Numerical Modeling and Verification of Seasonal Hindcast of Eastern Belt of Pakistan using Multi Model Ensemble Prediction System

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Numerical Modeling and Verification of seasonal hindcast of Eastern Belt of Pakistan using Multi Model Ensemble Prediction System

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The thesis entitled "Numerical Modelling and Verification of Seasonal Hindcast of Eastern Belt of Pakistan using Multi Model Ensemble Prediction System" submitted by Ms Sumera Gull Bhatti in partial fulfillment of Master of Philosphy of Science in Environmental Science has been completed under my guidance and supervision. I am satisfied with the quality of student's research work and allow her to submit this thesis, for further processes as per IIU rules and regulations.

Maria 27/9/12

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A thesis submitted to Department of Environmental Sciences, International Islamic University, Islamabad as a partial fulfillment of requirement for the award of the degree of Masters of Philosophy of Environmental Sciences

DEDICATION

I humbly thank *Allah Almighty*, the Merciful and the Beneficent, who gave me health, thoughts and co-operative people to enable me achieve this goal

I wish to dedicate this work to Holy Prophet Muhammad (Peace be upon him) and his companions who laid the foundations of Modern civilization and paved the way for social, moral, political, economical, cultural and physical revolution

&

I dedicate this work to

My loving mother
SURRIYA KOUSER

Who always wishes
to see me
Glittering high
on skies of Success
Like Galaxies

May ALLAH bless her! (Ameen)

DECLARATION

I hereby declare that the work present in the following thesis is my own effort, except where otherwise acknowledged and that the thesis is my own composition. No part of the thesis has been previously presented for any other degree.

Date 26-9-12.

27-9-12.
Sumera Gull Bhatti

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LIST OF ABBREVIATIONS

Acronym	Abbreviations
BS	Brier Score
BSS	Brier Skill Score
ECMWF	European Centre for Medium Range Weather Forecast
EPS	Ensemble Prediction System
ERA-40	European Centre for Medium Range Weather Forecast Re-Analysis -40
GCMs	Global Climate Models
Mm	Millimeter
MPI	Max Plank's Institute
NCEP	National Centers for Environmental Protection
PMD	Pakistan Meteorological Department
ROC	Relative Operating Characteristic
SPSS	Statistical Package for Social Sciences
UKMO	United Kingdom Meteorological Office
EMB	Eastern Monsoon Belt

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ABSTRACT

The performance of Global circulation models is inspected by using the probabilistic forecast. The ensemble technique offers significant information on uncertainty of each forecast. The probabilistic score (Brier Skill Score) was applied to calculate two main aspects i.e. reliability and resolution of forecast to check performance of predictive models. The skill of an EPS was assessed by comparing performances of probabilistic forecast and reference probabilistic forecast. The real time observations of Pakistan Meteorological Department (PMD) was taken as reference forecast while probabilistic forecast was the amount of rainfall in mm of selected areas using all initial conditions. Era-40 was also used as reference forecast for being so close to real time observation. A single model as well as Multi Model Ensemble Prediction System (MM-EPS) for seasonal forecast of rainfall was applied and tested at selected sites and areas. Multi-model ensemble strategy was a way to utilize the diversity of skillful predictions from different models. Forecasts with the MM-EPS system was executed and evaluated at selected areas for a period of 32 years from 1969 to 2000. Four models were selected for comparison. Relative Operative Characteristics (ROC) diagrams were pinpointing the effectiveness of the forecasting system. The results of the study indicated that for single model MPI had good skill and accuracy than all other selected models while for multi model all combinations showed good result as compared to single model but Multi Model III that was the combination of Meteo-France and MPI showed accurate and skill forecast including all initial conditions and alternatively eliminated initial conditions. Cross validation was applied to estimate the potential of the method to improve the accuracy of seasonal rainfall. In this study different models were used for seasonal forecasting. Decrease in cross-validation error could be allowed by eliminating the outlier values from the data set. Cross validation observations from single model were used to prioritize the single models for multi model scheme. Recommendations for the future of seasonal predictions and climate services were given.

CHAPTER 1

INTRODUCTION

INTRODUCTION

Pakistan is much diversified in spatial and seasonal variation of the climatic conditions (Hussain *et al.,* 2010). Pakistan lies between 23° and 37° North latitude and 61° and 76° East longitude. Latitudinal extent of the country is wide-ranging and stretches from the Arabian Sea in the southward side to the Himalayan Mountains in northward side. The country lies in sub tropical regions and partially in temperate regions. This is the land of 180 million people and major part of it is susceptible to climate change. Most of the population is facing destructive consequences of sea level rise and flooding due to rise in global temperature creating climatic shifts (Farooq *et al.*, 2005). The overall country has three physiographical regions; mountain ranges in the north and northwest 241,647 km^2 (Framji *et al.*, 1969). These mountain ranges act as roof tanks providing continuous supply of water to reservoirs. In the past century (1900-2000), the amount of precipitation has increased about 20% in northern Pakistan, 10% in central part and 40% in the southeast (IPCC, 2002). In the south-west, 242,683 km^2 area is covered by Plateau of Balochistan and the third region is plains of Indus River which covers the area of 311,766 km^2 (Framji *et al.*, 1969).

According to Pakistan's agro climatic classification, the semi arid and arid regions cover two- third of Pakistan (Chaudhry and Rasul, 2004). Consequently, mass portion of people are dependent on arid and semi arid regions for their survival through agro-pastoral activities. In Pakistan, agriculture is dependent on rainfall as well as on the irrigation system. This irrigation water comes from melting of snow in northern areas.

Climate variations and changes associated impacts and vulnerabilities are raising distresses globally. Unpredictability and climatic conditions of Pakistan is changing every year, giving rise to destructive hazards like floods, drought, cyclones and other which are being more devastating due to climate change then ever before (Huq *et al.*, 1999). Uncertainty of rainfall and irregular temporal and spatial distribution at one side causing flooding and on the other hand prolong dry spells evoking drought conditions (Lai *et al.*, 1998). Though in various parts of Asia and Africa the occurrence and severity of drought is greater than before in current decades, great number of verification shows that precipitation has also parade long term uncertain changes in various regions of the World (Wang *et al.*, 2001).

Dynamic component of the most up to date climatic system is the Asian monsoon system extending from the western Arabian Sea all the way stretching from East Asia and North Australia. These regions and localities are convectively attached and fluctuations in this convectively active region can consequently cause severe draught or flood over huge, heavily populated regions (Webster *et al.*, 1998). Two subsystems are present in the Asian monsoon one is the Indian (or South Asian) monsoon and second is the East Asian monsoon. The East Asian monsoon system has land area in the northward and in the southward direction, a maritime continental area in the west, and in the east Open Ocean is present.

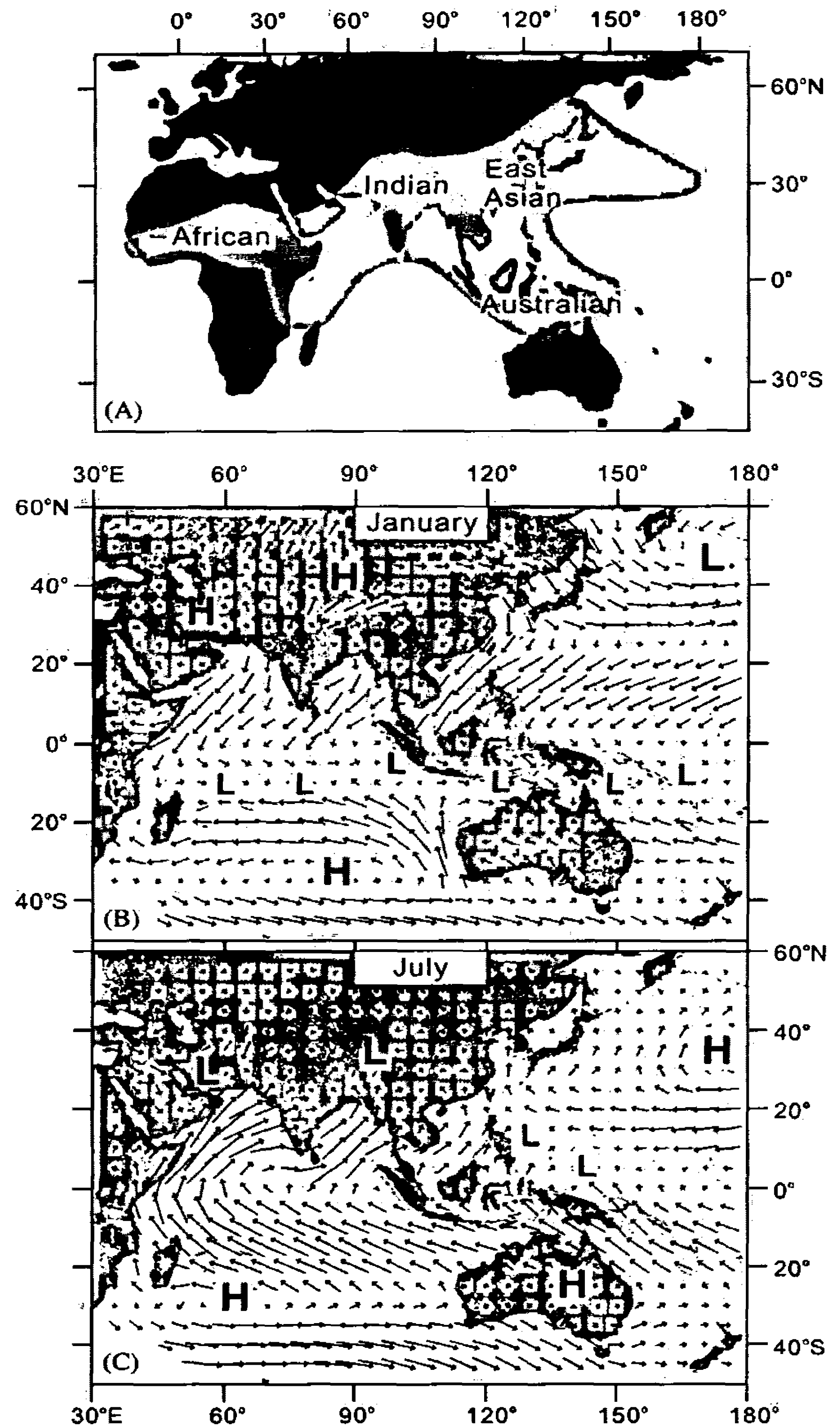

Fig. 1.1 Modern Asian monsoon system: (A) distribution of modern monsoonal regions in Asia, Africa and Australia (modified from Black, 2002); (B) pressure and surface wind pattern in winter and (C) in summer (redrawn from P. Wang et al., 2000). Wang, P., Prell, W., Blum, P., et al., 2000. Proceedings of Ocean Drilling Program. Initial Reports 184, College Station, TX

Related intensity of winter and summer monsoon and sensitivity to internal reaction mechanisms is because of geographic boundaries and associated conditions (Wang *et al.*, 2003). East Asian summer monsoon has the same phase response as the Indian summer monsoon (Morley and Heusser, 1997). The East Asian summer monsoon (EASM) domain determined by Wang and Lin (2002) covers the region of 20-45°N and 110-140°E. Monsoon seasons start in Pakistan with the commencement of July and towards ending of September this condition prevails.

According to the recorded data of 2006, the rainfall was in large excess in Rawalpindi, Jhelum, Badin, Nawabshah. In Lahore the rainfall was in slight excess with slight deficit in the same period. In Bahawalnagar, precipitation was in great deficiency. Jhelum is district of headquarters in Potohar region. Huge fluctuation exists in annual rain for Jhelum zone for the period 1992 -2008. For the period of years 1996, 1997, 1998 and 2006 positive anomalies were experienced. At the same time negative anomalies existed in the years 1999 and 2002. In the year 1997 the maximum amount of rain fall was recorded in 1997 which is a little more than 1300 mm. Fourth largest city of Pakistan is Rawalpindi, which represents rain fed zone of Potohar plateau. Annual rain for Rawalpindi zone has shown greater variability. Till now, the wettest year was 1994 and 2000 was recorded as the driest year. The variability in rainfall pattern has been recorded on the long and short term basis (Rashid *et al*, 2011).

Monsoon precipitation in Pakistan falls in summer from July to September and is the great support for country's water resources. This precipitation caters the great power supply demands as well as meet the peak water demands for field crops and reserves the requirements of less flow duration in coming 4 to 5 months. Being an agro-based financial system, weak monsoon or misconduct of existing water reserves can cause extremely sensitive shock wave. According to Economic Survey, 2007-08; like many developing countries Pakistan is facing challenges of land degradation and desertification. This severe haphazard is causing environmental problems including soil erosion, loss of soil fertility, flash floods, salinity, and deforestation and associated loss of biodiversity and carbon sequestration (Gazala and Rasul, 2011).

Throughout the summer monsoon period (July to September) in the Arabian Sea and Bay of Bengal systems and depressions are formed producing rainfall over low elevation plains of Pakistan. During the month of August peak rainfall occurs. Overall 60% rainfall is received during the summer season from June to September over vast area of Pakistan. Kharif crops especially during monsoon season are largely dependent upon the quantity and distribution of rainfall (Chaudhry, 1992).

Both winter and summer rainfall is received in sufficient amount. Due to western disturbances, the heaviest amount of rainfall is recorded in the months of February and April. March is the month with peak winter rainfall, while August is the month having greatest summer rainfall. Overall over the South and South East Asia the monsoon is the phenomenon with great advantages and impressions (Sarfaraz, 2007). In Pakistan, the off shores of mid latitude frontal systems which are western disturbances are the reasons of winter precipitation. These instabilities move towards the north easterly directions and carry moisture from Persian Gulf as well as from Arabian Sea. This increases winter rainfall over various parts of Pakistan. In rain fed localities, the rainfall is very significant for Rabi crop. The native regions of the capital city, Islamabad stretch out between latitude 32°–35° and longitude 68°–72° and have intense precipitation round the year.

The Himalaya Range in the north of the country receives annual rainfall between 760 mm and 1270 mm (ISDR, 2005) and in the Indus River System it contributes near about 72% of the mean annual flow (WWF, 2010). National Meteorological Network is the source for these rainfall data. In our country the allotment of stations is uneven. Station located in developed areas and meteorologically vital locations generally meet the terms with World Meteorological Organization (WMO) standards. Lowest amount of rainfall received in Southern Punjab, Baluchistan, and northern Sindh. As we move towards coastal areas amount of rainfall increases.

Many areas of NWFP, Kashmir, and Baluchistan and some parts in Punjab tolerate flash floods. These flash flooding is quite dangerous, e.g., in 2001 flash flooding in the Potohar Plateau region including cities Islamabad, Rawalpindi and KPK areas caused death of more than 230 people (IRFC, 2002). According to the report of Federal Flood Commission during the 2010 flash flooding 60% causalities were recorded in KPK.

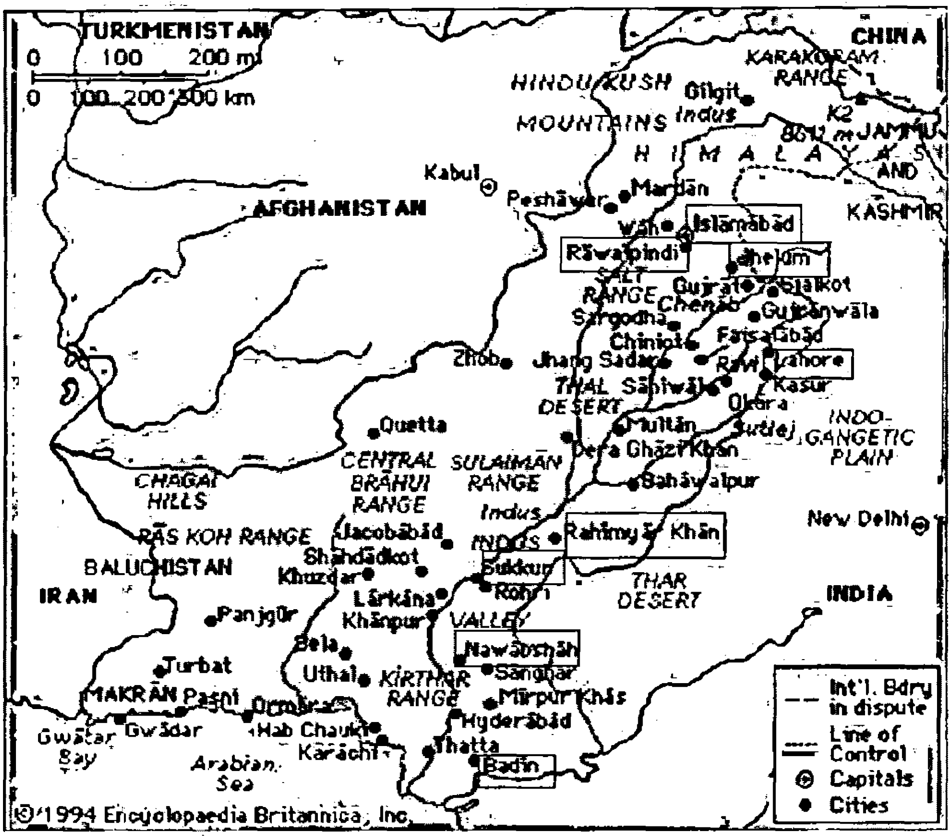

Figure1.2: Selected areas of Eastern Monsoon Belt

Multiple stressors such as droughts, plant diseases, policy changes and market fluctuations are faced by the nations of developing countries (Misselhorn *et al.*, 2005). Droughts and climate variability are one of the significant stressors in East Africa (Misselhorn, 2005). Radically, lot of rainfall variations is present in Pakistan. In the whole country, heavy rainfall is a characteristic feature of the 3 month period from July to September. Due to flood vulnerabilities, Pakistan stands on the 9th number globally having damages of thousands of people each year (Maryam *et al.*, 2012). Atmosphere is basically a non-linear and multifaceted system and because of its complexity it is impossible to predict about its exact state (Lorenz, 1969).

The numerical representation of the physical processes, resolution of emulated atmospheric dynamics and the sensitivity of the solution to the pattern of initial conditions and sub-grid parameterization makes the weather forecasts limited (Buizza *et al.*, 1999). For the implementation of ensemble methods of daily weather predictions, United States used the National Centers for Environmental Prediction (NCEP) and the European Center for Medium-Range Weather Forecasting (ECMWF) was adopted by United Kingdom in December 1992 (Kalnay, 2003). For the derivation of long array atmospheric dispersion models, the European Centre for Medium-range Weather Forecasts (ECMWF) ensemble prediction system (EPS) has been used. This method consists of 51 individual forecast members: one is taken as a control run and rest 50 perturbed realizations. For these basic initial conditions and stochastic physics perturbations are applied. Singular vectors method is used for the perturbation procedure and the assortment of the growing modes (Buizza and Palmer, 1995; Molteni *et al.*, 1996; Molteni and Buizza, 1999). To control and minimize the uncertainties ensemble forecasting Techniques like EPS are used for last 15 years. This has resulted in spatial and temporal multiple weather predictions (Palmer and Buizza, 2007). Structural and parametric uncertainty is resolved by ECMWF and other models, but they use indirect means. For case in point, unexpected rise in uncertainties in the analysis is adjusted by alternative sets of basic initial conditions to reflect perturbation (Buizza *et al.*, 2005). A multi decadal hindcast extending from 1948 to 2007 has been carried out. The time for the model was 6 hour the conditions like air temperature, humidity, cloud cover, precipitation, and sea level pressure and near surface wind speed and direction were carried out using NCEP/NCAR global atmospheric reanalysis (Kalnay *et al.*, 1996; Kistler *et al.*, 2001). At ECMWF for simulations, structural and parametric uncertainties were addressed by direct method of stochastic physics. Perturbing physical tendencies are involved at each step (Wendy, 2010). These features make the EPS forecasts a striking product for flood forecasting systems. Through this the potential to extend lead time and better quantify predictability can be achieved.

Earth's atmosphere is taken as the target for simulation models that are used to forecast the weather conditions like the instantaneous rate of change of temperature, pressure, wind, and humidity at any specified position in the atmosphere. In atmosphere there are various physical processes for example emission and absorption of radiations, clouds and precipitation formation, addition and removal of energy and moisture content in particular vicinity. Since analytical solution of these equations are almost impossible. By integration of climate models for extensive simulated time period or by carrying out various short term simulations, a procedure that is called "ensemble". This method is used globally by practitioners due to its convenience and provides long term climate statistics. Sophisticated simulations can be used to address long time scale variability.

A climate model is efficiently a ''weather simulator'' whose data and information are studied and analyzed to establish the simulated climate. It is based on computerized programming producing meteorological information for future predictions for particular location and altitudes provided to the system. A set of equations are used within any modern model. These set of equations are called primitive equation that are used to predict about the atmospheric conditions in future.

Extensions of natural science and models of macro-economic gave origin to early integrated models by adding various dynamic descriptions of forceful factors and impacts. After further advancement intrinsically integrated problem analyses were used for formation of new integrated models. Local factors causing global warming and associated effects of climate change within the range of regional climatic systems and the original features of rivers, vegetation cover, soil and water management systems are recognized due to the applications of these models. These factors and associated results show the climate change effects and their sensitivity effecting resources, society, economy and environmental shifts. Determination of these effects is key contributor in the vulnerability of regions ultimately proving main concerns related to climate change and environmental trends (McCarthy *et al.*, 2001).

Numerous aspects of climatic gears and their inter relationships can be simulated through Coupled General Circulation Models (CGCMs) providing mainly the sophisticated tools in climate research. Sky scraping cost is beard due to complicated results which are attained after ensemble and long simulations for statistically significant results (Reprise, 2008).

The scientific significance and practicality of interdisciplinary composite environmental numerical models has amplified immensely throughout the previous decades. Qualitative and developmental improvement in numerical modeling and computing capabilities are resultant features for this amplification. These environmental models may be fully coupled like atmosphere Vs Ocean, land chemistry, biospheric models and partly coupled models. Partially coupled models may be with chemistry element, off-line calculation and these are motivated by atmosphere-ocean land model. Complicated nature of chemical, biological and other processes involved create problems in one of the main problems in advancement and execution of modem high-quality high-resolution environmental models (Vladimir, 2006).

Several hundred models are present with changeable levels of organization, scope, temporal resolution, spatial explicitness and mechanistic severity (Christopher and Alan, 2001). For example Kickert *et al.,* (1999) discussed 125 models of all types. For reliable and skillful hydrologic ensemble forecast, reliability and skill of ensemble forecasts for precipitation and temperature are major requirements (Demargne *et al.*, 2007, 2010; Seo *et al.*, 2006). At present various sources are accessible for ensemble forecasts from numerical weather prediction (NWP). For production of operational ensemble forecasts important additional struggles will be adequately reliable for hydrological applications, chiefly for great precipitation quantity (Limin *et al.*, 2011). For flood forecasting systems ensembles of NWPs, known as EPS instead single deterministic forecasts are applied for operational and research flooding system worldwide (Cloke and Pappenberger,2009).

Precise category that is expected to occur in the future is determined by deterministic forecasts, however devoid of any uncertainty. To minimize the associated uncertainty and to achieve certain and detailed forecasts the idea of probabilistic forecasts has emerged during the recent past time. Probabilistic forecasting facilitates address factors of forecast uncertainty. Foremost two sources are contributors; one is uncertainty in basic initial conditions and second is atmospheric internal variability creating uncertainty. It is determined by identifying the probability distribution of expected possible outcomes. An EPS generate Probabilistic forecasts. Operationally EPS is the key source to determine the forecast uncertainty. An ensemble is collection of forecasts, and every entity as forecast in the ensemble is named as a member. An ensemble forecast consists of numerous members, and every ensemble member is generated by various methods either by considering a different numerical model of the atmosphere having own basic initial conditions, or has diverse deriving physics as compared to other members taken from the similar numerical model. A standard approach for production of an ensemble is to run the model with diverse basic initial conditions.

EPS was developed to conquer the issue of deterministic weather forecasting in the view of uncertainty and errors in the field of seasonal climate forecast. Probabilities of occurrences or non-occurrences of an event or collection of fully inclusive events is determined by probabilistic forecasts. Statement of the probability of occurrence of future events is applied to quantify uncertainty. Probabilistic forecasts are important sources for quantitative risk assessment as this system reduce the uncertainty of complex climatic systems. Thus Probabilistic forecasts have greater economic value as it has wide ranging applicability covering weather associated risks, generation of power and disease modeling. Richardson (2000) concluded that probabilistic forecasts resultant from an EPS are of much significant value than a deterministic forecast shaped by the same.

Different independent dynamical predictions are used as combined forecast is called multi-model ensemble forecasting. This multi-model ensemble forecasting technique is currently very familiar in the field of climate predictions. Detailed and reliable seasonal forecasts are determined by using multi-model ensemble. The thought for multi-model ensemble has been developed to address the issues of model error and initial basic conditions' uncertainties. Using many models in an ensemble is a most excellent way to overcome the model errors. Comparatively multi- model gives more reliable and efficient data then single model ensembles. This dominance of the multi-model approach is described in many studies and research. Multi- model gives more convincing seasonal forecast as compared to single model systems. The major purpose of forming composite of different forecasts in single multi-model ensemble system is to lessen the model errors, and to generate wide-ranging probabilistic forecasts of seasonal climate as compared to single model system. Improvements in forecast skills have taken place due to multi-model ensemble predictions that are discussed in various studies and researches. Seasonal forecast using single- model is more trivial as compared to multi-model systems.

Composition of the ensemble models should not be of the same type. Same type of model used for ensembles is single model ensemble but are referred as ensembles. While using different types are multi- model ensembles (Georgakakos *et al.*, 2004). Conclusively, ensembles can provide an approach for reduction of overall prediction errors and uncertainties (Sharkey, 1999).

Forecast verification is the investigation and evaluation of the superiority and excellence of a forecasting system using sample or samples of preceding forecasts and consequent observations (Jolliffe and Stephenson, 2003). Verification of forecasts is done against matching observations that happen actually. Seasonal forecasts can be either probabilistic or deterministic, and a forecaster can recognize the strengths and weaknesses by verifying these forecast systems. There are three most vital reasons for verification. One is to monitor forecast quality, secondly to advance forecast quality and finally qualitative comparison of different forecast systems.

Verification of seasonal forecast is done by using skill scores that is very important for decision making. The main purpose of skill scores is to map the variation in the achievement of a given series of forecasts formed in a standardized format and checked it in a standard purposeful way (Gilchrist, 1986). Skill is significantly complex to evaluate in seasonal forecasting when compared with short or medium range weather forecasting. This happens because of long time scale of the forecast, which reduces the frequency and hence the reduced frequency used to finish and evaluate forecasts (Zwiers and Storch, 2004). A standard probabilistic measure of skill is used for the verification of Probabilistic forecasts. Ability of forecasting systems is evaluated by skill scores predicting two events for two outcomes. These outcomes are occurrence and non occurrence. Brier Score is used to evaluate probabilistic forecasts of an event. (Brier, 1950; Murphy, 1973), the Brier skill score (Smith, 1997; Brocker and Smith, 2007a), the Rank Probability Score (Wilks, 1995; Epstein, 1969) and the Relative Operating Characteristic (Mason, 1982; Swets and Pickett, 1982; Palmer *et al.*, 2000; Toth *et al.*, 2003) were used to predict the seasonal forecast. World Meteorological Organization, Commission for Basic Systems Working Group (WMO/CBS) has documented the need to make available common verification techniques across differing forecast systems.

Present work is about probabilistic forecasts, therefore probabilistic skill measures are used to evaluate the performance of forecast system. In probabilities approaches and techniques, the three events are commonly used, first is upper-tercile which is above the median value, second is lower-tercile which is below the median value or lower of climatology and the third is the number of these events that can be amplified according to the requirement and conditions. Evaluation of these forecasts is done by ROC and BSS (Brier skill scores) verification methods. To verify probabilistic forecast, these techniques are widely applied in the field of seasonal forecasting. In this study, probabilistic forecast is the focus. The World Meteorological Organization (WMO) has recognized ROC and BSS as vigorous verification methods. ROC is a practical and valuable method for the assessment of probabilistic forecasts. ROC curve is basically on signal detection theory, which is a plot of hit rates and false alarm rate.

Aims and Objectives

The present study focuses on the validation of diverse climatic models for different climatic conditions particularly in the Eastern Monsoon Belt (EMB). Particularly it focuses on

- The determination of the skill of the probabilistic forecast for EMB based on Reliability demonstration and EPS for different climatic models.
- Verification of probabilistic forecasts by using ROC, Brier Score (BS), Brier Skill Score (BSS). .
- Validation of probabilistic forecast by using cross validation approach against the real time data obtained from PMD and simulated data of ERA-40.

CHAPTER 2

METHODOLOGY

METHODOLOGY

Monsoon is undoubtedly the principal contributor (about 65% to 70%) of the total annual rainfall. EMB is much diversified for climatic conditions and rainfall amount. Areas in this belt have their significance for water storage and consumption as well as various uncertain and unpredictable events have been occured.

2.1 Data Acquisition

Pakistan's overall rainfall and general climatic and weather information with appropriate literature of July, August, September and was collected from Digital Library of International Islamic University, Islamabad. The data of five general circulation models namely ECMWF, ERA-40, MPI, Meteo France and UKMO was acquired from PMD for eastern belt of Pakistan. Real time observations were also acquired from PMD for the cities. Summer Monsoon Rainfall hind cast of 32 years from 1969 to 2000 was processed for this belt in Pakistan covering ten major districts with central cities. These major districts are Islamabad, Rawalpindi, Jhelum, Lahore, Bahwalnager, Rahim yar Khan, Khairpur, Sukkur, Badin and Nawabshah. Statistics based numerical facts were acquired and proceedings of these districts was considered for monsoon season that prevails in the months of July, August and September.

2.2 Methods

Microsoft Excel 2010 spread sheets encompassing real time observational data of PMD and simulated data of specified climatic models were generated. Statistical software SPSS v 20.0 was used for data preparation. Rainfall data of ten districts for 32 years was acquired for validation, evaluation and assessment of data for seasonal rainfall hindcast.

Firstly ensemble forecast with all initial conditions for each of specified single climate model was completed. Percentiles were determined by using upper tercile (0.667) threshold value. Upper tercile represented maximum amount of rainfall in the belt. Climatological probability of real time data of PMD, simulated data of Era-40 and probability of relevant models were determined by calculated percentile values. Probabilistic forecast was calculated by using these probabilities. Probabilistic forecast with all nine initial conditions and with alternative conditions was computed. Then probabilistic forecast averages of each model was evaluated against the averages of real time data of PMD and simulated data of Era-40.

Brier Score (BS) was calculated for probabilistic forecast with all initial conditions and with alternative conditions to check the reliability, resolution and uncertainty of probabilistic forecast.

$$BS = 1/N\sum (A_i - B_i)^2 \quad \text{Eq no 1}$$

Where A_i is the probability of forecast

And B_i the actual and real time outcome of the incident at instance,

BSS is the mean square error in probability space and is calculated as;

$$BSS = 1 - BS/ BS_{reference} \quad \text{Eq no 2}$$

BSS was calculated by using probabilistic forecast with all initial conditions and with alternative initial conditions against Era-40 and PMD of each single model. Positive value of BSS represents skill forecast while negative values indicate no skill forecast or poor forecast.

Analysis was further processed to check the accuracy of probabilistic forecast by cross validation.

Proceeding the single model Ensemble forecast, multi model Probabilistic forecast was calculated by making the combinations of three different models viz., MPI and Meteo-France, MPI and ECMWF and ECMWF and Meteo-France. Each of these combinations gave eighteen initial conditions. Another combination of ECMWF, MPI and meteor-France resulted in twenty seven initial conditions. Data of these combinations was processed for Islamabad, Rawalpindi, Jhelum, Lahore, Bahawalnager, Rahimyar Khan, Khairpur, Sukkur, Badin and Nawabshah. Verification of the probabilistic forecast was done against PMD and Era-40. "BS" was computed for eighteen and twenty seven initial conditions as well as for alternatively eliminated initial conditions to check the reliability, resolution and uncertainty of probabilistic forecast. "BSS" was computed using eighteen initial conditions and alternatively eliminated each initial condition against PMD and Era-40. Accuracy and excellence of multi model was checked by cross validation method by plotting cross validation graphs.

2.3 Relative operating characteristic (ROC)

This technique was applied to check the skill of the forecast. ROC technique was applied to visualize, categorize and to highlight the combinations which give skill forecast for the selected areas. A ROC graph is a technique for visualizing, categorizing and selecting classifiers based on their performance. Visualization, categorization and selection of performance based classifiers were carried out by ROC graph. ROC offers great method to designate the quality of probabilistic forecast in weather and climate forecast systems. Quality of forecast is characterized by the area covered by the Roc curve. The area under the ROC curve characterizes the quality of a forecast system. It illustrates the system's aptitude to predict the occurrence or non-occurrence of the already identified events.

In case of ROC curve having hit rate of 1.0 without false alarm, predictability of forecast system is significant for probabilistic forecast. If the curve is above the diagonal and the area under the curve is more than 0.5, indicates the skill forecast. If the curve falls in false alarm portion that is below diagonal or having value below 0.5 may indicates poor forecast. The system fails to distinguish between hit and false alarm when area under curve would be 0.5. In this case forecast has no skill.

CHAPTER 3

RESULTS

Results

3.1 Single model probabilistic forecast for Eastern Monsoon Belt

The EMB and related seasonal rain belts presuppose significant variability and unpredictability at intraseasonal, interannual and interdecadal time scales. Monsoon rainfall occur both in winter and summer. Monsoon precipitation in summer is the major support of Pakistan's water resources which prevails from July to September. Monsoon is indisputably the prime provider (about 65% to 70%) of the total annual rainfall. Rainfall variability of east Asian summer monsoon as well as their relationship with different climatic factors is of utmost importance for climatologists, metereologist and ecologist as well.

The development and advancement of climate models with better skill, accuracy and resolution is of main concern. Prediction systems in hindcast studies which compares predicted data with real time weather conditions to check the efficiency of models for specified areas. Hindcast studies are required to assess the basis for skilful future forecasts, recognizing a large number of sets with different combinations for different cases to obtain statistically significant results. Understanding and reducing systematic model errors are also important.

The development of climate models with better horizontal and vertical resolution is a priority. Their potential to improve the representation of coupled ocean–atmosphere variability and stratospheric effects on surface and tropospheric climate anomalies prediction systems can be tested in hindcast studies. It uses systems to "forecast" historical periods based on available data. Climate model projection is found to give additional skill in some hindcast set. Understanding and reducing systematic model errors are also important.

3.2 Seasonal Hindcast using Ensemble Predictions Systems

By using EPS, seasonal hindcast of rainfall for different selected areas i-e Islamabad, Rawalpindi, Jhelum, Lahore, Bahawalnagar, Rahimyar Khan, Khairpur, Sukkur, Badin and Nawabshah in monsoon belt was computed for 32 years from 1969 to 2000 for the months of July, August and September. Maximum amount of rainfall was presented by "upper tercile".

For Islamabad ensemble forecast averages with all basic initial conditions of ECMWF, Meteo-France, MPI and UKMO were 181.75mm, 38.46mm, 58.34mm and 46.15mm respectively. Ensemble forecast averages of PMD and Era-40 were 752.95mm and 363.08mm respectively. Ensemble forecasts of all models were lower then ensemble forecast of PMD and Era-40 (Table 3.1). Probabilistic forecast of ECMWF, Meteo-France, MPI and UKMO was 0.33 while for PMD and Era-40 it was 0.34. "Brier Score" illustrated greater probabilistic error for ECMWF, Meteo-France, UKMO and MPI against PMD which made it less reliable while MPI was reliable against Era-40.

For Rawalpindi ensemble forecast with all nine initial conditions of ECMWF, Meteo-France, MPI and UKMO were 696.43mm, 20.26mm, 524.78 mm and 212.35mm respectively. Ensemble forecast for PMD and Era-40 was 752.95mm and 462.86mm respectively. Meteo-France value was very much lower then PMD and Era-40 (Table 3.1) . 0.33 was probabilistic forecast of all selected models whereas 0.34 was probabilistic forecast of PMD and Era-40. According to Brier Score probabilistic error was higher for ECMWF, Meteo-france, UKMO and MPI when computed against Era-40. Therefore these were not reliable models. While it was reliable for MPI against PMD.

Jhelum ensemble forecast using all initial conditions of selected models i-e ECMWF, Meteo-France, MPI and UKMO were 181.75mm, 38.46mm, 58.34mm and 46.15mm respectively. While ensemble forecasts of PMD and Era-40 were 583.01mm and 363.08mm respectively, which was greater then all models (Table 3.1). Probabilistic forecast of PMD and Era-40 was 0.34 while probabilistic forecast of ECMWF, Meteo-France and UKMO was 0.33. Only MPI prorbabilistic forecast was 0.34 alike to PMD and Era-40 value. According to Brier Score there was greater probabilistic error for ECMWF, Meteo-France, UKMO and MPI when calculated against PMD and was not reliable. MPI against Era-40 showed reliability.

Ensemble forecast of Lahore with all initial conditions of ECMWF, Meteo-France, MPI and UKMO were 1448.48mm, 57.97mm, 1002.69mm and 385.46mm respectively for rainfall. On the other hand ensemble forecasts of real time data PMD and Era-40 were 459.56mm and 779.28mm respectively. Probabilistic forecast of all selected models was lower than that of PMD and Era 40 (Table 3.1). According to "Brier Score" ECMWF and UKMO were not found reliable. However Meteo-France demonstrated good reliability when it was calculated against Era-40. While MPI was also reliable as probabilistic error was less.

Ensemble forecast averages for Bahawalnagar including all initial conditions of ECMWF, Meteo-france, MPI and UKMO were 266.69mm, 94.83mm, 173.38mm and 159.04mm rainfall respectively. Ensemble forecast averages of PMD and Era-40 were 127.35mm and 122.53mm respectively. ECMWF ensemble forecast was relatively higher than PMD and Era-40. Meteo-France, MPI and UKMO ensemble forecast were near to the real time data PMD and simulated data of Era-40. Probabilistic forecast of ECMWF, Meteo-France and MPI was 0.33 while UKMO probabilistic forecast average was 0.34. This value was similar to the probabilistic forecast 0.34 of PMD and Era-40. For Bahawalnagar Meteo-France is reliable model while MPI is reliable when calculated with PMD and not reliable with Era-40. "Brier Score" gave less probabilistic error for Meteo-France so it was reliable one. And MPI is reliable only against real time data PMD.

In case of Rahim Yar Khan Ensemble forecast with all initial conditions for ECMWF, Meteo-France, MPI and UKMO was 133.94mm, 221.92mm, 225.63mm and 37.58mm rainfall respectively. Ensemble forecast of Era-40 was 36.39mm. UKMO ensemble forecast was nearest to Era-40, while others had higher values. Probabilistic forecast of Era-40 was highest (Table 3.1). "Brier Score" illustrated good reliability in case of MPI as this model had lower probabilistic error. All other models had higher probabilistic error and lower reliability.

For Khairpur ensemble forecast with all initial conditions of ECMWF, Meteo-France, MPI and UKMO was133.94mm, 221.92mm, 225.63mm and 37.58mm respectively. While 36.39mm was the ensemble forecast of Era-40. UKMO ensemble forecast was very close to the Era-40 while all other forecast were higher then Era-40. Probabilistic forecast of all selected models was 0.33 (Table 3.1). "Brier Score" presented greater probabilistic error for ECMWF, Meteo-France and UKMO while this error was lesser for MPI making it a reliable model.

For Sukkur using all initial conditions ensemble forecast of ECMWF, Meteo-France, MPI and UKMO was 133.94m, 221.92mm, 225.63mm and 37.58mm rainfall respectively, while that of Era-40 was 36.39mm. Probabilistic forecast of Era-40 was higher than selected models (Table 3.1). ECMWF, Meteo-France and UKMO were not reliable models. These models had higher probabilistic error while MPI probabilistic Error was lower and it was reliable model.

Simulated amount of rainfall in Badin from ECMWF, Meteo-france, MPI and UKMO was 210.58mm, 352.58mm, 713.75mm and 125.16mm rainfall respectively. While ensemble forecast averages of PMD and Era-40 were 193.069mm and 60.286mm respectively. Calculations showed that Ensemble forecast of ECMWF and UKMO was near to the ensemble forecast of PMD but it was relatively higher than Era-40. While that of Meteo-France and MPI were much higher than PMD and Era-40. Probabilistic forecast of PMD and Era-40 was higher based on which only MPI was found reliable. "Brier Score" also showed that probabilistic error for ECMWF, Meteo-France and UKMO were high (Table 3.1).

For Nawabshah ensemble forecasts with all initial conditions of ECMWF, Meteo-France, MPI and UKMO was 92.61mm, 185.45mm, 641.35mm and 29.31mm respectively. While ensemble forecasts of PMD and Era-40 was 108.6656mm and 33.5158mm respectively. UKMO ensemble forecast was close to Era-40 and ECMWF ensemble forecast was close to PMD while other two models had higher ensemble forecast. Probabilistic forecast of PMD and Era-40 was higher than all others. "Brier

Score" showed significant probabilistic error in ECMWF, Meteo-france, UKMO and MPI when computed against PMD and had no reliability. Lower probabilistic error and good reliability was found for MPI vs Era-40.

Table 3.1: Results evaluated from climate models

City	Findings	PMD*	Era-40**	ECMWF	Meteo-france	MPI	UKMO
		Model					
Islamabad	Ensemble Forecast	752.95	363.08	181.75	38.47	58.34	46.15
	Probabilistic Forecast	0.34	0.34	0.33	0.33	0.33	0.33
	Reliability			0	0	0*/1**	0
	Brier Score			0.24*/0.27**	0.24*/0.28**	0.23*/0.19	0.32*/30**
Rawalpindi	Ensemble Forecast	752.95	462.86	696.42	20.26	524.78	212.35
	Probabilistic Forecast	0.34	0.34	0.33	0.33	0.33	0.33
	Reliability			0	0	1*/0**	0
	Brier Score			0.27*/0.26**	0.26*/0.24**	0.20*/0.28**	0.27*/0.35**
Jhelum	Ensemble Forecast	583.01	363.08	181.75	38.46	58.34	46.15
	Probabilistic Forecast	0.34	0.34	0.33	0.33	0.34	0.33
	Reliability			0	0	0*/1**	0
	Brier Score			0.28*/0.26**	0.28*/0.26**	0.26*/0.20**	0.32*/0.30**
Lahore	Ensemble Forecast	459.56	779.28	1448.48	57.97	1002.70	385.45
	Probabilistic Forecast	0.34	0.34	0.33	0.33	0.33	0.33
	Reliability			0	0*/1**	1	0
	Brier Score			0.27*/0.25**	0.23*/0.22**	0.20*/0.17**	0.28*/0.24**
Bahawalnagar	Ensemble Forecast	127.35	122.53	266.69	94.84	173.38	159.04
	Probabilistic Forecast	0.34	0.34	0.34	0.33	0.33	0.33
	Reliability			0	1	1*/0**	0
	Brier Score			0.29*/0.31**	0.22*/0.21**	0.22*/0.25**	0.34*/0.23**
Rahim Yar Khan	Ensemble Forecast	----	36.39	133.94	221.92	225.63	37.58
	Probabilistic Forecast	----	0.33	0.33	0.33	0.33	0.33
	Reliability			0	0	1	0
	Brier Score			0.28**	0.24**	0.22**	0.26**
Khairpur	Ensemble Forecast	----	36.39	133.94	221.92	225.63	37.58
	Probabilistic Forecast	----	0.33	0.33	0.33	0.33	0.33
	Reliability			0	0	1	0
	Brier Score			0.28**	0.24**	0.22**	0.26**
Sukkur	Ensemble Forecast	-----	36.39	133.94	221.92	225.63	37.58
	Probabilistic Forecast ----	-	0.34	0.33	0.33	0.33	0.33
	Reliability			0	0	1	0
	Brier Score			0.28**	0.24**	0.22**	0.26**
Badin	Ensemble Forecast	193.07	60.29	210.581	352.577	713.748	125.159
	Probabilistic Forecast	0.34	0.34	0.33	0.33	0.33	0.33
	Reliability			0	0	1	0
	Brier Score			0.29*/28**	0.24*/0.25**	0.20*/0.24**	0.32*/0.28**
Nawabshah	Ensemble Forecast	108.67	33.52	92.60	185.45	641.35	29.30
	Probabilistic Forecast	0.33	0.34	0.34	0.33	0.33	0.33
	Reliability			0	0	0*/1**	0
	Brier Score			0.29*/0.24**	0.28*/0.26**	0.24*/0.22**	0.29*/0.27**

* = PMD and ** = Era-40

3.3 Numerical modeling for Eastern Monsoon Belt

The Relative Operating Characteristic (ROC) measures the potential utility, and ability of the forecast to discriminate between two alternative outcomes: occurence and non-occurence. ROC was applied for representative areas of the Monsoon for calculated results with all initial conditions and alternatively eliminated initial conditions.

ISLAMABAD:

For Islamabad, ROC showed "skill forecast" for Era-40 against PMD. ROC showed "skill forecast" for ECMWF, Meteo-France and MPI will all initial conditions and with alternatively eliminated initial conditions. Only UKMO showed "poor forecast" against PMD. ROC curves plotted against Era-40 generated "skill forecast" only for MPI while ECMWF, Meteo-France and UKMO showed "poor forecast".

Table 3.2: Relative Operating Characteristics output for Islamabad

Sr. no	Model	Eliminated initial conditions	Average of probabilistic forecast	Area under the curve	Status of forecast
1	PMD Vs Era-40		----	0.58	Skill forecast
	PMD vs ECMWF		0.33	0.59	Skill forecast
		2	0.34	0.56	Skill forecast
		7	0.30	0.59	Skill forecast
		8	0.35	0.58	Skill forecast
	Era-40 vs ECMWF		0.33	0.47	Poor forecast
2	PMD Vs Meteo- France		0.33	0.55	Skill forecast
		0	0.32	0.50	No skill forecast
		1	0.35	0.53	Skill forecast
		2	0.34	0.55	Skill forecast
	Era-40 Vs Meteo- France		0.33	0.32	Poor forecast
3	PMD vs MPI		0.33	0. 61	Skill forecast
		0	0.34	0 .58	Skill forecast
		1	0.36	0.59	Skill forecast
		3	0.35	0.62	Skill forecast
		5	0.32	0 .62	Skill forecast
		8	0.30	0 .65	Skill forecast
	Era-40 vs MPI		0.33	0. 71	Skill forecast
4	PMD vs UKMO		0.33	0.33	Poor forecast
		1	0.35	0.36	Poor forecast
		2	0.32	0 .37	Poor forecast
		3	0.34	0.29	Poor forecast
	Era-40 vs UKMO		0.33	0..38	Poor forecast

Null hypothesis: true area = 0.5
Asymptotic Confidence Interval = 95%

Accuracy of the models for the duration of 32 years from 1969 to 2000 was checked by cross validation against PMD. Unusual values in the figures 3.1 presented that some extreme events must had occurred during the years where values are fluctuating from normal trends. These years are perturbing the accuracy and excellence of forecast.

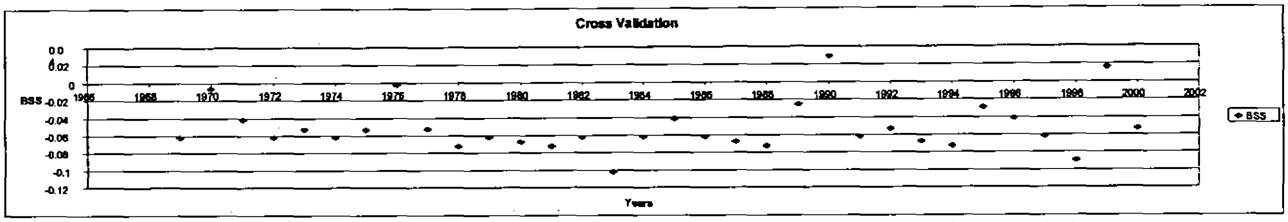

Figure 3.1a: Cross Validation of PMD Climatological Probability & ECMWF Probabilistic Forecast for Islamabad

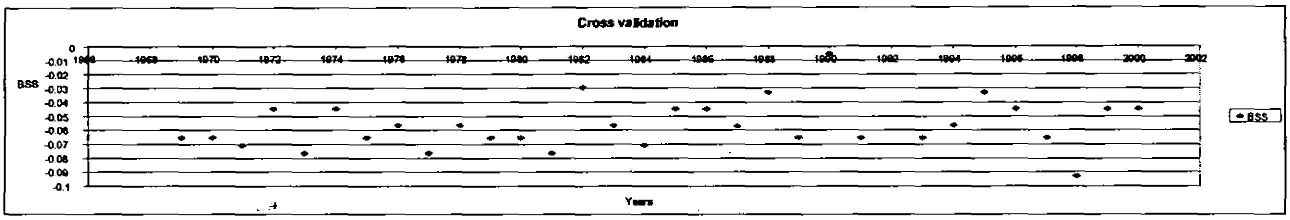

Figure 3.1b: Cross Validation of PMD Climatological Probability & Meteo France Probabilistic Forecast for Islamabad

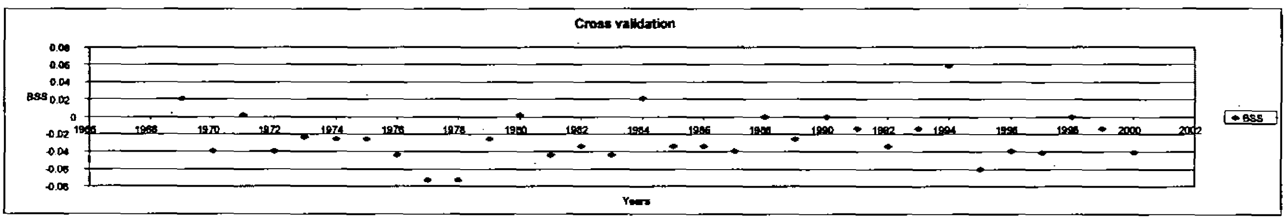

Figure 3.1c: Cross Validation of PMD Climatological Probability & MPI Probabilistic Forecast for Islamabad

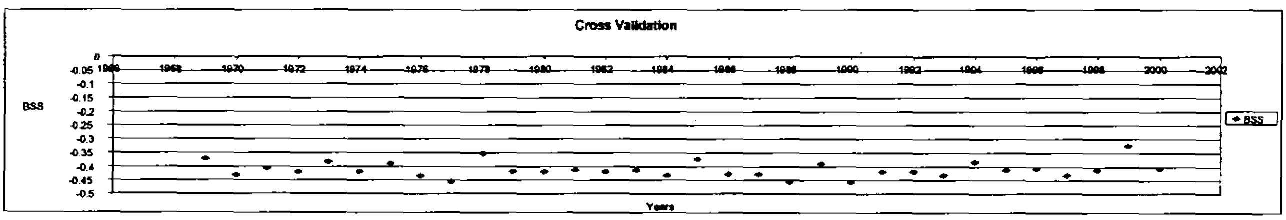

Figure 3.1d: Cross Validation of PMD Climatological Probability & UKMO Probabilistic Forecast for Islamabad

Cross validation checked the accuracy of forecast of associated models with Era-40 for the duration of 32 years from 1969 to 2000. Cross validation of selected models against Era-40 showed different extreme events during this time period (Figures 3.2)

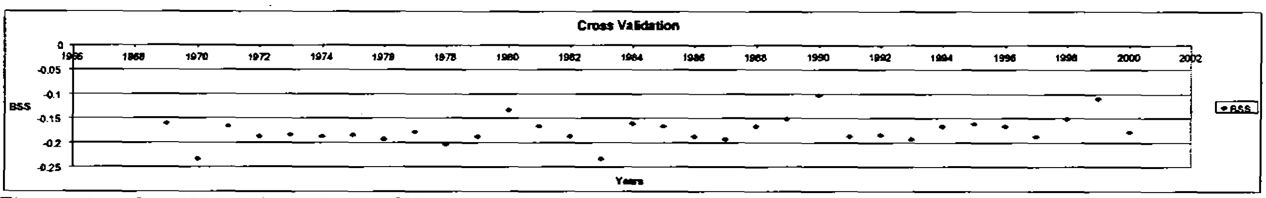

Figure 3.2a: Cross Validation of Era-40 Climatological Probability & ECMWF Probabilistic Forecast for Islamabad

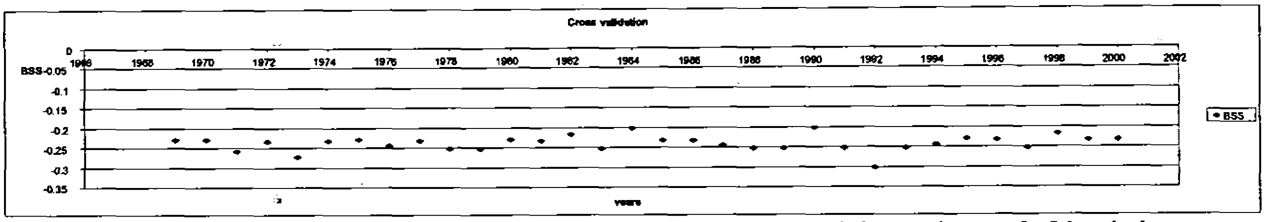

Figure 3.2b: Cross Validation of Era-40 Climatological Probability & Meteo France Probabilistic Forecast for Islamabad

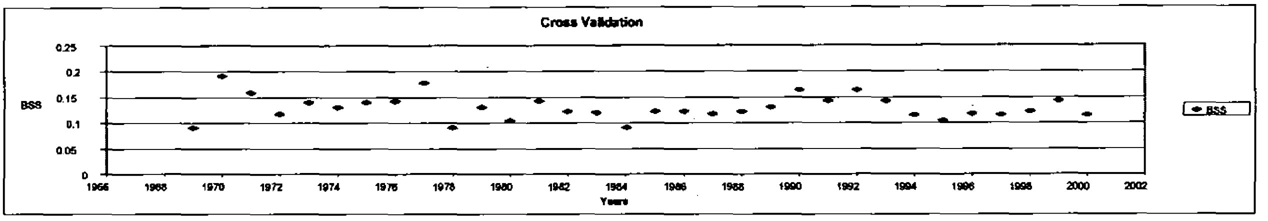

Figure 3.2c: Cross Validation of PMD Climatological Probability & MPI Probabilistic Forecast for Islamabad

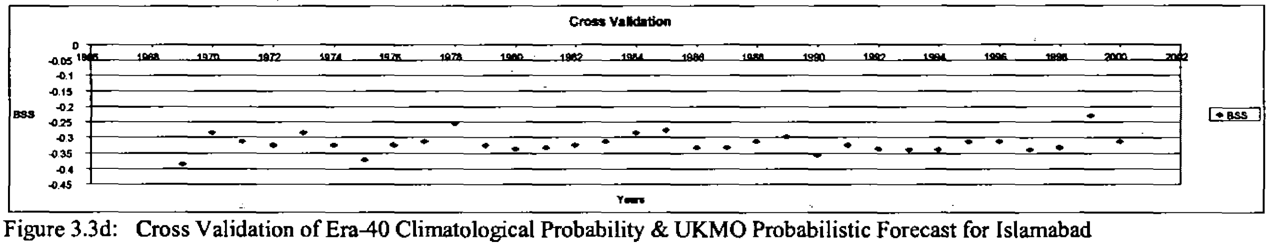

Figure 3.3d: Cross Validation of Era-40 Climatological Probability & UKMO Probabilistic Forecast for Islamabad

RAWALPINDI:

For Rawalpindi, ROC generated "skill forecast" for Era-40 against PMD. ROC performed against PMD showed "skill forecast" for MPI and UKMO with all nine initial conditions as well as alternatively eliminated initial conditions. ECMWF and Meteo-France generated "poor forecast". ROC curves plotted against Era-40 showed "skill forecast" for ECMWF only. Meteo-France, MPI and UKMO showed "poor forecast".

