ON THE SENSITIVITY OF TRENDS IN UPPER-AIR TEMPERATURE SERIES

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1. INTRODUCTION

The temperature changes in the atmosphere are essential part of the changes in the climate system, and thus are of great interest for specialists and for decision makers. A separate interest is given to the temperature changes in the troposphere, due to recently found discrepancies between the temperature trends in the troposphere and on the surface / 4 /.
The values of long period trends in the upper-air temperature series, as it is shown, depend on numerous factors, such as:

- Data origin (observing platform), data completeness and data quality;
- Data processing procedures applied;
- Exact period of time series for trend estimation;
- Statistical techniques used for trend estimation;
- Dependence of trend values on the geographical location, height by vertical;
- Dependence of trends on season (annual cycle);
- Whether the temporal inhomogeneity detection/correction procedures are applied to the series.

Several groups of researchers in various centers are making efforts to obtain and study the time series of temperature in the atmosphere, to inter-compare existing series of temperature anomalies, and to improve the series in a way providing trend estimates more realistic / 2,6,7 /. This paper demonstrates and discusses the problems of sensitivity of trends in the troposphere and in the lower stratosphere, that were obtained from the radiosonde data of global network, to some of the factors listed above.

2. DATA AND PROCESSING

The U/A temperature series used in this study, had monthly resolution and were based on CARDS dataset derivative MONADS - monthly statistics data set for the global network of radiosonde stations / 10 /. The period covered by the series, was 1958-2001. Monthly anomalies were calculated for temperature on standard pressure levels, and then recalculated for three layers in the atmosphere: troposphere (850-300 hPa), tropopause layer (300-100 hPa), and for lower stratosphere (100-50 hPa). The estimates were provided for the globe and for several latitude zones. The zones used in this study, were: Northern Extratropics (30N-90N), Tropics (30S-30N), and Southern Extratropics (90S–30S). A more detailed description for mechanism of data processing and series arrangement was contained in /9/. In / 8 /, these series were compared to the series of other sources, both radiosonde and satellite, and it was reported about their less variability and less trend values estimates than those of other series. Nevertheless, these series demonstrated high positive correlations with other series, as well as good agreement in other statistics, and reasonable qualitative agreement in signs of trends.

3. SENSITIVITY ESTIMATES

A. Sensitivity to period of series

Traditionally, trend estimates for temperature in the atmosphere, are provided for two periods of observation. First of them is the most long period of available radiosonde observations for the global network. This period begins in late 1950-early 1960s. In our study, however, we used the beginning of this period of 1964, which corresponds to more reliable data from most of the stations in the CARDS dataset. The second period is a shorter one, and begins since 1979, when the regular observations of temperature from NOAA polar orbital satellites began. Just this shorter period is of special interest to many researchers, because the essential warming detected on the surface within previous two decades, was not detected in the satellite troposheric time series, so that a vast discussion, continuing presently, was caused / 4 /. The dependence of trend estimates to period of series, in particular, the effect of adding single year to the series, was described earlier in / 9 /.

As shown on Fig.1, where the linear trends of U/A temperature based on Ordinary Least Squares (OLS) techniques were presented, the values of trends differ essentially between periods beginning at 1964 and at 1979.

For troposphere, trends for series beginning at 1964, are always positive, while for series, beginning at 1979, their values are highly sensitive to choice of ending year in the series. A strong ENSO phenomenon in 1998 caused switch from negative to positive values of trend for the Globe, as well as noticeable changes in the trend values for Tropics, Northern Extratropics, and Southern Extratropics (not shown here). These trend values, however, need to be considered as underestimated, compared to corresponding values from other authors / 3,8 /.

For lower stratosphere, the negative trends are much more noticeable. The shorter period (1979- late 90-s up to 2001) demonstrated more rapid cooling than the longer one (beginning at 1964). The tendency of increasing cooling rate is obvious as period of trend calculation that is beginning in 1979, is made longer by updating the most recent data.

