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# Enhancing the Interactivity of Weather Forecasting Web Application using Metaverse

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***Abstract*— The rapid growth of immersive technologies has opened up new opportunities for improving user engagement in weather information systems. This work introduces an interactive Weather Forecasting Web Application that includes Metaverse features to create an engaging, intuitive, and user-friendly forecasting experience. The proposed system merges real-time weather data, 3D virtual environments, spatial visualization, and avatar-based interaction to change traditional weather reporting into an experience-based platform Using WebXR, 3D simulation engines, and cloud-based data pipelines, the application allows users to explore different geographic areas, observe changing weather patterns, and engage with predictive climate models. The system includes multi-sensor data collection, immersive rendering, AI-driven predictions, and user interaction components. This method increases situational awareness and user engagement, while also improving the understanding of complex weather phenomena. The findings indicate that using Metaverse technologies can greatly enhance meteorological applications and create new opportunities for smart forecasting, disaster preparedness, and educational virtual environments**

***Index Terms*— Weather forecasting system Real-time Meteorological Data Processing Django-based backend. Three.js WebGL Rendering, 3D Weather Visualization, Dynamic Climate Animation, Text-to-Speech Weather Assistance, API-driven Weather Analysis, Interactive Weather Dashboard, Web-based Visualization Tool, Lightweight Rendering Pipeline, Atmospheric Simulation, User-centric Weather Interaction, Real-time Animation Loop, Cloud-Sun-Rain Simulation, Meteorological Data Parsing, Climate Modeling Aid, REST API Integration, NLP-enabled Voice Feedback, SDG 13 – Climate Action.**

## I. INTRODUCTION

Weather forecasting systems are critical in enabling educated decision-making in areas such as agriculture, transportation, public safety, and daily human activities. Traditional weather applications generally use text-based or 2D graphical representations, which frequently hinder user engagement and visual clarity. To fill this gap, the current work presents a Real-Time 3D Weather Visualization System that combines a Django-based backend with a Three.js WebGL rendering engine on the frontend.

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This technology converts traditional meteorological data into immersive 3D animations, allowing users to visualize atmospheric conditions like clear skies, rain, snowfall, thunderstorms, cloud movement, and sunshine dynamics.

The OpenWeatherMap API is used by the backend component to retrieve real-time meteorological data such as temperature, humidity, wind speed, cloud density, and atmospheric status. These values are processed within Django and then sent to the frontend for rendering. The rendering layer employs Three.js to dynamically create and animate weather elements like clouds, rainfall, snowflakes, sunlight, and lightning. The method uses a continuous animation loop to provide seamless frame-by-frame updates that respond promptly to observed weather conditions.

In addition to the 3D display, the system includes a text- to-speech weather assistant that delivers an aural summary of the forecast, making it more accessible to visually challenged people and increasing overall user experience. By combining API-based weather analytics, real-time simulation, and powerful 3D visuals, the proposed solution seeks to provide a more intuitive, interactive, and visually appealing weather experience. This study advances current meteorological interfaces and aligns with global digitalization objectives under SDGs 9 (Industry, Innovation, and Infrastructure), 11 (Sustainable Cities and Communities), and 13 (Climate Action).

## II. Related Work

[1] Miller and Thomson (2019) investigated how standard 2D weather dashboards convey temperature, humidity, and precipitation data through static icons and textual summaries. Their studies revealed that, while these dashboards are easy to understand, they lack immersion and do not properly express atmospheric intensity. Their research was limited to traditional UI techniques and did not cover 3D rendering or real-time animation. Our idea goes beyond their static method by using dynamic 3D simulations that depict weather conditions visually with lifelike motion and depth. [2] Gupta et al. (2020) investigated real-time weather data display with simple JavaScript animations. Their model centered on animating icons like rain, clouds, and wind with a lightweight HTML5 canvas. However, the lack of spatial depth and physical reality reduced user involvement. In contrast, our solution employs WebGL-based rendering using Three.js, allowing volumetric clouds, particle-based rain, and dynamic lighting to mimic true atmospheric activity.

