



Weather  Sentinel™

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Weather Sentinel™: Visualizing and analyzing the effects of weather in Satellite Tool Kit

Anthony Faulds
President & Senior Engineer

Introduction

Trinnovations has developed a weather tool referred to as the Weather Sentinel™. The Weather Sentinel™ enables users to effectively visualize and analyze the effects of predicted, real-time, and historical weather data in AGI's Satellite Tool Kit (STK). The Weather Sentinel™ is specifically built to interact with STK through STK/Connect, allowing users to visualize and analyze weather data in WSR-88D Level I and GRIB (GRIdded binary data) weather formats.

There are a variety of important features included in the Weather Sentinel™. These tools increase the utility of STK by allowing users to factor

in the implications of weather on orbits, vehicles, and facilities, and their respective paths (e.g., movement and communication). The current features of the Weather Sentinel™ include the following:

- Reporting tools
- 2D visualization
- 3D visualization
- Vehicle path visualization
- Assisted weather data download
- Weather data management
- Line-of-sight calculations
- Communications interference

Weather Data Formats

WSR-88D Level 1

WSR-88D Level 1 data is a Doppler radar format that measures reflectivity data, which shows the radar's signal reflected back to the radar by liquid and frozen droplets in the atmosphere. Base reflectivity data is gathered at all elevation angles surveyed in each volume scan, but only four of these elevation angles (tilts 0.5, 1.5, 2.5, and 3.5 degrees) are available to users outside the National Weather Service.

dBZ levels correspond to levels of precipitation intensity in terms of inches of rainfall per hour. The higher the dBZ level, the more intense the precipitation; they are directly proportional. "dBZ" stands for decibels of Z, Z being the reflectivity factor. The higher the reflectivity factor, the heavier the rainfall. This scale is logarithmic, so there is no factor one can use to multiply the dBZ level and arrive at the corresponding rainfall rate. Figure 1 shows approximate equivalents of dBZ and rainfall rates in inches per hour. Reflectivities in the range between 5 dBZ and 75 dBZ are detected when the radar is in precipitation mode. Reflectivities in the range between -28 dBZ and +28 dBZ are detected when the radar is in clear air mode.

dBZ level	Rainfall in inches/hour Precipitation Intensity
10 dBZ < .004	Very light rain or light snow
20 dBZ ~ .01	Light rain or moderate to heavy snow
30 dBZ ~ .08	Moderate rain or sleet showers
40 dBZ ~ .40	Moderate to heavy rain or sleet showers
50 dBZ ~ 1.75	Heavy thunderstorms
60 dBZ ~ 8.00	Intense to severe thunderstorms with hail

Figure 1. dBz to rain rate

Equation 1, shown below, demonstrates how to convert from dBz to inches of rain per hour.

$$\text{inches/hr} = (10^{\text{dBz}/10} / 200)^{0.625} \quad (1)$$

This data is compressed and made available through National Oceanic and Atmospheric Administration (NOAA) ftp sites in the form of WSR-88D Level 1 format. Each file contains one site at one time step, with over 200 sites located throughout the United States.

The Weather Sentinel™ allows users to utilize this format of weather data in visualizing weather as it applies to a variety of vehicles, facilities, scenarios 2D and 3D window, and communication attenuations. In addition, this data allows for analysis through reporting and adds detailed information to rain attenuation.

GRIB

GRIB stands for GRIdded Binary, which is an efficient method for transmitting and storing large volumes of gridded data. By packing information into the GRIB code, messages can be made more compact than human readable files like comma delimited, xml, or plain text bulletin files. GRIB can equally well serve as a data storage format, generating the same efficiencies relative to information storage and retrieval devices.

Unlike WSR-88D, GRIB can contain any type of weather information since it is simply a general compression technique for gridded data. NOAA, along with several other services, provides free and paid ftp locations to download weather data in this format. Several sites, including the Rapid Update Cycle, use current and past weather conditions to predict future weather conditions. These predictions are available as GRIB files.

GRIB data is stored in several different projections, including latitude/longitude, Mercator, Gnomonic, Lambert conformal, Gaussian latitude/longitude, polar, orthographic, and user defined grids. All of these projections are translated by the Weather Sentinel™ to render useful details in STK.

