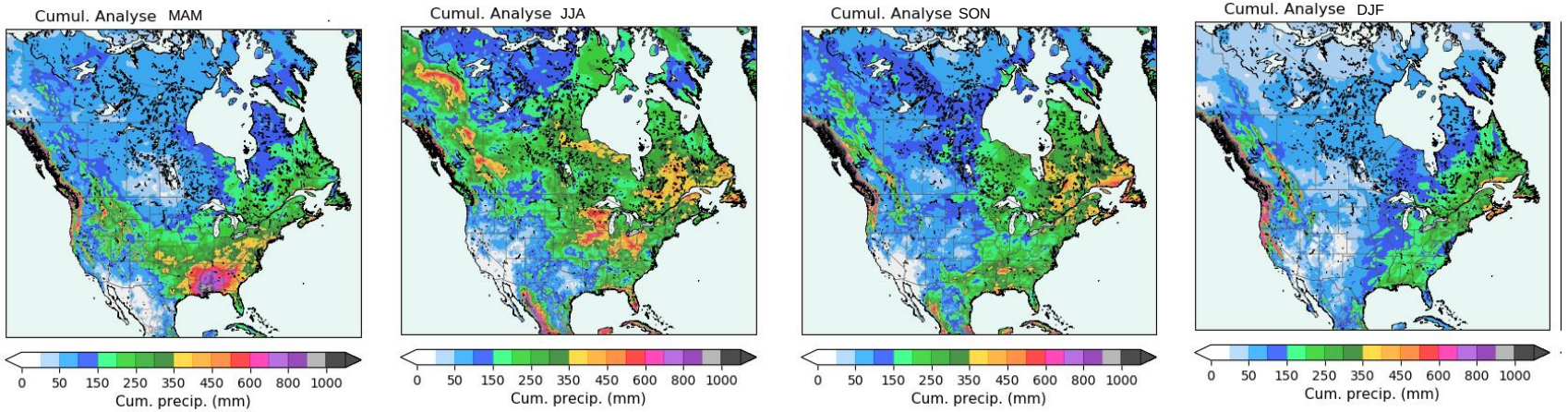
ECCC SURFACE AND PRECIPITATION REANALYSIS BASED ON GEM MODEL



Dimitrijevic Milena, Gasset Nicolas, Fortin Vincent*, Carrera Marco, Bilodeau Bernard, Muncaster Ryan, Gaborit Étienne, Roy Guy, Pentcheva Nedka, Bulat Maxim, Wang Xihong, Pavlovic Radenko, Lespinas Franck, Khedhaouiria Dikra and Mai Juliane*

** Lead contributors*

4th International Earth Surface Working Group, 5-7 April 2022, Virtual

MOTIVATION/OBJECTIVE

- Re-forecasting and re-analysis systems allows running the current model back in time and producing consistent, best-estimates of the past weather

- Limitations of existing reanalysis:

1. Atmospheric reanalysis (MERRA, ERA-I, ERA5…) generally assimilate atmospheric observations but often do not assimilate precipitation and observations of the land-surface state
2. Spatial resolution is usually too coarse to be fully suited for land-surface applications at the regional scale
3. Land-surface reanalysis (MERRA-Land, ERA-Interim Land, ERA5-Land…) are higher resolution, open-loops forced by atmospheric reanalysis; no assimilation, only precipitation adjustments

MOTIVATION/OBJECTIVE

Approach adopted by regional surface and precipitation reanalysis based on GEM model:

- Dynamical downscaling of reanalysis data to improve horizontal resolution and representation of land-surface (instead of just post-processing the atmospheric forcing's)

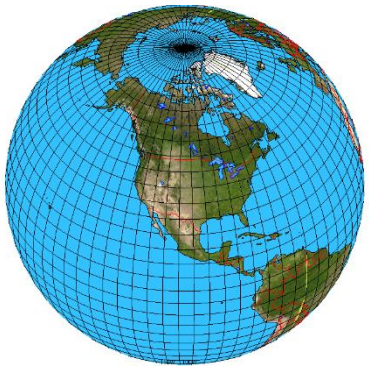
- Land-surface data assimilation of temperature, dew-point temperature, snow depth and precipitation (avoiding atmospheric and land-surface drift)

	atmospheric assimilation (often no land-surface assimilation)	**land-surface assimilation**	**no-assimilation**
comutational cost	high	moderate	low
examples	MERRA, ERA_Interim, ERA5	GEM surface reanalysis	MERRA-Land, ERA-I Land, ERA5 Land

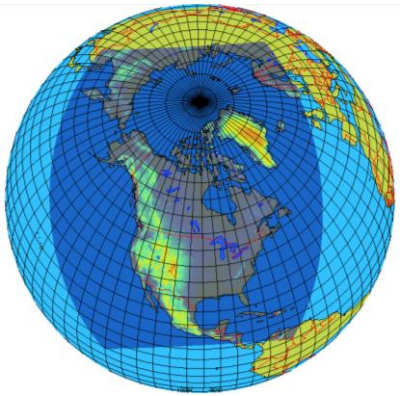
REANALYSIS METHODOLOGY

ERA-Interim:
1979 to 2018
(~80km/6h)

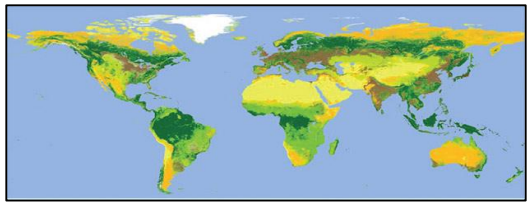
GEM GDRS (39 km) atmospheric model



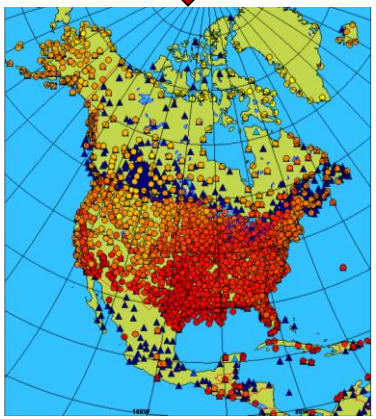
GEM RDRS (10 km) atmospheric model



Precipitation and surface data assimilation: CaPA and CaLDAS



GEM-Surf (39 km) surface model



GDRS: Global Deterministic Reforecast System
RDRS: Regional Deterministic Reforecast System
CaPA: Canadian Precipitation Analysis System
CaLDAS: Canadian Land Data Assimilation System

