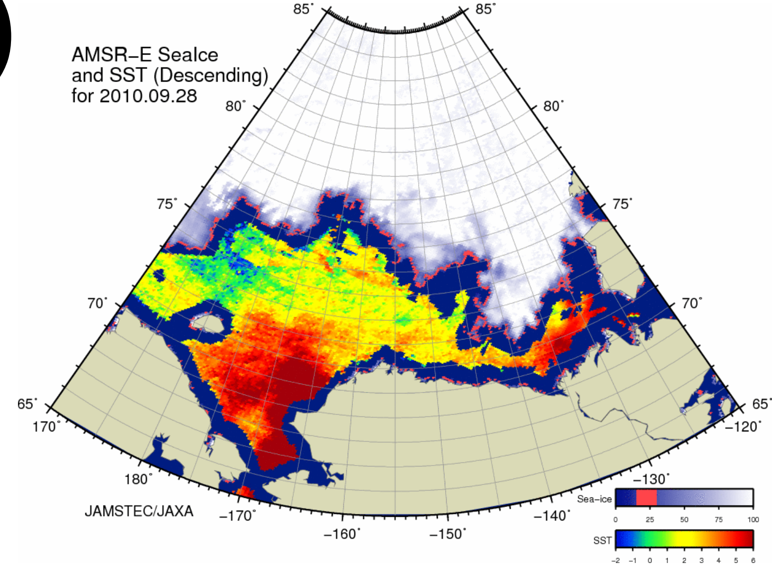


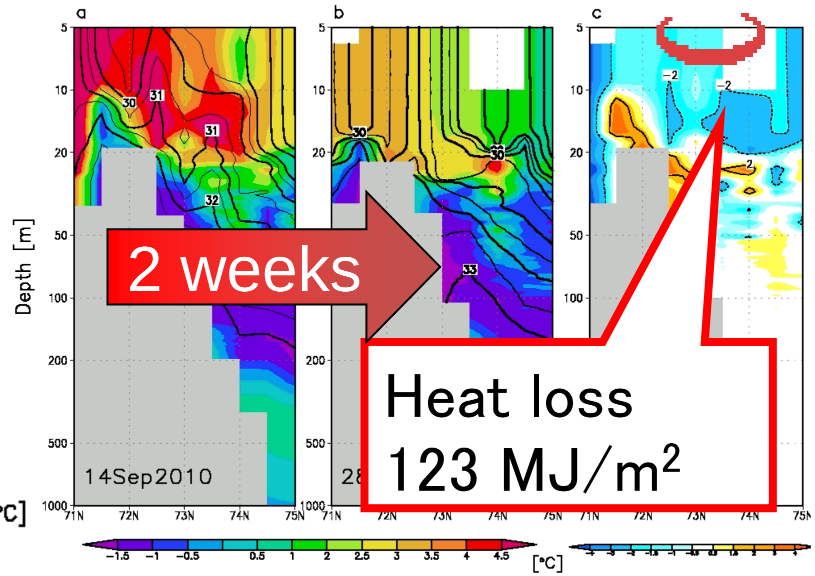


Courtesy J. Zhao

Arctic cyclone (2010 fall)







Inoue and Hori (2011 GRL)

How are MOSAiC science questions to be addressed?

a) Deploy manned, international drifting observatory in the central Arctic for at least one full annual cycle, preferably longer

- base for sophisticated local measurements of atmosphere, cryosphere, ocean, and biosphere (e.g., radars, lidars, towers, radiometers, soundings, ice/snow surveys, CTDs, …)
- center of distributed array of spatial measurements using automated observing stations (automated towers, ice buoys, floats), unmanned aerial and underwater vehicles (UAVs, AUVs, gliders), remotely operated vehicles (ROVs), and episodic aircraft campaigns (e.g., AWI Polar-5)
- during episodic intensive observing periods, coordinate measurements with larger array of ships (e.g., Russian drifting station; Japanese R/V Mirai; German R/V Polarstern; Swedish R/V Oden; Chinese; others?) and research aircraft (German Polar-5, U.S. aircraft?, British aircraft?)

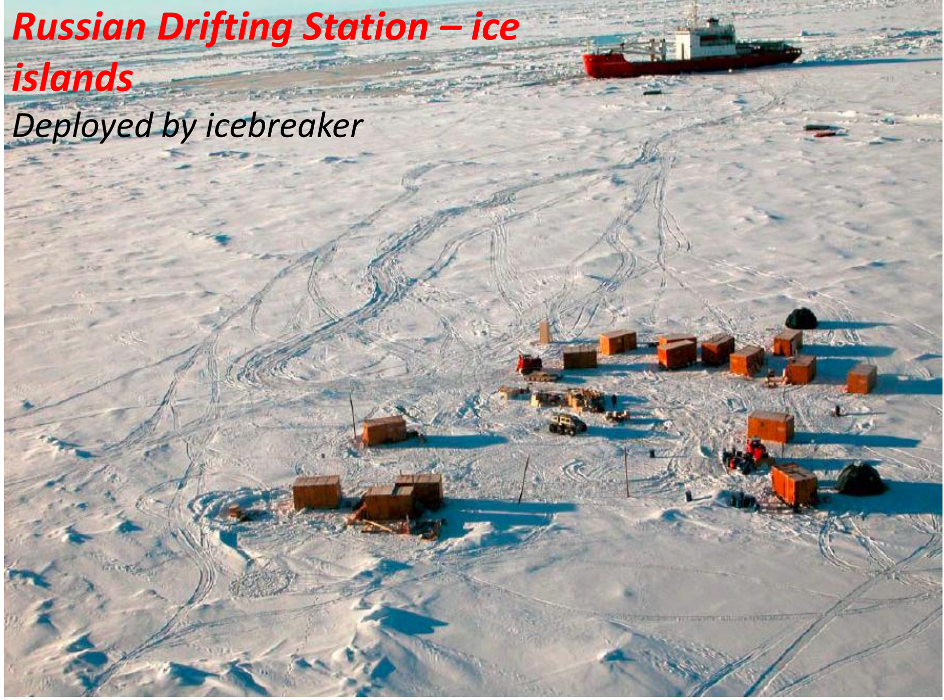
b) **Time deployment and design innovative logistical techniques to allow measurements of autumn freeze-up, heat loss from upper ocean to atmosphere, and formation of first-year ice**

c) **Engage modeling community to define/refine needed observations and coordinate planning [e.g., Year of Polar Prediction (YOPP) – 2017]**

Previous experience

- **Soviet/Russian drifting stations:**

Annual deployments provide unique long-term time series of basic meteorological and some cryospheric parameters. Lack important instruments/measurements for understanding processes related to clouds, aerosols, boundary layer, snow, sea-ice, ocean, biology interactions. Parameters increased for recent deployments.



