A Hybrid Multi-PRI Method to Dealias Doppler Velocities

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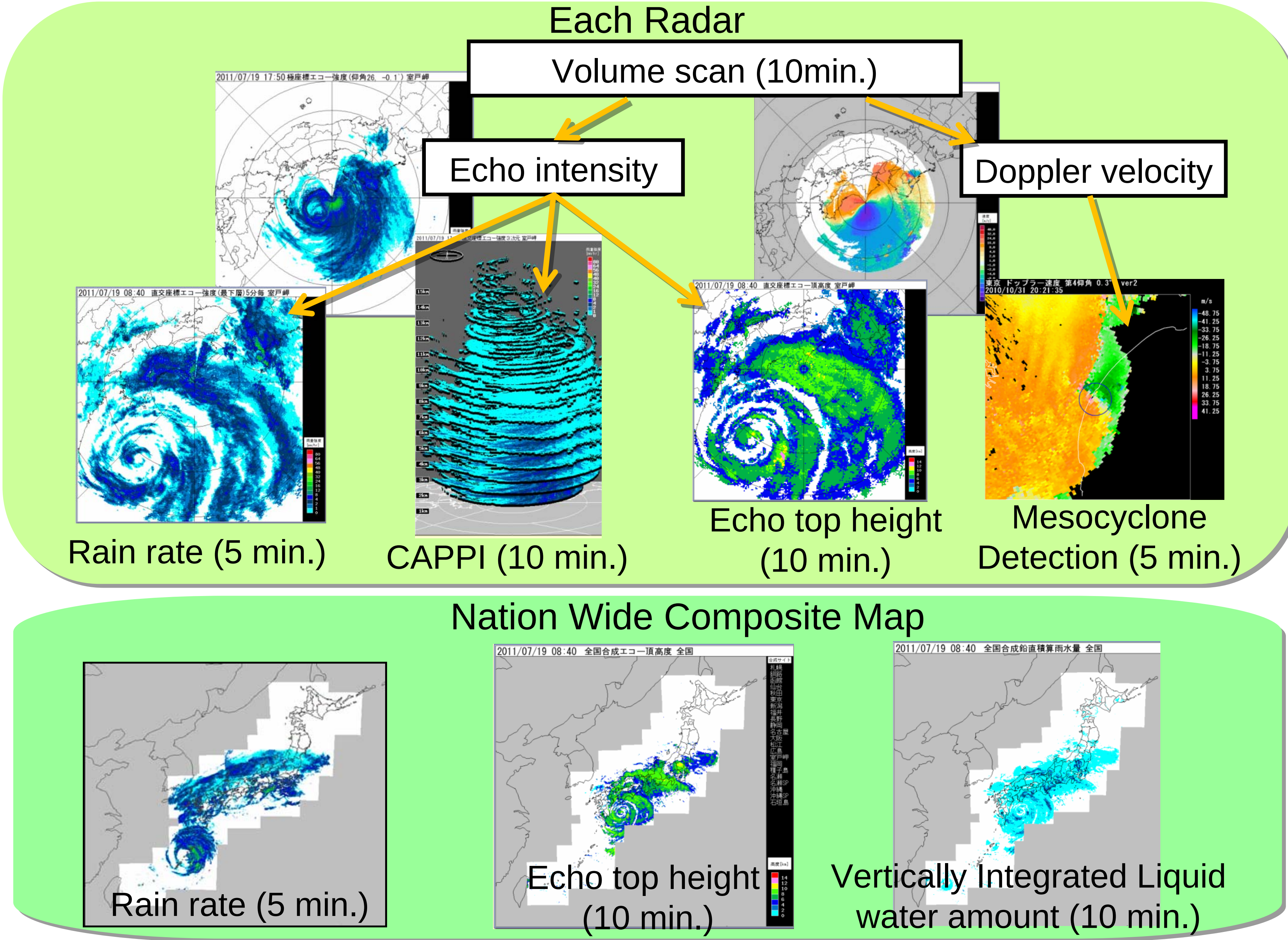
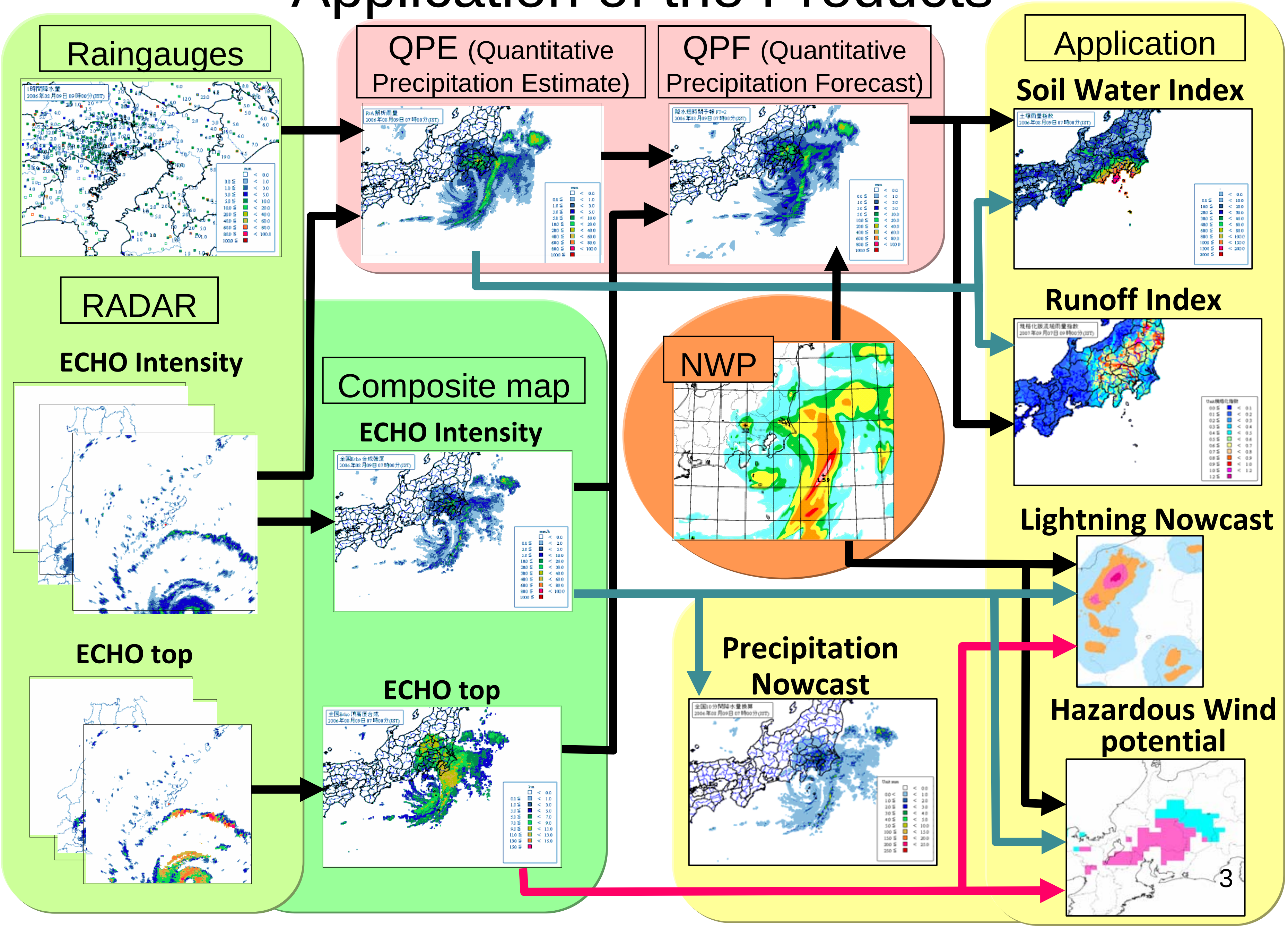
Products of JMA Weather Radars