B. Sensitivity to statistical techniques

The traditionally used statistical techniques of trend estimation is based on Ordinary Least Squares (OLS) method of linear regression. It is well known, that the OLS regression estimates are highly sensitive to in-practice violation of assumptions about distributions of variables, as well as they are sensitive to some features of real data, such as outliers, especially at the ends of series, and to abrupt changes in the mean level of signals at various parts of series. One alternative to OLS techniques is use of non-parametric, robust and resistant statistical techniques. Some samples of using such approaches were contained in an excellent assessing paper / 5 /. Later, the comparisons between OLS and non-parametric techniques both applied to series of radiosonde data, were provided in / 3 /. As a non-parametric techniques, there were used estimates based on Medians of Pairwise Slopes (MPS). It was noticed, that some less sensitivity of trends in U/A temperature to outliers was observed when MPS estimates were used rather than OLS. However, the differences between OLS and MPS techniques of U/A temperature trend estimates, were reported in / 3 / to be very small for global and zonal series, while for separate stations they could be more essential.

As soon as MPS is only one of the many statistical methods to obtain resistant (robust) trend estimates, in this study we performed the inter-comparisons between the OLS estimates of trends and three alternative to OLS techniques: These alternative techniques were: Medians of Pairwise Slopes (MPS), Least Trimmed Squares (LTS) and so called MM robust technique / 11 /.

Several comparisons between the techniques of statistical trend estimations, were performed. Fig 2 contains the comparisons of trend values in global troposphere (850-300 hPa), estimated by these four techniques. The trend estimates of temperature trends in troposphere are of special interest for many issues, and, as it was shown in the previous paragraph, if were calculated with OLS techniques, are strongly affected by adding outlying values to the ends of the series. The sign of the trend (positive or negative) is often the key question for troposphere temperature series. This is why we consider this comparison, notwithstanding our acknowledgement that numerically, absolute values of trends here may be underestimated.

The details of comparing the trend values from four techniques, one traditional and three alternative methods, are contained in the legend to the Fig.2. Needed to note that MM techniques looks to give results more robust to choice of exact period of series (and, thus, to potential outliers at the ends of the series), than both OLS and each of other statistical techniques (MPS, LTS). The latter two techniques, in their turn, look to be providing more robust estimates than traditional OLS technique does.

