Results of the Project

WERMED

Weatherrouting dans la Méditerranée

Weatherrouting

dans la Méditerranée.

EDITORS: A. Speranza, A. Delitala, K. Strataridakis

AUTHORS: Alessandro Delitala, Joel Azzopardi, Paolo Boi, Massimiliano Burlando, Federico Cassola, Piero Cau, Giacomo Cordina, Stefano Corsini, Christian De Bono, Aldo Drago, Lise Folso, V. Fragouli, Stefano Gallino, Albert Gambina, Vassiliki Kotroni, Kostas Lagouvardos, A. Maragoudakis, Stefano Mariani, Piero Marsiaj, Kostas Mazi, A. Milesi, Sara Morucci, Svetlana Music, Corrado Nieddu, Arianna Orasi, Laura Pedemonte, Corrado Ratto, Davide Sacchetti, Luca Sebastiani, Alessandro Seoni, Kostas Stararidakis, Elisabetta Trovatore, Antioco Vargiu, Luca Villa, Matthew Yeomans.

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June 2007

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ABSTRACT.

Ce livre dépeint les résultats du Projet *WERMED – Weatherrouting dans la Méditerranée*, un projet financé par le P.I.C. Interreg IIIB – MEDOCC sur l'axe et mesure 3.3 (*Transports Maritimes et Fluviaux*). Les fonds sont divisés comme suit : 1100000€ fonds Européens (FEDER), 674000€ fonds nationaux (Italiens, Grecques et Maltais) et 92200€ fonds propres des partenaires.

Les partenaires étaient les suivants :

- CINFAI (Consortium Interuniversitaire Nationale pour la Physique des Atmosphères et des Hydrosphères);
- APAT (Agence Nationale pour la Protection de l'Environnement et les Services Techniques);
- ARPAL (Agence Régionale pour la Protection de l'Environnement de la Ligurie);
- Région Sardinia (Département des Transports);
- Observatoire National d'Athènes;
- Région Crète (Département d'Informatique et Documentation);
- Université de Malta – Centre Opérationnelle Maltais.

Des autres institutions et opérateurs du transport maritime ont été :

- CETENA;
- SAR (Service Agrométéorologique Régional de la Sardaigne);
- ARPAS (Agence Régionale pour la Protection de l'Environnement de la Sardaigne);
- Autorité Maritime Maltaise;
- Grandi Navi Veloci;
- Minoan Lines.

Ce projet a évalué le potentiel du weather-routing modern, c'est-à-dire les techniques de navigation d'après des conditions météo-maritimes, dans la Méditerranée.

Ce livre dépeint les résultats du projet. Chaque chapitre résume une de ses actions et a été préparé de parts de ceux qui l'ont gérée.

ABSTRACT.

This book outlines results of project *WERMED – Weatherrouting dans la Méditerranée*, a project funded on P.I.C. Interreg IIIB – MEDOCC on axe and measure 3.3 (*Transports Maritimes et Fluviaux*). Funds are as follows: 1100000€ European (FESR), 674000€ national (Italian, Greek and Maltese) funds and 92200€ of partners' own ones.

Partners were the following:

- CINFAI (Consorzio Interuniversitario Nazionale per la Fisica delle Atmosfere e delle Idrosfere);
- APAT (Agenzia Nazionale per la Protezione dell'Ambiente e i Servizi Tecnici);
- ARPAL (Agenzia Regionale per la Protezione dell'Ambiente Ligure);
- Region of Sardinia (Transport Authority);
- National Observatory of Athens;
- Region of Crete (Informatics and Documentation Department);
- University of Malta – Malta Operational Centre.

A few more institutions and operators of marine transport were also involved:

- CETENA;
- SAR (Regional Meteorological Service of Sardinia);
- Malta Maritime Authority;
- Grandi Navi Veloci;
- Minoan Lines.

The projects assessed the potential of modern weatherrouting, i.e. navigation techniques by means of meteorological and sea conditions, in the Mediterranean.

