Cloud-convection feedback in brown dwarfs atmosphere

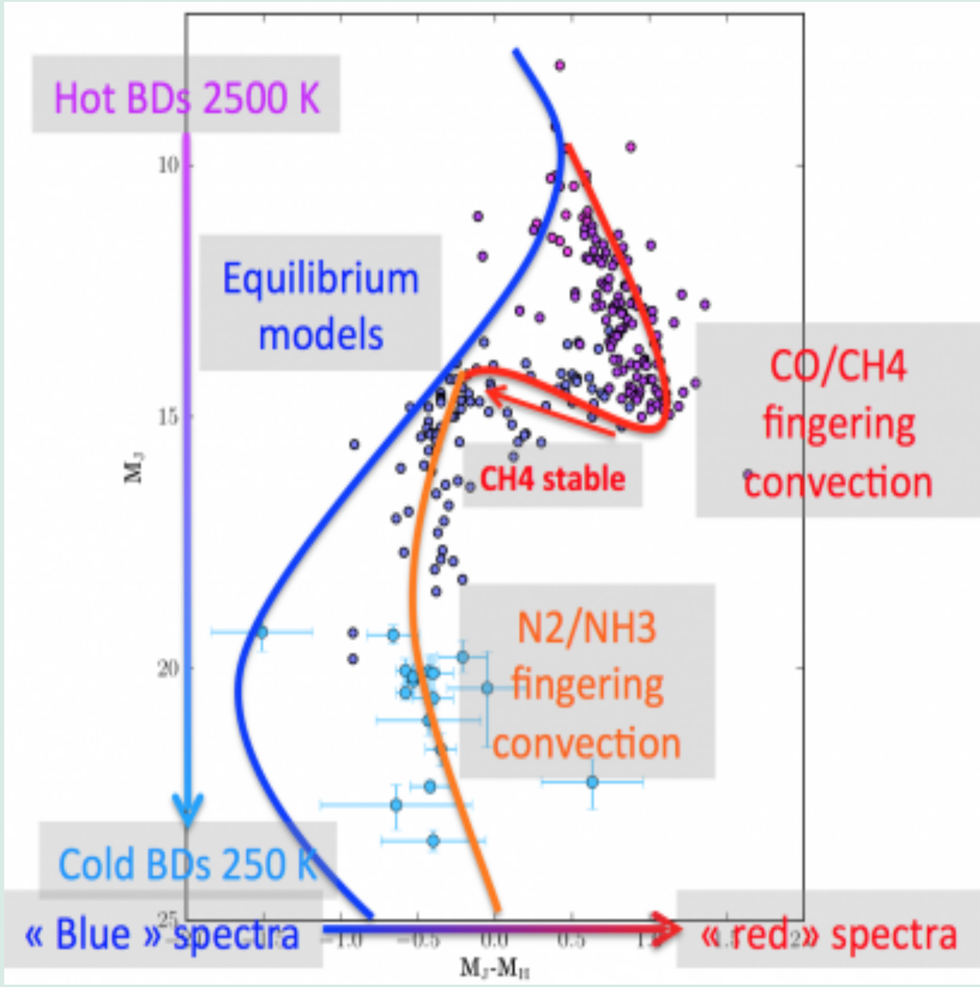
Maxence Lefèvre[1], Xianyu Tan[2], Elsie Lee[3] and Ray Pierrehumbert[4]

[1] LATMOS, SU/IPSL/CNRS/CNES, Paris, France ; [2] Tsung-Dao Lee Institute, Shanghai Jiao Tong University, People's Republic of China ; [3] Center for Space and Habitability, University of Bern, Switzerland ; [4] University of Oxford, UK

Introduction

Numerous observational evidence has suggested the presence of active meteorology in the atmospheres of brown dwarfs. A near-infrared brightness variability has been observed. Clouds have a major role in shaping the thermal structure and spectral properties of these atmospheres. The mechanism of such variability is still unclear, and neither 1D nor global circulation models can fully study this topic due to resolution.

