TWO APPROACHES FOR DETERMINING EXTREME YEARS OF GLOBAL ATMOSPHERIC TEMPERATURE

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ABSTRACT

Two different groups of indices have been defined to analyze the evolution of global temperature between 1958 and 1998. All the indices were evaluated at three different levels (850, 500 and 200 hPa), and averaged indices were calculated using the whole globe, continental areas and oceanic areas. The first group of indices analyzes the area of the world covered with higher and lower than normal temperatures, detecting a slight cooling in the 200 hPa level. The second group of indices studies the annual frequency of extreme events, and again, it is at 200 hPa where the most intense variation is detected. Finally, an analysis is performed to determine the regions most sensible to variations in the occurrence of extreme events. Tropical areas are mostly responsible of the variations detected in the second group of indices.

Keywords: climate extremes, global temperature, climate indices

1. INTRODUCTION

Global air temperature has experienced a positive trend during the last 100 years (*Gaffen et al., 2000; Santer et al., 2000*). The origin of this variation is attributed mainly to the effect of human activities (*Stott et al., 2001*). Anyhow, this trend does not show a regular behavior. It is composed by periods with trends of different signs and intensities (*Parker et al., 1994; Jones et al., 1999a*).

These variations in the mean temperature values are usually accompanied with variations in maximum and minimum temperature series. As a matter of fact, it has been detected that one of the mechanisms responsible for the positive global trend is that the trend toward higher maximum temperatures is different to that of the minimum temperatures (*Easterling et al., 1997; Jones et al., 1999b*). On the other hand, differences in temperature trends are expected when different height levels are analyzed, both for local and global studies (*Angell, 1999; Bengtsson et al., 1999; Santer et al., 2000; Vuille and Bradley, 2000*).

A good approach to quantify climate change is the use of indices. They can be readily understood by no-specialist, and can be used by policy-makers. Although many indices have been proposed, those based on frequency of extremes have been revealed very useful. They can be conventional climate extreme indicators such as frequency of very cold days or of very hot days, or areas affected by extreme temperatures (*Jones et al., 1999b*) or aggregate set of conventional climate extreme indicators such as the Climate Extreme Index (CEI) (*Karl et al., 1996*) or the Common Sense Climate Index (*Hansen et al., 1998*) that is a simple measure of the degree, if any, to which practical climate change is occurring.

The use of indices has the capability for representing not only temperature but some of the mechanisms or the consequences of the temperature trend (*Jones et al., 1999b*), and the possibility of not only analyzing the global situation, but also regional variations. For example, *Karl et al. (1996)* detected that extreme events in the USA have become more frequent during the second half of the 20th century.

In this work, two groups of indices will be defined to characterize the evolution of the temperature in the 1958–1998 period. The first group will analyze the evolution of the percentage of the world area covered with high and low temperatures. The second group will focus on the analysis of extreme events, analyzing the percentage of the total area where those events happen. Finally, a more precise analysis of these extreme situations will be performed to locate those regions of the world with the most intense variation in the occurrence of extreme events.

2. DATA AND METHOD

This study has been performed using the NCEP-NCAR reanalysis (*Kalnay et al., 1996; Kistler et al., 2001*), consisting on daily temperature data between January 1958 and December 1998. The data consists on a 2.5º latitude by 2.5º longitude grid. Three atmospheric levels: 850, 500 and 200 hPa, representing the lower, mid and high troposphere were considered..

In this paper two groups of indices will be defined and analyzed:

a) Difference between the area of the world dominated by temperatures above or below the average temperature (D)

D is defined by the difference between the area of the world with higher than average temperature minus the area covered with temperatures lower than average. It is expressed as the percentage of the analyzed area. Three different possibilities have been considered: global, oceanic and continental areas. Daily temperatures were compared with monthly averages at each grid point to avoid the seasonal effect.

