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Atmospheric Measurement Techniques Discussions
Interactive comment on Retrieval of three-dimensional wind fields from Doppler radar data using an efficient two-step approach by C. Lpez Carrillo and D. J. Raymond

Anonymous Referee #1

This manuscript is concerned with the description and testing of a variational dualDoppler radar wind retrieval algorithm. The constraints imposed in the analysis procedure are: observational constraints, which incorporate data from two or more Doppler radars (and possibly other data sources, e.g., dropsonde or sounding observations), a mass conservation constraint (sometimes referred to in the literature as a mass continuity constraint), and spatial smoothness constraints. The procedure is general enough to incorporate data from two or more stationary Doppler radars or from a so-called "pseudo-dual-Doppler radar", that is, data from an airborne-radar that, when appropriately processed, are equivalent to data gathered from two stationary Doppler radars.

The observational and mass conservation constraints are standard in dual-Doppler analysis procedures. The use of smoothness constraints is standard in variational (e.g., 3DVAR) analysis techniques. The new aspect of this study is a data gridding/reduction step designed to minimize loss of information and to generate estimates of the variances of the reduced velocities. Any improvements made in these directions would be of interest to radar and mesoscale meteorologists as it could potentially improve dualDoppler analyses of a variety of convective and non-convective weather phenomena.

The new retrieval is tested with pseudo-dual-Doppler radar data from a tropical depression. Unfortunately, the results from these tests are inconclusive. A comparison of the retrieved horizontal wind vectors with the horizontal wind vectors from an independent data source (dropsondes) does indicate a qualitatively good agreement (Fig. 8). But there is relatively little challenge in obtaining qualitatively reasonable horizontal wind components from dual-Doppler or pseudo-dual Doppler data, especially on the coarse analysis grid indicated on that figure. A more challenging problem and one of prime interest to mesoscale meteorologists is the analysis of the vertical wind component. Apparently it was not possible to evaluate the accuracy of the retrieved vertical wind component in this test case. In the future it would probably be better to consider a more stringent test of the algorithm, perhaps using high-spatial-resolution data from a numerical prediction model, in which the accuracy of all three retrieved velocity components (and especially the vertical component) could be evaluated. A high-resolution test case would also allow one to see how well structures of progressively higher wavenumber could be retrieved by the procedure.

Concerning the structure of the manuscript, readers new to the subject of dual-Doppler wind retrieval would benefit from a more thorough and critical review of the literature. For instance, in the discussion of loss of information at large elevation angles, the authors state that "The loss happens because, in a traditional method, the horizontal velocities are obtained first on a regular grid and then used for the vertical integration of the mass continuity equation." However, that statement only applies to the simplest of the traditional methods; there are also iterative traditional procedures conducted in Cartesian coordinates (i.e., not the COPLANE coordinate system) in which the mass conservation equation and the complete relation between the radial wind and the horizontal and vertical velocity components are satisfied (e.g., Brandes 1977; Ray et al. 1980; Hildebrand and Mueller 1985, Dowell and Shapiro 2003). It would probably also be good to discuss some of the other variational approaches of dual-Doppler radar wind analysis (e.g., Protat and Zawadzki 2000, Protat et al. 2001, Liu et al. 2005, Shapiro et al. 2009, Liou and Chang 2009). More importantly, however, a thorough discussion of the literature would help the reader understand what the main impediments are to obtaining accurate horizontal wind and vertical velocity fields. At the very least, there should be a discussion of problems stemming from the non-simultaneous nature of the observations and the impact of missing data, especially at lower and/or upper levels where the boundary conditions are applied.

References

Brandes, E. A., 1977: Flow in Severe Thunderstorms Observed by Dual-Doppler Radar. Mon. Wea. Rev., 105, 113120.

Dowell, D. C., A. Shapiro, 2003: Stability of an Iterative Dual-Doppler Wind Synthesis in Cartesian Coordinates. J. Atmos. Oceanic Technol., 20, 15521559.

Hildebrand, P. H., C. K. Mueller, 1985: Evaluation of Meteorological Airborne Doppler Radar. Part I: Dual-Doppler Analyses of Air Motions. J. Atmos. Oceanic Technol., 2, 362380.

