CHAPTER XX

StormGen: A Proposed Solution to Weather Simulation in NextGen Research

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ABSTRACT

Next Generation Air Transportation System (NextGen) concepts demand that both predicted and observed weather data are assimilated into air traffic management decision making. Consequently, research that evaluates concepts concerning weather decision making in NextGen requires the use of these weather data in the simulation environments. Current sources of real-world 3D convective weather data are often sparse, leave large coverage gaps, and are not constructed to meet specific research and concept evaluation requirements. As a result, there is a strong need for a simple and versatile tool that can be used for generating tailored, yet realistic weather for simulation-based research. StormGen, the software tool showcased in this paper, has been designed to produce convective weather systems for use in NextGen airspace simulations. StormGen provides a graphical user interface for the construction and placement of storm cells anywhere in a simulated contiguous United States airspace. StormGen functions support morphing of storm cells between different sizes, shapes, altitudes, positions, and intensities over time. The produced weather objects can be exported in multiple formats for use by other

simulation components, such as the Multi Aircraft Control System (MACS), the Cockpit Situation Display (CSD), and out-the-window flight simulator views. MACS is an emulation and simulation program which provides a small to large scale airspace environment, and air traffic controller (ATC) display, for current and future air traffic operations in the National Airspace System (NAS). CSD is a 2D and 3D volumetric multifunction interface designed to provide flight decks with a 4D depiction of the interrelationships between surrounding traffic, weather, and terrain within the proximate airspace. Both MACS and CSD are able to utilize the dynamically updated weather delivered by StormGen to display 2D weather information, while CSD is also able to display the 3D weather objects created by StormGen, either in 3D perspective views, or by simulating the 2D scans returned by a simulated airborne radar application. The resolution at which the dynamic weather is updated can be determined by the StormGen software, or the simulation environments displaying the weather information. Thus, it can support six-minute display updates similar to Nexrad, or the virtually continuous display updates found with airborne radars. Finally, depending on the scope and purpose of the simulation environment, the exported weather objects can be used to integrate and simulate the display of predicted (forecast) weather information. This capability is important for the development and evaluation of technologies proposed to utilize such predicted information. There are multiple proposed and planned improvements to StormGen, which would improve the realism of generated weather objects. For example, StormGen presently has a simplistic wind capability that is reflected in the temporal movement of storm cells. Ideally, the editor would support the creation and exporting of wind fields. It would also be advantageous to use publicly available images from ground-based weather radar for the creation of storm systems in StormGen. We envision StormGen to be a continually evolving tool for generating convective weather systems for simulation research in NextGen environments.

Keywords: NextGen, aviation, weather, simulation, storm model

1 BASIS FOR DEVELOPING A WEATHER CREATION APPLICATION FOR USE IN NEXTGEN RESEARCH

The Next Generation Air Transportation System (NextGen) requires the use of new technologies and processes to meet the requirements for increased capacity and efficiency, while maintaining safety and decreasing the impact on the environment. Far from developing isolated enhancements in the National Airspace System (NAS), the goal is to seamlessly combine concepts, procedures, and technologies to create a large cohesive system to meet the goals and demands of future air travel. It has been reported that weather impacts are responsible for 75% of all NAS delays (FAA, 2011). The prospect of increasing efficiency and throughput, while maintaining safety, is the main reason that the assimilation of weather into decision making was identified as one of eight concepts necessary to achieve NextGen objectives.

The weather integration concept identified as necessary for the success of NextGen demands that both predictive and observed weather data be assimilated into air traffic management decision making (JPDO, 2007). Single displays integrating weather and traffic information will be optimized with decision-oriented automation and human decision-making procedures, and all stakeholders will share access to a single authoritative weather source. Improved sharing and integration of weather information into automation and human decision-making capabilities will potentially result in less airspace being constrained by weather, leading to fewer delays and higher traffic throughput, and will allow weather-impacted operations that are at least as safe as those currently available.

Before NextGen visions can be realized, research will be needed to evaluate concepts and tools concerning decision making with relation to weather in simulated environments.

Weather data for use in a simulation-based experiment has the unique requirements that it must be realistic in the eyes of pilot and air traffic controller (ATC) participants, while being deterministic, repeatable, and tailorable to the experimental design. Previous attempts at creating such weather involve searching National Oceanic and Atmospheric Administration (NOAA) archives for weather data that are within range of meeting experimental requirements. The weather data would then be customized by applying translations, rotations, filters, etc., until the weather was close enough to the study's minimum requirements. Not only is this approach labor-intensive, but also relies on the ability to find appropriate weather data in the archives. When the experimental design requires dynamic weather that develops over time in a prescribed fashion, it may not be possible to find real-world weather that progresses as required.

