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A PROTOTYPE EXPERT SYSTEM TO FORECAST SEVERE WINDS IN THE WESTERN MEDITERRANEAN SEA

by

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A prototype expert system is designed to forecast severe winds in the western Mediterranean Sea. The first version of the expert system is to nowcast levante conditions in the Strait of Gibraltar and to nowcast/forecast mistral conditions in the Gulf of Lion. Rules of thumb for these events from the *Handbook for Forecasters in the Mediterranean* (Brody and Nestor 1980) are tested with observations during the period September 1988 through February 1989. Of the 19 rules listed in the *Handbook* for levante, five are used in the expert system without modification, six are modified and eight are discarded. Of the 41 rules for the mistral, 14 are used without modification, two are slightly modified and 25 are eliminated. The first step in each case is to select adjacent land stations whose observations best infer the presence of the gale wind conditions over the open seas, where in situ observations are not available. The basic approach in the expert system is to provide an ordered sequence of rules (based on the verifications during the six-month period) that the forecaster can continue to test until a forecast decision can be made with confidence. Operational testing is needed to refine the severe wind algorithm, which can be easily modified to include more empirical rules from expert forecasters in the future.

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A Prototype Expert System to Forecast Severe Winds in the Western Mediterranean Sea

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ABSTRACT

A prototype expert system is designed to forecast severe winds in the western Mediterranean Sea. The first version of the expert system is to nowcast levante conditions in the Strait of Gibraltar and to nowcast/forecast mistral conditions in the Gulf of Lion. Rules of thumb for these events from the *Handbook for Forecasters in the Mediterranean* (Brody and Nestor 1980) are tested with observations during the period September 1988 through February 1989. Of the 19 rules listed in the *Handbook* for levante, five are used in the expert system without modification, six are modified and eight are discarded. Of the 41 rules for the mistral, 14 are used without modification, two are slightly modified and 25 are eliminated. The first step in each case is to select adjacent land stations whose observations best infer the presence of the gale wind conditions over the open seas, where *in situ* observations are not available. The basic approach in the expert system is to provide an ordered sequence of rules (based on the verifications during the six-month period) that the forecaster can continue to test until a forecast decision can be made with confidence. Operational testing is needed to refine the severe wind algorithm, which can be easily modified to include more empirical rules from expert forecasters in the future.

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This study could not have been undertaken without the support of a great many people. My thanks go to Prof. Russell Elsberry for recognizing my need to return something to the Fleet. By allowing me to take on a project that was outside his area of interest, he allowed me to pursue my area of interest. CDR Kris Harper provided the programs to extract the data from the magnetic tapes provided by Dennis Laws of the Fleet Numerical Oceanography Center. Paul Dobos assisted me during my initial struggle to learn the PROLOG computer language and Jim Peak of Martin Marietta Data Systems helped me put the expert system into a useable format. Both of these men provided the encouragement that I needed to continue.

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I. INTRODUCTION

A. NEEDS ASSESSMENT

The United States Navy is a blue-water navy. The battleship U.S.S. New Jersey sailed on what was to be a short cruise of the Pacific and was redirected to a battle off the coast of Lebanon. In these days of diminishing assets and increasing responsibilities, similar events could be easily experienced by any battleship or carrier battle group. When a ship leaves port, the materials onboard will be what she takes to the fight. It is not possible for a ship to carry a forecaster who is an expert on every part of the world. Space limitations on the ship make it impossible to carry the forecaster handbooks and port guides for every part of the world. However, it would be possible to carry a series of floppy disks that could be used on a desktop computer. The purpose of this research is to test the feasibility of such a computer-based system, and, specifically, to develop a prototype model for the western Mediterranean area.

B. THE NAVY SEVERE WIND PREDICTION PROBLEM

U.S. Navy enlisted Aerographer Mates currently attend a combined forecasting school at Chanute Air Base, IL, with their U.S. Air Force and U.S. Marines Corps counterparts. When the combined portion of the school is completed, the Navy personnel attend another forecasting school called "Navy Unique", which consists of 240 hours of extra training to prepare Navy forecasters to go to sea.

While meteorology is a science, weather forecasting is, in part, an art. Forecasting at sea raises that art to a higher plateau. The Navy has a constant turnover of experienced personnel. Navy forecasters that are assigned to a two- or three-year ship-board tour may have to forecast meteorological phenomena from the tropics to the arctic. All this movement makes the job of the Navy forecaster that much more difficult and challenging. Many times a forecaster has become experienced enough to develop intuition and empirical rules for his/her current location when it is time to move on. An additional benefit of the proposed expert system is that such forecaster knowledge or new insights could be recorded as potential new rules and tested for incorporation into the system.

Even when the forecaster is thoroughly familiar with the "rules of thumb", the required data may not be available. This problem is especially true at sea due to communication difficulties. In certain parts of the Mediterranean, copying facsimile broadcasts of forecasts is virtually impossible. Therefore, a backup system such as the Western Mediterranean Gale Forecasting Program, which is being designed to primarily use Automated Weather Network (AWN) data, would be a tremendous asset.

C. THE EXPERT SYSTEM APPROACH

Bigger and faster computers have been necessary to handle the ever increasing amount of weather data. These large computers generally are in central locations, and forecasters at sea may not have access to these advanced computers. This expert system was created on a laptop computer and was designed to run on a desktop personal computer. It is designed to deal with conceptual information and non-mathematical data such as a forecaster's experience and intuition. In the expert system, the computer language is designed to use sets of facts and rules to infer new facts from which conclusions can be drawn.

The Turbo PROLOG[1] Language is chosen to be the language of this expert system. Unlike the PROLOG or LISP languages that are in general use by the Artificial Intelligence (AI) community, Turbo PROLOG does not require a mainframe computer. Furthermore, the language is relatively simple to learn, and the software can be commercially obtained for less than $100. While Turbo PROLOG is missing some of the features of the more complex versions, such advantages as portability and ease of operation and program development far outweigh the disadvantages. Appendix A describes the Turbo PROLOG language in greater detail.

D. THE PROTOTYPE SYSTEM

This prototype system for forecasting severe winds in the western Mediterranean area is designed to be a stand-alone system. It is constructed in modular form to be easily incorporated into a larger Mediterranean Severe Wind Forecasting System planned for the future. The rulebase is made up almost exclusively of rules taken from the *Handbook for Forecasters in the Mediterranean* by Brody and Nestor (1980) that are currently in use by the Naval Oceanography Command Center, Rota, Spain.

The goal of the prototype (and future versions) expert system is a menu-driven algorithm that could be resident on a floppy disk and could be

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[1]Turbo PROLOG software is a copyrighted product of Borland International, Inc.

executed on a desktop computer. Before or during entry into a new area, the Navy forecaster could quickly review the rules of thumb for that area that are included in the expert system.

II. DEFINING THE PROBLEM

A. METEOROLOGICAL ASPECTS

The Mediterranean Sea and surrounding land areas comprise one of the most complex meteorological environments in the world. The numerous orographic and topographic features in the region present an extremely difficult, albeit interesting, challenge for both the novice and expert forecaster. The complex interactions between mountains and deserts, high plateaus and coastal regions, blocking terrain and mountain gaps produce some extremely dangerous wind conditions, particularly over the open water. This open-water wind forecast problem is the subject of this research and the accompanying expert system.

Mediterranean wind regimes have been studied by meteorologists for years. This chapter examines local wind regimes in general, moves to local wind regimes and the associated orographic and topographic effects in the Mediterranean area, and discusses some of the forecasting problems in the western Mediterranean. The concluding section introduces an expert system approach that may contribute to improved forecasts in this difficult area.

1. Local Wind Systems

The word local can be misleading when describing the wind systems in the Mediterranean. These winds can extend several hundred kilometers and be affected by all scales of motion. Since synoptic and mesoscale motions are the most important to this discussion, they will be addressed here and the microscale and macroscale motions will be ignored.

Synoptic-scale circulations in the Mediterranean may dominate an area of hundreds or thousands of square kilometers and persist for many days. The mistral (discussed below) is one such phenomena that is the result of the combined effects of the synoptic circulation, a fall wind and a jet-effect wind.

In the mesoscale, channeling and cornering effects are among the orographically controlled flow phenomena. Winds through the Straits of Gibraltar, Bonifacio and Messina (Figure 1) are examples of increased wind speeds due to the effects of channeling and cornering. These circulations dominate areas from tens to hundreds of square kilometers and may last from minutes to a day or longer.

A complete discussion of local winds would include sea and land breezes as well as mountain and valley breezes. Because this research deals mainly with non-diurnal wind regimes, these local effects will be ignored. Downslope winds are important to the stronger wind regimes in the Mediterranean. Winds that blow down an incline are called katabatic winds. Their speeds can range from gentle mountain breezes to speeds in excess of 100 kt. Katabatic winds are further divided by temperature. A cold wind is known as a fall wind; a warm wind is known as a foehn wind. As mentioned previously, the mistral is a result of a fall wind combined with other factors.

As the name implies, fall winds flow from elevated plateaus. In winter, as snow accumulates on a plateau, a shallow dome of high pressure forms over the area as the overlying air is cooled. If the horizontal pressure gradient is strong, as when a storm approaches, or if the air flow is forced through a narrow channel, the wind can increase dramatically as the cold air rushes downslope. Wind speeds often exceed 100 kt, particularly along the northern Adriatic coast of Yugoslavia.

Figure 1. Map of Mediterranean area with political boundaries and major cities (Reiter 1975)

2. Uniqueness of the Mediterranean Sea

The Mediterranean Sea is a region of multiple complexities. Not only are there multinational considerations for the weather forecaster, but there are geographical and topographical considerations as well (Figure 1). The deep penetration of the Mediterranean Sea into the land masses causes complex interactions between the North Atlantic Ocean and the European, Asian and African continents. According to the Meteorological Office, Air Ministry (1962):

> the winds in many places in the Mediterranean at levels from the surface up to about 850 mb are controlled by purely local surface effects, such as differential heating of land, sea and mountain or the constraints imposed by topography. As a result the surface winds bear less obvious relationship to the pressure gradient than in many parts of the world and may be difficult to interpret save in the light of detailed local knowledge.

The major wind systems in the Mediterranean region (Figure 2) are known by many different names. Some of these wind systems were named many centuries ago and are associated with numerous topographic gaps (Figures 3 and 4). The levante and the mistral, which occur in the western Mediterranean, are considered two of the most important as far as naval interests are concerned. Therefore, only the levante and the mistral rules will be evaluated for possible inclusion in expert systems. Since orography and the general effects of topography play a significant role in Mediterranean weather patterns, they will be discussed in depth.

a. Orography

The Mediterranean Sea lies between 30°N and 46°N, and between 5°30'W and 36°E (Figure 4). It extends approximately 2,500 miles from east to

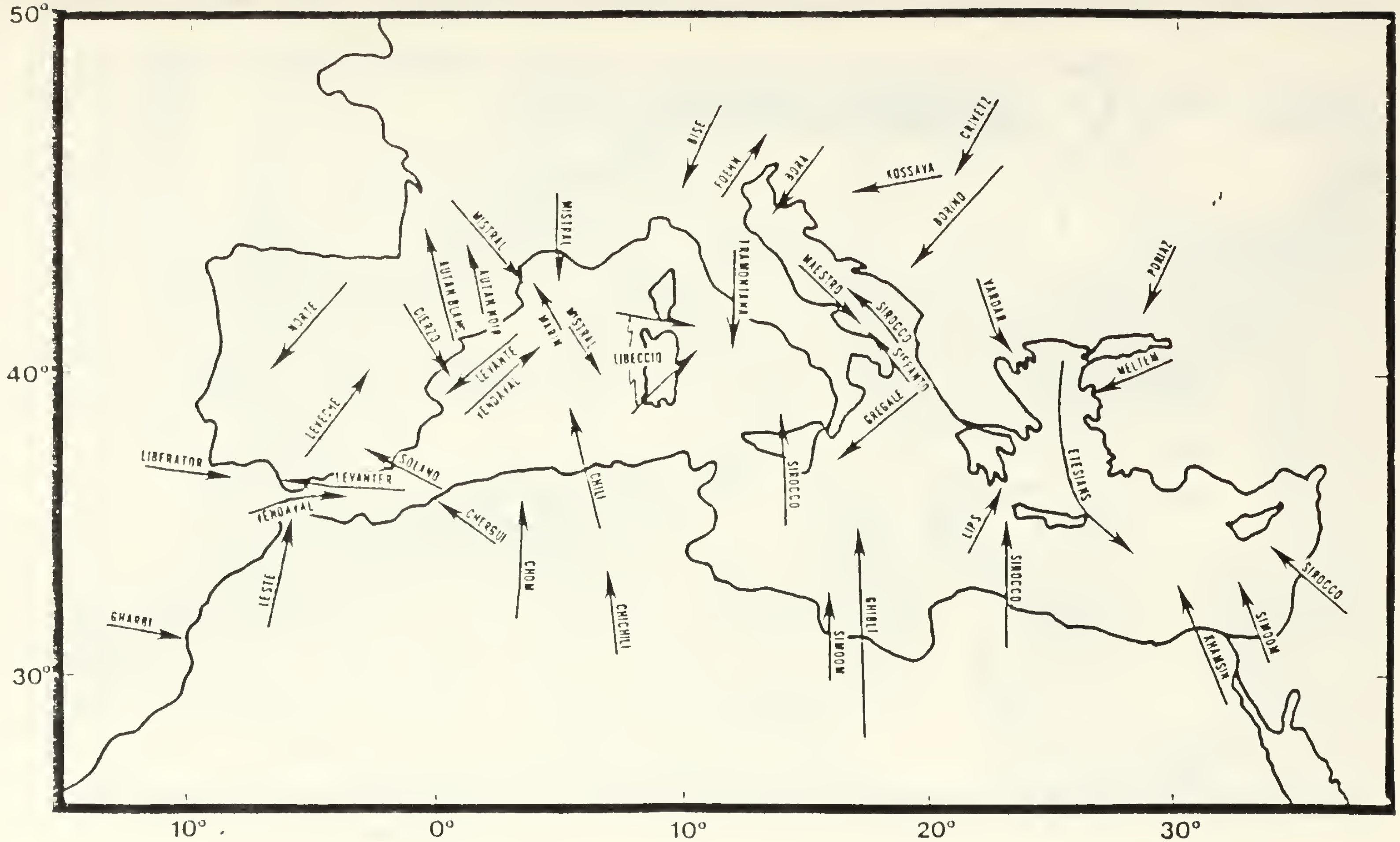


Figure 2. Major wind systems in the Mediterranean region (Reiter 1975)

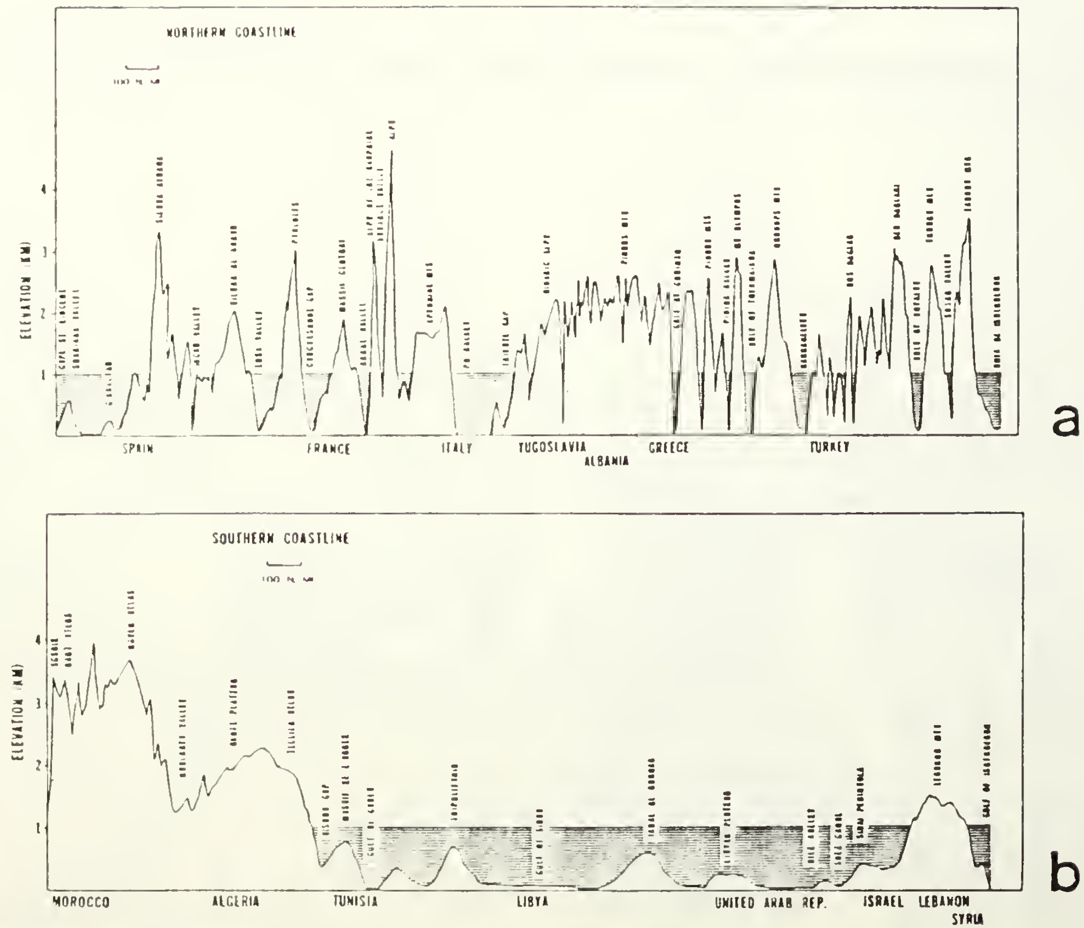


Figure 3. Cross sections, approximately parallel to (a) the northern and (b) the southern shores of the Mediterranean, and roughly 100 miles inland from the shore. Major orographic obstacles and gaps between mountains are indicated. Gaps below 1000 m are shaded. (Reiter 1975)

Figure 4. Map showing the topography of the Mediterranean area. (Reiter 1975)

west and approximately 500 miles north to south. The western outlet to the North Atlantic Ocean is through the Strait of Gibraltar, which is only eight miles wide at its narrowest point. The sea is enclosed by mountains lying close to the coast except along the North African coast east of Tunisia (Figure 4).

The Mediterranean Sea may be considered as being divided geographically into two basins by the peninsula of Italy and the island of Sicily. The western basin extends from the Strait of Gibraltar to the boot of Italy, while the eastern basin extends from Italy to the coast of Syria.

The western basin is surrounded by mountains over 3,000 ft high (Figure 4). The Iberian plateau in Spain, which covers most of the country, is generally between 1,500 and 3,000 ft but several mountain ranges exceed 6,000 ft. The Sierra Nevada and the Pyrenees (see Figure 3) each have one peak over 11,000 ft. North and east of the Pyrenees is the Garonne-Carcassonne gap, which separates the Pyrenees from the Massif Central of France. Farther to the east is the narrower Rhone-Saone Gap that separates the Massif Central from the Alps. The Alps rise to heights in excess of 10,000 ft and connect with the Apennines, which rise to peaks of 9,500 ft in central Italy. In Sicily, Mount Etna is more than 10,700 ft above sea level, with most of the other mountains about 3,000 ft high. The Strait of Gibraltar and the Alboran Channel separate the European mountains in Spain from the Atlas range in North Africa. The Atlas range lies parallel to the coast between 50 and 200 miles inland. Between 0° and 10°W, the higher Atlas ridges are over 10,000 ft with two peaks over 13,000 ft in the area between 6°W and 9°W near Marrakesh. Between 0° and 10°E, the mountains rise to heights between 3,000 and 6,000 ft, with one peak over 7,600 ft near 6°E. The coastal plain is narrow around the western basin except where the Rhone Valley enters the Gulf of Lion.

The western basin is separated into two water bodies by the mountainous islands of Corsica and Sardinia. Of the two, Corsica has the highest peaks with some exceeding 8,800 ft. Sardinia has only a small area over 3,000 ft. The Balearic Islands lie one hundred miles off the east coast of Spain. Majorca, which is the largest island, has a range of mountains in the northwest that are over 3,000 ft high.

b. Effects of Topography

Except over the southern shores east of Tunisia, the flow of air into the Mediterranean takes place mainly through gaps in the mountain ranges (Figures 3 and 4). The strong winds "funnelled" through these gaps are the most important and best known winds of the Mediterranean. The mistral is a northwesterly wind through the Alps-Pyrenees gap, and the levante is an easterly wind through the Strait of Gibraltar.

When the atmospheric pressure on one side of a mountain range is much greater than on the other side, there may be a significant wind increases through ravines. Examples of ravine winds are the bora and the mistral. In the vicinity of headlands, winds are often strengthened by horizontal confluence, and turbulence may occur due to eddy motion. Eddies in the lee of steep mountains, cliffs or hills may be particularly dangerous to aircraft and small vessels.

3. Forecasting Problems in the Western Mediterranean

The mountains to the north, the deserts to the south and the indented nature of many parts of the coast are responsible for the large number of regional and local wind regimes found in the Mediterranean. Large-scale topographical features of the surrounding land masses, such as major mountain gaps, are responsible for regional winds, while local winds are associated with minor features of the coastline and orography.

Correctly forecasting a levante is difficult because of the nature of the winds that occur in the region. The Strait of Gibraltar is only about eight miles wide and the winds on opposite sides of the Strait may be entirely different. One section of the Strait may be reporting gale conditions while another section is not. According to Rule 8 of Brody and Nestor (1980):

> during levante conditions in the Strait of Gibraltar, the area of maximum easterly winds is normally quite narrow, only about 2 n mi wide. This band of strong winds has been observed to extend 60 n mi westward of the Strait north of 36°N. A basic easterly airflow of about 15-20 kt produces a maximum band of 35 kt winds.

Chapter IV gives an indepth description of the levante.

Likewise, the mistral is difficult to forecast because of the combination of factors that contribute to its origin. A mistral is the result of the basic synoptic circulation, a jet-effect wind and a fall wind. An evening inversion over the Marseille station can easily fool a forecaster into believing that a light wind is blowing over the Gulf of Lion. When the inversion is destroyed during the morning, a very strong gale may be blowing over the water. A more detailed description of the mistral will be presented in Chapter V.

B. EXPERT SYSTEM ASPECTS

1. Prototype Scope

This limited prototype is the first step in the creation of a more complex expert system for the entire Mediterranean basin. At least two factors make this prototype step indispensable in creating a severe wind prediction system of this type. First, the complex nature of the phenomenon to be modelled, and the vast area to be covered, make the limited model a necessity. Second, the expert system concept needs to be tested and validated for this forecast application.

Due to the complexity of Mediterranean local wind systems, it would be very difficult to create an exhaustive model as a first step. L. R. Brody (personal communication, 24 May 1989) revealed that the rules of thumb had not been formally tested before inclusion in the *Handbook for Forecasters in the Mediterranean* (Brody and Nestor 1980). The rules had been collected from various sources and simply grouped in a logical order. Therefore, all the available rules had to be tested before the expert system could be produced. Testing the rules of thumb for the levante and the mistral portion in this study involved the collection and processing of over 72,000 pieces of information.

The second problem in developing a comprehensive Mediterranean severe wind forecasting system is that it has not been done previously. It is unclear whether such a system is feasible, or if it will be useful to the operational forecaster. Therefore, a limited prototype expert system is chosen as a reasonable goal for this research.

2. Selecting the Goal

The original intent of this research was to build a prototype expert system for most of the major wind regimes in the Mediterranean: levante, mistral, sirocco, bora and etesian. It quickly became apparent that the rules of thumb first had to be tested. Thus, this original goal was too ambitious. Since all of the ships attached to the U.S. Navy Sixth Fleet must enter the Mediterranean through the Strait of Gibraltar, the western Mediterranean area was chosen as the focus of this study.

In contrast to the expert system of Hagaman (1988), *in situ* observations of wind conditions over the open water are not available for the levante or mistral. Thus, the "goal" of the expert system could not be to forecast the series of 3 h wind observations that accompany the onset of each event in the archives. The first step in developing the expert system will be to infer the gale wind conditions from adjacent land stations. The absence of a specific observation as the "goal" also changes the approach in the expert system. As will be discussed in Chapter VI, the expert system will be structured to present an ordered series of rules that the forecaster can continue to test until a forecast decision can be made with some confidence. In some situations, the appropriate forecast will be obvious after only a few steps, and the forecaster can terminate the session. In more marginal situations and in the absence of recent ship observations, more steps or the complete sequence of rules may be examined.

III. DATA COLLECTION

A. STATION SELECTION

One objective of this project is to evaluate critically and to provide quantitative estimates of the degree of confidence in the "rules of thumb" that have been proposed for use by operational forecasters in the Mediterranean theater. These rules constitute the potential knowledge (rule) base for the Mediterranean Gale Forecasting Expert System. These rules of thumb from Brody and Nestor (1980) are considered to be the best available. They are widely used by the Naval Oceanography Command Center, Rota, Spain. Application of these rules of thumb require observations from the stations in Table 1.

Each of the stations in Table 1 contributed one or more of the meteorological variables necessary to evaluate a specific rule of thumb. Each rule and the associated meteorological variables are discussed in Chapters IV and V for the levante and mistral respectively.

The data for this project are from the archives of the Fleet Numerical Oceanography Center (FNOC), Monterey, California. Mr. Dennis Laws and his staff provided land synoptic data for every 3 h and upper-air and ship synoptic reports for every 6 h from September 1988 through February 1989.

The months of September through February were chosen for their variability. While summertime is an important levante period, it can occur in other seasons as well. The mistral is predominantly a wintertime phenomena.

