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2D VAR single Doppler lidar vector retrieval and its application in offshore wind energy

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Abstract

Remote sensors like Doppler lidars can map the winds with high accuracy and spatial resolution. One shortcoming of lidars is that the radial velocity measured by the lidar does not give a complete picture of the windfield necessitating additional data processing to reconstruct the windfield. Most of the popular vector retrieval algorithms rely on the homogenous wind field assumption which plays a vital role in reducing the indeterminacy of the inverse problem of obtaining Cartesian velocity from radial velocity measurements. Consequently, these methods fail in situations where the flow is heterogeneous e.g., Turbine wakes. Alternate methods are based either on statistical models (e.g., optimal interpolation [1]) or computationally intensive four dimensional variational methods [2]. This study deals with a 2D variational vector retrieval for Doppler lidar that uses the radial velocity advection equation as an additional constraint along with a tangential velocity constraint derived from a new formulation with gradients of radial velocity. The retrieval was applied on lidar data from a wind farm and preliminary analysis revealed that the algorithm was able to retrieve the mean wind field while preserving the small scale flow structure.

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Keywords: Doppler Wind lidars; Vector wind retrieval; 2D-VAR; Offshore Wind Energy; Wind turbine wakes; Wind turbine control; Optimization

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1. Introduction

Doppler wind lidars are becoming popular for remote wind measurements and have seen applications in atmospheric science, aviation safety and wind energy to name a few. One of the potential applications of Doppler wind lidars is in wind farm control techniques. The wind data from a lidar can be used to control individual turbines to maximize the power output of the entire wind farm. However, lidars can only measure radial velocity i.e., component of velocity along the lidar beam, requiring additional post processing steps to retrieve the full wind vector before being passed into a wind farm control algorithm. Majority of the vector retrieval algorithms in use today are based on the homogeneous wind field assumption (within the retrieval domain) and perform poorly in complex flow conditions (e.g. Wind turbine Wakes). Alternate methods based on 4D-VAR are prohibitively expensive and are often impractical to be employed in applications requiring real-time vector retrievals. To address this issue, a new computationally efficient 2D-VAR vector retrieval for low elevation PPI scans was developed and tested on data from an offshore wind farm. The following sections describe the formulation of this retrieval and present a preliminary validation of the retrieval using data from an offshore wind farm.

Nomenclature

u	Component of wind velocity in X-direction (East-West direction)
v	Component of wind velocity in Y-direction (North- South direction)
J	Cost function
LAT	Lowest Astronomical Tide
PPI	Plan position indicator
RHI	Range height indicator
VAD	Velocity Azimuth Display
VVP	Volume Velocity Processing
CFD	Computational Fluid Dynamics

2. Relevant work

Variational retrieval methods [3,4,5] can be broadly classified into two types [6]: a) Parameter identification techniques (PI) and b) 4D-VAR based methods. In the former, data from the radar/lidar is used to estimate the unknowns (e.g., Cartesian velocity) by fitting them to a set of control equations pertaining to reflectivity/ radial velocity conservation equation [7]. The resulting retrieval could be considered as a time-mean estimate over the acquisition time period. The latter method (i.e., 4D-VAR based) relies on a forecast model to obtain the wind field along with thermodynamic variables [8]. 4D-VAR methods have been known to be computationally expensive to implement and often limited by the underlying assumptions in the forecast model.

The PI techniques involve finding the best time-mean estimate of the control variables (**X** = [u,v,w…]) by minimizing a cost function (J(**X**)) of the form:

$$J(\mathbf{X}) = \frac{1}{2\Omega}\int \left(\sum W_i C_i^2\right)\, d\Omega \tag{1}$$

where, W_i are the weights pertaining to the relative importance of the constraints C_i, corresponding to the various control equations in a weak sense. Although, the control equations could be specified as strong constraints [9] or weak constraints [4,5] previous works [10,11] have shown that the weak constraint formulations perform better in the presence of model errors, especially with the reflectivity/radial velocity conservation equation.