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Detection and Estimation of Wake Vortex on Ultra Fast-Scanning Pulsed-Doppler Lidar

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Outline

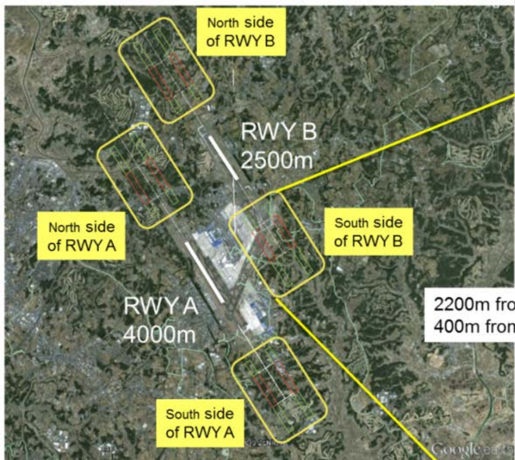
1. Introduction
- Narita Observation Campaign
- Motivation
- Lidar and Scanning Strategy

2. Examples of Estimated Results
- Simulation
- Application to Real Data

3. Conclusion

Introduction

- **Narita Observation Campaign**
  (see details in the PPT file by N. Matayoshi)



Narita Airport

- ➢ Development of WV database in Narita Airport, Japan
  - ✓ Large number of samples with high-quality estimation by using a fast-scanning Doppler lidar
  - ✓ Update of safe separation in RECAT-3
  - ✓ Traffic optimization

Lidar's RHI Plane

- ➢ Real-time detection, and estimation
  - ✓ Provide WV information in (quasi) real time

Introduction

- **Motivation**
  - Lidar – *Practical simpleness for observation*
    - ✓ Single-lidar observation
    - ✓ High scan rate

  ➡ **Windcube200S, Leosphere**

  - Algorithm – *High accuracy and robustness for low CNR*
    - ✓ Pulsed-Doppler lidar has low range resolution (tens of meters) with current technology
    - ✓ Need to extract small structure of a WV (< 15 m) from low range resolution (tens of meters) measurements.
    - ✓ Low-order moments of Doppler spectrum are not good enough because min and max velocities of a WV are not considered.
    - ✓ Detection of min and Max velocities in a Doppler spectrum is valid. But not robust for a low CNR condition

  ➡ **Proposal of a method with high estimation accuracy and robustness for a low CNR condition**

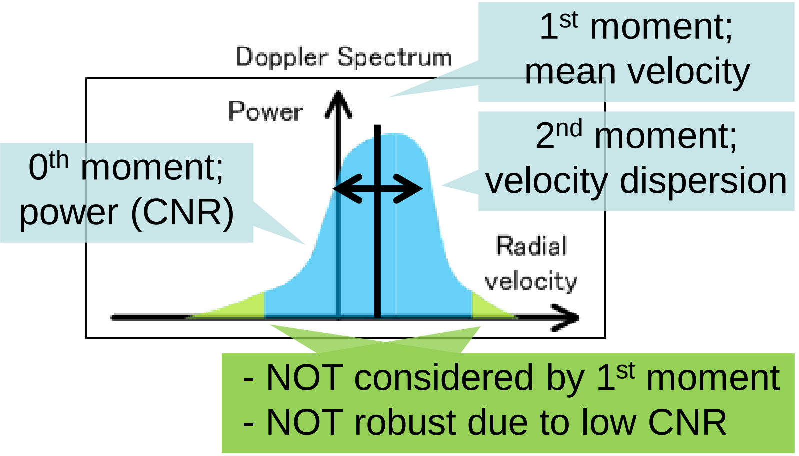
Introduction

- Lidar and Scanning Strategy
  - Lidar
    - ✓ Windcube200S, Leosphere
    - ✓ Pulsed-Doppler Type
    - ✓ Wavelength: 1543 nm
    - ✓ Max power: 5 mW
    - ✓ Pulse Repetition: 20 kHz
    - ✓ Digital Sampling rate: 250 MHz

  - Scanning Strategy
    - ✓ RHI: 0 – 40 deg for landing aircrafts
      20 – 60 deg for take-off aircrafts
    - ✓ Scan duration: 6 sec (+ 2 sec to reset)
    - ✓ Range sampling: Every 5 m; 100 – 885 m
      (physical range resolution: 48 m)
    - ✓ Elevation sampling: Every 0.2 deg
    - ✓ Velocity sampling: Every 3 m/sec; -30 – 30 m/sec

