Hydrol. Earth Syst. Sci. Discuss., 3, S1258–S1263, 2006
www.hydrol-earth-syst-sci-discuss.net/3/S1258/2006/

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

A. M. Makarieva and V. G. Gorshkov

Received and published: 25 October 2006

In response to the questions of A. Nobre:

The questions touch upon a few interesting problems, where the biotic pump approach could, in our view, be fruitfully applied to yield a solution. Within the limited time framework of the present discussion we now try to outline possible directions of further thought that stem from the biotic pump approach.

1) We mention in the paper that deforestation in the inner parts of the continent can compromise the existence of coastal forests due to the degradation of the continental biotic pump mechanism. Dr. Nobre asks how then the ancient colonization of the con-

tinents by forests could have occured, because it should have had apparently started from a coastal forest band to proceed inland. In short, our response is that the modern state of inner deforestation with a coastal forest remnant is not equivalent to the ancient state with an arid inner part of the continent and first forests colonizing the continent from the coast.

Consider a narrow band of natural forest with high leaf area index, which borders with the ocean on one side and with the desert on the other. Initially, the evaporative force is highest above the forest canopy. The forest sucks in both the oceanic and, even more so, the desert air. The input of arid air from the desert makes the air above the forest canopy drier, so the evaporative force above the forest diminishes. In the result, such a desert-bordering forest will receive less precipitation from the ocean than if it were adjacent to an extensive continental forest cover. We conclude that in order to survive and advance further inland, the desert-bordering forest must be to a considerable degree resistant to the dryness conditions.

The difficult task of colonizing land could not be solved by forests alone. It is likely that the land was first covered by some xeric vegetation. Due to the low, but non-zero, transpiration of these plants and the associated evaporative force, it was possible to lure the oceanic air a bit more inland. The vegetation became more mesic. Then the inner continent got covered by some kind of dry forests, these already ensuring substantial transpiration. Finally, under these well-prepared conditions the rainforests started their march to the continent interior.

So, when modern forests are destroyed by humans in the inner parts of the continents and replaced by rapidly eroding agricultural fields or dryness areas, while there remain narrow rainforest belts near the coast, the situation is not the same as in those ancient times. After the hundred million years' evolution on the rainy continent, with no fires or large-scale droughts, the newly-evolved rainforest plants may have become much less resistant to moisture shortage than those ancient land invaders could have used to be.

This does not mean at the theorem level that a narrow band of forest near the coast is inevitably destined to perish. However, these arguments highlight such a possibility and prepare one to witness the dieback of forests at the coastline with no surprise, if extensive zones of aridity and deforestation are created in the interior of the continent. Note, for example, that in the Australian transect (region 1 in Fig. 1 of our paper) there are no forest remnants on the coast.

2) In the first question Dr. Nobre mentioned the areas of equatorial dryness on the primordial Pangea continent; he noted that this would be unthinkable today taking into account the Intertropical Convergence Zone. If we assume that the paleodata about that ancient dryness are reliable, this is another argument in favor of the proposed explanation of Hadley circulation based on the evaporative force. At present one explains Hadley circulation by higher equatorial temperatures making warm air to expand and rise etc., while we claim that the equatorial air rises due to the higher evaporative force on the equator as compared to the tropics. Temperature of the dry equatorial surface of Pangea should have also been higher than in the tropics, however, apparently, the ITCZ did not form there, although it should have formed, according to the traditional account of Hadley cells. In our approach, it is clear why ITCZ and Hadley cells could not form at that time – because it was dry there, the evaporative force was zero, the equatorial air did not rise and did not suck in rains from the tropical regions.

Regarding the particular shape of atmospheric circulation at the time when Sahara was covered by forests, we do not think that it can be responsibly reconstructed in great detail. However, it is easy, in our view, to imagine possible patterns. If one compares atmospheric circulation over the arid areas of North Africa with that over moist forests of Equatorial Africa (see, e.g., Fig. 1 of Nicholson (2000)) one can see that over both areas winds have a meridional velocity component towards the equator. But over the forested area winds blow inland (i.e. with an eastward velocity component), while over the deserts they blow from the continent to the ocean (i.e. with a westward velocity component). It is readily imaginable that when Sahara was covered by forests, winds

used to blow inland in this region as well. Note also that equatorial African forests create an additional meridian-oriented convergence zone in the middle of the continent. This feature could have also been present when Sahara was green.

