Changes in nutrients of BB due to massive influx of organic and inorganic matter from coastal mainland.

Deviations, if any, in unique hydrographic and oceanographic features of the disturbed zones.

Species loss, changes in habitat heterogeneity and biotic interactions at inter-tidal zones of BB and AN and species recovery rates and sequences of coral reef communities in AN.

Considerable pre-tsunami data are available for the above-mentioned aspects of BB and AN in Quasim and Kureishy (see also references therein)\textsuperscript{14}. These are broad and prominent impacts. Subtle disturbances also need scientific attention; for instance, changes in food webs and biotic interactions like prey–predator relationships.

Tsunami-disturbed marine communities also offer good opportunities for experimentally testing available theories on disturbance. For instance, Connell\textsuperscript{2} hypothesized that in disturbanceless community, superior species will eliminate inferior species, thus reducing species richness; if disturbance is too large, the superior species will be eliminated and inferior species will colonize the system. Tsunami-disturbed coral reef and intertidal communities of AN are ideal systems for testing such hypotheses by long-term researches, which would yield valuable data on colonizing species that exploit the niches at disturbed habitats. Data on species diversity and community organization of coral reefs of AN are also available for comparative analysis\textsuperscript{14}.

Post-disturbance recovery of species with long lifecycle in disturbed habitats is another area of long-term research. This is because according to Huston\textsuperscript{5}, severe disturbance would eliminate such species from the community. Their recovery will also require relatively longer duration. Similarly, small-scale experiments may focus on single questions, while large-scale researches may test multiple hypotheses in an integrated fashion. Such researches are indispensable because both AN and BB constitute a significant part of the ‘exclusive economic zone’ of India. AN is one of the potential marine biophere reserves in India. Moreover, the possibility of occurrence of such events in future in this region cannot be ruled out\textsuperscript{10}. Thus systematic researches may reveal many facts regarding the impact of a high intensity disturbance, tsunami on marine communities. In brief, tsunami-disturbed Indian Ocean needs systematic researches on structural and functional components of marine communities in the light of established concept of disturbance in marine community ecology.


ACKNOWLEDGEMENTS. I thank the anonymous reviewer for comments and helpful suggestions. I also thank Dr S. Chandrasekar, Madurai for encouragement and help.

Received 5 September 2005; revised accepted 14 December 2005

N. KRISHNANKUTTY

1/2, E2 Road,
Chinnachokkikulam,
Madurai 625 002, India

Long-range monsoon rainfall prediction of 2005 for the districts and sub-division Kerala with artificial neural network

Weather forecasting (especially rainfall) is one of the most important and challenging operational tasks carried out by meteorological services all over the world. Weather prediction is a complicated procedure that includes multiple specialized fields of expertise. Lorenz\textsuperscript{3} separated weather forecasting methodologies into two main branches in terms of numerical modelling and scientific processing (AI) of meteorological data. The most widespread techniques used for rainfall forecasting are the numerical and statistical methods. Even though researches within these fields have been conducted for a long time, successes of these models are rarely visible.

The dynamical models are based on the system of nonlinear operator equations governing the atmospheric system. The physics and dynamics of the atmosphere can be better understood by none other than these set of governing equations. But in the absence of any analogue solution of this system of operator equations, numerical solutions based on approximations and assumptions are the only alternative. Furthermore, the chaotic behaviours of these nonlinear equations sensitive to initial conditions, make it more difficult to solve these equations. As a result, there is limited success in forecasting the weather parameters using the numerical model. The accuracy of the models is dependent upon the initial conditions that are inherently incomplete. These systems are not able to produce satisfactory results in local and short-term cases. The performances, however, are poorer for long-range predic-
Figure 1. Performance of neural network deterministic models during the independent period (1992–2004).

tion of monsoon rainfall even for the larger spatial scale and particularly, for the Indian region.

As an alternative, statistical methods in which rainfall time series are treated as stochastic, are widely used for long-range prediction of rainfall. The India Meteorological Department has been using statistical models for predicting monsoon
rainfall. Statistical models were successful in those years of normal monsoon rainfall and failed remarkably during the extreme monsoon years like 2002 and 2004. However, it is very difficult to get the same or better skill in predicting district rainfall as that of all-India monsoon rainfall using these statistical models. Two main drawbacks of these statistical models are:

(i) Statistical models are not useful to study the highly nonlinear relationships between rainfall and its predictors, even if one can consider models like power regression.