Table 3.3: Relative Operating Characteristics output for Rawalpindi

Sr. no	Model	Eliminated initial conditions	Average of probabilistic forecast	Area under the curve	Status of forecast
1	PMD vs Era-40		-----	0.65	Skill forecast
	PMD vs ECMWF		0.33	0.50	Poor forecast
		0	0.34	0.54	Skill forecast
		1	0.32	0.47	Poor forecast
	Era-40 vs ECMWF		0.33	0.54	Skill forecast
2	PMD Vs Meteo- France		0.33	0.40	Poor forecast
		3	0.34	0.39	Poor forecast
		8	0.32	0.41	Poor forecast
	Era-40 Vs Meteo- France		0.33	0.50	Poor forecast
3	PMD vs MPI		0.33	0.72	Skill forecast
		0	0.34	0.67	Skill forecast
		2	0.35	0.70	Skill forecast
		5	0.32	0.74	Skill forecast
		8	0.31	0.64	Skill forecast
	Era-40 vs MPI		0.33	0.46	Poor forecast
4	PMD vs UKMO		0.33	0.55	Skill forecast
		0	0.32	0.55	Skill forecast
		1	0.35	0.56	Skill forecast
		8	0.34	0.55	Skill forecast
	Era-40 vs UKMO		0.33	0.35	Poor forecast

Null hypothesis: true area = 0.5
Asymptotic Confidence Interval = 95%

Accuracy and excellence of forecast was ensured by cross validation method. Unusual values in figures 3.3 are disturbing the accuracy and excellence of forecast of relevant predictive model.

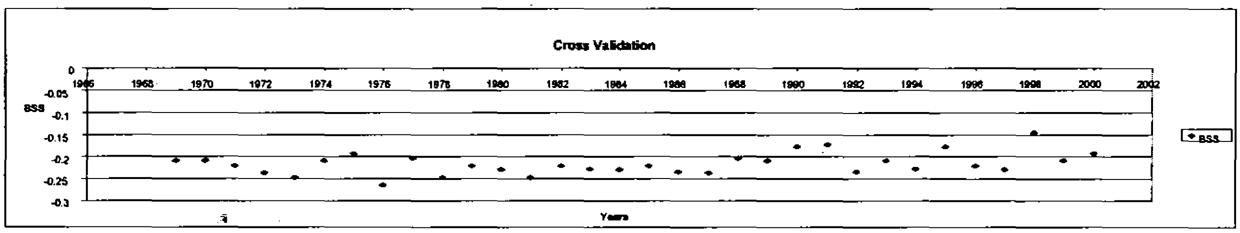

Figure 3.3a: Cross Validation of PMD Climatological Probability & ECMWF Probabilistic Forecast for Rawalpindi

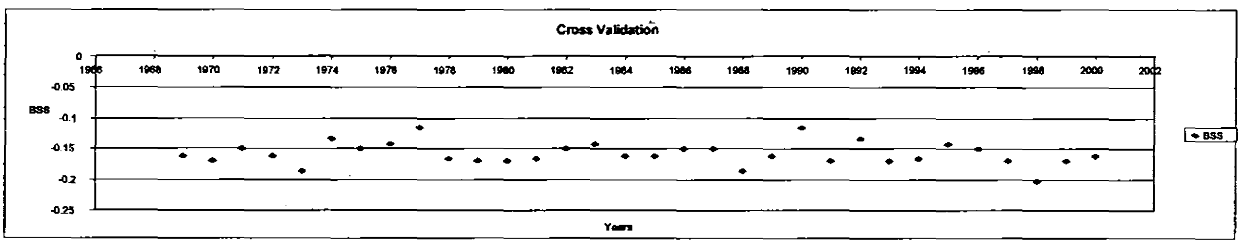

Figure 3.3b:Cross Validation of PMD Climatological Probability & Meteo-France Probabilistic Forecast for Rawalpindi

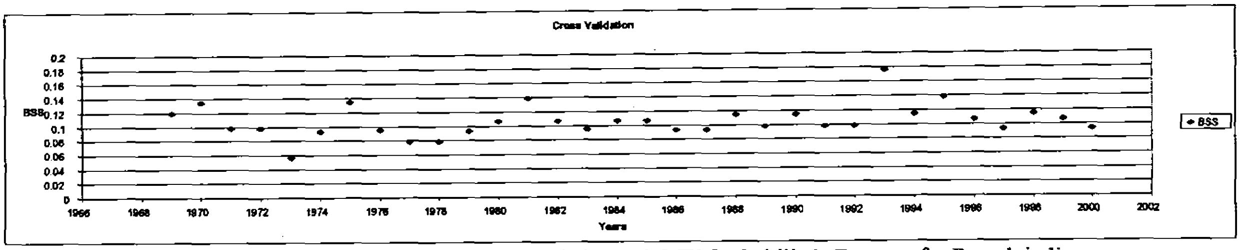

Figure 3.3c: Cross Validation of PMD Climatological Probability & MPI Probabilistic Forecast for Rawalpindi

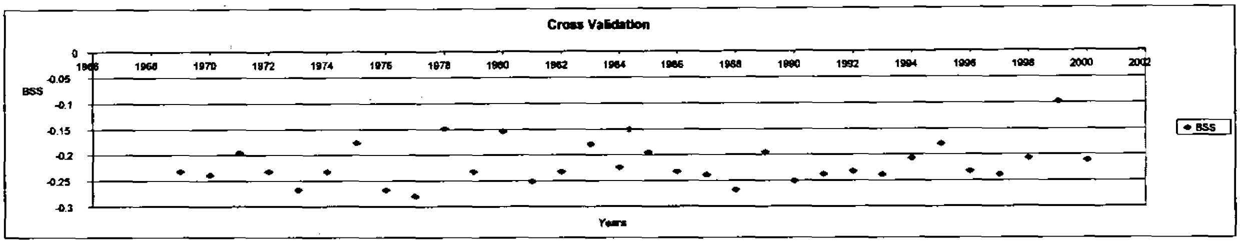

Figure 3.3d: Cross Validation of PMD Climatological Probability & UKMO Probabilistic Forecast for Rawalpindi

Cross validation was checked against Era-40 to find the accuracy of forecast. Yearly values of many years were disturbing the accuracy of forecast. Extreme occurrences were observed during different years (Figures 3.4).

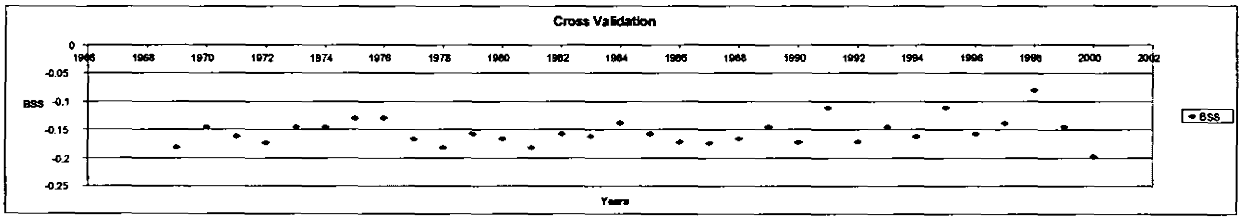

Figure 3.4a: Cross Validation of Era-40 Climatological Probability & ECMWF Probabilistic Forecast for Rawalpindi

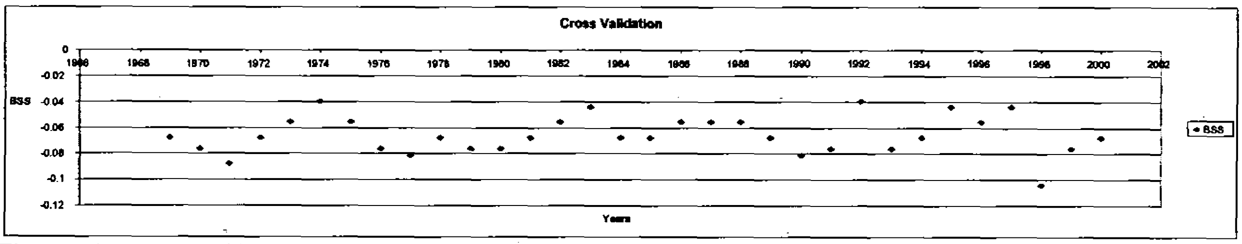

Figure 3.4b: Cross Validation of Era-40 Climatological Probability & ECMWF Probabilistic Forecast for Rawalpindi

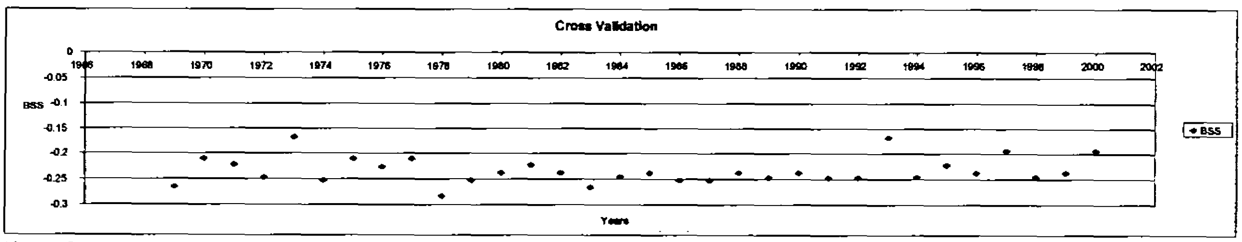

Figure 3.4c: Cross Validation of Era-40 Climatological Probability & MPI Probabilistic Forecast for Rawalpindi

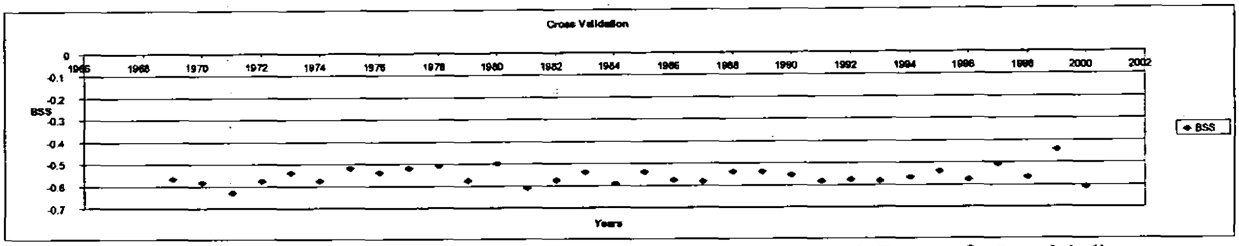

Figure 3.4d: Cross Validation of Era-40 Climatological Probability & UKMO Probabilistic Forecast for Rawalpindi

JHELUM:

For Jhelum, ROC curve plotted for Era-40 against PMD gave "skill forecast". All models showed "poor forecast" using all nine initial conditions and using them alternatively against PMD. While ROC curves were plotted against Era-40, only MPI showed "skill forecast" while all other selected models indicated "poor forecast".

Table 3.4: Relative Operating Characteristics output for Jhelum

Sr. no	Model	Eliminated initial conditions	Average probabilistic Forecast	Area under the curve	Status of forecast
1	PMD Vs Era-40		-----	0.65	Skill forecast
	PMD vs ECMWF		0.33	0.46	Poor forecast
		1	0.34	0.48	Poor forecast
		7	0.30	0.52	Skill forecast
		8	0.35	0.43	Poor forecast
	Era-40 vs ECMWF		0.33	0.46	Poor forecast
2	PMD Vs Meteo- France		0.33	0.35	Poor forecast
		0	0.32	0.34	Poor forecast
		1	0.35	0.36	Poor forecast
		2	0.34	0.33	Poor forecast
	Era-40 Vs Meteo- France		0.33	0.32	Poor forecast
3	PMD vs MPI		0.34	0.49	Poor forecast
		0	0.35	0.47	Poor forecast
		1	0.38	0.47	Poor forecast
		2	0.36	0.48	Poor forecast
		6	0.33	0.52	Skill forecast
		8	0.31	0.52	Skill forecast
	Era-40 vs MPI		0.33	0.69	Skill forecast
4	PMD vs UKMO		0.33	0.30	Poor forecast
		1	0.35	0.30	Poor forecast
		5	0.34	0.28	Poor forecast
		7	0.32	0.30	Poor forecast
	Era-40 vs UKMO		0.33	0 .381	Poor forecast

Null hypothesis: true area = 0.5
Asymptotic Confidence Interval = 95%

Accuracy of forecast was checked by cross validation method. Cross validation of models were carried out against both PMD and Era-40 separately. These unusual values in figures 3.5 are showing extreme events during 32 years.

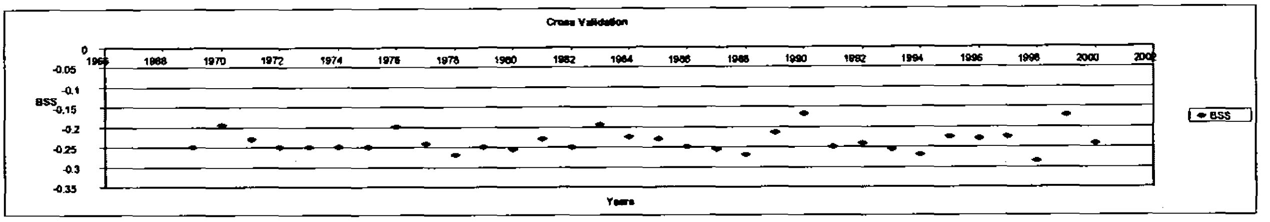

Figure 3.5a: Cross Validation of PMD Climatological Probability & ECMWF Probabilistic Forecast for Jhelum

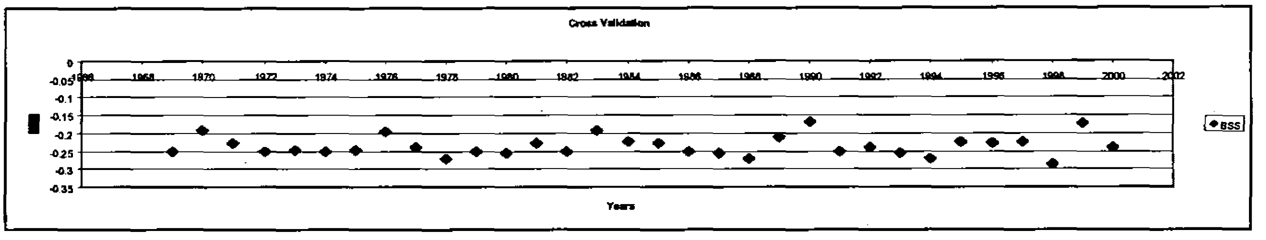

Figure 3.5b: Cross Validation of PMD Climatological Probability & Meteo France Probabilistic Forecast for Jhelum

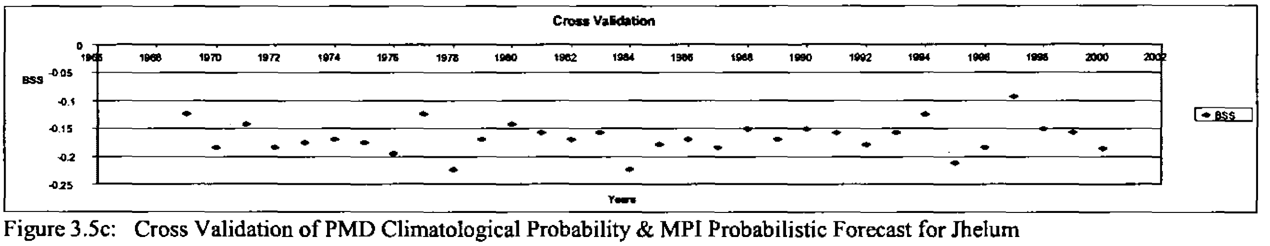

Figure 3.5c: Cross Validation of PMD Climatological Probability & MPI Probabilistic Forecast for Jhelum

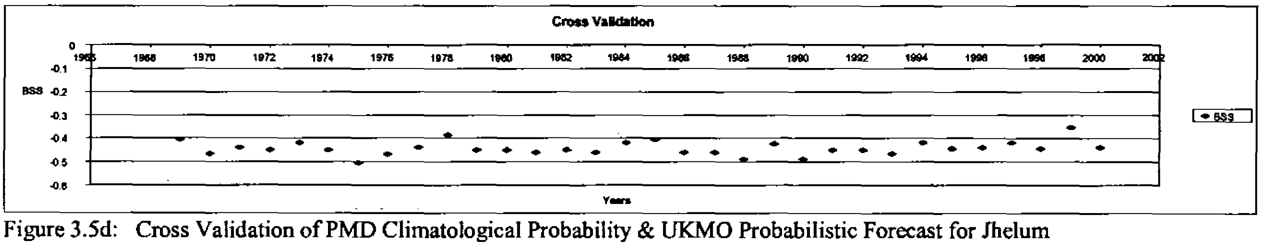

Figure 3.5d: Cross Validation of PMD Climatological Probability & UKMO Probabilistic Forecast for Jhelum

Cross validation against Era-40 in figures 3.6 showed extreme events during selected time phase for different selected models. MPI cross validation graph showed much disturbed values.different many years representing unusual events. Models can forecast accurately by eliminating these values during computation.

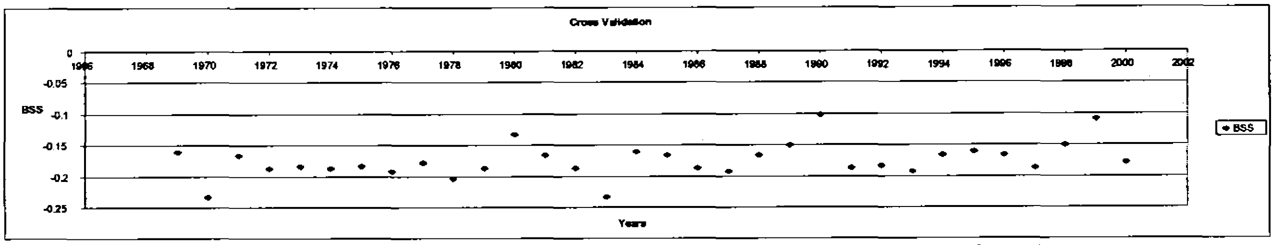

Figure 3.6a: Cross Validation of Era-40 Climatological Probability & ECMWF Probabilistic Forecast for Jhelum

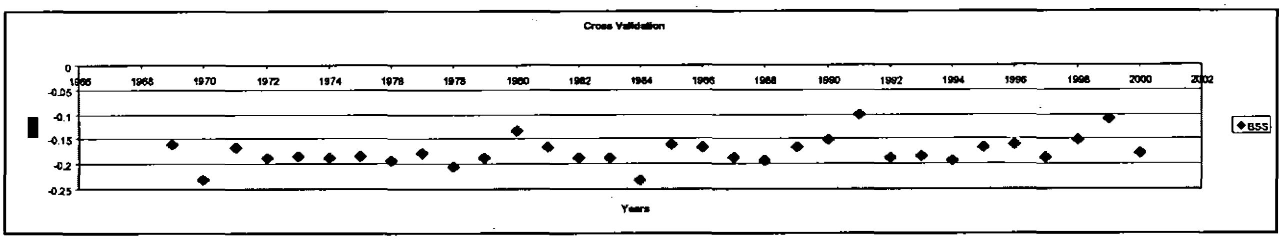

Figure 3.6b: Cross Validation of PMD Climatological Probability & Meteo France Probabilistic Forecast for Jhelum

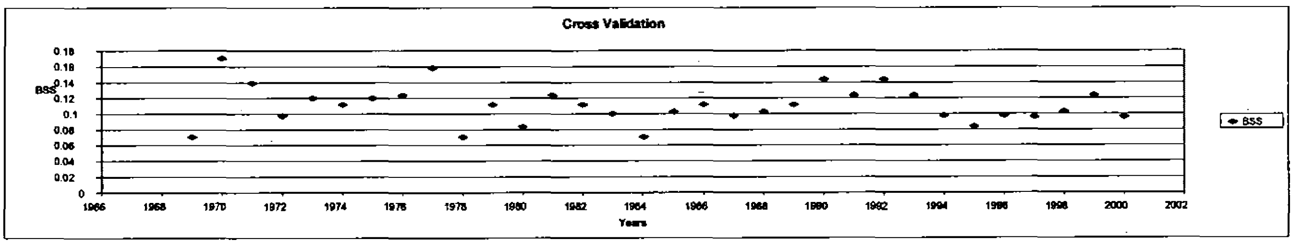

Figure 3.6c: Cross Validation of Era-40 Climatological Probability & MPI Probabilistic Forecast for Jhelum

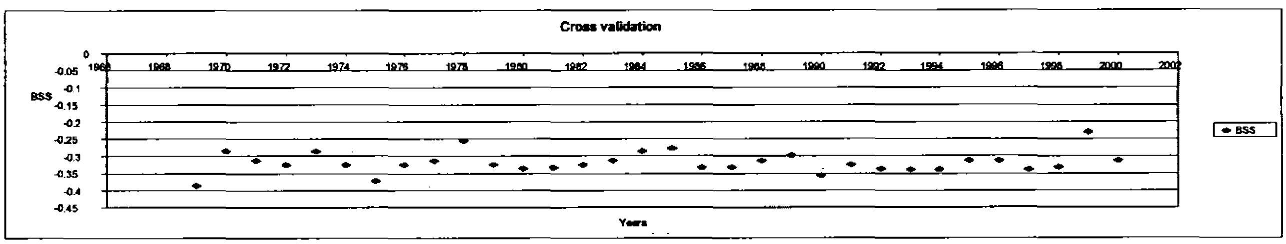

Figure 3.6d: Cross Validation of Era-40 Climatological Probability & UKMO Probabilistic Forecast for Jhelum

LAHORE:

For Lahore, ROC curve of PMD against Era-40 gave "skill forecast". ROC curves of Meteo-France, MPI and UKMO showed "skill forecast" with all initial conditions and alternatively eliminated initial conditions, Only ECMWF showed "poor forecast". ROC curves against Era-40 showed "skill forecast" for ECMWF, Meteo-France and MPI while "poor forecast" for UKMO.

Table 3.5: Relative Operating Characteristics output for Lahore

Sr. no	Model	Eliminated initial conditions	Average of probabilistic forecast	Area under the curve	Status of forecast
1	PMD Vs Era-40		-----	0.52	Skill forecast
	PMD vs ECMWF		0.33	0.43	Poor forecast
		0	0.35	0.44	Poor forecast
		4	0.32	0.42	Poor forecast
		5	0.34	0.43	Poor forecast
	Era-40 vs ECMWF		0.33	0.56	Skill forecast
2	PMD Vs Meteo- France		0.33	0.59	Skill forecast
		1	0.34	0.52	Skill forecast
		5	0.32	0.60	Skill forecast
	Era-40 Vs Meteo- France		0.33	0.60	Skill forecast
3	PMD vs MPI		0.33	0.69	Skill forecast
		2	0.34	0.70	Skill forecast
		3	0.36	0.65	Skill forecast
		4	0.35	0.67	Skill forecast
		8	0.31	0.68	Skill forecast
	Era-40 vs MPI		0.33	0.79	Skill forecast
4	PMD vs UKMO		0.33	0.54	Skill forecast
		1	0.34	0.52	Skill forecast
		4	0.35	0.54	Skill forecast
		7	0.32	0.55	Skill forecast
	Era-40 vs UKMO		0.33	0.43	Poor forecast

Null hypothesis: true area = 0.5
Asymptotic Confidence Interval = 95%

Cross validation of all specified models was applied against PMD real time data (Figures 3.7). Meteo-France presented very mixed data due to unusual occurences during the selected years (Figure 3.7c). These happenings are agitating the accuracy and excellence of forecast.

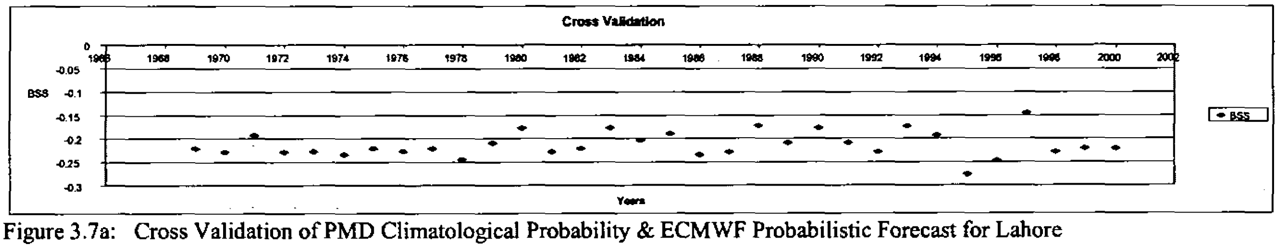

Figure 3.7a: Cross Validation of PMD Climatological Probability & ECMWF Probabilistic Forecast for Lahore

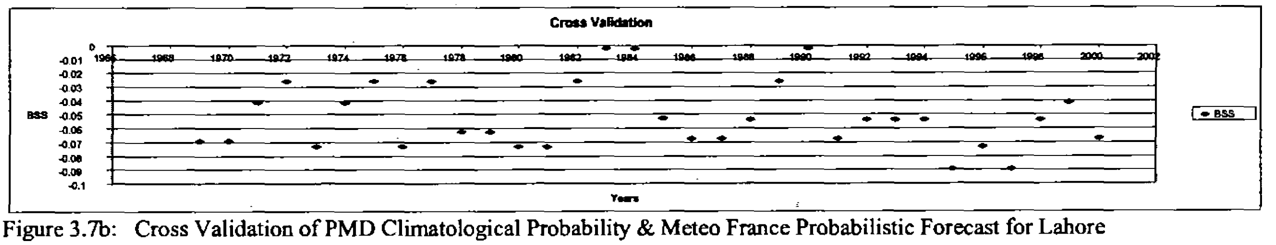

Figure 3.7b: Cross Validation of PMD Climatological Probability & Meteo France Probabilistic Forecast for Lahore

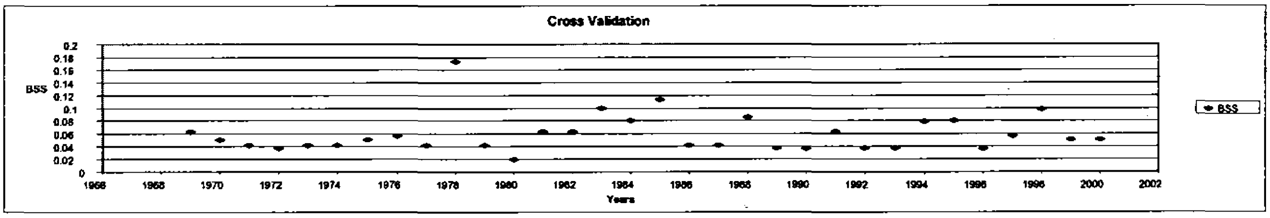

Figure 3.7c: Cross Validation of PMD Climatological Probability & MPI Probabilistic Forecast for Lahore

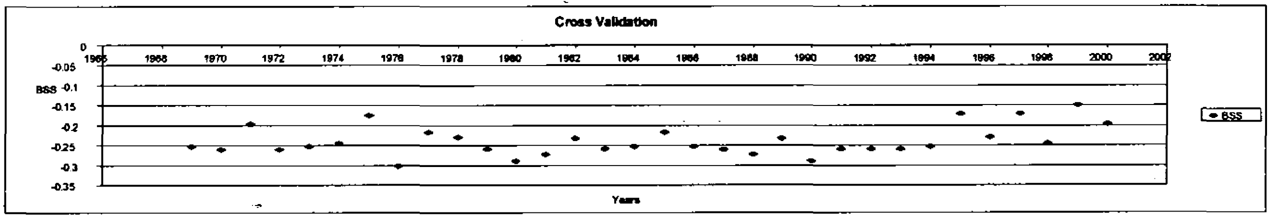

Figure 3.7d: Cross Validation of PMD Climatological Probability & UKMO Probabilistic Forecast for Lahore

Hindcast data of selected models was processed for cross validation against Era-40. fluctuating values are representative of unusual events during these 32 years. These outlying values in figures 3.8 are disturbing the accuracy of forecast.

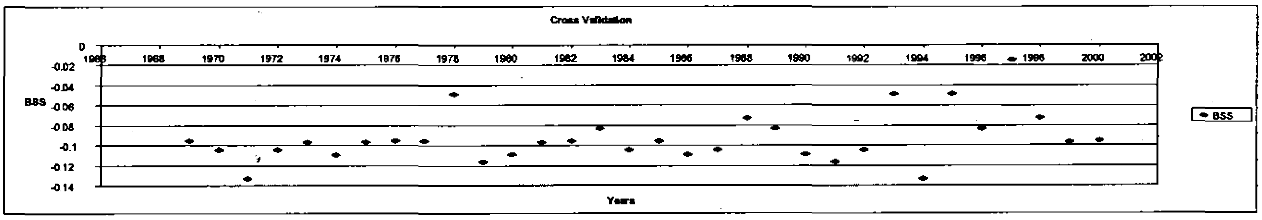

Figure 3.8a: Cross Validation of Era-40 Climatological Probability & ECMWF Probabilistic Forecast for Lahore

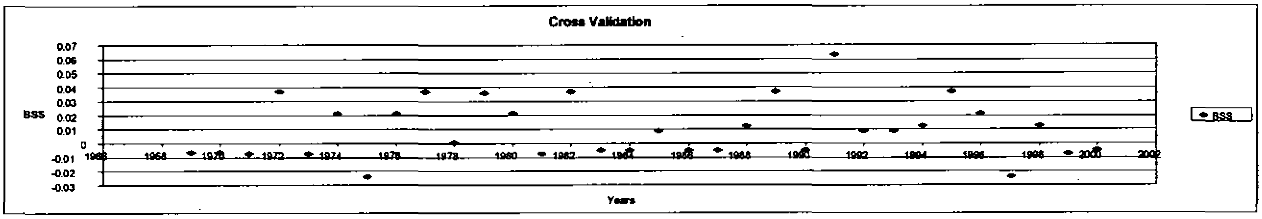

Figure 3.8b: Cross Validation of Era-40 Climatological Probability & Meteo France Probabilistic Forecast for Lahore

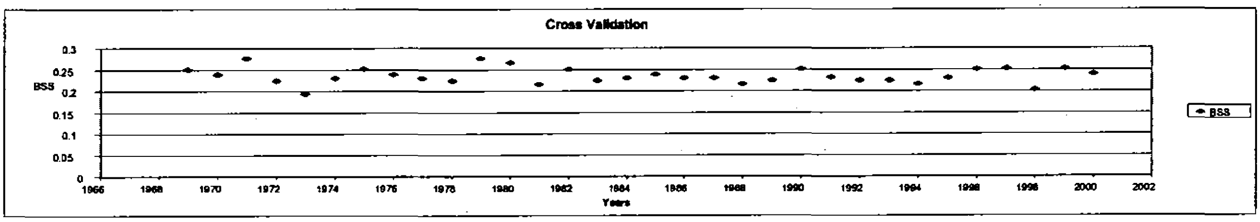

Figure 3.8c: Cross Validation of Era-40 Climatological Probability & MPI Probabilistic Forecast for Lahore

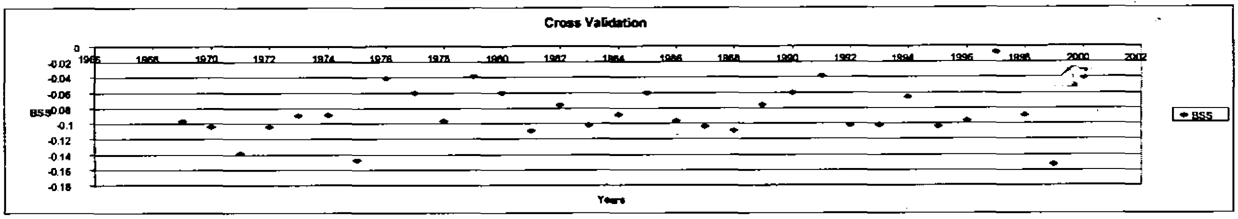

Figure 3.8d: Cross Validation of Era-40 Climatological Probability & UKMO Probabilistic Forecast for Lahore

BAHAWALNAGAR:

For Bahawalnagar, ROC generated "skill forecast" when curve was plotted for Era-40 against PMD. ECMWF gave "poor forecast" with all initial conditions and alternatively eliminated initial conditions against PMD and Era-40. UKMO gave "poor forecast" with nine initial conditions and by eliminating initial conditions alternatively, while model gave skillful forecast against Era-40. Meteo-France and MPI generated "skill forecast" with nine initial conditions and with alternativly eliminated initial condition against PMD and Era-40 (Table 3.6).

Table 3.6: Relative Operating Characteristics output for Bahawalnagar

Sr. no	Model	Eliminated initial conditions	Average of probabilistic Forecast	Area under the curve	Status of forecast
1	PMD Vs Era-40		----	0.65	Skill forecast
	PMD vs ECMWF		0.33	0.39	Poor forecast
		2	0.33	0.38	Poor forecast
		6	0.34	0.44	Poor forecast
	Era-40 vs ECMWF		0.33	0.29	Poor forecast
2	PMD Vs Meteo- France		0.33	0.58	Skill forecast
		2	0.34	0.65	Skill forecast
		5	0.32	0.65	Skill forecast
	Era-40 Vs Meteo-France		0.33	0.62	Skill forecast
3	PMD vs MPI		0.33	0.58	Skill forecast
		0	0.34	0.57	Skill forecast
		2	0.35	0.57	Skill forecast
		4	0.32	0.57	Skill forecast
		8	0.31	0.58	Skill forecast
	Era-40 vs MPI		0.33	0.54	Skill forecast
4	PMD vs UKMO		0.33	0.40	Poor forecast
		1	0.35	0.41	Poor forecast
		6	0.33	0.40	Poor forecast
		7	0.32	0.42	Poor forecast
	Era-40 vs UKMO		0.33	0.67	Skill forecast

Null hypothesis: true area = 0.5
Asymptotic Confidence Interval = 95%

For Bahawalnagar cross validation of data against PMD represented many unusual occurrences (Figure 3.9). Meteo-France indicated many outstanding events offering much diverse values. These eventual unusual values approach the poor and inaccurate forecast.

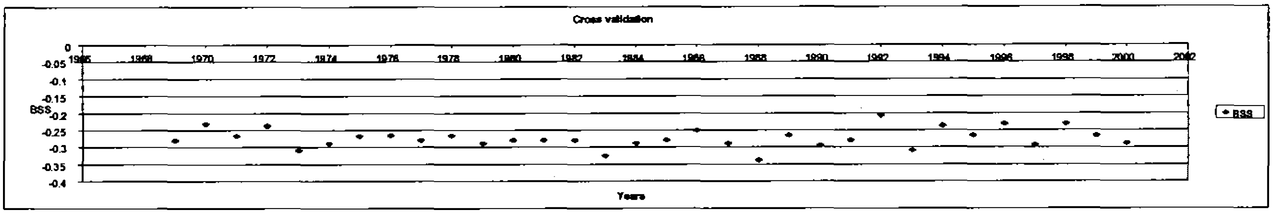

Figure 3.9a: Cross Validation of PMD Climatological Probability & ECMWF Probabilistic Forecast for Bahawalnagar

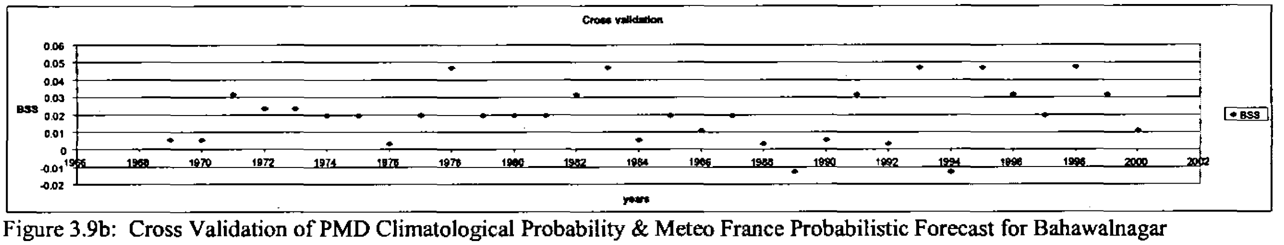

Figure 3.9b: Cross Validation of PMD Climatological Probability & Meteo France Probabilistic Forecast for Bahawalnagar

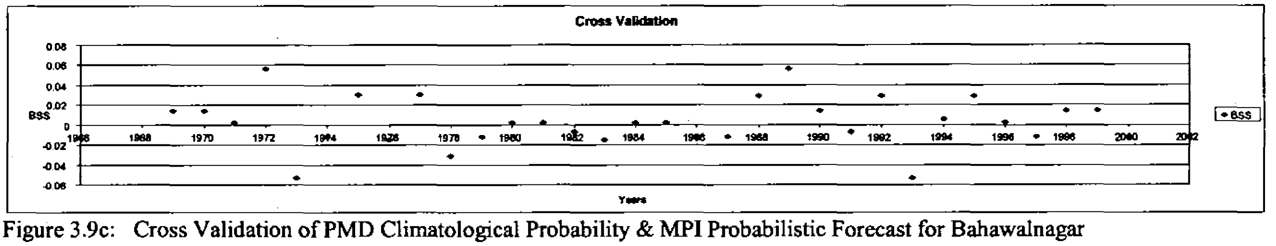

Figure 3.9c: Cross Validation of PMD Climatological Probability & MPI Probabilistic Forecast for Bahawalnagar

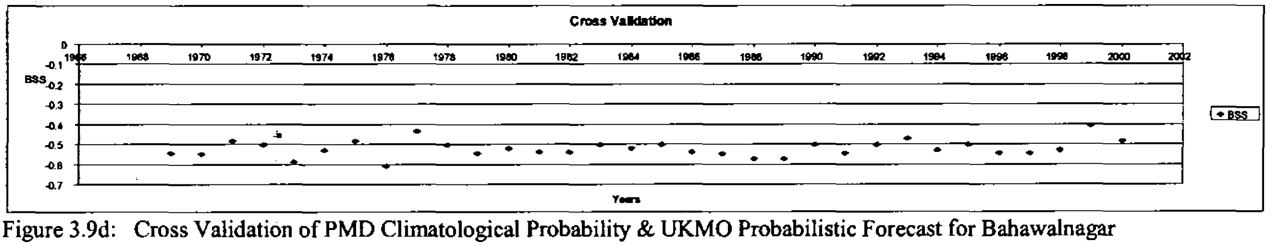

Figure 3.9d: Cross Validation of PMD Climatological Probability & UKMO Probabilistic Forecast for Bahawalnagar

Cross validation against Era-40 showed many extreme events during selected 32 years. These extreme events are disturbing the normal trend and effecting the accuracy of forecast of relevant predictive model.

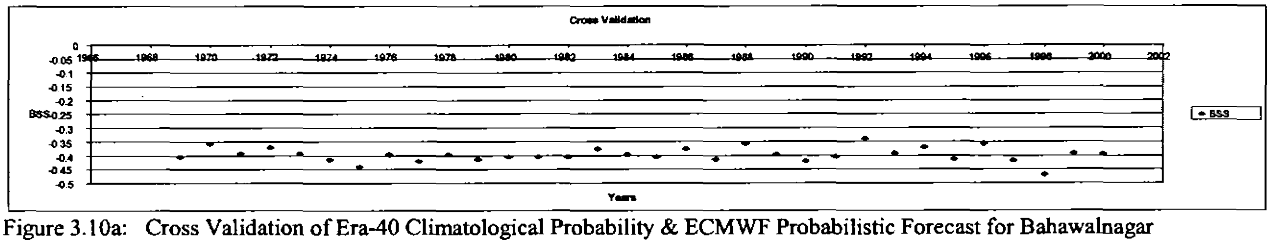

Figure 3.10a: Cross Validation of Era-40 Climatological Probability & ECMWF Probabilistic Forecast for Bahawalnagar

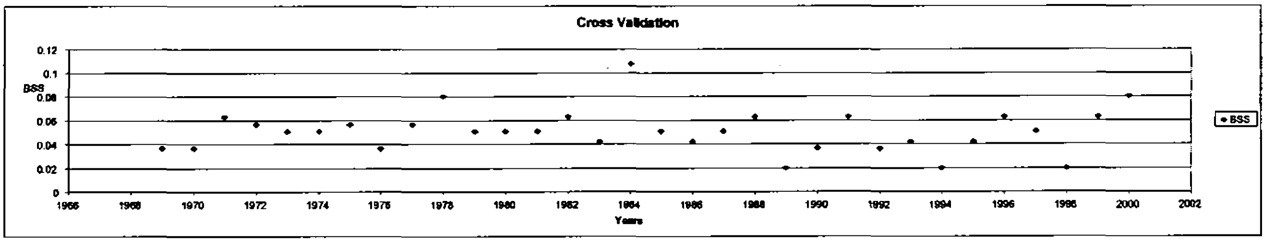

Figure 3.10b: Cross Validation of Era-40 Climatological Probability & Meteo France Probabilistic Forecast for Bahawalnagar

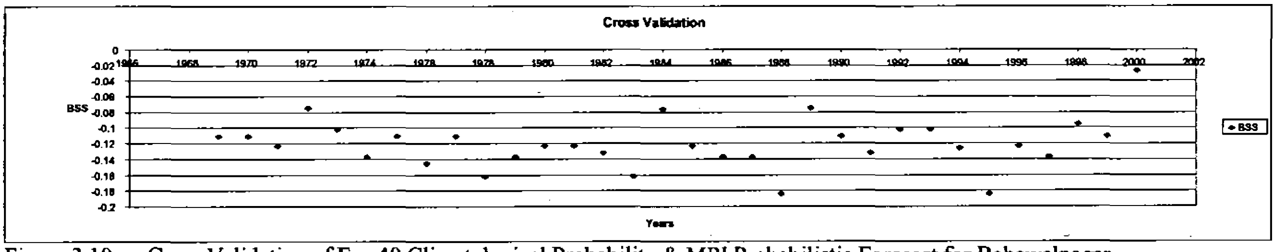

Figure 3.10c: Cross Validation of Era-40 Climatological Probability & MPI Probabilistic Forecast for Bahawalnagar

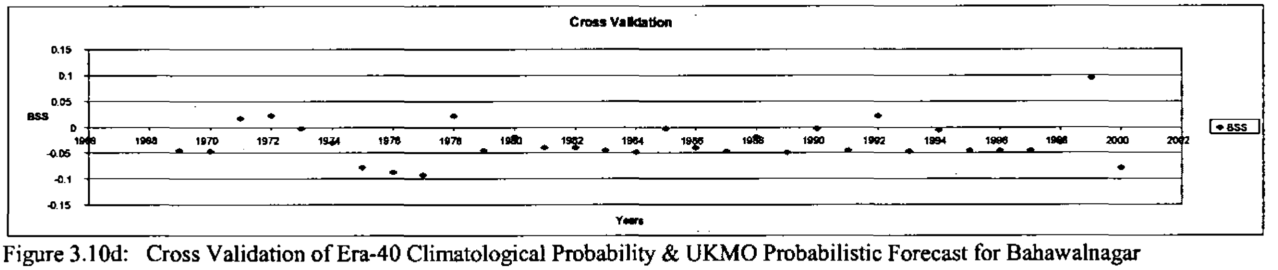

Figure 3.10d: Cross Validation of Era-40 Climatological Probability & UKMO Probabilistic Forecast for Bahawalnagar

RAHIMYAR KHAN

For Rahimyar Khan, ROC was performed only against Era-40 due to unavailability of PMD real time data. MPI and UKMO showed "skill forecast" with all initial conditions and with eliminated conditions alternatively. ECMWF and Meteo-Frane forecast did not have very good skill of forecast (Table 3.7).

Table 3.7: Relative Operating Characteristics output for Rahimyar Khan

Sr. no	Model	Eliminated initial conditions	Average of probabilistic forecast	Area under the curve	Status of forecast
1	Era-40 vs ECMWF		0.33	0.50	Poor forecast
		3	0.34	0.50	Poor forecast
		6	0.32	0.53	Skill forecast
		8	0.35	0.45	Poor forecast
2	Era-40 Vs Meteo- France		0.33	0.57	Skill forecast
		2	0.35	0.57	Skill forecast
		3	0.32	0.48	Poor forecast
		7	0.34	0.60	Skill forecast
3	Era-40 vs MPI		0.33	0.67	Skill forecast
		0	0.34	0.63	Skill forecast
		2	0.32	0.66	Skill forecast
4	Era-40 vs UKMO		0.33	0.58	Skill forecast
		0	0.32	0.56	Skill forecast
		1	0.35	0.61	Skill forecast
		3	0.34	0.57	Skill forecast

Null hypothesis: true area = 0.5
Asymptotic Confidence Interval = 95%

Rahimyar Khan data was only processed against Era-40 for cross validation. These processing highlighted events disturbing the accuracy of forecast for selected city (Figures 3.11).

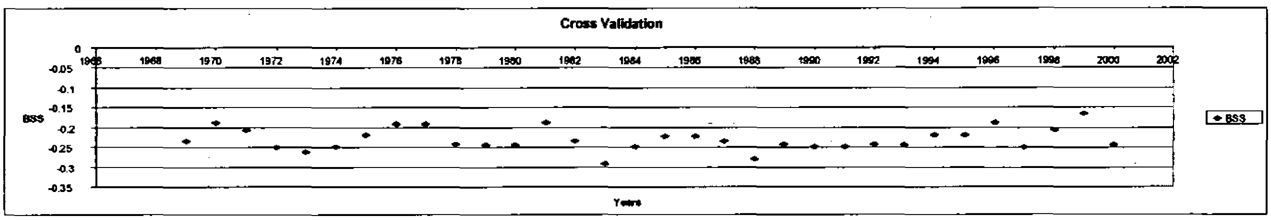

Figure 3.11a: Cross Validation of Era-40 Climatological Probability & ECMWF Probabilistic Forecast for Rahimyar Khan

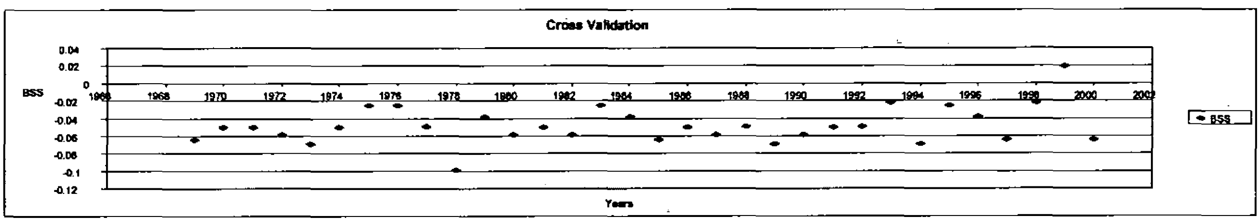

Figure 3.11b: Cross Validation of Era-40 Climatological Probability & Meteo France Probabilistic Forecast for Rahimyar Khan

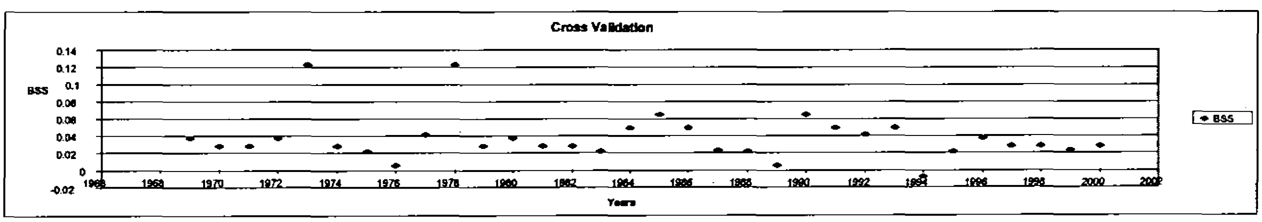

Figure 3.11c: Cross Validation of Era-40 Climatological Probability & MPI Probabilistic Forecast for Rahimyar Khan

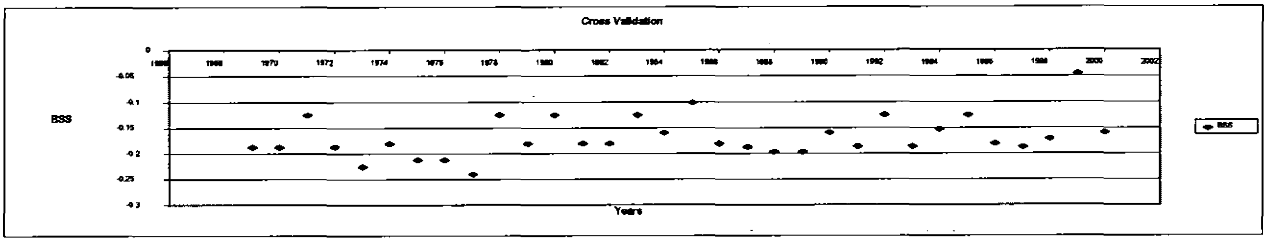

Figure 3.11d: Cross Validation of Era-40 Climatological Probability & UKMO Probabilistic Forecast for Rahimyar Khan

KHAIRPUR:

For Khairpur, only Era-40 was used for ROC due to unavailability of PMD data. ROC gave "poor forecast" with all initial conditions of ECMWF and by eliminating initial conditions seven and eight. Eliminating initial conditions five generated "skill forecast". Meteo-France gave "skill forecast" including all initial conditions and by ignoring initial conditions two and seven. Eliminating initial condition three generated "poor forecast". In case of MPI when ROC curve was plotted it gave "skill forecast" with all initial conditions and by eliminating initial conditions zero and six. UKMO had "skill forecast" covering all initial conditions and by alternatively eliminated initial conditions zero, four and eight.

Table 3.8: Relative Operating Characteristic output for Khairpur

Sr. no	Model	Eliminated initial conditions	Average of probabilistic forecast	Area under the curve	Status of forecast
1	Era-40 vs PF9		0.33	0.49	Poor forecast
		5	0.34	0.51	Skill forecast
		7	0.32	0.46	Poor forecast
		8	0.35	0.45	Poor forecast
2	Era-40 Vs Meteo-France		0.33	0.57	Skill forecast
		2	0.35	0.57	Skill forecast
		3	0.32	0.48	Poor forecast
		7	0.34	0.60	Skill forecast
3	Era-40 vs MPI		0.33	0.67	Skill forecast
		0	0.34	0.63	Skill forecast
		6	0.32	0.58	Skill forecast
4	Era-40 vs UKMO		0.33	0.58	Skill forecast
		0	0.32	0.56	Skill forecast
		4	0.35	0.59	Skill forecast
		8	0.34	0.58	Skill forecast

Null hypothesis: true area = 0.5
Asymptotic Confidence Interval = 95%

Rainfall data of Sukkur was applied for cross validation only against Era-40. For ECMWF, Meto-france, MPI and UKMO severe events were observed during 32 years (Figures 3.12). There severe events cause disturbance to the accuracy of forecast .

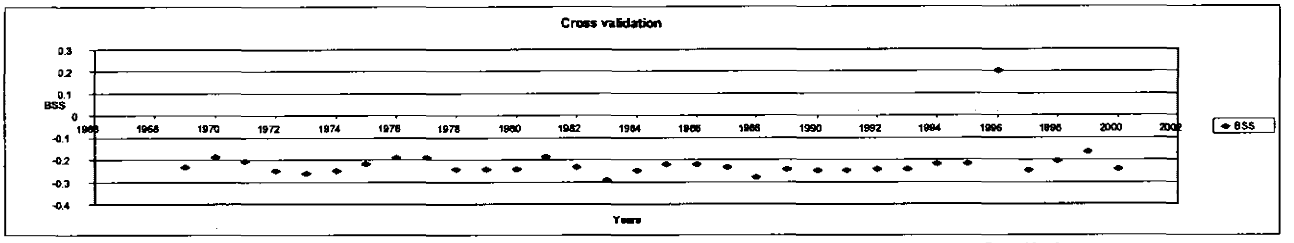

Figure 3.12a: Cross Validation of Era-40 Climatological Probability & ECMWF Probabilistic Forecast for Khairpur

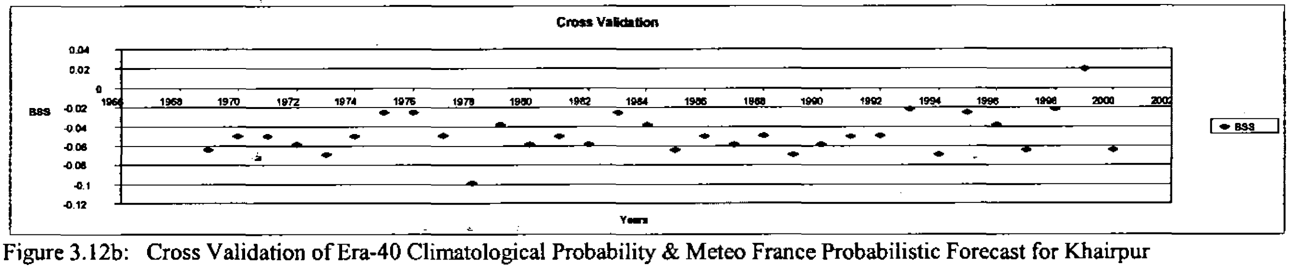

Figure 3.12b: Cross Validation of Era-40 Climatological Probability & Meteo France Probabilistic Forecast for Khairpur

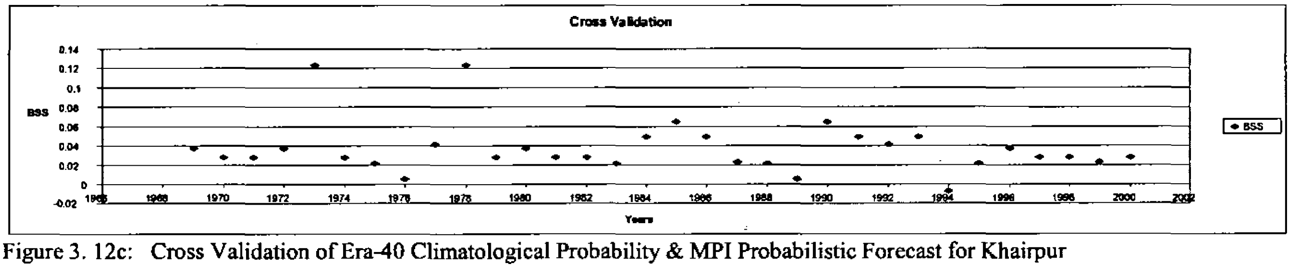

Figure 3. 12c: Cross Validation of Era-40 Climatological Probability & MPI Probabilistic Forecast for Khairpur

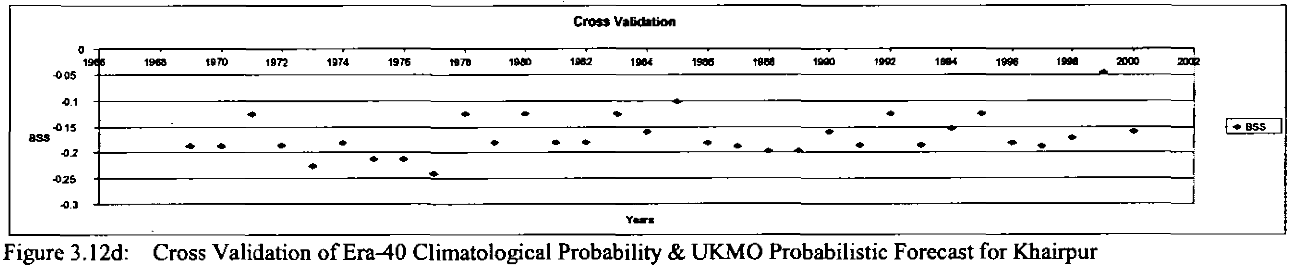

Figure 3.12d: Cross Validation of Era-40 Climatological Probability & UKMO Probabilistic Forecast for Khairpur

SUKKUR:

For Sukkur ROC was only calculated against Era-40. ECMWF and Meteo-France showed "skill forecast" as well as "poor forecast" for different cases. MPI and UKMO generated "skill forecast" with all nine initial conditions and with alternatively eliminated initial conditions.