Liou, Y.-C., Y.-J. Chang, 2009: A Variational MultipleDoppler Radar ThreeDimensional Wind Synthesis Method and Its Impacts on Thermodynamic Retrieval. Mon. Wea. Rev., 137, 39924010.

Liu, S., C. Qiu, Q. Xu, P. Zhang, J. Gao, A. Shao, 2005: An Improved Method for Doppler Wind and Thermodynamic Retrievals. Adv. Atmos. Sci., 22:90102.

Protat, A., I. Zawadzki, 2000: Optimization of Dynamic Retrievals from a MultipleDoppler Radar Network. J. Atmos. Oceanic Technol., 17:753760.

Protat, A., I. Zawadzki, A. Caya, 2001: Kinematic and Thermodynamic Study of a Shallow Hailstorm Sampled by the McGill Bistatic Multiple-Doppler Radar Network. J. Atmos. Sci., 58:12221248

Shapiro, A., C. K. Potvin, J. Gao, 2009: Use of a Vertical Vorticity Equation in Variational Dual- Doppler Wind Analysis. J. Atmos. Oceanic Technol., 26, 20892106.

Ray, P. S., C. L. Ziegler, W. Bumgarner, R. J. Seran, 1980: Single- and MultipleDoppler Radar Observations of Tornadic Storms. Mon. Wea. Rev., 108, 16071625.

Interactive comment on Atmos. Meas. Tech. Discuss., 3, 4459, 2010.

Response to comments from reviewer #1

1) Although, the usage of the anelastic mass continuity equation is standard in the synthesis of Doppler radar data, we would like to point out that the way it is included in our work differs from other variational approaches. For instance Gao et. Al (1999) and Liou and Chang (2009), Liu et al (2004) include it as a weak constraint. On the other hand, the mass continuity has been included as an strong constrain by some authors, Laroche and Zawaddski (1994), Protat and Zawadzki (1999), but they use the so called Adjoint technique. Our technique, does not need the Adjoint equations.

2) We are planning to test our technique in more stringent cases to address the retrieval of the vertical component of the velocity.

3) Concerning the structure of the manuscript:

- **a)** We have clarified our statement about the lost of information in the traditional methods, thanks.
- **b)** We have also added some discussion about the impact of data sampling on the retrieval and have included more references to guide the reader. We don't pretend the discussion to be thorough as should correspond to a review paper.

Anonymous Referee #2

One way to consider the signicance of this paper is to consider how it adds to what has already been discussed in the Gao et al (1999). The most obvious to me is in the treatment of the Doppler observations by examining the eigenvectors and eigenvalues associated with solving the Doppler projection equation alone and using them to determine if there is enough information to compute a wind solution at that grid point (as well as give an estimate of the Doppler variances at that grid point). In other ways this looks very similar to the what has already been discussed by Gao et al (1999).

I also dont see how this saves much time over (1) in Gao et al, since every grid velocity still has to be compared in some way to the all the good Doppler observations, within the radius of influence of the Doppler observations to the grid point. Once the summations of (2) of Gao et al are stored in the big solution matrix, they can be used over and over in any iterations of the solution. The added value seems to come from estimating the goodness of fit at each location, and how well conditioned the solution really is at any location.

Since the authors still show wind fields that extend beyond the data, in a way that is not only interpolation, but ALSO extrapolation, it would be good if they had shown at least example of the results of eigenvalues (perhaps the magnitude of the second largest eigenvector in the solution) to show where the wind field was well constrained by just the Doppler observations and the continuity equation....

It would also be good if the authors discuss how well they think this method will work when the analysis has a resolution closer to the that of the radar observations themselves (1 km).

Whats the point of the whole coplane discussion, since the vector normal to this plane (in which continuity will essentially be integrated) can vary considerably from grid point to grid point since the aircraft is a moving platform with changing attitude and direction of motion. There are ways this comparison to COPLAN can have value (as explanationto explain the direction continuity is integrated since wind constrained in other 2 independent vector directions) but they are not really discussed clearly.

The authors state (quite correctly) that Doppler observations in general have a much larger error than the dropsondes. Since this is so, it would have been good if the authors discussed the difference between their wind retrieval from radar only with the dropsonde observations, by comparing the sonde winds to winds in neighboring grid cells of the radar-only wind fields. This might not be a requirement in a paper discussing the meteorological aspects of the analyses, but since this is Atmospheric Measuring Techniques, such an examination would be good, even if only discussed. I think a table would be good, however.

