# Radar Applications 2
# Doppler velocity

1 February 2024

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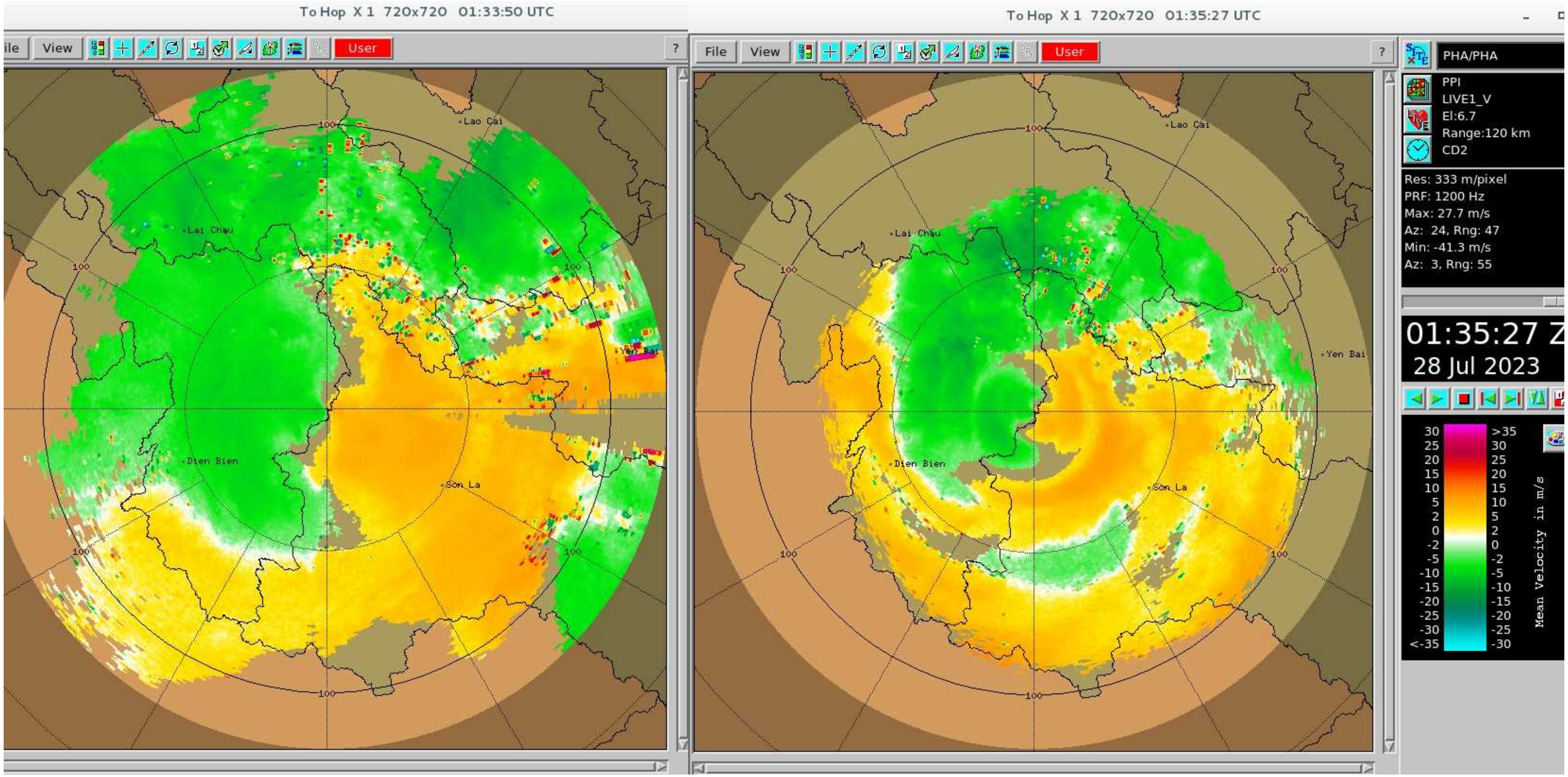
Former JICA / JMA

# What kind of information can you extract from these figures ?




EL=2.7deg PPI

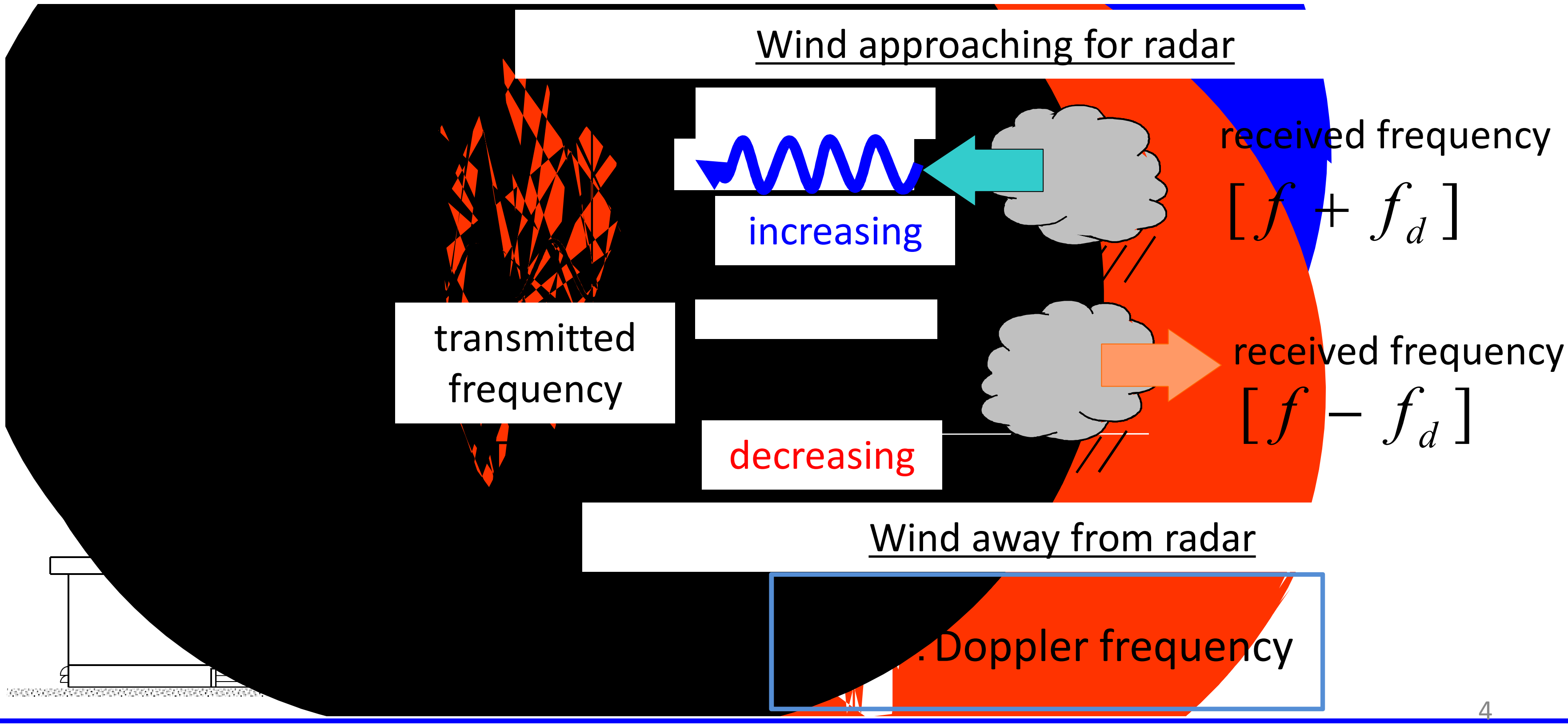
EL=6.5deg PPI

# Contents

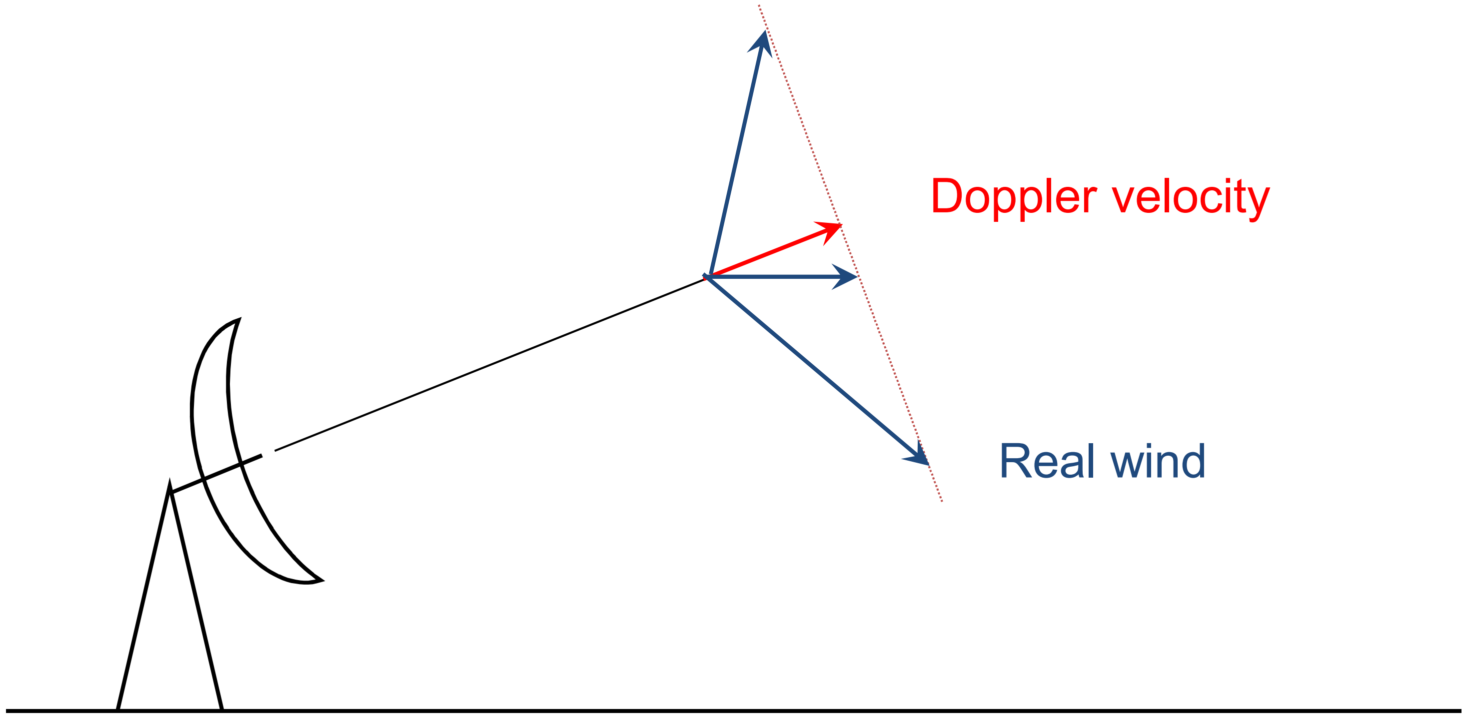
- Principle of Doppler velocity
- Applications of Doppler Observations
  – VAD, VVP
  – Low level wind shear detection
  – Mesocyclone detection
- Issues in using Doppler velocity
  – Velocity aliasing
  – Doppler velocity pattern
- Summary

# Principle of Doppler velocity

When radio wave reflected by moving raindrop or snow is received, its frequency changes. This amount of frequency change calls ‘Doppler frequency’. In case of target approaching, Doppler frequency increases (wavelength shortens), and in case of target separating, Doppler frequency decreases (wavelength lengthens).



# Meaning of Doppler velocity



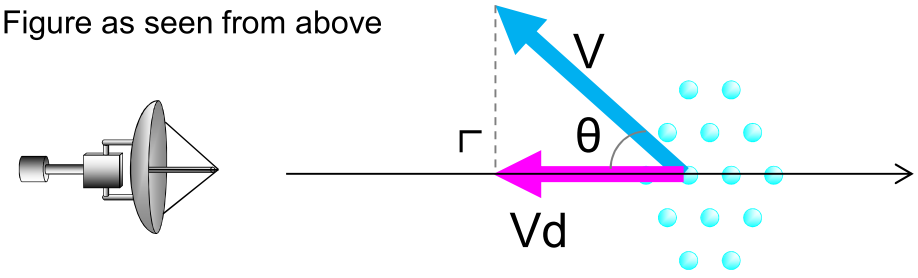

Doppler radar can not detect real wind directly, but can only detect the component of velocity along radar beam.

# 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

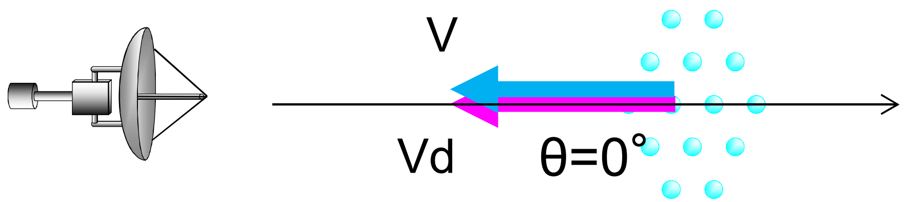



By putting θ as the angle formed by radial direction and the target's moving direction,