Initialisation + forcing

Initialisation

Assimilation

Surface observations

T, TD, PR, SD

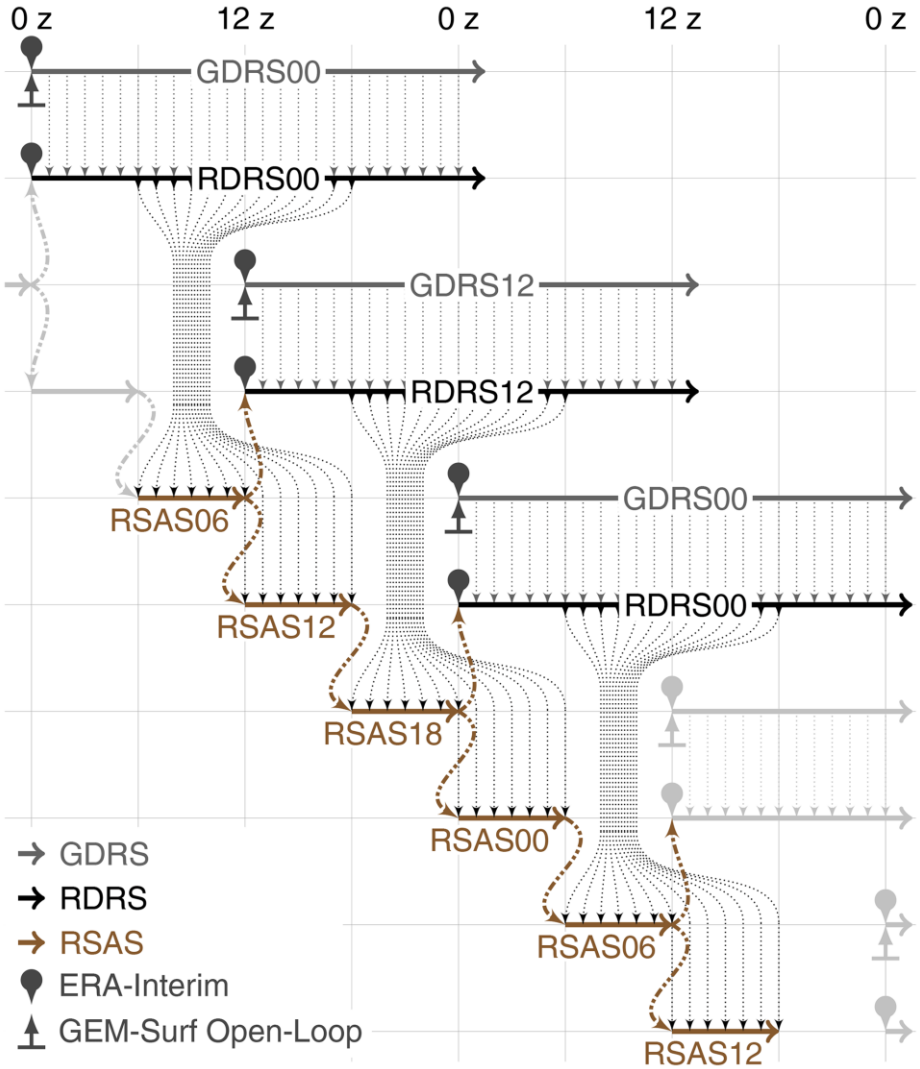
https://doi.org/10.5194/hess-25-4917-2021

REFORECAST CONFIGURATION

- **Global deterministic reforecast system (GDRS)**
  - 39km resolution (Yin-Yang uniform grid; 45 levels)
  - 12-h cycle (0Z and 12 Z)
  - 24-h reforecast
- **Regional deterministic reforecast system (RDRS)**
  - 10 km resolution (rotated lat-long; 80 levels; cover Arctic Ocean)
  - 12-h cycle (0Z and 12 Z)
  - 24-h reforecast

- **Regional Surface Assimilation System (RSAS)**

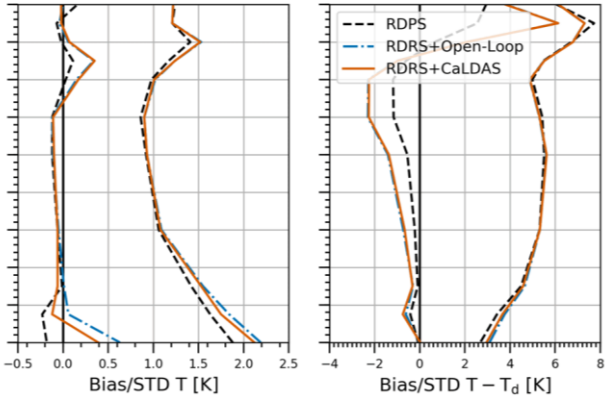
– Online precipitation and surface analysis
– Coupled with RDRS 10 km resolution (North-America only)
– 6h cycles



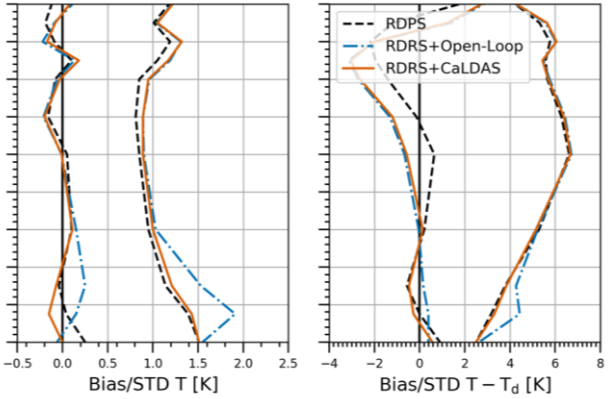
COUPLED RESULTS VS. OPEN LOOP

Atmospheric results

winter



summer



Bias and STDE against radiosonde from RDPS, RDRS+Open-Loop and RDRS+CaLDAS for North America

