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Prediction of terrestrial and extraterrestrial parameters by modelling and extrapolating their natural regularities

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सार - प्रेक्षित दीर्घावधि काल-खंडों में समुचित गणितीय फलन का उपयोग करके घटबढ़ की मूल विधाओं का बर्हिर्वेशन दीर्घकालिक मौसम पूर्वानुमान अथवा अल्पकालिक जलवायु पूर्वानुमान करने की एक पद्धति है। अनुभवों के आधार पर यह कहा जा सकता है कि ऐसी पद्धतियों से विश्वसनीय पूर्वानुमान किया जा सकता है बशर्ते निदर्शित काल-खंडों में समुचित नियमितता हो। समुचित प्रकार्य का चुनाव भी काल-खंड निदर्शन-बर्हिर्वेशन-पुर्वानुमान अथवा टी.एस.-एम.ई.पी., प्रक्रिया का महत्वपूर्ण कार्य है। संभवतः प्रभावशाली फिल्टरकारी माड्यूल का विकास इस विधि का एक इतना ही महत्वपूर्ण घटक है। फिल्टरकारी क्रिया विधि किसी भी काल-खंड की उच्च आवृत्ति अथवा अप्रत्याशित परिवर्तनों का प्रभावशाली ढंग से दमन करने में सक्षम होनी चाहिए जो निम्न आवृति विधा, अथवा प्रत्याशित, परिवर्तन में भी प्रभावशाली रह सके। इस शोध-पत्र में इन समस्याओं के समाधान को संभव बनाने वाली एक नवीन टी.एस.- एम.ई.पी. विधि का विकास किया गया है। आँकड़ो की अवधि (अथवा मूल अवधि) के किसी अपेक्षित तरंगदैर्ध्य के विभेदन हेतु काल-खंडों को तरंगों के साइन और कोसाइन प्रकारों में वियोजित करने के लिए विचलन हार्मोनिक विश्लेषण (वी.एच.ए.) का विकास किया गया है। क्लासिकल हार्मोनिक के विश्लेषण से तरंगदैर्ध्य मूल अवधि का नियत पूर्णांक गुणज प्राप्त होता है। समरेखण के लिए सिंग्यूलर स्पैक्ट्रमी विश्लेषण (एस.एस.ए.) का अनुप्रयोग किया गया है। काल-खंडों का प्रधान घटकों की नियत संख्या में वियोजित करने के लिए एस.एस.ए. क्रियाविधि उपलब्ध कराता है और उसके बाद इससे विचलन की मूल विधाओं का प्रतिनिधित्व करने वाले आरम्भ के कुछ प्रधान घटकों को पुनः मिलाकर वास्तविक काल-खडों का समरेखिक रूप प्राप्त किया गया है।

इस अध्ययन में सुस्पष्ट नियमितता वाले पार्थिव और पार्थिवेत्तर प्राचलों के चौबीस काल-खडों पर विचार किया गया है। इन्हे मुख्य रूप से पॉच श्रेणियों में विभाजित किया जा सकता है - (*i*) भारतीय क्षेत्रों में तूफानों / अवदाबों की संख्या की अंतःवार्षिक श्रृंखलाएँ, मौसमी और वार्षिक माध्य उत्तरी गोलार्द्ध स्थल क्षेत्र सतह वायु तापमान तथा वार्षिक माध्य सूर्य के धब्बों की संख्या (दीर्घकालिक /अल्पकालिक अथवा दोलन के चुने मामले); (*ii*) बलबोआ (अर्ध-द्विवर्षी दोलन का प्रतिनिधि) में 50, 30 और 10 hPa स्तरों पर क्षेत्रीय पवन का मासिक अनुक्रम; (*iii*) भारतीय क्षेत्र (मौसम से विशेष रूप से प्रभावित) में सतह वायु तापमान (एस.ए.टी) का मासिक अनुक्रम ; (*iv*) उष्णकटिबंधीय भारतीय समुद्रों और प्रशांत महासागर (एल-निनों/ला-निना से संबंधित अनावर्ती दोलन) के समुद्र सतह तापमान (एस.एस.टी) का मासिक अनुक्रम और (*v*) एन्सो क्षेत्रों (सीज़नैलिटि/मौसम और दोलन) में कुछ चुने हुए स्थानों के समुद्र स्तर दाब (एस.एल.पी.) का मासिक अनुक्रम सीज़नैलिटि/मौसम और/अथवा अनावर्ती दोलनों के प्रबल वियोजन के कारण बेहतर पूर्वानुमान क्रमशः एस.ए.टी. और एस.एस.टी. के लिए प्राप्त हुआ। उसके बाद एस.एल.पी. का स्थान रहा है। बलबोआ में निम्न समतापमंडलीय क्षेत्रीय पवन के लिए पूर्वानुमान संतोषजनक रहा है जिससे अर्ध-आवर्ती दोलनों का पता चलता है। भारत में तूफानों/अवदाबों की तीव्र ह्रासमान प्रवत्ति की वजह से इस विधि द्वारा उनकी संख्या का विश्वसनीय पूर्वानुमान करना संभव है। उत्तरी गोलार्द्ध सतह वायु तापमान विसंगति का पूर्वानुमान संतोषजनक नहीं पाया गया है।

ABSTRACT. Extrapolation of dominant modes of fluctuations after fitting suitable mathematical function to the observed long period time series is one of the approaches to long-term weather or short-term climate prediction. Experiences suggest that reliable predictions can be made from such approaches provided the time series being modelled possesses adequate regularity. Choice of the suitable function is also an important task of the time series modelling-extrapolation-prediction, or TS-MEP, process. Perhaps equally important component of this method is the development of effective filtering module. The filtering mechanism should be such that it effectively suppresses the high frequency, or unpredictable, variations and carves out the low frequency mode, or predictable, variation of the given series. By incorporating a possible solution to these propositions a new TS-MEP method has been developed in this paper. A Variable Harmonic Analysis (VHA) has been developed to decompose the time series into sine and cosine waveforms for any desired wavelength resolution within the data length (or fundamental period). In the Classical Harmonic Analysis (CHA) the wavelength is strictly an integer multiple of the fundamental period. For smoothing the singular spectrum analysis (SSA) has been applied. The SSA provides the mechanism to decompose the series into certain number of principal components (PCs) and then recombine the first few PCs, representing the dominant modes of variation, to get the smoothed version of the actual series.

Twenty-four time series of terrestrial and extraterrestrial parameters, which visibly show strong regularity, are considered in the study. They can be broadly grouped into five categories: (*i*) inter-annual series of number of storms/depressions over the Indian region, seasonal and annual mean northern hemisphere land-area surface air temperature and the annual mean sunspot number (chosen cases of long term/short term trends or oscillation); (*ii*) monthly sequence of zonal wind at 50- hPa, 30-hPa and 10- hPa levels over Balboa (representative of quasi-biennial oscillation); (*iii*) monthly sequence of surface air temperature (SAT) over the Indian region (strongly dominated by seasonality); (*iv*) monthly sequence of sea surface temperature (SST) of tropical Indian and Pacific Oceans (aperiodic oscillations related to El Niño/La Niña); and (*v*) sequence of monthly sea level pressure (SLP) of selected places over ENSO region (seasonality and oscillation). Best predictions are obtained for the SLP followed by SAT and SST due to strong domination of seasonality and/or aperiodic oscillations. The predictions are found satisfactory for the lower stratospheric zonal wind over Balboa, which displays quasi-periodic oscillations. Because of a steep declining trend a reliable prediction of number of storms/depressions over India is possible by the method. Prediction of northern hemisphere surface air temperature anomaly is not found satisfactory.

Key words - Time series modelling, Extrapolation, Prediction, Variable harmonic Analysis, Singular spectrum analysis, Indian climate, El Niño-southern oscillation, Quasi-biennial oscillation.

