# A Prototype of Knowledge Base System for Weather Monitoring and Forecasting

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***ABSTRACT***

*We present the model of both structured and unstructured knowledge of weather features in this paper. An inference engine that simulates the model which is empowered to dynamically acquire knowledge is proposed. The output of the inference engine serves as input to the user-friendly, interactive, intelligent and menu-driven decision support engine. The decision support engine is characterized by a cognitive filter and an emotional filter and it is built to objectively and subjectively access and evaluate the alternative weather forecasts produced by the inference enigine with a view to arriving at the 'best' weather forecast. The case study of the system has been carried out using the data collected from the Meteorological Data Distribution (MDD) system installed at the Murtala Mohammed International Airport, Ikeja, Lagos, Nigeria. The results obtained from the weather forecast for Lagos are presented. The objective of the study is to provide an intelligent, symbiotic and convivial system that would combine the skill of human experts in meteorology and the power of computing system in the bid to carry out the task of weather monitoring and forecasting. Moreover, the proposed framework can serve as a Computer Aided Learning (CAL) system for weather monitoring and forecasting by the students of meteorology.*

## 1. INTRODUCTION

A timely and accurate knowledge of weather conditions are vital and beneficial in many ways. A farmer may want to know the onset and cessation of rainfall in a given cropping season to guide his planting and harvesting for optimal yield. The domestic air service as well as international air service requires the foreknowledge of weather for safe and economical operations in the aviation industry. Outbreak of epidemics following natural disasters adversely affects both private and public health. Severe weather conditions such as cyclone, thunderstorms, squall, strong winds, heavy rain, fog and dusthaze usually impede road and marine transport. Commerce is usually low during severe weather conditions. Communications are affected in bad weather, for example, the radio and television signals are poorly received in poor weather conditions. Certain cultural traits and dressing are influenced by the local weather conditions. Meteorological information isneeded by architects in the design of buildings for a particular environment and utility. Civil engineers and construction experts must take cognizance of weather parameters in the design and construction of roads, bridges, dams, water reservoirs, fish pond, swimming pool and so on. Government authorities that are concerned with water resources management are generally concerned with definite information on rainfall, humidity, temperature, evaporation, soil moisture, runoff conditions and so on. Good weather condition boosts tourism, entertainment, sporting and social activities. The foreknowledge of weather conditions could be very crucial to strategic military operations in modern warfare.

Weather monitoring and forecasting require a considerable amount of climate data which must be collected, coded, verified, validated, and entered into computer store. Such data would from time to time be selectively retrieved, updated, maintained, statistically and synoptically analyzed, for use in the preparation of weather forecasts. The forecasting process involves a combination of predictors (decision variables) which may assume an exponential growth when they become very large. The combinatorial analysis of very large decision variables may be explosive if manual processing is used. An expert system is a computer system that has the store of knowledge in a given domain of human expertise and possesses a means of processing that knowledge using programs and rules. In weather forecasting, symbiotic and convivial expert system can perform quick computations, advise the forecaster of errors, explain the origins of particular data, interactively analyze synoptic and climate features, and generate proposals according to constraints formulated by the forecaster in `intelligent' dialogue sessions, as would take place in discussions among the human experts.

CLImate COMputing christened CLICOM [WMO/NOAA, 1988, Lianso 1994] is a project of the World Meteorological Organization (WMO) aimed at developing a standard computer software package to facilitate the computer storage, retrieval, statistical analysis, transfer and exchange of climate data. The CLICOM is very broad and capable of performing a variety of tasks that are related to climatological data processing. The human-computer communication mechanism of the CLICOM is very complex to the extent that it is difficult for the users to easily understand and exploit many of its facilities. Moreover, the direct incorporation of some modern commercial software packages in the CLICOM software design creates an additional burden on the user tutorial requirements.

