Chapter 9

Agro-climatic analysis for understanding climate change and variability

R. Raja*, B.B. Panda and A.K. Nayak
Central Rice Research Institute, Cuttack, Odisha, India
*e-mail: rajatnau@gmail.com

Agriculture will face significant challenges in the 21st century, largely due to the need to increase global food supply under the declining availability of soil and water resources and increasing threats from climate change. There is concern about the impacts of climate change and its variability on agricultural production worldwide. Current research confirms that, while crops would respond positively to elevated carbon dioxide (CO_2) in the absence of climate change, the associated impacts of high temperatures, altered patterns of precipitation, and possibly increased frequency of extreme events, such as drought and floods, will likely combine to depress yields and increase production risks in many parts of the world. In nutshell, climate change introduces new dynamics and uncertainties into agricultural production and considerable uncertainty remains about the intensity, duration, magnitude and location of impacts. Hence, visualizing and anticipating the processes and impacts of climate change on agricultural production systems are very important for making appropriate policy decisions. Combinations of general circulation models, regional circulation models, crop models, soil models, agro-ecological system models, and economic models are being used to illustrate potential impacts of climate change in the coming decades based on various climate scenarios (Olson et al., 2008; Hein et al., 2009; Thornton et al., 2010). In addition to the global/ regional models, agro-climatic analysis of a particular region can help in understanding the climatic characteristics and crop performance of the region and also to know the impact of climatic variability on its agriculture. This will facilitate thorough understanding of the climatic conditions, determining the suitable agricultural management practices for taking advantage of the favorable weather condition and avoiding or minimizing risks due to adverse weather conditions. This chapter deals with various models and methods of agro-climatic analysis which will help in understanding the climatic conditions of a region and in turn help in determining the suitable agricultural management practices to tide over the possible negative effects of climate change/ variability.

Global circulation models

The climate system is global. Observations, theory, and models are all needed in climate research. Comprehensive climate models are based on physical laws and allow for numerical simulations. The climate system is characterized by a broad range of spatial scales and time scales. Consequently, Global circulation models (GCMs) can effectively address large-scale climate features such as the general circulation of the atmosphere and the ocean, and sub-continental patterns of, for example, temperature and precipitation (Rummukainen, 2010). Climate models have been demonstrated to reproduce observed features of recent climate and past climate changes. There is considerable confidence that GCMs provide credible quantitative estimates of future climate change, particularly at continental and larger scales (Randall et al., 2007). Confidence in these estimates is higher for some climate variables (e.g., temperature) than for others (e.g., precipitation).

Regional circulation models

The resolution (grid scale) of GCMs is at best around 100–200 km (Meehl et al., 2007). Their real resolution is more like 6–8 grid distances, i.e., of the order of 1000 km (Grotch & MacCracken, 1991). This falls short of many key regional and local climate aspects, e.g. intensive precipitation. Very high global model resolution would of course give rise to simulation of regional and local aspects (Mizuta et al., 2006). Global circulation models of this kind are, however, still not feasible due to their high computational cost.

Hence, Regional circulation models (RCMs) were developed with the concept of 'downscaling'. Its purpose is to obtain regional or local detail from either sparse observations or low resolution numerical simulations. Regional models are sometimes called comprehensive, consistent, and physically based interpolator or, in more popular terms, a magnifying glass. This does not imply that RCMs are simple. Their description of climate processes is as complex as in comprehensive GCMs. Downscaling can in principle be applied to refine any data, regardless of its resolution. The two main downscaling methods are known as statistical and dynamical downscaling. The former involves finding robust statistical relationships between large scale climate variables (e.g., the mean sea level pressure field) and local ones (such as temperature or precipitation). There is a wealth of specific methods for this (Christensen et al., 2007). As already has been alluded to, dynamical downscaling by means of RCMs (Christensen et al., 2007) relies on the same physical–dynamical description of fundamental climate processes that is at the core of GCMs. There are two further approaches to dynamical downscaling. One of these is to use a high resolution atmospheric global model (Christensen et al., 2007). Another technique is a global model with a variable-resolution grid (Fox-Rabinovitz et al., 2008; Lal et al., 2008). In this case, the computational grid is made dense over the region of interest, but left sparser elsewhere. These two approaches have their own strengths and weaknesses.

