NUMERICAL MODELS OF JET ACTIVITY CAUSED BY BASAL SUBLIMATION OF CO_2 ICE.

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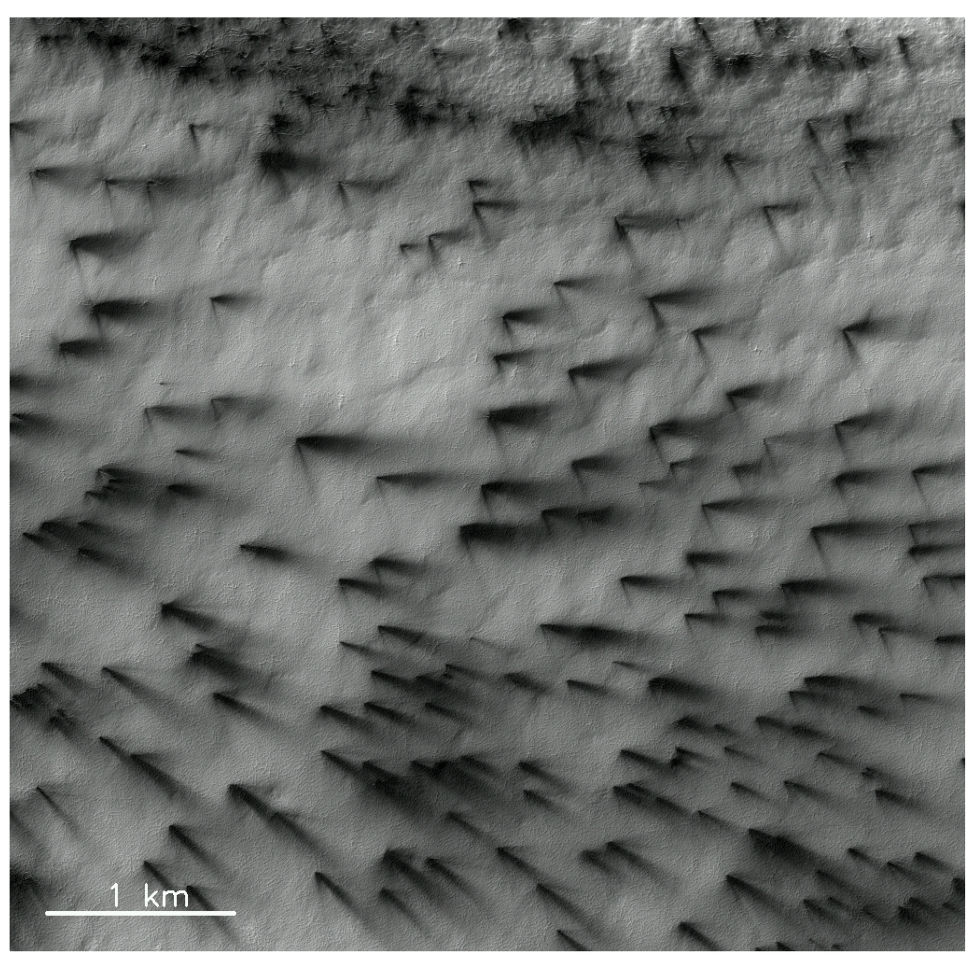
Introduction:

The currently accepted paradigm for formation of fan-like deposits on the seasonal CO_2 slab ice in the southern polar region of Mars was sketched out by [1] and described in more detail by [2], [3], and [4]. Observations have been interpreted as being the consequence of the unique properties of CO_2. In a form of solid-state greenhouse effect, an impermeable layer of translucent CO_2 slab ice is penetrated by sunlight. The sunlight heats the surface below but the high opacity of CO_2 at infrared wavelengths prevents cooling. This leads to sublimation at the ice-substrate interface with subsequent pressure build-up. When the pressure becomes sufficient to exploit a weakness, it is released by venting. The gas then carries with it entrained dust particles which are subsequently deposited on the ice surface and are visible to remote sensing instruments such as HiRISE and CRISM.

[3] attempted to derive parameters of the outflow. Although the estimates on flow rates and jet altitudes were of considerable value, the interaction between the dust particles and the gas, and the details of the flow require more sophisticated gas dynamics modelling. This has been undertaken in a series of papers and we review the results herein.

