Environment and Climate Change Canada | Environnement et Changement climatique Canada

A description of the Canadian Surface Reanalysis-Land (CaSR-Land) and Rivers (CaSR-Rivers)

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Canada

Symposium Ouranos, Montréal, 28-29 January 2025

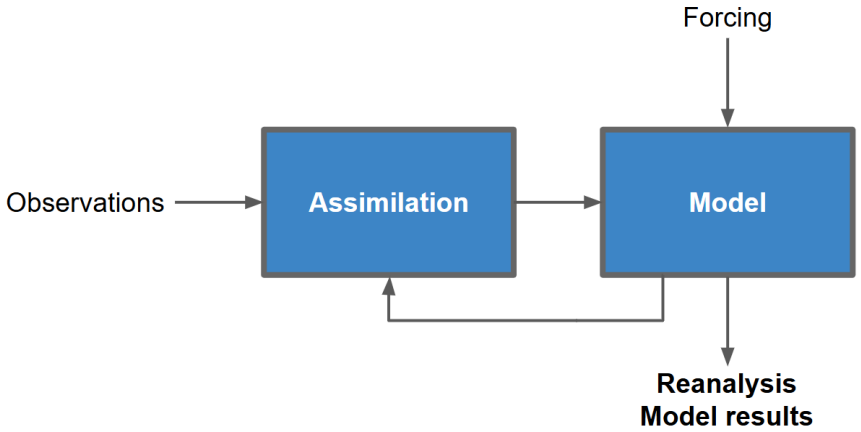
REANALYSIS, OVERVIEW AND RELEVANCE

- **What is reanalysis?**

Reanalysis data provide the most complete picture currently possible of past weather and climate. They are a blend of observations with past short-range weather forecasts rerun with modern weather forecasting models. They are globally complete and consistent in time and are sometimes referred to as "maps without gaps"

Source: ECMWF (https://www.ecmwf.int/en/about/media-centre/focus/2023/fact-sheet-reanalysis)

- **How are reanalysis produced ?**



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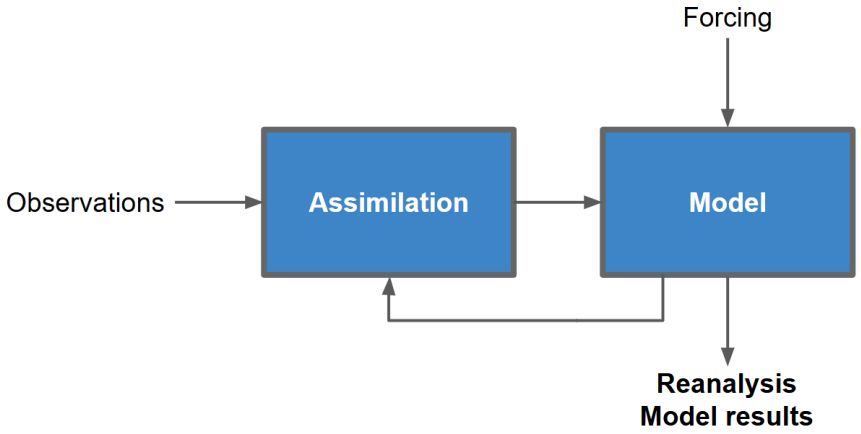
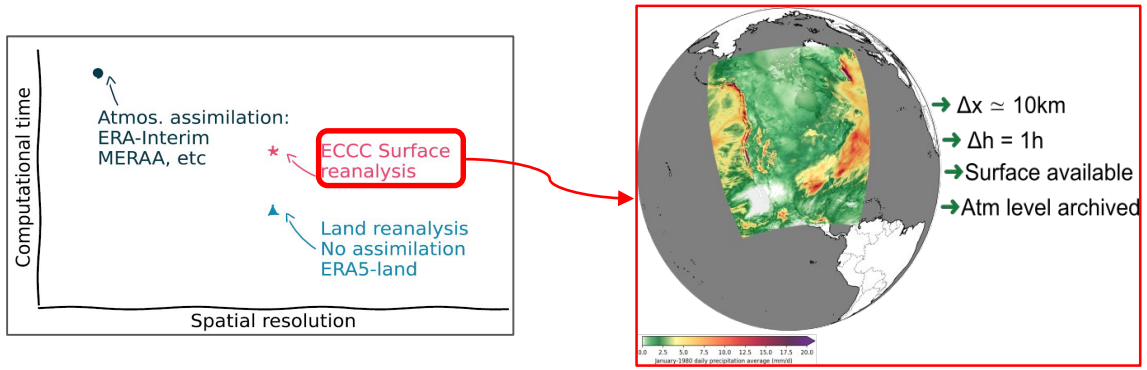


- **The surface reanalysis at Environment and Climate Change Canada (ECCC)**
  - The Canadian Surface Reanalysis (CaSR, Gasset et al., 2021) is based on online and offline subsystems – all based on existing ECCC operational systems

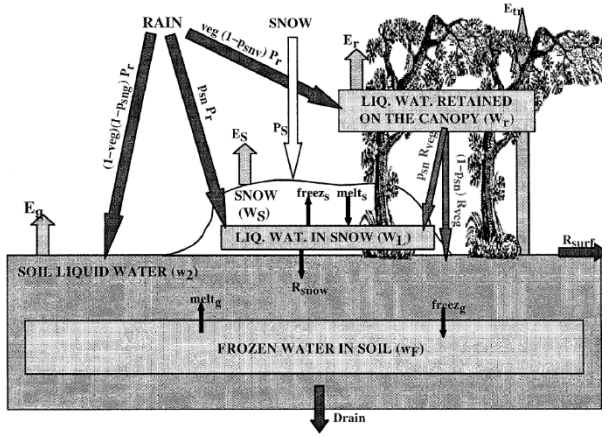


Source: Figure courtesy of the CaSR team

  - **CaSR**: Provides atmospheric and land-surface descriptions across multiple vertical layers
  - **ISBA Model**: Utilized as part of land-surface assimilation and model processing
  - **Presentation**: Nicolas Gasset will discuss updates to the new CaSR version in Session 9 (16:00–17:30)

WHY TWO NEW REANALYSIS PRODUCTS AT ECCC ?