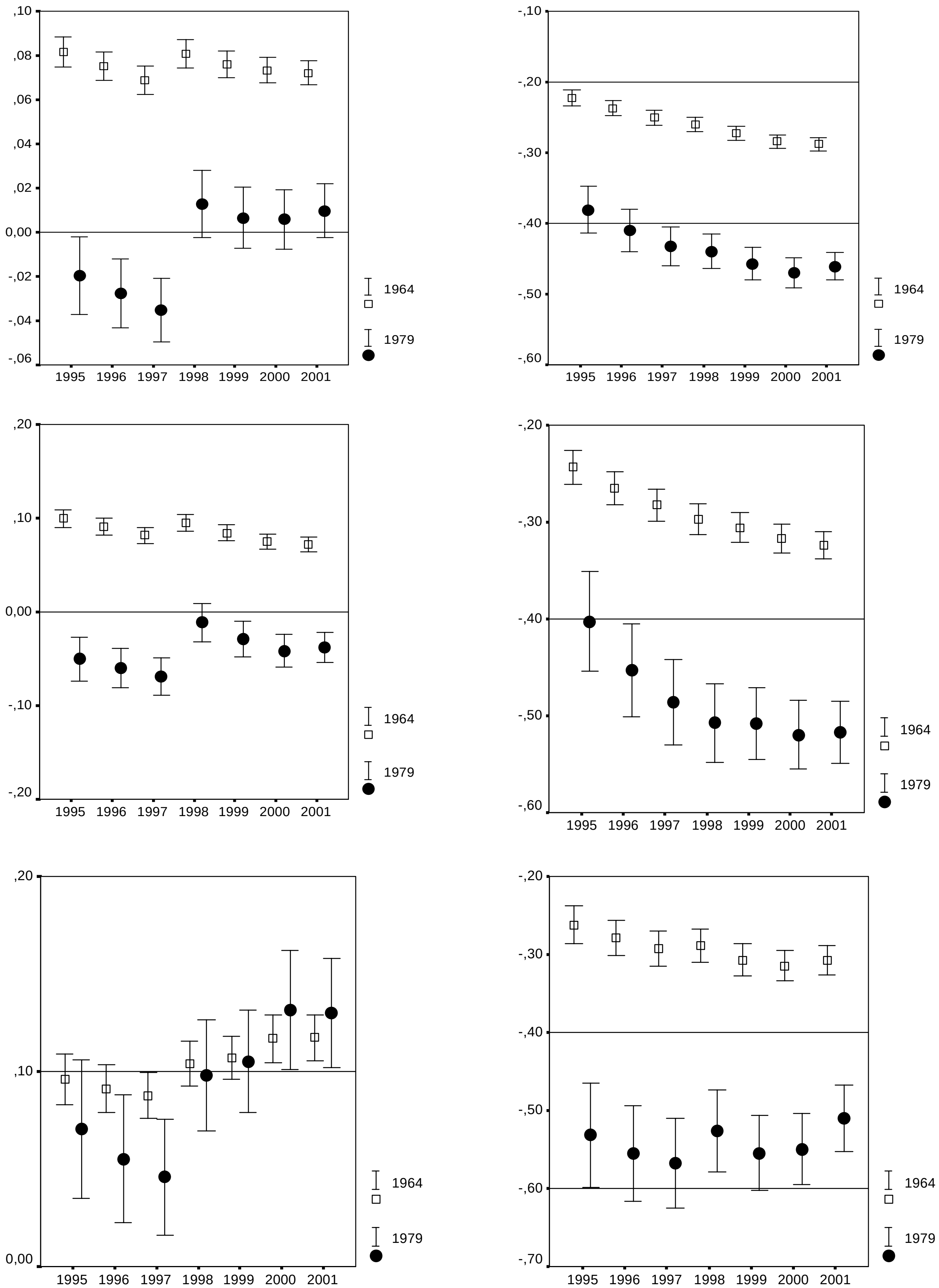

Fig.1. Values of linear trends plus/minus standard deviation of trend (deg. C/10 years) for series beginning in 1964 (empty squares) and in 1979 (solid dots), depending on the last year in the series (1995 through 2001).

Left panel –for troposphere (850-300 hPa), right panel – for lower stratosphere (100-50 hPa). Top row – for Globe, middle row – for Tropics (-30-+30), bottom row – for Northern Extratropics (+30-+90)

