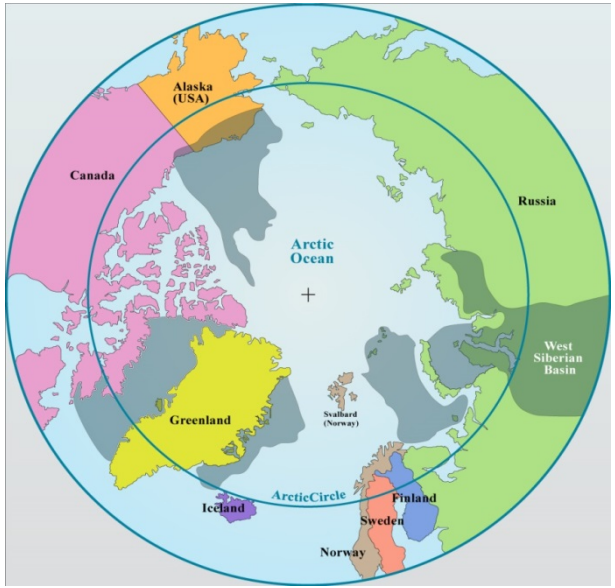


Arctic-HYCOS:
Arctic Hydrological Cycle Observing System

INTEROS Virtual Meeting. Feb 11, 2021

Dr. Alain Pietroniro, P.Eng., Former Executive Director, National Hydrological Service, Environment and Climate Change Canada
Currently, Professor and Chair in Water Resources Sustainability and Climate Change, Schulich School of Engineering,
Department of Civil Engineering, University of Calgary

Presentation Outline

1. Overview of the World HYCOS program
2. Description of the Arctic HYCOS implementation
3. Arctic-HYCOS objectives and progress
4. Preliminary applications of the data

WHYCOS

WORLD HYDROLOGICAL CYCLE OBSERVING SYSTEM

- Arctic-HYCOS is a component of the World Meteorological Organization (WMO)'s **World Hydrological Cycle Observing System (WHYCOS)** framework program
- The WMO has been instituting the WHYCOS since 1993 to:
  - enable the establishment of hydrological observation systems around the world
  - enable development of regional/international databases of high quality hydrological data
  - advocate for the free and regular exchange of up-to-date data

All HYCOS Projects:

Implemented Projects

- **Med-HYCOS:** 18 countries of the Mediterranean rim
- **SADC-HYCOS:** 11 countries of the South African Development Community
- **AOC-HYCOS:** 11 countries from Western and Central Africa

Projects under implementation

- **Niger-HYCOS:** Niger River in Africa
- ***Arctic-HYCOS:*** *Countries in the Arctic drainage basin*
- **Volta-HYCOS:** Volta River in the north tropical zone of Africa
- **Carib-HYCOS (CIC):** Caribbean continental countries and Islands **Pacific-HYCOS:** Pacific Island Countries
- **Mekong-HYCOS:** Cambodia, Laos, Thailand and Vietnam

Project proposals in development

- **Sava-HYCOS:** Bosnia, Croatia, Montenegro, Serbia and Slovenia
- **Senegal-HYCOS:** Guinea, Mali, Mauritania, Senegal
- **IGAD-HYCOS:** 9 countries in the African Intergovernmental Authority on Development
- **Hindu Kush Himalaya-HYCOS:** Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, Pakistan
- **Lake Chad-HYCOS:** Fourth Largest lake in Africa
- **Aral-HYCOS:** Five Central Asian States
- **CONGO-HYCOS:** Western Central Africa

WHYCOS

WORLD HYDROLOGICAL CYCLE OBSERVING SYSTEM

WHYCOS Policies and Partners:

- The data policy states that countries are the owners of the data they generate
  - The respective National Hydrological Services are responsible for the validation of their data in accordance with national regulations

- Support for WHYCOS projects comes from:
  - **The WMO Secretariat**, supported by the **WHYCOS International Advisory Group**, which ensures that component projects are implemented in agreement with the global WHYCOS concept
  - WHYCOS is also a fundamental contributor to the development of the **WMO Hydrological Observing System (WHOS)**, a simple web-based portal providing access to the near real-time hydrological data in standard data formats (including WaterML 2.0)

- Another objective is to promote global data exchange and scientific cooperation
  - Project-generated data are used by global data centres operating in cooperation with the WMO, such as the **Global Runoff Data Centre (GRDC)**