- **Limitations of CaSR v2.1**
  - The CaSR system is currently not designed to directly produce outputs for soil variables and hydrological processes. Its primary focus is on providing high-quality forcings for advanced surface and hydrological models
  - ISBA model, integrated with CaSR, has demonstrated certain limitations in its applications
  - CaSR is based on CaLDAS-Screen assimilation method, which is not appropriate for hydrology (noisy and tenfold over-estimation of river dischage during summer)



Interaction between Soil-Biosphere-Atmosphere (**ISBA**) Land-surface model (Bélair et al., 2003a,b)

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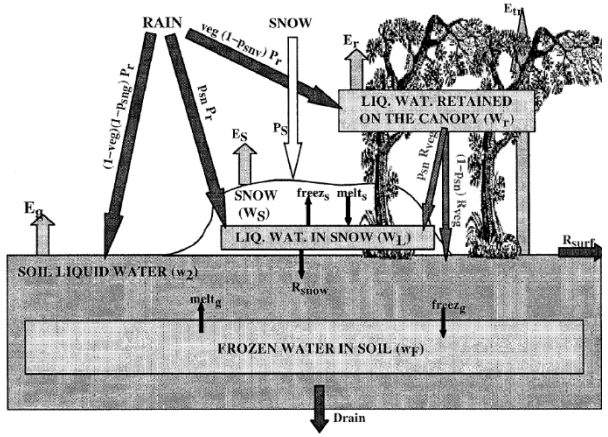
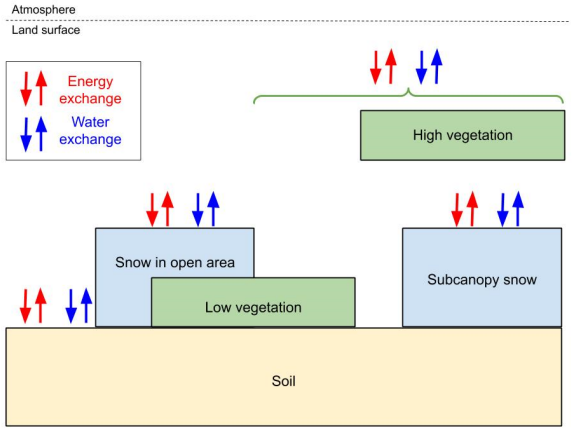


Interaction between Soil-Biosphere-Atmosphere (**ISBA**) Land-surface model (Bélair et al., 2003a,b)

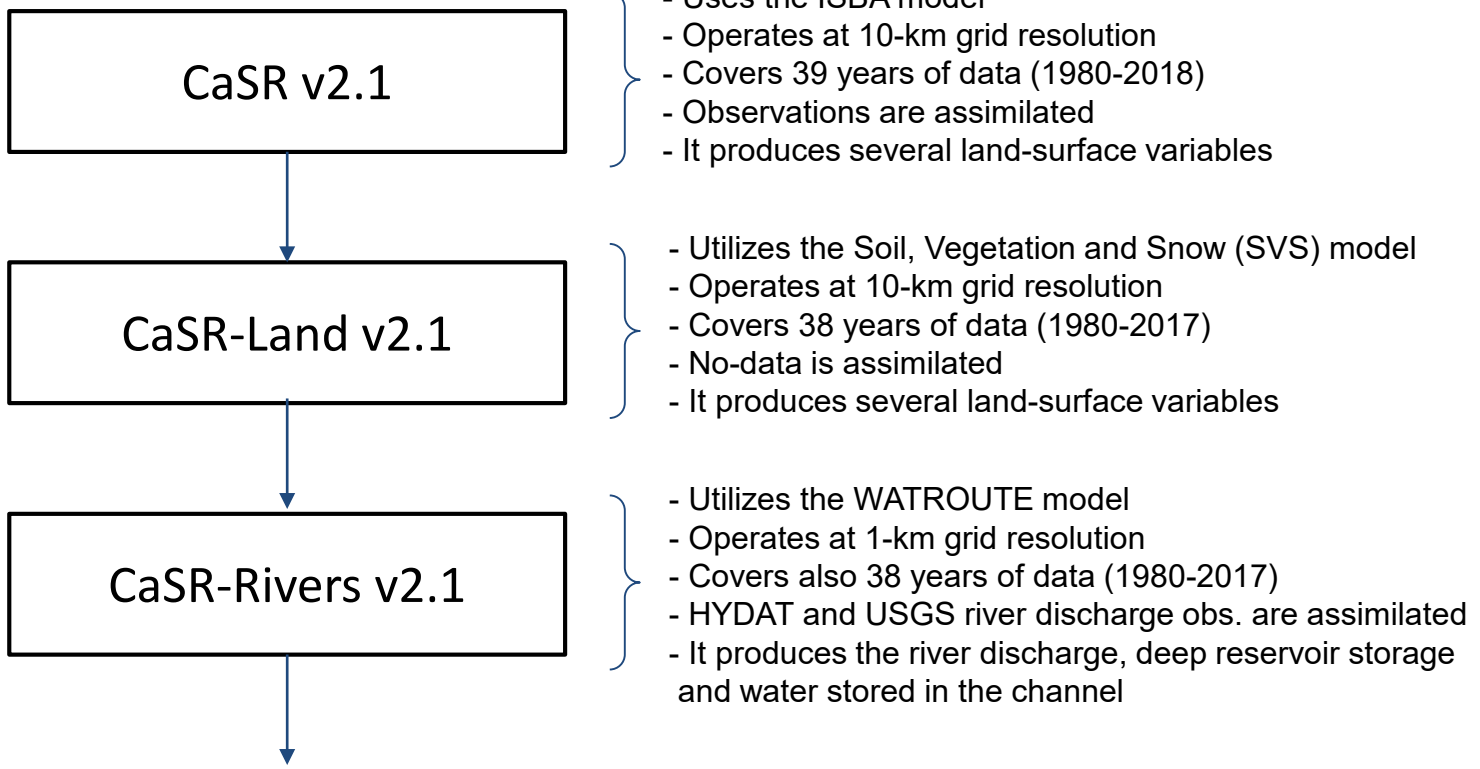
- **Why CasR-Land and CaSR-Rivers ?**
  - The offline land-surface simulations driven by CaSR employ SVS land surface model, which is a a more advanced model compared to ISBA
  - These simulations ensure the closure of water and energy balances throughout the simulation period
  - They provide consistent and reliable input data for hydrological modeling
  - This marks the first instance of river reanalysis being produced at ECCC



Soil, Vegetation and Snow (**SVS**) Land-surface model (Alavi et al., 2016; Husain et al. 2016; Leonardini et al., 2021)