Features

Reporting Tools

STK Requirements – STK/PRO, STK/Connect

Applying weather to a report is similar to Vehicle Path (discussed in a later section), but can be applied to facilities also. The report feature attaches weather data to a vehicle as a report. Weather Sentinel™ linearly interpolates all weather data in four dimensions. The dimensions are latitude, longitude, altitude, and time. The reporting function on vehicles and facilities grabs the time and position information. For vehicles, this involves grabbing points in between waypoints and calculating the weather using the 4D interpolation scheme. For facilities, the position of the facility is used and 3D interpolation (latitude, longitude, and altitude) is calculated at each time step of the weather.

The reports generated can be viewed alongside, or in the same window as STK native data. With this data, the user can manipulate the data using the report tool, graph tool, dynamic display tool, or strip chart. With these tools, weather phenomena and their maximum, minimum, and averages can be calculated over the time period of interest. Using STK/VO, users can display the report dynamically in the VO window to effectively show the 3D vehicles and wind speed, for example, in the same window.

2D Visualization

STK Requirements – STK/PRO, STK/Connect

Using STK's 2D visualization window, the Weather Sentinel™ allows users to visualize weather data as it is applied to orbits, vehicles, and facilities. The Weather Sentinel™ creates color images of weather that cover the globe and attaches them to the 2D window. The weather data visualized can be vector or scalar. The tool applies color regions according to the color scale defined in the Weather Sentinel™ GUI. For this option, the 4D interpolation scheme is not used. The weather is plotted at the resolution presented in one of the formats mentioned above. The 2D visualization is time animated so that the play feature of STK can be used and a more global picture of weather can be visualized.

3D Visualization

STK Requirements – STK/PRO, STK/Connect, STK/VO

The Weather Sentinel™ provides 3D visualization in STK using various types of data related to weather, such as scalar data (e.g., temperature) at multiple altitudes, vector data (e.g., wind velocity) at multiple altitudes, and clouds at multiple altitudes. Using STK primitives, weather objects are shown

by the Weather Sentinel™ in the VO window next to vehicles and facilities. One of the big advantages for 3D visualization is that weather can be shown at a specific altitude or multiple altitudes. Similar to the 2D visualization of weather, data is shown at the resolution in the data files so any point shown on the globe is a point in the weather file.

Vehicle Path Visualization

STK Requirements – STK, STK/Connect

Weather analysis along a vehicle path, combined with the visualization of gridded data, makes the Weather Sentinel™ a useful tool in mission planning. With user-defined color scales, paths can be displayed demonstrating the weather a vehicle will encounter when it arrives at a specific portion of the vehicle path. This feature of the Weather Sentinel™ provides users with information needed to make decisions regarding vehicle paths, and changes to those paths, based on the predicted weather to be encountered. All of this is accomplished without animating STK. To compute this data, the 4D interpolation is used at points in between and including waypoints. In a couple seconds, an immediate visual sign of what weather the vehicle will encounter is displayed.

Depending on the source and weather file type, this visualization can be used for historical reasons (i.e., to study past missions) or with forecasted weather for mission planning. This, combined with STK's new feature of quickly moving waypoints, makes it simple to plan around weather.

Weather Download

STK Requirements - None

Many websites offer weather data; however, these data files are often difficult to find and there is no consistent naming convention or extensions for these types of files. The Weather Sentinel™ offers a feature that aids in this confusion. Most users interested in weather are not weather experts, but are interested in how weather may affect their mission or scenario. The Weather Sentinel™ has a search feature that helps to find relevant weather in a region or weather type. The search engine spans across many weather sources. The search engine describes the weather sources, how to download the files, what the naming convention is, and uses in STK.

The Weather Sentinel™ can be used to load weather from downloaded data, or data that may be found in a secure area. The Weather Sentinel™ conforms to the data format standards and therefore can read files that are in that format regardless of source.

Weather Data Management

STK Requirements - None

The Weather Sentinel™ allows users to store a weather database, which can be applied to STK. The storage of this database is convenient because it enables the user to organize weather files by naming and assigning icons to each one. This increases the effectiveness of the user-interface in applying many different weather files to STK. The tool is optimized so that when weather is applied to STK, intermediate files are created. These intermediate files are not recreated until something about the weather has changed. This is similar to a just-in-time compiler. The first time weather is applied it may take about a minute, but subsequent use of that weather takes only seconds.

