Cloud-convection feedback in brown dwarfs atmosphere

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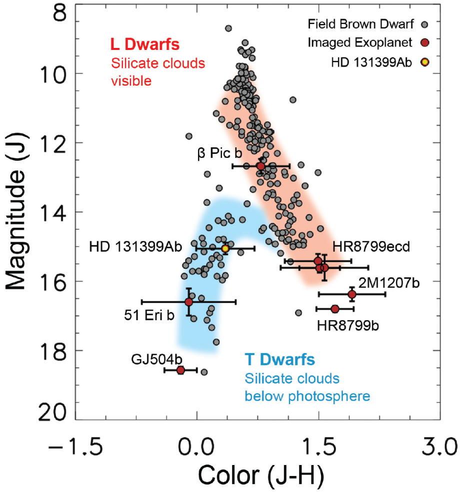
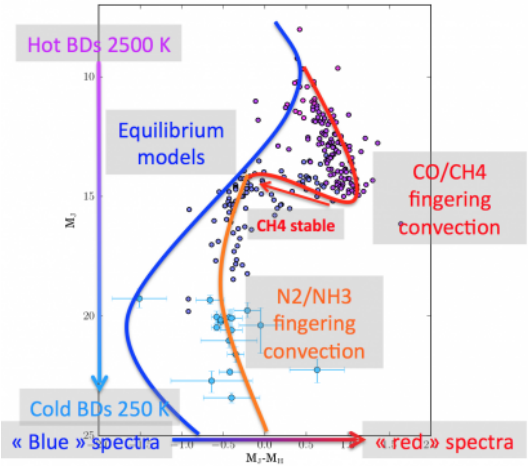
Brown dwarfs Observations

$\sim$ 2000 objects



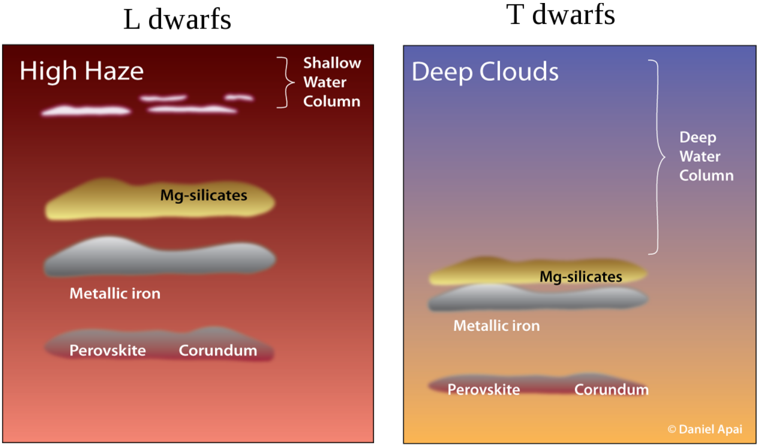
Fingering convection in CH_4/NH_3 changes thermal structure



