**Annotated Bibliography for Fish Creek ISP (organized by themes)**

**Theme / Question 1: How will a warming climate affect connectivity of aquatic habitats? How likely is loss of connectivity to disrupt fish movements and access to summer feeding, spawning or wintering habitat?**

Concept:

Burn, C. R. (1995). "The hydrologic regime of Mackenzie River and connection of "no-closure" lakes to distributary channels in the Mackenzie Delta, Northwest Territories." Canadian Journal of Earth Science **32**: 926-937. Lake connectivity is defined by sill or outlet elevation relative to river flood frequency elevations and also considered relative to lake ice thickness. Classification of lakes as no-closure (year round and summer), low-closure, and high-closure (isolated). Erosion and sediment deposition can be an important process in changes in lake classes.

Francis, J. A., D. M. White, et al. (2009). "An arctic hydrologic system in transition: feedbacks and impacts on terrestrial, marine, and human life." Journal of Geophysical Research **114**(G04019): 1-30. A heuristic graphical approach to understanding Arctic system interactions and feedbacks suggest, among other things, that 1) uncertainty in atmospheric drivers is related to net precipitation (amount and rain vs. snow), 2) the role of changing precipitation on tundra vegetation succession is uncertain, and 3) terrestrial vegetation plays a key role hydrologic system feedbacks.

Hershey, A. E., G. M. Gettel, et al. (1999). "A geomorphic-trophic model for landscape controls of Arctic Lake food webs." BioScience **49**(11): 887-897. The geomorphic-trophic hypothesis is a conceptual model presented as a decision tree whereby fish species distribution is determined by geomorphic features of the landscape, including lake depth, lake surface area, and outflow gradient. By quantifying the landscape criteria for each fish species, it is possible to determine fish community structure for a given lake. Fish community structure in turn affects benthic and pelagic invertebrate communities.

Jorgenson, M. T. and Y. Shur (2007). "Evolution of lakes and basins in northern Alaska and discussion of the thaw lake cycle." Journal of Geophysical Research **112**(F02S17): 1-12. This work provides a revision of thaw lake succession, suggesting non-cyclic processes starting at initial ponding of water to degrade variable ice content permafrost, sediment redistribution, eventual drainage by expanding stream networks, and reformation of ponds in drained basins depending on sediment type and ice content. This suggests differing formation processes ice-rich marine silts (true thaw lakes) vs. deeper lakes that form in the sand sea region. Analysis resulted in a lake classification of thermokarst, depression, and riverine lakes across much of the Alaskan Arctic Coastal Plain.

Lesack, L. F. W. and P. Marsh (2010). "River-to-lake connectivities, water renewal, and aquatic habitat diversity in the Mackenzie River delta." Water Resource Research **46**(W12504): 1-16. The duration and timing of river-lake connectivity is linked to lake water balance and water and nutrient renewal. The degree of connectivity can vary greatly among lakes in low lying delta or floodplain environments creating a diverse mosaic of aquatic habitats, productivity, and food webs.

Analysis:

Arp, C. D., M. S. Whitman, et al. (2012). "Drainage network structure and hydrologic behavior of three lake-rich watersheds on the Arctic Coastal Plain, Alaska." Arctic, Antarctic, and Alpine Research **44**(3). This paper is focused on the Fish Creek watershed and quantifies variation in lake and stream habitat including connectivity and lake classes in relation to surficial geology. The relationship of this hydrographic structure to runoff characteristics is made, namely that the extent and proportions of lakes and drained lake basins creates variable responses in snowmelt and baseflow runoff.

Bowling, L. C. and D. P. Lettenmaier (2010). "Modeling the effects of lakes and wetlands on the water balance of Arctic environments." Journal of Hydrometerology **11**: 276-295. Lake and wetland storage deficit is a key parameter in predicting both snowmelt and rainfall runoff in Arctic Coastal Plain watersheds. Satisfying storage deficits is necessary for event runoff to occur indicating the important role of interannual variability in lakes levels and hydrologic responses.

Jorgenson, M. T., Y. L. Shur, et al. (2006). "Abrupt increase in permafrost degradation in Arctic Alaska." Geophysical Research Letters **33**(L02503):1-4. Analysis of imagery since 1945 in Fish Creek watershed suggests recent degradation of ice wedge networks to form thaw pits that were thought to be previously stable for 1000’s of years. This pattern corresponded with increased summer air temperatures. This form of permafrost degradation could result in enhanced tundra drainage to thaw pits and formation of drainage networks, and affect large portions (10-30%) of tundra lands surfaces.