Methodology

- Traditional Methods
  - Measurement
    - ✓ Pulsed-Doppler lidar has low range resolution of tens of meters (much larger than core size of WV).
    - ✓ Based on 1st moment: Min and max velocities of a WV are NOT considered.
    - ✓ Addition of 2nd moment: Doppler spectrum is approximated by a (symmetry) Gaussian distribution. But Gaussian is NOT suitable for a WV case.
    - ✓ Based on min and max velocities in a Doppler spectrum: Can provide high estimation accuracy. But not robust for low CNR. (In general, fast-scanning links to low CNR)

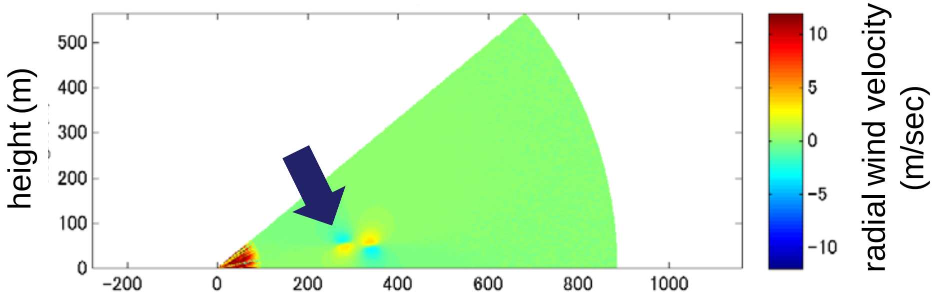


  - Deterministic Calculation
    - ✓ Measurement always includes fluctuation.
    - ✓ Need to consider measurement error especially in a low CNR condition

Example of Estimation Results

- Simulation Case 1/4
  - Large cores (left: 6.0 m, right: 6.5 m)
  - No background wind

Simulated Radial Wind Field



	Parameters	1st moment based method	Proposed method	Simulation Truth
Left	y (m)	279.7	279.8	280
	z (m)	55.5	55.0	55
	Γ_{5-15} (m^2/sec)	−183.6	−318.2	−281.0
Right	y (m)	341.4	340.7	340
	z (m)	50.4	50.1	50
	Γ_{5-15} (m^2/sec)	205.1	347.5	301.9

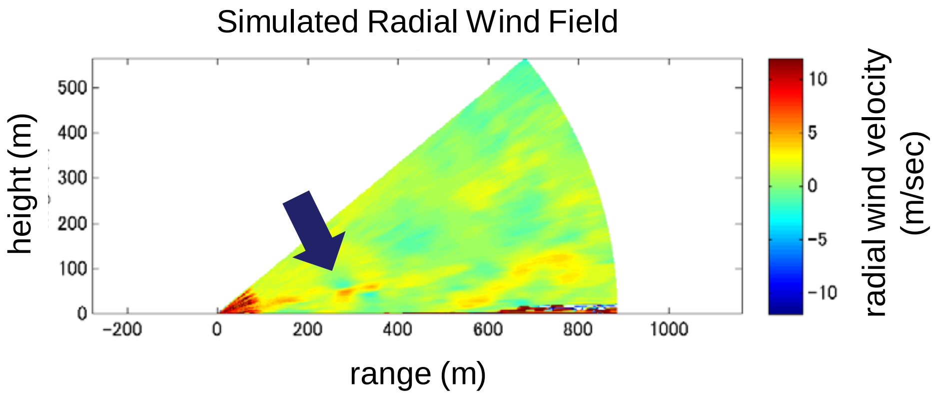
Both methods show excellent agreements in estimated location.

For circulation, errors are reduced roughly from 65% to 10% .

空へ挑み、宇宙を拓く JAXA

Example of Estimation Results

- Simulation Case 2/4
  - Large cores (left: 6.0 m, right: 6.5 m)
  - With background wind