Major revisions separated from general discussion above:

1) I tend not to agree with the 1 m/s error estimate for the airborne Doppler radial velocities. I would accept this generally for a ground-based Doppler radar, but not one on a platform that is moving, may be turning, banking, etc. It would have been good if the authors discussed the difference between their wind retrieval from radar only with the dropsonde observations, by comparing the sonde winds to winds in neighboring grid cells of the radar-only wind fields. This might not be a requirement in a paper discussing the meteorological aspects of the analyses, but since this is Atmospheric Measuring Techniques there should be such an examination, even if only in discussion. I think a table or figures devoted to that examination of accuracy would be good, however. This comparison to sondes might also require a finner-resolution analysis of the winds in a region with good Doppler radial velocity observations from two sufficiently independent directions.

2) I think there should be at least one figure displaying the structure and nature of the eigenvalues in the interpolation, probably the second largest eigenvalue, since it is indicative of the quality expected of the wind analysis, or at least indicating the problem is well posed at that grid point.

3) In lines 267-289, there is not sufficient description of the ELDORA radar or the dropsonde capabilities, nor are there good references for these, even if these are simply from an NCAR tech memo. I'm sure there are at least the papers by Hock and Franklin for the dropsondes.

4) Also from Line 243-4: In step 2, how do you constrain the wind in the direction unconstrained by the dual-Doppler observations, the one which will be constrained eventually by the continuity constraint. How do you fill all the points with no Doppler observations in this first step, or are you not actually computing a wind at this point, and I am misunderstanding.

I have a number of more specic comments.

Line 51. It looks like you meant Gao et al (1999) and not Gao (1999).

Line 108: and N is the total number of radial-velocity observation influencing the grid point

Line 201: Do you actually think the radial velocities that you incorporate in your analyses have an error less than 1 m/s. This error is true in a random sense for observations from a non-moving platform, where the attitude of the platform is known very accurately, but how accurate do you think these observations really are, even after careful quality control from NCAR? The main error comes from projection of the aircraft motion on the Doppler radial. This is another reason for some comparison of the radar-only analysis with dropsondes.

Line 203: What constitute bad gridded velocities? Velocities that don't have at least two good eigenvalues out of 3? Isn't there value in using the Doppler observations from just one radar, if you are going to compute a solution in grid cells without sufficient observations from two radars? They can help constrain the analysis, even if not completely. I would not say this if you were not including extrapolated winds in your displayed analyses. Perhaps you do use the first eigenvector even if you don't use the second, when constraining the filled (extrapolated and interpolated) analyses you show in the paper.r....

What do you do with the Doppler observations near the radar, where scanning can produce enough observations, in enough independent directions to produce a wind estimate, even without continuity, within a single grid cell? Do you keep all three eigenvectors in that case? Since you use a very coarse grid, this ought to be possible near your flight track. You might state what you do if you get 3 good eigenvectors, or do you ever get three good eigenvectors?

Line 333 Since you have computed variances of the reduced velocities on the analysis grid, it would have been good to see such an example plotted, or something said about how this number varied, and over what range you accepted the data.

Line 334 Shanno and Phua (1976) is not in the reference section. Should this be Shanno and Phua (1980)?

Interactive comment on Atmos. Meas. Tech. Discuss., 3, 4459, 2010.

Response to comments from reviewer #2

- Yes, our technique is similar to the technique used by Gao et al (1999), but our technique uses the anelastic mass continuity as strong constraint.
- As we understand the algorithm proposed by Gao et al, there are two nested iterations: The outer loop that updates the velocity field and the inner loop where a search for a descent direction is found (using the conjugate method of Navon and Legler). It is true that the summation (2) is required only once during the inner loop, but once the velocity field is updated, the summation (2) has to be recalculated. This summation is essentially a comparison between the current velocity field and all Doppler velocities. Our method requires a comparison between the current velocity field and the gridded velocity data, which substantially reduced the computations.
- We agree that presenting the results for the eigenvalues is important and have added plots (see attached figures: 1, 2, 3, 4, and 5) to show their behavior and the error associated with them. However, keep in mind that the eigenvalues come from the data griding step and are not available in data void regions.

