# A comprehensive database on synoptic and local circulation over Sicily for mesoscale applications

M. RANCI ([1]), G. GRAZIANI ([2]) and M. T. PARESCHI ([1])

([1]) *CSGSDA-CNR - Via Santa Maria 53, Pisa, Italy*

([2]) *Environment Institute, Joint Research Center - Ispra, Italy*

(ricevuto il 3 Febbraio 1997; revisionato il 14 Aprile 1998; approvato il 21 Luglio 1998)

**Summary.** — The aim of this work is to present a database of information available on the island of Sicily (Italy) to be used for the evaluation and/or the calibration of the numerical mesoscale meteorological models. The database relates to land type and land cover of the island as well as to meteorological fields collected at various locations over a time span of various years. The analysis of the database provides information on spatiotemporal variability of characteristic meteorological patterns on the mesoscale range over the island. Specific wind and temperature values characteristic of the regional circulation on the island are presented in the database and analyzed in this paper. The available data have different sources (fixed monitoring stations or measuring campaigns, remote-sensing instruments), and refer to vertical soundings or to measurements at fixed heights. Air temperature, wind speed and wind direction are among the meteorological parameters taken into account. The temporal frequency of the data ranges from 10 minutes to 24 hours.

PACS 92.60 – Meteorology.

## 1. – Introduction

Sicily is the biggest island in the Mediterranean Sea, laying between 36°-38° latitude North and 12°-16° longitude East. It has a triangular shape and an extension of about 26 000 km$^2$ (fig. 1a). The size of the island together with its shape are such that the Coriolis force plays a fundamental role in determining the wind circulation patterns. The availability of data on the so-called mesoscale range is therefore necessary for any modeling-activity evaluation or set-up. In this paper such a database is presented as the result of the collection of measurements at various locations by means of different instruments over a time span of some years. The data bank provides information on the land type, land use, elevation of the terrain, wind temperature and moisture fields obtained by integrating the data present in various banks with information from the literature.

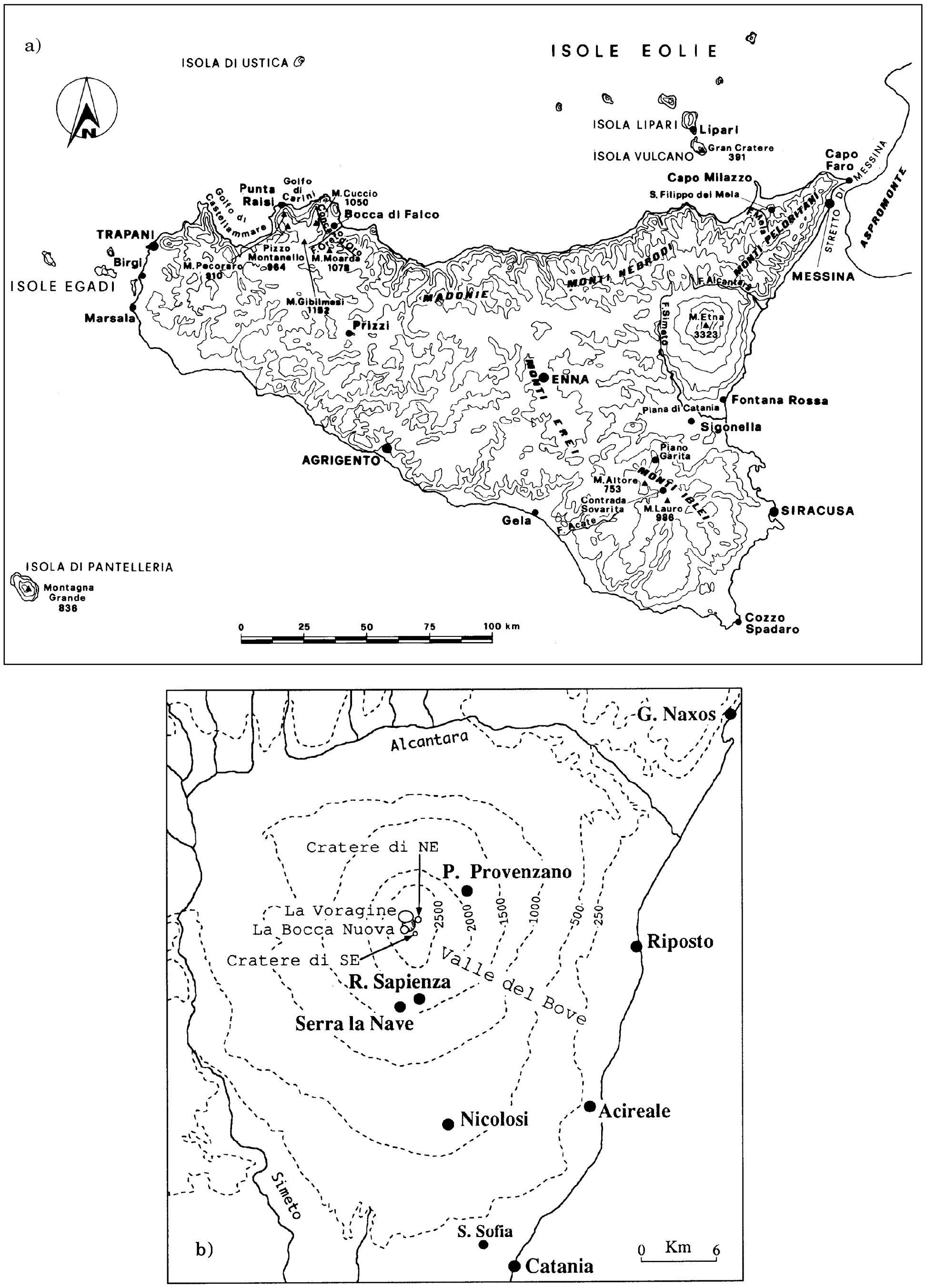



Fig. 1. – Map of Sicily (a), with a zoom on the Etnaean area (b), with geographic locations and station names where data are available.

An analysis of these data allows us to give a picture of the large-scale circulation which can be used to properly initialize atmospheric flow models. The data collected at the various monitoring stations are analyzed with special attention to those in the region of the Etna volcano. The highly complex terrain and the large gaseous emission rates from Etna, in fact, make the area particularly interesting for atmospheric dispersion modeling. The statistical distribution of daily trends of wind intensity and direction and air temperature are considered and interpreted in view of the morphological characteristics of the surrounding area. Particular attention is given to a limited time period (23-24 July, 1994). For these two days a large variety and density of data is available and they are thus particularly suitable for initializing and evaluating a mesoscale flow model. Both synoptic and local circulations over Sicily are reconstructed by integrating the information concerning various locations.

Due to the vast amount of information present in the data bank, only a general analysis is presented here. The organized data set on file, and the software developed to analyze it are available to those willing to have better insight into a particular time period or a specific region [1].

## 2. – Description of the data bank structure

The content of the data bank is summarized in table I below, which is divided into three parts (*a*, *b*, *c*) reporting respectively:

*a*) the list of the locations where meteorological information is available with geographical information (locations and height a.s.l. of the stations);

*b*) the nature of available data (wind velocity, air temperature, etc.), the frequency of measurements and the height above ground level where measurements were carried out;

*c*) the instrumentation used for measurements and the source of data. The locality names quoted are indicated in the referenced maps (fig. 1).

The information included in the data bank can be summarized in the following three topics:

– Topographic, land use, land type data,

– Synoptic atmospheric circulation data,

– Local atmospheric circulation data.