Russian Drifting Station – ice islands

Deployed by icebreaker

- **SHEBA:**

Sampled full annual cycle with some sophisticated instrumentation, including cloud measurements and solid ice, mass, & energy budgets. Some oceanographic measurements also made. Failed to characterize aerosols, trace gases, boundary layer structure, cloud dynamics, and broader dynamical context for local measurements.

Surface Heat Budget of the Arctic Ocean (SHEBA; 10/1997-10/1998)

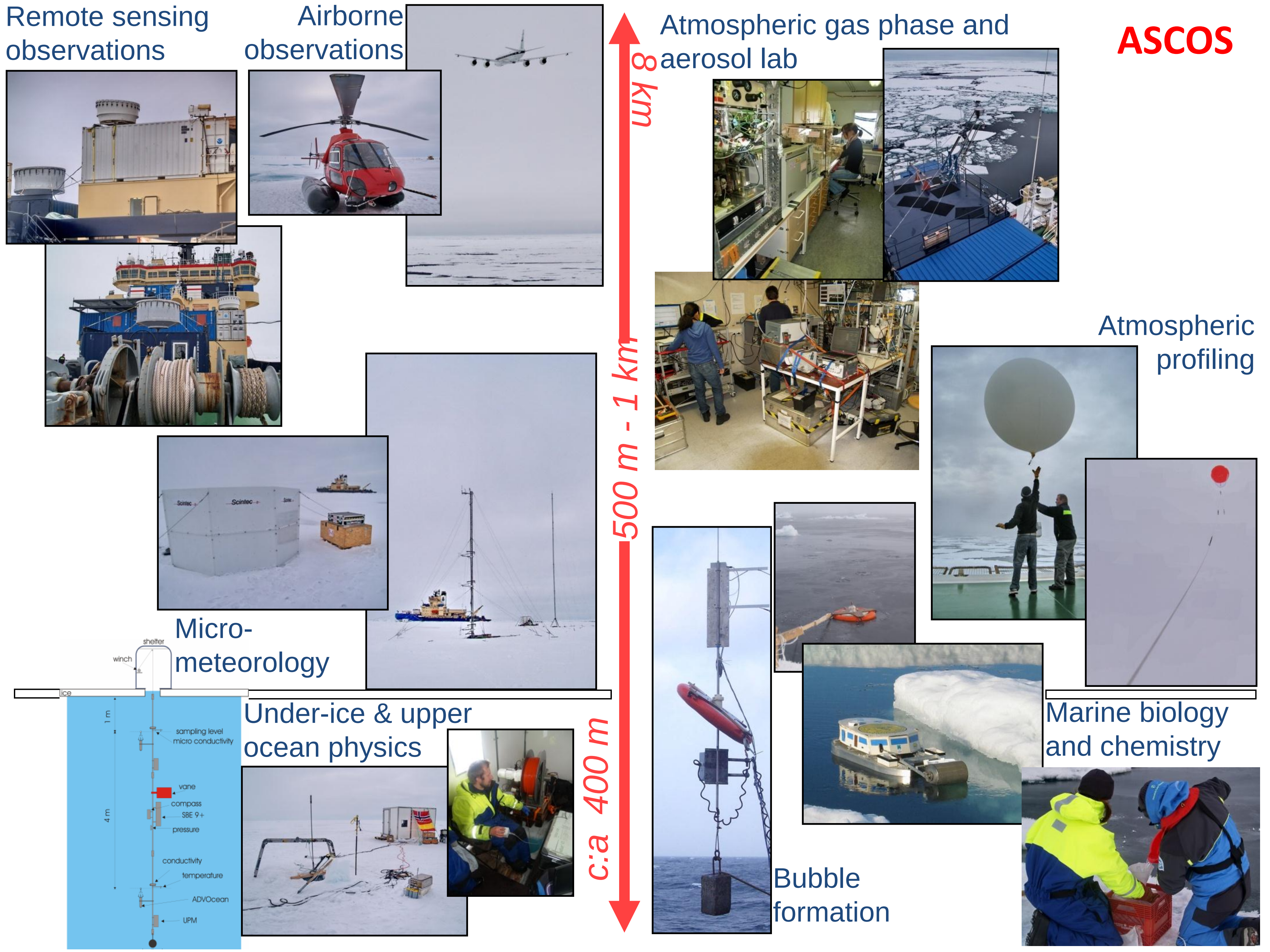
Continuous icebreaker facility and on-ice deployment

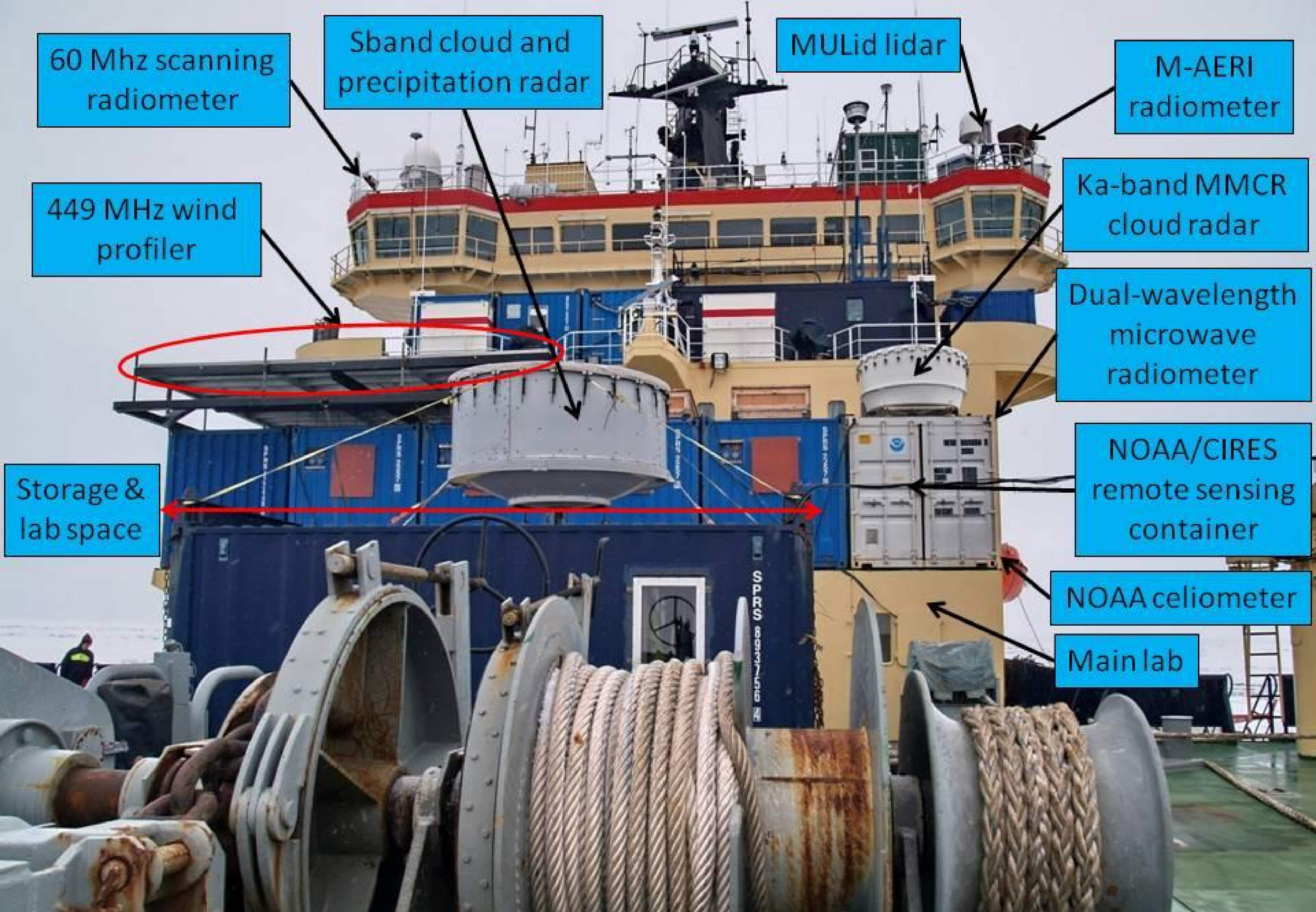
- **Short-term deployments (LEADEX, AOE-2001, ASCOS, …):**

