5.6 RTFV: A REAL TIME FORECAST VERIFICATION SYSTEM

Elizabeth Ebert*
Bureau of Meteorology, Melbourne, Australia

Barbara Brown
NCAR Research Applications Laboratory, Boulder, Colorado

1. INTRODUCTION

An important component of the forecast process is the evaluation, or verification, of the forecast. This is necessary not only to quantify the forecast accuracy, but also to understand the nature of the forecast errors so that subsequent forecasts can be improved. Moreover, when objective guidance is available from more than one source, verification helps the forecaster to make an informed choice among the guidance products or create a combination of them.

To help forecasters realize maximum benefit from radar-based nowcasts and very short range forecasts, we are developing a Real Time Forecast Verification system (RTFV) that uses the latest radar analyses and site-based observations to automatically and objectively verify predictions in near real time. It will be used during the Beijing 2008 Olympics WWRP Forecast Demonstration Project (B08FDP), which will demonstrate several state-of-the-art nowcast systems providing 0-6 h objective guidance on convective storm tracks, precipitation, and severe weather events (Yu 2005). This is the first time that a real time verification system will be available during a forecast demonstration project or similar program.

2. DESCRIPTION

RTFV verifies and inter-compares a variety of nowcast and forecast systems against common reference datasets. To illustrate the variety of forecast and observation types that can be used in the system, Tables 1 and 2 list the nowcast systems and observational data that will be available during B08FDP.

* *Corresponding author address:* Elizabeth Ebert, Bureau of Meteorology Research Centre, GPO Box 1289, Melbourne, Australia 3000; e-mail: e.ebert@bom.gov.au

Gridded nowcasts will be available for a large number of meteorological variables, although reflectivity and rain amount are the most prevalent. Cell tracking algorithms will nowcast the location, intensity, and motion of thunderstorm cells as well as detect and predict severe weather that may be associated with them. Observational data to verify the nowcasts include surface observations at point locations and several gridded radar products. All but the spotter observations will be available in near real time.

In order to compare nowcasts of one spatial type against observations of a different spatial type (for example, gridded rain nowcasts against gauge data, or nowcast threat areas against thunderstorm cell detections) RTFV includes routines to transform data between point, cell, area, and grid spatial representations (Table 3).

The system automatically generates three types of verification products:
(a) visual products such as contour plots, time series at locations of interest, and scatter plots to allow subjective comparison of nowcast and observed variables;
(b) plots of standard objective verification scores such as root mean square error, probability of detection, critical success index, and many others (see, for example, the WWRP/WGNE JWGV web page on verification methods, http://www.bom.gov.au/bmrc/wefor/staff/eee/verif/verif_web_page.html) computed for the most recent 3 h period (this is configurable). Probabilistic and cell comparison statistics are also computed for those types of forecasts;
(c) tables of the above verification scores.

These products are generated whenever new observational data become available and there are relevant nowcasts valid at that time. Verification products are written to graphics (.png) and text files and copied to a web server for display via an interactive web viewer.

In addition to automatic near real time verification, RTFV can also be run manually via a graphical user interface (GUI). This enables retrospective verification of case studies, comparison of several nowcast products, and aggregation of results across any period of time.

When RTFV is run via the GUI the user may choose to apply one or more sophisticated diagnostic verification techniques to further investigate the nature and causes of forecast errors. These state of the art spatial verification methods include the evaluation of multi-scale statistical properties (Harris et al. 2001), the entity-based CRA (contiguous rain area) method of Ebert and McBride (2000), the Method for Object-based Diagnostic Evaluation (MODE) (Davis et al. 2006), the intensity-scale method of Casati et al. (2004), and the Practically Perfect Hindcast approach of Brooks et al. (1998).

The system is highly configurable so that all aspects of the input can be easily modified to suit new nowcast products, observations, domains, etc. The design also allows new verification techniques to be easily added, providing a testing platform for advanced verification methods.

RTFV currently uses a file system as its input data structure to facilitate the input of nowcast and observational data from disparate sources. For the B08FDP project the input data will be provided in netCDF format (gridded products and AWS data) and XML format (cell-based products; see Ebert et al. this volume for a description of the XML format for nowcasts).

Verification output is also sent to a file system. In principle databases could be used to hold input and/or output data. The most recent data is held in memory to speed up processing, and the memory is flushed from time to time.