**2**·1. *Topographic and land use information in the database.* – A large portion (52%) of Sicilian land is hilly, 25% is mountainous and only 23% is covered by plains (the largest being the plains of *Catania* and *Gela*). In the northern part of the island, a ridge of mountains called, from the East to the West, *Peloritani*, *Nebrodi* and *Madonie*, runs parallel to the sea, up to Palermo, reaching elevations of 1000-2000 m. In this region the typical vegetation found is basically oak, chestnut and beech trees. In the western part, mountains form irregular groups, while in central and southern Sicily the territory is heterogeneously formed of hills, large valleys and terraces. With the exception of the area of *Gela*, there the land is dedicated to the cultivation of cereals, and, more recently, to specialized shrubbery like olives and almonds. In the eastern part of the island, Mount *Etna* (3323 m a.s.l.) stays as a rather isolated

TABLE I*a*. – *The geographical information* (*UTM coordinates and height over sea level*).

| | Locality name | Lat. N | Long. E | Height a.s.l. |
|---|---|---|---|---|
| 1 | Acireale | 37° 36′ | 15° 10′ | 194 m |
| 2 | Catania - Fontana Rossa | 37° 28′ | 15° 03′ | 17 m |
| | - Sigonella | 37° 24′ | 14° 55′ | 22 m |
| 3 | Contrada Sovarita (Vizzini, Ct) | 37° 10′ | 14° 48′ | 760 m |
| 4 | Cozzo Spadaro | 36° 41′ | 15° 08′ | 51 m |
| 5 | Enna | 37° 34′ | 14° 17′ | 965 m |
| 6 | Etna3000 | — | — | — |
| 7 | Gela | 37° 05′ | 14° 13′ | 33 m |
| 8 | G. Naxos | 37° 49′ | 15° 15′ | 35 m |
| 9 | Lipari - Castellaro | 38° 29′ | 14° 55′ | 417 m |
| 10 | Messina - Town | 38° 12′ | 15° 33′ | 51 m |
| | - Capo Faro | 38° 15′ | 15° 38′ | 0 m |
| 11 | Nicolosi | 37° 36′ | 15° 02′ | 730 m |
| 12 | Palermo - Bocca di Falco + Luparello | 38° 06′ | 13° 08′ | 116 m |
| | - Punta Raisi | 38° 11′ | 13° 06′ | 21 m |
| 13 | Pantelleria | 36° 49′ | 11° 58′ | 170 m |
| 14 | Piano Garita (Militello, Ct) | 37° 16′ | 14° 46′ | 600 m |
| 15 | Prizzi | 37° 43′ | 13° 26′ | 1035 m |
| 16 | Provenzano | 37° 47′ | 15° 02′ | 1810 m |
| 17 | Riposto | 37° 44′ | 15° 12′ | 10 m |
| 18 | R. Sapienza | 37° 42′ | 14° 59′ | 1910 m |
| 19 | S. Filippo del Mela | 38° 11′ | 15° 17′ | 100 m |
| 20 | Serra la Nave | 37° 41′ | 14° 58′ | 1725 m |
| 21 | Sicily | (6.5° E; 30° N) | (21.5° E; 43.5° N) | — |
| 22 | Siracusa | 37° 04′ | 15° 18′ | 20 m |
| 23 | Trapani - Birgi | 37° 55′ | 12° 30′ | 14 m |
| 24 | Ustica | 38° 42′ | 13° 11′ | 251 m |
| 25 | Vulcano - Beach | 38° 25′ | 14° 57′ | 3 m |
| | - Heliport | 38° 25′ | 14° 59′ | 10 m |
| | - Gelso | 38° 22′ | 14° 59′ | 3 m |
| | - Cardo | 38° 23′ | 14° 58′ | 345 m |
| | - GNV Centro Carapezza | 38° 25′ | 14° 57′ | 10 m |

The site *Etna3000* does not appear on the map and is not related to spatial coordinates because it refers to vertical profiles carried out in many localities in Sicily and Calabria and subsequently interpolated to a point approximately coincident with the top of mount Etna in the horizontal direction and to 3000 m vertically.

structure. In the southern part of the island, beyond the plain of *Catania*, *Iblei* mountains degrade down to the sea.

The description of this complex topography has been obtained from two Digital Elevation Models (DEM) [2]. The first is a regular matrix with a pixel resolution of $240 \times 240$ m. The other is a TIN (Triangulated Irregular Network) of the Etnean area, constituted by $4 \cdot 10^6$ points, obtained from a map with a scale 1:10 000 (fig. 2).

Vegetation coverage plays a major role in the sea-breeze regime, influencing the diurnal sea-land excursion of temperature. Detailed information on vegetation coverage was obtained by NOAA-AVHR satellite data, with a pixel resolution of $1.1 \times 1.1$ km. Channel bands Ch1 and Ch2 (0.58–0.68 and 0.725–1.10 $\mu$m) were used; the first is related to chlorophyll absorption in the visible red (proportional to chlorophyll content in vegetation), while, in the region of band Ch2, there is the near-IR plateau, where the reflectance is governed by leaf tissue and cellular structure (proportional to

TABLE I*b*. – *The main characteristics of the available data measured in each place.*

| | Data | Frequency | Heigt from soil |
|---|---|---|---|
| 1 | $T_{max}$, $T_{min}$ and wind direction | 1 day | |
| | $T_{max}$, $T_{min}$ | 10 years | 15–20 m |
| 2 | $u$, $v$, $T$ | 3 hours | 1.5 m |
| | $u$, $v$, $T$ | 3 hours | 1.5 m |
| 3 | $u$, $v$ | 10 min | 15 m |
| 4 | $u$, $v$, $T$ | 3 hours | 1.5 m |
| 5 | $u$, $v$, $T$ | 3 hours | 1.5 m |
| 6 | $u$, $v$ | 1 day | — |
| 7 | $u$, $v$, $T$ | 3 hours | 1.5 m |
| 8 | $u$, $v$, $T$ vertical profiles up to 6 km | — | — |
| 9 | $u$, $v$ | — | — |
| 10 | $u$, $v$, $T$ | 3 hours | 1.5 m |
| | $u$, $v$ | 10 min | 7, 15, 78, 128, 164, 232 m |
| | $T$ | 10 min | 7, 117, 202 m |
| 11 | $u$, $v$, $T$ vertical profiles up to 6 km | — | — |
| 12 | $u$, $v$, $T$ | 3 hours | 1.5 m |
| | $u$, $v$ | 3 hours | 1.5 m |
| | $T$ | 1 month | 1.2 m |
| 13 | $u$, $v$, $T$ | 3 hours | 1.5 m |
| 14 | $u$, $v$ | 10 min | 15 m |
| 15 | $u$, $v$, $T$ | 3 hours | 1.5 m |
| 16 | $u$, $v$, $T$ vertical profiles up to 6 km | — | — |
| 17 | $T$ vertical profiles up to 6 km | — | — |
| 18 | $u$, $v$, $T$ vertical profiles up to 6 km | — | — |
| 19 | ($u$, $v$, $w$) v.p. from 60 m up to 360 m, D$z$ = 30 m | 1 hour | — |
| 20 | $u$, $v$ | 30 min | 10 m |
| 21 | $u$, $v$, $T$, P 3D fields | 6 hours | 1000, 925, 850, 700, 500, 400, 300, 250, 200 mb |
| 22 | $T$ v.p. from 100 m up to 1300 m, D$z$ = 10 m | 1 hour | — |
| | ($u$, $v$, and $w$) v.p. from 50 m up to 500 m, D$z$ = 25 m | 30 min | — |
| 23 | $u$, $v$, $T$ | 3 hours | 1.5 m |
| | $u$, $v$, $T$ vertical profiles up to 2 km | 12 hours | — |
| | $u$, $v$ and $T$ vertical profiles up to 3 km | 6 hours | — |
| 24 | $u$, $v$, $T$ | 3 hours | 1.5 m |
| 25 | $u$, $v$, $T$ vertical profiles up to 6 km | — | — |
| | $T$ vertical profiles up to 6 km | — | — |
| | $u$,$v$ | 1 hour | 6 m |
| | $u$, $v$ | 25 min | 12 m |
| | $u$, $v$, $T$ | 1 hour | 5 m |

The lack of information regarding the frequency with which some measurements are carried out means that they are single measurements. $u$, $v$ are wind velocities along $x$, $y$ directions, respectively; $T$ is the air temperature, $P$ is the pressure.

TABLE Ic. – *The source of the available data measured in each place.* OGUM = *Osservatorio Geofisico Università di Modena*, ING = *Istituto Nazionale di Geofisica*, CIPA = *Consorzio Industriale Protezione. Ambientale*, OCP = *Osservatorio Collegio Pennisi*, GNV = *Gruppo Nazionale di Vulcanologia*, CSA = *Centro Sperimentale di Agrimicultura*, CSF = *Centro Sperimentale di Floricultura*, AM = *Aeronautica Militare*, ECMWF = *European Centre Meteorological Weather Forecasting*, CRE = *Centro Ricerca Elettrica*, Fx = *fixed instrument*, Fl = *on file*, C = *campaign*, P = *on paper*, A = *anemometer*, T = *thermometer*.

