127 INTEGRATED VELOCITY RETRIEVAL ON RADAR NETWORK ENVIRONMENT

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1. INTRODUCTION

Sensor network is getting attention for detecting hazardous weather phenomena and retrieving physical parameters more efficiently and accurately. Collaborative Adaptive Sensing of the Atmosphere (CASA) [1] has proposed a radar network system using short-range X-band radars for mutually enhancing among weather radars. The Ku-band broadband radar network (Ku-BBR network) consists of a shorter-range and higher-resolution weather radars in Ku-band [2]. And in an airport, where weather information plays an important role for its safety operation, both a radar and a lidar are installed (especially in major airports) in order to cover all weather conditions (a radar and a lidar are mainly for rain and fair weather conditions, respectively) [3]. Now an integrated retrieval method on sensor network environment is demanded to estimate velocity more accurately than single-radar environment.

Both a radar and lidar observes radial component of velocity. It is essential for meteorological use to retrieve 2-D or 3-D velocities from measurements of radial velocities. In single-radar/lidar environment, Volume Velocity Processing (VVP) has been utilized for this purpose [4]. However, it is well known that a large volume with angular width of a few tens of degrees must be defined to accomplish estimation accurate enough for a practical use. This is because enough dependency for orthogonal directions is not extracted by radial velocities within narrow angular width. Instead of the stability, spatial resolution is decreased by linearly fitting a wide angular width. For better retrieval, dual-radar environment has been utilized. However, a velocity measurement in each range gate has its own probabilistic property (accuracy), as written in [5]. Therefore, it is important to consider the probabilistic property of velocity measurement due to signal-to-noise ratio for proper integrated estimation. Nevertheless, in a case that one radar measures velocity with high accuracy in a desired point but another does not, the integrated approach may output a worse estimation than the single-radar approach. Further, for integrated retrieval by different sensors such as in radar/lidar environment, it is more important to consider probabilistic properties because probabilistic properties of each sensor are quite different.

In this paper, integrated retrieval for 2/3-D velocities from radial velocities on a sensor network environment is proposed. As an initial study, this paper focuses radar-network environment. To formulate between 2/3-D velocities to radial velocities of radars, an improved VVP formulation, which is proposed in another paper of us in this conference, titled "IMPROVED VELOCITY VOLUME PROCESSING (VVP) WITH PROBABILISTIC PROPERTY OF VELOCITY MEASUREMENTS FOR A SCANNING RADAR/LIDAR" [6], is applied, The improved VVP formulation can be extended to a radar network environment. The VVP formulation is solved by a Minimum Mean Square Error (MMSE) scheme. Considering the probabilistic properties of measured radial velocities in each radar by MMSE scheme, 2/3-D velocity is optimally calculated in probabilistic sense.

This paper is organized as follows. Section 2 describes the extended formulation of our VVP to radar network environment. Section 3 shows results of numerical simulation. Section 4 concludes this paper.

2. METHODOLOGY

2.1 IMPROVED VVP FORMULATION FOR RADAR NETWORK ENVIRONMENT

In the improved formulation, every 2/3-D velocity on Cartesian grids of a desired area is defined. Expressing in 2-D for simplicity, the 2-D velocity vector on a Cartesian coordinate $\mathbf{v}_C$ is as below.

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$$\mathbf{v}_C = \begin{bmatrix} v_{Cx}^{(1)} & v_{Cy}^{(1)} & v_{Cx}^{(2)} & v_{Cy}^{(2)} \\ \cdots & v_{Cx}^{(N)} & v_{Cy}^{(N)} \end{bmatrix}, \quad (1)$$

where $v_{Cx}^{(n)}$ and $v_{Cy}^{(n)}$ are an x- and y-component of velocity on the *n*-th Cartesian grid, respectively. *N* is the number of Cartesian grids in a desired area. A transition matrix $\mathbf{T}$, which translates $\mathbf{v}_C$ to a 2-D velocity vector on each radar polar coordinate is defined as

$$\begin{bmatrix} \mathbf{v}_P{}^{(1)} \\ \mathbf{v}_P{}^{(2)} \\ \vdots \\ \mathbf{v}_P{}^{(L)} \end{bmatrix} = \mathbf{T}\mathbf{v}_C, \quad (2)$$

where

$$\mathbf{v}_P{}^{(l)} = \begin{bmatrix} v_{Px}^{(l,1)} & v_{Py}^{(l,1)} & v_{Px}^{(l,2)} & v_{Py}^{(l,2)} \\ \cdots & v_{Px}^{(l,M)} & v_{Py}^{(l,M)} \end{bmatrix}. \quad (3)$$

