Summary of the Science Planning Workshop for the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC)
June 27-29, 2012
Boulder, CO USA
Oct 5, 2012

1. Workshop Overview

A 2.5-day science planning workshop for a proposed project called the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) was held in Boulder, Colorado, June 27-29, 2012. The MOSAiC concept is to establish an international, multi-year, manned, drifting observatory in the central Arctic sea-ice pack to obtain comprehensive observations of interdependent atmosphere, sea-ice, and ocean processes that are important to the Arctic climate system. The drifting observatory will act as a centerpiece for a mosaic of coordinated and distributed observational activities throughout the Arctic Basin. Together these observational activities will comprise a testbed for process, regional, and global model evaluation and development. The workshop objectives were to clearly delineate the high-level science drivers and questions concerning the central Arctic climate that can and should be addressed using a drifting observatory and related activities. Emphasis will be on defining fundamental questions that capture the important process-level linkages between the Arctic sea-ice, ocean, and atmosphere. An additional objective is to develop pathways towards broader coordination of these activities within the Arctic science community. Workshop results will contribute towards the development of a MOSAiC Science Plan. The MOSAiC activity is being organized under the International Arctic Science Committee (IASC).

The workshop was supported by IASC, the Cooperative Institute for Environmental Sciences (CIRES) at the University of Colorado, and the Environmental System Research Laboratory of the U.S. National Oceanographic and Atmospheric Administration (NOAA). Key Arctic issues for the atmosphere, cryosphere, ocean, and biosphere were discussed, with an emphasis on those involving interdisciplinary interactions. Among the 41 participants, the atmosphere and cryosphere were represented approximately equally, while slightly fewer oceanographers and biogeochemists attended.

Dr. Matthew Shupe welcomed the participants, introduced the MOSAiC concept, and described the structure of the workshop. The participants were charged with a) establishing broad, overarching science themes that can be addressed from a drifting observatory; b) indentifying important disciplinary elements; c) making interdisciplinary linkages; d) prioritizing scientific themes; and e) networking for potential MOSAiC participants and leaders. A science-driver presentation of the broad, interdisciplinary scientific context and issues for MOSAiC and the workshop was given by Dr. Ola Persson.

The workshop then began with two keynote overview presentations of science issues for each of the disciplines except biology, for which one keynote presentation was given by three scientists. The atmospheric issues were presented by Drs. John Walsh and Michael Tjernström; the cryospheric issues by Drs. Donald Perovich and Sebastian Gerland; the oceanographic issues by Drs. Craig Lee and Jinping Zhao; and the biological issues by Drs. Carin Ashjian and Brice Loose and Mr. Jeff Bowman. The formal presentation portion of the workshop concluded with two shorter presentations of the science issues driving the ongoing Russian drifting station project and the observational priorities of the French-led Ice-Atmosphere-Arctic Ocean

Observing System (IAOOS) project. Both of these projects plan to collaborate with MOSAiC. A key component of the workshop was the subsequent break-out sessions where the main science issues presented by the keynote speakers were discussed and refined in smaller groups. The results of these break-out groups were then presented to the workshop plenary, with further discussion and refinement. This plenary discussion resulted in a general consensus of the broad science objectives of the MOSAiC project. Some details of the science objectives were discussed by the keynote speakers and in the breakout sessions, as were some of the logistical requirements and ideas. These are summarized in sections 2, 3 and 4 below. These details were not the primary objective of this workshop, and will need future refinement before inclusion in a MOSAiC science plan. The broad science objectives of MOSAiC, described in section 5, were the key objective and outcome of this workshop. The Appendices give the workshop participants, the agenda, and a group photograph.

Despite the oppressive heat and the threatening wildfires in the Boulder area, the workshop participants were successful in achieving most of the workshop objectives. A workshop dinner at the Gold Hill Inn in the local mountains spurred additional conversation and allowed important networking between individuals in different disciplines who may otherwise not have the opportunity to meet.

2. Science Issues Presented by Keynote Speakers

2.1 Atmospheric Overview - John Walsh

For his atmospheric science discipline overview with a large-scale perspective, Dr. Walsh identified six main science issues for the Arctic. These are:

1) What is the Arctic Ocean's role as a source/sink of greenhouse gases, aerosol particles, and other chemical species? Focus on DMS and methane. Are increases in mid-latitudes being augmented or offset by exchanges at the surface of the Arctic Ocean? Is reduced sea ice cover (area and thickness) altering the Arctic Ocean's role in the global carbon and sulfur budgets? What is the role of dimethyl sulfide for cloudiness?

2) How much has sea ice loss contributed to polar amplification of the recent warming? a) Increased solar absorption and increased sensible heat release from ocean. b) changes in atmospheric humidity & cloudiness due to enhanced evaporation; c) increased influxes of atmospheric heat and moisture from lower latitudes; d) increased inflows of oceanic heat from the North Atlantic and North Pacific.

3) Can a station in the Arctic Ocean provide information relevant to springtime ozone depletion? Measure spectral distribution of downwelling radiation, upper atmosphere profiles, others?

4) Can field measurements elucidate linkages between reduced autumn ice coverage and mid-latitude wintertime atmospheric circulation anomalies? Enhanced summer heating of upper ocean substantial; subsequent release of heat to atmosphere not fully understood (i.e., temporal & vertical distributions), but warming of lower troposphere strongly indicated; mechanisms linking heating of Arctic troposphere to midlatitude weather/climate anomalies need elucidation.

5) How much is the atmosphere contributing to the extreme ice retreat of recent summers? Quantitative diagnosis requires estimates of downwelling SW and LW radiation anomalies

(clouds, water vapor), wind forcing/ice advection, Atlantic and Pacific water inflow, and effects of changes in surface albedo.

6) How do storm events interact with the ice cover and upper ocean? What are the effects of storms on the ice/ocean state? What are the effects of the lower boundary changes on storms? Atmospheric soundings from the vicinity of polar lows have been found to enhance regional model simulations of system. Surface fluxes should be important to the development of the system. Observational guidance needed for choosing the most appropriate boundary layer parameterizations.

2.2 Atmospheric Overview - Michael Tjernström

Dr. Tjernström described the atmospheric boundary layer over the Arctic Ocean, emphasizing its generally cloudy nature. He pointed out that the boundary layer is a vertically continuous system with the following processes:

1) heat flux from ocean through the ice & vice versa;

2) turbulent fluxes through the atmospheric boundary layer;

3) boundary layer clouds and interactions with aerosols; and

4) radiation interactions with clouds and surface;

that all play key roles to impact the Arctic and global climate system.

