Atmos. Chem. Phys. Discuss.,
https://doi.org/10.5194/acp-2017-17-EC2, 2017

Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Quantifying the global atmospheric power budget" *by* Anastassia M. Makarieva et al.

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Received and published: 22 June 2017

The article makes the following statements

"Here gas (water vapor) is created by evaporation and destroyed by condensation with a local rate $\dot{\rho} \neq 0$ (kg m−3 s−1). As we will show, in this case each of the four candidate expressions W_I, W_{II}, W_{III} and W_{IV} are distinct. In a moist atmosphere the velocity notation in Eqs. (1)-(4) becomes ambiguous: is it the velocity of gaseous air alone or the mean velocity of gaseous air and condensate particles?... Consider an atmospheric parcel in a still atmosphere composed of pure water vapor. Let it condense into a droplet. Now the parcel's reduction in volume $dV/dt < 0$ is due to the work of the intermolecular forces driving condensation. It is not due to some other air

parcel expanding. equation of state...As a result, the expression for global atmospheric power does not explicitly depend on condensation rate. However, it is during such condensation-induced rapid expansion of the neighboring air parcels that the macroscopic pressure gradients can form to drive atmospheric circulation and determine the magnitude of atmospheric power W (9). The conventional view is that the circulation arises when some air parcels receive more heat than others and thus begin to expand. The cause of condensation-driven circulation is different. Here air parcels expand after condensation has reduced the concentration of gas in the adjacent space."

I am struggling to understand these statements based on a back of the envelope calculation of the rate of doing work. Let's take the expression due to density changes

$$\frac{dw}{dt} = RT\frac{d\ln\alpha}{dt}$$

For a very rough estimate of the displacement of air due to condensation, water vapor occupies, say 1/1000th of the volume on average in the atmosphere. When water vapor condenses, it turns into cloud, occupying perhaps 1/10th of the atmosphere. Condensate has an effectively negligible volume in comparison to water vapor, so condensation to form clouds concerns 1/10,000th of the atmosphere, that is $d\ln\alpha \sim 1\times10^{-4}$. Now, we consider that clouds condense over timescales roughly equivalent to the buoyancy period or about 100 s, therefore $d\ln\alpha/dt \sim 1\times10^{-6}$. Multiplying by $RT \sim 10,000$ J/kg, we obtain a rate of doing work of 0.01 W/kg.

Now let's compare this to the latent heat release associated with condensation, also a molecular scale phenomenon since it is associated with phase changes. Using similar numbers, we might estimate a globally averaged condensate density of order 0.1 g/kg. Multiplying by the latent heat of condensation and dividing as before by the buoyancy period, one obtains.

$$\frac{dw}{dt} = \frac{dm}{dt}L$$

which works out to 2.5 W/kg.

So it would seem that of these two microscopic elements of work, the one discussed in the paper is negligible. Latent heat release is considered the primary mechanism for cloud production, since by reducing density, it enables cloud parcels to be positively buoyant with respect to their surroundings. LES models of cloud development appear to reproduce cloud phenomena very well without accounting for any reduction in atmospheric volume due to condensation. What is missing?

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