The evolution of these indices for the whole period (1958–1998) shows a dramatic leap in the late 1970 (not shown). This leap has been previously documented, and it is mainly attributed to the introduction of satellite data during that period (*Hurrell and Trenberth, 1998; Fiorino, unpublished data; Kistler et al., 2001*). To asses the significance of the late 1970's leap, mobile trends were computed for the nine different *D* indices (global, continental and oceanic indices at 850, 500 and 200 hPa levels). Fig. 1 shows that every single series starting prior to 1971 and ending after 1980 has an intense positive trend for every level and areal coverage, while those series starting prior to 1971

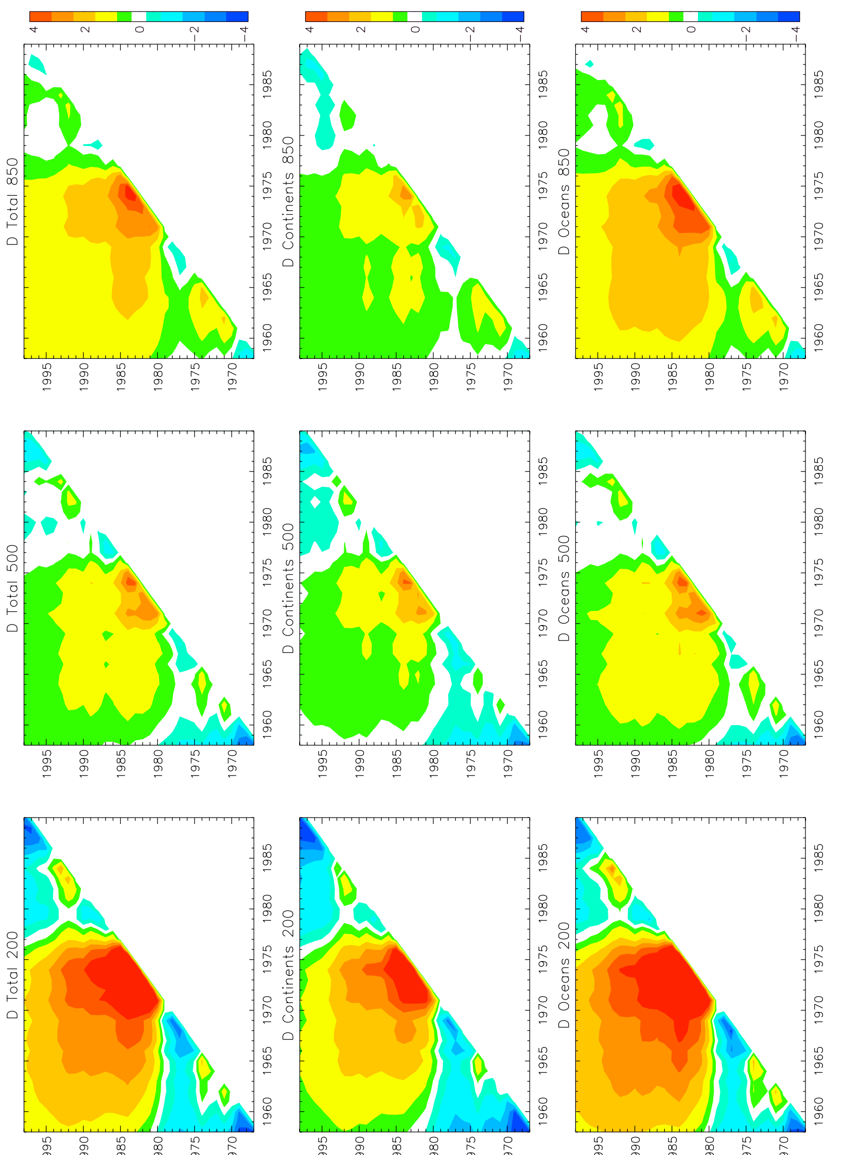

Fig. 1. Trend analysis of *D* indices. Abscise axis represents the starting year of the series and ordinates the ending year. 11 years is the minimum analyzed period. Areal coverage and pressure level are included in the figure title. Color scale represents variations per year.

and ending before 1977, or starting after 1979, have a less regular pattern, with lower trends and variable sign. This result leads us to compute new D indices using the periods 1958–1978 and 1979–1998 independently. Two new different average temperatures were computed, one for the earlier and one for the later period. D indices were computed for the two subperiods independently, and a complete 1958–1999 series was obtained by adding up those two independent subseries ($D_{1958-1978} + D_{1979-1998}$). In this way, the spurious variation detected in the original series during the late 1970s is eliminated.

