ENSO EVENTS RECORDED IN THE GULIYA ICE CORE

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Abstract. Based on the ENSO chronology and climatic information recovered from the Guliya ice core in the Tibetan Plateau, China, the ENSO teleconnection was investigated. The results showed that the negative precipitation anomalies are significantly associated with El Niño years but poorly with negative anomaly of δ^{18}O. Thus, the ice core records can be used as an archive of extremely global climate anomalies such as ENSO events.

1. Introduction

In the last few decades, many reports have suggested that in the lower latitudes, sometimes even in the middle and higher latitudes, the annual variations of precipitation were related to the events of El Niño and Southern Oscillation (ENSO), which were caused by large-scale interactions between ocean and atmosphere (Rasmusson and Wallace, 1983; Ropelewski et al., 1987; Bradley et al., 1987). In most regions at the lower and middle latitudes of the earth, the ENSO events have significantly influenced annual climatic changes (Whetton and Rutherfurd, 1994). Although the ENSO events are aperiodic, they occur at a frequency of 2–10 years (Rasmusson and Carpenter, 1982). A generally used index of the ENSO event (SOI) is calculated from the atmospheric pressure difference between Tahiti and Darwin.

In the last decade, ENSO events during the pre-instrumental period have been examined by using proxy data such as precipitation and other variables (Diaz et al., 1992). However, the most detailed chronological analysis of such ENSO events came from the Peruvian coastal flooding records, which were normally associated with El Niño occurrences (Hamilton and Garcia, 1986; Quinn et al., 1987; Quinn and Neal, 1992). The QN chronology (Quinn and Neal, 1992), which extended from 1525 to 1987 AD, suggested that the El Niño phenomena had occurred throughout the Spanish colonization in Latin America with low variation frequency. The teleconnection chronology of El Niño and La Niña was produced from the pattern feature of ENSO on a global scale (Whetton and Rutherfurd, 1994). However, different chronologies have been reported (Whetton and Rutherfurd, 1994; Quinn et al., 1987; Quinn and Neal, 1992).

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The studies in relation to the impact of ENSO events on climatic changes in China (Wang and Zhao, 1981; Guo, 1987) suggested that a long-term connection existed between SST and the position and strength of the west Pacific subtropical high-pressure system, which has a great effect on the precipitation in eastern China. As investigated in the relationship between precipitation variation in the semi-arid region of northern China and ENSO events by Wang and Li (1990), precipitation deficit in northern China is associated with El Niño years.

To better understand and predict ENSO events, its past records are needed. Fortunately, the ice cores that preserved the paleoclimate information can provide long-term detailed records in relation to these extreme events (Thompson et al., 1984). Here, we focus on discussing the relationships between the ENSO events and the climate records (precipitation and δ^{18}O) in the Guliya ice core, Tibetan Plateau.

2. The Guliya Ice Core and Analytical Methods

The Qinghai-Tibetan (Q-T) Plateau, China, with an average altitude of over 4500 m, is considered to be potentially sensitive to the anticipated global warming of the next century (Hansen and Lebedeff, 1987). Ice cores drilled from several places on the Plateau (Yao et al., 1995a) have been used to reconstruct paleoclimatic changes.

The Guliya is the deepest polar-type ice cap in central Asia, with an area of 376 km^2 (Yao et al., 1997). Three ice cores with respective lengths of 308.7 m, 93.2 m and 34.5 m were successfully taken at 6200–6700 m a.s.l. on the ice cap (35°17′ N, 81°29′ E) (Thompson et al., 1995; Yao et al., 1995b) in the West Kunlun Mountains, Q-T Plateau, and the longest one reached the bedrock. The 308.7 m ice core at 6200 m a.s.l. was drilled (Figure 1) using an electromechanical corer from a dry borehole to 200 m and a thermal corer with an alcohol-water mixture from 200 m to bedrock (308.6 m). The ice temperature in the core is –15.6 °C, –5.9 °C and –2.1 °C corresponding to the depths of 10 m, 200 m and the bottom, without hiatus and visible horizontal layers existing throughout the core. Measurements of Mass balance in 1990 and 1991 indicate that the ice cap receives $\sim$200 mm (H_2O equivalent) of accumulation per year (Thompson et al., 1997; Yao et al., 1997).