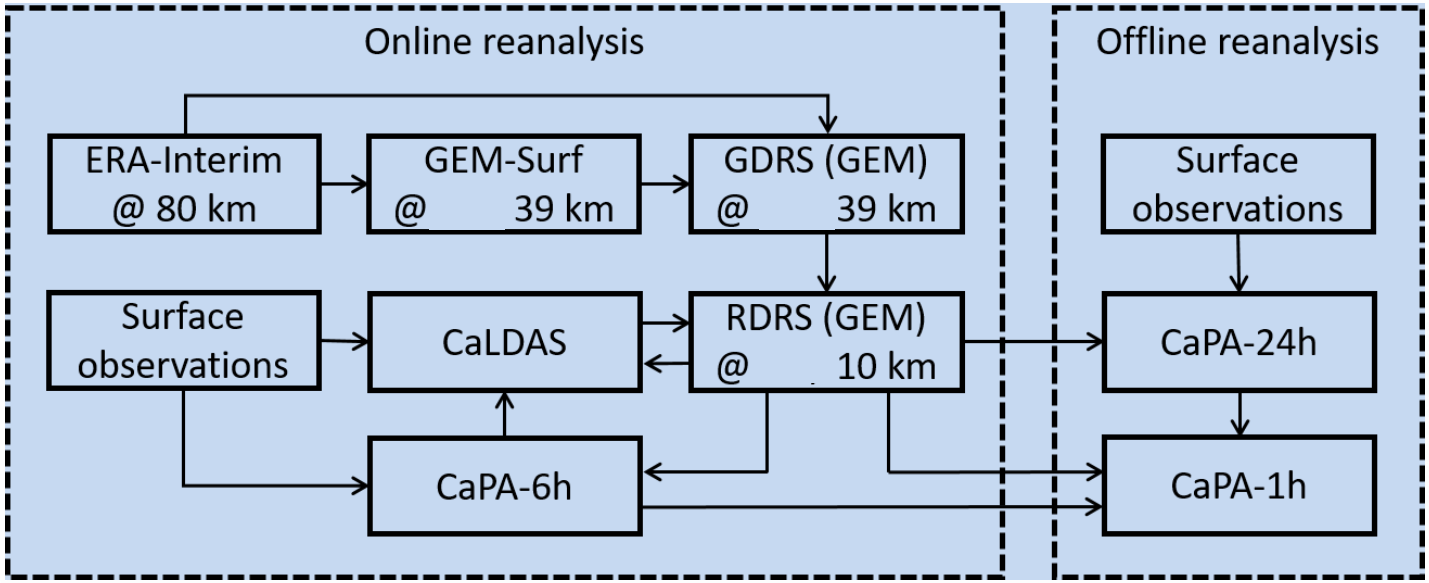
Surface results

RMSE change (%) RDRS + Open-Loop − RDRS + CaLDAS		1 Feb 2011 to 1 Jul 2011 to 00:00 UTC	1 Feb 2011 to 1 Jul 2011 to 12:00 UTC	31 Mar 2011 31 Aug 2011 00:00 UTC	31 Mar 2011 31 Aug 2011 12:00 UTC
Alaska plus Canadian Arctic	T_d	7.45	8.87	6.07	5.22
	T	5.59	7.63	8.09	8.11
	$\|\|U\|\|$	–0.10	–0.12	0.17	–0.01
Canada west	T_d	5.52	4.32	**15.51**	7.48
	T	3.76	2.77	9.97	**13.88**
	$\|\|U\|\|$	–0.13	–0.11	0.91	2.05
Canada east	T_d	2.41	2.76	6.22	5.75
	T	2.20	4.22	3.77	3.96
	$\|\|U\|\|$	0.13	0.10	–0.12	–0.23
United States of America west	T_d	**15.86**	**14.24**	**22.35**	**21.32**
	T	5.84	5.20	**10.33**	**10.66**
	$\|\|U\|\|$	0.42	1.02	1.23	2.41
United States of America east	T_d	8.35	9.47	**21.29**	**23.13**
	T	–3.61	0.55	**16.86**	**17.77**
	$\|\|U\|\|$	0.16	0.70	0.86	3.42
Canada	T_d	5.29	5.22	**12.68**	7.67
	T	4.30	5.04	8.19	**10.72**
	$\|\|U\|\|$	–0.02	–0.03	0.40	0.89
United States of America	T_d	**12.83**	**12.23**	**22.10**	**21.85**
	T	2.63	3.40	**13.69**	**13.86**
	$\|\|U\|\|$	0.32	0.85	1.10	2.98
North America	T_d	6.88	6.82	**15.20**	**11.73**
	T	3.60	4.45	9.34	**11.30**
	$\|\|U\|\|$	0.00	0.06	0.49	1.22

