Project Report
ATC-289

The Design and Validation of the ITWS Synthetic Sensor Data Generator

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12 April 2000

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16. Abstract
The Integrated Terminal Weather System (ITWS) is an aviation safety and air traffic management decision support system that acquires data from various FAA and NWS sensors and generates a number of products for dissemination to FAA facilities managing air traffic in the terminal area. The development and demonstrations of ITWS have been conducted over a multi-year period at several major airports (Memphis, TN, Orlando, FL, Dallas, TX, and New York, NY). Although there are many meteorological events observed at these four airports, the experimental test data sets obtained will not fully suffice for ITWS qualification testing because of limitations in the severity of the weather events and because of the sensor configurations available at these locations.

This report describes the design and validation of the Synthetic Data Generator (SDG), which is a tool to provide a production ITWS system with meteorologically consistent scenarios and full ITWS sensor configurations that will create maximal computational loads that can be expected when the system is deployed. Also, the SDG will be a tool for ongoing ITWS maintenance and support. As such, the SDG will complement the extensive experimental data sets collected at the four ITWS demonstration sites.

The SDG is designed to specify parameters for a collection of meteorological models describing the various weather phenomena, their motion, appearance, and growth/decay. The software creates several three-dimensional (3D) grids of reflectivity and velocity at each time-step. Finally, the SDG generates sensor (i.e., TDWR, NEXRAD, ASR-9) data by applying the model for each specific sensor's measurements to the 3D grids.

The validation of the meteorological model and the sensor model data have been accomplished using a display tool and by assessing results numerically.

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ITWS, microburst, ASR, gust front, TDWR, radar, NEXRAD, sensor data

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ABSTRACT

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1. INTRODUCTION

The Integrated Terminal Weather System will provide aviation weather information in the terminal and transitional en route areas to improve the safety and efficiency of air traffic operations. This system utilizes data from several radars: the Next Generation Weather Radar (NEXRAD), the Terminal Doppler Weather Radar (TDWR) and the Airport Surveillance Radar (ASR-9) as well as the Low Level Windshear Alert System (LLWAS), commercial aircraft, surface sensors, the National Lightning Detection Network (NLDN), and forecast models to create its weather products. [1]

The ITWS system is currently in full-scale development, and production systems will be deployed at many of the major airports in the US. The Synthetic Data Generator (SDG) tool was developed to create synthetic weather data for validation of the production ITWS's system performance and for use by the FAA ITWS program support facility once the ITWS is deployed. The design of the SDG was driven by the following guidelines:

1. The meteorological phenomena models need have only the complexity necessary to test ITWS algorithms.
2. The models for sensor observations need to satisfy only the initial operational capability (IOC) ITWS algorithm requirements.
3. Computational complexity and computer storage requirements should be minimized whenever possible.

This tool allows a user to create dynamic scenarios in which meteorological phenomena (convective storms, microburst outflows, gust fronts, stratiform rain, etc) grow, move, and decay. The SDG also will be used to provide meteorologically consistent sets of sensor input data for computational load testing at sites that do not have a functional prototype; to verify various site adaptation parameters; to validate algorithm mathematical computation after software changes; and to test Y2K modifications of the ITWS prototype algorithms.

This report describes the design and validation of the SDG software. The basic approach of the SDG is to create models of meteorological phenomena from user-specified parameters, describing its physical characteristics, location, motion, and evolution. The model data are written to Cartesian grids, updated every 30 seconds, to model the motion and time evolution of meteorological phenomena effectively. Sensor observations (radar, LLWAS, surface sensors, lightning, etc.) are then created from the Cartesian grids. As a final step, data from the meteorological models and the sensor models are validated using a display tool and by assessing results numerically.

The report is organized in the following manner. An overview of the processing steps used to create the synthetic data is provided in Section 2. A description of the Cartesian grids used to store the meteorological model data is presented in Section 3. The meteorological models are discussed in Section 4, the creation of the sensor observations is described in Section 5, validation of the Cartesian model grids and the sensor observations are presented in Section 6, and the conclusion in Section 7 contains a summary of recommendations for next steps.

2. OVERVIEW OF APPROACH

The SDG is organized into four high-level functional sections: user interface, weather phenomena models, 3D grids, and sensor models. The algorithmic flow for the SDG is as follows. At the interface, the user enters a set of parameters that characterize weather phenomena as a function of time. Examples of weather phenomena include microbursts, gust fronts, convective storms, and stratiform rain. The parameters for such weather include characteristics such as location, size, strength, reflectivity, and winds. Next, the weather phenomena models, using a simple analytic approach, create a map of "weather" on 3D grids by applying the parameters entered at the user interface. Since the weather phenomena are entered as separate parameters, the models must resolve any conflicts or overlap. Next, 3D grids are created to represent the atmospheric variables over the region being modeled. Then, the sensor models such as the Terminal Doppler Weather Radar (TDWR), Airport Surveillance Radar (ASR-9), Next Generation Weather Radar (NEXRAD), and Low Level Wind Shear Alert System (LLWAS) generate sensor data by resampling the 3D grids into archive files that are in the sensor's native coordinates and data formats that are consistent with those used by the ITWS system. The resampling performed by the sensor models attempts to accurately simulate the sensors atmospheric sampling techniques.

The 3D grids, weather phenomena models, and the sensor observation models are described in detail in the next three sections. Figure 1 shows the basic functions of the SDG and the relationship between the functional sections.

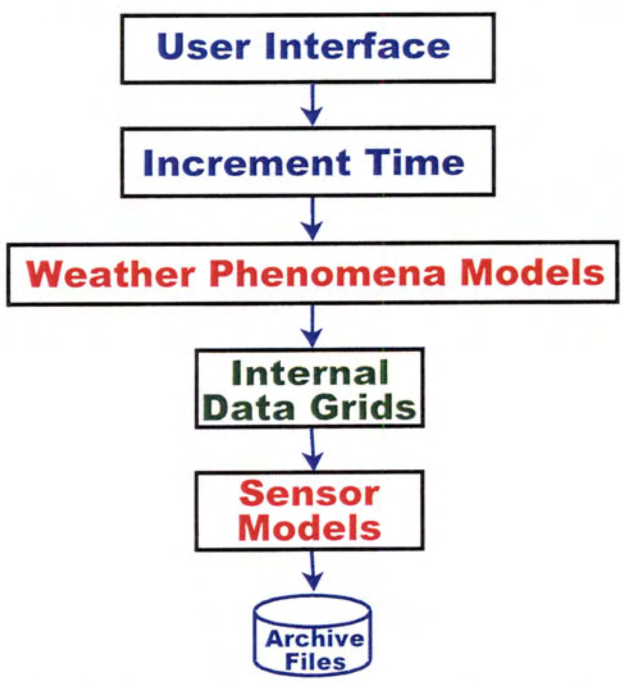

Figure 1. Basic functions of the Synthetic Data Generator.

The first step in generating the synthetic data is for the user to prepare a parameter file with all of the information required for the desired case. Several different types of parameters must be specified. First, the user must determine the basic set of parameters that include such information as the start time, location, grid size and desired update rate of the SDG. Next, the parameters for the various phenomena models are specified. These parameters include information on the location, size, strength, event start time, and duration. Finally, the user specifies the sensor model parameters. These include information on the number of radars, location of each radar, scan strategy of each radar, flight path of MDCRS data, location of surface observations, etc. It is assumed that the user will specify a meteorologically consistent parameter set.

The next step in the algorithm is to create and initialize the 3D grids. In order to minimize internal memory storage and maintain the spatial resolution and spatial extent required in the meteorological models, the algorithm uses four different types of grids: the "Basic" grid, the TDWR grid, the ASR AP grid, and the Lightning grid. The Basic grid covers the entire domain of interest in the SDG at a low resolution. The TDWR grid provides very high resolution for the TDWR coverage region. The ASR AP grid provides additional product information for the ASR-9 radar at a resolution and coverage appropriate for the ASR-9. The Lightning grid provides lightning stroke information for use by the lightning sensor model. Both the TDWR and ASR AP grids fit entirely within the Basic grid coverage area. Also, a separate TDWR and ASR AP grid is defined for each TDWR or ASR-9 radar in the parameter file. During processing, the Basic grid is subsampled to initialize the TDWR grid prior to modeling the microburst and gust front phenomena. The 3D grids are described in Section 3.

Once all of the grids are initialized, the algorithm maps the meteorological phenomena onto the 3D grids as shown in Figure 2. Each of the phenomena models are initialized with the user-supplied parameters, and then the model computes the meteorological variables stored in the 3D grids. Each model is described in detail in Section 4.

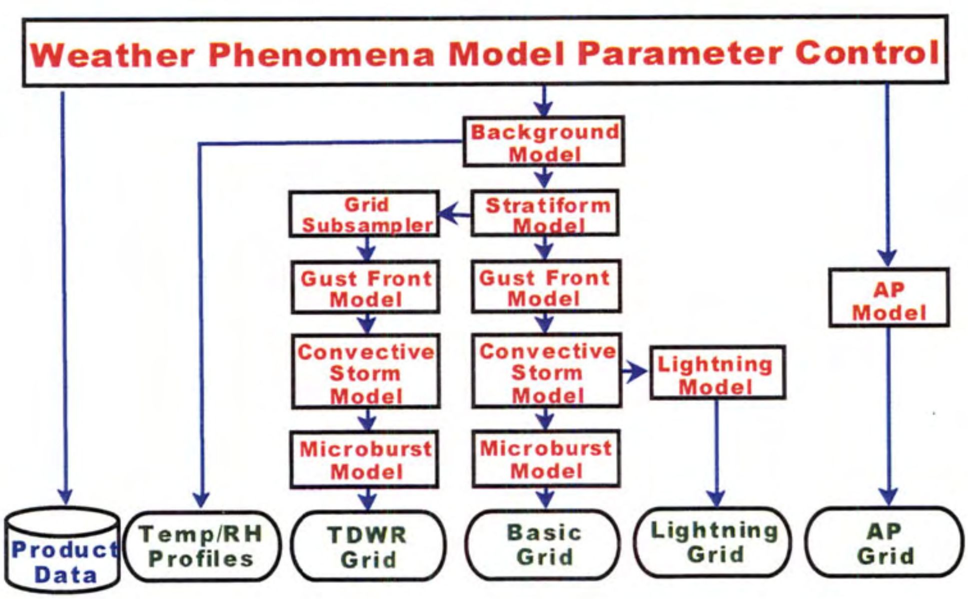

Figure 2. Data flow diagram for the Weather Phenomena Models.

The user must specify a meteorologically consistent set of parameters. However, in some instances, the user may specify weather phenomena that will overlap one another in the 3D grids. In all cases, these conflicts must be resolved for the algorithm to model a "realistic" scenario. Each model's method of handling overlap is described in the next section. However, to help simplify the number of rules employed within these models, a specified order of priority is used, and a basic set of rules is applied for each meteorological variable. The models are run from the lowest priority to the highest priority. After each model is complete, the output generated is used as the "background" for the next set of models. The priority mapping is as follows:

1. Background (Lowest Priority)
2. Stratiform rain
3. Gust Front
4. Convective storm
5. Microburst (Highest Priority)

For each model computing a reflectivity value at a grid point, the background reflectivity value obtained from the grid is compared to the computed reflectivity. The higher magnitude reflectivity takes precedence, and is stored in the grid. For each model generating a velocity value, the background velocity and the computed velocity for each grid point are added to produce an output velocity value.

Figure 3 illustrates the final step in the SDG. This step produces sensor-specific data sets from the 3D grids. This is accomplished by performing a set of operations for each sensor model that reads the 3D grids, processes the data in a manner similar to the sensor's behavior, and then outputs the data in a format accessible by the ITWS algorithms. In the case of the TDWR and NEXRAD, a pencil beam simulation model is used to simulate a typical scan strategy employed by the sensor. In the case of the ASR-9 radar, a fan beam simulation model is used to simulate a vertically integrated reflectivity value that can then be converted to a six-level precipitation estimate. For many sensors and products such as MDCRS, LLWAS, Surface Obs, RUC, etc., the nearest grid point is used.

Until this point, the basic function of the SDG was to manipulate 3D grids with models of phenomena that the ITWS must actively detect and track. However, several products required by the ITWS are detected and tracked by algorithms prior to receipt by the ITWS. These include the NEXRAD product generator and the National Lightning Detection Network (NLDN). The NEXRAD product generator produces the ITWS information on hail, mesocyclones, and tornadoes. The NLDN provides information on the location and type of individual lightning strikes. Since these phenomena cannot be represented within the 3D grids, the SDG handles these as point products. For each mesocyclone, tornado, etc., the algorithm keeps track of the location, size, strength, etc. of the individual phenomena. Priority of these products is not a concern since they do not manipulate the 3D grids.

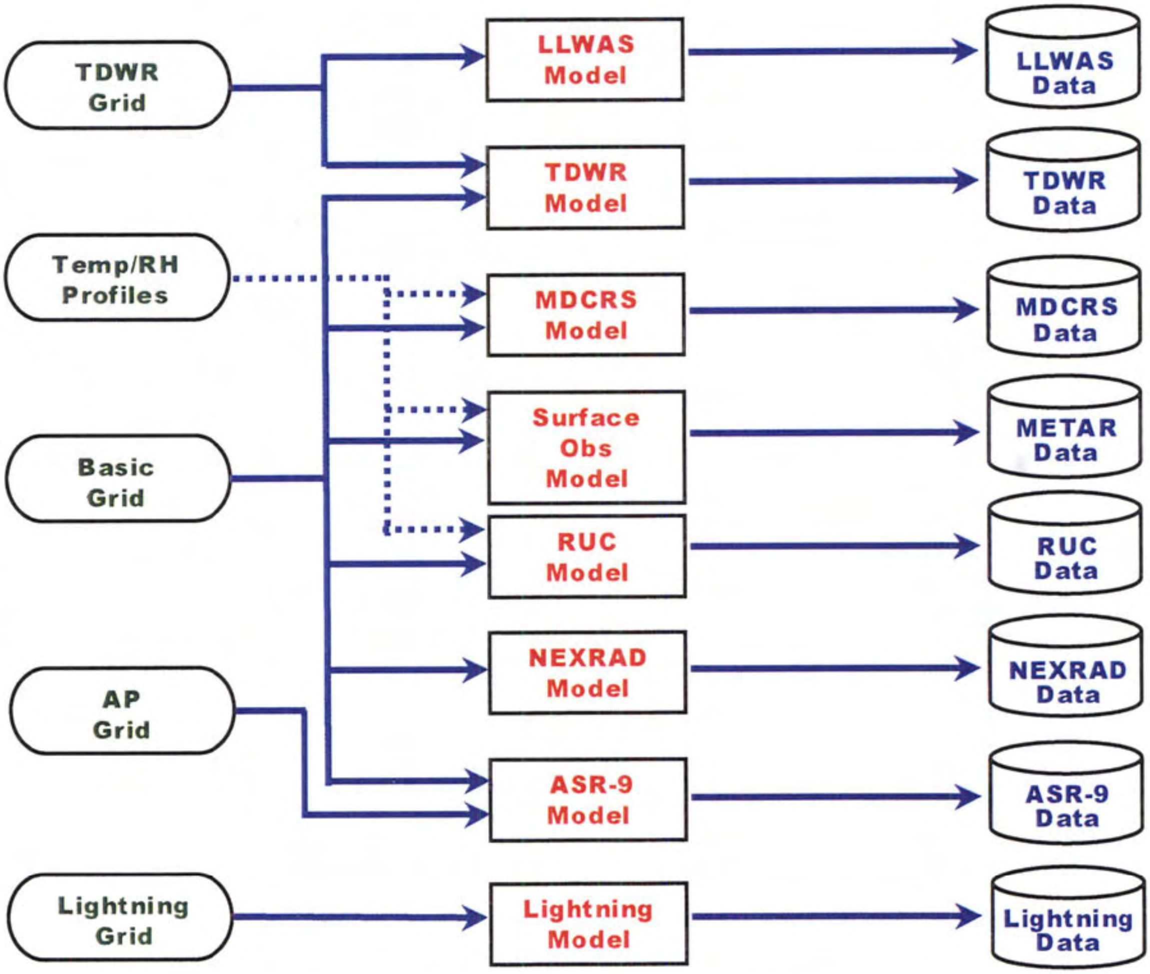

Figure 3. Data flow diagram for the sensor models.

3. 3D METEOROLOGICAL GRID

Although the meteorological models are run before the data are written to the 3D meteorological grids, for purposes of clarity it is best first to provide information about the 3D meteorological grids.

To represent several of the meteorological phenomena (microburst outflows and gust fronts) accurately, a high-resolution grid of radar reflectivities and horizontal vector velocities is required. This high resolution is not needed for all the products and is not needed over the entire domain of coverage. Since the size of the meteorological grids impacts both computer memory and computation time, several grids of data are created to handle the model resolution required as an intermediate step in computing sensor observations. This section addresses the types of grids produced as well as the computation and sizing issues associated with these grids.

