Water-Ice Cloud Thermal Effects at the Phoenix Mission Landing Site

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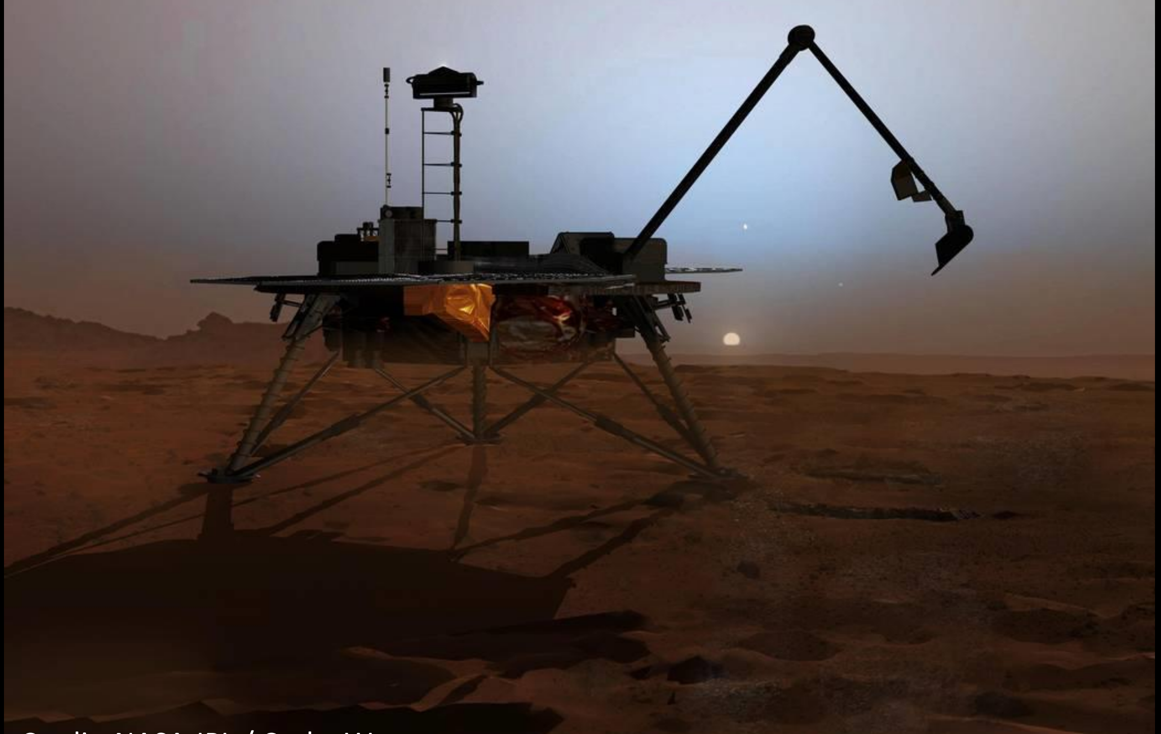
Abstract

On Mars, radiatively active water-ice clouds can affect surface temperature by enhancing downwelling longwave radiation. Images and LIDAR data of water-ice clouds were reported over 150 days of operation during the Phoenix mission. By modelling the temperature record using an energy balance equation, a full record of cloud activity at the Phoenix site is built. The clouds typically produce a warming effect of less than 4 K, but clouds toward the end of the mission warm the near-surface temperature by up to 8 K.