Doppler velocity(Vd) is expressed as

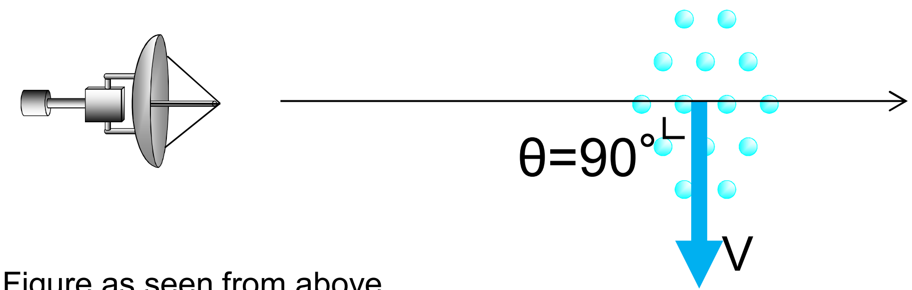
$$Vd=V\cos\theta$$

Figure as seen from above




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

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



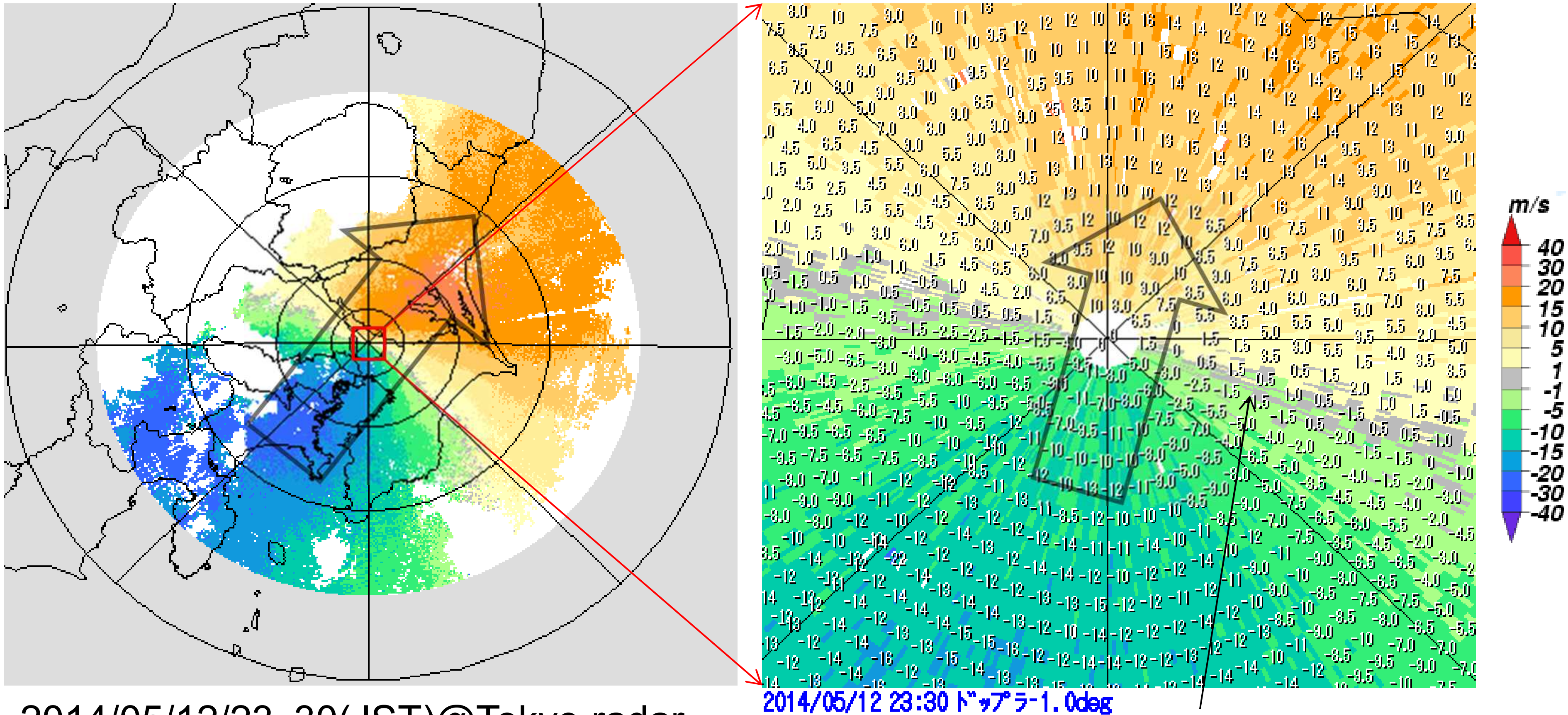

When θ=π/2, Doppler velocity is 0.

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

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.

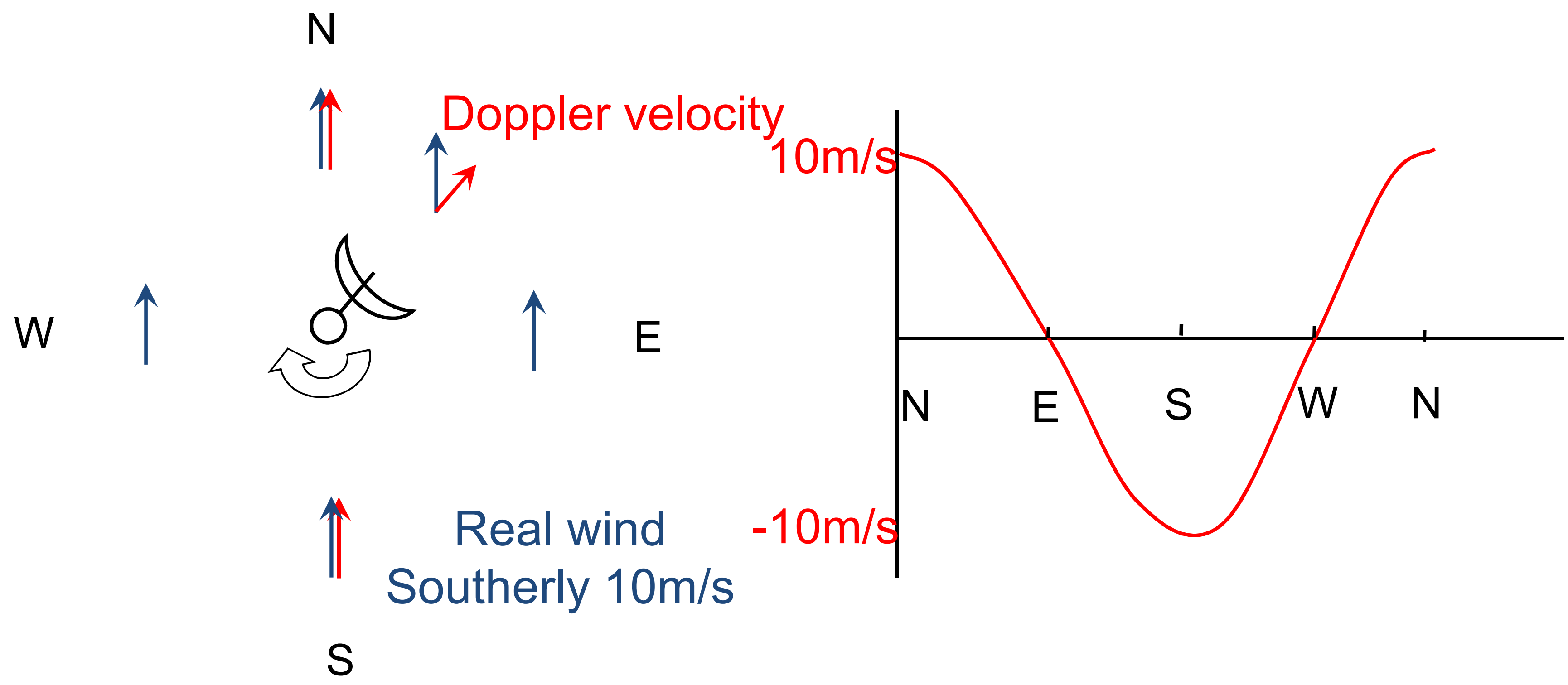



2014/05/12/23：30(JST)@Tokyo radar

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

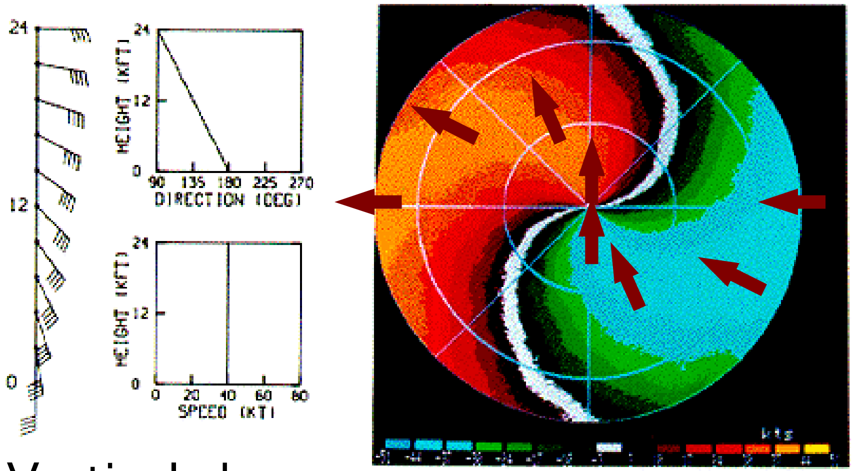
# Estimation of wind speed / direction by VAD method

# Estimation of wind speed / direction（VAD method）



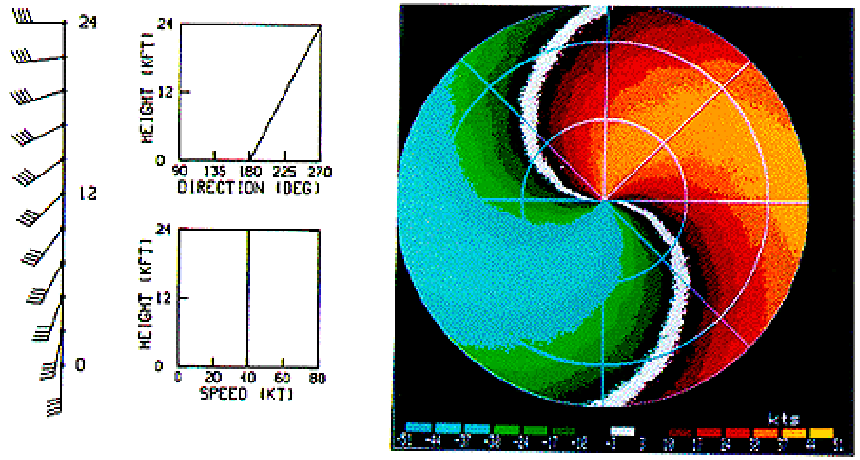
## Vertical shear (wind direction)

