Exploring Atmospheric Dust and Climate

Facilitator Guide

Exploring Atmospheric Dust and Climate is a collection of activities that aims to increase public understanding of how atmospheric dust affects climate change. Learning the story of dust helps us to better understand Earth's climate system and provides clues about how to mitigate current climate warming. Designed for engagement at museums, science centers, and outreach events, the activities could also be implemented in formal education settings from upper elementary through high school.

Activities in this collection:

DUST TALES

DUST on the MOVE

Pumping Iron: How Dust Can Change the Climate

SOS Science On a Sphere®

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UCAR CENTER FOR SCIENCE EDUCATION

Exploring Atmospheric Dust and Climate

Facilitator Guide

Introduction

The UCAR Center for Science Education developed this suite of activities to engage the public around the central science topics addressed through an NSF-funded research project called *PIRE DUST: Dust stimulated draw-down of atmospheric CO_2 as a trigger for Northern Hemisphere Glaciation*. Both the project and the activities described in this guide explore how atmospheric dust deposition changes over time, how dust is transported from source regions and eventually ends up in the ocean, and how adding dust to iron-limited portions of the ocean increases the drawdown of atmospheric CO_2 through ocean productivity. The project represents a multi-year, international collaboration between scientists across multiple disciplines: geology, oceanography, atmospheric chemistry, paleontology, and environmental sciences, each investigating a unique aspect of the connection between Earth's past and present climate and atmospheric dust.

This facilitator guide provides a description, materials list, suggestions for set up, and facilitation instructions for each of the following activities:

While each activity works as a stand-alone experience, they provide a more comprehensive exploration of atmospheric dust when they are done together. *Dust Tales* explains the nature of dust on Earth, including how dust dispersal changes through time and space, and answers questions about where dust comes from, how it ends up in the ocean, and why this is important for understanding climate. *Dust on the Move* provides a hands-on experience with samples of dust and the opportunity to test how wind can transport tiny particles over large distances, making tangible the idea that dust can, in fact, end up in the ocean. *Pumping Iron* illustrates the complex web of interactions between the Earth's spheres (geosphere, atmosphere, hydrosphere, and biosphere) involved in making iron (dust) available to phytoplankton in the ocean, thus cooling the climate through the drawdown of atmospheric CO_2.

DUST TALES

The story of atmospheric dust and how it affects the Earth's climate.

Dust Tales

Dust Tales is an interactive Google slide deck that tells the story of atmospheric dust, including where the dustiest places on Earth are located, where dust comes from, how it moves around the Earth, how atmospheric dust has changed throughout Earth's history, what times of year are dustier than others, and how atmospheric dust affects Earth's climate. The story is told through a collection of data maps.

The interactive slide deck is designed to have app functionality, allowing visitors to navigate through the story independently or for a facilitator to guide navigation through the story alongside them. *Dust Tales* would work well on a touchscreen display, iPad/Tablet stand, or a laptop cart within an exhibit space.

Dust Tales is best for individuals or small groups and can take between 5-10 minutes to complete, depending on the level of engagement.

Required Materials

- *Dust Tales* Google slidedeck
- iPad/Tablet or laptop

Instructions for Setup

- Make a copy of the *Dust Tales* interactive slide deck for your use.
    - Save your copy of the *Dust Tales* interactive slide deck wherever you keep your educational content. You can edit your copy if desired.
- Set up a tablet, laptop, or touchscreen device to display the *Dust Tales* interactive slide deck.

Instructions for Facilitation

Below are key points for interpretation of the maps and prompts to engage your audience as they explore the interactive slide deck. However, visitors may prefer to explore independently, and the slide deck is set up to work well even without facilitation.

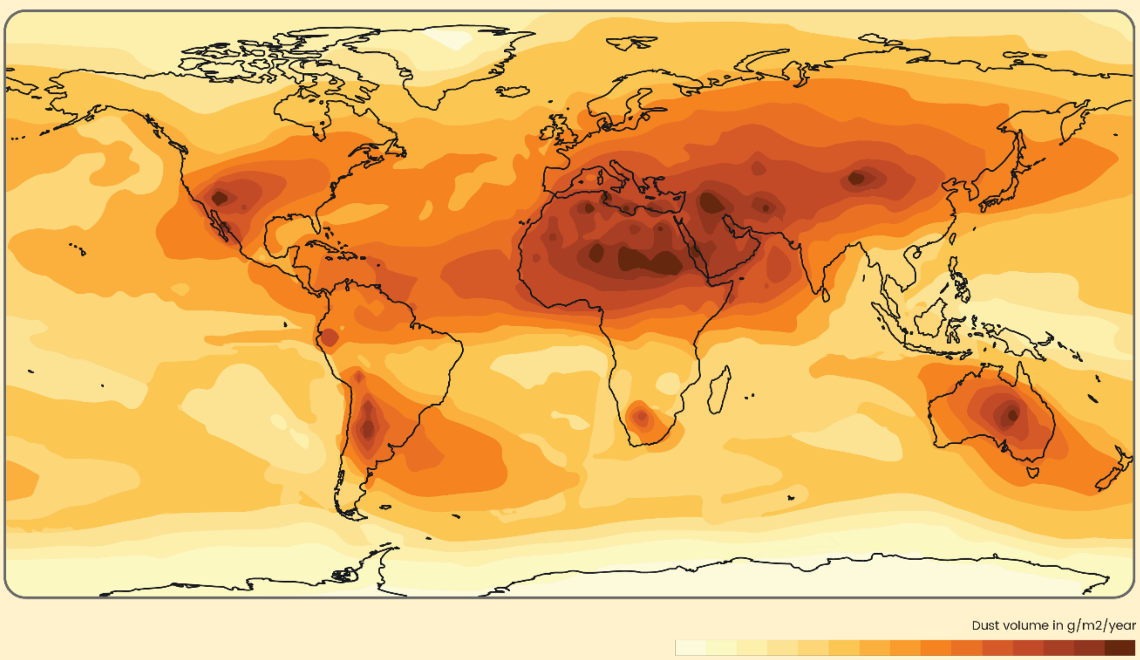
- **Invite visitors to learn about the story of atmospheric dust through the interactive slide deck.**
    - *"The Earth is a dusty place! There is enough dust to affect things like the weather and the climate, and living things, too!*

- Note: You might want to distinguish between dust that is created in the Earth system and household dust - we're not talking about dust bunnies from under the bed! This dust comes from the erosion of rock materials.

