**A FOREIGN EXCURSION; A STROLL ALONG MARS' POLAR CAPS.** Hugh H. Kieffer, *Celestial Reasonings, Genoa, NV 89411-1057, USA (hhkieffer@gmail.com)*, and the Mars Seasonal Cap Community * .

Mars' permanent and seasonal polar caps have provided many surprises, and involve a number of physical processes that do not occur naturally on Earth. From the discovery that the two perennial caps have different surface composition to the observations of black ice, vents, "spiders", dark and bright transient fans, organized fractures, enriched minor gases, zoned transient spots, dune flow activation, massive epitaxial growth, scarp retreat, interannual frost variation, cap edge storms, ... the surprises continue.

These processes will be described as if you are there.

**Fundamentals:** Mars atmosphere is, by mass, 97% $CO_2$, 1.7% Ar, 1.2% $N_2$ , 70 ppm $H_2O$ (variable) and 0.1% others. The mean annual global surface pressure is 623 Pa and varies 25.6% each Mars year . This variation is driven by condensation/sublimation of the seasonal caps; the total $CO_2$ needed to reproduce the annual pressure cycle is 741 Pa. Radiation cooling of the winter caps cools the surface until the $CO_2$ saturation temperature is reached and it condenses, as snow or frost or ice; 145K at the south pole surface and 150K at the north. Mars atmosphere normally contains dust, the average opacity is 0.3. Water vapor is concentrated near the spring/summer cap edge, the North being much "wetter". Dust or ice grains that remain suspended for long have effective diameters no more than a few $\mu$m; grains of 10 $\mu$m diameter will fall from 10 km in 20 sols.

This is a trip of the imagination; but it is not imaginary, only outside humans experience. We start on a pleasant late summer afternoon; We first visit the south, where many of the exotic features were discovered.

**Late summer:** There are three distinct surface types: 1) Solid $CO_2$, 10's of m thick; traditionally called the residual or perennial polar cap. The residual $CO_2$ cap is rimmed nearly everywhere by 2) water ice exposed at the surface, there are also 100 km patches detached from the $CO_2$ cap. Between the patches and all around the exposed ice is 3) desiccated soil a few cm thick, but water-ice-rich soil underlies this for a large region; this is the polar layer deposit (PLD).

**Fall:** In early fall, very thin cirrus appears, virtually invisible even though the atmosphere is as clean as it ever gets ; these are high $H_2O$ clouds visible only at twilight. As the days grow short, perhaps a few grains of water-ice fall and $CO_2$ frost begins to form at night. At first this frost sublimes every day, then abruptly it persists through the day (albedo positive feedback); winter is here and the surface temperature will be virtually invariant at 145K until late spring. All is quiet at first, what little wind there is is directly DOWN, as the atmosphere flows into the surface and $CO_2$ condenses. There are two kinds of winter, governed by local atmosphere composition and surface winds . Where the Ar and $N_2$ accumulate near the surface (height scale cm ?) local diffusion gradients cause hoar frost to grow, this will be bright frost. In other places, mixing is fast enough to prevent $CO_2$ depletion and a thin-film of dense solid $CO_2$ grows; this will become massive epitaxial growth resulting in a layer a meter thick with individual grains up to 10 cm (or more) in size forming a conformal coat over the topography. The regional distribution of slab-ice versus frost is thought to be controlled by global circulation set up by the extreme topography of the Hellas basin.

**Winter:** The negative radiation budget is balanced by condensation of $CO_2$. There are local "cold spots" seen from above, some at or on the ground where the $CO_2$ grains are so small that they do not radiate efficiently and others caused by thick high clouds. The amount of solid $CO_2$ increases quantitatively close to predictionas of simple net-radiation models. Both frost and slab deposits contain tiny grains of dust and $CO_2$-ice, both with radius order of 1 $\mu$m and mass fraction order of 10 ppm, carried in on the condensation wind.

Outside the perennial cap, heat-flow from the annual thermal wave sublimes $CO_2$ at the base of the cap and creates gas; where the new cap is not porous, pressure builds, the slab levitates and vents occur along weaknesses due to stress fracture or erosion starting along triple-grain boundaries. The jetting vigor decays slowly in proportion to reduction of the seasonal heat-flow but as the slab thickens the pressure under the slabs increases. One-quarter of the atmospheric $CO_2$ condenses; the average Argon and Nitrogen concentration increases 6-fold pole-ward from 75° S, peaking at the winter solstice.

**Spring:** With the initial spring sunrise things happen much faster on equator-ward slopes, whether sides of rocks, or spider-mounds or dunes or longer slopes. Most of the sunlight is absorbed in dust grains distributed roughly uniformly through the $CO_2$; these form tiny pressurized gas bubbles and migrate down or along ice-grain triple junctions to upper or lower slab surface, leaving clean ice. Sunlight then is absorbed by the underlying soil surface and the slab sublimes from the bottom. The ice surface heaves and falls (cm ?) as the sub-slab pressure builds and is relieved when new vents open.

