Atmospheric Visualization Using Augmented Reality

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Objectives

- Expand our existing extended reality (XR) portfolio by developing a mobile augmented reality (AR) application for atmospheric science visualization
- Develop interactive visualizations of global atmospheric circulation
- Integrate atmospheric data into an AR environment
- Display atmospheric data on both a flat world map and a virtual 3D globe.

Atmospheric Circulation Models

- **Single-cell model:** Represents an idealized, non-rotating Earth with strong solar heating at the equator and cooling at the poles. Warm air rises near the equator, moves forward poleward aloft, sinks near the poles, and returns toward the equator near the surface.
- **Three-cell model:** Incorporates the effects of Earth's rotation and the Coriolis force. The circulation in each hemisphere is divided into the Hadley, Ferrel, and Polar cells, producing more realistic global wind patterns, including the trade winds, westerlies, and polar easterlies.

Conceptual and AR Models

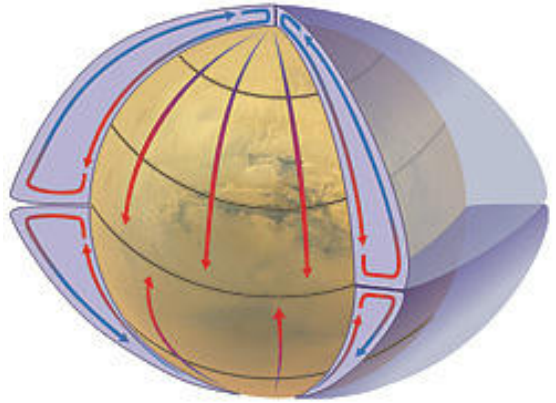


Figure 1: Single cell diagram [1]

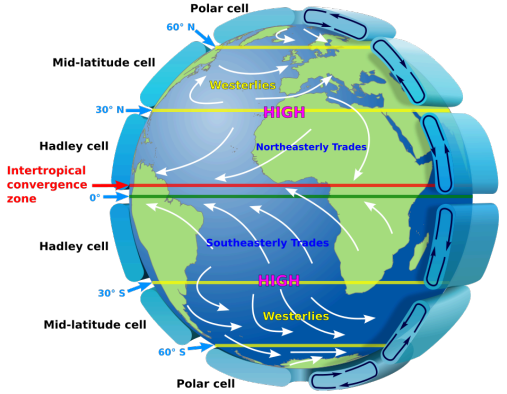


Figure 2: Three cell diagram [2]

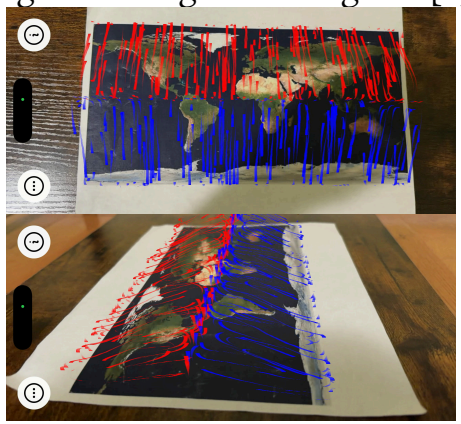


Figure 3: Single cell simulation

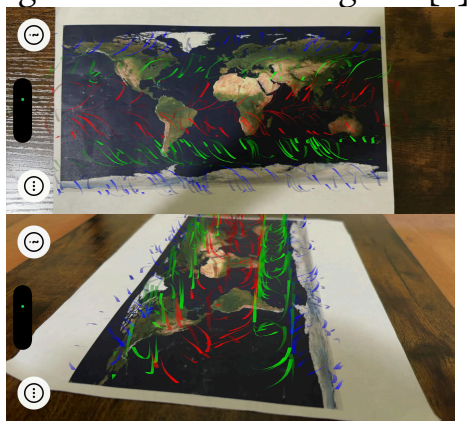


Figure 4: Three cell simulation

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Real Atmospheric Data

- ERA5 climatological wind fields: Zonal, meridional, and vertical wind components were averaged over 1991-2025 at each latitude, longitude, and pressure level
- The ERA5 visualization highlights the predominantly zonal (east-west) circulation of the real atmosphere, including major westerly and easterly wind belts
- The processed wind fields were converted into 3D textures for efficient visualization in Unity

Particle Simulation

- Particles are initialized at random locations within the visualization domain
- Particle motion is driven by local wind vectors at each particle's position
- Single- and three-cell wind vectors are calculated from equations describing atmospheric circulation
- Real wind vectors are sampled from the processed 3D textures

