LIQUID PHASE EQUILIBRIA FOR HABITABILITY. Sugata P. Tan, Planetary Science Institute, Tucson, AZ (mailing address: 1043 Boswell Dr., Laramie, WY 82070; e-mail address: stan@psi.edu).

Introduction: Unlike gas and solid phases, which are ubiquitous in the Universe, liquid phase only exists in very narrow ranges of temperature and pressure (see Fig. 1). Therefore, it is not surprising that liquid phase is rarely found even in the Solar System. Only Earth and Titan, which is the largest moon of Saturn, have liquids on their surfaces. Other bodies that have liquids must keep them under surface, even if the body supposedly lies within the habitable zone (e.g. Mars).

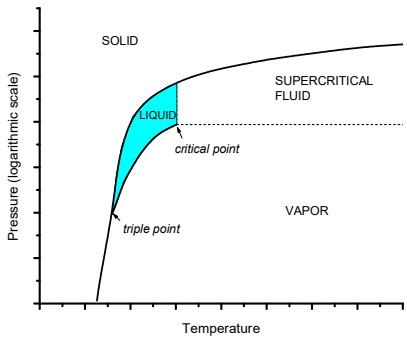

Fig. 1. Typical phase diagram of pure substance: liquid phase occupies small ranges of temperature and pressure (blue region). Mixtures have similar behavior.

It has been widely recognized in the scientific community that water is not an absolute condition for the existence of life, though it is the case on Earth for life as we know it. However, it is hard to believe a life form without liquids, because the other phases (gas and solids) do not have properties to support the operation of most biochemical processes and metabolism of life beings. Unless the beings do not have physical bodies, they need liquids in their flesh, even though not necessarily water. Therefore, it is also common to assume that life first emerged in liquids before evolving to more advanced form on land.

It is an observable fact that planetary bodies, in the Solar System and beyond, revolve around their parent stars. This motion introduces climate patterns to most of the bodies, in which the temperature and pressure change accordingly and affect the atmospheres and their interaction with the surfaces. On Earth, these changes lead to phase changes of the existing liquid, i.e., water; becoming vapor in hot days and solid ice in winter. The solid must not jeopardize any beings that live in liquids. The only phase behavior that can protect life from complete solidification is the density inversion where the density of solid is less than that of its liquid; on Earth water ice floats in water. The solid that sits on the liquid surface is the heat insulator that keeps the liquid from freezing due to the coldness of winter.

In this presentation, Titan's fluid will be used as an example for analyses, whether or not the liquid phase can persist in extremely cold weather and whether it undergoes density inversion in the case of solid formation. Study of the fluid in the example is complementary to our knowledge of water on Earth.

Method: The analysis tool is a thermodynamic equation of state (EOS) known as CRYOCHEM [1,2] that has been successfully applied to describe Titan's surface liquids in the seas [3] and solid solutions in the tropopause [4]. In near future, when the atmospheric chemical composition and temperature/pressure profile of extraterrestrial bodies, including exoplanets, are reliably measured, these data are all the input that the EOS needs to analyze the phase behavior of the atmospheres and any liquids that may exist on the surface. The existence of liquid phase predicted by the EOS, even if it is non-water liquid, would amplify the habitability of the body, perhaps by an exotic physical life form unknown to us as of today. The EOS offers a useful tool in the search of habitable worlds in many years to come before interstellar travel is possible.

Titan's liquid. It was shown that Titan's liquid is in thermodynamic equilibrium with the atmosphere [1,3]. The whole atmosphere is subject to condensation into liquid or solid phases as it consists of mainly nitrogen and methane and has extremely low surface temperature of about 90 K in the northern polar region that hosts most of Titan's lakes/seas. The liquid is dominated by methane, ethane, and nitrogen [3,5]. It will be discussed in the presentation that Titan's fluid may be sufficiently modeled as a mixture of these three components.

Extremely cold liquids. It can be shown that it is possible to encounter liquid phase in nitrogen/methane/ethane atmospheres at an extreme condition, e.g. 62 K and low pressure of 0.1 bars. This is counterintutitive as the condition generally allows only vapor and solid phases. It would give wider range of conditions where liquid phase can exist, the implication of which for the limiting conditions of habitability in distant worlds may be subsequently inferred.

References: [1] Tan S. P. et al. (2013) *Icarus, 222,* 53–72. [2] Tan S. P. et al. (2013) *Fluid Phase Equilib., 360,* 320-331. [3] Tan S. P. et al. (2015) *Icarus, 250,* 64–75. [4] Tan S. P. et al. (2016) *AGU Fall Meeting,* Paper # P53B-2207. [5] Mastrogiuseppe M. et al. (2013) *Geophys. Res. Lett*., 41, 1432-1437.