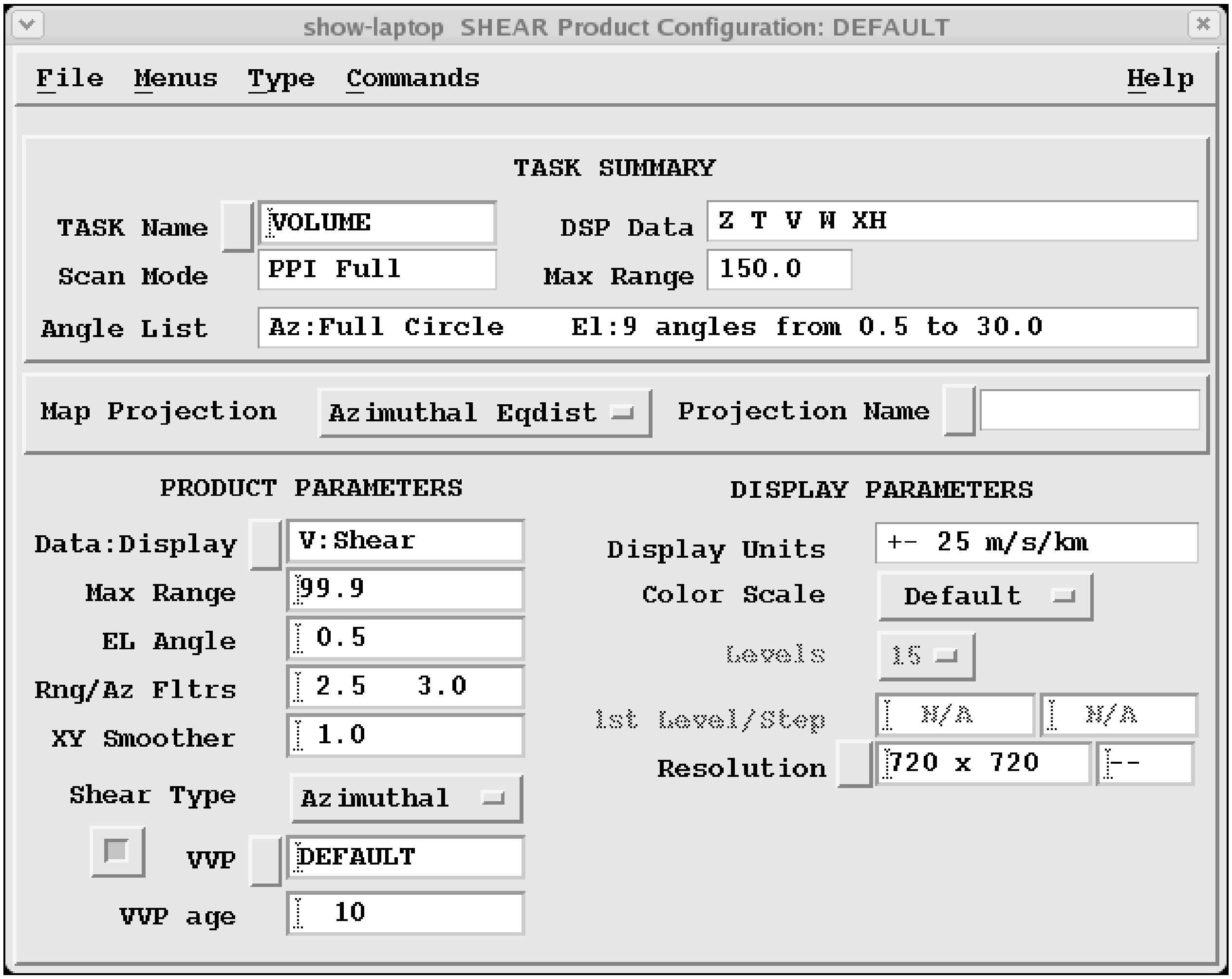
3.5 SHEAR: Wind Shear



This section describes the fields of the Product Configuration menu that are unique to SHEAR products. For general information, see these other sections of this chapter:

- Task Summary area, Section 2.1.1.
- Map Projection Area, Section 2.1.2
- Product Parameters, see Section 2.1.3.
- Display Parameters area, Section 2.1.4.

