A 35-YEAR NORTH AMERICAN PRECIPITATION AND SURFACE RETROSPECTIVE ANALYSIS

EXECUTIVE SUMMARY AND FINAL REPORT

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Environment and Climate Change Canada (ECCC) has designed a system which can provide accurate and consistent estimates of precipitation and surface state (including all major components and fluxes of the surface water cycle). This system is based on components of ECCC's operational weather and environmental prediction system, but it has been modified in order to be able to simulate any period in time between 1980 and 2015, and to cover all of North America as well as the Arctic Basin in the same 15-km domain. This report provides description of the method and of the dataset produced as part of the project. The current draft of a scientific paper on the subject is provided in an appendix.

KEY MESSAGES

- This IWI project was initiated in July 2015, with the primary objective of obtaining a 35-year precipitation reanalysis dataset based on the Canadian Precipitation Analysis (CaPA).
- CaPA is a precipitation analysis system that blends precipitation observations from various sources with a first guess provided by a numerical weather prediction (NWP) model. This approach allows ECCC to estimate precipitation even in areas with limited gauge and radar coverage. It also provides a seamless analysis across the Canada-USA border. A limitation of CaPA is that it relies on data from Global Environmental Multiscale (GEM) NWP model. This data is not available at the required resolution (at least 15-km) prior to June 2004.
- A surface reanalysis and atmospheric reforecast system has been designed in order to circumvent this problem. This system allows running GEM and CaPA back in time to 1980.
- The methodology has been applied to the years 2010-2014. This new product has a bias and skill signature similar to that of the 10-km configuration of GEM currently operational at ECCC.
- The product is available for all Canada-USA transboundary watersheds.
- The data has already been provided to scientists in Canada and in the USA for use in other projects in support of the International Joint Commission.
- The daily precipitation analyses from this configuration of CaPA have been made available on the web.
- A paper will be submitted soon for publication in a scientific journal.
- Production of a dataset covering the years 1980-2018 should begin during FY 2018-19.

CONTENTS

THE NEED FOR A PRECIPITATION AND SURFACE REANALYSIS SYSTEM

Near real-time high-resolution estimates of precipitation and surface variables (including component Net Basin Supplies) are available from operational and experimental systems developed and operated by Environment and Climate Change Canada (ECCC). In particular, ECCC uses the Canadian Precipitation Analysis (CaPA) system to provide near real-time information on precipitation for most of North America, including all Canada-USA transboundary watersheds.

ECCC, however, does not currently produce either a reanalysis or climatology of these estimates. This requires running atmospheric forecast and analysis systems back in time for many decades, which has never been done by ECCC in part because of the very significant cost in both human and computer resources of running not only the atmospheric model but also the data assimilation system.

Yet, a reanalysis would allow bias correction of current estimates and forecasts, and help decision maker understand and communicate by how much the current and forecasted state of the system differs from the recent past. Although other reanalysis products exist, they have many limitations:

- They often show strong discontinuities at the Canada-USA border (for example NARR and NLDAS)
- They are provided at fairly low horizontal resolution (such as ERA-Interim/Land and MERRA Land), thus not adequately resolving important local features such as the Great Lakes
- They generally do not incorporate information from most climate stations (in particular Canadian stations).

There is therefore a need for a higher resolution precipitation and surface reanalysis product that relies on more accurate climate station data and that is seamless at the Canada/US border. This has clear applications for adaptive management of transboundary watersheds.

AN OPPORTUNITY FOR A PRECIPITATION AND SURFACE REANALYSIS

In November 2014, however, ECCC started to produce operational global ensemble reforecast based on the ERA-Interim reanalysis for the 1995-2012 period at 50-km resolution (Gagnon et al. 2014). This reforecast system demonstrated the ability to initialize the Global Environmental Multiscale (GEM) model with non-ECCC data, thus allowing running it back in time without the need for an associated atmospheric assimilation system. A dynamical downscaling to finer resolution such as 15-km would then be relatively straightforward, as this is the current horizontal resolution of the Regional Ensemble Prediction System for North America. In the spring of 2015, ECCC informed the IJC that this presented an opportunity for developing a precipitation and surface reanalysis system which could be used for adaptive management of transboundary watersheds.

A NOVEL APPROACH FOR PRECIPITATION AND SURFACE REANALYSIS

In July 2015, ECCC was tasked by the International Watersheds Initiative (IWI) to develop a prototype of a system that would allow retrospective analysis of precipitation and surface variables over the period 1980-2015. Considering the complexity of the ECCC's forecast and assimilation systems, it was decided to rely essentially on systems that are designed and tested for operational analysis and forecasting. Key components from ECCC systems for the project are listed below.

