THE EFFECT OF DEFORESTATION ON THE WATER CYCLE IN THE AMAZON BASIN: AN ATTEMPT REFORMULATE THE PROBLEM. (*)

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SUMMARY

If widespread deforestation in Amazon results in reduced evaporative water flux, then either a decrease in evaporation is compensated locally by reduced rainfall, or else changed moisture balance expresses itself downwind in the yet undisturbed forest. The question of where rain will occur is crucial. It is suggested that the appearance of clouds and the occurrence of rainout is governed primarily by the interplay of local meteorologic and physical geography parameters with the atmospheric stability structure except for a few well-defined periods when rain is dominated by large scale atmospheric instability. This means that the study of these phenomena (local heat balances, studies on cloud formation mechanism, vertical atmospheric stability, etc.) must be made on the scale of the cloud size, a few tens of kilometers at most.

The fear had been expressed that the evaporation water flux from the Amazon basin would be reduced as the result of a widespread deforestation program (Friedmann, 1977) and that as a consequence the water balance coul be upset both locally and worlwide. Emphasis in recent research programs was thus directed towards quantifying the water cycle in the Amazon basin and, in particular, to the assessment of the percentage of the re-evaporated moisture in the precipitation. Classical water balance estimates (Villa Nova, 1976; Marques **et al.**, 1977) indicated that about one half of the precipitation in the basin originates from recycled moisture, which is released within the basin through transpiration of the forest plants and by evaporation from its surface. Data on the (inland) gradient of the isotopic composition of rainfall (Salati **et al.**, 1979) confirmed the

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importance of the recycled moisture in the hydrologic cycle of the Amazon basin.

Any change of this re-evaporation flux obviously results in a commensurate change in the amount of precipitable water in the downwind atmosphere. It was implied that there would then be an automatic and equivalent change in rainfall. Two scenarios can then be considered:

a) that the system response occurs "on the spot" so that a decrease in evaporation is compensated locally by a reduced rainfall. Nothing much would then be changed in the hydrologic situation of the virgin forest further afield. Indeed the case of the Marajo Island at the mouth of the Amazonas, of which the half which has no forest is also markedly deficient in rainfall, could be taken as an indication that such a situation might be a stable one. It should be pointed out, however that it is sofar not clear wheter the reduced rainfall at Marajo is indeed the result of the deforested state of the island or whether, conversely, the absence of trees is a consequence of a negative water balance which occurs there because of its geographic position near the open sea. This is another version of the question: which came first the hen or the egg?

b) The other possibility to be considered would be that the changed moisture balance expresses itself downwind in the (yet) undisturbed forest. This scenario is, of course, fraught with danger as the moisture deficiency can then propagate inland, cutting a swathe into the forest and encroaching progressively into virgin territory.

Obviously the question of where rain will occur, is a very crucial one.

The whole problem has, however, even wider ramifications. Very basic meteorological considerations make it appear most unlikely that the consequences of deforestation can be "contained" within the area concerned or indeed be simply controlled by the local water balance. The meteorological role of the immense tropical clouds (cumulo-nimbus towers) is the dissipation of the heat excesses which accumulate at these low latitudes (Riehl, 1969); the latent heat flux is here a dominant term. Whereas the large scale water transport may not be affected by a change in the updraft flux (e.g. reduction of the frequency of cloud formation) because an equivalent reduction in evaporation compensates for any decrease in precipitation, and vice versa, as described above, such accounting cannot be applied to the heat transport; the elimination of even some of the convective cells necessarily reduces the heat flux and perturbs the heat balance both locally and globally. Alternative dissipation mechanisms then evolve to take care of the excess heat; these might, secondarily, even affect the regional water balance.

These are quite general considerations; on the more detailed scale the whole concept of local linkage between evaporation and precipitation amounts must be questioned: the response of the rain pattern to environmental change does not seem to be dictated by water balance considerations alone and is not necessarily proportional to, or even in phase with, the evaporative water flux. We believe that the question of the effect of deforestation on the regional and local precipitation patterns can only be answered when the more fundamental question of the "why, where and when" of rainshowers in the basin has been solved. Unlike most other regions where the detailed precipitation pattern is dictated by distinct weather systems (cyclones, fronts etc.) or by the topographical features (orography), one rarely finds the development of a large weather pattern such as fronts throughout the Amazonas and there is almost no altitude variation. Indeed only some of the heavy autumn rains during February-May along the Atlantic seashore seem to be correlated with the position of the Intertropical Convergence Zone (Ratisbona, 1969) [these rains are marked by a very negative values of both 18_O and 2_H (Salati **et al.**,)] and some of the precipitation in the southern and central parts of the basin can be attributed to the advection of polar air masses, although the cold fronts proper seem to peter out before even reaching the center of the basin (Ratisbona, 1969). [These latter rain events are characterised by moderately depleted isotopic values (Matsui, Salati and Gat, this conference)]. In the majority of cases, however, there is a predominantly westward drift of tropical marine air which appears to be in a rather delicately balanced (neutral) state. Cloud formation and the ensueing rain are then triggered by minor local perturbations such as a hot spot or by turbulence initiated by surface roughness elements, and hindered by any process which would stabilise the air column, for example by cooling as a result of excess evaporation. The local albedo and the surface structure may well be the key elements which determine the pattern of onset of rain, although the degree of saturation of the surface air which results from local water balance also has to be considered (the distance to the dew point obviously determines the scale of initial lifting which is required). As deforestation affects these variables in addition to the atmospheric moisture load, it will be necessary to take these factors into account in order to define the system's response in time and space.

The contention of this presentation is that the appearance of clouds and the occurrence of rainout is governed to a large extent by the interplay of the local meteorologic and physical-geographic parameters with the atmospheric stability structure, except during a few well defined periods during which rain is dominated by large scale atmospheric instabilities. The study of these phenomena must then be made on the scale of the cloudsizes, e.g. that of a few ten kilometers at most. The clouds, whose formation is determined by the local conditions are, however, responsible for most of vertical heat and mass transport over the basin (Riehl, 1969). Their frequency of occurence, rainout efficiency etc. will thus dictate the extent to which energy inbalances remain in the system. Regional and global responses to any such inbalances thus also depend, in the final analysis, on the local phenomena, although the exact meteorological or climatic form which such reaction may take will require a synoptic-scale approach to the system.

The research priority of the micro-scale phenomena appears to be clearly indicated. These should include local heat balances, studies on cloud formation mechanism as well as detailed measurements of the local atmospheric (vertical) stability.

RESUMO

Se o desmatamento de grandes áreas no Amazonas resultar numa redução do fluxo de

água evaporativa, ou a queda na evaporação é compensada localmente por uma redução na chuva, ou então a mudança no equilíbrio da humidade refletir-se-á na direção do vento, na floresta ainda não perturbada. A questão crucial é quando ocorrerão as chuvas. Sugere-se que o aparecimento de nuvens e ocorrência de chuvas são primordialmente determinados pela interação dos parâmetros geográficos locais, meteorológicos e físicos, com a estrutura da estabilidade atmosférica, exceção feita a alguns períodos bem definidos quando a chuva é dominada em larga escala por uma instabilidade atmosférica. Isto significa que o estudo destes fenômenos (balanço térmico local, estudos sobre o mecanismo de formação de nuvens, estabilidade atmosférica vertical, etc.) deve ser feito de acordo com a extensão das nuvens, no máximo a algumas dezenas de quilômetros.

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