THE PASCAL MARS SCOUT MISSION.

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Introduction: Except for Earth, Mars is the planet most amenable to surface-based climate studies. Its surface is accessible, and the kind of observations that are needed, such as meteorological measurements from a long-lived global network, are readily achievable. Weather controls the movement of dust, the exchange of water between the surface and atmosphere, and the cycling of CO_2 between the poles. We know there is a weather signal, we know how to measure it, and we know how to interpret it.

Pascal seeks to understand the long-term global behavior of near-surface weather systems on Mars, how they interact with its surface, and, therefore, how they control its climate system. To achieve this, Pascal delivers 18 Science Stations to the surface of the planet that operate for three Mars years (5.6 Earth years). The network has stations operating in the tropics, midlatitudes, and polar regions of both hemispheres. During entry, descent, and landing, each Pascal probe acquires deceleration measurements to determine thermal structure, and descent images to characterize local terrain. On the surface, each Science Station takes daily measurements of pressure, opacity, temperature, wind speed, and water vapor concentration, and monthly panoramic images of the landing environment. These data will characterize the planet's climate system and how atmosphere-surface interactions control it.

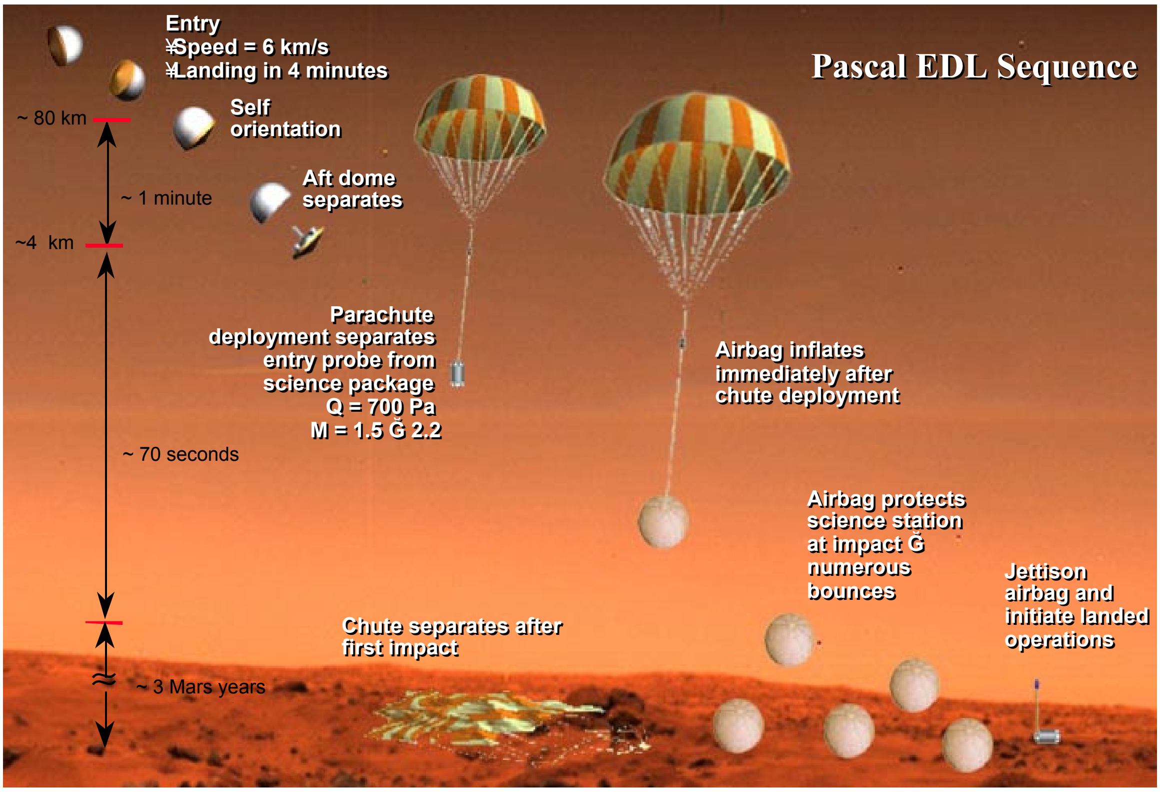

Figure 1. Pascal entry, descent, and landing sequence.

