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NEWS & VIEWS

VENUS

Express dispatches

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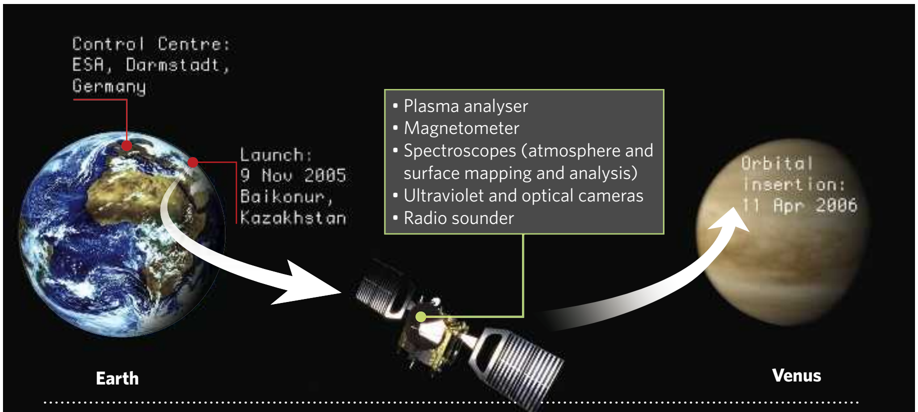
The Venus Express mission has returned its first findings on the harsh atmosphere of our sister planet. It's another step towards explaining how Venus turned out so differently from our balmy home.

Venus is the planet closest to Earth not just in distance, but also in mass, radius, density and chemical composition (Fig. 1). Yet where Earth's benign climate has fostered life, Venus is a hellish place — its surface hot and dry, its crushing atmosphere made up of carbon dioxide permeated by clouds of sulphuric acid. How did it all go wrong?

The European Space Agency's Venus Express probe was launched in November 2005 to address some big issues associated with this question. Where is Venus's water, and what is its history? What is the weather like on Venus, and is it different from that on Earth? What does the precise composition of Venus's atmosphere tell us about its evolution? The first results from Venus Express are presented in eight papers elsewhere in this issue[1–8].

We start with water. The most abundant volatile compound on Earth (where the oceans are 300 times more massive than the atmosphere), water is present only in tiny amounts on Venus, all of it in the atmosphere — about 200 parts per million, either as vapour or dissolved in its sulphuric-acid clouds. There are no oceans: Venus's surface temperature of about 730 kelvin (457 °C) means that water could not exist as a liquid there, even if it were abundant. Two other signature substances, nitrogen and CO_2, are present in about the same amount on both planets. The latter admittedly appears in different places: on Venus, it makes up 96.5% of the massive atmosphere, where it creates a surface pressure some 92 times that of Earth's; on Earth, it turns up in the extensive limestone deposits that precipitated from CO_2 dissolved in the water of the oceans.

Because Venus is close to Earth in so many ways, it seems likely that the two planets started out similarly. Venus must once have had an ocean's worth of water, but lost it somehow. Water vapour is a heat-trapping greenhouse gas, whose atmospheric abundance is controlled by evaporation from the oceans. If Earth were to move closer to the Sun, the temperature of its oceans would rise and more water would evaporate, increasing the temperature still further. At a certain point it would become a runaway greenhouse, with the oceans boiled off and all the water residing in the atmosphere[9].



Earth		Venus
149.6	Distance from Sun (10^6 km)	108.2
365 days	Orbital period	225 days
6,371	Mean radius (km)	6,051
5.98	Mass (10^{24} kg)	4.87
5,515	Mean density (kg m^{-3})	5,245
2.2	Rock–metal mass ratio	3.0
0.55	Radius of core–mantle boundary (% of radius)	~0.45
23 h 56 min	Rotation period (with respect to the stars)	243 days
24 h	Mean solar day	117 days

IMAGES: ESA

Figure 1 | Voyage to Venus — the essential facts and figures of the European Space Agency's Venus Express mission.

