Examining the 2018 Summer Global Dust Storm on Mars's Lower Atmosphere from NASA's Mars Reconnaissance Orbiter

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ABSTRACT

The colonization of Mars is potentially the most revolutionary study in space exploration since man landed on the moon. It would be an enormous step for humankind being able to colonize the red planet: a freezing, faraway, uninhabitable desert. But protecting the human species from the end of life on Earth could save trillions of lives. Whether or not the research is the most important research in the history of the human race, or an absurd daydream, researchers are constantly digging for information about Mars in order to develop the best technology for humans to survive. The primary goal of this project is to investigate the 2018 global dust storm that occurred on Mars in order to determine its atmospheric properties. This will enable scientists and engineers to create instruments that will help future astronauts withstand the harsh conditions on the red planet. This project will examine the data from the recent global dust storm obtained by Mars Reconnaissance Orbiter (MRO) missions. MRO's goals are to understand Mars's atmosphere, to determine how the loss of atmospheric gas changed the Martian climate, and to scan for evidence of past or present water. To analyze NASA's planetary data, a program used by NASA's Jet Propulsion Laboratory called Interactive Data Language will be used. At the end of the project, the results and information obtained will characterize the conditions on Mars and relate to its colonization project. Hopefully, there's enough evidence to hypothesize and conclude how Mars changed from a warm, wet planet early in its history to the cold, dry world we see today.

Introduction

There are many predictions on how Mars transformed from a warm, wet planet early in its history to the cold, dry world we see today[1]. The most common theory is called plasma processing[2]. Planetary scientists believe Mars lost its atmosphere in the course of billions of years. This process is started by the sun's solar winds which emit light in the form of high-energy photons. When a photon at an extreme ultraviolet wavelength enters a planet's atmosphere, it can collide with a molecule in the atmosphere. When the molecule absorbs the photon, the energy from this impact can kick off an electron, leaving behind an ion. The stray electron will eventually recombine with another ion and the energy the electron gives to this reaction is sometimes enough to split the molecule into its component parts, giving those parts a lot of speed and launching them out into space[3]. Even though this process occurs continuously in most atmospheres, the escape of atoms over billions of years can contribute to the overall loss of a planet's atmosphere. Another factor is the magnetic field. Earth is protected from the sun's intense solar winds due to our present magnetosphere, but Mars was not so lucky. According to the researchers, Mars does not have a magnetosphere and has much less mass and gravity, resulting in the atmosphere unable to hold on to the atmospheric particles[4]. Mars atmosphere is slightly stable present-day because of one main thing:

the volcanoes[4]. The volcanic out-gassing from the planet's interior balances out the atmosphere lost to the solar wind.

To discuss some properties of Mars's atmosphere, its atmospheric pressure is about 600 Pa on average. it is less than 1% of the earth's atmospheric pressure which is about 101,300 Pa[5]. Mars thin atmosphere does not protect the planet from the Sun's radiation nor does it contain the heat absorbed by the surface[6]. The surface is constantly filled with small particles of dust (iron oxide), giving the planet the reddish hue. Currently, Mars's atmosphere consists of about 95.32% of carbon dioxide, 2.7% of nitrogen, 1.6% of argon, 0.13% of oxygen, 0.08% of carbon monoxide, and other minor amounts of water, nitrogen oxide, neon, hydrogen-deuterium-oxygen, krypton, and xenon[7].

The main cause of Martian dust storm forms is the sun. When radiative heat of sunlight reaches the surface of Mars, it warms the air closest to the surface, leaving the upper air cooler[8].Then, the warm air rises up, taking dust with it. Larger storms only happen during summer in Mars southern hemisphere because that's when the planet is closer to the sun. During that time, Mars is hottest and therefore the radiative heat forces are strongest. Small or normal storms happen almost every day but planet-encircling dust storms occur every 5.5 Earth years or 3 Mars years[8]. Large global dust storms put enough dust in the air to completely cover the planet and block out the sun. Figure 1 illustrates the darkness global dust storms can create.

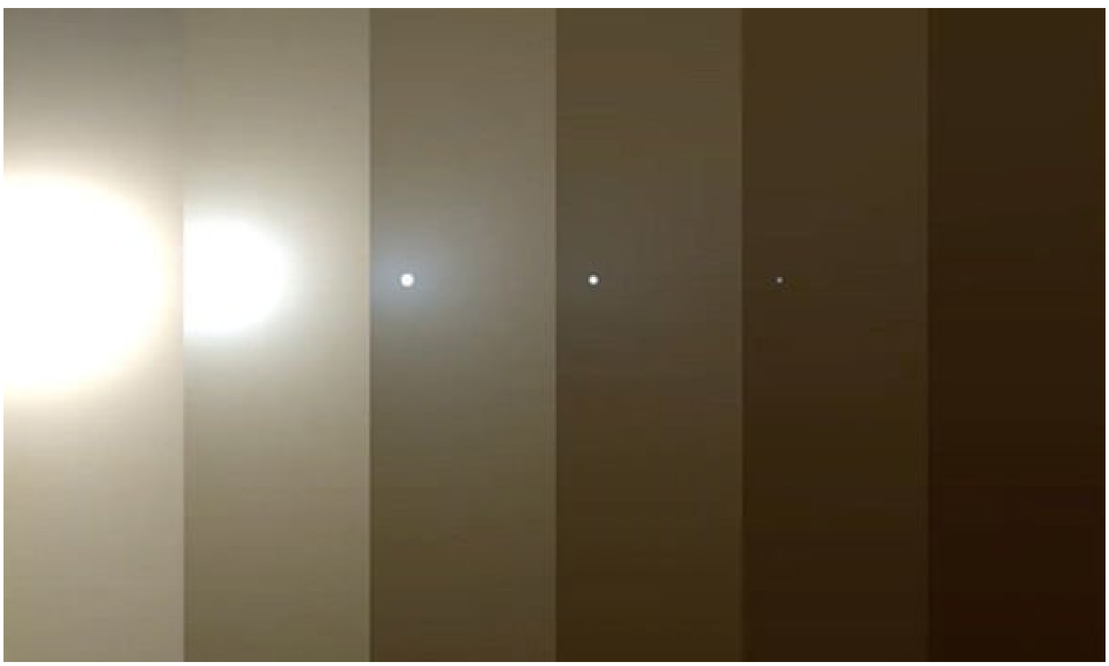

Figure 1. This NASA composite illustrates the strength of Martian dust storms. From left to right, you can see the planet's supply of light decreasing as the storm takes over. Image from Fish, Tom. "NASA Opportunity Rover Dead: Why NASA Will NOT Rescue Mars Rover." Express.co.uk, Express.co.uk, 15 Feb. 2019, www.express.co.uk/news/science/1087351/nasa-opportunity-rover-mars-rover-mission-rescue-space-news.

However, that can also doom the storm itself because once the whole planet is covered, there is darkness, causing the storm to eventually die a few months later. Scientists still don't know why global dust storms occur every 5-6 years. In terms of location, dust storms typically begin in lower areas like craters and spread out from there. Most of the global dust storms started on Hellas Planitia[9], the largest visible impact crater known in the Solar System.

The history of dust storms date back to 1796 when Astronomer H. Flaugergues noted "yellow clouds" (now known to be clouds of dust) on Mars.[10] However, it wasn't until the mid-1900s when humans had the technology to see the first extensive observations of a planet-encircling dust storm on Mars. As technology advances toward the 21st century, spacecrafts like Mariner 9 and Viking lander 1 detected a few global dust storms. Ground-based telescopes and the Mars Global Surveyor continued to monitor both regional and global dust storms. It wasn't until 2001 when scientists were truly able to study and witness a global dust storm accurately due to the advances in technology. In 2001, the Hubble Space Telescope captured Martian seasonal dust activity in Hellas Planita and the North Pole where a few regional dust storms developed into a near-global dust storm. In 2007, another global dust storm occurs where both NASA's Mars exploration rovers (Spirit and Opportunity) survives the storm. MRO detected the most recent global dust storm in 2018 where it was recorded to be the most intense storm seen[11]. Figure 2 illustrates the intensity of the global dust storm in 2018 compared to a regular normal year at Mars. It even ended Mars's Rover Opportunity's mission due to the dust covering the solar panel operations. NASA continues to use Mars's spacecrafts to further observe and study its atmospheric properties and detect future dust storms.