Tremblin et al. 2015, 2016, 2017, 2019

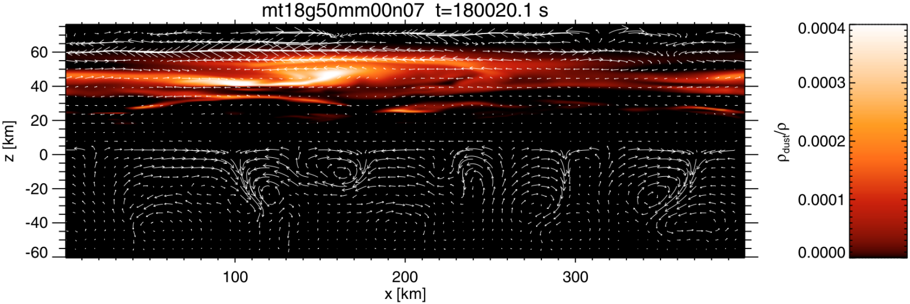
Mechanism

Impact of different cloud coverage



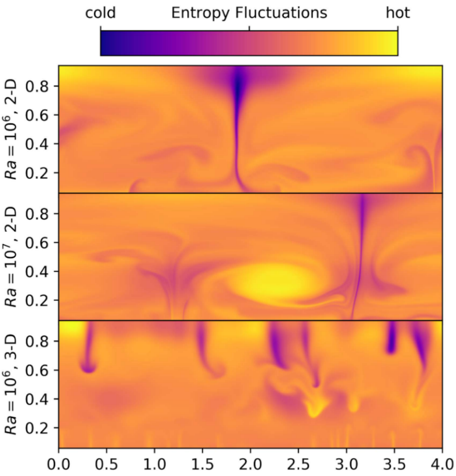
Previous studies

Freytag et al (2010) : 2D



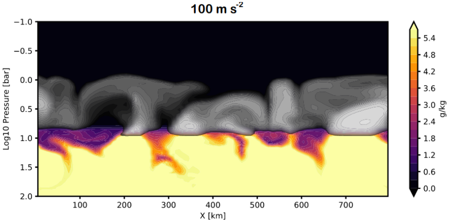
Previous studies

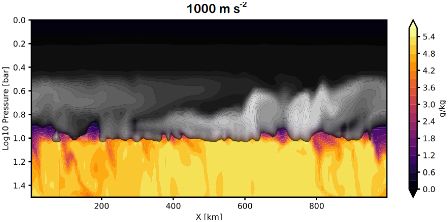
Bordwell et al. (2018) : 3D no clouds



Previous studies

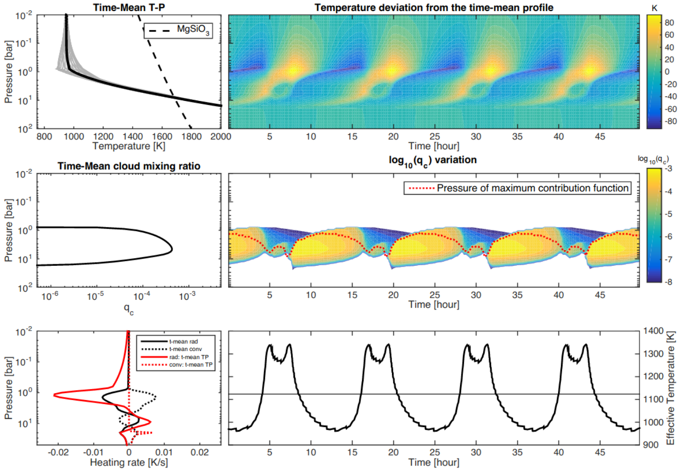
Zhang (2020) : 2D $MgSiO_3$ clouds





Previous studies

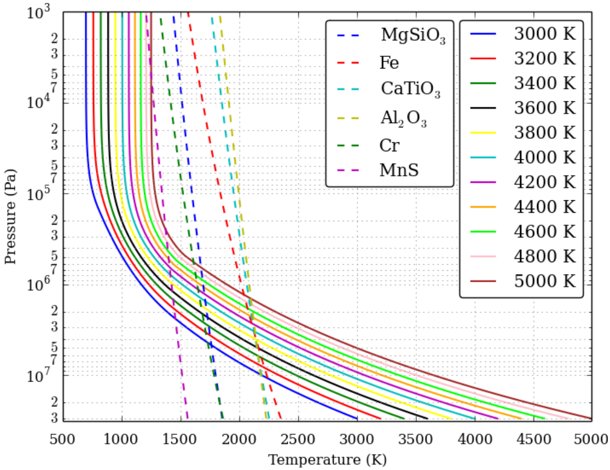
Tan et al. (2019) : 1D $MgSiO_3$ clouds



Modelling

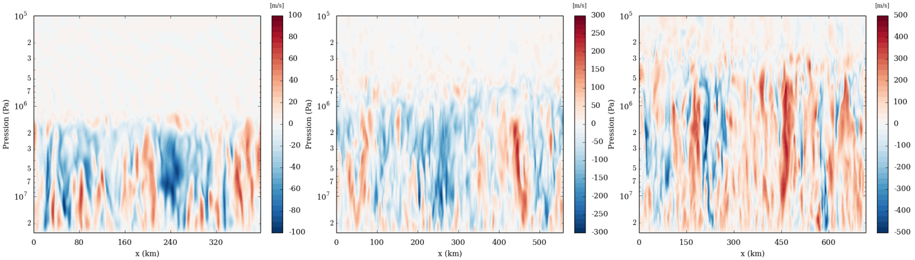
TP profiles

1D from Tan et al. (2019)