Table 3.9: Relative Operating Characteristics output for Sukkur

Sr. no	Model	Eliminated initial conditions	Average of probabilistic forecast	Area under the curve	Status of forecast
1	Era-40 vs ECMWF		0.33	0.49	Poor forecast
		3	0.34	0.49	Poor forecast
		6	0.32	0.53	Skill forecast
		8	0.35	0.45	Poor forecast
2	Era-40 Vs Meteo- France		0.33	0.57	Skill forecast
		2	0.35	0.57	Skill forecast
		5	0.32	0.58	Poor forecast
		7	0.34	0.60	Skill forecast
3	Era-40 vs MPI		0.33	0.67	Skill forecast
		0	0.34	0.63	Skill forecast
		7	0.32	0.67	Skill forecast
4	Era-40 vs UKMO		0.33	0.58	Skill forecast
		2	0.32	0.59	Skill forecast
		4	0.34	0.59	Skill forecast
		8	0.35	0.58	Skill forecast

Null hypothesis: true area = 0.5
Asymptotic Confidence Interval = 95%

Rainfall forecast data of selected models was only processed for cross validation against Era-40. Extreme events were recorded during different years affecting the accuracy of forecast (Figures 3.13).

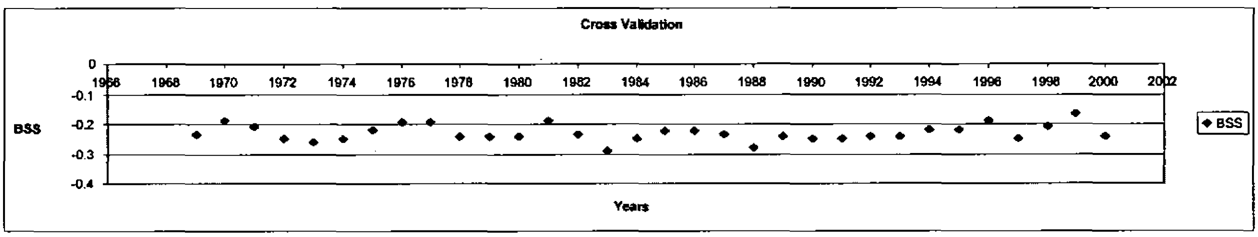

Figure 3.13a: Cross Validation of Era-40 Climatological Probability & ECMWF Probabilistic Forecast for Sukkur

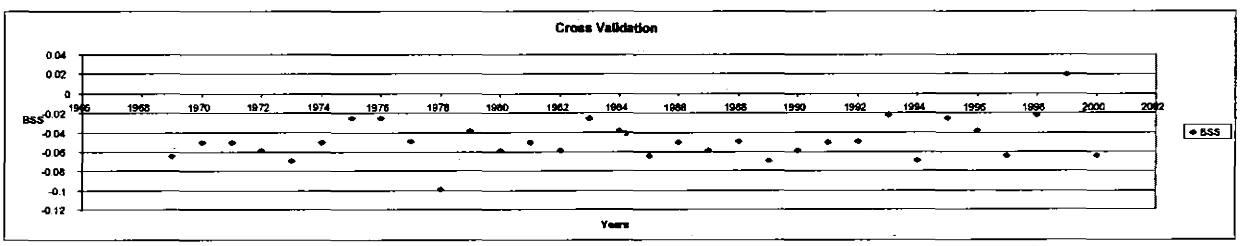

Figure 3.13b: Cross Validation of Era-40 Climatological Probability & Meteo France Probabilistic Forecast for Sukkur

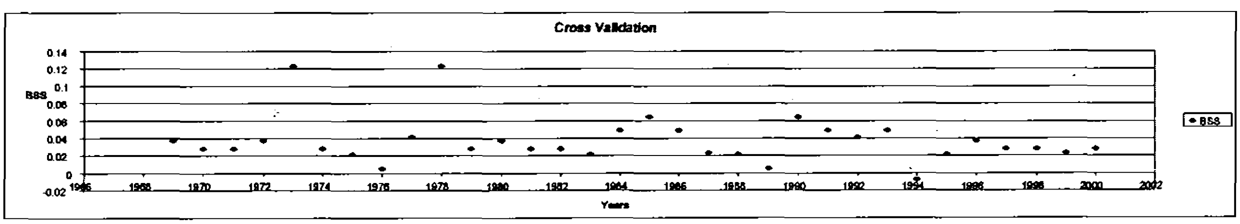

Figure 3.13c: Cross Validation of Era-40 Climatological Probability & MPI Probabilistic Forecast for Sukkur

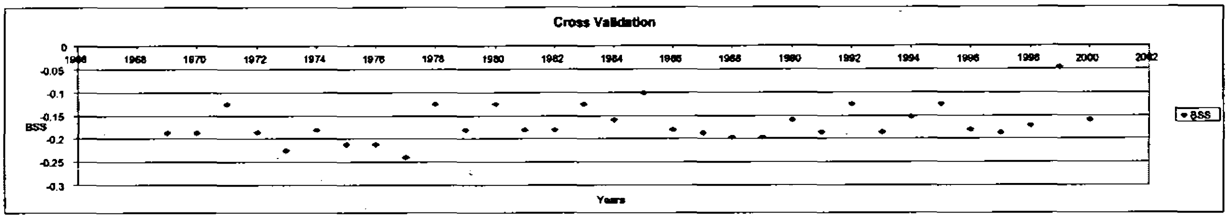

Figure 3.13d: Cross Validation of Era-40 Climatological Probability & UKMO Probabilistic Forecast for Sukkur

BADIN:

Skill of forecast was tested by Relative Operating Characteristic (ROC). For Badin, It gave "skill forecast" when curve was plotted for Era-40 against PMD. When all models results were plotted against PMD, ECMWF presented "poor forecast" while Meteo-France and MPI showed skillful forecast with all initial conditions and with alternative initial conditions. UKMO generated "skill forecast" by eliminating initial condition four against PMD while with all initial condition and by eliminating initial conditions three and five generated "poor forecast". ECMWF plotted against Era-40 gave depicted forecast as "poor forecast". Meteo-France, MPI and UKMO generated "skill forecast" when ROC curve was plotted against Era-40.

Table 3.10: Relative Operating Characteristics output for Badin

Sr. no	Model	Eliminated initial conditions	Average of probabilistic forecast	Area under the curve	Status of forecast
1	PMD vs Era-40		------	0.65	Skill forecast
	PMD vs ECMWF		0.33	0.43	Poor forecast
		0	0.34	0.47	Poor forecast
		1	0.35	0.45	Poor forecast
		6	0.32	0.42	Poor forecast
	Era-40 vs ECMWF		0.33	0.46	Poor forecast
2	PMD vs Meteo- France		0.33	0.55	Skill forecast
		0	0.34	0.54	Skill forecast
		3	0.32	0.60	Skill forecast
		7	0.35	0.55	Skill forecast
	Era-40 vs Meteo- France		0.33	0.58	Skill forecast
3	PMD vs MPI		0.33	0.68	Skill forecast
		0	0.36	0.67	Skill forecast
		2	0.32	0.72	Skill forecast
		3	0.35	0.69	Skill forecast
		4	0.34	0.66	Skill forecast
		8	0.31	0.68	Skill forecast
	Era-40 vs MPI		0.33	0.58	Skill forecast
4	PMD vs UKMO		0.33	0.49	Poor forecast
		3	0.32	0.47	Poor forecast
		4	0.34	0.52	Skill forecast
		5	0.35	0.48	Poor forecast
	Era-40 vs UKMO		0.33	0.57	Skill forecast

Null hypothesis: true area = 0.5
Asymptotic Confidence Interval = 95%

For Badin, in figures 3.14 cross validation of different models against PMD highlighted the years with unusual occurrences. The values representing unusual events create hurdles for better forecast.

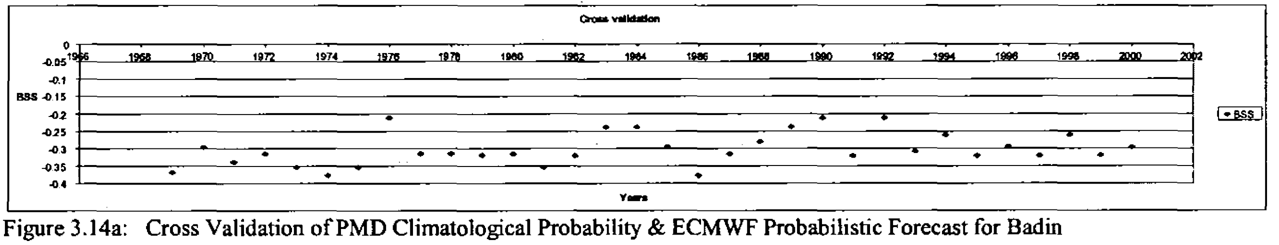

Figure 3.14a: Cross Validation of PMD Climatological Probability & ECMWF Probabilistic Forecast for Badin

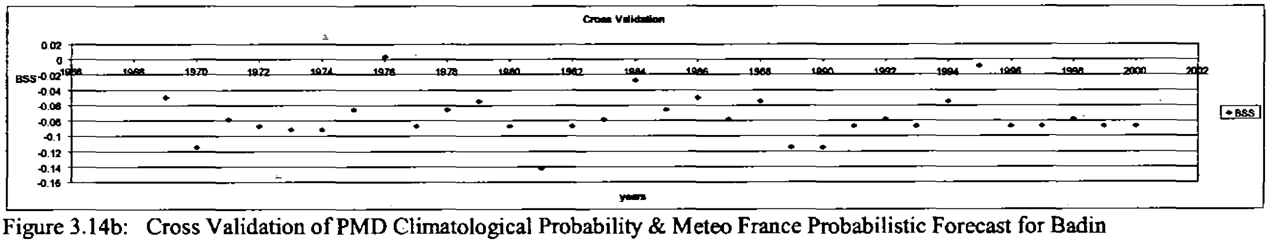

Figure 3.14b: Cross Validation of PMD Climatological Probability & Meteo France Probabilistic Forecast for Badin

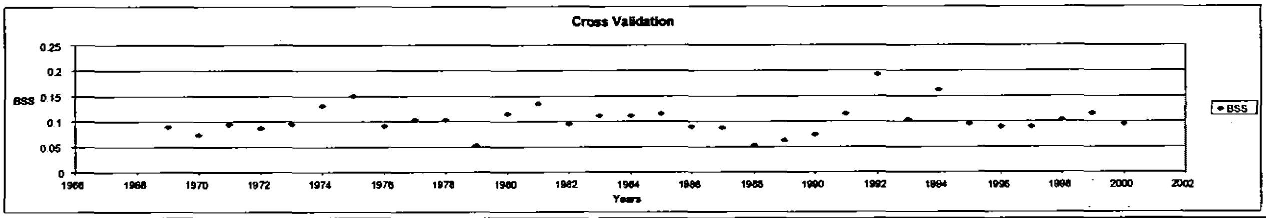

Figure 3.14c: Cross Validation of PMD Climatological Probability & MPI Probabilistic Forecast for Badin

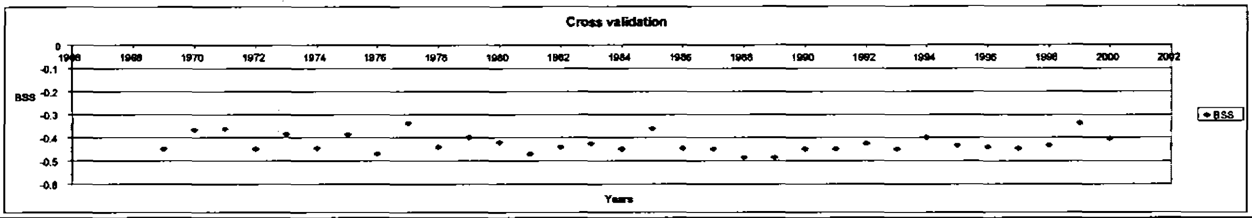

Figure 3.14d: Cross Validation of PMD Climatological Probability & UKMO Probabilistic Forecast for Badin

For Badin, cross validation of different models against Era-40 found the years with extreme events in figures 3.15. These values create hurdles for better and brilliant forecast. Eliminating these values during dealing out may offer better and accurate forecast for Badin using simulated data of Era-40.

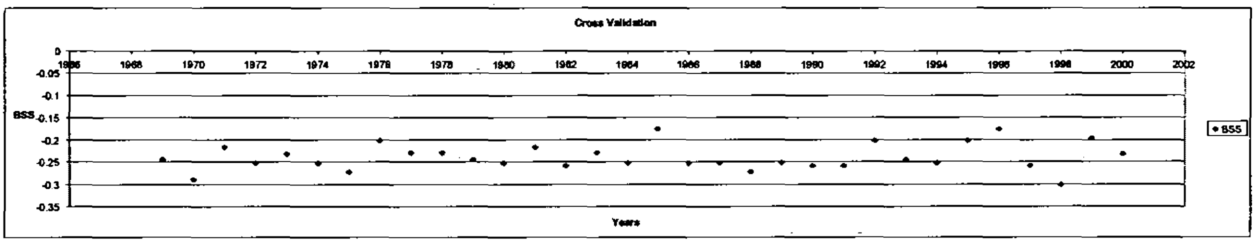

Figure 3.15a: Cross Validation of Era-40 Climatological Probability & ECMWF Probabilistic Forecast for Badin

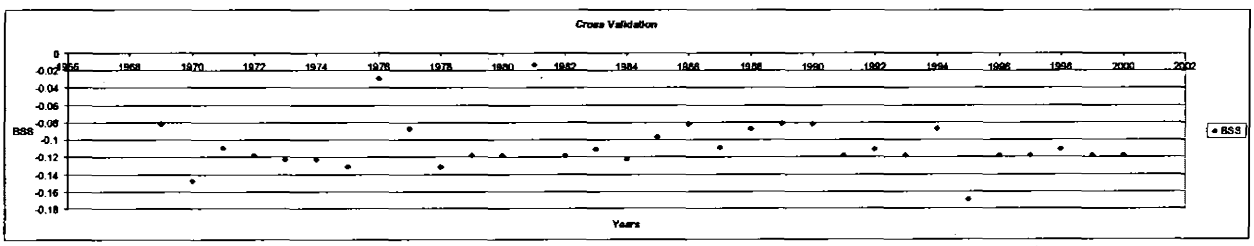

Figure 3.15b: Cross Validation of Era-40 Climatological Probability & Meteo France Probabilistic Forecast for Badin

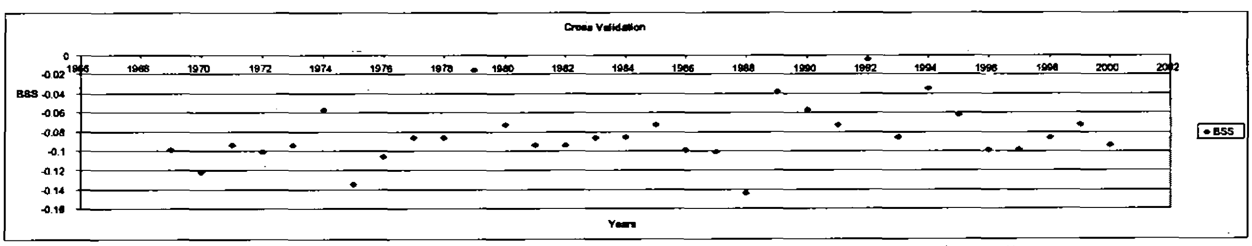

Figure 3.15c: Cross Validation of Era-40 Climatological Probability & MPI Probabilistic Forecast for Badin

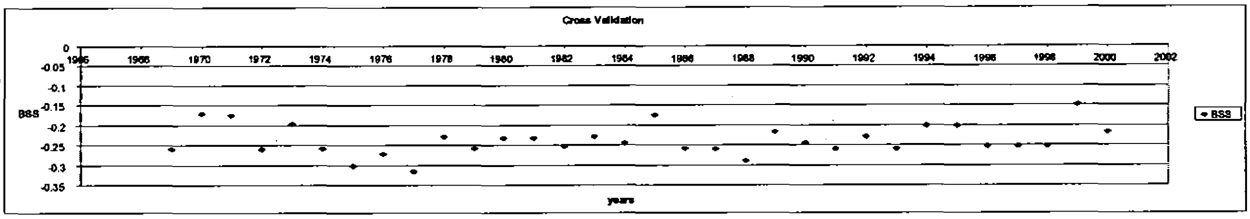

Figure 3.15d: Cross Validation of Era-40 Climatological Probability & UKMO Probabilistic Forecast for Badin

NAWABSHAH:

For Nawabshah, ROC curve was plotted for Era-40 against PMD which generated "skill forecast". For all models ROC curves were plotted against PMD. MPI and UKMO gave skillful forecast while ECMWF and Meteo-France did not produce good skill of forecast against PMD. While against Era-40 "skill forecast" was observed for ECMWF and MPI other two models showed "poor forecast".

Table 3.11: Relative Operating Characteristics output for Nawabshah

Sr. no	Model	Eliminated initial conditions	Average of probabilistic forecast	Area under the curve	Status of forecast
1	PMD Vs Era-40		------	0.65	Skill forecast
	PMD vs ECMWF		0.33	0.44	Poor forecast
		2	0.34	0.40	Poor forecast
		3	0.35	0.45	Poor forecast
		5	0.32	0.38	Poor forecast
	Era-40 vs ECMWF		0.33	0.60	Skill forecast
2	PMD Vs Meteo- France		0.33	0.47	Poor forecast
		0	0.34	0.42	Poor forecast
		2	0.36	0.43	Poor forecast
		8	0.32	0.45	Poor forecast
	Era-40 Vs Meteo- France		0.33	0.47	Poor forecast
3	PMD vs MPI		0.33	0.56	Skill forecast
		2	0.34	0.55	Skill forecast
		8	0.32	0.57	Skill forecast
	Era-40 vs MPI		0.33	0.60	Skill forecast
4	PMD vs UKMO		0.33	0.51	Skill forecast
		7	0.32	0.49	Skill forecast
		8	0.34	0.49	Skill forecast
	Era-40 vs UKMO		0.33	0.54	Poor forecast

Null hypothesis: true area = 0.5
Asymptotic Confidence Interval = 95%

For Nawabshah cross validation of different models against PMD presented the years with extreme events and occurrences. These values create hurdles for accurate forecast (Figures 3.16).

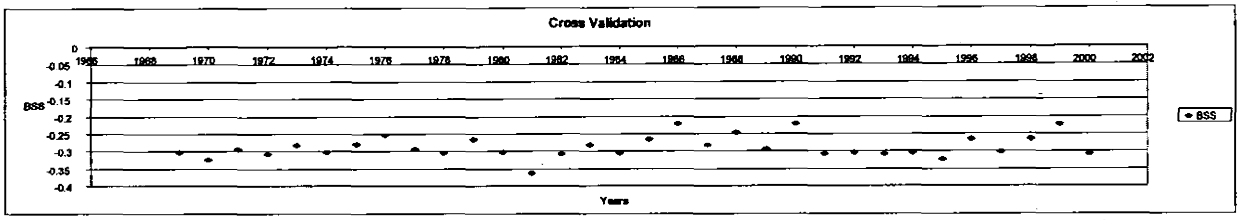

Figure 3.16a: Cross Validation of PMD Climatological Probability & ECMWF Probabilistic Forecast for Nawabshah

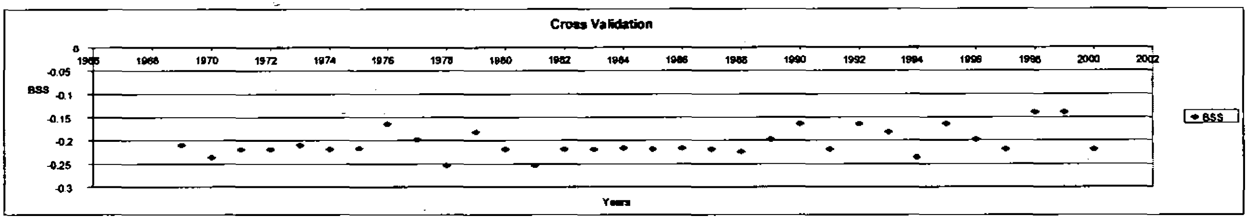

Figure 3.16b: Cross Validation of PMD Climatological Probability & Meteo France Probabilistic Forecast for Nawabshah

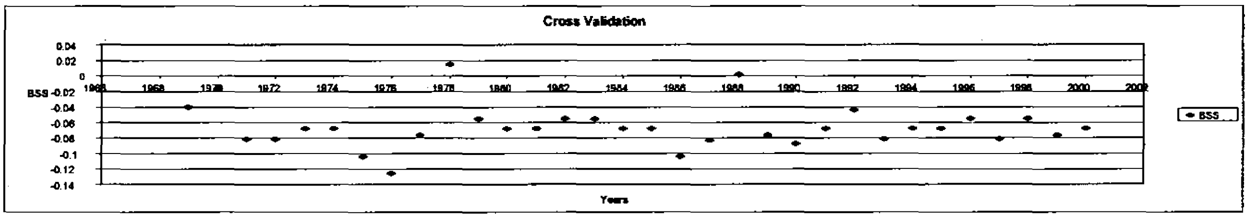

Figure 3.16c: Cross Validation of PMD Climatological Probability & MPI Probabilistic Forecast for Nawabshah

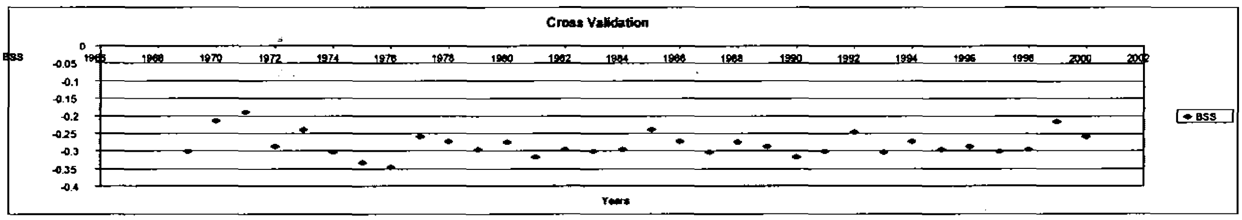

Figure 3.16d: Cross Validation of PMD Climatological Probability & UKMO Probabilistic Forecast for Nawabshah

Cross validation of different models against Era-40 highlighted the years with unusual occurrences in figures 3.17. These severe events agitate the accuracy of forecast however efficiency and accuracy of forecast can be enhanced.

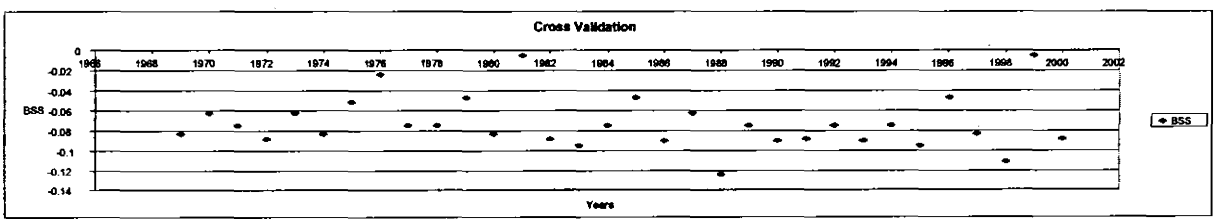

Figure 3.17a: Cross Validation of Era-40 Climatological Probability & ECMWF Probabilistic Forecast for Nawabshah

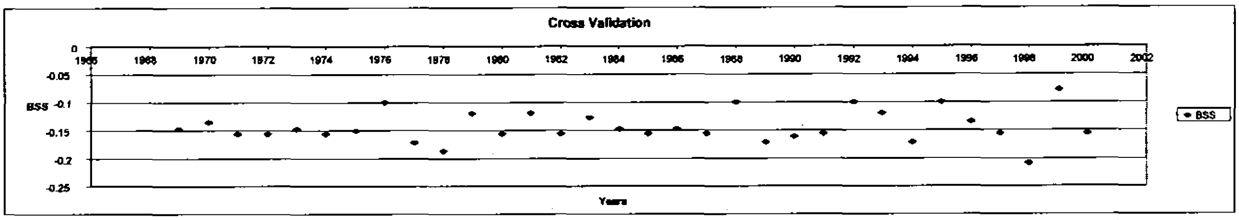

Figure 3.17b: Cross Validation of Era-40 Climatological Probability & Meteo France Probabilistic Forecast for Nawabshah

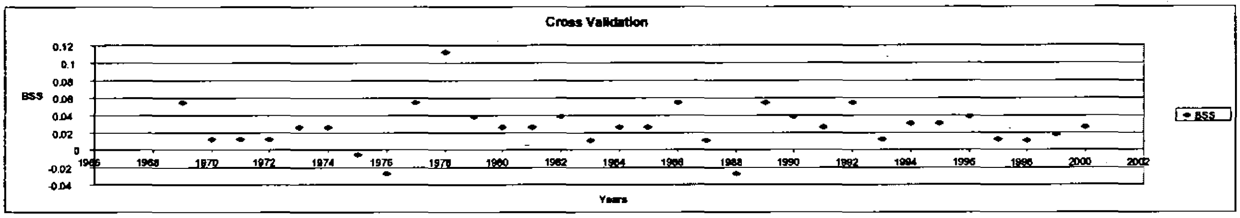

Figure 3.17c: Cross Validation of Era-40 Climatological Probability & MPI Probabilistic Forecast for Nawabshah

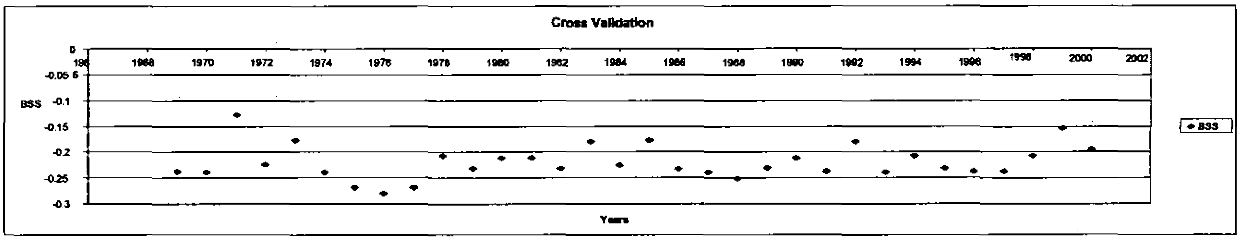

Figure 3.17d: Cross Validation of Era-40 Climatological Probability & UKMO Probabilistic Forecast for Nawabshah

3.4 Multi model probabilistic forecast for Eastern Monsoon Belt

Multi-model methods were used in various forecasting applications such as economic and weather forecasting as early as the 1960s. Multi-model combinations are approached to analyze the simulation results from multiple models that participated in reducing vulnerabilities and enhancing efficiency of combinations. These multi-model techniques provide consensus predictions and selected by linearly combining individual model predictions according to different weighting strategies i-e the models with better skill are combined together.

Due to the inadequacies, of numerical models forecast errors grow with increasing lead time. To reduce these imbiguities various models are combined to form multi models. In this study two kinds of errors: initial condition errors and model errors were refered respectively. For the prediction of the climatic and weather conditions, these two kinds of errors are not really separable because the estimation of the initial conditions involves a forecast model and thus initial condition errors are affected by model errors.

Different combinations of these models were formed to determine the most accurate forecast. Multi-model ensemble averages produced by these methods have shown to consistently perform better than single model predictions when they are evaluated based on various predictive skill and reliability scores. ECMWF and Meteo-France were combined as these models had "skill forecast" in many cases during hindcast study. ECMWF was combined with MPI. In this case MPI had better skill and accuracy as single model. MPI was combined with ECMWF for much better accuracy and skillful forecast.

3.5 Seasonal Hindcast using Multi Model Ensemble Predictions Systems

By using MM-EPS, seasonal hindcast of rainfall for different selected areas i-e Islamabad, Rawalpindi, Jhelum, Lahore, Bahawalnagar, Rahimyar Khan, Khairpur, Sukkur, Badin and Nawabshah in monsoon belt was calculated for 32 years. Selected months for study were July, August and September. "Upper tercile" was used for maximum amount of rainfall. Mainly four multi models were formed: multi model I was formed by combining ECMWF with Meteo-France, multi model II consisted of ECMWF and MPI, multi model III was formed by combining Meteo-France and MPI and finally the last multi model IV was the combination of ECMWF, Meteo-France and MPI.

For multi model I probabilistic forecast of all selected areas was 0.33 presenting a "good forecast". Against PMD multi model I was not reliable for any of the selected area while against Era-40 it showed reliability only for Lahore. Multi model II probabilistic forcast was 0.33 while only Jhelum forecast was 0.34 hence all selected areas showed "good forecast". Against PMD multi model II showed reliability for Islamabad, Rawalpindi and Lahore. While it was reliable for Islamabad, Jhelum, Lahore, Rahimyar Khan, Khairpur, Sukkur and Nawabshah when it was calculated against Era-40. Probabilistic forecast for multi model III was 0.33 only Jhelum had 0.34 indicating "good forecast" for all selected areas. This model was reliable for Islamabad, Rawalpindi, Lahore, Bahawalnagar and Badin against PMD while against Era-40 multi model III showed reliability for Islamabad, Jhelum, Lahore, Bahwalnagar, Rahimyar Khan, Khairpur, Sukkur, Badin and Nawabshah. Multi model IV probabilistic forecast was 0.33 for eight selected areas only Jhelum and Sukkur had 0.34. Against PMD multi model IV was reliable for Islmabad, Rawalpindi, Lahore and Badin while against Era-40 it showed reliability for Lahore, Rahimyar Khan, Khairpur, Sukkur and Nawabshah.

Table 3.12: Results evaluated from climate multi models

City				Multi model I	Multi model II	Multi model III	Multi model IV
	Findings	PMD*	Era-40**	ECMWF+Meteo-France	ECMWF+ MPI	Meteo-France+ MPI	ECMWF+Meteo-France+MPI
Islamabad	Probabilistic Forecast	0.34	0.34	0.33	0.33	0.33	0.33
	Reliability			0	1	1	1*/0**
	Brier Score			0.23*/0.26**	0.21*/0.21**	0.21*/0.22**	0.21*/0.23**
Rawalpindi	Probabilistic Forecast	0.34	0.34	0.33	0.33	0.33	0.33
	Reliability		0	0	1*/0**	1*/0**	1*/0**
	Brier Score			0.25*/0.23**	0.22*/0.25**	0.22*/0.24**	0.22*/0.24**
Jhelum	Probabilistic Forecast	0.34	0.34	0.33	0.34	0.34	0.34
	Reliability		0	0	0*/1**	0*/1**	0
	Brier Score			0.26*/0.26**	0.25*/0.21**	0.25*/0.22**	0.25*/0.23**
Lahore	Probabilistic Forecast	0.34	0.34	0.33	0.33	0.33	0.33
	Reliability		0	0*/1**	1	1	1
	Brier Score			0.23*/0.22**	0.22*/0.19**	0.20*/18**	0.21*/19**
Bahawalnagar	Probabilistic Forecast	0.34	0.34	0.33	0.33	0.33	0.33
	Reliability			0	0	1	0
	Brier Score			0.24*/0.24**	0.24*/0.27**	0.21*/0.22**	0.23*/0.24**
Rahim Yar Khan	Probabilistic Forecast	0.34	0.33	0.33	0.33	0.33	0.33
	Reliability		0	0	1	1	1
	Brier Score			0.24**	0.22**	0.21**	0.22**
Khairpur	Probabilistic Forecast	0.34	0.33	0.33	0.33	0.33	0.33
	Reliability		0	0	1	1	1
	Brier Score			0.24**	0.22**	0.21**	0.22**
Sukkur	Probabilistic Forecast	0.33	0.34	0.33	0.33	0.33	0.34
	Reliability			0	1	1	1
	Brier Score			0.24**	0.22**	0.21**	0.22**
Badin	Probabilistic Forecast	0.34	0.34	0.33	0.33	0.33	0.33
	Reliability			0	0	1	1*/0**
	Brier Score			0.25*/0.25**	0.23*/0.24**	0.20*/0.22**	0.22*/0.23**
Nawabshah	Probabilistic Forecast	0.33	0.34	0.33	0.33	0.33	0.33
	Reliability			0	0*/1**	0*/1**	0*/1**
	Brier Score			0.27*/0.24**	0.24*/0.21**	0.23*/0.22**	0.24*/0.22**

- = PMD and ** = Era-40

3.6 Numerical Modelling For Multi Model Ensemble System

Using selected models, multi models were formed to signify the skill and accuracy of models for rainfall forecast in selected areas of EMB.

3.6.1 Multi model I

Multi model forecasting was used to improve the accuracy of forecast to reduce uncertainties and subsequent consequences. Skill of forecast i-e quality of forecast was checked by ROC . Covered area value above 0.5 represents the "skill forecast" and covered area value below 0.5 depicts false alarms or "poor forecast". For multi models ECMWF was combined with Meteo-France and probabilistic forecast was calculated with 18 initial conditions. Alternatively all initial conditions were eliminated and were computed against PMD and Era-40 for all selected cities. Probabilistic forecast having same value was randomly selected for ROC. It gave "skill forecast" for Islamabad, Lahore, and Nawabshah. Forecast of Rawalpindi, Jhelum, Bahawalnagar and Badin were a "poor forecast" when computed with all initial conditions against PMD.

Probabilistic forecast with all initial conditions was calculated against Era-40. "Skillful forecast" for some selected areas was obtained. Probabilistic forecast of Rahimyar Khan, Khairpur and Sukkur were calculated only against Era-40 due to unavailability of PMD real time data. "Skill forecast" was obtained for Rawalpindi, Lahore, Rahimyar Khan, Khairpur, Sukkur, Badin and Nawabshah. When ROC curve was plotted against Era-40 there was "poor forecast" for Islamabad, Jhelum and Bahawalnagar.

Table 3.13: Relative Operating Characteristics output for multi model (ECMWF and Meteo-France)

Sr No	City	Model ECMWF + Meteo-France	Eliminated Initial conditions	Average of probabilistic forecast	Area under the curve	Status of forecast
				0.33	0.60	Skill forecast
		vs PMD	8	0.32	0.60	Skill forecast
1	Islamabad		13	0.34	0.57	Skill forecast
			14	0.33	0.63	Skill forecast
		vs Era-40		0.33	0.42	Poor forecast
				0.33	0.46	Poor forecast
2	Rawalpindi	vs PMD	11	0.34	0.46	Poor forecast
			13	0.33	0.45	Poor forecast
		vs Era-40		0.33	0.55	Skill forecast
				0.33	0.36	Poor forecast
3	Jhelum	vs PMD	8	0.32	0.37	Poor forecast
			13	0.34	0.36	Poor forecast
		vs Era-40		0.33	0.42	Poor forecast
				0.33	0.51	Skill forecast
4	Lahore	vs PMD	9	0.33	0.52	Skill forecast
			12	0.34	0.53	Skill forecast
		vs Era-40		0.33	0.60	Skill forecast
				0.33	0.46	Poor forecast
5	Bahawalnagar	vs PMD	12	0.34	0.49	Poor forecast
			18	0.33	0.39	Poor forecast
		vs Era-40		0.33	0.38	Poor forecast
				0.33	0.54	Skill forecast
6	Rahim Yar Khan	vs Era-40	6	0.34	0.55	Skill forecast
			11	0.33	0.51	Skill forecast
				0.33	0.54	Skill forecast
7	Khairpur	vs Era-40	15	0.33	0.54	Skill forecast
			16	0.34	0.54	Skill forecast
				0.33	0.54	Skill forecast
8	Sukkur	vs Era-40	15	0.33	0.54	Skill forecast
			16	0.34	0.54	Skill forecast
				0.33	0.47	Poor forecast
9	Badin	vs PMD	2	0.33	0.47	Poor forecast
			17	0.34	0.48	Poor forecast
		vs Era-40		0.33	0.54	Skill forecast
				0.33	0.72	Skill forecast
10	Nawabshah	vs PMD	9	0.34	0.71	Skill forecast
			12	0.35	0.71	Skill forecast
		vs Era-40		0.33	0.60	Skill forecast

Null hypothesis: true area = 0.5
Asymptotic Confidence Interval = 95%

Cross validation calculates the accuracy of forecast. Accuracy of forecast is being affected by extreme events. These extreme events show unusual distribution pattern. Cross validation was performed for Multi models against PMD and Era-40.

Cross validation with PMD in Islamabad showed extreme events in the years of 1990, 1998 and 1999. Extreme events in Rawalpindi had occurred in 1974, 1975, 1977, 1990, 1995 and 1998. In case of Jhelum below and above rainfall were in the years of 1990 and 1998. After cross validating the values of Lahore in years 1978, 1984, 1990, 1995 and 1996 demonstrated unusual rainfall pattern. In 1972, 1978, 1988, 1992, 1995, 1996 and 1998 below and above rainfall must had occurred for Bahawalnagar. Multi model cross validation of Badin presented extreme events in 1970, 1976, 1981, 1984 and 1985. In Nawabshah extreme events were observed in 1976, 1981, 1990 and 1999. Data is normalized by eliminating outlier values existing above and below average. This reveals better and accurate forecast.

Cross validation of all selected cities were also performed against Era-40. Cross validation of Islamabad data illustrated extreme events in 1980, 1984, 1990, 1998 and 1999. For Rawalpindi yearly values of 1974, 1975, 1990, 1995, 1997, 1998 and 2000 were disturbing the accuracy of forecast. For Jhelum only 1990 data represented above normal rainfall. Lahore hindcast data presented many unusual events in many years like 1971, 1977, 1978, 1982, 1988, 1989, 1991, 1993, 1995, 1996, 1997 and 1998. Bahawalnagar hindcast presented below and above rainfall in 1984, 1988, 1996 and 1998. PMD was not established since 1969 in Rahimyar Khan, Khairpur and Sukkur so no real time data is available from 1969. Cross validation of Rahimyar khan, Khairpur and Sukkur was only performed against Era-40. 1970, 1971, 1975, 1976, 1977, 1981, 1995, 1996, 1998 and 1999 yearly values of these districts presented unusual data disturbing accuracy of forecast. Extreme rainfall occurred in Badin in 1970, 1976, 1981, 1984, 1985, 1992, 1996 and 1998. Unusual events were presented by values in years i-e 1976, 1979, 1981, 1992, 1998 and 1999 for Nawabshah. Data is normalized by removing outlier values existing above and below average. This exposes better and accurate forecast.

Islamabad

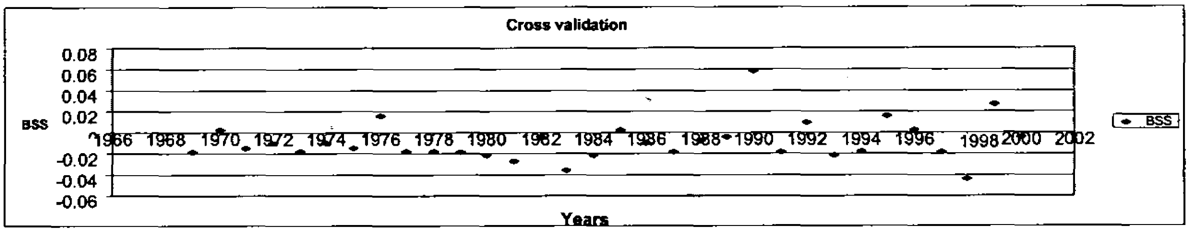

Figure 3.18a: Cross Validation of PMD Climatological Probability & ECMWF+Meteo-France Probabiistic Forecast for Islamabad

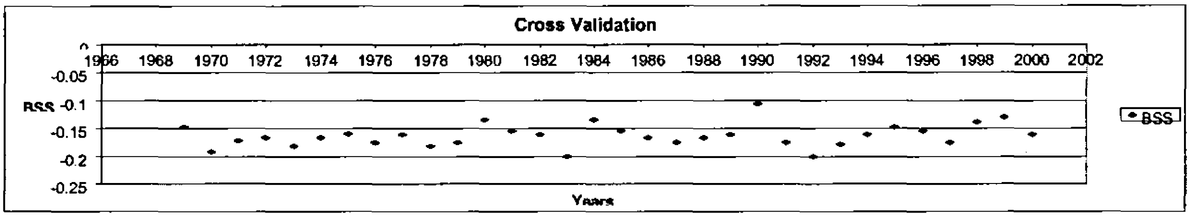

Figure 3.18b: Cross Validation of Era-40 Climatological Probability & ECMWF+Meteo-France Probabilistic Forecast for Islamabad

Rawalpindi

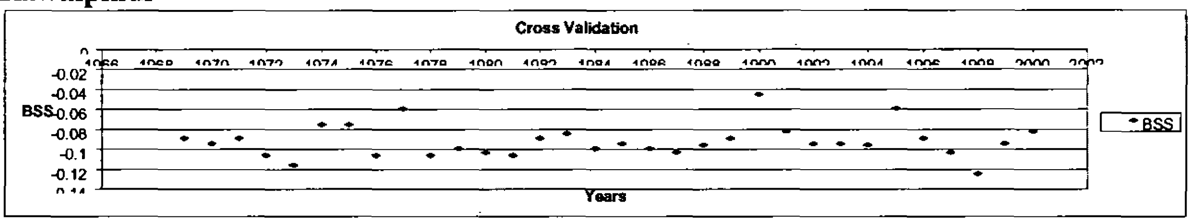

Figure 3.18c: Cross Validation of PMD Climatological Probability & ECMWF+Meteo-France Probabilistic Forecast for Rawalpindi

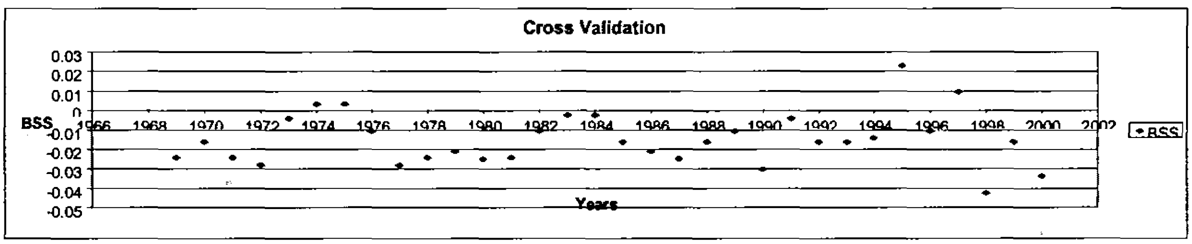

Figure 3.18d: Cross Validation of Era-40 Climatological Probability & ECMWF+Meteo-France Probabilistic Forecast for Rawalpindi

Jhelum

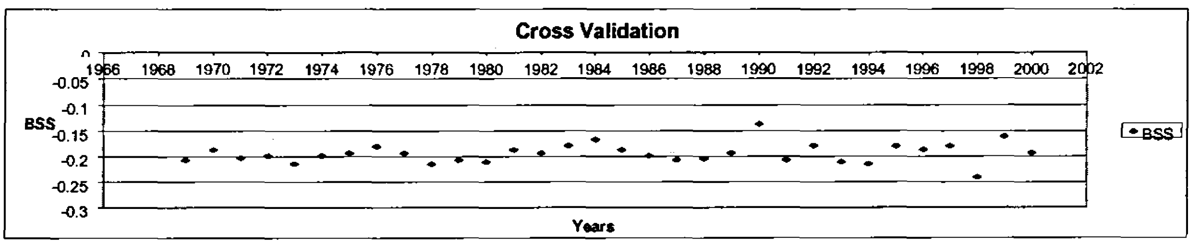

Figure 3. 18e: Cross Validation of PMD Climatological Probability & ECMWF+Meteo-France Probabilistic Forecast for Jhelum

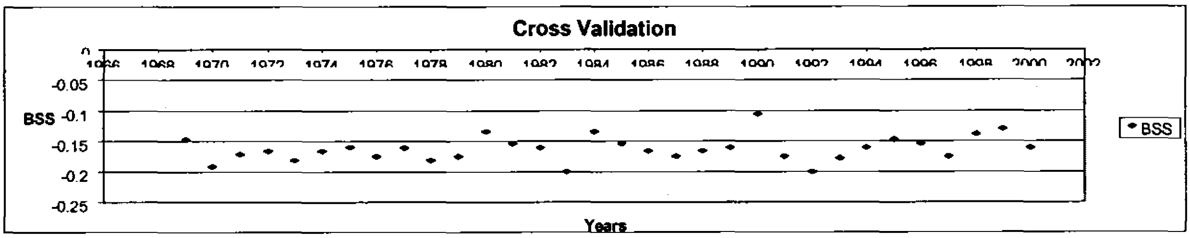

Figure 3.18f: Cross Validation of Era-40 Climatological Probability & ECMWF+Meteo-France Probabilistic Forecast for Jhelum

Lahore

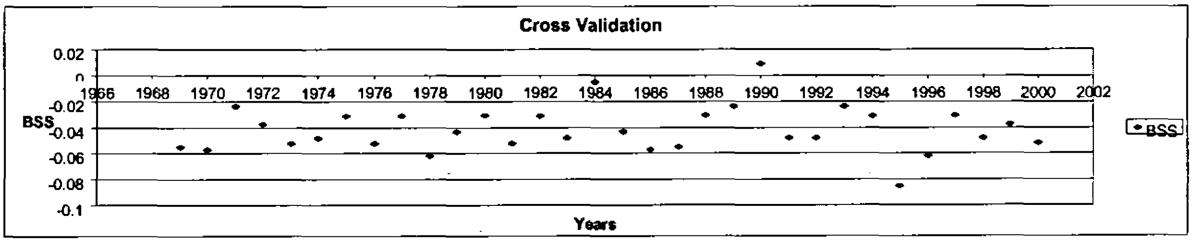

Figure 3.18g: Cross Validation of PMD Climatological Probability & ECMWF+Meteo-France Probabilistic Forecast for Lahore

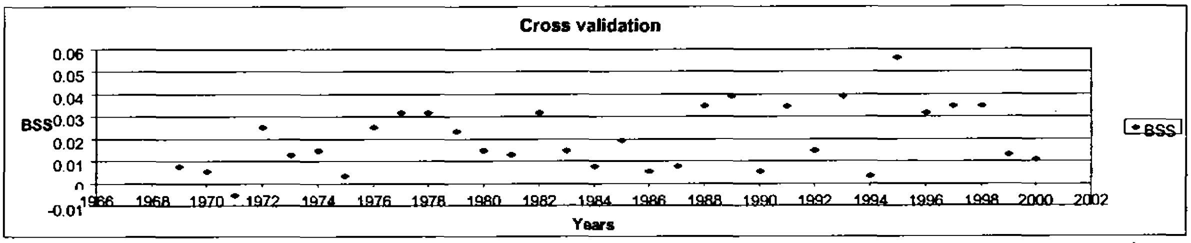

Figure 3.18h: Cross Validation of Era-40 Climatological Probability & ECMWF+Meteo-France Probabilistic Forecast for Lahore

Bahawalnagar

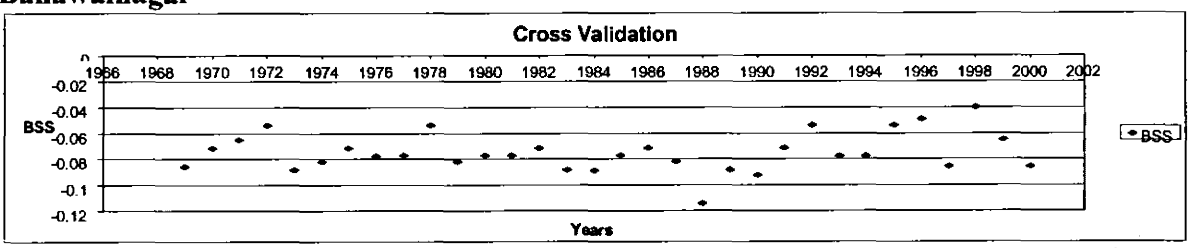

Figure 3.18i: Cross Validation of PMD Climatological Probability & ECMWF+Meteo-France Probabilistic Forecast for Bahawalnagar

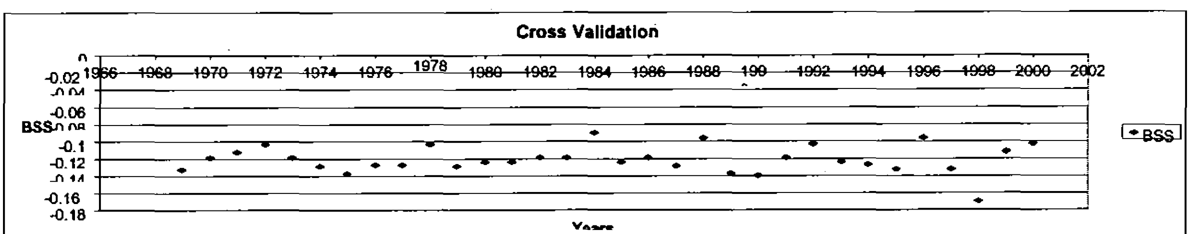

Figure 3.18j: Cross Validation of Era-40 Climatological Probability & ECMWF+Meteo-France Probabilistic Forecast for Bahawalnagar

Rahimyar Khan

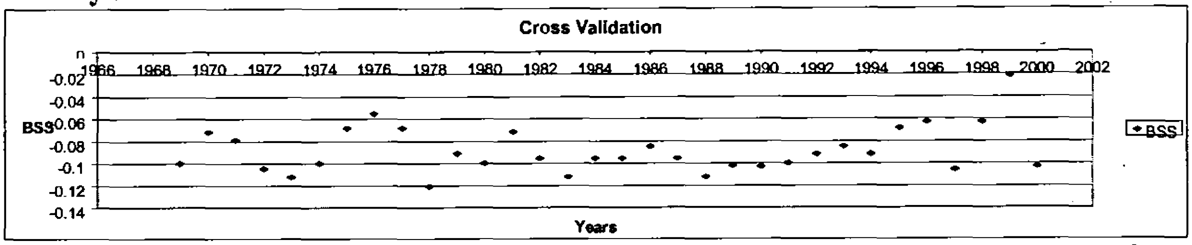

Figure 3.18k: Cross Validation of Era-40 Climatological Probability & ECMWF+Meteo-France Probabilistic Forecast for Rahimyar Khan

Khairpur

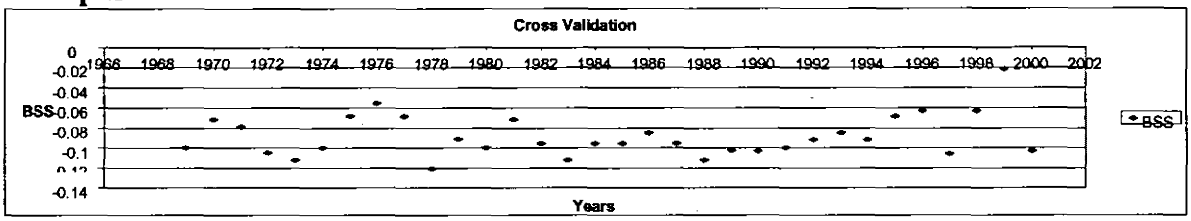

Figure 3.18 l: Cross Validation of Era-40 Climatological Probability & ECMWF+Meteo-France Probabilistic Forecast for Khairpur

Sukkur

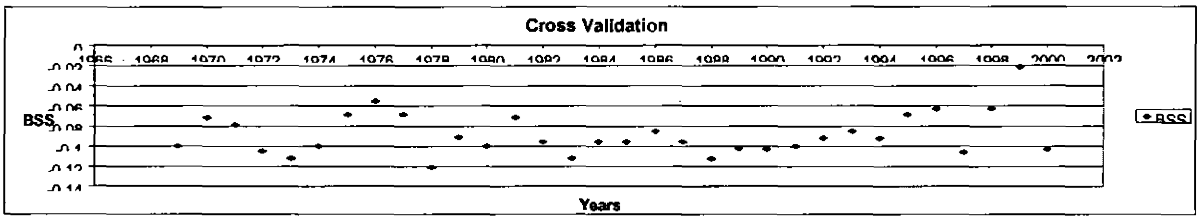

Figure 3.18m: Cross Validation of Era-40 Climatological Probability & ECMWF+Meteo-France Probabilistic Forecast for Sukkur

Badin

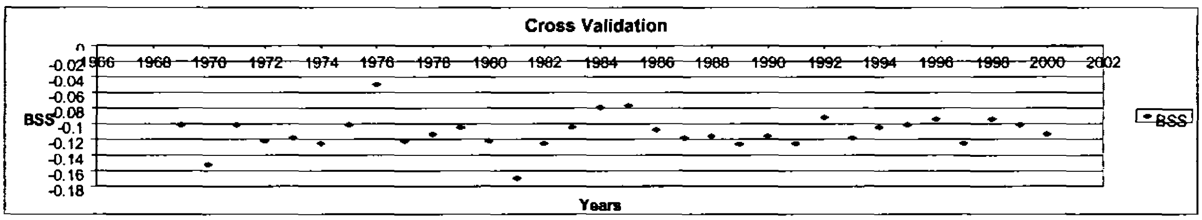

Figure 3.18n: Cross Validation of PMD Climatological Probability & ECMWF+Meteo-France Probabilistic Forecast for Badin

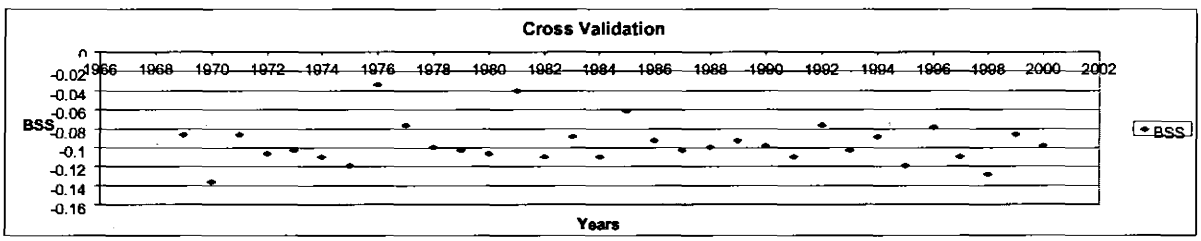

Figure 3.18o: Cross Validation of Era-40 Climatological Probability & ECMWF+Meteo-France Probabilistic Forecast for Badin

Nawabshah

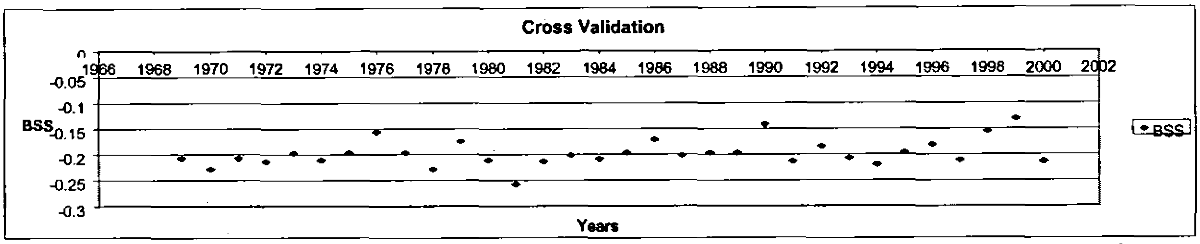

Figure 3.18p: Cross Validation of PMD Climatological Probability & ECMWF+Meteo-France Probabilistic Forecast for Nawabshah

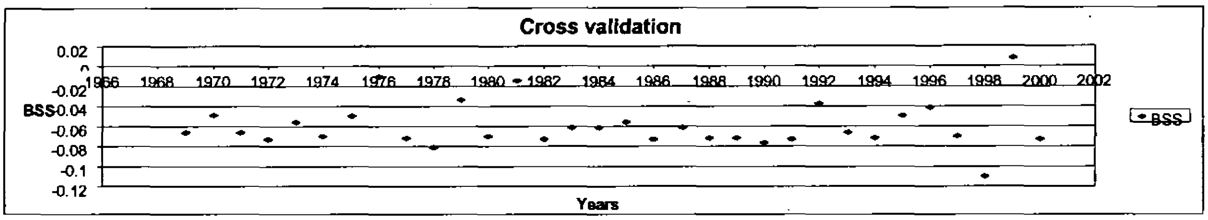

Figure 3.18q: Cross Validation of Era-40 Climatological Probability & ECMWF+Meteo-France Probabilistic Forecast for Nawabshah

3.6.2 Multi model II

All models have their specific features and conditions for rainfall forecasting. Though accuracy and skill of forecast can be enhanced by multi model methods to minimize the uncertainties and damages. ROC carried out the quality of multi model forecast. To maximize the efficiency of models ECMWF was combined with MPI. Using all eighteen initial conditions probabilistic forecast was calculated for selected areas. All initial conditions were alternatively eliminated and forecast of all conditions were calculated against PMD and Era-40. Probabilistic forecast was randomly selected for ROC to check the skill of forecast. Including all initial conditions forecasts of Islamabad, Rawalpindi, Lahore, Badin and Nawabshah generated good "skill forecast" when calculated against PMD. Bahawalnagar did not produce very skillful forecast using multi model approach. ROC curves plotted against Era-40 gave "skill forecast" for Islamabad, Rawalpindi, Jhelum, Lahore, Rahimyar Khan, Khairpur, Sukkur, Badin and Nawabshah. Only Bahawalnagar again did not generated good "skill forecast".

