Comments on "The Impact of Doppler Lidar Wind Observations on a Single-Level Meteorological Analysis"

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The paper by Riishøjgaard et al. (2004) investigates the assimilation and impact of prospective Doppler wind lidar (DWL) line-of-sight (LOS) single-perspective winds in meteorological analysis. It is argued that single-component wind observations are far less effective in reducing wind analysis error than vector wind information. This work has relevance because the prospects are good that space-based DWL instruments will provide accurate wind profiles of single-perspective LOS wind profile measurements in the future. Riishøjgaard et al. rightly argue that the usefulness of such winds needs to be well addressed in the design phase of space missions. The forthcoming European Space Agency Atmospheric Dynamics Mission (ADM), called Aeolus, is referred to in this context.

The Riishøjgaard et al. study is carried out in an idealized and very simplified framework. Our concerns are 1) that the simple framework poorly represents the characteristics of a state-of-the-art global data assimilation system for numerical weather prediction (NWP) and 2) that the DWL scenarios that are discussed have abundant and unrealistic coverage and quality.

As such, their conclusions may be misleading for, and contribute little toward, the critical design considerations for an affordable space-based DWL. The results (and the quality of the analyzed wind fields) could be far more realistic and, in our view, far more favorable for LOS winds in a more carefully designed experiment.

The NWP analysis problem would be severely underdetermined if it were based on the observations alone. To overcome this problem, data assimilation typically combines the information provided by the relatively sparse observations with a short-range forecast on a dense grid (Daley 1991). Because the NWP model state is poorly observed, it is critical that local observation increments are carefully distributed spatially in a wider area. This process is done based on statistical knowledge of the background error structures. In a four-dimensional variational data assimilation (4DVAR) analysis system, information on the temporal evolution of the model state is also exploited. Around any local observation, information on the multivariate spatial correlation of the background errors, as represented in the background-error covariance matrix **B**, is used to provide a spatially coherent update of the model atmospheric state. For LOS wind analysis, the **B** covariance structures are crucial in both spatially interpolating the observed wind component and inferring the spatial pattern of the unobserved component of wind as well as the associated temperature and pressure increments.

The design of the **B** matrix and the sampling strategy of the DWL space mission are the two most important factors that determine the impact of the data, both in real application and within the simplified framework of Riishøjgaard et al. In the case in which **B** is poor, this would generally result in spatially poor analyses, especially when the observations are sparse or when one or several analysis variables are unobserved. In a relatively dense observation network, on the other hand, the multivariate spatial structures associated with many observations will overlap and the effect of an imperfect **B** will diminish (by oversampling).

Our specific comments are in two areas. The first is that the Riishøjgaard et al. paper uses a synthetic vortex

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in a domain of 2000 km × 3000 km. In many areas of this size over the ocean no single wind profile observation is available today. The addition of just a few wind profiles could demonstrate the potential of a DWL in space, provided they are accurate enough, just as sparse radiosondes over land today have a substantial impact on Northern Hemisphere weather analyses. More extensive sampling would be very costly and unrealistic to achieve in the short term, even if it is very desirable. The paper uses hundreds of observations within the domain, a fact that appears to be of little practical relevance. The assumed DWL wind component observation error (1 m s^{-1}) would be very difficult to achieve, given instrument limitations and the spatial representativeness errors resulting from atmospheric variability within an NWP model grid box. In conclusion, an unrealistically large observation impact is assumed.

The second area of comment is that if **B** is correctly specified in the study and if sufficient observations are available, then the analysis (in the limit) will be very good, in both the LOS direction and the orthogonal direction (e.g., Žagar 2004). However, in Riishøjgaard et al.'s Fig. 6 this clearly does not happen: even for large numbers of LOS observations, the analysis remains poor, particularly in the cross-LOS direction. The reason for this poor performance lies in **B** and its poor correspondence with the feature to be analyzed. The wave to be analyzed has a length scale of about 1500 km, whereas the length scales in **B** are not discussed in the paper. However, from Riishøjgaard et al.'s Fig. 3 one may infer that the analysis length scale is small, probably around 200 km. The implication is that the information inferred by the analysis in the cross-LOS direction will be on the 200-km scale, which is highly inappropriate for the particular wave feature to be recovered.

Note that in the case in which both wind components are densely observed, the information about the true length scales (in both directions) is provided by the observations, enabling the analysis to recover the larger-scale wave. However, we noted above that such dense DWL wind profiling is unlikely to occur in the near future.

The appropriate method for this kind of study would be to draw random-sample perturbations (the wave structures to be analyzed) from a population with covariance **B** to ensure a statistical correspondence between the features to be analyzed and the structures modeled by **B** [a method adopted, e.g., by Žagar (2004)]. This approach would more realistically represent the problem of data assimilation and has not been done in Riishøjgaard et al.'s study. Their study on its own does not provide the required detailed information on which to base a mission design.

It is worth emphasizing that the Aeolus instrument and measurement concept have been carefully designed to maximize the accuracy and representativeness of the LOS wind profile measurements (Stoffelen et al. 2005). Detailed simulations of the expected data have been performed (Marseille and Stoffelen 2003; Tan and Andersson 2005). These simulations account for large state-dependent variations in observation error arising from 1) the propagation of the lidar beam through realistic heterogeneous cloud and aerosol fields and 2) altitude-dependent representativeness error. They infer that Aeolus data can be expected to receive appreciable weight, comparable to that given to radiosonde and wind profiler data, in a state-of-the-art data assimilation system.

Advanced assessment of the value of a new component of the global observing system remains a complex issue. All available assessment techniques suffer from limitations, and further research is needed to refine the approaches. Nonetheless, diverse studies of expected Aeolus data impact have been performed (Žagar 2004; Marseille et al. 2001; Stoffelen et al. 2005, manuscript submitted to *Quart. J. Roy. Meteor. Soc.*) and consistently show scope for the ADM concept to demonstrate the positive impact of a space-based DWL instrument. The ADM Aeolus mission is due for launch in September of 2008, and, if it is successful, follow-on operational missions are envisaged.

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