e.g., ASCOS: Sophisticated gas, aerosol, cloud, boundary layer, and energy budget observations. Lacked sufficient observations of the ice mass budget and ocean energy flux contributions. Lasted for only 3-5 weeks.

Previous experience – why insufficient?

- **Not comprehensive enough:** Must observe many important systems together; ultimately process interactions and feedbacks are important (and more difficult to understand!)
- **Not long enough:** Important processes often vary with season AND the system has memory that impacts future responses. Short campaigns will miss many of the important contextual details
- **Not representative:** Observations at a single location or time of year may not characterize other times or locations. Spatial and temporal variability are likely important. Some processes likely to have different significance in the "New Arctic"


ASCOS
Remote sensing observations
Airborne observations
Atmospheric gas phase and aerosol lab
8 km
500 m - 1 km
c:a 400 m
Atmospheric profiling
Micro-meteorology
Scintec
shelter
winch
ice
1 m
sampling level
micro conductivity
vane
compass
SBE 9+
pressure
4 m
conductivity
temperature
ADVOcean
UPM
Under-ice & upper ocean physics
Bubble formation
Marine biology and chemistry



Onboard Atmospheric Remote Sensing - R/V Oden, ASCOS (Aug. 2008)

Where ?

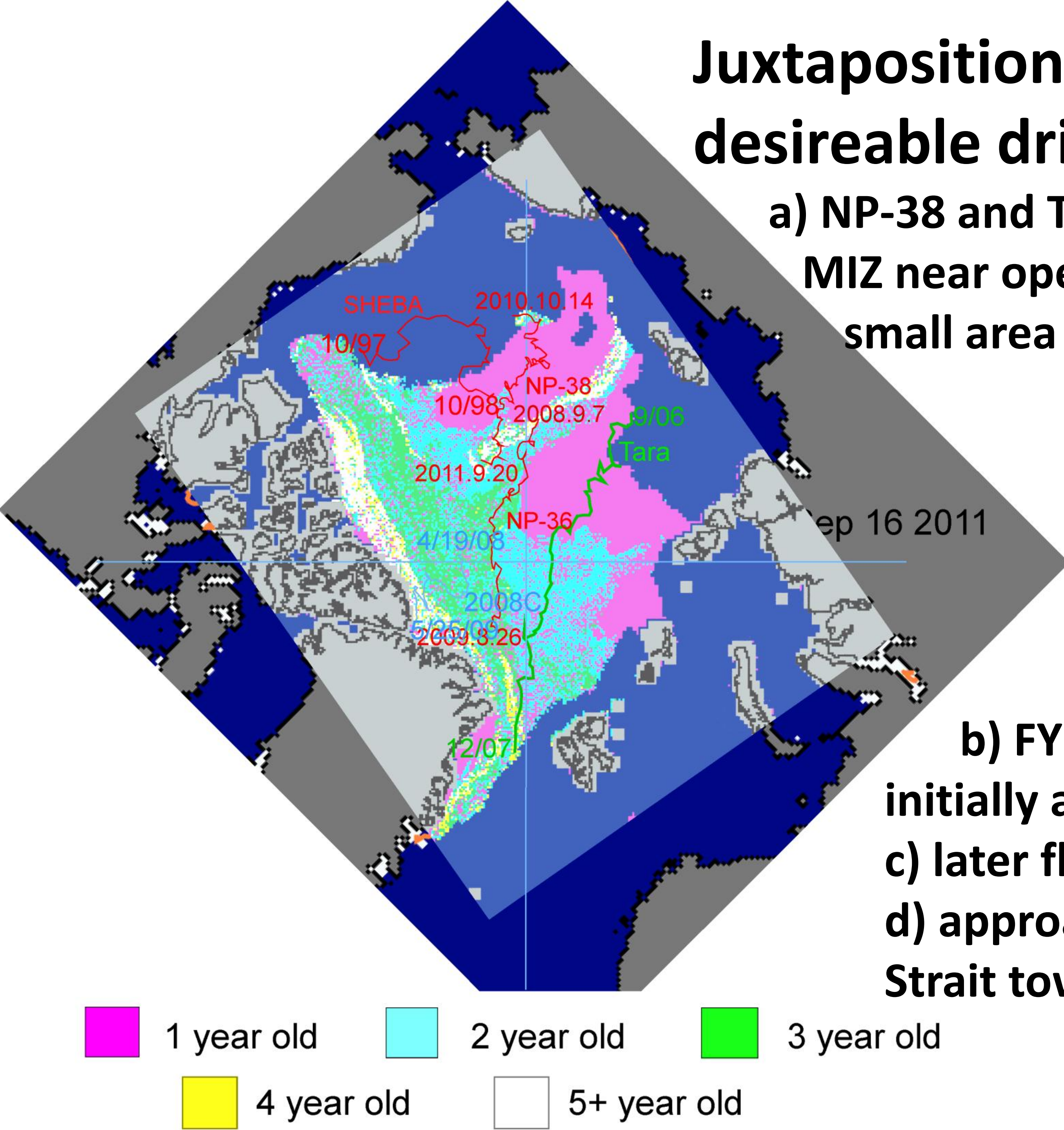
Determining Factors:

1) Scientific issues (understanding the “new”, predominantly FYI, Arctic)!
2) Length and mode: Needs to be drifting for at least a year
3) Ice quality: Ice needs to be strong enough to hold heavy equipment safely, not deform to easily and still be representative for the science to be done – access to both FYI and MYI
4) Maintenance, resupply and some of the science: Needs to be within flight range (for some critical) portions of the deployment
5) Satellite cover: i.e. A-Train < 82°N

Alternatives discussed:

1) **Trans-Arctic drift**
2) Beaufort Sea
3) North of Canadian archipelago

Juxtaposition of ice age with desireable drift tracks



a) NP-38 and Tara tracks start in MIZ near open water (NP-38 on small area of MYI; Tara on FYI)

b) FYI and open water initially accessible;
c) later floe becomes MYI
d) approaches MIZ in Fram Strait towards drift end

Anticipated Logistical Issues

1) Set-up in MIZ in the fall – require floating platforms (icebreaker, barge?)
2) Start-location close to territorial waters – prior approval & collaboration
3) Resupply, crew, & science staff exchange; emergency evacs

   - what land departure points would be available? Russia, U. S., Canada, Greenland, Norway

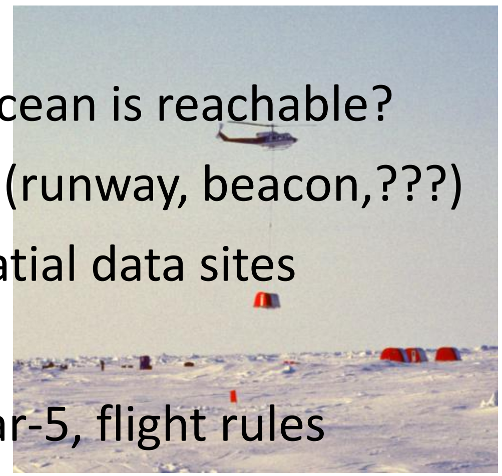
   - how far out over the Arctic Ocean is reachable?

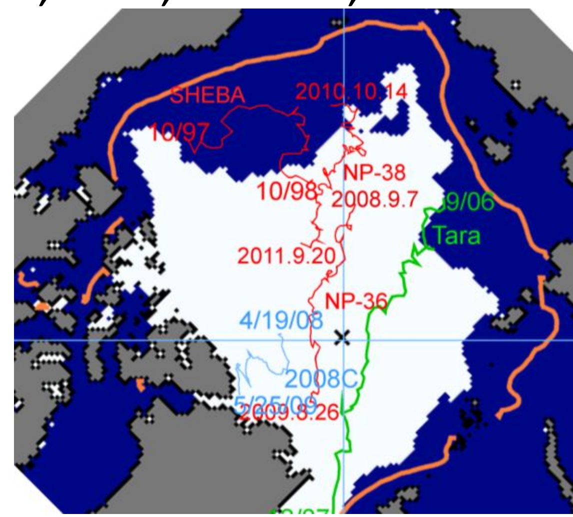
   - infrastructure at observatory (runway, beacon,???)

4) Deployment/maintenance of spatial data sites

   - ice, MIZ, water locations

   - need for helicopter, UAV, Polar-5, flight rules





5) array of R/V for intensive observational periods
   – international coordination?

6) on-ice safety: polar bears, “ice tectonics”

7) Logistics provider – individual preexisting group
   or international team?

MOSAiC Development Plans

Key milestones :

1) the Boulder Workshop - June 27-30, 2012 -coordinate MOSAiC science research topics, with a science plan ideas/draft as an output.

2) Coordinate AODS (Arctic Ocean Drift Study) with MOSAiC – Workshop, Winnipeg, 9/16-17/2012

3) the establishment of a Scientific Steering Group for MOSAiC

4) develop MOSAiC Science Plan - autumn, 2012

5) Winter 2012-2013: MOSAiC SSG meeting to finalize science plan and begin draft of MOSAiC Implementation Plan. (in Finland?)

6) February-March 2013: Summarize Science and Implementation Plans for Arctic Observing Summit

7) MOSAiC Implementation Plan - draft by Feb. 1; final version by June 30, 2013

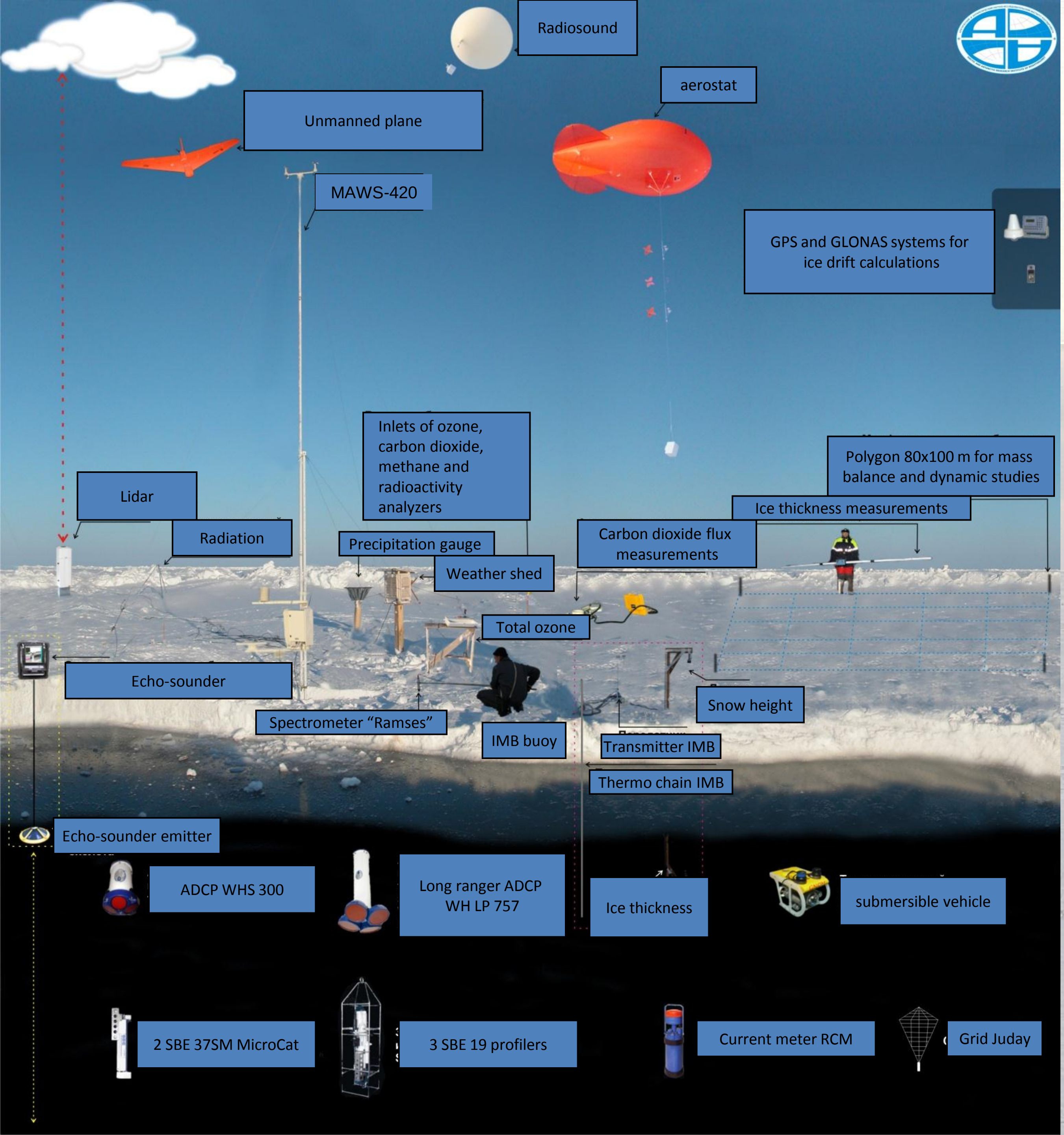
8) Open MOSAiC Science and Implementation Workshop – Spring /Summer 2013?