UNDERSTANDING CASR-LAND AND CASR-RIVERS

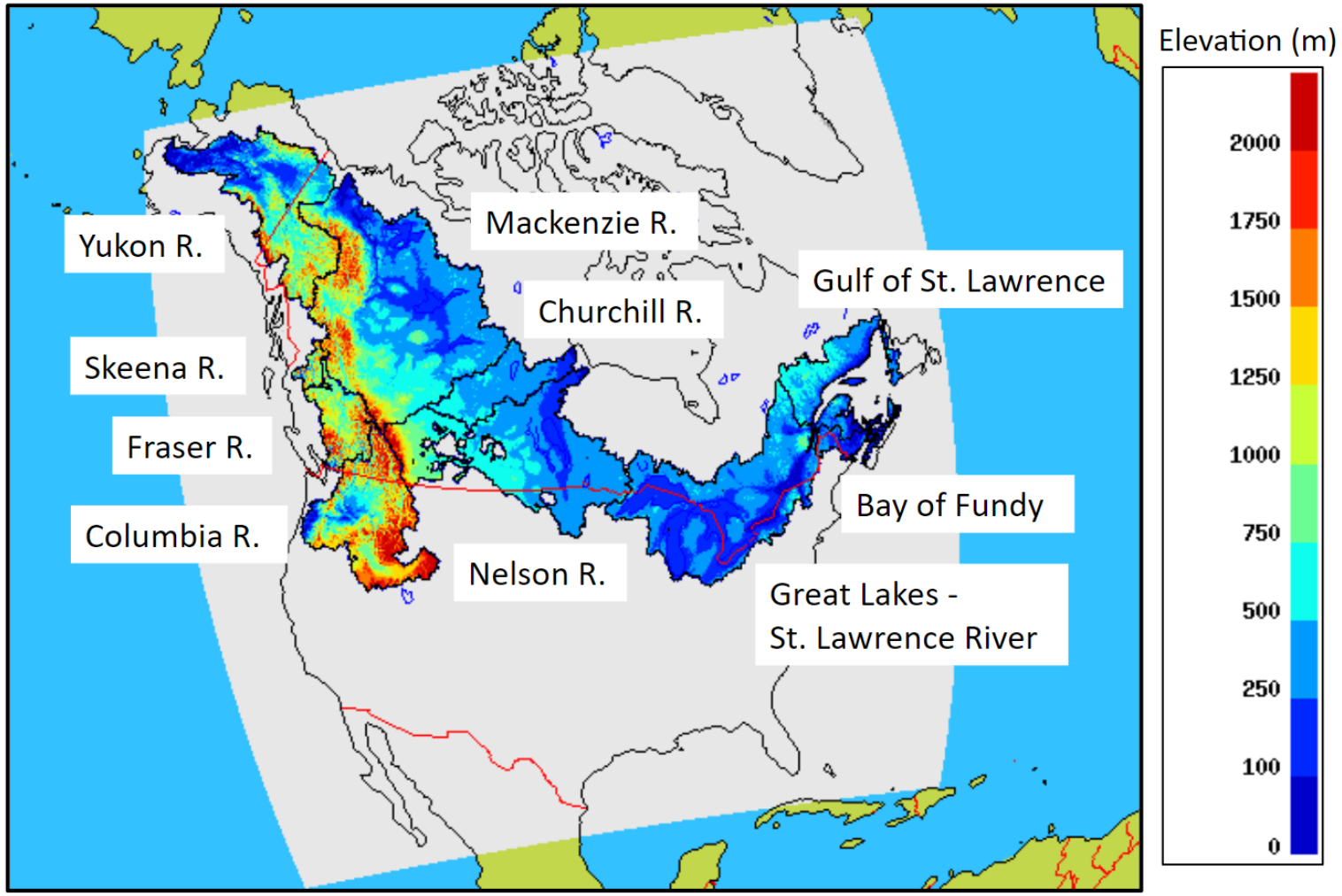
- The production relies on:
  - models and tools developped and **used operationaly** at the Canadian Centre for Meteorological and Environmental Prediction (CCMEP)
  - the model structure of **GEM-Hydro** (Gaborit et al., 2025, 2017; Vionnet et al., 2020)
- CaSR v2.1 provides the atmospheric forcing to drive CaSR-Land
- CaSR-Land fields are used to pilot CaSR-Rivers



SIMULATION DOMAINS

- Spatial domain
  - CaSR-Land covers most of the North-America
  - CaSR-Rivers cover 10 watersheds over Canada and US, corresponding to the ~55% of the Canadian surface
- Temporal domain
  - From 1980 to 2017

CaSR-Land (grey); CaSR-Rivers (colours)



EVALUATION HIGHLIGHTS

- Evaluations performed against the most up-to-date historical in-situ observations and against CaSR v2.1
- Fields evaluated are: 1.5 air and dew-point temperatures, snow depth, snow water equivalent, soil moisture, river discharge
- CaSR-Land v2.1 performs better than CaSR v2.1 for all evaluated variables due to the integration of a more sophisticated land-surface model into CaSR-Land
- CaSR-Rivers evaluation shows encouraging results

Summary of improvements

Impact level	color
Neutral	
Minor	
Major	

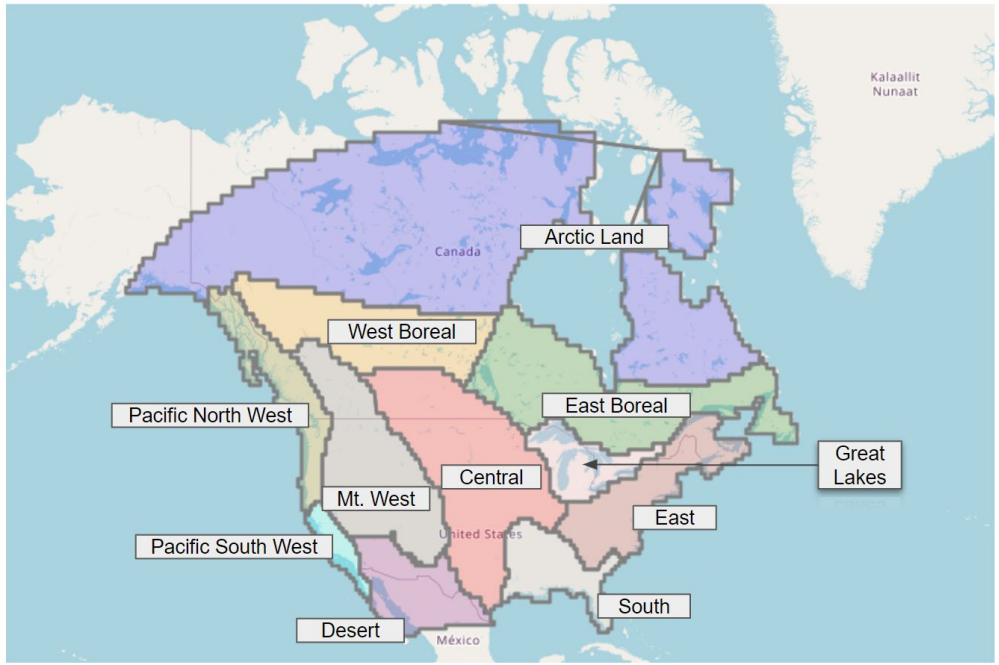
For CaSR-Land v2.1, the **impact level** represents the degree of improvement relative to the original CaSR v2.1 dataset. In the case of CaSR-Rivers v2.1, it reflects the level of enhancement compared to the open-loop simulation.