As Dr. Nobre mentioned, not all deserts are at 30 $^\circ$ North or South. For example, the deserts of Central Asia are at 40-50 $^\circ$ N; so are the arid zones of North America, Gobi in China. Additionally, and also importantly, not all areas at 30 $^\circ$ N or S are deserts, if we recall climates of China and India at these latitudes. Absence of deserts at high latitudes might have to do with a shorter history of human settlements or a different lifestyle (hunting) of ancient people living in temperate climates as compared to their tropical conspecifics.

On the other hand, some areas should apparently be more prone to desertification than the others, and here modern Hadley circulation can play a role. The evaporative force acting on a territory at 30 $^\circ$ N or S (e.g., Sahara) must counteract both the evaporative force of the oceanic surface at the same latitude, as well as the evaporative force of the oceanic surface or forests at lower latitudes. When forests on such an area are disturbed, the evaporative force there diminishes and moist air can be stolen from that area by the equatorial forests and adjacent ocean that feature high evaporative forces.

3) The origin of inland savannahs in South America is an interesting problem, which cannot be resolved without a serious study of all the relevant data, including the precise geography of savannas and the cultural history of humans on those areas. Our general idea is that aridity in the inner parts of the continent should owe itself to disturbances of coastal forests. Coastal forests can still persist as a narrow belt in modern South America, but these are not intact, pristine forests (with no fragmentation, no selective cutting, no burning, no human overexploitation). Weakened coastal forests cannot run the moisture pump the same efficiently as natural forests do. To sum up, recalling the first question of Dr. Nobre, we state that deforestation of the inner parts of the continent weakens the continental biotic pump and makes moisture conditions less favorable for the existence of coastal forests; vice versa and even more critically, disturbance of

coastal forests can weaken the continental biotic pump to the degree totally prohibiting forest existence in the middle part of the continent.

4) Regarding the presence of monsoon climate in South America. In our understanding of the Amazonian circulation we, to a large degree, relied on the work of Zhou and Lau (1998). The main "classical" feature of monsoon climate is the reversal of winds (to and from land) in different seasons. This feature is absent in South America. Indeed, the classical reversal of wind directions is only apparent when the annual mean easterly component is removed from surface winds, cf. Fig. 9 in Zhou and Lau (1998).

Namely this feature is essential for our considerations. For our approach it is most important that despite the differential heating of land and ocean, the Amazon forests are able to ensure that the surface winds on average blow from ocean to land. In deserts, the annual mean direction of surface winds is from land to ocean. In the intermediate cases the mean annual wind velocity can be zero, as is approximately the case with classical monsoons.

Nevertheless, we mention in the paper that when the ocean is warm, it is more difficult (or even impossible) for the forest to pump moisture inland. In this case high transpiration does not serve to suck in moisture from the ocean. Instead, it serves to prevent the formation of strong land-to-ocean winds, which would originate be this transpiration negligible (as during the dry season in classical monsoon climates). These winds, should they originate, would blow forest moisture away to the ocean, thus adding to the gravitational losses of runoff water. Thus, high transpiration during the dry season is a protection against the worse – even if it is impossible to make the oceanic moisture come to the forest, the forest tries at least not to lose its own atmospheric moisture to the ocean. Remarkably, in this situation the more intensively the forest transpires moisture, the less moisture it loses.

References

Nicholson, S. E.: The nature of rainfall variability over Africa on time scales of decades

to millenia, Global and Planetary Change, 26, 137-158, 2000.

Zhou, J. and Lau, K.-M.: Does a monsoon climate exist over South America?, J. Climate, 11, 1020-1040, 1998.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 3, 2621, 2006.