1. Introduction

Extrapolation through modelling of temporal fluctuations is one of the approaches to long-term weather or short-term climate prediction. Origin of such approaches can be traced as back as 1936 (Clayton, 1936), but in the past few decades the method regained considerable prominence in the research circle (Kane and Teixeiro, 1990; Kane and Trivedi, 1988; Schickedanz and Bowen, 1977 and others). Though non-committal to physical explanation the method does work on the principle 'future depends upon the past via the present'. The application is simple, easily manageable and requires limited database. Reliability of prediction by this method depends upon the degree of regularity present in the series being modelled. Here non-Gaussian features like seasonality, long term/short term trend and epochal pattern will be treated as part of regularity in the variations. The series can be said to possess greater regularity if fewer waveforms explain large or most portion of the actual series variance. Most of the terrestrial and some extra-terrestrial parameters do show adequate regularities if sampled on appropriate interval in the time continuum. But the series may be noisy if sampling is done too frequently on the one hand, and valuable and useful information may be lost if sampling interval is taken too large on the other hand. This choice one can exercise if data is yet to be collected. But long period data of large number of terrestrial and extraterrestrial parameters are already available on certain temporal scales. In the new endeavour the first prime task is to prepare the time series, if need be apply time-averaging and/or appropriate low-pass filter, such that different types of regularities are retained. For example, the inter-annual series of monthly, seasonal or annual mean of atmospheric and oceanic parameters may not display any regularity but tremendous regularity can be seen if monthly/seasonal values are arranged in sequence year after year. This regularity is due to restoration of seasonality.

The next major task is the choice of mathematical function to represent the variations in the series. Fourier (or harmonic) is one of the most commonly used functions. Though well known for conservation of variance, Fourier is a kind of forced analysis, that is the series is decomposed into finite number of sine and cosine waveforms whose wavelengths are integer multiple of the data length. In this study, the harmonic analysis has been modified to compute the sine and cosine waveforms of any wavelength (within the data length) in order to catch the realistic periodicities. Fourth modification to the existing approach is to make the method committal to the one-step-ahead term to-be-extrapolated, the existing methods are non-committal. The term is assigned some guess value and is augmented with the available series being modelled. Selected harmonics are combined and the generated value at the to-be-extrapolated term is suitably scaled to get an estimate at the term. The last modification incorporated is to get a reliable estimate of the actual value at the term of extrapolation since in the modelling and extrapolation processes smoothed series was utilized. The methodology developed with suitable modification for these considerations is tested for large number of land, atmospheric and oceanic parameters and an extraterrestrial parameter (annual mean sunspot number).

2. The Methodology

As indicated previously there are five modules of the presently developed methodological approach to the time series modelling, extrapolation and prediction (TS-MEP) problem, temporal smoothing, variable harmonic analysis (VHA), selection of harmonics adequate to reproduce the dominant features of the series being modelled, determination of scaling factor between extrapolated values and smoothed values, and determination of scaling factor between extrapolated values and actual values. A brief description of different processes is given below. Computational steps of the application of the method are detailed by taking one practical example at the end of this section.

2.1. *Low-pass filtering using SSA*

Experiences suggest that fitting complicated function to noisy raw time series does not generally lead to satisfactory results though the series may possess some interesting predictable component. And application of some arbitrary filter does not provide requisite solution to the problem 'to carve out predictable low frequency variation'. Relatively recent development the Singular Spectrum Analysis (SSA) provides a flexible approach to smoothing. Through a multivariate manipulation the given series is resolved into finite number of principal components (PCs) and later the first few PCs are recombined to get the smoothed series. The number of PCs to be recombined will depend on the reliability of extrapolation and prediction by the method developed here. The process starts from first PC and the next PC in order is included successively, the details are given in Vautard *et al*. (1992).

The SSA extracts as much reliable information as possible on dominant modes of fluctuations in the preceding period without using prior knowledge about the underling physics or biology of the system and thus provides valuable information to develop predictive models. It is essentially a linear analysis and prediction method. Its superiority over classical spectral methods lies in the data adoptive character of the eigenelements it is based on. SSA is based on principal component analysis (PCA) in the vector space of delay coordinates for a time series. The principle axis of a sequence of M-dimensional vectors ($X_i, 1 \le i \le N$) can be given by expanding it with respect to an orthonormal basis ($E^k, 1 \le k \le M$) :

$$X_{i+j} = \sum_{k=1}^{M} a_i^k E_j^k, \qquad 1 \le j \le M \tag{1}$$

The projection coefficients a_i^k are called the principal components (PCs), and the basis vectors E_i^k are the empirical orthogonal functions (EOFs). The vectors E_j^k are the eigenvectors of the j^{th} eigenvalue of the variance-covariance matrix of embedding dimension M of the sequence X_i, M is also called lag or the window length. In contradistinction with the classical PCA, where M is the fixed dimension of the data vectors, in SSA it is chosen by the user. The building block of the SSA is the lagged - covariance matrix T_x of the process X_i. The matrix has a Toeplitz structure, *i.e.* constant diagonals corresponding to equal lags :

$$T_x = \begin{pmatrix} c(0) & c(1) & c(2) & . & . & . & c(M-1) \\ c(1) & c(0) & c(1) & c(2) & . & . & c(M-2) \\ c(2) & c(1) & c(0) & c(1) & . & . & c(M-3) \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ c(M-1) & c(M-2) & & & . & . & c(0) \end{pmatrix} \tag{2}$$

where $c(j)$, $0 \le j \le M$-1, is the covariance of X_i at lag j. From among different available expressions the following is used to calculate $c\,(j)$,

$$c(j) = \frac{1}{N-1} \sum_{i=1}^{N-j} X_i X_{i+j} \tag{3}$$

Subroutines of the commercial packages can be used to calculate eigenvalues of the T_x matrix, their eigenvectors and the scores or principal components. The principal component is defined as the orthogonal projection coefficient of the original series onto its EOF :

$$a_i^k = \sum_{j=1}^{M} x_{i+j} E_j^k, \qquad 0 \le i \le N - M \tag{4}$$

If variance contribution by first few principal components is substantially large, it would indicate that the sequence X_i possesses strong regularity.

The smoothed series of the desired length N can be reconstructed, can also be called reconstructed components (RCs), from projection of any specified subset of principal components of length N-M onto their eigenvectors using the following three expressions obtained from the least squares solution (Vautard *et al*., 1992) :

$$\left(R_\xi x\right)_i = \frac{1}{M} \sum_{j=1}^{M} \sum_{k \in \xi} a_{i-j}^{k} E_j^{k} \qquad for \; M \leq i \leq N-M+1 \tag{5}$$

$$\left(R_\xi x\right)_i = \frac{1}{i} \sum_{j=1}^{i} \sum_{k \in \xi} a_{i-j}^{k} E_j^{k} \qquad for \; 1 \leq i \leq M-1 \tag{6}$$

$$\left(R_\xi x\right)_i = \frac{1}{N-i+1} \sum_{j=i-N+M}^{M} \sum_{k \in \xi} a_{i-j}^{k} E_j^{k} \qquad for N-M+2 \leq i \leq N \tag{7}$$

The reconstructed series $(R_\xi x)_i$ is now subjected to the variable harmonic analysis and extrapolation rather than the actual series (X_i). To begin with the most dominant mode of fluctuations represented by the first PC is considered, then the reconstructed series using the first 2 PCs, later the reconstructed series using the first 3PCs and so on. The process continues as long as reliable extrapolation of the series is realized. The variance of the reconstructed series would provide a measure of predictability of the given series. This is the special advantageous feature of the SSA, that it allows to combine those modes of fluctuations whose reliable extrapolation can be realized.

