Validation of EarthCARE product using vertical wind measurement by wind profiler radars

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50-MHz MUR in Japan

50-MHz EAR in Indonesia

1.3-MHz WPR in Japan

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Background and purpose of the study

- Cloud Profiling Radar (CPR) onboard the EarthCARE (EC) satellite (EC-CPR) is the first radar that measures reflectivity-weighted Doppler velocity ($V_{\mathrm{air+Z}}$) from the space. $V_{\mathrm{air+Z}}$ product of the EC-CPR is expected to improve the accuracy of the EC product.
- Because $V_{\mathrm{Z+air}}$ is the sum of reflectivity-weighted Doppler velocity relative to the air (V_{Z}) and vertical wind velocity (W) (i.e., $V_{\mathrm{air+Z}} = V_{\mathrm{Z}} + W$), effects of W on $V_{\mathrm{air+Z}}$ need to be evaluated.
- Wind profiler radars (WPRs) are useful for measuring W both in cloud and precipitation regions. The study aims at demonstrating that measurements of W, radar reflectivity factor (Z_{e}), $V_{\mathrm{air+Z}}$, V_{Z} by 50-MHz and 1.3-GHz WPRs are useful for validating EC-CPR products.
- Also, problems that inhibit accurate measurement of W by WPRs are solved for realizing ground-based campaigns after the launch.

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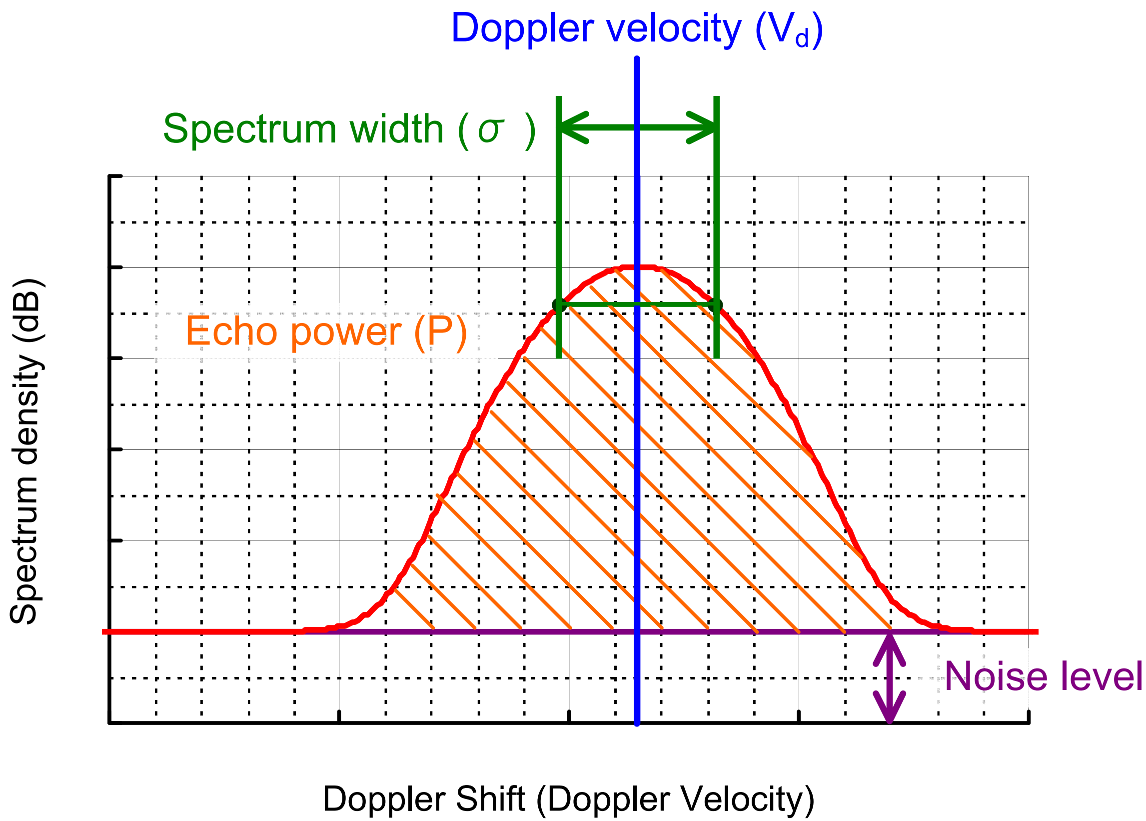
Achievements in this year’s study

- A simple and fast method for calculating the 0th, 1st, and 2nd moments of the Doppler spectra collected by WPRs is established. The method can be used in the clear-air and cloud regions. The achievement is submitted to the refereed journal (Radio Science).
- Measurement results of veritcal wind velocity (W) in the boundary layer by a 1.3-GHz range-imaging WPR at the Shigaraki MU Observatory are analyzed in detail. The achievement is submitted to the refereed journal (SOLA).
- A method for obtaining W in the presence of hydrometeor echoes is developed. Now we are processing data collected by the 50-MHz band MU radar.

Frequency power (Doppler) spectrum of radar signals



- Turbulent echo follows Gaussian distribution.
- 0th, 1st, and 2nd order of spectrum moments (Echo power P, Doppler velocity V_d, spectral width σ; spectral moments) are estimated from Doppler spectrum and they are used for knowing wind velocity and turbulence intensity.

Method for calculating the spectral parameters

Step (1)

Produce a Doppler spectrum.

Step (2)

Determine a Doppler velocity range (echo range) used for calculating spectral parameters.

(a) Produce a smoothed Doppler spectrum by running average (RA).

(smoothing)

(b) Find a peak of the smoothed Doppler spectrum.

(peak search)

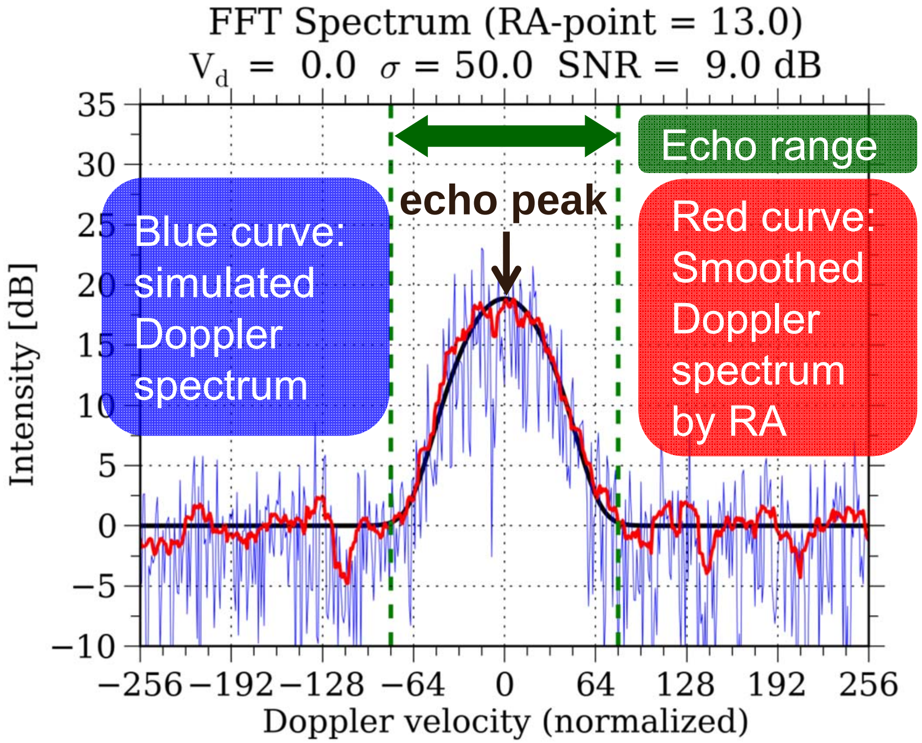
(c) Determine an echo range in which the spectrum peak is contained and the signal intensity > noise intensity.

(echo range determination)

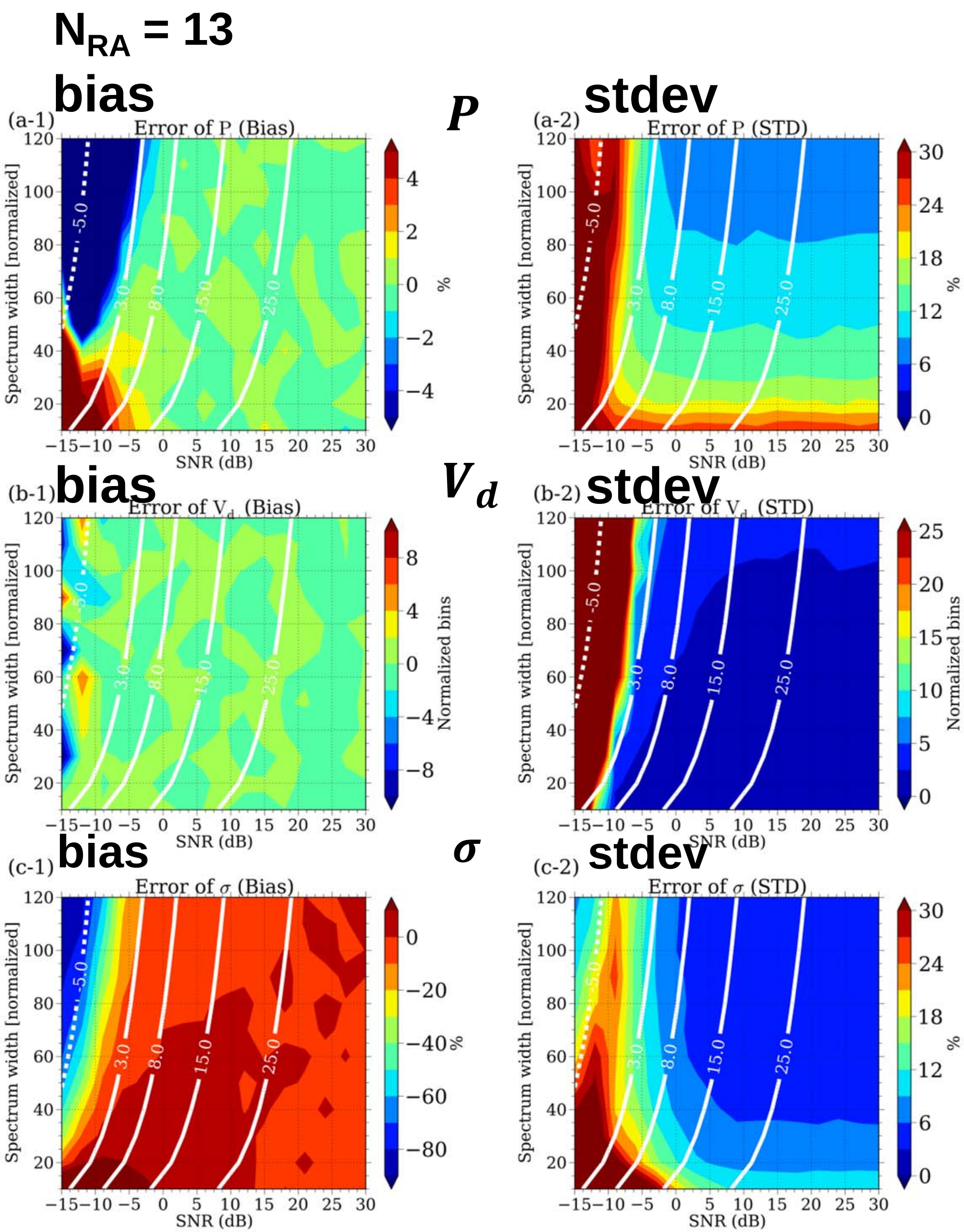
Step (3)

Calculate spectral parameters using the Doppler spectrum calculated in (1) and the echo range determined in (2).

- Use moment method for calculation.
- Unsmoothed Doppler spectrum is used.