Thompson et al. (1995, 1997) and Yao et al. (1996) have described in detail the field and laboratory methods used in climatic and environmental studies in the Guliya ice core.

A variation of δ^{18}O values in Guliya ice core has been used as a proxy for historical temperature changes in the Q-T plateau. Much work in the Q-T plateau has proved that there is a positive relationship between δ^{18}O and temperature (Yao et al., 1995a,b, 1996). The accumulation on the Guliya ice cap was measured in three ways: (1) accumulation stakes, (2) visible stratigraphy in pits, and (3) insoluble particulate β and tritium horizons (Thompson et al., 1995). The precipitation in the Guliya ice core is estimated by the net accumulation on the Guliya ice cap. As

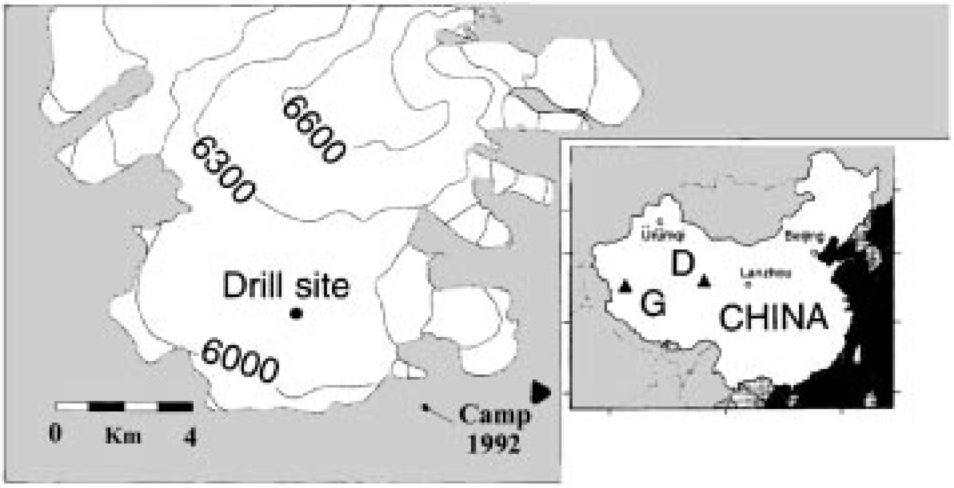

Figure 1. The locations of the Guliya (G) and Dunde (D) ice caps and the site where the 308.6 m Guliya ice core was drilled. Drill site elevation, 6200 m above see level (after Thompson et al., 1997).

studied by Yao et al. (1996), net accumulation on this ice cap is close to the actual precipitation.

Figure 2 shows the annual variations of the δ^{18}O and net accumulation in the Guliya ice core from 300 BP. In order to remove the long-period variations, we re-expressed the series as anomalies from a smoothed version of the series. The smoothing used a 10-year Gaussian, and the ends of the series were padded so that all data could be used (using the method of Jones et al. (1986) and Whetton and Rutherfurd (1994)). The smoothed series are shown in Figure 2. The deviations (as anomaly records) of the raw data from smoothed curved (i.e., high-pass filtered data (Figure 3)) were used in subsequent analyses to ensure that any marked trends are not simply due to long period fluctuation in the data sets.

In the climate time series analysis, the accumulative anomaly chart is often used to determine the trend of a period, i.e., whether the negative anomaly or the positive anomaly is dominant (Whetton and Rutherfurd, 1994). In this study we use this technique to compare net accumulation and δ^{18}O series with ENSO chronology.

