HOLOCENE CHANGES OF RAINFALL AND RIVER DISCHARGE IN NORTHERN SOUTH AMERICA AND THE EL NIÑO PHENOMENON

With 3 figures

THOMAS VAN DER HAMMEN and ANTOINE M. CLEEF

Zusammenfassung: Holozäne Niederschlags- und Abflußänderungen im nördlichen Südamerika und das El Niño-Phänomen

Die Zeiträume mit niedrigen Hochwasserständen im unteren Magdalena - Cauca - San Jorge-Gebiet, wie sie durch die horizontale Ausdehnung von Torflagen (bzw. die Häufigkeit datierter Torflagen in Bohrprofilen) zu rekonstruieren sind, stimmen gut mit den datierten Perioden niedriger Seewasserstände in den nördlichen Anden überein. Trotz einiger lokaler Unterschiede ergeben sich ebenfalls gute Übereinstimmungen mit Perioden niedriger Hochwasserstände in Zentral-Amazonien und im mittleren Caquetá-Flußgebiet. Daten über die Niederschlagsvariation während der letzten 1500 Jahre, wie sie sich aus den Mächtigkeiten der Eis-Jahresschichten der Quelccaya-Eiskappe im Hochland von Peru ableiten lassen, weisen eine nahezu perfekte Übereinstimmung mit der Kurve der unterschiedlichen Torfausdehnung im unteren Magdalena-Cauca-San Jorge-Gebiet auf. Damit wird zum einen die vorliegende Interpretation bestätigt, während sich daraus zum anderen der synchrone Charakter der Abfolge von Trocken- und Feuchtphasen für weite Teile des nördlichen Südamerika ergibt. Vergleiche des Southern Oscillation Index mit dem Abfluß des Magdalena-Flusses während der letzten 50 Jahre erweisen eine sehr gute Korrelation zwischen El Niño-Jahren und niedrigen Abflußwerten. Darum mögen die holozänen Trockenphasen als eine Art von „Mega-El Niño-Phänomen" aufgefaßt werden. Sie mögen in bestimmten anderen Gebieten des nördlichen Südamerika durch Feuchtphasen repräsentiert werden.

The headwaters of the Magdalena, Cauca and San Jorge rivers are in the Northern Andes, draining the western part of the Eastern Cordillera, the Central Cordillera and the eastern part of the Western Cordillera of Colombia. The three rivers come together in a very extensive floodable area, the lower Magdalena-Cauca-San Jorge area. The eastern slopes of the Andes are drained in the north by headwaters of the Orinoco river system and further south by the headwaters of the Amazonas river system. It is not surprising therefore, that there is a close relation between rainfall in the Andes during the wet seasons, and the level of river inundations in the lowlands. In the extensive backswamp lakes (cienagas) of the lower Magdalena, zones of marsh vegetation develop along the shores, being of special interest the broad zone of "floating meadows" of dominating grasses, that root somewhere at the shore, and extend "floating" far inward, forming a thick peaty carpet. Stratigraphic and palynological study of sections from the recent sediments of these lakes (e. g. WIJMSTRA 1967) revealed the presence of peat-layers in the clayey, silty to sandy deposits, that were formed in the marshy shore vegetation, especially in the "floating meadows". Being underlain and overlain by open water sediments, they evidently represent phases of considerable extension, stranding and rooting of these meadows during low water level periods. A next high water level period then covered the floating meadow peat with open water river lake sediments. It was also established that during these low water level peat-forming periods *Cecropia* (a river side pioneer tree) could invade the stranded meadow, while *Byrsonima, Curatella* and *Ouratea,* dry forest to savanna trees/shrubs extended, while wet forest elements decreased. All this confirms the correlation of peaty layers in the lower Magdalena-Cauca-San Jorge area, with relatively dry periods of lower rainfall and relatively low high water levels.

Nine boreholes made in the area, until a depth between 40–50 m, were sampled for palynological studies and the peaty layers were dated by radiocarbon analysis. They represent the Holocene sedimentary infill of the basin. A total of 25 dates of peat layers of these boreholes are available, and were used for the elaboration of a frequency curve of dated main peat layers (VAN DER HAMMEN 1986). This curve is reproduced in Fig. 1 (left) and gives an indication of the relative extension of peat layers in time and in space. For the last 3000 years the next curve of Fig. 1 was constructed, using the dates already available, and moreover 12 dates of dark humic layers in the lower San Jorge area (PLAZAS et al. 1988). It will be clear that, especially when only 1 date for a time-interval is available, the statistical value is relatively low, although this is difficult to quantify. The significance, however, will increase considerably if there is coincidence with other curves (see below). The curves suggest drier periods around 7000 BP, 5500 BP, 4700 BP, 4000 BP, 2700/2500–2300 BP, 2150–2050 BP, ca. 1500–1300 BP and 750–650 BP.

