Environment and Climate Change Canada

WORLD METEOROLOGICAL ORGANIZATION

Norwegian Meteorological Institute

Russian Federal Service for Hydrometeorology and Environmental Monitoring

ACF Arctic Climate Forum

Arctic Climate Forum Consensus Statement

2021-2022 Arctic Winter Seasonal Climate Outlook

(along with a summary of 2021 Arctic Summer Season)

CONTEXT

Arctic temperatures continue to warm at a rate that is more than twice the global mean. Annual surface air temperatures over the last 5 years (2016–2020) in the Arctic (60°–85°N) have been the highest in the time series of observations for 1936-2020[1]. Starting in 1936, summer 2021 was the fifth warmest with an anomaly of the surface air temperature +1.4°C relative to the 1961-1990 period. The March winter sea ice extent of 2021 tied for the tenth lowest since 1979. The September sea ice extent of 2021 was the twelfth lowest and the September sea ice volume was the seventh lowest since 1979 (minimum records in 2012)[2].

To support Arctic decision makers in this changing climate, the recently established Arctic Climate Forum (ACF) convened by the Arctic Regional Climate Centre Network (ArcRCC-Network) under the auspices of the World Meteorological Organization (WMO) provides consensus climate outlook statements in May prior to summer thawing and sea-ice break-up, and in October before the winter freezing and the return of sea-ice.

The role of the ArcRCC-Network is to foster collaborative regional climate services amongst Arctic meteorological and ice services to synthesize observations, historical trends, forecast models, and to integrate regional expertise to produce consensus climate statements. These statements include a review of the major climate features of the previous season, and outlooks for the upcoming season for temperature, precipitation and sea-ice. The elements of the consensus statements are presented and discussed at the Arctic Climate Forum (ACF) sessions with both providers and users of climate information in the Arctic in May and October, the latter typically held online.

This consensus statement, coordinated by the North American Node of ArcRCC-Network, is an outcome of the 8th session of the ACF held online on 27-28 October 2021 and hosted by Denmark.

1 Review of Hydrometeorological processes in the Northern Polar Region, AARI, 2016-2021; http://www.aari.ru/misc/publicat/gmo.php

2 http://psc.apl.uw.edu/research/projects/arctic-sea-ice-volume-anomaly/

Icelandic Met Office

ILMATIETEEN LAITOS METEOROLOGISKA INSTITUTET FINNISH METEOROLOGICAL INSTITUTE

NOAA

SMHI

DMI

HIGHLIGHTS

Less extreme summer 2021 surface air temperature (SAT) anomalies over the Western Siberia, Chukchi, Alaska and Canada regions along with negative upper ocean heat content anomalies, contributed to close to normal ice conditions in these regions. Opposite conditions in the Nordic and Eastern Siberia regions resulted in several 'heat waves' and well below normal ice extents in the Barents and parts of the Kara and Laptev Seas.

Above normal temperatures forecast for all Arctic regions next season (November 2021 to January 2022) will continue to have implications for sea-ice.

Temperature: The summer 2021 average surface air temperatures were above normal (1961-1990) for most of the Arctic domain, with Eastern Siberia observing record-breaking temperatures. Slightly below normal temperatures were observed in parts of Chukchi Sea and Canadian Arctic. In the Arctic seas, the highest positive anomalies were for the northern part of the Greenland and Norwegian Seas, as well as in the Asian sector (the Laptev and East Siberian Seas). In the Laptev Sea region, the SAT anomaly was +2.6C , the second highest since 1936.

Above normal temperatures are expected to continue across the majority of the Arctic next season (November 2021 to January 2022).

Precipitation: On average, total precipitation for the Arctic region in summer 2021 was equal to 99.1% of normal (1961-1990). The least amount of precipitation was for the Eastern Siberia and American regions with more abundant precipitation observed in the Nordic region.
Impacts of precipitation and evaporation included lesser drainage than normal (1991-2020) for almost all Great Arctic rivers with more significant negative anomalies for Lena for all months. Greater drainage was seen in some months for Anadyr and Enisey rivers.

Wetter than normal conditions are expected across the majority of the Arctic region next season (November 2021 to January 2022).

Sea-ice: The Northern Hemisphere September 2021 minimum sea-ice extent was the 12th lowest since 1979. While the Barents and Laptev Seas were completely ice free in advance of this date, ice conditions in parts of Kara, Eastern Siberian and Beaufort Seas along with parts of the Canadian Arctic Archipelago, were close to the 40 year normal. Both the NWP and the NSR remaining blocked in the transit straits which is opposite to last 5 year period. Area and thickness of both residual and second year ice in September this year for the Arctic Basin was much greater than that for 2019 or 2020.

Later than normal fall freeze-up is expected for Baffin Bay and the East Siberian, Kara, Labrador, and Laptev Seas; near normal to early freeze-up is expected for all other regions. Below to near normal 2021 maximum sea ice extents are forecast for the majority of the Arctic.

Understanding the Consensus Statement

This consensus statement includes: a seasonal summary and forecast verification for temperature, precipitation, and sea-ice for previous 2021 Arctic summer season (June, July, and August 2021); an outlook for the upcoming 2021-2022 Arctic winter season (November 2021, December 2021, and January 2022). Figure 1 shows the regions that capture the different geographic features and environmental factors influencing temperature/precipitation. Figure 2 shows the established shipping routes and regions used for the sea-ice products.

Figure 1: Regions used for the seasonal summary and outlook of temperature and precipitation

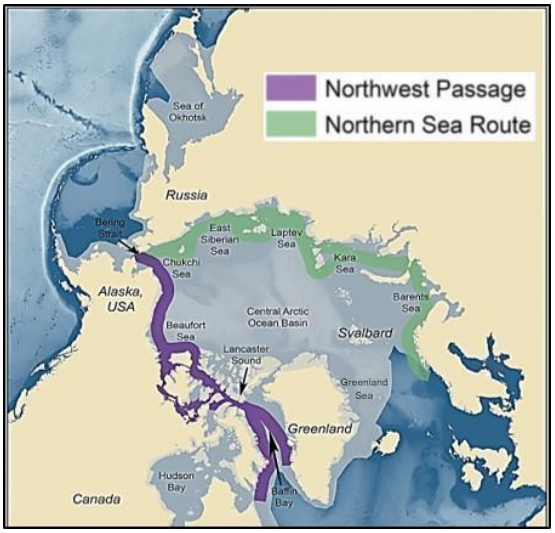

Figure 2: Sea-Ice Regions. Map Source: Courtesy of the U.S. National Academy of Sciences

The temperature and precipitation forecasts are based on eleven WMO Global Producing Centers of Long-Range Forecasts (GPCs-LRF) models and consolidated by the WMO Lead Centre for Long Range Forecast Multi-Model Ensemble (LC-LRFMME). In terms of models' skill (i.e. the ability of the climate model to forecast the observed seasonal climate), a multi-model ensemble (MME) approach essentially overlays all of the individual model performances. This provides a forecast with higher confidence in the regions where different model outputs/results are consistent, versus a low confidence forecast in the regions where the models don't agree. The MME approach is a methodology well-recognized to be providing the most reliable objective forecasts.

The majority of the sea-ice extent and freeze-up forecasts are based on the Canadian Seasonal to Inter-annual Prediction System (CanSIPSv2). The Baltic Sea forecasts are developed using outputs from the ECMWF Long-Range Forecasts, UK MetOffice, and NOAA CFSv2. A multi-model ensemble that will include forecasts from the following WMO GPC-LRFs is under development: ECCC/MSC (CanSIPSv2), NOAA (CFSv2), Meteo-France (System 5), UK MetOffice (GloSea5) and ECMWF (SEAS5). When sea-ice extent is at its maximum in March of each year, forecasts are available for the following peripheral seas where there is variability in the sea-ice edge: Barents Sea, Bering Sea, Greenland Sea, Northern Baltic Sea, Gulf of St. Lawrence, Labrador Sea, and Sea of Okhotsk. In addition forecasts for sea-ice freeze-up are available for Hudson Bay, East Siberian Sea, Kara Sea, Laptev Sea, Chukchi Sea and the Beaufort Sea. Winter outlooks for key shipping areas are provided by the Arctic and Antarctic Research Institute, US, Canadian, Norwegian and Finnish ice services, and are based on statistical model guidance and forecast expertise.

