# Numerical climate modeling and verification of selected areas for heat waves of Pakistan using ensemble prediction system

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**Abstract.** Depending upon the topography, there is an extreme variation in the temperature of Pakistan. Heat waves are the Weather-related events, having significant impact on the humans, including all socioeconomic activities and health issues as well which changes according to the climatic conditions of the area. The forecasting climate is of prime importance for being aware of future climatic changes, in order to mitigate them. The study used the Ensemble Prediction System (EPS) for the purpose of modeling seasonal weather hind-cast of three selected areas i.e., Islamabad, Jhelum and Muzaffarabad. This research was purposely carried out in order to suggest the most suitable climate model for Pakistan. Real time and simulated data of five General Circulation Models i.e., ECMWF, ERA-40, MPI, Meteo France and UKMO for selected areas was acquired from Pakistan Meteorological Department. Data incorporated constituted the statistical temperature records of 32 years for the months of June, July and August .This study was based on EPS to calculate probabilistic forecasts produced by single ensembles. Verification was done out to assess the quality of the forecast t by using standard probabilistic measures of Brier Score, Brier Skill Score, Cross Validation and Relative Operating Characteristic curve. The results showed ECMWF the most suitable model for Islamabad and Jhelum; and Meteo France for Muzaffarabad. Other models have significant results by omitting particular initial conditions.

## 1. Introduction

The terms temperature, atmospheric composition wind speed and direction, pressure and density determine the initial condition of atmosphere at a particular instant. The averages of these parameters are taken into account to determine the climate of an area. Intensity of the radiations emitted from the sun and features of the earth plays a fundamental determining role [1].The changes in topography and local features occur within the atmosphere or over the earth surface in a systematic way and orderly pattern, hence creating an identifiable pattern of climatic differences from place to place [2].

Climate, over along interval of time, determines the landscape, and the plants and animals of a region. Over geological time, climate has helped to shape mountains, build up the soil, determine the nature of the rivers, and build flood plains and deltas [3].

Hence, climate is decisive to the world. Significant change in global climate has been witnessed around the world. Though, it is not a new experience in the Earth's history. During the long geological period, extreme weather events have always been the part of earth’s climate. Climate varies from decade to decade, reliable averages of the frequency and magnitudes of extreme events require weather observations over longer periods. The studies of this long period observation of climate have shown the rapid increase in the temperature of the earth. However, the present change in climatic conditions has pronounced effect. The rationale behind this cause is the amplified concentration of greenhouse gases from the value of about 280 ppm to 379 ppm in 2005 resulting from the anthropogenic activities. This has resulted in the boost in the global temperature by 0.76° C during the last century [4].

Consequently there is a dire need to understand the basics of climate; the changes occurring in it. Developing countries are the most vulnerable to present climate change impacts due to the unavailability of resources to adapt: socially, technologically and financially, as at this time developing countries are facing lack of food and water [5].

Changes in some types of extreme events have already been observed in various parts of the world because of the global climate change, for example, increases in the frequency and intensity of heat waves and heavy precipitation events [6].

Climate change has threatened the world as whole. Amongst the most susceptible region of the world, South Asian Region is of utmost significance. Countries in this region have geographical and ecological assortment. Pakistan is the second largest country of the South Asia, where the variations in geography greatly shapes the climate of the country. Lying at extreme north-west corner of the Indo-Pak subcontinent between latitudes $24^{o}$N to $37^{o}$N and longitudes $60^{o}$E to $75^{o}$E, occupies sub-tropics and partially temperate region of the world where the Climatic conditions vary from hot, dry summers to mild winters [7].

Pakistan being a developing country is more prone to the impacts posed by the changing climate because of its agrarian based economy. As a consequence of climate change, there is a rise in mean temperature of 0.6-1.0°C throughout the country as well as 0.5 to 0.7% increase in solar radiation over southern half of the country. In addition to this water logging, desertification of land, growing frequency of pest attacks and weather related disasters has been observed through out the country [7]. With the little increase in temperature there is a significant increase on the extreme events. In recent years, the number of hot days has been increased resulting in the frequent occurrence of the heat waves throughout the country. Heat waves are referred as the above normal hot weather for days to week [6-7].