The CLIMate dataBASE christened CLIMBASE [Agrhymet 1992] is a project of the Agrhymet Meteorological Centre, Niamey, Niger, aimed at building and organizing a historical climate data collected by ground stations for use in third party application programs. The CLIMBASE appears to be a full-featured climate database software but it lacks the integration of different derived climate elements desirable for weather monitoring and forecasting. Moreover, the existing verification and validation schemes which border on security, privacy, access right and authorization are not adequate.

A number of work has been carried out in the Federal University of Technology, Akure (FUTA) on the development, operation and maintenance of Knowledge Based System for weather monitoring and forecasting [Akinyokun 1994, Anyiam and Adewole 1995, Anyiam et al. 1997, Anyiam 1998]. In this paper, we report the results obtained from the most recent research work on weather monitoring and forecasting. The case study of the system has been carried out using the data collected from the Meteorological Data Distribution (MDD) system installed at the Murtala Mohammed International Airport, Ikeja, Lagos, Nigeria. The results obtained from the weather forecast for Lagos on December 10, 1998 are presented. The objectives of the research work carried out in FUTA are as follows:

a. To provide a simple and complete computer based intelligent, interactive symbiotic and convivial system that would combine the weather experts skills and computing power to carry out the task of weather monitoring and forecasting more effectively and efficiently than could be done by a forecaster or computer alone.

b. To provide a means of self-education of weather forecasting by the meteorologist, forecaster, students of meteorology, pilots, navigators, dispatchers, sailors or any persons that are directly or indirectly affected by weather conditions.

## 2. CONCEPTUALIZATION OF WEATHER KNOWLEDGE BASE SYSTEM

The weather knowledge base system is made up of a knowledge base, inference engine anddecision support engine. The conceptual representation of the knowledge base system is presented in Figure 2.1.

