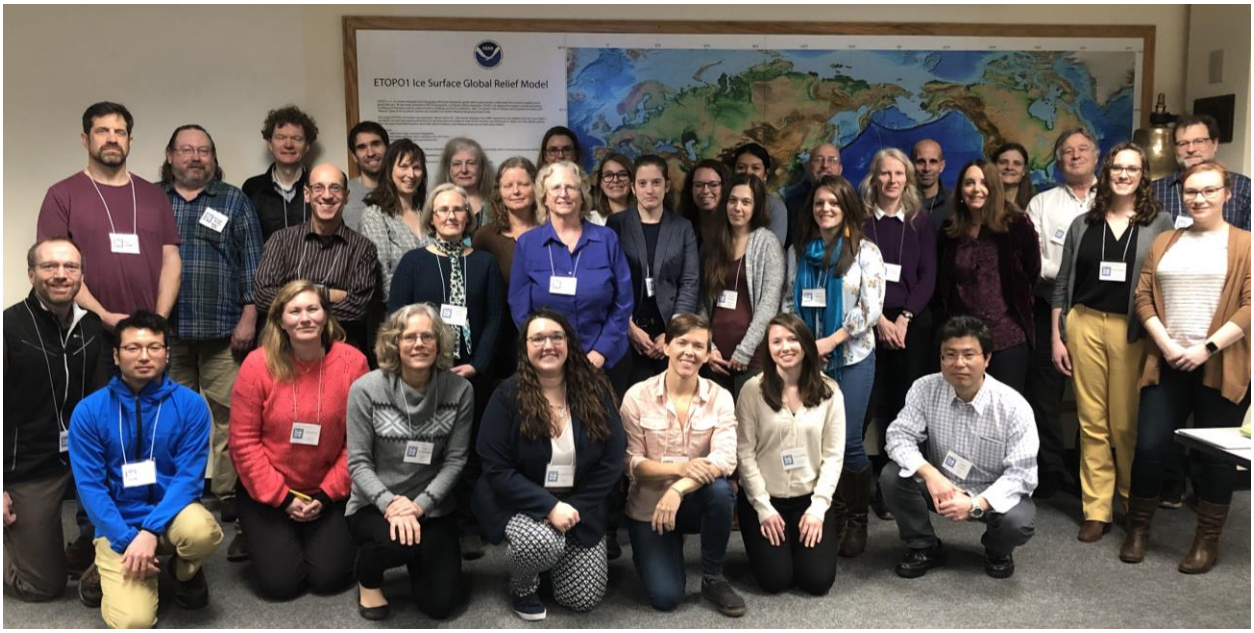
Distributed Biological Observatory

The Distributed Biological Observatory (DBO)
5th Data Workshop Final Report

January 22-23, 2020
NOAA / PMEL
Seattle, Washington, USA



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https://arcticdata.io/catalog/portals/DBO

Introduction

Since 2010 the Pacific Arctic Group (PAG) has endorsed the Distributed Biological Observatory (DBO), which is focused on ship-based research in the northern Bering, Chukchi and western Beaufort seas. The PAG established the DBO as the framework for standard sampling of select physical, chemical and biological measurements at stations set along transect lines. The DBO serves as a "change detection array" along a latitudinal gradient extending from the northern Bering Sea to the Barrow Arc, and a longitudinal gradient east from there to Cape Bathurst in the Canadian Beaufort Sea. DBO sampling regions are centered on locations of high productivity, biodiversity and rates of biological change.

The DBO sampling framework was initially tested during a **2010-2011 Pilot Study**, which consisted of international ship occupations of two of the DBO sites, one in the SE Chukchi Sea and one across upper Barrow Canyon in the NE Chukchi Sea. Results of the DBO Pilot Study were the central topic at a **March 2011 DBO workshop in Seoul, Korea**, held immediately prior to the international Arctic Science Summit Week (ASSW). Subsequently, the **1st DBO data workshop was held February 27-March 1, 2013** at the US National Oceanic and Atmospheric Administration (NOAA)/Pacific Marine Environmental Laboratory (PMEL) facility in Seattle, Washington. The purpose of the meeting was to discuss the results from the 2010-2012 DBO effort under PAG leadership, share data sets, develop a draft international data policy for this observing effort, and organize collaborative publications. The **2nd DBO data workshop was held October 29-31, 2014** at the USA NOAA/PMEL in Seattle, Washington, USA. This data workshop continued development and implementation of the DBO through presentation of data results, discussion of measurement protocols, and development of visualization products for disseminating of the DBO findings to the science community, science managers and the general public. We also discussed new DBO lines in the western and eastern Beaufort Sea and development of DBO lines in the northern Barents Sea in the Atlantic Arctic through input from Norwegian collaborators. During the **3rd DBO data work held March 9-13, 2016** at the US NOAA/PMEL in Seattle we discussed DBO results from the DBO1-5 sites, the new Beaufort Sea lines DBO6-8, and developing plans for an Atlantic DBO network. We also identified manuscript topics for the first DBO Special Issue in Deep Sea Research II that was subsequently published (Grebmeier et al. 2019). During **4th DBO data workshop held November 8-9, 2017** at PMEL/NOAA in Seattle we discussed recent DBO field results from ship-based samples and moorings, remote sensing results, modelling activities, update on DBO synthesis products, the Atlantic DBO planning, and discussion of the DBO data parameter files and data archiving.

The following report provides a summary of the **5th DBO data workshop held January 22-23, 2020** attended by 50 national and international participants. The workshop had three objectives:

1. Present results from the 2010-2019 DBO field programs, including summaries from DBO DSR special issue papers,
2. Develop a conceptual model for the Pacific DBO and discuss ongoing or developing modeling efforts, and
3. Discuss data parameter file and data archiving.

We provide summaries related to the final workshop agenda (Appendix A), with the relevant presentation hyperlinked to this report and available on a public website (http://arctic.cbl.umces.edu).

Wednesday-22 January, 2020

Welcome & Logistics

Logistics (Jessica Cross, PMEL/NOAA, pp1a)
Jessica provided information on local logistics, including informing all participants to have their NOAA Id's with them at all times and that visitors must be accompanied by a NOAA employee when walking about the building.

Introduction (Jackie Grebmeier, UMCES CBL, ppt1b)
Jackie provided the agenda for the 5th DBO Data Workshop, including the following 3 objectives:

1. Present highlights and results from the 2010-2019 DBO field programs
2. Develop a conceptual model for the Pacific DBO and discuss ongoing or developing modeling efforts, and
3. Discuss data parameter file and data archiving.

Highlights of DBO 2010-2019 data time series

Remote Sensing

Karen Frey (Clark University, ppt2a)
Karen presented results of optical, biogeochemical, and satellite remote sensing observations across the DBO. Most of this work has been done in DBO regions 1-5 on the Sir Wilfrid Laurier summer cruises. It was noted that there have been remarkable shifts in the Bering region in particular and at DBO4 in the northern Chukchi Sea. Data collections were both through satellite time series and ship-based measurements. Satellite-based parameters included: (1) Sea Ice Cover: concentration, annual persistence, timing of breakup, and timing of freeze-up; (2) Chlorophyll-a Concentration; (3) Primary Productivity; and, (4) Sea Surface Temperature. Ship-based collections and measurements included: (1) Chlorophyll-a Concentration (Pheophytin-a Concentration), (2) Suspended Particulate Matter (SPM) (Inorganic and Organic), (3) Chromophoric Dissolved Organic Matter (CDOM) (Absorption and Spectral Slope Parameters), (4) Dissolved Organic Carbon (DOC), (5) Phytoplankton ID (Imaging FlowCytobot (IFCB)/Luisa Young); and, (6) Water Column Optical Profiles. Examples of the trends in annual sea ice persistence (days/year) showed summer loss of multiyear sea ice in the Pacific Arctic and winter loss of first-year sea ice in the Atlantic Arctic over a 2000-2018 year time period as compared to 1979-2018. There was a focus on sea ice cover at DBO1 showing a sea surface temperature anomaly in July 2019. Satellite-based chlorophyll-a snapshots over time were also shown with a peak in May for all 5 DBO regions.

Hisatomo Waga (IARC/University of Alaska Fairbanks, ppt2b)
Hisatomo presented results of satellite-detected interannual variations in fall phytoplankton blooms in the DBO 1-3 regions. Daily 9 km MODIS/Aqua chl-a data was used to detect the presence of chl-a peaks in the fall using a minimum of one chl-a value every 20 days. Hisatomo presented maps of presence/absence of fall blooms in the DBO 1-3 regions for 2003 and 2016. It was noted that interannual variations in the fall bloom tend to be increasing in DBO3 and decreasing in DBO1 over time. In summary, DBO1 seems to be showing less frequent fall blooms and DBO3 more frequent fall bloom,

while DBO2 shows insignificant temporal variations. Decreasing and increasing trends in benthic biomass in the DBO1 and DBO3 regions could indicate cascading impacts up to higher trophic levels. Potential drivers should be investigated.

Physical Oceanography/ Moorings

Phyllis Stabeno (NOAA, ppt2c)
Phyllis presented results on DBO1 and the long-term mooring, M8. She provided graphics showing patterns of sea ice change in the Eastern Bering Sea over time (1988-2019). A rapid decline in sea ice occurred in 2019 with ice being gone by March 1st due to ice and northward wind events. Why was the cold pool so small in 2018 (an anomaly)? Temperature and salinity cause continual warming. From November to April temperature is about 1 °C above normal directly due to lack of ice. But after April, bottom temperatures begin to warm in parallel with atmospheric warming, a finding usually seen in the surface layer, and she attributed to the lack of sea ice and associated brine injection in winter, thus an anomaly associated with salinity differences. Bottom water temperature are normally ~ 3-4 °C, so continuing warmer conditions for 2019 result from salinity and temperature patterns at mooring M8. It was also observed that there were different types of algal blooms in the food web in the northern Bering Sea for 2018 and 2019. Graphics shown include ice retreat and copepod (*Calanus* spp) life stages over time for the M8 mooring. Finally, Chukchi Sea freeze up is so much later that it may affect the Eastern Bering Sea from 2019-2020.