Fig. 1: Data related to level of river inundation and of lakes during the Holocene. From left to right: frequency curves of radiocarbon dated peat layers in the lower Magdalena-Cauca-San Jorge valley; intervals of low lake-levels (dated peaty intercalations in lake sediments) for the Northern Andes; curve of relative level of the river for Central Amazonia (based on 14C dates and pollendiagrams); frequency curve of radiocarbon dated peaty layers for the middle Caquetá river valley

Daten zur Höhe der Fluß- und Seenwasserstände im Holozän

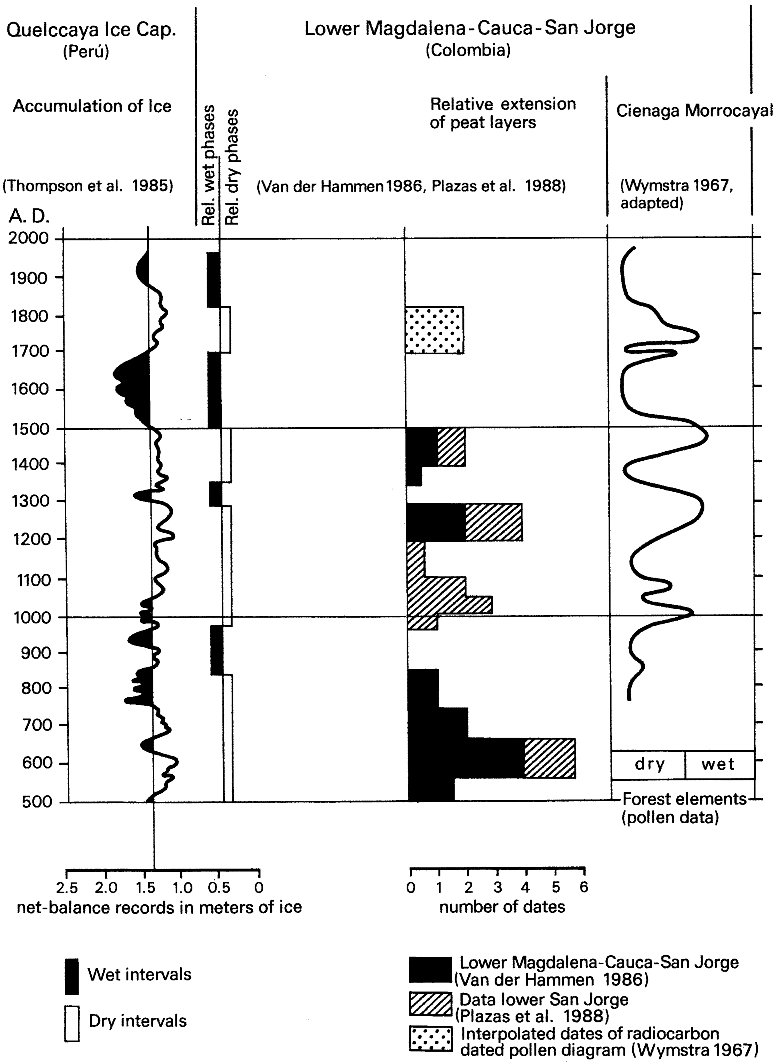

Fig. 2: Accumulation of ice (precipitation) on the Quelccaya ice cap (Peru) for the last 1,500 years, compared to the curve related to level of river inundation in the lower Magdalena-Cauca-San Jorge valley. From left to right: Quelccaya ice cap, accumulation of ice; sequence of drier and wetter phases; relative extension of peat layers; dry forest/wet forest relation (based on palynological data and inter-/extrapolation of radiocarbon dates)

Eisablagerung (Niederschläge) der Quelccaya-Eiskappe (Peru) während der letzten 1500 Jahre, verglichen mit Zeugnissen der Flußwasserstände im unteren Magdalena-Cauca-San Jorge-Tal

Another drier interval is indicated in the pollen-diagram of Morrocayal (Wijmstra 1967), between ca. 250 and c. 175 AP (see Fig. 2, extreme right).

As there should be an intimate relation between rainfall in the Andes and the water levels in the lower Magdalena-Cauca-San Jorge area, it is interesting to compare these curves with the data on radiocarbon dated lake-levels in the Andes (reviewed in van der Hammen 1986). The corresponding sequence is also given in Fig. 1, and a considerable correspondence is evident for the ca. 4700, the ca. 4000, the 2700-2300/2100 and the 750-650 (-450) periods, and there seems to be an equivalent of the ca. 3500 date.