Table 3.14: Relative Operating Characterictics for multi model (ECMWF and Meteo-France)

Sr No	City	Model ECMWF+MPI	Eliminated Initial conditions	Average of probabilistic forecast	Area under the curve	Status of forecast
1	Islamabad			0.33	0.64	Skill forecast
		Vs PMD	8	0.32	0.65	Skill forecast
			9	0.34	0.64	Skill forecast
			11	0.35	0.63	Skill forecast
		Vs Era-40		0.33	0.68	Skill forecast
2	Rawalpndi			0.33	0.63	Skill forecast
		Vs PMD	16	0.34	0.64	Skill forecast
			18	0.32	0.60	Skill forecast
		Vs Era-40		0.33	0.50	No skill forecast
3	Jhelum			0.34	0.48	Poor forecast
		Vs PMD	10	0.34	0.46	Poor forecast
			11	0.35	0.46	Poor forecast
			18	0.32	0.53	Skill forecast
		Vs Era-40		0.34	0.67	Skill forecast
4	Lahore			0.33	0.63	Skill forecast
		Vs PMD	14	0.34	0.62	Skill Forecast
			18	0.32	0.59	Skill forecast
		Vs Era-40		0.33	0.77	Skill forecast
5	Bahawalnagar			0.33	0.50	Skill forecast
		Vs PMD	1	0.34	0.48	Poor forecast
			14	0.32	0.51	Skill forecast
			18	0.33	0.50	Poor forecast
6	RahimYar Khan			0.33	0.57	Skill forecast
		Vs Era-40	15	0.34	0.57	Skill forecast
			16	0.33	0.51	Skill forecast
7	Khairpur			0.33	0.57	Skill forecast
		Vs Era-40	10	0.34	0.55	Skill forecast
			12	0.33	0.55	Skill forecast
8	Sukkur			0.33	0.57	Skill forecast
		Vs Era-40	11	0.34	0.58	Skill forecast
			12	0.33	0.55	Skill forecast
9	Badin			0.33	0.58	Skill forecast
		Vs PMD	5	0.34	0.58	Skill forecast
			8	0.32	0.57	Skill forecast
		Vs Era-40		0.33	0.50	Poor forecast
10	Nawabshah			0.33	0.52	Skill forecast
		Vs PMD	5	0.33	0.53	Skill Forecast
			9	0.34	0.54	Skill forecast
		Vs Era-40		0.33	0.65	Skill Forecast

Null hypothesis: true area = 0.5
Asymptotic Confidence Interval = 95%

Accuracy of multi model was calculated by cross validation method. Extreme and unusual weather and climatic conditions were disturbing accuracy of forecast of all selected areas. Cross validation of selected cities data was performed against PMD and Era-40. Cross validation against PMD highlighted various unusual events disturbing accuracy of forecast. In case of Islamabad values of 1971, 1976, 1978, 1983, 1990, 1994 and 1999; for Rawalpindi values of 1969, 1970, 1975, 1988, 1990, 1991, 1993 and 1995; values of 1978, 1983, 1990 and 1997 for Jhelum; values of 1973, 1984, 1990, 1991, 1992, 1994, 1997 and 1998 for lahore, Bahawalnagar data of years i-e 1972, 1973, 1989, 1992 and 1993; values of 1970, 1979, 1985, 1988 and 1992 for Badin and Nawabshah extreme events was observed in 1976, 1978, 1981 and 1988. These all yearly outlying values are disturbing the accuracy of forecast. Data is normalized by eliminating outlying values existing above and below average. This reveals better and more accurate forecast.

Multi model accuracy and excellence was also performed against Era-40. These values showed different results. Cross validation of Rahimyar Khan, Khairpur and Sukkur was only done against Era-40 due to unavailability of real time data PMD since 1969. Values of years 1973, 1977, 1978, 1983 and 1988 are perturbing the accuracy of forecast for these districts. Islamabad values of 1978, 1983, 1990 and 1999; Rawalpindi values of 1970, 1973, 1975, 1976, 1978, 1990, 1993 and 1995; Jhelum data of the years i-e 1978, 1983, 1990 and 1999; Lahore value of only one year 1997; Bahawalnagar hindcast data of 1998; Badin values of 1970, 1975, 1979, 1985, 1988, 1992, 1994, 1995 and 1999 and Nawabshah hindcast values of 1977, 1978, 1979, 1981, 1988, 1989, 1992, 1996 and 1999 were agitating the accuracy of forecasts. Data is normalized by eliminating outlying values existing above and below average. This reveals better and more accurate forecast.

Islamabad

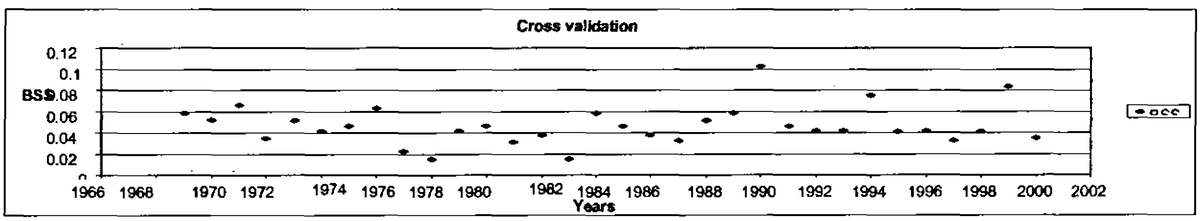

Figure 3.19a: Cross Validation of PMD Climatological Probability & ECMWF+MPI Probabilistic Forecast for Islamabad

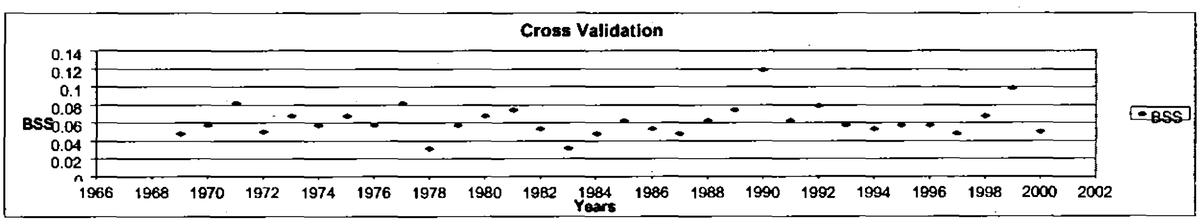

Figure 3.19b: Cross Validation of Era-40 Climatological Probability & ECMWF+MPI Probabilistic Forecast for Islamabad

Rawalpindi

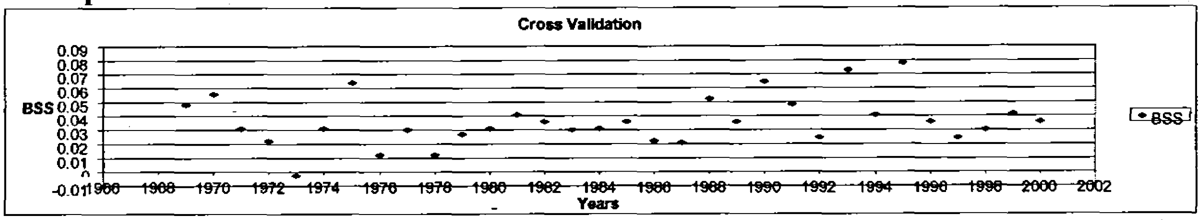

Figure 3.19c: Cross Validation of PMD Climatological Probability & ECMWF+MPI Probabilistic Forecast for Rawalpindi

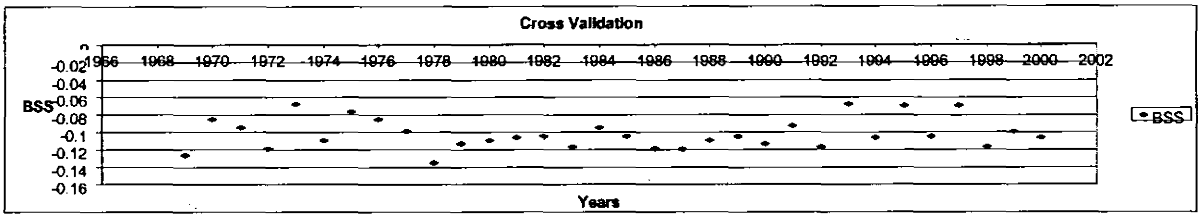

Figure 3.19d: Cross Validation of Era-40 Climatological Probability & ECMWF+MPI Probabilistic Forecast for Rawalpindi

Jhelum

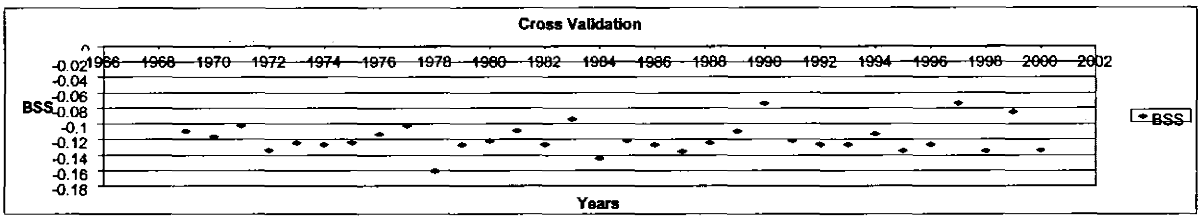

Figure 3.19e: Cross Validation of PMD Climatological Probability & ECMWF+MPI Probabilistic Forecast for Jhelum

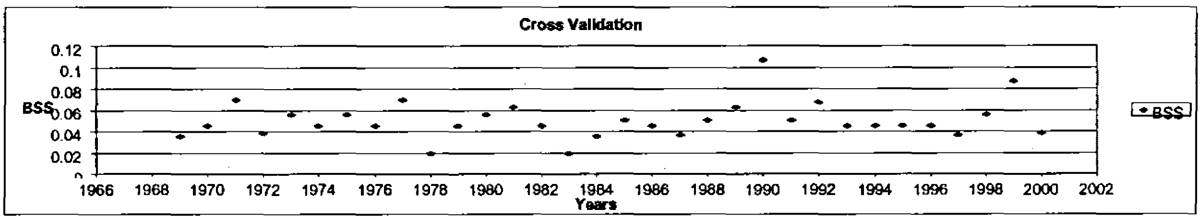

Figure 3.19f: Cross Validation of Era-40 Climatological Probability & ECMWF+MPI Probabilistic Forecast for Jhelum

Lahore

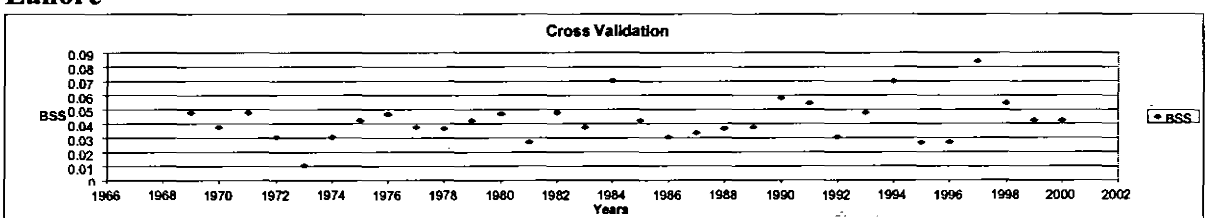

Figure 3.19g: Cross Validation of PMD Climatological Probability & ECMWF+MPI Probabilistic Forecast for Lahore

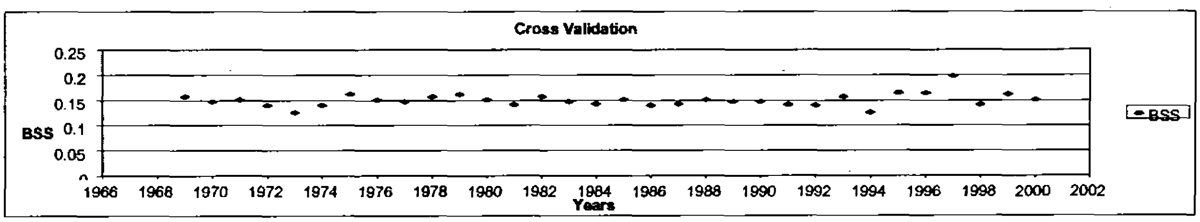

Figure 3.19h: Cross Validation of Era-40 Climatological Probability & ECMWF+MPI Probabilistic Forecast for Lahore

Bahawalnagar

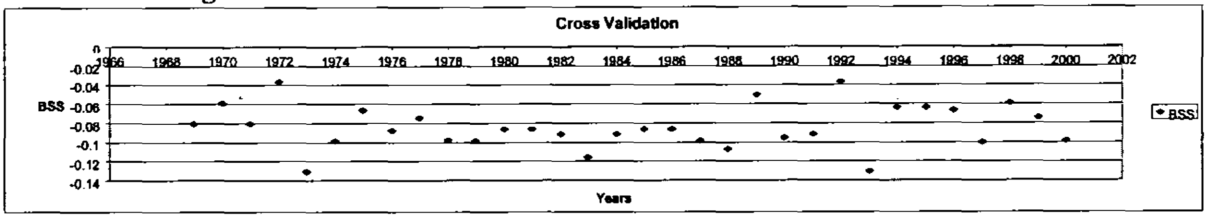

Figure 3.19i: Cross Validation of PMD Climatological Probability & ECMWF+MPI Probabilistic Forecast for Bahawalnagar

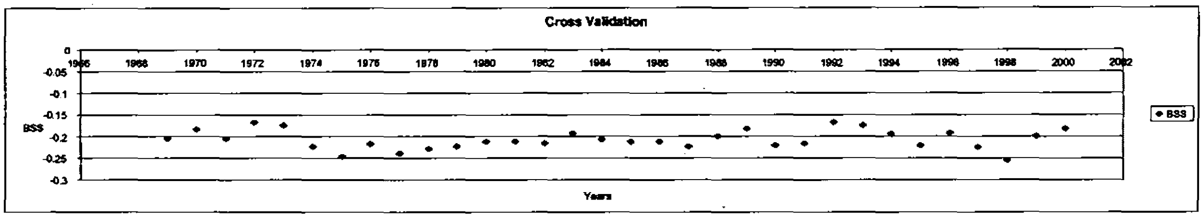

Figure 3.19j: Cross Validation of Era-40 Climatological Probability & ECMWF+MPI Probabilistic Forecast for Bahawalnagar

Rahimyar Khan

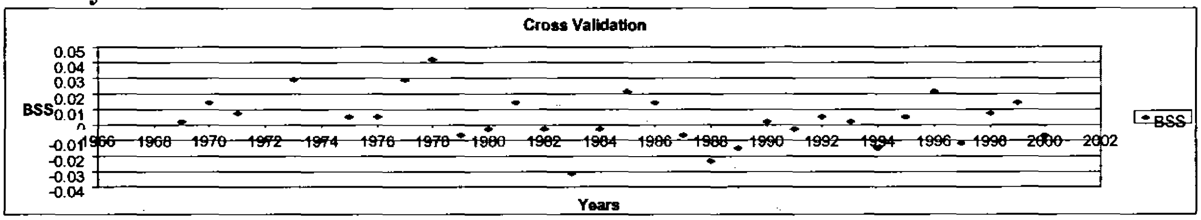

Figure 3.19k: Cross Validation of Era-40 Climatological Probability & ECMWF+MPI Probabilistic Forecast for Rahimyar Khan

Khairpur

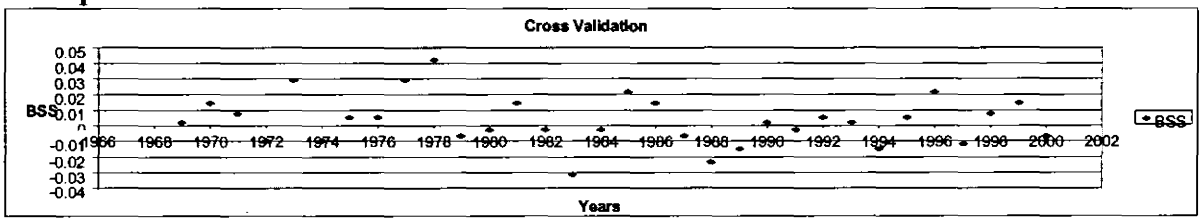

Figure 3.19 l: Cross Validation of Era-40 Climatological Probability & ECMWF+MPI Probabilistic Forecast for Khairpur

Sukkur

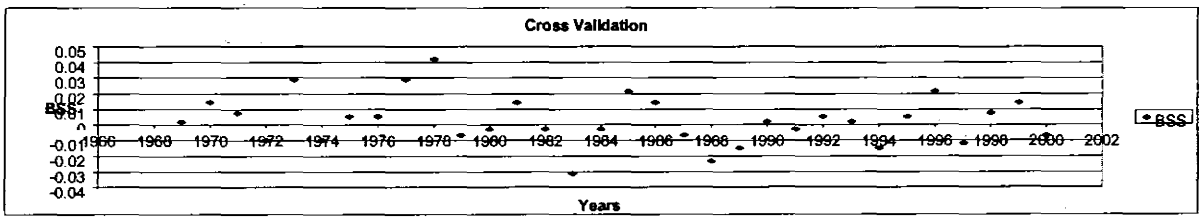

Figure 3.19m: Cross Validation of Era-40 Climatological Probability & ECMWF+MPI Probabilistic Forecast for Badin

Badin

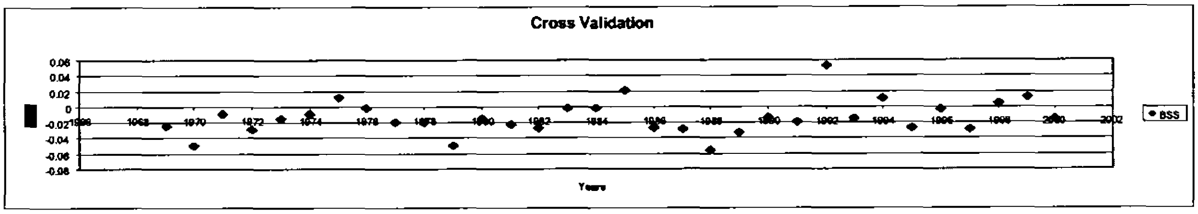

Figure 3.19n: Cross Validation of PMD Climatological Probability & ECMWF+MPI Probabilistic Forecast for Badin

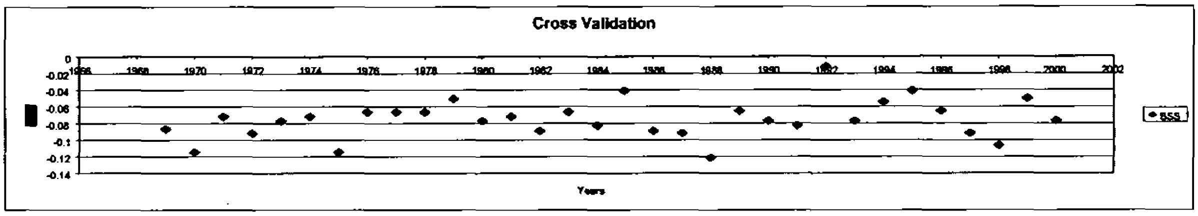

Figure 3.19o: Cross Validation of Era-40 Climatological Probability & ECMWF+MPI Probabilistic Forecast for Badin

Nawabshah

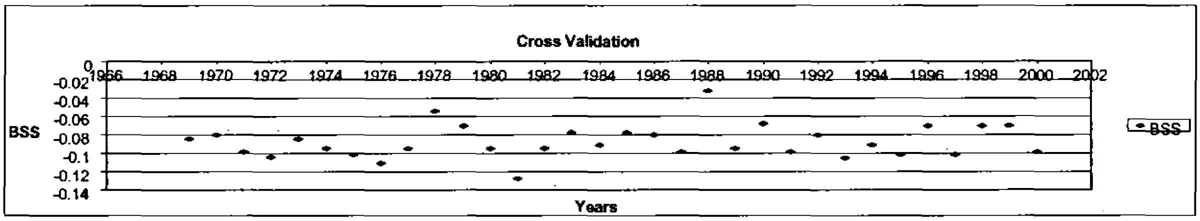

Figure 3.19p: Cross Validation of PMD Climatological Probability & ECMWF+MPI Probabilistic Forecast for Nawabshah

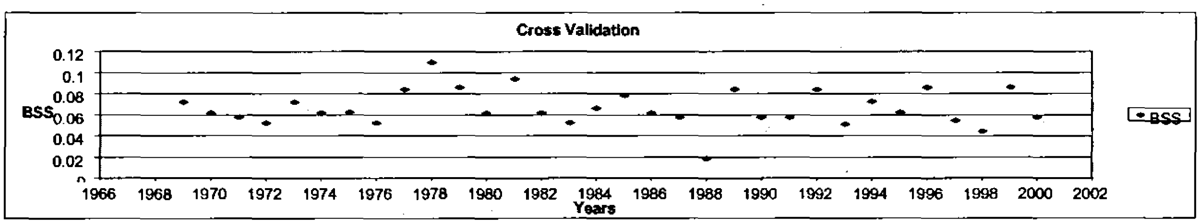

Figure 3.19q: Cross Validation of Era-40 Climatological Probability & ECMWF+MPI Probabilistic Forecast for Nawabshah

3.6.3 Multi model III

Uncertainties and vulnerabilities can be lessened by combining the model for better and accurate forecast. ROC was applied to carry out the quality, skill of forecast for multi models. All models have their specific features and conditions for forecasting the rainfall. Though accuracy and skill of forecast can be improved by multi model methods to minimize the worries and consecutive results. ROC carried out the quality of multi model forecast. To get the most out of these models Meteo-Frnce and MPI were combined and probabilistic forecast was calculated using eighteen initial conditions. This overall forecast and forecast with alternatively eliminated initial conditions were computed against PMD and Era-40 one by one. Forecast of Islamabad, Rawalpindi, Lahore, Bahawalnagar, Badin and Nawabshah was "skill forecast", only Jhelum did not generate "skill forecast" using all eighteen initial conditions and alternatively eliminated initial conditons against PMD real time data. Forecast of Islamabad, Jhelum, Lahore, Bahawalnagar, Rahimyar Khan, Khairpur, Sukkur, Badin and Nawabshah was "skill forecast" when ROC curves were plotted against Era-40.

Table 3.15: Relative Operating Characteristics for multi model (MPI and Meteo-France)

Sr No	City	Model MPI+ Meteo-France	Eliminated Initial Condition	Average of probabilistic forecast	Area under the curve	Status of forecast
1	Islamabad	vs PM		0.33	0.64	Skill forecast
			11	0.35	0.63	Skill forecast
			12	0.34	0.63	Skill forecast
			18th	0.32	0.67	Skill forecast
		vs Era-40		0.33	0.64	Skill forecast
2	Rawalpndi	vs PMD		0.33	0.59	Skill forecast
			10	0.34	0.55	Skill forecast
			18th	0.32	0.54	Skill forecast
		vs Era-40		0.33	0.46	Poor forecast
3	Jhelum	vs PMD		0.34	0.41	Poor forecast
			11	0.35	0.39	Poor forecast
			15	0.33	0.44	Poor forecast
			18th	0.32	0.44	Poor forecast
		vs Era-40		0.34	0.61	Skill forecast
4	Lahore	vs PMD		0.33	0.70	Skill forecast
			14	0.34	0.70	Skill forecast
			18th	0.32	0.69	Skill forecast
		vs Era-40		0.33	0.77	Skill forecast
5	Bahawalnagar	vs PMD		0.33	0.67	Skill forecast
			9	0.32	0.67	Skill forecast
			11	0.33	0.65	Skill forecast
			12	0.34	0.68	Skill forecast
		vs Era-40		0.33	0.62	Skill forecast
6	RahimYar Khan	vs Era-40		0.33	0.64	Skill forecast
			10	0.34	0.62	Skill forecast
			16	0.33	0.59	Skill forecast
7	Khairpur	vs Era-40		0.33	0.64	Skill forecast
			11	0.34	0.65	Skill forecast
			12	0.33	0.64	Skill forecast
8	Sukkur	vs Era-40		0.33	0.64	Skill forecast
			7	0.34	0.65	Skill forecast
			9	0.33	0.64	Skill forecast
9	Badin	vs PMD		0.33	0.66	Skill forecast
			9	0.32	0.67	Skill forecast
			12	0.33	0.65	Skill forecast
			14	0.34	0.67	Skill forecast
		Era-40		0.33	0.59	Skill forecast
10	Nawabshah	vs PMD		0.33	0.52	Skill forecast
			3	0.35	0.50	No skill forecas
			11	0.34	0.52	Skill forecast
		vs Era-40		0.33	0.61	Skill forecast

Null hypothesis: true area = 0.5
Asymptotic Confidence Interval = 95%

Accuracy and excellence of forecast was performed by cross validation. Cross validation was performed against PMD and Era-40 one by one to carry out the accuracy and efficiency of multi models formed by combining Meteo-France and MPI. Cross validation against PMD gave many values affecting the accuracy of forecast. Islamabad data showed outlying values in the years 1977, 1978, 1988, 1990 and 1994; Rawalpindi values of 1973, 1975, 1981, 1990, 1993 and 1995; Jhelum values of years i-e 1978, 1990 and 1997; values of years i-e 1973, 1978, and 1984 for Lahore; Bahawalnagar values of 1972, 1973, 1993 and 1995; and Badin values of 1975, 1976, 1984, 1992, 1994 and 1995 were representing below and above rainfall during these years. Nawabshah cross validation showed very scattered data. Values of 1975, 1976, 1979, 1981, 1986, 1992, 1995, 1998 and 1999 were presenting extreme events. These all yearly diverse values showed that some extraordinary weather and climatic conditions must have occurred during these years. Data is normalized by eliminating outlying values existing above and below average. This reveals better and more accurate forecast.

Cross validation of multi model was also performed against Era-40. Rahimyar Khan, Khairpur and Sukkur were only computed against Era-40 as real time data of PMD was not available for these districts. For these values of 1973, 1989, 1993 and 1994 illustrated extreme events affecting the accuracy of forecast. In case of Islamabad values of 1970, 1975, 1977, 1978 and 1990; values of Rawalpindi for years i-e 1973, 1975, 1978, 1993, 1995, 1997 and 2000; Jhelum values of 1977, 1978, 1988, 1990 and 1997; Lahore data of 1973, 1979, 1980, 1982 and 1991; Bahawalnagar data of years i-e 1972, 1973, 1984, 1993, 1998, 1999 and 2000 and Nawabshah data of 1975, 1976, 1979,1992, 1995, 1998 and 1999 illustrated unusual values due to extreme events. Badin cross validation showed very much divers results indicating unusual events. During modeling procedure these values are disturbing the accuracy and efficiency of forecast. These values are disturbing the accuracy of forecast. Data is normalized by eliminating outlying values existing above and below average. This reveals better and more accurate forecast.

Islamabad

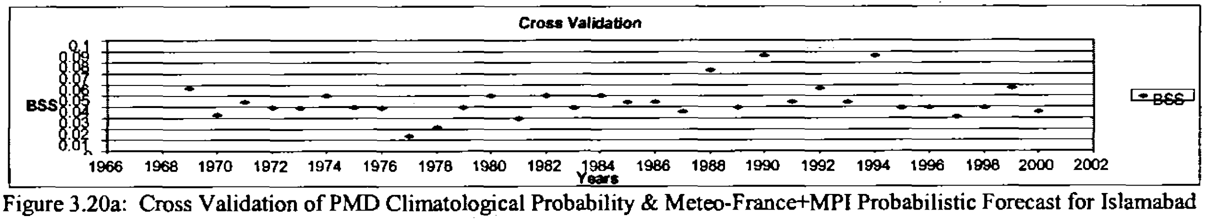

Figure 3.20a: Cross Validation of PMD Climatological Probability & Meteo-France+MPI Probabilistic Forecast for Islamabad

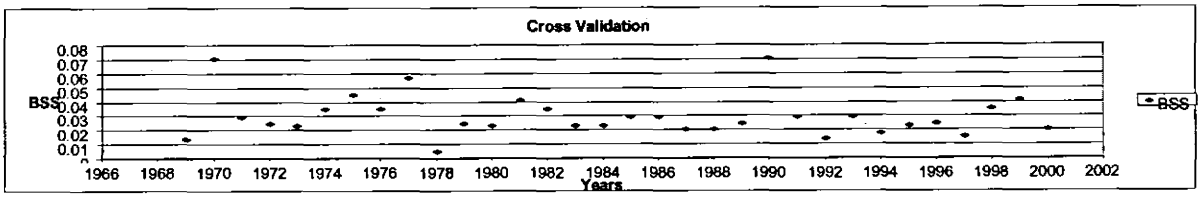

Figure 3.20b: Cross Validation of Era-40 Climatological Probability & Meteo-France+MPI Probabilistic Forecast for Islamabad

Rawalpindi

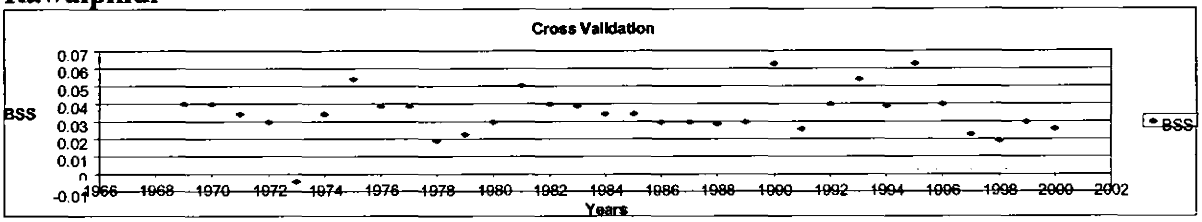

Figure 3.20c: Cross Validation of PMD Climatological Probability & Meteo-France+MPI Probabilistic Forecast for Rawalpindi

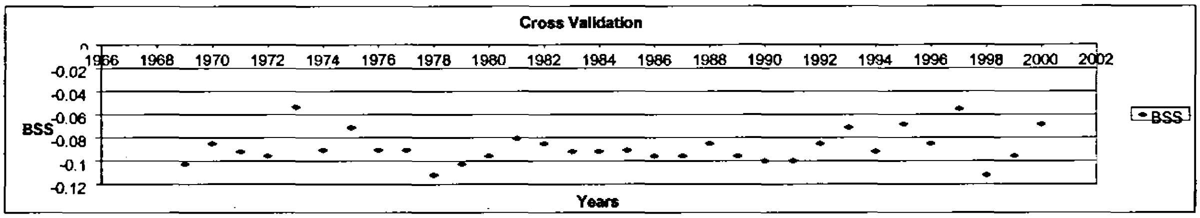

Figure 3.20d: Cross Validation of Era-40 Climatological Probability & Meteo-France+MPI Probabilistic Forecast for Rawalpindi

Jhelum

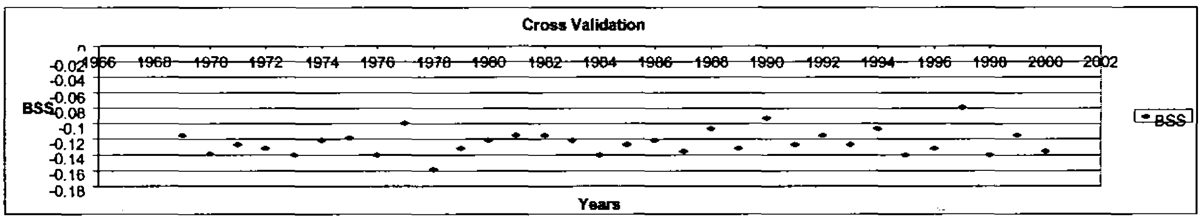

Figure 3.20e: Cross Validation of PMD Climatological Probability & Meteo-France+MPI Probabilistic Forecast for Jhelum

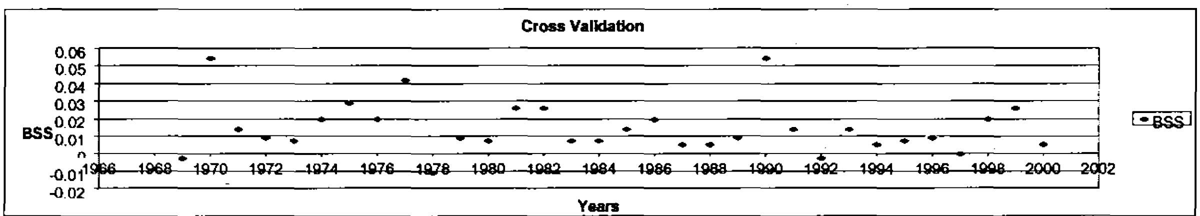

Figure 3.20f: Cross Validation of Era-40 Climatological Probability & Meteo-France+MPI Probabilistic Forecast for Jhelum

Lahore

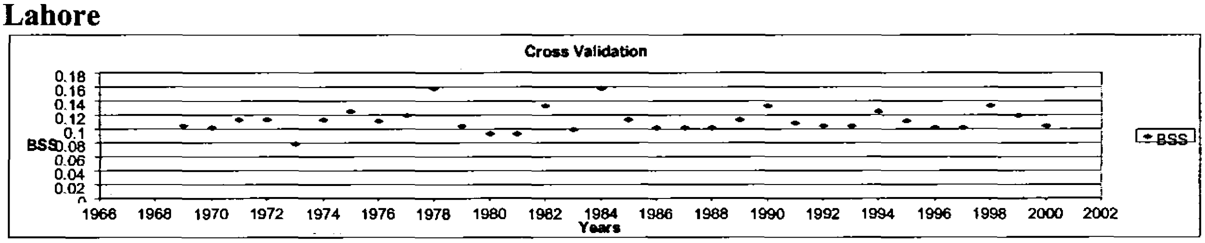

Figure 3.20g: Cross Validation of PMD Climatological Probability & Meteo-France+MPI Probabilistic Forecast for Lahore

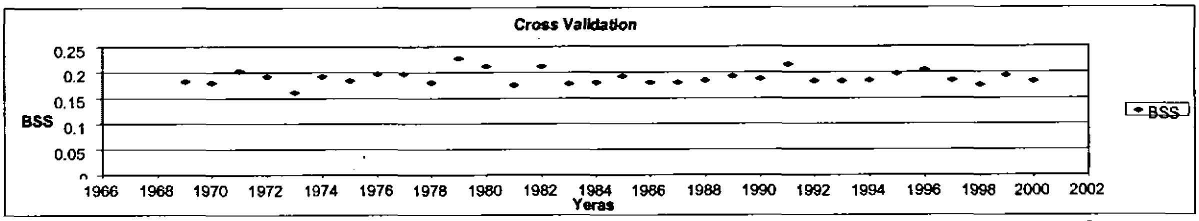

Figure 3.20h: Cross Validation of Era-40 Climatological Probability & Meteo-France+MPI Probabilistic Forecast for Lahore

Bahawalnagar

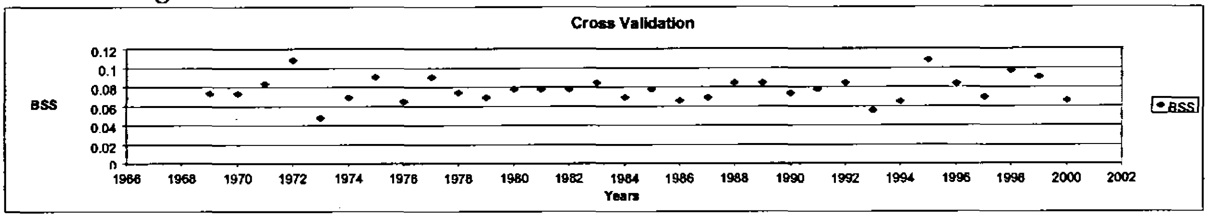

Figure 3.20i: Cross Validation of PMD Climatological Probability & Meteo-France+MPI Probabilistic Forecast for Bahawalnagar

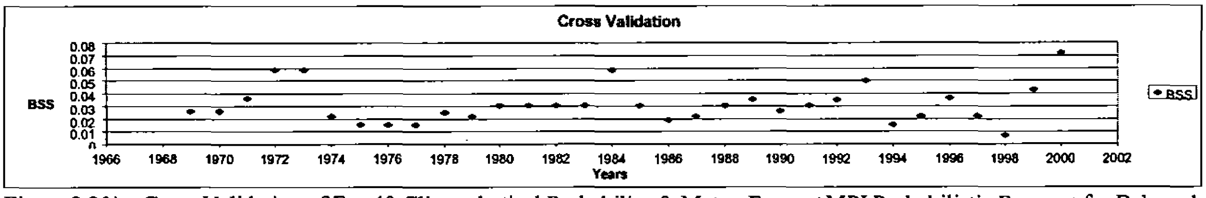

Figure 3.20j: Cross Validation of Era-40 Climatological Probability & Meteo-France+MPI Probabilistic Forecast for Bahawalnagar

Rahimyar Khan

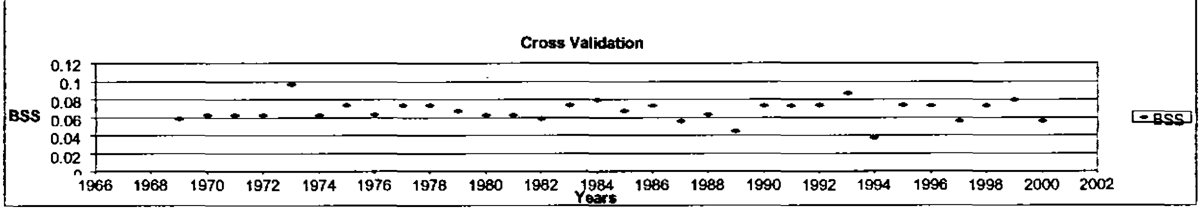

Figure 3.20k: Cross Validation of Era-40 Climatological Probability & Meteo-France+MPI Probabilistic Forecast for Rahimyar Khan

Khairpur

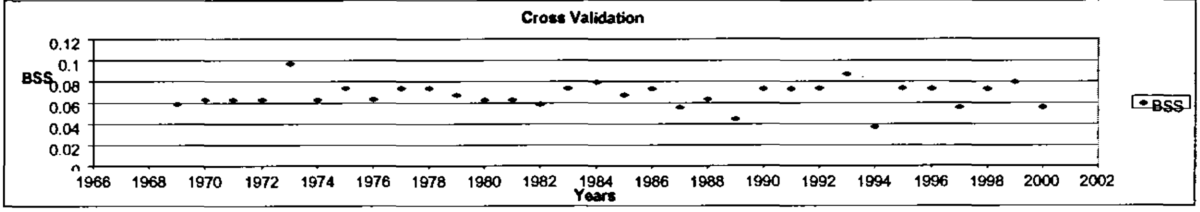

Figure 3.20 l: Cross Validation of Era-40 Climatological Probability & Meteo-France+MPI Probabilistic Forecast for Khairpur

Sukkur

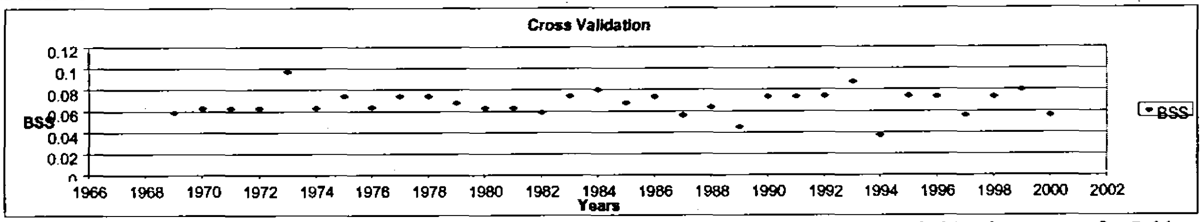

Figure 3.20m: Cross Validation of Era-40 Climatological Probability & Meteo-France+MPI Probabilistic Forecast for Sukkur

Badin

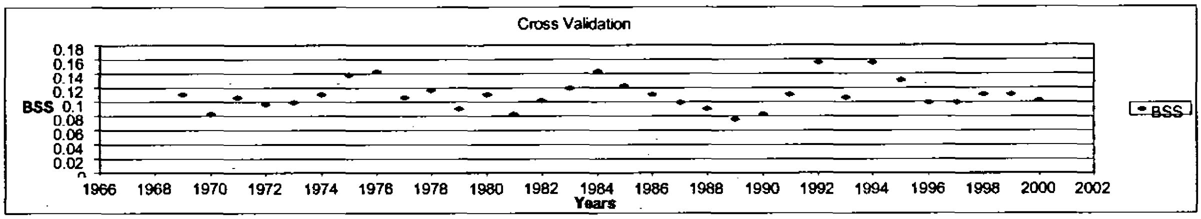

Figure 3.20n: Cross Validation of PMD Climatological Probability & Meteo-France+MPI Probabilistic Forecast for Badin

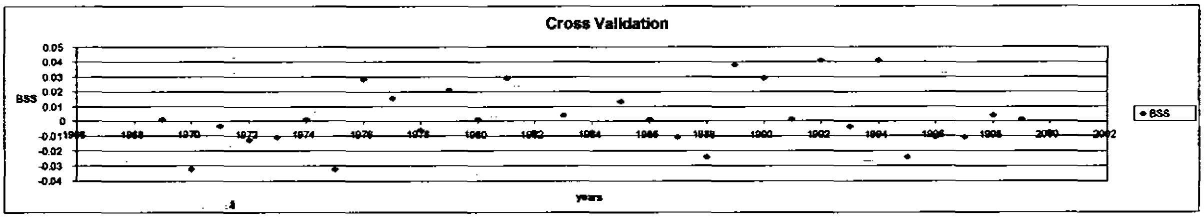

Figure 3.20 o: Cross Validation of Era-40 Climatological Probability & Meteo-France+MPI Probabilistic Forecast for Badin

Nawabshah

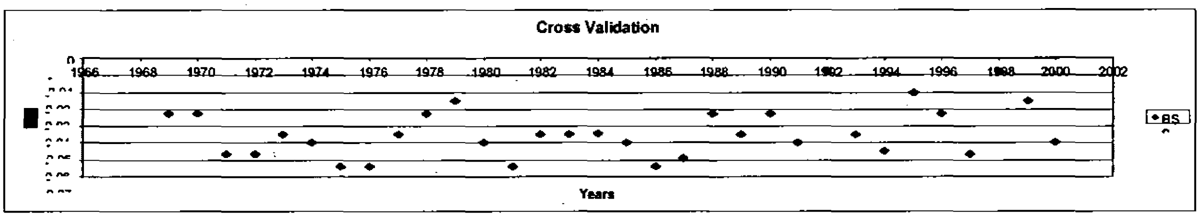

Figure 3.20p: Cross Validation of PMD Climatological Probability & Meteo-France+MPI Probabilistic Forecast for Nawabshah

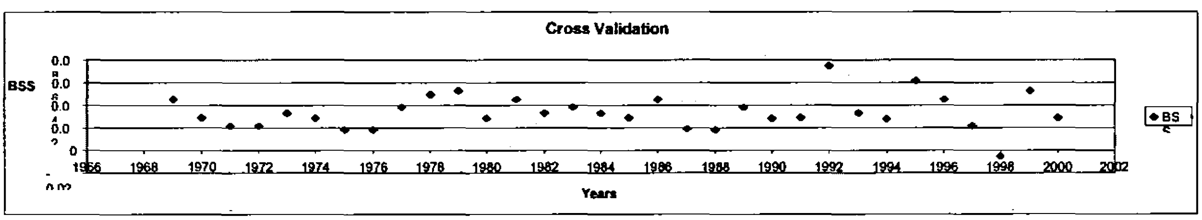

Figure 3.20q: Cross Validation of Era-40 Climatological Probability & Meteo-France+MPI Probabilistic Forecast for Nawashah

3.6.4 Multi model IV

Models were combined to magnify the skill and accuracy of forecast. Worries and catastrophic events can be narrowed by combining the model for improved and precise forecast. ROC was performed to bring out the quality, skill of forecast for multi models. Every one model has their unambiguous characteristics and settings for rainfall forecasting. However accuracy and skill of forecast can be improved by multi model methods to curtail the uncertainties and successive vulnerabilities. ROC clutch out the quality of multi model forecast. To get maximum benefits from these models ECMWF, Meteo-Frnce and MPI were combined to calculate the probabilistic forecast. This overall probabilistic forecast with twenty seven initial conditions and probabilistic forecast with alternatively eliminated initial conditions were calculated against PMD and Era-40. Islamabad, Rawalpindi, Lahore, Bahawalnagar, Badin and Nawabshah showed "skill forecast" while Jhelum generated "poor forecast" against PMD. Islamabad, Jhelum, Lahore, Rahimyar Khan, Khairpur, Sukkur, Badin and Nawabshah generated "skill forecast" while Rawalpindi and Bahawalnagar gave "poor forecast" using twenty seven initial conditions collectively against Era-40.

Table 3.16: Relative Operating Characteristics for multi model (ECMWF, Meteo-France and MPI)

Sr. No	city	Models ECMWF + Meteo-France + MPI	Eliminated Initial Condition	Average of probabilistic forecast	Area under the curve	Status of forecast
1	Islamabad	vs PMD		0.33	0.65	Skill forecast
			8	0.32	0.67	Skill forecast
			16	0.34	0.67	Skill forecast
			26	0.33	0.62	Skill forecast
		vs Era-40		0.33	0.62	Skill forecast
2	Rawalpindi	vs PMD		0.33	0.56	Skill forecast
			15	0.33	0.59	Skill forecast
			21	0.34	0.54	Skill forecast
		vs Era-40		0.33	0.49	Poor forecast
3	Jhelum	vs PMD		0.33	0.40	Poor forecast
			8	0.33	0.44	Poor forecast
			16	0.34	0.42	Poor forecast
			20	0.35	0.38	Poor forecast
		vs Era-40		0.33	0.59	Skill forecast
4	Lahore	vs PMD		0.33	0.64	Skill forecast
			12	0.34	0.65	Skill forecast
			26	0.33	0.65	Skill forecast
		vs Era-40		0.33	0.77	Skill forecast
5	Bahawalnagar	vs PMD		0.33	0.56	Skill forecast
			12	0.33	0.56	Skill forecast
			18	0.34	0.55	Skill forecast
		vs Era-40		0.33	0.45	Poor forecast
6	Rahimyar Khan	vs Era-40		0.33	0.61	Skill forecast
			15	0.33	0.61	Skill forecast
			22	0.34	0.62	Skill forecast
7	Khairpur	vs Era-40		0.33	0.61	Skill forecast
			4	0.33	0.59	Skill forecast
			17	0.34	0.62	Skill forecast
8	Sukkur	vs Era-40		0.33	0.61	Skill forecast
			13	0.33	0.55	Skill forecast
			22	0.34	0.62	Skill forecast
9	Badin	vs PMD		0.33	0.58	Skill forecast
			2	0.33	0.56	Skill forecast
			24	0.34	0.60	Skill forecast
		vs Era-40		0.33	0.54	Skill forecast
10	Nawabshah	vs PMD		0.33	0.50	Skill forecast
			20	0.34	0.50	No Skill forecast
			23	0.33	0.51	Skill forecast
		vs Era-40		0.33	0.66	Skill forecast

Null hypothesis: true area = 0.5
Asymptotic Confidence Interval = 95%

To further reduce uncertainties and to enhance the accuracy of forecast multi model was formed with combination of ECMWF, Meteo-France and MPI. Cross validation was performed to check the accuracy of multi model. Cross validation of multi model was performed against both PMD and Era-40. Islamabad data of 1976, 1988, 1990, 1994 and 1999; values of 1987 and 1991 for Rawalpindi, Jhelum data of 1978, 1990, 1997, 1998 and 1999; Lahore data of 1973, 1984 and 1990; Bahawalnagar data of 1972, 1973, 1988, 1992, 1993, 1995 and 1998; Badin data of years i-e 1975,1976, 1984, 1985, 1992 and 1994 and Nawabshah values of 1981, 1990, 1998 and 1999 were demonstrating extreme events during these years in selected ten districts. Data is normalized by eliminating outlying values existing above and below average. This reveals better and more accurate forecast.

Cross validation was performed against Era-40 to check the accuracy of multi model against Era-40, the simulated data that is almost equal to real time data of PMD. Rahimyar Khan, Khairpur and Sukkur cross validation was done against Era-40 as real time data was not available from 1969. For Islamabad values of 1977, 1978, 1983, 1990 and 1999; values of 1973, 1975, 1978, 1993, 1995, 1997 and 1998 for Rawalpindi; Jhelum values of 1977, 1978, 1983, 1990, 1997 and 1999; values of 1972, 1973, 1975, 1998 and 2000 for Bahawalnagar pointed out below and above rainfall. Cross validation of Badin and Nawabshah showed very much scattered values. These all yearly values represented unusual occurrences. Cross validation of multi model against Era-40 for Lahore showed normal rainfall during time scale. Ignoring these extreme eventual values can create better forecast to condense vulnerabilities and uncertainties. . Data is normalized by eliminating outlying values existing above and below average. This reveals better and more accurate forecast.

