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Discontinuities in temperature and contour heights resulting from change of instruments at Indian radiosonde stations

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सार — भारत में पचास और साठ के दशकों में उपयोग होने वाले घड़ीनुमा (सी) और पंखानुमा (एफ) रेडियोसौंड धीरे-धीरे बदलकर साठ के दशक के अन्तिम वर्षों तक श्रव्य अधिमिश्रित (ए० एम०) प्रकार के सौंडे उपयोग में आने लगे थे। संयंत्रों के परिवर्तनों के फलस्वरूप ताप और समोच्च रेखा ऊंचाइयों के मासिक माध्यों का समय-शृंखलाओं में विच्छिन्नता प्रतीत होने लगी। इस पहलू की विस्तृत जांच, सन् 1951 से 1984 ई० की अवधि के लिए आंकड़ों का उपयोग कर भारतीय छह रेडियोसौंडे केन्द्रों के पांच मानक समदाबीय तलों के वर्ष के चार प्रतिनिधि महीनों के लिए ताप और समोच्च रेखा ऊंचाइयों के माध्य मासिक मानों द्वारा की गई है। यथार्थ सांख्यकीय परीक्षणों से यह प्रदर्शित किया गया है कि उन केन्द्रों में, जिनमें प्रारंभ में 'सी' प्रकार के रेडियोसौंडों का उपयोग किया, ताप और समोच्च रेखा ऊंचाइयों पर्याप्त रूप में गिरी हैं और यह गिरावट उस समय 'एफ' प्रकार के रेडियोसौंडों के उपयोग करने वाले केन्द्रों में कम पर्याप्त थी। दोनों संयंत्रों द्वारा मापों में आपसी अन्तर, स्थान और ऋतु से असम्बन्धित दिखाए गए हैं। इस प्रकार मानकर ताप और समोच्च रेखा ऊंचाइयों के लिए मानक अन्तरों और उनके मानक त्रुटियों की संगणना सभी पांच तलों के लिए की गई हैं।

ABSTRACT. In India, Chronometric (C) and Fan (F) type radiosondes which were used in the fifties and sixties, were gradually replaced by Audio Modulated (AM) type sondes in the late sixties. The change of instruments apparently resulted in discontinuities in the time series of monthly means of contour heights and temperatures. This aspect has been examined in detail by studying the mean monthly values of contour heights and temperatures of six Indian radiosonde stations for five standard isobaric levels for four representative months of the year by using the data for the period 1951 - 84. It has been shown by rigorous statistical tests that contour heights and temperatures fell substantially at stations that used C-type initially and that the fall was less substantial in those that used F-type first. The differences between the measurements by the various instruments have been shown to be independent of location and season. Thereupon the standard differences and their standard errors for contour heights and temperatures have been computed for all the five levels.

1. Introduction

Upper air data from aerological soundings form important inputs in conventional and numerical weather prediction for short and medium time scales (1 to 10 days). Time series of monthly, seasonal and annual values of upper air parameters provide basic material in studies relating to climatic changes from one year to another over a period of several years.

Radiosonde carried aloft by balloons furnish the observational data for determining the vertical variation of temperature, pressure and humidity in the atmosphere. The computation of contour heights of standard isobaric levels from the observational data involves the surface pressure as well as the thermal structure between the surface and the pressure levels concerned. When we are dealing with daily data over a synoptic network employing different types of sondes it is necessary to ensure that there are no systematic differences in the performance characteristics of the instruments which would vitiate the horizontal gradients. Also over a country where more than one type of instrument has been in operation or where there has been change of instrument it is necessary to ensure that the time series of the mean monthly values of the parameters are homogeneous before utilisation for climatological studies.

In India, radiosonde observatories were established in mid-forties. Initially two types of instruments were used, the so called Chronometric type (C-type) at stations roughly north of 22°N and the Fan type (F-type) in stations south thereof. During late sixties these were gradually replaced by Audio-Modulated type (AM-type). At present there are about 33 radiosonde observatories in India which take two ascents daily at 00 GMT & 12 GMT, using AM-type sondes. With the introduction of AM-type radiosondes, a discontinuity seems to