Artist's Rendition of the Phoenix Lander



Credit: NASA JPL / Corby Waste

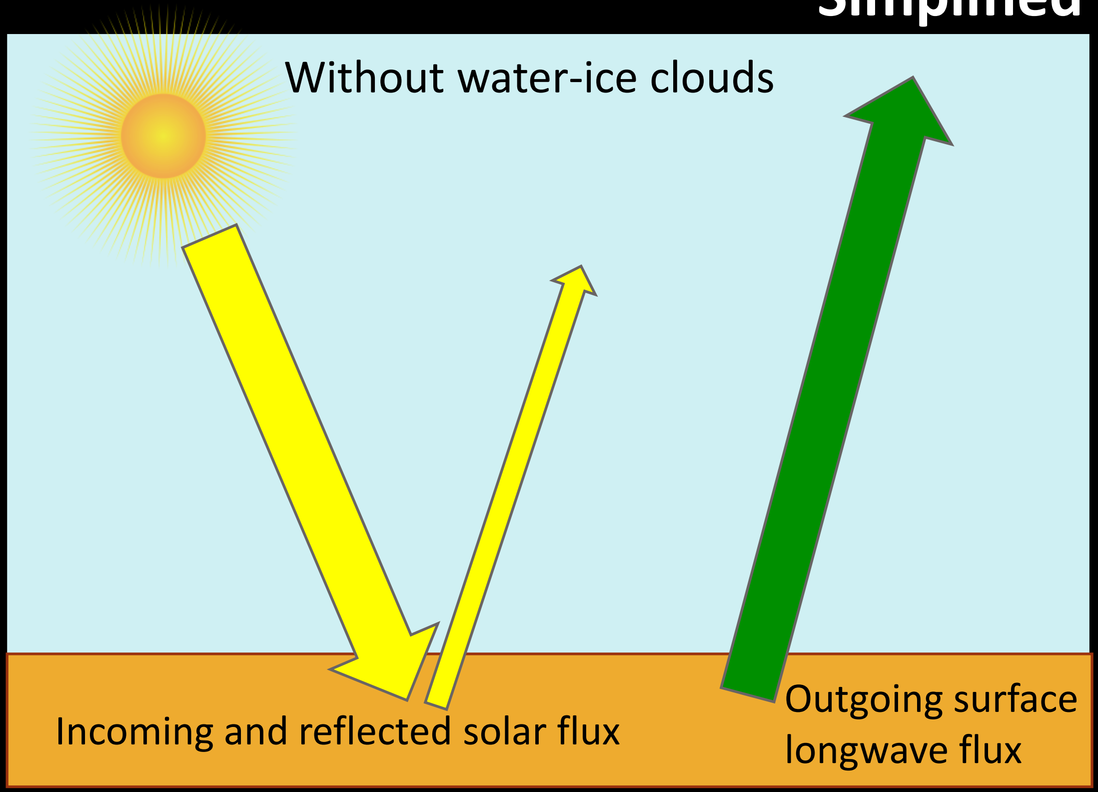
Water-ice cloud Thermal Effects

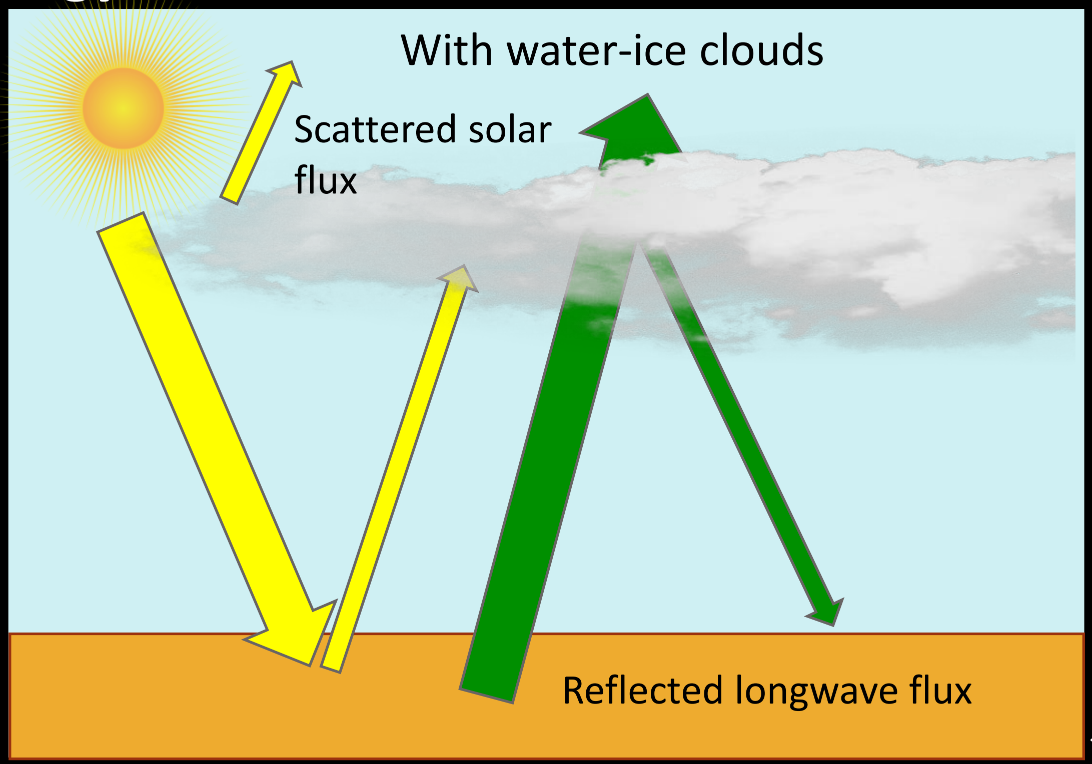
- On Mars, diurnal temperatures are driven by the balance of incoming solar flux and outgoing longwave flux from the surface[1]
- Radiatively-active water-ice clouds scatter visible-band solar flux, and absorb and reflect longwave flux back toward the surface, producing a warming effect on the near-surface temperature[2]

