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Preliminary estimates of climate change on Indian subcontinent during the global warming of limited scale

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सार — सोवियत रूस में उपलब्ध भारतीय उपमहाद्वीप के वायुमंडल के आंकड़ों के सांख्यकीय संसाधन के आधार पर उत्तरी गोलार्द्ध के तापमान के भौगोलिक बंटन और बदलते माध्य वार्षिक सतह पवन तापमान सहित वर्षा क्षेत्र का पूर्वानुमान लगाया गया है।

गोलार्द्ध पर सतह पवन तापमान का औसत लिया गया और इनके परिवर्तन के चिह्न भारत के ऊपर साधारणत: समान ही है। किन्तु ऐसा प्रतीत होता है कि प्रत्येक ऋतु में, उपमहाद्वीप में ऐसे प्रदश विद्यमान रहते हैं जहां ऐसी घटनाओं की संभावना 0.5 से भी कम होती है। ग्रीष्म (जून-अगस्त) में ऐसे प्रदेशों का क्षेत्र अधिकतम होता है। इनमें उपमहाद्वीप के उत्तरी, उत्तर-पश्चिमी और केन्द्रीय भाग भी शामिल हैं।

यह दर्शाया गया है कि उत्तरी गोलार्द्ध में वार्षिक माध्य सतह पवन तापमान में वृद्धि पूरे भारत की कुल वर्षा, विशेषरूप से उपमहाद्वीप के पश्चिमी तट के आसपास हुई। वर्षा में वृद्धि साथ-साथ होती है। तथापि भूमंडलीय तापीय प्रवृत्ति में परिवर्तनों से सम्बन्धित विस्तृत प्रतिमान प्राप्त करने के लिये अपेक्षाकृत अधिक व्यापक विश्लेषण की आवश्यकता है।

ABSTRACT. Basing on statistical processing of the data on Indian subcontinent climate available in the USSR the estimates have been obtained of geographical distribution of temperature and precipitation fields with changing mean annual surface air temperature of the northern hemisphere.

Signs of changes of surface air temperature averaged over the hemisphere and these over India are usually the same. But it appears, that for every season there exist regions on the subcontinent where the probability of such events is less than 0.5. In summer (Jun-Aug) the area of these regions is maximum. They include northern, northwestern and central parts of the subcontinent.

It is shown that an increase in mean annual surface air temperature of the northern hemisphere is accompanied by an increase of precipitation totals over the entire India, especially along the western coast of the subcontinent. However, to obtain the detailed rainfall pattern associated with global thermal regime changes, a more comprehensive analysis is needed.

1. Introduction

Over the last hundred years due to the burning of ever increasing amounts of fossil fuel, an anthropogenic change of atmospheric gas composition has taken place: the concentration of carbondioxide has grown, and during the last several decades the content of other optically active trace gases (methane, nitrogen oxides, freons etc) has increased. All these changes results in strengthening the 'greenhouse effect' of the atmosphere and, therefore, in changing surface air temperature on a global scale (Budyko & Izrael 1987, Budyko & Vinnikov 1976, Budyko 1972).

At present there are well-recorded changes in global mean surface air temperature over the last hundred years (Jones *et al.* 1986, Vinnikov *et al.* 1987). The major causes of these changes have been revealed (Budyko & Izrael 1987, Hansen *et al.* 1981, Vinnikov & Groisman 1981) and sufficiently substantiated forecasts of its forthcoming change are available (Budyko & Izrael 1987, etc). Therefore, of most importance are empirical diagnostic studies of the relationships between global surface air temperature and regional climate (Vinnikov & Groisman 1979; Verma *et al.* 1985; Wigley *et al.* 1980). These relationships can be used jointly with the forecasts of global temperature variations to construct scenarios of future regional climatic change. Such an approach is as especially justified, since the modern climate models reliably predicting the sign and scale of pending anthropogenic variations in the hemispheric mean temperature due to man made fluctuations in atmospheric gas composition, yield different results about forthcoming regional climatic changes. The uncertainty of the forecasts of changing geographical distribution of precipitation is particularly large.