| | Source | | | Instruments | Period of time |
|---|---|---|---|---|---|
| 1 | OCP | Fx | P | A + T | 1882-1897/1913-1940 |
| | CSA | Fx | P | A + T | 1993, July and August 1995 |
| 2 | AM | Fx | Fl | A + T | 1994 (*) |
| 3 | ENEL-CRE | Fx | Fl | A | May '93 - April '94 |
| 4 | AM | Fx | Fl | A + T | 1994 (*) |
| 5 | AM | Fx | Fl | A + T | 1994 (*) |
| 6 | AM | Fx | Fl | radio-sounding | 1988 - 1995 for 3 or 4 days a month (*) |
| 7 | AM | Fx | Fl | A + T | 1994 (*) |
| 8 | ING + OGUMAM | C | P | sounding balloon | 25/07/94 |
| 9 | Dr. Cicala | C | Fl | A | 19/07/94 - 31/07/94 (*) |
| 10 | AM | Fx | Fl | A + T | 1994 (*) |
| | University of M. | Fx | Fl | A | 1994 (*) |
| | University of M. | Fx | Fl | T | 1994 (*) |
| 11 | ING + OGUMAM | C | P | sounding balloon | 23/07/1994 (*) |
| 12 | AM | Fx | Fl | A + T | 1994 (*) |
| | AM | Fx | Fl | A + T | 1994 (*) |
| | Palermo's CSF | C | P | T | 1993, 1994 |
| 13 | AM | Fx | Fl | A + T | 1994 (*) |
| 14 | ENEL-CRE | Fx | Fl | A | May '93 - April '94 |
| 15 | AM | Fx | Fl | A + T | 1994 |
| 16 | ING + OGUM | C | P | sounding ballon | 24/07/1994 (*) |
| 17 | ING + OGUM | C | P | sounding ballon | 23/07; 24/07; 27/07/1994 |
| 18 | ING + OGUM | C | P | sounding ballon | 27/07/1994 |
| 19 | ENEL | Fx | Fl | SODAR | 12/01-28/01/88; 1/06/-25/07/89 |
| 20 | Obs. of Catania | Fx | P | A | 18-31 July 1994 (*) |
| 21 | ECMWF-Reading | — | Fl | — | 21/07/94-26/07/94 |
| 22 | Siracusa's CIPA | Fx | Fl | RASS | 7 July-3 August '92; 29 May-10 August '94 (*) |
| | Siracusa's CIPA | Fx | Fl | SODAR | 28 June-2 August '93; 28 May-1 August '94 |
| 23 | AM | Fx | Fl | A + T | 1994 (*) |
| | AM | Fx | Fl | radio-sounding | 07; 09/87, 02; 07; 12/88, 07; 12/93; 07/94 (*) |
| | AM | Fx | Fl | radio-sounding | 19-31 July 1991 |
| 24 | AM | Fx | Fl | A + T | 1994 (*) |
| 25 | ING + OGUM | C | P | sounding-balloon | 21/07/1994, 28/07/1994 |
| | ING + OGUM | C | P | sounding-balloon | 21/07/94 |
| | | C | Fl | A | 20/07/94-30/07/94 (*) |
| | ENEL-CRE | C | Fl | A | 8/07/94-8/09/94 (*) |
| | GNV | C | Fl | A + T | July 1994 (*) |

The whole data bank is now on file except for the historic series in Acireale.
(*) indicates that the dataset contains information on 23rd and 24th July 1994.

the density of green leaves). The normalized difference vegetation index, NDVI (fig. 3), is

$$\mathrm{NDVI} = (\mathrm{Ch2} - \mathrm{Ch1})/(\mathrm{Ch2} + \mathrm{Ch1})$$

which enhances the vegetation reflectance over chlorophyll absorption. The thicker and more thriving the vegetation covering, the higher the NDVI value. In fig. 3, NDVI values, over the range 0–255, have been organized in five different classes, represented with different colors, and the corresponding classes are reported in table II.

**2**·2. *Synoptic meteorological data.* – The main source of synoptic data such as the wind, humidity and temperature profiles is the Italian Air Force at *Trapani* (see fig. 1a). Information from the same source is also available for the top of Mount *Etna*, obtained by linear interpolation of wind data at *Trapani* (37° 55′ N, 12° 30′ E), *Brindisi* (40° 39′ N, 17° 57′ E), and *Naples* (40° 51′ N, 14° 18′ E), and hereafter called *Etna3000*. This piece of information must be used with caution, since the presence of the volcano top, just above 3000 meters, alters the circulation and limits the validity of the linear treatment.

The vertical profiles of air temperature and air pressure during summer months are more often reported in the data set on the atmosphere vertical structure provided at *Trapani*; therefore their analysis is more statistically relevant. According to the stored information, the troposphere's height is about 10-12 km during the cold season and reaches 15 km in the summer months; the temperature decreasing rate is lower than that of an adiabatic atmosphere (average 6.66 °C/km); the temperature difference between the two seasons is 10-15 °C at every altitude within the troposphere, as expected at latitude 370° N (fig. 4). The vertical trend of air pressure coincides with the Standard Atmosphere's profile in both seasons. Hence, there is of evidence on the presence of the middle Atlantic anticyclone nor that of thermal flow. In the data set,

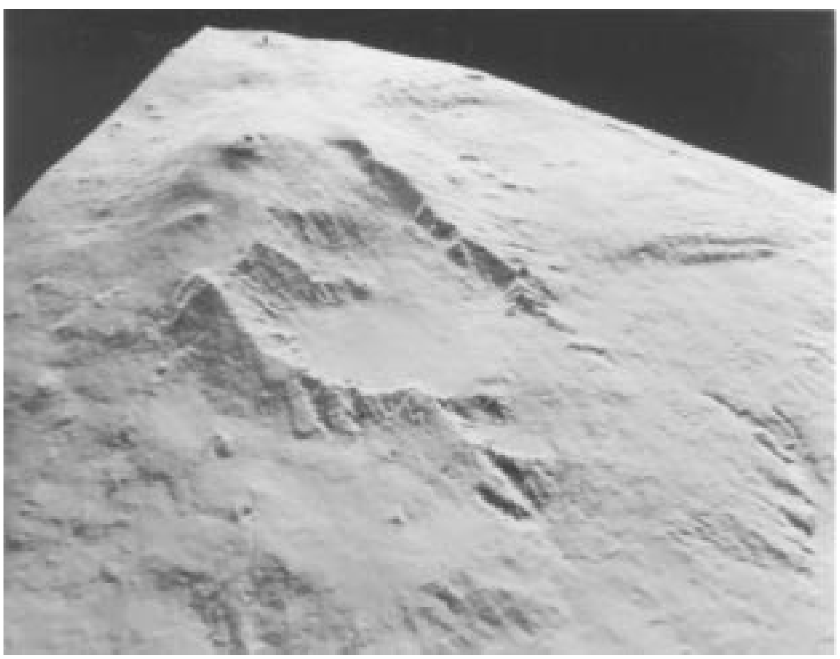


Fig. 2. – TIN of the Etnaean region.

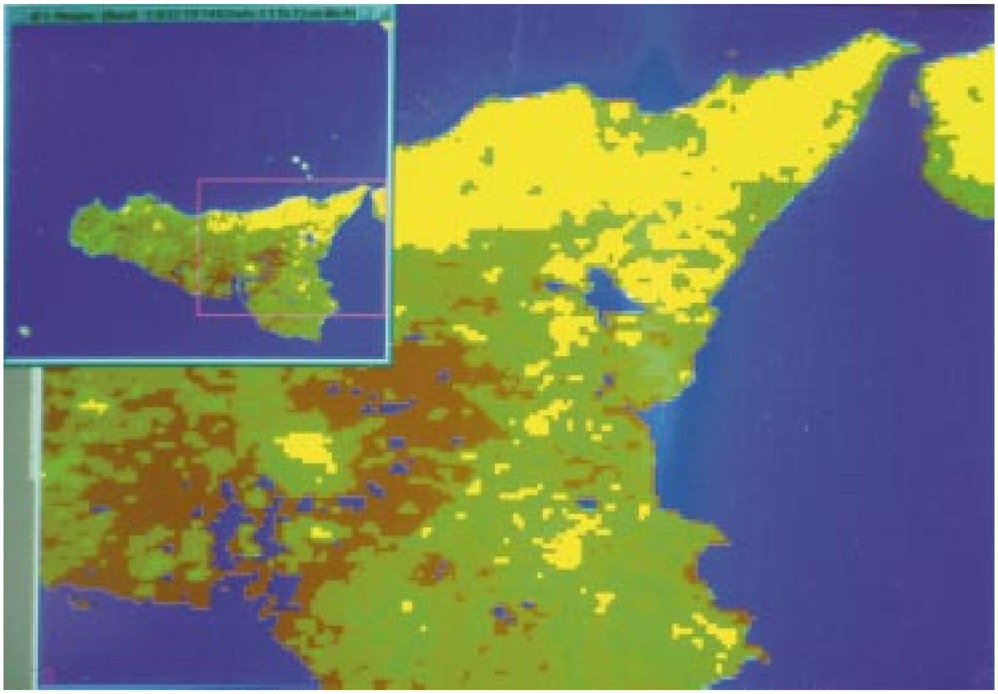


Fig. 3. – Normalized difference vegetation index (NDVI) for Sicily, obtained by a NOAA-AVHR image.