The optional SHEAR product can detect wind shear in the atmosphere. Wind shear is associated with a variety of phenomena:

Microbursts	Associated with convective storms. Extremely hazardous to aircraft during landing or takeoff. Microbursts are characterized by positive values of the radial shear (strongly divergent outflow) in a roughly circular region, typically less than 3 km in size.
Gust Fronts	Caused by cold outflow from a convective storm (perhaps a microburst) colliding with the surrounding air. They are characterized primarily by negative values of the radial shear (convergence). However, depending on the geometry, they can also create positive values of the radial shear and azimuthal shear of either sign.
Mesocyclones	Characterized by rotation. Mesocyclones are associated with tornados. The azimuth shear is used to detect mesocyclones.
Cold Fronts	Similar to gust fronts, but much larger in extent.
Atmospheric Waves	Produced at a variety of wavelengths and intensities. The shear values can be positive or negative, depending on the nature of the wave and the "phase" being observed.

These phenomena, except for atmospheric waves, are shown schematically in Figure 3–5.

There are three different types of basic shear values that can be computed for the radial component of the wind:

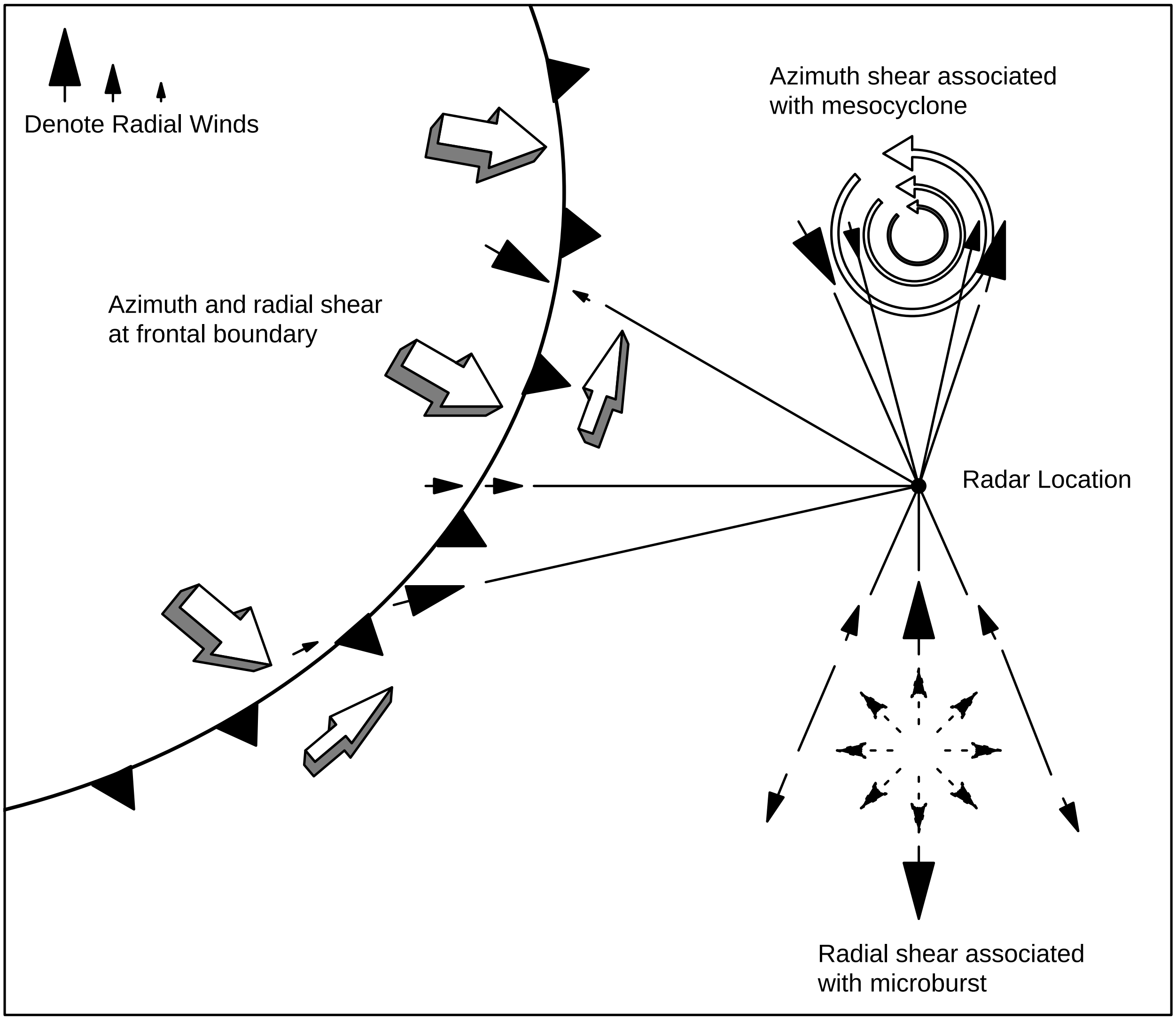
- **Radial shear —** computed by differencing the radial velocity in range. Positive values are for radial velocity increasing (more away) with range. Divergence of the radial wind is positive.
- **Azimuthal shear —** computed by differencing the radial velocity in azimuth. Positive values are for radial velocity increasing (more away) in the clockwise direction. This corresponds to positive vorticity.
- **Elevation shear —** computed by differencing the radial velocity in elevation. Positive values are for radial wind increasing (more away) with height.