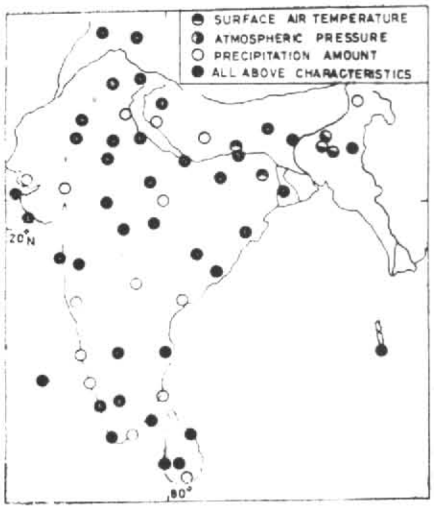
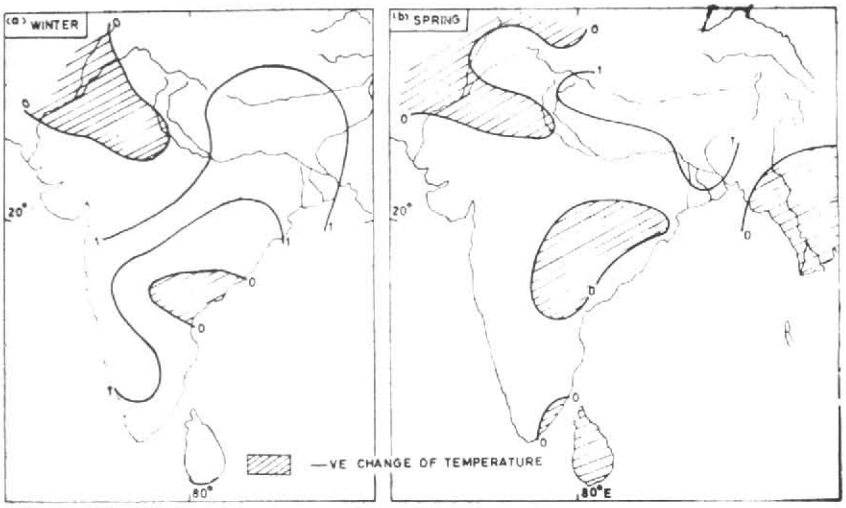
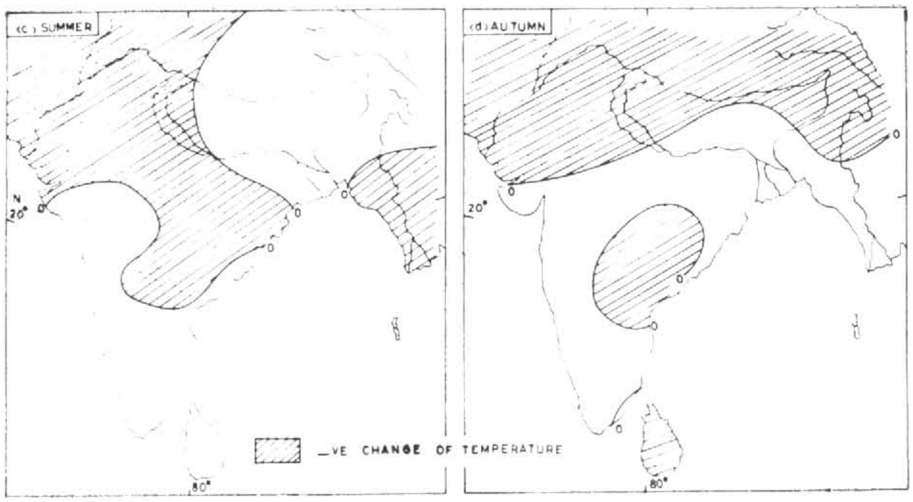


Fig. 1. The map of the station network used. There are measurement data for (i) temperature, (ii) pressure and (iii) precipitation and for all these 3 parameters



Figs. 2 (a&b). Relative changes in surface air temperature with the northern hemisphere warming : (a) winter and (b) spring. Shaded areas indicate negative changes of temperature



Figs. 2 (c&d). Relative changes in surface air temperature with the northern hemisphere warming (c) summer and (d) autumn. Shaded areas indicate negative changes of temperature

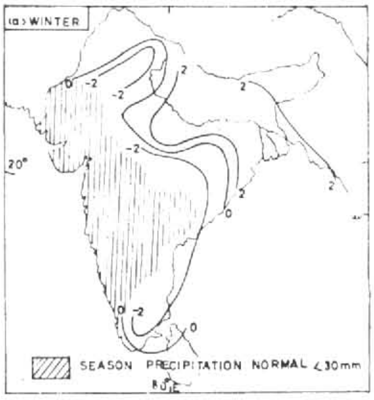


Fig. 3 (a). Changes in precipitation (% of normal) with a 0·1°C warming of N.H. in winter

