





This project is sponsored by the NCAR 2016/2020 SIParCS Internship Program.

> Developers: Nihanth Cherukuru, Shiqi Sheng

# Meteo AR



Augmented reality technologies superimpose virtual objects on real world images. The visualization shown here depicts NOAA Sea Surface Temperatures during the 2015 El Niño. NOAA collects and combines these data from sources such as satellites, buoy networks, and ships.

Visualization: Matt Rehme, CISL, NCAR.

## NCAR

### Exploring GeoScience with Augmented Reality

### Meteo AR (http://bit.lv/NcarMeteoApp) is

an **Augmented Reality** (AR) application that displays interactive virtual objects, like an animated globe or a hurricane, over real world imagery that is captured by your mobile device's camera. The app works with the downloadable "<u>science sheets</u>" that include background information about science topics like El Niño, Hurricanes, and Climate Change to help you understand and interpret what you are seeing.

When you point your mobile device's camera to the black and white markers on a printed science sheet, a 3D, interactive virtual image will appear, which you can rotate and explore with a finger swipe.

Additionally, by using the special marker image shown at

she left on this she witten that of press "prev" or "next" to sequentially display new virtual objects. Pressing "Rot On/Off" toggles rotation.









### See the movie!





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# Science Topic:



## El Niño

El Niño is a warming of the central to eastern tropical Pacific that occurs every two to seven years, on average. During an El Niño event, sea surface temperatures across a watery expanse often as large as the United States can warm by 1–3°F or more for a period of from a few months to a year or two.

As warm surface water in the Pacific is shifted thousands of miles east of its usual location, the showers and thunderstorms nurtured by convection above this warm tropical water also change location. These changes can cause prolonged wet or dry conditions and related atmospheric heating anomalies. In turn, the anomalous heating sets up planetary-scale waves in the atmosphere that radiate away from the region, especially into the hemisphere experiencing winter. These are "teleconnections"—large-scale, long-lasting shifts in atmospheric circulation that can affect much of the globe. The effects extend throughout the Pacific Rim, across large parts of North America, and on to eastern Africa and other regions. — *Information courtesy UCAR*.

The visualization depicts data from the NOAA 1/4° daily Optimum Interpolation Sea Surface Temperature (OISST). The data are combined from sources such as satellites, buoy networks, and ships. The OISST analyses are named for the key satellite sensor used: in this case, the Advanced Very High Resolution Radiometer (AVHRR). *Visualization: Matt Rehme, CISL, NCAR.* 









## Science Topic:



### See the movie!





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This visualization shows a six ensemble average of the Community Climate System Model 4 (CCSM4) monthly surface temperature anomaly from Jan 1850 to Dec 2100, from CMIP5 historical + RCP8.5 scenario. - Visualization: Tim Scheitlin, CISL, NCAR.

### **Climate Change**

Climate is always changing, but the changes we've observed in the last several decades are best explained as a combination of natural and human-made causes. Since the start of the industrial revolution in the late 1700s, humans have increasingly burned fossil fuels to create heat and electricity and to power vehicles and factories. Fossil fuels, such as coal, oil, and natural gas, emit greenhouse gases, especially carbon dioxide, as they combust. Greenhouse gases warm Earth's atmosphere by absorbing and trapping outgoing radiation from the Earth and reradiating some of this energy back to the surface.

The amount, or concentration, of CO2 gas in the atmosphere has risen more than 40 percent since the industrial revolution. CO2 concentration in the atmosphere is now at its highest point in the last 800,000 years. Each year, the CO2 concentration increases by about 0.5 percent.

Despite the normal variability of Earth's climate, which includes periods of natural warming and cooling, scientists now expect that the greenhouse gases added to the atmosphere from human activity will cause the overall temperature trend to continue increasing. – Information courtesy UCAR.









# Science Topic: Hurricane Odile



See the movie!





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This visualization is a 15-minute HWRF simulation (1251x1251x61) of Hurricane Odile shortly after it made landfall. The surface represents absolute vorticity (12e-5 s-1) colored by relative humidity.

- Visualization: Tim Scheitlin, Matt Rehme, CISL, NCAR.
- Computational Modeling: Mrinal Biswas, RAL/DTC, NCAR.

Hurricane Odile made landfall on the Baja California Peninsula in September 2014 as a category 3 storm. It was originally forecast to curve out to sea, and as a result only minor weather alerts were issued, and 26000 endangered foreign tourists remained on the peninsula.