This could well have been what happened on Venus. The planet might have started out in its present orbit with a massive atmosphere made of water vapour, which sunlight then split into hydrogen and oxygen. Hydrogen, being lighter, escaped into space, whereas the heavier oxygen hung around and oxidized the crust to create the planet's hot, dry surface. Conventional hydrogen is lost faster than its heavier isotope deuterium, and evidence for this huge loss of water comes from the high ratio of deuterium to hydrogen on Venus, which is 100–150 times the value on Earth. The first measurement of this ratio[10] was based on droplets of sulphuric acid that clogged the inlet leak of the mass spectrometer aboard NASA's Pioneer mission to Venus, launched in 1978. Instruments on Venus Express have now confirmed and refined the high value[1].

The escape mechanism operating today probably involves the solar wind — the stream of charged particles emanating from the Sun — which strips atoms and ions out of the atmosphere. But the details are contradictory. Venus has no appreciable internal magnetic field, so the solar wind is deflected by magnetic fields induced in the planet's atmosphere. But whereas results from Venus Express's magnetometer indicate[2] that the solar wind does not enter the atmosphere, and so cannot affect its evolution, the mission's plasma analyser shows[3] that positively charged hydrogen and oxygen ions are escaping in the planet's wake at higher rates than are neutral atoms. The net result is that hydrogen and oxygen are being lost in the same 2:1 proportions as they are found in the water molecule[3]. The absolute rates still have to be worked out; as far as plotting Venus's

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history is concerned, the escape mechanism could well have been different in the past, when water was much more abundant on the planet.

The extreme weather found in Venus's remaining CO_2-dominated atmosphere offers us several contrasts with Earth. The greater mass of Venus's atmosphere should store heat and distribute it more effectively than occurs on Earth, and temperature differences should therefore be much smaller. Results from the Pioneer probe[11] were consistent with this idea. Venus Express's programme of radio occultations — in which the spacecraft passes a radio signal tangentially through the atmosphere to measure its temperature — set out to test it further. The surprising result[4] is that the day–night temperature difference is large — between 30 and 40 K at the altitude range 55–60 km, within Venus's clouds (Fig. 2). Heat stored from sunlight is not enough to raise the temperature by this amount during the day. Enormous downdrafts might heat the air by compression, but they would have to be swifter than any global-scale downdrafts on Earth. A further possibility is that clouds and gas in the atmosphere partially absorbed the radio signal, inducing an error in the derived temperatures[4].

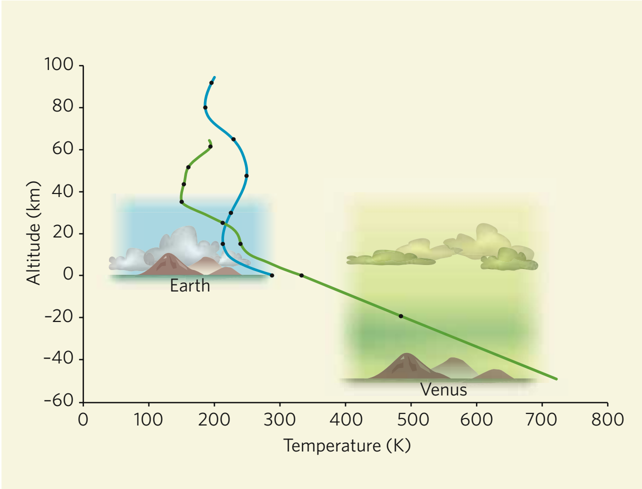

Figure 2 | Ocean of air. Venus's crushing atmosphere is composed of 96.5% carbon dioxide and 3.5% nitrogen; Earth's more clement envelope comprises roughly 79% nitrogen, 20% oxygen and 1% argon (dry air), with significant traces of other gases, chief among them carbon dioxide. (Moist air contains a few per cent of water vapour.) In this comparison of the two atmospheres' vertical structures, the zero of altitude of the temperature profiles (solid lines: blue, Earth; green, Venus) is fixed where the pressure is equal to Earth's sea-level pressure, 1 bar. Black dots on the temperature profiles indicate where the pressure has increased or decreased by a factor of 10; Venus's lower atmosphere extends almost 50 km below the 1 bar level, such that at the surface the pressure is 92 bars. The temperature there averages 730 K, compared with Earth's average surface temperature of around 288 K (15 °C). Relative to the 1-bar level, clouds in both atmospheres — of water on Earth, of sulphuric acid on Venus — occupy roughly the same altitude range, and the lower atmosphere of Venus is relatively cloud-free. The tallest mountains rise 12 km above the average surface level on Venus and 9 km above sea level on Earth.

