Chapter 4

Weather and Climate Forecasts for Agriculture

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4.1Need for and Requirements of Weather Forecasts for Agriculture

4.1.1. Climate-Based Strategic Agronomic-Planning

Weather plays an important role in agricultural production. It has a profound influence on the growth, development and yields of a crop, incidence of pests and diseases, water needs and fertilizer requirements in terms of differences in nutrient mobilization due to water stresses and timeliness and effectiveness of prophylactic and cultural operations on crops. Weather aberrations may cause (i) physical damage to crops and (ii) soil erosion. The quality of crop produce during movement from field to storage and transport to market depends on weather. Bad weather may affect the quality of produce during transport and viability and vigor of seeds and planting material during storage.

Thus, there is no aspect of crop culture that is devoid of the impact of weather. However, (a) the weather requirements for optimal growth, development and yield of crops, incidence, multiplication and spread of pests and diseases and susceptibility to weather-induced stresses and affliction by pests and diseases vary amongst crops, with the same crop with the varieties and with the same crop variety with its growth stages. Even on a climatological basis weather factors show spatial variations in an area at a given time, temporal variations at a given place and year to year variations for a given place and time. For cropping purposes weather over short time periods and year-to-year fluctuations at a place over the selected interval have to be considered. For any given time-unit the percentage departures of extreme values from a mean or median value, called the coefficient of variability, is a measure of variability of the parameter The shorter the time-unit, the greater is the degree of variability of a weather parameter. Again, intensity of the above three variations differ amongst weather factors. Over short periods of time, rainfall is the most variable of all parameters, both in time and space. In fact for rainfall the short-period inter-year variability is large, which necessitates expressing variability in terms of percentage probability of realizing a given amount of rain or specify the minimum assured rainfall amounts at a given level of probability.

For optimal productivity at a given location crops and cropping practices must be such that while their cardinal phased weather requirements match the temporal march of the concerned weather element(s), endemic periods of pests, diseases and hazardous weather are avoided. In such strategic planning of crops and cropping practices, short-period climatic data, both routine and processed (like initial and conditional probabilities), have a vital role to play.

4.1.2. Weather Vagaries

Despite careful agronomic planning on a micro scale to suit local climate crops experience various types of weather vagaries on a year-to year-basis. The effects of weather anomalies are not spectacular. Deviations from normal weather occur with higher frequencies in almost all years, areas and seasons. The most common one is delay in start of the crop season due to rainfall vagaries in case of rainfed crops (as observed in semi arid tropics) and temperature vagaries (as observed in tropics, temperate zones and subtropics) or persistence of end of the season rains in case of irrigated crops. The other important one is the deviations from the normal features in the temporal march of various weather elements. The effects of weather vagaries on crops build up slowly but are often widespread enough destabilize the national agricultural.

4.1.3. Usefulness of Weather Forecasts.

Occurrences of erratic weather are beyond human control. However, it is possible to adapt to or mitigate the effects of adverse weather if a forecast of the expected weather can be had in time. Rural proverbs abound in giving thumb rules for anticipation of local weather and timing of agricultural operations in light of expected weather. Basu (1953) found no scientific basis for anticipation of weather in many proverbs/folk lore in vogue. In a recent study Banerjee et al. (2003) have arrived at conclusions similar to that of Basu (1953). However the proverbs/folklore show that the keenness of farmers to know in advance the likely weather situations for crop operations is time immemorial. Agronomic strategies to cope with changing weather are available. For example delay in start of crop season can be countered by using short duration varieties or crops and thicker sowings. However, once the crop season starts the resources and technology get committed and the only option then left is to adopt crop-cultural practices to minimize the effects of mid-seasonal hazardous weather phenomena on the basis of advanced intimation of their occurrences. For example, effects of frosts can be prevented by resorting to irrigation or lighting up of trash fires. Thus, the usefulness of medium range weather forecasts with a validity period that enables farmers to organize and carry out appropriate cultural operations to cope with or take advantage of the forecasted weather is warranted. With the rapid advances in Information

Technology and its spread to rural areas, the demand for provision of timely and accurate weather forecasts for farmers is on the increase.

4.1.4. Essential requirements of Weather Forecasts for Agriculture.

Receipt of forecasts of late start of the crop season necessitates agronomic changes from the normal at the field level. Organization and execution of such a strategy comes under the category of high cost decisions and will take quite sometime. Therefore, pre-seasonal forecasts must have a validity period of at least 10 days and not less than a week. Field-measures to counter the effects of forecasted hazardous weather, pests, diseases etc take time and hence mid-seasonal forecasts must preferably be communicated 5 days and not less than 3 days in advance. Dissemination of weather forecasts after their formulation to agricultural users should be quick with minimum possible temporal lag. Some of the measures like pre-seasonal agronomic corrections, control operations against pests and diseases, supplementary irrigation and pre-poning of crop harvests will be high cost decisions. Therefore, the weather forecasts must not only be timely but must also be very accurate. Weather forecasts must ideally be issued for small areas. In the case of well-organized weather systems the desired areal delineation of forecasts can be realized. In other cases the area(s) to which the weather forecasts will be applicable must be unambiguously stated.

4.1.5. Some Unique Aspects of Agricultural Weather Forecasts.

There are some aspects of weather forecasts for agriculture that are quite distinct from synoptic weather forecasts. In synoptic meteorology the onset and withdrawal of the monsoon is related to changes in wind circulation patterns in the upper atmosphere and associated changes in precipitable water content of air in the lower layers. Preparation of field for sowing and sowing of crop with adequate availability of seed zone soil moisture requires copious rains. Rains that do not contribute to root zone soil moisture of standing crops are ineffective. Agriculturally Significant Rains, ASRs (Venkataraman, 2001) are those that enable commencement of cropping season and that contribute to crop water needs. For agricultural purposes it is the start and end of ASRs that are important. ASRs may be received early as thundershowers or may be delayed. Venkataraman and Krishnan (private communication) have drawn attention to the feasibility of commencement of cropping season much ahead of the monsoon season in Karnataka, Kerala, West Bengal and

Assam in India with the help of pre-monsoon thunderstorm rains. The climatological dates of withdrawal of monsoon and end of ARS in a region can also differ significantly. Both start and end of ASRs in a province may show intra-regional variations.

Use of Dependable Precipitation, DP at various probability percentage levels and Potential Evapotranspiration have been suggested for delineation of start and end of crop growth period on a climatological basis (Cocheme and Franquin, 1967; Brown and Cocheme, 1973; Venkataraman, 2002) and have been used in many regions. The methods however differ in time-units employed, probability level chosen for DP and fraction of PET used as a measure of adequacy of crop-rainfall. Based on considerations of level of Evaporative Power of AIR, EPA, rainfall amount required to overcome the evaporative barrier and phased moisture needs of crops demands Venkataraman (2001) had suggested (a) use of weekly or decadal periods and (b) that commencement and end of ASR be taken as the one when DP at 50% probability level begins to exceed PET and become less than 50% of PET respectively. Monthly values of PET can be interpolated to derive short period values. So when rainfall probability data for weeks or dekades and monthly values of PET are available the commencement and end of ASRs can be easily delineated.

While clear weather is required for sowing operations it must be preceded by antecedent seed zone soil moisture storage. Thus, forecasts of clear weather following a wet spell are crucial. Such forecasts of dry spells following a wet spell are also required for the initiation of disease control measures. There are areas where frequent thunderstorm activity precedes the arrival of rains associated with well-defined weather systems and the rains once started persist without any let up. In such cases the agronomic strategy should be to utilize pre-seasonal rains for land preparation and resort to dry sowings in anticipation of rain in the next few days. Land preparation can be done on post-facto receipt of thundershowers. However, dry-sown seeds will get baked out in absence of rains. It is prudent to sow on receipt of forecast of impending rains. So forecasts of rainy season become crucial in such areas. In temperate regions frost can cause severe menace to agricultural productivity. Frosts normally occur when the screen temperatures reach zero degrees centigrade. The depression of radiation minimum temperature of crops below the screen minimum will vary with places and seasons. The radiative cooling will be maximal under cold nights with clear skies and minimal with warm night temperatures with cloudy skies. Thus due to nighttime radiative cooling of crop canopies, crop-frosts can occur even when screen temperatures are above zero degrees centigrade. Similarly Dew, which influences the crop water needs and the incidence of diseases, can get deposited over crops at lower relative humidities than what is deducible from a thermohygrograph. The Frictional layer near the ground is ignored by the synoptic meteorologist but low level winds in this layer influence the long-distance dispersal of insects (like desert locusts) and disease spores (wheat rusts).

It is hence clear that the types of forecast for critical farming operations would have some unique features that would require further processing of some elements of synoptic weather forecasts. The above aspect is dealt with in a detailed manner and on a weather element-wise basis in a subsequent chapter.

4.2 Characters of present weather forecasts

A deterministic definition states that "weather forecast describes the anticipated meteorological conditions for a specified place (or area) and period of time"; an alternative and more probabilistic definition states that "weather forecast is an expression of probability of a particular future state of the atmospheric system in a given point or territory". In view of the above a Weather forecast may be defined as a declaration in advance of the likelihood of occurrence of future weather event(s) or condition(s) in a specified area(s) at given time-period(s) on the basis of (i) a rational study of synoptic, three-dimensional and time-series data of sufficient spatial coverage of weather parameters and (ii) analyses of correlated meteorological conditions. The positive effect of weather forecasts in agriculture is maximized if weather forecasters are aware of the farmer's requirements and farmers know how to make the most use of the forecasts that are available. Response amongst varieties of a crop to weather phenomenon is one of degree rather than of type. However, the type and intensity of weather phenomenon that cause setbacks to crops vary amongst crops and with the same crop with its growth stages. Because of crop-weather reasons, crops and cropping practices vary across areas even in the same season.

In the provision of weather forecasts for agriculture the emphasis should be on the look out for incidence of abnormal weather and prevalence of aberrant crop situations. Now, one cannot determine abnormality unless one knows what the normal picture is, both with reference to crops and weather. Thus, the first step in familiarizing the weather forecasters with the weather warning requirements of farmers is the preparation of "Crop Guides to Forecasters" (i) giving the times of occurrence and duration of developmental phases from sowing to harvest of major crops in the regions of their forecast interest and (ii) specifying the types of weather phenomenon for which weather warnings and forecasts are to be issued in the different crop Phases. Such guides can be used by the forecasters to prepare period-wise, region-wise calendars of agricultural weather warnings. In the crop guide to forecasters normal values of important weather elements in the crop season, for the national short-time period adopted for agrometeorological work, should also be given and such guides made available to the farming community so that any farmer will know immediately the normal features of weather for a given crop and season in his place. The week is the accepted time-unit for agrometeorological work in India. The Crop-weather calendars in use in India, using the week as the time-unit, vide a sample depicted in Figure 4.2.1, are excellent examples of the type of compiled information that would assist forecasters in framing weather warnings and forecasts for use of farmers.

In weather forecasting we now have a very wide range of operational products that traditionally are classified in the following groups:

1. Now-casting (NC)
2. Very Short Range Forecast (VSRF)
3. Short Range Forecast (SRF)
4. Medium Range Forecast (MRF)
5. Long Range Forecast (LRF)

Each weather forecast can be defined on the basis of the following criteria:

1. dominant technology
2. temporal range of validity after emission
3. characters of input and output time and space resolution
4. broadcasting needs
5. accuracy
6. usefulness

Table 1 shows a general description of different types of weather forecasts founded on criteria from 1 to 5; Table 2 presents an almost qualitative description founded on criteria 5 and 6.

Table 1 – Definition of weather forecasts

Type of weather forecast	**Acronym**	**Definition**	**Characters of output**	**Dominant technology**	**Other aspects**	**Time and space resolution of typical products**
Now-casting	**NC**	**A description of current weather variables and 0 - 2 hours description of forecasted weather variables**	**A relatively complete set of variables can be produced (air temperature and relative humidity, wind speed and direction, solar radiation, precipitation amount and type, cloud amount and type, etc.)**	**Analysis techniques, extrapolation of trajectories, empirical models, methods derived from forecaster experience (rules of thumb). Basic information is represented by data from networks of Automatic Weather Stations, maps from meteorological radar, images from meteorological satellites, local and regional observations and so on)**	**A fundamental prerequisite for NC is the operational continuity and the availability an efficient broadcasting systems (eg: very intense showers affecting a given territory must be followed with continuity in provision of information for final users.**	**Typical time resolution is 1 hour; typical space resolution is of the order of gamma mesocale (20-2 km).**
Very short-range forecast	**VSRF**	**Up to 12 hours description of weather variables**	**A relatively complete set of variables can be produced (see nowcasting)**	**Analysis techniques, extrapolation of trajectories, interpretation of forecast data and maps from NWP (LAM and GM), empirical models, methods derived from forecaster experience (rules of thumb). The basic information is represented by data from networks of Automatic Weather Stations, maps from meteorological radar, images from meteorological satellites, NWP models, local and regional observations and so on)**	**A fundamental prerequisite for VSRF is the availability an efficient broadcasting systems (eg: frost information must be broadcasted to farmers that can activate irrigation facilities or fires or other systems of protection).**	**Typical time resolution is 1-3 hours; typical space resolution is of the order of beta mesocale (200-20 km).**

Short-range weather forecast (*)	**SRF**	**Beyond 12 hours and up to 72 hours description of weather variables**	**A relatively complete set of variables can be produced (see nowcasting)**	**Interpretation of forecast data and maps from NWP (LAM and GM), empirical models, methods derived from forecaster experience (rules of thumb). The basic information is represented by data from networks of Automatic Weather Stations, maps from meteorological radars, images from meteorological satellites, NWP models, local and regional observations and so on)**	**In SRF the attention is centred on mesoscale features of different meteorological fields. SRF can be broadcasted by a wide set of media (newspapers, radio, Tv, web, etc.) and can represent a fundamental information for farmers.**	**Typical time resolution is 6 hours; typical space resolution is of the order of alfa or beta mesoc (2.000-20 km).**

Medium-range weather forecast (*)	**MRF**	**Beyond 72 hours and up to 240 hours description of weather variables**	**A relatively complete set of variables can be produced (see nowcasting)**	**Interpretation of forecast data and maps from NWP (GM), empirical models derived from forecaster experience (rules of thumb). The basic information is represented by NWP models. Techniques of "ensemble forecasting" are adopted in order to overcome the problem of depletion of skill typical of forecasts founded on NWP models. Instead of using just one model run, many runs with slightly different initial conditions are made. An average, or "ensemble mean", of the different forecasts is created. This ensemble mean will likely have more skill because it averages over the many possible initial states and essentially smoothes the chaotic nature of climate. In addition, it is possible to forecast probabilities of different conditions.**	**In MRF the attention is centred on synoptic features of different meteorological fields. MRF can be broadcasted by a wide set of media (newspapers, radio, Tv, web, etc.) and can represent a fundamental information for farmers.**	**Typical time resolution is 12-24 hours; typical space resolution is of the order of alfa mesocale (2.000-200 km).**

Long-range forecast	**LRF**	**From 12-30 days up to two years**	**Forecast is usually restricted to some fundamental variables (temperature and precipitation); other variables like wind, relative humidity and soil moisture are sometimes presented. Information can be expressed in absolute values or in term of anomaly.**	**Statistical (e.g.: teleconnections), and NWP methods. Coupling of atmospheric models with ocean general circulation models is sometimes adopted in order to enhance the quality of long-range predictions.**	**An Extended-range weather forecast (ERF), beyond 10 days and up to 30 days, is sometimes considered.**	**Typical time resolution is 1 month; typicall space resolution is of the order of the beta macroscale (10.000 – 2.000 km)**

(1) It is recently observed that SRF and MRF are converging toward a unique kind of forecast, due to the fact that Numerical Weather Prediction (NWP) models are the base for SRF and MRF too. It could be more correct to distinguish between forecasts based on Global Models - GM & Limited Area Models - LAM((from now to h + 72 h) and forecasts based only on GM (from h+72 to h + 7-15 days).

Table 2 – Accuracy, usefulness and main limitations of weather forecasts for agriculture.

Type of weather forecast	**Accuracy (*)**	**Usefulness**		**Main limitations**
		Real	**Potential**	
Nowcasting	**Very high**	**Very low**	**Low**	**Unsuitability of broadcasting system; insufficient flexi agricultural technology.**
Very short-range forecast	**Very high**	**Low**	**Moderate**	**Unsuitability of broadcasting system; insufficient flexi agricultural technology; farmer's doesn't know how to most use of available forecasts.**
Short-range weather forecast	**High**	**Moderate**	**High**	**Further adaptation of forecasts to farmer's requireme needed; farmer's doesn't know how to make the most available forecasts.**
Medium-range weather forecast	**High or moderate until 5 days; lower after.**	**High**	**Very high**	**Further adaptation of forecasts to farmer's requireme needed; farmer's doesn't know how to make the most available forecasts.**
Long-range forecast	**Very low**	**High in warning of delays in arrival of weather systems. Very low otherwise**	**Poor**	**Reliability (the reliability of LRF is higher for the trop mid latitudes. This is because tropical areas have a mo amount of predictable signal, whereas in the mid-latitu random weather fluctuations are usually larger than th predictable component of the weather).**

(*) Subjective judgement of a weather forecaster working at mid latitudes. The judgement is referred to cloud coverage, air temperature and precipitation occurrence.

4.3 Considerations regarding the agricultural weather forecasts

4.3.1 Elements of agricultural weather forecasts

An agricultural weather forecast should refer to all weather elements, which immediately affect farm planning or operations. The elements will vary from place to place and from season to season. Normally a weather forecast includes the following parameters.

- amount and type of coverage of sky by clouds
- rainfall and snow
- maximum, minimum and dew point temperatures
- relative humidity
- Wind Speed and Direction
- Extreme events like heat and cold waves fog, frost, hail, thunderstorms, wind squalls and gales, low pressure areas, different intensities of depressions, cyclones, tornados

An agricultural weather forecast should contain the following information also:

- bright hours of sunshine
- solar radiation
- dew
- leaf wetness
- pan evaporation
- soil moisture stress conditions and supplementary irrigation for rainfed crops
- advice for irrigation timing and quantity in terms of pan evaporation
- Specific information about the evolution of meteorological variables into the canopy layer in some specific cases
- Micro-climate inside crops in specific cases.

The weather requirements for each rice farming operation in the humid tropic are given in Table 3.

Table 3. Summary of weather requirements for each rice farming operation in the humid tropics

FARMING OPERATION	SKY CONDITION DURING FARMING OPERATION	SOIL (MOISTURE) CONDITION	LEAF WETNESS DURATION	AIR TEMPERATURE (^{O} C)		WIND SPEED (kmph) FARMING OPERATI
1. LAND PREPARATION (Handhoeing/plowing/harrowing/ rotavating of lowland farms)	**Clear or cloudy day desirable**	**Moist or wet** **Dry Surface and Moist Sub-surface Desirable**	**Not applicable**	**≤ 40 desired**	**≥ 15 desired**	**≤ 50 for comfort of workers**
2. SEEDING in seedbed or field, **$A_{I.}$ dry seeds,** **$A_{2.}$ pre-germinated**	**Clear or cloudy**	**$A_{I.}$ Moist, $A_{2.}$ Wet**	**Not applicable**	**< 33 desired**	**≥ 15 desired**	**< 20 desired to minimize evaporation**
3. TRANSPLANTING Seedlings	**Clear or cloudy day**	**Wet**	**Not critical**	**≤ 40 desired**	**≥ 15 desired**	**0-30 for comfort of workers**
4. HANDWEEDING/CULTIVATING. (Upland farms)	**Clear to partly cloudy day**	**Moist or dry**	**Not critical**	**≤ 40 desired**	**≥ 15 desired**	**≤ 50 During operation**
5. IRRIGATION	**Clear or cloudy day**	**Moist or dry**	**Not critical**	**Not critical**	**≥ 15 desired**	**Not critical**
6. SPRAYING Pesticide or foliar fertilizer **B_{I-} ground application** **B_{2-} aircraft application**	**Clear day desired; partly cloudy day and/or night acceptable. (Visibility be adequate for low level flight of aircraft)**	**$B_{I.}$ Moist or dry desired for dry application in upland farms** **$B_{2.}$ Not critical for low land rice farms or aircraft application**	**Leaves should be dry at spraying time; no rain until at least 4 hrs. after spraying**	**< 33 desired**	**≥ 15 desired**	**B1. 0-18 (for ground a** **B2. 4-14 (for aircraft a**

THRESHING/SUN DRYING CLEANING GRAIN	**Clear to partly cloudy for threshing and cleaning grains; clear for sun drying**	**Dry surface for operation**	**Not applicable**	**No upper limit**	**≥ 15 desired**	**≤ 25** **During grain cleaning operation**

4.3.2 Format of forecast

Formats of forecasts for agriculture are highly variable in different agricultural contexts in function of the strong variability of users, crops, agro-techniques, etc.

Specialised forecasts can be referred to crops, animal husbandry, forestry, fisheries and horticulture.

Issues of forecasts cannot be devoid of a technical slant but the forecast has to be frames in as simple a dialogue as possible to enable the farmer to readily grasp its content. Therefore, use of "intermediaries" (employed by the National Meteorological Services and/or the extension wing of agricultural services) as a vital link between the forecasters (and their products) and the farmers to explain to the farmers the use of forecasts as agrometeorological services for field operations must be provided for.

A forecast produced for educational purpose and released weekly by University of Milano (IT) is presented in Figure 4.3.2.1. This product is composed of three main parts:

- a general evolution

- forecast for seven days (cloud coverage, precipitation, wind, air temperature, other phenomena like foehn, frost, etc.)

- forecast of water balance, net primary production and growing degree days.

4.3.3 Forecasts for agricultural purposes

For arriving at forecasts additionally needed for agricultural purposes as detailed above, the initially framed forecasts would require to be modified/ processed. A more specific description of processing of weather forecasts of single weather variables for agricultural uses is presented hereafter.

A) Sky Coverage

Forecast of sky coverage can be defined adopting some standard classes like sky clear (0-2 octas), partly cloudy (3-5 octas), most cloudy (6-7 octas), overcast (8/8). It is also important to give information about the character of prevailing clouds. For example high clouds produce a depletion of global solar radiation quite different from that produced by mid or low clouds. It is also important to give an idea of the expected variability of sky coverage in space and time. A probabilistic approach can be also adopted in order to increase the usefulness of this kind of information.

B) Bright Sunshine

Sun shining though clouds will not affect crop performance as in such a case the reduction will be in diffuse radiation from the sun-lit sky and the latter is only a fraction of Total Global Solar Radiation. So in cloud cover forecast the fraction of cloud covering the sun should also be specified in addition to the total cloud cover.