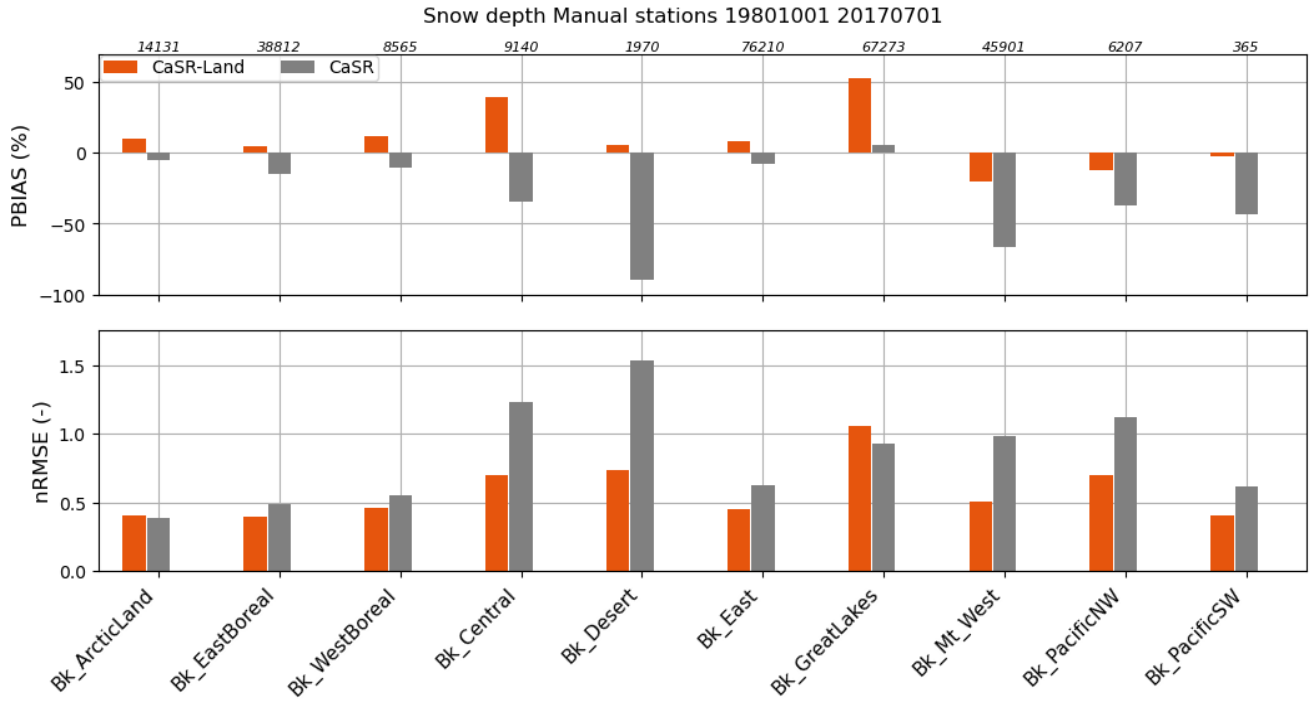
Model	Fields	Impact level
CaSR-Land v2.1	Snow water equivalent	
	Snow depth	
	1.5 m air temperature	
	1.5 m dew-point temperature	
	10 m wind speed	
	Soil moisture	
CaSR-Rivers v2.1	River discharge	

EVALUATION OF SNOW DEPTH FOR THE PERIOD 1980-2017

- Manual snow depth observations were utilized as part of the evaluation process
- Snow depth field from CaSR v2.1 results from a snow analysis. Then, the use of manual data allows an independent evaluation of the snow analysis
- CaSR-Land shows better PBIAS and nRMSE compared to CaSR on **Western domains**
- CaSR-Land also shows better PBIAS than CaSR over all the rest of the domains, except **Great Lakes, Central** and **Arctic Land**. It is not clear why CaSR-Land degrades the scores in these regions
- Similar results are obtained for the **SWE** (not shown in this presentation).

Bukovsky (Bk) regions selected for the evaluation





DATA DISSEMINATION

- Guidelines for variable selection
  - CaSR-Land

    - Prioritize variables used for piloting hydrological models

    - Avoid replicating the variables already disseminated in CaSR v2.1, except for those that demonstrated superior performance, such as snow depth and soil moisture
  - CaSR-Rivers

    Variables already disseminated by ECCC's operational Deterministic Hydrological Prediction System (DHPS)
- Temporal resolution
  - Time steps include 1-hour, 12-hour or 24-hour intervals depending on the variable
- File format
  - Data provided in NetCDF format
- Data Platforms
  - The Canadian Surface Prediction Archive (CaSPAr), will host the full dataset for comprehensive access
  - Federated Research Data Repository (FRDR) will host the 2014-2017 subset of data, corresponding to the dataset referenced in the submitted article

CaSPAr
Canadian Surface Prediction Archive

Model	Variable	Time Resolution
CaSR-Land	Accumulation of surface runoff amount	1 h
	Accumulation of lateral sub-surface runoff amount	1 h
	Drainage amount through base of soil model	1 h
	Accumulation of aggregated surface evaporation	1 h
	Accumulation of land surface evaporation amount	1 h
	Fraction of area occupied by soil in the model grid	1 h
	Aggregate surface radiative temperature	1 h
	1.5 m air temperature	1 h
	1.5 m dew point temperature	1 h
	U-component of the wind	1 h
	V-component of the wind	1 h
	Snow depth	24 h
	Snow water equivalent	24 h
	Volumetric water content of soil (for seven layers)	24 h
CaSR-Rivers	River discharge	1 h
	Deep reservoir storage	12 h
	Water stored in the channel	12 h

OUTLINE OF NEXT STEPS

- CaSR-Land v3.1
  - Forced by CaSR v3.1
  - Horizontal resolution is under discussion, with potential options being 2.5 km, 10 km, or both
  - Same simulation period of CaSR v3.1 (1980-2023)
  - Same domain of CaSR v3.1
  - Latest official and closed version of ECCC's Systems
  - Simulate small lake dynamics with the Canadian Small Lake Model (CSLM)

- CaSR-Rivers v3.1
  - Forced by v3.1 of CaSR-Land
  - Add more river basins according to the latest Deterministic Hydrological Prediction System (DHPS) version
  - With updated version of data assimilation system and of WATROUTE model as per the most recent version of DHPS
  - Updated quality control of assimilated streamflow data

SUMMARY AND CONCLUDING REMARKS

- Two new derived products, **CaSR-Land** and **CaSR-Rivers**, have been developed at ECCC, covering North America and 10 watersheds across Canada for the period 1980–2017
- **CaSR-Land v2.1**, which integrates the SVS model, has demonstrated improved results compared to **CaSR v2.1**
- CaSR-Land and -Rivers v2.1 data is close to be disseminated through CaSPAr
- Discussions are underway for CaSR-Land and -Rivers v3.1 version

THANK YOU FOR YOUR ATTENTION

Questions and/or comments?

