TREC Application in Tropical Cyclone Observation

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1. Introduction

In the course of developing a nowcasting system SWIRLS (Short-range Warning of Intense Rainstorms in Localized Systems) for rainstorm monitoring and rainfall prediction, a cross-correlation algorithm called TREC (Tracking Radar Echoes by Correlation) was adopted to track echo movement between two consecutive radar imageries (Lai et. al., 1999). The technique was first used to determine the movement of the entire storm cluster (Hilst and Russo, 1960; Kessler and Russo, 1963; Crane, 1979; Bjerkaas and Forsyth, 1980). With the availability of higher resolution radar data, this technique was extended to retrieve the individual motion vectors of embedded storm cells (Rinehart and Garvey, 1978; Rinehart, 1979; Smythe and Zrnic, 1983; Tuttle and Foote, 1990).

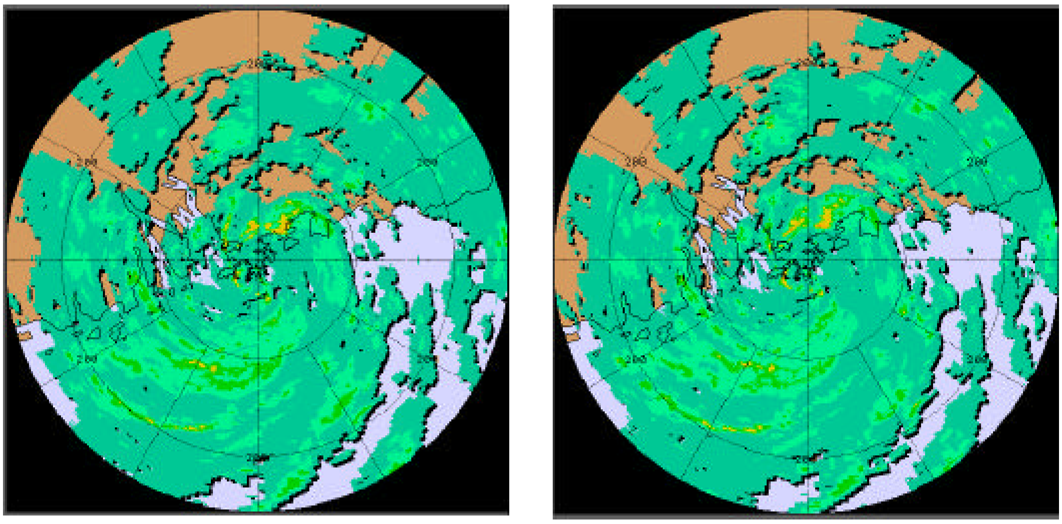
The main advantage of using correlation method is that the computation is not tedious, requiring only information from one single radar at two different observation times. Although the derived motion field is essentially two-dimensional in the horizontal and does not include strong vertical motion normally expected in convective cloud systems, the approximation should be good enough given that the effect of horizontal advection should be more pronounced if only short-term motion is considered.

Although the primary interest of TREC is intense convection embedded with mesoscale weather systems, a bonus by-product emerged as the algorithm was tested out in an operational environment. This short paper documents three prominent cases in which TREC made its mark in tropical cyclone observation – from Typhoon Victor in 1997 when the prototype TREC was still under development in the research laboratory, through a weak tropical depression in 1998 when TREC was under operational trial, to Typhoon Maggie in 1999 after TREC, as part of SWIRLS, was fully implemented for forecasting operation at the Hong Kong Observatory.

2. Demonstration of TREC Capability

(a) Typhoon Victor (August 1997)

Figure 1 shows the radar reflectivity patterns at 18:54 and 19:00 HKT (Hong Kong Time) on 2 August 1997. Figure 2 shows the TREC output, as derived from the two reflectivity patterns in Figure 1, after a 3-pass objective analysis with interpolated wind vectors inserted to pixels with no reflectivity returns.



(a) (b)

Figure 1 – Reflectivity patterns of Victor on 2 August 1997: (a) at 18:54 HKT; (b) at 19:00 HKT.

