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RANGE EXTENSION OF DOPPLER RADAR BY COMBINED USE OF LOW-PRF AND PHASE DIVERSITY PROCESSED DUAL-PRF OBSERVATIONS

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1. INTRODUCTION

Range-velocity ambiguities of Doppler radar (e.g., Doviak and Zrnić 1993) prevent combination of long observation range (R_{max}) and high unambiguous velocity limit (V_{max}). This dilemma is severe for C band radars, which are operationally used in Japan. However, Doppler velocity data with longer R_{max} and high V_{max} is desirable for wind field monitoring of wider area, especially for tropical cyclone (TC) wind field retrieval (e.g. Lee et al. 1999).

To mitigate the ambiguities, several methods have been developed. Figure 1 shows examples of relations between R_{max} and V_{max} for C band Doppler radar with some of those methods.

Methods using two pulse reputation frequencies (PRFs) such as dual-PRF and dual-PRT (DP, e.g., Sirmans et al. 1976; Dazhang et al. 1984) can extend V_{max} to several times (e.g., four times) as high as that of single PRF (SP) observation. DP with two low-PRFs (LDP, e.g., 600/480Hz) satisfies both R_{max} of 250 km and V_{max} of 33 m/s. However, the V_{max} is not enough for TC observation.

Triple PRT scheme with three low PRFs (Tabary et al. 2006) or Multi-PRI transmitting/processing (Cho, 2005) can extend V_{max} much higher than DP. However, the schemes require special hardware to produce the multiple PRT.

Phase diversity processing (Joe et al., 1997) can extend R_{max} to twice. Combined use of phase diversity processing and DP (hereinafter PDP) satisfies both R_{max} of 320 km and V_{max} of 53 m/s. However, data in the second-trip echo region are frequently missing, depending on the signal power ratio of the second-trip echo to the first-trip echo.

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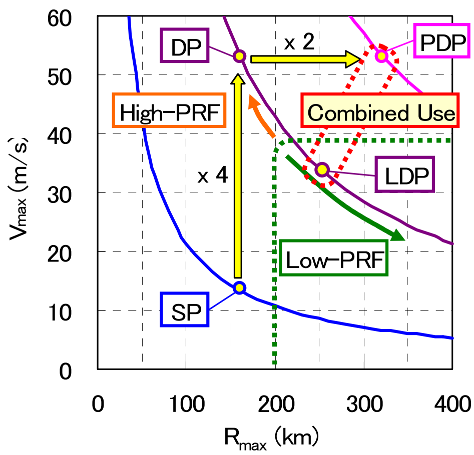

Fig. 1. Inversely proportional relations between observation range (R_{max}) and unambiguous velocity limit (V_{max}) of SP (blue), DP (purple) and PDP (pink) for C band Doppler radar. Our strategy uses low-PRF and PDP observation data in combination (red dotted frame).

We propose a strategy to satisfy both long R_{max} and high V_{max} without frequent data missing. Section 2 and 3 describe the strategy and its detail procedure, respectively. Section 4 describes tests of the strategy using real data. A conclusion follows in Section 5.

2. STRATEGY

Our strategy is applying the Hybrid Multi-PRI dealiasing method (Yamauchi, et al. 2006, hereinafter HMP) to two scans of Doppler velocity data that observed with low-PRF and observed with PDP. The first-trip echo region of the low-PRF observation should cover desired long observation range. The V_{max} of the PDP observation should cover desired velocity limit.

HMP can robustly correct a sparsely distributed velocity field from one or more scans of Doppler velocity data observed with two or more PRFs. Therefore, HMP can derive thickly distributed velocity field with high V_{max} even in second-trip echo region of PDP using the two scans of data.

3. PROCEDURE

Figure 2 schematically shows a procedure for the strategy. Two scans of raw Doppler velocity data observed by low-PRF and PDP are inputted to HMP processing. The procedure assumes that the two scans observe same radial velocity field.

In first step, HMP makes reference data from the two scans of data. The reference data is a local spatial linear approximation/interpolation of the two raw Doppler velocity fields. In "Areal Multi-PRI processing", even sparsely distributed data in the second-trip echo region of PDP scan are useful to estimate feasible approximation of Doppler velocity with high V_{max}. In "Subareal Continuity processing", thickly distributed data of low-PRF scan, of which V_{max} is low, are useful to spatially expand the feasibly approximated area.

In second step, raw Doppler velocities of the each two scans are dealiased to the nearest value to that of the reference data. The dealiased Doppler velocity data of the low-PRF scan satisfy both long R_{max} and high V_{max} without frequent data missing.