The hurricane inflicted widespread damage, flooding and power outages in Mexico and the Southwestern United States, resulting in 1.2 billion dollars in damage.

Researchers at the National Center for Atmospheric Research (NCAR) in Boulder, CO, created this simulation using the Hurricane Weather Research Forecast, an advanced hurricane prediction system developed by the National Oceanic and Atmospheric Administration (NOAA).

Using computing and storage resources at NCAR and NOAA, the simulation combines dropsonde data, conventional observations and satellite data into a 3-D grid with 3KM horizontal resolution and 61 vertical levels, providing a highly detailed glimpse into the processes and evolution of this hurricane over a 6-day period. The system, now deployed for real-time storm tracking, fills gaps in previous weather simulations to provide a more accurate assessment of intensity, structure and expected rainfall for severe storms.









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# Science Topic:



This visualization shows surface wind speed across the planet over the course of one year. Brighter areas represent higher wind speeds.

- Visualization: Matt Rehme, CISL, NCAR.
- Computational Modeling: Susan Bates and Nan Rosenbloom, NCAR.

## Surface Wind Speed

The magnitude of surface wind speed during a one year period is shown in this visualization using data from a high resolution (1/4 degree) simulation of present day climate using the Community Earth System Model (CESM).

Bright, rotating areas represent storm systems that move through the mid-latitudes in both hemispheres, and sharp lines in the wind field are weather fronts tied to these storms.

Things to to look for:

- Wind speeds are higher over the ocean and are reduced by surface friction after storms make landfall. Land masses in the Northern Hemisphere slow storm propagation in the mid-latitudes. Whereas in the Southern Hemisphere, strong westerly winds are unhindered between 40-50 degrees south, giving rise to the term "the roaring 40s."
- The Hawaiian Islands sit in the path of the Trade Winds, creating a wind shadow on the leeward (downwind) side of the islands.
- Tropical storms that stray out of the tropics can be captured by synoptic storms, curving them eastward and transporting large amounts of heat, moisture, and energy to higher latitudes









See the movie!



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See the NASA Earth Video!





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# Science Topic: Earth



Textures for this image are from the NASA Visible Earth project, part of the EOS project Science Office located at NASA Goddard Space Flight Center.

Earth, our home planet, is a beautiful blue and white ball when seen from space. The third planet from the Sun, it is the largest of the inner planets. Earth is the only planet known to support life and to have liquid water at the surface. Earth has a substantial atmosphere and magnetic field, both of which are critical for sustaining life on Earth.

Most of the Earth's surface (70%) is covered with water, and the remaining 30% is taken up by the seven continental landmasses. However, underneath the water that fills the oceans, and the dirt and plants that cover the continents, the Earth's surface layer is made of rock. This outer layer formed a hard, rocky crust as lava at the surface cooled 4.5 billion years ago.

The crust is broken into many large plates that move slowly relative to each other. Mountain ranges form when two plates collide and their edges are forced up. In addition, many other surface features are the result of the moving plates. The plates move about one inch per year, so millions of years ago the continents and the oceans were in different positions. About 250 million years ago, most of the land was connected together, and over time has separated into seven continents. – Information courtesy Windows to the Universe









See the movie!

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# Science Topic:



Detailed computer simulations like this help scientists study the climate and see the time evolving patterns of circulation and seasonal changes. This CESM simulation shows water vapor in the earth's atmosphere at hourly time steps. - *Visualization: Tim Scheitlin, CISL, NCAR.* 

## Water Vapor

Climate models use mathematical equations to describe the behavior of the Earth system that impact climate. Sophisticated climate models are increasingly able to include details such as clouds, rainfall, evaporation, and sea ice. Thousands of climate researchers use global climate models to better understand the long-term effects of global changes such as increasing greenhouses gases or decreasing Arctic sea ice. The models are used to simulate conditions over hundreds of years, so that we can predict how our planet's climate will likely change.

Relying on complex mathematical descriptions of real-world phenomena, scientists can compare Earth system model results against real-world observations to more effectively take appropriate action, whether scientific or policy related.

A primary NCAR activity is creating models that enhance human understanding of the atmosphere, and the Earth system. In this example, we are showing the hourly results of an ultra high resolution run from a climate model called the Community Earth System Model (CESM). All model parameters (temperature, wind speed, humidity, etc.) are calculated at each of the millions of grid points in the model at each of those hourly time steps. That's a lot of calculating... sounds like a job for a supercomputer! - *information courtesy UCAR*.











#### See the movie!





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## Science Topic:



This simulation illustrates the potential for future drought worldwide over the decades and is based on current projections of future greenhouse gas emissions.

