Utilization of Doppler velocity

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Hiroshi Yamauchi
Observation Department
Japan Meteorological Agency

Contents

- Issues in using Doppler velocity
  – Velocity aliasing
  – Doppler velocity pattern
- Applications of Doppler Observations
  – Low level wind shear detection
  – Mesocyclone detection
  – VAD
- Summary

(1) Velocity Aliasing (Folding)

- Doppler velocity V_d is determined by Doppler frequency f_d .

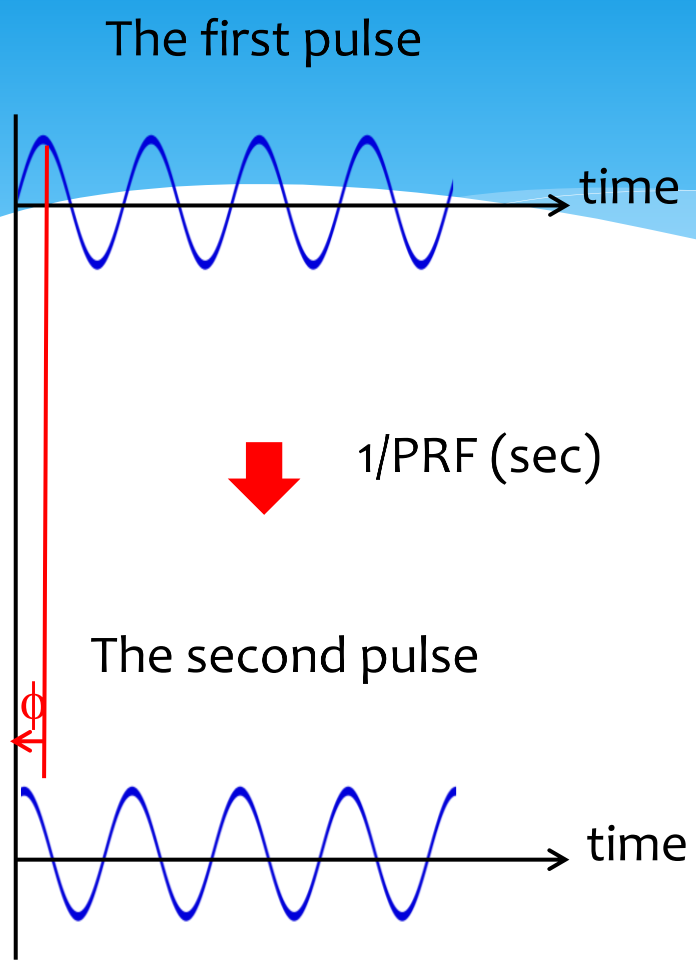
$$V_d = -\frac{\lambda f_d}{2}$$

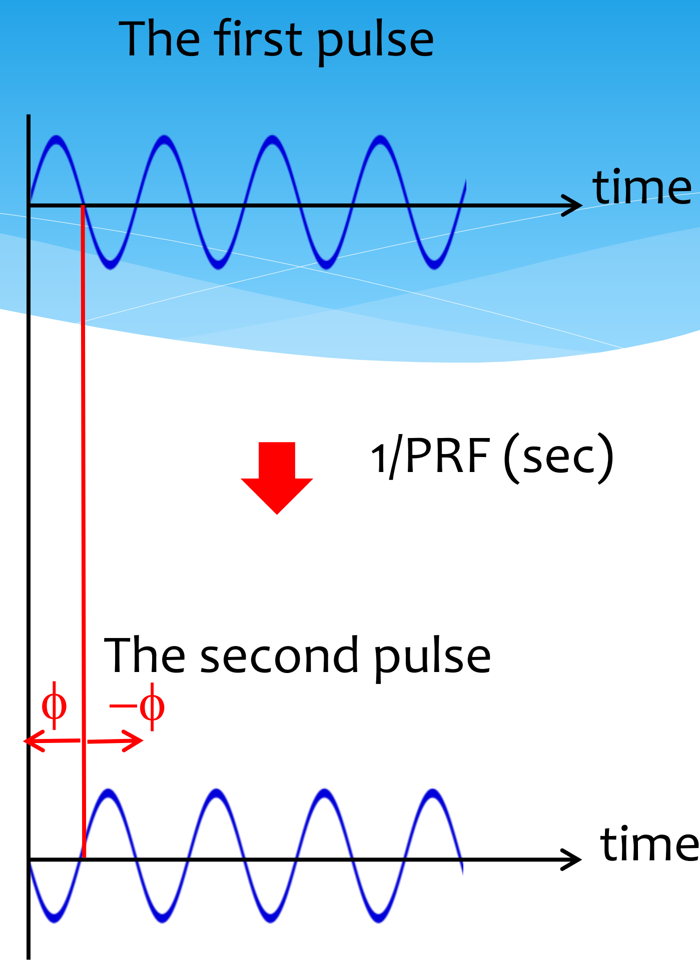
- However f_d is too small to be directly measured. So f_d is measured using phase difference of pulse to next pulse.
- Then maximum measurable Doppler velocity (V_{nyq}) is determined by PRF (pulse reputation frequency).

$$V_{nyq} \equiv V_{\max} = \frac{\lambda \cdot PRF}{4}$$

- If true Doppler velocity V_d is larger than V_{nyq}, V_d is aliased (folded) to be a value ranging between $-V_{nyq}$ and $+V_{nyq}$.

a. f_d measurement using phase change



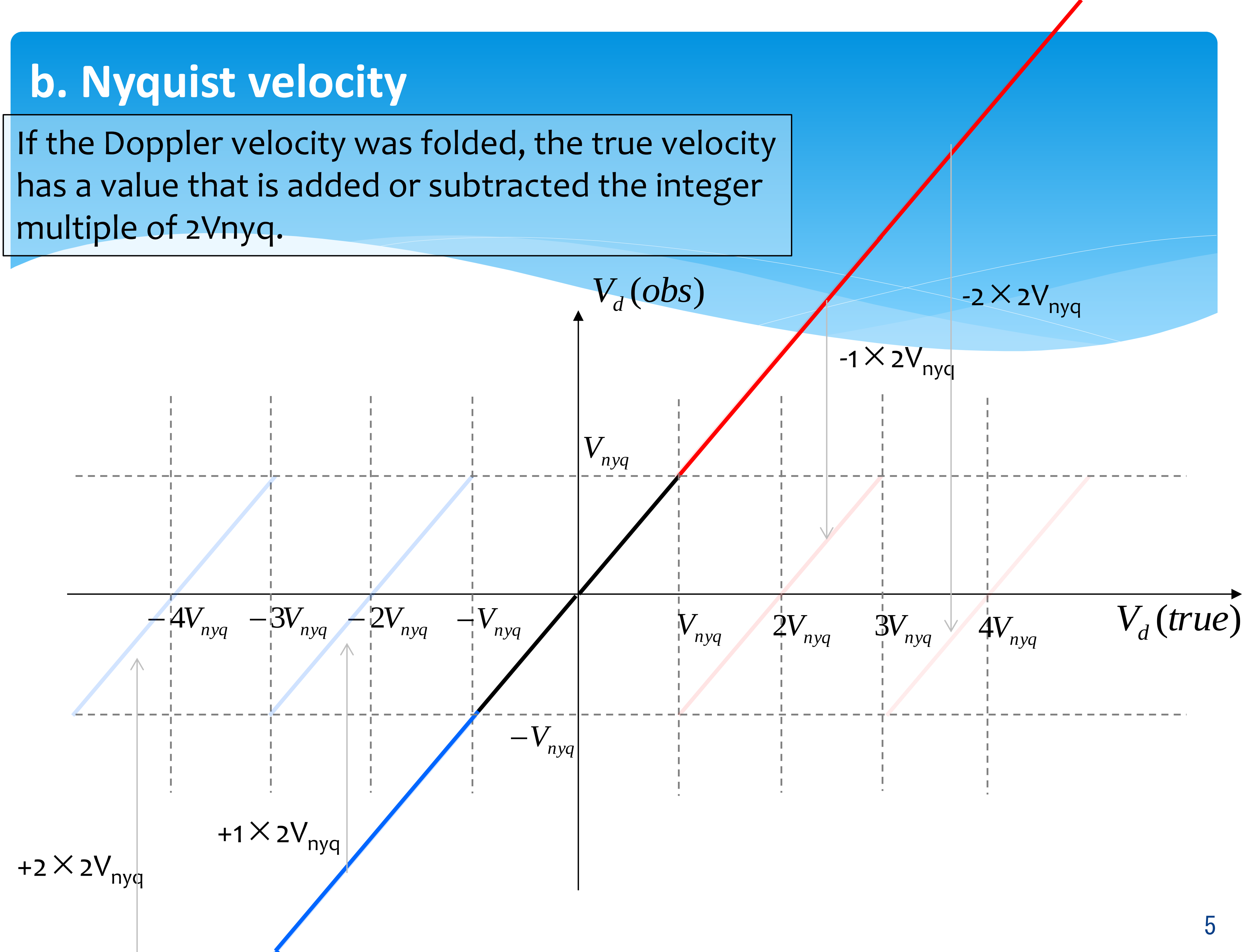


$2\pi f_d = \phi \,/\, (1/PRF)$ (rad / sec)

If true phase change ϕ is equal or larger than π, it is aliased to be a value ranging between $-\pi$ and π.

b. Nyquist velocity

If the Doppler velocity was folded, the true velocity has a value that is added or subtracted the integer multiple of 2Vnyq.



c. Range–velocity ambiguity (Doppler dilemma)