ATMOSPHERIC CIRCULATION

Summary for June, July, and August 2021:

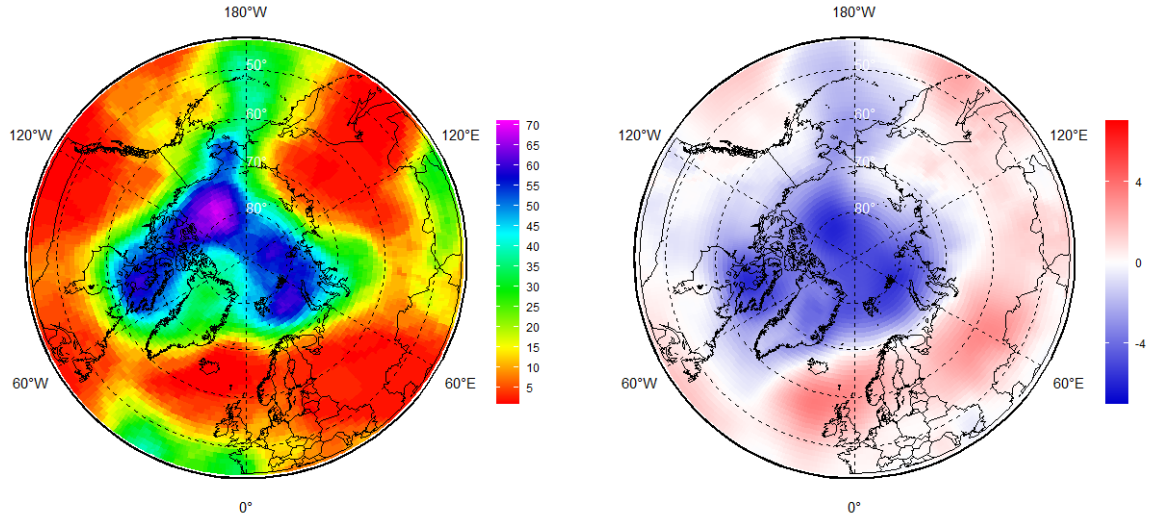

Figure 3: June, July and August (JJA) 2021 Geopotential height 500hPA (H500) rank for 72 analyzed JJA in the 1950-2021 period (left) and mean sea level pressure anomaly based on the 1991-2020 reference period (right). Red indicates higher H500 heights, and in general, higher MSLP, while blue indicates lower H500 heights and MSLP. Maps produced by the Arctic and Antarctic Research Institute http://www.aari.ru. Data sources CCCS ERA5

During the summer months the center of the polar vortex shifted from the central Arctic in June, to the Canadian Arctic Archipelago and northern coast of Taimyr in July and to the Beaufort Sea in August. These changes in circulation are reflected in the H500 patterns for June, July and August (Figure 3, left, dark blue and violet areas) and subsequent changes in cyclonic and anticyclonic activity underneath (Figure 3, right, blue and red areas) .

TEMPERATURE

Summary for June, July, and August 2021:

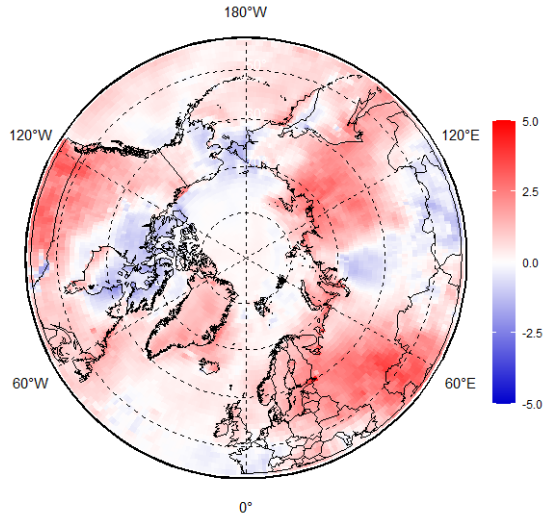

Figure 4: June, July and August (JJA) 2021 surface air temperature (SAT) anomaly based on the 1991-2020 reference period. Red indicates warmer than normal temperatures, and blue indicates cooler than normal temperatures. Map produced by the Arctic and Antarctic

Summer 2021 was characterized by an average surface air temperature (SAT) anomaly (relative to 1961-1990) of +1.4°C and was the 5th warmest since 1936. The SAT anomaly for the latitudinal zone of 70-85°N was +1.2°C and 7th in rank, and for the latitudinal zone 60-70°N, the SAT anomaly was +1.5°C and 4th in rank since 1936. Regional analysis shows the most significant positive SAT anomalies in the Eurasian sector (red areas in Figure 4). The SAT anomaly for the Eastern Siberia region was +2.9C and was the warmest year 1936. The southern Chukchi and eastern Beaufort Seas were characterized by slight negative SAT anomalies (blue areas in Figure 4). In the Arctic seas, the highest positive anomalies were for the northern part of the Greenland and Norwegian Seas, as well as in the

Asian sector - the Laptev and East Siberian seas. In the Laptev Sea area, the SAT anomaly was +2.6C and the second highest since 1936 (see technical summary for greater detail).

Verification for June, July, and August 2021:

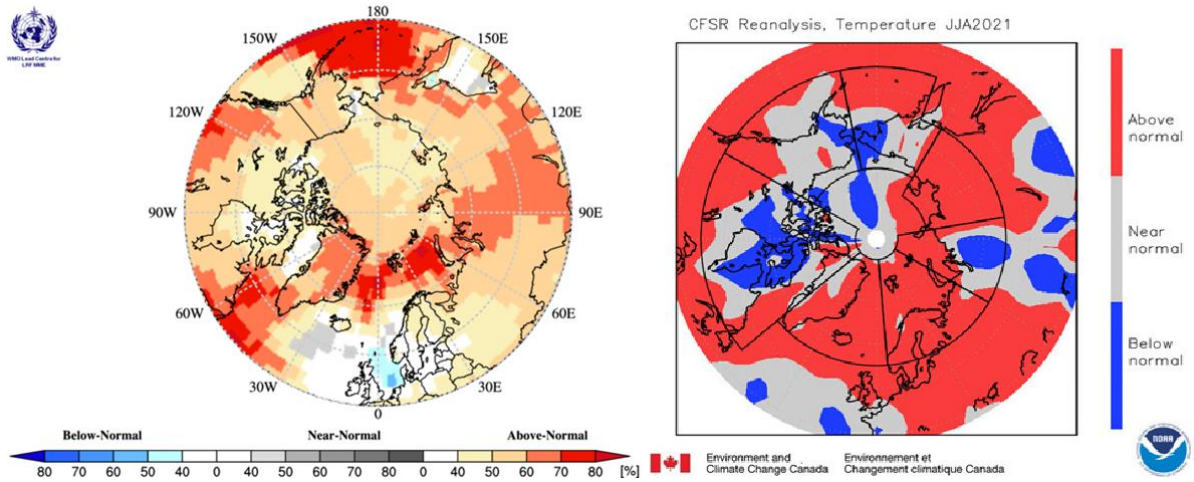

Figure 5: (Left) Multi-model ensemble (MME) probability forecast for surface air temperatures: June, July, and August 2021. Three categories: below normal (blue), near normal (grey), above normal (red); no agreement amongst the models is shown in white. Source: www.wmolc.org. (Right): NCAR (National Center for Atmospheric Research) Climate forecast System Reanalysis (CFSR) for air temperature for June, July, and August 2021.

The JJA 2021 temperature forecast was verified by subjective comparison between the forecast (Figure 5, left) and re-analysis (Figure 5, right), region by region. A re-analysis is produced using dynamical and statistical techniques to fill gaps when and where meteorological observations are not available.

