# MARS METEOROLOGY

**Ages:**
Grades 9-12

**Duration:**
45 minutes

**Materials:**
**Per student or group of students:**

- Copies of Mars Mission Map showing where the Phoenix mission landed (http://mars.jpl.nasa.gov/msl/news/images/20081124a/MSL_4sites_globe.jpg)
- Video projector for sharing the MARCI Weather Report (http://www.msss.com/msss_images/latest_weather.html) & for the closing dust devil video animation (http://www.jpl.nasa.gov/video/index.cfm?id=1072)
- One copy of student sheets per student
- Calculators
- Markers

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## OVERVIEW

Students will study the weather conditions observed on the surface of Mars by the Phoenix Lander in order to better understand how atmospheric scientists study and model weather, and to see how scientists may use their understanding of the Earth's atmosphere to study atmospheres and weather on other planets – like Mars. After a brief introduction to the basic weather parameters used by scientists, the class will be broken into four weather teams. These teams will work as small groups to analyze (through basic statistical calculations), plot, and discuss the Phoenix observations for a 60-sol (Martian day) period of time. From their plots, they will have the tools to state the general surface weather conditions for a specific location on Mars, during a particular period of time (season). Students focus on the data showing day to night (diurnal) temperature trends, pressure trends, and average wind conditions for the given time period. They will conclude the activity by developing additional science questions prompted by this data and should discuss how they would research/study these particular questions and what additional data that they would need to do so (a suggestion for future research work).

## OBJECTIVE

The students will be able to:

- Observe changes in weather conditions on the surface of Mars for a 60 day (sol) time period as recorded by the Mars Phoenix Lander at one location in 2008
- Calculate basic statistics for temperature, pressure, and/or wind data
- Interpret the Mars surface observations to develop an understanding of the atmospheric conditions found there
- Analyze and discuss atmospheric properties of Mars and any observed data trends
- Describe some challenges that atmospheric scientists face in forecasting weather conditions on Mars

**BEFORE YOU START:** Become familiar with the important features in the Mars Phoenix Lander meteorological data and the student worksheets.

## ACTIVITY

Show the MARCI Weather Report video clip for the current week and present a Mars Weather Forecast, using the weather discussion text from the webpage: http://www.msss.com/msss_images/latest_weather.html. Discuss (briefly) with the students, how the Mars weather report compared to the ones that they are used to here on Earth. What was similar? What was different? What atmospheric properties do atmospheric scientists use to predict the weather? Record the key weather parameters on a whiteboard. Explain that today they will become atmospheric scientists and study the weather data collected by the NASA Mars Phoenix Lander.

Describe the activity to the class: The students will be taking 60 Sols (Martian days) worth actual NASA Phoenix Mars Lander surface weather observations and using them to make basic statistical calculations of the temperature, pressure, and wind data. They will then use their calculations to make simple graphs and plots in order to interpret and characterize the weather on Mars, much as atmospheric scientists would do. These calculations and processes of analysis are similar to the procedures that are important for developing numerical weather prediction (computer) models like those used on Earth (and Mars). Break the class into 4 weather teams: 1) Wind Direction; 2) Wind Speeds; 3) Temperature; and 4) Atmospheric Pressure; have the teams work together to complete their tasks and then bring them together to compare and discuss their findings. Teams may want to divide the calculations among their members to complete the activity more quickly.

## *ACTIVITY (CONTINUED)*

**Procedure:**

1. Distribute the materials. Make sure to point out that the data spreadsheet is two-sided.
2. Tell students that this is data collected by the Mars Phoenix Lander, taken from the surface of Mars around 68°N latitude and ~126°W longitude. This is located on the northern polar plains, in an area known as Vastitas Borealis, where it continued to operate successfully for more than five months (far beyond its planned 90-day lifespan)!
3. Use the video projector to point out the location in the Mars Mission Map and distribute copies to each group.
4. Have the student groups' work together to complete their student worksheets. Encourage them to divide the tasks among the members of the group (if desired).
5. Have each team come together and discuss the activity questions for their team. They should summarize their work and findings to share with the class. One person should be chosen by each team to represent their team and share their results with the class.
6. Bring everyone back together and let each team spokesperson share their results – they should explain what their team did and address their answers to their team activity questions.
7. Have the teams compare their results and discuss their findings.
8. Conclude the lesson by asking the students to think about all of their findings and to consider what remaining questions that they have about the weather and climate on Mars. Show the 3D Dust Devil animation on the video projector: http://www.jpl.nasa.gov/video/index.cfm?id=1072
    a) What questions does this data create?
    b) What new data would you want to help address these questions?