As a result of excessive heating, heat islands are formed in the areas where the non-reflectivity, water resistance surfaces and vegetation cover is low. Building materials, such as stone, concrete, and asphalt incline heat at the surface. In urban areas the effect of heat island enhances the impact of heat waves [8-9] and in addition lack of vegetation reduces heat lost due to evapotranspiration [10]

Urban areas have high population densities so the energy demand is also high resulting in the high demand of air conditioning during summers [8] that results in the increased local and regional air pollution. The emissions, from power generation, in turn increases absorption of radiation [9] and create inversion layers. Hence, slow dispersion of pollutants produced in urban areas occurs [11].

Focusing the climate of Pakistan, there is a great variation in the summer and winter temperatures [12]. The prolonged high temperature and high humidity is considered as weather hazard. The high heat index can cause a health risk to the people engaged in outdoor activity even for small time period [13].

In the present situation in which world has turned into global village and the frequency of extreme event causing lot damage to the life and infrastructure, the forecasting of various constituents and factors of climate and weather has become an important affair. In particular, it has now become a significant tool in order to prepare the man for the incoming disruptions in the climatic system of the earth that may be in form of increased rainfall or extreme temperatures.

Hence, regarding the importance of climate forecasting in the present scenario, this study stresses on the establishment of the early warning system in Pakistan to determine the frequency of extreme event i.e., heat waves.

Numerous climate models are operating around the world that computes the climatic conditions and gives prediction about the future climate. These can either be global circulation model (GCM) or a regional Circulation model (RCM). The most reliable global climate models used, now a day, are European Centre for Medium Range Weather Forecast (ECMWF), Max Plank's Institute (MPI), United Kingdom Meteorological Office (UKMO), Meteo France, and European Centre for Medium Range Weather Forecast Re-Analysis-40 (ERA-40). GCMs simulate large-scale patterns of seasonal variation. Pakistan, lack its own Global circulation model for the climate forecasting, therefore, one of the basic aims to purse the current research is to suggest the best suitable General Circulation Model for accurate seasonal weather prediction for the selected areas.

In 2011, the predictability of the 2010 floods in Pakistan was studied using the three data sets of TRMM, GPCP data and CMORPH analyzed the data for 51 members of ECMWF EPS. The study showed the ability of the ECMWF EPS to predict the extreme event in the country in order to establish an early warning system. Therefore such a system can help to have hydrological forecasts in Pakistan to anticipate for the losses from devastating floods [14].

The Numerical Weather Predication of the climate models depends upon the sensitivity of initial condition and the uncertainties associated with the forecast model being used [15]. To find out the level of uncertainties probability is calculated from these forecasts. Based on the historical data observations, statistical techniques are mostly used to determine Probabilistic forecast. It provides the estimation of climatic risks incorporating the uncertainties into it [16].

The inaccurate initial condition and insufficiency of numerical models turn into a source of forecast errors. These errors classified as; initial condition errors and model errors, provide the forecast with some uncertainty, limits the quality of forecast. As a response to these limitations Ensemble Forecast system is used to predict the probability distribution of forecast. Ensemble forecasting predicts the probability distribution of the state of atmosphere for future, in a quantitative manner [15]. In the current study, the validity of the climate model and Ensemble forecast has been checked in order to verify if the selected models can give skillful forecast for the selected areas.

To quantify the relationship between the observation and the probabilistic forecasts verification is carried out in order to access the quality of the forecast. A forecast is considered to be deficient until the success of it is not determined [17]. To verify the probabilistic forecasts, Use of Relative Operating Characteristic Skill Score, Brier score and Brier Skill Score is done. The quality assessment helps to find and spot out the strengths and weakness of a forecast. It also helps in determining the best suitable verification technique by comparison of different methods [18]. Brier score measures the probability of the forecast whether it will occur or not. It is sometimes hard to interpret therefore converted into brier skill score [19].Brier skill score, being a standard measure, is used to access the skill of a forecast. It is applied to both single model and multi model ensemble. The Relative Operating Characteristic (ROC) is a graph of sensitivity (y-axis) vs. 1– specificity, where the area under the curve shows the forecast's accuracy; a verification method to check the skill of the forecast by comparing the hit rate and the false-alarm rate [20]. The series of threshold for the probabilistic forecast is plotted between the false alarm rate and the hit rate [21].

