Real World Globes - The Arsia Mons Elongated Cloud (AMEC) - Globe Activity

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Purpose:
- To understand the past climate of Mars and how it has changed over time.
- To investigate a specific example of a unique meteorological phenomenon on Mars.
- To understand and recognize the underlying similarities in physical meteorological processes between Earth and Mars.
- To understand the processes of orographic lifting and cloud formation.
- To understand seasonal weather patterns on Mars.
- To investigate how geography influences weather phenomena.

Target Audience:
- High school students

Materials:
- Planet Mars Albedo Globe™ or Planet Mars TopoGlobe™
- Clear 18" hemisphere
- Spherical ruler
- Spherical protractor
- Dry-erase markers, eraser, calculator

Introduction:

Mars is a planet of extremes. While liquid water is now known to have flowed on its surface billions of years ago, it has now completely dried up. In fact, Mars is a thousand times drier than the Atacama desert of Chile, the driest place on Earth! However, all of this water did not disappear all at once. There is interesting recent evidence from NASA/JPL's Curiosity Rover through observations of stratified rock formations on the slopes of Mount Sharp (Aeolis Mons) in Gale crater that Mars underwent several periods of dry climate, followed by periods of wet climate. About 3 billion years ago, the water disappeared for good. While there have been several hypotheses about how this occurred, it is known that a large quantity of the water once present on the surface of Mars became “locked-up” as hydrated minerals, which is now part of Martian rocks. However, the bulk of the water is now believed to have been lost to space when Mars’ atmosphere was stripped away by the persistent solar wind (streams of high-energy charged particles from the Sun). The stripping away of Mars’ atmosphere lowered the global atmospheric pressure, eventually reaching the vapor pressure of water, allowing the water to boil away into space. The question now becomes: Why was the solar wind able to strip away Mars’ atmosphere? And why hasn’t this happened on Earth?

Earth, like many other planets, generates its own magnetic field (called the **geomagnetic field**). This magnetic field is directly produced via a dynamo effect of circulating liquid metal currents in the Earth’s outer core (figure 1).

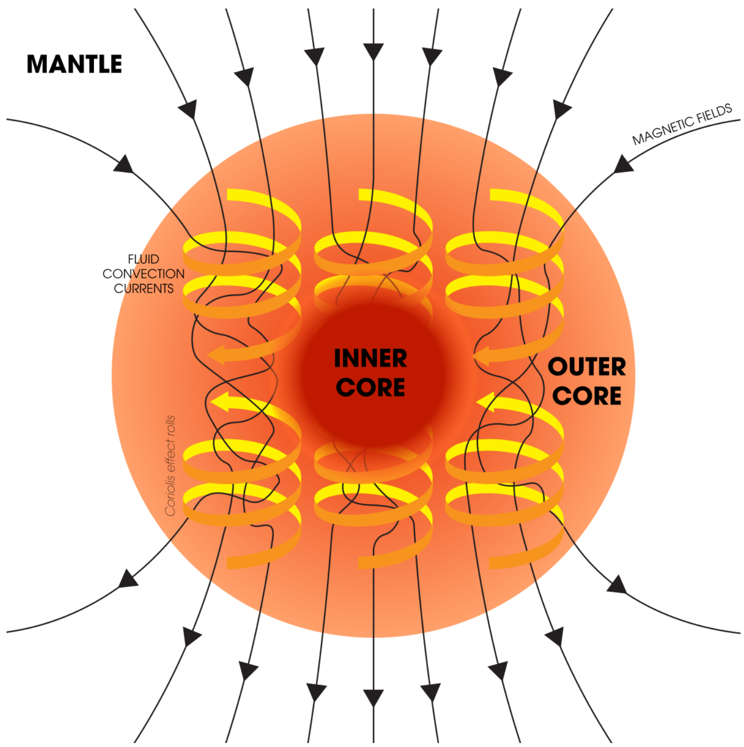

Figure 1: Dynamo theory. Circulating convection currents of liquid metal in Earth’s outer core is thought to be the source of Earth’s magnetic field. (Courtesy of Wikipedia).

This magnetic field surrounds the Earth (the **magnetosphere**) and deflects the incoming charged particles of the solar wind around the Earth. This deflection distorts the Earth’s magnetosphere, creating a **bow shock** and tapered tail (**magnetotail**). By deflecting these high-energy charged particles, the magnetosphere shields the Earth (and its atmosphere) from being stripped away by the momentum of these particles (figure 2).