The Pascal mission is named after 17th century French scientist, Blaise Pascal, who pioneered measurements of atmospheric pressure. Pressure is the most critical measurement because it records the "heartbeat" of the planet's general circulation and climate system.

Mission Overview: Pascal launches on a Delta-II Heavy in Sept. 2007 and arrives at Mars in Oct. 2008. A flyby carrier spacecraft (S/C) delivers its 18 self-orienting probes on direct approach using three separate release events, and propulsive time-of-arrival adjustments for global coverage. Entry, descent, and landing for each probe are accomplished using an aeroshell for initial deceleration, a parachute once well into the atmosphere, and an air bag for final impact deceleration. The landed Science Stations then deploy the camera, begin autonomous operations (See Fig. 1).

Each Pascal science station gathers data on a preprogrammed schedule, with atmospheric pressure and opacity measured once per Martian hour, wind speed and temperature every fifteen minutes, and water vapor concentration twice per Martian day. Panoramic images are acquired at least once per Martian month. The data are transmitted to an orbiter, nominally once per week. Pascal will utilize the Mars orbital infrastructure for communications relay services. This simplifies the science station design, by eliminating the need for a direct to Earth link. When Pascal arrives at Mars in October 2008, the Mars Reconnaissance Orbiter, scheduled for launch in 2005, will be available to serve as Pascal's primary communications relay. Should these missions go forward, Mars Express, Mars Premier, and the G. Marconi missions could serve as alternate relays for Pascal.

Pascal's baseline mission duration of three Mars years is enabled by its long-life Milliwatt Power Generator (MPG), which generates approximately 40 milliwatts of electrical power from a small thermopile connected to a standard Radioisotope Heater Unit (RHU). The thermal output of the RHU also provides environmental control for the science station electronics. The MPG provides several key advantages over a solar array for the Pascal application, including immunity from dust accumulation and diurnal cycles, as well as significant mass and volume savings. Electrical power is stored for usage during peak periods such as data transmission and water vapor measurements, with power conserved by duty-cycling the science station electronics. Electrical output of the MPG slowly decays over time as the RHU output declines, but is still projected to be greater than 20 milliwatts after 10 Mars years (18.8 Earth years), offering the potential for an extended mission well beyond the baseline 3 Mars years.

Science Goals and Objectives: Pascal's primary science goal is to characterize the Martian climate system and how it is controlled by near-surface circulation systems. This goal naturally includes the nature of aeolian processes, the role of global and small-scale circulations, and comparative planetary meteorology. Pascal's science objectives are therefore to: (1) measure the seasonal cycles of dust, water, and CO_2; (2) measure the near surface signature of global and small scale circulation systems; (3) relate those measurements to understanding how these circulation systems control the climate system and modify the surface; and (4) provide a basis for comparative meteorology.

Pascal Mission Science - The Climate System: The main goal of the Pascal mission is to characterize the Martian climate system, i.e., the dust, water, and CO_2 cycles, and how these cycles are coupled with each other and are controlled by the general circulation.

The Dust Cycle. Pascal will define the global dust cycle. First, its opacity measurements provide information on how the general circulation redistributes dust around the planet. Second, dust will accumulate on the station exterior, which may slowly degrade the opacity measurement, thereby providing a direct indication of the dust accumulation rate and surface sinks. Finally, Pascal's wind speed measurements will define the erosive potential at each site, and thereby provide similar information on surface sources.

Global dust storms on Mars spread dust to great heights (~50 km) and last for months. They occur in some years but not others. This suggests they are a threshold phenomenon, perhaps triggered by an atmospheric normal mode or the enhancement of tidal and Hadley circulations. Certainly, feedbacks between dust heating and wind systems are important. But which wind systems and how? Alternatively, the dust source might be limited, and cycling between hemispheres accounts for the variability. Without a global network, it is impossible to distinguish between these possibilities. While a global dust storm cannot be guaranteed during Pascal's baseline mission, the historical record suggests the probability is good.