The RTFV application is being prototyped in the Interactive Data Language (IDL) to take advantage of existing verification code and IDL's excellent graphical capabilities. In the future the application may be recoded in Python which is an open source object-oriented language with most of the important functionality found in IDL.

3. SAMPLE OUTPUT

Figure 1 shows an example of the RTFV GUI that is used to run the verification system manually. The interface has three tabbed pages: a *visual* page for subjective nowcast evaluation, a *statistics* page for quantitative verification, and a *diagnostics* page for diagnostic verification using recently developed spatial verification techniques. The displays on all three pages are linked via the data selections shown on the left of the GUI. This example shows verification results for nowcasts made using the Spectral Prognosis (SPROG) algorithm (Seed 2003), verified against radar rainfall estimates made using a standard Z-R relationship.

When the RTFV GUI is started the visual page is displayed first. This "quick look" display allows the user to get a qualitative impression of nowcast quality. The forecast and observed spatial fields are plotted; forecast/observation overlays and difference maps can also be displayed. Time series plots at multiple locations show how well the nowcasts performed at individual sites. Correspondence plots of various sorts (scatter plots, quantile-quantile plots, and conditional quantile plots, e.g. Wilks 1995) give a more direct comparison of forecast/observation pairs across the whole domain. Zooming and looping capabilities are linked across all of the visual displays.

Quantitative verification results are featured on the statistics page. RTFV computes a wide variety of verification statistics to evaluate many aspects of nowcast quality including accuracy, bias, reliability, and so on. The results are normally shown as a function of lead time. Categorical and probabilistic statistics can also be shown as a function of threshold (for example, rainfall thresholds might be 1 mm, 5 mm, 20 mm, etc.) Figure 2 shows a sample statistics plot in which the accuracy of precipitation nowcasts (as measured by the critical success index) is seen to be greater for lighter rain rates and shorter lead times. These plots of aggregated statistics show overall performance across several forecast realizations. Box-whiskers plots (Figure 3) show the distribution of statistics for individual forecasts, giving an idea of how accurate any individual forecast is likely to be.

Diagnostic verification can be initiated from the diagnostic page. The output depends on the method chosen. For the SPROG nowcast shown in Figure 1 the intensity-scale method of Casati et al. (2004) suggests that the nowcast errors were greatest at small scales and larger rain intensities

(Figure 4). The CRA verification method of Ebert and McBride diagnosed the location error to be only about one kilometer, with the resulting breakdown of the total error as about 2% due to displacement, 7% due to rain volume, and 91% due to fine scale pattern errors (Figure 5).

4. FINAL COMMENTS

The Real Time Forecast Verification system is still under development in the Bureau of Meteorology. It has been tested with nowcast data available in the Bureau and with many, but not all, of the data types that will be available during the B08FDP.

The real-time running of RTFV during the Beijing 2008 Olympic Games should help forecasters to make best use of the many nowcast products that they will have available. This will be a good opportunity to investigate how *quantitative* real time verification information can be integrated into the forecast process.

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6. REFERENCES

Bowler, N.E., C.E. Pierce, and A.W. Seed, 2007: STEPS: A probabilistic precipitation forecasting scheme which merges an extrapolation nowcast with downscaled NWP. *Quart. J. Royal Meteorol. Soc.*, 132, **2127-2155.**

Brooks, H.E., M. Kay and J.A. Hart, 1998: Objective limits on forecasting skill of rare events. *19th Conf. Severe Local Storms, AMS*, 552-555.

Casati, B., G. Ross, and D.B. Stephenson, 2004: A new intensity-scale approach for the verification of spatial precipitation forecasts, *Meteorol. Appl.*, **11**, 141-154.

Davis, C., B. Brown, and R. Bullock, 2006: Object-based verification of precipitation forecasts. Part I: Methods and application to mesoscale rain areas. *Mon. Wea. Rev.*, **134**, 1772–1784.

Ebert, E., 2005: A real time forecast verification system. *WWRP Symposium on Nowcasting and Very Short Range Forecasting, Toulouse, France, 5-9 September 2005.*

Ebert, E., S. Dance, D. Scurrah, R. Potts, and E. Dozortseva, 2007: An XML format for nowcast data. *33rd Intl. Conf. Radar Meteorology, AMS, 6-10 August 2007, Cairns, Australia.*

Ebert, E.E. and J.L. McBride, 2000: Verification of precipitation in weather systems: Determination of systematic errors. *J. Hydrology*, **239**, 179-202.