Application of the Products

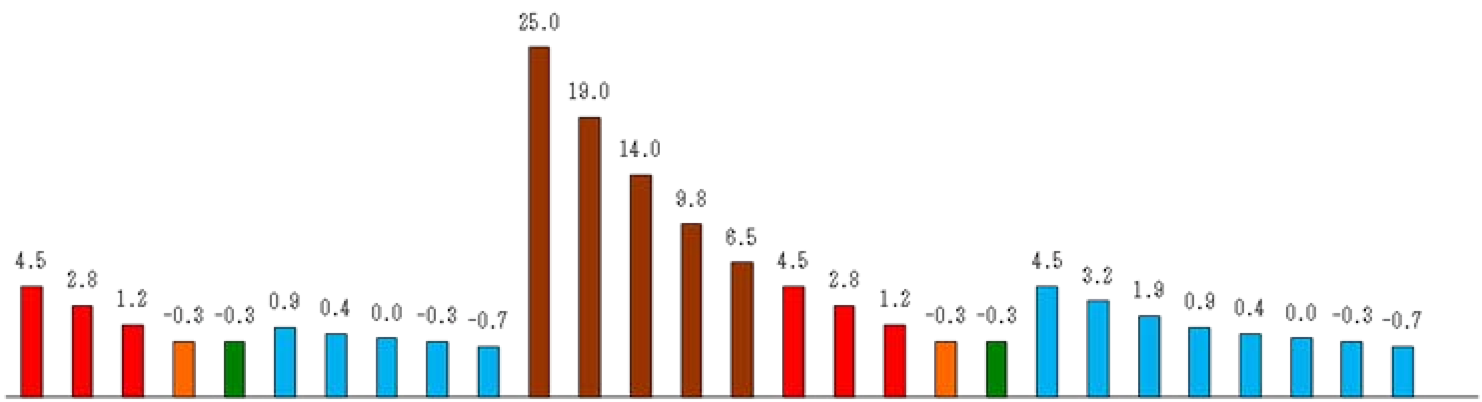


Scan Sequence

For producing 3D intensity data and high resolution Doppler velocity data, Doppler radars conduct a sequence of scans every 10 minutes like the one shown below.

Scan Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Elevation angle	4.5	2.8	1.2	-0.3	-0.3	0.9	0.4	0.0	-0.3	-0.7	25.0	19.0	14.0	9.8	6.5	4.5	2.8	1.2	-0.3	-0.3	4.5	3.2	1.9	0.9	0.4	0.0	-0.3	-0.7	10.0

	Mode	Observation rage	PRF
	Velocity Observation	150km	940/752Hz
	Velocity & Reflectivity Observation	150km	940/752Hz
	Velocity Observation	250km	940/752Hz
	Velocity Observation	250km	600/480Hz
	Reflectivity Observation	400km	330Hz



Doppler Radar Scan Sequence (Fukuoka Radar)

Dealiasing Issue

Range-Velocity ambiguities

Range and velocity aliasing of pulsed Doppler radar prevent combination of long observation range and high unambiguous velocity limit.

Doppler velocity dealiasing methods

Continuity methods (e.g. Ray and Ziegler, 1977)

Simple hardware and processing
Need correct start point data

Dual PRI methods (e.g. Sirmans et al, 1976, Dazhang et al, 1984)

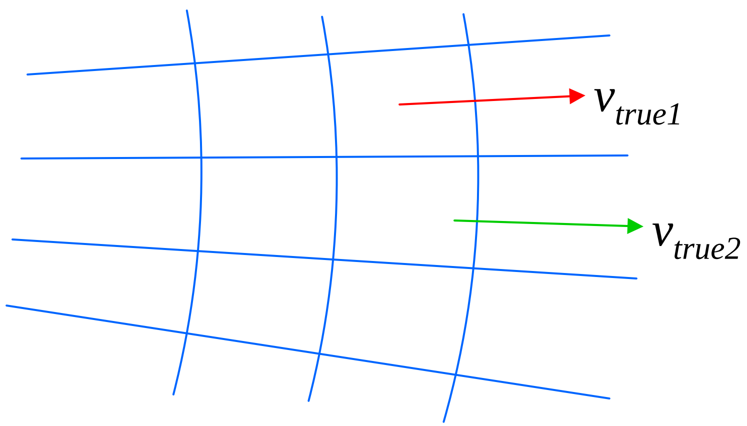
Special hardware to make dual PRI observation.
Correct start point data is not needed.
Used in Canada, Europe, and Australia.

(Simple) Dual PRF method (=SDP)

Principle

If the true Doppler velocities in two adjacent bins are sufficiently close, then the Nyquist folding number can be uniquely derived from the difference between the two observed (folded) Doppler velocities in the two bins.

$$\begin{cases} v_{true1} = v_{obs1} + n_1 \cdot 2V_{nyq1} \\ v_{true2} = v_{obs2} + n_2 \cdot 2V_{nyq2} \end{cases}$$



$$\begin{cases} n_1 = -l + (R-1) \cdot round(l/R) \\ n_2 = -l + R \cdot round(l/R) \end{cases}$$

$$l = \frac{\Delta v_{obs}}{2(V_{nyq1} - V_{nyq2})}$$

where

v_{true1}, v_{true2} : true Doppler velocities, $v_{true1} \fallingdotseq v_{true2}$
v_{obs1}, v_{obs2} : observed Doppler velocities, $\Delta v_{obs} = v_{obs1} - v_{obs2}$
V_{nyq1}, V_{nyq2} : Nyquist velocities, $V_{nyq1} : V_{nyq2} = R : R\text{-}1$
n_1, n_2 : Nyquist folding numbers
$round$: rounding function
R : Nyquist number

(Simple) Dual PRF method (=SDP)

Causes of dealiasing failure

1. Sparsely distributed data (No adjacent data)

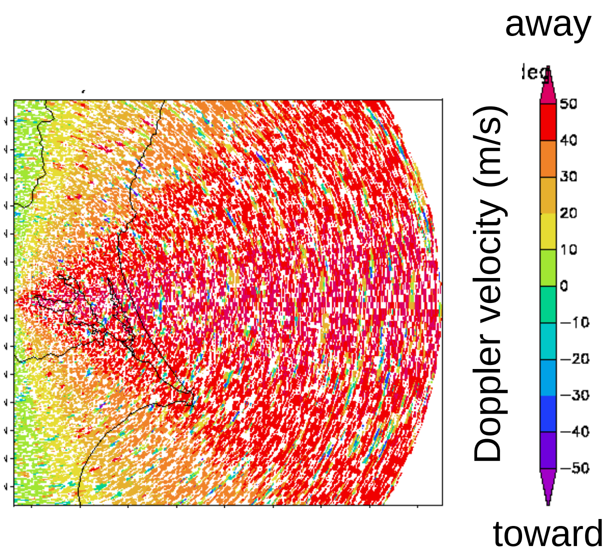
   Δv_{obs} cannot be derived.