Explosive Jet Activity:

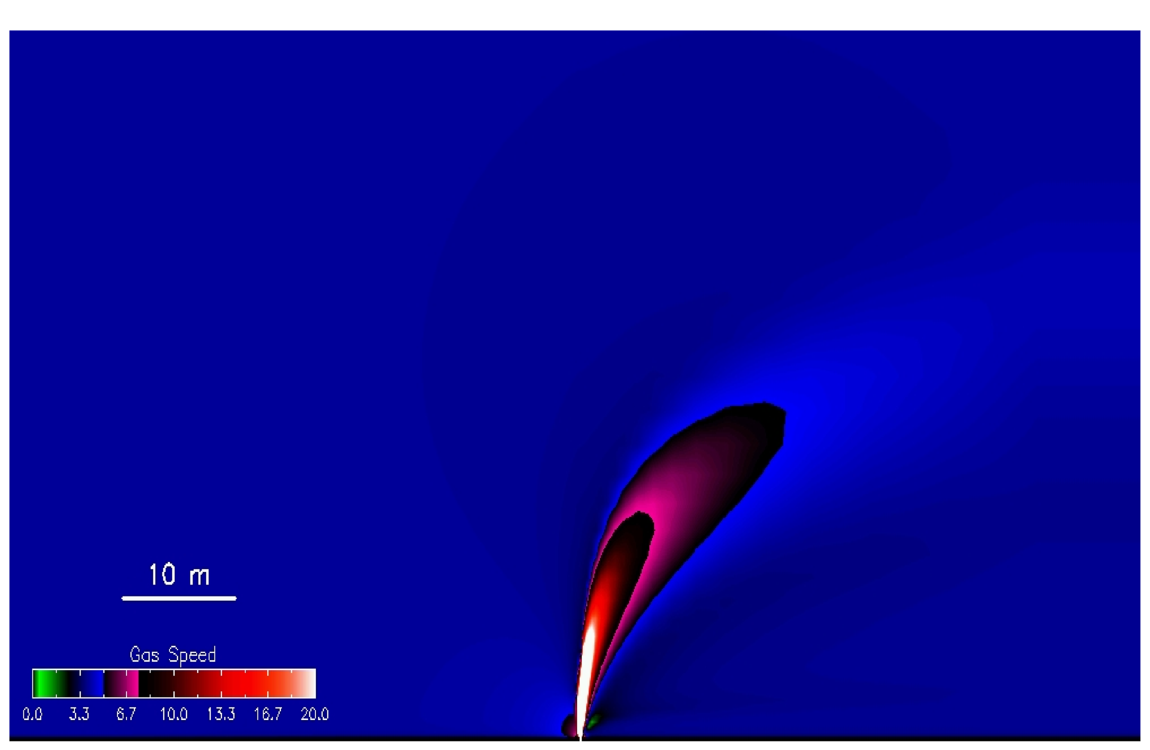
It is widely assumed that the first activity after the arrival of southern spring is quasi-explosive in nature. The fluid dynamics of these "explosive" jets has been investigated by [6] to determine the influence of several parameters (including outflow mass and velocity, vent geometry, slope, and wind) on the structure of the gas jet and the resulting deposition pattern of dust/sand. A range of source parameters were investigated. The code used also allowed varying degrees of mass loading by dust. This showed, e.g., how gas could be dragged by the falling dust back towards the surface in high mass loading cases. Jets reaching 80-100 m high and vent velocities in excess of 160 m/s could be modelled using realistic input. We note that the vent diameter and structure are essentially unknown although the vent length is constrained by the depth of the seasonal slab. The peak dust velocity is a strong function of this depth and the particle size because of the gas-dust coupling.



