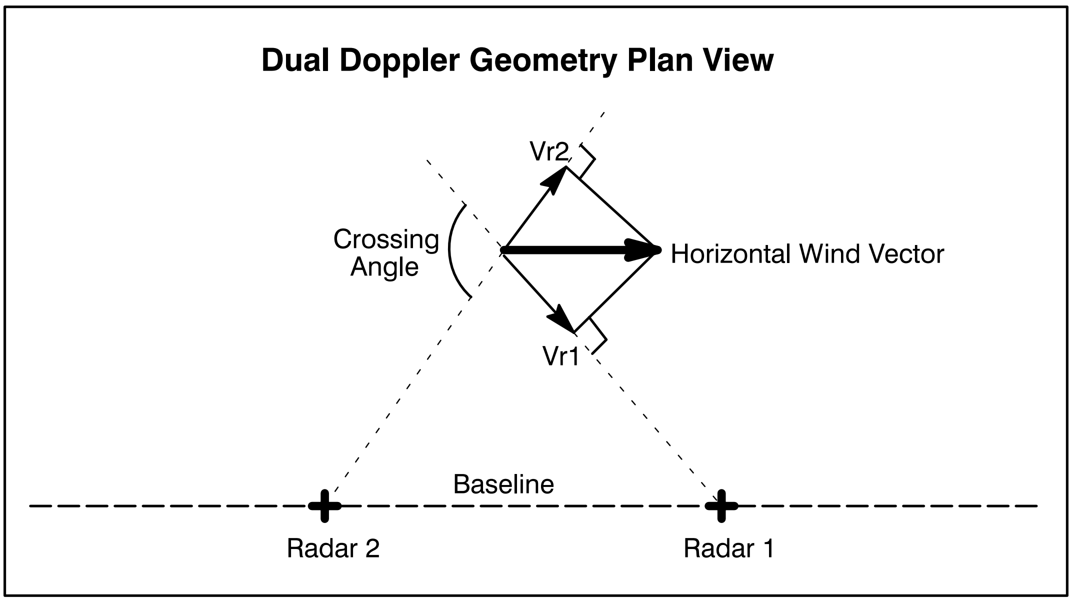
3.4 NDOP: Multiple Doppler

Overview

A single Doppler radar measures one component of a 3D wind vector, i.e., the component of wind towards or away from the radar — the radial wind. We can think of the 3D wind vector as being made up of the 2D horizontal wind and the vertical wind. Typically the horizontal wind is much stronger than the vertical wind, except in local areas of strong convection.

With a second Doppler radar, we can measure two components of the wind, provided that the radar beams are crossing at some angle (not parallel). If the vertical component of the wind is assumed to be small, then with two radars we can measure the horizontal wind.

The figure below shows a plan view (looking down) of the dual Doppler geometry. The horizontal wind is sampled by each radar which measures the radial component of the wind, Vr1 and Vr2. These two radial velocity measurements at the same point, along with some simple trigonometry, can be used to estimate the horizontal wind at the point, provided that the crossing angle is not 0 or 180 degrees (parallel beams).



This means that along the baseline (crossing angle 0) or at far ranges (crossing angle 180) we cannot use the algorithm, since the two radars will essentially measure the same radial wind.

While in theory the crossing angle could be anywhere between 0 and 180 degrees, our radial velocity measurements are not perfect so that in practice, a crossing angle of <20 degrees will lead to unreliable wind estimates.

The NDOP product performs the dual Doppler algorithm to obtain estimates of the horizontal wind field. NDOP makes two assumptions:

- The vertical wind is assumed to be weak as compared to the horizontal wind.
- The input radial velocity measurements represent the radial velocity of the air, i.e., the velocity is unfolded and corrected for particle fallspeed.

The output of the NDOP product is a multi-level grid of horizontal wind vectors. These can be displayed by themselves, or overlaid on other echoes.

The remainder of this chapter discusses:

- Input radial velocity fallspeed correction and unfolding. NDOP typically uses the corrected radial velocity data Vc which is described.
- NDOP Product Configuration Menu
- NDOP display and coverage

3.4.1 Input velocity corrections

Corrected Radial Velocity Vc

The IRIS corrected velocity (Vc) can include correction for fallspeed and velocity folding. The fallspeed correction is based on VT–Z relationships above and below the melting level. The unfolding correction is based on a VVP product.