TABLE 1

Radiosonde stations considered for the study

Station	Location		Type of radiosonde initially used	Date of start of the radiosonde observatory	Date of change over from C/F type to AM type
	Lat. (°N)	Long. (°E)			
Calcutta	22° 4′	88° 3′	C	16 Mar 1944	1 May 1968
Jodhpur	26° 2′	73° 0′	C	17 Apr 1946	22 Feb 1969
Delhi	28° 4′	77° 1′	C	3 Dec 1943	7 Dec 1967
Madras	13° 0′	80° 1′	F	29 Jun 1946	19 Jul 1970
Nagpur	21° 1′	79° 0′	F	1 Oct 1946	12 Nov 1968
Trivandrum	8° 3′	76° 6′	F	1 Jul 1947	1 Oct 1970

have been produced in the monthly mean values of upper air parameters. This has been briefly discussed in regard to mean monthly temperatures by Henry Vande Boogaord (1977). Analysing the data for some Indian radiosonde stations he pointed out that the change of instrument was apparently responsible for the lowering of the temperatures noticed especially at upper tropospheric levels. The performance characteristics of the C and F type radiosondes have been studied in detail by Ananthakrishan *et al*. (1966) who drew attention to the existence of a systematic and substantial difference in the performance of the two instruments. Thus, the horizontal distribution of daily as well as mean monthly upper air parameters in fifties and sixties, when C and F type radiosondes were in operation, would show a spatial discontinuity roughly along 22°N. The time series of mean monthly contour heights and temperatures of standard isobaric levels for a given station would show a discontinuity starting at the month of the change over of the instrument. The user of the data has to take cognizance of these discontinuities failing which wrong conclusions could be reached in interpretation. The object of this study is to test the monthly means of upper air parameters of some Indian stations for homogeneity, to examine the discontinuity arising due to instrumental changes and to estimate the corrections to be applied to make the series homogeneous.

2. Data

The 34 years period (1951-84) has been taken as the period of the study and six radiosonde stations, *viz.*, Delhi, Calcutta, Jodhpur, Nagpur, Madras and Trivandrum have been considered. These stations are well distributed over India and can be taken as being respresentative stations of the regions in which they are located. The C-type radiosonde was used at the first three stations and F-type at the remaining three before being replaced by the AM-type. The latitudes and longitudes of the six stations, date of starting of the upper air soundings and the date of the change over from C/F-type to AM-type are given in Table 1 (India Met. Dep. 1984). The four months January, April, July and October representative of the four seasons winter, pre-monsoon, monsoon and post-monsoon, have been considered. The mean monthly contour heights and temperatures at the constant pressure levels 850, 700, 500, 300 and 200 mb have been chosen as the variables to be tested. In all, these gave rise to 240 time series of monthly mean values, 120 series each for geopotential heights and temperatures each with a length of 34.

The data were extracted from the publication '*Monthly Climatic Data for the World*' for the period 1951-83. For the year 1984, the data was collected from daily weather charts and the monthly means were worked out. The monthly mean values utilised in the study are the averages of 00 and 12 GMT upper air observations.

3. Analysis of data

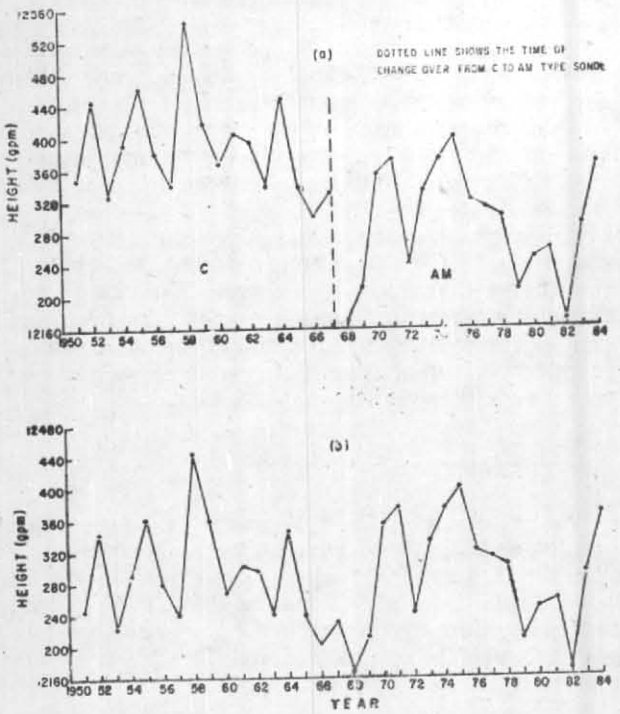
Let X denotes any one of the 240 time series mentioned in Sec. 2 and X_1 and X_2 denote those parts of the series pertaining to C/F and AM type sondes respectively. The lengths of X_1 and X_2 can be ascertained from Table 1. If X_1 and X_2 are homogeneous and trend free but X is not, we can suspect a discontinuity in X. The series X, X_1 and X_2 were tested for homogeneity by using the runs test (Thom 1966) and for trend by computing the linear trend based on the method of least squares. The significance of difference of means of X_1 and X_2, say $(\bar{X}_1-\bar{X}_2)$ was tested at 5% level by the students 't' test (Mitchell *et al.* 1966) after adjusting the lenghts of X_1 and X_2 for persistence by using the formula given by Brooks and Carruthers (1953). Graphical analysis was also employed. If thereupon we become convinced about the existence of a genuine discontinuity in X, either X_1 or X_2, but 'preferably X_1 could be corrected by subtracting $(\bar{X}_1-\bar{X}_2)$ from each member of X_1 which leads to a series, say X_1'. If X_1' is combined with X_2 a new series, say X' with same length as that of X results. If it is homogeneous and trend free X' can be taken as the corrected series. Thus, X' and not X represents the true nature of the variation of the concerned variable with respect to time. The above analysis was done for every series.

