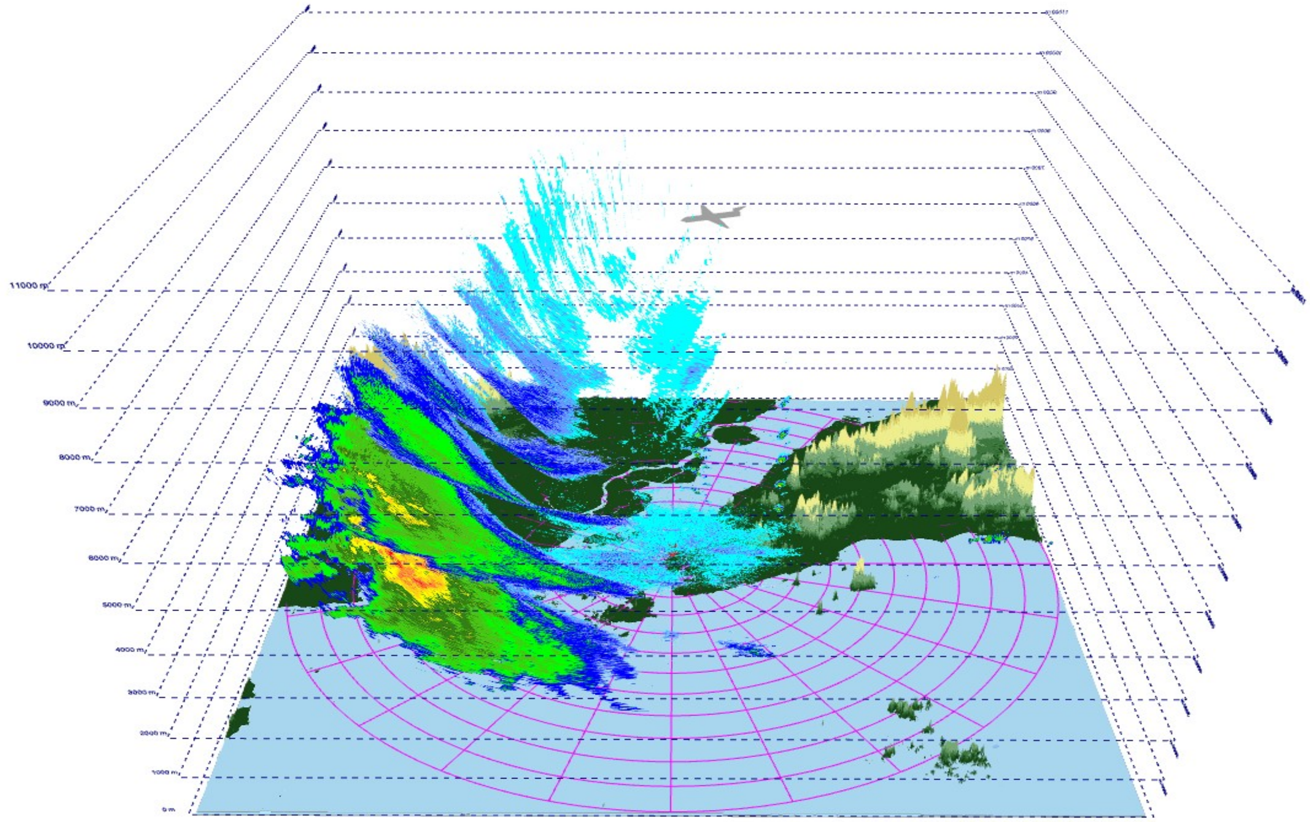
Cassandra 3D

(**C**lassification, **A**nalysis, **S**election, **S**imulation and **R**ecognition of **A**tmospheric objects in **3D**)



Introduction

“Cassandra 3D” was designed for visualization, analysis, and movements detection of meteorological objects and hard targets. The utility displays radar parameters in 3D, filters noise, identifies meteorological objects, and analyzes data by elevation, azimuth, height, and distance.

The program runs on Linux and Windows platforms. “Cassandra 3D” was written from scratch and does not contain any third-party code.

The input data are radar parameters from different scans in HDF5, GRIB, and netCDF formats.

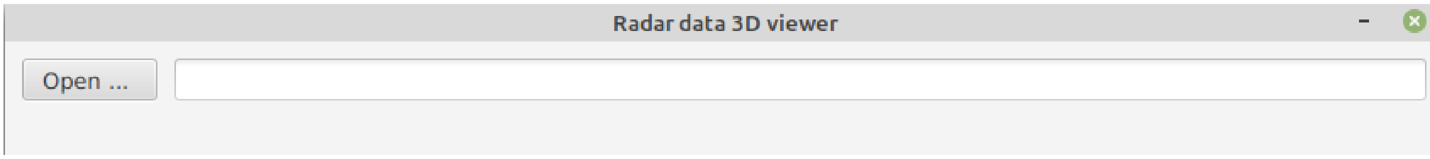
"Cassandra 3D" comprises two modules:

The first module extracts data from radar scans and defines a color palette to display this data. This module can also generate a three-dimensional terrain within the radar range.

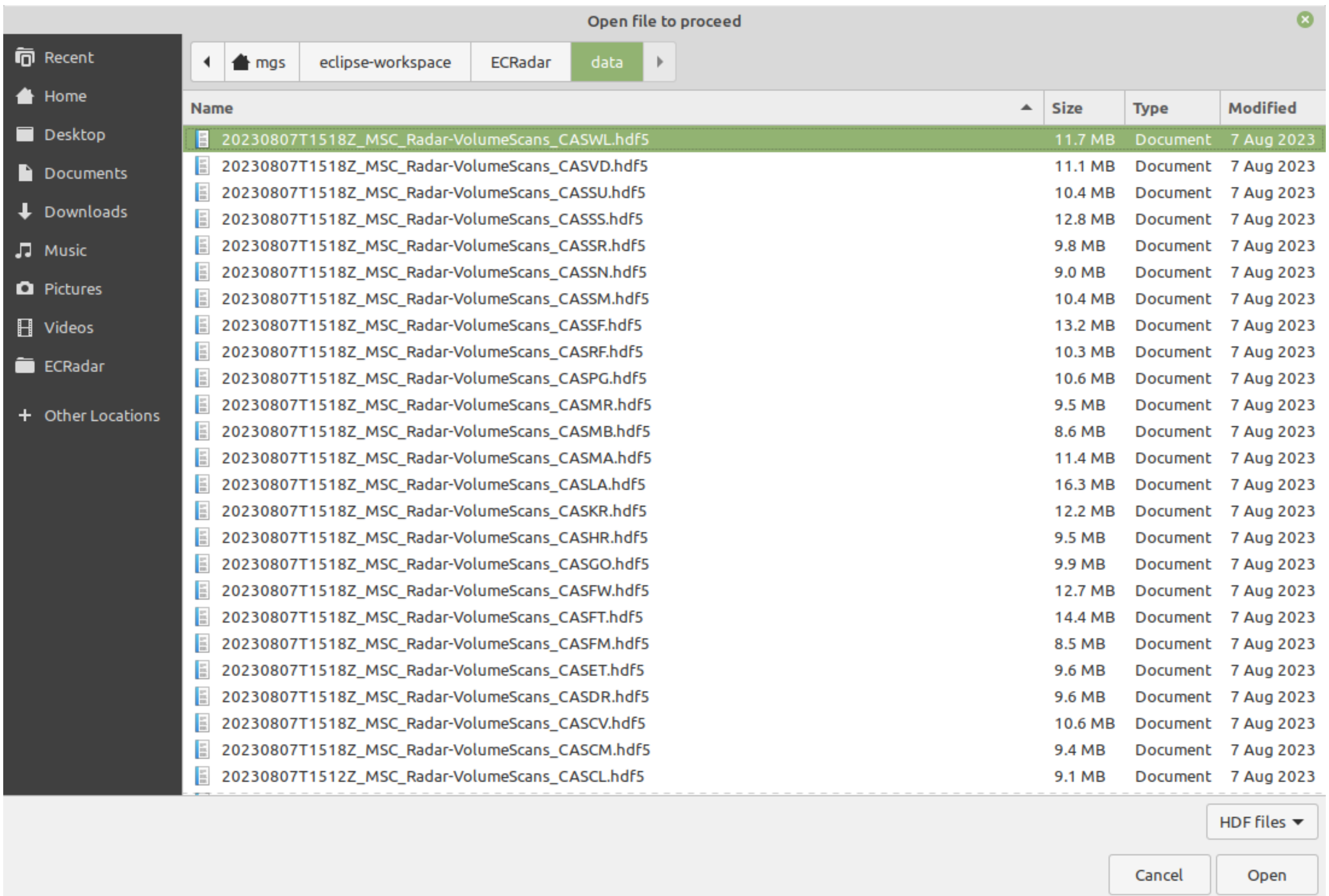
The second module visualizes, compares, filters, and classifies radar data. It uses a web browser to display data in 3D and can operate in both online and offline modes.

1. Data preparation module

Launch the “Cassandra 3D” program and click the **Open** button.



Next, choose an HDF5 file containing one or more parameters from multiple scans.



After selecting the file, a new window will appear (refer to Fig. 1.1). The top section of the window displays a list of available parameters, corresponding scanning angles, and miscellaneous system information. The bottom section of the window shows the controls for color coding the selected data.

1.1 Data section

At the top of the window, you can find the data section which shows a list of radar parameters and their corresponding scan angles. This section also displays various system information.

The appendix 1 provides a complete list of radar parameters, including reflectivity (DBZH), radial velocity (VRADH), differential phase (PHIDP), etc.

The text box below will display information related to the selected parameter, including its name, abbreviation, unit of measurement, scanning date and time, as well as the location of the radar system (latitude, longitude, and elevation). In addition, a list of available scan angles will also be provided.

To the right of the Parameter selector, you will see a list of available scans. Once you have selected the parameter you are interested in, you can choose one or more scans to display its data in 3D. If you wish to select all available scans, simply click on the "**Select all**" button. If you want to clear all selections, click on the "**Clear all**" button.

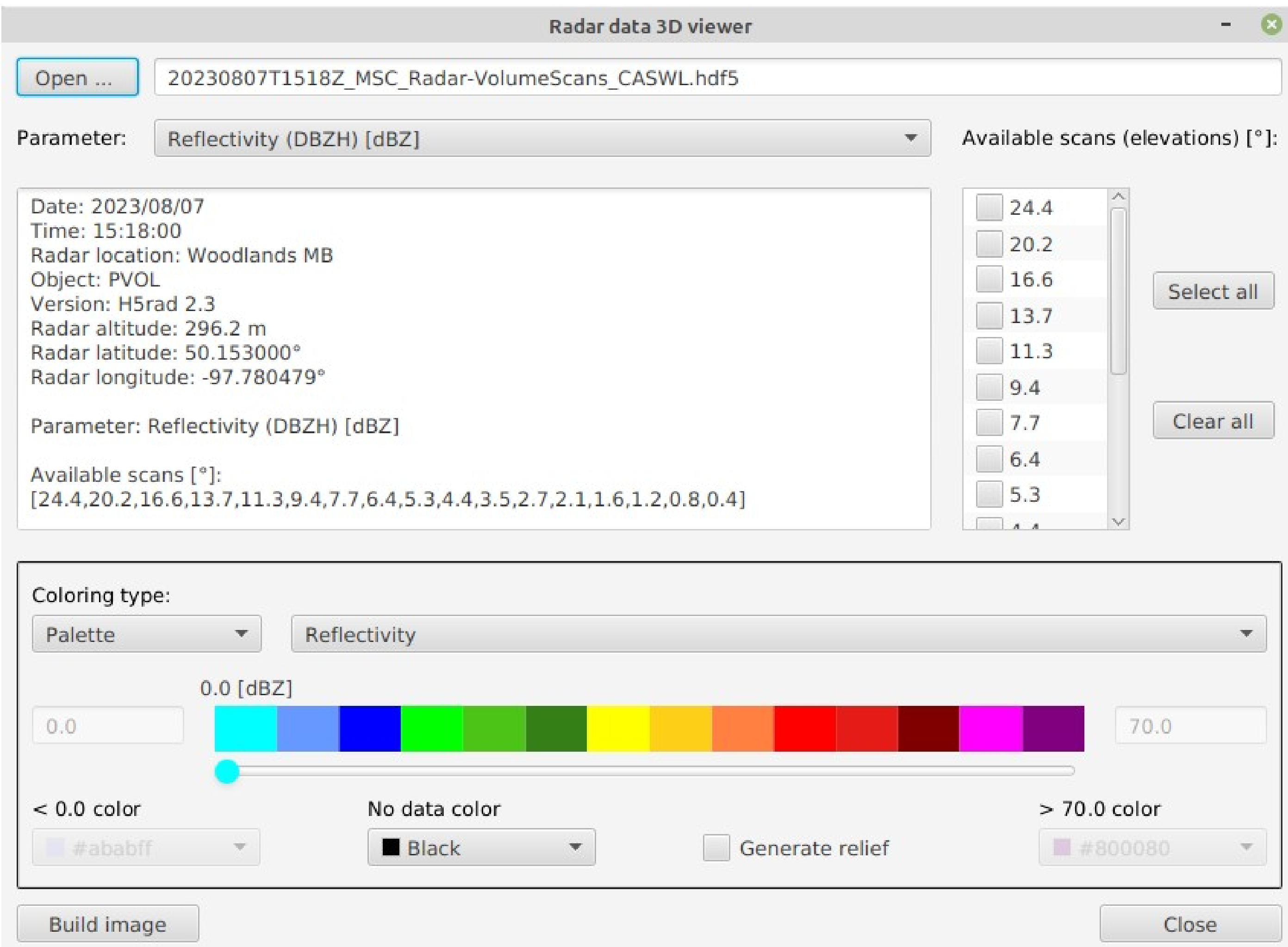


Fig. 1.1 Data preparation module.

As an example, let's select the following radar scans for further display in 3D for the Reflectivity parameter: 24.4°, 16.6°, 13.7°, 11.3°, 7.7°, and 6.4° (see Fig. 1.2).

The radar's coordinates are 50.153°N and 97.78049°W, with an elevation of 296.2 meters in WGS-84. The radar is situated in Woodland, Manitoba, Canada, and the data was received on July 8, 2023, at 15:18 (UTC).