C) Solar Radiation

The main parameters, extraterrestrial radiation, Ra and possible sunlight hours, N required to derive solar radiation, Rs from bright hours of sunshine, n, are readily available on a weekly basis for any location and period (Venkataraman, 2002). The relationship between the ratio of Rs/Ra and n/N t is a straight-line type. The value of the constants, however, varies with seasons and locations but are readily determinable.

D) Precipitation

Snow and rainfall are probably two of the most difficult forecasted variables. Quantitative forecasting of rainfall, especially of heavy downpours, is extremely difficult and realizable only within a couple of occurs of their occurrence and using highly sophisticated Doppler Radars. However, for crop operations quantitative forecast of rain is not half as important as forecast of (i) non-occurrence of rains (dry spells) and (ii) type of rain spell that can be expected.

Forecasts of rain can be defined adopting some standard classes (Table 4) that could be defined in function of the climate and the agricultural context of the selected area. A probabilistic approach (Table 4) is quite important in order to maximise the usefulness of this forecast.

Adopting the scheme of Table 4 it is possible to produce daily information like this:

- Most cloudy or overcast with rainfall (class 3, high probability)

- Partly cloudy with improbable rainfall (class 2, very low probability)

- Sky clear with absence of precipitation.

Table 4 - Rainfall classes for a period of 24 hours. The classes presented are referred to a European area (Po plain, North Italy) and can be quite different for other areas.

Quantity: class 1: <1 mm (absent); class 2: 1-10 mm (low); class 3: 10-50 mm (abundant); class 4: >50 mm (extreme)
Probability per the defined class of quantity: <1%=very low; 1-30%=low; 30-70%=moderate; >70%=high

Use of the same terms for likelihood of occurrence of rainfall and rainfall amounts as at Table 4 above will confuse the public. It is better to use different terms for the two purposes. Thus, for forecasts on chances of occurrence of rain plain language such as Nil, Very Low, Low, High and Very High chance should be used. If quantity can also be forecast, plain language terms such as scanty = < 1mm; moderate = 1-10mm; Heavy = 10-50mm and Very Heavy = > 50mm should be used. The probability of occurrence of a given quantity of rainfall will vary with places and periods. So if probability is to be indicated for quantum of rain it should be based on climatological values of assured amounts of rainfall at various probability percentages in the area(s) and the period to which the forecast refers.

Fog can contribute significantly to crop water needs and can be measured by covering the funnel of a raingauge with a set of fine wires. Quantitative data on fog precipitation may not be available. However, nomograms for predicting occurrence of fog at airports are available with forecasters and the same can be adopted for use in agricultural weather forecasts.

Dew is an important parameter influencing leaf-wetness duration and hence in facilitating entrance of disease spores into crop tissues, Dew is beneficial in contributing to water needs of crops in winter and in helping survival crops during periods of soil moisture stress, as the quantum of Dew collected per unit area of crop surface is many times more than that recorded with Dew Gauges. Dew is also desirable for using pesticides and fungicides in form of dust. The meteorological conditions required for dew formation are the same as those for fog formation except for the need for absence of air-turbulence in the air layers close to the ground and crop-canopy temperature being lower than the screen temperatures. Thus, nomograms used by forecasters for predicting fog can be used to predict dew in absence of low-level air turbulence and by factoring into the temperature criteria the expected depression of crop-minimum temperatures below the screen minimum.

E) Temperature

Forecast of air temperature is important for many agrometeorological applications. Forecasts of temperature of soil, water, crop canopies or specific plant organs are also important in some specific cases. Crop species exhibit the phenomenon of Thermoperiodicity, which is the differential response of crop species to daytime, nocturnal and mean air temperatures (examples: Solanaceae to Night temperatures; Papillionaceae to Daytime temperatures and Graminaceae to mean air temperatures). It is possible to derive mean day and night time temperatures from data of maximum and minimum temperatures.

Forecasts of temperature are generally expressed as range of expected values (e.g.: 32-36°C for maximum and 22-24°C for minimum). If forecast is referred to mountainous territories, temperature ranges could be defined for different altitudinal belts, taking into account also the effects of aspect. A particular attention could be reserved to temperature forecasts in particular moments of agricultural cycle, taking into account the values of cardinal and critical temperatures for reference crops.

Other thermal variables with a specific physiological meaning (e.g.: accumulation of thermal units or chill units) can be the subject of specific forecasts. However, the base temperature above which the accumulations will apply varies with crop types (Examples: Wheat, Maize and Rice: 4.5, 10 and 8 degrees centigrade respectively). Therefore, for forecasting dates of attainments of specific phenological stages of crops, time-series data showing actually realized heat or chill accumulations up to the time of issue of forecasts by various crops have to be maintained. A probabilistic approach can then be adopted to forecast the probable dates of specific crops reaching particular phenological stages.

F) Humidity

For the day as a whole Dew Point temperature is a conservative parameters and is easier to forecast as changes in Dew Point temperatures are associated with onset of fresh weather systems. From maximum, minimum and dew point temperatures, minimum, maximum and average humidities can be arrived at. The user-interests understand the implications of the term Relative Humidity much better than other measures of moisture content of air like vapour pressure and precipitable water. So ultimate forecast has to be in terms of Relative Humidity. Forecast of relative humidity can be important in some specific cases. Probability of critical values (very high or very low) could be also important.

G) Wind speed and direction

Forecast of wind speed is important for many different agricultural activities. Wind direction could be defined too. It is important to give an idea of the expected variability in speed and direction of wind. The monthly Wind Roses at a station is a climatological presentation which indicates the frequency of occurrence of wind from each of the 8 accepted points of the compass and frequencies of occurrence of defined wind speed ranges in each of the 8 directions. Wherever possible the wind roses must be looked into before issue of forecasts.

For agricultural purposes wind speed and direction are required at 2 meters height. But, weather forecasts of wind refer to heights greater than 2 meters. Change in wind direction between 2 meters and the forecast height will not occur. However, wind speed at 2 meters will be considerably lower than at the forecast height. Ready reckon tables to convert wind speeds at any height to that at 2 maters are available and may be used to forecast wind at 2 meters height.

The term Kilometres Per Hour, KmpH, is much better understood by user interests than the terms Beaufort Scale, Meters per Second, MpS or Knots. So wind speeds must be forecast for 2 meter height in KmpH.

H) Leaf Wetness

Leaf wetness is produced by rainfall or dew, or fog. Duration of this phenomenon can be important in order to plan different activities like distribution of pesticides, harvest of crops and so on. Leaf wetness is a parameter that is scarcely recorded. A number of empirical methods cited by Matra et al. (2005) have been used to derive leaf-wetness durations from meteorological parameters. It is possible to derive the hourly march of temperatures from maximum and minimum temperatures (Venkataraman, 2002) The temperatures during night hours have to be decreased by a value equal to the depression of the radiation minimum below the screen minimum. As mentioned earlier, dew point temperature is a conservative parameter. Thus, the number of hours when dew point temperature is above the adjusted air temperature will give leaf wetness duration. Now the time taken for the moisture deposited on the crop leaves to evaporate has also to be included in the leaf wetness duration. The amount of moisture deposited on the crop may be many times more than indicated by instruments. So the estimated moisture deposition has to be multiplied by a crop factor and the product divided by the evaporative power of the morning air. As a thumb rule two hours after sunrise may be added to the estimated duration of leaf wetness. .

I) Evapotranspiration

Forecast of evapotranspiration can be important in order to improve the knowledge of water status of crops. This kind of forecast is founded on correct forecast of solar radiation, temperature, relative humidity and wind speed. For real-time use forecasts of evapotranspiration has to be founded on forecast of Pan Evaporation as detailed below.

The Evaporative Power of Air, EPA determines the peak water needs of vegetative crops and is the datum to which all measurements of evapotranspiration, ET should relate. FAO (Allen et al., 1998) has advocated the use of Reference Evapotranspiration ETo as a standard measure of EPA. Computation of ETo requires data of net radiation over a green crop canopy, low level wind and saturation deficit of air. An empirical method to compute ETo from routinely available meteorological data has been proposed. ETo refers to turf grass. Agricultural crops have peak water needs greater than that of turf grass and tall crops can have higher peak water needs than short ones. Data to compute ETo on an operational basis are neither available widely nor readily.

Evaporation from pans filled with water, EP is subject to weather-action in a manner similar to that of EPA. EP is also easily measured. Methodology to compute ETo usung measured values of solar and atmospheric radiation and use of the same to derive ratios of ETo to EP at a number of stations covering typical climate regimes have been detailed by Venkataraman et al. (1984), Use of pan coefficients to derive ETo under varied surroundings and typical setting of the pans have been suggested (Allen et al., 1998). Data on EP and studies relating ET of crops to EP are available. The ratio of peak ET to EP, called Relative Evapotranspiration, RET can vary in space and time but is not difficult of determination.

J) Water Balance

A quantitative forecast of (i) the probability of water excess or stress for rainfed crops and (ii) the timing and amount of irrigation for irrigated crops are very highly useful. This kind of forecast for rainfed crops is founded on correct forecast of precipitation and evapotranspiration. The water balance approach to arrive at soil moisture excess or deficiency would require daily forecasts of rain in the first month of crop growth and on a short-period basis thereafter. Influence of physiological control on crop water uptake during maturity (Hattendorf et al., 1988; Venkataraman, 1995) is also important. Since irrigation water is applied ahead of crop-water consumption for forecasts of irrigation scheduling forecasts of evapotranspiration and likely rainfall amounts on a short-period basis will do.

K) Extreme Events

The low level of predictability of extreme events acting at meso or micro scale (frost, thunderstorms, hail, tornadoes, etc.) is an important limitation to the usefulness of forecasts for agriculture. In Table 5, obtained from a subjective evaluation founded on state of art forecast technologies, is represented the level of predictability of some extreme events with strong effects on agriculture.

In order to give correct information to farmers, the adoption of a probabilistic approach could be important.

Table 5 – predictability of some extreme events relevant for agriculture; data are estimated for European area.

Extreme event	**Predictability**			
	NC	**VSRF**	**SRF**	**MRF**
Frost	**High**	**High**	**Low**	**Low**
Thunderstorms	**High**	**Moderate**	**Low**	**Low**
Showers	**High**	**Moderate**	**Low**	**Low**
Hail	**Low**	**Very low**	**Un**	**Un**
Tornadoes	**very low**	**Un**	**Un**	**Un**
Wind gales	**High**	**High**	**Moderate**	**Low**

Very low: <1%; low: 1-30%; moderate: 30-70%; high: >70%; un = unpredictable (forecast can't be produced with present technologies).

4.4. Special agricultural weather forecasts

Special agricultural weather forecasts provide the necessary meteorological information to aid farmers in making certain special "crop and/or cost saving" decisions on farm operations. For the same temporal distribution of weather parameters, different crops will react differently. Again, the effects of weather or weather-induced stresses and incidence of pests and diseases are critically dependant on the state and stage of crops during which they occur. The effects of anomalies of a weather element on a given crop are location-specific. Again, the crop fetches may range from large areas of mono-crops to small, dispersed areas of variegated crops Thus the requirement for these special forecasts will vary between and within the seasons, from place to place, from crop to crop and with the kind of operation i.e., cultivation, post harvest processing etc.

Special forecasts are normally issued once every day for a specific operation and generally cover the next 12-24 hours, with a further out look if necessary. These special weather forecasts must be written by a trained agricultural meteorologist in consultation with farm management specialists for the current problems. They are normally issued for planting, irrigation, applying agricultural chemicals, cultivation, harvest and post harvest processing, as well as for serving other weather related agricultural problems associated with the crop, its stage and location. Temperature bulletins for protection against freezing are also issued as special forecasts in areas where crops may suffer damage from freezing.

4.4.1 Field preparation

Field preparation for rainfed crops is weather dependent. In any dry land areas the amount of rainfall is very meagre and farmers should take advantage of even minimum showers. Otherwise the moisture is lost. Minimal tillage is the current agronomic mantra for conserving moisture, retaining nutrients and keeping weeds out. Optimum soil moisture profile characterised by top dry soil, sub-surface moist soil and wet soil in the seeding zone is required to carry out field preparation for dry land farming. The prediction of the exact time of occurrence of rainfall in a particular location helps to initiate field preparation. Example: "Pre monsoon showers are expected in 37th standard week of this year and farmers are requested to initiate field preparation activities before this week".

4.4.2 Sowing/planting

Seed germination is dependent upon proper light and moisture besides, soil temperature. Even with no nutritional or soil moisture constraints rot foraging capacities vary amongst crops in the same soil and of the same crop in different soils. Alternating temperatures assist the germination of many species of seeds and do not unfavorably affect the germination of those that do well under constant temperatures. The amplitude, which is the difference between maximum and minimum temperatures decrease with depth and become negligible at depth of 30 cm. Hence soil temperatures at 30 cm can be taken as constant. The temperature range at which soil temperatures will equal that of air will principally depend on texture and structure of soil. Under a ground shading crop the depth of no diurnal change is pushed up compared to that over a bare soil. For germination and crop establishment the soil temperature regime at depth of 7.5 to 10.0 cm is of importance. At these depths the maximum and minimum soil temperatures tend to follow that of the screen temperatures.

Thus the diurnal variations in soil temperatures in the seed zone are beneficial and not harmful. However, some species of seeds are light sensitive and for them the depth of sowing and adequacy of soil moisture at the desired depth are critical. In dryland agriculture gap filling to correct for poor germination is often not possible. Excess germination can be corrected by thinning and the dryland farmer would prefer very good germination followed if necessary by thinning. The farmer must, therefore, know the existing soil temperature and what the changes in soil temperature and moisture will be. Of the above two parameters soil moisture is more important. The rooting pattern also varies from crop to crop. Further, for many crop seeds, light is necessary to initiate germination. Knowledge of the likely values of the above two parameters will help farmers avoid sowing under soil conditions which would lead to a poor initial crop stand, correction of which is many times not possible and if possible may hinder germination and emergence and which consequently would require the resowing of the expensive seeds.

When direct planting is resorted to, the prevailing weather conditions dominate the crop stand and establishment. Agronomic measures to modify soil temperatures and conserve seed zone moisture to ensure proper germination in marginally adverse weather conditions are possible. From maximum and minimum values of surface soil temperature or air temperature it is possible to arrive at temperature amplitudes for given depth of soil in a given type of soil. Thus, parameters that are of interest, namely temperature below and above soil surface, atmospheric humidity and soil moisture need to be forecasted.

Soil temperature forecasts are normally issued once daily prior to and during the normal planting season. They should give the present observed conditions throughout the area with a forecast of changes during the succeeding 3 days, since most of the crops need one life irrigation for the emerging plumule/radicle to protrude the soil surface when seeds are sown. An example:

"Bright sunshine during next three days will cause soil temperatures to rise sharply. Soil temperatures at normal seeding depths are expected to reach and maintain levels favorable for cotton and groundnut seed germination by early next week. Further, atmospheric temperature will be very high for the next few days which may affect establishment of seedling to be planted".

4.4.3 Application of agricultural chemicals

Use of agricultural chemicals is inevitable in crop production. However, over-use of agrochemicals like fungicides and pesticides, especially of the systemic types and inorganic nitrogenous fertilizers lead to (i) contamination of food produce and soil (ii) pollution of air, aquifers and water reservoirs and (iii) development of chemo-resistant strains of pests, diseases and weeds. Weather forecasts as detailed in the ensuing sections on control of insects, diseases and weeds can not only help minimize the quantum of application of agrochemicals but also make the applications effective. Agrochemicals constitute a sizeable fraction of the farmer's total cash out lay in any given production system. Minimization of use of agrochemicals will reduce the cost of cultivation to the farmer and help in increasing the acreage of assured protection and nutrition of crops even with available resources.

The critical weather elements governing the judicious application for efficient utilization are atmospheric temperature, precipitation, soil moisture content during the past and succeeding 24 hours and the speed and direction of winds, with emphasis on any changes in speed or direction during the forecast period. Precipitation can dilute or wash off the chemicals. Agricultural chemicals which require special attention to meteorological factors are herbicides, growth regulators, hormones, insecticides, fungicides and nutrients as well as those used for soil fumigation and rodent control. Only an agricultural meteorologist well-versed in current farm operations can be aware of the different chemicals in current use and their varying requirements.

4.4.3.1 Foliar application

Choice of agrochemicals for application to soils has to be carefully done to avoid (i) contamination of soil (ii) leaching to groundwater aquifers and (iii) running off to water reservoirs. If the same effects can be achieved by aerial sprays foliar application is to be preferred. Many times soil conditions preclude application of chemicals to soils. Under those circumstances foliar applications have to be resorted to. Temperatures at the time of application and immediately following are extremely important and can determine effectiveness of foliar application of nutrients and herbicides. For certain herbicides like Glyphosate, the effectiveness is more if the atmospheric temperature is high at the time of application and the succeeding 2 to 4 hours. On the other hand, for foliar application of nutrients atmospheric temperature should be lower for avoiding phytotoxicity coupled with soil moisture availability.

4.4.3.2 Soil application

Precipitation is the most important factor that decides efficiency of the chemical applied through soil. Precipitation in the succeeding 24 hours is the critical limit. Limiting the amount of treatment through the effective use of weather information also leads to minimum pollution of ground water and run off.

Examples of forecasts for application of agricultural chemicals are:

"Wind speeds are expected to be mostly favorable for application of agricultural chemicals today and tomorrow. Wind direction will be variable and wind speed will range from 6 to 13 km h^{-1} in the forenoon and will become southerly with speeds of 13 to 24 km h^{-1} during the late afternoon. Temperatures are likely to exceed 27° C tomorrow. So caution should be exercised in applying oil-based sprays".

or

"Heavy rain is expected in the next 24 hours and so foliar application of chemicals may be postponed".

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4.4.4 Evaporation losses for irrigation

Irrigation water is costly to farmers in most of the agro ecosystems nowadays. Over-use can be both expensive and detrimental to the crop, while under-use can result in loss of crop quantity as well as quality. Estimates of daily consumptive use can be related to the free water loss from a Class A type evaporation pan: the free water loss over the previous day for an area is obtained from the actual values recorded, while the loss for the succeeding 24 hours must be forecast based on the forecasts of rain, wind, relative humidity and bright hours of sunshine. For example due to wetting of its surroundings by rain the evaporation from a pan can be 20 to 30% lower than with dry surroundings. For the derivation of solar radiation from bright hours of sunshine and of potential evapotranspiration from either pan evaporation or from associated wind and vapour pressure deficit terms linear approximations have been derived.. Consumptive use rate can be estimated not only from evaporation pan losses, but also from evaporation and shade temperature measurements, or from formulae deduced from the energy balance equation. With these values a farmer can be informed of the field water loss occurring after the last rain or irrigation and taking into consideration the expected rainfall advised on the timing and quantum of irrigation In this connection it is worth mentioning that Portugal had won the second prize in the INSAM contest on best examples of agrometeorological services (2004/2005) for assistance to farmers to obtain irrigation needs quantitatively.

Examples of water loss forecasts are:

"Free water loss during the past 24 hours average 0.6 cm. Expected free-water loss today is 0.6 cm and tomorrow is 0.8 cm. Rainfall probability will remain low for the remainder of the week and crop will begin to suffer from moisture stress in 4 days' time. Supplementary irrigation of 7 cm in two days' time is recommended".

or

"Rain is likely to occur in the next 24 hours in most of the areas in this region and so farmers may postpone their irrigation for this period".

4.4.5 Weeding

Weeds are one of the most major afflictions for farming and successful farming includes weed management also. Because of climatic influences, the distribution of weed flora across regions and their composition in a region vary greatly. There is no broad-spectrum weedicide effective against all weeds and at same time non-toxic to crop plants. So herbicide prescription is a specialized job. Again, the indication is that over-use of herbicides for a long period of time will lead to chemo-resistance in weeds. So herbicide applications must be minimal but effective. There are two methods of weed management viz., hand/mechanical weeding and chemical weeding. For certain herbicides prevailing weather decides the effectiveness of the application such as in the case of non-selective herbicides. Rain immediately after chemical weeding will render the operation infructuous and amount to wastage of money. Rains will help in the germination of dormant weed seeds or help in better growth expression of weeds. Thus clear weather following rain will assist hand/mechanical weeding.

Examples of weeding forecasts are:

"Rain is likely to occur in the next 24 hours in most of the areas in this region and so farmers may postpone application of chemical herbicides and hand/mechanical weeding operations".

or

“Following rain spell of last 3 days, weather will remain dry for the rest of the week. Hand/mechanical weeding and chemical weeding in 2 to 3 days time is recommended

4.4.6 Crop harvest and post harvest operations (including crop curing/drying of meat and fish)

Harvest of the agricultural produce and immediate processing of the same before storage assume utmost significance than any other field operations as a few days of fickle weather at the end of the crop season can be ruinous. The forecast for such activities should be of high order to ensure that (i) whatever yield is possible to be saved on the field is saved and (ii) what is gained on the field is not lost off it. While the general agricultural weather forecast should supply the meteorological information necessary for harvest operations, post harvest operations such as curing and storage require special forecasts of certain elements. The primary weather factors for crop harvest are rainfall and atmospheric temperature, while for post harvest operations besides the above, sunshine, wind, relative humidity and dew are also important. Precipitation may increase the moisture content in the straw of rice crop, which may delay harvest operation. Besides, low temperature may also delay the same. Precipitation may leach the quality of forages. Simple post-harvesting operations include simple drying, example in case of medicinal plants. . Light winds assist in the winnowing operations that separate grain from chaff. In absence of wind, blowers have to be used. Low temperature in the atmosphere may delay drying and subsequent conversion of certain valuable medicinal compounds in to less preferred products. In crops like tobacco, this may involve complex processes involving enzyme reactions that are influenced by humidity and temperature. It is worthwhile here to mention that to ensure high quality end product either from crop or meat and fish, accurate weather forecast of curing and action based on the same are highly essential.

An example of rice harvest forecast:

“Rain is expected in the ensuing week. Accordingly harvest may be done earlier.”

An example of tobacco curing forecast:

"Good tobacco curing weather prevailed during the past 24 hours. Highly drying weather today and tomorrow will tend to cause excessively rapid drying of tobacco. Shed should be partly closed to slow the drying".

An example of meat drying forecast:

"Maximum temperature is expected to be around 30^0 C in the next 3 days. Farmers should take advantage of this period for meat and fish drying."

4.4.7 Control of plant diseases

Most plant diseases set in under conditions of wet vegetation and develop and spread when the wet weather clears. The rate of development of a disease depends on temperature. The cardinal and optimal temperatures for development vary with the disease organisms. Therefore, effective and economic control of most diseases primarily requires a vegetative wetting forecast. This forecast will include the number of hours during which vegetation was wet from rain, fog or dew during the preceding 24 hours, the temperatures during this period and a prediction of the hours of wetting and of the temperature and sky conditions during the succeeding 24 hours. With this information the farmer can be advised to obtain maximum control with a minimum number of chemical applications.