- **What's the Deal with Dust?** *(dust deposition in current climate conditions map)* Focus on noticing the distribution of dust on Earth through the following question prompts:
  - *What do you notice about dust? Are there patterns in where the dust is?*
  - *Which parts of the world are the dustiest? Which parts are the least dusty? Why might this be?*
  - *Find your location on this map. How dusty is it at your location? Compare where you are to other places on the Earth.*
  - *Is there more dust in the ocean or on the land? Which parts of the ocean seem to have more dust than others?*

Dust Deposition in Current Climate Conditions

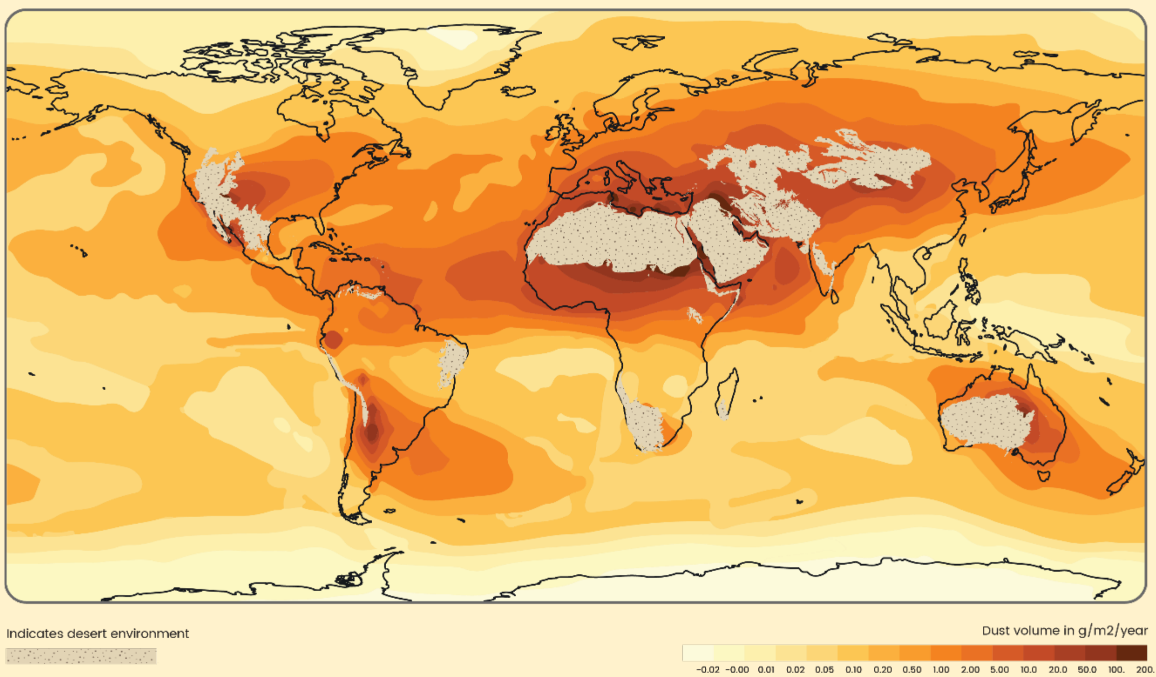
The map below shows where the dust is deposited (area) and the amount of dust deposited in different areas (volume). Warmer colors mean more dust. There appears to be more dust in the tropics and mid-latitudes than in the polar regions. While the dustiest places are over the continents, high volumes of dust are deposited in the ocean. Places with higher amounts of dust in the ocean are adjacent to the places on land with the most dust. For example, North Africa appears to have the most dust, and the Atlantic Ocean also has high amounts of dust.



- **Where does dust come from?** *(deserts of the world map)*
  Focus on the dust source regions of the world, the deserts, with the question prompts:
    - *Where does dust come from?*
    - *What connections do you see between the deserts and the dusty places on Earth?*
    - *Which dust source region is closest to where you live? How might dust from this place affect you?*

Deserts of the World

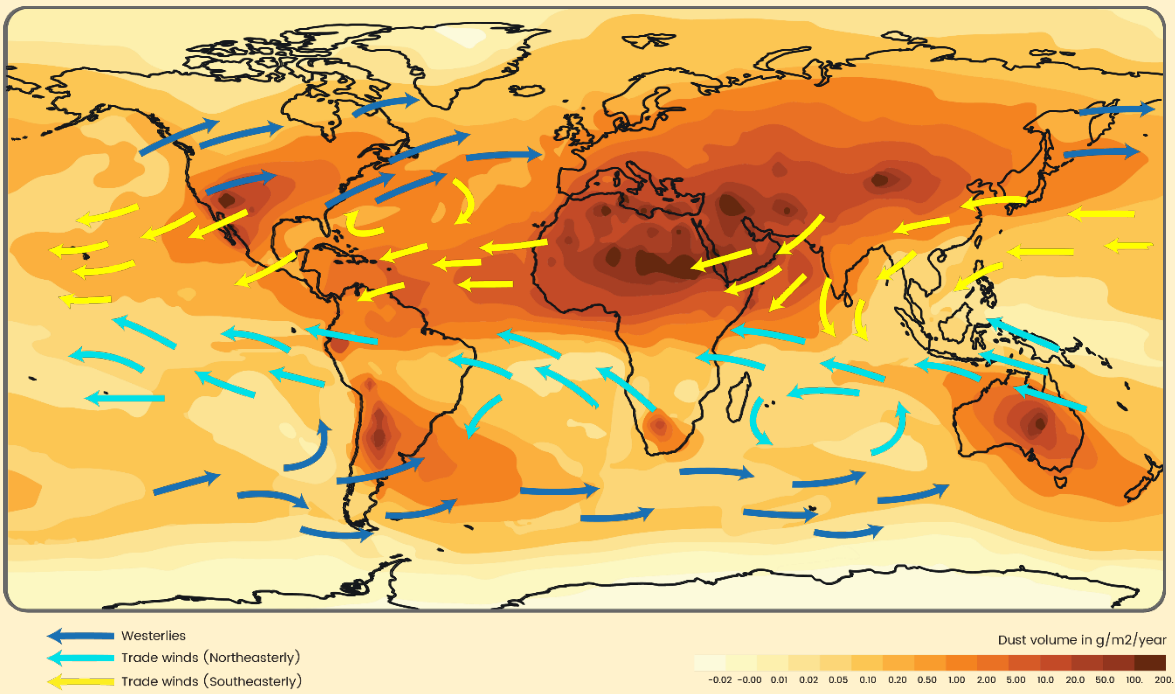
Dust comes from desert areas with arid, windy climates. The areas with the highest dust deposition correlate with the locations of Earth's major deserts. The Sahara Desert is the largest dust source region on Earth. Dust from the Sahara causes massive summer dust storms over North Africa and can impact air quality in the Caribbean and US.



