Wargaming: Toward the Development of a Generative AI for Weather Simulation

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ABSTRACT

Weather simulation represents a critical factor affecting the course and outcome of battles in wargaming. Adverse weather conditions, such as precipitation or fog, can limit visibility or degrade weapon accuracy. On the other hand, favorable weather conditions can significantly impact military operations, offering several advantages that enhance overall effectiveness and success. In the wargaming context, designers create more realistic training scenarios by incorporating weather simulation. The weather simulation model currently being implemented within the USMC Wargaming System consists of two main capabilities: dynamic weather simulation and the ability to apply historical weather data. While the purpose of dynamic weather simulation is to produce a synthetic weather environment, historical weather data can be used to reproduce weather conditions from past conflicts, allowing wargame designers to create more realistic scenarios for training and analysis. During the scenario design phase, designers review the available historical weather data to determine if it is appropriate for the anticipated wargame scenario. They may want to know, “What will be the temperatures for the next seven days?”, or “What is the expectation of precipitation for the timeframe of the wargame?”. To do so, the designers employ the tools at their disposal to display and examine the weather data. A generative AI for weather simulation will significantly enhance this task and can be used as a complementary tool alongside legacy tools.

This paper explores the key components and considerations in developing such a generative AI system. The foundation of the proposed generative AI system lies in the utilization of a comprehensive weather ontology that captures the interrelationships and dependencies among various weather-related variables. It encompasses meteorological parameters, geographic features, and atmospheric phenomena, providing a rich semantic understanding of the wargaming domain. Finally, the paper will explain how the newly developed weather ontology will be incorporated into the system architecture of a prompt-based generative AI for weather simulation.

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INTRODUCTION

Weather conditions can have a significant impact on military operations (Atkinson, 1973; Downing, 2015; Füssel, 2015). For instance, adverse weather conditions such as rain, fog, and snow can limit visibility, affect weapon accuracy, and impact mobility, making it more challenging for military forces to achieve their objectives. On the other hand, favorable weather conditions, such as clear skies and calm winds, can significantly impact military operations, offering several advantages that enhance overall effectiveness and success (Weatherly et al., 2004; Bae et al., 2021). In the wargaming context, designers can create more realistic scenarios by incorporating weather simulation (Johnson, 2019). This can provide military planners with insights into how weather conditions affect military operations and help them develop strategies that consider weather conditions (Kennedy, 2014). As the climate changes, weather patterns will likely become more extreme and unpredictable, which could have significant implications for military operations. Wargame designers can help military planners prepare for these changes by simulating future weather conditions and developing strategies to mitigate their impact.

Generally, wargaming follows a seven-step process: 1- Define, 2- Scope, 3- Design, 4- Develop, 5- Rehearse, 6- Execute, and 7- Assess. Weather simulation is critical for many of these steps (Tran et al., 2023). Especially during the “Design” phase, the wargame designers select and review the available historical weather data to determine if it is appropriate for the anticipated wargame scenario that can be used to model the likely weather conditions during the anticipated timeframe of the wargame. The wargame designers will also determine if the simulation of dynamic weather will be required for the scenario. The weather simulation scenario, which may contain both historical weather data and dynamic simulated weather, can be used within the wargame to inform decisions about the deployment of forces and equipment, the timing of operations, and the allocation of resources. Currently, the wargame designers employ available tools at their disposal to display and review the weather data. This task can be significantly enhanced if a generative AI system is available to them.

This paper explores the key components and considerations in developing such a generative AI system. The foundation of the proposed generative AI system lies in the utilization of a comprehensive weather ontology that captures the interrelationships and dependencies among various weather-related variables. It encompasses meteorological parameters, geographic features, and atmospheric phenomena, providing a rich semantic understanding of the wargaming domain. Finally, the paper will explain how the newly developed weather ontology will be incorporated into the system architecture of a prompt-based generative AI for weather simulation.

RELATED WORKS

Weather simulation has been a critical area of research for many decades. Virtual environment and gaming are disciplines of simulation that often incorporate weather simulation. In his study, Tien (2018) provides an overview of the use of weather in video games. He examines the different ways that weather has been used in games and the effects it can have on gameplay and immersion. However, most game developers tend to focus on aesthetics and kinetics, or, in simpler terms, graphics and animation, and weather is usually introduced merely for aesthetic purposes (Barton, 2008; Mushtaq et al., 2018). Additionally, several studies explore how weather can be used to create interesting and engaging gameplay mechanics in video games, enhancing the sense of immersion (Chen and Fu, 2016; Crick and Grange, 2013).

Recently, weather simulation and prediction have been targets for improvement through the application of artificial intelligence (AI) and machine learning (ML) techniques. Anochi et al. (2021) proposed a new approach to seasonal precipitation prediction based on AI techniques. In their study, the authors demonstrated the capability of neural networks for seasonal precipitation forecasting over South America by using a large dataset from 1980 to 2016 to train season-specialist neural network models. A hybrid method for rainfall forecasting, integrating feature extraction and prediction techniques, was proposed by Joseph (2013). The dataset used in his study was obtained from the National Oceanic and Atmospheric Administration (NOAA); it spanned more than 50 years and consisted of various weather features such as humidity, pressure, temperature, and wind speed. Nguyen et al. suggested the use of two models, namely the Seasonal Auto-Regressive Integrated Moving Average (SARIMA) model and the Long Short-Term Memory (LSTM) model, to predict precipitation in the central province of Vietnam. The input data were collected for analysis at three meteorological stations for the period 1980–2018. The authors concluded that both neural network methods, SARIMA and LSTM, can improve the accuracy of forecasting monthly precipitation.

