3.3 GEOGRAPHICAL DISTRIBUTION OF THE VERTICAL TEMPERATURE PROFILE TRENDS DERIVED FROM RADIOSONDE OBSERVATIONS

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1. INTRODUCTION

Long-term changes in the horizontal and vertical temperature profiles are an important component in the detection and attribution of climate change. Major efforts have been made to estimate the variations in the recent trends in the global-mean surface and the lower to mid-tropospheric temperature using three sources of measurements: surface observations, satellite observations and radiosonde observations. (Hansen et al. 1999; Christy et al. 2000; Parker et al. 1997; NRC, 2000; Gaffen et al. 2000a). Radiosondes have the advantage of a higher vertical resolution. Although there is agreement on the cooling trend of the stratosphere, the geographical distribution of the vertical temperature structure of the troposphere is less well known. Gaffen et al. (2000b) created maps of the horizontal distribution of the trends *for each standard pressure level* using the CLIMATE TEMP radiosonde data. Following Brown et al. (2000), Lanzante et al. (2003) examined the horizontal variations in *lapse rate trends* (surface minus 700 hpa) for 1979-97 with the radiosonde temperature data from CARDS Project. In this paper, we report the vertical temperature profile trend using the radiosonde data used in producing the NCEP/NCAR Reanalysis (Kalnay et al. 1996).

2. DATA

The radiosonde temperature data used in this study are the quality-controlled monthly mean radiosonde observations available at both 00z and 12z, from the 52 year NCEP reanalysis archives. Data for each station include monthly mean observations at 16 pressure levels: 1000, 925, 850, 700, 600, 500, 400, 300, 200, 150, 100, 70, 50, 30, 20, and 10 hPa. We exclude the level at 925 hPa due to lack of data for most of the stations.

We focus on the trend during the period 1979-99. Since not all stations have a full record in this time period, the requirement of at least 6 non-missing months of data per year for each single level has applied. In addition, we only consider stations with at least 10 valid pressure levels out of a total of 15 levels, from 10 hPa to 1000 hPa. There are 340 out of 1638 stations that meet these two conditions. We use the anomaly data to compute the trend after removing the annual cycle of the observation at each station. The trends at each vertical level are computed as the difference between two time period averages: the decade 1990–1999 minus 1979–1989. We compute the trends for 00z and 12z separately and average them to get the mean trends. The average between 00Z and 12Z is not applicable to stations (mostly in the Southern Hemisphere) that only have one radiosonde observation per day.

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3. METHODOLOGY

3.1 Mass weighted vertical mean trends

Trends are computed for 15 pressure levels. To get the trend between two pressure levels, the mass weighted average is used to account for the different mass at different layers. The mass weighted trends averaged between pressure levels p_1 and p_2 are calculated by using formula:

$$trend = \frac{\int_{p_1}^{p_2} trend_{p_i} \bullet dp_i}{p_2 - p_1}$$

where dp_i is the pressure difference between two adjacent pressure levels at pressure level i.

3.2 *Trend classification method*

We classify the station trends using two criteria: the *column trend* and the shape of the vertical trend profile in the troposphere. First the whole column trends for troposphere levels (200-to-1000 hPa) are used to separate the stations into two groups, one with the positive column trend and the other with the negative column trend. Then the vertical trend structures in the troposphere are examined. Starting from the first top level (typically at 10 or 20 hPa) and going down along the vertical trend profile, we find the first level where the sign of the trend changes from negative to positive. We then do a linear regression on the vertical trend profile between this first zero-trend level and the surface. We classify the trends into four types based on the slope of the linear regression line: those displaying more warming in the lower troposphere than the upper troposphere (type LT), more warming at the upper troposphere than the lower troposphere (type UT), nearly constant trend but not zero throughout the troposphere (type CT), and nearly zero trend throughout the troposphere (type ZT). Note that there are both positive and negative column trend cases for each of these four types except type ZT. Therefore combining the two criteria together we have a total of 7 categories: LT+, CT+, UT+, LT-, CT-, UT- and ZT.