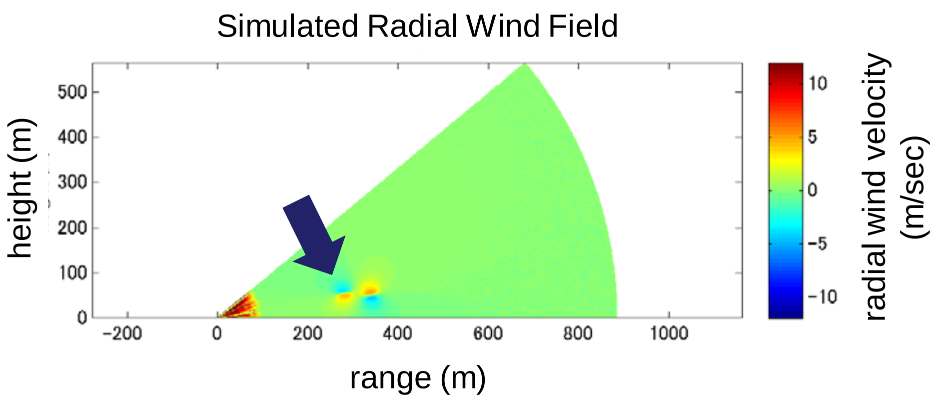


	Parameters	1st moment based method	Proposed method	Simulation Truth
Left	y (m)	284.6	279.2	280
	z (m)	56.4	55.3	55
	Γ_{5-15} (m^2/sec)	−194.9	−316.3	−281.0
Right	y (m)	336.3	339.8	340
	z (m)	50.9	50.0	50
	Γ_{5-15} (m^2/sec)	185.4	298.8	301.9

Even with background wind, accuracy is almost equivalent.

Example of Estimation Results

- Simulation Case 3/4
  - Small cores (left: 3.0 m, right: 2.0 m)
  - No background wind



	Parameters	1st moment based method	Proposed method	Simulation Truth
Left	y (m)	279.7	280.0	280
	z (m)	54.9	55.0	55
	$\Gamma_{5\text{-}15}$ (m^2/sec)	−213.1	−397.6	−358.8
Right	y (m)	341.4	337.5	340
	z (m)	50.4	49.7	50
	$\Gamma_{5\text{-}15}$ (m^2/sec)	265.5	471.1	427.7

Small WVs (cores < range gate, 5 m) are also estimated with equivalent accuracy.

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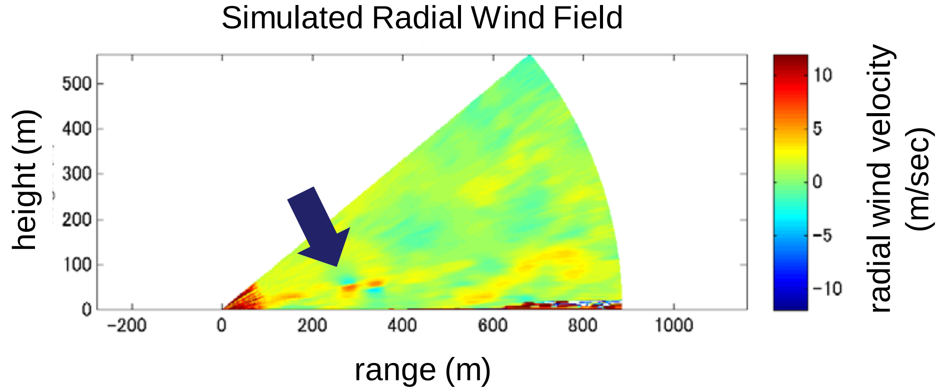
Example of Estimation Results

- Simulation Case 4/4
  - Small cores (left: 3.0 m, right: 2.0 m)
  - With background wind

