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Hydrology and Earth System Sciences Discussions

HESSD

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Interactive Comment

Interactive comment on "Comment on "Biotic pump of atmospheric moisture as driver of the hydrological cycle on land" by A. M. Makarieva and V. G. Gorshkov, Hydrol. Earth Syst. Sci., 11, 1013–1033, 2007" *by* A. G. C. A. Meesters et al.

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Here we respond to the comments of Referee 1 who summarized the debate going around equation (13) of the DP authors and briefly mention some comments of Referee 2. Indeed, using the phrasing of Referee 1, can the sustained imbalance of one component (water vapor) be associated with a sustained dynamical imbalance of air as a whole or, as the DP authors proposed, this bulk imbalance will be "restored" to equilibrium by the dynamic air flow?

When, to celebrate publication of an important paper, we open a bottle of champagne, the gas originally squeezed in the bottle moves dynamically away from the bottle. This dynamic gas movement can be viewed as relaxing the initial disequilibrium pressure difference (imbalance) between the bottle and the room. Indeed, the motion rapidly extinguishes, air pressures in the bottle and in the room equate, "mechanical equilibrium" (p. 412 of the DP) is restored.

Consider, however, quite a different example: when air spirals towards the hurricane center along a horizontal pressure difference of a few dozen millibars between the hurricane center and outer environment, no "restoration" of pressure equilibrium occurs. At any point, air comes and goes at very high velocities, yet the pressure difference is sustained unaffected by this intense movement. Similarly, air movement around a vacuum-cleaner does not equate air pressures between the two opposing sides of the engine (where air comes in and comes out), i.e. it does not "restore" any pressure equilibrium in the room where the vacuum-cleaner operates.

These three examples show that it is not sufficient just to consider **an initial pressure difference and a dynamic motion initiated by this difference** in order to conclude, as the DP authors do in their thought experiment (p. 412), that this motion will "restore" pressure equilibrium, an idea now supported also by Referee 1. That is, the presence of a dynamic motion along a pressure gradient per se **says nothing** about whether the pressure difference will be sustained or eliminated (equilibrium "restored").

It is in principle impossible to say what happens to the disequilibrium pressure difference **without considering the power of those processes that create and sustain that difference.** In the above case of the bottle of champagne, the power of such processes is zero - after the bottle is opened, there is nothing to sustain or re-create the initial pressure difference, which therefore ultimately relaxes to equilibrium via dynamic gas movement. However, if we were to celebrate a number of important papers and were enthusiastically opening one bottle after another, then the small dynamic flux of compressed gas from a bottle to the room would be sustained for all the time during which the bottles continued to be opened.

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In the case of the evaporative force, the process that sustains the disequilibrium air pressure difference is water vapor condensation. Referee 2 genuinely submitted a key argument to this discussion (S244): "the pressure is proportional to the number of molecules per unit volume and to the temperature. ... One cannot physically distinguish between the effect on the pressure within an air parcel of, respectively, the water vapour molecules and the "dry air" molecules." Namely for this reason condensation of water vapor lowers local pressure of air in the volume where condensation takes place. We repeat: it is **water vapor** that disappears, and it is the pressure of **air as a whole** that is lowered in the result. Once again: removal of **vapor** ("imbalance of one component") immediately lowers **air pressure** ("causes imbalance of whole mixture"), for the reason brilliantly formulated by Referee 2.

Therefore, consideration of the power of condensation **radically** changes the thought experiment discussed in the DP and by Referee 1. Governed by the initial pressure difference, moist air starts moving dynamically upwards and perhaps "aims" to restore the equilibrium. However, as it moves upward in the gravitational field, the air parcel cools and water vapor condenses. This condensation lowers local air pressure and, very much like a new bottle of champagne opened, sustains the disequilibrium pressure difference. (At this point the explanatory power of the thought experiment is depleted: what exactly non-equilibrium pressure difference will be sustained in numerical terms can be only decided from a simultaneous numerical consideration of condensation power and atmospheric friction power, e.g., as outlined on p. 1026 of MG2007; the thought experiment no longer helps. We also mention another misconception of the DP authors: as soon as the saturated moist air starts ascending and cooling, water vapor immediately starts condensing and condenses all the time the air parcel moves, with most vapor depleted by 2 km height. The DP authors instead put forward an idea for condensation to occur "long after the end of the experiment" (S174)). In contrast, if there is no condensation, the original disequilibrium pressure difference is rapidly "relaxed" to equilibrium by air movement, the scenario Referee 1 tends to support.

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We emphasize that the classical school which Referee 1 mentioned when explaining his position towards the evaporative force has overlooked namely this: Condensation of **water vapor** lowers pressure of **air as a whole**. Namely this critical role of phase transitions revealed in the biotic pump theory was characterized as a significant contribution to the extant understanding of atmospheric physics (http://www.cosis.net/copernicus/EGU/acpd/8/S8669/acpd-8-S8669.pdf). We note in passing that for this reason the fluxes produced by condensation have nothing to do with molecular diffusion (another major statement of the DP supported by Referee 3) - instead, these are dynamic fluxes of moist air that are caused by air pressure drop caused by condensation.

Thus, we would particularly like to bring to the following fact to the attention of all discussion participants, readers and the Editor: On the moment of publication of this comment, over seven weeks of exchange of opinions, the core of the biotic pump physics - the power of water vapor condensation and its effect on air pressure - remains neglected by the parties supporting the DP (including Referees 1, 2 and 3), with a symptomatic statement delivered by the DP authors themselves in their last comment: "We understand even less why the analysis of our thought experiment would have to be modified by considerations about condensation" (S174).

It is not that the condensation power (which is enormous in intense circulation events like hurricanes and approximately equal to the power of evaporation in the stationary large-scale circulation) just sustains water vapor disequilibrium (see, e.g., S245 in the comments of Referee 2), which further may or may not sustain dynamic air flows (the main point of the DP). Instead, condensation power is the power that, via water vapor removal, immediately lowers air pressure and sustains the non-equilibrium air pressure difference that makes moist air move. It **also** sustains the vertical disequilibrium of water vapor. (There can be other physical processes (not condensation) that would sustain water vapor disequilibrium (e.g., in the horizontal plane); the power of dynamic air flows caused by such processes will be different from the power of dynamic air flows

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caused by condensation.) To summarize, to criticize biotic pump without numerically considering the power of condensation is logically the same as to complain about zero performance of a vacuum-cleaner that is not connected to the electric power supply.

After the interested reader agrees with these statements, the next step we would advise to take is to read our short comment "Biotic pump is driven by condensation" (S59), where we have attempted to present all essential considerations in a concise quantitative form. In particular, we show once again (cf. p. 1026 in MG2007) how the power of condensation (which is equal to the power of the evaporative force) is quantitatively related to water vapor disequilibrium and vertical velocity of air movement.

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 6, 401, 2009.

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