The computer has enabled pathologists and physiologists to develop biological models relating the development of disease pathogens on plants. By introducing meteorological data, either daily or hourly, into these models, conditions favourable to disease development and the potential severity of outbreak can be estimated for many diseases such as leaf blight and stalk-rot of corn.

An example of root diseases forecast:

"Excess moisture prevailing in the root zone of vegetable crops, in the past 7 days, may develop root diseases like root rot etc. Farmers are advised to go for soil drenching with suitable fungicides to avoid heavy crop loss".

4.4.8 Control of noxious insects

Within broad limits weather is one of the principal factors controlling insect occurrence and governing their general distribution and numbers. Weather factors, acting in combination, can either foster or suppress insect life, e.g. temperature and humidity control the time interval between successive generations of insects as well as the number produced in each generation. Feeding habits are also controlled by weather and climate. Large-scale, low-level wind patterns are an important factor in the migration of insect pests. As regards insecticides used to control pests, weather controls not only the insect's susceptibility but also the effectiveness of the pesticides.

Insect and plant biological computer modelling, using meteorological and insect light-trap data as input, is helping to determine the time and severity of economically damaging outbreaks of the corn borer and alfalfa weevil. Biometeorological models have been developed for the emergence of adult mosquitoes and the periodicities of their flight activities leading to displacement from breeding sources to infest urban and agricultural areas. They demonstrate the importance and practical use of weather and climatological data to determine strategy, tactics, and logistics in programmes to monitor and control pests and their vectors. The seasonal abundance and date of emergence of mosquitoes following first flooding of eggs are predicted from cumulative variation from normal of air temperature and solar radiation. Flight activity and dispersal of flies from breeding sites to infest agricultural and urban areas are predicted from 24-hour projections of temperature, humidity and wind conditions that provide optimum hygrothermal environments for energy metabolism. The projections for optimum flight periods from daily synoptic weather forecasts facilitate the detection of invasions of pests' and disease vectors and also the timing of pesticide applications to intercept and eliminate pest infestations during displacement from breeding areas.

Example of mosquito control forecast:

"The incessant rains and floods may act as brooding grounds for mosquitoes. The municipal authorities are advised to spray suitable chemicals in the water bodies to avoid mosquito borne diseases. Besides, farmers are advised to drain water from the stagnating places".

Example of rice hoppers forecast:

“The low temperature prevailing since past 15 days and incessant rains may encourage the attack and development of Rice hoppers. Farmers are advised to take suitable prophylactic spray measures”.

4.4.9 Transportation of agricultural products

Most agricultural products must be transported fairly long distance from the place of production to the market place. During transportation the temperatures of the produce of many crops must be held within very narrow limits to prevent deterioration and spoilage. Therefore, the heating and cooling of containers transporting them may be required. An accurate forecast of the maximum and minimum temperatures along the normal transport route is needed to plan the type of transport equipment and its utilization. Temperatures may be given for section for which they are not normally supplied, such as high, cold mountain passes, or hot, dry desert areas. A short weather synopsis for the period would also be valuable.

Transportation and commodity-handling agencies have expressed the need for climatological and meteorological information to improve decision-making in their logistics. For example, a series of snowstorms during the period of 28 January – 4 February 1977 in southern Ontario severely disrupted the provincial milk-collection system. The effects of these storms were manifold; not only was the schedule of the milk collection trucks disrupted, with serious losses resulting to the milk producers, but the trucking equipment sustained serious damage and life of one driver was lost during a blinding snowstorm in a railway-crossing accident. The system handling a perishable commodity like milk must depend on intricate scheduling geared to the farmers’ storage capacity, in this case 2.5 days of milk production. Therefore, the collection trucks have to come every second day. In the case of Ontario, delays of three to four days resulted and the farmers (who often obtain 450 kg per milking), having no room to store the milk, were forced to pour it away, causing a considerable loss. The transportation system incurred a set-back in the form of equipment loss and damage, overtime pay for extra hours worked and even injury and death of one driver.

Example of transport of onions forecast:

“The low temperature prevailing in the past 7 days may lead to deterioration in the quality of harvested onion for transport through germination. Farmers are advised to make pucca package arrangement to counteract the low temperature.”

4.4.10 Operation of agricultural aviation

Aircraft are used for a wide variety of operation in agriculture and forestry. Because they operate at low altitudes, much below those of regular transport aircraft, they require specific details not available in routine aviation forecasts, which usually include ceiling, visibilities and turbulence. For example, to achieve successful results, low-level (surface to 30 m) wind drift and stability factors are needed while the strength of the surface inversion is extremely important if ultra-volume sprays (where particles size may be as small as 10 μ m) are to be used. Vertical motions of more than 0.5 cm s-1 will cause such spray droplets to rise and disperse throughout the atmosphere rather than settle on the crop.

Example of dusting and sprinkler irrigation forecast:

“Heavy winds are expected at a speed of 60 km/ hr today. Farmers are advised to avoid dusting operations as well as operation of sprinkler irrigation system”

4.4.11 Prevention of damage due to chilling, frost and freezing

Minimum temperature forecast is an integral part of hilly and subtropical/ humid region farming. These regions need a special minimum forecast system particularly during the cropping season. This critical information will aid the farmers in allocating their resources like labour and other agricultural inputs in a judicious manner to avoid crop losses. The forecast should include the minimum temperature expected in the next 24 hours. This may be station specific or for a particular region as a whole. As long a lead-time as possible is extremely important for some crops like Citrus, Apple etc.

Example of frost damage forecast:

"Ground frosting is expected in the ensuing three days in certain parts of the northern localities and may damage the grain crops. Suitable precautionary measures must be taken to avoid crop damage"

Special minimum temperature bulletin:

"A strong cold front moved through the agricultural districts late yesterday and very cold and dry air now covers the entire area. Temperatures are expected to drop sharply tonight from near 10^0C at sunset to below 0^0C by 0100. By sunrise minimum temperatures are expected to range from -7 to -4^0C in the coldest low-lying areas and from -4 to 2^0C in the higher locations. Minimum temperatures forecast for key stations tonight are as follows:

Key station A: -4^0C
B: -6^0C
C: -7^0C
D: -4^0C
E: -3^0C
F: -4^0C
G: -5^0C

Growers should relate their locations to the nearest key stations. Outlook for tomorrow night: continuing very cold with minimum temperatures generally -5 to -2^0C.

4.4.12 Forestry operations

From the selection of sites for afforestation to the planning of harvest of the forest products, weather forecast plays a significant role for the foresters. In many afforestation programmes seeds of forest trees are sown from an aircraft. Under these circumstances the precipitation plays a significant role in the germination and growth the plant stands. When saplings of trees are planted precipitation plays a key role in their establishment. Other than precipitation, the prevailing micro-climate too decides the stand establishment. .A forester can easily manipulate the micro-climate through artificial mulching and other methods

Fire is one of the greatest problems of forest management. The moisture content of inflammable parts of forest trees derived from measurements of physical atmospheric parameters is used to determine when fire danger alerts should be issued in some countries. Direct relationships exist between weather and potential fire danger and fire behaviour. Day-to-day reports and forecasts of temperature, relative humidity, wind, precipitation, thunderstorms and critical moisture content of inflammable parts are needed. Fire danger forecasts determine whether logging operations should continue and whether parks and forests should remain open for recreational purposes. The special forecasts should alert the forestry personnel to the danger of fires starting (caused either by humans or by lightning) and the potential rate of spreading, once started. Fire advisories are continuously issued on site to assist in controlling and stopping the fire.

4.4.13 Fishery operation

Weather and climate affect fisheries more than any other category of food production. Weather affects safety and comfort of fishermen as most of the fishing occurs when fish is sufficiently aggregated. Cyclonic storms affect the safety of the fishing vessel, especially when the wavelength approaches the ship's length. Short term weather forecasts can be very crucial for planning fishery operations. Information on the intensity and tracks of cyclonic storm are immensely useful for the safety of the fisherman operating in the oceans. Fog is another weather element affecting fishing and safety. Weather also affects fish behaviour, aggregation, dispersal and migrations, Wind, currents, light and temperature as also lunar periodicity affect the behaviour of fish as well as other aquatic life (Cushing, 1982).

The growth of individual fish is closely allied to the temperature of the water. Temperature not only influences the distribution and movements of fish, but also subtly affects many important biological processes, such as the number of eggs laid, incubation time, survival of the young, growth rate, feeding rate, time it takes to reach maturity and a host of other physiological processes. Other climatic factors, such as the degree of insolation, are influenced by cloud cover, while climate-dependent environmental variables, such as changes in water quality and quantity, are associated with rainfall (Boyd and Tucker, 1998). These factors can act as physiological stimuli, particularly for the timing of the onset of reproduction (Lajus, 2005). For marine fisheries, slight changes in environmental variables such as temperature, salinity, wind speed and direction, ocean currents, strength of upwelling, and predators can sharply alter the abundance of fish population (Glantz and Feingold, 1992).

Productive aquaculture sites need good water flow to remove solid and dissolved wastes and maintain high oxygen levels in the cages. Any increase in the frequency or severity of storms as a result of climate change could be devastating for aquaculture operations (see also Chapter 13 of this Guide).

Most riverine fish populations depend on the floodplains associated with the river for feeding and breeding during the wet season. The catch of fish in the flood zones has been directly correlated with the intensity of the floods in previous years, higher floods in one year giving better catches a year or two later. The response of fish to flood conditions is not only dependent on the quantity of the flood, but also on the form of the flood curve and its time.

Although some of its effects may be beneficial, El-Nino may have strong detrimental effects on the fisheries and marine ecosystem. Increased frequency of El-Nino events which are likely in the warmer atmosphere, could lead to measurable declines in plankton biomass and fish larvae abundance in coastal waters of south and Southeast Asia. The area off western South America is one of the major upwelling regions of the world, producing 12 to 20% of the world's total fish landings (IPCC, 2001). In such upwelling regions, nutrient rich deep waters are brought to the illuminated surface layers (i.e. upwelled) where they are available to support photosynthesis, and thus large fish population (e.g. Kapetsky, 2000).

With the advent of remote sensing methods, fisheries can be studied using satellite and aircraft data. One of the important parameters that can be measured with sufficient accuracy is the Sea Surface Temperature (SST), which has been related to the concentration of fish population. Anomalies in the water temperatures of major oceanic currents have resulted in low commercial fish catch in recent years e.g., declines in sardine catch in the Sea of Japan associated with changing patterns of the Kuroshio current in ENSO years (Yoshino, 1998). Here, it has been shown how sea surface temperature can be mapped on a regular basis, and pass it on to the fishermen who could concentrate on high potential areas and improve the catch.

SST derived from NOAA-AVHRR satellite serve as a very useful indicator of prevailing and changing environmental conditions and is one of the important parameters which decides suitable environmental conditions for fish aggregation. SST images obtained from satellite imagery over three or four days are combined and the minimum and maximum temperatures are noted down.

These values are processed to obtain maximum contrast of the thermal information. These are filmed to prepare relative thermal gradient images. From these images, features such as thermal boundaries, relative temperature gradients to a level of 1 degree centigrade, level contour zones, eddies and upwelling zones are identified. These features are transferred using optical instruments to corresponding sectors of the coastal maps prepared with the help of Naval Hydrograph charts. Later, the location of the Potential Fishing Zone (PFZ) with reference to a particular fishing centre is drawn by identifying the nearest point of the thermal feature to that fishing centre. The information extracted consists of distance in kilometres, depth (for position fixing) in metres and bearing in degrees with reference to the North for a particular fishing centre. The PFZ maps thus prepared are sent to the fishermen for their use through facsimile transmission (FAX) or other mode (Das, 2004).

4.4.14 Safeguarding animal husbandry

It is well documented that the stress of adverse environments lowers productive and reproductive efficiency in farm animals. Hot or cold weather can adversely affect the performance of livestock, by exceeding their coping capabilities. The impact of hot environments can be severe, particularly for high producing animals. Specific responses of an individual animal are influenced by many factors, both internal and external. Growth, milk, eggs, wool, reproduction, feed conversion, energetics, and mortality have traditionally served as integrative performance measures of response to environmental factors.

Temperature-dependant performance response functions have been developed for growing beef cattle, swine, broilers, and turkeys, for conception rate and milk production of dairy cows, and for egg production of hens (Hahn, 1994).

4.4.14.1 Housing and production

Behavioral responses to environment may suggest alterations of management for animals subjected to specific conditions and may be useful in controlling the thermal environment. Other mitigating factors include physical characteristics of the surroundings (e.g., flooring materials) and behaviors permitted by the production system (e.g., animals huddling in clod conditions or moving to another microclimate such as that provided by hovers).

Bruce (1981) estimated that the lower critical temperature for grouped nursery pigs on a solid concrete floor is 2^{0}C higher than on a perforated metal floor and 5^{0}C higher than on a straw-bedded floor. His evaluation also estimated that lower critical temperature for pigs penned singly is about 6^{0}C higher that for grouped pigs, the difference being the huddling effect. A lower practical temperature limit of 3^{0}C is suggested by CIGR (1984) for housed livestock to avoid freezing of waterlines and other management problems. Table 6 depicts the air temperature recommended for housing various livestock from various climate zones of the world to avoid adverse weather periods.

Table 6: Recommended air temperature for housing various livestock

Species/classification	**Weight (kg)**	**Ideal Temperature, (^{0}C)**
Poultry:		
Hens	**-**	**18 to 24**
Broilers, young	**-**	**27 to 28**
Broilers, finishing	**-**	**20 to 22**
Turkeys, young	**-**	**29**
Turkeys, finishing	**-**	**16 to 19**
Swine, restricted-fed (2xM)	**5**	**24 to 32**
	20	**21 to 31**
	40	**18 to 30**
	80	**14 to 28**
	140	**12 to 30**
Veal calf	**-**	**-5 to 20**
Rabbits*		
Fattening	**0.5 to 2.5**	**16 (12 to 30 acceptable)**
Adult	**4 to 5**	**15 (10 to 30 acceptable)**
Doe and litter	**Ave.**	**18 (15 to 30 acceptable)**

***Target relative humidity = 75%**

An instructive example is in South Africa, where du Preez and colleagues (du Preez et al., 1990a; 1990b; 1990c) have been mapping the monthly national Temperature-Humidity Index (THI) values from 563 weather bureau stations covering the whole country as an aid to the optimum provision of livestock management. They found that the heat stress areas expanded from August to January and contracted during the remainder of the year. There is a risk of moderate to advanced heat stress for dairy cattle during the period November to March. Their advice based on THI values is given in Table 7. Given an adequate volume of meteorological data the probabilities for different THI values can be calculated for the various seasons and thus their potential impacts on production can be considered.

Table 7: Proposed practical and economical actions to protect dairy cattle in South Africa & Namibia in relation to THI values over 70 (from du Preez et al., 1990b)

THI values*	LWSI category +	Proposed Precautions
≤ 70.0	**Normal**	**Natural or artificial shade.**
70.0 – 71.9	**Alert**	**Shade and/or well ventilated barns, ad libitum water at shaded troughs.**
72.0 – 77.9	**Critical**	**Former, plus overhead sprinklers and large fans in holding areas adjacent to the milking parlour; alter diet; consider heat resistant breeds; limit stressful handling of stock to cooler hours of day or night.**
78.0 – 81.9	**Danger**	**Former, plus shade over feed bunks and sprinklers with fans at feed bunks.**
≥ 82.0	**Emergency**	**Occurs only on individual days. All former precautions applicable.**

*** THI or Temperature-Humidity Index. Various formation are available (WHO, 1989). du Preez used T dry bulb + (0.36 × T dew-point) + 41.2 with all temperatures in ^{0}C**

+ LWSI or Livestock Weather safety Index

If the soil moisture deficit is being regularly monitored, it is possible to estimate pasture growth. Thus using climatological and synoptic forecasts of probable conditions, and weighted by dairy cow distribution, it is possible to predict milk production. The New Zealand Meteorological Service provides such a prediction to the NZ dairy Board (Starr, 1988). For many years L. P. Smith provided a nine-month forecast of winter milk production in the United Kingdom (Smith, 1968).

4.4.14.2 Assessment of pasture productivity and grazing

The assessment of seasonal pattern of grass growth rates given in their model by Brereton et al. (1987) was used to calculate the number of days when the growth rate exceeded a value of 40 kg dry matter $ha^{-1}day^{-1}$. This was used as a gross measure of the regional differences in the length of the grazing season. The model data were also used to estimate the date in spring when yield was sufficient for grazing to begin (1500 kg dry matter ha^{-1}). The analysis indicates that the variation in grass growth regionally and yearly is sufficiently great to have a significant impact on the technical and the economic performance of farms.

Brereton et al. (1996) studied the pattern of seasonal production of pasture for selected locations in mid-latitude Europe and found that the pattern is predictable in broad terms as a function of the changing weather from season to season within each year and grazing systems are assembled accordingly. The basic objective of systems is to achieve high utilization efficiency by maintaining a balance between herbage availability and herbage demand. The balance is usually achieved by adjusting the size of the grazing area progressively during the year in line with the progressive changes in herbage growth rate. The scheme of adjustment of the proportion of land allocated to grazing or silage is based on a notional "normal" pattern of weather during the year. But even in "normal" years, when total herbage production is near the expected average, the supply of herbage can alternate between surplus and deficit several times during the year.

The efficiency of a grass-based livestock production system depends on the maintenance of a critical balance between herbage demand and supply throughout the grazing season. If the supply is allowed to exceed demand, herbage is under-utilized, herbage quality deteriorates and subsequent animal performance suffers. Where herbage supply falls short of demand, animal performance is reduced and overgrazing can result in thinning of the sward and reduction in herbage growth rate. There is variety of options available to the grassland farmer to make the adjustments to the system that are necessary to maintain an optimum sward-animal balance as the supply of herbage varies. For example, where herbage is surplus to requirements part of the grazing systems can be withdrawn temporarily and the herbage saved as silage. In paddock-grazing systems, in some circumstances, the grazing cycle can be extended, effectively storing grass in the field as a standing crop. In periods of herbage deficit an obvious option is to feed saved silage. The cycle can be shortened within limits temporarily.

4.4.14.3 Forecasting diseases

A variety of livestock parasites, such as Ostertagiasis, Fascioliasis, and various tick and mosquito species, can now be reliably forecast using meteorological data. This was reviewed in (WMO, 1978) and updated in (WMO, 1989); the latter also reviewed metabolic and infectious diseases. See also Starr (1988).

Tactical meteorological information is of obvious value in protecting livestock against the immediate dangers of (extreme) weather. It is also of value in disease control. For example, the incidence of Swayback, a congenital Hypocuprosis of sheep, can be forecast using the number of supplemental feeding and the probability of frozen ground. Timely forecasts of the need for feeding supplemental copper to pregnant ewes affect the incidence of the disease in newborn lambs if shepherds use the information. Similarly, after a period of cold spring weather there is a sudden rise in temperature triggering the growth of young grass and a reduction in the absorption of magnesium and the consequent excess potassium acting as a magnesium antagonist. Clinical attacks of ovine hypomagnesaemia usually occur some five warm days after the temperature change (Smith, 1975; Hugh-Jones, 1994).

In order to benefit the livestock owners, epidemiologists have traditionally depended upon intervention programmes, preventive and control actions to confront an ongoing disease outbreak. In order to do this a new concept of disease forecasting has emerged that seeks to forewarn and forecast the devastating disease problems to take appropriate preventive measures so that the production system is not affected. Forecasting of animal diseases is a powerful tool of epidemiology that depends on reliable past information/data on the vital parameters associated with the occurrence of diseases. Climatic conditions in an area are major parameters that facilitate induction of diseases in epidemic forms. A few examples of disease forecasting are described here (Burman et al. 2002).

(i) Forecasting system for Fascioliasis: this system was based on appraisal of rainfall recorded on each day. A day in which 1 mm or more rainfall was recorded was counted as wet day and a positive correlation was found between the number of wet days during June and

September and incidence of Fascioliasis. Minimum 1 mm rainfall has been considered for wet days based on the less evaporative demand on a cloudy day. The comparison of actually recorded and forecast rates in several areas in the globe confirmed the relationship between the prevalence and the number of wet days. The initial system did not take into consideration the environmental temperature during various months and hence the predicted and the actually occurred values were found at variance in certain areas. The forecasting system was modified by taking into account the mean weekly temperatures and wet days when compared to the standard. The modified forecasting system gave an accurate forecast of incidence in all the geographic areas. A year having 12 or wet days per month from June to September was taken as standard year for comparison purpose.

(ii) Forecasting of Foot and Mouth Diseases (FMD): the spread of FMD in various areas in UK were predicted on the basis of quantity of virus emission by infected animals, meteorological conditions like humidity, wind velocity, wind direction and rainfall. The actually recorded outbreaks at various places conformed to the predicted values. Similar predictions were also made in the case of Newcastle Disease of poultry in U.K.

(iii) Forecasting for vector borne diseases: mosquitoes, midges, mites, flies etc. are hot weather insects that have fixed thresholds for survival and are prevalent mostly in tropical countries. Anopheline mosquitoes and Falciparum malaria transmission are sustained only where the winter temperature is kept above 16^0C while the variety of mosquitoes that transmit dengue, *Aedes aegypti*, is limited by the 10^0C winter isotherms. Shifts in the geographic limits of equal temperature that accompany global warming may extend the areas that are capable of sustaining the transmission of these diseases.

4.4.15 Protecting Horticulture and Arboculture (non forest trees) plants

The use of past observations can become an essential ingredient to predicting future conditions and modifying the zone forecast for a farm in a form of response farming. The information collected will also allow the grower to place protection equipment in those areas where it will most likely be needed. During a radiation frost, careful records of past occurrences can help make the critical decision of whether or not to begin protection measures. This is especially critical in areas where overhead irrigation is used. Microclimate information gathered before the establishment of a crop can help the grower select site, type, and amount of protection equipment.

According to Wurr (1997) the horticulturist's objective is to supply the product at the right time, of the right quality and with the right uniformity. All of these requirements are affected by the weather, and involve aspects of crop scheduling, crop prediction and crop management. In the area of crop management, more accurate weather prediction would offer opportunities to interactively modify crop scheduling as the season progresses; develop improved prediction systems for crop maturity; predict rates of crop deterioration or loss of marketability; delay transplanting to avoid deleterious field conditions; adjust transplant raising conditions to provide more consistent transplants; develop improved irrigation scheduling; optimize glass house crop environments: e.g. if solar radiation could be predicted, even hours ahead, carbon dioxide levels for tomato production could be optimized; similarly if temperature could be predicted days ahead, the cost of heating could be optimized; develop good predictions of yield; improve prediction of pest activity; improve prediction of disease incidence.