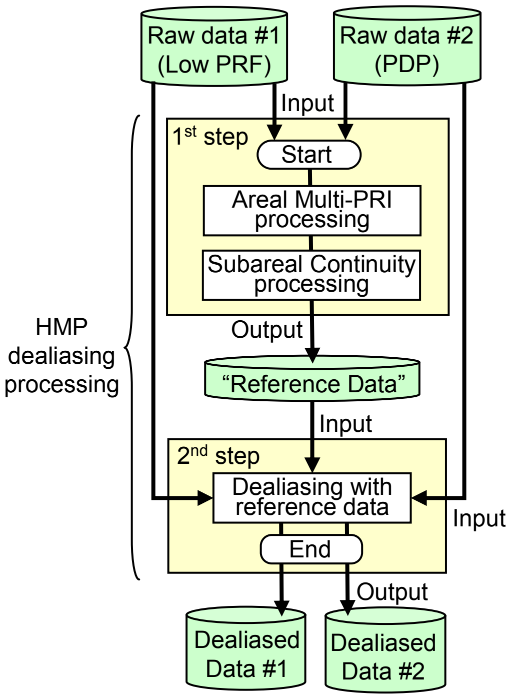

Fig. 2. A procedure of combined use of low-PRF and phase diversity processed dual-PRF (PDP) observations.

4. TESTS WITH REAL DATA

The procedure was tested with real data of two typhoon cases observed by the Meteorological Research Institute C-band Doppler radar. The one case has moderate Doppler velocity gradient. The other case has large Doppler velocity gradient. Expected observation range and unambiguous velocity limit were 250 km and 53 m/s, respectively. The processing time for a set of scans were approximately 5 to 10 seconds using Pentium 4 workstation.

4.1 A Moderate Doppler Velocity Gradient Case

The case of the typhoon DANAS on September 11, 2001 has moderate Doppler velocity gradient. Doppler velocity data were collected with two scan modes; low-/dual-PRF (LDP, PRF = 600/480 Hz, V_{max} = 33 m/s) and phase diversity processed high-/dual-PRF (PDP, PRF = 940/752 Hz, V_{max} = 53m/s). Observation ranges of the both modes are 250 km.

Figure 3 shows the raw data (reflectivity and Doppler velocity) of the two scans and the HMP processing results (reference data and dealiased Doppler velocity of the two scans). Inner circle of each figure indicates the range of the first-trip echo region of PDP (160 km). The TC center located 225 km away southwestward from the radar.

Raw Doppler velocities of LDP and PDP around the region "A" are erroneously dealiased due to moderate azimuthal gradient of Doppler velocity (Fig. 3(c), Fig. 3(d)). Data of LDP at the region "B" are erroneously dealiased due to the small V_{max} of 33 m/s (Fig. 3(c)). A large number of PDP data are missing in the second-trip echo region "C" (Fig. 3(d)).

As shown in Figure 3(f), the aforementioned erroneously dealiased velocities and data missing are fairly mitigated in the HMP processing result of LDP. Strong wind (more than 40 m/s) region near the TC center are clearly presented in the result. Except small isolated echoes only observed with low-PRF, more than 96% of LDP velocity data were correctly dealiased.