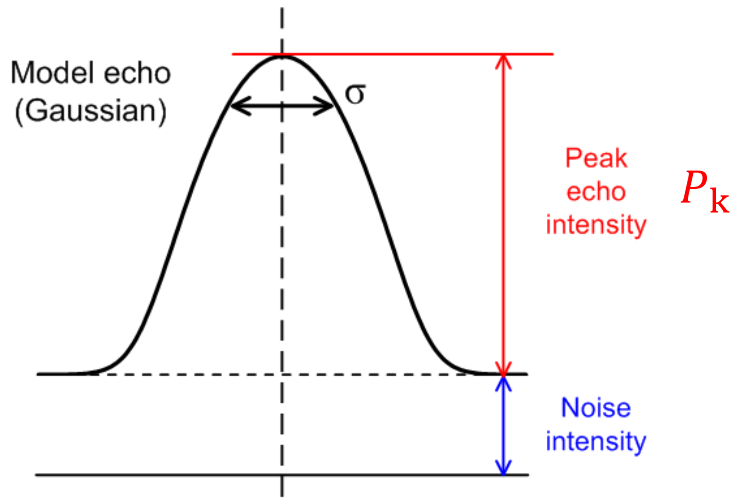


Factors that determine errors of spectral parameters



- For P_{k} > 8 dB, the errors are independent of SNR, and depend only on σ.
- For P_{k} < 3 dB, estimation errors have close relations with estimation errors.

→ Information of P_{k} and SNR is useful for estimating errors of spectral parameters.



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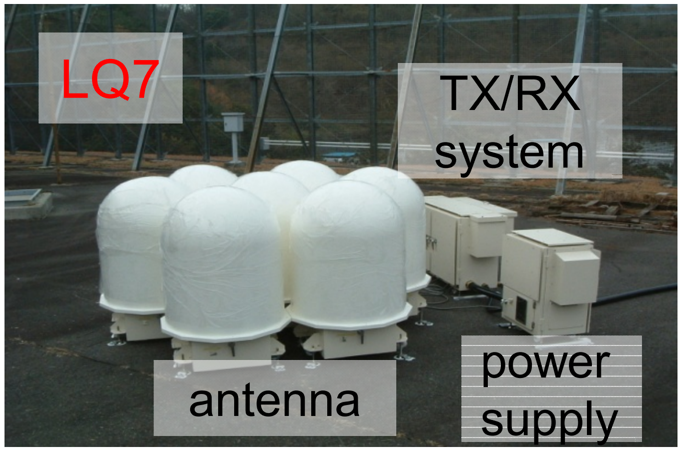
1.3-GHz range imaging wind profiler radar

- 2.8-kW peak power.
- Phased array antenna composed of seven Luneberg elements (6°beam width and steer vertical and four oblique directions with 14.2° zenith angle).
- Range imaging (RIM) capability using five frequencies with 250-kHz intervals and 1-MHz span.
- Oversampling (OS) capability up to 10 MS s^{-1}.



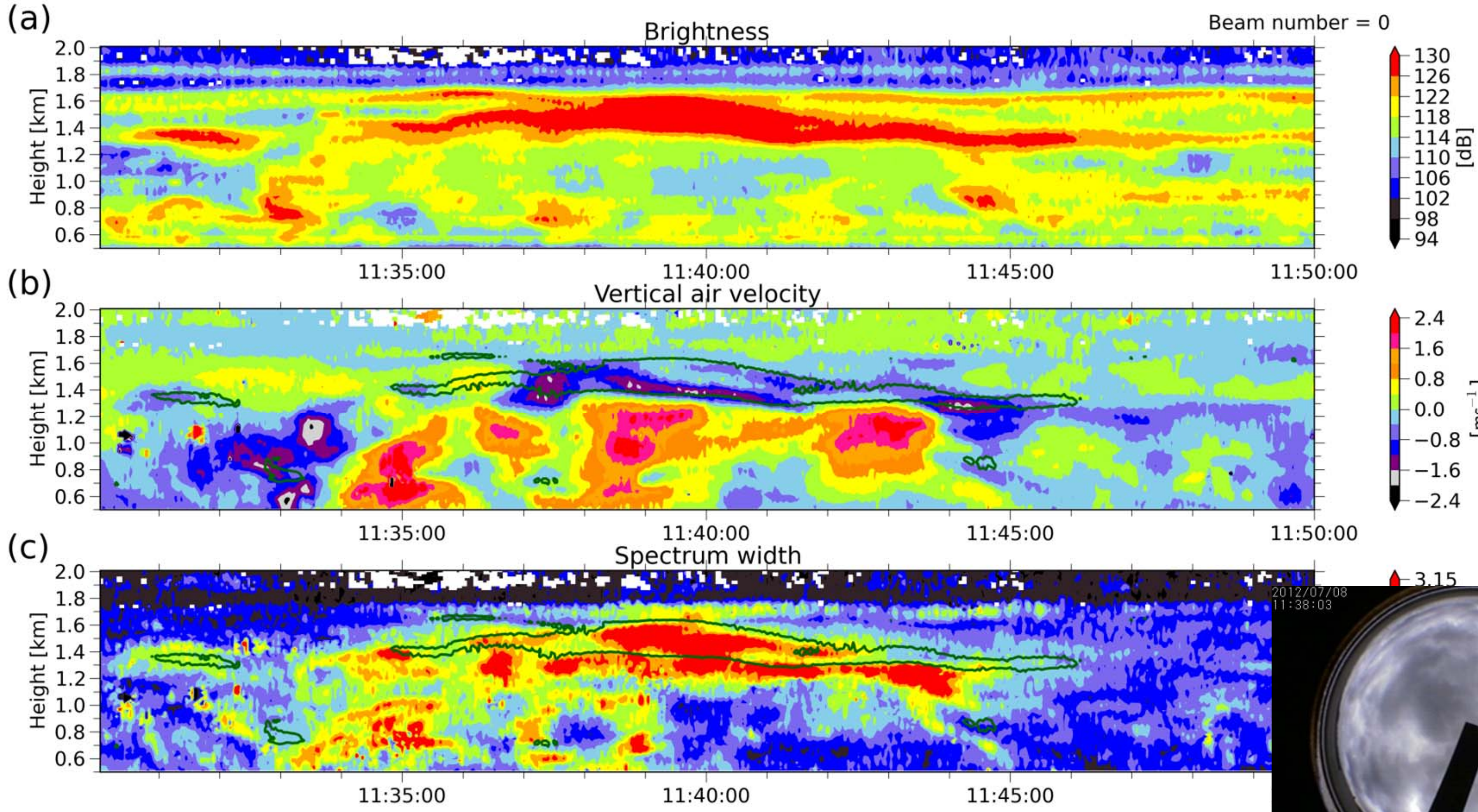
+

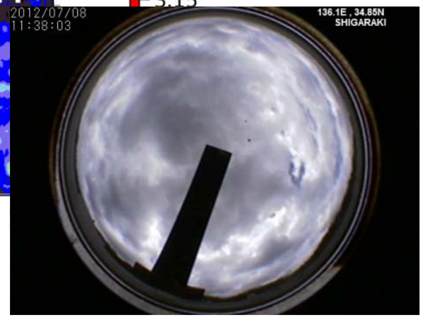
PC

software radio receiver (USRP2)

Configurable Digital Receiver PI developed

Fine-scale W motions in the clouds (Case 1)





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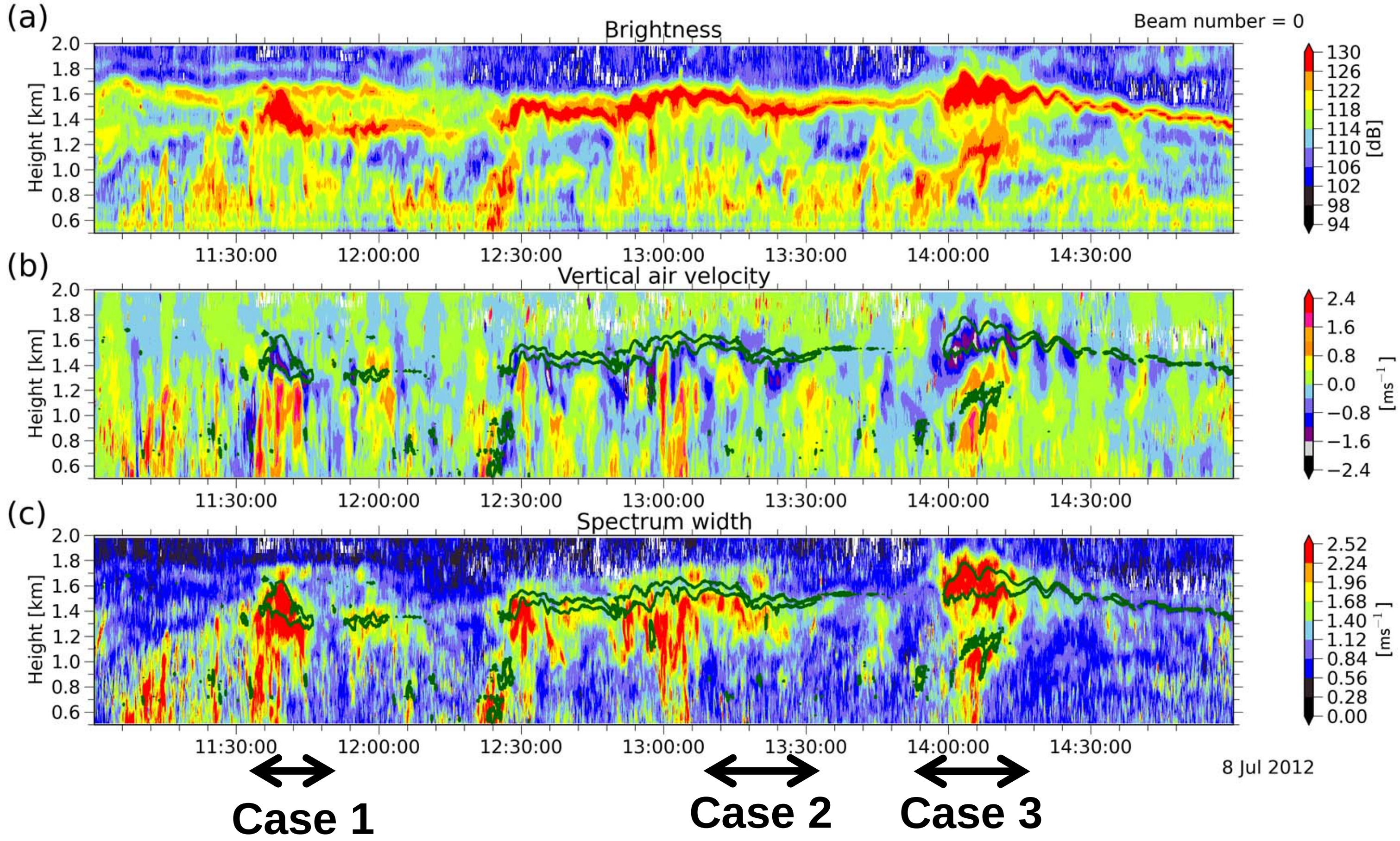
- With the passage of the cloud, upward W was observed.
- Downward W was also observed above the heights of the upward W. Downward W must be treated with care because contamination of hydrometeor echoes can happen (collocated cloud radar measurements are necessary for further investigation!)

Fine-scale W motions in the boundary layer clouds



- When low-level clouds existed over RIM-LQ7, upward W and enhanced small-scale W perturbations (spectrum width) were observed.
- Downward W was observed above the height of upward W (must be treated wit care because of possible contamination of hydrometeors).