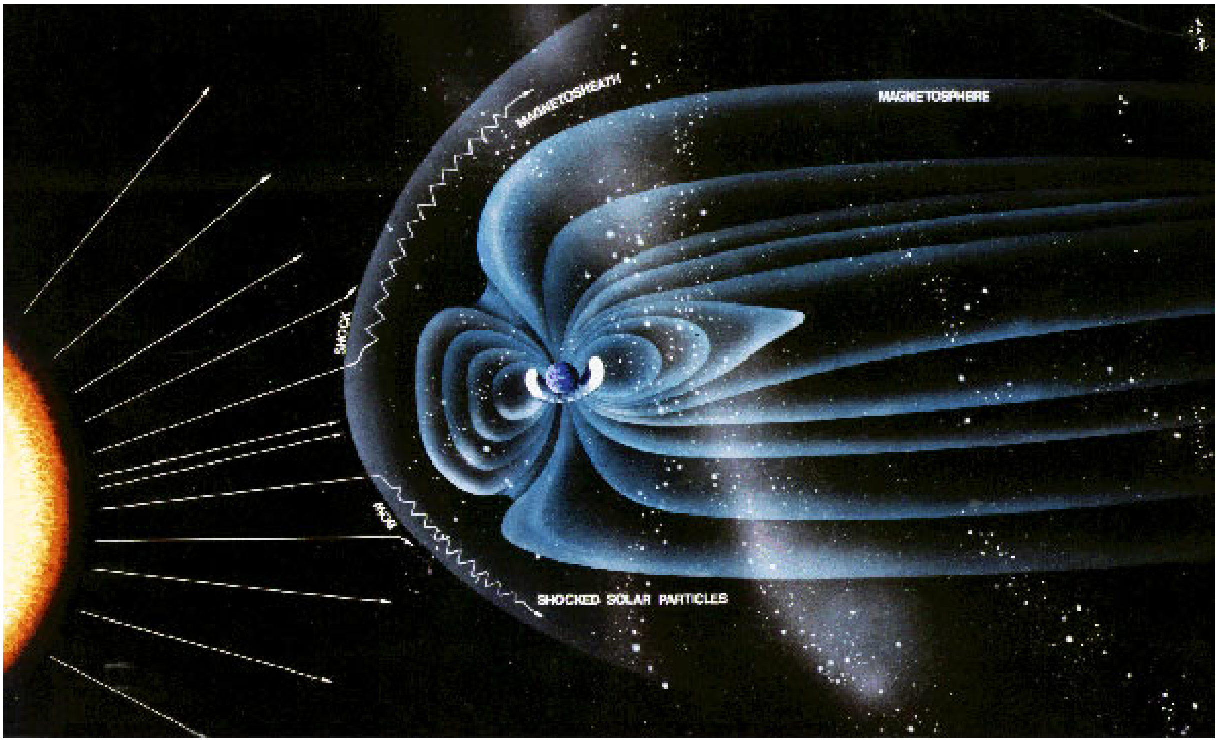

Figure 2: Earth's magnetosphere protects the Earth from the incoming high-energy charged particles composing the solar wind. This protects the Earth, acting like a shield. (Courtesy of The National Air and Space Museum).

For reasons not completely understood, Mars lost its magnetic field billions of years ago. The current primary hypothesis is that Mars' core cooled and solidified (**core crystallization**). Without a liquid metal outer core to support convection currents, the dynamo effect was lost, and the magnetic field ceased - leaving Mars' atmosphere vulnerable to the onslaught of the solar wind.

The atmosphere of Mars:

Mars' atmosphere is extremely thin. It is composed primarily of carbon dioxide (CO_2), molecular nitrogen (N_2), and argon (Ar), with trace amounts of water vapor (H_2O), molecular oxygen (O_2), carbon monoxide (CO), molecular hydrogen (H_2), and other noble gases. Compare this to the atmosphere of Earth (figure 3).