Trends obtained from the new series will probably under-estimate the real trend. They assume that the whole leap is spurious, though different analysis performed with instrumental data have shown an intense variation in global mean temperature values in the late 1970s (*Hansen et al., 1999; Hansen et al., 2002; Jones and Moberg, 2003*).

b) Extreme temperature events: H and C indices

These indices are based on the annual number of days above (below) a threshold for extreme warm (cold) temperature. In this paper, an extreme hot (cold) day is accounted when its temperature is above (below) the percentile 90 (percentile 10) of the considered period for every gridpoint. The percentage of the analyzed area characterized by this extremely hot (cold) temperature defines our H (C) index. To avoid the 1979 leap, the 1958–98 period was divided into two sub-periods and the results assembled for the complete time span (using a method similar to that used with D). Obviously, H or C index should be around 10% in average.

Indices H and C include in a single number the behavior of the whole analyzed area. In order to distinguish among different local variations, the number of extremely hot (cold) days per year has been computed at each gridpoint to evaluate its local trend. This analysis provides information about the regions where extreme situations show the highest variation, and thus, are responsible for the variations detected with the former H and C indices.

3. RESULTS

3.1. Global Temperature

The evolution of nine indices included in the first group is presented in Figs. 2–4. These figures show the daily evolution of index D defined using the whole world area (Fig. 2), the oceans (Fig. 3) and the continents (Fig. 4). All the figures include the corresponding three vertical levels. The one-year running mean and trends for the periods 1958–98, 1958–78 and 1979–98 of every series have been superimposed.

The evolution of index D_{GLOBAL} (Fig. 1) shows a different behavior in the lower troposphere compared to mid and high levels. The 850 hPa level is characterized by a very slight positive trend for the complete period, and more intense trends when the 1958–78 and 1979–98 subperiods are analyzed. A negative trend is also evident during the first decade of the studied period, while a positive one is recorded during the last years. The evolution of the indices in the 500 and 200 hPa levels are characterized by slightly negative trends. While at 500 hPa the trend is caused mainly by the cooling observed during the 1958–78 period, the 200 hPa level has significant negative trends during both

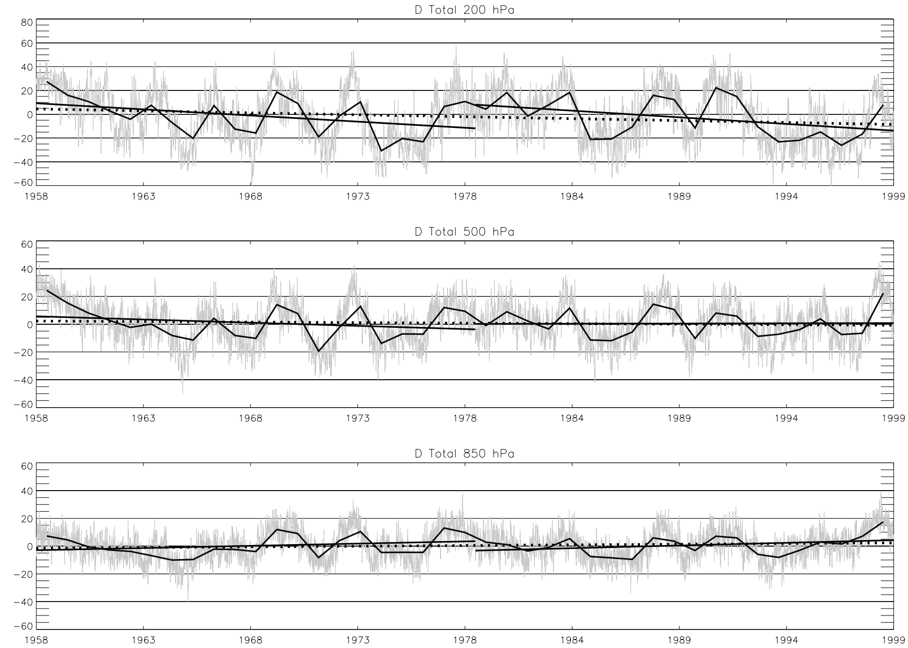

Fig. 2. Daily evolution of indices D_{GLOBAL} at 200 hPa, 500 hPa and 850 hPa. 365 days moving average and trend line are overplotted in the three figures. (*X*-axis: time, *Y*-axis: percentage of the area covered by high temperature that exceed that covered with low temperature). Trends for the subperiods 1958–78 and 1979–98 are included.