**QUESTIONS AND KEY**

**1. Q.** How would you rate the quality of the Phoenix data? Why?
**A.** The data is pretty complete – a pretty good dataset. However, there are missing data. The wind data is missing several days' worth of observations. The data would be better if it did not have these gaps.

**2. Q.** How is the atmospheric surface pressure changing over time? Is there a trend or pattern?
**A.** Yes, the surface pressure is decreasing over time. This could indicate a change in season, but more information would be needed to determine the true cause (confirm this assertion).

**3. Q.** What observations can you make from the data (temperature & winds)?
**A.** There is a large temperature change from daytime maximums to nighttime minimums.
The predominant wind direction was from the North, with an overall average wind speed of 16 km/hr. The winds out of the NE had the greatest average wind speed (18.9), and the smallest average wind speed was from the NNW (9 km/hr); however, this value was based off of only 1 data point.

**4. Q.** Do you notice any trends or patterns in the data (temperature & pressure)? If so, explain.
**A.** The temperatures and pressures are generally decreasing over time. The winds are most likely to blow out of the N, NE, S, & SE. The students did not analyze the wind direction/speed for changes over time, although this would be a nice extension activity.

**5. Q.** How would you interpret these observations? How does it compare to Earth?
**A.** Mars is a very cold, windy, and predominantly sunny (and dry) place. It experiences dramatic temperature variations from day to night (diurnal). There is evidence that the data was collected as Mars was entering its cold season (winter) at that location, since the temperature and pressure was decreasing over time. If you were on Mars, you could expect the wind to be blowing at a moderate speed of 15-20 km/hour from the N, NE, S, or SE. Mars is much colder and experiences much larger temperature fluctuations from day to night than the Earth. It also has a much lower atmospheric pressure (thinner atmosphere) as compared to Earth.

**6. Q.** What could you say about Mars weather? What can you say about climate from this data set?
**A.** We can characterize the weather as in questions #2-5 for this specific location on Mars. However, we cannot state anything about the climate of Mars based just on this data. Climate requires data covering a much longer period of time over a much larger area before any it can be used to characterize a planets climate (decades at least). However, scientists can use computer models to make predictions based on the weather observations available.

**7. Q.** Why do you think atmospheric scientists are interested in understanding the wind conditions on Mars?
**A.** Many possible answers here. Primarily, scientists are interested in being able to accurately forecast Martian weather for missions and possible future human habitation. They are also interested in better understanding its atmosphere and climate both past and current, and are working to develop better computer models to help in these endeavors.

## EXTENSIONS

Apply this lesson structure to more recent NASA mission data from the Mars Science Laboratory aboard the Curiosity rover! The resources listed below will supply the data needed. Please note that you may need the students to alter the graphs and charts within this lesson as data ranges likely differ to a certain extent from mission to mission. It is recommended that you supply graph paper for this purpose. Have students compare and contrast their results between the Phoenix and MSL mission data. Considerations to keep in mind: location of observations, season (time of "year" on Mars), types of data available, quality and density of data available, etc.

- Rover Environmental Monitoring Station (REMS) Information (including data graphs and latest REMS news): http://mars.jpl.nasa.gov/msl/mission/instruments/environsensors/rems/
- Mars Weather from REMS: http://marsweather.com/data
- Mars Weather on Twitter (@MarsWxReport): https://twitter.com/MarsWxReport

## BACKGROUND

Weather is the state of the atmosphere at any given time, including atmospheric properties such as temperature, pressure, precipitation, and cloud cover. Climate on the other hand, is the totality of weather over a long period of time at one place or over a region. Climate results from the accumulated impact of weather day after day. Mars possesses weather circulations and patterns similar to what we see on Earth, but has many differences that we do not yet fully understand.

Atmospheric scientists measure important properties of the atmosphere such as temperature, pressure, and winds in order to better understand and predict future weather and climate. These atmospheric data are also used to compile statistics that are used to develop numerical weather prediction (computer) models. Numerical Weather Prediction is the basis of Global Circulation and Climate Models. Scientists need accurate weather observations and data in order to initialize the Global Circulation Models (GCMs) and verify their accuracy in relation to real world observations and events. Real-world observations help to reveal deficiencies in the models, allowing scientists to improve both their models and their own understanding of the complex atmospheric system. These models are very useful in predicting future weather conditions and patterns, as well as climates of the past.

