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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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In response to the comments of B. van den Hurk:

Before turning to the two interesting issues raised by Dr. van den Hurk, calibration of the exponential decline of precipitation with distance from the ocean and low versus tall vegetation in the biotic pump, we would like to comment on the more general statement that the physics of the biotic pump mechanism, as we describe it in our paper, is not easy to comprehend.

When writing the paper we worked hard to present the results in the clearest possible form. But, in our view, it is very difficult, not to say impossible, to know in advance which

issues are to be perceived by the reader as transparent, and which – as problematic, especially as we aimed our findings to be judged by scientists with very different backgrounds, like hydrologists, ecologists, meteorologists or physicists-theoreticians. In the course of this interactive discussion we hope that many issues have been clarified, but also many new things have emerged. As reflected in our responses to the comments, in the revised text we plan to accommodate a lot of changes further toward the clarity of presentation. And we do have a plan of a follow-up paper devoted to the physics of the evaporative force, as explicitly suggested in the comments of Dr. Dovgaluk and Dr. van den Hurk. At the same time, irrespective of the biotic pump issue, we believe that, however clear their presentation could be, new scientific results can rarely be evaluated without spending considerable time on their analysis. We would thus like to use this opportunity to sincerely thank all the participants of the discussion for their time and interest. The authors have benefited greatly from the detailed, constructive and informed comments and criticisms that have so far appeared in the course of the discussion.

1) "Passive geophysical fluxes" of moisture transport

Observations summarized in Fig. 2, Section 2.1 of the paper, show that over the non-forested areas precipitation declines exponentially with distance from the ocean. While the mean e-folding length l of this decline is a few hundred kilometers, one can also see (e.g., region 4a in Table 1 and p. 2627) that it can be much smaller, of the order of a few tens of kilometers. The main physical principle formulated in Section 3.3 is that the horizontal fluxes of air (and atmospheric moisture) should be directed from areas with high evaporation to areas with low evaporation. On the basis of this principle the phenomena of the ocean-bordering deserts, monsoons and foresed river basins are explained. Moisture can never be transported from the ocean to "absolute" deserts that lack evaporation completely. Thus, such deserts represent areas with infinitely small e-folding length of precipitation decline, where $l \to 0$. In the areas where some vegetation cover (but not forests) and, hence, considerable evaporation do exist, the value of l increases from zero up to several hundred kilometers, but precipitation continues to decline away from the ocean. Finally, in natural forests with high evaporation, where precipitaiton does not decrease with distance x from the ocean at all, l should be infinite and the exponent $\exp(-x/l) \to 1$. To maintain optimal soil moisture and to compensate for the river runoff in the entire river basin, the forest has to manage the huge ocean-to-land flux of atmospheric moisture in such a manner that precipitation is not too large near the coast (where the moisture flux F is the largest), but is sufficient in the innermost continental parts (where F reaches its minimum value). This biotic control eliminates the proportionality between precipitation P and moisture flux F, that was discussed in Section 2.1.

Thus, we come to the conclusion that the existence and quantitative characteristics of the ocean-to-land moisture flux are in all cases profoundly affected by the properties of the vegetation cover, ranging from complete absence of vegetation to natural forests. It is suggested in the comment that some regional properties of atmospheric circulation can dictate the major properties of the moisture flux on the non-forested areas. Within such reasoning one refrains from answering the question what determines then the properties of the atmospheric circulation itself. As also mentioned previously by Dr. Nobre, such an approach to the regional precipitation problem is common. However, since the above-mentioned physical principle revealing the link between regional evaporation and regional circulation is formulated, this approach is no longer satisfactory — properties of regional atmospheric circulation cannot be considered as an external, vegetation-independent constraint on the regional precipitation regime.

While massive forests are apparently able to solve the task of providing themselves with sufficient moisture via pumping moisture from the ocean, the other vegetation types cannot do the same. The notion of “passive geophysical fluxes” was introduced in the paper in Section 2, prior to discussion of the biotic pump physics in Section 3, to emphasize this difference in the observed spatial precipitation patterns. After introducing the results of Section 3, this notion becomes rather ambiguous. Upon further thinking during these months we now think that this notion should be replaced

by “fluxes observed over non-forested territories”. Strictly speaking, the definition of passive geophysical fluxes can be relevant only for description of atmospheric circulation between the ocean and lifeless land, i.e. absolute desert, where, according to the above principle, these fluxes should be zero.

To summarize: the observed exponential decline of precipitation with distance from the ocean in the non-forested ares is dictated by the regional parameters of the evaporative force on land and in the ocean. The major parameter here is the properties of vegetation cover, including the degree of its disturbance.