In addition to the basic shears, there are combinations of these which are computed by taking the RMS values. For example, the total combined shear magnitude is:

$$\mathrm{SQRT}\ (\ \mathrm{RAD}^2 + \mathrm{AZ}^2 + \mathrm{EL}^2\ )$$

where RAD, AZ and EL denote the basic shear values. Combined shears are positive.

Figure 3–5: Schematic Examples of Wind Shear



ℹ **SIGMET does not warrant that the SHEAR product will detect all hazardous shear conditions. Whenever convective storms are in an air terminal area, there is danger of microburst. Normal precautions to avoid suspected wind shear should be used, even if the SHEAR algorithm does not detect shear. The SHEAR product is only one of many indicators that such a hazardous condition may exist. SIGMET, Inc. shall not be liable for damages of any kind for failure of the SHEAR algorithm to detect hazardous wind shear or for false alarms that may occur from use of the SHEAR algorithm.**

To open the SHEAR Product Configuration menu:

Choose **Type–>SHEAR** from the menu bar. You can use **File–>Open** to load an existing product into the menu.

Data : Display

V Shear

EL Angle

The elevation angle of data you want to display. Wind shears associated with gust fronts and microbursts are usually low-level phenomena, so angles of 1 degree or less are typically used to detect these.

Rng/Az Filter

The first number defines the range length scale for the SHEAR product, in km. This distance determines the size of the skip that the SHEAR product can tolerate when differencing over missing data. It also specifies the length of the the radial smoother, which is applied before the XY smoother.

The second number is the azimuth length scale in degrees.

Shear Type

Choose one of three types of shear to be computed:

Radial
Azimuthal
Elevation
AZ+EL
Rad+AZ
Rad+EL
Rad+AZ+EL

Radial Shear — The bin-to-bin difference in the radial velocity.
Azimuthal Shear — The azimuth-to-azimuth difference in the radial velocity.
Elevation Shear — The difference between the radial velocity at the selected and next higher elevation angle. Requires a volume scan.
Combined Shears — The RMS value of the three basic types of shears in all of the various combinations.

VVP

Select the name of a VVP product. The wind speed and direction from the nearest VVP wind product of this name is used to remove the effects of the mean wind on the azimuth shear calculation. This VVP product should be scheduled to run. Use of the azimuth or combined shear is not recommended without this correction.