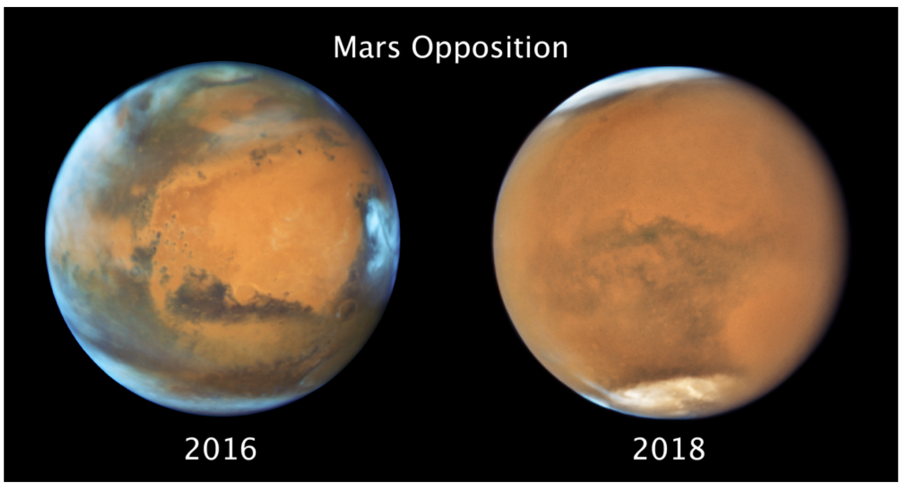

Figure 2. This an image of comparing Mars's Dust Storms in two different time periods. 2016 shows normal dust storms. 2018 shows a global dust storm. The brownish-organe hues demonstrate the dust storms while the white are the polar ice caps. Image from "Gravity Assist Podcast: Mars Dust Storm with Melinda Kahre." Astrobiology Magazine, Fox News, 29 Aug. 2018, www.astrobio.net/mars/gravity-assist-podcast-mars-dust-storm-with-melinda-kahre/.

The Mars Reconnaissance Orbiter has 6 main instruments to scan for evidence of past or present water[12]. Other missions include imaging geological structures, scanning atmospheric layers, and observing the planet's weather, season, and climate changes[13]. One example of MRO's major discoveries was published last year about the possibility of liquid water being present seasonally on present-day Mars[14]. It has also provided the strongest evidence yet that liquid water flows intermittently on present-day Mars.

The Mars Climate Sounder (MCS) is the main instrument that is going to be focused on for this research. The data analysis is directly from the MCS. The MCS observes the temperature, humidity, and dust content of the Martian atmosphere, making measurements that show variations in Mars's current weather and climate[15]. A sounder is an instrument that measures changes in atmospheric temperature or composition with height. The MCS "sees" in nine channels across the electromagnetic spectrum, mainly the visible and infrared ranges. The visible range is the equivalent of what the human eye can see. The infrared range corresponds roughly to heat, being able to "see" how hot something is. There is one channel in the visible and near-infrared range that examines how the solar energy interacts with the atmosphere and the surface, providing insight and understanding into Martian climate. The rest of the eight channels in the thermal infrared range are used to measure temperature, pressure, water vapor, and dust[15]. MCS observes Mars's atmosphere and takes measurements every 5 kilometers (3 miles) in vertical "slices" through the atmosphere and combines these slices into daily, three-dimensional, global weather maps for both daytime and nighttime[15]. The weather maps represent temperature, pressure, humidity, and dust in various layers of the atmosphere. These measurements are similar to what meteorologists use to understand and predict weather and climate on Earth.

For measurement purposes, local time is indicated in military time in order to convert it from Martian to earth time. A Martian day is almost the same as earth time. Earth has 24 hours a day while Mars has 24 hours, 37 minutes, and 35 seconds in a day[16]. So, whether we look at either time, they aren't too far apart. Location is going to be based on latitude and longitude. Furthermore, solar longitude is the Mars-Sun angle measured from the Northern Hemisphere. It tells us information about Mars's season. Figure 3 illustrates Mars at different angles and its infrared signature.

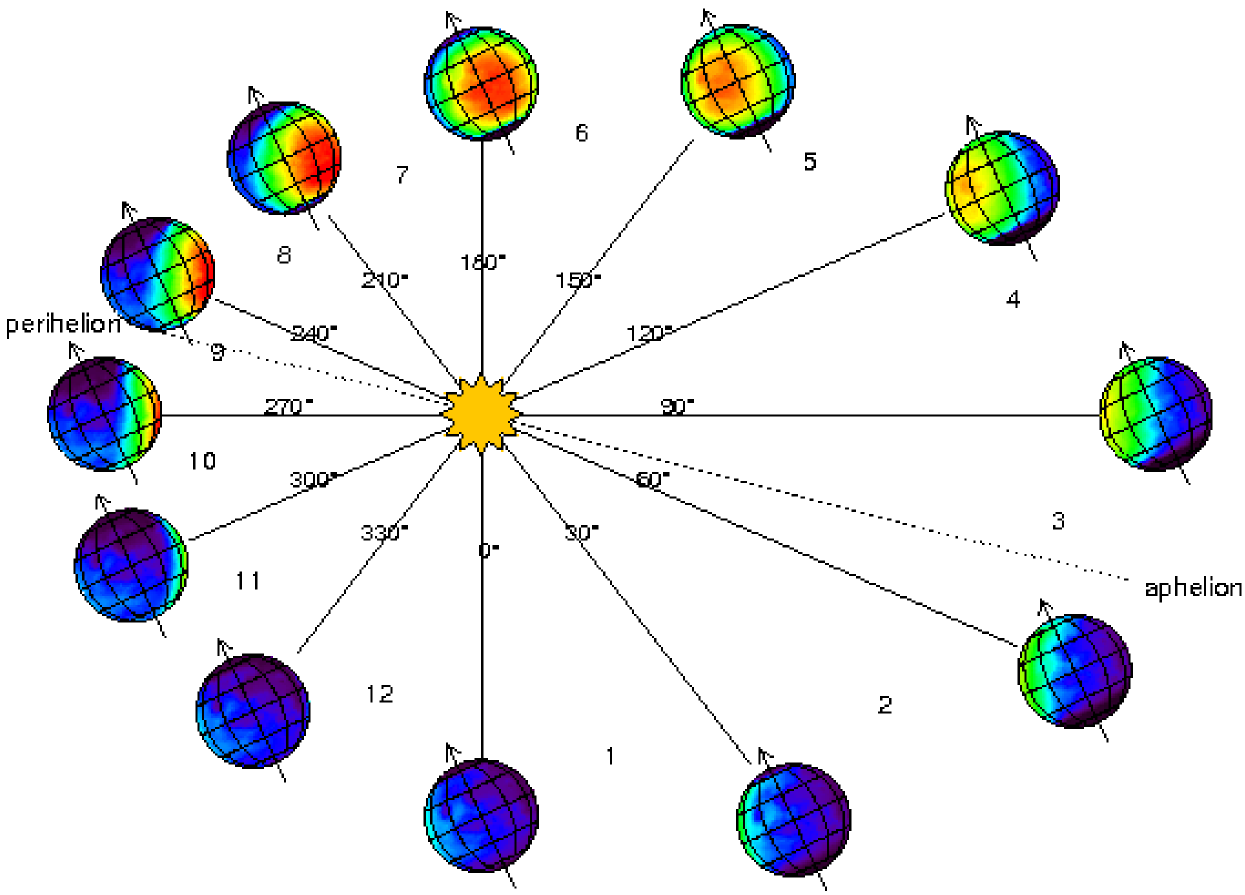

Figure 3. Image of Martian Seasons and Solar Latitude. The heat signatures represent the seasons during different orbiting angles. Image from http://www-mars.lmd.jussieu.fr/mars/time/solar_longitude.html

When the Ls is at 0 degrees, spring occurs. Every 30 degrees represents a month. Ls=90 corresponds to summer, Ls=180 corresponds to fall, and Ls=270 corresponds to winter[17].