Overall, past works related to weather prediction with AI have focused on enhancing forecast accuracy, improving model efficiency, and better understanding the complex dynamics of the atmosphere to provide more reliable weather forecasts and climate projections. We have been unable to identify any literature to date documenting the utilization of AI to simulate weather, specifically for wargaming purposes.

WARGAMING WEATHER SIMULATION MODELS

The current USMC Wargaming Weather Simulation model consists of two main simulation capabilities: the historical weather data and a dynamic weather simulation.

1. Historical Weather Data

Historical weather data is a valuable tool for simulating environmental conditions, allowing researchers and planners to make informed decisions about future conditions and develop appropriate responses and mitigation strategies. In the context of wargaming, historical weather data is used to simulate weather conditions experienced in past conflicts so wargame designers can create more realistic scenarios for training and analysis. For example, wargames that simulate World War II battles may use historical weather data to replicate the actual weather conditions experienced during those battles. This can provide valuable insights into how weather influenced the outcomes of the battles and help military planners develop strategies that take weather conditions into account.

Historical weather data can also be used in wargames to create more challenging scenarios. By introducing adverse weather conditions such as rain, snow, or fog, wargame designers can simulate the impact that such conditions can have on military operations. This can help military planners develop contingency plans for adverse weather conditions and prepare for unexpected weather events that could affect operations. There are two main historical weather data resources: the National Oceanic and Atmospheric Administration (NOAA) and the Environmental Data Cube Support System (EDCSS).

1.1. National Oceanic and Atmospheric Administration (NOAA)

NOAA historical weather data refers to archived weather-related information collected and recorded by NOAA, a scientific and regulatory agency within the United States Department of Commerce, over many decades. This data includes a wide range of weather observations, such as temperature, precipitation, wind speed and direction, atmospheric pressure, humidity, and more, collected from a variety of sources including weather stations, buoys, and satellites. Therefore, the spatial and temporal resolution of historical weather data from NOAA can vary depending on the specific dataset and the source of the data.

NOAA maintains a comprehensive database of this historical weather data, which includes observations dating back to the mid-19th century. The data is used by researchers and analysts to study past weather patterns and trends and to support a range of applications, such as weather and climate forecasting, agricultural planning, and risk assessment for natural disasters. Access to NOAA historical weather data is typically available through various platforms, including the National Centers for Environmental Information website, which provides access to data archives and online tools for data retrieval and analysis. Additionally, NOAA provides access to specialized datasets, such as long-term climate records and extreme weather events, through its Climate Data Online (CDO) portal.

1.2. Environmental Data Cube Support System (EDCSS)

The EDCSS is a software system used for environmental data management and analysis. It is designed to support the collection, processing, storage, and analysis of environmental data in the form of multidimensional data cubes.

EDCSS works by integrating various data sources, such as satellite imagery, weather data, and ground-based observations, and transforming them into standardized, multidimensional data cubes that can be easily queried and analyzed. The spatial and temporal resolution of historical weather data from EDCSS utilized within the USMC Wargaming is 15 km and one hour, respectively.

The EDCSS has been under development by Atmospheric and Environmental Research (AER) since 2007. AER delivers all EDCSS software to the government as open source and requires no commercial or proprietary software or hardware to operate. Today, the EDCSS is a mature technology routinely employed for Combatant Commander (COCOM) Joint Training Exercises, Air Force Combat Air Forces Distributed Mission Operations (CAF DMOs), Navy Fleet Synthetic Training (FST), and the Office of the Secretary of Defense Planning and Analysis communities.

2. Dynamic Weather Simulation

The purpose of dynamic weather simulation is to produce a synthetic weather environment covering a large area, potentially of the entire globe, and thereby provide simulated weather information at any location within the wargaming area. The centralized dynamic weather model provides consistent and correlated weather information to all participants in a distributed exercise. The simulation model is based on the International Standard Atmosphere (ISA) to support a wide range of atmospheric parameters and weather effects, such as the following:

2.1. Temperature

Temperature can have a significant impact on military equipment and personnel. For instance, it influences the type of lubricants used and affects engine warm-up periods. The sustained rates of fire for weapons are directly related to temperature. High temperatures can cause gun tube droop or reduced battery life. Both extreme heat and cold can reduce a soldier's physical and mental performance. For example, extremely high temperatures increase personnel water consumption, while extremely low temperatures reduce personnel effectiveness as it can cause hypothermia and wearing bulky clothing reduces mobility.

2.2. Pressure and Air Density

In the real world, the atmosphere is usually in hydrostatic balance. In other words, the atmospheric pressure at a point is a function of the weight of the column of air above it. This column of air has a density that varies with altitude as temperature varies with altitude. Hydrostatic balance defines how pressure decreases as a function of altitude. The weather simulation model achieves this by calculating the pressure profile based on the surface or sea-level pressure and the temperature profile at a specific location. Air pressure, also known as barometric pressure, affects military equipment and personnel. For instance, many types of equipment, such as aircraft and drones, have altitude restrictions due to the impact of air pressure on their operation. Additionally, air pressure changes can affect the accuracy of sensors used in military equipment, such as altimeters or barometers. The performance of military personnel at high altitudes can also be affected, as air pressure changes can cause fatigue, headaches, and other symptoms that can reduce a soldier's physical and mental performance. Barometric pressure changes can make the perceived height above terrain inaccurate, especially with large changes in a short period of time, such as during a frontal passage. If not properly accounted for, this can lead to weapon inaccuracies or flight into terrain.