The present book describes the results of the project. Each chapter outlines an action and has been cured by the people involved into it.

SOMMARIO.

Il libro riassume i risultati del progetto *WERMED – Weatherrouting dans la Méditerranée* finanziato col P.I.C. Interreg IIIB – MEDOCC sull'asse e misura 3.3 (*Transports Maritimes et Fluviaux*). Il finanziamento è suddiviso come segue: 1100000€ di fondi europei (FESR), 674000€ di fondi nazionali (italiani, greci e maltesi) e 92200€ di fondi propri dei partner.

I partner erano i seguenti:

- CINFAI (Consorzio Interuniversitario Nazionale per la Fisica delle Atmosfere e delle Idrosfere);
- APAT (Agenzia Nazionale per la Protezione dell'Ambiente e i Servizi Tecnici);
- ARPAL (Agenzia Regionale per la Protezione dell'Ambiente Ligure);
- Regione Sardegna (Assessorato dei Trasporti);
- Osservatorio Nazionale di Atene;
- Regione Creta (Dipartimento Informatica e Documentazione);
- Università di Malta – Centro Operativo di Malta.

Sono stato coinvolti anche le seguenti istituzioni ed i seguenti operatori del trasporto marittimo:

- CETENA;
- SAR (Servizio Agrometeorogico Regionale per la Sardegna);
- ARPAS (Agenzia Regionale per la Protezione dell'Ambiente della Sardegna);
- Autorità Marittima Maltese;
- Grandi Navi Veloci;
- *Minoan Lines.*

Il progetto ha valutato il potenziale delle moderne tecniche di navigazione meteorologica (*weather-routing*) nel Mediterraneo.

Il presente libro descrive i risultati del progetto. Ogni capitolo riassume un'azione ed è stato curato da coloro che l'anno condotta.

ΠΕΡΙΛΗΨΗ

Η παρούσα έκδοση περιλαμβάνει τα αποτελέσματα του έργου *WERMED – Weatherrouting dans la Méditerranée*, το οποίο χρηματοδοτήθηκε από το Πρόγραμμα P.I.C. Interreg IIIB – MEDOCC, Άξονα και Μέτρο 3.3 (*Transports Maritimes et Fluviaux*). Η χρηματοδότηση ήταν: 1.100.000 € από Ευρωπαϊκή Επιτροπή (ΕΤΠΑ), 674.000 € από Εθνική (Ιταλία, Ελλάδα, Μάλτα) και 92.200 € Ιδιωτική συμμετοχή των εταίρων.

Οι Εταίροι του έργου ήταν:

- CINFAI (Consorzio Interuniversitario Nazionale per la Fisica delle Atmosfere e delle Idrosfere);
- APAT (Agenzia Nazionale per la Protezione dell'Ambiente e i Servizi Tecnici);
- ARPAL (Agenzia Regionale per la Protezione dell'Ambiente Ligure);
- Region of Sardinia (Transport Authority);
- ΕΘΝΙΚΟ ΑΣΤΕΡΟΣΚΟΠΕΙΟ ΑΘΗΝΩΝ;
- ΠΕΡΙΦΕΡΕΙΑ ΚΡΗΤΗΣ (Κέντρο Τεκμηρίωσης και Πληροφορικής);
- University of Malta – Malta Operational Centre.
-

Λοιπά Ινστιτούτα και Ναυτιλιακές Εταιρίες που χρησιμοποίησαν τα αποτελέσματα του έργου:

- CETENA;
- SAR (Regional Meteorological Service of Sardinia);
- Malta Maritime Authority;
- Grandi Navi Veloci;
- ΜΙΝΩΪΚΕΣ ΓΡΑΜΜΕΣ.

Το έργο εξέτασε τις δυνατότητες της σύγχρονης πρακτικής αναφορικά με τη δρομολόγηση πλοίων, π.χ. ναυσιπλοΐα στη Μεσόγειο βασισμένη σε τεχνικές πρόγνωσης μετεωρολογικών και θαλάσσιων συνθηκών.