## 2. Materials and methods

Three stations were selected to access the variability of the temperature over Pakistan in order to determine the occurrence of heat waves and to check out the validity of the selected climate models in these areas to give accurate forecast.

### *2.1. Islamabad*

The capital city of Pakistan lies 33° 42' N, 73º 10 E'. The climate of Islamabad varies from an average daily low of 1° C in January to an average daily high of 40° C in June. Half of the annual rainfall occurs in July and August, averaging about 255 millimeters in each of those two months. Temperature reaches to -4o C in winters and to 50 0 C in summers [22] However the climatic change that's has been occurring throughout the globe has affected the climate of Islamabad, too. The occurrence of several heat waves has been reported in the capital city. A major heat wave was reported on June 21, 1994, when the temperature reached to 46.5$^{o}$C. The recent episode of the event was recorded in May-June 2012, when the temperature touched the 50$^{O}$ C mark on thermometer.

### *2.2. Muzaffarabad*
Muzaffarabad, the capital of the Pakistan Held Jammu & Kashmir, is situated at the confluence of the Jhelum & Neelum Rivers, lies at 32° 44' N latitude and 74° 54' E Longitude. The mean maximum and minimum temperatures during the month of July are about 35°c and 23°c; and in January 16°c and 3°c respectively. The average annual precipitation of the district is 1511mm [23]. Heat waves has been occurring in the past in Muzzaffarbad, however their frequency has been increased in last five years. Recently in July 2012, heat waves touched the city when temperature reached 43 $^{O}$C.

### *2.3. Jhelum*
Jhelum lies on the right bank of right bank of river Jhelum ranging from at 32°56′ of North latitude to 73°44′ in East longitude. During the summers, Jhelum experience extremely hot and humid weather and warm and generally dry in winter. The temperature reaches to 45.7 °C (114.3 °F) from April to June, whereas in winter the minimum temperature recorded is 1.8 °C (35.2 °F) [23]. A major Heat wave occurred during June 2005 in Jhelum, resulting in the rise in water level in river Jhelum. Recently, in 2010, extreme heat waves have been reported when the temperature of the city has reached to 48$^{o}$C.

## 3. Method
Research was carried out in a systematic way. The major steps involved were data acquisition, data analysis, data validation evaluation and assessment. By using Microsoft Excel 2010 and SPSS v20.0, the preparation of data for analysis was done. 32 years temperature data, for three areas was collected to validate, evaluate and assess for the seasonal hindcast. For the analysis, Microsoft Excel 2010 spread sheets comprising real time data of PMD and simulated data of the climate models were created.

The first step for the analysis was to calculate ensemble forecast, using nine initial condition of each of the five climate models used in the study that includes; ECMWF, MPI, Meteo France, ERA-40 and UKMO. To determine the percentiles upper and lower tercile (0.667) threshold values were used. The percentile values were then used to find out the climatological probability of real time data of PMD, simulated data of ERA-40 and probability of respective climate model. Using the probability obtained for each of the nine initial conditions, probabilistic forecast was computed by using all the nine initial condition and by using them alternatively. These were then compared with the probabilistic forecast of PMD and ERA-40. Brier score was calculated for reliability, resolution and uncertainty and brier skill score to check the skill of the probabilistic forecast.

$$BS= 1/N\sum (A_i - B_i)^2$$

Where $A_i$ is the probability that was forecast,
And $B_i$ the actual outcome of the event at instance,

The brier skill score being the mean squared error in probability space was calculated as;

$$BSS= 1- BS/ BS_{\text{reference}}$$

BSS was calculated for all the Initial condition and then for alternatively used initial condition with ERA-40 and PMD. It was taken as, if Brier skill score is positive it indicates a skill forecast, however if a BSS is negative it shows the poor forecast. To assess the accuracy of the probabilistic forecast, Cross validation was done. For which graphs were plotted. SPSS v20.0 was used to verify the probabilistic forecast by using Relative Operating Characteristic (ROC). If the ROC curves have hit rate of 1.0 and no false alarms, probabilistic forecast could be perfectly predictable by the forecast system. If it falls in the false alarm region, the forecast would be poor.