$v_{Px}^{(l,m)}$ and $v_{Py}^{(l,m)}$ are an x- and y-component of velocity on the *m*-th radar polar grid in the *l*-th radar, respectively. *L* and *M* are the number of radar polar grids in a desired area and and the number of radars in a radar network, respectively. $\mathbf{v}_P{}^{(l)}$ is connected to a radial wind vector $\mathbf{v}_r{}^{(l)}$ by a projection matrix $\mathbf{P}$ as below

$$\begin{bmatrix} \mathbf{v}_r{}^{(1)} \\ \mathbf{v}_r{}^{(2)} \\ \vdots \\ \mathbf{v}_r{}^{(L)} \end{bmatrix} = \mathbf{P} \begin{bmatrix} \mathbf{v}_P{}^{(1)} \\ \mathbf{v}_P{}^{(2)} \\ \vdots \\ \mathbf{v}_P{}^{(L)} \end{bmatrix}, \quad (4)$$

where

$$\mathbf{v}_r{}^{(l)} = \begin{bmatrix} v_r^{(l,1)} & v_r^{(l,2)} & \cdots & v_r^{(l,M)} \end{bmatrix}. \quad (5)$$

$v_r^{(l,m)}$ is a radial component of velocity on the *m*-th radar polar grid in the *l*-th radar. Thus, the improved VVP formulation connecting $\mathbf{v}_C$ to $\mathbf{v}_r$ is expressed as

$$\mathbf{v}_r = \mathbf{PT}\mathbf{v}_C \equiv \mathbf{H}\mathbf{v}_C, \quad (6).$$

where

$$\mathbf{v}_r = \begin{bmatrix} \mathbf{v}_r{}^{(1)} \\ \mathbf{v}_r{}^{(2)} \\ \vdots \\ \mathbf{v}_r{}^{(L)} \end{bmatrix}. \quad (7)$$

The improved VVP formulation is well discussed in [6]. The main difference between this paper and [6] is that $\mathbf{H}$ is better conditioned because its multi-directional observation makes more independency in the measurement vector $\mathbf{v}_r$.

2.2 MMSE Solution for VVP

As in [6], the MMSE is applied to Eq. (7) of this paper. Considering additive noise, velocity measurements are expressed as

$$\mathbf{v}_r = \mathbf{H}\mathbf{v}_C + \mathbf{n}, \quad (8)$$

where $\mathbf{n}$ is an additive noise vector. The MMSE solution for the linear equation (8) $\hat{\mathbf{v}}_C$ is expressed as

$$\hat{\mathbf{v}}_C = \mathbf{R}_{v_C}\mathbf{H}^T\left(\mathbf{H}\mathbf{R}_{v_C}\mathbf{H}^T + \mathbf{R}_n\right)^{-1}\mathbf{v}_r \quad (9)$$

where $\mathbf{R}_{v_C}$ and $\mathbf{R}_n$ are covariance matrices of $\mathbf{v}_C$ and $\mathbf{n}$, respectively. The MMSE solution for the VVP is also elaborated in [6].

3. Numerical Simulation

Numerical simulation is carried out to show a result example of the proposed approach. In the simulation, a radar network consisting of two radars (*L*=2) is assumed for simplicity. A velocity field output from a large eddy simulation (LES), which is the same data set as in [6], is applied as truth, then radial velocity fields of each radar are calculated from it. Finally, measurement noise is added to the radial velocities. The additive noises are 0-mean Gaussians whose standard deviation is 1 m/sec for one radar and 2 m/sec for the other. It is assumed that the standard deviation is known. In Figure 1, Panel (a) shows the truth of the simulation. Panels (b) and (c) show estimated results of the traditional VVP and the proposed VVP method, respectively. From the comparison between Panels (b) and (c), the proposed VVP method accomplishes more correct solutions. In addition to, high spatial resolution, large errors of [6] appearing in the