After describing the structure of the Arctic atmospheric boundary layer as revealed by the few available observations, he went on to show how these processes and structures are often not captured by the regional and global climate models, thereby illustrating aspects that are poorly understood and modeled. The outstanding Arctic atmospheric science issues implied by his presentation include:

1) the Arctic boundary layer is defined in context of the vertical thermal, humidity, and cloud structure of the lower troposphere, with temporal variability. Measurements of this atmospheric structure and associated processes are very limited and generally incomplete, especially when it comes to non-summer seasons.

2) clouds are poorly represented in models, including regional and global climate models. Aspects that are poorly reproduced and whose processes we still don't understand include cloud phase determination; cloud interactions with aerosols; microphysical, dynamical, and thermodynamic interactions; radiative responses to microphysical variations.

3) processes linking clouds, cloud microphysics, BL structure, radiative fluxes, BL fluxes, BL turbulence, and precipitation are complex and are current topics of research. Potentially important processes that are poorly understood, are currently under study, and could benefit from year-round measurements as proposed for MOSAiC include: a) formation and impacts of cloud-top moisture inversions; b) coupling/decoupling of vertical eddies formed by cloud-top cooling with surface-based turbulence; c) role and source(s) of aerosols as CCN and IN for producing clouds and modulating cloud phase and surface cloud forcing in the low-concentration Arctic environment; d) long-range transport vs local sources of aerosols.

4) documenting and understanding the heterogeneity of near-surface processes, the atmospheric impact of this heterogeneity, and the likely reduction of heterogeneity with height in the atmosphere

2.3 Sea ice overview - Don Perovich

Dr. Perovich began by noting that all previous long term drift stations (Nansen, IGY, AIDJEX, SHEBA, DAMOCLES, NP Stations) had many things in common, including that all were on multi-year ice (MYI). However, from the late 1980's to late 2000's, the ice cover has shifted to be predominantly first-year ice (FYI; or seasonal ice). FYI is not just thinner, but different in many ways. Our knowledge of FYI is through "snapshots". This includes short-term measurements of initial growth, salinity, temperature, structure, mechanical properties, and electromagnetic properties. However, we need "long movies" as illustrated by questions such as "how do [physical] properties evolve?", "how is dynamics influenced?", "how is sunlight partitioned?", "how does it end?", "What changes in parameterizations?", and "What is the impact on the system?" He then identified some key questions to understand this New Arctic Ocean:

<u>First year ice</u>

- What is the evolution of the physical properties of first year ice?
    - Structural, morphological, optical, mechanical
- What does it take for first year ice to survive?
- What is the final decay phase of sea ice?
- What do we need to change [in our understanding and in models] for first year ice?:
    - Ice dynamics – ridging, lead formation, ice motion
    - Feedbacks – ice albedo, cloud radiation, ice growth
    - Solar heat in the ice and ocean
    - Biogeochemistry – gas exchange, primary productivity
- What new parameterizations are needed for first year ice?
- How does first year ice behave in the system?

<u>General</u>

- What about snow?
- What are the temporal and spatial variabilities?
- Is the current sea ice state and trajectory irreversible?
- What are relative contributions to ice loss?
- What's happening in the Chukchi and Beaufort Seas?
- What parameterizations need to be improved?

The key sea-ice observations needed to address these questions include

- Dynamics
- Thermodynamics
- Heterogeneity
- Evolution
- Balances
    - Heat, mass, water
    - Sunlight
- Snow

Dr. Perovich then identified some challenges that will be encountered when making the observations needed to answer the above questions. These challenges include

1) the observations need to be made on a large range of scales

small – ice core analysis plus micro tomography; information on ice structure, salinity, temperature, brine volume, porosity, permeability, connectivity

local - mix of old & new techniques; information on snow depth, snow properties, ice topography, thickness, mass balance, water budget, ridges, melt ponds, solar partitioning, heterogeneity

large – satellites, aircraft, autonomous vehicles, integrated autonomous sites (mini MOSAiCs): atmosphere, ice, ocean (air temp, press, humidity, wind velocity, radiation, mass balance, web cams, ocean fluxes, ocean profiles of temperature, salinity integrate ocean, ice, atmosphere, biogeochemsitry)

Use a scaled networked approach: to span scales from local to aggregate to large scales, integrate techniques, system elements using nested measurements

2) The observational and modeling activities must be integrated, and this collaborative planning must be done from the beginning

- Integrate observers and modelers
- Span the scales
- Evaluate feedbacks
- Assimilate datasets
- Synthesize results
- Look for synergy

3) A logistical challenge will be to determine "where to park" (where to start the drifting observatory). What is a good location on both large and local scales?

Finally, Dr. Perovich summarized the needed activities to make MOSAiC a reality ("The Road Ahead"). These include

- Collaboration during planning
- Incorporate new technologies
- Combine:
    - Dynamics
    - Thermodynamics
- Coordinate:
    - Atmosphere
    - Ice
    - Ocean
    - Biogeochemistry
- Integrate:
    - In situ observations
    - Autonomous observations
    - Remote sensing observations
    - Models
- Focus on the interactions of the system

2.4 Sea ice overview - Sebastian Gerland

Dr. Gerland described the process understanding and measurements needed to improve the understanding of mass and energy budgets of sea ice:

a) Shortwave and longwave energy absorption at the surface, along with albedo and relevant snow & ice data, and penetration of shortwave radiation to the water

b) Turbulent fluxes of latent and sensible heat at the surface, turbulent fluxes of heat and salt at the underside of the ice

c) Pull all together to understand/parameterize the growth and melt of ice. The "complete" picture

The sea-ice specific processes to be studied include

a) melt pond processes

b) superimposed ice

c) refreezing of leads

d) biogeochemistry

e) spectral reflectance dependence on ice thickness, snow thickness, snow distribution

f) under-ice radiation, spectral snow and ice transmissivity, spatial variation

g) surface radiation

He also discussed the likely applications and use of the MOSAiC results for climate research. These include model improvements (also supporting operational services), remote sensing (calibration, validation), method and instrument development including low impact applications, ecosystem understanding, education, engineering, and shipping.