2.3. Humidity

Humidity is the concentration of water vapor in the air and can affect sensor performance. For instance, high humidity can degrade the performance of military equipment and sensors.

2.4. Cloud Effects

Clouds can affect both military equipment and personnel in multiple ways. Cloud cover can impact the performance of thermal imaging systems, which in turn influences the ability of military personnel to detect and identify targets. Reduced visibility can make it harder for military personnel to navigate and identify potential threats. Low clouds or fog can also pose challenges for aerial operations, such as safe aircraft takeoff and landing.

2.5. Precipitation and Storm Model

In a wargame simulation, a storm represents both a visual and meteorological challenge. Rain and snow precipitated from storms can degrade road trafficability or impair visibility. They also impair the ability of sensor systems to acquire targets. Strong winds, hail, and lightning strikes can damage military equipment. Storms can disrupt supply chains and transportation, making it more difficult to get necessary supplies and equipment to military personnel.

2.6. Wind Effects

Wind can pose significant challenges for military operations. It can impair mobility, damage military equipment such as communication systems, and reduce the accuracy of weapon systems. The dynamic weather simulation model provides both steady wind and wind with random variations, including the following:

- Gust: a sudden and brief increase in wind speed
- Fluctuation: a smooth continuous variation of the steady wind
- Turbulence: an atmospheric property that produces chaotic changes in the wind
- Dust and Sand: High winds, even from helicopter rotor blades, can significantly degrade visibility

For the context of AI model training, dynamic weather simulation can be used to generate synthetic datasets that either mimic real-world weather conditions or enhance the diversity and robustness of the historical weather dataset. In summary, by leveraging weather simulation models to generate synthetic datasets, we can overcome limitations in real-world data availability, improve the scalability of AI systems, and explore a wider range of scenarios and conditions for AI system training and testing purposes.

THE USAGE OF WEATHER SIMULATION IN WARGAME SCENARIOS

Weather Simulation of Global and Local Regions

Depending on the wargame research question, objective, and complexity, wargame designers define the required size of the area (i.e., gaming area) where a wargame scenario will be played. A major battle could require a gaming area of several hundred square miles. Therefore, the weather simulation system must provide the capabilities to define both global weather patterns and weather patterns that occur in specific regions (i.e., local regions). Global weather simulation is applied to the entire wargaming area, while local region weather is applied to small areas of the scenario, such as cities or towns. Local weather is critical for a wargame because it is affected by processes not usually represented in global weather models, such as the formation of storms, local winds, or local clouds. A high-fidelity wargame simulation should provide the capability to define both global and local weather profiles. For each wargame scenario, a dynamic weather simulation is used to define the simulated weather for the entire gaming area. By leveraging historical weather data, several local weather profiles are defined and applied to smaller regions within the gaming area. Local regions can overlap with each other as well. Figure 1 illustrates this feature of weather simulation.

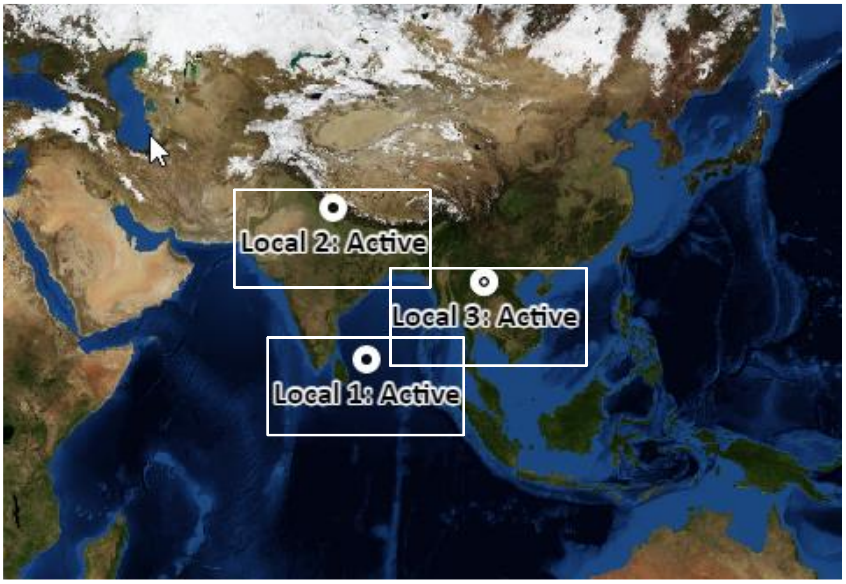

Figure 1. Global Weather and Local Weather

Historical Weather Data augmented by the Dynamic Weather Simulation

Generally, historical weather data is used to recreate weather conditions in past conflicts, and dynamic weather simulation is used to modify existing wargame scenarios by introducing adverse weather conditions such as rain, snow, or fog. However, wargame designers can also create more realistic scenarios for training and analysis by using both historical weather data and dynamic weather simulation in the same scenario. There are a great number of use cases where both historical weather and dynamic simulation weather are used in wargame scenarios. The following are the two most popular use cases:

1. The first use case is a typical wargame scenario using high-resolution historical weather simulation for the main gaming area where most of the past combat actions happened, complemented with dynamic weather simulation for the area outside of the main gaming area. The concept of this use case is illustrated in Figure 2. The EDCSS box delimits the historical weather. Outside of the EDCSS box, the dynamic weather simulation provides weather simulation. The dynamic weather simulation can also define “local regions” that represent a specific local weather profile. Storm objects can also be defined and inserted into the weather scenario.