RMSE change against SYNOP observations between RDRS+Open-Loop and RDRS+CaLDAS

https://hess.copernicus.org/articles/25/4917/2021/hess-25-4917-2021.html

OFFLINE CAPA 24 H PRECIPITATION REANALYSIS AND FORCING'S



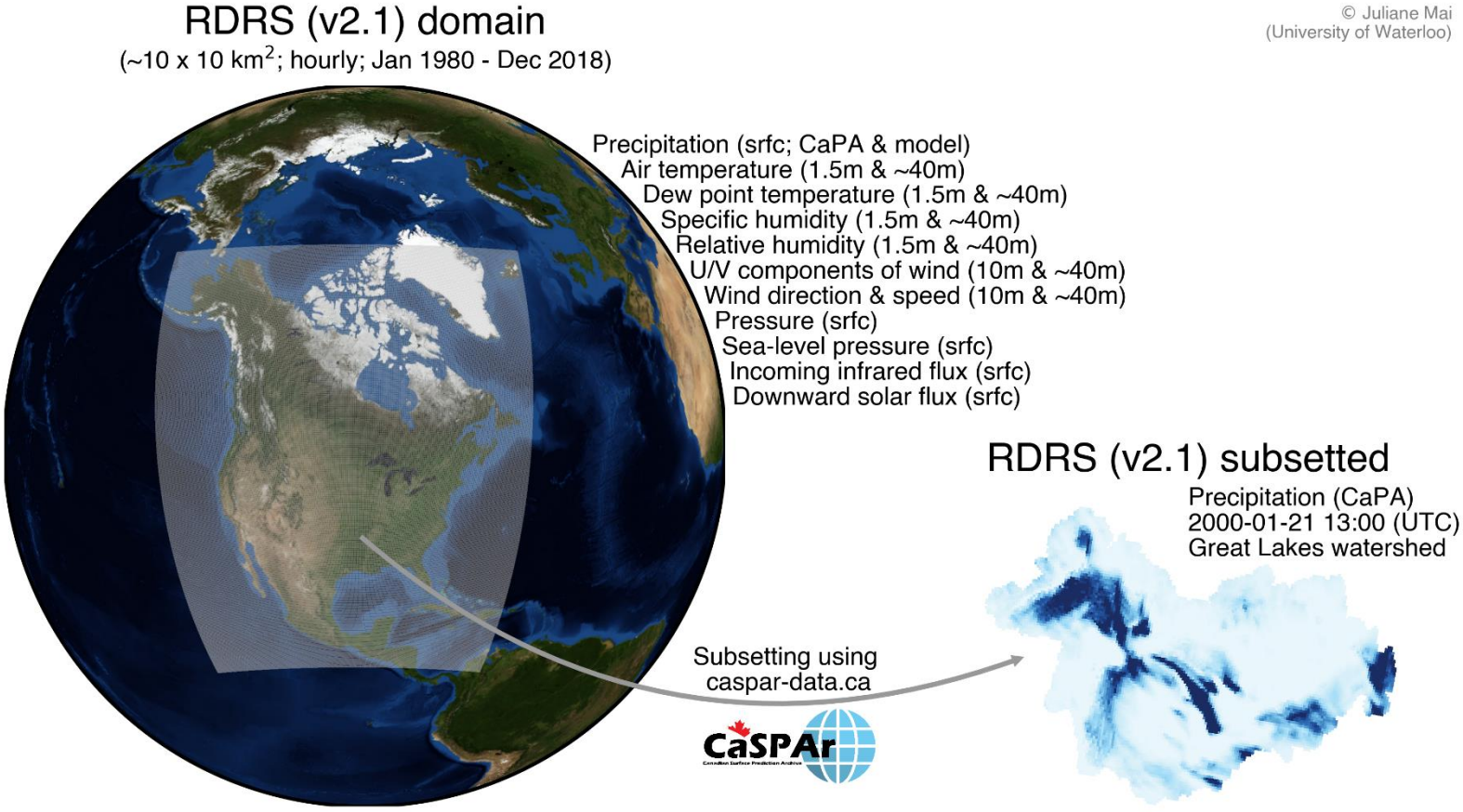
- **Offline CaPA reanalysis**

* additional networks of daily precipitation (AdjDlyRS, SHEF, RMCQ)
* 24-h pcp accumulations from other networks could be easily added

- **Hourly forcing's and precipitation**

* combining best estimates from RDRS outputs with offline pcp analysis
* final product: 1-h forcing's at 10 km resolution over North America
* Driver to other models

HOURLY FORCING'S VARIABLES



❖ ***Short-term solution:***
(https://caspar-data.ca/caspar)

2010120212.nc is covering covering
2010.12.02 13UTC -2010.12.03 12UTC

❖ ***Long-term plan:***
Direct ECCC data access under development (GeoMet)
https://eccc-msc.github.io/open-data

RDRS - REANALYSIS – STATUS UPDATE

Details on versions (available trough CaSPAr):

- RDRS_v1 period: 2010-2015 at 15 km resolution.
- RDRS_v2 period: 2000-2018 at 10 km resolution and
- RDRS_v2.1 period: 1980-2018 at 10 km resolution
  (maximum snow density bug corrected and Integrated Surface Database used prior to 2000)

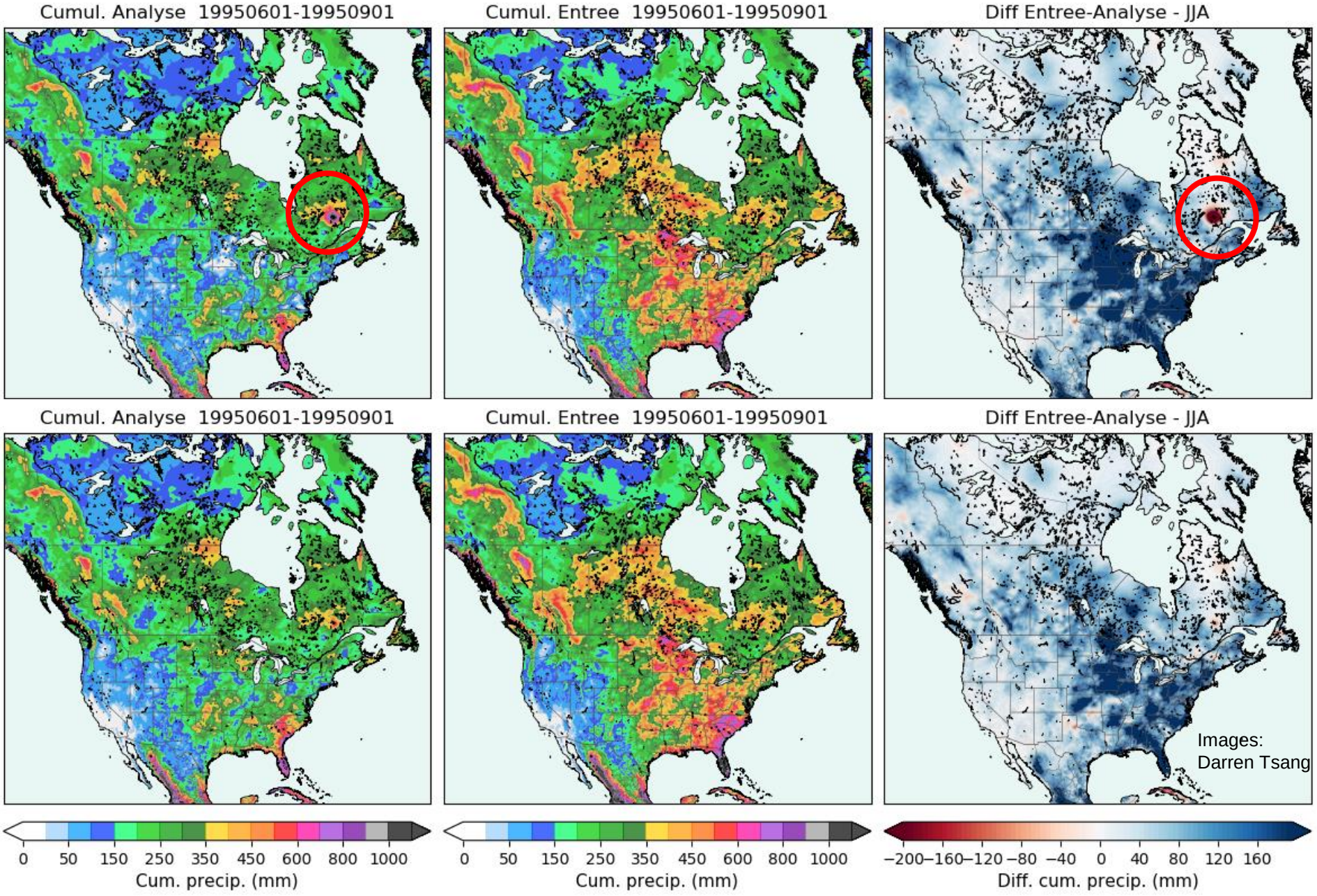
- Article published in HESS (Hydrology and Earth system sciences) 2021, September 7th:

https://hess.copernicus.org/articles/25/4917/2021/hess-25-4917-2021.html

UPDATE ON CAPA REANALYSIS V2.1

- Integrated Surface Database (ISD) of hourly precipitations from NOAA used for years 1980-1999
- Quality Controlled database, relatively new to ECCC, some inconsistencies discovered after the facts when maps of accumulated precipitation inspected
- False zero precipitation cleaned: monthly precipitations at 0 mm for more than 75% of the days and model precipitations greater than 15 mm
- Also very high monthly precipitations compared to model precipitation not detected by daily CaPA quality control are cleaned
- Impact is local, limited to grid points close to faulty stations and also limited in time
- Identified list of problematic month-stations, eliminated from final version