The Water Cycle. VL and MGS data show that water is exchanged between the surface and atmosphere on seasonal and possibly diurnal time scales (Fig. 2). The only known surface reservoir for water, however, is the residual north polar ice cap. No such reservoir has been detected at the south pole. Is the north cap the only source of atmospheric water? Or are there other sources such as water absorbed in the regolith? One interpretation of recent Thermal Emission Spectrometer (TES) observations is that there are other sources. Indeed, Odyssey's neutron experiment has revealed significant hydrogen, presumably water ice, in the top meter of the surface, but it is unclear to what extent this ice is exchanging with the atmosphere.

Water is the key to understanding life on Mars.

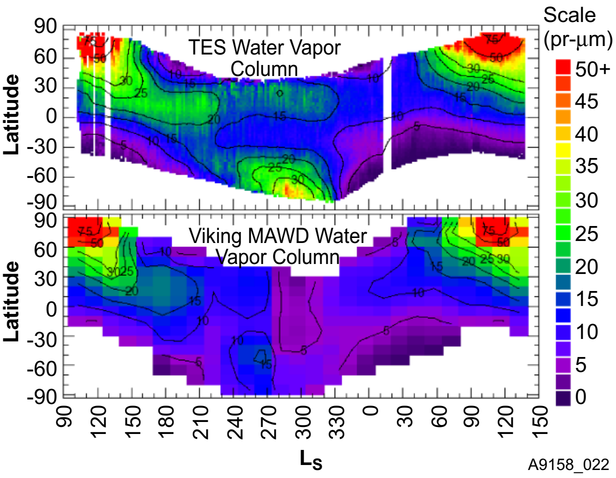

Figure 1. TES and Viking observations of column water abundance as a function of season. (Credit M. Smith).

Where the water resides and in what form are crucial inputs regarding the search for life. While today's water on Mars is in solid or gaseous form, it seems that liquid water has been on the surface in the recent past. Furthermore, there are regions where liquid water might exist temporarily under the right conditions.

Pascal provides the first in situ measurements of near-surface water vapor concentration with enough sensitivity to detect small diurnal variations (several ppms). Pascal will sharpen our understanding of diurnal regolith-atmosphere exchange, and map the distribution of exchangeable reservoirs of near-surface water.

The CO_2 Cycle. The observed semiannual oscillation of daily-averaged surface pressures largely reflects the condensation and sublimation of CO_2 in the polar regions (Fig. 3). The deepest minimum occurs during southern winter when the planet is farthest from the sun. However, the measured difference between the northern and southern winter minima is more pronounced than indicated by simple insolation-based models, and can be reconciled only if additional heat sources are included in the north cap's winter energy budget.

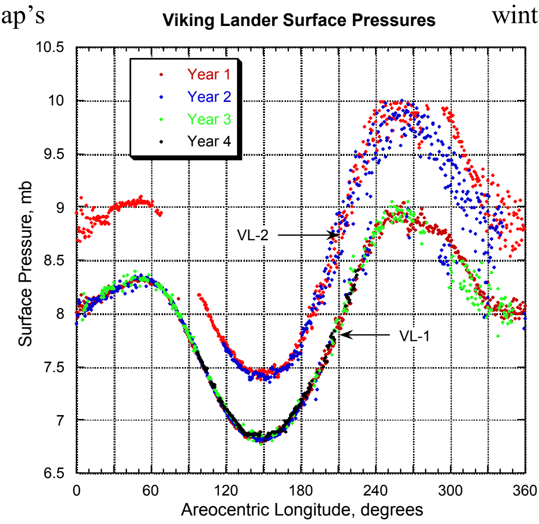

Figure 3. Daily average surface pressures at the Viking Lander sites.

However, meteorology can also modulate the CO_2 signal. An accurate measurement of the CO_2 cycle requires a suitable network of stations to average out these effects. The Pascal network will be able to extract the annual CO_2 cycle with high accuracy. By measuring the seasonal variation in global mean surface pressure, Pascal provides upper limits on the size of the polar caps. Further constraints come from temperature data, which signal their advance and retreat. Together with data on dust distributions and near-surface circulation patterns, these data will help diagnose the polar cap heat balance and provide critical constraints on models of the CO_2 cycle.