(ii) There is no ultimate end in finding the best predictors. It will never be possible to get different sets of regional and global predictors to explain the variability of the two neighbouring regions having distinguished rainfall features. For example, in two smaller nearby districts, viz. Kottayam (mean monsoon rainfall 199.0 cm) and Idukki (mean monsoon rainfall 269.6 cm), of Kerala having contrasting rainfall characteristics, large-scale regional or global predictors have limited role.

The neural network technique is able to get rid of the above two drawbacks. Since 1986, the neural network technique has drawn considerable attention from research workers, as it can handle the complex and nonlinear problems better than the conventional statistical techniques. It has been successfully applied to a variety of problems. It has a strong potential for pattern recognition and signal processing problems and also has the ability to predict future values of the time series from itself. Elsner and Tsonis have shown that the neural network can be successfully used to predict the cha-


Table 1. Root mean square error for models during training period (1952–91) and independent period (1992–2004) and the standard deviation of monsoon rainfall for the 14 districts. Forecast rainfall for the year 2005 is also given.

<table>
<thead>
<tr>
<th>District</th>
<th>SD (% of mean)</th>
<th>RMSE (% of mean)</th>
<th>Forecast for SW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Training period</td>
<td>Independent period</td>
</tr>
<tr>
<td>Alapuzha</td>
<td>19.0</td>
<td>5.4</td>
<td>10.3</td>
</tr>
<tr>
<td>Cannur</td>
<td>19.1</td>
<td>8.8</td>
<td>17.0</td>
</tr>
<tr>
<td>Ernakulam</td>
<td>19.5</td>
<td>5.8</td>
<td>8.1</td>
</tr>
<tr>
<td>Kottayam</td>
<td>20.2</td>
<td>6.9</td>
<td>9.5</td>
</tr>
<tr>
<td>Kozhikode</td>
<td>20.5</td>
<td>9.7</td>
<td>12.6</td>
</tr>
<tr>
<td>Malappur</td>
<td>20.5</td>
<td>6.6</td>
<td>10.2</td>
</tr>
<tr>
<td>Palakkad</td>
<td>22.6</td>
<td>8.4</td>
<td>8.5</td>
</tr>
<tr>
<td>Kollam</td>
<td>23.1</td>
<td>5.9</td>
<td>5.7</td>
</tr>
<tr>
<td>Thrissur</td>
<td>19.6</td>
<td>5.1</td>
<td>15.1</td>
</tr>
<tr>
<td>Thiruvananthapuram</td>
<td>30.2</td>
<td>6.7</td>
<td>13.4</td>
</tr>
<tr>
<td>Idukki</td>
<td>24.5</td>
<td>17.7</td>
<td>12.6</td>
</tr>
<tr>
<td>Kasaragode</td>
<td>16.4</td>
<td>6.6</td>
<td>9.2</td>
</tr>
<tr>
<td>Pathanamthitta</td>
<td>20.8</td>
<td>6.3</td>
<td>8.1</td>
</tr>
<tr>
<td>Wynad</td>
<td>21.9</td>
<td>6.8</td>
<td>5.0</td>
</tr>
</tbody>
</table>

otic series. The internal dynamics of the time series can be better classified by neural network technique.

Neural network technique is useful both for stochastic and deterministic forecast processes. In deterministic forecast process, rainfall time series is treated as deterministic and even chaotic. It uses rainfall data of the past years to forecast future rainfall. Attempts to predict all-India southwest monsoon rainfall using deterministic forecast were already made by many scientists. In spite of obtaining some accuracy in prediction during the test period, the success was not so appreciable in the real operational forecasting.

In the present study we have constructed homogeneous time series for shorter sub-regions (districts) of Kerala. The popular feed-forward neural network with back-propagation learning algorithm is used. An attempt has been made to predict the monsoon rainfall for the districts of Kerala. Finally, prediction for the subdivision (Kerala) as a whole, based on the area weighted districts forecast has been done. This is compared with the forecast made using the subdivisional rainfall time series.

We have selected 36 rain gauge stations having maximum data availability. Missing years of data (less than 10%) are replaced by neighbouring (within 2 km) rain gauge station data. Even after this replacement, monthly rainfall values for few stations and for few years were missing and these were replaced by their monthly mean values. Each of the 14 districts of the state has two or more representative stations. The station averages are calculated only up to the district level. Thus the rainfall data series so constructed are homogeneous spatially as well as temporally. Rainfall over the state was calculated as the area weighted rainfall for the district rainfall.