3.1 Basic Grid (low resolution)

To represent the meteorological phenomena (except for microburst outflows and gust fronts), a 3D grid with vertical and horizontal resolution of 0.5 km is sufficient. This grid contains three products: reflectivity, u component velocity data, and v component velocity data and is recomputed every 30 seconds. Only one grid of this type is produced with coverage over the entire area in which ITWS products are created. Data from the meteorological models with locations that fall within the domain of the grid and time stamps that are valid at the grid time will be added to the grid in the following order:

1. Set the grid values to the specified background reflectivity and velocity values.
2. Set the appropriate grid points to the stratiform reflectivity and velocity values.
3. Set the appropriate grid points to the gust front reflectivity and velocity values.
4. Set the appropriate grid points to the convective storm reflectivity and velocity values.
5. Set the appropriate grid points to the microburst outflow velocity values.

In cases where models overlap, the data generally are added according to the rules described in Section 2.

If the Basic grid is to cover all products displayable at an ITWS site, the grid size needs to extend up to 200 nm (400 km) from each of the NEXRADs within the TRACON and to an altitude of 15 km. Applied to the NY TRACON, this would yield a grid extent as great as 1,000 km x 800 km x 15 km. Given that there are three products stored in the grid and a resolution of 500 m horizontally and vertically, the overall size of the NY Basic Grid would be 12×10^6 cells.

It is highly desirable that the grid for a time-step fit within computer memory and that grid computation time be reasonable. If necessary, some compromises are possible. For example, since one NEXRAD product (composite reflectivity) accounts for much of the grid, this product could be computed easily from storm horizontal and vertical extents alone. Also, grid values could be calculated for only the regions where terminal winds are computed from NEXRAD and TDWR or where there is overlapping ASR-9/NEXRAD coverage.

3.2 TDWR Grid (high resolution)

Microburst outflows and gust fronts are of concern only for the TDWR radar algorithms. To represent microburst outflows and gust fronts accurately, a grid with 0.1 km horizontal and vertically resolution is required. This grid will contain three products: reflectivity, u component velocity data, and v component velocity data and is recomputed every 30 seconds. This grid is created for each TDWR radar and fits spatially within the region covered by the Basic Grid. Each TDWR grid is created by adding data from the meteorological models with locations that fall within the domain of the grid and time stamps that are valid at the grid time, in the following order:

1. Subsample the low resolution Basic grid containing: background reflectivity and velocity, and stratiform rain reflectivity and velocity, to the high resolution grid.
2. Set the appropriate grid points to the gust front reflectivity and velocity values.
3. Set the appropriate grid points to the convective storm reflectivity and velocity values.
4. Set the appropriate grid points to the microburst outflow velocity values.

In cases where models overlap, the data are added according to the rules described in Section 2.

To cover the region of microburst and gust front detection, each TDWR grid needs to extend 65 km from a TDWR radar and to an altitude of 1.0 km. Given that there are three products stored in the grid and both the horizontal and vertical resolution are 100 m, the overall size is 17×10^6 cells.

3.3 ASR AP (Anomalous Propagation) Grid

Data from the ASR-9 radar may be contaminated by anomalous propagation (AP) clutter. A radar beam has a normal curvature, but under certain atmospheric conditions, such as temperature inversions and cold surface outflows, this curvature may become greater. As the beam bends more toward the surface of the earth, ground clutter can be returned. This AP clutter is often difficult to distinguish from normal returns.

The AP grid is a two-dimensional (2D) grid with a horizontal resolution of 1 km. It contains the PRECIP product and is updated every 30 seconds. Since AP data need to be modeled for each ASR-9 in the region, a separate AP grid is created for each ASR-9 radar. Like the TDWR grid, each ASR AP grid fits spatially within the region covered by the Basic grid. The grid is computed by setting the appropriate grid points to the AP model reflectivity values defined by the user.

Each ASR AP grid extends 120 km from an ASR-9 radar. Given that there is only one product stored in the grid and the horizontal resolution is 1000 m, the overall size is 14400 cells.

3.4 Lightning Grid

To represent the lightning phenomena, a 2D grid is defined. This grid will have the same horizontal resolution and spatial extent as the Basic grid. However, in this grid, each grid point will represent the number of lightning strokes detected within the last 30 seconds.

The lightning grid will be of the same dimensions as the Basic grid, thus covering up to 200 nm from each of the NEXRADs in the TRACON. Applied to the NYC TRACON, with one lightning product and one vertical layer, the lightning grid will have an overall size of 3×10^6 cells.

4. WEATHER PHENOMENA MODELS

The SDG allows for modeling background reflectivities and wind, stratiform precipitation, convective storms, microburst outflows and gust fronts. The data generator also models anomalous propagation regions. These regions are false radar echoes that are caused by the radar beam bending under certain atmospheric conditions. Each of the models is controlled by a set of user-specified parameters, and data are written out to one of the Cartesian grids (Basic, TDWR, ASR, or Lightning).

Overlapping data from different models are generally governed by the priority list described in Section 2. Reflectivity values for the current model overwrite reflectivity values from previously run models if the newer reflectivity values are greater, and velocity values are generally the vector summation of the velocity from the previously written models and the current model. The user must be careful when specifying overlapping phenomena, especially those that have high velocity values such as microburst outflows. In the future, refinements may be made to the logic for handling overlapping data.

The models are controlled by sets of parameters. There are parameters that describe the characteristics of the phenomena (size and shape, reflectivity, winds, temperature and humidity), the location of the phenomena, its speed and direction, and its time evolution.

The generation of data from a model will be referred to as an "event" in the sections below, with a specified start time and duration. For the time evolution of the models, the model data are re-calculated every time the Cartesian grids are updated (every 30 seconds).

In each section below, a description is given of the model used to create synthetic data for each of the weather phenomena. A list of the parameter settings and a picture (or time series of pictures) of the resulting Cartesian output data is shown.

4.1 Background

The background model is used by the algorithm to initialize the 3D grids. The user provides the model with a profile of atmospheric variables as a function of altitude. These variables include reflectivity, wind speed and direction, temperature, and humidity. The user must also provide information on the number of levels (or observations) in the profile and the altitudes of these levels. It is assumed the user will provide a profile level at each horizontal plane in the Basic 3D grid.

In the simplest synthetic data case, the user inputs only one background profile in the middle of the 3D grid. In this case, the algorithm would assign all horizontal grid points at each level with the profile level provided. Figure 4 shows an example of a layer of the model data with only one profile specified.

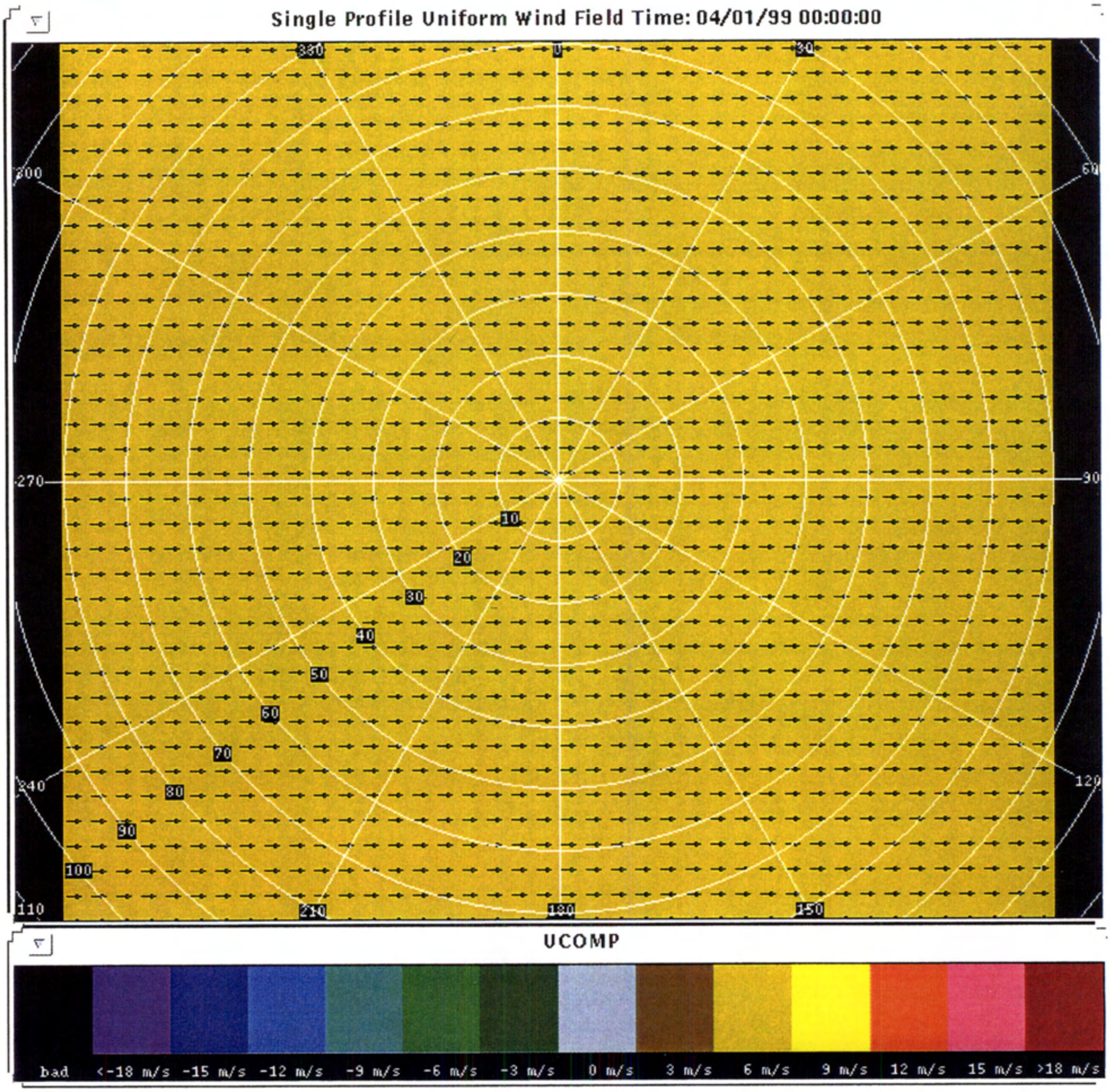

Figure 4. A layer of the Cartesian grid showing the model wind vectors overlaid on the U-component velocity data when a single profile is specified.

In more sophisticated synthetic data cases, the user may input multiple profiles at several different horizontal locations in the 3D grid. From this information, the algorithm interpolates a value for each variable at each bin in the grid from the atmospheric profiles provided. Figure 5 shows an example of a layer of the model data with several profiles specified.

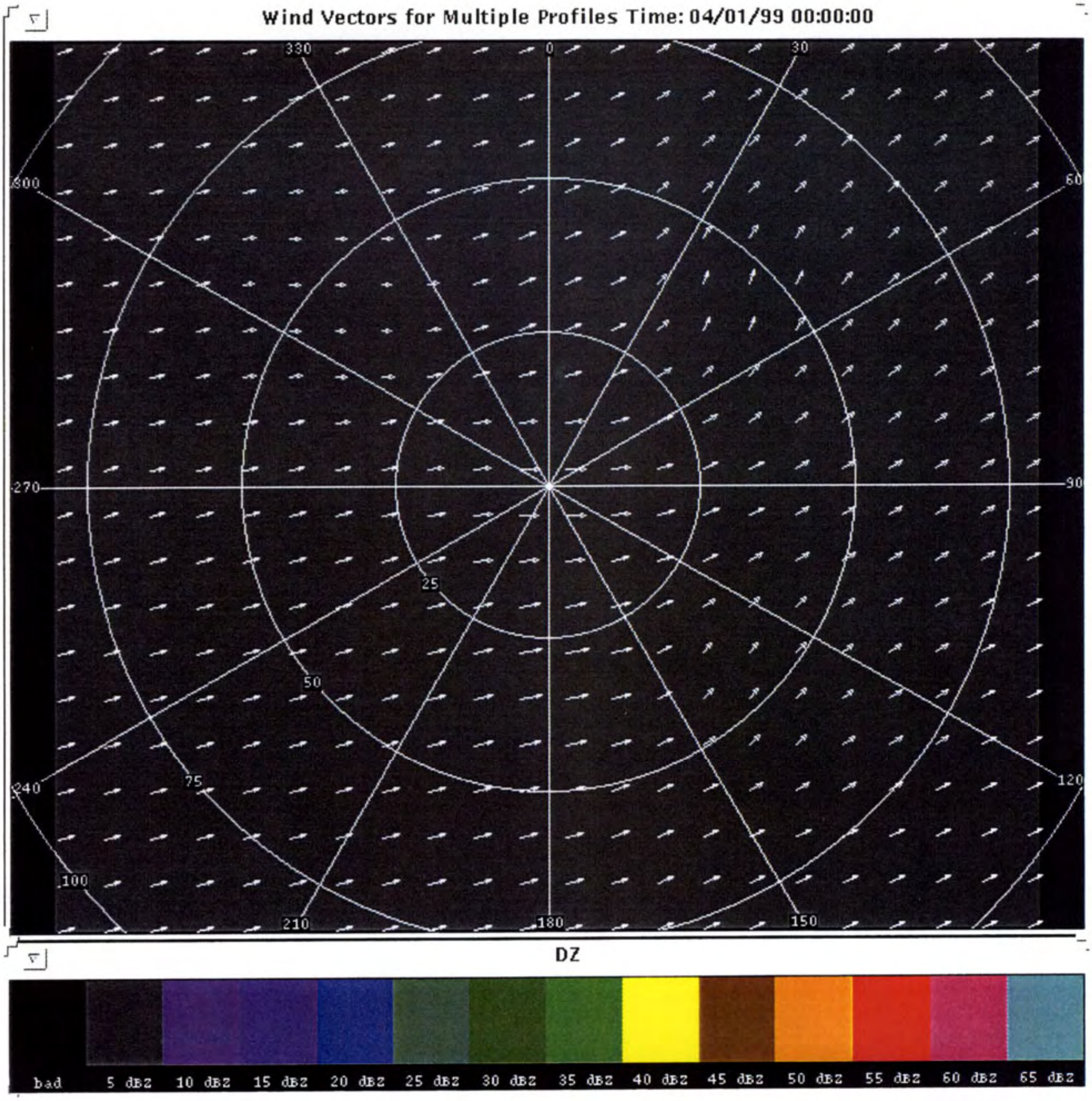

Figure 5. A layer of the Cartesian grid showing the model wind vectors overlaid on reflectivity data when multiple profiles are specified.

Each background profile supplied by the user may vary over time by supplying the profile characteristics at discrete time steps within the model run. The algorithm compares the current model time with the set of user-supplied profiles and determines the two profiles nearest in time. From these two profiles, the algorithm interpolates the profile parameters to represent the current time and then performs all calculations as described above.

A list of the parameter settings for the background model are found in Table A-1 of the Appendix.

4.2 Stratiform Precipitation

Stratiform precipitation is represented by a vertical cylinder of constant reflectivity. The horizontal winds associated with the stratiform precipitation may vary as a function only of altitude. As a refinement to the code, spatial variability of the winds may be extrapolated from a grid representation that is input by the user.

The user profile time variation of storm parameters is linear. For the first implementation, the only parameters that vary with time are the stratiform cylinder center X and Y locations. The stratiform reflectivity value, minimum cylinder altitude, and maximum cylinder altitude are kept constant for the duration of the event.

Time variation of the X and Y cylinder center location values is as follows:

$$X_c = X_o + ut$$

$$Y_c = Y_o + vt$$

where X_o and Y_o are the locations of the center of the cylinder at the start time of the event, u and v are the storm horizontal motion components, and t is the time offset (from the start of the event).

Figure 6 shows an example of several stratiform rain models grouped together to form a region of stratiform precipitation.