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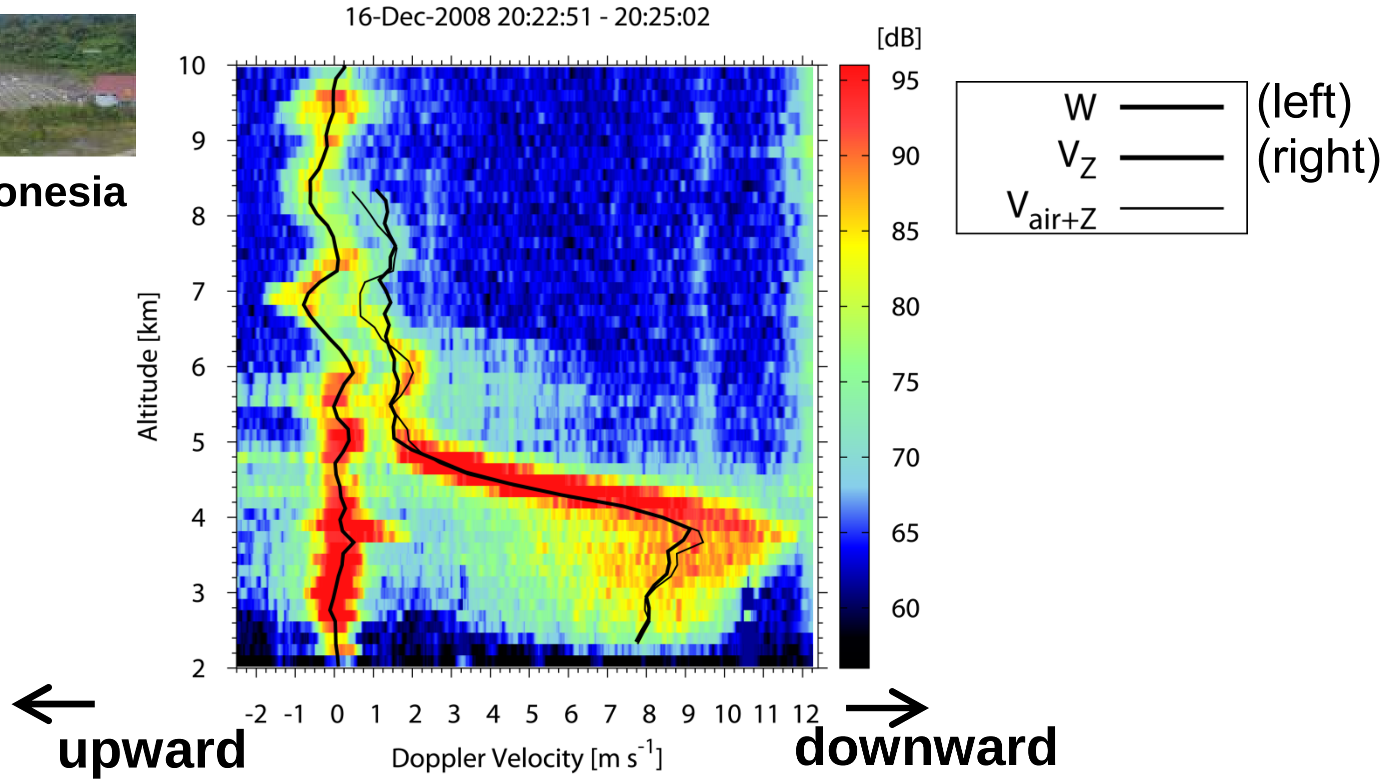
50-MHz WPR can measure W in precipitation

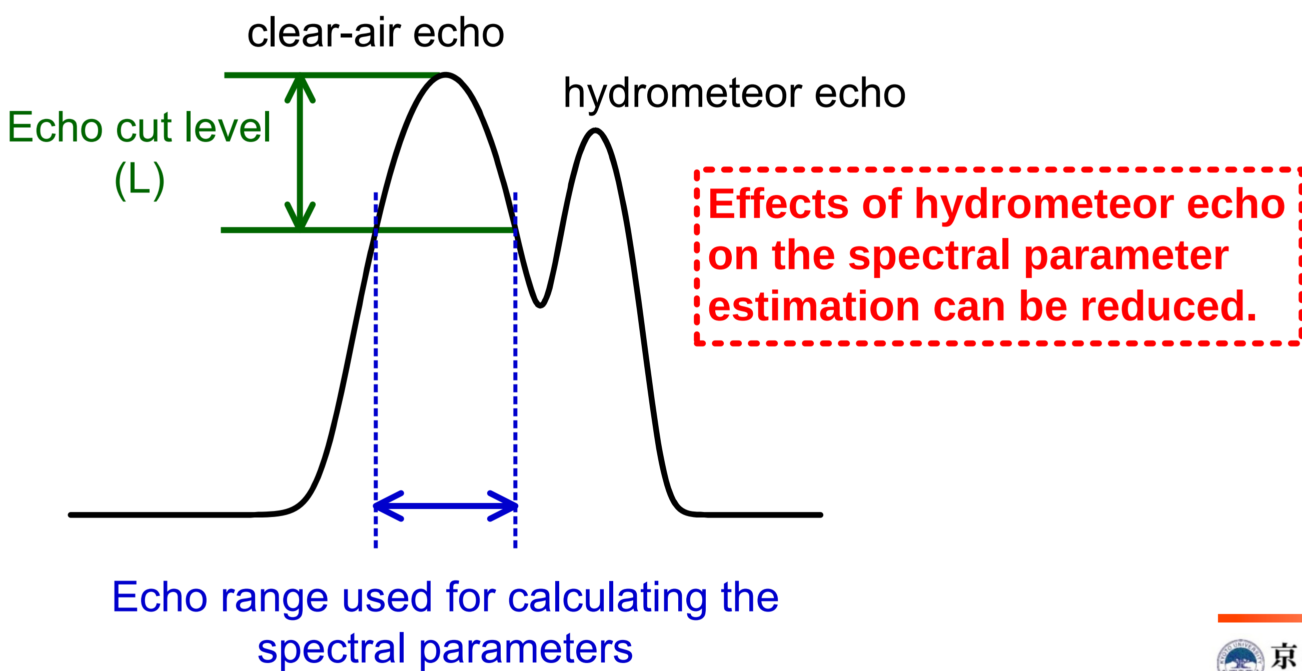
50-MHz EAR in Indonesia



- Vertical wind (W) and hydrometeor fall velocity relative to the ground (V_{air+Z}) are separately detected in the Doppler spectra.
- 50-MHz WPRs are only instrument that can measure both W and V_Z ($= V_{air+Z} - W$) simultaneously.

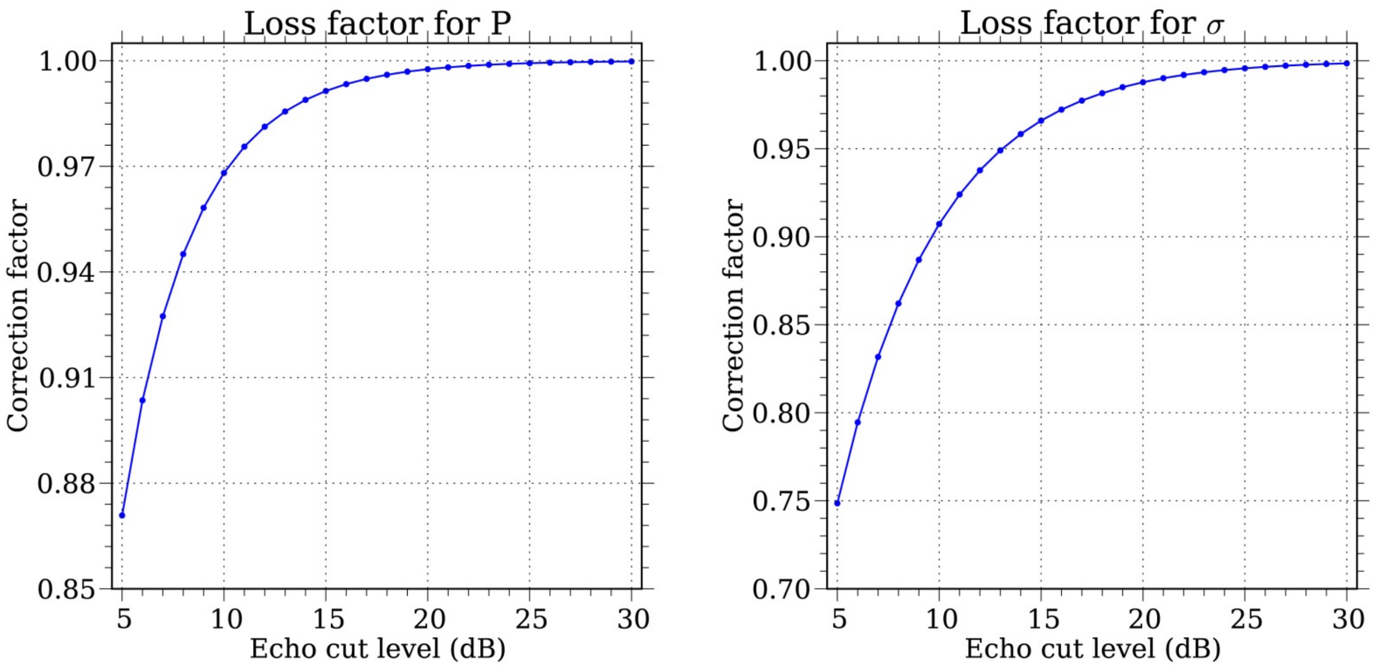
Method to obtain W in precipitation: Basic concept

- Clear-air echoes and hydrometeor echoes (especially for cases of snowflakes with small fall velocity) locate closely with each other.
- By selecting the echo region which are not affected by hydrometeor echoes, downward mis-estimation of W and overestimation of echo power (P) and spectrum width (σ) can be reduced.



Method to obtain W in precipitation: Basic concept

- Because we limit the Doppler velocity range used for calculating the spectral parameters, echo power (P) and spectrum width (σ) are underestimated.
- Based on the common assumption that a clear-air (turbulent) echo follows Gaussian distribution, the loss factors are corrected.



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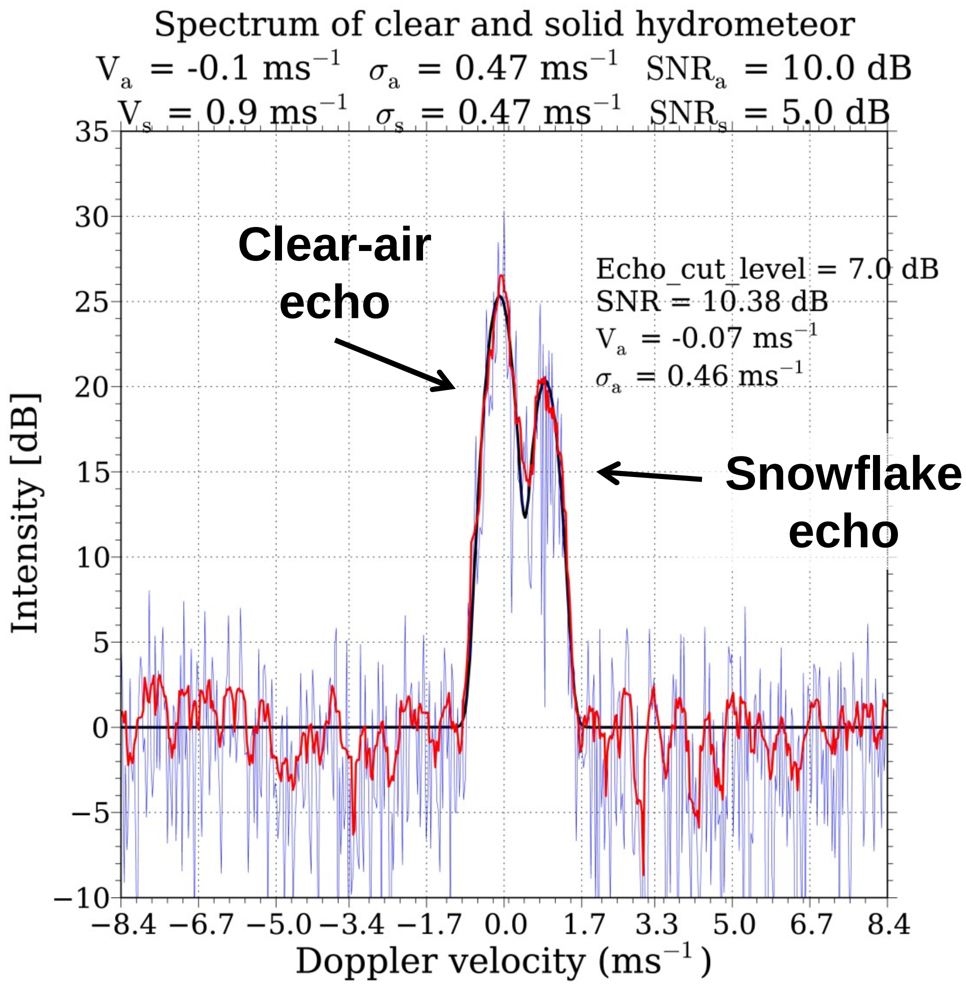
Simulated Doppler spectrum in precipitation



The measurement parameter of the MU radar in the 2009 experiment is used for the simulation.