- At this point, we can only say that as long as there are enough observations at a given resolution, the method should work. We believe that such statement is unnecessary.
- The point of the COPLANE discussion is to offer an example where reduction of radial velocities can be done without losing information. For more complicated geometries, strict COPLANE cannot be applied, but the reduction with minimal loss of information can still be accomplish. In that sense, the first step of our technique is an extension of the COPLANE technique. The integration of the mass continuity is, of course, implicitly done by the variational scheme.
- We have added two figures (see attached figures: 6 and 7) to address the differences between gridded dropsonde data and retrieved wind velocities.

Response to Major Revisions from reviewer #2

1. We agree. We have added a set of plots (see attached figures: 1, 2, 3, 4, and 5) to show the nature of the eigenvalues. Since the error of the components of the gridded velocities is given by the reciprocal of the square root of the eigenvalues, some of the added plots show the horizontal distribution of these errors.
2. We have added references that describe the ELDORA and dropsonde capabilities as well as the quality control applied to the data.
3.
   - During the step 2, the wind field is computed at each grid point. During this step the wind velocity is initialized to zero at every grid point. The constraint from the data is only active at grid points with good gridded velocities. Eventually, the data constrain will be propagated to the grid, by the action of the mass continuity constraint and also the smoothing constraint.
   - Although the comparison between dropsonde velocities and retrieved winds seem unrealistic, given that the actual situation has convective components that affect the dropsonde measurements, but that tend to be smoothed out for the retrieved mesoscale fields. We decided to illustrate this difference using the gridded sounding velocities. We have included two figures (see attached figures: 6 and 7) that show differences between gridded dropsonde velocities and a) velocities retrieved using only radar data, and b) velocities retrieved using radar plus dropsonde data.

Response to specifics comments from reviewer #2

Line 51 thanks, we do mean Gao et al(1999). This has been fixed.

Line 108 thanks, we changed observation to observations.

Line 201 These topic is discussed in some detail in Jorgensen et. al (1983), Hildebrand and Muller. For our data set, the ELDORA quality report (which is now referenced in our paper) also discuss this issue. The authors show that when there are sufficient good data from the inertial navigation system of the plane, then it is possible to remove the aircraft velocity from the data. However, in some instances this will not be possible and the error as you pointed out will be larger due to the projections of the plane velocity on the radials. For our purposes, having a larger error on each radial velocity will only mean that the fit has to be relaxed to take into account the larger variance in the observations.

Line 203

- In the case presented in the paper, Dual Doppler Analysis, bad gridded velocities are those that do not come from sufficiently independent directions. We eliminate gridded velocities if they met any of the following criteria:

  a) their second largest eigenvalue is smaller than 0.03;

  b) the number of contributing measurements at each grid point was less than 50.

  Criteria a) means that the geometry of the observations is not enough to consider a local Dual-Doppler synthesis. This could happen if most of the observations are taken from the same general direction. Criteria a) may appear to be enough, however after examining scatter plots of the second largest eigenvalue versus the magnitude of the velocity along the corresponding eigenvector, we notice that some magnitudes were still to large to be real. Perhaps we had most of the contributing observations pointing in the same general direction and only a few in an independent direction. Since we did not have counts for observations for each possible direction, we try to complement criteria a) by adding criteria b), which in this case was enough to eliminate the large magnitudes observed in the scatter plots.

- Regarding the value in using the Doppler observations from just one radar, we agree that those observations can in principle help in constraining the resultant field. However, this potential was not researched for these paper. In the present case only data that a given grid point can produce at least a Dual-Doppler local synthesis is used to constrain the three-dimensional velocity field.

- Regarding points where we have three components of the velocity, Our threshold does not preclude the usage of the 3 gridded velocities It is clear, from a newly added figure (see attached figure 1) , that there are many instances where even the smallest eigenvalue is larger than the threshold. So it seems that we have enough information to obtain the three components of the velocity. Hence when the information is there, we use it to constrain the retrieval.

Line 333 We agree, we have added some figures (see attached figures: 6 and 7) to show the behavior of the square root of the variance (so, it has the same units as the velocity).

Line 334 Yes it is Shanno and Phua (1980). This has been fixed.