Two recent observations regarding the CO_2 cycle require a meteorological network to verify and interpret. First, the residual south polar cap may be disappearing at the rate of 0.06-0.12 mb per Mars decade. If all the disappearing CO_2 remains in the atmosphere, Pascal's pressure sensors have the potential to detect it if the stations survive long enough (10-20 Mars years), or if the signal is larger than estimated. Second, though contrary to the implication of the VL pressure data, MOLA observations show that more CO_2 is deposited in the northern Mars hemisphere than in the southern. From the seasonal variation of the global mean surface pressure, Pascal will be able to confirm or refute this finding.

Aeolian Processes. Today, mostly aeolian processes shape the surface of Mars, though water may also have played role. Images from the surface and from orbit show a wide variety of wind-related features including dunes, yardangs, streaks, drift deposits, variable albedo patterns, and ventifacts. Given its 4.5 billion year history, most of the surface of Mars is likely to have been affected by aeolian processes.

Pascal's descent and landed images, wind speed and temperature measurements, will provide the data needed to investigate aeolian processes. Wind-related features within view of the Pascal stations can be mapped showing types, locations, and orientation. Pascal descent images will provide broader geologic settings. Time variations then can be correlated with wind speed measurements to infer the threshold wind speed for lifting. With wind speed and temperature data, estimates of the surface aerodynamic roughness from rock size distributions, and boundary layer theory, Pascal will determine the profile of near surface winds and the shear stress they exert on the surface. Pascal's large network will characterize the global aeolian environment and provide insight into the role of wind vs. water in shaping the planet's surface.

Pascal Mission Science - The General Circulation: Our current perception of general circulation on Mars is depicted Fig. 4. Each of the depicted wind systems has a unique signature in surface pressure.

The Hadley Circulation. Significant seasonal changes in the structure and intensity of the Hadley circulation are predicted. The equinox circulations are weak and two celled with the rising branch centered near the equator. The solstice circulations are strong and single celled with the rising branch near 25° latitude. Furthermore, the equinox regime is short-lived (~30 sols), and the northern winter solstice circulation is stronger than the southern winter circulation. Models also show significant expansion and intensification of the Hadley cell with dust loading, and a pronounced zonally asymmetric structure. These features are difficult to verify remotely. The rising and descending branches of the Hadley cell should be accompanied by low- and high-surface pressure signals, respectively, 10-25% of the mean pressure. Thus, Pascal will monitor seasonal variations in the structure and intensity of the Hadley circulation from pressure (and wind) measurements.

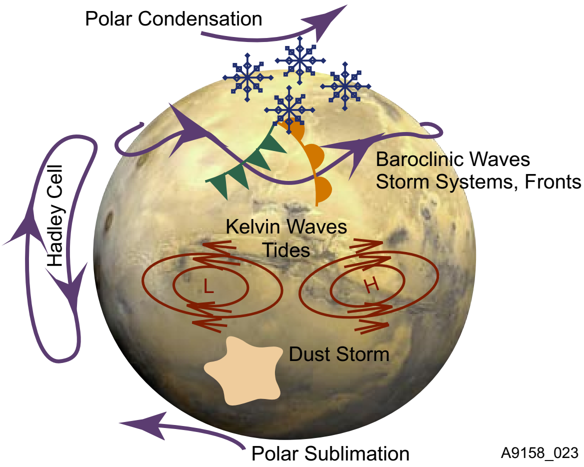

Figure 4. Cartoon of the General Circulation on Mars

Transient Eddies. Transient baroclinic eddies have been detected by the VLs. Except for the wavenumber 1 disturbances, these eddies are relatively shallow. Observation of their surface signatures is the best way to characterize them and their associated dust and water transports. Key aspects that require better understanding are the differences in vigor between hemispheres, whether certain regions are favored for storm growth and decay, and their degree of regularity. Transient eddies appear to be more vigorous in northern hemisphere than in the southern hemisphere, and they seem to favor certain regions for growth and decay. On occasion, they exhibit a higher degree of regularity than those on Earth do. Pascal's global network will provide a time series of meteorological data that can reveal the structure and intensity of these disturbances and how they effect the meridional transport of dust and water.

Stationary Waves. Models suggest topographically-forced winter mid-latitude stationary waves propagate vertically and are deep (> 40 km), while those in the tropics and summer hemisphere are shallow and trapped. Deep waves can be detected from orbit, but near-surface circulations are difficult to see. Recent TES data reveal the existence of deep wintertime stationary waves. Prominent wavenumber 1 and 2 disturbances are seen in both hemispheres. The models also produce deep wavenumber 1 and 2 stationary eddies. Monthly mean pressure data from Pascal can detect and map these waves, and reveal their true nature and structure.