For illustration, we consider the 200 mb October contour height series over Delhi where the change over of instruments took place on 7 December 1967. The series X_1 and X_2 were found to be homogeneous and trend free but X was heterogeneous and showed a falling trend. The difference of means $\bar{X}_1-\bar{X}_2=100$ gpm was found to be significant at 5% level. As the discontinuity in X and the fall in heights due to the change of instruments was convincingly evident, X' was formed and was found to be homogeneous and trend free. Figs. 1(a) and 1(b) show the original heterogeneous series X and the corrected homogeneous series X'.

All the 240 series were similarly tested and $(\bar{X}_1-\bar{X}_2)$ and its standard error were computed for each.

4. Significance of difference of means

Analysis of difference of means and their significance revealed that in respect of Delhi, Jodhpur and Calcutta which used C-type sonde initially, the difference was significant in 103 out of the 120 series and not significant in the ramaining 17. We, therefore, conclude that generally constant pressure heights and temperatures have fallen substantially in stations that used C-type radiosonde initially and that necessary corrections must be applied before using the data.



Figs. 1(a&b). (a) Time series of mean monthly 200 mb height of Delhi for the month of October and (b) Corrected series

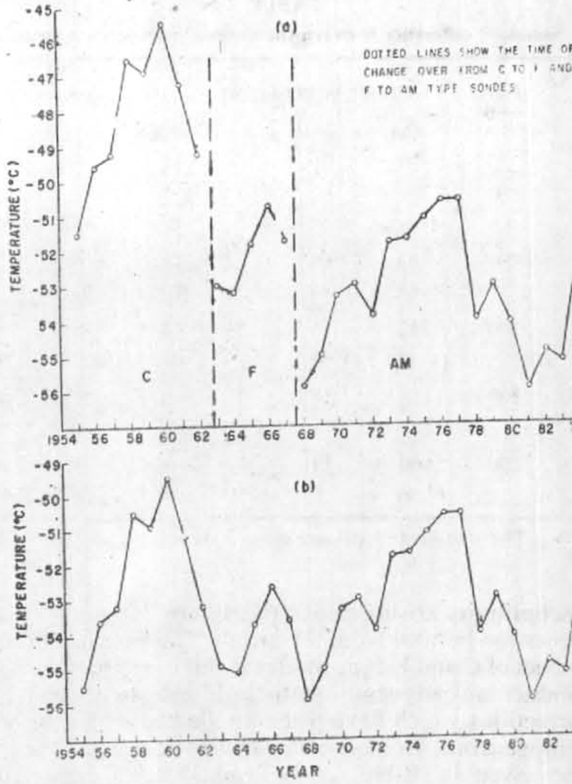


Fig. 2(a&b). (a) Time series of mean monthly 200 mb temperature of Bombay for the month of April and (b) Corrected series

Out of the 120 series in respect of Madras, Trivandrum and Nagpur, which switched over from F-type to AM-type, the difference was not significant in 108 series and significant in the remaining 12. However, it was found that the differences were all generally uniformly positive and even though not significant at 5% level, may have become significant if a higher level of significance had been used. Thus, by taking a total view, we conclude that a slippage of mean though not very significant has occurred as a result of switch over from F-type to AM-type. It would be prudent to incorporate the corrections even though failure to do so may not result in any serious error. That the (C-AM) differences are significant and (F-AM) differences are not, clearly shows that there is a significant difference between the performances of C and F type sondes and that soundings obtained from these two types which were initially used in India would not be comparable. As discussed in Sec.1, the same conclusion was arrived at by Ananthakrishnan *et al.* (1966), but by an entirely different approach, *i.e.*, by studying the data obtained from simultaneous C and F-type ascents at several stations.