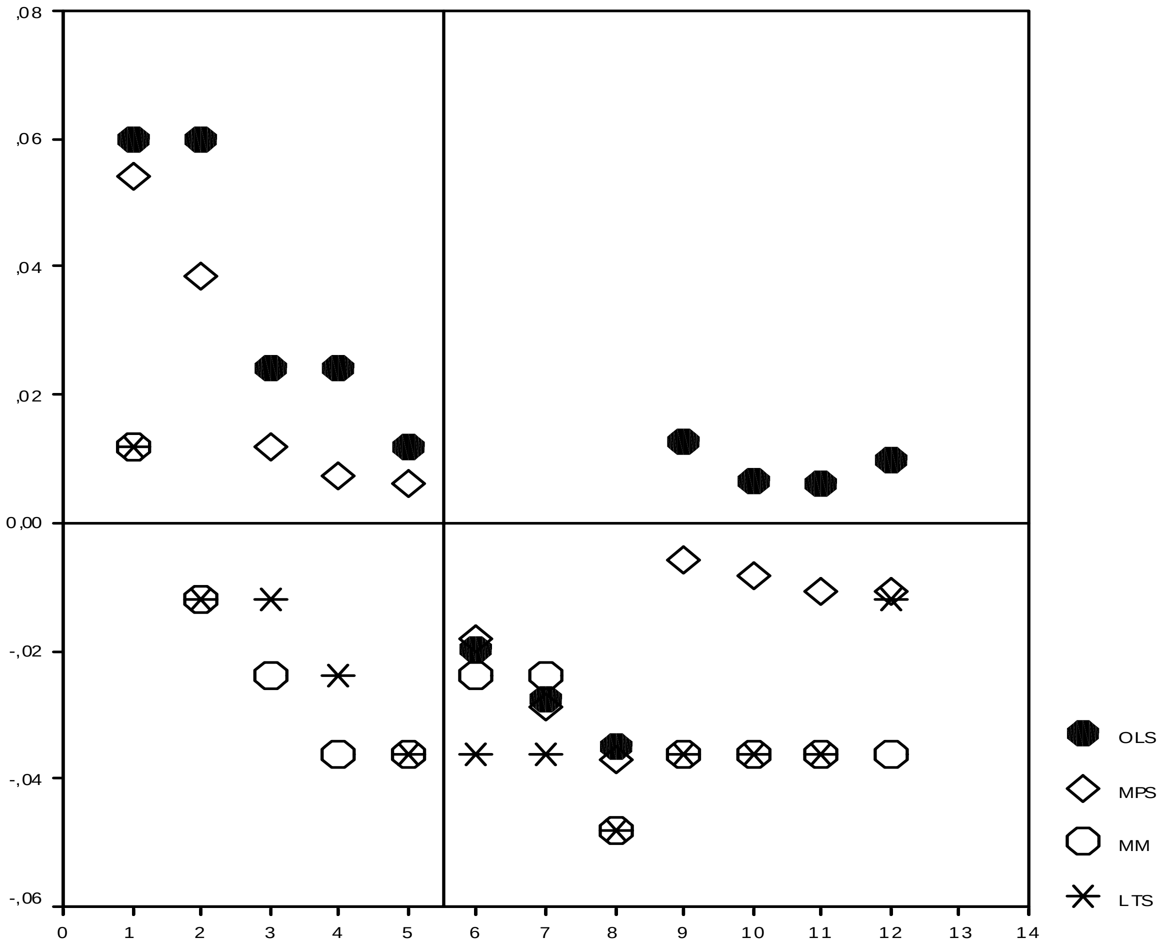

Fig.2. Trends in global temperature of troposphere (in deg. C/10 years) as estimated by various statistical techniques.
Solid dots – Ordinary Least Squares (OLS)
Empty diamonds –Medians of Pairwise Slopes (MPS)
Empty circles – MM Method (MM) /11/
Stars – Least trimmed squares (LTS)
Vertical axis – values of trends (deg. C/10 years), horizontal axis: Left half – trends for series ending at 1998 but beginning at 1974 to 1978 (marked from 1 to 5 correspondingly), Right half – trends for series beginning at 1979 but ending at 1995 to 2001 (marked from 6 to 12 correspondingly).-

4. INHOMOGENEITY DETECTION

While the radiosonde data were collected mainly for operational prediction goals, they are strongly affected by temporal inhomogeneities, which may be caused by various factors (changes of instruments, processing algorithms, transfer procedures, etc.). Thus, the usage of these data for climate monitoring problems needs to consider the effects of the inhomogeneities on the values of trends. The problems of sensitivity of radiosonde derived estimates of temperature trends is in the focus of many researchers / 3 /. Several groups of scientists work over methods of radiosonde derived temperature series homogenization. A special workshop arranged at NCDC/USA in 2000, provided comparison of these methods from various authors. The workshop outlined that the results from each method differ dramatically from those obtained by other methods / 2 /. The efforts of researchers on homogenization of radiosonde time series continue / 6,7 /, promising to produce more realistic vision of temperature changes in the atmosphere, meanwhile the existing trend estimates are distorted by abrupt changes in the series. However, this process is long and requires lot of efforts. To be solved successfully, the problem of homogenization needs both formal methods and unformal considerations to be applied.
The problem of homogenization radiosonde temperature time series includes several stages / 6 /, and detection of abrupt shifts in the series, as well as estimation of their magnitudes, is the first stage. Here

we present some preliminary results related to detection and estimation of abrupt changes in the U/A temperature series. The algorithm used in this study, is purely statistical. We acknowledge that purely statistical methods are not sufficient for the full solution of homogenization problem. However, they are useful, to detect time points that could potentially be artificial level shifts (LS), so that ongoing use of both statistical and non-statistical (based on station history metadata) methods should discriminate these potential points, between those connected to real climate processes, and those are "real" inhomogeneities in the series.
The statistical method used here, is based on AutoRegression- Integrated Moving Average (ARIMA) approach to time series analysis.
The strategy of the statistical outlier detection is based on AutoRegression- Integrated Moving Average approach to the analysis of time series, and consists of the following steps /1/.

