Canadian Sea Ice and Snow Evolution: The CanSISE Network: Third Annual Progress Report

SECTION 1. INTRODUCTION, PROGRESS ON PROJECTS AND DELIVERABLES

CanSISE integrates Canadian research on modeling and prediction of seasonal snow, sea ice cover, and related climate variability. Proposed in 2012 as a new collaborative group, CanSISE brings to bear state of the art observational data and climate model systems to assess and improve Canada's capacity to understand and predict aspects of climate that are linked to snow and sea ice.[1] We emphasize rigorous model-observation comparison and assessment, accounting for model and observational uncertainty, in the context of anthropogenic climate change and natural climate variability. We focus on EC climate prediction systems in an international setting and link our activities to those in modeling centres worldwide. As a project focused primarily on data mining activities, with additional in-kind computing support provided by EC and Compute Canada, our funds are devoted almost entirely to salaries and training of student and postdoctoral researchers (highly qualified personnel or HQP).

The Project Year 1 (2013-2014) Report reflected initial set-up of the network. The Project Year 2 (2014-2015) Report summarized considerable progress on research, filling the complement of HQP, completion of the major CanSISE sponsored "CanESM Large Ensemble" simulation set, and improving our Network's web presence. We were able to address most of the previous concerns of the external reviewers (we will mention some comments in passing or through endnotes). This Project Year 3 Annual Report (Feb. 2015 to Jan. 2016) highlights progress on our research projects, applied research results leading to improved capacity in the CanSIPS climate prediction system, successful workshops, progress on the Deliverable 1 report and recommendations following from it (covered in the rest of this section). We will also discuss our budget (Section 2, Tables, Appendix A), and past and pending international proposals (not funding direct research costs), and management, operations, HQP and partnerships in Section 3. We briefly look ahead to the midterm evaluation of the Climate Change and Atmospheric Research program (CCAR) in Section 4. Updated membership list and presentations/publications are presented in Appendix B and Appendix C.

Projects and Deliverables

1. For **Research Area A (***S/SI Prediction and Projection***)**, **Project A1** (*Improved observational datasets for initialization and verification***)** improves existing retrieval methods and data records and quantifies inter-dataset consistency. Since Project Year 2 we have identified new aims and applications for this project, which will continue to be updated in the coming years. In Project Year 3 Research Associate Mudryk and the Derksen team published an intercomparison of northern hemisphere snow water equivalent (SWE) and snow-cover extent that benefited projects in all three research areas of the network. The result product is a blend of 5 snow products that is termed "Blended-5". The work for Blended-5, first described last year, involved detailed assessment of several daily, gridded Northern Hemisphere snow water equivalent (SWE) datasets derived from satellite passive microwave measurements and reanalysis driven land models, in order to quantify the spatial and temporal consistency of the satellite retrievals relative to land surface assimilation systems, physical snow models, and reanalyses. This was published this year in a paper by Mudryk et al.. In more recent work this year, all datasets were also compared to independent in situ reference datasets in order to determine absolute uncertainty and bias. By quantifying spread, bias, and skill in satellite and land surface model derived datasets, this analysis is providing new understanding of the uncertainty in available snow products used to derived observational trends and evaluate climate models. CanSISE support of RA Mudryk continues to be critical to this effort.

   At our regional workshop in Victoria in September 2015, we identified a need to create a multidataset product in the area of sea ice to complement the Blended-5 snow dataset. Contributing to this is York University's Haas group, with PDF Bajish CC and undergraduate summer student Pittana (intern from May to August 2015). Broad comparisons of Arctic sea ice observations with CanESM2 model simulations show large systematic differences with respect to ice concentration, ice thickness, and ice drift (see Project C2.1 below). Additional airborne ice thickness data and satellite data in the Arctic in 2015, in particular over the Beaufort Sea and Northwest Passage, gathered with the support of other projects (MEOPAR, ESA Cryosat validation) will starting in

Project Year 4 be used for comparison with CanSIPS and CanESM2 model results. Given the value of the Blended-5 dataset for snow in the projects described below, and the time and resources required to assemble it, it is clear that a concerted effort needs to be made to create a multi-source dataset for sea ice and to make sure that both sea ice and snow datasets are kept up to date. This is clearly along the lines of our original proposed work and we believe will be feasible to design and undertake in the remaining years of the Project. The creation and maintenance of multi-source datasets for sea ice and snow will be a key recommendation of the Deliverable 1 report.

2. For **Project A2.1** (*Assessment of prediction skill for snow, sea ice and related variables*), in the area of snow, the previous collaboration of Merryfield and CanSISE PDF Sospedra-Alfonso with Kharin to compute deterministic and probabilistic skill measures for CanSIPS SWE predictions based on different verification products was extended to include the Blended-5 snow dataset developed under Project A1 (item 1 above). Use of Blended-5 for verification was found to result in higher skill scores than when individual products were used. This is a potentially very important result: the creation of this blended dataset apparently reduced errors in our observational estimates. Thuse improved skill derived from an improvement in the quality of the verification data and not an improvement of the forecast per se. These results together with work characterizing SWE potential predictability under project A4 are described in a paper in preparation by Sospedra-Alfonso et al.
3. For **Project A2.2** (*Improved CanSIPS snow/land surface initialization*), Merryfield continued working with Berg and CanSISE PDF Ambadan to examine the influence of the initialization of snow and soil moisture on subseasonal predictions at the 15 to 60 day range in CanCM3 hindcasts that were originally performed for the GLACE-2 project, focusing on initialization in early spring rather than in summer which was the focus of GLACE-2. Realistic initialization of snow and soil moisture was found to have discernible positive effects on forecasts of near surface temperature over the temporal range considered, especially near the seasonal snow line. Also, realistic SWE initialization was found to have an influence comparable to that of liquid and solid soil moisture. A Climate Dynamics paper by Ambadan et al. describing this work has been published. Ambadan is continuing his work on this theme evaluating the impact of snow initialization on subsequent anomalies of soil moisture for improved seasonal prediction of boreal spring seasonal to sub-seasonal climate forecasts, a manuscript on this application is in preparation. A new PDF, Dr. Manoj Kizhakkeniyil has been recruited to begin in January 2016 to begin work on the initialization of the seasonal forecast systems CanSIPS using Canadian Land Data Assimilation System (CLDAS) to be carried out with Dr. Bélair (this work follows from commitments in our original proposal). M.Sc. student Williamson has written a manuscript and presented a paper at the AGU/CGU 2015 on the development of a soil freeze thaw observation network for comparison with satellite data from the Soil Moisture Active Passive Satellite and with land surface models.
4. For **Project A2.3** (*Improved CanSIPS sea ice initialization*), CanSISE PhD student Dirkson, now in his second year of graduate study, completed work with Merryfield and A. Monahan of Victoria on a statistical method to obtain estimates of the distribution of Arctic sea ice thickness that can be used to initialize seasonal forecasts in real time. The method uses past statistical relationships between ice thickness and variables that are observable in real time, such as sea ice concentration and sea level pressure. This technique, which improves considerably on the method used currently to initialize sea ice thickness in CanSIPS, is described in a paper by Dirkson et al. published in Geophysical Research Letters. In continuing this line of investigation, Dirkson has developed an new version of the sea ice thickness statistical model that has improved representation of interannual variability, and is analysing several sets of CanSIPS hindcasts that use different methods for sea ice thickness initialization. Initial results show marked improvements in CanSIPS forecasts of sea ice concentration when ice thickness fields from the statistical models and PIOMAS are employed for initialization.
5. **Project A2.4** (*Streamflow predictions/Western Cordillera*) aims to use recently developed statistical downscaling methods to predict the Fraser River Basin's streamflow on seasonal timescales. Ph.D. student Snauffer continued work comparing observational products in comparison to manual snow

survey station values over British Columbia, and then training an artificial neural network (ANN) model and predicting station SWE values. ANNs with the lowest mean station RMSEs were found to include the best performing gridded products, and also compared well with the Variable Infiltration Capacity (VIC) model run over four major BC watersheds. Further improvements were found by incorporating SWE from the basic one-layer energy balance SnowMelt model of the R package EcoHydRology (driven by bias-corrected ANUSPLIN precipitation and temperature values). Adding passive microwave satellite data to the ANN has also been tested – though there was no significant improvement in the mean station RMSE. This project is working toward the development of a high-resolution SWE dataset for BC, which will then serve as a basis for downscaling CanSIPS SWE forecasts. To make VIC based hydrological projections computationally affordable, CanSISE co-PI Hsieh used an ANN to emulate the VIC model. An ANN was trained using predictors from the CMIP3 climate projections and using predictands (streamflow and SWE) from the VIC model output. Future work will involve driving the ANN VIC emulator with CMIP5 output to produce streamflow and SWE projections for various scenarios.