Thermal Tides. Tidal theory and models predict significant sun-synchronous thermal tides on Mars that are modulated by nonmigrating eastward and westward components. The nonmigrating modes (e.g., Kelvin waves) are excited by zonally-varying forcing and may play a role in global dust storm development. Pascal will map the spatial distribution of tidal amplitudes from which tidal modes can be identified. The sun-synchronous component of the semidiurnal tide is particularly important (diagnostic of global heating and dust loading) and easy to identify (the dominant mode has distinct latitudinal structure). Furthermore, Pascal's pressure sensors have enough resolution to distinguish between forced and normal modes.

Small Scale Circulations. Smaller-scale circulations, including drainage winds and upslope flows, valley winds, katabatic flows, etc., are probably important for the dust and water cycles as well. Signatures of these smaller-scale flows will be present in the meteorological data, especially in the wind speed and temperature measurements, and need to be isolated to analyze properly the large-scale circulation components. The use of atmospheric mesoscale models will help detect and interpret the signatures of smaller-scale circulations in Pascal's data. Learning about smaller-scale circulations will make it possible to more clearly analyze the large-scale circulation components, and will provide insight into how smaller-scale processes influence the climate system and the local environments on Mars.

Pascal Network Requirements: Pascal's science objectives depend on the number of landers and how they are configured. The rationale for a large global network is based on the need for latitudinal coverage, longitudinal coverage, and sites of meteorological interest.

Latitudinal Coverage. The Martian general circulation should be sampled in tropical, mid-latitude, and polar regions. Consequently, three latitudinally separated stations in each hemisphere (six in total) are the minimum. However, longitudinal coverage is essential for capturing structural information, assessing zonal means, and deducing the CO_2 mass budget.

Longitudinal Coverage. Planetary waves are mostly zonally coherent and propagate at varying phase speeds. 2m+1 stations are needed to unambiguously diagnose their spatial structure (m=wavenumber). Consequently, longitudinal deployment of stations is determined by the highest wavenumber feature to be characterized. For Mars, most of the power is concentrated in m=1 and m=2 disturbances. Thus, 3-5 stations around a latitude circle are needed to diagnose these waves. Stations should be placed in mid-latitudes of each hemisphere and, to the extent possible, in predicted storm zones. Higher wavenumber features can be inferred using cross-correlation analyses between sites.

To measure the global mean surface pressure, many well-distributed stations are needed to separate the weather signal from the CO_2 cycle signal. Since the former is out of phase in the two hemispheres, while the later is in phase, wide coverage in both hemispheres is required.

Special Sites. Sites of special meteorological and geological interest should also be considered. Such places include regions where dust storms tend to develop, where models predict interesting weather, where MOC images suggest liquid water may have been present, and where Odyssey shows substantial subsurface ice.