9) Summer 2013: Submit MOSAiC Science and Implementation Plans to appropriate funding agencies and international organizations with interest. Identify and propose/begin necessary preparatory instrument development/modeling .

10) Further planning and logistics meetings 2014-2015; proposal submissions late 2014 or 2015.

11) Begin deployment, October 2016? October 2017?


End
Fin
Ende
Slut



Overview of observations, organized at drifting station “North Pole – 39” and future “North Pole” stations

Courtesy A. Makshtas

Scope of Future Work at Russian North Pole Stations

1. Study of polar cloudiness

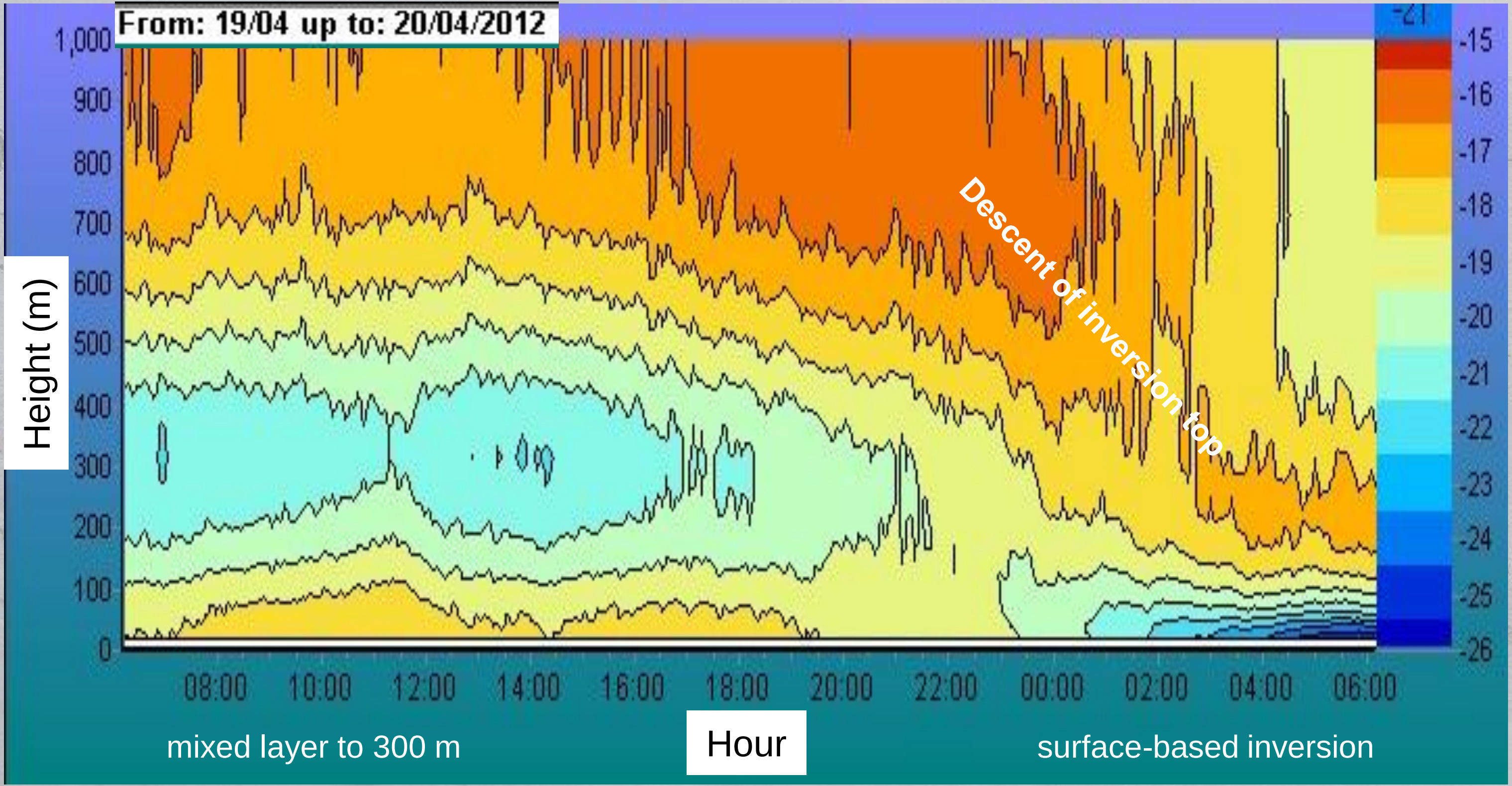
2. Detailed investigations of atmospheric surface and boundary layers
   - studies of stable boundary layers
   - improve/validate parameterizations of BL for forcing sea-ice models
   - improve/validate mesoscale models, esp. surface characteristics