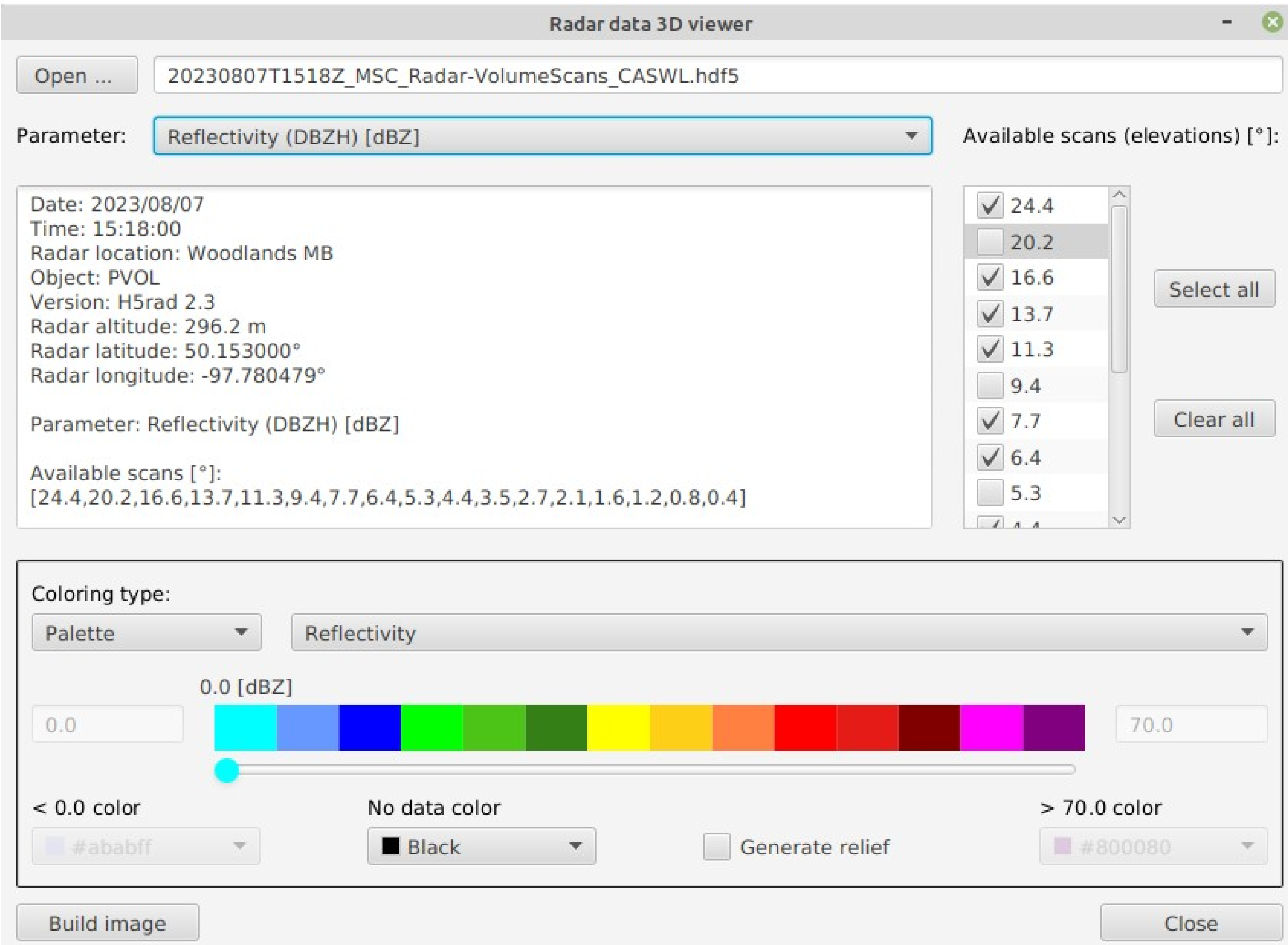


Fig. 1.2 Selection of radar scans for further display in 3D.

1.2 Color coding section

The coloring section is located at the bottom of the window and is used to match data values and palette colors.

The section consists of the following parts: a **Coloring type** selector, a color palette, and a range of data to display, defined by the minimum and maximum values (see Fig. 1.3). Here, you can also choose colors for data that falls outside of this range, as well as for NaN values.

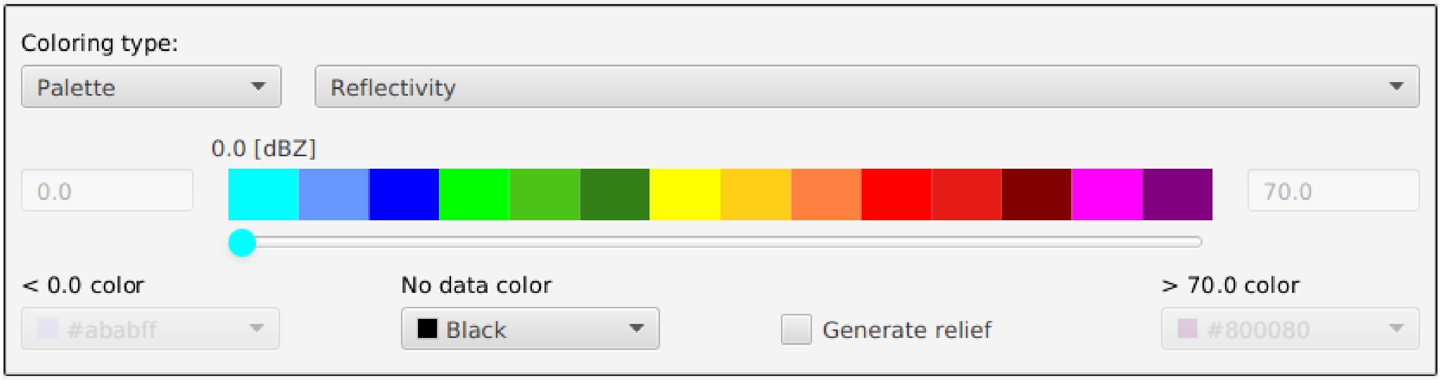


Fig. 1.3 Controls of the color coding section.

The following coloring options are available:

1) Pre-defined palettes (**Palette**)
2) Palettes defined by starting and ending colors and the number of elements in between (**Color range**)
3) Color sequences generated by **Sinebow** algorithm

1.2.1 Pre-defined palettes (Palette)

There are pre-defined standard color palettes available for many radar parameters. For instance, a pre-defined palette of 14 colors corresponds to the reflectivity coefficient for the range from 0 to 70 dBZ, with 5 dBZ step (refer to Fig. 1.3). The standard color palettes, range of values, and units of measurement for each parameter are provided in Appendix 1.

When you choose a parameter that has a standard color palette through the **Parameter** control, the **Palette** mode is automatically selected. This sets up a color range and palette based on the selected data. For instance, when you choose the reflectivity parameter, the color mode is set to **Palette**, and the **Reflectivity** palette is automatically selected (refer to Fig. 1.2). The parameter data range lies between 0 to 70 dBZ.

To color code data, you may use any of the available palettes by selecting it from the list, as shown in Fig. 1.4. The editable minimum and maximum values of the selected parameter are located to the left and right of the color palette. These values determine the range of data that will be color-coded by the selected color palette. As you move the slider cursor along the color palette, you can see which color corresponds to a specific value or range of values.

For example, in Fig. 1.5, the **Temperature** color palette was selected for the **Reflectivity** parameter, and the minimum value was set to 10 and the maximum to 50 dBZ. White color corresponds to reflectivity values of 10 dBZ, 50 dBZ values will be colored black, and data having the value of 20 dBZ will be represented by blue color.

In some cases, it may be necessary to display data that falls outside of the specified range. To achieve this, colors can be assigned to values that are below the minimum or above the maximum. You can select these colors by using the controls located to the left and right of the color palette, respectively, and below the minimum and maximum values. For instance, in Fig. 1.6, gray color was chosen for reflectivity values that are less than 10 dBZ, while values greater than 50 dBZ were represented by the color purple.

To create a new palette, you can use any text editor. Each color value is written in RGB hexadecimal notation, such as 0x00 0xff 0xff. Once you have created the palette, save it in the **palettes** directory, and it will be available for use along with the existing palettes.

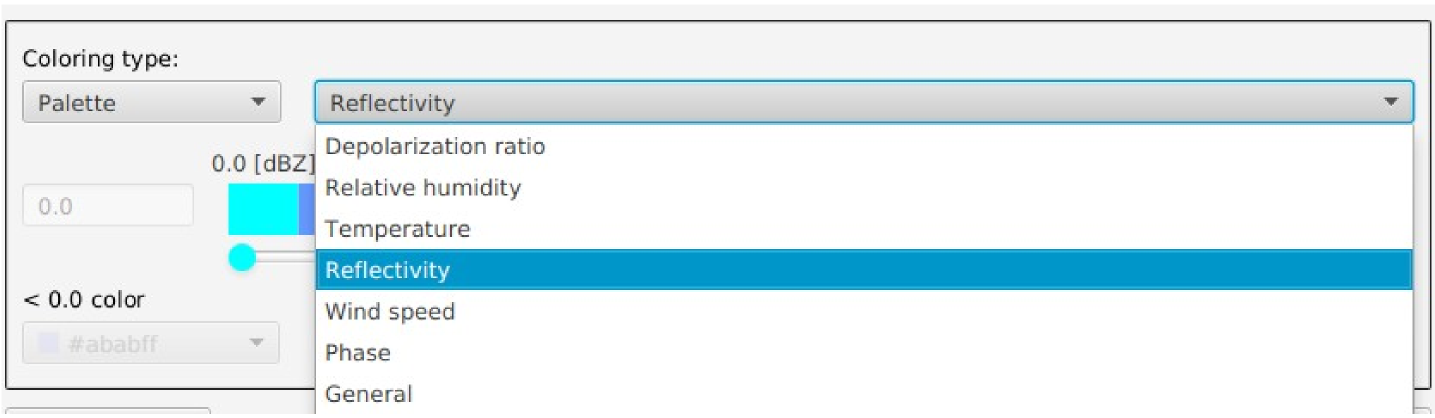


Fig. 1.4 List of available color palettes.

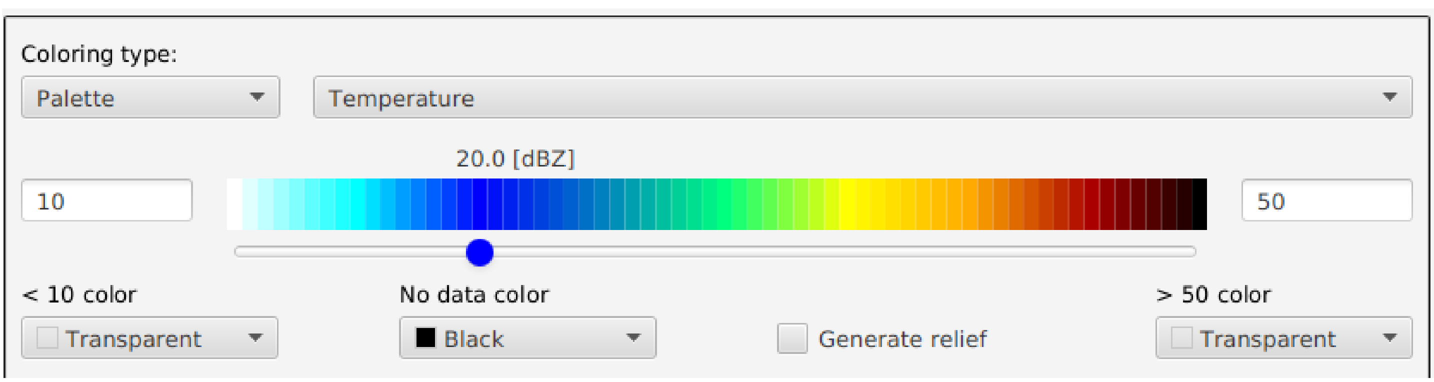


Fig. 1.5 Selecting a palette and setting the data range for color coding.

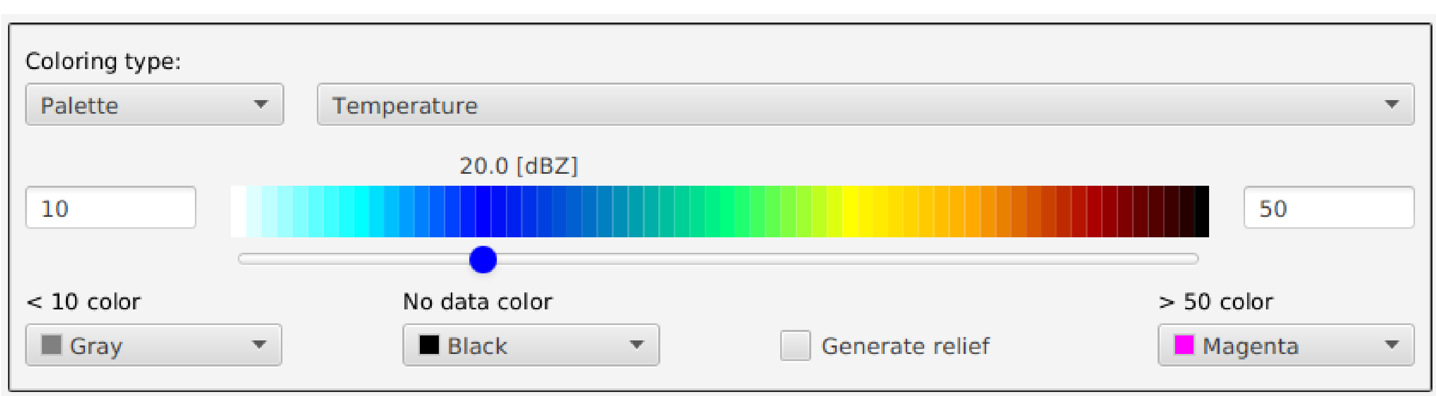


Fig. 1.6 Setting colors to display data outside the selected interval.

1.2.2 Color range

If you select a parameter that doesn't have a corresponding color palette, the **Color range** mode will be automatically chosen. In this mode, the color palette is generated based on the color that corresponds to the minimum value (**From**) to the color that corresponds to the maximum value (**To**) of the selected parameter. You can adjust the number of colors in the palette using the selector labeled **Intervals**.

In the example shown in Fig. 1.7, the coefficient of correlation was selected. The **Color range** mode was automatically selected, where blue represents a correlation coefficient of 0, and red represents a value of 1. The color palette consists of 20 elements, and by moving the slider cursor along the palette, you can see which color corresponds to a specific value or range of values of the correlation coefficient.

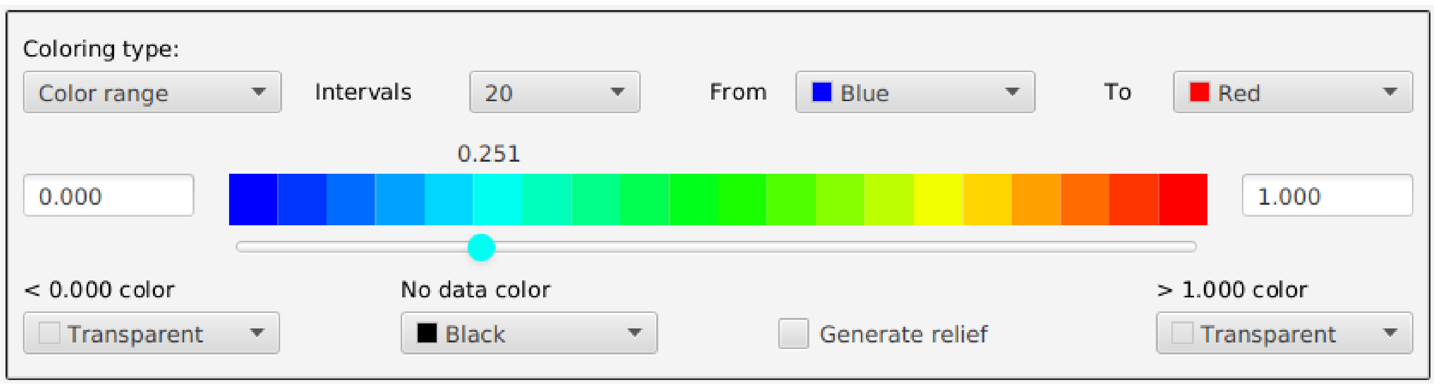


Fig. 1.7 The color palette from blue to red for the correlation coefficient.

If you need to display data that falls outside the color coding range, there are color pickers available below the minimum and maximum values. For instance, in Fig. 1.8, the color white represents correlation coefficient values less than 0.1, whereas black corresponds to values greater than 0.9.