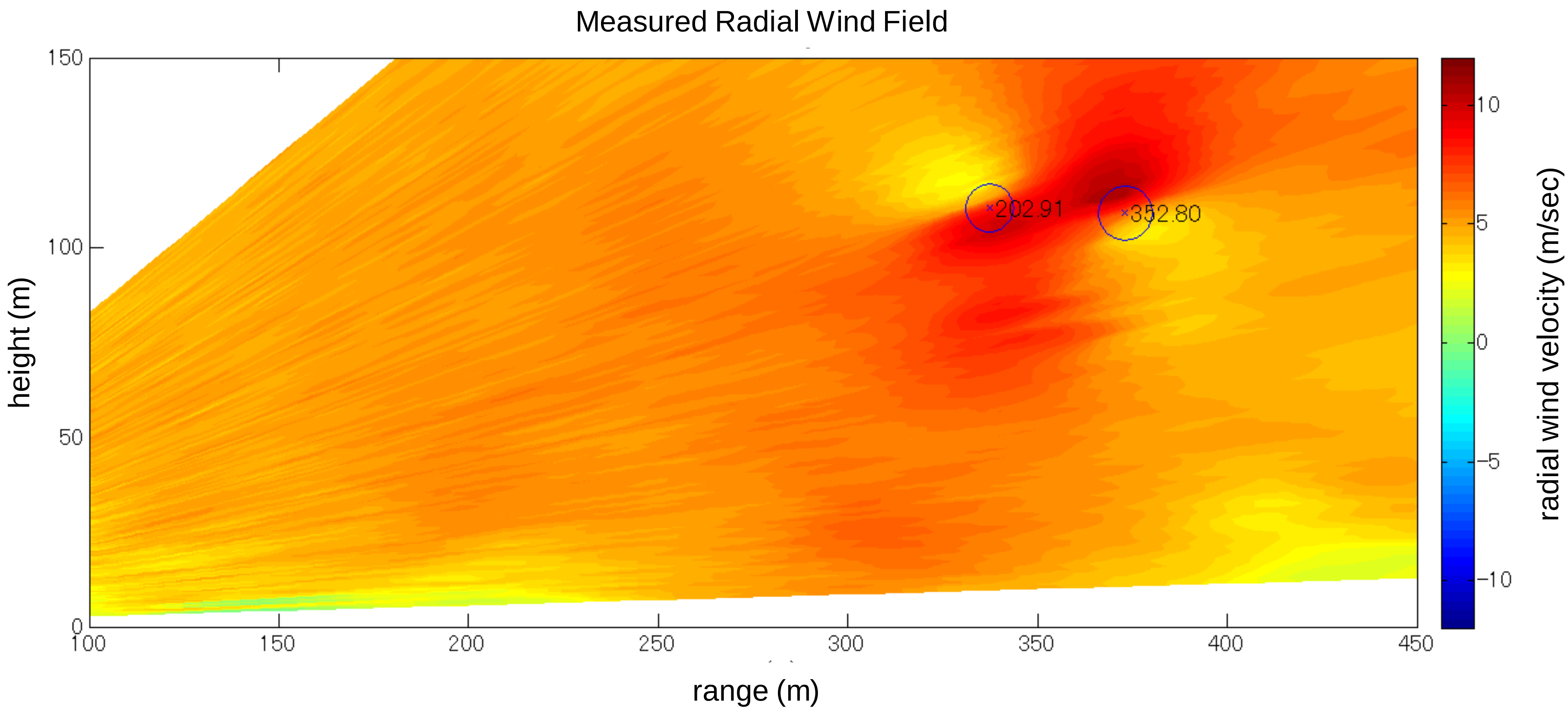


	Parameters	1st moment based method	Proposed method	Simulation Truth
Left	y (m)	279.5	280.1	280
	z (m)	55.9	55.2	55
	Γ_{5-15} (m^2/sec)	−245.9	−408.4	−358.8
Right	y (m)	336.2	341.4	340
	z (m)	50.9	50.1	50
	Γ_{5-15} (m^2/sec)	262.1	440.2	427.7

Even with background wind, accuracy is almost equivalent.