Maximum detectable range

$$r_{\max} = \frac{c}{2 \cdot PRF}$$

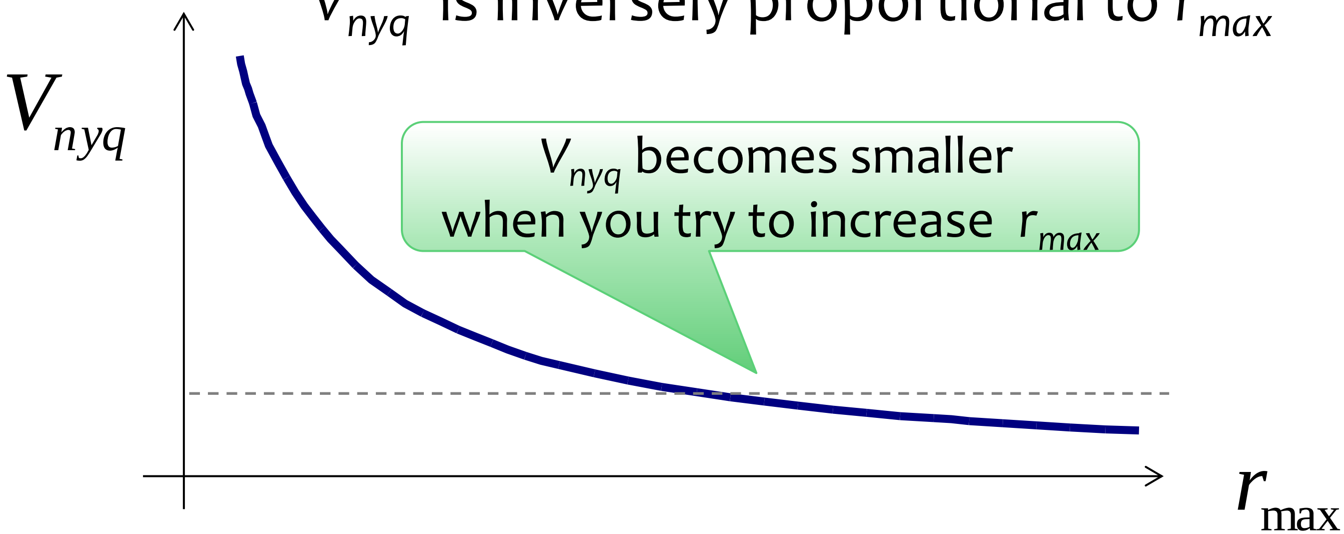
const

$$V_{nyq} = \boxed{\frac{c\lambda}{8}} \cdot \frac{1}{r_{\max}}$$

Maximum detectable velocity

$$V_{nyq} = \frac{\lambda \cdot PRF}{4}$$

V_{nyq} is inversely proportional to r_{max}

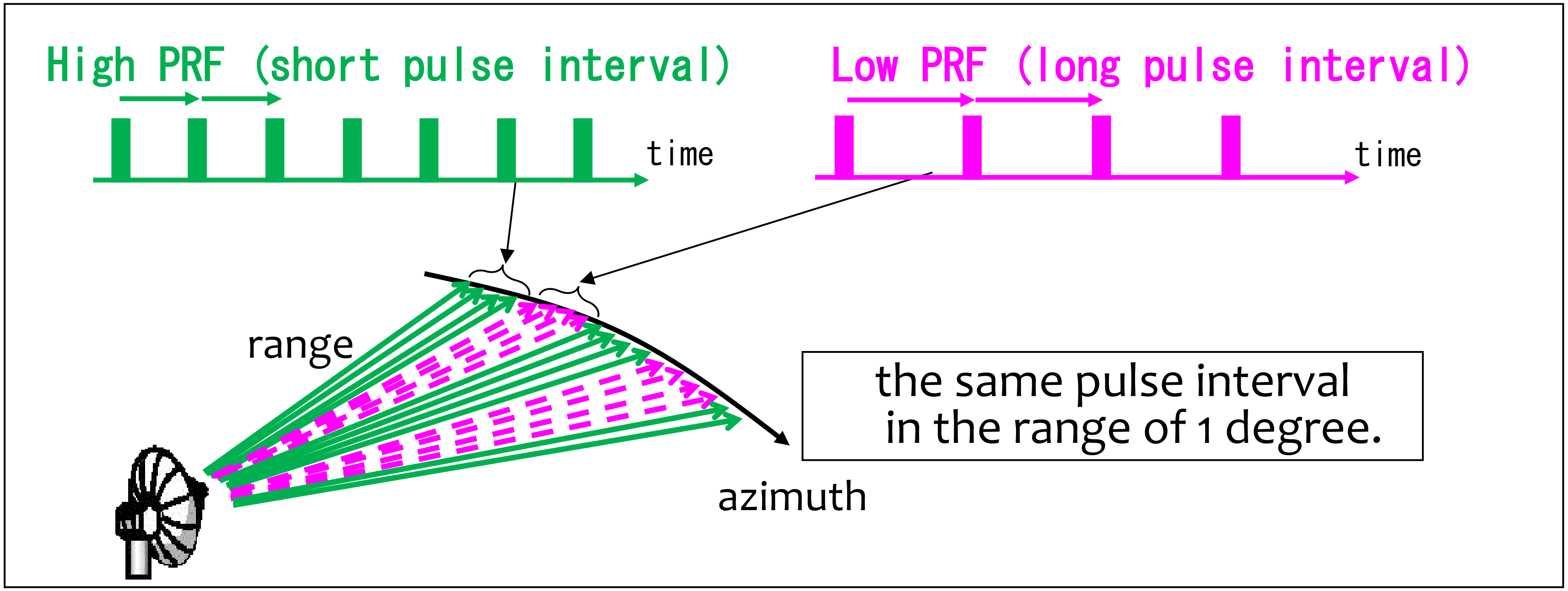


Range-Doppler Dilemma

Because the observation limit is highly dependent on the PRF, it is necessary to set correctly the PRF in accordance with the observation purpose.

d. Dual-PRF method (Dealiasing of Doppler velocities)

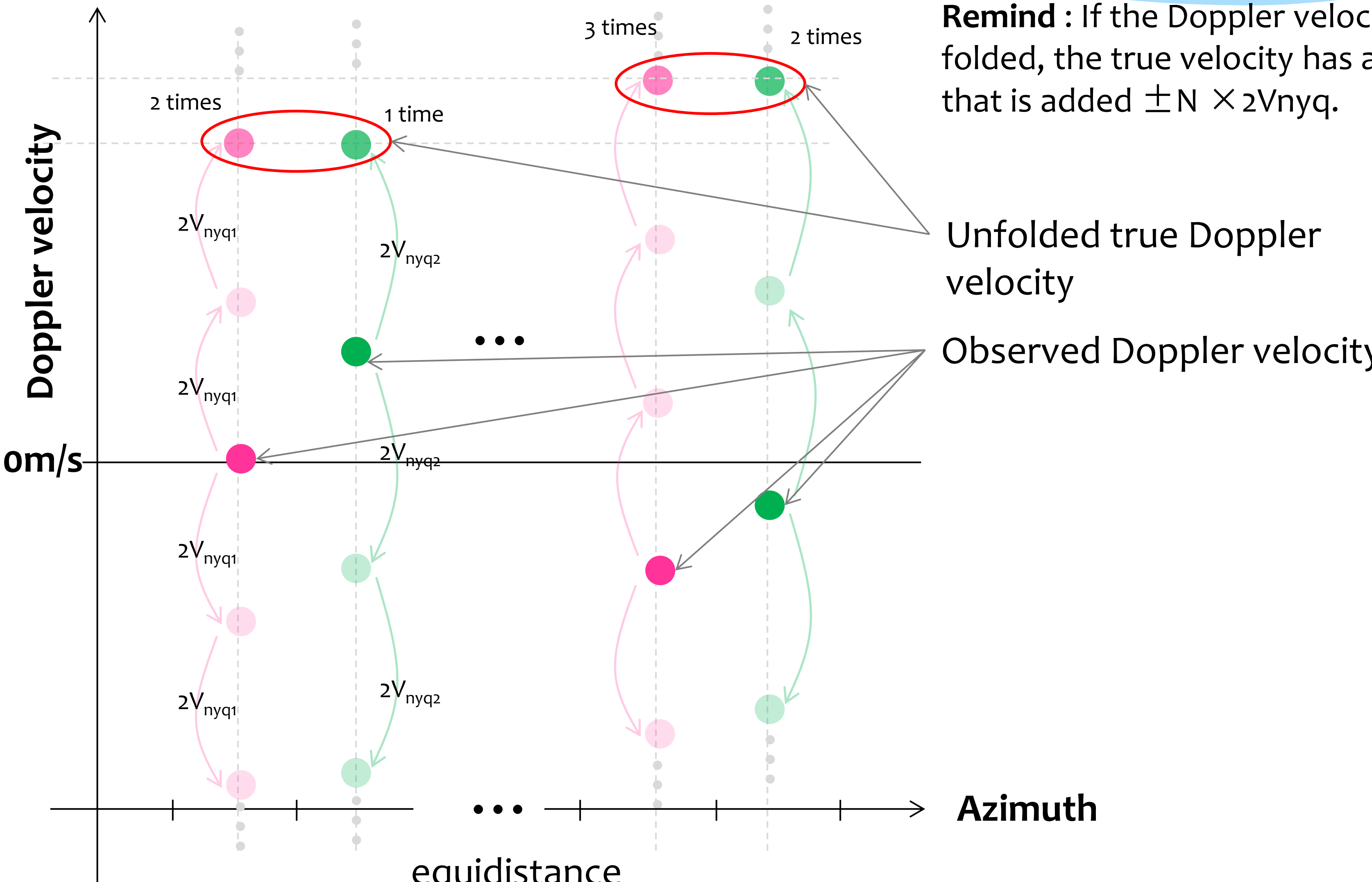
Radio wave is transmitted with PRFs changed at regular interval (azimuth of about 1 degree), and you can increase measurable doppler velocity.



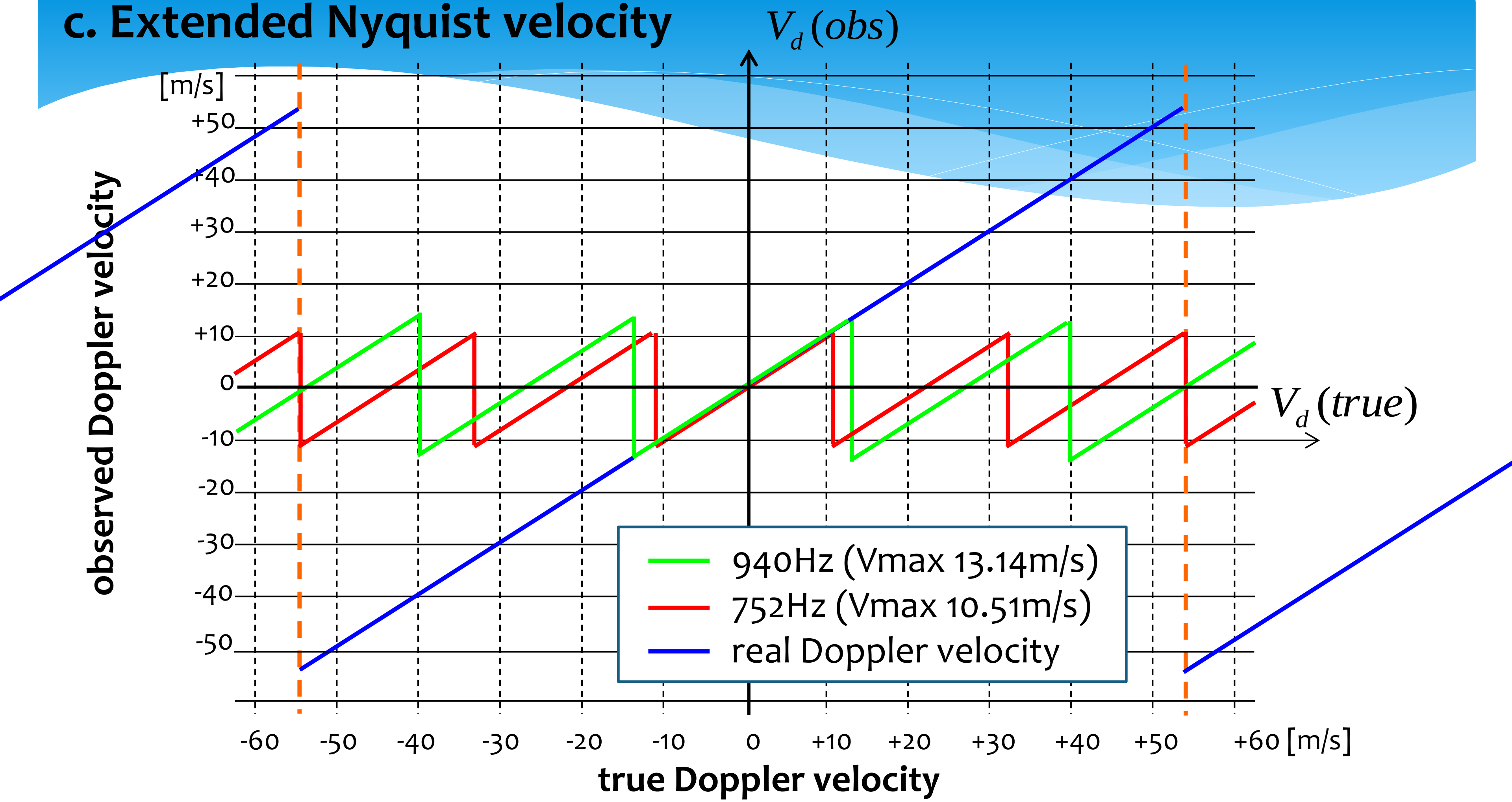
a. the concept of dual-PRF method

If it is assumed that 2 different PRF observed same target, the true Doppler velocity can be estimated from the difference of 2 Doppler velocities obtained by these 2 PRF.