For example, in India the nation’s agricultural planning is primarily dependent on the reasonably accurate prediction of the total amount of rainfall from the beginning of June to the end of September. This kind of prediction comes under the category of long-range forecast (LRFs). On the basis of LRFs, various precautionary measures can be planned and adopted. For example, if an LRF indicates below-normal rainfall, then necessary products could be purchased from the international market well in advance. Also, adequate arrangements could be made for the transport, storage, and distribution of such products. The government authorities can work out various plans and schemes to counter the adverse situation well in advance, and the strategies can be used at various levels, such as states, districts, and villages.

Prediction of rainfall, its intensity and duration well in advance in the month of May for June and July may for example help the guava growers to cultivate ‘Mrig bahar’ to have more quality yield. Prediction of rainfall in the month of August -September for October to February may help grape growers to adjust planning for pruning, mango growers for protection of plants from problems of mango hoppers and powdery mildew. Prediction of untimely rains, windstorm etc. will help banana, mango and grape growers to protect their plants from these hazards well in time. Prediction of occurrence of a cold wave (night temperature below 6 to 7 ^{O}C) will help the banana, papaya and grape growers to protect their crops well in advance so that they can take measures like copious watering, smudging etc. Prediction of a heat wave (above 45 ^{O}C) will help the banana, coconut and areca nut growers to take suitable measures. Prediction of frost well in time may help the growers of vegetables like peas, beans, okra etc. to take suitable measures for protection of their crops.

In the USA, integrated pest management (IPM) in fruit orchards has been facilitated in the Intermountain states through the products of the Sustainable Agriculture Research Education (SARE) project. IPM awareness has been increased in participating states, with many growers using weather data and prediction programs to schedule cultural operations in their orchards. Insect and disease control, pheromone release, irrigation, freeze prevention, maturity indices and fruit damage have benefited from weather database prediction programs (Seeley, 2002).The Table 8 shows some characteristics of frost/freeze protection for horticultural crops (Perry, 1994).

Table 8. Characteristics of frost/freeze protection methods.

	Advantages	**Disadvantages**	**Comments**
Site Selection	**Preventive measure -- choose location with good cold air drainage.**		**Best method of frost protection; visualize air flow and/or monitor minimum temperatures.**
Heaters	**Radiant heat helpful in freeze; installation costs lower than irrigation; allows delay; no risk if rate not adequate.**	**Fuel oil expensive.**	**Free-standing or pipeline; free-standing heaters need no power source.**
Irrigation	**Operational cost lower than heaters; can be used for other cultural purposes such as drought prevention.**	**Installation costs relatively high; risk damage to crop if rate inadequate; ice buildup may cause limbs to break; over-watering can waterlog soils; does not provide protection in wind above 5 mph.**	**Plant part protected by heat of fusion; fixed-rate design delivers more protection than generally necessary; irrigation must continue until melting beings; backup power source essential.**
Wind	**Can cover 10-acre area**	**Not effective in wind above 5 mph**	**Mixes warm air near top of**

machines	**if flat and round; installation cost similar to heaters.**	**or advective freeze.**	**inversion down to crop height; may be used with heaters; may use helicopters.**
Fog	**Blocks outgoing radiant heat and slows cooling.**	**Has potential but is not currently practical.**	**Uses greenhouse effect to trap heat in crop canopy and limit radiative cooling**

4.5 AGRICULTURAL ADVISORIES OR AGROMETEOROLOGICAL SERVICES

"Agricultural advisories" or in the language of this Guide, Agrometeorological Services (see Chapter 1 and for example Stigter, 2007) is an act of advice by internal experts of NMHSs, to crop growers/livestock producers on the basis of possible future weather and climate conditions on "what to do" or "what not to do" for maximizing the advantages and minimizing the losses in production. Weather and climate forecasts have little importance unless they are operationally used. This paragraph will be on weather forecasts. Good examples of climate forecasts as agrometeorological services in combination with other information can for example be found in Abdalla et al. (2002), Harrison (2005) and Meinke and Stone (2005).

For maximum advantage of weather forecasts, agrometeorological advisories are issued in consultation with experts of other concerned disciplines and considering the past, present and predicted weather and its spatial-temporal behaviour. Any appropriate forecast on weather has tremendous benefits in terms of pre-facto management of the negative impacts of vagaries of weather. This is because the cost of pre-facto risk reduction due to weather is much smaller than the post-facto management of the losses (Rathore et al., 2006). These advisories recommend (i) implementation of certain practices or the use of special materials to help effectively prevent or minimize possible weather-related crop damage or loss, e.g. spraying advice based upon past and forecasted weather conditions to combat crop diseases and insects; sowing advice for better germination and plant stand; harvesting advice to obtain optimum crop maturity and quality etc and (ii) initiation of cultural practices which are weather sensitive. A famous example in Africa is that developed in Mali (e.g. Konare, 1988; Stigter, 2006). In the operation of agrometeorological services it has been found that extension-intermediaries between products of NMHSs and farmer oriented organizations and farmers would be extremely helpful in getting agrometeorological services established and applied (see also Chapter 1 and for example Stigter, 2004).

An added advantage of such services is that wherever and whenever operated, it helps in reducing the environmental pollution through the optimal use of agricultural chemicals. Some agrometeorological advisories are being issued by almost all the developed and developing countries on various spatial and temporal scales. In actual practice much is still left to be desired to achieve the expectations of a decade ago (Wieringa, 1996; Stigter, 2004). However, increasing needs, commercialization and competition have improved this situation (e.g. Stigter, 2006). Geographically large countries like USA, China, Russia and India now have national bodies/organizations for issuing advisories on county/state/agroclimatic region basis (see an example from India later in this paragraph), while small countries like Slovenia and the Netherlands, issue advisories on national basis (e.g. Wieringa, 1996).

Some developed countries (USA, Russia and European countries), which have advanced computing and communication systems may consider catering to the small temporal scale for agricultural related advices, and updating of advisories frequently (in hours), while developing countries (like India, see 4.5.4) issue advisories in a span of 3-10 days, which enable the farmers to take ameliorative measures. For the agricultural sector, location-specific weather forecasts in the medium range are, therefore, very important. These services may contain advices on all the farm operations or some specific operations such as: pest management (e.g. DACOM, 2003), irrigation scheduling (e.g. Maia et al., 2005), and livestock management (e.g. Rivero Vega, 2005). An example of an agricultural advisory from India has been given in Annexure-I.

4.5.1 Preparation of Agricultural Advisories (Agrometeorological Services)

The formation of agrometeorological services in forecasting _requires close linking of various data-providers and expertise from different fields. The basic requirement is that the forecasted data must be for the desired period and for the specific location under consideration. The National Centre for Medium Range Weather Forecasting, NCMRWF in India for example provides from a T-80 General Circulation Model location-specific weather forecast for six parameters, viz. rainfall, cloud cover, wind direction and speed, and minimum and maximum temperature twice a week with a resolution of 150 km x 150 km. These forecasts are further subjected to statistical and synoptic interpretation (Rathore et al., 2006).

A panel of experts then discuss the present, past and future_status of weather and crop conditions and recommend the appropriate operations for better farm management based on such forecasts. Priority is given to predominant crops of the region and most prevailing problems keeping in view the relative economic importance. Management practices like what, when and how to sow; when and how much to irrigate; what measures to be adopted for plant and animal protection from stresses caused by pest and disease, temperature, wind, and rainfall etc are suggested. Animal shelter, nutrition and their health are affected by weather to a large extent (see Chapter 12 of this Guide and section 4.4.14) and hence must find a place in the services. On the basis of local agrometeorological and farming information and the weather forecasts, the subject matter specialists discuss the options and consequent effects and then decide the advises for the action by the farmers in respect of the items related to their expertise. All these together constitute the agricultural advisory (Singh et al., 1999).

4.5.2 Panel of experts

Ideally a panel of subject matter specialists from agricultural science and animal science is constituted for the preparation of agrometeorological services. The panel may include agrometeorologist, agronomist, soil scientist, plant pathologist, entomologist, horticulturist, nematologist, sericulturist, and specialists from agriculture extension, animal husbandry and plant breeding. The experts from all fields have to discuss the current crop situation and animal conditions and anticipated weather conditions for preparation of services for the farmers and user-interests of a region.

4.5.3 Information requirements

Weather information: weather information required for services involve weather summary of the recent past, for example the preceding week, climatic normals for the advisory period, and weather forecasts for the advisory period.

Agrometeorological information: this includes some indices related to agricultura*l* production such as Crop Moisture Index, Drought Severity Index for the recent past.

Crop Information: the information on present crop status is very important for the preparation of advisories, which contains type, state, and phenological stage of crops; infestation of pest and diseases and their severity; other crop stresses such as nutrient stress, water stress, thermal stress etc.

Soil information: the preparation of advisories also takes account of the spatial distribution of soils. The information on soil types, physico-chemical properties, nutrient status of soils, moisture status, elevation*,* contour and slope of soils is required for preparation of advisories

Other information: information on topography of the region, land cover and land use, irrigation facilities, irrigated and rainfed areas, availability of agricultural inputs and market trends are also considered for preparation of advisories.

4.5.4 The example of Agro-meteorological Advisory Service (AAS) of NCMRWF: a preliminary impact assessment (Rathore et al., 2006)

The entire exercise of impact assessment of this AAS is being guided and monitored by a national committee of experts constituted for this purpose. The AAS units selected 4 villages_for the study. In general, units selected 40 AAS and 40 non-AAS farmers for survey work. The farmers chosen by random sampling for both categories (AAS & non-AAS) by all units generally are literate (metric) in the middle-aged group having medium to large land holdings. The data reveal that the inputs used quantitatively and significantly vary among and between AAS and non-AAS farmers. Significant differences are observed in human labour, fertilizer and plant protection chemicals used. However, the timeliness of proper agro-advisories given for various farm operations viz. irrigation, application of fertilizer and plant protection chemicals save the crops from possible moisture stress, nutritional stress and pest attack, which contributes to better growth and development of crops, qualitatively and quantitatively. The non-AAS farmers use the same quality of inputs but their timing of applications is different with respect to AAS farmers. This does not control nutritional and water stress and pest attack with the same efficiency, which ultimately leads to differences in crop yields. The season-wise preliminary results are given below in a Table 6. Details may be found in Rathore et al. (2006).

Table 9. Economic Impact of AAS of NCMRWF: Preliminary results

Crop	**Station name**	**% Increase /Decrease in cost of production (per acre)**	**% Increase /Decrease in crop yield (per acre)**	**% Increase /Decrease in Profit (per acre)**
Cotton	**Hisar**	**1**	**14**	**10**
	Coimbatore	**-4**	**16**	**16**
Rice	**Ludhiana**	**-6**	**9**	**18**
	Kalyani	**-3**	**21**	**29**
Wheat	**Ludhiana**	**-6**	**9**	**17**
Mustard	**Hisar**	**-3**	**8**	**13**

In conclusion, AAS farmers received medium range weather forecast based agro-advisories including optimum use of inputs for different farm operations. Due to judicious and timely utilization of inputs, cost of production for the AAS farmers reduced approximately by 3-6%. At the same time yield level of the AAS farmers also increased by 8 to 21%. The increased yield level and reduced cost of production, led to increased net returns of 10 to 29% for AAS farmers. These are preliminary results because inputs differ among and between farmers. Care has been taken to delineate impacts of weather based farm advisories but it is extremely difficult to segregate them from general agronomic advice, which also is part of the bulletin. Hence the results do reflect impacts of those activities also which are not weather based. Nonetheless, all is part of the advisory system.

Annexure 1

Agromet Advisory Services Bulletin
Issued by India Meteorological Department
State : Maharashtra

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A

Past Weather Summary (1.8. 05 to 3. 8. 05)	Weather Forecast
SW monsoon was vigorous over North Madhaya Maharashtra & active over Konkan & Vidarbha. Rain has occurred at most places in South North Madhaya Maharashtra & at many places in Marathwada. Chief amounts of R/F in cm: 1.08.2005:-Mahabaleshwar 31, Bhira 29, Santacruz 21, Gaganbawda 19, Colaba 16, Alibag 13, Ratnagiri & Harnai 10 each, Pune & Nagpur 6 each, Kolhapur & Akola 5 each. 2.08.2005:-Mahabaleshwar 39, Bhira 27, Santacruz & Ratnagiri 15 each, Harnai 10, Colaba 9, Dahanu 7, Pune 6, Patan & Mehekar 5 each. 3.08.2005:-Mahabaleshwar 18, Dahanu 17, Ratnagiri 9, Bhira 7, Pune (Pashan) 2, Aurangabad & Akola 1 each.	Moderate rain is likely to occur at many places in Konkan, Vidarbha & Madhaya Maharashtra & at a few places in Marathwada. Warning:-Heavy rain is likely to occur at isolated places in Thane & Raigad districts & in Vidarbha during next 48 hours. Outlook:- Decrease in rainfall activity.

State and Stage of the crops and the advisories

81 % sowing of Kharif crops was completed on 22nd July. Paddy crop has damaged in the districts of Raigad, Ratnagiri, Thane, Sindhudurga, Kolhapur & Western talukas of Pune & Satara districts due to recent heavy rainfall & also the crops as Soya bean, Groundnut, Jowar are likely to be damaged in the districts of Kolhapur, Sangli, Satara, Nanded & Parbhani districts. As heavy rain spell is decreasing slowly, re transplanting of Paddy in Konkan, South Madhya Maharashtra & Western Pune if nursery is available or sprouting seed sowing may be started after current rain spell. Sunflower or Caster seed may be sown as contingency crop in Madhya Maharashtra, Marathwada & Vidarbha where crop has damaged. Late sowing or re sowing may be started after complete current rain cessation. Vegetable crops are likely to be affected by Aphids & Jassids due to warm high humidity so farmers are advised to apply plant protection measures after current rain spell.

The details of the cropwise information and the necessary advisories are given below

Crop	Stage	State	Agromet/Agricultural Advisories
Sugarcane Presea-sonal (M.Mah., Marathwada, Vid.)	Active vegetative growth	Satisfactory, crop is under flood on the banks of Panchaganaga & Krishna river in South Madhya Maharashtra due to very heavy rain.	Drain out excess water from the field & apply plant protection measures for standing crop after complete rain cessation. On the incidence of white Woolly Aphids, release 2500 larvae of Crysoperla Carnea or 1000 eggs or pupa of Konobathra Aphidivhora per hectare on leaves early in the morning after current spell of rain on a non rainy day.

Kharif Jowar (M.Mah., Marathwada, Vid.)	Early vegetative growth	Moderately satisfactory in Kolhapur, Sangli, Satara, Western Pune, Nanded & Parbhani due to heavy rain & satisfactory in other districts.	Excess water may be drained out from the field.
Bajra (M.Mah., Marathwada, Vid.)	Early vegetative growth	Moderately satisfactory in Kolhapur, Sangli, Satara, Western Pune, Nanded, Hingoli & Parbhani due to heavy rain & satisfactory in other districts.	Drain out excess water from the field & apply plant protection measures for standing crop after complete rain cessation. A dose of 65 kg Urea / ha. may be applied after current spell of rain on a non rainy day.
Rice (Konkan, M.Mah., Vid.)	Seedling / Transplanting / (Early tillering In Konkan & South Madhya Maharashtra)	Crop is in poor state in all the districts of Konkan & in Kolhapur, Sangli & Westerly parts of Pune & Satara. Satisfactory in other districts, mild incidence of Stem borer in Thane & Army worm & Silver shoot in Sindhudurga district.	Postpone the transplanting seedlings in Konkan & Madhya Maharashtra & Vidarbha. For the control of Stem borer use 10 G Phorate 10 kg or 5 G Quinolphos 15 kg/ ha. or spray 850 ml Endosulphon / ha. in 500 liter water after current spell of rain on a non rainy day .
Groundnut (M.Mah., Marathwada, Vid.)	Early vegetative growth	Satisfactory, crop is likely to be damaged in Kolhapur, Sangli, Nanded, Hingoli, Parbhani & Westerly parts of Pune & Satara.	Excess water may be drained out from the field.
Soyabean (M.Mah., Marathwada, Vid.)	Early vegetative growth	Satisfactory, crop is likely to be damaged in Kolhapur, Sangli, Nanded, Parbhani & Satara.Mild incidence of Leaf roller in Nagpur & Kolhapur and Army worm & Semi lopper in Amraoti division.	Drain out excess water from the field & apply plant protection measures for standing crop after complete rain cessation.
Irrigated Cotton (Vidarbha)	Early vegetative growth / Active vegetative growth	Satisfactory, crop is likely to be damaged in Amraoti, Yeotmal	Excess water may be drained out from the field. A dose of 33 kg Nitrogen / ha. May be given by ring method after current spell of rain.
Kharif cotton (M.Mah., Marathwada, Vid.)	Early vegetative growth	Moderately satisfactory, crop is likely to be damaged in Nanded, Parbhani Amraoti, Yeotmal. Mild incidence of Aphids & Jassids in Nagpur & Nashik division.	Drain out excess water from the field & apply plant protection measures for standing crop after complete rain cessation.

4.6 Probability Forecasts

4.6.1 The rationale for probability forecasts

Agricultural predictions require forecasts of meteorological variables several days, weeks and even months ahead to enable informed management decisions. However, it is well known that the climate system is chaotic and, therefore, accurate weather and climate forecasting is impossible due to the uncertainty in the initial conditions (Palmer, 2005) and structural inadequacies of prediction models (Palmer et al., 2005) given by the uncertainty in the present knowledge and representation of the processes involved in generating weather and climate variability. There is a need to address the uncertainty problem in such a way to distinguish between those occasions on which forecasts deteriorate rather slowly with lead time (relatively skilful forecasts) and those occasions when they deteriorate rather rapidly with lead time (relatively unskillful forecasts). The answer to this question requires addressing the feasibility of quantifying the uncertainty in forecasts, in a stochastic manner.

The rationale for probability forecasts has a scientific and an economic component (Murphy, 1998). First, weather and climate forecasts must be expressed in terms of probabilities (or equivalent modes of expression) to accommodate the uncertainty inherent in the forecasting processes. As the amount of uncertainty can be situation dependent, the level of uncertainty associated with a given forecast can be properly conveyed in a stochastic sense through the use of probabilities. In general, forecasts expressed in a non-probabilistic format are unable to accurately reflect the true state of knowledge concerning future conditions of a forecast system. Weather forecasts must be expressed in probabilistic terms to enable the end users to make the best possible decisions, as reflected by their levels of economic and/or social welfare.

Probability forecasting is not expected to be only considered in the formulation of weather and climate forecasts for agricultural purposes, but to be extended to the agricultural predictions themselves. Probability forecasts have already been demonstrated to have superior benefits in some agricultural applications that make use of meteorological and climatological information. _

In particular, crop yield prediction has benefited from a collaborative effort within the seasonal climate forecast community. Challinor et al. (2005) and Cantelaube and Terres (2005) show examples of probability forecasts of annual crop yield and compare the benefits versus non-probabilistic forecasts.

4.6.2 Formulation

Probability forecasts differ from non-probabilistic forecasts in that, depending on the expected likelihood of occurrence of an event, a probability value between 0 and 1 to possible future states is assigned. This probability is only a component of the probability distribution function (PDF) of the variable, which gives a probability forecast value for each possible event. Within the paradigm of deterministic prediction, a signal refers to the location of the mean of the PDF and its deviation from the climatological mean, whereas the noise is represented by the PDF's spread. For probability predictions, a signal is represented as the entire forecast PDF and its difference from the climatological PDF. This concept allows for an interesting definition of predictability: a variable x can be considered predictable if the forecast PDF of x differs sufficiently from the climatological PDF of the same variable to influence relevant decision makers in making better decisions than without forecast information.

Forecast uncertainty can be quantified by a variety of methods, including subjective, statistical and dynamical ensemble methods. Similarly, probability forecasts can be generated through different methods. By considering a wide range of forecast information, forecasters can subjectively prepare probability forecasts. Alternatively, statistical/empirical techniques can be used either on their own, based on historical observational data (e.g. Mason and Mimmack, 2002), or in combination with dynamical models and its past verification statistics (Kruizinga and Murphy, 1983; Coelho et al., 2006). It is certainly true that not all probability forecasts produced by these methods are precise. Nevertheless, it can be stated without equivocation that probability forecasts exhibit reasonable skill (and skill considerably in excess of that achieved by the corresponding non-probabilistic forecasts) and can be produced for most if not all weather conditions of interest.

Predictions using dynamical models of the climate system may require further explanation given their present ubiquity and continuous progress. Predictions with dynamical models require a good estimate of the initial conditions of the atmosphere and the ocean. Since the initial conditions can never be measured with infinite precision, the error propagation created due to prior abstractions in initialization fundamentally limits our ability to forecast precisely (Thompson, 1957). Small perturbations of the initial conditions grow fast, leading to a rapid loss of initial information and predictability. Lorenz (1963) confirmed this sensitivity in numerical simulations of a three-equation based simplification of atmospheric convection.

Forecast models are run many times from slightly different initial conditions, all of them consistent with the error introduced to estimate the best possible initial-condition. This means that the forecaster has an ensemble of forecasts available at the same time and, hence, this technique is otherwise known as ensemble forecasting (Molteni et al., 1996; Toth and Kalnay, 1997). The ensemble can be used to produce probability forecasts without relying on statistical methods based on past events (Hagedorn et al., 2005). Assuming that the forecasts are independent realizations of the same underlying random process, an estimate of the forecast probability of an event is provided by the fraction of the forecasts predicting the event among all forecasts considered. Figure 4.6.1 shows an example of such probability forecasts produced with the ECMWF monthly ensemble forecast system (see caption for details).

However, errors in the sampling of the set of initial conditions and in the dynamical model structure make the dispersion of an ensemble forecast can at best only approximate the forecast PDF (Hansen, 2002). This may lead to overconfidence in probability assessment based in ensemble relative frequencies. Some statistical methods have been considered to correct these errors and provide sound probability forecasts based on ensemble forecasts (Wilks, 2006).

The widespread interest in the development and application of ensemble prediction is a sign that the meteorological and climatological operational communities acknowledge explicitly the uncertainty inherent in the forecasting process. An opportunity now exists to provide the full spectrum of users with reliable probabilistic information concerning the likelihood of occurrence of future conditions through probability forecasting.

Dynamical predictions of weather and climate suffer from structural model uncertainty, in addition to uncertainties in initial conditions. Model uncertainty arises mainly because of the process of parameterization, i.e. the way in which sub-grid scale motions are represented in weather and climate models (Palmer et al., 2005). At present, there is no underlying theoretical formalism from which a PDF of model uncertainty can be estimated. A pragmatic approach relies on the fact that dynamical forecast models have been developed somewhat independently at different climate institutes. An ensemble comprising such quasi-independent models is referred to as a multi-model ensemble (Palmer et al., 2004a; 2004b). This is an approach that can be easily extended to the user model component to increase the skill of the end-user predictions.