CAPA ANALYSIS – PROBLEMS CORRECTED



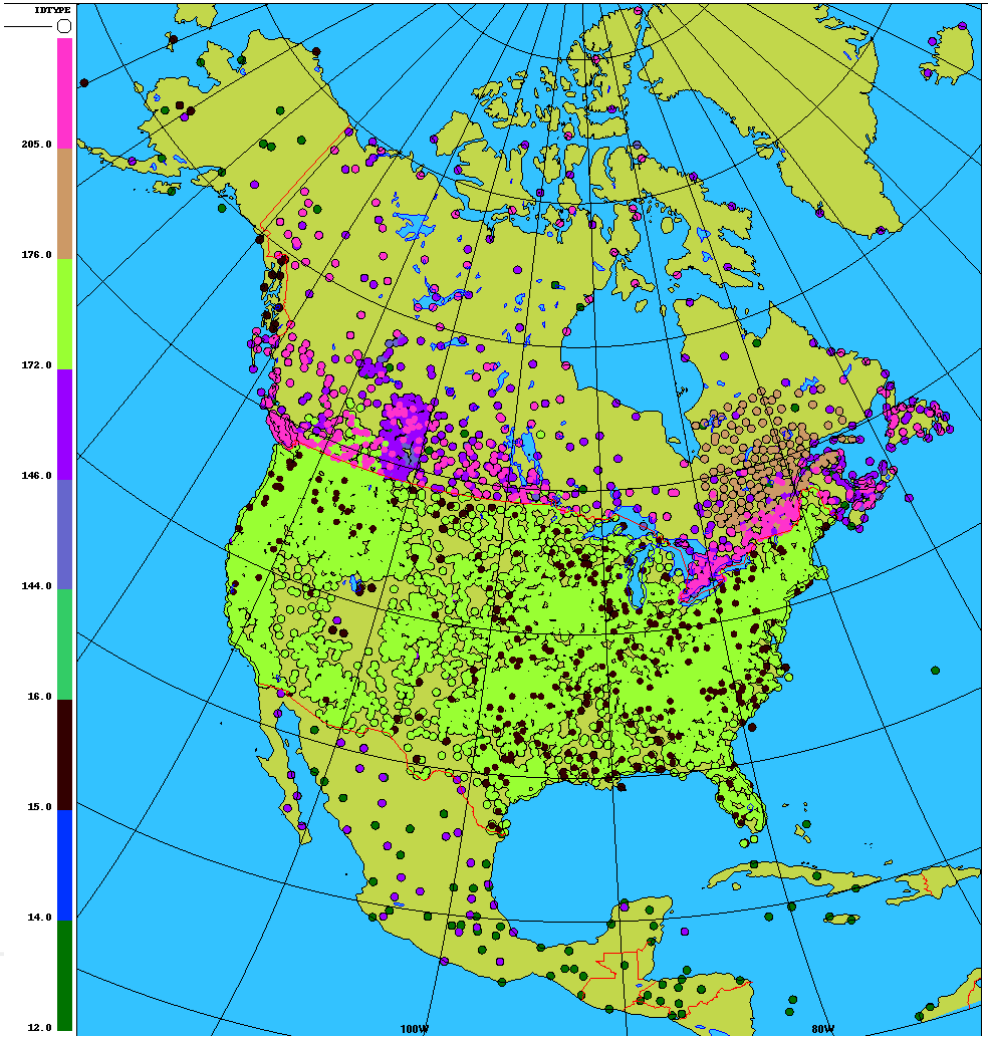
CAPA ANALYSIS - SURFACE OBSERVATION DATASETS 1980-2018

Precipitation networks used:

	SYNOP		METAR	SWOB
Type	manual	automatic		Hourly surface obs.
Number	**1400**	**2290**	**3667**	**627**
Note:				20130701-20171231

Additional daily precipitation networks:

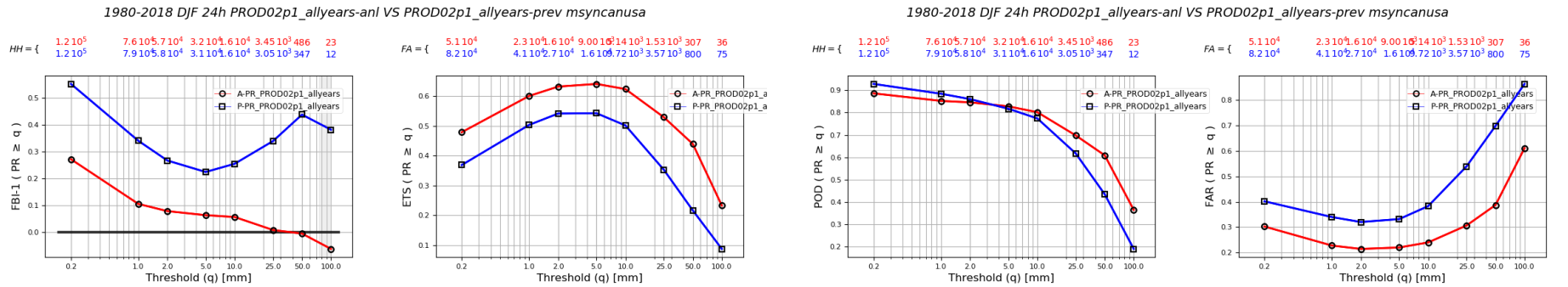
	RMCQ	SHEF	AdjDlyRS
Type	Quebec	US stations including CoCoRaHS	climate
Number	**225**	**21326**	**3094**
Note:	201104 - 201712	starting 2000 24-acc. only	24-acc. only