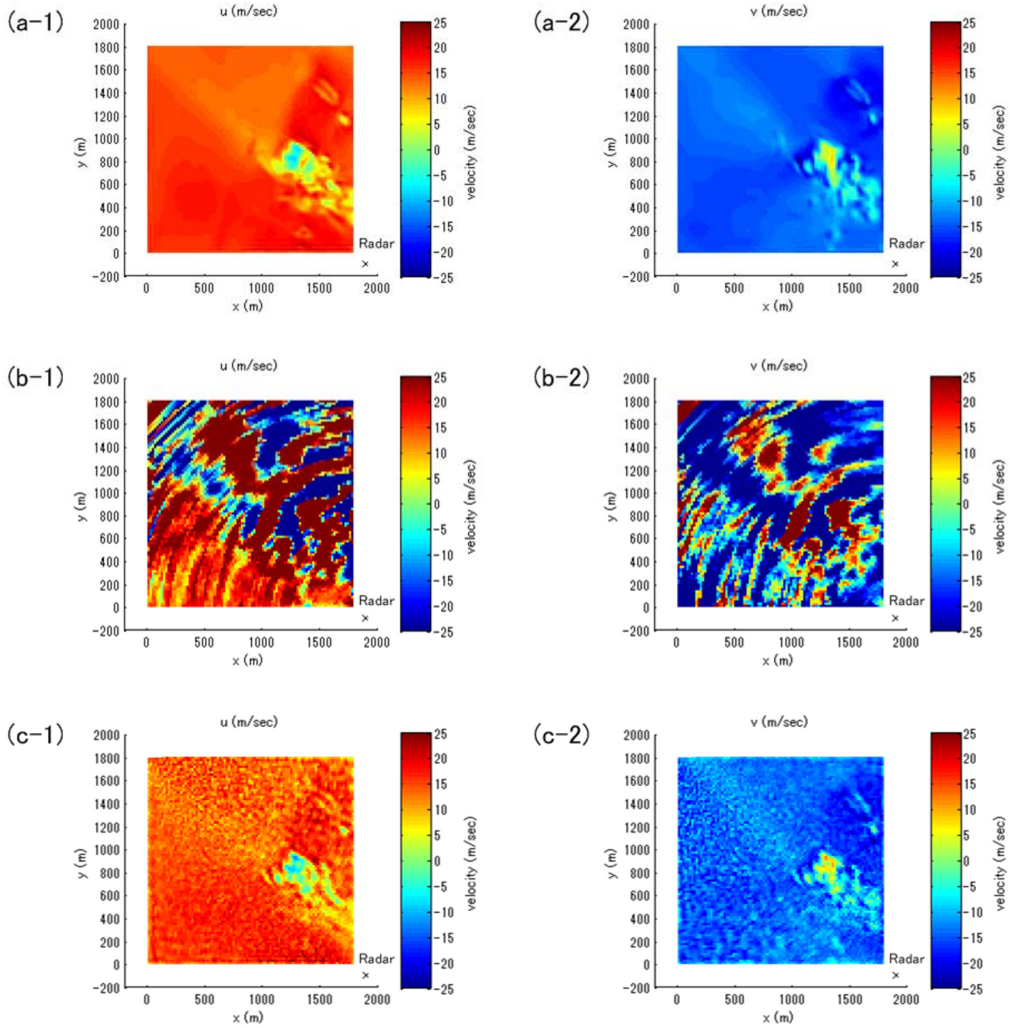

Figure 1: An Example of Simulation Results

edge of area are also correctly estimated.

4. CONCLUSION

An algorithm for retrieving 2-D velocity from radial velocities in radar network environment is proposed. The improved VVP algorithm proposed in another paper of us [6] is naturally extended to a radar network environment as indicated in Eqs. (1) to (9). And the extension enhances the estimation accuracy as indicated in Figure 1. One of important features in the proposed formulation is constraints can be added for the solution part. For example, by utilizing equation of continuity of incompressive flow, solution is possible to be more accurate.

ACKNOLEDGMENT

The authors would like to thank Dr. S. Obayashi and members of his research group at Tohoku University for providing simulated velocity field data, and also thank Dr. K. Yamamoto at Japan Meteorological Agency for productive discussions.

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