Harris, D., E. Foufoula-Georgiou, K.K. Droegemeier and J.J. Levit, 2001: Multiscale statistical properties of a high-resolution precipitation forecast. *J. Hydromet.*, **2**, 406-418.

Seed, A.W., 2003: A dynamic and spatial scaling approach to advection forecasting. *J. Appl. Meteor.* , **42**, 381–388.

Wilks, D.S., 1995: *Statistical Methods in the Atmospheric Sciences. An Introduction.* Academic Press, San Diego, 467 pp.

Wong, M.C., W.K. Wong, and E.S.T. Lai, 2006: From SWIRLS to RAPIDS: Nowcast applications development in Hong Kong. *PWS Workshop on Warnings of Real-Time Hazards by Using Nowcasting Technology, Sydney, Australia, 9-13 October 2006.*

Yu, X., 2005: Overview of Beijing 2008 Olympics WWRP Nowcast FDP and implementation plan. *WWRP Symposium on Nowcasting and Very Short Range Forecasting, Toulouse, France, 5-9 September 2005.*

Table 1. Nowcast systems to be available in the WWRP Beijing 2008 Forecast Demonstration Project.

System*	Forecast Range	Spatial Resolution	Output Products
Beijing-ANC	0-1 h	2 km	Reflectivity; storm evolution
CARDS	0-1 h	(cell)	Location, intensity and track of storm cell; severe weather elements including hail size, gust, downburst, mesocyclone
GRAPES	0-3 h	2 km	Reflectivity; rain amount
	0-1 h	(cell)	Location, intensity and track of storm cell; severe weather elements including wind gust, hail, tornadoes, flash-flood
MAPLE	0-3 h	1 km	Reflectivity; rain amount
Niwot (auto,manual)	1-6 h	5 km	Reflectivity
STEPS	0-3 h	1-2 km	Rain amount; probability of precipitation
SWIRLS	0-6 h	2 km	Rain amount; probability of precipitation
	0-1 h	(cell)	Location, intensity and track of storm cell; severe weather elements including lightning; hail; downburst/wind gust
TIFS	0-1 h	1 km	Storm probability; threat area
	0-1 h	(cell)	Location, intensity and track of storm cell
TITAN	0-1 h	(cell)	Location, intensity and track of storm cell; hail probability
Forecast VDRAS	0-2 h	4 km	Wind, temperature, humidity
WDSS	0-1 h	(cell)	Location, intensity and track of storm cell; severe weather elements including hail size, gust, downburst, mesocyclone

*Explanation of acronyms:

ANC	Auto-NowCaster
CARDS	CAnadian Radar Decision System
GRAPES	Global/Regional Assimilation and PrEdiction System
MAPLE	McGill Algorithm for Precipitation nowcasting using semi-Lagrangian Extrapolation
STEPS	STochastic Ensemble Prediction System
SWIRLS	Short-range Warnings of Intense Rainstorms in Localized Systems
TIFS	Thunderstorm Interactive Forecast System
TITAN	Thunderstorm Initiation, Tracking, Analysis, and Nowcasting
VDRAS	Variational Doppler Radar Assimilation System
WDSS	Warning Decision Support System

Table 2. Observational data to be available for verifying nowcasts in the WWRP Beijing 2008 Forecast Demonstration Project.

Observations	Elements	Data interval
AWS (136 stations)	Rain amount, temperature, wind speed and direction; some stations also record pressure and relative humidity	5 min
Rain gauges (28 stations)	Rain amount	60 min
Merged radar-gauge analysis	Rain amount	60 min
Radar	Reflectivity; rain amount (estimate); wind analyses; thunderstorm location	6 min
Lightning detection network	Lightning location, number, etc.	Real time
Manned observation station	Weather phenomena; cloud amount; etc.	Various

Table 3. Spatial transformations included in RTFV.