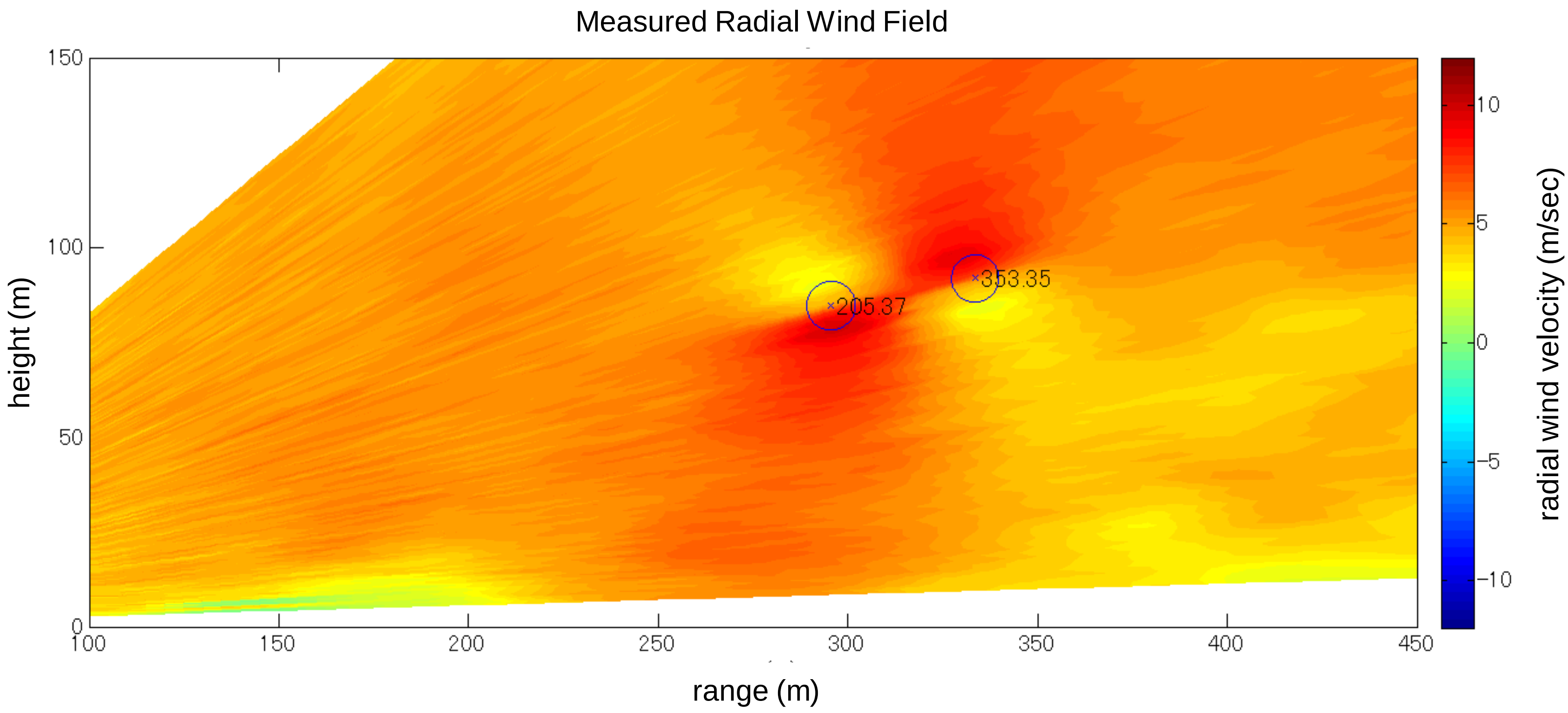
Example of Estimation Results

◆ Application to Real Data 1/6
Temporal progress of WVs (8 sec interval between adjacent RHIs)



