PRELIMINARY VENUSIAN FROST LINE CALCULATIONS REGARDING SURFACE-ATMOSPHERE INTERACTIONS. S. T. Port[1], G. Hashimoto[2], [1]University of Arkansas, Fayetteville, AR, 72701; saraport@email.uark.edu, [2] Okayama University, Okayama, Japan

Introduction: Though the abundance of sulfur dioxide (SO_2) in the Venusian atmosphere is relatively high, around 130-180 ppm, its interactions with the surface and other atmospheric gases is not well understood [1-4]. SO_2 is a greenhouse gas, and may influence the temperature of Venus [4-6], but its strength as such has not been well studied. In addition, SO_2 would also have a hand in cooling the planet due to it being a precursor for H_2SO_4, a high albedo compound known for deflecting incoming solar radiation [5-9] and comprises 75% of the clouds found on Venus [5-8].

If we assume that Venus is in equilibrium, then there must be sulfur containing minerals on the surface to balance with the atmosphere. Studies of the Venusian surface have shown high radar reflective material at the mountain tops of Venus [10-11]. The altitude where the reflectivity changes depends on the mountain range, but can be found between 2.5-4.75 km in altitude [12]. One of the more well discussed and debated sources of the signal is pyrite (FeS_2) [10,12]. Pyrite is sensitive to temperature and has a high enough dielectric constant to explain the signal [10,12]. Therefore, we assume that it is the source of the radar reflective material, and that SO_2 abundance is controlled by the Pyrite-Magnetite buffer:

$3FeS_2 + 16CO_2(g) = Fe_3O_4 + 6SO_2(g) + 16CO(g)$. Anything below the critical altitude, also known as the frost line, will be converted into magnetite (Fe_3O_4) [5,12-14].

We expect that Venus is not static and has undergone periods of heating and cooling [9]. Thus, our aim was to observe how a surface temperature change would affect Venus through characterizing the critical altitude where the radar signal first changes, the SO_2 concentration, the temperature profile of the atmosphere, and the radiative flux of the atmosphere.

Methods: Several programs coded in Fortran were used to complete our research. Here we studied surface-atmosphere interactions. In the future we plan to study the effect of temperature on the radiative flux of the atmosphere.

In the surface - atmosphere interaction calculations we used the core gases studied by Krasnopolsky, 2007 [15]: CO_2, N_2, SO_2, HCl, CO, COS, HF, and NO. The surface only contained two minerals, as we assumed that all iron was found in either pyrite or magnetite. Our temperature profiles were modeled after VIRA, but calculated to fit an adiabatic curve to the top of the troposphere. We assumed that on Venus pyrite is stable when SO_2 is 130 ppm, therefore based on the initial parameters we inputted into the code, we were able to set the frost line to be at 3.35 km, close to the average on Venus. We then increased the surface temperature to determine where the frost line would change in altitude. This required the combined use of the code, and an equation taken from Hashimoto et al., 2000 [5], $S_{tot}=S_{atm}+S_{max}(Hz_{py})$. S_{tot} is the total abundance of sulfur found in SO_2 and pyrite on Venus, S_{atm} is the total amount of SO_2, S_{max} is the maximum possible abundance of sulfur that can be found in pyrite, and Hz_{py} is the percent area above the critical altitude. This method also informed us on the SO_2 abundance at the new frost line. Our tested surface temperature range was between 722 and 765 K.

Table 1: Atmospheric composition used to study the lower atmosphere to determine the frost line.

CO_2	0.965
N_2	0.034
SO_2	1.3E-4
COS	2.7E-5
H_2O	3.0E-5
CO	8.0E-6
HCl	5.0E-7
HF	5.0E-9
NO	5.5E-9

Results: There was a direct correlation between surface temperature and the altitude of the frost line. As the temperature increased the frost line moved upwards and the amount of SO_2 found in the atmosphere increased. An increase in surface temperature of around 10 degrees K resulted in a shift of 0.16 km, meanwhile an increase in 30 degrees K moved it up 0.88 km. A drop of 10 degrees K brought the frost line down 0.09 km.

Discussion: When calculating the frost line and the SO_2 concentration in the lower atmosphere we had some difficulty with the CO abundance. Past studies have stated that CO is very low in abundance in the lower atmosphere, approximately 15–17 ppm [16-17]. When we used the program to calculate the CO abundance at equilibrium, we only included gaseous compounds, and found that CO should be around 5 ppm at the surface, and decrease with altitude. To amend this issue, CO was fixed at 8 ppm before we began to study the surface/atmosphere interactions. In the future we plan to remedy this issue by altering the code to increase CO to a higher abundance that better reflects conditions found on Venus.