Table 1. June, July, August 2021: Regional Comparison of Observed and Forecasted Arctic Temperature

Regions (see Figure 1)	MME Temperature Forecast Agreement	MME Temperature Forecast	NCAR CFSR Reanalysis (observed)	MME Temperature Forecast Accuracy
Alaska and Western Canada	Moderate	Above Normal	Mostly near normal	20% hit, 80% miss
Central and Eastern Canada	Low to moderate	Above normal	Below and near normal in the center. Above normal in the east and west.	20% hit, 80% miss
Western Nordic	Low to Moderate	Mostly above normal, below normal in the north	Above normal	90% hit
Eastern Nordic	Low to Moderate	Above normal	Above normal	hit
Western Siberia	Moderate	Above normal	Below and near normal in the south and center, above normal in the north	Miss (over land)
Eastern Siberia	Moderate	Above normal	Above normal	hit

Chukchi and Bering	Moderate	Above normal	Near and below normal over land	Miss (over land)
Central Arctic	Low to moderate	Above normal	Mostly near or below normal	20% hit, 80% miss

Above normal surface air temperatures over the Western Nordic, Eastern Nordic and Eastern Siberia were accurately forecast for the JJA 2021 season (Figure 5, Table 1). In the Chukchi and Bering and Western Siberian regions, above normal temperatures were accurately forecast over ocean areas (Figure 5, red areas) but below normal to near normal temperatures were observed over land (Figure 5, right, blue and grey areas). Above normal to near normal temperature observed over much of Canada, Alaska and the Central Arctic (Figure 5, right, blue and grey areas) were missed in the model forecast.

Outlook for winter 2021-2022:

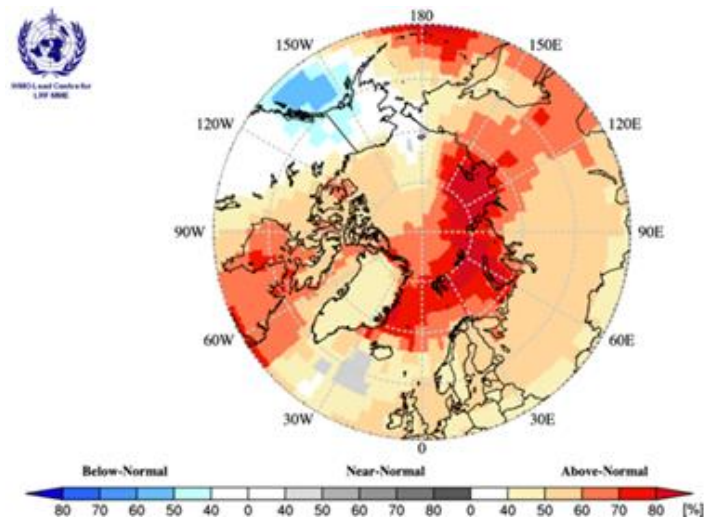

Figure 6: Multi model ensemble probability forecast for surface air temperature for November 2021, December 2021 and January 2021. Three categories: below normal (blue), near normal (grey) and above normal (red); no agreement amongst the models (white). Source: www.wmolc.org.

Surface air temperatures during winter 2021 (NDJ: November 2021, December 2021, and January 2022) are forecast to be above normal across the majority of the Arctic regions (yellow, orange and red areas in Figure 6) with the exception of Alaska and Western Canada where the there is no clear signal or agreement in model forecasts (white areas in Figure 6). Above normal temperatures with moderate confidence (blue areas in Figure 6) is forecast for the North Pacific and coastal areas. The confidence of the forecast is low over Alaska and Western Canada (white and light blue areas in Figure 6). The confidence in the forecast is high over Central/Eastern Canada, and over Eastern Siberia (red areas in Figure 6) and moderate over the Eastern/Western Nordic, Western Siberia, Central Arctic and Chukchi and Bering Seas (yellow and orange areas in Figure 6).

Table 2. Winter (NDJ) 2020-2021 Outlook: Regional Forecasts for Arctic Temperatures

Region (see Figure 1)	**MME Temperature Forecast Agreement***	**MME Temperature Forecast**
Alaska and Western Canada	Low	Below Normal
Central and Eastern Canada	High	Above normal
Western Nordic	High	Above normal
Eastern Nordic	Moderate	Above normal
Western Siberia	Moderate	Above normal

Eastern Siberia	High	Above normal
Chukchi and Bering	Moderate	Above normal
Central Arctic	Moderate	Above normal

*: See non-technical regional summaries for greater detail

PRECIPITATION

Summary for June, July, and August 2021:

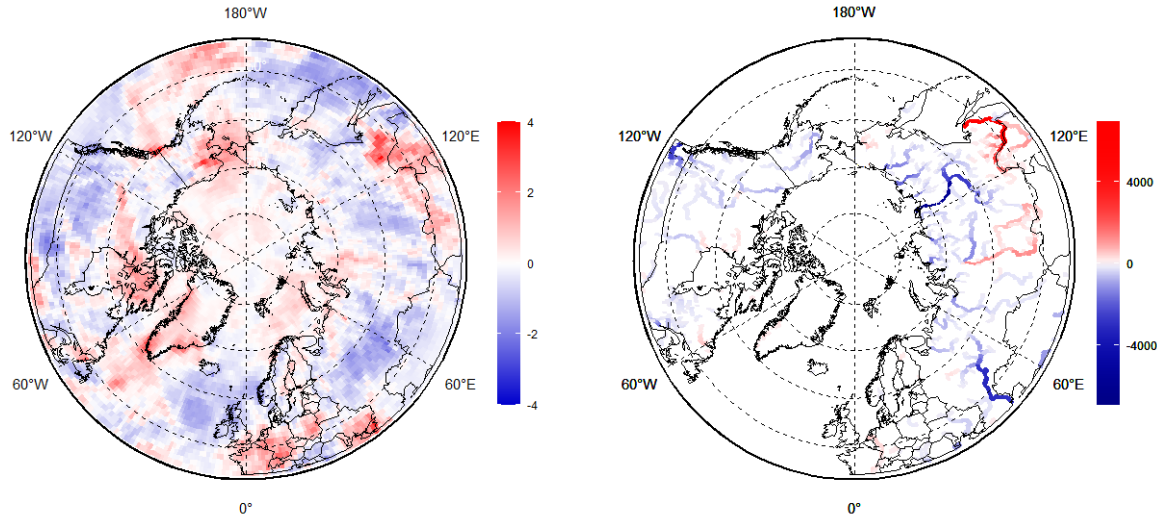

Figure 7. June, July, and August (JJA) 2021 precipitation (left) and river discharge (right) anomalies based on the 1991-2020 reference period; red (blue) indicates wetter/greater drainage (drier/lesser drainage) than normal conditions. Map produced by the Arctic and Antarctic Research Institute http://www.aari.ru. Data source: CCCS ERA5 and ERA5-GloFAS

During June, July and August 2021, wetter than normal conditions were observed over most of the Nordic regions, the eastern Canadian Arctic and western Alaska (red areas in Figure 7, left). Drier than normal conditions were observed across the Russian Arctic and western Canada (blue areas in Figure 7, left) (see technical summary for greater monthly detail).

Analysis of the interannual changes of surface precipitation observed at the stations during 1936-2021 (not shown here), shows a tendency (statistically insignificant) towards a decrease in summer liquid precipitation for the whole region. In the Arctic seas, over the 1936-2021 period, with the exception of the northern Greenland and Norwegian Seas, as well as the Beaufort Sea, a downward trend in precipitation is observed. The largest decrease in precipitation is for the Eurasian Seas. In the last 30-year period, a tendency towards an increase in the amount of liquid precipitation has appeared in some latitudinal zones, mainly due to the increase in liquid precipitation in the East Nordic and West Siberia regions. However, the values of the linear trends in these areas are not statistically significant.

The impact of wetter/drier regions due to precipitation and evaporation processes were reflected in the JJA 2021 Arctic rivers discharge (Figure 7 right), lesser drainage than normal was seen for practically all Great Arctic rivers with more significant negative anomalies for the Lena River (all months) and the Indigirka and Kolyma Rivers (June). Greater drainage was seen for the Anadyr River in June and the Enisey River in July. Arctic river discharge in summer 2021 in the Eurasian Arctic was similar to summer 2020, this is not the case for the American sector where in summer 2020 the Mackenzie and Yukon rivers experienced greater discharge than normal.