Arctic-HYCOS Study Area & Committee

Arctic-HYCOS Study Area:

- The project aims to collect and share hydrological data and information for the transnational **Arctic basin**
- This includes the Arctic Ocean, Northern Seas, and land areas of contributing streamflow (to ~45°N)

Project Steering Committee (PSC)

- Membership includes one representative from:
  - Each Arctic Council Member State, principally coming from the National Hydrological Service
  - WMO Executive Council Panel of Experts on Polar Observation, Research and Services (EC-PORS)
  - WMO Hydrology and Water Resources Programme
  - Global Runoff Data Centre (GRDC)
- The first annual PSC meeting was held in Geneva in 2014, after initial discussions dating back to 2000

2018 Project Steering Committee
Arctic Countries
USA
Canada
Iceland
Norway (& Svalbard)
Sweden (no flow to Arctic Ocean)
Finland
Russia
Support and Experts
WMO Secretariat
Global Runoff Data Centre (GRDC)
WMO hydrological working group
Research contracts

Map source: Wordpress, Iakovos Alhadeff (2015)

Arctic-HYCOS Project Purpose

The purpose of the Arctic-HYCOS Project is to allow for **the collection and sharing of hydrological data** and information, to allow researchers achieve the following scientific goals:

1) To evaluate **freshwater flux** to the Arctic Ocean & Seas

2) To monitor changes and enhance understanding of the **hydrological regime of the Arctic region**

3) To **estimate flows in ungauged regions** and **develop models** for enhanced **hydrological prediction** in the Arctic region.

- The Arctic-HYCOS mission directly supports further international cooperation in the study and assessment of hydrological processes in the Arctic drainage basins.
- The Arctic-HYCOS project not only provides a means for sharing data but also serves as a means to learn from other countries' methods and experiences.

Overall Project Objective

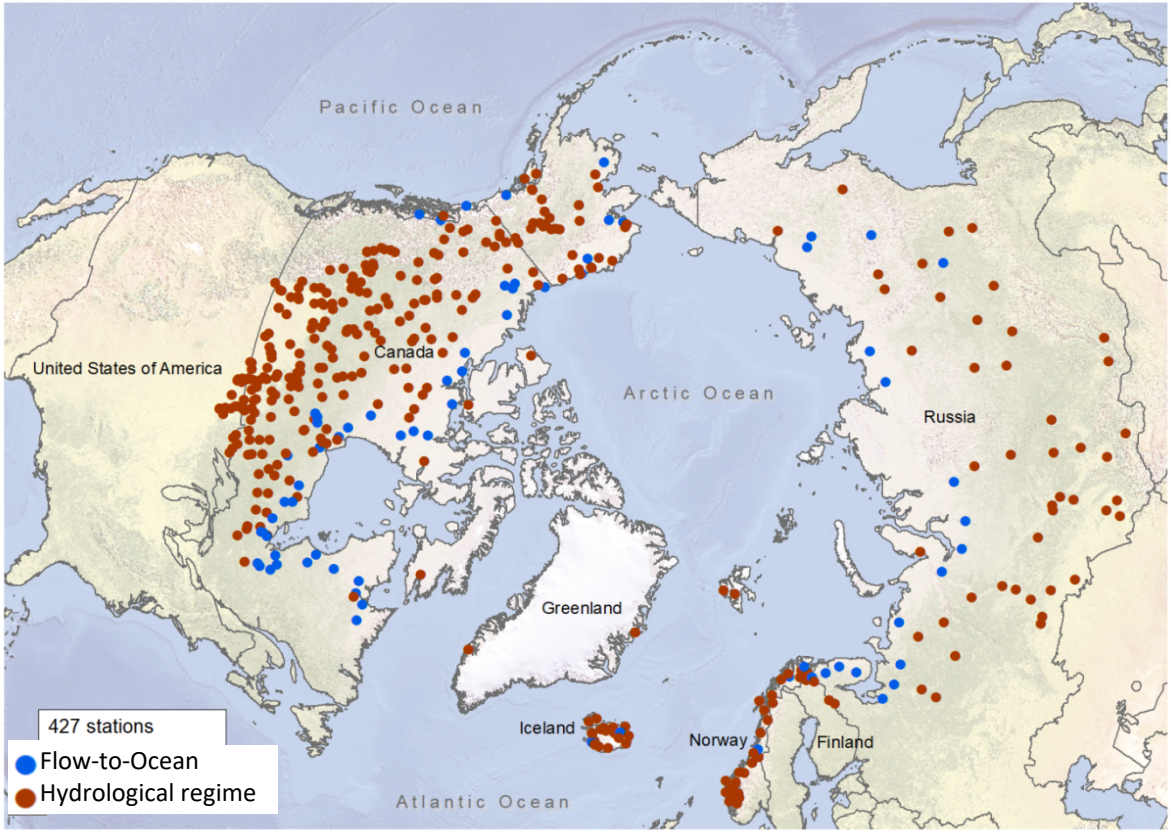
The project objective is to regularly collect, manage and share high quality hydrological data from a defined **Basic Network of Hydrological Stations (BNHS) in the Arctic basin**