SUPPLEMENTARY MATERIAL

REFERENCES

- Bélair, S., Brown, R., Mailhot, J., Bilodeau, B., & Crevier, L. P. (2003). Operational implementation of the ISBA land surface scheme in the Canadian regional weather forecast model. Part II: Cold season results. *Journal of Hydrometeorology*, *4*(2), 371-386.
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- Gaborit, É., Mai, J., Princz, D. *et al.* Hydrologic outputs generated over the Great Lakes with a calibrated version of the GEM-Hydro model. *Sci Data* **12**, 127 (2025). https://doi.org/10.1038/s41597-025-04409-x
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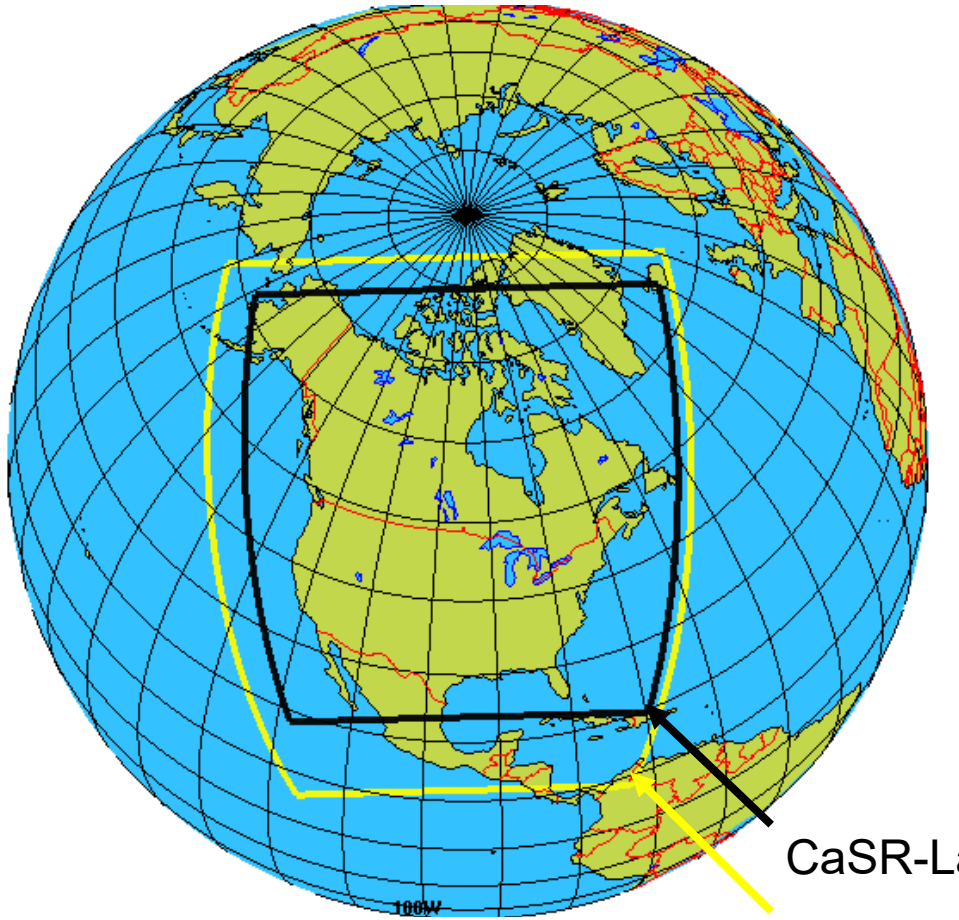
HOW USERS CAN EXPLOIT THIS DATA

- **Observing System**:
  - Improve observational quality, support homogenization of long-term data records, and provide initial estimates for ungauged locations in Canada
- **Modeling**:
  - Drive models and applications, including small-scale models with reanalysis as boundary conditions
- **Climatologies**:
  - Develop tools like the Agroclimate and Peak-Flow Atlases of Canada
- **Anomalies**:
  - Analyze WMO-standard anomalies across Canada
- **AI Applications**:
  - Train AI models for flood prediction and hydrological risk analysis
- **Post-Processing**:
  - Estimate return periods for risk assessment

ATTRIBUTES OF CASR AND CASR-LAND V2.1



Atribute	CaSR v2.1	CaSR-Land v2.1
Horizontal resolution	10 km	
Initial conditions	ERA-Interim	
Temporal coverage	1980-2018	1980-2017
Land-surface model	ISBA	SVS
Assimilation of observations	YES	NO

OBSERVATION DATASETS USED IN THE EVALUATION

Model	Fields (acronym)	Network*	Data availability	Evaluation period (selected months)
CaSR-Land	Snow water equivalent	CanSWE, US-NE, US-NRCS	1928-	1980-2017 (Oct-Dec)
	Snow depth			
	1.5 m air temperature	SYNOP	1980-	1980-2017 (OND, JFM, AMJ, JAS)
	1.5 m dew-point temperature			
	10 m wind speed			
	Soil moisture	ISMN	1952-	1996-2017 (May-Sept)
CaSR-Rivers	River discharge	HYDAT, USGS	1850-	1980-2017

* Network description:

CanSWE : Canadian Historical SWE dataset (Vionnet et al., 2021)
US-NE : US snow surveys from New England states (MacKay et al., 1994)
US-NRCS : US snow surveys from Alaska and Western US (US Department of agriculture, 2008)
SYNOP : North American Surface Synoptic Observations
ISMN : International Soil Moisture Network (Dorigo et al., 2021)
HYDAT : Canada's hydrometric data portal
USGS : U.S. Geological Survey