2. Large random noise

   Δv_{obs} with large random noise misleads us to wrong folding number.

3. Large velocity gradients

   The true Doppler velocities in two adjacent bins are not sufficiently close. Then Δv_{obs} misleads us to wrong folding number.



Hybrid Multi-PRI method (HMP)

1. Sparsely distributed data

2. Large random noise

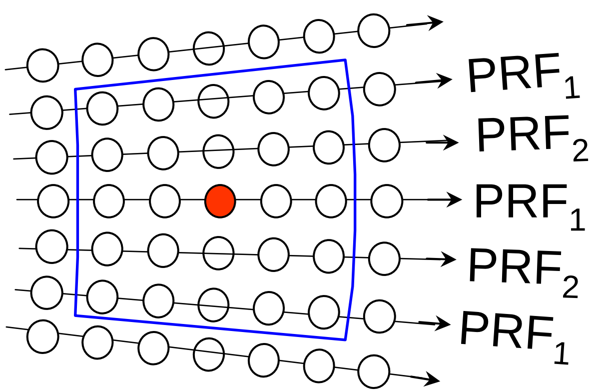
3. Large velocity gradients

Proposed Improvement

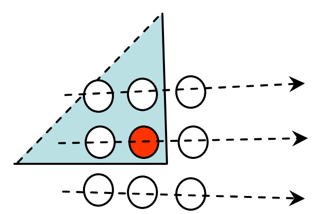
Use more data bins in wider area.

Assume that Doppler velocities in the wider area can be spatially approximated by liner polynomial.

Use smaller subarea for linear approximation in very large velocity gradient region.

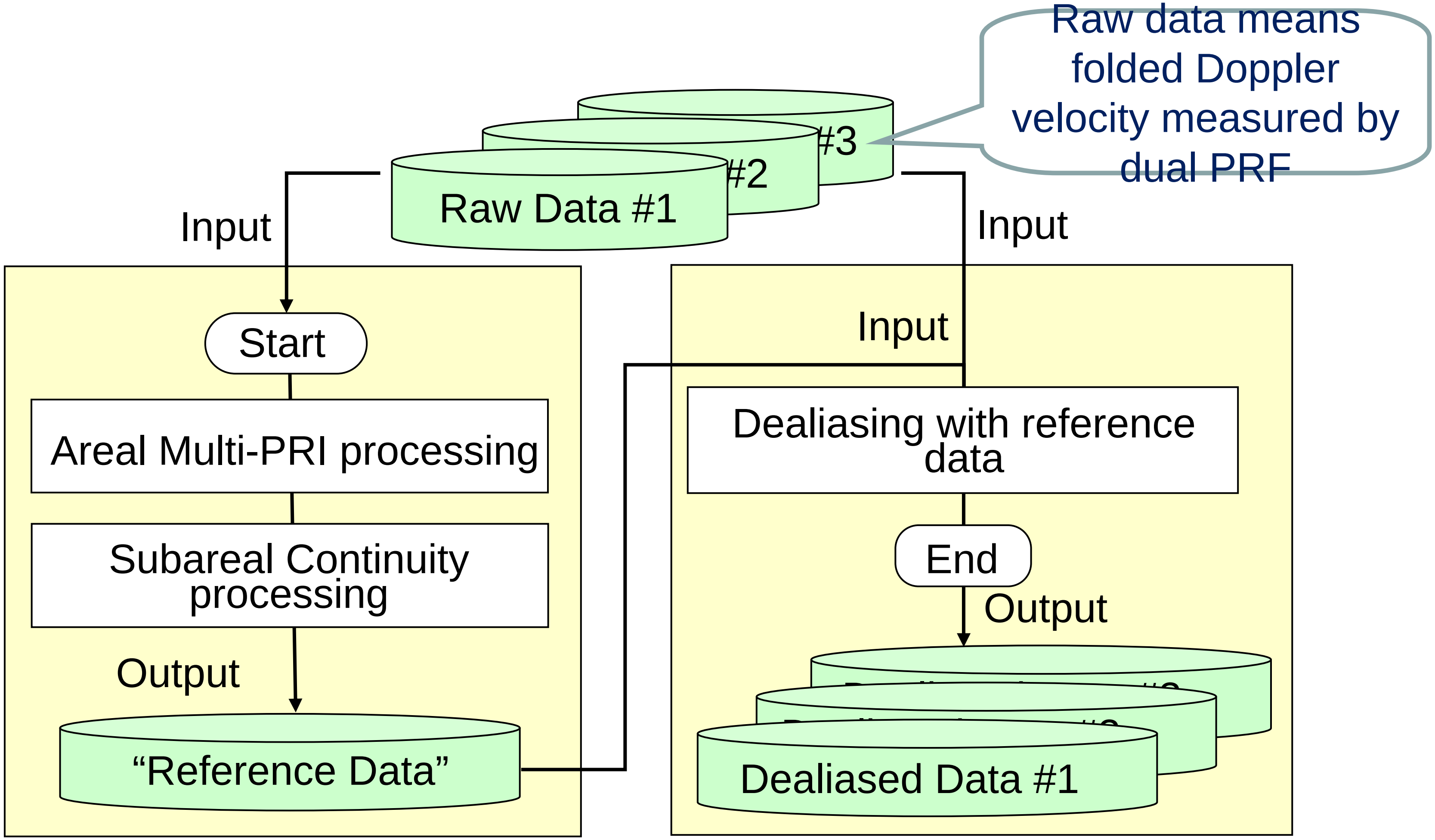


Example of data sampling area (5 x 5) for comparatively wider area



Example of data sampling area for comparatively smaller subarea

Procedure of HMP



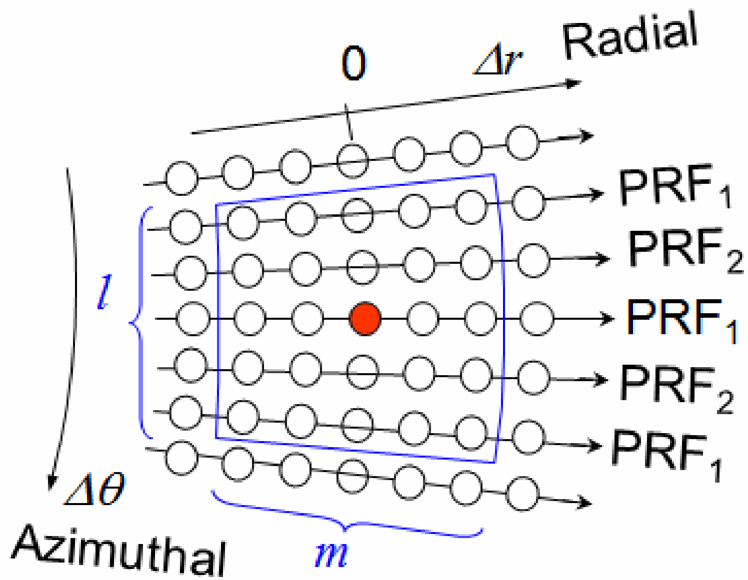
Producing "reference data" from "raw data"