CAPA 24H VERIFICATION V2.1 REANAL VS FRCST 1980-2018

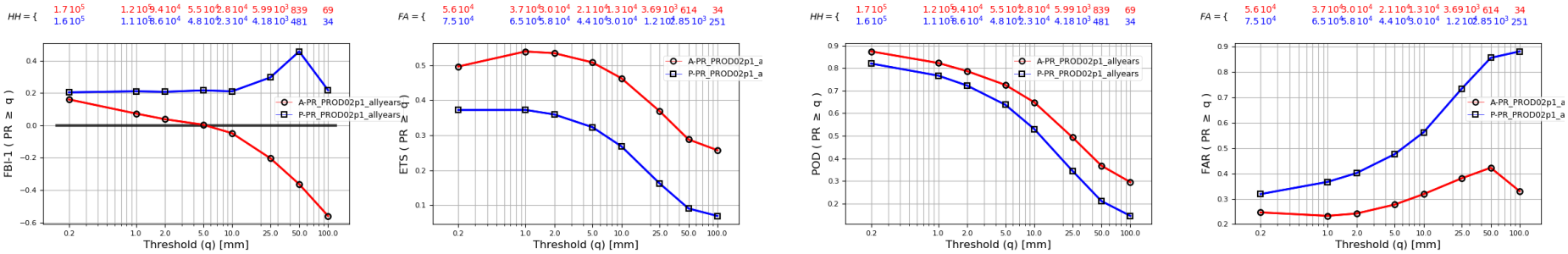
Winter (DJF)

FBI – 1 ETS POD FAR



Summer (JJA)

FBI – 1 ETS POD FAR



$$\text{FBI} = \frac{h+f}{h+m} \qquad \text{ETS} = \frac{h-h_R}{h+f+m-h_R} \qquad \text{POD} = h/(h+m) \qquad \text{FAR}=f/(c+f)$$

h-hits f-false alarms

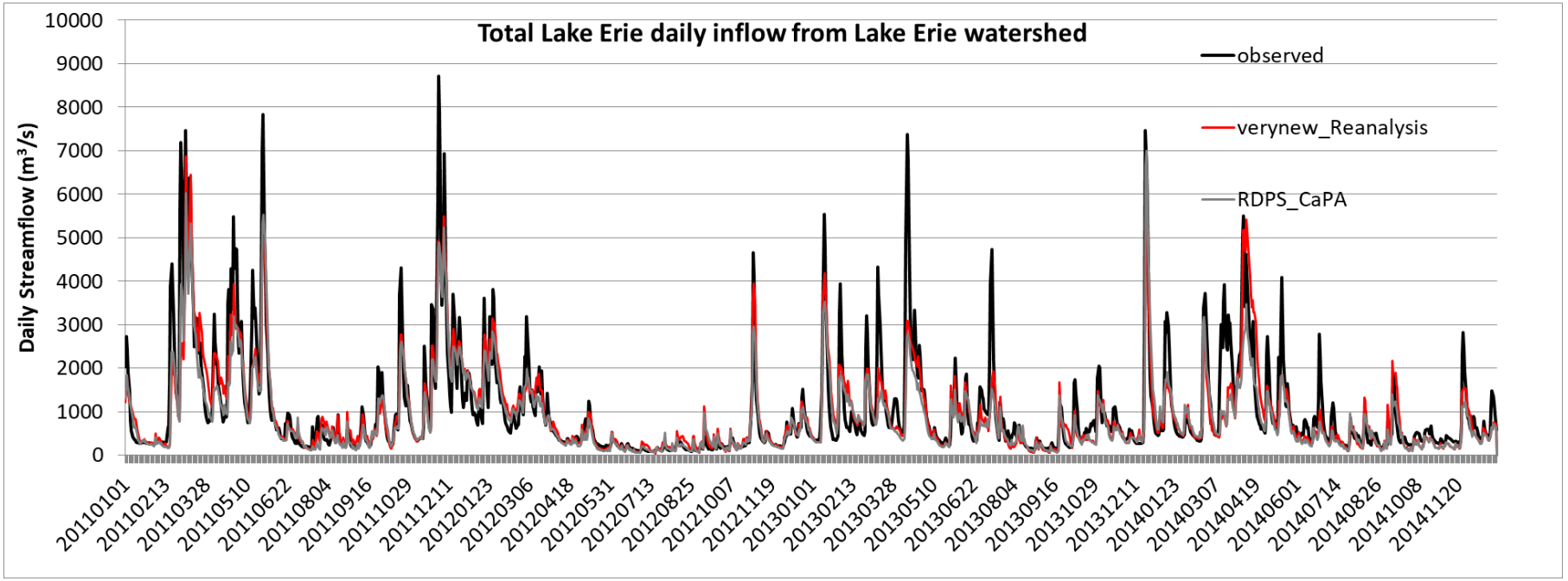
m-misses c-correct rejections

$h_R = (h+f)(h+m)$

hits expected by chance

HYDROLOGICAL APPLICATION: STREAMFLOW SIMULATIONS

- Watroute (routing model) simulation of streamflow using 10 km reanalysis forcing's RDRS+CaPA against RDPS+CaPA forcings and observed streamflow



Thanks to É. Gaborit

Other studies using RDRS forcing's fields:

- Great Lakes Runoff Intercomparison Project Phase 3: Lake Erie (GRIP-E). Journal of Hydrologic Engineering, 26(9), 05021020.
- Great Lakes Runoff Intercomparison Project Phase 4: Great Lakes (GRIP-GL). Hydrol. Earth Syst. Sci. Discussions, [preprint]. Accepted for dicussion Mar 29, 2022.

