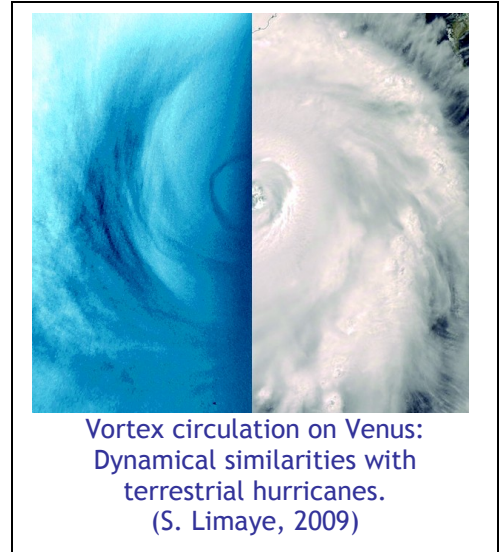# Exploring Venus: Why measure winds?

Introduction

This planetary science student research module serves as an introduction to planetary atmospheres and weather with the use observation and modeling skills. In simpler terms, this refers to the task of predicting weather or climate. On Earth, particularly in mid latitudes, weather is highly variable and we rely on weather forecasts. Lately, we have grown accustomed to weather forecasting far into the future, i.e. future climates.

What is weather and what is the difference between weather and climate? What makes weather or climate predictable? How can we predict weather or climate? What observations do we need or can we make on Earth and other planets to improve our understanding of weather? What instruments do we need? Why study weather on planets other than the Earth? As one can see, there are numerous questions that can be explored. The individual student researcher like you can investigate those questions based on your unique interests and needs.

Vortex circulation on Venus: Dynamical similarities with terrestrial hurricanes. (S. Limaye, 2009)
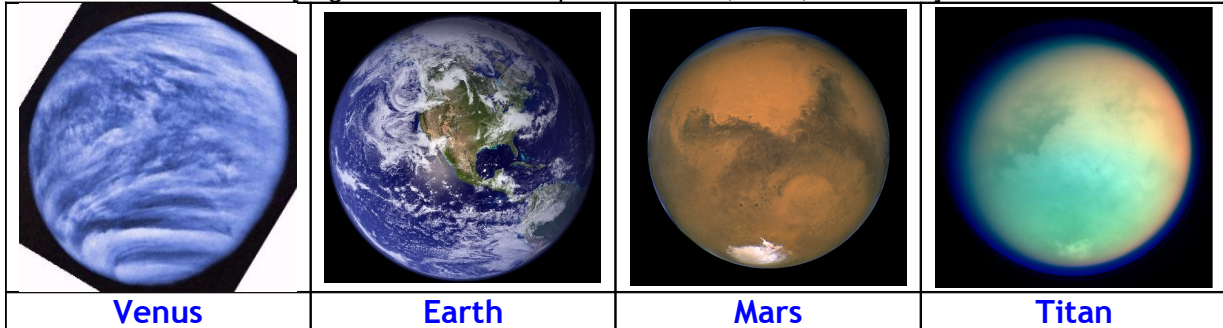
In Physics, experiments are an integral part of scientists' approach to understanding our physical world. When it comes to weather, experiments, (especially controlled) on a planet-wide is a monumental task. In the last few centuries, along with natural changes, human activity has introduced unprecedented changes in the surface and atmosphere of the Earth, which could be considered an uncontrolled experiment on a global scale. **Planets with atmospheres, particularly in our solar system provide us with a natural comparative laboratory with a different set of conditions.** Thus, if we apply the same theory and models to other atmospheres, in effect we have a controlled experiment to study weather and climate under differing conditions.

The dawn of the age of space exploration has given us the ability to explore planets other than our own and observe their atmospheres. We can now monitor the weather on our immediate neighbors on a daily basis. Currently, there are many orbiters and landers observing Mars with more missions planned in the near future. The European Space Agency's Venus Express is the only ongoing mission orbiting Venus at the present. What are the similarities in the observations of the weather on these two planets when compared to the Earth? What are the differences? The similarities can be observed when the same instruments and data gathering techniques are used to observe the atmospheres of different planets. The differences come from the practical challenges of deploying instruments on the surface or in the atmosphere (balloons, aircraft, and instrumented towers) to collect meaningful observations for comparison.