Rebecca Woodgate (UW, ppt2d)
Rebecca provided an update on what's new in the Bering Strait, including annual trends, change, drivers, and implications – How strange were recent years? Data has been collected from moorings in the Bering Strait since 1990 (29+ years). These year round moorings in the US mid-channel include A1, A2, A3, and A3' and are mostly near bottom. Measurements of the Alaskan Coastal Current started in 2001 at A4. Total flow is approximated at Climate site (A3) and Alaskan Coastal Current site (A4). Trends in annual mean to 2018 were presented which show significant trends from Climate Site (A3) in: transport (increasing), temperature (warming), and salinity (freshening), as well as increasing heat (almost doubling since the 1990s) and freshwater fluxes (mostly driven by transport). Transport variability was also examined showing recent change due to both wind change and pressure head (PH) change. The trends in PH are significant and are in almost all months, but no significant trend in wind. Peralta-Ferriz and Woodgate (2017) find relationships to the Arctic (East Siberian Sea) ocean mass change to help explain the cause in PH trends, but they are still being investigated. How strange were recent years? Based on a look at the 30 day smoothed temperature series from 2016-2019, there seems to be early warming and warming later in the year several degrees above "normal", similar to Karen Frey's satellite findings mentioned earlier. Patterns of warming are earlier (1.3 days/yr), freezing later (0.6 days/yr), and longer open water (2 days/yr). Also, melt was in mid June, and is now in May; waters above 0°C occurred starting mid-November and is now extending later (December+); and there are now more than 6 months of seawater with temperatures above 0°C. But there are no significant trends in the Alaskan Coastal Current. For his MS Thesis (June 2019), Brett Morris examined seasonality and forcing factors of the Alaskan Coastal Current in the Bering Strait from July 2011 to July 2012. A series of graphs comparing 30 day smoothed trends in salinity, transport, and freshwater transport for heat and salinity between 2016 and 2019 indicate that winters show large change. Large freshwater events are occurring, especially in winter, showing that the traditional seasonal cycle is missing. Maximum salinities in the 1990s were around 33psu (winter) and are now 32.5psu (summer), and winter water is less dense (~0.5 kg/m^3). Cruise reports with preliminary plots of CTD sections, underway data, and mooring results can

be found here: http://psc.apl.washington.edu/HLD/Bstrait/bstrait.html. Plans for next cruise is for September 2020, note that the Norseman2 is now with SVA, Alaska.

Robert Pickart (WHOI, ppt2e)
Bob presented results about the Atlantic water boundary current from repeat DBO6 occupations. It was noted that the DBO6 line has been extended from the shelf to ~800m depth and includes part of the Beaufort Gyre. He showed maps of mean absolute dynamic topography and surface flow vectors (2013-2014) as well as section maps of DBO6 showing potential temperature (as well as indicating breaks in Pacific winter water and Atlantic water) and absolute geostationary velocity indicating onshore and offshore Atlantic Water core water. Bob then present graphics exploring the work being done tracking the current from upstream sources. He made reference to the Unified Database of the Arctic and Subarctic Hydrography (UDASH), see Behrendt et al. (2018) and posed the question: why are there two branches when he expected to see one? He describes finding four different classes of T/S structures showing graphics of the different profiles and noting that they were similar to Rebecca's observations. Percentage of point and bump profiles were shown that match the branches. In summary, he found 1) there are two branches of the Atlantic Water boundary current in the southern Canada Basin, flowing beneath and counter to the Beaufort gyre; 2) these branches transport comparable amounts of Fram Strait Branch Water (order 0.4 Sv); 3) the branches emerge from the Chukchi Borderland due to a topography-driven bifurcation; and 4) the continental slope branch experiences more mixing which results in a distinct T/S structure. Next steps include: (1) Investigate the propagation of warm anomalies, and (2) Use mooring data to flesh out the relationship between the Atlantic water boundary current and the Beaufort gyre.

Bill Williams (Fisheries and Oceans Canada, ppt2f)
Bill presented updates on the DBO8 Cape Bathurst Canada benthic hotspot, particularly the bowhead whale feeding location. Cape Bathurst upwelling is topographically enhanced by isobath convergence from the shelf to the cape as shown in images from July 26-28, 2008. Time series of upwelling at the hotspot moorings were also presented, including Cape Bathurst, 38m (2010-2019) and Hershel Island, 40m (2014-2019) and both sites were redeployed in 2019. He would like to correlate the time series to wind that drives upwelling/downwelling and in an event-based way with a goal of finding drivers of primary production.

Shigeto Nishino (JAMSTEC, ppt2g)
Shigeto presented Japanese activities for DBO hydrography and moorings including projects for GRENE (2011-2016) and ArCS (2015-2020) programs. He called attention to a special issue in the journal Biogeosciences, particularly the article, "Catastrophic reduction of sea ice in the Arctic Ocean – its impact on the marine organisms and ecosystems in the polar region". He also provided snapshot summaries of mooring results on fall blooms, ocean acidification, and zooplankton dynamics for DBO3. For DBO5, Shigeto described the motivation to examine volume and heat fluxes in Barrow Canyon during summer 2010 using 6 occupations of repeat hydrographic sections. Heat flux was consistent with that estimated from mooring and wind data near the section. Now they have more CTD and ADCP occupations for 2010-2019 so they will be able to examine interannual variabilities of parameter fluxes of the DBO5 section. The following observations were made for Barrow Canyon volume, fresh water and heat fluxes: heat flux was large in 2003, 2007, 2010, 2012, 2016, 2017 and 2018; large heat input through the Barrow Canyon into the Canada Basin occurred more frequently in the 2010s compared with the 2000s; and anomalous warm water (10 °C) was observed in 2019, probably due to less sea ice in the Chukchi Sea. Some observations in regard to eddies and their impacts on the Arctic marine ecosystem were made. It was noted that sea ice retreat causes high biological productivity on the

nutrient-rich shelves and enhances eddy activity and ocean currents in the deep basin area. As a result, the plankton habitat is expanding along the eddy pathways. Also, a large warm-core eddy was found in the Canada Basin during the R/V Mirai cruise in 2010. In regards to submesoscale sea ice-ocean interactions in marginal ice zone it was noted that signatures of ocean eddies, fronts, and filaments are commonly observed within these marginal ice zones. Shigeto also provided details for the planned R/V Mirai Arctic Ocean cruises for 2020 and 2021, including a SAS ship-based sampling campaign in 2020 and a SAS with intensive ice-edge survey in 2021. He said that the ice edge in the CAO is lacking available data but it expected to have unique conditions of atmosphere and ocean environments and ecosystems. Contrast between the ice and open water zones could cause strong winds and currents, upwelling eddies, and mixing. Melt water could cause strong stratification, freshening, cooling, and input of chemical components and organisms to the ocean. He also posed the question: How does the ice edge phenomena impact material cycles (e.g., CO_2 exchange and nitrogen fixation) and ecosystems (e.g., phytoplankton biomass and community structure, biological production, settling of ice algae and particles, benthic environment and ecosystem, and seabird migration)?

Hydrography

Sarah Zimmerman (Fisheries and Oceans Canada/ IOS, ppt3a)

Sarah provided results from DBO hydrography from recent July programs, including July 2016 to 2019 Sir Wilfred Laurier cruises. She summarized her results as: the Sir Wilfrid Laurier July time series shows 2019 continues to warm, and increase in salinity in the N. Bering Shelf and Bering Straight region. Their counterbalanced effect on density means the density range stays about the same; nutrient spatial distribution remained the same, but in 2019 the local maximums had even higher concentrations than the previous 3 years. The DFO Team is also developing a method for improving CTD oxygen accuracy when no water samples are available. The method will use multiple sensors and frequent in-house 2-point calibrations**.** She provided a series of graphics exploring that parameter patterns of variables from CTD measurements for DBO1-5 (particularly comparing 2016-2019). The following is an overview of the water parameters on the Bering and Chukchi Shelf during July: the section zigs and zags such that it always runs West to East for the zonal sections – Alaskan Coastal Water (warm and fresh) shows up a bit with in the eastern stations of DBO2/Bering St, but more strongly at eastern ends of DBO3 (Pt Hope) and DBO5. Along DBO1 there is the cold pool water, transitioning to the salty and nutrient rich Anadyr/Bering Shelf water moving northward. Anadyr Water reappears somewhat in the center of DBO3 (nutrient signature is high as well). The Chukchi Shelf is cold/salty, but it's the deeper Barrow Canyon waters that have higher nutrients. A comparison of temperature plots from 2016-2019 at 5m and 40m depths showed a warming at surface and at depth on the Bering Shelf, in the Bering Strait area and Southern Chukchi Shelf. In 2019 water was ~2 to 3 °C warmer than 2016 in these areas. The old pool south of St Lawrence Island in 2018 and 2019 does not get below -1°C, with 2017 unusually warm in the Northern Chukchi Shelf at depth. For similar plots for salinity it was observed that salinity is increasing in the surface and at depth on the northern Bering Sea Bering Strait area. 2019 is 0.5 to 1.75 PSU saltier than 2016 in most of these areas. In 2019 the western Bering Strait region is over 33 PSU and 3°C (unusually salty, warm). 2017 has saltier surface in N Chukchi Shelf less sea ice melt? Nutrients are much higher in 2019 than other years. 2018 varies a bit from Phyllis Stabeno's work, but maybe collections were out of synch. More results can be seen in Sarah's presentation.