Research Goals

The primary goal is to be able to create a program where it can read direct data from MRO. One of the important steps is to be able to obtain the files during summer of 2018. The program needs to be able to convert each data set into multiple plots. These plots include "Pressure V.S. Temperature" and "Pressure V.S. Dust". All these scientific properties of temperature, pressure, and dust refer to Mars's atmosphere. After analyzing these plots, we collect the points at a specific pressure for each plot and combine them all into one significant graph of "Temperature V.S. Dust". After the graphs are created, conclusions are drawn from the "Temperature V.S. Dust" graphs and used to characterize Mars's atmosphere. Other factors will be examined such as location and time of the data.

Methodology

The research took place at the University of Arizona's Lunar and Planetary Laboratory (LPL).To obtain the files from MRO, we needed to explore NASA's Planetary Data System (PDS)[18]. NASA's PDS is full of archived digital data returned from NASA's planetary missions and is used by planetary scientists for research. The main focus is the data obtained from NASA's MRO mission. The data is collected from an instrument that's part of the spacecraft called the Mars Climate Sounder (MCS). Even though the data is public, one cannot download the files and data directly from that website. In order to download the actual files, we had to get permission from the Mars Orbital Data Explorer[19], one of NASA's PDS Geosciences Nodes. NASA's PDS Geosciences Nodes is held by Washington University in St. Louis and it archives and distributes digital data related to the study of the surfaces and interiors of terrestrial planetary bodies.They work directly with NASA missions to help them generate well-documented, permanent data archives. The main PDS node that we are looking for are the atmospheres. After obtaining the necessary MCS data from MRO, we took one sample data from January 1st, 2018 to use as a testing subject for the rest of the data.

One of the first steps was figuring out what program to use to read the MRO files which was in the format of PDS3. Even though it was a struggling start to figure out which software to use at first, we eventually found out a program called Interactive Data Language (IDL). IDL was the correct one to read the PDS3 files. Dr. Yelle received an IDL file script from Dr. David Kass who works at the Jet Propulsion Laboratory that reads the PDS3 files or more specifically, the MCS files. The MCS files were contained as a .tab file extension because it was used for tab-separated data files. These files contain a table of information that stores columns of data that is separated by tabs. Dr. Yelle edited the file script so it would be able to convert each .TAB file into multiple CSV files. CSV stands for "Comma-Separated-Values". We wanted to program the IDL file to where it could split and organize the MCS data from one file into different files. The original MCS file had millions of numbers and values that were all over the place. Figure 4 demonstrates an insignificant sample of the raw and direct MCS data from the MRO spacecraft. Our task was to format the data into something more readable. IDL was able to read the files from the spacecraft and turn it into .CSV files that made it better to analyze.

After IDL was able to successfully convert the sample MCS (or .TAB) file into 358 .CSV files, we had to take it to the next step. The next step was to find another software that can read the 358 profiles. For more efficient naming purposes, we called the CSV files, profiles. We decided that python was the best programming language to use to read the profiles. We downloaded another software called Anaconda Navigator which has a program inside of it called Spyder. Spyder is a platform environment for scientific programming in the Python language. We created two scripts for python because one script will convert the profiles into a list and the other script is going to use the first script to create plots. Coding the scripts took a couple months due to many errors and testing. The important python packages we used in our code was called "matplotlib" where it helped create the different plots and "numpy", where it organized the data

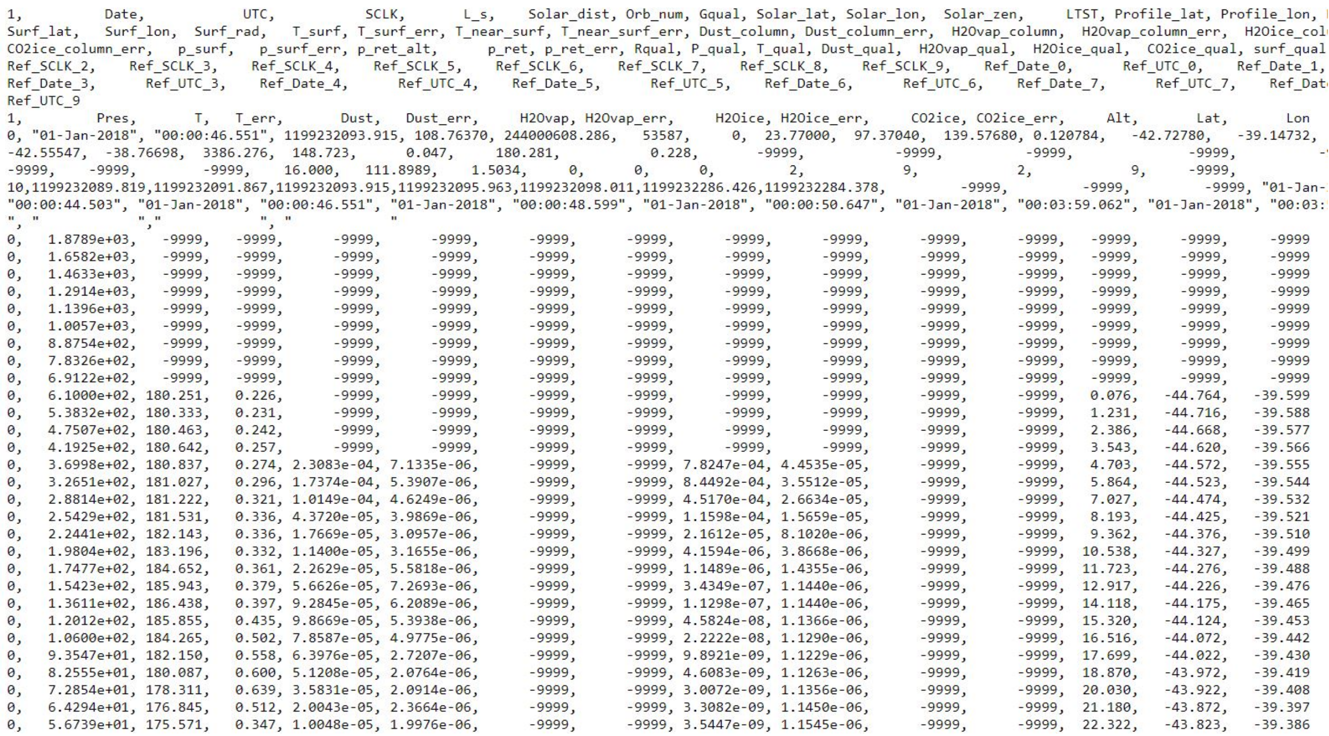


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Figure 4. Image of a tiny sample of the raw and direct data from MCS file obtained from MRO spacecraft.

into arrays. Dr. Yelle and I both tried to write many different commands to convert the files. Even though it took a couple of months, we managed to get Spyder to read the profiles.

During the coding process, there were two different plots we wanted to create for the MCS sample data. The first was being able to create two plots for each profile, meaning in total, there would be 716 plots total. The purpose of doing this is to be able to identify patterns across each profile. Each data set already contains the values we needed for temperature (in Kelvins), dust (in Km^{-1}), and pressure (in Pascals). Again, each profile needed two plots: one plots measuring Temperature V.S. Pressure while the other Dust V.S. Pressure. However, I just started with one profile (one .CSV file) for now because I needed to code the right formatting of the plots. Figure 5 illustrates the two plots we would need for each profile, including an annotation about the location and time the data was taken.

The whole point of plotting these two measurements was to observe the temperature and how much dust there was at a certain pressure in Mars's atmosphere. As long as we were able to plots one profile, we were able to code the script where it can loop through the rest of the 358 profiles and put all 716 plots into a PDF file. Refer to figure 6 for an easier interpretation.

After creating 716 plots, we skimmed through them to find a correlation between temperature and dust in each pair of plots. We mainly saw an odd curve or shape when the pressure was about 100 Pa. Interpolation is a mathematical term for when we want to estimate a value within the range of a discrete set of known data points. I was able to successfully program python to calculate the interpolation for all 716 plots. We also added a feature on all 716 plots where it would pinpoint the location of our data points. This is for tracing our line of evidence and giving proof of where our points came from. Figure 7 shows the plots with the red intersection lines.

The next step in our plotting session was to take all the interpolation points and graphing "Temperature V.S. Dust". However, figure 8 indicates that there is no correlation between the two axis.