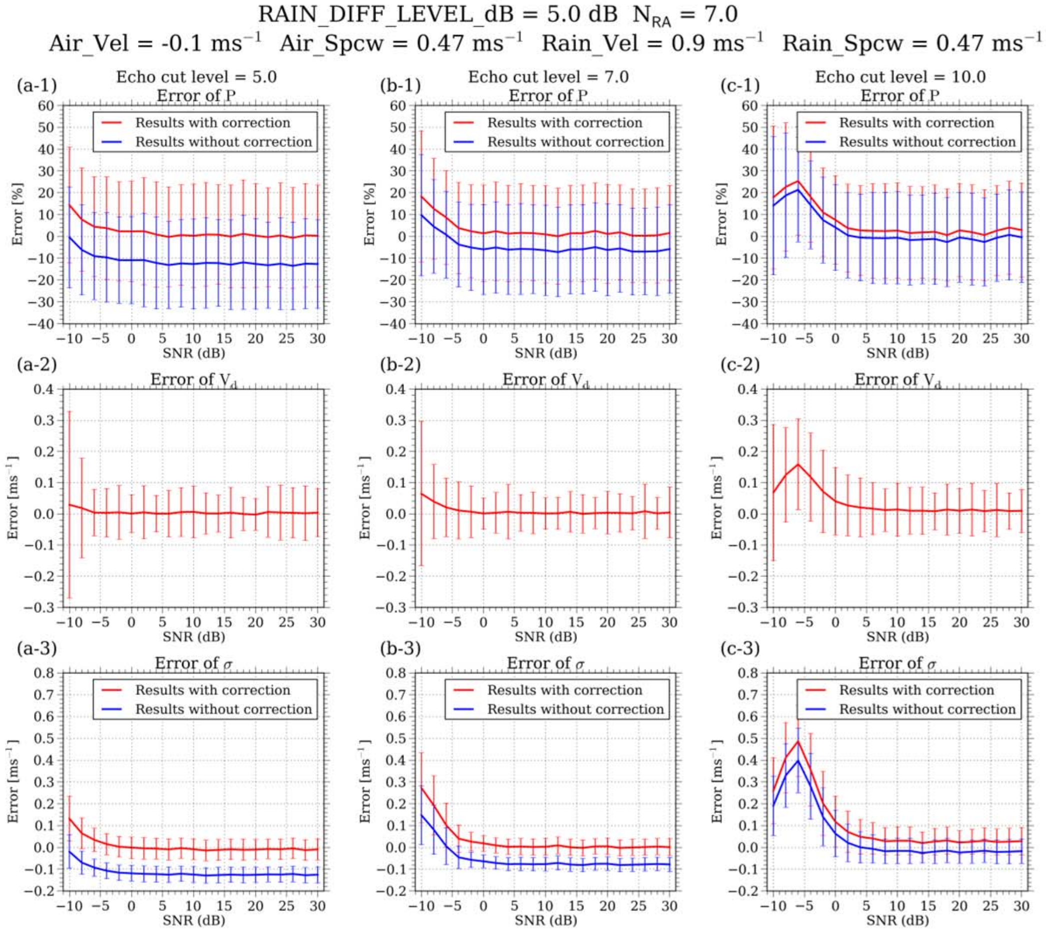
Cut level consideration by numerical simulation (N_{RA} = 7)

Cut level = 5 dB **Cut level = 7 dB** **Cut level = 10 dB**

P error

V_d error

σ error



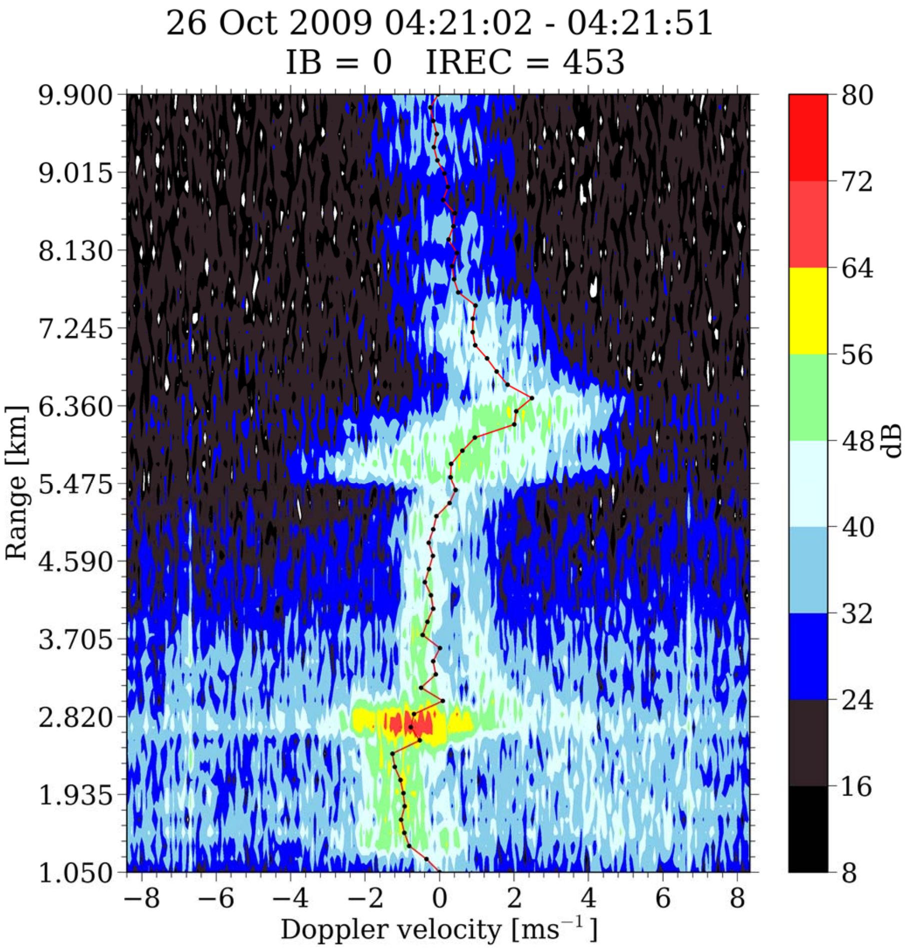
N_{RA} = 7

N_{RA}: Number of running average points

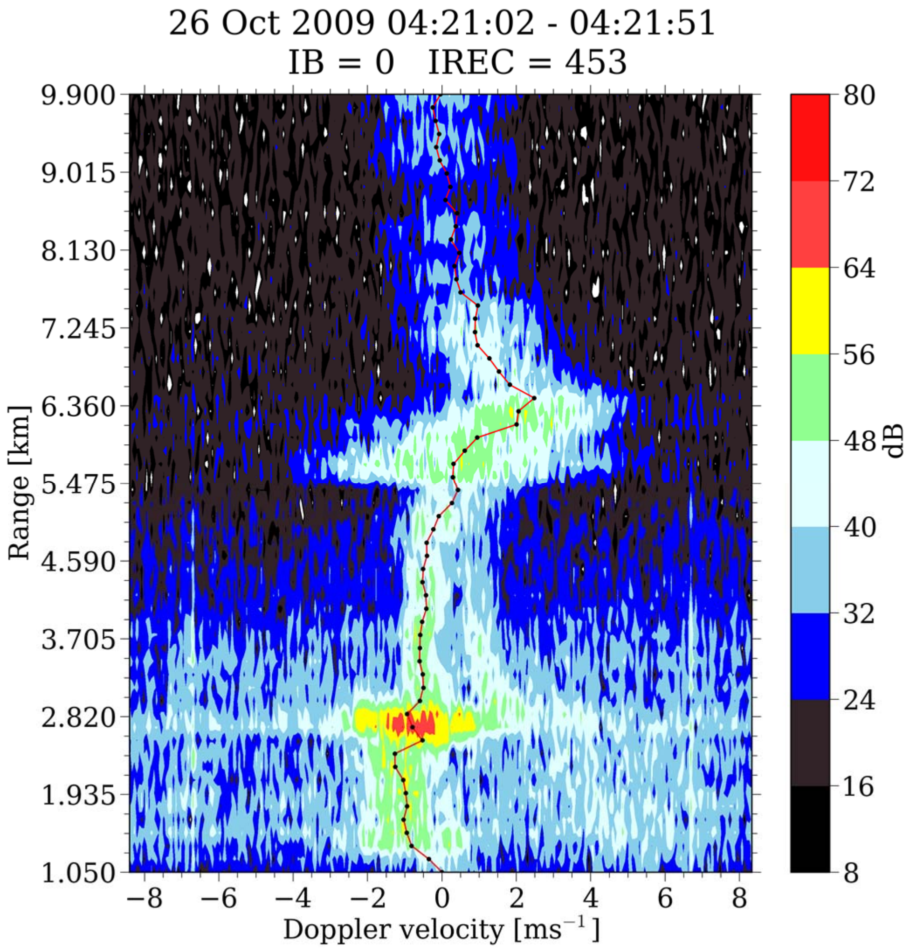
- Increasing the cut level causes the overestimation of P and σ by causing the contamination of hydrometeor echo.
- The cut level must be set so that it rejects the contaminations.