4. HORIZONTAL PATTERN OF TEMPERATURE CHANGES

Figures 1, 2, and 3 illustrate observed temperature trends in three atmospheric layers: 1) 30-to-100-hPa, 2) 300-to-500-hPa, and 3) 700-to-1000-hPa. These mass weighted vertical mean trends are calculated by using the formula shown in section 3.1. The results are generally consistent with other studies, showing cooling in the stratosphere, and warming below, increasing towards the earth's surface. The global mean trends derived here for the period 1979-1999, within the vertical section in each figure, are -0.71K, 0.17K and 0.24K, per decade, respectively.

Figure 1 (30-to-100-hPa section) depicts the lower stratosphere down to the tropical tropopause. Cooling at 30-to-100-hPa appears to be globally widespread, with very few stations having a warm trend. In contrast, warming in the troposphere is indicated for 77% to 80% of the stations, as shown in Figures 2 and 3. This result is consistent with that from Lanzante et al, (2003). They found warming in the troposphere only significant during a longer, 40-year, period, i.e., 1957 through 1997 but not significant during a shorter one, i.e. 1979 through 1997.

In the lowest layer, 700-to-1000-hPa (shown in Fig 3), the most pronounced warming is found in the middle to high latitude regions of the Northern Hemisphere, such as Eastern China, Canada, Eastern United States and Western Europe. In the tropics, about half of the stations exhibit a warming trend and the rest show a small cooling. Most stations in Alaska, Eastern Europe, tropical Western Pacific, South America and Africa show lower tropospheric cooling. The 300-to-500-hPa layer trends are similar to those in 700-to-1000-hPa, except for Alaska, Yellow Sea and East China Sea where the patterns are reversed. The vertical trends difference is discussed more detail in the next section.

5. VERTICAL STRUCTURE OF THE TRENDS

As mentioned in section 3.2, all of the 340 stations are classified into 7 categories. Temperature trends computed as a function of pressure level for each of the seven categories are displayed in Fig 4. The trend vertical profiles confirm again that stratospheric cooling has been observed in all stations. However, there are only 234 stations showing a positive column trend for tropospheric levels while 61 stations show a cooling trend. The remaining 45 stations show little temperature changes throughout the troposphere (type ZT). Type LT+ shows warming trend throughout the whole troposphere with more warming in the surface-lower troposphere while type LT- has the similar profile shape but with cooling in the middle-upper troposphere. 82 stations display a nearly constant warming trend from the surface throughout the troposphere (type CT+) and 5 stations show constant small cooling trends. There are 62 stations exhibiting more warming at the upper troposphere than the lower troposphere (type UT+) and 21 stations with cooling trend at the lower levels and warming or zero trend at the upper troposphere (type UT-).

6. GEOGRAPHICAL DISTRIBUTION OF THE VERTICAL TREND PROFILES

6.1 Differential trends in surface-lower troposphere and in middle-upper troposphere

Fig 5 shows the differential trends in vertical direction (difference between 700-to-1000-hPa minus 300-to-500-hPa). Although trends in 700-to-1000-hPa layer have some similar patterns as those in 300-to-500-hPa layer, it is evident that there exist also differences. In Eastern China, Korea, Japan, Canada and Western Europe, most stations show more warming in the lower troposphere than aloft, corresponding to type LT in Section 3, whereas more warming in upper troposphere shows up in Mongolia, Australia, South America and Antarctica. A small vertical gradient of trend (type C) is the dominant type in the United States.