Στην παρούσα έκδοση το κάθε κεφάλαιο αντιστοιχεί σε ξεχωριστή δράση του έργου WERMED.

SUMMARY FOR POLICY-MAKERS.

A. Speranza.

From a technical point of view the structure of WERMED is, overall, quite simple: the project is focused on assistance to navigation by means of weather forecast and its post-processing in terms of marine state forecast for the consequent optimization of routes with respect to practical priorities dictated by navigation decision makers. A few key points appear immediately clear here:

- Wind analysis & forecast plays a central role. wWnd is, in fact, the forcing agent influencing directly and indirectly (through waves and currents) the motion of vessels. That the structure of wind field is particularly complex in the Mediterranean area is well known since the time when navigation was born; but it is only in the last few decades that the ability of adequately observing and modelling it has been acquired thanks to the international cooperative work of a couple of generations of scientists in the field.
- The great tradition of international cooperation in Meteorology makes it particularly easy and natural to perform – even on a daily basis - service operations coordinated among groups operating in different nations.
- There is a great potential for improvement of the weather routing services as technical innovation (remote sensing from space, in particular) makes new devices available.

However WERMED is a project of inter-regional cooperation, as well. The basic purpose is, therefore, to contribute to the development of "European Regional Space". In this respect, the above mentioned traditional attitude to international cooperation was instrumental in setting up and/or reinforcing "bounds" among the various regions involved in the project. In this respect the thesis that "universal"[1] knowledge is a powerful tool for cooperation was once more – if needed! – proved.

Future development will:

- bring other nations (regions) into the network of cooperation for routing optimization;
- extend the assistance from open sea to port areas,
- extend the assistance to other (beyond weather) aspects of routing (security, for example).

In so doing other (non-technical) components of civil society shall be involved in this genuinely trans-boundary activity.

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[1] It is worth remembering here that the very concept of "university" stems from "universal"!

I. CURRENT PRACTICES OF WEATHERROUTING.

A. Drago, *list of other contributors.*

Introduction

Ship weather-routing services are becoming more reliable as technological advances in telecommunications, ship tracking and positioning, and the skill of atmospheric and marine forecasts improves. Weatherrouting dans la Méditerranée (WERMED) is an Interreg IIIB MEDOCC project that targets to develop an experimental system for weather-routing in the Mediterranean Sea and analyse its potential in the region.

Weather-routing is a means of optimizing shipping routes on the basis of meteo-marine conditions. Unfavourable conditions at sea often cause considerable delays in marine transportation with increases in operational costs and fuel consumption. The forecasting of wind, sea state and currents permits an anticipated assessment for optimisation of routes to enable the most convenient navigation at lowest costs, minimal risks to the environment and highest safety to crew, passengers and cargo.

The project is led by the Italian agency CINFAI (Consorzio Interuniversitario per la Fisica delle Atmosfere ed Idrosfere) and brings together partners from some of the main MEDOCC countries namely Italy, Spain, France and Malta with clear maritime interests.

One of the WERMED tasks consists in the preparation of a review on weather-routing. The overarching aim of the review is to provide indicators and strategies to be followed by the WERMED project, and more specifically to:

- ⇒ assess the current status of weather routing with particular reference to applications/ services existing in the Mediterranean;
- ⇒ identify the key resources and technologies (eg: modelling/forecasting, remote sensing; communications; software development; etc.) that are necessary for providing weather routing services and identifying bottlenecks/ constraints/ strengths;
- ⇒ identify advances in technology as well as innovative applications that can improve the quality of the service;
- ⇒ provide a perspective on the potential of weather routing in the Mediterranean.