Remind : If the Doppler velocity was folded, the true velocity has a value that is added ±N ×2Vnyq.



c. Extended Nyquist velocity



In dual-PRF method, maximum measurable Doppler velocity is determined by the least common multiple of two frequency.

$$940\,[\mathrm{Hz}] : 752\,[\mathrm{Hz}] = 5 : 4 \qquad 600\,[\mathrm{Hz}] : 480\,[\mathrm{Hz}] = 5 : 4$$

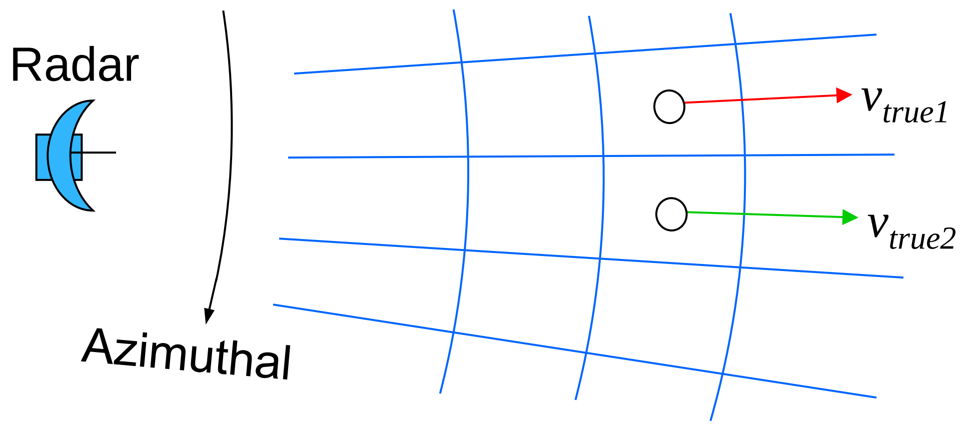
$$V_{\max} = 10.51 \times 5 = 52.5\ [\mathrm{m/s}] \qquad V_{\max} = 8.37 \times 4 = 33.5\,[\mathrm{m/s}]$$

b. How to calculate unfold velocity

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

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

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



where

v_{true1}, v_{true2} : true Doppler velocities, $v_{true1} ≒ v_{true2}$

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

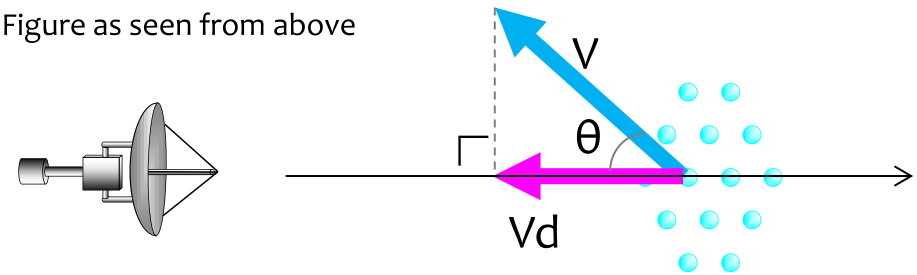
round : rounding function

(2) Radial velocity

Doppler radar can only observe the radial component of target's velocities.

Vd : Doppler velocity
V : Target's moving velocity

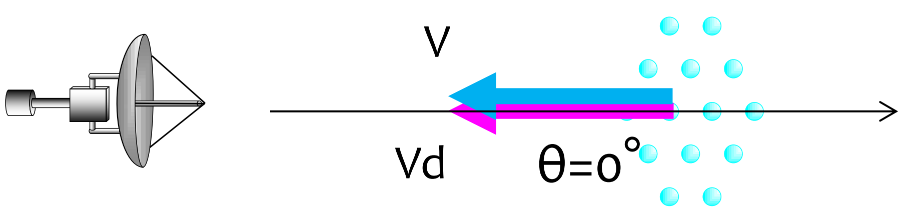
Figure as seen from above



By putting θ as the angle formed by radial direction and the target's moving direction, Doppler velocity(Vd) is expressed as

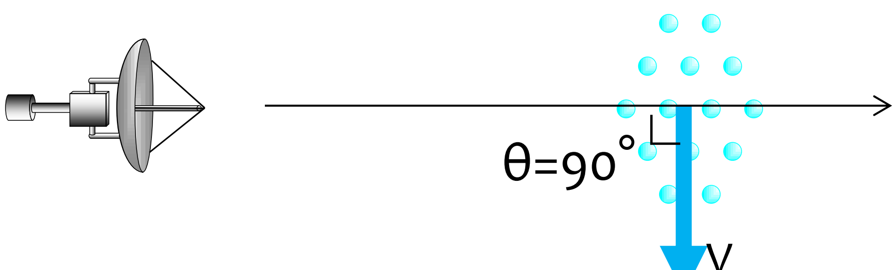
$$Vd = V\cos\theta$$

Figure as seen from above



When θ =0 , Doppler velocity is equal to target's moving velocity.

$$Vd = V\cos(0) = V$$



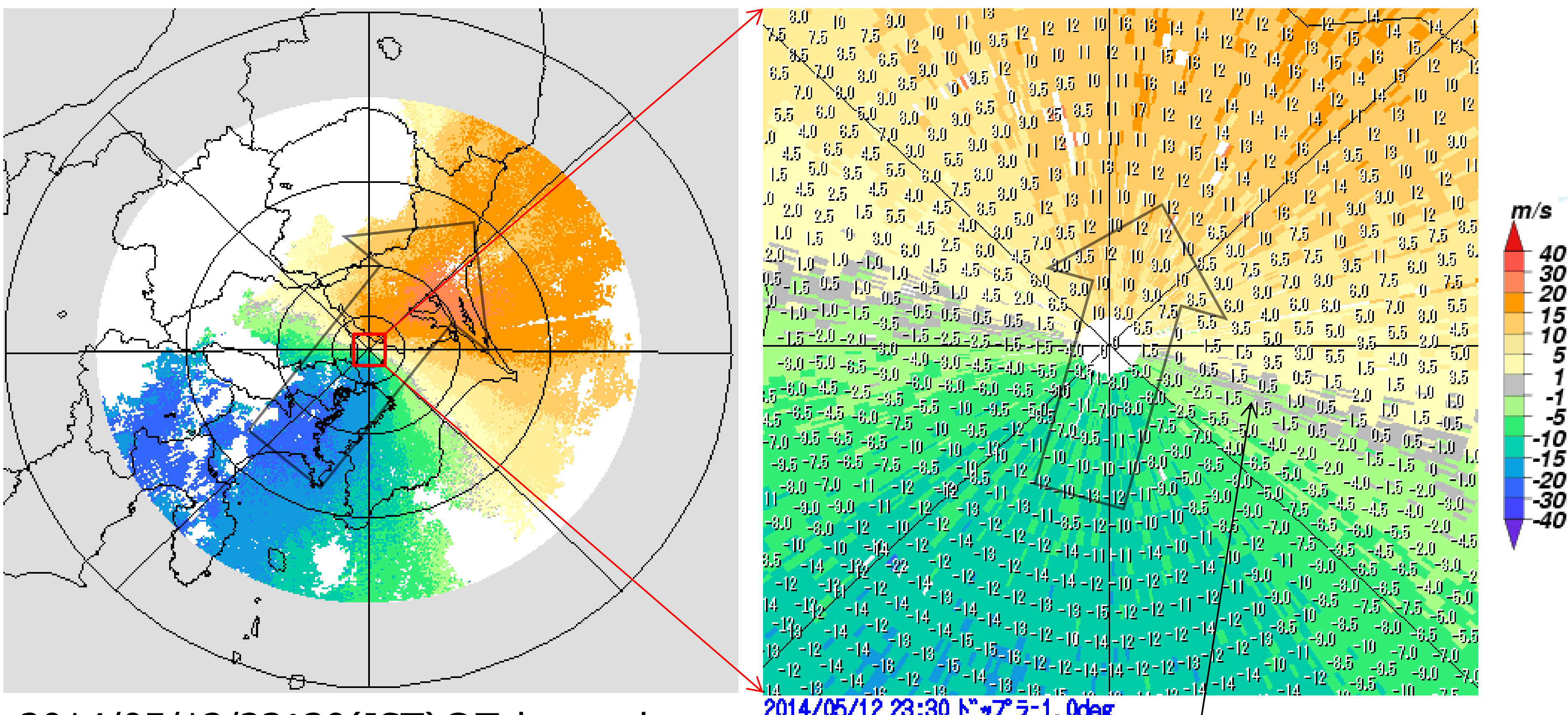
When θ=π/2, Doppler velocity is 0.

$$Vd = V\cos(\pi/2) = 0$$

Figure as seen from above

Typical pattern of Doppler Velocity (uniform flow)

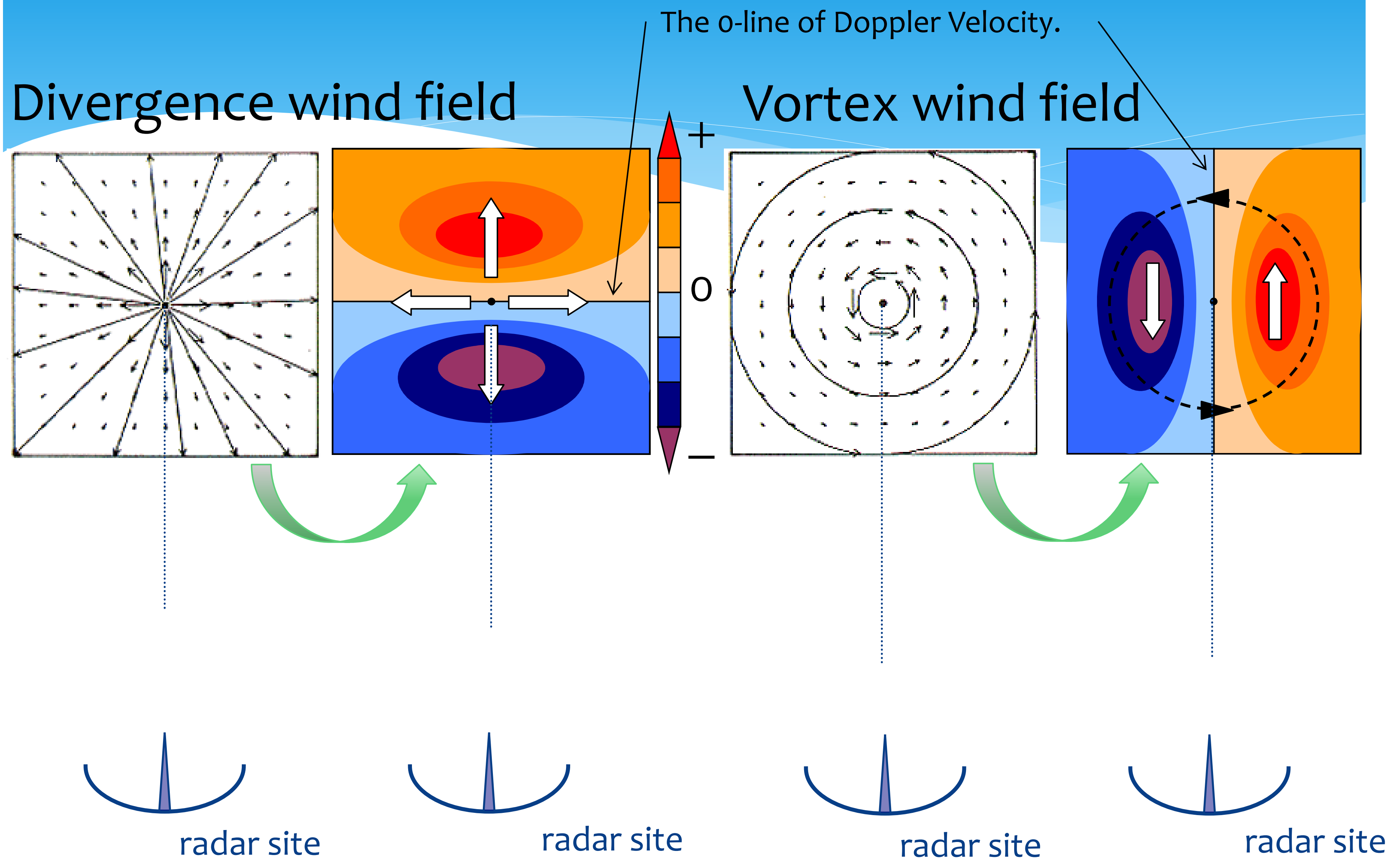
Doppler radar can only observe the radial velocity.
Conventionally, positive Doppler velocities are drawn in warm color,
in contrast, negative Doppler velocities are drawn in cold color.



