# Digital Terrain Editing and Virtual Reality Visualization to Communicate Snow Coverage and Depth Change Related to Thermal Impacts

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**Abstract:** This research involves the application of DEM modifications from national weather data along with landscape visualization tools to explore future climate change adaptation, potential landscape performance and strategic management at the Arbutus Pond in Newcomb, NY. In terms of yearly and numerical reports of weather conditions by Adirondack Ecological Center (AEC), patterns of thermal impacts are potentially correlated with natural phenomenon such as snow depth changes. This observation is valuable as environmental inspection for snow patterns and further understanding of collaboration for landscape architects. Using a combination of a DEM modification Photoshop plugin along with terrain 3D modeling and computer game development software, we visualized several snow depth scenarios which were used to potentially inform land of recreation, forest and water quality management. Data collected from the SC-ACIS – Applied Climate Information System was selected for initial reference with each factor at large distances and timescales to represent variations of snow accumulation. Real-time rendering game design software was used to develop photorealistic renderings in order to visualize snow depth changes that occurred as a result of various perspectives to further explore the topic of snowfall and climate change by the workflow – from GIS to 3D to real-time virtual reality (VR) immersion.

**Keywords:** Snow, DEM, climate, VR, immersion

## 1 Introduction

Algorithmic snowfall and accumulation calculation is common and time-tested, and can be used to approximate patterns of snow movement and resulting elevation change due to snow (Saltvik et al. 2006, Moeslund et al. 2005). Most research concerning computational snowfall rendering has similarly focused on computational modelling of snow particles to visually capture the general manner in which snow falls and accumulates in the landscape (FEARING 2000, HAGLUND et al. 2002, REYNOLDS et al. 2015, KANG et al. 2019). While these methods are instrumental in forming the mathematical basis for our study, they are limited in their ability to cover large scales, and in their ability to account for slope and terrain aspect information which influence snow accumulation and melt (ANDERSON & MCNAMARA 2014). These factors are able to be computationally simulated in two dimensions (KUMAR et al. 2013). Few projects have attempted to computationally visualize real-world snow accumulation data in 3D, with possibly the closest being research to visualize general conditions of snow and ice using a DEM (HUANG & HAN 2016).

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We aim to build on these advances by digitally simulating the impact of slope and aspect on snow accumulation and snow melt using 3D modeling techniques. We also aim to communicate their impact on landscape character to viewers through the use of real-time video game rendering for animation and virtual reality immersion. These immersive technologies are important in their ability to communicate environmental changes to the landscape, especially when those changes are impacted by climate change (HUANG 2021).

The project of generating a virtual environment based on annual snow accumulation associated with thermal impacts relies on existing terrain and weather data. Weather reports of temperature observation are conducted through the collaboration between Adirondack Ecological Center (AEC) and Anonymous Institution. The approach attempts to visualize snow depth data correlated with observed and reported time periods. The site of data collection is visualized based on the location nearby Arbutus Pond in Newcomb, NY, focusing on the winter months for the purpose of gathering sufficient information on snow accumulation. Our visualization approach begins with the application of two-dimensional (2D) database information to transform a 3D terrain model, which is then exported to virtual reality visualization software to allow engagement and communication with the public (Figure 1).

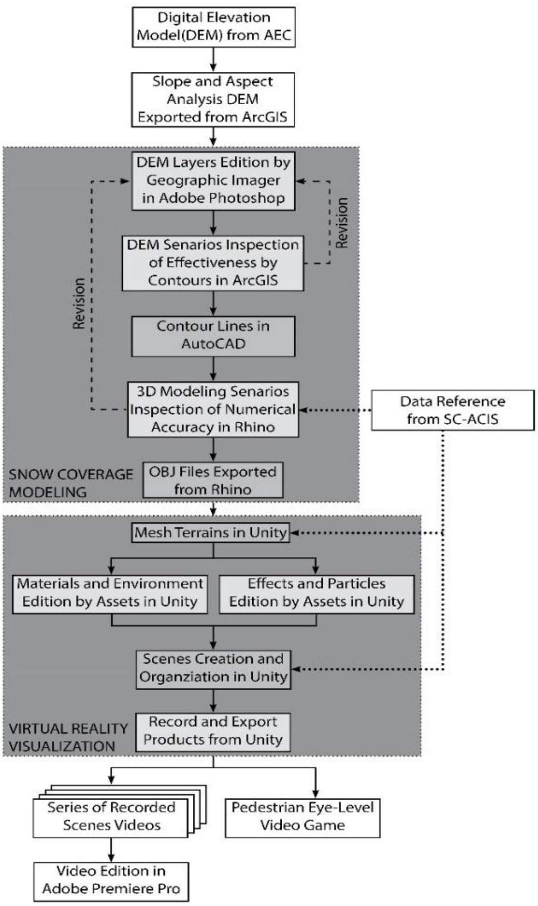


**Fig. 1:**
The workflow of generating an immersive virtual environment for snow patterns from 2D databases to 3D spatial landscape modelling