Application to the measurement data

Processed without new method

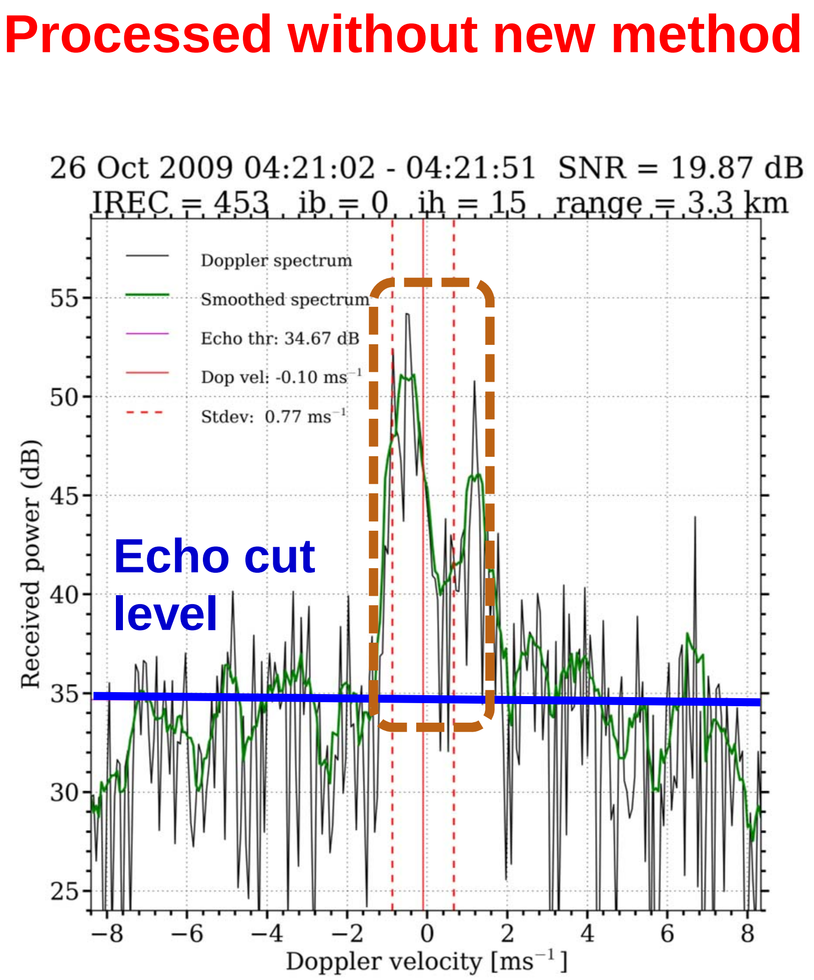


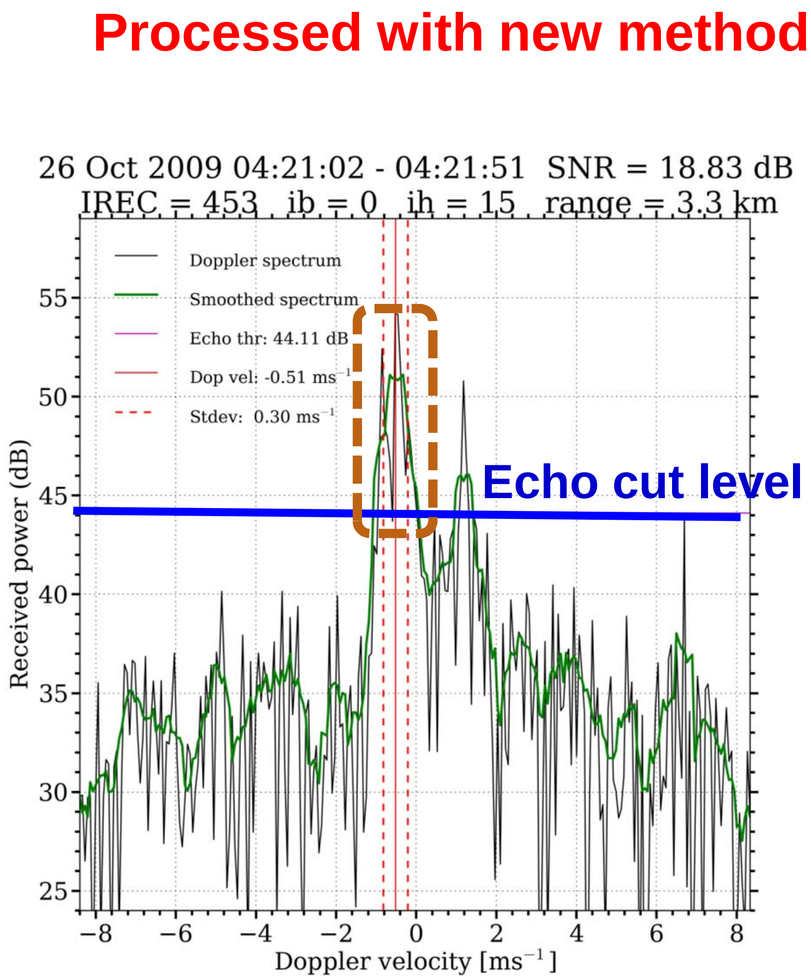
Processed with new method



Mis-estimations of W are overcome by the new method.

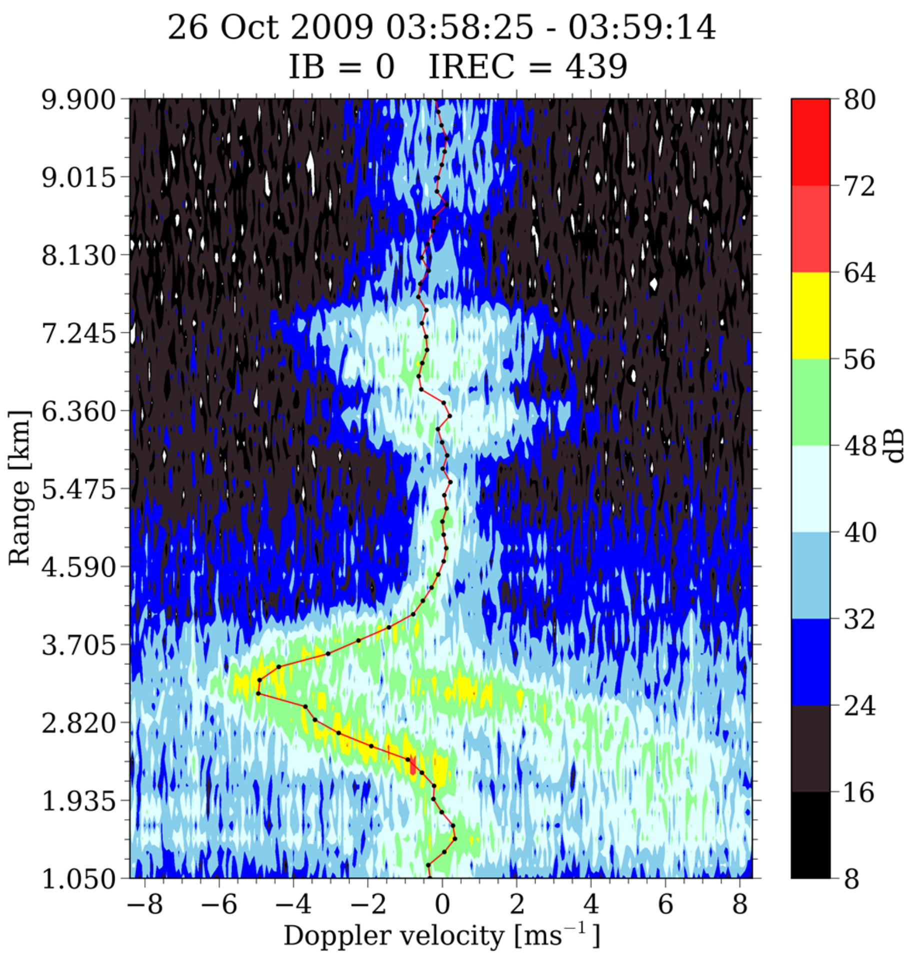
Application to the measurement data





Mis-estimation of Doppler velocity are overcome by varying the echo cut level.

Processed results in convective rainfall



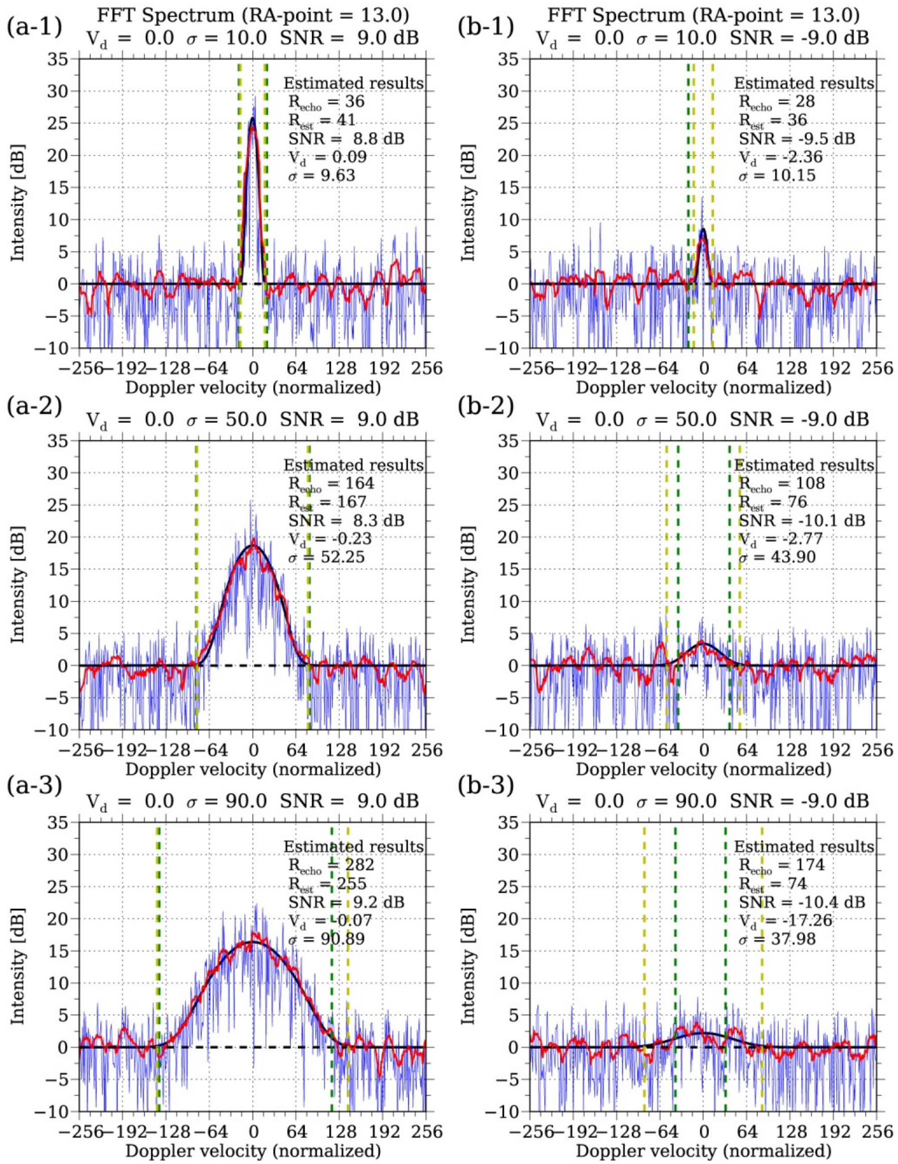
- Upward motions reaching ~5 m s^{-1} are observed.
- Such vertical wind (W) information is necessary validating EC products.

Conclusions and future plan

- The simple and fast method for calculating the 0th, 1st, and 2nd moments of the Doppler spectra (spectral parameter) collected by WPRs is established.
- Programs and skills for producing W products collected by a 1.3-GHz WPR (as installed in Koganei NICT) are obtained.
- A method for obtaining vertical wind velocity (W) in the presence of hydrometeor echoes is developed.
- From now, we finish the production of W, Z_{e}, and V_{Z} data collected by the MU radar and other radars, and provide the research community for validating the EC product.
- Also a method for retrieving microphysical properties of clouds and precipitation by using W product is developed.

Examples of simulated Doppler spectra

SNR = 9dB **SNR = -9dB**



- Results for narrow σ of 10 (0.33 m s^{-1}), large σ of 50 (1.64 m s^{-1}), and very large σ of 90 (2.95 m s^{-1}). m s^{-1} values are for the MU radar.
- "echo range", in which the intensity of clear-air echo is greater than the noise level, is determined. Spectral parameters are calculated using the Doppler spectrum points within the echo range.
- The echo range is determined with the spectrum smoothed by 13-point running average.
- For SNR of -9 dB, estimation accuracy degrades (Accuracy assessment required!).

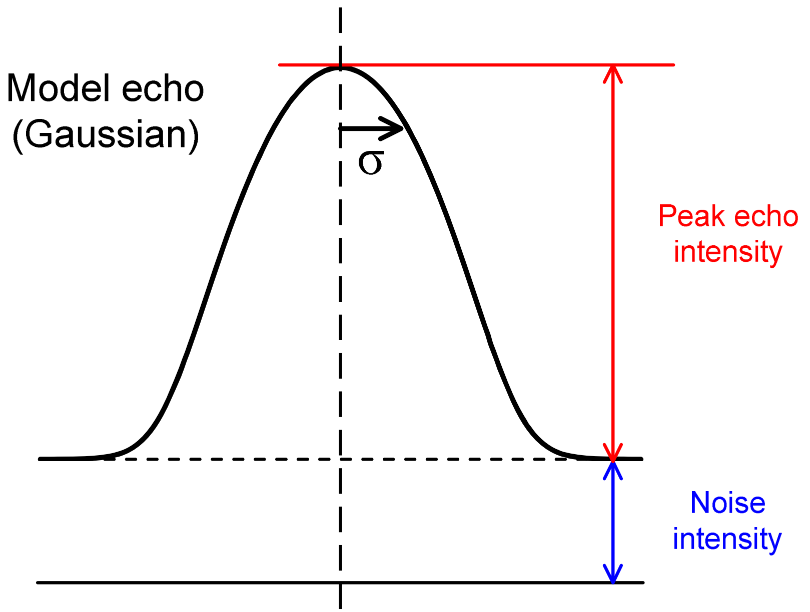
Simulation settings

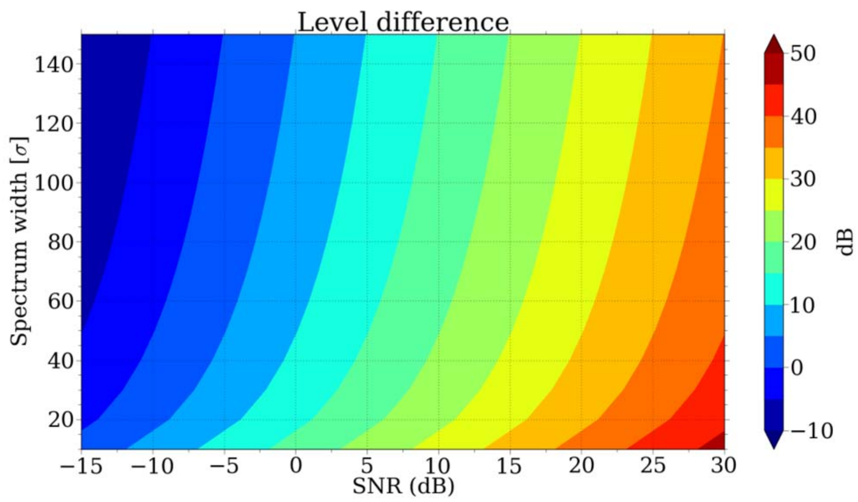
Simulation parameters	
Number of spectrum bins (NDATA)	512
SNR range	-15 dB ~ 30 dB, 3 dB step
Spectrum width in half-power full width (σ)	10, 50, 90 (normalized) 0.7, 3.3, 5.9 m s^{-1} (MUR) 0.4, 2.1, 3.7 m s^{-1} (LQ7)
Doppler velocity (V_d)	0.0
Number of calculation times	1000

- NDATA = 512 is frequently used for MUR and LQ7 in the RIM mode.
- We assume that a Doppler spectrum of echo follows Gaussian distribution and has perturbations following χ^2 distribution.
- Mean (bias) and standard deviation (STD) errors of the spectral parameters are calculated for detailed investigations.
- Error estimation using 1000 simulated Doppler spectra gave the statistically significant results.