- **What moves the dust around?** *(wind patterns map)*
  Now focus on how dust is carried from the source regions to where it is deposited. Use the following prompts:
  - *How does the dust get from the deserts to the ocean?"*
  - *Choose a desert on the map and follow the arrows to find out where dust from there might end up.*
  - *Where does the dust that ends up in North America come from?*
  - *Where does the dust that ends up in the Pacific Ocean come from?*

Wind Patterns

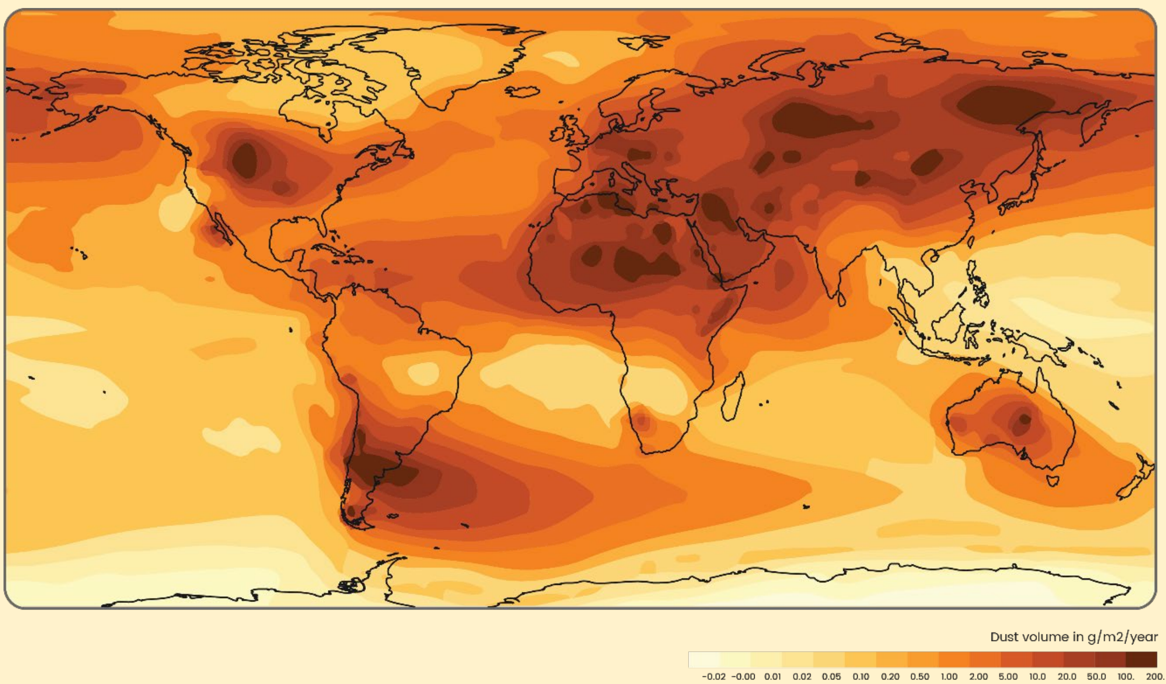
The arrows indicate the direction of air movement across the Earth's surface due to prevailing winds. The prevailing winds are influenced by global convection and the Earth's rotation (the Coriolis effect). Dust is carried by winds from the deserts and deposited along the path of the blowing winds. Thus, dust originating in North Africa is carried west across the Atlantic Ocean by the trade winds and deposited in Central and North America. Dust from Northern Asia is carried east by the westerlies and deposited in the North Pacific Ocean.



- **Has it always been this dusty?** *(dust deposition during the Last Glacial Maximum)* Explain that this map shows dust deposition during the height of the last ice age. This is called the Last Glacial Maximum (LGM), and it occurred approximately 22,000 years ago when it was much cooler on the Earth. Compare the dust map with current conditions to the LGM dust map:
    - *What is different between the maps?*
    - *Why might certain times in Earth's past be dustier than others?*
    - *How might a cooler climate (such as during an ice age) cause more dust?*

Dust deposition during the Last Glacial Maximum

The LGM map shows more dust, in both area and volume of dust deposition, than the map of current climate conditions. When Earth's climate is cooler, there is more ice at the poles and at continental and oceanic ice sheets. The movement of glaciers grinds against the rock, creating dust. Colder weather also produces higher wind speeds due to higher temperature gradients. Thus, increased erosion due to glacial movement and increased winds due to cold temperatures suggest that cooler climates make the Earth a dustier place. Observations of the thickness of dust layers in the geologic record also support that cooler climates correlate with increased dust deposition.



DUST TALES

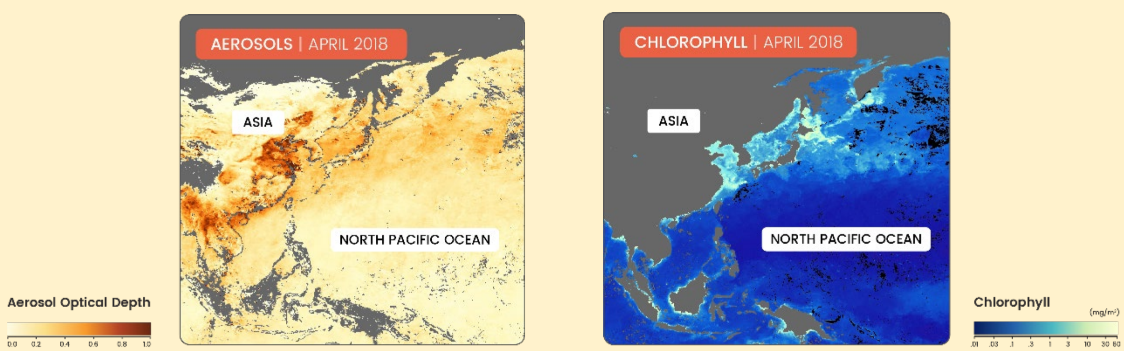
- **How does dust affect Earth's Climate?** *(aerosols and chlorophyll)*
  Focus on what happens when dust gets in the ocean and how this can affect the global climate.
  - Point out that measuring aerosols is a way to measure dust in the atmosphere. And measuring chlorophyll is a way to measure phytoplankton.
  - It may be of interest to distinguish between how dust entering the ocean affects climate and how dust in the atmosphere affects climate. Dust in the atmosphere influences the climate by scattering light and absorbing energy from the Sun. These maps instead focus on how dust in the ocean affects climate.
    - For younger audiences, you may want to make sure they understand what climate is.
  - Question prompts:
    - *How could dust change the climate?*
    - *What is the connection between the aerosols map and the chlorophyll map?*
    - *The dust contains lots of iron, which helps phytoplankton to grow. What kinds of changes could result from lots of dust entering the ocean?*