TABLE 1. REPORTING STATIONS FOR SURFACE AND UPPER AIR OBSERVATIONS TO EVALUATE LEVANTE AND MISTRAL CONDITIONS. THE NORMAL REPORTING INTERVALS ARE 3 H FOR SURFACE AND 12 H FOR UPPER AIR STATIONS.

Levante	Mistral
surface	
08306 Palma	07579 Orange
08359 Alicante	07587 Lus La Croix Haute
08449 Rota	07643 Montpellier
08458 Tarifa	07647 Istres
08482 Malaga	07650 Marseille/Marignane
08490 Alboran	07690 Nice
08495 Gibraltar	07747 Perpignan
60101 Tangier	16506 La Maddalena
60127 Taza	
60155 Casablanca	
300 mb	
08221 Madrid	none
08359 Alicante	
08495 Gibraltar	
500 mb	
	07110 Brest
none	07510 Bordeaux
700 mb	
08495 Gibraltar	none

The Naval Environmental Display System (NEDS) was used to generate the graphical displays to evaluate the position of the jet steam, location of the 500 mb trough, position of cut-off lows and general synoptic conditions. The most helpful products were the European Center for Mid-range Weather Forecasting (ECMWF) 500 mb height fields and sea level pressure analyses. The 12 h FNOC North Atlantic maps for the surface, 500 mb and 300 mb were used to fill gaps in the ECMWF coverage of the pressure/height fields.

No satellite data are used in this study because this preliminary system is designed to be used by a forecaster in the field who may not have access to any satellite information. The observations required for applying the expert system should be available from the World Meteorological Organization (WMO) data received over a regular Automated Weather Network (AWN) broadcast. The flexibility to add new sources of data is one of the major advantages of the expert system approach. Consequently, rules of thumb related to satellite imagery could be added later.

B. DATA PROCESSING

The FNOC data were provided on tape and microfiche. It was then transferred to the computers at the Naval Postgraduate School (NPS) Interactive Digital Environmental Analysis (IDEA) Lab. A program written by CDR Kristine Harper was used to extract the required observations at the stations listed in Table 1.

The observations were extracted and recorded manually on special forms in daily packets (see sample in Appendix B). For example, the surface winds at Tarifa, Gibraltar, Taza and Alboran Island are given in adjacent columns for ease in determining if levante conditions exist. Similarly, the sea level pressure differences at selected stations and the associated wind speeds are grouped for ease of comparison.

Each rule of thumb in Brody and Nestor (1980) is included in the daily packet. The first page of the mistral form (Appendix B) will be used to illustrate the procedure. Rule 9 from Brody and Nestor (1980) is:

> The probability of mistral occurrence is greatest (r=0.58) when the 850mb wind direction over Nimes is from 350°; it decreases with winds east or west of 350°, reaching near zero for winds from 240° and 090°.

The rules indicated by an asterisk (*) on the same page indicate that winds over the water will be approximately double those of Perpignan and Marignane. Rules with an ampersand (&) indicate that an approximation of the wind speeds over the water can be obtained by adding 10 kt to the reported winds at Montpellier and Istres. The format of the form is designed for ease in comparing the rules of thumb. A monthly summary sheet also is prepared for levante and mistral conditions.

C. DATA COVERAGE

Although data coverage in the Mediterranean area can at times be sporadic, most of the stations of interest reported regularly. The station combinations required to report in tandem are shown in Table 2. When the stations reported and how often observations are available is illustrated in Table 3. Since only 3 h data are considered in this study, stations that report more often are only considered as reporting every 3 h. Similarly, upper-air

TABLE 2. DUAL REPORTING STATION COMBINATIONS, NUMBER OF TIMES THE STATIONS ACTUALLY REPORTED TOGETHER AND PERCENTAGE OF POSSIBLE REPORTS. ALL STATIONS REPORT EVERY 3 HOURS.

stations	number of times dual stations reported together/percentage of possible reports
Gibraltar-Tangier	795/58
Rota-Malaga	903/66
Palma-Casablanca	1251/91
Alicante-Casablanca	306/89
Perpignan-Marignane	1219/89
Perpignan-Nice	1224/89
Marignane-Nice	1266/93

TABLE 3. LEVANTE AND MISTRAL REPORTING STATIONS, TIMES THEY WERE EXPECTED TO REPORT, AND ACTUAL NUMBER OF TIMES THEY REPORTED COMPARED TO THE PERCENTAGE OF POSSIBLE REPORTS DURING SEPTEMBER 1988 TO FEBRUARY 1989.

Levante Stations		
station	**expected reporting times**	**number of times actually reported/ percentage of possible reports**
Alboran	06UTC, 12UTC and 18UTC	239/47
Alicante	06UTC and 18UTC	319/93
Casablanca	every 3 hours	1237/93
Gibraltar (winds)	every 3 hours	1257/92
Gibraltar (pressure)	every 3 hours	828/94
Madrid	00UTC and 12UTC	330/96
Malaga	every 3 hours	1288/94
Palma	every 3 hours	1319/96
Rota	every 3 hours	925/68
Tangier (winds)	every 3 hours	594/43
Tangier (pressure)	every 3 hours	725/53
Tarifa	06UTC thru 18UTC	719/79
Taza	every 3 hours	354/26
Mistral Stations		
station	**expected reporting times**	**number of times actually reported percentage of possible reports**
Bordeaux	00UTC and 12UTC	281/82
Brest	00UTC and 12UTC	271/79
Istres	every 3 hours	1053/77
La Maddalena	03UTC to 18UTC	889/82
Lus La Croix Haute	every 3 hours	201/15
Marseille/Marignane	every 3 hours	
(winds)		1252/92
(pressure)		1319/96
Montpellier	every 3 hours	1148/84
Nice	every 3 hours	1286/94
Orange	every 3 hours	925/68
Perpignan (winds)	every 3 hours	1167/85
(temperature)	1113/81	
(pressure)	1247/91	

stations are only considered to report at 00 UTC and 12 UTC even if they report more often. The major problems were that Tarifa does not report during the evening hours (21 UTC to 03 UTC), Alboran Island only reports at

06 UTC and 18 UTC, and Lus La Croix Haute, which is a key station for detecting mistral onset, reports sporadically at best. In building this data base, it became apparent that certain rules never met gale criteria, while others met gale criteria too often. For instance, Taza (levante Rule 5) never met gale criteria. As is explained more thoroughly in the next chapter, Taza was eliminated during this step since the winds from an easterly direction never exceeded 12 kt during the four months for which data are available.

Once the applicability of a rule was established, the required data were tabulated in 3 h increments. For instance, the rule for Gibraltar indicates that if the winds are from an easterly direction, they should be doubled to give a more accurate approximation of the winds occurring in the Strait of Gibraltar. This will be discussed in more detail in Chapter IV.

IV. GENERATING THE LEVANTE RULE BASE

A. METEOROLOGICAL DESCRIPTION

Levante is the Spanish term for an east or northeast wind that occurs along the coast of Spain from southern France to the west of the Strait of Gibraltar. The English use the term levanter, which is more specifically applied to easterly winds in the Strait of Gibraltar and the Alboran Channel. Levante will be used here to describe the easterly wind in the Alboran Sea and the Strait of Gibraltar (Figure 5).

The levante can occur in association with five typical pressure and wind patterns (Figure 6). The most common situation (Figure 6a) occurs when the Azores anticyclone ridges northeast across Spain and southern France. With high pressure over western Europe and relatively low pressure over the western Mediterranean, the levante will be widespread from the Strait of Gibraltar to the Balearic Sea (Figure 6b). The levante will be localized in the Alboran Channel and the Strait of Gibraltar when a high pressure cell is located over the Balearic Isles (Figure 6c). During the winter (November through April), the levante will often precede the arrival of a cold front from the west (Figure 6d). Finally, an intense cyclone located south of the Balearic Isles (Figure 6e) produces a gale force levante ahead of the low along the east coast of Spain and over the Balearic Sea.

According to Brody (1980), the following combination of factors results in the levante:

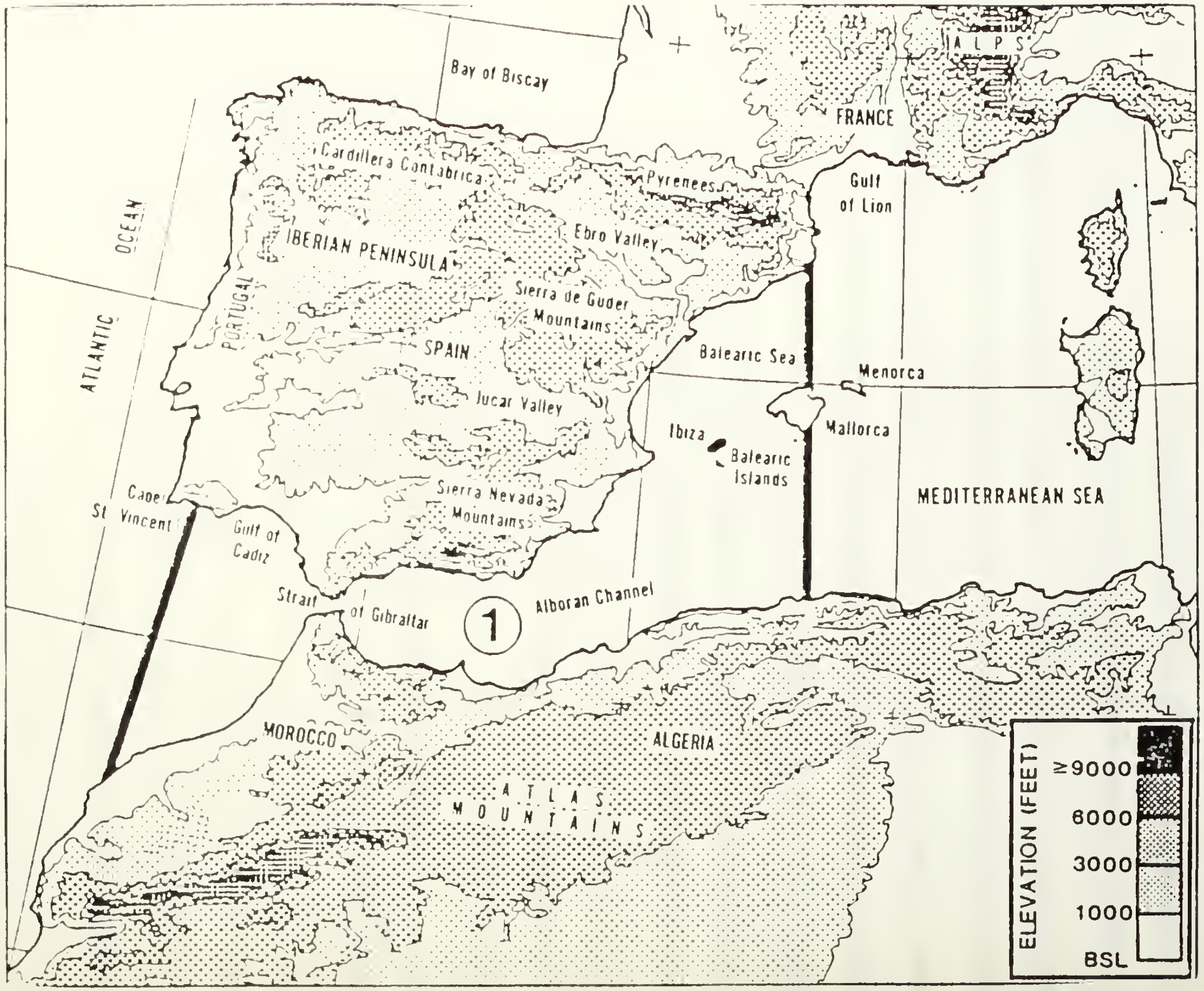
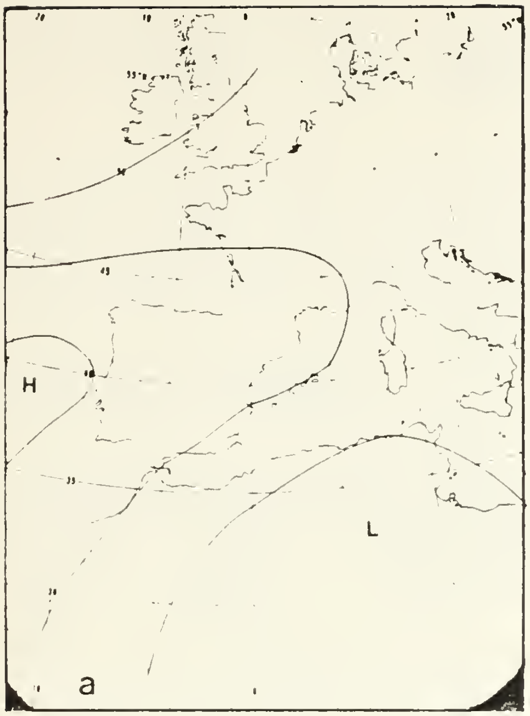


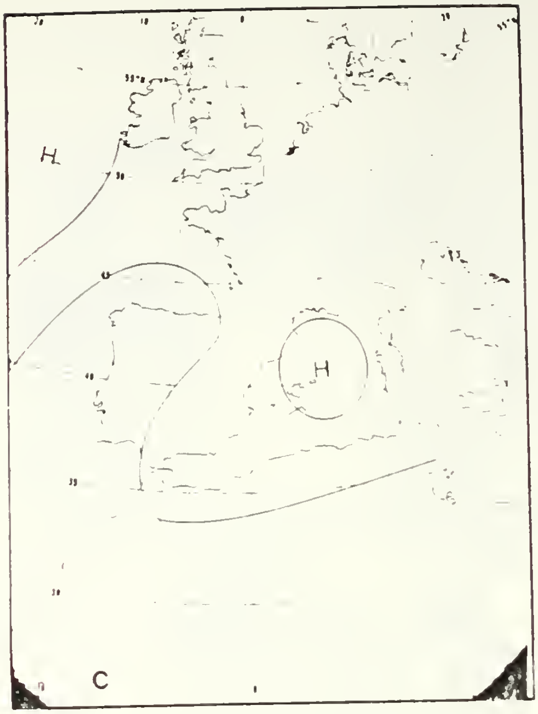
Figure 5. Topographical map of Gibraltar-western Mediterranean area (Brody and Nestor 1980)



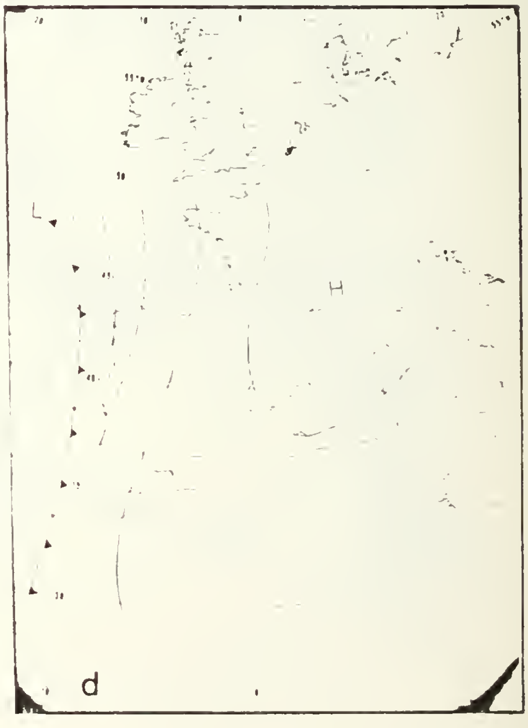
(a) Azores anticyclone extending over Spain and southern France.

(b) Anticyclone over western Europe and low pressure over the western Mediterranean.

Figure 6. Typical pressure and wind patterns associated with the levante (Brody and Nestor 1980)

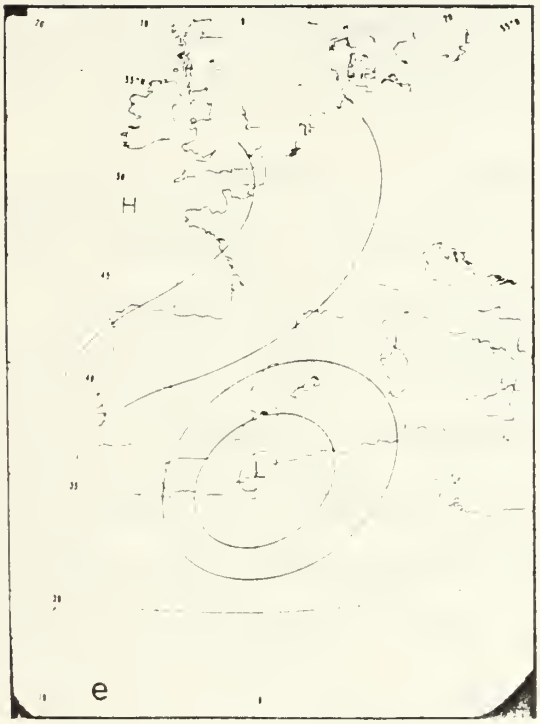


(c) Anticyclone over the Balearic Islands.



(d) Cold front approaching the Strait of Gibraltar from the west

Figure 6. Continued



(e) Intense cyclone south of the Balearic Islands.

Figure 6. Continued

(1) The basic circulation resulting in a surface pressure gradient over this area from northeast to southwest with highest pressure to the north and or east.

(2) Large-scale channeling of the air flow through the Alboran Channel and Strait of Gibraltar. The channeling effect produces a much wider variety of localized pressure distributions in association with the levante; e.g., low pressure to the west or south of Gibraltar will cause a levante.

(3) A local jet-effect increase in the vicinity of the Strait of Gibraltar, caused by the orographic configuration of the two coastlines. The narrow band of maximum easterlies caused by this effect extends a considerable distance west of the Strait; although this band generally is only about 2 n mi wide, it sometimes can expand to a width of 30 n mi.

Although the levante is mainly a summertime phenomenon, it may occur during other seasons as a result of approaching cold fronts or depressions. The weather associated with a summertime levante is generally good, although warm air moving over relatively colder water produces fog and low stratus in the Strait. One of the main indicators of levante is the appearance of clouds in the satellite imagery at the eastern portion of the Strait of Gibraltar. The weather during the other three seasons is more in keeping with the system's frontal nature. Low clouds, heavy rains and low visibilities occur along the east coast of Spain. If the air mass is cold and unstable, convective activity is common. Heaviest rains occur as a result of orographic lifting along the mountains on the east coast of Spain.

B. RULES OF THUMB AND DISCUSSION

The following rules are taken from the *Handbook for Forecasters in the Mediterranean* (Brody and Nestor 1980). They are the major source used by the Naval Oceanography Command Center, Rota, for forecasting significant weather events in the Mediterranean Sea and surrounding areas. In the western Mediterranean-Gibraltar section of the *Handbook*, 89 rules are listed for forecasting local weather phenomena. Of the 89 rules, 19 are directly related to levante. These 19 rules have been evaluated during the six-month period addressed in this study, for possible inclusion in the expert system. Five rules have been used without modification, six others have been used with only slight modification and eight rules have been considered unsuitable for inclusion into the expert system.

One of the difficult aspects of evaluating the gale wind condition forecast rules for the Strait of Gibraltar is that there is no *in situ* observation of the wind speed. Gale conditions may go unobserved if no ships are present or do not report. Consequently, two locations in the Strait of Gibraltar, Tarifa and Gibraltar (see Figure 7), have been examined to find which wind report is more reliable when compared to the ship reports in the Strait of Gibraltar and approaches for the same observation time.

A comparison of gale force wind conditions reported by Tarifa and ships of opportunity can be found in Table 4. The four possible categories for comparison are: both Tarifa and a verifying ship report in the Strait of Gibraltar or approaches are in a gale situation; both are in a no gale situation; Tarifa is reporting gale conditions and no ship report is available reporting gale conditions; or Tarifa is not in gale criteria and a ship is reporting winds exceeding 30 kt. For the purpose of this study, Tarifa is considered to be in gale criteria if the station is reporting 34 kt or greater. A ship is considered to be in gale criteria if it is reporting 30 kt or greater. Different speed criteria are

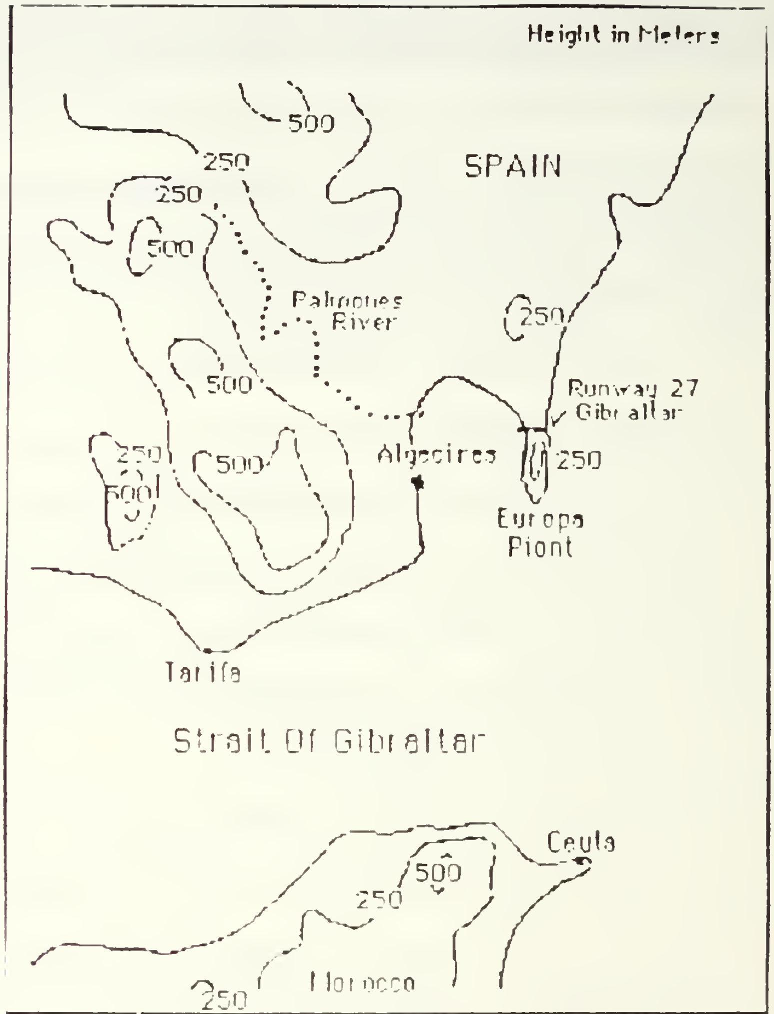


Figure 7. The Strait of Gibraltar and surrounding area

used because the ship wind observation might not be as accurate as that of Tarifa. In the case of a gale forecast, it is better to be conservative and advise a ship when marginal gale conditions seem to exist.

TABLE 4. COMPARISON OF GALE WIND CONDITIONS REPORTED AT TARIFA AND ACTUAL REPORTS OF GALE FORCE WINDS BY SHIPS OF OPPORTUNITY IN THE STRAIT OF GIBRALTAR AND APPROACHES (ONLY EASTERLY EVENTS ARE INCLUDED). GALE FORCE WINDS AT TARIFA ARE DEFINED AS EQUAL OR GREATER THAN 34 KT AND FOR SHIPS EQUAL OR GREATER THAN 30 KT. *OF THESE 17 EVENTS, 10 WERE WITHIN 5 KT OF GALE CONDITIONS.

Tarifa	Gale	No Gale	Gale	No Gale
Ship	Gale	No Gale	No Gale	Gale
Sep	8	23	13	1
Oct		Data Missing		
Nov	9	41	1	5
Dec	10	31	4	5
Jan	4	58	4	6
Feb	1	16	2	0
Number of Events	32	170	24	17 *
Percentage of Events (%)	13	70	10	7
Total Number of Events	202		41	
Percentage of Total Events (%)	83		7	

Based on Table 4, gale and no gale conditions at Tarifa are confirmed from ship reports 83 percent of the time. In 24 gale wind conditions at Tarifa, the existing ship reports did not confirm gale conditions in the Strait. This may occur because the ships were not in the correct location or because the Tarifa report does not correctly indicate gale winds in the Strait. Finally, 17 confirmed gale conditions by ships are not indicated by Tarifa winds exceeding 34 kt. Thus, the Tarifa winds provide a correct indication of gale conditions in the Strait in 83 percent of the reports. Since Tarifa does not report at night (Table 3), other stations were tested to see if there was a better choice for the benchmark station.

Rule 6, to be discussed later, calls for the wind speed at Gibraltar to be doubled whenever there is an easterly wind. This doubling of the wind speeds results in a larger variability of the forecast winds in the Strait of Gibraltar. A similar comparison with Gibraltar wind reports and the ship reports indicated agreement for only 63 percent (not shown) of the reports (Table 5). Even though Gibraltar has a larger number of observations than Tarifa (Table 5), the larger variability of the winds make it an unstable indicator of the forecast winds in the Strait of Gibraltar. Therefore, the Tarifa wind report is chosen as the indicator of gale wind conditions in the Strait of Gibraltar. The number of events comparing the Tarifa wind reports with ship observations are small compared to Tarifa versus other reporting stations listed in Table 5. Tarifa could only be compared with ship reports at 6 h synoptic times (excluding 00 UTC when Tarifa does not report). However, Tarifa usually could be compared to other reporting stations at 3 h intervals whenever both reported (see Table 3).

Each of the 19 rules that pertain to levante conditions in the Strait of Gibraltar will be listed and then discussed as to suitability for use in the expert system.

TABLE 5. COMPARISON OF GALE WIND CONDITIONS REPORTED AT TARIFA AND AT THE OTHER STATIONS LISTED IN THE RULES OF THUMB THAT ARE INCLUDED IN THE EXPERT SYSTEM. THE NUMBERS IN THE BLOCK REPRESENTS THE NUMBER OF EVENTS/PERCENTAGE OF EVENTS.