Verification for June, July, and August 2021:

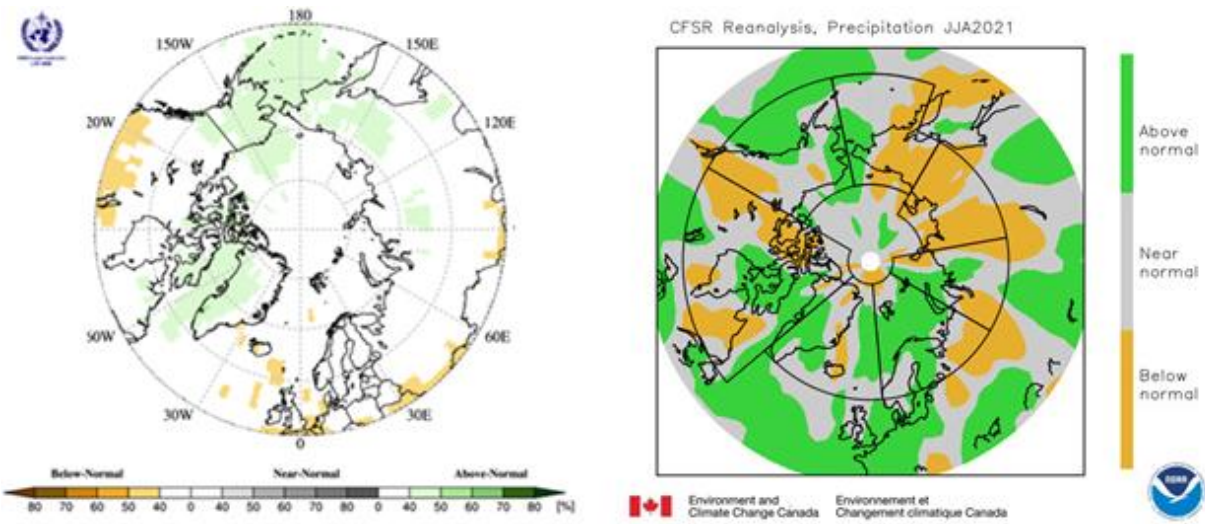

Figure 8: Multi-model ensemble (MME) probability forecast for precipitation (left): June, July, and August 2021. Three categories: below normal (brown), near normal (grey), above normal (green); no agreement amongst the models is shown in white. Source: www.wmolc.org. NCAR CFSR for precipitation (right): June, July, and August 2021.

The JJA 2020 precipitation forecast was verified by subjective comparison between the forecast (Figure 8, left) and re-analysis (Figure 8, right), region by region. Similar to temperature, precipitation re-analysis is produced using statistical techniques to fill gaps when meteorological observations are not available.

Overall, the accuracy of the JJA 2021 precipitation forecast was low (Figure 8, Table 3) and there was no model signal and agreement (white areas Figure 7, left) in over half of the Arctic domain. Regions where the model correctly predicted precipitation anomalies are: the north Bering and south Chukchi Seas; Baffin Bay and Baffin Island in Eastern Canada; and west Greenland in Eastern Nordic node.

Table 3. June, July, August 2021: Regional Comparison of Observed and Forecasted Arctic Precipitation

Regions (see Figure 1)	MME Precipitation Forecast Agreement	MME Precipitation Forecast	NCAR CFSR Reanalysis (observed)	MME Precipitation Forecast Accuracy
Alaska and Western Canada	Low	Above normal in west	Mostly below and near normal	90% miss
Central and Eastern Canada	Low	Above normal in the east, below normal in the south-west	Below and near normal over the continent	50% where forecast
Western Nordic	Low	Above normal over Greenland	Below normal over Iceland, above normal over central Greenland	90% where forecast
Eastern Nordic	No agreement	No forecast	Near and above normal in Scandinavia, below and near normal in the east	n/a

Western Siberia	No agreement	No forecast	Near normal and below normal over the southern contin ent	n/a
Eastern Siberia	Low	Above normal in the east	Mostly below normal	miss
Chukchi and Bering	Low	Above normal	Mostly below normal	miss
Central Arctic	No agreement	No forecast	Mostly near normal	n/a

Outlook for winter 2021-2022:

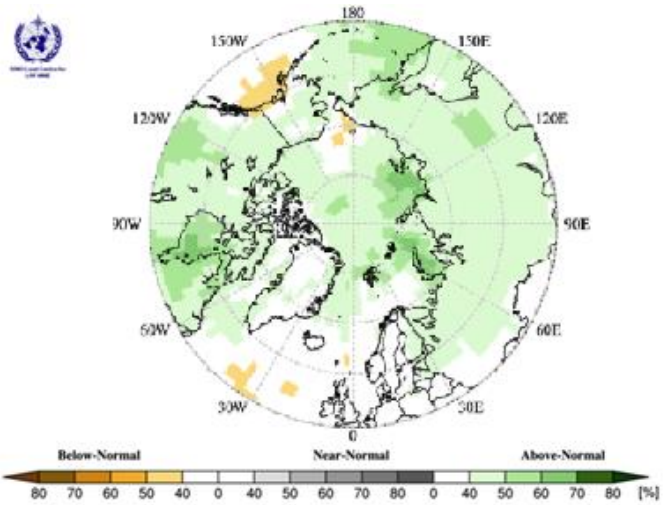

Figure 9: Multi model ensemble probability forecast for precipitation for November 2021, December 2021 and January 2021. Green indicates wetter conditions, orange drier conditions and white, no agreement between the models. Source: www.wmolc.org.

Precipitation during winter 2021-2022 (NDJ: November 2021, December 2021, and January 2022) is forecast to be above normal over the majority of the Arctic region. Forecast confidence is generally low (light green areas in Figure 9, Table 4). Exceptions are large areas in the Western and Eastern Nordic regions where no agreement between models (white areas in Figure 9, Table 4) yields no forecast for precipitation . Below normal precipitation with low confidence (light orange areas Figure 8, Table 4) is forecast for the northern Bering Sea and small regions in the Southern Chukchi Sea.

Table 4. Winter (NDJ) 2021-2022 Outlook: Forecasted Arctic Precipitation by Region

Region (see Figure 1)	MME Precipitation Forecast Agreement*	MME Precipitation Forecast
Alaska and Western Canada	Low	Above normal over land, below normal over the North Pacific
Central and Eastern Canada	Low	Above normal
Western Nordic	No agreement	No forecast
Eastern Nordic	Low	Above normal
Western Siberia	Low	Above normal
Eastern Siberia	Low	Above normal
Chukchi and Bering	Low	Above normal
Central Arctic	Low	Above normal

*: See non-technical regional summaries for greater detail

POLAR OCEAN

Summary for June, July, and August 2021:

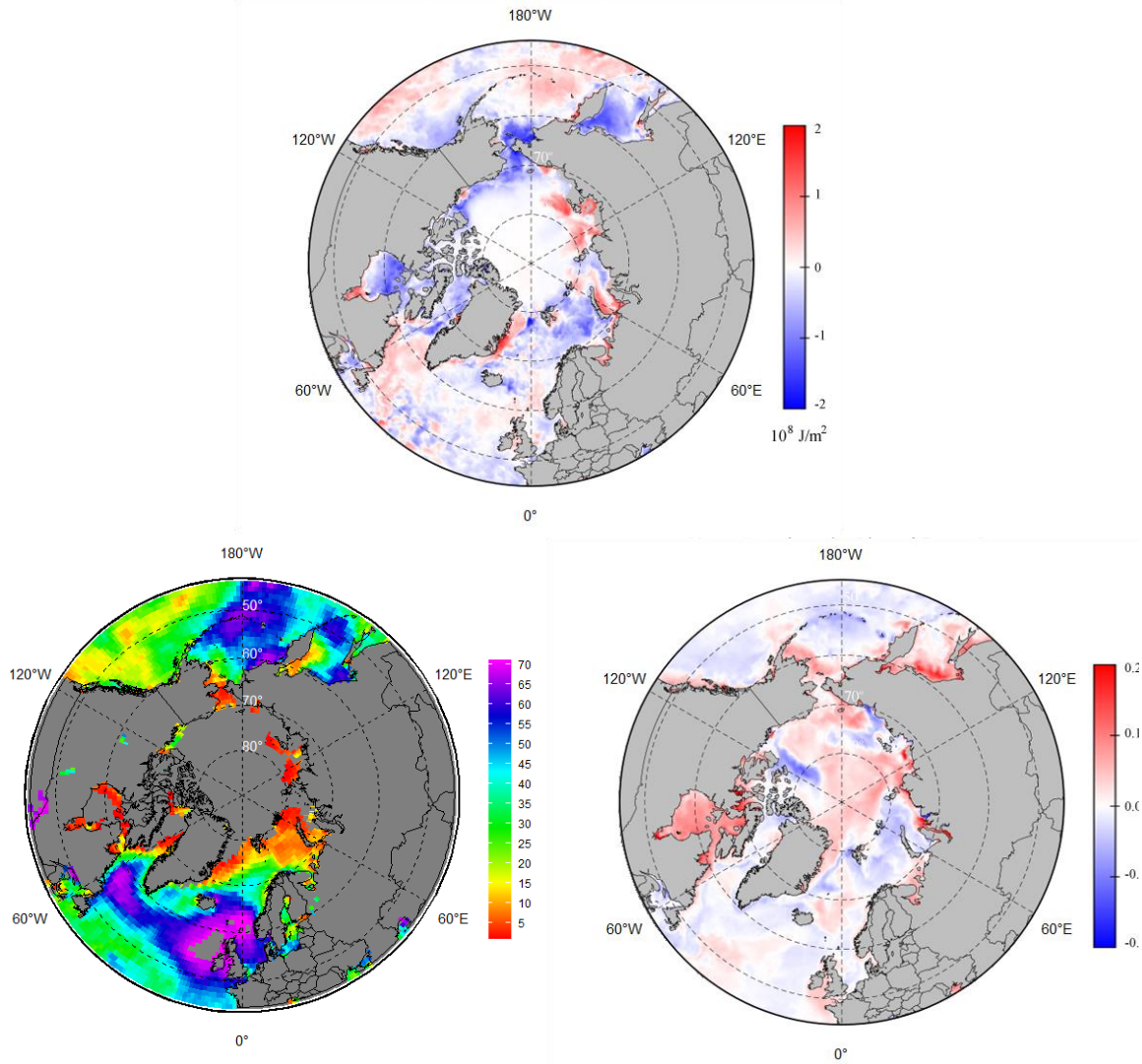

Figure 10. JJA 2021 Heat Content 15 m anomaly (top), wind waves and swell rank (bottom left) and pH anomaly (bottom right). Anomalies are given for 1993-2020 period, rank - for 1950-2021 period. Map produced by the Arctic and Antarctic Research Institute http://www.aari.ru. Data source: CCCS MEMS and ERA5.

Prominent lower than average Heat Content (HC) over the 1993-2020 period (figure 10, top) was observed during JJA 2021 in the central Barents, Chukchi, Bering, Beaufort and Labrador Seas with higher HC values observed in the southwest Kara, Laptev, parts of Greenland, Svalbard and FJL waters. Due to lesser summer sea ice extent, the Chukchi and Bering Seas, parts of Eurasian shelf seas and the Canadian Arctic were exposed to more storms than normal (figure 10, bottom left) with calmer conditions observed in parts of the Nordic and Bering regions. Numerical models for summer 2021 show both positive pH anomalies (Arctic Basin, Laptev Sea, NE part of Kara Sea, Chukchi, Hudson Bay) and negative pH anomalies (Kara, ESS, Greenland Sea) relative to the 1993-2020 period (figure 10, bottom right), which is similar to summer 2020. The negative anomalies may point to acidification processes though this needs further validation, for example, additional salinity and/or pH sensors on buoys (DBCP and International Arctic Buoy Program) or other monitoring initiatives (e.g Arctic Monitoring and Assessment Program).

SEA SURFACE TEMPERATURE

Outlook for winter 2021-2022:

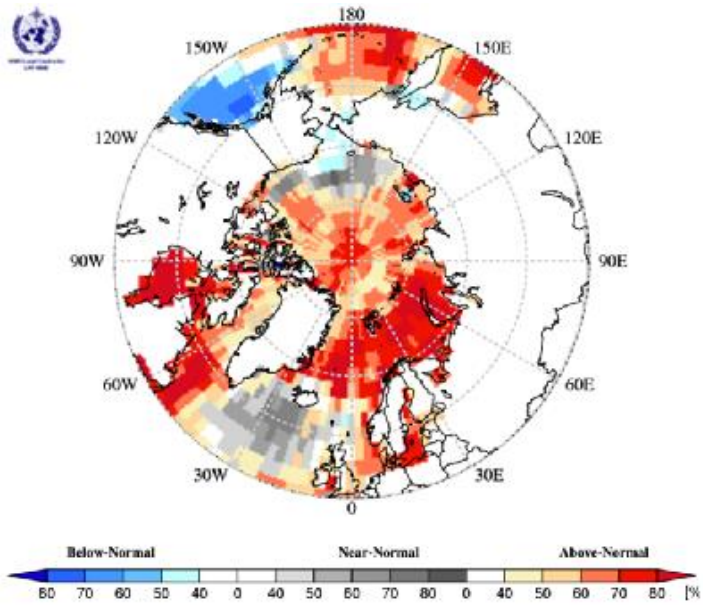

Figure 11. Multi model ensemble probability forecast for sea surface temperature for November 2021, December 2021, and January 2022. Three categories: below normal (blue), near normal (grey), above normal (red) and no agreement amongst the models (white). Source: www.wmolc.org

Sea surface temperature (SST) during winter 2021-2022 (NDJ: November 2021, December 2021, and January 2022) is forecast to be above normal for most of the Arctic (red areas Figure 11, Table 5). Forecast confidence is highest (dark red areas Figure 11, Table 5) for the Barents, Kara Greenland and South Labrador Seas as well as Hudson Bay. Cooler than normal SSTs are forecast for the Gulf of Alaska, North Pacific ocean and south Chukchi Sea (blue areas in Figure 11), forecast confidence is low to moderate (Table 5). Near normal SSTs are forecast for the North Atlantic Ocean and regions in the Chukchi and East Siberian Seas (grey areas, Figure 11); confidence is low to moderate (Table 5).

Table 5. Winter (NDJ) 2021-2022 Outlook: Forecasted Arctic Sea Surface Temperature by Region

Region (see Figure 1)	**MME Sea Surface Temperature Forecast Agreement***	**MME Sea Surface Temperature Forecast**
Alaska and Western Canada: Beaufort Sea, Gulf of Alaska and North Pacific Ocean	Moderate	Below normal in the Gulf of Alaska and North Pacific, near normal in the Beaufort Sea
Central and Eastern Canada: Canadian Arctic Archipelago, Hudson Bay, Baffin Bay and Labrador Sea	Moderate to high	Above normal
Western Nordic: Greenland and Norwegian Seas	Moderate to high	Above normal in the Greenland and Norwegian Seas, near normal in the North Atlantic
Eastern Nordic: Barents Sea	High	Above normal
Western Siberia: Kara Sea	High	Above normal
Eastern Siberia: Laptev Sea	Moderate	Above normal
Chukchi and Bering: Sea of Okhotsk and the Chukchi, Bering and East Siberian Seas	Moderate	Above normal in the Sea of Okhotsk and Bering Sea, Near normal in the East Siberian Sea and below normal in the Chukchi Sea
Central Arctic: Arctic Ocean	Moderate	Above normal

*: See non-technical regional summaries for greater detail

SNOW WATER EQUIVALENT (experimental product)

Outlook for winter 2021-2022:

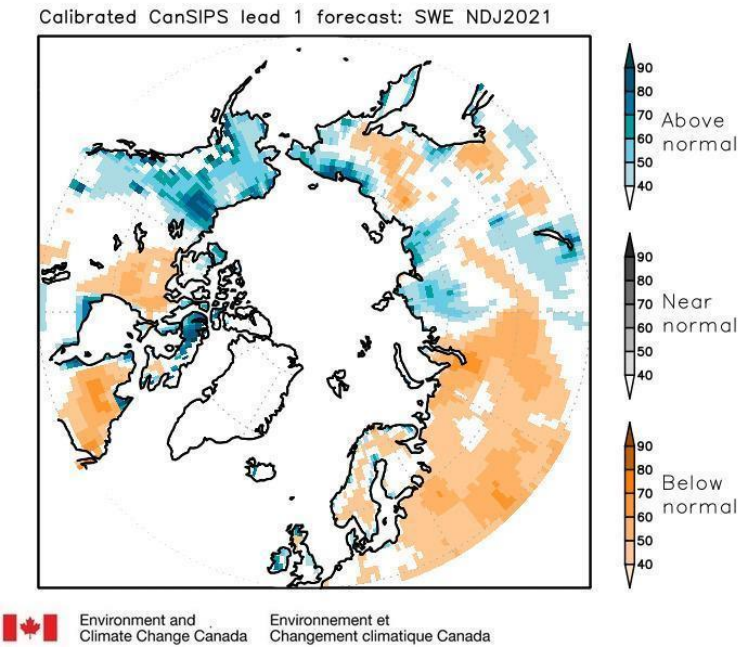

Figure 12: Canadian Seasonal to Interannual Prediction system probability forecast for snow water equivalent for November 2021, December 2021 and January 2022. Three categories: below normal (blue), near normal (grey), above normal (red) and no agreement amongst the models (white).