# 2 Methods

## 2.1 Snow Coverage Modeling

To begin our analysis, we used data from the station of SC-ACIS – the Applied Climate Information System, which provides access to climate data from daily U.S. weather stations in the Global Historic Climate Network, an integrated database of climate summaries (U.S. Climate Resilience Toolkit 2022). For this study, the SC-ACIS data was sampled from the weather station in Newcomb, NY (Figure 2). Terrain lidar data was converted to a Digital Elevation Models (DEM) in ArcGIS for use in our geospatial analysis of snow accumulation data. Our analysis began with an examination of the topographical factors which can impact snow melt and accumulation. An important consideration was the relationship between slope, aspect, and snow depth. The most common slope angle range on which avalanches occur is between 36 to 38 degrees (KNOFF 2016). However, it is important to note that not all avalanches start on slopes with these precise angles. If a gentle slope of 25 degrees or less is connected to a larger, steeper slope, it is still possible to trigger a slide. Therefore, we could deduce that slopes greater than the range of 25-36 degrees are likely to have the least snow accumulation. Additionally, we confirmed the need to examine the relationship between solar exposure and snow melt through an analysis of both slope and aspect. To perform these slope and aspect geospatial analyses in ArcGIS, we used the Surface Slope and Surface Aspect tools. The resulting raster images were exported as DEM-TIFF files for modification.

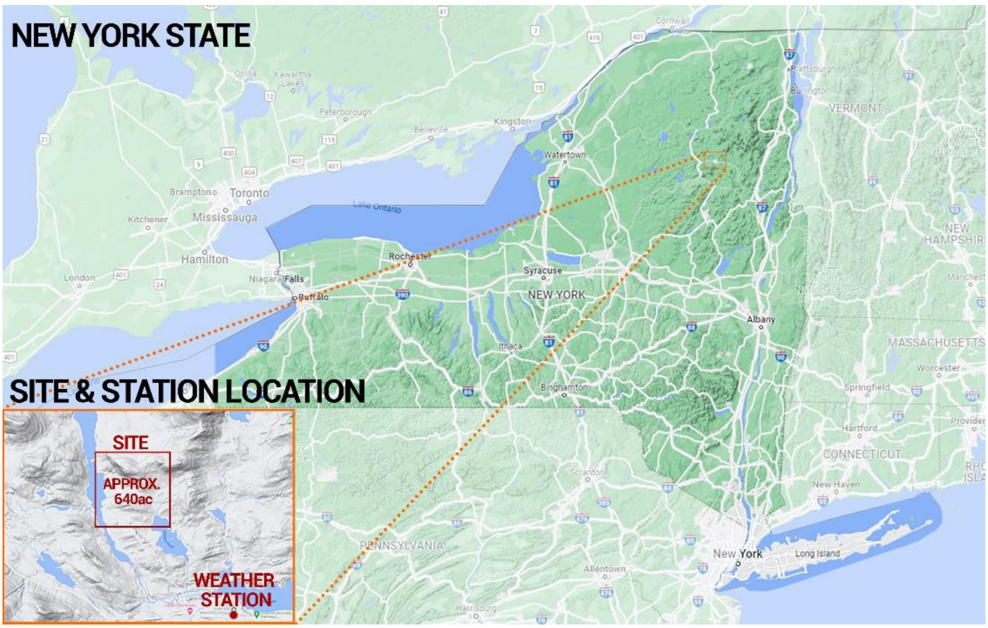


**Fig. 2:** The location of the site and the weather station

In order to manipulate the topography to represent additive snow melt based on slope, we used a combination of Rhino and an Adobe Photoshop plugin called Geographic Imager, produced by Avenza Systems Inc. The combination of these tools enabled us to perform raster digital elevation manipulation while retaining a higher degree of geospatial accuracy than would otherwise be possible. Geographic Imager has been used to model speculative changes to terrain such as erosion due to sea level rise (ACKERMAN et al. 2019). Opening our GIS raster images in Geographic Imager, we then developed a method for using color and tonal range adjustments to modify the elevation values in the DEM as indicated through our slope and aspect analysis in order to depict snow accumulation and snow melt. We did this by selecting the areas of the DEM with the slope greater than 25 degrees, which were colored red in our raster image, using the Photoshop Color Range selection tool as a systematically controlled pixel analysis to select those areas (Figure 3 and Figure 5).