The module emphasizes some basic concepts employed by scientists every day and then focuses on the measurement of cloud motions as proxy for atmospheric winds which are needed in understanding the weather on the planets. On Earth, the knowledge of global winds is crucial in our ability to forecast weather by using them in numerical models. <u>Winds are key in the transport of heat (energy), trace constituents (water vapor), and momentum, all critical ingredients for weather on any planet.</u>

Venus Compared to Earth, Mars, and Titan

[Figure 1. Venus Compared to Earth, Mars, and Titan]

| Venus | Earth | Mars | Titan |

[Table 1. Some Physical Properties of Venus, Earth and Mars]

Property	Venus	Earth	Mars	Titan
Size				
Radius at equator (km)	6052	6378	3394	2576
Radius at the pole (km)	6052	6356	3375	2576
Mass (compared to Earth)	0.814	1	0.107	0.0225
Gravity (compared to Earth	0.902	1	0.377	0.138
Orbit				
Tilt of rotation axis to orbit plane	177°	23.5°	25.19° (ranged between ~20° – 45° in its history!)	0°
Length of the year (days)	224.7	365.25	687	29.65 years (Sun)
Length of day (w.r.t. stars)	243.16	23h 56m	24h 37m 22s	15.85 days
Length of day (w.r.t. Sun)	116.7	24 h	24h 39m 35s	
Atmosphere				
Surface Pressure (bars)	90	1.013	~0.01	1.5
Average Temperature (°C)	473	27	-30	-160
Typical difference between day and night side (°C)	0 at the surface ~20 at cloud top	~20	~100	?
Typical difference between equator and pole (°C)	<10 up to 70 km (?)	~60	~80	?
Cloud Cover	100%	~50%	~10% (?)	100%
Oceans	None	75 % surface	None at present	Methane Lakes on surface, possible water ocean underneath the surface

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Earth and Venus represent two very different worlds: one is very hospitable for life; the other presents an extremely hostile and inhospitable environment for life as we know it. If Earth and Venus formed from the same solar nebula in the same general neighborhood of the Sun and are similar in size, how or why did they evolve to their very different present states? The table below compares some basic physical characteristics of the planets with highlighting of key differences.

While Mars and Earth are very similar in tilt of the rotation axis and the length of the day, Venus and Titan, a moon of Saturn with an atmosphere thicker than Earth's share not only a slow rotation rate, but also relatively fast winds at the equator (compared with the speed of the surface due to rotation). Both Earth and Titan have presence of liquids on the surface – Methane lakes on Titan and oceans and lakes of water on Earth.

[Table 2. Atmospheric Processes on Venus, Earth and Mars]

| Property / Phenomenon / Process	Venus	Earth	Mars
Airglow	Yes	Yes	Yes (?)
Aurora	No	Yes	No
Clouds	Global cover of 75% Sulfuric acid, 1 micron radius cloud droplets and overlaid by a haze of smaller particles	~ 50% cover at multiple levels. Water droplets and ice crystals, dust	Global cloud cover variable and at most ~10%. Frozen carbon dioxide, water ice, dust)
Intrinsic Magnetic Field	No	Yes	Very weak
Lightning	Some evidence	Yes	
Oceans/Lakes	No	Yes	None at present, likely in its ancient past
Plate Tectonics	No	Yes	Low probability
Precipitation	No	Yes	Possible, but not observed – atmosphere freezes out
Seasons	Not significant	Yes	Yes, both due to inclination of the rotation orbit and influenced somewhat by the orbit eccentricity
Water (underground)	Not likely	Yes	Possible
Volcanoes (Active)	?	Yes	Low probability
Weather	Large hemispheric vortex centered over each pole.	Cyclones, thunderstorms, rain, snow	Cyclones, dust devils, some precipitation (carbon dioxide and water ice/snow)
Winds (surface)	~ 1 m/s	~ 2 m/s	~ 5 m/s

