Penetration depth of rainy downdrafts in abyssal planetary atmospheres

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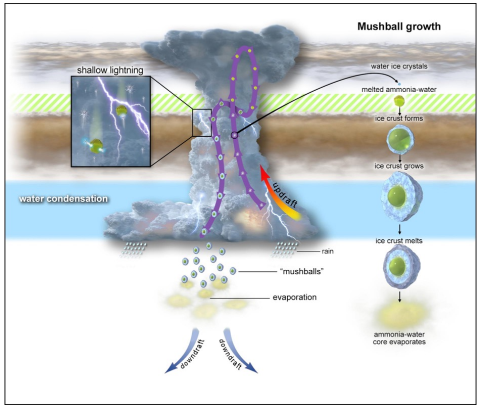
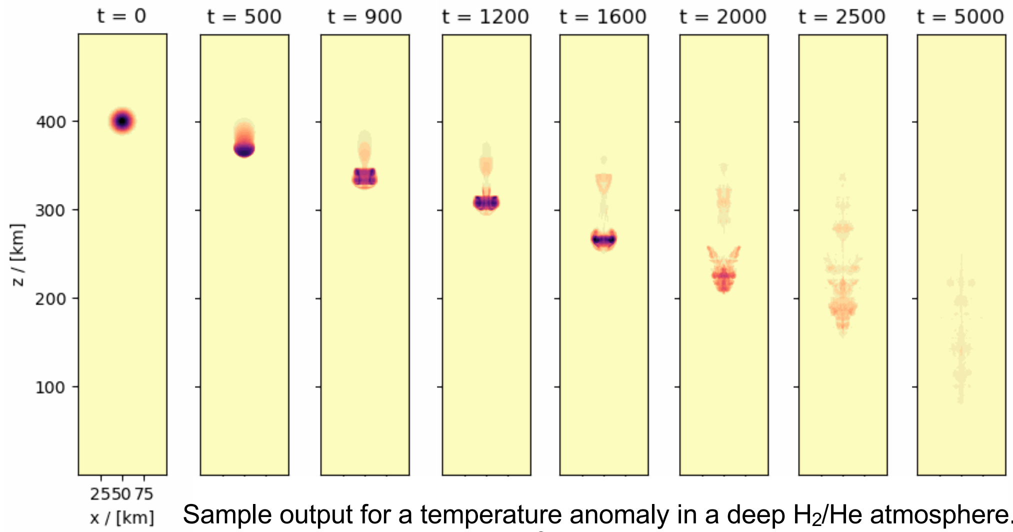
Motivation:



Juno MWR observations appear to indicate a depletion of ammonia at depth. To what extent can these observations be understood with fluid mechanics? That is, even if precipitation vaporizes, that does not necessarily mean it will immediately mix.



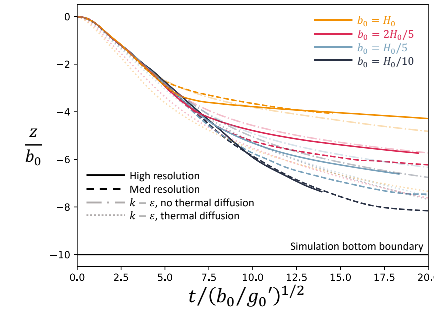
Sample output for a temperature anomaly in a deep H_2/He atmosphere. b=40km, res=500m, g=9.8m/s^2, ΔT=15K, p_0=4bars, T_0=130K.

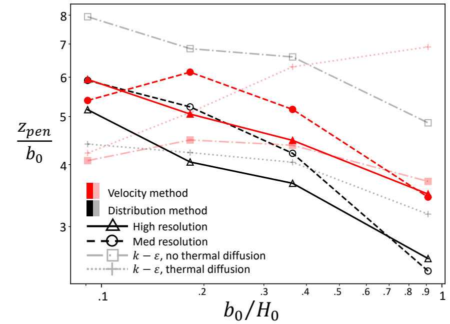
Method:

Linear theory based on self-similarity arguments adapted for a highly compressible environment as a framework to compare against high resolution hydrodynamic 3D simulations (SNAP) to assess the validity of the simplified assumptions. At the moment, we define "penetration depth" to be the depth at which the maximum entropy perturbation has decreased by a factor of $1/e$. Numerical stability achieved with a Reimann solver method; we are implementing a $k-\varepsilon$ explicit turbulence closure model for resolution independent solutions.

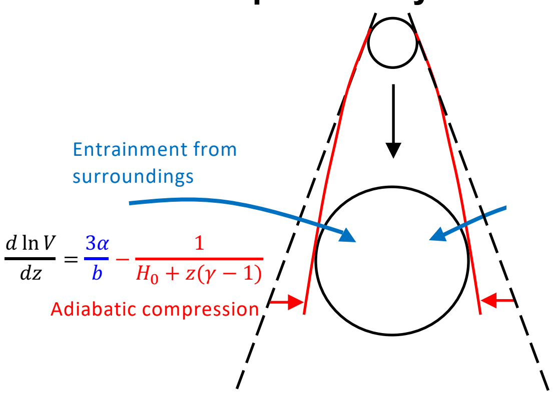
Results:

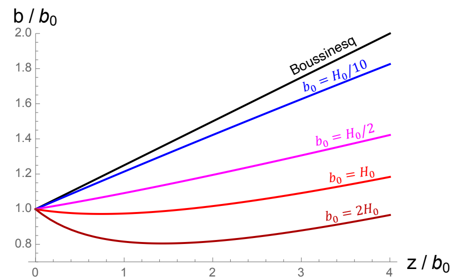
Thermals can penetrate to great depths, down 100s of km or 10s of bars, before efficiently mixing with their environment.

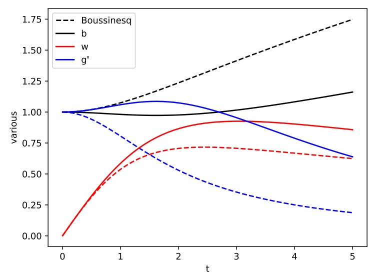




Effects of compressibility







Compression of downwelling parcels can provide a focusing effect by keeping thermals spatially localized despite entraining surroundings. However, this also increases hydrodynamic stresses, enhancing turbulent mixing. These complex dynamics require explicit modeling

Conclusion:

In the context of Jupiter, our findings suggest that concentrated precipitation can coherently penetrate to on the order of a hundred kilometers (tens of bars) beneath its initial vaporization level without mixing with its environment, consistent with Juno MWR measurements. More broadly, we might expect compositional gradients of volatiles beneath their cloud levels to be a general feature of stormy giant planets.