3. Results and Discussion

If we use the QN El Niño chronology, from 1690 to 1987 (nearly 300 years), there were a total of 87 El Niño years, of which 60 El Niño years (69%) corresponded to negative precipitation anomalies (Figure 3). In other words, the precipitation was reduced in these 60 El Niño years. In another 71 years (from 1844 to 1915 AD), there were 27 El Niño years, of which 20 El Niño years were associated with negative precipitation anomalies. This was especially true during 1844–1862, when

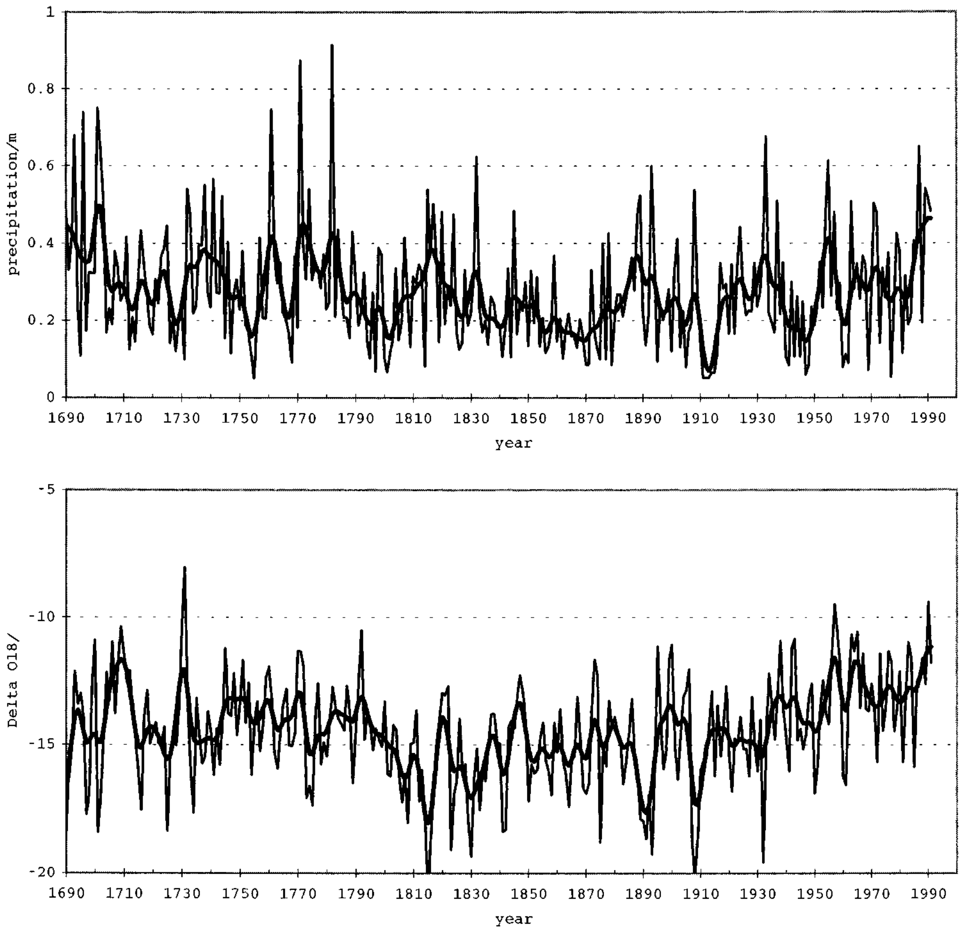

Figure 2. The annual variations of net accumulation and δ^{18}O in the Guliya ice core since 300 BP. Smoothed curves constructed using a ten-year Gaussian filter are superimposed on each curve. Deviations of the raw data from smoothed curves (i.e., high passed filtered data) were used in subsequent analyses.

a total of 9 El Niño events occurred consistenly with the reduced precipitation in the Guliya. Exceptionally, the precipitation anomalies in the Guliya ice core were positive in 27 El Niño years. Among these 25 El Niño years (1709–1979), 12 years are not listed in Whetton and Rutherfurd's chronology (1994). Hamilton and Garcia (1986) pointed out that some ENSO events did not have typical mid-latitude signals. Of course, not all of the years with reduced precipitation must be El Niño years, as precipitation can also be affected by other factors.

