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Forecast Using Indian DWR Data

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Use of SWIRLS Nowcasting System for quantitative precipitation forecast using Indian DWR data

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Abstract

Local severe storms are extreme weather events that last only for a few hours and evolve rapidly. Very often the mesoscale features associated these local severe storms are not well-captured synoptically. Forecasters thus have to predict the changing weather situation in the next 0-6 hrs based on latest observations, an operational process known as “nowcast”. Observational data that are typically suited for nowcasting includes Doppler Weather Radar (DWR), wind profiler, microwave sounder and satellite radiance. To assist forecasters in assimilating the weather information and making warning decisions, various nowcasting systems have been developed by various institutes in recent years. Notable examples can be found from the list of participating systems in the two forecast demonstration projects organized by WMO for the Sydney 2000 and Beijing 2008 Olympic, including Auto-Nowcaster (U.S.), BJ-ANC (China-U.S.), CARDS (Canada), GRAPES-SWIFT (China), MAPLE (Canada), NIMROD (U.K.), NIWOT (U.S.), STEPS (Australia), SWIRLS (Hong Kong, China), TIFS (Australia), TITAN (U.S.) and WDSS (U.S.). A common feature of these systems is that they all use rapidly updated radar data, typically once every 6 minutes.

The nowcasting system SWIRLS (“Short-range Warning of Intense Rainstorms in Localized Systems”) has been developed by the Hong Kong Observatory (HKO) and was put into operation in Hong Kong in 1999. The system has since undergone several upgrades, the latest known as “SWIRLS-2” being in 2008 to support the Beijing 2008 Olympic Games. At the invitation of India Meteorological Department (IMD), SWIRLS-2 is being adapted for use and test at New Delhi in connection with the 2010 Commonwealth Games with assistance from HKO.

SWIRLS-2 ingests a range of observation data including SIGMET/IRIS DWR radar product, raingauge data, radiosonde data, lightning data to analyze and predict reflectivity, radar-echo motion, QPE, QPF, as well as track of thunderstorm and its associated severe weather, including cloud-to-ground lightning, severe squalls and hail, and probability of precipitation. SWIRLS-2 uses a number of algorithms to derive the storm motion vectors. These include TREC (“Tracking of Radar Echoes by Correlation”), GTrack (Group tracking of radar echoes, an object-oriented technique for tracking the movement of a storm as a whole entity) and lately MOVA (“Multi-scale Optical flow by Variational Analysis”). This latest algorithm uses optical flow, a technique commonly used in motion detection in image processing, and variational analysis to derive the motion vector field. By cascading through a range of scales, MOVA can better depict the actual storm motion vector field as compared with TREC and GTrack which does well in tracking small scales features and storm entity respectively. In this paper the application of TREC and MOVA to derive the storm motion vector and QPF using Indian DWR data would be demonstrated for a thunderstorm event over Kolkata.

Keywords: SWIRLS, TREC, GTrack, MOVA, storm motion vector, QPF, Thunderstorm

1. Introduction

Convective heavy rainfall event is one of the most disastrous weather phenomena affecting a large population and of common interest to tropical countries. Accurate forecast of these events are crucial for early warning of potential hazard to minimize loss of life and property. For the realistic prediction of these events, there is a need for a very high resolution nowcasting system with sophisticated strategies for ingesting data of high temporal and spatial density.

For any nowcasting system the most important source of volumetric information on meso-scale in the current operational observing system is the Doppler Weather Radar (DWR). The installation of four GEMATRONIC METEOR 1500S model DWRs at Chennai (during the year 2002), Kolkata (2003), Machilipattanam (2004) and Vishakhapatnam (2006) has heightened the prospects for the operational implementation of nowcasting system to explicitly predict the evolution of mesoscale phenomena. The DWR scans with beam width of 1° create 360 beams radials of information per elevation angle. A full volume scan takes about 15 minutes. This provides high resolution measurement of radial velocity and velocity spectrum width to ranges of 250 km and of reflectivity to ranges of 300 km.