CaSR-Land/SVS 10 km vs CaSR v2.1/ISBA 10 km

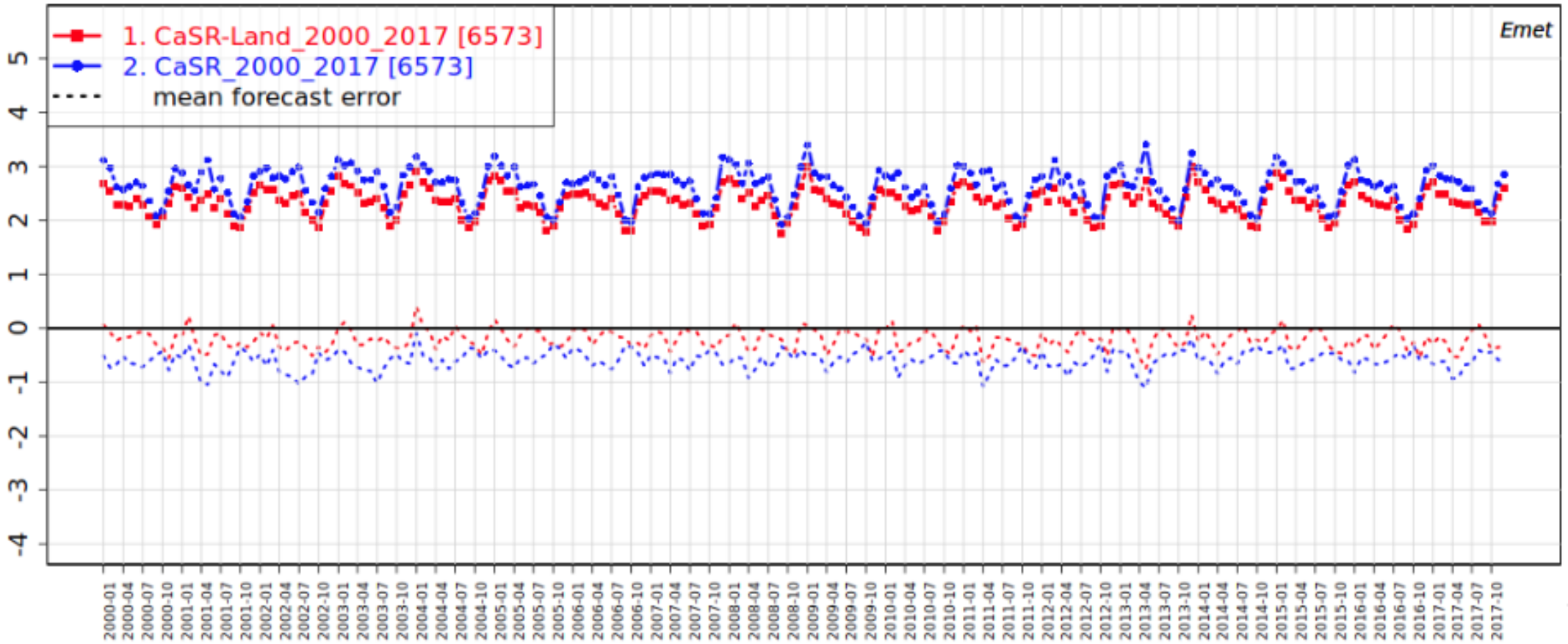
rmse CaSR-Land_2015_2016 / CaSR_2015_2016		20151001 / 20151231	20160101 / 20160331	20160401 / 20160630	20160701 / 20160930
		All	All	All	All
Arctic Land CLIM	TD	0.28%	-0.82%	-6.24%	-4.13%
	TT	0.30%	1.09%	9.22%	3.81%
	UV	3.59%	1.60%	2.43%	4.35%
Central CLIM	TD	14.04%	14.41%	5.16%	8.54%
	TT	12.02%	17.17%	1.71%	0.69%
	UV	-0.32%	-1.10%	0.34%	-0.98%
Desert CLIM	TD	-0.36%	-1.60%	1.97%	1.64%
	TT	9.18%	10.89%	6.29%	-0.64%
	UV	1.59%	0.86%	0.41%	0.27%
East Boreal CLIM	TD	1.24%	1.34%	-0.98%	0.67%
	TT	2.90%	4.56%	17.21%	5.62%
	UV	2.12%	1.23%	2.71%	2.94%
East CLIM	TD	5.07%	7.28%	0.14%	4.78%
	TT	4.08%	8.99%	9.31%	6.90%
	UV	4.53%	3.90%	2.90%	2.10%
Great Lakes CLIM	TD	6.21%	8.68%	-3.62%	3.71%
	TT	3.72%	9.46%	9.01%	2.35%
	UV	3.58%	3.03%	3.18%	2.40%
Mt West CLIM	TD	7.97%	5.96%	3.38%	3.22%
	TT	8.60%	6.02%	1.50%	-4.26%
	UV	-1.48%	-1.37%	-1.22%	-2.94%
North America plus	TD	7.97%	7.41%	0.60%	3.54%
	TT	9.86%	10.99%	9.06%	3.23%
	UV	0.93%	0.39%	1.53%	1.28%
Pacific North West CLIM	TD	1.14%	4.53%	-3.60%	-3.07%
	TT	-7.18%	0.33%	9.31%	-0.73%
	UV	-4.22%	-3.92%	-0.92%	-0.50%
Pacific South West CLIM	TD	13.78%	8.24%	11.97%	12.92%
	TT	34.51%	19.02%	6.65%	26.05%
	UV	-10.45%	1.99%	-0.27%	-16.65%
South CLIM	TD	10.43%	5.37%	6.94%	11.16%
	TT	11.35%	11.77%	12.97%	11.57%
	UV	4.51%	4.97%	2.02%	-1.20%
West Boreal CLIM	TD	10.48%	12.02%	-4.67%	2.92%
	TT	10.05%	16.19%	10.68%	0.95%
	UV	2.60%	0.00%	3.51%	3.59%

EVALUATION OF TD, TT AND UV FOR THE PERIOD 2015-2016

- The most significant enhancements of the RMSE of CaSR-Land compared to CaSR correspond to the months of **OND and JFM**
- Degradation of CaSR-Land for TD during **AMJ** months
- Degradation of CaSR-Land for UV in the **Western regions**
- Improvement of CaSR-Land compared to the CaSR across all variables within the **North America plus** domain

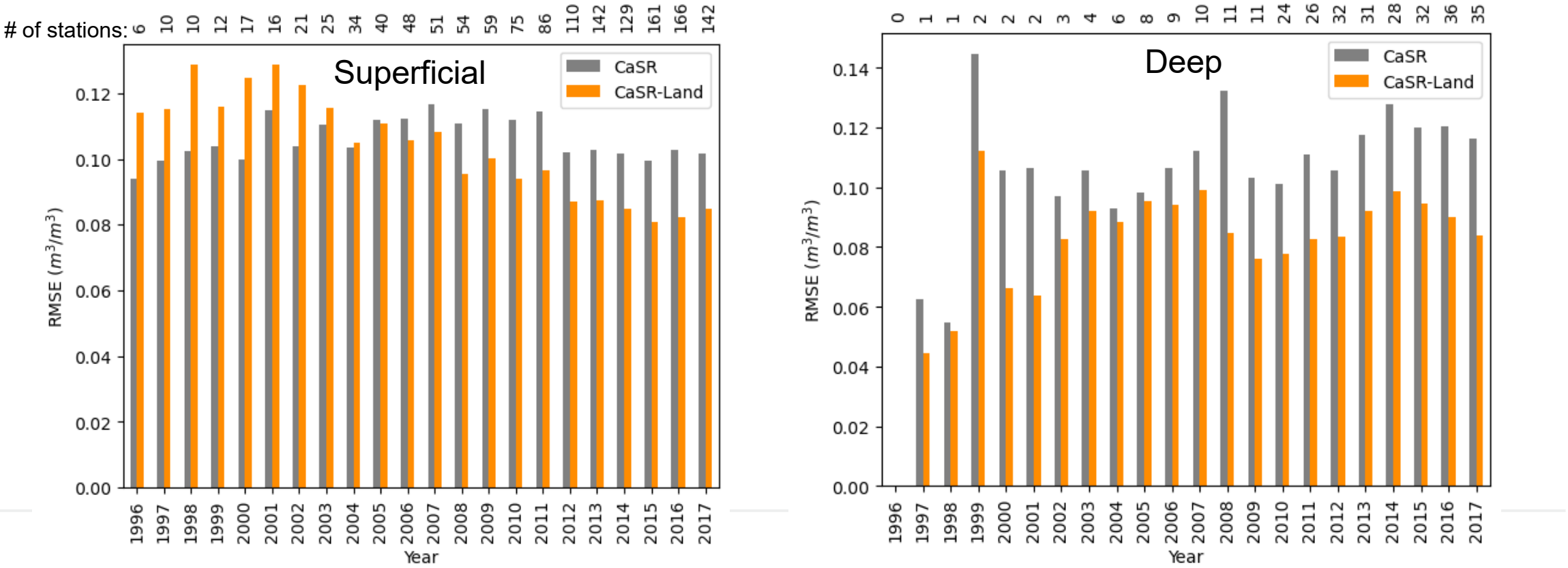
EVALUATION OF 1.5 m AIR TEMPERATURE FOR THE PERIOD 2000-2017

- CaSR-Land shows improvements of the RMSE with respect to CaSR for 1.5 m air temperature
- The most significant improvement of the RMSE of CaSR-Land with respect to CaSR occurs during the months from January to June
- The bias, as illustrated by the dotted lines in the figure, clearly demonstrates an improvement in CaSR-Land