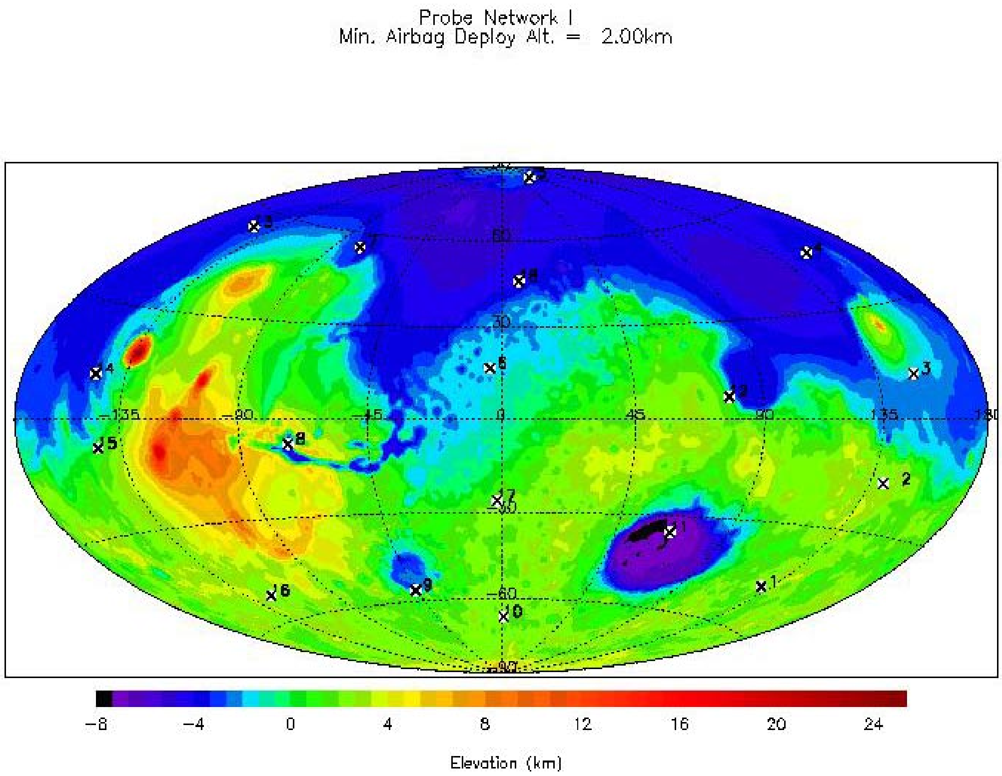

Figure 5. Sample network achievable for the 2007 launch opportunity

Sample Network. A sample network configuration based on our probe targeting/release scenario and EDL constraints is shown in Fig. 5. This configuration has four stations in the tropics of each hemisphere, four stations in midlatitudes of each hemisphere, and one station in the polar regions of each hemisphere. This network also samples sites of special meteorological and geological interest (e.g., Vallis Marineris, Hellas, and the North Polar residual ice cap), and Odyssey's ice rich high latitudes. Clearly, this network satisfies the science requirements.

Pascal Instrument Payload: The Pascal payload consists of accelerometers and descent cameras for entry science; and pressure, temperature, wind speed, water vapor, and panoramic images for network science.

Pressure Sensors (PS). The Pascal PS is a repackaged version of the commercially available Druck RPT-200 which is widely used in applications where high accuracy (±0.01% F.S.) and long-term stability (<100 ppm) are of paramount importance: including terrestrial weather stations monitoring long-term trends, precision engine tests, and as a transfer pressure standard. The manufacturer calibration only extends down to 35 mb and -25 C, but extensive testing of a commercial unit in a thermal vacuum chamber found that it performs just as well over the lower range of pressures and temperatures expected on the surface of Mars. Using a NIST-traceable MKS barotron for reference, more than 100,000 data points were collected over a two-week period during which the temperature was cycled daily between -60° C and +25° C and the pressure cycled hourly between vacuum and 12 mb. The maximum residual difference between the reference pressure and the derived best-fit calibration function was +/-0.01 mb, so the accuracy requirement of +/-0.03 mb is well satisfied.

The RPT sensor consists of a pressure-sensitive silicon diaphragm, 15 µm thick, and a resonating element attached to its underside, both micromachined from the same silicon wafer. Its remarkable long-term stability results from the negligible fatigue degradation of single crystal silicon and the absence of any electronic devices inherent in the transducer mechanism. The sensor chip is bonded to a second silicon wafer, which holds the drive and pickup electrodes, thus forming a sealed cavity, which is evacuated. As applied pressure deflects the diaphragm, the tension in the resonator increases, causing the resonant frequency (34 kHz at 6 mb) to increase at a rate of ~2 Hz/mb. Interface electronics produce a Transistor Transistor Logic (TTL) square wave output. In addition, output from an integral silicon diode thermometer (-2 mV/K unamplified) is used to provide temperature compensation. The resolution of the measurement is set by the frequency sensitivity to pressure, the clock frequency, and count duration. At a clock frequency of 10 MHz, 0.4 seconds integration leads to a pressure resolution of 0.005 mb, which also meets the science requirement (0.01 mb).

Opacity Sensors (OS). The French-provided OS is a repackaged and slightly modified version of the ODS to be flown on the Netlander mission. The modified sensor consists of a single visible channel photo-diode detector, a 5–decade log amplifier, and electronics. Photons of sunlight between 300-700 nm pass through an optical head to the silicon diode detector. The optical head has an annular field of view of 30-50° from the zenith, which is wide enough to allow the observation of both scattered, and direct plus scattered sunlight. The amplifier then compares the current delivered by the detector ($5\ 10^{-10}$ to $5\ 10^{-5}$ A) to the current of a reference source. The output of the amplifier is a 0-5 v analog signal to be stored and transmitted in 10 bits, allowing a resolution in optical depth of 0.01.