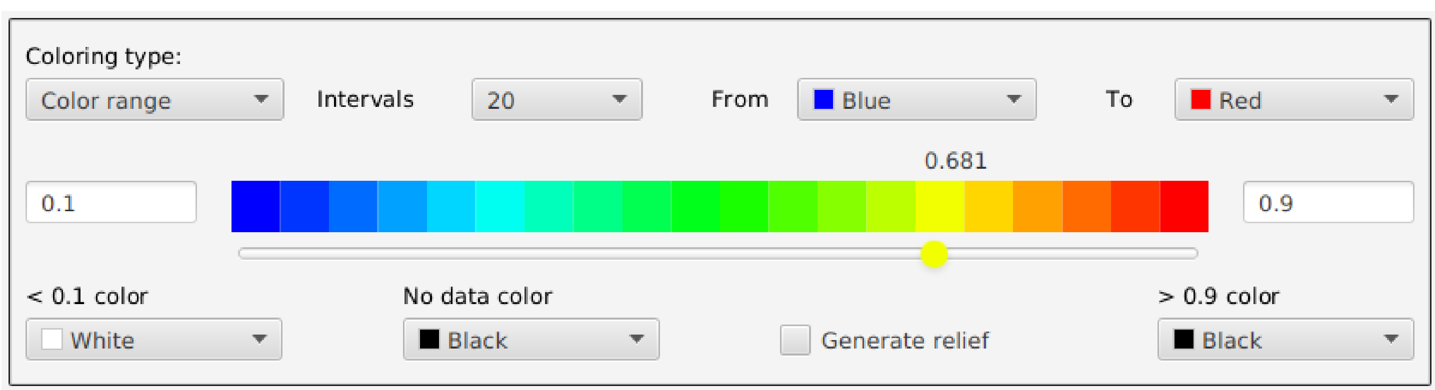


Fig. 1.8 Setting colors to display data outside the selected interval.

1.2.3 Color sequences generated by Sinebow algorithm

Using the well-proven Sinebow algorithm, you can easily generate smooth color ranges by specifying the number of intervals and allowing the color palette to be generated automatically.

In Fig. 1.9, the **Signal Quality Index** was chosen and a color palette with 10 intervals was displayed. By sliding the cursor along the palette, you can easily determine which color corresponds to a specific signal quality value or range.

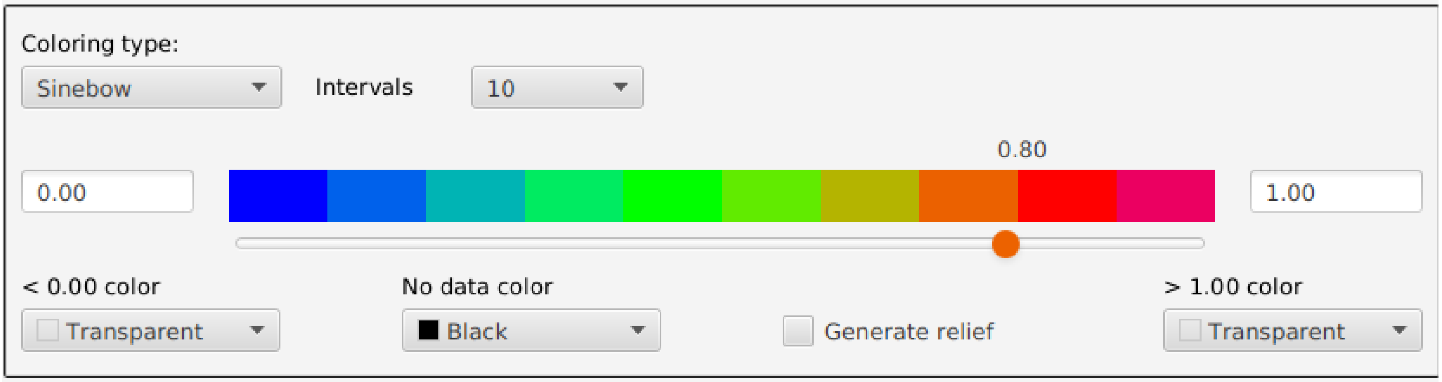


Fig. 1.9 Color palette generated by Sinebow algorithm.

To view data that falls outside the color coding range, you can utilize the color pickers located below the minimum and maximum values. To illustrate, in Fig. 1.10, the color yellow corresponds to signal quality values less than 0.1, whereas black is used for values greater than 0.9.

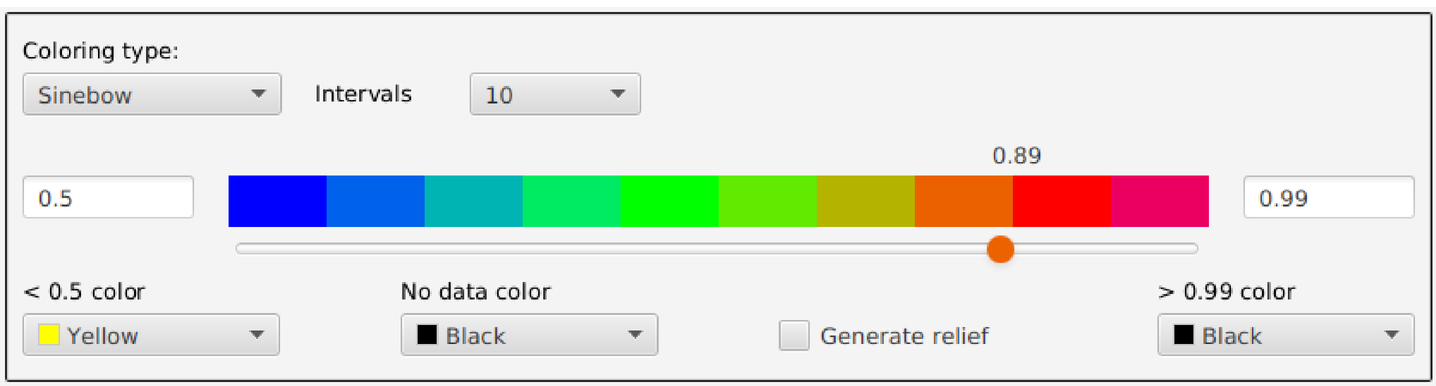


Fig. 1.10 Setting colors to display data outside the selected interval.

Sometimes radar data may contain unreliable values, which are encoded as NaNs or filled values. Use the **No data color** picker to set a color for these values.

When you click on the "**Build image**" button (as shown in Fig. 1.1), a 3D model will be generated using the selected data and color palette. If the "**Generate relief**" checkbox is selected, a three-dimensional model of the terrain within the radar range will also be created. The 3D data model and terrain will then be displayed in the visualization module.

2. Visualization module

This part of “Cassandra 3D” displays, compares, filters, and classifies radar parameters. The utility filters noise, identifies meteorological objects, and analyzes data by elevation, azimuth, height, and distance. The visualization module uses a web browser to render data in 3D and may work in both online and offline modes.

The visualization module is shown in Fig. 2.1 and consists of:

- The main area in the center where data from radar scans displayed
- Color palette located in the upper left corner of the screen
- Menu for setting of visualization parameters. Located at the upper right corner
- Region to display data selected by a mouse click (bottom left)
- Info zone to display radar coordinates and location located at the lower right corner

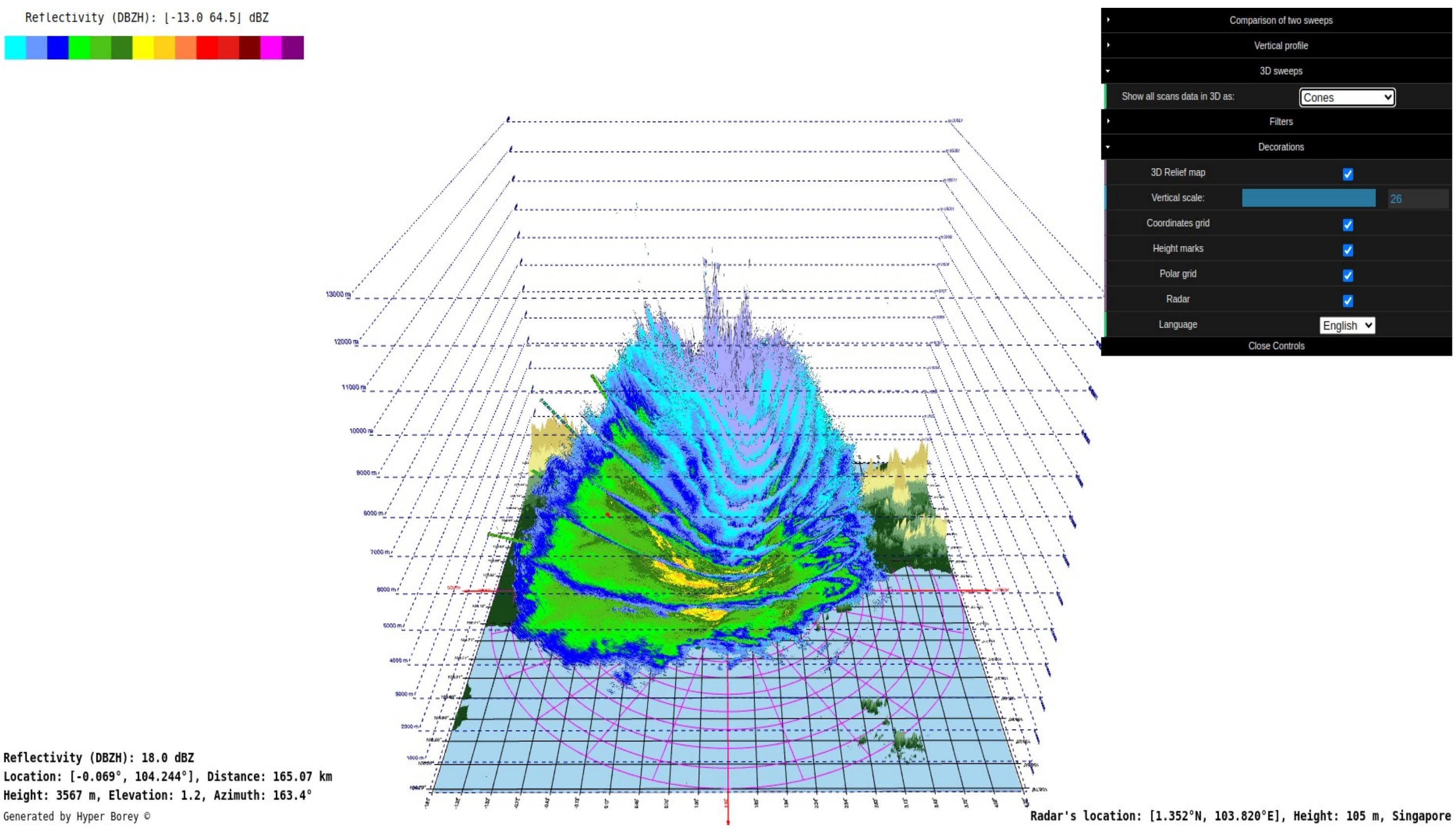


Fig. 2.1 Visualization module of the “Cassandra 3D” program.

You can use the mouse to perform various actions such as zooming in or out, rotating, and changing the vertical scale of the viewing area. Additionally, you can move the point of view and navigate within the analysis space by using the navigation keys (up, down, right, and left arrows).

2.1 The main area to display data from radar scans

This section is situated at the center of the screen and it displays radar data for one or several scan angles that are chosen in the data preparation module (refer to section 1.1).

The position of weather phenomena and solid targets on the screen is determined by their geographic coordinates and the elevation angle of the radar. The color scheme of the displayed data is determined by the palette set in the color coding section (refer to section 1.2).

The main area encompasses various tools that aid in localization and navigation within the analysis space. These tools include:

1) Geographical grid of latitude and longitude
2) Radial (polar) grid of distance and azimuth
3) Height grid ranges from the sea level to the highest altitude at which the signal was received by radar
4) Terrain that falls within the radar range

Section 2.5, “**Visualization and analysis of radar parameters using the menu**” provides more information on working with data and methods of visualizing it.

2.2 Color palette

The color palette can be found at the upper-left corner of the screen. It is the same palette that is set in the color coding section (refer to section 1.2 for details). Data coloring is performed according to this palette.

As you move the mouse cursor over the color palette, the selected data range will be highlighted. For instance, in Fig. 2.2, reflection coefficient values ranging from 20 to 25 dBZ are highlighted in white.

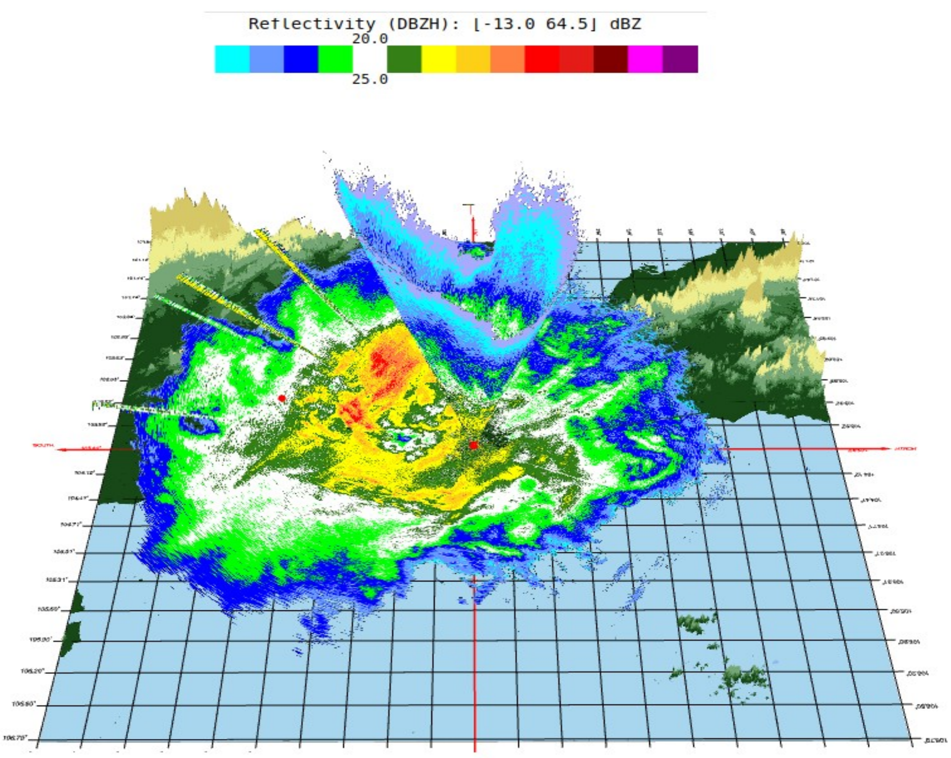


Fig. 2.2 Highlighting a range of data according to the selected color in the palette.

2.3 Region to display data selected by a mouse click

In the lower-left corner of the screen, you will find the data display area. Upon double-clicking any object on the screen, a red dot will appear at the same position, and the following information will be displayed in the lower-left corner of the screen:

1) The value, name, abbreviation, and unit of measurement of the radar parameter at the double-clicked position.
2) The latitude and longitude of the selected object.
3) The distance between the selected point and the radar location.
4) The altitude of the selected object.
5) The elevation angle of the selected scan and azimuth angle from the radar position.

For example, in Fig. 2.2 the selected point corresponds to the following parameters:
Reflection coefficient (DBZH): 20.0 dBZ
Coordinates: [-0.042°, 105.047°]
Distance: 206.73 km
Height: 2995 m
Elevation angle: 0.8°
Azimuth: 138.6°

Distances from the radar to a specific point are calculated by taking into account the height of the object selected. To figure out the distance from the radar to the object's projection on the Earth's surface, you need to multiply the displayed distance by the cosine of the elevation angle.

When you double-click on another object, the red dot moves to the new position and updates the data display area with parameters of the selected object.

When you double-click on a coordinate grid, the following information will be displayed:
1. The latitude and longitude of the location.
2. The distance from the selected point to the radar location.
For example: Coordinates: [2.748°, 101.372°], Distance: 313.68 km

If you double-click on the 3D terrain surface, the corresponding geographic coordinates and altitude above sea level are displayed.
For example: Coordinates: [3.563°, 101.838°], Height: 1127 m.

When you double-click anywhere outside the coordinate grid or any meteorological object, all information in the data display area will be erased and the red dot will disappear.