One of the mission goals of the Mars Phoenix Lander was to characterize the climate of Mars. Phoenix landed during the Martian fall and collected its data as Mars headed into its long dark (polar) winter. The interaction between the ground surface and the Martian atmosphere that occurs at this time is critical to understanding the present and past climate of Mars. To gather data about this interaction and other surface meteorological conditions, Phoenix provided the first weather station in the Martian polar region, with no others currently planned. Data from this station will have a significant impact in improving global climate models of Mars. However, more observational data is still needed. While Phoenix completed important work towards providing valuable station data, many more data sets for multiple locations across the planet during all of the Martian seasons will be necessary to develop more accurate GCM's capable to reconstructing past climates and predict future ones on Mars.

## RESOURCES

**Phoenix Weather Information (from the Canada Space Agency)**
http://www.asc-csa.gc.ca/eng/astronomy/mars/phoenix/temperature.asp

**MARCI (MRO) Data**
http://geo.pds.nasa.gov/missions/mro/default.htm

**Mars Exploration Data Archive**
http://atmos.pds.nasa.gov/data_and_services/atmospheres_data/Mars/Mars.html

**Mar Phoenix Lander Fact Sheet**
http://phoenix.lpl.arizona.edu/pdf/fact_sheet.pdf

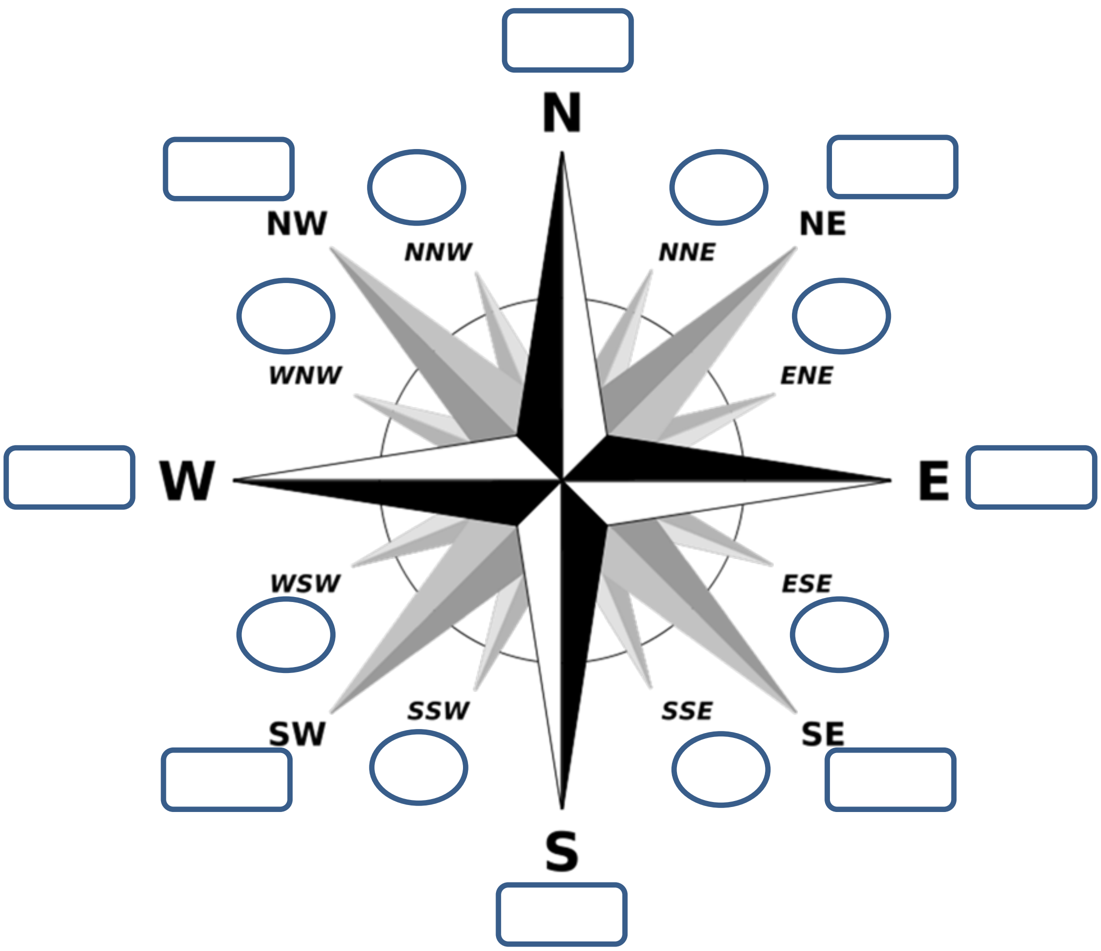
# Weather Team #1: Mars Wind Directions
## Student Sheet