6. For **Project A3** (*Analysis of interannual to multidecadal S/SI predictions and projections*) Derksen, Mudryk, and the CCCma are contributing to the development of coupled climate model experiments within the World Meteorological Organization/Climate and Cryosphere (WMO-CliC) Earth System Model Snow Model Intercomparson Project (ESM-SnowMIP). ESM-SnowMIP is addressing one of the cryosphere 'grand challenges' identified by the World Climate Research Programme. The overall goals are to perform coupled climate model simulations with prescribed (observed SWE; observed albedo) versus freely evolving snow conditions to identify snow feedbacks on the atmosphere, and perform offline simulations over a few select supersites to allow evaluation with comprehensive observations. The CanESM2 Large Ensemble (proposed by CanSISE) and the NCAR CESM Large Ensembles help characterize internal model variability for a large number of climate realizations, for comparison to the spread in observations provided by multiple snow extent and SWE datasets (see project A1). The natural variability in the ensembles will be used to better understand the mechanisms driving snow cover variability in the presence of anthropogenic forcing. This comparison is providing input into CanSISE Deliverable 1 (see below). We can now characterize more precisely the level of consistency with the models between the Blended-5 SWE data across the seasonal cycle and in light of internal variability (ms in prep by Mudryk et al.).
7. For **Project A4** (*Assessing limits to S/SI predictability*) CanSISE PDF Sospedra-Alfonso continued work with Kharin on the calculation of potential predictability (PP) of snow water equivalent in CanSIPS. Building on previous work involving approximate PP calculations, they have obtained a more robust statistical estimation of PP using an analysis of variance technique (ms in prep).
8. For **Research Area B (***Attributing change in S/SI and modelling its impacts*), **Project B1** (*Drivers of S/SI change: High latitude temperature and precipitation*) was largely completed in Years 1-2. **Project B2** (*Detection and attribution of northern hemisphere SCE changes*), focused on attribution of spring snow cover extent to anthropogenic influence through a formal detection and attribution analysis of SCE changes based on several different observational datasets, including a blended multi-source dataset extending from the first half of the 20th century to present day (the "Blended-5" snow dataset described above only covers the satellite era). NH SCE extent changes in these datasets were analysed using responses to anthropogenic and natural forcings combined (ALL) and to natural forcings alone (NAT) from the CMIP5 models (ms in prep).
9. **Project B3** (*Implications of precipitation and snow cover changes on water resources*) comprises several subprojects on impacts of large-scale climate change to snow on hydrological characteristics in the Western Cordillera:
   a. At PCIC, a project on attribution of the regional SWE/summer runoff decline in Western Canada due to climate change will be in progress through Year 4. Detection and attribution of the multi-decadal trend in the snow water equivalent (SWE) and summer runoff of four river basins with distinct hydro-climatic characteristics that are located in BC has been conducted. A suite of ten CMIP5 GCMs were used including ensembles of 40 climate simulations of the

responses to both anthropogenic and natural forcing signals combined (ALL), responses to natural forcings alone (40 ensembles, NAT) and ~4200 years of preindustrial control simulations (CTL). These simulations were downscaled to daily time series at 1/16° spatial resolution to drive the Variable Infiltration Capacity (VIC) hydrologic model. The observed, i.e. manual snow survey, and VIC reconstructed SWE were then projected onto the multi-model ensemble means of the VIC simulated SWE based on the responses to different forcings using the optimal fingerprinting approach. A manuscript describing the results is in preparation.

b. Also taking place at PCIC in Year 3 were studies led by Research Associate Kumar on general controls on the detectability of hydrologic change. While changes in precipitation have been detected and attributed to anthropogenic forcing, this has not translated into a clear detection of changes in stream flow and runoff. Part of the cause is traced to the highly heterogeneous nature of the terrestrial branch of the hydrological cycle (due to heterogeneous land surface properties); energy limited regimes need to be distinguished from moisture limited regimes. The region in western Canada that is the focus of the attribution study described above is energy, rather than moisture limited (ms in revision for Water Resource Research). Another study considers projected hydrologic change and contributes to the current active discussion of the validity of the "wet gets wetter, dry gets dryer" (WWDD) paradigm for change over land areas. We find that the WWDD signal is weaker over land (particularly in areas that are already dry), and that evaluation of where the WWDD holds in the current climate can be obscured by internal variability. A paper by Kumar et al. is in revision for GRL.

c. Déry's group at UNBC conducted simulations with the Variable Infiltration Capacity (VIC) model (Liang et al. 1994) forced by CMIP5 data; they estimated projected future changes in snow hydrology of Fraser River Basin by focusing on its major sub-basins, three hydro-climatic sub-regions and different elevations; and they accounted for uncertainties in CMIP5 driven VIC simulations by comparing RCP4.5 and RCP8.5 scenarios and inter-model simulations. This was the first work to extensively account for the impact of future changes in FRB snowpack levels and their variation with different elevations using VIC-based downscaling of CMIP5 projection forcings. Analyses reveal widespread and regionally coherent spatial changes in snowfall, SWE and SC over most of the FRB by the 2050s. While the mean annual precipitation is found to increase in the FRB, the fraction of precipitation falling as snow decreases by 20-30% in the 2050s. Substantial declines are seen in snow accumulation and snow covered areas across FRB's sub-regions particularly in the Rocky Mountains. The projected changes show future onsets of FRB springtime snowmelt around 20-25 days earlier than the current onsets, producing more winter and spring runoff for the Fraser River main stem at Hope, BC. The contribution of snowmelt to runoff is found to be declining for all of the Fraser's sub-basins, with the maximum decline of 20% in Stuart and Nautley sub-basins. Amplified decreasing rates of SWE and SC are found at higher elevations, reflecting more sensitivity of mountainous snowpacks to climate change. The results of this project have important implications for quantitative impacts assessment of climate driven future changes in the FRB's hydrology (ms led by UNBC PDF Islam in prep). In Year 4, difference between the GCM results and projected changes in precipitation extreme indices over the FRB will be assessed, along with the role of large-scale teleconnections.

d. At CCCma, Fyfe, with Dersken, Mudryk and others, led a study on unavoidable snowpack loss over the Western U.S. Cordillera. This extends CanSISE activities to include the entire North American continent. Snowpack loss over the Western U.S. Cordillera has occurred over recent decades associated with a general surface warming over North America. They used updated observations and land reanalyses to estimate a 24 ± 7% reduction in winter snowpack over the Western U.S. Cordillera from 1982 to 2010 which is consistent with that obtained from the CanESM Large Ensemble of climate model simulations forced with natural (volcanic and solar) and anthropogenic (greenhouse gas, aerosol, ozone and land use) changes but is inconsistent with natural forcing changes alone. They showed that winter snowpack in the 2030s will very likely be 37 to 54% lower than the 1980s (p = 0.9) with especially unfavourable decadal variability raising the percent loss from 54 to 65% (p = 0.1). These losses are independent of future forcing scenario and hence are unavoidable. They suggest that such losses will have major consequences, including from an associated 32 to 44% decline in Columbia River summer outflow (p = 0.9). Underpinning this work are two products stimulated by CanSISE: the CanESM Large Ensemble and the Blended-5 snow dataset.