2. The model and and data used

In (Vinnikov & Groisman 1979) the concept of empirical model of modern climatic change has been proposed. As follows from the climate models, the modern climatic change can be characterized to a first approximation by a change in one variable, *i.e.*, in the mean surface air temperature. Model calculations (Manabe & Wetherald 1975, Wetherald & Manabe 1975 etc) and the analysis of empirical data for the period of instrumental observations (Vinnikov & Groisman 1981, 1982) have shown that although the physical mechanisms associated, for example, with changing stratospheric aerosol layer and atmospheric CO_2 concentration differ considerably, the corresponding most important features of zonal change pattern of surface air temperature are similar. Moreover, all low frequency variations (with the period of more than 5 years) of this pattern in extratropical zone of the northern hemisphere (north of 20°N) for last hundred years could be described (Vinnikov & Groisman 1979) with the help of one variable, the mean annual surface air temperature averaged over the hemisphere, and matrix of constant coefficients (whose estimates have been obtained from observational data). Therefore, the authors assumptions (Vinnikov & Groisman 1979) that determinate changes in global climatic variables should correspond to determinate changes in local climate seems to be valid. In those cases when the contribution of global factors is significant, it could be estimated from empirical data for the instrumental observation period.

A set of statistical estimates for the parameters describing the relationship between changes in global climatic variables and these in local climatic characteristics for different seasons of the year is, by definition, an empirical model of climate change (Vinnikov & Groisman 1979). Annual mean surface air temperature averaged over the extratropical zone of the northern hemisphere (north of 17.5 °N) has been used in this study as a global variable. Later on this model yielded the geographical distribution of estimates of linear structural relationship (α) between global variable and major local climatic characteristics (atmospheric pressure, precipitation and temperature) (Groisman 1981, Kovyneva 1982, 1984; Vinnikov 1986; Vinnikov & Groisman 1979).

It has been detected that insignificant changes in global temperature that have taken place during the last hundred years are accompanied with noticeable, and in some cases dramatic, changes in regional climatic conditions.

The estimation technique for α, the instrumental variable method used in (Vinnikov & Groisman 1979) is similar to the regressive analysis. In a simple statistical model:

$$Y_i(t) = \alpha_i T(t) + \beta_i + E_i(t),$$

where, t is the time, i the number of local climatic characteristic, Y_i, $E_i(t)$ the random model error, β the biased parameter, asymptotically unbiased estimates α_i are found by formula:

$$\alpha_i = \frac{\text{cov}\,(Y_i, Z)}{\text{cov}\,(T, Z)},$$

where the operator cov means covariance of variables in brackets and $Z(t)$ is the instrumental variable. The conditions of using the variable as instrumental are the close correlation of $Z(t)$ with true value $T(t)$ and the absence of any relationship between $Z(t)$ and $E(t)$ and error of determining $T(t)$. Below variable Z_u adopted in (Vinnikov & Groisman 1979) is used for $Z(t)$. In this model β_i is the interfering parameter. Its value depends on choosing of reference points for T and Y_i. (For example, if the mean values of T and Y_i are chosen as such reference points, then zero will be an acceptable estimate of β_i).