**1. Record the number of observations for each wind direction.**

| Wind Direction | Number of Times Observed | Wind Direction | Number of Times Observed |
|---|---|---|---|
| N | | S | |
| NNE | | SSW | |
| NE | | SW | |
| ENE | | WSW | |
| E | | W | |
| ESE | | WNW | |
| SE | | NW | |
| SSE | | NNW | |

How many total wind observations were obtained over the 60 sols (days)? _______

**2. Enter the values for the frequency of each wind direction report from the Phoenix surface observations below.** In other words, please record the total number of wind observations for each wind direction in the boxes below for the given dataset. *Note: If there was a wind shift on a particular sol (day), then you and your group must decide how to classify the wind direction for that report and must record your reasoning in the data notes box below.*




**DATA NOTES:**

3. **Calculate the percentage out of total observations for each wind direction and enter the information in the table below.** You should add these percentages next to the proper direction on the previous wind diagram.

*Percentage = Total number of data reports for a specific direction ÷ Total number of actual wind direction observations*

| Wind Direction | Percentage | Wind Direction | Percentage |
|---|---|---|---|
| N | | S | |
| NNE | | SSW | |
| NE | | SW | |
| ENE | | WSW | |
| E | | W | |
| ESE | | WNW | |
| SE | | NW | |
| SSE | | NNW | |

## QUESTIONS:

- How would you rate the quality of the Phoenix data? Why?
- What observations can you make from the data?
- How would you interpret these observations?
- What could you say about Mars weather from this data set? What about its climate?

# Weather Team #2: Mars Wind Speeds
## Student Sheet

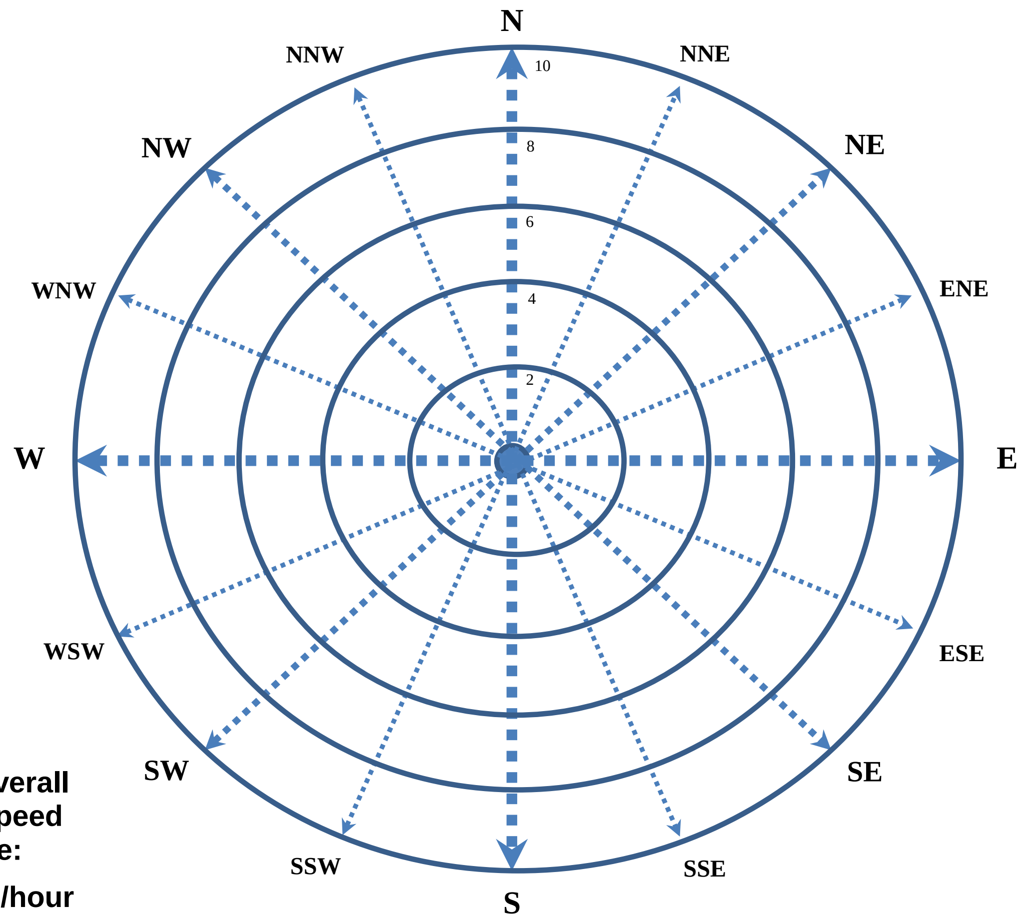
**1. Record the wind speed observations for each direction in the table below and then calculate the average wind speed for each direction and record it below.**