A. It is supposed, that shock signatures (regression variables describing some changes of the mean responses), - are affecting the time series. At each point of the series, the forward stepwise regression variable selection process is going, so that the solution to include or not to include shock signature at each point, is made based on hypothesis testing. The alternative hypotheses are H0: shock signature is equal to 0, versus H1: shock signature is not equal to 0.
B. After one selection stage over all points of time series is completed, those shock signatures which improve the model, are detected. Their number is to be small. The data set is augmented by additional regression variables corresponding to the detected outliers.
C. The few of these additional regression variables are to be included to the model. At this step, it is needed to look attentively, if these candidates to level shift points correspond to other considerations about presence of outliers (based on metadata, etc.). If needed, few of additional regression variables, not corresponding not to detected outliers, but to unformal consideration, may be also included in the model.
D. New model with re-estimated parameters, is provided.
E. Steps A and B are repeated. If no outlier is detected in re-estimated model, the total set of detected outliers is limited to those previously found. Else, if additional outliers are detected, and their consideration similar to that provided at steps A to C, gives further improvement of model, it is re-estimated again. This process continues until no outlier is detected, or no refinement of model can be achieved. Anyway, the amount of new regression variables must be small.

Again, though we realize that radiosonde temperature time series homogenization process can not be limited to statistical procedures only (see / 3,6 /), we applied these statistical techniques to some of radiosonde temperature time series, both to spatially averaged and to series for separate stations. The results for the outlier detection process are presented below.
Fig. 3 contains the plots of time series for temperature anomalies in troposphere and in lower stratosphere, for the Globe, Tropics and Northern Extratropics. The detected level shift moments are shown as reference lines for the time axis. The statistical procedure enables to detect abrupt warming in troposphere in the 1976-1977, reported by many authors, but this is valid for Global series only, but not for Tropics and Northern Extratropics. However, similar abrupt warming in 1976-1977, in Tropics and Northern Extratropics, is evident on series visually. A noticeable warming shift in 1998 (strong ENSO phenomenon) is detected by the algorithm in all zones, while the ongoing cooling shift after the end of this ENSO episode, is detected in Global and Tropical, but not Northern Extratropical series.
For lower stratosphere, the detected level shifts are connected to step-like cooling shifts going after the end of warming episodes following the well known volcanic eruptions. As soon as the number of stations used for calculating these series, was essential and all they potentially contained inhomogeneities caused by various factors and taking place at independent different moments, it is difficult to expect the detections of level shifts in the series, other than those caused by genuine climatic processes.