2. The second use case allows the wargame designers to re-create an initial weather condition similar to a specific past conflict and then use the dynamic weather simulation to simulate a variant of future weather profiles. By using historical weather conditions from a particular time and place, the wargame designers can create a starting point for a wargame scenario that accurately reflects the desired conditions of the environment. The dynamic weather simulation will use this initial weather profile and insert additional weather objects (e.g., storm) to simulate the future weather condition while the wargame is executing. This technique of weather simulation is often employed during the “Wargame Course-of-Action (COA)” Develop and Assess phases.

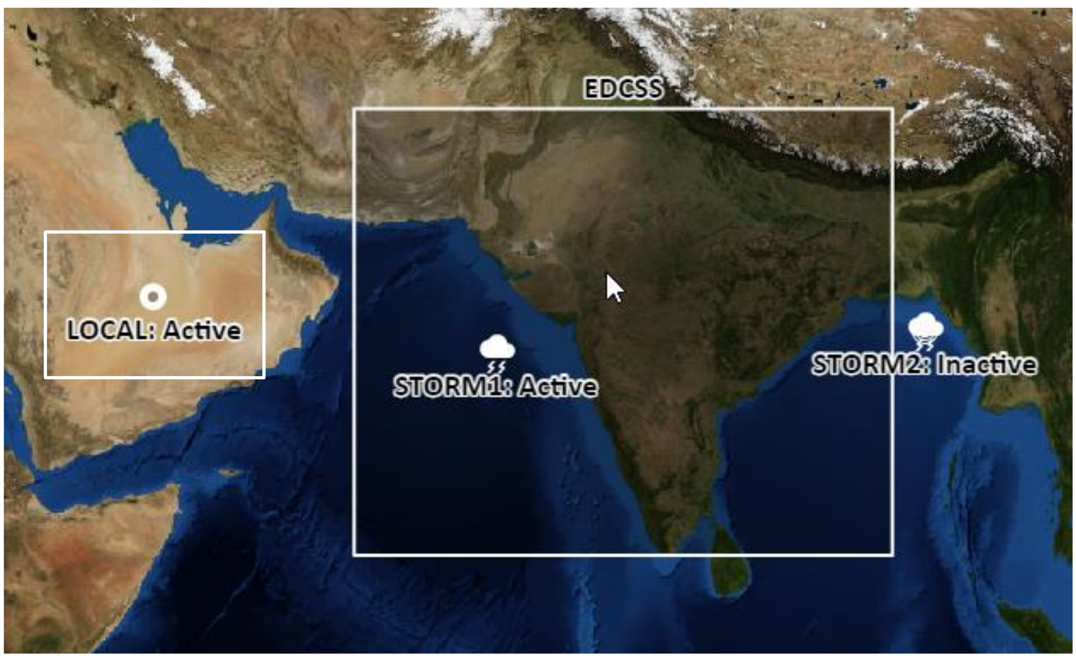

Figure 2. Historical Weather Data (EDCSS) Augmented with Dynamic Weather Simulation

Historical Weather Data Review and Selection: Limitation of the current approach

During the “Design” phase, wargame designers select and review the available historical weather data to assess its suitability for the anticipated wargame scenario, ensuring it models the likely weather conditions during the anticipated time frame of the wargame. To do so, the wargame designers use a map display to select the gaming area and then choose the required historical weather data for this area. The selection is filtered by specifying the date, month, and year of the desired weather data. Once the selection is completed, the user interface allows the wargame designers to select weather parameters (temperature, air pressure, cloud coverage, sea state, etc.) to be examined. The data of the selected weather parameter is then displayed within the wargaming area on the map. The selected weather data can then be examined hour-by-hour for a specific date, month, and year.

While this approach is useful for allowing the wargame designers to examine the available weather data and determine if these data are appropriate for the wargame scenarios, it represents a cumbersome and time-consuming method.

WARGAMING WEATHER SIMULATION ONTOLOGY

Motivation for Using Ontologies in the development of a Generative AI for weather simulation

The ontology is the knowledge representation of the domain. An ontology consists of classes and subclasses of the domain of knowledge (Erraguntla et al., 1994; Hilera et al., 2010; Benjamin et al., 2006). Defining an ontology for weather simulation helps capture the interrelationships and dependencies among various weather-related variables. It encompasses meteorological parameters, geographic features, and atmospheric phenomena, providing a rich semantic understanding of the wargaming domain. Incorporating an ontology into the design of a generative AI system amplifies its capacity to comprehend, rationalize, and produce content tailored to the distinct realm of weather simulation in wargaming scenarios, as opposed to other weather simulation contexts. This integration ensures coherence and adherence to domain-specific knowledge throughout the system's operations.