Tarifa VS.	Rule	Gale Gale	No Gale No Gale	Gale No Gale	No Gale Gale
ship	5	32/13	170/70	24/10	17/7
Malaga- Rota pres diff	4	27/8	250/73	51/15	15/4
Malaga - Rota pres diff modified	4M	51/15	250/73	27/8	15/4
Gibraltar	6	64/9	477/70	50/7	97/14
Alboran	8	30/20	49/33	7/5	62/42
Alboran modified	8M	26/18	70/47	11/7	41/28
Palma - Casablanca pres diff	47	58/12	313/67	49/11	45/10
Palma - Casablanca pres diff modified	47M	84/18	313/67	23/5	45/17
Alicante- Casablanca pres diff	72	0/0	148/80	36/19	1/1
Alicante - Casablanca pres diff modified	72M	35/19	148/80	1/5	1/5
LXGB-GMTT pres diff	R7	62/21	189/64	18/6	28/9

RULE 5: DURING LEVANTE CONDITIONS IN THE STRAIT OF GIBRALTAR, EASTERLY WINDS AT TWO STATIONS--TARIFA AND

TAZA GIVE A CLOSE APPROXIMATION OF THE WINDS IN THE STRAIT.

Discussion: Rule 5 is introduced first because it represents the benchmark with which all the other levante rules are to be compared. Rule 5 is a combination of two rules, one dealing with Tarifa and the other with Taza. In agreement with Rule 5, the winds at Tarifa are representative of the actual winds in the Strait (Table 4). However, the winds at Taza proved to be unreliable. On the 202 occasions from September 1988 to February 1989, when Tarifa and Taza wind speeds were available at the same time, Tarifa was in gale conditions (>=34 kt) 60 times when Taza did not report gale force winds. Taza did not report winds in excess of 12 kt except during February when the winds were westerly. Whereas Tarifa is located on a point of land projecting into the Strait of Gibraltar, Taza is located in a mountain pass between the Rif Mountains to the north and the Middle Atlas Mountains to the south (Figures 7, 8, and 9). The influence of the Taza Gap on the orographic steering of the winds through the area is considerable. Although an easterly flow may increase the wind speed as winds are channeled through the Taza Gap, such conditions were not observed in this study. Therefore, the Taza report will be excluded from further consideration and this aspect of Rule 5 will not be included in the expert system.

Because Tarifa does not report from at least 21 UTC to 03 UTC, other rules are necessary to cover this period. These rules will be listed and discussed in numerical order, as no attempt was made to prioritize the rules.

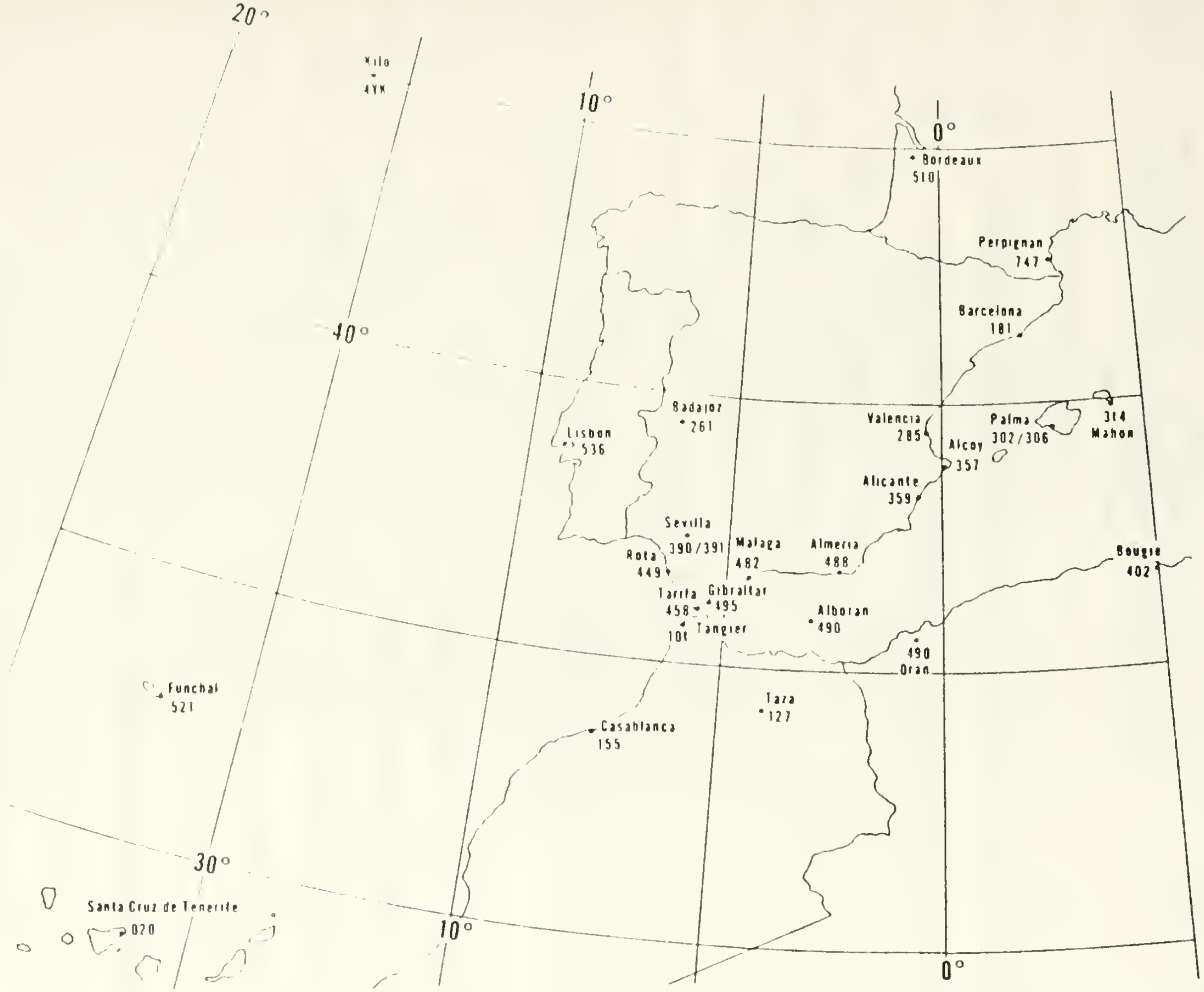


Figure 8. Station locator map for the Gibraltar-western Mediterranean area. (Brody and Nestor 1980)

Figure 9. Mountain ranges of Morocco (Nelson 1985)

RULE 1: FORECASTING SUDDEN ONSET OF LEVANTE CONDITIONS IN THE GIBRALTAR AREA DURING THE SUMMER REQUIRES THE TRACKING OF OLD COLD FRONTS AS THEY MOVE SOUTHWESTWARD ALONG THE COAST OF SPAIN. MOVEMENT OF THESE COLD FRONTS CAN BE FOLLOWED BY OBSERVING CHANGES IN HUMIDITY AND WIND DIRECTION FROM THE NORMAL SEA BREEZE AT COASTAL STATIONS. TWO VERY USEFUL STATIONS ARE ALICANTE AND MALAGA.

Discussion: This rule is not included in the expert system for two reasons. First, the three hourly verification data are not frequent enough to detect a shift in wind direction corresponding to a sudden onset of levante conditions. Second, hourly monitoring of the conditions at each of these stations would place a considerable burden on the watch team to keep running the program. An additional comment at the end of the program might remind the watch team to be aware of conditions at these stations.

RULE 2: A GALE FORCE LEVANTE IN THE STRAIT OF GIBRALTAR WILL COMMENCE WHEN NORTHWESTERLY WINDS AT 300 MB OVER CENTRAL AND SOUTHERN SPAIN VEER TO 040°.

Discussion: This rule is included in the expert system, even though it is not considered very useful because of the limited times that it can be applied. Since upper-air observations are only taken at 00 UTC and 12 UTC, it would require that the wind direction change have occurred some time in the previous 12 h for the rule to be applied. It is more likely that a wind shift to 040° at 00 UTC or 12 UTC would add credence to the gale recommendation. During the six-month period, a northwest wind shifted to 040° on only six days and resulted in a gale each time. However, a gale occurred on 37 days with no windshift at the observation time. Furthermore, the wind was 040° on 10 observations that did not also have a gale force levante.

RULE 3: STRATUS, COMMON ALONG THE COAST OF PORTUGAL, IS NORMALLY PUSHED APPROXIMATELY 100-200 N MI OFF THE COAST AT THE START OF A LEVANTE IN THE ROTA AREA. AT TIMES THIS MOVEMENT PRECEDES THE LEVANTE AND THUS SHOULD BE WATCHED CLOSELY AS AN INDICATOR OF LEVANTE ONSET.

Discussion: Because this rule would be very difficult to apply without the use of satellite imagery, it is not included in the expert system. A comment at the end of the program could serve as a reminder to the watch team to look for stratus movement offshore.

RULE 4: STRONG LEVANTE WINDS IN THE STRAIT OF GIBRALTAR OCCUR WHEN THE PRESSURE DIFFERENCE, MALAGA MINUS ROTA, IS 4 MB OR MORE. A 4 MB DIFFERENCE WILL PRODUCE LEVANTE WINDS OF 30-35 KT IN THE STRAIT.

Rule 48 is similar to Rule 4 and, therefore, will be included here for continuity.

RULE 48: THE PRESSURE DIFFERENCE, MALAGA GREATER THAN ROTA, IS RELATED TO LEVANTE CONDITIONS--ALTHOUGH NOT AS DIRECTLY AS THE PALMA/CASABLANCA PRESSURE DIFFERENCE. A 3 MB DIFFERENCE INDICATES LEVANTE CONDITIONS IN THE STRAIT OF GIBRALTAR. A 5 MB DIFFERENCE IS ASSOCIATED WITH EASTERLY GALES IN THE STRAIT OF GIBRALTAR AND LEVANTE CONDITIONS AT ROTA.

Discussion: As indicated in Table 5, this rule is satisfied 81 percent of the time. Of the 343 total events, 277 are either gale or no gale events. In a test run of the expert system, four out of the 17 no-gale/gale events at Tarifa would have been converted to gale events by this rule. The major problem with this rule is that the intensity does not seem to verify. Although the gale versus no gale comparison showed a good correlation, the forecast wind speeds are less than the Tarifa wind speed used as a standard. To determine the proper pressure difference to assign to various wind speeds, the gale force wind speed and the concurrent pressure difference are compared. Each >=34 kt wind speed that occurs, and all the pressure differences that are recorded at that speed, are rank ordered from highest to lowest. A pressure difference of 3 mb or better occurs at gale force wind speeds 24 more times then previously indicated. If the critical difference is reduced to 3 mb (vice 4 mb), an additional 24 gale events verify. The 24 gale events picked up with this modification were in column 3 originally as indicated by Malaga-Rota having 51 gales previously when matched with non gales. With this adjustment to the pressure difference, the 24 gale events are moved to column 1. Further testing indicates that the intensity forecast should be adjusted to 30-38 kt for pressure differences of 3 mb to 4 mb, and 38-45 kt for a difference of 4 mb to 4.5 mb, and winds exceeding 45 kt for a pressure difference over 4.5 mb. These intensity criteria will be incorporated into the expert system.

RULE 6: DURING LEVANTE CONDITIONS, DOUBLE THE WIND SPEED READINGS OF SUSTAINED EASTERLY WINDS AT GIBRALTAR FOR A CLOSE APPROXIMATION OF THE MAXIMUM WIND SPEED IN THE STRAIT OF GIBRALTAR.

Discussion: The wind speeds at Gibraltar do not vary greatly when compared with Tarifa. On 20 Sep 1988, the Gibraltar winds were from the same direction as at Tarifa and doubling the Gibraltar winds did make them agree with the Tarifa wind to within + or -5 kt. During the 24 Sep 1988 gale, the Tarifa and Gibraltar winds were from the same direction twice and the doubled Gibraltar winds were too low by 15 and 8 kt. On 4 Sep 1988 when the Tarifa wind direction was 100° and the Gibraltar wind direction was 090°, the doubled Gibraltar wind speeds varied from an agreement within 10 kt to as much as 16 kt too low. Although more research is needed to determine what factors contribute to these variations, this rule verified 79 percent of the time (Table 5). Of the 688 events, 541 of them were gale or no gale events. This rule has a tendency to err on the high side. For example, the Gibraltar wind speed indicates a gale condition on 14 percent of the occasions when the Tarifa wind suggests a no gale condition in the Strait of Gibraltar. Conversely, on 7 percent of the occasions that Tarifa indicated a gale, the Gibraltar wind condition indicated a no gale condition. Since these verification statistics are considered satisfactory, this rule is included without modification in the expert system.

RULE 7: THE HEAVIEST CONCENTRATION OF LOW STRATUS, FOG AND HAZE DURING LEVANTE CONDITIONS ARE FOUND IN THE ALBORAN CHANNEL SOUTH OF 36°N.

Discussion: Because this rule would be difficult to verify without satellite imagery, it is not included in the expert system.

RULE 8: DURING LEVANTE CONDITIONS IN THE STRAIT OF GIBRALTAR, THE AREA OF MAXIMUM EASTERLY WINDS IS NORMALLY QUITE NARROW, ONLY ABOUT 2 N MI WIDE. THIS BAND OF STRONG WINDS HAS BEEN OBSERVED TO EXTEND 60 N MI WESTWARD OF THE STRAIT NORTH OF 36°N. A BASIC EASTERLY AIRFLOW OF ABOUT 15-20 KT PRODUCES A MAXIMUM BAND OF 35 KT WINDS.

Discussion: This rule is included in the expert system with a slight modification. Although the Alboran Island report does give a good indication of the winds in other parts of the Alboran Channel, the rule for the winds in the Strait of Gibraltar verifies only 53 percent of the occasions (Table 5). If the Alboran wind criterion is increased to 20-25 kt, the verification rate increases to 65 percent. Therefore, the rule has been included in the expert system with the modification to require winds of 20-25 kt at Alboran Island. Notice in Table 5 that by raising the criteria for the wind speed from 15 to 20, the number of gale events in column 1 decreased from 30 to 26 while the number of no gale events in column 2 increased from 49 to 70. This is in direct contrast with the Rota-Malaga modification (4M), which lowered the criteria and increased the gale events in column 1 from 27 to 51 and decreased the gale/no-gale events in column 3 from 51 to 27.

RULE 9: DURING LEVANTE CONDITIONS THROUGH THE STRAIT OF GIBRALTAR, AN EDDY IN THE LOW-LEVEL FLOW IS FOUND WEST AND SOUTH OF THE STRAIT. THIS EDDY IS AT TIMES DISTINGUISHABLE IN THE LOW CLOUDS ON SATELLITE IMAGERY. A COLD OCEAN EDDY IS ALSO SOMETIMES NOTED IN THE SAME AREA.

Discussion: Due to the lack of satellite imagery, this rule is excluded from the expert system.

RULE 10: LEVANTE CONDITIONS IN THE STRAIT OF GIBRALTAR CAN PRODUCE VERY HIGH SEA STATES.

Discussion: Since this is a statement rather than a rule, a comment might be included at the end of the program. However, the presence of high sea states accompanying levante conditions is rather obvious.

RULE 11: FORECAST A LEVANTE TO END, ESPECIALLY IN THE STRAIT OF GIBRALTAR-ALBORAN CHANNEL AREA, WHEN A DEPRESSION ACROSS THE BRITISH ISLES OR FRANCE AND ITS COLD FRONT BEGINS TO CROSS THE IBERIAN PENINSULA. SINCE WESTERLIES REPLACE EASTERLIES WHILE THE FRONT IS SOME DISTANCE TO THE NORTH, THE FRONT NEED NOT PROGRESS AS FAR SOUTH AS GIBRALTAR FOR THE LEVANTE TO CEASE.

Discussion: As a cold front approaches, the winds will veer from east to west and thus end the levante. When the levante will cease depends on the speed of the approaching front. This rule is included in the expert system with a statement that the levante will soon cease. The timing of the end of the levante is left to the forecaster's judgement because it calls for information that is beyond the scope of this prototype expert system.

RULE 24: THE 700 MB WIND (e.g. OVER GIBRALTAR) IS A GOOD INDICATOR OF MOVEMENT OF A SURFACE LOW APPROACHING THE STRAIT OF GIBRALTAR. IF THE 700 MB WIND BACKS TO 210° AT GIBRALTAR A SURFACE LOW CAN BE EXPECTED TO REDEVELOP (INTENSIFY) EAST OF THE STRAIT. WHEN THIS TYPE OF MOVEMENT IS FORECAST, GALE FORCE EASTERLY WINDS CAN BE EXPECTED TO CEASE AS THE CYCLOGENESIS OCCURS EAST OF GIBRALTAR.

Discussion: This rule is excluded from the expert system because the Gibraltar winds shifted to 210° only four times during the six months. In one of these cases, the wind shift occurred when a levante was not in progress. In a second case, the levante continued for 36 h. In the third case, a levante began within 18 h. Only in one case did the levante cease within 12 h. More successful verifications would have to be found before this rule is included in the expert system.

RULE 47: THE STRENGTH OF THE LEVANTE CAN BE APPROXIMATED BY USING THE PRESSURE DIFFERENCE, PALMA MINUS CASABLANCA. A +6 MB DIFFERENCE IS ASSOCIATED WITH LEVANTE CONDITIONS (15-25 KT EASTERLIES) IN THE STRAIT OF GIBRALTAR. A +8 MB DIFFERENCE IS ASSOCIATED WITH GALE FORCE (>33 KT) EASTERLIES IN THE STRAIT AND LEVANTE CONDITIONS AT ROTA.

Discussion: As indicated in Table 5, this rule verifies on 79 percent of the occasions. Of the 465 events, 371 were gale or no gale events. However, the pressure difference criteria seem to be too high, which results in underforecasting the wind speeds. By reducing the required pressure difference to 6 mb for a forecast of winds of 30-35 kt, an additional 26 gale events verify. This raises the correct gale/no-gale percentage to 85 percent. Similarly, the wind speeds for a 8 mb pressure difference are raised from >33 kt to >40 kt in the expert system.

RULE 49: DURING PERIODS OF LEVANTE IN THE VICINITY OF ROTA, EVEN WHEN WINDS ARE NOT ACTUALLY BLOWING AT THE STATION, A NOCTURNAL LOW-LEVEL JET IS USUALLY PRESENT. THIS JET, FOUND BETWEEN 1000-3000 FT, HAS WIND SPEEDS UP TO 50 KT AND USUALLY MARKS THE TOP OF THE TEMPERATURE INVERSION.

Discussion: This rule was not evaluated due to absence of significant level data in the available soundings.

RULE 50: THE END OF LEVANTE CONDITIONS AT ROTA IS OFTEN RELATED TO THE DISAPPEARANCE OF A SURFACE TROUGH WEST OF ROTA.

This rule is similar to Rule 52.

RULE 52: DURING LEVANTE CONDITIONS AT ROTA, A WEAK UPPER-LEVEL TROUGH IS USUALLY PRESENT TO THE SOUTHWEST OF ROTA. THIS UPPER-LEVEL TROUGH APPEARS TO REINFORCE THE SURFACE TROUGH OFF THE COAST--A NECESSARY CONDITION FOR THE LEVANTE AT ROTA.

Discussion: A comment concerning the upper-level trough is added to the expert system. An end to levante conditions at Rota does not necessarily indicate an end to the levante conditions in the Strait of Gibraltar. However, no levante conditions will occur at Rota without the trough.

RULE 51: DIURNAL WIND VARIATIONS DURING LEVANTE CONDITIONS AT ROTA ARE: MAXIMUM WIND SPEEDS 1500-2100 GMT DURING THE SPRING AND EARLY SUMMER; MINIMUM WIND SPEEDS 0100-0500 GMT DURING LATE SPRING AND EARLY SUMMER; AND REDUCED DIURNAL VARIATIONS IN AUGUST AND SEPTEMBER.

Discussion: As this statement is not really a rule, it is not included in the expert system.

RULE 72: THIS RULE PROVIDES GUIDANCE FOR FORECASTING SURFACE WINDS AT GIBRALTAR FOR FRESH OR STRONG WIND SITUATIONS. THE ALICANTE/CASABLANCA PRESSURE DIFFERENCE PRODUCES THE FOLLOWING WINDS:

PRESSURE DIFFERENCES	EASTERLIES	WESTERLIES
5-10 MB	15-25 KT	15-20 KT
10-15 MB	25-30 KT	20-30 KT
> 15 MB	30-40 KT	> 30 KT

ONSET IS IMMEDIATELY BEHIND A FRONT. EASTERLY WINDS ARE USUALLY PRECEDED BY A STRONG MISTRAL IN THE GULF OF LION 24 HOURS BEFORE FLOWING INTO THE REGION OF SLACK PRESSURE GRADIENT EAST OF SPAIN. DIRECTIONS ARE USUALLY BACKED ABOUT 20° FROM THE LOCAL GRADIENT WIND AT GIBRALTAR. SEA BREEZE EFFECTS ONLY OCCUR IF THE 2000 FT WIND IS LESS THAN 20 KT. THERE ARE NO KATABATIC EFFECTS.

Discussion: This rule has limited utility because the two stations only report simultaneously twice a day. According to Table 5, the verification is (perhaps deceptively) good at 80 percent. As in previous rules, the major problem is with the intensities since no gale events occurred with the specified pressure differences. If the critical pressure difference is decreased to >5 mb for wind speeds of 30-40 kt, an additional 35 gale events are predicted. This changes the percentage of correct gale and no gale events to an outstanding 99 percent. Of the 185 total events in the sample, 183 are correctly predicted. This modified pressure difference criteria has been incorporated into the expert system.

The following rule is from the Naval Oceanography Command Center, Rota, Spain (1983) *Forecaster's Handbook.*

ROTA RULE 7: APPROXIMATE WINDS IN THE STRAIT OF GIBRALTAR WITH RESPECT TO THE GIBRALTAR-TANGIER (LXGB-GMTT) PRESSURE GRADIENT: (HIGHER PRESSURE AT LXGB).

2 MB	E 30-38 KT
3 MB	E 36-45 KT
4 MB	E 43-53 KT
5 MB	E 48-58 KT

Discussion: This rule verified in 85 percent of the gale and no gale events. It has been incorporated into the expert system.

V. GENERATING THE MISTRAL RULE BASE

A. METEOROLOGICAL DESCRIPTION

The mistral is a north wind that blows through the three major valleys along the Gulf of Lion (Figure 10). It is a strong, gusty, cold and dry wind. Wind speeds are often greater than 60 kt in the lower valleys with higher wind speeds in the Gulf of Lion. In general, the mistral is characterized by offshore winds along the coast of the Gulf of Lion. At times, gale and even storm force winds may extend beyond the bounds of the western Mediterranean and influence the weather of the entire Mediterranean basin. According to Brody and Nestor (1980), the mistral is a result of the following factors:

(1) The basic circulation that creates a pressure gradient from west to east along the coast of southern France. This pressure gradient is normally associated with Genoa cyclogenesis.

(2) A fall wind effect caused by cold air associated with the mistral moving downslope as it approaches the southern coast of France and thus increases in wind speed.

(3) A jet-effect wind increase caused by the orographic configuration of the coastline. This phenomenon is observed at the entrance to major mountain gaps such as the Carcassone Gap, Rhone Valley and Durance Valley. It is also observed in the Strait of Bonifacio between Corsica and Sardinia.

(4) A wind increase over open water resulting from the reduction in the braking effect of surface friction.

The authors continue:

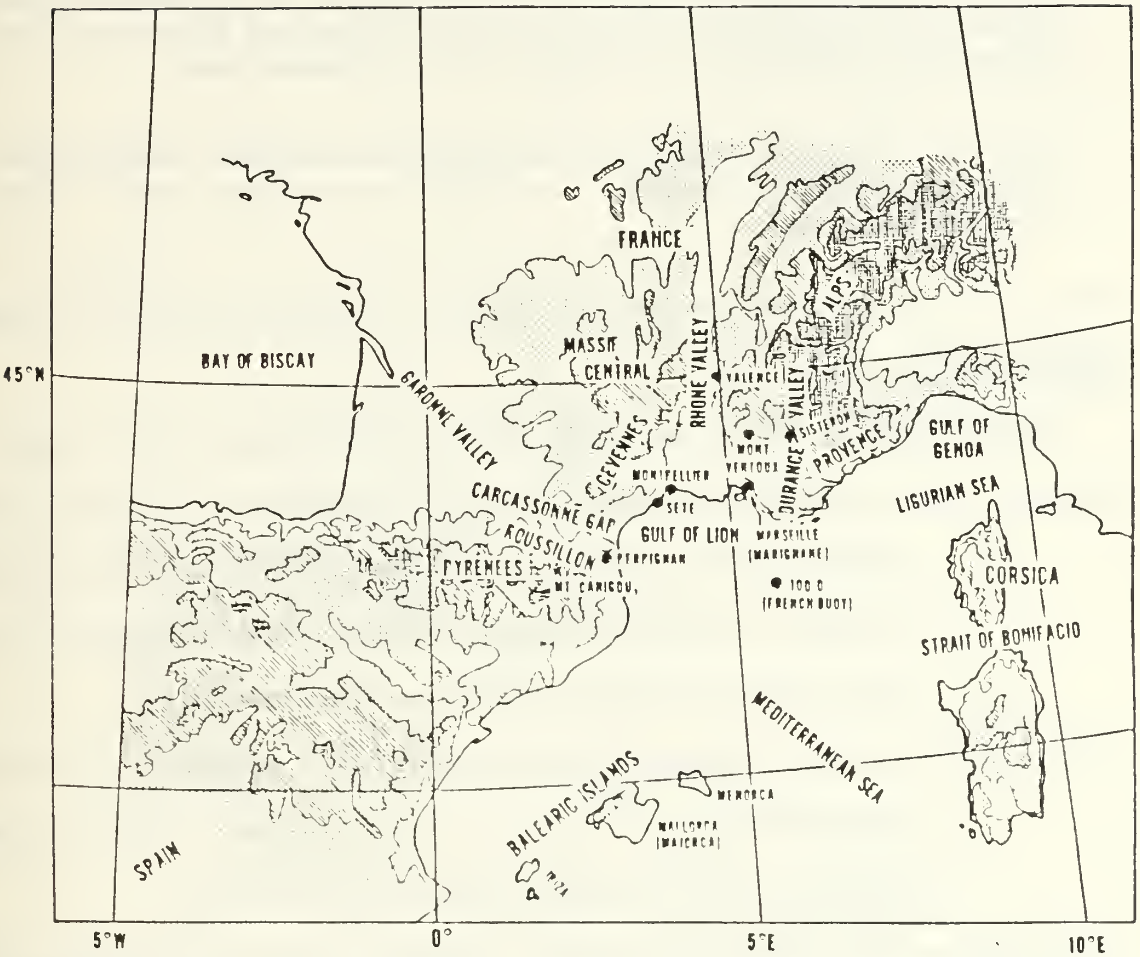


Figure 10. Locator map for the mistral (Brody and Nestor 1980)

Mistrals are observed in association with three particular upper-level (500 mb) large-scale flow patterns. These flow patterns are classified as types A, B and C ...