2.4 Region to display radar coordinates

In the lower right corner of the screen, you can see information about the geographic location of the radar. This information includes the latitude, longitude, altitude above sea level, and the name of the locality where the radar is located.

For instance, if you look at the data of a radar shown in Fig. 2.1, you'll find that it is located in Singapore and has latitude coordinates of 1.352° N and longitude of 103.820° E. It is positioned at an altitude of 105 meters above sea level.

2.5 Visualization and analysis of radar parameters using the menu

The menu for adjusting visualization parameters can be accessed from the upper right corner. See Fig. 2.3 for the primary options.

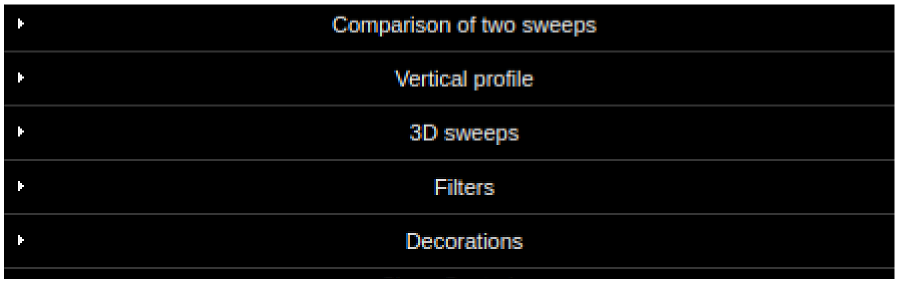


Fig. 2.3 The primary options available on the menu.

2.5.1 Comparison of two sweeps

This menu block is used to compare data from different scan angles. This menu features two selectors for scan angles and two for data visualization method (refer to Fig. 2.4).

The following data visualization methods are available:

1) **Cone**. Displays the radar sweep as a cone surface.
2) **Cone mesh**. Shows the scanning volume.
3) **Plane**. The cone scan is projected onto a plane and transferred to the maximum height at which the reflected signal was received.
4) **Projected plane**. Projects scanning data onto the plane of the Earth's surface.
5) **None**. Hides the image of the selected scan.
6) **Cone points**. The cone scan points are projected onto a plane and transferred to the maximum height at which the reflected signal was received.
7) **Plane points**. Displays the radar sweep as points on the cone surface.
8) **Projected points**. Projects scanning data as points onto the plane of the Earth's surface.

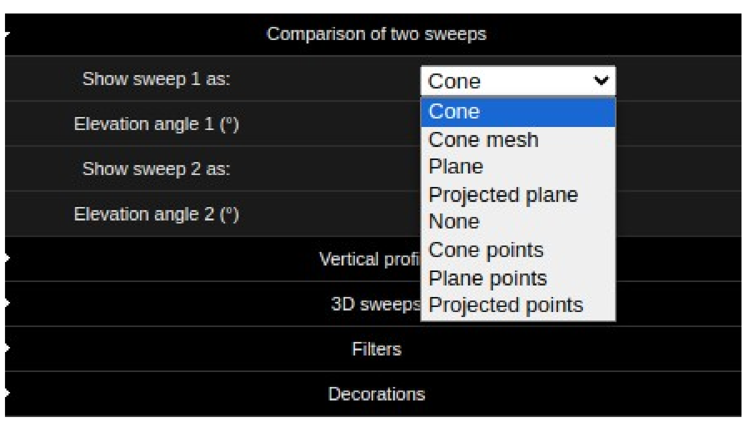


Fig. 2.4 Menu to compare data from two radar sweeps.

Here are some examples of how to display data from two radar scans.

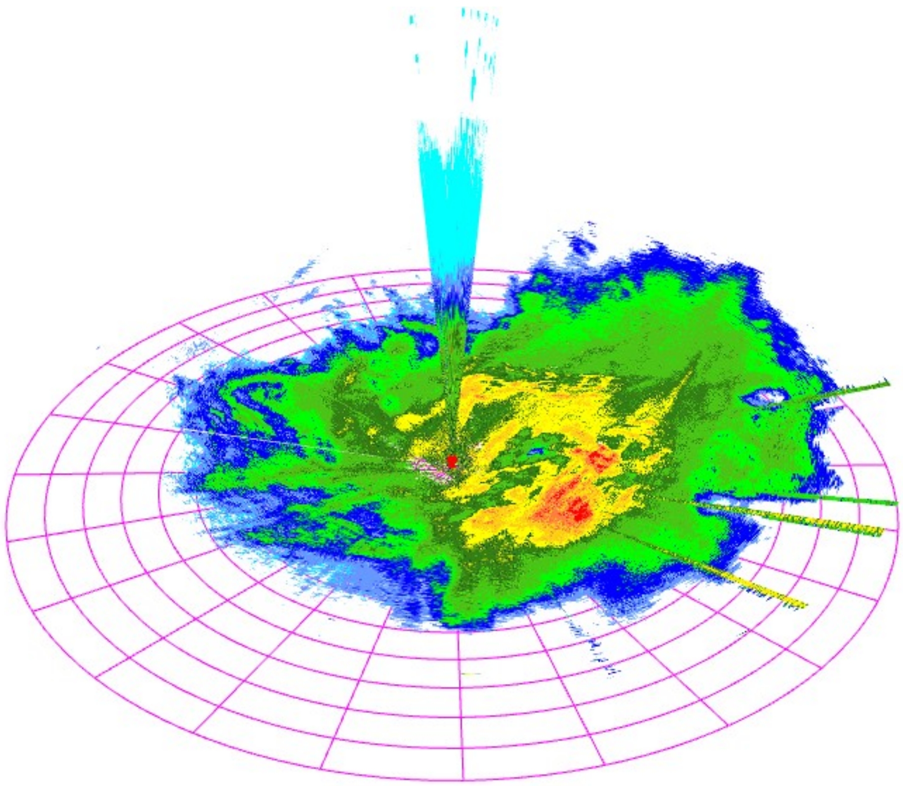


Fig. 2.5 Two cone-shaped scans are presented for elevation angles of 24.4° and 0.4°.

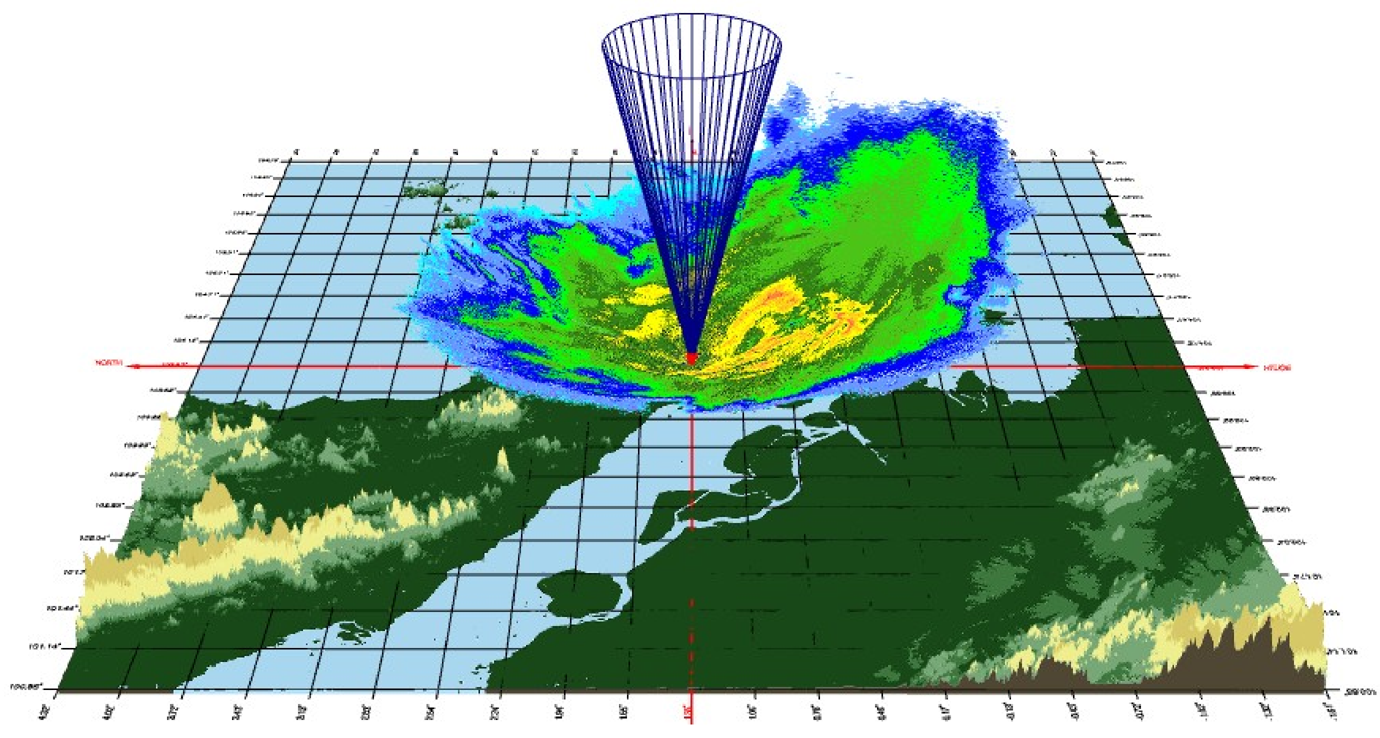


Fig. 2.6 Results for elevation angles of 11.3° and 1.2° are presented as a cone mesh and a cone respectively.

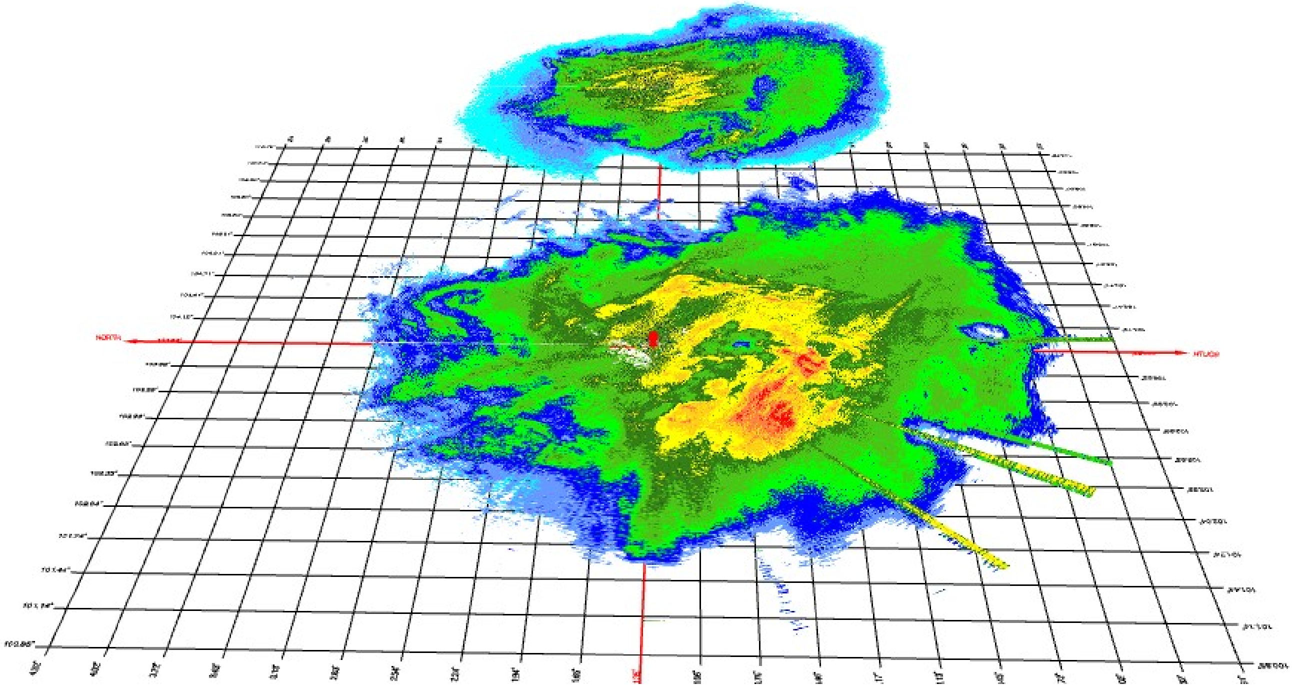


Fig. 2.7 Scanning results were obtained for elevation angles of 2.7° and 0.4°. The first scan is displayed as a plane, and the second is shown as a plane projection onto the surface of the Earth.

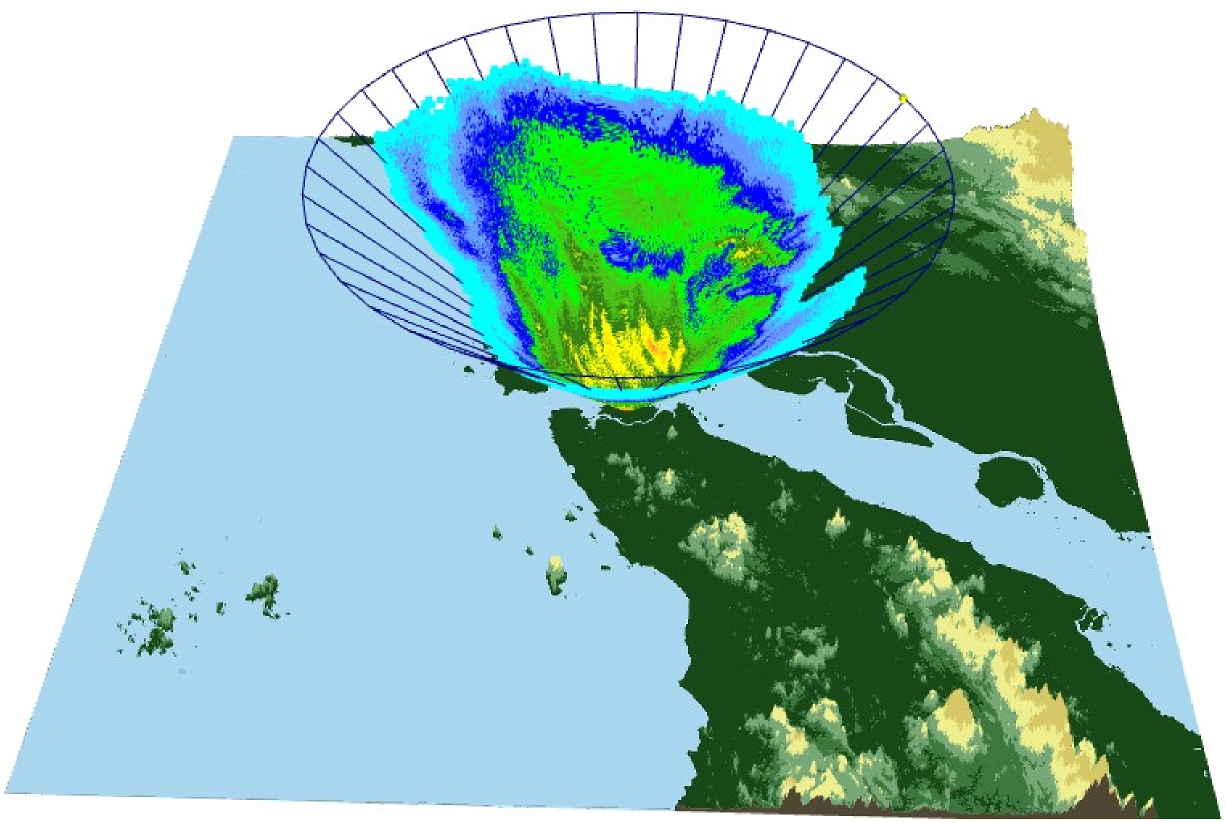


Fig. 2.8 Both sweeps used the same 2.7° elevation angle. The first scan is shown as cone points, and the second is displayed as a cone mesh.