Clouds during the Phoenix Mission

- The Phoenix lander touched down in the northern arctic of Mars (68.2°N), operating up to and through summer solstice for 150 sols
- Water-ice clouds were detected throughout the mission by the Surface Stereo Imager (SSI)[3] and LIDAR[4]
- In the latter part of the mission, a regular nightly cycle of clouds were seen[4]

Simplified energy balance





Phoenix Instruments

- Three temperature sensors measured air temperature every two seconds as part of the meteorological (MET) suite
- This study uses data from the temperature sensor located 2 m from the surface

Temperature Model

- For each sol, the ground temperature is modelled using a subsurface conduction scheme[5] with an energy balance equation (Eq. 1)
- At each time step, the air temperature at 2 m is coupled to the ground temperature (Eq. 2)
- The modelled air temperature is plotted against MET temperature data to determine the amount of reflected flux from water-ice clouds needed for the model to match the data

Equations used

The surface energy balance is given by:[6]

$$G = S(1-\alpha) + LW\downarrow - LW\uparrow - H - LE + R \qquad (1)$$

S	Solar flux
α	Surface Albedo
$LW\downarrow$	Downwelling longwave flux
$LW\uparrow$	Upwelling longwave flux
H	Sensible heat flux
LE	Latent heat flux
R	Reflected flux from water-ice clouds

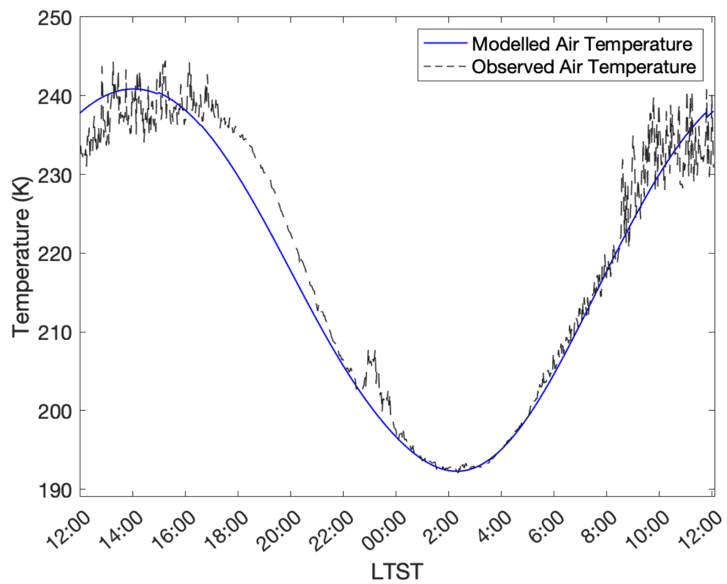
- R is maintained as an independent parameter, which is varied on 2-hour intervals within the model