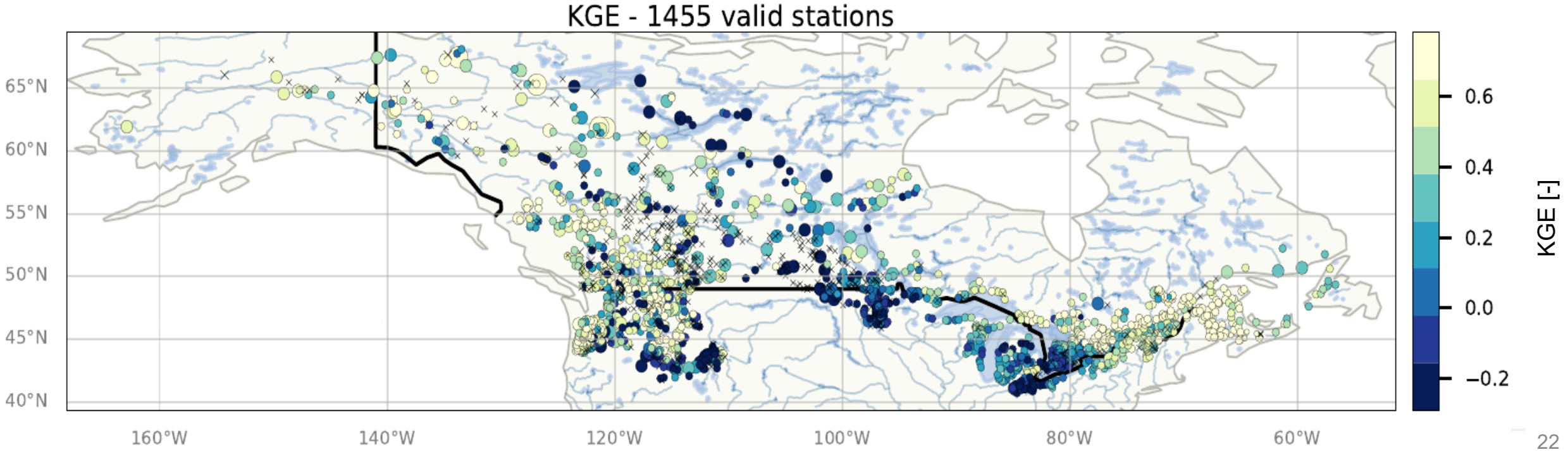
SOIL MOISTURE EVALUATION (1996-2017)

- Yearly evaluation between May 1 and September 30 for the superficial (0-5 cm) and deep (0-100 cm) layers
- CaSR-Land v2.1 outperfomed CaSR v2.1 RMSE after 2004 in the superficial layer and all years in the deep layer
- CaSR v2.1 RMSE was smaller than CaSR-Land v2.1 prior 2005 in the superficial layer due to fewer stations concentrated in Southeast US
- Improvements in soil moisture estimation by CaSR-Land v2.1 are more evident in the deep layer