10. For **Project B4** (*Detection and attribution of Arctic sea ice and snow cover extreme* events), work is proceeding on three fronts. The PCIC/CCCma collaboration has been training PhD student Mueller to work in this area. Preliminary work demonstrates (as expected) that the observed decline in September Arctic sea ice extent is due to anthropogenic forcing of the climate system; Mueller is developing a PhD thesis proposal to be defended in 2016, which is dealing in part with the question of whether the usual practice of using control runs to estimate internal variability in detection and attribution studies is appropriate in the case of Arctic sea-ice extent, since large changes in sea-ice extent could be expected to affect the amount of unforced (i.e., internal) variability in sea-ice extent. At the same time Zwiers is collaborating with a Korean group from Pohang University on a detection and attribution study that is considering the regional distribution of changes in Arctic sea-ice cover and is evaluating the extent to which low frequency internal variability associated with Atlantic Multidecadal Variability may have played a role in the observed sea-ice extent decline. A paper is in the final stages of preparation. Finally, in the fall of 2015, PCIC and CCCma recruited PDF Kirchmeier-Young, to undertake an event attribution study of the extreme Arctic sea-ice extent minima that were observed in 2007 and 2012. Preliminary comparisons of the CanESM Large Ensemble to observations show that biases will have to be accounted in the event attribution project.
11. For **Research Area C** (*Snow and sea ice processes and climate interactions*), in Project Year 2 we renamed **Project C1.1-i** with the title *Snow-albedo feedback and other climate interactions*. PDF Sospedra-Alfonso extended previous work examining the relative influences of temperature and precipitation interannual variability on variability of snow. Specficially, a previous analysis based on station observations in a regional domain encompassing the central Rocky Mountains was extended to the entire Northern Hemisphere in CanESM2 simulations. A boundary was defined that delineates generally more southern regions where snow variability is influenced more strongly by temperature from generally more northern regions where snow variability is influenced more strongly by precipitation. This boundary was shown to migrate poleward in 20th and 21st century climate simulations.

    At Waterloo, for the Fletcher group's snow albedo feedback work, Thackeray et al. (2015) developed a skill metric that was used to highlight deficiencies in the simulation of snow-covered surface albedo and snow cover among CMIP5 models. The CanESM2 model was found to perform very well in this respect, placing 2nd out of 16 CMIP5 models over the Northern Hemisphere extratropics. In Project Year 4, the group plans to use this metric to quantify model improvements related to the cryosphere, both in the Canadian models, and also the NCAR CESM models that we run in the University setting. The group also submitted a review paper that received excellent reviews (Thackeray and Fletcher, *Proceedings of Physical Geography*, in revision) that synthesizes the current state of knowledge, importance, outstanding issues, and future directions related to the topic. In the final quarter of Y3, Chad Thackeray will design and run a new set of simulations using the NCAR CESM model, and its land model component CLM4 run in offline mode, which aim to quantify the climate impact of biases in simulated surface albedo. This set of simulations will take us a long way toward completing our research goals for item C1.1i.
12. **Project C1.1-ii** (*Sea-ice albedo feedback*) was slated to begin in **Year 3** and was explored through undergraduate research projects in Year 2. Our proposed has been broadened to a project entitled *Sea-ice albedo feedback and related feedback processes.* In Project Year 3, University of Toronto Ph.D. student Blackport (see Project C2.1 below) identified an unanticipated cloud-ice response operating in his NCAR CESM sea ice loss simulations (see Project C2.1). In this work, the amount of cloud ice over the Arctic and the fraction of cloud ice to total cloud amount increases in response

to sea ice loss in the NCAR CESM1 model, which stands in contrast to intuition and to results obtained from the older NCAR CCSM4 model. Blackport has undertaken a budget analysis of the cloud microphysical processes in the model to see if a simple explanation of this behaviour can be found. He is also examining the potential radiative impact of the changes to cloud ice, whether it acts to enhance or attenuate the warming associated with sea ice loss. Toronto Ph.D. student Hay pursued analysis of coupling between high latitude heat fluxes and wind stresses in the vicinity of the marginal ice zone in high resolution coupled simulations of CESM1. Toronto PDF Tandon, starting with CanSISE in April 2015, has begun an investigation of regional Arctic feedbacks between sea ice and atmospheric circulation in the context of Arctic decadal variability to follow on recent work of Tandon and Kushner on North Atlantic decadal variability.

13. **Project C1.2** (*Changes of wind-driven ice drift and deformation in relation to ice thickness variations in observations and GCMs*) UG student Pittana and PDF Bajish at York continued their comparison of observations of seasonal variations of snow on sea ice from ice mass balance buoys (IMBs) with reanalyses and simulations from NCEP, a snow climatology (Warren et al., 1999), CanESM2, and CCSM4. In addition, long-term trends were retrieved from time series of NCEP, CanESM2, and CCSM4 data. Results showed that seasonal snow accumulation partially compares well in reanalyses and models with observations, considering that the IMB measurements represent measurements through space and time along the drift path of the ice, and that they observe local conditions at the buoy site rather than average snow conditions in a larger region corresponding to a model grid cell. In some cases, individual snow fall events were represented both in the observations and reanalysis. There was better agreement between observations and models than with the agreement with CanCM model results carried out in 2014.
14. For **Project C1.3** (*Towards improved sea ice physics and dynamics in the Canadian GCMs*) the McGill group led by Tremblay and Slavin further developed their modeling evidence, supported by observations, for strong Ekman pumping velocities beneath active leads (Linear Kinematic Features, LFKs) where discontinuity in the sea-ice drifts and the surface ice-ocean stresses momentum transfer are present. They use a high resolution coupled ice-ocean model forced with contemporaneous atmospheric forcing. They find that simulated vertical velocities near LKFs can extend hundreds of meters below the surface, into the Warm Atlantic Layer. Averaged over the Beaufort Sea, results suggest that wintertime heat fluxes associated with Ekman pumping beneath active LKFs are sufficient to melt about 11 cm of sea ice and that this process, not represented in lower-resolution global climate models, can be important in controlling recent Beaufort Sea sea-ice decline, in the overall Arctic sea-ice mass balance, and in amplification of projected thinning of sea ice in the near future. A paper is in the final stages of internal reviews before submission.
15. **Project C2.1** (*Changes in sea ice extent and impacts on circulation*) is a topic of considerable interest and work in various groups internationally. Reviewer comments on Project Year 2's report suggested that we should be careful to highlight those aspects of this problem that are unique and original to CanSISE. We point out that although this problem is well studied, emerging results are not consistent and the number of modeling studies is still much smaller than technically similar work carried out in areas such as tropical-midlatitude connections or European response to North Atlantic SST anomalies. There are three subprojects going on in this area within the network, all of which provide new insights to these important problems that have strong implications for Arctic influences on midlatitude variability in general and Canadian climate in particular:
    a. At CCCma, McCusker and Fyfe analyzed the impact of Arctic sea ice loss on Eurasian cooling. Previous studies suggest that recent Eurasian cooling is due to ice loss in the Barents-Kara Sea (situated north of Eurasia). Their research shows, using the CanESM Large Ensemble and other climate simulations, that this ice loss is unlikely the cause of the cooling. Rather, the model simulations suggest that Eurasian cooling in winter is due to the transport of polar air by a long-lived randomly-generated circulation feature over the Barents-Kara Sea. These results improve our knowledge of high-latitude climate variability and change, with implications for impacts and adaptation in human and natural high-northern latitude systems (ms in prep).

b. In Toronto, Blackport and Kushner have published a study on the response to imposed sea ice loss in the coupled model CCSM4. They find that in that model the atmospheric response outside the Arctic region is very limited after the effects of internal variability are averaged out. Strikingly, they find that temperature variability at all timescales, and other measures of atmospheric variability at most timescales, are reduced in response to sea ice loss. In continuing work in preparation, Blackport has continued his coupled model simulation work and has developed a physical attribution framework using pattern scaling ideas to separate the atmospheric circulation response to low-latitude surface temperature changes from sea ice related changes in the context of coupled models. This framework suggests, for example, that greenhouse warming driven tropical surface temperature changes will drive increases in precipitation over the North Pacific, while sea ice changes will increase precipitation over the west coast of North America. The coupled climate simulations carried out here, on Compute Canada resources, are unique in several aspects.