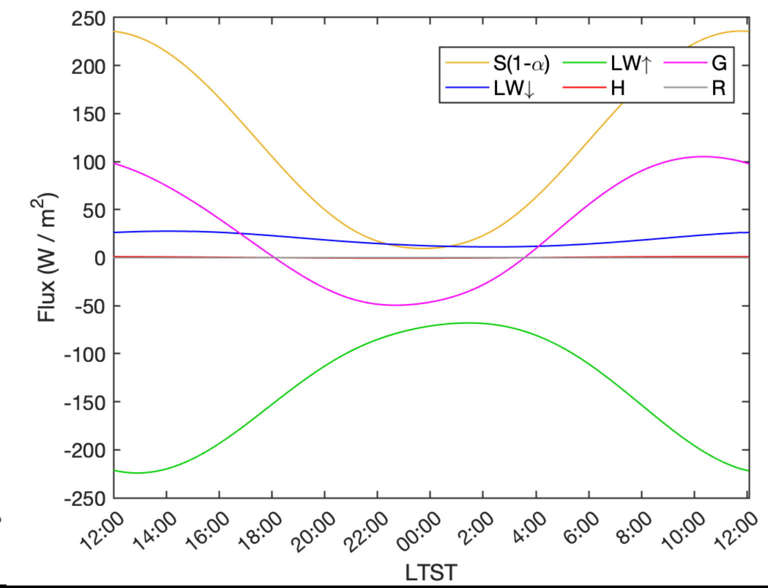
The air temperature is found using the sensible heat flux:[6]

$$H = k^2 c_p u \rho_a f(R_b) \frac{T_g - T_a}{ln^2\left(\frac{z_a}{z_0}\right)} \qquad (2)$$

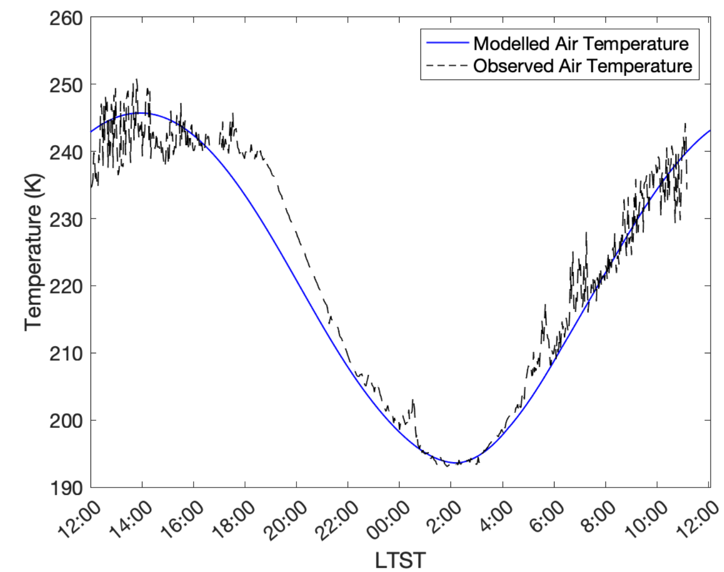
Results: Modelled temperature and energy balance for one sol

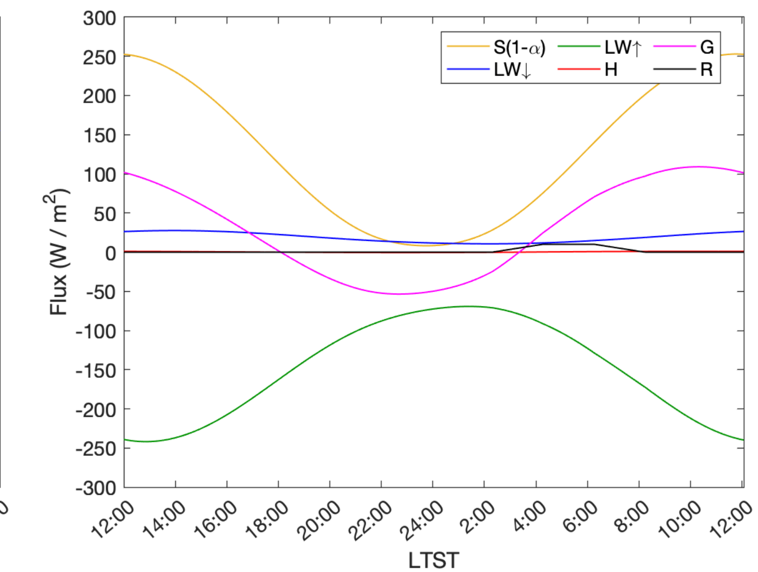
Sol 9, L_s = 80.48° Without clouds; temp increase = 0 K