Lee Cooper (UMCES CBL, ppt3b)

Lee presented results on stable isotopes of oxygen ($\delta^{18}O$) and some other sampling and analytical work. He noted that short edited video segments from each DBO station for years 2016, 2017, and 2019 have

been posted on Youtube and can be accessed through Lee's channel at the following link: https://www.youtube.com/channel/UCAwu4_1yYfG2LjN33zBhRFQ (note that video quality for 2018 was too poor to publish). Lee examined fractions of melted sea ice and runoff in surface waters using $\delta^{18}O$ showing results for cruises during AMBON and DBO-NCIS Healy cruises from 2017. For AMBON2017, he found that runoff accounted for up to 14% of surface water and melted sea ice accounted for <1% to 5.5% of surface water. Linked t-test showed that expected vs. observed is significantly different for most years based on analysis between 1987 and 2018. Assumptions include: 1) $\delta^{18}O_{end\text{-}member}$ of freshwater in Bering Strait inflow remains ~-19.3‰, 2) Salinity of upper halocline remains 33.1 change in freshwater volume is proportional to $(\delta^{18}O_{end\text{-}member})(x)$ = [(33.1) * original $\delta^{18}O$ value of upper halocline)] relative to: $(\delta^{18}O_{end\text{-}member})(x)$ = [(33.1) * new $\delta^{18}O$ value of Upper halocline)], and 3) Change from -1.1 to -1.6‰ corresponds to 45% increase in freshwater flow.

John Nelson (Fisheries and Oceans Canada, ppt3c)

John presented results of Sir Wilfrid Laurier underway measurements from Victoria to Barrow from 2007-2019, and DBO zooplankton updates. The geographical and temporal extent of the C30/DBO annual cruise was shown and it was noted that the cruise is approximately 3 weeks in July every year with a time series that began in the late 1990s (though the underway system was not started until the early 2000s). Measurements include a "continuous" assessment of temperature, salinity, fluorescence (2008 onwards), dissolved oxygen, dissolved nitrogen, and the continuous plankton recorder (CPR; since 2018). He noted that dissolved N_2 and dissolved O_2 taken together and accounting for solubilities and non-biological driver (wind) can be used to derive Net Community Production.

For underway sensor work future plans include: 1) calibrate and "clean up" underway time series to use for assessment of how the sea surface conditions have been changing over the past decade, and link this analysis to other data sets including but not limited to directly derived DBO data sets, and 2) evaluate how changes and ocean conditions and productivity may be effecting higher trophic level taxa and what the future may bring. For recent relevant issues, John recommends noting the Extreme mortality and reproductive failure of common murres resulting from the northeast Pacific marine heatwave of 2014-2016 as indicated in the Piatt et al. 2020 PLOS One paper and other popular press and government reports discussing bird die-off in Alaska. John also showed maps of temperature changes from 2007-2016 of the cruise track as well as temperature anomalies showing warmer hotspots in more recent years including a significant increase in 2018 and 2019. He also provided an update on zooplankton work with a list of DBO samples with ongoing taxonomy progress (working with IOPAN in Poland for example). He noted that they are having trouble finding taxonomists, but that they are pretty well calibrated from year to year. Finally, he noted that the CPR (used in 2018, 2019, and 2020) is a super effective mechanical tool to physically measure not only plankton but microplastics.

Jackie Grebmeier (for KOPRI, ppt3d)

Jackie presented results for scientists at KOPRI for DBO3 from 2014-2017 and 2019, including physical, chemical and biological measurements during similar sampling periods in the summer. They looked at patterns of temperature, salinity, phosphate, nitrite+nitrate, chla, ammonia, and DOC from west to east for these time periods during ARAON cruises to explore whether the influences of Anadyr Water and Alaska Coastal Water has increased. They noted that there has been warming over time (collection in August) with really high nutrients in the west in 2019. For DBO3, It was suggested that clams might be pumping out ammonia over time to enhance bottoms waters. The question was posed as to whether we can see higher DOC concentration in the eastern stations on this transect/ They also explored surface distributions of river water and its impact by examining river fraction, riverine DOC and heteroptrophic

bacteria. In summary: 1) in 2019, more higher salinity water and nutrient concentrations were observed in the western stations in DBO3, suggesting the influence of Anadyr Water became stronger; 2) the higher nutrient concentrations observed in DBO3 could have an impact on the primary production in the central Arctic region; 3) KOPRI's data set from 2014 to 2017 (and 2019??) shows that DOC concentration has increased in the easternmost station of DBO3, probably due to the increasing influence of Alaska Coastal Water or terrestrial DOC; 4) if riverine DOC input keeps increasing, it would significantly impact on the carbon cycle in the central Arctic Ocean; and, 5) therefore, long-term monitoring observations are required to understand environmental change in the Arctic Ocean. The 2020 ARAON cruise is planned to start August 1 from Nome to Barrow.

Export Fluxes, Lower and Upper Trophics:

Catherine Lalande (Université Laval, ppt4a)
Catherine discussed annual cycles of export fluxes of biogenic matter in the northern Bering and Chukchi Seas based on long-term monitoring using sequential sediment traps deployed on moorings near DBO sites. Collection time periods for each DBO region include: DBO 4 – 2015-2016 (Chukchi Ecosystem Observatory), 2018-2019, 2019-2020; DBO3 – 2017-2019 (ASGARD); DBO2 – 2017-2019 (ASGARD); and, DBO1 – 2020-2023 (monitoring the SLIP region). She observed that chl-a and diatom fluxes were almost as high in spring as in fall, with seasonal development differences of zooplankton and meroplankton communities. Catherine also examined seasonal changes in zooplankton fecal pellet carbon fluxes, total particulate matter, and particulate organic carbon fluxes. She also provided preliminary results for POC fluxes for DBO2,3, and 4, and noted that high-resolution biological time-series measurements are providing critical information to track biodiversity, seasonal development of the phytoplankton, zooplankton, and meroplankton communities, and food supply to the benthos.

Lower Trophics

Luisa Young (Clark University, ppt4b)
Luisa presented on phytoplankton community structure and satellite-based sea ice melt pond observations across the DBO region. She used MODIS 500m satellite imagery to quantify melt pond fraction on Arctic sea ice. Luisa noted that melt ponds are distinguishable from sea ice and open water compared to MODIS imagery, in which the reflectance of those surface features are mixed due to the pixel size. A brief overview of the approach to develop training sites and optimization algorithms that identify the most "representative" endmembers per class reduces inter class confusion and is applied to a Multiple Endmember Spectral Mixture. Luisa provided an example of aerial imagery and noted that they are currently at the accuracy assessment stage. Once this is completed they will be able to develop the time series study and take a more in depth look at melt pond evolution and trends in the DBO sites. They can then compare those trends with sea ice state: timing of sea ice breakup, freeze-up as well as with environmental data such as SST. She also provided an example of the number of images captured in a 5 ml sample using the Imaging Flow Cytobot (IFCB) for each of the DBO stations as well as images of the phytoplankton communities in those samples. Some of the research questions they hope to answer include: 1. What types of phytoplankton we see? 2. What are their abundance? 3. How do they vary over the latitudinal and longitudinal gradient? 4. Harmful Algal Bloom (HAB) types? Abundance/Counts? 5. Incorporate other parameters such as size to look at how phytoplankton size is distributed over the DBO sites, and 6. Relate the data back to other bio-physical variables (i.e. temperature, salinity, nutrients, incoming PAR).

Don Anderson/Robert Pickart (WHOI, pre-recorded, ppt4c)

Don presented his study on harmful algal blooms (HABs) and how they are increasing the risk of human poisoning syndromes, specifically from consuming shellfish. The study gathers data from the cruises of Healy 1801, 1803, and 1901. Currently there is only sparse data regarding the abundance, distribution, and dynamics of these toxin producing organisms. The collected data indicates an increasing trend of activity and concentration of these organisms due to warming temperatures and decreasing ice distribution. The project focuses on two of the most harmful HAB dinoflagellate species that produce toxins, *Alexandrium catenella*, and *Pseudo-nitzschia*. In both 2018 and 2019, a large amount of *A. catenella* cyst beds were recorded in the Chukchi Sea, with concentrations up to 17,000 per cm^{-3}. These beds were present from 200 km offshore and up to 600 km alongshore. The Bering Strait and Beaufort Sea regions recorded positive, but much lower cyst concentrations. For scale representation, the two cyst maps were displayed of the Alaskan Arctic (2018) and the Gulf of Maine (2010). The seedbeds in the Arctic region is 5 times larger than the Gulf of Main and contains around 6.4 times more *A. catenella* cysts. Don's past research confirms that the Gulf of Maine has supported large-scale recurrent HABs for many decades. Data from Healy 1801 reveals a high concentration of vegetative *A. catenella* cells, the maximum being at around 5,000 cells/L in the Chukchi Sea, high enough to cause dangerous toxicity in other regions. For Healy 1901, the blooms were documented at around 8000 cells/L, located just north of the Bering Strait. Evidence suggests that blooms in this region may be locally originating and self-seeding, which can lead to recurrent events. There are also patches of cells present (~1000 cells/L) near Utqiagvik, suggesting the possibility of a second bloom mechanism via the transport of established blooms from the south. Bottom temperature measurements recorded during August 2018 at Ledyard Bay suggested a strong correlation with rapid cyst germination, showing robust growth at 6-8°C. Results were also conclusive in the Chukchi Sea for sea surface temperatures, with 8-10°C supporting *A. catenella* growth and development. Healy 1803 documented the presence of highly toxic *Pseudo-nitzschia* (*P. australis*/*P. seriata*) between DBO2 and DBO5 stations. Many unknown species recorded at the DBO6 station line in the western Beaufort Sea and most of the eastern waters had undetermined toxicity levels. Future studies are being planned to determine whether the HABs in the Alaskan Arctic are recent occurrences or date back further in time.