Lesack, L. F. W. and P. Marsh (2007). "Lengthening plus shortening of river-to-lake connection times in the Mackenzie River Delta respectively via two global change mechanisms along the arctic coast." Geophyscial Research Letters **34**(L23404): 1-6. This paper analyzes a long-term dataset describing the lake connectivity in terms of timing and duration and classifying lakes as open or closed systems. They show a shift in the duration of connectivity in varying portions of the watershed because of changes in sea level in low elevation lakes and timing and intensity of breakup peakflows in higher elevation lakes.

Woo, M. and X. J. Guan (2006). "Hydrological connectivity and seasonal storage change of tundra ponds in a polar oasis environment, Canadian High Arctic." Permafrost and Periglacial Processes **17**: 309-323. Seasonal water balance and corresponding surface and subsurface connectivity is investigated in an area of tundra ponds. All ponds were connected briefly by surface flow following snowmelt and rapidly became isolated to minor subsurface flows during the rest of the summer except during rainfall events. Changes in the active layer thickness or lateral breaching could change the relative water balance of such tundra ponds.

Woo, M. and C. Mielko (2007). "An integrated framework of lake-stream connectivity for a semi-arid, subarctic environment." Hydrological Processes **21**: 2668-2674. Channel flow connectivity among a chain of lakes is investigated according to lake water balance relative to outlet elevations. This analysis shows that basic fill-spill principles can be applied to understanding stream-lake connectivity where changes in watershed runoff, precipitation, and evaporation can each affect downstream connectivity depending on individual lake and lake outlet characteristics.

Methods:

Brock, B. E., B. B. Wolfe, et al. (2007). "Characterizing the hydrology of shallow floodplain lakes in the Slave River Delta, NWT, using water isotope tracers." Arctic, Anarctic, and Alpine Research **39**(3): 388-401. Sampling water isotopes and TSS from set of lakes occupying differing hydrogeomorphic settings was used to classify lakes according to river-lake connectivity and summer water balance dynamics.

Kline, T. C., W. J. Wilson, et al. (1998). "Natural isotope indicators of fish migration at Prudhoe Bay, Alaska." Canadian Journal of Fisheries and Aquatic Sciences **55**: 1494-1502. Stable isotope can be used to differentiate and understand life histories and trophic levels for freshwater, marine, anadromous, and amphidromous species in Arctic environments. Suggest that monitoring isotopic signatures of certain species (broad whitefish, Arctic cisco, Dolly Varden) during extreme year (high or low water runoff) can show responses foraging at different trophic levels.

Pohl, S., P. Marsh, et al. (2007). "Modeling the impact of climate change on runoff and annual water balance of an arctic headwater basin." Arctic **60**(2): 173-186. Results from a spatially explicit runoff model run using future climate projections suggest much earlier runoff peaks of similar magnitude and higher overall runoff. Midwinter melt events are also more likely.

**Theme / Question 2: How will stream and lake temperatures and water chemistry respond to warmer air temperatures? Too what extent would warmer temperatures result in increased primary and secondary productivity, increased fish growth rates, decreased age of maturity, increased metabolic demands?**

Concept:

Lesack, L. F. W. and P. Marsh (2010). "River-to-lake connectivities, water renewal, and aquatic habitat diversity in the Mackenzie River delta." Water Resource Research **46**(W12504): 1-16. The duration and timing of river-lake connectivity is linked to lake water balance and water and nutrient renewal. The degree of connectivity can vary greatly among lakes in low lying delta or floodplain environments creating a diverse mosaic of aquatic habitats, productivity, and food webs.

Analysis:

Bowden, W. B., M. N. Gooseff, et al. (2008). "Sediment and nutrient delivery from thermokarst features in the foothills of the North Slope, Alaska: potential impacts on headwater stream ecosystems." Journal of Geophysical Research **113**(G02026): 1-12. This paper pertains to foothills landscapes and documents increases in sediment and nutrients downstream of thaw slumps and other thermokarst features, which may impact stream productivity and benthic communities. It is uncertain whether other thermokarst associated with low-lying terrain, lake erosion, lake drainage, channel migration, or headward expansion on the ACP could contribute similar changes to aquatic ecosystems.