The higher one goes in Venus's atmosphere, the faster the winds blow, and the smaller the day–night temperature differences become. Wind speeds are measured relative to the solid planet, and Venus is a slow rotator: it spins once relative to the stars every 243 Earth days, and, viewed from a point on the surface, the Sun rises, and sets, every 117 Earth days. (Venus's solar day is considerably shorter because, uniquely in the Solar System, it spins slowly backwards relative to its orbital motion. How it got into this state and how it stays there are unanswered questions[12], although tides raised by the Sun in the massive atmosphere probably have something to do with it.)

At the tops of the clouds, an altitude of nearly 70 km, the wind speeds approach 100 metres per second (360 km h^{-1}) — three times hurricane force and 2.5 times the speed of the jet streams that can help or hinder aeroplane pilots 11 km up in Earth's atmosphere. Venus Express confirmed these high winds by tracking clouds, made visible by an unknown absorber of ultraviolet light, that varied dramatically from day to day[5].

One feature that Venus shares with Earth and many other planets is the presence of large areas of circulating air at its poles, known as polar vortices. Earth's polar vortices appear in the winter of each hemisphere above a core of cold polar air. The polar vortex identified on Venus, by contrast, has a cold collar[4,6], inside which there is a curious, dipole-shaped feature about 10 K warmer than its surroundings. Again, solar heating alone cannot explain this warm dipole. The compressive effect of intense downdrafts is a possible cause: the dipole might be an extension of a 'Hadley circulation', a system consisting of hot air rising at low latitudes and cold air sinking at the poles, with a return flow at deeper levels. On Venus, the equator is warmer than the poles at altitudes above 65 km (ref. 4). What keeps a Hadley circulation going under these circumstances is not so clear[13].

Because the solid planet spins so slowly, Venus's atmosphere creates its own rotation. The direction of rotation is the same as that of the planet — backwards relative to the orbital motion. The influence of the Sun grows with increasing altitude, as the air becomes thinner, and a smaller amount of absorbed energy can produce a larger temperature change. The Sun takes over entirely at altitudes above 90 km, and the circulation shifts from rotation about the polar axis to flow from the day side to the night side. Evidence for this day–night circulation comes from compounds such as nitric oxide, carbon monoxide and oxygen, which are produced on the day side and transported to the night side, and from compounds such as hydrogen fluoride and hydrogen chloride, which are destroyed on the day side and transported as chemical by-products to the night side[1,7].

A final, intriguing point of comparison between the atmospheres of our own planet and Venus concerns lightning: there shouldn't be any on Venus, whose clouds are like terrestrial smog clouds, which do not produce lightning. And indeed, no clear-cut visible flashes were to be seen on either the day or the night side of the planet. Yet Venus Express detected whistlers[8] — low-frequency electromagnetic waves that last for a fraction of a second and are thought to originate with an electrical discharge. Cells of convecting air were seen on the day side[5], but the amount of cloud material in the cells is around 100 times less than that in a terrestrial thunderstorm. On Earth, that would not be enough material to charge the clouds.

The evidence for electrical storms on Venus is thus contradictory. Their existence would be surprising, but perhaps we have simply not thought of all the ways that electricity can be generated in a planetary atmosphere. If our intuition, based on terrestrial experience, is failing us, it wouldn't be for the first time.

Venus Express has enough fuel to last until 2013. As the mission controllers learn what the spacecraft can do, the observation sequences will become more ambitious, and the amount we know about Venus will grow. From 2011, Venus Express will be accompanied by Japan's Planet-C spacecraft, also known as Venus Climate Orbiter. Other future Venus missions might use balloons to measure the winds and sample trace gases and their isotopes, or to grab rocks from the hot surface and take them up to cooler altitudes for analysis. If one day we can follow climate processes on Venus as we follow them on Earth, then we might begin to understand weather in general. ■

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