## 4. Results and discussions
By the use of ensemble prediction system, the seasonal forecast of heat waves for selected areas for the months of May, June and July were computed with one month lead time April. The heat waves were presented by “upper tercile”. The results obtained provided with the following conclusions.

For Islamabad the average of real time observation of PMD for 32 years i-e., 1969-2000 for heat waves came out to be **29.48**, while the average of ERA-40 is **16.88**. By using these values climatological probability obtained from PMD was **0.34.**

**Table 1.** Results evaluated from climate models for Islamabad.

| Model | Ensemble forecast | Probabilistic Forecast | | | Climatological probability | | Reliability | Resolution |
|---|---|---|---|---|---|---|---|---|
| | | All conditions | Excluding Zero | Excluding Nine | PMD | ERA-40 | | |
| **ECMWF** | 18.10 | 0.33 | 0.34 | 0.33 | Skill | Skill | High | Low |
| **Meteo France** | 15.09 | 0.33 | 0.32 | 0.34 | Skill | Poor | High | Low |
| **MPI** | 19.96 | 0.33 | 0.34 | 0.27 | Skill | Skill | High | Low |
| **UKMO** | 13.23 | 0.30 | 0.32 | 0.33 | Poor | Poor | High | Low |

For Jhelum the average of real time observation of PMD for 32 years i-e., 1969-2000 for heat waves came out to be **31.4**, while the average of ERA-40 was **32.5**. Climatological probability obtained, by using these values, from PMD was **0.34.**

**Table 2.** Results evaluated from climate models for Jhelum.

| Model | Ensemble forecast | Probabilistic Forecast | | | Climatological probability | | Reliability | Resolution |
|---|---|---|---|---|---|---|---|---|
| | | All conditions | Excluding Zero | Excluding Nine | PMD | ERA-40 | | |
| **ECMWF** | 30.8 | 0.33 | 0.34 | 0.34 | Skill | Skill | High | Low |
| **Meteo France** | 31.51 | 0.33 | 0.32 | 0.34 | Skill | Poor | High | Low |
| **MPI** | 30.26 | 0.33 | 0.33 | 0.32 | Poor | Poor | High | Low |
| **UKMO** | 30.78 | 0.33 | 0.34 | 0.32 | Poor | Poor | High | Low |

The average of real time observation of PMD for Muzaffarabad from 1969 to 2000 i.e., 32 years for heat waves obtained was **28.10**, while the average of ERA-40 was **8.06**. By using these values climatological probability obtained from PMD was **0.34.**

**Table 3.** Results evaluated from climate models for Muzaffarabad.

| Model | Ensemble forecast | Probabilistic Forecast | | | Climatological probability | | Reliability | Resolution |
|---|---|---|---|---|---|---|---|---|
| | | All condition | Excluding Zero | Excluding Nine | PMD | ERA-40 | | |
| ECMWF | 10.64 | 0.33 | 0.33 | 0.33 | Poor | Poor | High | Low |
| Meteo France | 8.72 | 0.33 | 0.32 | 0.34 | Skillful | Skillful | High | Low |
| MPI | 14.93 | 0.33 | 0.35 | 0.27 | Skillful | Poor | High | Low |
| UKMO | 7.08 | 0.33 | 0.33 | 0.34 | Skillful | Skillful | High | Low |

ERA-40 project for forty five year (45) global time series has been completed in 2003. This analysis is used widely to find out the climatic changes around the globe [24]. These provides with the useful recognition of original observational errors. As the forecast made by the global climate models, especially ECMWF, is almost accurate therefore the observational errors are small [25]. More or less,

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similar results were obtained while comparing the ensemble forecast made by the models used in the study. The outcomes show Ensemble forecast being close to the ERA-40., is a good forecast but poor as compared to PMD, concluding ERA-40 to be an accurate analysis to compare ensemble forecast observational average.

To study severe weathers event in United Kingdom, a system through the output of the ECMWF to give a probabilistic forecast for applying the calibration to the EPS model was established. The output was modified for the probabilistic early warnings and was verified over 2 winter seasons. The probabilistic skill scores were applied. The results gave the probabilistic forecast to be an ideal application for ensemble prediction system. They suggested the EPS work in a better way for the medium range, and may need other perturbation strategies for successful short-range ensemble prediction [26].