Chelsea Wegner Koch (UMCES CBL, ppt4d)

Chelsea explored the production, contributions and utilization of sea ice algae in the DBO region using IP_{25} and other diatom biomarkers noting that these markers have been growing in popularity but have not been applied in the Arctic. She provided examples of Highly Branched Isoprenoids (HBIs), or lipids produced by diatoms, including Sea Ice Associated Diatoms (IP_{25} Producers), Pelagic Diatoms (Known III Producers) and an Internal Standard that is not found in marine sediments. She showed conditions for HBI synthesis in ice state conditions including: permanent ice cover, lasting ice cover, stable ice-edge/ polynya conditions, seasonal ice cover, and dominantly ice-free and how HBI biomarkers can be applied to the Arctic food web. HBI depositional patterns across the DBO for 2012-2019 showed overall, two distinct regions of varying HBI proportions. DBO 1-3 tends to be comprised of primarily pelagic HBI signal with minimal IP_{25} concentrations. There are east-west gradients in DBO3, making it transitional. DBO 4-5 has a consistently strong sympagic signal with elevated IP_{25} concentrations. She also showed that the relationship between H-print and April – June monthly mean sea ice concentrations from 2012-2017 was moderate ($p<0.001$, $R^2=0.46$, n=184). Patterns of ice-derived organic matter uptake by benthic macrofauna for the HLY1801 cruise for DBO regions 1-5 were shown for predator-scavenger, surface deposit, sub-surface deposit, suspension, and suspension-surface deposit feeding strategies. Variations of ice-derived resources within feeding guilds in the NE Chukchi Sea as well as variation of ice-derived resources within major taxa were also shown. Walrus harvest patterns were also shown for 1997-2016

for the North Slope (summer/fall), St. Lawrence Island (spring), and Bristol Bay (fall). The study found that a stronger sea ice signal occurred in diets of walrus harvested while foraging in the Chukchi Sea. However, there as no difference between DBO regions in the Chukchi Sea in 2012 – the record low sea ice year for the Arctic,.

Jackie Grebmeier (UMCES CBL, ppt4e)

Jackie presented on time series benthic biomass and composition in the DBO regions. Patterns of annual sea ice persistence and sea surface temperature anomalies were shown. Annual sea ice persistence (# of days/year of sea ice presence) across the DBO1–8 regions in the Pacific Arctic from 2013–2018 showed: decreasing sea ice cover over time and lowest level sea ice persistence in northern Bering Sea. Sea surface temperature anomalies from July 2018-2019 included >5°C in the northern Bering and Chukchi Seas surface waters with the difference between 2019-2018 highlighting the warm water in DBO1 and DBO4-5. Patterns of rich benthic communities on the western side of the Bering/Chukchi Sea system from 2000-2012 showed "foot prints" of high benthic biomass reflecting pelagic-benthic coupling and export of carbon to sediments. Macrofauna was dominated by amphipods, bivalves, polychaetes, and sipunculids.

Jackie provided summaries of observations and results for DBO 1,2, and 3. In DBO 1, threatened spectacled eiders have been keyed to sea ice and specific bivalves. They predominantly feed on 3 species of bivalves and in a shallow shelf system with high cascade potential from lower to higher trophic levels. Ocean acidification has a potential to dissolve bivalve shells and the extent and duration of the cold pool (<0°C) in the region is critical to benthic infauna by exclusion of benthic fish and epibenthic predators. Sea ice extent and chlorophyll-a concentration patterns in the DBO SLIP region were shown over time. Daily time series of sea ice concentrations in the SLIP region she highlighted the 1981-2010 mean, with 2012 (one of the highest ice year covers on record) and 2018/2019 (lowest ice years on record). Mean chlorophyll-a concentrations for the SLIP region were shown for 2003-2019 and showed higher chl-a values earlier when ice was present (May) and lower chl-a values later with low sea ice cover. Results for macrofaunal biomass and composition at time series stations (DBO1: SLIP1-5) south of St. Lawrence Island were shown for 2000-2015. Time series benthic biomass in the DBO1 showed a significant declining trend in the southern SLIP1-3 stations and average values using the Mann-Kendall (Kendall's tau) trend analysis ($p<0.0001$). Macrofaunal composition for SLIP time series sites in DBO1 indicated a change in dominance from bivalve to polychaete macrofauna in 2008 at the southern sites. For DBO2 (Chirikov Basin), an exploration of decadal data indicated that the ampeliscid amphipod prey hotspot was contracting spatially northward and polychaetes and bivalves are replacing amphipods in the SW and NW, respectively. Macrofaunal biomass and composition at time series stations for DBO2 (UTBS stations) north of St. Lawrence Island were shown for 2000-2015. Time series benthic biomass trends in the DBO2 region shows variability in recent years with only one significant trend at northwest time series station UTBS4 using the Mann-Kendall (Kendall's tau) trend analysis ($p<0.0001$). Macrofaunal composition for UTBS time series sites in DBO2 indicated that UTBS5 was dominated by ampeliscid amphipods in the 1980s, but changed to bivalves in the early 2000s and became dominated by polychaetes from 2003 onwards. DBO3 macrofaunal biomass and composition at time series stations (UTN1-7) in the SE Chukchi Sea were also shown for 2000-2015. The time series benthic biomass in the DBO3 indicated significant increasing trends at UTN1 in the south and UTN5 in the north, as well as in average values. The high biomass region has been expanding since 2012. Macrofaunal composition for UTN time series sites in DBO3 show a large bivalve biomass expansion southward from UTN5 to UTN2 since 2012 coincident with observations of increased primary production in SEC5 (Arrigo and van Dijken 2015). Work on zooplankton in the DBO3 region by Russ Hopcroft relates

copepod abundance to hydrographic conditions, finding that warm years are dominated by small *Pseudocalanus* while lipid-rich *Calanus* is more abundant in cold years. Jackie also provided several examples of environmental stressors occurring in the Pacific Arctic, including that ocean acidification could impact ecosystem services in the Arctic region based on experimental responses of three Arctic bivalves to pH and food availability (Goethel, et al. 2019). Corrosive waters are prevalent on the SE side of Hanna Shoal seasonally, an area of focused carbon deposition and high bivalve biomass. Additionally, Harmful Algal Blooms (HABs) are increasing in the Pacific Arctic along with declining sea ice, more sunlight and warmer seas.

Christina Goethel (UMCES CBL, ppt4f)

Christina presented on sediment oxygen consumption in the Pacific Arctic and the impacts of increased temperature and food supply on the benthic community and individual dominant organisms. The focus was on three regions, DBO 1, 3, and 4 from 2018 and 2019 for the core experiments. Goals of the core experiments included: how does increasing temperature affect the sediment community oxygen consumption (SCOC), how does food availability affect SCOC, and what is the contribution of the dominant organism in each of the regions to the overall SCOC? Experiments were conducted in 2018 and 2019 aboard the USCGC Healy and sediment cores were also collected in July aboard the Sir Wilfrid Laurier in 2018 and 2019. Preliminary core results for 2019 food indicate no significant difference between feeding and non-feeding in either temperature (1 °C unfed - "ambient" and 1°C fed). Preliminary results for 2019 indicated no significant difference between two temperatures (4°C unfed and 1°C unfed); however sorting for the community structure to correct for organisms that were living in the core is almost complete and may modify the final values. As an example, a HLY1801 core without *Serripes* vs. with *Serripes* was 11.05 vs 37.68 mmol $O_2\,m^{-2}\,day^{-1}$, respectively, posing the question, what is the impact and contribution of individuals? Christina provided a table of dominant organism results from 2019 for *Macoma calcarea* and *Ennucula tenuis* at DBO1, *M. calcarea* at DBO3, and *M. calcarea* and *Ampeliscidae* at DBO4. An example of individual respiration rates for 2018 data was provided from HLY1801, with DBO3.8 cores averaging 13.26 mmol $O_2\,m^{-2}\,day^{-1}$ and an individual (*M. calcarea*) being 0.105 mmol $O_2\,m^{-2}\,day^{-1}$ (or, 0.8% of total). She is still working to figure out the best way to compare values. Future work includes temperature experiments planned for both cores and individuals being repeated in August 2020 (no food experiment repeat) at the same stations in DBO1 and DBO3 for comparisons to 2018 and 2019.

Caitlin Meadows (The University of Chicago, ppt4g)

Caitlin presented the challenges facing the cold-water carbonate community due to the decline of Aragonite in the Arctic Region. The under-saturation of Aragonite in the arctic is starting to reach the lowest level yet (<1.0), which will affect calcification and shell bearing animals. This trend has not only affected shell preservation, but geologists have also noted poor preservation in cores. With dated shells from the surface mixed layer of the continental shelf habitats the rates of loss in bioturbated sea beds can be estimated. Through the collection of *Macoma sp*. and *Nuculana sp*. shells, L-Shaped Age Frequency Distribution (AFD) is found in the Arctic, with documented high loss but persistence of some shells. Numerical age range of shells is currently unknown; however, it is possible that L-shaped, mostly recently dead with strong pre-mortem loss of shells are greater than some threshold age. Stabilization and time-to sequestration will be calculable. Caitlin concludes that shell disintegration is via microbial maceration or other loss of organic matrix, not due to mineral dissolution. Microbial activity dominates early post-mortem disintegration and she notes the presence of microbial deposition of calcium carbonate in the oldest shells.