When you double-click on any of the compared objects, a red dot will appear at the same position, and the following information will be displayed in the lower-left corner of the screen:

1) The value, name, abbreviation, and unit of measurement of the radar parameter at the double-clicked position.
2) The latitude and longitude of the selected object.
3) The distance between the selected point and the radar location.
4) The altitude of the selected object.
5) The elevation angle of the selected scan and azimuth angle from the radar position.

Distances from the radar to a specific point are calculated by taking into account the height of the object selected. To figure out the distance from the radar to the object's projection on the Earth's surface, you need to multiply the displayed distance by the cosine of the elevation angle.

In the given example, the weather object illustrated in Fig. 2.7 possesses the following attributes:

Reflectivity (DBZH): 8.5 dBZ
Coordinates: [-0.456°, 105.094°]
Distance: 246.18 km
Height: 5268 m
Elevation: 1.2°
Azimuth: 144.8°

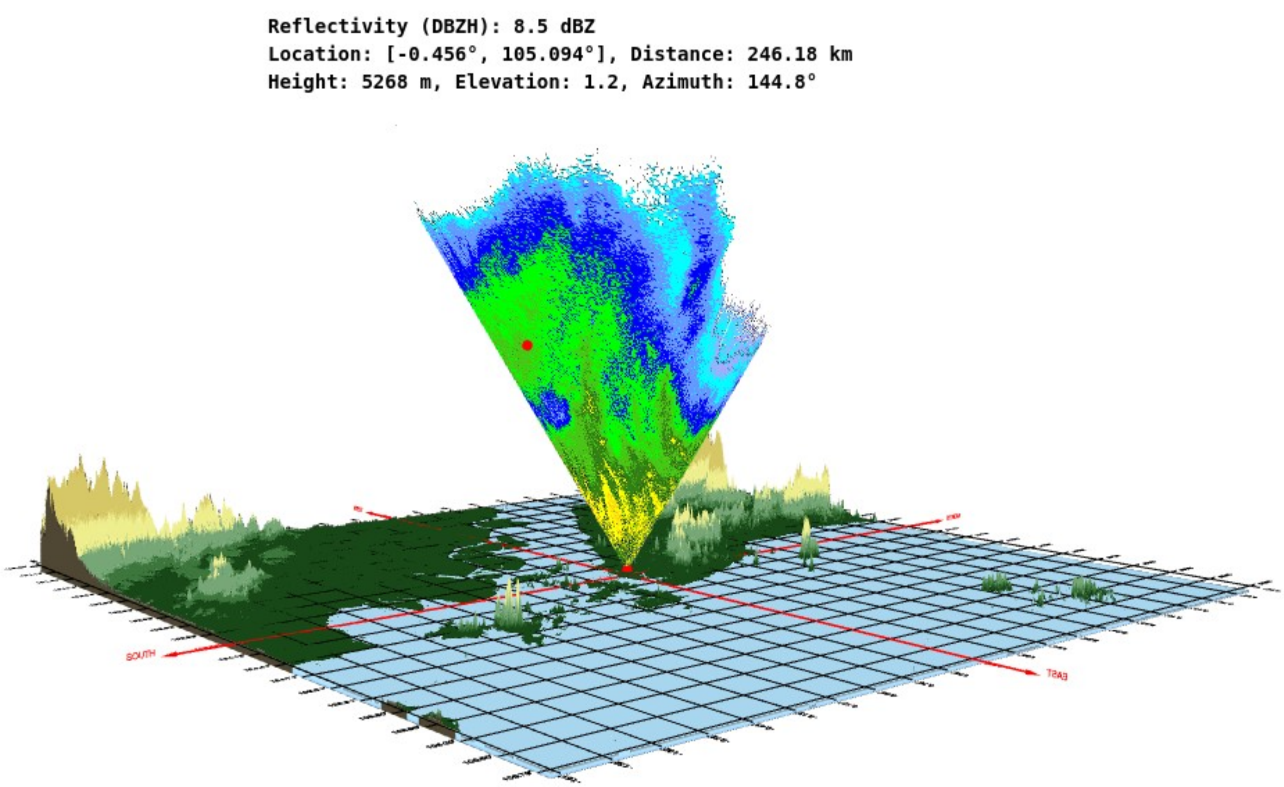


Fig. 2.9 The attributes of the object that has been selected and located within the scanning cone.

2.5.2 Vertical profile

This menu option is designed to show radar information from all scanning angles towards the chosen azimuth. The menu has two selectors for setting the azimuth angle (between 0 to 360 degrees) and the vertical profile display format (refer to Fig. 2.10):

1) **Plane**. Crossing half-plane from the radar position in the direction of a given azimuth.
2) **Points**. All the points where the reflected signal was detected from the selected azimuth's sweeps.
3) **None**. Hides the vertical profile image.

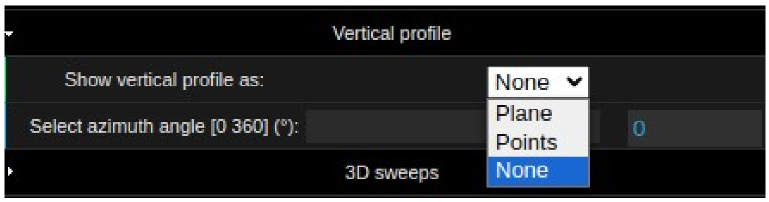


Fig. 2.10 Menu for managing vertical profile display parameters.

In Fig. 2.11, a vertical profile is shown as a crossing half-plane along an azimuth of 160° for the reflection coefficient at the following elevation angles: 24.4°, 20.2°, 16.6°, 13.7°, 11.3°, 9.4°, 7.7°, 6.4°, 5.3°, 4.4°, 3.5°, 2.7°, 2.1°, 1.6°, 1.2°, 0.8°, 0.4°.

Fig. 2.12 displays points that make up the vertical profile of the reflection coefficient along an azimuth of 100° for the same scanning angles.

When you double-click on the vertical profile surface, a red dot appears at the same position, and the following information displays in the lower-left corner of the screen:

1) The value, name, abbreviation, and unit of measurement of the radar parameter at the double-clicked position.
2) The latitude and longitude of the selected object.
3) The distance between the selected point and the radar location.
4) The altitude of the selected object.
5) The azimuth angle from the radar position.

Distances from the radar to a specific point are calculated by taking into account the height of the object selected. To figure out the distance from the radar to the object's projection on the Earth's surface, you need to multiply the displayed distance by the cosine of the elevation angle.

For example, the selected location on the plane of a vertical profile has the following properties (see Fig. 2.11):

Reflectivity (DBZH): 25.6 dBZ
Coordinates: [2.278°, 101.994°]
Distance: 101.01 km
Height: 2071 m
Azimuth: 160°

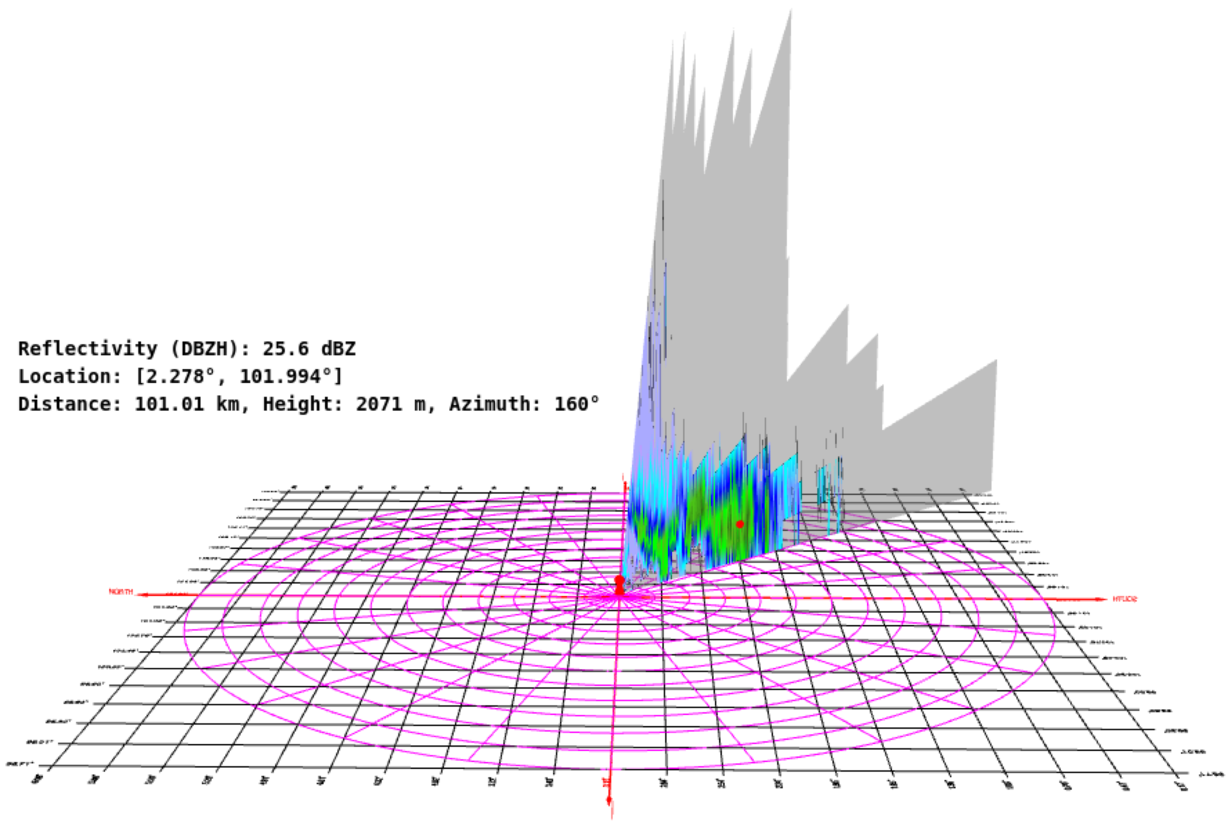


Fig. 2.11 Vertical profile of reflectivity coefficient as a crossing half-plane along an azimuth of 160°.

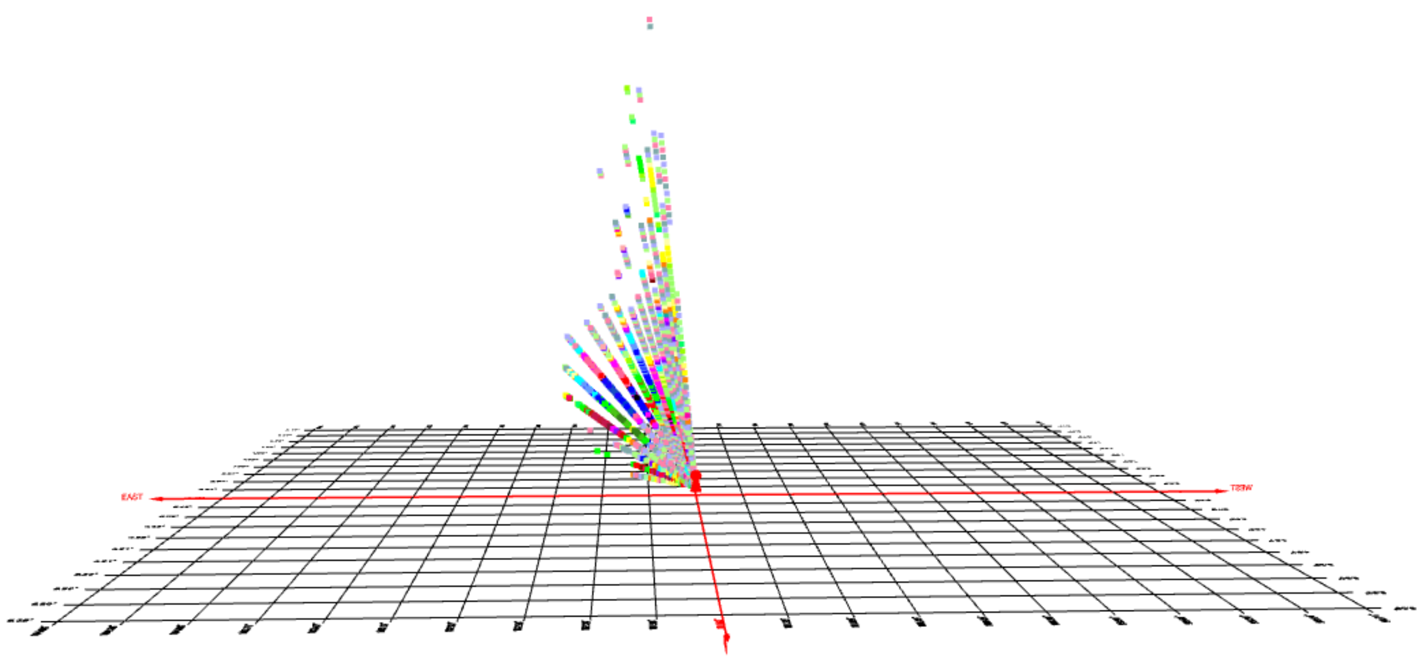


Fig. 2.12 Vertical profile of the reflection coefficient as points received along an azimuth of 100°.

2.5.2 3D sweeps

This menu block is used to display data from all available scanning angles. Available options for visualizing radar sweeps are shown in Fig. 2.13:

1) **Cones**. Data from all available radar sweeps are displayed as scan cones. See Fig. 2.14.
2) **Cone meshes**. Displays the scanning volumes of all radar sweeps. See Fig. 2.15.
3) **Planes**. Every scan is projected onto a plane and transferred to the maximum height at which the reflected signal was received this sweep. This display mode visually resembles a “fir” pattern. See Fig. 2.16.
4) **Projected planes**. All scans projected onto the plane of the Earth's surface. See Fig. 2.17.
5) **None**. Hides the images of all scans.

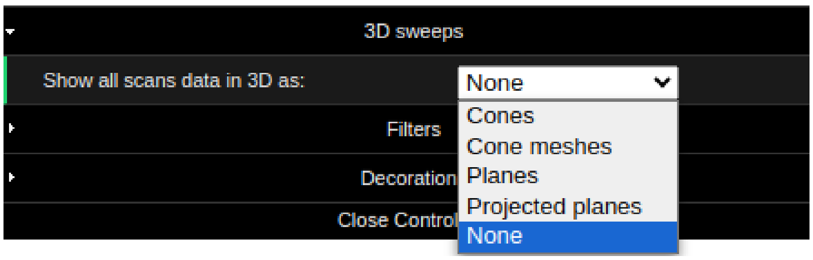


Fig. 2.13 Menu for managing the display parameters of all available radar scans.

When you double-click on any sweep, a red dot will appear at the same position, and the following information will be displayed in the lower-left corner of the screen:

1) The value, name, abbreviation, and unit of measurement of the radar parameter at the double-clicked position.
2) The latitude and longitude of the selected object.
3) The distance between the selected point and the radar location.
4) The altitude of the selected object.
5) The elevation angle of the selected scan and azimuth angle from the radar position.

In “**Cone meshes**” mode, the same parameters will be displayed, with the exception of point 1.

Distances from the radar to a specific point are calculated by taking into account the height of the object selected. To figure out the distance from the radar to the object's projection on the Earth's surface, you need to multiply the displayed distance by the cosine of the elevation angle.