4.6.3. Probability forecasts at different scales

The features described above are applicable to the whole range of probabilistic forecast systems, from medium-range weather, through monthly up to decadal and longer climate time scales, which are available with a varying updating frequency, as described in Rodwell and Doblas-Reyes (2005). Users may want to employ all these systems in an integrated forecasting system, updating decisions as new probability forecasts are available. For instance, managers might have access to probability seasonal forecasts once a month. This information can somehow be merged with that provided by monthly forecasts available once a week to improve the first few weeks of the seasonal forecast information. Similarly, given that long-term decisions in agricultural systems are made at the interannual timescale, adaptation to ongoing climate change can be achieved by training the users to employ seasonal-to-interannual climate probability forecasts.

4.6.4 Probabilistic forecast formats

Probabilistic forecast information can be conveyed in explicit, quantitative terms in the form of probability distributions or as categorical probabilities; implicitly in the form of time series; and qualitatively as narrative. Table 10 summarizes strengths and limitations of each.

4.6.5.1 Probability distributions

Forecasts of continuous quantities (e.g., precipitation, temperature) are appropriately interpreted, and expressed graphically as shifts from the climatological probability distribution. Probability distributions can be expressed in either cumulative, or density (or mass in the discrete case) forms. A *cumulative distribution function* (CDF) expresses the probability that a random variable X takes on a value less than or equal to a given x, or $F_X = \Pr\{X \leq x\}$ (Fig. 4. 6.1a). A CDF increases smoothly for continuous variables, and in discrete jumps for discrete variables.

Probability of exceedance (also known as the complementary cumulative distribution function, or CCDF) is simply one minus the cumulative distribution function: $F_X^c(x) = \Pr\{X > x\} = 1 - F_X(x)$ (Fig. 4. 6.1b). Probability of exceeding a particular threshold (i.e., a

CCDF), as in case of rainfall, appears to be easier to understand than probability of an outcome below a threshold (i.e., a CDF), as will be the situation with temperatures in winter.

For a continuous variable, the *probability density function* (PDF) is the first derivative, or slope, of the CDF. Graphically, it appears as the familiar "bell curve" for the normal distribution (Fig. 4. 6.1c), and shows the relative probability of every outcome. A histogram is used to represent the probability distribution of a discrete variable (known as a *probability mass function*, or PMF), and to approximate the distribution of a continuous variable based on number of observations within each interval.

Both CDF and PDF are of value for farming decisions. Curves and histograms associated with probability density may be more familiar even to secondary school students. However, use of CDF over PDF is preferable as a CDF graph relates probabilities and climatic thresholds and, it is relatively easy to relate a CDF to a time series.

4.6.5.2 Categorical probabilities

Simple event probabilities are the appropriate way to express uncertainty about high-impact meteorological events when the primary concern is about whether the event occurs and not its intensity. Example is the need for knowing likely occurrence of rain and not the quantity for control operations against pests and diseases. The climatological probability that a given event E will occur is estimated by its historic relative frequency, and defined as the limit as the number of observations N approaches infinity: $\Pr\{E\} = \lim_{N \to \infty} N_E / N \cong N_E / N$. A forecast provides additional information that modifies the climatological probability.

Categorical probability formats are also used routinely to express forecasts of continuous meteorological quantities of interest to agriculture. The climatological distribution is divided into categories such as above and below median or terciles (e.g., the wettest, middle and driest third of past years) or percentage probability of realization of (i) a given value of a parameter and/or (ii) given situation. The forecast is expressed as a shift from the probabilities that define the categories. Categorical probability formats lend themselves to maps. Colour-coding represents the probability associated with a particular category (e.g., above-median), or the dominant category in the case of tercile forecasts. Probability shifts can be represented independent of the fine-scale spatial variability of climatological quantities.

The tercile format is being used for issue of operational forecasts and regional climate outlooks. The tercile and other categorical probability formats are not recommended as a primary means of presenting location-specific forecasts to user-interests. Categorical probability formats discard potentially useful distribution information, and impose thresholds that have no intrinsic relevance to decisions. Ambiguity about the definition of categories (O'Brien et al., 2000; Patt and Gwata, 2002), a tendency to confuse shift in probability with shift in direction from "normal" (Dalgleish, Dept. Psychology, Univ. Queensland, pers. commun.) and a tendency to anchor on the most probable category make interpretation difficult in the absence of substantial training.

4.6.5.3 Time series and analogs

A time series of observations and hindcasts based on an operational forecast model may be a useful complement to forecast distribution formats. It can reduce some of the non-clarity behind probabilistic forecasts by allowing users to evaluate the forecast system's uncertainty based on past performance. However, showing hindcasts as expected values carries the risk of mis-communicating a deterministic interpretation, particularly if the current forecast value appears in the graph.

Time series graphs can also be used to highlight analogous years (e.g., El Niño or La Niña years) when predictors (e.g., SSTs, SOI) were similar to the current year. This illustrates how the current state of predictors can shift the distribution of expected outcomes, and may be a useful way to present a probabilistic forecast that is based on such categorical predictors. Although forecasts that are based on continuous or multivariate predictors could also serve as a basis for selecting years when predictors were most similar to their current values, the probability distribution of the resulting analog years will generally not be consistent with estimates from hindcast residuals (section 4.6.6.2) or GCM ensemble distributions (section 4.6.6.3).

For time-series data, bar graphs appear to be easier to interpret than points or line graphs. For a visual representation of relative depth of a column of accumulated precipitation, farmers can participate in drawing rainfall depths to scale, then filling in bars and adding axes.

4.6.6. Deriving forecast distributions

This section briefly summarizes three objective methods to derive forecast probability distributions. For each method, probability distributions can either be represented empirically as illustrated, or by fitting the data to a theoretical distribution – typically gamma for precipitation amounts, and normal for mean temperatures. We do not address the simpler case of forecasting the probability of a discrete event.

4.6.6.1 From analogs

Statistical forecasting based on historic analogs involves classification of predictors into a few categories, such as El Niño, neutral and La Niña based on SSTs in the equatorial Pacific; then taking the set of past years falling within the category that corresponds to current conditions as a forecast distribution. Historic analogs provide a simple, intuitive approach to deriving and explaining probabilistic forecasts.

The marked year-to-year variations in the temporal distribution of a weather parameter on a short period basis restrict the use of the concept of analogous years to specific situations like late or early setting in or early withdrawal or persistence of weather systems. Spurious predictors, artificial forecast skill and systematic underestimation of forecast uncertainty – risks inherent in statistical forecasting – are particular concerns for the analog method when the number of categories and limited record length lead to small sample sizes within each category. Use of credible predictors and independent validation and hypothesis testing, are essential to limit these biases.

4.6.6.2 From hindcast residuals

Figure 4.6.2a shows a hypothetical time series of mean temperature observations (y) and hindcasts ($\hat{y}$), derived from sampling a multivariate normal distribution, and calibrated to the observations by linear regression. The distribution around the current forecast $\hat{y}_T$ is estimated by the distribution of hindcast residuals $\varepsilon_i = y_i - \hat{y}_i$, centered on $\hat{y}_T$. Subtracting predictions from observations yields a time series of hindcast residuals (ε), (Fig. 4.6.2b), which are then sorted to derive a residual CDF (Fig. 4.6.2c). The forecast distribution for 2001 is obtained by adding its expected value, $\hat{y}_{2001} = 12.0^{\circ}\mathrm{C}$, to each ε (Fig. 6.2d). The method is applicable to statistical or dynamic forecast models, and accounts for the overall prediction error of the forecast system. Distributions derived from historic analogs (section 6.3.1) are a special case, which uses the subset of ε from years within the given predictor class.

For strongly skewed variables, the magnitude of forecast residuals, and therefore the spread of a forecast distribution, tends to increase in the direction of skewness. Because rainfall amounts tend to be positively skewed, forecast uncertainty tends to be greater in wet than in dry years. The residual distribution will not capture this bias unless the skewness is corrected using a transformation of the predictand and/or the predictor. Raising to a power < 1 (e.g., $y'=y^{1/2}$, $y'=y^{1/3}$, $y'=\ln(y)$, $y'=1/y$) can correct positive skewness. Box and Cox (1964) provide an objective procedure for selecting an optimal power transformation that can be automated in a spreadsheet. The forecast distribution is derived from the transformed series, and then the inverse transformation applied to the entire forecast distribution.

4.6.6.3 From ensemble forecasts

Several operational climate centres derive probabilistic long-range forecasts from ensembles of multiple GCM integrations. Initializing GCMs with different atmospheric conditions gives an indication of the uncertainty associated with initial conditions. Use of several different GCMs captures uncertainty associated with model structure and assumptions. The spread of resulting predictions can be interpreted as a measure of forecast uncertainty, but must be calibrated before forecasts can be expressed as probability distributions at a local scale. There is not yet a consensus about the best calibration method. (Doblas-Reyes et al. 2005; Palmer et al. 2005).

4.6.7 Interpretation and attributes of probability forecasts

Forecast probabilities can be interpreted as a relative frequency or as the forecaster's degree of belief. In the former interpretation the uncertainty is a property of the system under consideration whereas in the latter case the uncertainty is a property of the person issuing the forecast (Murphy, 1998). Measurement of the statistical consistency between the predicted probabilities and the actually realized frequencies is known as Reliability. The ability of the probability forecast system to delineate situations under which an event occurs with lower or higher frequency than the climatological frequency is known as resolution. Measurement of the variability of the forecast PDF with reference to the climatological PDF is known as Sharpness. Ideally a skillful probabilistic forecast should seek a trade-off between high reliability and resolution. In a perfectly reliable forecast system sharpness is identical to resolution. However, when reliability is not perfect, resolution and sharpness should not be confused. For a detailed discussion on and availability of tools relating to measures of reliability, sharpness and resolution, Jolliffe and Stephenson (2003) may be referred to.

4.6.8 Communicating probabilistic forecast to farmers

4.6.8.1 Keys to understanding and applying probabilistic information

There are fundamental difficulties in understanding and applying probabilistic information for decision making (Nicholls, 1999; Tversky and Kahneman, 1981). However, agricultural meteorologists can help farmers overcome some of these difficulties, particularly in settings that allow direct interaction.

Natural frequencies. Presenting information in the form of frequencies (e.g., "Belle Glade gets more than 160 mm of rainfall in January to March in about 10 out of every 20 years") rather than the equivalent but more abstract notion of probability of a future outcome (e.g., "the probability of getting more than 160 mm of rainfall next January to March at Belle Glade is 50%") tends to improve interpretation of probabilistic information (Gigerenzer and Hoffrage, 1995).

Relate to experience. Work of Hansen et al. (2004) suggests that probabilistic information acquired from personal experience is processed and applied more effectively than information acquired from statistical descriptions. Because farmers' livelihoods are weather-dependent and inherently probabilistic, they can be expected to understand uncertainty from their own experience, although not necessarily in formal probability language or formats. Helping farmers map probabilistic forecast information into their own experience base can therefore enhance the utility of the information.

Trust and transparency. Building up of trust in the credibility of information provided takes time and deliberate planned efforts. For this, communicating probabilistic information in a transparent manner, and not as a "black box," is essential, as it allows farmers to shift their trust from the information provider to the data and the process. Presenting past performance of the forecast system against observations, and explaining (in simplified terms) the process of deriving probabilistic forecasts, contribute to transparency and hence of confidence.

4.6.8.2 Teaching probabilities to farmers

The logical progression of the following processes has proven to be a useful way to introduce farmers to probabilistic long-range forecasts and has been effective and well received in a workshop setting with smallholder farmers in Kenya, and a subset in a self-directed tutorial with farmers in Florida, USA.

Relate measured time series to farmers' experience. For example, elicit farmers' qualitative memory of climatic conditions for the past 5 years. Then present observations from a nearby station, and allow farmers to plot as a time-series bar graph and then validate the measured outcomes against their collective memory.

Convert the time series to relative frequency or probability. Starting with a blank graph with quantity (e.g., seasonal rainfall) on the x-axis and frequency (e.g., "Years with at least this much rain") on the y-axis, allow farmers to sort from lowest to highest (if using probability of exceedance) onto the new graph. Connect the points, and change the y-axis from number of years to relative frequency or probability. Emphasize the consistency between the two formats.

Provide enough explanation and repetition to ensure understanding. Discuss, for example, rainfall associated with a given probability, probability associated with a given rainfall threshold, and the range of likely rainfall. It may be useful to draw hypothetical shifts, and discuss their interpretation. One way to explain a shift of the climatological distribution to the right or left is to ask farmers to identify and discuss the climate in locations that are somewhat wetter or dryer.

Repeat the procedure for, e.g., El Niño or La Niña years. Educating the rural communities about El Niño and La Niña, will help convey the notion that a forecast is a shift of the climatological distribution, even if operational forecasts are more complicated or not based on ENSO. By this point, farmers should be comfortable enough with the formats to allow use of prepared time-series graphs with El Niño or La Niña years highlighted, and prepared shifted CDF or probability of exceedance graphs.

Relate forecast distributions to decisions. Organization of brainstorming sessions amongst farmers about potential management responses to either hypothetical or actual forecasts will help in reinforcing both appropriate interpretation and their relevance for farming decisions

Use culturally relevant indigenous forecasts, gambling analogies or other analogies of decisions under uncertainty. This aspect of the process requires detailed understanding of local culture and language.

Provide accelerated experience through decision games. Well-designed games that link real or imaginary payouts to decisions and sampled probabilistic outcomes allow farmers to experience, in a short time, a number of imaginary forecasts, decisions and sampled climatic outcomes; and imaginary or real payouts. Spinners and draws of color-coded objects (e.g., candies, buttons) have been used effectively to sample outcomes in proportion to prescribed forecast probabilities in educational decision games.

Table 10. Alternative formats for probabilistic forecasts.

Format	Use	Strengths	Weaknesses
		Probability Distribution	
Histogram, Probability density (PDF)	Present entire forecast distribution of a measured quantity.	Provides full distribution information. Good at conveying relative probability of different outcomes, skewness, tails. More likely exposed to PDF than CDF in school.	Derivation of PDF difficult to explain. Difficult to compare multiple distributions. Interpretation might require training.
Cumulative distribution (CDF)	Present forecast distribution of a measured quantity. Compare multiple distributions.	Provides full distribution information. Directly relates climatic thresholds and probability. Straightforward to derive from, relate to, historic series. Can compare multiple distributions.	Interpretation usually requires some training.
Probability of exceedance (CCDF)	Present forecast distribution of a measured quantity. Compare multiple distributions.	*Same as for CDF.* Belief that Pr{$X>x$} is easier to understand than Pr{$X\leq x$}.	Interpretation usually requires some training
Box plots	Present forecast distribution percentiles (0, 25, 50, 75, 100) of a measured quantity. Compare multiple distributions.	Intermediate information between full distribution and simple range. Percentiles (quartiles, median) and extremes explained as, e.g., "*k* out of *n* years." Can compare multiple distributions.	Interpretation usually requires training.
Error bars	Present a simple measure of uncertainty of a measured quantity on a deterministic (e.g., time series) graph.	Reduces distribution to expected value and a range.	Potential ambiguity due to multiple error metrics. Ignores low-probability, high-impact events
		Categorical Probabilities	
Probability of occurrence	Present probability that a discrete event will occur.	Appropriate format for extreme, high-impact events.	Inappropriate for continuous quantities.
Probability of exceeding median (or mean)	Probabilistic representation of spatial distribution of a forecast measured quantity.	Simplest probabilistic representation. Lends itself to mapping. Useful when relative, not absolute, outcomes are relevant.	Discards distribution information. Imposes artificial thresholds. Tendency to confuse shift in probability wit shift in direction from "normal." Tendency to anchor on most probable catego Local interpretation requires climatology information.
Terciles	Probabilistic representation of spatial distribution of a forecast measured quantity.	"Standard" for many operational forecasting institutions. Lends itself to mapping. Substantial existing experience and educational material.	*Same as probability of exceeding median.* Interpretation usually requires training. Potential misunderstanding of category boundaries.
		Time series	
Analog years	Possible supplement to aid explanation of formal probability formats.	Provides an intuitive explanation of forecast in terms of past years with similar forecast.	Resulting distributions inconsistent with mo rigorous methods. No clear evidence of relative ease of understanding.
Predicted and observed series	Possible supplement to aid understanding and transparency of formal probability formats.	Useful for explaining basis for probabilistic forecasts in terms of past performance. Evidence farmers desire as complementary information. Allows users to intuitively validate probabilistic forecasts.	Danger of contributing to deterministic interpretation. Danger of anchoring if the current forecast i included.
		Narrative	
Narrative	Text-based media (e.g., radio). Supplement to formal probability formats.	Text-based media (e.g., rural radio) sometimes has greatest reach at lowest cost.	Qualitative descriptors of probability prone t inconsistent interpretation. Difficult to explain basis for forecasts or the climatology context with text alone.

4.7 General public weather forecasts

The provision of weather warnings and forecasts to the general public is one of the primary roles of all National Meteorological and Hydrological Services and is intended for relatively large areas where agricultural production may be diversified. These forecasts are limited to the meteorological elements and factors and should include forecasts of maximum and minimum temperatures, type, duration and amount of precipitation, cloudiness and wind speed and direction. Agriculture, fishery, forestry, water resource management, etc. among many other sectors directly benefit from the service. To be effective, forecasts and warnings must obviously reach those who are to use it in a timely fashion, should be presented in a suitable manner and be readily understood and usable. Since the forecasts are concerned with stating the weather probabilities of certain areas over certain time periods, the phraseology used should be in accordance with these probability aspects rather than precise, and flexible rather than rigid. The forecasts should be related to well defined regional localities where configuration implies some degree of homogeneity of weather patterns (WMO, 2001).

The interpretation of the weather's influence on crops or agricultural operations is not mentioned in the general forecast. Such interpretations must be made only by agricultural meteorologists with a thorough knowledge of current agricultural techniques and operations.

4.8 Now-casting and very short range forecasts

4.8.1 Definitions

Nowcasting (NC) and Very Short Range Forecasting (VSRF) techniques were created for fields like civil protection or transportation; nevertheless in the last few years their importance for agriculture is rapidly growing due to the improvement of techniques for production and broadcasting of forecast information and the increasing flexibility of agro-techniques to cope with variability of weather conditions. A short definition and some general characteristics of NC and VSRF have been presented in Table 1 of paragraph 4.2.

NC is the extrapolation of current weather to some future time (up to 2 hours), mainly based on the behaviour of existing phenomena as described by intensive observations; VSRF is the anticipation of events beyond the period during which extrapolation usually works (up to 12 h) (Schlatter, 1986). NC and VSRF focus on meso and micro scale weather events, with spatial scales below 1000 km and time scales of some hours.

In the state of the art services, NC is very close to VSRF from the point of view of applied forecast techniques and it is not easy to make a clear separation between the two techniques (Heijboer et al., 1989; Coiffier, 2004); for this reason they will be jointly discussed in this paragraph. Some authors (e.g. Schlatter, 1986) say that NC could be exclusively based on extrapolation techniques and doesn't involve knowledge extensively applied for VSRF (physics, dynamics or the application of numerical and conceptual models).

4.8.2 Operational activities

Main basic information for NC and VSRF are presented in Table 11. Agricultural and biological data, ground-truth or remote sensed (e.g.: local and regional observations of crop phenology, pests and diseases, agricultural practices) are important ancillary data for production of useful and reliable agrometeorological information (e.g.: now-casting of precipitation or frost can be useful for a given crop only during particular phenological phases).

A schematic diagram of flows of information and operational activities that characterise Nowcasting and Very Short Range Forecasts is shown in Figure 4.8.2.1.

Table 11. Nowcasting and Very Short Range Forecast: main basic information for the forecaster.

	Class	**Data**
DataMonitoring	Punctual atmospheric data	local and regional observations of atmospheric phenomena (cloud coverage, present and past weather events)
		data from networks of Automatic Weather Stations
	Remote sensed atmospheric data	maps from systems for lightning detection
		images from polar and geostationary meteorological satellites
		maps from meteorological radar
		Sodar data

Forecasted data	Data from numerical models	products of NWP models (LAM and GM)
		Products form biological models (e.g.: phenological models)

Usually the forecaster’s work for NC and VSRF consists in (i) producing a reference forecast based on available information and (ii) checking whether the actual behaviour of the selected phenomena agrees with the forecast one. This latter task needs real time comparison of forecast values with real-time synoptic and/or remote sensed data. When the actual evolution differs from the forecasted one, the forecaster should be able to adjust his forecast and to amend the products delivered toward the end-users. This task becomes particularly critical when a severe weather event is taking place. Fore example, in the specific case of heavy precipitation (Horváth and Geresdi, 2003) the adjustment of the forecast over small areas with the help of the whole set of available tools and the preparation of alarm bulletins totally f takes up the time of the forecaster (Coiffier, 2004).

The consequence is that it is crucial to have available techniques to (i) organise the whole available data in a georeferenced framework (ii) interpret the existing information and (iii) display in real time the information for forecaster. Automatic techniques useful for these aims are:

- Geographic Information Systems (GIS)
- techniques for assimilation and quality check of data;
- techniques for analysis of spatial data;
- tools to detect differences between the forecast and the actual situation
- numerical and conceptual models adapted to territory and operational activity.

All the above listed techniques could be fault-tolerant and could operate also with reduced sets of data (Mouchart and Rombouts, 2005).

Geographic information systems are useful for the management of different kinds of basic data as georeferenced layers (Olaya, 2004). *Assimilation* is the first phase of the operational chain of NC and VSRF and a fundamental aspect for the quality of NWP models products (Macpherson, 2001). Quality-check of data is crucial to avoid the negative effect of wrong data undetected by normal quality control procedures which, usually doesn’t work in real time (e.g.: the effect of wrong hourly rainfall data on quality of NC and VSRF). Real time quality control procedures (checking of absolute and relative - spatial, temporal, intersensor and intersystem - consistency) are needed to eliminate outlayers of faulty data and to highlight questionable data that need a particular attention of the forecaster (Daley, 1993).

Analysis of spatial data is founded on geostatistical approaches in order to describe the spatial features of meteorological phenomena (Goovaerts, 1997) and to extrapolate their behaviour, field of motion and trajectory (Steinaker et al., 2000) from observations and remote sensed imagery. *Automatic tools* to detect differences between the forecast and the present situation are useful in order to minimise the subjective decisions of the forecaster and the possibility of error. Also in this case the availability of a GIS technology is an important element for obtaining satisfying results.