Type A. A blocking ridge in the eastern Atlantic and a long-wave trough over Europe produces a strong northwesterly flow over western France (Figure 11a). This is a meridional flow situation.

Type B. A blocking ridge extends northeastward from the eastern North Atlantic over northern Europe and a low pressure belt covers the Mediterranean (Figure 11b). Meridional flow predominates.

Type C. A series of depressions dominate the European mid-latitudes, and westerly winds prevail over the Mediterranean (Figure 11c). This is a zonal-flow situation.

Notice that the three types often blend so that classification can be extremely difficult.

The following is a brief look at the climatology associated with a mistral:

Strength: Wind speeds often exceed 40 kt and occasionally reach over 100 kt particularly in the coastal region between Marseille and Toulon. Maximum winds occur when the sea level isobars are at an angle of 30° to the three major gaps mentioned above.

Direction: Generally northwest to north-northeasterly depending on the gap through which the wind is being funnelled. Over the open water, the wind is predominantly from 320°-340°.

Horizontal extent: Although normally confined to the Gulf of Lion with decreasing strength southeastward, a severe mistral occasionally will produce strong winds as far south as North Africa.

Seasonal variations: Possible during all seasons, but most prevalent during the winter and spring.

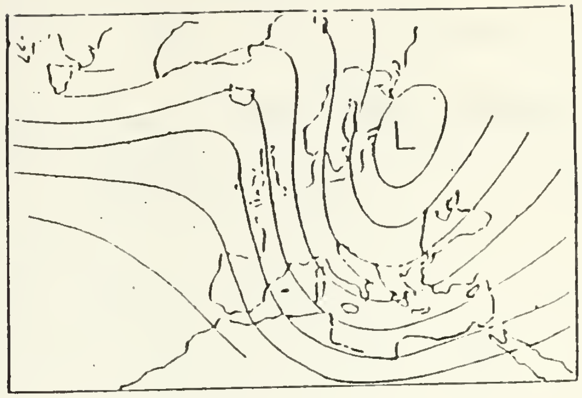


Figure 11-a. Upper-level flow pattern showing the British Air Ministry Type A.

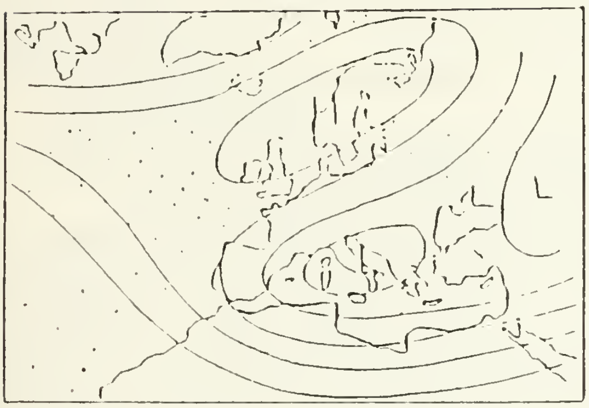


Figure 11-b. Upper-level flow pattern showing the British Air Ministry Type B.

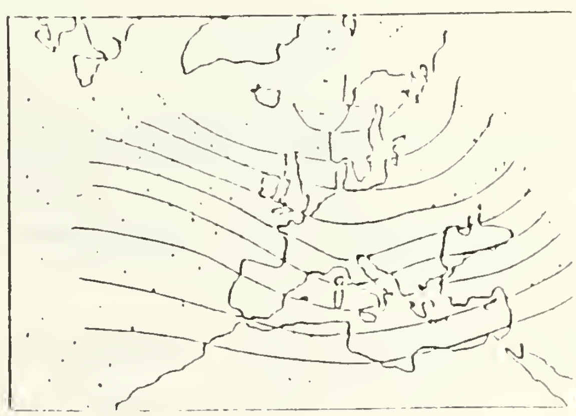


Figure 11-c. Upper-level flow pattern showing the British Air Ministry Type C. (Brody and Nestor 1980)

Diurnal variations: Coastal areas experience maximum mistral winds during the afternoon while open-ocean areas have maximum winds at night.

Sea state: Sea heights increase rapidly at the onset of a mistral. Although typical sea heights are 12-15 ft, heights of 24 ft have been observed in the Gulf of Lion during storm force mistral conditions. Farther to the south, in the vicinity of Sardinia, seas of 30 ft can be expected and are occasionally forecast to occur.

Associated weather: The mistral is a katabatic wind. As the cold air descends through the valleys, it spreads out. Skies are usually clear except for a few altocumulus standing lenticular visible on satellite imagery. Precipitation is rare; however, as the cold air moves across warmer water, convection is likely to occur.

Unique features: A sharp shear line between high and low wind speeds occurs downstream from the eastern edge of the Pyrenees. According to Reiter (1975), the USS Forrestal reported that during her 1965-1966 deployment:

> a definite shear line was found to exist during all mistrals... Winds to the west of the shear lines were northerly 8 to 16 kt, and the seas were 3 to 5 ft. In the shear line, winds and seas increased markedly; to the east of the shear line, winds were 35 to 45 kt and seas were 14 to 20 ft... When the line was marked by clouds, the shear usually seemed to be very sharp.

Duration: Several days, but prolonged events have occurred especially when the jet stream is oriented parallel to the mountain gaps.

B. RULES OF THUMB AND DISCUSSION

The following rules, which are taken from the *Handbook for Forecasters in the Mediterranean* (Brody and Nestor 1980), apply to forecasting the occurrence of mistral conditions. In the section of the *Handbook* concerning forecasting in the Gulf of Lion and downwind areas of the western Mediterranean, 68 rules are listed, and 41 of these are directly related to the mistral. As in the case of the levante, these 41 rules have been evaluated during the six-month period for possible inclusion in the expert system. Of the 41 rules, 14 have been used without modification, two have been used with only slight modification, and 25 are considered unsuitable for inclusion in the expert system.

1. The Benchmark

As with levante, the problem of no *in situ* observations of the wind speed makes wind forecasts for the Gulf of Lion difficult to verify. Similar to other open-water areas, gale conditions may go unobserved if no ships are present or do not report. Since the weather buoy TOQD in the Gulf of Lion (Figure 12) is no longer functioning, land station observations must be used to infer the gale conditions over open water.

Rule 28 is chosen as the benchmark in the Gulf of Lion.

RULE 28: USE THE TABLE BELOW TO ESTIMATE WIND SPEED ASSOCIATED WITH A MISTRAL IN THE GULF OF LION.

PRESSURE * DIFFERENCE (MB)	PERPIGNAN AND NICE	PERPIGNAN AND MARIGNANE	MARIGNANE AND NICE
3		30-35 KT	30-35 KT
4		40	40
5		45-50	45-50
6	30-35 KT		
8	40		
10	45-50		

* HIGHEST PRESSURE AT PERPIGNAN

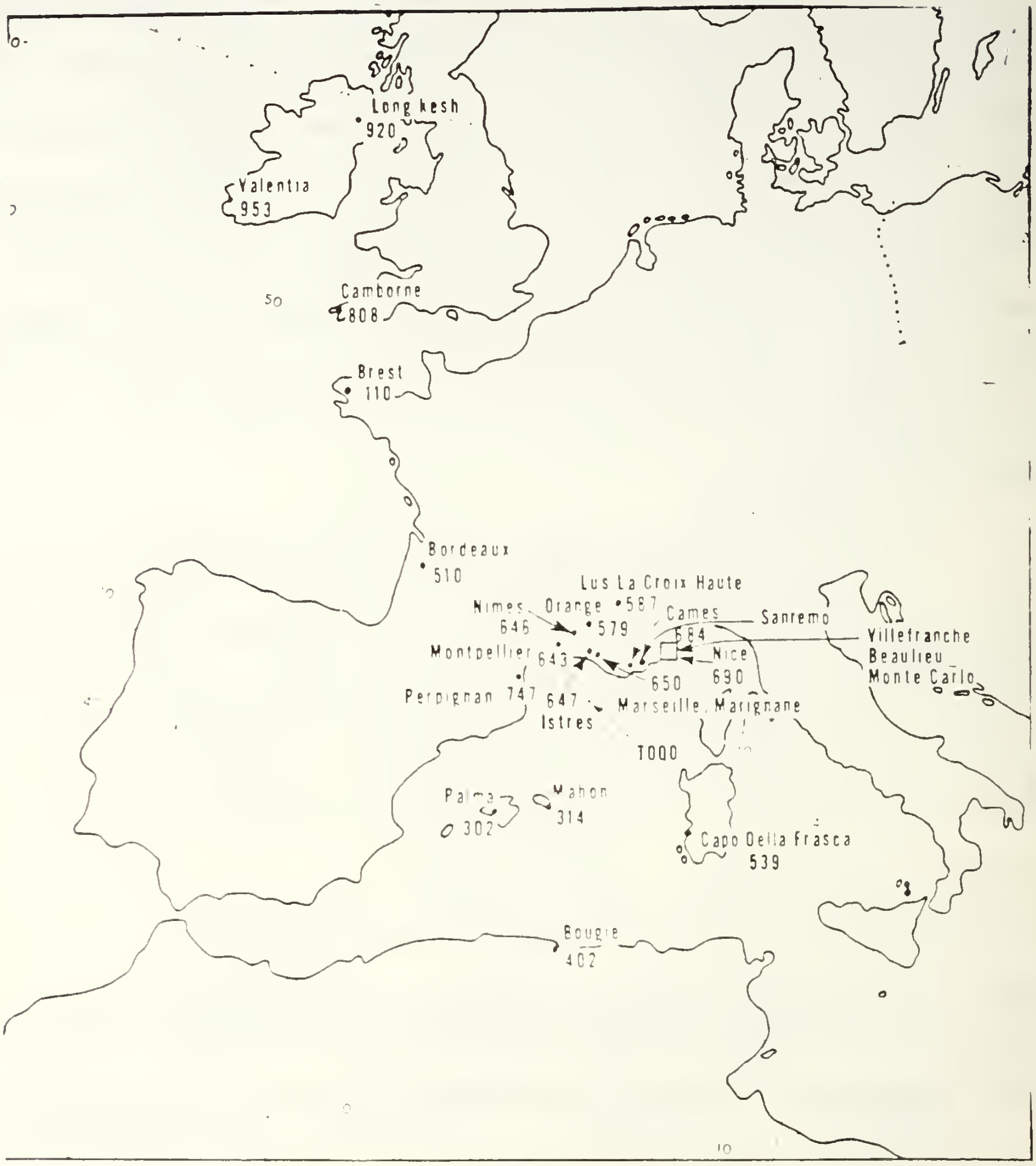


Figure 12. Station locator map for the Gulf of Lion-west Central Mediterranean area. (Brody and Nestor 1980)

Discussion: Using the gale/no-gale method described above, the wind speeds derived from the pressure differences between Perpignan and Nice, Perpignan and Marignane or Marignane and Nice are confirmed over 80 percent of the time (Table 6). Rule 28 is chosen as the benchmark for this study because these three stations cover the entire Gulf of Lion, whereas other rules apply only to limited areas in the Gulf.

The individual breakdowns of each of the pressure difference pairs is found in Table 6. The verification rate (in excess of 80 percent) achieved by each pair provides a very good correlation between the ship reports and

TABLE 6. GALE WIND CONDITIONS INFERRED FROM PRESSURE DIFFERENCES BETWEEN PERPIGNAN MINUS NICE, PERPIGNAN MINUS MARIGNANE AND MARIGNANE MINUS NICE VERSUS REPORTS BY SHIPS OF OPPORTUNITY IN THE GULF OF LION (ONLY WESTERLY TO NORTHERLY EVENTS INCLUDED).

Perpignan--Nice	Gale	No Gale	Gale	No Gale
ship report	Gale	No Gale	No Gale	Gale
Number of Events	43	267	29	27
Percentage of Events	12	73	8	7
Total Number of Events	310		56	
Percentage of Total Events	85		15	
Perpignan--Marignane	Gale	No Gale	Gale	No Gale
ship report	Gale	No Gale	Gale	No Gale
Number of Events	41	252	42	27
Percentage of Events	11	70	12	7
Total Number of Events	293		69	
Percentage of Total Events	81		19	
Marignane--Nice	Gale	No Gale	Gale	No Gale
ship report	Gale	No Gale	No Gale	Gale
Number of Events	34	74	22	45
Percentage of Events	9	74	6	11
Total Number of Events	326		67	
Percentage of Total Events	83		17	

the pressure differences. The total number of events vary because a missing observation at one of the three stations eliminates two of the three pressure differences in Table 6. No one pressure pair is chosen to stand alone in the expert system, because the forecast area is so large (Figure 6) that all three pressure differences must be tested to see if any one of the three pairs verify. Due to the mesoscale nature of the highest winds in the mistral, one or two pairs often indicate gale force winds occurring while the third pair does not. For example, from 09 UTC 12 December 1988 until 21 UTC 15 December (a total of 21 periods), the Perpignan and Nice pressure difference (16 periods) and the Perpignan and Marignane pressure difference (20 periods) indicated that a nearly continuous gale (at times storm) force mistral was occurring. The Marignane and Nice pressure difference for the same time period indicated gale force mistral conditions to be occurring at only five observation times.

Many reasons may contribute to the variations between the three pressure differences. One synoptic scenario occurs with a front approaching the Mediterranean basin from the Bay of Biscay and an area of low pressure extending down the Carcassonne Gap into the Gulf of Lion (see Figure 10). As lower pressure arrives, the gradient tightens and causes gale force winds to occur on the western side of the Gulf of Lion. When the low pressure becomes firmly entrenched in the Gulf of Lion, the pressure gradient across the entire Gulf tightens and gale force winds engulf the whole area. As the system continues to move eastward into the Gulf of Genoa, the gradient in the eastern Gulf continues to increase while the gradient in the western Gulf decreases. This common wintertime occurrence illustrates why all three pressure differences in Rule 28 are needed in the expert system.

A single pressure difference verification of gale along with a ship report of gale force wind conditions in the Gulf of Lion is considered enough for verification of Rule 28. This rule is used without modification in the expert system.

The remaining 40 rules in the *Handbook* pertain to mistral conditions in the Gulf of Lion and downwind areas of the Western Mediterranean. Each will be listed and discussed as to suitability for use in the expert system.

2. Mesoscale Aspects

The following five rules represent local wind events. They are the most qualitative of the rules in the *Handbook*. They are included in the expert system at the beginning of the decision-making process just after Rule 28. The rules discussed in this section and summarized in Table 7 should be used as the nowcasting portion of the expert system for locations in the western Mediterranean.

RULE 21: LUS LA CROIX HAUTE WILL PROVIDE A 2-3 H ADVANCED NOTICE OF MISTRAL ONSET. THIS WIND SPEED REPORT WILL CLOSELY APPROXIMATE THE WIND SPEED IN THE GULF. (NOTE: USEFULNESS OF THIS STATION LIMITED BY THE FACT IT ONLY REPORTS EVERY 3 H.)

Discussion: This rule did not indicate a single gale in the Gulf of Lion during the 204 observations in the six-month period. Since the station always indicated no gale conditions, Rule 21 is excluded from the expert system.

RULE 22: ORANGE GIVES A GOOD 3-4 H WARNING OF A GALE FORCE MISTRAL WHEN WINDS AT THIS STATION INCREASE TO

25 KT NORTHWESTERLY. HOURLY REPORTS ARE AVAILABLE FROM THIS STATION.

Discussion: This rule also was not effective in determining gale force wind conditions in the Gulf of Lion. Of the 907 concurrent events, only 13 verified as gale events and 11 were erroneous gale events. Of the other 883 events, 633 were no gale events and 250 were gale/no-gale (the pressure difference indicated gale and the Orange observation indicated no gale). This yielded a percentage of 71 percent for similar events.

After some testing, the wind criteria were modified to include wind directions from 300° to 360° (vice 340°) and wind speeds of greater than or equal to 15 kt. Based on the modified criteria, 94 gale events and 564 no gale events are correctly identified, 80 no-gale/gale events occur, and 169 gales are forecast when no gale events occur. This change only improved the similar percentages to 72 percent (Table 7).

It is clear that other factors may be affecting this rule and more testing of wind directions and wind speeds needs to be done. However, the modified rule is included in the prototype expert system.

RULE 23: BY OBSERVING CHANGES IN THE NORMALLY STRONG AFTERNOON SEA BREEZE (EAST-SOUTHEASTERLY DIRECTION) AT PERPIGNAN, IT IS POSSIBLE TO FORECAST THE BEGINNING OF A MISTRAL IN THE GULF OF LION. IF, AT THIS STATION, THE WIND SHIFTS NORTHERLY WITH SPEEDS INCREASING TO 25-30 KT AND THE TEMPERATURE DROPS AT LEAST 3°F, A STRONG MISTRAL (40-50 KT) WILL BE BLOWING IN THE GULF OF LION WITHIN 6 H.

Discussion: This rule did not verify once during the six-month study. Three hourly observations are not frequent enough to detect the sudden changes required by this rule. Therefore, it is not included in the expert system.

TABLE 7. COMPARISON OF GALE WIND CONDITIONS AT THE INDICATED STATIONS TO THE WIND SPEEDS DERIVED BY TAKING THE PRESSURE DIFFERENCE BETWEEN PERPIGNAN-NICE, PERPIGNAN-MARIGNANE AND MARIGNANE-NICE (ONLY WESTERLY TO NORTHERLY EVENTS INCLUDED).

Pressure Difference	Gale	No Gale	Gale	No Gale
Orange (Rule 22M)	Gale	No Gale	No Gale	Gale
Number of Events	94	564	169	80
Percentage of Events	10	62	169	80
Total Number of Events	658		249	
Percentage of Total Events	72		28	
Pressure Difference	Gale	No Gale	Gale	No Gale
Perpignan (Rule 29)	Gale	No Gale	No Gale	Gale
Number of Events	145	862	150	19
Percentage of Events	12	73	13	2
Total Number of Evetns	1007		169	
Percentage of Total Events	86		14	
Pressure Difference	Gale	No Gale	Gale	No Gale
Marignane (Rule 29)	Gale	No Gale	No Gale	Gale
Number of Events	111	898	184	8
Percentage of Events	9	75	15ds	1
Total Number of Events	1009		192	
Percentage of Total Events	84		16	
Pressure Difference	Gale	No Gale	Gale	No Gale
Montpellier (Rule 30M)	Gale	No Gale	No Gale	Gale
Number of Events	36	832	246	6
Percentage of Events	3	74	22	1
Total Number of Events	868		252	
Percentage of Total Events	78		22	
Pressure Difference	Gale	No Gale	Gale	No Gale
Isres (Rule 30)	Gale	No Gale	No Gale	Gale
Number of Events	51	758	193	` 16
Percentage of Events	5	74	19	2
Total Number of Events	809		209	
Percentage of Total Events	79		21	

RULE 29: WIND SPEEDS OVER OPEN WATER DURING A MISTRAL WILL BE APPROXIMATELY DOUBLE THOSE MEASURED AT

PERPIGNAN OR MARIGNANE EXCEPT IN STORM CONDITIONS, WHEN THE RATIO WILL BE LOWER.

Discussion: This rule is included without modification in the expert system. The 86 percent verification for Perpignan and the 84 percent for Marignane (Table 7) combine to produce a very reliable rule.

RULE 30: A GOOD INDICATION OF THE INTENSITY OF A MISTRAL IN THE GULF OF LION CAN BE OBTAINED BY ADDING 10 KT TO THE WIND SPEED REPORTED BY EITHER MONTPELLIER OR ISTRES.

Discussion: The rule for Montpellier verified for 76 percent of the similar events if the wind speeds are greater than or equal to 24 kt. However, only four events are identified by this criteria. If the wind speed is modified to greater than or equal to 15 kt, the percentage is increased to 78 percent and 36 gale events are identified (Table 7). Thus, this modified wind speed criterion for Montpellier is incorporated into the expert system.

The rule for Istres detected 51 gale events and verified 79 percent of the similar events (Table 7). This portion of Rule 30 is included in the expert system.

3. Intensity Aspects

Rules 31 and 32 relate to the intensity of the storm. These rules apply to the nowcasting portion of the expert system, and similar to their counterparts in Table 7, are located before the synoptic rules in the expert system. The gale/no-gale format for determining a similar event no longer applies here (Table 8). A success (false alarm) will be recorded when the condition in the rule is satisfied and an event occurs (does not occur). A failure will be recorded when the rule is not satisfied and yet an event occurs.

RULE 31: IF THE 500 MB WINDS REPORTED AT EITHER BORDEAUX OR BREST ARE NORTHWESTERLY AT 65 KT OR GREATER, STORM WARNINGS INSTEAD OF GALE WARNINGS ARE INDICATED FOR THE GULF OF LION.

Discussion: This rule is included in the expert system since 11 successes, only two false alarms and five failures occur when the rule applies (Table 8).

RULE 32: MAXIMUM MISTRAL WINDS OCCUR WHEN THE SURFACE ISOBARS ARE AT AN ANGLE OF 30° TO THE VALLEYS OF EITHER THE GARONNE, THE RHONE OR THE DURANCE WITH LOW PRESSURE TO THE SOUTHEAST.

Discussion: Rule 32 is included in the expert system even though 41 failures, 20 false alarms, and only 36 successes occur (Table 8). Some of the failures can be eliminated by requiring that a gale force wind condition is observed before this rule is applied.

TABLE 8. SUCCESSES, FAILURES AND FALSE ALARMS FOR THE INTENSITY RULES OF THUMB FOR THE MISTRAL PORTION OF THE EXPERT SYSTEM.

RULE	FALSE ALARMS	SUCCESS	FAILURE
INTENSITY RULES			
31	2	11	5
32	20	6	41

4. Synoptic-scale Aspects

The next 11 rules discussed are somewhat qualitative and are considered nebulous at best. It can be difficult to use some of these rules definitively. For example, when the position of a surface trough is required to be at an exact location to satisfy Rule 1 and the trough is a little east or west of that location, a judgement by the forecaster is required. Because most of the rules in this section refer to forecast situations that are not clear cut, they are used in the expert system in such a way that they only indicate the possibility of a mistral. Unlike the more quantitative wind speed rules (Rules 28-30), these 11 rules must be used in combination with other rules.

When the *Handbook* was written, the surface wind event guidance from numerical models was considered somewhat questionable. Consequently, the forecaster had to rely on conceptual models such as in Figure 11. Many of the rules in this section are related to these conceptual models. Even though many improvements have been made in the numerical models over the past decade, this numerical guidance may not be available to the Mediterranean Fleet. Therefore, the rules that pertain to onset are to be used in lieu of numerical guidance whenever that guidance is unavailable. Consequently, they are placed at the end of the mistral section of the prototype expert system and may be used or discarded as the case warrants.

RULE 1: IN ASSOCIATION WITH A TYPE A LARGE-SCALE FLOW PATTERN AS SHOWN IN FIGURE 11A, FORECAST THE START OF A MISTRAL WITHIN 48 H WHEN A SURFACE FRONTAL TROUGH IS LOCATED JUST SOUTH OF ICELAND AND IS BACKED BY AN EXTREMELY STRONG SURGE OF COLD AIR TO THE EAST OF GREENLAND. (NOTE: THE LONGWAVE RIDGE AXIS IS WEST OF ICELAND; THIS RULE IS BIASED TOWARD ESTABLISHED RATHER THAN DEVELOPING PATTERNS.)

Discussion: This is a very weak rule. Of the 54 times it applied (Table 9), 36 events were considered false alarms, in eight cases the mistral occurred in 48 h or less and the remaining 10 events did not result in a mistral occurring within 48 h. A false alarm is defined here if a mistral did not result when the rule was satisfied. A forecast is considered a success if the mistral is observed 48 h or closer to the start of a mistral. A failure is defined to occur if the rule is not satisfied until after the event actually occurs or if the mistral occurs without prior success of the rule within the 48 h time limit. Even though more research is recommended to determine how best to apply this rule, Rule 1 is included in the prototype expert system because it represents the best rule of thumb available for 48 h onset. A warning about its reliability is added to the expert system summary.

TABLE 9. SUCCESSES, FAILURES AND FALSE ALARMS FOR RULES FROM THE MISTRAL PORTION OF THE EXPERT SYSTEM.