Islamabad

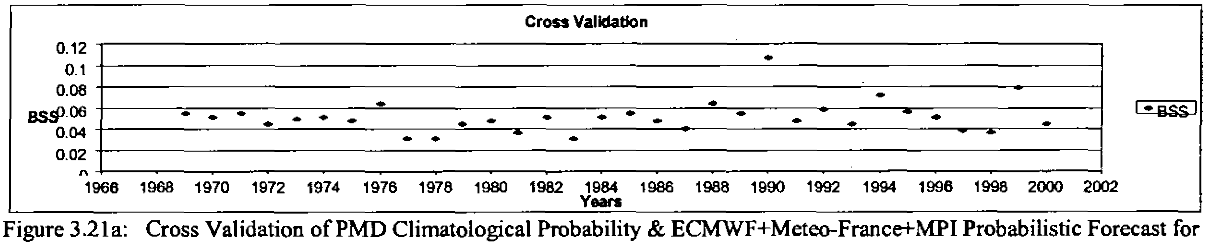

Figure 3.21a: Cross Validation of PMD Climatological Probability & ECMWF+Meteo-France+MPI Probabilistic Forecast for Islamabad

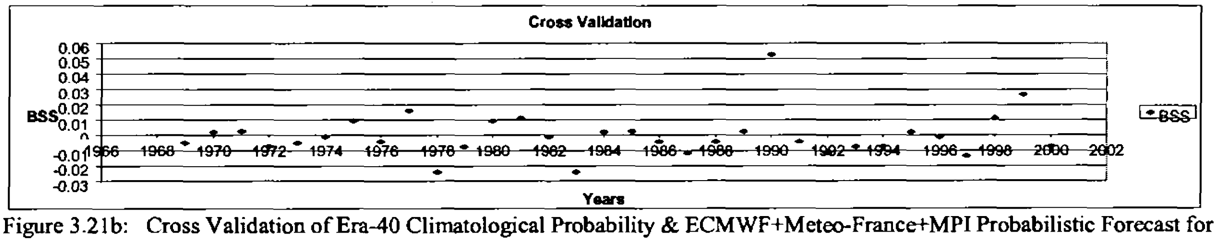

Figure 3.21b: Cross Validation of Era-40 Climatological Probability & ECMWF+Meteo-France+MPI Probabilistic Forecast for Islamabad

Rawalpindi

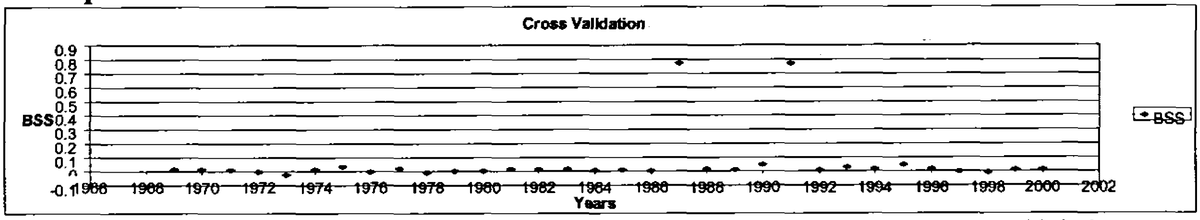

Figure 3.21c: Cross Validation of PMD Climatological Probability & ECMWF+Meteo-France+MPI Probabilistic Forecast forRawalpindi

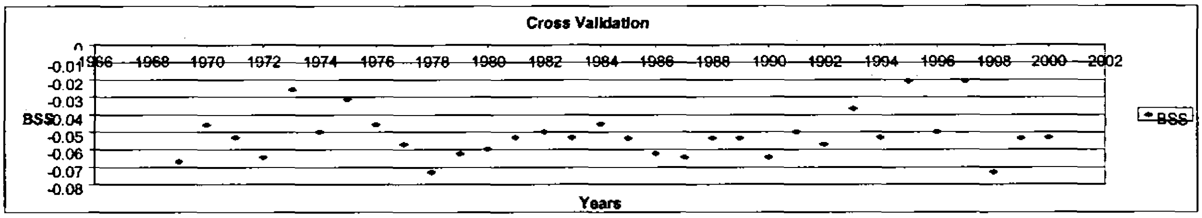

Figure 3.21d: Cross Validation of Era-40 Climatological Probability & ECMWF+Meteo-France+MPI Probabilistic Forecast for Rawalpindi

Jhelum

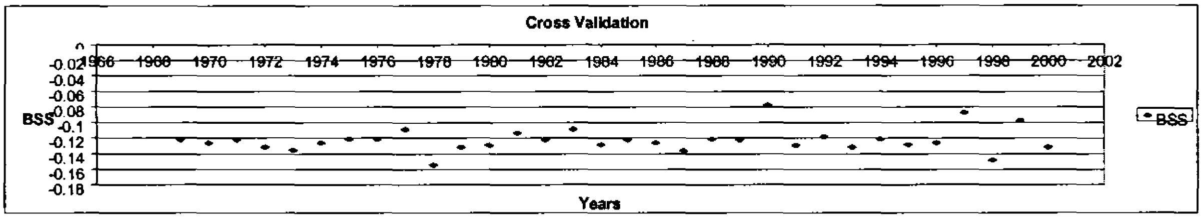

Figure 3.21e: Cross Validation of PMD Climatological Probability & ECMWF+Meteo-France+MPI Probabilistic Forecast for Jhelum

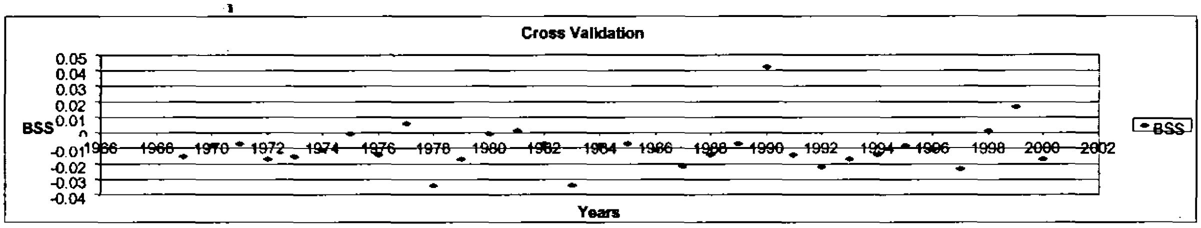

Figure 3.21f: Cross Validation of Era-40 Climatological Probability & ECMWF+Meteo-France+MPI Probabilistic Forecast for Jhelum

Lahore

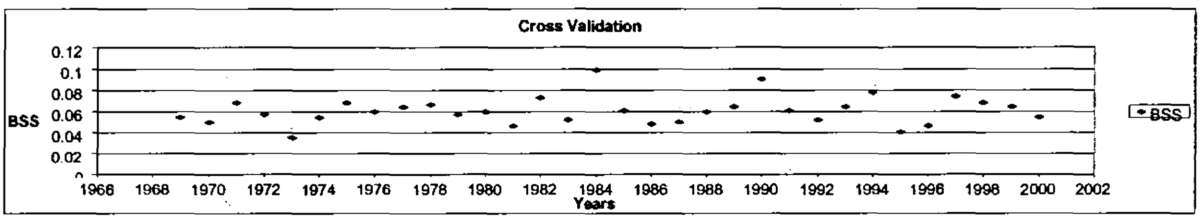

Figure 3.21g: Cross Validation of PMD Climatological Probability & ECMWF+Meteo-France+MPI Probabilistic Forecast for Lahore

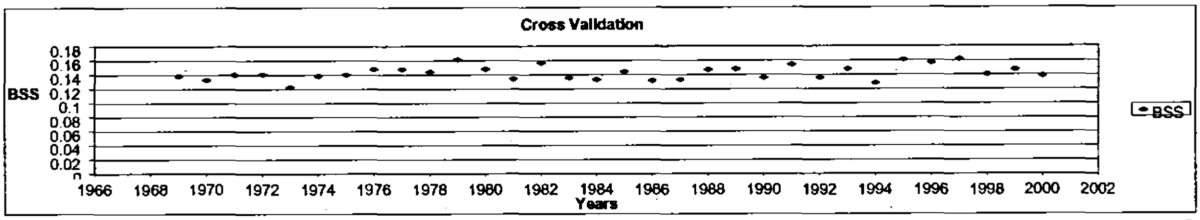

Figure 3.21h: Cross Validation of Era-40 Climatological Probability & ECMWF+Meteo-France+MPI Probabilistic Forecast for Lahore

Bahawalnagar

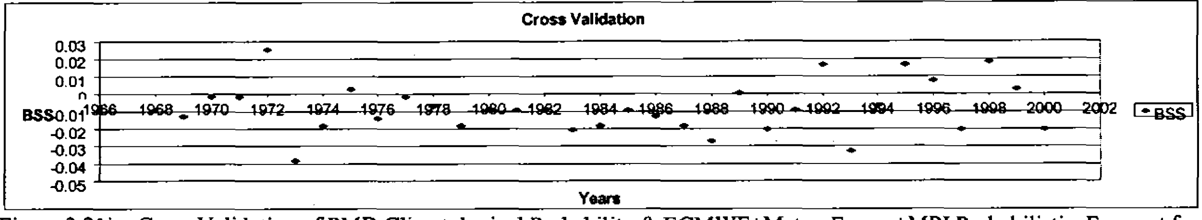

Figure 3.21i: Cross Validation of PMD Climatological Probability & ECMWF+Meteo-France+MPI Probabilistic Forecast for Bahawalnagar

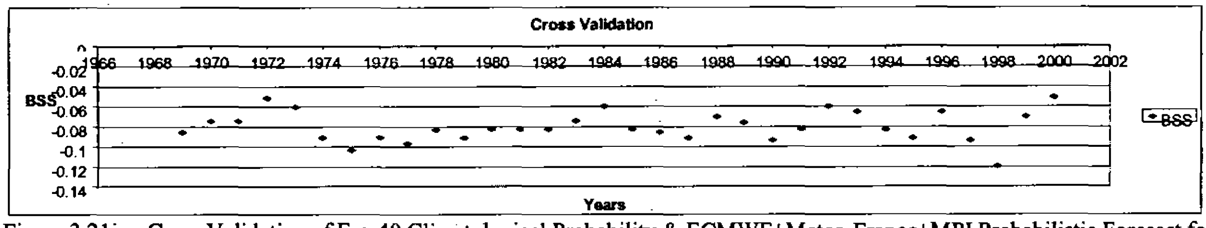

Figure 3.21j: Cross Validation of Era-40 Climatological Probability & ECMWF+Meteo-France+MPI Probabilistic Forecast for Bahawalnagar

Rahimyar Khan

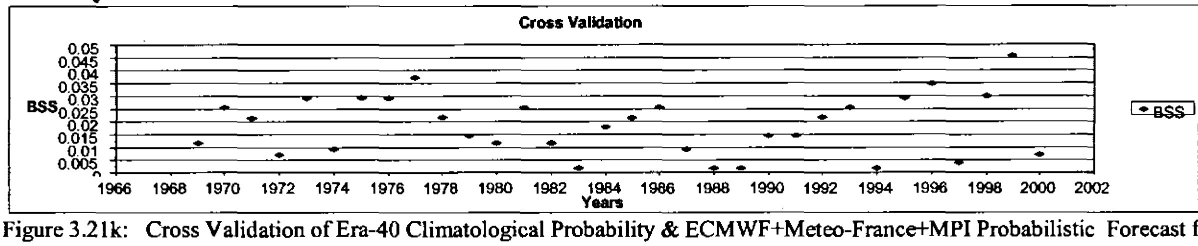

Figure 3.21k: Cross Validation of Era-40 Climatological Probability & ECMWF+Meteo-France+MPI Probabilistic Forecast for Rahimyar Khan

Khairpur

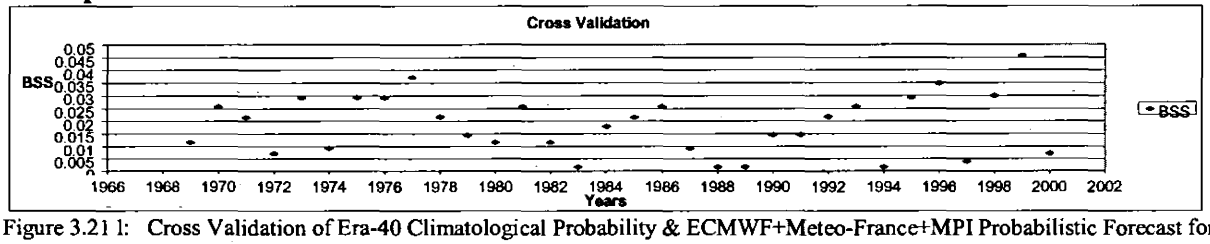

Figure 3.21 l: Cross Validation of Era-40 Climatological Probability & ECMWF+Meteo-France+MPI Probabilistic Forecast for Khairpur

Sukkur

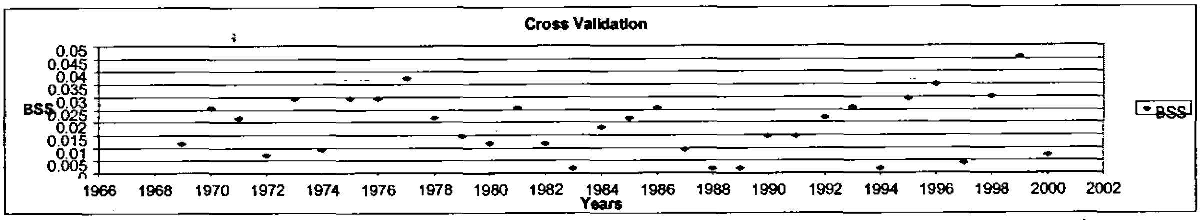

Figure 3.21m: Cross Validation of Era-40 Climatological Probability & ECMWF+Meteo-France+MPI Probabilistic Forecast for Sukkur

Badin

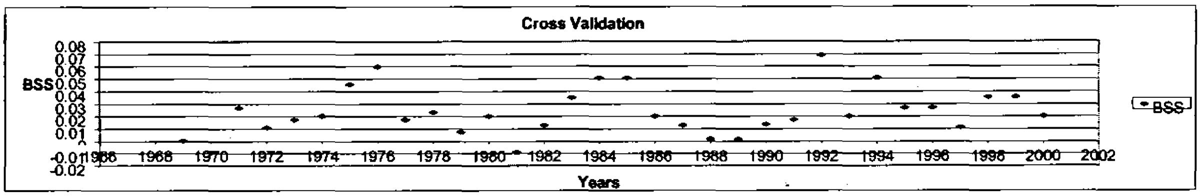

Figure 3.21n: Cross Validation of PMD Climatological Probability & ECMWF+Meteo-France+MPI Probabilistic Forecast for Badin

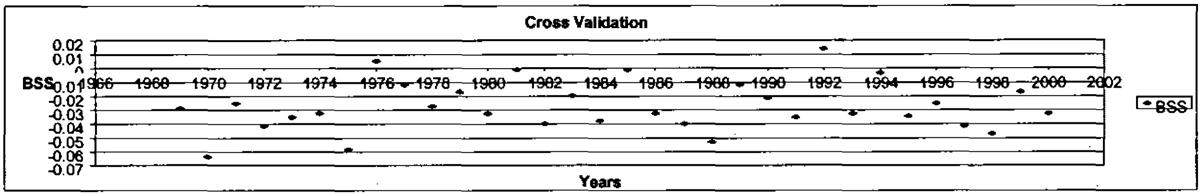

Figure 3.21 o: Cross Validation of Era-40 Climatological Probability & ECMWF+Meteo-France+MPI Probabilistic Forecast for Badin

Nawabshah

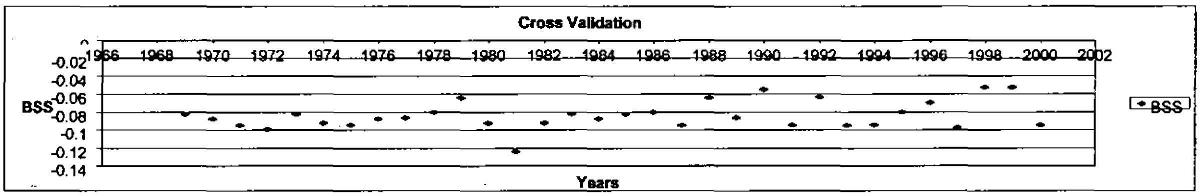

Figure 3.21p: Cross Validation of PMD Climatological Probability & ECMWF+Meteo-France+MPI Probabilistic Forecast for Nawabshah

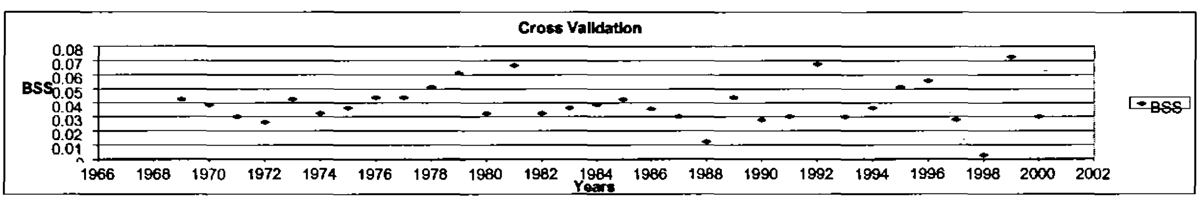

Figure 3.21q: Cross Validation of Era-40 Climatological Probability & ECMWF+Meteo-France+MPI Probabilistic Forecast for Nawabshah

CHAPTER 4

DISCUSSION

DISCUSSION

Pakistan is at the western edge of the pluvial region of the monsoon. Various studies have proved that the massive Asian summer monsoon system is divided into Indian and East Asian Monsoon system. Both systems are highly dependent and inter related to one another (Yihui and Chan, 2005).

Almost 50% of the annual rainfall occurs in summer with the advent of the monsoon season (Suleman, 1995). The monsoon season in Pakistan extends from July to September with an average monthly temperature <30°C, rainfall exceeds upto 6cm (2.4inches), humidity >55%, pressure >1010mb, and evapotranspiration >5mm (0.2inches) (Khan at el., 2010). In Pakistan data on average rainfall is available from PMD.

Ensemble forecasts are formed by the combinations of multiple integrations of numerical weather prediction models. Uncertainties are represented by ensembles of regionally used climatic models having integration domains (Leutbecher and Palmer, 2008). Historical studies of different periods are significant contribution to assess the skill of forecast for different climatic regions using different climatic models. However, advanced and well managed improvements can play key role for future forecast better skill. Thus, the advantages and usefulness of EPS exists usually in variety of various possible solutions presented to a particular meteorological forecast problem.

By using EPS, rainfall seasonal forecast for selected areas for three months i-e July, August and September was calculated with one month lead time i-e June. "Upper tercile" was used to present maximum rainfall.

First selected area in the EMB represented the capital (**Islamabad**), the capital of Pakistan, which is a planned city constructed since 1960 at the foot of the Margala Hills. Annual highest rainfall of 1,732 mm was recorded in 1983. Islamabad rainfall hindcast for 1969 to 2000 of four different selected models were different. Using ensemble forecast, probability density functions of different states can be estimated (Toth and Kalnay, 1997). The ensemble forecast of PMD and Era-40 were 752.95mm and 363.08mm respectively. Ensemble forecast of ECMWF, Meteo-France, MPI and UKMO was much below then ensemble forecast of PMD and Era-40, leading to "poor forecast". The Bangladesh system integrates the similar statistically provided ensemble rainfall forecasts coupled to hybrid hydrological model as discussed by the Webster in 2010. Climatological probabilistic forecast of PMD and Era-40 was 0.34 while probabilistic forecast of selected models was 0.33 presenting it as a good probabilistic forecast (Table 3.1).

Reliability, resolution and uncertainty of forecast were checked by "BSS. Against PMD it showed "no reliability" of selected models for all selected areas. Skill of forecast was shown when ROC curves were plotted against PMD and ECMWF with all initial conditions and with eliminated initial conditions 2, 7 and 8. Meteo-France offered "skill forecast" with all initial conditions and with alternatively eliminated initial conditions 0, 1 and 2. ROC curve applied for MPI gave "skill forecast" covering all initial conditions and eliminating initial conditions 0, 1, 3, 5 and 8. Western Mediterranean area showed the high skill correlation values (N0.80) for daily rainfall (Martin *at el.*, 2010). UKMO gave "poor forecast" for all initial conditions and with alternatively removed initial conditions 1, 2 and 3 (Table 3.2).

Reliability, resolution and uncertainty of forecast was checked against Era-40 it showed reliability only when MPI was computed for Islamabad as in Table 3.1. These models were then processed against Era-40. ECMWF, Meteo-France and UKMO generated "poor forecast". Only MPI produced "skill forecast" against Era-40 (Table 3.2).

Accuracy of forecast of selected models was verified through cross validation. PMD showed accurate forecast of all selected models although Meteo-France and MPI showed more extreme events (Figures 3.1). Cross validation in figures 3.2 against Era-40 also demonstrated accurate forecast of ECMWF, Meteo-France, MPI and UKMO for

Islamabad. Harnack and Lanzante in 1985 applied the cross validation techniques by eliminating each entity from data set for rainfall.

Rawalpindi lies along the ancient trade route from Persia and Europe across Khyber Pass to India. Similar to neighboring Islamabad, Rawalpindi features a humid subtropical climate with long and very hot summers, a monsoon and short, mild, wet winters. According to PMD real time data, the average annual rainfall is 39 inches (990 mm), most of which falls in the monsoon season. Ensemble forecast average of 32 year from 1969 to 2000 for PMD and Era-40 was 752.95mm and 212.35mm respectively. Ensemble rainfall forecast of ECMWF was good one when compared with PMD while with Era-40 no model had shown good ensemble forecast (Table 3.1) A multi year analysis using the European Centre for Medium Range Weather Forecasts (ECMWF) 15 days EPS showed that summer rainfall of 2010 in Pakistan was well predictable out to 6–8 days (Webster, 2010). Many conditions affect EPS when it is applied to small spread values of rainfall (Martin *at el.*, 2010). Climatological probabilistic forecast of PMD and Era-40 was 0.34 whereas probabilistic forecast of all selected models using all initial conditions was 0.33 conclusively all four models that offers good probabilistic forecast including all nine initial conditions and alternatively eliminated initial conditions.

BSS applied against PMD for reliability, resolution of forecast showed reliability for MPI only and rest of the three did not show reliability (Table 3.1). ROC curves against PMD and ECMWF with all initial conditions and eliminating initial condition 1 generated "poor forecast" however probabilistic forecast produced "skill forecast" by eliminating initial conditions 0. Assessment of the predictability of rainfall using simulated model ECMWF by using all accessible hindcast data showed correlations between predicted and real time observed data which generated useful prediction skill was ≥0.7 for rainfall forecast (Webster *at el.*, 2011). Meteo-France gave "poor forecast" with all basic initial conditions and eliminating initial conditions 3 and 8. MPI presented "skill forecast" covering all initial conditions and eliminating initial conditions 0, 2, 5 and 8. UKMO probabilistic forecast with all initial conditions and by eliminating initial conditions 0, 1 and 8. (Table 3.3).

No model was reliable when BSS was calculated against Era-40 (Table 3.1). ROC curves for Era-40 and ECMWF generated "skill forecast" with all initial conditions while Meteo-France, MPI and UKMO presented "poor forecast" (Table 3.3).

Cross validation graphs against PMD and Era-40 of four models for rainfall showed many years of extreme events. Cross validation approach indicated accurate forecast of four models for selected areas on EMB in Pakistan as in figures 3.3 and 3.4. By using values elimination approach by cross validation these biased results can be ignored for better forecast. Cross validation approach showed better results of almost 95% credible intervals for Pakistan spatio- temporal monsoon rainfall (Hussain *at el.*, 2010).

Jhelum district stretches from the river Jhelum to the Indus. In winter it is very cold and summer is very hot. The average rainfall varies from 48 to 69mm per annum that is less than the required quantity. The average rainfall for 32 years of PMD and Era-40 was 583.01mm and 363.08mm respectively. ECMWF, Meteo-France, MPI and UKMO had low ensemble forecast when compared against PMD and Era-40. Verification of EPS performance was carried out through through relationship between skill and climatology (Buizza, 1997). Climatological probabilistic forecast of PMD and Era-40 was 0.34 while 0.33 was the good probabilistic forecast using all nine initial conditions of ECMWF, Meteo-France and UKMO, MPI had best probabilistic forecast 0.34 (Table 3.1).

None of the model showed reliability for Jhelum based on BSS against PMD. "Skill forecast" was acquired for ECMWF by eliminating initial condition 7. This model gave "poor forecast" with all initial conditions and by eliminating initial condition 1. Meteo-France prodced "poor forecast" with all initial conditions and by eliminating initial conditions 0, 1 and 2. MPI gave "poor forecast" with all initial conditions and by eliminating initial conditions 0, 1 and 2, while by eliminating initial conditions 6 and 8 "skill forecast" was acquired for MPI. Probabilistic forecast of UKMO was "poor forecast" with all initial conditions and by eliminating initial condition 1, 5 and 7 (Table 3.4).

According to BSS only MPI indicated reliability against Era-40 (Table 3.1). ECMWF, Meteo-France and UKMO did not produce "skill forecast" however MPI produced "skill forecast" against Era-40 (Table 3.4). Greater skills in circumstances as climatologies vary between samples was determined. Summary of "skill forecast" for single number forecast with different climatological event frequency was evaluated. "Skill forecast" for single number forecast with different climatological event frequency and greater skill with varying samples was determined (Hamill and Juras, 2006).

Cross validation method was adopted for the verification of forecast of four selected models. In figures 3.5 and 3.6 cross validation against PMD and Era-40 showed almost accurate forecast. MPI cross validation against Era-40 showed mush scattered data and inaccurate forecast as shown in figure 3.6c. Sub sample replication and cross validation approach in group form was used to calculate the skill of climatological reconstructions (Lough and Fritts, 1985).

The climate of **Lahore** features a hot semi-arid climate with rainy, long and extremely hot summers, dry and warm winters, a monsoon and dust storms. The average monsoon rainfall of Lahore is 470.1 millimetres. The average rainfall for 32 years of PMD and Era-40 was 459.56mm and 779.28mm respectively (Table 3.1). Ensemble forecast of selected models varied when compared with PMD and Era-40. Climatological probabilistic forecast of PMD and Era-40 was 0.34 close to probabilistic forecast of selected models with all initial conditions and alternatively eliminated initial conditions.

Reliability, resolution and uncertainty were calculated by applying BSS. Against PMD, MPI showed good reliability. ROC curves for ECMWF generated "skill forecast" when all initial conditions were plotted against PMD while "poor forecast" was attained by eliminating initial conditions initial conditions 0, 4 and 5. Meteo-France ROC curves showed covered areas above diagonal so forecast was skill when plotted with all initial conditions and by eliminating initial conditions 1 and 5 against PMD. MPI gave "skill forecast" using all initial conditions and by eliminating initial conditions 2, 3, 4 and 8. Skill of heavy rainfall with different variables was calculated by Hamill and Whitaker (2006). UKMO produced "skill forecast" including all initial conditions and by eliminating initial conditions 1, 4 and 7 (Table 3.5).

According to BSS Meteo-France and MPI showed reliability against Era-40 (Table 3.1). ECMWF, Meteo-France and MPI gave "skill forecast" while UKMO did not generate "skill forecast" against Era-40 (Table 3.5).

Cross validation of four selected models against PMD and Era-40 highlighted many years with extreme events. Cross validation graphs plotted against PMD indicated accurate forecast while graphs plotted against Era-40 gave almost accurate forecast with abundant extreme events in selected 32 years (figures 3.7 and 3.8). Eliminating these extreme events may generate better and accurate forecast. compared 30 year seasonal climatic variables including temperature and rainfall was compared with respect to their mean using cross validation method and reduced errors and ambiguities (Seiler, 2009).

Bahawalnagar 32 years average rainfall of real time observation of PMD and Era-40 was 127.35mm and 122.53mm respectively (Table 3.1). Ensemble forecasts of Meteo-France, MPI and UKMO were near to ensemble forecast of PMD and Era-40 indicating good forecast while ECMWF ensemble forecast was much higher then PMD and Era-40 indicating poor ensemble forecast. Great areas covered by ROC curves indicated greater quality of EPS, that was indicative of the significance of EPS (Martin *at el.,* 2010). Climatological probabilistic forecast of PMD and Era-40 was 0.34. Probabilistic forecasts were computed with all initial conditions and by eliminating them alternatively. Probabilistic forecast of all models were good forecast against climatological probabilistic forecast of PMD and Era-40 (Table 3.1).

BSS against PMD showed the reliability of Meteo-France and MPI.
In past weatlier forecast studies many authors used common probabilistic metric, the ROC, in a comparison of ensemble forecast methods (Hamill *et al.* 2000). The ROC curves were

plotted against the climatological probability of PMD and Era-40 to check the skill of the forecast obtained from the models with all initial conditions and by alternatively eliminated initial conditions. ECMWF gave "poor forecast" when ROC curve was plotted against PMD with all initial conditions and by eliminating initial conditions 2 and 6. Meteo-France gave "skill forecast" including all initial conditions and eliminating initial conditions 2 and 5. MPI gave "skill forecast" when ROC curve was plotted with all initial conditions and with alternatively eliminated initial conditions 0, 2, 4 and 8. UKMO probabilistic forecast was "poor forecast" with all initial conditions and alternatively eliminated initial conditions 4, 6 and 7.

Only MPI showed reliability against Era-40 to forecast rainfall in advance to minimize the risks and hazards. According to the BSS probabilistic forecast had low resolution when all models were calculated against PMD and Era-40. (Table 3.1)
ECMWF produced "poor forecast" while Meteo-France, MPI and UKMO produced "skill forecast" against Era-40 (Table 3.6). This skill score has achieved recognition as facilitating an analysis of model bias and provide an assessment of the nature of the models prediction error (Miyakoda et al., 1972). Many skill score was applied to check the skill but ROC skill was considered most skillful. Area under the curve above 0.5 tells the Hit rate of forecast thus Meteo-France is more skillful.

Cross validation against PMD showed almost accurate results for ECMWF, MPI and UKMO. While Meteo-france showed more diverse data representing more extreme events leading to poor accuracy of model as in figures 3.9. Cross validation against Era-40 showed accuracy of four models (Figures 3.10). Cross validation method generated more accurate results by alternatively eliminating conditions and made independent predictions for each data set (Bunke and Droge, 1984).

For **Rahimyar Khan** ensemble forecast average of 32 years of Era-40 was 36.39mm. Ensemble forecasts of ECMWF, Meteo-France and MPI was much higher then Era-40 while UKMO had good ensemble forecast (Table 3.1). Previous studies by Smith *et al* 2007 and Keenlyside *et al* 2008 employed simple and precise approaches to produce small ensembles of hindcasts having disturbed initial conditions. These approaches promoted great variety in simulated outcomes. Climatological probabilistic forecast for Era-40 was 0.33 similar to probabilistic forecasts of four models computed with all initial conditions. During forecasting of different climatic parameters through simulated models errors and uncertainties are involved.

Verification of reliability, resolution and uncertainty of forecast was done by BSS against Era-40. Only MPI was reliable model. According to the BSS probabilistic forecast of all selected model had low resolution against Era-40 (Table 3.1). The area covered by the curve determined the skillful or the "poor forecast". Skill of probabilistic forecast was checked by the ROC curves against Era-40. For ECMWF it gave "poor forecast" with all initial conditions and by eliminated initial conditions 3 and 8. "Skillful forecast" was obtained eliminating initial condition 6. Meteo-France with all initial conditions and by eliminated initial condition 3 and 8 gave "skill forecast". Only 3 initial condition elimination gave "poor forecast". MPI gave "skill forecast" for all initial conditions and by eliminating initial conditions 0 and 2. UKMO with all initial conditions and by eliminating initial conditions 0, 1 and 3 gave skill forecast. Area covered by the curve determines the status of forecast (Table 3.7). For Rahim yar Khan MPI and UKMO are more skillful as compared to ECMWF and Meteo-France. Predictions skills were used to assess ocean monitoring in greater dispersed and dynamic areas (Taylor, 2001 and Robinson et al., 2002).

Accuracy and excellence of models was calculated by cross validation. Cross validation graphs were plotted against Era-40 to verify the cross validation method. Cross validation of all selected models generated accurate forecast against Era-40 (Figures 3.11).

For **Khairpur** rainfall ensemble forecast average of Era-40 for 32 years was 36.39mm (Table 3.1). Ensemble forecasts of ECMWF, Meteo-France and MPI was greater then Era-40 while, UKMO had good ensemble forecast when compared against Era-40. Ensemble methods are considered to be among the best ways for future climate and weather predictions in the face of uncertainty (Parker 2010). Climatological probabilistic forecast of Era-40 and probabilistic forecast of all selected models using all nine initial conditions was 0.33. Using ensemble forecast, different probability functions of individual selected areas can be estimated with differences in standard deviation representing the analysis uncertainty (Toth and Kalnay, 1997).

Reliability, resolution and uncertainty were only verified against Era-40 using BSS which revealed the MPI as the more reliable model (Table 3.1). In this study, probabilistic forecast of four models was reliable with nine initial conditions and with eliminated conditions alternatively. BSS expressed the low resolution of four selected models against Era-40. ROC was applied against Era-40 which gave "poor forecast" with all initial conditions of ECMWF and by eliminating initial conditions 7 and 8. Eliminating initial condition 5 generated "skill forecast". Meteo-France gave "skill forecast" including all initial conditions and by ignoring initial conditions 2 and 7, while eliminating 3 initial condition generated "poor forecast". MPI gave skill forecast with all initial conditions and by eliminating initial conditions 0 and 6. UKMO had "skill forecast" covering all initial conditions and by alternatively eliminated initial conditions 0, 4 and 8 (Table 3.8). ROC generates more skillful results as compared to other verification methods. Area under the curve decides the status of forecast. For Khairpur MPI and UKMO generated more "skillful forecast" as compared to ECMWF and Meteo-France. Previous hindcast studies are required to determine the basis for generating skillful future forecasts, indicating a need of large data set to obtain statistically significant results, to find out different phases of past decadal variability and also different sources of predictability may be quantified and understood (Murphya at el 2010).

Cross validation approach proved that models had almost accurate forecast. Accuracy was disturbed by different extreme events happened during different years as shown in figures 3.12. The situation in which predictor set was evaluated on the basis of priority having large sample size and different variables has been determined (Davis 1976, 1977, 1978, 1979 and Chelton, 1983).

For **Sukkur** ensemble forecast average for rainfall using 32 years data of Era-40 was 36.39mm. ECMWF, Meteo-France and MPI ensemble forecasts were higher then Era-40 whereas, UKMO when compared against Era-40 had good ensemble forecast. Operational forecasts based on ensemble predictions system have produced by National Centers for Enviromental Prediction (NCEP) and the European Centre for Medium-Range Weather Forecasts (ECMWF) (Tracton and Kalnay 1993; Palmer et al., 1993). Climatological probabilistic forecast of Era-40 was 0.34 close to probabilistic forecast of all selected models using all nine initial conditions. Error and Uncertainties are involved during forecast by using different models for climatic predictions (Table 3.1).

Reliability, resolution and uncertainty of forecast were only calculated against Era-40 using BSS. MPI was categorized as the more reliable model (Table 3.1). Skill score decomposition was utilized in order to differentiate between the two main aspects that were reliability and resolution of the forecast performance (Frederic, 2010). In this work probabilistic forecast of all selected models was reliable using nine initial conditions and with alternatively eliminated initial conditions. Using BSS low resolution of four selected models against Era-40 was calculated. Skill of probabilistic forecast obtained from selected models by using all initial conditions and by alternatively eliminated conditions was checked by plotting the ROC curves against Era-40. ROC for ECMWF showed "poor forecast" with all initial conditions and by omitting initial conditions 3 and 8, while eliminating initial condition 6, gave "skill forecast". Meteo-France generated "skill forecast" with all conditions and by eliminating initial conditions 2, 5 and 7. MPI made "skill forecast" with all initial conditions and by alternatively eliminated initial conditions 0 and 7. UKMO also produced "skill forecast" with all initial conditions and by alternatively eliminated initial conditions 2, 4 and 8 (Table 3.9). Observational uncertainty for heavy rainfall using forecast models to predict rainfall was determined (Hamill and Juras, 2006). ROC produces more skillful results as compared to other verification methods. Area under the curve determines either forecast is skill or "poor forecast". For Sukkur MPI and UKMO showed more "skillful forecast" then

ECMWF and Meteo-France. Good positive skill was evaluated where metrics for forecast were calculated from composites of forecasts (Hamill and Juras, 2006).

Cross validation approach was verified by drawing cross validation graphs for all models against Era-40. These graphs showed that all models had accurate forecast against Era-40. "Skill forecast" of predictive models was evaluated and it was recommended that true skills can be increased by decreasing artificial skill (Shapiro, 1984).

For **Badin** rainfall real time observation of PMD and Era-40 for 32 years was 193.07mm and 60.29mm respectively. Ensemble forecast of ECMWF was good when compared with PMD. The ECMWF EPS as "skillful forecast" was assessed when compared with reference forecast (Atger, 2010). Meteo-France and MPI had higher ensemble forecast while UKMO had lower then PMD whereas for Era-40 all the selected models had higher ensemble forecasts. Climatological probability of PMD and Era-40 was 0.34 close to probabilistic forecast of four selected models (Table 3.1). ECMWF, Meteo-France, MPI and UKMO had good probabilistic forecast using all nine initial conditions and alternatively eliminated initial conditons against PMD and Era-40. Single probability distribution forecast for estimation of conditional probability for verification from given probability distribution was determined (Wilson, 1995).

Reliability, resolution and uncertainty of probabilistic forecast were verified by BSS only MPI showed higher reliability for rainfall forecast against PMD and Era-40 (Table 3.1). In the present work, all selected models probabilistic forecast using nine initial conditions and with alternative conditions was reliable and all models produced low resolution when probabilistic forecast was computed against PMD and Era-40.

Against PMD, ECMWF forecast was "poor forecast" with all initial conditions and by alternatively eliminated initial conditions 0, 1 and 6. Meteo-France gave "skill forecast" with all initial conditions and by eliminating initial conditions 0, 3 and 7. MPI generated "skill forecast" with all initial conditions and by alternatively eliminated initial conditions 0, 2, 3, 4 and 8. UKMO generated "skill forecast" by eliminating initial condition 4, while generated "poor forecast" with all initial condition and by eliminating initial conditions 3 and 5. ECMWF plotted against Era-40 gave "poor forecast". Meteo-France, MPI and UKMO generated "skill forecast" against Era-40 (Table 3.10). Amongst all four selected model for rainfall forecast, MPI had good reliability and "skillful forecast" for Badin.

Cross validation graphs for four models were plotted against PMD and Era-40 for the verification of cross validation approach. Cross validation results showed accuracy of forecast against PMD and Era-40 (Figures 3.14).

For **Nawabshah** real time ensemble forecast of PMD and Era-40 for 32 years was 108.67mmn and 33.52mm rainfall respectively (Table 3.1). ECMWF had good ensemble forecast when compared with PMD. The ECMWF EPS methodology was illustrated by Molteni *et al* (1996) while the significance of the more recent, advance, higher resolution system were discussed in Buizza *et al.*, 2005. Ensemble forecast of Meteo-france and MPI is higher and lower in case of UKMO when compared with PMD. UKMO had good ensemble forecast among the four selected models when compared with Era-40. Climatological probabilistic forecasts of PMD and Era-40 were 0.33 and 0.34 respectively. Meteo-France, MPI and UKMO had good probabilistic forecast when calculated against PMD while ECMWF had good probabilistic forecast when evaluated with Era-40.

Reliability, resolution and uncertainty of forecast were calculated by BSS against PMD as no model showed reliability. Against PMD, ECMWF gave "skill forecast" with all initial conditions and poor forecast by eliminating initial conditions 2, 3 and 5. Meteo-France generated "poor forecast" with all initial conditions and alternatively eleiminated initial conditions 0, 2 and 8. MPI gave "skill forecast" with all initial conditions and by eliminating initial conditions 2 and 8. UKMO also gave "skill forecast" with all initial conditions and by eliminating initial conditions 7 and 8.

Only MPI showed reliability against Era-40 as shown in table 3.1. Resolution of models is independent of average amplitude of grid spread; rather it is dependent on daily variations. This variability can be improved by increasing ensemble size (Frederic Atger, 1999). In the current work, all selected models probabilistic forecast using nine initial conditions and with alternative conditions was reliable and all models produced low resolution when probabilistic forecast was computed against PMD and Era-40. ECMWF and MPI produced "skill forecast" covering all initial conditions while Meteo-France and UKMO with all initial conditions was "poor forecast" against Era-40 (Table 3.11). The ROC was suggested as s good verification approach to check the skill of forecast. Conclusively MPI was the more reliable model with greater covered area value (Mason, 1982).

Cross validation graphs for all selected four models were plotted against PMD and Era-40 separately for the verification of cross validation approach. Cross validation graph results illustrated accuracy of forecast against PMD and Era-40 as indicated in figures 3.16 and 3.17.

Research still continues with the aim of improving the deterministic model performance by counting more information in the process explanation and superior quality of input information, new procedures have been developed to advance the results produced by the models currently available for real world applications. Among these, ensemble atmospheric dispersion modeling (Galmarini et al., 2001) has clearly shown a promising potential. Uncertainties investigated during ensemble studies are handled by two methods, Multi-model ensemble studies and perturbed-physics ensemble studies (Parker, 2010). Adopting multi-model ensemble strategy is most possible way to exploit the diversity of skillful predictions from diverse group of predictive models (Duan *at el.*, 2007). The multi-model approach of constructing ensembles from different available AOGCMs has been shown to provide improved estimates of uncertainty in seasonal forecasts compared to single-model ensembles using only perturbed initial conditions (Hagedorn *at el.*, 2005).

The priority can be equal for all models in the simplest case, or be determined through certain regression-based methods. In the latter case, the priorities are the regression coefficients. The use of artificial neural network (ANN) techniques to estimate the model priorities has been explored. (Shamseldin and Connor, 1999).

Vulnerabilities and disasters are managed at global scale by using early warning of climatic conditions by applying many predictive models. To minimize model errors and biased behavior of single models four multi models were formed. In **multi model 1** ECMWF was combined with Meteo-France. Climatological probabilistic forecast of PMD for specified areas in EMB of Pakistan was calculated. 0.34 was the probabilistic forecast of Islamabad, Rawalpindi, Jhelum, Lahore, Bahawalnagar, RahimYar Khan, Khairpur and Badin whereas it was 0.33 for Sukkur and Nawabshah. Climatological probabilistic forecast of Era-40 was 0.34 while probabilistic forecast for Islamabad, Rawalpindi, Jhelum, Lahore, Bahawalnagar, Sukkur, Badin and Nawabshah while for Rahimyar Khan and Khairpur it was 0.33. All selected areas had good probabilistic forecast using a combination of 18 initial conditions of two models i-e ECMWF and Meteo-France. (Table 3.12)

BSS was applied for multi model to check the reliability, resolution and uncertainties of two models combined. BSS of these combined models were calculated against PMD. For verification of this approach ROC was applied for multi model against PMD using all eighteen initial conditions and eliminated initial conditions alternatively. Probabilistic forecasts of Islamabad, Lahore, and Nawabshah were the "skill forecast" and probabilistic forecast of Rawalpindi, jhelum, Bahawalnagar and badin was not "skill forecast" with all initial conditions against PMD. While in case of alternatively eliminated initial conditions probabilistic forecast for Islamabad eliminating 8^{th} , 13^{th} and 14^{th} , for both Lahore and Nawabshah 9^{th} and 12^{th} initial conditions elimination generated skill forecast. Probabilistic forecast eliminating 11^{th} and 13^{th} initial conditions for Rawalpindi, 8^{th} and 13^{th} for Jhelum, for Bahawalnagar 12^{th} and 18^{th}, for Badin 2^{nd} and 7^{th} initial conditions elimination generated "poor forecast".

ECMWF and Meteo-France in cumulative form did not have reliability for all selected areas against PMD. Reliability, resolution and Uncertainty of probabilistic forecast were checked against Era-40 (Table 3.12). Multi model 1 had reliability only for Lahore while no reliability for other selected areas. Resolution of this multi model was low for selected areas of EMB. Multi model 1 with eighteen initial conrditions was reliable for Islamabad, Lahore, Rahimyar Khan, Khairpur, Sukkur and Nawabshah against Era-40 as in table 3.13.

Cross validation is a verification method used by alternatively eliminating each value from the data set. Cross validation graphs were plotted against PMD and Era-40 to verify this approach. Cross validation results showed almost accurate forecast for Multi model 1 (Figures 3.18).

In **Multi model 2**, the climatological probabilistic forecast of Islamabad, Rawalpindi, Jhelum, Lahore, Bahawalnagar, RahimYar Khan, Khairpur and Badin was 0.34 while for Sukkur and Nawabshah it was 0.33. Climatological probabilistic forecast of Era-40 for Islamabad, Rawalpindi, Jhelum, Lahore, Bahawalnagar, Sukkur, Badin and Nawabshah was 0.34 while 0.33 was the value for Rahimyar Khan and Khairpur. Hence good probabilistic forecast was obtained using multi model 2 with 18 initial conditions (Table 3.12).

Reliability, resolution and uncertainty of probabilistic forecast were checked by BSS. Multi model 2 had reliability for Islamabad, Rawalpindi and Lahore against PMD. Recently ROC has made important part of the World Meteorological Organization's verification standard (WMO 1992). Islamabad, Rawalpindi, Lahore, Bahawalnagar, Badin and Nawabshah generated "skill forecast" for multi model 2 against PMD. Forecast of Jhelum was "poor forecast" against PMD. In case of alternatively eliminated 8^{th}, 9^{th} and 11^{th} initial condition of Islamabad, 16^{th} and 17^{th} initial conditions of Rawalpindi, 18^{th} initial condition of Jhelum, 14^{th} and 18^{th} initial condition of Lahore, 14^{th} initial condition of Bahawalnagar, 5^{th} and 8^{th} initial condition of Badin and 5^{th} and 9^{th} initial condition elimination of Nawabshah gave "skill forecast" against PMD. While probabilistic forecast eliminating 10th and 11th initial condition of Jhelum and 1st initial condition of Bawalnagar generated "poor forecast" (Table 3.14).

Multi model 2 had good reliability for Islamabad, Jhelum, Lahore, Rahimyar Khan, Khairpur, Sukkur and Nawabshah against Era-40 (Table 3.12). Rahimyar Khan, Khairpur and Sukkur forecasts were only calculated against Era-40. Islamabad, Rawalpindi, jhelum, Lahore, Rahimyar Khan, Khairpur, Sukkur, and Nawabshah probabilistic forecast was "skill forecast" against Era-40. Forecast of Bahawalnagar and Badin was "poor forecast" against Era-40.Due to great interest by scientist, researchers and authors, huge increase in the skill of weather forecasts has occurred in recent decades (Simmons & Hollingsworth, 2002). Multi model 2 with eighteen initial conditions was reliable for Islamabad, Rawalpindi, Lahore, Rahimyar Khan, Khairpur, Sukkur, Badin and Nawabshah.

Cross validation demonstrated accurate forecasts for predefined areas in EMB of Pakistan against PMD and Era-40. This cross validation drew attention towards extreme events occurred as shown in Figures 3.19 from 1969 to 2000 disturbing the accuracy of forecast for multi model 2 however eliminating these values from data set can offer more accurate and better forecast. Cross validation can be applicable in all cases where model building rule is based on computational calculations (Michaelsen, 1986).

Multi model 3

Meteo-France and MPI were combined to form multi model 3. PMD climatological probabilistic forecast for particular areas in EMB of Pakistan was calculated. The climatological probabilistic forecast of Islamabad, Rawalpindi, Jhelum, Lahore, Bahawalnagar, RahimYar Khan, Khairpur and Badin was 0.34 while for Sukkur and Nawabshah it was 0.33. Climatological probabilistic forecast of Era-40 for Islamabad, Rawalpindi, Jhelum, Lahore, Bahawalnagar, Sukkur, Badin and Nawabshah was 0.34 while 0.33 was the value for Rahimyar Khan and Khairpur (Table 3.12). Conclusively Meteo-France and MPI had good probabilistic forecast using 18 initial conditions.

Reliability, resolution and uncertainties of multi model (Meteo-France+MPI) were confirmed by using BSS against PMD demonstrated that multi model 3 had reliability for Islamabad, Rawalpindi Lahore, Bahawalnagar and Badin. Probabilistic forecast with all 18 initial conditions of nine selected areas of EMB was skill forecast only Jhelum did not generate "skill forecast" with all eighteen initial conditions when ROC was applied against PMD. 11^{th}, 12^{th} and 18^{th} initial conditions elimination of Islamabad; 10^{th} and 18^{th} initial conditions elimination of Rawalpindi; 14^{th} and 18^{th} initial conditions elimination of Lahore; 9^{th} , 11^{th} and 12^{th} initial conditions elimination of Bahawalnagar; 9^{th} , 12^{th} and 14^{th} initial conditions elimination of Badin and 3^{rd} and 11^{th} initial conditions elimination of Nawabshah presented "skill forecast". On the other side Jhelum with all initial conditions and by eliminating 11^{th}, 14^{th}, 15^{th} and 18^{th} initial condition generated "poor forecast"(Table 3.15). A forecast is symbolized as synoptically useful when daily anomaly correlation score exceeds the 0.60 criteria (Hollingsworth et al., 1980). Many studies have shown that values greater than 0.60 indicates a noticeable correspondence and usefulness between simulated forecast and observed meteorological patterns

BSS against Era-40 showed that multi model 3 was reliable for Islamabad, Jhelum, Lahore, Bahawalnagar Rahimyar Khan, Khairpur, Sukkur, Badin and Nawabshah (Table 3.12). Rahimyar Khan, Khairpur and Sukkur probabilistic forecasts were only calculated against Era-40. Islmabad, Jhelum, Lahore, Bahawalnagar, Rahimyar Khan with all initial conditions and by eliminating 10^{th} and 16^{th} initial conditions, Khairpur using all initial conditions and by eliminating initial condition 7 and 9, Sukkur with all initial conditions and by eliminating 3^{rd} and 11^{th} initial conditions as well as Badin and Nawabshah forecasts were "skill forecasts". Only Rawalpindi forecast was "poor forecast". Applicability of the ROC in the field of meteorology was proposed by Mason (1982), Stanski *et al.* (1989), and Harvey *et al.* (1992). Multi model 3 with 18 initial conditions was reliable for Islamabad, Rawalpindi, Lahore, Bahawalnagar, Rahimyar Khan, Khairpur, Sukkur, Badin and Nawabshah (Table 3.15).

Cross validation of multi model 3 against PMD and Era-40 generated accurate results. However these cross validation graphs drew attention towards extreme events occurred from 1969 to 2000 that are disturbing the accuracy of forecast for multi model 3 as in figures 3.20. A wide range of methods to determine the statistical behavior of cross validation has been used (Stone, 1977; Efron,1983 and Bunke and Droge, 1984).

Multi model 4

ECMWF, Meteo-France and MPI were combined in multi model 4 work as a single unit for rainfall forecast. The climatological probabilistic forecast of PMD for Islamabad, Rawalpindi, Jhelum, Lahore, Bahawalnagar, RahimYar Khan, Khairpur and Badin was 0.34 while for Sukkur and Nawabshah it was 0.33. Climatological probabilistic forecast of Era-40 for Islamabad, Rawalpindi, Jhelum, Lahore, Bahawalnagar, Sukkur, Badin and Nawabshah was 0.34 while 0.33 was for Rahimyar Khan and Khairpur (Table 3.12). Conclusively ECMWF, Meteo-France and MPI had good probabilistic forecast using twenty seven initial conditions. Some of the complex post processing methods have the potential to improve probabilistic forecast for temperature, rainfall and other weather quantities.(Brocket & Smith, 2007; Hagedorn, Hamill, & Whitaker, 2008; Hamill, Whitaker, & Mullen, 2006; Wilson, Beauregard, Raftery, & Verret, 2007).

BSS of multi model 4 was applied to check the reliability of forecast. BSS against PMD demonstrated that ECMWF, Meteo-France and MPI had reliability for Islamabad, Rawalpindi, Lahore, and Badin. A Relative Operating Characteristic curve was used for wind speed forecasts at five days lead that indicated a highly skilful forecast (Hamill and Juras, 2006). Probabilistic forecast including 27 initial conditions of nine selected areas out of ten of monsoon belt gave "skill forecast" only Jhelum did not generate "skill forecast" with all twenty seven conditions against PMD. Eliminating 11th, 16th and 26th initial conditions of Islamabad; 15th and 21st initial condition of Rawalpindi; 8th, 16th and 20th initial condition of Lahore; 12th and 18th initial condition of Bahawalnagar; 2 and 24th initial condition of Badin and 20th and 23rd initial condition of Nawabshah presented "skill forecast". On the other side Jhelum with all initial conditions and by eliminating 8th, 16th and 20th initial conditions gave "poor forecast" shown in table 3.16. Many suitable initial conditions were identified, to run weather and climate. He assigned values to models with various initial conditions for forecasting weather and climate (Parker, 2010). Characteristics of the ROC have been discussed by Buizza *et al.* (1998), Mason and Graham (1999, 2002), Juras (2000), Wilson (2000), Buizza *et al.* (2000a,b), Wilks (2001), Kheshgi andWhite (2001), Kharin and Zwiers (2003),Mason (2003), and Marzban (2004). The technique has been used to diagnose ensemble forecast accuracy, for example by Buizza and Palmer (1998), Buizza *et al.* (1999), Hamill *et al.* (2000), Palmer *et al.* (2000), Richardson (2000, 2001a,b),Wandishin *et al.* (2001), Ebert (2001), Mullen and Buizza (2001, 2002), Bright and Mullen (2002), Yang and Arritt (2002), Legg and Mylne (2004), Zhu *et al.* (2002), Toth *et al.* (2003), and Gallus and Segal (2004).

BSS against Era-40 showed that multi model 4 was reliable for Lahore, Rahimyar Khan, Khairpur, Sukkur and Nawabshah (Table 3.12). Multi model 4 had low resolution for selected areas. The resolution of weather forecasting models and good resolution for grid points was determined (Parker, 2010). Rahimyar Khan, Khairpur and Sukkur probabilistic forecasts were only designed against Era-40. Rahimyar Khan eliminating 15^{th} and 22^{nd} initial conditions, Khairpur 4 and 7^{th} initial conditions elimination and Sukkur 13^{th} and 22^{nd} initial condition elimination gave "skill forecast". Islmabad, Lahore, Rahimyar Khan, Khairpur, Sukkur, Badin and Nawabshah forecasts were "skill forecasts". Rawalpindi, Jhelum and Bahawalnagar forecast was "poor forecast" against Era-40. The Relative Operating Characteristic approach was used by Swets 1973 and Harvey *et al.* 1992 for forecasting different weather events. Multi model 4 with twenty seven initial conditions were good for Islamabad, Rawalpindi, Lahore, Bahawalnagar, Rahimyar Khan, Khairpur, Sukkur, Badin and Nawabshah.

Cross validation graphs against PMD showed almost accurate forecast for all selected areas in Pakistan. Further verification was done by drawing the cross validation graphs against Era-40 that showed accurate forecast excluding Badin and Nawasbshah. These areas graphs highlighted many extreme events during 32 years leading to poor accuracy of multi model for these areas of Pakistan to predict the amount of rainfall (Figures 3.21). Double cross validation procedures to estimate the skill of forecast having large number of variables was adopted (Stone, 1974).

CONCLUSION

Numerical weather prediction models were tested against PMD real time observation and Era-40. This led to the acquisition of predicted values of different models and identification of extreme events with significant lead time.

Single model probabilistic forecast with ECMWF, Meteo-France, MPI and UKMO was a "good forecast" for selected areas i-e Islamabad, Rawalpindi, Jhelum, Lahore, Bahawalnager, Rahimyar Khan, Khairpur, Sukkur, Badin and Nawabshah. However, ECMWF and UKMO were "not reliable" models for any of the selected area when tested against PMD and Era-40. Meteo-France was found reliable for Bahawalnagar only against PMD and Era-40 while it was "reliable" for Lahore against Era-40. MPI has "good reliability" against PMD for Rawalpindi, Lahore, Bahawalnager and Badin. MPI was found "reliable" for Islamabad, Jhelum, Lahore, Rahimyar Khan, Khairpur, Sukkur, Badin and Nawabshah, when calculated against Era-40.

Multi model probabilistic forecast was found "good" in different combinations i-e ECMWF with Meteo-France; ECMWF with MPI; and ECMWF, Meteo-France and MPI collectively. Against PMD multi model I was reliable for Islamabad, Rawalpindi and Lahore, With multi model II it was found reliable for Islamabad, Rawalpindi, Lahore, Bahawalnager and Badin. Multi model III was reliable against PMD for Islamabad, Rawalpindi, Lahore, Bahawalnager and Badin while multi model IV had reliability for Islamabad, Rawalpindi, Lahore and Badin.

Against Era-40 combination of ECMWF and Meteo-France (multi model I) was reliable for Lahore; combination of ECMWF with MPI (multi model II) gave reliability for Islamabad, Jhelum, Lahore, Rahimyar Khan, Khairpur, Sukkur and Nawabshah; combination of Meteo-France with MPI (multi model III) was reliable for Islamabad, Jhelum, Lahore, Bahawalnager, Rahimyar Khan, Khairpur, Sukkur, Badin and Nawabshah and lastly multi model IV showed reliability for Lahore, Rahimyar Khan, Khairpur, Sukkur and Nawabshah

RECOMMENDATIONS

During the Monsoon season the rainfall in Pakistan is generally considered with beneficial effects. However sometimes maximum amount of rainfall exceeds its threshold level consequently caused wide range damage while, investigations and researches are done to find most significant solution of this problem to save country economy and natural resources of country but have to take steps as soon as possible to reduce vulnerabilities and disasters. The most suitable solution having significant results is early warning systems. a forecasting system for rainfall can be used to predict future rainfall with accuracy and can be used for early warning systems. And in conclusion, it was exposed that the forecast is an individual constituent only in a series of measures to be performed for an early warning system.