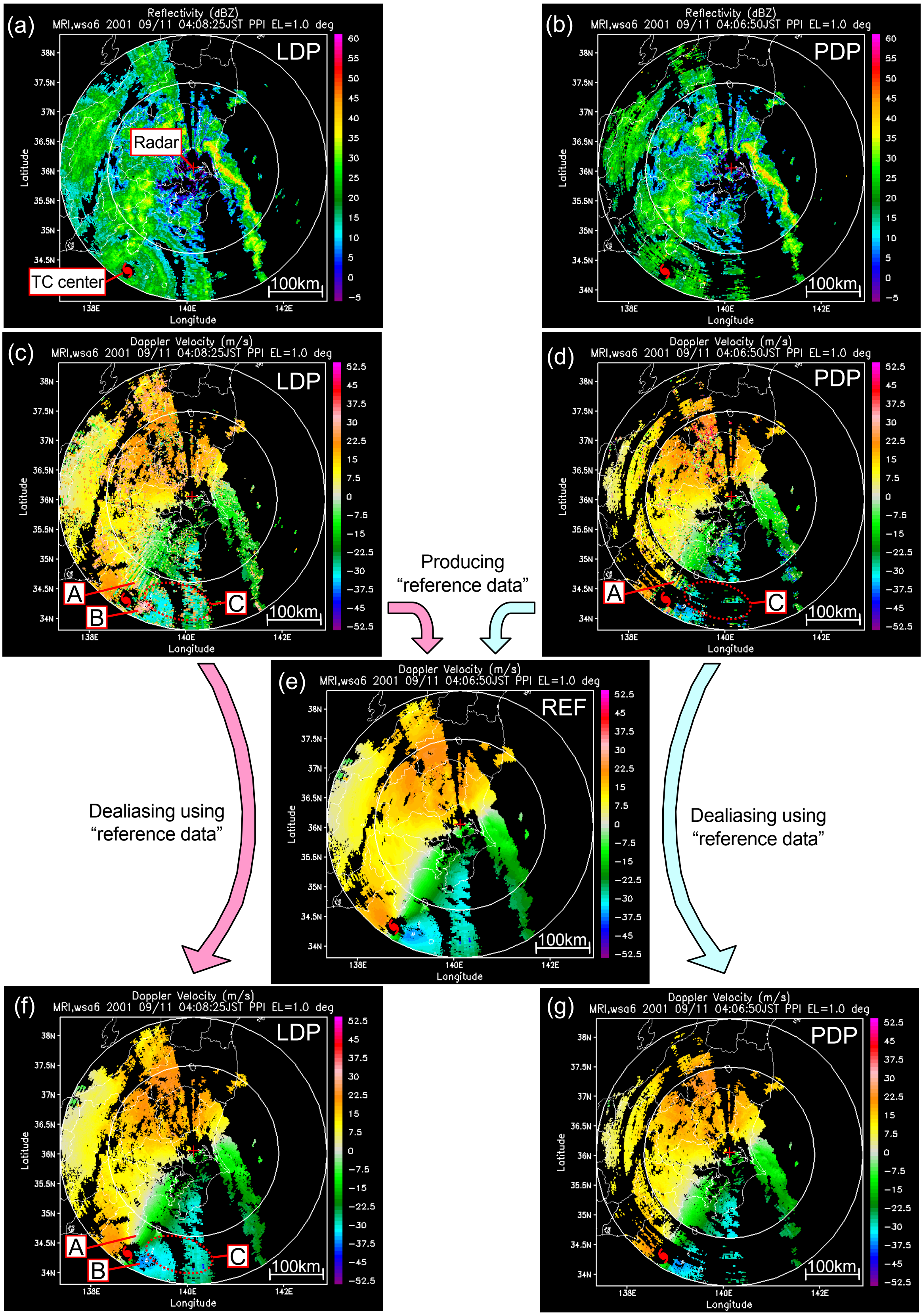

Fig. 3. Raw data and HMP processing results for a moderate Doppler velocity gradient case. Each figure shows reflectivity of LDP (a) and PDP (b), raw Doppler velocity of LDP (c) and PDP (d), reference data produced by HMP (e), dealiased Doppler velocity of LDP (f) and PDP (g). Inner and outer circles indicate the range of 160km and 250km from radar, respectively.