c. At McGill, Tremblay's group has developed two projects in this area. With Ph.D. student Desjardin the group has analyzed the sea ice/ocean evolution of the CCSM3 and CCSM4 models' temporal evolution of the minimum sea ice extent in the Arctic Ocean. In CCSM3, abrupt reductions in summer Arctic sea ice are present in all ensemble members leading to a seasonally ice-free Arctic as early as 2040 (Holland et al, 2006). In all ensemble members, the abrupt sea ice declines are preceded by a pulse of heat of Atlantic origin into the Arctic Ocean, causing an increase in open water area, and absorbed solar radiation at the surface triggering the positive ice-albedo feedback. In CCSM4, no abrupt reductions in summer Arctic sea ice are simulated; instead, the model simulates a slow decline in sea ice leading a seasonally ice-free Arctic by the end of the century. A key difference between the two versions of the CCSM is the partitioning of ocean heat of Atlantic origin between Fram Strait and the Barents Sea gate. Ocean heat transport differences in the models drive profound differences in the sea ice evolution and consequent feedbacks in clouds and sea ice. In the second project, Gervais has continued work on how patterns of Arctic air masses will be affected by sea ice loss and polar amplification. The CESM Large Ensemble is used to define regimes of equivalent potential temperature variability using self-organizing maps. Under climate change, a pattern with negative θe850 anomalies situated over the central Arctic will become less frequent with time, while there is an increase in the frequency of patterns with either positive or negative θe850 anomalies over North America, associated with more intense ridges and troughs in the 500hPa flow. Physical attribution of these trends suggests that there will be enhanced forcing of baroclinic waves owing to reduced sea ice over the western Arctic. This work is also unique and has been well received.

16. **Project C2.2** (S/SI response to teleconnected forcing) started as scheduled in Project Year 3 after preliminary work in Year 2. Bichet, prior to departing to LGGE in Grenoble, France, completed part of this analysis. She has developed a framework based on Bichet et al. 2015 to estimate the portion of past and projected trends in land-surface temperature, precipitation, and snow cover associated with greenhouse warming, using a modelling approach that is tightly constrained by observed trends in sea surface temperatures and sea ice. Using this approach she finds that a significant portion of Northern European snowcover has exhibited retreat that is attributable to greenhouse warming (communicated to continental climate by changes in sea surface temperatures). Changes to Western North American snow have been dominated by modes of internal variability such as the Pacific Decadal Oscillation. This work was part of a proof-of-concept study that will be submitted by the end of this Project Year 3 (January 2016). It was well received when presented at the NCAR CESM Workshop in Breckenridge and the WCRP Decadal Climate Variability and Predictability meeting in Trieste, Italy. In Year 4 we will analyze future projections using the Bichet et al. framework.

17. For **Project C3.1** (*Declining SCE: Characteristics and causes*), work by Research Assistant Hernández-Henriquez (UNBC) described last year was published in Environmental Research Letters. This focused on identifying the mechanisms contributing to recent springtime SCE reductions in North America and Eurasia. Ongoing research (led by UNBC Ph.D. student Allchin)

includes establishing Northern Hemisphere SCE trends to determine which regions are undergoing significant reductions or increases in SCE, investigating at grid-point and biome level of shifts in snowcover duration, and also in frequency of transitions between snow-on and snow-off states in different contexts. EC's Derksen led work, Arctic spring snow conditions for 2014 and 2015 in the context of the historical record as a contribution to the NOAA Arctic Report Card and State of the Climate Report. In addition, new satellite climate data records documenting frozen (FR) season and snow cover extent (SCE) changes were analysed from 1979 to 2011 over all northern vegetated land areas (≥45°N). New insight on the spatial and temporal characteristics of seasonal frozen ground and snowmelt changes were revealed by integrating the independent FR and SCE data records.

18. **Project C3.2-i** (*Changes in sea ice area and type in the Canadian Arctic Archipelago*) and **Project C3.2-ii** (*Changes in pan-Arctic SIE, thickness and snow on ice*), were originally envisioned as beginning in Project Year 4 (2016-2017). This work is led by EC collaborator Howell and co-PI Haas. For C3.2i, results are being published of the first ever airborne electromagnetic ice thickness surveys over the Northwest Passage within the Canadian Arctic Archipelago carried out in April and May 2011 and 2015. These show modal thicknesses between 1.8 and 2.0m in all regions. Mean thicknesses over 3m and thick, deformed ice were observed over some multiyear ice regimes shown to originate from the Arctic Ocean. Thick ice features more than 100m wide and thicker than 4m occurred frequently. Results indicate that even in today's climate, ice conditions must still be considered severe. These results have important implications for the prediction of ice breakup and summer ice conditions, and the assessment of sea ice hazards during the summer shipping season. For C3.2ii: Efforts to retrieve snow depth on sea ice using the NASA Operation IceBridge (OIB) snow radar have described uncertainties related to vertical heterogeneity of snow, ice deformation, and radar side lobes. To evaluate these potential uncertainties, an OIB mission was flown near Eureka, Nunavut as part of the 2014 OIB Arctic campaign. A series of 12 parallel flight lines covered a narrow swath of first year sea ice, approximately 50 km in length. Immediately following the OIB mission, an intensive 10-day field campaign was completed to characterize snow and ice properties within the footprint of the OIB snow radar at multiple scales. More than 30,000 geo-located snow depth measurements were collected along the primary transect with 94% located within the snow radar footprint. OIB 'quick-look' (QL) snow depth on sea ice retrievals were evaluated using in situ measurements taken over immobile first-year ice (FYI) in the Canadian Arctic Archipelago and multi-year ice (MYI) in the Lincoln Sea during March of 2014. Comparison of QL retrievals with in situ measurements along a 50 km FYI transect showed good agreement was found over in undeformed level FYI ice conditions with reduced agreement over deformed ice. This dataset will allow for an improved characterization of snow depth on sea ice, contributing to model initialization and verification for CanSIPS and CanESM2.

19. For the CanSISE Network Deliverables, our **Deliverable 1 Report** (*Assessment of S/SI Biases, Projections, and Predictions in the Canadian GCMs*) from diagnostic Projects in Research Areas A and C on CanSIPS and CanESM2 will be finished by the end of Project Year 3 (January 2016), as per our commitment last year. The report focuses on the performance of CanESM and the CanSIPS systems over the Canadian land mass, with additional analyses for the Northern Hemisphere as a whole.[2] The report provides an overview of temperature, precipitation, snow cover, and sea ice simulations of the CanESM model in the context of international modeling efforts and observational uncertainty; comments on impacts that the current horizontal resolution of CanESM has on sea ice and snow simulations, particularly over the Canadian Arctic Archipelago; comparisons of recent trends in seasonal snow cover and sea ice with available observations (some developed under CanSISE), accounting for observational uncertainty; documentation of advances in CanESM and CanSIPS stimulated by the CanSISE activity. The report will recommend that 1) increased attention to snow and sea ice processes be a key objective of subsequent model development, 2) careful attention should be paid to the land-sea mask and resolution of the model in the vicinity of the CAA, especially for planned future development, 3) plans should be made to create a multi-dataset sea ice dataset to complement the "Blended 5" snow dataset developed under CanSISE, and 4) NSERC

should continue to encourage EC and the Canadian research community to continue to collaborate on diagnostic evaluation of its modeling systems. The report will be provided to EC management and posted on the CanSISE website. We are tentatively planning to provide either a summary for the CMOS Bulletin or an article for the peer reviewed literature, depending on the overall scientific content of the final report. In Project Year 4 goals and a draft report on Deliverable 2 (*Assessment of Canadian Snow and Sea Ice for the next decade*) will be produced in time for a planned fall meeting of the network. Deliverable 3 (*ACRE – Attribution of Cryospheric Events*) will be developed in Project Year 5, and in our planned extension to Year 6 Deliverable 4 (*Observations to improve snow and sea ice prediction*) will be produced.

SECTION 2. BUDGET AND PLANS

Table 1 (after Section 4) summarizes budgeting and spending in Project Year 3, anticipated carryover into Project Year 4, and Project Year 4 planned expenditures. Shown in the table are Project Year 3 award amounts, actual expenditures from 01/02/15-30/09/15, projected expenditures from 01/10/15-31/01/16, and the estimated carryforward for Project Year 4. Our carryforward at the end of Year 3 is approximately $168K (cumulative from Years 2 and 3). The main source of this underspend is a result of the departures of HQP at PCIC, UNBC, and Toronto. At the same time, we found that this year we overspent in the category of travel and had to turn down some travel requests for our HQP. We have also identified a need to hire an additional person at the Research Associate level to work on our new sea ice multisource data initiative. In addition, we see our workshops as increasingly vital to the functioning of the network and so think it is very important to add an all network workshop (see next section) that was not part of our previous budget. We propose to reprofile our budget as follows: 1) In Year 4, we will budget $845K (versus the originally proposed $778K) that accounts for the additional personnel hire and the additional travel and workshop costs. 2) In Year 5 we will budget $787K (versus the originally proposed $687K) that accounts for the personnel hire and enhanced travel/closing workshop costs. The budget for Year 6 remains unchanged.