Aerosols and chlorophyll

More dust (aerosol) from Asia enters the North Pacific Ocean during April and May. Areas in the North Pacific Ocean where the most dust is deposited also show the highest concentration of chlorophyll, which indicates that phytoplankton are abundant. An increase of phytoplankton also means that more CO_2 is drawn out of the atmosphere via photosynthesis. Thus the addition of dust to the North Pacific and subsequent decrease in atmospheric CO_2 concentration can result in a cooling effect on the climate.

Proxy data for past climates indicate that during times of increased dust, there was also a decrease in atmospheric CO_2, which suggests that the ocean's biological pump (how marine organisms influence the global carbon cycle) could have been responsible for cooling the climate in the past.

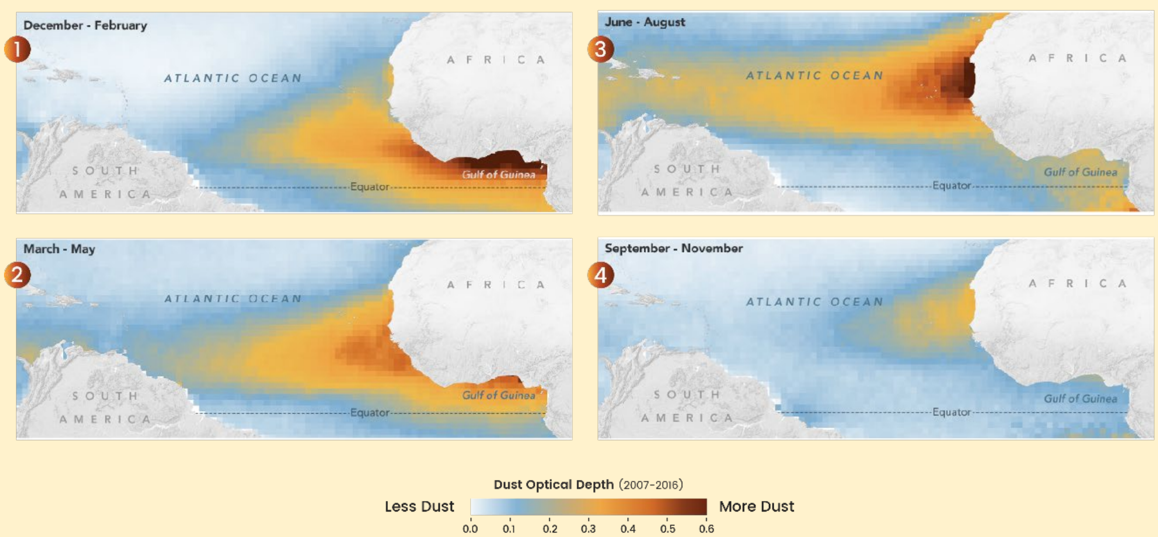
Note: Dust influences the larger climate system but is by no means the only factor responsible for cycles of ice ages and interglacials. The role of dust is a more recent area of scientific research.



- **Are certain times of the year dustier than others**? *(dust off the Sahara throughout the year)*
  Help visitors see that the amount of dust in the atmosphere changes throughout the year.
  - *What time of year does the most dust get into the ocean from the Sahara Desert?*
  - *How does the dust from the Sahara end up in the Atlantic Ocean?*
  - *Why might the amount of dust change throughout the year?*

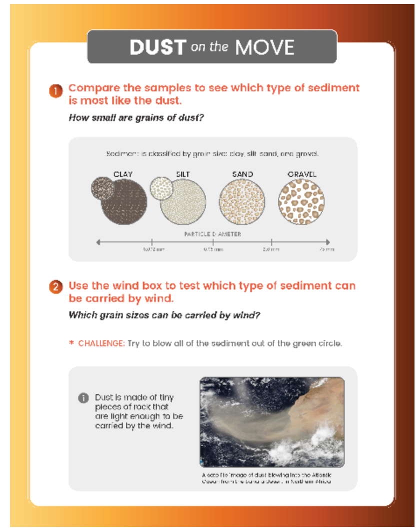
Dust off the Sahara throughout the year

Changing weather patterns throughout the year are causing some months to be dustier than others. Air pressure and wind patterns, coupled with hot, dry conditions, lead to an increase in dust over the Sahara during the summer months. Strong convective systems create massive dust storms and a layer of hot, dry, dusty air, also known as the Saharan Air Layer (SAL). This dust cloud moves out over the Atlantic every few days and can even reach as far west as the US. In the fall months, changes in sea surface temperatures cause the trade winds to weaken, which results in less dust blowing west from the Sahara.



- **How do we know so much about dust?** *(image of geologist in the field)*
  - The geologist is in Junggar Basin, Xinjiang Province, China, a major dust-producing area in Asia, studying the rocks that erode into dust.
    - *How could studying rocks and fossils help to understand the Earth's climate?*
  - This image provides an opportunity to mention the *DUST PIRE* research project, where scientists from China and the US worked together to discover clues about Earth's climate in the past and how it was affected by dust. (See introduction for more information about the project.)

Dust on the Move



The *Dust on the Move* activity is a hands-on experience to help visitors learn what atmospheric dust is by considering how grains of dust compare in size to other common sediments and to explore how dust disperses from source regions across the surface of the Earth. There are two parts to the activity. First, samples of dust, clay, silt, fine and coarse sand, and gravel are examined in test tubes and under magnification. Then there is a wind box where visitors use a handheld fan to test which grain sizes can be transported by wind.