2) Low versus tall vegetation in the biotic pump

It is suggested in the comment that the higher evaporation over forests as compared to low but equally well-watered vegetation can be explained by the lower albedo of forest canopies, which makes more solar energy available for evaporation in forests.

The flux of molecules from the liquid to gaseous phase depends on temperature only, see formula (C2), p. S1453 in the first response to Dr. de Melo Jorge Barbosa. At a given temperature the maximum rate of evaporation (i.e. the net flux of water vapor into the atmosphere) depends therefore on the cumulative area of the evaporating surfaces. Thus, at a given temperature the evaporation flux from the well-watered low vegetation with low leaf area index is smaller than the evaporation flux from an equally well-watered forest with high leaf area index. At equal albedos and equal amounts of available solar energy the additional energy for evaporation is taken from advection. For example, the relatively low temperature of the Amazon forest canopies as compared to the sea surface temperatures of the Atlantic (see comment of Dr. Nobre) leads to the situation when the warm Atlantic winds provide the forest with additional energy for evaporation. Short bursts of intense evaporation from the large evaporative surface of a high leaf area forest can be achieved at the expense of locally accumulated heat. Low leaf area vegetation is deprived of such an opportunity.

The effects of albedo are definitely important and should be investigated. However, the difference in the available solar radiation caused by the difference in albedo between low and tall vegetation is of the order of only tens of per cent. For example, if forest albedo is as low as 10%, while the albedo of low vegetation is as high as 30%, the forest will receive about 30% more solar radiation than the low vegetation.

In the meantime, leaf area index can differ by ten and more times between dense forests and low, sparse vegetation. From this we conclude that the leaf area index effect should be quantitatively much more significant. Moreover, at low leaf area index (and, hence, low potential for evaporation) the available solar energy can be converted to senisble heat.

Another issue raised in the comment is the issue of control of the loss of moisture by stomata closure. The evaporative force mechanism predicts that the higher the flux of evaporation, the higher the flux of moisture from the ocean. This means that on the level of forest ecosystem the diurnal rhythm of stomata closure/opening does not play the role of a mechanism preventing water loss. As we suggested in the paper (p. 2651, lines 1-7), the large-scale role of stomata closure can consist in regulating the diurnal precipitation regime. When stomata are opened, there is large flux of evaporation and an intensive upward motion that supports clouds. When stomata close, the flux of evaporation, the evaporative force and the upward air motion diminish, so that the liquid moisture previously accumulated in the atmosphere can precipitate.

In Section 3.4 we have outlined a mechanism for water loss prevention that can be realized in tall close canopies, see also (Gorshkov and Makarieva, 2006; Makarieva, Gorshkov and Li, 2006, in press). Due to the high leaf area index and high degree of canopy closure, the daytime temperature lapse rate under the canopy is negative (i.e., temperature increases from the surface to the canopy), i.e. $\Gamma_{ob} < 0 < 1.2$ K/km. This means that under the canopy water vapor is in hydrostatic equilibrium and there are no uncontrolled vertical fluxes of water vapor from under the soil surface. In contrast, in open canopies during the daytime $\Gamma_{ob} >> 1.2$ K/km. All water evaporated from the leaf surfaces is rapidly lost into the atmosphere.

Generally, the evaporative force mechanism provides a new look on the problem of water use and water loss by the forest ecosystem. During the (relatively) dry season the evaporation from the forest should be enhanced to diminish or eliminate altogether the land-to-ocean air fluxes that steel the ecosystem's moisture (p. 2648, lines 8-19). On the contrary, during the wet season too high evaporation can produce excessive rainfall leading to devastating floods; forest should therefore be able to control its evaporation against being too high during the wet season.

As is well-known, the properties of non-forest — low and sparse — vegetation cover are exactly the opposite. Evaporation from the ecosystem drops radically during the dry season and dramatically increases during the wet season. In the first case it results in severe droughts, in the second — in floods. Only natural forests, provided they are allowed to occupy a sufficient continental area, can guarantee a stable precipitation regime without extreme events.

References

Gorshkov, V.G., Makarieva, A.M.: Biotic pump of atmospheric moisture, its links to global atmospheric circulation and implications for conservation of the terrestrial water cycle, Preprint No. 2655, Petersburg Nuclear Physics Institute, Gatchina, Russia, 2006.

Makarieva, A.M., Gorshkov, V.G., and Li, B.-L.: Conservation of water cycle on land via restoration of natural closed-canopy forests: Implications for regional landscape planning, Ecological Research, in press.

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