Dr. Gerland spent significant amount of time describing the methodology and instrumentation that could be used during the MOSAiC drift for sea-ice measurements, showing numerous examples. A significant emphasis was placed on newer, high-tech methods, and included:

a) electromagnetics for ice thickness (snow+ice), snow measured separately with pole

b) airborne methods – EM Bird (ice thickness), laser altimetry, airborne photography

c) AUVs, UAVs, ROVs – mapping of properties at local to regional scales

d) Fixed installations

e) autonomous measurements of spectral radiation, albedo, transmission, real-time data transfer

f) Ice tethered platforms, SAMS IMB, moored upward looking sonar, Metocean IMB, O-Buoy

g) surface and under-ice heat, CO_2, momentum, salt fluxes - eddy correlation analysis with measurements of currents, temperature, salinity, ice drift, under-ice current profiles, vertical CTD profiles, temp sensor string – water column stability & forcing

h) snow pit studies, sea-ice core analyses

i) remote sensing for regional context (calibration and validation) – SAR, Radarsat-2, ESA CryoSat-2 – yields ice thickness

Dr. Gerland then made some remarks regarding the need for a spatially and disciplinarily coordinated network of observations to support the main MOSAiC drift site. The MOSAiC drift station needs to have mobile or autonomous systems, with systematic coordinated sea ice measurements providing simultaneous measurements at several sites. Integration of sea-ice measurements with atmospheric and oceanic measurements needs to be improved. An enhanced use of coordinated arrays of buoys and moorings is needed, as is long-term monitoring at coastal sites for comparison to the Arctic Ocean sites and validation.

He also discussed previous scientific drifts (e.g. Fram, NP stations, Tara, SHEBA), pointing out that continuous year-round monitoring at one or a few locations in addition to the international MOSAiC site would provide a long-term data set that would provide some spatial variability and would be complementary to less frequent more intensive observations of spatial variability obtained from, e.g., mobile platforms.

He also raised the question whether we are missing crucial processes that are needed to improve understanding. His view was that continued and enhanced focus on model improvements of small scale processes is essential. These processes include radiative fluxes, snow processes, frost flowers, thin ice formation, frazil ice, and melt ponds. The science community also needs to consider the possibility of new process scenarios in the "New Arctic" that have not been considered a priori.

2.5 Ocean overview - Craig Lee

The title of Dr. Lee's presentation was "Expanded Spatial and Temporal Sampling of Small-Scale Physical and Biogeochemical Processes". A key point at the beginning of his presentation was that with the decrease in extent, thickness, and age of the sea ice in the "New Arctic", ocean processes that were previously damped have now been enhanced. This includes enhanced wind-driven mixing on the shelves and in the interior and more exposure of the ocean to propagating waves. This may lead to more heat and light through the surface, more small-scale ocean structures, changes in halocline water formation, stronger internal waves, and changes in thermohalocline structures. We might expect significant changes in ocean mixed-layer depth and variability, with greater regions of ice-free summers. The contrast between the "Old" and New" Arctic is illustrated in Fig. 1. from Rainville et al (2011), presented by Dr. Lee.

Using examples from the Canada Basin, which has now become a seasonal ice region, Dr. Lee discussed the need to

1) improve and validate mixed-layer models (which are currently too deep, show lack of variability, and don't account for 3D aspect of ocean mixing)

2) investigate mesoscale eddies, occurring in the intra pycnocline at 40-70 m depth and having lateral scales < 10 km. Temperature, salinity, and potential vorticity measurements suggest these eddies form at the 80° N front, and modulate internal wave propagation and lateral advection. They are possibly long-lived, and may become more prevalent with strengthening fronts and boundary currents.

3) understand restratification and bloom initiation by mixed-layer (ML) eddies. These are interactions between mixed-layer formation, chlorophyll bloom, wind mixing and convection, establishing kilometer-scale patches.

4) understand biological and biogeochemical response to sea ice decline

- Reduced sea ice thickness and extent heightens ocean response to atmospheric forcing.
- Ekman pumping depresses pycnocline. Nitrocline and subsurface chlorophyll maximum follow.
- Increased melt and fresh water input strengthens stratification at ML base, damps mixing, prevents ML deepening.
- Nitrate limitation limits new productions, favors smaller plankton.
- Shallow ML enhances light availability, but deep nitrocline enhances role of light limitation.

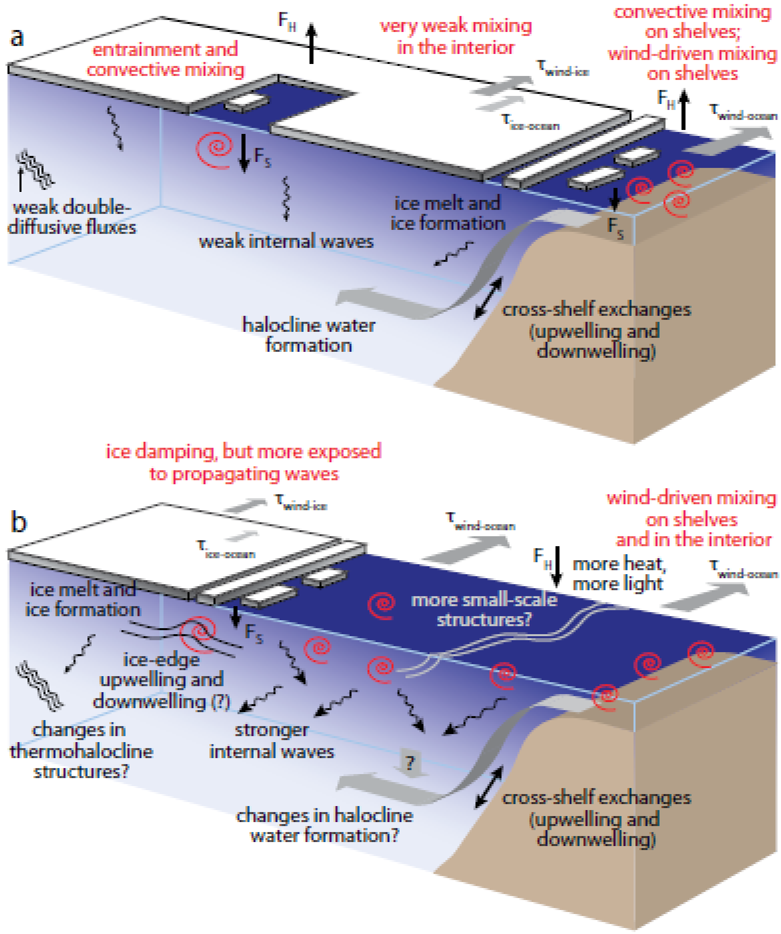

Figure 1. (a) Schematic of the dominant mixing processes in the Arctic Ocean with a relatively small seasonal ice-free area that is more representative of previous decades. Locally, the Arctic Ocean is mostly driven by thermohaline forcing (heat and salt fluxes, F_h and F_S, respectively) associated with ice formation and ice melts on the continental shelves and in polynyas. Wind stress (τ_{wind}) only plays a significant role on the shelves in the summer. Because of its relative rigidity at small scales, the sea ice effectively acts as a frictional boundary layer, both inhibiting internal wave generation and damping existing internal waves as well as small-scale and mesoscale upper ocean features. (b) Schematic of the dominant mixing processes for an Arctic Ocean with large ice-free areas. Both wind and thermohaline forcing are important in driving the ocean. The wind, acting directly over large areas of open water, generates more internal waves and more small-scale structures (fronts, eddies), which would have been damped out by the ice cover. The internal waves propagate to the deep interior, potentially enhancing mixing, modifying stratification and exchange of properties, and eroding the coherent staircase currently observed throughout the Arctic Ocean. (from Rainville et al 2011)

Observations from the Canada Basin were also used to illustrate the importance of, and changes to, the ocean near-surface temperature maximum (NSTM). The NSTM has warmed by 1.5°C, freshened by 4 psu between 1993-2009, and moved northward over the last 2 decades. Its formation is related to solar penetration of the ocean, melting of sea ice, and other sources of fresh surface water to form the summer halocline which traps the NSTM. Research is ongoing to better describe how the NSTM is formed and relationship with the summer halocline. Dr. Lee furthermore described the need to understand the processes linking the surface ML temperature evolution in summer and fall with sea-ice growth in the subsequent winter and sea-ice thickness.