| Wind Direction | Observed Wind Speeds (list all below) | Average Wind Speed (km/hr) |
|---|---|---|
| **N** | | |
| NNE | | |
| NE | | |
| ENE | | |
| **E** | | |
| ESE | | |
| SE | | |
| SSE | | |
| **S** | | |
| SSW | | |
| SW | | |
| WSW | | |
| **W** | | |
| WNW | | |
| NW | | |
| NNW | | |

How many total wind observations were obtained over the 60 sols (days)? ________

***NOTES:***

2. **Plot your data on the 'Wind Rose' & Write the Percentage next to each one.** Draw a solid arrow along the dotted line for each wind direction to show the frequency of that direction for the observed time period. Each circle represents 2 observations. So, for example, if a North wind was observed 8 times total, you would draw a solid, straight arrow along the N dotted line to the fourth circle from the center of the wind rose. Do this for each wind direction that had an observation for the Phoenix dataset.




3. **Calculate the overall average wind speed and enter it here:**

   __________ **km/hour**

***QUESTIONS:***

- How would you rate the quality of the Phoenix data? Why?
- What observations can you make from the data?
- How would you interpret these observations?
- What could you say about Mars weather from this data set? Can you state anything about its climate?

# Weather Team #3: Mars Temperatures
## Student Sheet

1. **How many total temperature observations were obtained over the 60 sols (days)? _______**

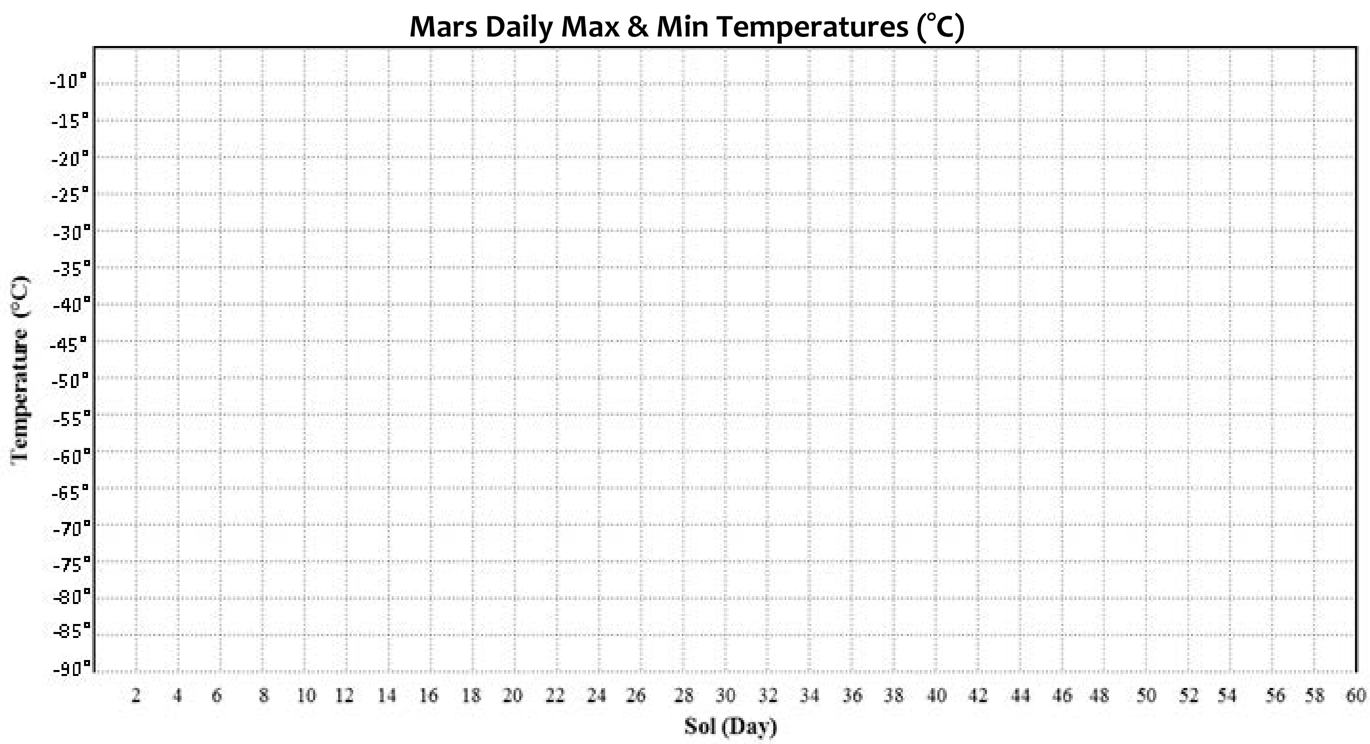
2. **Calculate the Overall Average Maximum Temperature ($T_{max}$) for the Phoenix dataset and enter it here.** *Note: Average = sum of all $T_{max}$ observations ÷ total number of Tmax observations*