R&D PLANS

Working on version 3 of the reanalysis:

- Use ERA5 instead of ERA-I for the initialization
- Update all components of the system (GEM 5, updated version of CaLDAS/CaPA)
- Tests with CaLDAS-Sat and/or CaLDAS with SVS
- Implement some of the innovation from operational CaPA (in priority: assimilate satellite IMERG data, improve treatment of observation in winter…)
- Interested in using changing land cover trough years

ERA 5 GEM4 VS ERA-I GEM4

GDRSers5R / GDRS2018smco813		JFM	AMJ	JAS	OND
Alaska plus Canadian Arctic	P0	0.40%	0.58%	0.32%	0.88%
	TD	2.71%	8.90%	4.78%	4.42%
	TT	3.19%	4.65%	3.69%	4.79%
	UV	2.70%	3.79%	3.94%	3.19%
Asia	P0	1.21%	1.59%	1.70%	1.25%
	TD	2.99%	1.41%	2.36%	1.14%
	TT	0.72%	3.63%	5.21%	-2.13%
	UV	2.38%	1.93%	1.06%	2.43%
Canada	P0	0.86%	0.75%	0.47%	0.45%
	TD	6.84%	8.19%	1.37%	3.09%
	TT	5.07%	3.29%	5.01%	2.08%
	UV	1.83%	3.34%	2.61%	2.10%
Canada East	P0	2.84%	1.89%	1.77%	2.15%
	TD	9.11%	10.88%	6.71%	4.24%
	TT	8.24%	-0.55%	4.49%	6.49%
	UV	2.13%	2.39%	1.47%	1.86%
Canada South	P0	1.12%	0.81%	0.56%	0.39%
	TD	8.16%	7.97%	1.40%	2.70%
	TT	5.77%	3.00%	5.34%	1.43%
	UV	1.84%	3.33%	2.48%	2.01%
Canada West	P0	-0.48%	-0.16%	-0.50%	-1.28%
	TD	7.16%	5.71%	-0.76%	2.10%
	TT	2.34%	7.09%	5.83%	-0.37%
	UV	1.50%	4.37%	3.60%	2.20%
Europe	P0	0.22%	0.52%	0.06%	0.09%
	TD	8.73%	15.04%	8.66%	7.50%
	TT	6.72%	8.45%	7.88%	7.13%
	UV	2.60%	2.90%	2.97%	2.45%
Great Lakes Watersheds	P0	2.09%	1.51%	0.74%	1.57%
	TD	9.35%	11.28%	5.65%	5.50%
	TT	9.30%	4.09%	5.30%	6.18%
	UV	3.16%	3.37%	1.59%	2.59%
Mexico	P0	-0.06%	-0.20%	-0.07%	-0.01%
	TD	0.03%	-3.32%	3.55%	2.90%
	TT	4.01%	6.25%	4.32%	3.85%
	UV	2.30%	2.65%	3.08%	3.80%
North America	P0	0.68%	0.31%	0.24%	0.15%
	TD	8.67%	7.09%	3.77%	3.49%
	TT	5.76%	4.63%	6.40%	2.53%
	UV	2.12%	3.45%	2.66%	2.23%
North America East	P0	2.93%	1.98%	1.55%	2.12%
	TD	10.51%	11.88%	7.25%	5.85%
	TT	8.08%	0.90%	6.50%	6.73%
	UV	2.31%	2.69%	1.74%	2.11%
North America West	P0	-0.60%	-0.56%	-0.53%	-1.07%
	TD	6.55%	4.14%	1.85%	2.30%
	TT	3.61%	7.50%	6.68%	-0.15%
	UV	1.89%	4.29%	3.69%	2.36%
North America plus	P0	0.64%	0.36%	0.30%	0.43%
	TD	7.53%	7.39%	3.66%	3.38%
	TT	5.12%	4.72%	6.20%	2.46%
	UV	2.20%	3.39%	2.91%	2.34%
United States of America	P0	-0.16%	-0.56%	-0.41%	-0.24%
	TD	9.36%	6.33%	8.95%	4.23%
	TT	5.51%	9.87%	10.33%	4.43%
	UV	3.36%	3.75%	3.33%	3.27%
United States of America East	P0	3.33%	2.29%	0.11%	1.98%
	TD	13.03%	15.11%	8.39%	9.56%
	TT	7.02%	9.50%	11.58%	6.98%
	UV	2.88%	3.58%	2.71%	3.13%
United States of America West	P0	-0.78%	-1.03%	-0.53%	-0.73%
	TD	5.99%	0.66%	9.07%	0.71%
	TT	4.22%	11.15%	9.93%	2.14%
	UV	4.26%	3.54%	4.05%	3.50%

ERA 5 GEM5 VS ERA-5 GEM4

GDRSGEPS5era5 / GDRSers5R		JFM	AMJ	JAS	OND
Alaska plus Canadian Arctic	P0	9.44%	8.08%	6.49%	4.86%
	TD	1.18%	1.69%	5.11%	2.61%
	TT	-2.13%	1.73%	3.96%	0.12%
	UV	-0.30%	-0.46%	0.35%	-0.98%
Asia	P0	12.49%	12.00%	13.55%	14.03%
	TD	2.96%	3.72%	5.87%	4.89%
	TT	3.40%	4.95%	9.02%	3.22%
	UV	4.49%	0.76%	1.38%	4.39%
Canada	P0	16.69%	16.60%	17.43%	16.70%
	TD	3.43%	1.81%	6.43%	10.65%
	TT	5.75%	6.97%	7.94%	7.98%
	UV	0.75%	1.47%	2.10%	1.15%
Canada East	P0	18.08%	18.50%	19.12%	18.29%
	TD	1.12%	-0.04%	5.96%	7.94%
	TT	5.67%	6.31%	4.80%	9.83%
	UV	1.86%	2.65%	3.98%	2.02%
Canada South	P0	15.86%	15.82%	16.78%	16.25%
	TD	3.74%	2.29%	6.52%	12.35%
	TT	7.07%	7.65%	8.20%	8.54%
	UV	0.84%	1.51%	2.29%	1.23%
Canada West	P0	13.54%	13.04%	14.27%	14.02%
	TD	5.77%	4.76%	6.75%	14.38%
	TT	7.69%	8.62%	10.83%	8.08%
	UV	-0.40%	0.20%	-0.16%	-0.04%
Europe	P0	12.04%	11.47%	11.30%	11.51%
	TD	4.80%	5.23%	7.41%	9.29%
	TT	3.75%	7.29%	9.32%	8.99%
	UV	1.40%	1.79%	2.58%	2.16%
Great Lakes Watersheds	P0	16.50%	16.41%	16.27%	16.10%
	TD	4.49%	1.54%	7.25%	11.91%
	TT	7.15%	-2.32%	5.92%	15.05%
	UV	1.63%	2.40%	3.27%	1.81%
Mexico	P0	22.42%	21.89%	20.57%	20.81%
	TD	3.57%	4.36%	7.50%	6.86%
	TT	1.39%	2.18%	7.03%	2.87%
	UV	9.94%	4.56%	5.21%	9.09%
North America	P0	11.85%	11.15%	11.82%	11.85%
	TD	3.84%	2.34%	5.87%	10.16%
	TT	5.68%	6.63%	7.86%	7.39%
	UV	1.17%	1.37%	1.88%	1.55%
North America East	P0	16.38%	16.65%	17.24%	16.52%
	TD	1.52%	1.02%	7.05%	7.89%
	TT	4.91%	5.93%	5.54%	8.39%
	UV	2.26%	2.67%	3.68%	2.43%
North America West	P0	8.69%	7.42%	8.09%	8.58%
	TD	4.09%	3.64%	5.24%	11.17%
	TT	5.99%	7.04%	9.75%	6.71%
	UV	-0.38%	-0.64%	-0.33%	0.33%
North America plus	P0	12.12%	11.57%	12.08%	11.76%
	TD	2.84%	2.26%	5.80%	8.64%
	TT	4.30%	5.92%	7.41%	6.18%
	UV	1.30%	1.17%	1.70%	1.39%
United States of America	P0	1.76%	-0.13%	0.37%	1.27%
	TD	1.64%	1.39%	3.53%	2.79%
	TT	-0.24%	0.61%	5.64%	0.24%
	UV	3.11%	0.59%	0.87%	3.56%
United States of America East	P0	5.23%	4.19%	5.06%	4.80%
	TD	4.36%	5.95%	10.35%	7.92%
	TT	2.94%	4.34%	9.19%	4.84%
	UV	4.14%	2.97%	2.87%	4.64%
United States of America West	P0	1.08%	-0.98%	-0.66%	0.75%
	TD	-2.01%	-0.50%	-0.75%	-0.93%
	TT	-4.87%	-4.59%	1.00%	-4.56%
	UV	0.89%	-3.30%	-2.54%	1.20%
	P0	8.94%	9.02%	9.02%	9.03%