The Hong Kong Observatory nowcasting system SWIRLS (Short-range Warning of Intense Rainstorms in Localized Systems) has been in operation since 1999 [Lai & Li 1999]. Its second-generation version (referred to as SWIRLS-2) has been under development and real-time testing in Hong Kong since 2007. To support the 2008 Beijing Olympic Games, a special version of SWIRLS-2 [Yeung *et al.* 2009] was deployed for the Beijing 2008 Forecast Demonstration Project (B08FDP) under the auspices of the World Weather Research Programme (WWRP) of the World Meteorological Organization (WMO).

The original SWIRLS focused primarily on rainstorm and storm track predictions. The much enhanced SWIRLS-2 comprises a family of sub-systems, responsible respectively for ingestion of conventional and remote-sensing observation data, execution of nowcasting algorithms, as well as generation, dissemination and visualization of products via different channels. It embraces new nowcasting techniques, namely: (a) blending and combined use of radar-based nowcast and high-resolution NWP model analysis and forecast; (b) detection and nowcasting of high-impact weather including lightning, severe squalls and hail based on conceptual models; (c) grid-based, multi-scale storm-tracking method; and (d) probabilistic representation of nowcast uncertainties arising from storm tracking, growth and decay.

In this study, capabilities of TREC and MOVA techniques of SWIRLS in depicting the storm motion vector using Indian DWR data is discussed. The motion vector field so derived can then be applied to forecast the future position of the storm cells or individual reflectivity pixels for QPF.

2. Experiment

2.1 Synoptic Observation, Radar Observation & Observed Rainfall

Case selected for this study is the thunderstorm event of 11 May 2009 over W. Bengal. On 11 May 2009 there was cyclonic circulation in lower levels over Bihar & neighbourhood. Trough from this extended upto extreme south peninsula across Chhattisgarh, Telangana and Rayalaseema. Another cyclonic circulation hanged over Arunachal Pradesh and adjoining Assam & Meghalaya (Fig.2(a)). These led to significant moisture incursion at low level over the area. Meanwhile, a trough extended from Arunachal Pradesh to NW Bay of Bengal in middle troposphere (Fig. 2(b)). At 200 hPa, a significant westerly trough with jet maxima over the region resulted in strong upper-level divergence (Fig. 2(c)).

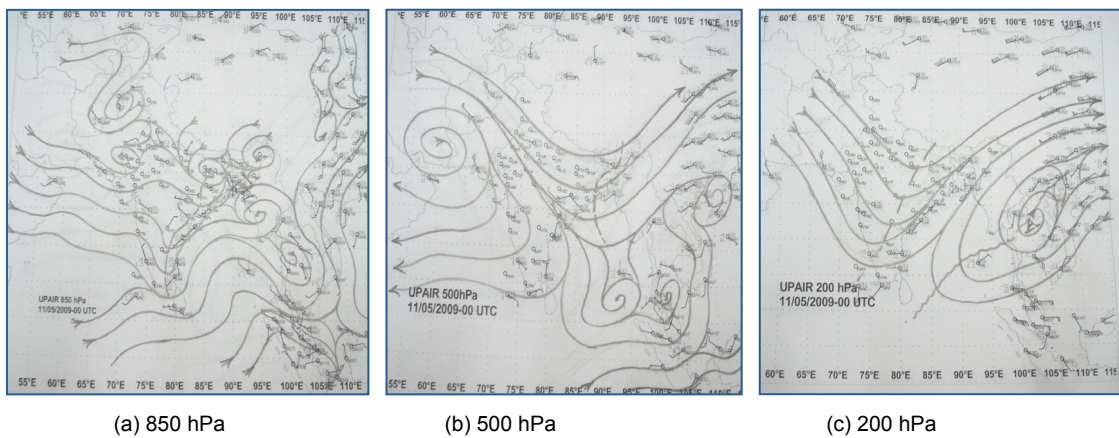


Fig. 2 — Streamline analysis over India, Bay of Bengal and Indochina on 11 May 2009