subperiods. The last decade is characterized by a trend toward warmer conditions at 500 hPa, while at 200 hPa the trend has the opposite sign. Apparently, while in the upper troposphere there is a slight trend for colder than normal conditions during the second half of the 20th century, more intense for upper levels, in the lower level no trend is evident and if any, it would be very slightly positive.

Figs. 3 and 4 show the evolution of indices *D* over the oceans and continents respectively. Indices *D* for the oceans are very similar to those observed globally: slightly negative trend at 500 and 200 hPa, though more intense in the upper level, and a very weak positive trend in the lower level. The indices calculated for continental areas follow the same pattern, though in this case, the 850 hPa series has no trend at all. The most remarkable difference is related to the bigger variability of the daily indices, with intense variations from high positive to high negative values in very short periods of time (850 hPa intra-annual mean range of variability over the oceans is approx. 30-40 *D* units, while over the continents it rises to approx. 50–60 *D* units. The variation is not so intense in 500 and 200 hPa series).

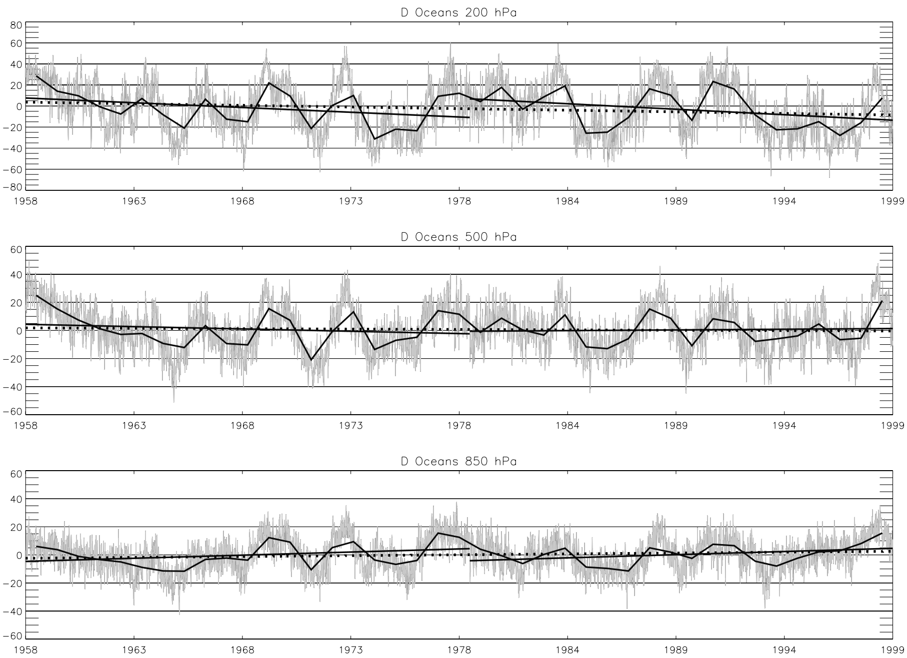

Fig. 3. As Fig. 2 but for D_{OCEANS}.

3.2. Extreme temperatures

Variations in averaged areas covered by colder or warmer than average temperatures may be caused by variations in the number of extreme temperature episodes. To verify this hypothesis *C* and *H* indices were calculated. *C* index accounts for the percentage of the analyzed area where temperature was below percentile 10 of the series (two subperiods were independently estimated to determine these series), so, it is associated to extreme cold episodes. *H* index is related to extreme hot episodes, and it is associated to the percentage of the analyzed area where temperature is higher than the corresponding percentile 90.

