EARTH AND SPACE SCIENCE **Autumn 2018**
431 *PRINCIPLES OF GLACIOLOGY* 4 Credits, SLN 14855
505 *THE CRYOSPHERE* 4 Credits, SLN 14871

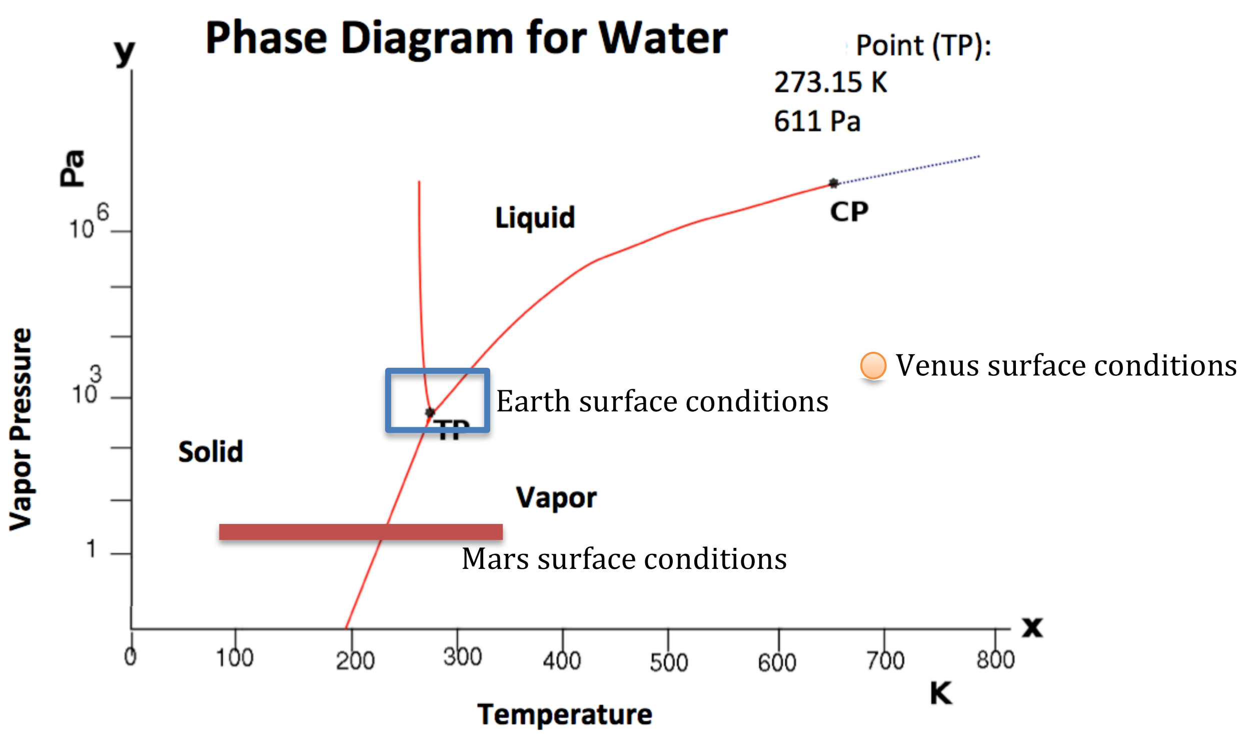
Lab Week 2 – Phase Changes and Water Behavior

Question 1: Liquid, Solid or Vapor?

a) Plot the following on the provided phase diagram using any resources available:

Earth at sea level
Martian surface on the equator during summer
Martian surface at the North Pole during winter
Venus surface

Hint: $P_v = VMR \times P_a$
P_v = vapor pressure
VMR = Volumetric Mixing Ratio
(amount of water in atmosphere)
P_a = atmospheric pressure



For Earth at sea level:

$$P_v = VMR \times P_a = 0.04 \times 101325 \text{ Pa} = 4000 \text{ Pa}$$

Our values are based on the definition of standard pressure and the maximum amount of water vapor that is present in Earth's atmosphere, which is about 4% (common knowledge). Water vapor and temperature vary about 0-4% and $\pm$40°C (from 0°C) on Earth's surface. This means that our plot for Terran conditions is right around the TP.