The accuracy of the ensembles of forecasts of selected models has been evaluated by applying different probabilistic verification measures that are commonly used in the field of meteorology. Different ensembles of different models can be compared and improvements can be made for better forecast with the help of skill scores. Though, the verification measures provide beneficial information about the forecast and investigator can made better results by reducing the biasness of models that enhances the confidence on forecast system using different numerically simulated models. Specifically most of the forecast properties are displayed by cross validation graphs and this graphical information can be prepared for any other critical threshold limit of any weather and climatic event as well as can be establish for any lead time of interest. Consequently it should be an instrument for decision making process in which decision makers can make decisions by keeping in mind the previous forecast performance for future predictions. Capable areas of research for completing this target include the role of restrictiveness and guidance in forecasting support systems.

Here we have final recommendations: firstly the way to use verification methods and final conclusions should be fully explained in journals, articles and texts as small variations according to situation can dramatically change skill scores and accuracy of forecast method adopted.

If these rainfall forecasts models are combined to each other on the basis of their skill and accuracy then extensive and frequent risks of greater and prolonged flooding can be measured, actions can be taken to mitigate the impacts and to reduce vulnerabilities before time. There is obvious requirement for additional inter-disciplinary research and investigations to make possible more efficient implementation of multi model forecasting systems by using seasonal forecast information. Supplementary pilot schemes need to be planned and must be executed to encourage the incorporation of decision makers, forecast developers and providers through the development of forecast and early warning systems.

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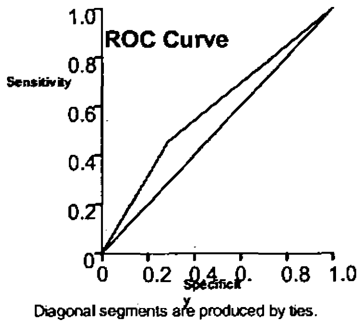
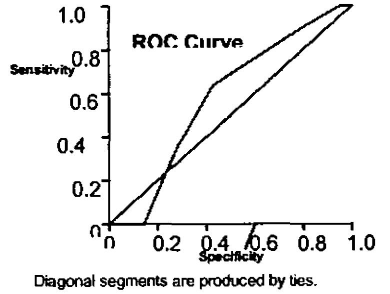
Annexure I

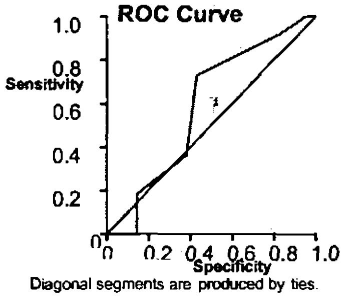
Islamabad



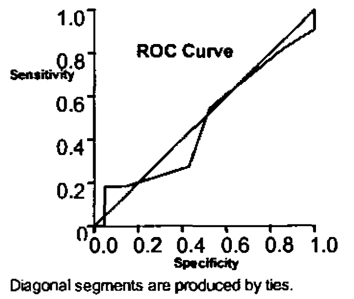


PMD vs PF 8

ECMWF

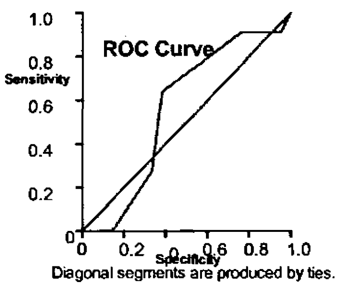


PMD vs PF 9

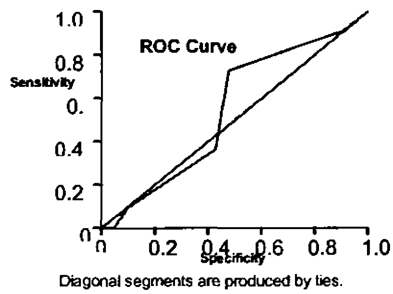


Era 40 and PF 9

Meteo-France



PMD vs PF 2



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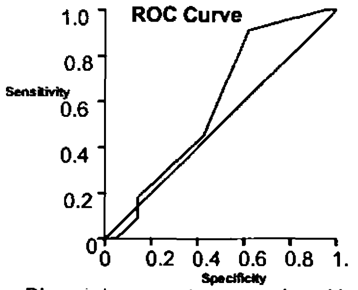

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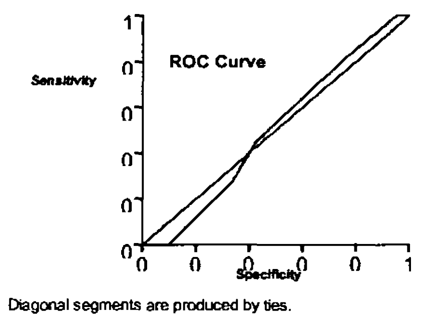
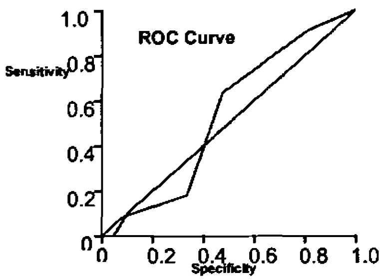
PMD vs PF 7



PMD vs PF 0



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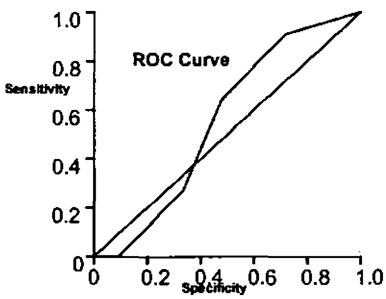
PMD vs PF 1



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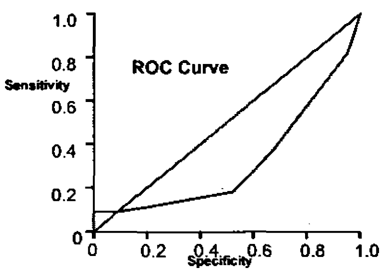

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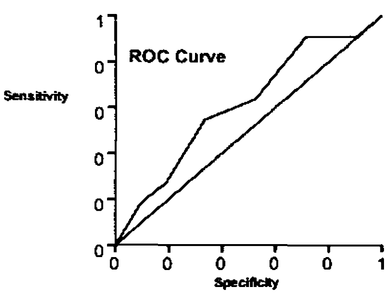
Era 40 vs PF9

MPI



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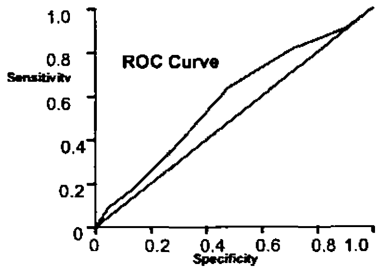
PMD vs PF 9



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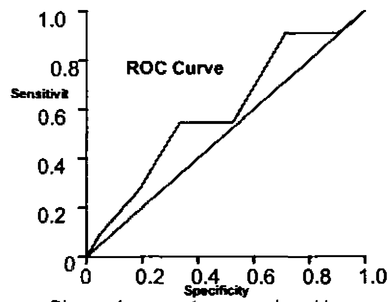

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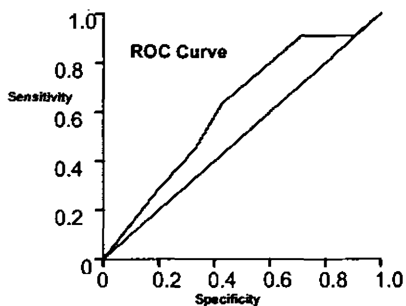
PMD vs PF 1



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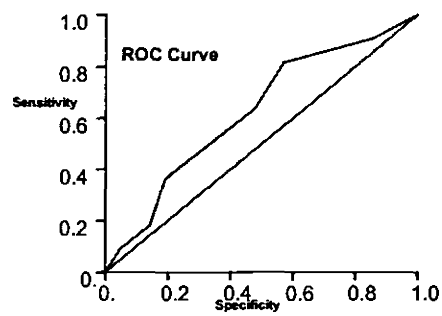

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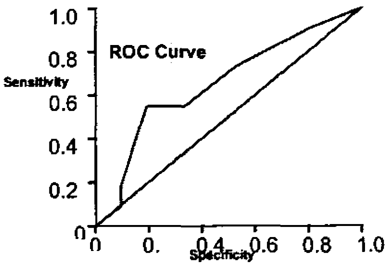

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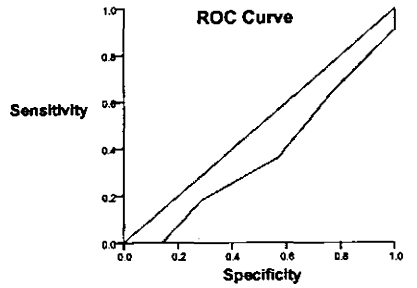
PMD vs PF 8



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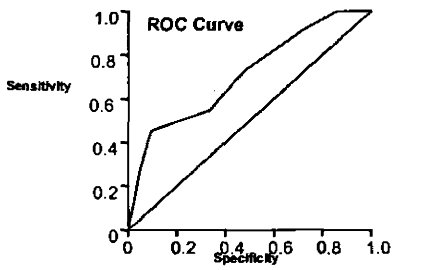

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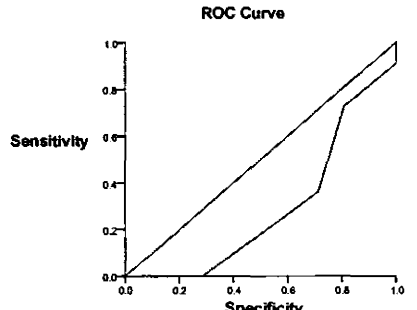
Era 40 and PF 9



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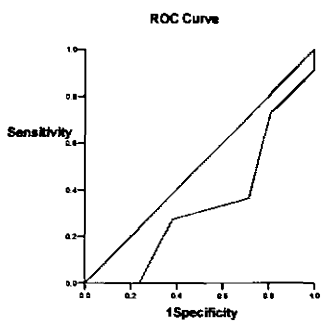
PMD vs PF 3

UKMO



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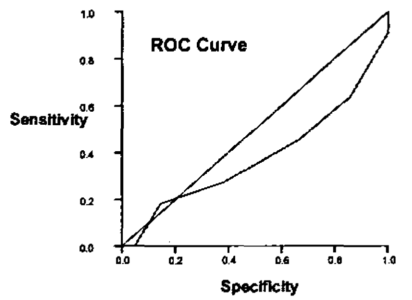

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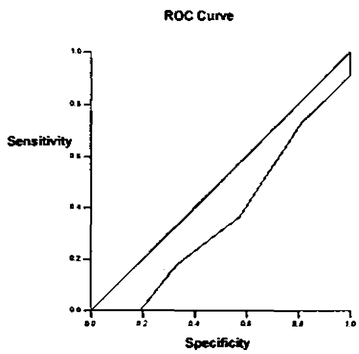
Era-40 vs PF 9

Rawalpindi



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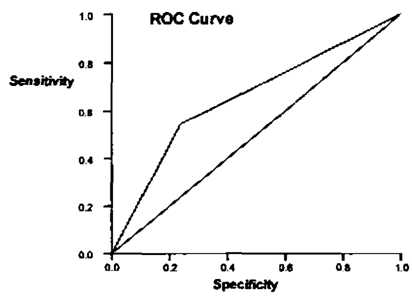
PMD vs PF1



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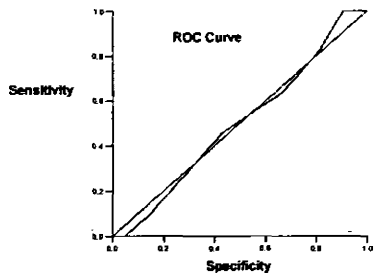
PMD vs Era-40

ECMWF



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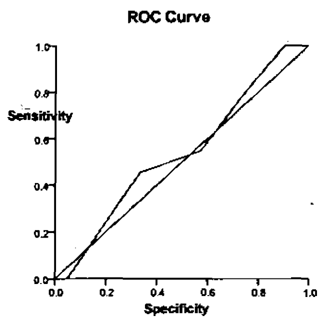

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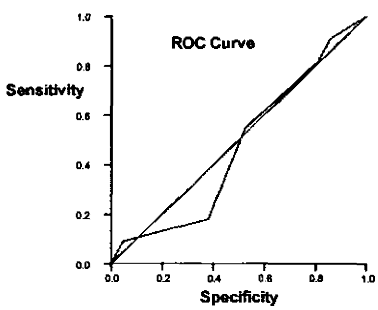

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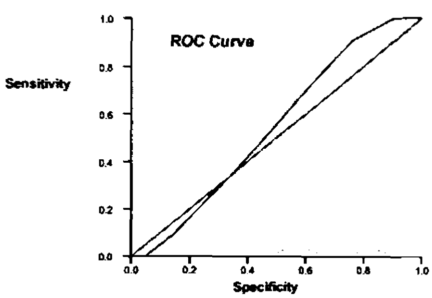
PMD vs PF 1



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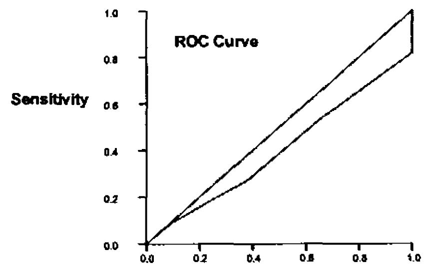
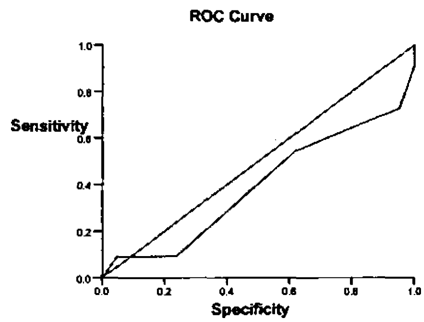
Era-40 vs PF 9

Meteo-France



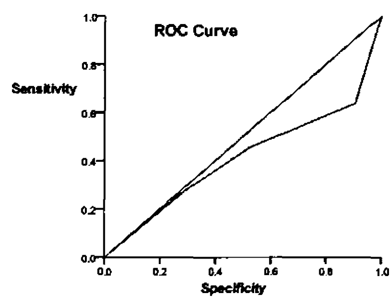
Diagonal segments are produced by ties.

PMD vs PF 9



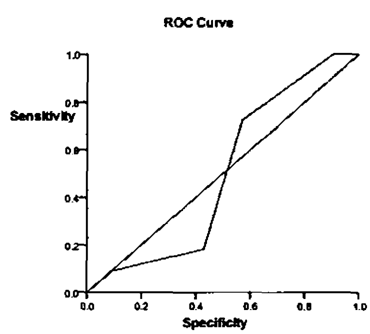
Diagonal segments are produced by ties.

PMD vs PF 3



Diagonal segments are produced by ties.

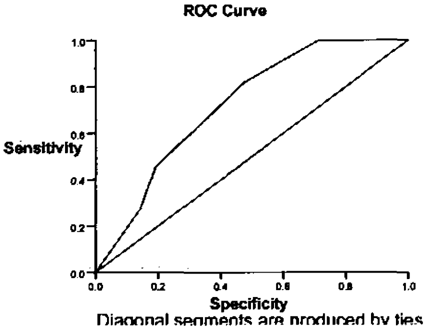
PMD vs PF 8



Diagonai segments are produced by ties.

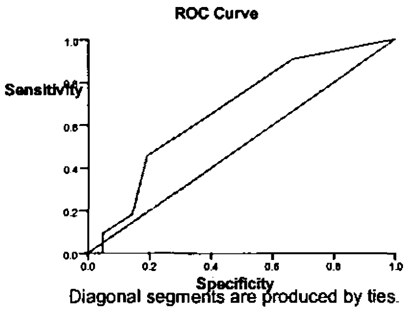
Era-40 vs PF 9

MPI



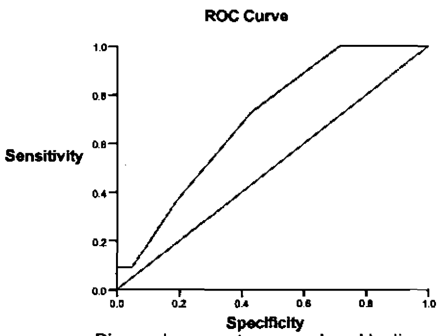
Diagonal segments are produced by ties.

PMD vs PF 9



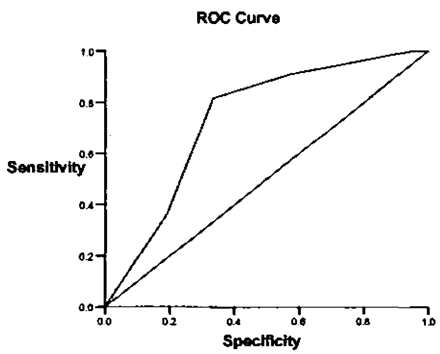
Diagonal segments are produced by ties.

PMD vs PF 0



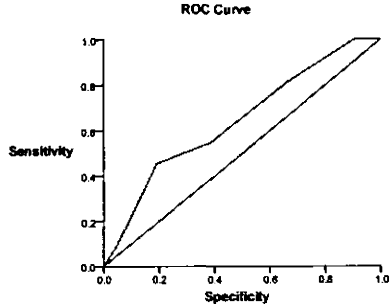
Diagonal segments are produced by ties.

PMD vs PF 2



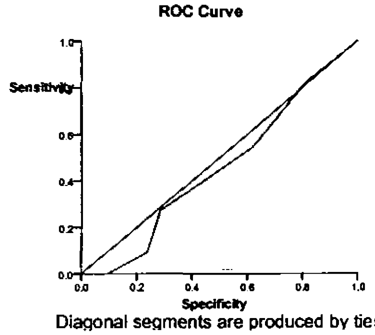
Diagonal segments are produced by ties.

PMD vs PF 5



Diagonal segments are produced by ties.

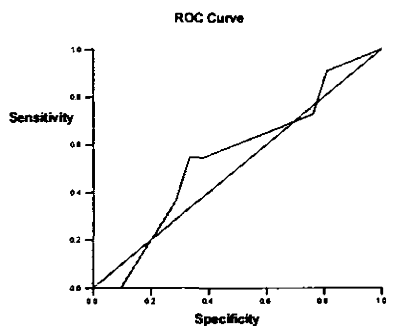
PMD vs PF 8



Diagonal segments are produced by ties.

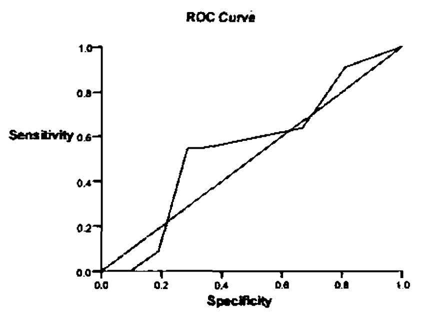
Era-40 vs PF 9

UKMO



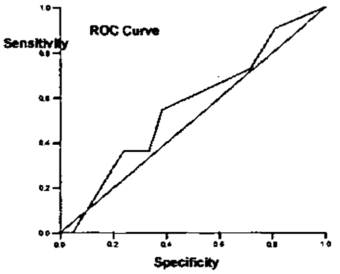
Diagonal segments are produced by ties.

PMD VS PF 9



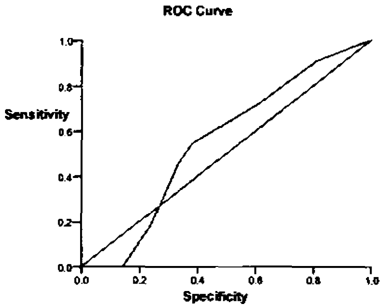
Diagonal segments are produced by ties.

PMD vs PF 0



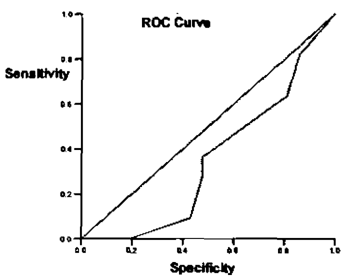
Diagonal segments are produced by ties.

PMD vs PF 1



Diagonal segments are produced by ties.

PMD vs PF 8

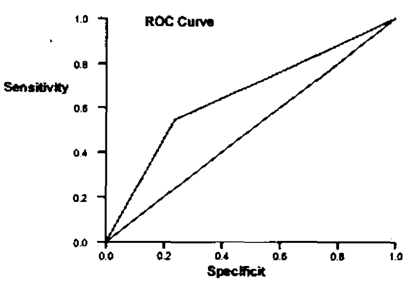


Diagonal segments are produced by ties.

Era-40 vs PF 9

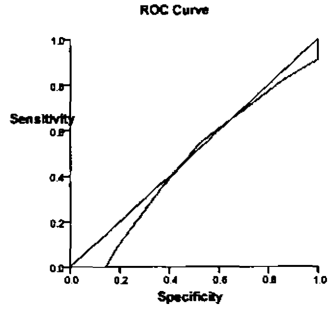
Jhelum

ECMWF



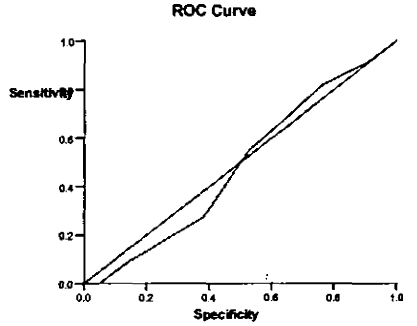
Diagonal segments are produced by ties

PMD vs Era-40



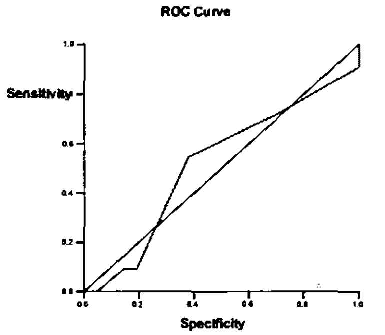
Diagonal segments are produced by ties.

PMD vs PF 9



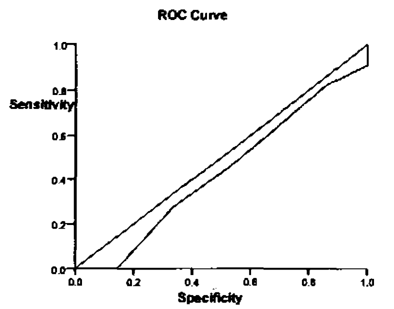
Diagonal segments are produced by ties.

PMD vs PF 1



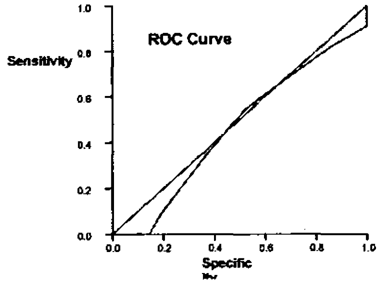
Diagonal segments are produced by ties.

PMD vs PF 7



Diagonal segments are produced by ties.

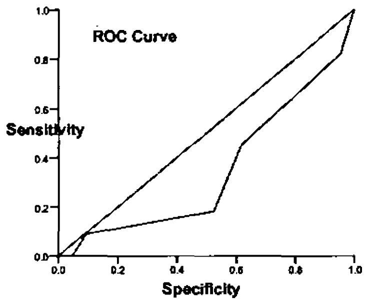
PMD vs PF 8



Diagonal segments are produced by ties.

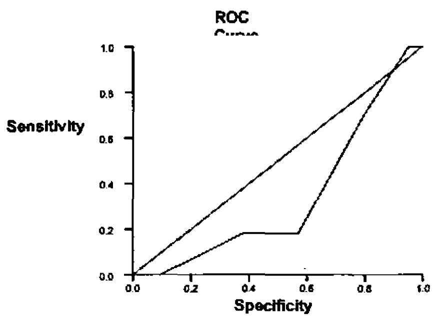
Era-40 vs PF 9

Meteo-France



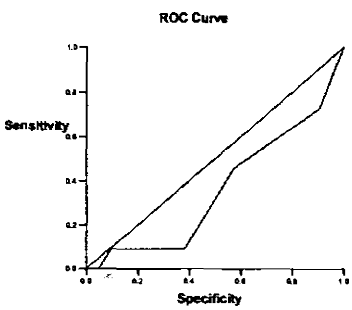
Diagonal segments are produced by ties.

PMD vs PF 9



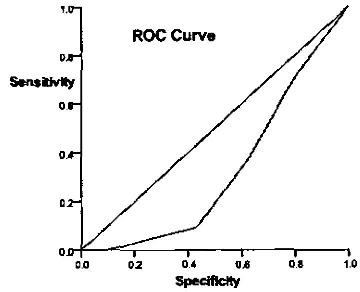
Diagonal segments are produced by ties.

PMD vs PF 0



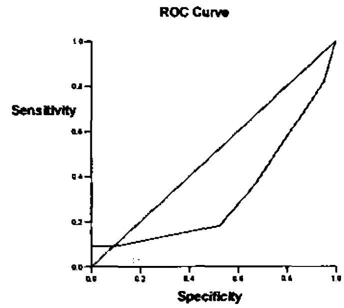
Diagonal segments are produced by ties.

PMD vs PF 1



Diagonal segments are produced by ties.

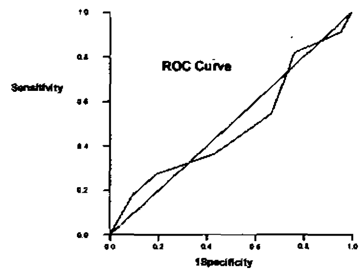
PMD vs PF 2



Diagonal segments are produced by ties.

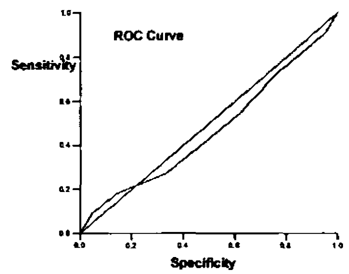
Era-40 vs PF 9

MPI



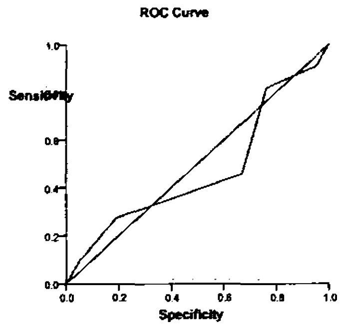
Diagonal segments are produced by ties.

PMD vs PF 9



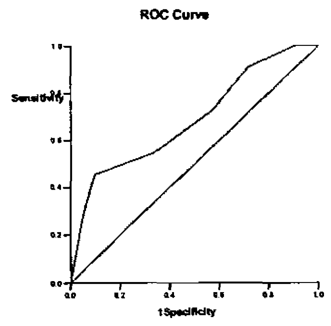
Diagonal segments are produced by ties.

PMD vs PF 0



Diagonal segments are produced by ties.

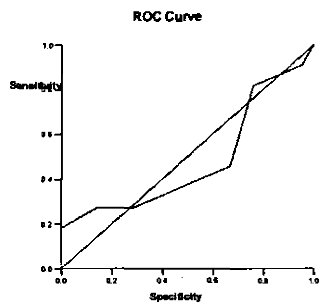
PMD vs PF 1



Diagonal segments are produced by ties.

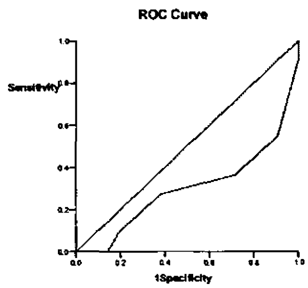
Era-40 vs PF 9

UKMO



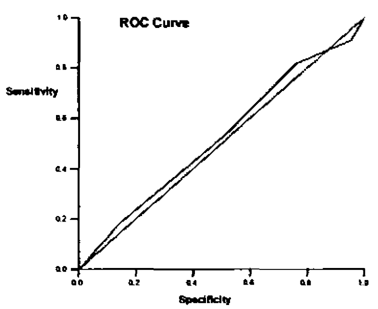
Diagonal segments are produced by ties.

PMD vs PF 2



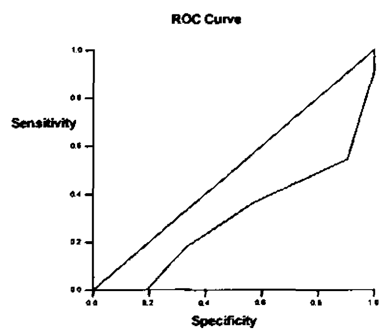
Diagonal segments are produced by ties.

PMD vs PF 9



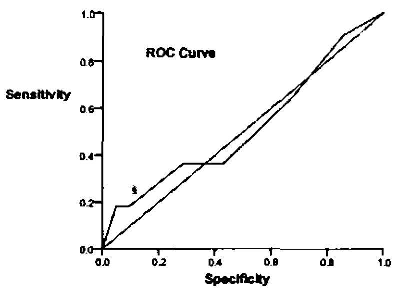
Diagonal segments are produced by ties.

PMD vs PF 6



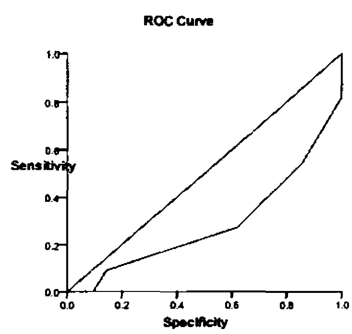
Diagonal segments are produced by ties.

PMD vs PF 1



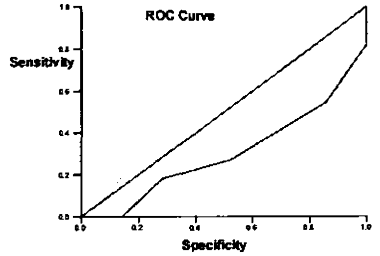
Diagonal segments are produced by ties.

PMD vs PF 8



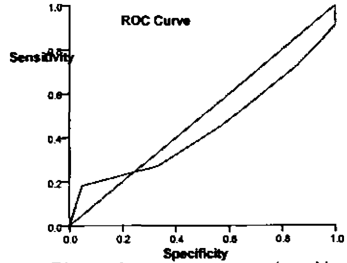
Diagonal segments are produced by ties.

PMD vs PF 5



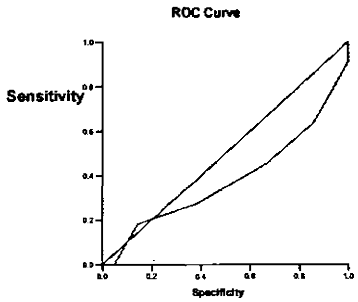
Diagonal segments are produced by ties.

PMD vs PF 7



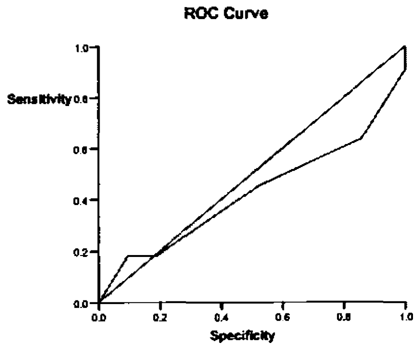
Diagonal segments are produced by ties.

PMD vs PF 0



Diagonal segments are produced by ties.

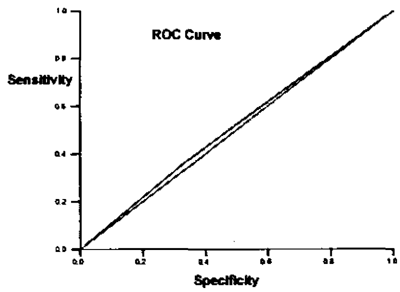
Era-40 vs PF 9



Diagonal segments are produced by ties.

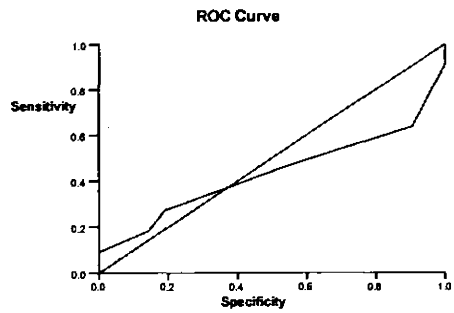
PMD vs PF 4

Lahore
ECMWF



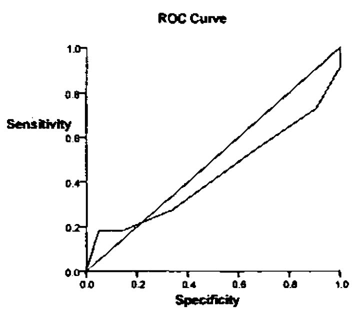
Diagonal segments are produced by ties.

PMD vs Era-40



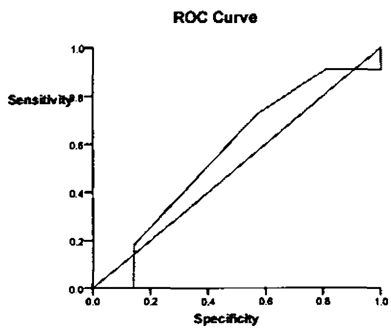
Diagonal segments are produced by ties.

PMD vs PF 5



Diagonal segments are produced by ties

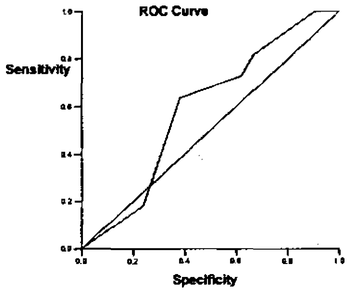
PMD vs PF 9



Diagonal segments are produced by ties.

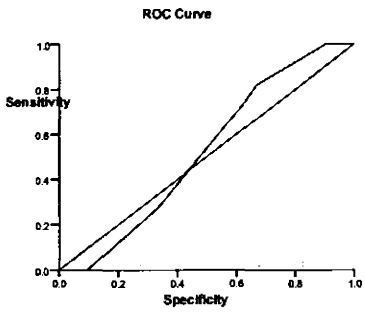
Era-40 vs PF 9

Meteo-France



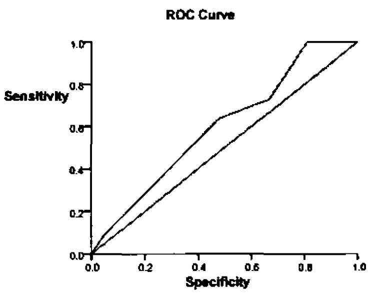
Diagonal segments are produced by ties.

PMD vs PF 9



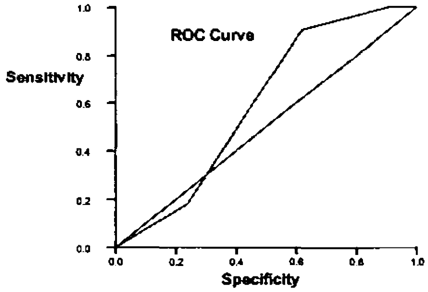
Diagonal segments are produced by ties.

PMD vs PF 1



Diagonal segments are produced by ties.

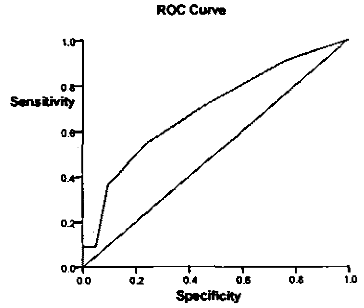
PMD vs PF 5



Diagonal segments are produced by ties.

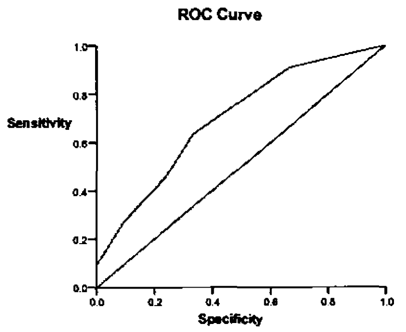
Era-40 vs PF 9

MPI



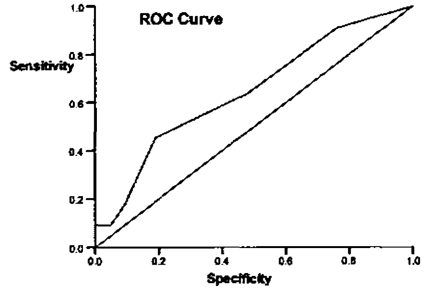
Diagonal segments are produced by ties.

PMD vs PF 9



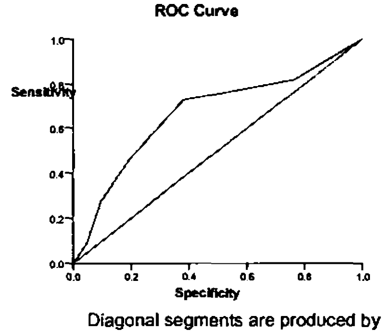
Diagonal segments are produced by ties.

PMD vs PF 2



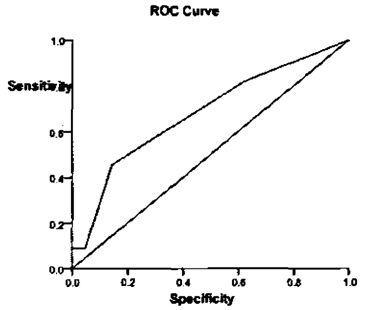
Diagonal segments are produced by ties.

PMD vs PF 3



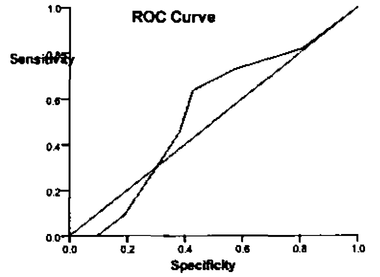
Diagonal segments are produced by ties.

PMD vs PF 4



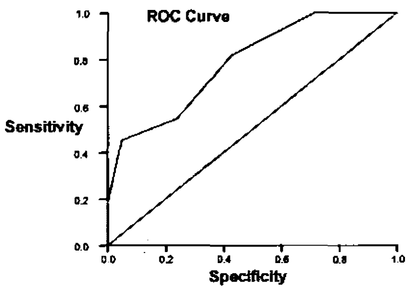
Diagonal segments are produced by ties.

PMD vs PF 8



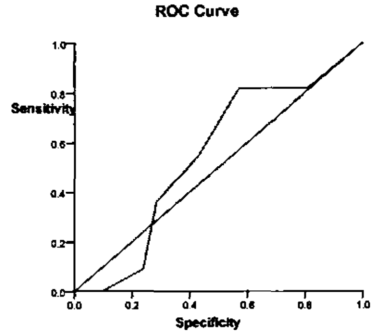
Diagonal segments are produced by ties.

PMD vs PF 4



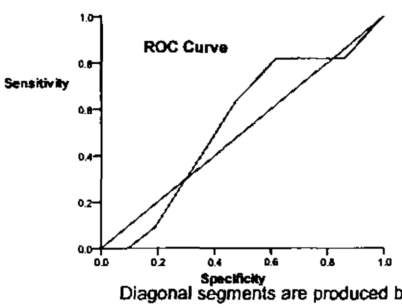
Era-40 vs PF 9

UKMO



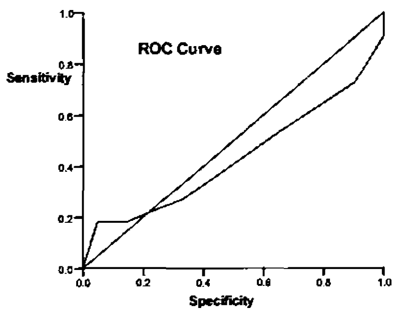
Diagonal segments are produced by ties.

PMD vs PF 7



Diagonal segments are produced by ties.

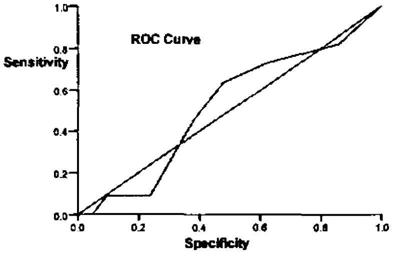
PMD vs PF 9



Diagonal segments are produced by ties.

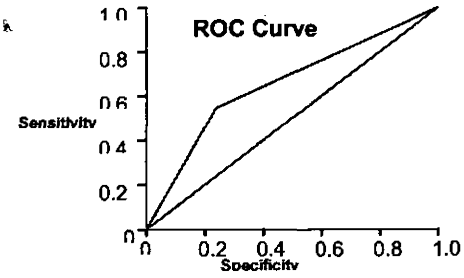
Era-40 vs PF 9

BAHAWALNAGER
ECMWF



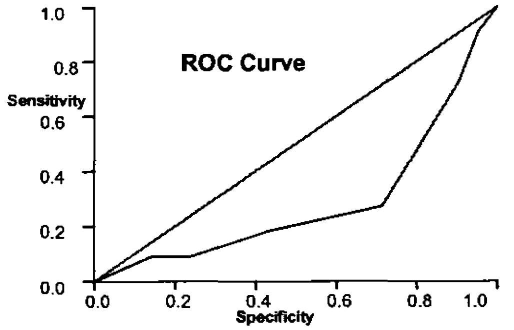
Diagonal segments are produced by ties.

PMD vs PF 1



Diagonal segments are produced by ties.

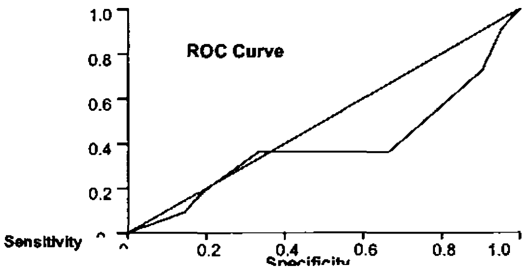
PMD vs ERA 40



Diagonal segments are produced by ties.

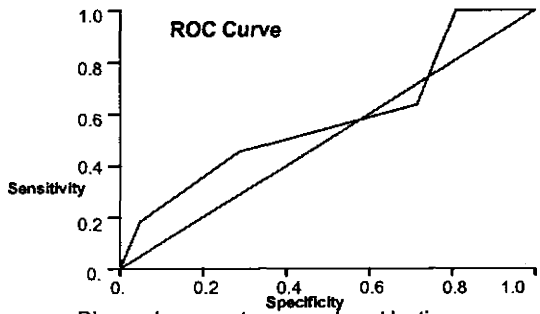
ERA 40 vs PF 9

Meteo- France



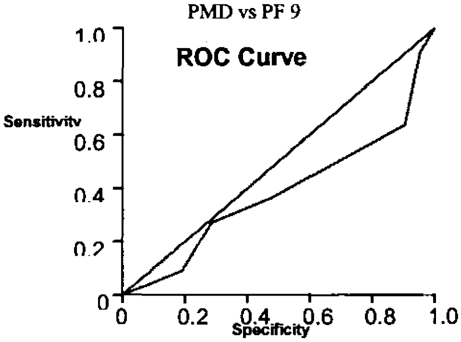
Diagonal segments are produced by

PMD vs PF 9



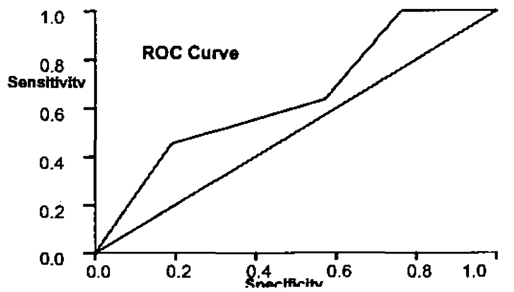
Diagonal segments are produced by ties.

PMD vs PF 9



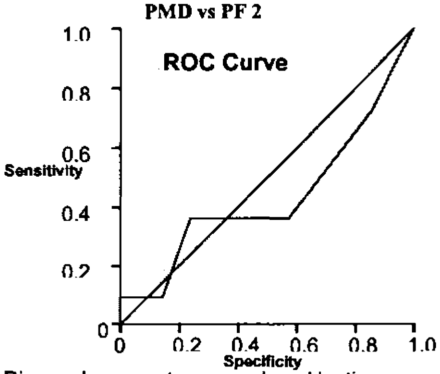
Diagonal segments are produced by ties.

PMD vs PF 2



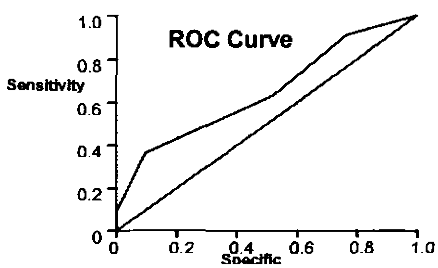
Diagonal segments are produced by ties

PMD vs PF 2



Diagonal segments are produced by ties.

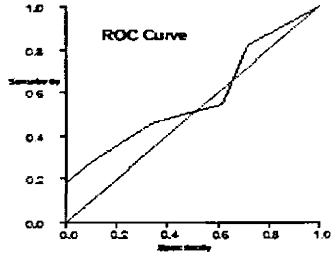
PMD vs PF 6



Diagonal segments are produced by ties

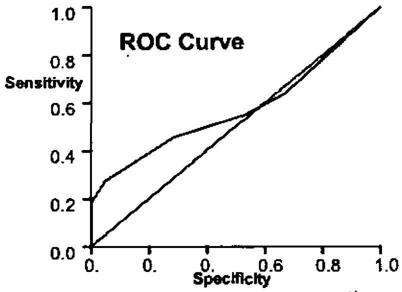
PMD vs PF 5

MPI

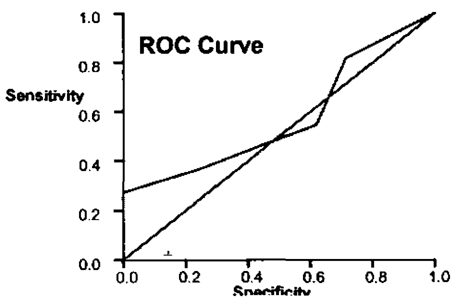


Diagonal segments are produced by ties.

PMD vs PF 9

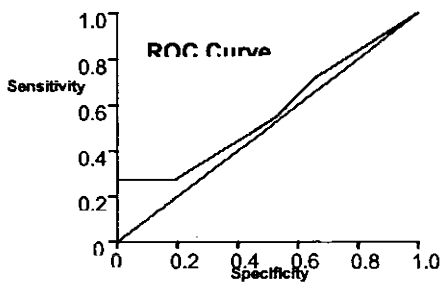


PMD vs PF 0



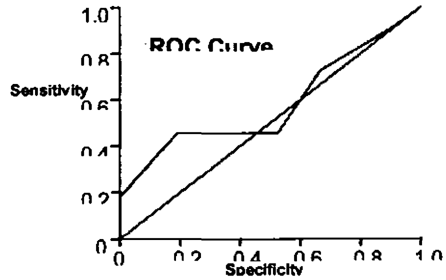
Diagonal segments are produced by ties.

PMD vs PF 2



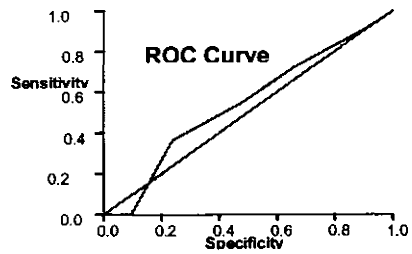
Diagonal segments are produced by ties.

PMD vs PF 4



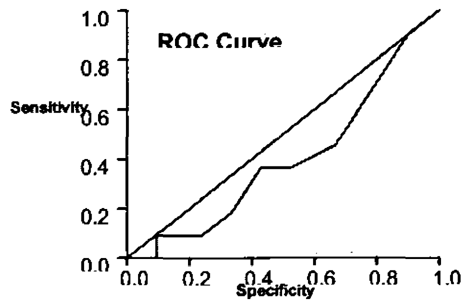
Diagonal segments are produced by ties.

PMD vs PF 8



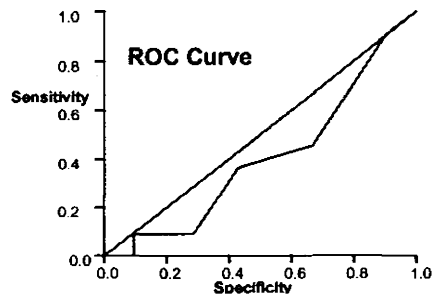
Era 40 vs PF 9

UKMO



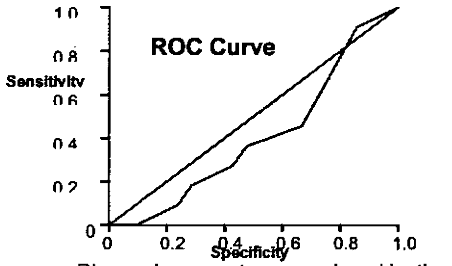
Diagonal segments are produced by ties.

PMD vs PF 9



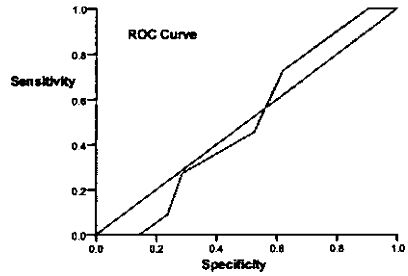
Diagonal segments are produced by ties.

PMD vs PF 6



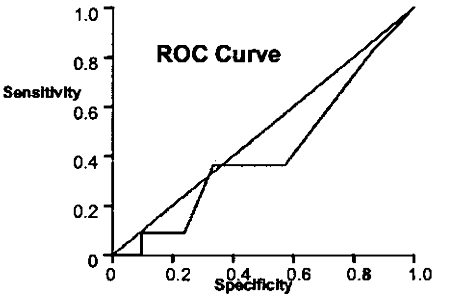
Diagonal segments are produced by ties

PMD vs PF 4



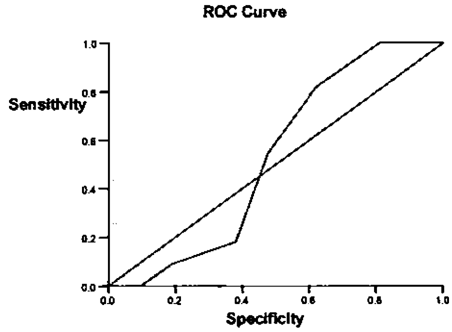
Diagonal segments are produced by ties.

Era-40 vs PF 3



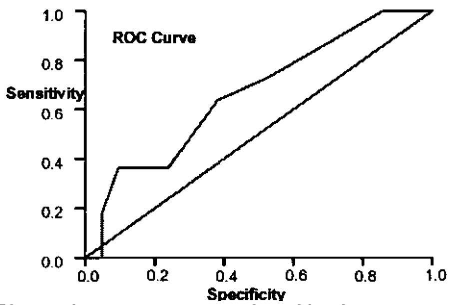
Diagonal segments are produced by ties.

PMD vs PF 7



Diagonal segments are produced by ties.

Era-40 vs PF 6

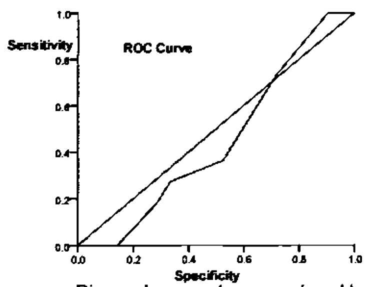


Diagonal segments are produced by ties.

Era 40 Vs PF 9

Rahim yar Khan

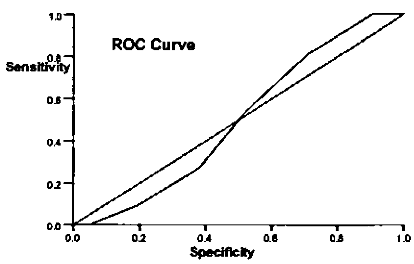
ECMWF



Diagonal segments are produced by ties.

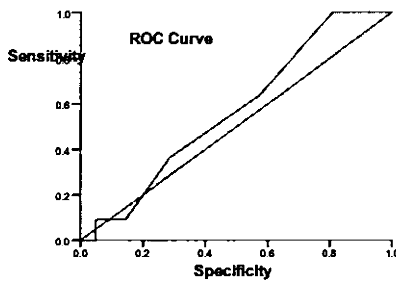
Era-40 vs PF 8

Meteo- France



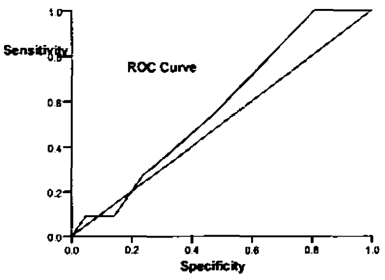
Diagonal segments are produced by ties.

Era-40 vs PF 9



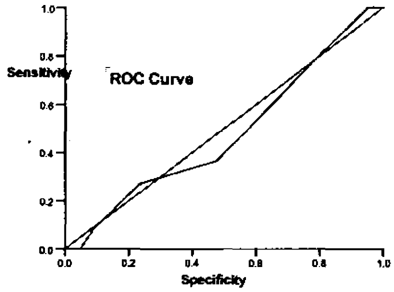
Diagonal segments are produced by ties.

Era-40 vs PF 9



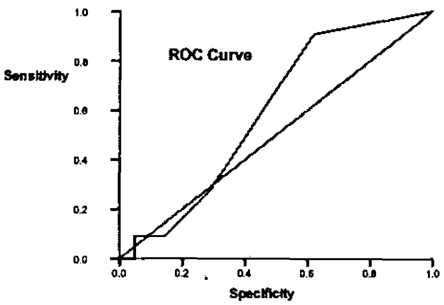
Diagonal segments are produced by ties.

Era-40 vs PF 2



Diagonal segments are produced by ties.

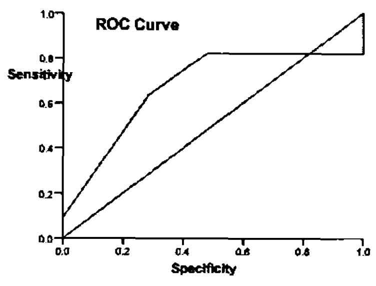
Era-40 vs PF 3



Diagonal segments are produced by ties.

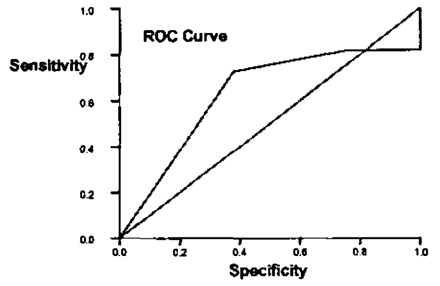
Era-40 vs PF 7

MPI



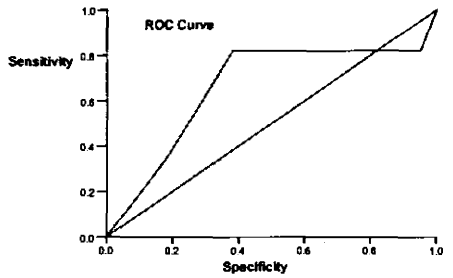
Diagonal segments are produced by ties.

Era-40 vs PF 9



Diagonal segments are produced by ties.

