Hydrol. Earth Syst. Sci. Discuss., 6, S243–S246, 2009
www.hydrol-earth-syst-sci-discuss.net/6/S243/2009/

Hydrology and Earth System Sciences Discussions

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.

Anonymous Referee #2

Received and published: 6 March 2009

In my opinion this very well written comment should be published in your journal after some justice is done to the literature on the subject of adjustment to hydrostatic balance.

The central theme of the comment by Meesters et al. is concerned with the question how hydrostatic balance in the atmosphere is restored after it has been disturbed by injection into the atmosphere of water vapour molecules by evaporation of liquid water from the Earth's surface and by condensation of water vapour within the atmosphere and removal of condensed water from the atmosphere as rain.

The answer to the question how the atmosphere adjusts to hydrostatic balance depends on the vertical density-stratification of the atmosphere. The vertical density stratification can be either hydrostatically stable or hydrostatically unstable. In the former case the adjustment to hydrostatic balance will take place principally by sound waves (Bannon, 1995; van Delden, 2000). In the latter case adjustment to hydrostatic balance will take place by convection.

Understanding the meaning of the concept of pressure exerted by a gas is central to the understanding of what causes the bulk movement of air in the atmosphere in both cases, i.e. the movement of a coherent volume of air (sometimes referred to as an “air parcel”) consisting of billions to trillions of molecules.

Let us perform a thought experiment and confine our attention to the effect of evaporation. Consider an atmosphere that is in a state of stable hydrostatic equilibrium. Suppose water vapour is added to an air parcel of unit volume consisting initially of “dry air” molecules only. As a consequence of this the total number of molecules within this air parcel increases. Assuming that this does not change the temperature or the volume of the parcel, and assuming also that the mixture of dry air and water vapour within the parcel of unit volume behaves as an ideal gas, we may state that the pressure within the parcel increases. This is so because, according to the equation of state for an ideal gas, the pressure is proportional to the number of molecules per unit volume and to the temperature. Both temperature and pressure are physical concepts that apply only to a large number of molecules within a specific volume of space. 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. Therefore, I agree fully with the statement by Meesters et al. on p. 408 of their discussion paper saying that replacing the “traditional” assumption of bulk hydrostatic equilibrium of an air parcel with an assumption of component equilibrium for dry air is untenable.

Due to the addition of water vapour to the air parcel in question a difference in pressure between this air parcel and its environment, which contains less molecules per unit volume, is generated. This pressure difference is the germinal state for the generation of a “wave of expansion” (Lamb, 1932, chapter 10) or sound wave. The air parcel in question expands at the cost of the immediate environment, whereby the pressure in the air parcel decreases and the pressure in the immediate environment increases. The propagation of the sound wave into the environment of the air parcel is accompanied by relatively weak macroscopic oscillating motions, ultimately leaving behind an atmosphere that is again in hydrostatic balance, assuming that the evaporation does not make the atmosphere hydrostatically unstable. According to this theory the process of hydrostatic adjustment is not accompanied by a systematic flow of molecules (dry air or water vapour) over large distances.

A systematic macroscopic or bulk flow of dry air molecules as well as of water vapour molecules can only take place if the density stratification is hydrostatically unstable. Hydrostatic instability leads to convection. Convection mixes the constituents under the constraint of conservation of mixing ratio. The distribution of those constituents that have a long life time in the atmosphere, such as oxygen and nitrogen, which remain in the atmosphere for many years, thus tends towards a constant mixing ratio up to a height of nearly 100 km above sea-level. Water vapour molecules have a relatively short life time in the atmosphere, because they enter the atmosphere principally at the Earth’s surface due to evaporation and leave the atmosphere as rain on average 10 days later. Therefore, the mixing of water vapour molecules, *together* with the “dry air” molecules (i.e. oxygen and nitrogen molecules), due to the macroscopic motion, will not establish a water vapour distribution with constant mixing ratio throughout the atmosphere.

In conclusion, in agreement with Meesters et al., I do not believe that the “evaporative force” as proposed by M&G exists in the real atmosphere. This does not mean that I do not believe that some kind of biotic pump exists in Earth’s atmosphere. Therefore, further work on this subject is well worth pursueing.

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

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