However, in 48 El Niño years (55.2%) the δ^{18}O anomalies are negative and in 39 El Niño years (44.8%) are positive. Thus, the El Niño years are poorly related to the negative δ^{18}O anomalies in the Guliya ice core.

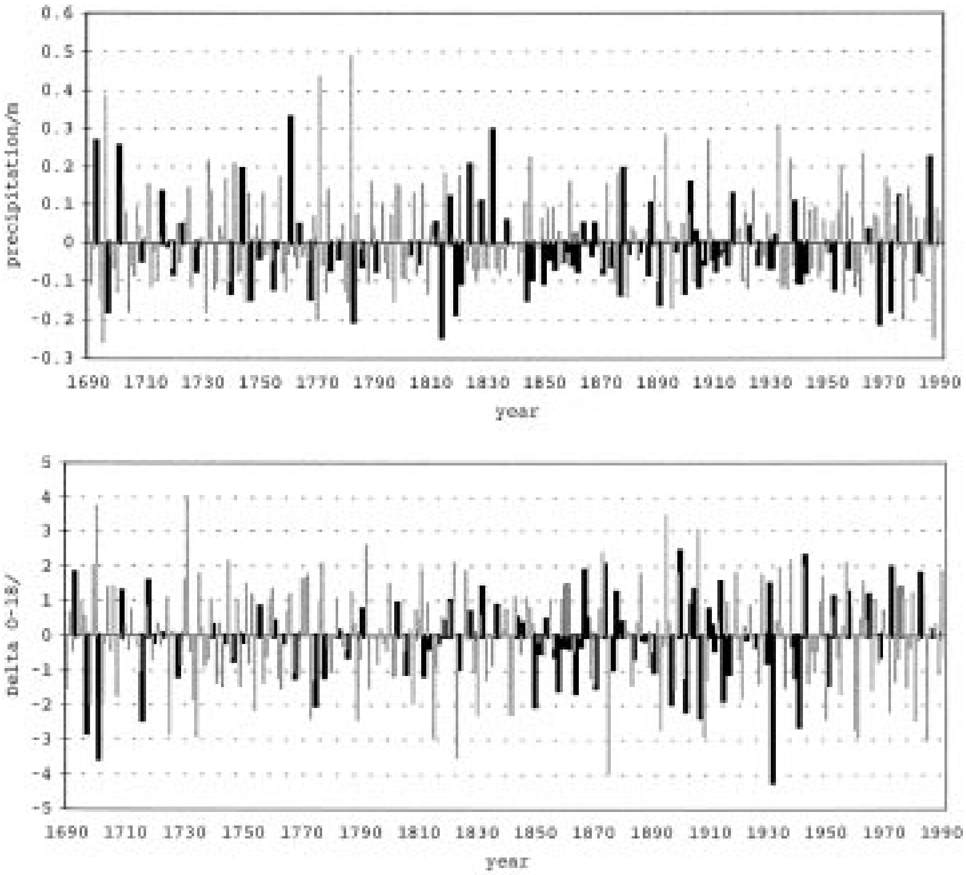

Figure 3. The anomalies of the net accumulation and δ^{18}O in the Guliya ice core. In this figure, the anomalies are the deviations of the raw data (net accumulation and δ^{18}O in the Guliya ice core) from smoothed curves (i.e., high-pass filtered data). Bolded bars are QN El Niño years.

Figure 4 shows the accumulative anomalies of precipitation and δ^{18}O in QN El Niño years. The anomalies were accumulated only for the years contained in the El Niño chronology; anomalies for other years were not used. Where a series in this plot shows a downward trend, there is a tendency for negative anomalies in the series to be associated with El Niño occurrences, and thus can indicate changes over time in the strength of any relationship between El Niño and the regional series. Note also that high pass filtering has been applied to the continuous data sets before this analysis to ensure that any marked trends are not simply due to long period fluctuation in the data sets. It is the slope of the accumulative anomaly that is important rather than its position relative to the zero.