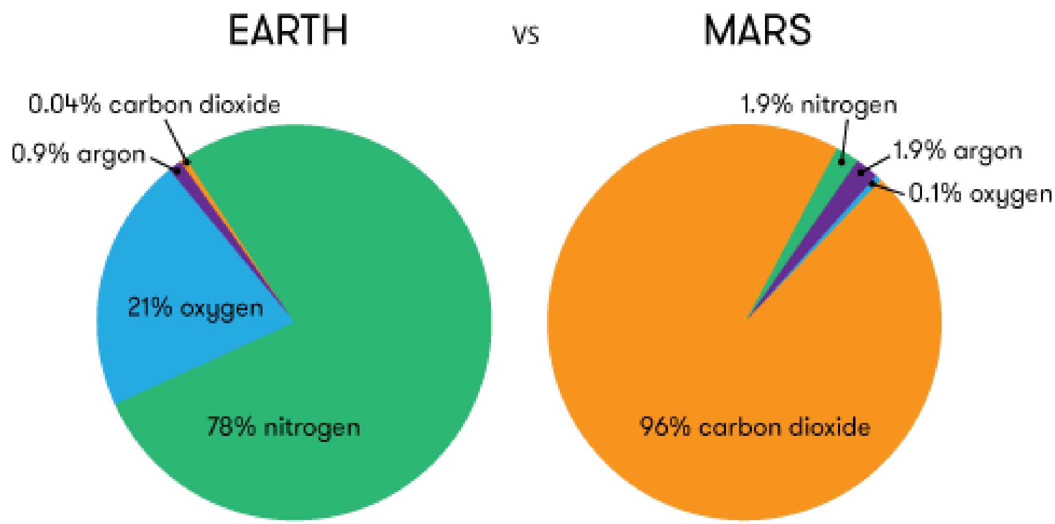

Figure 3: Comparison of the atmospheric composition of Earth and Mars. (Courtesy of The Australian Academy of Sciences).

In addition to a drastically different chemical composition, Mars' atmospheric pressure is extremely low compared to that of Earth. On Earth, the average atmospheric pressure at sea level is 1013.25 hPa (hectopascals). However, on Mars the average atmospheric pressure at the elevation of the **areoid** ("sea level" equivalent for Mars) is only 6.1 hPa...just 0.6% that of Earth!

What little water there is on Mars is either frozen at the polar ice caps or, if in the atmosphere, exists as ice crystals at extremely high altitudes forming thin cirrus clouds (figure 4). A very small amount of water exists as water vapor (gas phase water) in the tenuous atmosphere of Mars. The source of most of this water actually comes from meteors as they burn up in Mars' atmosphere. It is the presence of this small amount of atmospheric water vapor that is important in the formation of clouds on Mars.

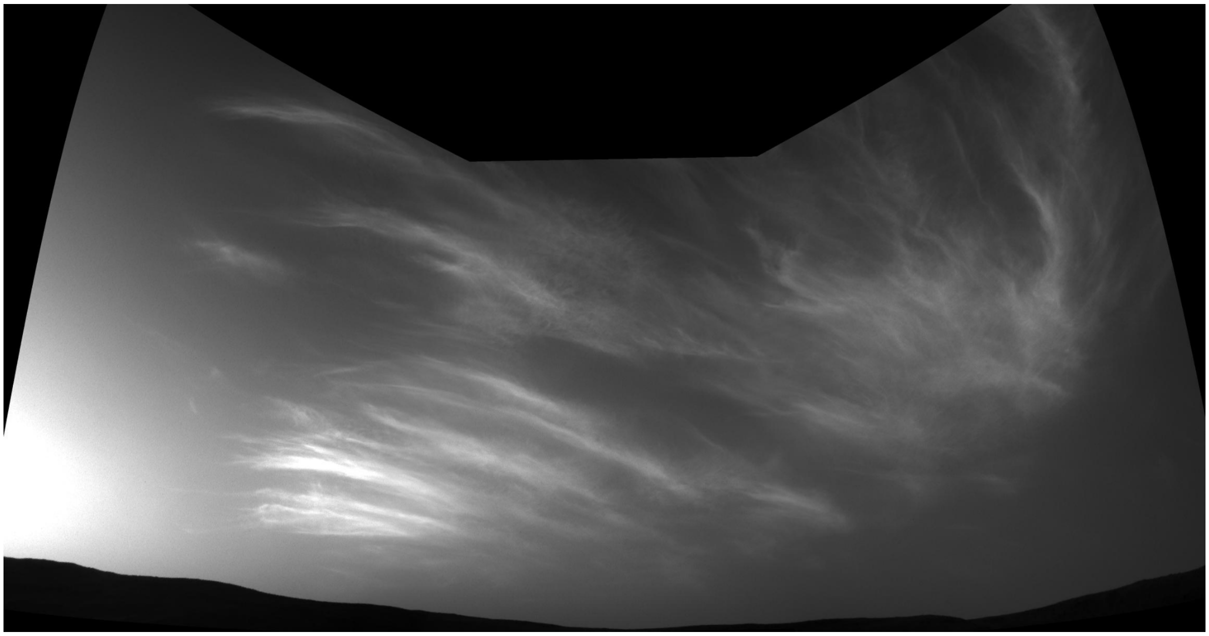

Figure 4: High altitude cirrus water-ice clouds on Mars, taken by Curiosity Rover from Gale crater. (Courtesy of Space.com)

Orographic cloud formation:

Orographic clouds are clouds that are formed by the forced uplift of air over an elevated topographic feature, such as a mountain or a mountain range. This is known as **orographic lift**. As the air is forced upward, it expands and cools adiabatically. If this air cools sufficiently (down to the dew point) the water vapor present in the air will condense into water droplets, forming what is seen as a cloud (figures 5 and 6).