Vc can be generated in either of two places:

- Vc can be generated when the data are collected from the signal processor. This is configured in the TASK Configuration Menu.
- Vc can be generated when RAW restored from tape or received over the network are re-ingested (to make ingest files). This is configured in the **setup** utility.

Note that in the second case, if Vc is already in the data when they are re-ingested, it will be re-calculated from V. When Vc is generated, the uncorrected radial velocity V is still preserved.

The first way, generating Vc when the data are ingested from the signal processor, is the recommended way for real time operation. The second way is useful for archive data, or in systems where the communication bandwidth is limited so that the extra burden of transmitting Vc (as well as the standard radial velocity) is too much for the network.

Fallspeed Correction for Vc

A key assumption is that the vertical airmotions are weak as compared to the horizontal airmotions. This means that the radial winds are assumed to be caused by the horizontal wind only. However, while vertical airmotions may be weak, the fallspeeds of the hydrometeors (of order 1 to 10 m/s for rain) can make a significant contribution to the radial velocity. Therefore it is necessary to correct the radial velocities for the effect of fallspeeds.

The effect of particle fallspeed depends on the sine of the elevation angle. For example at 0 degrees elevation, the fallspeeds do not effect the radial velocity. At 30 degrees elevation angle (a typical maximum elevation in a volume scan), then half of the fallspeed would be observed (sine 30 = 0.5). Thus a 10 m/s fallspeed (hail and rain mixed) would contribute 5 m/s to the radial wind which is significant.

The fallspeed correction in Vc is made using a VT–Z relationship (terminal fallspeed – reflectivity). These take the general form of $VT=aZ^b$. Since the particles are very different above and below the melting level, it is important to use different VT–Z relationships for these two cases. The default relationships used in IRIS are:

- Above the melting level (snow and graupel) $VT = 0.8\ Z^{0.06}$
- Below the melting level (rain) $VT = 2.70\ Z^{0.11}$

Here Z is in mm^6/m^3 and VT is in m/s. For a discussion of VT–Z relationships refer for example to a text on radar meteorology such as Battan's book (Battan, Louis, J., 1973: **Radar Observation of the Atmosphere**, University of Chicago Press, p 132).

These relationships are entered by your system manager in the **setup** utility. In addition, the average height of the freezing level is input for each month of the year.

The VT–Z relationships, and freezing level estimation will not be perfect, but they will improve the radial velocity estimates as compared to performing no correction. The corrections obtained will be of the order 1–5 m/s depending on the elevation angle. The corrections will have essentially no effect (<1 m/s correction) for elevation angles less than 5 degrees.

Radial Velocity Input for NDOP– Unfolding for Vc

The NDOP product assumes that velocities are unfolded or dealiased. A Doppler radar has a limit on the unambiguous velocity which is:

Vu = +– (Wavelength*PRF)/4

Radial velocities that exceed this are said to be folded. On a color display with blue representing radial velocity toward the radar and red representing radial velocity away from the radar, a fold will appear as an adjacent blue-to-red color shift.

Unfolding can be performed in the signal processor itself (e.g., using the dual PRF technique), or can be done by IRIS when Vc is generated.