- Network to include stations collecting the following data:
    a) daily **discharge** data; and
    b) daily **water temperature** data.
- Both quality assured historical data and provisional near real-time data
- Data to be shared freely in an online database

Basic Network of Hydrological Stations

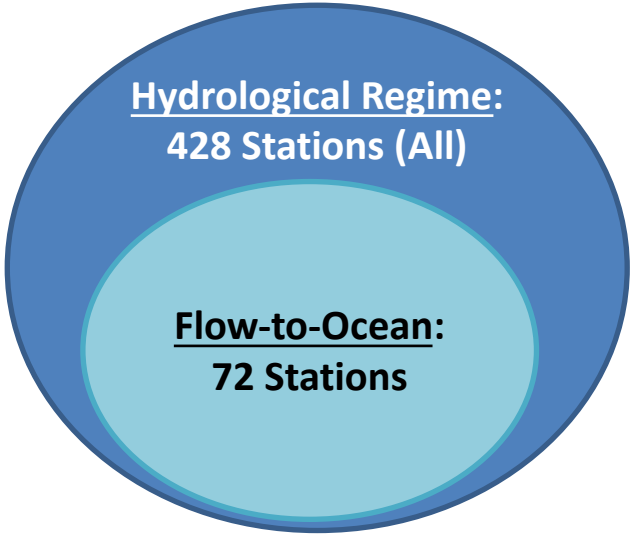
Station lists were created from existing stations of the national hydrological networks in the Arctic basin:

- **Hydrological Regime Network A**: Stations suited to study changes in the Arctic hydrological regime (covering the entire land mass draining into the Arctic Ocean and northern seas)
- **Flow-to-Ocean Network B**: Freshwater Flux to the Arctic Ocean (the most downstream stations, but restricted to stations with a drainage area >5000 km^2)



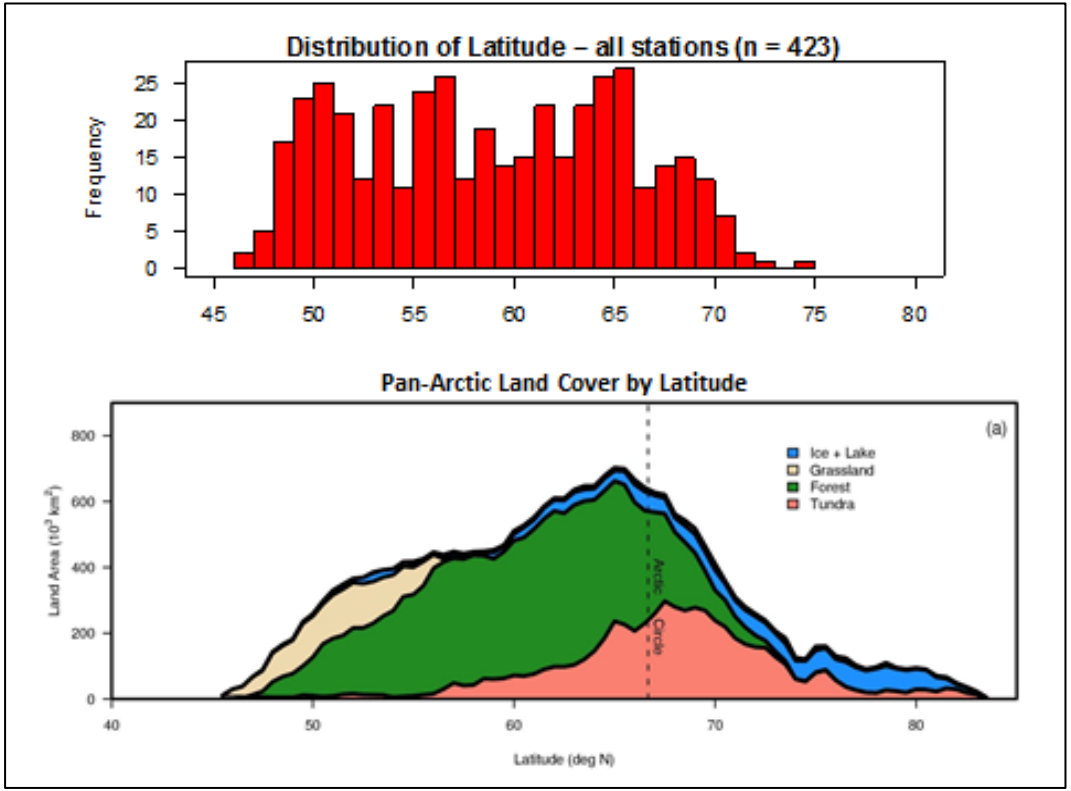
Map source: Dr. Ana Requena, Postdoctoral fellow, McMaster University