2.2. *The Variable Harmonic Analysis (VHA)*

In order to determine periodicity of the dominant modes of fluctuation the reconstructed series is subjected to the variable harmonic analysis. Schickedanz and Bowen (1977) have modified the Fourier or classical harmonic analysis to compute the harmonics whose wavelength is not necessarily integer multiple of the data length, and called as the non-integer harmonic analysis. The non-integer harmonic analysis has been further modified and named as variable harmonic analysis (VHA). In contradistinction with classical harmonic analysis, where number of harmonics is limited to half the number of data points and all of them close at the end points, in the VHA, depending upon wavelength resolution within the fundamental period, any number of harmonics can be computed in which all non-integer harmonics will be open ended. Other notable differences are sine functions and cosine functions of two different harmonics as well as sine and cosine functions of the same harmonic are orthogonal in classical analysis, they are correlated, albeit weakly, in the VHA. Continuity of waveforms beyond the fundamental length makes the VHA a potential tool for extrapolation. The sine coefficient (a) and cosine coefficient (b) of the VHA are defined by the expressions :

$$a_p^i = \left(\frac{2}{N}\right) \sum_{j=1}^{N} x_j \, \mathrm{Sin}(2\pi \; j \; / \; P) \tag{8}$$

$$b_p^i = \left(\frac{2}{N}\right) \sum_{j=1}^{N} x_j \cos\,(2\pi \; j \; / P) \tag{9}$$

$$2 < p < P$$

In which p is the wavelength of the variable harmonic numbered as i, i is a counter for the number of waveforms that are calculated. The wavelength p of the particular harmonic and the fundamental period P are related as follows:

$$p = P - \beta \; (i - 1) \tag{10}$$

where β is the resolution of wavelength for the estimation of harmonics. The wavelength p of the harmonic with i equal to one will be equal to the fundamental period P, with i equal to two p will be equal to P - β, with i equal to three p will be equal to P - 2β and so on. In Eqs. (8) and (9) p is taken greater than 2 to suppress high frequency variations.

Few effective variable harmonics making specified contribution to the total variance can be identified and the series (X_i) can be regenerated using the expression,

$$X_j = \overline{X} + \sum_{l=1}^{k} \left[a_j \, sin(\,2\pi lj \,/\, P\,) + b_j \, cos(\,2\pi lj \,/\, P\,)\right] \tag{11}$$

where k denotes the subset of selected variable harmonics.

2.3. *Identification of effective variable harmonics*

As indicated, unlike classical harmonic analysis the harmonics of the VHA are correlated, higher the wavelength resolution greater the correlation, particularly between the neighbouring harmonics. In order to identify effective variable harmonics that would be adequate to represent the 'dominant' modes of fluctuations an objective technique similar to the forward selection of independent parameters in the multiple linear regression has been applied. The technique was earlier developed and used by Singh (1994) for the optimization of observations for the area-averaged rainfall series of the Indian region. The results of the technique are consistent with the theoretical expectations (Wigley *et al.*, 1984). The regenerated series from the combination of selected variable harmonics is extrapolated one-step-ahead also. In a stepwise manner about 30 independent extrapolated values were obtained. The harmonics are selected such that the highly significant and satisfactory correlation between extrapolated values and corresponding reconstructed values, as well as between extrapolated values and corresponding actual values is obtained. No statistical test has been applied, yet it is seen that the additional harmonic explained at least 1% variance. In general, the number of selected harmonics is also kept limited to about 4 to 6, not exceeding 10 in any case.

2.4. *Estimation of scaling factor*

The extrapolated values provide only a signal of smoothed/actual values. It needs to be calibrated properly to get absolute magnitude of the smoothed/actual values. The resulting mathematical expression for calibration will be referred as 'scaling factor'. Perhaps for every time series 'scaling factor' is going to be unique. There are numerous factors that are likely to affect the estimate of scaling factor. Some of them are :

(*i*) Type (diurnal, monthly/seasonal sequential or interannual), quantity (length) and quality of data sequence being analysed.

(*ii*) Degree and type of regularity (long-term/short-term linear/non-linear trends, seasonality, oscillation, epochal behaviour *etc.*) present in the sequence.

(*iii*) Number of selected harmonics, their period, amplitude and phase, and the correlation of the individual selected harmonics as well as their multiple correlation with the smooth/actual series.

For real-time prediction the extrapolated value is suitably treated by the scaling factor to get the magnitude of prediction in absolute unit.

2.5. *The application*

To further elaborate the methodology computational steps for modelling and extrapolation/prediction of a long period interannual series (1877-1997) of number of storms/depressions of the summer monsoon period June through September over the Indian land area and neighbouring seas are given below in order.

(*i*) Compute the variance and the auto-covariances upto lags 35 (35 was decided after trials), and prepare the symmetric Toeplitz matrix.

(*ii*) Evaluate all the 35 eigenvalues of the Toeplitz matrix and their corresponding eigenvectors.

(*iii*) Find out principal components from orthogonal projection of the space-centered actual series onto the respective eigenvectors.

(*iv*) Reconstruct the series of full length N (1877-1997) by combining the first few principal components using the expressions (5) - (7).

(*v*) Consider initially a long portion of the reconstructed series N-m (1877-1966) and substitute the (N-m+1) th term (1967) with the mean of the series 1877-1966.

(*vi*) Subject the series 1877-1967 to the VHA using the wavelength resolution of 0.5 years. (The wavelength resolution of 0.5 is finalized after trials using different wavelength resolution and repeating the entire process of calculations).

(*vii*) Select an optimum number (say upto about 4 or 6, but not more than 10) of variable harmonics whose linear combination shows the highest correlation with the reconstructed series.

(*viii*) Recombine the selected harmonics and find the extrapolated value at the (N-m+1)th term (1967).

(*ix*) Repeat the different calculations from item nos. *v* to *viii* in the next step, but consider the reconstructed series of length N-m+1 (1877-

1967), substitute the (*N*-*m*+2)th term (1968) with mean of the series 1877-1967, compute the different variable harmonics at wavelength resolution of 0.5 years, select the optimum number of harmonics showing highest correlation with the reconstructed series and extrapolate the combination of selected harmonics for the (*N*-*m*+2)th term.

(*x*) Continue the process using one additional term each time till the full series (1877-1997) is not utilized in the analysis and the extrapolated value at the term *N*+1 (1998) is not obtained from the combination of selected harmonics.

(*xi*) Findthe product-moment correlation coefficient (CC) between extrapolated values of the period 1967 to 1997 (*m*=31) and the corresponding reconstructed values, that between extrapolated values and corresponding actual values.

(*xii*) Estimate the least-squares linear regression of the reconstructed values (1967-97) on the extrapolated values. This will be referred to as '*scaling factor I*' in the text.

(*xiii*) Estimate the least-squares linear regression of the reconstructed values (1967-97) on the actual values. This will be referred to as '*scaling factor II*' in the text.

(*xiv*) Adjust the number of selected harmonics so that the most reliable estimate of scaling factors is obtained.

(*xv*) Treat the extrapolated value for the year 1998 suitably by the scaling factors and get the predicted number of monsoon storms/ depressions for the year.

Two predictions will be obtained after treating the extrapolated value by two scaling factors. Though, in general, the difference is not likely to be large, the prediction obtained after treating the extrapolated value by the *scaling factor I* should be accepted as more reliable. But it may be noted that this is true if the time series being used shows strong regularity. Results of monsoon storms/depressions are discussed along with other parameters in Section 4.

3. Data used

Judiciously chosen 24 time series have been subjected to modelling, extrapolation and prediction processes in order to gauge the merit of the method developed here. Representative of fluctuation features of land, ocean, atmosphere and solar parameters the different series are expected to provide wide variety of cases in respect of regularity. Also, they show linkages with the Indian summer monsoon, either as a part of global teleconnections or regional forcings. Based on their nature of variations and the role they play in the Indian summer monsoon studies the different series can be broadly grouped into seven categories.