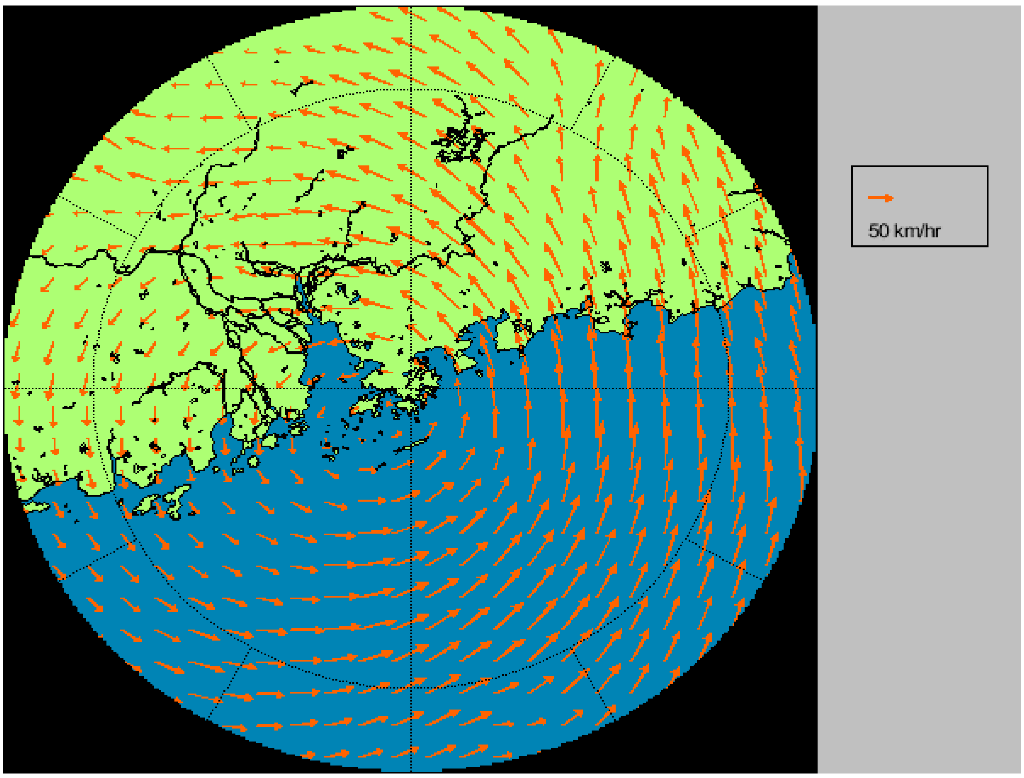
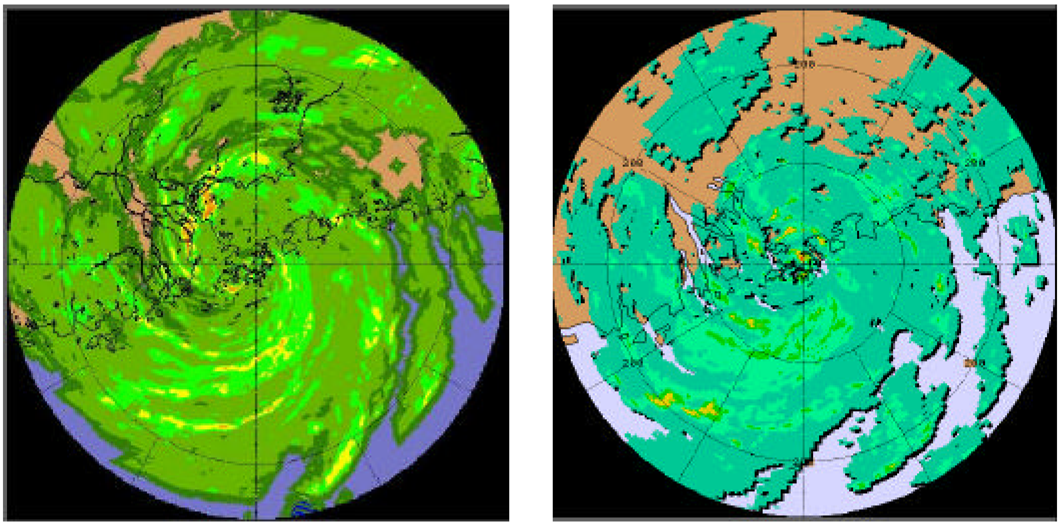


Figure 2 – TREC-analyzed wind field of Victor from the reflectivity patterns shown in Figures 1a and 1b.