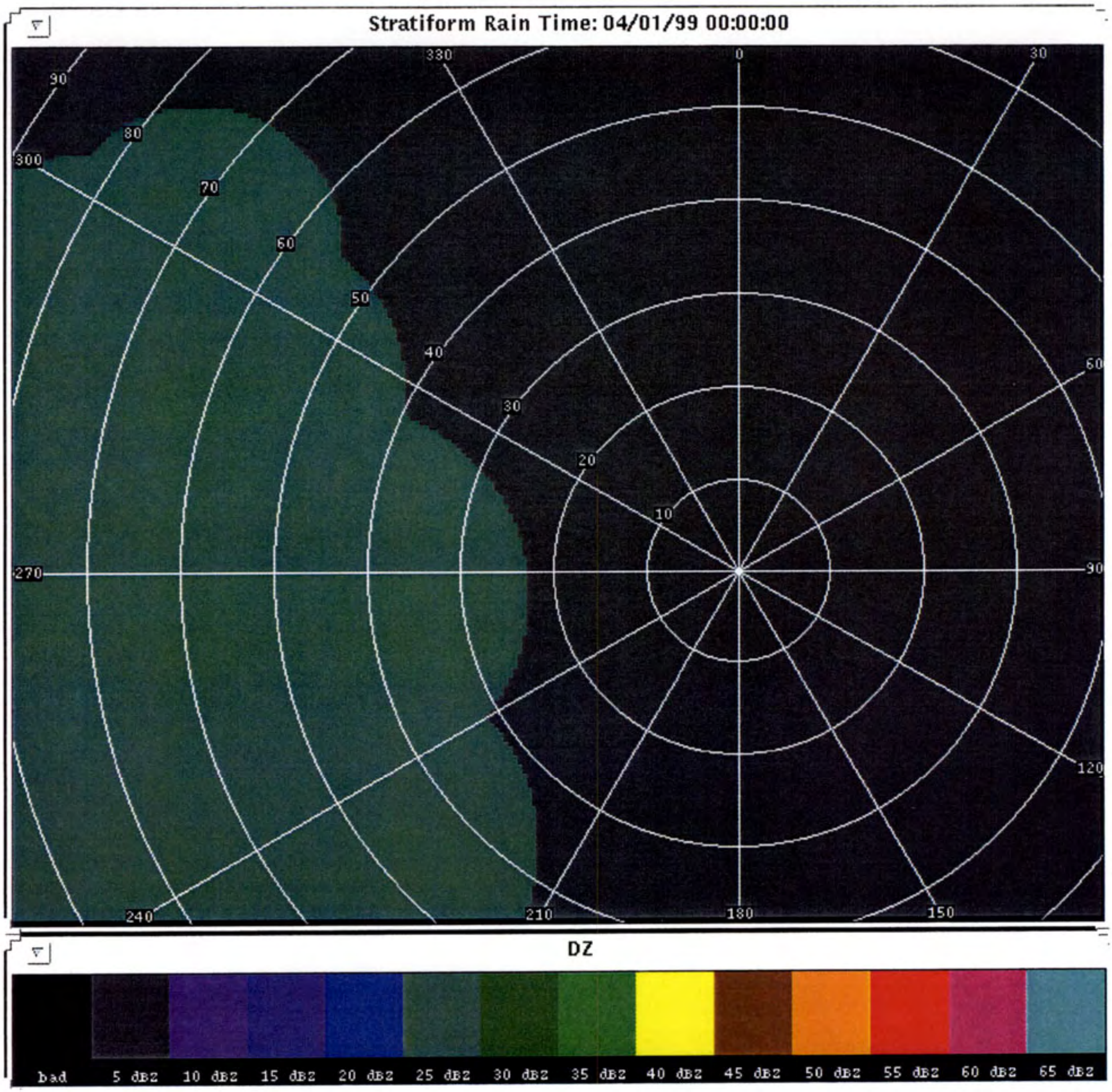

Figure 6. A layer of the Cartesian grid showing the stratiform rain reflectivity model data.

A list of the parameter settings for the stratiform precipitation model is found in Table A-2 of the Appendix.

4.3 Convective Storms

A Convective Storm is represented by a vertical ellipsoid with a horizontal and vertical radius (see Figure 7). Reflectivity values in the ellipsoid taper smoothly from the maximum value at the centroid to a minimum value at the edges according to a Cressman taper (see Figure 8). The calculated convective storm value at each location is compared to the value of the data already placed in the Cartesian file from the previous models. If the convective storm reflectivity value is greater than the data already in the Cartesian file, the new value is written. Therefore, the minimum reflectivity value at the edge of the convective storm is the value of the data already placed in the Cartesian file from the previous models, or zero, whichever is greater. The horizontal winds associated with the convective storms are specified only within the ellipsoid region defined for the reflectivity values and are constant with time and are a function of altitude only.

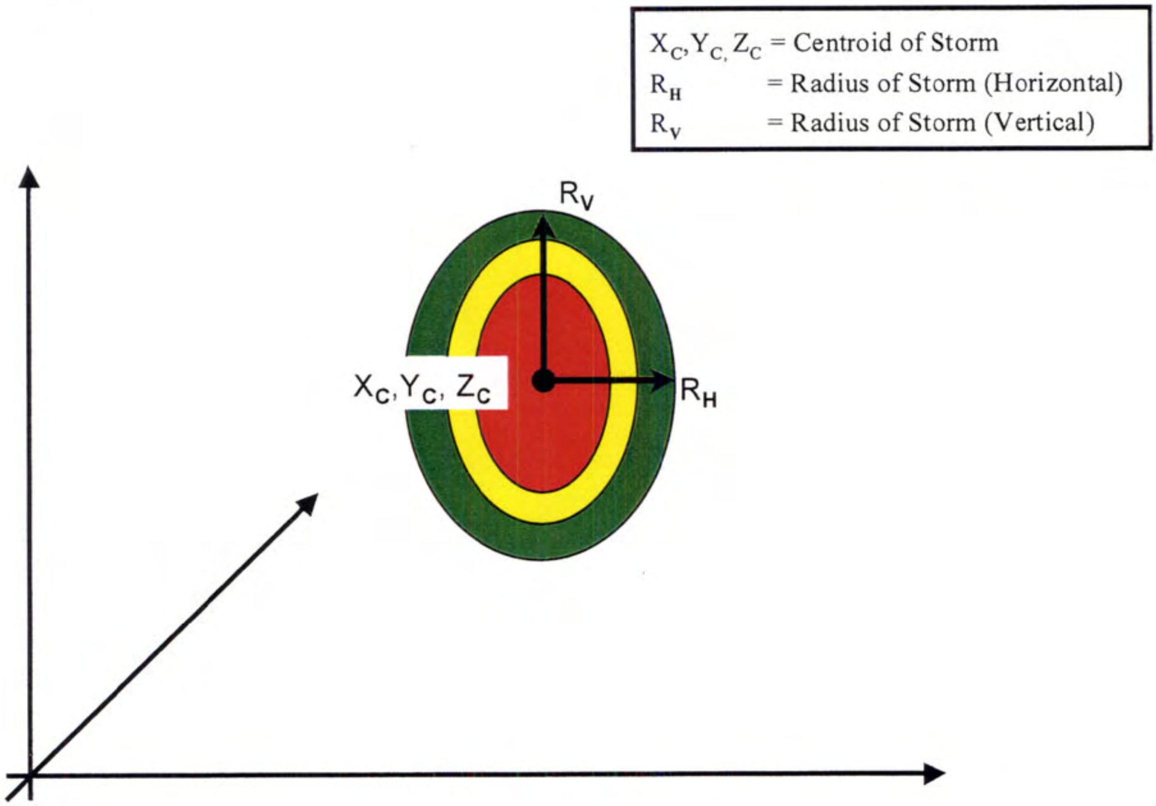

Figure 7. The convective storm model ellipsoid.

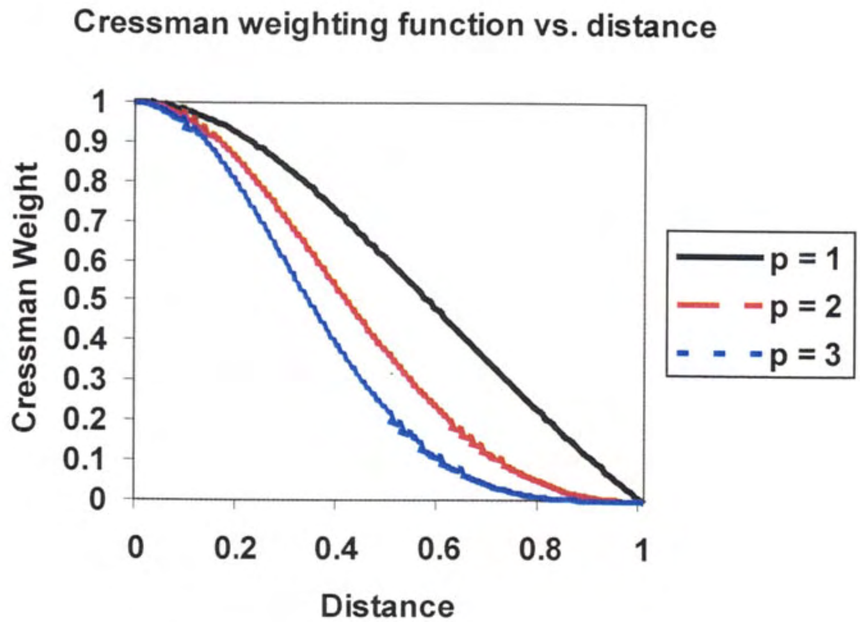

Figure 8. Plot of the Cressman weighting function vs. distance. Distance is equal to 0 at the center of the storm and 1 at the outer edge. The exponent "p" controls the influence of the weight with distance.

The user profile time variation of storm parameters is linear. Parameters that may vary with time include the ellipsoid X and Y center location, the ellipsoid Z (altitude) center location, the vertical and horizontal radii, and the maximum centroid reflectivity. The time variation of these parameters is modeled to approximate the storm time profiles shown in Figure 9.

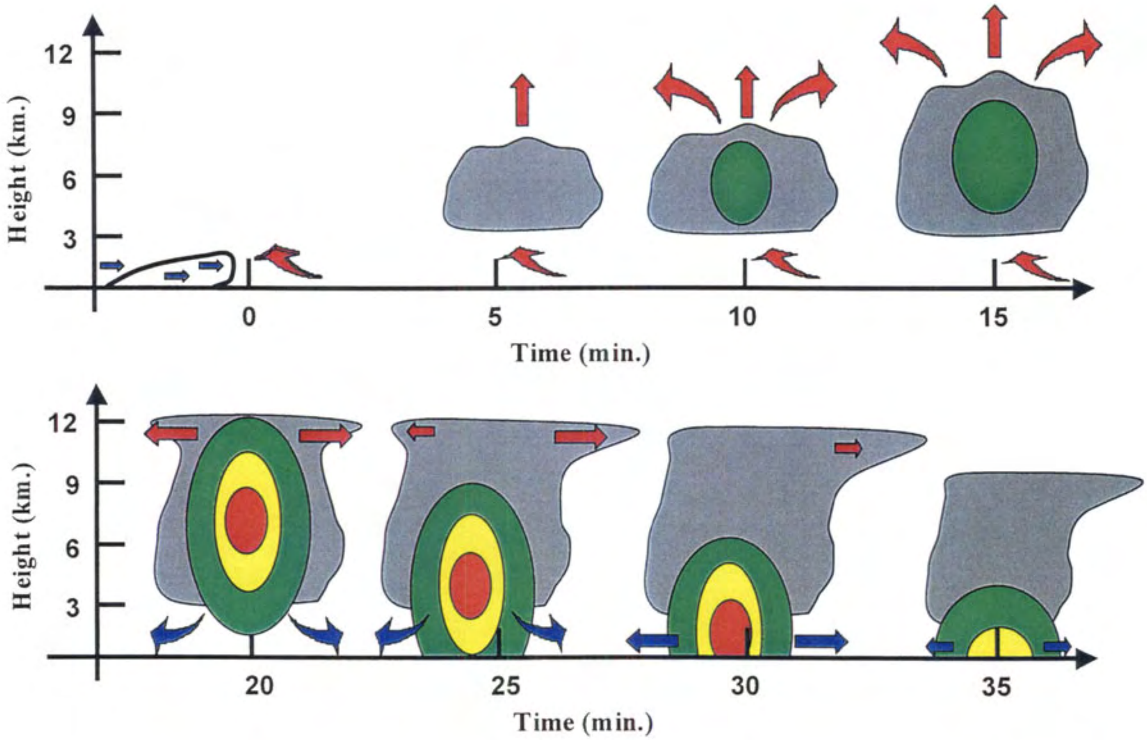

Figure 9. Typical time variation of vertical profiles of convective storm radar reflectivity.

Time variation of the X and Y ellipsoid centroid location values is as follows:

$$X_c = X_o + ut$$

$$Y_c = Y_o + vt$$

where X_o and Y_o are the locations of the storm centroid at the start time of the event, u and v are the storm horizontal motion components, and t is the time offset (from the start of the event).

Time variation of the Z ellipsoid centroid location value is more complicated. The Z centroid value is kept constant until a user-specified time is reached. At this time, the centroid drops linearly from the starting altitude to zero over the remainder of the event. This way, the convective storm is allowed to "grow" at a constant altitude and then descend to the surface of the earth.

Time variation of the horizontal and vertical ellipsoid radii values is done in two parts. For each value, the user sets a maximum radius and a time at which the maximum radius is reached. Radius values are zero at the start time of the event and increase linearly until the time of the maximum radius. From this time on, the radius values remain constant until the end of the event. Though the horizontal and vertical ellipsoid radii values are calculated in the same manner, the maximum values and the times at which the maximum values are reached may be set differently.

The time variation of the maximum reflectivity value is handled in a similar manner to the horizontal and vertical ellipsoid radii values described above. The maximum reflectivity value is zero at the start of the event, increases linearly to its user-specified maximum value at a user-specified time, and remains constant until the end of the event. All other reflectivity values in the storm are set based upon the Cressman taper from the maximum value at the centroid to the minimum value at the edge of the storm (zero or the current value in the Cartesian file).

Figure 10 is a time series of vertical cross sections through the 3D grid generated by the convective storm model.

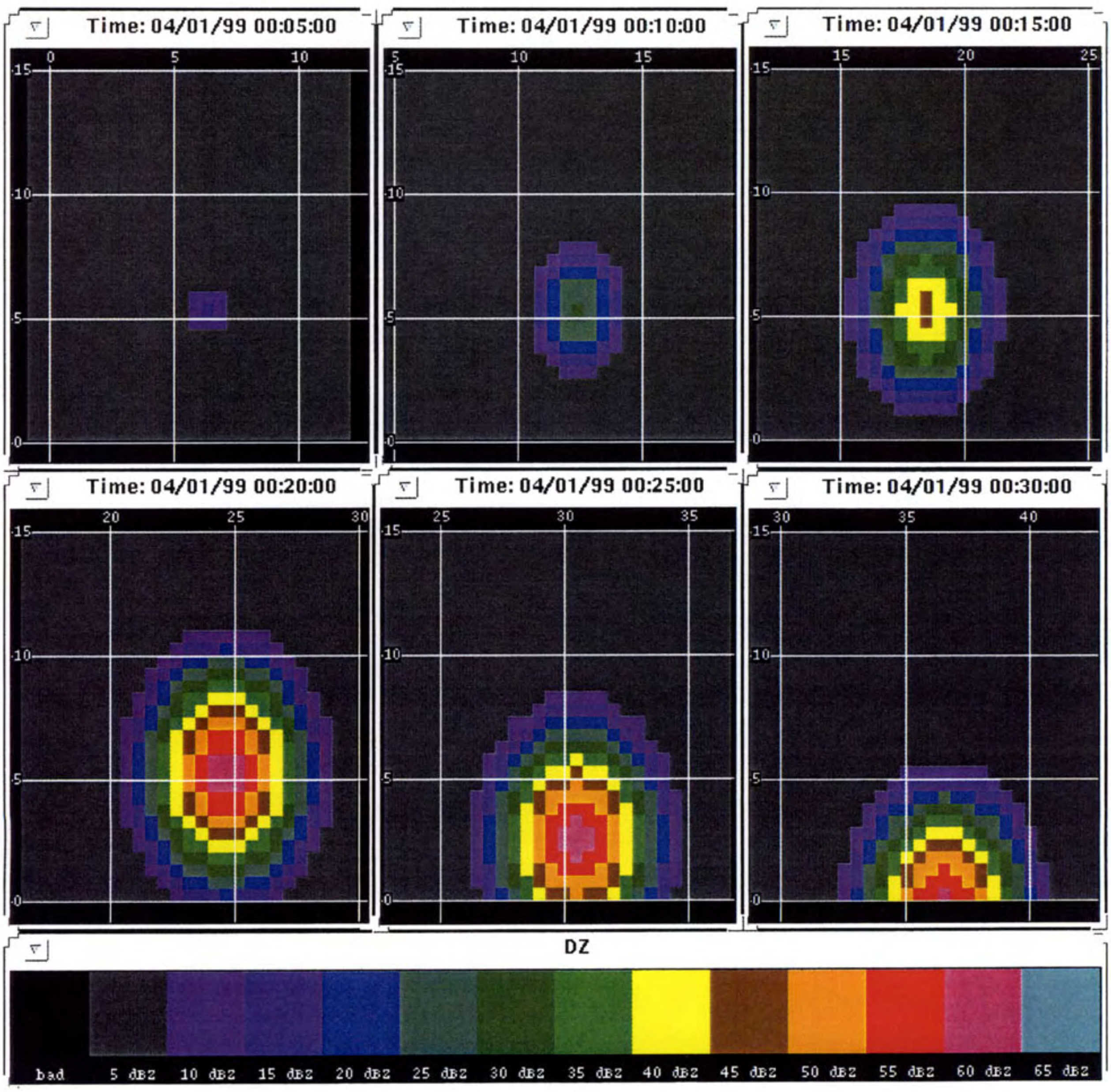

Figure 10. Time variation of vertical profiles of convective storm reflectivity model data.

A list of the parameter settings for the convective storm model can be found in Table A-3 of the Appendix.