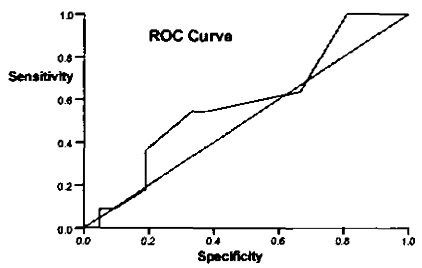
Era-40 vs PF 0



Diagonal segments are produced by ties.

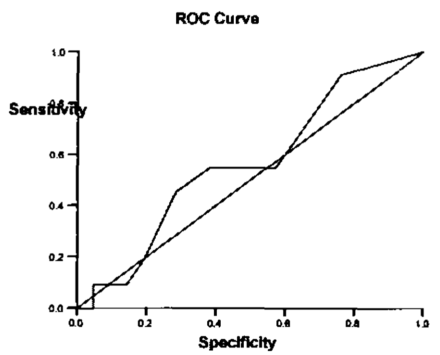
Era-40 vs PF 2

UKMO



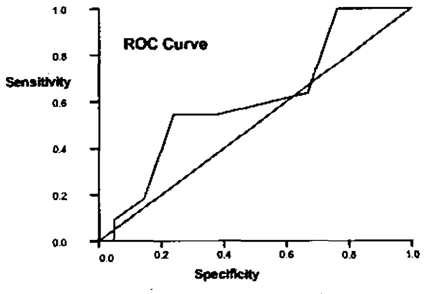
Diagonal segments are produced by ties.

Era-0 vs PF 9

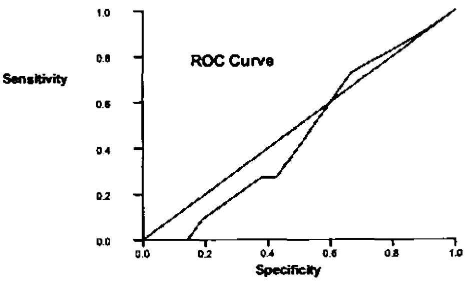


Diagonal segments are produced by ties.

Era-40 vs PF 0

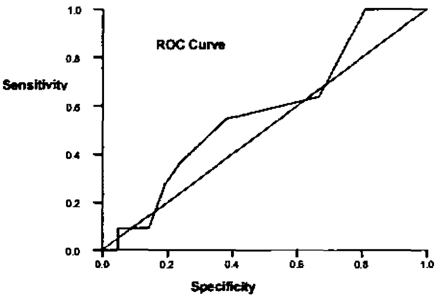


Diagonal segments are produced by ties.



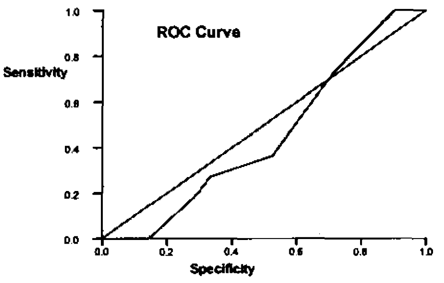
Diagonal segments are produced by ties.

Era 40 vs PF 7



Diagonal segments are produced by ties.

Era-40 vs PF 3



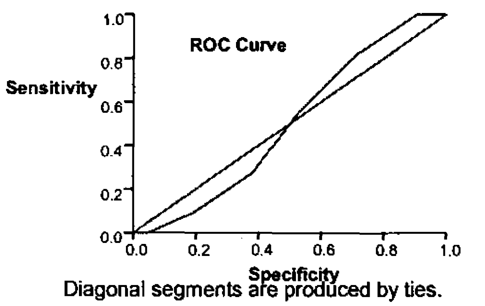
Diagonal segments are produced by ties.

Era 40 vs PF 8

Khairpur

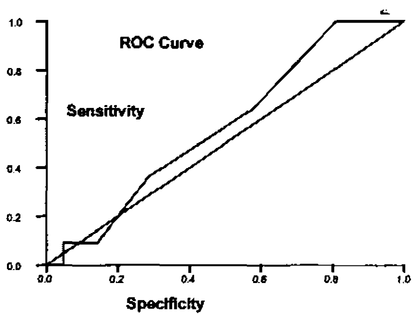
ECMWF

Meteo-France



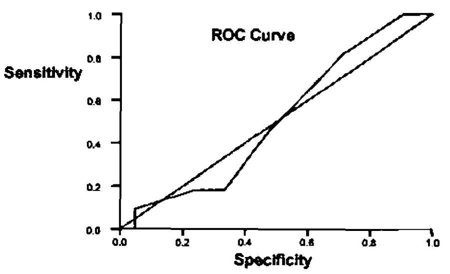
Diagonal segments are produced by ties.

Era 40 vs PF 9 **Era**



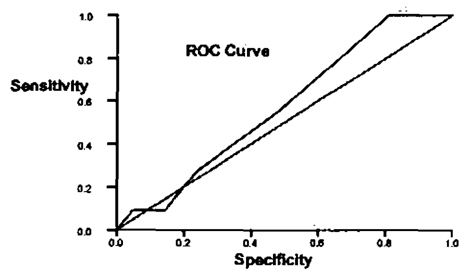
Diagonal segments are produced by ties.

Era-40 vs PF 9



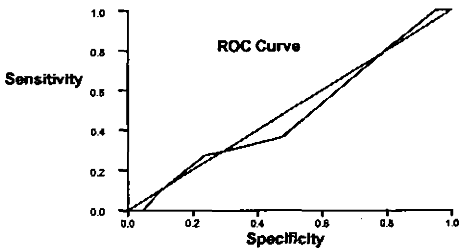
Diagonal segments are produced by

Era 40 vs PF 5

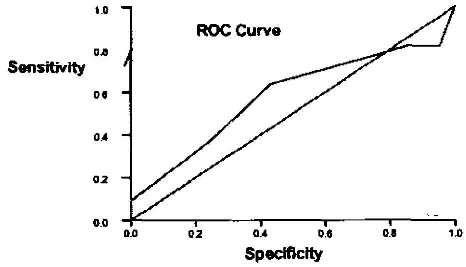


Diagonal segments are produced by ties.

Era-40 vs PF 2

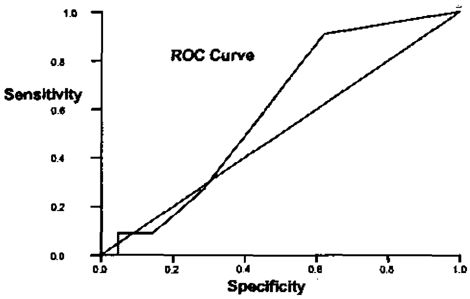


Diagonal segments are produced by ties.
Era-40 vs PF 3



Diagonal segments are produced by ties.
Era-40 vs PF 6

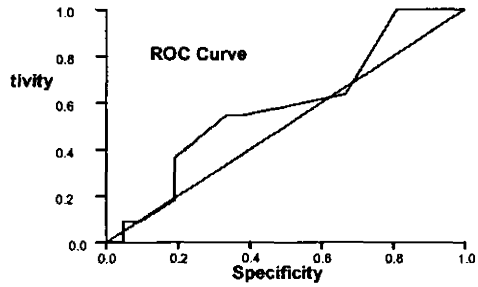
UKMO



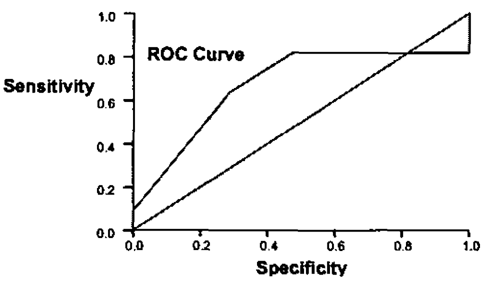
Diagonal segments are produced by ties.

Era-40 vs PF 7

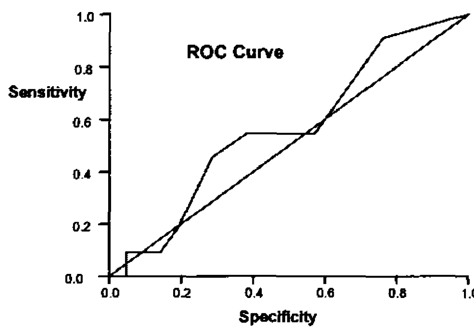
MPI



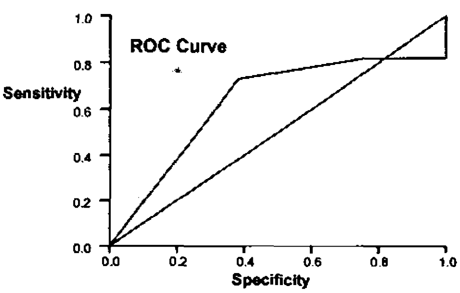
Diagonal segments are produced by ties.
Era-40 vs PF 9



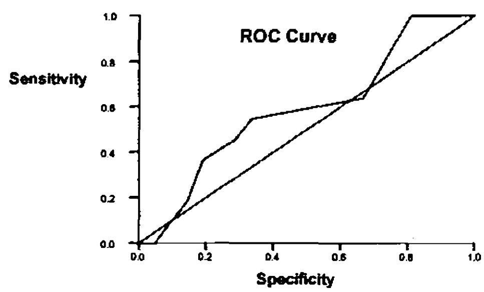
Diagonal segments are produced by
Era-40 vs PF 9



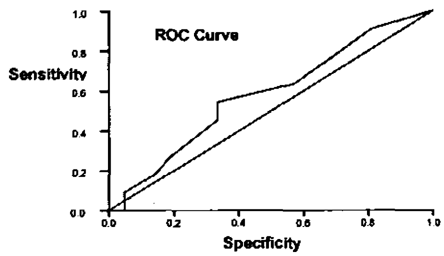
Diagonal segments are produced by ties.
Era-40 vs PF 0



Diagonal segments are produced by ties.
Era-40 vs PF 0

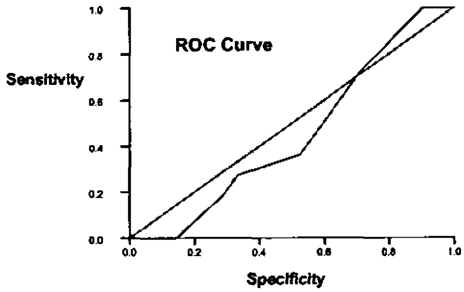


Diagonal segments are produced by ties.
Era-40 vs PF 4



Diagonal segments are produced by ties.

Era-40 vs PF 8



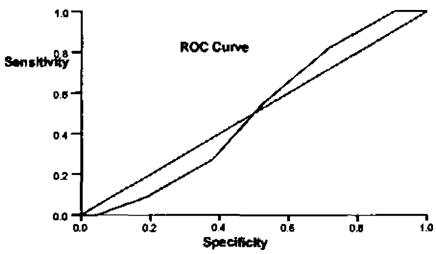
Diagonal segments are produced by ties.

Era-40 vs PF 8

SUKKUR

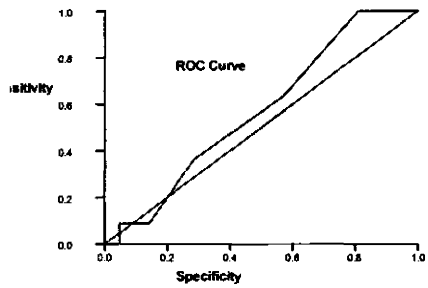
ECMWF

Meteo-France



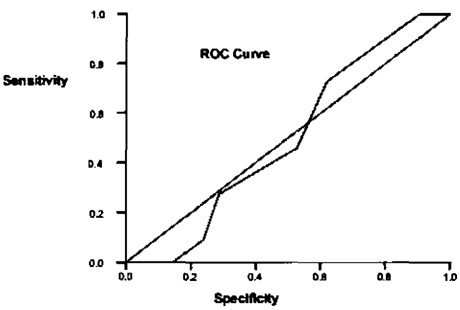
Diagonal segments are produced by ties.

Era-40 vs PF 9



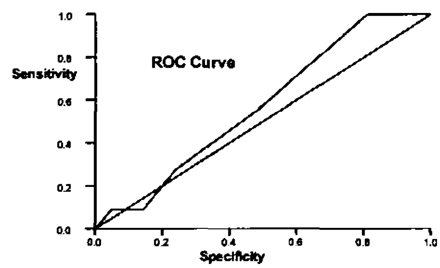
Diagonal segments are produced by ties.

Era-40 vs PF 9



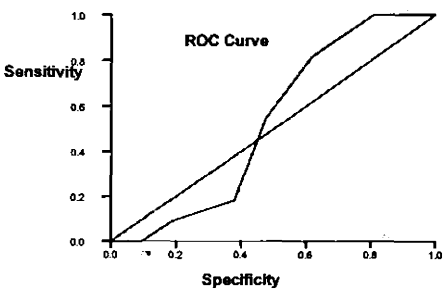
Diagonal segments are produced by ties.

Era-40 vs PF 3



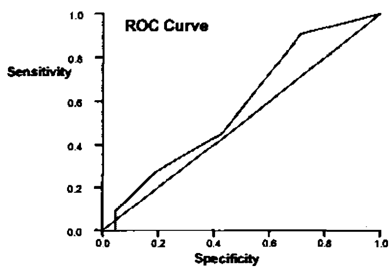
Diagonal segments are produced by ties.

Era-40 vs PF 2



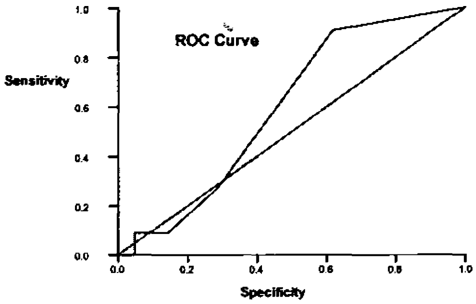
Diagonal segments are produced by ties.

Era-40 vs PF 6



Diagonal segments are produced by ties.

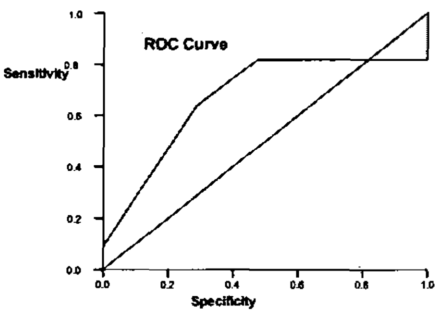
Era-40 vs PF 5



Diagonal segments are produced

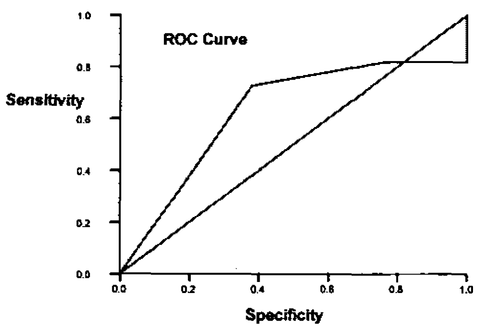
Era-40 vs PF 7

MPI



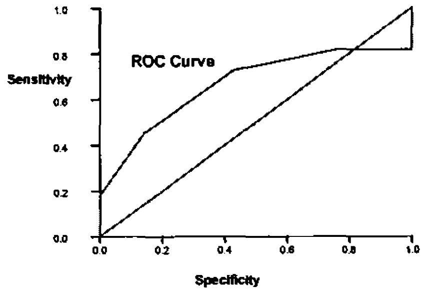
Diagonal segments are produced by ties.

Era-40 vs PF 9



Diagonal segments are produced by ties.

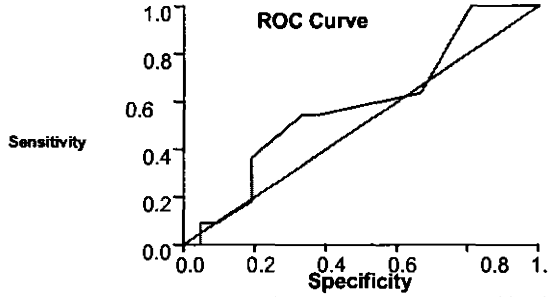
Era-40 vs PF 0



Diagonal segments are produced by ties.

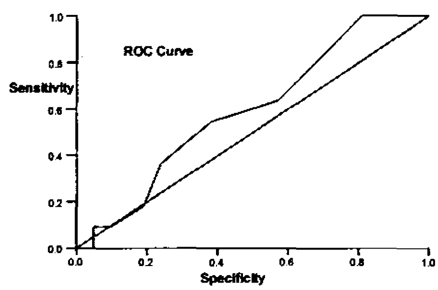
Era-40 vs PF 7

UKMO



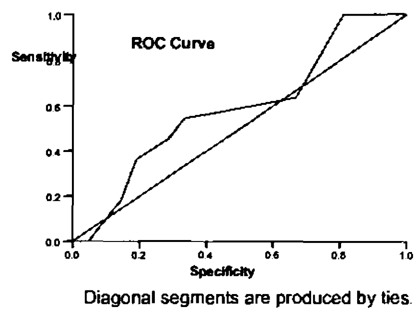
Diagonal segments are produced by ties.

Era-40 vs PF 9



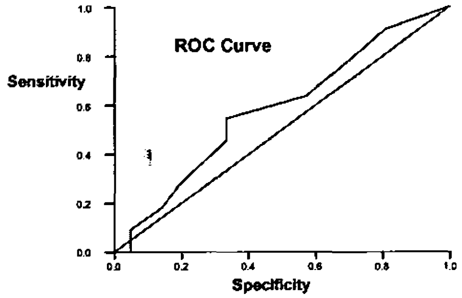
Diagonal segments are produced by ties.

Era-40 vs PF 2

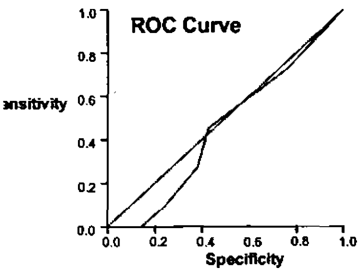


Diagonal segments are produced by ties.

Era-40 vs PF 4

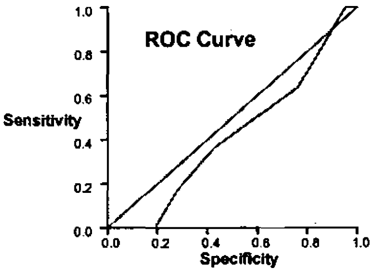


Diagonal segments are produced by ties.
Era-40 vs PF 8

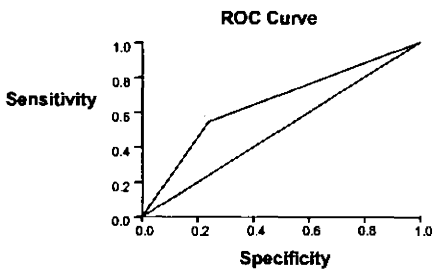


Diagonal segments are produced by ties.
PMD vs PF 1

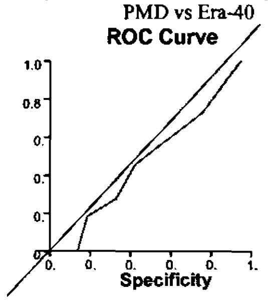
Badin
ECMWF



Diagonal segments are produced by ties.
PMD vs PF 6

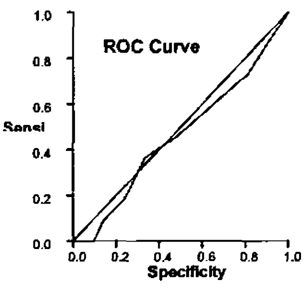


Diagonal segments are produced by ties.
PMD vs Era-40

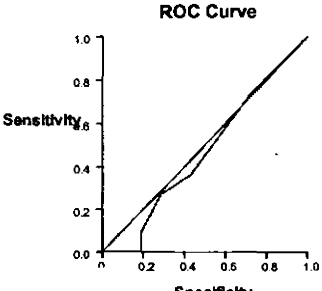


Diagonal segments are produced by ties.

PMD vs PF9

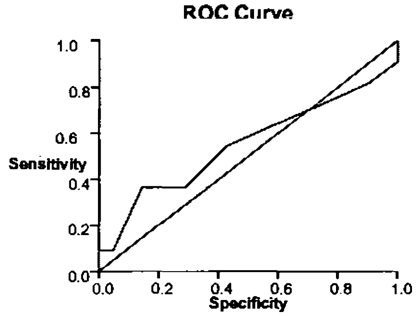


Diagonal segments are produced by ties.
ERA 40 vs PF 9



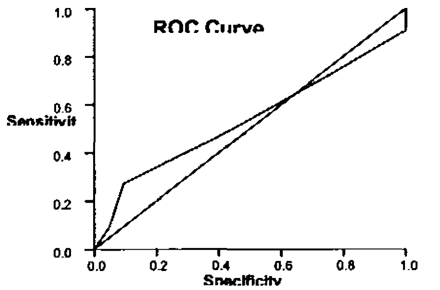
Diagonal segments are produced by ties.
PMD vs PF 0

Meteo-France



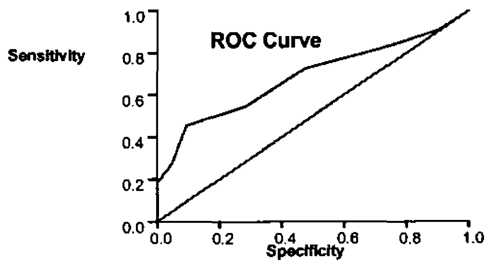
Diagonal segments are produced by ties.
PMD vs PF 9

MPI



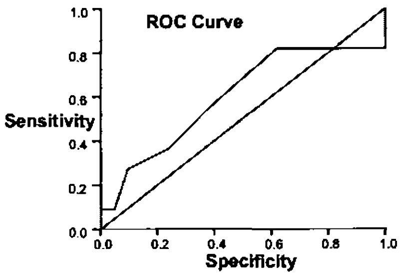
Diagonal segments are produced by ties.

PMD vs PF 0



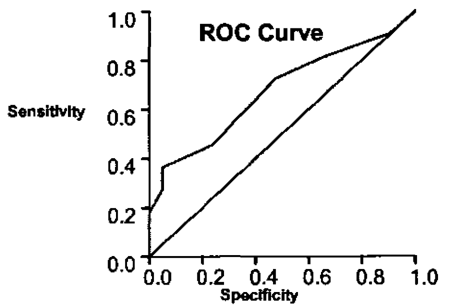
Diagonal segments are produced by ties.

PMD vs PF 9



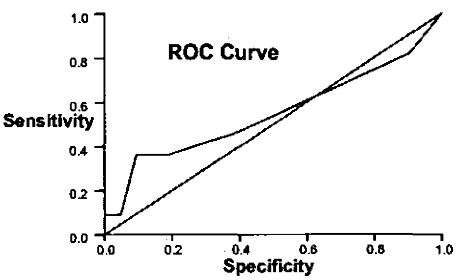
Diagonal segments are produced by ties.

PMD vs PF 3



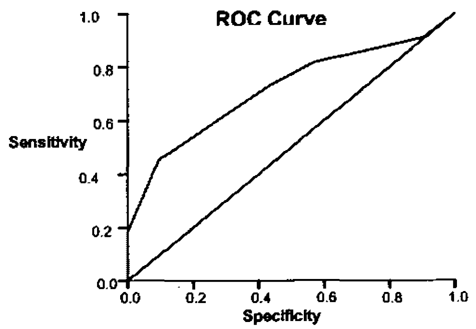
Diagonal segments are produced by ties.

PMD vs PF 0



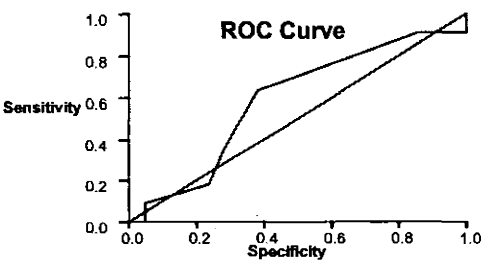
Diagonal segments are produced by ties.

PMD vs PF 7



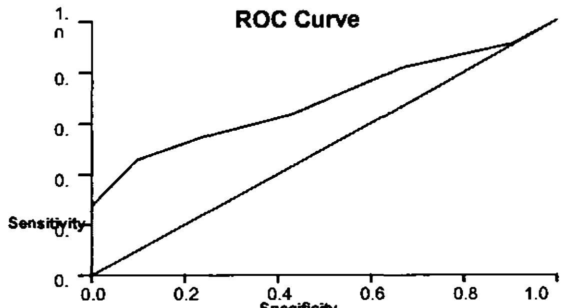
Diagonal segments are produced by ties.

PMD vs PF 2



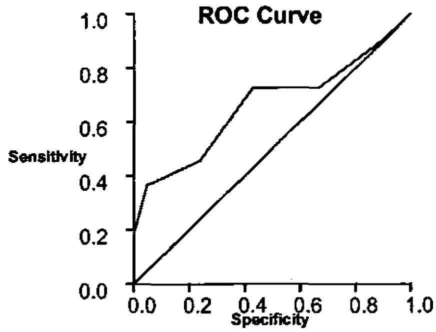
Diagonal segments are produced by ties.

Era-40 vs PF 9



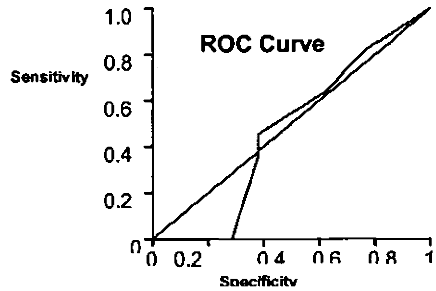
Diagonal segments are produced by ties.

PMD vs PF 3



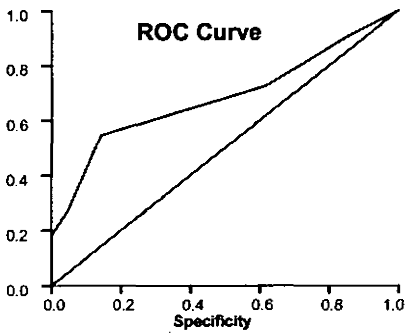
Diagonal segments are produced by ties.

PMD vs PF 4



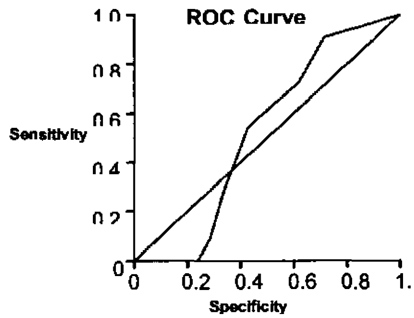
Diagonal segments are produced by ties.

PMD vs PF 3



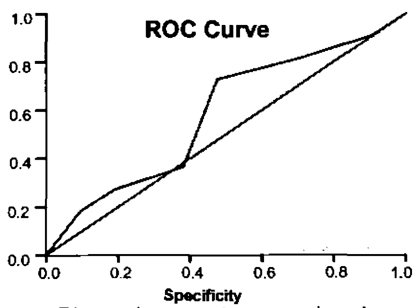
Diagonal segments are produced by ties.

PMD vs PF 8



Diagonal segments are produced by ties.

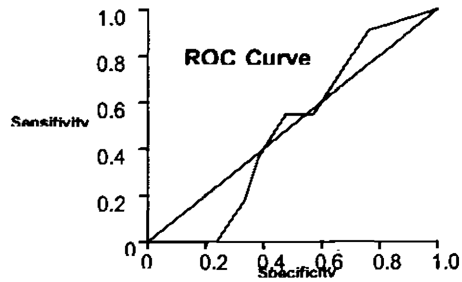
PMD vs PF 4



Diagonal segments are produced

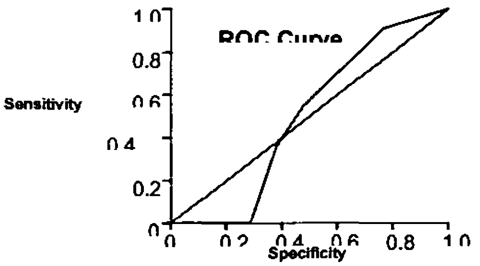
ERA 40 and MPI

UKMO



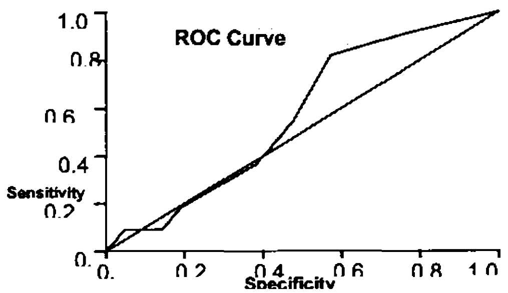
Diagonal segments are produced by ties.

PMD vs PF 5



Diagonal segments are produced by ties.

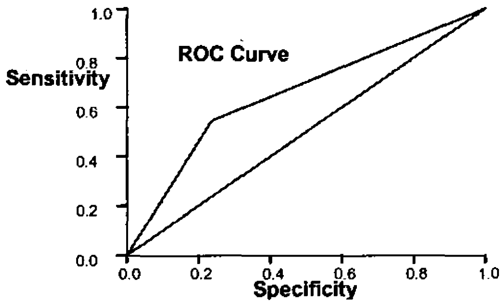
PMD vs PF9



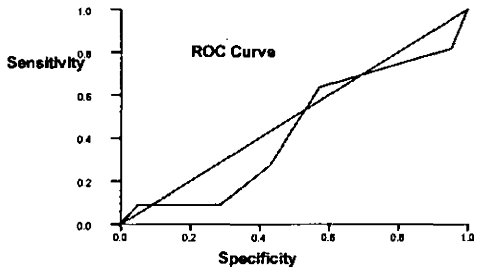
Diagonal segments are produced by ties

ERA 40 vs UKMO

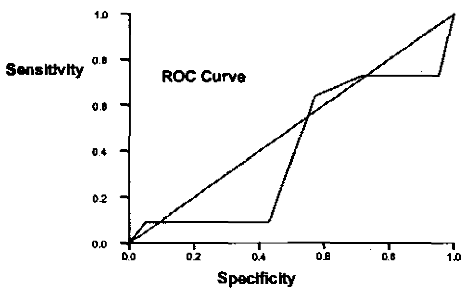
NAWABSHAH
ECMWF



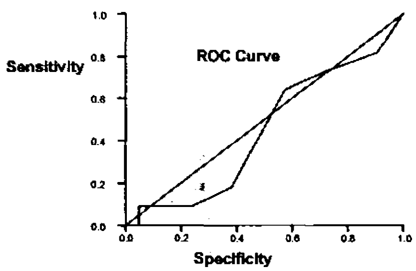
Diagonal segments are produced by ties.
Era-40 vs PMD



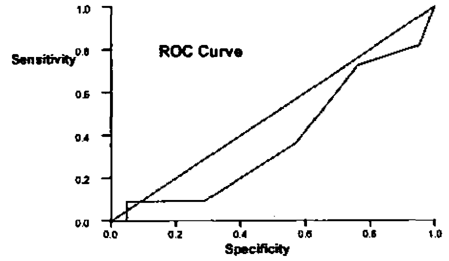
Diagonal segments are produced by ties.
PMD vs PF 9



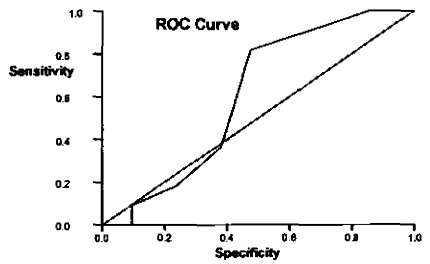
Diagonal segments are produced by ties.
PMD vs PF 2



Diagonal segments are produced by ties.
PMD vs PF 3

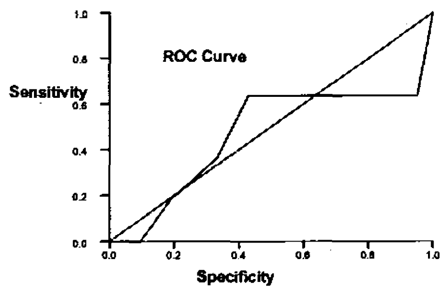


Diagonal segments are produced by ties.
PMD vs PF 5



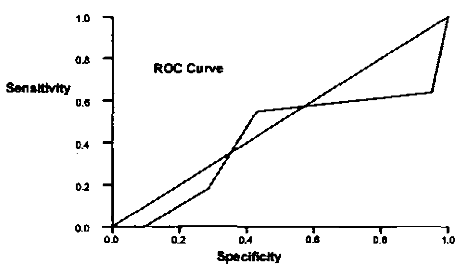
Diagonal segments are produced by ties.
Era-40 vs PF 9

Meteo-France



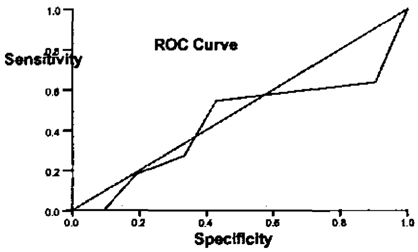
Diagonal segments are produced by ties.

PMD vs PF 9



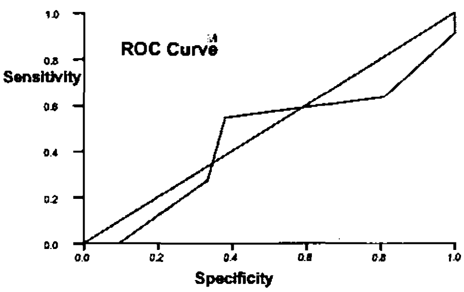
Diagonal segments are produced by ties.

PMD vs PF 0



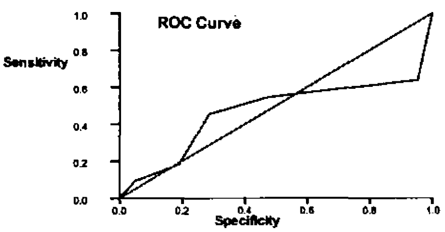
Diagonal segments are produced by ties.

PMD vs PF 2



Diagonal segments are produced by ties.

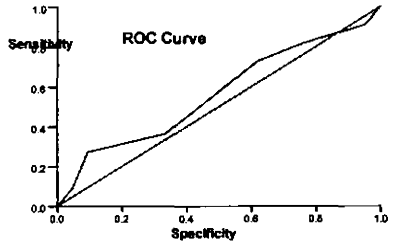
PMD vs PF 8



Diagonal segments are produced by ties.

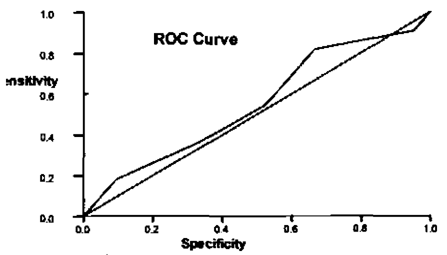
Era-40 vs PF 9

MPI



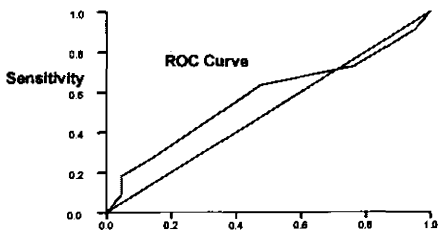
Diagonal segments are produced by ties.

PMD vs PF 9



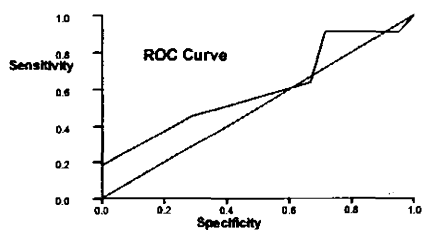
iagonal segments are produced by ties.

PMD vs PF 2



Diagonal segments are produced by ties.

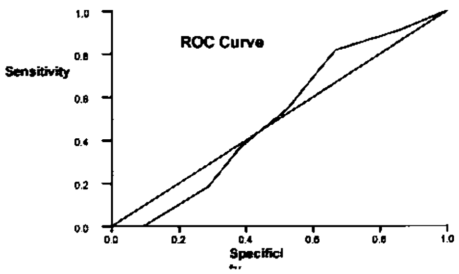
PMD vs PF 8



Diagonal segments are produced by ties.

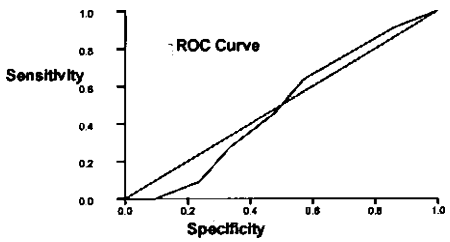
Era-40 vs PF 9

UKMO



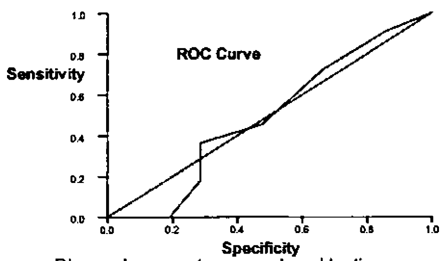
Diagonal segments are produced by ties.

PMD vs PF 9



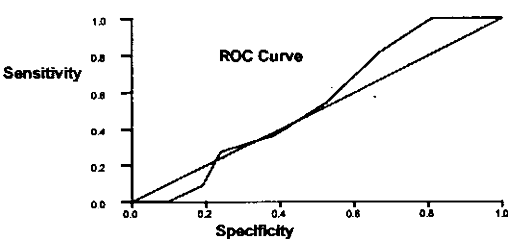
Diagonal segments are produced by ties.

PMD vs PF 7



Diagonal segments are produced by ties.

PMD vs PF 8

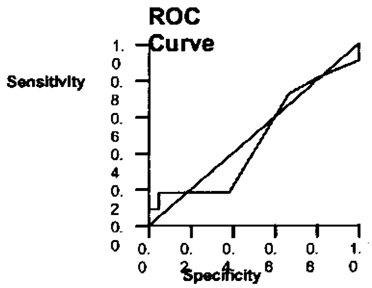


Diagonal segments are produced by ties.

Era-40 vs PF 9

Badin

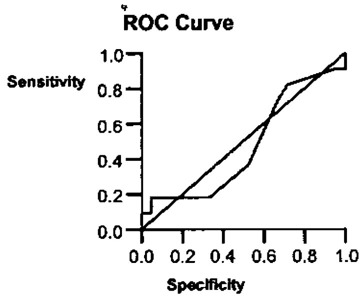
ECMWF + Meteo-France



Diagonal segments are produced by ties.

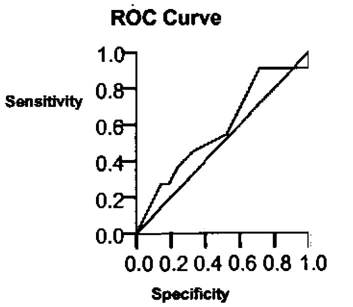
ecmwf+mf vs PMD

ECMWF+ MPI



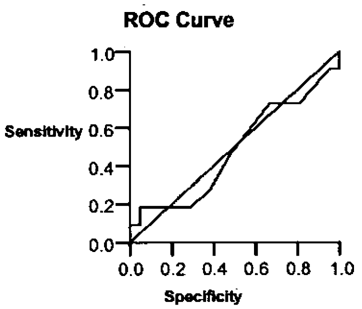
Diagonal segments are produced by ties.

PF 2 vs PMD



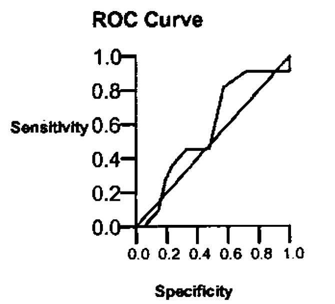
Diagonal segments are produced by ties.

ECMWF+MPI vs PMD



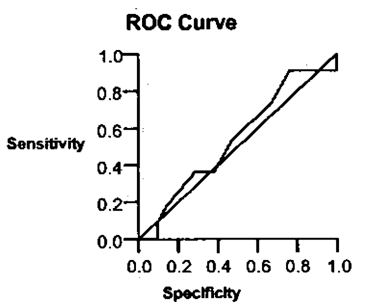
Diagonal segments are produced by ties.

PF 17 vs PMD



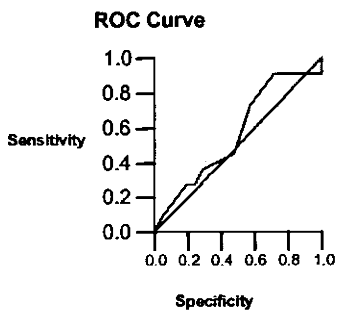
Diagonal segments are produced by ties.

PF 5 vs PMD



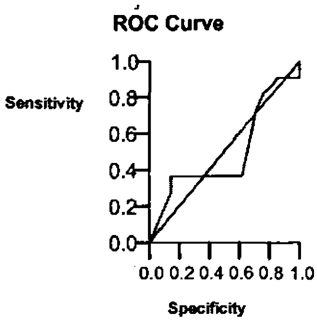
Diagonal segments are produced by ties.

PF 18 vs Era-40



Diagonal segments are produced by ties.

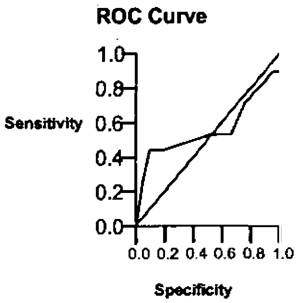
PF 8 vs PMD



Diagonal segments are produced by ties.

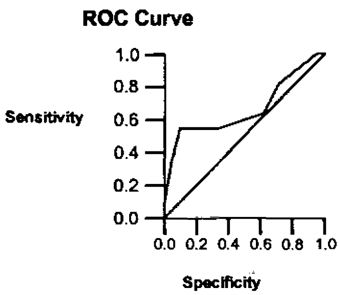
PF 18 vs Era-40

MPI + Meteo-France



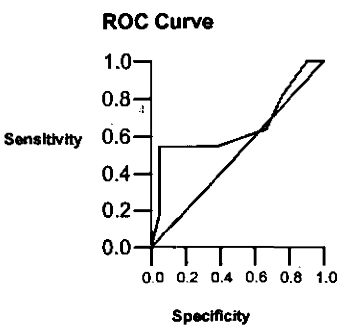
Diagonal segments are produced by ties.

MPI +Meteo-France vs PMD



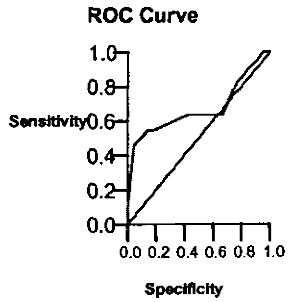
Diagonal segments are produced by ties.

PF 8 vs PMD



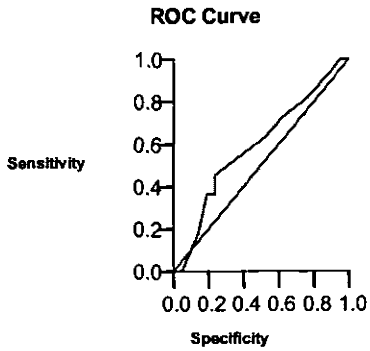
Diagonal segments are produced by ties.

PF 12 vs PMD



Diagonal segments are produced by ties.

PF 14 vs PMD

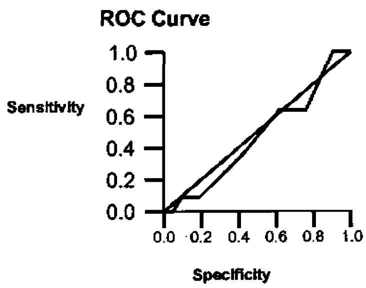


Diagonal segments are produced by ties.

PF 18 vs Era-40

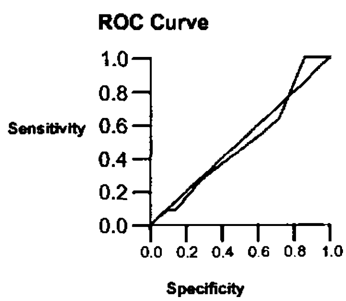
Bahawalnager

ECMWF + Meteo-France



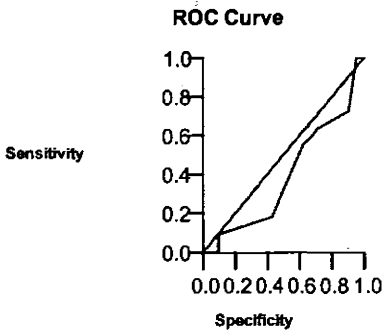
Diagonal segments are produced by ties.

PF 18 vs PMD



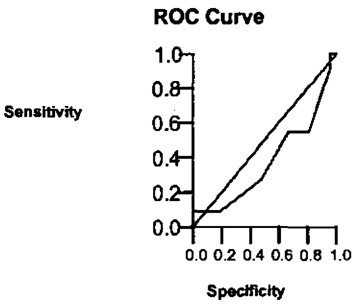
Diagonal segments are produced by ties.

PF 12 vs PMD



Diagonal segments are produced by ties.

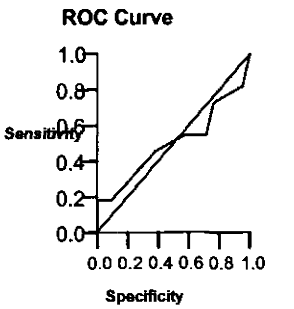
PF 18 vs PMD



Diagonal segments are produced by ties.

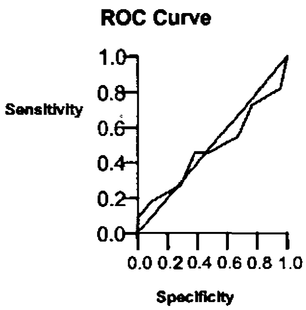
PF 18 vs Era-40

ECMWF + MPI



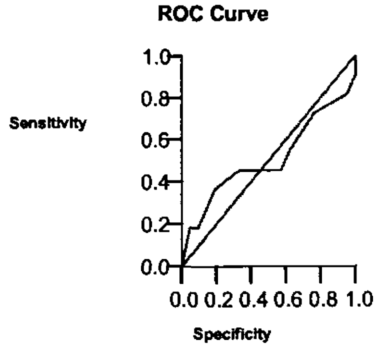
Diagonal segments are produced by ties.

PF (all) vs PMD



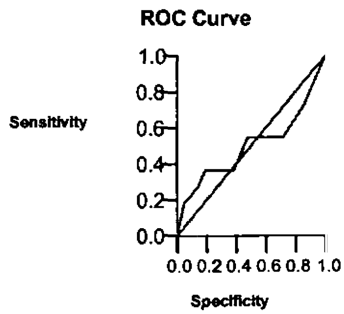
Diagonal segments are produced by ties.

PF 1 vs PMD



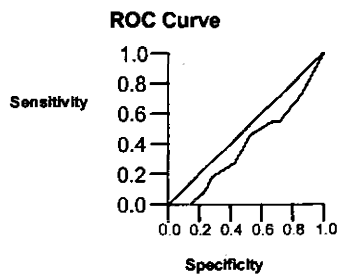
Diagonal segments are produced by ties.

PF 14 vs PMD



Diagonal segments are produced by ties.

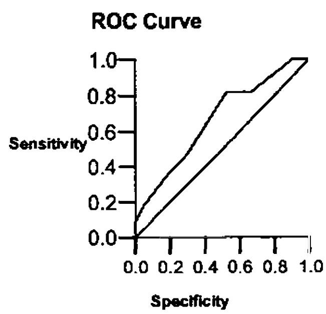
PF 18 vs PMD



Diagonal segments are produced by ties.

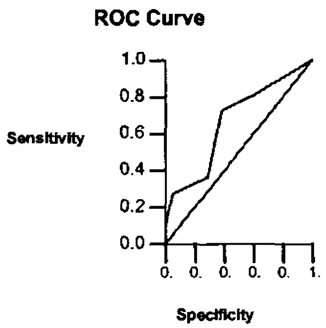
PF 18 vs Era-40

MPI + Meteo-France



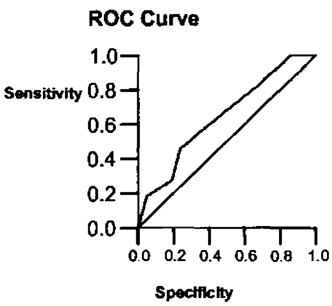
Diagonal segments are produced by ties.

PF 18 vs PMD



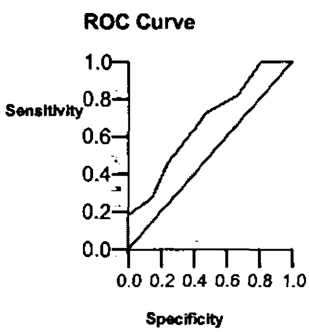
Diagonal segments are produced by ties.

PF 9 vs PMD



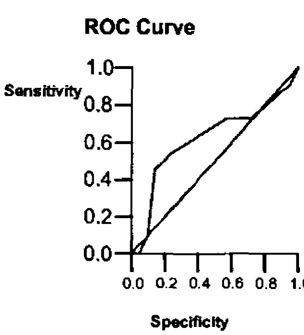
Diagonal segments are produced by ties.

PF 11 vs PMD



Diagonal segments are produced by ties.

PF 12 vs PMD

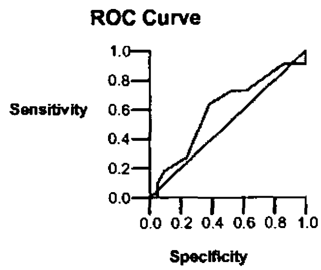


Diagonal segments are produced by ties.

PF 18 vs Era-40

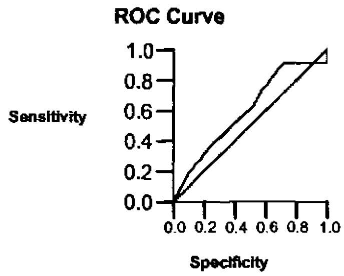
Islamabad

ECMWF + Meteo-France



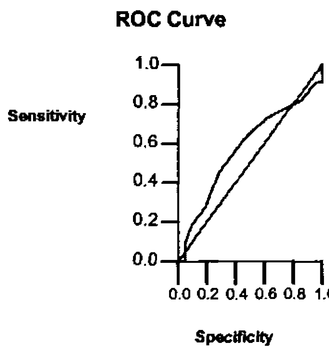
Diagonal segments are produced by

PF18 vs PMD



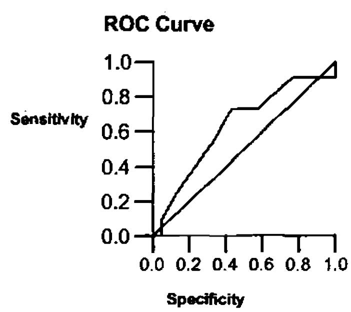
Diagonal segments are produced by ties.

PF8 vs PMD



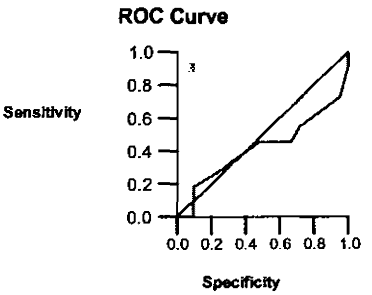
Diagonal segments are produced by ties.

PF 13 vs PMD



Diagonal segments are produced by ties.

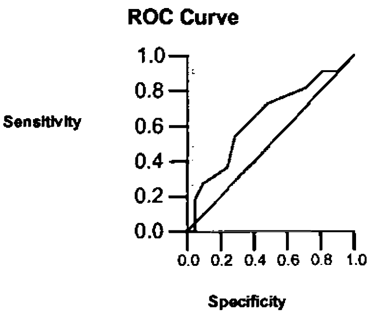
PF14 vs PMD



Diagonal segments are produced by ties.

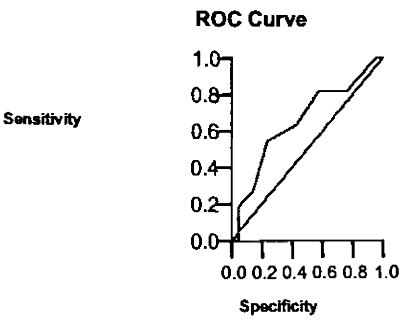
PF 18 vs Era-40

ECMWF + MPI



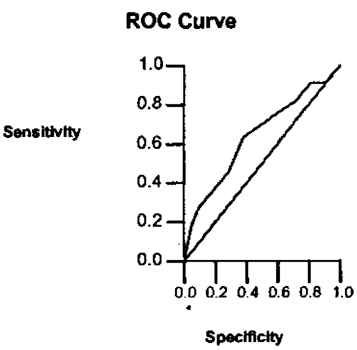
Diagonal segments are produced by ties.

PF 18 vs PMD



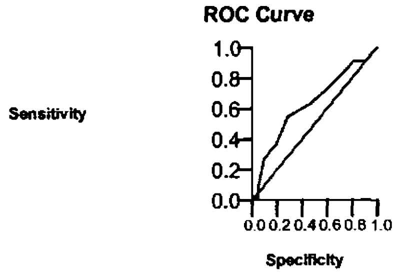
Diagonal segments are produced by ties.

PF 8 vs PMD



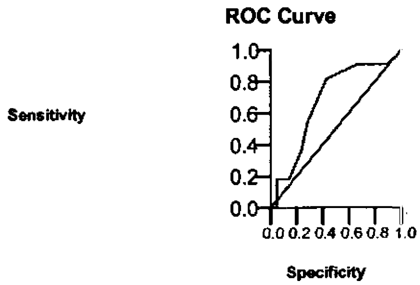
Diagonal segments are produced by ties.

PF 9 vs PMD



Diagonal segments are produced by ties.

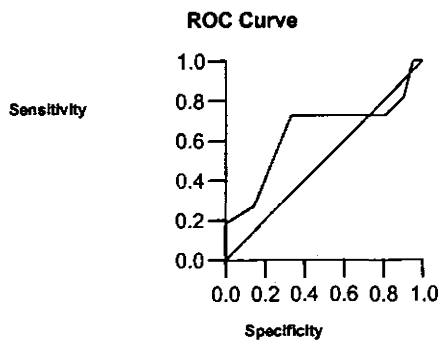
PF 11 vs PMD



Diagonal segments are produced by ties.

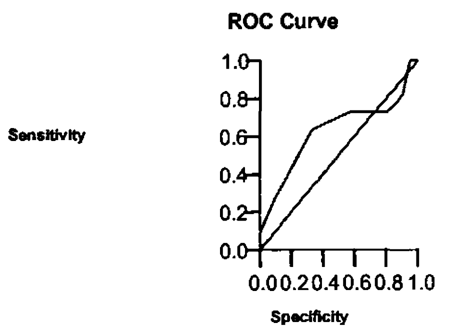
PF18 vs Era-40

MPI + Meteo-France



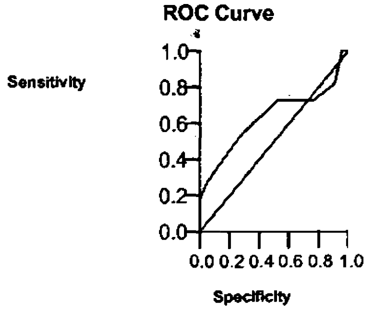
Diagonal segments are produced by ties.