Observation type	Forecast type	Match type(s)	Nowcast/forecast example(s)
point	point	point	Point forecast of wind speed
point	cell	point	WDSS nowcast of thunderstorm and severe weather verified against spotter report
point	grid	point	Rainfields rainfall analysis verified against gauge obs
point	threat area	point	Threat area for Tstorms verified against spotter report
cell	cell	cell, grid (point)	TITAN cell track forecast verified against TITAN cell analysis
cell	threat area	grid	TIFS threat area verified against TIFS cell analysis
grid	point	point	Point rain forecasts verified against Rainfields analysis
grid	cell	grid, (point)	TIFS rain cells verified against Rainfields analysis
grid	grid	grid, (point)	NWP verified against Rainfields analysis
grid	threat area	grid	TIFS threat area verified against lightning analysis

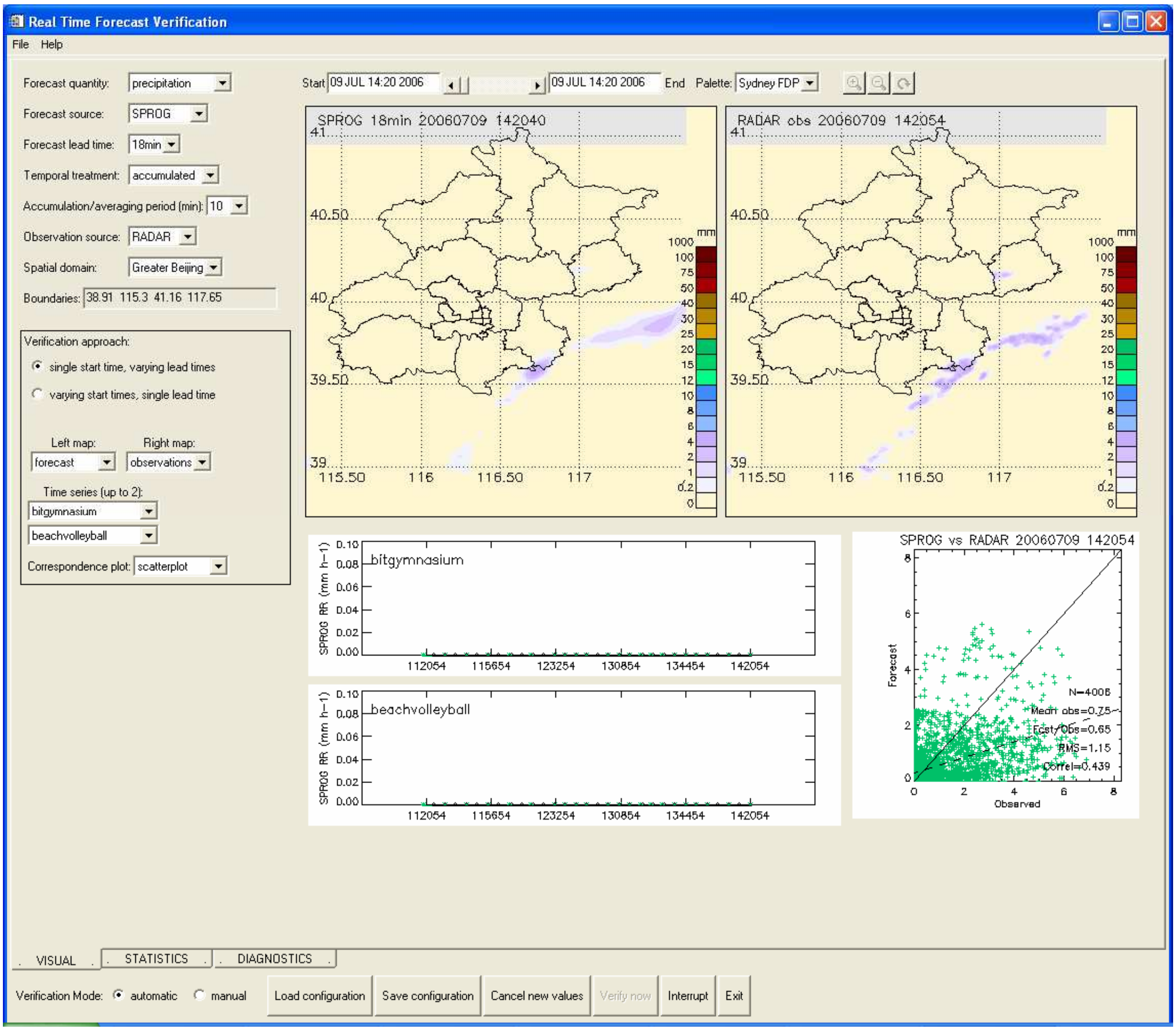

Figure 1. RTFV user interface. In this example an 18 minute SPROG nowcast is verified against RADAR observations.