4.4 Gust Fronts

Gust fronts are represented by a straight line moving boundary with an associated "thin line" reflectivity feature (see Figure 11) and velocity field that extends behind the gust front (to permit estimating the winds after the gust front passage). The gust front velocity field consists of a front transition zone, a region of maximum velocity, a region of winds behind the gust front, and a rear transition zone. The front and rear transition zones taper the velocity values from the background to the maximum (front transition) and from the winds behind to the background (rear transition). See Figures 12 and 13.

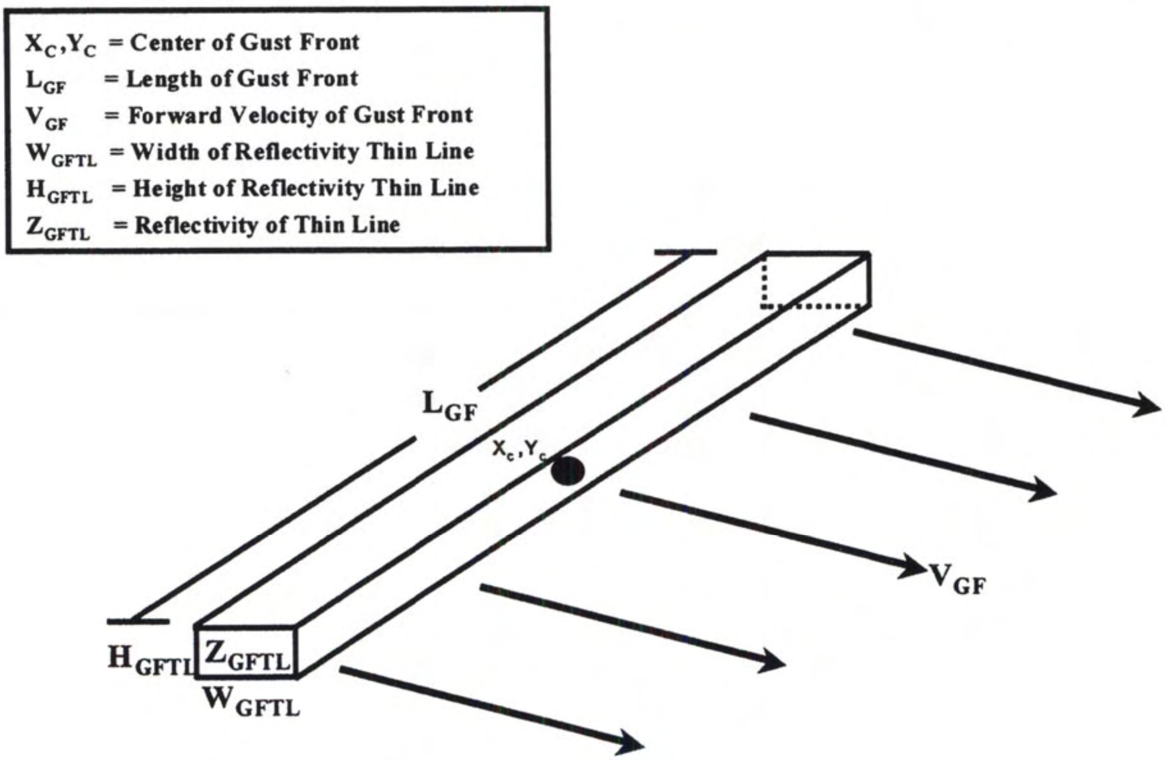

Figure 11. The gust front reflectivity model.

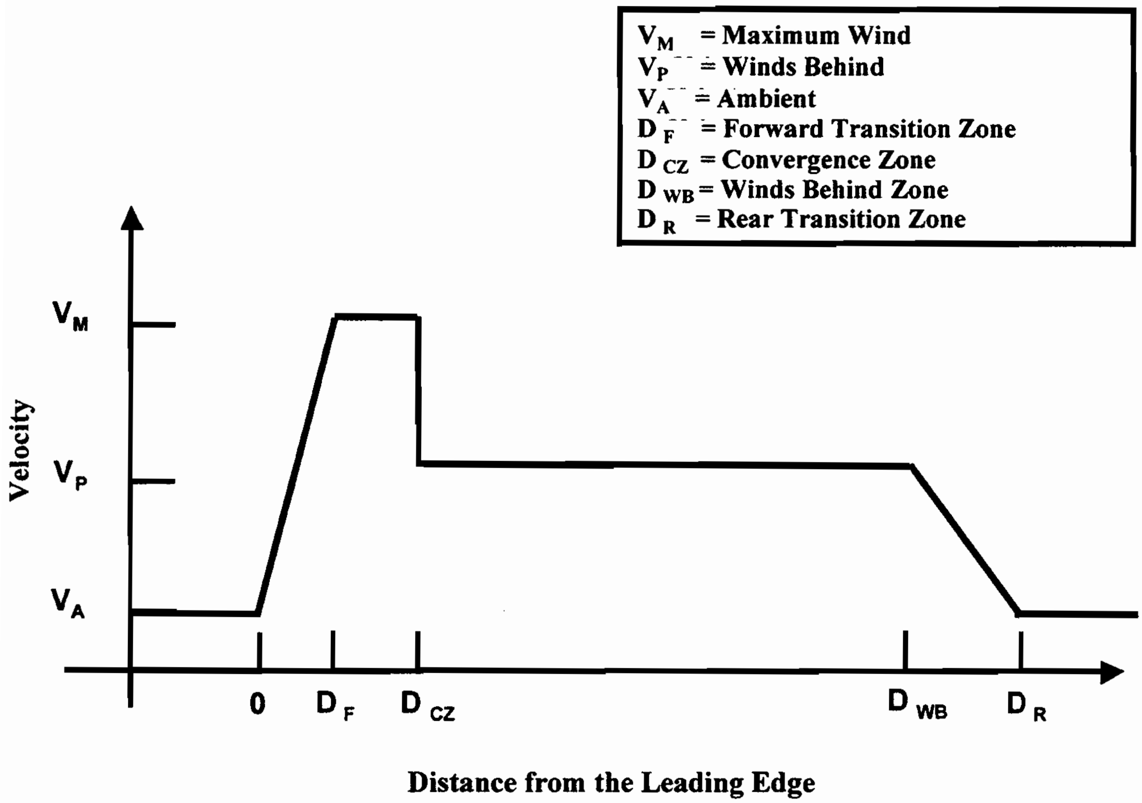

Figure 12. The gust front velocity model.

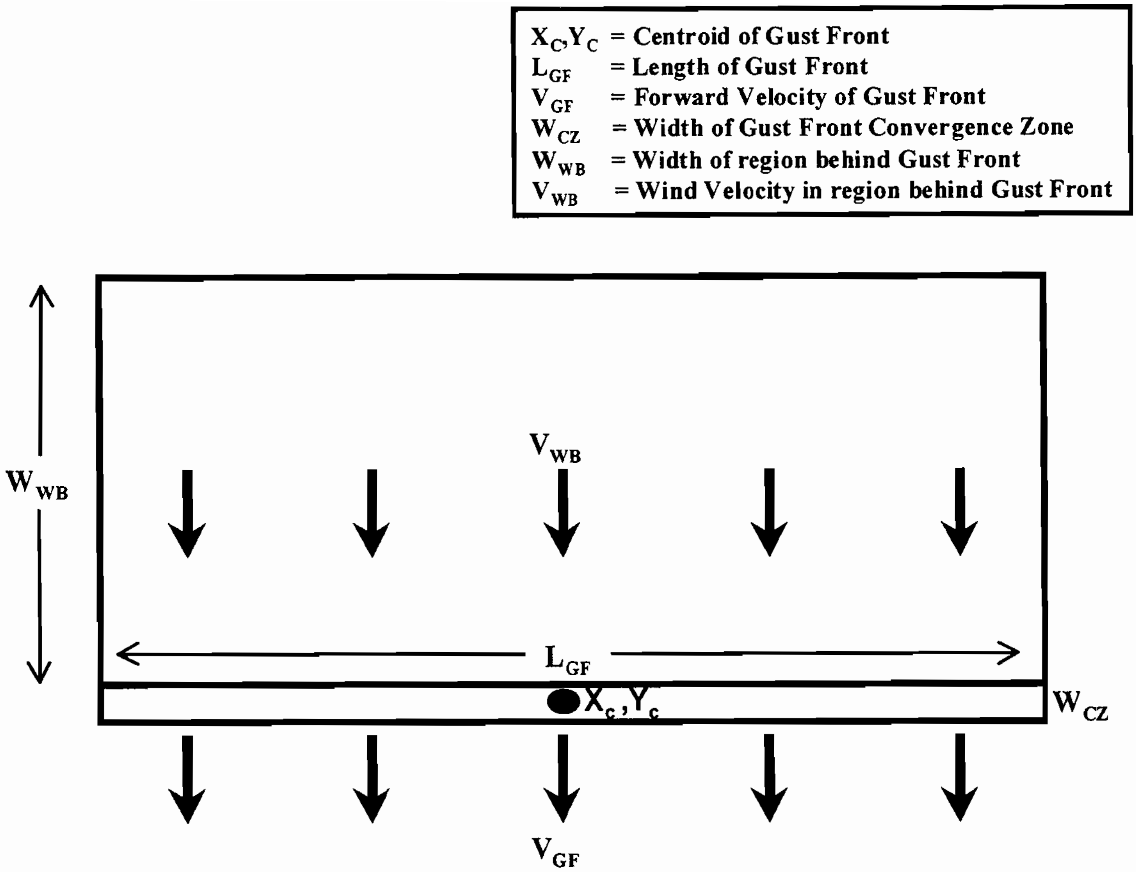

Figure 13. The gust front velocity model showing the winds behind the gust front.

The user profile time variation of gust front parameters is linear. Parameters that may vary with time are the X,Y center location, the gust front length, the thin line reflectivity value, and the velocity convergence value.

Time variation of the X and Y outflow center location values is as follows:

$$X_c = X_o + ut$$

$$Y_c = Y_o + vt$$

where X_o and Y_o are the locations of the gust front center at the start time of the event, u and v are the storm horizontal motion components, and t is the time offset (from the start of the event). Unlike many of the other models, the gust front parameters (except for the X,Y center location and the maximum gust front length) vary linearly from a user-specified maximum value at the event start to a minimum value (or zero) at the event end. The gust front length varies from a user-specified minimum value at the event start to a maximum value at the event end.

Figure 14 shows an example of the modeled gust front thin line and Figure 15 shows an example of the modeled gust front winds.

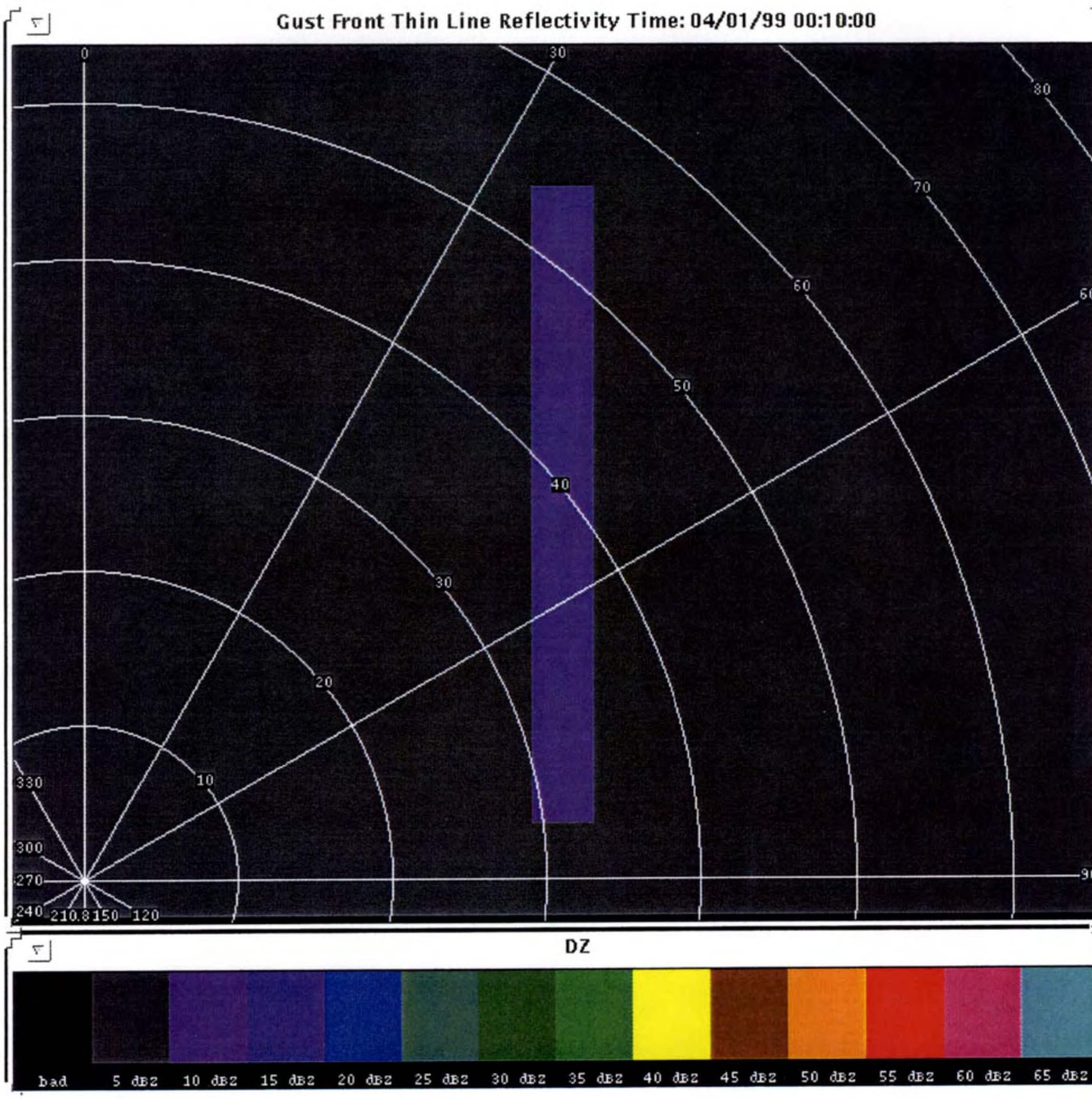

Figure 14. A layer of the Cartesian grid showing the gust front reflectivity model data.

A list of the parameter settings for the gust front model can be found in Table A-4 of the Appendix.

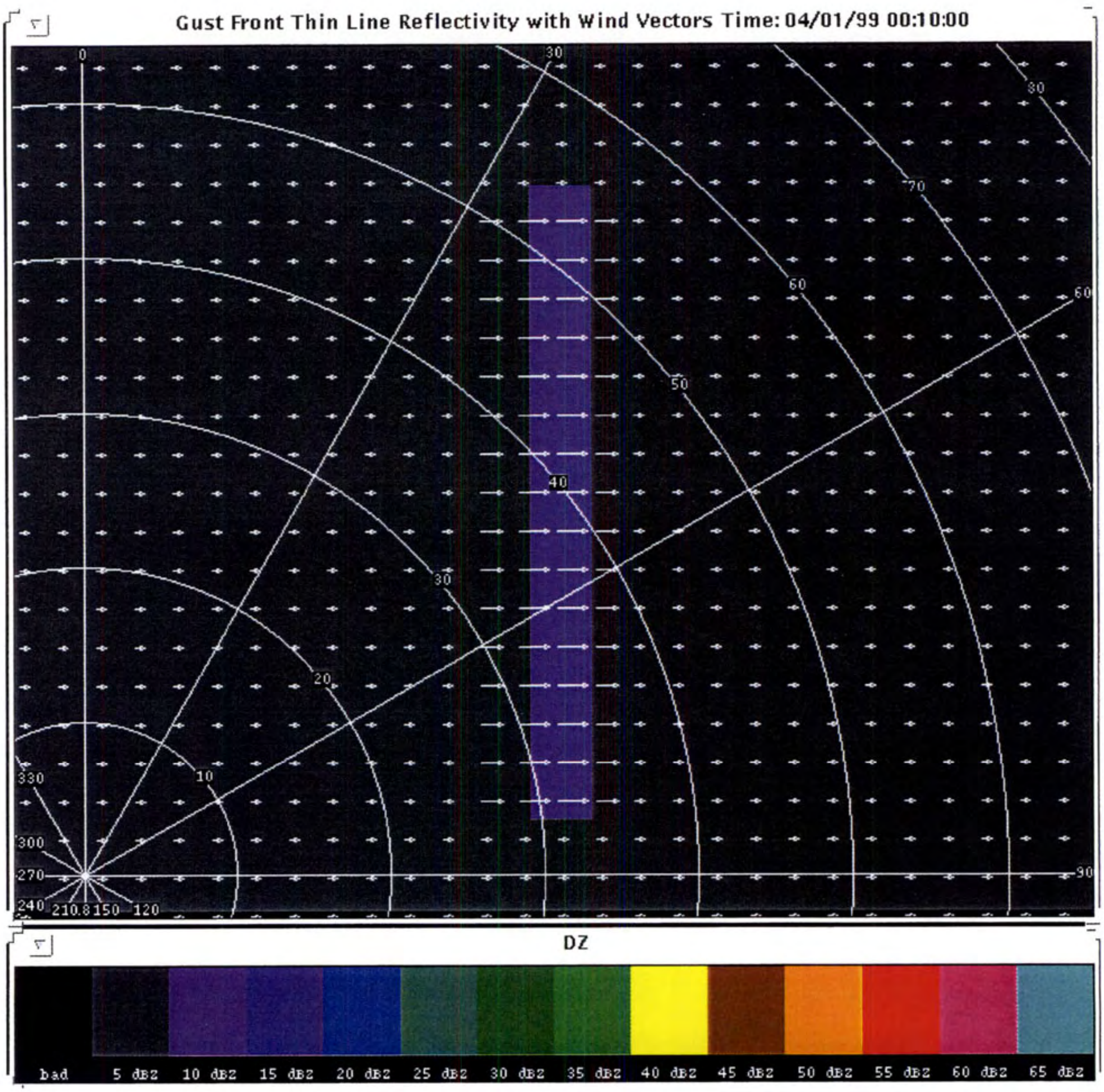

Figure 15. A layer of the Cartesian grid showing the gust front velocity model data.