At the time, the reliability of the TREC algorithm was still very much under scrutiny. The close approach of Victor provided a perfect opportunity to test the algorithm. The analyzed output was consistent with what one would expect in the wind structure of a northward moving cyclone. The computed wind strength was of the correct order of magnitude. The location of the TREC-analyzed circulation centre agreed well with those obtained from radar, satellite and surface observations. Even the asymmetry in terms of stronger southerly winds on the eastern sector as compared to the weaker northerly winds on the western half was well depicted.

The whole reflectivity pattern was then extrapolated using the semi-Lagrangian integration scheme (Staniforth and Cote, 1991) to produce forecast reflectivity patterns at 6-minute interval. Figure 3a is the predicted reflectivity pattern after one hour of forward integration. It compared well with the actual observed reflectivity field shown in Figure 3b, despite the fact that the echoes had undergone changes in intensity in the interim. As an application tool, it vindicated the use of TREC as a basis to make short-term forecasts, especially when advection was the dominant factor in situations such as tropical cyclone rainbands.



(a) (b)

Figure 3 – (a) One-hour forecast reflectivity pattern valid at 20:00 HKT on 2 August 1997;
(b) Actual observed reflectivity pattern at 20:00 HKT on 2 August 1997.

(b) Tropical Depression (September 1998)

The usefulness of TREC in tropical cyclone analysis was further demonstrated in the case of a tropical depression on 12 September 1998. The system had an extensive but poorly organized circulation and, in all probability, with multiple low-level circulation centres as well. While most of the warning positions were located further to the south, a smaller scale vortex much closer to the coast appeared for a short time on the radar screen that evening, as suggested by the TREC winds (Figure 4). In fact, the history and continuity of this weak secondary centre could be traced from the visible satellite imageries earlier in the day (Figure 5). The presence of a transient vortex was consistent with wind reports from the coastal stations in southern China.

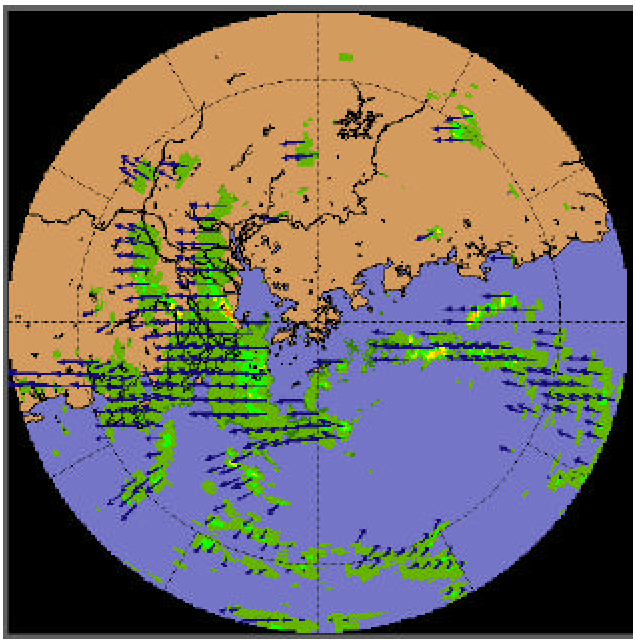
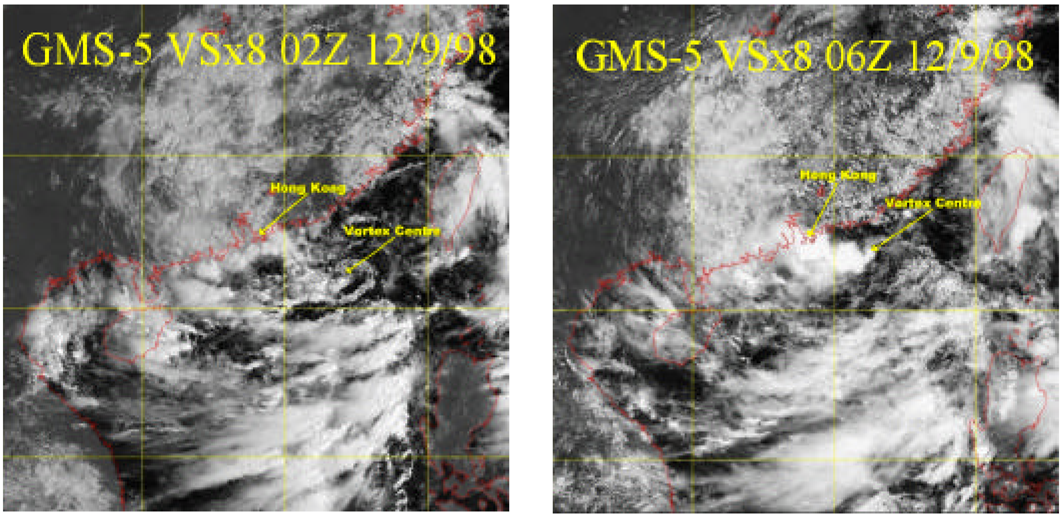