SECTION 3. INTERACTION WITH PARTNERS, RESEARCH TEAM AND TRAINING

Our partnership and management model continues to rely on frequent telecons, alternating between entire-Network and steering committee (SC) meetings (or SC plus Advisory Panel). This year we have added a *research report* component to the all-network telecons. In this component, one of our network HQP (e.g. Tandon at Toronto or Ambadan at Guelph) provides an update to the network of their research. This was in response to a request from the HQP at our all-network workshop in March to increase the scope of the telecons to matters outside the regular network business. We have been challenged to work with our previous software, "Go To Meeting" in the face of audio feedback issues and firewall security issues with some of our partners, and thus have moved towards a WebEx based approach which is now being tested. Minutes for these meetings continue to be posted for members on the CanSISE website www.cansise.ca. As an outreach component of the network, we have solicited and posted interview-style research summaries from HQP on the website, to provide a more accessible means of summarizing the Network's activities for the public.

Our regional face to face meetings have become increasingly important as our research proceeds. This year we held regional meetings in Toronto and Victoria, as well as an all-network workshop in Toronto with our international panel and all funded participant groups. These meetings, particularly the all-network Workshop in March and the regional Victoria meeting in September, provided an excellent sense of progress and strong collaboration and HQP participation across the network.

Our active partnership model was described in last year's report. Almost every project described above involves a partnership between University and Environment Canada or PCIC researchers. The generation of the CanESM Large Ensemble has represented a great example of resource commitment of EC to the benefit of the Canadian modeling community. As in previous years, we list key collaborations between partners: Berg/Merryfield/Kharin, Haas/Howell/Derksen, Kushner/Derksen/Brown, Kushner/Fyfe, Fletcher/Derksen/Brown, Zwiers/Zhang/Gillett, Déry/Brown/Derksen, Déry/Zwiers.

Regarding international partnerships, last year we applied to the Belmont Forum's Arctic Call involving CanSISE and several EC scientists at CRD and MRD[3]. The proposal, led internationally by

Bitz (U. Washington, CanSISE AP member) was unfortunately not funded owing, according to reviews, to an insufficient emphasis on social science research in the collaborative group assembled.[4] This year we were invited to support three other proposals: 1) a U. Bergen proposal on the Dynamics of Midlatitude-Arctic Teleconnections, for the Norwegian government's *Klimaforsk* call. As part of this we invited Dr. Camille Li of Bergen to become a CanSISE international collaborator. 2) CanSISE international collaborator James Screen of U. Exeter invited us to partner in his modeling proposal to UK NERC on the "Global Atmospheric Response to Evolution of Arctic Sea Ice". 3) We are invited to participate in a proposal led by T. Vihma on Arctic climate and midlatitude connections for the EU Horizon 2020 call. These proposals if successful will provide us with opportunities to engage in polar research at an international level. In addition to these proposals, Kushner helped represent Canada's efforts in these areas at the WCRP/PCPI sea-ice prediction workshop in Reading (Mar. 2015) and the WCRP workshop on decadal variability and prediction in Trieste (Nov. 2015).

We are pleased that EC management continues to provide excellent support for our activities, including active organization, participation, and travel support for our workshops; supervising of HQP and sharing of research results and data resources; and easy frequent interactions between the principles in CanSISE. We believe that the CanSISE project has been helpful in achieving concrete progress in EC's climate prediction systems. For example, Merryfield has shown how the Blended-5 dataset and related work with the Berg group at Guelph has led to the successful trial of an experimental snow-depth forecast product that will eventually become operational within CanSIPS. This together with sea ice thickness initialization improvements from Dirkson's work (see projects under A2) suggests that CanSISE's research approach has been effective in advancing Canada's climate prediction capacity.

We continue to link to other CCAR Networks, e.g. co-sponsoring sessions at the upcoming CMOS meeting with CCRN and CNRCWP. Assuming our reprofiled budget is approved, we plan to hold our next network workshop by partially overlapping with the CCAR NETCARE Network's annual meeting in October 2016 in Toronto, to discuss possible joint projects.

Regarding HQP, this year some of our senior HQP left the Network, typically reflecting the two-year limit on PDF positions, which lead to gaps in positions filling. This has prompted some reprofiling of the budget as detailed above. These and other HQP are moving to good positions with promising career potential. Examples include Research Associate Kumar who is now posted at NOAA ESRL, CanSISE PDF Bichet who is now posted at the LGGE in Grenoble, France, and CanSISE PDF McCusker who was promoted to a CanSISE Research Associate in November 2015. HQP appear to have a solid understanding of network aims, as was very evident at the March and September meetings.

Section 4. CONCLUSION

In our view, the CanSISE Network continues to serve as an effective model of partnership between University and government researchers with a shared scientific focus on enhancing climate prediction system development and observational dataset development, in the area snow and sea ice and related climate parameters for Canada and the Arctic. Highlights this year included the production and publication of the Blended-5 snow dataset and its application in a variety of research projects, the extensive use inside and outside CanSISE of the CanESM Large Ensemble, which was proposed by our network, and the production of the Deliverable 1 report, which will provide input that we hope will be helpful for future planning in model and observational work at EC. HQP training and promotion of continues to be a central focus, and we have encouraged HQP to take the best professional opportunities they can even though this might lead to some delays of our achieving project goals. As part of its midterm review of the CCAR programs, NSERC has asked us for additional information on the operation, successes, and challenges involved in this program. We intend to survey our membership in the coming weeks to obtain their perspective on the overall performance of the nework, and summarize the results of this survey in our response to NSERC's request for input. To assist us in this, we would appreciate feedback from the reviewers on this year's report, specific to CanSISE, and any further comments that will help inform our contribution to the midterm review of the CCAR program.

Endnotes

[1] *Review of the CanSISE Project's organization*: CanSISE partners seven Universities (British Columbia, Guelph, McGill, Northern British Columbia, Toronto, Victoria, and Waterloo); Environment Canada (Climate Research Division in Downsview, CCCma in Victoria, CIS in Ottawa); the Pacific Climate Impacts Consortium (PCIC), and NSERC. The Research Areas of CanSISE aim to (A) improve EC's capacity to forecast seasonal snow cover and sea ice and related hydroclimate variables on timescales ranging from seasonal to the decadal; (B) support efforts to quantitatively attribute the impacts of human influence on snow/sea-ice related process; and (C) improve scientific understanding of snow/sea-ice processes and their coupling to atmosphere-ocean circulation. Through the research undertaken, CanSISE also aims to produce Deliverables in which, with respect to snow/sea-ice and related processes, (1) EC's prediction systems are evaluated, (2) an assessment of variability in the near-term (next 10-20 years) is produced, (3) human influence and related impacts is analyzed, and (4) key aspects of future observational network design are developed.

[2] If the reviewers wish to see a draft version of the report prior to its release in January, please make the request to NSERC and we can send the draft via the NSERC office.

[3] The Canadian request to NSERC was limited to $50K total for three years, for travel and support of network activities and not for the direct costs of research

[4] The Canadian team, for its part, would not have been able to gain a commitment from social science researchers without an existing social science research network to work with, given the small funds available.