4.5 Microburst

The microburst outflow is specified as a separate event from the convective storm but in most cases will be correlated in time and location by the user through parameter settings. The outflow is represented by a symmetrical region of velocity diverging from a center point. Outflow velocities are the vector summation of the velocity already in the grid and the radial outflow value so that there are no large radial shear discontinuities at the edge of the outflow region. The outflow has a user-specified depth, radius (overall), radius (of the maximum velocity), and maximum velocity value. See Figure 16.

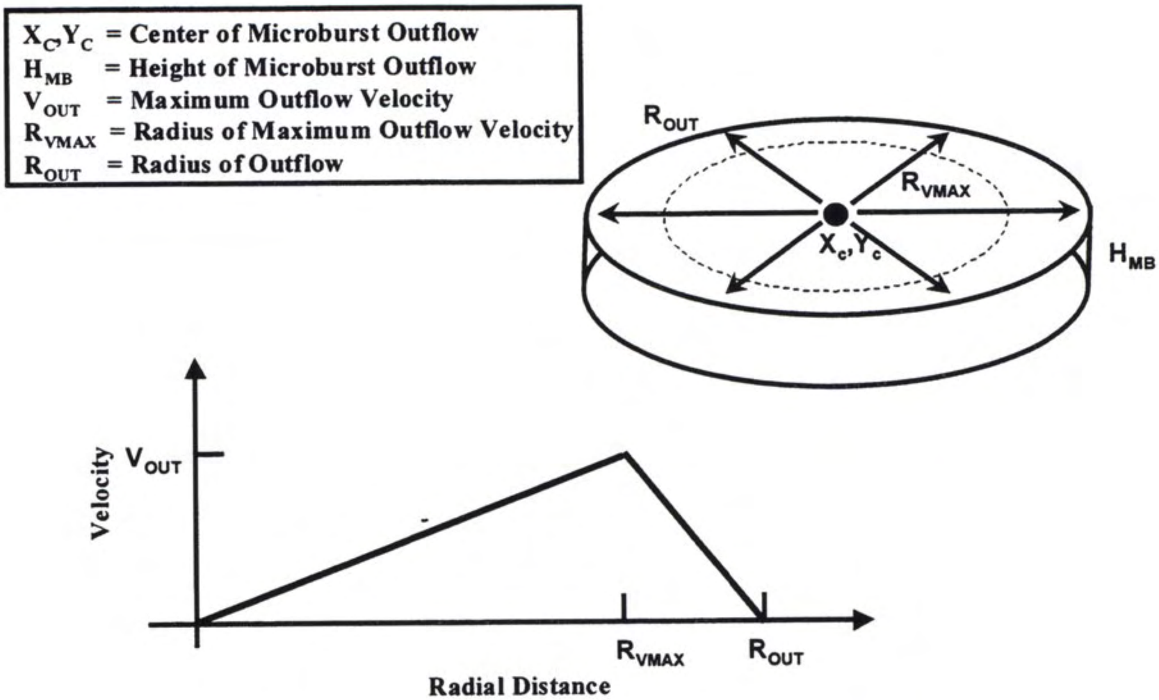

Figure 16. The microburst outflow surface velocity model.

The user profile time variation of outflow parameters is linear. Parameters that may vary with time are the X,Y center location, the overall radius, the radius of the maximum velocity, and the outflow velocity. For the initial implementation, the outflow depth does not vary with time.

Time variation of the X and Y outflow center location values is as follows:

$$X_c = X_o + ut$$

$$Y_c = Y_o + vt$$

where X_o and Y_o are the locations of the outflow center at the start time of the event, u and v are the storm horizontal motion components, and t is the time offset (from the start of the event). The other parameters have an initial value of zero, increase linearly to a user-specified maximum value at a user-specified time, then decrease linearly to zero at the end of the event.

A modification to the microburst outflow model will be made to allow microburst outflows to be linked to convective storms. When this link is made, the x and y location, speed, and direction parameters for the microburst outflow will be set to those of the specified convective storm.

Figure 17 shows an example of the grid surface data generated by the outflow model.

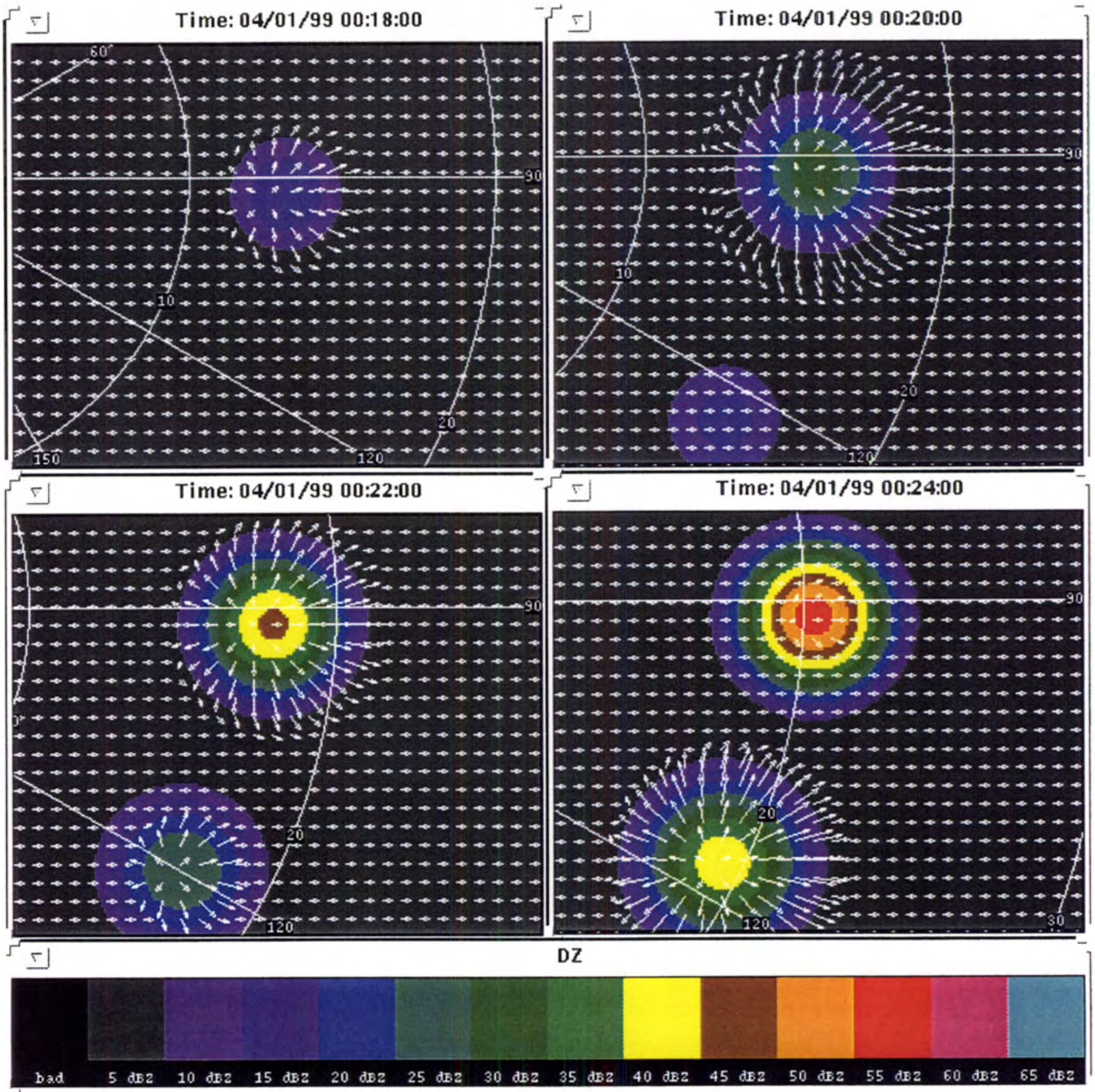

Figure 17. Time variation of a convective storm and microburst outflow. The surface wind vectors from the microburst outflow model are shown over the surface layer of the convective storm model reflectivity data.

A list of the parameter settings for the microburst outflow model is found in Table A-5 of the Appendix.

4.6 Anomalous Propagation Clutter (AP)

Anomalous propagation (AP) clutter returns may affect the ASR-9 radar under certain atmospheric conditions. Because of the spatial and temporal smoothing performed by the ASR-9 weather channel processor, it is often difficult to distinguish regions of AP from real weather data.

The AP model has two modes of operation that may be chosen by the user. The first mode is to generate AP data from a 2D version of the convective storm ellipsoid model. The second mode is to input a 2D data file that contains real AP data observed from an ASR-9. The mode of operation is chosen within the parameter settings. If the second mode is chosen, the model would require only the name of the data file.

In the first mode the AP data are represented by a 2D version of the convective storm ellipsoid model where values decrease from a maximum value at the center to a minimum value at the edge, according to a Cressman taper (see Figure 8). AP data are created for the PRECIP product of the ASR radars only.

The user profile time variation of the AP parameters is linear. Parameters that may vary with time are the X,Y center location, the radius of the AP region, and the maximum PRECIP level.

Time variation of the X and Y AP center location values is as follows:

$$X_c = X_o + ut$$

$$Y_c = Y_o + vt$$

where X_o and Y_o are the locations of the AP center at the start time of the event, u and v are the storm horizontal motion components, and t is the time offset (from the start of the event). Like the convective storm model, the AP parameters (except for the X,Y center location) vary linearly from zero at the event start to a maximum value at a user-specified time, to zero again at the event end.

A list of the parameter settings for the AP model can be found in Table A-6 of the Appendix.

4.7 NEXRAD Point Products (Hail, Mesocyclone, Tornado)

Several products available to the ITWS are provided by the NEXRAD product generator. It is assumed that the number of these products is not large, therefore the SDG provides these products as point products defined by parameters supplied by the user. The SDG handles these as pass-through products that do not need modification by the algorithm and are assumed to be consistent with the overall weather depictions defined by the user.

A list of the parameter settings for the NEXRAD point products can be found in Tables A-7 (hail), A-8 (mesocyclone), and A-9 (tornado) of the Appendix.

4.8 NLDN Point Products (Lightning)

The National Lightning Detection Network (NLDN) provides lightning data as a point product for each lightning stroke detected by the system. Since each convective storm could have numerous lightning strikes during its lifetime, it is not feasible for the user to provide parameters specifying each and every lightning strike. To simplify the modeling of this product, two assumptions are made in the lightning model. First, it is assumed that lightning is associated only with convective storms specified by the user. Second, it is assumed that the lightning strikes will be uniformly distributed throughout the convective storm.

The lightning model defines a 2D grid with the same dimensions as the Basic grid. Next, it determines the number of grid points contained within the region of the convective storm. From the user-supplied flash rate parameter, the algorithm determines the number of grid points that contain a lightning stroke. This is accomplished by dividing the flash rate by the number of grid points. Fractional information is stored within the algorithm to allow a summation of strokes per bin over the entire region. Once a 2D grid of strokes is generated, the algorithm generates an NLDN lightning detection for every grid point containing a lightning strike; if multiple strikes are required for a grid point, the multiple NLDN detections would be generated for the grid point.

Since the lightning model is associated with the convective storm model, all parameters used within the lightning model for location and motion are obtained from the convective storm model (see Section 4.3). The time variation of the lightning flash rate is done in a similar manner to the convective storm maximum reflectivity parameter. The flash rate is set to zero at the start of the event, increases linearly to a user-specified maximum value at a user-specified time, and decreases linearly to zero at the end of the event.

A list of the parameter settings for the lightning model can be found in the convective storm section in Table A-3 of the Appendix.

5. SENSOR OBSERVATION MODELS

5.1 Pencil Beam Radar (TDWR, NEXRAD)

The pencil beam radar simulation model resamples the 3D Cartesian gridded data into a polar coordinate system. The resampling is accomplished by simulating the sweep of the radar in three dimensions (range, azimuth, elevation). A radial is defined as the collection of data along an azimuth in range. A tilt is defined as a collection of radials at a given elevation height. Finally, a scan is a collection of tilts at several different elevation angles. For a pencil beam radar, the user must supply parameters to specify the number of tilts in a volume scan and the elevation angle of each of these tilts. The algorithm determines the maximum range, number and width of each radial beam, and gate spacing, depending upon the type of radar being simulated.

The pencil beam radar simulator must account for differences in update rates between the gridded data and the time it takes to complete a full volume scan. This is accomplished by tracking internally the length of time to complete each elevation tilt and the next elevation tilt required from a volume scan. As each update of the 3D data is completed, the pencil beam radar model will determine which elevation tilts should be updated from the current 3D grid.

For each elevation tilt, the algorithm begins by looping through all the radials in the tilt. For each radial, the algorithm will loop through each range gate along the radial. At each gate, the algorithm defines an elliptical region centered on the gate that is related, in azimuth and elevation, to the width of the radar beam. Data collected close to the radar may use only one or two grid points within the 3D grid. However, data collected at longer ranges may use as many as five grid points. The reflectivity (Z) and velocity (V) products are computed from the 3D grids using the formulas below. The velocity product is reflectivity weighted. The signal-to-noise (SN) product is derived from the reflectivity product by assuming a constant multiplier.

$$Z = [W_B\, Z(R, A, E) +$$

$$0.5W_B\, Z(R, A+0.5B_A, E) +$$

$$0.5W_B\, Z(R, A-0.5B_A, E) +$$

$$0.5W_B\, Z(R, A, E+0.5B_E) +$$

$$0.5W_B\, Z(R, A, E-0.5B_E)\,] \,/$$

$$[\,W_B + 4\,(0.5W_B)\,]$$

$$
\begin{aligned}
V = [&W_B\, Z(R, A, E)\, V(R, A, E) + \\
&0.5\, W_B\, Z(R, A+0.5B_A, E)\, V(R, A+0.5B_A, E) + \\
&0.5\, W_B\, Z(R, A-0.5B_A, E)\, V(R, A-0.5B_A, E) + \\
&0.5\, W_B\, Z(R, A, E+0.5B_E)\, V(R, A, E+0.5B_E) + \\
&0.5\, W_B\, Z(R, A, E-0.5B_E)\, V(R, A, E-0.5B_E)]\ / \\
[&W_B\, V(R, A, E) + \\
&0.5W_B\, Z(R, A+0.5B_A, E) + \\
&0.5W_B\, Z(R, A-0.5B_A, E) + \\
&0.5W_B\, Z(R, A, E+0.5B_E) + \\
&0.5W_B\, Z(R, A, E-0.5B_E)\ ]
\end{aligned}
$$

$$SN = [C\, Z(R,A,E)] / R^2$$

Where: R = range from radar

A = azimuth in degrees

E = elevation angle

B_A = Width of radar beam in azimuth

B_E = Width of radar beam in elevation

W_B = Weighting Factor (= 1.0)

C = Constant Multiplier

$Z(R, A, E)$ = reflectivity value of the nearest grid point to R, A, E.

$V(R, A, E)$ = velocity value of the nearest grid point to R, A, E.

For the TDWR and NEXRAD radars, several special cases must be addressed.

1. Some TDWR tilts generate only reflectivity data. In these cases, the velocity calculation is ignored.
2. The NEXRAD scans twice at some tilts, measuring reflectivity on the first tilt and velocity on the second. For the purposes of this simulation, the two tilts are computed as a single tilt. The reflectivity data initially are calculated at 0.25 km. resolution [to permit its use in equation (2)] and then averaged to yield a 1 km range resolution output that an actual NEXRAD produces.

3. Velocity aliasing and obscuration by range-folded echoes are not addressed by the current TDWR and NEXRAD models.
4. Reflectivity and velocity value fluctuations due to finite measurement times and receiver noise are not modeled.
5. Earth curvature and refractivity-index-induced bending are ignored in computing the grid cell altitude for a given range and elevation angle.