Sol 64, L_s = 105.51° With clouds; temp increase = 1.8 K



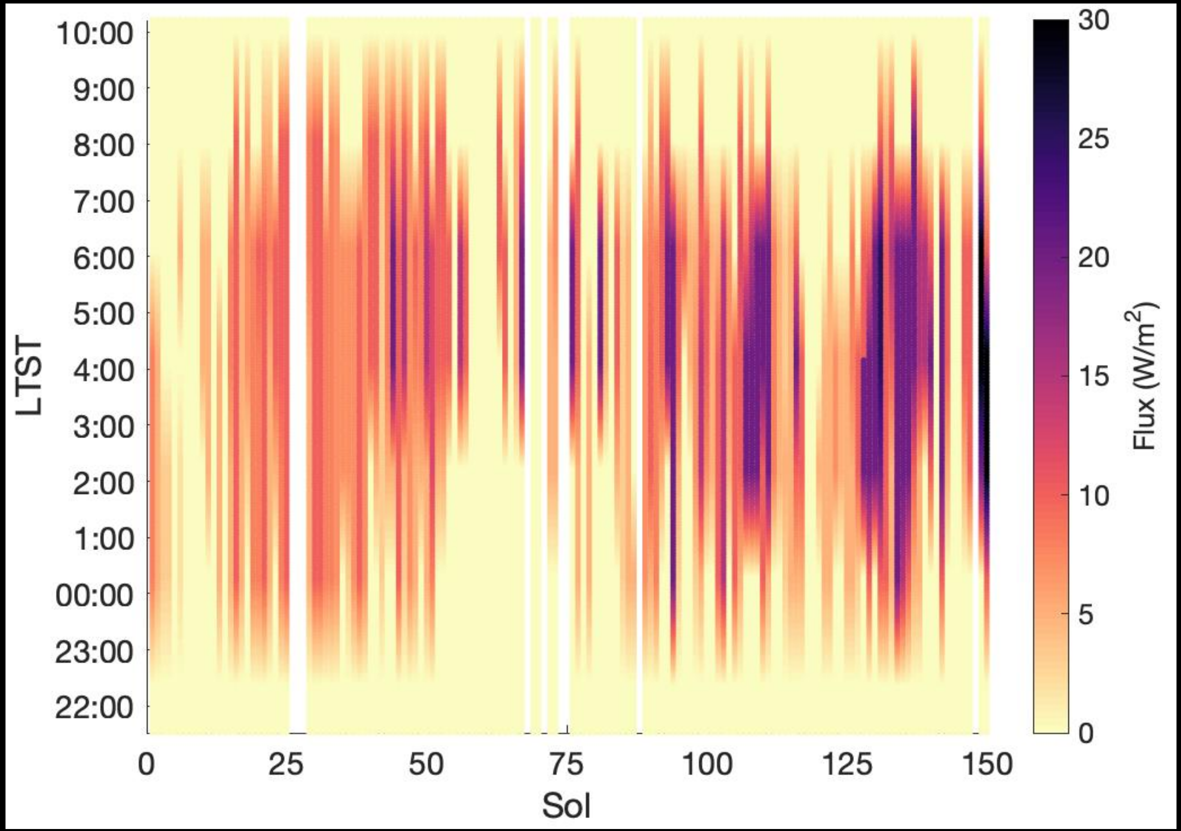


The modelled 2 m atmospheric temperature is plotted against the MET data for sol 9 and sol 64 of the mission to represent two runs with differing values of *R* (reflected flux from water-ice clouds).