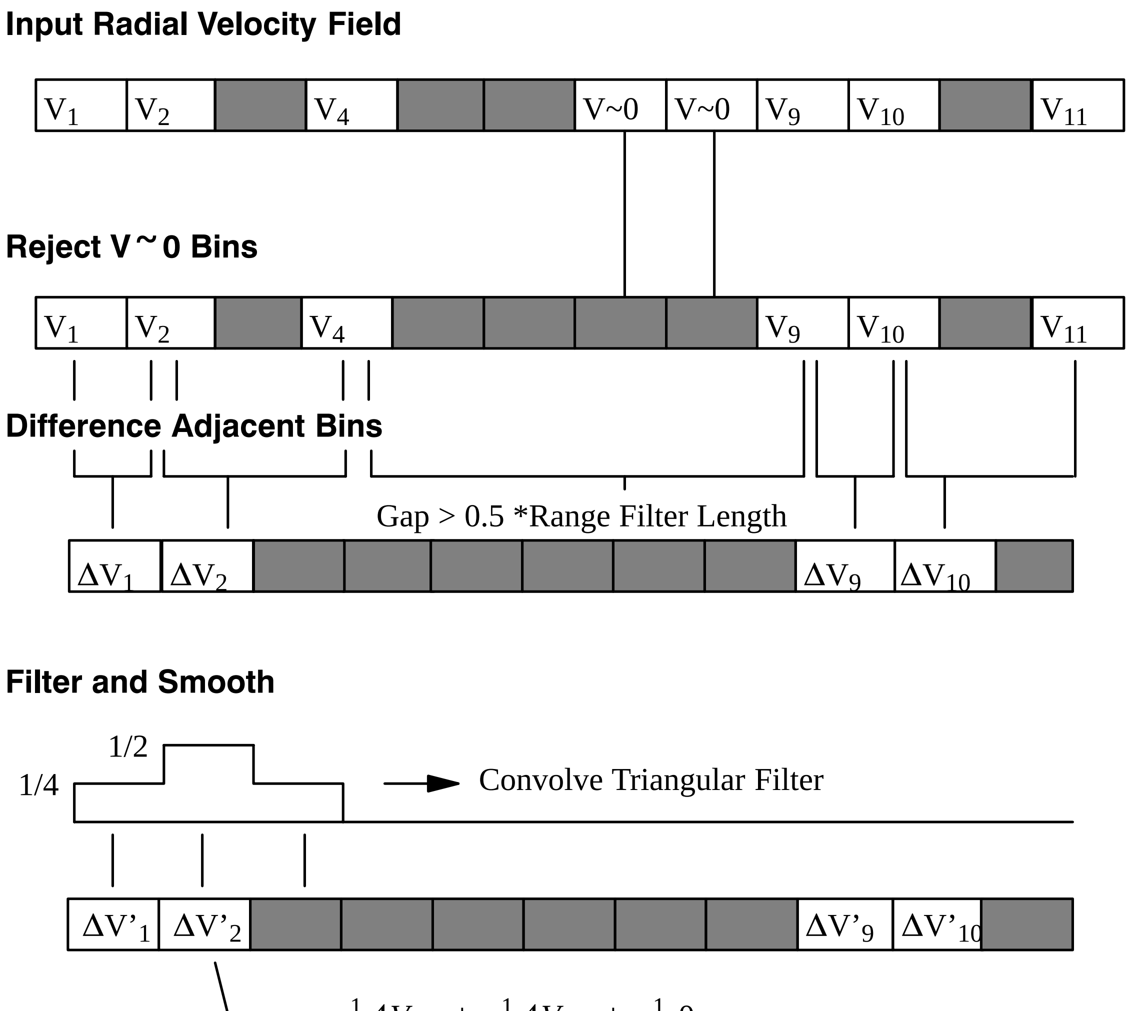
VVP Age

The maximum number of minutes between the data for the VVP product and the data for the SHEAR product. This prevents old VVP winds from being misapplied. If no VVP product is found in this time window, then no mean wind correction is applied when computing the azimuth shear.

3.5.1 The SHEAR Algorithm

The SHEAR algorithm depicted in Figure 3–6 is for radial shear, but the azimuth shear is similar in “B-scan” space (range-azimuth).