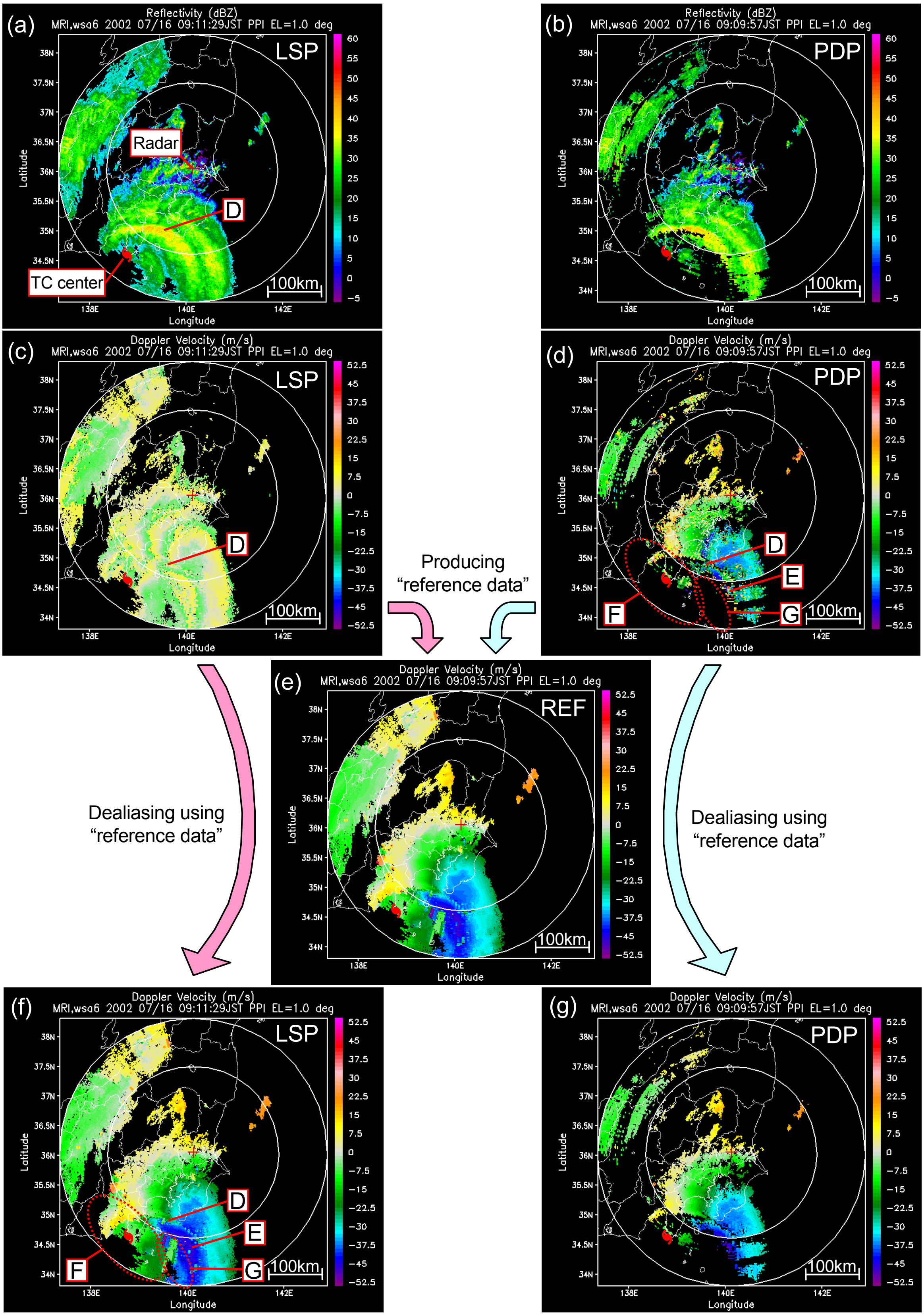

Fig. 4. Raw data and HMP processing results for a large Doppler velocity gradient case. Each figure shows reflectivity of LSP (a) and PDP (b), raw Doppler velocity of LSP (c) and PDP (d), reference data produced by HMP (e), dealiased Doppler velocity of LSP (f) and PDP (g). Inner and outer circles indicate the range of 160km and 250km from radar, respectively.

4.2 A Large Doppler Velocity Gradient Case

The case of the typhoon HOLONG on July 16, 2002 has large Doppler velocity gradient along its rain-band. Doppler velocity data were collected with two scan modes; low-/single-PRF (LSP, PRF = 600 Hz, V_{max} = 8.6 m/s) and phase diversity processed high-/dual-PRF (PDP, PRF = 940/752 Hz, V_{max} = 53 m/s). Observation ranges of the both modes are 250 km.

Figure 4 shows the raw data and the HMP processing results. Inner circle of each figure indicates the range of the first-trip echo region of PDP (160 km). The TC center located 200 km away southwestward from the radar.

Large Doppler velocity gradient along rain-band "D" and strong wind around "E" makes raw Doppler velocity pattern of LDP quite complicated (Fig. 4(c)). A large number of PDP data are missing in the second-trip echo region "F" (Fig. 4(d)). Especially in the region "G", there are no PDP data.

As shown in Figure 4(f), the HMP processing result of LSP clearly presents Doppler velocities of strong wind shear region along "D", strong wind region "E" (more than 50 m/s) and the region around the TC center "F". However, there are dealiasing failures in the region "G". This is because PDP data is not available for producing reference data in the region.

5. CONCLUSION

A strategy to extend observation range of Doppler radar is proposed. The strategy is to apply the HMP method to two scans of Doppler velocity data that observed with low-PRF and observed with PDP.

A procedure for the strategy was tested with real data of two typhoon cases observed by the Meteorological Research Institute C-band Doppler radar. Expected observation range and unambiguous velocity limit were 250 km and 53 m/s, respectively. The test results for the typhoon DANAS case, which has moderate Doppler velocity gradient, sufficiently present Doppler velocity field around TC center located 225 km away from the radar. The test results for the typhoon HOLONG case, which has large Doppler velocity gradient, also sufficiently present Doppler velocity field around TC center, strong velocity (more than 50 m/s) region and strong wind shear region. However, there are dealiasing failures in the region where PDP data are not available for producing reference data.

The results demonstrate the procedure succeeded to extend observation range of Doppler radar with high unambiguous velocity limit as far as PDP data are available. The procedure should be modified using some continuity methods or VAD type methods to mitigate dealising failure in the region where PDP data are not available. This procedure has been used for the lowest elevation scan of Japan Meteorological Agency operational Doppler radar observation since April 2006.

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