Upper Trophics

Dan Cooper (for Libby Logerwell, NOAA/NMFS/AFSC, ppt5a)
Dan provided results of benthic fish (and crab) work from 2017 and 2019. Maps of arctic cod, walleye pollock, saffron cod, and snow crab distributions in relation to temperatures were shown for 2017 noting that arctic cod was abundant and energetically dense. Maps for 2019 indicated similar results for most distributions, but arctic cod was barely found higher than 70°N latitude. In 2017, only juvenile Pacific cod were found during this survey but were found in other trawls. Sediment type at stations for fish and invertebrate distribution models were also shown for 2017 and 2019.

Catherine Berchock (NOAA/AFSC) (for Janet Clarke, UW, ppt5a)
Catherine presented results of Aerial Surveys of Arctic Marine Mammals (ASAMM) data from July-October 2010-2019 for DBO 3,4,5,6,7, and 8. Gray whale hotspot and subarctic cetaceans were observed in DBO3. Bowhead whales, gray whales, and belugas were observed in DBO4 and 5, and both bowhead whales and belugas were observed in DBO 6, 7, and 8. Unexpected sightings included subarctics near Herald Shoal and gray whales in the eastern Beaufort Sea. On-effort cetacean sightings for DBO3 and Herald Shoal included an active gray whale hotspot in Hope Canyon. There was some overlap of subarctics with gray whales, but they were largely found in shallower water. During fly-in, subarctics were observed near Hanna Shoal from July-October 2019 which were the first sightings in this area. Also observed was the northernmost visual sighting of fin whales and the westernmost humpback sightings in the northeastern Chukchi Sea. On-effort cetacean sightings in DBO 4 included gray whales in the SE quadrant. Bowhead whales were broadly distributed, mainly in September and October and belugas were few and far between. In DBO5, gray whales were sighted shoreward of Barrow Canyon while bowhead whales and belugas were mainly in Barrow Canyon. No bowheads were seen in the Chukchi in September and October 2019 despite excellent survey efforts. DBO 6 and 7 data were collected from July-October, 2010-2018 only. DBO8 data was collected in August 2019 only. Bowheads and belugas were only in the DBO areas. Bowheads were observed on the shelf and slope in summer and almost exclusively on the shelf in fall 2019 when distribution was significantly farther from shore and in deeper water. Belugas were predominantly on the slope in both seasons, but far fewer belugas were observed in the fall compared to summer. There was an unexpected sighting of 15 gray whales seen west of Tuktoyaktuk Peninsula on 21 August 2019 which was the most gray whales sighted in the Canadian Beaufort in one day or in single year.

Catherine Berchock (NOAA/AFSC, ppt5a)
Catherine also presented on the Arctic Long-Term Integrated Mooring Array (ALTIMA) for the period 2010-2019, including a map and results of long-term mooring passive acoustic data and associated patterns for DBO1-5. These data included passive acoustic recorder results from September 2010 to September 2019 for bowhead whales (Arctic species which summers in the Beaufort Sea and winters in the Bering Sea), walrus (Arctic species that summers in the Beaufort Sea and winters in the Bering Sea), humpback whale (subarctic species that summers in the Bering Sea and winters further south), and gray whales (subarctic species that summers in the Bering Sea and winters further south). Some observations include: bowhead whales in DBO1 seem to track with the ice; in DBO 2 and 3 there is a continued winter presence but walrus tend to go away when the ice does; and, humpback whales are pretty consistent in DBO 2 and 3 in contrast to gray whales which have especially decreased in DBO2 (detections have gone down in recent years). In 2016, there was some detection of right whales near DBO1 but they usually hang out further south and eat copepods.

Jackie Grebmeier (UMCES/CBL) (for Kathy Kuletz (USFWS), ppt5b)
Jackie provided an update on seabirds in the DBO area. USFWS has collected seabird survey data in the DBO area since 2007 (support from NPRB and BOEM). Map shows survey effort in the region, with locations of DBO polygons and major seabird colonies. Waffle graph shows abundance of birds (each square = 0.1 bird/km2), with abundance highest in DBO2. It also shows species composition within those DBO polygons. Short-tailed shearwaters (don't breed in AK, a southern hemisphere migrant) were abundant in 5 of 8 DBO's. In DBO2, the small planktivorous auklet (Least Auklet) was the most abundant species. Abundance and species richness was very low in the 3 Beaufort DBOs. A cluster analysis (2007-2015) (Kuletz et al. 2019; DSRII) of the at-sea survey data was used to identify 6 major seabird communities and showed that the population of these species appeared to align with shelf domains, major currents, and regional features. The most dominant species were the Northern Fulmar, Least auklet, Short-tailed shearwater, Thick-billed murre and the Crested auklet. In this time series, the Short-tailed shearwater was the most abundant species in 5 of 8 DBO stations. This seabird breeds off New Zealand and feeds in Alaska during the summer. A survey effort done in 2019 also surveyed 3,716 km of transects in the DBO region, mostly focusing on the Chukchi Sea region. The highest density of total seabirds (birds/km^2, in 3-km segments) was at the DBO3 (Hope Basin) and DBO4 and 5 in the NE Chukchi Sea. Again, the Short-tailed shearwater accounted for the majority of distribution patterns of seabird abundance within and around the DBO stations. It is noted that seabird die off events have occurred in Alaska every year since 2015. However, there is no conclusive pattern since the yearly mortality events happen with different species in different areas. In 2019, the main die off event occurred in August (around 5,800 seabirds) with the majority being Short-tailed shearwaters, with 89% of the overall carcass population. The larger counts of carcasses (1,000-2,000) were documented in Bering Strait, Bristol Bay, Kotzebue Sound, and the SE Bering Sea around St. Paul. There is no indication that HABs or disease were a factor, although the birds documented were emaciated. Much larger die offs occurred in the SE Bering Sea.

Connection to societal issues and coastal observing

Kelly Kaspar (Michigan State University, ppt6)
Kelly presented on her work from the DBO-NCIS program during HLY1901 (2019) linking coupled human and natural systems approaches with the DBO. In particular she provided maps and charts describing marine mammal observations that included 62 hours of watch effort, 78 independent sightings (187 to 215 individual marine mammals), and 10 species (6 cetaceans and 4 pinnipeds – including an observation of a fur seal at DBO4-station 5 which is unusual but not unheard of). She also noted a co-sighting of a killer whale and Minke whale in DBO1. Kelly provided a graphical representation of the links between human-nature interactions, such as shipping traffic and the environmental risks posed by shipping which include: oil spills, nutrient deposition, noise pollution, and direct ship-strikes on cetaceans. She noted that environmental risks posed by shipping happen more often than one would think. Across the Bering Sea (a critical shipping corridor), bowhead and gray whales may be more susceptible to shipping danger seasonally, so Kelly evaluated shipping traffic from 2011-2013 to examine this issue. Some of the conclusions she reached include: DBO data provide a unique opportunity to examine the spatial and temporal patterns of physical processes and their effects on biological patterns, and pairing DBO data with information on human influences in the region (e.g., shipping) can help us to better understand the interactions between humans and the natural environment.

Status of efforts for pan-Arctic DBO

Bodil Bluhm (UiT, ppt7a)
Bodil presented a conceptual approach towards an Atlantic-DBO on behalf of the planning group for this effort. She provided a regional context showing the current flows, shelfs and straits of the Atlantic inflow interacting with the Arctic water north of Svalbard. Comparing late summer temperatures of 2018 and 2019 for the Atlantic-Arctic transition, she noted that the Arctic is a very different system. Issues such as oil leases related to whether the ice edge would move northward have political implications. Time series on the functional shifts of fish due to temperature changes is ongoing. It was documented that fish in the north are now more piscivorous, and less benthivorous, thus a "borealization" of species in comparison to data collected in 2004 and 2012. There is also an increase in connectivity through generalist feeders. She also noted repercussions for the Arctic cod, *Boreogadus sp*., due to the reduction of zooplankton and overall Arctic water area. However, an increase in the population of krill was observed, a positive aspect for young cod and capelin. There is also indications of an increase in deep sea cucumber populations in various ecosystems around the world, tied to above average vertical flux. Another trend is the macro-algal increase since the year 2000. These trends are believed to be associated with structural and functional shifts in the ecosystem. She highlighted the Nansen Legacy efforts to measure seasonal and inter-annual variation in processes. Further plans for an Atlantic DBO effort include coordination, building on long-term multi-national transects, and continuing efforts to seek support for a web-based joint platform.

Christie Morrison (Fisheries and Oceans Canada, ppt7b)
Christie presented updates of the Canadian Beaufort Sea Marine Ecosystem Assessment (CBS-MEA) and ship-based and mooring trophic studies on DBO8. CBS-MEA is an ecosystem based program conducted off of a science capable commercial fishing trawler. She provided a program overview for 2012-2014 that addressed information gaps for deep-water fish communities relevant to offshore oil and gas exploration and development as well as for 2017-present which includes a comprehensive research and monitoring approach for the offshore to advance the understanding of relationships between oceanographic drivers and ecosystem responses. She explained that the DBO8 line is an area of upwelling; however, the area is strongly stratified, with the lower Pacific layer holding the majority of nutrients. Surface waters are quickly depleted in nutrients, and their sampling generally takes place post-bloom. The exception was 2014, which was a very different year for the entire ecosystem, including whales. 2018 was an ice impacted year and ice remained heavy on the Mackenzie Shelf and extended into Amundsen Gulf which made access to stations difficult/not possible. In 2018 we see freshened surface water later in the season due to ice melt. There is evidence of an upwelling event near shore with higher nutrient concentrations in the surface waters of stations DBO1(8.1) and DBO2(8.2). Chlorophyll concentrations also increase near shore and near the ice edge. Sampling upwelling events is something they try to target each year as it is very important for the productivity of the area.