Numerical models are useful in NC and VSRF for prognostic and diagnostic purposes (Kaspar, 2003). Classical examples are given by energy balance models useful for analysis and forecast of temperatures of vegetation (Bonan, 2002) or hydrological models useful to forecast runoff and floods due to strong rainfall (Jones, 1998; Gwangseob and Barros, 2001; Bowler and Pierce, 2004; Olaya, 2004; Grimbacher and Schmid, 2005). Availability of NWP models parameterised and validated for the reference territory and the weather phenomena for ready implementation in forecasting can be a great help. The usefulness of NWP prognoses can be evaluated on the basis of and taking into account the velocity of meso-scale development of weather phenomena This means that (i) time and spatial scales of NWP outputs must be defined in order to satisfy the whole operational requirements for phenomena that show a very rapid meso-scale development (Heijboer et al., 1989) and (ii) the assimilation procedure of NWP must be defined in order to receive local observational inputs with hourly or sub-hourly time step.

Conceptual models are useful in order to provide (Conway et al., 1999) (i) definition of phenomena in terms of features recognisable by observations, analyses or validated simulations, (ii) description of the life cycle of phenomena (time of appearance, size, intensity and accompanying weather), (iii) statement of the controlling physical processes which enables the understanding of the factors that determine the mode and rate of evolution of the phenomena (iv) specification of the key meteorological fields demonstrating the main processes, (v) guidance for predicting formation using the diagnostic and prognostic fields that best discriminate between development and non-development and (vi) guidance for predicting movement, evolution, senescence and disappearance. Advantages from conceptual models for forecaster involved in NC and VSRF are summarised in Table 12. Some conceptual models with examples are mentioned in Table 13.

Table 12 Some reasons of the usefulness of conceptual models for forecaster (Conway et al., 1999)

Usefulness
1. help for understanding and diagnosing phenomena
2. a synthesis of all available information
3. a four dimensional "mental picture" of atmosphere
4. the basis for isolating weather processes
5. the basis for extracting the main signals from complex patterns
6. tools for assisting diagnosis of numerical models
7. a supplement to numerical models for the nowcasting scale
8. tools for identifying errors in the numerical forecast
9. a fast forecast method
10. an independent forecast method
11. a forecast method particularly for hazardous weather
12. the possibility of filling in the gap of data

Table 13 Some conceptual models with some examples

Conceptual model type	**Examples**
models of fronts and frontal substructures, including topographical influences	**frontal models like model using conveyor belts (Browning and Mason, 1981)**
models of convective phenomena	**supercell thunderstorms (Ray, 1986)**
models of fog, frost and low cloudiness	**Radiation fog (Guedalia and Bergot, 1994) radiation or advective frost (Stull, 1997)**
models of topographically induced weather features	**sea/land breezes (Atkinson, 1981)**
Other models	**Forecasting of dust storms (Barnum et al., 2004)**

Further improvements in VSRF and NC could be obtained not only by means of enhancement of operational and broadcast techniques but also by means of an increase of continuity of operations of agrometeorological services that can be also obtained by means of the increase of the degree of automation of procedures.

4.8.3 Operational examples

Nowcasting and very short range forecast can be useful for many different agricultural activities (Table 14).

Table 14 Examples of use of nowcasting and very short range forecasts for agriculture

OBJECTIVE	PRINCIPAL FORECASTED VARIABLES
Manage works without produce soil compaction	**Precipitation**
Manage field activities during the growing period of crops	**Temperature, wind and precipitation**
Mminimize the waste of biocides applied against weeds, pests and diseases	**Temperature, wind and precipitation**
Manage mitigation activities against frost	**Temperature of air and crop tissues**
Manage harvest activities for different crops	**Precipitation, relative humidity, wetness of crops**
Prevent and mitigate the effects of flash floods or debris flow	**Precipitation**

4.8.4.1 Nowcasting and Very short range forecast of frost

Nowcasting and very short range forecast of frost is very important for the management of agricultural practices against this event (e.g.: low volume irrigation, ground-based fans, trash-fires). In Italy some agrometeorological services used specific NC and VSRF outputs during the period crops were exposed to risk of late frost (from February to April) or early frost (October and November).

Friuli Venezia Giulia is a region located in North-East Italy with a significant presence of fruit trees (apple, pear, peach and actinide). Usually frost is very frequent during winter but during spring and fall frosts pose a significant risk for fruit growing. For this reason, several orchards are provided with low volume irrigation devices that are used against spring frost and, in some situations, against fall frost (e.g.: risk for actinide fruits).

In order to switch on the irrigation, it is important to know when the frost will take place. The ARPA (Agenzia Regionale per la Protezione dell'Ambiente, Regional Agency for Environmental Protection) of Regione Friuli Veneza Giulia has produced a tool called ANGELA (Algoritmo di Nowcasting per le GELAte – Algorithm for nowcasting of frost), that works routinely during periods potentially exposed to the frost risk giving the forecasted temperature evolution from sunset to sunrise.

ANGELA is fed from sunset to the end of the night with the following data:

1. Minimum temperature subjective forecast. This is the forecast of the minimum temperature for the incoming night issued by the forecaster. It's the synthesis of (i) NWP outputs, (ii) all weather stations meteorological data and (iii) the forecaster's skill.

2. Hourly night-time temperature measurements gathered from automatic weather stations. These data are refreshed every hour so they give an up to date snapshot of the ground temperature field.

The physical model implemented in ANGELA for the night-time temperature drop is that of Reuter (Pelosi 1986). In this model the ground temperature is function of sunset temperature and the time passed since the sunset:

$$\boxed{T_n = T_s - K \cdot n^{1/2}}$$

In this equation T_n is the temperature at n hours from the sunset in ºC, T_s is the temperature recorded at sunset in ºC, K is the temperature drop coefficient and n is the number of hours since sunset. In spite of its simplicity, the model is quite realistic if the coefficient K is updated every hour during the night. The initialisation of the model is done with the forecaster's minimum temperature, the sunset temperature and the length of the night in hours, assuming that the lower temperature is reached at the end of the night. In this step two values for K are computed: one concerning the pure minimum temperature issued by the forecaster and the other concerning the forecaster's minimum temperature minus 2 ºC. This is done to give two extreme values for *K: Kmax* and *Kmin* which define the range for the K values computed in the further steps. The starting K is the simple average of the two extremes. Every hour after sunset, for each automatic weather station, the observed temperature is used to compute the new constants K. To give more robustness to the forecasts, that is to issue temperature forecasts without too much fluctuation during the whole night, the applied K is constrained in the defined range by means of linear combination of *K, Kmax* and *Kmin*. Furthermore a quality check on observed temperatures is performed in order to avoid the use of local spikes.

Once the observed temperatures are available at CSA and the ANGELA temperature forecasts are computed, an automatic connection with a local television broadcasting station updates the forecast, making them available to everybody by means of a delete system in real time.

In the last years ANGELA system was also adopted by ARPA of Regione Veneto.

In Trentino the frost warning service is run by the Agrarian Institute of S. Michele (IASMA) and Meteotrentino. The service is aimed at providing minimum temperature forecasts to apple growers and crop practices assistants. Frost nowcasting is disseminated via the web, while real-time temperatures (10º updating) are available via Teletext and SMS on demand. For a selected number of stations, mechanistic models have been calibrated which yield, site by site, the best estimates of minimum temperature when suitable meteorological conditions are predicted for the following night (clear sky, very stable atmosphere and calm or very light wind). If such conditions are assessed by the local meteorological service, models are implemented and issued on the web. Reuter algorithm (Pelosi 1986) is also applied in an hourly update mode, correcting the hourly temperature decrease by recorded temperature data. Another approach consists in post-processing atmospheric models outputs by machine learning techniques; a "Random Forest" algorithm is applied to the fields predicted by ECMWF (temperature, wind, humidity, geopotential, sky cover…) at the control time 06 AM of the following day. The temperature forecast is improved with respect to the raw model output, and the forecast is available about 10 hours before sunset.

4.9 Short and Medium Range Forecasts

4.9.1 Definition

Short and Medium Range Forecasts describe the behaviour of weather variables (precipitation, air temperature, sky coverage and solar radiation, wind velocity and direction, etc.) and weather phenomena (frontal systems, anticyclones, tropical cyclones, squall lines, etc.). The typical range is beyond 12 hours and up to 72 hours for Short Range Forecasts (SRF) and beyond 3 days and up to 10 days for Medium Range Forecasts (MRF).

A short definition and some general characteristics of SRF and MRF have been presented in Table 1 (Paragraph 4.2).

4.9.2 Usefulness for agriculture

SRF and MRF are important for farmers in order to plan the day's work on activities like:

- preparatory activities, such as land preparation and preparation of plant material
- planting or seeding/sowing

- crops, fruit trees and vine management; application of fertiliser, irrigation; thinning, topping, weeding; pest and disease control
- management of grazing systems
- harvesting, on-farm post-harvest processing and transporting of produce
- livestock production (dairy enterprises, beef systems, lamb and other livestock systems)

Furthermore quantitative forecasts are an important source of data for simulation models that produce information useful for farmers (simulation of crop phenology, water and nutrient cycles, crop production, weed, disease and pest cycles, etc.).

4.9.3 State of technology

Forecast technology is constantly evolving due to the increase of scientific knowledge of atmospheric system and the evolution of following technologies:

- monitoring tools like satellites, networks of automatic weather stations, radars, lightning detection systems and so on;
- forecasting tools like Numerical Weather Prediction (NWP) techniques, statistical methods, empirical models, methods derived from forecaster experience (rules of thumb).

The activity of weather forecaster in now-casting and very short range forecast are founded on analysis and extrapolation of trajectories referred to a relatively wide set of products (radar maps, meteorological satellite images, NWP models, local and regional observations and so on). In short and medium range forecasts the evolution of atmospheric variables is mainly derived by numerical methods (NWP). The experience of the forecaster is important in order to evaluate the accuracy of outputs of one or more models for the particular area (topography, distance from sea, soil use, etc.).

The work of forecasters has evolved significantly over the years to take advantages of both scientific and technological improvements. The skill of numerical models has improved so much that some Centres have implemented automating routine forecasts to allow forecasters to focus on high impact weather or areas where they can add significant value. It is not easy to determine a standard way to create weather forecasts since the methods used depend on several factors (Coiffier, 2004):

1. the forecast range;

2. the size of the domain to be covered (large portion of the globe, a regional domain, a small country, a city);
3. the geographical context and related climatology (mid-latitudes, tropical or equatorial areas, isolated islands);
4. the potential risk associated with the expected weather at various ranges;
5. the organisation of the forecast service (multipurpose or specialised for agriculture);

6. the technical environment (available external and/or internal NWP products, in situ observations, satellite and radar images, lightning detection network. Infrastructure catering to the needs of the foecaster; web access;

7. the know-how of forecasters (professional experience and operational experience referred to the selected area);
8. the reference end-user for forecasts (e.g.: general purpose services or specialised ones for fields like agriculture, civil defence, aviation, marine, hydrologic and water management service, road administration, etc.);
9. the reliability of the current state of weather variables.

4.9.4 Forecasts and NWP

Numerical Weather Prediction provides useful information for up to approximately 6-12 days (120-240 hours) in the future. It is based on solving a complex set of hydrodynamic equations that describe the evolution of the atmosphere, subject to the initial atmospheric state and initial conditions at the Earth's surface. Since the initial state is not known perfectly, all forecasts begin with estimates. Unfortunately the system is very sensitive to small changes in the initial conditions (it is a chaotic system) and this limits the ability to forecast the weather deterministically beyond 6-12 days.

MRF are founded on the use of the output of one or more global Numerical Weather Prediction (NWP) models. Moreover SRF redaction is founded on Local Area Models (LAM). At present, the availability of LAM until 2-3 days after their emission can be considered the limit between SRF and MRF.

It’s important to define these forecasts and describe the principal inputs (NWP etc.) and outputs, with some significant examples. Model Output Statistics (MOS) are statistical methods applied to outputs of NWP in order to improve the forecast skill for local or microscale phenomena that aren’t correctly modelled in a mechanistic way (e.g.: frost, maximum temperature, rainfall quantity or probability and so on).

4.9.5 Probabilistic approach to SRF and MRF

An important evolution in SRF and MRF is represented by the introduction of a probabilistic approach to future states of weather. The same terminology adopted by weather-men is sometimes an expression of this uncertainty (see Table 15).

An example of a subjective probabilistic forecast for a vine area of Italy is represented in Table 16. Probability of precipitation was needed by farmers in order to distribute pesticides during vegetative period.

Table 15 Quantitative aspects and incertitude in forecasts of precipitation expressed by means of words used by forecasters (information taken from the National Weather Service Brochure, "Is it Going to Rain Today? Understanding the Weather Forecast." - NWS-NOAA)

PROBABILITY OF PRECIPITATION	TERMS USED
0%	NONE
10%	Slight Chance – Isolated
20%	Slight Chance
30-50%	Chance – Scattered
60-70%	Likely – Numerous
80-100%	Categorical ("Rain this afternoon")

General rules	The likelihood of occurrence of precipitation is stated as a percentage
	A measurable amount is defined as 0.01" (one hundredth of an inch) or more (usually produces enough runoff for puddles to form)
	The measurement is of liquid precipitation or the water equivalent of frozen precipitation
	The probability is for a specified time period
	The probability forecast is for any given point in the forecast area
Examples	1) In a precipitation forecast the following terms of duration imply a high probability (80-100%) of occurrence: brief, occasional, intermittent, frequent
	2) If a forecast for a given county says that there is a 40% chance of rain this afternoon, then there is a 40% chance of rain at any point in the county from noon to 6 p.m. local time. This point probability of precipitation is determined by the forecaster by multiplying two factors: Forecaster certainty that precipitation will form or move into the area X Areal coverage of precipitation that is expected
	3) If the forecaster was 80% certain that rain would develop but only expected to cover 50% of the forecast area, then the forecast would read "a 40% chance of rain" for any given location.
	4) If the forecaster expected a widespread area of precipitation with 100% coverage to approach, but he/she was only 40% certain that it would reach the forecast area, this would, as well, result in a "40% chance of rain" at any given location in the forecast area.

Table 16 Example of probabilistic approach to precipitation forecast. Ersal –Project for rationalisation of pesticide distribution on vineyards. Forecast of rainfall for vine areas of Francacorta, Cellatica, Botticino, Valtenesi and Lugana. Wednesday 2 July 1997.

Day	**PROBABILITY OF RAINFALL**
Thursday	**0**
Friday	**2**
Saturday	**1**
Sunday	**2**

Classes of probability of rainfall: 0 = absent (0%); 1 = low probability (0-30%); 2 = Medium probability (30-70%); 3 = High probability (>70%)

Ensemble forecasts are a mathematical method able to account for the inherent uncertainly in MRF and SRF. The traditional weather forecasts are founded on the output of the best models available and used until they lose their skill due to the growth of small errors in the initial conditions. In medium range forecast, model skill is typically lost after 6 days or so, depending on the season. An alternate method that produces forecasts with skill up to 15 days after the initial forecast uses what is called "ensemble forecasting" method introduced to produce improved medium range (3-15 days) weather forecasts". Instead of using just one model run, many runs with slightly different initial conditions are made. An average, or "ensemble mean", of the different forecasts is created. This ensemble mean is likely to be better because it averages over the many possible initial states and essentially smoothes the chaotic nature of climate. In addition, it is now possible to forecast probabilities of different conditions because of the large ensemble of forecasts available.

4.9.5.1 Operational services and SRF/MRF for agriculture

4.9.5.1.1 Agrometeorological Forecasting and Advisory service

Agrometeorological Forecasting Services (or Agrometeorological Sections of general purpose Meteorological Services) are organizations that produce information specialised for agriculture, forestry and fisheries. Agrometeorological (advisory) services are acts by such Services for operational use. Some examples are hereafter discussed.

4.9.5.1.1a Forecasts of cold spells and paddy rice

Cold spells during differentiation of flower organs are a significant risk for rice crop in extreme areas of boreal (e.g.: France, Italy, Cina) and austral hemisphere (e.g.: Australia). The drop of temperatures below the critical threshold (10-15°C for most of the mid latitude varieties) causes male sterility with significant drop of production. Cold spells are frequently triggered by synoptic and mesoscale phenomena (outbreaks of arctic air and related thunderstorms) that can be relatively easily forecasted by means of SRF and MRF. Farmers that receive this information can act by increasing the level of water in ponds.

4.9.5.1.1b Output of NWP models and agrometeorological simulation models

The Agrometeorological Research Station at Braunschweig of the German Weather Service (Deutscher Wetterdienst, 2004) has developed the agrometeorological advisory system AMBER. In AMBER, Kalman filtered results of LAM models LM and GME at hourly intervals for locations of weather stations as well as measured data at these locations are used as boundary conditions for agrometeorological models. These are namely the models AMBAV and AMBETI which calculate agrometeorological quantities for different crops and types of soil. These, in turn, are used to run a variety of subsequent models. By the model AMBAV the actual evapotranspiration for a variety of crops and types of soil is calculated considering soil moisture and crop development, which is derived from the phenological observations. In the model AMBETI Braden calculates temperatures, water transport and moisture for several depths of different soils and for several canopies, including soil chill as well as the development and melting of a snow cover. The interception of precipitation and radiation by crops and transmission of radiation into crop canopies as well as, leaf wetness and leaf temperatures are modelled.

With the help of these results of agrometeorological models for the individual locations, the subsequent information is carried out by means of more specific agrometeorological models:

- occurrence of specific plant diseases and pests
- advices for the need for spraying and other agricultural management/farming activities
- soil tractability

- optimal time for planting, irrigating and fertilising for different crops
- estimate the extent of volatilisation run off and infiltration of fertilisers, fungicides and pesticides
- forecast of grain humidity, yield and harvest quality
- estimate the optimal harvest time for different crops and of each crop for different types of soil.

From the multitude of different results, those of interest for different groups of clients, e.g. irrigating farmers, vegetable cultivators, animal producers, are selected and presented in different tables and figures. These results are automatically sent by e-mail and by telefax to clients like individual progressive farmers, machinery groups and agricultural organisations for the surroundings of given location.

4.9.5.1.1c Forecasts and distribution of waste or nutrients

In recent years, large animal feeding operations in USA have come under intense scrutiny. The rise in numbers has occurred at a time of increased awareness of the effects of non-point source pollution. Regional initiatives, such as the Chesapeake Bay Program, have focused in part on the non-point pollution caused by animal feeding operations. Environmental catastrophes, such as the North Carolina hog farm spillage in the wake of Hurricane Floyd, have served to increase the spotlight on large concentrated animal feeding operations.

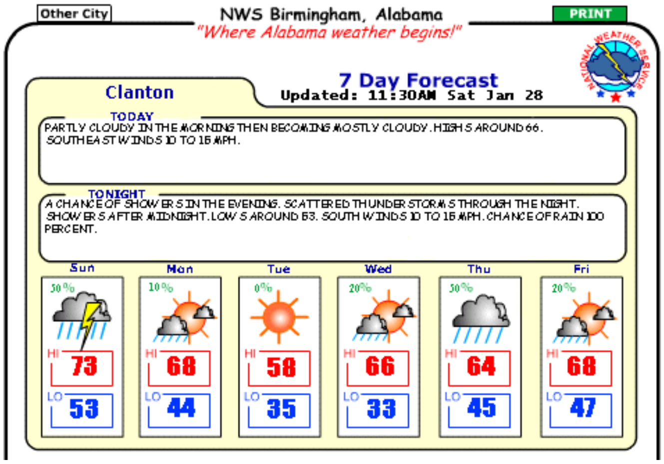
National rules were defined in order to carry out operations like animal feeding or waste distribution without nutrient/pollution run-off. In particular Natural Resources Conservation Service (NRCS) technical standards and guidelines state that waste/wastewater may not be discharged on land (i) when the soil is saturated, frozen, covered with ice or snow (ii) during precipitation, or (iii) when significant precipitation is reasonably expected within the next 72 hours. In consequence of these rules discharge of wastes/wastewater over land is founded on two forecast products of National Weather Service:

- a valid NWS FORECAST (Figure 4.8.2.1) as primary information.
- a FARMERS MAP (Figure 4.8.2.2) as secondary tool that can be utilised to evaluate whether land application activities can be conducted when the FORECAST alone would not.

Farmers can dispose animal waste/nutrient on land if NWS FORECAST predicts less than 50% rain chance for each of the next 72 hours. In this case Farmers Map isn't needed. On the contrary, if NWS predicts 50% or greater rain chance for each of the next 72 hours, farmer can use land for disposal only if FARMERS MAP shows that the area in which the application will take place is white (not red). In other words the FARMERS MAP is intended to provide farmers with an additional option when the percent chance of rain is elevated, but the amount of rain predicted is low (not expected to cause runoff from the field). If a farmer needs to use land for disposal when the rain prediction is 50% chance or greater sometime during the next 72 hours, they can view the FARMERS MAP (available in the internet site of NWS), verify that their area is white (not RED), print a copy for their records, and then use the land disposal according to their Nutrient Management Plan (NMP) prepared as part of their facility's comprehensive Waste Management System Plan (WMSP).

Use of land application for disposal is not authorized up to 72 hours prior to a significant chance or amount of rain. However, use of land application for disposal may commence or resume immediately following the rain provided that the weather prediction for the next 72-hours is favorable, and field conditions meet NRCS technical standards and guidelines.

Fig. 4.8.2.1 – Example of NWS FORECAST available at http://www.srh.noaa.gov/bmx/data/forecasts/Clanton_forecast.html



NWS Birmingham, Alabama
"Where Alabama weather begins!"

Clanton

7 Day Forecast
Updated: 11:30AM Sat Jan 28

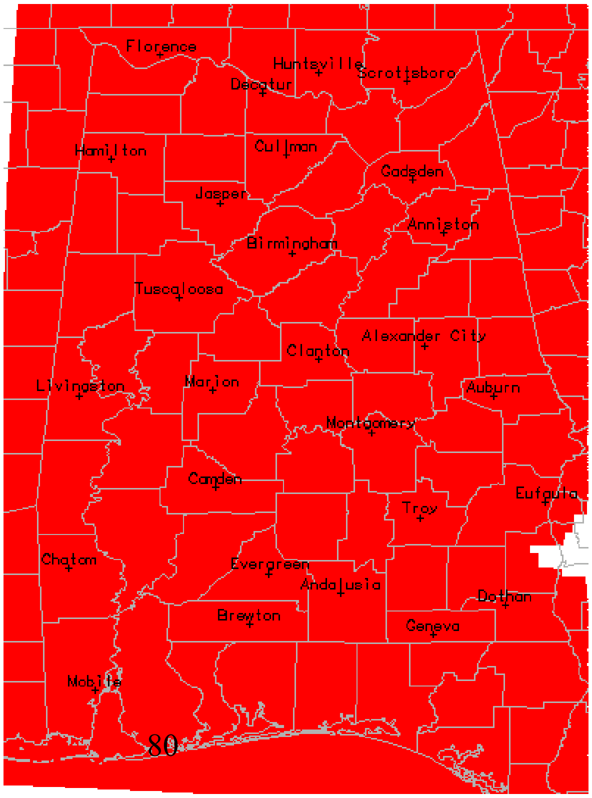
TODAY
PARTLY CLOUDY IN THE MORNING THEN BECOMING MOSTLY CLOUDY. HIGHS AROUND 66. SOUTHEAST WINDS 10 TO 15 MPH.