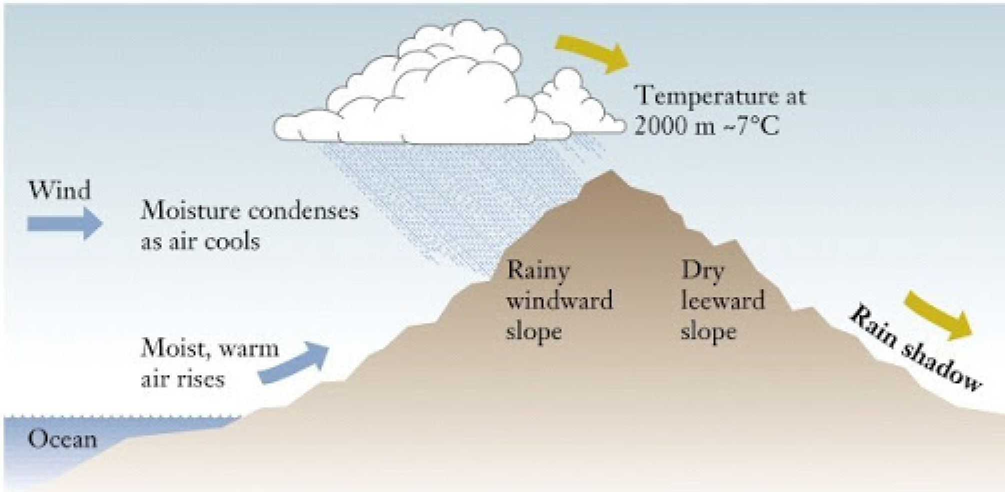

Figure 5: Orographic clouds are formed by the forced uplift of air over a mountain or mountain range. If sufficient moisture condenses out of the vapor phase, it will form a cloud and may produce precipitation on the windward side of the mountain. This leaves the leeward side of the mountain relatively dry, forming a rain shadow. An example of this can be seen along the coastal mountain range of California, as well as the Sierra Nevada mountain range. This produces arid rain shadow conditions in the California Central Valley and the Great Basin.

Figure 6: In this image altocumulus lenticularis (lenticular clouds) are forming over the summit of a prominent mountain. These are a common type of orographic cloud. (Courtesy of Tourism on the Edge).

The Arsia Mons Elongated Cloud (AMEC):

A unique, seasonally-recurring meteorological feature on Mars is the **Arsia Mons Elongated Cloud (AMEC)**. Originally observed from orbit by the Viking 2 lander in 1976, it was a relatively obscure and poorly-understood feature on Mars. Recently, with the arrival of permanently-orbiting Mars observation satellites (such as Mars Express (MEX), and the Mars Reconnaissance Orbiter (MRO)) high-resolution as well as wide-angle cameras have been able to capture photos of this interesting cloud (figure 7).