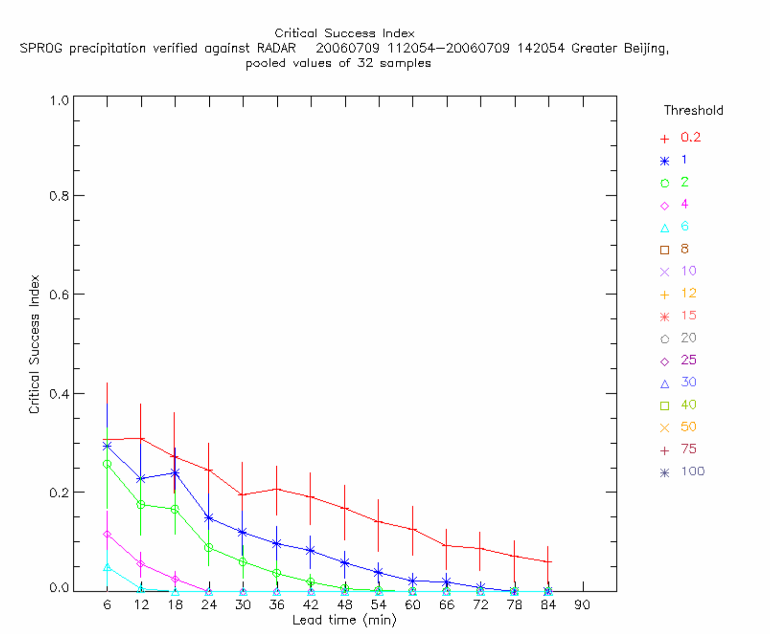

Figure 2. Critical success index, CSI (hits / hits+misses+false.alarms) for SPROG precipitation nowcasts over Beijing during a 3-hour period ending 1421 UTC on 9 July 2006. The vertical bars indicate the 90% confidence intervals on the statistics.

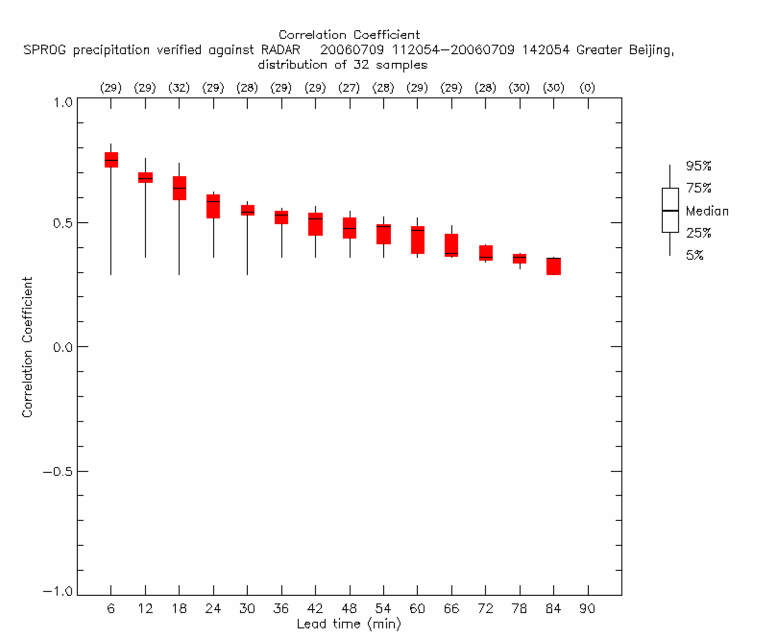

Figure 3. Distribution of spatial correlation coefficients for individual SPROG precipitation nowcasts over Beijing during a 3-hour period ending 1356 UTC 9 July 2006.