No clouds, solar metallicity

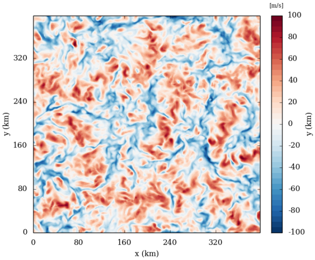
3000 K 4000 K 5000 K



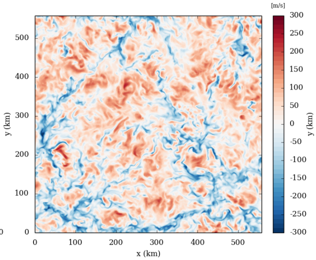
Convective depth increases with temperature

No clouds, solar metallicity

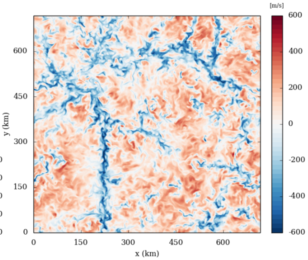
3000 K



4000 K



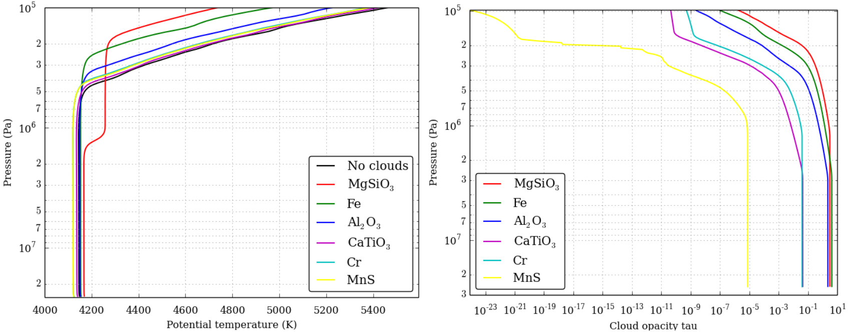
5000 K



Cell diamemeter and vertical wind increase with temperature

Clouds, solar metallicity

4000 K and cloud particle density 10^8 kg^{-1} (free parameter)



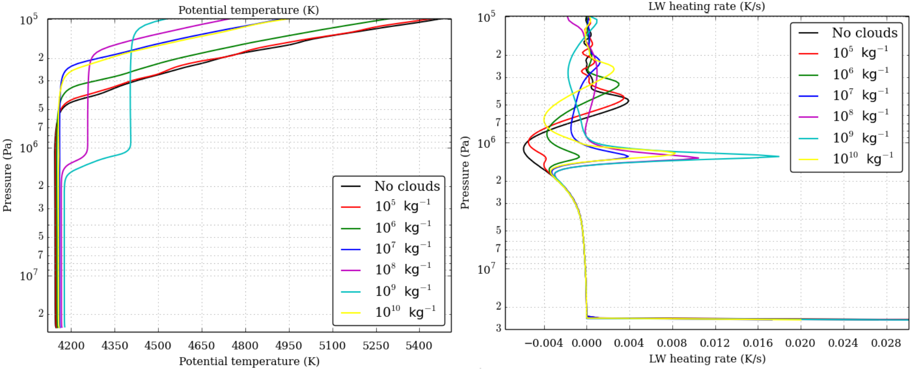
$MgSiO_3$: strong impact

Fe and Al_2O_3 : impact

$CaTiO_3$, Cr and MnS : very few impact (small abundance and thin layer)

$MgSiO_3$ clouds, solar metallicity

4000 K



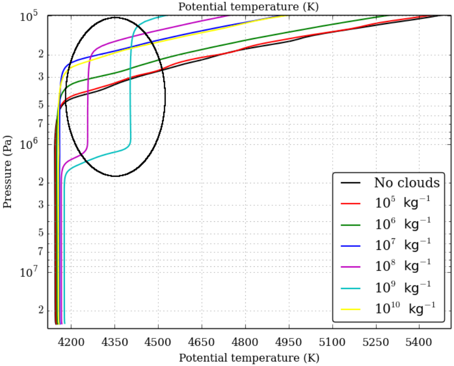
$1e^8$ kg^{-1} and $1e^9$ kg^{-1} cases : datached cloud layer → scattering albedo