TABLE II. – *Classes in which* NDVI *values are organized.*

| SPECTRAL RANGE | CLASS DESCRIPTION | R - G - B | COLOUR |
|---|---|---|---|
| 0 - 9 | sea, naked rock, built-up area | 0 - 0 - 255 | blue |
| 10 - 24 | bare area, soil, urbanized area | 143 - 105 - 0 | brown |
| 25 - 39 | thin grassy vegetation, bush | 143 - 178 - 0 | olive-green |
| 40 - 59 | vegetated area, cultivation | 0 - 255 - 0 | green |
| 60 - 255 | blooming forest tree, wood | 255 - 255 - 0 | yellow |

the wind is found to blow from a direction between 270° (W) and 315° (NW) over an altitude of 3000 m during both seasons, but with a higher speed during winter. In the first 3 km of atmosphere, a typically westerly wind blows in winter with a speed of 6 m/s at soil level, accelerating and turning clockwise with increasing altitute becoming a north-westerly wind with a speed of 13 m/s at 3000 m. This winter value is found to be the most frequent also in the data set *Etna3000*. The data also indicate that all the directions between North-West and North-East clockwise have a high frequency, but with a highly variable and often low speed. Moreover, a strong wind (15 m/s) from WSW-SW is also quite likely to occur, probably associated to the incoming of Atlantic depressions into Mediterranean Sea [3].

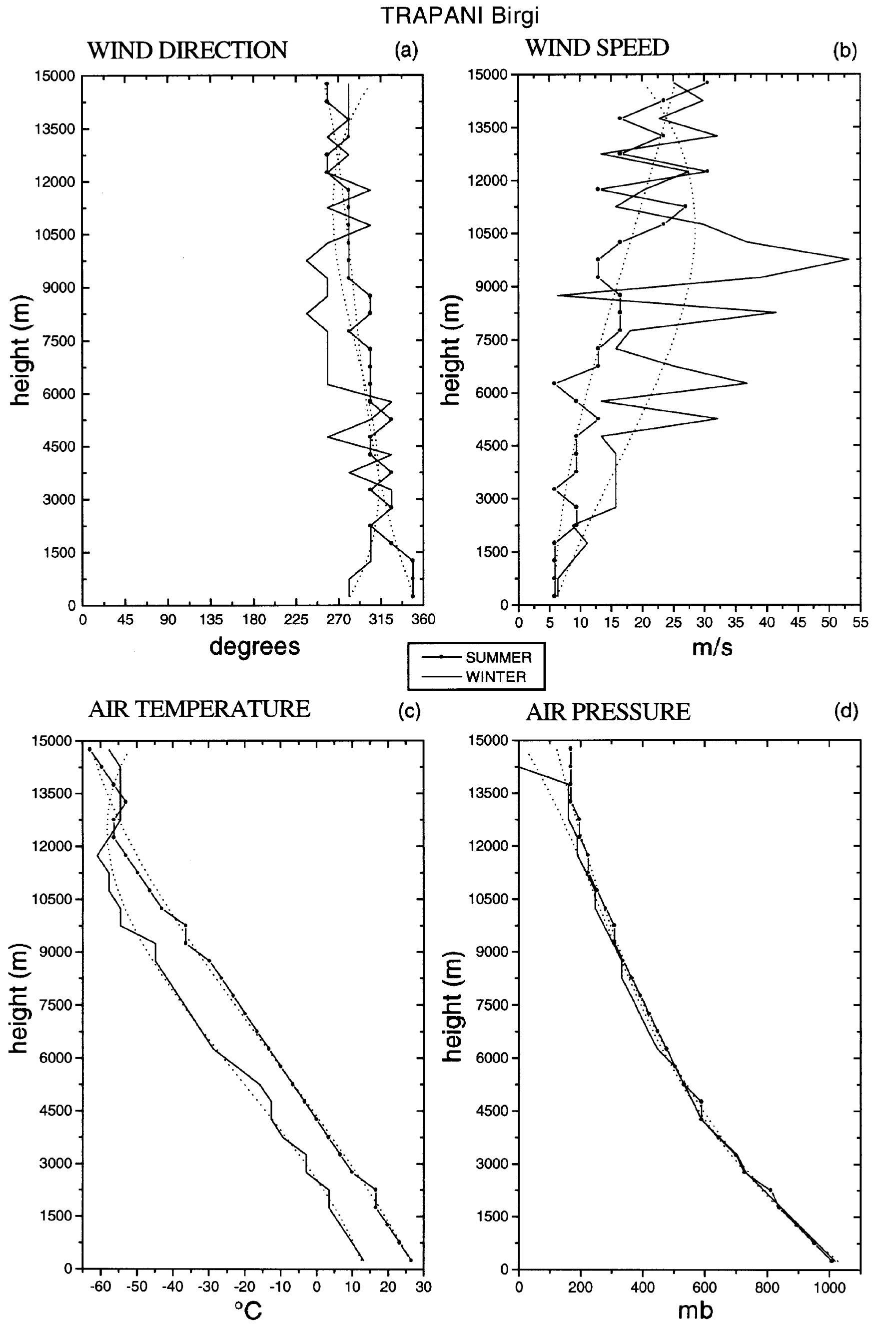



Fig. 4. – Most probable values of wind direction (a), wind speed (b), air temperature (c) and air pressure (d), with fitting on the frequency at Trapani Birgi during the hottest and the coldest seasons.

During summer, a 6 m/s flow from NNW representing sea breeze is the most frequent at surface level, and turns counterclockwise with height to become a north-westerly wind at 3 000 m as in wintertime, but its speed does not exceed 8 m/s. The values in data set *Etna3000* confirm the large frequency of the flow from 315°. They also indicate a moderate occurrence in summertime of a wind from 280° somewhat weaker when compared to that blowing during the other seasons. The little information available on the spring and autumn flows indicates that the two seasons are interested almost exclusively by flows from NNW and SW. In particular, three flows are frequent (from 325°, 280° and 235°) blowing slightly faster in autumn. Due to dynamic and thermodynamic effects, the island circulation and meteorology is characterized by many different flows. In Sicily, synoptic winds prevail from W-NW [4, 5], associated with cyclonic phenomena over the Atlantic Ocean. Strong SW winds, *Libeccio*, occur during winter, preceding the onset of depressions over the central-southern Tyrrhenian Sea. The strongest SE winds, *Scirocco*, are normally observed in mid-autumn (November) and in late spring (May). A weak *Scirocco* sometimes occurs in winter and very rarely in summer. Northerly and NEly winds, *Tramontana*, are generally moderate to weak, and only when deep and delimited cells of low pressure move from the Tyrrhenian Sea towards the outer Ionian Sea they reach high intensity [6].

**2**.3. *Characteristic local circulation patterns present in the data set.* – The locations where meteorological data are available at ground level are shown in fig. 1 and can be grouped as follows according to the type of circulation occurring:

*A*) *Etnaean* area (*Catania Fontana Rossa*, *Catania Sigonella*, *Acireale* and *Serra la Nave*): influenced by the presence of the volcano;

*B*) Localities at which, according to the data set, synoptic circulation seems to dominate on local winds (*Ustica*, *Pantelleria*, *Enna*, *Trapani Birgi*, *Contrada Sovarita* and *Piano Garita*);

*C*) Localities at which thermal circulation is clearly present (*Palermo Punta Raisi*, *Palermo Bocca di Falco*, *Messina*, *Gela*, *Cozzo Spadaro*, *Siracusa*, and *S. Filippo del Mela*);

*D*) *Aeolian Archipelago* (*Vulcano* and *Lipari* islands).

A brief description of local wind and temperature patterns at these localities follows, with the exception of the Aeolian Archipelago, for which a specific analysis has been already presented [5].

*A*) In the *Etnaean* area, meteorological information is available at three locations: *Catania* and *Acireale* near the East coast, and *Serra la Nave*, on the volcano's southern slopes (fig. 1b). Due to its dimension, Mount *Etna* deeply influences circulation in eastern Sicily, strongly modifying synoptic wind and originating slope breezes. Since Mount Etna has a height above the planetary boundary layer, the plume from the Central Crater undergoes minor dispersion and can travel over large distances before deposition. Traces of *Etnaean* sulfur compounds have been found over the Alps [7]. A well-known effect related to Mount *Etna* is the large vapor emission known as "*contessa effect*". This is a lenticular-shaped cloud forming downwind toward the East, above the *Bove* valley (fig. 1). When the flow is perturbed by an obstacle, oscillations are induced that depend on the flow intensity, on the air stability and on the dimension of the obstacle. These three physical quantities are combined in the Froude number (Fr). It is the ratio of the inertial to the buoyant forces: $\pi U/NL$, where $U$ is the flow intensity, $N$ the Brünt-Vaïsala frequency $[(g/\theta)\, d\theta/dz]^{1/2}$, $L$ is the typical width of the obstacle and $\theta$ is the potential temperature. For an isolated topographic obstacle (such as *Etna*), Fr varies in a wide range of values. For westerly synoptic winds and stable conditions, Fr values of about 1 are frequently obtained ($L \sim 10\,000$ m, $N \sim 2 \cdot 10^{-2}$ s$^{-1}$, $U = 15$–$20$ m/s). Consequently, non-hydrostatic lee waves are formed in the flow on the downwind side of the mountain, which are dumping off over the sea. If sufficient moisture is present, standing lens-shaped clouds can form along the crests of these waves giving rise to the above-mentioned effect.