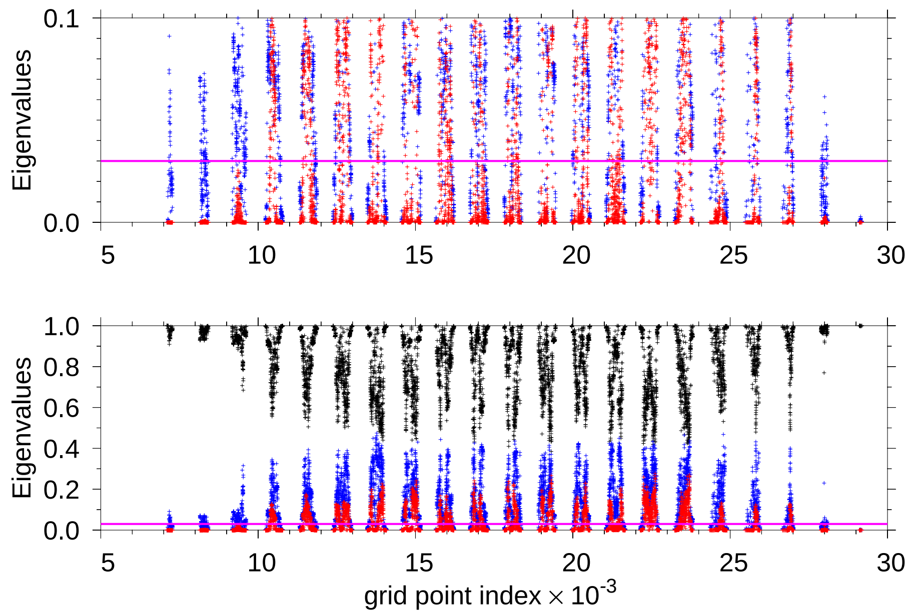

Figure 1: The lower panel shows the eigenvalues for each grid point that has at least 50 radar observations associated with it. For each point, the largest eigenvalue is shown in black, the second largest in blue, and the smallest in red. The horizontal axis is just the grid point index obtained by traversing the grid in C-style order(the last index varying the fastest). The horizontal line in magenta indicates the threshold value used to accept the associated velocity. The upper panel is a zoom-in of the lower panel.