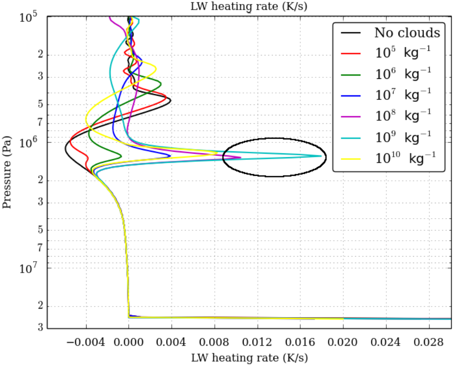
$1e^7$ kg^{-1} and $1e^{10}$ kg^{-1} cases : small impact

$1e^5$ kg^{-1} and $1e^6$ kg^{-1} cases : limited impact

$MgSiO_3$ clouds, solar metallicity

4000 K





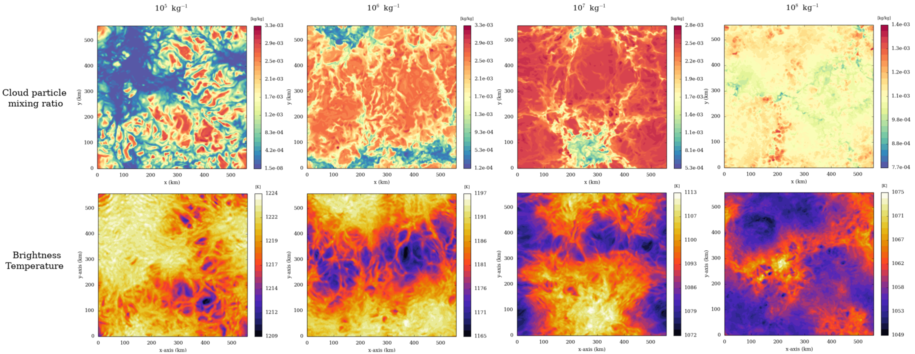
$1e^8\ kg^{-1}$ and $1e^9\ kg^{-1}$ cases : datached cloud layer $\rightarrow$ scattering albedo