Figs. 5 and 6 show the evolution of indices *C* and *H*. 200 hPa series show that extreme cold episodes are becoming more frequent, with an areal coverage of approximately 9% at the beginning of the analyzed series and 11% at the end. Hot episodes show the opposite trend, going from 11% of the total area in the late 50s to 9% in the late 90s. Mid and low troposphere series do not show positive nor negative trends for any of these indices. A positive trend is observed in *C* values both at 500 and 850 hPa early in the analyzed period, opposed to a negative trend in the same years observed in *H* indices at both levels.

Fig. 7 shows the variation of extreme temperature days in the low troposphere. Areas with trends significantly different from zero are located over tropical regions. A trend toward more episodes of extreme cold dominates the Eastern and Central tropical Pacific Ocean, while the Indian Ocean, the Western Pacific and some areas of the Atlantic Ocean

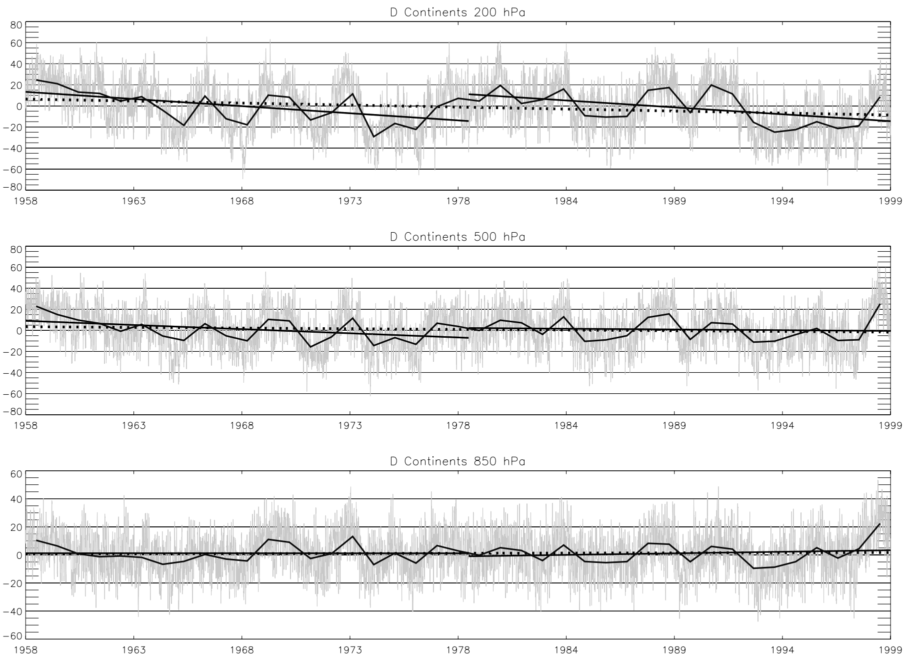

Fig. 4. As Fig. 2 but for $D_{\mathrm{CONTINENTS}}$.

are experiencing a lower number of cold days. Some continental areas over the Sahel and Asia are experiencing a higher frequency of cold days, while it is decreasing over some areas of Scandinavia and the south Pole. Extremely hot days occurrence is becoming more frequent over most of the Indian ocean, extensive areas of the Atlantic coasts of South America, a broad region of the Southern Hemisphere extratropical Pacific Ocean, and equatorial areas over Africa. They are reducing their frequency over wide areas of Australia, three broad regions of the Western Pacific Ocean, both in the tropics and the extratropics and some continental areas over Western Africa, the Himalayas and some areas of the Antarctic continent.

All over Indonesia there is a general trend for more hot and less cold days, as it does over Madagascar, an equatorial band over Africa and South America coasts of the Atlantic Ocean. On the other hand, over the Pacific coast of Peru more cold and less hot events are taking place, resembling an ENSO like structure. Apparently, colder extremes are becoming more frequent on the Peruvian coasts, which suggests a higher number of cold ENSO events, as suggested by *Timmermann (1999)*. On the other hand, Fig. 7 does not detect the positive temperature trend observed over the Niño 1, 2 and 3 regions (*Cai and Whetton, 2001*), which seems to confirm the hypothesis that the total elimination of the 1978–79 leap has hidden the existence of some trends.