The city of *Catania* lies on the East coast of Sicily at the end of the south-eastern slope of the volcano. The available data were measured at two distinct locations of the city:

– at the airport *Fontana Rossa,* right outside the city in the industrial area, and

– at the airport of *Sigonella*, a few kilometers inland in the plain.

In both places, westerly winds always blow during the night and easterly winds during daytime. In fig. 5 a typical time series for *Fontana Rossa* is given. The night flow is the sum of synoptic flow (obstructed by mount *Etna* in its northern component) and land breeze; the daily circulation is a typical sea breeze. Approximately, this is what we expected; however, nocturnal flow tends to be more WSWly than WNWly, showing no sign of the drainage flow from the *Simeto* valley at *Sigonella*, nor from the SE slope of the volcano at *Fontana Rossa*. The direction indicates that, even in the nights with weak synoptic wind, the drainage flows are probably canceled by another local thermal circulation. This may be due to the fact that, during the early hours of the night, the sea breeze generated on the SW coast during the previous day is still noticeable on the plain; it continues to advance as a gravity current and, finally, it is split into two parts by the volcano, passing through the saddle between the *Iblei* and the *Erei* mountains (see fig. 1). During early morning, sea breeze starts to develop at *Fontana Rossa* and then reaches *Sigonella*. Once again, there are no signs of the existence of any slope wind in the data, probably due to the fact that slope winds start earlier but are much weaker than sea breeze. As soon as this develops, the former dies out since the two winds are in opposite directions. The night flow intensity of the breeze is around 2 m/s or 3 m/s; higher strengths sometimes present in the data are due to particular synoptic situations. The diurnal breeze grows to 5 m/s or 6 m/s during spring and summer. The often low sea breeze intensities found in the data indicate that opposing synoptic wind is sometimes strong enough to weaken the flow, and the days in which it allows the breeze to grow stronger are quite rare. At 21:00 LST the sea breeze has lost its propelling power, but there might be situations, even in spring, during which, under favorable stability conditions, it still keeps blowing. The local regime also may occur in winter, with later on setting and with earlier decadence.

The air temperature at *Catania* shows the hottest value of 30 °C during the summer days and the coldest one below 5 °C on winter nights. The daily temperature excursion is in both cases around 10 °C in both places (slightly less at *Sigonella* during summer).

The Observatory of *Acireale* was installed at the end of the last century and has worked for more than 40 years since then. From the long historical records available [8], excellent climatological information can be obtained. For instance, average values of minimum and maximum daily air temperature indicate that a sea breezes regime should be present almost all over the year. This is confirmed by quite

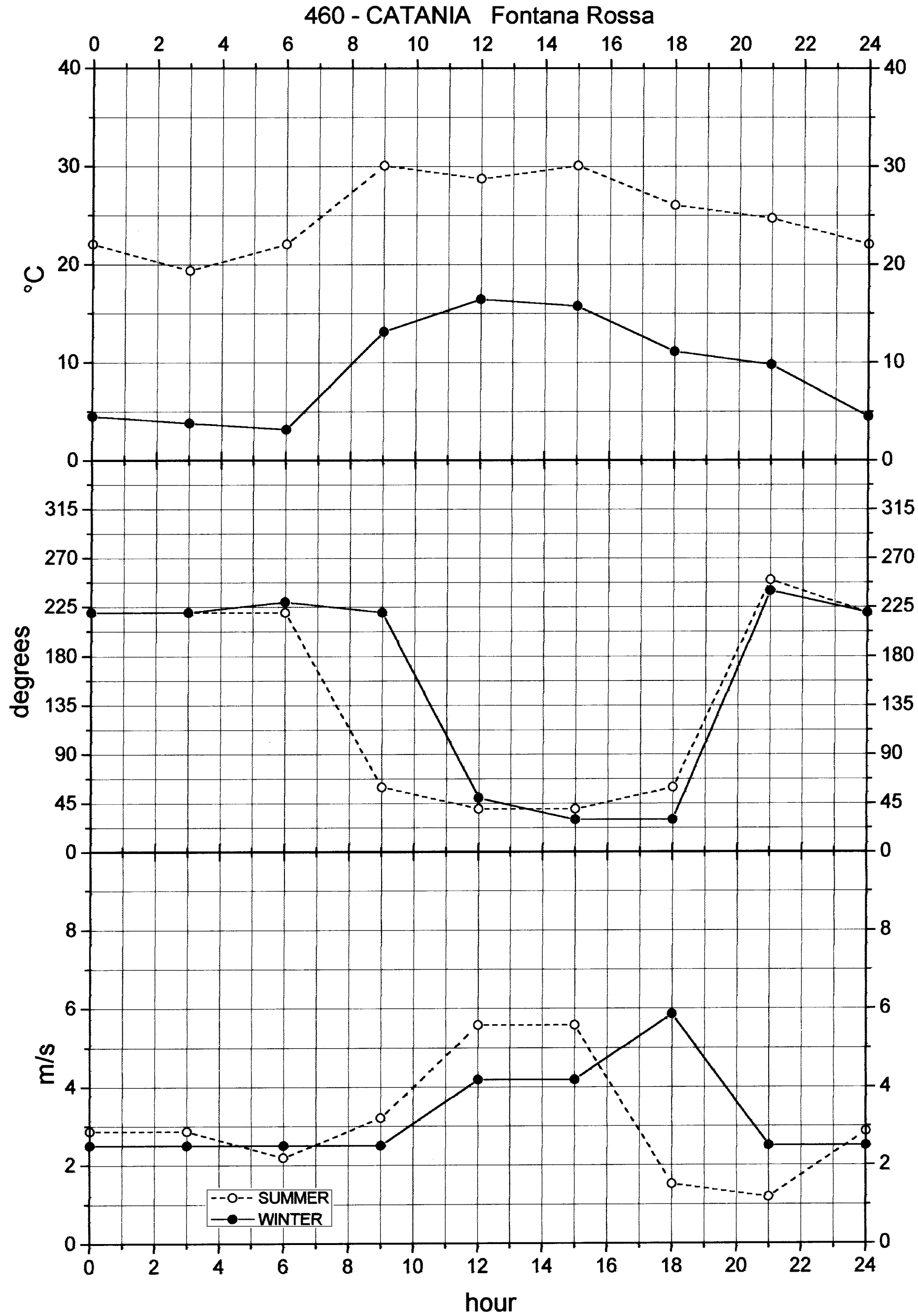



Fig. 5. – Typical diurnal trend of air temperature and wind field at soil level at Catania Fontana Rossa.

low diurnal excursions throughout the year, ranging from a minimum of about 7.5 °C in January to a maximum of about 10.5 °C in July. Wind values are reported, divided into "lower-level" and "upper-level" winds. The lower-level winds frequency distribution shows two peaks in January, corresponding to East and West direction. In summertime, the East frequency is very much enhanced due to the daily sea breeze. The upper-level winds show a clear preference to blow from a western direction in all seasons, as is expected in a Mediterranean site. The flow intensity is increased by the local topography. This tendency is very stressed in summertime, since in winter, N or NW winds are also likely to occur.

At *Serra la Nave* (1 725 m a.s.l., on a tableland, at the Mount *Etna* SSW slope) the measured wind fields reported in the annual bulletin (1965-1981) [9] reflect the typical synoptic conditions at this latitude, with mainly westerly and north-westerly flows, blowing with higher intensities during winter months. Easterly winds are detected almost exclusively during highly perturbed periods (*e.g.*, December 1972). Also southerly and south-easterly flows are very rare as monthly averages (those winds probably blow for very short periods of time) with the exception of summer 1977. Mean values of wind speed are below 3 m/s probably because of site location on the lee side of the volcano. The annual trend of 10 day mean values of maximum air temperature ranges from 5 °C to 25 °C; that of the minimum from $-12$ °C to 10 °C. Diurnal thermal excursion is most frequently between 6 °C and 8 °C. These values are sensibly different from those obtained on the plains, indicating that the altitude and the location of the station are such that the mild breezes from the sea do not reach up to there.

*B*) In these localities the most probable wind is a quite strong W-NWly synoptic flow blowing during the summer and winter months. In each locality, though, the synoptic circulation is modulated by local thermal circulation to some extent. Diurnal thermal excursion is very low either because of the high exposure to large-scale flow that advects constant temperature air, or because of the proximity to the coast where sea breezes take cold marine air reducing the diurnal heating rate or for both these reasons.