6.2 Horizontal distribution of the vertical trend profiles

Fig 6 shows simultaneously the characteristics of the trends in both horizontal and vertical directions. The triangles direction indicates a warming (upward) or cooling (downward) trend in troposphere, respectively. Four colors express the shape of the vertical trend profiles. It is apparent that in Eurasia, Antarctica and Australia, most stations show warming trends in troposphere (upward triangles), but differ in vertical trend shape (color). Stations in Eastern China, Korea, Japan, Canada and Western Europe exhibit more warming in lower troposphere (LT+) while type CT+ dominates over the US. Stations in Mongolia, Eastern-Northern China, Alaska and Australia show more (UT+) or at least the same (CT+) warming in upper troposphere than in lower troposphere. Many stations with type ZT are found in Southern China. It is interesting that in Alaska trends in lower troposphere could be positive or negative but in upper troposphere are always positive. Southeastern America and Africa, although having few rawinsondes, show decreasing trends (UT- or CT-).

In the tropics, due to the low density of radiosondes, the warming and cooling types are mixed with all seven types present. This indicates that the average trend over the whole tropical area is not well defined from radiosondes alone due to insufficient spatial sampling.

7. SUMMARY

In this work, we examine the temperature trends in stratosphere and troposphere using the radiosonde data set from the NCEP 52-years reanalysis archives. In particular, we focus on the vertical profiles of the tropospheric temperature trends and their geographical distribution. Our results show that in the 1979-1999 period stratospheric cooling takes place at almost every station, whereas tropospheric warming is apparent in about 3/4 of the stations. Most stations in Eurasia, Antarctic and Australia, show warming trends in troposphere but differ in the vertical distribution of the warming. South America and Africa show either small or negative trends, although the number of rawinsondes is small. The signal in the tropics is mixed.

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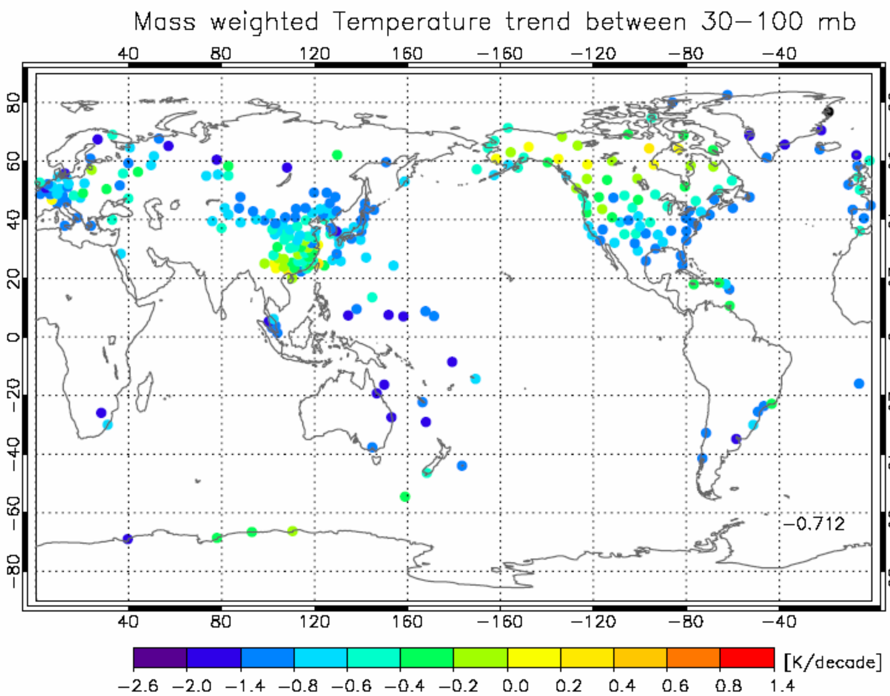

FIG. 1. Temperature trends over the 21 year period 1979-99 for 30-to-100-hPa layer (K/decade)

