Velocity resolving

The technique used to compute the plasma flow by resolving the line-of-sight velocities (**V**i) measured by the radar varies according to the antenna mode used. Basically, there are three common modes of antenna motion for measuring the plasma convection:

- three positions for height-resolved measurements of the electrodynamic parameters overhead,
- elevation scans for measurements of some of the electrodynamic parameters in our meridian, over about 3-deg of latitude, and
- composite scans for measurements of some of the electrodynamic parameters over many degrees of latitude.

Each mode has certain advantages and assumptions. Here we describe the antenna modes, the technique we use to resolve the velocities, the assumptions inherent to each and the advantages of each.

<u>Three positions and RVEL3PV</u> – **E** and height-resolved **V**r from overhead

This mode is the most straightforward of the three. The radar antenna cycles through a series of three positions, dwelling at each for a finite length of time. Depending on ionospheric conditions and signal strength, this may vary from 1 minute to 5 minutes at each position. Obviously, the longer the antenna dwell, the better the statistics. However, this mode assumes temporal stability of the plasma, so the longer dwells can introduce errors due to changes in the plasma flow and compromise the validity of this technique during dynamic periods.

In our standard mode (used for the LTCS and CADITS World Days, as well as many other experiments), we cycle through the following positions:

azimuth	elevation
141	80 (approximately parallel to **B** at F-region altitudes)
261	70
21	70

and dwell at each for 3 minutes. We have picked these three positions as they are near enough to overhead to combine measurements that are separated by only 250-km distance (at the typical peak of the *F* region) and yet far enough from vertical to be sensitive to the horizontal component of the flow. The azimuth of each is separated by 120 deg. The antenna cycle time is 10-1/2 minutes.

When the data are processed for computing the electrodynamic parameters, the data from one antenna dwell are integrated together. This creates a series of line-of-sight measurements that cycles through the three positions and they are used as input to the program RVEL3PV to resolve the velocities and compute the average *F*-region electric field. The velocities from gates at similar altitudes from each of the three antenna positions are combined, and the result is an altitude profile of the resolved velocity. To compute the electric field, the resolved velocity profile above 180-km altitude is averaged, weighted by the signal-to-noise ratio (SNR). This average *F*-region velocity is used to compute the **E** field, assuming the ions are **E**x**B** drifting.

The velocity resolving program uses antenna positions 1, 2 and 3 and computes the electric field and height-resolved velocities. These values are given the start time of the first position and the end time of the third position. Then position 1 is discarded and the program uses the original positions 2 and 3 and the next position 1, and repeats the process. If the antenna dwells are of 3-minute duration, and accounting for antenna movement time between dwells, then there will be a new set of electrodynamic parameters every 3-1/2 minutes (1-2-3, 2-3-1, 3-1-2, 1-2-3, etc.), each resolved velocity spanning a period of 10-1/2 minutes (the antenna cycle time).

This method assumes temporal stability for the duration of the antenna cycle and homogeneity of the plasma over the measurement volume, which is 250-km in diameter in the *F* region and 90-km diameter in the *E* region for the three positions listed above. Further analysis of these data can provide calculations of other *E*-region electrodynamic parameters.

Elevation scans and PVEEST – **V**r and **E** vs. latitude

An elevation scan (or el-scan) is when data are recorded while the antenna stays at a fixed azimuth and moves in elevation at a controlled rate. (The rate can either be constant or variable. The variable scan rate is such that it provides constant ground tracking at a specific altitude—it moves more slowly at lower elevation angles and more quickly near overhead. Our first-stage processing program can integrate the data either for a specified length of time or over a specified angular range.) The most common elevation scans are near the magnetic meridian and are perpendicular to our local L shell. These el-scans are at 153/333 deg azimuth and scan from 30 deg above one horizon, up through the zenith, and down to 30 deg above the opposite horizon. The resolved velocities from these meridional el-scans can be derived with the PVEEST program.

The derivation uses the equation of motion for the ions in the *E* and *F* regions. Above about 150-km altitude, the effect of collisions becomes negligible, and the ion equation of motion becomes:

V=(**E**x**B**)/**B****2 (where **E** is the electric field, **V** is the ion velocity, and **B** is the magnetic field).

Below about 150-km altitude, the ion equation of motion includes additional terms involving the ion mass, the ion-neutral collision frequency, the neutral wind, and the ion-gyro frequency [*de la Beaujardiere, Vondrak and Baron*, 1977, JGR, Vol. 82, No. 32, pp. 5051-5062, and *Doupnik, Brekke and Banks*, 1977, JGR, Vol. 82, No. 4, pp. 499-514].