For example, the radial velocity at a selected point has the following parameters (see Fig. 2.17):

Radial velocity (VRADH): 12.6 m/s
Coordinates: [2.799°, 101.892°]
Distance: 43.65 km
Height: 4375 m
Elevation: 5.3°
Azimuth: 148.0°

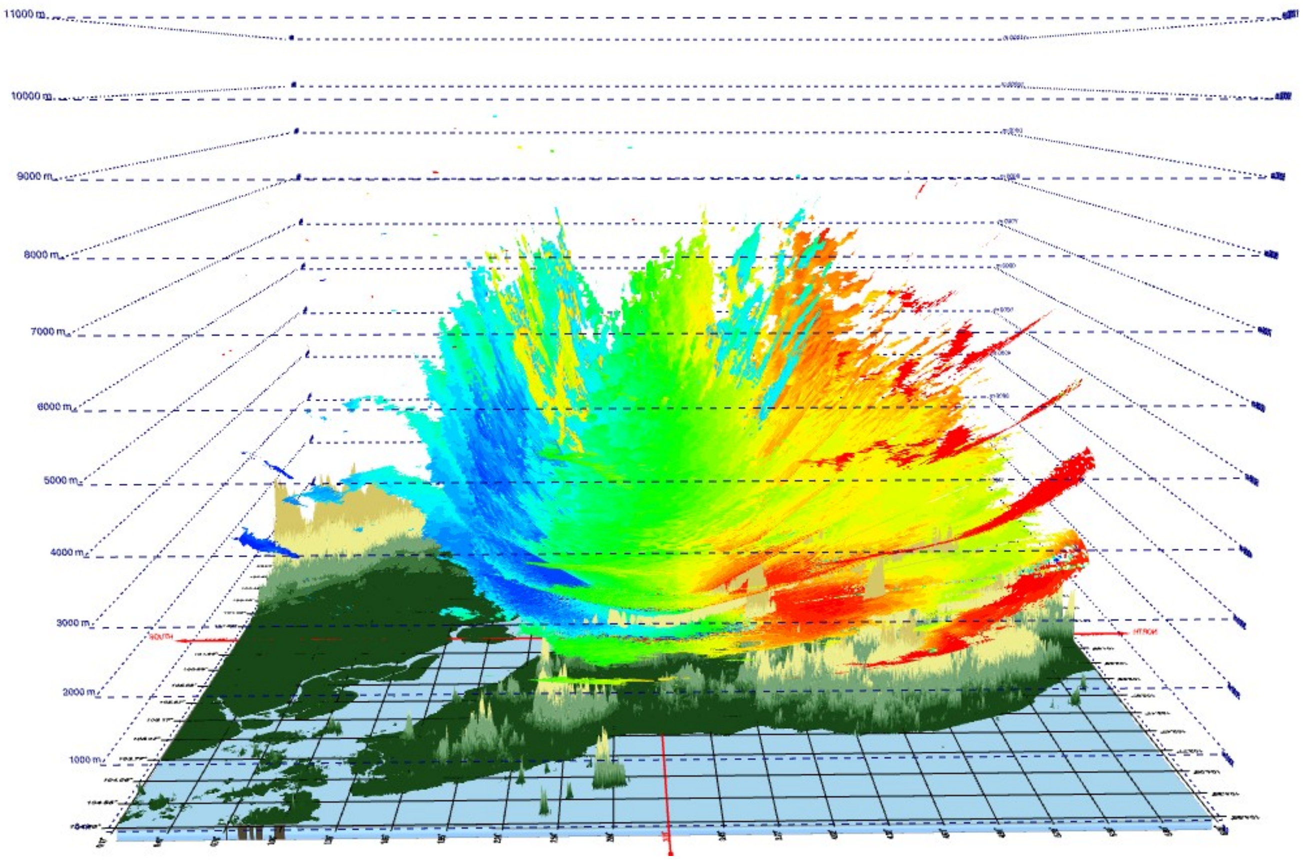


Fig. 2.14 Sweeps of radial velocity displayed as scanning cones.

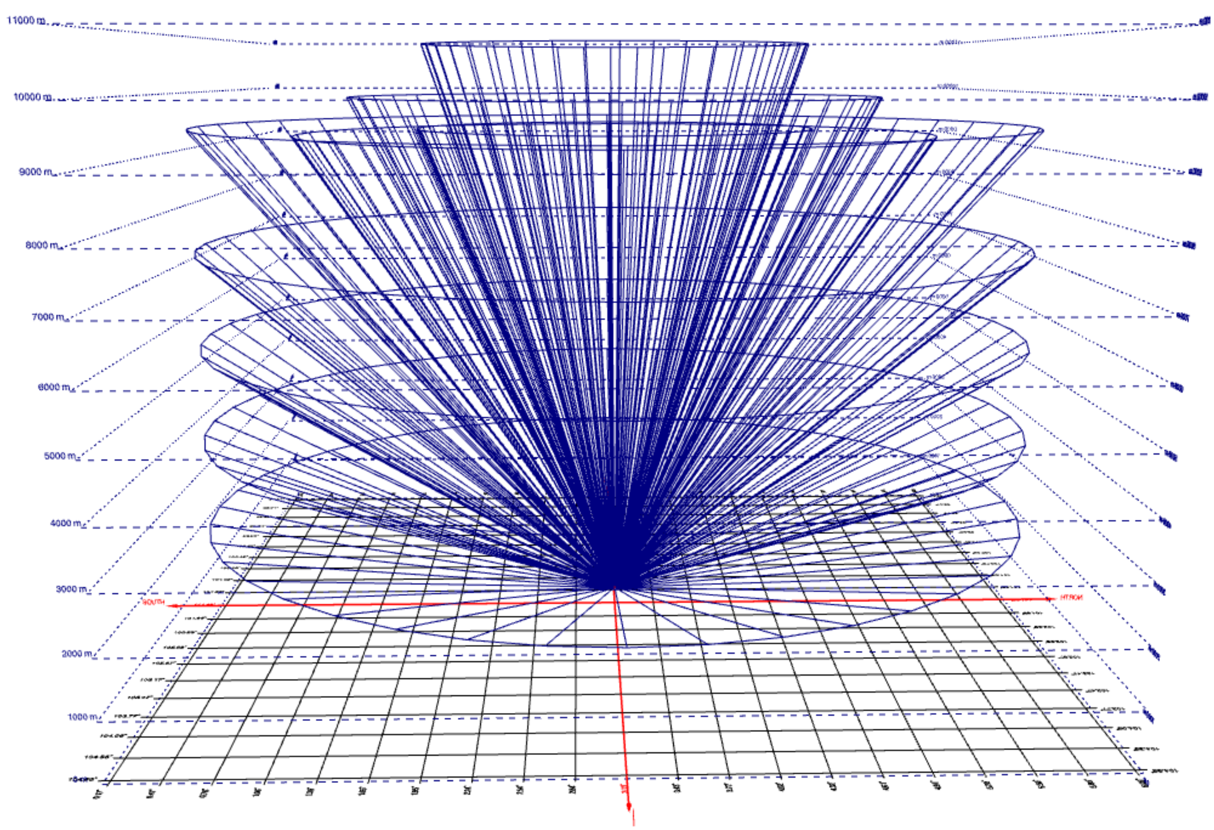


Fig. 2.15 Scanning volumes of all radar scans.

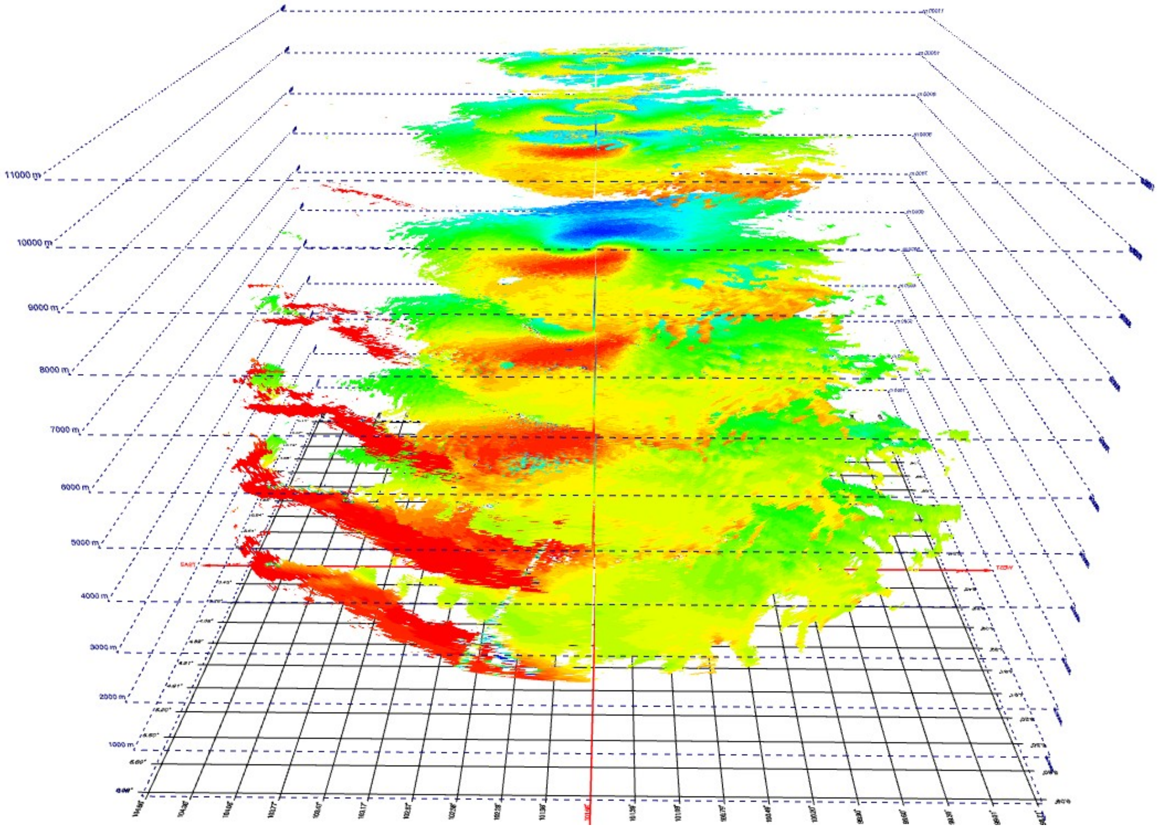


Fig. 2.16 Radial velocity scans, presented as planes.

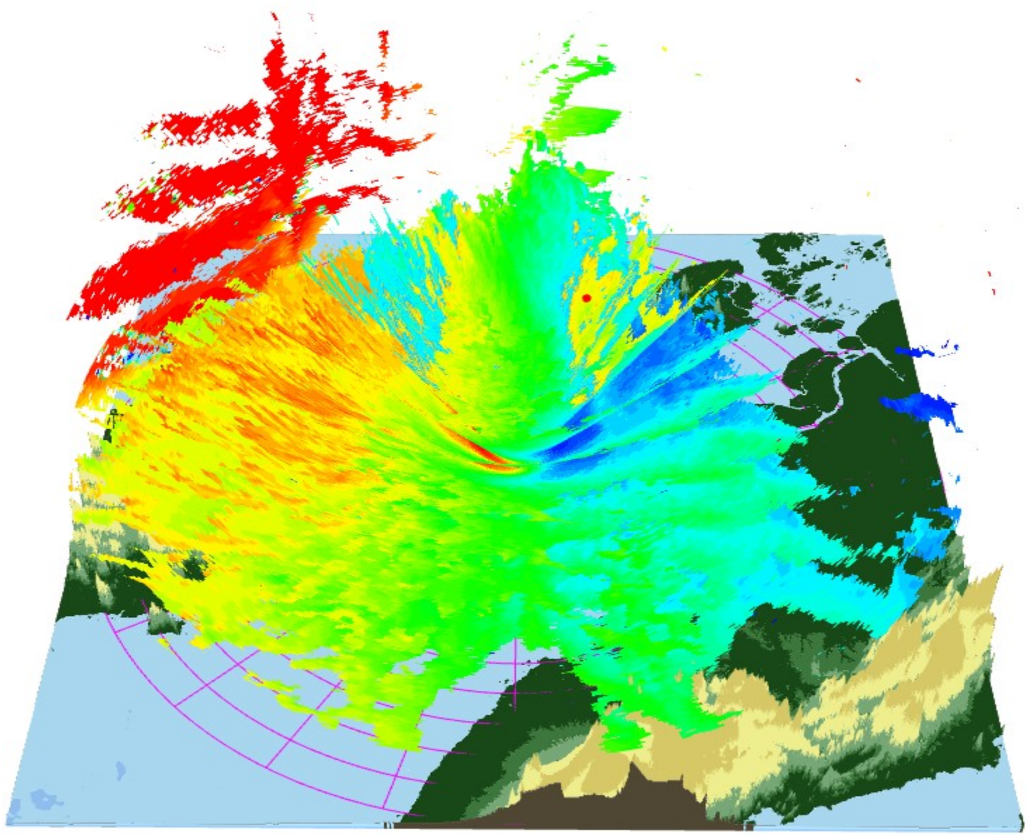


Fig. 2.17 Selection of a meteorological object by double clicking the mouse.

2.5.3 Filters

The filters menu is used for selecting and categorizing various parameters of radar. The available options in the menu are displayed in Fig. 2.18. These options include filtering by parameter value, where only data within the specified range is displayed. You can also filter by azimuth angle to display only objects lying in the specified sector. Additionally, you can filter by distance from the radar and by the height of meteorological objects or solid bodies.

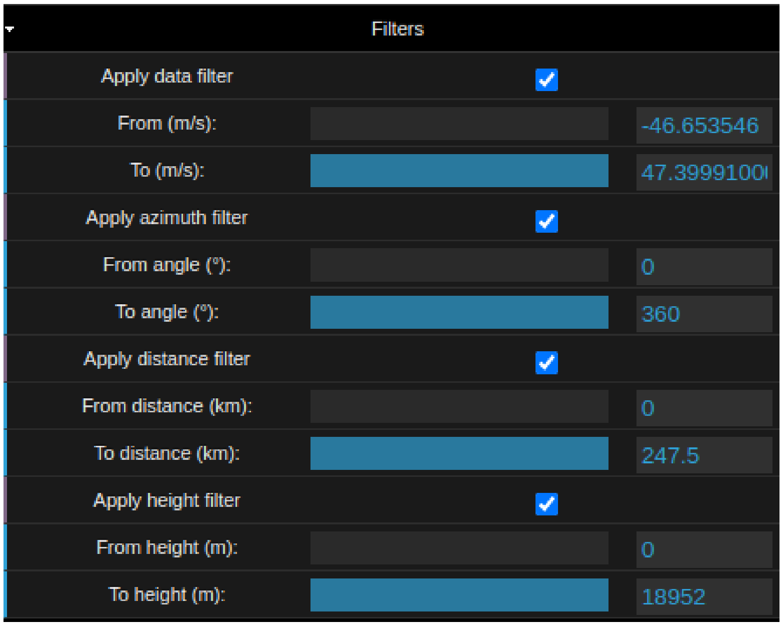


Fig. 2.18 Filters menu.

Filtering can be applied to any display mode and can be used individually or in combination. The filters can be applied to radial velocity of the moving objects, as shown in Fig. 2.19 to 2.23.

In Fig. 2.19 a filter by value is applied. The radial velocities are displayed as scan cones. Objects moving with a radial speed less than 20 m/s will not be shown.

Fig. 2.20 shows the scans of radial velocity in the sector from 230° to 340° in azimuth. All the data are presented in the form of planes.

In Fig. 2.21 a distance filter is applied. The visible range is from 100 to 200 km. The data shown as the a projection onto the Earth's surface.

Fig. 2.22 shows one sweep of the radial velocity. The sweep is displayed as a scanning cone having elevation angle of 2.7°. Filter by height from 1500 to 5000 m is applied.

Filters may be combined as in Fig. 2.23. Here two filters were applied together: by distance and by height. Only objects located at the range from 50 to 200 km of radar position and the altitude from 1500 to 5000 m are displayed. The data sweeps are shown as cone scans.