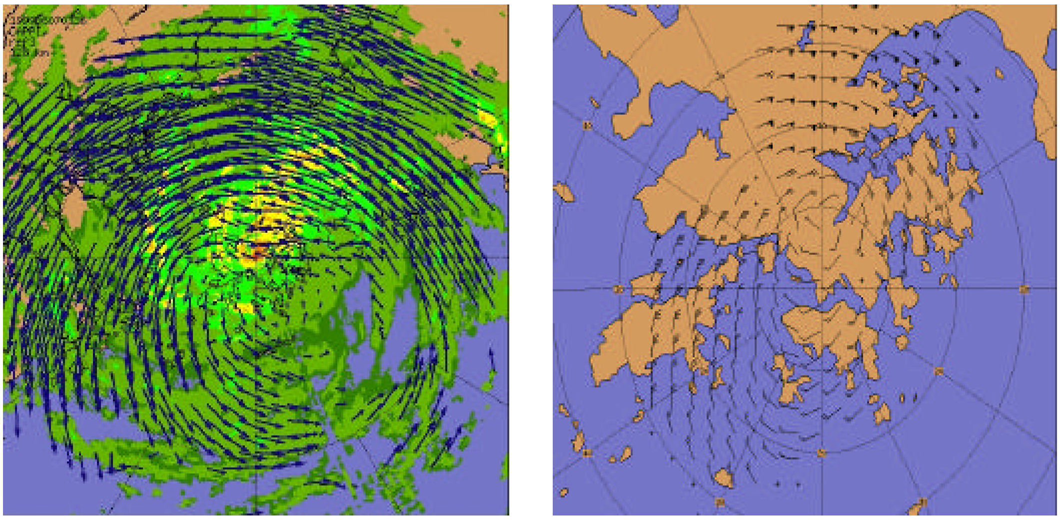
Figure 4 – TREC analysis at 19:18 HKT on 12 September 1998, suggesting a weak circulation centre within 200-km range cirle in the southeastern quadrant.



(a) (b)

Figure 5 – GMS5 visible satellite imageries on 12 September: (a) at about 10 a.m. HKT and (b) at about 2 p.m. HKT. A low-level centre appeared to be drifting westwards to the southeast of Hong Kong.

(c) Typhoon Maggie (June 1999)



(a) (b)

Figure 6 – (a) TREC-analyzed wind field (128-km range) and (b) dual-Doppler wind field (42-km range) of Maggie at 03:36 HKT on 7 June 1999.

By the time TREC became operational in April 1999, a new Doppler radar had also been installed at Tai Mo Shan, the highest peak in Hong Kong. In tandem with the old Doppler radar at Tate's Cairn located about 10 km to the east, a dual-Doppler wind field was derived when Typhoon Maggie passed between the two radars in the early hours of 7 June 1999. This provided a perfect opportunity to validate TREC wind analysis.