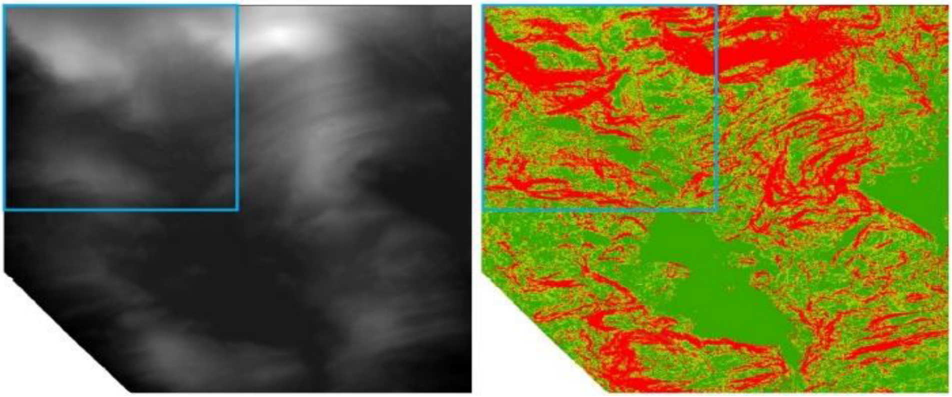

**Fig. 3:** Left: Existing DEM of Arbutus Pond within focused inlet area. Right: Slope analysis of existing DEM in ArcGIS.

We then created a new Photoshop layer and filled those with a pure white color, hex coded as #ffffff, with a high degree of fuzziness to create a gradient of filled color which more naturally blends with the surrounding terrain. Similarly, we reduced snow accumulation by applying the Color Range tool once again to select southeast-facing terrain from the colorized aspect analysis raster image (the areas colored green, cyan, and azure), then darkening those areas to indicate surfaces that would experience snow melt from the impact of radiant heat (Figure 4 and Figure 5).

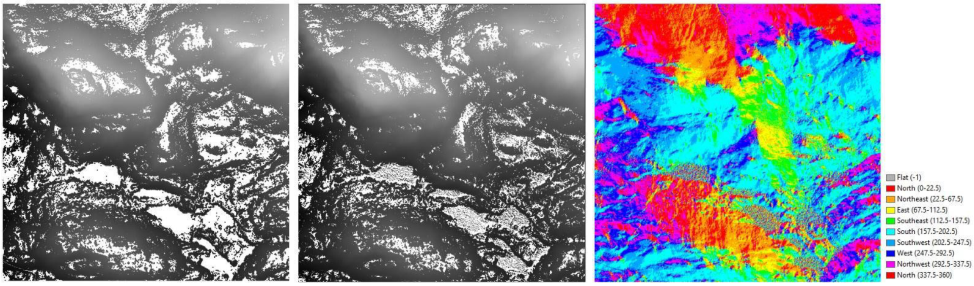


**Fig. 4:** Left: Modified DEM reflecting snow coverage, created using Geographic Imager. Middle: Modified DEM reflecting snow coverage after solar exposure, created using Geographic Imager. Right: Aspect analysis of existing DEM in ArcGIS representing potential areas of sun exposure.

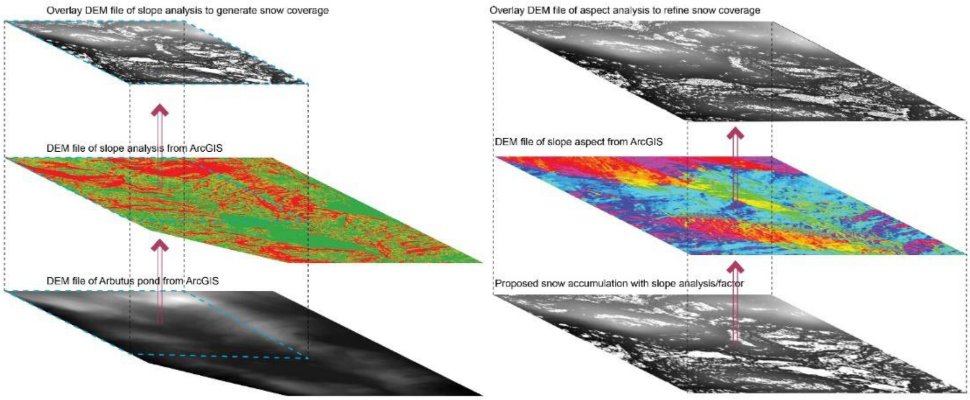


**Fig. 5:** Left: Process of generating snow coverage referenced slope analysis, created using Geographic Imager. Right: Process of generating snow coverage suffered from solar exposure referenced aspect analysis, created using Geographic Imager.