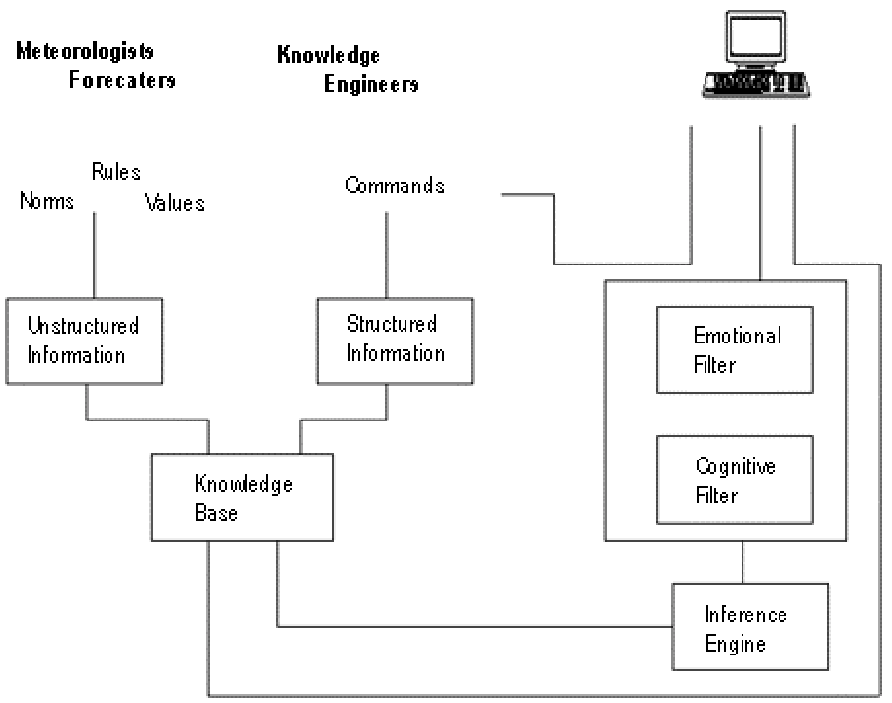


Figure 2.1 - Conceptual Diagram of Knowledge Base System

### 2.1 Knowledge Base

The knowledge base is composed of both structured and unstructured knowledge of weather features. The structured knowledge is concerned with the facts, rules, states and events of weather which are commonly agreed upon and widely shared by the human experts in weather monitoring and forecasting. It is, indeed, the knowledge acquired by study. The unstructured knowledge is that which is acquired by the human experts from experience. It is heuristic knowledge or that which is acquired by good practice, guesses and judgement. The knowledge base is conceptualized as a semantic network of relations. A relation is a two dimensional table where a row represents a record of a file and a column represents a record field (attribute). The general form of a relation is given by: R [$a_1$, $a_2$, $a_3$, ..., $a_n$] where R represents the name of a relation and the set {$a_1$, $a_2$, $a_3$, ..., $a_n$} represents the attributes of the relation R [Codd 1970]. Thus, a relation corresponds to a weather parameter while an attribute describes a temporal or spatial feature of a parameter.

The set of relations that are currently being considered for weather monitoring and forecasting are as follows:

MET-STATION [station-id, station-name, country, state, local-govt, longitude, latitude, elevation]

RAINFALL [station-id, start-date, end-date, start-time, end-time, amount]

TEMPERATURE [station-id, start-date, end-date, start-time, end-time, max-temp, min-temp]

DEW-POINT-TEMP [station-id, start-date, end-date, start-time, end-time, maximum, minimum]

SOIL-TEMP [station-id, start-date, end-date, start-time, end-time, max-05, min-05, max-10, min-10, max-20, min-20, max-50, min-50, max-100, min-100]

EVAPORATION [station-id, start-date, end-date, start-time, end-time, piche, pan]

SUNSHINE [station-id, start-date, end-date, start-time, end-time, hours-of-sunshine]

RADIATION [station-id, start-date, end-date, start-time, end-time, gunbellali, global-solar, direct-solar, reflected-solar, net-all-wave]

SURFACE-WIND [station-id, start-date, end-date, start-time, end-time, max-speed, min-speed, direction, gust-max-speed, direction-of-gust-max]

REL-HUMIDITY [station-id, start-date, end-date, start-time, end-time, maximum, minimum]

VAPOUR-PRESSURE [station-id, start-date, end-date, start-time, end-time, amount]

ATMOS-PRESSURE [station-id, start-date, end-date, start-time, end-time, station-pressure, sea-level-pressure]

CLOUD-COVER [station-id, start-date, end-date, start-time, end-time, total, wmo-lvl1, wmo-lvl2, wmo-lvl3, wmo-lvl4]

UPPER-AIR-SOUNDING [station-id, start-date, end-date, start-time, end-time, level, pressure, height, temp,dew-point-depression, wind-direction, wind-speed]

VISIBILITY [station-id, start-date, end-date, start-time, end-time, horizontal-visibility]

ALTIMETER-SETTING [station-id, start-date, end-date, start-end-time, horizontal-visibility]

SURFACE-CHART [station-id, synop-date, fcast-date, synop-time, wind-dir, wind-speed, pressure-system,duration, pressure -tendency, itd-position, visibility]

925-Hpa-CHART[station-id, synop-date, fcast-date, synop-time, wind-dir, wind-speed, pressure system, duration,itd-position]

850-Hpa-CHART [station-id, synop-date, fcast-date, synop-time, wind-dir, wind-speed, pressure-system, duration, geopotential-east, geopotential-west, easterly-wave, easterly-westerly-trough, itd-position].

700-Hpa-CHART [station-id, synop-date, fcast-date, synop-time, wind-dir, wind-speed, pressure-system, duration, geopotential-east, geopotential-west, easterly-wave, easterly-westerly-trough, itd-position].