Both parts of the activity can be displayed together on a single tabletop or on a large activity cart. Dust on the Move is best for individuals or small groups that can rotate between examining the samples with the microscope and interacting with the wind box. Allow 5-10 minutes to complete both activities, depending on the level of engagement.

Required Materials

- Dust on the Move sign
    - pdf file available at scied.ucar.edu/atmospheric-dust-climate
- Tabletop sign holder
- Test tube rack with six sediment samples in closed-top test tubes
- 10-gallon glass tank with lid
- Handheld fan and USB charging cable (second fan as backup)
- Wind funnel for fan
- Rubber bands (2)
- Container of sediment (fine sand, coarse sand, gravel)
- Digital handheld microscope & accessories
- Wheel of samples (dust, clay, silt, fine sand, coarse sand, and gravel)
- Laptop or iPad/tablet to view microscope images

Instructions for Setup

- Ensure that the fan battery is charged via the USB charging cable. A second fan is provided as a backup.
- Attach the wind funnel (clear plastic 2L bottle top) to the hooks on the back of the fan using the provided rubber bands. Hook a rubber band around the mouth of the funnel and then stretch around to hook on the back of the fan. Repeat for the other side. (photo 1)

Photo 1

Instructions for Setup continued

- Empty the sediment from the provided container into the tank. Gently shake the tank to distribute the sediment across the bottom of the tank. Make sure there is sediment inside the area of the green circle that is attached to the tank bottom. (photo 2)
- Secure the microscope on the included stand and place it in the middle of the round sediment samples tray (wheel of samples). Adjust the stand so that the microscope touches the top of the sample containers. (photo 3)
- Connect the microscope to your laptop or device (see instructions for pairing the microscope with your laptop or device below) and use the focus adjustment knob to focus the image on your device's screen. Don't forget to remove the lens cover from the microscope!
- Place the test tube rack with sediment tubes near the wheel of samples. *Note*: *You may want to attach the test tubes to the rack with wire cabling to ensure that visitors don't accidentally remove them from the display.*
- Display the *Dust on the Move* sign, in the sign holder, near the tank and wheel of samples.

Photo 2

Photo 3

Using the Digital Microscope

The microscope must be paired with a laptop or wifi enabled device to display the images. If using a laptop, connect the microscope directly to a USB port. If using a tablet or smartphone, you will need to connect the microscope to the Wifi Magic Box, which will send the images to your device via local network wifi. You will likely need to install an app on your laptop or device to display the microscope images. The exact setup instructions depend on the device you are connecting. Refer to the Juision General Microscope website for the most updated instructions for pairing the microscope with your device.

If you have trouble pairing your device to the microscope, reference the Juision General Microscope website or the booklet included in the packaging for troubleshooting.

Included equipment: microscope with removable lens cover, adjustable stand, Wifi Magic Box, Micro USB cable, and storage case

Use with Mac: Plug the microscope into your laptop's USB port and operate using the Pluggable Digital Viewer application.

- To install *Pluggable Digital Viewer* on your Mac, follow the instructions from the Juision General Microscope website: https://jiusion.com/art/microscope.
- From the Pluggable Digital Viewer, select the settings icon and choose the UVC PC Camera from the Device dropdown menu (if your laptop has a built-in camera, it will likely be selected by default)

Use with iPhone or iPad: Plug the microscope into the Wifi Magic Box and operate using the HD Wifi app on your device.

- Install HD Wifi from the Apple app store onto your device
- Connect the microscope to the Wifi Magic Box and press the power button on the magic box (the microscope light should turn on).
- Ensure that the magic box is charged in advance or connected to a power source via the USB cable.
- In the settings menu on your iPhone or iPad, select the magic box as your wifi network.
- The wifi magic box functions as a local network. You must connect your iPad or iPhone to this local network for the microscope to work with your device.
- Open up the HD Wifi app on your device. You may have to give the app access to your camera, but the microscope should now display on your device.
- Be sure to keep your device in close proximity to the microscope and magic box so that you don't lose connection.

Use with PC or Android: You can use multiple apps to connect the microscope to your PC or Android device. In some cases, you might be able to use the microscope without installing additional software. To learn about the recommended apps and instructions for pairing with the microscope, visit the Juision General Microscope website: https://jiusion.com/art/microscope.

Facilitation Instructions

Sediment samples: How small are grains of dust?

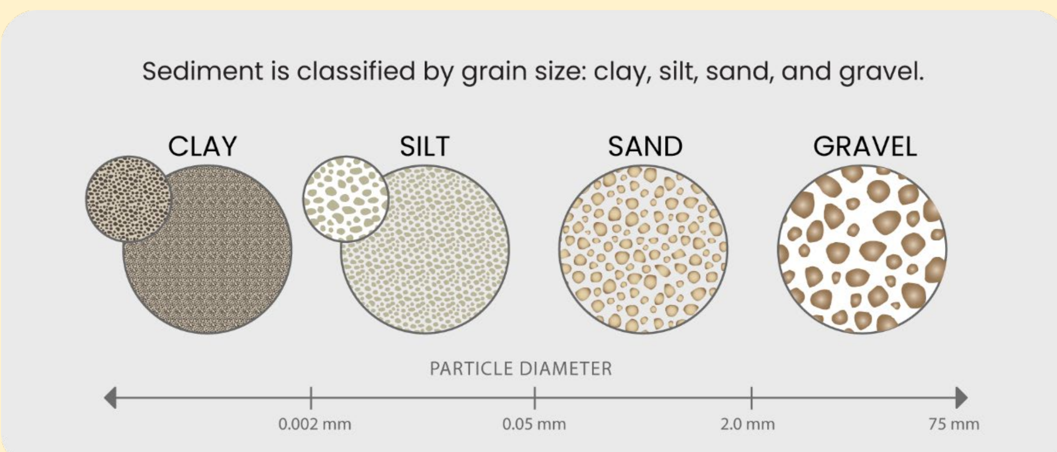
- Allow visitors to examine each of the six sediment samples with the microscope. Prompt them to notice differences in grain size and consider which sediment is most similar to the dust sample. Encourage visitors to hold the test tubes and compare the different samples to one another.