The review was conducted under the leadership of the IOI-Malta Operational Centre (University of Malta) in collaboration with the other WERMED partners and is presented in this document. Contributions from partners were made mainly through a dedicated questionnaire (refer to Annex 1). The services of a Maltese expert, Capt. A. Gambina, were sought to get first hand information and experiences from an operator in the field.

1.0 Weather Routing - Current Practice

Ship weather-routing consists in determining an optimum track for ship voyages on the basis of weather forecasts, sea state and a ship's individual characteristics. It is based on the minimization of a cost function, integrated on time from the departure to the arrival of the ship. Such a function depends on the forecasted weather, sea state and currents along the route and on consumption of fuel and oil. Factors of comfort and safety can be also included especially in the case of cruise liners carrying passengers. The cost function is significantly influenced by effects of the wind and wave fields on the ship's motion. Such an effect is, for example, strongly influenced by the direction and height of waves and by the direction and intensity of the wind. The description of meteo-marine conditions along the route, both from a climatological point of view and as forecasted variables, thus constitute an essential element of ship routing.

Trans-oceanic weather-routing is of benefit where the following criteria are present:

- ⇒ the voyage is relatively long, in excess of 1500 nautical miles, generally trans-oceanic and westbound rather than east and with ship performance curves showing greater fluctuation of performance with head seas.
- ⇒ weather is a major factor in determining the track to be followed or the operation in question (e.g. rig move);
- ⇒ waters are navigationally unrestricted thus offering a choice of routes;
- ⇒ a region or season exhibit extremes of weather in fluctuating patterns (these occur notably in the latitudes of the baroclinic zone in winter).

There are two general types of commercial ship routing services which in broad terms differ in the way they are executed either via advice from a shore-based organization or on board of the own vessel. In both cases the optimum route is not only based on weather data but also on ship specific information such as type of vessel, nature of cargo, etc. The first uses techniques to forecast conditions and compute routing recommendations which are subsequently transmitted in concise form to the ship. The second assembles and processes weather and sea conditions data and transmits this to ship for on-board processing and direct routing advice. Weather-routing companies are able to transfer digitised data directly to the vessel. This data is converted via dedicated software into weather and route information.

The former system allows for more sophisticated and elaborated processing through the use of a more powerful computing backbone available on shore. The shore-based weather router has access to data that is not normally available on board, such as information from the European Centre for Medium-Range Weather Forecasts and National Oceanic and Atmospheric Administration (NOAA).

Examples of marine weather forecasts in the Mediterranean are those issued by the various weather bureaus:

- ⇒ Centro Nazionale Di Meteorologia E Climatologia Aeronautica (CNMCA) - Meteomar
- ⇒ Meteo France - Météo Marine.
- ⇒ Turkish State Meteorological Service – Marine Forecast Report

Information on board a vessel is conventionally received by the ship using text and facsimile reception. The use of high speed data transfer has facilitated a marked improvement in the quality of weather information received, and the dedicated weather facsimile receiver and the manual plotting of weather systems on to weather charts are fast becoming a thing of the past.

On the other hand the latter system allows more flexibility in the hands of the ship's master. Faster data flows through new telecommunication media, and greater access to computing power has led to hybrid services with a shift towards increased on-board intervention in changing parameters, selecting routes and displaying data.

In common with any forecasting organisation, the relevant weather data utilised includes:

⇒ Synoptic surface analysis;
⇒ Surface prognosis (12, 18, 24, 24, 36, 72 hours);
⇒ Upper air charts;
⇒ Distribution of ice and icebergs;
⇒ Wave height;
⇒ Swell height and direction;
⇒ Nephanalysis