For the surface of Venus:

$P_v = VMR \times P_a = 4 \times 10^{-4} \times 10^7 \text{ Pa} = 4000 \text{ Pa}$

Here we have to dig a little deeper, but several space probes visited Venus in the 1970s and remote-sensing data (brightness temperatures) and modeling are also useful. One such manuscript that presents a range of values is:

Lewis, J. S., 1970. Venus: Atmospheric and Lithospheric Composition. Earth and Planetary Science Letters 10, 73–80.

For this exercise the exact values are not crucial, and I choose values in the middle of the range of direct measurements (collected at very few points and possible not representative of true surface conditions) and remote-sensing measurements (which require calibrations which may be especially dubious through the thick Venusian atmosphere). Reasonable values for surface temperature, surface pressure, and water vapor volumetric mixing ratio are 700 K, 100 bar = 10 MPa, and 4×10^{-4}, respectively.

For any reasonable range of values, conditions are still well within the sector of the phase diagram where only water vapor is a stable phase for the water molecules.

For the surface of Mars:

$P_v = VMR \times P_a = 4 \times 10^{-3} \times 10^3 \text{ Pa} = 4 \text{ Pa}$

For this exercise, we consider pressures at low elevations and higher values of water vapor volumetric mixing ratio, which will serve as an upper bound on the vapor pressure (thus we are looking conditions that are the most favorable possible for the presence of liquid water).

Like Venus, many spacecraft (including numerous rovers) have visited the Martian surface and made direct measurements. There are also a plethora of peer-reviewed remote-sensing and modeling studies that are easily searchable using Google Scholar or Web or Science. A few that I found useful for this exercise are:

Hecht, M. E., 2002. Metastability of Liquid Water on Mars. Icarus 156(2), 373–386.

Savijarvi, H., 2006. A model study of the atmospheric boundary layer in the Mars pathfinder lander conditions. Quarterly Journal of the Royal Meteorological Society 125, 483–493.

Maltagliati, L., F. Montmessin, A. Fedorova, O. Korablev, F. Forget, and J.-L. Bertaux, 2011. Evidence of Water vapor in Excess of Saturation in the Atmosphere of Mars. Science 333(6051), 1868–1871, doi: 10.1126/science.1207957.

Surface temperatures on Mars range between about 120 K to 310 K. Even though it can get quite warm on Mars, vapor pressures are low enough that if there is ephemerally liquid water from melting ice at low latitudes in summer, it quickly reverts to the vapor phase, leaving no liquid water on the surface.

b) Based on your calculations, what phases of water are stable on the Earth's surface? Martian surface? Venusian surface?

On Earth's surface, liquid water, water vapor, and ice Ih (normal hexagonal ice with ABAB stacking) are all stable.

On the surface of Venus, only water vapor is stable.

On the surface of Mars, water vapor and ice Ih (normal hexagonal ice with ABAB stacking) are stable.

c) The Phoenix Martian Lander has observed vapor water pressures over 100 times of what is expected from your calculation in part a). Given that information, is liquid water stable on Mars? Why?

If water vapors were a few hundred times higher, conditions would approach that of the triple point. For the values we used, the vapor pressure would still be slightly below that of the triple point. One might entertain the thought that for all combinations of values within the complete range of temperatures and vapor pressures observed, conditions might at times approach the triple point. The data from the surface probes, however, indicate that the ambient surface conditions in summer, even during warm and humid periods, never remain near the triple point very long, and any liquid water that would from, quickly changes to the vapor phase.

d) There has been some recent evidence for flowing liquid water on Mars that quickly disappears. How is liquid water possible given what you know?

Given the conditions explored above, it is not possibly for liquid water to persist on the Martian surface in sufficient quantities or durations to flow. However, if subsurface ice melted in summer and was mixed with salts, the saturation vapor pressure curve for water would be depressed with respect to both temperature and pressure, allowing water to possibly persist sufficiently long to flow.

A peer-reviewed manuscript that reviews this evidence is:

Ojha, L., M. B. Wilhelm, S. L. Murchie, A. S. McEwen, J. J. Wray, J. Hanley, M. Masse, and M. Chojnacki, 2015. Spectral evidence for hydrated salts in recurring slope linae on Mars. Nature Geoscience 8, 829–832, doi: 10.1039/ngeo02546.