## 2.2 Inference Engine

The inference engine, basically, adopts the forward chaining technique.The basic method of forward chaining arbitrarily starts by firing the first rule in the knowledge base and setting its conclusion to a "True List". The next rule in the knowledge base which uses the first rule's conclusion as one of its premises is fired and the procedure continues until all the rules are fired one after the other. The transcript of a typical forward chaining inference procedure is presented as follows:

==> IF ITD position is greater than $15^{o}$N and it is less than or equal to $21^{o}$N
THEN it is wet season

==> IF it is wet season
AND 850 Hpa vortex is intensifying
THEN weather is indicated

==> IF 850 Hpa vortex is weakening
THEN weather is NOT indicated

==> IF weather is indicated
AND wind direction is greater than 180 and it is less than or equal to 240
AND wind speed is greater than 10
THEN moisture is available

==> IF moisture is available
AND 700 Hpa Easterly wave is defined
AND Westerly and Easterly troughs are phased
THEN Deep convection is indicated

==> IF moisture is available
AND Deep convection is indicated
THEN Rain and Thunderstorm are expected

The 'True List' of the inference drawn above is as follows:

a. It is wet season
b. Weather is indicated
c. Moisture is available
d. Deep convection is indicated
e. Rain and Thunderstorm are expected

## 2.3 Decision Support Engine

Most people regard experience, intuition, value judgement and personal preference as vital ingredients of decision making process. These elements represent the parameters or factors of the cognitive filter and emotional filter. Decision making can be substantially improved upon by the application of the two filters which can systematically bring together all the ingredients that are desirable for an effective recipe for actions.

A true decision support engine helps the decision-maker to form preferences, make judgements and take decisions. Decision-making process has three components: namely: people, information technology and preference technology (emotional and cognitive filters). The people involved are primarily those having problems, in this case, the forecasters. The information technology consists of the computing system that handles the storage, processing, analysis of relevant information and providing software modeling assistance to determine the consequences of pursuing different alternatives. The third ingredient, preference technology (emotional and cognitive filters) helps to clarify both the objective and subjective value judgements made when evaluating the possible consequences of the alternative results.

Forecasters often waste time and resources using office technology to gather information in the hope of having sufficient facts desirable for decision-making. In this work, an attempt has been made to incorporate a decision support engine that helps the forecaster to translate a fuzzy problem into a more structured and manageable one. This is achieved through the dialogue sessions provided by the chart discussion module. By engaging the forecaster in a series of dialogues, emotional and cognitive elements filter the factors that may impede the making of meaningful and realistic decisions. The emotional elements comprise fatigue, stress, joy, sadness, anger, love and hate. The cognitive elements comprise intuition, experience, perception and so on. The focus is on the person, not on computing system. Thus, the proposed system helps the forecaster in forming preferences, making judgements and decisions.

## 3. CASE STUDY OF WEATHER KNOWLEDGE BASE

In our research, an attempt has been made to develop and implement a prototype of knowledge base system capable of monitoring and forecasting weather. The prototype is developed in Microsoft Access Database Management System and Visual Basic Language Application environment. It is implemented in a LAN environment that is characterized by Compaq Proliant as the file server, eight Compaq Deskpro 2000 as workstations and Microsoft NT Back Office as the distributed operating system. The prototype has been tested using the data obtained from Meteorological Data Distribution (MDD) System installed at the Murtala Mohammed International Airport, Ikeja, Lagos, Nigeria. The MDD System is a dedicated communication computer that receives alphanumeric data from Rome and Toulouse and graphical messages (weather charts) from Global Data Processing System (GDPS) Centres such as Meteo-France, European Centre for Medium Range Weather Forecasting (EC-MRWF), UK.

A weather monitoring and forecasting expert views the knowledge base system in a top down manner and gains access to it by supplying a valid user name and password, both of which serve as the access right control mechanism. If the access right is granted, the system presents a scenario of easy-to-understand main menu and subsequently some submenus. Any option of the main menu or a submenu selected shall call an inference procedure or module of a particular step in the weather monitoring and forecasting process. An inference procedure is interactive in nature and guides the human expert intelligently but always leaving the final decisions to the human expert. The transcript of the login menu is presented in Figure 3.1.

| YOU ARE PLEASE WELCOME<br>TO METEOCAST |
| --- |
| Please enter the following:<br><br>User Name:<br>Password: |