We have used a three-layer neural network with one input layer, one hidden layer and one output layer to develop the model. The transfer function used here is the sigmoidal function and the most popular 'back propagation learning algorithm' is used to train the network. Three neurons are used in the hidden layer. Details of neural network technique are available in the literature and are not presented here. Training of the networks is continued till the mean square error becomes less than a pre-assigned value ranging from 0.0005 to 0.001.

The neural network technique has been used to reconstruct the assumed deterministic dynamics of the time series data earlier for the all-India monsoon rainfall prediction. In the present study data for 1941–2004 have been used, of which the first 51 years (1941–1991) of data are used for training the network and data for the period 1992–2004 are used independently. Fourteen separate neural network models were developed to forecast the southwest monsoon rainfall for all the fourteen districts of Kerala. We have used the past five years of data to predict the sixth year rainfall. It has been found that the past eleven years are most useful to predict the immediate monsoon rainfall of the next year for most of the fourteen districts. Therefore, we have selected immediate past eleven years of data to predict the 12th year southwest monsoon rainfall. Since the past eleven years of data are used and the training period was taken as 51 years, we have 40 patterns. Total number of free parameters to be evaluated is therefore 40, including biases (3 x 12 + 4 = 40). Also, we have constructed a separate neural network model using the subdivision rainfall series data of Kerala.

Fourteen separate deterministic neural network models were developed for each of the fourteen districts of Kerala viz. Alapuzha, Cannur, Ernakulam, Kottayam, Kozhikode, Malappuram, Palakkad, Kollam, Thrissur, Thiruvananthapuram, Idukki, Kasaragode, Pathanamthitta and Wynad. The root mean square errors (RMSE) for all the models during the training period (1952–1991) and the independent period (1992–2004) are given in Table 1. The RMSE values for the independent period (1992–2004) are less than the standard deviation for all the districts. It is even less than one-third of the standard deviation values for Kollam and Wynad, less than half of the standard deviation for Ernakulam, Kottayam, Malappuram, Thiruvananthapuram, Palakkad and Pathanamthitta. This clearly indicates the skill of the models.

Performance of all these models (Figure 1) is exceptionally good for all the years up to 2003. However, performance is not good for the year 2004 for some of the districts. One of the reasons for the large differences between forecast and actual values for 2004 is non availability of rainfall data of all these 36 stations. We have taken actual rainfall values for
<table>
<thead>
<tr>
<th>Model</th>
<th>Training period rmse (in mm)</th>
<th>Independent period rmse (in mm)</th>
<th>Correlation coefficient with actual during independent period</th>
<th>Forecast for SW monsoon 2005 (Actual in mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dist. area wt.</td>
<td>102.24 (4.78)</td>
<td>133.95 (6.26)</td>
<td>0.95</td>
<td>2160.35 (100.90)</td>
</tr>
<tr>
<td>Subdivision</td>
<td>167.32 (7.82)</td>
<td>284.53 (13.29)</td>
<td>0.48</td>
<td>2485.4 (116.09)</td>
</tr>
</tbody>
</table>

For prediction in a deterministic way, neural network technique is the most efficient way, where the time series itself is used for prediction. Performance of the regression technique in deterministic forecast is poor. We have examined the most widely used multiple regression technique to see the superiority of the nonlinear neural network model over linear multiple regression model in deterministic forecast. Results are presented only for the case of Wyanad district. In multiple regression also, we have taken similar number of input parameters, i.e., previous 11 years monsoon rainfall to predict the 12th year value. The development period is also considered to be same, i.e., 1952–91. Figure 5 is a comparison of the multiple regression model with the neural network model. Clearly, the performance of neural network model is far superior than the multiple regression model. Similar results are also obtained for all districts.

In this study, we have found that the deterministic neural network models perform well for smaller spatial scale, i.e., district monsoon rainfall forecast. Moreover, forecasts have a longer lead time as they can be made a year in advance. No other model (except the deterministic neural network model) so far has been able to forecast district and sub-district long-range monsoon forecast so accurately. We have also found that contrary to downscaling, up-scaling is the best way for long-range prediction, as we have seen that performance of the model for district forecasts is better than the sub-district deterministic forecast.


Received 25 April 2005; revised accepted 7 December 2005

P. GUHATHAKURTA

India Meteorological Department,
Shivajinagar,
Pune 411 005, India
e-mail: pguhathakurta@rediffmail.com