(*i*) Interannual sequence of annual total and summer monsoon total of the number of storms/depressions over the Indian land areas and neighbouring Bay of Bengal and Arabian Sea (1877-1997).

(*ii*) Interannual sequence of seasonal and annual mean surface air temperature (SAT) anomaly of the northern hemisphere (1901-96).

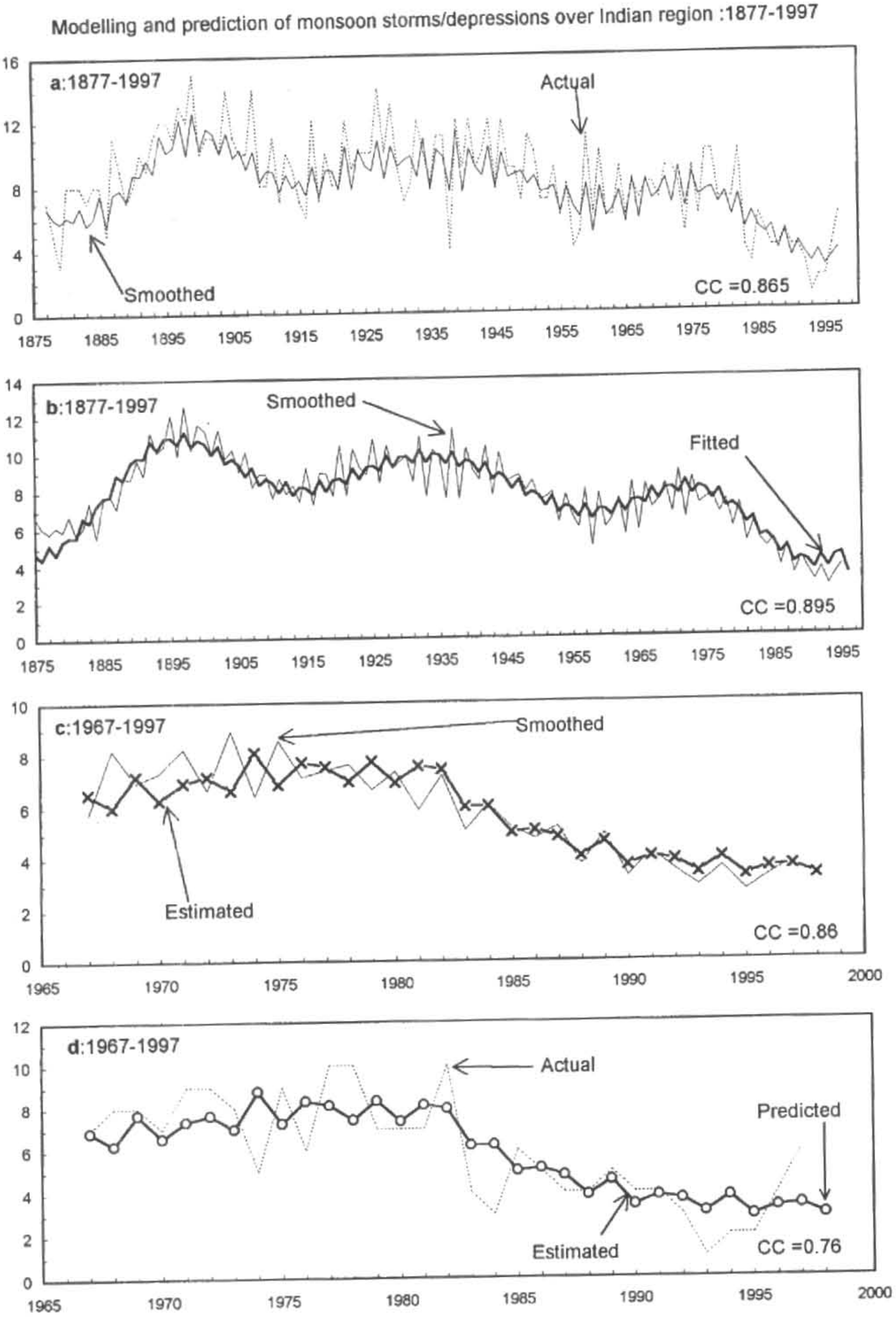
(*iii*) Annual mean sunspot number (Waldmeier) (1800-1995).

(*iv*) Monthly sequence of zonal wind recorded over Balboa (9°N, 80°W) at 50-hPa (20 km) level (1951-87); 30-hPa (24 km) level (1951-87); and 10- hPa (30km) level (1958-86).

(*v*) Monthly sequence of surface air temperature (SAT) over central India (mean of Nagpur and Akola; 1941-87); and east coast of India (mean of Calcutta, Chennai, Visakhapatnam and Masulipatnam; 1941-87).

(*vi*) Monthly sequence of sea surface temperature (SST) at Puerto Chicama (8°S, 79°W; 1941-89); over Indonesian region (120°E-160°E, 5°S-15°S; 1949-91); Niño-1+2 area (0-10°S, 80°-90°W; 1951-86); and Niño-3 area (0°-10°S, 80°-90°W; 1951-86); and Niño-4 (5°N-5°S, 160°E-150°W; 1951-86).

(*vii*) Monthly sequence of sea level pressure (SLP) at Bombay (18°54′N, 72°49′E; 1941-93); Cape Town (33°56′S, 18°29′E; 1951-86); Tahiti (17°32′S, 149°35′W; 1941-90) and Darwin (12°28′S; 130°51′E; 1941-90); and over west central India (mean of Jodhpur, Ahmedabad, Mumbai, Indore, Sagar and Akola; 1941-90) and South America (mean of Cardoba, Santiago and Buenos Aires; 1941-90).



Figs. 1(a-d). Actual and reconstructed smoothed (8 PCs) interannual time series (1877-1997) of the number of monsoon storms/depressions over the Indian region and neighbouring seas (a); reconstructed series and the series generated from the combination of 4 selected variable harmonics (b); reconstructed values and the estimated value (obtained after treating the extrapolated values by the 'scaling factor I' for the period 1967-97; (c) and the actual values and the estimated values (obtained after treating the extrapolated values by the 'scaling factor II' for the period 1967-97(d)

TABLE 1

The parameters whose time series is considered in the study for modelling, extrapolation and prediction. The numbers given in different column are self-explainatory