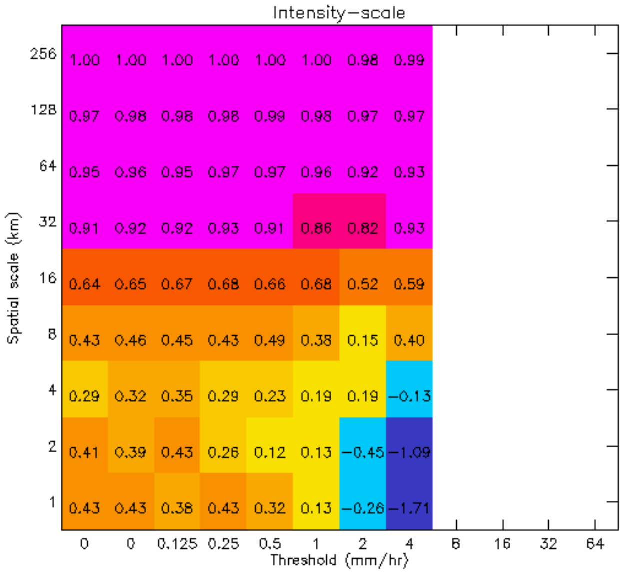

Figure 4. Intensity-scale verification of the SPROG nowcast shown in Fig. 1.

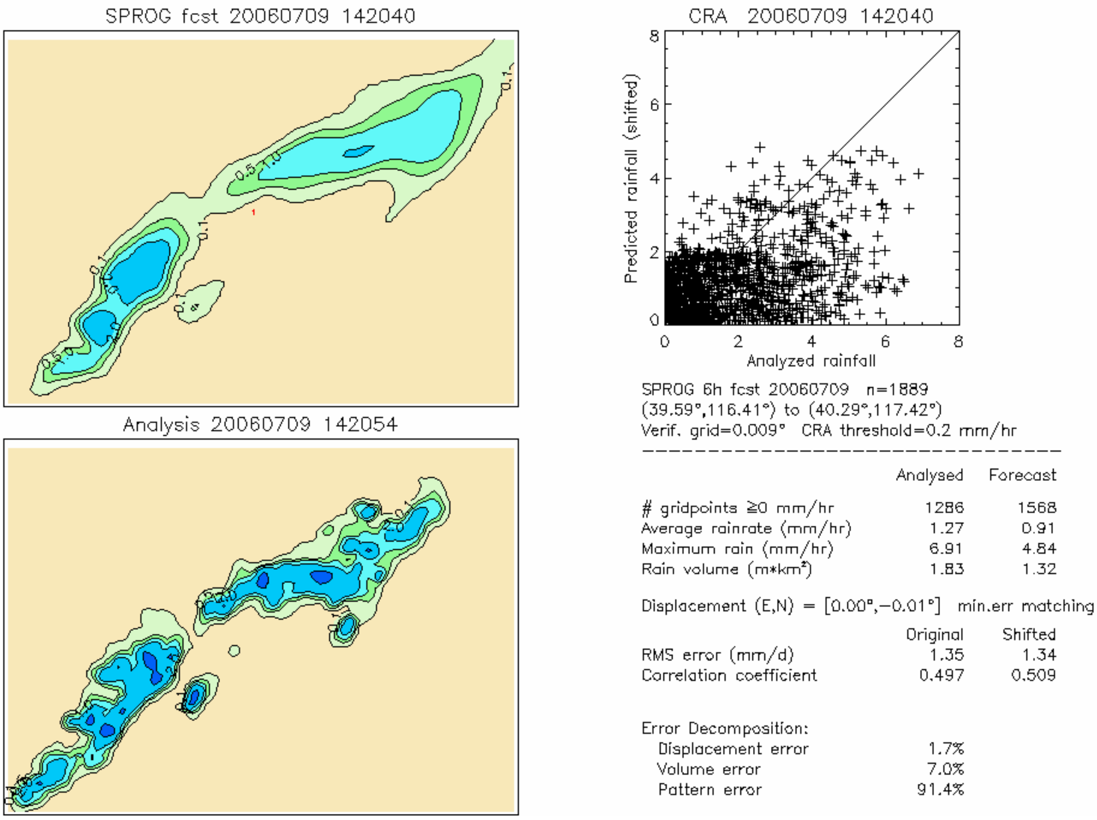

Figure 5. CRA verification of the SPROG nowcast shown in Fig. 1.