When we now turn to the Amazonian river system, we dispose of a curve published by Absy (1979), based on radiocarbon dates and palynological data of intervals interpreted as corresponding to low river inundation levels; partly this is also based on the extension and stranding of floating meadows. This curve is based on data from the central Amazone basin in Brasil, and is reproduced in Fig. 1. The curve represents the last 4000 years, and there is a very good coincidence with the three main dry periods registered in the lower Magdalena.

Recently another set of data became available, from the Middle Caquetá river, one of the larger affluents of the Amazone river, in Colombia. The curve is based on the frequency distribution of some 30 radiocarbon dates of peat horizons in the otherwise minerogene Holocene sediments of the floodable valley (VAN DER HAMMEN et al. 1992). Here again, a more extensive deposition of peaty sediments, especially in backswamp areas, may be expected if the high river levels during the wet season do not reach (or only reach with low frequency) these areas because of a lower river discharge during the wet seasons and hence because of lower rainfall in the capture area (including especially the headwaters in the Andes).

The curve (extreme right in Fig. 1) shows in general a good correspondence with the other ones, with one major exception. There is a drier period between ca. 2700 and ca. 1300 BP, uniting the drier intervals between 2700–2300/2050 BP and ca. 1500–1300 BP, the period between ca. 2000 and 1700 being the one with the greatest peat frequency.

Recently data on precipitation during the last 1500 years in Peru became available from a totally independent data-set: thickness of annual layers in the glacier ice of the Quelccaya Ice Cap (THOMPSON et al. 1985). The curve is represented in Fig. 2 (left). The dark areas towards the left showing relatively high values of accumulation/precipitation and the white areas, towards the right, relatively low values (relatively dry periods). These data may be compared with those from the lower Magdalena-Cauca-San Jorge, including the radiocarbon dated peat frequency and the dated pollendiagram of the same time interval. There is a surprisingly good coincidence between the two data-sets, that are totally independent. This on one hand confirms the interpretation of the radiocarbon dated peat frequency, and on the other hand shows that the sequence of drier and wetter intervals occurs at the same or almost the same time, in the Peruvian Andes and in the Colombian Andes and lower Magdalena-Cauca-San Jorge river area. There is also a correlation with the two drier periods represented in the upper part of the Amazonas curve, and approximately, with the uppermost part of the Caquetá curve. For all this we may accept the interpretation and correlation of other earlier Holocene drier intervals, between 10 000 and 1500 BP, showing that (the effects of) a number of larger fluctuations of rainfall is approximately contemporaneous in a relatively large area.

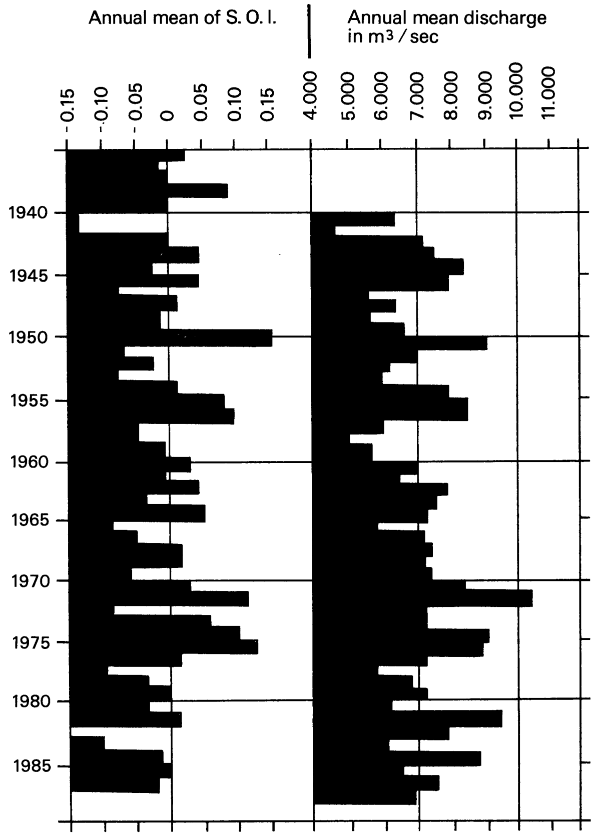

Fig. 3: Annual mean of Southern Oscillation Index (S.O.I.) compared with annual mean discharge in m³/sec of the Magdalena River since 1940. According to data published by DUEÑAS (1992)

Jahresmittel des Southern Oscillation Index (S.O.I.) verglichen mit dem mittleren Jahresabfluß (m³/sec) des Magdalena-Flusses seit 1940

DUEÑAS (1992) published data of the last 50 years of the mean annual discharge of the Magdalena river, comparing it with the Southern Oscillation Index (S.O.I.) (Fig. 3). He concluded that there is a close relation between the two data sets, and that a strong El Niño phenomenon means low discharge values of the river. This means relatively low precipitation in the capture area.