center: radar site



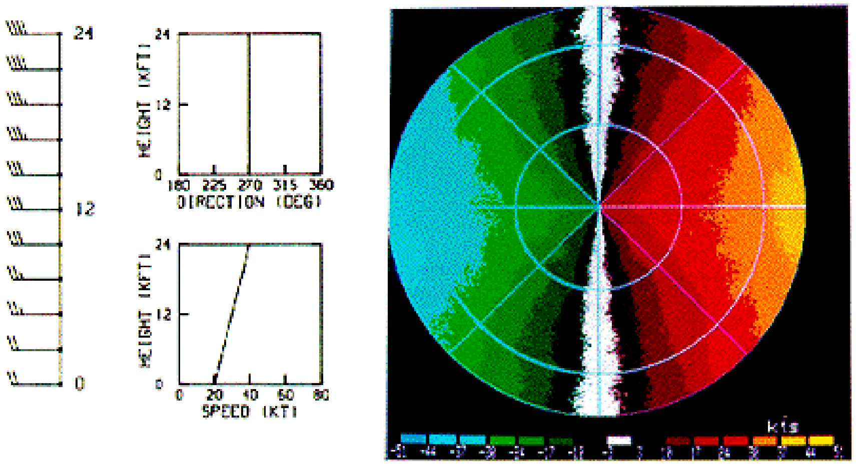

## Vertical shear (wind direction)

center: radar site



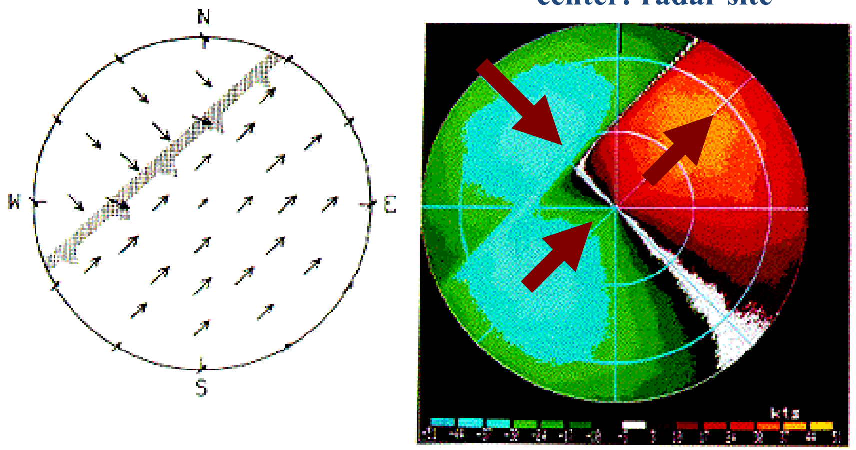

## Vertical shear (wind speed)

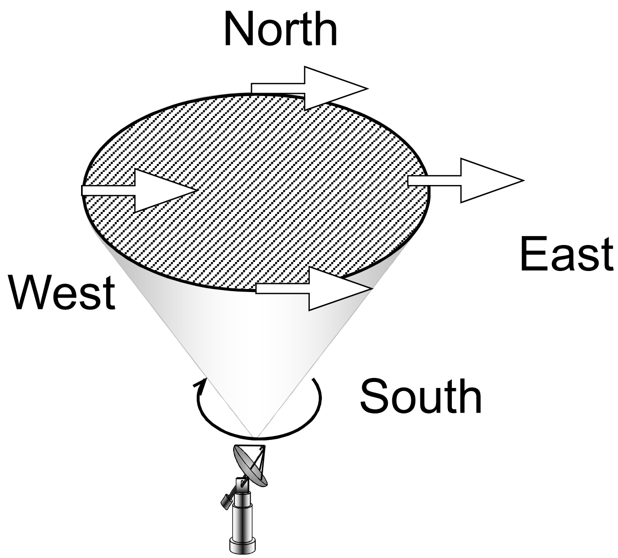
center: radar site



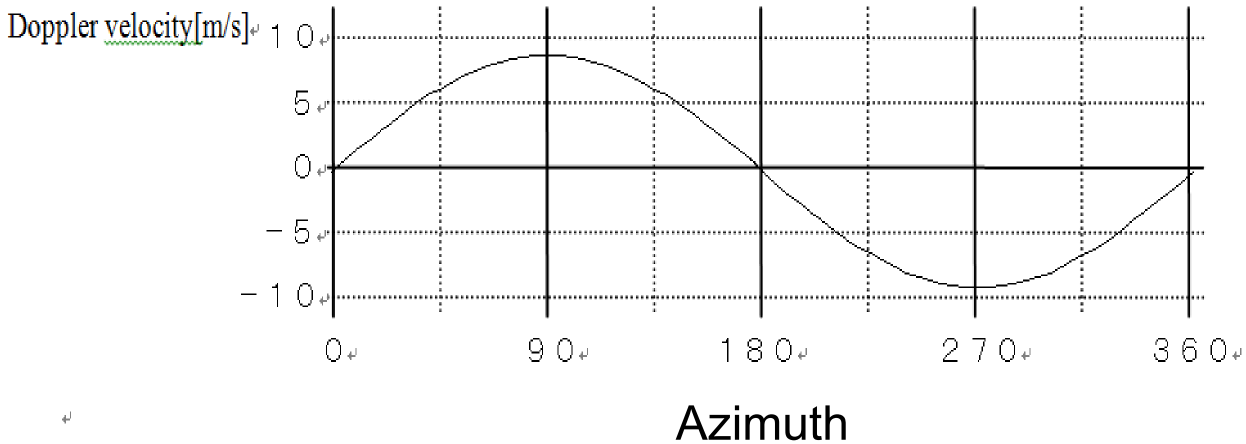

## Horizontal shear (wind direction)

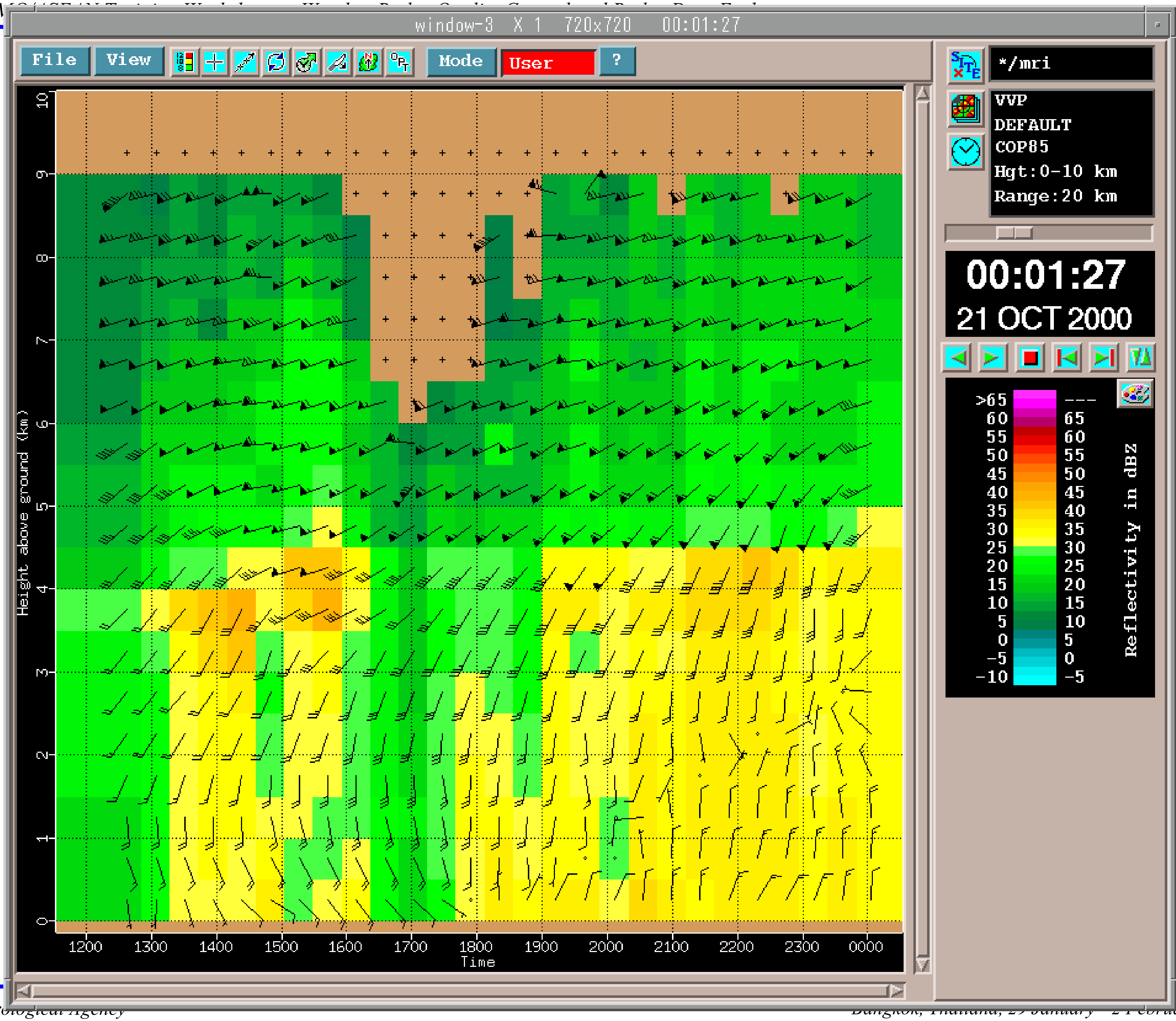
center: radar site





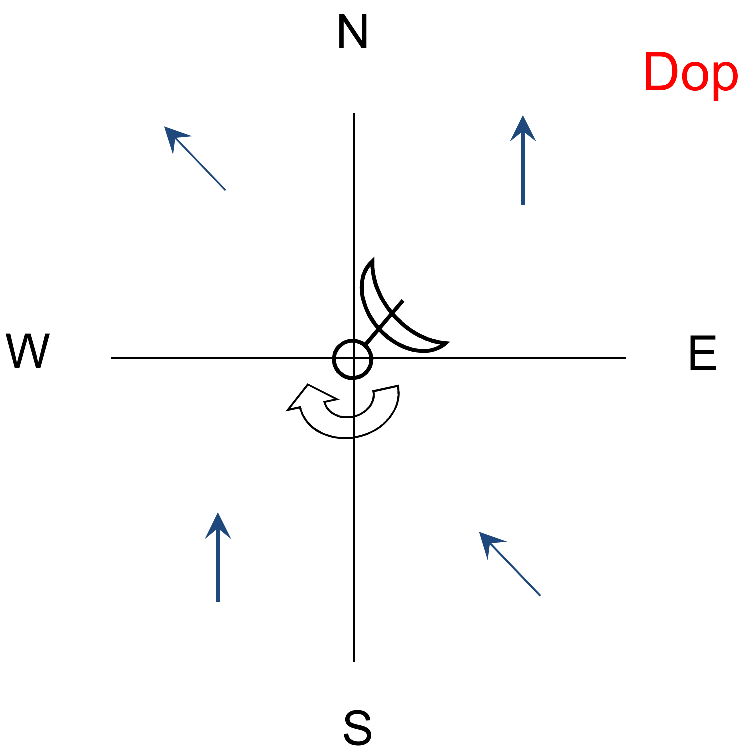

Convert from Doppler velocity to wind speed / direction by VAD method.

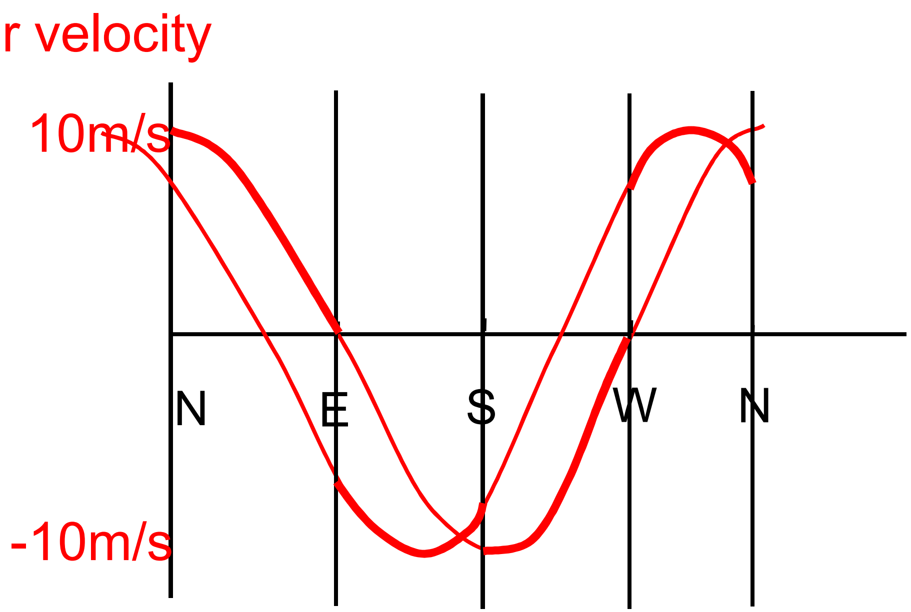



window-3 X 1 720x720 00:01:27
File
View
Mode
User
?
*/mri
VVP
DEFAULT
COP85
Hgt:0-10 km
Range:20 km
00:01:27
21 OCT 2000
Height above ground (km)
Time
1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 0000
Reflectivity in dBZ
>65 60 55 50 45 40 35 30 25 20 15 10 5 0 -5 -10
--- 65 60 55 50 45 40 35 30 25 20 15 10 5 0 -5

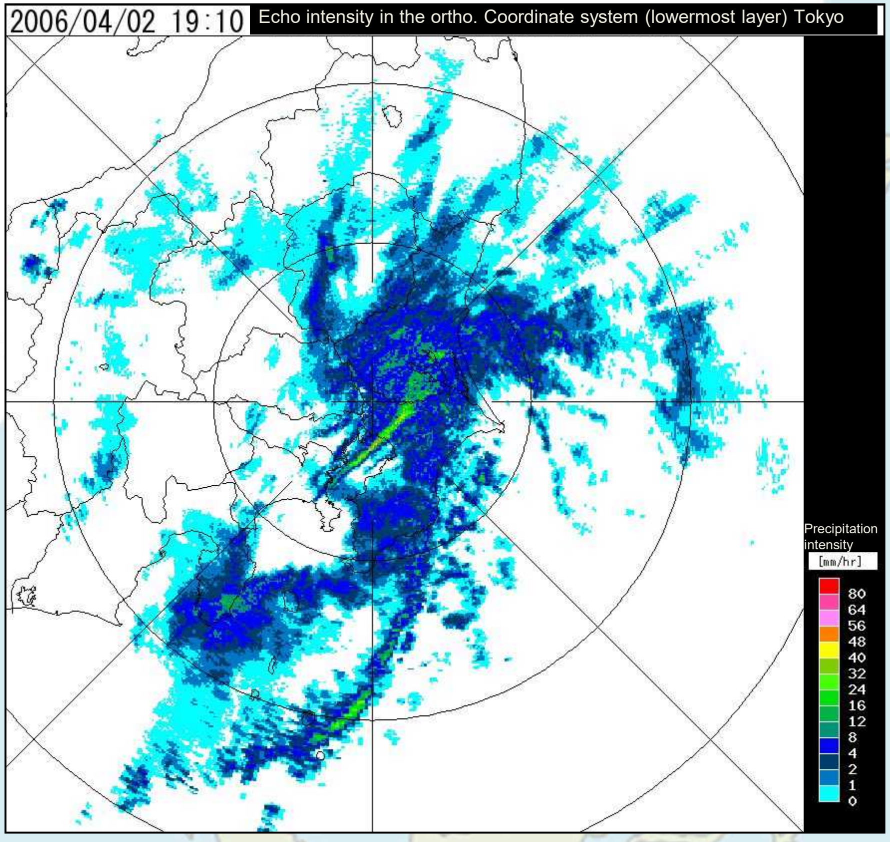
# Estimation of wind field by VVP method