- The Global Environmental Multiscale (GEM) model is the atmospheric forecast model operated at ECCC in various configurations, ranging from low resolution seasonal forecasts (100-km) to very high-resolution sub-hourly forecasts (250-m).
- The Canadian Precipitation Analysis (CaPA) system provides real-time gridded precipitation analyses over North America at resolutions ranging from 10 km to 2.5 kmand for accumulation periods of 6-h and 24-h. It relies on the GEM atmospheric model to obtain a background field of precipitation that is modified based on ground, radar and satellite observations of precipitation.
- The Canadian Land Data Assimilation System (CaLDAS) provides near real-time gridded surface analyses (surface layer temperature and dew point, soil temperature, soil moisture and snow depth on the ground) every three hours. It relies on CaPA to obtain precipitation and on GEM to get background fields of snow depth and atmospheric surface layer temperature and humidity. These fields are then modified based on ground and satellite observations.

The workflow of the system is a three-step process, illustrated by Figure 1. Each of these steps can be performed independently, which is a major advantage of the methodology.

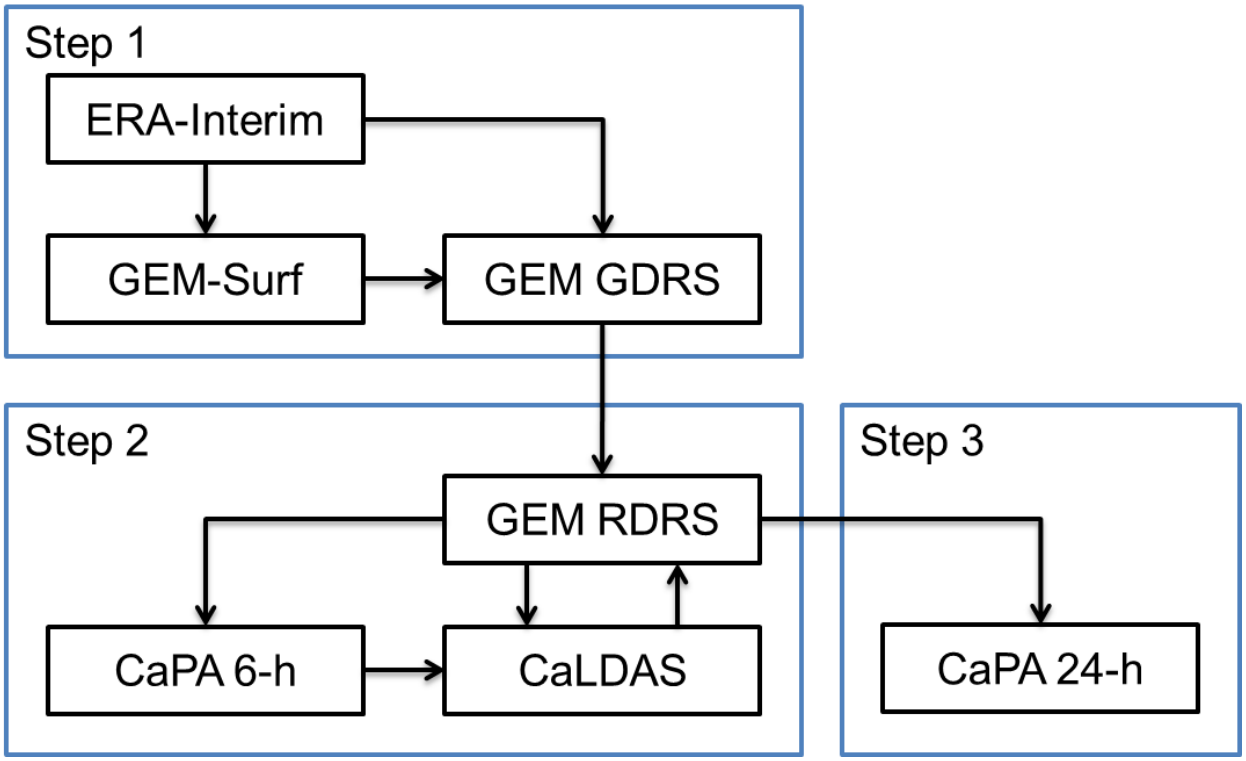


Figure 1: Overview of the methodology developed to obtain a surface and precipitation reanalysis

Step 1: Global atmospheric and land-surface modelling

- Upper-air reanalyses are obtained from the ERA-Interim reanalysis produced by the European Centre for Medium-Range Weather Forecasts (ECMWF) for the period of interest.
- Forced by ERA-Interim, the land-surface model of GEM (GEM-Surf) is run in open-loop over the whole globe for the period of interest at a resolution of 50-km.
- Every 12 hours (at 00 UTC and 12 UTC), a global configuration of the GEM model at 50-km resolution is initialized from ERA-Interim upper-air fields and land-surface initial conditions provided by the open-loop surface model run. It is run for 24 hours. This configuration of GEM is named the Global Deterministic Reforecast System (GDRS).