Basic Network of Hydrological Stations



Country	Network A: All Stations	Network B: Flow to Ocean
Canada	244	39
Finland	8	1
Greenland	2	0
Iceland	23	3
Norway	30 (2 on Svalbard)	3
Russia	61	17
USA	60	9
TOTAL	**428**	**72**

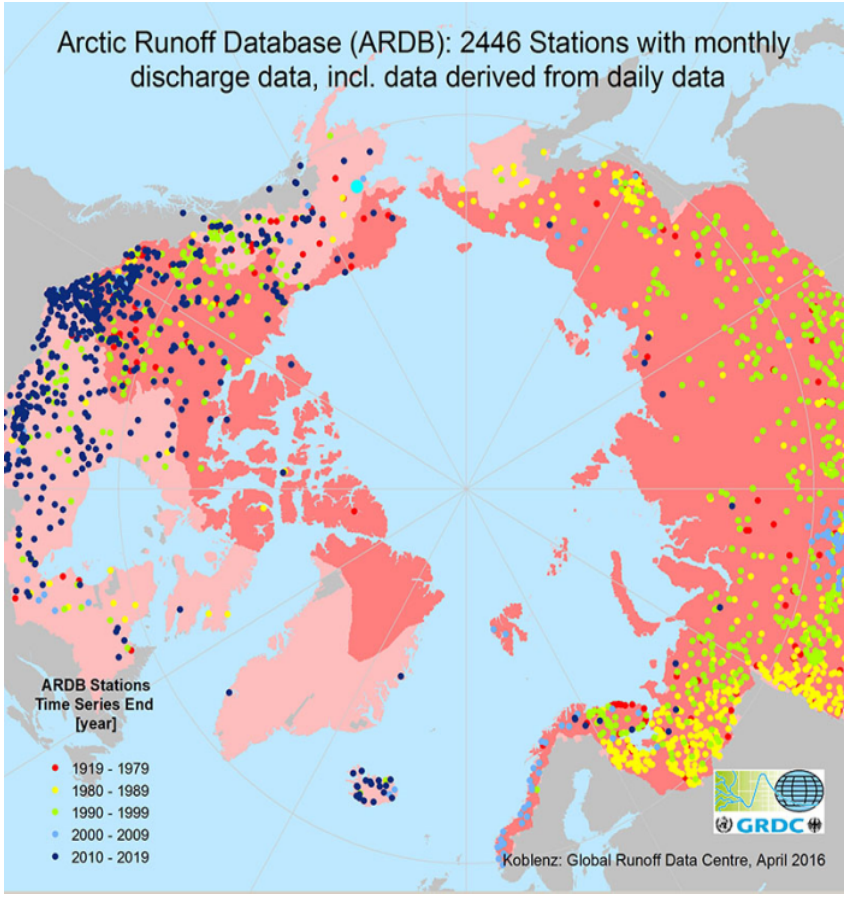
Latitude and Land Areas of Stations



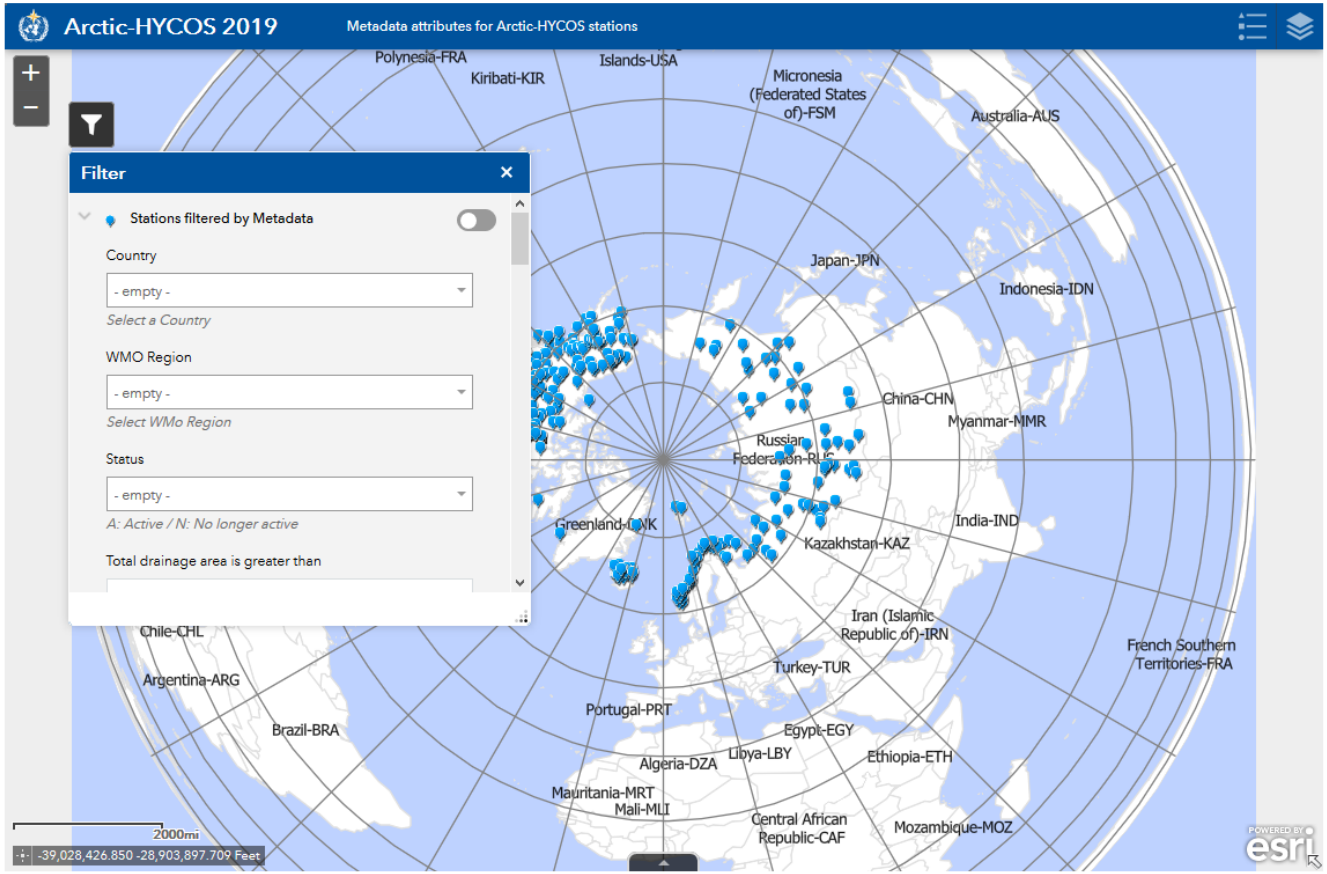
Global Runoff Data Centre (GRDC)

The GRDC provides the central depository for all Arctic-HYCOS data and metadata

- Data for the station lists are already included in the GRDC's Arctic Runoff Data Base (ARDB)
- Data is to be provided by the NHSs directly to the GRDC, and will then be fed to the Arctic-HYCOS web portal



Arctic-HYCOS Web Portal (draft)



https://hydrohub.wmo.int/en/projects/Arctic-HYCOS

- Free and unrestricted access to data and metadata
- Metadata to sort/filter stations and download subsets
- Data hosted by GRDC but accessed through this “window”