3. Investigate spatial characteristics and radiative properties of sea ice cover

4. Comprehensive study of atmospheric ozone (from surface to stratosphere)

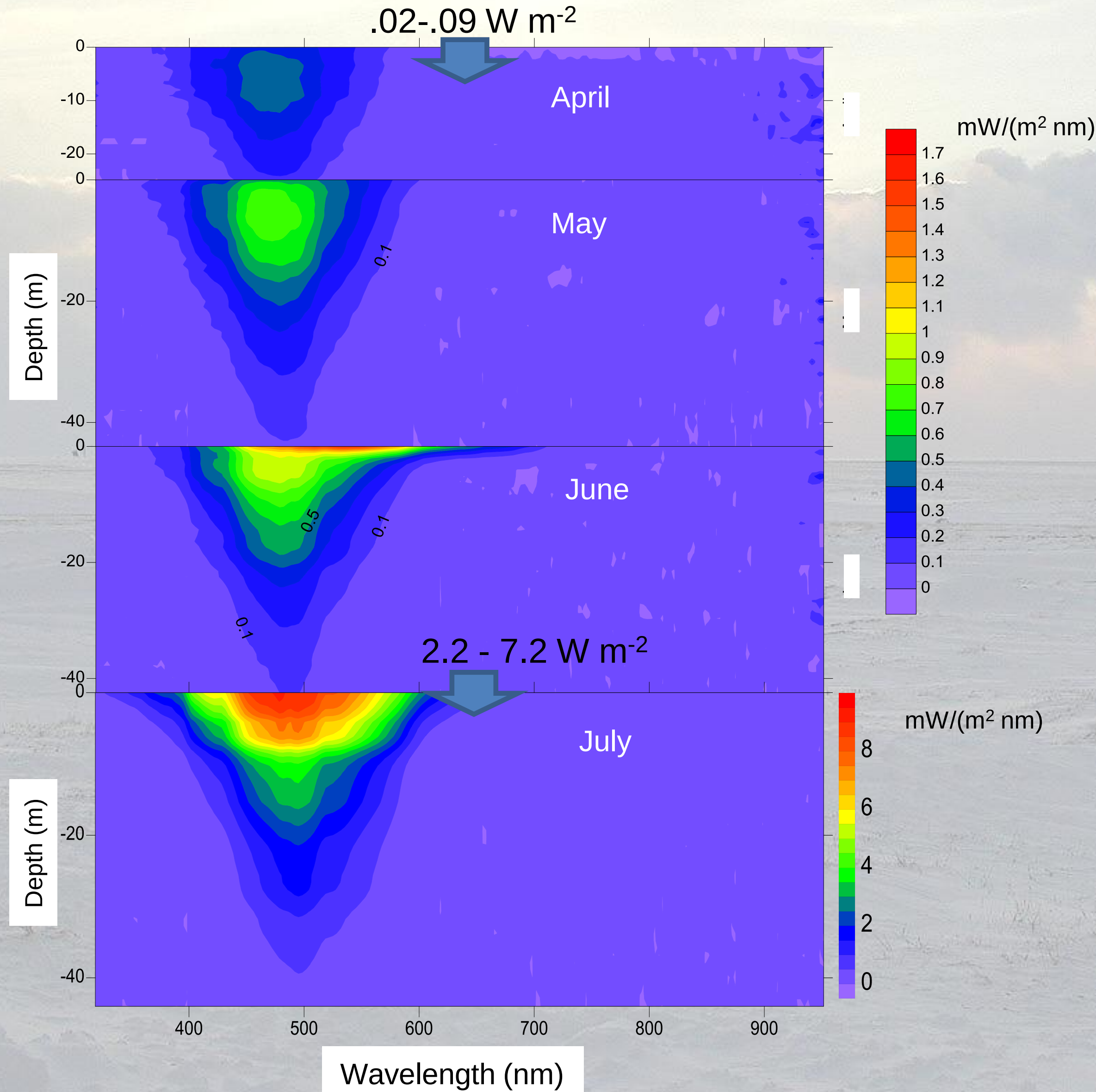
5. Study of greenhouse gas concentrations and ice/ocean fluxes

Detailed atmospheric boundary-layer processes: New approach with microwave 56.7 GHz temperature profiler at "North Pole 39"