The airport of *Trapani Birgi* lies on the West coast of Sicily, half-way between *Trapani* and *Marsala*. The surrounding area is flat with the main hills located about 20 km East. The two flows are thus very difficult to separate during the daily hours since they have the same direction (NW); however, the data seems to show that sea breeze develops sometimes even during the cold season.

Both *Ustica* and *Pantelleria* islands are quite small and sea breezes are probably too weak to overtake synoptic flow and are seldom detected.

*Enna* stands on a high peak (968 m) of the *Erei* mountains, right in the middle of Sicily. The westerly flows are often disturbed by other flows such as the thermal circulation developing on the steep slopes of the hill and those developing on the southern coast of the island. For this reason, the local circulation can be considered as a modulation of the general flow. In fact, the temporal trend of the wind does not indicate the presence of any diurnal cycle.

*Contrada Sovarita* and *Piano Garita* are placed over two egg-shaped tablelands (760 m and 600 m a.s.l., respectively) in the southern corner of Sicily. The circulation of the winds in this part of the island is only partially affected by the sea breeze from the western coast (around *Agrigento*), and modulated by the slopes and the valleys of the *Iblei* mountains. The distance from the nearest eastern coast is large enough to prevent sea breezes to reach these locations. This is due also to the flow rotation when it penetrates inland. The Coriolis force, in fact, pushes the breeze from *Catania*'s flatland towards mount *Etna*; the sea breeze from the coast near *Gela* is deviated too, and weakened enough by the vegetated valleys to prevent it from overriding the nearby mountain. The only sea breezes that could eventually reach the area (from the SE coast) are obstructed by Mount *Lauro*, the highest topographic peak (986 m) of southern Sicily.

Many instruments are located in the northernmost and easternmost corner of the island. In addition to the data recorded at *Messina* (at soil level with a 3 hour frequency), at *Capo Faro*, located where the *Strait of Messina* channels the NWly synoptic winds (often southerly or northerly in wintertime), some instruments measure the wind at different heights with very high frequency. It is very difficult to reconstruct the wind circulation over this area because of the interaction among different flows that prevent the formation of a clear diurnal cycle. These are thermal flows mainly due to the various orientations of the coastline, and the proximity of high mountains (*Etna* in Sicily and *Aspromonte* in the *Calabria* peninsula).

*C*) These localities are characterized by a synoptic flow that strongly interacts with thermal circulation. The measurements indicate that at almost every hour of the day, the latter has higher probability of being detected; this is often true even during the coldest months.

The measurements at Palermo refer to the military airport of *Bocca di Falco* placed between the city and the plain behind it. Other data come from the city's airport of *Punta Raisi* on the short SW-NE coast of the cape between the two bays of *Castellammare* and *Carini*, West of Palermo. Because of its location, *Punta Raisi* is subjected to strong synoptic winds, but still thermal breezes circulation is strong enough to make the most probable wind follow a diurnal trend (especially in summertime). Due to the high mountains surrounding *Palermo*, *Bocca di Falco* is much less exposed to high synoptic winds than *Punta Raisi*. Moreover, due to its location behind the city, the breeze intensity is reduced by the obstruction of the urban settlement (2 km wide). As a result, regular sea/land breezes, strengthened by the kata/anabatic flows from mountains behind the city, develop throughout the year.

*Gela* is characterized by a very mild climate. The topography around the city with its plain intensifies the sea and land breezes with up-slope and down-slope winds, respectively. Except for winter months in which many other flows are present, in the afternoon the sea breeze turns West because of the Coriolis force, and is reinforced by the synoptic flow.

*Cozzo Spadaro* is located at the southernmost end of the island, on a cape, with 270° of sea all around, and plain land North-West of it. This implies that the most probable wind direction is not very well defined throughout the day, since it may arise from the interaction of breezes with comparable strength but flowing from different directions. During winter, however, weak sea breezes from the NE develop, so that the typical day consists of only the main flow from the WSW.

The measurements at *Siracusa* consist of temperature and wind vertical profile from a RASS and a SODAR during summer. From the data, it can be noticed that although NWly winds blow quite frequently during the day, the sea breeze develops almost daily (fig. 6), and over 200 m it cannot be distinguished from the synoptic flow. Vertical speed probability distribution confirms the presence of the breeze by showing upward and downward flows during the day up to 300 m. Nocturnal air temperature vertical profiles indicate of inversion at about 150 m.

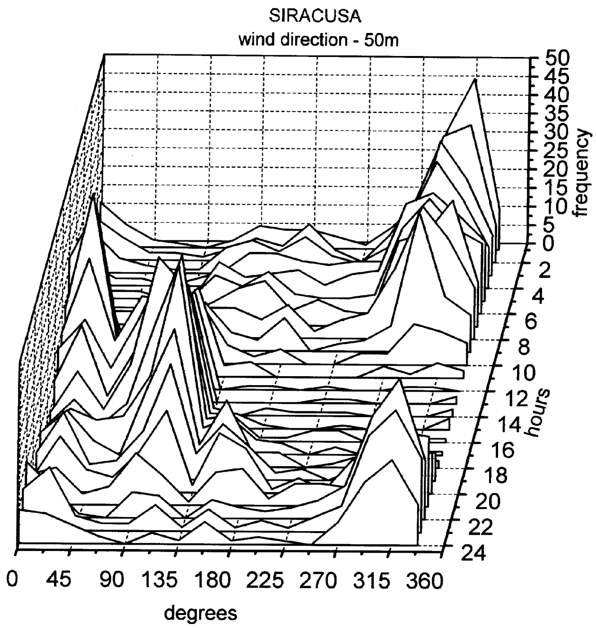



Fig. 6. – Probability distribution of wind direction with time in Siracusa at 50 m height.

*S. Filippo del Mela* seems to be influenced by a sea/land breeze circulation establishing at the E-W coast of *Milazzo* peninsula (about 4 km away), probably reinforced by the wind that develops from the city down to the river valley on the steep

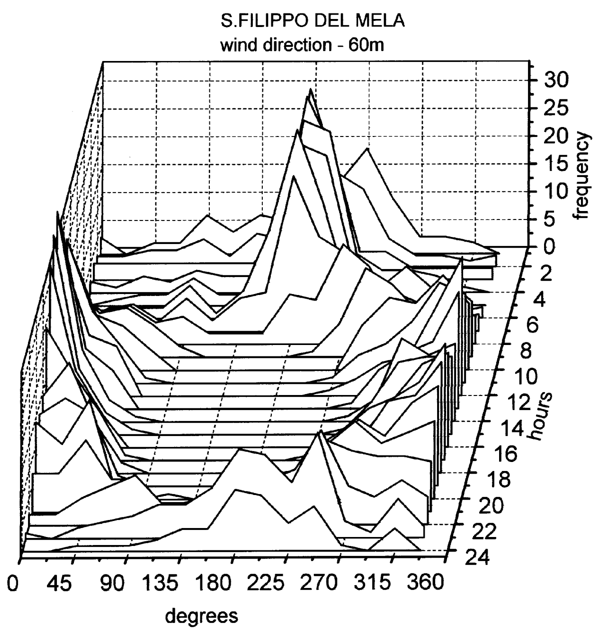



Fig. 7. – Probability distribution of wind direction with time in S. Filippo del Mela at 60 m height.

and East-facing slope (fig. 7). On the contrary, there is no trace of a SW-NE circulation at the West coast of the peninsula. The land breeze shows a very low intensity and it is quite shallow, while sea breeze has a depth of approximately 300 m. The data set includes a few measurements corresponding to winter days. From the data no clear wind field structure can be determined.

## 3. – Data for mesoscale model evaluation: 23 and 24 July 1994

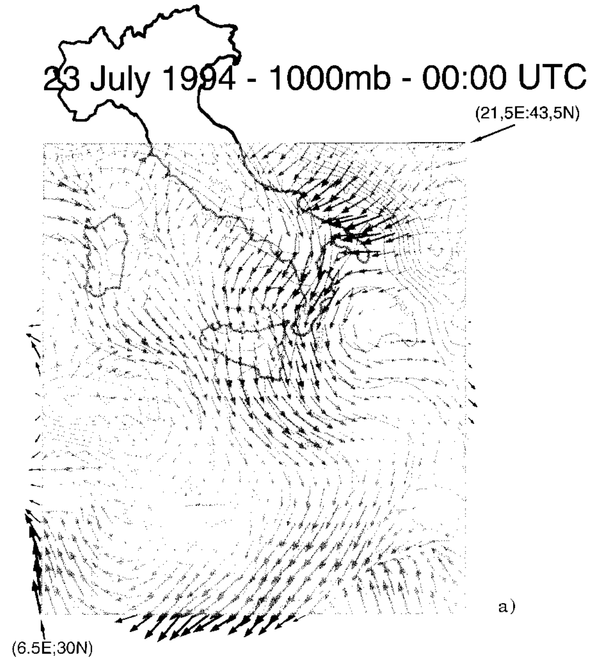
The period of time which is better represented in the data bank is the second half of July 1994. A couple of days within this period, 23rd and 24th, were considered to be useful for model validation. In fact, a large amount of meteorological information relative to that short period is available (in table I*c*) data sets containing information on these two days are marked with an asterisk). Moreover, images over the area were acquired during those days by the MIVIS (Multispectral Infrared and Visible Imaging Spectrometer) airborne imaging spectrometer within the CNR-LARA (Laboratorio Aereo per Ricerche Ambientali) project [4] and included in the data set.