Dual-Doppler winds were in general stronger than TREC winds, though both were of the same order of magnitude. The former, applied to a smaller area locally (i.e. 42-km range), gave a smoother field with a circulation centre in agreement with that observed from the AWS (Automatic Weather Stations) surface data. TREC field was in comparison less well defined near the core of Maggie and the deduced circulation centre tended to shift slightly southwards. The problem could be partly due to the difficulty in maintaining continuity in the tracking of individual radar echoes as the rain cells drifted over the hilly terrain of Hong Kong.

3. Discussion

As a nowcasting tool, TREC has proven its worth in the estimation of radar echo movement and forms the basis for quantitative precipitation forecast in SWIRLS. Operational experience so far has shown that rainfall forecasts in the first couple of hours with TREC input are generally acceptable when advection is the dominant mechanism, as is often the case in tropical cyclone rainbands.

But increasingly, forecasters also like to refer to TREC analysis for monitoring tropical cyclone winds and for position fixing. While TREC is undoubtedly a useful supplementary information source, it has not been specifically designed for operational tropical cyclone warnings. Applicability and reliability of TREC for such purposes are subject to a more comprehensive study in which TREC analyses in the case of Maggie will be compared with results obtained from other observational platforms, including those from wind profilers and the conventional upper-air sounding. Questions that need to be addressed include: interpretation of TREC winds as 6-minute (i.e. time between two successive radar scans) averaged vectors against other more conventional bases such as 1-minute or 10-minute means, echo growth and decay that may complicate or contaminate the TREC analysis, the treatment (or the lack of it) of the translational component in tropical cyclone motion within the TREC analysis, etc.

While it is always difficult to validate without the convenience of ground truth, it is also highly unlikely that absolute truth will come from one single method. In all probability, TREC, together with dual-Doppler technique and other observational input, will in future form part of an operational analysis package. Because of the short separation distance between the two Doppler radars in Hong Kong, the usefulness of dual-Doppler analysis will be confined to a limited range. In contrast, TREC has a larger effective range though it may suffer locally because of the disruptive influence of orography. The challenge is to assimilate, reconcile and optimize the information derived from such different sources into a physically meaningful picture, probably in the context of a numerical first-guess and re-analysis, and thereby paving the way for routine mesoscale analysis in the monitoring and prediction of tropical cyclones and other severe weather systems.

References

Bjerkaas, C.L., and D.E. Forsyth, 1980: Operational test of a three-dimensional echo tracking program. *Preprints 19th Conf. Radar Meteorology,* Miami Beach, Amer. Meteor. Soc., 244-247.

Crane, R.K., 1979: Automatic cell detection and tracking. *IEEE Trans. Geosci.Electron.,* **GE-17**, 250-262.

Hilst, G.R., and J.A. Russo, Jr., 1960: An objective extrapolation technique for semi-conservative fields with an application to radar patterns. Tech. Memo. No. 3, Travelers Weather Research Center, Hartford, CT.

Kessler, E. III, and J.A. Russo, Jr., 1963: Statistical properties of weather echoes, *Preprints 10th Weather Radar Conf.,* Washington, DC, Amer. Meteor. Soc., 25-33.

Lai, E.S.T., P.W. Li, and W.K. Wong, 1999: SWIRLS – an evolving nowcasting system. Hong Kong Observatory Tech. Note (to be published).

Rinehart, R.E., 1979: Internal storm motions from a single non-Doppler weather radar. NCAR/TN-146+STR, 262pp.

______, and E.T. Garvey, 1978: Three-dimensional storm motion detection by conventional weather radar. *Nature,* **273,** 287-289.

Smythe, G.R. and D.S. Zrnic, 1983: Correlation analysis of Doppler radar data and retrieval of the horizontal wind. *J. Climate and Appl. Meteor.,* **22**, 297-311.

Staniforth, A. and J. Cote, 1991: Semi-Lagrangian integration schemes for atmospheric models – a review. *Mon. Wea. Rev*., **119**, 2206-2223.

Tuttle, J.D. and G.B. Foote, 1990: Determination of the boundary layer airflow from a single Doppler radar. *J. Atmos. Ocean. Tech.,* **7**, 218-232.