In particular for this study, Probabilistic forecast was calculated through EPS by using the nine initial conditions and then by using them alternatively for the forecast of extreme event. Climate models are not subtle to the initial conditions. However, change in the initial value problem and boundary value problem are the basic reasons of change in accuracy of the probabilistic forecast for the area under study [27]. With all the initial conditions and alternatively using them the probabilistic forecast were calculated. And the results formulated from table 1, table 2 and table 3, states that by eliminating those initial conditions of each of the climate models that are not suitable for the areas under study; an almost accurate forecast probabilistic forecast can be obtained.

Probabilistic forecasts during forecasting include uncertainty. To verify the reliability, resolution and uncertainty of probabilistic forecast, Brier Score was used. Brier skill score results that the probabilistic forecast of ECMWF, MeteoFrance and MPI is the skill forecast for Islamabad while using the alternative initial condition; all the forecasts were skill forecasts when Brier Skill Score was calculated against PMD except for UKMO that has poor skill for PMD. To validate the reliability, resolution and uncertainty of probabilistic forecast against ERA-40, Brier score was again applied and it results that the probabilistic forecast of ECMWF and MPI to be skill full while stating the forecast of MeteoFrance and UKMO to be poor for Islamabad.

For Jhelum, probabilistic forecast of ECMWF and MeteoFrance is the skill forecast against PMD while using the alternative initial condition to calculate the probabilistic forecast; except for MPI and UKMO. When Brier score was applied against ERA-40 for Jhelum, it results that the probabilistic forecast of ECMWF to be skill, however the forecast of MeteoFrance, MPI and UKMO to be poor for Islamabad and for Muzaffarabad, probabilistic forecast of MeteoFrance, MPI and UKMO is skill forecast, while using the alternative initial condition to calculate the probabilistic forecast against PMD; except for ECMWF that has poor skill. Brier score against ERA-40, results that the probabilistic forecast of MeteoFrance and UKMO to be skill while stating the forecast of ECMWF and MPI to be poor for Muzaffarabad.

Reliability is one of the most important aspects to verify the quality of the forecast. The research carried out worldwide on the global climate models, focusing ECMWF, on the extreme events has shown the higher reliability [28]. In the current study, probabilistic forecast of all the four models is reliable by using all nine initial conditions and by using them alternatively also the Brier skill score shows that the Probabilistic forecast has the low resolution when calculated against the PMD and ERA-40 each of the four models.

However there are few factors that cause slight changes in the results given by these models. Therefore, to measure the accuracy and the performance of predictive model, cross validation was applied. Analyzing the cross validation graphs from the four models the results obtained verified the cross validation approach to give forecast almost similar to the forecaster's prediction in addition to take objectivity in account.

**Table 4.** Cross validation results.

| Model | Result | Extreme Event Years |
|---|---|---|
| **Islamabad** | | |
| ECMWF | Accurate forecast | 1981, 1993, 1994. |
| Meteo France | Almost Accurate forecast | 1970, 1982, 1990, 1993, 1994, 1998. |
| MPI | Accurate forecast | 1970, 1980, 1990, 1993, 1998. |
| UKMO | Accurate forecast | 1981, 1984, 1990, 1994, 2000. |
| **Jhelum** | | |
| ECMWF | Accurate forecast | 1981, 1993, 1994. |
| Meteo France | Almost Accurate forecast | 1970, 1982, 1990, 1993, 1994, 1998. |
| MPI | Accurate forecast | 1970, 1980, 1990, 1993, 1998. |
| UKMO | Accurate forecast | 1981, 1984, 1990, 1994, 2000. |
| **Muzaffarabad** | | |
| ECMWF | Accurate forecast | 1980, 1984, 1993, 1995 2000 |
| Meteo France | Almost Accurate forecast | 1970, 1973, 1988, 1990, 1995 |
| MPI | Accurate forecast | 1969, 1970, 1980, 1994, 2000 |
| UKMO | Accurate forecast | 1969, 1981, 1982, 1986 |

Cross validation results shows all the models have almost accurate forecast for selected areas. It has been studied that the high model accuracy is the lack of predictive ability of the model. However, if proper cross-validation is applied a fine forecast can be obtained [29]. While the current study showed that the scattered graph of cross validation of MeteoFrance is more scattered as compared to the graphs of other three models. The value of the years causing more scattering represents the occurrence of extreme events in these years. If these years of extreme event be eliminated the forecast can be made more accurate. Hence the accuracy of the cross validation is in accordance with the studies carried out previously.