Epifauna was sampled with a 2mm mesh benthic beam trawl. In 2018 richness variation was relatively low in the DBO8 region with 78 taxa found at station 3 and 28 taxa found at station 2. Cumulative biomass was low at shallow station 2 and highest at station 6. Fish and hydroacoustics data were collected by bottom trawling at stations. Echovalidation of acoustic signals showed more than 85% Arctic cod in water column catches for 2017, 2018, and 2019. At the moorings, an Acoustic Zooplankton Fish Profiler (AZFP) collected data at 50 m and 300 m at four frequencies to assess patterns of biological movement. CTD, hydrophone, and VEMCO receiver data were also collected at moorings. 2020 field plans include the CBS-MEA field season (August – September) and mooring turn around from the CCGS Sir Wilfrid Laurier.

Jackie Grebmeier (UMCES/CBL, for Jean-Éric Tremblay et al., ppt7c)
Jackie presented information about the Nutrient Transports and living marine Resources Across the Inuit Nunangat 2019-2022 (NTRAIN) program. The objectives of NTRAIN include:

1. Resolve nutrient flows through the Canadian Archipelago and their impact on the "downstream" Northwest Atlantic (by enriching existing ArcticNet time series, adding new ones at strategic locations and collaborating with national and international programs);
2. Evaluate how these flows are affected by regional microbial processes versus those that occur remotely in source waters;
3. Assess how basic planktonic variables (e.g., Chl *a*, POC/PN) and the lipid composition of organic matter respond to variability and change in the physico-chemical environment;
4. Provide a factual basis to assess the marine ecosystem's carrying capacity with respect to the production of nutritious marine wildlife;
5. Develop local capacity for the monitoring of nutrients in coastal waters.

Planned measurements include: physical variables (salinity, temperature), dissolved inorganic macro nutrients (nitrite, nitrate, ammonium, phosphate, silicate), stable N and O isotopes in nitrate, dissolved organic macro-nutrients (urea, DON, DOP), dissolved inorganic micro-nutrients (trace metals, e.g. iron), particulate organic matter (POC, PN, POP, BSi), lipid classes and fatty acid profiles of organic matter, stable C and N isotopes in particulate organic matter, and microbial community composition (molecular) and N-cycling genes (DNA/RNA), as well as modeling water transports across gateways (NEMO).

Modeling Efforts within the DBO

Mike Steele (APL/UW, ppt8a)
Mike discussed modeling the biological response to changing sea ice and ocean conditions in the Beaufort and Chukchi Seas. He noted that there seems to be a "spin up" in the Beaufort Gyre (BG) and showed a series of graphics of changes in the gyre from 1950-1990 (5 cm/s) and 2008-2011 (20 cm/s) as well as a thickening of the "freshwater lens", although it is probably not a linear process, but rather episodic. 2007 was a special year because sea ice loosened up and retracted early and there was a lot of freshwater collection, but could the gyre be spinning down? Mike noted that the central BG pycnocline is rising, which could be ice-ocean friction, eddies, wind…? Why could BG changes be important to a biologist? Nutrient-rich winter Pacific Water gets pushed around by the BG and could influence upwelling of nutrients? Jinlun's BIOMAS model of sea ice-ocean-bio shows the Beaufort Sea is influenced by the BG, but things are more complicated for the Chukchi Sea. Mike showed a series of up/downwelling graphics for time periods of 1992-2018, 2004-2016 (minus 1992-2018), and 2017-2018. It seems that high/low phytoplankton and zooplankton biomass influence a strong/weak BG. Other research they are working on includes modeling of melt ponds (declining total area, but no change per area of ice) as well as sea ice seasonality through investigating public data sets on the timing of Northern Hemisphere melt, retreat, freeze, advance, etc.

Jackie Grebmeier (UMCES/CBL, for Zhixuan Feng et al., ppt8b)
Jackie presented on modeling the changing physical and biological drivers for the northern Bering and Chukchi continental shelf. Sea ice is a fundamental component of the high-latitude marine system and ecosystem. Yet, the Arctic has been losing sea ice strata since the 1980s. An animation of daily sea ice extent from a prior year minimum in September 2016 to the following year maximum in March 2017 was shown. Arctic sea ice appears to have reached a record low wintertime maximum extent on March 7, according to scientists at NASA and the NASA-supported National Snow and Ice Data Center (NSIDC)

in Boulder, Colorado. Attention was drawn to the Pacific Arctic region, Bering and Chukchi Seas, which are influenced by the seasonal sea ice. The northern Bering and Chukchi Seas are areas in the Pacific Arctic region characterized by high northward advection of Pacific Ocean water, with seasonal variability in sea ice cover, water mass characteristics, and pelagic and benthic processes. This region is experiencing declining seasonal sea ice extent and earlier sea ice retreat along with increased ocean temperatures and freshwater content. These changes can drive shifts in marine species composition and carbon cycling and are in part tied to Pacific water advection into the Arctic, a key factor influencing hydrography, biogeochemical processes and associated ecosystem function. The advection of heat, nutrients, organic carbon, and organisms supplies the shelves of the northern Bering and Chukchi Seas with large amounts of transported material that adds substantially to seasonal in situ production. The study explores food supply mechanisms to the benthos under the changing environmental conditions. A schematic provided an overview of sympagic-pelagic-benthic coupling processes in this shelf marine ecosystem during productive seasons, mainly spring and summer. The overarching question posed was: What physical and biological processes contribute to the formation of the benthic biomass hotspots and how will changes in the Arctic system affect the persistence of these hotspots? The Biology-Ice-Ocean Modeling and Assimilation System (BIOMAS) was also described for the pan-arctic domain. A NEMURO 11-component lower trophic level model has also been adapted to the Arctic Ocean. This new model has both physical and biological components as our forcing. The biogeochemical model was developed using the framework of NEMURO model, a collaborative effort from a PICES working group a decade ago. A graphic comparing chl-a modeled from 1998-2014 to satellite data was shown with a correlation of 0.64, $p<0.001$ as well as the Bering Sea Green Belt with model validation of the Bering Strait throughflow using mooring data. Primary productivity is related to sea ice dynamics in the spring/summer and 2000 (more ice) was compared to 2018 (less ice). Significant warming of bottom water in recent years was represented in the model looking at 2000 and 2018 bottom water temperature. There was also strong inter-annual variability in NPP. In 2018, NPP decreased at SLIP, but increased at NECS and BC.

Data access and management: National and International Data Access

Jackie Grebmeier (UMCES/CBL, ppt9a)

Jackie provided an update on the DBO data parameter file and archiving as well as a broad perspective of DBO data management. These goals include:

- Strong international collaboration in a data policy for sharing and access
- International collaboration in data collection in 8 sampling transects
- DBO parameter file profile to inventory data parameters collected on transect lines, upper trophic level surveys, moorings, and satellites
- DBO data effort to facilitate data sharing and synthesis activities
- National and International distributed archive centers can rely on the DBO parameter file for exchange and access

She provided some excerpts from the 2015 DBO Data policy and well as some points of interest including:

- All participants fill out DBO parameter file of what core data type were collected at each station on each DBO line and/or within each DBO regional bounding box
- new CBL DBO project website in 2020 for data parameter templates posting and submission (send completed form to Alynne Bayard (bayard@umces.edu); produce summary matrix annually; website will also have links to US Arctic Data Center new DBO project site, other national and international DBO partner data archives

- Participants then submit data + metafile to own national archives, with agreement to share results on set DBO transect lines and within bounding boxes
- DBO has an agreed international data policy

She noted that there are 4 DBO parameter files available for mooring, satellite, upper trophic, and transect data and provided an example of a transect file that has been filled out. Jackie also provided an introduction to the NSF Arctic Data Center (https://arcticdata.io) and noted that ADC has a DBO data discovery portal (https://arcticdata.io/catalog/portals/DBO) and that CBL will develop a new DBO project page.

Jeanette Clark (Arctic Data Center, ppt9b)

Jeanette provided an introduction to the NSF Arctic Data Center (ADC) and noted that the DBO is one of the greatest producers of ADC data. She explained that one of the main goals of ADC is to preserve data for as long as possible and make it searchable/useable while also providing support and training about reproducible research. She noted that the next ADC training workshop will be in October 2020. Another goal is "data rescue", including obscure or differently formatted data and to make it available. ADC also encourages publication of scripts, programs, software, basically anything that helps reproducibility. Jeanette discussed aspects of the ADC website such as data preservation, computer reproducibility, data discovery and custom searching, data portals and project information, as well a summary of the data submission process. She emphasized that an important component of this process is to include DBO relevant search terms in metadata, such as vessel name, transect/regional information, and other relevant keywords, such "DBO". Potential future directions include: highlighting research products, improving search tools such as adding search fields and improving old metadata records, replicating DBO data across repositories, and synthesis data products. During discussion it was noted that even though no one is directly funded to do synthesis work, it needs to be a priority and ADC is interested in exploring this as part of their renewal funding. The new DBO data project page for data download is https://arcticdata.io/catalog/portals/DBO.

Shigeto Nishino (JAMSTEC, ppt9c)

Shigeto presented information about JAMSTEC's Data and Sample Research System for Whole Cruise Information data site (DARWIN - http://www.godac.jamstec.go.jp/darwin/e). He also showed a snapshot of the Arctic Data archive System (ADS) including atmosphere, ocean and land data in the Arctic region data site (https://ads.nipr.ac.jp/) noting that R/V Mirai data in DARWIN are linked to ADS.