RULE	FALSE ALARMS	SUCCESS	FAILURE
ONSET RULES			
1	36	8	10
6	1	4	15
8	0	8	14
11	7	27	12
13	18	16	7
14	3	7	12
16	9	8	13
17 (C)	4	8	11
17 (A)	4	13	6

RULE 2: IN ASSOCIATION WITH A TYPE C LARGE-SCALE FLOW PATTERN AS SHOWN IN FIGURE 11C, FORECAST THE START OF A MISTRAL WITHIN 48 H WHEN (1) A SURFACE FRONTAL TROUGH AND UPPER SHORT-WAVE TROUGH ARE 24° OF LONGITUDE TO THE WEST OF THE GULF OF LION, (2) THE SHORT-WAVE RIDGE IS 12° WEST, AND (3) BOTH ARE PROGRESSING AT A SPEED OF 12° PER DAY. (NOTE: THE 'RULE OF THUMB' IN THIS CASE IS THAT THESE SHORT-WAVE RIDGES AND TROUGHS REPLACE EACH OTHER IN 24 H, I.E., THERE IS A TENDENCY TOWARD A 48 H PERIODICITY OF FRONTAL SYSTEMS MOVING INTO FRANCE AS LONG AS THE HIGH-INDEX CIRCULATION IS MAINTAINED. MISTRALS IN THIS SITUATION MUST BE SHORT-LIVED.

Discussion: This rule is difficult to verify because the available charts did not give sufficient information to evaluate it. Of the 30 possible events, only two are successfully forecast and 12 false alarms and 16 failures occur with this rule. Until more research can be done, this rule is excluded from the expert system.

RULE 5: IN ASSOCIATION WITH A TYPE B LARGE-SCALE FLOW PATTERN AS SHOWN IN FIGURE 11B, FORECAST THE START OF A MISTRAL WITHIN 24 H WHEN: (1) THE 500 MB TROUGH MOVES OVER OR JUST SOUTH OF THE SOUTH COAST OF FRANCE; AND (2) THE ASSOCIATED SURFACE LOW APPEARS IN OR NEAR THE GULF OF GENOA.

Discussion: This rule was excluded from the expert system because six false alarms, only two successes and 17 failures occur when it applies.

RULE 6: THE PROBABILITY OF MISTRAL OCCURRENCE IS GREATEST (CORRELATION COEFFICIENT, R = 0.62) IF THE 500 MB WIND DIRECTION AT BORDEAUX IS 330° TO 340° OR 040° TO 050°, WHEN THE 500 MB TROUGH REACHES NIMES. THE PROBABILITY DECREASES RAPIDLY AS DIRECTION CHANGES EITHER TO THE WEST OR EAST FROM THE 330° TO 050° BAND.

Discussion: This rule was included in the expert system even though the failure rate was high. Of 20 events, 15 are failures and only four are successes (Table 9), but only one false alarm occurs. The rule describes a general condition during which mistral conditions may occur. For this rule to be useful, it only needs to have a low rate of false alarms. The number of failures is not a problem. The expert system will only recognize positive responses to the question "is the 500 mb wind direction at Bordeaux 330° to 340° or 040° to 050°?" If the answer is "no" it will not be applied. As with the other rules in this category, a failure is just a missed opportunity to forecast a mistral.

RULE 8: A MISTRAL IS LIKELY TO OCCUR WITH A TYPE A SITUATION (FIGURE 11A) WHEN: (1) THE LONG-WAVE TROUGH IS

OVER OR JUST PAST THE SOUTH COAST OF FRANCE; AND (2) A NORTHWESTERLY (WEST THROUGH NORTH-NORTHEAST) CURRENT WITH MAXIMUM SPEED OF AT LEAST 50 KT AT 500 MB SO ORIENTED THAT IT POINTS TOWARD THE GULF OF LION.

Discussion: Of the 22 occasions when this rule applies, no false alarms, eight successes and 14 failures occur (Table 9). Once again, the failure rate is not a problem because a negative answer causes the expert system to give no response. Therefore, this rule is included with a good deal of confidence in the expert system.

RULE 11: IN ASSOCIATION WITH A TYPE A LARGE-SCALE FLOW PATTERN (FIGURE 11A) A MISTRAL WILL OCCUR IF THE 500 MB WINDS OVER ENGLAND OR IRELAND ARE NORTH-WESTERLY 50 KT OR MORE.

Discussion: This rule is the most successful of all those tested. Of the 46 events, only seven false alarms, 27 successes and 12 failures occur (Table 9). Consequently, Rule 11 is included in the expert system.

RULE 12: IF A CUTOFF LOW AS SEEN AT 500 MB FORMS OVER NORTHEAST FRANCE AND PRODUCES A NORTHWESTERLY FLOW AT 500 MB OVER THE SOUTH COAST, A MISTRAL MAY OCCUR EVEN THOUGH 500 MB WIND SPEEDS DO NOT REACH 50 KT AND THE JET AXIS IS LOCATED FAR TO THE WEST AND SOUTH.

Discussion: This rule is not included in the expert system because only two successes, 19 failures and five false alarms are found in the 26 events.

RULE 13: A MISTRAL GENERALLY SETS IN WHEN THE SURFACE FRONT OR TROUGH PASSES PERPIGNAN, OR THE 500 MB TROUGH PASSES BORDEAUX. (NOTE: THESE TWO EVENTS ARE EXPECTED TO OCCUR NEARLY SIMULTANEOUSLY.)

Discussion: This rule is included in the expert system because 16 successes occurred in the 41 events, even though 18 false alarms and seven failures also occurred (Table 9). In combination with other rules, this rule will make the forecast recommendation stronger.

RULE 14: IN ASSOCIATION WITH A TYPE C LARGE-SCALE FLOW (FIGURE 11C), A MISTRAL WILL OCCUR IF A DEEPENING 500 MB TROUGH MOVES OVER THE SOUTH COAST OF FRANCE AND IS FOLLOWED BY A 500 MB RIDGE BUILDING AT ABOUT THE LONGITUDE OF IRELAND AND SPAIN.

Discussion: This rule is included in the expert system even though only seven successes occurred in 22 events. Only three false alarms and 12 failures occurred (Table 9). Based on the evaluations in this study, Rule 14 may be more successful if it is applied in association with a Type B block. More research is needed to increase the success rate of this rule.

RULE 16: IN ASSOCIATION WITH A TYPE A LARGE-SCALE FLOW PATTERN (FIGURE 11A), A MISTRAL WILL START WHEN THE 500 MB SHORT-WAVE ARRIVES OVER PERPIGNAN.

Discussion: This rule did not verify as well as expected. Of 30 events, nine false alarms, 13 failures and only eight successes were found (Table 9). Of the eight successful events, three occurred after the start of the mistral. Although this rule is included in the prototype expert system, it should be used only with other rules. A comment to this effect has been included in the expert system.

RULE 17: IN ASSOCIATION WITH A TYPE C LARGE-SCALE FLOW PATTERN (FIGURE 11C), A MISTRAL WILL START WHEN A NORTHWESTERLY JET STREAM ARRIVES OVER THE BAY OF BISCAY.

Discussion: During the six-month study, four false alarms, eight successes and 11 failures occurred during Type C block conditions (Table 9). When the rule was applied to Type A block conditions, 13 successes and only four false alarms and six failures occurred. It appears that the Type C (Type A) block rule is more appropriate in the summer (winter). Although more research is needed in this area, the rule is included in the expert system.

5. Rules not Tested

This next group of rules were untested and thus were not included in the expert system. They are separated according to the reason that they were untested. First, some rules are combined in other rules and, therefore, are not evaluated separately.

RULE 3: IN ASSOCIATION WITH A TYPE A LARGE-SCALE FLOW PATTERN (FIGURE 11A), FORECAST THE START OF A MISTRAL WITHIN 24 H WHEN THE FRONTAL AND 500 MB SHORT-WAVE TROUGHS EXTEND ACROSS SOUTHERN (OR SOUTHEASTERN) ENGLAND AND THE BAY OF BISCAY, AND THE SHORT-WAVE RIDGE IS LOCATED OVER SPAIN AND FRANCE. (NOTE: THE LONG-WAVE RIDGE AXIS IS WEST OF ICELAND. THIS RULE IS BIASED TOWARD ESTABLISHED RATHER THAN DEVELOPING PATTERNS.)

RULE 4: IN ASSOCIATION WITH A TYPE C LARGE-SCALE FLOW PATTERN (FIGURE 11C), FORECAST THE START OF A MISTRAL WITHIN 24 H WHEN THE SURFACE AND 500 MB SHORT-TROUGHS EXTEND FROM THE IRISH SEA SOUTHWARD OVER PORTUGAL, AND THE SHORT-WAVE RIDGE IS OVER SOUTHERN FRANCE. (NOTE: THIS PATTERN IS POORLY DEFINED IN THIS HIGH-INDEX SITUATION.)

RULE 19: THE MISTRAL WILL START WHEN ONE OF THREE DIFFERENCES IS ACHIEVED: PERPIGNAN-MARIGNANE, 3 MB; MARIGNANE-NICE, 3 MB; OR PERPIGNAN-NICE, 6 MB. A DIFFERENCE USUALLY OCCURS FROM 0 TO 24 H AFTER A CLOSED GENOA LOW APPEARS, BUT IT OCCASIONALLY OCCURS EARLIER.

The following rules were not tested due to a lack of upper-level sounding data.

RULE 7: THE PROBABILITY OF MISTRAL OCCURRENCE WITH A BLOCKING PATTERN IS GREATEST (R = 0.30) IF, AT THE TIME THE TROUGH REACHES NIMES, THE NIMES HEIGHT DEVIATION FROM NORMAL IS ABOUT +200 MB. FOR PROGRESSIVE SYSTEMS, THE PROBABILITY INCREASES FROM R = 0.26 FOR DEVIATIONS OF +75 M TO R = 0.98 FOR DEVIATIONS OF -350 M.

RULE 10: THE PROBABILITY OF MISTRAL OCCURRENCE INCREASES WITH THE NORTH COMPONENT OF THE 850 MB WIND AT NIMES, REACHING R = 0.93 FOR 50 KT.

Rule 41 was not evaluated due to a lack of data.

RULE 41: MISTRALS DURING LATE AUTUMN AND EARLY WINTER MAY OCCUR WHEN AIR-SEA TEMPERATURE DIFFERENCES (WATER WARMER THAT AIR) REACH 6°C OR MORE. AT THESE TIMES THERE IS POOR VISIBILITY IN THE LOWEST 30 M OF THE ATMOSPHERE BECAUSE OF A LAYER OF SPRAY. THESE MISTRAL SITUATIONS ARE ALSO ASSOCIATED WITH DAMAGE TO HARBOR INSTALLATIONS ALONG THE ALGERIAN AND TUNISIAN COASTS BECAUSE OF THE UNUSUALLY HIGH SEA AND SWELL.

Some rules were not included in the expert system because they depend on satellite data that may not be available to the forecaster.

RULE 20: WAVE CLOUDS, SUCH AS OBSERVED ON HIGH-RESOLUTION DEFENSE METEOROLOGICAL SATELLITE PROGRAM (DMSP) SATELLITE IMAGERY, ARE OBSERVED OVER THE MASSIF CENTRAL OF SOUTHERN FRANCE APPROXIMATELY 6 H BEFORE THE START OF A MISTRAL.

RULE 25: FORECAST MISTRAL WINDS TO INCREASE DURING A TYPE A LARGE-SCALE FLOW PATTERN (FIGURE 11A) IN ABOUT 24 H AFTER A NEW COLD FRONT OR MINOR TROUGH APPEARS IN THE NORTHWEST CURRENT OVER SOUTHERN ENGLAND, AND THE MAXIMUM SPEED AT 500 MB IN THE CURRENT INCREASES AT LEAST 10 KT WHILE THE INFLECTION POINT (IP)

RETROGRADES OR REMAINS STATIONARY; OR WITH THE PASSAGE OF THE NEW COLD FRONT OR MINOR TROUGH.

RULE 26: SATELLITE OBSERVATIONS INDICATING A STRONG MISTRAL WILL EXHIBIT THE FOLLOWING FEATURES: CLOUDY OVER FRANCE AND CLEAR OVER THE WATER AREA SOUTH OF THE 1000' WATER DEPTH CONTOUR; CLEAR OVER THE GULF OF LION BUT A CLOUD MASS, PARALLEL TO THE COAST, LYING 75-150 N MI OFFSHORE; WISPY CLOUD STREAKS EXTENDING FROM 315° TO 360° INTO OFFSHORE CLOUDS.

RULE 27: WAVE CLOUDS EXTENDING FROM SARDINIA TO TUNISIA, VIEWED ON SATELLITE IMAGERY, ARE GENERALLY ASSOCIATED WITH GALE FORCE MISTRAL SITUATIONS.

The next two rules relate to a future research project and will be evaluated later for use in another section of the Mediterranean Wind Forecaster.

RULE 15: GENOA LOWS OCCUR ALMOST SIMULTANEOUSLY WITH THE ONSET OF THE MISTRAL IN THE GULF OF LION, AND THEY INVARIABLY FORM WHEN CONDITIONS ARE RIGHT FOR A MISTRAL TO OCCUR.

RULE 18: IF A 500 MB TROUGH EXTENDS FROM CENTRAL EUROPE SOUTHWARD OVER NORTH AFRICA, A SURFACE LOW FROM ALGERIA MAY PROPAGATE NORTHWARD, INTENSIFY IN THE GULF OF GENOA, AND INITIATE A MISTRAL.

Although some rules provide valuable information, they are statements rather than rules and, therefore, are not included in the expert system.

RULE 24: STRONGEST WINDS ASSOCIATED WITH A MISTRAL DO NOT OCCUR UNTIL AFTER THE PASSAGE OF THE UPPER-LEVEL (500 MB) TROUGH. THIS OCCURS WELL AFTER THE SURFACE COLD FRONTAL PASSAGE.

RULE 33: THE EASTERN BOUNDARY OF THE MISTRAL EXTENDS DOWNWIND FROM THE WESTERN EDGE OF THE ALPS THROUGH SAN REMO.

RULE 34: THE WESTERN BOUNDARY OF THE MISTRAL HAS THE FOLLOWING CHARACTERISTICS:

(1) THE BOUNDARY IS GENERALLY NARROW, 2-20 N MI WIDE.

(2) LARGE CHANGES IN WIND AND SEA CONDITIONS ARE OBSERVED ACROSS THE BOUNDARY: WINDS GENERALLY ARE 8-16 KT TO THE WEST AND 35-45 KT TO THE EAST OF THE BOUNDARY, WHILE SEAS ARE 3-5 FT TO THE WEST AND 14-20 FT TO THE EAST.

(3) THE BOUNDARY DEFINING THE LIMIT OF THE MISTRAL APPEARS TO MOVE GENERALLY FROM EAST TO WEST ESPECIALLY IN THE REGION OF THE BALEARIC ISLANDS. AT TIMES IT OSCILLATES FROM SOUTHWEST MALLORCA TO NORTHEAST MENORCA.

(4) THE BOUNDARY OCCASIONALLY IS MARKED BY A LINE OF LOW CLOUDS; AT OTHER TIMES IT IS CLEAR AND CAN ONLY BE OBSERVED BY THE DIFFERENT EFFECTS OF THE WIND ON THE SURFACE OF THE SEA.

(5) A RELATIVELY ACCURATE LOCATION OF THE BOUNDARY IS A LINE DRAWN TO THE NORTH AFRICAN COAST THROUGH THE STATIONS AT PERPIGNAN, MAHON AND BOUGIE.

RULE 35: THE STRONG MISTRAL WINDS WHICH OCCUR ON THE CYCLONIC SIDE OF AND UNDERNEATH THE JET AXIS, WILL EXTEND AS FAR SOUTH OR SOUTHEAST AS DO THE TROUGH AND JET STREAM.

RULE 36: APPLIES PRIMARILY TO TYPE A LARGE-SCALE FLOW PATTERNS (FIGURE 11A). IF A DEEP TROUGH EXTENDS TO SICILY OR ALGERIA, THE MISTRAL USUALLY EXTENDS INTO THE REGION OF SICILY AND MALTA OR, IN EXTREME CASES, TO ALGERIA.

Because of the potential impact of the following statement, a comment might be added to the program to alert the forecaster to this situation.

RULE 40: DURING STRONG MISTRAL CONDITIONS IN THE GULF OF LION, A STRONG DIURNAL WIND VARIATION IN THE SEA AREA NORTH OF MALLORCA HAS BEEN OBSERVED, POSSIBLY THE RESULT OF OSCILLATION OF THE SHEAR LINE DESCRIBED IN RULE 34. DAYTIME WIND SPEEDS APPEAR TO BE MORE THAN TWICE AS STRONG AS THOSE AT NIGHT; IN ONE ACTUAL CASE, 10-20 KT DAYTIME WINDS DECREASED TO 4-6 KT AT NIGHT.

The following rules are best left to the forecaster to evaluate from other sources.

RULE 37: IN ASSOCIATION WITH A TYPE A LARGE-SCALE FLOW PATTERN (FIGURE 11A), SURFACE WINDS USUALLY DECREASE, I.E., THE MISTRAL CEASES WHEN THE JET AXIS MOVES EASTWARD AND THE ANTICYCLONIC REGIME IS ESTABLISHED. THIS RULE EFFECTS THE CONTROL ON THE SURFACE PATTERN THAT IS EXERCISED BY THE UPPER AIR PATTERN.

RULE 38: THE MISTRAL WILL CEASE WHEN THE CYCLONIC REGIME AT THE SURFACE GIVES WAY TO AN ANTICYCLONIC REGIME. INDICATIONS OF THIS CHANGE ARE:

(1) THE SURFACE WIND DIRECTION BECOMES NORTH TO NORTHEAST.

(2) THE 500 MB RIDGE BEGINS TO MOVE OVER THE AREA.

(3) HIGH PRESSURE AT THE SURFACE BEGINS TO MOVE INTO THE WESTERN BASIN OF THE MEDITERRANEAN.

(4) THERE IS A CHANGE THAT REDUCES THE PRESSURE DIFFERENCE BETWEEN FRANCE AND THE WESTERN BASIN.

RULE 39: COLD ADVECTION ON THE WESTERN FLANK OF A BLOCKING RIDGE OVER THE EASTERN ATLANTIC MAY HERALD

THE BREAKDOWN OF THE LONG-WAVE PATTERN AND, HENCE OF THE MISTRAL. THIS RULE APPLIES TO TYPES A AND B LARGE-SCALE FLOW PATTERNS WHERE BREAKDOWN OF THE RIDGE, RATHER THAN EASTWARD MOVEMENT, RESULTS IN CESSATION OF THE MISTRAL.

Another rule, even though untested, was included in the expert system. It is the first rule queried by the expert system in the mistral portion of the program. If this rule fails, the program need not be run because there can be no mistral.

RULE 9: THE PROBABILITY OF MISTRAL OCCURRENCE IS GREATEST (R = 0.58) WHEN THE 850 MB WIND DIRECTION OVER NIMES IS FROM 350°; IT DECREASES WITH WINDS EAST OR WEST OF 350°, REACHING NEAR ZERO FOR WINDS FROM 240° AND 090°.

Discussion: Even though this rule could not be tested due to a lack of data, it is included in the expert system since this rule is in general use. This rule provides a quick evaluation of conditions. A mistral is excluded if winds are from 240° or 090°. As the expert system is tested by Naval Oceanography Command Center, Rota this rule should be used with caution until its accuracy is assessed. A comment is included that indicates the rule has not been tested.

6. Summary

The mistral portion of the expert system is divided into two segments, a nowcasting portion and a forecasting portion. The rules in Tables 7 and 8 are used to give a nowcast for specific areas of the Gulf of Lion. The rules in Table 9, due to their synoptic nature, are considered qualitative and should be used only when numerical model guidance is unavailable.

VI. THE PROLOG ALGORITHM

A. INTRODUCTION

Two approaches are used to build an expert system. The first approach involves inputting data at the start of the program, letting the expert system process the information and reporting a solution or solutions (see Appendix A). The second approach is to have the expert system interrogate the user, process that information and give a timely response to that single point. The expert system continues in this fashion, interrogating and responding to each question until all of the data have been processed.

When a forecast solution can be clearly verified, the first approach is the best since all the information can be processed at one time with no further interaction by the user. If a single, quantitative or categorical forecast solution is not available, as in the case of the levante or mistral, then the second approach is best. The Western Mediterranean Gale Forecasting Program is an example of this second approach in which a series of rules are examined until the forecaster has accumulated enough evidence to decide that a gale does or does not exist.

B. THE APPROACH

This approach of interrogation and rule by rule solution is chosen for four reasons. First, it allows the forecaster to determine quickly (in most cases) whether a gale is occurring in the forecast area. If there is a questionable situation, the forecaster can continue to examine as many rules as necessary until he/she has made a decision. The program can be terminated at anytime by simply pressing the control and break keys. It is not necessary to execute the entire program (as in the first approach) before a solution is determined.

The second reason for this type of expert system is that it can save time for the watch team. The *Handbook for Forecasters in the Mediterranean* (Brody and Nestor 1980) lists so many rules for the levante and the mistral (refer to Chapters IV and V) that it is very easy for the forecaster to forget one or more of them as the forecast deadline approaches. With all the applicable rules included, the forecaster executes the program through all the rules of thumb that apply to the forecast situation. While the forecaster may forget a rule, the expert system will not.

The third reason for using this approach is its value as a training aid. Summertime in the western Mediterranean can be very peaceful. Major severe weather events are rare and winds, except for the summertime levante, are generally light and variable. The peaceful nature of the area changes dramatically as the winter season approaches. The expert system can be used to alert the forecast team of the rules that need to be considered during the winter months. The different portions of the expert system highlight the important mesoscale events as well as the synoptic-scale events that should be closely monitored.

The fourth, and probably the most important reason for this simplistic approach, is that it can be modified easily by the user. The purpose of an expert system is to simulate the reasoning of a forecaster and result in the same decision that an experienced forecaster would give under similar circumstances. As new rules are developed, views change or further verifications indicate that certain rules are no longer valid, this system can be modified easily. Unlike a FORTRAN program that may involve interrelated structural aspects, Turbo PROLOG makes these additions or deletions quite simple. Only a few clauses may need to be changed to update the expert system. It is truly a futuristic system limited only by man's ability to acquire new skills and translate them into the Turbo PROLOG language.

C. THE EXPERT SYSTEM

The Western Mediterranean Gale Forecasting Program is divided into two segments. The first segment deals with nowcasting levante winds and the second with forecasting mistral winds. At the beginning of each session, the user is provided the main menu that has a choice of three options (Figure 13). The sequence of events that is initiated with each option will be explained below. Although no prior knowledge of the Turbo PROLOG language is needed to understand this discussion, a basic familiarity with elementary PROLOG concepts may be obtained from Appendix A.

```
WELCOME TO THE WESTERN MEDITERRANEAN FORECASTING
PROGRAM
Which would you like to do?
    1) Make a levante forecast
    2) Make a mistral forecast
    3) Exit from the system
SELECT:
```

Figure 13. Main program option menu that is displayed at the start of a session.

1. Levante

Option 1 from the main menu initiates the levante forecast sequence, which is summarized in the flowchart in Figure 14. The program begins by requesting the surface wind observation from Tarifa (Rule 6). If the Tarifa report is unavailable, the Gibraltar surface wind observation is requested. If the Tarifa report is available, the program tests the wind direction. If an easterly component is reported at Tarifa, wind speeds greater than or equal to 47 kt will result in a conclusion that a storm force levante is blowing in the Strait of Gibraltar. If the Tarifa wind speed is in the storm range, the program directly exits to the test of the Gibraltar wind observation. If the Tarifa wind is less than 47 kt, but greater than or equal to 34 kt, the conclusion is that a gale force levante is occurring in the Strait of Gibraltar. If neither of these criteria applies, the program next tests Rule 6 regarding the Gibraltar wind speed. Rule 6 is that the Gibraltar wind speed is to be doubled if the wind is from 060° to 120°. The criteria for storm or gale force wind conditions are examined as described above for Tarifa, and the answer is displayed on the screen (Figure 15). Notice that the adjective "modified" is added to remind the user that the reported winds have been altered. Once a rule has succeeded, and a comment has been output on the screen, the expert system provides an option to move to the next rule of thumb or to exit if the forecaster has accumulated enough information to make a decision.