In this study, a convective-resolving model is coupled to gray-band radiative transfer in order to study the coupling between the convective atmosphere and the variability of clouds over a large temperature range with a domain of several hundred kilometers

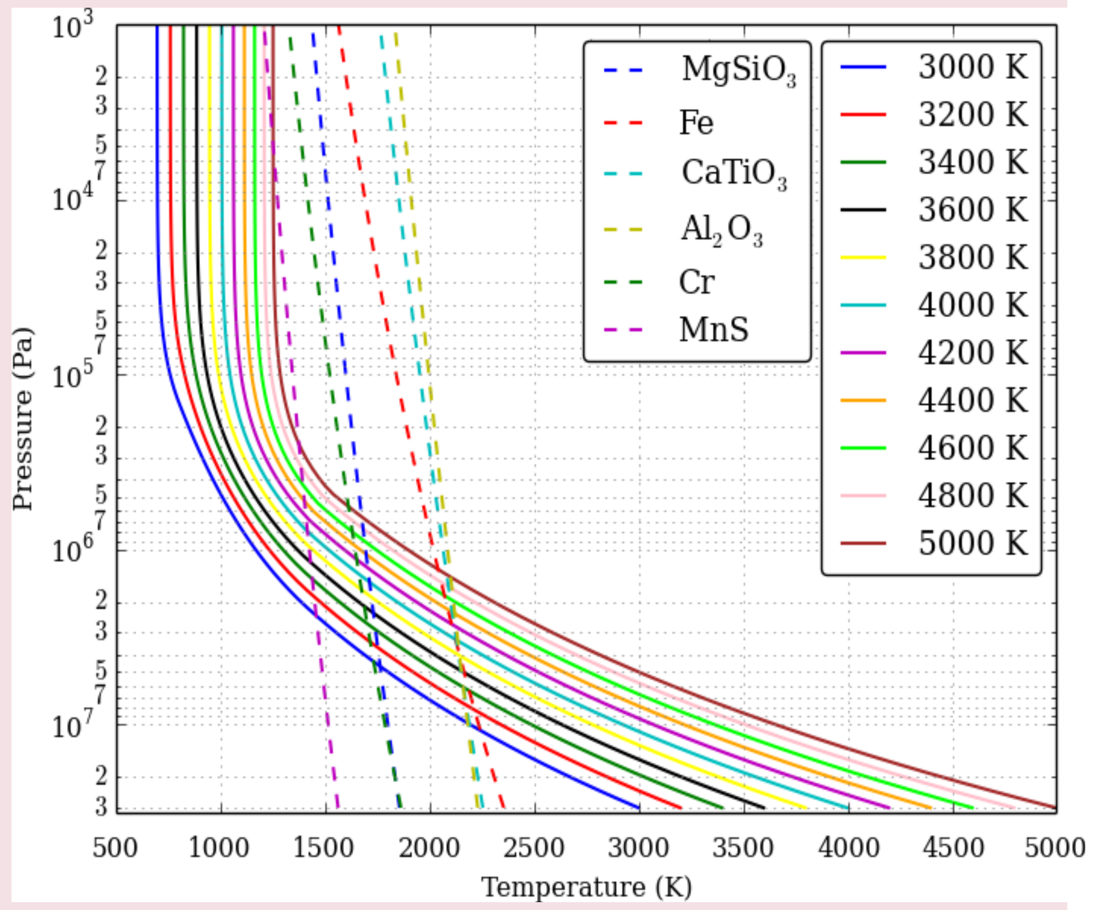


Model description

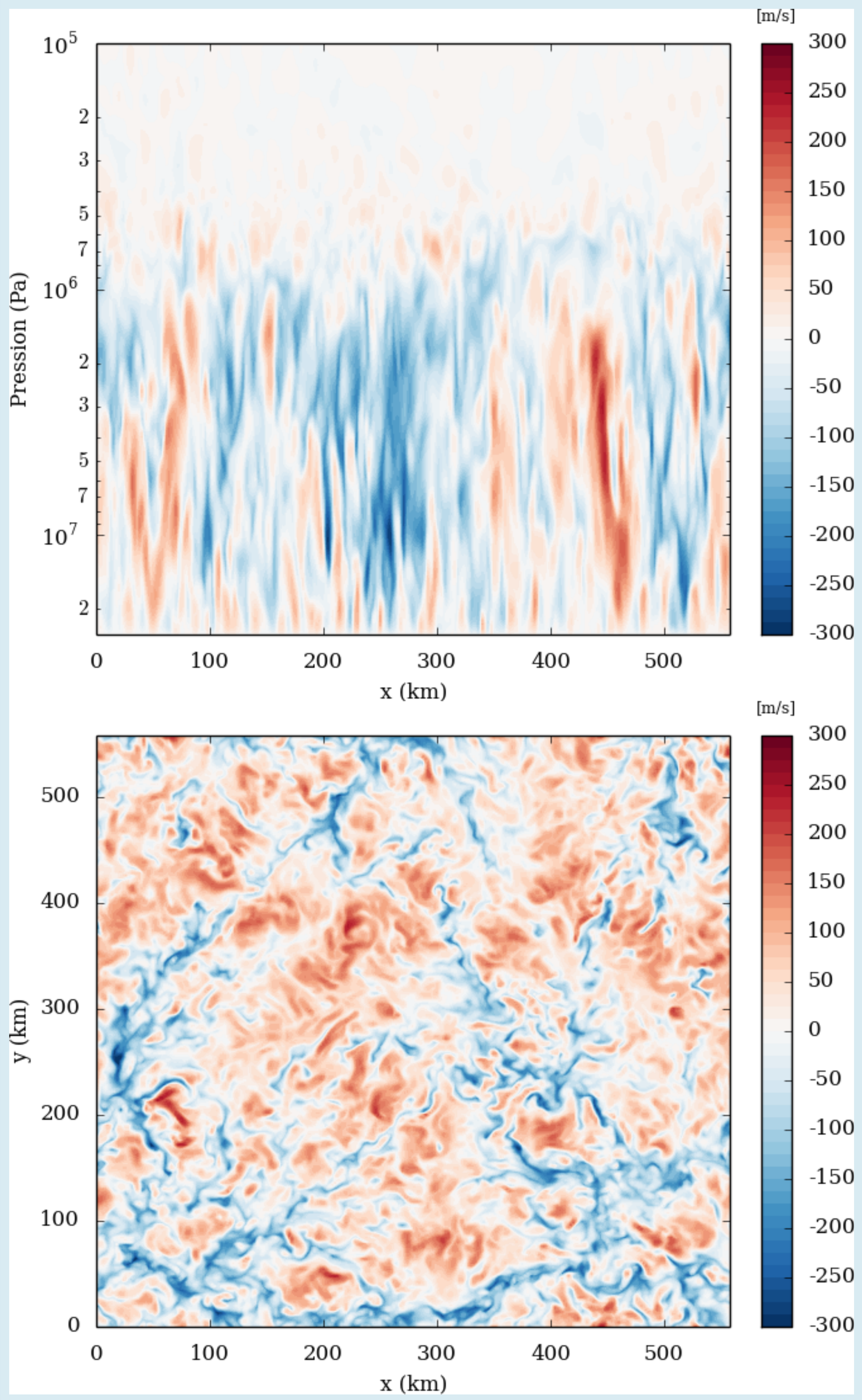
The CRM is using the nonhydrostatic, compressible dynamical core CM1 version 19 (Bryan Fritsch 2002) in Large-Eddy Simulation mode.

The radiative transfer used is a plane-parallel, two-stream approximation, with a gray atmosphere with a single broad thermal band for simplicity and computational efficiency using the numerical package TWOSTR. Absorbing, emitting, and multiple-scattering atmospheres are taken into account. The interactions of cloud particles with radiation by absorption and scattering are parameterized by an extinction coefficient, a scattering coefficient, and an asymmetry parameter.