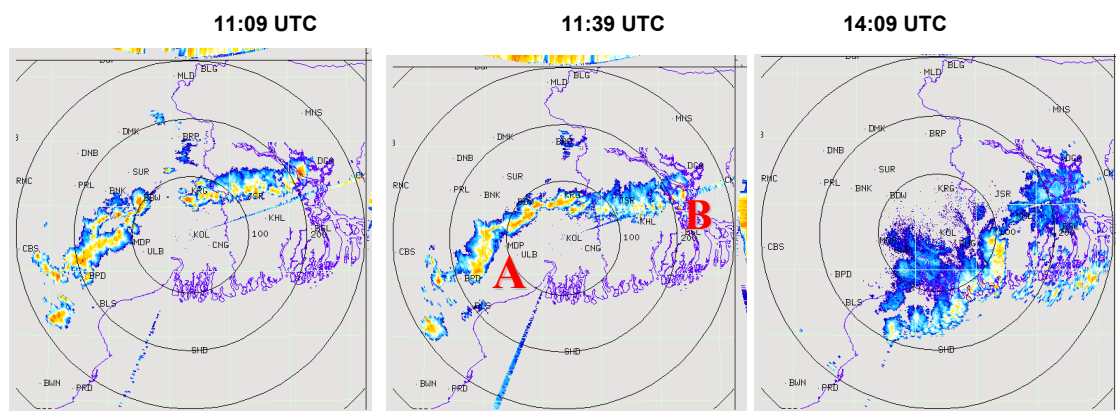


Fig.3 Radar reflectivity ("MAX" product) as observed by DWR Kolkata on 11 May 2009

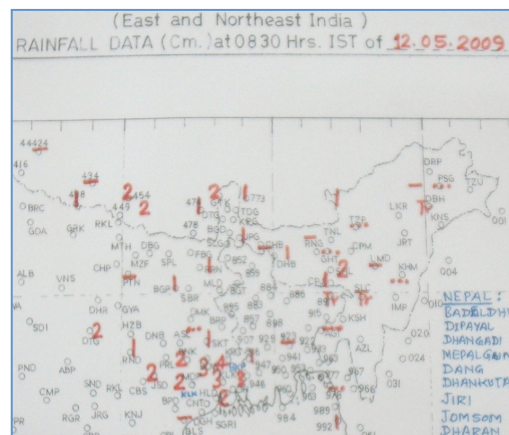


Fig. 4 Observed 24-hour rainfall (red scribbles in unit of cm) India ending at 03 UTC on 12 May 2009

On 11 May 2009 Kolkata DWR observed that thunderstorms started developing at 09:39 UTC with six small meso cells (labeled "A" in Fig. 3(b)) observed in the north-west region about 200 km from Kolkata. At the same time, another line of echo (labeled "B" in Fig. 3(b)) was observed about 100 km to north of Kolkata. By 11:09 UTC, the six meso cells moved southeastwards and merged as one large cell about 100 km northwest of Kolkata. Meanwhile the line of echo moved south to about 80 km north of Kolkata. At

11:39 UTC, these cells merged and were seen as one organized east-west band of convections. At 14:09 UTC, the echoes, which continued to head southeastwards to over 100 km southeast of Kolkata, started dissipating over Bay of Bengal. Corresponding radar images Maximum Reflectivity (Z) are shown in Fig. 3.

The 24-hour accumulated rainfall (between 03UTC 11 May 2009 to 03 UTC 12 May 2009) occurred under influence of the thunderstorm is shown in the Fig. 4. Highest rainfall was recorded at Barrackpur (West Bengal), totaling 40 mm from this episode.

2.2 SWIRLS TREC motion vector and QPF

Fig. 5 shows the TREC motion vector at 11:39 UTC. The southeastward motion of the storm cells to northwest of Kolkata (labeled “A” in Fig. 3(b) and Fig. 5) was well captured by TREC. The speed of motion, around 40 km/hr, also agreed reasonably well with the actual observation (about 50 km/hr). TREC also correctly depicted the southward to southwest motion of the line of echo to north of Kolkata (labeled “B” in Fig. 3(b) and Fig. 5). The southeast motion vector associated with storm cell “A” and the southwest motion vector near the western end of storm cell “B” comes handy in elucidating the merging of storm cell “A” and “B”.

While the storm motion vector field depicted in Fig. 5 looks generally reasonable, a region of erroneous storm motion vectors was observed near the spike to the southwest. While the spike remained more or less stationary, as the intensity of individual pixel varied from scan to scan, the highest cross-correlation between successive scans of each pixel was not with its own self resulting in erroneous storm motion vectors. This points to the importance of quality controlling the raw radar data before ingesting into SWIRLS.