Dealiasing "raw data" using "reference data"

Procedure of HMP

Areal Multi-PRI processing

- Folding number is determined by the goodness of fit.



$$\begin{cases} v_{raw,i}(V) = v_{raw}(\Delta r_i, \Delta\theta_i, k) \\ V_{nyq,i}(V) = V_{nyq}(\Delta r_i, \Delta\theta_i, k) \end{cases}$$

$$(\,for\; i = 0, \ldots, N-1)$$

$$V = v_{raw,0} + 2nV_{nyq,0}$$

$(n$: Nyquist folding numbers)

$$v_{can,i} = v_{raw,i} + 2V_{nyq,i}\,\mathrm{round}((V - v_{raw,i})/2V_{nyq,i})$$

$$v_{app,i}(V) = v_0(V) + a(V)\,\Delta r_i + b(V)\,\Delta\theta_i$$

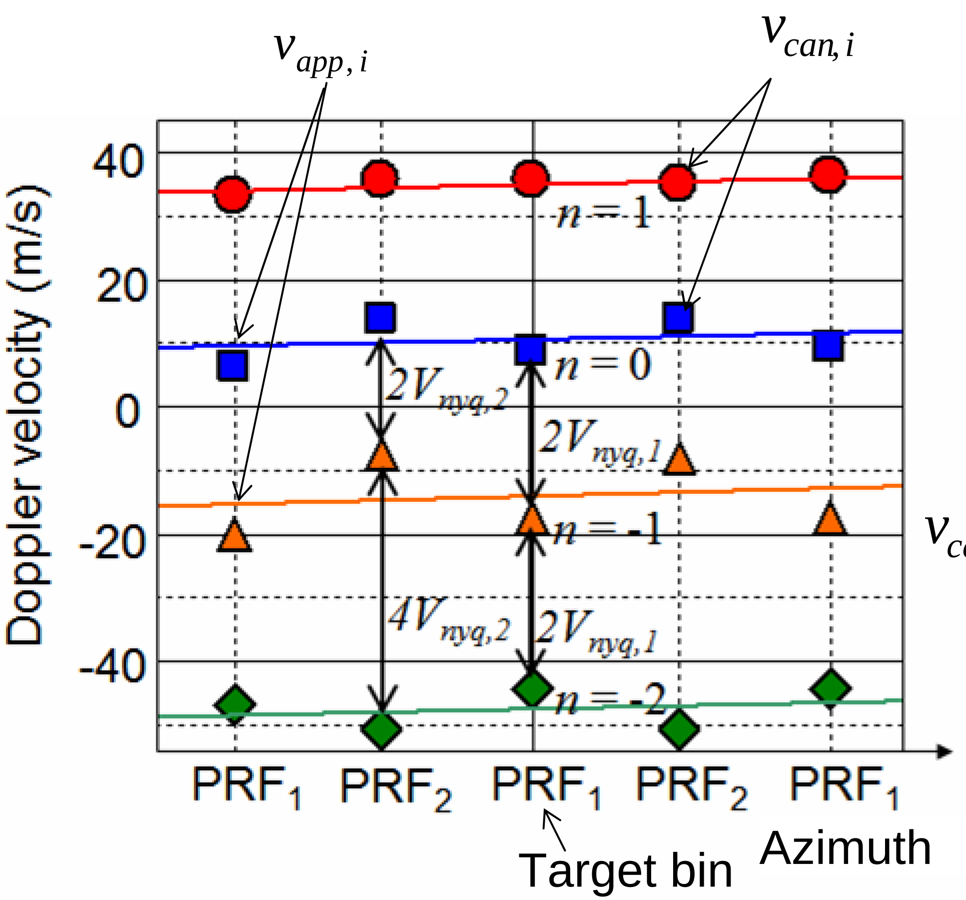
$$S\,(V) = \sqrt{\frac{1}{N}\sum_{i=0}^{N-1}\left(\frac{v_{app,i}(V) - v_{can,i}(V)}{2V_{nyq,i}}\right)^2}$$

$$v_{ref} = v_0\,^*$$

Procedure of HMP

Areal Multi-PRI processing

- Folding number is determined by the goodness of fit.



A slice along the azimuthal direction of the candidate and approximated Doppler velocity fields of each possible unfolded Doppler velocity.

$$\begin{cases} v_{raw,i}(V) = v_{raw}(\Delta r_i, \Delta \theta_i, k) \\ V_{nyq,i}(V) = V_{nyq}(\Delta r_i, \Delta \theta_i, k) \end{cases}$$

$$(\text{for } i = 0, \ldots, N-1)$$

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$$v_{ref} = v_0{}^*$$

Procedure of HMP

Areal Multi-PRI processing
- Quality control and Interpolation

$$v'_{app,\,j} = v_0' + a'\,\Delta r_j + b'\,\Delta\theta_j$$

$$\sigma(V) = \sqrt{\frac{1}{(N'-3)} \sum_{j=0}^{N'-1} \left(v'_{app,\,j} - v_{ref,\,j}\right)^2}$$