The peak echo level can be an indicator for quantifying estimation errors

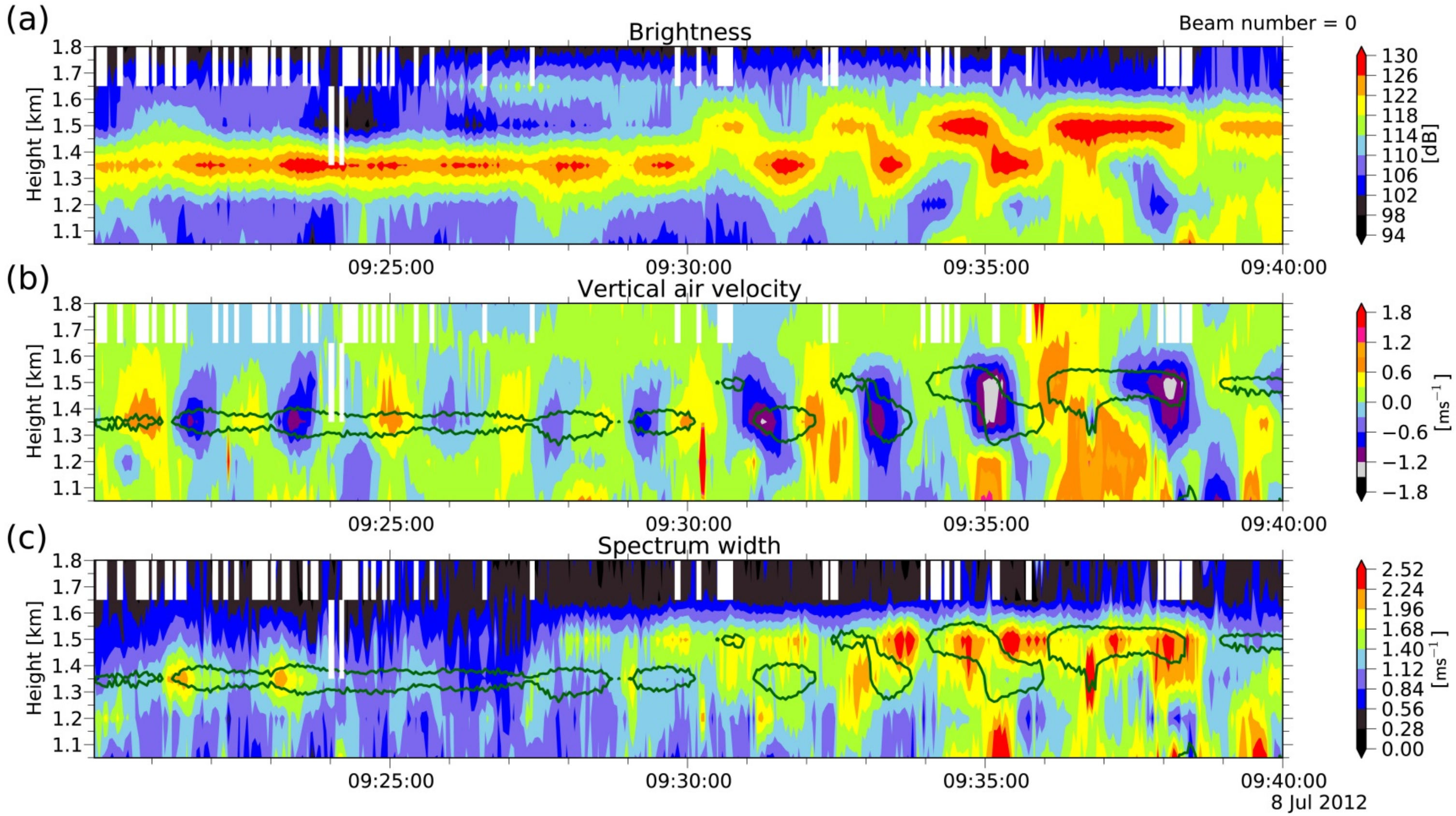
- In order to examine factors that determine errors of the spectral parameters, a peak echo intensity of the modeled echo (P_k) is introduced.
- P_k increases with the increase of SNR, and decreases with the increase of spectrum width (σ).





Gravity wave measurement with neither RIM nor OS

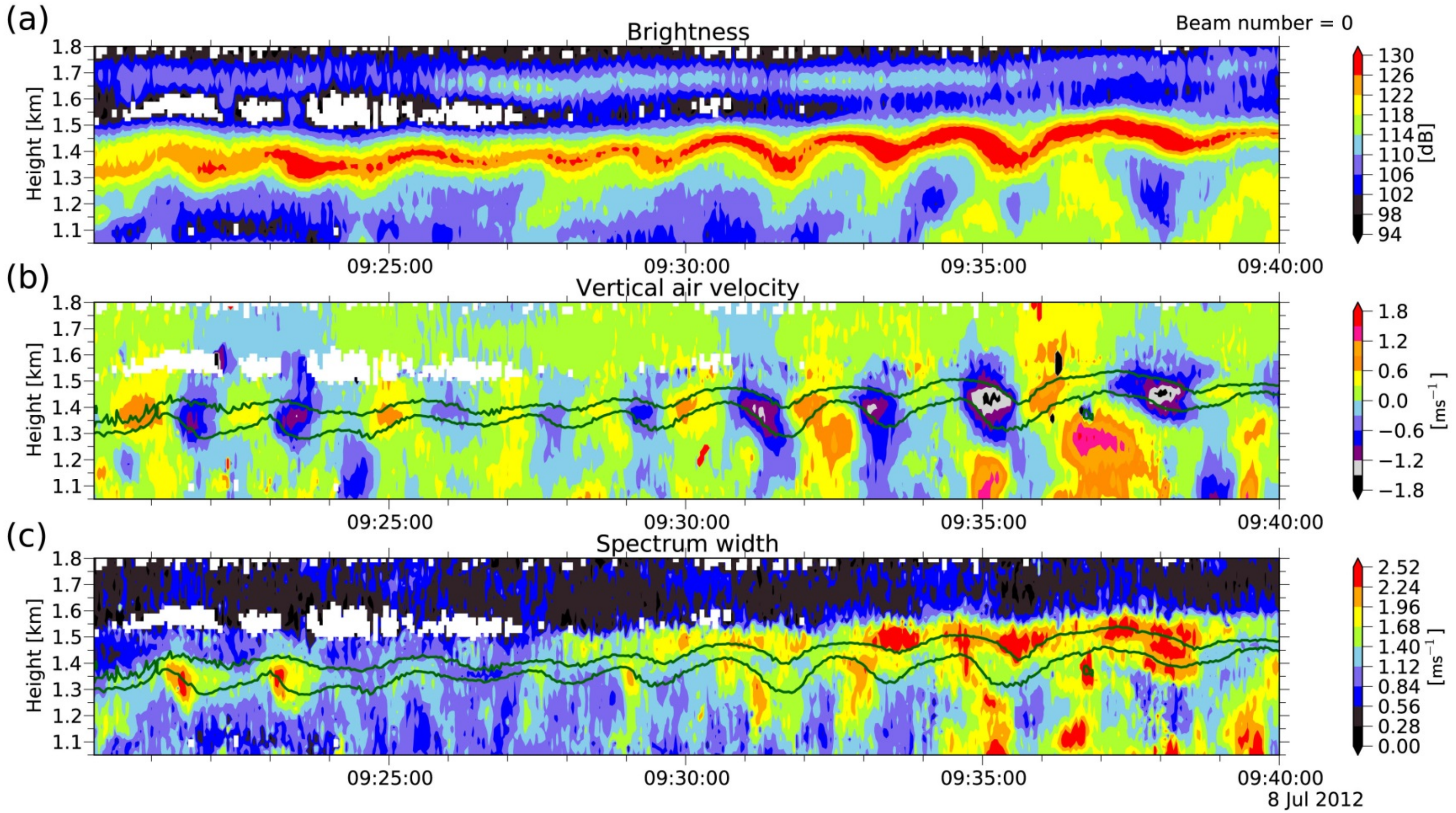
Time resolution = 3 s



Though oscillatory motions of vertical wind (W) were observed, vertical displacements of the echo layer were not well resolved owing to the coarse vertical resolution (150 m for the present case).

Gravity wave measurement using RIM plus OS

Time resolution = 3 s



- By improving range resolution using RIM plus OS, the oscillatory *W* motions with a vertical scale < 100 m and time scale < 1 min were resolved.
- The *W* oscillations were likely caused by an internal gravity wave in the entrainment zone of the boundary layer.

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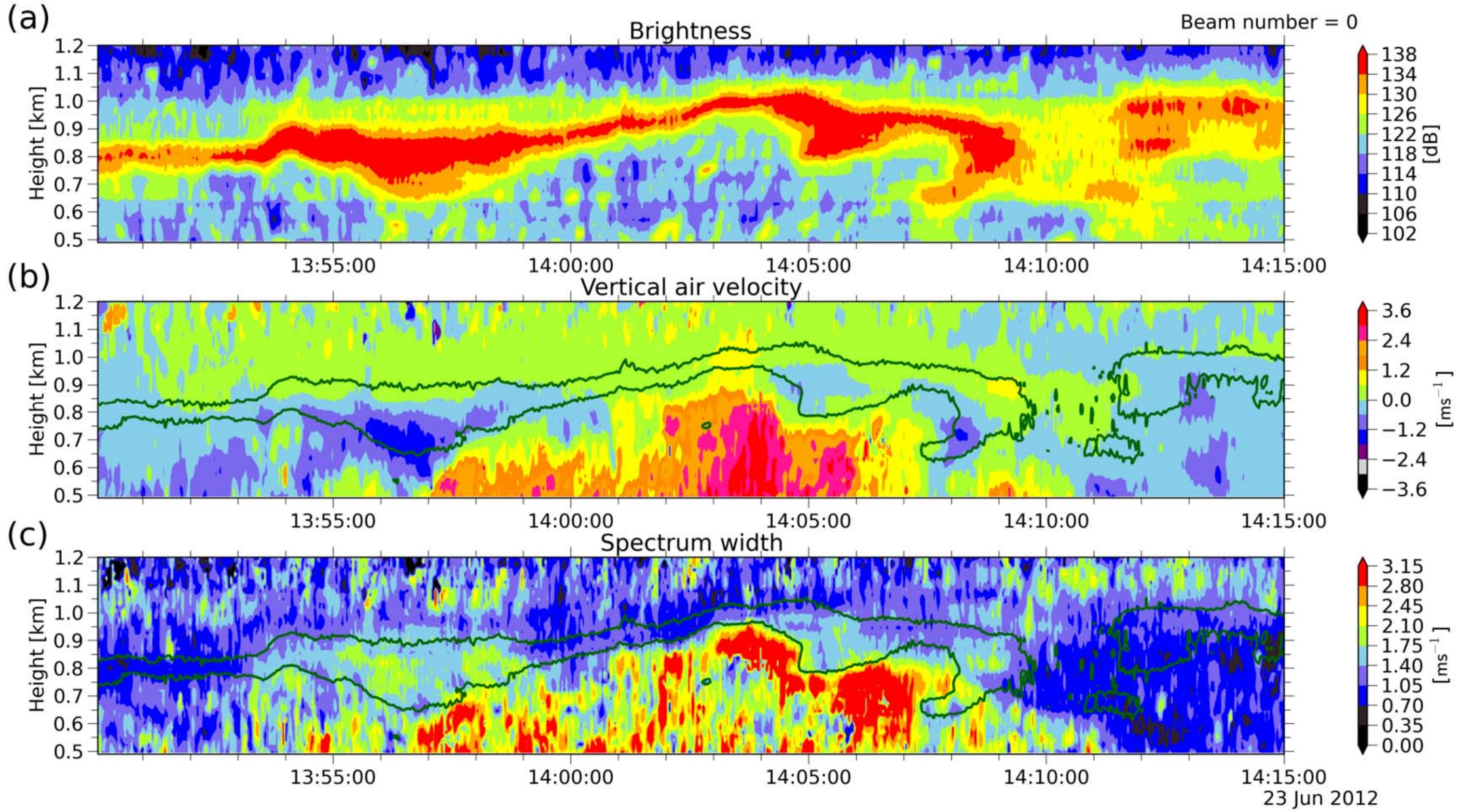
Dissipation of the thermal