Hobbie, J. E., B. J. Peterson, et al. (1999). "Impact of global change on the biogeochemistry and ecology of an Arctic freshwater system." Polar Research **18**(2): 207-214. In Toolik region, warmer air temperatures are expected to deepen the active layer and contribute additional phosphorous to streams and lakes. This will enhance aquatic ecosystem productivity. In addition to eutrophication, warmer water temperatures will increase stratification and together lower winter oxygen levels. Lake trout will be replaced by burbot as top predator.

Kokelj, S. V., B. Zajdlik, et al. (2009). "The impact of thawing permafrost on the chemistry of lakes across the subarctic boreal-tundra transition, Mackenzie Delta Region, Canada." Permafrost and Periglacial Processes **20**: 185-199. Retrogressive thaw slumping along lake shorelines and watershed causes elevated ion concentrations and enhanced turbidity in lakes. These effects varied regionally.

Lantz, T. C. and S. V. Kokelj (2008). "Increasing rates of retrogressive thaw slump activity in the Mackenzie Delta region, N.W.T., Canada." Geophyscial Research Letters **35**(L06502): 1-5. Aerial photographic analysis over two time period since 1950 suggest an increase in the number of retrogressive thaw slumps in relation to increasing summer air temperatures. Thaw slump material and solutes contribute to altering stream and lake water chemistry. The revegetation of these slump features may also provide important habitat.

Methods:

Kline, T. C., W. J. Wilson, et al. (1998). "Natural isotope indicators of fish migration at Prudhoe Bay, Alaska." Canadian Journal of Fisheries and Aquatic Sciences **55**: 1494-1502. Stable isotope can be used to differentiate and understand life histories and trophic levels for freshwater, marine, anadromous, and amphidromous species in Arctic environments. Suggest that monitoring isotopic signatures of certain species (broad whitefish, Arctic cisco, Dolly Varden) during extreme year (high or low water runoff) can show responses foraging at different trophic levels.

Reist, J. D., F. J. Wrons, et al. (2006). "General effects of climate change on Arctic fishes and fish populations." Ambio **35**(7): 370-380. This review paper suggests that a lack of basic knowledge of fish biology and habitat interactions prevents quantitative predictions of responses to climate change. A set of approaches to projecting fish responses to climate change (primarily water temperature) are reviewed.

**Theme / Question 3: What is the likelihood that climate change will alter the availability of key freshwater bird habitats? Specifically, should we anticipate any population-level effects from either a change in the rate of lake area, or widespread drying of shallow (e.g., polygonal terrain) wetlands?**

Concept:

Francis, J. A., D. M. White, et al. (2009). "An arctic hydrologic system in transition: feedbacks and impacts on terrestrial, marine, and human life." Journal of Geophysical Research **114**(G04019): 1-30. A heuristic graphical approach to understanding Arctic system interactions and feedbacks suggest, among other things, that 1) uncertainty in atmospheric drivers is related to net precipitation (amount and rain vs. snow), 2) the role of changing precipitation on tundra vegetation succession is uncertain, and 3) terrestrial vegetation plays a key role hydrologic system feedbacks.

Jorgenson, M. T. and Y. Shur (2007). "Evolution of lakes and basins in northern Alaska and discussion of the thaw lake cycle." Journal of Geophysical Research **112**(F02S17): 1-12. This work provides a revision of thaw lake succession, suggesting non-cyclic processes starting at initial ponding of water to degrade variable ice content permafrost, sediment redistribution, eventual drainage by expanding stream networks, and reformation of ponds in drained basins depending on sediment type and ice content. This suggests differing formation processes ice-rich marine silts (true thaw lakes) vs. deeper lakes that form in the sand sea region. Analysis resulted in a lake classification of thermokarst, depression, and riverine lakes across much of the Alaskan Arctic Coastal Plain.

Rawlins, M. A. and others (2010). "Analysis of the Arctic system for freshwater cycle intensification: observations and expectations." Journal of Climate **23**: 5715-5737. GCMs predict increasing precipitation, evapotranspiration, and river discharge and many observations confirm these predictions throughout the Arctic. Precipitation is predicted increase relative to evaporation and melting of excess ground ice may contribute to increasing river discharge.