$1e^7\ kg^{-1}$ and $1e^{10}\ kg^{-1}$ cases : small impact

$1e^5\ kg^{-1}$ and $1e^6\ kg^{-1}$ cases : limited impact

$MgSiO_3$ clouds, solar metallicity

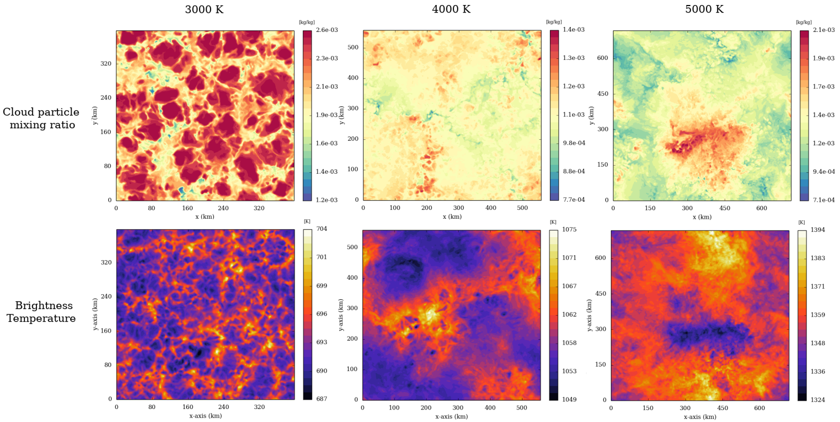
Impact cloud particle number at 4000 K



Cloud holes at low cloud particle density

$MgSiO_3$ clouds, solar metallicity

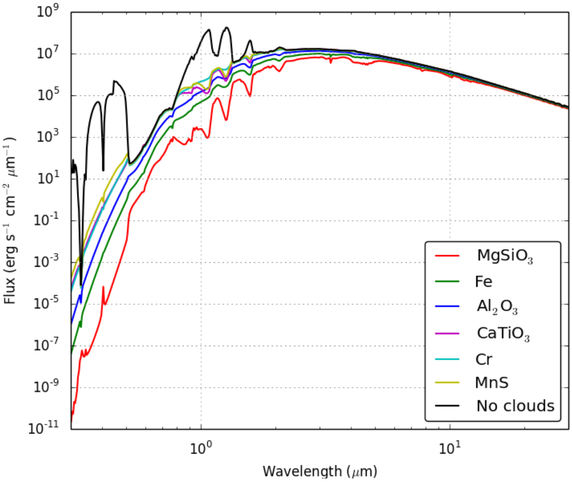
Impact of Temperature at $N_c = 10^8$ kg^{-1}



Cloud aggregation at high temperature → larger cloud holes

Emission spectra

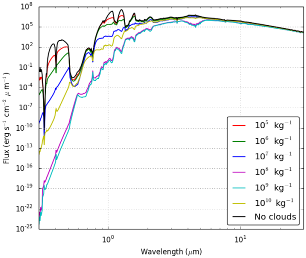
4000 K and $N_c = 10^8$ kg^{-1}



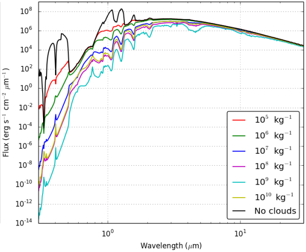
Emission spectra

$MgSiO_3$

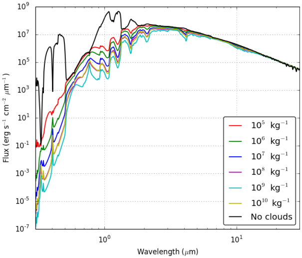
3000 K



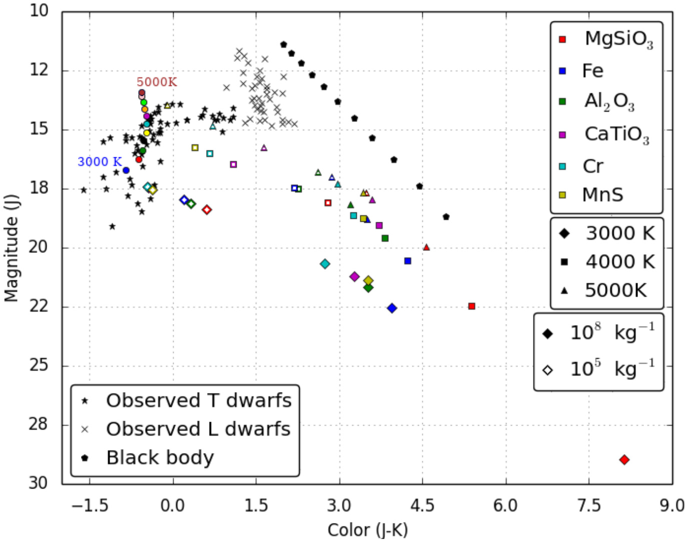
4000 K



5000 K



Emission spectra



Conclusions & Perspectives

- Increase of the convection depth with temperature
- Strong impact of $MgSiO_3$ and moderate impact of Fe and Al_2O_3
- Limited impact of $CaTiO_3$, Cr, MnS
- Strong effect of the particle size, around 1 μm for most impact
- Detached convective layer for some particle size

Next

- Chemistry scheme with Shang-Min Tsai
- Non-grey radiative transfer
- $g = 100$ m/s^2
- More sophisticated microphysics : Nucleation, Shape, Distribution

Model Configuration

3D CM1 non-hydrostatic dynamical core
coupled with grey RT freedman et al (2014)

Parameter	Value
Gravity (m s^{-2})	1000
Heat Capacity (J K^{-1})	13000
Mean Molecular mass (g/mol)	2.23
Surface Pressure (Pa)	$3\ 10^7$
Surface Temperature (K)	$3000<T_s<5000$, fixed
Metallicity	Solar, 10x Solar
Wind shear	None
Vertical domain	up to $1e^3$ Pa
Horizontal domain	dx = 2 km, 200x200 for 3000 K and 360x360 for 5000 K
Boundary condition	doubly periodic and sponge layer at the top