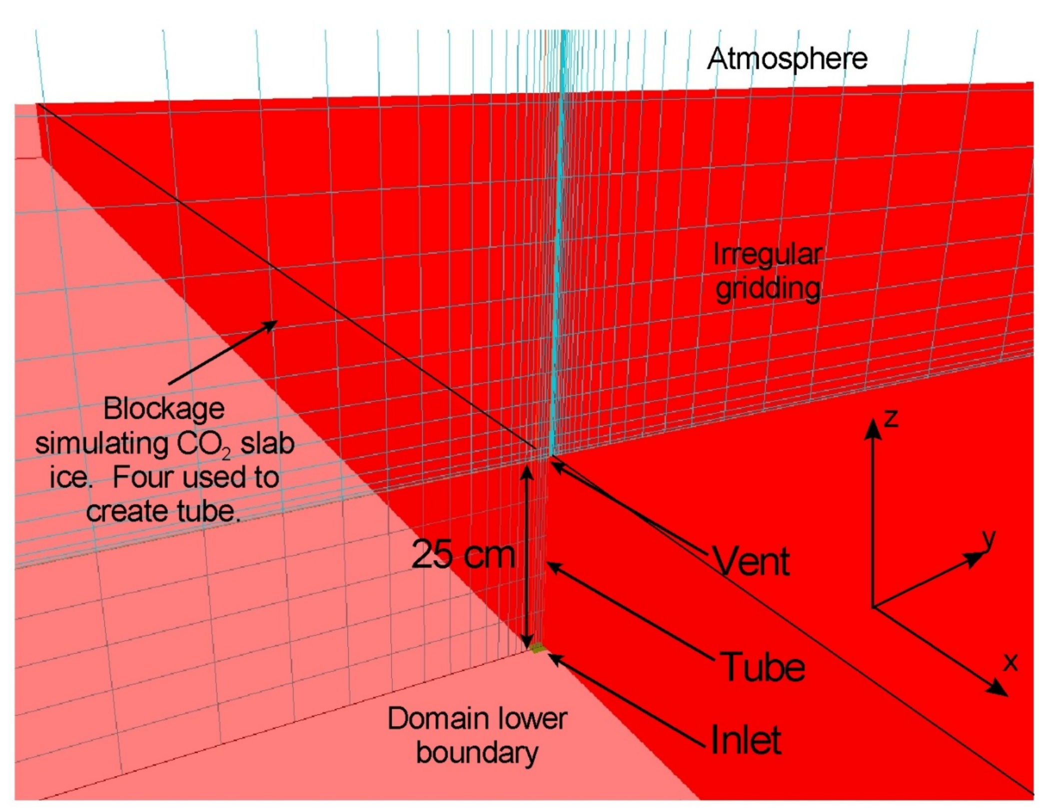
Jet activity in Inca City showing multiple fans with well-defined orientations.

Modelling Approach

- Commercial CFD code being used; irregular grid
- 101 m x 101 m x 151 m domain (fully 3-D) (typical values)
- 611 Pa CO_2 ambient atmosphere.
- 0.2 m x 0.2 m inlet through a 0.25 m or 2.5 m (square) tube.
  - Inlet cross-section modified to test influence on results.
- Source equivalent pressure and inflow rate varied
  - Upper limit set as the over-burden pressure of CO_2 ice. (~6000 Pa)
- Gravitational acceleration of Mars taken into account.
  - A slope has been modelled.
  - Influence of wind has also be simulated
- Temperature balance included (i.e. energy eq. solved)
- Non-absorbing surface.
- Dust loading included in the computation
- Steady-state solution sought. (The explosive event is of course transient but can be considered steady-state over period of 30-60 seconds. Outgassing timescale estimated at 2 hours.)



Model result showing the gas speed in a jet in the presence of a 4 m/s wind from the left. Velocities > 20 m/s are shown in white.



The set-up of the explosive model using an irregular Cartesian grid.

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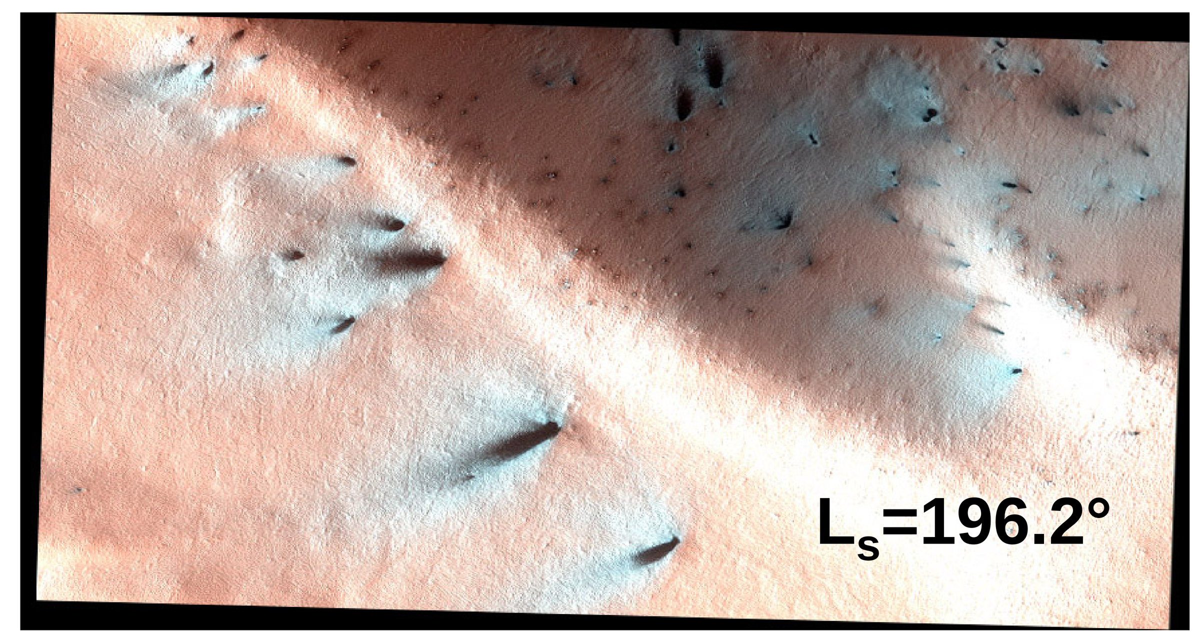
Steady-state (diurnal) jet activity:

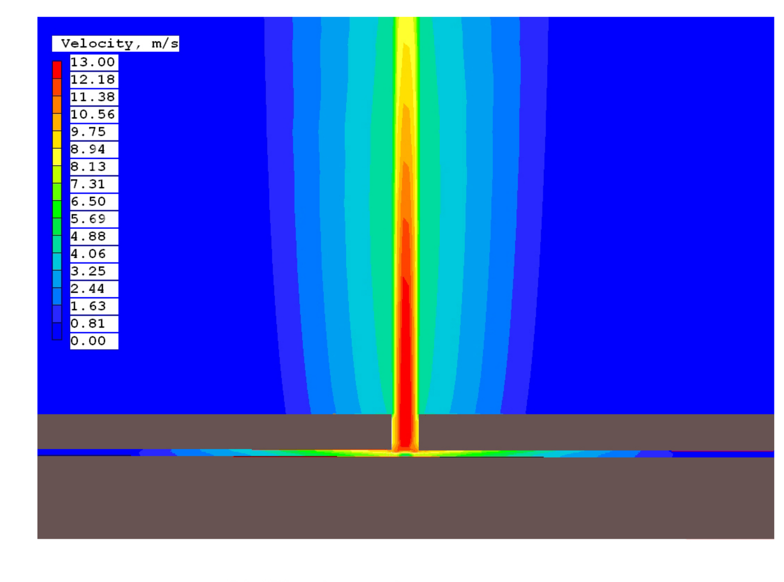
A steady-state case has been investigated in [7]. This is interesting because, first, observations have consistently shown evidence of fan-deposits going in different directions from (apparently) the same source (see Figure) and second, fans have been seen to "grow" over several days.

Re-sealing mechanisms for the vent are conceivable [5] but a vent which remains open indefinitely and responds to the sub-surface gas sublimation alone may be an alternative. In [7], the gas produced under the slab was allowed to flow to the vent driven by gas pressure alone. The motion of dust particles within the cavity was also calculated. Basal sublimation leads to pressure gradients which force gas out of an idealised vent at ~10-15 m/s [7; see Figure]. This is sufficient to carry dust particles with radii in the 30-100 micron range out of the vent.

A possible scenario is that the longest fan could be the result of the initial outburst. If the vent does not re-seal, then steady-state outgassing can occur. The pressures are lower within the cavity and consequently gas and dust velocities at the vent are lower. As the local wind varies over timescales of days to weeks, the fan orientation responds to it and new, smaller fans are created.



Fans in Inca City showing bright material surrounding the darker dust deposits.



A steady-state case showing the gas velocity beneath the ice layer. Velocities in excess of 10 m/s are evident in the cavity.