When combined with a language model in a Generative AI system, the weather ontology can complement and enhance its capabilities in several ways. For instance, it enhances semantic understanding since the weather ontology provides a structured representation of wargaming weather concepts and their interrelations, enabling the AI system to understand the meaning of words and phrases in a more precise and contextually accurate manner (Goled, 2021). This semantic understanding goes beyond mere keyword matching, allowing the AI to grasp the underlying concepts and their relationships within the wargaming domain. Additionally, the weather ontology can capture wargaming domain-specific knowledge in a structured format, making it easier for the prompt-based generative AI system to reason and make inferences within the wargaming domain. By incorporating wargaming weather simulation ontology, the language model can leverage specialized knowledge to provide more accurate and relevant responses to user queries or tasks.

Weather Ontology for Wargaming

Figure 3 shows the Wargaming Weather Ontology. The two main classes of the wargaming weather ontology are:

- **WargamingWeatherData** refers to weather-related information specifically tailored for use in wargaming scenarios. Weather data for wargaming is provided primarily in two ways: historical weather data from EDCSS and synthetic weather forecasts that would provide useful information for wargaming operations. The WargamingHistoricalWeatherData subclass contains the formats for the EDCSS weather reports while the WargamingWeatherForcast subclass contains the synthetic weather forecasts.

- **WargamingWeatherObjects** are foundational objects used to build the conceptual weather objects, data, and reports for wargaming. The contained subclasses are meant to be standalone and generic, but they may also be used to build other classes and objects in the main class. These objects are categorized into two subcategories: constructs and weather. Constructs contain objects that do not describe weather or are not weather themselves such as time, location, distance, etc. These objects are vital in both weather reports (both historical and synthetic) and general weather concepts, but are not sufficiently descriptive, in a wargaming sense, if used standalone. Weather contains all the weather objects or phenomenon that can be used in data or reports. The subclasses are further categorized into the domains (air, land, sea, and outer space) they occur in and are restricted to, and domain independent weather that has no restriction or can occur in multiple domains simultaneously.