ERA 5 GEM5 VS ERA-I GEM4

GDRSGEPS5era5 / GDRS2018smco813		JFM	AMJ	JAS	OND
Alaska plus Canadian Arctic	P0	10.98%	10.06%	8.10%	7.37%
	TD	4.53%	10.66%	8.92%	7.38%
	TT	1.87%	6.92%	8.22%	5.62%
	UV	2.43%	3.90%	4.32%	2.17%
Asia	P0	13.68%	13.56%	15.18%	15.11%
	TD	5.15%	4.47%	8.01%	6.15%
	TT	3.84%	8.72%	14.06%	1.84%
	UV	6.66%	2.55%	2.29%	6.74%
Canada	P0	17.42%	17.15%	17.56%	16.98%
	TD	10.72%	9.90%	8.40%	13.50%
	TT	10.77%	9.68%	12.90%	9.64%
	UV	2.74%	5.00%	4.67%	3.30%
Canada East	P0	20.59%	20.19%	20.69%	20.26%
	TD	10.05%	10.27%	12.30%	12.03%
	TT	13.50%	5.73%	9.21%	15.93%
	UV	4.00%	5.06%	5.49%	3.79%
Canada South	P0	16.63%	16.29%	16.88%	16.45%
	TD	12.20%	9.86%	8.38%	14.62%
	TT	12.45%	10.19%	13.27%	9.96%
	UV	2.85%	5.00%	4.68%	3.22%
Canada West	P0	13.21%	12.98%	13.67%	13.09%
	TD	13.74%	9.89%	6.19%	15.59%
	TT	11.56%	14.92%	15.86%	7.80%
	UV	1.34%	4.85%	3.69%	2.22%
Europe	P0	12.31%	12.11%	11.44%	11.65%
	TD	13.83%	20.08%	16.62%	16.82%
	TT	10.99%	15.10%	15.58%	15.96%
	UV	4.12%	4.67%	5.52%	4.69%
Great Lakes Watersheds	P0	19.51%	19.00%	18.31%	18.74%
	TD	12.90%	11.96%	13.44%	16.81%
	TT	15.93%	2.68%	11.51%	20.66%
	UV	4.96%	5.72%	5.25%	4.37%
Mexico	P0	23.02%	22.18%	21.28%	21.28%
	TD	7.25%	5.31%	8.55%	8.32%
	TT	6.38%	9.31%	12.76%	7.20%
	UV	15.00%	10.37%	12.33%	17.03%
North America	P0	12.91%	11.98%	12.42%	12.46%
	TD	12.32%	10.18%	9.25%	13.08%
	TT	11.30%	10.43%	13.85%	9.60%
	UV	3.37%	4.76%	4.52%	3.80%
North America East	P0	19.04%	18.50%	18.72%	18.53%
	TD	12.14%	12.76%	14.35%	13.38%
	TT	12.83%	7.81%	11.64%	14.69%
	UV	4.57%	5.36%	5.38%	4.55%
North America West	P0	8.94%	7.94%	8.57%	8.56%
	TD	12.57%	8.48%	6.69%	12.73%
	TT	10.35%	13.77%	15.10%	6.11%
	UV	1.59%	4.12%	3.49%	2.73%
North America plus	P0	13.21%	12.47%	12.76%	12.60%
	TD	10.88%	10.15%	9.14%	11.79%
	TT	9.63%	9.82%	13.30%	8.61%
	UV	3.54%	4.59%	4.66%	3.78%
United States of America	P0	1.71%	-0.40%	-0.06%	1.05%
	TD	11.68%	11.53%	12.47%	7.54%
	TT	5.84%	11.31%	15.96%	5.58%
	UV	6.39%	4.05%	4.16%	6.77%
United States of America East	P0	8.28%	6.30%	5.13%	6.66%
	TD	16.97%	19.96%	19.28%	16.93%
	TT	9.66%	13.68%	19.79%	11.59%
	UV	6.99%	6.42%	5.49%	7.79%
United States of America West	P0	0.02%	-1.94%	-1.11%	0.01%
	TD	6.77%	5.86%	8.44%	-0.93%
	TT	1.10%	8.09%	11.53%	-1.05%
	UV	4.89%	0.59%	1.39%	4.82%

COMPARAISON ERA 5 GEM 4 VS ERA 5-GEM5 (GEPS CI-3) RMSE

ERA5 GEM5:
GEM5-ERA5-ROMAX fix

ERA 5 GEM4:
GEM4-ERA5-noROMAX fix

ERA-Interim GEM4:
GEM4-ERA-I-noROMAX fix

FINAL REMARKS

- Version 3 of the reanalysis is planed to be completed in 2 years after migration to the new supercomputer
- Produce 1980-2020 initialized with ERA5 instead of ERA-Interim
- All components updated to the operational versions of the corresponding systems

ECCC SURFACE AND PRECIPITATION REANALYSIS SYSTEM BASED ON GEM MODEL

Thank you!

Milena Dimitrijevic

Meteorological Research Division
Enviroment and Climate Change Canada