The pressure difference rules are grouped in the next portion of the program. Rota Rule 7 requires the sea level pressure observation at both Gibraltar and Tangier (Figure 16). The Palma minus Casablanca sea level pressure difference is tested next because of the high frequency of the

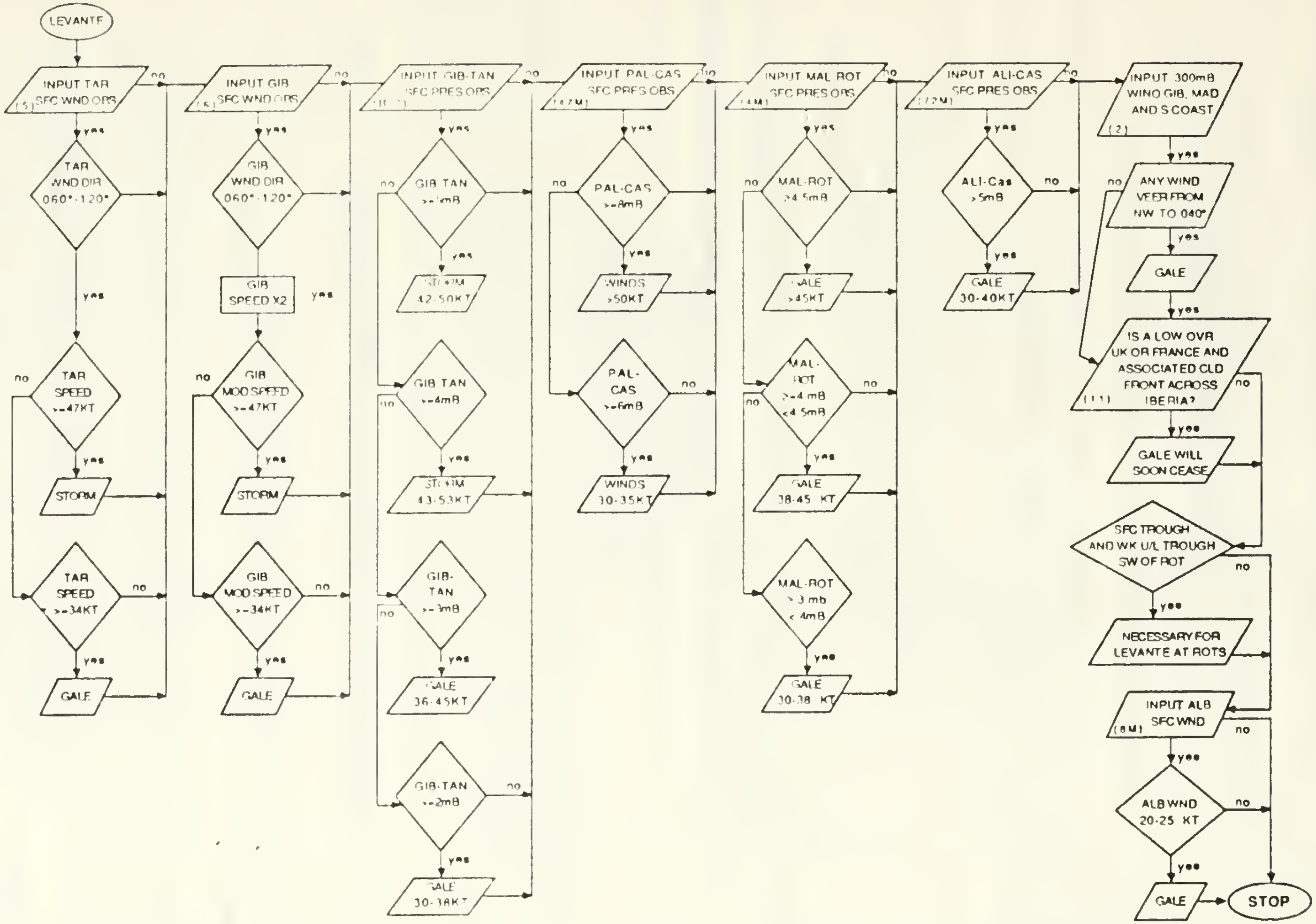


Figure 14. Flowchart of the levante portion of the program. TAR=Tarifa, GIB=Gibraltar, TAN=Tangier, PAL=Palma, CAS=Casablanca, MAL=Malaga, ROT=Rota, ALI=Alicante, MAD=Madrid, ALB=Alboran

simultaneous observations from these stations. The 1251 reports for Palma and Casablanca, compared to 903 reports for Rota and Malaga, and the 306 reports for Alicante and Casablanca (Table 2), is considered a significant advantage.

> **LEVANTE FORECASTER**
>
> Enter surface wind direction at Gibraltar (08495) as ddd
> 090
>
> Enter surface wind speed at Gibraltar (08495) as ss
> 25
>
> The modified wind speed at Gibraltar is 50.
> Based on Rule 6 a storm force levante is
> occurring in the Strait of Gibraltar.
>
> Press return to continue or control break to end this session.

Figure 15. Sample screen from the Levante Forecaster that has modified the Gibraltar wind speed

> **LEVANTE FORECASTER**
>
> NOTE: This section calls for the pressure difference between Gibraltar (08495) and Tangiers (60101). If either one is missing enter 000 for both. If one sea level pressure is in the 900's and the other is in the 1000's enter the complete number for both.
>
> Enter the sea level pressure at Gibraltar (08495) as pp.p
> 1002.3
>
> Enter the sea level pressure at Tangiers (60101) as pp.p
> 998.3
>
> Based on Rota Rule 7 a 36 to 45 kt wind is occurring in the Strait of Gibraltar.
>
> Press return to continue or control-break to end this session.

Figure 16. Sample screen from the Levante Forecaster showing a pressure difference rule of thumb (Rota Rule 7).

After the forecaster has evaluated all of the sea level pressure differences, the 300 mb wind shift over central and southern Spain is tested. If the wind direction has veered from the northwest to 040° at Madrid, Gibraltar or Alicante, the conclusion is that a gale is possible in the Strait of Gibraltar. If not, the system next checks for a surface low over the United Kingdom or France and an associated cold front across Iberia. Next, the system tests for a weak upper-level trough southwest of Rota. If there is a trough, the statement that this is "a necessary condition for the levante at Rota" will appear. Finally, the system checks whether a 20 to 25 kt wind is occurring in the Alboran Channel. If so, the system response is "a gale force levante is occurring in the Strait of Gibraltar". Regardless of the answer to the last question, the final screen in the levante program appears (Figure 17). The user may terminate the program or continue with the mistral portion.

LEVANTE FORECASTER

You are at the end of the Levante program. If you wish to run the Mistral program press enter to continue. If you wish to exit hit the control-break keys.

Press return to continue or control-break to end this session.

Figure 17. Sample screen for the levante-mistral interface.

In future versions, the termination of the session will trigger a summary of all inputs and successful conclusions to rules. In addition to being a useful reference for the forecaster during this and subsequent watches, the entry into the data base with subsequent verification information will be useful for post-season analysis for modifying the expert system.

2. Mistral

The second option from the main menu initiates the mistral forecast sequence, which is summarized in the program flowchart in Figure 18. The initial data request is for the 850 mb wind direction over Nimes (Rule 9). If the wind direction is either 090° or 240°, the conclusion is that no mistral can exist. A comment to the effect that this rule was not tested also will appear. This rule is presented first because if it is true, the user need not proceed further.

The next section of the program tests the pressure differences at Perpignan and Nice, Perpignan and Marignane, and Marignane and Nice (Rule 28). The same process is followed as described in the levante portion as each pair is tested for storm or gale conditions.

Next, the program asks for the wind direction at Perpignan (Rule 29). If the wind direction is from 300° to 040°, the wind speed is doubled and a screen similar to Figure 16 appears. If the wind direction for Marignane is from 280° to 040°, the wind speed at this station is also doubled.

Rule 30 is tested next. As discussed in Chapter V, the rule with the modification to Montpellier now adds 19 kt to the wind speed instead of 10 kt. This simple type of modification is an indication of how easily the program can be modified (see the add_nineteen_mon portion of the mistral program in Appendix C). The Istres portion of Rule 30 is tested next.

The only remaining onset rule (Rule 22M) is tested next. If the wind direction is from 300° to 360° and the wind speeds are greater than or equal to 15 kt, a comment appears that "a gale force mistral will be occurring within 3 to 4 h." This is the end of the nowcasting portion of the mistral program.

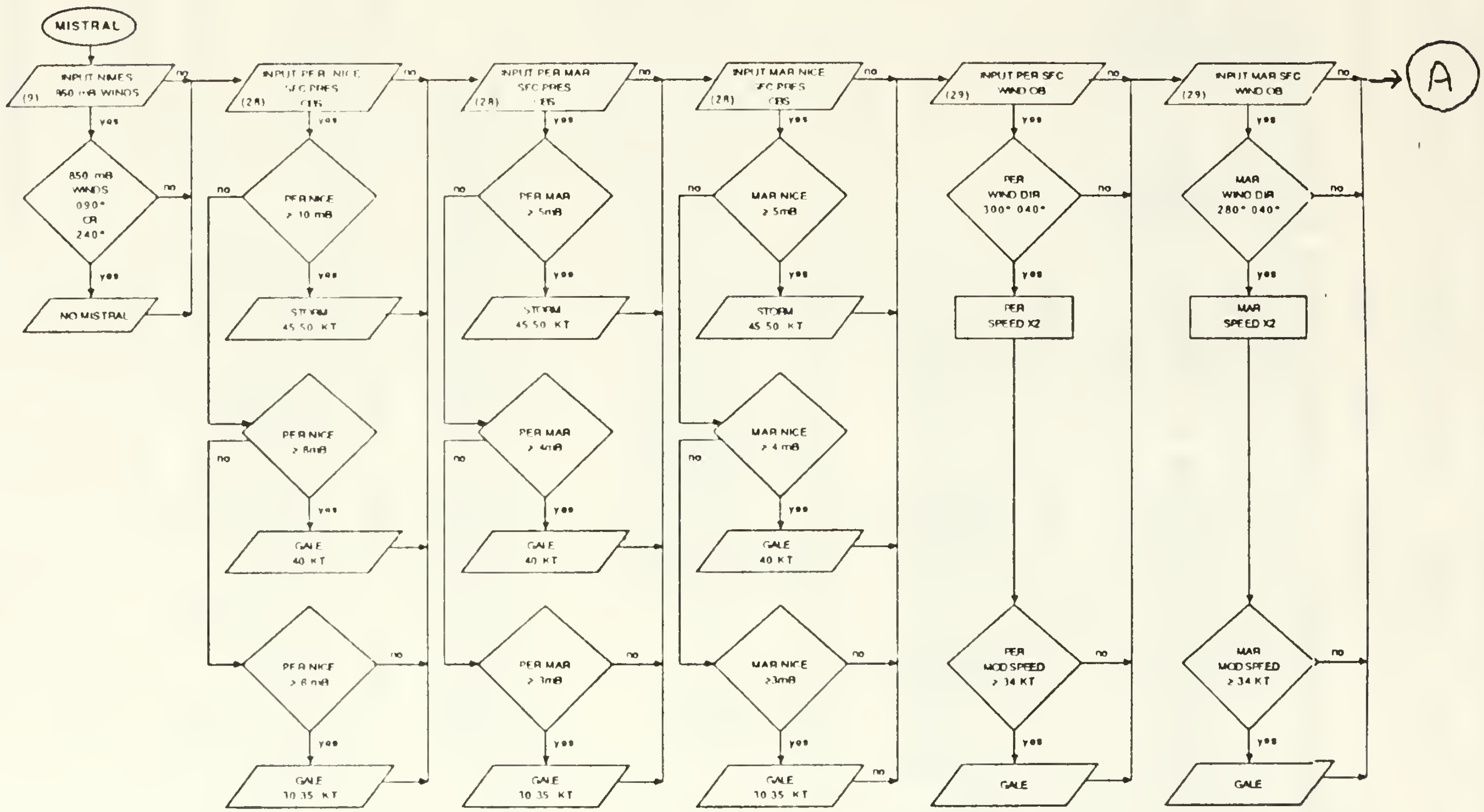


Figure 18. Flowchart of the mistral portion of the program. PER=Perpignan, MAR=Marignane, MON=Montpellier, IST-Istres, ORA=Orange

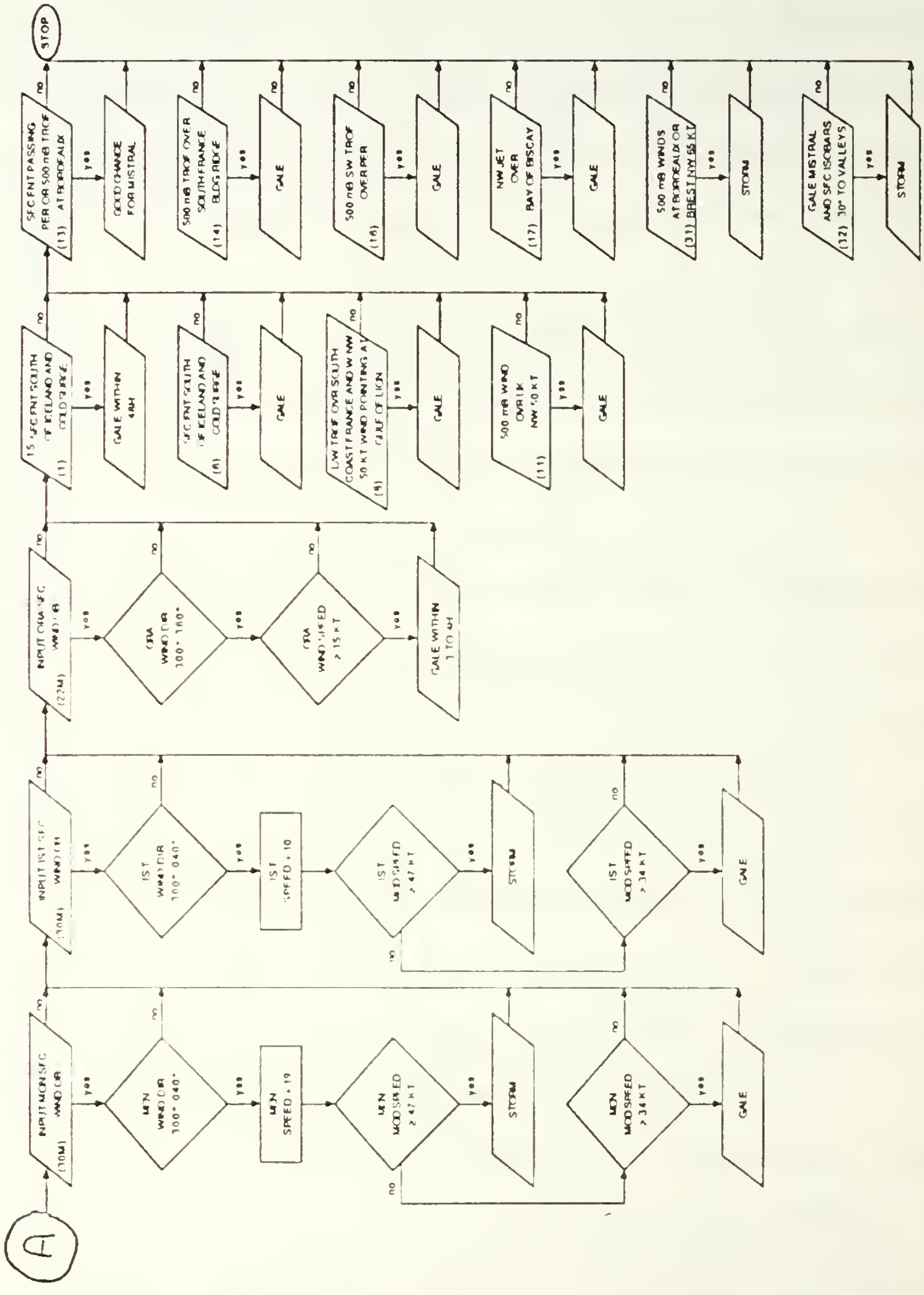


Figure 18. Continued

As discussed in Chapter V, the next sequence of rules represent the synoptic-scale aspects of the expert system. They are included last because they are not expected to be used unless numerical guidance in unavailable. These rules are a series of yes/no questions as in Figure 19. For Rule 1, the user is asked if there is a surface trough south of Iceland and an extremely cold surge of air east of Greenland. A yes response triggers the statement "forecast of a gale force mistral within 36 h to 48 h." The system then cycles through the rules of thumb in the order listed in Table 9. The intensity of the event is checked by using Rules 31 and 32 (Table 8). If either of these rules succeeds, the expert system respondswith a recommendation of a STORM rather than a GALE force mistral.

MISTRAL FORECASTER
In association with a Type A large-scale flow pattern (Fig II-2), is there a surface front located south of Iceland with a cold air (extremely strong) surge east of Greenland (Yes/No)? YES
Based on Rule 1 recommend forecast of a gale force mistral in the Gulf of Lion within 36 h to 48 h.
Press return to continue or control-break to end this session.

Figure 19. Example of the Mistral Forecaster showing a synoptic scale type rule of thumb (Rule 1).

The final question in the mistral portion of the expert system has not been mentioned above because it does not pertain to only mistral events. A United States Navy ship homeported in the Strait of Bonifacio has a small boat operation that could be affected by high winds and seas. This rule asks for the wind direction and wind speed at La Maddalena. This question is to alert the watch team to wind conditions in the Strait of Bonifacio for warning the ship. The user may then continue with the levante section or exit the program.

3. Exit

If the user selects this option, the system currently responds "This session is now terminated. Have a nice day." A future update of the Western Mediterranean Gale Forecasting Program will include a summary of the entire session to the point at which the user terminated. As previously mentioned, this program is not meant to be used in its entirety in every session. Rather, the forecaster should continue until he/she feels comfortable with a forecast decision. Whereas the entire program may be executed on some days, only the first two or three rules may be necessary to make a decision on other days. If the forecaster assistant is executing the program, the entire program should be run and a printed copy of the session summary should be submitted to the forecaster.

VII. SUMMARY AND RECOMMENDATIONS

A. SUMMARY

The purpose of this research is to test the feasibility of an expert system for predicting local winds based on rules of thumb from forecaster handbooks and forecaster knowledge and intuition. The goal is to derive a computer-based program in the form of floppy disks and a desktop computer that could be used by Navy forecasters onboard ships.

Unlike land station forecasts for which in situ observations are available for deriving and verifying local winds, forecast verification over the open water is a much more difficult process. Surface wind direction and speed, sea level pressure and temperature, and upper-level wind observations at 24 stations in the western Mediterranean basin were collected during September 1988-February 1989. Synoptic data from the northern and eastern North Atlantic and the western Mediterranean areas also were analyzed to test the rules of thumb to be entered in the expert system. During that period, 72,000 pieces of data were examined.

L. R. Brody (personal communication, 24 May 1989) confirmed that the rules of thumb in the *Handbook for Forecasters in the Mediterranean* (Brody and Nestor 1980) had never been formally tested. Therefore, the testing of the rules of thumb for the levante and the mistral was an essential step. Each rule was compared to a chosen benchmark: the Tarifa wind for the levante (Tables 4 and 5) and the pressure differences between Perpignan, Marignane and Nice for the mistral (Tables 6 and 7). Of the 19 rules listed in the

Handbook for levante, five are used in the expert system without modification, six are modified and eight are discarded. Of the 41 rules for the mistral, 14 are used without modification, two are slightly modified and 25 are eliminated. These 11 rules for the levante and 16 rules for the mistral make up the Western Mediterranean Gale Forecasting Program. Most of the verifications are in excess of 72 percent for the rules included in the expert system. The only exception is the Alboran Island report with a verification rate of 65 percent. Therefore, the expert system is considered a success and should be operationally tested and expanded to other local winds.

B. RECOMMENDATIONS

The prototype expert system is primarily a nowcasting system. No attempt was made to test the forecasting capabilities of the system by inputting forecast data from the stations. As subjective or numerical model forecasts for specific locations improves, the expert system could be applied to forecast the levante or mistral onsets and provide mesoscale wind forecasts in the Mediterranean basin. Second, the major reference source for the rules of thumb was the *Handbook for Forecasters in the Mediterranean* (Brody and Nestor 1980). It is recommended that a survey be sent to the operational weather offices in the Mediterranean area requesting an updated list of rules of thumb. The new rules could be tested with the data base generated here and validated rules could be added to the system.

C. CONCEPT VALIDATION

While there is a continuous need for more and better observations, some of the problem lies not in the data acquisition but in data management. New systems, such as radar wind profilers and remote sensing systems, will only enhance the data management problem. Forecasters will have to prioritize carefully what is needed to make a forecast. Forecasters also need to improve analysis skills and understanding of the physical processes that control the atmosphere. The expert system is one of the tools that forecasters can use to organize their data, process the most useful data, apply new understandings and produce more timely and accurate forecasts.

By combining the most accurate forecasting rules of thumb into a manageable, user friendly expert system, the bulky forecaster handbooks may be replaced in the future. The forecaster can be prompted with a set of questions that apply to the event. By reviewing the applicable rules with the aid of the expert system, the novice forecaster can efficiently hone his/her forecast skills. Although this prototype expert system is just an advanced form of the decision tree, it can lead a forecaster quickly through the decision-making process and hopefully lead to a correct forecast.

The expert system is not meant to replace the forecaster. Rather, it is meant to augment his skills. As with any tool, it must be used prudently. The expert system is never distracted by trivial or misleading meteorological events that sometimes cause the human forecaster to lose track of the big picture. In the structure adopted here, the system continues to ask questions until the forecaster has the information needed to make a forecast recommendation. The proper use of the Western Mediterranean Gale Forecasting Program in conjunction with the forecaster's analytical skills should prove to be a powerful team in future forecast decisions regarding the Mediterranean local wind systems.

Consideration should be given to developing expert systems for other operationally-important mesoscale and synoptic-scale weather events. A similar support system exists for refractivity and acoustics. This type of forecast system appears to offer logical solutions to fleet operational needs involving the atmosphere and ocean. Such forecasting techniques need to be placed into the Geophysical Fleet Mission Program Library (GFMPL) as soon as possible.

APPENDIX A. TURBO PROLOG PRIMER

The following appendix, written by Bruce M. Hagaman in September 1988 for his thesis, *A Prototype Expert System To Forecast Typhoon Conditions At Cubi Point, Philippines,* is included in its entirety to help the reader understand the PROLOG language.

A. INTRODUCTION

The first version of PROLOG (Programming in Logic) was created in the early 1970's by Alain Colmerauer at the University of Marseilles. PROLOG is increasingly popular, and is becoming accepted as the standard for small-scale artificial intelligence/expert system applications. While several versions of PROLOG are available, they all have similar structure.

The term programming really does not apply to PROLOG products in the conventional sense of FORTRAN, BASIC or other languages commonly used in numerical applications are known as procedural languages. Procedural languages require the programmer to create the algorithm, or procedure, that is to be followed exactly when the program is executed. Such a procedure-oriented program will always follow the same path through the set of instructions until the conclusion is reached. Each calculation or branch in the program's flow must be explicitly prescribed by the programmer in the code.

In contrast, PROLOG is a declarative language, and the logic does not require an exact sequence of steps to be followed to arrive at a conclusion or result. Rather, the program (the term, though inaccurate, is till used to describe a discrete set of PROLOG code) consists of a set of facts and a set of rules related to the problem under consideration. In response to a query, a PROLOG program accesses only those facts and rules necessary to determine all possible solutions. No instructions have to be included to specify how to sort through the facts or rules. The structure of PROLOG allows different paths to be taken if necessary with each program run.

B. PROLOG FACTS

Facts are written in so-called predicate form, and represent objects and their relationships. These objects can be numbers, people, things, words or whatever is needed for the problem. A typical example of predicate structure is *owns(lauren, bicycle)*[2] , where the predicate "owns" describes the relationship between its two arguments "lauren" and "bicycle." PROLOG facts can represent abstract ideas such as ownership, or more concrete relationships such as *weight(bob, 185)* for "Bob weighs 185 lbs.", or *father(julie, george)*, for "Julie's father is George." Facts can have any number of objects as their arguments, depending upon what is to be represented. For example one method to represent the fact that Johnny's parents are Fred and Sybill is *parents(johnny, fred, sybill)*.

In PROLOG facts, the specifics of the relationship between various objects is never explicitly defined. It is enough to simply assert that a relationship (e.g., father, owns, weight) does exist, whatever the form or implications of that relationship might be. The names given to the objects or the

---

[2] Throughout this appendix, Turbo PROLOG syntax will be observed. Predicates and their constant arguments will be represented by names beginning in lower case letters, and variable names will begin with upper case letters.

relationships are really irrelevant and (with a few exceptions noted late) have no intrinsic meanings in PROLOG. The significance of the objects' names is in their location in a predicate. For instance, *father(a,b)* and *father(c, d)* mean that the relationship that is implied by "father" holds for "a" and "b" also applies for "c" and "d". Although no rule exists that states that the "father" relationship must imply that one object is the male parent of the other, common convention and good programming practice dictate that object and predicate names should be chosen to make the program read as much like standard English as possible.

To illustrate how a set of facts is used in PROLOG to respond to a query, consider the program in Fig. 22 consisting only of a set of facts about ownership. In Turbo PROLOG, the "predicates" paragraph consists of statements of all predicates used in the program with designation of their argument types. The "clauses" paragraph lists the actual facts and rules (discussed later) that comprise the program.

If the query *?-owns(sally, dog)* is input, the PROLOG program will execute a search the data facts to see if the query can be proven true. Since there is a fact base which exactly matches the query, the program outputs *TRUE.*

If the query *?-owns(john, X)* is entered, the response would be a list of objects which John owns, specifically

X - ball

X - bike

2 solutions. This output contains all values for the query variable X found after a search of the data base that make the query a true statement. In Turbo PROLOG, the entire data base is searched and all values that satisfy the query are outputted, while other versions of PROLOG only return the first such value.

```
predicates
owns(symbol, symbol)
clauses
owns(john, ball).
owns(jack, ball).
owns(john, bike).
owns(sally, dog).
```

Figure 20. Example PROLOG program 1. Simple PROLOG program describing ownership of several objects from which inferences about ownership can be made using queries.

The query could also be entered without any constants named in the argument list, such as *?-owns(X, Y).* The result will be all pairs of X and Y that satisfy the query:

X = john, Y = ball

X = jack, Y = ball

X = john, Y = bike

X = sally, Y = dog

4 solutions.

C. PROLOG RULES AND BACKTRACKING

Logic is the tool that allows generation or inference of new facts from the knowledge base of facts included int he PROLOG program. The rule of logic most often used in PROLOG is called modus ponens, which imply says that if fact A implies fact B, and fact A is true, then fact B must be true as well. "If

Sue is a mother, and if mothers have a child, then Sue has a child" is an example of the application of *modus ponens.*

Modus ponens is incorporated into all PROLOG rule statements included in programs. A rule corresponding to the statement about Sue could be *has_child(sue):-mother(sue),has_child(mother),* where the symbol ":-" roughly translates as "if", and the comma means "and". Notice that in PROLOG structure, the conclusion is on the left side of a rule statement, and the conditions are on the right side.