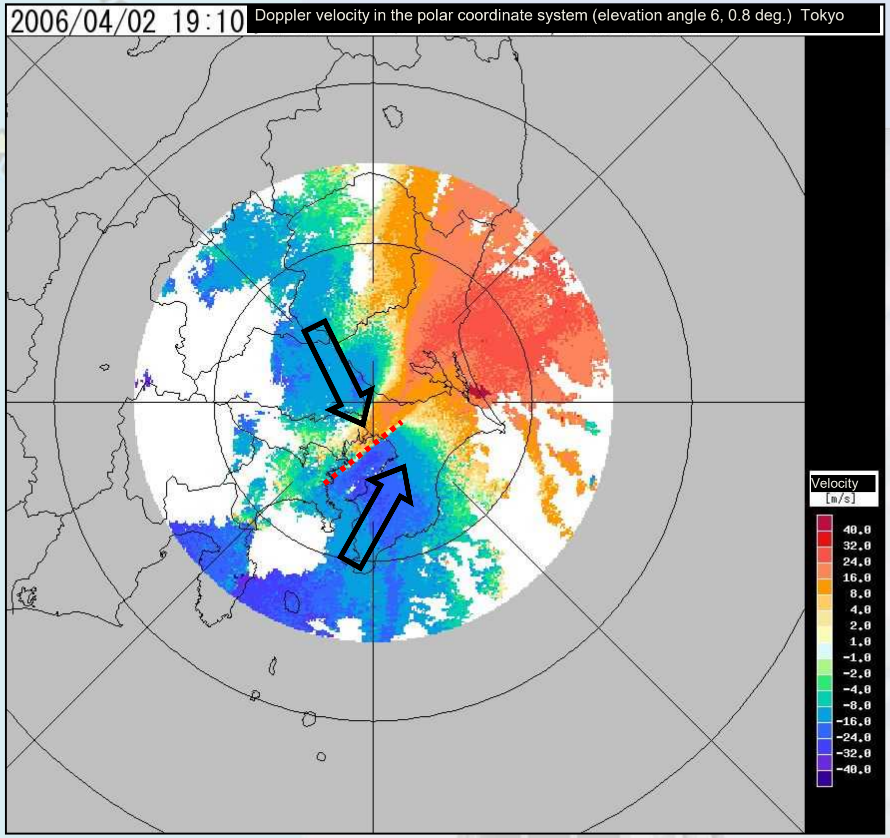
# Estimation of wind field（VVP method）



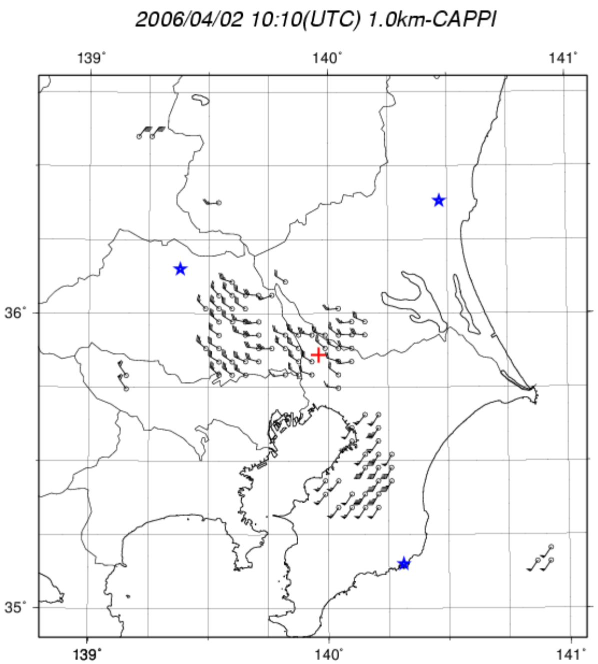



# Observation of convergence line

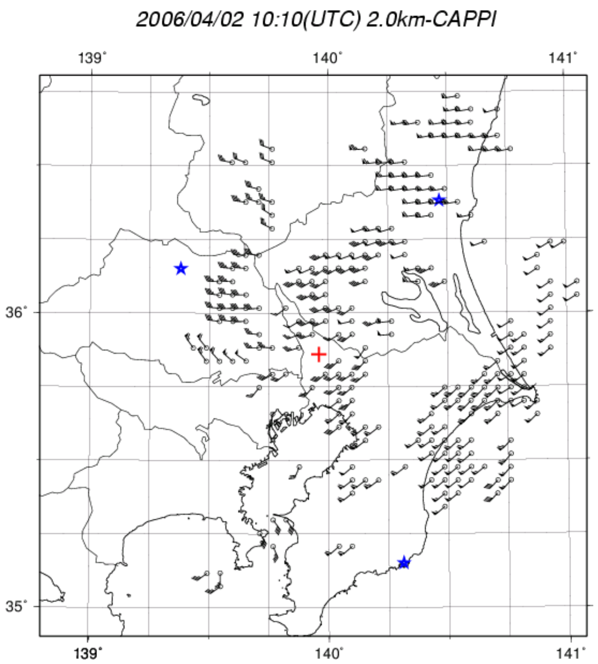


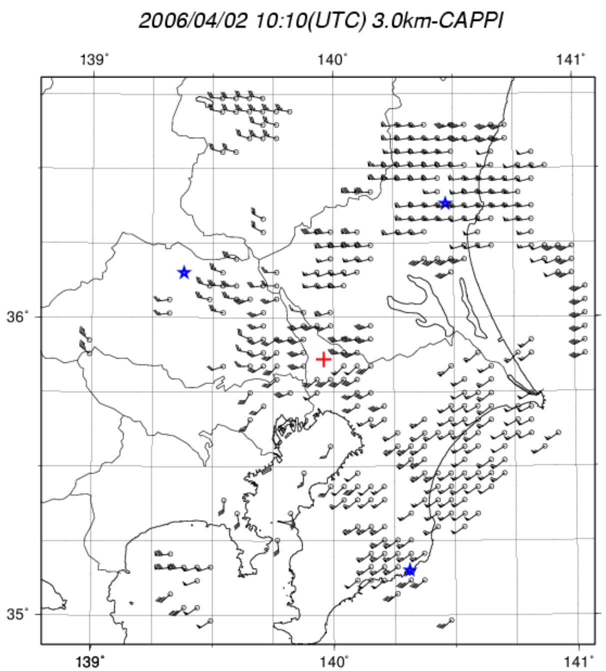
# Wind field around convergence line (VVP)