Another disadvantage in using historical weather information is that this "real-world" weather data is not actually weather: it is data generated from weather models or sensors. For example, most convective weather data is weather radar scan data, subject to beam physics, attenuation, blind spots in the scan pattern, and other hardware artifacts. A volume scan from a weather radar can be composited down to a 2D map that is usable in a 2D display. However, for advanced 3D displays, it is impossible to recreate the 3D weather that gave rise to the initial radar data. Once the weather data is created, there is also an issue of how this data will be consumed by simulation components.

A typical airspace simulation facility will comprise multiple components, such as ATC consoles, cockpit simulators, traffic generators, etc., invariably from multiple vendors or organizations. Each component may have its own mechanism for ingesting weather data, with an associated native data format. For a valid simulation, all components must be using the same weather, despite differences in their respective capabilities in terms of dimensionality (2D versus 3D), fidelity, and update rate. Therefore, all weather data, no matter the source, must be modified according to the specifications required by each system, and in a file format required for consumption by each system trusting that the same resultant weather is achieved for all simulation components.

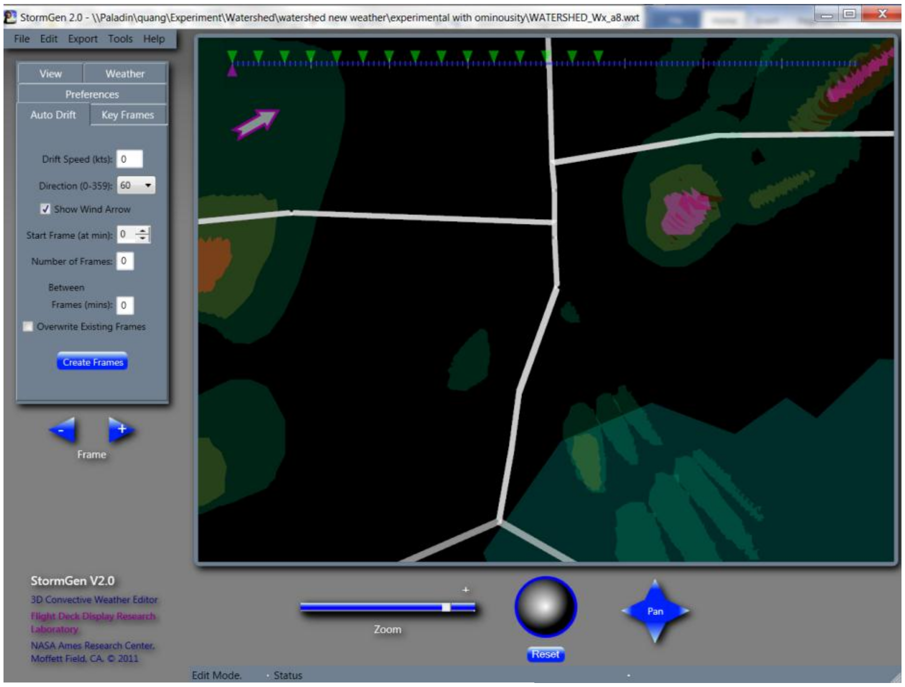

Figure 1 StormGen interface, with sectors.

Given that current sources of real-world 3D convective weather data often fail to meet specific research and concept exploration requirements, a strong need was identified for a simple and versatile tool that can be used for generating realistic weather for simulation research, one that can export that data in multiple formats for multiple consumers. StormGen, the software tool showcased in this paper, has been developed to fulfill the need in producing convective weather systems for use in NextGen airspace simulations (see Figure 1).

2 STORMGEN'S CAPABILITIES AND FEATURES

StormGen provides a graphical user interface for the construction and placement of storm cells anywhere in a simulated contiguous United States airspace. Individual cells can be manipulated to tailor both the initial weather state, and the development of weather over time, to exact user requirements. Some of the adjustment options include: rotation, resizing, shifting, shell intensity, shell altitude, cell contour smoothness/roughness, cell propagation, cell replacement, automatic cell dissipation, automatic cell growth, automatic cell drifting, and the ability to adjust the individual polygons making up a cell. Built-in StormGen functions also support the automatic morphing of storm cells between different sizes, shapes, altitudes, positions, and intensities over time. Beyond individual storm cell manipulation, features allow the interaction of multiple storm cells in the simulation environment over a period of time. For example, storm cells can be made to converge, creating a larger cell, or divide, creating multiple smaller storm cells, each with their own attributes and characteristics.