- Question prompts:
  - *What do you notice about each of the samples?*
  - *How are the samples different from each other? (Notice differences in color, texture, grain size, or particle shape)*
  - *Compare the different samples. Which one is most like the dust?*
  - *How is dust similar to/different from the other samples?*

What's in the test tubes?	
Dust	The dust samples used in the activity were collected in the field from either China or Argentina. Some samples were mechanically separated from a source rock substrate in the lab.
Gravel	This gravel is crushed stone made of unconsolidated rock fragments, not from any particular location.
Coarse sand	The coarse sand is a loose aggregate of silica with 0.5-1.0mm grain size, not from any particular location.
Fine sand	This sand is commercial or utility-grade with 0.075-0.425mm grain size, not from any particular location.
Red sand *in the wind box only*	This is a type of fine sand sourced from Moab, Utah. Sand is formed naturally from the erosion of rock material.
Silt	This silt loam is sourced from Nephi, Utah. Silt is a dust-like sediment formed by erosion due to water or ice with a grain size of 0.008-0.0625 mm.
Clay	This clay is sourced from Aurora, Utah. A loose, slippery material, clay forms from the erosion of rocks that contain feldspar and has a grain size of less than four micrometers (μm).

Sediment classification

Dust is a mixture of fine particles of varying composition, including metal oxides, carbonates, and clay, that are lofted into the atmosphere. The exact mineral composition of dust varies depending on the source region. The DUST PIRE project studied dust from China, including the North Tibetan Plateau. Also called aeolian dust, these aerosol-sized particles come from dry regions with high winds. Dust is most similar to silt in terms of grain size. Grain size is measured by finding the diameter of the grain. The smaller the grain size, the easier the wind can transport the sediment.



Wind box: Which grain sizes can be carried by the wind?

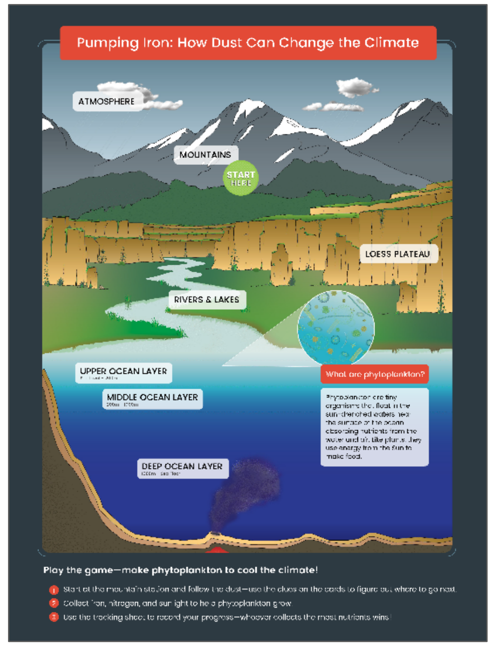
- Invite visitors to use the wind box to test which sediment sizes are easiest to move with air. The air from the fan represents wind. Three sediments with different grain sizes (gravel, coarse sand, fine sand) are in the tank.
  - Demonstrate reaching through the opening in the tank lid to operate the fan. Note: do not allow visitors to remove the fan from inside the tank through the lid as this may damage the air funnel.
  - Tell visitors that they can change the fan's speed to replicate low/high wind.
- Question prompts:
  - *(Before starting) Which of the sediments do you think will be most affected by the wind? Why?*
  - *How will changing the wind speed affect the movement of the particles?*
  - *Why are the red sand particles so much easier to move with the wind?*
  - *(After testing) Do you think dust particles are light enough to be carried thousands of miles across the Earth by the wind? Why or why not?*

What to Expect

Visitors should notice that the fine sand moves easily, the coarse sand moves when you concentrate the wind directly on it (but still not as much as the fine sand), and the gravel barely moves. They should conclude that smaller grain sizes will transport more easily by wind.

Dust, which is smaller than sand, would be moved by wind more easily than these larger and heavier grains. You may wish to explain that this wind box doesn't include dust because it is too easily blown and escapes the box.

Pumping Iron: How Dust Can Change the Climate



Pumping Iron is a station-based game meant to illustrate the movement of dust throughout different parts of the Earth system and the effects on the climate when iron-rich dust settles into the ocean and stimulates phytoplankton growth, which then leads to the drawdown of carbon dioxide from the atmosphere through photosynthesis.

Players draw cards and are sent to different stations, collecting nutrients that phytoplankton need to live along the way - iron, nitrogen, and sunlight. Whoever has collected the most nutrients wins! But players might get stuck at the bottom of the ocean, become part of a cloud, or be eaten by a whale along the way.

The game will take ten or more minutes to play, including about three minutes to explain gameplay, 5-7 minutes to play the game, and 2-3 minutes for the conclusion.

Required Materials

**Print materials listed below can be downloaded as pdf files from the Exploring Atmospheric Dust and Climate website*: scied.ucar.edu/atmospheric-dust-climate

- **Introduction Poster:** is the visual anchor for how the stations fit together as a system.
- **Station Signs:** (7 total) able to stand up on a tabletop or floor.
- **Game Cards:** (cards that match each station) provide instructions for how to move through the game.
- **Card Placement Mats:** (7 total) show where to place the draw pile and discard pile at each station.
- **Tracking Sheet:** one ½ sheet per player (could be a paper consumable or laminated for write-on/wipe-off reusability); allows players to track which stations they have visited and keep track of nutrients they have collected throughout the game.
- **Conclusion Sign:** provides wrap-up and connection between dust, phytoplankton, and climate.
- **Golf pencils or dry erase pens:** one for each player; to record on the tracking sheet.

Additional Materials:

**additional materials are optional but recommended*

- Small clipboards (6"x9") to use with the tracking sheet
- Small baskets to keep the draw piles and discard piles organized
- Easel or stand to display the Introduction Poster
- Sign holders (horizontal/landscape orientation) for station signs

Tip: using small baskets to hold the card decks will help keep the stations tidy. Print out extra copies of the card placement mat and cut out the picture showing where to place the cards. Tape into the bottom of the baskets.

Instructions for set up

- The *Pumping Iron* game requires enough space for multiple players to move easily between stations throughout the game. The picture (below) shows stations set up along one side of a long table, but other options include using two tables arranged in an L-shape or parallel, or even three tables in a U-shape.