Altitude 1 km




Altitude 2 km




Altitude 3 km

# Other useful applications of Doppler Observations

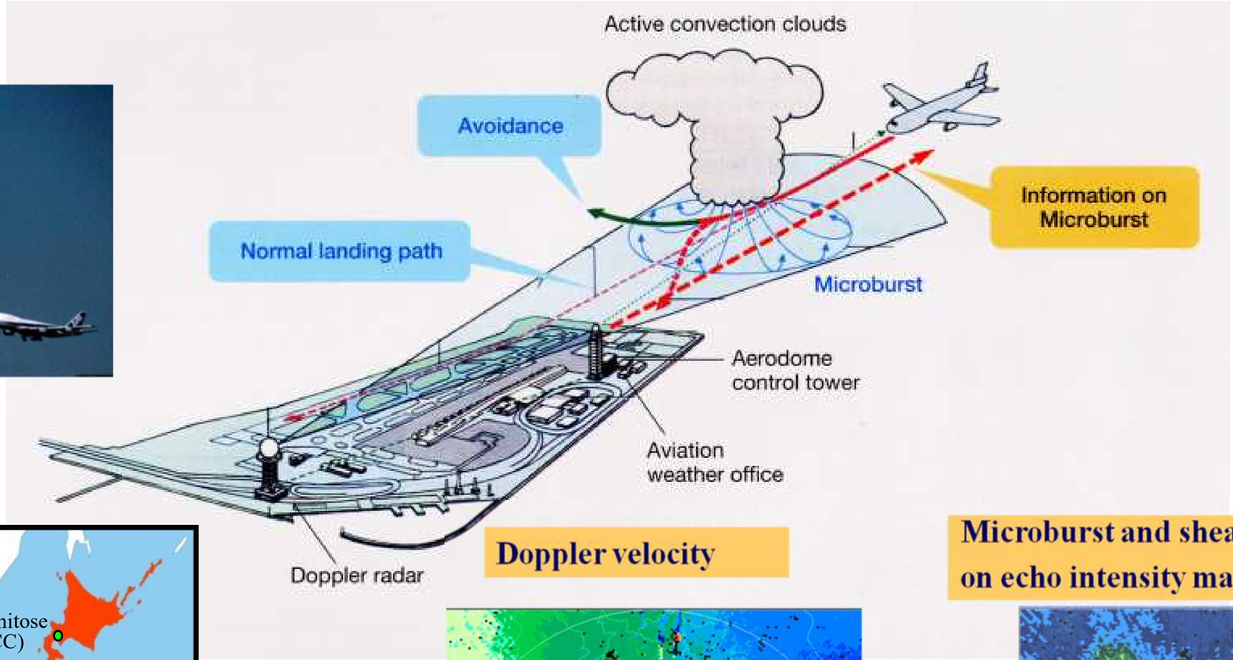
1) Microburst / Shear line detection

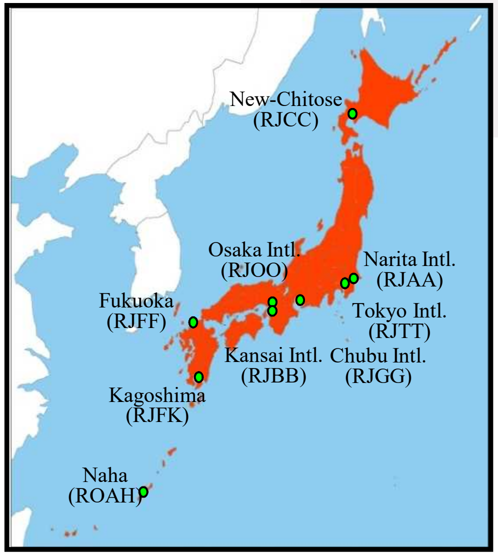
– for Airport weather

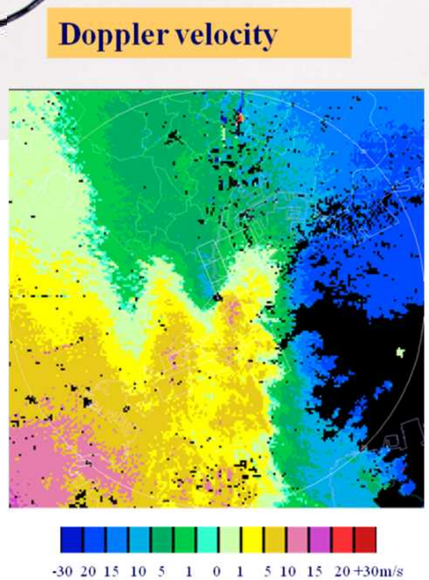
2) Mesocyclone detection

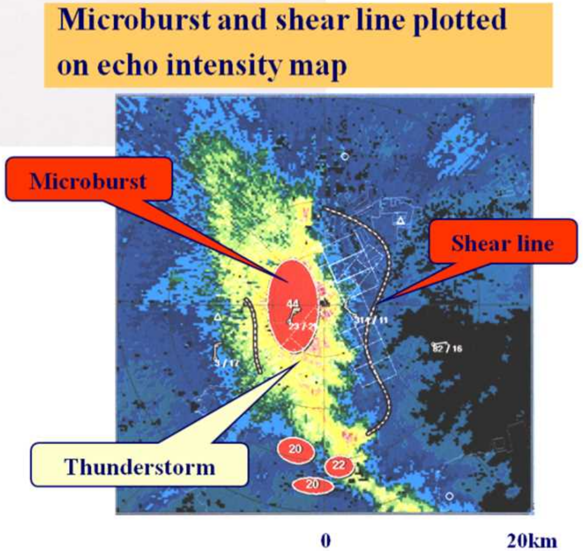
– Hazardous wind potential nowcast

# Microburst detection

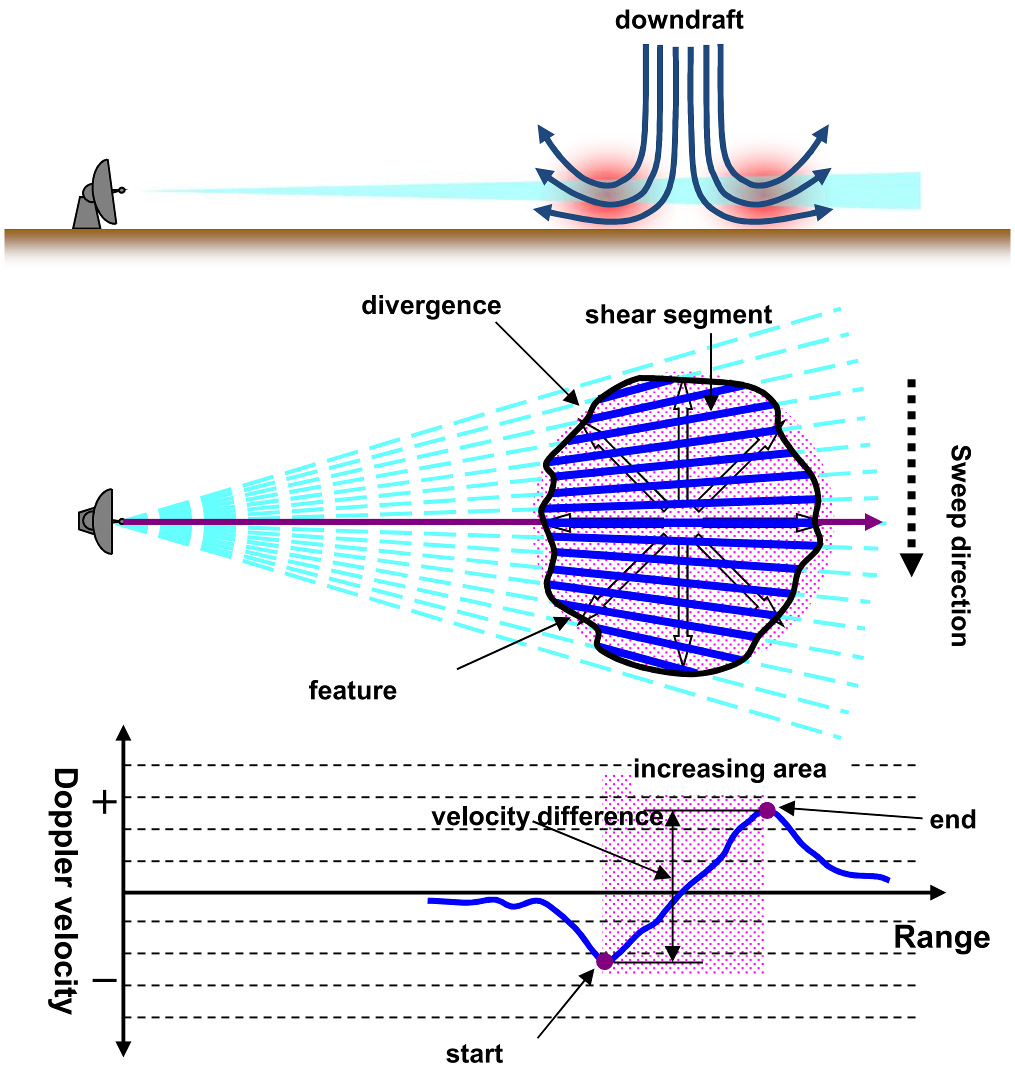


# Detection Algorithm of Microburst in JMA




## 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

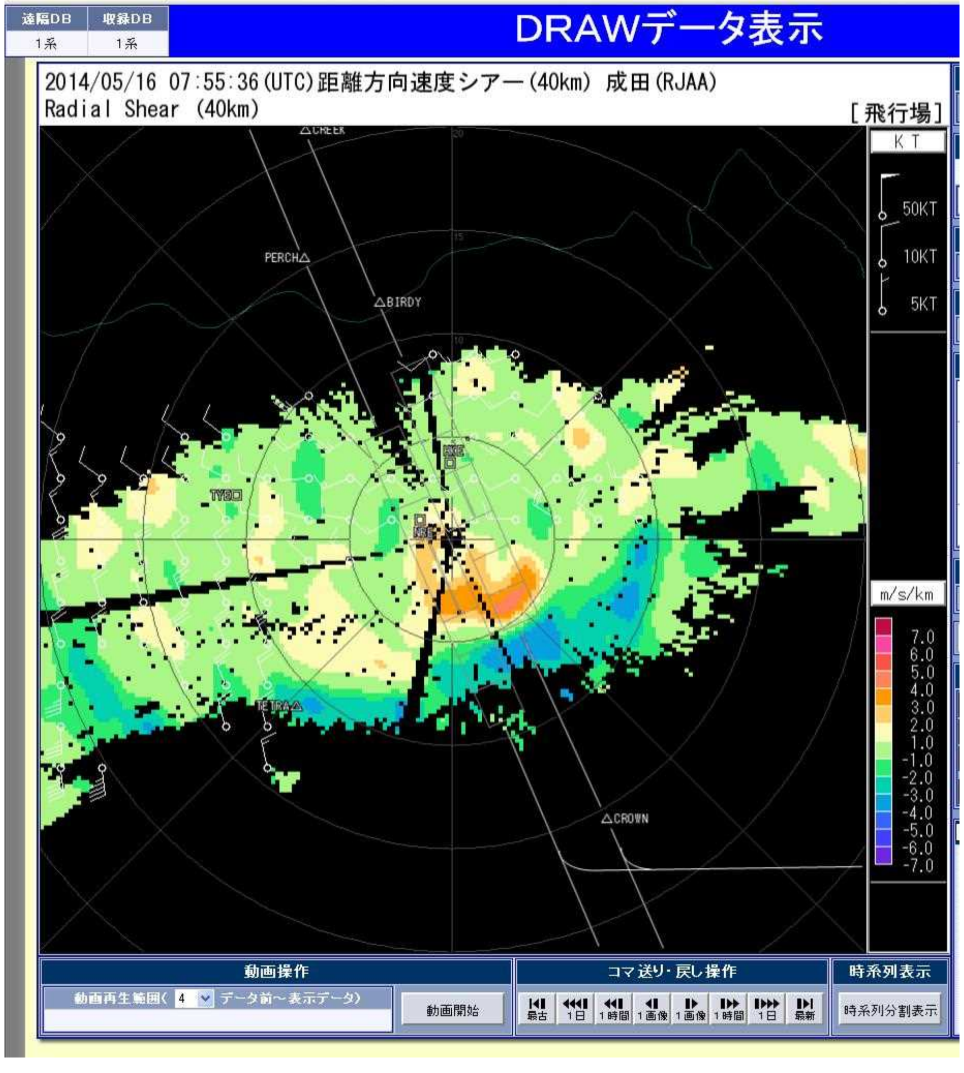
## Step2. Define feature

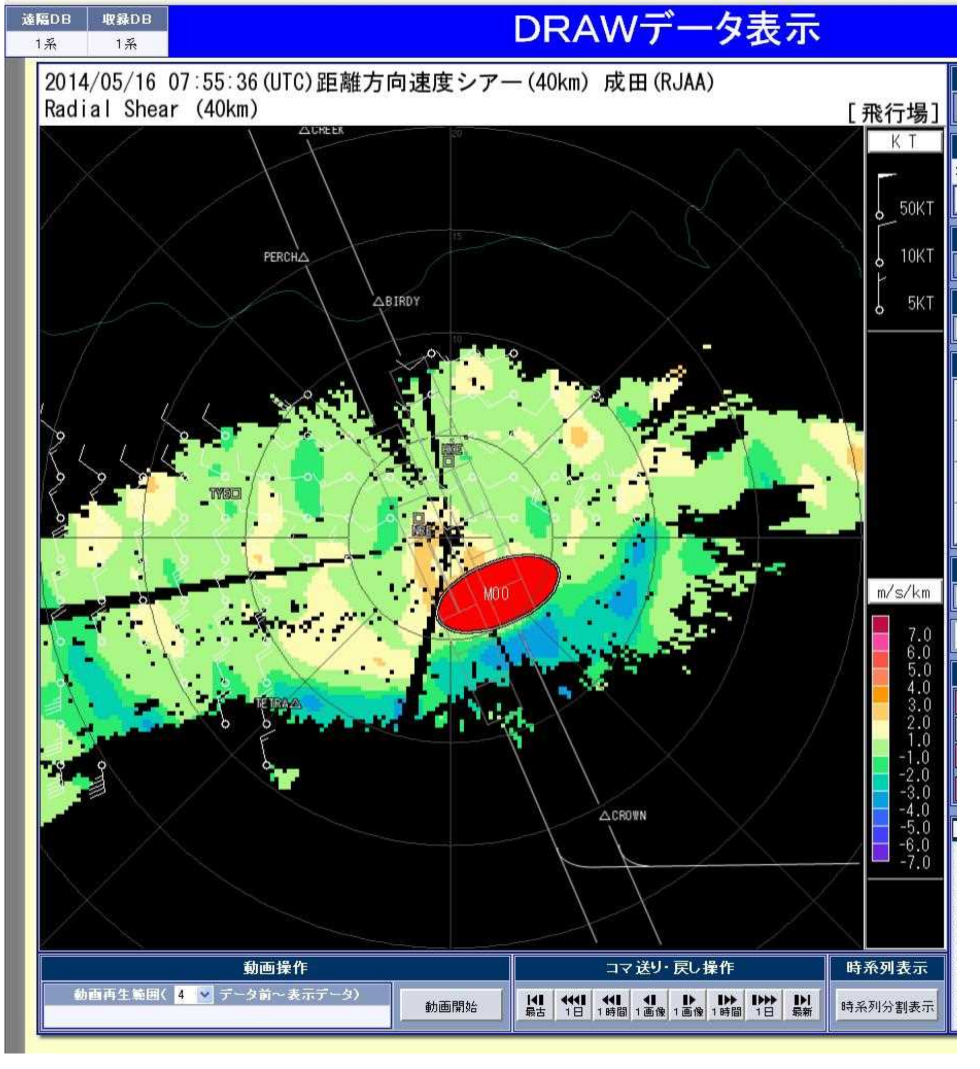
Define feature by combining adjacent segments.

## Step3. Define Microburst

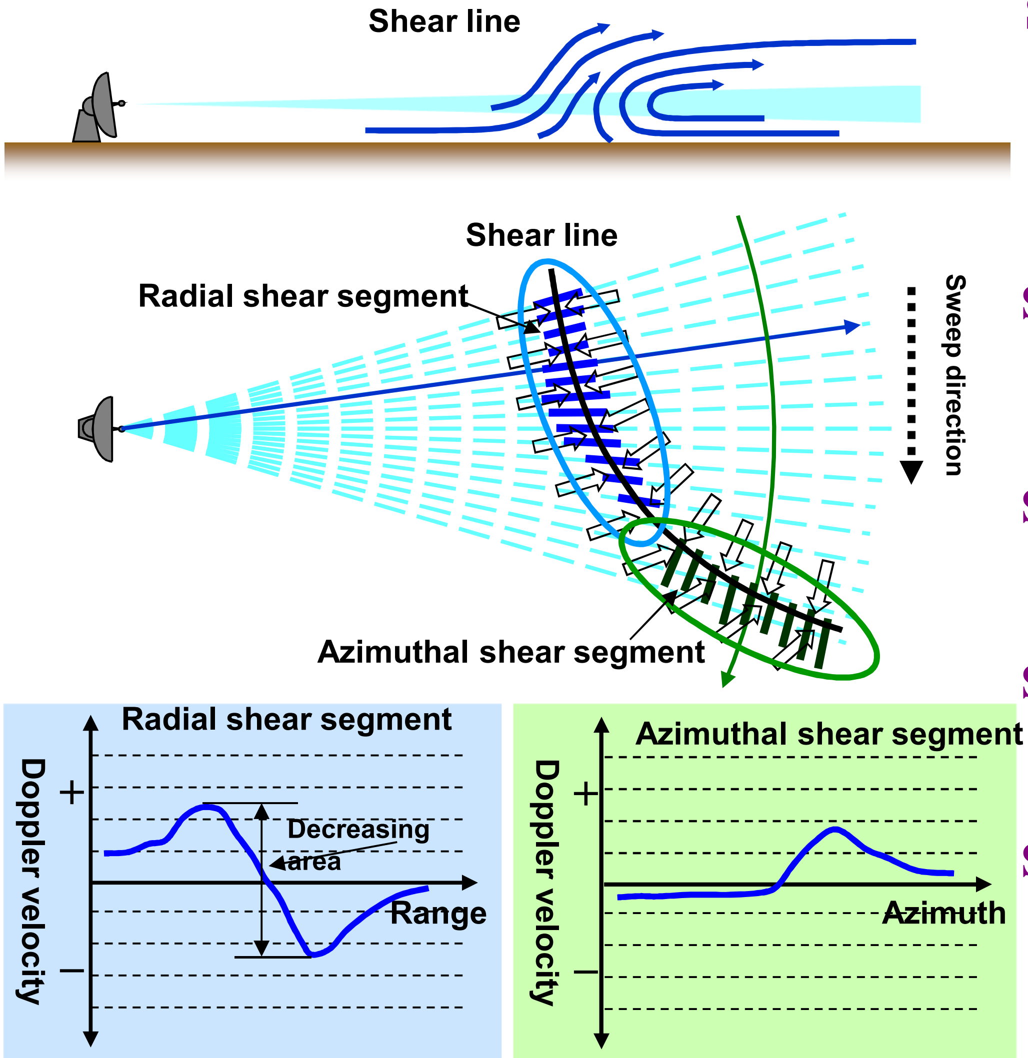
1. Area of feature more than 3km$^2$
2. Maximum velocity difference more than 8m/s
3. Time correlation between present detection and past

# 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.

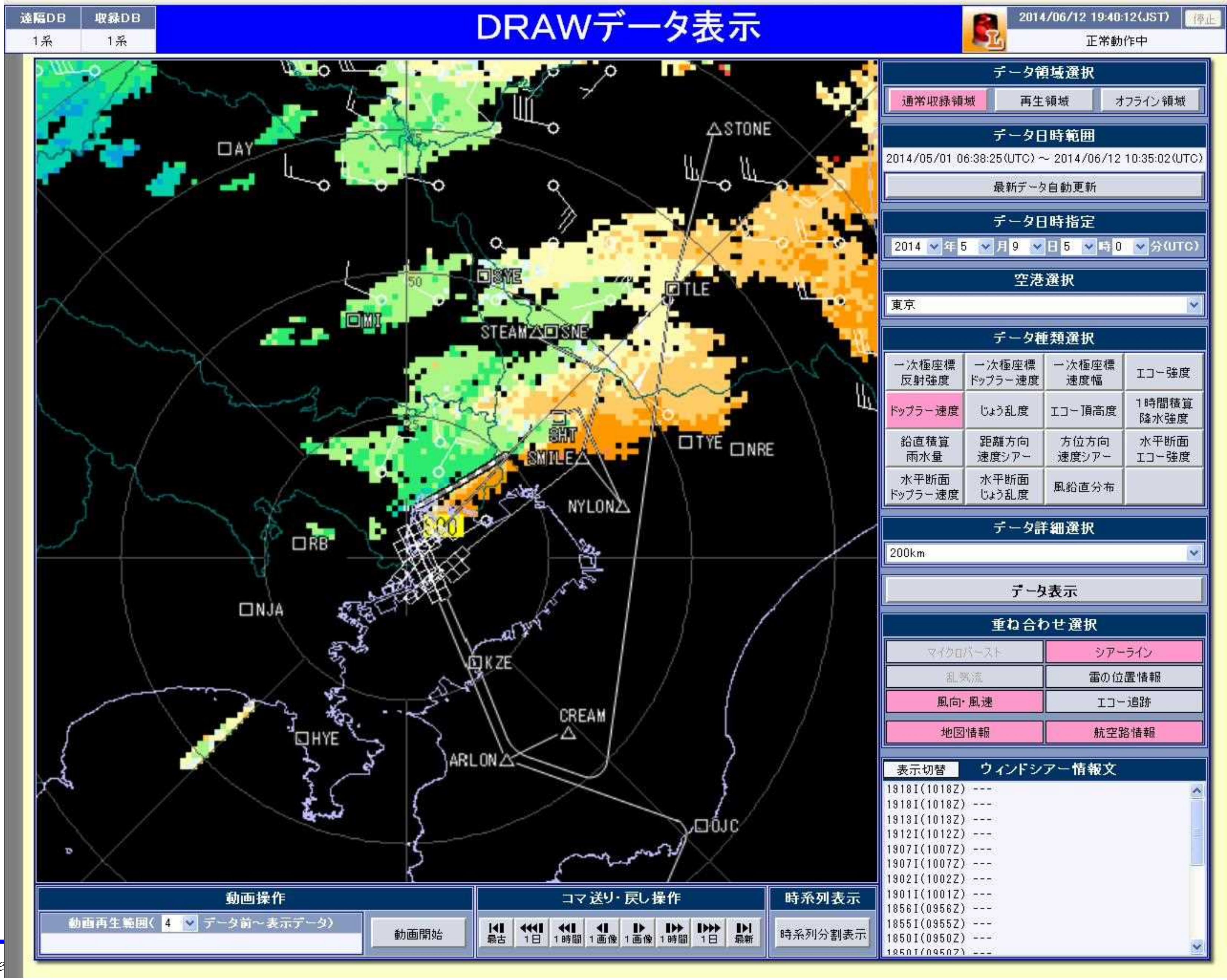
## Step4. Define shear line

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

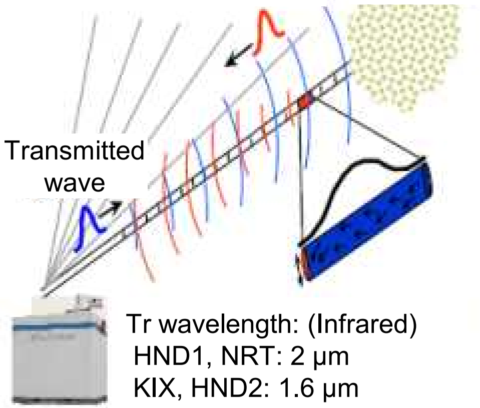
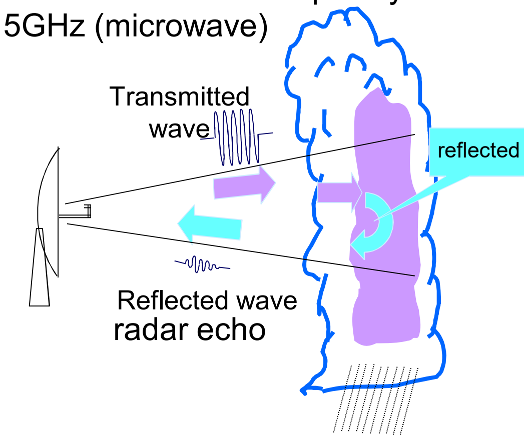
## Step5. Wind vector