Although evidence suggests the presence of liquid water on the surface of Venus in the past, at present the surface is dry, like present day Mars. The loss of the surface water is believed to have played a role in the warming of the surface and the lower atmosphere through the "greenhouse effect" which is also what makes the Earth have a comfortable climate at most latitudes. The amount of carbon dioxide and the thick layer contribute to the trapping of heat emitted by the hot surface and the lower atmosphere in the near infrared region of the spectrum. However, there are a few wavelengths where the radiation from the lower atmosphere and surface can escape to space without absorption, but scattered by the atmosphere. Mars (due to Carbon Dioxide) and Titan (Methane) are also warmed a little by the greenhouse effect, but not as strongly as Venus. Besides the greenhouse effect, the four atmosphere bearing bodies in our solar system exhibit many of the same atmospheric processes (Table 2) through similar mechanisms.

Unsolved Venus Mysteries

[Science content retrieved from ESA's Venus Express website: http://www.esa.int/esaMI/Venus_Express/SEMFPY808BE_0.html]

Greenhouse effect, clouds and winds

On the global scale, Venus's climate is strongly driven by the most powerful greenhouse effect found in the Solar System. The greenhouse agents sustaining it are water vapour, carbon dioxide and sulphuric acid aerosols. About 80% of the incoming solar radiation is reflected back to space by the cloud layer, about 10% is absorbed by the atmosphere and only 10% manages to get through it and heat the surface. However, the thermal radiation emitted by the surface gets trapped by the same atmosphere. The result is an amazing 500 °C difference between the surface and cloud-top temperatures.

Greenhouse effect on Venus
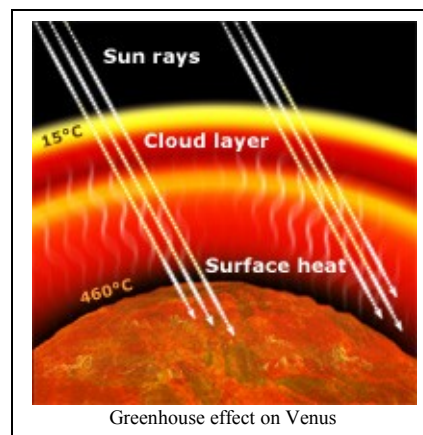
Are there other gases sustaining such an efficient planetary greenhouse? How is the heat transported from the surface to the cloud layer: through radiation or dynamic mechanisms such as turbulence?

Mysterious ultraviolet markings on the clouds

Looking at Venus's thick cloud layer in visible wavelengths would not reveal much. However, by looking at the clouds in other wavelengths, like infrared and ultraviolet light, a very different world appears. The clouds on Venus are very inhomogeneous in all directions. This is possibly due the formation of enormous cumulus-type clouds. Furthermore, the upper clouds are marked by areas visible in the ultraviolet light that mysteriously absorb half of the whole solar energy received by the planet.

What is the origin of these ultraviolet markings? What makes their absorption power so high?

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<u>Hurricane winds and huge atmospheric vortexes</u>

The lower atmosphere of Venus has a dramatic and peculiar behavior. At the level of the cloud tops, the atmosphere rotates at a formidable velocity, with wind speeds up to 360 kilometers per hour. The speed of the winds then progressively decreases to almost zero at the planet surface, where it becomes a gentle breeze, only able to raise dust.

What mechanisms cause this 'zonal super-rotation'?

Furthermore, two enormous vortices, with very complex shapes and behaviors, rotate vertically over the poles, recycling the atmosphere downwards. The vortex at the North Pole, the only one previously observed in some detail, has a peculiar double 'eye' shape, surrounded by a collar of cool air. It completes a full rotation in only three Earth days.

How are the super-rotation and the polar vortices linked? How does the global atmospheric circulation on Venus work?

No model is able to simulate so far the dynamics of the atmosphere of Venus as too few data are available. [End of retrieved content]

How do we observe weather (atmospheric conditions) on planets?

Before the space age, weather observations were made at the surface of the Earth (thus, no observations over the oceans!) and by balloons launched from surface stations. Over the years these were supplemented with observations from passenger and cargo ships and airplanes. Today, we use weather satellites to measure temperatures, water vapor in the atmosphere and winds.