From the analysis of Figs. 8 and 9 it seems reasonable to deduce that trends in C and H indices in the mid and high troposphere are mainly caused by variations over the tropical areas. A broad band of positive trends for the number of cold days per year is observed at

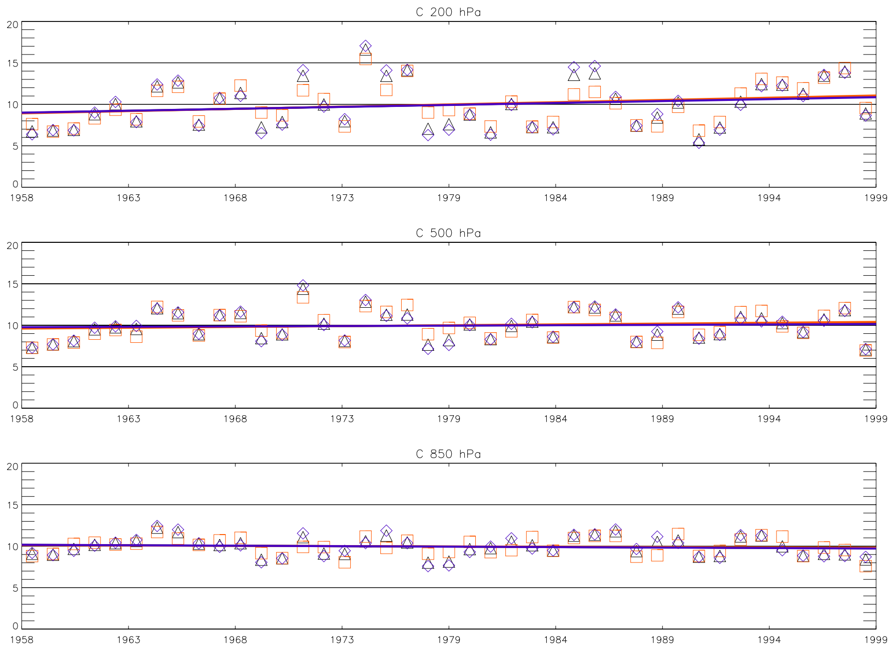

Fig. 5. Yearly evolution of indices *C* (global, oceanic and continental) and trend lines for those indices. Trends for the subperiods 1958–78 and 1979–98 are overplotted.

500 hPa covering most of the tropical areas, being even wider and more intense at 200 hPa. In the Northern Hemisphere small areas with trends of the same sign as the tropical ones are observed. Trends with the opposite sign are observed in mid and high latitudes of the Southern Hemisphere. When hot days trends are analyzed, the situation is almost reversed, negative trends are observed over the tropical areas, while positive trends are located in mid and high latitudes of the Southern Hemisphere.

4. DISCUSSION AND CONCLUSIONS

New analysis of global temperature trends have been performed using indices that considered different possible explanations of the observed global warming. The first significant conclusion has been the existence of a leap in the NCEP reanalysis dataset in the late 1970s, most probably related the inclusions of satellite data in the reanalysis. In the present paper, this leap was extracted from the signal.

Mean temperature variations seem to be more intense in the high troposphere, where a trend toward colder conditions is evident in the complete analyzed period and in the two subperiods in which it was divided to eliminate the reanalysis leap. For lower levels, series without this leap do not show intense trends, as it should be expected from previous analysis of instrumental data.