The 1-hour accumulated QPF from 11:39 UTC, obtained by applying the Semi-Lagrangian advection technique using the TREC storm motion vector obtained above, is given in Fig. 6. The 1-hour accumulated QPF was forecast to be between 20 – 30 mm to the northeast of Kolkata.

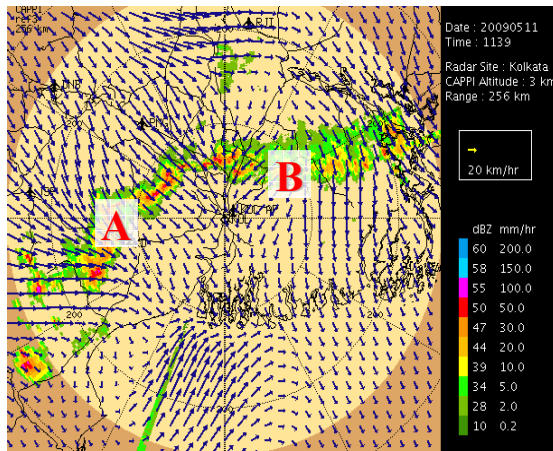


Fig.5 — SWIRLS TREC motion vector fields at over east and northeast 11:39 UTC on 11 May 2009

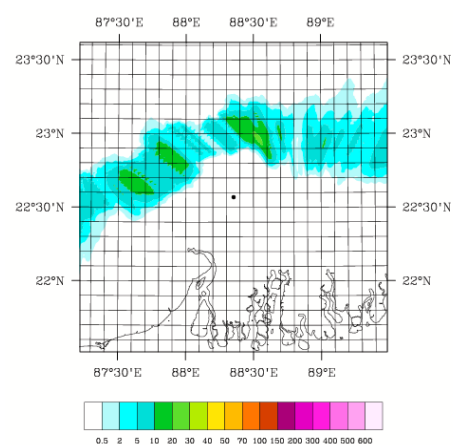


Fig.6 — SWIRLS 1-hour QPF derived from TREC motion vector fields at 11:39 UTC on 11 May 2009

2.3 SWIRLS MOVA motion vector and QPF

Fig. 7 shows the result of MOVA with the first-level (domain wide) tracking supplemented with FFT analyzed displacement vectors. Comparing to the TREC motion vectors, the most prominent difference is

the “uniformity” of the MOVA field due to the enforcement of smoothness constraint. For this reason, the erroneous tracking due to the interference spike echoes was avoided naturally. The tradeoff here is that the smaller scale motions, namely the convergence of storm cell “A” and “B”, was lost. Further tuning of the smoothness constraint is required for MOVA to reveal the smaller scale features.

In terms of motion speed, MOVA tracked cell “A” to be travelling at about 55 km/h. Comparing to TREC’s estimate of about 40 km/h and the observed speed of 50 km/h, MOVA in this case provides a better speed for the storm cell as a whole.

The 1-hour accumulated QPF Obtained by applying the same Semi-Lagrangian advection technique, based on the MOVA storm motion vector at 11:39 UTC is given in Fig. 8. The pattern in general was very similar to that based on TREC motion vector (Fig. 6) though with a higher motion vector speed, the affected area was larger and closer to Kolkata

Fig. 9 shows the 150-minute forecast reflectivity based on the MOVA motion vector fields at 11:39 UTC. The main body of the echo associated with storm cell “A” had already moved offshore while that associated with storm cell “B” still lingered along the coast. This compared well with the actual radar observations given in Fig. 3, suggesting that MOVA was indeed capable of capturing the large scale storm motion.