S. No. 1	Parameter 2	Data period (No. of data points, N) 3	Lags 4	No. of PCs combined (% variance contained) 5	Wavelength resolution for the VHA 6	Variable harmonics combined and CC achieved 7	CC between extrapolated and smoothed values (m=31) 8	CC between extrapolated and actual values (m=31) 9
1	No. of monsoon storms / depressions	1877-1997 (121)	35	08 (74.82)	0.5 years	4 (0.895) 121,37,62, 2.5 yrs.	0.86	0.76
2	Annual storms/ depressions	1877-1997 (121)	35	08 (77.8)	0.5 years	5 (0.90) 121,37.5,26,19.5 48 yrs.	0.74	0.69
3	Winter NH temp.	1900- 1996 (97)	25	02 (43.56)	0.5 years	5 (0.90) 53,97,36.5,27 17.5 yrs.	0.95	0.63
4	Spring NH temp.	1900- 1996 (97)	25	03 (63.49)	0.5 years	5 (0.92) 97,58.5,36.5,27, 5 yrs.	0.82	0.55
5	Summer NH temp.	1900- 1996 (97)	25	04 (77.7)	0.5 years	4 (0.91) 56.5,97,7.5, 88 yrs.	0.85	0.66
6	Autumn NH temp.	1900-1996 (97)	25	02 (39.59)	0.5 years	5 (0.97) 16.5,97,35.5,49,3 4.5 yrs.	0.95	0.41
7	Annual NH temp.	1900-1996 (97)	25	04 (73.69)	0.5 years	4 (0.92) 53.5,97,35.5, 26 yrs.	0.83	0.66
8	Annual sunspot no.	1800-1995 (196)	45	14 (96.35)	0.5 years	5 (0.896) 11,10,108.5,10.5, 12 yrs.	0.85	0.84
9	Balboa 50-hPa zonal wind	Jan'1951-Dec'1987 (444)	40	06 (92.43)	1 month	6 (0.948) 28,12,33,24,25, 37,21 mon.	0.94	0.84
10	Balboa 30 hPa zonal wind	Jan'1951-Dec'1987 (444)	40	06 (94.48)	1 month	7 (0.943) 28,12,33,24, 25,37,20mon.	0.97	0.85
11	Balboa 10 hPa zonal wind	Jan'1958-Dec'1986 (348)	40	07 (93.70)	1 month	7 (0.947) 28,12,33,24,37, 21,91 mon.	0.95	0.91
12	SAT over central India	Jan'1941-Dec'1990 (564)	40	28 (99.60)	1 month	2 (0.988) 12, 6 mon.	0.99	0.99
13	SAT over east coast of India	Jan'1941-Dec'1987 (564)	40	09 (97.95)	1 month	2 (0.988) 12, 6 mon.	0.997	0.97
14	SST over Indonesia	Jan'1949-Dec'1991 (516)	40	15 (95.16)	1 month	3 (0.977) 12,6,176mon.	0.99	0.96
15	SST over Niño-1+2 area	Jan'1951-Dec'1986 (432)	40	07 (93.84)	1 month	7 (0.956) 12,44,75,40,21, 13,94 mon.	0.98	0.92
16	SST over Niño-3 area	Jan'1951-Dec'1986 (432)	40	07 (91.68)	1 month	7 (0.956) 12,44,75,40,21, 23,94 mon.	0.98	0.92
17	SST over Niño-4 area	Jan'1951-Dec'1986 (432)	40	07 (83.26)	1 month	9 (0.882) 59,121,225,12, 44,32,39, 78,48 mon.	0.796	0.766
18	SST at Peurto Chicama	Jan'1941-Dec'1989 (588)	40	06 (77.97)	1 month	7 (0.865) 12,42,62,45, 24,34,75mon.	0.83	0.69
19	SLP at Bombay	Jan'1941-Dec' 1993 (636)	40	07 (95.84)	1 month	1 (0.981) 12 mon.	0.99	0.97

TABLE 1 (*Contd.*)

1	2	3	4	5	6	7	8	9
21	SLP at Cape Town	Jan’1951-Dec’1986 (432)	40	13 (91.95)	1 month	5 (0.973) 12,71,6,122, 177 mon.	0.93	0.88
22	SLP at Tahiti	Jan’1941-Dec’1990 (600)	45	12 (85.90)	1 month	6 (0.922) 12,6,29,58, 76,67 mon.	0.93	0.89
23	SLP at Darwin	Jan’1941-Dec’1990 (600)	45	8 (92.66)	1 month	4 (0.97) 12, 61, 42, 248 mon.	0.97	0.92
24	SLP over S. America	Jan’1951-Dec’1986 (432)	40	12 (91.28)	1 month	5 (0.973) (12, 315, 6, 23,32 mon.	0.96	0.92

4. Results

4.1. *Number of monsoon storms/depressions over the Indian land areas and the neighbouring seas*

There are four vital signatures, which suggests for a long term large-scale climatic changes over the Indian region and neighbourhood. These are :

(*i*) Long term increasing trend in the annual surface air temperature over India at the rate of 0.6C/100yr (Hingane *et al*., 1985).

(*ii*) Contracting tendency in the arid regions of India (Singh *et al*., 1992a).

(*iii*) Westward shift in total rainfall and rainstorm activities over India (Singh *et al*., 1992b; Singh *et al*., 1999).

(*iv*) Declining trend in the number of storms/depressions over Indian land areas and neighbouring seas (Bhalme, 1972).

These changes are inter-linked and are associated with global warming caused by ‘greenhouse effect’ due to increasing load of greenhouse gases in the atmosphere. Here we are concerned with the decreasing trend in the number of storms/depressions over the Indian region and neighbouring sea during summer monsoon season June through September. The time series of number of monsoon storms/depressions for the period 1877-1997 is presented in Fig. 1(a). From 6 in 1870s the number of monsoon storms/depressions rose to 12 in late 1890s and then started decreasing, albeit dominated by low frequency mode fluctuations, and came down to 3 in 1990s. Increasing trend in rainfall over northwest India and decreasing trend over northeast associated with changes in the circulation of the Indian summer monsoon resulting from strengthening of the upper tropospheric circumpolar westerlies caused by warming of the northern hemisphere surface air are reported by Singh *et al.* (1992 a&b). Keeping in view this reported result and the proposed theory it can be speculated that meridional component of the summer monsoon over Arabian Sea has increased to give higher rains over northwest India and the Bay of Bengal branch has decreased to produce lesser rainfall over the northeast. This situation is resulting in the decline of cyclogenesis and the number of monsoon storms / depressions over the Indian region, particularly the eastern parts. But from this mechanism which operates on climatological scales (average conditions) does not seem possible to suggest deterministic numerical model to predict the decline in the number of storms/ depressions. With great regularity in the fluctuations the time series of number of storms/depressions provides a genuine case for the MEP processes by the present method.

The reconstructed/smoothed series of the number storms/depressions developed from the combination of 9 principal components derived from the variance-covariance symmetric Toeplitz matrix of the size 35 x 35 showed the CC of 0.87 with the actual series Fig. 1(a). The smooth series is subjected to the VHA and harmonics are computed at wavelength interval of half a year. In the optimi-zation process (item nos. v to ix of the Application Section) about 5 harmonics entered the selection with their linear combination showing the CC of ~ 0.90 with the smoothed series, shown in Fig. 1(b). The CC between the one-step - ahead extrapolated values for the period 1967-97 and the corresponding reconstructed values is 0.86 Fig. 1(c), and with the corresponding actual values 0.76 Fig. 1(d). The magnitude of CCs suggests that the estimated scaling factors of the process are quite reliable. Important details of the method are given in Table 1. After treating the extrapolated value by the scaling factor the predicted number of monsoon storms/depressions over the Indian region for the year 1998 is about 3. The actual number for the year 1998 is 4.

4.2. *Annual number of storms/depressions over the Indian land areas and the neighbouring seas*

The annual number of storms/depressions is expected to provide more specific information regarding fluctuations of the circulation features over the Indian region. There is a remarkable similarity between fluctuations of the annual number of storms/depressions and the monsoon storms/depressions of the period 1877-1997. The reconstructed component from the combination of the first eight principal components derived from the variance-covariance Toeplitz matrix of the size 35×35 explained 77.8% variance of the annual number of storms/ depressions series. Five selected variable harmonics by the optimization method showed the correlation of 0.9 with the reconstructed series. The correlation of one-step-ahead extrapolated values for the period 1967-97 with the corresponding reconstructed values is 0.74, and that with actual values is 0.69. The predicted number of storms/depressions for the year 1998 was 11, the actual number came 12. Details of the modelling, extrapolation and prediction processes are given in Table 1.

4.3. *Northern hemisphere surface air temperature variations*

Besides the Northern Hemisphere surface air temperature is regarded as a reliable indicator of the global warming (Jones *et al.*,1986) it is one of the potential predictors for the Indian summer monsoon (Verma *et al.*, 1985). Development of predicting model for the NH temperature would be of great significance to the scientific as well as practical problems. Table 1 gives the important information for the MEP processes of the seasonal and annual temperature anomaly series of the northern hemisphere. The results are however displayed only for the annual series in Fig. 2. It is seen that only the reconstructed smooth series produced from the combination of first 2 to 4 principal components, representing mostly the non-linear trend, can be modelled and predicted with considerable degree of reliability but getting reliable estimate of actual anomaly is not reliable, particularly for autumn and spring seasons (Table 1). This is because long term trend accounts limited portion of the variance in those series. Better prediction of temperature of different seasons can be expected from the analysis of the actual seasonal values kept in the sequence. Unfortunately they are not available to us.