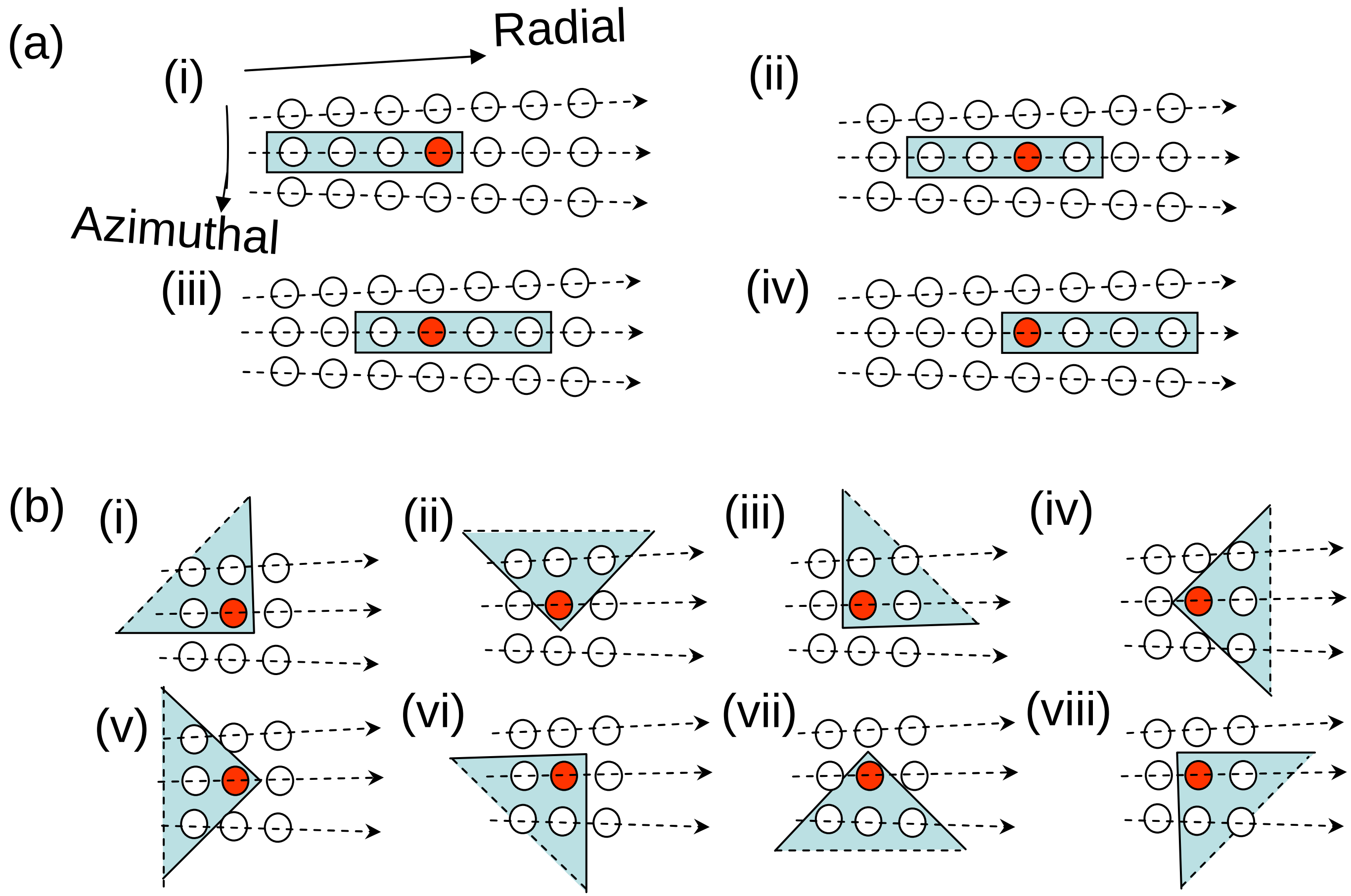
$$\begin{cases} v_{ref} = v_0' & \text{(If it satisfy a given condition)} \\ v_{ref} = NILL & \text{(If it does not satisfy a given condition)} \end{cases}$$

HMP processing parameters				
N	≥ 12		N'	≥ 10
|a|, |a'|	$< V_{nyq} / \Delta r_{res}$		|b|,|b'|	$< V_{Nyq} / \Delta\theta_{res}$
S	< 0.1		σ	$< V_{Nyq1} - V_{Nyq2}$

Procedure of HMP

Subareal continuity processing

This processing produces reference data for bins in areas with large Doppler velocity gradients where areal multi-PRI processing is not applicable.



A spatial linear approximation is applied using the velocity , v'_{can} , to derive the approximation of the unfolded Doppler velocity. The approximated value that has the smallest sigma in the available all sampling patterns is set to the reference data of the target bin.

$$v'_{can} = v_{raw} + 2V_{nyq}\ \mathrm{round}\ ((v_{ref,ave} - v_{raw}) / 2V_{nyq})$$

Here, $v_{ref,ave}$ is a mean of reference Doppler velocities in the corresponding subarea.

Procedure of HMP

Dealiasing with reference data

The measured velocity, raw Doppler velocity in each bin is dealiased to be the closest value to the reference Doppler velocity in the bin by adding or subtracting one or more Nyquist intervals, which is shown in the equation below. This is the final outputted dealiased velocity of each bin.

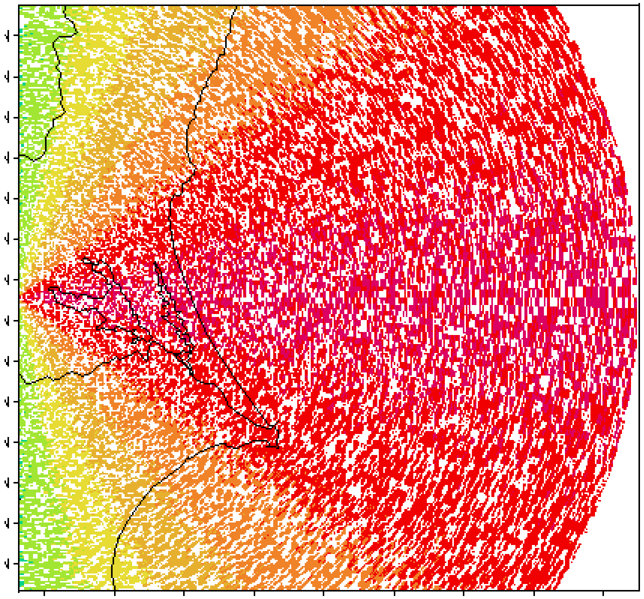
$$v = v_{raw} + 2V_{nyq}\,\mathrm{round}\,((v_{ref} - v_{raw})/2V_{nyq})$$

If neither areal multi-PRI nor subareal continuity processing yields reference velocity, dealiased velocity is not produced for the bin. Thus, reference data also used as a validation filter.

Evaluation using Simulation Data

Influences of missing data and random noise in the uniform wind fields and Rankin vortex

Doppler radar observation parameters	
Transmitting frequency	5260 MHz
PRF1/PRF2 (ratio)	940 / 752 Hz (5:4)
Nyquist velocities (V_{Nyq1} / V_{Nyq2})	13.4 / 10.7 m/s
Maximum unfolding velocity $(V_{\max})$	52.5 m/s
Observation range	160 km
Range resolution (Δr_{res})	250 m
Azimuthal resolution $(\Delta \theta_{res})$	1 deg.



Simulated uniform wind field with speeds of 50 m/s.

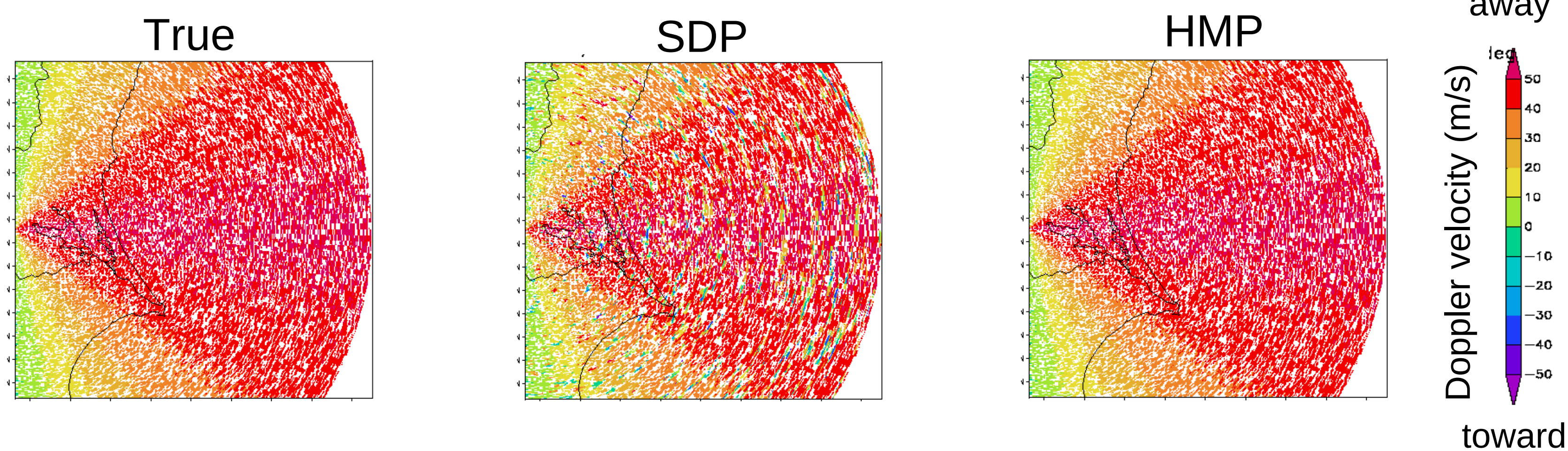
Missing data rate is 20 %.