   Average $T_{max}$ = ____________°C

3. **Calculate the Overall Average Minimum Temperature ($T_{min}$) for the Phoenix dataset and enter it here.**

   Average $T_{min}$ = ____________°C

4. **Plot the Daily Maximum Temperature below as a line graph with a circle for each data point and label the line '$T_{max}$.' Repeat for the Daily Minimum Temperatures, plotting a line graph with triangles for each data point and label the line '$T_{min}$' on the same graph.** Make sure to label each line. Use a red pencil for max temperatures and a blue pencil for minimum temperatures to draw your lines (if available).




**DATA NOTES:**

5. **Calculate the temperature variation for the first 30 Sols (Martian days) and record the values in the table below.** *Note: Daily Temperature Variation =* $T_{max} - T_{min}$

| Sol | Temperature Variation (°C) | | Sol | Temperature Variation (°C) | | Sol | Temperature Variation (°C) |
|---|---|---|---|---|---|---|---|
| 1 | | | 11 | | | 21 | |
| 2 | | | 12 | | | 22 | |
| 3 | | | 13 | | | 23 | |
| 4 | | | 14 | | | 24 | |
| 5 | | | 15 | | | 25 | |
| 6 | | | 16 | | | 26 | |
| 7 | | | 17 | | | 27 | |
| 8 | | | 18 | | | 28 | |
| 9 | | | 19 | | | 29 | |
| 10 | | | 20 | | | 30 | |

How does the variation change over time (if at all)?

**DATA NOTES:**

**QUESTIONS:**

- How would you rate the quality of the Phoenix data? Why?
- What observations can you make from the temperature data?
- Do you notice any trends or patterns in the data? If so, explain.
- How would you interpret these observations? How do you think it compares to Earth?
- What could you say about Mars weather from this data set? Can you say anything about its climate?