DUEÑAS then suggests that the fluctuations recorded in the curves of the lower Magdalena-Cauca-San Jorge we just discussed, are also related to the El Niño phenomenon (hence a long Paleo-ENSO record). Recently much information on Paleo-ENSO records has been published (e. g. ORTLIEB a. MACHARÉ 1992). The data from the lower Xingu river (an affluent of the Amazonas) are especially interesting (PEROTA 1992). He found three major interruptions in human settlements of shellmounds, between 2255 and 1485 BP, 1200 and 1090 BP and between 840 and 550 BP. PEROTA relates these intervals with highwater local disturbance, and he also concludes that the river level was 2,9 m below the present one before 2250 AP. All this again seems to be in good agreement with the lower Magdalena and Amazonas curves of Fig. 1.

It may very well be, that the Holocene changes of river level and precipitation recorded here to be contemporaneous in relatively large parts of the Andes and Amazonas, and representing, at least partly, periods of several hundreds of years, are caused by some mega „El Niño" phenomenon. In the cases presented here, the relation would be mostly of low precipitation values. However the reverse might also occur. The case of the 2000–1500 BP dry period in the Caquetá river, coinciding with a wet period in the Central Amazone, the Xingu river, the Magdalena and the Andes, might then be related by a shift of the limit between wet and dry El Niño in the capture area of the river. The 2700/2500–2300/2100 dry period seems to be one of the most prominent, and in relation to this, the Caquetá case might be interesting to study in more detail, for a possible better understanding. It will, however, be necessary to obtain more curves from different areas in Northern South America, and in general more abundant dates and data, to be able to evaluate better the changes of rainfall patterns in the area and their possible relation to the El Niño phenomenon.

A time-series analysis of the Magdalena-Cauca-San Jorge and the Caquetá curves showed the possible existence of periodicities in the order of 150, 200, 350, 500, 600 and 1100 years. The statistical basis is low and the signal feeble, but it is noteworthy that these are ciphers repeatedly recorded in the analysis of paleo-climatic curves. In more detailed data sets, ciphers of 80, 40 and 22 years were also found (e. g. WIJMSTRA et al. 1984). The shorter periods are apparently related to sun-spot cycles, and it might be that these and the longer periods have to do with differences in solar energy/radiation received by the earth.

These are only suppositions, but they may help to direct and intensify our research that (once much more detailed data in space and in time have been obtained), may enable us to project the phenomena into the future.

References

ABSY, M. L.: A palynological study of Holocene sediments in the Amazone basin. Thesis Univ. of Amsterdam. Amsterdam 1979.

DUEÑAS, H.: The Paleo ENSO record in the Lower Magdalena basin, Colombia. In: ORTLIEB, L. a. MACHARÉ, J. (eds.): Paleo ENSO Records. Intern. Symp. Lima, Extended Abstracts. Lima 1992, 81–85.

ORTLIEB, L. a. MACHARÉ, J. (eds.): 1992. Paleo ENSO Records. International Symposium Lima, Extended Abstracts. Lima 1992.

PLAZAS, C.; FALQUETTI, A. M.; VAN DER HAMMEN, T. a. BOTERO, P.: 1988. Cambios ambientales y desarrollo cultural en el Bajo Río San Jorge. In: Museo del Oro, Belotín 20. Bogotá 1988, 55–88.

THOMPSON, L. G.; MOSLEY-THOMPSON, E.; BOLZAN, J. F. a. KOCI, B. R.: A 1500 - year record of tropical precipitation in Ice Cores from the Quelccaya Ice Cap, Peru. In: Science 229, 1985, 971–973.

VAN DER HAMMEN, T.: Fluctuaciones holocénicas del nivel de inundaciones en la cuenca del Bajo Magdalena-Cauca-San Jorge (Colombia). In: Geología Norandina 10. Bogotá 1986, 11–18.

VAN DER HAMMEN, T.; URREGO, L. E.; ESPEJO, N.; DUIVENVOORDEN, J. F. a. LIPS, J. M.: Late glacial and Holocene sedimentation and fluctuations of river water level in the Caqueta river area (Colombian Amazonia). In: Journ. Quaternary Science 7(1), 1992, 57–67.

WIJMSTRA, T. A.: A pollen diagram from the Upper Holocene of the lower Magdalena Valley. In: Leidse Geol. Meded. 39, 1967, 261–267.

WIJMSTRA, T. A.; HOEKSTRA, S.; DE VRIES, B. J. a. VAN DER HAMMEN, T.: 1984. A preliminary study of periodicities in percentage curves dated by pollen density. In: Acta Bot. Neerl. 33(4), 1984, 547–557.