Dr. Lee then summarized observations of Arctic Ocean mixing, noting that it has been traditionally very weak in the ice-covered interior. For instance, the double-diffusion heat flux is active only where other mixing is weak, and it is too weak to bring heat stored in Atlantic Water into contact with sea ice. Other mixing occurs by internal waves generated by bottom topography, producing upward propagating energy, or by internal waves responding to topography of the bottom of the ice, propagating energy downward. In general, the internal wave field is 10-100X less energetic than at lower latitudes. There are higher mixing rates near the shelves and near large bottom topography. It is very low in the deeper ocean of the Canada Basin and the Makarov Basin. The observations Dr. Lee presented suggest that strong mixing and elevated vertical shear only occur in ice-free conditions when wind generation of waves is possible.

Dr. Lee summarized the observational priorities for the Arctic Ocean during MOSAiC as:

- Persistent, continuous year-round sampling.
- Fully 3-dimensional sampling- spatial scope and resolution to complement temporal sampling.
  - Physical, biological and bio-optical variables.
  - Exploit well-equipped, floating laboratory [during MOSAiC] to combine intensive, in situ process-type sampling with extensive, distributed autonomous sensors (spatial coverage and scope). Have ship as center of a large, autonomous array.
  - Measurements from ship provide calibration and inform interpretation. Build proxies to leverage these onto the much larger number of autonomous sensors.
  - Exploit opportunity to build and evaluate proxies, providing lasting utility.
  - MOSAiC will offer an exceptional instrument test platform- good time for difficult instrument development efforts.
  - Need to understand chlorophyll & nitrate evolution as function of time, depth and seasonal/synoptic processes

The oceanic measurements need to utilize a variety of observational devices. These include ship-based CTD rosettes, floats, and gliders for obtaining calibration, correction and proxy data; ice-based automated observatories (IABP, ITP, POPS, IMB, AOFB); Arctic floats which probe the surface for leads (necessary for communications), profile to 1500 m, and have a 3-5 year endurance; ice-capable long-range gliders provide data from the surface to 1000 m, move slowly, and have a 10-12 month endurance; automated underwater vehicles provide transects and repeated lateral surveys on a 1-5 km scale. They can provide spatial mapping of radiation, temperature, salinity, and turbulence.

The observational objectives for upper ocean physics include:

1. measurements of the vertical structure of temperature (T), salinity (S), and scalar microstructure providing long-term, high-vertical-resolution observations of upper ocean heat content, fresh water content, stratification, and turbulent diffusivity

2. Turbulent fluxes across the base of the surface well-mixed layer (entrainment fluxes at the mixed-layer base) using isopycnal-tracking turbulence flux package and acoustic current meter with fast response T and C. This provides long-term eddy-correlation estimates of vertical turbulent fluxes to quantify entrainment rates and vertical transport between heat-carrying subsurface waters and surface mixed layer

3. Detailed observations of T, S and turbulent fluxes close to ocean-ice interface using vertical arrays of turbulence flux packages with thermistor strings and additional conductivity sensors,

including adaptive re-location of arrays and recovery of equipment. These would provide long-term observations of vertical fluxes of momentum, heat, and salt; detailed, near-interface structure of T and S; and ocean boundary layer currents.

4. Repeated, lateral, Autonomous Underwater Vehicle (AUV) surveys of T, S, spectral optics, and turbulence within the ocean boundary layer providing long-term, high-horizontal resolution observations of lateral gradients associated with variable ice type and coverage, spatial mapping of radiation entering upper ocean, and horizontal variability in T, S, and turbulence.

The objectives for the ocean biology and chemistry include making measurements to:

1) Quantify the seasonal cycles in biology and chemistry, addressing the questions "What are the life histories of the dominant plankton? (phytoplankton, zooplankton, microzooplankton)", "What is the timing and mechanism of nutrient regeneration? ", "What is the timing of primary and secondary production and how are their phenologies linked?", "What are the growth rates of different components of the ecosystem?"

2) Perform ecosystem studies during winter, including chemical transformations, addressing the questions **"**What is the ecosystem doing during winter?", "Which species are dormant? And which are active?", "What are the overwintering mechanisms of the different organisms and trophic levels?"

3) Perform "long-term" (weeks-months) biological process studies, which is possible with the establishment of a stable platform (ship) with on-board laboratory facilities. Because of the cold temperatures, many zooplankton and fish grow at slower rates than in lower, warmer latitudes. Hence, quantification of growth and development rates is difficult, particularly in a controlled environment

4) Better understand ecology during Spring and Fall transitions, addressing the questions "How does the ecosystem shut down during the fall-winter transition?", "When does epontic and pelagic primary production commence and how does it evolve?", " What is the importance of melt ponds and leads to the timing of primary production?", "What is the importance of the epontic algal community to pelagic grazers?"

2.6 Ocean overview - Jinping Zhao

China is concerned that Arctic changes are impacting their climate by producing extreme events such as ice storms, drought, and dust storms. The Arctic Ocean influences China's climate via 3 or 4 pathways. The main ocean topics of concern described by Dr. Zhao that could be addressed by MOSAiC are:

1. Extremely low sea ice concentration in central Arctic and the climatic effects of open water (enhanced surface solar radiative heat absorption, enhanced air-sea turbulent heat flux, enhanced ice melting, impacts on central Arctic weather & precipitation type). Need to understand its causes and consequences better.
2. Four main sea ice drifting patterns are identified in Arctic Ocean. These change on monthly, seasonal and annual time scales with only a modest correlation with the AO index. [What drives these different patterns? What causes switching between them? Does the recent

appearance of low ice concentration in the Central Arctic play a role in switching between patterns? Does likely thinning of the sub-ice Ekman layer play a role?]