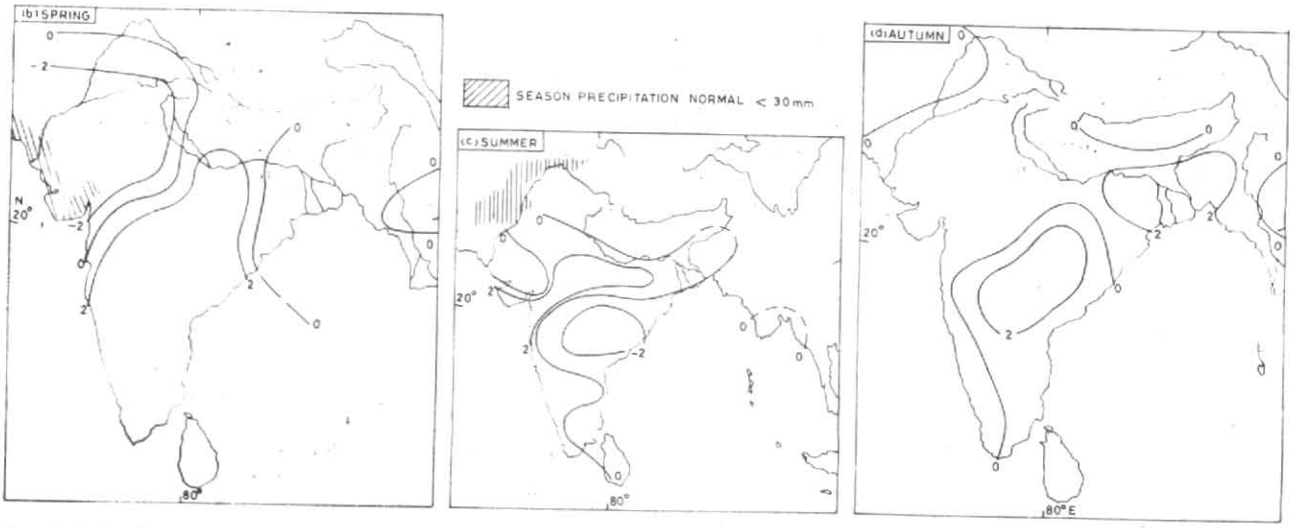
The main emphasis is these studies has been given to high and middle latitudes which are provided in the USSR with the greatest amount of homogeneous time series of meteorological observations. At the same time, the tropical regions (including India) for which only meagre empirical data are available in the USSR, either have not been studied, the results turned out to be insufficiently accurate. Nevertheless, even in the primary study (Vinnikov & Groisman 1979) on the basis of limited data (Borzenkova 1981) the reliable inference has been drawn that at the beginning of the rain period (from May up to July) precipitation increases along the western coast of Indian subcontinent with a small (0.5° C) hemispheric warming (Table 1). More detailed (however, still rough) estimates have been obtained in (Kovyneva 1984, Vinnikov 1986). Fig. 1 shows the map of the network of stations whose data we have used in studying possible climatic change occurring when global warming develops in the territory of India. As the major regional climatic characteristics we have considered surface air temperature atmospheric pressure at sea level and precipitation totals. The data set used in the estimation of parameters α_i, for Indian territory was collected from all the main climatological archives available in the USSR, including the international archive "*World Weather Records*" (Fig. 1). It contains mean monthly measurement data on the indicated three characteristics up to 1973 inclusive. The stations with observational data series for not less than 60 years (in badly elucidated regions for not less then 50 years) have been processed.

3. Results and discussion

Below are given the conclusions about probable climatic change in India with the northern hemisphere warming that can be drawn by analyzing the obtained field of α estimates.

Atmospheric pressure — We were able to estimate only the sign of atmospheric pressure changes. Throughout all the seasons of the year and on the average for the entire year atmospheric pressure somewhat decreases over the whole territory of India, particularly, this is noticeable in northern India.

Temperature — In Fig. 2 are presented the estimates of changes in surface air temperature when changing the northern hemisphere temperature. They are dimensionless and show how much the local air temperature changes when the mean annual hemispheric surface air temperature varies by 1°C. Throughout the year, air temperature decreases in the east of the central part and in the northwest of India. In this case, the former region changes insignificantly from season to season and the



Figs. 3 (b-d). Changes in precipitation (% of normal) with a 0.1°C warming of the northern hemisphere : (b) spring, (c) summer and (d) autumn Areas with the season precipitation normal < 30 mm are shaded

TABLE 1

Estimates of changing precipitation totals over three months (May-July) on the western coast of Indian subcontinent associated with mean annual surface air temperature of the northern hemisphere (using the materials of Vinnikov & Groismar 1979)

Precipitation normal	950 mm
α	21%/0.5°C (or 200 mm/0.5°C)
95% confidence interval for α	7 : 38%/0.5°C (or 60 : 360mm/0.5°C)
σ_{ϵ}^2	84%

σ_{ϵ}^2 — error's variance of empirical model

latter does more considerably. This takes place more noticeably in summer (Jun-Aug) and autumn (Sep-Nov).

In summer the area of air temperature decrease develops to the east up to the central region. In autumn, this area retreats to the north remaining, however, large.

It is possible to compare the materials in Fig. 2 with estimates of linear trends of temperature at Indian stations during the last 100 years obtained in (Hingane *et al.* 1985). In this period mean annualy globally averaged surface air temperature have increased by approximately by 0.5°C (Vinnikov *et al.* 1987, Jones *et al.* 1986 etc). Therefore, the coincidence of signs is expected to occur for linear trends from Hingane *et al.* (1985) and estimates of parameter α in Fig. 2. Really for winter (Dec-Feb) and spring (Mar-May)—the two seasons for which it is possible to make direct comparisons—these signs coincide [Table 1 in Hingane *et al.* (1985) and Figs. 2(a&b) of present paper]. In the above works other seasons are differently chosen.