For the precipitation recorded in the Guliya ice core, there was strong evidence of association between reduced precipitation and El Niño years from 1770 onwards, except for a marked reversal in the relationship around 1815–1835 (Fig-

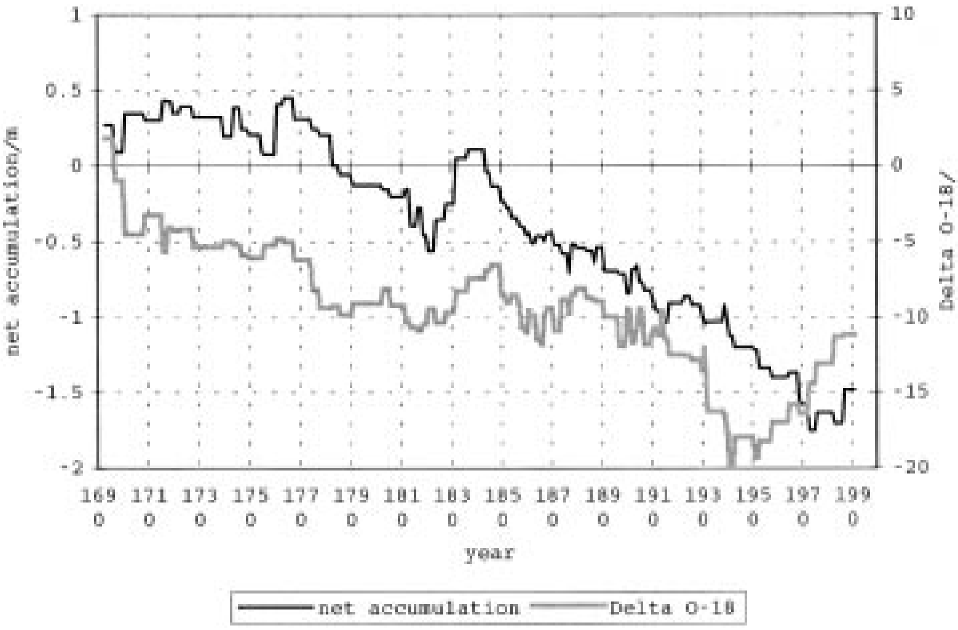

Figure 4. Cumulative anomalies from the net accumulation and δ^{18}O in Guliya for the years of QN El Niño. Starting from the first year in each series, anomalies are accumulated only for the years contained in the QN El Niño chronology; anomalies for other years are not used. A downward trend in a curve represents a tendency for negative anomalies in the series to be associated with QN El Niño. Note that the slope of the cumulative anomaly curve is important rather than its position relative to zero.

ure 4). Prior to 1770, there was no marked tendency for accumulative anomaly. Whetton et al. (1996) pointed out that there was a tendency for negative anomalies except during the period 1710–1760 AD when the relationship reversed.

For the temperature recorded in the Guliya ice core, there was also evidence of association between low temperature and El Niño years from the beginning (1690) to 1940, except for a marked reversal in the relationship between 1815–1835 and 1865–1880. From 1940, a marked reversal in the relationship also existed.

The statistical significance of any relationships can be tested with a Mann–Whitney U-test by comparing values during QN El Niño years with the values in the full series. A one-tailed test is appropriate in testing the expected negative trend (Whetton and Rutherfurd, 1994). The test was applied to three subdivisions of the data (1690–1991, 1690–1840, 1841–1991), and the results are given in Table I.

For the whole period (1690–1991), the precipitation recorded in the Guliya ice core in El Niño years shows a significant decrease ($P < 0.05$), and this is especially true for the period from 1841 AD forward ($P < 0.005$). However, the negative anomaly trend of δ^{18}O is poorly related to the QN El Niño years, especially from 1940 AD when it is markedly opposite.