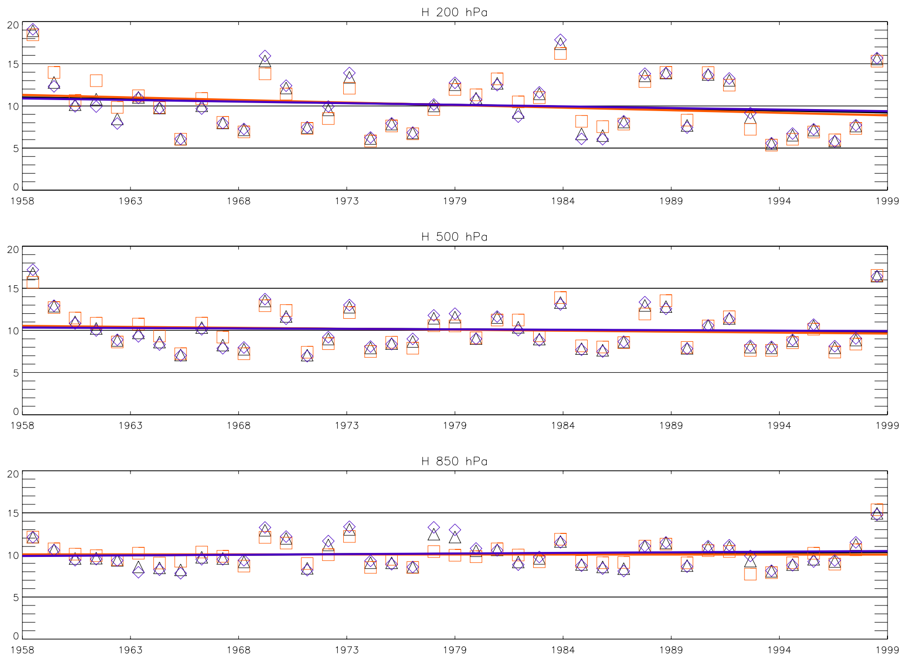

Fig. 6. As Fig. 5 but for indices *H*.

The analysis of extreme temperature variations locates in the upper tropospheric levels the most dramatic variations. Extremely cold episodes are increasing their frequency of occurrence while extremely hot episodes are decreasing. Apparently, these changes are mostly produced by variations over low latitude areas, where trends of the corresponding sign for *C* and *H* are detected when the number of cold or hot days is analyzed for every single gridpoint. Lower troposphere trend maps (Fig. 7) presented some ENSO like patterns, which support the idea of the relationship between the evolution of ENSO indices and global temperature data. Extratropical areas over the Pacific Ocean in the Southern Hemisphere show an opposite trend, lowering the global trends for *C* and *H* series.

Thus, it can be concluded that the intense variation of temperature detected in the late 1970s was, partly at least, due to natural causes and not only to instrumental problems. A complete elimination of the 1978–79 leap has leaded to an under-estimation of global temperature changes, both for mean and extreme temperature values.

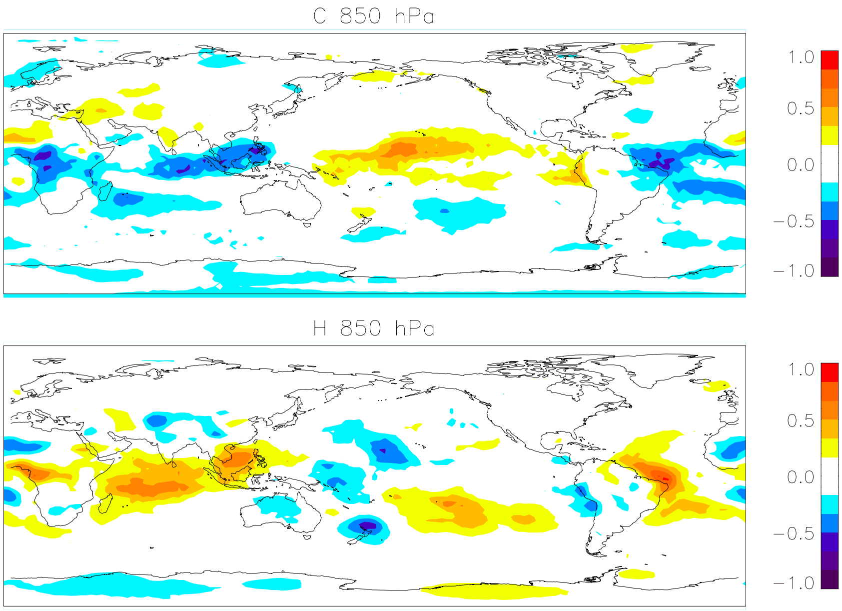

Fig. 7. Trends spatial distribution for local *C* and *H* indices at 850 hPa. Color scale represents the slope value the whole 1958–98 period (days per year).