Appendix C: Publications and Presentations in Year 3

Published, in press, and accepted articles directly supported by CanSISE[v]

1. Ambadan, J T, Berg, A A, and Merryfield, W J, 2015: Influence of snow and soil moisture initialization on sub-seasonal predictability and forecast skill in boreal spring. Climate Dynamics, doi:10.1007/s00382-015-2821-9. (Theme A Project 2.2, directly supported by CanSISE)

2. Bichet, A., Kushner, P.J., Mudryk, L.R., Terray, L., Fyfe, J. (2015) Estimating the sea surface temperature response to anthropogenic forcing using pattern scaling based methods., Journal of Climate, doi:10.1175/JCLI-D-14-00604.1. (C2.1, directly supported by CanSISE)

3. Dirkson, A, Merryfield, W J, and Monahan, A H, 2015: Real time estimation of Arctic sea ice thickness through maximum covariance analysis. Geophysical Research Letters, 42, 4868-4877, doi:10.1002/2015GL063930. (Theme A Project 2.3, directly supported by CanSISE)

4. Fletcher, C. G., C. W. Thackeray, and T. M. Burgers, 2015: Evaluating biases in simulated snow albedo feedback in two generations of climate models. J. Geophys. Res. Atmospheres, 120, 2014JD022546, doi:10.1002/2014JD022546 (Theme C, directly supported by CanSISE).

5. Hernández-Henríquez M A, Déry S J, Derksen C, 2015: Polar amplification and elevation-dependence in trends of Northern Hemisphere snow cover extent, 1971-2014, Environmental Research Letters, 10, 044010, doi: 10.1088/1748-9326/10/4/044010. (Themes B2 and C3.1, directly supported by CanSISE)

6. Mudryk, L.R., Derksen, C., Kushner, P.J., Brown, R. (accepted) Characterization of northern hemisphere snow water equivalent datasets, 1981-2010 Journal of Climate, doi: 10.1175/JCLI-D-15-0229.1. (Project A1, directly supported by CanSISE)

7. Najafi M.R., Zwiers F., Gillett N., 2015: Attribution of Arctic Temperature Change to Greenhouse Gas and Aerosol Influences, Nature Climate Change, 5, 246-249. (Project B1, directly supported by CanSISE)

8. Sospedra-Alfonso, R, Melton, J H, and Merryfield, W J, 2015: Effects of temperature and precipitation on snowpack variability in the central Rocky Mountains as a function of altitude. Geophysical Research Letters, 42, doi: 10.1002/2015GL063898. (Theme C Project C1, directly supported by CanSISE)

9. Sospedra-Alfonso, R, Mudryk, L, Merryfield, W J, Derksen, C, 2015: Representation of snow in the Canadian Seasonal to Interannual Prediction System: Part I. Initialization. Journal of Hydrometeorology, doi:10.1175/JHM-D-14-0223.1. (Theme A Project A2.1, directly supported by CanSISE)

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10. Sospedra-Alfonso, R., L. Mudryk, W. Merryfield, and C. Derksen. In press. Representation of snow in the Canadian Seasonal to Interannual Prediction System: Part I. Initialization. Journal of Hydrometeorology. DOI: 10.1175/JHM-D-14-0223.1

11. Thackeray, C.W., Fletcher C.G., and Derksen C., 2015: Quantifying the skill of CMIP5 models in simulating seasonal albedo and snow cover evolution. J. Geophys. Res. Atmos., 120, 5831-5849, doi: 10.1002/2015JD023325 (Theme C, directly supported by CanSISE)

12. Williams, J., L.B. Tremblay, R. Newton, R. Allard, 2015: "Dynamic preconditioning of the September sea-ice extent minimum", Journal of Climate. Theme A3, directly supported by CanSISE.

Published Articles related to CanSISE Science[vi]

Haas, C., and S. E. L. Howell, 2015: Ice thickness in the Northwest Passage, Geophys. Res. Lett., 42, doi:10.1002/2015GL065704. (Theme A, related to CanSISE science)

Kwok, R., and C. Haas, 2015: Effects of radar sidelobes on snow depth retrievals from Operation IceBridge. J. Glac., 61(227), doi: 10.3189/2015JoG14J2292015. (Theme A, related to CanSISE science)

Le Fouest , V., M. Manizza , B. Tremblay , M. Babin, 2015: "Modeling the impact of riverine DON removal by marine bacterioplankton on primary production in the Arctic Ocean", Biogeosciences, 12(11):3385-3402, DOI:10.5194/bg-12-3385-2015, 2015. Theme C1.3, related to CanSISE

Lemieux, J.-F., L. B. Tremblay, F. Dupont, M. Plante, G. C. Smith, and D. Dumont, 2015: "A basal stress parameterization for modeling landfast ice", J. Geophys. Res. Oceans, 120, 3157–3173, doi:10.1002/ 2014JC010678. Theme C1.3, related to CanSISE

Sirven, J., L.B. Tremblay, 2015: `` Analytical study of an isotropic viscoplastic sea ice model in idealized configurations'', Journal of Physical Oecanography, Vol. 45, No. 2, 331-354, doi:10.1175/JPO-D-13-0109.1. Theme C1.3, related to CanSISE

Swart, N.C., J.C. Fyfe, E. Hawkins, J.E. Kay and A. Jahn. Influence of internal variability on Arctic sea-ice trends. Nature Climate Change 5 (2015).

Tremblay LB, Schmidt GA, Pfirman S, Newton R, DeRepentigny P., 2015: ``Is ice-rafted sediment in a North Pole marine record evidence for perennial sea-ice cover?'' Phil. Trans. R. Soc. A 373: 20140168. http://dx.doi.org/10.1098/rsta.2014.0168. Theme A3, related to CanSISE

In press articles related to CanSISE science

King, J., S. Howell, C. Derksen, N. Rutter, P. Toose, J.F. Beckers, C. Haas, N. Kurtz, J. Richter-Menge, 2015: Evaluation of Operation IceBridge quick-look snow depth estimates on sea ice, Geophys. Res. Lett., in press (Theme A, related to CanSISE science)

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Gagne, M.-E., J.C Fyfe and N. Gillett. Impact of aerosol emission controls on future Arctic sea ice cover. Geophysical Research Letters, in-press (2015).

Garnaud, C., S. Belaire, A. Berg, T. Rowlandson and E. Tetlock. Hyper-resolution land surface modelling in the context of SMAP Cal-Val. Journal of Hydrometeorology. In Press. doi:10.1175/JHM-D-15-0070.1 (Related research though not directly funded. Publication uses models that will be used in A2.2 initialization work and involves network collaborators).

Accepted articles related to CanSISE science

Blanken, H., L.B. Tremblay, S. Gaskin, A. Slavin, 2015: `` Arctic Oil Spills: A Risk Assessment of Transport in Sea Ice and Ocean Surface Waters from Ten Potential Spill Sites Marine Pollution Bulletin, Marine Pollution Bulletin. Theme C1.2, related to CanSISE

Hata, Y., L.B. Tremblay, 2015: ``A 1.5D Anisotropic Sigma-Coordinate Thermal Stress Model of Sea Ice: validation against an Ice Stress Buoy deployed in the Canadian Arctic Archipelago'', Journal of Geophysical Research. Theme C1.3, related to CanSISE

Submitted

DeRepentigny, P., L.B. Tremblay, R. Newton, S. Pfirman, 2015: "Patterns of Sea-Ice Retreat in the Transition to a Seasonally Ice-Free Arctic, Journal of Climate, in revision. Theme A3, directly supported by CanSISE.

Gagne, M.-E., Fyfe, J.C., Gillett, N.P., Polyakov, I. and G.M. Flato. Aerosol-driven increase in Eastern Arctic sea ice from 1945 to 1975. In revision stage in Nature Climate Change (2015).

Kang, D. H., Gao, H., Shi, X., Ul Islam S. and Déry, S. J., 2015: Impacts of a rapidly declining mountain snowpack on streamflow timing in Canada's Fraser River Basin, submitted to Scientific Reports.

Kumar, S., F. Zwiers, P. Dirmeyer, D. Lawrence, R. Shreshta, A. Werner. Terrestrial Contribution to the Heterogeneity in Hydrological Changes under Global Warming. Water Resources Research (in revision).

Kumar, S., R. Allan, F. Zwiers, D. Lawrence, and P. Dirmeyer. Revisiting Trends in Wetness and Dryness in the Presence of Internal Climate Variability. Geophysical Research Letters (in revision).

Najafi M.R., Zwiers F., Gillett N., in review: Attribution of the Spring Snow Cover Extent Decline in Northern Hemisphere, Eurasia and North America to Anthropogenic Influence, Climatic Change.