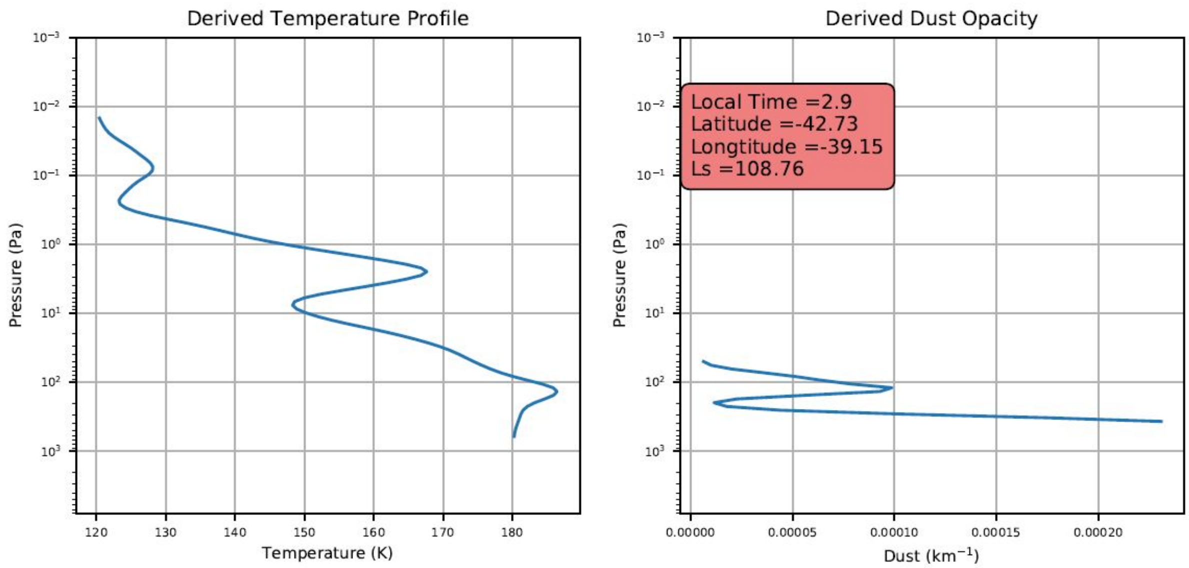

Figure 5. These 2 plots are one pair sample profiles out of the 716 plots.

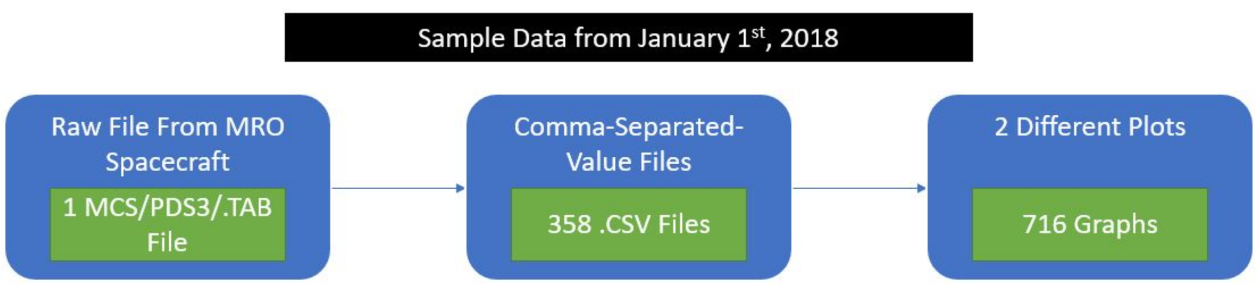

Figure 6. Flow Chart of converting one file to another. The sample data from January 1st is used as an example.

We then looked at more interpolation points aside from 100 Pa. We created more graphs of "Temperature V.S. Dust" for the interpolation at 10, 30, 50, 70, and 100 Pa. I also tried it at 1000 Pa but it resulted in fewer data points. We concluded that this particular data did not have the critical information we were looking for. The main two interpolation points we are going to look at is at 100 Pa and 10 Pa.

In addition to the two graphs, we wanted to compare what happens to one particular area and time during a global dust storm. Therefore, we created two graphs at 100 Pa: The global dust storm that happens all around mars and the global dust storm that happens at the southern hemisphere during the day time. The dust storms are most active during the day. The southern hemisphere was a focused location because most global dust storms start from there and it is where evidence of water lies. Analyzing the southern hemisphere will give us some information on the composition of the atmosphere in that particular location and time. Daytime was set from 7 am to 5 pm. The southern hemisphere was set with the latitude between -60 to 60 degrees. We did not create two graphs at 10 Pa because it seemed that most of the time,

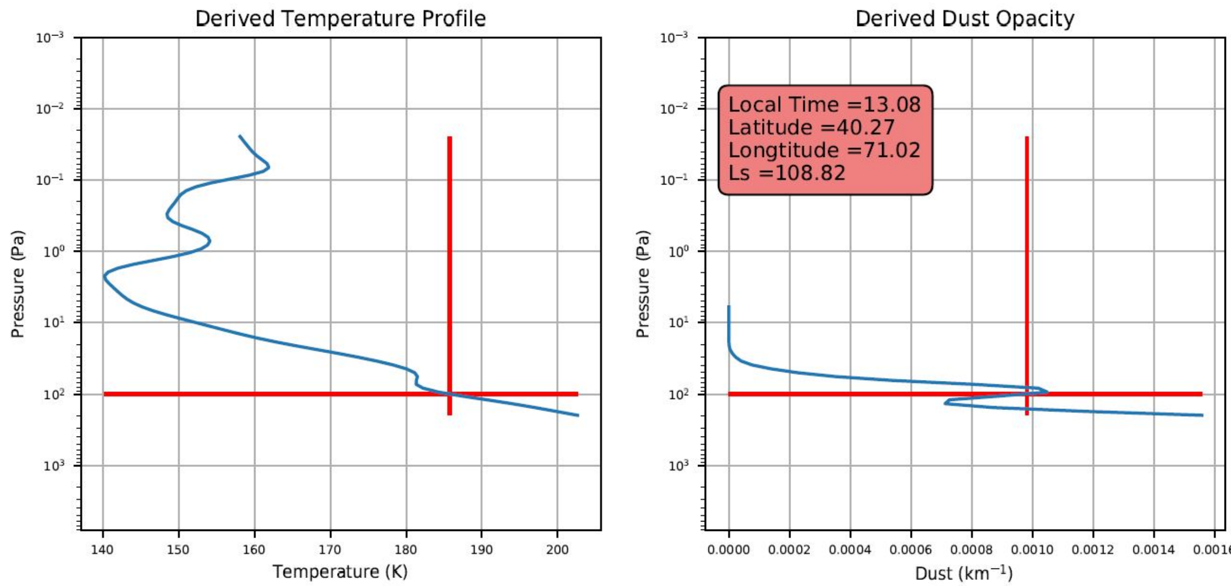

Figure 7. These 2 plots are one pair sample profiles out of the 716 plots.The red intersection lines indicate where we got our points for the Temperature V.S. Dust graph.

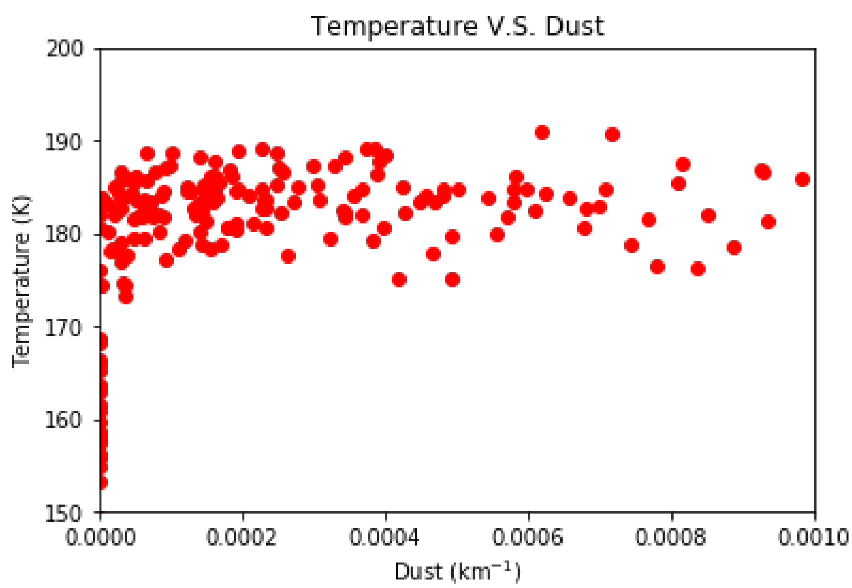

Figure 8. "Temperature V.S. Dust" Graph at the interpolation of 100 Pa. The graph has approximately 358 points from the 358 .CSV files. Result: No correlation. The "slope" is flat.

there was not a lot of dust that was there. Each graph takes at least 2 minutes to produce and therefore takes about 6 minutes in total.