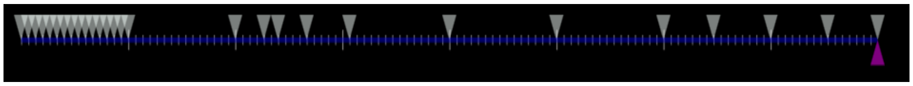

Figure 2 The key frame time-line allows for arbitrary placement of frames for weather manipulation over time.

In addition to placing storm cell objects at different points in space, StormGen is able to place the cell objects at different points in time. Objects located at designated time locations occupy a "key frame," and StormGen can use a morphing function to interpolate frames between the existing frames to change the cell's placement, size, intensity, shape, etc. (see Figure 2). In other words, a user can design the weather in a start frame, and design the weather in a frame 15 minutes later. Then, instruct StormGen to automatically generate intervening frames, in which the weather morphs between frames (see Figure 3).

The time-line has a notional resolution of 1-minute; when a weather frame is created, a marker, the inverted triangle, is inserted on the time-line to represent the new frame's temporal location within the overall weather scenario. Any frame can be manipulated temporally by dragging its marker along the time-line. Individual frames can be exported as files to be consumed by simulation components. This control over frame exporting allows the same weather scenario to be exported as time-synchronized weather to consumers with different update rate requirements: for example ground displays with a 15-minute update rate and cockpit radar displays that can take advantage of the 1-minute resolution data. The temporal resolution at which the dynamic weather is updated can be determined by the simulation environments displaying the weather information. For example, the CSD is able to interpolate between frames to create weather snapshots that are 1-second apart.

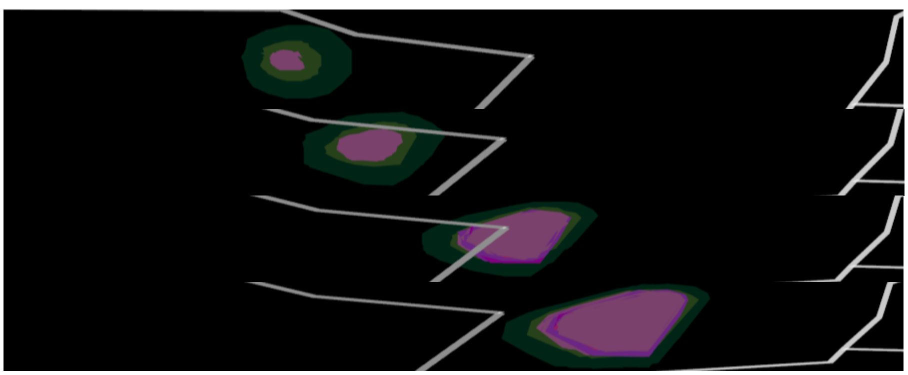

Figure 3 The above time interval series shows the same weather cell as its size, placement, shape, and intensity are automatically morphed by StormGen.

Depending on the design, scope, and purpose of the simulation environment, the created weather objects can be used to integrate and simulate the display of predicted forecast weather information. This capability is especially important for the development and evaluation of technologies proposed for use in a NextGen environment, which will be required to use such predicted information.

In StormGen, each storm cell object is a simple 3D model based on an idealized conceptualization of a typical supercell thunderstorm. A simple modeled cell conceptually comprises three “shells” of intensity which model nominal threshold levels of storm moisture content, which determine levels of radar reflectivity (high, medium, and low). Each of the intensity shells is a set of two-dimensional polygons, each possessing an assigned altitude, intensity value, and object ID. A single polygon represents a 2D slice, at a particular altitude, through a 3D region where the precipitation is of a particular intensity (see Figure 4).

Development of a weather scenario begins with the choice of one of the set of predefined cell objects from the provided template. Additional cell objects can also be added to the existing pallet of choices. Once inserted, cell objects can be merged to create weather patterns of arbitrary complexity.

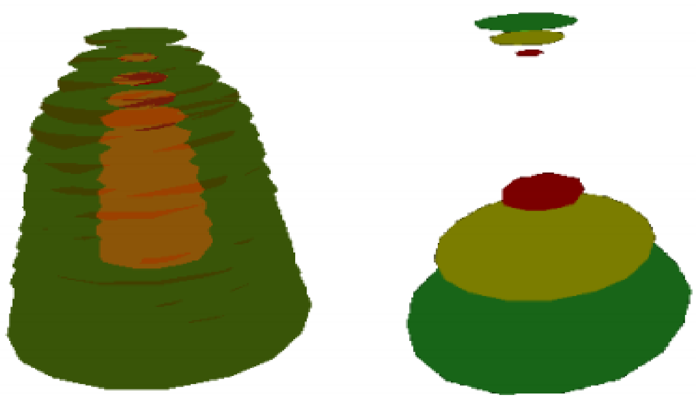

Figure 4 Two distinct views of a single storm cell. Each of the three shells comprises a set of polygons at multiple altitudes. The cell displayed on the left is a 3D view with partially transparent shells. The cell displayed on the right shows only the top and bottom polygons of each shell in the cell.

