GLACIATION ESCAPE ON EARTH-LIKE PLANETS LIMITED BY CO₂ CONDENSATION. M. Turbet¹, F. Forget¹, J. Leconte², G. Tobie³, B. Charnay⁴, F. Selsis² & E. Bolmont⁵. ¹Laboratoire de Météorologie Dynamique, IPSL, UPMC (martin.turbet@lmd.jussieu.fr), ²Laboratoire d’astrophysique de Bordeaux; ³Laboratoire de Planétologie et Géodynamique. ⁴LESIA, Observatoire de Paris. ⁵Laboratoire AIM Paris-Saclay, CEA/DRF.

Introduction: It is widely considered that the carbonate-silicate cycle [1] is the main agent - through volcanism - to trigger deglaciations by CO₂ greenhouse warming on Earth and by extension on Earth-like planets, when they get in frozen state. We use the LMD-G 3D Global Climate Model (with both CO₂ and H₂O cycles) to simulate the ability of planets initially completely frozen to escape from glaciation episodes by accumulating enough gaseous CO₂ [2,3].

Around a Sun-like star: We find that planets that are initially completely frozen and which accumulate CO₂ through volcanism can evolve in different climate regimes depending on their insolation and obliquity. Initially the greenhouse effect of CO₂ is too weak to trigger a deglaciation. The planet stays in a snowball state but keeps accumulating CO₂ in the atmosphere. Then, if CO₂ continues to accumulate, two outcomes are possible 1) The greenhouse effect of CO₂ is sufficient to raise the surface temperatures in equatorial regions above the melting temperature of water ice and the planet escapes from glaciation. 2) The greenhouse effect of CO₂ is too weak to raise the surface temperatures of the poles above the condensation temperature of CO₂ and CO₂ collapses there. The planet is locked in a global glaciated state, with two permanent CO₂ polar ice caps. Quantitatively, we find (see Fig. 1) that planets with Earth-like characteristics orbiting a Sun-like star may never be able to escape from glaciation if their orbital distance is greater than 1.27 AU (62% of the Solar constant), because CO₂ would condense at the poles (the cold traps) forming permanent CO₂ ice caps [2].

Furthermore, for planets with a significant water ice cover, we find that CO₂ ice deposits (1.6x denser than H₂O) should be gravitationally unstable [2,3]. They get buried beneath the water ice cover in geologically short timescale ~10⁶ yr, mainly controlled by the viscosity of water ice. CO₂ could then be permanently sequestered underneath the water ice cover, in the form of CO₂ liquids, CO₂ clathrate hydrates and/or dissolved in subglacial water reservoirs. This would considerably increase the amount of CO₂ trapped and further reduce the probability of deglaciation.

Around a M-dwarf: The water ice bolometric albedo is considerably reduced around cool stars [4], making the scenario of CO₂ polar condensation less efficient. However, planets orbiting M-dwarfs are subject to tidal locking. The temperature on the nightside of a synchronous planet can be extremely low, favoring CO₂ condensation. This possibility, already explored in [3], will be presented at the Habitable Worlds 2017 conference.

Figure 1: Climate regimes reached as function of the distance from a Sun-like star and the CO₂ partial pressure, assuming a cold start [2]. Figures correspond to Earth-like planets with 0/23.5° obliquity (for upper/lower panels, respectively). The red color depicts the region where deglaciation is observed. The blue region represents glaciated states where CO₂ collapses permanently. The white region describes cases where none of this two previous conditions were reached.