Breakout groups to discuss DBO sampling and data protocols, coordination activities (physical oceanography, hydrography, lower and upper trophics, modeling, future activities, etc…)

Lee Cooper – Data Management Group (UMCES/CBL, ppt10a)

Lee summarized the group discussion about data management and coordination. The main outcomes of this discussion included the need to maximize data collection and sharing. This included: making it useful to outside constituencies, noting that it was not like traditional outreach for STEM, research networking using SAON road map, and including specific cases such as food security (indigenous communities – specifically the Pacific Arctic sector). Getting feedback from indigenous communities is considered particularly important. For instance, Hajo is working with ADC to fund synthesis work, resources need to be allocated for indigenous food security, DBO researchers and local communities should connect, and there is a challenge to bridge communities and ship-based research. The topic of synthesis driven by researchers was also addressed, including: assembling data is challenging and time consuming, critical data sets should be earmarked, and examples of DBO-related "low hanging fruit" include marine

mammal and CTD data. Jeanette Clark from ADC provided the example of her work on the Salmon and People grant that involved around 100 researchers. It was also noted that there is a need for research coordination, such as network funding to support coordination among countries and the need for visualization tools (e.g. remote sensing data). JAMSTEC's approach may not be feasible with ADC, but NOAA locally has some strengths for visualization. Outreach to other researchers and other constituencies is also an important factor in data-related issues. Issues of concern include: visualizations vs. code/methods to generate them, getting credit for data (what are the metrics for how your data are being used), and modeling outputs how to share (examples include ARGO and the Chesapeake Bay Program). What are important data sets to focus on for use in synthesis research? Examples include: CTD (easiest to access/concise), mooring data, marine mammal citations, and other biological data. There are also issues with using data, including: machine learning (can this help), what percentage of data are immediately or readily usable, data comparability challenges, and compiling large data sets (e.g. CTD). An initial synthesis project could be "the parameter file": what, where, when, etc… The issue of NOAA vs. international vs. NSF data archiving was also addressed, such as needing pointers to international archives, needing more information about NOAA data archives, different data and metadata requirements (e.g. NCEI linkage), and different standards, protocols, units, etc. are a challenge. ADC has a NOAA employee (Sheekla Baker-Yeboah), so NOAA funded data could go through that route.

Rebecca Woodgate – Physical Oceanography Discussion (ppt10b)

Highlights from this discussion group included: 1) winter water changes (where, drivers, impacts – Rebecca is going to work with Phyllis on a "salinity" story for the DBO region so contact Rebecca if interested); 2) nutrient story (DBO gap of nutrient sensors on moorings – possible consideration of a new DBO site west of Barrow Canyon that is en route for many ships and is near Phyllis' C-9 mooring); 3) warming story (what happened to the blob and what are the impacts); and 4) source waters for the DBO region – is it changing? Not DBO only? New DBO things to consider: 1) new DBO site around the PACO line (0.5Sv of PW heading west from Barrow Canyon – lots of prior observations from Bob, Phyllis, etc. and enroute for many ships); 2) nutrient measurements on moorings; and, 3) data/communication. Data debate and communication problems include: ADC doesn't want NOAA data (although, as Jeanette mentioned, ADC does have a NOAA facilitator), NCEI won't take NOAA formatted data, and data is spread on many sites so it hard to pull together. Some basic solutions include: list databases on DBO website (e.g. SAS does this), list of observational products on a website, list of model tools and DBO-friendly modelers, and a DBO email list (e.g. Jackie's cruise list is awesome). It was noted that some project office to pull all of this together onto a website and keep it up to date would be helpful.

Chelsea Wegner – Lower and Upper Trophic Discussion (ppt10c)

Chelsea provided a summary of the lower and upper trophic discussion where they outlined issues and suggested approaches including:

- Seasonality of measurements and cruise timing
    - Shoulder seasons are of growing importance as sea ice retreats earlier
    - Missing the blooms and the ice-biology connections
    - Dependent on ship availability, need for ice breakers, working with multiple agencies
    - Use of sediment traps and mooring data to justify this to program managers
- Cruise schedules in advance of field season – International Programs
- Establishing virtual teams for coordinated measurements
    - Nutrients
    - Phytoplankton/HABs
    - Zoops/Larval Fish

    - Benthic
    - Birds
    - Mammals
    - Fish
    - Physical Oceanography/Moorings*
- Protocol manuals/ SOPs for each of the measurements
    - Build off existing materials from MOSAiC and Nansen Legacy, modified for DBO.
    - No expectation for researchers to change their methods
    - Will benefit time series analyses where instrumentation shifts
- Science gaps
    - Under sampling at some DBO regions
    - Beaufort Sea
    - Develop a heat map of sample collection at DBO sites
    - Carbon export
- Using technology to address science gaps
- Future directions….. eDNA?
    - Triggers for adaptive sampling
- Modeling, forecasting and data issues
    - Spatial resolution insufficient for modeling and forecasts, particularly for plankton/primary production
    - Lack of rate measurements, rates are what modelers want
    - Data repositories and data managers
- Marine mammal observations
    - Ship based obs + moorings are working well together
    - Limited by funding to have observers out, volunteer based initiatives would help but experience required

Sustained DBO Sampling

Hajo Eicken (IARC/UAF, ppt11a)

Hajo presented long term observations from data collected from 1981 to 2017 to help predict Arctic system change. He also questions the best way to observe and share data among the relevant data users such as the research community and information products users. The solution proposed is the ROADS (Roadmap for Arctic Observing and Data Systems) process from SAON (Sustaining Arctic Observing Network), a tool to stimulate multinational resource mobilization around specific plans with clear value propositions, to create joint utilization of Indigenous Knowledge and science, and to coordinate engagement and ensure that maximal benefits are delivered to SAON's intended users. It is suggested that a collaboration between DBO research and SAON ROADS has the potential for offering new data and information products. He also discussed how the Arctic Observing Summit (AOS) would like to provide a community-driven, science-based guidance for the design, implementation, coordination and sustained long-term operation of an international network of Arctic observing systems that serves a wide spectrum of needs. In order to achieve this goal, a forum is suggested to create coordination and exchange between academia, government agencies, Indigenous and local communities, industry, non-governmental organizations and other Arctic stakeholders involved in or in need of long-term observations. For the 2020 Observing Summit in Akureyri, Iceland, the themes include: food security and Indigenous needs, observation in support of adaptation and mitigation, data interoperability and federated search, and observation in support of global action. He notes that there is a clear disconnect

(or, gap) between what is being collected by DBO researchers and management of coastal zones. Also, native communities in Alaska have increasingly taken a jaded view of how research activities result in outcomes for them. How can we make DBO datasets more useful to native communities in management of food security and environmental management?

Jackie Grebmeier (UMCES/CBL, ppt11b)
Jackie presented the PAG 2019 fall meeting agenda topics that occurred in Zhejiang Province, China in October 2019. Of note, Bill Williams of Canada will be the new PAG chair. The 2020 PAG meeting is planned for October or November in Victoria, Canada.

Jackie Grebmeier (UMCES/CBL, ppt11c)
Jackie presented information on DBO in the US Interagency Arctic Research Policy Committee (IARPC) Marine Ecosystem Collaborative Team (MECT) activities. She included a timeline of such activities including plans for the next 5 years and continuation of DBO in MECT activities and milestones. She also provided a list of core ship-based sampling (CTD and ADCP, chlorophyll, nutrients, carbon products, plankton (size, biomass and composition), benthos (size, biomass and composition) Seabird and marine mammal surveys, fishery acoustics and bottom trawling (every 3-5 years)) and autonomous sensor sampling (gliders, moorings, saildrone and satellite observations). Also provided was a list of examples of additional sampling on various DBO cruises in 2019 (national and international), including: optical studies for satellite calibration, colored dissolved organic matter (CDOM) and dissolved organic carbon (DOC), alkalinity, sea ice tracers (e.g., Oxygen-18), ocean acidification and carbon cycling, phytoplankton growth rates (primary production), lower trophic production studies, epifaunal and fish biodiversity studies, benthic camera for videos of benthos, genetics for microbial, meiofaunal, macrofaunal, and epifaunal studies, moorings and saildrones, gliders, contaminants and potential HABs impacting various trophic levels. Of particular note is that DBO sampling is embedded in larger process-study cruises. She also provided performance elements of collaborative efforts with numerous agencies such as NASA, NOAA, NSF, DOI-BOEM, and DOI-FWS. These include: 4.3.1 Continue Distributed Biological Observatory (DBO) sampling in regions 1-5 and make data publicly available through upload of metadata to the Earth Observing Laboratory/DBO data portal, now moved to the Arctic Data Center; 4.3.2-Continue DBO coordination activities including annual workshops, via participation in the Pacific Arctic Group (PAG), and produce the first Pacific Arctic Regional Marine Assessment (PARMA) in 2018; and, 4.3.3-Build connections between DBO and existing community-based observation programs and encourage data sharing. For example, the DBO Implementation Plan discusses fostering connections to existing community-based observation programs in an effort to link offshore observations of biological change to local observations and Indigenous Knowledge. Jackie also mentioned that the US is working towards an International Pan-Arctic DBO with the Atlantic (A) DBO including Norway, Germany, Poland, UK, and France, including research efforts in physical oceanography, plankton, benthos, vertical flux, and molecular studies as well as moorings, time series, coordinating initiatives, and planned initiatives. Five A-DBO transect lines have been suggested and a summary for the Pan-Arctic network include: Pacific DBO (ongoing), Atlantic DBO (developing), Baffin Bay DBO (developing), and Davis Strait DBO (developing).

2nd DBO DSR Special Issue Discussion

Jackie Grebmeier (UMCES/CBL, ppt12)
Jackie posed the questions:

1. Do we want a 2nd DBO special issue (SI) of papers?
2. If so, do with DSR2 (1st DBO volume with DSR), or other journal?
3. Potential papers? Send draft title, author to Jackie Grebmeier jgrebmei@umces.edu by March 15, 2020 to see if we have enough for a SI
4. Timeline?-submissions fall 2020/winter 2021?