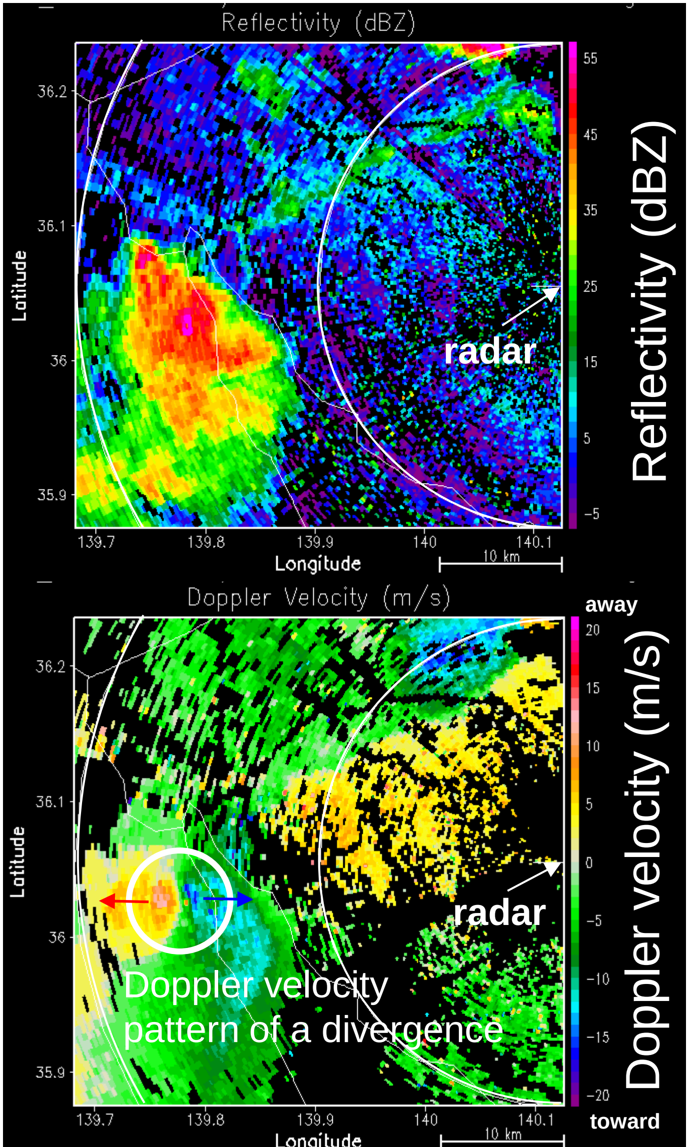
2014/05/12/23:30(JST)@Tokyo radar

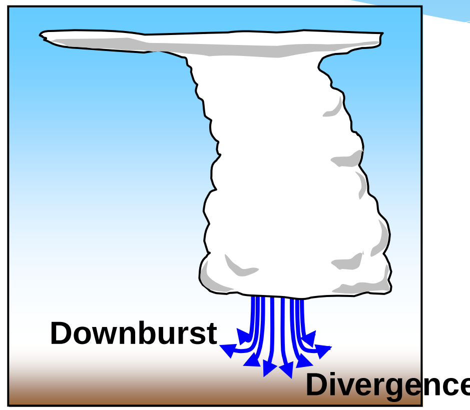
The 0-line of Doppler Velocity is perpendicular to the real wind direction.

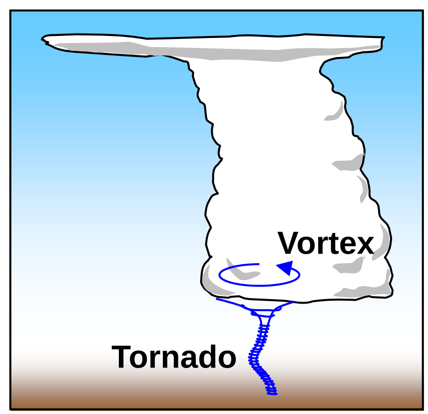
Typical pattern of Doppler Velocity (divergence and vortex)



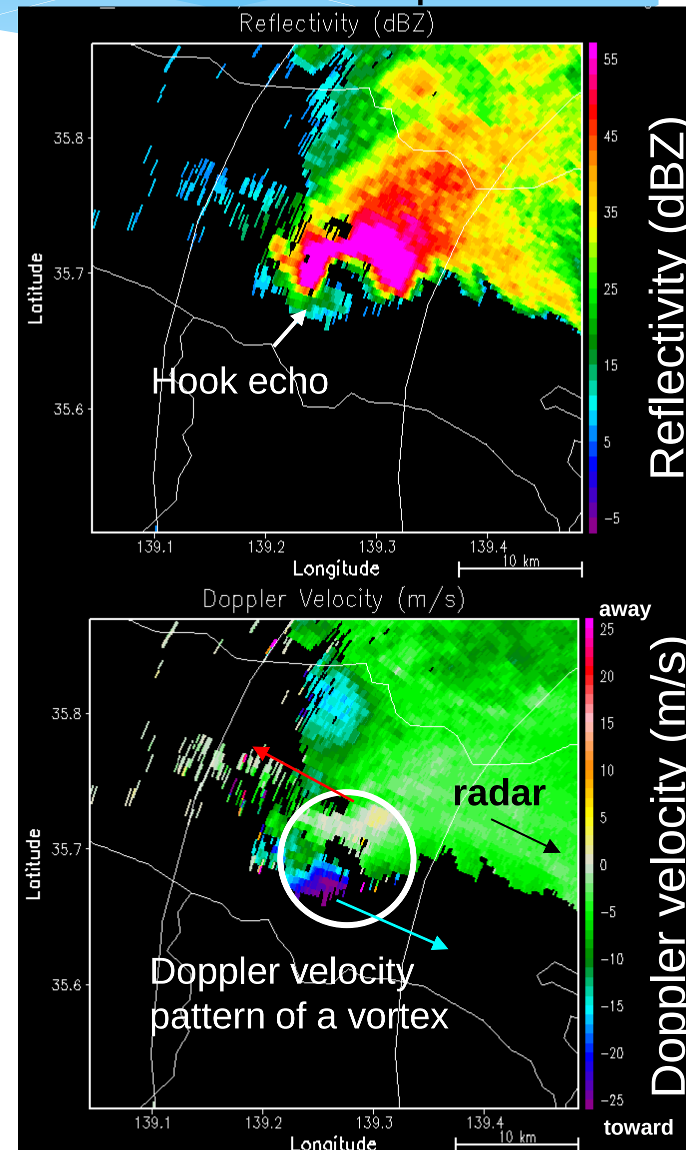
Downburst







Tornadic Supercell

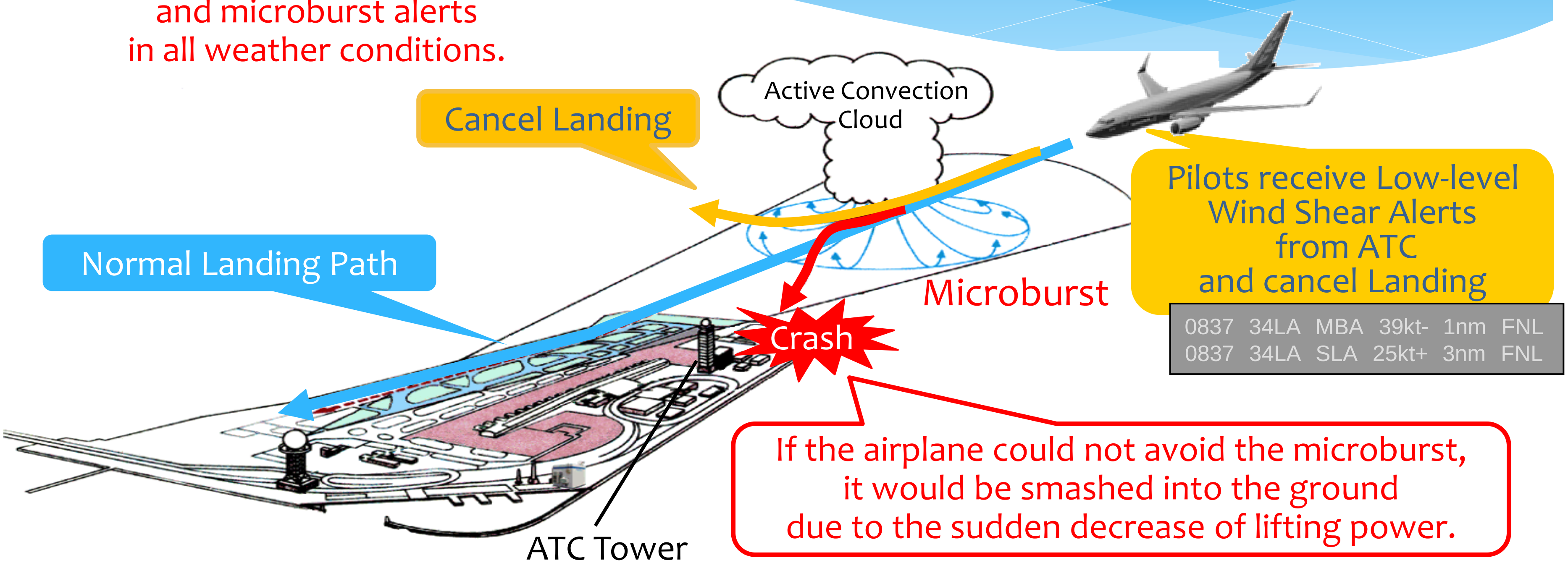


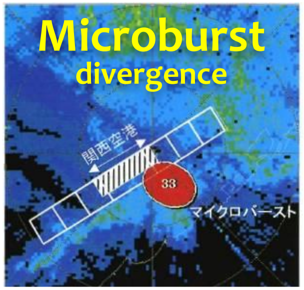
Applications of Doppler Observations

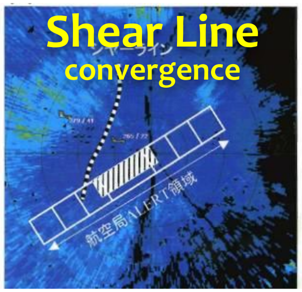
1) Microburst detection
   – Airport weather
2) Mesocyclone detection
   – Hazardous wind potential nowcast
3) Velocity Azimuth Display (VAD)
   – Vertical wind profile

1) Microburst detection

JMA provides low-level wind shear
and microburst alerts
in all weather conditions.

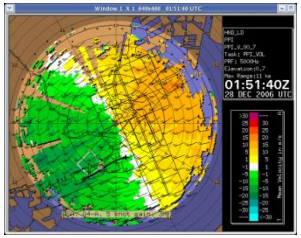






DRAW (TDWR) detects low-level wind shears in Rainy condition.