To measure the skill of the forecast the area under the curve of relative operating characteristic was considered. The ROC curves were plotted to check the skill of the probabilistic forecasts obtained from the models against the climatological probability of PMD. The ROC was plotted for the probabilistic forecasts obtained from the climate models against the climatological probability of PMD and ERA-40 for each of the five models using all the nine initial conditions and by eliminating the initial condition ‘zero’ and ‘nine’

**Table 5.** Relative operating characteristic output for Islamabad.

| Model | Eliminated Initial Condition | Area Under The Curve | Status |
|---|---|---|---|
| | | 0.810 | Skill forecast |
| ECMWF vs. PMD | 0 | 0.825 | Skill forecast |
| | 9 | 0.818 | Skill forecast |
| ECMWF vs. ERA-40 | | 0.848 | Skill forecast |
| | | 0.758 | Skill forecast |
| Meteo France Vs. PMD | 0 | 0.751 | Skill forecast |
| | 9 | 0.721 | Skill forecast |
| Meteo France Vs. ERA-40 | | 0.693 | Skill forecast |
| | | 0.745 | Skill forecast |
| MPI vs. PMD | 0 | 0.742 | Skill forecast |
| | 9 | 0.723 | Skill forecast |
| MPI vs. ERA-40 | | 0.721 | Skill forecast |
| | | 0.682 | Skill forecast |
| UKMO vs. PMD | 0 | 0.665 | Skill forecast |
| | 9 | 0.688 | Skill forecast |
| UKMO vs. ERA-40 | | 0.682 | Skill forecast |

**Table 6.** Relative operating characteristic output for Jhelum.

| Model | Eliminated initial conditions | Area Under the Curve | Status |
|---|---|---|---|
| | | 0.777 | Skill forecast |
| ECMWF Vs. PMD | 0 | 0.781 | Skill forecast |
| | 9 | 0.747 | Skill forecast |
| ECMWF vs. ERA-40 | | 0.723 | Skill forecast |
| | | 0.712 | Skill forecast |
| Meteo France Vs. PMD | 0 | 0.695 | Skill forecast |
| | 9 | 0.684 | Skill forecast |
| Meteo France Vs. ERA-40 | | 0.641 | Skill forecast |
| MPI vs. PMD | | 0.576 | Poor forecast |
| | 0 | 0.571 | Poor forecast |
| | 9 | 0.587 | Poor forecast |
| MPI vs. ERA-40 | | 0.387 | Poor forecast |
| | | 0.613 | Skill forecast |
| UKMO vs. PMD | 0 | 0.604 | Skill forecast |
| | 9 | 0.628 | Skill forecast |
| UKMO vs. ERA-40 | | 0.636 | Skill forecast |

**Table 7.** Relative operating characteristic output for Muzaffarabad.

| Model | Eliminated initial conditions | Area Under the Curve | Status |
|---|---|---|---|
| | | 0.617 | Skill forecast |
| ECMWF Vs. PMD | 0 | 0.558 | Poor forecast |
| | 9 | 0.587 | Poor forecast |
| ECMWF vs. ERA-40 | | 0.706 | Skill forecast |
| | | 0.600 | Skill forecast |
| Meteo France Vs. PMD | 0 | 0.628 | Skill forecast |
| | 9 | 0.578 | Poor forecast |
| Meteo France Vs. ERA-40 | | 0.628 | Skill forecast |
| | | 0.452 | Poor forecast |
| MPI vs. PMD | 0 | 0.450 | Poor forecast |
| | 9 | 0.407 | Poor forecast |
| MPI vs. ERA-40 | | 0.738 | Skill forecast |
| | | 0.645 | Skill forecast |
| UKMO vs. PMD | 0 | 0.665 | Skill forecast |
| | 9 | 0.654 | Skill forecast |
| UKMO vs. ERA-40 | | 0.545 | Poor forecast |

Skill scores from linear error in probability space and relative operating characteristics has been compared to find out the skill of the climate model to predict the future state. For this the Australian seasonal rainfall forecast for summers and winters hindcast for 27 years has been done. Different skill score showed different skills. However the skill of the ROC was found to be the most skill full [30].