ERA5 Wind Visualization in AR

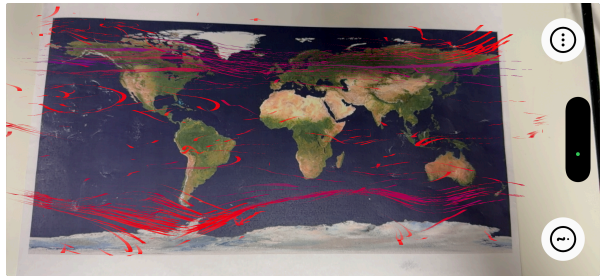


Figure 5: ERA5 climatological wind field on an equirectangular map

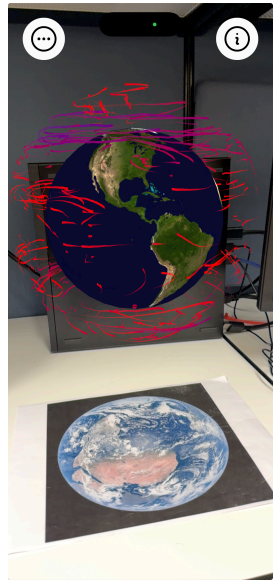


Figure 6: ERA5 climatological wind field on an AR globe

AR Image Tracking

- Images are added to a reference library
- Simulation activates when the camera detects an image from the reference library
- Scanning a flat world map overlays data directly on the printed map
- Scanning a circular Earth image generates an interactive 3D globe with the same data overlaid on its surface

Temperature and Lightning Data Layers

- Temperature data from the same ERA5 reanalysis, averaged over 35 years
- Temperature is split into 10 pressure levels (1000–100 hPa), selectable in the app
- Lightning data from GOES-19 GLM observations on August 11, 12:00–18:00 UTC
- Temperature and lightning data are converted and stored as 3D textures
- Shaders sample the 3D textures to overlay gradients representing each dataset

Temperature and Lightning Layers

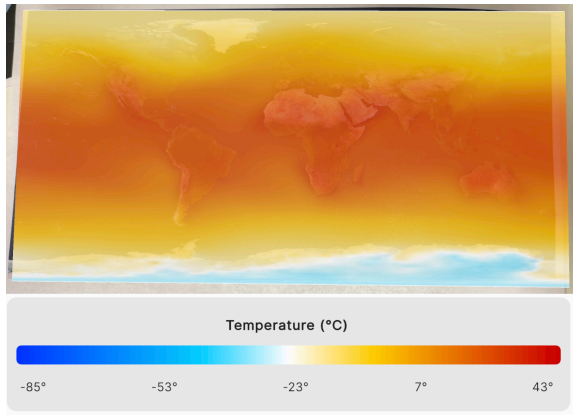


Figure 7: Temperature overlay at 900 hPa (~1 km altitude)

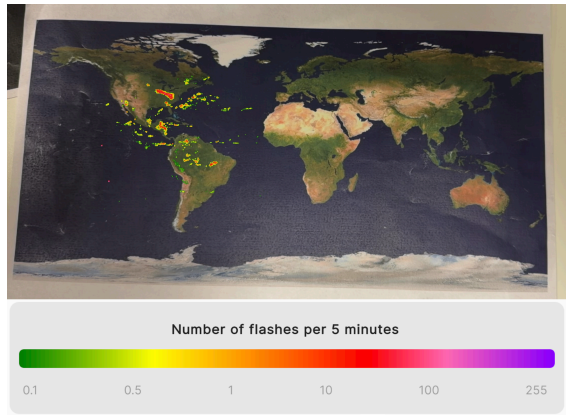


Figure 8: Lightning flash frequency overlay — Americas, August 11, 2026

Results

- Developed a functional AR application for visualizing idealized and data-driven atmospheric circulation
- Implemented conceptual single-cell and three-cell circulation models using particle-based flow
- Integrated 35 years of ERA5 reanalysis data and GOES-19 GLM lightning observations to visualize climatological wind, temperature, and atmospheric activity
- Demonstrated the contrast between idealized meridional circulation cells and the predominantly zonal circulation found in ERA5 wind data.
- Currently preparing the application for publication on Apple and Android platforms

Future Work

- Add the Walker circulation to demonstrate tropical zonal circulation and its relationship with ENSO, including how it changes during El Niño, La Niña, and neutral conditions.
- Simulate the geostationary orbits and observational coverage of the GOES-18 and GOES-19 satellites.
- Expand AR tracking from flat images to a custom 3D CISESS landmark that visitors can scan to access interactive atmospheric visualizations.

[1] "Global atmospheric circulations | national oceanic and atmospheric administration." [Online]. Available: https://www.noaa.gov/jetstream/global/global-atmospheric-circulations

[2] Kaidor, "Català: descripció del fitxerРусский: Схема циркуляции атмосферы вокруг Земли.English: Global circulation of Earth's atmosphere displaying Hadley cell, Ferrell cell and polar cell.." [Online]. Available: https://commons.wikimedia.org/wiki/File:Earth_Global_Circulation_-_en.svg

Demo Video

https://drive.google.com/file/d/1lIVw1sMEx1xW5SMfbTE6CljguQTIyFEJ

Download Application

https://xr.cisess.umd.edu/atmosphere-ar/