An experimental probabilistic seasonal forecast for snow water equivalent (SWE) over land is from the Canadian Seasonal to Interannual Prediction System (CanSIPS) (Figure 12, Table 6). The winter 2021-2022 (NDJ: November 2021, December 2021, and January 2022) forecast for SWE depends on the region with large regions of low confidence (light orange and light blue areas in figure 12) or no model agreement (white areas in Figure 12). Below normal SWE (orange areas in Figure 12) is forecast for central and eastern Canada, and the Eastern Nordic and Western Siberia regions. Above normal SWE (blue areas in Figure 12) is forecast for the Canadian Arctic Archipelago, western Canada, Alaska and along the coast of Chukchi, East Siberian and Bering Seas. Some of these coastal regions of above normal SWE forecasts have moderate confidence (dark blue areas in Figure 12).

Table 6. Winter (NDJ) 2021-2022 Outlook: Forecasted Arctic Snow Water Equivalent by Region

Region (see Figure 1)	**MME Snow Water Equivalent Forecast Agreement***	**MME Snow Water Equivalent Forecast**
Alaska and Western Canada	Low to moderate	Above normal
Central and Eastern Canada	Moderate to no agreement	Above normal in the Canadian Arctic Archipelago and south and eastern Hudson Bay; below normal over the rest of the region
Western Nordic	No model agreement	No forecast
Eastern Nordic	Low	Above normal
Western Siberia	Low	Above normal
Eastern Siberia	Low to no agreement	
Chukchi and Bering	Moderate to no agreement	Above normal in coastal areas, below normal inland

Central Arctic	No forecast	No forecast

*: See non-technical regional summaries for greater detail

SEA ICE

Summary for June, July, and August 2021:

Surface air temperature anomalies and the heat content (HC) of the upper layer of the polar oceans influenced the rate of melt this summer. Negative anomalies of ocean heat content in the upper 15 meters of the ocean in June 2021 and further in summer (figure 10, top left) slowed ice melt in the Kara, East Siberian and Chukchi Seas. A slow melt was reinforced by negative or neutral surface air temperature anomalies in June, July and August 2021 (Figure 4) over parts of the Canadian Arctic, Chukchi Sea, Arctic Basin and eastern parts of the Kara and East Siberian Seas.

The 4.8 mln km^2 minimum sea-ice extent reached on September 12, 2021 is a 0.9 mln km^2 increase compared to last year's minimum and is the 12th lowest minimum sea-ice extent since 1979, with the minimum summer sea-ice extent observed in 2012 (3.35 mln km^2). Estimates of the sea-ice volume based on numerical reanalysis (HYCOM-CICE, PIOMAS, not shown here) also show a slight recovery with a sea-ice volume higher than last year and comparable to September 2017. Ice massifs of thick FYI were present in the Eurasian Arctic throughout the summer and were still present in mid-September (Figure 13, green areas); as a result, the northern sea route was not consistently ice free this summer. Sea ice conditions in the Beaufort Sea and the Canadian Arctic Archipelago were close to normal with the Northwest Passage closed (Figure 13).

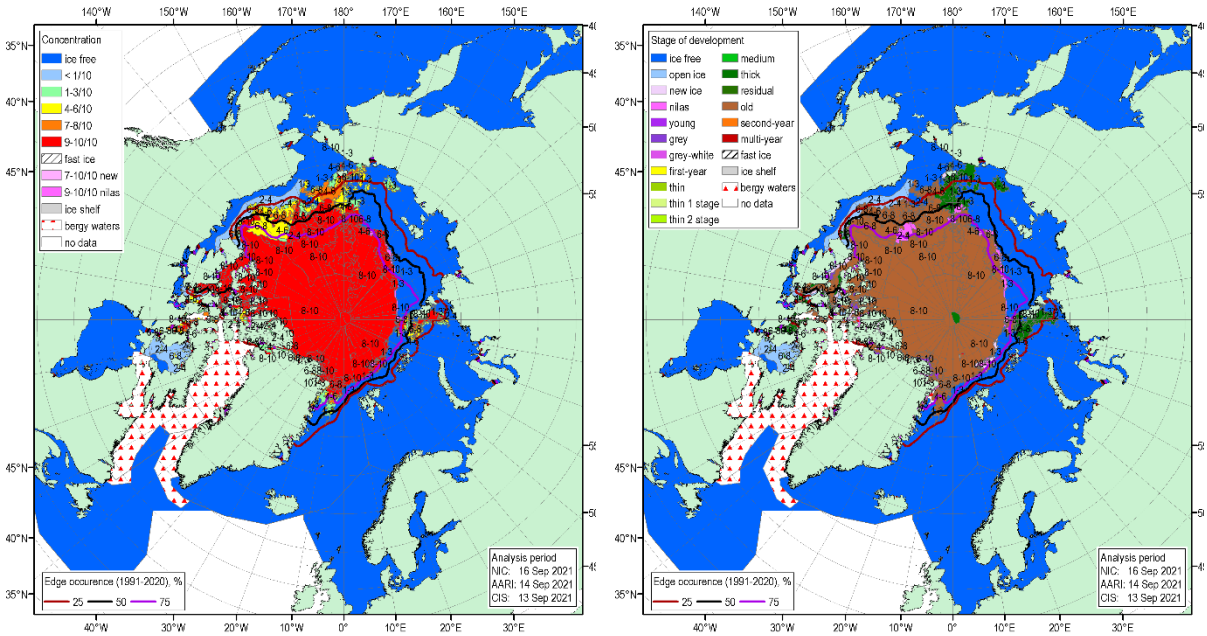

Figure 13: Blended Arctic sea-ice chart (AARI, CIS, NIC) for 13-16 September 2021 and sea-ice edge occurrences for 11-15 September for 1991-2020 reference period. Left: total concentration, right: predominant stage of development

Verification for September 2021:

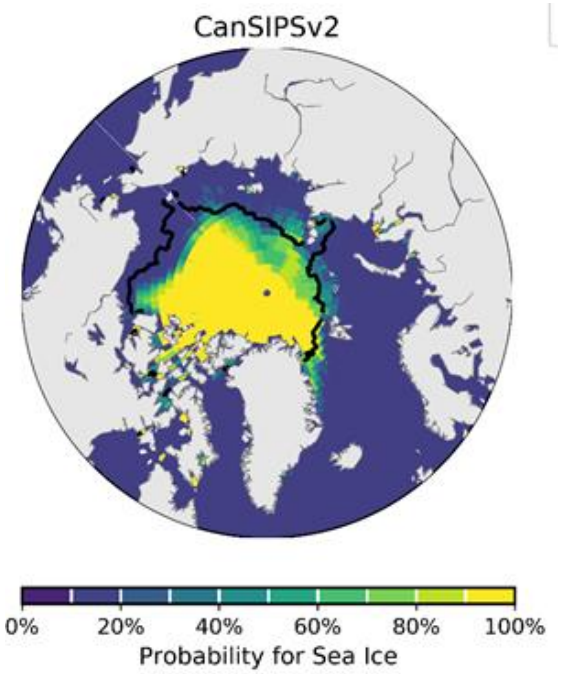

Figure 14. September 2021 probability of sea ice at concentrations great than 15% from CanSIPSv2 (ECCC). The observed September 2021 ice edge is shown in black

The forecast for September 2021 sea-ice extent (Figure 14) was based on output from CanSIPSv2. Forecast accuracy was high for most regions (Table 7). Below normal ice extent was correctly forecast for the Kara, Laptev, East Siberian and Barents Seas and near normal ice extent was correctly forecast for the Beaufort and Chukchi Seas. The model missed the record breaking low ice extent in the Greenland Sea with a near normal forecast and the near normal ice extent in the Canadian Arctic Archipelago with a below normal forecast.