5. Standard differences between C, F and AM-type sondes

The computations done so far have yielded 12 (C-F) and (C-AM) differences for a given level and parameter. We denote such a set of 12 differences by $y_1, y_2, \ldots\ldots,$ y_{12}. Let μ and σ be the mean and standard deviation of the y's. We would now like to test whether the differences are independent of station and season. Let $(x_1, x_2, \ldots, x_n)$ be a sample corresponding to a station or season drawn from y's and $\bar{x}$ be the sample mean. Thus, there would be 4 seasonal and 3 station means for which the values of n are 3 and 4 respectively. The standard error of $\bar{x}$ is $\sigma/\sqrt{n}$. If the difference between μ and $\bar{x}$, which could be tested by t-test, is not significant for the 4 seasonal and 3 station means, it could be concluded that y's are independent of station and season. This means that the variation amongst the y's are merely sampling differences. The mean can, therefore, be considered as a standard difference for the given level and parameter. The standard error of μ is $\sigma/\sqrt{12}$.

The above test was done for all the 20 sets of (C-F) and (C-AM) differences. In all the cases it was found that for a given level and parameter the differences are independent of station and season. The standard difference μ and its standard error were computed for each level and parameter. The details are given in Table 2.

The standard difference can be thought of as the true difference between the performance characteristics of the two types of sondes (*i.e.*, C/F type with AM-type) for the appropriate level. This can also be used in homogenising times series of monthly means of upper air parameters especially for stations that do not have sufficiently lengthy data in respect of both the types of instruments to use the method described in Sec. 3. An example is the case of Bombay, which had all the three types of radiosondes, *viz.*, C-type from 7 September 1954, F-type from 25 February 1963 and AM-type from 1 January 1968 onwards. The 200 mb mean temperature for Bombay for the month of April for the period 1955-84 is shown in Fig. 2(a). The series is heterogeneous and

TABLE 2

Standard difference between the various radiosonde instruments

Level (mb)	Contour height (gpm)			Temperature (°C)		
	C-AM	F-AM	C-F	C-AM	F-AM	C-F
850	9	4	5	1·5	0.4	1.1
	(1.2)	(0.9)	(1.1)	(0.1)	(0.1)	(0.1)
700	17	10	7	1.5	0.5	1.0
	(1.6)	(1.4)	(1.5)	(0.2)	(0.1)	(0.1)
500	32	16	16	1.5	0.4	1.1
	(1.3)	(1.3)	(1.3)	(0.0)	(0.1)	(0.1)
300	58	21	37	2.7	0.7	2.0
	(2.7)	(2·7)	(2.7)	(0.2)	(0·2)	(0.2)
200	100	29	71	4.0	1.9	2.1
	(3.9)	(5.3)	(4.6)	(0.4)	(0.2)	(0.3)

The standard errors are given in brackets

discontinuity arising due to the different types of instruments can be seen from the graph. The lengths of data in respect of C and F-type sondes in this case are too short to conduct any rigorous statistical tests to estimate the corrections which have to be applied to make the series homogeneous. However, we can use the standard corrections given in Table 2, *i.e.,* subtract 4°C and 1.9°C from the mean temperatures obtained from C & F-type sondes respectively. The corrected homogeneous series thus obtained is exhibited in Fig. 2(b). It is also evident from the standard differences of C and F types that the C-type sondes reported consistently higher heights/ temperatures as compared to those of the F-type sondes. The (C-F) difference can be obtained by subtracting the standard difference for F-type sondes from that of the C-type for each level and parameter. The differences thus computed are given in Table 2. While analysing the spatial distribution of a variable for a day or a month when C or F or both types were in operation it is advisable to apply corrections to the data taking AM-type as the standard one or to suitably apply the (C-F) differences to data of C/F-type stations, so that comparisons between wind field and height/temperature field for a given isobaric level are meaningful. It is, however, convenient to take the AM-type, which is presently used, as the standard one.

6. Conclusions

The above study has shown that contour heights/ temperatures reported by F-type sondes were lower than those reported by C-type sondes and that AM-type sondes reported still lower values. By analysing the time series of monthly means of six representative stations of four representative months the approximate magnitude of the performance difference between the three different type of sondes have been computed. The user of the Indian upper air data must be aware of the heterogeneity introduced by the change in instrument. This matter has also to be taken cognizance while working out of climatological means from the pooled data generated by various types of sondes, to avoid erroneous conclusions being derived out of them. The corrections derived in this note may be of some help in this respect.

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