Metadata

- **General station metadata**:
  - Station name, #, river, operator, lat/long, drainage area size, period of record, flags for “real time” and “Flow-to-Ocean”
- **Extended metadata:**

Downstream station	Indication if the station is the most downstream, or if not, what the ID of the next downstream station is.
Shapefile of the total station drainage area	Flag noting if a vector shapefile of the station drainage area is available
Regulation	• Basins with structures providing significant flow regulation, based on the country’s standards, are considered regulated • Suggestion that “regulated” be defined as when structures control > 5% of the basin area.
Land Use Change	• Significant land use change: if >10% of the surface area of the basin has been modified from natural conditions
Discharge Data Quality Flag **awaiting development by international experts	General assessment of the accuracy of the derived discharge: - For each station or for each data point? based on the stability of the rating curve? - Separate station flags for ice-cover vs open-water conditions - Linkages with the Commission for Hydrology (CHy) Advisory Working Group and their “Project X” on discharge uncertainty

Practices and Procedures

- Summarize and recommend **standard international practices** for hydrological data collection in northern environments

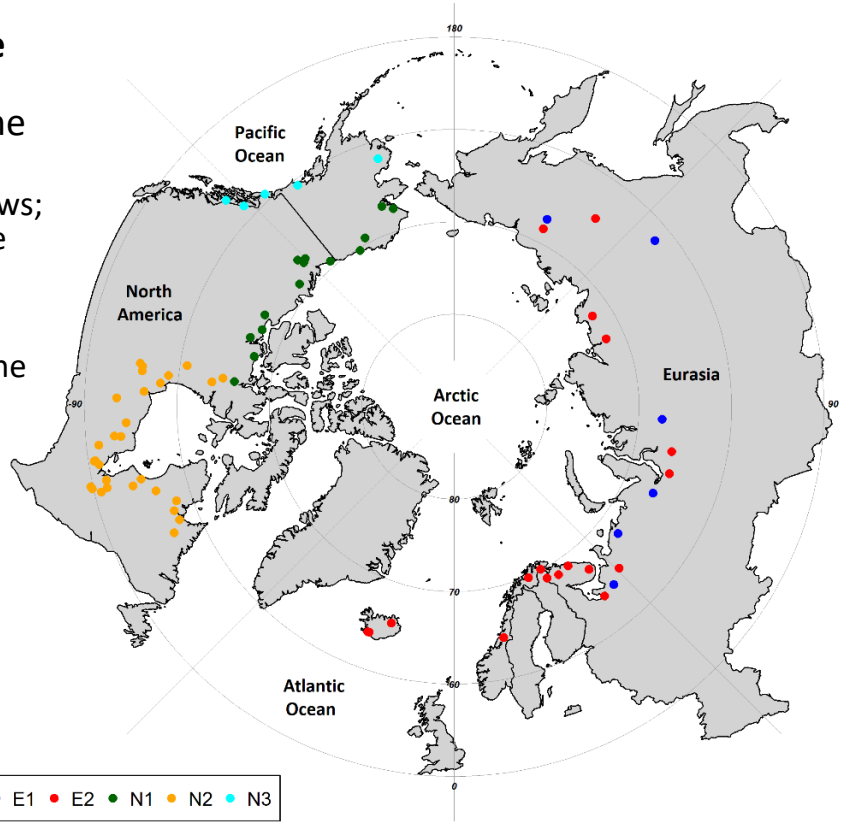
- Current review of standard procedures includes:
  - **flow estimation techniques during ice covered conditions**
  - **Water temperature monitoring**
  - **River and lake ice:** ice-thickness, freeze-up and break-up dates
- Future work:
  - measurement of flow using **hydro-acoustics** (under-ice)
  - **metadata** definitions and standards

- The committee aims to provide a list of recommended practices and procedures to be considered for adoption by all Arctic-HYCOS countries
  - Could serve as a reference document for all cold climate countries
  - These efforts may also lead to potential improvements to existing WMO standards and recommended practices and procedures.