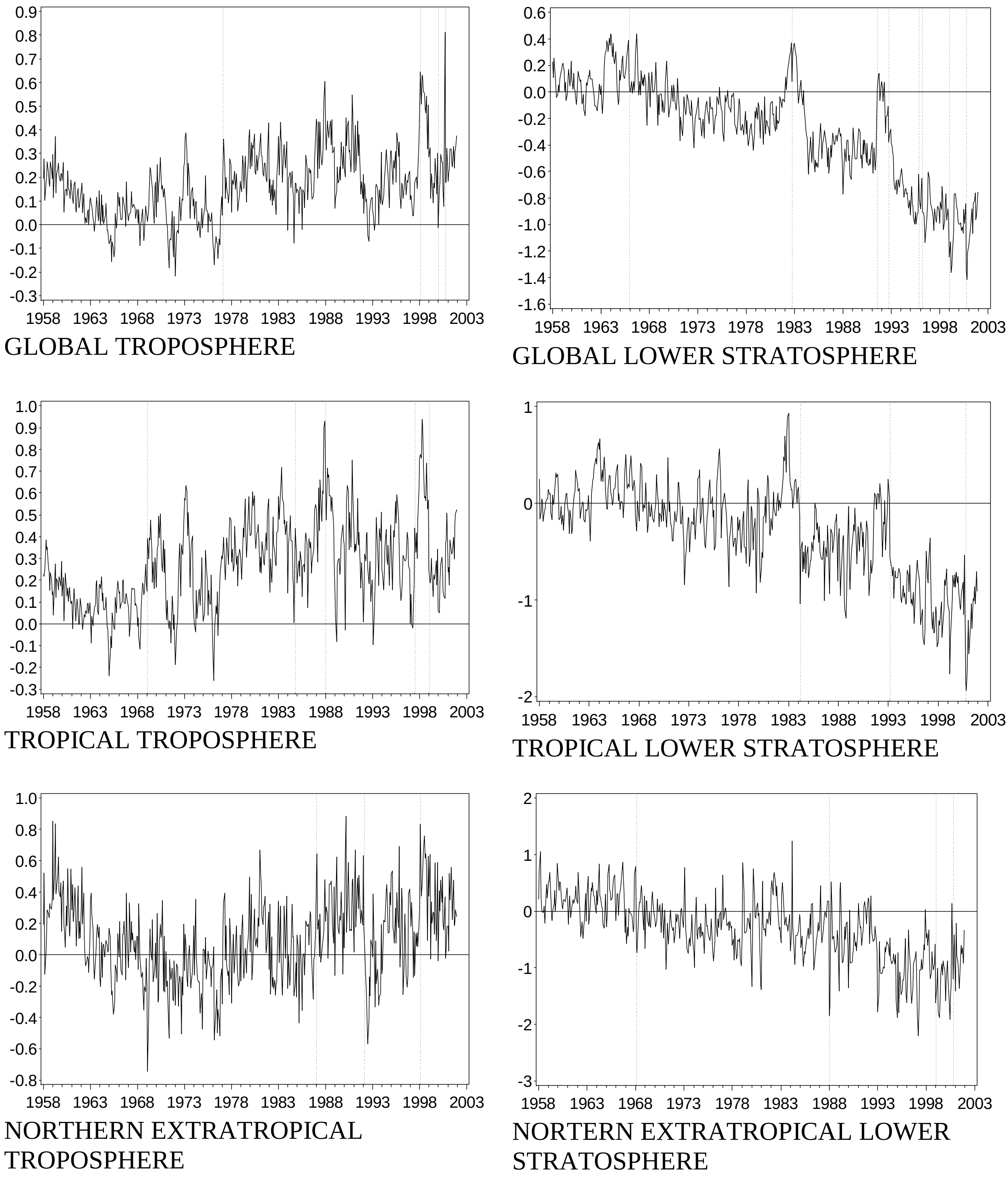

Fig.3 The Level Shift (LS) moments detected in the series of U/A temperature anomalies (shown as vertical dotted lines). The footnotes define series for troposphere and for lower stratosphere, and zones for which the LS were detected.