Table 7. Summer 2021: Regional Comparison of Observed and Forecasted Minimum Sea-Ice Extent

Regions (see Figure 2)	CanSIPS Sea-Ice Forecast Confidence	CanSIPS Sea-Ice Forecast	Observed Ice Extent	CanSIPS Sea-Ice Forecast Accuracy
Barents Sea	High	Below normal	Below normal	Hit
Beaufort Sea	High	Near normal	Near normal	Hit
Canadian Arctic Archipelago	Moderate	Below normal	Near normal	Miss
Chukchi Sea	High	Near normal	Near normal	Hit
Eastern Siberian Sea	Moderate	Below normal	Below normal	Hit
Greenland Sea	High	Near normal	Below normal	Miss
Kara Sea	High	Below normal	Below normal	Hit
Laptev Sea	High	Below normal	Below normal	Hit

Outlook for Fall Freeze-up 2021:

Sea-ice freeze-up is defined as the date where ice concentration exceeds 50% in a region. The outlook for fall freeze-up shown in Figure 15 (left) displays the sea-ice freeze-up anomaly from CanSIPSv2 based on the nine-year climatological period from 2012-2020. The qualitative 3-category (high, moderate, low) confidence in the forecast is based on the historical model skill

(Figure 15, right). A summary of the forecast for the 2021 fall freeze-up for the different Arctic regions is shown in Table 8.

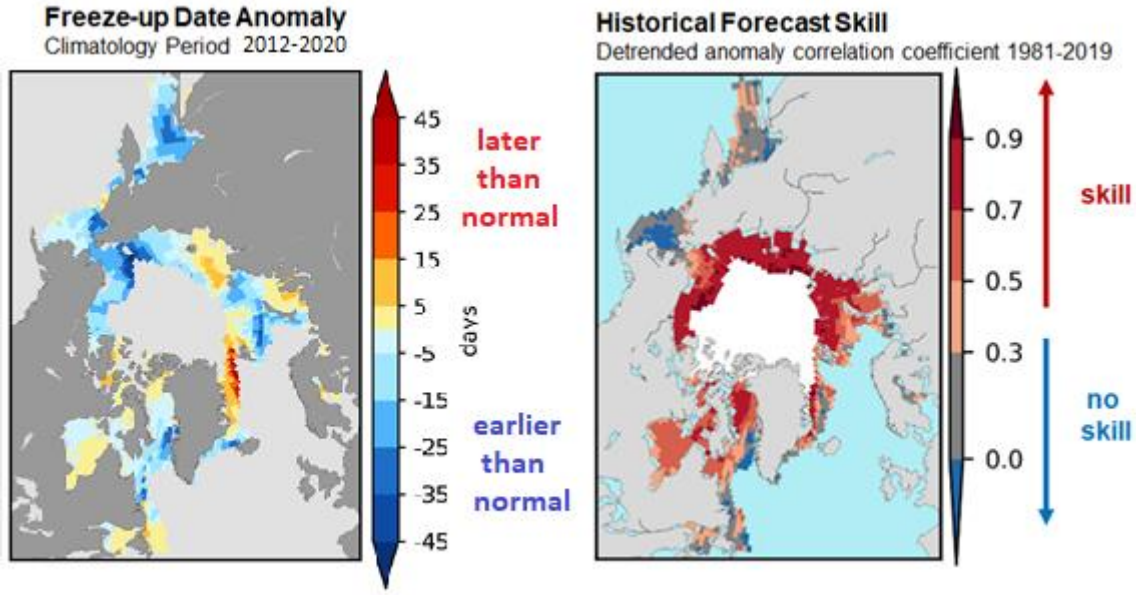

Figure 15: Forecast for the 2022 winter freeze-up (left) expressed as an anomaly (difference from normal), where freeze-up is defined as the date when the ice concentration exceeds 50%. The historical forecast skill (right) is defined as the detrended anomaly correlation coefficient based on the 1981-2019 period.

Table 8: Winter 2021-2022 Regional Outlook for Arctic Sea Ice Freeze-up

Regions (see Figure 2)	CanSIPSv2 Sea-Ice Forecast Confidence	CanSIPSv2 Sea-Ice Freeze-up Forecast
Baffin Bay	Moderate	Near normal
Barents Sea	High	Late
Beaufort Sea	High	Early
Bering Sea	Low	Near normal to early
Chukchi Sea	Moderate	Early
East Siberian	High	Near normal to early
Greenland Sea	High	Late
Hudson Bay	Moderate	Near normal
Kara Sea	High	Early
Labrador Sea	Moderate	Early
Laptev Sea	High	Near normal to late
Sea of Okhotsk	Low	Early

Outlook for the March 2022 Maximum Sea Ice Extent:

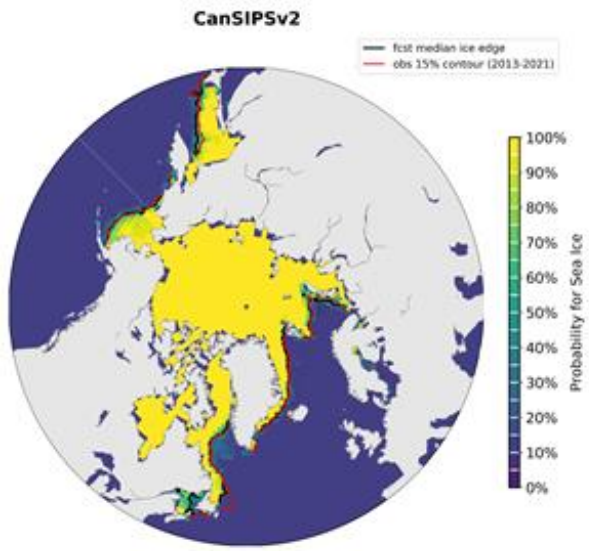

Figure 16. March 2021 probability of sea ice at concentrations greater than 15% from CanSIPSv2 (ECCC). The forecast median ice extent is shown in black and the observed mean ice edge 2013-2021 is shown in red.

Maximum sea ice extent normally occurs during the month of March in the northern hemisphere. Table 9 categorizes the sea ice extent forecast confidence and relative extent (near normal, below normal, above normal) by Arctic region with respect to an average ice extent based on the 2013-2021 period. Figure 16 shows the probability of sea ice presence at concentrations greater than 15% and the forecast mean ice extent (black) along with the 2013-2021 mean extent (red). The ice extent is forecast to be near normal with the exception of below normal ice extent in the south Labrador Sea and Gulf of St. Lawrence.

Table 9. Winter 2021 Regional Outlook for March Sea Ice Extent

Regions (see Figure 2)	CanSIPSv2 March Ice Extent Forecast Confidence	CanSIPSv2 March Sea Ice Extent Forecast
Barents Sea	Moderate	Near normal
Bering Sea	High	Near normal
Greenland Sea	Low	Near normal
Northern Baltic Sea	Moderate	Near normal
Gulf of St. Lawrence	Low	Below normal
Labrador Sea	Low	Below normal
Sea of Okhotsk	High	Near normal

Outlook for key shipping regions:

Gulf of St. Lawrence: Below normal sea ice conditions are expected this winter based on current sea surface temperatures, forecasted surface air temperatures and numerical model guidance. Forecasted lighter ice conditions should mitigate any significant difficulties encountered in the Gulf and in individual ports. The expected winter air temperature regime may delay freeze-up significantly and reduced ice thickening may lead to rapid and early spring break-up. However, conditions are not expected to reach the historic lows achieved last winter.

The Baltic Sea: The Baltic Sea ice season 2021-2022 is expected to become average or slightly lower than average, when compared to 21st-century winters. The seasonal sea-ice forecast was issued in October. Navigation will be affected by ice mainly in the Bay of Bothnia,

the coastal zone of the Sea of Bothnia and in the eastern Gulf of Finland. During milder ice seasons, sea ice tends to be more dynamic, and consequently, obstructs navigation to a relatively high degree.

Svalbard and Barents Sea: In the upcoming winter season, the sea-ice freeze-up time around Svalbard and in the northern part of the Barents Sea is expected to be late to near normal. The March 2022 sea-ice extent in this area is expected to be near normal. However, since the model does not show if the sea-ice extent is composed of older ice advected into the area or new ice grown in situ, the impact for users is difficult to ascertain.

