Hydrology and Earth System Sciences Discussions

Interactive comment on "Biotic pump of atmospheric moisture as driver of the hydrological cycle on land" *by* A. M. Makarieva and V. G. Gorshkov

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As a physicist who have just recently changed field from astrophysics to meteorology I must say that I read this paper with great interest. It goes into the details of the physical meaning of meteorological concepts.

However, I do have some concerns about some of the physical and meteorological arguments used by the authors which I would like discuss. For the time being, I will only discuss section 3.1, where most of the concepts are. I will enumerate my comments with the corresponding page and line number.

P2633, L20 Atmospheric air is not always in hydrostatic equilibrium (although it is always trying to be), and probably you don't think that it is. Better to have this paragraph rephrased.

P2634, L8 An isothermal atmosphere is not a good approximation, only the constant molar mass is... And only so because of the atmospheric circulation and turbulence which keeps the atmosphere mixed (Feynman), and there is no large sources or sinks of N_2 or O_2.

P2634, L14 I don't think that immediately above the wet soil or open water the air is saturated of water vapor. If it was like that, no extra water would ever evaporate because the exchange of H_2O molecules between the soil and this first saturated layer would always be in equilibrium. In the atmosphere, turbulence keeps recycling the surface air so that it is (almost) never totaly saturated.

P2634, Eq. 9 - You should mention that in deriving eq (9) two assumption are made: $V_{liq} << V_{gas}$ (good) and $Q_{H_2O} = cte$, i.e., temperature independent (bad). However, since enthalpy of both liquid and vapor change with temperature, the difference between them, i.e. the enthalpy of vaporization is also temperature dependent. Temperature dependence of enthalpy can be estimated based on heat capacity, C_p, which, for simplicity can be taken as a constant. Then one can write:

$$Q_{H_2O}(T2) = Q_{H_2O}(T1) + \Delta C_p(T2 - T1)$$

A more sophisticated expression is found in Bruining et al (2003):

$$Q_{H_2O}(T) = (7.1845e12 + 1.10486e10 * T \\ -8.8405e7 * T^2 + 1.6256e5 * T^3 - 121.377 * T^4)^{1/2}$$

where T is temperature in K, Q_{H_2O} is in J/Kg. Rearranging the terms and writing in ^oC

instead of K, one can approximate this expression by a linear equation:

$$Q_{H_2O}(T) = 45KJ/mol(1 - \frac{T}{1161^oC})$$

This represents a decrease of 1000J/mol for every 25^oC increase in temperature. If you believe this linear dependence is weak enough that you can neglect it, you should give the arguments for that.

P2634, eq10 On the other hand, maybe you should avoid writing the approximate equation (9) at all. Instead, use directly the differential (and exact) form of the Clausis-Clapeyron equation:

$$\frac{dP}{P} = \frac{\Delta Q_{H_2O}}{R} \frac{dT}{T^2}$$

and equation (10) follows immediately.

P2635, L14 I don't understand why do you need the approximation $exp(-z/H) \simeq 1$ when deriving (11) from $h_w = h_{H_2O}$.

P2635, last paragraph.

First you described the situation $\Gamma = \Gamma_{H_2O}$ as corresponding to a fully saturated atmosphere in hydrostatic equilibrium. In this paragraph you say that, for $\Gamma < \Gamma_{H_2O}$, there is only a superficial saturated layer and that the water is also in hydrostatic equilibrium. If the first layer is saturated in both cases, it will have the same partial pressure of H_2O in both cases (assuming the same surface temperature). Hence, since for the second case there is less water vapor in the atmosphere, the column should not be in equilibrium (for the water vapor). There should be a tendency to expand the column and distribute the total column water vapor in a vertical profile that is in equilibrium. In such a situation, the surface air would always be drying out (losing water to the upper levels

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by diffusion or turbulent fluxes) while at the same time, water from the surface should be evaporating. Therefore, there should be fluxes of water vapor into the atmosphere (at least enough to keep the diffusion process).

P2636, L1

It is not the same molecules that evaporated into air that immediately condense. The equilibrium is maintained because air and surface exchange the same amount of water molecules, which are carrying (on average) the same energy, but these are not (necessarily) the same molecules.