TONIGHT
A CHANCE OF SHOWERS IN THE EVENING. SCATTERED THUNDERSTORMS THROUGH THE NIGHT. SHOWERS AFTER MIDNIGHT. LOWS AROUND 53. SOUTH WINDS 10 TO 15 MPH. CHANCE OF RAIN 100 PERCENT.

	Sun	Mon	Tue	Wed	Thu	Fri
	50%	10%	0%	20%	50%	20%
HI	73	68	58	66	64	68
LO	53	44	35	33	45	47

Fig. 4.8.2.2 Example of NWS FORECAST MAP available at http://www.srh.noaa.gov/bmx/data/FARMERS_MAP/farmers_map.html

Alabama Animal Waste/Nutrient Land Application Map
Issued:Jan 27,2006 10:19PM Based on Current 72 Hour Forecast
Valid Until:01-28-2006 10:19AM



Areas in red are unfavorable for spreading of waste/nutrients
Areas in white are favorable for spreading of waste/nutrients
Click <here> to go to the forecast page

4.9.5.1.1d Examples of operational Agrometeorological services in India

India Meteorological Department (IMD) renders Agromet Advisory Services (AAS) to the farming community of the country in the form of bulletin. These advisories are prepared jointly by the experts of IMD and agricultural specialists of respective State Department of Agriculture and are tailored to the requirements of farmers in the state. These bilingual (in local/regional language and also in English) bulletins are disseminated on a real time basis through All India Radio, Doordarshan Kendras, newspapers and website of the IMD.

All the AAS centres of IMD actively monitor crop state, occurrence of pests and diseases and extreme weather events throughout the country. Accordingly, it issues forewarning for the pests and diseases and remedial measures to overcome from the extreme weather events etc. These are communicated to the users and also for the planners in time to safeguard the crops and for updating the status of agriculture at policy level in the respective states of the country. AAS centre at north-western parts of the country also monitors Desert Locust situation in Northwest India and issues advisory to all the concerned State Department of Agriculture. Some examples on agrometeorological service in different regions of India are listed below:

Northwest India:

Severe frost conditions prevail in Himachal Pradesh and Jammu & Kashmir during second week of January. Snow fall likely to occur at a few places over Himachal Pradesh and Jammu & Kashmir divisions for the next five days. Under these circumstances, farmers in the above states were advised to take following precautionary measures:

- Irrigation should be given to protect the standing crops from ground frost as adequate soil moisture keeps the soil comparatively warm and save it from frost.
- Smoking should be done to protect the crop due to ground frost.
- In the morning two men holding rope should move across field so that dew formed over the leaves should fall down.
- Protect the young saplings of orchard trees from cold injury by covering them with polythene or paddy straw.

- As morning humidity will be of the order of 85% in Punjab and Haryana, there will be chance of rust diseases incidence (above economic threshold level) on wheat. It is advised to monitor the diseases incidences and apply Mancozeb at the rate Mancozeb @ 2 g / litre of water. Use 200 litres of water for one acre.

East India:

(i) Blast disease may appear in the seedbed of rice during this period due to prevailing weather conditions in West Bengal. If noticed, spray Ediphenphos 50% @ 1 ml or Triamiphos 48% @ 1 ml or Carbendazime 50% @ 1 ml per litre of water. 75 litres of water is required to spray 25 satak of seed bed land.

(ii) Downy mildew is reported in cucurbits in Orissa and the disease intensity is expected to increase further under the prevailing weather condition. To control downy mildew spray Redomyl / Mancozeb @ 2 g / litre of water. Use 200 litres of water for one acre.

Northeast India:

(i) There is a chance of incidences of pod borer on red gram during this period in Assam under prevailing weather condition. To control pod and apion borer spray Melathion 50EC @ 1.5 ml per litre of water or Fenitrothion 50EC @ 2 ml per litre of water on a non-rainy day.

(ii) As there was no significant rainfall in most of the districts in Assam during last few weeks and dry weather will prevail for next five days, apply required irrigation wherever crops are at pod formation stage.

South India:

(i) There was no rainfall for the last five weeks in all the districts of Andhra Pradesh and no significant rainfall is expected for the next five days. Under the circumstances, apply irrigation to the standing crops to bring the soil moisture to its field capacity.

(ii) Release predators like Dipha sp, adopt wider spacing, inter-crop with soybean and pulses of short duration and ratoon sugarcane to control wooly aphids in Mysore, Mandya, Hassan, Bidar & Bangalore districts in Karnataka.

(iii) Attack of red palm weevil is reported in coconut in Kerala. Fill leaf axil with Sevidol 8 G @ 25 gm mixed with fine sand 200 gm per tree and trunk hole filling and sealing with 10 ml. DDVP in 1 litre of water.

West India:

(i) The lowest minimum temperature of -02.0°C recorded at Pilani on 09.01.06. in Rajasthan. Cold wave conditions accompanied with ground frost likely to occur in extreme north of Jaipur and Bikaner divisions for the next five days. The following precautionary measures may be taken.

- Irrigation should be given to protect the standing crops from ground frost as adequate soil moisture keeps the soil comparatively warm and save it from frost.
- Smoking should be done to protect the crop due to ground frost.
- In the morning two men holding rope should move across field so that dew formed over the leaves should fall down.
- Protect the young saplings of orchard trees from cold injury by covering them with polythene or paddy straw.

(ii) As temperature is abruptly high i.e. 3 – 9^0C above normal in Rajasthan, maturity of barley and wheat may be advanced by about 10 – 12 days which may lead to shorter reproductive phase and lower yield of crops. Apply irrigation at frequent interval to barley, wheat, gram, cumin, beans and vegetables to supplement the high rate of transpiration from the crop as temperature is 3 – 9^0C above normal and there was no rain over the State for last few weeks and the dry weather will prevail for next five days.

Central India

As there was no significant rain during last few weeks and dry weather is likely to prevail during next few days in Madhya Pradesh and Chattisgarh, apply irrigation to the standing crops to bring soil moisture to its field capacity.

4.9.5.1.2 General purpose meteorological services

General purpose services produce and broadcast forecasts for very wide categories of end - users. These services could survey the needs of farmers and give information useful for this particular category of users, especially when this information is crucial for quantity and quality of production.

4.10 Long Range Forecasts

(contents of the paragraphs of this section have been mainly derived from http://www.ecmwf.int/products/forecasts/seasonal/documentation/ch1_2.html)

LRF are forecasts for periods greater than 1 month in advance.

4.10.1 The basis of LRF

Despite the chaotic nature of the atmosphere, long term predictions are possible to some degree thanks to a number of components which though showing variations on long time scales (seasons and years) are to a certain extent predictable (ECMWF, 2005). The most important of these components is the ENSO (El Nino Southern Oscillation) cycle that refers to the coherent, large-scale fluctuation of ocean temperatures, rainfall, atmospheric circulation, vertical motion and air pressure across the tropical Pacific. It is a coupled ocean-atmosphere phenomenon centred over the tropical Pacific but the scale of the fluctuations is quite vast, with the changes in sea-surface temperatures (SSTs) often affecting not just the whole width of the Pacific but the other ocean basins too, and the changes in tropical rainfall and winds spanning a distance of more than one-half the circumference of the earth. El Niño episodes (also called Pacific warm episodes) and La Niña episodes (also called Pacific cold episodes) represent opposite extremes of the ENSO cycle. The ENSO cycle is the largest known source of year-to-year climate variability (ECMWF, 2005).

Changes in Pacific sea surface temperature (SST) are not the only cause of predictable changes in the weather patterns. There are other causes of seasonal climate variability. Unusually warm or cold sea surface temperatures in the tropical Atlantic or Indian ocean can cause major shifts in seasonal climate in nearby continents. For example, the sea surface temperature in the western Indian Ocean has a strong effect on the precipitation in tropical eastern Africa, and ocean conditions in the tropical Atlantic affect rainfall in northeast Brazil. In addition to the tropical oceans, other factors that may influence seasonal climate are snow cover and soil wetness. When snow cover is above average for a given season and region, it has a greater cooling influence on the air than usual.

Soil wetness, which comes into play most strongly during warm seasons, also has a cooling influence. All these factors affecting the atmospheric circulation constitute the basis of long-term predictions (ECMWF, 2005).

To summarise, seasonal forecasts provide a range of possible changes that are likely to occur in the season ahead. It is important to bear in mind that, because of the chaotic nature of the atmospheric circulation, it is not possible to predict the daily weather variations at a specific location months in advance. It is not even possible to predict exactly the average weather, such as the average temperature for a given month (ECMWF, 2005).

4.10.2 Statistical and dynamical approaches to LRF

4.10.2.1 Statistical approach to LRF and related limits

A possible starting point for seasonal forecasting is a good knowledge of climate, that is, the range of weather that can be expected at a particular place at a particular time of year. Beyond a simple knowledge of climatology, statistical analysis of past weather and climate can be a valid basis for long-term predictions. There are some regions of the world and some seasons when statistical predictions are quite successful: an example is the connection between the rainfall in March-May in the Nordeste region of Brazil and the sea surface temperatures in the tropical Atlantic in the months before and during the rainy season (ECMWF, 2005).

Another example is the experimental forecasts of El Nino based on the study of correlation of this phenomenon and patterns of sea surface temperature, surface pressure and wind (Adams et al., 2003).

In theory a very long and accurate record of the earth's climate could reveal the combined (and non-linear) influences of various factors on the weather, and analysis of many past events could average out the unpredictable parts. In practice the 50-100 year records typically available represent a very incomplete estimate of earth's climate. In addition seasonal predictions based on past climate cannot take full account of anthropogenic or other long-term changes in the earth's system (ECMWF, 2005).

4.10.2.2 NWP approach to LRF and related limits

An alternative approach is to use the numerical weather prediction method by solving the complex set of hydrodynamic equations that describe the evolution of the Earth's climate system. For an NWP based seasonal forecast it is important to consider both the atmospheric and oceanic components of the Earth's system. In fact, the air-sea interaction processes that describe the complicated interchange between the atmosphere and ocean are essential to represent the ENSO cycle. Just as for synoptic range NWP forecasts, the calculation depends critically on the initial state of the climate system, particularly the tropical Pacific Ocean for ENSO. Because of the chaotic nature of the atmosphere, a large number of separate simulations are made. They will all give different answers as regards the details of the weather, but they will enable something to be said about the range of possible outcomes, and the probabilities of occurrence of different weather events (ECMWF, 2005).

If the numerical models were very realistic, and if very large ensembles of such calculations could be performed, then the probability distribution of weather to be expected in the coming months would be accurately described. To the extent that predicted distribution differs from normal because of the initial conditions of the ocean/atmosphere/land-surface, the ensemble calculations could predict the correct seasonal forecast "signal". Unfortunately there are a number of problems that limit the seasonal forecast skill. Numerical models of the ocean and atmosphere are affected by errors, observations of the ocean are sparse, and techniques for estimating the extra uncertainty that this introduces are not yet well developed (ECMWF, 2005).

4.10.3 Reliability of LRF

The benefits of seasonal forecasting are likely to be most evident in forecasts for the tropics. This is because tropical areas have a moderate amount of predictable signal. This explains the use of LRF as a component of early warning systems (Sinha Ray, 2000) in order to extrapolate the potential occurrences of ENSO related extreme weather/climate events. Models which transfer projected ENSO signals directly into agricultural stress indices have been developed for agricultural application (ECMWF, 2005). In contrast in mid-latitudes random weather fluctuations are usually larger than the predictable component of the weather.

Much work will be needed to relate probabilities of large-scale weather patterns to detailed impacts and applications. It must be remembered, however, that there are tight limits on what is physically possible to achieve with a seasonal forecast system. It will only be possible to predict a range of likely outcomes. In many cases this range will be relatively large, and there will always be a risk of something unexpected happening. In many parts of the world, most of the variability in the weather will remain unpredictable (ECMWF, 2005).

Some seasonal forecasts available today are issued with probabilities (or error bars) which have been properly calibrated against past cases. An example is the Canonical Correlation Analysis (CCA) prediction of El Nino variability, which is regularly shown in the NOAA Climate Diagnostics Bulletin. Such forecasts are probably fairly reliable, but they have very wide error bars: they may state that in 6 months time there might be strong El Nino conditions, or fairly strong La Nina conditions, or anything in between (ECMWF, 2005).

4.10.4 Quality control of forecasts

4.10.4.1 Quality control data

Quality check of forecasts is an instrument for services and for end-users. In particular end-users can choose better forecast products and services. Thornes and Stephenson (2001) presented six attributes of a weather forecast that make up the total quality: reliability, accuracy, skill, resolution, sharpness and uncertainty.

The reliability of a forecast can be measured by calculating the bias. This will show if the forecasters are consistently over-forecasting the number of particular events (e.g. frosts or snow).

The percentage of correct forecasts is a very simple measure of forecast accuracy.

There are many different skill scores (e.g.: *Pierce Skill Score, Odds Ratio Skill Score)* that attempt to assess how much better the forecasts are than those which could be generated by climatology, persistence or chance.

Resolution is important in the forecasting of precipitation – being able to distinguish between, for example, snow, sleet, freezing rain, hail, drizzle and rain. Sharpness is a measure of the spread of the forecasts away from climatology, e.g. a forecast method that can predict frosts in spring as well as winter shows high sharpness whereas a forecast method that can only predict frosts in winter has low sharpness. Uncertainty relates to the climate, for instance some areas have comparatively fewer frosts than others.

A number of measures of forecast quality are therefore required, but in order to avoid confusion they must be easy to calculate and their statistical significance should be testable (Thornes and Stephenson, 2001). The production and release of quality control data is important in order to guide the choice of the right weather prediction by farmers. If quality data aren't available, agrometeorologists or farmers can use directly observed data (meteorological measurements of temperature, precipitation and so on, sky coverage and weather phenomena) in order to evaluate the skill of forecasts. Statistical analysis can be carried out by means of on parametric methods.

4.10.4.2 Feed-back to operational services

The feed-back of end-users is important in order to improve the forecast performance of services and single forecasters.

4.11 Dissemination of weather forecasts and advisories

Any information irrespective of its nature and importance is useless until and unless it is promptly delivered to the users (e.g. Vogel and O'Brien, 2006). Reliability of forecasts, expected weather-induced risks or weather-induced losses, and farmers' attitudes towards risk will affect the use of weather forecasts. Meinke et al. (2006) introduce salience, credibility and legitimacy as essential factors. All these factors can be assessed through the participation of farmers (e.g. Onyewotu et al., 2003; Roncoli, 2006). Farmers' risk bearing ability (income and assets) and individual characteristics such as vulnerability and preparedness will determine his/her attitude and adaptation skills towards risk. This combined with expected weather-induced losses will decide whether a farmer will be willing to use weather forecasts. Based upon his experience of traditional weather forecasts and expected losses due to adverse weather at different stages of crop growth, the extent of use of forecasts by farmers at different seasons and crop growth stages may vary. Thus, particularly in developing countries there could be a number of categories of forecast and information-using farmers (Rathore et al., 2006). In China it was concluded from large surveys that farmers of different income levels and rural people of different agriculture related occupations had clearly other information needs, other information sources and other uses of information also in relation to levels of education (Tan Ying and Kees Stigter, unpublished results). In this context the target groups of users may be different for weather forecasts services for agriculture and other agricultural advisories.

Weather forecasts are generally more used by highly skilled professionals such as researchers, extension workers, policy makers and progressive farmers. On the other hand, agricultural advisories are more used by formally less educated farmers for farm management. There are some similarities and dissimilarities for these two target groups. The first group of users may rely more on fast electronic transfer systems of information such as internet, CD, floppy, VSAT, email etc. Conventional methods of communications such as bulletins, pamphlets, posters, postal letters, newspapers, radio, TV, (mobile) phone, pagers, local announcements, village meetings, local time-bond markets and personal communication are better to reach the second group of users (e.g. Rijks and Baradas, 2000). With the advent of computers and Internet, emphasis is often being given to electronic communication systems. However, TV and radio services are still the best ways of communicating advisories among rural people as these are not only fast methods, but also large and illiterate masses can be contacted. Broadcasting of advisories in the local language provides an edge on other means of communication (WMO, 1992; Weiss et al., 2000). For TV and radio there remains the drawback that information appears only for short periods, unless taped, while much Internet based information can be accessed for a longer time.

4.11.1 New dimensions in dissemination technology

There is very fast technological advancement in information technology. It has been well claimed that the present century will be of information technology. Easily available fast Internet facilities, supercomputers, high capacity servers, efficient linking between information points have added the much needed boost in the information technology. While in the last century the communication systems were mostly one-way communications, in the present century interactive communication systems are being discussed more profoundly. There are some examples of interactive communication systems for agricultural advisory dissemination, which are being adopted commercially by the most advanced providers and users in USA, Japan and some European countries. However, the choice of technology must be carried out at a very local level and farmers have to be reached and exposed to services information. This applies to developed and developing countries alike (see also Chapter 17 of this Guide).

4.11.2 Internet based communication systems

The advantage of Internet based interactive system is that spatial variability in soil and management practices can be addressed. Farmers are advised for their farm-specific problems (e.g. Maia et al., 2005). Local weather conditions, type of soil, type of crop and phenological stage, as well as level and type of insect-pest infestation is considered for advising for decision making on sowing, harvesting, irrigation, nutrient management and chemical application (e.g. DACOM, 2003). In this system, users have choice to provide the observed field conditions or to manipulate the input levels to analyze the different possible scenarios. An example from Denmark will elucidate this system. It should, however, also be realized that there is a serious risk that in many areas of the world we can't reach farmers through internet or other new technologies and we create auto-referential services.

4.11.3 "PlanteInfo **(www. PlanteInfo.dk)***" and other Internet case studies*

The Danish Institute of Agricultural Sciences (DIAS) and Danish Agricultural Advisory Centre (DAAC) jointly started the web based online information system "PlanteInfo" for decision support for crop production in 1996 on an experimental basis. PlanteInfo has gone through many alterations for almost a decade and now has reached maturity to advise on agricultural activities to farmers. More than 2% of farmers and 50% of crop advisers in Denmark are actively using PlanteInfo system. Most of the contents of PlanteInfo are delivered as personalized web pages requiring login; PlanteInfo holds information on user's geographical position and provides automatically web pages based on local weather observations and forecasts.

PlanteInfo as an agrometeorological service_provides information concerning arable crops (spring and winter wheat, spring and winter barley, oat, winter rye, triticale, spring and winter rape, peas, sugar beet and potato), fodder crops (grass and maize), vegetables (carrots, cauliflower, cabbage and onion) and fruits (strawberry and apples). A simple mechanistic simulation model runs in the background on input data generated by PlanteInfo (Thysen and Jensen, 2004). Crop development and soil characteristics are considered for the decision making on irrigation and nutrient management. A separate module provides information on pest and diseases on the basis of weather parameters (temperature sum, soil temperature sum, rainy days, rainfall, humidity etc), and current state of crop as well as weeds, pests and diseases. Farmers are required to select the type of crop and cultivars and other input parameters like weather station, soil type etc. from a look up table. Same time farmer is supposed to furnish information on sowing, crop stage, amount of nitrogen applied, irrigation and previous crop (for residue management). The output is provided as a document, which can be used after considering the local conditions.

Other web-based systems, which provide agrometeorological services for crop management include SAgMIS in the Republic of Slovenia for irrigation management (Susnik & Kurnik, 2004); IRRINET, BIDRICO and PLASMO in Italy for irrigation management (Rossi et al., 2004), irrigation and frost management (Gani et al., 2004), and grapevine downy mildew control (Orlandini et al., 2004), respectively; and ISIP (Information System for Integrated Plant Production) in Germany for plant protection (Röhrig and Sander 2004). Another web-based system was developed by Paz and Batchelor (2003) for soybean crop in USA but forecasted weather was not included and it does not deliver advices.

Internet is also used in non-interactive mode for dissemination of agrometeorological services. They are kept in text-form on Internet, which are accessible for users from certain URLs for example www.agmet.igau.edu.in (Sastri et al., 2005). Advisories are also sent from Internet to the users by the email list servers, which require the email address of the users.

The Advice concept (Thysen and Jensen, 2004) is aiming at bridging the information gaps and interest conflicts between information providers, information users (farmers) and intermediates (local advisers). It was observed over time that farmers are not enthusiastic to adopt the computer based interactive advanced technology of advisory dissemination due the unwillingness to invest sufficient time in learning how to use the technology. But in recent past, agriculture is becoming an enterprise and a large number of professionals are engaged in the work of commercially_advising the farmers.

4.11.4 Mobile phone based communication system

Mobile phones based dissemination systems of services are used in both interactive and non-interactive mode. The most advantageous feature of mobile phone based systems is that farmers are able to communicate with the web-based systems, while in the field and can request for advice concerning a newly discovered problem. Farmers can also update the farm database immediately after observations or application of treatments. In PlanteInfo, Irrigation Manager has been optimised to advise on irrigation scheduling for individual fields. The Irrigation Manager requires set-up with information on soil type, crop and emergence date. Local weather data (observed and forecasted) are provided by the PlanteInfo weather database. The request is sent from the mobile (smartphone) to the PlanteInfo server, which is directed to the PlanteInfo Mobile homepage. Users can access the PlanteInfo system on mobile and generate the desired output in an interactive mode.

Mobile based communication system can also be used to get services and_information in non-interactive mode. This mode is generally used for receiving the weather forecast or warning of weather hazards such as frost, flash flood, and forest fire. PlanteInfo system provides services and information related to weather and agricultural warnings in both modes of mobile communication.

A frost warning system through Short Messaging Service (SMS) was launched in Friuli Venezia Giulia of North-East Italy in 2003. This region is prone to frost especially in the months of March-May and November. Algoritmo di Nowcasting per le GELAte (ANGELA) model forecasts the night temperatures with a time resolution of one hour. Frost warning is sent to farmers through SMS twice per night, for taking necessary action to protect the crop (Gani et al., 2004). Probable time and the region of frost occurrence are mentioned in SMS. Norwegian Meteorological Institute (NMI) in Norway using VIPS (Folkedal and Brevig, 2004) and Governmental Extension Services (GES) in Germnay using ISIP (Information System for Integrated Plant Production) (Röhrig and Sander 2004) are providing information and services for crop protection through SMS since 2003. An_SMS system of information and_services transmission is also being tested by Environmental Agency of the Republic of Slovenia (EARS) for irrigation management (Susnik and Kurnik, 2004).