After creating the code, the final step is getting all the files from June and repeating the same steps for each file. June was chosen as it was the critical time period for the 2018 global dust storm. Each MRO folder has specified a day with 6 files, each representing 6 different time periods during the day. Each of the 6 files contains data for 2 orbits. Therefore, indicating that the MRO spacecraft orbits around Mars 12 times a day. For example, all 716 plots were from January 1st, 2018 for the first two orbits. We were able to have access to all the data files from June. However, there are 30 days of June we have to look at. Remember, each day has 6 files (6 different time periods). (30 days x 6 files = 180 more files). Furthermore, there would be 180 files to look at with 3 significant graphs to look for each. In total, there would be an end result of 540 graphs I would have to analyze. Refer to figure 9 for an easier interpretation.

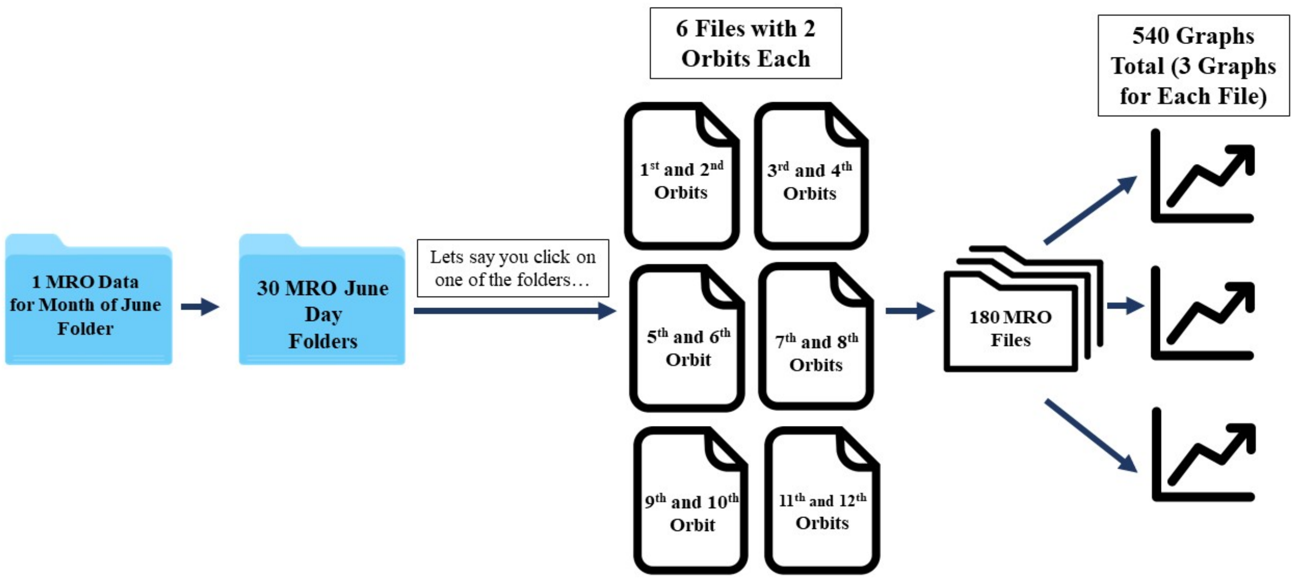

Figure 9. Diagram of calculating how many MRO data files we are going to graph.

Finally, there was another feature we wanted to add where we could distinguish the time the data was taken: daytime and nighttime. Therefore, we created some graphs where it would demonstrate the difference between the data taken during the day and the data during the night.

We ran into some errors along the way. Some files were corrupted due to not being able to find any data, causing the program to become confused and result in an error. However, most of them were an easy fix.

Results

After 150 hours of reading the 180 files of June, we chose a SAMPLE atmospheric collection of the data at an atmospheric pressure of 100 Pa. There is a change in correlation from June 1st, 2018 to June 15th, 2018. It was really interesting how a positive correlation formed as you went from June 1st to the 15th (figure 10) There's a positive slope starting to form from day one. However, the correlation started becoming scattered after the 18th (figure11). One conclusion is that it could be that the dust storm is slowly dying down causing the atmosphere to encounter odd results. On average, the highest temperature the dust can reach when when it is at 100 Pa is 240 K while the lowest average temperature is 140 Pa.

Another finding is the sample atmospheric collection of the data at an atmospheric pressure of 10 Pa. It starts off scattered starting day 1 (figure 12) but then starts to form a particular shape after the 18th day (figure 13). The temperature starts to rise as the dust increases but then becomes flat as it reached a certain limit. The highest average temperature at 10 Pa is around 220-240 K while the lowest average temperature is 140 Pa.

The local time graphs (figure 14)were random sample data from June in order to illustrate the daytime and nighttime of the graphs. The blue triangles demonstrate that the data was taken during the day while the red dots demonstrate that the data was taken at night. There really is not much a difference but on average temperature. However, after closer inspection, it seems that nighttime has a lower average temperature.

Finally, the graph with the specific location and time is demonstrated in figure 15. The graph shown below is a sample of a June data but most are similar in pattern. We predicted that the temperature would be highest and the dust would be most active when it is located in the southern hemisphere and during the daytime. Our prediction seems accurate.

Discussion

Based on our analysis, it seems that when a global dust storm occurs, the maximum average temperature of Mars's atmosphere goes up. The sample data from January 1st, 2018 is an example of when a global dust storm is not occurring. The average maximum temperature for a regular day at Mars is around 190 K (figure 8). However, the extreme 20-50 K difference demonstrates that normal dust storms causes temperatures to rise even further. Approximately after June 9th, the temperature rose up to 240 K, indicating the intense rise in temperature when a global dust storm occurs. In addition, it seems that there is a limit to which the temperature can rise.

According to the local time graphs, the average temperature for nighttime is slightly lower than average temperature for daytime. The reason that there is only a small difference in the average temperature for both times is because when a global dust storm occurs, the atmosphere is able to retain enough heat to keep from cooling significantly at night.

The graphs where we pinpointed the southern hemisphere and during the daytime reveals that dust storms are possibility most active there since the maximum temperature is around 240 K, indicating that even though there isn't much difference in terms of time, there seems to be specific locations for which dust storms start. In the southern hemisphere, there are more craters and one of the biggest craters there is Hella Planita[9].

In relation to Mars's past, this type of evidence can indicate the possibility that the majority of the planet is completely dry. On earth, one of the main causes for dust storms to stop occurring is when it reaches a wet area such as a lake, river, etc. it is rare however due to dust storms arising when a gust front or other strong wind blows loose sand and dirt from a dry surface and therefore no wetland is nearby. Dust storms only occur for a short amount of time compared to Mars in certain areas since earth is 71% approximately covered in water. If there are global dust storm on Mars, it indicates how there is almost no water on the surface. However, this doesn't prove that water doesn't exist beneath the surface.

In relation to Mars's future projects, engineers wouldn't need to worry too much about the speed of the dust themselves because it is very low. One of MRO's mission is to analyze the surface of Mars from orbit and with scientific study, determine which geographical area is safe or hazardous for humans to land in the future. Since we see that global dust storms tend to occur in very low areas such as craters and in the southern hemisphere, it is most likely a good idea to avoid creating a Mars base or habitat in or close to those areas. However, since there seems to be a pattern that global dust storms happen every decade, engineers should prepare future machinery for colonization to sustain the rise in temperature when they occur. The global dust storm also pointed out a lesson that future rovers should be made to survive these severe dust storms. When rover Opportunity was shut down due to the dust particles covering the solar operations of the robot, it was no longer functioning properly.That's why future rovers are running based on other types of energy options rather than just solar power. These dust particles are significantly small, indicating that engineers and scientists in the future should make sure the machines are compatible to not have dust interfere with Mars's machinery. Of course, other conditions in relation to having a habitable Mars base is to have a breathable environment due to the intense amount of carbon dioxide and radiation in the atmosphere.