P2636, L7

The reasoning starting at line 7 is not clear enough.

For instance, how does a situation where $\Gamma > \Gamma_{H_2O}$ appear? For $\Gamma = \Gamma_{H_2O}$ the atmosphere is completely saturated, .i.e., the maximum possible amount of water vapor (given by the PV diagram) is present at any heigh z. Any extra water vapor, at any level, would immediately condensate, warming the column and reducing Γ.

Moreover, at line 11 you say that *"excessive moister is precipitating"*, but at line 8 you said that $p_w(z) = p_{H_2O}(z)$, so there is not excess of water.

Another question: why $\Gamma > \Gamma_{H_2O}$ means the column is saturated? Think of the atmosphere over a desert region, there is no water vapor... Hence do you mean that $\Gamma > \Gamma_{H_2O}$ is not possible?

Any given vertical profile of humidity must be such that $0 < p_{vap}(z) \leq p_{H_2O}^{sat}(z)$, for all z. When $\Gamma > \Gamma_{H_2O}$, $h_{H_2O} < h_w$. If vapor at the surface is saturated, then any possible humidity profile will be out of hydrostatic equilibrium. However, if the surface is not saturated, the profile cannot be in equilibrium above height:

$$p_w(z) = p_w^{surf}e^{-z/h_w} = p_{H_2O}(z) = p_{H_2O}^{surf}e^{-z/h_{H_2O}}$$

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or

$$z_{max} = ln\left(\frac{p_{H_2O}^{surf}}{p_w^{surf}}\right)\frac{h_w h_{H_2O}}{h_w - h_{H_2O}}$$

but the profile can be in equilibrium (but not necessarily) below this height.

In any of these two cases, there will be an upward motion of water vapor trying to restore the equilibrium, within the part of the atmospheric column which is out of equilibrium. Notice that this upward motion does not depend on the profile being that of saturation. Supose, for instance, a particular profile p_1 that starts at saturation at the surface:

$$p_1(z) = p_{H_2O}^{surf}exp[-2*z/H_2O]$$

This profile is not the saturation profile and since $0.5*h_{H_2O} < h_{H_2O} < h_w$, it is out of hydrostatic equilibrium and will induce vertical motions. However, there will not be precipitation.

Just trying to summarize: you based your argument on the fact that the surface is always saturated of water vapor and hence, when $\Gamma > \Gamma_{H_2O}$, the full profile is out of balance. This will lead to an upward motion. Moreover, since the column is fully saturated and lower air is moister then upper air, there will be precipitation during this updraft.

The points that I (particularly) need some clarification in this argument are:

1) Is the surface always saturated? In line 20 of this page you say it is not.

2) Why the column should be fully saturated (and not like $p_1(z)$)?

P2637, L21

Quoting: *"After averaging over a horizontal scale exceeding the characteristic height h of the atmosphere, mean Archimedes force turns to zero. This means that the total air volume above an area greatly exceeding h^2 cannot be caused to move anywhere by the Archimedes force."*

This assertion is not obvious at all and you should give a proof of that. In fact, consider a mesoscale convective complex. These systems which extend over large areas (typical size 100km x 100km) show strong updrafts associated with intense convection of buoyant parcels. Isn't this a counter example?

P2638 I5

Quoting: *"It equally acts on air volumes with positive and negative buoyancy,..."*

You started the section 3 saying that air meant dry air... so if there is no water vapor, there should be no such force, right?

After that you say:

"Quantitative consideration of this force, which creates upwelling air and water vapor fluxes (...)

Why should this "force" act on dry air? If "dry air" molecules are in a state of hydrostatic balance they should not move... If only water vapor is out of equilibrium, only the H_2O molecules should diffuse upwards trying to bring the vertical profile to equilibrium. And this would happen for all lapse rates between $\sim 1.2km$ and $6 \sim 9.8km$ which is quite a wide range (and therefore an important effect). In fact, you start section 3.2 citing Landau and Lifschitz about this subject. Could you give a more precise citation (chapter and page number) for equation 14?

REFERENCES

Feymman: "The Feymman Lectures on Physics", chapter 40-1

Bruining, 2003: J. BRUINING et al., "Steam injection into water-saturated porous rock",

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