Analysis:

Bowling, L. C. and D. P. Lettenmaier (2010). "Modeling the effects of lakes and wetlands on the water balance of Arctic environments." Journal of Hydrometerology **11**: 276-295. Lake and wetland storage deficit is a key parameter in predicting both snowmelt and rainfall runoff in Arctic Coastal Plain watersheds. Satisfying storage deficits is necessary for event runoff to occur indicating the important role of interannual variability in lakes levels and hydrologic responses.

Hinkel, K. M., W. R. Eisner, et al. (2003). "Spatial extent, age, and carbon stocks in drained thaw lake basins on the Barrow Peninsula, Alaska." Arctic, Anarctic, and Alpine Research **35**(3): 291-300. Lakes have been draining continually over last 5500 yrs and appear to occur at uniform rate suggesting these events are not climatically controlled. Lake reestablishment in DTLBs may be indicated by polygon coalescence and driven by hydrologic and fluvial geomorphic processes, such as changing atmospheric water balance, runoff, headward erosion, or stream evulsion.

Jones, B. M., C. D. Arp, et al. (2009). "Arctic Lake Physical Processes and Regimes with Implications for Winter Water Availability and Management in the National Petroleum Reserve Alaska." Environmental Management **43**(6): 1071-1084. Analysis of lake area extent on the Arctic Coastal Plain suggest that interannual variability can be explained by precipitation with no trends detected over a 25 year period. Changes in lake ice thickness may reduce or increase overwinter habitat and water supply depending on lake bathymetry. Locally, lake drainage or coalescence creates dramatic changes in habitat.

Jorgenson, M. T., Y. L. Shur, et al. (2006). "Abrupt increase in permafrost degradation in Arctic Alaska." Geophysical Research Letters **33**(L02503):1-4. Analysis of imagery since 1945 in Fish Creek watershed suggests recent degradation of ice wedge networks to form thaw pits that were thought to be previously stable for 1000’s of years. This pattern corresponded with increased summer air temperatures. This form of permafrost degradation could result in enhanced tundra drainage to thaw pits and formation of drainage networks, and affect large portions (10-30%) of tundra lands surfaces.

Marsh, P., M. Russell, et al. (2009). "Changes in thaw lake drainage in the western Canadian arctic from 1950 to 2000." Hydrological Processes **23**: 145-158. Analysis of the rate of lake drainage for a 10000 km2 area shows an average of 1 drainage per year over a 50 year period and this rate decreased during this period. A high number of drained lakes observed in 1989 corresponded to a warm relatively wet summer with deeper active layers and moderately high lake levels.

Plug, L. J., C. Walls, et al. (2008). "Tundra lake changes from 1978 to 2001 on the Tuktoyaktuk Peninsula, western Canadian Arctic." Geophysical Research Letters **35**(L03502): 1-5. Larger lakes were found to both expand and contract during two periods analyzed using Landsat imagery. Variability was best explained by precipitation in the preceding year and its suggested that such variability masked lake change due to thermokarst expansion.

Pohl, S., P. Marsh, et al. (2007). "Modeling the impact of climate change on runoff and annual water balance of an arctic headwater basin." Arctic **60**(2): 173-186. Results from a spatially explicit runoff model run using future climate projections suggest much earlier runoff peaks of similar magnitude and higher overall runoff. Midwinter melt events are also more likely.

Rovansek, R. J., L. D. Hinzman, et al. (1996). "Hydrology of a tundra wetland complex on the Alaskan arctic coastal plain, U.S.A." Arctic and Alpine Research **28**(3): 311-317. Tundra pond water balance is dominated by snowmelt that fills storage deficit that typically occurs during the previous summer when E exceeds P. Evaporation losses are highest in the early summer. Using a static catchment area for pond or lake water balance studies is problematic due in low-relief tundra due to snow damming and variable storage deficits and contributing areas.

Sturm, M. and G. E. Liston (2003). "The snow cover on lakes of the Arctic Coastal Plain of Alaska, U.S.A." Journal of Glaciology **49**(166): 370-380. Snow cover on Arctic lakes tends to be thinner, denser, and of longer drift wavelength than tundra environments. Intralake patterns of snow accumulation may impact lake hydrology, lake ice growth, and long term lake evolution.