The primary assumption in regional modeling is that data on the climate; large-scale information is used to force an RCM over a limited area. Such a regional domain, as compared to a global one, allows for high resolution without a prohibitive increase in computational cost. Driving data are supplied to the regional model as lateral (and often also sea surface) boundary conditions. The basic set of boundary conditions contains temperature, moisture, and circulation (winds), as well as sea surface temperature and sea ice. An accurate treatment of boundary conditions is a central issue in regional modeling.

The Inter-governmental Panel on Climate Change (IPCC) has projected the following changes in climate with respect to South Asian region (Christensen et al., 2007) as a whole using GCMs/RCMs:

Temperature

For the A_1B scenario (which assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies with balanced use of fossil and non-fossil energy resources), the MMD (multi-model data set) - A_1B models show a median increase of 3.3°C in annual mean temperature by the end of the 21st century. The median warming varies seasonally from 2.7°C in JJA (June, July, August) to 3.6°C in DJF (December, January, February), and is likely to increase northward in the area, particularly in winter, and from sea to land. Studies based on earlier Atmosphere-Ocean general circulation models (AOGCM) simulations support this picture. The tendency of the warming to be more pronounced in winter is also a conspicuous feature of the observed temperature trends over India. Downscaled projections using the Hadley centre regional model (HadRM2) indicate future increases in extreme daily maximum and minimum temperatures throughout South Asia due to the increase in greenhouse gas concentrations. This projected increase is of the order of 2°C to 4°C in the mid-21st century under the IPCC Scenario I992a in both minimum and maximum temperatures. Results from a more recent RCM, providing regional impacts for climate studies

(PRECIS) indicate that the night temperatures increase faster than the day temperatures, with the implication that cold extremes are very likely to be less severe in the future.

Precipitation and associated circulation systems

Most of the MMD-A_1B models project a decrease in precipitation in DJF (the dry season), and an increase during the rest of the year. The median change is 11% by the end of the 21st century, and seasonally is –5% in DJF and 11% in JJA, with a large inter-model spread. The probabilistic method of Tebaldi et al. (2004a) similarly shows a large spread, although only 3 of the 21 models project a decrease in annual precipitation. This qualitative agreement on increasing precipitation for most of the year is also supported by earlier AOGCM simulations.

In a study with four GCMs, Douville et al. (2000) found a significant spread in the summer monsoon precipitation anomalies despite a general weakening of the monsoon circulation. They concluded that the changes in atmospheric water content, precipitation and land surface hydrology under greenhouse forcing could be more important than the increase in the land-sea thermal gradient for the future evolution of monsoon precipitation. Stephenson et al. (2001) proposed that the consequences of climate change could manifest in different ways in the physical and dynamical components of monsoon circulation. Douville et al. (2000) also argue that the weakening of the *El Nino* southern oscillation (ENSO)-monsoon correlation could be explained by a possible increase in precipitable water as a result of global warming, rather than by an increased land-sea thermal gradient. However, model diagnostics using European centre hamburg model (ECHAM4) to investigate this aspect indicated that both the above mechanisms can play a role in monsoon changes in a greenhouse gas warming scenario. Ashrit et al. (2001) showed that the monsoon deficiency due to *El Niño* might not be as severe, while the favourable impact of *La Niña* seems to remain unchanged. In a later study using the Centre national de recherches météorologiques (CNRM) GCM, Ashrit et al. (2003) found that the simulated ENSO monsoon teleconnection shows a strong modulation on multi-decadal time scales, but no systematic change with increasing amounts of greenhouse gases.