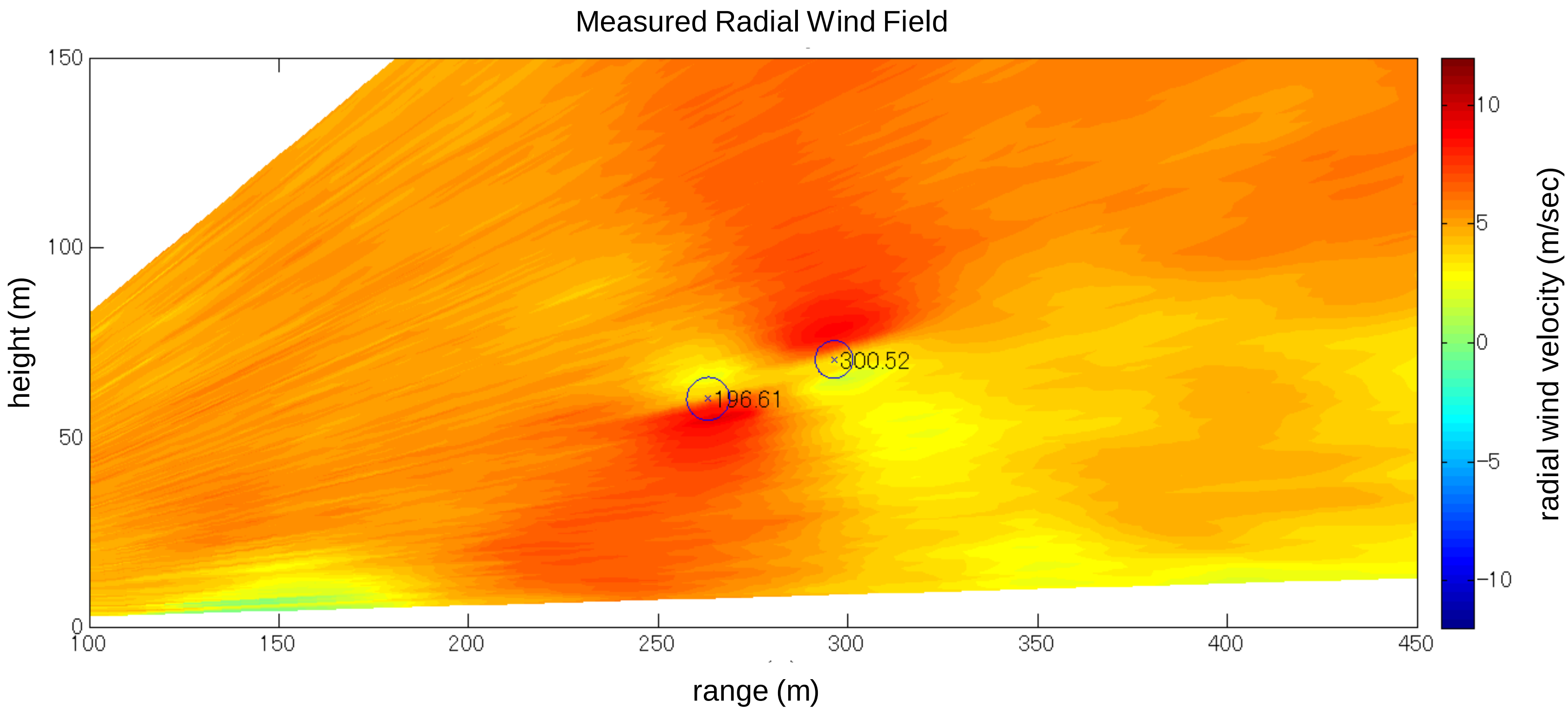
Example of Estimation Results

- Application to Real Data 2/6
  Temporal progress of WVs (8 sec interval between adjacent RHIs)