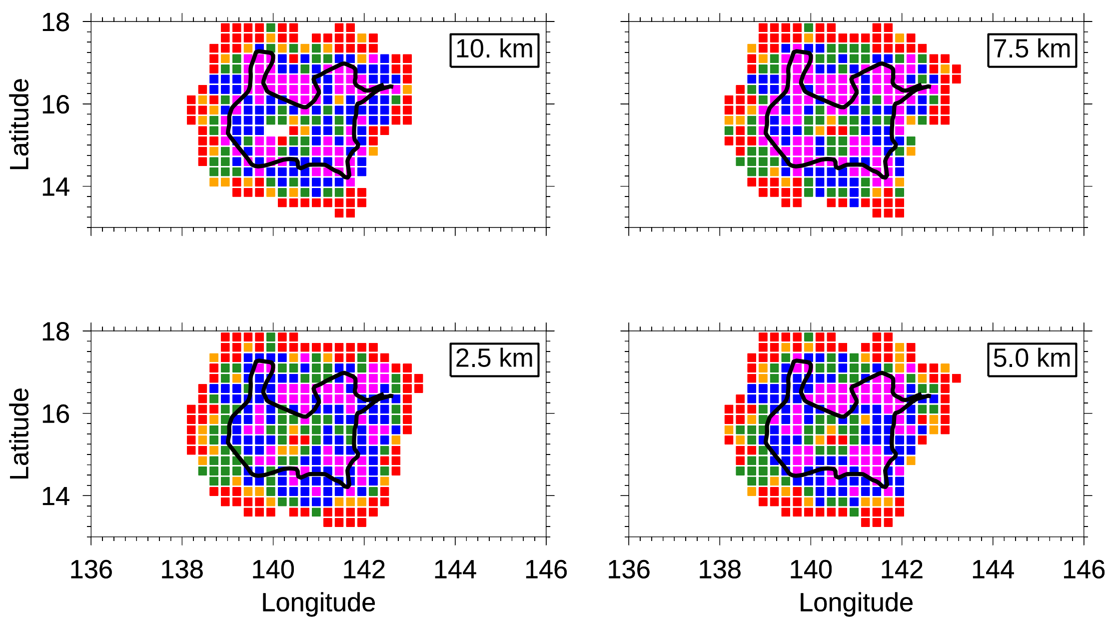

Figure 2: This figure shows plan views of the error associated with the component of the gridded velocity along the eigen-direction with the second largest eigenvalue,a_2 (the error plotted is defined as $\sigma_2 = a_2^{-1/2}$). The marks represent grid points that had more than 50 radar observations associated with them. Marks in red represent errors larger than five ms^{-1}; errors between five and four ms^{-1} are shown in orange, between four and three ms^{-1} in green, between three and two in blue, and between two and one in magenta (no points had errors smaller than 1). The thick black line represents the aircraft track.

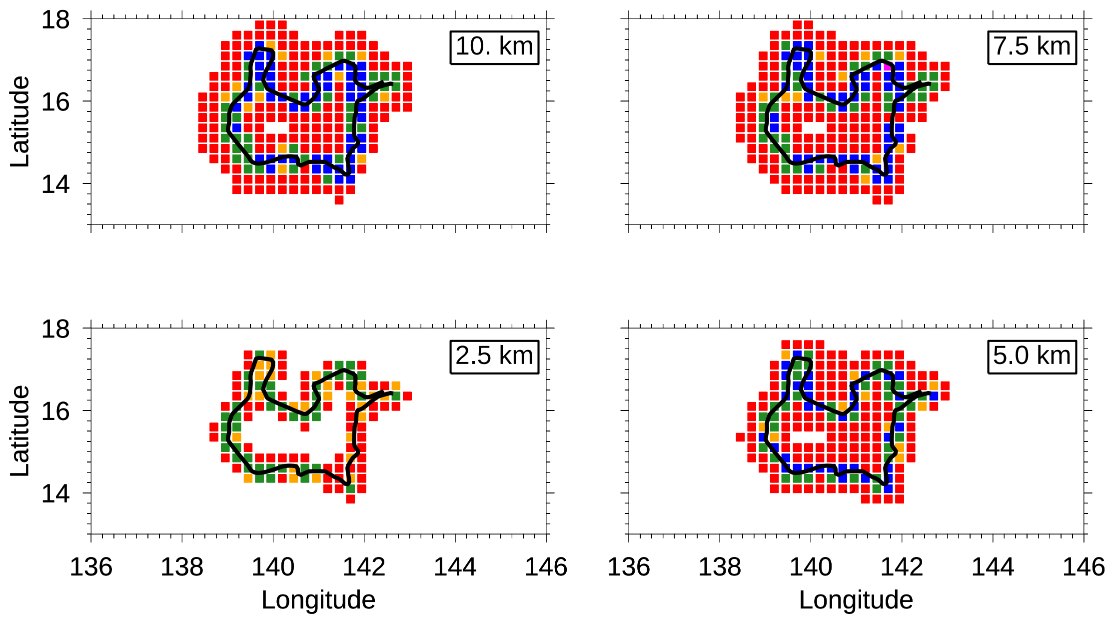

Figure 3: Same as in figure 2, but for the error associated with the component of the gridded velocity along the eigen-direction with the smallest eigenvalue.

