On the diversity of terrestrial planets : possible atmospheres, climate modelling and climate unstabilities.

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To prepare a mission like Echo or to address scientific questions like the probability of habitable planets, one has to imagine and conceive the possible atmospheres and climates that may exist on terrestrial planets, including super-Earths. The first key question is related to the volatile inventories and the compositions of the atmospheres. Our experience in the solar system, which contains only a few terrestrial atmospheres and which may well be atypical in the galaxy, is probably not sufficient to tell us about the diversity of possible atmospheres. In fact, in contrast to what is observed in the solar system, recent exoplanets discoveries suggest that there may be a continuum of planetary sizes between Earth-size and Neptune-size bodies. In theory, the nature of a planetary atmosphere depends on complex processes which are difficult to model : origins of volatile, atmospheric escape, geochemistry, long-term photochemistry. Nevertheless, robust physical constrains exists which can help us to speculate on what may or may not exist, depending on the planet size, its final distance for its star and the star type and its activity. Assuming that the atmosphere is known, the possible climates on a given planet around a given star can be explored using Global Climate Models analogous to the ones developed to simulate the Earth climate as well as Mars, Venus, Titan, Triton, Pluto. In spite of the apparent complexity of climate systems, our experience in the solar system suggest that relatively complete and realistic climate simulator can be developed by combining a few components like a “dynamical core”, a radiative transfer solver, a parametrisation of subgrid-scale turbulence and convection, a thermal ground model, and a volatile phase change code. Many of these components can be applied without major changes to various terrestrial planets, and have been tested in various conditions. On this basis we can aspire to build reliable climate predictor for exoplanets. However, whatever the accuracy of the models, predicting the actual climate regime on a specific planet will remain challenging because climate systems are affected by strong positive feedbacks. They can drive planets with very similar forcing and volatile inventory to completely different state. For instance the coupling between temperature, volatile phase changes and radiative properties results in strong instabilities such as runaway glaciations, runaway greenhouse, etc. As of today, an estimation of the diversity of terrestrial atmospheres and climates remains a challenging task. This investigation also shows that a project like Echo, even if it may not be able to characterize the atmosphere of an Earth-like planet in the habitable zone, can address a lot of key questions on the various processes which ultimately control the habitability of planets.