4.4. *Annual mean sunspot number*

Numerous workers in the past have attempted to demonstrate that terrestrial weather and climate are influenced by the 11 and 22-year sunspot cycles (King, 1975; Wilcox, 1975). Several studies have shown the influence of sunspot activities on the fluctuations of the Indian summer monsoon (Bhalme *et al.*, 1981; Bhalme and Jadhav, 1984). Bhalme and Jadhav (1984) have demonstrated that large-scale flood years over India show a strong tendency to occur in the positive (major) sunspot cycle than in the negative (minor) sunspot cycle, a useful information for long-term prediction. Prediction of sunspot numbers can be useful to such schemes of monsoon forecasting. Results of the one-step-ahead prediction of the annual sunspot number by the present method using data of 1800-1995 are given in Table 1. The correlation between extrapolated values and the corresponding actual sunspot numbers for the period 1965-1995 is 0.84. It will be of great help if atleast one complete minima or maxima cycle is predicted, then the present method has to be developed for longer lead-time prediction, which would warrant a separate study.

4.5. *Zonal wind over Balboa at 50-hPa, 30-hPa and 10-hPa levels*

Equatorial stratosphere between 60 hPa and 10 hPa shows a complete reversal in the direction of the zonal wind over a period of about 24-30 months. This spectacular phenomenon is known as the Quasi-Biennial Oscillation (QBO). The monthly zonal wind recorded over a equatorial station called Balboa (9°N, 80°W) at three levels 50- hPa (20 km; Jan 1951-Dec 1987), 30- hPa (24 km; Jan 1951-Dec 1987) and 10- hPa (30 km; Jan 1958-Dec 1986) is modelled and predicted by the present method. It may be noted that the QBO shows downward propagation at the rate of about 1-2 km/month (Reed, 1965), and winds at all the three levels are highly correlated with the Indian summer monsoon (Mukherjee *et al.* 1985; Bhalme *et al.*, 1987; Singh, 1995). Results of the MEP processes are given in the Table 1 for all the three series, but for 10- hPa level they are depicted also in Fig 3. Reconstructed component from the combination of 6-7 principal components shared 92-94% variance with the actual series, and 6-7 variable harmonics of the reconstructed series computed at the wavelength reso- lution of 1 month showed CC exceeding ~ 0.94 with the actual series. A reliable prediction of actual wind can be made from the extrapolated value of reconstructed smooth curve for different levels, the most reliable pre diction being for the 10 hPa level (CC=0.91).

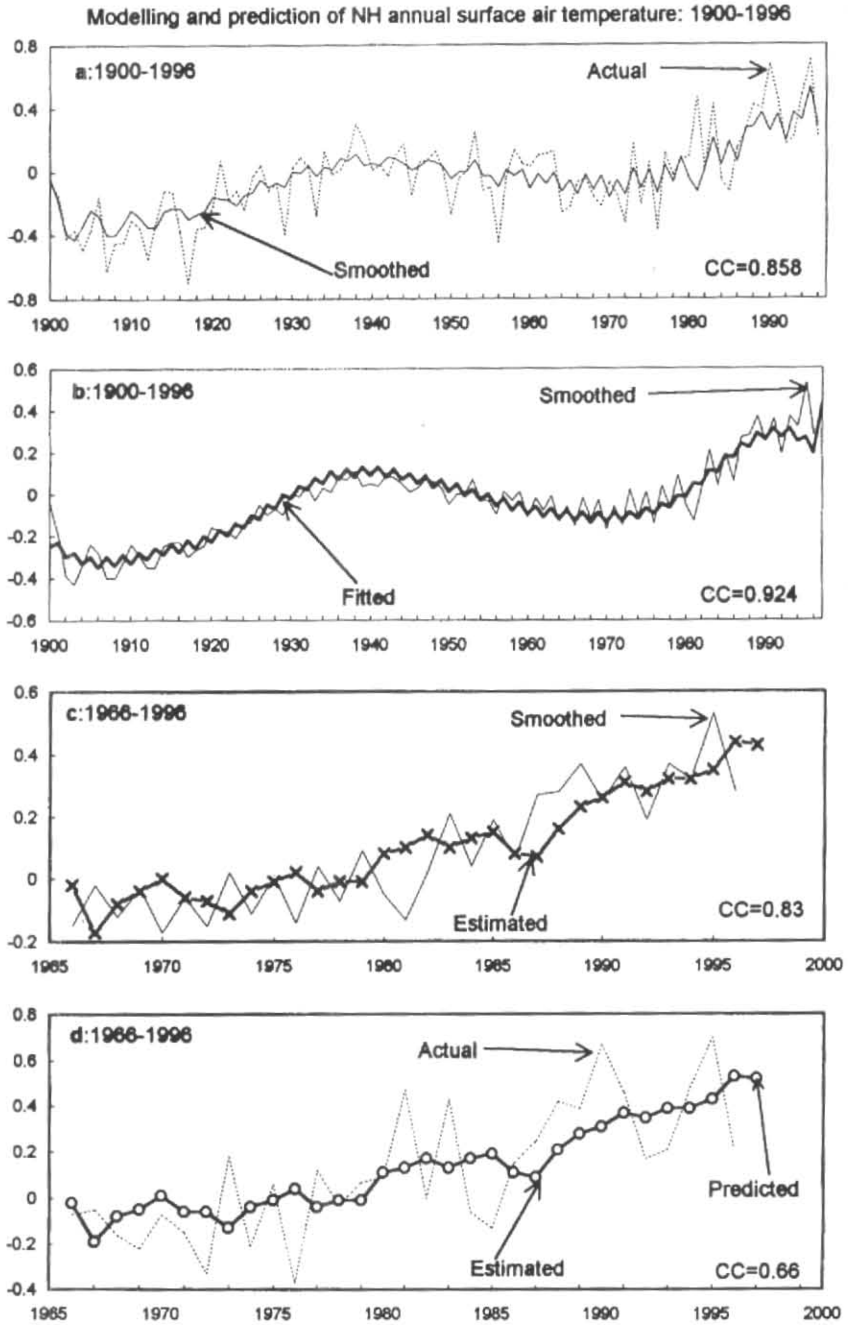


Fig. 2. Same as in Fig. 1, but for the annual surface air temperature series (1900-96) of the northern hemisphere

4.6. *Surface air temperature over the Indian region*

It is commonly believed that atmospheric thermal condition over the Indian subcontinent during winter and summer seasons plays a crucial role in the northward propagation and the rain-giving performance of the Indian summer monsoon in the following season. This led the investigators to examine the association between the surface air temperature of the Indian land areas and the summer monsoon rainfall over the region (Walker, 1914;