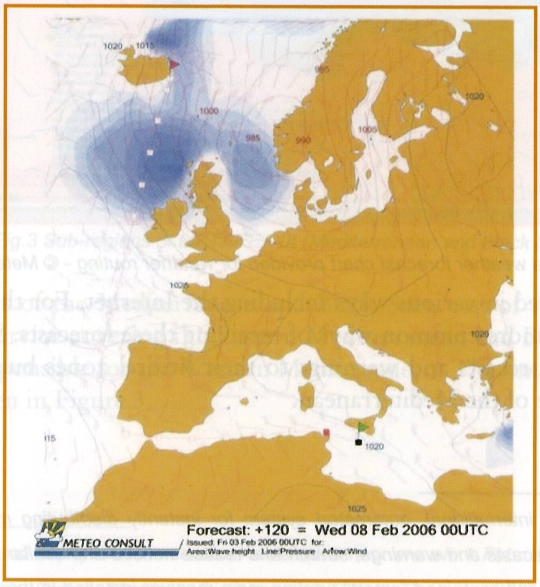


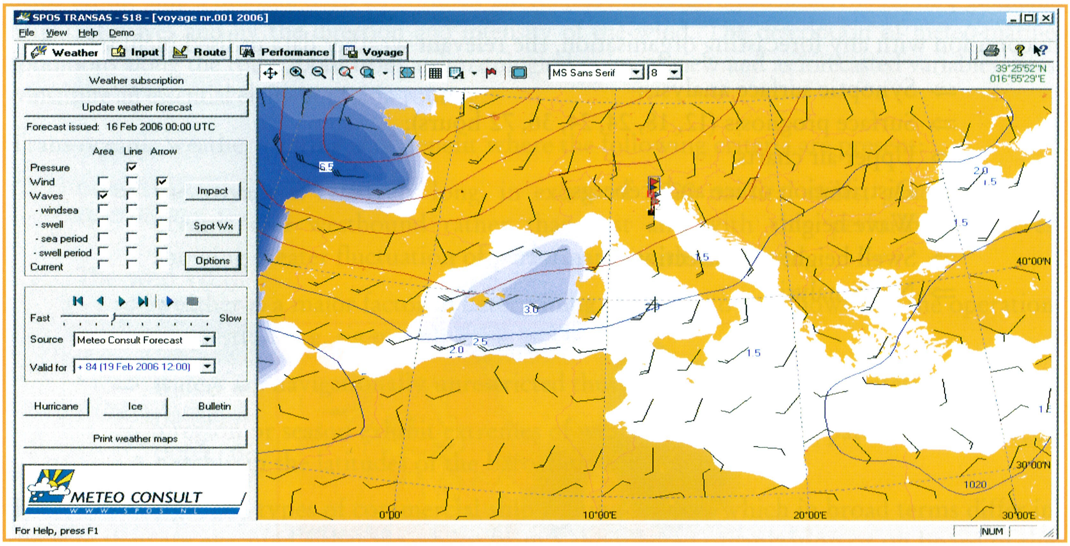
Fig.1 Typical chart for a weather routing service including the Mediterranean © Meteo Consult

However the mariner is really more interested in the graphical representation of point information or 2D fields for wind speed and direction and of sea wave and swell height. The ship's position and route can then be overlaid on the area displayed. The relevant weather data is usually updated every six hours and transferred as a file on demand to be downloaded to a dedicated weather-routing PC. The results are then either viewed on the PC screen or printed out.

Fig.1 is the printed output from a typical weather-routing system in the case of a vessel planning her route from Malta to Iceland.

The software is designed to allow the user on board a vessel to project the vessel's position ahead in 12 hour steps for five days in time and plan the vessel's route accordingly. Fig. 4 is a snapshot showing the screen from a PC installed with SPOS software from the Dutch company Meteo Consult. As can be seen, the features that are available are numerous depending on the level of subscription by the customer.

The Danish company DMI provides a similar service through the WISE PC programme intended for shipboard installation. The Master may request graphic weather forecasts for any part of the world at any time. If the vessel is on a weather-routing contract the routing advice is automatically forwarded to the system in graphics.