Upcoming DBO Discussions

Jackie Grebmeier (UMCES/CBL, ppt13a)
Jackie provided oral and poster session topics and descriptions for the Ocean Science Meeting (San Diego, CA, Feb. 2020) and working group details for the Arctic Science Summit Week (Akureyri, Iceland, March 2020).

Shigeto Nishino (JAMSTEC, ppt13b)
Shigeto provided details about the Sixth International Symposium on Arctic Research (ISAR-6) in March 2020 in Tokyo, Japan, including the Synoptic Arctic Survey sessions and side meeting agendas.

Jackie Grebmeier (UMCES/CBL, ppt13c)
Jackie provided a summary of the Synoptic Arctic Survey – Taking the pulse of the Arctic Ocean System, from the Shelves to the Pole – The International Distributed Biological Observatory and the Developing Synoptic Arctic Survey. Some background information include: the rapidly changing sea ice conditions and linkage to atmospheric and oceanographic components, accelerated opening of the Central Arctic Ocean for human use (e.g., transportation, potential fisheries, military use) as well as potential for cascading ecosystem changes in the high Arctic and girdling Arctic seas highlight the need for coordinated data collections and analysis. The **D**istributed **B**iological **O**bservatory (**DBO**) – is a coordinated, network of international time series observations in the Pacific Arctic being expanding to a pan-Arctic effort; an example for the Synoptic Arctic Survey activities. The **S**ynoptic **A**rctic **S**urvey (**SAS**) - a bottom-up, researcher driven initiative to define the present state of the Arctic Ocean and understand the major ongoing transformations, with an emphasis on water masses, the marine ecosystem and carbon cycling through research cruises in 2020/2021. The 2020/2021 SAS effort is a pan-Arctic, multi-ship, multi-disciplinary study in August/September that will collect standard environmental data to determine status and trends of the opening Arctic Ocean. Present state and major ongoing transformations of the Arctic marine system (specifically the ecosystem and carbon system) include: Describe the present state of the Arctic Ocean to provide the foundation against which future states can by compared to quantify change. Three key foci include: 1) physical drivers of importance to the ecosystem and carbon cycle, 2) ecosystem response, and 3) carbon cycle and ocean acidification. This is envisioned to repeat each decade. Some recommendations/findings from the SAS planning workshop in May 2019 include:

- Core parameters for the three focus areas refined
- Spatial and temporal scales of sampling refined
- The importance of non-core, non-focus area measurements that can be easily collected during the cruises emphasized (e.g., meteorological, topography, gravity)
- Data management plan discussed – networked data storage with open access within program

- Modeling can provide greater spatial and temporal context; the SAS measurements can improve biogeochemical modeling
- Pre-fieldwork and post-fieldwork synthesis activities need to be defined and emphasized
- Ideas advanced for engagement of local, indigenous communities including participation on cruises and pan-Arctic science fairs

Lee Cooper (UMCES/CBL, ppt13d)
Lee presented an overview of WG39 and WGICA activities from the PICES 2019 Annual Meeting (Connecting Science and Communities in a Changing North Pacific). These efforts have a North Bering Sea and Chukchi Sea focus and for more information, you can contact Libby Logerwell (libby.logerwell@noaa.gov).

End of Meeting

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Appendix A

AGENDA-FINAL

5th DBO Data Meeting Final Agenda
January 22-23, 2020, NOAA/PMEL, Seattle, WA, USA

January 22, 2020 – Wednesday (0800 – van transport from Silver Cloud Hotel to PMEL for check-in)

0900 **Welcome and Logistics: Jessica Cross, PMEL/NOAA**

0910 **1. Meeting Objectives and Overview of the DBO (Jackie Grebmeier)**

0920 **2. Highlights of DBO 2010-2019 data time series** (~5-10 min presentations max from each speaker; more composite time if a group talk (e.g. Upper trophics); **(BOLD is discussion Lead)**

Remote sensing, hydrography and moorings **(Phyllis Stabeno)**

- Optical, biogeochemical, and satellite remote sensing observations across the DBO (Karen Frey)
- Satellite-detected fall phytoplankton blooms in the DBO regions (Hisatomo Waga)
- Physical oceanography/moorings
  - DBO1 results from M8 (Phyllis Stabeno)
  - What's new in the Bering Strait (Rebecca Woodgate)
  - The Atlantic water boundary current from repeat DBO6 occupations (Robert Pickart)
  - DBO8-Cape Bathurst (Bill Williams)
  - Japanese activities for DBO: hydrography and moorings (Shigeto Nishino)

10:30 Coffee Break

1100 Hydrography **(Jessica Cross)**

- Hydrography results from recent July DBO cruises aboard the CCGS Sir Wilfrid Laurier (Sarah Zimmerman)
- Oxygen-18 as a water mass tracer in the Pacific Arctic (Lee Cooper)
- Flow through system results from the CCGS Sir Wilfrid Laurier DBO cruises (John Nelson)

11:30 **Continue Highlight Presentations: Export Fluxes, Lower and Upper Trophic levels (Jackie Grebmeier)**

- Annual cycles of export fluxes of biogenic matter in the Bering and Chukchi Seas (Catherine Lalande)
- Lower trophics
  - Phytoplankton community structure and satellite-based sea ice melt pond observations across the Distributed Biological Observatory (DBO) (Luisa Young)
  - Harmful algal blooms in the Bering, Chukchi, and Beaufort Seas in 2018 and 2019 (Don Anderson/Robert Pickart)
  - Exploring the production, contributions and utilization of sea ice algae in DBO using IP25 and other lipid biomarkers (Chelsea Wegner)
  - Time series benthic biomass and composition in the DBO regions (Jackie Grebmeier)

1220 **Lunch (NOAA Cafeteria, no host)**

1330 **Continue Highlight Presentations**

- Lower trophics **(Jackie Grebmeier)**
  - Sediment oxygen consumption in the Pacific Arctic: Impacts of increased temperature and food supply on the benthic community and individual dominant organisms (Christina Goethel)
  - The fate of cold-water carbonate: the scale of time averaging of molluscan aragonite on the productive Alaskan Arctic shelf (Caitlin Meadows)

1350 Upper trophics **(Catherine Berchok)**

- Catherine Berchok, Libby Logerwell, Janet Clark) et al. (Catherine Berchok**)**
- Seabirds in the DBO – 2019 Update (Kathy Kuletz by Jackie Grebmeier)

1440 **3. Connection to societal issues and coastal observing** (**Jackie Grebmeier)**

- Linking coupled human and natural systems approaches with the Distributed Biological Observatory (Kelly Kapsar)

1500 Coffee break

1530 **4. Status of efforts for pan-Arctic DBO** (Atlantic, Beaufort Sea, Baffin Bay) **(Jackie Grebmeier)**

- Atlantic DBO and connection to Nansen Legacy project (Bodil Bluhm UiT)
- Canadian Beaufort Sea Marine Ecosystem Assessment (CBS-MEA): ship-based and mooring trophic studies on DBO8 (Christie Morrison, Andrea Niemi, Andrew Majewski)
- NTRAIN (2019-2022)-Nutrient transports and living marine resources across the Inuit Nunangat updates (Jean-Éric Tremblay et al. by Jackie Grebmeier)

1630 Discussion & wrap up

1700 End day and van transport to hotel - **Group Dinner (no host, 7 pm, location Piatti Restaurant in University Village)**

January 23, 2020 – Thursday (0800-van transport from Silver Cloud Hotel to PMEL)

0900 **Overview of Day 1 and plan for Day 2 (Jackie Grebmeier)**

0915 **5. Modeling efforts within the DBO** (**Lee Cooper)**

- Modeling the biological response to changing sea ice and ocean conditions in the Beaufort and Chukchi Seas (Mike Steele)
- Modeling the changing physical and biological drivers for the northern Bering and Chukchi continental shelf (Zhixuan Feng by Jackie Grebmeier)

0945 **6. Data access and management**: **National and International Data Access** (**Jackie Grebmeier**)

- DBO data parameters file (Jackie Grebmeier)

- Introduction to the NSF Arctic Data Center (Jeanette Clark)
- NOAA Data Submissions (Eugene Burger)
- Japanese Data Centers, DARWIN and ADS (Shigeto Nishino)

1030 **7. Charge to Break-out groups (Jackie Grebmeier), then Coffee break**

1100 **Breakout groups to discuss DBO sampling and data protocols, coordination activities (physical oceanography, hydrography, lower and upper trophics, modeling, future activities) (Jackie Grebmeier)**

1230 Lunch (NOAA Cafeteria, no host)

1345 **Brief out from breakout groups and open discussion**

- physical oceanography
- hydrography
- lower trophics
- upper trophics
- modeling

1430 **8. Sustained DBO sampling (Jackie Grebmeier)**

- DBO Data Users/Providers community can interface with the Arctic Observing Summit 2020 and SAON (Hajo Eicken)
- DBO as one of Pacific Arctic Group's core activities (Jackie Grebmeier)
- DBO within the US-IARPC Marine Ecosystem Collaborative Team and planning for next US 5 yr. IARPC plan (Jackie Grebmeier)

1500 Coffee break

1530 **9. 2nd DBO DSR special issue discussions** (Jackie Grebmeier)

1600: **10. Upcoming DBO discussions (Jackie Grebmeier)**

- AGU/ASLO Ocean Sciences Meeting, San Diego, CA, USA-February 2020 (Jackie Grebmeier)
- ISAR-6, SAS session and side meeting, Tokyo, Japan-March 2020 (Shigeto Nishino)
- ASSW2020, Akureyri, Iceland, March 2020 (Jackie Grebmeier)

1615 Action Items & Timeline: future plans, open discussion (Jackie Grebmeier)

1700 End of workshop and van transport to hotel

Appendix B-5th DBO Data Workshop Participants

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