+ All Weather Observation

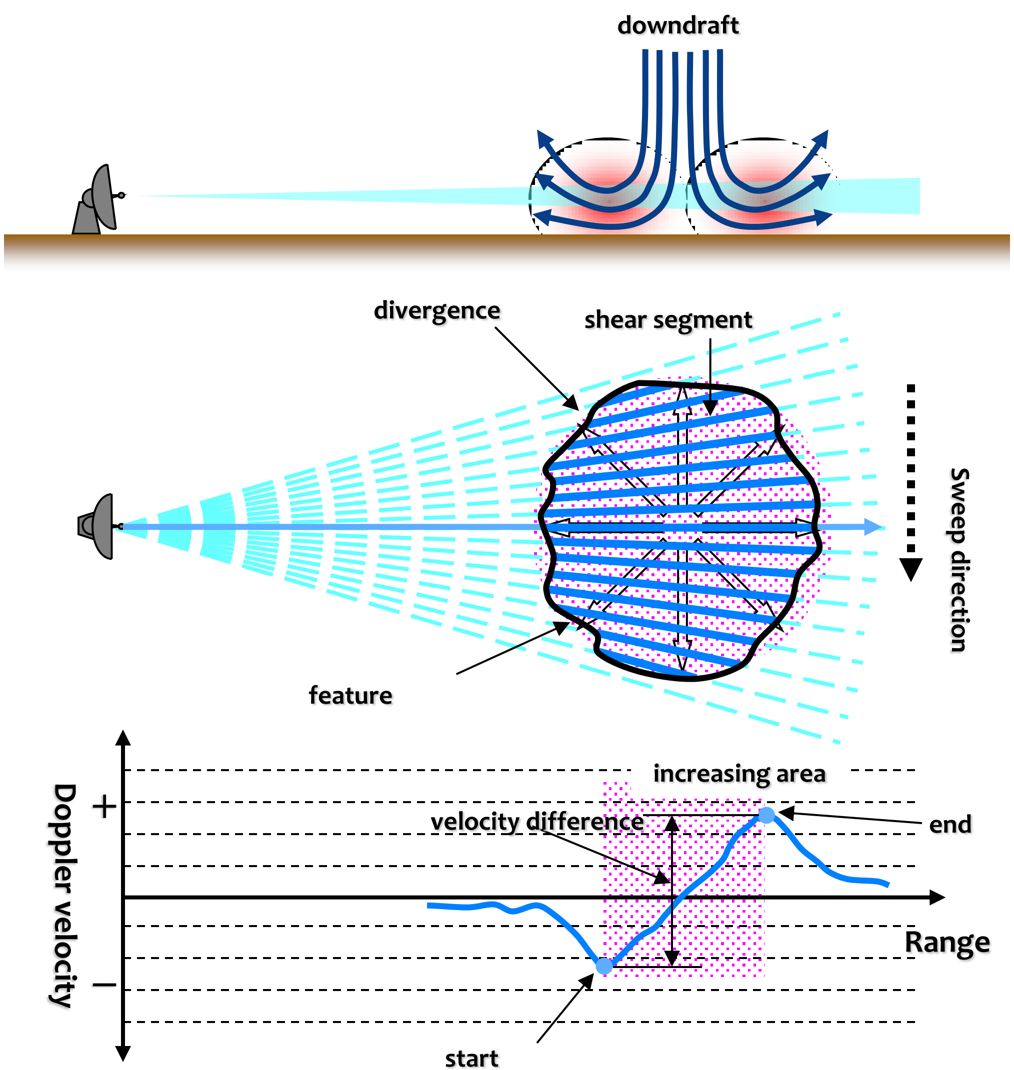


Doppler LIDAR detects low-level wind shears in Sunny or Cloudy condition.

DRAW: Doppler Radar for Airport Weather (a Japanese version of a TDWR)

LIDAR: Light Detection and Ranging

Detection Algorithm of Microburst in JMA



Step0. QC

Error data removal

Step1. Define shear segment

1. Search area of incresing Doppler Vel.
2. Start and end shear more than 2.5m/s/450m
3. Maximum velocity difference more than 5m/s

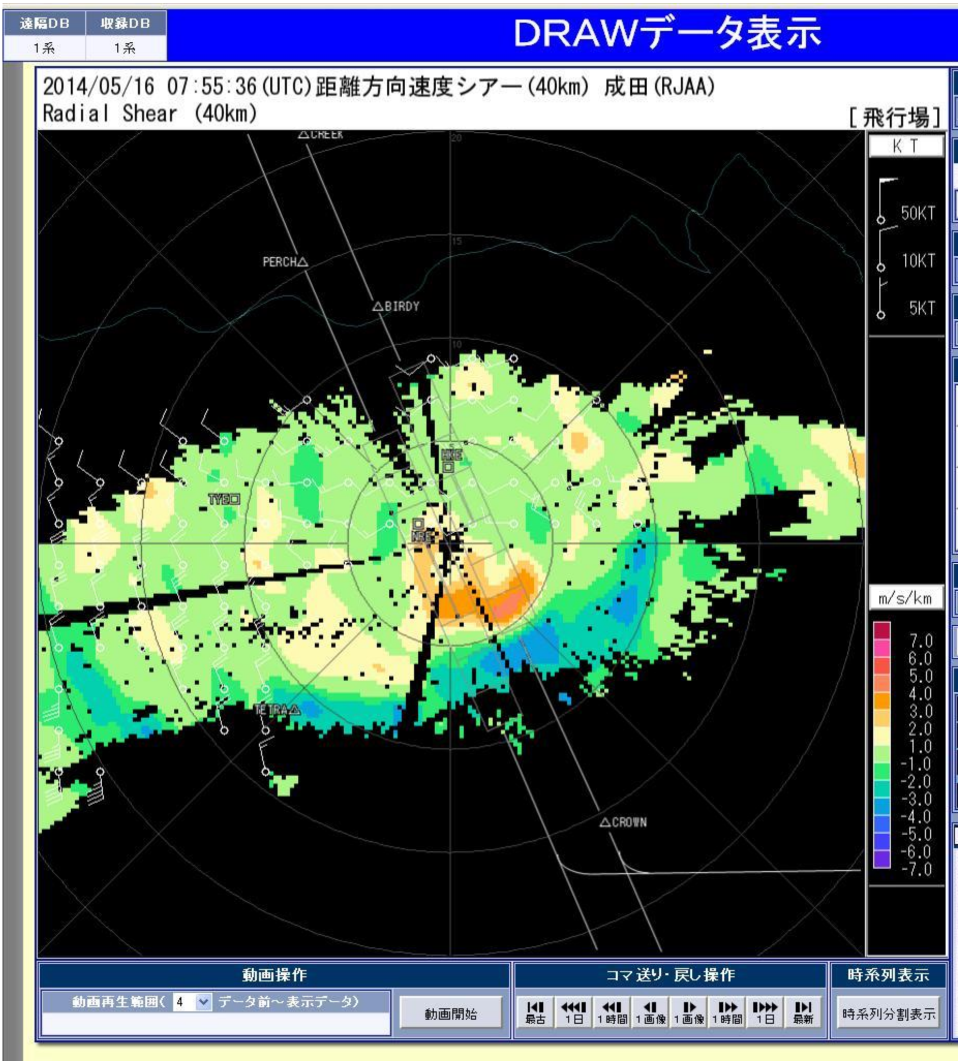
Step2. Define feature

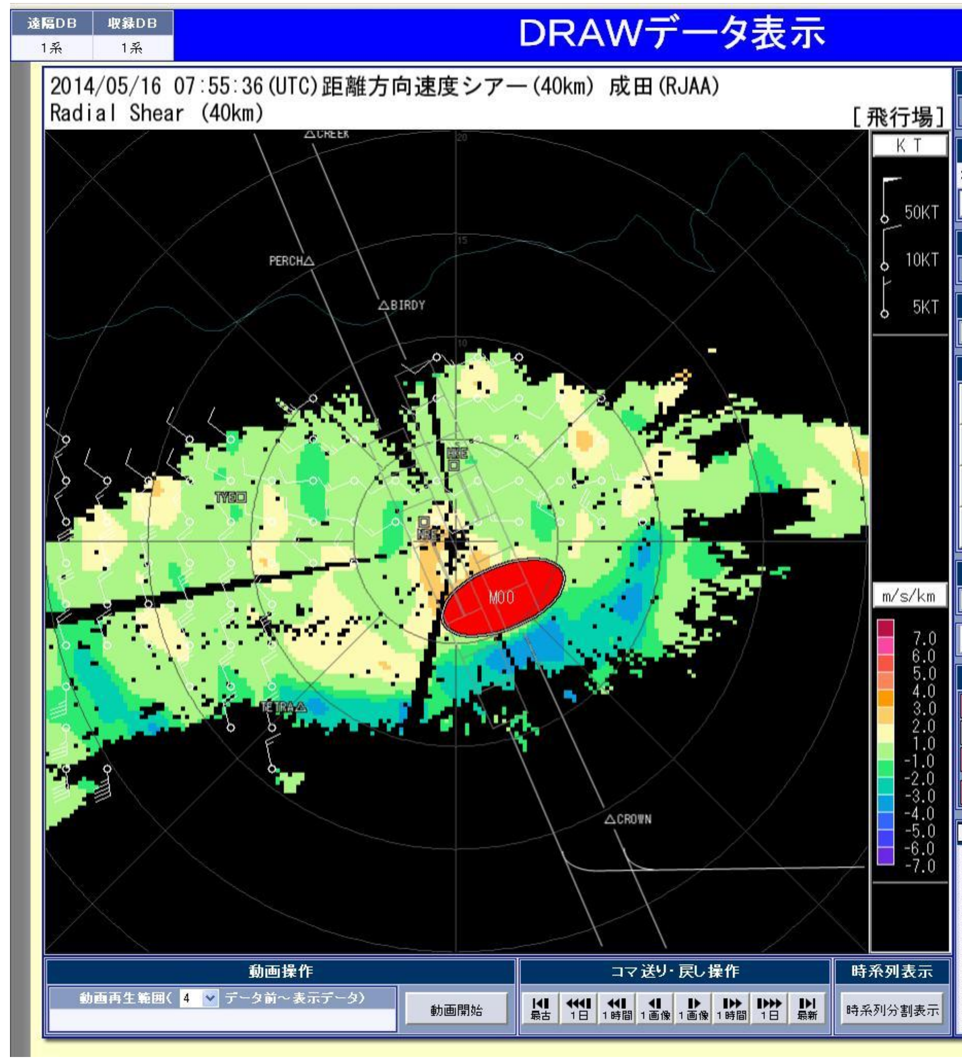
Define feature by combining adjacent segments.

