Large Equatorial Seasonal Cycle during Marinoan Snowball Earth

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In the equatorial regions on Earth today, the seasonal cycle of the monthly mean surface air temperature is <10°C. However, deep (>1 m) sand wedges were found near the paleoequator in the Marinoan glaciogenic deposits at ~635 million years ago, indicating a large seasonal cycle (probably >30°C). Such observations have been used to argue that the Earth had a very high obliquity (>54°) during that time, leading to the proposal of high-obliquity hypothesis. Although the hypothesis was criticized for not being able to find a mechanism for the Earth to return to a low-obliquity state, there was no other explanation for the observed large equatorial seasonal cycle. Through numerical simulations, we show that the equatorial seasonal cycle could reach >30°C at various continental locations if the oceans are completely frozen over, as would have been the case for a snowball Earth, or could reach ~20°C if the oceans are not completely frozen over, as would have been the case for a waterbelt Earth or slushball Earth. It is pointed out that the eccentricity is important for the equatorial seasonal cycle especially when the climate is cold and dry. These large equatorial seasonal cycle above are obtained at the maximum eccentricity of the Earth orbit, i.e., 0.0679, and will be approximately 10°C smaller if the present-day eccentricity is used. For these seasonal cycles, theoretical calculations show that the deep sand wedges form readily in a snowball Earth while hardly form in a waterbelt Earth. Therefore, our results remove a loophole of the (hard) snowball Earth hypothesis, while make the waterbelt Earth and high-obliquity Earth hypotheses much less appealing.