Standard deviation of random noise is 2 m/s.

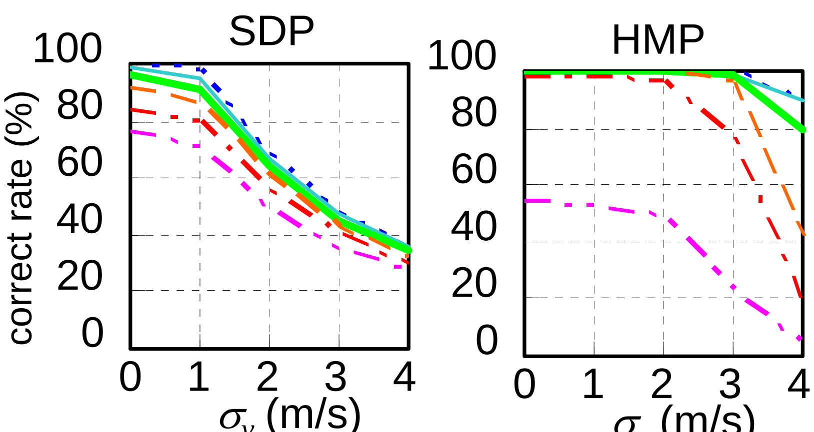
Evaluation using Simulation Data

Influences of missing data and random noise

Uniform wind field with speeds of 50 m/s.
Missing data rate is 20 %.
Standard deviation of random noise is 2 m/s.

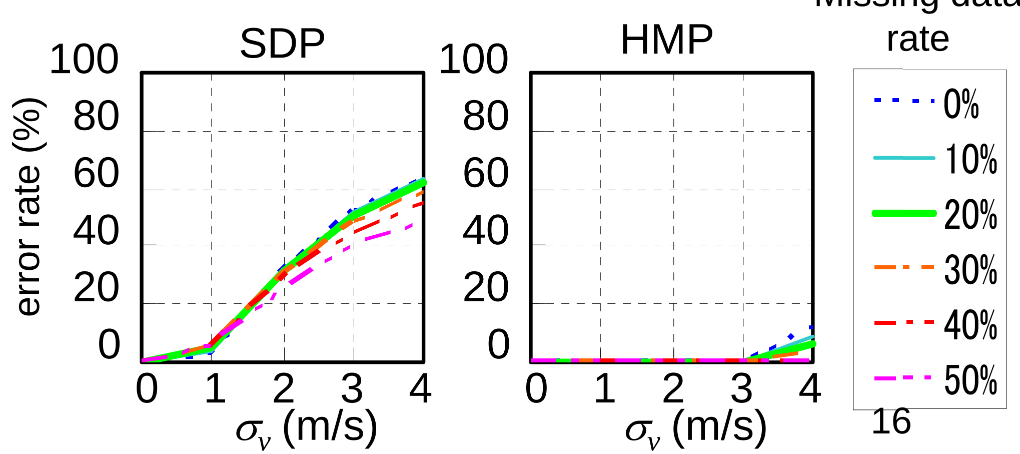


(a) Correct rate



Standard deviation of random noise

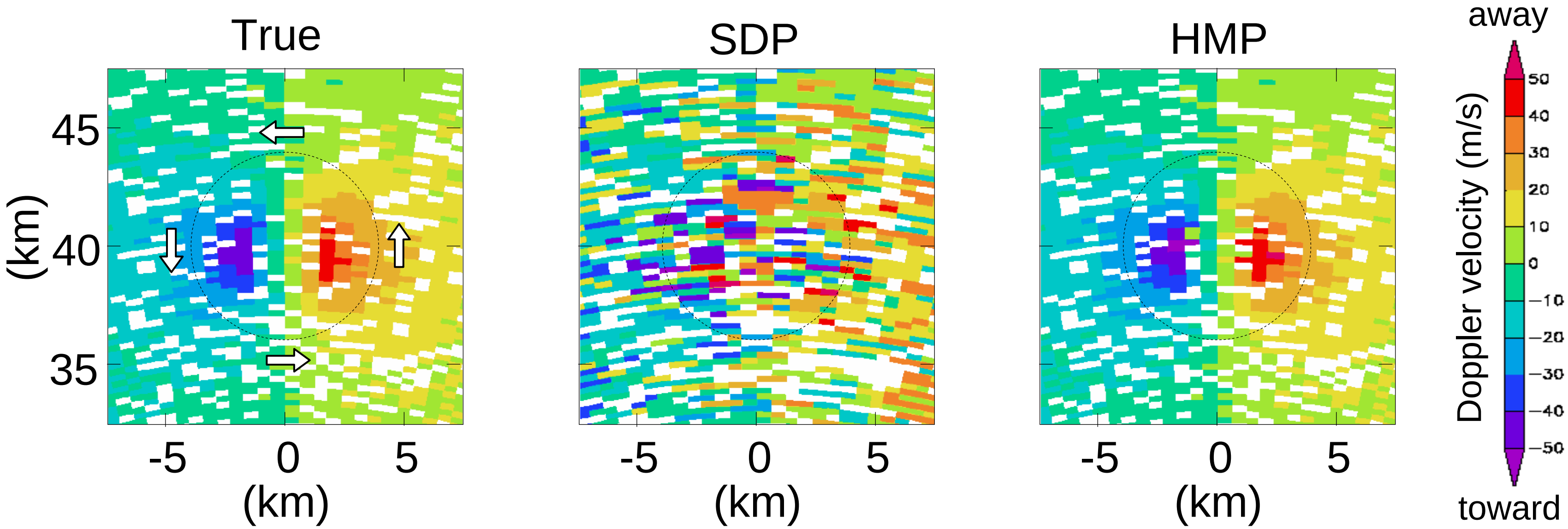
(b) Error rate



Standard deviation of random noise

Evaluation using Simulation Data

Performance on wind field features (Rankine vortex)

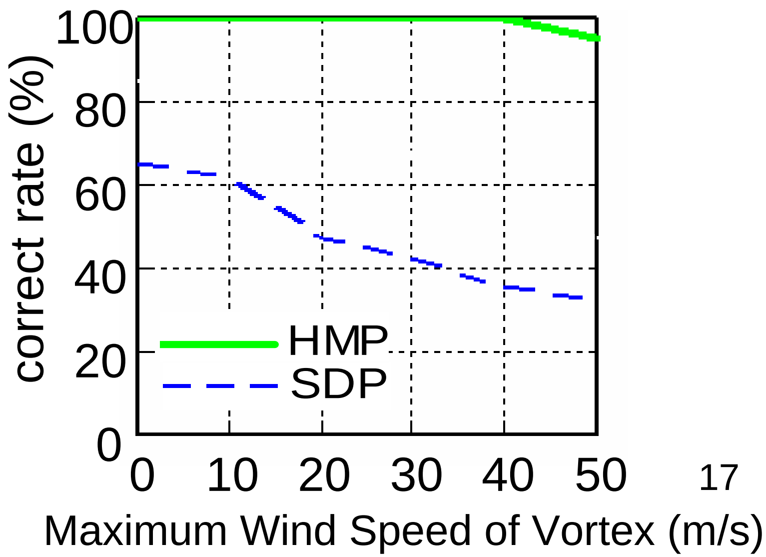


Rankine vortex located 40km away from radar.