Step3. Define Microburst

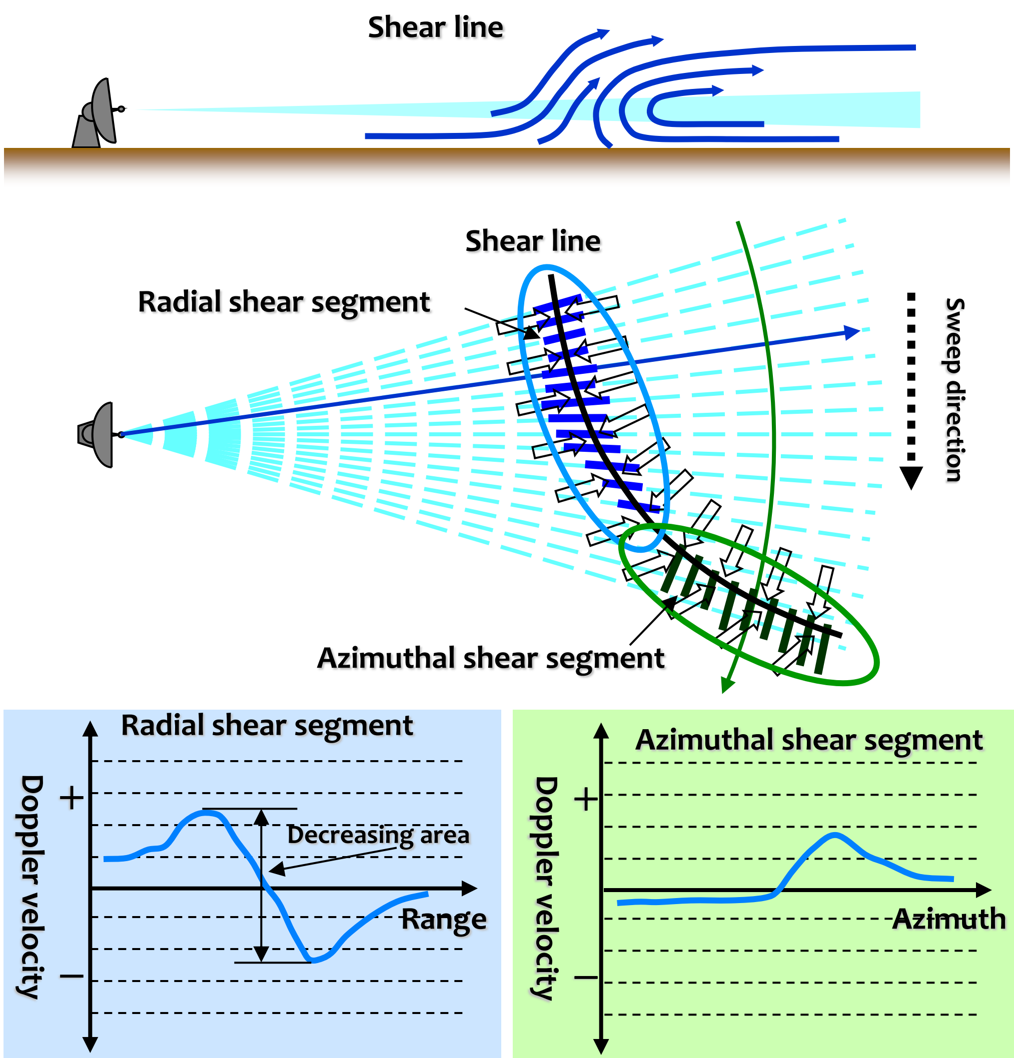
1. Area of feature more than $3km^2$
2. Maximum velocity difference more than 8m/s
3. Time correlation between present detection and past

Example of Microburst Detection





Detection Algorithm of Shear line in JMA



Step0. QC

Error data removal

Step1. Radial shear segment

1. Search area of incresing Doppler Vel.
2. Maximum shear more than 2.0m/s/km
3. Maximum velocity difference more than 5m/s

Step2. Azimuthal shear segment

1. Search area of Doppler Vel. change
2. Maximum shear more than 0.9m/s/deg.

Step3. Define feature

Define feature by combining adjacent segments.