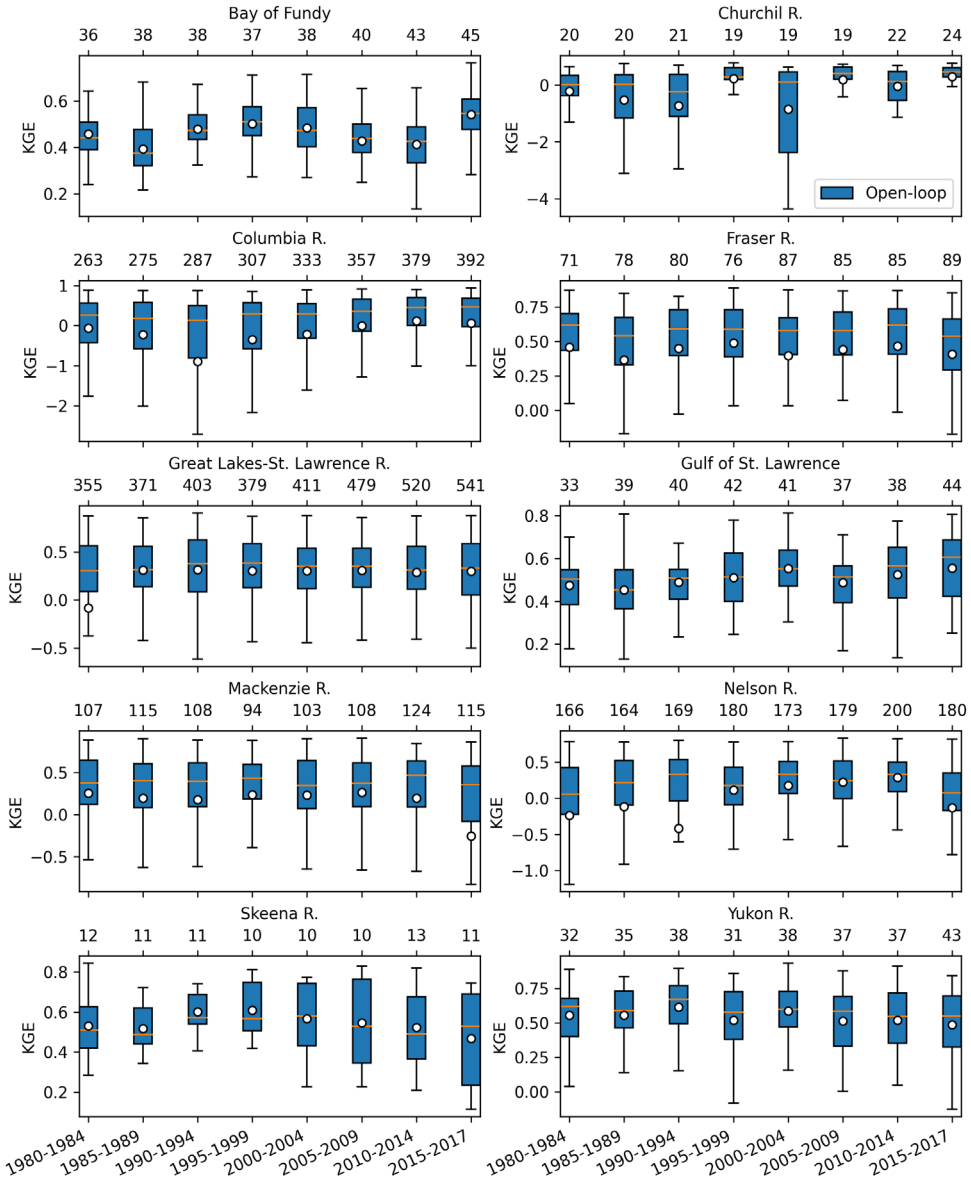
EVALUATION OF THE OPRN-LOOP FOR THE PERIOD 2014-2017

- GEM-Hydro (the open-loop version of CaSR-Rivers) successfully captures river discharge dynamics in most basins across the Western region
- The prairie and central areas demonstrate poorer performances due to the misrepresentation of subgrid lakes and wetlands
- The eastern basins generally perform well, except in the agricultural areas

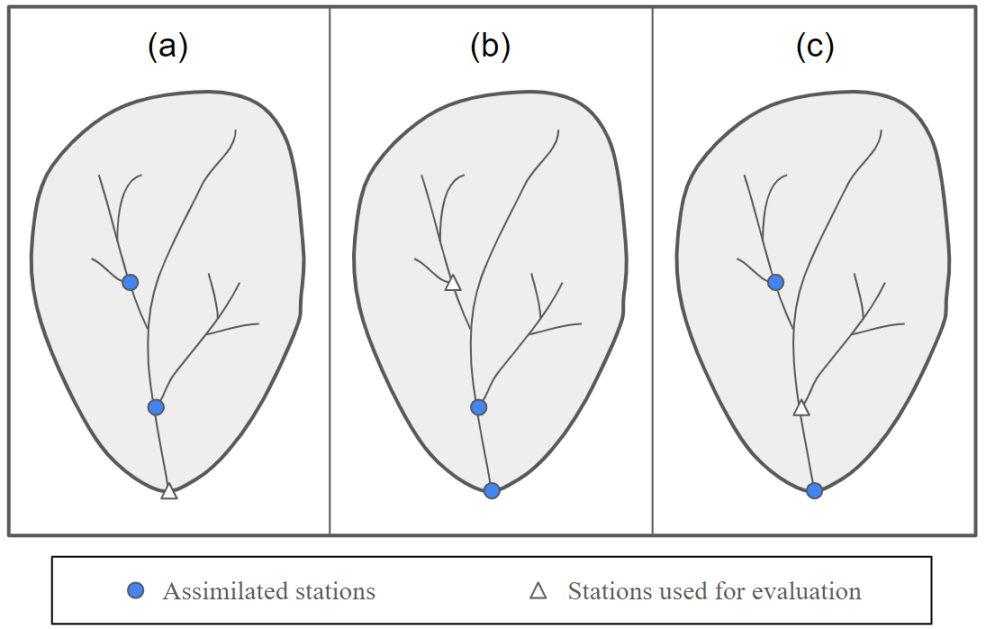


OPEN-LOOP ASSESSMENT FOR THE 1980-2017 PERIOD

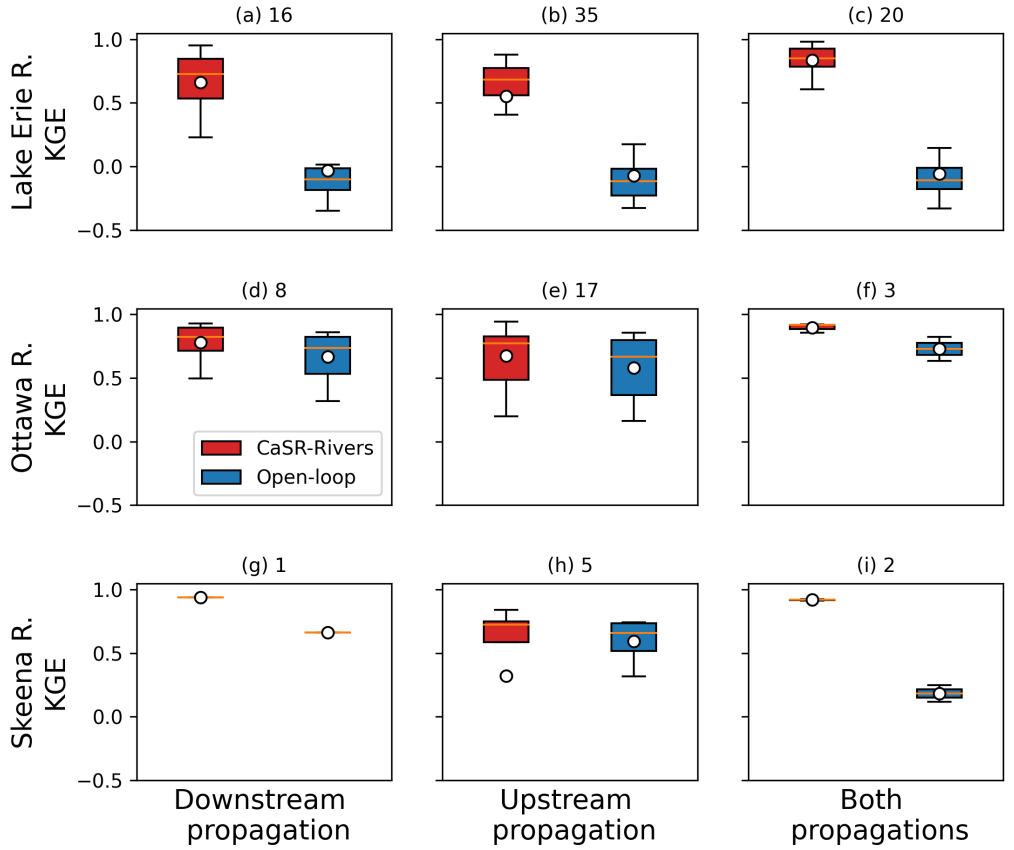
- Stable Overall Trends: KGE scores remain stable (1980–2017) with notable declines in specific periods and basins.
- Performance Challenges: Declines in Churchill (1985–2004) and Columbia/Great Lakes (1990–1994) reveal model limitations.
- Need for Investigation: Highlights the need to explore factors affecting model accuracy in these regions.



ASSESSMENT OF THE CASR-RIVERS V2.1



Configurations of the experiments used in the evaluation of CaSR-Rivers' assimilation technique: (a) Evaluation of the insertion and downstream propagation; (b) Evaluation of the upstream propagation; (c) evaluation of both propagations.



ASSIMILATED RIVER FLOW OBSERVATIONS INTO CASR-RIVERS

A total of 1704 gauges from the Canadian Hydrometric Database (HYDAT) and the United States Geological Survey (USGS) historical data were assimilated