# Weather Team #4: Mars Atmospheric Pressure
## Student Sheet

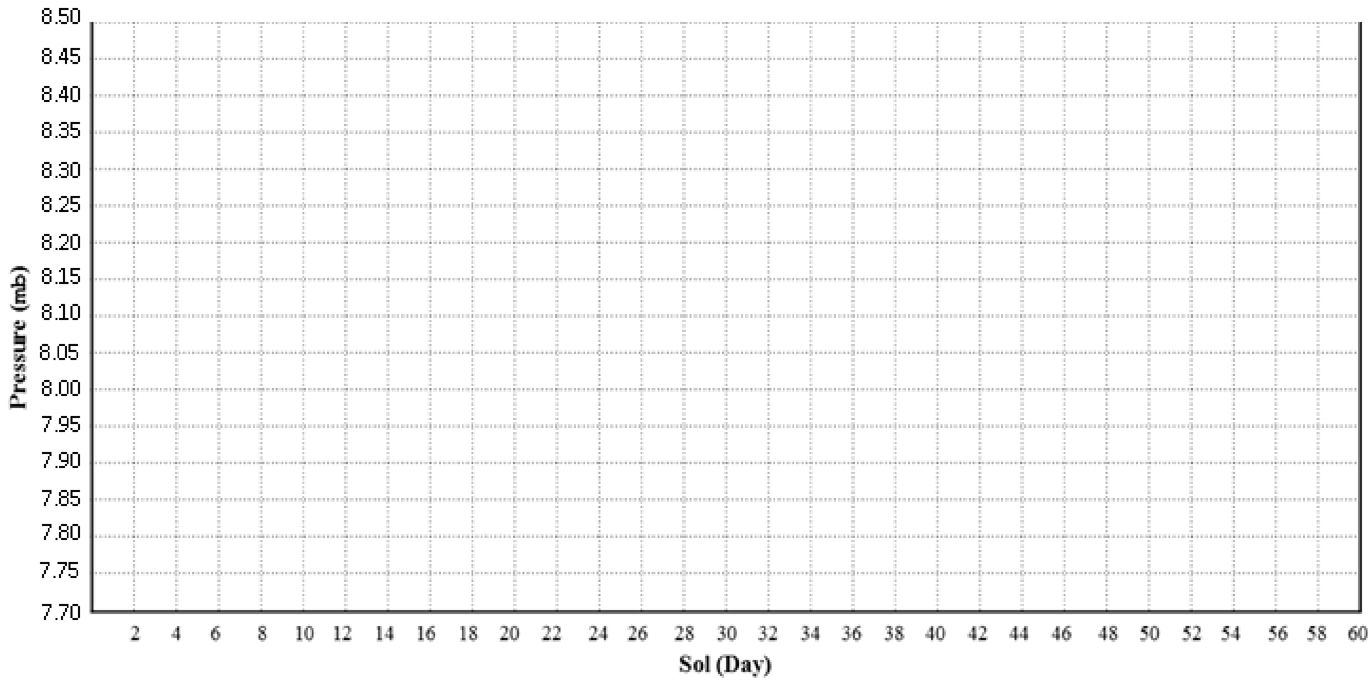
1. **How many total pressure observations were obtained over the 60 sols (days)? _______**

2. **Calculate the Overall Average Atmospheric Surface Pressure for the Phoenix dataset and enter it here.** *Note: Average = sum of Pressure observations ÷ total number of pressure observations*

   Average Pressure = ____________millibars (mb)

3. **Plot the Daily Pressure observations below as a line graph.**

**Mars Daily Surface Pressure (mb)**




4. **Determine the pressure tendency. How is the pressure changing over time? Is there a trend or pattern?** Record your observations and interpretation here. Add a straight line to your graph to represent the tendency (note: line can be sloped).

## QUESTIONS:

- How would you rate the quality of the Phoenix data? Why?
- What observations can you make from the pressure data?
- Do you notice any trends or patterns in the data?  If so, explain.
- How would you interpret these observations?  How do you think it compares to Earth?
- What could you say about Mars weather from this data set?

# Phoenix Mars Lander - Surface Weather Observations - Pg.1

| Sol | Ambiant Conditions | $T_{min}$ (ºC) | $T_{max}$ (ºC) | Pressure (mb) | Wind Speed (km/hr) | Wind Direction | Visibility (km) |
|---|---|---|---|---|---|---|---|
| 1 | Sunny and Clear Skies | -80 | -30 | 8.50 | 20 | NE | No Data |
| 2 | Sunny with Dust Activity | -80 | -30 | 8.50 | No Data | No Data | Moderate |
| 3 | Sunny with Dust Activity | -80 | -35 | 8.54 | 20 | NW | Hazy |
| 4 | Increasing Dust Activity | -80 | -30 | 8.50 | No Data | No Data | Decreasing |
| 5 | No Data | -80 | -30 | 8.50 | No Data | No Data | No Data |
| 6 | No Data | -80 | -30 | 8.50 | No Data | No Data | Clearing |
| 7 | No Data | -83 | -29 | 8.50 | No Data | No Data | Clearing |
| 8 | Sunny | -83 | -31 | 8.49 | No Data | No Data | Clear |
| 9 | Sunny | -82 | -25 | 8.50 | No Data | No Data | No Data |
| 10 | Sunny | -82 | -25 | 8.45 | No Data | No Data | Clear |
| 11 | Sunny | -81 | -34 | 8.45 | 18 | S | Clear |
| 12 | Clear with Dust Haze | -80 | -30 | 8.45 | 18 | S | Fair |
| 13 | Clear with Dust Haze | -80 | -32 | 8.45 | 14 | SE | Fair |
| 14 | Clear with Dust Haze | -80 | -35 | 8.40 | 14 | E | Fair |
| 15 | Clear with Dust Haze | -78 | -28 | 8.40 | 14 | S | Fair |
| 16 | Sunny | -82 | -34 | 8.40 | 14 | SW | Fair |
| 17 | Sunny | -82 | -32 | 8.35 | 14 | SW | Fair |
| 18 | Sunny | -80 | -31 | 8.34 | 19 | N | No Data |
| 19 | Sunny | -81 | -33 | 8.34 | 17 | S | No Data |
| 20 | Sunny | -79 | -32 | 8.33 | 21 | N | No Data |
| 21 | **NO DATA** | | | | | | |
| 22 | Sunny | -80 | -32 | 8.29 | 21 | S | Clear |
| 23 | Sunny | -79 | -32 | 8.29 | No Data | No Data | Clear |
| 24 | Sunny | -80 | -31 | 8.31 | 14-25 | SE | Clear |
| 25 | Sunny | -80 | -28 | 8.30 | 14-18 | S | Clear |
| 26 | Sunny | -78 | -32 | 8.31 | 11-18 | S | Clear |
| 27 | No Data | -79 | -31 | 8.30 | No Data | No Data | No Data |
| 28 | No Data | -78 | -31 | 8.30 | No Data | No Data | No Data |
| 29 | Sunny | -80 | -34 | 8.22 | 16 | N | Clear |
| 30 | Clear with Dust Haze | -79 | -33 | 8.17 | No Data | No Data | Moderate |