Woo, M. and X. J. Guan (2006). "Hydrological connectivity and seasonal storage change of tundra ponds in a polar oasis environment, Canadian High Arctic." Permafrost and Periglacial Processes **17**: 309-323. Seasonal water balance and corresponding surface and subsurface connectivity is investigated in an area of tundra ponds. All ponds were connected briefly by surface flow following snowmelt and rapidly became isolated to minor subsurface flows during the rest of the summer except during rainfall events. Changes in the active layer thickness or lateral breaching could change the relative water balance of such tundra ponds.

Zhang, T. and M. O. Jeffries (2000). "Modeling interdecadal variations of lake-ice thickness and sensitivity to climatic change in northernmost Alaska." Annals of Glaciology **31**: 339-347. Variation in maximum lake ice thickness is investigated over a fifty year period on the Arctic Coastal Plain. A wide range of variability is first due to snow and second temperature suggesting the potential for changes in shallow lakes that freeze to the bed.

Methods:

Labrecque, S., D. Lacelle, et al. (2009). "Contemporary (1951-2001) evolution of lakes in the Old Crow Basin, Northern Yukon, Canada: remote sensing, numerical modeling, and stable isotope analysis." Arctic **62**(2): 225-238. This paper used multiple approaches to analyze lake change and documents variable change according to lake size over two time periods. An overall pattern in lake size reduction during the latter period corresponds to more arid climate conditions and shifts in the Arctic and Pacific Decadal Oscillations.

Frohn, R. C., K. M. Hinkel, et al. (2005). "Satellite remote sensing classification of thaw lakes and drained thaw lake basins on the North Slope of Alaska." Remote Sensing of Environment **97**(1): 116-126. 50-75% of the Arctic Coastal Plain is covered by either thaw lakes or drained thaw lake basins (DTLBs) and the latter of which can be effectively identified and map using Landsat imagery. The outer ACP is covered by a higher proportion of DTLB relative to thermokarst lakes, while the inner ACP has a higher proportion of thermokarst lakes relative to DTLBs.

Turner, K. W., B. B. Wolfe, et al. (2010). "Characterizing the role of hydrological processes on lake water balances in the Old Crow Flats, Yukon Territory, Canada, using water isotope tracers." Journal of Hydrology **386**(1-4): 103-117. This paper recognizes the inherent regional variability in lake and lake basin water balance processes in permafrost landscapes. Primarily using water isotope data, lakes are characterized as snow-melt dominated, rainfall-dominated, ground-water influenced, and evaporation dominated. It is suggested that these classes can be used to predict hydrological responses to climate change.

**Theme / Question 4: Is there evidence for the existence or future development of a “trophic mismatch” between birds and aquatic invertebrates? Consider both timing/quantity and composition/quality of the food base in relation to energetic demands.**

Concept:

Francis, J. A., D. M. White, et al. (2009). "An arctic hydrologic system in transition: feedbacks and impacts on terrestrial, marine, and human life." Journal of Geophysical Research **114**(G04019): 1-30. A heuristic graphical approach to understanding Arctic system interactions and feedbacks suggest, among other things, that 1) uncertainty in atmospheric drivers is related to net precipitation (amount and rain vs. snow), 2) the role of changing precipitation on tundra vegetation succession is uncertain, and 3) terrestrial vegetation plays a key role hydrologic system feedbacks.

Hershey, A. E., G. M. Gettel, et al. (1999). "A geomorphic-trophic model for landscape controls of Arctic Lake food webs." BioScience **49**(11): 887-897. The geomorphic-trophic hypothesis is a conceptual model presented as a decision tree whereby fish species distribution is determined by geomorphic features of the landscape, including lake depth, lake surface area, and outflow gradient. By quantifying the landscape criteria for each fish species, it is possible to determine fish community structure for a given lake. Fish community structure in turn affects benthic and pelagic invertebrate communities.

Analysis:

Kling, G. W., W. J. O'Brien, et al. (1992). "The biogeochemistry and zoogeography of lakes and rivers in arctic Alaska." Hydrobiologia **240**: 1-14. This paper provides a nice synoptic overview of zooplankton and benthic invertebrate distribution from the foothills to coastal plain and how these communities relate to lake and stream water chemistry and physical regimes.

Stone, R. S., E. G. Dutton, et al. (2002). "Earlier spring snowmelt in northern Alaska as an indicator of climate change." Journal of Geophysical Research **107**(D10): 1-15. A variable but downward trend is detected in snowmelt date in Barrow of 8 days over 35 years. This has important implications for surface energy balance and vegetation phenology.