3. Ekman Drift under sea ice during summer and the shallowing of the Ekman layer during summer due to stratification from melt water and its effects on drift velocity; open water may allow Langmuir cells to enhance vertical mixing; need to observe drift and mixing under sea ice for long period
4. Near surface temperature maximum (NSTM) and wind-driven mixed layer are the two basic water structures. NSTM more common in Canada Basin since 2002, being observed earlier, generally colder now; forms in late June; dependent on presence of surface stratification from melt. Need to understand formation mechanism of NSTM better and its relationships to stratification, depth of pycnocline, and depth of solar penetration. What determines NSTM depth and spatial distribution? What is fate of this heat during autumn freeze-up and winter ice growth? The seasonal evolution of NSTM is still unclear. Is NSTM forming elsewhere in Arctic Ocean?
5. Heat dissipation zone above Atlantic Water – need to understand relative magnitudes of molecular diffusion, double diffusion, & turbulent diffusion and their spatial variability. Double diffusive measurements in western Canada Basin show this to be small relative to other turbulent processes, which are themselves small (< 1 W m^{-2}).
6. Optical attenuation caused by biomasses – quantitative relationships to biomass, impacts on vertical heating profile and spatial variability need to be better understood
7. Division of the summer and winter Pacific Waters

2.7 Biology, Biogeochemistry overview – Carin Ashjian, Brice Loose, Jeff Bowman

The biology and biogeochemistry keynote presentation was given by three different speakers, each giving a shorter presentation.

2.7a Carin Ashjian:

Dr. Carin Ashjian provided her thoughts on the ecological science issues that could be addressed by the MOSAiC observatory, first describing the Arctic food web from ice algae and phytoplankton, through zooplankton, to the ice-based mammals, and then asking some key questions (and subquestions).

1) How will the ecosystem respond to the conditions of the "new Arctic"?

This question requires quantification of biological and chemical distributions, stocks, and transformations, and then addressing the following sub-questions

- How will changing ocean conditions (warmer temperatures) impact critical ecosystem processes?
  - Life histories of the dominant plankton (phytoplankton, zooplankton, microzooplankton)
  - Timing of primary and secondary production and linkages of the phenologies
  - Production/Growth rates of different components of the ecosystem
- What is the timing and mechanism of nutrient regeneration?
- What is the duration and magnitude of primary production under the sea ice and what limits it (light or nutrients)?
- Will the changing sea ice conditions result in increased primary production that will cascade upwards through the ecosystem?

2) What happens to the ecology during and at spatial/temporal transitions

- How does the ecosystem shut down / ramp up during the fall-winter and winter-spring transitions?
- When does epontic and pelagic primary production commence and how does it evolve? What is the importance of melt ponds and leads to the timing of this primary production?
- How patchy is ice algae? How does ice algae cover impact albedo and the penetration of light into the water column?
- What is the importance of the epontic algal community to pelagic grazers? How do the grazers impact the distribution of ice algae?
- How does spatial heterogeneity in the physical environment (e.g., ice cover, fronts, vertical structure) impact biological distributions and processes and produce patchiness in those characteristics?

3) What happens to the ecosystem during winter, including chemical transformations?

- What is the ecosystem doing during winter?
- Which species are dormant? And which are active?
- What are the overwintering mechanisms of the different organisms and trophic levels?

4) How does the ecology relate to the physical system?

- Carbon flux: Consumption and production of carbon
- Ocean Optics
- Production of aerosols
- Changes in albedo and ice melt associated with ice algae

Other biology/ecosystem issues that can addressed during MOSAiC discussed by Dr. Ashjian include a) determining the temporal and spatial variability of ocean acidification, b) if and how ecosystem model parameterizations can be improved, and c) if the benthos is impacted by the pelagic system and the sea ice, which are far above in the center of the basins. Finally, Dr. Ashjian made the point that the establishment of a stable platform (ship) with on-board laboratory facilities will permit long-term (weeks-months) biological process studies. Because of the cold temperatures, many zooplankton and fish grow at slower rates than in lower, warmer latitudes. Because of this, quantification of growth and development rates is difficult, particularly in a controlled environment

2.7b Brice Loose

Dr. Brice Loose discussed the MOSAiC science needs from the perspective of carbon and biogeochemistry of the sea-ice zone. His main emphasis was the need to measure primary production plus gas exchange at the same time in sea-ice zone in conjunction with the atmospheric, oceanic, and sea-ice physical measurements. This would allow the testing of the DIC Pump hypothesis, properly examine primary production and carbon uptake, and the CO2 rectification hypothesis. Gas exchange transfer coefficients are usually inferred but rarely measured, though the latter could be done at MOSAiC. They are believed to be dependent on open water fraction. Furthermore, air-gas exchange depends on aqueous turbulence, such as produced by shear in the ice-ocean boundary layer, buoyant convection/stratification, short period gravity waves (wind waves) and interactions with ice floes. Again, these processes will be measured by others at MOSAiC. Dr. Loose also suggested that other gas exchange measurement techniques could be tested, including the sampling of radon or the O_2/Ar ratio.

2.7c Jeff Bowman

Mr. Bowman began by stating that most of what we know regarding the biology of (Arctic) sea ice is biased toward summertime basal ice because that is when the biomass is greatest and the access is easiest. However, microbial activity in sea ice occurs throughout the annual cycle, suggesting that year-round measurements would be of value. Furthermore, bacteria are distributed throughout the ice column, concentrating at the top and bottom. However, sharp environmental gradients and other stressors at the top and bottom of the ice column may induce physiological responses of significance to chemistry and physics, such as DMSP production and conversion to DMS (T, S, UV); methylhalide formation, including iodomethane (S, UV, H_2O_2); EPS production (S, T, UV). The latter involves C export, calcium carbonate polymorph selection, brine channel blockage, and enhanced connectivity. These environmental stressors and the response processes need to be studied further. Finally, Mr. Bowman made the point that biologically active ice is more connective than sterile ice. This has implications for permeability of gas, nutrient renewal, and ice strength. Hence, the biological activity needs to be measured so its impact on these physical processes is understood. Laboratory studies of these processes have limitations since EPS varies in concentration and composition and the impact of changing EPS on the sea-ice properties is unknown. Hence, both the community composition and the physiological state have physical and chemical impacts, and one can't be understood without measurements of the other.

To integrate these concepts into MOSAiC, a baseline for predictive (physio) biogeochemistry must be established by determining a set of chemical and physical conditions of who is present, how many are there, and what they are doing. This potentially feeds back to the initial conditions. Furthermore, basic biology is lacking for the central Arctic, and little effort or equipment is required to produce a long time series of basic parameters. In addition at key time points, detailed community composition should be assessed in combination with rate measures and flux measures.