To validate our color and tonal range adjustments against real-world dimensions, the modified DEM files were saved and imported into ArcGIS in order to examine the results of darkening and lightening the DEM in Photoshop. We developed two sets of elevation contours, one of the existing DEM and one of the altered DEM. By comparing the two sets of contours, we were able to determine the relative elevation change that resulted from our Photoshop brushwork. Through trial and error, we were able to establish that a 1% layer opacity and a range of between 50%-83% of white fill settings corresponded to 1 foot of increased snow depth. This analysis of color range properties and elevation change allowed us to use precise values to achieve specific elevation changes in Photoshop, enabling us to adjust snow coverage on the terrain consistent with weather data sources. We then generated typical DEM variations in Photoshop in order to represent changes in snow coverage over a single winter season, relying on SC-ACIS data to determine these changes as effective through raster files modification. After producing a series of DEM files representing changes in snow coverage, we translated these into 3D models by exporting their respective contours as CAD files and converting them to detailed triangular terrain meshes in Rhinoceros 3D. Using Rhinoceros' Analyze toolbar, we used the Distance command to compare each modified terrain mesh to the original existing conditions terrain mesh. This allowed us to measure the difference in elevation values between two terrain meshes, comparing these values against their corresponding DEM values associated with SC-ACIS data to confirm their accuracy (Figure 6).

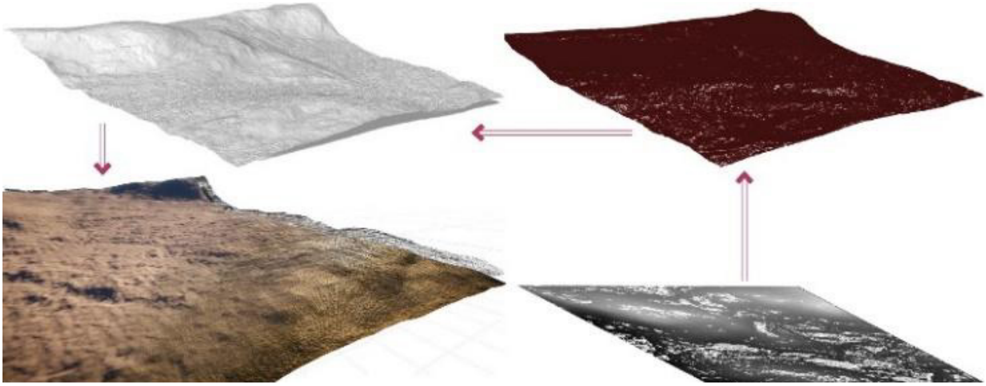

**Fig. 6:** Process of generation from DEM through contour lines and 3D digital modeling to Unity, a cross-platform game engine, for high quality rendering and an interactive virtual environment through High Definition Render Pipeline (HDRP)

## 2.2 Virtual Reality Visualization

Although the Rhinoceros terrain meshes were useful in measuring and visualizing changes in snow coverage at a large scale, the models lacked real-world environmental characteristics such as materials, atmosphere, and vegetation. We believed these details were necessary to visually communicate the changes in landscape character to our intended audience, which includes individuals interested in maintaining the land for recreation, forest management, water quality management, and climate change adaptation. However, it will be critical to do comparative testing with users in the future to understand whether this level of realism is essential to communicate the landscape's character. To accomplish the level of representation we needed for this audience, we used Unity, a real-time game development platform that can be used to create 2D and 3D games, interactive simulations, animations, and still image renderings. It is important to note that in our workflow we used Unity primarily for real-time visualization, and not for any geospatial editing.