5.2 Fan Beam Radar (ASR-9 "Weather Channel")

The fan beam radar simulation model resamples the 3D Cartesian gridded data into a polar coordinate system. The ASR-9 radar emits two radar beams simultaneously at a "high" and a "low" elevation (see Figure 18). The "high" beam is used to depict the weather near the radar while the "low" beam is used at longer ranges. The fan beam simulation performs temporal and spatial smoothing to merge the two beams into one radar tilt. For a radial of data, the closest measurements to the radar will be derived from the "high" beam while the long-range measurements are derived from the "low" beam.

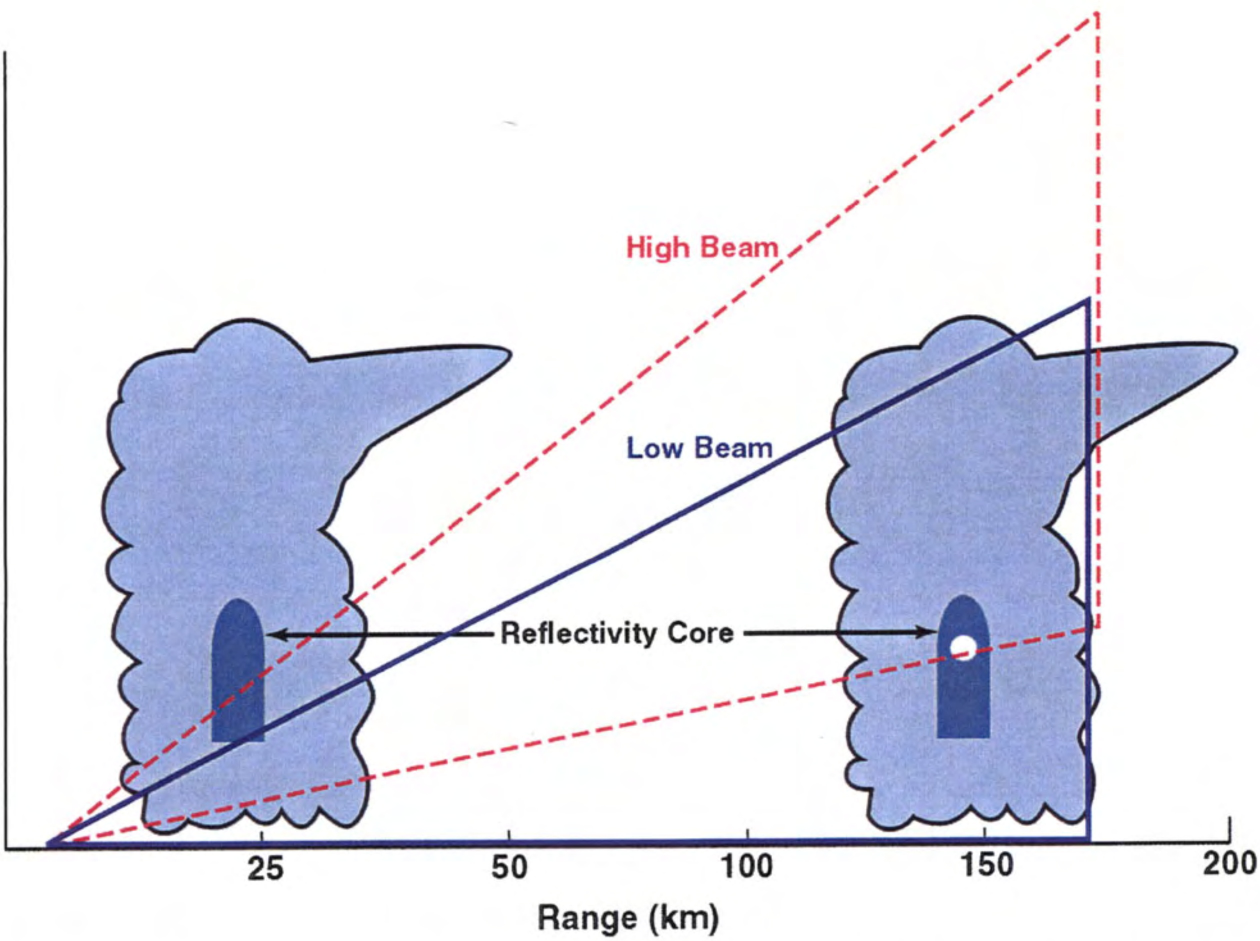

Figure 18. ASR-9 radar fan beam elevation angles. The high beam is the dashed red line, while the low beam is the solid blue line.

The algorithm begins by looping through all the radials in an ASR-9 scan. The ASR-9 radar radial spacing is 1.4° in azimuth. For each radial, the algorithm loops through each range gate along the radial. The ASR-9 radial gate spacing is 0.5 nm in range. At each range gate, the algorithm weights the contribution from a series of elevation angles, starting at the ASR minimum elevation angle to the maximum elevation angle. The ASR-9 "raw" polar output is the weighted sum of the reflectivity values using the antenna beam pattern as a function of range and altitude. In the final step of computing the raw ASR-9 data, the algorithm applies a bias factor provided by the user to allow simulation of an ASR-9 radar with calibration errors.

Once the "raw" polar reflectivity output is computed, the algorithm begins performing a series of operations to smooth and threshold the ASR-9 data. The first step is to perform a beam-filling correction that is range dependent along a radial. Once this is complete, the reflectivity data are thresholded to the NWS six-level precipitation values. Finally, a series of median filters are applied to the data. The first is a sixteen-gate range median filter. Next, a 5-of-9 spatial filter is applied to a 3x3 (3 gates by 3 radials) array. Finally, a Highest-of-9 spatial filter is applied to the same 3x3 array.

As was the case for the TDWR and NEXRAD models, fluctuations in measured ASR-9 reflectivities due to finite measurement time and receiver noise are not modeled.

The final step in the fan beam model is to simulate Anomalous Propagation (AP). This is accomplished by using a grid of AP data (see Section 4.6) that is associated with the ASR-9 radar being modeled. At each range gate and radial the corresponding Cartesian grid point is determined in the AP gridded data. Any AP value determined from the grid that is non-zero will overwrite the value at the range gate and radial previously computed.

5.3 Surface Sensor Observations (METAR and LLWAS)

To obtain a set of surface observations, the user specifies a set of reporting stations that are assumed to be at the lowest vertical grid layer. The 3D grid point closest to the station is used to create the wind observation. The temperature and humidity observations are taken from the background profile at the surface layer. If multiple background profiles are specified, interpolation will be performed in a manner similar to that used in the background model (see Section 4.1).

5.4 MDCRS Observations

To obtain a set of MDCRS observations, the user specifies a set of flight paths for aircraft arriving and departing the airports within the grids. Several points along the flight path may be specified as fixes or locations where the aircraft will change its heading. The user also specifies an update rate for the MDCRS observations. The algorithm tracks the aircraft position along the flight path and determines when an update is required. Having determined that an update is required, the grid point velocity closest to the MDCRS observation point will be output, along with a temperature and humidity profile obtained from the background profile. If multiple background profiles are specified, interpolation will be performed similar to that used in the background model (see Section 4.1).

5.5 Synoptic Model Observations (RUC)

The synoptic scale models used by the ITWS provide information on the temperature, humidity, and wind at several locations in the grid. Since the synoptic models are 3D grids similar to those generated by the SDG, the algorithm simply resamples the finer resolution synthetic grid into the synoptic model grid using a weighted average of each variable. The locations of the synoptic model grid points are user-defined parameters.

6. MODEL VALIDATION

There are two steps in validating the input model data. First, the model grids need to be checked for accuracy, and second, the sensor data derived from these grids needs to be verified.

6.1 Meteorological Models

Validation of the gridded data can be performed by displaying the reflectivity and velocity grids with overlaid information about the location, size, and strength of the user-specified meteorological phenomena. The "overlaid information" is in the form of boxes or circles that represent the size and location of the phenomena.

The display tool used for this validation can display:

1. Grids of reflectivity and velocity
2. Icons of gust fronts, microburst, and storm cells on the grids
3. Vectors showing wind, strength, and direction
4. Location information—grid reference point and distance markers
5. Surface sensor locations

An analyst using this tool can assess that the input meteorological phenomena are in the correct location and have attributes matching those specified. By looking at the gridded reflectivity, the analyst can easily determine whether the reflectivities associated with storm cells, gust front thin lines, stratiform rain, and the background appear in the correct grid locations. Similarly, by looking at the grid wind vectors with icon overlays, the analyst can confirm that the grid winds at locations with model microbursts and gust fronts match those specified and that the background wind strength and direction are correct.

Each of the meteorological models was verified using this tool to check that the phenomena were in the correct location and had the attributes specified by the user. The 3D structure of the phenomena as well as its time evolution also were verified by looking at all of the vertical "layers" of data at each grid update time for the duration of the event.

Some examples of the verification process are included. Figure 19 shows the 5000 m layer of reflectivity data for several convective storms with overlaid circles representing their diameters (at 5000 m) and grid locations. Figure 20 shows a time series of the surface layer of reflectivity of one of the convective storms, with wind vectors from its outflow. A circle is created from the outflow parameters that represent the outflow diameter and location. Figure 21 shows a surface layer of data (both reflectivity and u-component velocity) for a gust front with a box overlaid that shows the location of the thin line and the associated velocity regions.

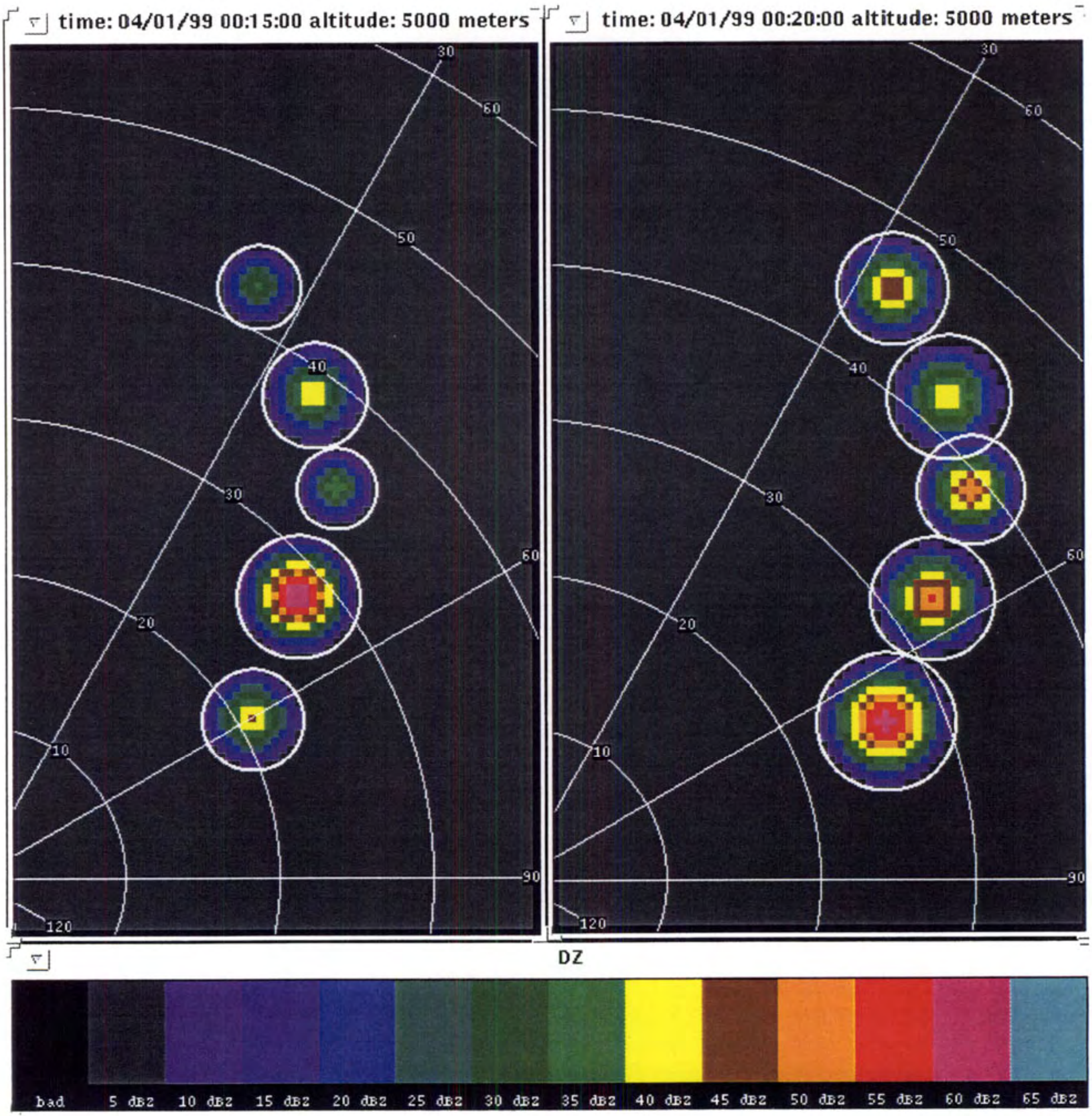

Figure 19. The 5000 meter (altitude) layer of the Cartesian grid showing convective storm model reflectivity data at two times. Circular icons representing the location of the storm data are created from the input parameters and are used to verify the location of the model data.

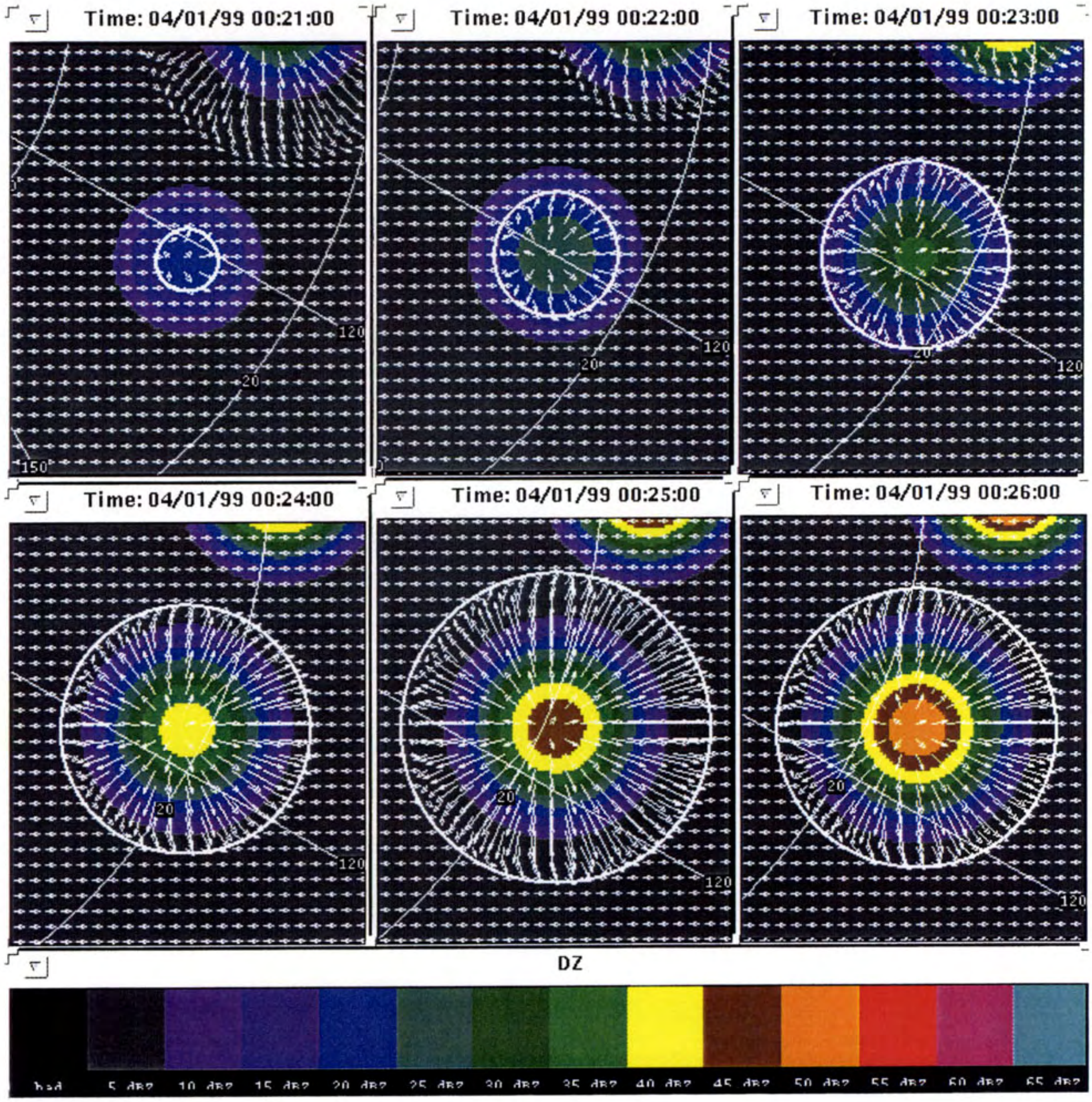

Figure 20. A time series of surface convective storm model reflectivity data with microburst outflow model wind vectors overlaid. Circular icons representing the location of the microburst outflow are created from the input parameters and are used to verify the location of the model data.