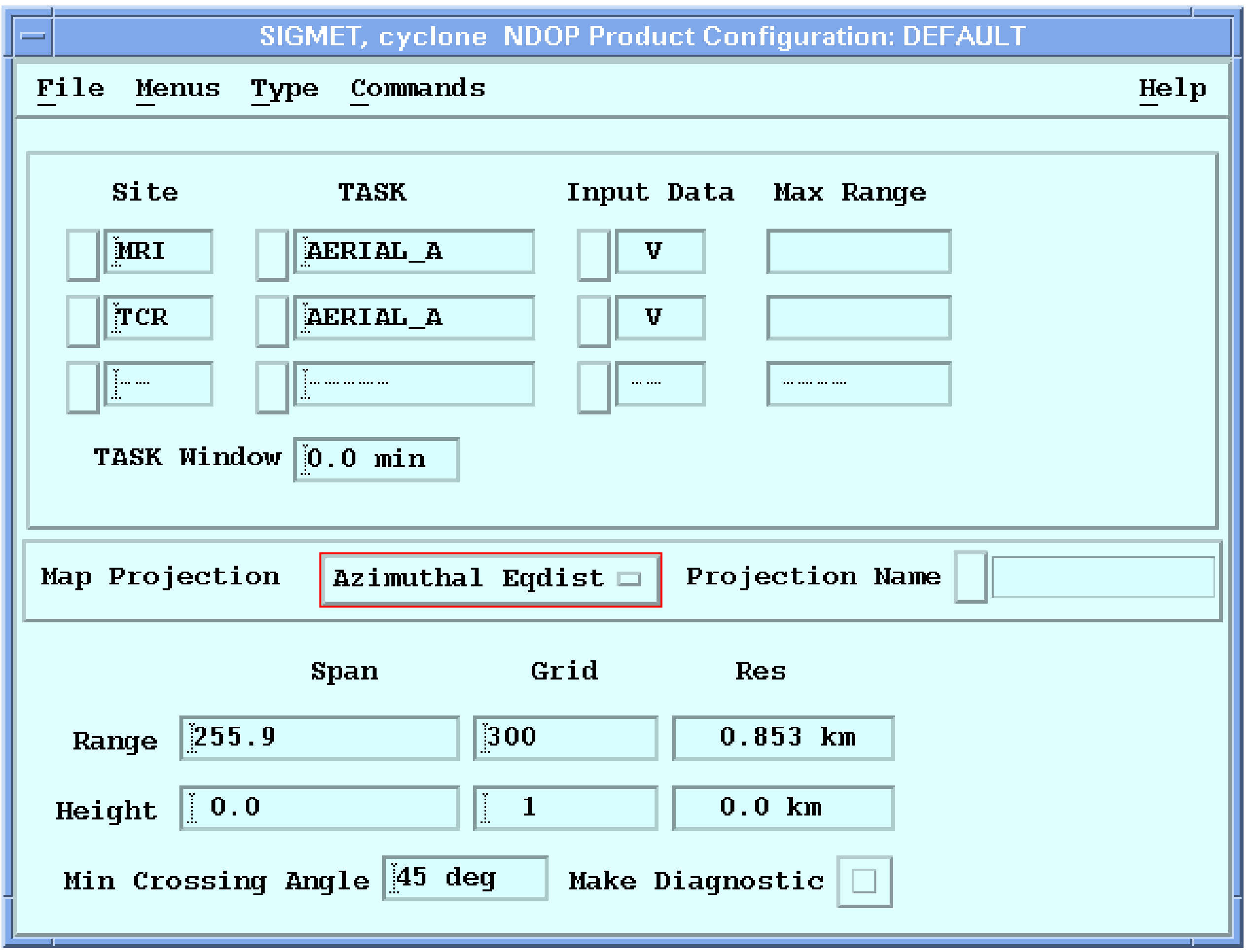
The unfolding for Vc is based on a VVP product which assumes that the wind field varies linearly with distance from the radar. The VVP product used by Vc must have the special name "UNFOLD" and must be available on the system where the unfolding is being performed. This technique achieves 3 times unfolding. For example, for an S band system operating at 1000 Hz PRF (range 150 km), the unambiguous velocity is +–25 m/s. With unfolding the unambiguous velocity will be +–75 m/s (+–150 knots) which can handle most extreme meteorological situations.

As with the fallspeed correction, the Vc unfolding correction can be made at ingest when data are collected from the signal processor (selected in the TASK Configuration Menu) or at reingest (selected in **setup**).

The VVP unfolding technique works very well provided that there is adequate echo coverage and that the wind field is approximately linear in its variations. In the vicinity of strong shear lines or fronts, this may not be the case.

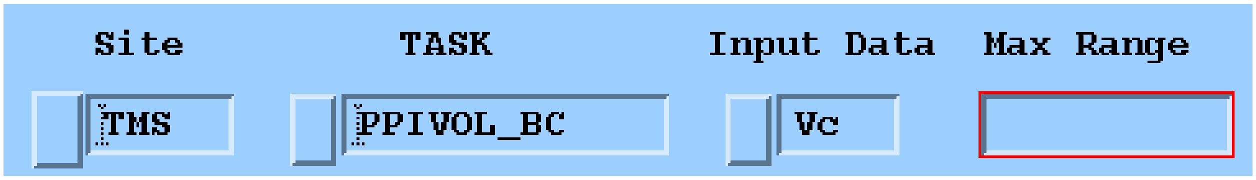
i **If you are using dual-PRF velocity unfolding and it is adequate to prevent folding it is recommended that you not use the VVP-based unfolding in Vc since you may actually harm the data in some extreme cases.**

3.4.2 Product Configuration



The Product Configuration menu for NDOP is shown above. The top section is used to configure what sites and TASK's will supply the input data. The center section describes what projection shall be used. The bottom section is used to specify the parameters of the product generation such as the resolution and the minimum allowed crossing angle.