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# Phoenix Mars Lander - Surface Weather Observations - Pg. 2

| Sol | Ambiant Conditions | $T_{min}$ (ºC) | $T_{max}$ (ºC) | Pressure (mb) | Wind Speed (km/hr) | Wind Direction | Visibility (km) |
|---|---|---|---|---|---|---|---|
| 31 | Clear with Dust Haze | -79 | -31 | 8.16 | No Data | No Data | Moderate |
| 32 | Clear with Dust Haze | -80 | -33 | 8.14 | 11 | NE | Moderate |
| 33 | Sunny | -80 | -34 | 8.15 | 11-14 | SE | Fair |
| 34 | Clear with Dust Haze | -79 | -32 | 8.15 | No Data | No Data | Fair |
| 35 | Clear with Dust Haze | -78 | -33 | 8.15 | 11-22 | W | Fair |
| 36 | Sunny | -79 | -33 | 8.11 | No Data | No Data | Clear |
| 37 | Sunny | -79 | -33 | 8.20 | No Data | No Data | Clear |
| 38 | Clear with Dust Haze | -80 | -33 | 8.08 | 10 | N | Fair |
| 39 | Sunny | -78 | -32 | 8.07 | 13 | N | Clear |
| 40 | Sunny | -78 | -29 | 8.07 | 9 | NW | Clear |
| 41 | Sunny | -80 | -30 | 8.06 | No Data | No Data | Clear |
| 42 | Sunny | -78 | -34 | 8.00 | 16 | E | Clear |
| 43 | Sunny | -79 | -30 | 8.04 | No Data | No Data | No Data |
| 44 | Sunny | -78 | -30 | 8.04 | 16 | SE | Clear |
| 45 | Sunny | -80 | -31 | 8.04 | 14 | SE | Clear |
| 46 | Sunny | -79 | -29 | 8.02 | 9 | NNW | Clear |
| 47 | Sunny | -79 | -30 | 8.01 | 17 | N | Clear |
| 48 | Sunny | -78 | -30 | 8.00 | 13 | ESE | Clear |
| 49 | Sunny | -78 | -31 | 7.99 | 17 | N | Clear |
| 50 | Sunny | -79 | -27 | 7.99 | 20 | NE | No Data |
| 51 | Sunny | -78 | -29 | 7.96 | 18 | ESE | Clear |
| 52 | Sunny | -80 | -30 | 7.95 | 19 | ESE | Clear |
| 53 | Sunny | -79 | -28 | 7.94 | 17 | E | Clear |
| 54 | Sunny | -78 | -31 | 7.94 | 16 | NE | Clear |
| 55 | Sunny | -80 | -30 | 7.93 | 12 | NE | Clear |
| 56 | Sunny | -80 | -28 | 7.90 | 14 | NE | Clear |
| 57 | Sunny | -80 | -28 | 7.90 | 22 | N | Clear |
| 58 | Sunny | -80 | -31 | 7.90 | 17 | E | Clear |
| 59 | Sunny | -81 | -31 | 7.89 | 19 | NE | Clear |
| 60 | Sunny | -80 | -30 | 7.87 | 18 | N | Clear |