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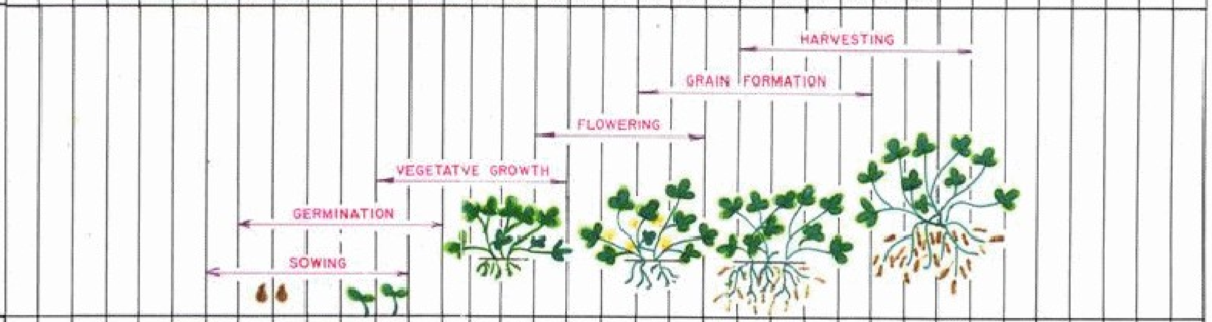
CROP WEATHER CALENDAR

STATE : ANDHRA PRADESH
CROP : GROUNDNUT(K)
VARIETY : TMV-2, JL-24, TMV-2, K3 (IMPROVED)
SOIL : RED SANDY LOAM/ SANDY CLAY LOAM
DISTRICTS : KHAMMAM, WARANGAL, KRISHNA, KARIMNAGAR
NON-IRRIGATED
DURATION : 100 - 110 DAYS

Weather warnings	Rain	> 50 MM	> 50 MM	> 30 MM
	Duration Of Wet Spell	> 10MM FOR 3 DAYS	> 30 MM FOR 3 DAYS	> 30 MM FOR 3 DAYS
	Cloudy Weather		CLOUDY WEATHER	CLOUDY WEATHER
	Drought	> 20 DAYS	> 20 DAYS	> 20 DAYS
	High Winds			
	Temperature	MAX.TEMP. > 35°C, MIN. TEMP. < 10°C	MAX. TEMP. > 40°C, MIN. TEMP. < 18°C	MAX. TEMP. > 40°C, MIN. TEMP. < 18°C
	Hail Storm			HAILSTORM
Weather conditions favourable for incidence of pests and diseases	Pests	APHIDS, ROOT GRUB, LEAF FOLDER LEAF MINOR	APHIDS, THRIPS, LEAF FOLDER, LEAF MINOR	RED HAIRY CATERPILLAR
	Weather	CLOUDY WEATHER, RAIN, HIGH RH WITH LOW TEMP.	LOW TEMP AND HUMIDITY, CLOUDY WEATHER, AND RAINS	LOW TEMP AND LOW RH, CLOUDY WEATHER RAINS
	Diseases	COLLAR ROT, STEM ROT, WILT, LEAF WEBBR	TIKKA, LEAF SPOT, SPEDOTIVE, BUDNECROSIS	TIKKA LEAF SPOT, RUST, ROOT ROT, COLLAR ROT
	Weather	HIGH RH, LOW TEMP, CLOUDY WEATHER	HIGH RH, LOW TEMP, CLOUDY WEATHER	HIGH RH, LOW TEMP, CLOUDY WEATHER

Standard weeks		22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Normal phase wise Water requirement(mm)						54.3		118.4				172.5				127.6				99.5								
Weekly normal weather	Rainfall(mm)total			28.3	44.2	48.8	50.3	54.9	57.4	64.1	51.7	42.1	43.2	48.2	43.3	47.3	39.8	42.7	38.6	25.1	21.2	23.0	18.1	19.0	13.3			
	Max.temp. °C			37.5	36.0	34.0	33.6	33.1	33.1	32.7	31.8	32.2	32.5	31.8	32.2	32.2	32.6	32.7	32.7	33.3	33.1	32.6	32.3	31.6	31.5			
	Min.temp. °C			26.6	26.3	25.4	25.0	24.9	25.0	24.7	24.5	24.5	24.6	24.6	24.4	24.2	24.4	24.3	24.1	23.7	23.3	22.7	22.0	21.5	20.4			
	Sunshine hours			5.6	5.6	4.0	4.0	4.9	4.7	4.8	4.	4.9	5.9	4.3	5.0	4.5	6.0	5.4	5.8	5.3	6.7	7.2	7.3	7.8	8.1			
Months		JUNE					JULY					AUGUST				SEPTEMBER				OCTOBER				NOVEMBER				

Life history and mean dates of important epochs of crop growth



D.D.G.M.(AGRIMET), I.M.D., PUNE 1996.

SSH → Sunshine hours, DUR → Duration, RH → Relative Humidity

Chapter 4 of GAMP, Figure 4.3.2.1

Università degli Studi di Milano

Faculty of Agriculture – Department of Crop Science

CAMPUS WEATHER FORECAST

Thursday 16 June '05

authors: Luigi Mariani and Domenico Ditto

(Students that want to co-operate to this forecast may contact prof. Luigi Mariani)

Forecast produced for educational aims. The use for commercial or operational aims is explicitly denied. Servizio Meteorologico dell'Aeronautica and ARPA – Servizio Meteorologico regionale are the authorities for operational weather forecasting in Lombardia. Our data is not an alternative or substitute for the official weather forecasts.

GENERAL EVOLUTION

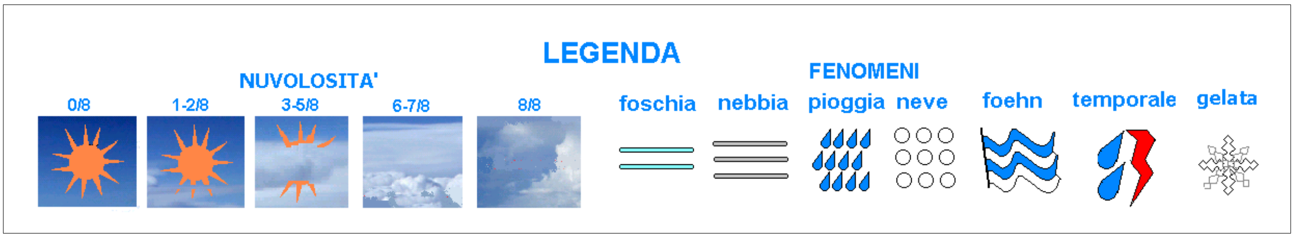
A ridge of the subtropical anticyclone gives conditions of stability and advects hot and humid air masses from North Africa towards Po plain. For the reference period weather will be sunny or almost sunny without significant probability of rainfall. Light winds or calm. Predictability of forecasted weather types: high until Monday, medium for Tuesday; low for the following days.

FORECAST FOR MILAN EAST – FACULTY OF AGRICULTURE

cloudiness and significant phenomena							
Thu 17/6	Fri 18/6	Sat 19/6	Sun 20/6	Mon 21/6	Tue 22/6	Wed 23/6	Thu 24/6
☀	☀	☀	☀	☀	☀	⛅	⛅
						💧	

Detailed forecast	
Thursday 17	**Friday 18**
Sunny throughout the day with a few scattered clouds No precipitation is expected. Light winds or calm. Low Temperature 20°C; High temperature 31°C.	Sunny throughout the day with a few scattered clouds. No precipitation is expected. Light winds or calm. Low Temperature 22°C; high temperature 30°C.
Saturday 19	**Sunday 20**
Sunny throughout the day. No precipitation is expected. Light winds or calm. Low Temperature 23°C; high temperature 30°C.	Sunny throughout the day. No precipitation is expected. Light winds or calm. Low Temperature 24°C; high temperature 30°C.
1.6.1 Monday 21	**Tuesday 22**
Sunny throughout the day. No precipitation is expected. Light winds or calm. Low Temperature 24°C; high temperature 31°C.	Sunny throughout the day. No precipitation is expected. Light winds or calm. Low Temperature 23°C; high temperature 29°C.
Wednesday 23	**Thursday 24**
Cloudy with low probability of rain (class 2; probability: very low). Light winds or calm. Low Temperature 23°C; high temperature 28°C.	Cloudy without rain. Light winds or calm. Low Temperature 24°C; high temperature 28°C.

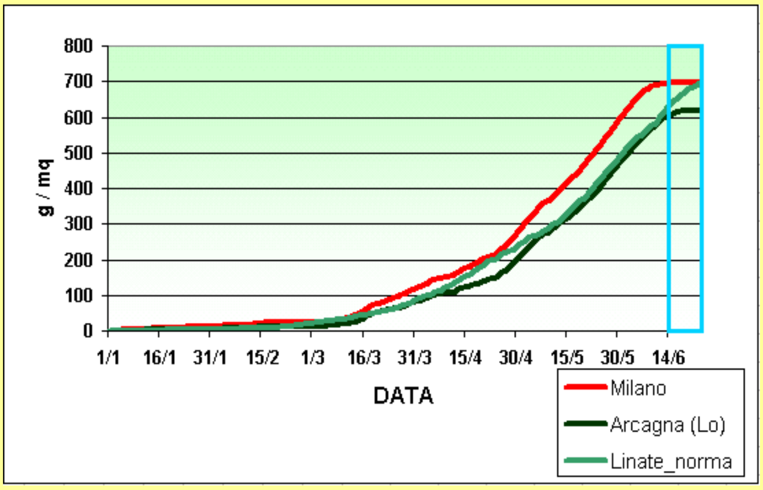
Pluviometric classes in 24 hours: Quantity: class 1: <1 mm (absent); **classe 2:** 1-10 mm (low); **classe 3:** 10-50 mm (abundant); **classe 4:** >50 mm (extreme) **probability for the reported class of quantity**: <1%=very low; 1-30%=low; 30-70%=moderate; >70%=high



AGROMETEOROLOGICAL MODELS - 1 january / 23 june 2005

(cyan boxes are for simulations carried out on forecasted meteo data)

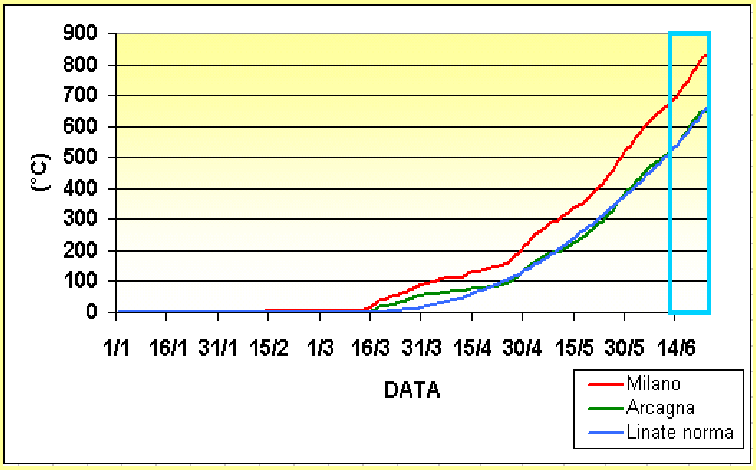
1. Net Primary Production (NPP)



Net Primary Production (NPP) represents the organic carbon cumulated by plants. In this case NPP is referred to a meadow of C3 plants (Arrhenatheretum) ed is estimated by SIM_PP model (Mariani, Bocchi e Maugeri) [Carbon data = g m^{-2}]

COMMENT TO DATA
The storage of carbon was stopped due to soil water shortage. In these conditions the total storage at Milano, that in the previous period was above the normal due to the UHI effect, is reached by normal production (Milano Linate).

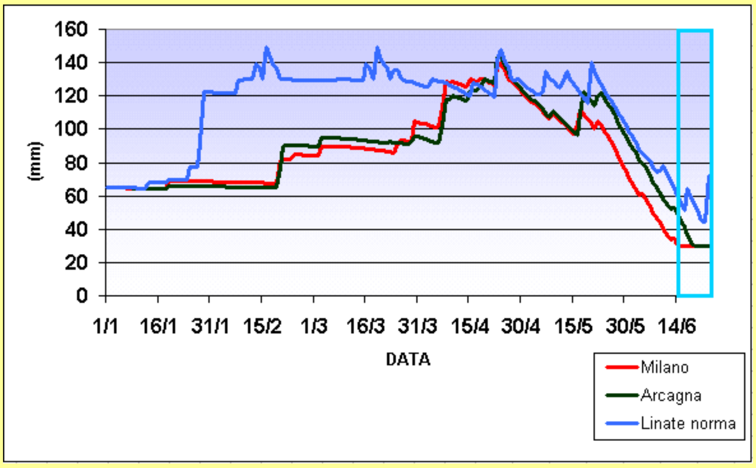
2. HEAT UNITS - BASE 10°C



Thermal units (TU) are calculated subtracting 10°C from mean daily temperatures and cumulating only positive values.
They represent a measure of thermal resources for plants which present minimum cardinal of 10°C (summer crops, vine).

COMMENT TO DATA
Very close to normal TU calculated for Arcagna. Positive anomaly for TU cumulated at Milano, forecasted in increase also for the next week.

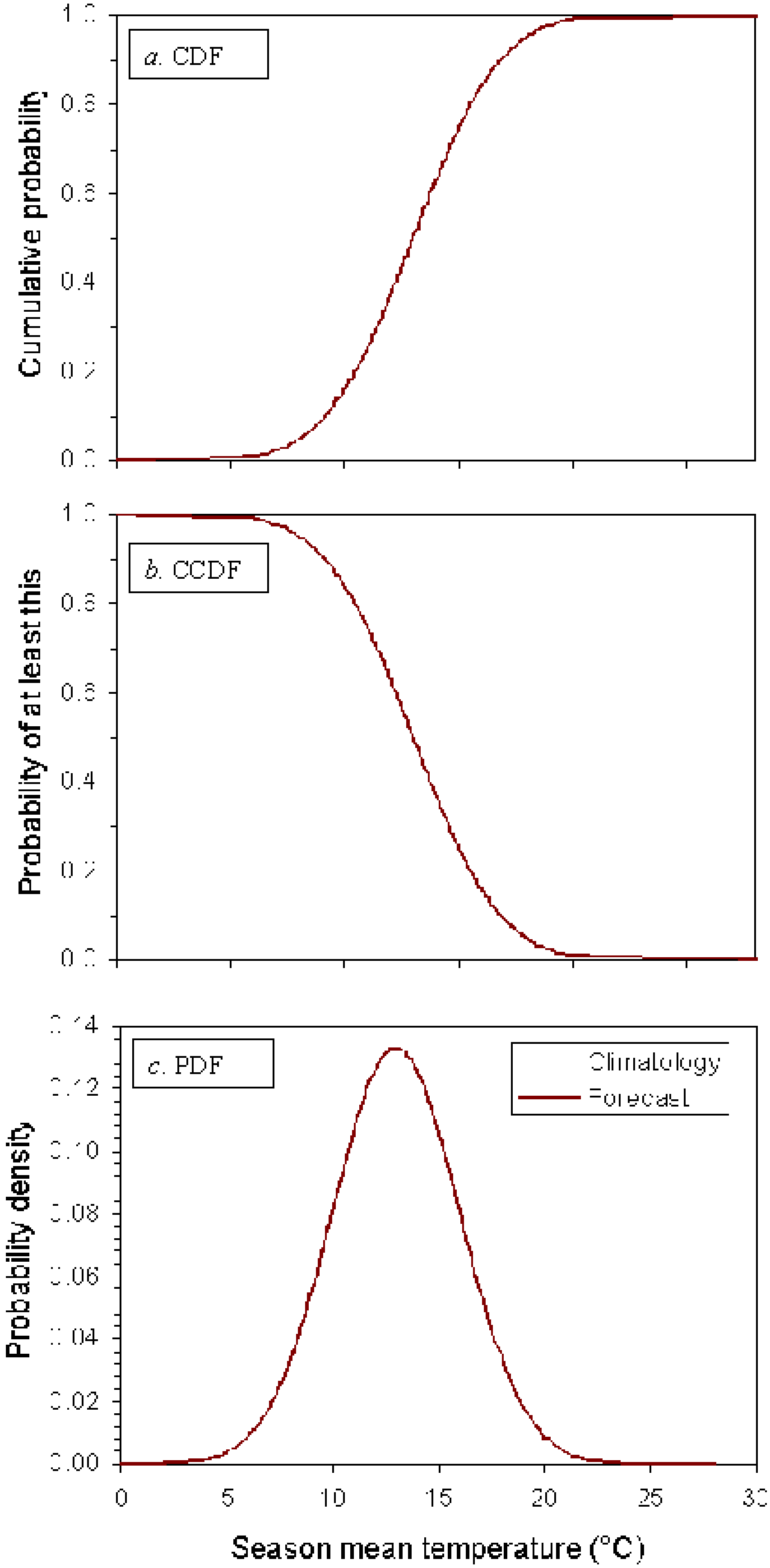
1.6WATER

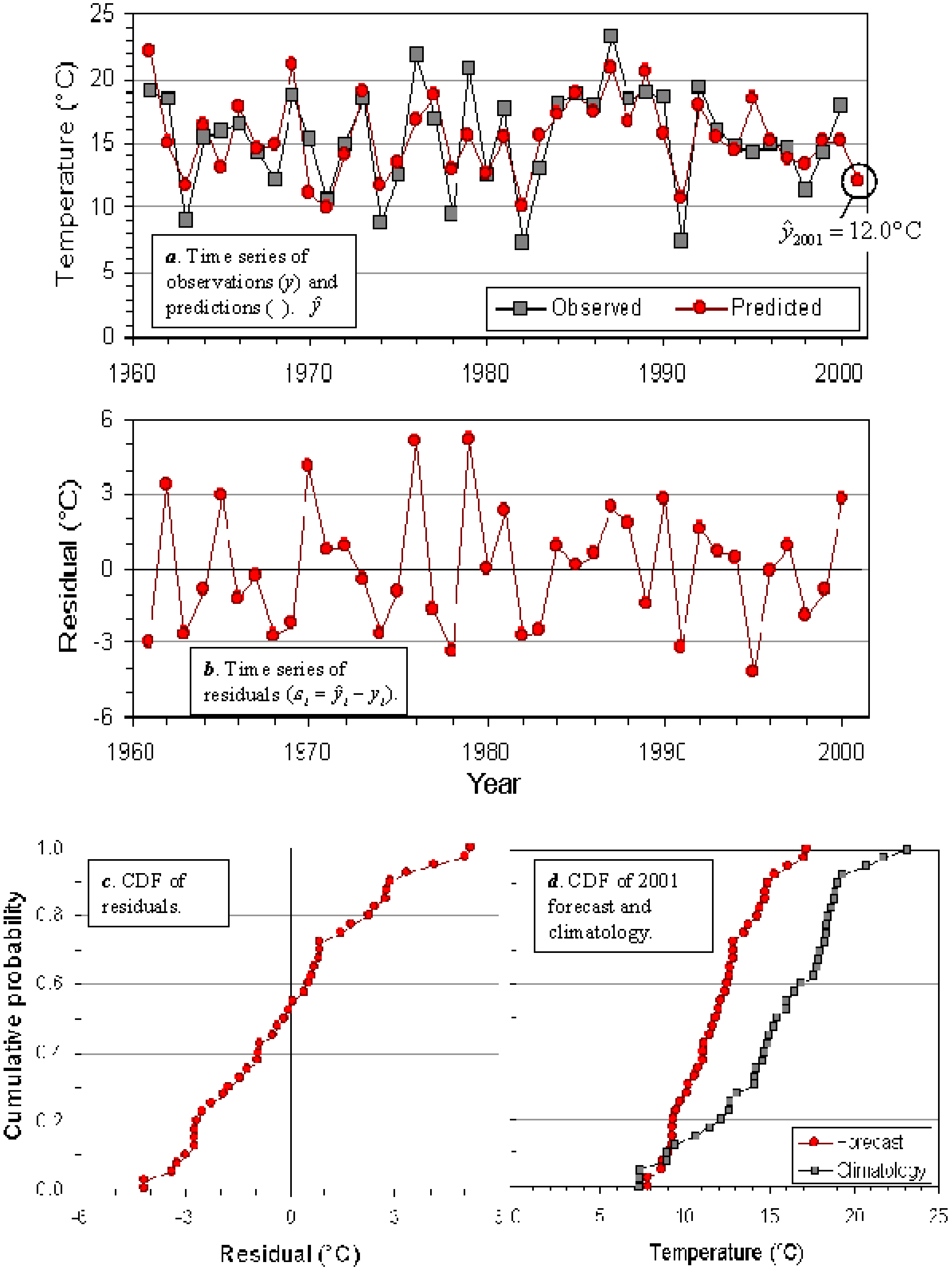


Soil water balance (WB) gives a quantitative evaluation of soil water useful for plants. This WB is carried out with the water balance unit of SIM_PP model (Mariani, Bocchi e Maugeri). Reserve is composed by a single reservoir with field capacity of 130 mm and wilting point of 30 mm. Water content at the beginning of balance was 50% of the AWC.

COMMENT TO DATA
The low levels of spring rainfall justify the anticipate emptying of soil water storage.

Sources of data: for the esperimental farm of Arcagna we used data of meteorological station of Montanaso (www.ucea.it); for Milano Linate the reconstruction of daily data was carried out by means of a data generator to monthly climate data 1971-2000 of Servizio Meteorologico dell'Aeronautica


a. CDF
Cumulative probability
1.0
0.8
0.6
0.4
0.2
0.0
b. CCDF
Probability of at least this
1.0
0.8
0.6
0.4
0.2
0.0
c. PDF
Probability density
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Climatology
Forecast
0
5
10
15
20
25
30
Season mean temperature (°C)


25
20
15
10
5
0
Temperature (°C)
1960
1970
1980
1990
2000
a. Time series of observations (y) and predictions ( ). $\hat{y}$
Observed
Predicted
$\hat{y}_{2001} = 12.0°C$
6
3
0
-3
-6
Residual (°C)
1960
1970
1980
1990
2000
Year
b. Time series of residuals ($\varepsilon_t = \hat{y}_t - y_t$).
1.0
0.8
0.6
0.4
0.2
0.0
Cumulative probability
-6
-3
0
3
6
Residual (°C)
c. CDF of residuals.
0
5
10
15
20
25
Temperature (°C)
d. CDF of 2001 forecast and climatology.
Forecast
Climatology