Winds in any atmosphere are caused by differences in horizontal distribution of pressure and thus knowledge of winds over the globe can be used to obtain basic information needed for determining the atmospheric state at the time of the measurement of winds. This, along with other measurements, such as temperature and moisture content at different vertical levels and at several horizontal locations provides the basis for numerical simulation of the "weather" through the use of physics based equations based on the laws of motion and thermodynamics. This is the basis for weather modeling and prediction.

On Earth, measurements of winds is now made possible globally through tracking of clouds from satellite images to supplement the surface measurements and those obtained by tracking balloons launched twice a day from approximately 1500 stations around the world, of which about 70 are launched within the US. On Venus and other planets with atmospheres, cloud tracking provides us with the only practical means of obtaining the winds on a global basis. Table 3 indicates the satellites which are being used to obtain cloud motions on Venus, Earth and Mars. On Earth, cloud motions have been observed to be good indicators of the ambient wind. On Venus, scientists have similarly compared cloud motions with actual winds (measured by drift of balloons and entry probes) and also found them to be in good agreement.

Much of the weather prediction on Earth relies on daily wind observations made around the world. The weather models have been adapted for use on other planets as well, and we are beginning to explore how well we can understand the "weather" on other planets by examining how close to the actual conditions the simulated results can be.

[Table 3. Weather satellites around planets]

Orbit	Venus	Earth	Mars
Polar *(Both Weather and Satellite Move!)*	Venus Express (European Space Agency mission operating since April 2006)	NOAA-14 NOAA-15 NOAA-16 AQUA (NASA) Terra (NASA) DMSP	Mars Odyssey Mars Surveyor Mars Reconnaissance Orbiter Mars Express --- past --- ⇓⇓ ⇓⇓ Mars Global Surveyor
Equatorial (synchronous) ("Weather moves but the satellite doesn't" - *Verner E. Suomi*)	None	GOES-East GOES-West MSG (Meteosat-8) Meteosat -7 INSAT 3A (India) Kalpana-1 (India) MTSAT (Japan) FY-2C (China)	None

One Step at a time

This student research project module and included activities enable exploration of the same process used by our scientists to learn more about the atmospheric conditions of Venus. You as student researchers will become members of our Venus Express Science Team by using the mission's data to conduct you own investigation, learn key concepts and develop the critical thinking skills essential for scientific discovery.

As we learn more about Venus, many aspects appear different when compared to Earth. Some are easy to understand, but others are not so simple. For example, why do the winds blow in only one general direction every where in the atmosphere that we have measured? If the planet rotates slowly, why are the winds not blowing from day side to night side? We now know this day-night circulation does occur on Venus, but at very high altitudes where the atmosphere is very thin. By launching more sophisticated missions to observe Venus, scientists are currently trying to find answers to the major questions that remain to be answered about Venus. Some of those relevant to the atmosphere are:

- Why is the day so long?
- Why does it rotate backwards (or why is it turned upside down?)
- Why are the winds so fast?
- Why is it so hot?
- Why are the poles not so cold even if little sunlight shines there?

You, as a student researcher, can begin to answer these important questions by learning about the winds on Venus.

- *Is there weather on planets?*
- *What drives weather on planets?*
- *How do we observe weather on planets?*
- *Can we predict weather?*
- *How do we predict weather?*
- *What can observing weather on other planets tell us?*

Things to keep in mind:

What controls weather?
- Physical characteristics of the planet - atmosphere, rotation rate
- External Energy Input - size and shape of orbit
- Internal Energy Input

Observational data (information) on current weather
- Clouds – amount, type, and where (*horizontal and vertical*)
- Winds – how fast, which direction, where (*horizontal and vertical*)
- Temperature – how hot or cold and where?
- Precipitation – what kind, how much, where?
- Lightning – how often and where?
- Phenological observations. (*e.g. times when buds appear, freeze/thaw dates of lakes*)

Indicators of Past Climate
- Wind streaks, dunes
- Signatures of Floods
- Tree Rings, core samples – soil and ice
- Lake freezing and thawing dates

Good luck and enjoy !

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