Conclusion

The 2018 summer global dust stormed that occurred on Mars is one of the most studied event for Mars. Data collected during that time period was used widely by scientists around the world in order to find out more about the properties of Mars, leading evidence to its past and preparation for its future colonization. This project was focused on finding out the properties of its atmosphere by finding the relationship between dust and temperature from the MRO spacecraft. The findings resulted that global dust storms can possibly cause a rise in the atmosphere's temperature no matter the location or time. To be more specific, it seems that dust storms are more active in Mars's southern hemisphere and during the day, resulting in temperatures to be highest in that particular location and time. Moreover, even though average temperatures during the night are slightly lower compared to the day, the atmosphere doesn't let the heat escape from the atmosphere. Therefore, allowing temperatures to remain the same throughout the night.

The main limitation for this research was time. The other possible goal was to study its upper atmosphere with data from MAVEN. However, due to time constraints, data files from Mars Atmosphere and Volatile EvolutioN (MAVEN) will not be analyzed at the time. However, for future research suggestions, analyzing the data from MAVEN will help us examine if the relationship between dust and temperature is the same at a different atmospheric pressure. MAVEN was developed by NASA to study the Martian atmosphere while orbiting Mars.

"Temperature V.S. Dust" Graphs at Interpolation 100 Pa

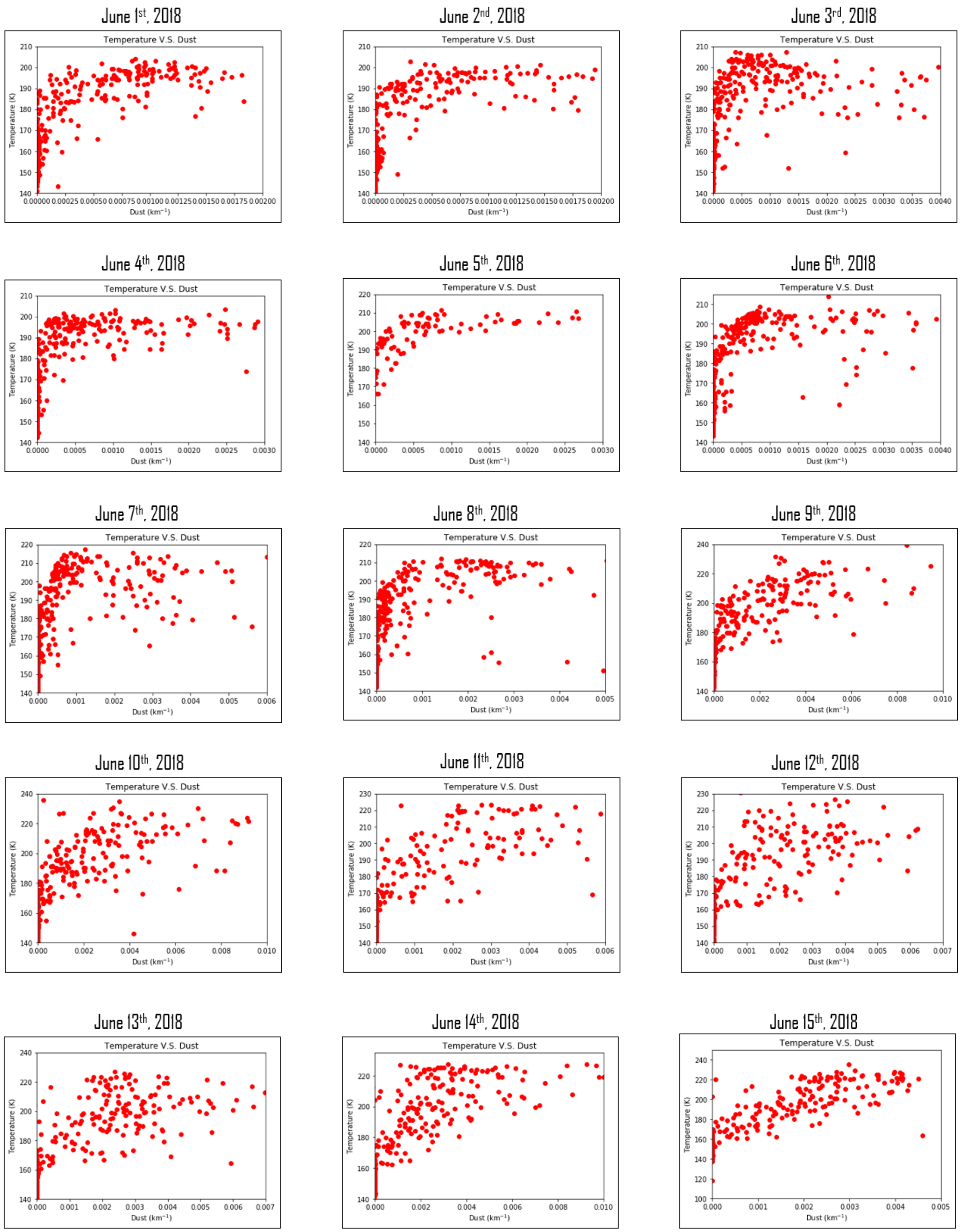

Figure 10. Sample set of "Temperature V.S. Dust" Graphs at Interpolation 100 Pa from June 1st to 15th.

"Temperature V.S. Dust" Graphs at Interpolation 100 Pa

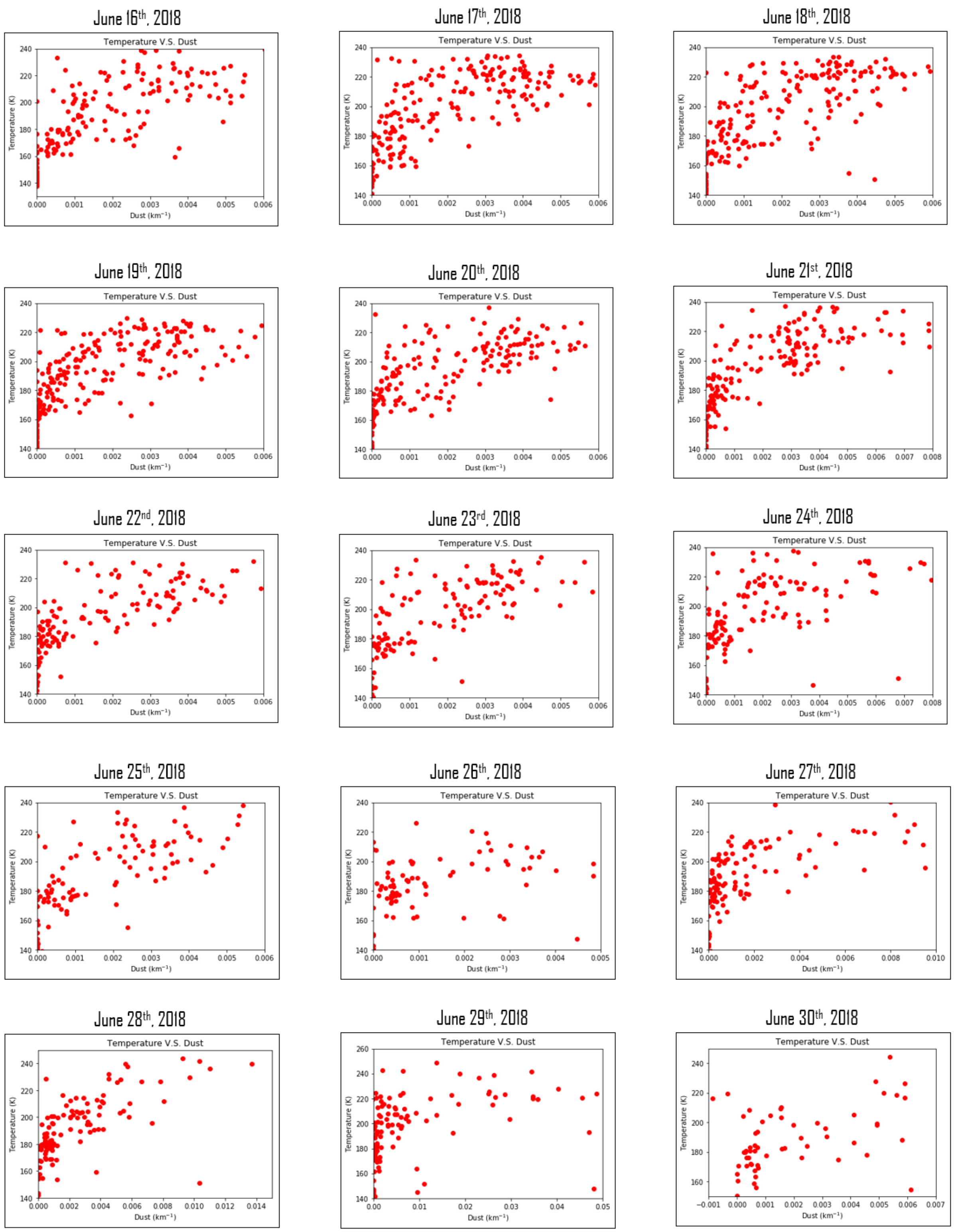

Figure 11. Sample set of "Temperature V.S. Dust" Graphs at Interpolation 100 Pa from June 16th to 30th.