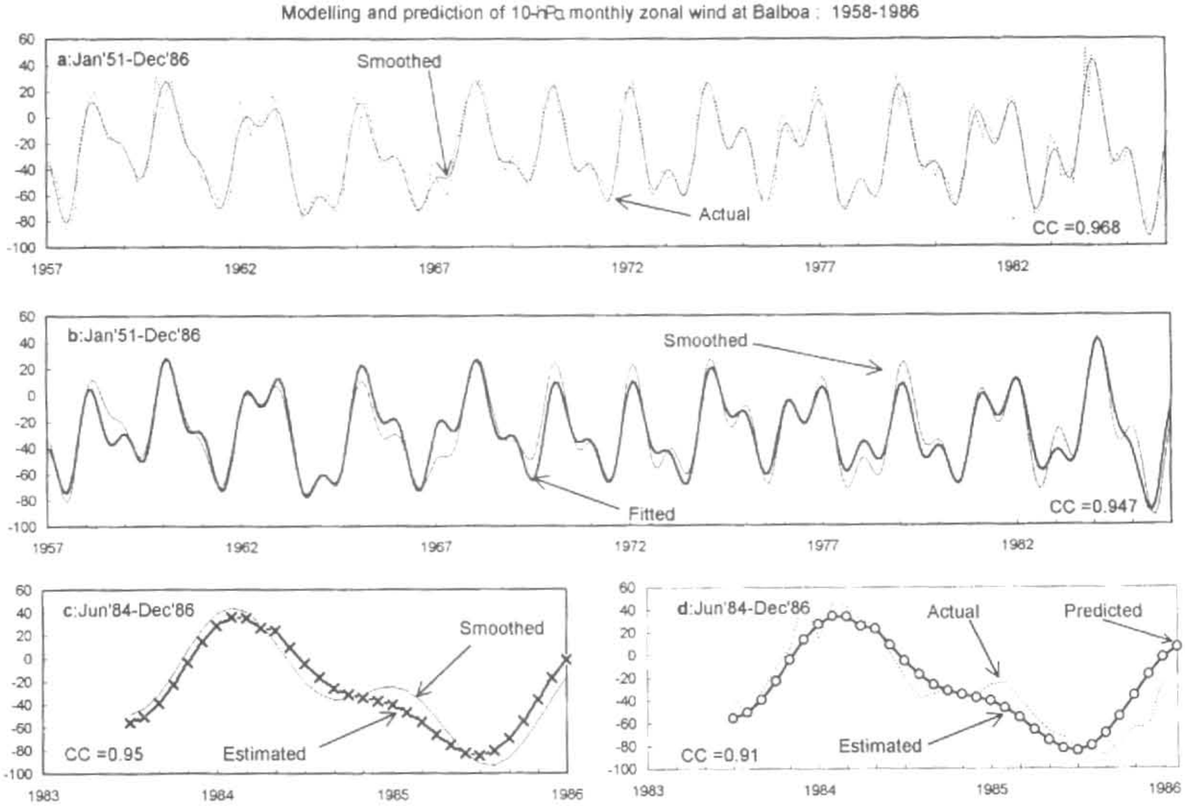


Fig. 3. Same as in Fig. 1, but for the monthly sequence of 10-hPa zonal wind at Balboa during Jan 1958 to Dec 1986

Mooley and Paolino, 1988; Parthasarathy *et al.*, 1990; Singh , 1995 and many others). Two time series with monthly mean temperature kept in sequence one from central India (mean of Nagpur and Akola) and another from east coast of India (mean of four stations Calcutta, Chennai, Visakhapatnam and Machilipatnam) are considered for the MEP processes here. Due to moderating effect of the marine environment there is limited domination of seasonality in the temperature variations along the east coast of India, whereas the effect is quite prominent over the central parts due to continentality factor. In case of central India the reconstructed series using 7 PCs shared 96.6% of its variance with the actual series (Jan 1941-Dec 1987), combination of two selected variable harmonics showed the CC of 0.98 with the reconstructed series and the independent extrapolated values of the period Jun 1985 to Dec 1987 (m=31) showed the CC of 0.97 with the corresponding actual values. It seems a quite reliable prediction of monthly temperature over central India can be made using the present approach.

For east coast of India, the reconstructed series by clubbing 9 PCs shared about 98% variance common with the actual series (Jan 1941 to Dec 1987), and jointly only two selected variable harmonics of the reconstructed series accounted for 97.6% of its total variance. The CC between the only extrapolated values of the period Jun 1985 to Dec 1987 (m=31) and the corresponding actual values is 0.978.

It may be interesting to note that two harmonics were adequate to describe the dominant modes of temperature fluctuations under Indian conditions irrespective of regional differences in the seasonality factor.

4.7. *Sea surface temperature over the tropical Pacific and Indian regions*

As the mechanism of El Niño involves exchange of water between the Indian Ocean and the Pacific Ocean (Wyrtki, 1975 & 1985) predicting rising/declining tendency of SSTs over different parts of the tropical Indo-Pacific oceans would be useful to know whether El Niño is going to develop, intensify or weaken. The SSTs are considered from different parts of the El Niño region in the study. The characteristics of monthly sequence of SST from different parts of the Indo-Pacific region are Some what different. We quote two extreme cases: for the

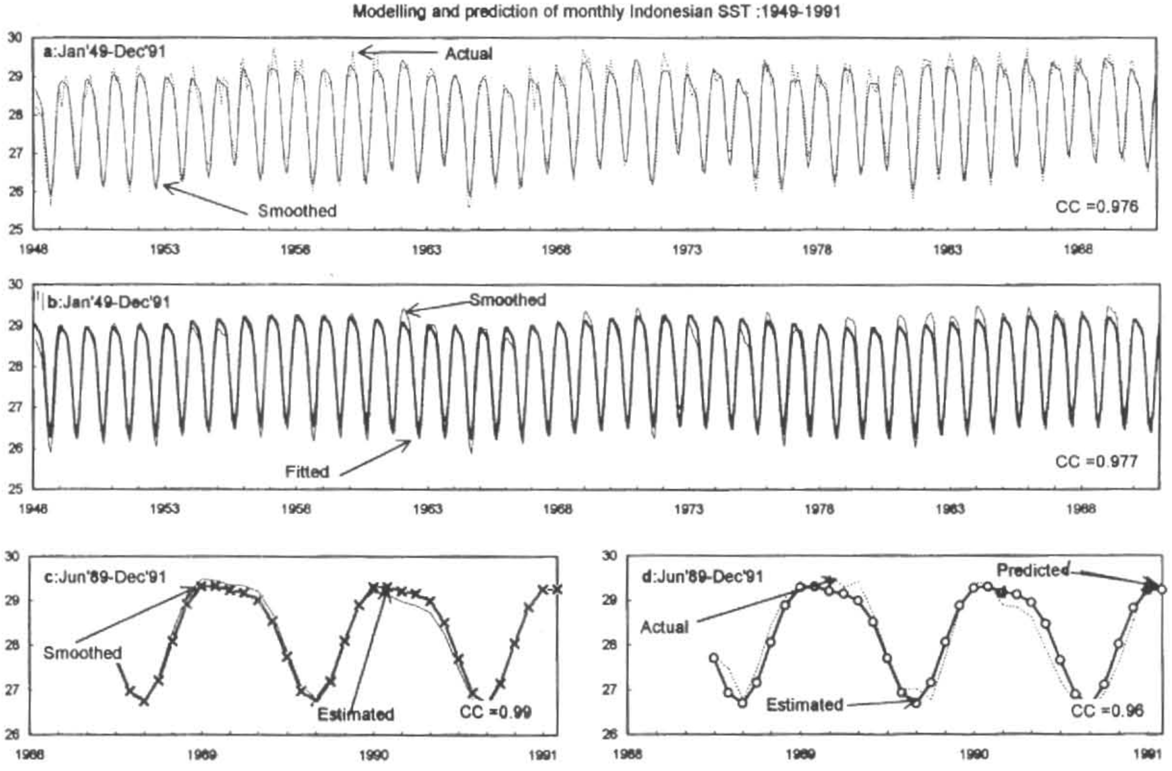


Fig. 4. Same as in Fig. 1, but for the monthly sequence of SST around the Indonesian region during Jan 1949 to Dec 1991

Indonesian region the reconstructed series from the combination of 15 principal components, explaining 95% variance of the actual sequence, was predictable, whereas for Puerto Chicama the reconstructed series using 7 PCs, explaining only 78% variance was found predictable.