Step 2: Regional atmospheric modelling and land-surface data assimilation

- Every 12 hours (at 00 UTC and 12 UTC) a regional configuration of the GEM model at 15-km resolution covering North America and the Arctic ocean is initialized and forced at the lateral and top boundaries of the domain by the outputs of the 50-km GEM model run. It is run for 24 hours. This configuration of GEM is named the Regional Deterministic Reforecast System (RDRS).
- Short-term forecasts (with lead times of 6 to18 hours) from the regional configuration of the GEM model are used to obtain a first guess for CaPA. Accumulations of precipitation over each 6-h period are obtained.
- Short-term forecasts from the regional configuration of the GEM model are used together with CaPA to force CaLDAS at 15-km resolution. CaLDAS provides initial conditions of soil temperature, soil moisture, and snow conditions for the next run of the GEM regional model.
- This cycle is repeated until the end of the period of interest.

Step 3: Final precipitation analysis

- CaPA analyses performed during step 2 only incorporate in-situ data providing 6-h precipitation accumulations. Most climate stations only report 24-h totals.
- A final precipitation analysis is performed with the CaPA system in which these stations are added.

TIMINGS

To complete one month of reforecast and retrospective analysis, it typically takes 1.6 days and requires 288 CPU cores. Running sequentially for 35-years would therefore take 1.6 x 12 x 35 = 672 days. In order to speed up production, it is recommended to split the 35-year time period in seven periods of five years, each preceded by a one-year spin-up period. If sufficient CPU resources are available, the seven time windows can be run in parallel, and the production time can be reduced to 1.6 x 12 x 6 = 115 days. It would however require 2016 cores.

DELIVERABLES

In addition to the development of the methodology, the goal of the project was to generate and evaluate a five-year dataset based on this methodology. The period 2010-2014 was selected because it allowed for comparisons to be made with operational GEM and CaPA systems.

Production of the 5-year GEM reforecast and CaPA reanalysis was completed during the spring of 2017. Daily precipitation accumulations from the CaPA system were made available to the public on a web site, accompanied by a technical report (Gasset et al., 2017a). The product is also mentioned in a literature review on CaPA products and applications (Fortin et al., 2018).

General information on CaPA products can be found here:

http://collaboration.cmc.ec.gc.ca/cmc/cmoi/product_guide/submenus/capa_e.html

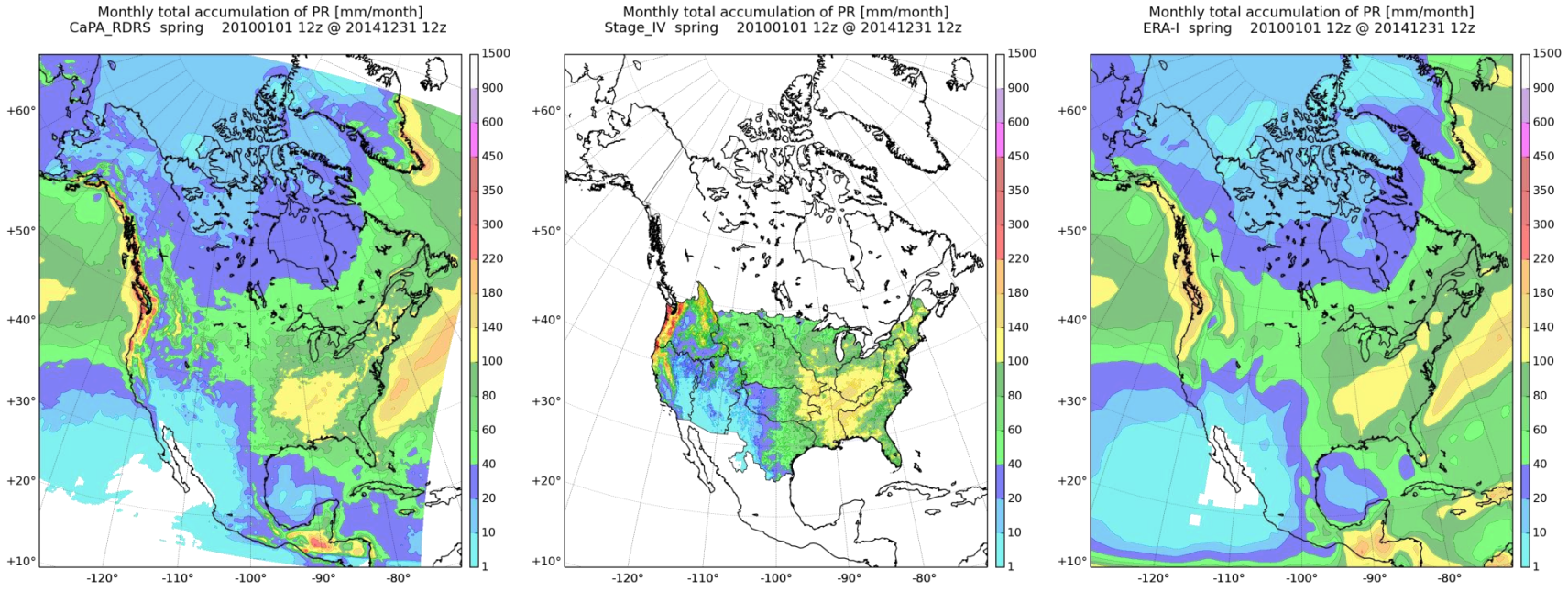
To obtain the 2010-2014 CaPA-RDRS dataset, click on "Re-analyses archives in GRIB2 format, starting from 2002", and then on "capa_hindcast_rdrs_v1".