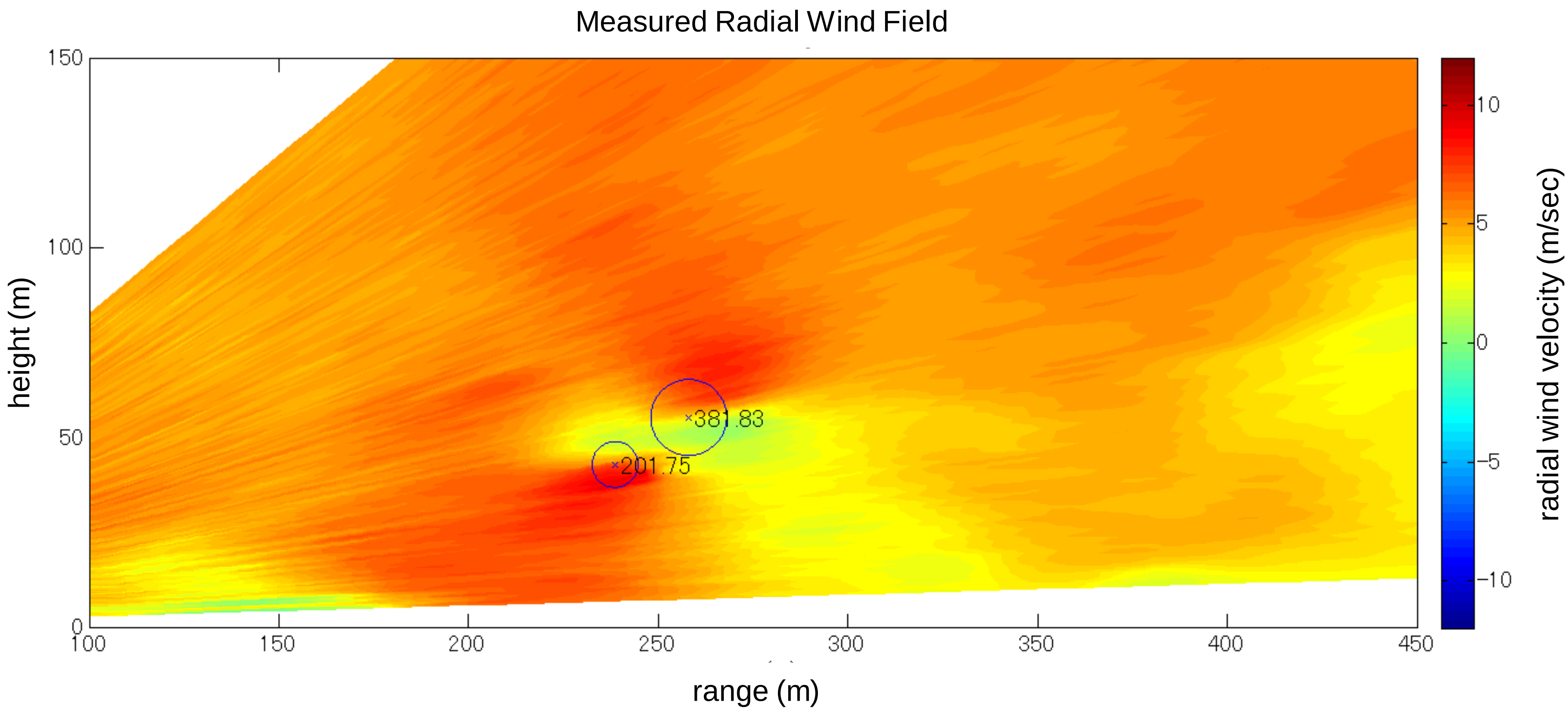
Example of Estimation Results

- Application to Real Data 3/6
  Temporal progress of WVs (8 sec interval between adjacent RHIs)



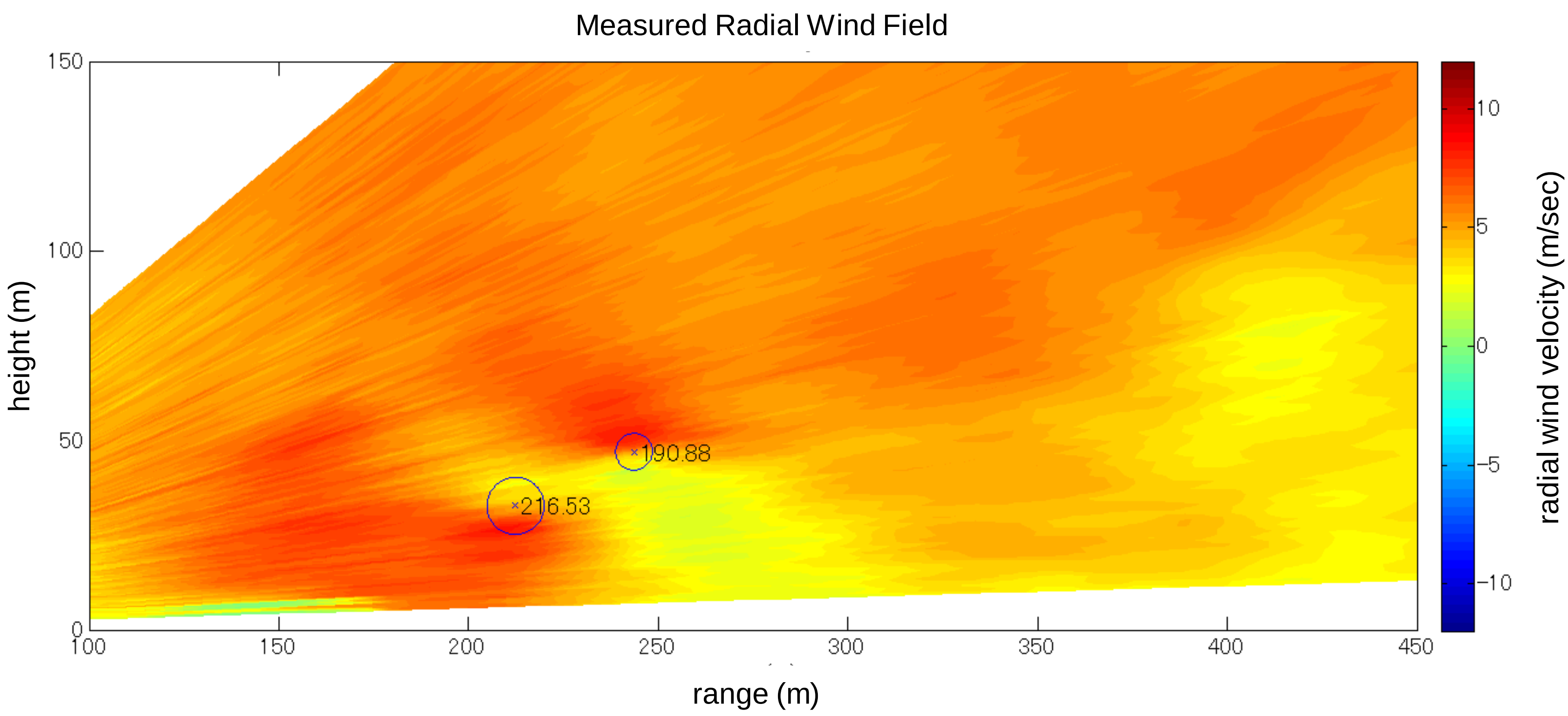
Example of Estimation Results

- Application to Real Data 4/6
  Temporal progress of WVs (8 sec interval between adjacent RHIs)