Specifying TASK's and Sites



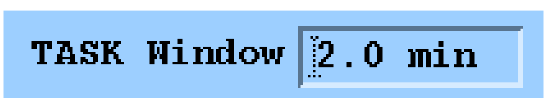
Click the left **Site** button to get a list of sites and select the site. The first site field will be used as the product site. When the NDOP products appear in inventories such as the Product Output Menu or Quick Look Window, they will be associated with this site.

Click the **TASK** button to get a list of TASK's (based on the ingest files on your system). If the TASK that you want is not in the list, simply type in the TASK name. For the **TASK** field you can use the customary wild card conventions in IRIS, such as:

- PPI* Use any TASK that starts with PPI
- PPIVOL_A Use only the A part of the hybrid TASK
- PPIVOL_BC Use only the BC parts of the hybrid TASK.

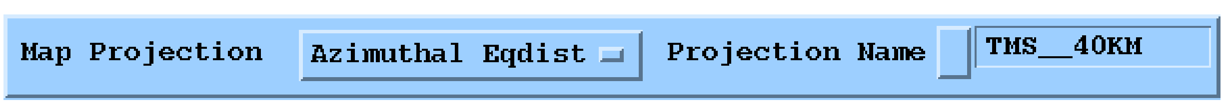
If you have specified a single TASK, the range field will be filled-in with the maximum range of the data for that TASK. However, if you use a wild card or hybrid TASK specification (as in the examples) the Range field will be blank.

Finally select the input data — either V or Vc (radial velocity or corrected radial velocity).



The **TASK (time) Window** is the maximum time difference that will be tolerated for combining the data from the two radars. If the difference in the TASK start times is greater than this value, NDOP will not make the product. This is to avoid problems caused by advection and temporal changes that could cause inappropriate winds to be combined. The example value of 2 minutes is typical.

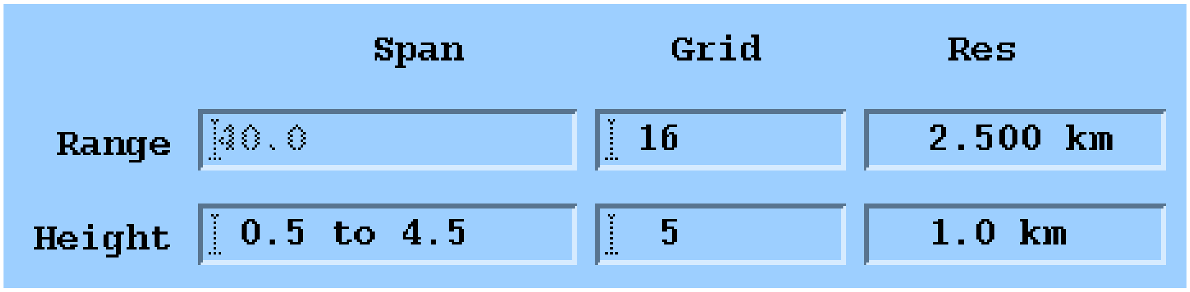
NDOP Projection



It is recommended that you specify a map projection for NDOP. Please refer to **Section 2.1.2** for more information on Map Projections. The projection should be at a convenient point perhaps between the radars and cover a range that is no more than approximately 4 times the baseline length. This is typically the useful range of the NDOP product.

If you do not specify a **Projection Name**, then the data will be centered on the location of the first radar site in the list above.

Output Resolution



The NDOP product produces wind vectors on a 3D grid. Here you specify the characteristics of the grid.

The **Range Span** is the distance in km from the center of the projection, east to the edge of the projection, analogous to a radar range. It is specified either in the named projection, or, if you are not using a **Projection Name**, you can type-in the range. Again a max range of about 4 times the baseline length is typical.

The **Range Grid** is an integer that specifies the number of points in the output array that will be used to represent the Range Span. This value is typed-in.