Figure 3–6: Radial Shear Algorithm Schematic



$$\Delta V'_2 = \frac{\frac{1}{4}\Delta V_1 + \frac{1}{2}\Delta V_2 + \frac{1}{4}0}{W_2}$$

$$where \quad W_2 = \frac{1}{4}\delta_1 + \frac{1}{2}\delta_2 + \frac{1}{4}\delta_3$$

and $\delta_n = 0$ if ΔV_n *is thresholded, else* $\delta_n = 1$

If the weight W is $\leq \frac{1}{2}$, *then bin is thresholded (eliminates speckle bins).*

Point Clutter Bin Removal

Point clutter bins produce erroneous high shear values when they are differenced with surrounding valid velocities. The first step in the shear algorithm is to remove obvious clutter bins which were not canceled by the signal processor clutter filter. All velocity bins having a velocity within 2% of zero velocity (as compared to the full velocity range) are tagged as potential Clutter Bins. A Clutter Length Scale is defined as 1/3 of the Range Filter Length value in km. Contiguous runs of Clutter Bins that are less than or equal to the Clutter Length Scale are rejected. For example, suppose the bin spacing and Range Filter Length values are selected so that Clutter Length Scale corresponds to 3 range bins. Then any single isolated Clutter Bin would be rejected, as would runs of 2 or 3 clutter bins. Runs of 4 or more clutter bins would not be rejected because they are interpreted as real weather. Regardless of the Clutter Length Scale, isolated clutter bins (single bins) will always be removed.

Differencing (radial difference example)

The next step is to perform the range differencing of the radial velocities. The radial wind shear algorithm computes the shear by taking the bin-to-bin difference on a PPI surface. If the differencing algorithm encounters a blank bin, it skips out in range to the next valid bin to take a difference, provided the bin is within 0.5*Range Filter Length. For example, if the Range Filter is set to correspond to 3 bins, the differencing algorithm differences over a gap of one bin, but not over a gap of 2 or more bins. The velocity differences are placed as close as possible to the center of the difference interval, to the nearest bin that is less than or equal to half of the difference interval.

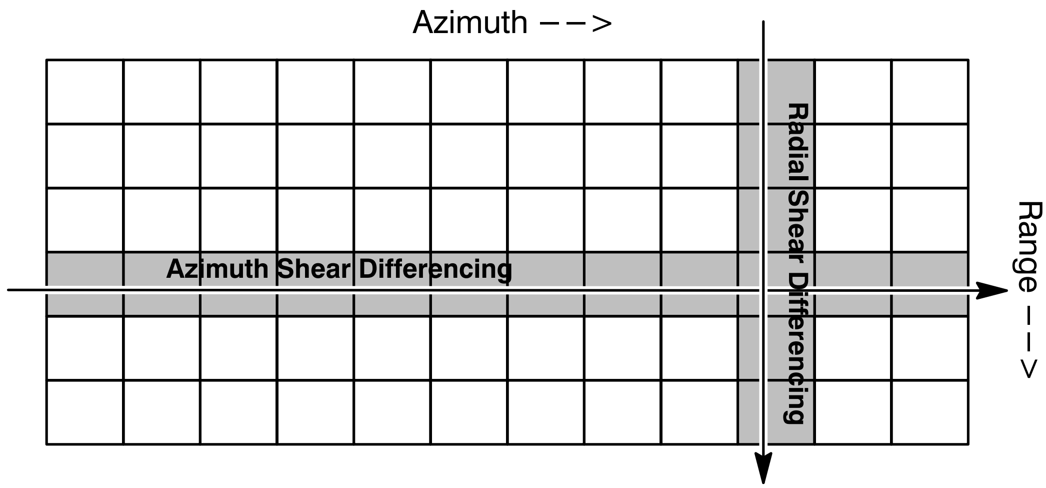
Smooth the Differences

Differencing is inherently noisy. The next step is to smooth the computed differences. This not only reduces the noise, it also fills in small gaps of missing bins and cancels any remaining isolated bins. The smoothing algorithm uses a triangular window whose total width is equal to the Range Filter Length value. The sum of the weights defined by the triangular filter is always 1 unless a bin is thresholded. In Figure 3–6, the Range Filter Length corresponds to 3 bins. Each velocity in the filter range is multiplied by the corresponding weight and then summed. The mean is obtained by dividing by the total weight. Thresholded bins are not weighted. If the total weight is less than or equal to 0.5, the shear value is rejected. This eliminates isolated bins. This approach can also fill gaps. A longer range filter rejects a longer run of isolated bins and fills a longer gap.