Time-slice experiments with ECHAM4 indicated a general increase in the intensity of heavy rainfall events in the future, with large increases over the Arabian Sea and the tropical Indian Ocean, in northern Pakistan and northwest India, as well as in northeast India, Bangladesh and Myanmar (May, 2004). The HadRM2 RCM shows an overall decrease by up to 15 days in the annual number of rainy days over a large part of South Asia, under the IS92a scenario in the 2050s, but with an increase in the precipitation intensity as well as extreme precipitation (Krishna Kumar et al., 2003). Simulations with the PRECIS RCM also projected substantial increases in extreme precipitation over a large area, particularly over the west coast of India and west central India (Rupa Kumar et al., 2006). Dairaku & Emori (2006) show from a high-resolution AGCM simulation (about 1.5 degrees) that the increased extreme precipitation over land in South Asia would arise mainly from dynamic effects, that is, enhanced upward motion due to the northward shift of monsoon circulation. Based on regional HadRM2 simulations, Unnikrishnan et al. (2006) reported increases in the frequency as well as intensities of tropical cyclones in the 2050s under the IS92a scenario in the Bay of Bengal, which will cause more heavy precipitation in the surrounding coastal regions of South Asia, during both South-west and North-east monsoon seasons.

Agro-climatic analysis at micro level

Climate and weather are the important integrated factors determining the status of agriculture. The influence of weather on crop performance is operative even before the crop seed is sown. The physical, chemical and biological compositions of soils are greatly affected by weather. Weather also indirectly influences the outbreak of pest and diseases by interfering with agricultural operations. The yield potential of a crop is mainly depends on weather even though climate decide the choice of the crop. It regulates the living condition of plants and animals, their growth and multiplication. More than 50% of variation in yield of a crop is due to weather. Different set of analysis are used for analyzing the weather variables for different purpose (Table 1).

TABLE 1. *Types of analyses used in analyzing weather variables*

S. No.	Name of the analysis	Purpose
1	Co-efficient of variation for rainfall	Variability of rainfall
2	Initial probability for rainfall	Dependability of rainfall
3	Conditional probability for rainfall	Predicting rainfall
4	Onset & with drawl of monsoon	Agricultural planning
5	Length of growing period	Selection of crops and designing of suitable cropping pattern
6	Return period	Identifying the frequency of quantum of RF occurrence
7	Markov-chain analysis	Probability of wet and dry spell weeks
8	Trend analysis of climatic parameters	Statistical testing for trend, change and ran domness in rainfall and other time series data
9	Extreme event analysis	To find out weather phenomena that are at the extremes of the historical distribution

Co-efficient of variation for rainfall

Indian agriculture continues to face rainfall variability. The main features of rainfall variability are its quantity and distribution during the cropping period. Co-efficient of variation (CV) is used to understand such behavior.

Assessing the rainfall variability in terms of time and space enables for planning agricultural operations on a sustainable basis. There are several methods of variability analysis available and out of which estimation of co-efficient of variation is quite simple and more suited for agricultural purposes. This is because, there exists a strong relationship between CV and rainfall dependability. The greater the CV, the lesser is the dependability. Similarly, lower the rainfall, the greater the CV.

The formula used in this method is

$$CV = (\text{Standard Deviation}/\text{Mean}) \times 100$$

For doing such analysis, rainfall data from long term records are required at least for a block of 30 years as per the World Meteorological Organization (WMO) standard. The blocking of 30 years must be in such a way that starting year should be the beginning of a decade and terminal year should be the end of the decade. eg. 1961-90, 1971-2000. By experience, the following are the threshold levels of CV for any interpretation (Veeraputhiran et al., 2003).

Particulars	*Threshold level of CV*
Yearly RF	< 25%
Seasonal RF	< 50%
Monthly RF	< 100%
Weekly RF	< 150%
Daily RF	< 250%

Initial and conditional probabilities

The concept of estimation of probabilities with respect to given amount of rainfall is extremely useful for planning agricultural operations. Two types of probabilities i.e., initial and conditional probabilities are commonly used for analyzing the rainfall in respect of planning agricultural operations. This is very important because all the agricultural operations especially under dry land condition in a given area is dictated by rainfall events.

Initial probability

Initial probability (IP) indicates the minimum quantity of rainfall to be expected for a particular time series data. For computing the initial probability, the concerned time series rainfall data are arranged in descending order. The simple method used for computing initial probability is:

Initial probability = (Sample size (n) x Probability required in percentage (p))/100

For example if 30 years rainfall data were taken for analyzing 50 per cent rainfall probability means, IP = (30 x 50)/100 = 15

After arranging 30 years rainfall data of particular time series in descending order, identify the 15th number from the top and this would be 50 per cent probable rainfall amount.