Lefevre et al A&A 2022

Model Configuration

Clouds

Considered : $MgSiO_3$, Fe, Al_2O_3, $CaTiO_3$, Cr, MnS

Lognormal particle size distribution

Free parameter : Number cloud particle density, between N_c 10^5 and 10^{10} kg^{-1}

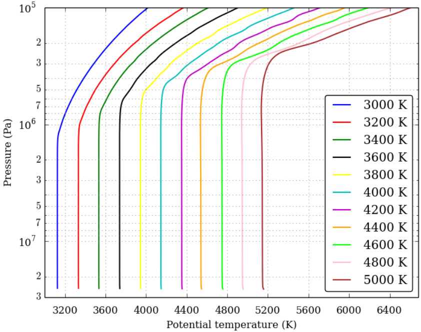
Source at the bottom then advected by convection

Radiatively active with Rosseland mean coefficient

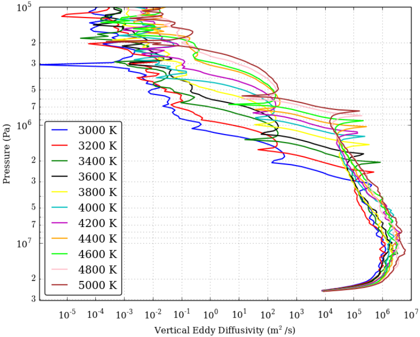
Settling is present

No clouds, solar metallicity

Potential temperature



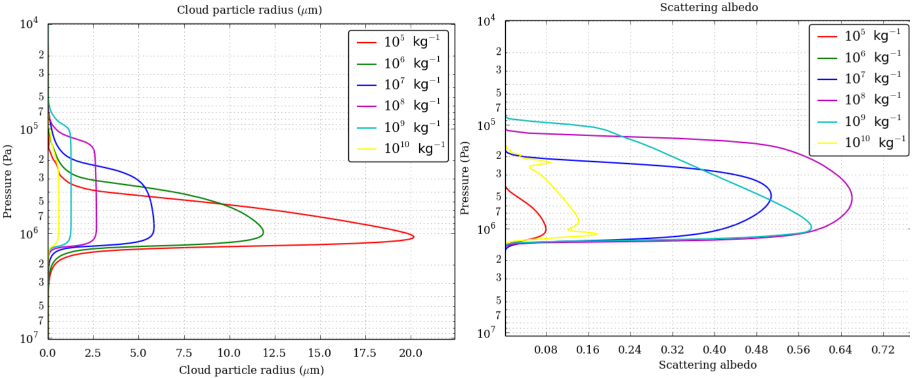
Vertical eddy diffusion



Depth increases with temperature

$MgSiO_3$ clouds, solar metallicity

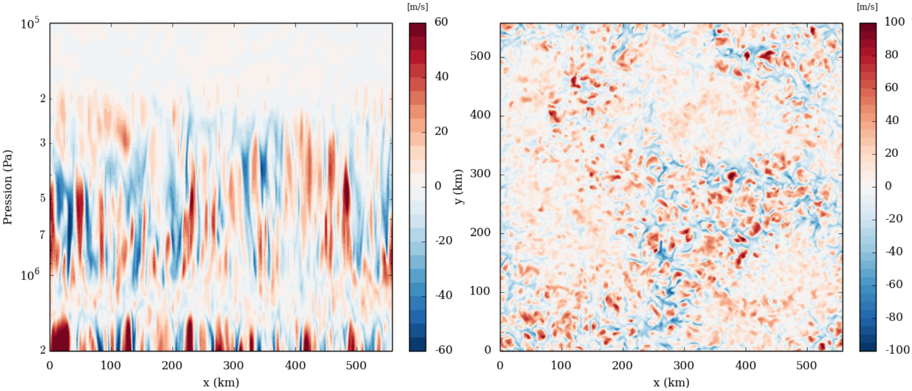
4000 K