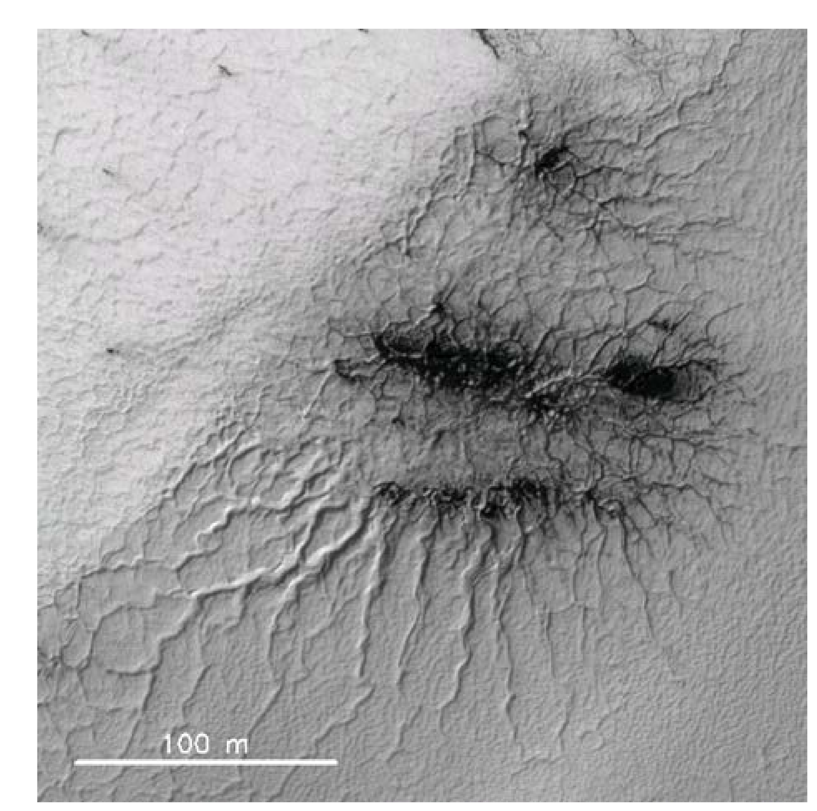
Effects of the Adiabatic Expansion:

[8] suggested that freezing out of the CO_2 (as a "snow") would explain the bright deposits seen surrounding dark fans in CRISM and HiRISE data (see Figure above). This concept is very attractive but has two issues. Firstly, the ambient atmosphere is a heat source so that the region in the flow where the gas is above its equilibrium vapour pressure is very limited. Secondly, unless the snow can reach 10s of microns in size the interaction with the ambient atmosphere will strongly influence their motion and they do not follow the trajectories of dust particles in the presence of slopes or winds. Two alternative mechanisms have been proposed. In [6], downward flow of CO_2 arising from dust drag was postulated to condense on the surface to produce a bright deposit. [9] proposed the cleaning of the top layer of ice as large dark particles sink through it when heated by the Sun. The latter may be favoured by the existing observations.

"Spider" Production and Growth:

The presence of araneiform (spider-like) structures in the southern seasonal cap area has been known for many years. However, there are two significant additional observations. Firstly, the positions of fans on the surface are, in general, the same from year-to-year. Secondly, fans originate not from the centre of spiders but on their margins [5; see Figure right]. The drapping of the CO_2 ice slab over the spider edge may well create a weak point in the slab. This then defines the place where activity initiates. The flow of gas and dust to the vent then erodes the "wall" of the spider leading to lateral growth of the depression.

Future measurements should attempt to confirm the size of the dust jets via stereo imaging (something which has still eluded us possibly because of low optical thickness), and should attempt to detect changes at spider sites.



Jet emission is usually observed from the margins of the spiders. Here we see a large example.

References: [1] Kieffer, H. H., Annual punctuated CO2 slab-ice and jets on Mars, paper presented at the 2nd International Conference on Mars Polar Science and Exploration, Univ. of Iceland, Reykjavik, 21– 25 Aug. 2000.; [2] Kieffer, H.H., Journal of Geophysical Research (Planets), 112, E08005, 2007.; [3] Kieffer, H. H., et al. Nature, 442, 793–796, doi:10.1038/nature04945, 2006.; [4] Piqueux, S., et al. J. Geophys. Res., 108(E8), 5084, doi:10.1029/2002JE002007, 2003.; [5] Thomas, N., et al. Icarus, 205, 296-310, 2010.; [6] Thomas, N., et al. Icarus, doi:10.1016/j.icarus.2010.12.016, 2011.; [7] Thomas, N., et al. Geophys. Res. Lett., 38, L08203, doi:10.1029/2011GL046797, 2011.; [8] Titus, T. et al. Bright fans in Mars' cryptic region caused by adiabatic cooling of CO_2 gas jets. AGU Abstract P41A-0188, 2007.; [9] Pommerol, A., et al., J. Geophys. Res. (Planets), 116, 8007, doi: 10.1029/2010JE003790, 2011.