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

# Example of Shear Line Detection

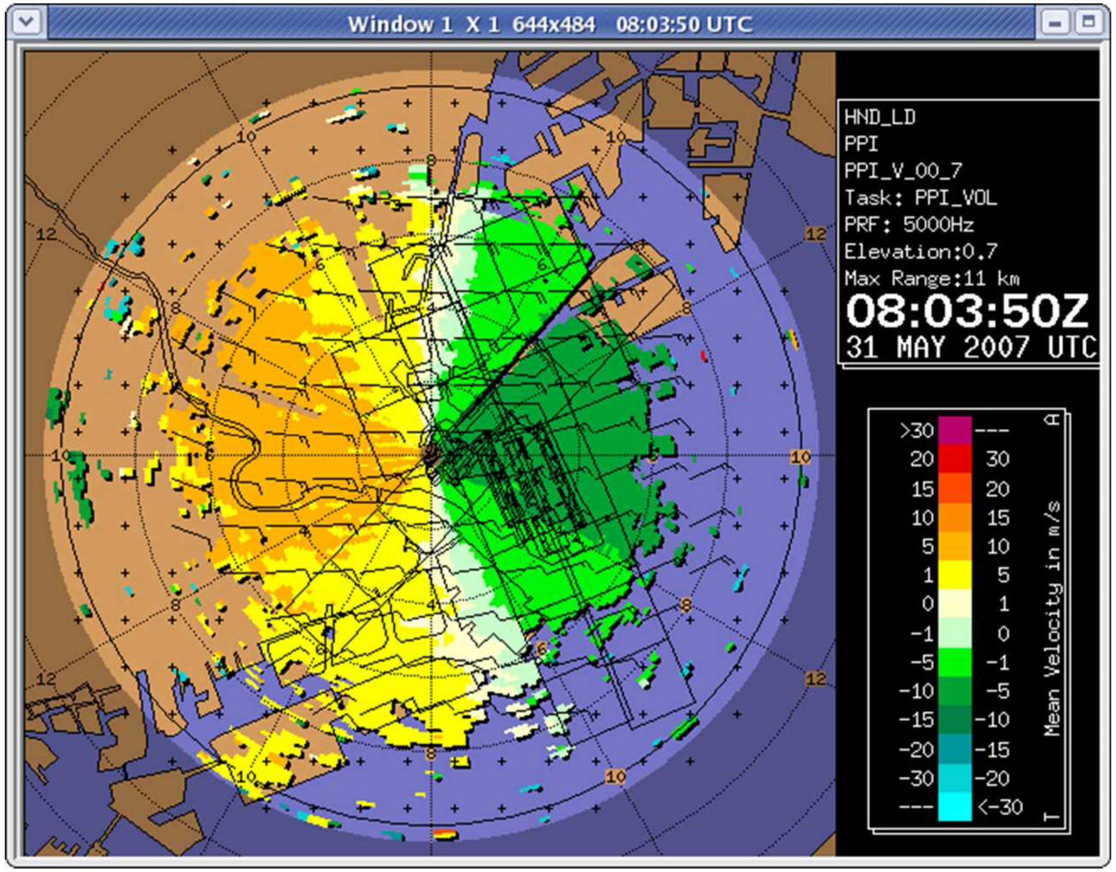


# Wind Shear Observation in All Weather Conditions

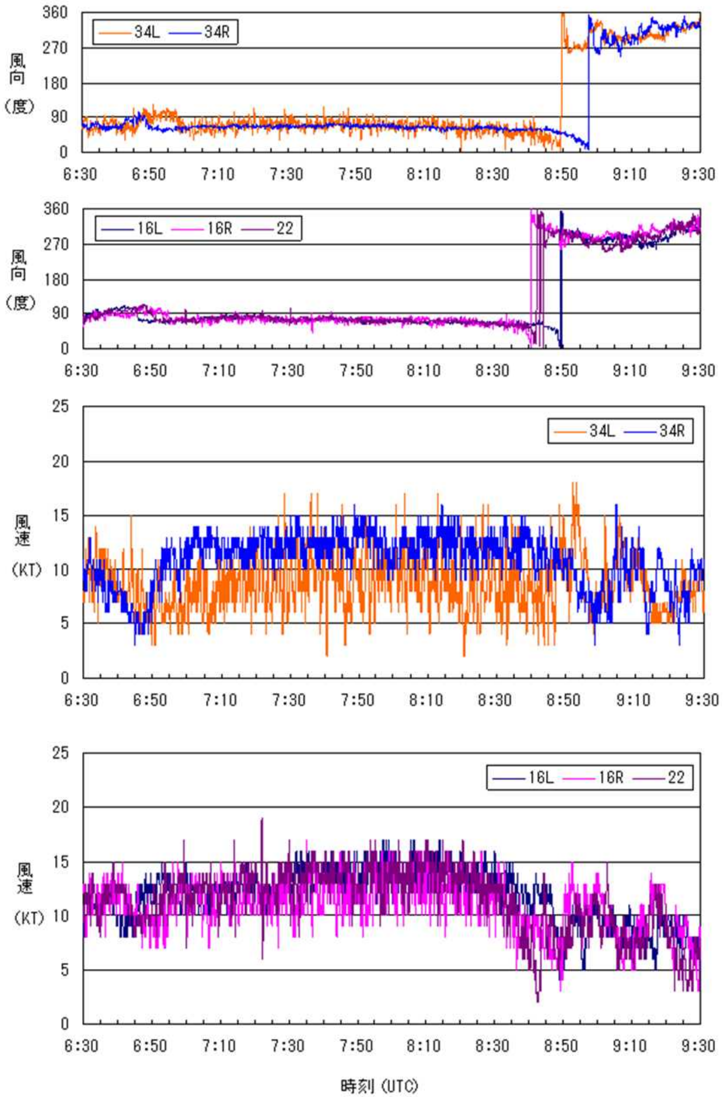
| | Purpose | Measuring method | Detection range | Observation intervals | |
|---|---|---|---|---|---|
| **Doppler LIDAR** | **In Sunny or Cloudy condition, detects low-level wind shears**  |   Tr wavelength: (Infrared)<br>HND1, NRT: 2 μm<br>KIX, HND2: 1.6 μm | **wind shears**<br>**Radius 10km**<br>**(HND1:15km)** | **About**<br>**2 minutes** | **LIDAR and DRAW is different in observation conditions and detection range, complementing each other.**<br><br>**Monitor low-level wind shears 24/7 regardless of rainy condition and non-precipitation.** |
| **Doppler Radar** | **In Rainy condition, detects low-level wind shears and sudden changes by microbursts generated by developed thunder cloud**  | Transmitted wave frequency：<br>5GHz (microwave)   | **Rain area, wind distribution**<br>**Radius 120km**<br><br>**wind shears**<br>**Radius 60km**<br><br>**Microburst**<br>**Radius 20km** | **Airspace mode**<br>**About**<br>**6 minutes**<br><br>**Airfield mode**<br>**About**<br>**1.2 minutes** | |

# LLWS detected by Lidar on 31 May 2007 at Tokyo International Airport

【PIREP】0854UTC：WS FM E TO W BLW 200FT ON FNA RWY34L




**Time chage of Doppler velocity observed by Lidar**

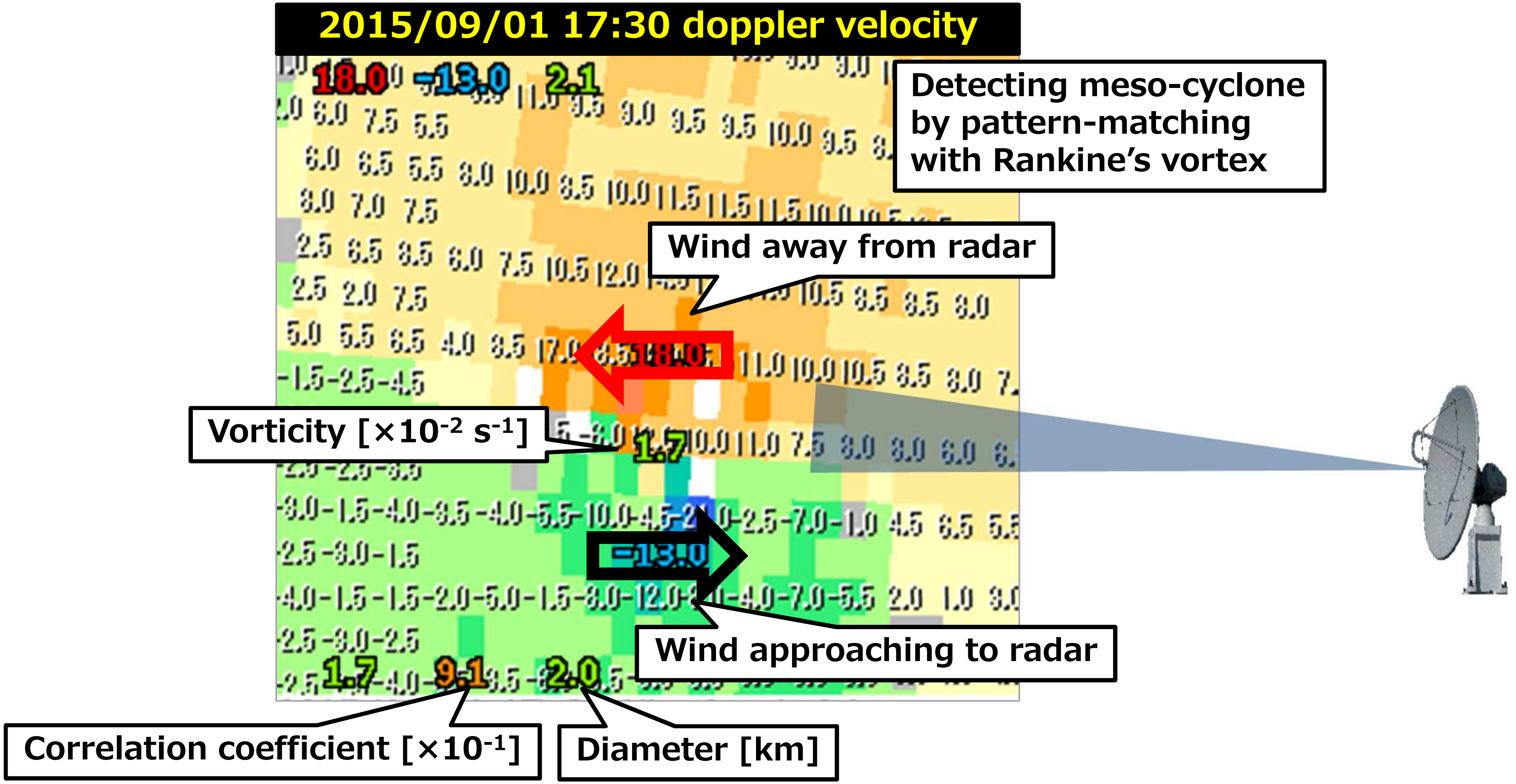



Wind direction / speed observed by anemometers

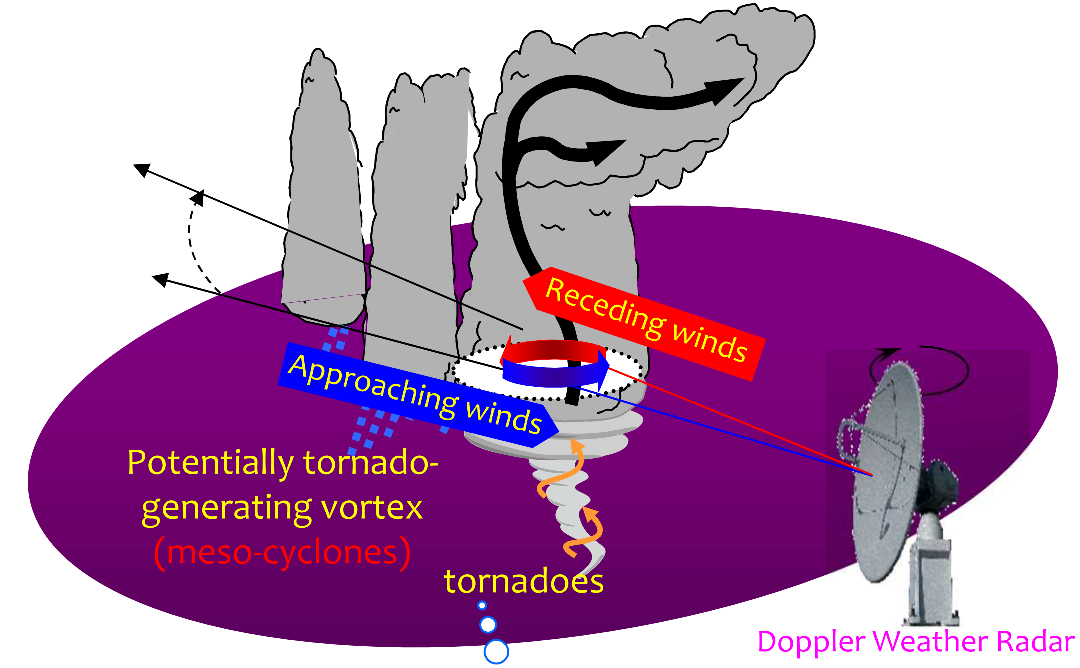
# Mesocyclone

# Rapid analysis of tornado or other gust events

## Meso-cyclone analysis

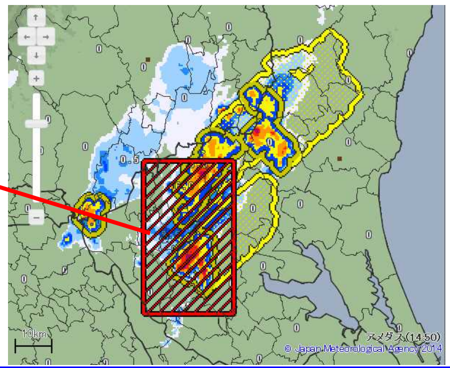


# Detection of "meso-cyclones" using Doppler Radars



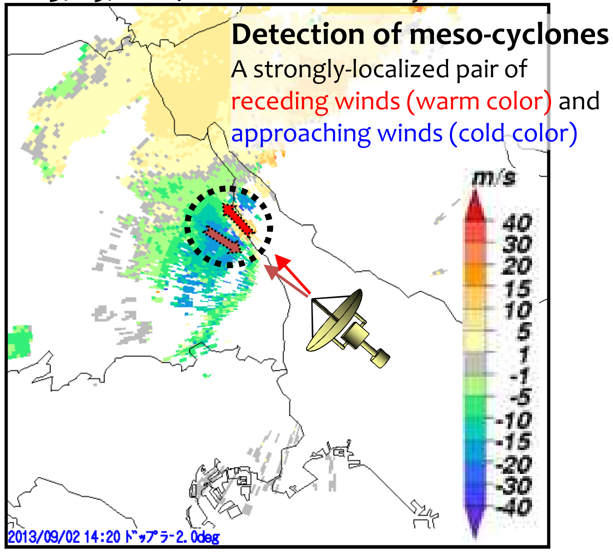

**Detection of the potential outbreak area of tornadoes/gusts using radar observation data and numerical prediction results**