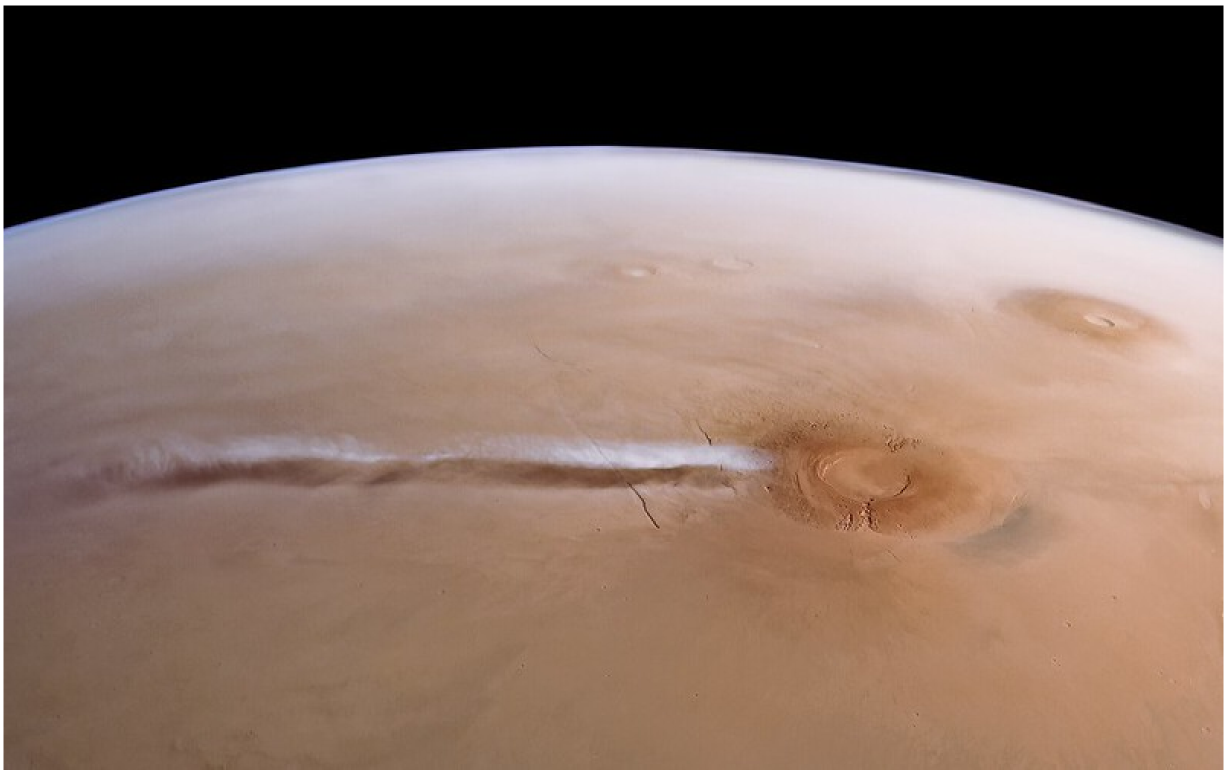

Figure 7: The Arsia Mons Elongated Cloud (AMEC) forms on the western slope of the extinct volcano Arsia Mons (seen on the right in this photo taken from orbit). During its formation it elongates and extends westward as a result of the prevailing easterly winds found at its particular latitude and altitude.

The AMEC forms around the time of the Martian summer solstice in the southern hemisphere (northern winter) and rapidly forms just before sunrise. It is an ephemeral, yet daily event, lasting only a few hours and then quickly disappears before noon local time. It is formed as a result of orographic lifting in the atmosphere, where the prevailing easterly winds blow in moisture-laden “air” in a westward direction. As this air is forced to rise over the elevated terrain of Arsia Mons (which, at nearly 18 km, or 58,300 feet in elevation, is the third highest mountain on Mars) moisture quickly condenses out of the vapor phase and forms a stream-like cloud of ice crystals at an altitude of about 45 km above the northwestern portion of Daedalia Planum.

This cloud has an approximate width of 150 km and can reach a length of up to 1800 km! (Figure 8).

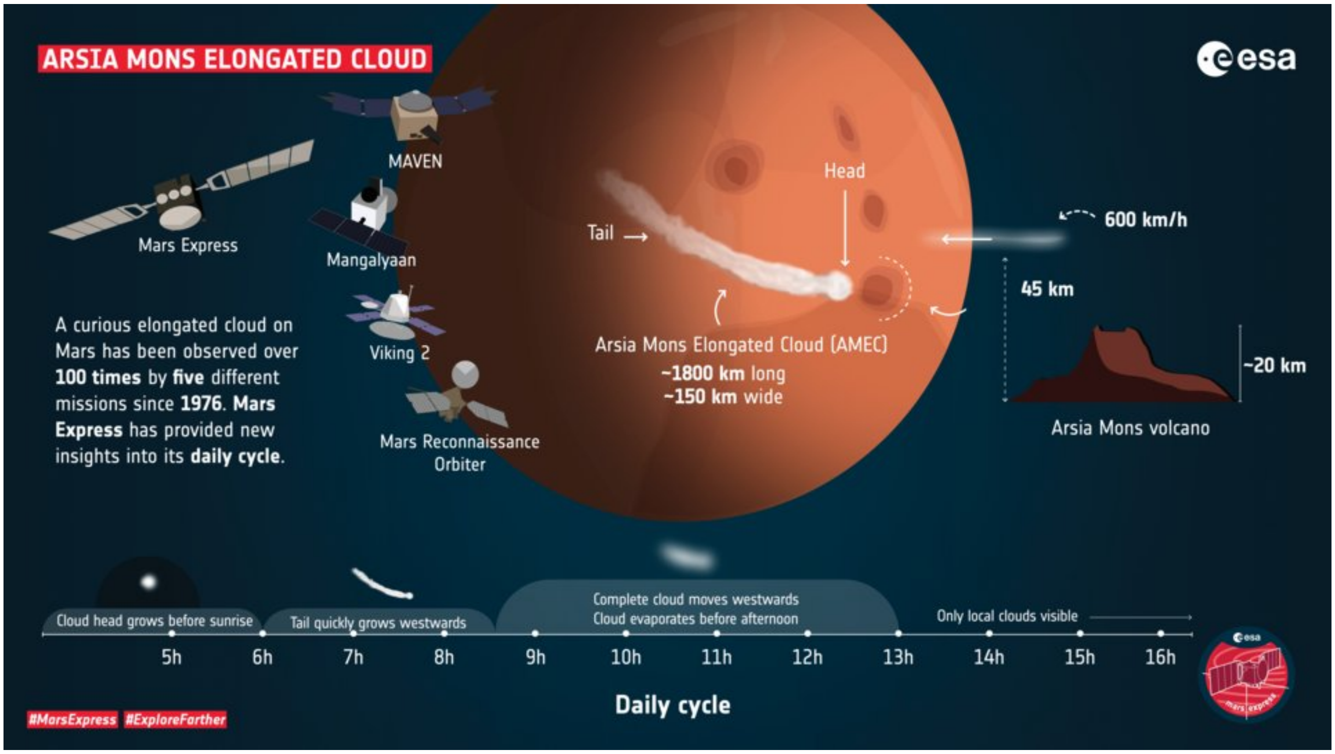

Figure 8: Informational graphic about the AMEC. (Courtesy of Universe Today).