PF (all) vs PMD



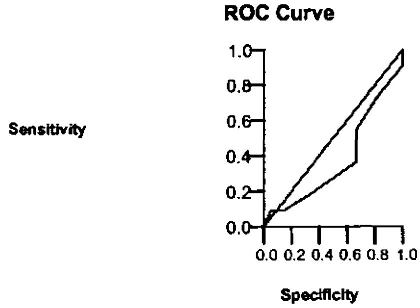
Diagonal segments are produced by ties.

PF 11 vs PMD



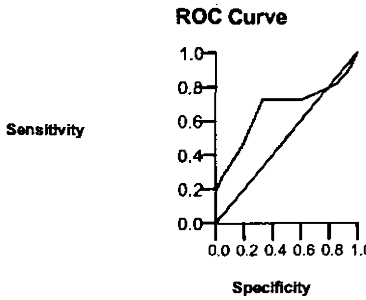
Diagonal segments are produced by ties.

PF 12 vs PMD



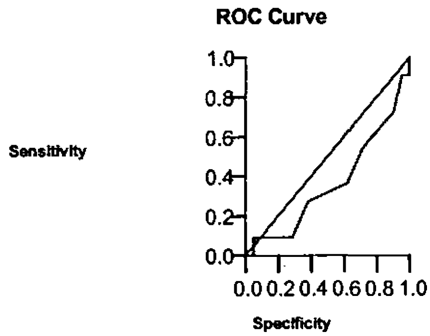
Diagonal segments are produced by ties.

PF 8 vs PMD



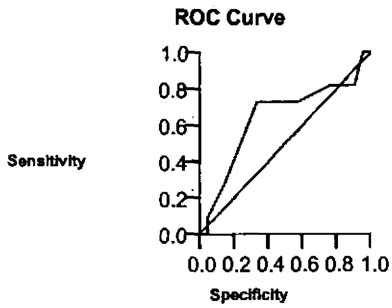
Diagonal segments are produced by ties.

PF 18th vs PMD



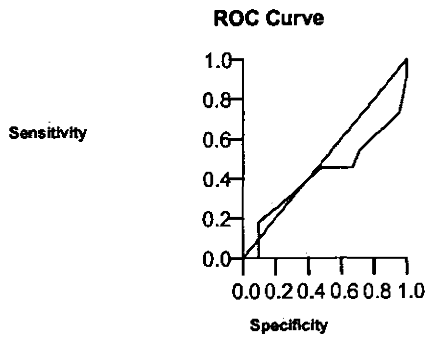
Diagonal segments are produced by ties.

PF 13 vs PMD



Diagonal segments are produced by ties.

PF 18 vs Era-40.

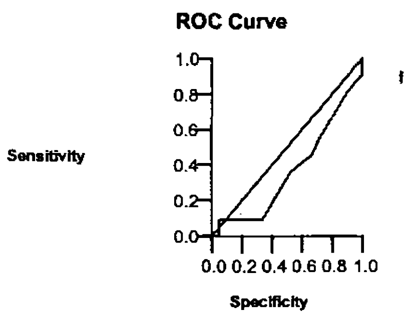


Diagonal segments are produced by ties.

PF18 vs Era-40

Jhelum

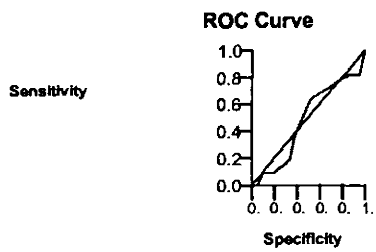
ECMWF + Meteo-France



Diagonal segments are produced by ties.

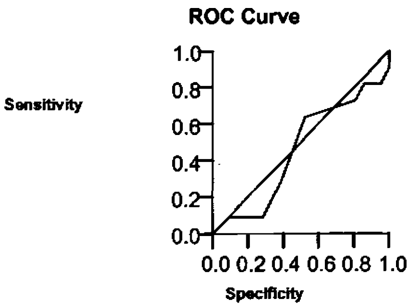
PF 18 vs PMD

ECMWF + MPI



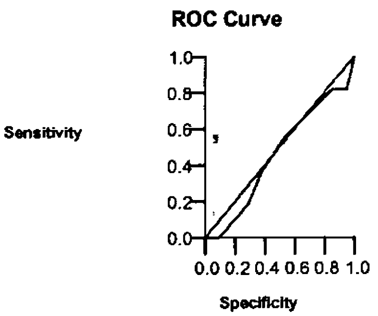
Diagonal segments are produced by ties.

PF 18 vs PMD



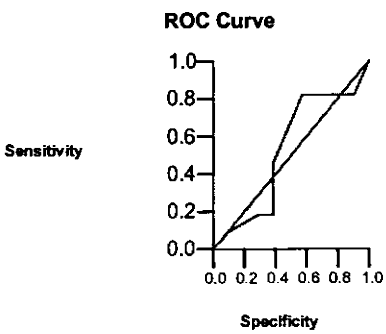
Diagonal segments are produced by ties.

PF 10 vs PMD



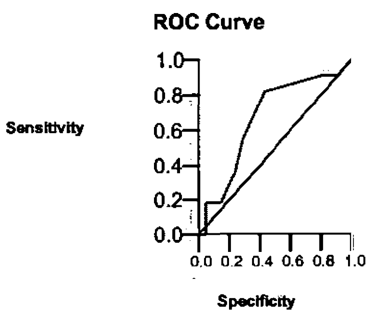
Diagonal segments are produced by ties.

PF 11 vs PMD



Diagonal segments are produced by ties.

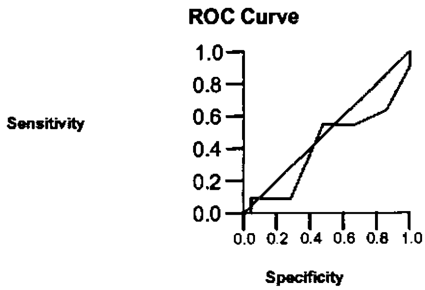
PF 18th vs PMD



Diagonal segments are produced by ties.

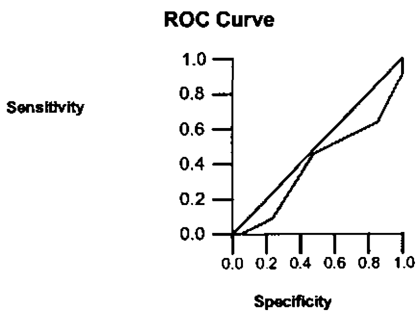
PF 18 vs Era-40

MPI + Meteo-France



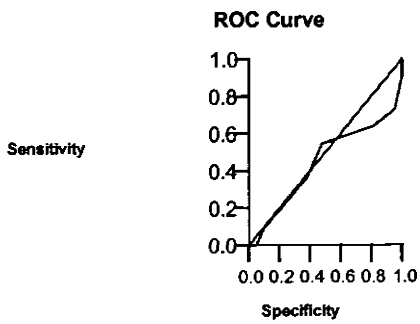
Diagonal segments are produced by ties.

PF 18 vs PMD



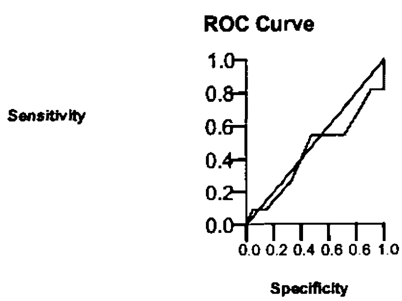
Diagonal segments are produced by ties.

PF 11 vs PMD



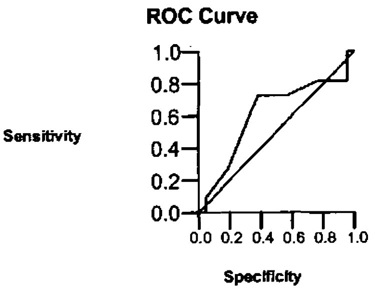
Diagonal segments are produced by ties.

PF 15 vs PMD



Diagonal segments are produced by ties.

PF 18th vs PMD

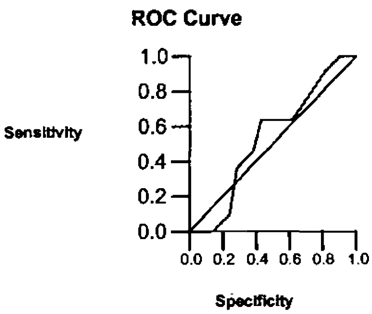


Diagonal segments are produced by ties.

PF 18 vs Era-40

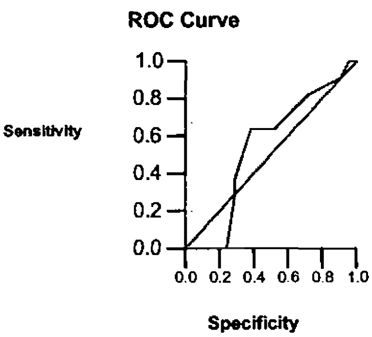
Khairpur

ECMWF + Meteo-France



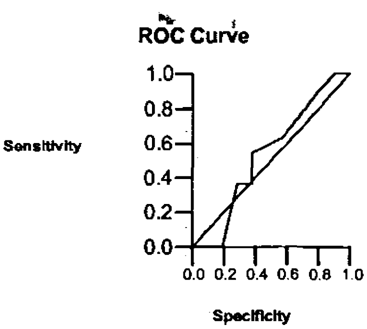
Diagonal segments are produced by ties.

PF 18 vs Era-40



Diagonal segments are produced by ties.

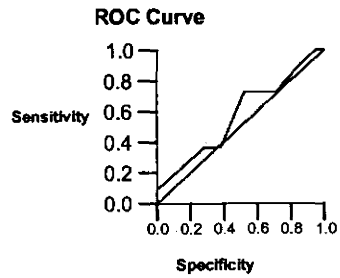
PF 15 vs Era-40



Diagonal segments are produced by ties.

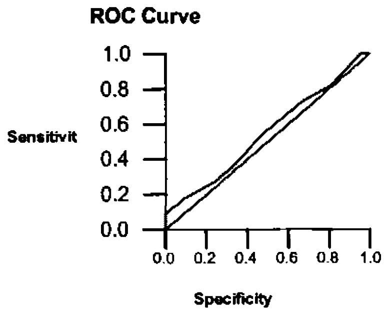
PF 16 vs Era-40

ECMWF + MPI



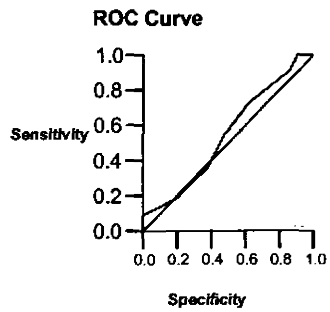
Diagonal segments are produced by ties.

PF 18 vs Era-40



Diagonal segments are produced by ties.

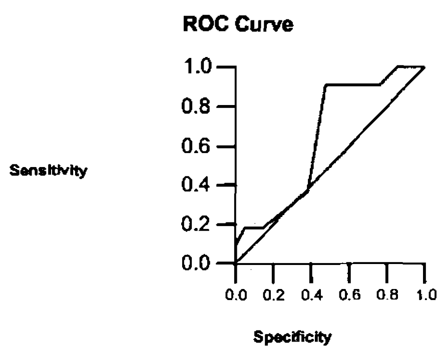
PF 10 vs Era-40



Diagonal segments are produced by ties.

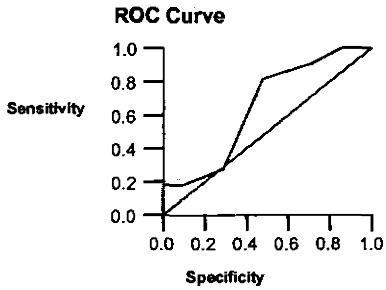
PF 12 vs Era-40

MPI + Meteo-France



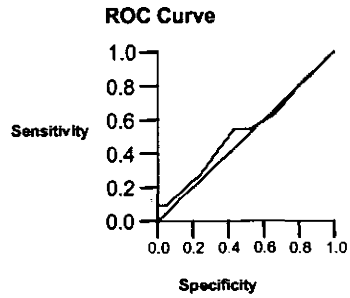
Diagonal segments are produced by ties.

PF 18 vs Era-40



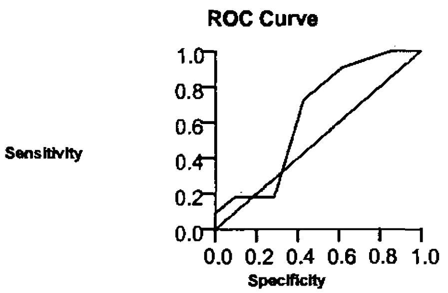
Diagonal segments are produced by ties.

PF 11 vs Era-40



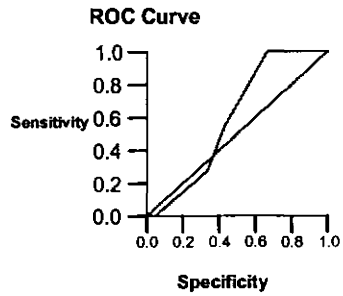
Diagonal segments are produced by ties.

PF 12 vs PMD



Diagonal segments are produced by ties.

PF 12 vs Era-40

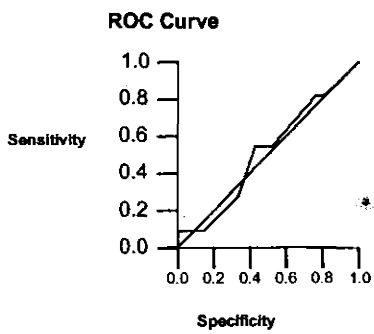


Diagonal segments are produced by ties.

PF 18 vs Era-40

Lahore

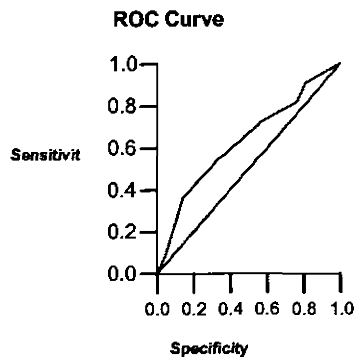
ECMWF + Meteo-France



Diagonal segments are produced by ties.

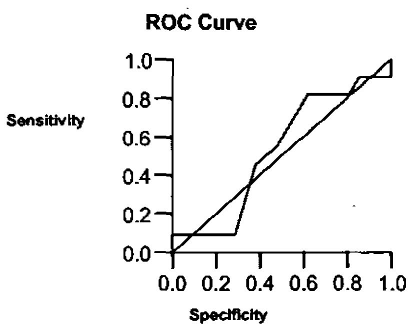
PF 18 vs PMD

ECMWF + MPI



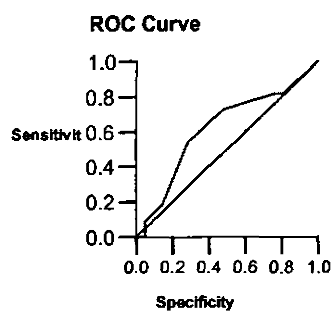
Diagonal segments are produced by ties.

PF 18 vs PMD



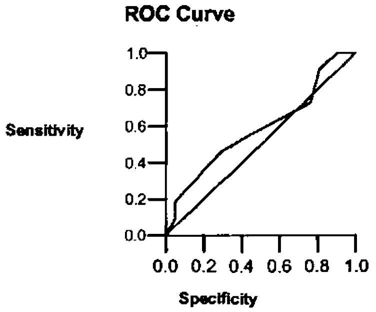
Diagonal segments are produced by ties.

PF 9 vs PMD



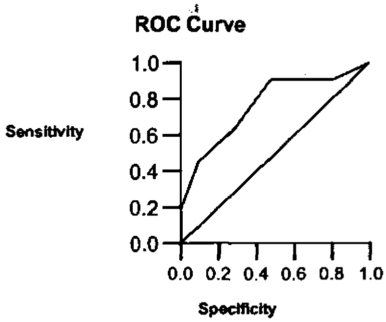
Diagonal segments are produced by ties.

PF 14 vs PMD



Diagonal segments are produced by

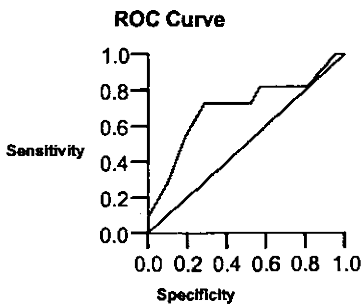
PF 18th vs PMD



Diagonal segments are produced by ties.

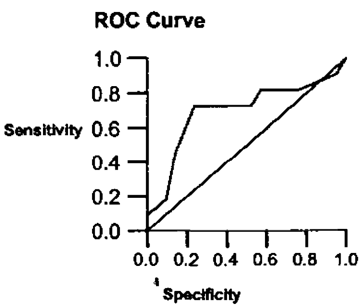
PF 18 vs Era-40

MPI + Meteo- France



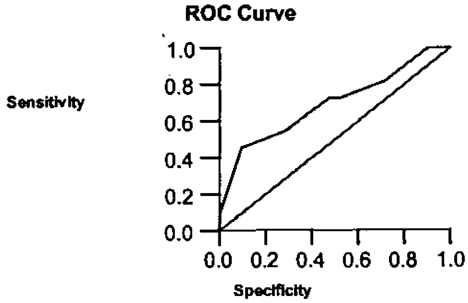
Diagonal segments are produced by ties.

PF 18 vs PMD



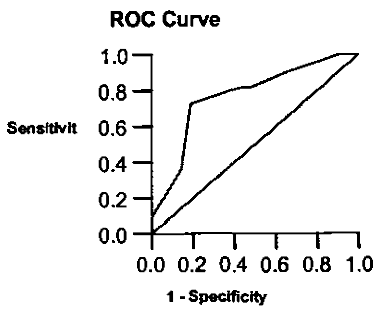
Diagonal segments are produced by ties.

PF 14 vs PMD



Diagonal segments are produced by ties.

PF 18th vs PMD

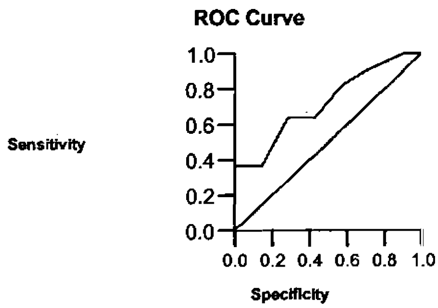


Diagonal segments are produced by ties.

PF 18 vs Era-40

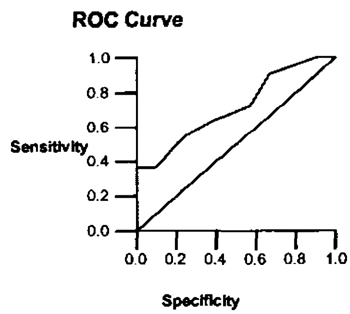
Nawabshah

ECMWF + Meteo-France



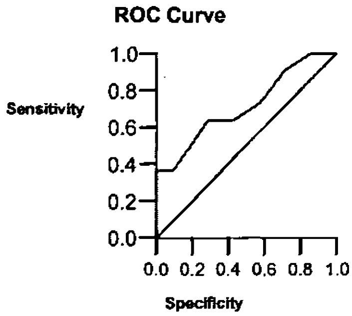
Diagonal segments are produced by ties.

PF 18 vs PMD



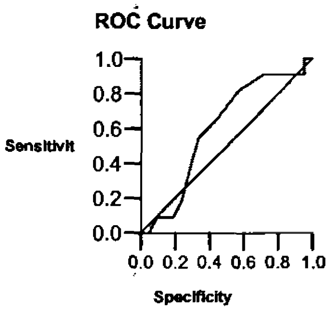
Diagonal segments are produced by

PF 9 vs PMD



Diagonal segments are produced by ties.

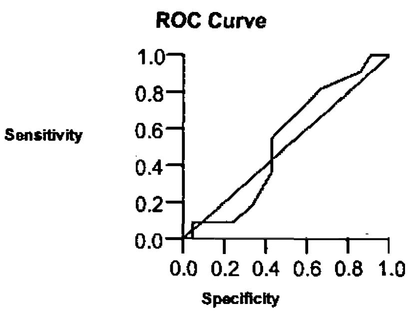
PF 12 vs PMD



Diagonal segments are produced by ties.

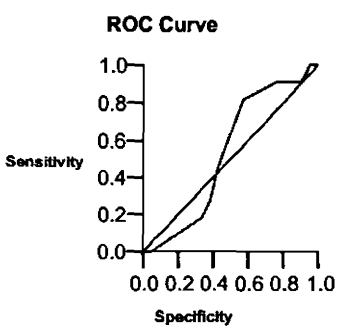
PF 18 vs Era-40

ECMWF + MPI



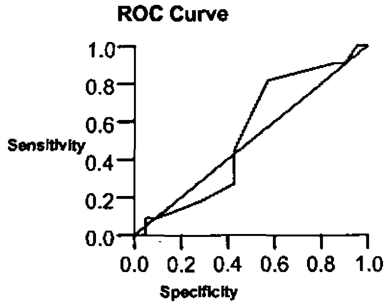
Diagonal segments are produced by ties.

PF 18 vs PMD



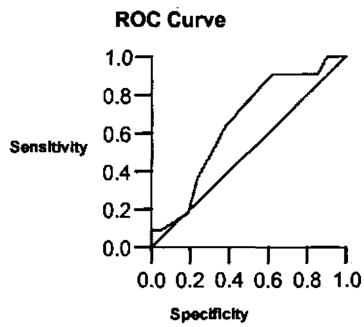
Diagonal segments are produced by ties.

PF 5 vs PMD



Diagonal segments are produced by ties.

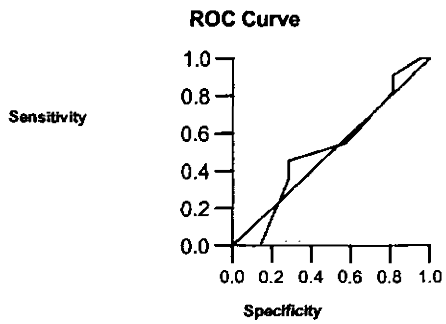
PF 9 vs PMD



Diagonal segments are produced by ties.

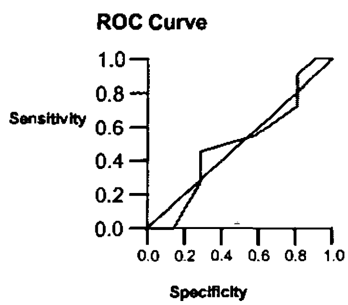
PF 18 vs Era-40

MPI + Meteo-France



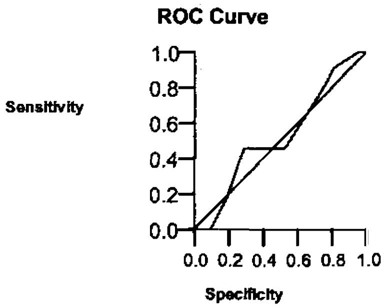
Diagonal segments are produced by ties.

PF 18 vs PMD



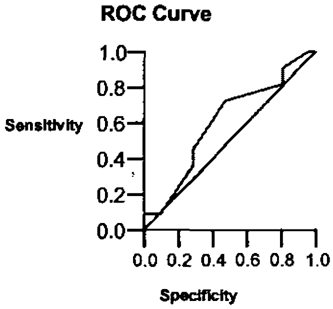
Diagonal segments are produced by ties.

PF 3 vs PMD



Diagonal segments are produced by ties.

PF 11 vs PMD

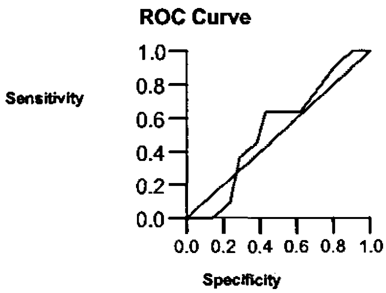


Diagonal segments are produced by ties.

PF 18 vs Era-40

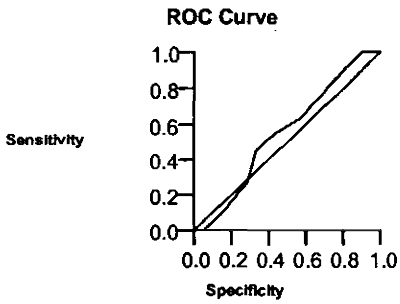
Rahim Yar Khan

ECMWF + Meteo- France



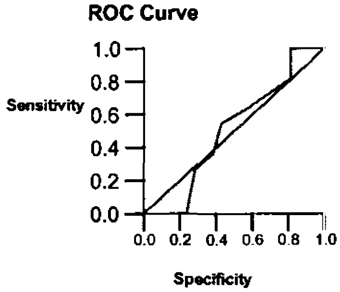
Diagonal segments are produced by ties.

PF 18 vs Era-40



Diagonal segments are produced by ties.

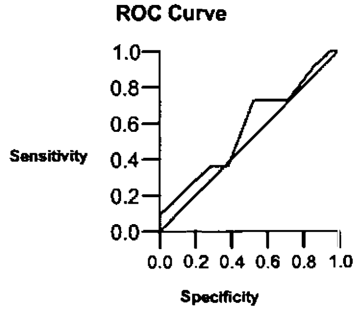
PF 6 vs Era-40



Diagonal segments are produced by ties.

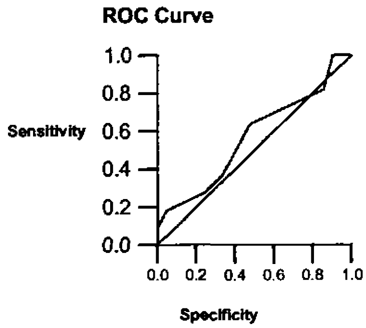
PF 11 vs Era-40

ECMWF + MPI



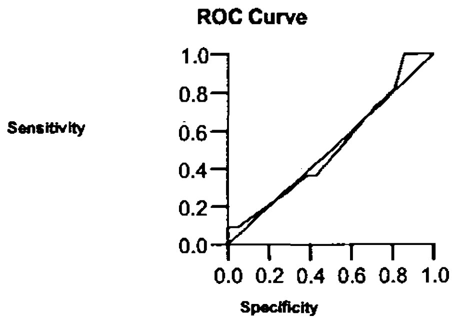
Diagonal segments are produced by ties.

PF 18 vs Era-40



Diagonal segments are produced by ties.

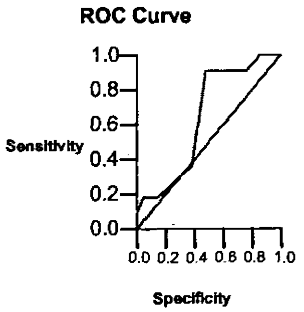
PF 15 vs Era-40



Diagonal segments are produced by ties.

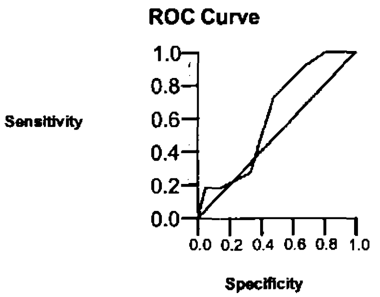
PF 16 vs Era-40

MPI + Meteo-Frances



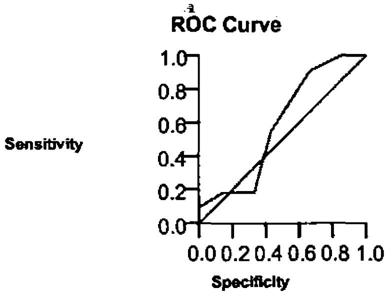
Diagonal segments are produced by ties.

PF 18 vs Era-40



Diagonal segments are produced by ties.

PF 10 vs Era-40

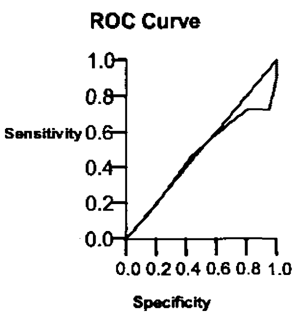


Diagonal segments are produced by ties.

PF 16 vs Era-40

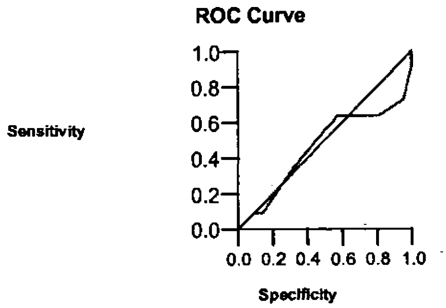
Rawalpindi

ECMWF + Meteo-France



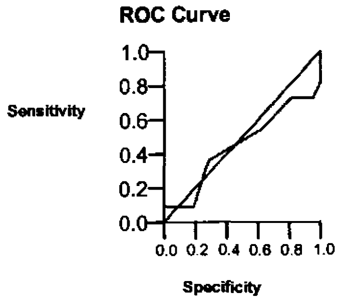
Diagonal segments are produced by ties.

PF 18 vs PMD



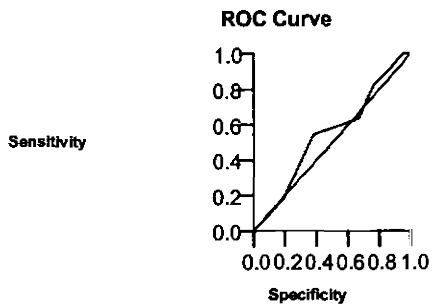
Diagonal segments are produced by ties.

PF 11 vs PMD



Diagonal segments are produced by ties.

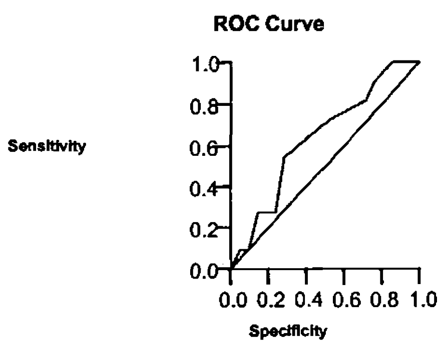
PF 13 vs PMD



Diagonal segments are produced by ties.

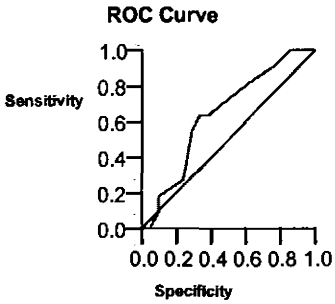
PF 18 vs Era-40

ECMWF + MPI



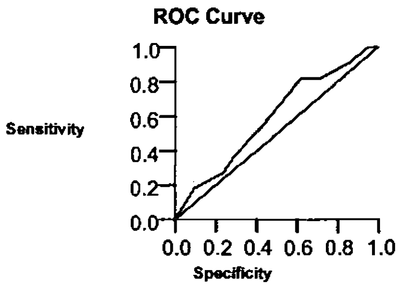
Diagonal segments are produced by ties.

PF 18 vs PMD



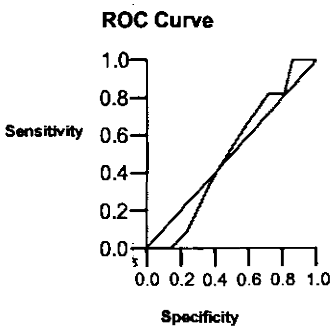
Diagonal segments are produced by ties.

PF 16 vs PMD



Diagonal segments are produced by ties.

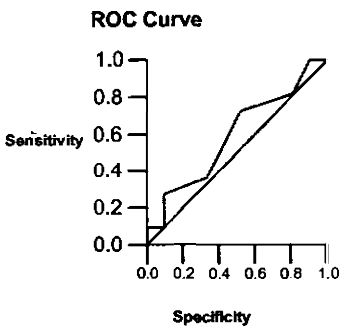
PF 18th vs PMD



Diagonal segments are produced by ties.

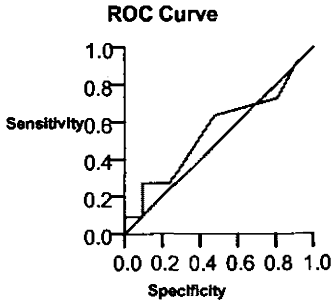
PF 18 vs Era-40

MPI + Meteo- France



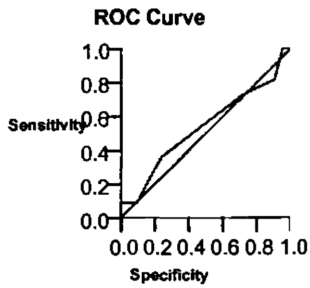
Diagonal segments are produced by ties.

PF 18 vs PMD



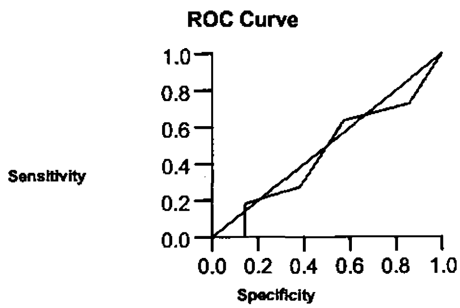
Diagonal segments are produced by ties.

PF 10 vs PMD



Diagonal segments are produced by ties.

PF 18th vs PMD

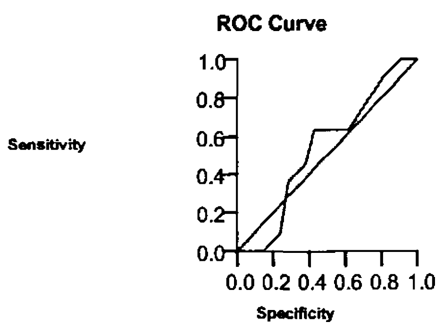


Diagonal segments are produced by ties.

PF 18 vs Era-40

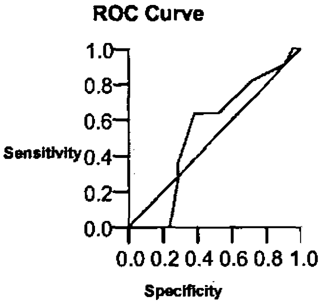
Sukkur

ECMWF + Meteo-France



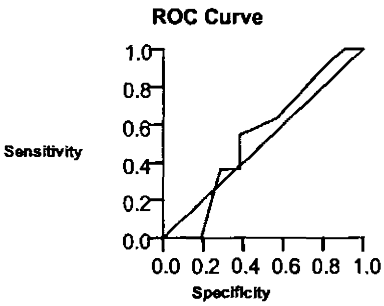
Diagonal segments are produced by ties.

PF 18 vs Era-40



Diagonal segments are produced by ties.

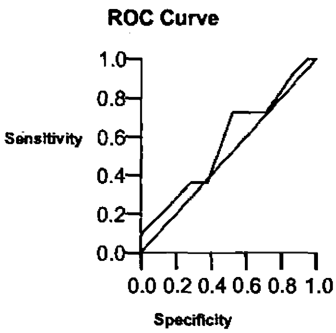
PF 15 vs Era-40



Diagonal segments are produced by ties.

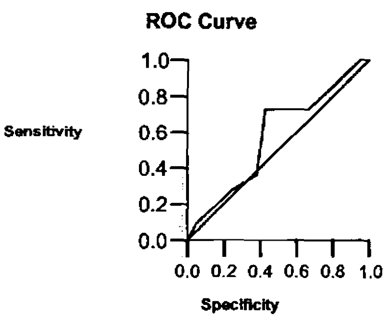
PF 16 vs Era-40

ECMWF + MPI



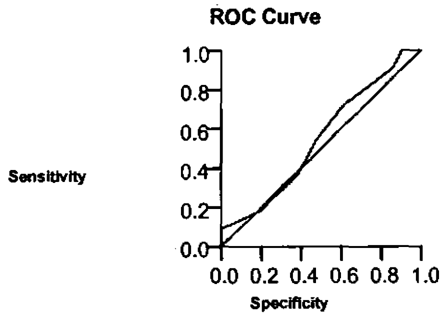
Diagonal segments are produced by ties.

PF 18 vs Era-40



Diagonal segments are produced by ties.

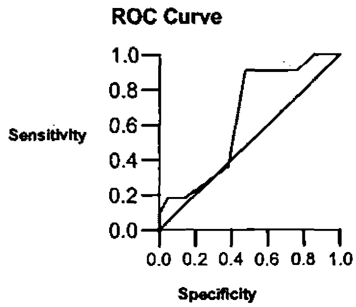
PF 11 vs Era-40



Diagonal segments are produced by ties.

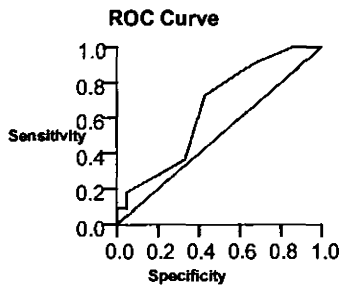
PF 12 vs Era-40

MPI + Meteo- France



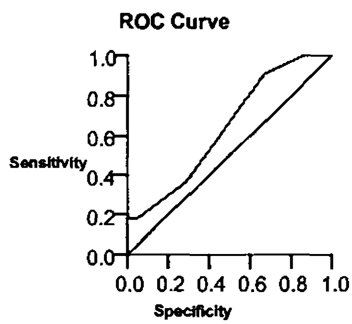
Diagonal segments are produced by ties.

PF 18 vs Era-40



Diagonal segments are produced by ties.

PF 7 vs Era-40

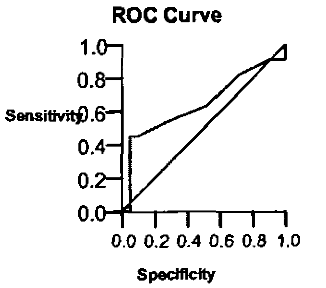


Diagonal segments are produced by ties.

PF 9 vs Era-40

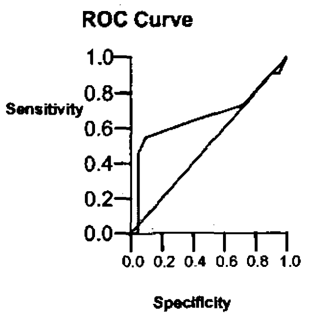
ECMWF + Meteo-France + MPI

Islamabad



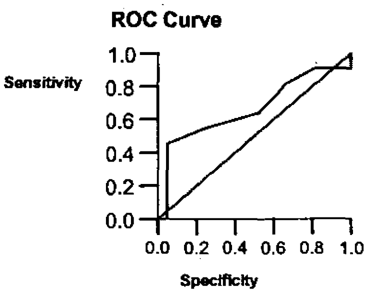
Diagonal segments are produced by ties.

PF 27 vs PMD



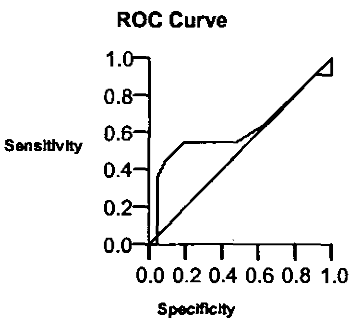
Diagonal segments are produced by ties.

PF 8 vs PMD



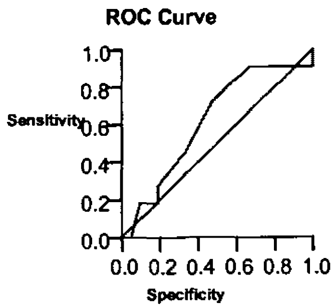
Diagonal segments are produced by ties.

PF 16 vs PMD



Diagonal segments are produced by ties.

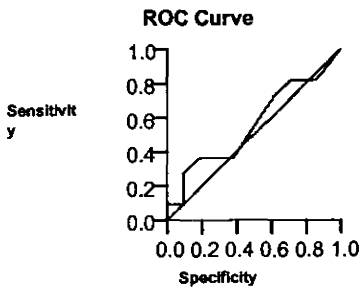
PF 26 vs PMD



Diagonal segments are produced by ties.

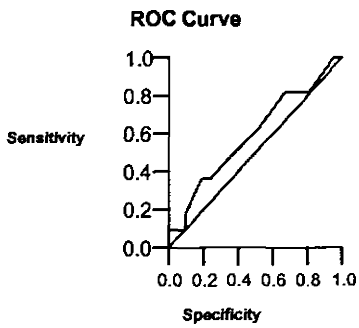
PF 27 vs Era-40

Rawalpindi



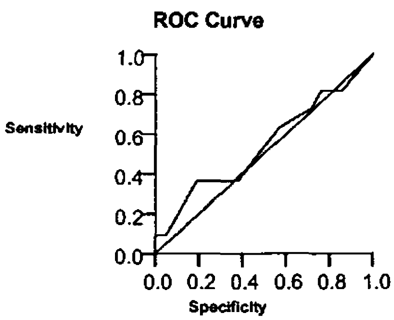
Diagonal segments are produced by ties.

PF 27 vs PMD



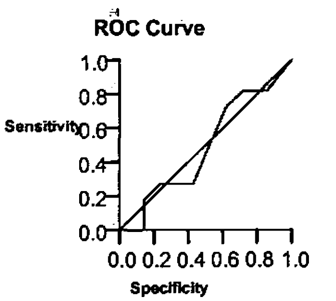
Diagonal segments are produced by ties.

PF 15 vs PMD



Diagonal segments are produced by ties.

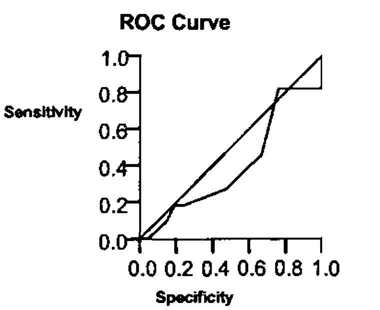
PF 21 vs PMD



Diagonal segments are produced by ties.

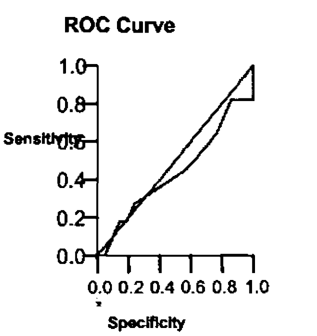
PF 27 vs Era-40

Jhelum



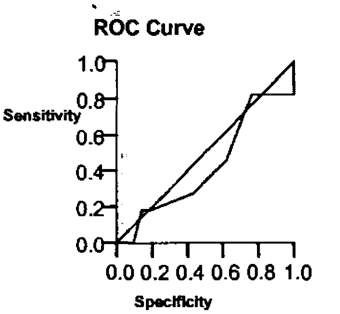
Diagonal segments are produced by ties.

PF 27 vs PMD



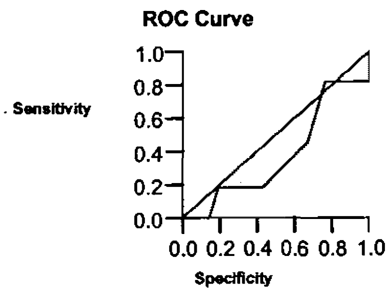
Diagonal segments are produced by ties.

PF 8 vs PMD



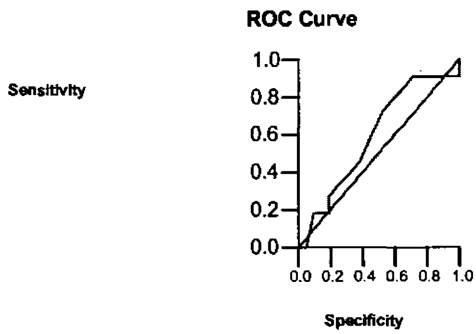
Diagonal segments are produced by ties.

PF 16 vs PMD



Diagonal segments are produced by ties.

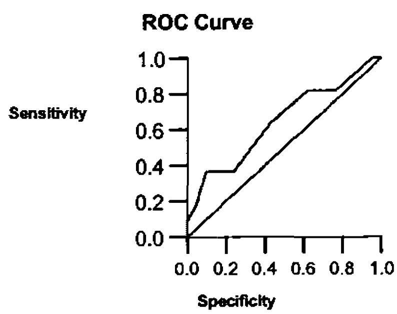
PF 20 vs PMD



Diagonal segments are produced by ties.

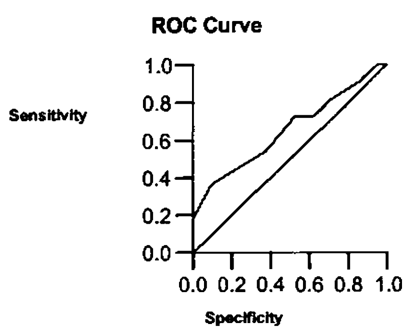
PF 27 vs Era-40

Lahore



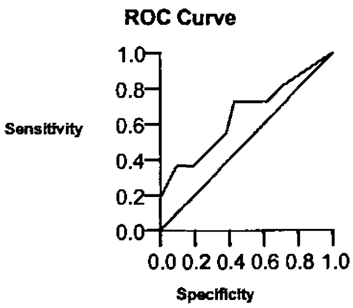
Diagonal segments are produced by ties.

PF 27 vs PMD



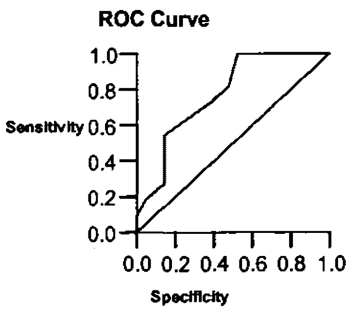
Diagonal segments are produced by ties.

PF 12 vs PMD



Diagonal segments are produced by ties.

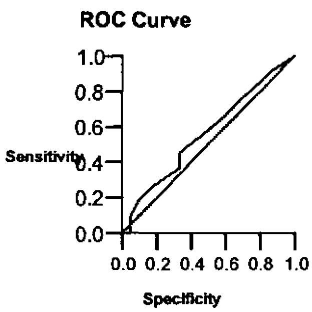
PF 26 vs PMD



Diagonal segments are produced by ties.

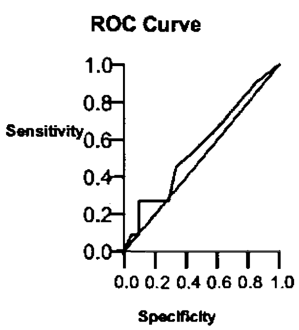
PF 27 vs Era-40

Bahawalnager



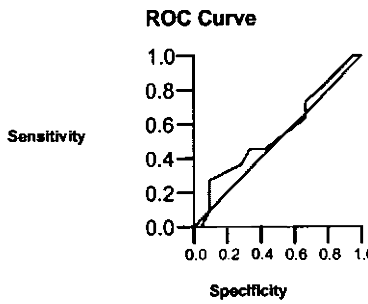
Diagonal segments are produced by ties.

PF 27 vs PMD



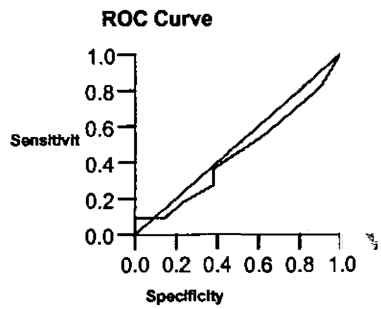
Diagonal segments are produced by ties.

PF 12 vs PMD



Diagonal segments are produced by ties.

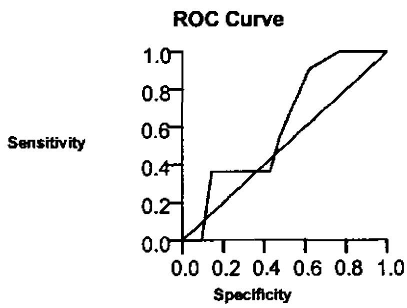
PF 18 vs PMD



Diagonal segments are produced by ties.

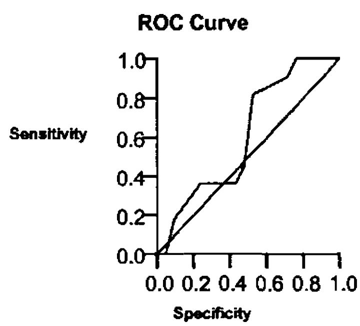
PF 27 vs Era-40

Rahim Yar Khan



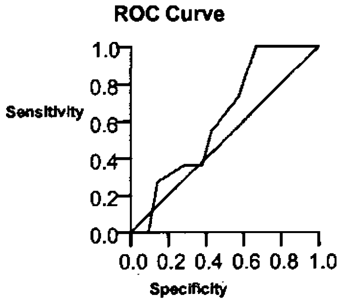
Diagonal segments are produced by ties.

PF 27 vs Era-40



Diagonal segments are produced by ties.

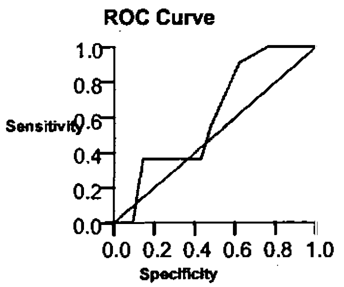
PF 15 vs Era-40



Diagonal segments are produced by ties.

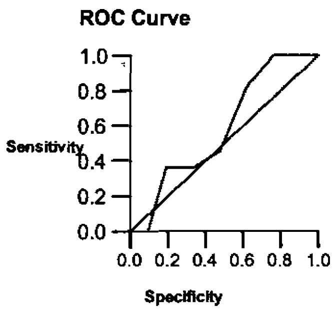
PF 22 vs Era-40

Khairpur



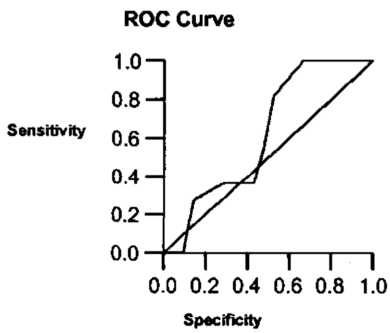
Diagonal segments are produced by ties.

PF 27 vs Era-40



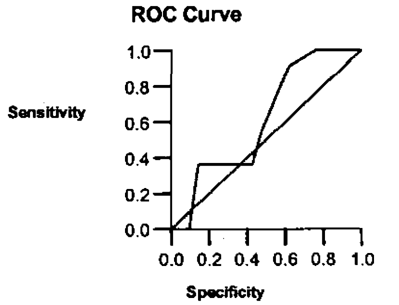
Diagonal segments are produced by ties.

PF 4 vs Era-40



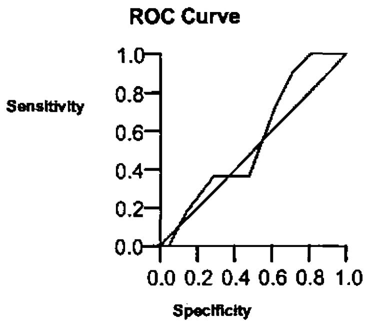
Diagonal segments are produced by ties.

PF 17 vs Era-40



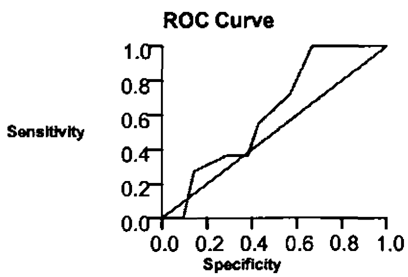
Diagonal segments are produced by ties.

PF 27 vs Era-40



Diagonal segments are produced by ties.

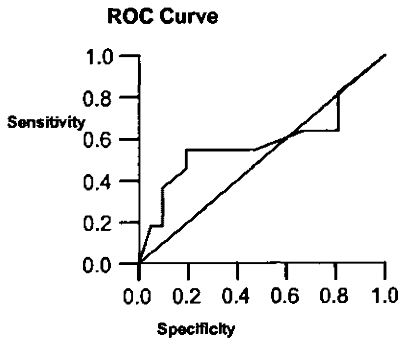
PF 13 vs Era-40



Diagonal segments are produced by ties.

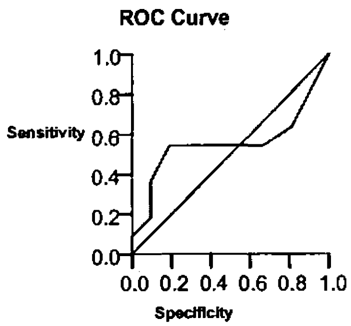
PF 22 vs Era-40

Badin



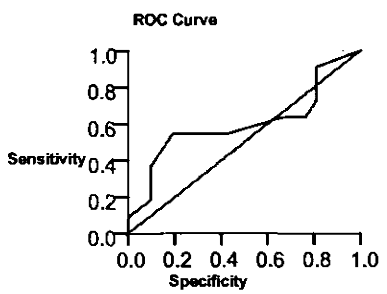
Diagonal segments are produced by ties.

PF 27 vs PMD



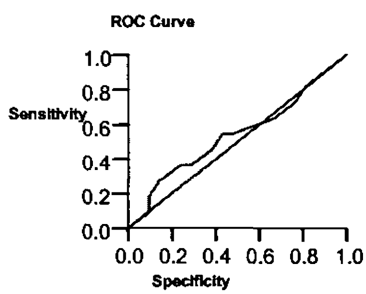
Diagonal segments are produced by ties.

PF 2 vs PMD



Diagonal segments are produced by ties.

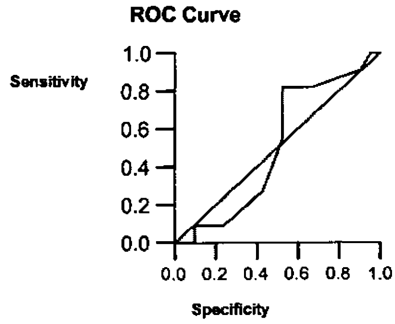
PF 24 vs PMD



Diagonal segments are produced by ties.

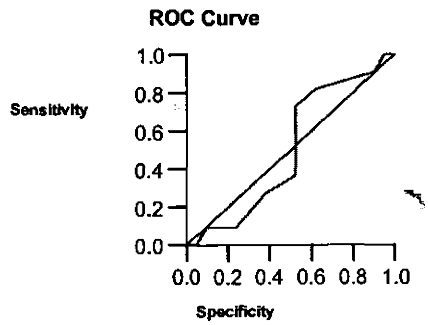
PF 27 vs Era-40

Nawabshah



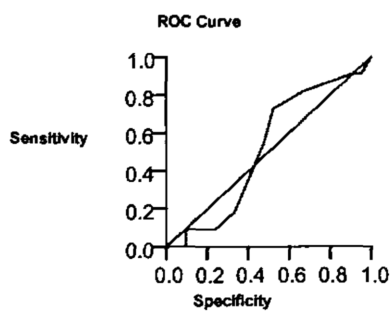
Diagonal segments are produced by ties.

PF 27 vs PMD



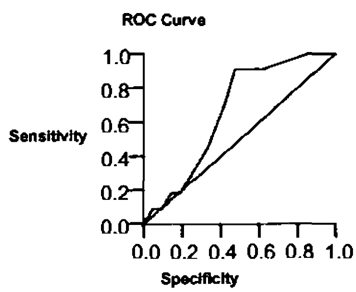
Diagonal segments are produced by ties.

PF 20 vs PMD



Diagonal segments are produced by ties.

PF 23 vs PMD



Diagonal segments are produced by ties.

PF 27 vs Era-40