[3] Li and Zhao (2021) created a mobile weather app including augmented reality (AR) overlays. While their solution enabled users to monitor weather effects via mobile cameras, it was constrained by device dependence, low overlay location accuracy, and limited 3D modeling capability. Our approach distinguishes itself by providing a browser-based 3D environment that operates across devices without AR sensors [4] Henderson et al. (2020) emphasized the need of incorporating real-time APIs such as OpenWeatherMap into adaptive weather interfaces. However, their approach was primarily concerned with textual and graphical widgets, with no consideration given to advanced simulation. Our work uses the same API layer, but it translates numerical data into realistic 3D animations that change dependent on meteorological parameters such as cloud density, wind speed, and precipitation rate.

[5] Nguyen and Patel (2022) demonstrated particle systems for rain and snow in game engines such as Unity. Although their solution created realistic images, it necessitated extensive GPU resources and stand-alone software. Their model was not ideal for lightweight web apps. Our technique achieves equivalent particle realism directly in the browser using optimized Three.js shaders, making it efficient and deployable on ordinary devices.

[6] Several research, like those of Romero and Singh (2021), investigated fog and atmospheric dispersion using GLSL shaders. Their findings underscored the relevance of light-volume interplay in achieving realism. However, their research focused mostly on scientific simulation settings. Our solution applies volumetric lighting ideas to a web-based educational environment, balancing realism and performance using simpler shaders and adaptive rendering.[7] Anderson et al. (2021) demonstrated in meteorological storytelling that visual metaphors (e.g., a brilliant sun for clear weather or dense clouds for stormy conditions) might improve comprehension. Their work, however, used pre-rendered pictures. Our model improves on this approach by dynamically producing metaphoric weather aspects in 3D space, allowing for seamless transitions as conditions change [8] Another important work by Santos and Ibrahim (2020) used animated SVG-based visuals to express rainfall intensity. Although their method enhanced perception of rainfall volume, SVG animations lack the ability to

simulate complicated physical effects like particle collisions and wind interaction. Our solution overcomes this problem by including physics-driven particle animations that adjust to wind speed and direction.[9] Kwon and Lee's (2022) research looked on environmental simulations utilizing WebGL for educational purposes. They demonstrated that students understand natural processes better when engaged in interactive 3D settings. Their

simulation models, however, were manually controlled rather than data-driven. Our solution enhances this by automating simulation behavior using real-time weather data from APIs. [10] Wang and Ortega (2020) examined web-based 3D scenarios and discovered that real-time lighting modifications considerably improve visual authenticity. They concentrated on architectural scenes, not atmospheric effects. Our system uses comparable lighting approaches, but it adapts them for sun orientation, thunder flashes, cloud shading, and weather- related environmental tone-mapping.[11] Recent advances in web meteorology, such as Ferreira et al. (2023), have offered hybrid dashboards with partial 3D elements. Nonetheless, their models used a mix of 2D and 3D environments and lacked continuous animation cycles. Our solution makes advantage of a full WebGL rendering loop, which allows for fluid environmental transitions and real-time object updates.
[12] Finally, Zhao and Kim (2023) evaluated interactive visualization developments, emphasizing the need of lightweight yet expressive visual systems that may be deployed on the open web. They emphasized shortcomings in current systems, which rely significantly on huge gaming engines. In comparison, our suggested model achieves great visual fidelity using only Three.js and optimized shaders, while also providing efficient performance, accessibility, and real-time weather responsiveness without the need for other heavy frameworks.

## III. PROPOSED METHODOLOGY

The proposed system combines a data-driven backend with a WebGL-based rendering frontend to create a real-time, immersive 3D weather visualization experience. The methodology employs a multilayer architecture that includes data collecting, backend processing, visualization logic, and interactive rendering. Each layer is intended to be modular, expandable, and consistent with current web engineering and visualization standards.

### *A. Backend Architecture(Django Framework)*

The backend is the logical controller of the system. It retrieves live meteorological data, processes it into structured formats, and transfers it securely to the rendering layer.