*Provision of effective information on the risk of tornado outbreaks*

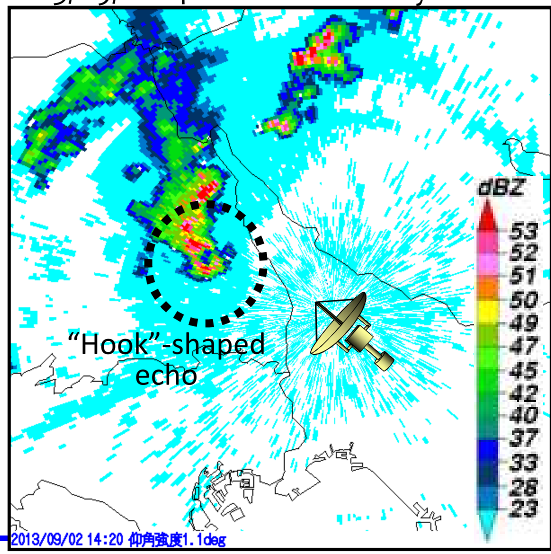


*(JMA Web page)*
http://www.jma.go.jp/en/highresorad/

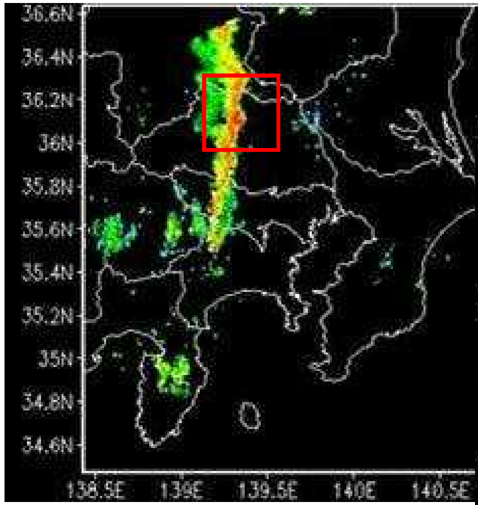
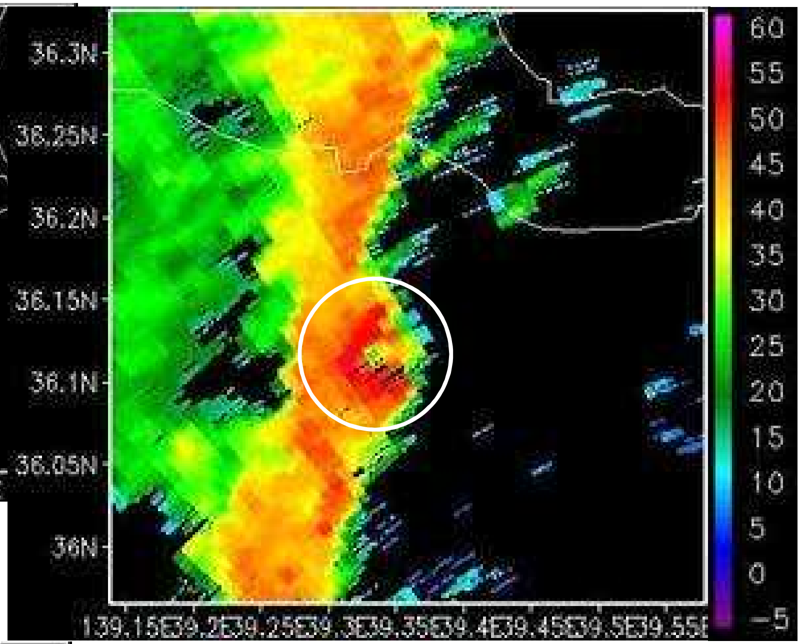
Radial-wind component
2013/09/02 14:20JST Tokyo-radar



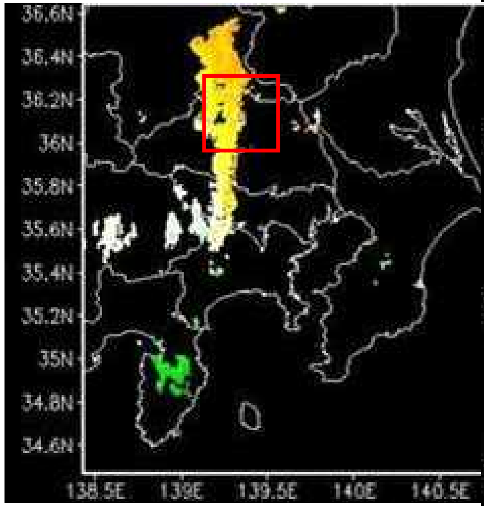
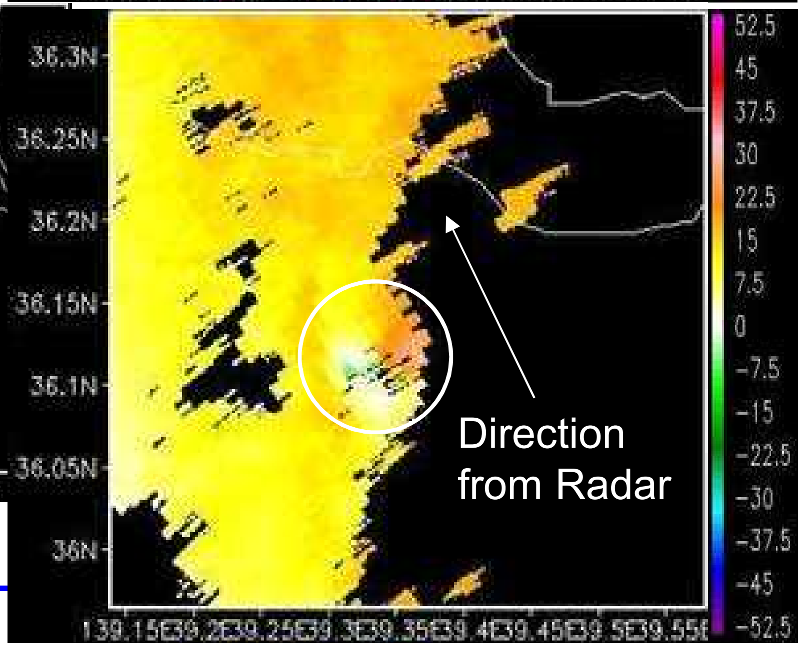

Echo intensity
2013/09/02 14:20JST Tokyo-radar



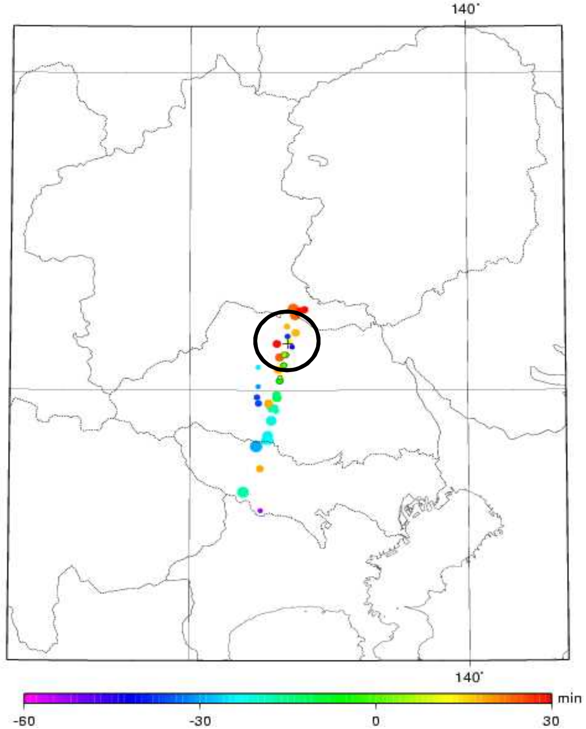
# Example of automatic meso-cyclone detection

Radar Reflectivity


Doppler Velocity




1h before tornado

30min after tornado

**Series of detected meso-cyclones**

August 8, 2003

# Velocity aliasing (folding)

# Velocity Aliasing (Folding)

- Doppler velocity $V_d$ is determined by Doppler frequency $f_d$ .

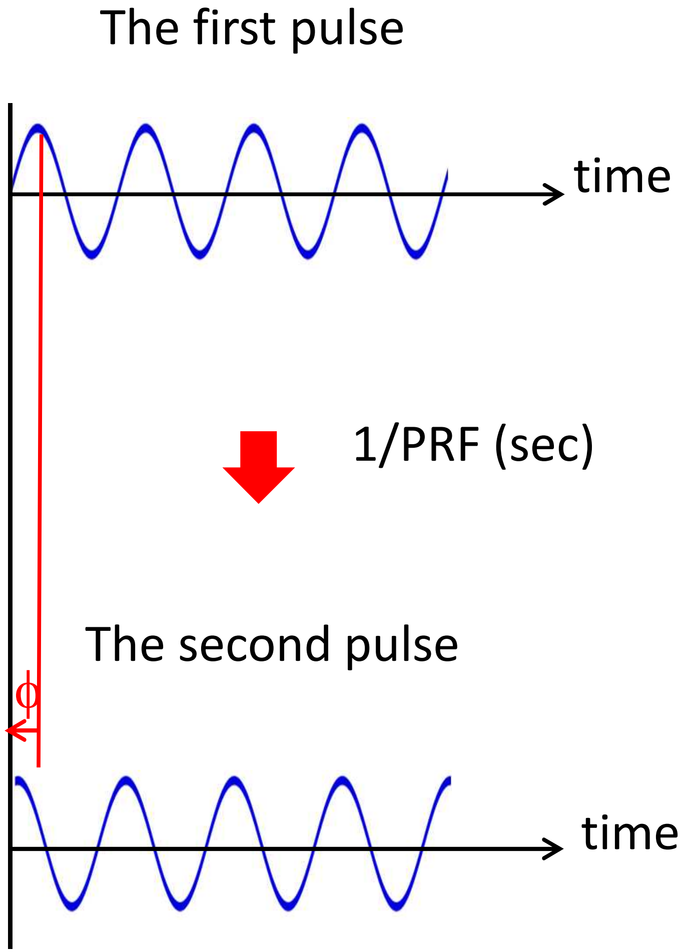
$$V_d = -\frac{\lambda f_d}{2}$$

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

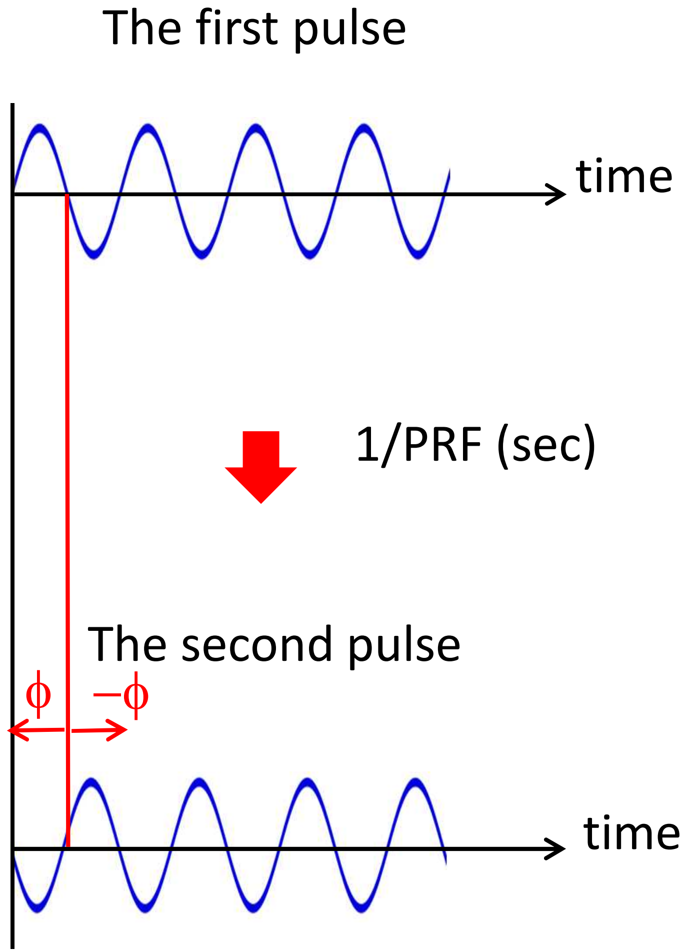
$$V_{nyq} \equiv V_{\max} = \frac{\lambda \cdot PRF}{4}$$

- 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



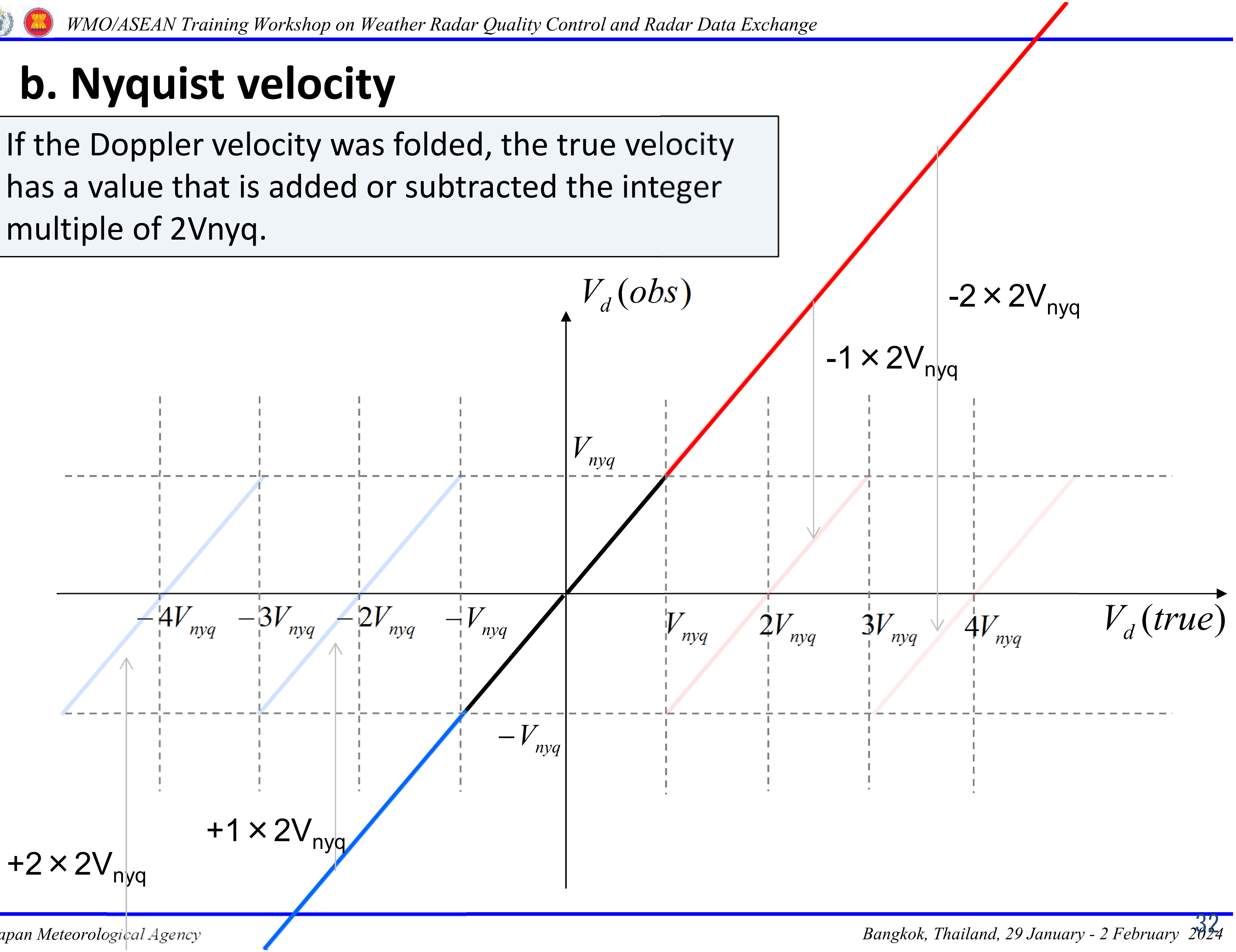

$2\pi f_d = \phi$ / (1/PRF) (rad / sec)