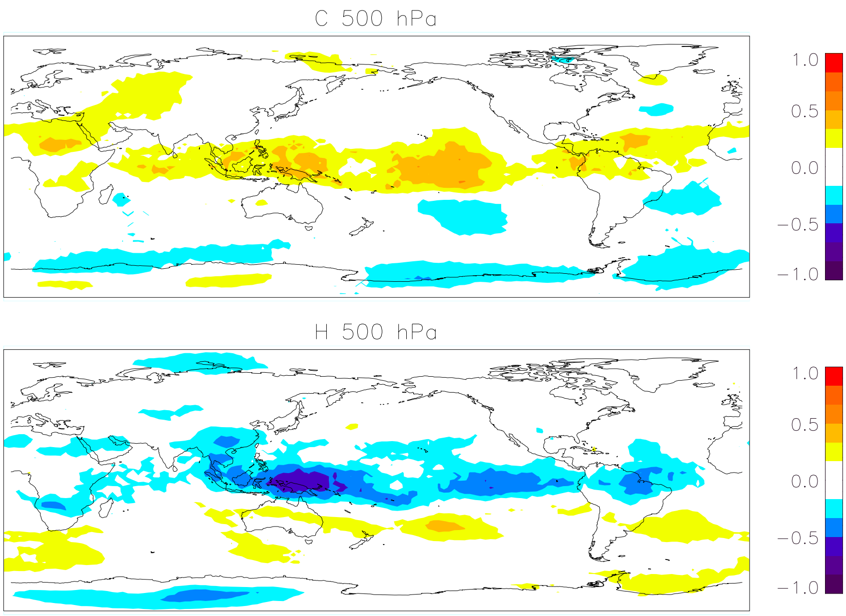

Fig. 8. As figure 7 but at 500 hPa level.

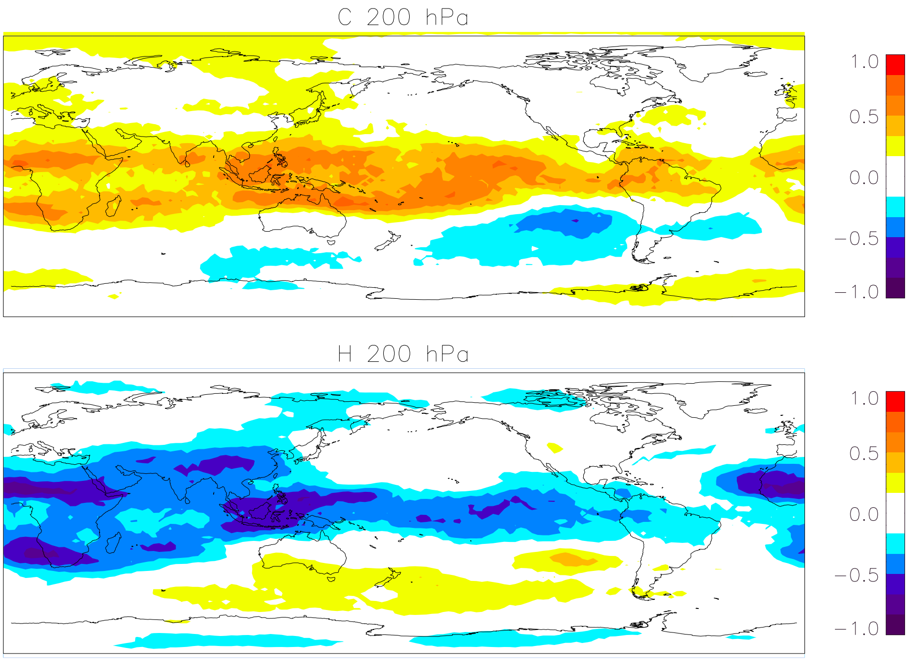

Fig. 9. As Fig. 7 but at 200 hPa level.

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