MODELLING THE HYDROLOGICAL CHANGES DURING THE HOLOCENE IN THE ALTIPLANO

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INTRODUCTION

The Altiplano presents different caracteristics that are interesting to carry on quantitative studies on the relations between climate and hydrology. It is situated at the boundary between different types of climate (10°S-24°S). The hydroclimatic conditions have varied drastically over the past 20 000 years. At present the rainfalls originate mainly from the low latitudes of the Atlantic ocean. The tropical conditions induce a marked season of rains (November to February) and a marked latitudinal gradient of the rain amount (750 mm yr^{-1} in the north, 250 mm yr^{-1} in the south). During the past, the chemical composition of oceanic sediments in front of the Chilean coast (Lamy *et al.*, 2000) show that the latidudinal gradient of rain amount was probably much lower. Such situation could be linked to water vapour flow from high latitudes.

The aim of the presentation is to testify the usefulness of convergent approaches from transient hydrologic modelling and from general atmospheric circulation modelling to reconstruct and/or predict future hydrological changes in response to climate modifications and to the extent of human influence on continental area.

CONSTRAINTS OF HYDROLOGIC MODELLING TO CLIMATIC RECONSTRUCTION

Two hydrologic proxies of the Altiplano were used to carry on hydrologic simulations over the period from 15 000 years B.P. to present. One corresponds to the different water levels of two major lakes in the northern and southern sub-catchments of the Altiplano (10°S-24°S). The other is the evolution of chemical composition of groundwater along the flow paths in a phreatic aquifer in the central part of the Altiplano.

TRANSIENT MODELLING OF LACUSTRINE REGRESSIONS

The Altiplano is an endoreic catchment (196,000 km^2) whose low point is situated in the southern part. Around 15 000 years ago, this low point was occupied by a huge lake of 54 000 km^2. Isotopic data and hydrological constraints indicate that this lake was fed mainly by rainfall on the southern part of the Altiplano and not mainly by inflow from the northern part of the catchment (Coudrain *et al.*, 2001). This study reinforces the argument that the latitudinal gradient of rain amount was probably much lower during this lacustrine phase. Just before or during the early stage of the Holocene, the two major lakes of the Altiplano experienced a water level decrease of around 100 m (Abott *et al.*, 1997). Different simulations with climate changes (precipitation decrease, temperature increase and disappearance of a seasonal rainfall distribution) were carried out. The two subcatchments, the Titicaca one in the northern part, and the Uyuni one in the southern part, present very different shapes. Because of their morphologic difference, the duration of a 100 m decrease of the water level may be interpreted in different ways (Condom *et al.*, submitted). For the northern subcatchment, a 100 m decrease in less than one thousand years should correspond to a change of the climatic parameters among the highest values considered (decrease of rain amount of 15%, increase of temperature of 5°C, and/or disappearance of the seasonal repartition of rain over the year). For the southern sub-catchment, the reservoir effect is negligible. Hence, a 100 m decrease in more than one century must correspond to a progressive change of the climatic conditions.

TRANSIENT MODELLING OF CHEMICAL ELEMENT TRANSFER IN SUB-SURFACE

In an area of 3500 km^2 in the upstream part of the southern sub-catchment of the Uyuni salar transient modelling was carried on over 11 000 years (Coudrain *et al.*, 2001 & 2002). The progressive transfer of different chemical elements (chloride, strontium) between surface, unsaturated zone and the phreatic aquifer was computed. The amounts of the different terms of inflow and outflow have changed during the Holocene according to the climatic evolution. As a consequence, the input, transport and output of chemical elements have also changed during this period. The objective of the study was to reconstruct the time evolution of these terms of the water and chemical balances of the aquifer during the Holocene in accordance to present observed data. The results of the hydrogeological simulations are consistent with the following conclusions: (i) the southern sub-catchment was not fed by significant flow from the northern catchment between approximately 9000 and 4000 years B.P., and (ii) major rain events occurred between 4000 and 2000 years.

CONSTRAINTS OF CLIMATIC MODELLING TO HYDROLOGIC RECONSTRUCTIONS

A study is under development on the links between the general atmospheric circulation and the regional climatic conditions in the central Andes. The first step conducted was on the present variability of the climatic conditions. A simulation on 1000 years with the present orbital conditions was carried on with the coupled model that takes into account the associated processes between ocean and atmosphere. The results show that the sea surface temperatures change with a periodicity of about one to two centuries. However, considering the extreme situations of these computed results, the rainfall amounts over South America are not changed significantly. Hence, at this stage the working hypothesis is that the coupled processes between oceanic and atmospheric flows are not sufficient to induce significant changes in the rainfall amount in the Andes. Significant changes in precipitation should be bound to orbital variations and/or to changes in the land surface as it has been already computed and published for Western Africa. However, more work is needed to check the validity of such preliminary conclusion.