The transport of condensable gas particles is represented by two tracers, one for the gas phase and one for the condensed phase. In the temperature range considered, four representative clouds that could be affected by convective activity: enstatite, iron, perovskite, and corundum. The cloud particle number N_c is a free parameter set between 10^5 and 10^10, and is assumed constant throughout the atmospheric column. Cloud particles are assumed to immediately reach their terminal fall speed.



Cloud-free Atmosphere

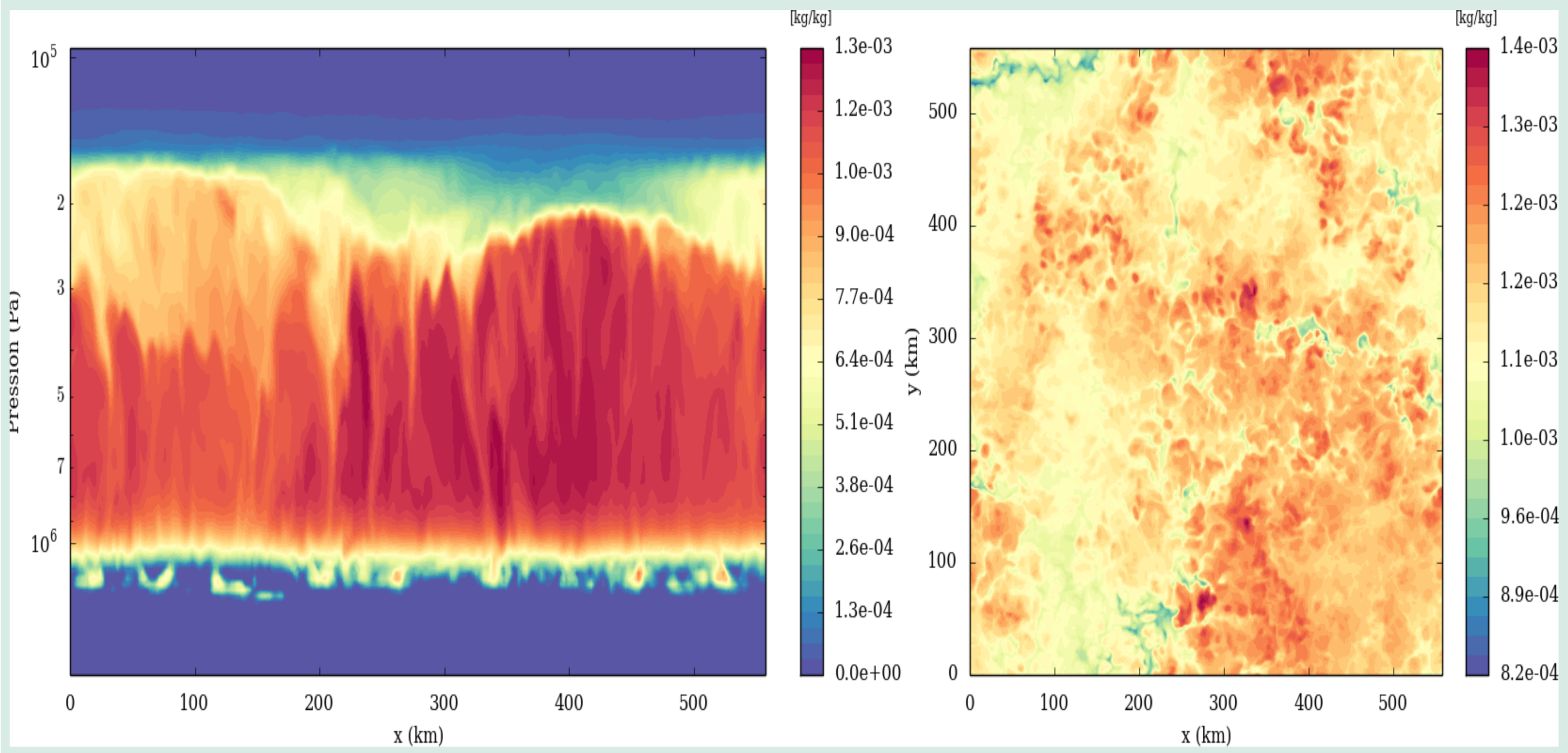


10 different temperature cases:
from 3000 K to 5000 K at the bottom,
i.e. 860 K to 1500 K of effective temperature

The temperature trend has an impact on the convection depth—a hotter atmosphere will exhibit higher vertical wind, with a value six times higher between the two extreme temperature cases presented here. The convective layer organizes itself on the horizontal plane with polygonal cells with a diameter that will vary in temperature, from 80 km at 3000 K to 300 km at 5000 K.