PROLOG relies on a method called backtracking to reach a conclusion when the query involves rules. The first step in backtracking is to find the rule that has to be true or false to answer the query. PROLOG then tries to satisfy the conditions of this rule, which may involve further rules. Eventually, this backward tracking through the layers of rules will lead to the known facts, which allows an evaluation of the rules back toward the original rule. Only when all of the conditions of the original rule applying to the query are found to be true is the answer *TRUE* or the appropriate values of any query variables printed out. If any of the conditions can not be satisfied, the response to the query is *FALSE.*

Consider the program in Fig. 23 (after Clocksin and Mellish, 1984) as an example to illustrate the backtracking process. In response to the query *?-uncle(elaine, Uncle),* the program will first check the fact base to see if information about Elain's uncle is known. Not finding any facts that match the query, the program pointer shifts to the first rule it can find about uncles in general. In this case, Elaine ("A") has an uncle "B" if she ("A") has parents "X" and "Y", and if "Y" has a brother "B". From the "parents" data, "Y" is equal to Alice. With this "parents" condition satisfied, the program tries to satisfy the second condition, which becomes *brother(alice, B)*, where "B" is th answer for "uncle" desired in the query. From the relative positions of the arguments i the "brother" condition, "C" becomes "alice", and "D" becomes "Uncle". Because there is no fact or rule to allow *parents(alice, X, Y)* to be satisfied, the "brother" rule fails. This failure will cause a transfer back to the first "uncle" rule, which thus fails.

The program pointer then moves to the second rule for uncle. Since the first condition can be satisfied just as before, the program moves on to try to satisfy the second condition, which has become *brother(bob, Uncle)*. Now a fact exists that satisfies the first condition in the "brother" rule, so that "X" and "Y" become Bob's parents Fred and Barbara, respectively. The remaining three "brother" conditions are examined to find someone else whose parents are Fred and Barbara ("X" and "Y"), who is not the same as Bob, and who is a male. From the data, it is clear that Joe satisfies all these conditions, so Uncle is set to "joe". With the "brother" rule satisfied, all the conditions for the "uncle" rule are also satisfied, and the answer printed is

Uncle = joe

1 solution.

Another use of the same program can illustrate the capability in PROLOG to find all possible solutions to a query involving rules and facts. A question can be phrased with variables only, as in *brother(A, B)*, which asks the program to find anyone "A" who has a brother "B". Since none of the facts directly answer the question, the "brother" rule must be checked. Since no "uncle" information is required, these rules are simply ignored for this problem. Since rules and facts are always examined from top to bottom, the first set that satisfies the conditions for "brother" are Elaine and Jim. However, all other possible solutions are sought in Turbo PROLOG, which results in

A = elaine, B = jim

A = bob, B = joe

A = joe, B = bob

3 solutions.

In PROLOG, the last two solutions are not the same, since they mean that Joe has a brother named Bob, and Bob has a brother named Joe, and neither implies the other. The program must be modified if these responses are considered to be redundant.

A distinctive feature of Turbo PROLOG is that it will display all possible solutions to a query, unless otherwise specified. Other versions of PROLOG require a carriage return after output of the first response for each additional answer. In all versions of PROLOG, the query can be input by the user each time the program is run, as in the above examples, or it can be an integral part of the program, as a "goal" that the program tries to satisfy automatically.

Another unique feature of Turbo PROLOG is that variable types must be explicitly declared, as in FORTRAN. Because the variables from the program above represent people, not real or integer numbers or character strings, they were declared as "symbols". Although this requirement can cause confusion in the programming and debugging stages, especially in a large program with many variables and predicates, it is necessary for the compiler in the Turbo PROLOG package to run efficiently.

```
predicates
male(symbol)
female(symbol)
parents(symbol, symbol, symbol)
uncle(symbol, symbol)
brother(symbol, symbol)
clauses
male(jim).
male(bob).
male(fred).
female(alice).
female(elaine).
female(barbara).
parents(elaine, bob, alice).
parents(jim, bob, alice).
parents(bob, fred, barbara).
parents(joe, fred, barbara).
uncle(A, B):-parents(A, X, Y), brother (Y, B).
uncle(A, B):-parents(A, X, Y), brother (X, B).
brother(C,D):-
    parents(C, X, Y), parents (D, X, Y), not (C=D), male (D).
```

Figure 21. Example PROLOG program 2. Simple PROLOG program defining a set of family relationships. Sufficient facts are included about specific family members to make fairly complex inferences about these relationships using queries.

Turbo PROLOG has many other significant features, most of which are shared with other versions of PROLOG. A large set of built-in predicates are provided, including some mathematical functions such as sin(x), cos(x), tan(x), exp(x), ln(x) and sqrt(x), as well as the standard mathematical operators and comparisons (+, -, *, /, >, <, =, etc.). Turbo PROLOG also has a unique set of commands that allows for various colored outputs, as well as graphics and window commands.

This appendix serves as only a brief introduction to the structure and use of PROLOG. It is flexible but very complex language, and it is very different from the more familiar numerical languages. Clocksin and Mellish (1984) provide more information on other aspects of this language, including the powerful tools of PROLOG recursion and list processing techniques.

APPENDIX B. DATA PROCESSING FORMS

The following sample of forms were used to record and process the data for this study.

DATE: 19 SEP 88

LEVANTE YES NO

Surface Winds (kt)

Z/	GIB * (08495)	TARIFA @ (08458)	TAZA @ (60127)	ALBORAN (08490)	TANGIERS (60101)
00	100/20	X	090/06	X	120/28
01					
02					
03	100/22	X	090/06	X	120/28
04					
05					
06	100/22	100/40	090/06	090/25	120/30
07					
08					
09	100/22	100/36	090/04	X	120/40
10					
11					
12	100/20	100/36	090/04	X	100/42
13					
14					
15	120/17	100/37	090/06	X	100/40
16					
17					
18	150/15	X	090/04	X	100/35
19					
20					
21	100/16	X	090/04	X	120/34
22					
23					

* DOUBLE (6)

@ GOOD APPROXIMATION OF WIND IN STRAIT (5)

SURFACE PRESSURE (mb X 10)

Z/	LXGB	GMTT	(a) SPREAD mb	(a) SPREAD fcst wnd	MALAGA	ROTA	(b) DIFF mb	(b) DIFF fs	PALMA	CASA-BLANCA	(c) DIFF mb	(c) DIFF fs	ALI-CANTE	CASA-BLANCA	(d) DIFF mb	(d) DIFF fs
00	211	177	34	36-45	224	X			258	152	106	>33	X	152		
01																
02																
03	207	174	33	36-45	222	191	31		251	146	105	>33	X	146		
04																
05																
06	206	175	31	36-45	220	194	26		258	154	104	>33	248	154	94	25-30
07																
08																
09	218	185	33	36-45	230	X			265	166	99	>33	X	166		
10																
11																
12	219	185	34	36-45	229	203	26		259	168	91	>33	X	168		
13																
14																
15	213	170	43	43-53	223	X			247	164	83	>33	X	164		
16																
17																
18	215	175	40	43-53	224	192	32		247	167	80	>33	250	167	83	25-30
19																
20																
21	227	186	41	43-53	238	X			252	X			X	X		
22																
23																

(a) SPREAD: Easterly (R7)

2mb	30-38 kt
3mb	36-45 kt
4mb	43-53 kt
5mb	48-58 kt

(b) DIFF (48)

4mb	30-35 kt
>4mb	strong Levante
5mb	Levante conditions at Rota

(c) DIFF (47)

6mb	15-25 kt
8mb	>33 kt in Strait and Levante conditions at Rota

(d) DIFF

	WIND (kt) East	WIND (kt) West
5-10mb	15-25	15-20
10-15mb	25-30	20-30
>15 mb	30-40	> 30

DATE:

MISTRAL YES NO

(9) 850 mb IF WIND OVER NIMES IS 350 - GREATEST POSSIBILITY OF OCCURRENCE

DIRECTION: 00Z: ____________ 12Z: ____________

****** NO MISTRAL IF WINDS ARE FROM 90° OR 240° ******

SURFACE WINDS (KTS)

	(23)* PERPIGAN	* MARIGNANE	& MONTPELLIER	& ISTRES	LA MAD	ONSET (21) LUS LA CROIX HAUTE	(22) ORANGE
	(07747) TEMP	(07650)	(07643)	(07647)	(16506)	(07587)	(07579)
00							
01							
02							
03							
04							
05							
06							
07							
08							
09							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							

(29) * DOUBLE OVER OPEN WATER EXCEPT IN STORM CONDITIONS
(30) & ADD 10 KTS FOR WINDS IN GULF OF LION
(21) GIVES 2-3 HR NOTICE OF ONSET
(22) GIVES 3-4 HR NOTICE OF ONSET
(23) WIND SHIFT NORTHERLY, SPEEDS INCREASING TO 25-30 KTS AND TEMP DROP >3° F - 40-50 KT MISTRAL WITHIN 6 HRS.

DATE:

MISTRAL

PAGE 2

INTENSITY FORECAST

SURFACE PRESSURE (mb)

Z/	(28) PERPIGNAN (07747)	NICE (07690)	MARIGNANE (07650)	P - N DIFF	P - M DIFF	M - N DIFF
00						
01						
02						
03						
04						
05						
06						
07						
08						
09						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						

3mb		30-35	30-35
4mb		40	40
5mb		45-50	45-50
6mb	30-35		
8mb	40		
10mb	45-50		

DATE:

MISTRAL PAGE 3

TYPE SURFACE

A B C (1) SFC TROUGH LOCATED SOUTH OF ICELAND WITH COLD AIR (STRONG SURGE) EAST OF GREENLAND

00Z: YES NO 12Z: YES NO

THEN FORECAST ONSET IN 48 HOURS

A B C (2) SFC FRONT AND UPPER S/W TROUGH 24° OF LONGITUDE WEST OF GULF OF LION, S/W RIDGE 12° WEST, AND BOTH ARE PROGRESSING AT 12° /DAY.

00Z: YES NO 12Z: YES NO

THEN FORECAST ONSET IN 48 HOURS

(6) 500 mb (WIND DIR) 00Z 12Z (330°-340° OR 40°-50°)
BORDEAUX
and
500 mb TROUGH
NIMES YES NO YES NO

(7) +200mb HT DEVIATION YES NO YES NO

A B C (8) 500mb NW WIND OF AT LEAST 50 KTS POINTS TOWARD GULF OF LION

00Z: YES NO 12Z: YES NO
and
LONG WAVE TROUGH OVER/JUST PAST SOUTH COAST OF FRANCE

00Z: YES NO 12Z: YES NO

A B C (5) 500mb TROUGH OVER OR JUST SOUTH OF THE SOUTH COAST OF FRANCE

00Z: YES NO 12Z: YES NO
and
SFC LOW IN OR NEAR GULF OF GENOA

00Z: YES NO 12Z: YES NO

A B C (11) 500mb WINDS OVER ENGLAND OR IRELAND NW >50 KTS

00Z: YES NO 12Z: YES NO

(WEAK) (12) 500mb CUTOFF LOW FORMS OVER NE FRANCE AND NW FLOW OVER SOUTH COAST

00Z: YES NO 12Z: YES NO

NEAR SIMULT-ANEOUS ONSET (13) SFC FRONT/TROUGH PASSES PERPIGNAN

00Z: YES NO 12Z: YES NO

OR

500mb TROUGH PASSES BORDEAUX

00Z: YES NO 12Z: YES NO

A B C (14) 500mb TROUGH DEEPENS OVER SOUTH COAST FRANCE AND A FOLLOWING 500MB RIDGE BUILDING AT LONGITUDE OF SPAIN AND IRELAND

00Z: YES NO 12Z: YES NO

A B C (16) 500mb S/W TROUGH OVER PERPIGNAN

00Z: YES NO 12Z: YES NO

ONSET SHAKEY (18) 500mb TROUGH FROM CENTRAL EUROPE SOUTHWARD OVER N AFRICA

00Z: YES NO 12Z: YES NO

INTEN-SITY (31) 500mb WINDS NW >65 KTS (FCST STORM VICE GALE)

BORDEAUX 00Z: YES NO 12Z: YES NO

BREST 00Z: YES NO 12Z: YES NO

INTEN-SITY (ANY OF THESE WORK) (32) SURFACE ISOBARS AT AN ANGLE OF 30° TO VALLEYS

GARONNE 00Z: YES NO 06Z: YES NO 12Z: YES NO 18Z: YES NO

or RHONE 00Z: YES NO 06Z: YES NO 12Z: YES NO 18Z: YES NO

or DURANCE 00Z: YES NO 06Z: YES NO 12Z: YES NO 18Z: YES NO

WITH LOW PRESSURE TO THE SOUTHEAST - THEN MAX MISTRAL WINDS

TYPE

A B C (17) 300mb WIND - NORTHWEST JET ARRIVES OVER BAY OF BISCAY

00Z: 12Z:

(41) LATE AUTUMN AND EARLY WINTER: AIR-SEA TEMP DIFF >6° C

YES NO

(10) NORTH COMPONENT OF 850 mb WIND AT NIMES IS 50 KTS OR MORE

00Z: YES NO 12Z: YES NO

APPENDIX C. WESTERN MEDITERRANEAN GALE FORECASTING PROGRAM

```
/* W           W    III    N   N    DDDD      SSSS     */
/*  W         W      I     NN  N    D   D     S        */
/*   W   W   W       I     N N N    D    D    SSSS     */
/*    W W W W        I     N  NN    D   D        S     */
/*     W   W        III    N   N    DDDD      SSSS     */

/*  WINDS.PRO  */
/*  Written by LT. Marcia L. Jones on 16 June 1989      */

code = 3000

domains
  list = string*


predicates
  greeting
  goal1(STRING)
  start_levante
  menuget(STRING,LIST,STRING)
  getint(INTEGER)
  retreat(STRING,LIST,STRING,INTEGER,INTEGER)
  outlist(LIST,INTEGER,INTEGER)
  selectlist(LIST,INTEGER,INTEGER,STRING)
  delay
  screen_space
  start_mistral
  gale(INTEGER,INTEGER)
  pres1
  pres2
  pres3
  pres4
  pres5
  pres6
  pres7
  solve(INTEGER)
  solve_dif1(REAL,REAL)
  solve_dif2(REAL,REAL)
  solve_dif3(REAL,REAL)
  solve_dif4(REAL,REAL)
  solve_dif5(REAL,REAL)
  solve_dif6(REAL,REAL)
  solve_dif7(REAL,REAL)
  reply(INTEGER,INTEGER)
  shift_mad
  shift_gib
  shift_ali
  front
  trough
  air_flow
```

```
  direction
  veer_mad(INTEGER,INTEGER)
  veer_gib(INTEGER,INTEGER)
  veer_ali(INTEGER,INTEGER)
  reply_pres1(REAL,REAL,REAL)
  reply_pres2(REAL,REAL,REAL)
  reply_pres3(REAL,REAL,REAL)
  reply_pres4(REAL,REAL,REAL)
  reply_pres5(REAL,REAL,REAL)
  reply_pres6(REAL,REAL,REAL)
  reply_pres7(REAL,REAL,REAL)
  double_per(INTEGER)
  double_mar(INTEGER)
  reply_double_per(INTEGER,INTEGER)
  reply_double_mar(INTEGER,INTEGER)
  add_nineteen_mon(INTEGER)
  reply_add_nineteen_mon(INTEGER,INTEGER)
  add_ten_ist(INTEGER)
  reply_add_ten_ist(INTEGER,INTEGER)
  onset_ora(INTEGER,INTEGER)
  onset_orange
  onset_front
  la_mad
  la_mad_wind(INTEGER,INTEGER)
  bord_wind
  long_wave
  uk_500mb_wind
  front_pass
  south_coast
  short_wave_per
  jet
  storm
  angles
  ending
  next
  other

goal
  greeting,
  menuget("Which would you like to do?",["Make a levante forecast",
  "Make a mistral forecast","Exit from the system"],X),goal1(X).

clauses
  greeting:-
    makewindow(1,7,15,"",0,0,25,80),shiftwindow(1),
    cursor(1,0),
    write("                WELCOME TO THE LEVANTE/MISTRAL
FORECASTER"),
    cursor(5,0).
  goal1("Make a levante forecast"):-
    start_levante, solve(_), pres1, pres2, pres3, pres4, shift_mad,
shift_gib,
    shift_ali, front, trough, air_flow, next,
    goal1("Make a mistral forecast").
  goal1("Make a mistral forecast"):-
```

```
    start_mistral, direction, pres5, pres6, pres7, double_per(_),
double_mar(_),
    add_nineteen_mon(_), add_ten_ist(_), onset_front, onset_orange,
    bord_wind, long_wave, uk_500mb_wind, front_pass,
    south_coast, short_wave_per, jet, storm, angles, la_mad, other,
    goal1("Make a levante forecast").
  goal1("Exit from the system"):-
    ending.

/*******************************************************************/
/*************************** LEVANTE ****************************/
/*******************************************************************/
  start_levante:-
    makewindow(2,7,15,"Levante Forecaster",0,0,25,80),nl,
    write("This program will ask for surface and upper air
data"),nl,
    write("for the Strait of Gibraltar and approaches."),nl,nl,nl,
    write("Based on the responses a forecast recommendation"),nl,
    write("for gale force levante conditions in the"),nl,
    write("Strait of Gibraltar and approaches will be
forthcoming."),nl,nl,nl,
    write("Continue this run by responding to the prompts"),nl,
    write("on the screen. If at any time you wish to terminate
this"),nl,
    write("session hit the control-break keys."),nl,nl,nl,
    write("                **** NOTE: If there are no data
available"),nl,
    write("                           for a station - enter zero.
****"),nl,
    delay,

/* The following "rules of thumb" are taken from "Local Area
Forecasters */
/* Handbook, Rota, Spain" and "Handbook for Forecasters in the
Mediterranean"*/
/* by L.R. Brody and LCDR M.J.R. Nestor, RN.     */

    cursor(1,0),
    write("Enter the wind direction at Tarifa (08458) as ddd"),nl,
    readint(Tarddd),nl,
    write("Enter the wind speed at Tarifa (08458) as ss"),nl,
    readint(Tarss),nl,nl,nl,
    gale(Tarddd,Tarss).

  solve(Gibss):-
    cursor(1,0),
    write("Enter surface wind direction at Gibraltar (08495) as
ddd"),nl,
    readint(Gibddd),nl,
    write("Enter surface wind speed at Gibraltar (08495) as
ss"),nl,
    readint(Gibss),nl,nl,nl,
    Modgib = Gibss * 2,
    reply(Gibddd,Modgib),nl,nl,nl.
```

```
/************************** INTENSITY *****************************/

  pres1:-
    cursor(1,0),
    write("          NOTE: This section calls for the pressure
difference"),nl,
    write("             between Gibraltar (08495) and Tangiers
(60101)."),nl,
    write("               If either one is missing enter 000 for
both."),nl,
    write("          If one sea level pressure is in the 900's and
the other"),nl,
    write("           is in the 1000's enter the complete number
for both."),nl,
    nl,nl,write("Enter the sea level pressure at Gibraltar (08495)
as pp.p"),nl,
    readreal(Gibp),nl,
    write("Enter the sea level pressure at Tangiers (60101) as
pp.p"),nl,
    readreal(Tanp),nl,nl,nl,
    solve_dif1(Gibp,Tanp).

  pres2:-
    cursor(1,0),
    write("          NOTE: This section calls for the pressure
difference"),nl,
    write("             between Palma (08306) and Casablanca
(60155)."),nl,
    write("               If either one is missing enter 000 for
both."),nl,
    write("          If one sea level pressure is in the 900's and
the other"),nl,
    write("           is in the 1000's enter the complete number
for both."),nl,
    nl,nl,write("Enter the sea level pressure at Palma (08306) as
pp.p"),nl,
    readreal(Palp),nl,
    write("Enter the sea level pressure at Casablanca (60155) as
pp.p"),nl,
    readreal(Casp),nl,nl,nl,
    solve_dif2(Palp,Casp).

  pres3:-
    cursor(1,0),
    write("          NOTE: This section calls for the pressure
difference"),nl,
    write("             between Malaga (08482) and Rota
(08449)."),nl,
    write("               If either one is missing enter 000 for
both."),nl,
    write("          If one sea level pressure is in the 900's and
the other"),nl,
    write("           is in the 1000's enter the complete number
for both."),nl,
```

```
    nl,nl,write("Enter the sea level pressure at Malaga (08482) as
pp.p"),nl,
    readreal(Malp),nl,
    write("Enter the sea level pressure at Rota (08449) as
pp.p"),nl,
    readreal(Rotp),nl,nl,nl,
    solve_dif3(Malp,Rotp).

  pres4:-
    cursor(1,0),
    write("          NOTE: This section calls for the pressure
difference"),nl,
    write("             between Alicante (08354) and Casablanca
(60155)."),nl,
    write("               If either one is missing enter 000 for
both."),nl,
    write("          If one sea level pressure is in the 900's and
the other"),nl,
    write("           is in the 1000's enter the complete number
for both."),nl,
    nl,nl,write("Enter the sea level pressure at Alicante (08354)
as pp.p"),nl,
    readreal(Alip),nl,
    write("Enter the sea level pressure at Casablanca (60155) as
pp.p"),nl,
    readreal(Casp),nl,nl,nl,
    solve_dif4(Alip,Casp).

/*******************************************************************/

  shift_mad:-
    cursor(1,0),
    write("Enter the previous 12h 300 mb wind direction at Madrid
(08221)"),
    write("as ddd"),nl,
    readint(Madpud),nl,
    write("Enter the current 300 mb wind direction at Madrid
(08221) as ddd"),
    nl,readint(Madudd),nl,nl,nl,
    veer_mad(Madpud,Madudd),nl,nl,nl.

  shift_gib:-
    cursor(1,0),
    write("Enter the previous 12h 300 mb wind direction at
Gibraltar (08495)"),
    nl,write("as ddd"),nl,
    readint(Gibpud),nl,
    write("Enter the current 300 mb wind direction at Gibraltar
(08495) "),nl,
    write("as ddd"),nl,
    readint(Gibudd),nl,nl,nl,
    veer_gib(Gibpud,Gibudd),nl,nl,nl.

  shift_ali:-
    cursor(1,0),
```

```
    write("Enter the previous 12 h 300 mb wind direction along the
"),nl,
    write("south coast of Spain as ddd"),nl,
    readint(Alipud),nl,
    write("Enter the current 300 mb wind direction along the south
coast "),nl,
    write("of Spain as ddd"),nl,
    readint(Aliudd),nl,nl,nl,
    veer_ali(Alipud,Aliudd),nl,nl,nl.

  front:-
    cursor(1,0),
    write("Is there a cold front over the UK or France and the
associated "),nl,
    write("cold front beginning to cross the Iberian Peninsula
(Yes/No)? "),nl,
    readln(Ans),nl,nl,nl,
    upper_lower(Ans,"yes"),
    write("           Based on Rule 11 if a gale force
levante"),nl,
    write("           is in progress forecast it to cease
soon."),delay.
  front:-delay.

  trough:-
    cursor(1,0),
    write("Is there a surface trough and a weak 500 mb trough"),nl,
    write("present southwest of Rota (08449)(Yes/No)?"),nl,
    readln(Ans),nl,nl,nl,
    upper_lower(Ans,"yes"),
    write("        Based on Rule 52 this upper-level trough appears
to"),nl,
    write("        reinforce the surface trough off the coast which
is"),nl,
    write("          a necessary condition for the levante at
Rota."),delay.
  trough:-delay.

  air_flow:-
    cursor(1,0),
    write("Is there a basic easterly flow of about 20 to 25 kt or
greater"),nl,
    write("at Alboran Island (08490)(Yes/No)?"),nl,
    readln(Ans),nl,nl,nl,
    upper_lower(Ans,"yes"),
    write("      Based on Rule 8 a basic easterly flow of 20 to 25
kt at"),nl,
    write("     Alboran Island will produce a maximum band of 35 kt
winds."),nl,
    write("          Therefore is a gale force levante is
occurring"),nl,
    write("                    in the Strait of Gibraltar."),delay.
  air_flow:-delay.

  next:-
```

```
   cursor(1,0),
   write("You are at the end of the Levante program. If you wish to
run"),nl,
   write("the Mistral program press enter to continue. If you
wish"),
   nl,write("to exit hit the control-break keys."),delay.

/*******************************************************************/

    gale(Tarddd,Tarss):-
      Tarddd >= 060, Tarddd <= 120,
      Tarss >= 34, Tarss < 48,!,
      write("                Based on Rule 5 a gale force levante
is"),nl,
      write("                occurring in the Strait of
Gibraltar."),delay.
    gale(Tarddd,Tarss):-
      Tarddd >= 060, Tarddd < 120,
      Tarss >= 48,!,
      write("               Based on Rule 5 is a STORM force is
levante"),nl,
      write("                 occurring in the Strait of
Gibraltar."),delay.
     gale(_,_):-delay.

    reply(Gibddd,Modgib):-
      Gibddd >= 060, Gibddd <=120,
      Modgib >= 34,!,
      write("             The modified wind speed at Gibraltar is
",Modgib,"."),
      nl,write("             Based on Rule 6 a gale force levante
is"),nl,
      write("              occurring in the Strait of
Gibraltar."),delay.
    reply(_,_):-delay.

    solve_dif1(Gibp,Tanp):-
      Value1 = Gibp - Tanp,
      reply_pres1(Gibp,Tanp,Value1),nl.

    solve_dif2(Palp,Casp):-
      Value2 = Palp - Casp,
      reply_pres2(Palp,Casp,Value2),nl.

    solve_dif3(Malp,Rotp):-
      Value3 = Malp - Rotp,
      reply_pres3(Malp,Rotp,Value3),nl.

    solve_dif4(Alip,Casp):-
      Value4 = Alip - Casp,
      reply_pres4(Alip,Casp,Value4),nl.

    reply_pres1(_,_,Value1):-
      Value1 >= 5,!,
```

```
      write("          Based on Rota Rule 7 recommend setting STORM
warnings"),
      nl,write("                    in the Strait of
Gibraltar."),nl,
      write("                A 48 to 58 kt wind is occurring.
"),delay.
    reply_pres1(_,_,Value1):-
      Value1 >= 4,!,
      write("          Based on Rota Rule 7 recommend setting STORM
warnings"),
      nl,write("                    in the Strait of
Gibraltar."),nl,
      write("                A 43 to 53 kt wind is occurring.
"),delay.
    reply_pres1(_,_,Value1):-
      Value1 >= 3,!,
      write("            Based on Rota Rule 7 a 36 to 45 kt
wind"),nl,
      write("            is occurring in the Strait of
Gibraltar."),delay.
    reply_pres1(_,_,Value1):-
      Value1 >= 2,!,
      write("            Based on Rota Rule 7 a 30 to 38 kt
wind"),nl,
      write("            is occurring in the Strait of Gibraltar.
"),delay.
    reply_pres1(_,_,_):-delay.

    reply_pres2(_,_,Value2):-
      Value2 >= 8,!,
      write("           Based on Rule 47 a gale force wind of
greater than"),nl,
      write("             40 kt is occurring in the Strait of
Gibraltar"),nl,
      write("                   with levante conditions at Rota."),
      delay.
    reply_pres2(_,_,Value2):-
      Value2 >= 6,!,
      write("             Based on Rule 47 a 30 to 35 kt wind
is"),nl,
      write("             occurring in the Strait of
Gibraltar."),delay.
    reply_pres2(_,_,_):-delay.

    reply_pres3(_,_,Value3):-
      Value3 >= 4.5,!,
      write("             Based on Rule 48 winds greater than 45
kt"),nl,
      write("             are occurring in the Strait of
Gibraltar."),delay.
    reply_pres3(_,_,Value3):-
      Value3 >= 4, Value3 < 4.5,!,
      write("             Based on Rule 48 a 38 to 45 kt wind
is"),nl,
```

```
      write("                occurring in the Strait of
Gibraltar."),delay.
    reply_pres3(_,_,Value3):-
      Value3 >= 3, Value3 < 4,!,
      write("                Based on Rule 48 a 30 to 38 kt wind
is"),nl,
      write("                occurring in the Strait of
Gibraltar."),delay.
    reply_pres3(_,_,_):-delay.

    reply_pres4(_,_,Value4):-
      Value4 >= 5,!,
      write("                Based on Rule 72 a 30 to 40 kt wind
is"),nl,
      write("                occurring in the Strait of
Gibraltar."),delay.
    reply_pres4(_,_,_):-delay.

    veer_mad(Madpud,Madudd):-
      Madpud >= 300, Madpud <=340,
      Madudd = 040,!,
      write("                Based on Rule 2 a gale force levante
is"),nl,
      write("                 occurring in the Strait of
Gibraltar."),delay.
    veer_mad(_,_):-delay.

    veer_gib(Gibpud,Gibudd):-
      Gibpud >= 300, Gibpud <=340,
      Gibudd = 040,!,
      write("                Based on Rule 2 a gale force levante
is"),nl,
      write("                 occurring in the Strait of
Gibraltar."),delay.
    veer_gib(_,_):-delay.

    veer_ali(Alipud,Aliudd):-
      Alipud >= 300, Alipud <=340,
      Aliudd = 040,!,
      write("                Based on Rule 2 a gale force levante
is"),nl,
      write("                 occurring in the Strait of
Gibraltar."),delay.
    veer_ali(_,_):-delay.

/*****************************************************************/
/************************** MISTRAL ****************************/
/*****************************************************************/

  start_mistral:-
    makewindow(3,7,15,"Mistral Forecaster",0,0,25,80),nl,
    write("This program will ask for surface and upper air
data"),nl,
    write("for the Gulf of Lion, coastal France and upstream
areas."),nl,nl,nl,
```

```
    write("Based on the responses a forecast recommendation"),nl,
    write("for gale and storm force mistral conditions in the Gulf
of Lion"),nl,
    write("and downstream areas will be forthcoming."),nl,nl,nl,
    write("Continue this run by responding to the prompts"),nl,
    write("on the screen. If at any time you wish to terminate
this"),nl,
    write("session hit the control-break keys."),nl,nl,nl,
    write("               **** NOTE: If there are no data
available"),nl,
    write("                          for a station - enter zero.
****"),
    delay.

  direction:-
    cursor(1,0),
    write("Is the 850 mb wind direction over Nimes (07646) from 090
or"),nl,
    write("from 240"),nl,
    write("(Yes/No)? "),nl,
    readln(Ans),nl,nl,nl,
    upper_lower(Ans,"yes"),
    write("           Based on Rule 9 there can be no mistral"),nl,
    write("               with winds from this
direction."),nl,nl,nl,
    write("        Warning: This rule has not been formally
tested."),nl,nl,
    write("            Hit control break to end this
session."),delay.
  direction:-delay.

/************************* INTENSITY ****************************/

  pres5:-
    cursor(1,0),
    write("         NOTE: This section calls for the sea level
pressure"),nl,
    write("         difference between Perpignan (07747) and Nice
(07690)."),nl,
    write("               If either one is missing enter 000 for
both."),nl,
    write("            If one is in the 900's and the other in the
1000's"),nl,
    write("                  enter the complete number for
both."),nl,nl,
    write("Enter the sea level pressure at Perpignan (07747) as
pp.p"),nl,
    readreal(Perp),nl,
    write("Enter the sea level pressure at Nice (07690) as
pp.p"),nl,
    readreal(Nicp),nl,nl,nl,
    solve_dif5(Perp,Nicp).

  pres6:-
    cursor(1,0),
```

```
    write("          NOTE: This section calls for the sea level
pressure"),nl,
    write("    difference between Perpignan (07747) and Marginane
(07650)."),nl,
    write("           If either one is missing enter 000 for
both."),nl,
    write("         If one is in the 900's and the other in the
1000's"),nl,
    write("                 enter the complete number for
both."),nl,nl,
    write("Enter the sea level pressure at Perpignan (07747) as
pp.p"),nl,
    readreal(Perp),nl,
    write("Enter the sea level pressure at Marginane (07650) as
pp.p"),nl,
    readreal(Marp),nl,nl,nl,
    solve_dif6(Perp,Marp).

  pres7:-
    cursor(1,0),
    write("          NOTE: This section calls for the sea level
pressure"),nl,
    write("     difference between Marginane (07650) and Nice
(07690)."),nl,
    write("           If either one is missing enter 000 for
both."),nl,
    write("          If one is in the 900's and the other in the
1000's"),nl,
    write("                 enter the complete number for
both."),nl,nl,
    write("Enter the sea level pressure at Marginane (07650) as
pp.p"),nl,
    readreal(Marp),nl,
    write("Enter the sea level pressure at Nice (07690) as
pp.p"),nl,
    readreal(Nicp),nl,nl,nl,
    solve_dif7(Marp,Nicp).

/************************** LAND STATIONS **************************/

  double_per(Perss):-
    cursor(1,0),
    write("Enter wind direction at Perpignan (07747) as ddd"),nl,
    readint(Perddd),nl,
    write("Enter wind speed at Perpignan (07747) as ss"),nl;
    readint(Perss),nl,nl,nl,
    Modper = Perss * 2,
    reply_double_per(Perddd,Modper),nl,nl,nl.

  double_mar(Marss):-
    cursor(1,0),
    write("Enter wind direction at Marignane (07650)"),nl,
    readint(Marddd),nl,
    write("Enter wind speed at Marginane (07650)"),nl,
    readint(Marss),nl,nl,nl,
```

```
    Modmar = Marss * 2,
    reply_double_mar(Marddd,Modmar),nl,nl,nl.

  add_nineteen_mon(Monss):-
    cursor(1,0),
    write("Enter the wind direction at Montpellier (07643) as
ddd"),nl,
    readint(Monddd),nl,
    write("Enter the wind speed at Montpellier (07643) as ss"),nl,
    readint(Monss),nl,nl,nl,
    Modmon = Monss + 19,
    reply_add_nineteen_mon(Monddd,Modmon),nl,nl,nl.

  add_ten_ist(Istss):-
    cursor(1,0),
    write("Enter the wind direction at Istres (07647) as ddd"),nl,
    readint(Istddd),nl,
    write("Enter the wind speed at Istres (07647) as ss"),nl,
    readint(Istss),nl,nl,nl,
    Modist = Istss + 10,
    reply_add_ten_ist(Istddd,Modist),nl,nl,nl.

/************************ ONSET RULES *************************/

  onset_front:-
    cursor(1,0),
    write("In association with a Type A large-scale flow pattern
(Fig II-2)"),
    nl,write("is there a surface front located south of Iceland
with a"),nl,
    write("cold air (extremely strong) surge east of Greenland
(Yes/No)?"),nl,
    readln(Ans),nl,nl,nl,
    upper_lower(Ans,"yes"),
    write("             Based on Rule 1 recommend forecast of a
mistral"),nl,
    write("                  in the Gulf of Lion within 36h to
48h."),nl,nl,
    write("              Warning: This is a very weak rule and
should"),nl,
    write("              be used only in combination with other
rules."),delay.
  onset_front:-delay.

  onset_orange:-
    cursor(1,0),
    write("Enter the wind direction at Orange (07579) as ddd"),nl,
    readint(Oraddd),nl,
    write("Enter the wind speed at Orange (07579) as ss"),nl,
    readint(Orass),nl,nl,nl,
    onset_ora(Oraddd,Orass),nl,nl,nl.

/******************************************************************/

  bord_wind:-
```

```
    cursor(1,0),
    write("Is the 500 mb wind direction at Bordeaux (07510) 330- to
340- or"),nl,
    write("040- to 050- when the 500 mb trough reaches Nimes
(07646)(Yes/No)?"),
    nl,readln(Ans),nl,nl,nl,
    upper_lower(Ans,"yes"),
    write("                      Based on Rule 6 a good probability
exists"),nl,
    write("                              that a mistral will occur."),nl,
    write("                As the wind shifts west or east from the 330-
and 050-"),nl,
    write("                           the probability decreases
rapidly."),delay.
  bord_wind:-delay.

  long_wave:-
    cursor(1,0),
    write("Is there a long-wave trough over or just past the south
coast"),nl,
    write("of France and a west through north-northeast current
with a "),nl,
    write("maximum speed of at least 50 kt at 500 mb pointing
towards "),nl,
    write("the Gulf of Lion (Yes/No)?"),nl,
    readln(Ans),nl,nl,nl,
    upper_lower(Ans,"yes"),
    write("                                   Based on Rule 8 a
mistral"),nl,
    write("                             is likely to occur in this
situation."),
    delay.
  long_wave:-delay.

  uk_500mb_wind:-
    cursor(1,0),
    write("In association with a Type A large-scale flow pattern
(Fig II-2),"),
    nl,write("is the 500 mb wind over England or Ireland
northwesterly 50 kt"),
    nl,write("or more (Yes/No)?"),nl,
    readln(Ans),nl,nl,nl,
    upper_lower(Ans,"yes"),
    write("          Based on Rule 11 recommend setting gale force
mistral"),nl,
    write("                              warnings in the Gulf of
Lion."),delay.
  uk_500mb_wind:-delay.

  front_pass:-
    cursor(1,0),
    write("Is the surface front or trough passing Perpignan, or the
500 mb"),nl,
    write("trough passing Bordeaux (Yes/No)?"),nl,
    readln(Ans),nl,nl,nl,
```

```
    upper_lower(Ans,"yes"),
    write("                    Based on Rule 13 if these two events
occur"),nl,
    write("                    near simultaneously there is a good
chance"),nl,
    write("                           that the mistral will set
in."),delay.
  front_pass:-delay.

  south_coast:-
    cursor(1,0),
    write("In association with a Type C large-scale flow pattern
(Fig II-4),"),
    nl,write("is there a deepening 500 mb trough moving over the
south coast"),
    nl,write("of France and a following 500 mb ridge building at
about the"),nl,
    write("longitude of Ireland and Spain (Yes/No)?"),nl,
    readln(Ans),nl,nl,nl,
    upper_lower(Ans,"yes"),
    write("            Based on Rule 14 recommend setting gale force
mistral"),nl,
    write("                        warnings in the Gulf of
Lion."),delay.
  south_coast:-delay.

  short_wave_per:-
    cursor(1,0),
    write("In association with a Type A large-scale flow pattern
(Fig II-2),"),
    nl,write("has the 500 mb short-wave trough arrived over
Perpignan (07747)"),
    nl,write("(Yes/No)?"),nl,
    readln(Ans),nl,nl,nl,
    upper_lower(Ans,"yes"),
    write("            Based on Rule 16 recommend setting gale force
mistral"),nl,
    write("                        warnings in the Gulf of
Lion."),nl,nl,
    write("              Warning: This is a very weak rule and should
be used"),nl,
    write("                    only in combination with other
rules."),delay.
  short_wave_per:-delay.

  jet:-
    cursor(1,0),
    write("In association with a Type C large-scale flow pattern
(Fig II-4),"),
    nl,write("has a northwesterly jet stream arrived over the Bay
of Biscay"),
    nl,write("(Yes/No)?"),nl,
    readln(Ans),nl,nl,nl,
    upper_lower(Ans,"yes"),
```

```
    write("                    Based on Rule 17 recommend setting
gale force"),nl,
    write("                        mistral warnings in the Gulf of
Lion. "),delay.
  jet:-delay.

/**************************** STORM *******************************/

  storm:-
    cursor(1,0),
    write("Are the 500 mb winds at either Bordeaux (07510) or Brest
(07110)"),
    nl,write("greater than 65 kt from the northwest (Yes/No)?"),nl,
    readln(Ans),nl,nl,nl,
    upper_lower(Ans,"yes"),
    write("               Based on Rule 31 recommend setting STORM
warnings"),nl,
    write("                              in the Gulf of Lion."),delay.
  storm:-delay.

  angles:-
    cursor(1,0),
    write("Are the surface isobars at an angle of 30 degrees to the
valleys"),
    nl,write("of either the Garonne, the Rhone or the Durance
Valley"),
    nl,write("with low pressure to the southeast and is there
currently"),
    nl,write("a gale force wind occurring in the Gulf of Lion
(Yes/No)?"),nl,
    readln(Ans),nl,nl,nl,
    upper_lower(Ans,"yes"),
    write("               Based on Rule 32 recommend setting STORM
warnings"),nl,
    write("                              in the Gulf of Lion."),delay.
  angles:-delay.

/**************************** OTHER *******************************/

  la_mad:-
    cursor(1,0),
    write("Enter the wind direction at La Maddalena (16506) as
ddd"),nl,
    readint(Lamddd),nl,
    write("Enter the wind speed at La Maddalena (16506) as ss"),nl,
    readint(Lamss),nl,
    la_mad_wind(Lamddd,Lamss),nl,nl,nl.

  other:-
    cursor(1,0),
    write("You are at the end of the Mistral program. If you wish
to run"),nl,
    write("the Levante program press enter to continue. If you
wish"),
    nl,write("to exit hit the control-break keys."),delay.
```

```
/************************ HOUSEKEEPING *************************/

  menuget(S1,L,S2):-write(S1),nl,nl,outlist(L,Max,1),nl,
    write("SELECT: "),getint(Reply),
    retreat(S1,L,S2,Reply,Max).

  getint(R):-readln(X),str_int(X,R),!.
  getint(R):-getint(R).

  retreat(_,L,S2,Z,Max):-Z<=Max,Z>0,!,selectlist(L,Z,1,S2),nl.
  retreat(S1,L,S2,Z,Max):-Z>Max,!,clearwindow,write("Invalid
selection"),nl,
    menuget(S1,L,S2).
  retreat(S1,L,S2,Z,_):-Z<1,!,clearwindow,write("Invalid
selection"),nl,
    menuget(S1,L,S2).

  outlist([],0,_).
  outlist([X|L],N,C):-nl,write("   ",C,")  ",X),nl,C1=C+1,
    outlist(L,N1,C1),N=N1+1.

  selectlist([X|_],N,N,X):-!.
  selectlist([_|L],Z,N,S):-N1=N+1,selectlist(L,Z,N1,S).

  screen_space:-cursor(X,_),X<17,!.
  screen_space:-delay,clearwindow.

  ending:-
    write("This session is now terminated. Have a nice
day."),nl,nl,nl.

  delay:-cursor(22,0),write("Press return to continue or control-
break"),
    write(" to end this session."),
    readln(_),
    clearwindow.

/***************************************************************/

     solve_dif5(Perp,Nicp):-
      Value5 = Perp - Nicp,
      reply_pres5(Perp,Nicp,Value5),nl.

    solve_dif6(Perp,Marp):-
      Value6 = Perp - Marp,
      reply_pres6(Perp,Marp,Value6),nl.

    solve_dif7(Marp,Nicp):-
      Value7 = Marp - Nicp,
      reply_pres7(Marp,Nicp,Value7),nl.

    reply_pres5(_,_,Value5):-
      Value5 >= 10,!,
```

```
      write("          Based on Rule 28 a 45 to 50 kt wind is
occurring"),nl,
      write("         in the Gulf of Lion. Recommend setting STORM
warnings."),
      delay.
    reply_pres5(_,_,Value5):-
      Value5 >= 8,!,
      write("                    Based on Rule 28 a 40 kt wind
is"),nl,
      write("                     occurring in the Gulf of
Lion."),delay.
    reply_pres5(_,_,Value5):-
      Value5 >= 6,!,
      write("               Based on Rule 28 a 30 to 35 kt wind
is"),nl,
      write("                   occurring in the Gulf of
Lion."),delay.
    reply_pres5(_,_,_):-delay.

    reply_pres6(_,_,Value6):-
      Value6 >= 5,!,
      write("         Based on Rule 28 a 45 to 50 kt wind is
occurring"),nl,
      write("        in the Gulf of Lion. Recommend setting STORM
warnings."),
      delay.
    reply_pres6(_,_,Value6):-
      Value6 >= 4,!,
      write("              Based on Rule 28 a 40 kt wind is"),nl,
      write("               occurring in the Gulf of Lion."),delay.
    reply_pres6(_,_,Value6):-
      Value6 >= 3,!,
      write("          Based on Rule 28 a 30 to 35 kt wind is"),nl,
      write("              occurring in the Gulf of Lion."),delay.
    reply_pres6(_,_,_):-delay.

    reply_pres7(_,_,Value7):-
      Value7 >= 5,!,
      write("         Based on Rule 28 a 45 to 50 kt wind is
occurring"),nl,
      write("        in the Gulf of Lion. Recommend setting STORM
warnings."),
      delay.
    reply_pres7(_,_,Value7):-
      Value7 >= 4,!,
      write("           Based on Rule 28 a 40 kt wind is"),nl,
      write("            occurring in the Gulf of Lion."),delay.
    reply_pres7(_,_,Value7):-
      Value7 >= 3,!,
      write("          Based on Rule 28 a 30 to 35 kt wind is"),nl,
      write("              occurring in the Gulf of Lion. "),delay.
    reply_pres7(_,_,_):-delay.

    reply_double_per(Perddd,Modper):-
      Perddd >= 000, Perddd <= 040,
```

```
      Modper >= 34,!,
      write("                   The modified wind speed for open
waters"),nl,
      write("                       downstream of Perpignan is
",Modper,"."),nl,nl,
      write("                 Based on Rule 29 a gale force mistral
is"),nl,
      write("                        occurring in the Gulf of
Lion."),nl,
      write("                   The doubling of the wind speed does
not"),nl,
      write("                        apply during storm
conditions."),delay.
    reply_double_per(Perddd,Modper):-
      Perddd >= 300, Perddd <=360,
      Modper >= 34,!,
      write("                   The modified wind speed for open
waters"),nl,
      write("                       downstream of Perpignan is
",Modper,"."),nl,nl,
      write("                 Based on Rule 29 a gale force mistral
is"),nl,
      write("                        occurring in the Gulf of
Lion."),nl,
      write("                   The doubling of the wind speed does
not"),nl,
      write("                        apply during storm
conditions."),delay.
    reply_double_per(_,_):-delay.

    reply_double_mar(Marddd,Modmar):-
      Marddd >=000, Marddd <= 040,
      Modmar >= 34,!,
      write("                   The modified wind speed for open
waters"),nl,
      write("                        downstream of Marginane is
",Modmar,"."),nl,nl,
      write("                 Based on Rule 29 a gale force mistral
is"),nl,
      write("                         occurring in the Gulf of
Lion."),nl,
      write("                    The doubling of the wind speed does
not"),nl,
      write("                         apply during storm
conditions."),delay.
    reply_double_mar(Marddd,Modmar):-
      Marddd >= 300, Marddd <= 360,
      Modmar >= 34,!,
      write("                  The modified wind speed for open
waters"),nl,
      write("                       downstream of Marginane is
",Modmar,"."),nl,nl,
      write("                Based on Rule 29 a gale force mistral
is"),nl,
```

```
      write("                    occurring in the Gulf of
Lion."),nl,
      write("              The doubling of the wind speed does
not"),nl,
      write("                   apply during storm
conditions."),delay.
    reply_double_mar(_,_):-delay.

    reply_add_nineteen_mon(Monddd,Modmon):-
      Monddd >= 000, Monddd <=40,
      Modmon >= 47,!,
      write("        The modified wind speed at Montpellier is
",Modmon,"."),nl,
      write("         Based on Rule 30 a storm force mistral
is"),nl,
      write("              occurring in the Gulf of Lion."),delay.
    reply_add_nineteen_mon(Monddd,Modmon):-
      Monddd >=300, Monddd <=360,
      Modmon >= 47,!,
      write("        The modified wind speed at Montpellier is
",Modmon,"."),nl,
      write("         Based on Rule 30 a storm force mistral
is"),nl,
      write("             occurring in the Gulf of Lion."),delay.
    reply_add_nineteen_mon(Monddd,Modmon):-
      Monddd >= 000, Monddd <=40,
      Modmon >= 34,!,
      write("        The modified wind speed at Montpellier is
",Modmon,"."),nl,
      write("         Based on Rule 30 a gale force mistral
is"),nl,
      write("              occurring in the Gulf of Lion."),delay.
    reply_add_nineteen_mon(Monddd,Modmon):-
      Monddd >=300, Monddd <=360,
      Modmon >= 34,!,
      write("        The modified wind speed at Montpellier is
",Modmon,"."),nl,
      write("         Based on Rule 30 a gale force mistral
is"),nl,
      write("             occurring in the Gulf of Lion."),delay.
    reply_add_nineteen_mon(_,_):-delay.

    reply_add_ten_ist(Istddd,Modist):-
      Istddd >= 000, Istddd <= 040,
      Modist >= 47,!,
      write("           The modified wind speed at Istres is
",Modist,"."),nl,
      write("          Based on Rule 30 a storm force mistral
is"),nl,
      write("              occurring in the Gulf of Lion."),delay.
    reply_add_ten_ist(Istddd,Modist):-
      Istddd >= 300, Istddd <= 360,
      Modist >= 47,!,
      write("           The modified wind speed at Istres is
",Modist,"."),nl,
```

```
      write("          Based on Rule 30 a strom force mistral
is"),nl,
      write("               occurring in the Gulf of Lion."),delay.
    reply_add_ten_ist(Istddd,Modist):-
      Istddd >= 000, Istddd <= 040,
      Modist >= 34,!,
      write("           The modified wind speed at Istres is
",Modist,"."),nl,
      write("          Based on Rule 30 a gale force mistral
is"),nl,
      write("              occurring in the Gulf of Lion."),delay.
    reply_add_ten_ist(Istddd,Modist):-
      Istddd >= 300, Istddd <= 360,
      Modist >= 34,!,
      write("           The modified wind speed at Istres is
",Modist,"."),nl,
      write("          Based on Rule 30 a gale force mistral
is"),nl,
      write("               occurring in the Gulf of Lion."),delay.
    reply_add_ten_ist(_,_):-delay.

    onset_ora(Orsddd,Orass):-
      Orsddd >= 300, Orsddd <= 360,
      Orass >= 15,!,
      write("            Based on Rule 22 a gale force mistral will
be"),nl,
      write("           occurring within 3 to 4 hr in the Gulf of
Lion."),delay.
    onset_ora(_,_):-delay.

    la_mad_wind(Lamddd,Lamss):-
      Lamddd >=220, Lamddd <= 360,
      Lamss >= 25,!,
      write("              Check the winds in the Strait of
Bonifacio."),nl,
      write("               Small boat operations may be affected
by"),nl,
      write("                             this wind speed."),delay.
    la_mad_wind(Lamddd,Lamss):-
      Lamddd >=040, Lamddd <= 130,
      Lamss >= 25,!,
      write("              Check the winds in the Strait of
Bonifacio."),nl,
      write("               Small boats may be affected by"),nl,
      write("                             this wind speed."),delay.

    la_mad_wind(_,_):-delay.
```

REFERENCES

Brody, L. R., and M. J. R. Nestor, 1980: Handbook for forecasters in the Mediterranean, Part 2: Regional forecasting aids for the Mediterranean Basin. NAVENVPREDRSCHFAC Technical Report TR 80 - 10, 178 pp.

Clocksin, W., and C. Mellish, 1984: *Programming in PROLOG*, Springer-Verlag, 2nd ed., 297 pp.

Hagaman, B. M., 1988: A prototype expert system to forecast typhoon conditions at Cubi Point, Philippines. Master's Thesis, Naval Postgraduate School, Monterey, CA, 93943, 82 pp.

Naval Oceanography Command Center, Rota, Spain, 1983: *Local Area Forecaster's Handbook - Rota, Spain*, 70 pp.

Meteorological Office, Air Ministry, 1962: *Weather in the Mediterranean, General Meteorology*, Vol. 1. Her Majesty's Stationery Office London, 2nd ed., 373 pp.

Nelson, H. D., Ed., 1985: Morocco A Country Study. (5th ed, DA Pam 550-49.) Washington: GPO for Foreign Area Studies, The American University, 448 pp.

Reiter, E. R., 1975: Handbook for forecaster's in the Mediterranean, weather phenomena of the Mediterranean Basin, Part 1: General description of the meteorological processes. ENVPREDRSCHFAC Technical Paper No. 5-75, 344 pp.

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