TABLE I

The average anomaly of the Guliya ice core series in QN El Niño years. The statistics are based on the Mann–Whitney U-test. The significance is showed by asteroid: $P < 0.1$ (*), $P < 0.05$ (**), $P < 0.01$ (***), $P < 0.005$ (****)

Series	Whole period	1690–1840	1841–1991
Precipitation	–2.23**	–0.32	–2.93****
$\delta^{18}O$	–0.10	–0.43	–0.27

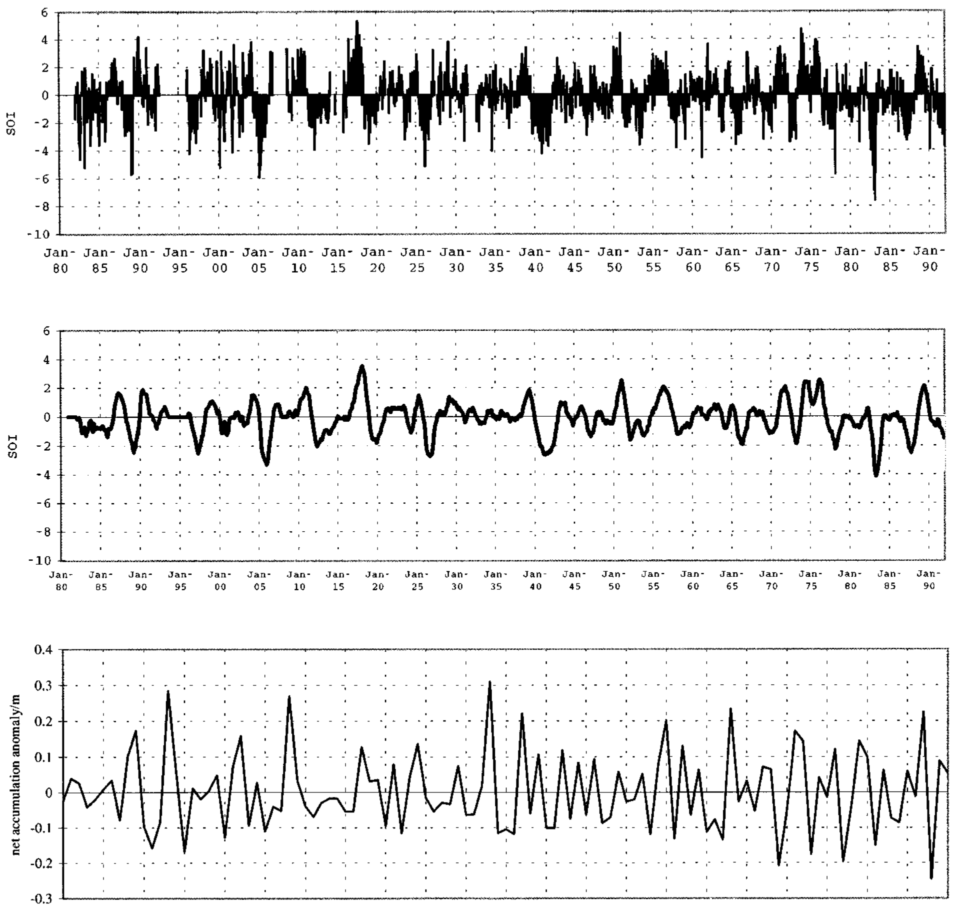

Figure 5. Comparison of the SOI with the anomalies of the precipitation recorded in the Guliya ice core during 1882–1991. The SOI is monthly variation and the smoothed curve constructed using a 12-month moving average is also shown in Figure 5.

In order to confirm the relationship between ENSO events and the climate anomaly, the SOI from 1882 to 1991 were used to compare with the precipitation in Guliya (Figure 5). The SOI is a monthly value. In most cases, the reduced precipitation in Guliya was associated with the lower SOI from autumn to spring and vice versa. The correlation efficient between SOI (October–February, average) and the precipitation anomalies could reach to 0.28 (whole period) or 0.37 (1935–1991).

4. Conclusion

The negative anomalies of the precipitation recorded in the Guliya ice core are significantly correlated with ENSO events. However, the negative δ^{18}O anomalies are poorly correlated with El Niño years.

The ice core records can be used as a proxy to study the nearly global climate anomaly associated with ENSO events. The variation of the precipitation recorded in the Guliya ice core show a teleconnection with ENSO events. Such teleconnections, although statistically significant, are relatively weak for some periods.

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