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VULNARABILITY OF GLACIERS TO THE CURRENT CLIMATE IN THE TROPICAL ANDES (BOLIVIA, PERU AND ECUADOR)

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Due to the strong sensitivity to atmospheric changes, mountain glaciers have become valuable tools for surveying evolution of the global climate (IPCC, 2007; Francou and Vincent, 2007; 2009). But the homogeneity of the signal of glacier retreat is disturbed 1) by the complexity of the response of glaciers to climatic variables, 2) by the ice dynamics, which introduces a delay between the climate input and the glacier response, 3) and by the climate variability at regional scale. For this reason, it is more suitable to compare glacier mass balance data, but this detailed information is only available at regional scale on few instrumented glaciers. The glacier observation program developed by IRD and partners in the tropical Andes since the early 1990s allows the question to be addressed in the inter-tropical region from Bolivia (16°S) to Ecuador (0°28S) on the basis of a continuous data set from 6-8 representative glaciers over the two last decades, completed by discrete information since the 1950s (Francou et al., 2007; CAN et al., 2007) **[Figure 1].** It is clearly visible that the magnitude of glacier retreat increased dramatically after the 1980s, with losses for specific net balance close to 5-10 m of water equivalent per decade since 1991 and shrinkage rates as high as 30-50% in glacier areas and volumes over the three last decades (Jordan et al., 2005; Soruco et al., 2009a; 2009b). In such conditions, the most vulnerable have been the small-sized glaciers situated at low elevation (<5500 m a.s.l.), many of them being almost extinct (Ramirez et al., 2001). This evolution denotes drastic changes occurred at high elevation in climatic conditions, which appear closely linked to the evolution of the sea surface temperature in the tropical Pacific (Vuille et al., 2008). Superimposed on the warming trend since 1976, warm/cold ENSO events in the central Pacific have introduced a strong interannual variability by imposing distinct ablation and accumulation conditions. Since net accumulation is generally higher during the cold events, ablation is much more marked during the warm events, particularly in summer (ONDJ) in Bolivia and during the equinox in Ecuador (AM and SO) (Francou et al., 2003; 2004). Even if glaciers in the tropics are situated at very high elevation (<500 hPa), and can be considered as relatively preserved from the direct warming of atmosphere (via the sensible heat flux), mass balance and temperature appear to be strongly correlated at month/year scale. This can be explained by an efficient feed-back with the nature (liquid/solid) and frequency of precipitation (Wagnon et al., 1999; Favier et al., 2004a; 2004b; Sicart et al., 2005). When atmosphere is cold (La Niña), solid precipitation is able to maintain a high albedo snow cover at low elevation, that leads to a low short-wave radiative balance and weak ablation rates at the glacier surface (Wagnon et al., 2001). The opposite situation occurs during the El Niño situations, when atmosphere in the high Andes is unusually warm (and in some places dry, as in Bolivia) and rain present at 5000 m and more, allowing ablation to be particularly severe up to high elevation (Equilibrium Line Altitude at 5300/5500 m). Albedo is thus a key-factor of the current glacier depletion due to the fact that on the tropical glaciers short-wave radiation is by far the main source of energy for melting ice. Since climate models predict in the future higher temperature at high elevation in the Central Andes (Bradley et al., 2004), glaciers appear to be particularly vulnerable in the course of the next decades. Comparing glaciers in the Tropics and in higher latitude massifs, glaciers of central Andes experiment since 30 years retreat rates which are not unusual at world scale (Francou and Vincent, 2007; 2009) **[Figure 2]**. But due to the small size and the high sensitivity of these glaciers to increasing temperature, many of them will be in risk of extinction in the next decades.

