Journal of Hydrology 531 (2015) 296–307

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Assimilation of radar quantitative precipitation estimations in the Canadian Precipitation Analysis (CaPA)

Vincent Fortin [a,*], Guy Roy [b], Norman Donaldson [c], Ahmed Mahidjiba [d]

[a] Recherche en prévision numérique environnementale, Environment Canada, Canadian Meteorological Centre, Dorval, Québec H9P 1J3, Canada
[b] National Laboratory for Severe Weather Meteorology, Environment Canada, Place Bonaventure, Montréal, Québec H5A 1K6, Canada
[c] Cloud Physics and Severe Weather Research Section, Environment Canada, 14780 Jane Street, King City, Ontario L7B 1A3, Canada
[d] National Prediction Operations, Environment Canada, Canadian Meteorological Centre, Dorval, Québec H9P 1J3, Canada

ARTICLE INFO

Article history:
Available online 4 August 2015

Keywords:
Quantitative precipitation estimation
Weather radar
Optimal interpolation
Verification
Numerical weather prediction

SUMMARY

The Canadian Precipitation Analysis (CaPA) is a data analysis system used operationally at the Canadian Meteorological Center (CMC) since April 2011 to produce gridded 6-h and 24-h precipitation accumulations in near real-time on a regular grid covering all of North America. The current resolution of the product is 10-km. Due to the low density of the observational network in most of Canada, the system relies on a background field provided by the Regional Deterministic Prediction System (RDPS) of Environment Canada, which is a short-term weather forecasting system for North America. For this reason, the North American configuration of CaPA is known as the Regional Deterministic Precipitation Analysis (RDPA). Early in the development of the CaPA system, weather radar reflectivity was identified as a very promising additional data source for the precipitation analysis, but necessary quality control procedures and bias-correction algorithms were lacking for the radar data. After three years of development and testing, a new version of CaPA–RDPA system was implemented in November 2014 at CMC. This version is able to assimilate radar quantitative precipitation estimates (QPEs) from all 31 operational Canadian weather radars. The radar QPE is used as an observation source and not as a background field, and is subject to a strict quality control procedure, like any other observation source. The November 2014 upgrade to CaPA–RDPA was implemented at the same time as an upgrade to the RDPS system, which brought minor changes to the skill and bias of CaPA–RDPA. This paper uses the frequency bias indicator (*FBI*), the equitable threat score (*ETS*) and the departure from the partial mean (*DPM*) in order to assess the improvements to CaPA–RDPA brought by the assimilation of radar QPE. Verification focuses on the 6-h accumulations, and is done against a network of 65 synoptic stations (approximately two stations per radar) that were withheld from the station data assimilated by CaPA–RDPA. It is shown that the *ETS* and the *DPM* scores are both improved for precipitation events between 0.2 mm and 25 mm per 6-h, and that the *FBI* is unchanged.

1. Introduction

Accurate real-time quantitative precipitation estimation (QPE) plays an important role in flood prevention and mitigation (WMO, 2010), and can also provide a valuable source of information for numerical weather prediction (NWP) systems (Lopez, 2011), which can then lead to improvements in quantitative precipitation forecasts (QPF). The design of a national real-time precipitation analysis system is inherently constrained by the amount and nature of the observational data available for assimilation. Like other countries having large variations in population density across its territory, Canada has a gauge network and a weather radar network both geared towards more populated areas. This makes it challenging to develop a high-resolution gridded precipitation product based on gauge and radar observations alone.

In order to provide nation-wide QPE, the Meteorological Service of Canada (MSC) uses an optimal interpolation procedure that blends different sources of information on precipitation amounts (Environment Canada, 2014). This system, known as the Canadian Precipitation Analysis (CaPA), became operational at the Canadian Meteorological Center (CMC) in April 2011 (Fortin and Roy, 2011), but had been under development since 2003 (Mahfouf et al., 2007).

* Corresponding author at: Canadian Meteorological Center, 2121 North Service Road, Dorval, Quebec H9P 1J3, Canada. Tel.: +1 (514)421 4630.

E-mail addresses: vincent.fortin@ec.gc.ca (V. Fortin), guy.roy@ec.gc.ca (G. Roy), norman.donaldson@ec.gc.ca (N. Donaldson), ahmed.mahidjiba@ec.gc.ca (A. Mahidjiba).

http://dx.doi.org/10.1016/j.jhydrol.2015.08.003
0022-1694/

Due to the low density of the observational precipitation network in most of Canada, CaPA relies on a background field provided by the Regional Deterministic Prediction System (RDPS) of Environment Canada, an operational short-term NWP system for North America with a horizontal resolution of 10-km which is run four times per day (Mailhot et al., 2006). For this reason, the North American configuration of CaPA analysis is also known as the Regional Deterministic Precipitation Analysis (RDPA). Forecasts with lead times of 6–12-h are used for the background field, in order to avoid model spin-up issues. 6-h accumulations are provided at 00, 06, 12 and 18 UTC, and an additional 24-h accumulation product is generated at 12 UTC, in order to assimilate a large number of 24-h precipitation reports that are only available at 12 UTC. A preliminary analysis is normally available on Environment Canada's web site approximately one hour after the end of the accumulation period, and a final analysis is provided six hours later.