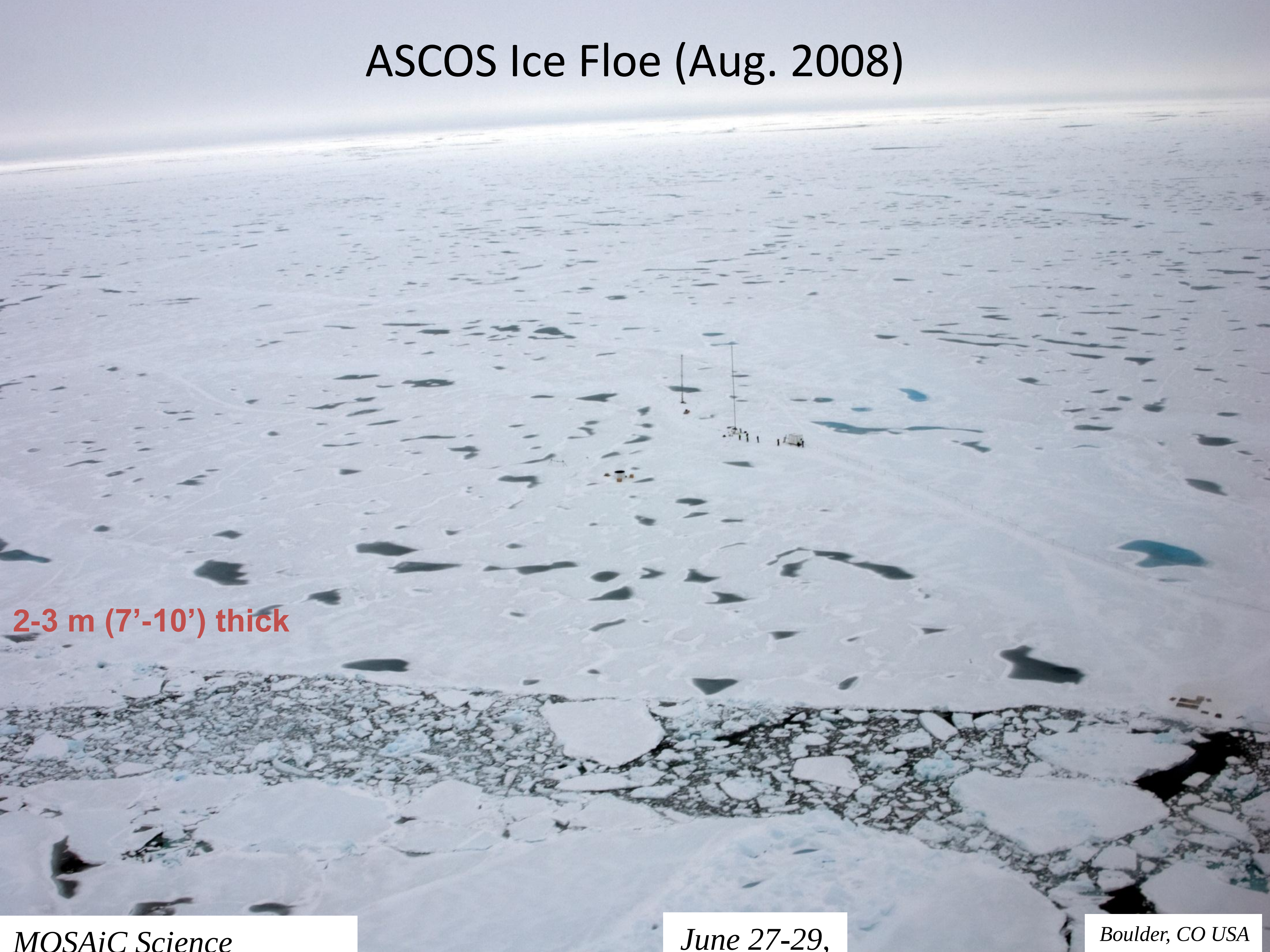
Courtesy
A. Makshtas

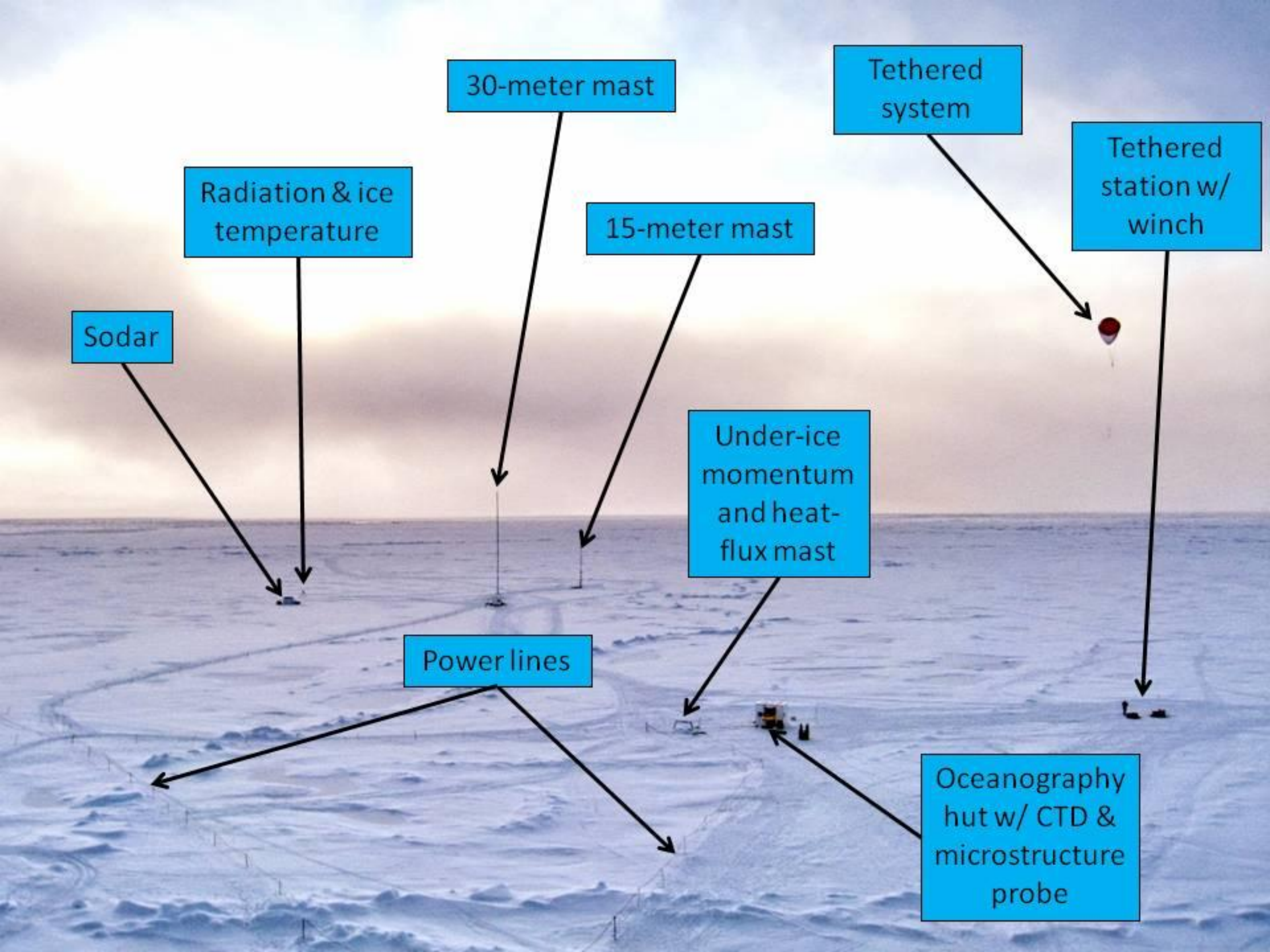
Solar energy penetration of sea-ice and redistribution in upper ocean as function of wavelength and month