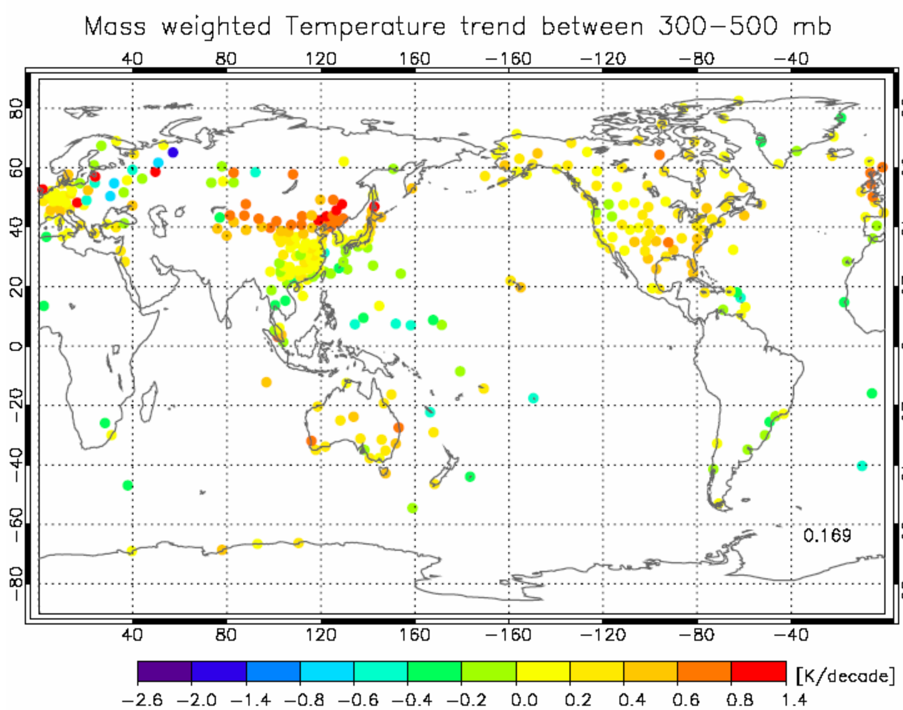

FIG. 2. Same as Fig 1 but for 300-to-500-hPa layer

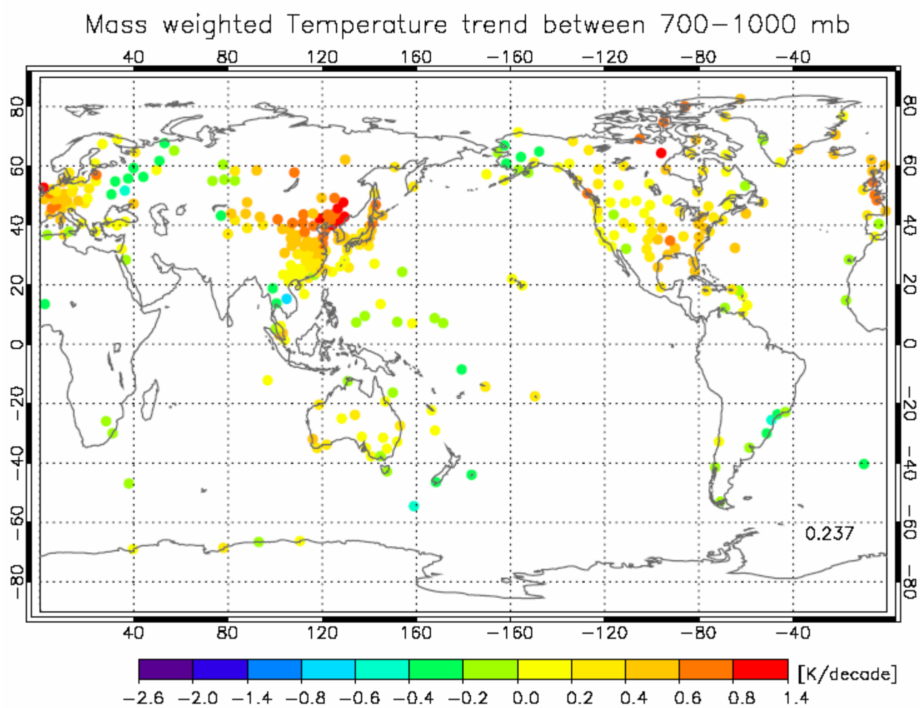

FIG. 3. Same as Fig 1 but for 700-to-1000-hPa layer

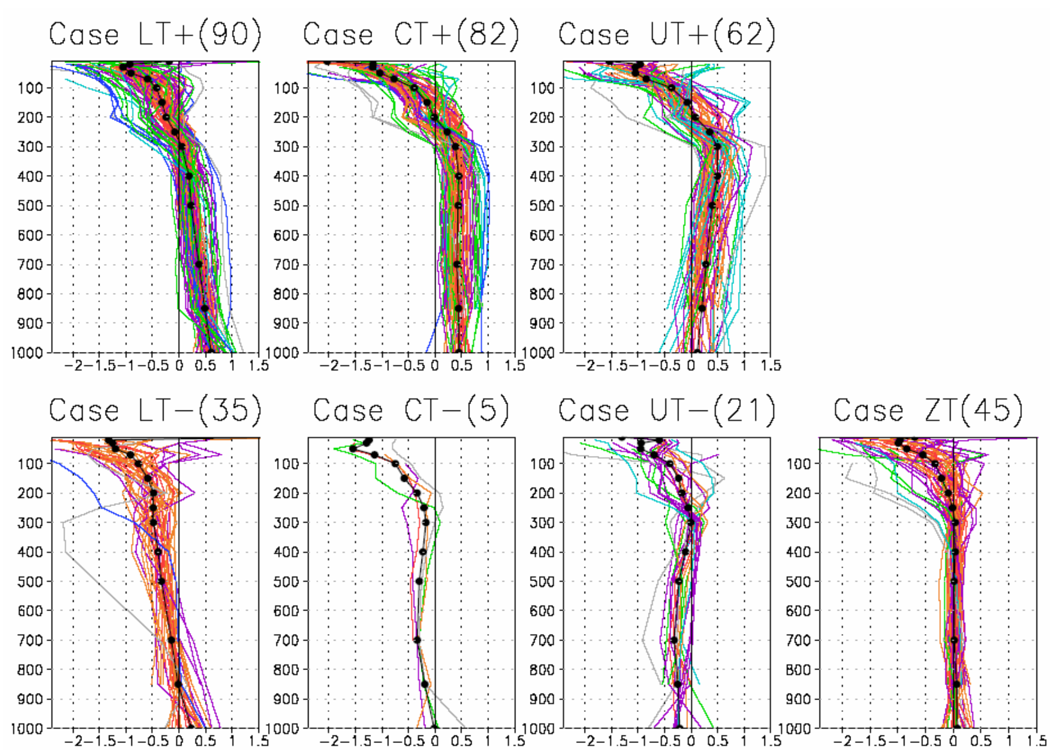

FIG. 4. Profiles of the temperature trends for 340 radionsondes. Profiles are displayed in seven categories: LT+, CT+,UT+,LT-,CT-,UT- and ZT which are defined in Section 3.2. The black curves are based on the average over all profiles in one category. Numbers in brackets correspond to the total stations number in that category.