Different types of products have been available to the public in near real-time since April 2011, including static images for selected domains and gridded fields in GRIB2 format. Users can also now rely on a web mapping service to view the analyses using their preferred tool for Geographic Information System (GIS) data, such as Google Earth™. For more details on data access see Appendix A.

CaPA–RDPA products are used in Canada for various environmental prediction applications, and in particular for hydrological modelling and forecasting (Eum et al., 2014; Bomhof and Jenkinson, 2014) and for snow depth prediction (Fortin et al., 2015). Another configuration of CaPA is also embedded within the Canadian land-data assimilation system (CaLDAS), and thus contributes to the estimation of soil moisture, soil temperature and snow depth in real-time over Canada (Carrera et al., 2015). These state variables are then used to initialize Environment Canada's national High-Resolution Deterministic Prediction System (HRDPS) which provides 48-h experimental weather forecasts at 2.5 km horizontal resolution (Mailhot et al., 2010).

The use of a model background in a gridded precipitation product is sometimes seen as a limitation, in particular for short-term forecast verification purposes, when in fact it can be a very valuable feature for many other applications. In Northwest Europe, at latitudes comparable to Southern Canada, Kidd et al. (2012) concluded from an intercomparison of high-resolution precipitation products that numerical weather prediction models are capable of producing consistent and accurate precipitation estimates when compared against a variety of gridded dataset products. Meteo-France is also providing a precipitation re-analysis based on a system similar to CaPA as part of the European Union funded project "European reanalysis and observations for monitoring" (http://www.euro4m.eu). Finally, the South African Weather Service has also found it useful to merge a satellite-based precipitation analysis with a short-term forecast in order to improve their flash flood guidance system (de Coning and Poolman, 2011).

Since its inception, a team of researchers and meteorologists at Environment Canada has continuously worked on evaluating and improving the CaPA analysis (Dimitrijevic et al., 2014; Lespinas et al., 2015; Fortin et al., 2012; Carrera et al., 2010). Small but significant improvements to the bias, skill and resolution of the products have been made over the years, but by far the largest improvement in skill has come from the assimilation of radar QPE. A new configuration of CaPA–RDPA system that assimilates radar has been extensively tested over the summers of 2013 and 2014. Large gains in skill were only obtained after major improvements were made to the procedure used to create the radar composite. A major upgrade to Environment Canada's primary radar processing URP (Unified Radar Processor) system (Joe et al., 2002) was also required. The decision to implement this configuration operationally was taken in September 2014, and the implementation was completed in November 2014, at the same time as other upgrades to Environment Canada's environmental prediction systems, including an upgrade to the RDPS system (Environment Canada, 2014).

This paper describes the different steps that the CaPA system goes through in order to create the radar composite, as well as the data assimilation strategy applied for merging this product with existing data sources. An objective evaluation of CaPA–RDPA with and without radar assimilation is then presented for the summer of 2014, and the additional impact of the RDPS upgrade is also discussed.

The paper is organized as follow. In Section 2, changes to the CaPA algorithm required in order to assimilate the radar QPE are described, together with the methodology developed to obtain a single radar composite for Canada. The protocol for assessing the skill and bias of CaPA products is also described. In Section 3, verification results are presented for different configurations of CaPA. These results are discussed is Section 4 and a brief conclusion follows.

2. Material and methods

This section presents the procedure developed to assimilate precipitation estimates from Canadian radars. It starts with a brief overview of the Canadian radar network and a summary of the optimal interpolation algorithm that CaPA uses for generating a precipitation analysis. The strategy selected for assimilating radar data is then described. It is divided in two main steps: (1) the production of a radar-based, bias-corrected gridded precipitation estimate from Canadian radars which we call the radar composite, and (2) the assimilation of this radar composite as an additional source of observation within CaPA–RDPA, in addition to gauges. Finally, the verification protocol that is used to assess the impact of this additional source of information on the bias and skill of the analysis is presented.

2.1. Configuration of the Canadian radar network

Fig. 1 presents the current network of Canadian radars, as well as the radar coverage at full range (256 km). Although many areas of the country are not covered by this network, the vast majority of the population is. There are currently 31 radars in the network. With the exception of the J.S. Marshall Radar observatory near Montreal (also known as the McGill radar), which is an S-band radar, all other radars are C-band with Doppler capability. Only two of the radars currently have dual-polarization capabilities as well (McGill and King City radars) but their outputs are not available for operational use. Hence, precipitation rate is obtained from radar reflectivity using a generalized Marshall-Palmer relationship (Marshall and Palmer, 1948). For each radar, a different precipitation-reflectivity relationship is used for liquid and solid precipitation. See Joe and Lapczak (2002) for more details on the Canadian radar network.

2.2. Overview of the optimal interpolation algorithm used by CaPA

This section provides an overview of the method used by CaPA to create a precipitation analysis. More details are found in Lespinas et al. (2015), in particular with respect to the quality-control procedures. CaPA relies on optimal interpolation (Daley, 1993) to combine the observations of precipitation with the background field from the RDPS system. This means that the analysis $x_A(s_0)$ at a given grid point location s_0 is obtained by applying a correction (or increment) to a first guess obtained from the