Trend Analysis – Flow to Ocean

- An "**Analysis of Trends in Annual Streamflow within the Arctic-HYCOS Dataset**" was completed in March 2018 through a contract between ECCC and Dr. Don Burn at the University of Waterloo
  - Dr. Martin Durocher and Dr. Ana Requena, Postdoctoral fellows; Dr. Donald Burn, Professor; Jennifer Pellerin, MASc candidate
- The study examines freshwater flow for the 72 Arctic-HYCOS flow-to-ocean stations
  - Annual streamflow for the 72 rivers were categorized as to the nature and location of the contribution to the Arctic Ocean
  - Trend analysis was then conducted for each of the seven composite annual discharge series for 1975 to 2015

Category	Description	Number of rivers	
E1	Eurasia to Arctic Ocean Rivers: six largest rivers	6	24
E2	Eurasia to Arctic Ocean Rivers: smaller rivers	18	
N1	North America Rivers to Arctic Ocean	14	48
N2	North America Rivers to HJUBs	29	
N3	North America Rivers to Pacific Ocean	5	
Total	Rivers to the Arctic Ocean and related waterbodies		72
AO	Rivers to Arctic Ocean		38



Trend Analysis – Methods

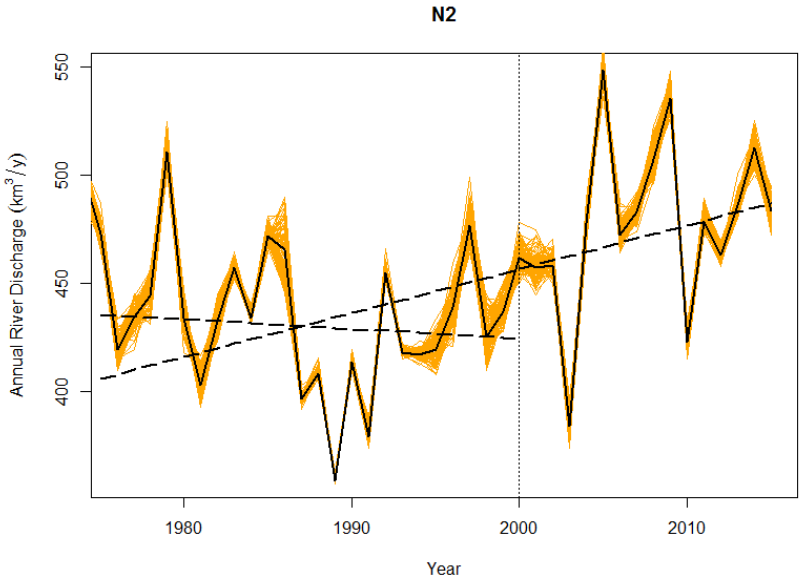


Figure: Aggregated annual discharge series for category N2 (North American rivers flowing to Hudson's Bay)

- The annual streamflow series in each river category were combined into 7 aggregated series based on the geographical categories
  - Missing data was infilled using linear regression with upstream stations, reconstruction using seasonal patterns on monthly data, and multiple regression on downstream stations
- The trend analyses were then conducted using multiple imputations
  - Block bootstrap method used to account for serial correlation
  - 100 generated time series created by adding random errors to reconstruct uncertainty and variability on the infilled data
- Long-term trends were assessed
  - Mann-Kendall non-parametric trend test was applied to the aggregated annual discharge to test for significance of trends, and
  - Theil-Sen slope was calculated to evaluate the annual discharge change for each aggregated river category

Trend Analysis - Results

- The results reveal a **general increase in freshwater flow to the Arctic** between 1975 and 2015, with this increase being more prominent from the Eurasian rivers than from the North American rivers.
- Annual discharge increase:
  - Total flow to the Arctic Ocean and related waterbodies = 8.7 $km^3/y/y$
  - Direct flow to Arctic Ocean (AO) = 5.8 $km^3/y/y$
- Cumulative discharge increase in 2015 compared to 1975:
  - 357.6 km^3/y to the Arctic Ocean and related waterbodies (11.9% increase in mean Q)
  - 239.6 km^3/y in direct discharge to the Arctic Ocean (11% increase in mean Q)

Category	Mean aggregated annual discharge (km^3/y)	Aggregated drainage area (km^2)	Annual discharge change ($km^3/y/y$)*	Mann-Kendall (p-value)	Annual discharge change by area ($mm/y/y$)**
E1	1584	7307998	5.3 (1.6)	**0.04**	0.7 (0.2)
E2	207	713232	1.0 (0.3)	**0.01**	1.4 (0.4)
N1	387	2111224	0.9 (0.5)	0.11	0.4 (0.2)
N2	451	2396865	2.0 (0.6)	**0.04**	0.9 (0.2)
N3	367	991245	0.1 (0.4)	0.35	0.1 (0.4)
Total	2996	13520564	8.7 (2.2)	**<0.01**	0.6 (0.2)
AO	2179	10132454	5.8 (1.8)	**0.01**	0.6 (0.2)