- On Sol 9, *R* = 0 W/m² over the duration of the run, indicating no clouds formed throughout this sol

- On Sol 64, *R* begins to increase at midnight local true solar time (LTST) and reaches a maximum of 10 W/m² at 04:00 LTST. By 08:00, *R* has dropped back to 0 W/m². This suggests clouds formed around midnight and dissipated by the early morning. The clouds warm the temperature by 1.8 K, compared to the same sol when modelled without clouds

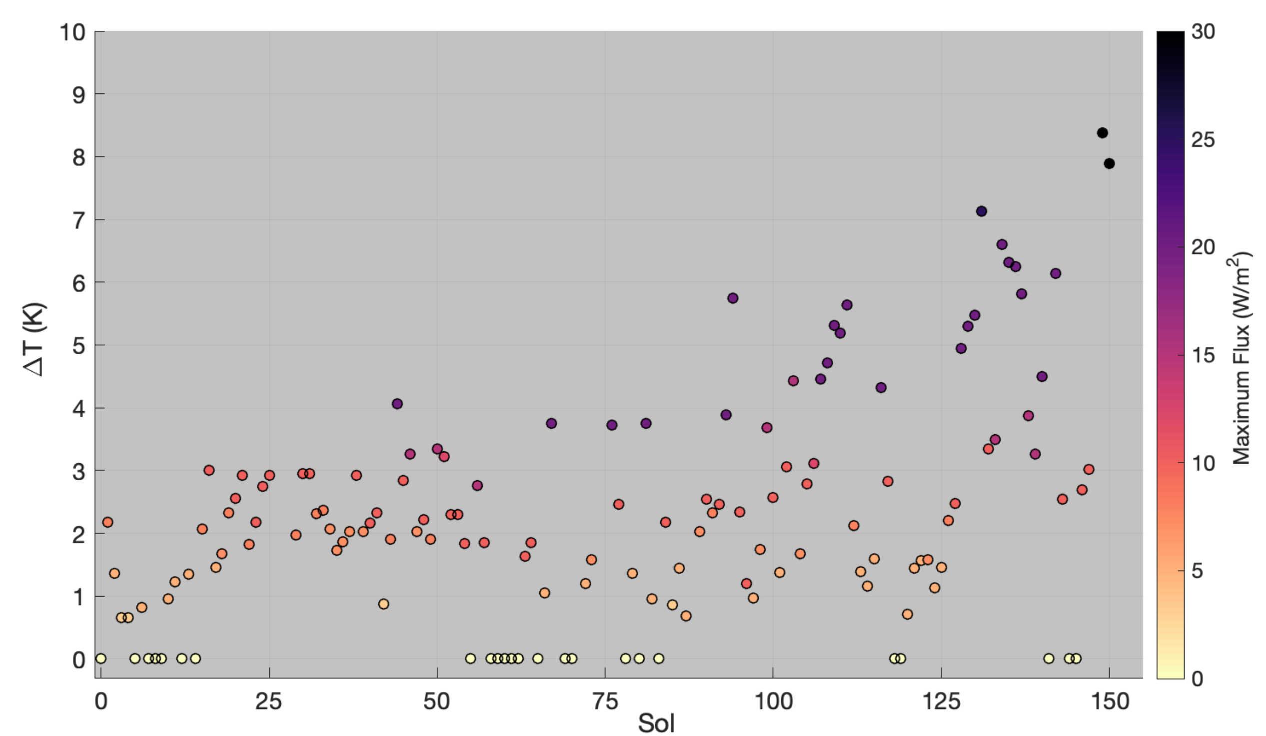
Full cloud record during Phoenix Mission



- The peak in cloud activity occurs toward the end of mission, higher *R* (Flux) suggests clouds with a higher optical depth
- Water-ice clouds and fog may have been present at Phoenix earlier than recorded by the SSI or LIDAR

Maximum temperature difference: model run with *R*=0 and calculated *R* values (left)

- The warming of the atmosphere due to water-ice clouds is typically around 1-4 K
- *R*-values greater than 20 W/m^2 produced warmings greater than 5 K
- Sol-to-sol variability in cloud thermal effects toward the end of the mission



Conclusions: A full record of water-ice clouds and the resulting thermal effect is found at the Phoenix Site

- Modelling the MET temperature data at the Phoenix site allows a full record of cloud activity to be built by analyzing the flux reflected from the clouds
- Small *R* values were seen at the beginning of the mission, corresponding to temperature increases of ~1-4 K compared to cloudless conditions
- The middle of the mission had several sols with *R* = 0, representing no cloud formation
- The peak in reflected flux occurs near the end of the mission, where the temperature increase can reach up to 8 K

Moving forward

- The *R* value can be related to other water-ice cloud properties, such as optical depth and ice particle radius
- This method may be used to build a cloud record at other locations on Mars

References

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