The vertical eddy diffusivity exhibits the same temperature trend as the depth of convection, varying by a factor of 3 between the two extreme temperature cases. The convective layer value is about 10^6 m^2 s^{-1}. This value of 10^6 m^2 s^{-1} is higher than the value obtained by Freytag et al. (2010) with convection-resolving modeling. With mixing-length theory, the estimation of the vertical eddy diffusion is comparable with that of Freytag et al. (2010). This value of the vertical eddy diffusivity in the convective layer is consistent with previous estimations (Lewis et al. 2010; Moses et al. 2011)

Impact of Clouds



Silicate clouds with $MgSiO_3$ are the ones with the most impact. The depth of the convective region is increased by heating at the cloud base, and for a particle radius around 1 μm, this heating destabilizes the atmosphere, leading to an independent detached cloud layer.

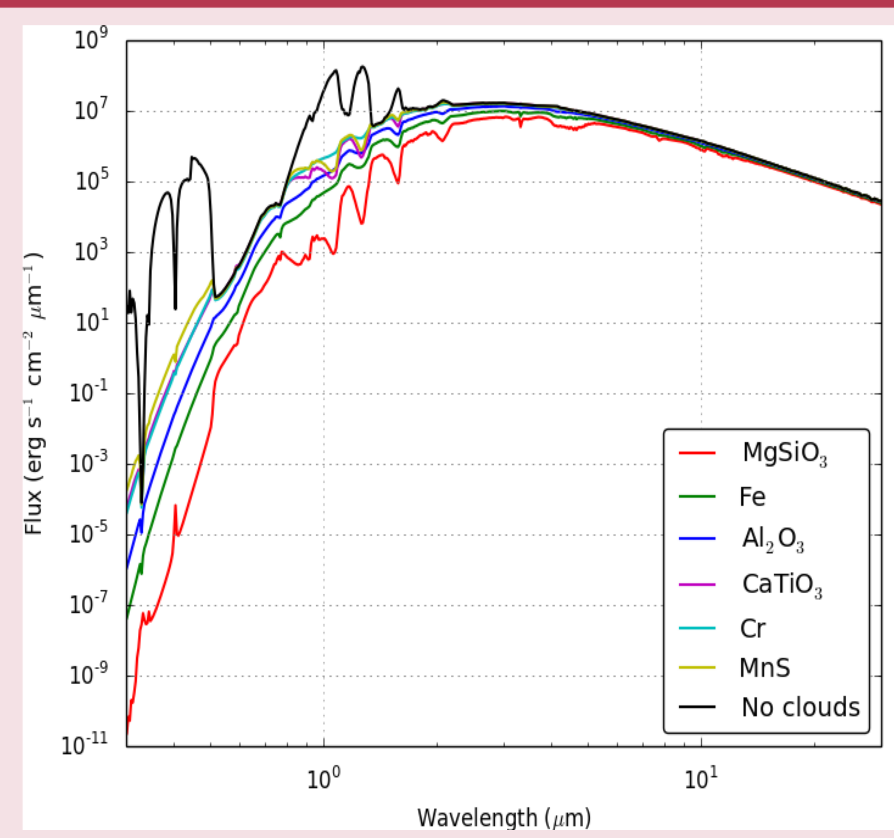
The Fe and Al_2O_3 clouds also have a significant impact on the deep convective layer depth, without engendering a detached cloud-convective layer. However, cloud particles of $CaTiO_3$, Cr, and MnS have limited impact on the convection depth.