**3**˙1. *Synoptic conditions.* – On Saturday 23, at 00:00 UTM, an Atlantic perturbation passed over the *Ionian* sea coming from northern Italy. The depression moved rapidly towards the SE while an anticyclone formed over northern Africa. This configuration determined a strong north-westerly flow over Sicily (fig. 8). By the end of the day, the cyclone faded away and higher pressure spread, causing low winds over the whole area. The ridge kept moving eastward during 24th July, allowing an extension of a trough of the Balkan depression to the South of Italy. This is why the wind kept blowing from NW over Sicily while it blew from NE on northern Italy. Obviously, there are some differences among those N-Wly flows, which depend on the position within the island and the time of day.

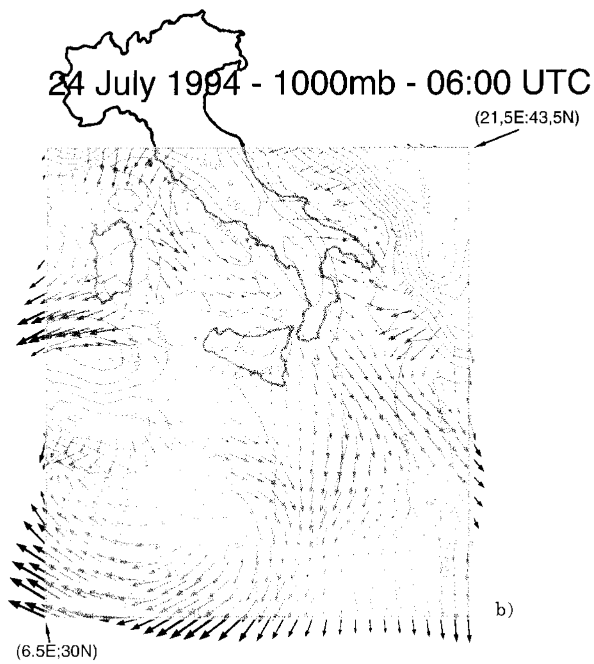
The air temperature is quite high during the whole month (positive anomalies are found concerning both extremes) [10]. No thermal advection takes place and the wind fields at sea level show diurnal cycles throughout the week.

The temperature vertical profiles measured at *Trapani* indicate the typical height of the troposphere to be approximately 15 000 m. Temperature profiles measured at *Riposto*, *Provenzano* and *Nicolosi* up to 6000 m match well with the data. Wind vertical profiles at *Trapani* and *Provenzano*, confirm that the wind blows from the NW at low levels with a much higher speed during 23rd, than during 24th July. At *Nicolosi*, on the lee side of mount *Etna*, a very weak southerly wind is detected early in the morning of day 23, probably representing the rising breeze. The flow turns anti-clockwise with height, because of the higher heating rate of the eastern slope, and becomes a strong synoptic flow from N-NW. It is interesting to note that a cold high-speed jet is present at about the height of the volcano, even though there is no capping inversion.

**3**˙2. *Local conditions.* – Due to the synoptic flow, the wind was blowing from the NNW almost everywhere in Sicily, during the night of 23rd July 1994. As expected, the higher intensities are at *Pantelleria* where the flows was channeled between Sicily and Africa thereby reaching 8 m/s. *Trapani* is also highly exposed to synoptic flow, but night land breeze probably slows it down to 4 m/s and turns it into a north-easterly wind. At *Enna*, the wind speed is below 4 m/s, possibly because of the opposing SW flow that was observed to be quite frequent at this location. Since *Messina* is the nearest




a)




b)

Fig. 8. – Wind field and geopotential height field calculated for the Central Mediterranean region at 1000 b on (a) 23/07/94 at midnight and on (b) 24/07/94 at 6:00 UTC.

locality to the center of the depression, a more westerly flow was detected. For the same reason, a more easterly wind was observed at *Ustica* and *Palermo Punta Raisi*, while Palermo *Bocca di Falco* looks to be much more protected by the city and the mountains. All the other localities examined show weaker flows: at *Catania*, *Serra la Nave*, *Cozzo Spadaro* and *Gela*, land breezes develop, the former two towns being on the lee side of Mount *Etna*, and the latter two towns protected by *Iblei* mountains and *Erei* mountains. At *Vulcano* and *Lipari* islands, the wind blows from NE and NW but the wind intensity does not exceed 1 m/s.

The localities more exposed to the synoptic wind such as *Pantelleria*, *Enna*, *Ustica* and *Palermo Punta Raisi* do not show any diurnal cycle. Also at *Messina* (fig. 9), *Palermo Bocca di Falco* and *Trapani* there is no evidence of an ordered diurnal cycle. However, the wind direction and intensity both change from those observed during the night. At the first two sites, the wind oscillates among different directions and the wind speed increases during the day. At *Trapani*, northerly winds become north-easterly during the night and north-westerly during the day. At *Catania Sigonella*, the see breeze arrives quite late, with a greater rotation and with a higher wind speed than usual (up to 8 m/s).

At *Serra la Nave*, the sea breeze and up-slope flow from SE does not take over synoptic wind (from WNW) until the afternoon. Over the *Eolian* islands, in the afternoon the wind turns to blow with high speed from the West at *Cardo*, *Gelso* and *Lipari*, while at *Centro Carapezza* in *Vulcano*, a locality which is much more protected by the surrounding topography, a weak wind flows from the two bays of *Porto Ponente* (NW) and *Porto Levante* (NE) and from the valley between the volcano and Mount *Lentia* (SW). (For the identification of these specific locations, refer to [5]).

During 24 July, the winds at surface level have similar trend as during the previous day, at the most exposed sites such as *Pantelleria*, *Enna*, *Ustica*, *Palermo Punta Raisi*, *Trapani* and *Messina*. At *Palermo Punta Raisi*, a diurnal sea breeze prevails until 12:00 LST. At *Cozzo Spadaro*, a breeze regime takes place, as well as at *Palermo Bocca di Falco* (from 1 m/s to 4.5 m/s), at *Gela* (but weaker than the previous day) and at *Serra la Nave* (from the East during the day and SSW during the night). At *Catania Fontana Rossa*, the thermal circulation dominates too (up to 5 m/s at 12:00 LST in accordance to what was found to occur more often), whilst further inland at *Catania Sigonella* the same strong winds of the day before are recorded. At *Lipari* and *Vulcano*, the wind speed is even lower than during 23rd July, it rotates from West anti-clockwise during the day at *Cardo*, and from SW clockwise at *Lipari*. It is interesting to note that some southerly flows have been detected during 24th July for very short time intervals. In particular, a SSW jet was identified at *Messina* during the night, a southerly flow at Enna in the afternoon. The direction of downslope flow at *Serra la Nave* is SSW instead of SW, as it might be expected by the orientation of the valley. A SSE flow is detected at *Catania Sigonella* for 15:00 LST and a SW wind around 18:00 LST at *Catania Fontana Rossa*.