Around the Indonesian region reliable prediction of monthly SST seems possible by extrapolating dominant mode of SST fluctuations of the preceding period, results are presented in Fig. 4. In case of Pureto Chicama however mere extrapolation of dominant mode of fluctuations does not seem adequate to predict SST. Strength of trade winds over tropical western Pacific may be an additional factor required to be considered to predict the Puerto Chicama SST. This will require multi-channel analysis, which is beyond the scope of the present study.

4.8. *Sea level pressure over tropical Pacific and Indian oceans*

Sea level pressure over tropical Indian and Pacific oceans is vital to understand tropical oscillations in general, and the southern oscillation and its teleconnec- tions in particular. There are numerous publications showing intimate relation between southern oscillation and the Indian summer monsoon (Parthasarathy and Pant, 1985; Shukla and Mooley; 1987; Singh 1995 are the very few). Monthly sequences of sea level pressure at Mumbai (1941-1993),Cape Town (1941-1990),Tahiti (1941-1990), Darwin (1940-1990) and over west central India (1941-1990) and South America (1941-1990) are modelled and extrapolated to make one-step-ahead prediction. The results are given in Table 1 for the different sequences. They are presented also in Fig. 5 for Mumbai. It may be noted that sea level pressure in the tropical region shows strong annual cycle. From these excellent results it can be said that monthly sea level pressure can be predicted with great accuracy. Experiences suggest that pressure, temperature or any other parameter with strong domination of seasonality can be directly (without smoothing) modelled and predicted with excellent results.

5. Discussion

The present method of time series modelling and extrapolation is an extension of extrapography, a method earlier developed by Singh (1999) for predicting seasonal/sub-seasonal rainfall across India. The classical harmonic analysis and the determination of a scaling factor are the two main components of the method

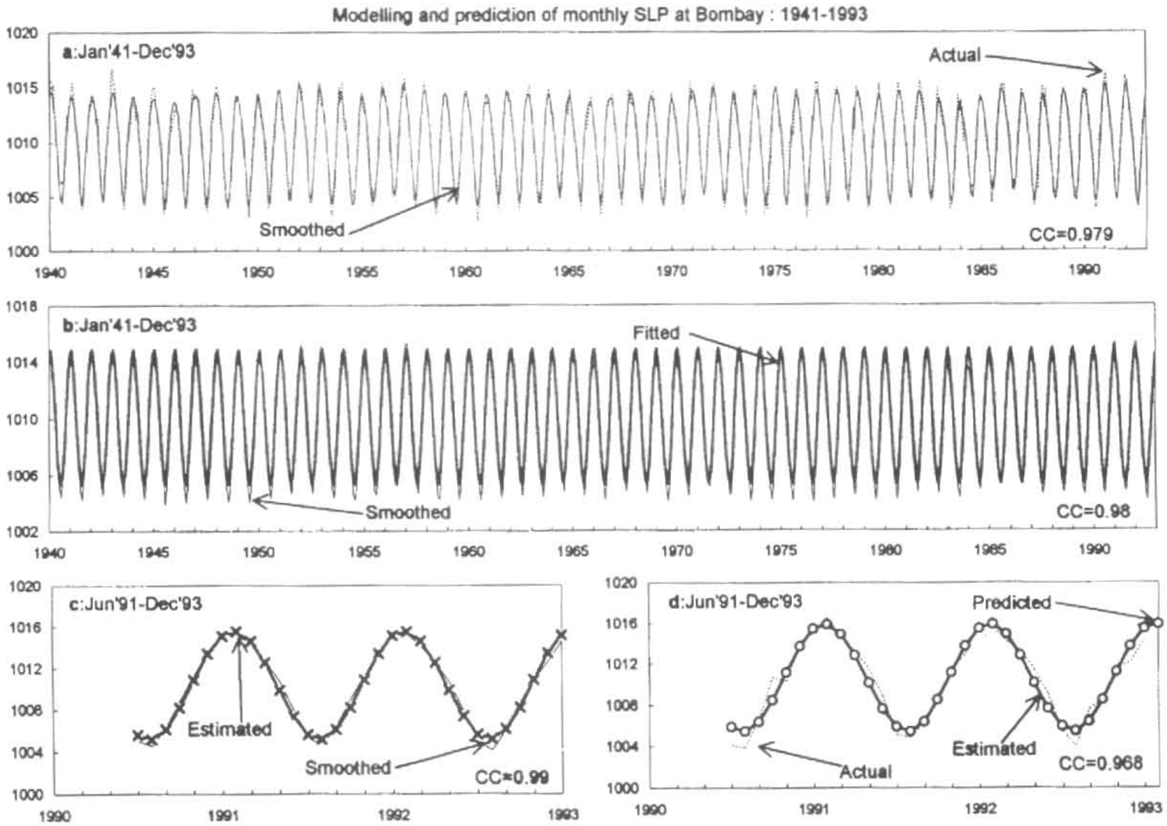


Fig. 5. Same as in Figure 1, but for the monthly sequence of SLP at Mumbai during Jan 1941 to Dec 1993

extrapography. Prior smoothing of time series under consideration is a new feature added to extrapography. Classical harmonic analysis has been replaced by a variable harmonic analysis, and an objective technique is used to select the optimum number of variable harmonics that would be adequate to reproduce the dominant modes of fluctuations of the series.

Smoothing suppresses the high frequency noise and trims out the few anomalous high/low values according to the dominant modes of fluctuations. Generally satisfactory to excellent results were obtained from the smoothed series. But the smoothing operation can be escaped if excellent results are obtained from the actual series directly. In classical harmonic analysis wavelength is always an integer multiple of the fundamental period, there is no such adherence in the variable harmonic analysis and harmonics can be computed for any desired wavelength within the data length. The method catches the genuine periodicity in the data sequence and the results reported here may provide quite useful information for detailed climatic investigations. Further, the harmonics are selected whose linear combination based on their linear combination showed the highest correlation with the smoothed/actual series. Multiple linear regression approach of Schickedanz and Bowen (1977) has also been tried in the study. Though results were better sometimes, it added lot of unpleasentness in understanding the effects of more than two harmonics.

Although numerous exercises were carried out by changing lags for the T_x matrix, the number of PCs for reconstructing the smoothed series, the optimum number of selected variable harmonics and the highest CC achieved between extrapolated values and smoothed/ actual values to arrive at the results reported here, it seems there still exists some scope to improve upon them. It is realized during the course of study that length and period of data are also important in getting better results. We have to choose the data of the most recent period such that best possible results are obtained.

This is particularly important where seasonality is not a dominant component of temporal variations, such as QBO, NH seasonal and annual temperature series and annual mean sunspot numbers.

6. Conclusion and remarks

The study has demonstrated that magnitude of terrestrial and extraterrestrial parameters of any particular period is not only dependent on its own value of the preceding periods but on other periods as well over a long period of time. Having achieved considerable success in our attempt to make reliable one-step-ahead prediction we were encouraged to try for longer lead-time prediction. Few selected cases were tried for two-step-ahead prediction but straight extension of the one-step-ahead prediction did not produce appreciable results in all the different cases. Some of the problems, which we have identified, are:

(*i*) how to deal with the one-step-ahead term that is whether to substitute the predicted value or fill it with long term mean or any other appropriate value while analyzing the time series for the two-step-ahead prediction;

(*ii*) how many principal components to combine in the reconstructed component, whether to continue with same reconstruction for the two-step-ahead prediction as for the one-step-ahead or to combine lesser number of components;

(*iii*) whether to extend the same harmonics for the two-step-ahead prediction also which are selected for one-step-ahead prediction or to go for the new selection, *etc.*

In nutshell considerable efforts will be required to modify the present method for longer lead-time predictions. We believe that the present method can prove to be a valuable contribution to the development of new tools for the time series modelling intended for extrapolation and prediction.

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