Conditional probability

Chance of occurrence of particular quantity of rainfall for agricultural operations like sowing, weeding, etc.

Conditional probability (Cp) = $((\bar{x} - x)/ s)$

where,

$\bar{x}$ = mean weekly rainfall
x = rainfall required
σ = standard deviation

Since the resultant value does not fall under normal distribution it has to be referred to 'Z' table and multiplied by 100 to find out the actual probability in percentage. If the percentage is >60, it can be accounted for planning.

Length of growing period

Length of growing period (LGP) is defined as the period in which the soil is able to provide the moisture requirement of the crops to meet its evapotranspiration. This means that if a plant is grown in an identified LGP, the probability of getting soil moisture stress is negligible. In other words, it is a potential period for reaping potential productivity under selected agro techniques. Many methods *viz.*, Moisture adequacy index, Starting and termination rain method , Rainfall stability period method, Hargreeves Moisture availability index method, FAO model and Jeevananda Reddy method have been employed to identify LGP of a particular region (Raja et al., 2011).

In respect of starting and termination rain method, the date of onset and the date of withdrawal of seasonal rainfall are taken into account and the length of period between onset and termination will be taken as LGP. The main feature of Indian rainfall is spatial and temporal variability and as a result, intra-seasonal variability is of a great importance. Hence in this method, the length of dry and wet spells within the growing period could not be brought out which again is a major limitation for agricultural planning.

Using of probability of weekly rainfall for computing Moisture availability index (MAI) under Hargreeves method is varying between different rainfall situations (high rainfall areas, assured rainfall areas and scanty rainfall areas). Hence assessing the right probability for weekly rainfall would be an additional exercise for this method.

The FAO model was used by National Bureau of Soil Survey and Land Use Planning, Nagpur to compute LGP for classifying the Indian areas into different Agro Ecological Regions and Agro Ecological Zones. In this method, if the consecutive monthly rainfall is more than 50% of potential evapotranspiration (PET) of that month, then this sequence is taken as LGP. In addition, the stored soil moisture at the end of the season is accounted in computing LGP. The limitation of this method is handling of macro level data on monthly basis. For proper agricultural planning, any method that uses weekly data would be more relevant.

The better available method would be Jeevananda Reddy method, which encompasses weekly rainfall and weekly PET. This method uses two approaches one for computing simple R/PE ratio; the other one is the computation of 14 weeks moving average. The quantity 14 weeks indicates 98 days, which is a safety period for a dry land crop to complete its life cycle from seeding to harvest.

Markov-chain analysis

Agricultural operations are determined by the certain amount of rainfall received in a period. There are specific amounts of rainfall required for the activities like land preparation, sowing and for various agricultural activities. Hence, estimation of probabilities with respect to a given amount of rainfall is useful for rainfed agricultural planning especially in semiarid region. Initial probability rainfall analysis will give percentage probability to get certain amount of rainfall in a given week. Probability of wet week is denoted as P(W) and dry week as P(D). Conditional probability rainfall analysis will give the percentage probability for wet week followed by wet week [P(W/W)], wet week followed by dry week [P(W/D)], dry week followed by dry week [P(D/D)] and dry week followed by wet week [P(D/W)]. It is also important to find out percentage probability of consecutive wet weeks (2W, 3W, 4W) and consecutive dry weeks (2D, 3D, 4D). Several techniques are in use to work out wet and dry spells .The initial and conditional probabilities as per the first order Markov chain model is widely used world over to understand the crop growing seasons based on dry and wet spells.

Trend analysis of climatic parameters

Intergovernmental panel on climate change (IPCC) reported that the impact of climate change is severe in lower latitudes, especially in seasonally dry and tropical regions, where crop productivity is projected to decrease for even small local temperature increases (1 to 2°C), which would increase the risk of hunger (medium confidence). Decreases in precipitation are predicted by more than 90% of climate model simulations by the end of the 21st century for the northern and southern sub-tropics. However, agricultural productivity can also be increased, costs reduced and impending crop shortfalls mitigated or avoided through the judicious use of information and knowledge about climate and weather, including early warning and agro-meteorological advisories. Time series analysis of rainfall and other meteorological parameters helps in understanding the behavior of a particular weather parameter over time in that region.