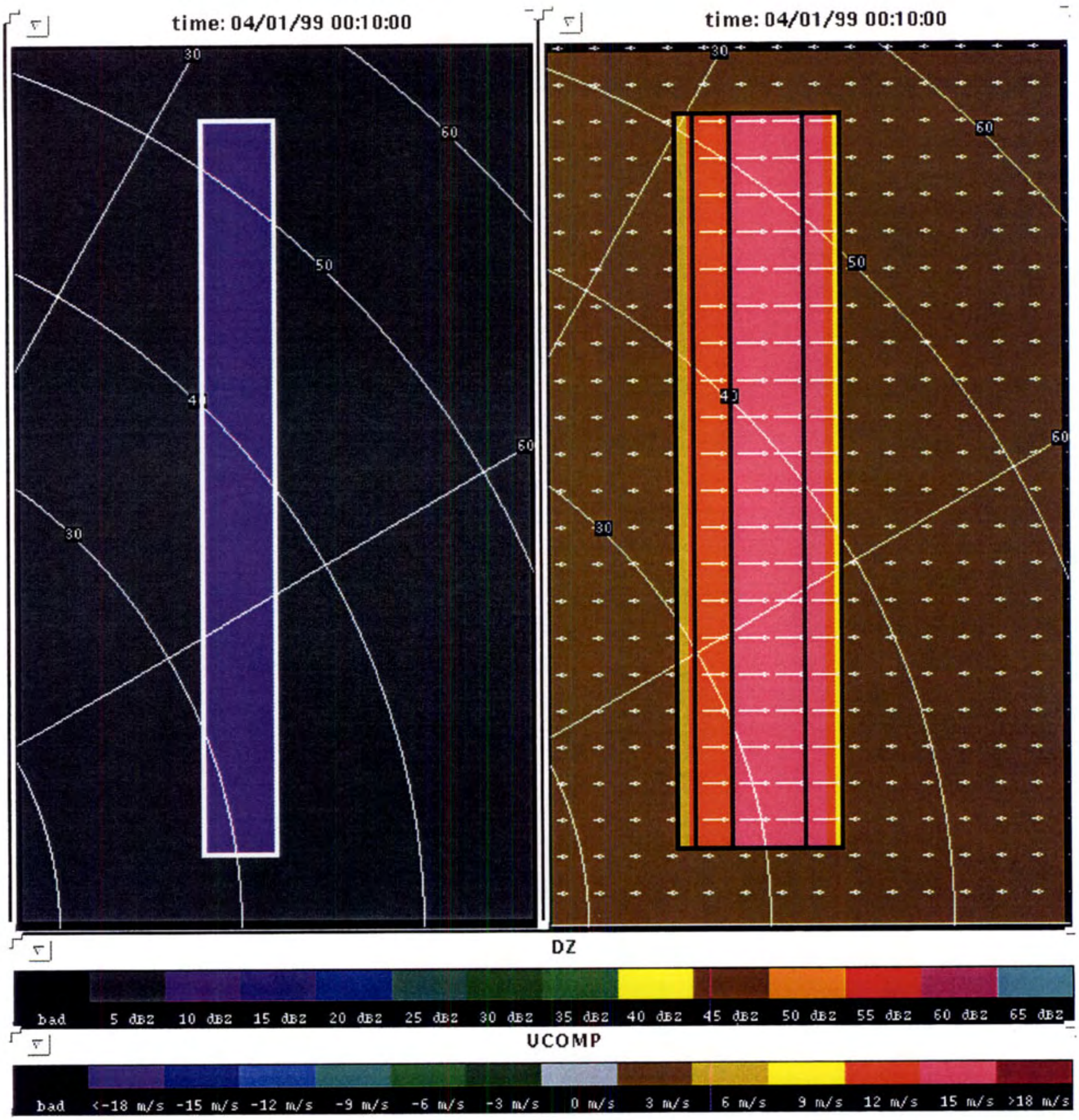

Figure 21. The surface layer of the Cartesian grid showing the reflectivity and u-component winds of a model gust front. Rectangular icons are created from the input parameters and are used to verify the location of the gust front thin line (left) and the regions of the gust front velocity field (right).

6.2 Sensor Models

Validation of the sensor data follows directly form the validated model grid data. The sensor data have been validated using different methods for pencil-beam radars, fan-beam radars, and surface sensors and MDCRS observations.

6.2.1 Pencil Beam Radar

Comparison of the pencil beam radar data to the model gridded data was completed by resampling the polar formatted radar data and comparing it to the grid. The reflectivity data were compared by defining several regions of higher reflectivity in the gridded model data and demonstrating that these regions were accurately depicted in the sensor output. An example of the reflectivity comparison is shown in Figure 22. For velocity, the polar velocity data were compared with the gridded velocity data by displaying vector velocity data from the gridded model data over the corresponding reflectivity field. Figure 23 shows an example of a microburst embedded in a convective storm. On the right side of the figure is the polar velocity field for the pencil beam radar.

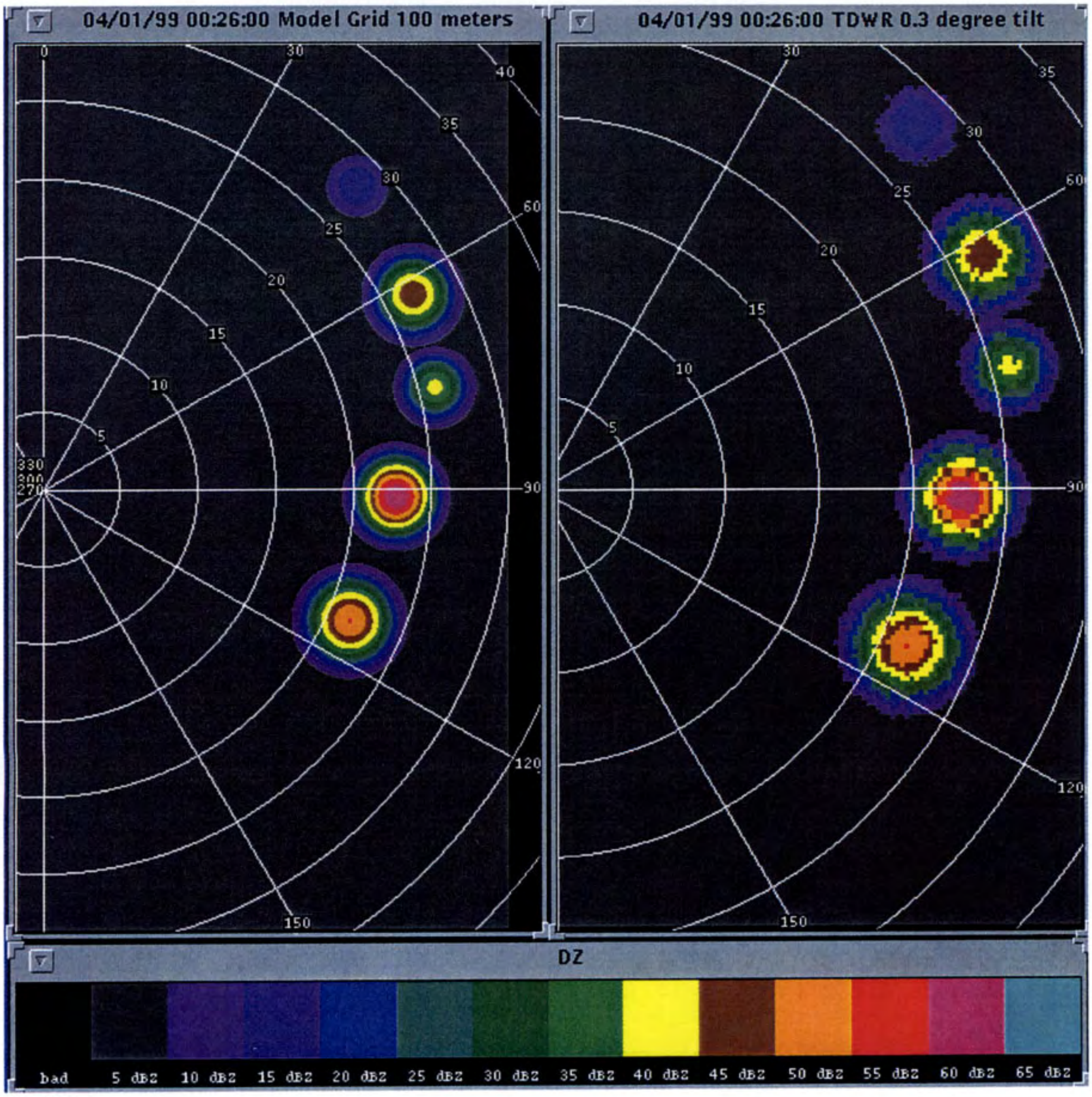

Figure 22. Cartesian model grid reflectivity data for a line of convective storms (left) and resampled polar TDWR data for the same storms (right). A comparison of the two is used to verify that the radar sensor model algorithm is working correctly.

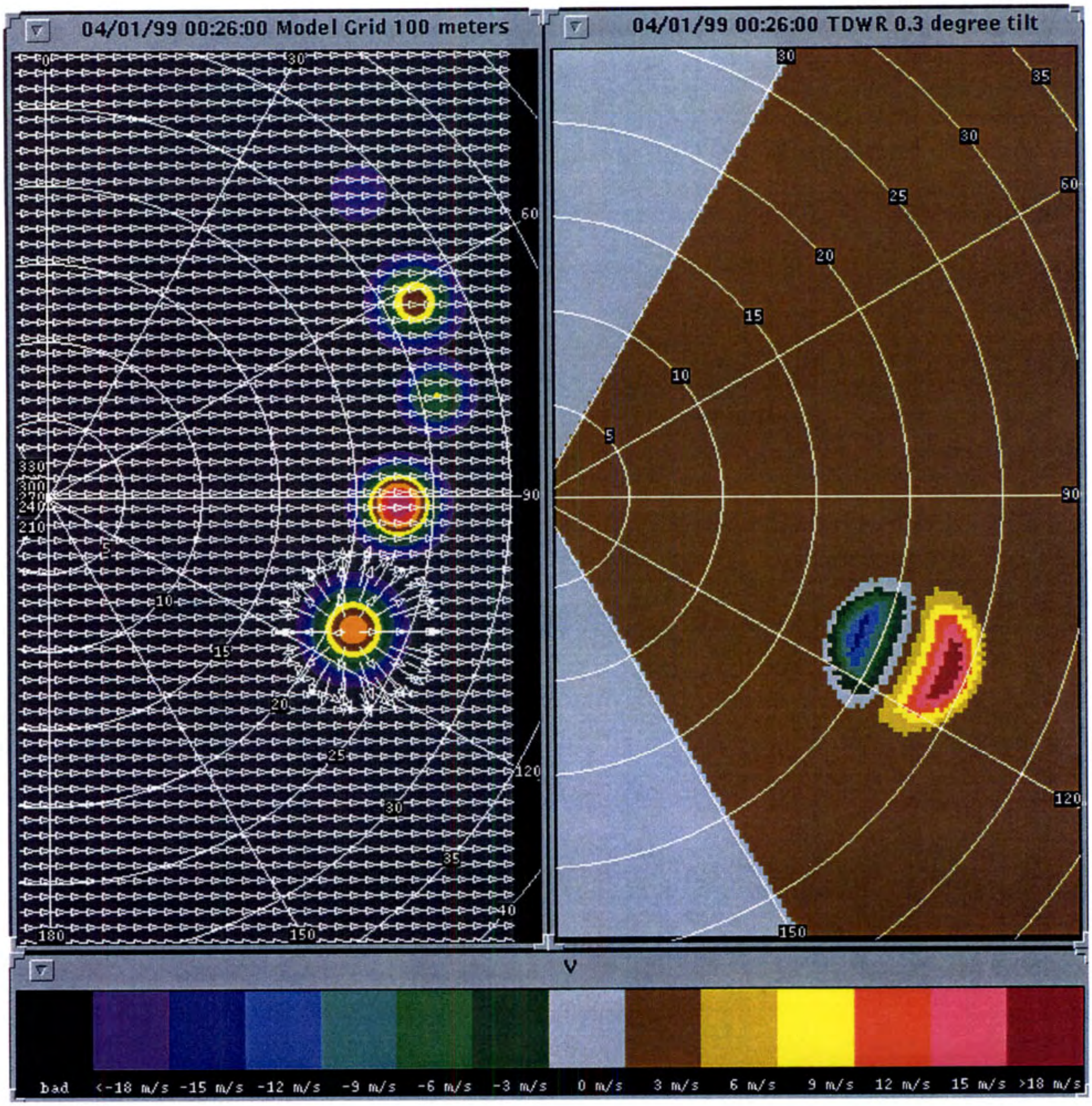

Figure 23. Cartesian model grid reflectivity data for a line of convective storms with microburst outflow vectors overlaid (left) and resampled polar TDWR velocity data for the same storm. A comparison of the two images is used to verify that the microburst outflow winds are represented correctly in the radar data.

6.2.2 Fan Beam Radar

The ASR-9 precipitation was compared with the gridded reflectivity data by determining the maximum reflectivity values from a vertical column at each grid point in the model data. The ASR-9 precipitation data were converted to the National Weather Service (NWS) six-level precipitation levels and resampled into a Cartesian grid with the same resolution as the model data. Two independent comparisons were performed. The first was to validate the proper processing of the gridded model data for storms, microbursts, and other weather phenomena. The second comparison uses a user-defined AP grid co-located with regions of higher reflectivity from the weather models. An example of a comparison of modeled convective storms and resampled ASR-9 six-level weather is shown in Figure 24. A comparison of modeled convective storms and AP and resampled ASR-9 six-level weather is shown in Figure 25.

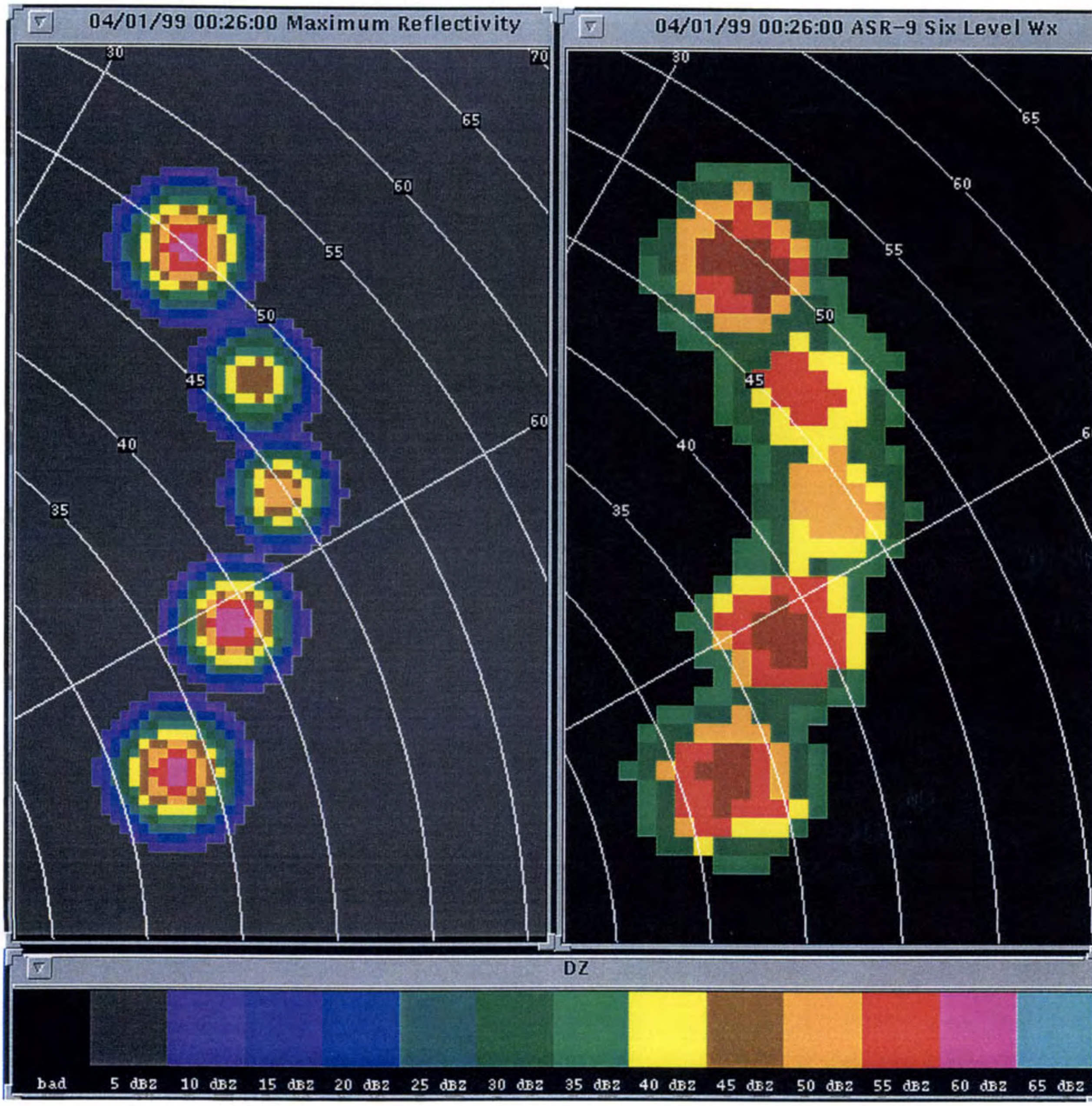

Figure 24. Cartesian model grid maximum reflectivity data for a line of convective storms (left) and resampled polar ASR-9 six-level data for the same storms (right). A comparison of the two images is used to verify that the convective storms are represented correctly in the radar data.