<u>3. Overviews of Collaborating Projects</u>

3.1 Russian Drifting Stations – A. Makshtas (edited and presented by O. Persson)

The rejuvenated Russian drifting station program (NP stations) has been ongoing and growing since 2003, and is based on the experience of the former Soviet Union drifting ice station program. Measurements are being made to address atmospheric, cryospheric, oceanic, and greenhouse gas science questions, and these include both manual measurements as well as newer methodologies using remote sensors and more sophisticated in-situ devices.

The atmospheric, ice, and oceanic science issues being addressed at the NP-stations include

1) characterizing low-level inversions
2) defining cloud characteristics (cloud fraction, height; measurement technique variability)
3) understanding atmospheric boundary layer thermal structure and the processes producing variability
4) documenting and understanding atmospheric O_3 depletion events in both the surface-layer/boundary layer and the stratosphere (i.e., Arctic "ozone holes")
5) improving measurement techniques (e.g., clouds, skin temperature)

6) validation of models: mesoscale (WRF), RCMs and reanalyses
- T, T_d, cloud fraction, BL thermal & kinematic structure
- surface characteristics

7) parameterization validations
- down-welling SW and LW radiation, incl. impact of clouds
- turbulent fluxes in stable boundary layer
- atmospheric boundary layer, for forcing sea-ice models

8) spatial and temporal variability of spectral albedo of snow/ice
– transects of snow depth, density, morphology, spectral albedo (e.g., every 2nd day)

9) spatial and temporal variability of sea-ice surface characteristics (e.g., leads, melt ponds, etc)

10) spatial and temporal variability of ice thickness

11) sub-surface ice structures

12) validation of modeled snow depth and ice thickness distributions

13) Temporal variability of solar radiation penetration of sea ice

14) Spectral and depth redistribution of solar radiation

15) Understanding greenhouse gas concentrations and fluxes – CO_2

The scope of future work at the NP stations is related to these issues. It includes

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

The Russian NP drifting station program is eager to collaborate with the international MOSAiC drifting observatory, both logistically and scientifically.

3.2 IAOOS Project

Dr. Christine Provost was to give this presentation, but she had to cancel her attendance at the last minute. The presentation was given by Claire Granier.

Through the French EQUIPEX call for investing in equipment of the future, 40 platforms are being designed and built to provide profiling from the atmosphere through the ice into the ocean. This project will extend from 2011 through 2019. This is an integrated approach, with simultaneous collection of real-time information of the state of the upper ocean, lower atmosphere and the Arctic sea ice in between. These buoy observations will complement satellite observations and numerical models. A distributed network of 15 buoys is planned to be operating at any one time during a 5-year period, with the expectation of deploying 6 new buoys each year as others exit through the Fram Strait. Each buoy is expected to have a 2-year lifespan. The first buoy will be ready for deployment in 2013.

These buoys will be unattended and autonomous, providing real-time data via a satellite link. The ice and ocean measurements on this buoy will include measurements of ice mass balance using a 6-m long chain of thermistors and heaters with a 2 cm resolution, surface temperature and pressure, and ocean profiling of temperature and salinity between 7 m and 800 m depth. The ocean profiling will use a tethered, mobile Seabird CTD. In addition, the buoys will house a microlidar and an optical depth sensor to provide information about the vertical structure and optical properties of the atmosphere. Such a network of microlidars has the potential for defining the spatial extent of cloud base and aerosol backscatter profiles.

An array of 15 distributed IAOOS buoys deployed during MOSAiC would provide spatial context for the intensive data from the MOSAiC drifting observatory.

3.3 R/V Lance Over-wintering

In his keynote presentation, Dr. Gerland mentioned the drifting station supported by the R/V Lance of the Norwegian Polar Institute, which is planned to be deployed north of Svalbard for about 6 winter months. It is currently in the planning and proposal phase. This may be during the winter 2013/2014 or 2014/2015. This project will be much smaller than MOSAiC in all respects, but experience from the R/V Lance drift could support planning for an international MOSAiC drifting station.

3.4 Arctic Ocean Drift Study (AODS)

Dr, Igor Polaykov summarized the objectives and plans for the Arctic Ocean Drift Study (AODS), to be deployed for two months in autumn 2015 in the Eurasian Basin. The objectives of this study are to measure the oceanic heat transport mechanisms that may be bringing the warmer Atlantic Water to the surface in this region. In particular, the double-diffusive mechanism is hypothesized to be important in this region. AODS will consist of an array of stations based on ice floes around a main site, and the field program will be supported by the R/V Amundsen ice breaker. In addition to ocean heat flux measurements, sea ice mass balance measurements, atmospheric measurements, and surface energy budget measurements are planned. Because of its interdisciplinary nature, its interest in oceanic, atmospheric, and surface energy fluxes, and the plans for an autumn deployment in a marginal ice zone (MIZ) region, AODS could be useful for testing potential MOSAiC instrumentation and for testing logistics of deploying an ice camp at that time of year in a MIZ.

4. Science Issues Described by Each Disciplinary Break-out Group

This section describes the science issues and other topics summarized by each break-out group.

4.1 Atmosphere

The atmospheric breakout group summarized its discussions by defining four overlapping atmospheric areas that need to be addressed during MOSAiC: 1) water budget, 2) boundary layer, 3) interactions with weather systems, and 4) stratospheric processes. Key topics within each area include:

Water budget

Net Precipitation
- Precipitation Formation and vertical structure
- Precipitation Phase (rain vs.snow)
- Wet deposition of aerosols and climatic impact (e.g. BC on snow, CCN transport)
- Timing of precipitation

- Precipitation rate (Synoptic vs.Stratus clouds)
- Impact of precipitation on surface radiation/conduction
- Evaporation
- Surface accumulation of precipitation

Cloud Evolution and Phase
- Mixed phase cloud formation and maintenance
- Liquid and ice nucleation

Arctic Water Vapor
- Sources and sinks
- Long range transport vs.local surface evaporation
- Bubble bursting and sea spray

Boundary Layer

Energy Budget
- Radiative and turbulent Fluxes

Vertical Structure, Transport, Mixing

Momentum Budget
- Impact by, and impact on cyclones
- Impact on surface (ice, ocean)

Aerosol Budget and processes
- Local vs. remote sources of aerosols
- Influence on surface albedo
- Impacts on the optical properties of clouds

Surface Layer Processes

Stable Boundary Layer Processes

Ozone Depletion
- Influence of increased bromine due to more leads and polynyas
- Impact on surface exchange processes

Interactions with Weather Systems

Influence of measurements on improving reanalyses
- Influence of location
- Influence of frequency of data assimilation
- Influence of having a point (or numerous points) in the central Arctic

Impact of large scale systems on local processes
- Boundary layer structure
- Cloud and precipitation properties
- Aerosol and water vapor transport

Influence of “new Arctic” on weather systems
- Increased heat and/or moisture fluxes
- Potential to capture detailed measurements of polar lows

Stratospheric Processes

Interactions between the stratosphere and tropospheric AO events
- Investigation of system memory

Long range teleconnections

Ozone hole
- Characterization of ozone hole in central Arctic
- Effect of tropospheric coupling on ozone depletion

Additional discussion also identified other questions and issues that need to be considered. The importance of considering the measurement scales was one such topic. Are the spatial scales relevant to GCM parameterizations? Spatial/temporal distributions should not only be measured, but also joint distributions of related processes. Measurements should try to obtain sufficient temporal scale for statistically significant relationships. The measurement spatial scales need also be considered for satellite validation efforts. Unmanned aerial vehicles (UAVs) will likely be an important means for obtaining atmospheric measurements at the proper spatial scales.