The Resolution is a display-only field calculated from:

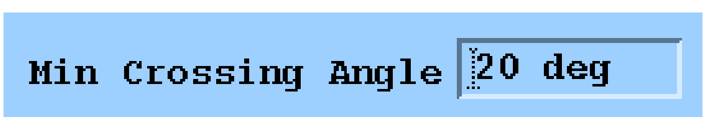
Range Res = (Range Span) / (Range Grid)

In the example, the Range span is 40 and the grid is 16, therefore the resolution is 2.5 km. The actual number of points in the output array that is made by NDOP will depend on the aspect ratio of the projection which may not be square. For a square projection and a grid specification of 16, the output array would be 32 X 32.

For the **Height Span**, specify a maximum and minimum height in km. The **Height Grid** is also specified. The resolution is then calculated from:

Height Res = (Max Height – Min Height) / (Height Grid – 1)

Min Crossing Angle

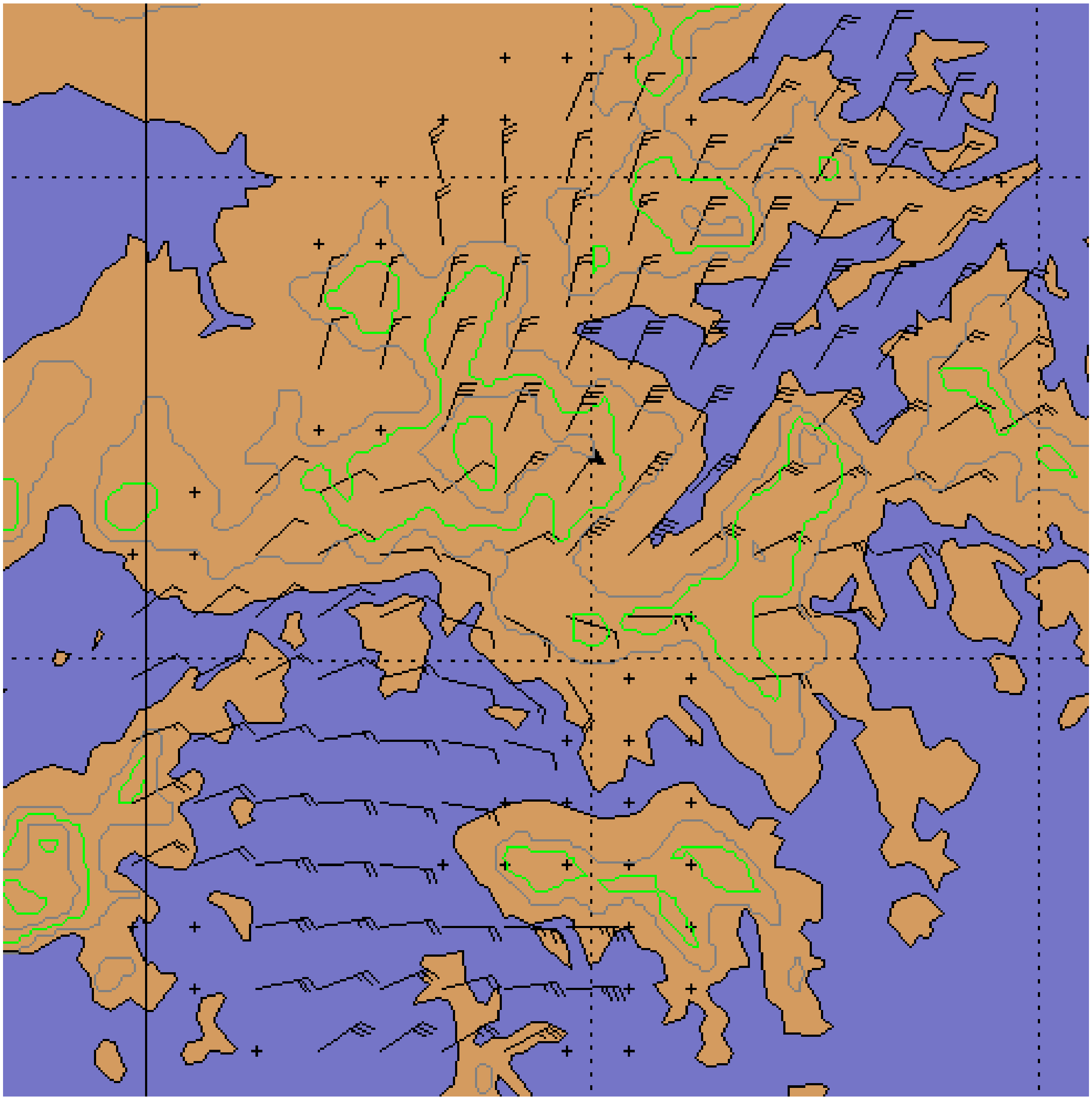


This is the minimum crossing angle that is used. The recommended value is 20 degrees. The same value is used by the algorithm to specify the maximum crossing angle, i.e., the max crossing angle = 180 – Min Crossing Angle.