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

# 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

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

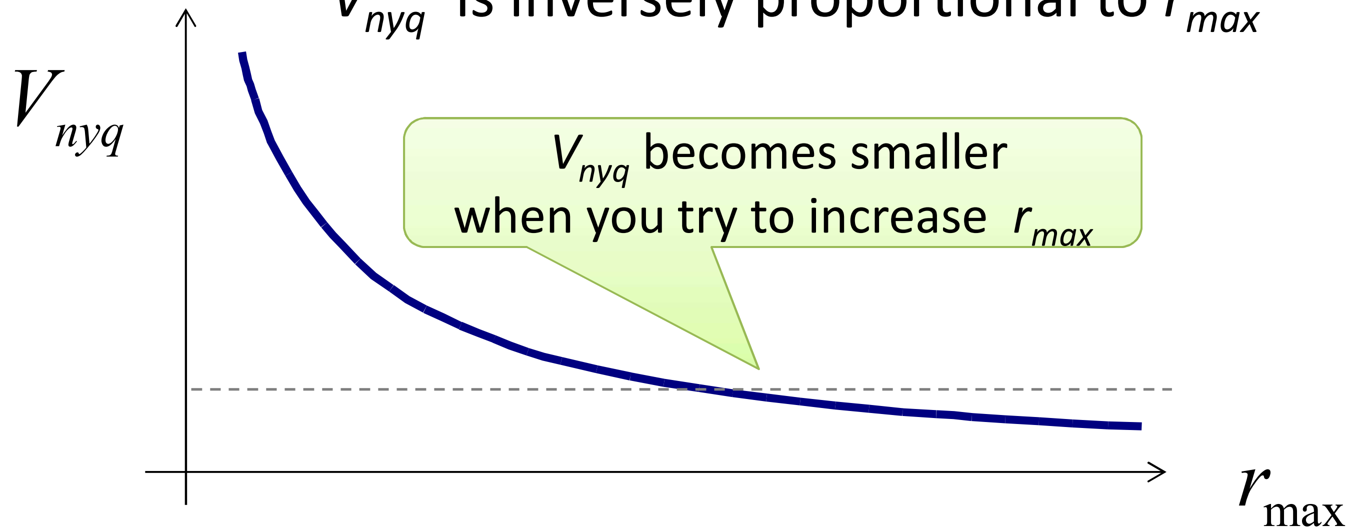
const

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

Maximum detectable velocity

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

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

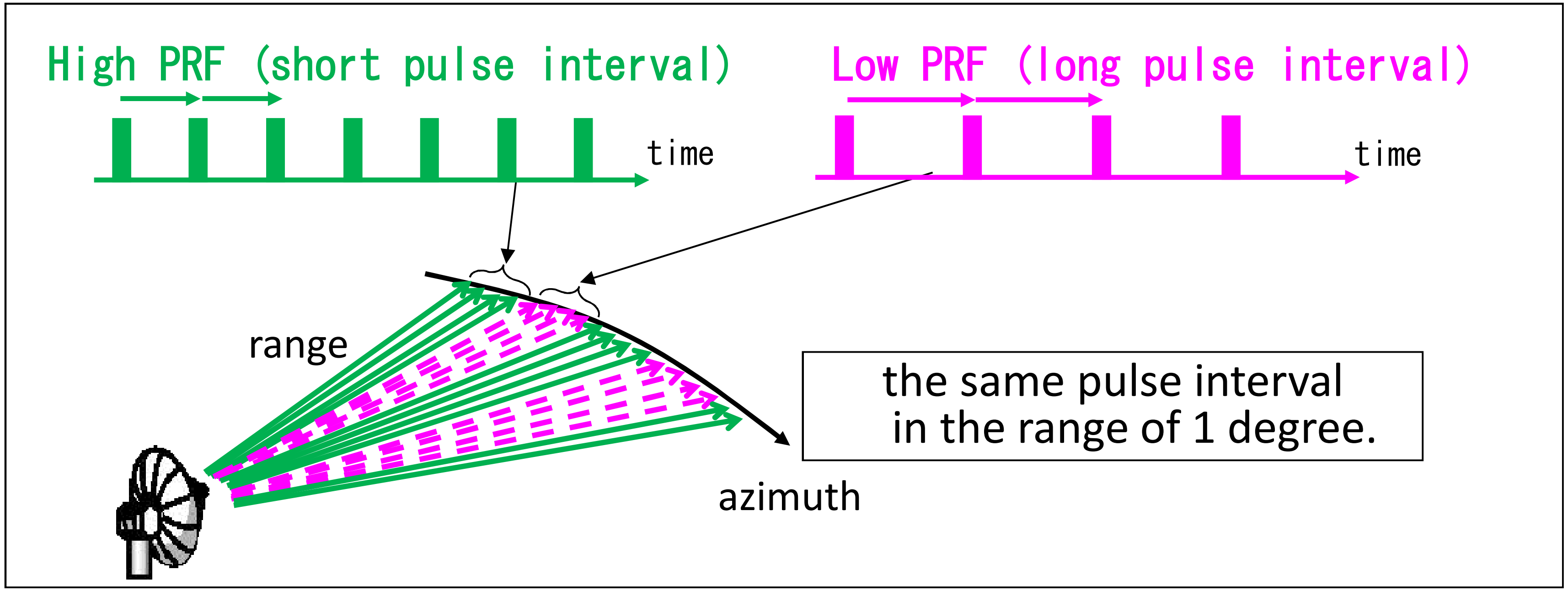



**Range-Doppler Dilemma**

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

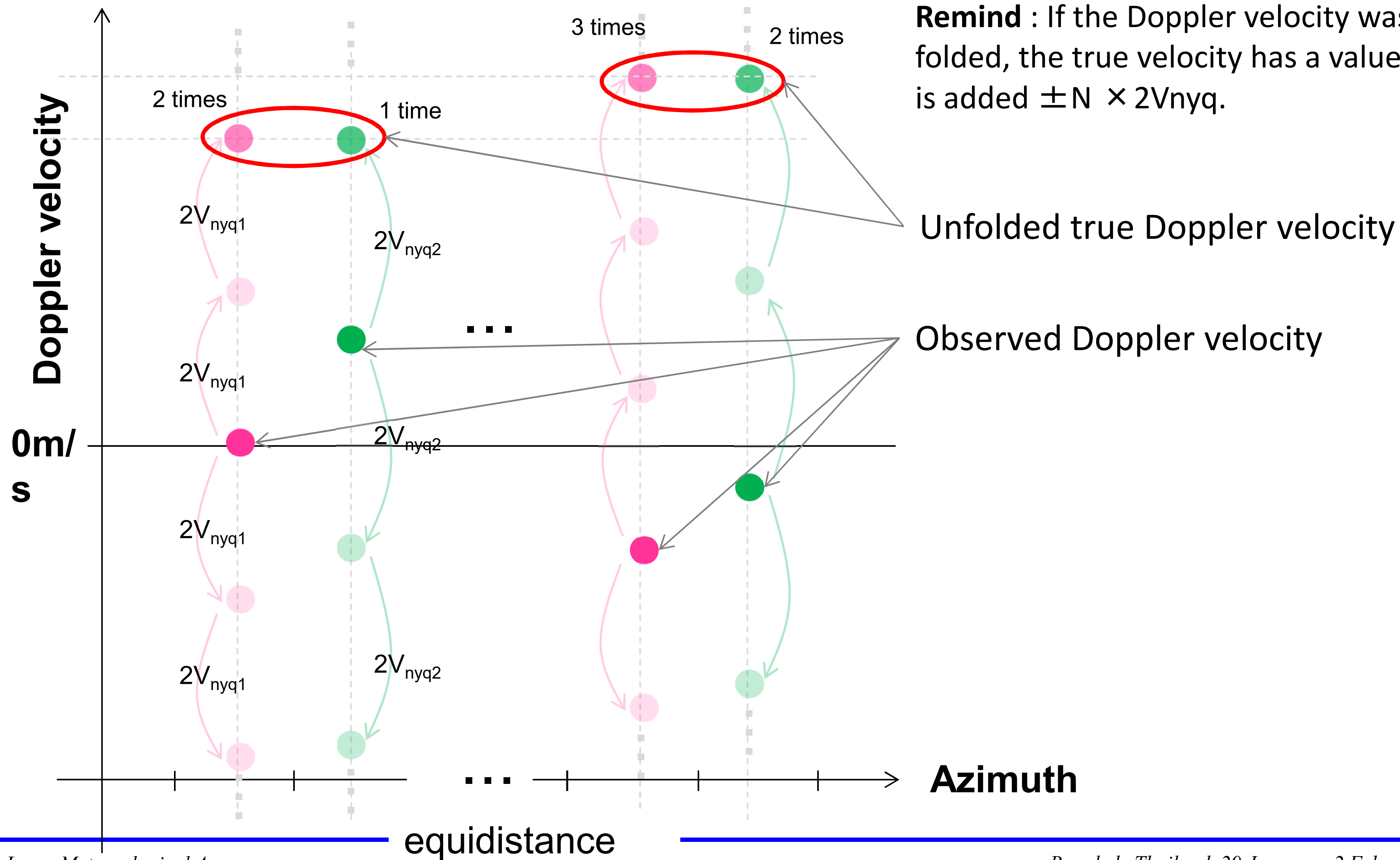
# d. Dual-PRF method (Dealiasing of Doppler velocities)

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



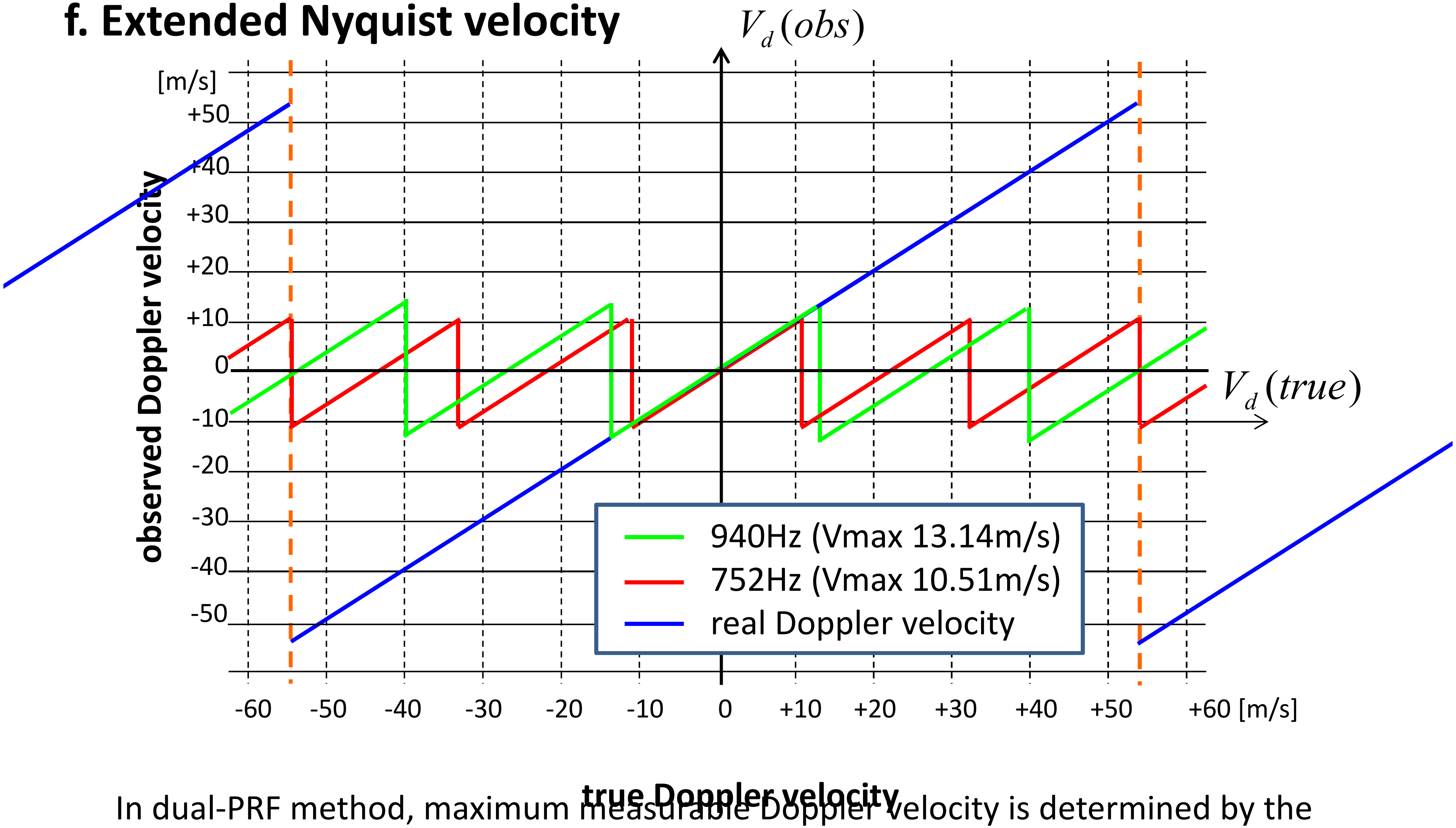
# e. the concept of dual-PRF method

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.

# f. Extended Nyquist velocity




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

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

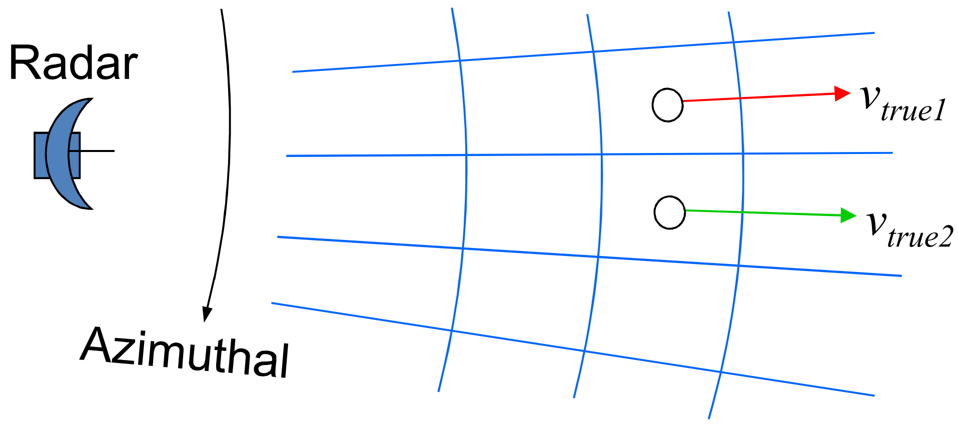
$$V_{\max} = 10.51 \times 5 = 52.5\ [\text{m/s}] \qquad V_{\max} = 8.37 \times 4 = 33.5\,[\text{m/s}]$$

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

# Thank you