StormGen includes interface controls, which give the ability to pan, tilt, and zoom within a 3D virtual airspace. To assist in the placement of weather objects, the ability is provided to selectively display key state outlines and airspace sector boundaries.

Additional features to aid in storm cell placement and movement include the display of navigation aids and other background markers, range rings, custom waypoints, and major airports (see Figure 6). Precise placement of weather is often essential to experiment design. For example, cases, such as the one illustrated in Figure 7, in which a storm cell is positioned to block arrivals, can be used to evaluate myriad concepts and tools designed to mitigate the effects of adverse weather.

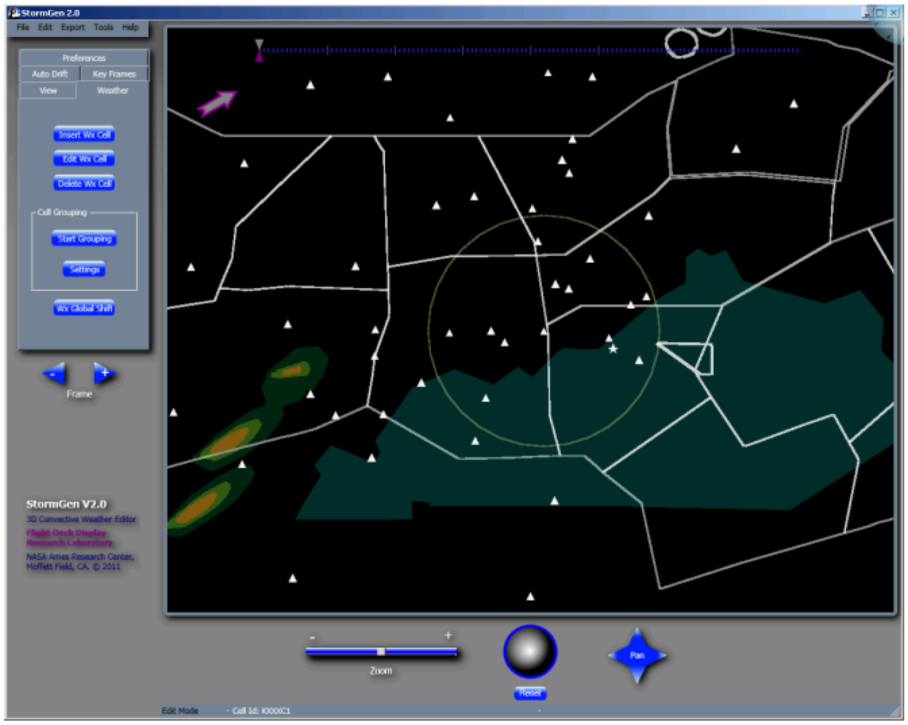

Figure 6 StormGen with sectors, waypoints, and a range ring around a navigation aid.

3 UTILIZING WEATHER CREATED BY STORMGEN IN NEXTGEN RESEARCH APPLICATIONS

The weather objects produced by StormGen can be exported in multiple formats for use by other simulation environments, such as the Multi Aircraft Control System (MACS), the Cockpit Situation Display (CSD), and the out-the-window view, powered by Microsoft® Flight Simulator X, of a medium fidelity, fixed-base 777 flight simulator.

MACS is an emulation and simulation program which provides a small to large scale airspace environment, and ATC display, for current and future air traffic operations in the NAS. Convective weather is displayed on the MACS ATC screen as an emulation of ground-based weather radar, and is a 2D bit-map pattern that is read in from a run-length encoded XML file.