TREND is software designed to facilitate statistical testing for trend, change and randomness in hydrological and other time series data. TREND has 12 statistical tests, based on the WMO/ UNESCO Expert Workshop on trend/ change detection. The TREND software program can be downloaded from the TREND homepage www.toolkit.net.au/trend. TREND requires a continuous time series as input data in comma separated value file (.csv file). TREND displays as an output the value of the test statistic, the critical values of the test statistic at 0.01 (90 % significant level), 0.05 (95 % significant level) and 0.1 (90 % significant level), and a statement of the test result, for all the statistical tests selected by the user.

Extreme event analysis

The weather outlook is of great help to agriculture operations. Certain rainfall amount and temperature thresholds have a great influence on crop production. Advises are given to the agricultural community about extreme events like heavy rainfall, prolong dry spell, and high and low temperature event would help to reduce losses to agriculture.

Goswami et al. (2006) using a daily rainfall data set found (i) significant rising trends in the frequency and the magnitude of extreme rain events and (ii) a significant decreasing trend in the frequency of moderate events over central India during the monsoon seasons from 1951 to 2000 and predicted a substantial increase in hazards related to heavy rain over central India in the future.

The frequency of droughts has varied over the decades in India. From 1899 to 1920, there were seven drought years. The incidence of drought came down between 1941 and 1965 when the country witnessed just three drought years. Again, during 1965-87, of the 21 years, 10 were drought years and the increased frequency was attributed to the ENSO. Among the drought years, the 1987 drought was one of the worst droughts of 20th Century, with an overall rainfall deficiency of 19%. It affected 59-60% of the crop area and a population of 285 million. In 2002 too, the overall rainfall deficiency for the country as a whole was 19%. Over 300 million people spread over 18 states were affected by the drought in varying degrees. Food grains production registered the steepest fall of 29 million tonnes (Samra, 2004). The frequency of occurrence of drought in different meteorological sub-divisions of India is given in Table 2.

TABLE 2. *Probability of occurrence of drought in different meteorological sub-divisions of India*

Meteorological sub-division	Frequency of deficient rainfall (75% of normal or less)
Assam	Very rare (Once in 15 years)
West Bengal, Madhya Pradesh, Konkan, Bihar and Odisha	Once in 5 years
South interior, Karnataka, Eastern Uttar Pradesh & Vidarbha	Once in 4 years
Gujarat, East Rajasthan, Western Uttar Pradesh	Once in 3 years
Tamil Nadu, Jammu & Kashmir and Telengana	Once in 2.5 years
West Rajasthan	Once in 2 years

Impact of climate variablity/ change on rice

The increase in temperature especially that of mean minimum night time temperature has adverse effect on rice productivity in terms of increased night respiration. Farmers have to adopt with the growing challenge of the increase in extreme climatic events associated with climate change, such as increasing severity and frequency of floods and drought, and their effect on crops, in particular rice, which is a major staple crop in India.

In predominantly rainfed eastern India, as a result of climate variability/change, there is change in monsoon pattern from the normal, which adds stress to the prediction of monsoon rain. The two components of seasonal monsoon rainfall which most influence the success of a given growing season are its total amount and its distribution. Though in nearly every year, sufficient total precipitation is received during the growing season the extreme distribution in limited rainy days leads to floods, and drought.

The impact of projected global warming on crop yields has been evaluated by indirect methods using simulation models. However, direct studies on the effects of observed climate change on crop growth and yield could provide more accurate information for assessing the impact of climate change on crop production. Peng et al. (2004) analyzed weather data at the International Rice Research Institute Farm from 1979 to 2003 to examine temperature trends and the relationship between rice yield and temperature by using data from irrigated field experiments conducted at the International Rice Research Institute Farm from 1992 to 2003. It was found that annual mean maximum and minimum temperatures have increased by 0.35°C and 1.13°C, respectively, for the period 1979–2003 and a close linkage between rice grain yield and mean minimum temperature during the dry cropping season (January to April). Grain yield declined by 10% for each 1°C increase in growing-season minimum temperature in the dry season, whereas the effect of maximum temperature on crop yield was insignificant. This finding provides a direct evidence of decreased rice yields from increased night time temperature associated with global warming.

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