"Temperature V.S. Dust" Graphs at Interpolation 10 Pa

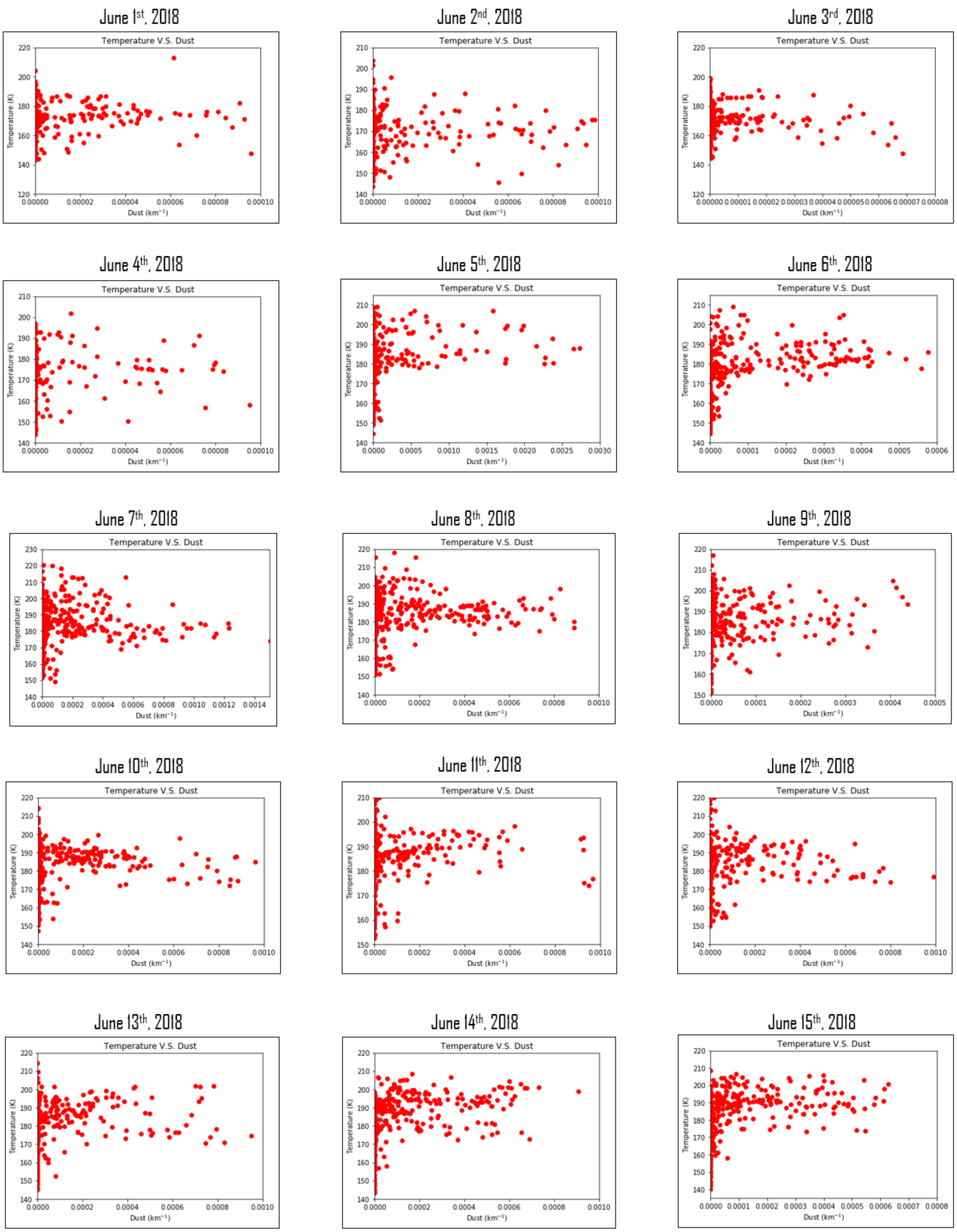

Figure 12. sample set of "Temperature V.S. Dust" Graphs at Interpolation 10 Pa from June 1st to 15th.

"Temperature V.S. Dust" Graphs at Interpolation 10 Pa

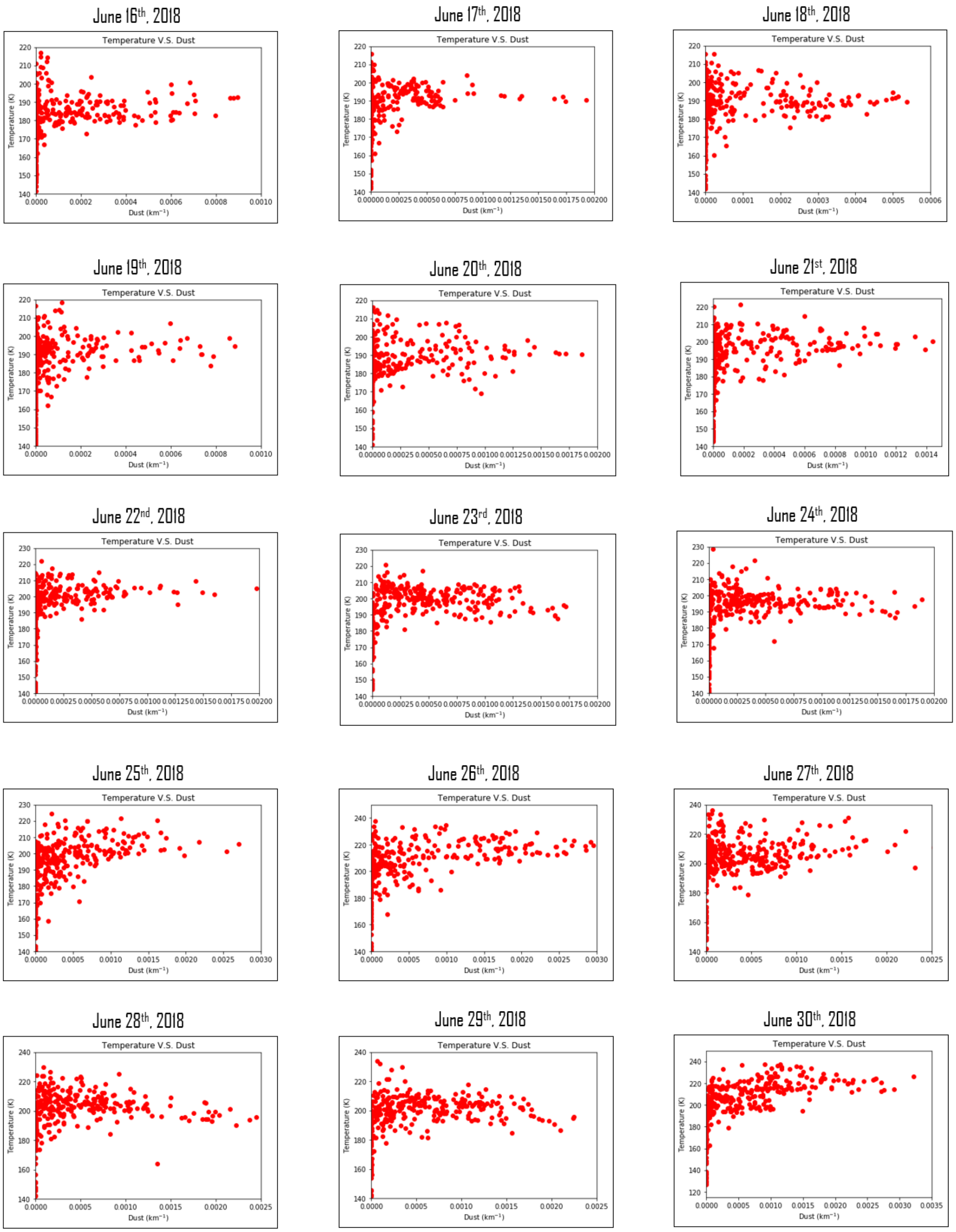

Figure 13. Sample set of "Temperature V.S. Dust" Graphs at Interpolation 10 Pa from June 16th to 30th.