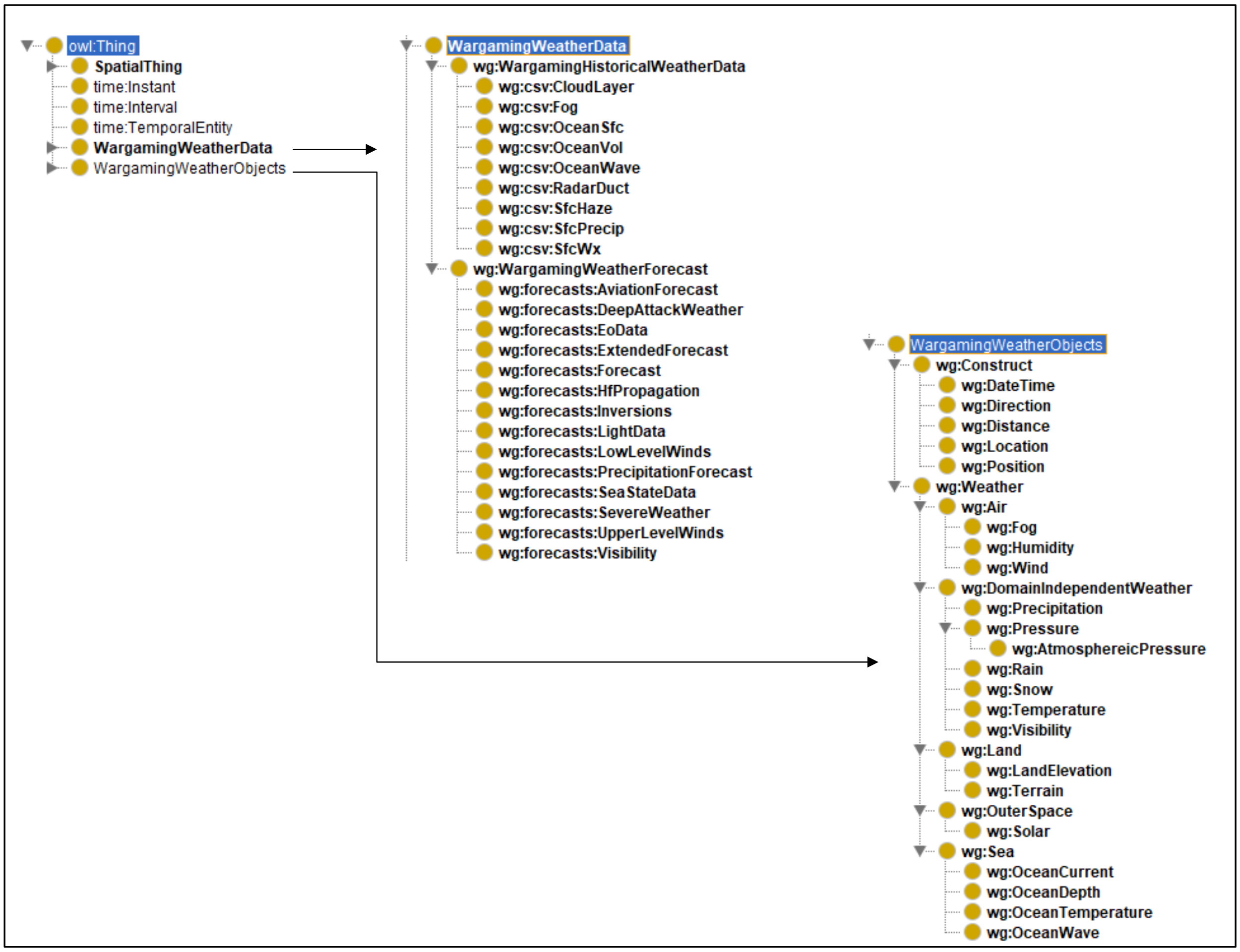

Figure 3. Wargaming Weather Ontology

GENERATIVE AI SYSTEM FOR WEATHER SIMULATION

Generative AI in weather simulation is a concept that involves using artificial intelligence algorithms and models to generate insights about weather conditions. It utilizes machine learning techniques to analyze historical weather data and develop models that can generate weather predictions based on the data used to train the system. In other words, generative AI works in weather simulation by analyzing large amounts of historical weather data and using this information to train machine learning models. These models can then generate predictions based on patterns and trends observed in the data.

For an application in wargaming, the AI model learns from large datasets of historical weather data, including variables like temperature, humidity, wind speed, atmospheric pressure, and cloud cover. By integrating this data for training, the AI model learns the complex relationships and patterns between these variables, enabling it to generate weather information that more closely resembles real-world weather conditions.

During the wargaming "design" phase, wargame designers can use a prompt-based generative AI system to interact with the AI model by inputting questions pertinent to historical weather data to generate answers. Basically, a prompt-based generative AI for weather is an artificial intelligence system specialized in generating weather-related information based on user-provided prompts or queries. Here's how a prompt-based weather generative AI typically works:

- **Prompt Input**: Users provide a prompt or query related to weather conditions. This could be a specific location (e.g., "What's the weather in New York City tomorrow?"), a time frame (e.g., "What will the weather be like this weekend in Los Angeles?"), or a general inquiry (e.g., "Give me the current weather in London.").

- **Understanding Context**: The AI analyzes the prompt using NLP techniques to understand key elements such as location, time, and type of weather information requested. It may also consider additional context, such as historical weather data or user preferences if available.

- **Data Processing**: The AI accesses relevant meteorological databases or real-time weather data sources to gather information related to the user's query. This data may include temperature, humidity, precipitation forecasts, wind speed, and atmospheric pressure, among other variables.

- **Answer Generation**: Based on the analyzed prompt and the retrieved weather data, the AI generates a weather report tailored to the user's request. This could involve providing specific details such as temperature ranges, chance of precipitation, expected weather conditions (e.g., sunny, cloudy, rainy), and any relevant weather advisories or warnings.

Generative AI System Architecture for Weather Simulation

Generative AI architecture refers to the overall structure and components of building and deploying generative AI models. For weather simulation and/or prediction application, the generative AI architecture consists of the following key components:

1. **Weather data collection and management**. In this study, we collected historical weather date from two difference sources: EDCSS and NOAA.

2. **Wargaming Weather Ontology**. We formulated a wargaming weather ontology, as elaborated in the preceding section, serving as the primary framework for conducting:

   a. Data labelling, as it provides a standardized vocabulary and hierarchy of concepts for annotating. The Ontology enables semantic annotation of data by associating data instances with specific concepts or classes defined in the ontology. This semantic enrichment enhances the interoperability, searchability, and reasoning capabilities of the data.
   b. The weather AI system leverages the weather ontology to generate text that is coherent, relevant, and aligned with the wargaming domain represented by the ontology.

3. **Data labeling and processing**. Data labeling is the practice of annotating unprocessed data, in this case, the historical weather data, with pertinent tags or labels. These labels offer the structure and context required for machine learning models to develop and produce precise predictions. In this study, we developed a wargaming ontology to be used as the main reference for performing data labeling. The weather wargaming ontology provides a standardized vocabulary and hierarchy of concepts for annotation.

   Data preprocessing encompasses cleaning the data, addressing missing values, and ensuring consistency across various variables and time periods. The Principal Component Analysis (PCA) method was utilized for both data preprocessing and dimensionality reduction. The primary rationale behind employing PCA is handling the immense size of historical weather data, which presents challenges in terms of storage and accessibility. PCA is applied in this study to streamline and condense the extensive dataset of correlated information derived from historical weather data. The objective is to extract and emphasize the most influential features or patterns within the data, thereby reducing its dimensionality while preserving essential information. The reduced-dimensional dataset obtained from PCA will later serve as the basis for training the AI model during the model training phase.