Thackeray, C.W., and Fletcher C.G., 2015: Snow albedo feedback: current knowledge, importance, outstanding issues and future directions. Progress in Physical Geography, in revision (Theme C, directly supported by CanSISE).

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Williamson M., J.R. Adams, A.A. Berg, C. Derksen, P. Toose and A. Walker. The detection of soil freeze/thaw using soil moisture probes: Implications for remote sensing validation networks. Submitted.

Presentations

Allchin M A, Déry S J, 2015: Biome-level analysis of trends in Northern Hemisphere snowcover duration and extent, 1971-2013, CanSISE West Workshop, Victoria, BC, 30 October 2015.

Ambadan, J, Berg, A A, and Merryfield, W J, 2015: Influence of snow and soil moisture initialization on sub-seasonal predictability and forecast skill in CanCM3, CanSISE Network Workshop 2, Toronto. (Theme A, directly supported by CanSISE)

Ambadan, J, Berg, A A, and Merryfield, W J, 2015: Influence of snow and soil-moisture initialization on sub-seasonal predictability skills of CanCM3 (poster), 49th CMOS Congress, Whistler, BC (Theme A, directly supported by CanSISE)

Bajish CC, Pittana M, Haas C, 2015: Evaluation of Arctic sea ice variability in CanSISE large ensemble of CanESM-2, CanSISE Workshop, Toronto, March 2015

Bajish CC, Pittana M, Haas C, 2015: Snow Climatology of Arctic Sea Ice: Comparison of Reanalysis and Climate Model Data with In Situ Measurements, AGU Fall Meeting, San Francisco, December 2015

Bichet, A. : Attribution of high northern latitude trends (1980-2010) using pattern scaling. Polar Climate Prediction Initiative Workshop, Reading, UK, March, 2015. (Project C2.1)

Bichet, A.: Decadal predictions (2010-2040) using pattern scaled sea surface temperature and sea-ice concentration. ICTP/WCRP Decadal Climate Variability and Predictability workshop, Trieste, Italy, November 2015. (Project C2.1)

Blanken, H., L.B. Tremblay, S. Gaskin, A. Slavin, 2015: ``Arctic oil spills: a risk assessment of transport in sea ice and ocean surface waters from current exploration sites'', E-proceeding of the 36th IAHR World Congress. Theme C1.2, related to CanSISE

Bouchat, A., B. Tremblay, "Using sea ice deformation to discriminate between different rheology"; 49th CMOS congress, Whistler, June 2015; Theme C1.2, related to CanSISE science.

Bouchat, A., B. Tremblay, "Using sea ice deformation to discriminate between different rheology"; ArcTrain annual meeting, Montreal, September 2015;

Bouchat, A., B. Tremblay, "Using sea ice deformation to discriminate between different rheology"; 4th FAMOS meeting, Hyannis (MA), November 2015; Theme C1.2, related to CanSISE science.

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Bourdages, L., J. Kay, B. Tremblay, (2015), "Surface inversion and sea ice mass balance", CESM workshop , June 2015, Breckenridge (Colorado); Theme C1.3, related to CanSISE science.

Bourdages, L., J. Kay, B. Tremblay, (2015), "Surface inversion and sea ice mass balance", Quebec Océan Annual meeting, November 2015, Quebec city. Theme C1.3, related to CanSISE science.

DeRepentigny, P., B. Tremblay, R. Newton, (2015), "Future geographical pattern of sea ice retreat", San AGU Fall Meeting, Francisco. Theme C1.2, related to CanSISE science.

DeRepentigny, P., B. Tremblay, R. Newton, (2015), "Future geographical pattern of sea ice retreat", CMOS Whistler. Theme C1.2, related to CanSISE science.

Déry S J, Hernández-Henríquez M A, Derksen C, 2015: Polar amplification and elevation-dependence in trends of Northern Hemisphere snow cover extent, 1971-2014, AGU/CGU Joint Assembly, Montreal, QC, 5 May 2015.

Dupont, F., M. Vancoppenolle, L. B. Tremblay, 2015: ``Comparison of different numerical approaches to the 1D sea-ice thermodynamic problem'', Ocean Modelling, 87, 20-29, 2015. Theme C1.3, related to CanSISE.

Dirkson A, Merryfield W J, Monahan A H, 2015: Sea Ice Thickness: Estimation in real-time from SLP and SIC through a Maximum Covariance Analysis, CanSISE Network Workshop 2, Toronto. (Theme A, directly supported by CanSISE)

Dirkson A, Merryfield W J, Monahan A H, 2015: Skill evaluation of CanCM3 seasonal sea ice hindcasts using improved thickness initialization. CanSISE West Workshop, Victoria. (Theme A, directly supported by CanSISE)

Gervais, M., B. Tremblay, J. Gyakum, E. Atallah, (2015), "Arctic sea ice decline and change in air masses", Cyclone Workshop, November 2015 , Theme C2.1, directly supported by CanSISE. Theme C2.1.

Gervais, M., J. Gyakum, B. Termblay, E. Atallah, (2015), "Arctic sea ice decline and change in air masses", Canadian Network for Regional Climate and Weather Processes, May 2015; Theme C2.1, directly supported by CanSISE.

Gervais, M., E. Atallah, J. Gyakum, B. Termblay (2015), "Arctic sea ice decline and change in air masses", CanSISE workshop, Toronto, March 2015; Theme C2.1, directly supported by CanSISE.

Hata, Y., L. B. Tremblay, 2015: "Anisotropic internal thermal stress in sea ice from the Canadian Arctic Archipelago", J. Geophys. Res. Oceans, 120, 5457–5472, doi:10.1002/2015JC010819. Theme C1.3, related to CanSISE.

Yukie Hata, B. Tremblay, (2015), "Internal thermal stress in landfast sea ice", CMOS Whistler, May 2015. Theme C1.3, related to CanSISE science.

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Yukie Hata, B. Tremblay, (2015), "Internal thermal stress in landfast sea ice", ArcTrain Meeting, Montreal. Theme C1.3, related to CanSISE science

Yukie Hata, B. Tremblay, (2015), "Internal thermal stress in landfast sea ice", FAMOS, Hyannis, Cape Cod, MA. Theme C1.3, related to CanSISE science.

Hernández-Henríquez M A, Déry S J, Derksen C, 2015: Polar amplification and elevation-dependence in trends of Northern Hemisphere snow cover extent, 1971-2014, CanSISE Workshop II, Toronto, ON, 12 March 2015.

Hernández-Henríquez M A, Déry S J, Derksen C, 2015: Polar amplification and elevation-dependence in trends of Northern Hemisphere snow cover extent, 1971-2014, 49th Annual CMOS Congress & 13th AMS Conference on Polar Meteorology and Oceanography, Whistler, BC, 3 June 2015.

Hsieh, WW, Cannon, AJ, Schnorbus, M, 2015: Using artificial neural networks to emulate the VIC hydrological model: Application to streamflow and snow water equivalent projections. Oral presentation at Congress of the Canadian Meteorological and Oceanographic Society, Whistler, BC. (Theme A)

Islam S. and Déry S., 2015: Assessing climate change impacts on the snowpacks and water availability of the Fraser River Basin, British Columbia, 49th CMOS/13th AMS Congress, Whistler, BC

Islam S. and Déry S., 2015: Assessing climate induced future changes in the hydrology of the Fraser River Basin, 2015 CanSISE workshop, Mar 11-13, 2015, Toronto, ON

Islam S, Déry S. and Werner A. T., 2015: Future climate change impacts on snow and water resources of the Fraser River Basin, British Columbia, 2015 CanSISE west workshop, October 30, 2015, Victoria, BC

Jutras, M., B. Tremblay, (2015), "Inertial oscillations, the sea ice mass balance and ocean mixing", CMOS Congress, June 2015, Whistler BC;

Jutras, M., B. Tremblay, (2015), "Inertial oscillations, the sea ice mass balance and ocean mixing", FAMOS, November 2015, Hyannis MA. Theme C1.3, science related to CanSISE.