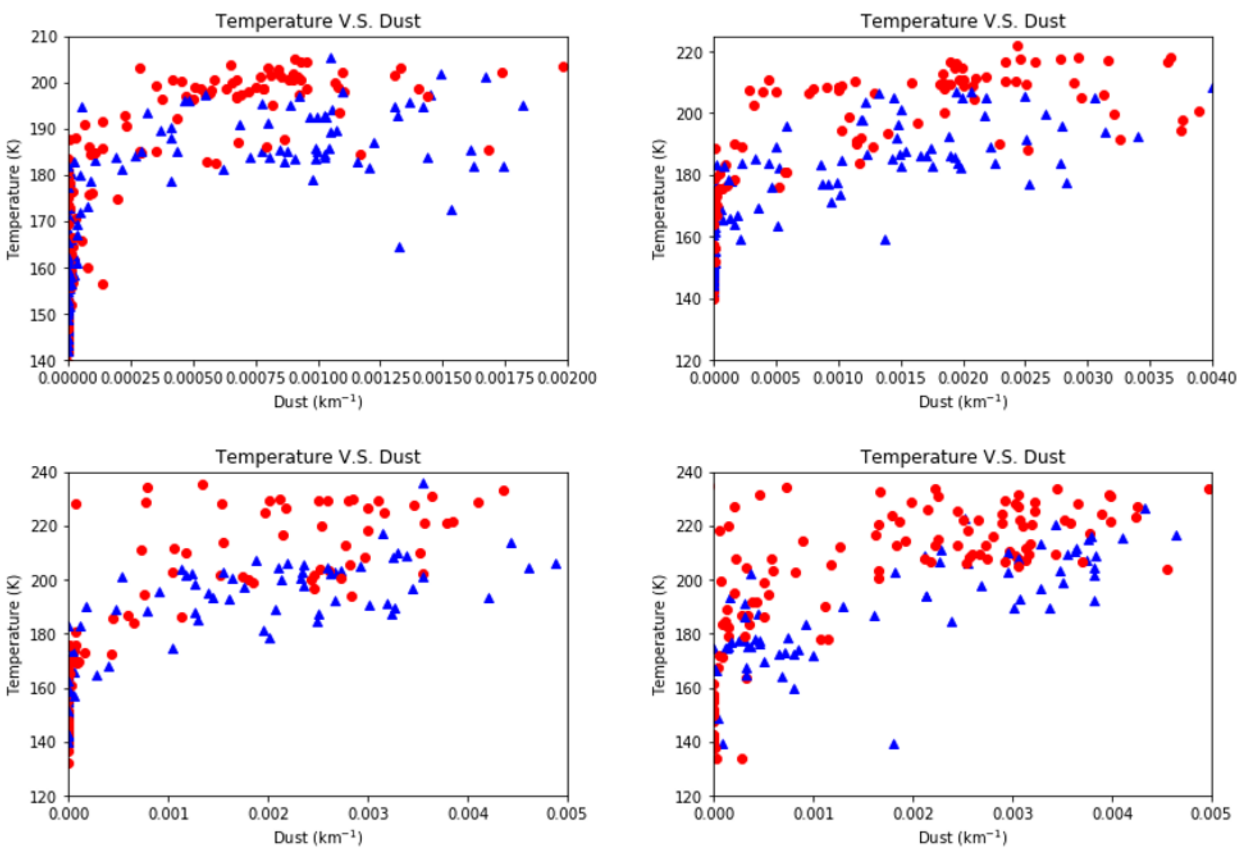

Figure 14. SAMPLE set of graphs illustrating the difference between daytime and nighttime of when the data was taken.

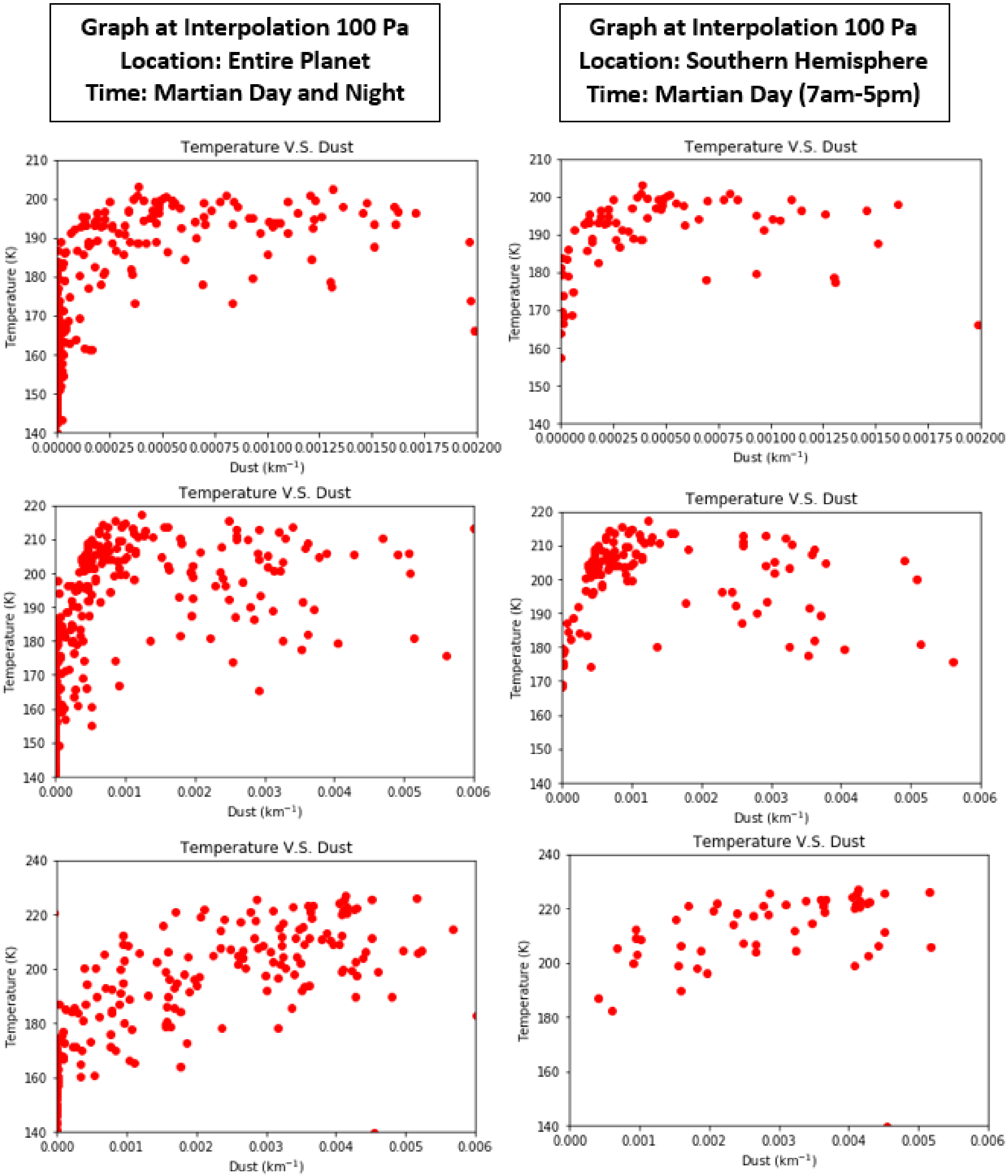

Figure 15. Left column shows the graphs at interpolation 100 Pa of the entire planet and all day and night. Right column shows the graphs at interpolation 100 Pa of only Mars's southern hemisphere and during the daytime only. The average temperature seems higher in general when it is located specifically at the southern hemisphere and during the daytime.

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