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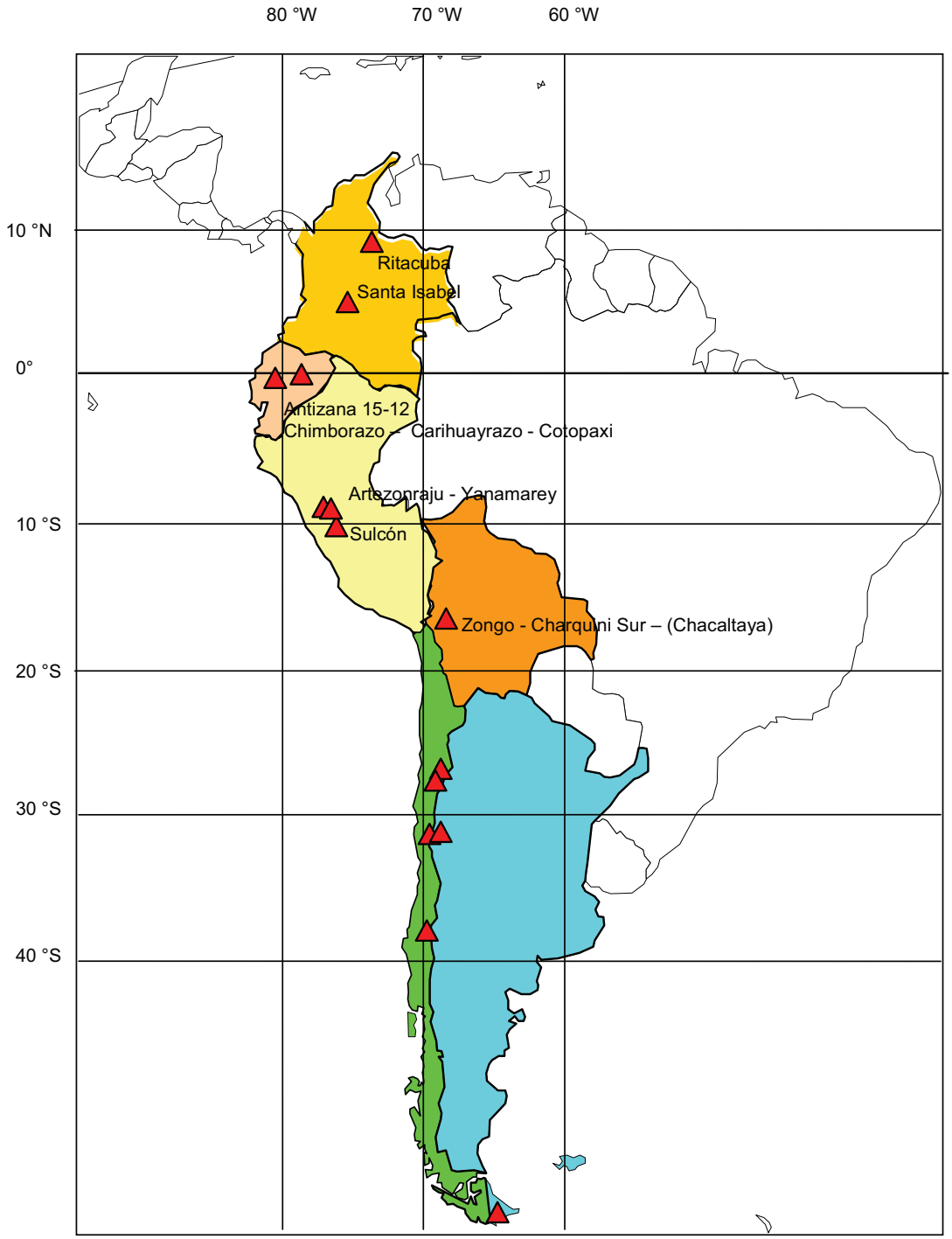

Figure 1. Map of distinct glaciers permanently monitored in South American from ground and aerial observations (red triangles). Names refer to central Andes glaciers.

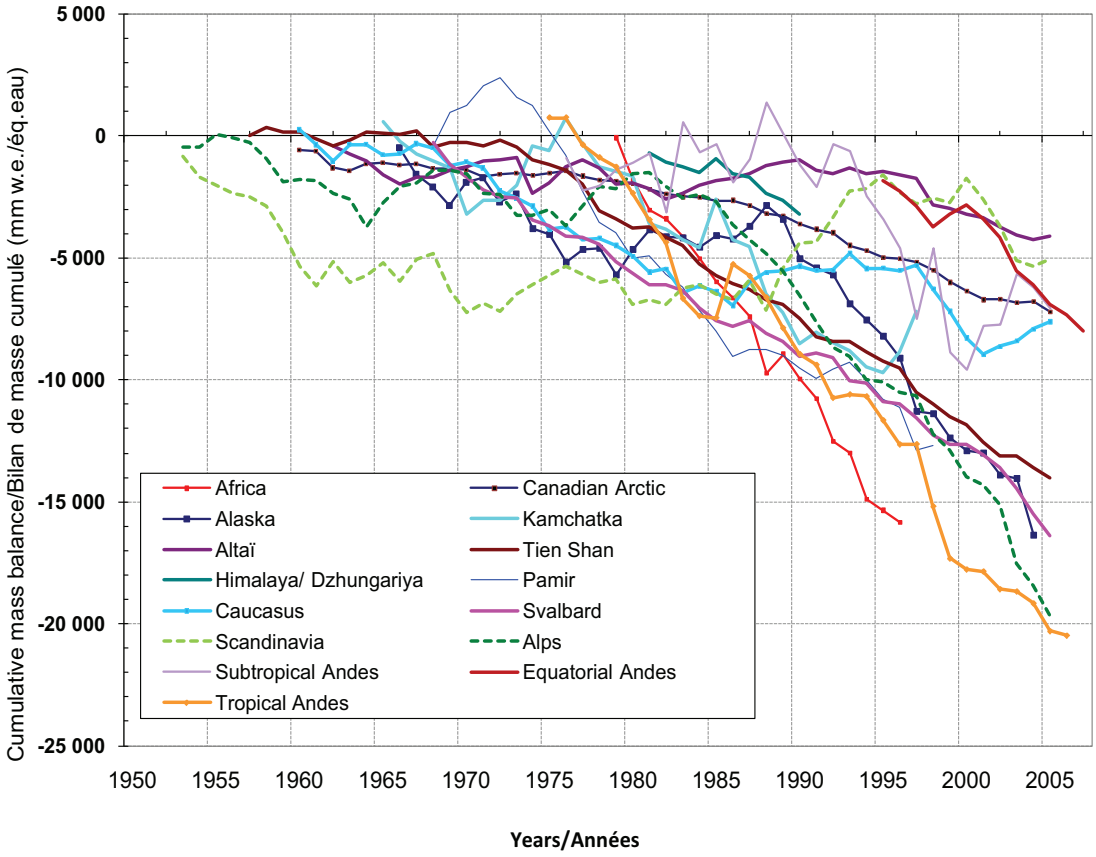

Figure 2. Cumulative mass balance of 76 glaciers in the world averaged by massifs (see Francou and Vincent, 2009). Tropical and Equatorial glaciers only include Zongo (Bolivia) and Antizana 15 (Ecuador) glaciers, respectively.