As stated previously, the new frost line was determined via the code and by $S_{tot}=S_{atm}+S_{max}(Hz_{py})$. This allowed us to evaluate where the frost line would be in equilibrium. Due to the interactive nature of the surface and atmosphere, by increasing the surface temperature, the frost line moves up in altitude, and also releases more SO_2, causing the frost line to move again, but further down in altitude. This process then decreases the amount of SO_2 in the atmosphere which causes the frost line to move upwards, etc. Using both methods we determined where the frost line would settle and how much SO_2 would be present in the atmosphere.

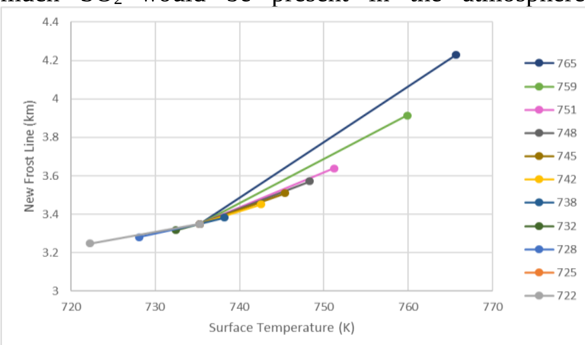

Figure 1: Preliminary data on the change in altitude of the frost line with shifting surface temperatures. Higher surface temperature resulted in a higher altitude, while a lower surface temperature resulted in a lower altitude.

An increase in surface temperature resulted in a larger change in altitude, than a cooling of the surface. This is expected as there is more surface area at a lower elevation, thus the frost line does not move as drastically.

It is important to note that we do not know if pyrite exists on the surface of Venus. Experiments completed in the past have argued that pyrite cannot be stable on Venus for any appreciable amount of time [13]. Therefore if pyrite truly is not present on Venus, then the SO_2 concentration will not be buffered by the pyrite-magnetite buffer, but by some other unknown buffer. Thus it is vital for future missions to determine if pyrite is present on Venus.

Conclusion: Our preliminary results indicate a solid initial step on determining the effect of varying the surface temperature on Venus. In the future we plan to observe the effects of varying surface temperature on the SO_2 concentration and on the longwave outgoing radiation on Venus. Venus has undergone periods of climate change in its past, and our final results may give clues as to if Venus has undergone any changes in climate in its recent past.

Acknowledgments: This work was funded by the NSF: EAPSI program, JSPS, and by the Sturgis International Fellowship.

References: [1] Prinn, R. G. (1985) *The Photochemistry of Atmospheres* (J. S. Levine, Ed.), pp. 281–336. Academic Press, New York. [2] Von Zahn et al. (1983) *Venus* pp. 299-430. Univ. of Arizona Press, Tucson. [3] Pollack, J.B., et al., (1993) *Icarus*, 103, 1-42 [4] Bezard, B., et al, (1993) *Geophys. Res. Letters*, 20, 15, 1587-1590 [5] Hashimoto, G. L., and Abe, Y. (2000) *Earth Planets Space*, 52, 197-202. [6] Taylor, F.W., (2010) *Planetary Atmospheres* pp. 141-144. Oxford University Press, New York [7] Krasnopolsky, V.A., and Parshev, V.A., (1983) *Venus* pp. 431-458. Univ. of Arizona Press, Tucson. [8] Fegley, B., et al., (1995) *Icarus*, 115, 159-180 [9] Bullock, M. A. and Grinspoon, D. (2001) *Icarus*. 150. 19–37. [10] Pettengill, G.H., Ford, P.G. and Nozette, S. (1982) *Science* 217, 640-642. [11] Ford, P.G., and Pettengill, G.H. (1983) *Science*, 220, 1379-1381 [12] Klose, K.B., Wood J.A., and Hashimoto, A. (1992) *J. Geophys. Res.* 97, 16353-16369. [13] Fegley Jr., B. and Treiman, A.H. (1992) *AGU, Geophys. Monograph No. 66*,7-71. [14] Zolotov, M.Y., *LPSC XXII* 1569-1570. [15] Krasnopolsky, V.A. (2007). *Icarus*. 91. 25-37. [16] Fegley Jr., B. (1997) *Icarus*, 128, 474-479. [17] Krasnopolsky, V.A., and Parshev, V.A., (1979) *Cosmic Re.*, 17, 630-637