The time evolution of the signal during the course of the day has been simulated with a Monte Carlo model for a variety of optical depths, particle size distributions, wavelengths, and sensor orientations. While the amplitude of the signal is sensitive to detector drifts and ageing, the ratio between the scattered and total sunlight is drift independent, allowing a daily check of calibration, as well as a robust measurement of optical thickness and dust accumulation. Based on a full day's measurements sampled once an hour (daytime only), the optical depth can be derived with an accuracy of better than 5%, while the effective radius and its variance can be determined to within 20%.

Temperature Wind Speed Sensors (TWSS). Gas temperature and wind speed will each be obtained by its own dedicated electrical resistance measuring sensor. For each sensor, a small-diameter platinum (or platinum/iridium) wire, well coupled thermally to the gas, will be vertically suspended between two diagonally aligned arms that will extend outward from the camera lens baffle. The two sensors will be mounted radially on either neighboring or opposing camera structure vertical support posts (to be determined in calibration). When a data collection session is initiated, a small magnitude known current (~20 mA) will be passed through both the temperature sensing wire and the wind speed sensing wire for 10-15 seconds in short intervals (several ms) at moderate frequency (> 1 Hz). The voltage drop measured across each of the wires will indicate that wire's resistance, which is directly related to that wire's temperature and thus the gas temperature. The wind sensing wire current will then be increased to ~70 mA and continuously maintained for 20-30 seconds, while the temperature measuring wire continues to experience the pulsed 20 mA current. During this high power period the voltage drop (hence, resistance and temperature) across both sensors will be measured at ~1 Hz. The temperature difference between the wind sensing wire temperature in its high power mode and the temperature of the temperature-sensing wire in its pulsed low power mode provides a measure of the overheat of the wind speed sensing wire. This overheat is related to the wind speed, with the reduction of overheat due to wind proportional to the square root of the wind speed.

Water Vapor Sensor (WVS). Pascal's WVS is based on tunable diode laser (TDL) absorption spectroscopy. It has three basic parts: a laser detector-head mounted on a thermoelectric (TE) cooler, an open-cradle optical Harriet cell of ~10 passes, and the sensor electronics including laser drive/signal chain/data processing electronics. The laser operates at 1.88 µm where there exists both a water and a carbon dioxide line. The Hariett cell optical assembly is exposed to the ambient environment. The laser beam passes 10 times between two mirrors separated by 5 cm. The optical assembly detects the attenuation of the beam due to water vapor absorption. The signals are relayed through to the CPU via signal processing electronics.

Accelerometers (AC). The accelerometers are unique silicon micro-machined, variable capacitance devices available from Honeywell (ASA 7000 Series) and Analog Devices (ADXL150). The ASA7002 ± 2g unit has a mass and power of 3.0 gm and 0.6 mW, and is hermetically sealed in a standard T0-8 can. The ADXL150 ± 50g unit has a mass and power of 5.0 gm and < 2 mW, and is hermetically sealed in a 14-lead surface mount cerpac package. Both units include ASICs that measure the movement of a micromachined inertial mass between two integral capacitance electrodes and output a voltage proportional to acceleration, and have been used extensively in aerospace applications.

The complete unit for each Pascal probe consists of 4 accelerometers mounted on the orthogonal faces of a hollowed, 25 mm rigid cubic block, together with miniaturized external power and signal conditioning electronics. A temperature compensation sensor is also mounted within the block. Total mass and power for the unit are 50 gm and 200 mW, respectively.

Each unit is bolted internally to the station as close as possible to the center of mass during entry. Two accelerometers, optimized for ± 2g and ±50g ranges, are aligned with the symmetry axis of the entry vehicle (Z-axis) and measure deceleration along the velocity vector throughout entry. Two orthogonal accelerometers (X & Y-axes), optimized for ± 2g ranges, measure angle of attack. The two Z-axis accelerometers cover a large dynamic range without gain switching, and provide redundancy. Each accelerometer output voltage is sampled every 0.2 seconds and digitized to 16 bits by the science station. The smallest deceleration that can be detected in the 10 Hz measurement bandwidth is limited by noise to 30 µg for the ± 2g range and 3000µg for the ±50g range. The measurement precision imposed by digitization is respectively 60 µg and 1500 µg for the two ranges.