Make Diagnostics

When pressed, the NDOP product will make an additional velocity CAPPI product. This is the input data used for the NDOP calculations.

3.4.3 Display and Algorithm Notes



An example of an actual NDOP Display (courtesy of the Hong Kong Observatory) is shown above. The example shows the low-level (1 km) winds for a projection 40 km across. Two S-band radar systems were used in this case.

The meteorological situation is an event of strong northerly winter monsoon flow over China colliding with easterlies over the sea. The overlap map shows the contours of the mountainous terrain north of Hong Kong. Note the 50 knot winds funnelling through the mountain pass to the north of Hong Kong.

The "+" points in the display show all regions where the crossing angle criterion was met. These regions are on either side of the baseline that connects the two radars. However, if there are no weather targets, then a wind cannot be calculated.

The algorithm takes the following steps to compute the grid point winds:

- Create 3D CAPPI's of radial velocity for the two radars in the common projection at the grid height spacing. The horizontal resolution of the CAPPI's is subject to the following constraints:
  1. The resolution of the CAPPI pixels is set to be twice the the spacing of the input radial velocity data. For example, for 125-m input bins, the CAPPI resolution will be set to 250 m.
  2. The number of CAPPI pixels for each output resolution grid element should be at least 9 (3 x 3). If this is not the case, then the resolution of the CAPPI is increased. In the same example, if the output resolution were 2 km then per the 250-m pixel spacing in (1) there would be 8 x 8 = 32 pixels for each output grid point.
  3. The maximum number of pixels in the CAPPI is 1100 X 1100. The CAPPI will be clipped at this value. For a 40 km range span (80 km total across the output array), there would be (4 pixels/km)*80 (km) = 320 pixels in the CAPPI (320 X 320 for a square projection).
- The data from the radial velocity CAPPI's are then processed with the multiple Doppler algorithms to obtain a grid of (x,y) wind vectors at the original CAPPI resolution (e.g., 320 x 320).
- The high-density wind vectors are averaged to reduce the data to the final output grid. Continuing the example, with 4 pixels per km in the CAPPI and a an output resolution of 2 km, we would average 8 x 8 = 32 wind vectors for each output grid point.
- To eliminate noise and speckle effects, a grid point is thresholded if there are fewer than 3 values to average or less than 25% coverage. In the example, the 25% would correspond to 8 wind estimates.

When the vector averages are computed, a Wind Quality Index (*WQI*) is also calculated and stored with the data. This is used for thresholding when the product is displayed, and the threshold can be adjusted by the user. See the description of the NDOP Display Options in the Quick Look Window Section 5.15.5.

The Wind Quality Index is computed from the variances $\sigma^2{}_x$ and $\sigma^2{}_y$ of the individual components of each (x,y) wind vector that is computed from the CAPPI data. For every CAPPI velocity pair that contributes to the final X and Y wind, the two variance terms are also computed so that WQI can be derived as:

$$WQI = 1.0 - \left(\sqrt{\frac{\sigma^2{}_x + \sigma^2{}_y}{2}} \;\; / \;\; V_{norm} \right)$$

where V_{norm} is a normalization term, and is the standard deviation that would result if uniformly distributed random vectors at half the Nyquist velocity were input to the algorithm, i.e., that case would produce a Wind Quality of zero.

$$V_{norm} = \left(\frac{V1_u + V2_u}{2}\right) / 2\sqrt{2}$$

where $V1_u$ and $V2_u$ are the Nyquist velocities for the two CAPPI input products.

Note that WQI is set to zero if the above calculation yields a negative number. Zero corresponds to a terrible fit among the dual Doppler winds that are averaged into each output grid; and 1.0 corresponds to perfect agreement of all the data