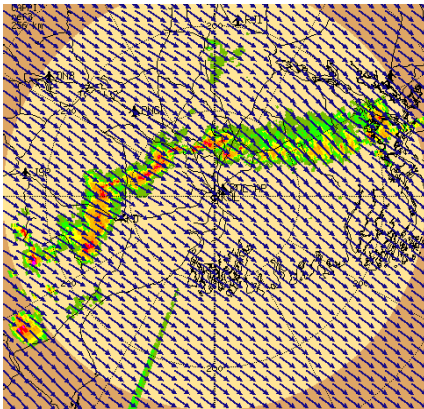


Fig. 7 — SWIRLS MOVA motion vector fields at 11:39 UTC on 11 May 2009

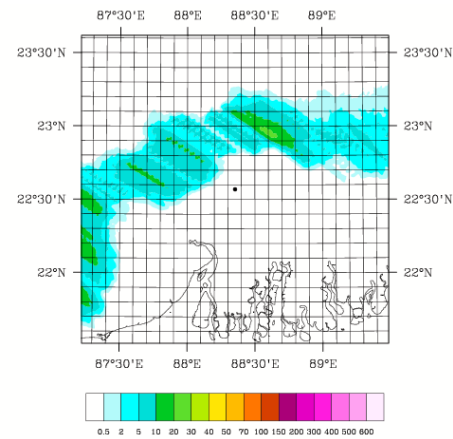


Fig. 9 - SWIRLS 1-hour QPF derived from MOVA motion vector fields at 11:39 UTC on 11 May 2009

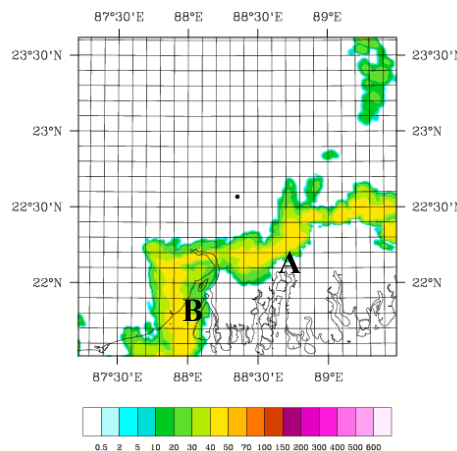


Fig.9 - Forecast reflectivity valid for 14:09 UTC derived from MOVA motion vector fields at 11:39 UTC on 11 May 2009

3. Discussion of results

Although SWIRLS radar tracking modules were successfully implemented in IMD, the current study revealed two major issues: one is the importance of quality controlling the data before ingestion to SWIRLS; the other is the need for rapidly updated radar data.

As discussed, erroneous motion vectors could be introduced due to spurious data. Although such spurious data usually occurs over rain free areas, the distorted motion vectors could still impact the QPF of SWIRLS, especially at long time integration, due to its use of backward semi-Lagrangian advection scheme [Staniforth & Cote 1991].

The lengthening of the time interval between successive CAPPI scans from 6 to 15 minutes posed an even greater challenge to the two tracking algorithms. With the much longer time interval, the shape and intensity of the radar echoes could have changed significantly, making it more difficult to track the echoes whether by maximizing the cross-correlation or minimizing the difference between successive CAPPI scans. Moreover for TREC, with the increase in the time interval between successive CAPPI scans, the search radius has to be increased. With a much larger search area, apart from much increased processing time, there is higher chance that a wrong echo be picked up to be correlated with the echo concerned, leading to wrong storm motion vectors. For MOVA, the issue due to the lengthening of time interval is even more serious as it undermines the fundamental assumption of optical flow: the displacement between successive images is small. Although the use of FFT to supplement the top level (full domain) optical flow was able to reasonably capture the large scale speed, as discussed, the MOVA motion vector field is very uniform. The feasibility to apply MOVA to other levels under these settings needs to be evaluated. Further testing and tuning of MOVA algorithm is required before deployment. The 150-minute forecast reflectivity compared reasonably well with the actual radar observation, suggesting that MOVA in general was capable of tracking the large scale storm motion.

4. Conclusions

The main objective of this study was to ingest the Indian DWR in SWIRLS nowcasting system for nowcasting of severe convective events over the Indian region. This task has been successfully accomplished. Preliminary result suggests that SWIRLS has the potential to be useful for providing nowcast guidance in India.

The SWIRLS software is highly portable, the implementation and adaptation of SWIRLS to Indian data turned out to be more difficult than expected. Future work includes further tuning and testing of the TREC and MOVA algorithms; tuning of the Marshall-Palmer relationship using DWR and rain gauge data in India. Finally is the compilation of verification statistics. It should be borne in mind that the current study is conducted using one case of Kolkata DWR, the applicability of these preliminary result need to be further evaluated.

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