- Visualization: Tim Scheitlin, CISL, NCAR.
- Data: Aiguo Dai, CGD, NCAR.

## Drought

The United States and many other heavily populated countries face a growing threat of severe and prolonged drought in coming decades, according to a new study by National Center for Atmospheric Research (NCAR) scientist Aiguo Dai. The detailed analysis concludes that warming temperatures associated with climate change will likely create increasingly dry soil conditions across much of the globe in the next 30 years, possibly reaching a scale in some regions by the end of the century that has rarely if ever been observed in modern times.

Using an ensemble of 22 computer climate models and a comprehensive index of drought conditions, as well as analyses of previously published studies, the paper finds much of the Western Hemisphere, along with large parts of Eurasia and Africa, may be at threat of extreme drought this century.

Dai cautioned that the findings are based on the best current projections of greenhouse gas emissions. What actually happens in coming decades will depend on many factors, including actual future emissions of greenhouse gases as well as natural climate cycles such as El Niño.

"We are facing the possibility of widespread drought in the coming decades, but this has yet to be fully recognized by both the public and the climate change research community," Dai says. "If the projections in this study come even close to being realized, the consequences for society worldwide will be enormous."

While regional climate projections are less certain than those for the globe as a whole, Dai's study indicates that most of the United States, especially the West, will be significantly drier by the 2030s. Large parts of the nation may face an increasing risk of extreme drought during the century.

- information courtesy UCAR AtmosNews.











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# Science Topic:



This simulation shows global weather for several days in October 2012, simulated by a cloud-resolving weather prediction model (MPAS).

- Visualization: Tim Scheitlin, CISL, NCAR.

- Data: Falko Judt, NCAR ASP Postdoc.

### **Global Weather Simulation**

The complex evolution of multiscale cloud systems illustrates the myriad of weather phenomena that populate our atmosphere.

Features of interest in this visualizaton include:

- the diurnal cycle of convection over central Africa and the Amazon rain forest;
- the birth, intensification, and demise of tropical cyclones in the Indian Ocean and Western Pacific;
- the recurring developments of extratropical cyclones along the midlatitude jet streams;
- the formation of orographic clouds downstream of the Rocky Mountains.

The simulation was created with the Model for Prediction Across Scales (MPAS), a collaborative project for developing atmosphere, ocean and other earth-system simulation components for use in climate, regional climate and weather studies.

The primary development partners are the climate modeling group at Los Alamos National Laboratory (COSIM) and the National Center for Atmospheric Research. For this experiment, MPAS was configured with a horizontal resolution of 4 km and 55 vertical levels. The animation time step is 12 min.









See the movie!

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## Science Topic:



This Community Climate System Model (CCSM) simulation required 7.5 million cpu hours to complete. CCSM is a coupled climate model for simulating the earth's past, present, and future climate states. This simulation assumes a future scenario of comparatively high greenhouse gas emissions (RCP8.5).

- Visualization: Tim Scheitlin, CISL, NCAR.



### Sea Ice Concentration

NCAR scientists use computer models to study the possible future impacts of climate change on sea ice. The models solve equations that simulate snow on sea ice, when it melts, how thick the ice will get, and many other variables.

Shown here at the Poles is the percent of ocean water covered by ice, which is called the sea-ice concentration, and projections of how it could change over time. The simulations show the month of September when sea ice is at its lowest concentration in the Northern Hemisphere. The colored contours over the rest of the ocean represent the sea surface temperature.

From 1850 to the late 20th century, the concentration of sea ice varies from year to year, but it is stable overall. After this period, greater sea ice losses are observed during the summer. By the year 2100 the Arctic is nearly ice-free in this simulation.

The models do not predict the exact year at which this happens, but the simulation shows how quickly the summertime ice concentration could disappear in the next 50 to 100 years.

Projected impacts of Arctic warming and declining sea ice include loss of habitat for polar bears and seals, as well as coastal erosion from permafrost thaw. Economic impacts may include the establishment of new shipping routes







To learn more about the Sun and its impact on the Earth, check out:

https://www2.hao.ucar.edu/



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# Science Topic:



These visualizations depict global views of the Sun's outer atmosphere. Combining observations from the twin NASA Solar Terrestrial Relations Observatory (STEREO) and Solar Dynamics Observatory (SDO) spacecraft we have a unique window to study the global "weather" patterns in the solar atmosphere. Visualization: Scott McIntosh, HAO, NCAR.