Mechanism of formation:

The prevailing easterly winds (analogous to the **trade winds** on Earth) blow in a westward direction near the equator. The cold, dense atmosphere of Mars causes what little “air” there is to stay close to the surface. As this air approaches the eastern end of the Valles Marineris canyon, it falls down into the canyon and warms up due to adiabatic compression. Due to the **Venturi effect** (the speeding up of a fluid as it passes through a narrow corridor), the “air” also accelerates to high speeds creating warm, fast-moving winds that blow westward through the canyon (red arrows in figure 9). As this “air” exits the western end of the canyon (at Noctis Labyrinthus) it rises, cools, and slows down. This “air” immediately encounters further uplift and cooling by Arsia Mons, which lies directly to the west of the canyon. As the air cools further, water vapor condenses into ice crystals, forming the cloud. The funneling of “air” through the massive, narrow Valles Marineris canyon concentrates and accelerates the air into a narrow stream as it exits the canyon and encounters Arsia Mons. This explains why the cloud is so narrow in width, yet elongated (due to the narrow stream of fast-moving winds emerging from the canyon) (figure 9).

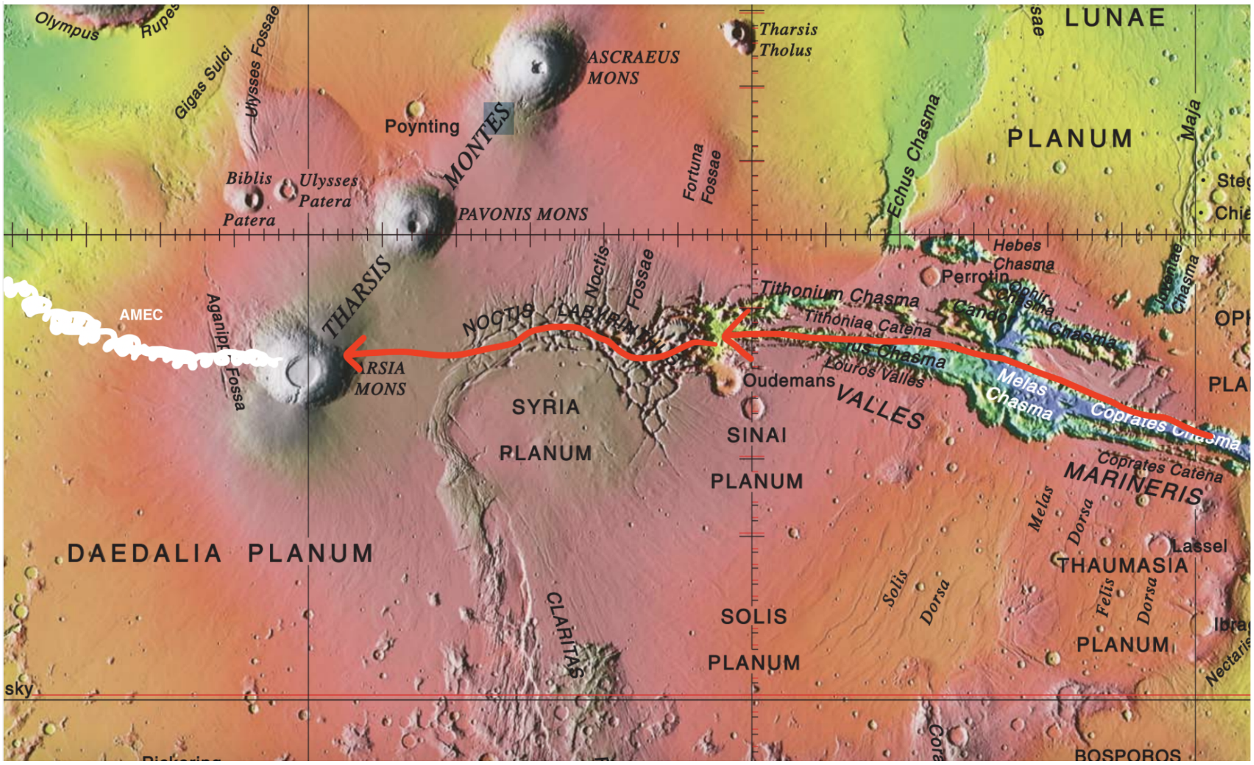

Figure 9: The prevailing easterly winds (analogous to the **trade winds** on Earth) blow in a westward direction near the equator and are shown as red arrows. These winds are concentrated and accelerated as they encounter the massive Valles Marineris canyon. As the winds exit the western end of this canyon they are directed toward Arsia Mons by the ascending terrain of Noctis Labyrinthus. Upon emerging from the canyon the "air" almost immediately encounters Arsia Mons, which induces rapid uplift as it emerges from the canyon. This leads to rapid water vapor condensation and freezing to form a narrow, elongated, and rapidly propagating cloud on the western slope of Arsia Mons (up to 600 kilometers per hour, or 370 miles per hour!) (Courtesy of USGS).

It is further speculated that the formation of the AMEC, which only forms around the time of the southern summer solstice (when atmospheric temperatures are highest in the southern hemisphere), arises as the result of a greater amount of water vapor present (warmer air holds more moisture). Therefore, it is the unique combination meteorological and topographic ingredients, including: warmer atmospheric temperatures, greater atmospheric moisture content, easterly trade winds, the presence of Valles Marineris to funnel, concentrate, and accelerate winds, and the immediate uplift of this "air" over a massive topographical relief feature (Arsia Mons) which leads to formation of this unique and very interesting seasonal cloud feature.

Activity 1 - Getting to know the geography of Mars (or *"areography"*):

1. Obtain the following materials:

    - Planet Mars Albedo Globe™ or Planet Mars TopoGlobe™
    - Clear 18” hemisphere
    - Spherical ruler
    - Spherical protractor
    - Dry-erase markers, eraser, calculator

2. Place the clear 18” hemispheres over the globe, and fasten together using the small plastic nuts and bolts. This will allow you to draw on the surface of the globe using the dry erase marker.