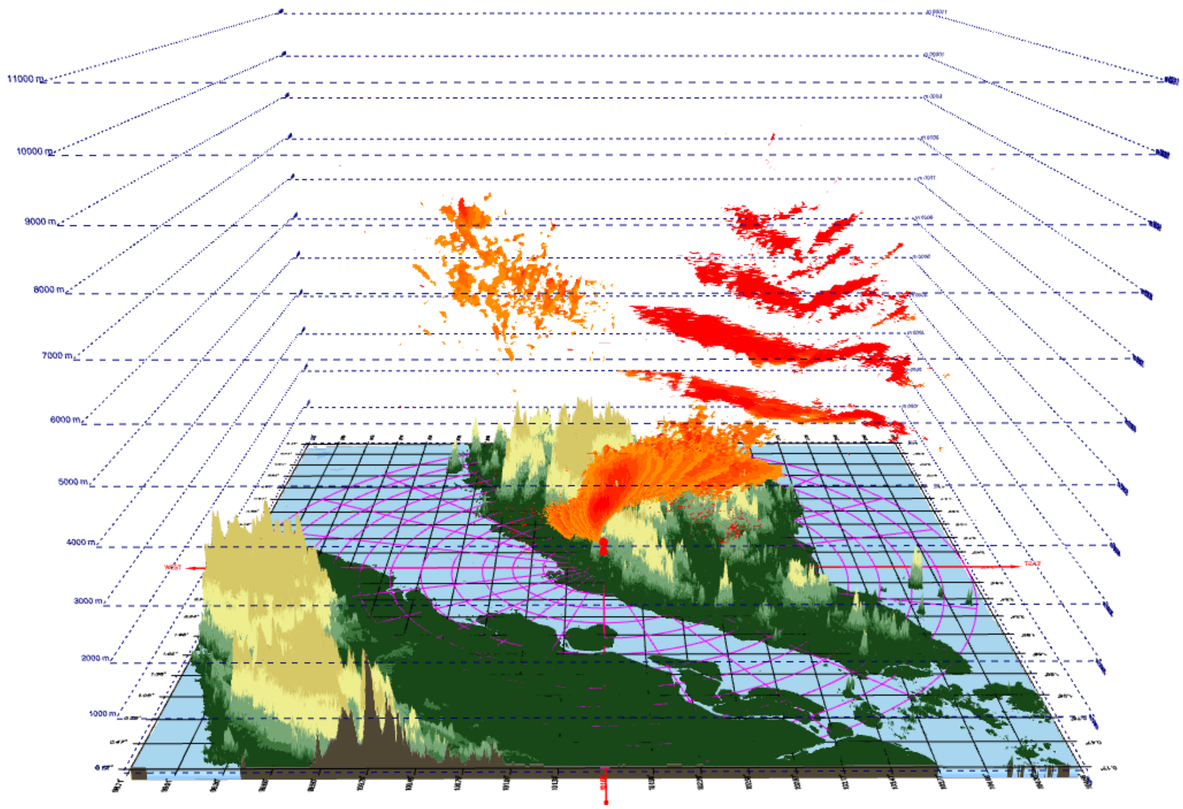


Fig. 2.19 Filtering by value of radial velocity.

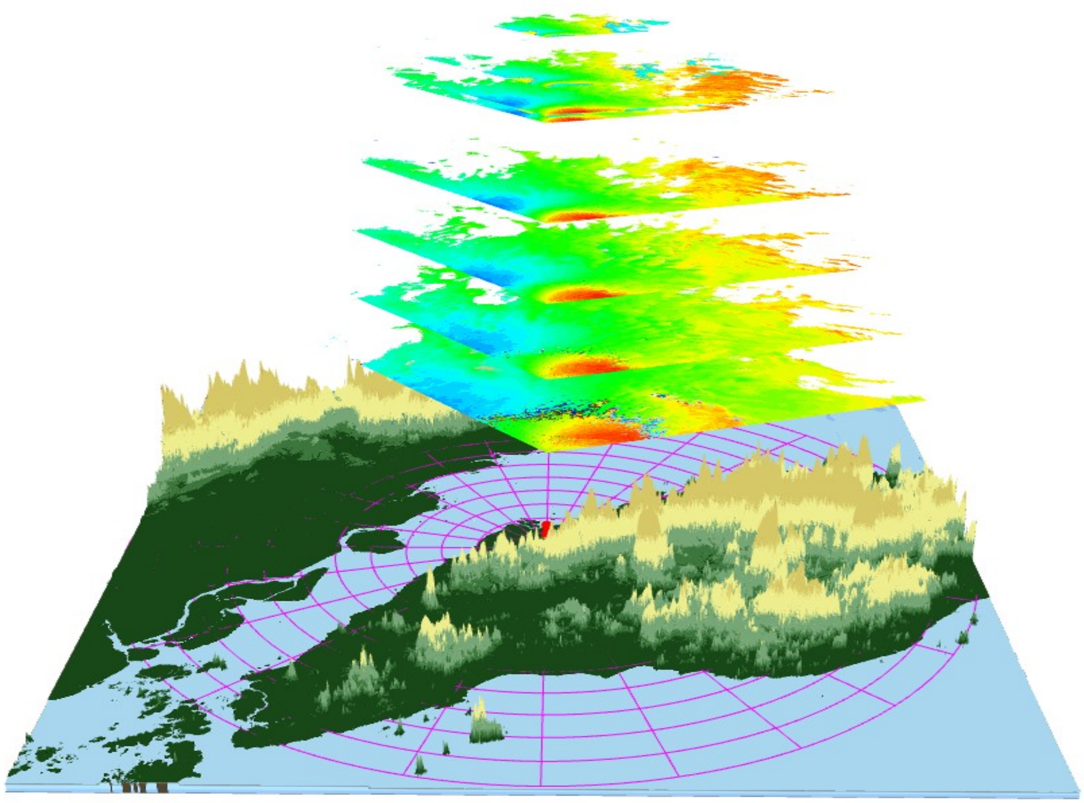


Fig. 2.20 Filtering by azimuth angle.

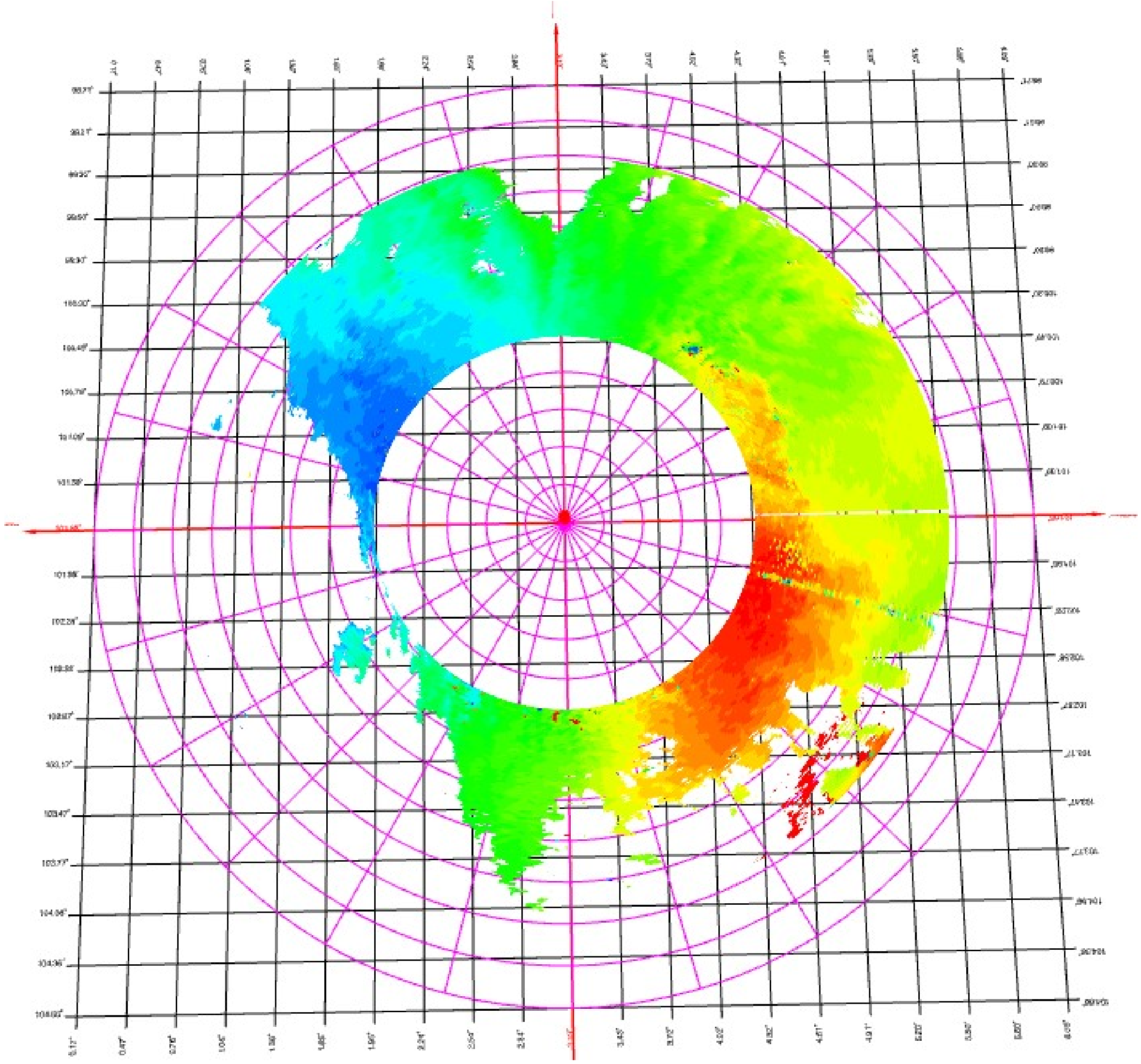


Fig. 2.21 Filtering by the distance from the radar position.

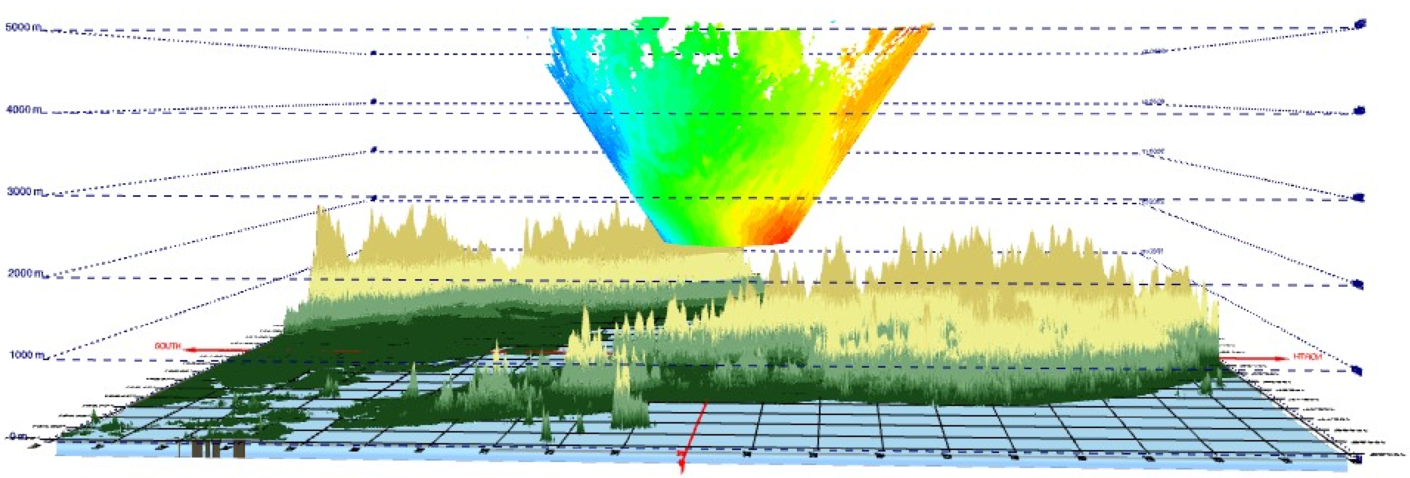


Fig. 2.22 Filtering by height.

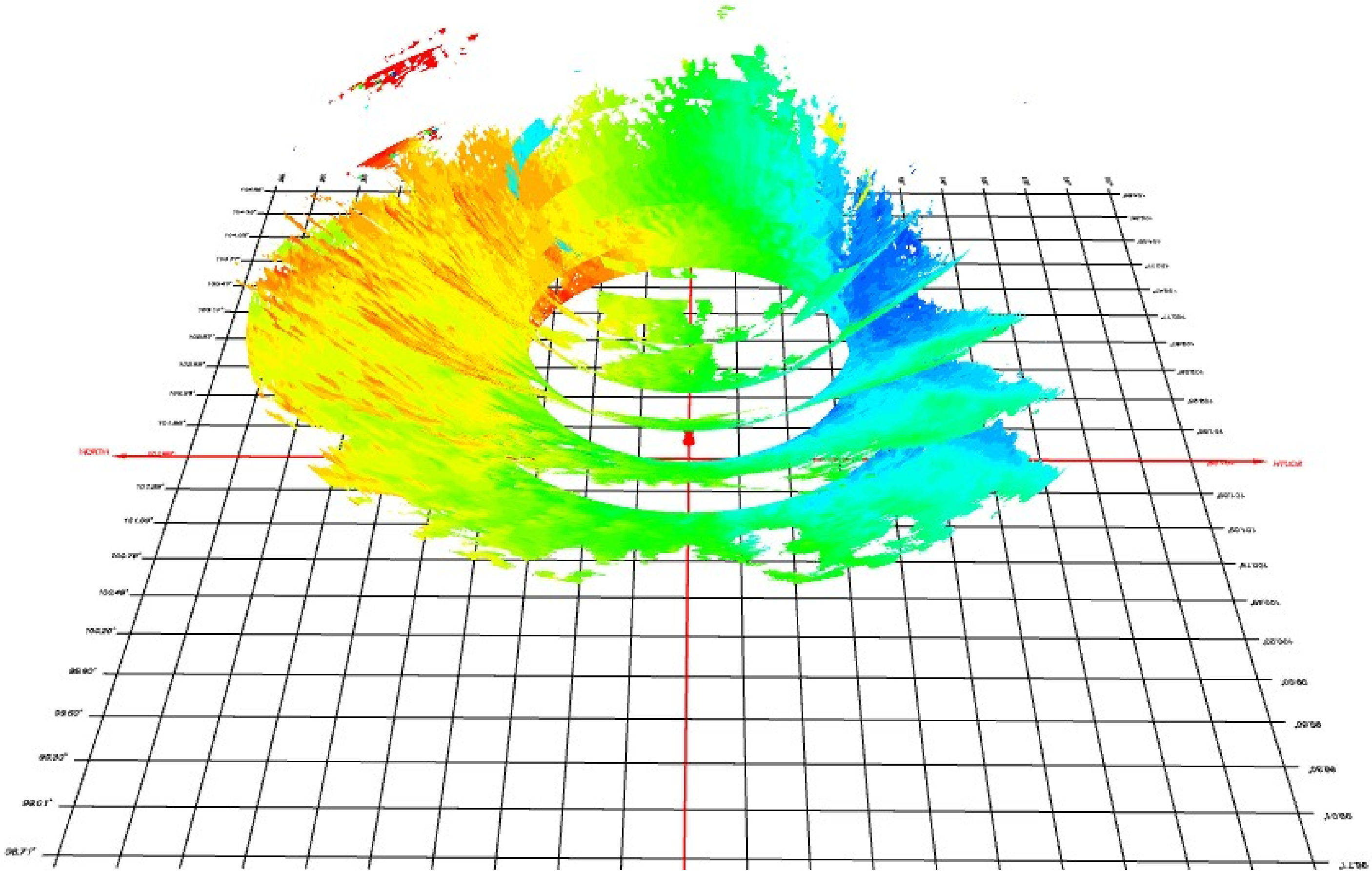


Fig. 2.23 Combined filtering by height and by the distance from the radar position.