Maximum wind speed (MWS) is 50 m/s at 2 km away from the vortex center.

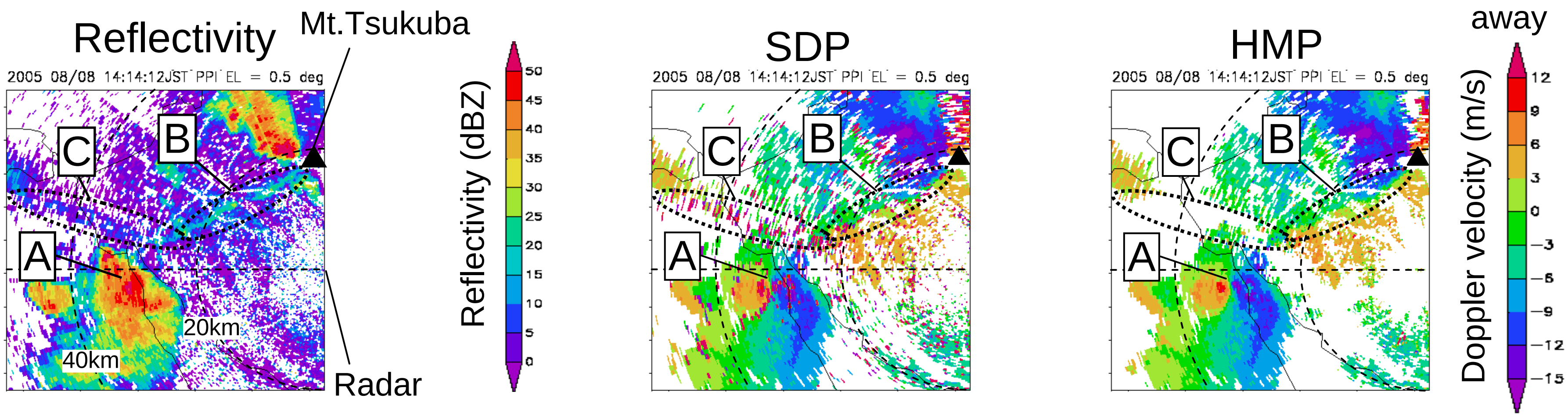
Missing data rate is 20%.

Standard deviation of random noise is 2 m/s.



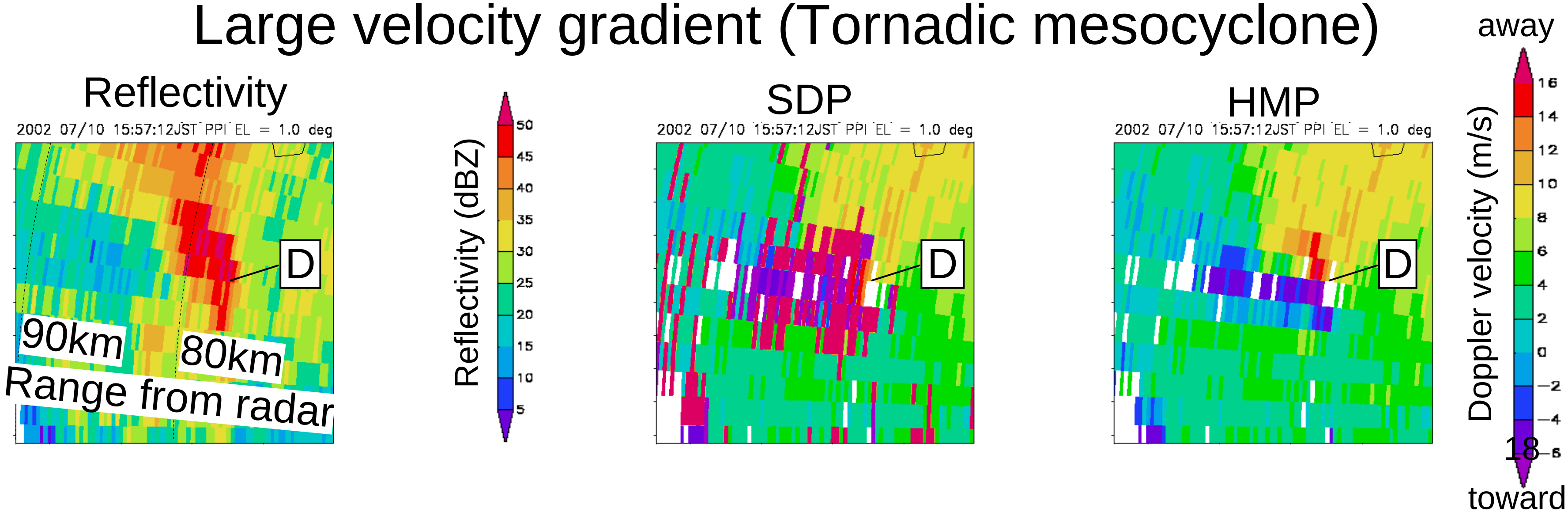
Application to Real Data

Sparsely distributed data (Gust front)