Precipitation — In Fig. 3 are given the estimates of changes (in % of the normal) in the seasonal precipitation totals when hemispheric warming amounts to 0.1°C. On the maps. the regions with the seasonal normal of falling precipitation not exceeding 30 mm are shaded. They are not studied in this work, because to analyse rare events of rainfall in this regions, it is necessary to use another technique and another kind of models.

In winter (Dec-Feb), precipitation increases in the northeast of India, along the middle and lower reaches of the *Ganges* river. In the north and along the eastern coast precipitation somewhat decreases in the course of global warming.

In spring (Mar-May), precipitation decreases in the northwest and northeast of India. In other regions it increases.

In summer (Jun-Aug) warming produces increased precipitation in the regions along the western coast of Indian subcontinent and over the most part of northern India. At the same time, in a number of regions of eastern part of Indian subcontinent in the territory of States of Andhra Pradesh and Orissa precipitation amount somewhat decreases.

In autumn (Sep-Nov) the pattern of changing precipitation is similar to this in summer. Only the regions with decreasing precipitation somewhat shift to the north and precipitation increases in Bengal.

Figs. 3(c) and 3(d) show that the rainfall over the main part of Indian territory increases in monsoon period (Jun-Sep) with the warming of hemisphere.

Really, as it may be seen from materials of (Parthasarathy *et al.* 1987), the probability of the occurrence of droughts decreased in the periods with high values of northern hemisphere temperature (1921-1960, 1980-1986). The same conclusion was drawn earlier in (Verma *et al.* 1985). In addition, it may be noted that the period of almost monotonous increase of global temperature in the first half of this century (Vinnikov *et al.* 1987, Jones *et al.* 1986) coincides with the period of the continuous increase in the 10-yr mean rainfall over India (Mooley & Parthasarathy 1984).

Not all features marked in the maps (Figs. 2 and 3) are statistically valid. In particular, this concerns the maps of precipitation changes. Actually, it is *a priori* clear that only a small part of variability of this most important local characteristic is described by changes in the mean annual hemispheric air temperature. Even if T increases by 0.5°C the changes in seasonal rainfall totals (in %) would be at least half its coefficient of variation and only for western coast of the subcontinent these values would be close to each other (*see* Table 1). However, this systematic part describing determinate changes in precipitation normals in the global warming and cooling becomes the first order factor when long-term global temperature trends of one sign appear. Judging by scenarios of future anthropogenic changes in this global temperature (Budyko & Izrael 1987) during several nearest decades, the estimates similar to those presented in Figs. 2-3 should be taken into account in long-term planning of man's activities, in particular, in the regions where temperature and (or) precipitation are its limiting factors.

It should be mentioned that the estimates of changes in temperature, pressure and precipitation have been obtained from measurement data for the instrumental meteorological observation period. The mean annual surface air temperature over this period varied within the ±0.5°C range. Therefore, all estimates and conclusions, given above are appropriate only in the indicated hemispheric temperature change range.

In a number of studies by Indian climatologists (Hingane *et al.* 1985, Parthasarathy 1984, Parthasarathy *et al.* 1987, Verma *et al.* 1985), there have been investigations about the tendencies of modern climate change in India and their relationship with global characteristics of the physical state of the earth's climatic system. In particular, statistically reliable evidence of the 'southern oscillation' effects on the weather in India have been obtained (Pant & Parthasarathy1981, Mooley & Parthasarathy 1983). The experience of evaluating the surface air temperature sensitivity to variations in atmospheric CO_2 concentration (Vinnikov & Groisman 1981 1982) show that taking account of a first order additional factor (atmospheric transparency for direct solar radiation) allows us not only to unbiasly estimate the parameters characterizing the climate sensitivity to carbon dioxide, but also to considerably narrow down the confidence intervals of these values.

The following measures seem to be promising for improving the estimates of the relationship between local climatic characteristics of the territory of India and global temperature :

(*i*) To essentially widen a set of climatic characteristics and to repeat estimations (carried out earlier in the USSR) by using full set of time series of local climatic characteristics important for economic activities on the subcontinent. The analysis (using the technique described in this work) of high quality rainfall data for Indian territory presented in Parthasarathy *et al.* (1987) could be one of the first steps in this direction.

(*ii*) To improve the technique for estimating the Indian climate sensitivity to global temperature variations taking into account the additional factors specific for the subcontinent.

(*iii*) To apply the results obtained in forecasting for the nearest decades, climatic change in the tropics (primarily, for India) due to unavoidable earth's temperature variations induced by anthropogenic fluctuations of atmospheric gas composition.

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