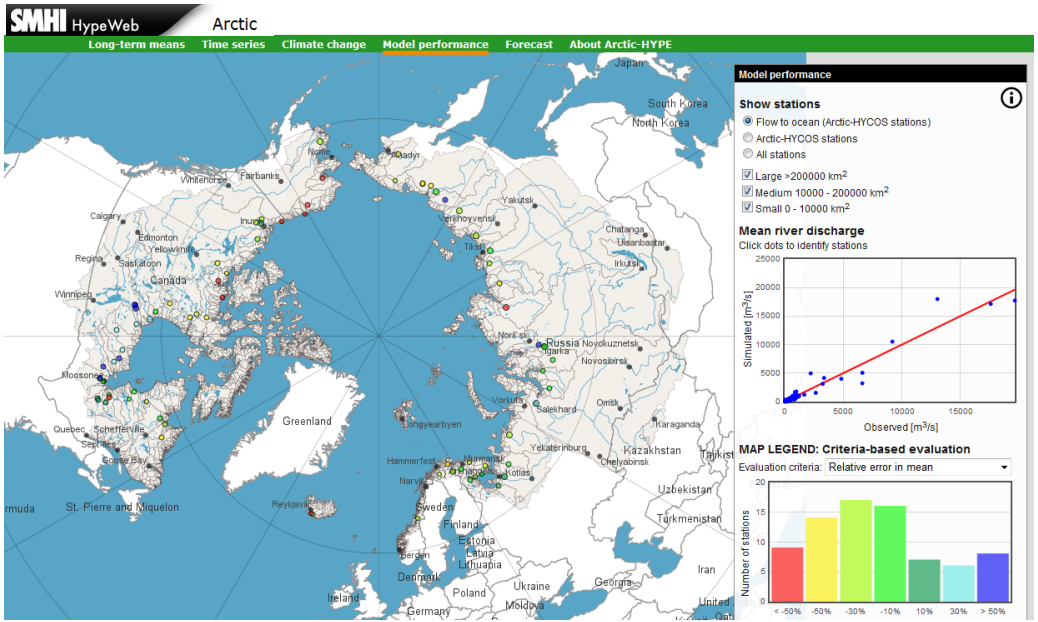
* *Theil-Sen slope;* ** *Theil-Sen slope divided by area.*

- *The value of the Theil-Sen slope represents the annual discharge change ($km^3/y/y$) for a given river category*
- *the p-value of the Mann-Kendall test indicates whether the trend is significant or not (bold = significant)*

Arctic-HYPE Model

A pan-arctic application of the **Hydrological Predictions for the Environment model (Arctic-HYPE)**, developed as a contribution to the Arctic-HYCOS project, to run hydrological forecasts of flow to the Arctic Ocean

- Developed by SMHI (Sweden, Gustafsson *et al*) in collaboration with U Manitoba (Canada; Stadnyk *et al*) and Melnikov Permafrost Institute (Russia; Lebedeva *et al*)
- Semi-distributed catchment based multi-basin hydrological model
- Forcing hydrological and meteorological data for 1961 – present, assimilating Arctic-HYCOS station discharge data
- Model key water storages and fluxes in the Arctic Ocean drainage basin:
  - explain observed trends in river flow (hydrological regimes)
  - estimate flow in non-gauged basins (flow-to-ocean)
- Daily hindcasts and 10-day forecasts have running since June 2017



http://hypeweb.smhi.se/

Next Steps

- The realities of COVID have delayed some progress for this past calendar year
- The HYCOS-TEAM has regrouped in Jan, 2021
- Workplan for 2021 is being developed.
  - Expanded membership now includes Andreas Peter Ahlstrøm for Greenland flows
  - Workplan for 2021 to be finalized by end of March

Questions?

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National Hydrological Service, Environment and Climate Change Canada

Remote control boat discharge measurements near Anchorage, Alaska, USA

Project Steering Committee in Sweden, 2018