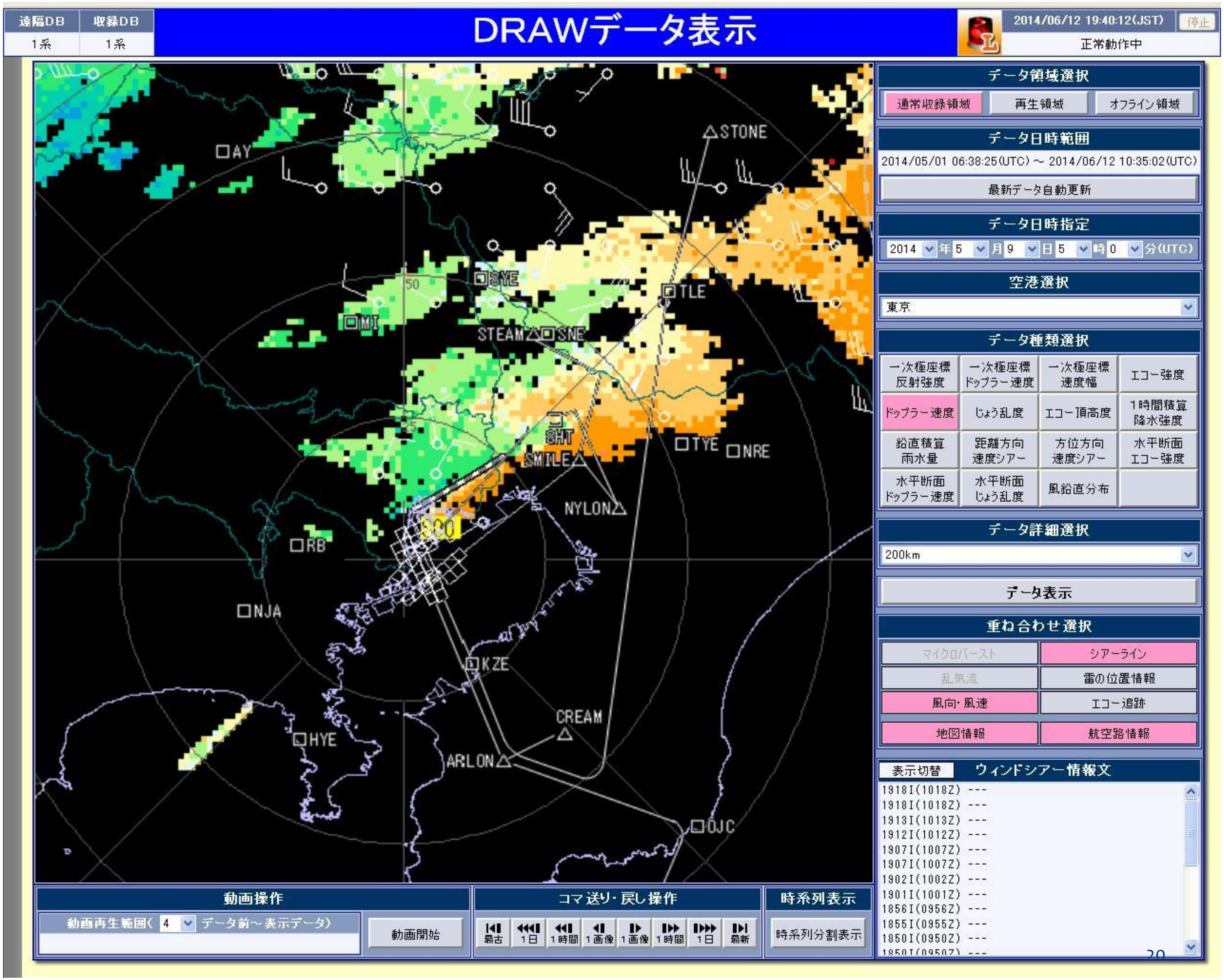
Step4. Define shear line

1. Length of feature more than 10km.
2. Correlation bettween el=0.7 and 1.1.

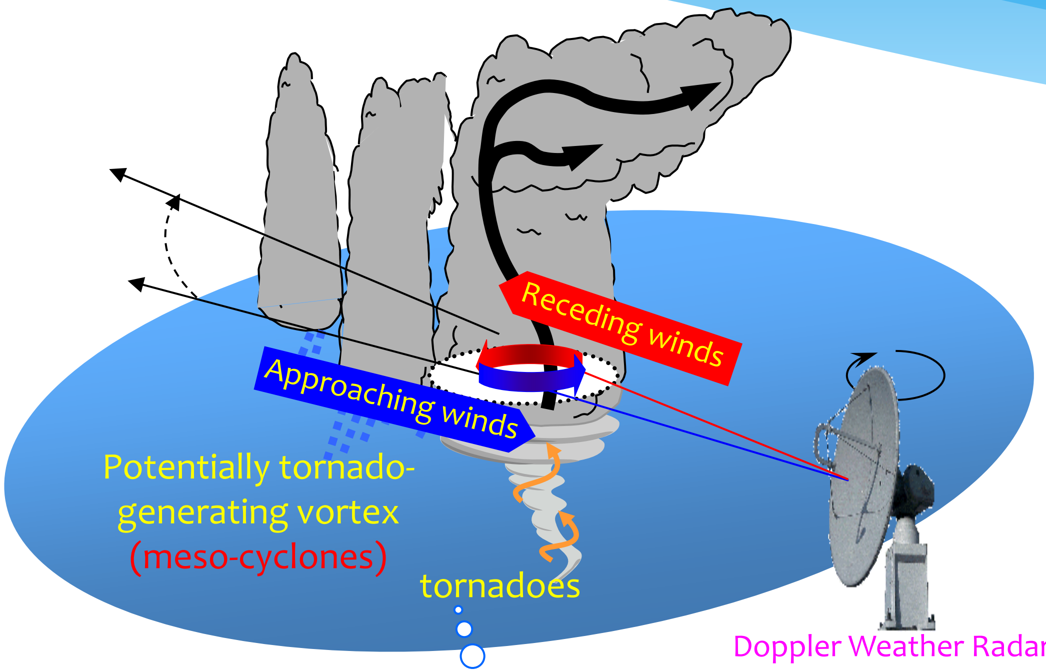
Step5. Wind vector

Calculate wind vector in both side of shear line by VVP method

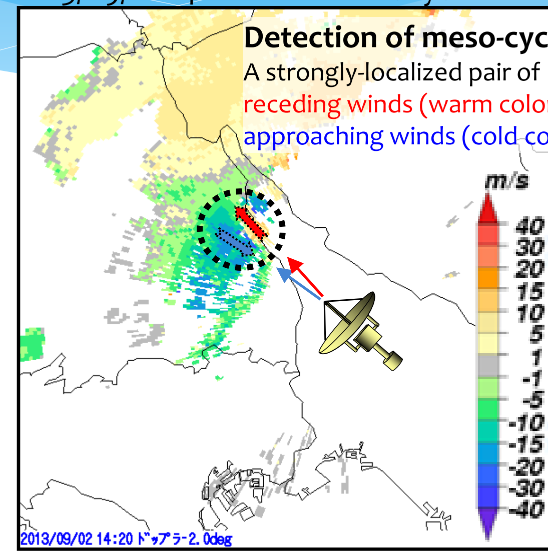
Example of Shear Line Detection



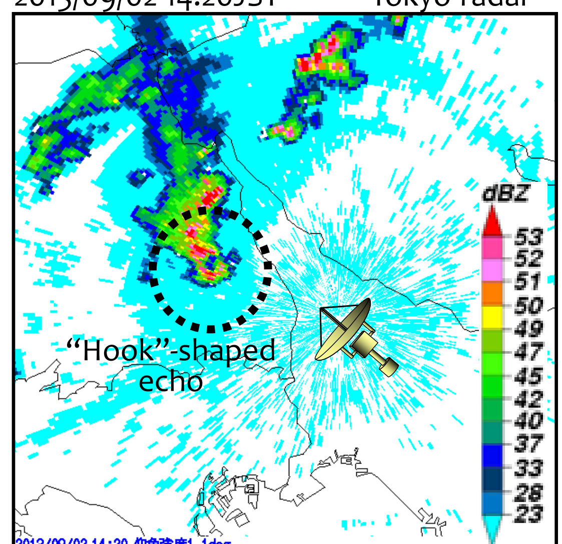
2) Meso-cyclone Detection



Radial-wind component
2013/09/02 14:20JST Tokyo-radar

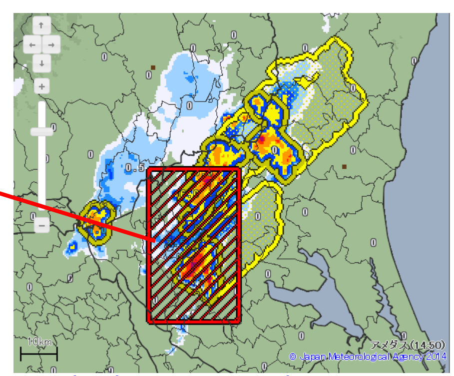


Echo intensity
2013/09/02 14:20JST Tokyo-radar



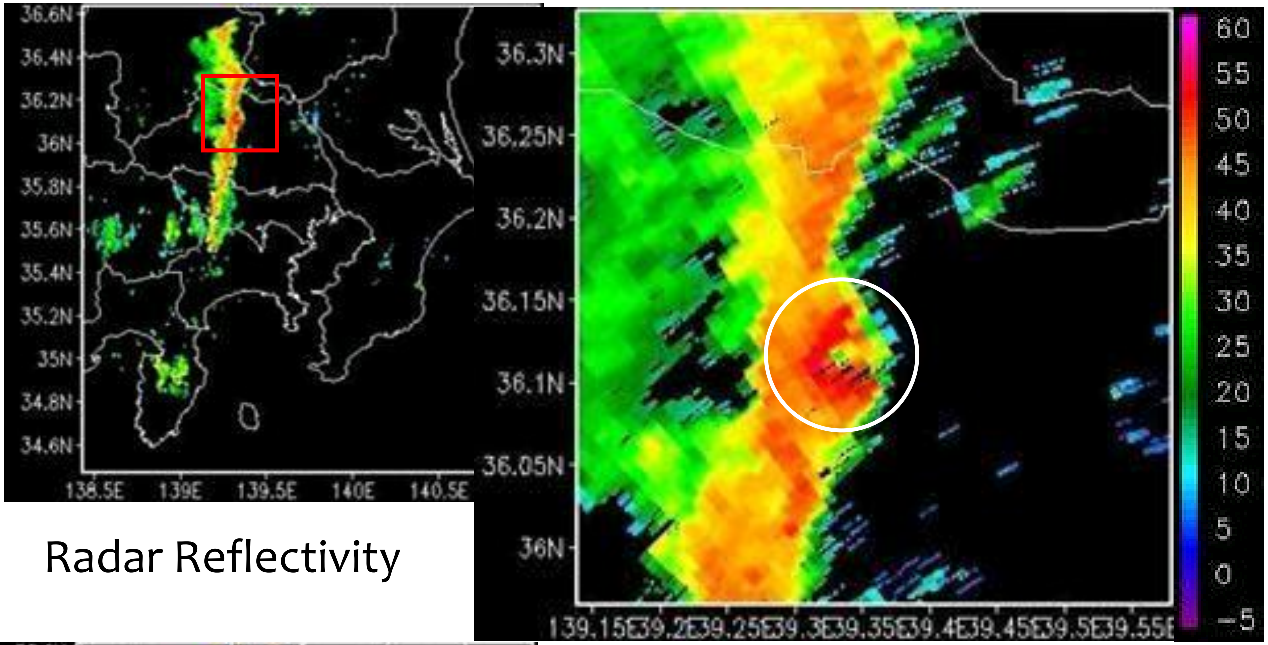
Detection of the potential outbreak area of tornadoes/gusts using radar observation data and numerical prediction results

Provision of effective information on the risk of tornado outbreaks

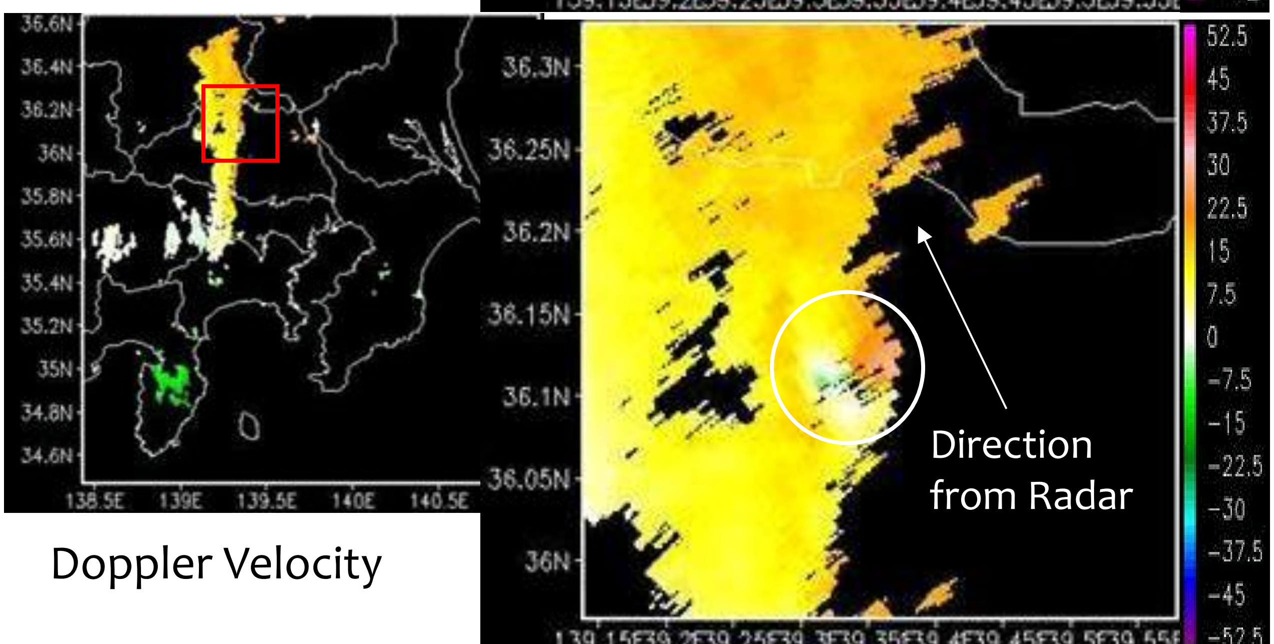


(JMA Web page)
http://www.jma.go.jp/en/highresorad/

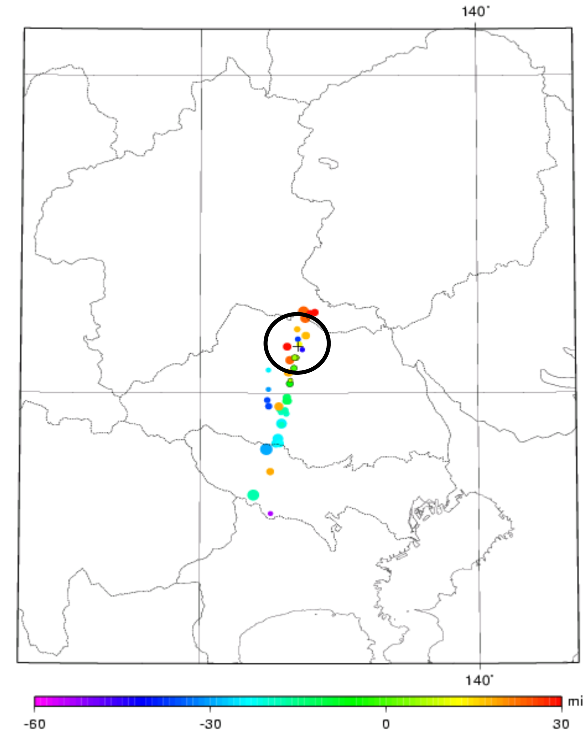
Example of automatic meso-cyclone detection



Radar Reflectivity



Doppler Velocity



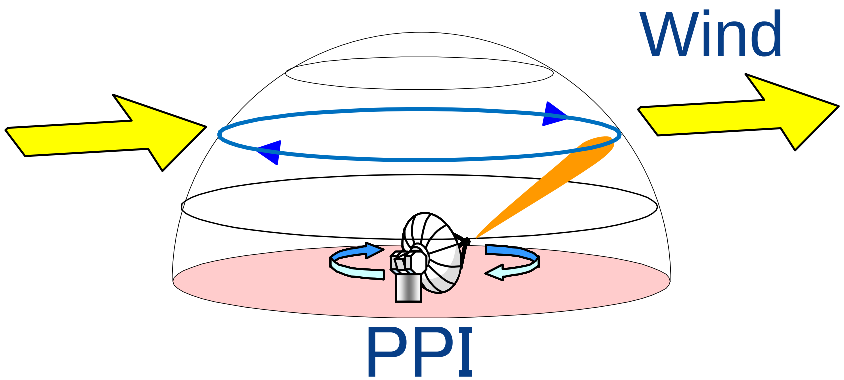
1h before tornado

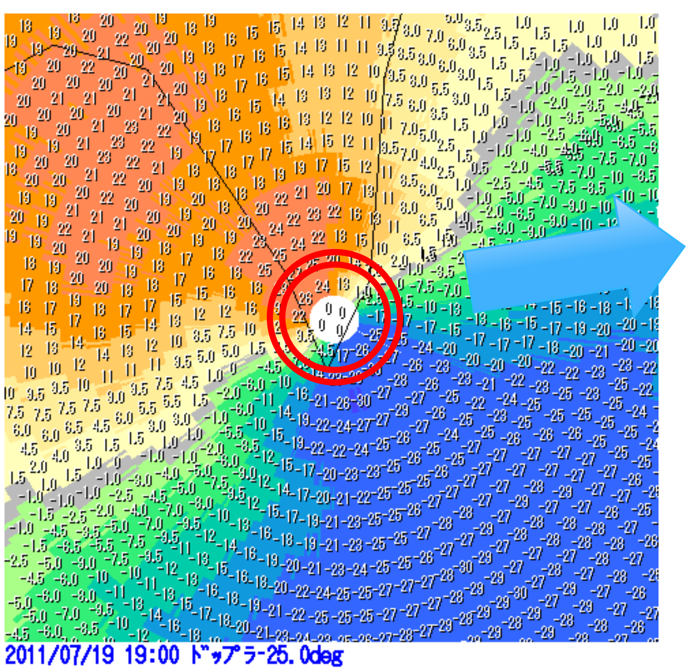
30min after tornado

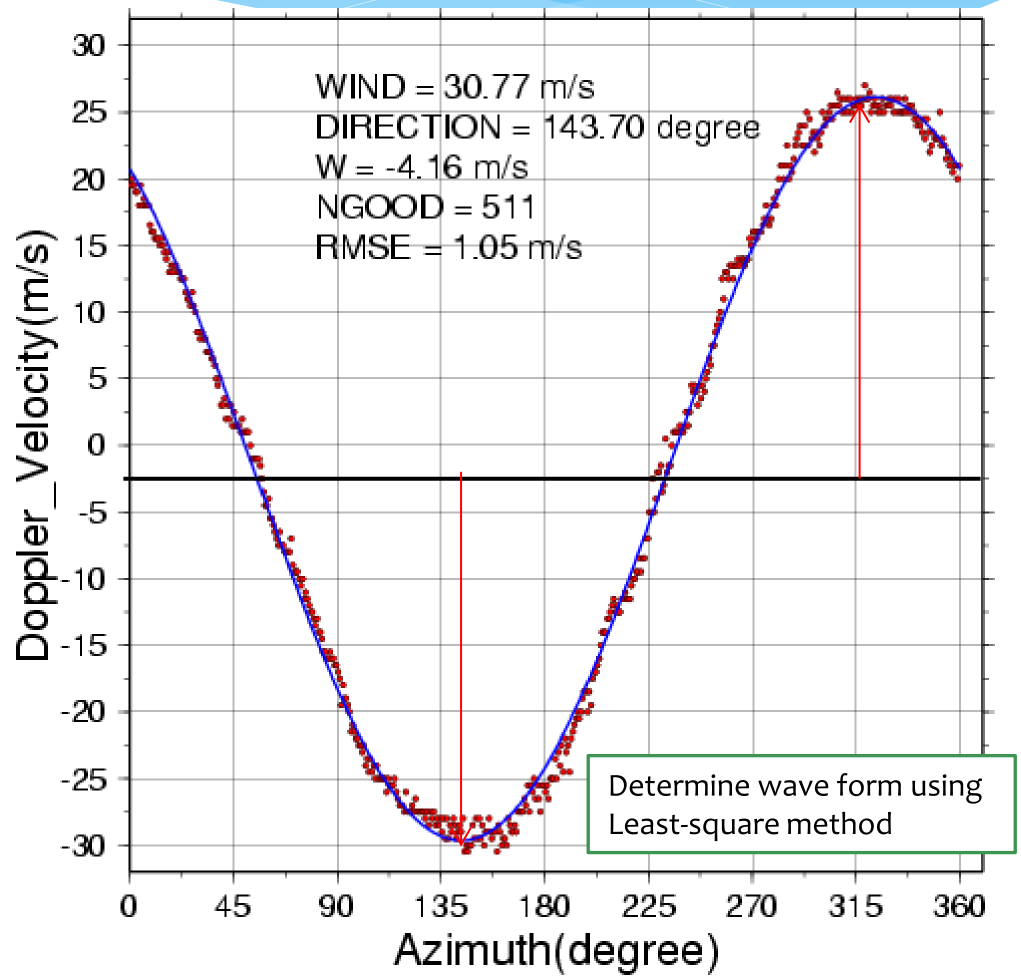
Series of detected meso-cyclones

August 8, 2003

3) Velocity Azimuth Display (VAD)