- The thermal with upward W of > 2 m/s dissipated in the stable layer with echo intensity of > 134 dB.
- Enhanced small-scale W perturbations (spectrum width) associated with the thermal dissipation were observed where enhanced upward W of 1.2 m s^{-1} terminated.

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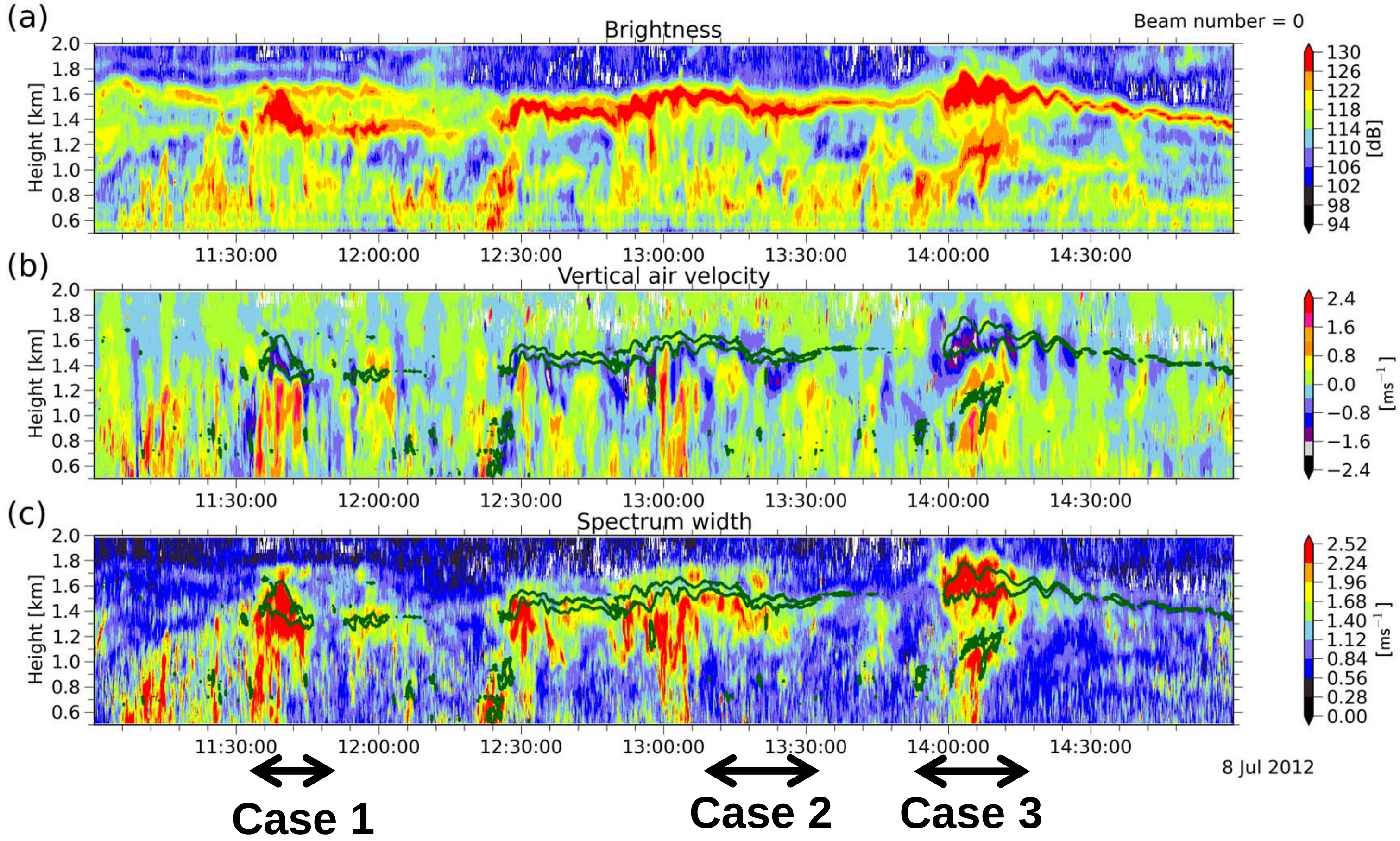
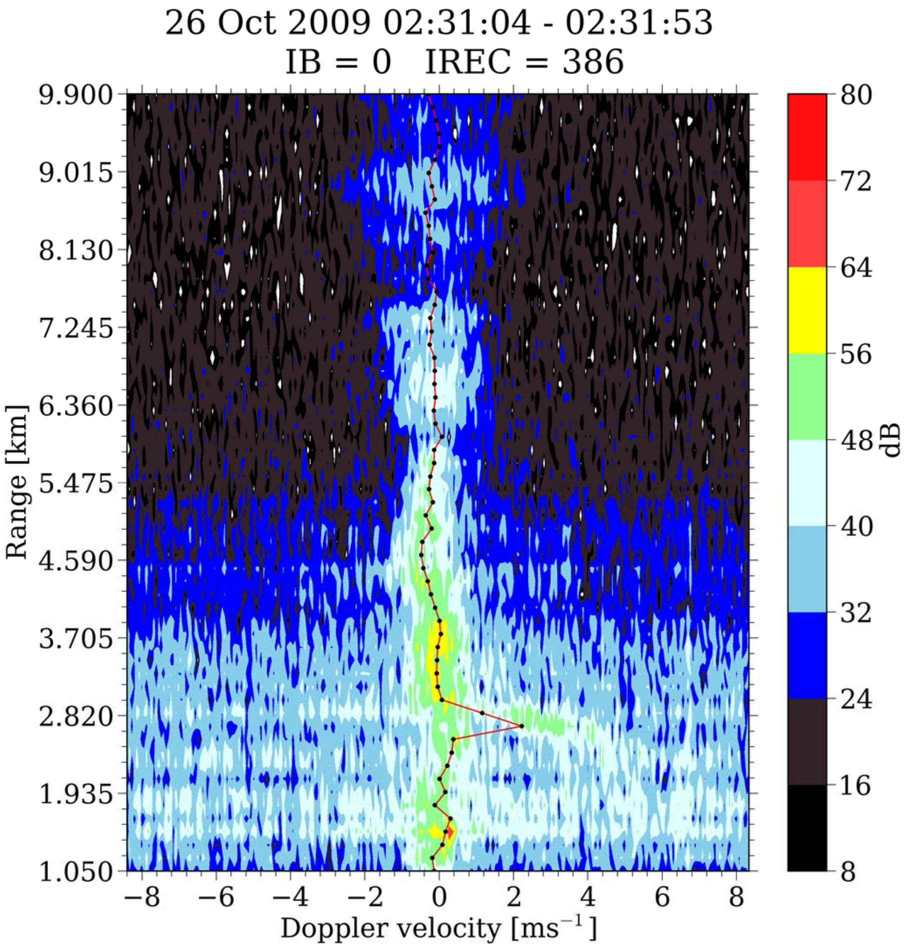
Fine-scale W motions in the boundary layer clouds



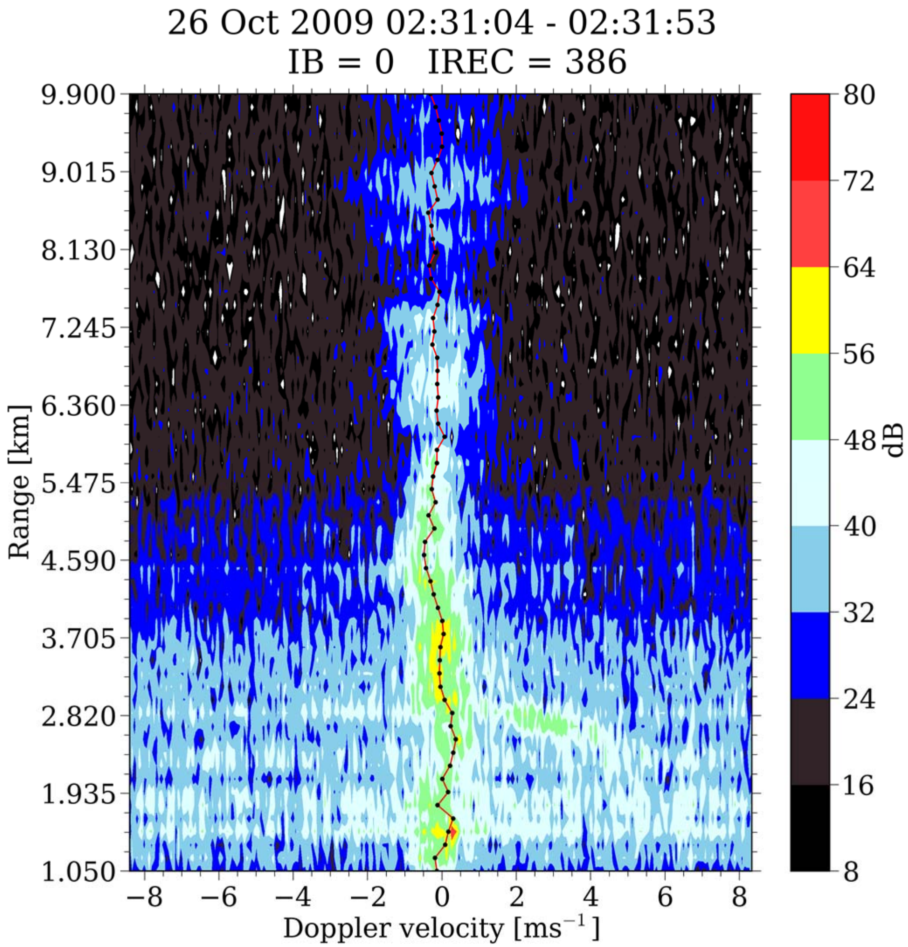
- When low-level clouds existed over RIM-LQ7, upward W and enhanced small-scale W perturbations (spectrum width) were observed.
- Downward W was observed above the height of upward W (must be treated wit care because of possible contamination of hydrometeors).