With an el-scan, we can only measure the component of the velocity parallel to the plane of the scan (the magnetic meridian, in this case). To calculate the other (zonal) component, the **V**(los) measured in the *E* region is used, where the effect of collisions is to reduce the ion speed and to rotate the ion velocity in the direction of the **E** field. The rotation angle of the ion velocity is proportional to the ratio of the ion-gyro frequency and the ion-neutral collision frequency, both of which we take from models. The reduction in the ion speed is proportional to the angle of the rotation and the ratio of the electric field to the magnetic field.

This behavior allows the full ion vector to be solved from the meridional el-scan by combining both *F* and *E* region measurements. The data from one complete scan are field-aligned. The line-of-sight velocities from *F*-region data gates along a specific field line are averaged (weighted by SNR). Each of these averaged **V**i's are combined with the measurement from the *E*-region data gates that are on the corresponding field line.

This technique:

- ignores the neutral wind,
- uses model data for the ion-gyro frequency and the ion-neutral collision frequency, and
- assumes the velocity parallel to **B** is zero.

Because the *F*-region measurement of **V**i is combined with the *E*-region measurement of **V**i, the spatial extent of the coverage of the resolved velocities using el-scans is limited to just a few degrees (approximately 3) of invariant latitude, where there are data sampled in the *E* region. An advantage of resolving velocities with this mode is its good temporal resolution, which assumes temporal stability of only some tens of seconds, at the most.

Composite scans and VEL2CMPBIN – **V**r and **E** vs. latitude

Another common antenna mode is composite scans (comp-scans), when the antenna is moving in both azimuth and elevation. This mode is often used for the WLS World Days and other experiments where the goal is to measure the convection over many degrees of latitude.

The comp-scans are designed to define a plane parallel at any given altitude to the magnetic meridian but offset to the magnetic east or west, and are tilted a specific amount from the zenith (most commonly 25 deg). These scans can be performed at a variable rate that results in constant ground tracking (slower at lower elevation angles and faster near overhead). They alternate between east and west of the site, and travel in the same (northward or southward) direction. For instance, the first scan may be the east comp-scan, from southeast to northeast, and the second scan would be the west comp-scan, from the southwest to the northwest. Then the east comp-scan would be repeated, followed by the west comp-scan, etc. The scan duration is normally four minutes, but that may vary with the experiment purpose and ionospheric conditions. The movement time between scans is less than one minute.

Using the program VEL2CMPBIN, the data are ordered in such a way as to combine the **V**i's from one comp-scan with the **V**i's from the same altitudes and latitudes from the opposite comp-scan. That is, the first line-of-sight record from the first east scan is paired with the first line-of-sight record from the first west scan. Each pair of data gates at the same altitude is combined to form the resolved velocity (using some assumptions, which are addressed below). Then the second line-of-sight records from each of the two scans are used, then the third, as so on until the last records from each scan are combined. As each pair of records is combined, they may produce values that overlap in latitude with values from other pairs of records – as the data gates increase in range, they also increase in altitude and distance from the radar site. Each pair of records may cover some degrees of latitude, particularly at the extremes of the scans.

After the data gates are paired from the matching line-of-sight records from this very first pair of comp-scans (east and west), the first comp-scan is discarded and the second comp-scan is then paired with the third comp-scan. The third comp-scan is then paired with the fourth comp-scan, etc. Each pair of line-of-sight records results in one output record that has:

- the mid-time between the begin time of the record from the first comp-scan and the end time of the record from the second comp-scan (approximately 4.5 minutes for our nominal case), and
- the latitudes and values of the east and north components of the resolved velocities.

To accommodate real-time viewing of the data from this mode, the resolved velocities from each pair of comp-scans are binned (in 1/4-deg latitude bins) and averaged and computed as velocity magnitude and direction.

With this technique, we assume:

- **V**-parallel is zero,
- longitudinal homogeneity, and
- temporal stability on the order of some minutes.

Obviously, if there are longitudinal differences in the plasma flow (for instance, due to a shear reversal that is not parallel to the L shell) or a temporal change from one scan to the next (as would happen with a substorm onset), then the validity of this technique is compromised. With good *F*-region signal, this mode can provide convection measurements covering as much as 13 degrees of latitude.