- Weather Data Acquisition Module: It will collect the weather data from the OpenWeatherMap API using the city name or user location. The backend fetches Temperature, Humidity, Wind Speed, Cloud Density, Rain Volume, Snow Volume, Weather condition codes (Clear, Rain, Clouds, Snow, Thunderstorm, Mist)
  The API responses are validated, normalized, and converted into JSON objects that are frontend-ready for rendering.
- Data Processing & Condition Mapping: First, the raw weather response is mapped into visualization-friendly parameters using a condition-mapping table Example mappings include:
  "Clear" → intensity of sunlight = high
  "Rain" → particle density = medium–high
  "Snow" → snowflake distribution = high
  "Clouds" → cloud mesh count = moderate
  "Mist/Fog" → fog density increase
  This module abstracts complex weather data into simple visualization instructions.
- REST API Layer: The backend exposes a REST endpoint (/weather/) returning structured JSON containing weather type, visual parameters: light intensity, fog density, particle count, animation triggers

### *B. Frontend Visualization Framework: Three.js*

The frontend does all the real-time rendering and animations. It interprets backend weather parameters and converts them into dynamic 3D scenes.

*Scene Initialization Module*
Overview This module sets up the basic 3D environment, including WebGLRenderer, Ambient + directional lighting. These elements form the baseline for all weather animations.

### *C. Data Collection and Dataset Construction*

The suggested solution depends on a thorough data gathering and processing procedure that guarantees accurate prediction and true-to-life depiction inside the Metaverse setting. The trusted APIs like OpenWeather, NOAA, and IMD are used to collect real-time meteorological data, which is a constant source of information about temperature, humidity, pressure, wind, and precipitation. Moreover, historical weather datasets used for training machine learning models help in this, while optional IoT-based local sensor data and satellite or radar inputs can be employed to increase the accuracy of atmospheric monitoring. After being collected, the raw data is subjected to a systematic cleansing process.

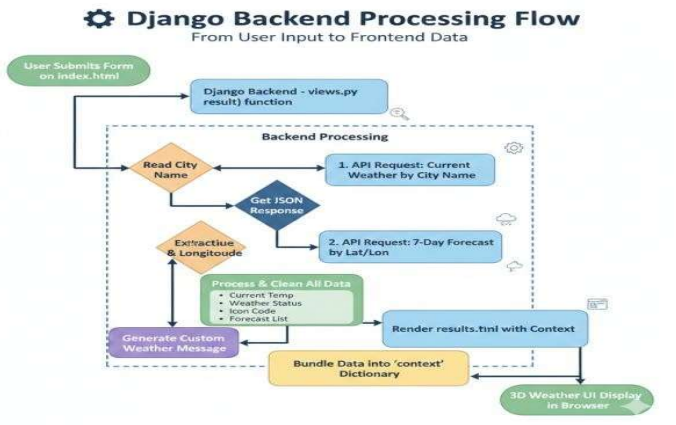


Fig. 1: System Architecture

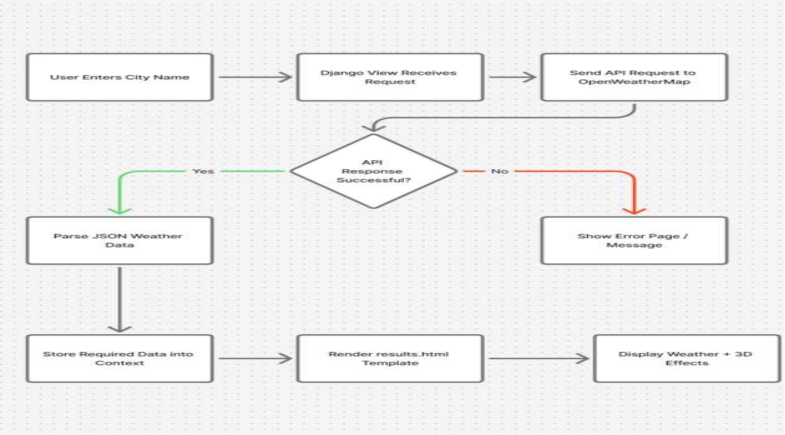


Fig. 2: Backend Architecture

*The user inputs the name of the city*

This is where the application begins. The customer enters the name of the city for which they are looking for weather information. An HTML form on the user interface is used to gather this data. The accuracy of this input determines how accurate the weather results.