Hourly forcing fields from GEM and CaPA were also obtained and converted to NetCDF format for use in other hydrological modelling projects:

- The data was provided to NCAR for use in testing a configuration of the WRF-Hydro hydrological model for the Great Lakes.
- The data was provided to the FloodNet research network for use in phase III of the Great Lakes Runoff Inter-comparison Project (GRIP), which focuses on Lake Erie. Phases I and II of GRIP were partially funded by IWI.
- The data was provided to technical working group members of the Lake Champlain and Richelieu River study board, for use in modelling the hydrological response of Lake Champlain's watershed, as well as the hydrodynamic response of Lake Champlain to wind set-up events.

Finally, a thorough evaluation of the dataset has been performed. Results from this evaluation were presented at the 2017 AGU Fall meeting (Gasset et al., 2017b). They are summarized in a draft scientific paper, to be submitted soon for publication in a scientific journal (Gasset et al., 2018). The most recent version of this manuscript is provided in an appendix to this final report.

Figure 2 aims to illustrate that this project succeeded in developing a methodology that can be used to obtain high-resolution precipitation estimates that are consistent with lower resolution estimates covering North America, and with higher resolution products covering only the USA. Figure 2 presents the 2010-2014 monthly mean precipitation for the spring months (March, April and May), from three precipitation products. Figure 2(a) shows the estimate from CaPA-RDRS (delivered as part of this project). Figure 2(b) shows the estimate from NOAA/MPE (Stage IV), which only covers the USA. It can be seen that the products are very similar over the USA. Figure 2(c) presents the ERA-Interim precipitation average, which is provided alongside the upper-air data that was used to drive the GDRS system. CaPA-RDRS is generally consistent with ERA-Interim, but provides more details on the precipitation field.



(a) (b) (c)

Figure 2: Monthly average of spring precipitation (March-April-May) over the years 2010-2014 from three products: (a) ECCC/CaPA-RDRS, (b) NOAA/MPE (Stage IV), and (c) ECMWF/ERA-Interim

CONCLUSIONS

A novel approach for precipitation and surface reanalysis, as well as atmospheric reforecasting, has been proposed. This technique is expected to be used to generate a precipitation and surface reanalysis over the period 1980-2015 by ECCC over the next few years. The spatial domain will encompass all of North America, thus including all Canada-USA transboundary watersheds. The delivery date will depend on the availability of the required computing resources. Once completed, the database will be useful for hydrological modelling studies as well as for reporting precipitation anomalies based on CaPA.

It is encouraging to see that the dataset is already being used for hydrological modelling work on transboundary watersheds. The data has indeed been provided to (a) NCAR in order to drive the WRF-Hydro model over the Great Lakes, (b) the FloodNet consortium to drive hydrological models over sub-watersheds of Lake Erie, and (c) members of the Lake Champlain and Richelieu River technical working groups to drive hydrological models over sub-watersheds of Lake Champlain as well as wind set-up model over the lake itself. Demand is expected to soar once the scientific paper on the dataset is published and the 35-year reanalysis is made available to the public.

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APPENDIX: LATEST DRAFT OF THE PAPER ENTITLED "TOWARD A 35-YEARS NORTH AMERICAN PRECIPITATION AND LAND-SURFACE REANALYSIS"