Application to the measurement data

Processed without new method



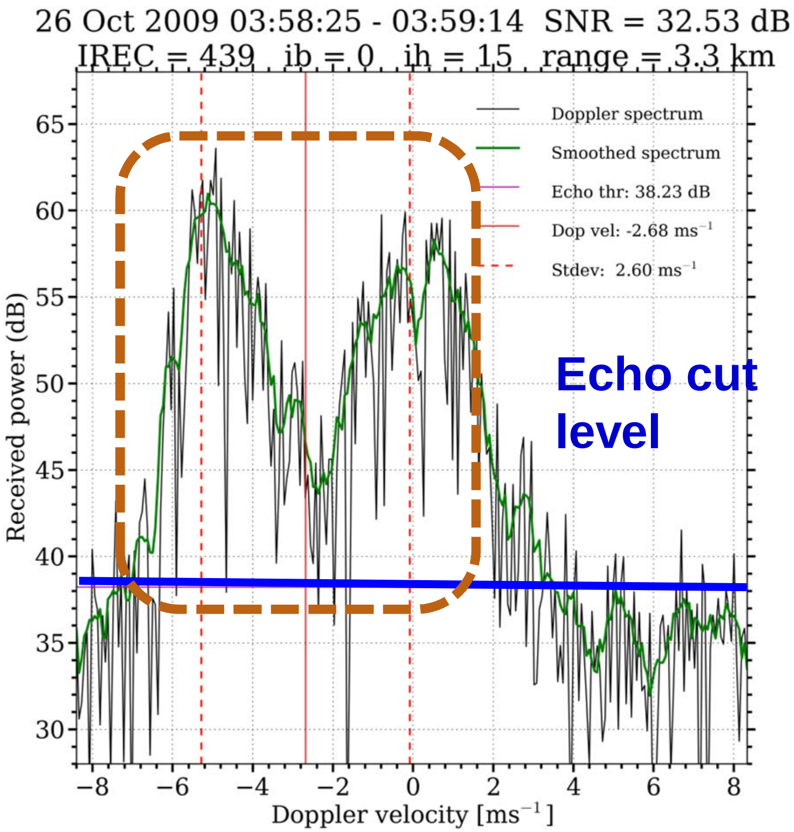
Processed with new method



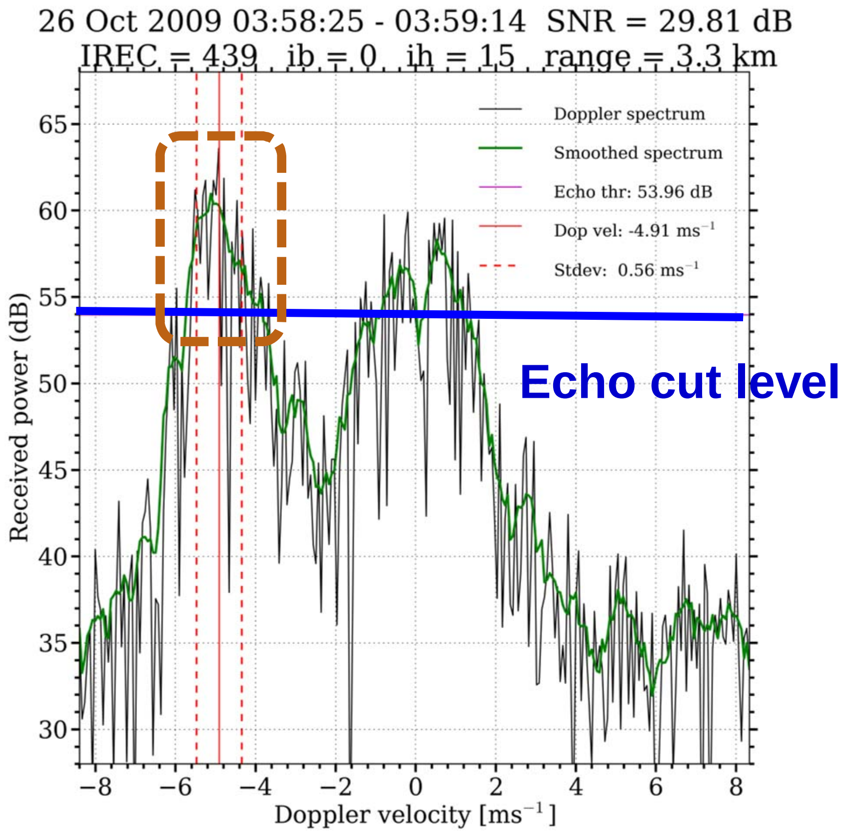
Mis-estimation of Doppler velocity at the bright band is overcome.

Application to the measurement data

Processed without new method

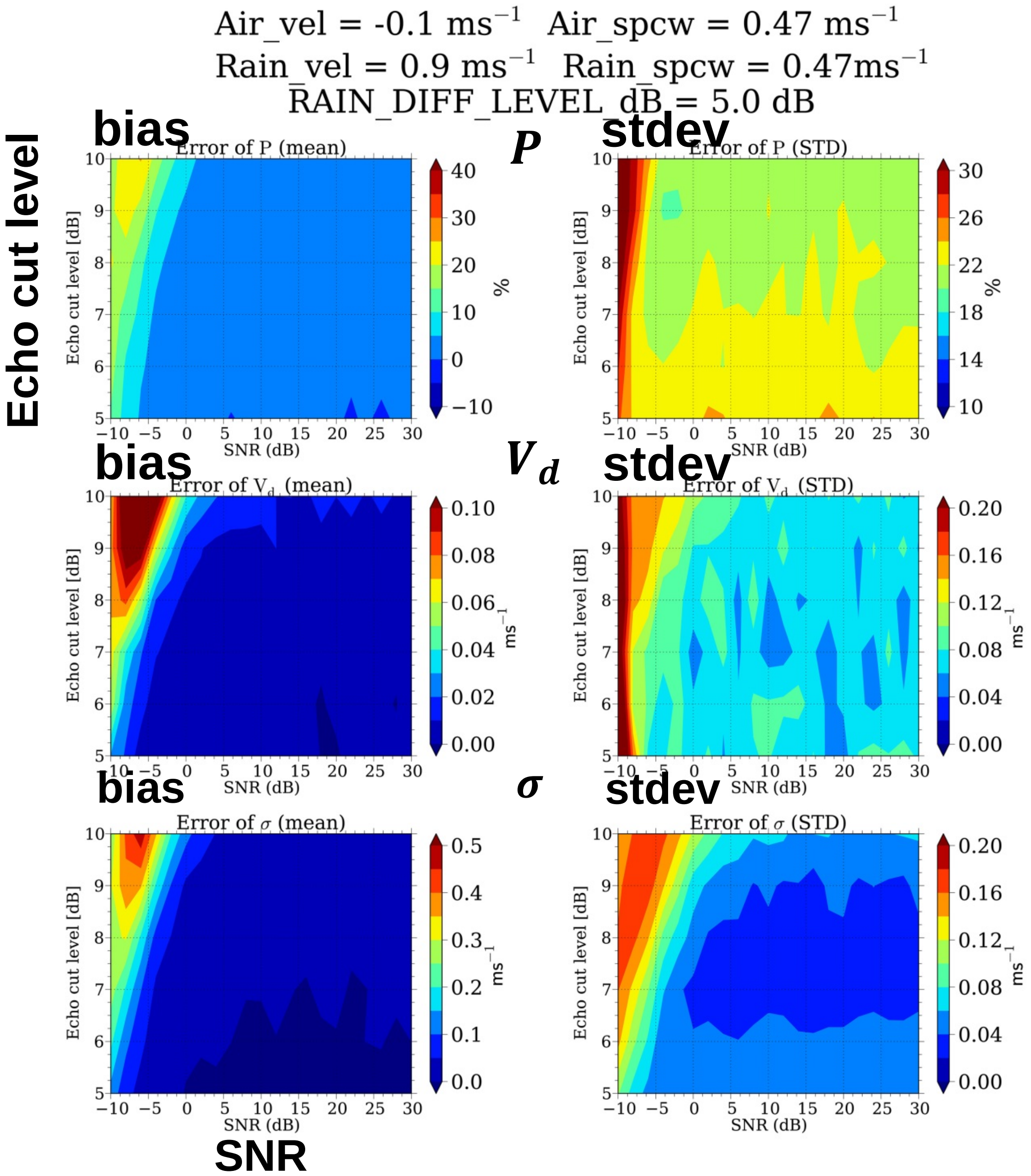


Processed with new method



Mis-estimation of Doppler velocity are overcome by varying the echo cut level.

Cut level consideration by numerical simulation



Because of the correction of P and σ, the measurement errors of them are as low as < 22 % and 0.04 m s^{-1} for echo cut level σ ≥ 7 dB.

N_{RA}=7

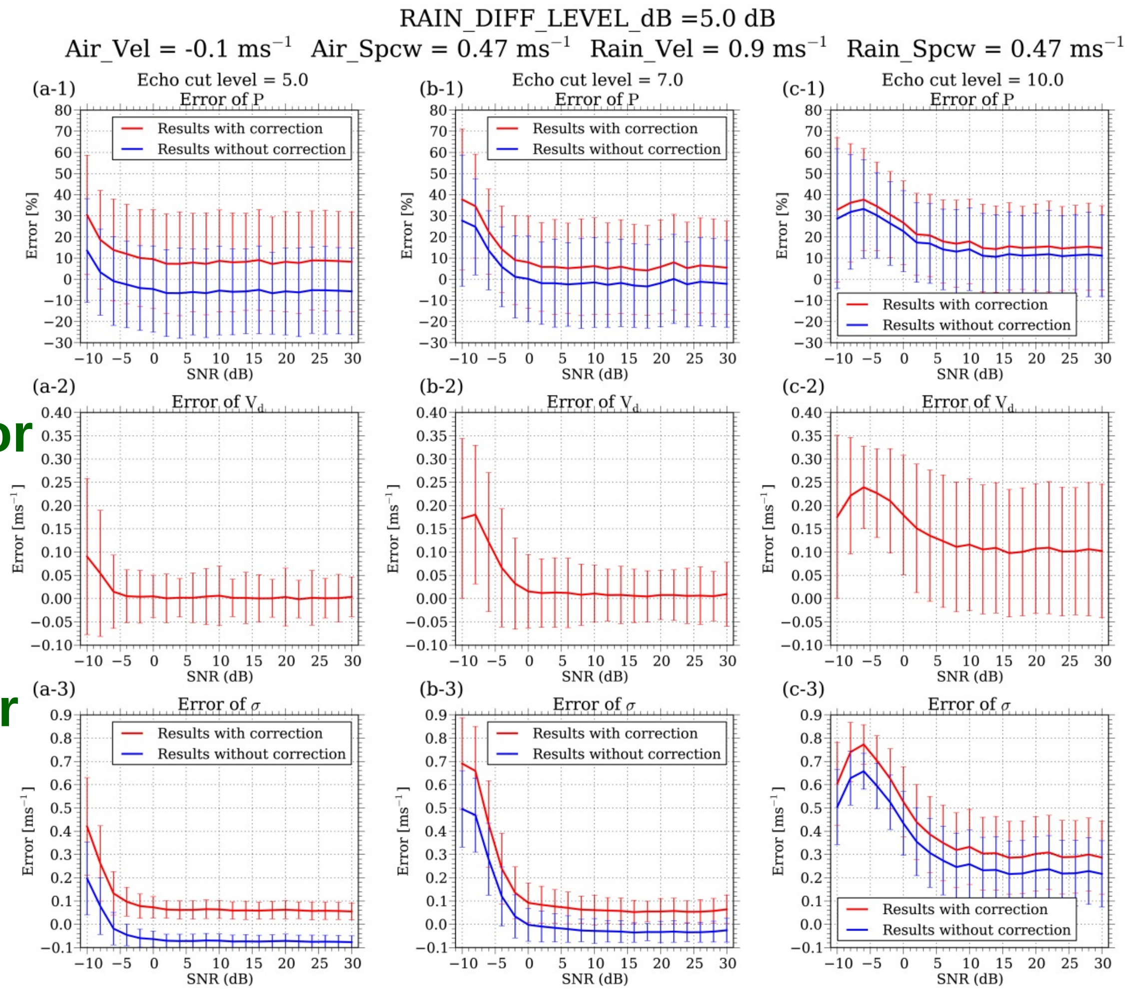
Cut level consideration by numerical simulation (N_{RA} = 13)

Cut level = 5 dB **Cut level = 7 dB** **Cut level = 10 dB**

P **error**

V_d **error**

σ **error**



N_{RA} = 13

N_{RA}: Number of running average points

- Increasing the number of RA points causes an overestimation of P and σ because of the overestimation of echo range.