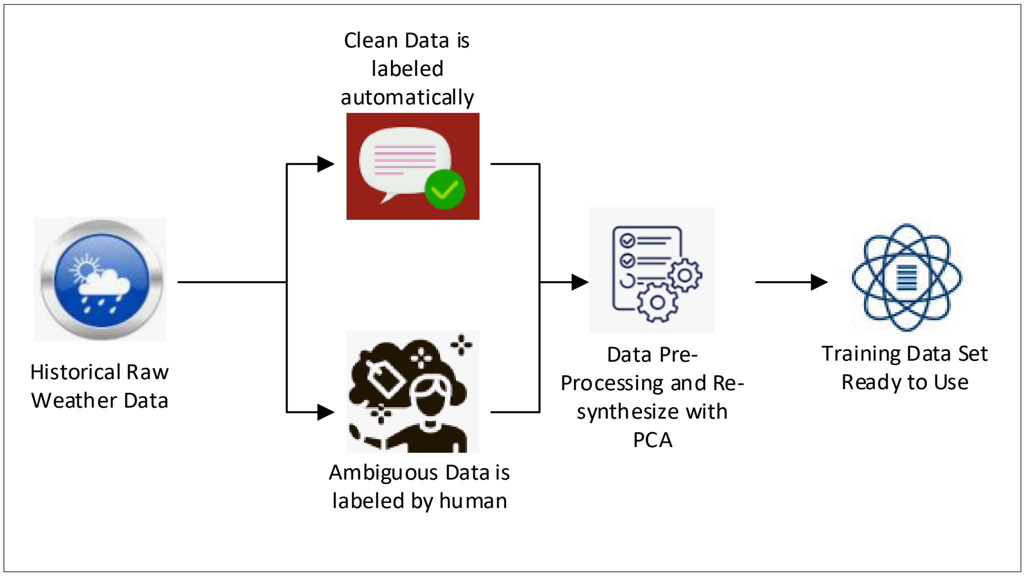

Figure 4. Data labelling and processing

4. **Model Selection and Training**. Model selection consists of choosing the appropriate machine learning algorithm, while model training consists of training the selected model with pre-processed data. For the weather simulation generative AI system proposed in this study, we evaluated the most common machine learning models used for weather prediction, such as Linear Regression, Decision Tree, Random Forest, Gradient Boosting Machine (GBM), Ridge Regression, and Support Vector Machine (SVM).

   We decided to use the Ridge Regression model since it is a statistical regularization technique used to correct for overfitting on training data. Ridge regression specifically corrects for multicollinearity in regression analysis. This is useful when developing machine learning models with a large number of parameters, particularly if those parameters also have high weights as in the historical data.

5. **Generative AI model**. Our end goal is to eventually develop a prompt-based generative AI system applied to wargaming weather simulation. A prompt-based generative AI must technically utilize any underlying model capable of generating text based on prompts. Large Language Models (LLMs) like ChatGPT are one of those models. We consider two alternate approaches: Rule-based System (RBS) and Small Language Model (SLM).

   A rule-based system is a model that follows predefined rules to generate responses based on prompts. While it lacks the flexibility and creativity of large language models, the model can still be effective for specific tasks, like weather simulation. While not as powerful as large-scale models like LLM, an SLM can still be used for prompt-based generation, especially in scenarios where computational resources or model size are constrained, or for specific domain knowledge tasks (e.g., wargaming weather simulation).

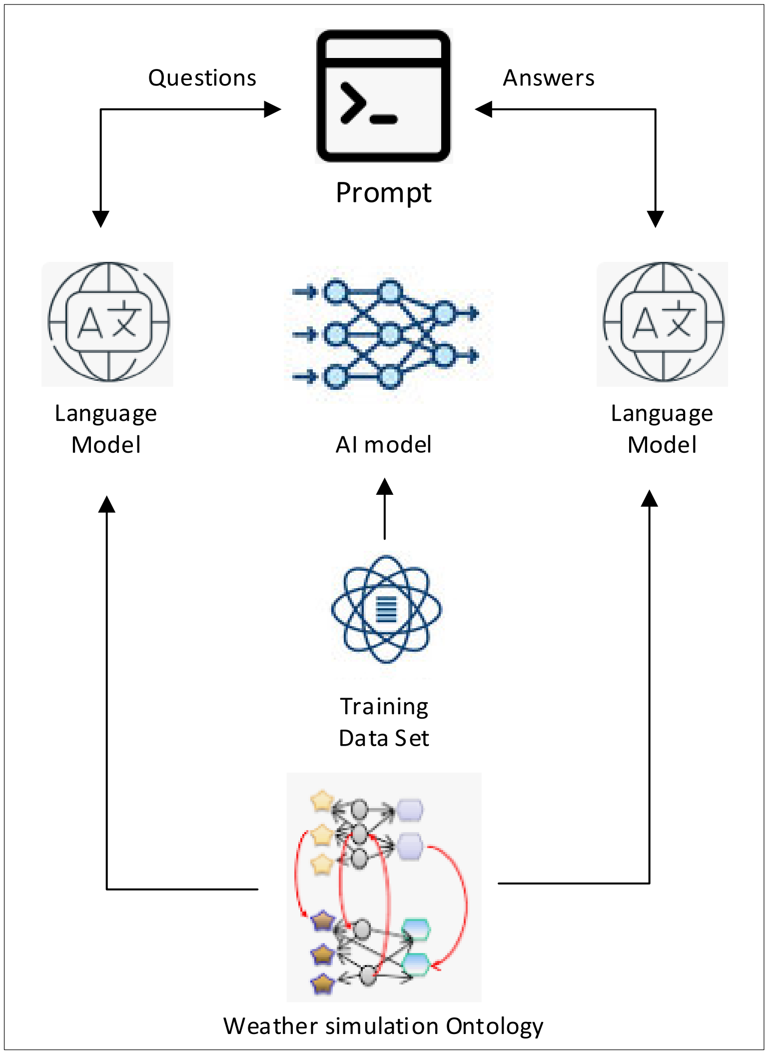

Figure 5. Weather Generative AI System Architecture

PROTYPE DEVELOPMENT AND RESULTS

We developed a prompt-based generative AI prototype to validate the concept of creating a weather generative AI system. The prototype should also help us understand the limitations and gather feedback from the wargaming community. Our vision is that wargame designers can eventually use the system to examine historical weather data by simply asking the system questions related to weather datasets.