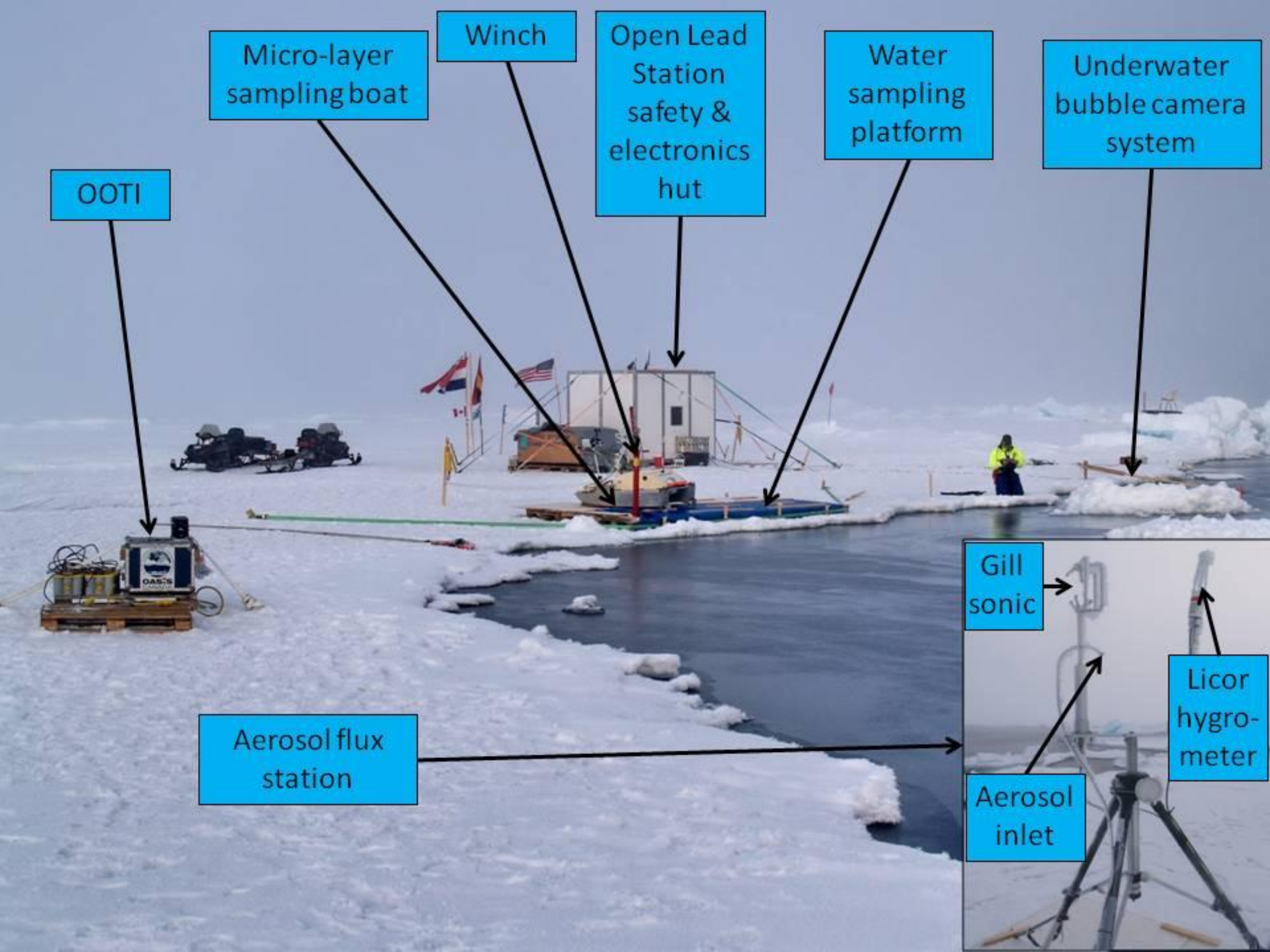


Courtesy
A. Makshtas

ASCOS Ice Floe (Aug. 2008)



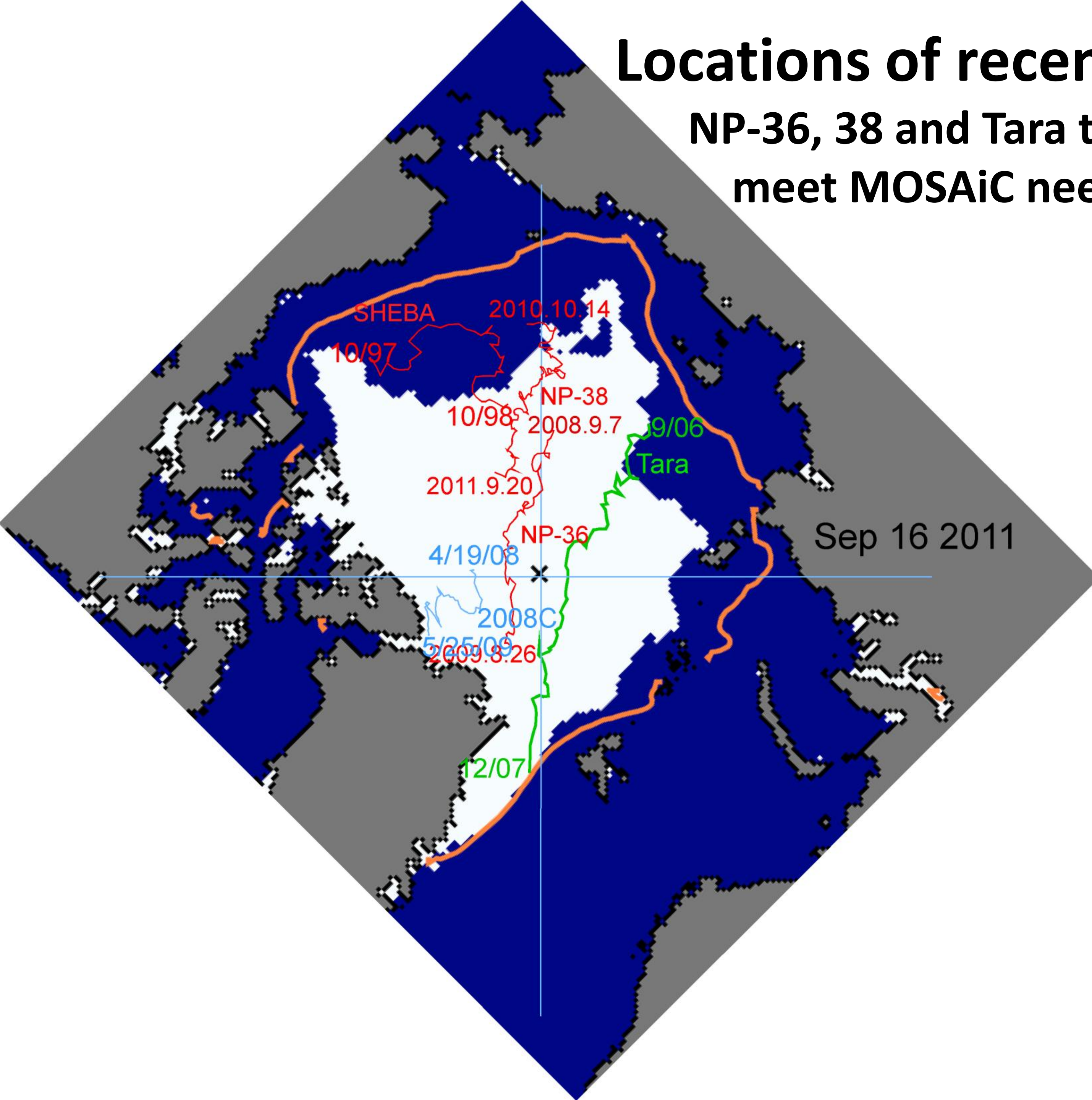

30-meter mast
Tethered system
Tethered station w/ winch
Radiation & ice temperature
15-meter mast
Sodar
Under-ice momentum and heat-flux mast
Power lines
Oceanography hut w/ CTD & microstructure probe



Micro-layer sampling boat
Winch
Open Lead Station safety & electronics hut
Water sampling platform
Underwater bubble camera system
OOTI
OASIS CANADA
Gill sonic
Licor hygro-meter
Aerosol inlet
Aerosol flux station

Locations of recent drifts

NP-36, 38 and Tara tracks would meet MOSAiC needs



Locations of recent drifts

Sep. 2012 sea ice extent

-requires deployment further north than 2011 conditions