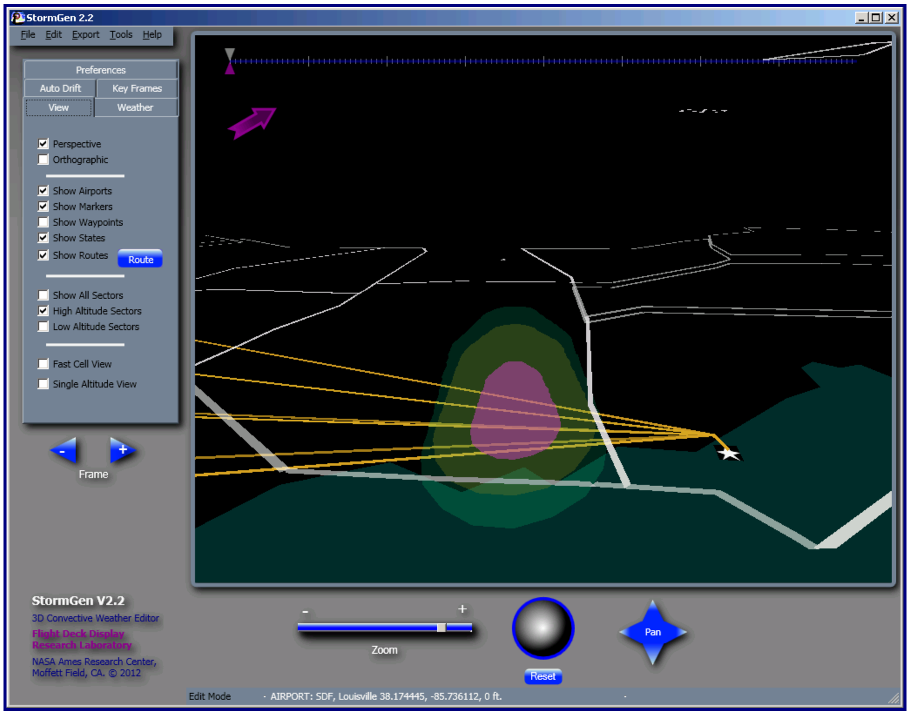

Figure 7 A storm cell positioned to block planned approaches into Louisville International airport. The user has tilted the visual in 3D to verify that the top of the storm is above the air routes.

The CSD is a 2D and 3D volumetric multifunction interface designed to provide flight decks with a 4D depiction of the interrelationships between surrounding traffic, weather, and terrain within the proximate airspace. The CSD can display convective weather either in 3D perspective views, or by simulating the 2D scans returned by anairborne radar application. Note that 3D data is essential for a realistic radar emulation, because it allows modeling beam height and tilt. The CSD reads weather data from a binary file containing 2D polygonal regions at multiple altitudes, which define the boundaries of a 3D volume.

StormGen provides an export function that outputs a 3D weather dataset in a format targeted for a specific system. For the CSD, it outputs the required polygonal regions, for MACS, it composites the 3D data to 2D, then encodes the data into XML. It can also export the data as composited 2D polygonal regions. StormGen provides a single place to host all the conversions necessary for heterogeneous simulation components to inter-operate using the same weather. It provides a single tool that a researcher can use to design and evaluate a weather scenario, which can then be used throughout the simulation environment.

StormGen has been used to produce weather for a number of experiments that used multiple simulation components. Often, the individual components have mechanisms to create weather for internal use, however guaranteeing that the same weather is used and displayed on heterogeneous components has heretofore been an intractable problem- one that StormGen has been designed to solve.

4 PLANS FOR FURTHER DEVELOPMENT OF STORMGEN

As with many software programs, the vision, scope, and use of StormGen continues to evolve. As such, the proposed, planned, and undertaken improvements to StormGen have similarly evolved. Some of these advances would improve the realism of generated weather objects. For example, StormGen presently has a simplistic wind capability that is reflected in the temporal movement of storm cells. Ideally, the editor would support the creation and exporting of wind fields, in addition to the weather objects. Another feature that would be advantageous would be the ability to use publicly available images of ground-based weather radar for the creation of storm systems.

Additionally, some weather systems, such as squall lines, have a typical structure and are common in certain geographic areas, during certain seasons. The StormGen user must currently create a larger weather system by placing each cell individually. A possible future enhancement would be to provide the ability to select and insert whole weather systems from a geographically and/or seasonally preferred set of systems.

5 CONCLUSION

Any large-scale advancement to systems and concepts of operation will require a simulation environment to develop and test proposed system components. In the case of integrating weather with decision making processes by users of the NAS, the StormGen program allows the creation and manipulation of convective storm cells over time. Not only does StormGen have the capability to manipulate single cells in regards to shape, intensity, position, size, etc., but it also has the ability to morph and model the interaction of multiple storm cells.

The storm systems and cells that are created by StormGen must be usable by simulation components in order to properly test the hypotheses of a study. To this end, StormGen can export its weather files in multiple formats for use by other software and simulation components. As NextGen concepts continue to evolve to meet the needs of updated requirements, StormGen must also progress to meet the needs of the studies being designed to evaluate NextGen technologies and concepts. As a result, StormGen has evolved to its current state because of improvements that were made over time, and will continue to evolve to meet the needs of integrating weather NAS simulations.

ACKNOWLEDGMENTS

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