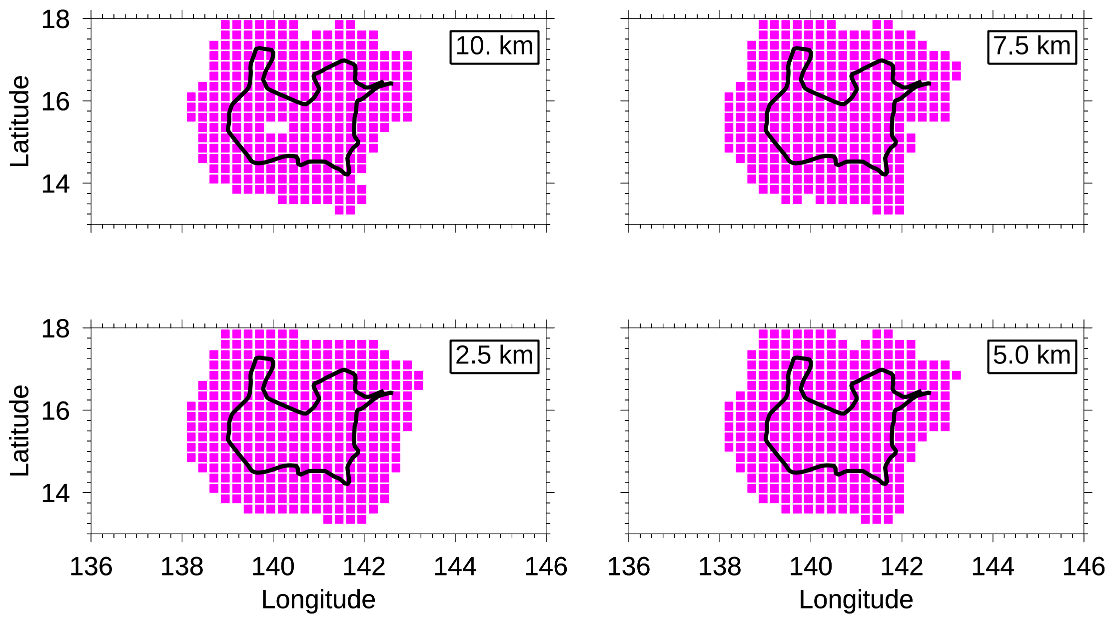

Figure 4: Same as in figure 2, but for the error associated with the component of the gridded velocity along the eigen-direction with the largest eigenvalue. This plot shows that the error associated with the largest eigenvalue is always between one and two ms^{-1}.

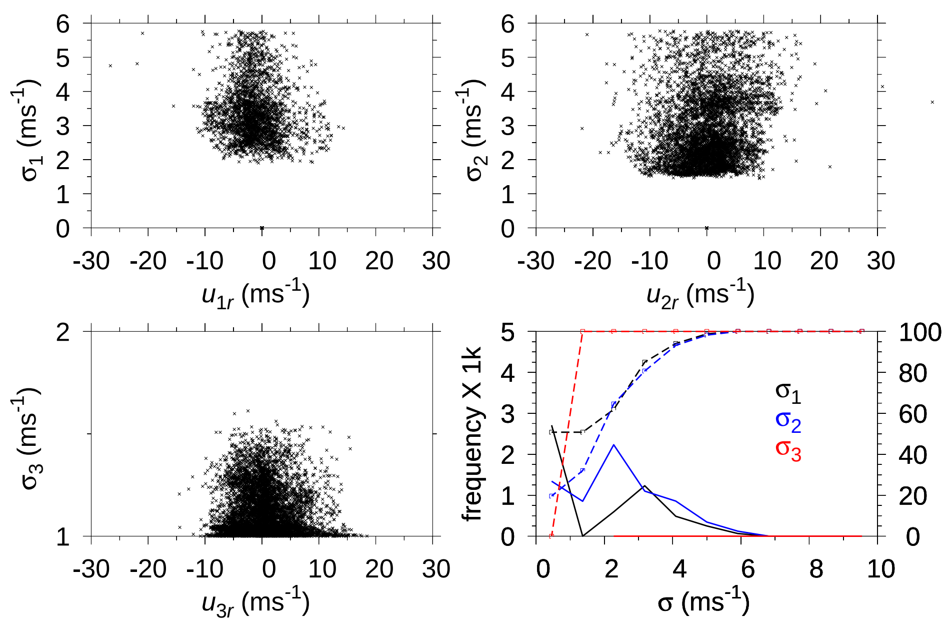

Figure 5: This figure shows the overall distributions of the errors for gridded velocities that have passed our quality control. The scatter plots show the behavior of the error as a function of its associated relative eigen-velocity ($\vec{u_r} = \vec{u} - \vec{v_s}$, where $\vec{v_s}$ is the storm velocity and $\vec{u}$ is the gridded eigen-velocity). The lower right panel shows histograms of the errors (solid lines) and their corresponding cumulative distribution functions (dashed lines).