Azimuth Shear Calculation

Figure 3–7 is a depiction of “B-Scan” space (a PPI surface). The coordinates are range and azimuth. The radial shear is obtained by differencing in range along a radial.

Figure 3–7: B-Scan Space (PPI surface)



The azimuth shear algorithm is analogous to the radial shear algorithm except that:

- Differencing is performed from ray–to–ray at constant range.
- The Azimuth Filter Length is specified in degrees.
- The final azimuth values are range normalized and corrected for the apparent azimuth shear caused by the mean wind. The mean wind value is obtained from the VVP algorithm. This correction is an optional step.

The mean velocity correction is discussed in detail in Figure 3–8.

Shear Magnitude

After both the radial and azimuth shears have been obtained, the next step is to compute the shear magnitude. This is simply the square root of the sum of the squares of the two shear values (radial and azimuth) associated with each bin. In the case where only a single shear is selected (radial or azimuth), this step is skipped.

Convert to Cartesian and Optional Final Cartesian Smoothing

The conversion to Cartesian transforms the B-scan values of the shear magnitude to X-Y coordinates. The algorithm is identical to the PPI algorithm, which uses a last-in approach for both range and azimuth filling. An optional 2D smoother with selectable length scale can be passed over the data at this point.

3.5.2 Optimizing for Microburst Detection

Accurate detection and timely reporting of microbursts in an air traffic control environment requires that the system be properly configured and optimized. This includes virtually all aspects of IRIS. SIGMET recommends that the customer hire a

Figure 3–8: Mean Velocity Shear Correction

The radial velocity can be expressed in terms of the u and v components of the wind (the vertical velocity is ignored here because the observations are typically near horizontal:

$$V_R = ucos\theta\sin\phi + v\sin\theta\sin\phi$$

where:

V_r	is the radial velocity
u	is the x-component of the wind (east)
v	is the y-component of the wind (north)
θ	is the the azimuth defined as positive CCW from the x-axis (east)
ϕ	is the elevation defined as positive upward

Let the wind be represented by a mean wind [u_o, v_o] and a perturbation wind [u’, v’], then

$$V_R = (u_o + u')\cos\theta\sin\phi + (v_o + v')\sin\theta\sin\phi$$

The azimuth derivative is then,

$$\frac{\partial V_R}{\partial\theta} = -u_o\sin\theta\sin\phi + v_o\cos\theta\sin\phi \quad + \quad \frac{\partial}{\partial\theta}\ [u'\cos\theta\sin\phi + v'\sin\theta\sin\phi]$$

where the first term is the apparent azimuth shear caused by the mean wind. Thus, when the azimuth derivative is computed, the correction term is applied as follows:

$$\frac{\Delta V_R}{\Delta\theta} + u_o\sin\theta\sin\phi - v_o\cos\theta\sin\phi \quad = \quad \frac{\partial}{\partial\theta}\ [u'\cos\theta\sin\phi + v'\sin\theta\sin\phi]$$

The values of u_o and v_o are obtained from the VVP algorithm. In terms of the azimuth β measured in the traditional radar sense (clockwise from north) the correction is,

$$\theta = 90 - \beta$$
$$u_o\cos\beta\sin\phi - v_o\sin\beta\sin\phi$$

qualified consultant to assist with tuning and evaluating the IRIS SHEAR algorithm, data acquisition, radar siting and warning reports. The optimization steps presented here serve only as guidelines and should not be substituted for a thorough evaluation of your particular site. Fortunately, IRIS provides many of the tools needed to perform such an evaluation.

The SHEAR product is first produced from specially constructed TASKS that are optimized for close-range, high-resolution measurement of radial velocity. The SHEAR products are then fed to the WARN product, which checks to see if the strength and size of the wind shear regions exceed a threshold value in the protected areas. Additional criteria, such as reflectivity aloft from a higher scan or a requirement to see the shear on two adjacent scans, can be added to the WARN product to reduce the false alarm rate if this is a problem for the particular location.