## Sun 360

Our planet lives in the atmosphere of our star, the Sun. The evolution of our star and its magnetic field drive the energy that feeds our atmosphere and can also cause great harm to our technologically-driven world.

For a very short period of time, from 2011 to 2014, the twin STEREO spacecraft provided observations from the side of the Sun that is hidden from direct observation on Earth. When combined with observations from the Sun-Earth line (from the SDO spacecraft) the three spacecraft provided mankind's first complete observation of the Sun.

Our study of these incredible observations is just beginning. The Sun's magnetism is constantly evolving, in these data sequences the brightest patches are those of very enhanced magnetism - the places where damaging solar storms come from. There are also persistently dark regions in the sequences - those are "coronal holes," the places where the Sun's super-fast wind comes from.

Watch how these magnetic weather patterns change with time, persist at certain longitudes, rotate around the star, and interact with each other. Understanding the patterns seen in this data is critical to understanding the processes that create the Sun's magnetic field and drive the "space weather" that fills the solar system.









To learn more about this science topic see:

www2.hao.ucar.edu/modeling waccm-x



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## Science Topic:



These visualizations are generated with output from NCAR Whole Atmosphere Community Climate Model – eXtended (WACCM-X), a chemistry-climate model that simulates the atmosphere from the surface to about 600 km.

Visualization: Dan Marsh, HAO, NCAR and Tim Scheitlin, CISL, NCAR. Computational Modeling: WACCM-X team, NCAR.

## NCAR

## Space Weather

Solar eruptions can generate 'superstorms' in the Earth's magnetosphere, thermosphere, and ionosphere that dramatically change its temperature and composition. On March 31, 2001, a superstorm caused the K index (a measure of geomagnetic activity) to reach 'extreme storm' values. A new model at NCAR (WACCM-X) is now simulating the effects of these superstorms. The animations show electron column density (TECU), neutral temperature (K), atomic-to-molecular composition ratio  $(O/N_2)$ , and the peak density NmF2 (m<sup>-3</sup>) and height hmF2 (km) of the F-region ionosphere. The disturbances start in the polar regions, driven by auroral currents, particle precipitation, and Joule heating, but then rapidly spread globally through a combination of electric fields and neutral dynamics. Notable is the "tongue" of ionization that crosses North America from east to west, very similar in timing and morphology to GPS observations, and the high latitude decreases in atomic oxygen caused by rising air driven by large heating rates in the auroral regions.



(left) The K index during the March 2003 superstorm. Source: NOAA







To learn more about this science topic visit the ECMWF website at https://www.ecmwf.int



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# Science Topic:



Data description: Daily time steps from the ECMWF ERA-Interim/LAND Global Climate Reanalyses dataset. The Grid size is .75 deg x .75 deg and the variable (snowfall) is measured in meters of water equivalent. *Visualization: Tim Scheitlin, CISL, NCAR.* 

### **ECMWF** Snowfall

Scientists and researchers combine data from many sources to create global datasets that describe the recent history of the atmosphere, land surface, and oceans. Data from computer models and observations are combined to produce "reanalysis" datasets, which were used to create this animation of annual (2010) snowfall across the globe.

Three buttons labelled Sf, Acc, and Ovl, let you toggle between the daily Snowfall (Sf), Annual Accumulation (Acc), and an Overlay (Ovl) of the two together.

A climate reanalysis gives estimates of atmospheric parameters such as air temperature, pressure and wind at different altitudes, and surface parameters such as rainfall, soil moisture content, and sea-surface temperature. Reanalysis data are used for monitoring climate change, for research and education, and for commercial applications.

The data shown here were provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) using their meteorological data archive (MARS) system. MARS is the largest of its kind in the world and continues to grow. As of January 2018, it contains around 200 petabytes of operational and research data, with about 200 terabytes being added daily. More than 400 billion meteorological fields are stored in MARS. - Information provided by the ECMWF web page.











This dataset was obtained from the Research Data Archive (RDA) managed by NCAR. https://rda.ucar.edu



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## Science Topic:



Data description: Hourly PBLH averaged over each month between 2000-2017 for each corresponding hour, obtained from the ECMWF ERA-5/LAND Global Climate Re-analyses dataset (DOI: <u>https://doi.org/10.5065/D6X34W69</u>). The Planetary Boundary Layer Height (PBLH) is measured in

meters above the earth surface. Visualization: Nihanth Cherukuru, CISL, NCAR.