The atmospheric discussions also considered questions regarding models, such as "What are the parameterizations that really need improvements?", "How can we best compare observations to models of various scales while implementing "apples-to-apples" comparisons? Using simulators?", "Can we use single column models in relation to MOSAiC efforts? If so, how do we obtain proper boundary conditions?"

The atmospheric break-out group also noted that previously undocumented events may be measured because detailed, long term measurements in the central Arctic are unprecedented and that this holds particularly true for the polar night measurements (e.g. longwave radiation in central Arctic).

The changing or "New Arctic" may also influence the atmospheric measurements. Will the changing Arctic produce changes to heat fluxes? Different precipitation/albedo properties? Different boundary layer structure? Atmospheric convection at high latitudes? Changes to the atmosphere-surface momentum transfer? Increase local aerosol emissions? Change large scale gradients and/or poleward transport?

Finally, the atmospheric measurements will clearly have strong links to other components of the system. The surface energy budget will link the atmosphere, sea ice, ocean, and biogeochemistry, while heat and momentum transfers will be important for the ocean and the sea ice as well as the atmosphere. Precipitation amounts and phase will have significant impacts on the sea ice, while the issue of atmospheric aerosol sources is clearly tied to ocean and biogeochemical processes. The low-level O_3 depletion is also linked to the biogeochemistry.

4.2 Cryosphere

The cryospheric break out group identified three "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?

It was noted that these broad objectives are similar to those posed for SHEBA. However, when considering the specifics, significant omissions occurred for SHEBA. These omissions included a priori identification of the needs of modelers. Some of the more specific sea-ice issues to be addressed and observations to be made during MOSAiC include:

- Measurements of Heterogeneity
  - Snow/Ice thickness distribution – airborne radar and EM, RS assets, UAVs

- Ice surface and bottom roughness – LiDAR. Multibeam on ROV
  - Snow redistribution-LiDAR
  - Internal melt-Micro CT
  - Under ice radiation field – logging spectroradiometers
- Observations of the "New Arctic" (open ocean – ice transition states)
  - Thin ice, upper ocean cooling.
  - Logistics challenges… must be met.
- Biological impacts
  - EPS – ice structure/strength interactions – molecular techniques
  - Light Transmission (time series) – logging spectroradiometers, ROVs
  - Porosity/permeability - nutrient cycling relations – Micro CT, analytical techniques
  - DMS production/release
  - Bacterial/algae linkages – molecular techniques
- Biogeochemical cycling
  - DIC pump to deep ocean
  - Brine movement
- Spatial/Temporal extensions
  - Cal/Val of remote sensing
  - Autonomous platforms

A way to prioritize these issues and observations is by considering their linkages to other disciplines and processes within the system. The linkage between the sea ice and each of the other disciplines are important for the following processes and observations:

Sea ice - Ocean
- Summer heating/fall freezing
- Freshwater exchange
- Deepwater formation
- Sediment entrainment
- Coupling, both momentum transfer and mixing

Sea ice - Atmosphere
- Long/Shortwave
- Snow
- Surface Roughness/Turbulent Flux

Sea ice - Biological Processes
- EPS – ice structure/strength interactions
- Light Transmission (time series)
- Porosity/permeability - nutrient cycling relations
- DMS production/release

4.3 Ocean and Biogeochemistry

The ocean and biogeochemistry break-out group defined one primary science question for the physical and biological topics of their group. They then included some more specific sub-questions under each primary question to illustrate the measurements needed and the implied interdisciplinary interactions. Their questions exemplify process uncertainties and unknown structures and processes in the "New Arctic."

- Will an ice reduced Arctic become more productive and what are the consequences of this to other components of the system?
  - Is production limited by light or by nutrients?
  - How do physical processes such as stratification, wind mixing, ice cover, ice topography interact with biological processes to determine the magnitude, timing, and type of primary production
  - What are the consequences of changing timing of production and magnitude to the other trophic levels and to ecosystem structure and function?
  - How will these changes in PP impact e.g., flux of gases, aerosol formation etc.
- Will an ice reduced Arctic become more stratified and what are the consequences of this to other components of the system?
  - What changes will be observed in the mixed layer under reduced ice?
  - What will be the net effect of the competition between changing stress and changing buoyancy?
  - Will small scale physical processes become more important?
  - How will changes in stratification and ice cover impact air-sea-ice heat flux and the formation of vertical hydrographic structure (e.g., NSTM)?
  - How will these physical processes change under the "new Arctic" ice conditions?

The group noted that these proposed measurements will permit us to better parameterize physical, biological, and chemical models, especially high frequency forcing and coupling. Furthermore, the group examined the question of why MOSAiC is needed to address these issues. They concluded that the MOSAIC installation will be extremely valuable as a

a) platform with capability for multiple types of sampling coincidentally at high temporal and spatial resolution. This information is necessary to address our questions
b) highly calibrated sensor network
c) resource with which to develop robust proxies with which to collect data using available sensor technology on ITPs, gliders, etc.
d) test bed for new instrumentation
e) facility from which to collect critical data in first year sea ice (ITPs cannot work in first year ice)

Having described these advantages of the MOSAiC concept for addressing the science question, the group also enumerated some of the logistical considerations that will need to be decided. The first of these logistical questions is "Where to park?". There is a desire to have access to first year ice, open water, and seasonal ice zone. Three geographic locations were considered: 1) SE Beaufort/Banks Island start, summer in SW Beaufort in seasonal ice and then open water; 2) SW Beaufort start/Arctic Grand Tour; 3) Eurasion Drift (Laptev to Fram). A logistical advantage of the first location is that the ship would be located near north coast of Alaska where it could be accessed by helicopters and other icebreakers (break-down ice camp, transfer gear on/off ship, supply replenishment). Other logistical needs that were identified as potentially important include a) a potential for repositioning during spring, summer, fall if drift carries us to disparate hydrographic regime, b) an icebreaker centered camp with satellite installations (e.g.,ITPs) up to 2-3 Rossby Radii (10 km) away and use of ROVs/AUVs/Gliders equipped with an expanded range of sensors to expand range of sampling, c) the need for helicopter support to establish/maintain/move remote installations, other remote sampling, sea ice reconnaissance, etc., and d) adaptive sampling/positioning of the satellite installations based on ship drift and done using helicopter

5. MOSAiC Broad Science Objectives Developed in Final Plenary Session

While the above summaries of the keynote presentations and break-out group reports provide some of the details of the science issues to be addressed by MOSAiC, a plenary session tried to further distill these ideas into broader since questions. The overarching guiding science question for MOSAiC arrived at by the workshop participants is: "What are the causes and consequences of an evolving and diminished sea ice cover?" Five broad sub-questions were identified:

- 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?