As recommended in Appendix B, an entire IRIS configuration should be set up for wind shear, so that when potentially hazardous weather approaches the terminal area, IRIS can be switched to wind shear monitoring mode by loading the configuration into the Radar Status menu. In addition, the WARN product can be operated in surveillance mode to alert the operator that the mode should be switched, or the automatic mode switching feature can be used. For example, the surveillance mode could consist of a 15 elevation volume scan sequence. The WARN product can be keyed on a severe storm indicator such as VIL. Whenever VIL exceeds a threshold value typical of severe storms for the area, and this VIL is within 30 km of the terminal, the WARN product can issue an alarm advising the operator or the automatic mode switch to change to the wind shear detection mode.

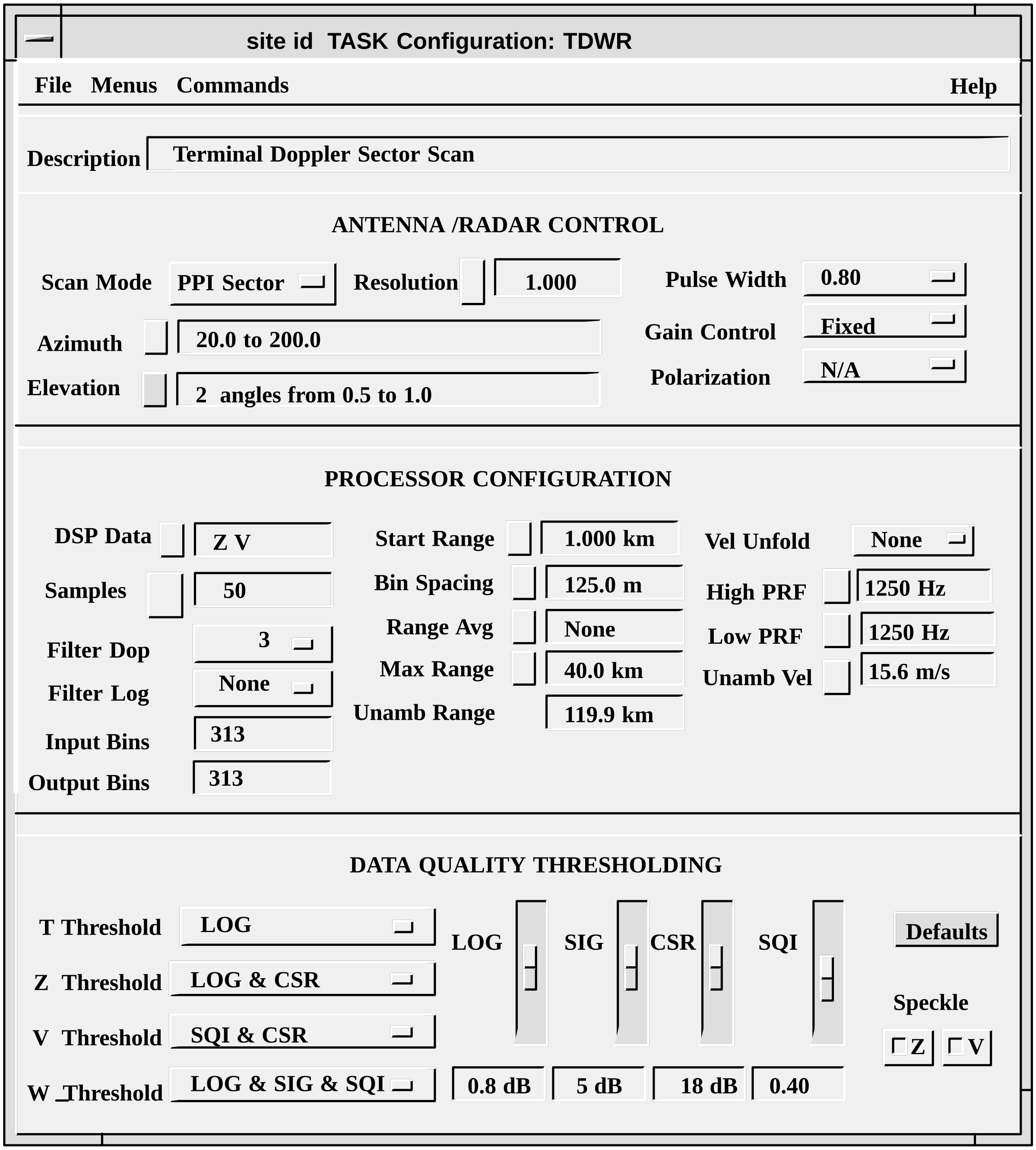
The TASK Configuration menu for wind shear detection should be optimized as shown in the example in Figure 3–9 for an RVP6 processor. This example uses high-resolution sampling in range (125 or 62.5 m). Microbursts are low-level phenomena, so it is best to configure elevation angles that are as low as can be tolerated by the surrounding clutter. Typically an angle set such as 0.5°, 1.0° and 5.0° is useful. The bottom two angles can be used for shear detection, while the upper angle can serve as the basis for an additional reflectivity aloft criterion for the WARN product. Sector scan mode is used to limit the data coverage to the terminal area which speeds the update rate.