Northern Sea Route (NSR): Both later and earlier than normal freeze-up and near to below normal sea-ice conditions are expected for the NSR this winter based on current and forecasted sea surface and surface air temperatures. The expected winter air temperature regime will most likely support the development of predominantly medium first-year ice in most of the area of the Kara and the Laptev Sea. Significant areas of the residual ice in NE Kara and N Eastern Siberian Sea would stimulate formation of the thick FYI in this region. Forecasted near normal ice conditions would increase risks of winter navigation in comparison to the same period in 2020 including transit Vilkitsky Strait which will be occupied with the 2nd year old ice, though that would hardly decrease intensity of navigation due to high ice classes and icebreaker support used. The expected higher than normal snow height would delay the start of the melting processes this spring in central and eastern parts of the NSR.

Sea of Okhotsk: Earlier than normal freeze-up and normal March 2022 sea-ice extent in the Sea of Okhotsk are expected based on current ocean and forecasted surface air temperatures, and numerical model guidance. That would increase risks of winter navigation in comparison to 2020.

MAJOR CLIMATE RELATED RISKS AND IMPACTS

Wildfires in Siberia

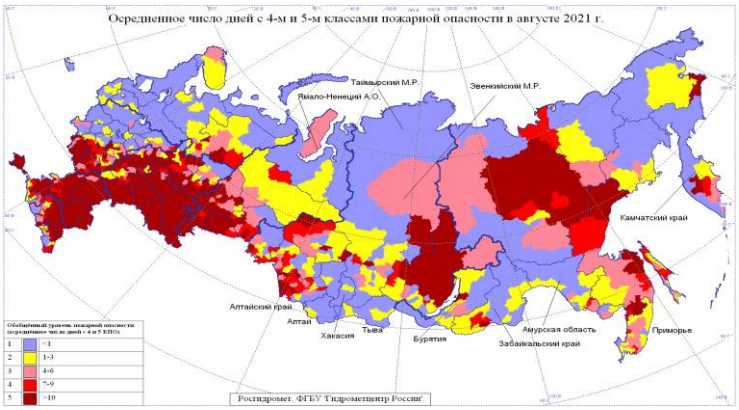

Figure 17. Number of days of 4th (high risk of fire hazard) and 5th (risk of extreme fire hazard) fire danger class in August 2021. Hydrometeorological Center of Russia.

Climate change is manifested not only in a general increase of the seasonal temperatures, but also in the shift of forest fires from the southern part of Russia to the Arctic zone. Abnormally hot and dry weather conditions in summer 2021 have developed stationary anticyclone over Siberia, contributing to the spread of wildfires and emergency events. The emergency regime was introduced in Sakha/Yakutia in June. Yakutsk, the capital of the republic, where one third of the total population lives, was covered by smoke for a month. On August 6-12 due to the greatest number of fire hazards (figure 17), concentration of pollutants in the air exceeded the maximum permissible norm by 5-21 times. During this period, 727 people complained of deteriorating health due to smoke, 40 were hospitalized. Flights were delayed and ferry services on the Lena River were suspended.

It should be noted that the situation with wildfire in the North American side of the Arctic was opposite with typical season burning largely confined to June & July. By late August total area burned appeared well below median.

Other ongoing regional impacts of climate change

<u>Alaska and Western Canada</u>

- Flooding in some communities from individual storms
- Sustained high levels on rivers produced dramatically increased permafrost thaw and river bank erosion
- Rapid raise of river and lake levels affecting communities

<u>Central and Eastern Canada</u>

- Increase risk of coastal flooding and thawing permafrost coastal erosion and community infrastructure
- All marine mammals with habitat on sea ice may be more difficult to harvest
- Crabbing for coastal communities may be impacted owing to lack of stable ice nearshore

<u>Western and Eastern Nordic</u>

- In Northern & Eastern Iceland wells dried up and challenges for agriculture due to very warm and dry weather
- In Scandinavia hotter and drier summer affected reindeer herd conditions (no colder shelters higher up, less greenery) with much rain in September leading to poor grazing in winter

<u>Western Siberia</u>

- A lot of maximum temperature records. Salekhard (capital of the Yamal-Nenets Autonomous Okrug) had record maximum temperature in June +28.3 (previous +24.2 in 1958).
- Due to a long period of warm weather the duration of insects' stay in the tundra increased (110 days instead of an average of 95), which is dangerous for deer, as

insects enter the respiratory tract of animals and lead to suffocation.

Eastern Siberia

- Residents of Krasnoyarsk region were forbidden to visit forests, make fires, burn garbage due to wildfires, though there was no case of forest fires moving to residential buildings and economic facilities
- In Sakha (Yakutia) 1695 wildfires were registered for 8 million hectares.
- Prolonged forest fires affected the decline in the popular extreme tourism in the taiga: Sakha (Yakutia), Krasnoyarsk Territory
- Animals "hang out» in the Taiga - several cases of bear attacks on people were recorded in the Krasnoyarsk Territory
- Because of the warm water in the Lena River (Yakutia), the fish during spawning “did not reach” 70 kilometers to the usual level so that local fishermen had to go upstream for fishing for tens of kilometers
- Due to thunderstorms in 23 towns power supply was interrupted, 6 power transmission towers were knocked down In the center of the Krasnoyarsk Territory.

Chukchi and Bering

- Hot weather and little rainfall led to drought, which caused forest fires.
- In the Magadan region, the total recorded area covered by fire exceeded 496 thousand hectares.

Central Arctic

- In general heavier ice conditions with thicker more concentrated residual ice, predominantly 70-80 cm, often more than 1m of thickness.
- Less amount of algae and biota on the ice bottom
- In general more favorable than in 2020 conditions for wildlife

Background and Contributors

This Arctic seasonal climate outlook was prepared for ACF-8. Contents and graphics were prepared in partnership with the Russian, United States, Canadian, Norwegian, Danish, Finnish, Swedish, and Icelandic meteorological agencies and contributions of the former JCOMM Expert Team on Sea-ice, former CCl/CBS Inter-Programme Expert Team on Regional Climate Activities, the GCW, the IICWG, and with input from AMAP.

The ArcRCC-Network, a collaborative arrangement with formal participation by all the eight Arctic Council member countries, is in demonstration phase to seek designation as a WMO RCC-Network, and its products and services are in development and are experimental. For more information, please visit https://arctic-rcc.org/acf-fall-2021

Acronyms

AARI: Arctic and Antarctic Research Institute
ArcRCC-Network: Arctic Regional Climate Centre Network https://www.arctic-rcc.org/
ACF: Arctic Climate Forum
AMAP: Arctic Monitoring and Assessment Programme
CAA: Canadian Arctic Archipelago
CanSIPSv2: Canadian Seasonal to Interannual Prediction System
CBS: WMO Commission for Basic Systems
CCCS: Copernicus Climate Change Service
CCl: WMO Commission for Climatology
CIS: Canadian Ice Service
CMEMS: Copernicus Marine Environment Monitoring Service
ECCC: Environment and Climate Change Canada
ECMWF: European Centre for Medium-Range Weather Forecasts
ESS: Eastern Siberian Seas
FYI: first-year ice stage of development
GCW: Global Cryosphere Watch
GloFAS-ERA5: CCCS operational global river discharge reanalysis
GloSea5: Met Office Global Seasonal forecasting system version 5
GPCs-LRF: WMO Global Producing Centres Long-Range Forecasts
HYCOM-CICE: HYbrid Coordinate Ocean Model, Coupled with sea-ICE
IICWG: International Ice Charting Working Group
IOC: Intergovernmental Oceanographic Commission
JCOMM: former Joint WMO/IOC Technical Commission on Oceanography and Marine Meteorology
LC-LRFMME: WMO Lead Centre for Long Range Forecast Multi-Model Ensemble
NIC: National Ice Center (United States)
NCAR: National Center for Atmospheric Research
NCAR CFSR: National Center for Atmospheric Research Climate Forecast System Reanalysis
NOAA/NWS/NCEP/CPC: National Oceanic and Atmospheric Administration/National Weather Service/National Centers for Environmental Prediction/Climate Prediction Center (United States of America)
NSIDC: National Snow and Ice Data Center (United States)
MME: Multi-model ensemble
NSR: Northern Sea Route
NWP: Northwest Passage
PIOMAS: Pan-Arctic Ice Ocean Modeling and Assimilation System
RCC: WMO Regional Climate Centre
RCOF: Regional Climate Outlook Forum
WMO: World Meteorological Organization