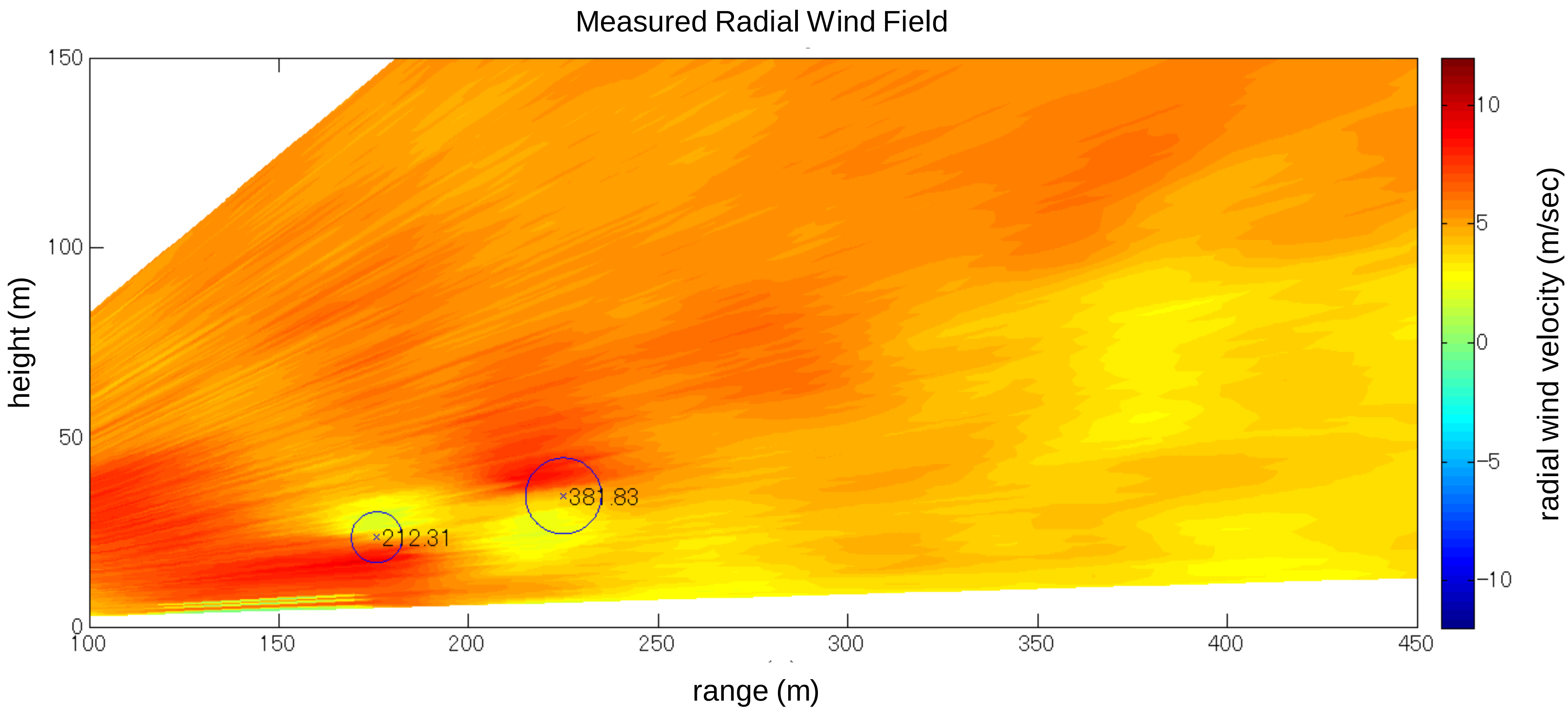
Example of Estimation Results

- Application to Real Data 5/6
  Temporal progress of WVs (8 sec interval between adjacent RHIs)



Example of Estimation Results

◆ Application to Real Data 6/6
Temporal progress of WVs (8 sec interval between adjacent RHIs)



Conclusion

- An algorithm to detect a WV and estimate WV parameters is developed.
- Motivation is to achieve high estimation accuracy even in a low CNR condition to obtain knowledge of WV characteristics with a large number of observations and to use it in real-time operations.
- Simulation results show a good estimation accuracy (location error is less than 1 m, circulation error is about 10 %)
- The application to real data resulted in a reasonable estimation.

- Statistical evaluation will be carried out with fresh (just-generated) WVs (comparing estimation with theoretical values derived from QAR data)