39°25'52"N
016°55'29"E

Forecast issued: 16 Feb 2006 00:00 UTC

	Area	Line	Arrow
Pressure		☑	
Wind	☐	☐	☑
Waves	☑	☐	☐
- windsea	☐	☐	☐
- swell	☐	☐	☐
- sea period	☐	☐	☐
- swell period	☐	☐	☐
Current	☐	☐	☐

Source: Meteo Consult Forecast

Valid for: + 84 (19 Feb 2006 12:00)

Fig.2 Sample weather forecast chart provided for weather routing - © Meteo Consult

Forecasts are disseminated in various ways including the Internet. For the mariner, VHF radio and NAVTEX[2] are the more common ways of receiving these forecasts. Some countries do not confine their weather forecasts and warnings to their littoral zones but also include offshore areas or cover the whole of the Mediterranean.

---

[2] [1]*NAVTEX is an international, automated system for instantly distributing maritime navigational warnings, weather forecasts and warnings, search and rescue notices and similar information to ships. A small, low-cost and self-contained "smart" printing radio receiver installed in the pilot house of a ship or boat checks each incoming message to see if it has been received during an earlier transmission, or if it is of a category of no interest to the ship's master. If it is a new and wanted message, it is printed on a roll of adding-machine size paper; if not, the message is ignored. A new ship coming into the area will receive many previously-broadcast messages for the first time; ships already in the area which had already received the message won't receive it again. No person needs to be present during a broadcast to receive vital information.*

In addition to the above, it is also possible to receive weather forecasts as part of the GMDSS[3] system. For broadcast purposes (in GMDSS) the world's oceans are divided into 16 METAREAS each the responsibility of a National Meteorological Service (NMS), named an Issuing Service. Other NMS may provide some information, as Preparation Services.

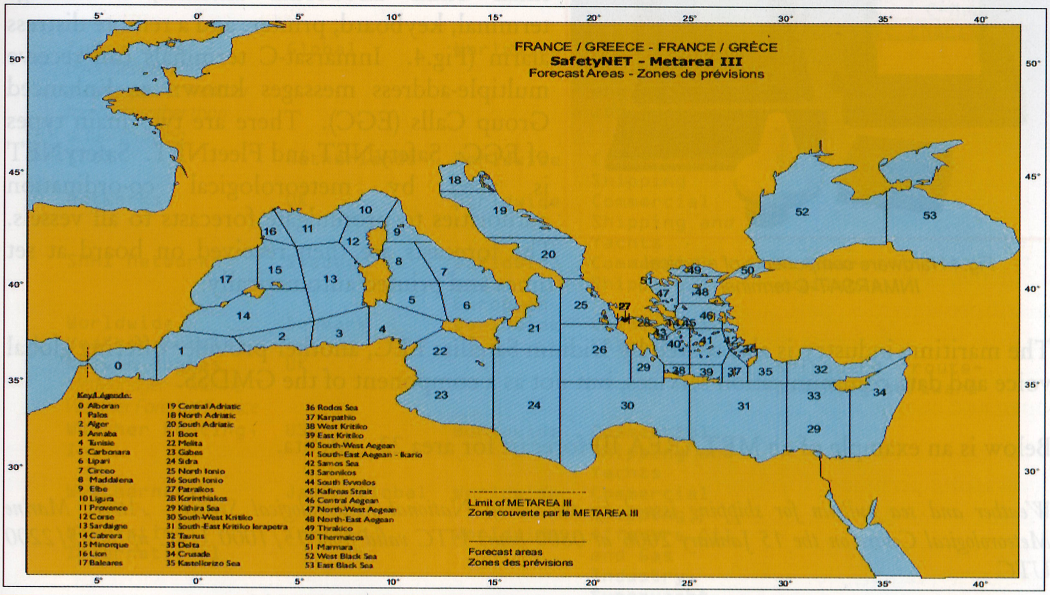


Fig.3 Sub-regions of METAREA III (Mediterranean and Black Seas)

METAREA III consists of the Mediterranean and Black Seas, east of the Straits of Gibraltar. Greece is the Issuing Service covering the Eastern Mediterranean and Black Sea. France is the Preparation Service responsible for the Western Mediterranean. The limits and forecast areas of METAREA III are given in Figure 3.