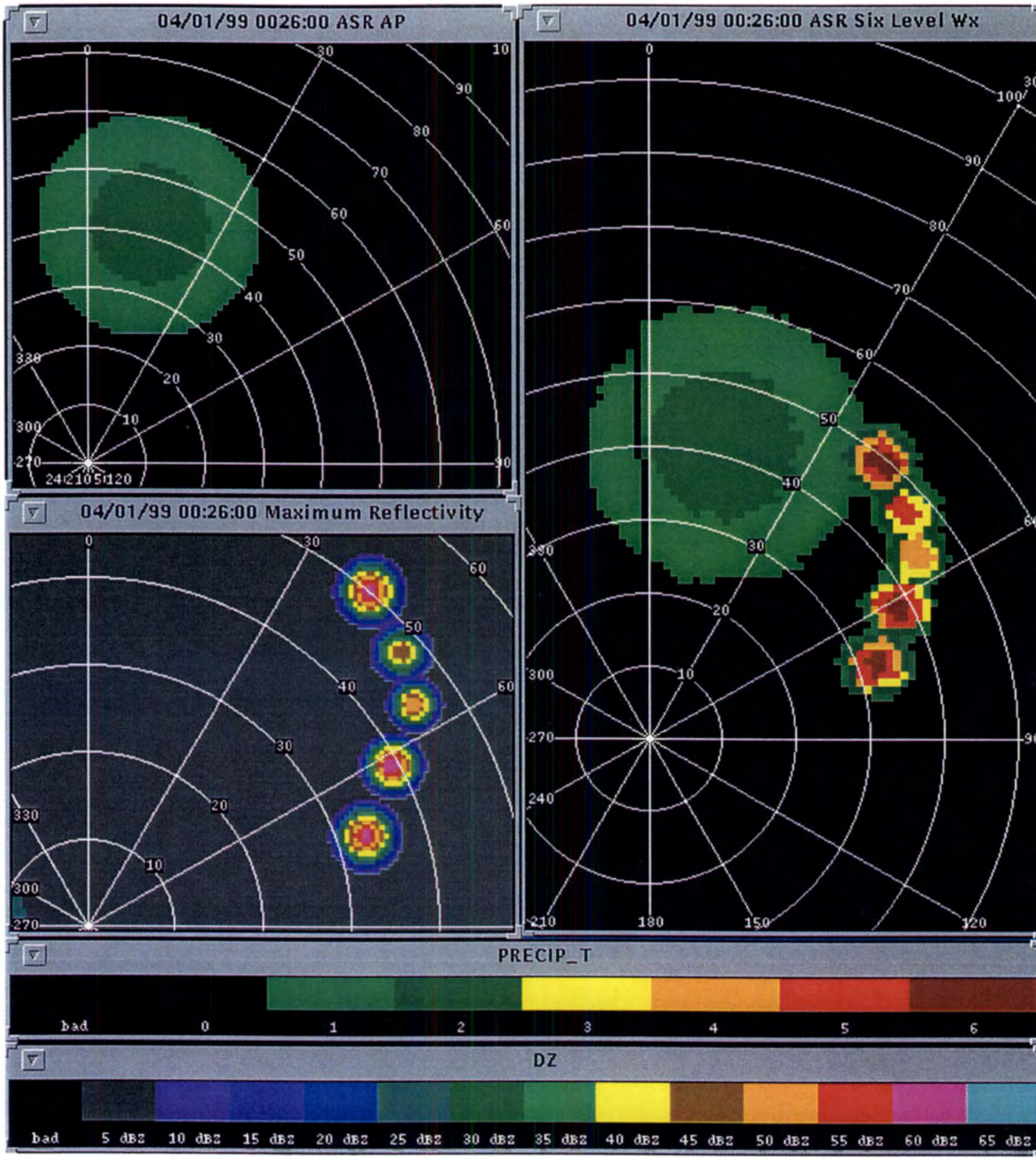

Figure 25. Anomalous Propagation model grid data for the ASR-9 radar (top left), Cartesian model grid reflectivity data for a line of convective storms (bottom left) and resampled polar ASR-9 six-level data computed with AP and storms (right). A comparison of the two images is used to verify that the AP is visible in the radar data.

6.2.3 Surface Sensors and MDCRS

Verification of the surface sensor and MDCRS data is completed by displaying the gridded model velocity data in vector format and overlaying the various surface and aircraft observations.

7. CONCLUSION

The SDG was created as a tool to provide a production ITWS system with meteorologically consistent scenarios and full ITWS sensor configurations for testing. The SDG also may be used for load testing at sites that do not have a functional ITWS prototype, verification of site adaptable parameters, validation of algorithm mathematical computations after software changes, and Y2K testing of the ITWS prototype algorithms.

This report described the design and validation of the SDG. The design of the SDG consists of two main components: running the meteorological models that create gridded data using the user-specified input parameters and extracting sensor observations from the gridded data. Characteristics and time evolution of each of the meteorological models, the four types of data grids, and the sensor models were described.

Validation of the meteorological model output (the data grids) and the sensor observations was performed by visually inspecting the data and by using tools that allowed for data comparisons. The gridded data were validated using a display tool to verify that the user-specified meteorological phenomena were in the correct locations and had the correct attributes. These data were checked over the entire 3D grid for the duration of the meteorological event. The sensor data were validated in two ways. Radar sensor data were resampled from polar to Cartesian and displayed on a grid. This grid was compared to the input meteorological grids used to create the radar sensor data. All other sensor data (surface observation, MDCRS, etc.) were validated by displaying the gridded model data and manually checking that the sensor data at each particular time and location used the correct grid values.

The sensor models could be extended to more accurately emulate the weather sensing process by:

1. Considering Earth curvature and normal atmospheric refractivity profiles in computing the grid point altitude corresponding to a given range and elevation angle;
2. Permitting beam blockage by hills, buildings, etc.;
3. Considering range and velocity folding for TDWR and NEXRAD;
4. More accurately estimating the SNR, (e.g., by considering the effects of STC);
5. Perturbing the computed reflectivities and velocities to account for the noise due to finite averaging and SNR (albeit this would require determining spectrum width); and
6. Considering ground clutter.

It should be noted that the effect of most of the sensor model simplifications made here is to increase the range at which a radar makes measurements and thus increases the computational load.

Future near-term applications of the SDG include creating synthetic data scenarios and testing the ITWS algorithms. As a result of the testing, refinements to the meteorological models will most likely be made. Also, the SDG is currently run from a very large parameter file. It is very time intensive to set all of the parameters needed to generate a weather scenario, and it is very difficult for the user to visualize the resulting scenario. A graphical user interface tool will be created to allow the user to specify the meteorological model parameters more easily and provide a way to view the resulting scenario before the software is run.

By improving the sensor models as described above, the SDG could be used as a tool for site-specific ITWS studies. An example of such a study would be assessing algorithm parameter settings for LaGuardia Airport (LGA) for coverage by the Kennedy (JFK) TDWR. There is a ridge between the JFK TDWR and Laguardia Airport that will impact TDWR detection capability for microbursts and gust fronts. An augmented SDG could be sued as a tool to optimize LGA wind shear detection by simulating various wind shear situations.

APPENDIX A
WEATHER PHENOMENA MODEL PARAMETERS

Table A-1.
Background Profile Parameters

Parameter	Units	Comments
start_time	n/a	Start time of the profile
id	n/a	Id name of the profile
x_start	meters	East-West starting location (offset from the grid reference point)
y_start	meters	North-South starting location (offset from the grid reference point)
ref_alt	meters	Altitude of the profile x_start, y_start location
sfc_pressure	millibars	Surface Pressure
levels	n/a	Number of levels to be specified
heights	meters	Height of each of the n_levels
reflectivity	dBZ	Array of background reflectivity values for each of the n_levels
wind_speed	m/s	Array of background wind speed values for each of the n_levels
wind_dir	degrees	Array of background wind direction values for each of the n_levels
temperature	degrees	Array of background temperature values for each of the n_levels
humidity	percent	Array of background humidity values for each of the n_levels

Table A-2.
Stratiform Rain Parameters

Parameter	Units	Comments
start_time	n/a	Start time of the stratiform rain
duration	seconds	Duration of the stratiform rain (end time = start_time + duration)
x_start	meters	East-West starting location (offset from the grid reference point)
y_start	meters	North-South starting location (offset from the grid reference point)
speed	m/s	Speed that the stratiform rain is moving
direction	degrees	Direction that the stratiform rain is moving
max_refl	dBZ	Maximum reflectivity of the stratiform rain region
max_radius	meters	Maximum radius of the stratiform rain region
min_alt_bottom	meters	Minimum altitude of the stratiform rain region
max_alt_top	meters	Maximum altitude of the stratiform rain region
time_max_refl	seconds	Time of the maximum reflectivity (max_refl)
time_max_radius	seconds	Time of the maximum radius (max_radius)
time_min_alt_bot	seconds	Time of the minimum altitude (min_alt_bottom)
time_max_alt_top	seconds	Time of the maximum altitude (max_alt_top)
levels	n/a	The number of "levels" in the stratifor rain region. Each level is a horizontal layer of the storm
heights	meters	The altitude of each of the levels
wind_speed	m/s	The wind speed of each of the levels
wind_dir	degrees	The wind direction of each of the levels

Table A-3.
Convective Storm Parameters

Parameter	Units	Comments
start_time	n/a	Start time of the storm
duration	seconds	Duration of the storm (end time = start_time + duration)
x_start	meters	East-West starting location (offset from the grid reference point)
y_start	meters	North-South starting location (offset from the grid reference point)
speed	m/s	Speed that the storm is moving
direction	degrees	Direction that the storm is moving
max_vert_rad	meters	Maximum height of the storm divided by two
max_horz_rad	meters	Maximum radius of the storm
max_refl	dBZ	Maximum reflectivity in the storm
max_refl_alt	meters	Altitude of the maximum reflectivity
max_flash_rate	strokes/min.	Maximum lightning flash rate associated with the storm
time_max_vert_rad	seconds	Time of the maximum height of the storm (max_halfheight)
time_max_horz_rad	seconds	Time of the maximum radius of the storm (max_radius)
time_max_refl	seconds	Time of the maximum reflectivity of the storm (max_refl)
time_alt_drop	seconds	Time that the storm centroid begins to descend
time_max_flash	seconds	Time of the maximum flash rate in the storm (max_flash_rate)
levels	n/a	The number of levels in the storm. Each level is a horizontal layer of the storm
heights	meters	The altitude of each of the levels
wind_speed	m/s	The wind speed of each of the levels
wind_dir	degrees	The wind direction of each of the levels

Table A-4.
Gust Front Parameters

Parameter	Units	Comments
start_time	n/a	Start time of the gust front
duration	seconds	Duration of the gust front (end time = start_time + duration)
x_start	meters	East-West starting location (offset from the grid reference point)
y_start	meters	North-South starting location (offset from the grid reference point)
speed	m/s	Speed that the gust front is moving
direction	degrees	Direction that the gust front is moving
angular_offset	degrees	Orientation of the gust front (where 0 is north)
dir_offset	degrees	Offset from the angular_offset to describe the forward direction of the gust front
min_length	meters	Minimum length of the gust front
max_length	meters	Maximum length of the gust front
refl_width	meters	Width of the gust front reflectivity thin line
refl_height	meters	Height of the gust front reflectivity thin line
max_refl	dBZ	Maximum reflectivity of the gust front thin line
max_vel_width	meters	Width of the gust front velocity convergence zone
max_vel_val	m/s	Maximum speed of the velocity convergence zone
max_vel_dir	degrees	Direction of the winds in the velocity convergence zone
vel_ftr_width	meters	Width of the region of transition between the background wind and the winds in the convergence zone (max_vel_conv_val, and vel_conv_dir)
vel_behind_width	meters	Width of the region of the "winds behind the gust front"
vel_behind_val	m/s	Speed of the winds int the region of the "winds behind the gust front"
vel_behind_dir	degrees	Direction of the winds in the region of the "winds behind the gust front"
vel_rtr_width	meters	Width of the region of transition between the "winds behind the gust front" (vel_behind_val, and vel_behind_dir) and the background wind.

Table A-5.
Microburst Outflow Parameters

Parameter	Units	Comments
start_time	n/a	Start time of the outflow
duration	seconds	Duration of the outflow (end time = start_time + duration)
x_start	meters	East-West starting location (offset from the grid reference point)
y_start	meters	North-South starting location (offset from the grid reference point)
speed	m/s	Speed that the outflow is moving
direction	degrees	Direction that the outflow is moving
max_height	meters	Maximum depth of the outflow
max_rad_maxvel	meters	Maximum radius of the outflow's maximum velocity
max_rad_outflow	meters	Maximum radius of the outflow
max_outflow_vel	m/s	Maximum velocity of the outflow (outflow delta V = max_outflow_vel * 2)
time_max_height	seconds	Time of the maximum depth of the outflow
time_max_rad_maxvel	seconds	Time of the maximum radius of the outflow's max velocity (max_rad_maxvel)
time_max_rad_outflow	seconds	Time of the maximum radius of the outflow (max_rad_outflow)
time_max_outflow_vel	seconds	Time of the maximum velocity of the outflow (max_outflow_vel)

Table A-6.
Anomalous Propagation Parameters

Parameter	Units	Comments
start_time	n/a	Start time of the AP
duration	seconds	Duration of the AP (end time = start_time + duration)
x_start	meters	East-West starting location (offset from the grid reference point)
y_start	meters	North-South starting location (offset from the grid reference point)
speed	m/s	Speed that the AP is moving
direction	degrees	Direction that the AP is moving
site_name	n/a	Name of the ASR radar for which this AP is valid
max_radius	meters	Maximum radius of the AP region
max_asr_level	n/a	Maximum PRECIP level of the AP
time_max_radius	seconds	Time of the maximum radius of the AP region (max_radius)
time_max_asr_level	seconds	Time of the maximum PRECIP level of the AP (max_asr_level)

Table A-7.
NEXRAD Point Product Parameters—Hail

Parameter	Units	Comments
start_time	n/a	Start time of the hail
duration	seconds	Duration of the hail (end time = start_time + duration)
x_start	meters	East-West starting location (offset from the grid reference point)
y_start	meters	North-South starting location (offset from the grid reference point)
speed	m/s	Speed that the hail is moving
direction	degrees	Direction that the hail is moving
posh	percent	Probability of severe hail value

Table A-8.
NEXRAD Point Product Parameters—Mesocyclone

Parameter	Units	Comments
start_time	n/a	Start time of the mesocyclone
duration	seconds	Duration of the mesocyclone (end time = start_time + duration)
x_start	meters	East-West starting location (offset from the grid reference point)
y_start	meters	North-South starting location (offset from the grid reference point)
speed	m/s	Speed that the mesocyclone is moving
direction	degrees	Direction that the mesocyclone is moving
radius	meters	Radius of the mesocyclone

Table A-9.
NEXRAD Point Product Parameters—Tornado

Parameter	Units	Comments
start_time	n/a	Start time of the tornado
duration	seconds	Duration of the tornado (end time = start_time + duration)
x_start	meters	East-West starting location (offset from the grid reference point)
y_start	meters	North-South starting location (offset from the grid reference point)
speed	m/s	Speed that the tornado is moving
direction	degrees	Direction that the tornado is moving

GLOSSARY

2D	Two dimensional
3D	Three dimensional
AP	Anomalous Propagation
ASR-9	Airpor Surveillance Radar version 9
FAA	Federal Aviation Administration
IOC	Initial Operational Capability
JFK	John F. Kennedy International Airport
LGA	LaGuardia International Airport
ITWS	Integrated Terminal Weather System
LLWAS	Low Level Wind Shear Alert System
MDCRS	Meteorological Data Collection and Reporting System
NEXRAD	NExt generation weather RADar
NLDN	National Lightning Detection Network
NWS	National Weather Service
RUC	Rapid Update Cycle
SDG	Synthetic Data Generator
SN	Signal-to-Noise
TDWR	Terminal Doppler Weather Radar
TRACON	Terminal Radar Approach Control
Y2K	Year 2000

REFERENCE

1. Evans, J.E., and E.R. Ducot, "The Integrated Terminal Weather System (ITWS)," Massachusetts Institute of Technology, *The Lincoln Laboratory Journal*, Fall 1994, Vol. 7, No. 2.