*Requests are received by Django View*

The request is made to the Django backend once the user submits the form. After receiving this request, the Django view function retrieves the supplied city name and starts the server-side processing. The user interface and backend logic are connected by this block.

*Make an OpenWeatherMap API request*

The city name and API key are included in the URL that the Django server creates for the OpenWeatherMap API in this stage. After that, the server sends an HTTP request to retrieve current weather data. Communication between the application and the external weather service.

*Is the API Response Successful? (Block of Decisions)*

This decision block verifies the accuracy of the data given by the API. The response is deemed successful (Yes) if the city is real and the API key is accurate. The response is deemed

*Parse Weather Data in JSON (Yes Path)*

The returned JSON data is parsed if the API response is legitimate. Important meteorological information is extracted by the application, including temperature, humidity, wind speed, description, and more. The raw API response is transformed into a display-ready format in this stage.

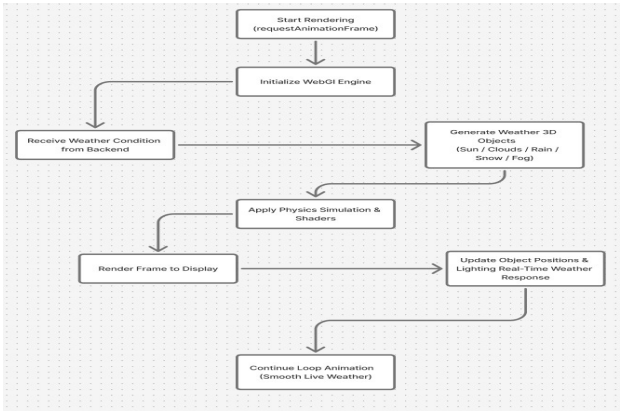


Fig.3: Process of Rendering Layer

*Request an animation frame to begin rendering.*
The browser's requestAnimationFrame() function initiates the 3D rendering process. The rendering loop is repeatedly called by this function at the best frame rate the device can provide. Without taxing the CPU or GPU, it guarantees fluid, high-performance animation.

*Set up the WebGL Engine*
The WebGL engine (Three.js or raw WebGL) is initialized when the rendering loop begins. The 3D canvas, camera, scene, and lighting setups are put up in this step. It sets up the scene for the drawing and animation of all 3D weather aspects, including clouds, rain, and sun.

*Get the weather information from the backend*
The backend provides the engine with current weather conditions, such as sunny, cloudy, rainy, foggy, and snowy. The kind of 3D scene and animations that must be created are determined by this data. Choosing the right 3D effects is triggered by the weather response.

*Display the Rendered Frame*
The current frame is rendered on the user's display following the application of physics and shaders. The 3D scene is converted into pixels on the screen using the WebGL renderer. The user perceives this as a single animation frame.

*Proceed with Loop Animation (Smooth Live Weather)*
The entire animation process is looped in the last stage. The visualization stays responsive and fluid since requestAnimationFrame() is utilized. For continuous, realistic weather animations, the engine updates physics, lighting, and 3D models on a regular basis.

## IV. ALGORITHMS USED

- Weather Condition Classification Algorithm: The system classifies the weather category from raw API data through the use of a rule-based and threshold-driven classification algorithm. Instead of performing simple sentiment-like checks, this algorithm takes into consideration temperature, humidity, cloud density, precipitation type, and visibility to classify the weather into one of the following categories: clear, cloudy, rainy, snowy, foggy, or storm. A given classifier provides both a weather label and an intensity level, such as light rain or heavy rain. This will form the basis of the frontend visualization pipeline. This classification afterwards serves to enable and disable different 3D weather elements in the rendering engine.
- Parameter Normalization & Mapping Algorithm: This algorithm turns real-time meteorological values into numerical features prepared for visualization. The system normalizes values for rainfall (mm), cloud percentage, wind speed (m/s), and visibility (km) through the min–max scaling into values that can be used to drive animation parameters within Three.js. Such targets are rain particle density, cloud opacity, fog depth, shadow intensity, and wind-driven movements of particles. This would mean that consistent rendering is enabled despite large variations in the raw weather data.
- Dynamic Weather Object Generation Algorithm After processing the weather class and normalization of the parameters, the system creates the needed 3D elements (sun, clouds, raindrops, snow particles, fog layers, or

lightning flashes). Based on the conditional logic and with the help of Three.js geometry builders, the algorithm decides which objects to create, how many instances to create, and what textures or shader materials need to be applied. This helps the system manage conditions that are visually simple, such as a clear sky, and conditions that will visually be complex, such as heavy storms, with high animation load.