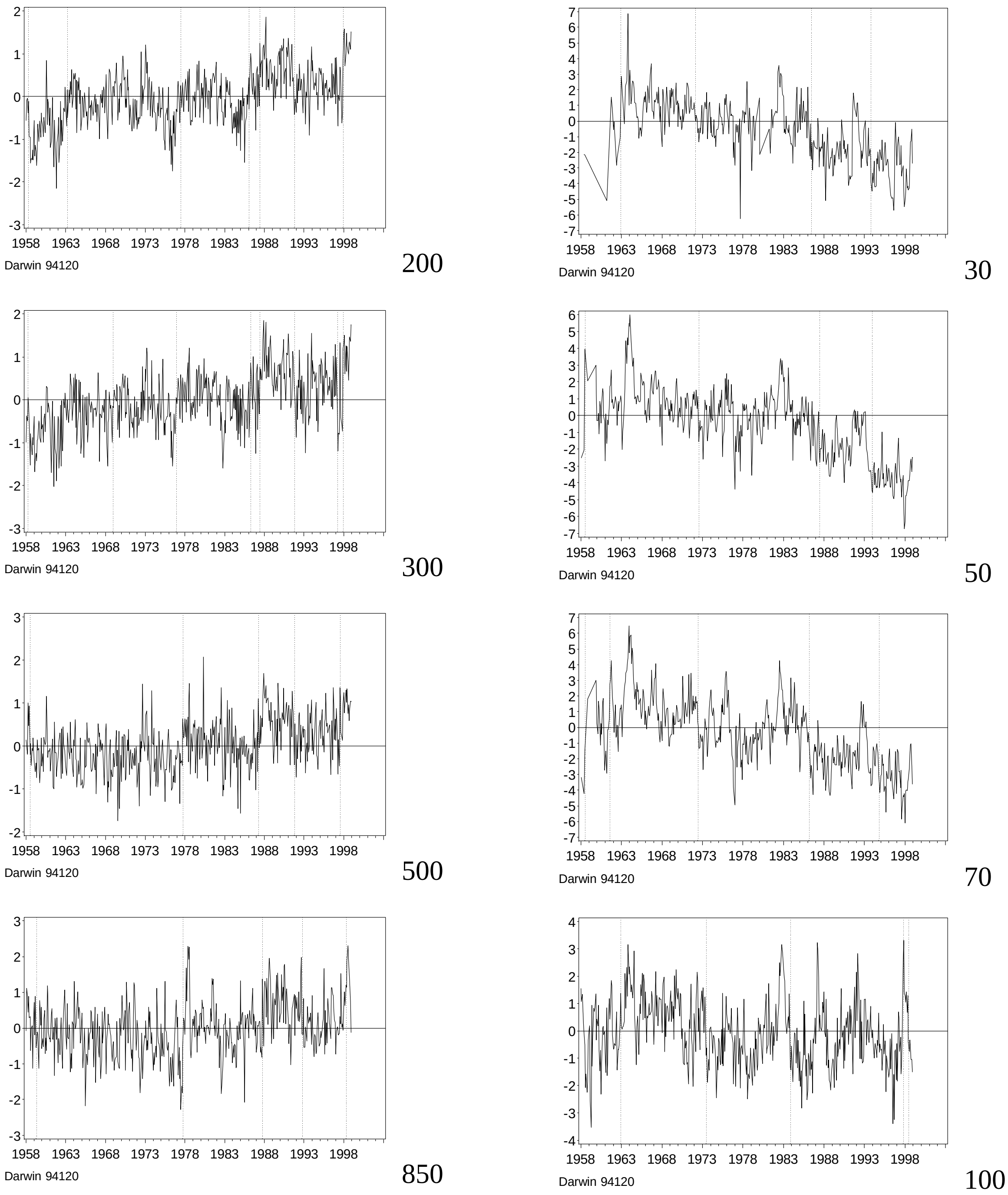

Fig.4. Level shifts detected for time series of temperature anomalies for station Darwin, Australia (94120), on separate standard pressure levels. Shift points are shown as dotted reference lines to the temporal axis. Left part – pressure levels 850, 700, 500, 300 and 200 hPa, going from bottom to top. Right part – pressure levels 100, 70, 50 and 30 hPa.

Within the CARDS Workshop on Adjusting Radiosonde Temperature Data for Climate Monitoring, which was arranged at NCDC at 2000 / 2/, the intercomparison was performed between various inhomogeneity detection/adjusting methods. A set of 12 radiosonde stations in various parts of the world, was selected for this intercomparison. We applied the ARIMA-based statistical detection method to time series for all of the 12 stations, used in /2/. Meanwhile the more complete results, and their intercomparison with the results obtained by other methods, will be contained in further publications, here, on Fig. 4, we demonstrate the level shifts detected in the series for one of selected

12 stations, Darwin, Australia (94120). Though the detection process was applied for each pressure level in an independent way, the vertical consistency of detected shifts is noticeable both for troposphere and for lower stratosphere.
A level shift reported in the time about 1988, is noticeable for all levels (as noted in /2/, this time interval contained some metadata events). As to the other level shifts detected in this study, they do not correspond to those reported in /2/, and their nature should to be under study.

As a conclusion, it is needed to note that further studies, based on data for Globe and zones, as well as for separate stations, are strongly required, as they should clarify many issues on the trend values, trend sensitivity and possible re-estimations of trends in the temperature series for troposphere and lower stratosphere.

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