The weather generative AI prototype used historical weather datasets from the cities of Orlando (from 1892 to today), Tampa (from 1939 to today), Atlanta (from 1930 to today), and Chicago (from 1946 to today) to train the AI system. The main weather data that the prototype considered and labeled are the daily min/max temperature and the amount of precipitation. Additional weather data, such as the average temperature of the week, etc., were also derived and used to train the system. Figure 6 demonstrates the operation of the prompted generative AI system, where wargame designers input weather-related questions and promptly receive answers generated by the AI system.

Figure 6. Generative AI for Wargame Weather Simulation

CONCLUSION

This paper presents an ontology developed to capture weather simulation attributes pertinent to the wargaming domain. In the context of data labeling and processing, the weather ontology refers to a formal representation of knowledge within a specific domain. It defines the concepts, entities, relationships, and constraints that exist within the domain, providing a structured framework for organizing and understanding data. Therefore, it was developed in this study with the purpose of standardizing the representation of weather simulation concepts, relationships, and processes within the wargaming domain. The benefit of using this ontology in the development of a generative AI system is the ability to reuse this same ontology independently of the AI development framework. We plan to release the ontology developed from this study as an open-source database, and it will be available for the modeling and simulation community to reuse for future developments of wargaming platforms.

To enhance the method of selecting and reviewing historical weather data during the wargame design phase, we proposed and described the key components of a prompt-based weather simulation generative AI system. A prototype of the weather generative AI system was developed as a proof of concept. This prototype will allow us to validate the feasibility of our AI solution and will be used to gather feedback from wargame designers. User feedback will help us gather additional ideas and improve the proposed generative AI system architecture.

REFERENCES

Anochi, J.A, Almeida, V. A, and De Campos Velho, H.F. (2021). Machine Learning for Climate Precipitation Prediction Modeling over South America. Remote Sens. 2021, 13, 2468.

Atkinson, G.D. (1973). Impact of Weather on Military Operation: Past, Present, Future. US Army War College, Carlisle Barracks, Pennsylvania.

Bae, S. J., Brown, I. T. (2021). A Brief History of Educational Wargaming in the Marine Corps. Journal of Advanced Military Studies. Volume 12. No. 2.

Barton, M. (2008). Game Studies - How's the Weather: Simulating Weather in Virtual Environments. The international journal of computer game research. Vol 8. Issue 1.

Benjamin, P., Patki, M. & Mayer, R. (2006). Using Ontologies for Simulation Modeling. Proceedings of the 2006 Winter Simulation Conference. L. F. Perrone, F. P. Wieland, J. Liu, B. G. Lawson, D. M. Nicol, and R. M. Fujimoto. pp. 1151-1159.

Chen, J., & Fu, C. (2016). Weather simulation in video games: A review. IEEE Transactions on Computational Intelligence and AI in Games, 8(3), 277-293.

Crick, T., & Grange, J. (2013). Dynamic weather systems in video games: An analysis of the principles, options and challenges. International Journal of Computer Games Technology, 2013, 1-12.

Department of the Army. U.S. Army Field Manual (FM) 34-81-1. Battlefield Weather Effect. 1992.

Downing, D. M. (2015). The influence of weather and climate in military history. In Military geosciences and desert warfare (pp. 103-132). Springer.

Erraguntla, M., Benjamin, P. C., Mayer, R. J. (1994). An architecture of a knowledge-based simulation engine. In J. D. Tew et al. (Eds.), Proceedings of the 1994 Winter Simulation Conference (673−680). San Diego, CA: Society for Computer Simulation International.

Füssel, H. M. (2015). Weather and war. Weather, Climate, and Society, 7(2), 106-115.

Hilera, José, and Luis Fernández-Sanz. 2010. Developing Domain-ontologies to Improve Software Engineering Knowledge. International Conference on Software Engineering Advances.

International Organization for Standardization, Standard Atmosphere, ISO 2533:1975, 1975.

Johnson, C. W. (2019). Weather in Wargaming: A Review. Journal of Defense Modeling and Simulation: Applications, Methodology, Technology, 16(2), 129-138.

Joseph, J. (2013). Rainfall Prediction using Data Mining Techniques. International Journal of Computer Application. 2013, 83, 11–15.

Kennedy, J. (2014). The impact of weather on military operations. Military Medicine, 179(1), 35-42.

Mushtaq, F., Abulibdeh, D., Khasawneh, M. T., & Al-Bashabsheh, A. (2018). Dynamic weather system in games: A review. International Journal of Advanced Computer Science and Applications, 9(9), 392-398.

Nguyen, H. G, Wang, Y., Tran, D. H., Le, P. A., and Nguyen, T. T. (2022). Monthly precipitation prediction using neural network algorithms in the Thua Thien Hue Province. Journal of Water and Climate Change. Vol. 15 (5).

Tien, R. A. (2018). Weather in video games: A review. Bulletin of the American Meteorological Society, 99(6), 1217-1225.

Tran, H (2023). Adding Weather to Wargame Simulation. Interservice/Industry Training, Simulation, and Education Conference Proceeding (I/ITSEC).

Weatherly, J. W. and Hill, D. R. (2004). The Impact of Climate and Extreme Weather Events on Military Operations. Proceedings for the Army Science Conference (24th). Orlando, FL.