**Figure 3.1 - Login Process**

At the successful login, the main menu, which is depicted in Figure 3.2, is displayed on the screen. Selecting the option 'Synoptic Analysis' from the main menu, a submenu showing the various atmospheric levels for which chart discussion could be carried out is displayed on the screen. The chart discussion is concerned with the diagnosis of weather symptoms on the synoptic charts that indicate the present state of the weather from which its future state could be determined. The chart discussion is carried out in the form of dialogue between the computer system and the forecaster as would take place between meteorological experts in the Central Forecast Office. The chart discussion submenu is depicted in Figure 3.3.

| MAIN MENU |
|---|
| 1. Synoptic Analysis<br>2. Forecast Preparation<br>3. Weather Monitoring<br>4. Consultation<br>5. Exit<br><br>Please Select an Option |

**Figure 3.2 - Main Menu**

| CHART DISCUSSSION SUBMENU |
|---|
| 1. Surface<br>2. 925-HPA<br>3. 850-HPA<br>4. 700 HPA<br>5. Exit<br><br>Please Select an Option |

**Figure 3.3 - Main Menu**

Selecting an option from the chart discussion dubmenu causes a display of a dialogue box. A dialogue box presents the relation of the surface chart, 925-hpa chart and 850-hpa chart one at a time. Each answer to a question in the dialogue box represents an attribute of the corresponding relation in the knowledge base. It is noted that these three relations represent the regular atmospheric levels that are often considered in the daily weather forecast in Nigeria. Nine synoptic charts were obtained for Lagos on February 10, 1998. A synoptic chart represents the graphics or computer mapping of the structured meteorological knowledge from which the unstructured knowledge is derived. The results obtained from the chart discussion on the February 10, 1998 for Lagos are as follows:

<u>Surface Chart</u>

| | |
|---|---|
| Station-id: | 65201 |
| Synoptic-date: | 10.02.1998 |
| Fcast-date: | 11.02.1998 |
| Synoptic-time: | 00 Hours |
| Wind-dir: | SW |
| Wind-speed: | 15 |
| Pressure-system: | Low |
| Duration: | 24 |
| Pressure-tendency: | -1 |
| Itd-position: | 9 |
| Visibility: | Decreasing |

<u>925-hpa Chart</u>

| | |
|---|---|
| Station-id: | 65201 |
| Synoptic-date: | 10.02.1998 |
| Fcast-date: | 11.02.1998 |
| Synoptic-time: | 00 Hours |
| Wind-dir: | SW |
| Wind-speed: | 15 |
| Pressure-system: | Low |
| Duration: | 24 |
| Itd-position: | 9 |

<u>850-hpa Chart</u>

| | |
|---|---|
| Station-id: | 65201 |
| Synoptic-date: | 10.02.1998 |
| Fcast-date: | 11.02.1998 |
| Synoptic-time: | 00 Hours |
| Wind-dir: | SW |
| Wind-speed: | 15 |
| Pressure-system: | Low |
| Duration: | 24 |
| Geopotential-east: | +ve |
| Geopotential-west: | -ve |
| Easterly-wave: | Yes |
| Easterly-westerly-trough: | No |
| Itd-position: | 9 |

| FORECAST PREPARATION SUBMENU |
|---|
| 1. Make Forecast<br>2. Prepare Products<br>3. Exit<br><br>Please Select an Option |

**Figure 3.4-Forecast Preparation Submenu**

The completion of the chart discusion prepares the system for the making of a forecast. To make the forecast, the option 'Forecast Preparation' is selected from the main menu. This causes a display of the Forecast Preparation submenu depicted in Figure 3.4. From the Forecast Preparation submenu, the option 'Make Forecast' is selected in order to make the actual forecast. Before proceeding with the forecast, the system takes the forecaster through a verification and validation processes with a view to certifying that the chart discussion was actually carried out for the intended Meteorological Station. The verification and validation process is carried out by holding dialogue with the knowledge base system whereby the station identity, station name and date of synoptic analysis are supplied. At the successful completion of the verification and validation exercise, the system presents on the screen the following message:

Synoptic analysis completed
Do you want to proceed with the forecast (Y/N)

When the forecaster responds with a 'Y' answer, the system proceeds to make the forecast. The transcript of the output report or forecast generated for Lagos and adjacent territories on February 10, 1998 is as follows:

**Weather forecast issued on february 10, 1998**
**Valid from 6 Hours to 21 Hours on February 11, 1998**

**Heavy rain is expected over Lagos and adjacent territories**

On the February 11, 1998, about mid morning, it was observed that the forecast came true. There was heavy rain in Lagos lasting for about 30 minutes. As a result of this, some parts of Lagos became flooded and this can be confirmed in [The Guardian of February 12, 1998]. It is noted that the system's forecast compares favourably with that forecast issued by the meteorological experts at the Central Forecast Office (CFO), Oshodi, Lagos.

The other features of the system can be exploited by selecting the option 'Weather Monitoring' of the main menu. The weather monitoring session will cause the display of the weather monitoring submenu depicted in Figure 3.5 and facilitate the insertion of a new record, modification of an existing record or deletion of an existing record of a given file.For example, the selection of any option in the 'Weather Monitoring' submenu would cause the display on the screen the 'Knowledge Base Files' submenu depicted in Figure 3.6.

| WEATHER MONITORING SUBMENU |
|---|
| 1. Insert New Records<br>2. Modify Existing Records<br>3. Delete Old Records<br>4. Exit<br><br>Please Select an Option |

**Figure 3.5 - Weather Monitoring Submenu**

The selection of the option 'Consultation' in the main menu takes a user into the consultation session. The 'Consultation' submenu is depicted in Figure 3.7. During the initial familiarization with the system, a user may need explanation and assistance on how to use the system. The tutorial session presents the user explanatory notes on meteorological knowledge and the processing that may be carried out. The selection of option 2 in the 'Consultation' submenu enables the user to retrieve information such as monthly weather summary.

| KNOWLEDGE BASE FILES SUBMENU | |
|---|---|
| 1. Met-station | 13. Vapour-Pressure |
| 2. Rainfall | 14. Atmos-Pressure |
| 3. Temperature | 15. Cloud-Cover |
| 4. Dew-Point-Temp | 16. Weather |
| 5. Soil-Temp | 17. Upper-Air-Sounding |
| 6. Evaporation | 18. Visibility |
| 7. Sunshine | 19. Altimeter Setting |
| 8. Radiation | 20 Surface Chart |
| 9. Surface-Wind | 21. 925-Hpa Chart |
| 10. Rel-Humidity | 22. 850-Hpa Chart |
| 11. Forecast | 23. 700-Hpa Chart |
| 12. ITD | 24. Exit |
| Please Select an Option | |

**Figure 3.6 - Knowledge Base Files Submenu**

| CONSULTATION SUBMENU |
|---|
| 1. Tutorial<br>2. Information Retrieval<br>3. Exit<br><br>Please Select an Option |

**Figure 3.7 - Consultation Submenu**

## 4 CONCLUSION

A knowledge base system for weather monitoring and forecasting has been presented in this paper. The major features of the system are as follows:

a. A meteorological knowledge base which facilitates the computer storage, retrieval and processing of the structured and unstructured knowledge of weather features.

b. An inference engine that simulates the forecaster's thinking, remembers the relevant forecasting rules, draws from the recorded previous forecasters' experience in the knowledge base to make realistic and meaningful predictions and empowered to dynamically acquire knowledge that gives the system the capability to learn from experience.

c. A user-friendly, interactive, intelligent and menu-driven decision support engine composed of a cognitive filter and emotional filter can help the forecaster to form preferences, make judgements, and decisions and explain the decisions made.

The knowledge base system has been tested for weather forecast in Lagos, Nigeria on February 10, 1998 and Kano, Nigeria on February 12, 1998 and the results obtained compared favourably with that forecast issued by the meteorological experts at the Central Forecast Office (CFO), Oshodi, Lagos.

Recently, the Department of Meteorology of the Federal University Technology, Akure, Nigeria where the authors have done collaborative research work acquired some equipment which is remotely connected to some computers in the department's laboratory for the purpose of capturing weather data and storing them online.

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