- Display the Introduction poster in a place that is easy to gather players around for instructions, such as on an easel or stand, or leaning up against a wall.
- Place the station sign, card placement mat, and matching card deck at each station.
- Have tracking sheets and pencils ready for players, ideally on small clipboards.
- Keep the conclusion sign with the facilitator to reference during the game wrap-up.

Number of players

- While there is no limit to the number of players who can join in, consider the best size for game management (more than eight players per round can be a bit chaotic unless you have a large space!).
- Use only Deck A for a small group of players (1-4).
- Add Deck B (expansion deck) if there are five or more players.

Instructions for Facilitating the Game

- **Gather players around the introduction poster and introduce the game storyline:**

  "This game tells the story of dust that travels all over the Earth and ends up in the ocean. The dust has lots of iron in it. Iron is a mineral that is needed by all living things, but there is very little iron in the ocean. When iron-rich dust gets into the ocean, it helps tiny organisms called phytoplankton live and grow. And when there are more phytoplankton in the ocean, it helps cool Earth's climate!

  To play the game, collect all the things that phytoplankton need to grow - iron, nitrogen, and sunlight. The more you collect, the more phytoplankton you make. And the more phytoplankton you make, the more it helps to cool the climate."

- **Point out the steps for gameplay at the bottom of the introduction poster with the players:**
  - Start at the Mountain Station and follow the dust -- use the clues on the cards to figure out where to go next.
  - Collect iron, nitrogen, and sunlight to help phytoplankton grow.
  - Use the tracking sheet to record your progress - whoever collects the most nutrients wins!
  - Encourage players to read the info on each station poster to learn why each place is important.

- **Give each player a tracking card and explain how to use it during gameplay:**
  - Players will mark on the tracking card to keep track of iron, nitrogen, and sunlight cards drawn during gameplay.
    - For younger players, point out that Fe stands for iron, N for nitrogen.
  - Players can also keep track of where they travel during the game by drawing lines or arrows to show the path taken from one station to the next.
    - Other options: circling all the places visited or making tic marks to keep track of how many times each place is visited.

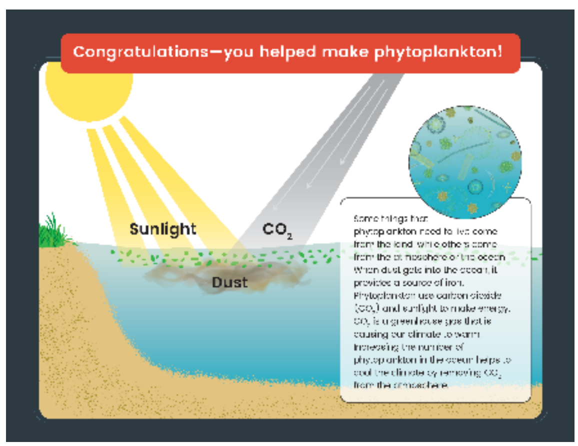
- **Starting the game:**
  - Players start at the Mountain station and draw a card to figure out what to do next.
  - With more than one player: If more than one person is playing, the youngest player should draw first. Then other players take turns drawing cards. After this

station, players' paths in the game will likely diverge as the cards send them to different locations. For example, one person may be sent to the atmosphere, while another is sent to the loess plateau.

- **Playing the game:**
    - Players proceed at their own pace-- take turns if more than one player is at the same station. Tell players that you will announce when the game is over.
    - Players mark on their tracking sheet each time they draw an iron, nitrogen, or sunlight card and return the card to the discard pile. They can also keep track of the places they visit throughout the game.
    - Shuffle the discard pile back into the deck and continue drawing cards if the draw pile runs out.
    - Players draw cards and move from station to station for 5-7 minutes, but adjust the time based on the number of players and player engagement.

- **Ending the game:** At the end of the 5 to 7-minute gameplay period, gather players together to debrief and share connections between phytoplankton and climate (illustrated on the conclusion sign).
    - Ask players about the nutrients they collected: Which did you collect the most of? Which was the hardest to find?
    - Ask players about the stations they visited: Did you visit every station? Which stations did you visit the most? What order did you visit the stations in? If multiple people played at the same time, did everyone visit the same stations?

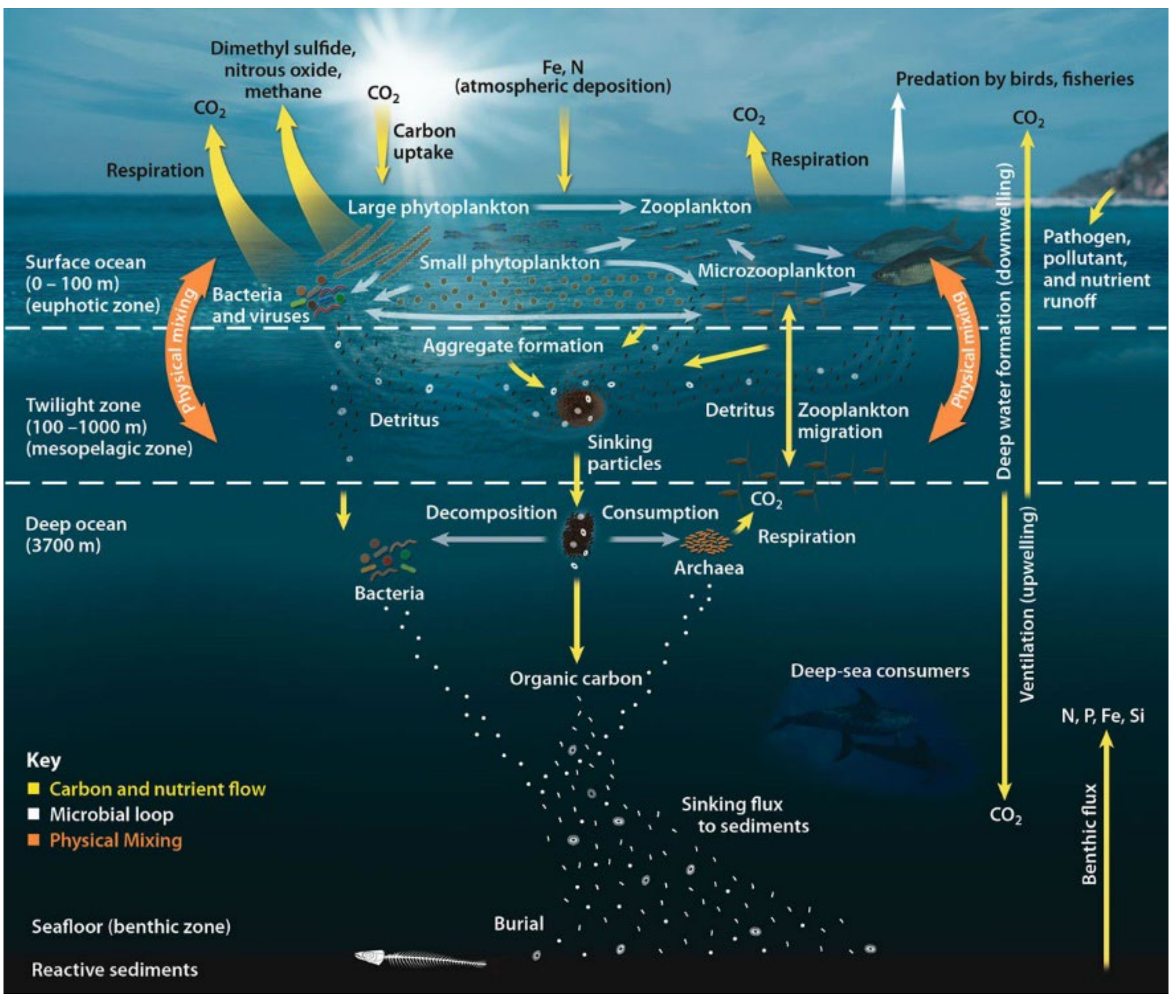
- **Explain the connection between dust, phytoplankton, and climate using the conclusion sign:**
    - Explain the connections between CO_2 and climate change. Ask players if they know how CO_2 gets into the atmosphere.
    - For teen and adult visitors, point out that the phytoplankton are removing CO_2 from the atmosphere through photosynthesis, just as plants do.