At most of the localities for which information on air temperature is available, its trend coincides with that found as the most probable during summer, but 1 or 2 °C lower on 23 July than during the following day. At *Trapani*, temperatures are lower than the most probable values. At *Ustica* and *Pantelleria* the thermal excursion results lower on Saturday (only 3 °C in Pantelleria) because of the strong winds, while at *Cozzo Spadaro*, which is repaired from this synoptic wind, thermal excursions are high compared to the typical values. Note that at *Catania Sigonella* there is a drop in air temperature corresponding to the SSE flow at 15:00 LST. This temperature drop might

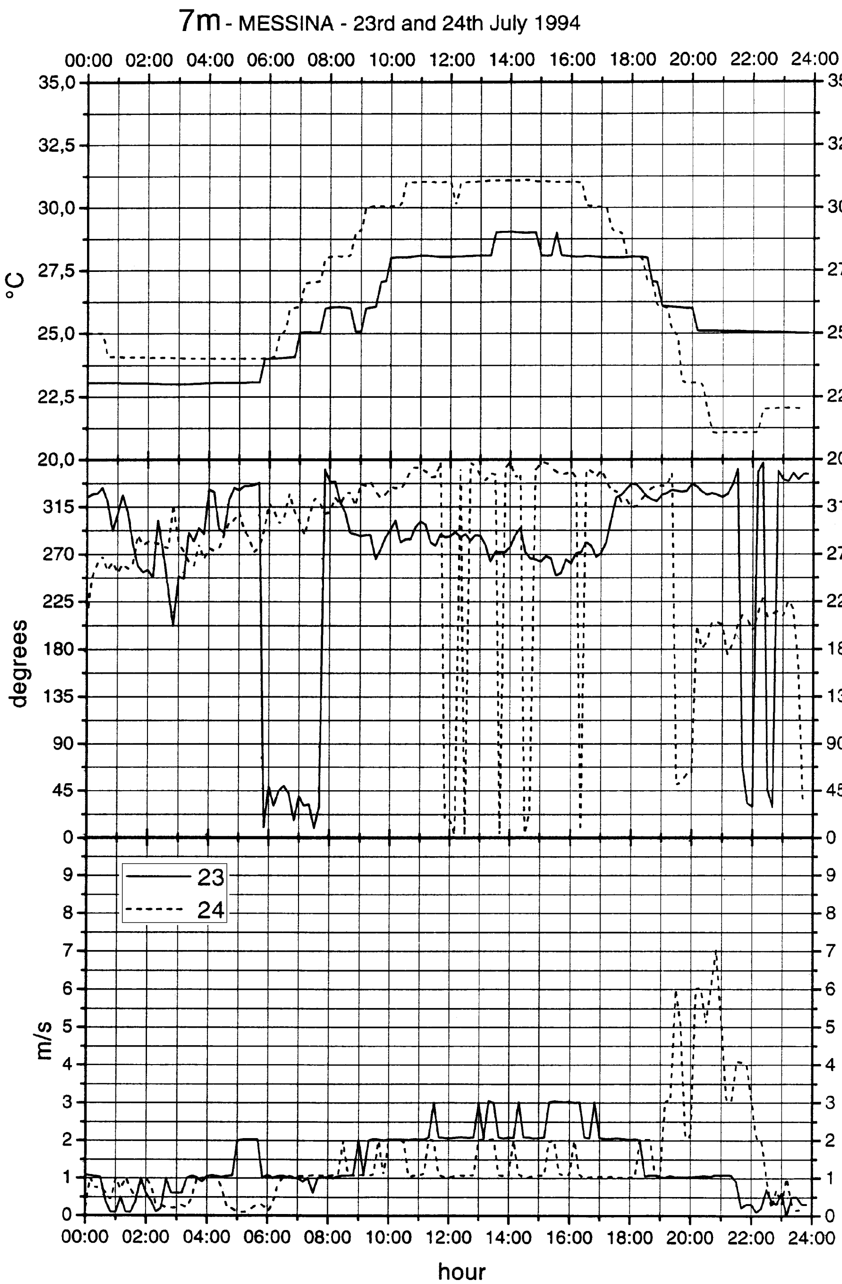



Fig. 9. – Diurnal trend of air temperature and wind field at 7 m in Messina Capo Faro on 23rd and 24th July 1994.

indicate the passage of the sea breeze front, since at the same time the temperature is lower at *Catania Fontana Rossa*.

No wind speeds were recorded at *Siracusa* during both days. Temperature profiles indicate the night inversion to be at around 200 m a.s.l., which is destroyed during the day.

## 4. – Conclusions

In this paper a large data set of meteorological information over the island of Sicily (Italy) is presented and described. The goal of the collection is to produce data information that could be of some use in understanding the circulation in such a complex area as Sicily. The relevance of such information lies in the fact that it can readily be used for many different purposes, such as, for example, atmospheric mesoscale flow and dispersion modeling activity of the gaseous emissions from the volcanoes existing in the area. Furthermore, the data sets and the software needed to analyze it are available to answer more specific questions on the meteorological field structure and its temporal evolution. The stored information was mainly commented for summertime and wintertime, *i.e.* in the two periods when either thermal effects dominate, or when synoptic wind effects are greater.

The detailed description of the data collected provide information on both the general and the local circulation on the island. The presence of topography also in proximity of the coastline, the proximity of the Italian mainland (*Calabria*) to the NE corner and that of *Etna* volcano (3323 m a.s.l.) to the East coast, greatly modify synoptic wind patterns. Sea breezes, developing from thermal effects for most of the year, but especially pronounced during summertime, may penetrate inland by several tens of kilometers.

The stored information, even if derived from various sources, has been thoroughly compiled and show to be self-consistent. The data set is a suitable base of reference for the evaluation or for the initialization of mesoscale flow models which can be used to study particular meteorological situations or atmospheric dispersion. In particular, the database allows one to model mesoscale scenarios, starting from different meteorological conditions and using locally based measurements rather than the output from general circulation models. An approach similar to this has been successfully applied to *Volcano* island, as far as the emission of crater fumaroles is concerned [11]. Future research will be focused on the use of the database to model volcanic gas dispersion from Mt. *Etna* in East Sicily.

* * *

This work was supported by the European Commission, Contract ENV4-CT96-0288, *Mitigation of Volcanic Risk by remote sensing techniques*. We wish to thank S. GALMARINI (JRC-Ispra), C. BLANCO (Catania), F. BUONGIORNO (Istituto Nazionale di Geofisica), C. CARRISTI and O. CEFALI (Università di Messina), A. CICALA (Lipari), P. FRANCIS (The Open University, Milton, Keynes, UK), A. GAMBADORO (Consorzio Industriale Protezione Ambiente della Provincia di Siracusa), A. PIAZZA and R. CASTAGNA (Ente Nazionale per l'Energia Elettrica - Centro Ricerca Elettrica), S. RINIERI (Aeronautica Militare), S. TEGGI (Osservatorio Geofisico, Università di Modena), M. VALENZA and P. CARUSO (Istituto di Geochimica dei Fluidi di Palermo), C. ZIMBONE (Osservatorio Collegio Pennisi di Acireale).

## REFERENCES

[1] RANCI M., GRAZIANI G., MAZZARINI F. and PARESCHI M. T., *A data bank of meteorological measurements over Sicily for mesoscale atmospheric flow model evaluation*, EUR Technical Report, no. 16456 EN, 1996.

[2] BRANCA M. S., CAVARRA L., FAVALLI M., INNOCENTI F., PARESCHI M. T., PASQUARÈ G. and TIBALDI A., *Un modello digitale del terreno per l'Etna. Implicazioni geomorfologiche e strutturali*, in *XIV Convegno Scientifico Annuale del Gruppo Nazionale per la Vulcanologia, CNR, Catania 2-4 Marzo 1998* (Felici Editore, Pisa) 1998, p. 55.
[3] FANTAUZZO F., *Dalla brezza all'uragano. Metorologia moderna* (ETS, Pisa) 1976.
[4] BOGLIOLO M. P., BUONGIORNO M. F., SALVI S., TEGGI S., PUGNAGHI S., ABRAMS M. J., PIERI D. C., REALMUTO V. J. and CALTABIANO T., *Ground measurements of physical parameters at Vulcano island and Mount Etna in support of the MIVIS remote sensing campaign "Sicilia-94"*, ING Technical Report no. 577, 1996.
[5] CARUSO P., GRAZIANI G., MOSCA S., MARTILLI A., PARESCHI M. T. and VALENZA M., *The Vulcano 1994 summer campaign, Nuovo Cimento C*, **19** (1996) 195-214.
[6] CICALA A., *Fisionomia climatica dell'isola di Vulcano*, in *Le isole Lipari: Vulcano* (Edinixe Editrice, Messina) 1987.
[7] ANFOSSI D. and SACCHETTI D., *Transport of Volcano Etna emissions towards the Alpine Region using ECMWF data, Nuovo Cimento C*, **17** (1994) 473-484.
[8] *Il clima di Acireale nei suoi elementi meteorologici - confronti con altri climi* (Osservatorio Collegio Pennisi, Stabilimento tipografico "900").
[9] AFFRONTI F. and BLANCO C., *Rapporti annuali sulle condizioni meteorologiche a Serra la Nave sull'Etna* (Osservatorio Astrofisico di Catania e Università degli Studi di Catania) 1965-1981.
[10] *AER Meteorologia, Climatologia, Agrometeorologia ambiente*. A cura del servizio meteorologico ERSA-REGIONE Emilia Romagna (Conti Editore) 1994.
[11] GRAZIANI G., MARTILLI A., PARESCHI M. T. and VALENZA M., *Atmospheric dispersion of natural gases at Volcano island, J. Volc. Geoth. Res.*, **75** (1997) 283-308.