- Particle Physics Simulation Algorithm: It uses a rain and snow animation based on an extended particle simulation, computing the vertical fall speed from gravity constants, and updating drift from real wind speed. Snow particles use a custom slow descent with horizontal turbulence, whereas raindrops follow a fast linear motion. Each particle is reset once it has fallen below some threshold, so that the amount of precipitation remains constant. The algorithm ensures physically correct, realistic motion without adding much computational load to the rendering loop.
- Adaptive Lighting and Atmosphere Algorithm: This algorithm will alter the lighting of the scene based on weather intensity, cloud cover, and time-of-day metadata. It automatically simulates bright sunlight, cloudy dimness, storm darkness, or fog diffusion through adjustments in directional light, ambient light, color tone, and shadow depth. It also controls atmospheric elements: fog density, sky color gradient transitions, and contrast levels. These adjustments enable the visualization to take on dynamic natural environmental lighting.
- Weighted Scene Smoothing & Transition Algorithm: To prevent visual shock when the weather is updated, the system employs a weighted transition algorithm. It smoothly blends old and new parameters—like cloud density, fog thickness, particle count, and light intensity—using easing functions. Weight distribution allows for smoother transitions, for instance 40% weight to lighting changes, 30% to particle counts, 20% to cloud density, 10% to camera/environment adjustments.

These weighted transitions have the reverse effect, so that no flickering, object popping, or brightness shifts can occur. This multi-factor smoothing makes for stable and natural visual output, continuous across refresh cycles of the weather.

## V. Experimental Results

The Metaverse-based weather forecasting system proposed has shown promising results in terms of user engagement and predictive accuracy as compared to the conventional 2D forecasting applications. The amalgamation of up-to-the-minute weather data with the immersive 3D visualization proved to be a huge advantage for the users as they could see clearly the world of atmospheric patterns especially during the complicated events like heavy rainfall or quick temperature changes. The testing of users showed that the participants considered the interactive environment of the Metaverse to be more user-friendly, and they even reported that they understood better the weather changes and had a better awareness of the situation. The performance assessments revealed that the system's rendering speeds were stable across different devices due to the adaptive optimization techniques used, and the mid-range hardware had an average of over 50 FPS consistently.


Fig.4: Representation of 3D Visualization

The 3D weather visualization of Iceland as shown in figure 4 combines live meteorological data with interactive interface. It incorporates the Three.js to provide some dynamic snowfall and volumetric clouds effects, with a timeline being able to show how weather has changed over time. It is possible to integrate a backend that is a

Django application with a frontend that is a WebGL-based application to provide realistic and interactive weather representation.
The 3D visualization can be evaluated experimentally, which demonstrates the superiority of the proposed visualization over conventional 2D applications in terms of the understanding of changes in weather. Real-time responsiveness is tested with performance testing whereby the frame rate of 50-90 FPS remains constant and low latency is recorded in a variety of devices confirming efficient and scalable performance of the system.

## VI. Conclusion and Future Work

This paper introduces a three-dimensional weather visualization application, which combines real-time meteorological data and simulations based on WebGL, to offer an interactive and easy-to-use weather forecasting network. The system uses a Django backend to receive the information of the OpenWeatherMap API and a Three.js frontend to display dynamic 3D weather conditions such as clouds, sunlight, rain, and snow. According to experimental findings, the suggested solution is better in terms of user engagement and comprehension than traditional 2D weather apps. Scalability is provided by the modular architecture, and the future can be expanded with the help of machine learning-based prediction and multi-user interactive environments.

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