- **Play another round of the game if there is interest:** Players can continue where they left off or start again at the Mountain Station, continuing to add nutrients to their tracking sheets. Debrief again, discussing differences between rounds to illustrate that the path dust takes as it travels around the Earth is not always the same.

Science facts related to the game

- Iron is very limited in the ocean, even though marine life, like phytoplankton, need iron to survive. Nitrogen is much easier to come by but often gets used up in the surface layer because there are so many living things there. All living things need nitrogen as well.
- Iron enters the ocean in three ways: as iron-rich dust settles on the surface and is consumed by marine organisms or sinks deeper into the water; from erosion of continental margins as the moving ocean breaks away pieces of rock from the edges of the submerged portion of the continents; and from hydrothermal vents on the ocean floor that spew minerals, including iron, into the water.
- The ocean works as a biological pump. Nutrients are consumed by marine organisms and are released back into the water as the dead organisms decompose and chemical interactions occur between marine life and the ocean environment. Sometimes nutrients are sequestered in the ocean floor for millennia, and sometimes the mixing of ocean layers brings nutrients from the ocean floor closer to the ocean surface.



Credit: [Wikipedia & Office of Biological and Environmental Research of the U.S. Department of Energy Office of Science]

- There are some places in the ocean where iron is limited, like the North Pacific Ocean, and some places where nitrate is limited, like the Atlantic Ocean. Conversely, nitrate is readily available in the North Pacific, and iron is available in higher concentrations in the Atlantic. The irregular distribution of nutrients throughout the ocean is influenced by many factors, including deep ocean circulation.
- When dust increases the amount of iron in the ocean in areas where iron is limited, like the North Pacific Ocean, more phytoplankton can grow. Phytoplankton remove CO_2 from the atmosphere through photosynthesis. As the climate continues to warm, these connections between iron, phytoplankton, and the drawdown of CO_2 are of increasing interest. Iron fertilization has been suggested as a climate intervention strategy, but there are concerns about potential negative impacts to ocean ecosystems.
  - How Can Adding Iron to the Oceans Slow Global Warming?
- In addition to being an important nutrient for life, nitrate is also a good indicator of where there is excess carbon at the surface. Because the phytoplankton are limited by iron (and light) in the North Pacific and the Southern Ocean, they can't use as much of the nitrate and carbon that is available at the surface, and thus these regions leak CO_2 into the atmosphere. Conversely, in the Atlantic, where there is plenty of light and iron, the phytoplankton use up the available nitrate and draws down atmospheric CO_2. In these regions, the lack of nitrate limits the phytoplanktons' capacity for carbon uptake, which is why iron is present at a high concentration. Carbon concentrations are important for understanding changes in climate.
- While phytoplankton play a key role in the drawdown of carbon dioxide and production of oxygen (they produce an estimated 80% of the world's oxygen), an overabundance of phytoplankton in the ocean is associated with the formation of dead zones, where oxygen-depleted waters lead to the death of marine life in that area. Dead zones are common along coastlines and where pollutants like nitrogen-rich chemical fertilizers enter the ocean, providing excess nitrate that leads to phytoplankton blooms.
  - Learn more about phytoplankton.
- The geologic record suggests that an increase of dust in the North Pacific Ocean may have influenced global cooling during the Pliocene (around 2.7 mya).

Additional Resources

Science on a Sphere®

For museums and facilities with access to a Science on a Sphere® (SOS), there is an *Exploring Atmospheric Dust and Climate* live program within the SOS Live Programs Catalog. Included are a facilitator script and an accompanying PowerPoint slide deck. The activities described in this guide could be used along with your Science on a Sphere®. If possible, set up the activities near your Science on a Sphere®, or direct visitors toward your Science on a Sphere® after they have finished engaging with the activities.

- What is SOS?

MeteoAR

View *Exploring Atmospheric Dust and Climate* as interactive augmented reality (AR) datasets using the MeteoAR app, a mobile device, and downloadable science sheets. Visit the NCAR MeteoAR website and follow the instructions to print the *Dust and Climate Part 1 and Part 2* science sheets and install the MeteoAR app onto a mobile device. The MeteoAR *Dust and Climate* datasets can accompany the other activities described within this guide and are a great option for facilities without access to a Science on a Sphere®. This activity would also work well for outreach events.

Exploring Atmospheric Dust and Climate Website

Resources related to the *Exploring Atmospheric Dust and Climate* activities, including print-ready files, this facilitator guide, and instructions for creating the hands-on activities, are available on the UCAR Center for Science Education website: scied.ucar.edu/atmospheric-dust-climate