Sturm, M., C. Racine, et al. (2001). "Increasing shrub abundance in the Arctic." Nature **411**: 546-547. This study uses repeat aerial and oblique photography to document changes in alder, willow, and birch at several locations on the North Slope and suggest a trend toward increase shrub abundance. This could have many implications to snow distribution, energy balance, and forage and habitat availability.

Methods:

Kline, T. C., W. J. Wilson, et al. (1998). "Natural isotope indicators of fish migration at Prudhoe Bay, Alaska." Canadian Journal of Fisheries and Aquatic Sciences **55**: 1494-1502. Stable isotope can be used to differentiate and understand life histories and trophic levels for freshwater, marine, anadromous, and amphidromous species in Arctic environments. Suggest that monitoring isotopic signatures of certain species (broad whitefish, Arctic cisco, Dolly Varden) during extreme year (high or low water runoff) can show responses foraging at different trophic levels.

Brock, B. E., B. B. Wolfe, et al. (2007). "Characterizing the hydrology of shallow floodplain lakes in the Slave River Delta, NWT, using water isotope tracers." Arctic, Anarctic, and Alpine Research **39**(3): 388-401. Sampling water isotopes and TSS from set of lakes occupying differing hydrogeomorphic settings was used to classify lakes according to river-lake connectivity and summer water balance dynamics.

**Papers applicable across all themes:**

Martin, P. D., J. L. Jenkins, et al. (2009). Wildlife Response to Environmental Arctic Change: Predicting Future Habitats fo Arctic Alaska. Report to the Wildlife Response to Environmental Change (WildREACH): Predicting Future Habitats of Arctic Alaska Workshop. Fairbanks, U.S. Fish and Wildlife Service**:** 138. A thorough literature review and discussion organizing consensus research and thought around Alaskan Arctic climate change, landscape responses, and relevance to habitat and biota.

Streever, B., R. Suydam, et al. (2011). "Environmental change and potential impacts: applied research priorities for Alaska's North Slope." Arctic **64**(3): 390-397. This paper reviews state of Alaska North Slope science relative to management and policy needs and make recommendations for applied science priorities. The need for strategic planning is strongly encouraged.

Rouse, W. R., M. S. V. Douglas, et al. (1997). "Effects of climate change on the freshwaters of arctic and subarctic North America." Hydrological Processes **11**: 873-902. This paper provides a thorough review of potential changes in Arctic aquatic ecosystems with respect to hydrology, light and thermal regimes, primary and secondary productivity. A number of potential scenarios for different arctic ecosystems are presented.

Post, E., M. Forschammer, et al. (2009). "Ecological dynamics across the Arctic associated with recent climate change." Science **325**(5946): 1355-1358. A number of observed and projected responses to Arctic climate change are reviewed. Themes for future research include winter research, understanding landscape heterogeneity as a buffer, scale dependent responses, and the impact of extreme events. The use of baseline studies are most informative in describing processes of Arctic ecosystem change.

**Other papers addressing relevant aspects of Arctic climate change:**

Kaufman, D. S., D. P. Schneider, et al. (2009). "Recent warming reverses long-term Arctic cooling." Science **325**(5945): 1236-1239. Proxy temperature records are used to reconstruct decadal scale temperature patterns during the past 2000 years, showing a long-term cooling trend following summer insolation patterns. This trend was reversed since 1950 with the five warmest decades recorded during the full period of analysis.

Lawrence, D. M., A. G. Slater, et al. (2008). "Accelerated Arctic land warming and permafrost degradation during rapid sea ice loss." Geophyscial Research Letters **35**(L11506): 1-6. Under a scenario of rapid sea ice loss, simulated western Arctic terrestrial warming is 3.5X 21st century global trends. This pattern occurs 1500 km inland and peaks in late autumn. Enhanced heating could lead to vulnerability of cold permafrost to degradation through the formation of taliks.

Serreze, M. C., J. E. Walsh, et al. (2000). "Observartional evidence of recent change in the northern high-latitude environment." Climate Change **46**: 159-207. This paper provides a thorough and comprehensive review of Arctic change showing among other things that air temperature is changing most rapidly in the winter and spring, precipitation increases in the autumn and winter, no trends in P-E, and reduced spring snowcover. Many other records are too short or sparse to assess change.