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A view to the possible habitability of ancient Venus over three billion years

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Abstract

The canonical view of Venus' climate history describes a world that has spent most of its history with surface liquid water, plate tectonics, and subsequently a stable temperate climate akin to that of Earth through much of its own hisory. Part of the rationale for this optimistic scenario is due to the high deuterium to hydrogen ratio measured by Pioneer Venus that may imply that Venus had a shallow ocean's worth of water until its global resurfacing event drove it into a runaway greenhouse state (see Figure 1). However, a dearth of observational data due to a lack of space missions to Venus has made this claim extremely hard to discount or confirm. Via a series of 3-D GCM simulations we demonstrate the viability of the canonical model using the data available to us today. We will also attempt to justify some of the assumptions given for the canonical model's viewpoint and in our 3-D simulations.

1. Introduction

The long-term evolutionary history of Venus' climate largely remains a mystery. This is because much of its ancient surface remains hidden to us and there is a lack of in-situ heavy noble gas isotope measurements (Kr & Xe) to constrain its water history. At the same time the work of [1] demonstrates two possible early evolutionary pathways. In the first scenario (Type 1) the surface of Venus' magma ocean crystallizes on a time scale similar to that of Earth's (approx. 10^6 years). This makes it possible to condense water on the surface of a cooled crystallized crust albeit at initially high pressures and temperatures as in Earth's early history [2]. In the second scenario (Type II) Venus loses all of its primordial water in its early history because of a long-lived magma ocean (~100 Myr) and steam atmosphere which is mostly lost to space. However recent work by [3]. shows that a large fraction of Earth's present-day water inventory may have come from the LHB and Late Veneer, and the same could have been true for Venus. Hence if Venus starts out as Type II but the magma ocean crystallizes by the time of the LHB and Late Veneer it still may have had enough condensable water on its surface for a shallow ocean and a habitable climate like that shown in [4]. A caveat to this scenario is that its primordial rotation rate needs to be slower than a 16-day long Earth sidereal day. A slow rotation rate early in its history may also be bolstered by recent work [5] showing that a shallow ocean may slow the rotation rapidly (of order millions of years) due to ocean tidal friction in the same way recent work has shown that modern Venus' atmosphere acts on its solid body to change its rotation rate [6].

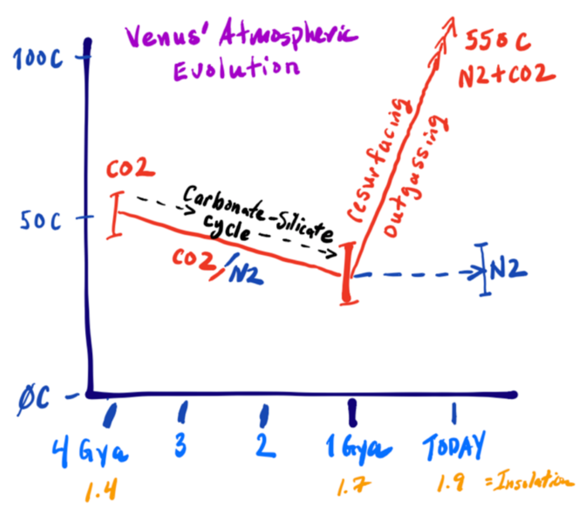

Figure 1: Venus' possible climate evolution

2. Methods

We have completed an ensemble of simulations using ROCKE-3D [7] a 3-D General Circulation Model. The simulations include four topography types: a.) Modern Venus Topography with a 310m water equivalent layer (WEL) deep ocean spread in the

lowest lying basins with resulting low latitude continents.
b.) Modern Venus Topography with 10m WEL.
c.) Modern Earth Topography w/a 310m deep ocean
d.) An Aquaplanet Topography of 158m depth. Each of these 4 simulations were run at 3 different epochs: 4.2 Giga-years ago (Gya), 0.715Gya and present day. These correspond to present day Earth insolation (1361 W/m^2) multiples of 1.4, 1.71 and 1.9. All use modern Venus orbital parameters and rotation rate. All atmospheres are 1bar pressure. However, the 4.2Gya simulations atmosphere consists of 90% CO_2 and 10% N_2, while those at 0.715 and present day utilize a modern Earth-like N_2 dominated atmosphere with 400ppmv CO_2 and 1ppmv CH_4. See Table 1. The rationale for these choices are informed by how we think the Earth's atmosphere may have evolved over the past 4Gy; starting out with a CO_2 dominated atmosphere and becoming N_2 dominated via the carbonate-silicate cycle.

Table 1: Venus simulation summary

Sim	S0X/Epoch$^+$	Topo/Atmosphere$^\#$	Atm*
A	1.4/4.2Gya	a,b,c,d	CO_2-N_2
B	1.7/0.7Gya	a,b,c,d	N_2
C	1.9/0.0Gya	a,b,c,d	N_2

+: S0X=multiple of present day Earth insolation (S0X=1=1361W/m^2)
#: See Methods section
: CO_2-N_2 = 90% CO_2, 10% N_2. N_2 = N_2 dominated with 400ppmv CO_2, 1ppmv CH_4.

(2)

3. Summary and Conclusions

A sketch of the simulation results for the global mean temperature as a function of insolation/time are shown in Figure 1. The take-away message is simple: why doesn't present day Venus have a mean surface temperature in the range of ~20-40C? Our hypothesis is that Venus may have had a stable climate for billions of years with a carbonate-silicate cycle similar to that of Earth. It is possible that the near-global resurfacing we see today that took place approximately 750Mya is responsible for its present- day climate. Major overturn events, or a proliferation of Large Igneous Provinces over millions of years [8,9] could have turned Venus' once stable temperate climate into the CO_2 dominated hot house of today.

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