Weaknesses break to initiate vents, allowing the $CO_2$ gas to escape as cold jets. In many places, this gas entrains dust which falls out adjacent to the vent or is broadcast downwind as fans. Fans are often regionally aligned, indicating wind direction when they formed, with some artistic patterns. In other locations dark splotch irregularities at meter-scale are probably responding to detailed topography. Apart from some consistency over spiders, the vents are different in detail each year. Vents occur with greatly varying spacing and can be aligned along polygonal patterns (cracks) or changes of slope. The fans, including the circular spots, are conspicuous and can be dark or bright or dark with bright rims. Some vents show bright fans in one or more directions different than the dark fans, indicating they formed at different times. In at least some places the brightness is caused by fresh $CO_2$ frost; but how it forms remains mysterious.

The jets themselves are nearly transparent, above eye level the opacity drops quickly, although well-shaped vents generate jets up to 150 m high. Down-wind from the jet, the grains fall out, bounce a bit. Dust in sunlight absorbs heat, so the grains cannot stay in contact with the ice, they must constantly be in motion, jostling around in little dimples and working their way down-slope, be it cm or m., until their abundance is adequate to form a mat. This leaves humps of clean $CO_2$; another positive-feedback process, and $CO_2$ spectral features re-emerge. From afar, the apparent temperature of the dry-ice and dust-mat mix rises a few K above the ice. When conditions are right, individual dust grains burrow down leaving tubules that increase scattering to form "blue halos" around the thicker dust coat. At $CO_2$ ice temperatures, $H_2O$ acts like an inert solid. As the $CO_2$ sublimes in the spring, the $H_2O$ grains captured during condensation are left on the surface. Unlike dust, they absorb little sunlight and may act to increase the albedo and hence reduce the $CO_2$ sublimation rate.

Dust thickness can reach a mm or so; the grains are on order 50 $\mu$m diameter. The grains wafted in during this past winter would not fall out, so the stuff forming the dark fans has gone through some process, probably involving minute amounts of $H_2O$, to aggregate into larger grains; a process that may take years to millennia. When and where the vented dust blocks most of the sunlight, sublimation occurs dominantly at the upper surface. Through the rest of the spring/summer, where this covers most of the source region for a vent, the jets become dormant.

Perhaps the most peculiar vent-related forms are "spiders", also called araneiform terrain; radiating, dendritic, bifurcating forms of channels that narrow downhill. Although venting is an erosional process, somehow the spiders grows into mounds over time. Spaced semi-regularly across level terrain, there are many varieties: thin, fat, patterned, isolated or being so dense they grade into connected lace terrain.

Over the residual cap, the albedo generally brightens with increasing insolation and decreases after solstice; there may be a weak brightening before the "crocus" date (when $CO_2$ finally disappears). Here, some scarps around $CO_2$ mesas are receding at measurable rates. Some sections of the dirty-water-ice areas have developed polygonal troughs which act to shield the $CO_2$ from direct sunlight, resulting in dry-ice patches later into the spring. Cold air flows off the cap as katabatic winds, creating local dust storms at the cap edges.

In some sub-polar craters with interior large dunes, dark spots develop along the crest, become dense and extend down-slope along furrows which are actively changing. By late spring, the contrast is gone but the furrows remain.

**Summer:** Finally, the crocus line passes us and we are standing of what looks like smooth sand or dust, but is 2/3 water ice, the Polar Layer Deposits (PLD), the accumulation of millinnea of residue of the seasonal cap process. If we a go toward the Dorsa Argentea sector, we find a large expanse of water-ice at the surface, without the PLD.

Spectrally, the residual south $CO_2$ cap contains about 0.03% of both dust and water; a roughly thousand-fold concentration from the seasonal ice. Reflectance spectral observations indicate spotty summer coverage of the perennial cap with $H_2O$ frost of about 200$\mu$m diameter; their origin is a mystery, as at 145K growth from a few $\mu$m would require the order of 100,000 yr.

The almost uncratered and generally bland polar terrain locally has sudued spider mounds. Unlike spiders, the dark cracks rarely leave a record into the summer.

**North cap differences:** This is a much "wetter" place; water vapor and ice are visible throughout the seasonal cap recession and afterwards. Spiders are much less common. $CO_2$ spectral signatures decrease monotonically through the spring. After the crocus date, the $H_2O$ grains can sublime and mix into the atmosphere. Some water goes pole-ward and refreezes to make bright frosts. Enough $H_2O$ is present to have a strong effect on the reflection spectrum, a few 10's of $\mu$m. A 6° wide annulus of water frost follows the crocus line and brightens the cap edge. There is significant year-to-year variation in detail, both in seasonal cap retreat and in late spring $H_2O$-frost patches. There is no permanent solid $CO_2$; the residual cap is dirty water ice.

Dunes play a larger role than in the south; dark spots (dust vents) at the crests and bases of dunes are common and the $CO_2$ gas activates lee-slope failures; these kick up small dust clouds. Also, chunks of solid $CO_2$ break off at the crest and slide down, leaving furrows with pits at the ends (this is about the only thing that has been replicated on earth).

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