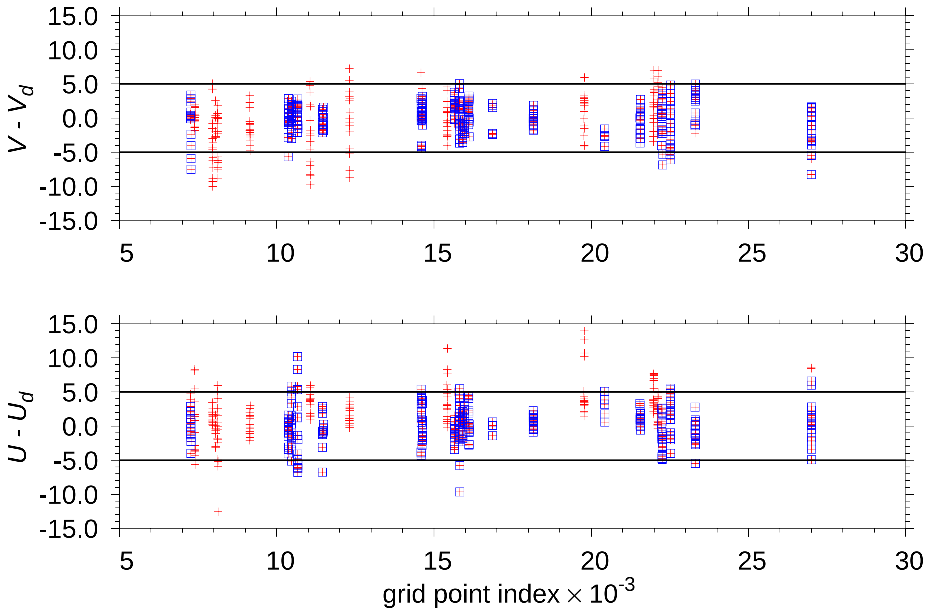

Figure 6: The upper panel shows the difference between the meridional component of the retrieved velocity (using radar data only) and the gridded sounding data. Red marks show this difference for all grid points where there are dropsonde observations, while blue boxes show which of those grid points have radar observations that constrained the retrieved velocity. The horizontal axis is just the grid point index obtained by traversing the grid in C-style order(the last index varying the fastest) The lower panel shows the same, but for the zonal component of the velocity.

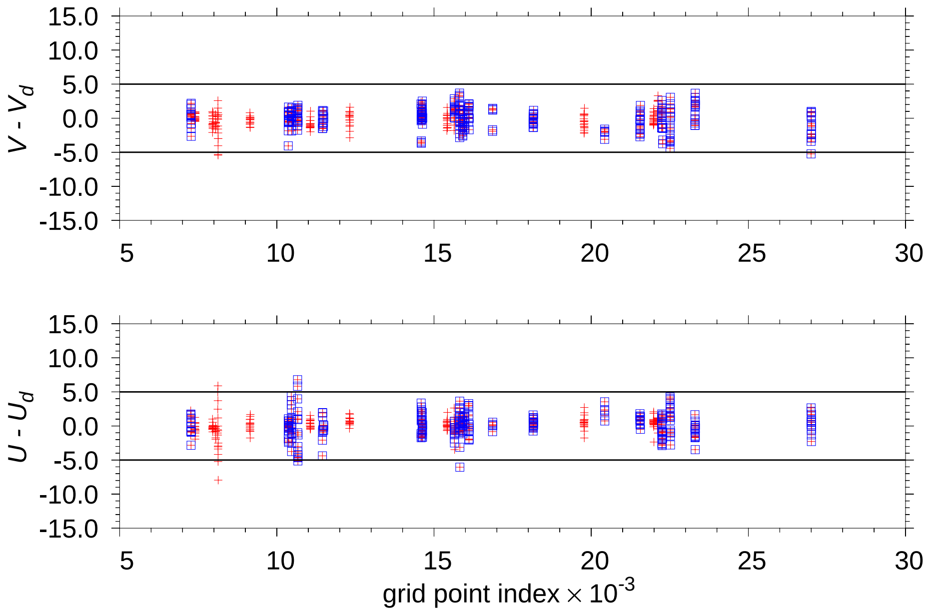

Figure 7: The upper panel shows the difference between the meridional component of the retrieved velocity (using radar and dropsonde data) and the gridded sounding data. Red marks show this difference for all grid points where there are dropsonde observations, while blue boxes show which of those grid points have radar observations that constrained the retrieved velocity. The horizontal axis is just the grid point index obtained by traversing the grid in C-style order(the last index varying the fastest) The lower panel shows the same, but for the zonal component of the velocity.