For changes in snow depth of over one foot, we were able to model these changes using Rhino and Geographic Imager. However, due to the limitations of layer opacity, we were unable to model changes of less than one foot. Therefore, for any changes under one foot, we simply changed the overall elevation of the 3D model in Unity to reflect smaller elevation changes of between one and eleven inches of snow depth. We exported our 3D models from Rhino as OBJ files, imported them into Unity, and aligned each mesh to the same origin point on the XYZ axis. While matching the coordination between Rhino and Unity, we made sure to align all versions of our terrain models at the same XYZ origin point so that they would retain identical locations when imported into Unity. All versions of terrain mesh were appropriately positioned, saved and organized. When models were prepared for rendering, we chose to use Unity's High Definition Render Pipeline (HDRP), a scriptable render pipeline built by Unity in order to make use of modern Compute Shader compatible pipelines. While this limited our model asset and environment toolset options significantly, it enabled us to use a wide variety of lighting techniques in order to produce visualizations to the highest standard possible in a real-time platform. Due to the very subtle variations in snow depth from year to year within our research, HDRP was necessary in order to capture the small changes within a perspectival view that is dynamic and can be fully animated in a 360-degree field of view. We purchased a preset scene package named Winter Environment, that included snow materials from scanned data, along with global wind settings, HDRP scene lighting, and winter tree models from photoscanned real-life vegetation. We used the Winter Environment to paint snow on the terrain using four different snow materials to indicate variations in snow coverage throughout the terrain. The snow painting was informed by referencing photographs of the area taken by the nearby Adirondack Ecological Center (Figure 7).

**Fig. 7:** Example of pedestrian perspective looking at the virtual environment of snow coverage in the forest at the inlet area of Arbutus Pond

To visually communicate the snow accumulation, we needed to use several dynamic rendering and interactivity tools in Unity. One such output was to create a Unity animated time-lapse of snow accumulation with data overlay. While a bird's-eye view would allow the audience to perceive the broader changes to snow accumulation throughout the forest, a ground-level view would allow the audience to perceive the detailed changes to snow level at a vantage point similar to the experience of standing within the forest. We chose to create ground-level views to communicate the subtle changes in forest character to the viewer, creating a series of short animations of each modified terrain to indicate these small changes to the snow's elevation. The animation frame remained focused on a static object, a boulder, so that the snow height could register visually against the object. We cross-faded these animations to appear as a single animation with changing snow elevation. We then overlaid leader lines with text to appear at each change in snow elevation in order to indicate the amount of elevation change and the date the elevation was recorded (Figure 8). In order to provide an interactive experience with the model, we also exported the scene as a first-person cross-platform game, where the audience could use a keyboard and mouse to "walk" through the forest and control the looping of the snow elevation changes via an interactive menu. The game walkthrough could be played on PC, mac, or Linux without additional software, and could also be loaded into a virtual reality Oculus headset for a more immersive experience.


**Fig. 8:** Variations in snowfall depth from the same perspective in Unity, demonstrating the immersive potential of real-time rendering to communicate changes in annual snow depth with the annotated dataset from SC-ACIS

## 3 Discussion

This data-informed visualization has the potential to clearly and effectively depict the spatial implications of otherwise abstract weather data, information that is often challenging to perceive at large distances and timescales. We can use these workflows to examine snowfall patterns in the landscape and understand whether there is a trend towards decreasing snow accumulation. This can help landscape architects comprehend and communicate the localized effects of climate change on the landscape, using visually accessible tools that can be easily understood by a range of viewer audiences. By allowing landscape architects to make recorded data visually and spatially explicit, this modeling may also be useful in recreational land management, water quality management, and climate change adaptation. This last item is critical: global climate models and downscaled regional models predict changes for the U.S. Northeast including a briefer winter season, with expectations of a shorter duration of persistent snowpack. The Adirondack area is one of the few places in the Northeast where persistent winter snow cover is expected to exist in future decades, underscoring the importance of visualization to understand these future conditions through the end of the 21st century.

Our next steps will aim to improve several areas of the research related to accuracy. Both data accuracy and visual realism are essential for the effective use of this workflow in landscape management. A key area to develop in future stages of this research is the relationship between snowfall accumulation and other environmental factors such as precipitation, infiltration, congealment, and condensation and evaporation impacting snow patterns (VAN MULLEM et al. 2004).

The use of real-time virtual reality perspectives to visualize real-world snowfall data can enable landscape architects to generate dynamic and informative visual media for a range of uses. The workflow is flexible in terms of landscape scale as well as time, allowing the visualization of data across large areas and time periods. Research projects using this workflow can be considered not only as individual site analyses, but also as a case study inventory of changing snow patterns over time which can inform landscape strategies for climate change adaptation.

# 4 Conclusion

The ability to control elevation change due to snow accumulation and snow melt is a beneficial tool to digitally measure and analyze changes to snow elevation over time, whether it is a single season or a comparison of multiple seasons. The additional ability to communicate these changes in a real-time game model which conveys realistic landscape materials, lighting, and vegetation opens up a wide array of audiences to engage with this data. These tools also have the potential to be used for simulation of future conditions, an important consideration for modeling and communicating the impacts of climate change. We hope that this workflow – from GIS to 3D to real-time virtual reality immersion – can be used to further explore the topic of snowfall and climate change.

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