A: downburst, B: gust front, C: convergence line in clear air echo region

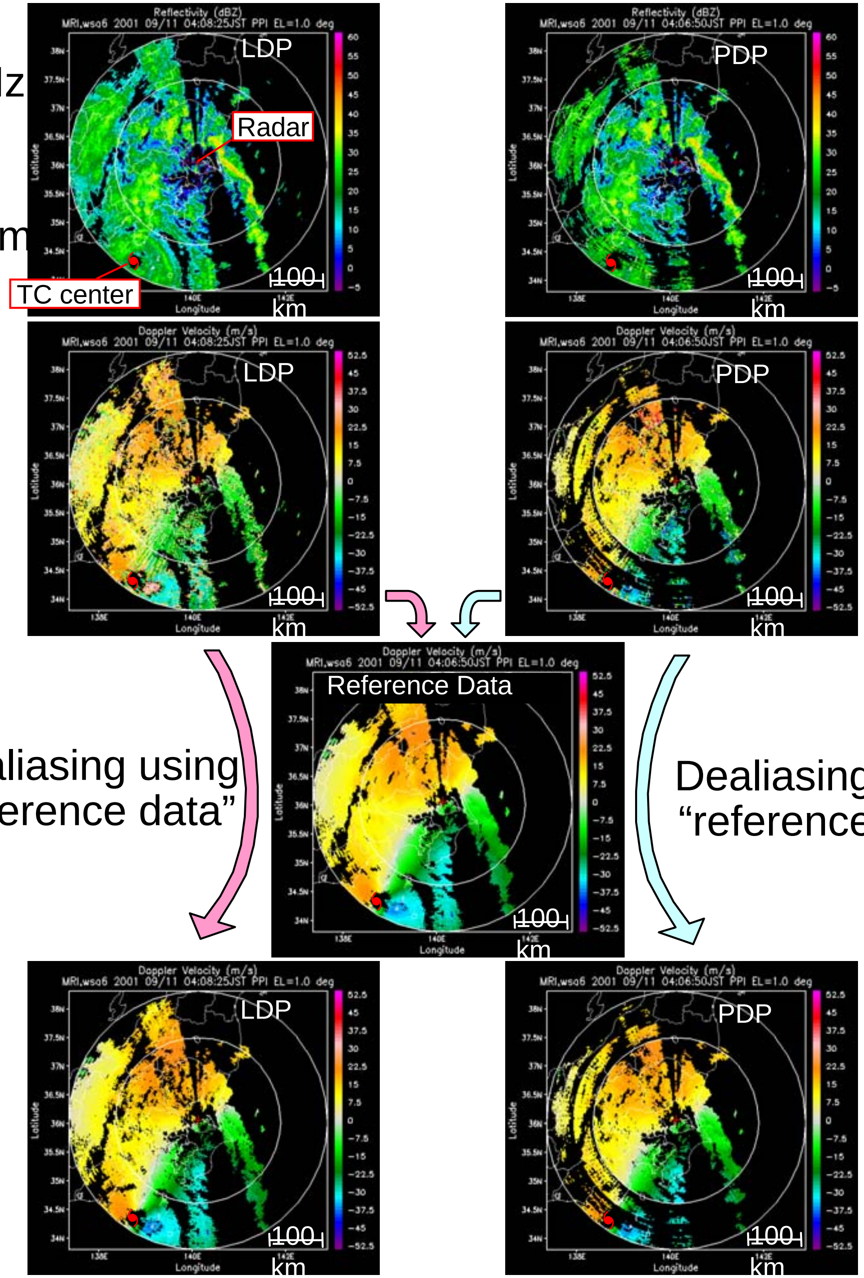
Large velocity gradient (Tornadic mesocyclone)



HMP Application to Range Extension

Low Dual-PRF (LDP)
PRF_1 / PRF_2 : 600 / 480 Hz
V_{max} : 33.4 m/s
First trip
echo range : 250 / 312 km

Phase diversity processed Dual-PRF
PRF_1 / PRF_2 : 940 / 752 Hz
V_{max} : 53.6 m/s
First trip
echo range : 160 / 200 km



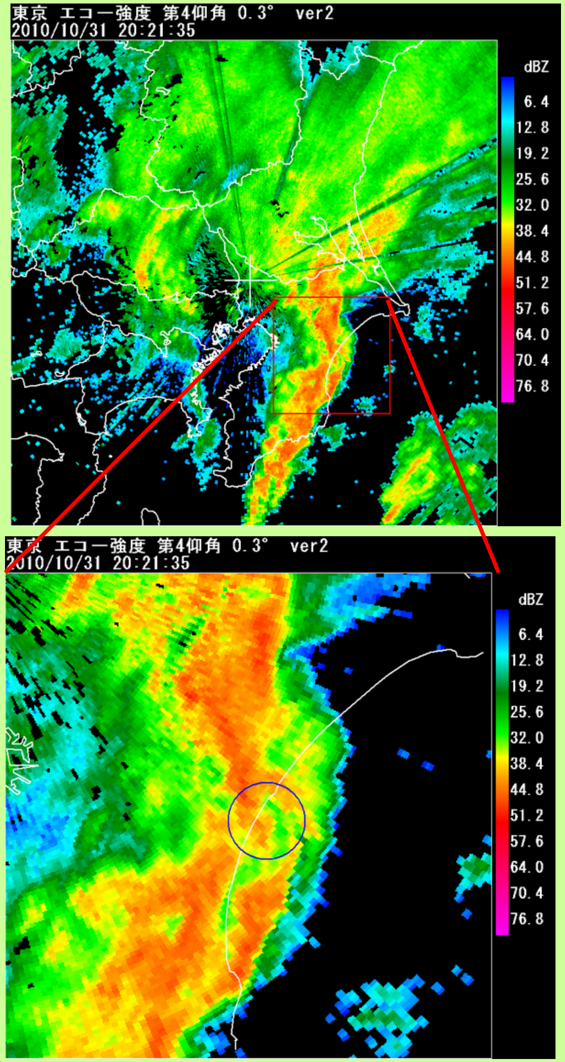
Dealiasing using “reference data”

Dealiasing using “reference data”

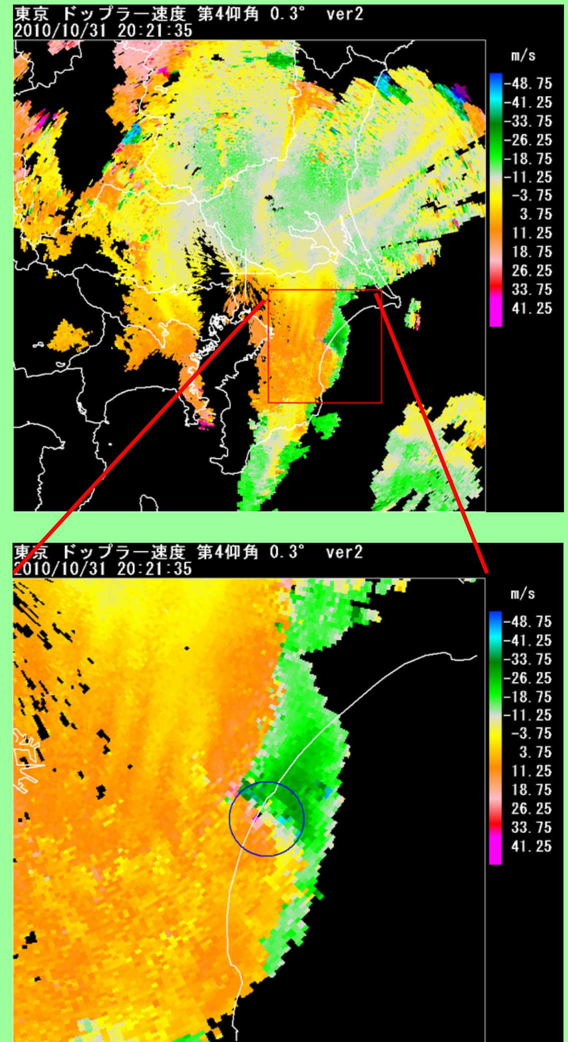
Tornadic Mesocyction observed by operational Tokyo Doppler weather radar

HMP has been used for operational Doppler weather radar observations since 2006.

Echo intensity



Dealiased Doppler velocity



Reference

HMP is described in

Yamauchi, H., O. Suzuki, and K. Akaeda, 2006: A Hybrid Multi-PRI Method to Dealias Doppler Velocities. SOLA, 2, 92-95
(This is available at http://www.jstage.jst.go.jp/article/sola/2/0/2_92/_article)

Thank you for your attention!