Therefore, by evaluating ROC for each of the five models for our study, the skill forecast has been confirmed, as Area under the cure (AUC) for most of the curve is found to be above 0.5 except for MPI for Jhelum and Muzaffarbad. It has been concluded that the forecast of the ECMWF is most skill full for each of the selected areas.

## 5. Conclusion

### *5.1 Islamabad*

The most accurate probabilistic forecast was obtained by eliminating initial condition 'zero' when alternatively using the initial conditions to calculate the Probabilistic Forecast by using single model ECMWF and MPI. While for MeteoFrance most accurate probabilistic forecast was obtained by eliminating initial condition 'ninth' and for UKMO by using all the initial conditions.

The Probabilistic forecast calculated from ECMWF, Meteo France, MPI and UKMO and verified against Brier Score shows that it has low resolution and high reliability for Islamabad. Cross validation shows that the forecast is accurate. Whilst, ROC verifies the probabilistic forecast of each of the four models as a skill forecast for Islamabad.

### *5.2. Jhelum*

The most accurate probabilistic forecast was obtained by eliminating initial condition 'zero' and 'ninth', when alternatively using the initial conditions to calculate the Probabilistic Forecast by using single model ECMWF. For MeteoFrance initial condition 'ninth' and by eliminating initial condition 'zero' for the determination of probabilistic forecast of the models MPI and UKMO.

The probabilistic forecast calculated from each of the four models and verified against Brier Score shows that it has low resolution and high reliability for Jhelum. The forecast is found to be accurate through cross validation and skill when verified against ROC for ECMWF, MeteoFrance and UKMO while for Jhelum, MPI it has poor skill.

*5.3 Muzaffarabad*

The probabilistic forecast was obtained by using all the initial conditions and alternatively using the initial conditions to calculate the Probabilistic Forecast by using single model ECMWF come out to be same. For MeteoFrance and UKMO, however the most accurate forecast was obtained by eliminating initial condition 'ninth' when alternatively using the initial conditions to calculate the probabilistic forecast and by using all the initial conditions for MPI.

The probabilistic forecast calculated and verified against Brier Score shows that it has low resolution and high reliability for Muzaffarabad for each of the five climate models. Cross validation shows the forecast to be accurate and ROC verified it to be skill forecast for Muzaffarabad for all four model except for MPI, which has a poor skill for Muzaffarbad.

## 6. Recommendations

The rapidly changing climate is resulting in the occurrence of extreme events that causes human life loss as well as infrastructure damage. Therefore climate and weather forecast system based on numerical modeling system incorporating ensemble prediction system should be developed in Pakistan in order to minimize the loss. On the basis of forecasts made by climate models, adaptations should be made by the concerned authorities for the extreme events that are likely to be more overstated in the future. Therefore, for climate forecasting, the ECMWF model is recommended to be used for the seasonal prediction of heat waves for Islamabad by eliminating the initial condition 'zero' for Jhelum by omitting initial condition 'zero' and 'ninth' and for Muzaffarabad with all the nine initial conditions. It is also suggested to use Meteo France by omitting initial condition 'ninth' for heat waves for all the three selected areas. MPI is proposed to be used by eliminating initial condition 'zero' for Islamabad and Jhelum while with all the initial conditions for Muzzaffarbad. For Islamabad UKMO is suggested to be used for seasonal predication by using all the initial conditions; for Jhelum, by omitting initial condition 'zero' and for Muzaffarbad by eliminating initial condition 'ninth'.

The climate models recommended includes almost all the significant physical developments that regulate climate and climate change, provides assurance in using these modeling system to predict the extreme events in the districts studied. As the probabilistic forecast provides the basis for the development of early warning system, the forecasters must use the seasonal forecast of the models used for the three districts being studied for developing an early warning system by giving the accurate prediction of extreme climatic events and natural hazards to protect the most vulnerable population of the country.

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