Other important science objectives of MOSAiC that do not directly include a science question were also identified. First, the MOSAiC observatory would be an important test-bed for the development of automated observing systems and instruments for all disciplines, and for satellite observational techniques. It would also be a key component in a modeling test-bed for understanding global impacts of Arctic observations. For the modeling community, MOSAiC is an important opportunity to improve the representation of critical and scale dependent processes impacting Arctic predictability given diminished sea ice coverage and increased model complexity. Key advantages that MOSAiC has over other shorter and more limited projects are that at least one full annual cycle will be captured, spatial heterogeneity will be better observed than in previous programs, and the modeling community will be integrated from the beginning to help define the scientific needs and implement the MOSAiC observational component. These advantages are important and the MOSAiC implementation plan needs to include them.

The workshop concluded with plenary discussions regarding international coordination activities, potential sources of support, and the needs to reach out to a variety of communities including satellite agencies, early career scientists, industry/commercial interests, and modeling centers.

Appendix A: Workshop Participants

Atmosphere (17)

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Appendix B: Workshop Agenda

The planned workshop agenda is given below. It was followed reasonably well, with some modifications. Dr. Christine Michel was unable to attend at the last moment, so three attendees with biological and biogeochemistry expertise kindly prepared and presented an overview of the main biological issues. Also, three shorter presentations on the Russian North Pole drifting stations, the IAOOS buoys, and the AODS field program were given on Thursday after the biology presentations, since these projects were closely related to the MOSAiC project, and plan to collaborate with it.

Wednesday, 27 June 2012: Room GB-124

Please try to arrive on site by 13:00 to allow for sufficient check in time.

13:30-14:00	**Welcome and General Workshop Overview – Matthew Shupe** Establish workshop objectives; Background on prior planning activities; Acknowledge support of IASC and others; Structure of meeting and associated logistics; Introduction of participants; Charge to participants
14:00-14:30	**Science Driver Overview – Ola Persson** Broadly paint the picture of the system as a whole and motivate the need to study the system as a whole; Indicate that there has been a great lack of observations in the central Arctic; Outline the very top-level difficulties with modeling the system as a whole
14:30-15:45	**Science Discipline Overviews – Atmosphere** What are the primary science questions? What has past work shown us? Model perspectives and needs. What specific observations are needed? • Presentation #1: Michael Tjernström – 30 min • Presentation #2: John Walsh – 30 min • Questions/discussion – 15 min
15:45-16:15	**Break – Beverages and light refreshments**
16:15-17:30	**Science Discipline Overviews – Sea-Ice** What are the primary science questions? What has past work shown us? Model perspectives and needs. What specific observations are needed? • Presentation #1: Don Perovich – 30 min • Presentation #2: Sebastian Gerland – 30 min • Questions/discussion – 15 min
17:30-17:45	**Wrap up, Logistics, Establish tomorrow's plan**
17:45	**Adjourn**
19:00	**Workshop dinner** Joint with *Arctic Boundary Layers Workshop* *Gold Hill Inn,* 401 Main St. Gold Hill, Colorado Charter bus pickup 6 pm at NOAA and 6:15 pm at hotels Return by about 10 pm

Thursday, 28 June 2012: Room GC-402

08:30-09:45	**Science Discipline Overviews – Ocean** What are the primary science questions? What has past work shown us? Model perspectives and needs. What specific observations are needed? • Presentation #1: Craig Lee – 30 min • Presentation #2: Jinping Zhao – 30 min • Presentation #3: Christine Michel – 30 min (Biological Focus) • Questions/discussion – 15 min
09:45-10:15	**Break - Beverages and light refreshments**
10:15-11:30	**Plenary Discussion** • General discussion • Other disciplines and/or scientific linkages to consider • Report from Russian colleagues • Breakout session structure and objectives, identify rapporteurs
11:30-13:00	**Lunch**
13:00-15:00	**Breakout Sessions: Individual Disciplines in parallel** • Identify highest level science questions and links to other disciplines • Discuss specific observational needs within discipline (although not "implementation") and links to others • Rapporteur collects ideas in slide form for presentation.
15:00-15:30	**Break - Beverages and light refreshments**
15:30-17:00	**Breakout Sessions: Individual Disciplines in parallel (continued)**
17:00-17:30	**Plenary Session – Wrap up and plan for tomorrow**
17:30	**Adjourn**

Friday, 29 June 2012: Room GC-402

08:30-10:00	**Plenary Session: Developing Science Drivers** Summary presentations of individual discipline science questions (15min each). General discussion of these topics, Identify cross-cutting themes.
10:00-10:30	**Break - Beverages and light refreshments**
10:30-12:00	**Plenary Session: Developing Science Drivers** Discussion of linkages and larger-scale connections between disciplines. Discussion of implications and other influences on the science objectives (i.e., commercial, ecosystems, communities, data users, other stakeholders)
12:00-13:30	**Lunch**
13:30-15:00	**Plenary Session: Developing Science Drivers** Discussion and formulation of high-level guiding science questions, working towards "rough" but "final" ideas.
15:00-15:30	**Break - Beverages and light refreshments**
15:30-17:00	**Plenary Session: Logistical Details** • Funding sources: Develop a list of potential agencies that should be engaged in this process so that individuals can help to lay the necessary ground work for drawing in future agency support. • International coordination strategies: IASC is an important vehicle. What others will help to support this general movement (CLiC, SAON, ISAC, AOS, etc.). Identify liaisons. • Engagement of key communities: satellite, operational models, commercial, other stakeholders, etc. Identify liaisons where needed. • Engaging young scientist participation: Connections with APECS, gaining participation of young scientists; Identify liaison. • Future planning activities
17:00	**Adjourn**

Appendix C: Workshop Group Photograph