Kang, DH, Gao, H, Shi, X, and Déry SJ, 2014: Canada's Fraser River Basin transitioning from a nival to a hybrid system in the late 20th century, AGU Fall Meeting, San Francisco, December 18th 2014

Kushner, P.J. et al.: Estimating the continental response to global warming using pattern-scaled sea surface temperatures and sea ice. Presented at 1) International Detection and Attribution (IDAG) workshop, Boulder, CO, January 2015; 2) NCAR CESM Workshop, Breckenridge, CO, June 2015; 3) ICTP/WCRP Decadal Climate Variability and Predictability workshop, Trieste, Italy, November 2015. (Project C2.1)

Kushner, P.J. (Tandon and Kushner paper): Does external forcing interfere with the AMOC's influence on North Atlantic & Arctic climate? Presented at 1) Polar Climate Prediction

Initiative Workshop, Reading, UK, March, 2015, 2) NCAR CESM Workshop, Breckenridge, CO, June 2015. (Project C1.1-ii)

Merryfield, W J, Sospedra-Alfonso, R, Mudryk, L, Derksen, C, Kharin, V V, Initialization, potential predictability and skill of CanSIPS forecasts of snow water equivalent. CanSISE Network Workshop 2, Toronto. (Theme A, directly supported by CanSISE)

Pittana, M, Bajish CC, Haas C, 2015: Snow climatology on Arctic Sea Ice: Comparison of reanalysis and climate model data with in-situ measurements. CanSISE East regional meeting, Toronto, July 2015.

Plante, M., B. Tremblay, (2015), "A linear elastic solid model for landfast sea ice", 49th CMOS congress, Whistler. Theme C1.3, related to CanSISE science.

Plante, M., B. Tremblay, (2015), "A linear elastic solid model for landfast sea ice", ArcTrain annual meeting, Montreal. Theme C1.3, related to CanSISE science.

Plante, M., B. Tremblay, (2015), "A linear elastic solid model for landfast sea ice", 4th FAMOS meeting, Hyannis (MA). Theme C1.3, related to CanSISE science.

Plante, M., B. Tremblay, (2015), "A linear elastic solid model for landfast sea ice", 14e AGA de Quebec Ocean, Québec. Theme C1.3, related to CanSISE science.

Renaud-Desjardins; L., B. Tremblay, (2015), "Rapid sea ice decline and ocean heat flux", CanSISE workshop, Toronto, March, 2015; Theme C1.3, directly supported by CanSISE

Renaud-Desjardins; L., B. Tremblay, (2015), "Rapid sea ice decline and ocean heat flux", Differential Equations, Probability and Sea Ice workshop, Salt Lake City, June, 2015; Theme C1.3, directly supported by CanSISE.

Renaud-Desjardins; L., B. Tremblay, (2015), "Rapid sea ice decline and ocean heat flux", Conference on Mathematics of Sea Ice, Vancouver, September, 2015, Theme C1.3, supported by CanSISE.

Snauffer, Andrew, 2015: Development of a Machine Learning SWE Estimation Model for BC: Early Results. Oral presentation at CanSISE Workshop, Toronto, ON. (Theme A, directly supported by CanSISE)

Snauffer, AM, Cannon, AJ, Hsieh, WW, 2015: Development of a Statistical Model for Snow Water Equivalent Estimates in British Columbia, Canada. Oral presentation at Congress of the Canadian Meteorological and Oceanographic Society, Whistler, BC. (Theme A, directly supported by CanSISE)

Snauffer, AM, 2015: Fusion of Snow Water Equivalent Data Products Using Machine Learning. Oral presentation at CanSISE West Regional Workshop, Victoria, BC. (Theme A, directly supported by CanSISE)

Snauffer, AM, Cannon, AJ, Hsieh, WW, 2015: Snow Water Equivalent Estimation Via Machine Learning in the Mountainous Region of British Columbia, Canada, accepted poster

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for AGU Fall Meeting, December 14-18, 2015, San Francisco, CA. (Theme A, directly supported by CanSISE)

Slavin A., B Tremblay, D. Straub, (2015), "Idealized simulation of Ekman pumping beneath active sea ice leads", , CanSISE workshop, Toronto, March 2015. Theme C1.3, directly supported by CanSISE.

Sospedra-Alfonso, R, Merryfield, W J, Changing influences of temperature and precipitation on snowpack variability in the Northern Hemisphere CanSISE Network Workshop 2, Toronto. (Theme C, directly supported by CanSISE)

Sospedra-Alfonso, R, Merryfield, W J, Changing influences of temperature and precipitation on snowpack variability in the Northern Hemisphere, 49th CMOS Congress, Whistler, BC (accepted for oral presentation) (Theme A, directly supported by CanSISE)

Sospedra-Alfonso, R, Merryfield, W J, Initialization and potential predictability of snow in the Canadian Seasonal to Interannual Prediction System (CanSIPS), 49th CMOS Congress, Whistler, BC (accepted for poster presentation) (Theme A, directly supported by CanSISE)

N. F. Tandon and P. J. Kushner, 2015: "Interference Between Forced and Unforced Climate Variability: Implications for the North Atlantic and the Arctic." CLIVAR-ICTP International Workshop on Decadal Climate Variability and Predictability, 16-20 November 2015, Trieste, Italy.

N. F. Tandon and P. J. Kushner, 2015: "Clarifying the Atmospheric Circulation's Role in Driving Arctic Sea Ice Loss." CanSISE Workshop, 24 July 2015, Toronto, Canada.

N. F. Tandon and P. J. Kushner, 2015: "Interference Between Forced and Unforced Climate Variability in the North Atlantic and the Arctic." University of Bergen GFI Seminar (invited), 4 May 2015, Bergen, Norway.

Thackeray, C.W., Fletcher C.G., Derksen C., 2015: The influence of canopy snow parameterizations on snow albedo feedback in boreal forest regions. 26th IUGG General Assembly 2015, Prague, Czech Republic (Theme C, directly supported by CanSISE)

Thackeray, C.W., Fletcher C.G., and Derksen C., 2015: Quantifying the skill of CMIP5 models in simulating seasonal albedo and snow cover evolution. American Geophysical Union Fall Meeting, San Francisco, December 2015 (Theme C, directly supported by CanSISE)

Tremblay, B., (2015), "Arctic Climate Change", Canadian Climate Forum, Ottawa. Theme C1.3 science related to CanSISE.

Tremblay, B (2015), "Global Climate Change", Northwest Passage Expedition – Worldwide Quest, Canadian Alumni Association, Northwest Passage – Kapitan Yoffe.

Tremblay, B (2015), "Arctic Climate Change", Northwest Passage Expedition – Worldwide Quest, Canadian Alumni Association, Northwest Passage – Kapitan Yoffe.

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Tremblay, B (2015), "Sea ice restoration" , Northwest Passage Expedition – Worldwide Quest, Canadian Alumni Association, Northwest Passage – Kapitan Yoffe.

Tremblay, B (2015), "Arctic Climate Change", American Chest Physician Annual Meeting, Montreal,

Tremblay, B., R. Cullather, P. DeRepentigny, R. Newton, S. Pfirman, (2015), Seasonal sea ice extent: How free is free?", AGU- Fall meeting, San Francisco.

Williamson, M., T. Rowlandson, J. Ambadan, A. Berg, W. Helgason. 2015. Assessing the Sensitivity of the Soil Moisture and Ocean Salinity (SMOS) Observed Brightness Temperature for Soil Freeze- Thaw Detection during Wet Snow Conditions. Joint Assembly of the American and Canadian Geophysical Union. Montreal, PQ, Canada.

Williams, J., B. Tremblay, (2015), "Plastic waves and stability of numerical scheme for sea ice models", Forum for Arctic Modeling & Observational Synthesis, November 2015, Cape Cod, MA, USA. Theme C1.3, science related to CanSISE.

Williams, J., B. Tremblay, (2015), "Plastic waves and stability of numerical scheme for sea ice models", Canadian Sea-ice Modeling Workshop, December 2015, Montreal, QC, Canada. Theme C1.3, science related to CanSISE.

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[v] We have grouped these papers together to clearly indicate which publications have come out in the reporting period that are directly supported by funds from the Network. There are 12 published, in press, and accepted papers.

[vi] In the following lists are papers that involve CanSISE researchers or collaborators but that are not directly supported by CanSISE, as well as papers that are not yet accepted (submitted/in revision) whether or not supported by CanSISE.

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