3. Locate the following areographic features on the globe:

    - Equator
    - Valles Marineris
    - Noctis Labyrinthus
    - Arsia Mons
    - Daedalia Planum

4. In which hemisphere (northern or southern) do the above areographic features occur? (Excluding the equator).

5. From **east to west**, list the above areographic features (excluding the equator). This is the sequence of features which the easterly (west-flowing) trade winds of Mars encounter.

6. Using a dry-erase marker (color of your choice), draw arrows denoting the flow of the easterly winds as they flow through Valles Marineris.

7. At the northern edge of the Oudemans crater (near the border between Sinai Planum and Syria Planum), the western end of Valles Marineris transitions from a long, deep flat-bottomed canyon into labyrinth of shallower, branched canyons (Noctis Labyrinthus). What do you think happens to the wind speed as the winds reach this transition?

8. Using a different-colored dry erase marker, draw arrows denoting the flow of the winds through Noctis Labyrinthus. If the winds have slowed down, draw shorter arrows.

9. As the canyons of Noctis Labyrinthus become shallower as you move toward the west, they eventually terminate at the northwestern edge of Syria Planum, where they continue to flow toward the west, and toward Arsia Mons. Using a different-colored dry-erase marker, draw arrows denoting the flow of the winds as they emerge from Noctis

Labyrinthus and flow toward Arsia Mons. What happens to this “air” as it approaches and ascends the slopes of Arsia Mons?

10. At the summit of Arsia Mons is a large, flattened crater-like depression (the volcanic **caldera**). The winds blow across this caldera (continuing toward the west) where they reach the western rim of the volcano. It is from this western rim that the AMEC begins to form.

Activity 2 - Mapping the AMEC:

1. From the western rim of Arsia Mons’ caldera (volcanic crater), moisture in the atmosphere begins to condense from a vapor directly into ice crystals, forming the beginnings of a cloud. This is due to the expansional cooling of the “air” as it ascended the eastern slope of Arsia Mons.

2. The average width of the AMEC is 150 km. If 1 cm on the globe represents 150 km in real-life, how many centimeters (cm) wide should your cloud be drawn?

3. Using the same globe scale (1 cm = 150 km), and the fact that the AMEC can reach lengths of up to 1800 km, how many centimeters (cm) long should your cloud be drawn?

4. Using satellite imagery data, it has been measured that the AMEC propagates in a west-northwest direction at a speed of nearly 170 meters per second (or about 600 km per hour!) Given the length of the cloud (1800 km), how many hours does it take for the AMEC to reach its full length?

5. Figure 10 shows the areographic extent of the AMEC - extending, at its longest point, in a northwest-curving path from the western slope of Arsia Mons to the southernmost edge of Amazonis Planitia, terminating near the equator.

6. Using figure 10 as a guide, on your globe draw an accurately-scaled AMEC cloud. Remember, the AMEC should be approximately 1800 km in length and 150 km wide. (Use your answers to questions 2 and 3 to know how many centimeters this corresponds to on your globe).