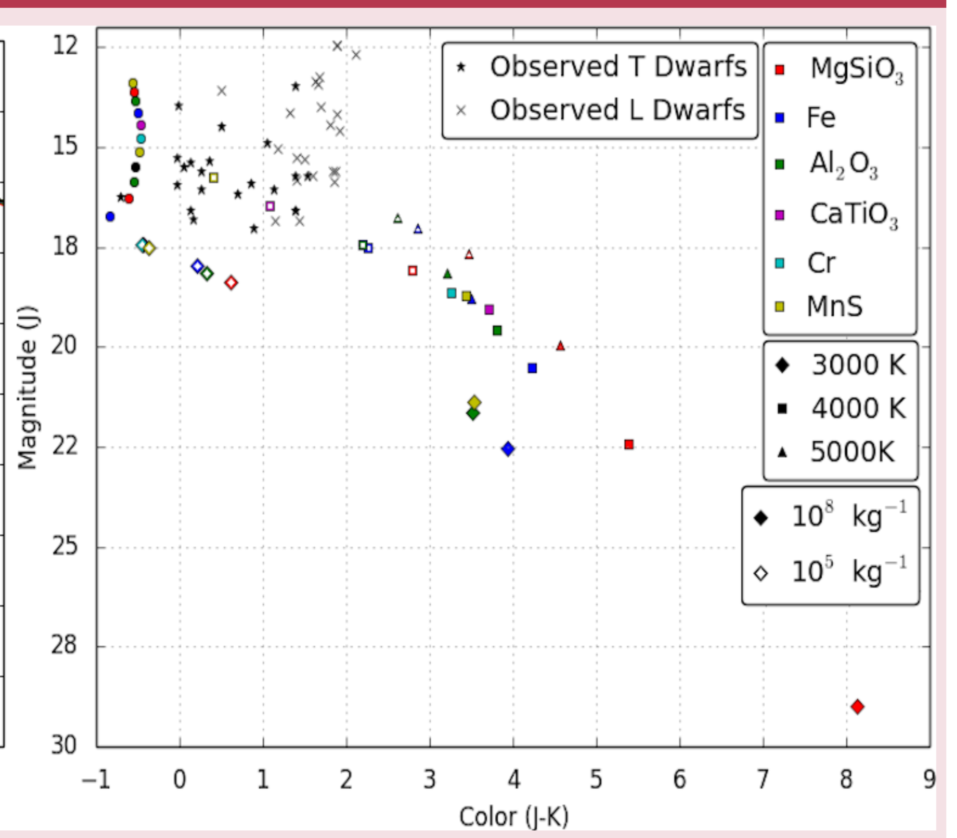
The cloud radius has a significant impact on the presence of cloud holes. For values around 1 μm , there is a complete cloud coverage. The temperature also has an impact on the presence of cloud holes.

Effect on the Emission Spectra

The different cloud composition affects more or less the convection depth and the thermal structure above and therefore impacts the thermal spectra. There is a decrease in the flux amplitude and a smoothing of the spectra due to the clouds. $MgSiO_3$ clouds have the most impact on the emission spectra

Colors of the coldest modeled temperatures are consistent with some observed T dwarfs. The cloud cases have a J magnitude consistent with observed T dwarfs, but with a much redder JK color. There is a strong effect of the cloud particle number density, shown here with 10^5 (empty symbols) and 10^8 kg^{-1}(filled symbols).





Author Contact : maxence.lefevre@latmos.ipsl.fr