CONCLUSIONS

Quantitative approach has been largely developed in hydrology/hydrogeology to study the repartition of continental water through different processes (evapotranspiration/runoff/underground flow) and into different reservoirs (lake/river/soil/aquifers/glacier). It is mainly used for the present and the last decades with available instrumental hydrologic data. It can be extended to other periods for which only proxy are available. For distant periods in the past or in the future, modelling continental flow can be very valuable. For example, it can be used for estimating the duration of the impacts of climate change on hydrological terms. In the case of the Altiplano, it has been shown that the present salinity of soil and groundwater is bound to the hydroclimatic conditions that prevailed since 15 000 years. Another example of usefulness of paleo-hydrological modelling is the computation of the duration of the changes of inundated area as a consequence of climatic change. This is important to evaluate the delay between the climate change and the corresponding water level changes of inland area.

It is finally important to note that major changes of inundated area may occur in few decades for modifications of rainfall amount and/or temperature of the order of what is predicted for the future decades of the present century. It is then urgent to strengthen convergent approaches between the ocean/atmospheric studies and the transient hydrological modelling.

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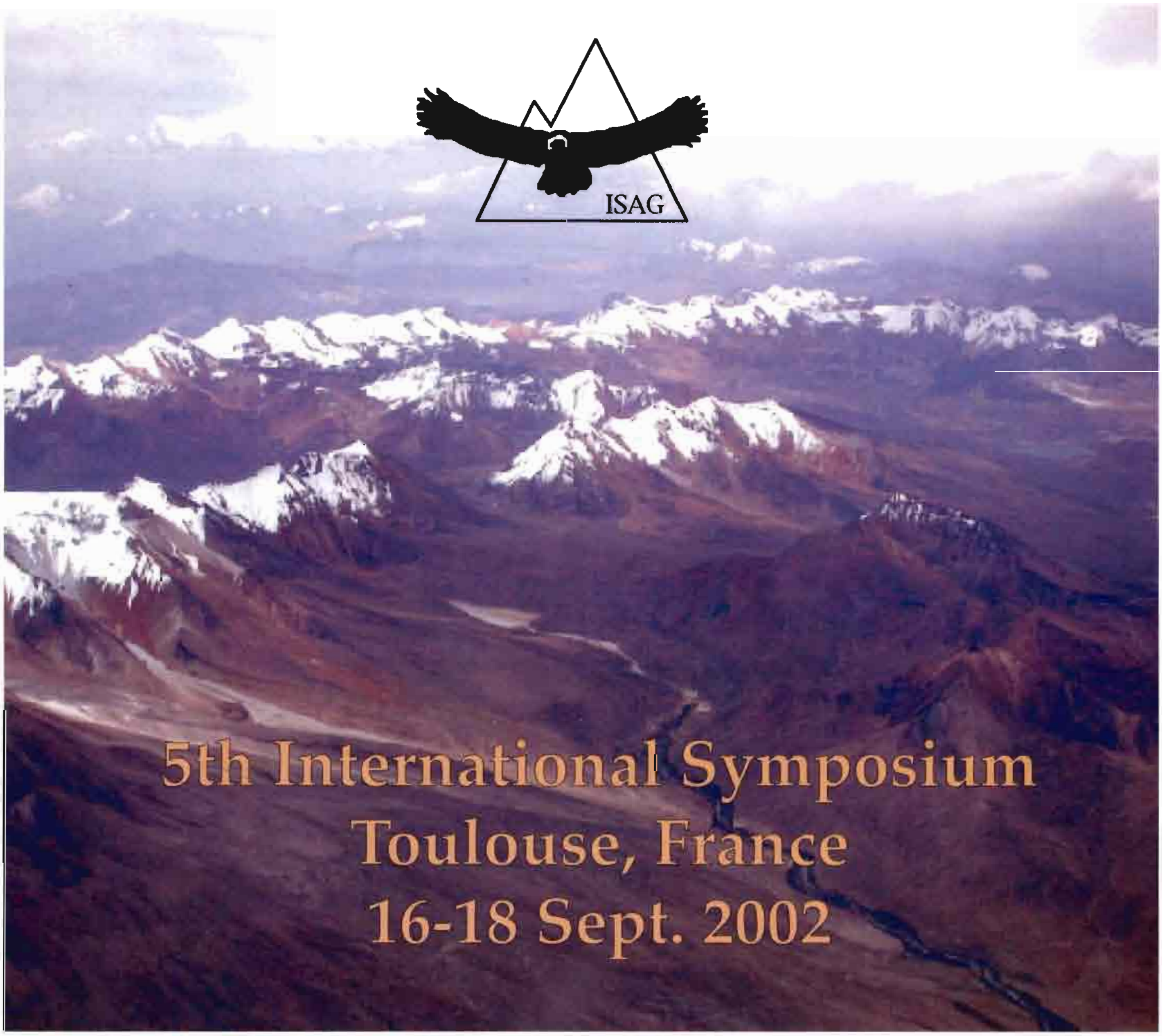

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