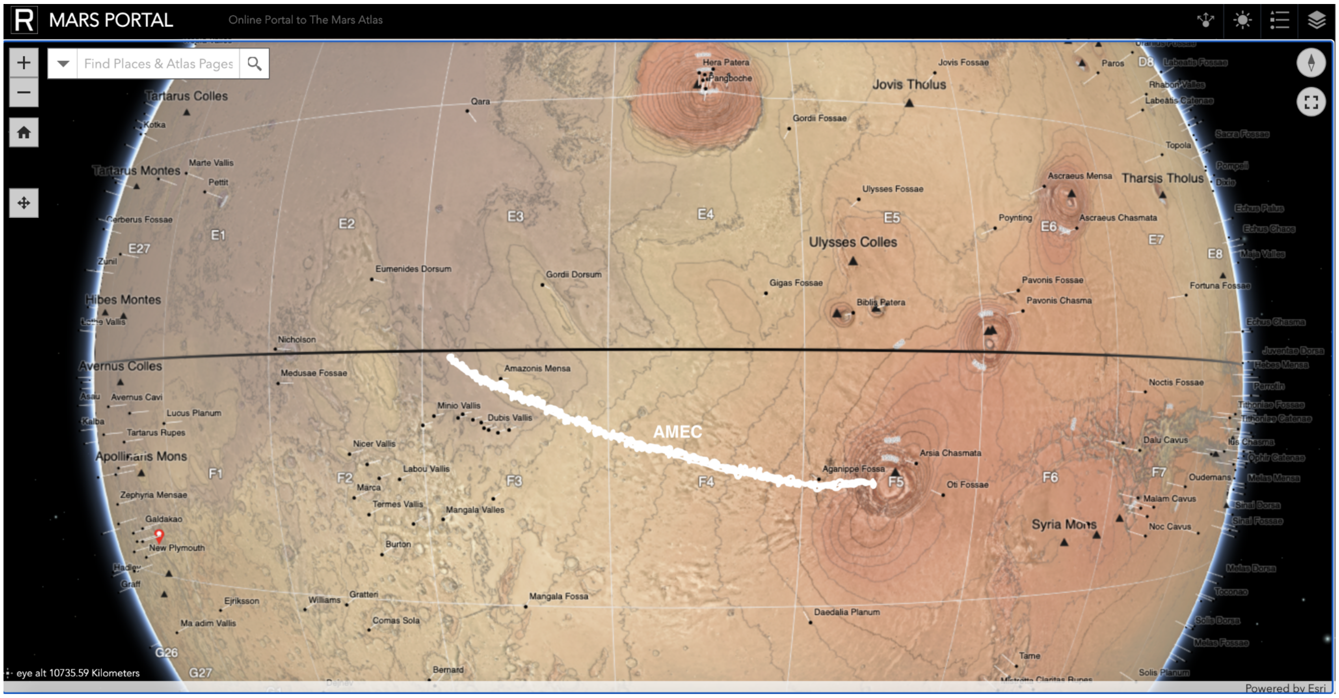

Figure 10: The AMEC extends westward from the western slope of Arsia Mons, and gradually curves northward toward the equator under the influence of the Coriolis effect. In this figure the AMEC is drawn as 1800 km in length along its curvature - extending from Arsia Mons to the southernmost edge of Amazonis Planitia terminating near the equator. (Made using the Red Mapper Mars Portal).

Follow-up questions:

1. The west-northwest propagation of the AMEC has been measured to be up to 600 km/hr (nearly 370 mph!) Given that the cloud forms at extremely high altitudes (45 km, or 148,000 ft.) propose a hypothesis as to why the cloud might propagate at such high speeds.

2. Arsia Mons is just one of several large extinct volcanoes found on Mars (others include Pavonis Mons, Ascraeus Mons, and Olympus Mons - all found within the massive Tharsis volcanic region). How does the unique areography of Arsia Mons and its surroundings provide the atmospheric conditions needed to form the AMEC?

3. If Arsia Mons were higher in elevation, how might that affect the characteristics of the AMEC?

4. The AMEC ice crystals that form the cloud evaporate as they approach the equator, causing the cloud to disappear. Provide an explanation of why this might be.

5. It is known that the Coriolis force is responsible for the curvature and northwest deflection of the cloud toward the equator. It is also known that the magnitude of the Coriolis force on a mass of air is directly proportional to its latitude (zero at the equator and maximum at the poles). Given this knowledge, propose the direction that a similarly-forming cloud on Pavonis Mons might take. (You will need to locate Pavonis Mons on the globe).

6. Research question: Water is extremely scarce on Mars (even in its vapor form). Therefore, if water is so scarce, how is it that there is enough water present in the dry Martian atmosphere to form such a large cloud? Where does this water vapor come from?