Descent Camera (DC). The Descent Camera is based on a 10 bit, 1 Megapixel Kodak monochrome CMOS active pixel array. The imaging chip is identical to that used by the LC. An F/2 lens provides a 28.4° field of view during descent allowing for a minimum 50% frame-to-frame overlap assuming a 25 m/sec horizontal drift. The frame-to-frame change in pixel resolution is less than a factor of 2 at all times during descent. A 30 nm wide red filter centered at 670 nm provides maximum surface contrast. A microprocessor local to the camera head controls the image chip, reads out the image data, and places it into local static memory. To insure minimum blurring and distortion each image is captured by the microprocessor in < 70 ms. Once in RAM the data are transmitted to the SS CPU via a 10 line parallel bus in ~5 seconds. The DC is fitted into the nadir side of the airbag and begins imaging immediately following airbag inflation and ends at surface impact.

Landed Camera (LC). The landed camera is based on a Kodak CMOS active pixel sensor looking up through a lens at a spherical mirror. The resulting view gives a 360° panorama view of the ground from the horizon down to 19° from the vertical. The camera body blocks the center of the image. There are four vanes supporting the mirror, which also show up in the image.

The camera will generate 1K x 1K x 10 = 10^7 bit images which are sent in serial form down the mast to the lander cpu. A microprocessor in the camera head controls the image chip, reads out the image and serializes it for transmission. Thermal testing has shown that image chip does not require heating even at 150 K ambient. The camera uses 120 mW during imaging. Each image takes 40 seconds to download to the lander. The camera uses a 670 nm filter, 30 nm wide to reproduce the red filter used in the Pathfinder images.

The area in the center of the image blocked by the camera body is used for an occasional sky opacity measurement to provide redundancy with the OS. The mirror has a hole in it allowing the lens to focus sunlight on a diffuser disc on the top of the camera. An occulting bar over the disc produces illuminated and shadowed regions that give a direct plus diffuse, and a diffuse only measurement, respectively. The difference between the two is related to the opacity of the atmosphere.

The camera is deployed from its canister by a Stacer mast. The Stacer is a BeCu strip, formed on a rod with a spiral wrap having large overlap. The Stacer is collapsed axially to a cylinder for storage. Releasing the mast returns the Stacer to its original shape. This will deploy the camera ~1 m above the lander. The canister is mounted on the rotatable external sensor housing of the lander and will be orientated upright before deployment.

The Pascal Science Team: The Pascal Science Team consists of government, industry, university, and international partners. NASA's Jet Propulsion Laboratory manages the overall mission. NASA's Ames Research Center oversees probe development. Ball Aerospace will build the spacecraft and conduct mission operations. ITT Aerotherm will develop the EDL systems, and Lockheed Martin Advance Technology Center will provide the fully integrated science station. The Department of Energy will integrate the power source. The Pascal Science Team is listed in Table 1.

Table 1. Pascal Science Team

Team Member	**Main Role**
R. Haberle, ARC	Principal Investigator
D. Atkinson, UI	Atmospheric Structure
J. Barnes, OSU	Mesoscale Circulations
J. Bauman, ARC	Dust Optical Properties
D. Catling, UW	Pressure Sensors
A. Colaprete, ARC	Descent Camera
F. Forget, LMD	Coordinate w/ Premier
R. Greeley, ASU	Aeolian Processes
A.M. Harri, FMI	Coordinate w/ Netlander
F. Hourdin, LMD	EOF Algorithms
C. Leovy, UW	Science Definition
J. Murphy, NMSU	Temp/Wind Sensors
J.P Pommereau, SA	Opacity Sensors
P. Rannou, SA	Opacity Retrievals
J. Schofield, JPL	Accelerometers
P. Smith, UA	Panoramic Camera
O. Talagrand, LMD	EOF's/GCM
C. Webster	Water Vapor Sensor
A. Zent	Deptuty PI