In addition to these organization features, the Weather Sentinel™ database has analysis and modification features that allow users to change the color scales applied to weather files. Various types of weather can have different scales applied to them, and a mission's tolerance to these scale values can vary as well. For example, one inch of snow is likely to affect a mission differently than one inch of rain, especially as it relates to a vehicle versus a facility. Specifications can be made to identify the types of weather, and their respective levels, most applicable to the analyses being conducted. Latitude, longitude, altitude, and time extents are also shown.

Another unique feature of the Weather Sentinel™ is the ability to specify the value and color of missing data. For visualization and analysis, this condition determines what will be displayed if the weather data has no value corresponding to a specific location and time. If this value is picked wisely, it will stop the skewing of data in reports, and the color for missing data is a visual cue that the weather is unknown.

Line of Sight Calculations

STK Requirements – STK/PRO, STK/Connect

STK can effectively calculate the line of sight between objects. However, one disadvantage to these calculations is the lack of consideration for the impact weather may have on the line of sight. Clouds, wave heights, and precipitation are examples of weather phenomena that can affect visual contact between objects. The Weather Sentinel™ contains a feature to add weather to STK's access calculation for line of sight to effectively incorporate this information into analyses.

When using Weather Sentinel™, a custom plug-in is invoked in STK that calculates the line of sight. There are two different weather types that

are currently handled by the tool. One type is clouds, which is usually found in GRIB files as cloud tops, cloud bottoms, or percentage of cloud cover. The other type is visibility, which is also found in GRIB files and is given in meters of visibility. For cloud tops and bottoms, visibility is calculated as to whether the line connecting the TO and FROM objects goes through a cloud. This also includes if the TO or FROM object is located in the clouds. The percentage of cloud cover is calculated using the same method and is passed back through the constraint in STK. The default is 50% visibility, but this can be manually changed in STK so that it is applicable to the analysis. The other file type, visibility, is calculated finding each object's visibility and the distance between them, then using the shortest visibility to determine whether there is line of sight or not. This plug-in works in conjunction with other constraints built into STK. Therefore, users have the power of use terrain masking, az-el masking, sun angle, etc., along with cloud and visibility data.

Line of sight calculations are an on/off capability. Weather Sentinel™ provides data that can be queried using the constraint reports to find the exact percentage of cloud cover, but when line of sight is calculated in STK, there is no partial line of sight. More advanced connection information can be found in the communication interference feature.

Communications Interference

STK Requirements – STK/PRO, STK/Connect, STK/Comm

Similar to the feature of calculating line of sight, STK has plug-ins to add information to communication calculations. When applying weather to the communication layer, a variety of variables may be affected, such as received power, bit-error rate, and signal-to-noise ratio. The Weather Sentinel™ uses the rain attenuation model already in STK, but applies actual inches of precipitation as opposed to yearly averages. The current models include Crane and ITU rain models. The WSR-88D format is one of the best freely available data files for inches of rain per hour. These detailed rain rates are calculated along the path of the communication link between the FROM and TO object. In other words, using historical, present, or predicted weather data, communications interference calculations can be made with greater accuracy for a variety of precipitation types using the Weather Sentinel™.

This plug-in affects both radar and radio frequency communications, adding to the attenuation models in STK or used in place of those models. This, like the line of sight constraint, is used in combination with STK's other loss models to calculate power received, bit-error-rate, and signal to noise ratio.

STK Integration

How tightly is Weather Sentinel™ integrated into STK? The Weather Sentinel™ does everything through STK/Connect, a TCP/IP communication protocol to control STK. With respect to the different features mentioned above, the purpose of Weather Sentinel™ is to not duplicate features of STK, but add weather data to an already powerful tool. When available, the reports are brought over in native STK units. A change in the STK global units will automatically convert Weather Sentinel™ data. The weather data can be viewed along side native STK reports and any other data imported into STK. The 2D and 3D weather are shown directly in STK and is visualized along side 2D and 3D STK objects. For constraints and communications, these plug-ins add to the built-in STK calculations and any other third-party or custom plug-ins.