The TASK Scheduler in wind shear detection mode should be set to provide an update rate (repeat time) of at least one complete TASK per minute. To provide optimal response, no other TASKS should be scheduled. This allows IRIS to devote its full resources to detecting microbursts.

The SHEAR product configuration should be optimized as follows:

- The Product Range field should be set to the maximum range of interest, and should roughly correspond to the input bin spacing.
- The 30 km range and 480 by 480 pixel product resolution in the example match the 125 m sampling in the TASK.
- In the example elevation angles of 0.5, 1.0 and 5.0, separate shear products can be configured for each of the lowest two angles.
- It is recommended to not use any additional XY smoothing when the SHEAR product is used for microburst detection because smoothing tends to diminish the peak values that are of interest in the shear calculation. The radial smoothing performed by the range filter, and the subsequent smoothing performed in the WARN product are adequate.

Figure 3–9: TASK Configuration for Microburst Detection



The WARN product looks at the SHEAR products to determine whether to issue a warning. In the example of two low-level scans (0.5° and 0.9°), each with its own SHEAR product, the WARN product can be set to examine each. A threshold level of 8 m/s/km is a good indicator of hazardous wind shear. A 1 km area threshold can be used which corresponds to roughly 64 pixels for the case of 125 m bin spacing, 30 km range and 480 X 480 product resolution.

The Product Output menu should be optimized to send the WARN product to a workstation so that personnel can view the situation display. The automatic output request should be made so that the shear product is sent every time that it is made. In addition, a workstation should be running the IRIS menus so that when windshear is detected, the audible warning message and text can be viewed. Warning messages are issued almost instantaneously when wind shear is detected. Within a few seconds of receiving a warning message, the situation display is presented. This depends on the speed of the communications link connecting your display. However, because the situation display is an overlay product without a complex picture, it can be transmitted very efficiently.

Wind shear detection algorithms are known to require tuning for each site. This requires that qualified personnel perform the necessary optimization for your particular meteorological and operational environment. It also requires that you go through a thorough evaluation phase to test your system on your particular site for your particular weather. It is recommended that you make and record a RAW product every time a microburst is detected and perform an analysis to determine weather it was a real event or a false alarm. To obtain a larger sample, you may want to expand the protected area to include all the total area around the radar to the maximum range of detection required (typically 20 to 30 km) for air terminal applications. Again, a qualified meteorologist should assist with this evaluation.

If it is determined that false alarms are occurring, there are several approaches you can take to balance sensitivity against false alarm rate. In tuning your system to reduce false alarms, it is important to make gradual changes and evaluate them on test cases that you have recorded. IRIS is ideal for this type of evaluation. Some examples of actions that you can take to reduce false alarms are as follows (note the reverse of each example can be used to increase sensitivity):

- Gradually increase the range filter in the SHEAR Product Configuration menu from 1 km to 2 km.
- Increase the SHEAR magnitude threshold in the WARN Product Configuration menu.
- Increase the threshold AREA size in the WARN Product Configuration menu up to 2 km.
- Require that two low-level scans from the same TASK both detect the SHEAR in the WARN product—a two-look test.
- Add a warning criterion that requires reflectivity aloft. This can be based on a dBZ PPI at a higher angle. However, be sure that dry microbursts are not common in your area. If they are, you may need to use a VIL criterion and employ more elevation angles in your associated TASK.