$1e^8$ kg^{-1}-$1e^9$ kg^{-1} cases : stronger opacities and scattering albedo

$MgSiO_3$ clouds, solar metallicity

4000 K and $N_c = 10^8\ kg^{-1}$

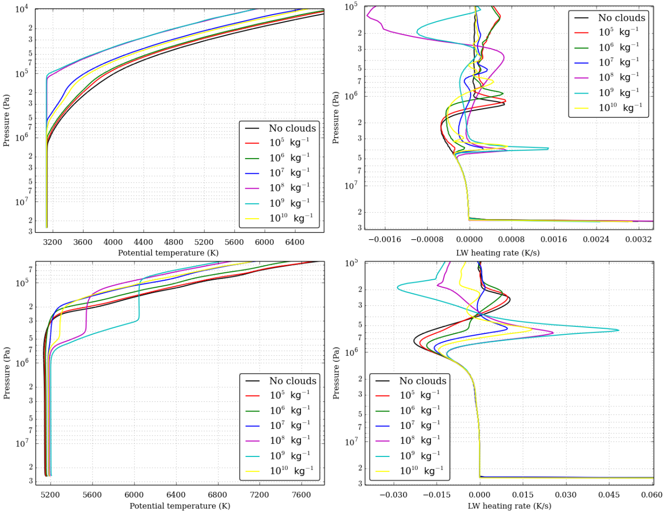


Different horizontal organisation to deep convective layer
Heating at cloud base too weak for complete convection layer

$MgSiO_3$ clouds, solar metallicity

3000 K

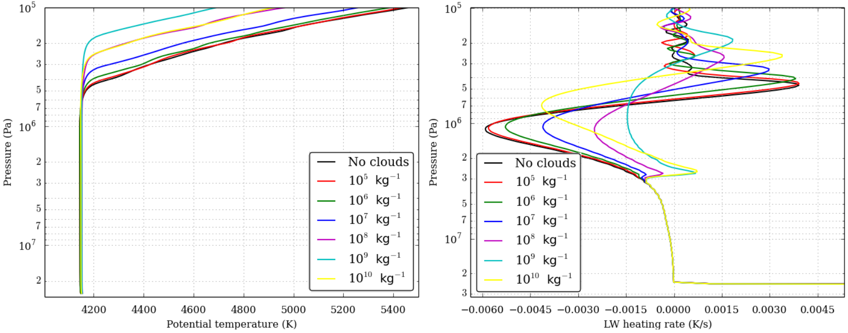
5000 K



Number detached layer increase with temperature : increasing scattering albedo

Fe clouds, solar metallicity

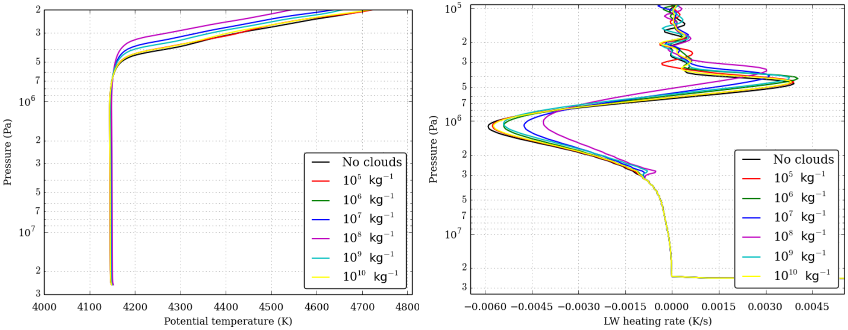
4000 K



No Detached convective layer

Al_2O_3 clouds, solar metallicity

4000 K

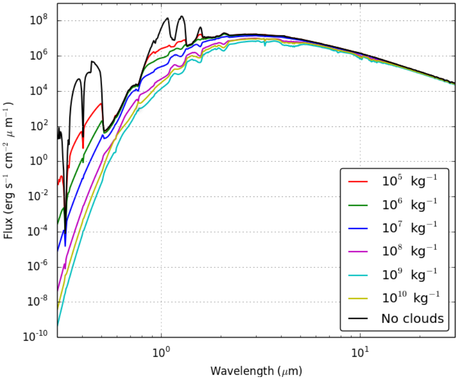


No Detached convective layer

Emission spectra

4000 K

Fe



Al_2O_3