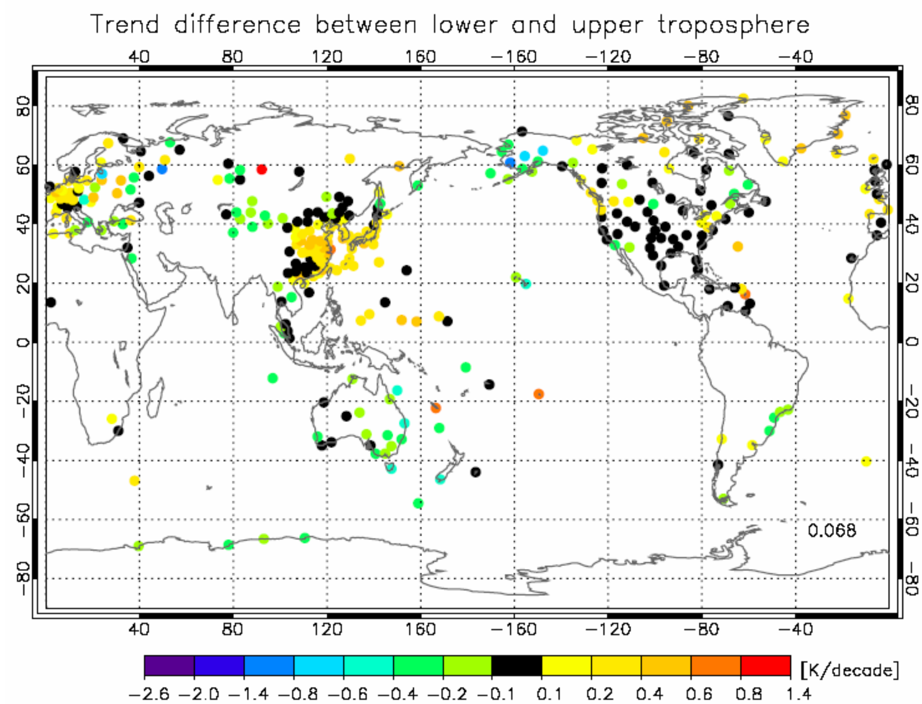

FIG. 5. Trends difference between 700-to-1000-hPa layer and 300-to-500-hPa layer (700-to-1000-hPa minus 300-to-500-hPa) for 1979-99

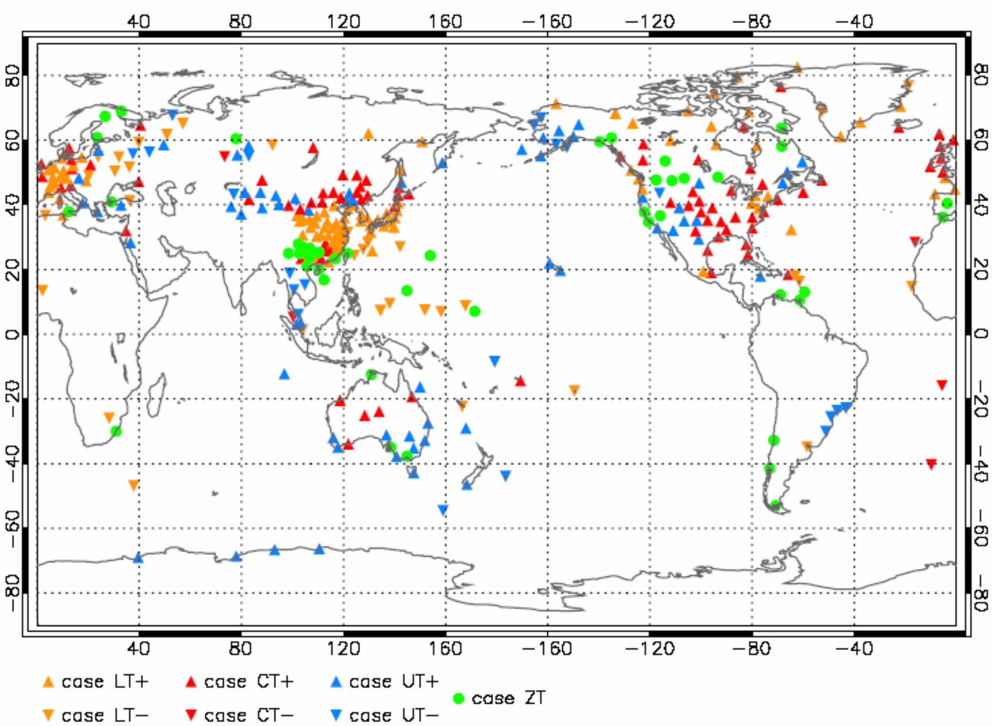

FIG. 6. Map of tropospheric temperature trends categories. Triangles with apex up or down indicate warming or cooling trend for tropospheric levels (200-to-1000 hPa). Colors indicate four types of shapes for trend profiles in troposphere.