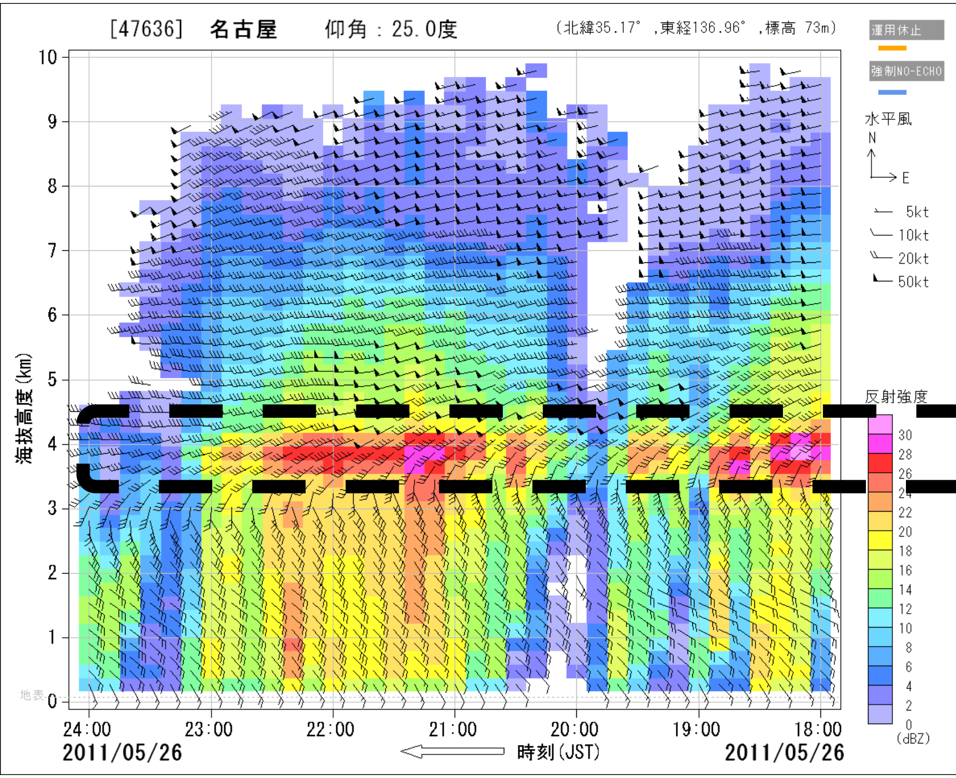




Courtesy of Kajiwara and Ono

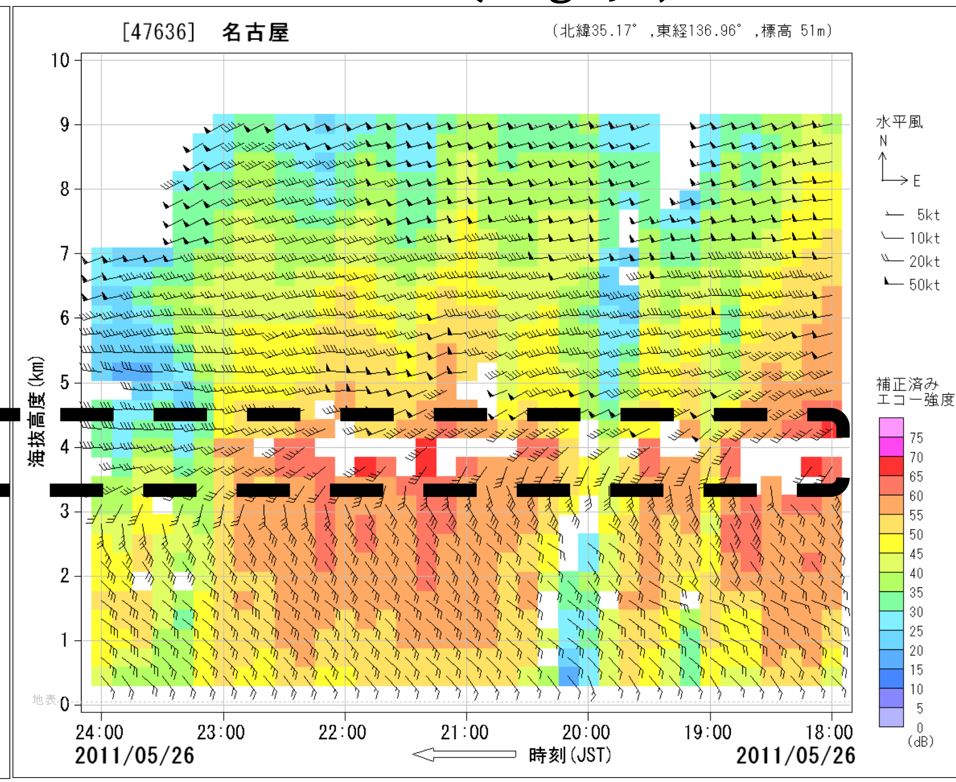
3) Velocity Azimuth Display (VAD)

VAD (Nagoya radar)



Color shade indicates reflectivity

Wind Profiler (Nagoya)



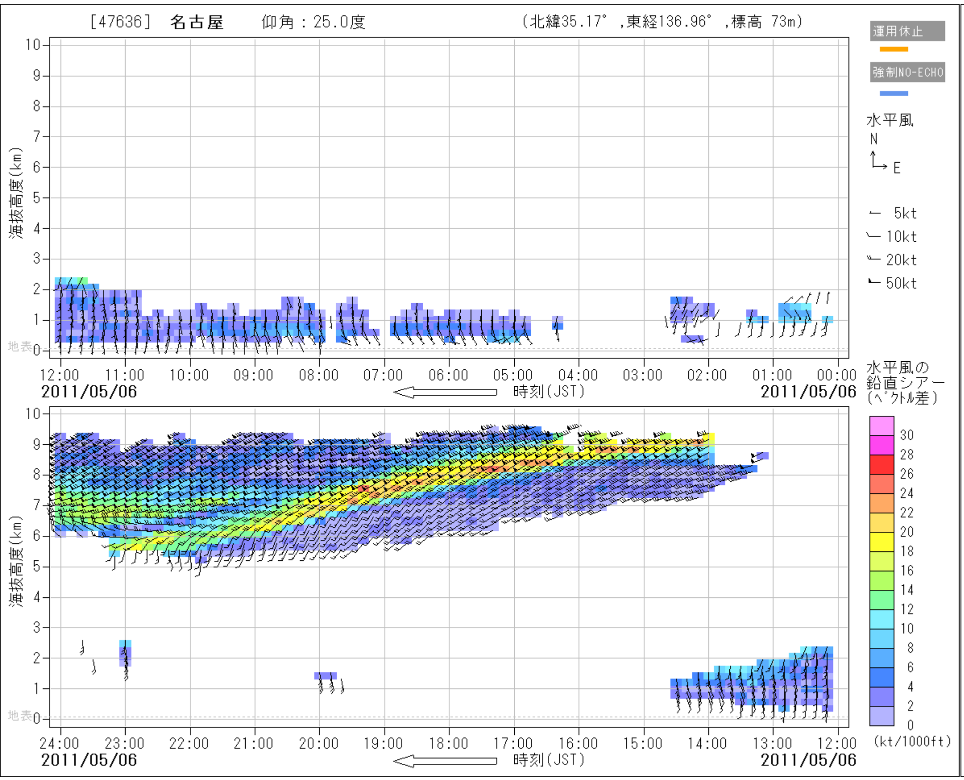
Color shade indicates signal level

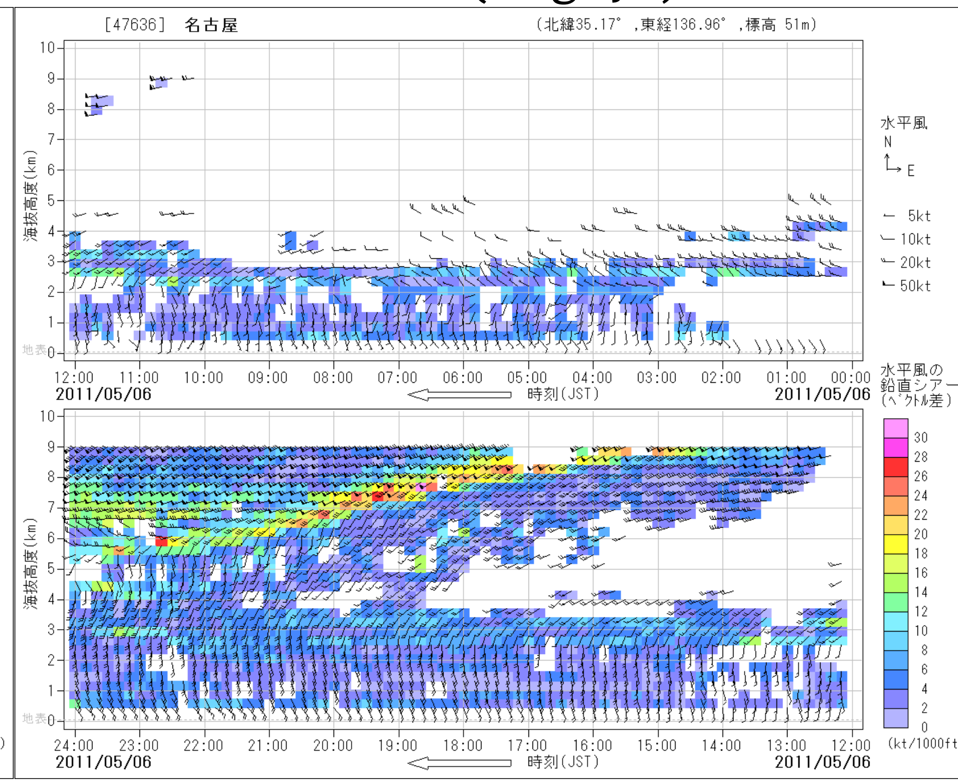
Courtesy of Kajiwara and Ono

3) Velocity Azimuth Display (VAD)

VAD (Nagoya radar)

Wind Profiler (Nagoya)





Color shade indicates vertical shear

Color shade indicates vertical shear

Courtesy of Kajiwara and Ono

Summary

- The maximum measurable Doppler velocity is determined by PRF and wave length.
- Dual-PRF method can extend maximum measurable Doppler velocity.
- Doppler radar can only observe the radial component of a target's velocity.
- Doppler velocity is useful for
  - Detecting low level wind shear
  - Detecting meso-cyclone
  - Retrieving vertical wind profile (VAD).