### Planetary Boundary Layer Height

Planetary Boundary Layer (PBL) is the lowest part of the atmosphere which is directly influenced by the Earth's surface. The top of the PBL often acts like a cap to trap air in the layers below thus having a major influence on atmospheric phenomenon like dispersion and concentration of pollutants (air quality), trade winds, cloud formation and, extreme weather to name a few.

The thickness of the planetary boundary layer, commonly referred to as the Planetary Boundary Layer Height (PBLH) is strongly influenced by the topography, ground cover, temperature and winds. Consequently, PBLH exhibits strong temporal variations (changing with time of the day and seasons) and spatial variations (changing from one place to another). Some feature that can be observed are:

- Deeper PBLH over dry subtropical land on summer days due to rising thermals and convective mixing.
- Deeper PBLH during the day than during nights.
- Fluctuations in PBLH are more pronounced over land than over oceans.

What other patterns do you observe? Pay attention to the diurnal cycle (i.e., changes between day and night), seasonal cycles (i.e., changes between seasons: summer vs winter). How do seasons influence the PBLH (Hint: observe the solar radiation/amount of daylight received)?







To learn more about this science topic visit the Exploring Atmospheric Dust and Climate website: <u>scied.ucar.edu/atmos</u> pheric-dust-climate



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## Science Topic:



Data description: The Dust and Climate (Part I) visualization was created using model data from Nullschool. Part I shows the circulation of dust in Earth's atmosphere throughout one calendar year (2018). The animation time step is three hours. Yellow indicates a higher volume of dust, green indicates moderate dust volume, and blue indicates lower dust volume.

Visualization: Cameron Beccario, <u>nullschool.net</u>



### Dust and Climate (Part I)

Dust is fine-grained sediment that erodes from rocks on the land, is carried into the atmosphere by wind, and eventually settles back onto the land and into the ocean. At any time, there is between 17-20 million tons of dust in the atmosphere.

Some places on Earth are dustier than others – notice that there is more dust around the desert regions. The Saharan Desert is the largest source of dust in the world! Dust moves in predictable patterns because it is carried by the winds, and some places, like the Atlantic Ocean, end up with more dust than others. Certain times of year are dustier, too. From about February through May, the Northern Hemisphere is really clouded with dust!

Scientists have known for a long time that dust in the atmosphere influences cloud formation, and that this can affect storms and surface temperatures. But we now understand how iron-rich dust deposited in the ocean can help to cool the climate by stimulating the growth of phytoplankton that remove carbon dioxide  $(CO_2)$  from the atmosphere during photosynthesis. When there is more dust, there is also more  $CO_2$  being removed from the atmosphere.

Atmospheric Dust and Climate (Parts I and II) was developed in conjunction with the NSF funded project *PIRE: DUST stimulated draw-down* of atmospheric  $CO_2$  as a trigger for Northern Hemisphere Glaciation.







To learn more about this science topic visit the Exploring Atmospheric Dust and Climate website: <u>scied.ucar.edu/atmos</u> pheric-dust-climate



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# Science Topic: Dust and Climate (Part II)



Data description: The Dust and Climate (Part II) visualizations were created using model data from MIT's Darwin Ecosystem Model. Part II includes three complementary datasets that suggest how iron-rich dust entering the ocean can affect the climate: chlorophyll concentration, iron concentration, and nitrate concentration. Darker colors indicate higher concentrations. The animation time step for each dataset is every three days, throughout one calendar year(2015).

Visualization: Jonathan Lauderdale and Oliver Jahn, MIT.

Three buttons labeled CL, FE, and NI let you toggle between chlorophyll concentration (CL), iron concentration (FE), and nitrate concentration (NI).

High chlorophyll concentrations indicate places where phytoplankton are abundant. Notice that the concentration of chlorophyll (phytoplankton) changes throughout the year. When chlorophyll concentrations are high there is more carbon dioxide (CO<sub>2</sub>) being removed from the atmosphere.

In order to live, phytoplankton need both iron and nitrate. Toggle between the iron and nitrate videos to compare iron and nitrate concentrations in two different areas – the North Pacific and the Atlantic. In the North Pacific there is not very much iron but there is plenty of nitrate. During dusty times when more iron-rich dust enters the sea there is an increase in phytoplankton. However in the Atlantic, even though iron is plentiful there isn't very much nitrate. Adding dust to the Atlantic doesn't have the same effect on phytoplankton abundance. Dust is only part of the story!

Dust and Climate (Part II) illustrates the connections between the Earth system and climate, which help us to understand natural processes that can provide solutions to climate change.