2.5.4 Decorations

The decorations menu contains a number of options to display coordinate grids, change vertical scale, select the program interface language, etc. The list of section parameters is shown in Fig. 2.24:

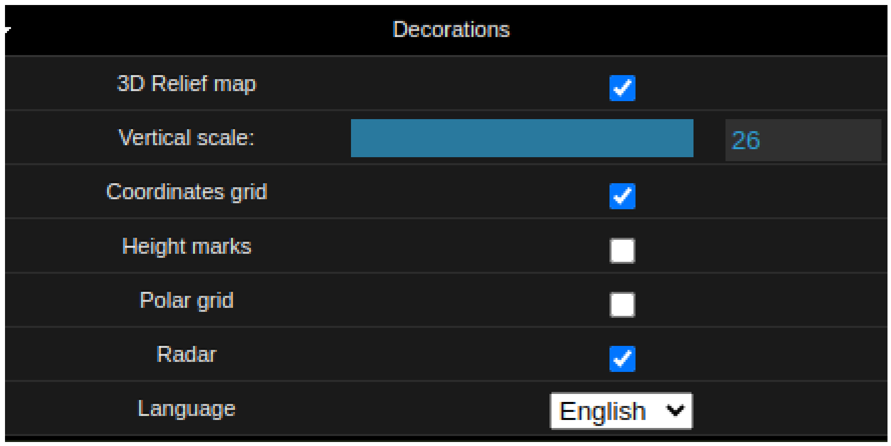


Fig. 2.24 Decorations menu.

1) **3D relief map**: displays or hides the 3D terrain within the radar range.
2) **Vertical scale**: shows how much vertical heights are stretched relative to horizontal distances.
3) **Coordinates grid**: defines geographic coordinates with equal increments of latitude and longitude, and also sets the north-south and west-east directions.
4) **Height marks**: shows a vertical grid from sea level to the highest altitude from where the reflected signal was received.
5) **Polar grid**: displays or hides polar coordinates on the Earth's surface.
6) **Radar**: displays or hides the radar location.
7) **Language**: lets you select the program interface language.

Usually, a radar's distance range significantly exceeds the maximum height of the scan. For example, a typical weather radar has a range of 240 km and a maximum altitude of about 20 km. At a 1:1 scale, almost all vertical coordinates will be visually located near the surface of the Earth. Fig. 2.24 shows that on a 1:1 scale, the 3D terrain is practically identical to a flat surface.

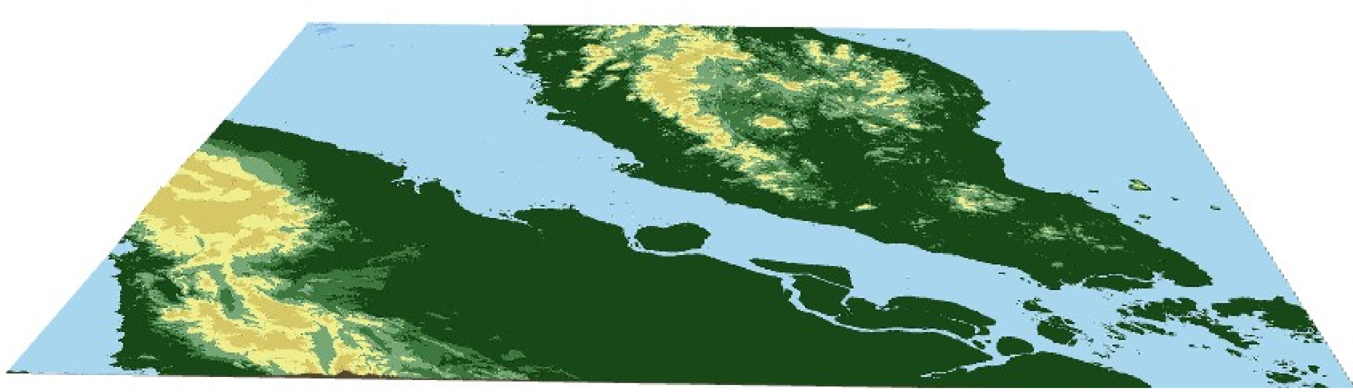


Fig. 2.24 3D terrain with 1:1 vertical scale.

Increasing the vertical scale allows you to better analyze and compare altitudes of meteorological objects and solid bodies. Fig. 2.25 shows the same terrain, but at a vertical scale of 23:1.

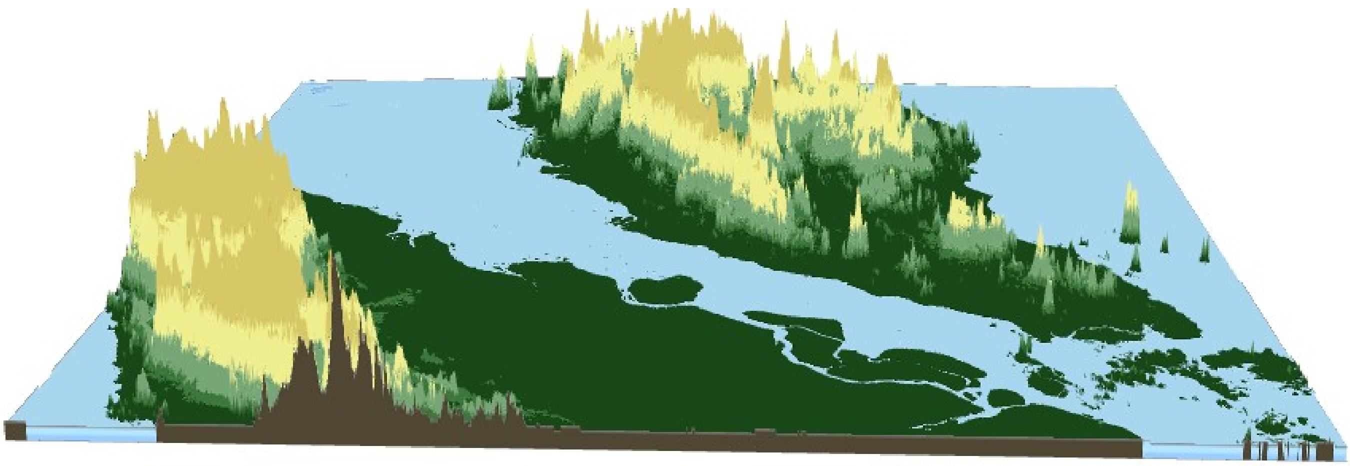


Fig. 2.25 3D terrain with 23:1 vertical scale.

Height markers help you find the altitudes of objects and the vertical coordinates of the terrain. Fig. 2.26 shows the 3D terrain with an elevation grid.

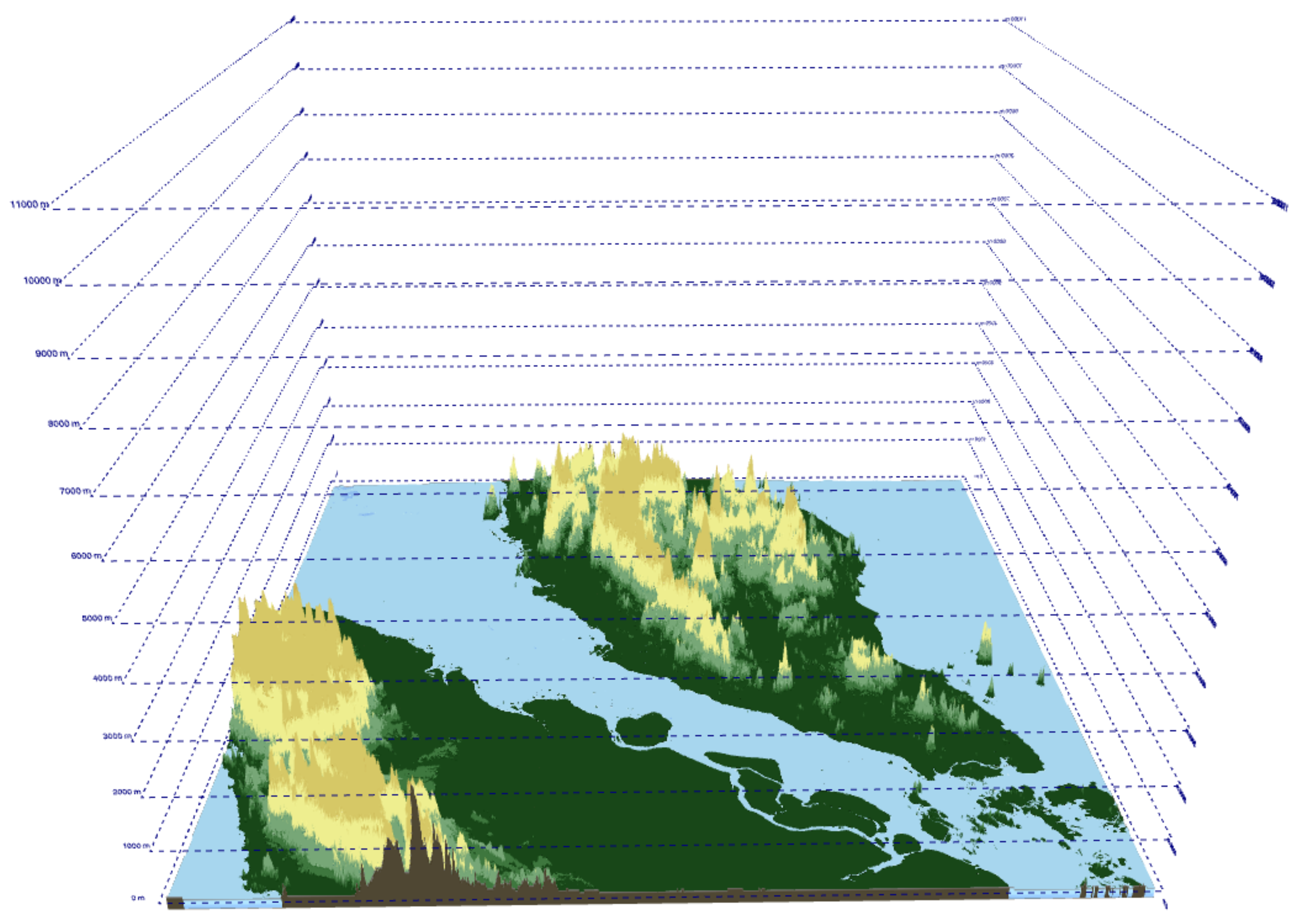


Fig. 2.26 3D terrain with height marks on a vertical scale of 23:1.

The coordinate and polar grids are shown in Fig. 2.27. The dimensions of the coordinate grid cells in latitude and longitude are 0.3°. The polar grid distance step is 20 km, and the azimuth angle step is 15°.

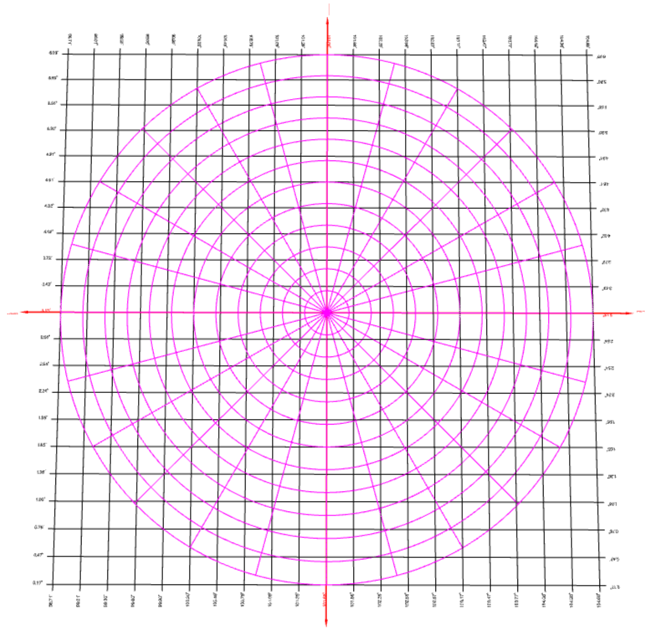


Fig. 2.27 Geographical and polar grids.

You can see the full set of decorations elements, including the radar, surrounding terrain, elevation markers, coordinate and polar grids, in Fig. 2.28.

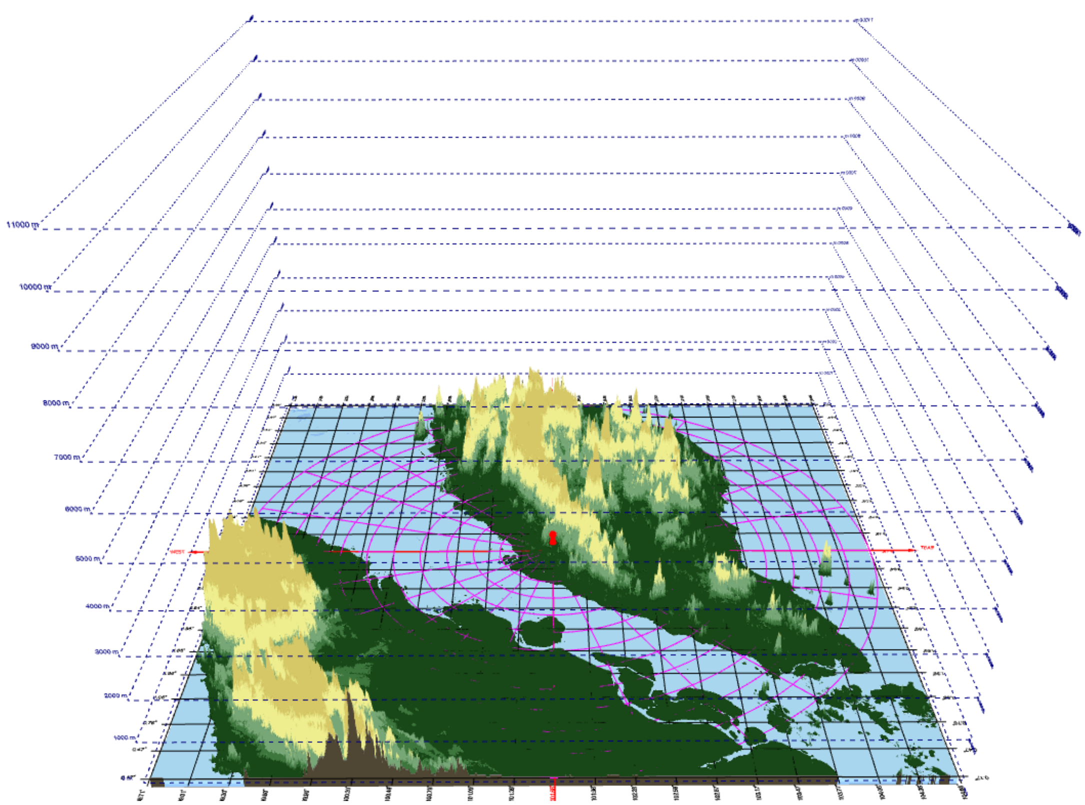


Fig. 2.28 3D terrain with height marks, geographical and polar grids and radar.

Appendix 1. List of supported parameters

Parameter name and abbreviation	Data range and unit	Standard palette
Reflectivity (DBZH)	[0, 70] dBZ	Reflectivity
Uncorrelated total reflectivity (TH)	[0, 80] dBZ	Reflectivity
Differential reflectivity (ZDR)	[-8, 8] dB	Reflectivity
Radial velocity (VRADH)	[-100, 100] m/s	Wind speed
Spectral width of radial velocity (WRADH)	[0, 30] m/s	Wind speed
Differential phase (PHIDP)	[-180, 180]°	Phase
Uncorrelated reflectivity (UPHIDP)	[-180, 180]°	Phase
Specific differential phase (KDP)	[-5, 5] °/km	Phase
Correlation coefficient (RHOHV)	[0, 1]	N/A
Signal quality index (SQIH)	[0, 1]	N/A