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[3] [2]Ship distress and safety communications entered a new era on 1 February 1999 with the full implementation of the Global Maritime Distress and Safety System (GMDSS) - an integrated communications system using satellite and terrestrial radio-communications to ensure that no matter where a ship is in distress, aid can be dispatched. In addition to distress and alerting requirements, the system also ensures the provision of Maritime Safety Information (MSI), both meteorological and navigational, on a global basis at sea. GMDSS consists of several systems, some of which are new, but many of which have been in operation for many years. The system is intended to perform the following functions: alerting (including position determination of the unit in distress), search and rescue coordination, locating (homing), maritime safety information broadcasts, general communications, and bridge-to-bridge communications. Specific radio carriage requirements depend upon the ship's area of operation. Under the GMDSS requirements, all ships are required to be equipped with Inmarsat and/or NAVTEX receivers, to automatically receive MSI

Forecasts are available on the Internet, but are received on board vessels either via NAVTEX or alternatively through INMARSAT[4] receiving equipment. Most vessels are equipped with INMARSAT-C system equipment.

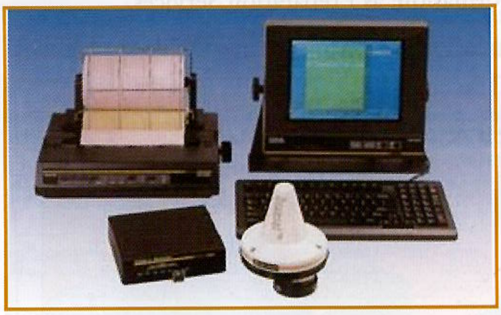

Fig.4 Hardware components of a typical INMARSAT-C terminal

A typical INMARSAT-C terminal includes a small omni directional antenna, a message terminal, keyboard, printer, and a remote distress alarm (Fig.4. Inmarsat-C terminals can receive multiple-address messages known as Enhanced Group Calls (EGC). There are two main types of EGC: SafetyNET and FleetNET. SafetyNET is used by meteorological co-ordination authorities to promulgate forecasts to all vessels. The forecasts are then received on board at set times and printed automatically.

The maritime industry is also served by Iridium Satellite LLC, another provider offering global voice and data communication services, but not as a component of the GMDSS.

Below is an example of an METAREA III forecast for area 22 – Melita.

Weather and sea bulletin for shipping issued by the Greek National Meteorological Service - Athens Marine Meteorological Centre on the 15 January 2006 at 0800 hours UTC valid from 15/1000 UTC up to 15/2200 UTC.

CYCLONIC 5 TO 6. MODERATE LOCALLY POOR. THUNDERSTORM

Weather Routing services are provided on a commercial basis by a number of companies. In the Admiralty List of Radio Signals, Volume 3 (1) a weather routing section lists organisations providing such a service. Other sources of information are the Internet and the maritime industry publications such as Safety at Sea International, Fairplay and Lloyd's List. Table 1 is a summary that includes information that originates from the service providers themselves.

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[4] *Satellite systems operated by Inmarsat, under contract to the International Maritime Satellite Organization (IMSO), are important elements of the GMDSS. Four types of Inmarsat ship earth station terminals are recognized by the GMDSS: the Inmarsat A, B, C and F77. The Inmarsat B and F77, an updated version of the A, provide ship/shore, ship/ship and shore/ship telephone, telex and high-speed data services, including a distress priority telephone and telex service to and from rescue coordination centers. Inmarsat C provides ship/shore, shore/ship and ship/ship store-and-forward data and email messaging, the capability for sending preformatted distress messages to a rescue coordination center, and the Inmarsat C SafetyNET service. The Inmarsat C SafetyNET service is a satellite-based worldwide maritime safety information broadcast service of high seas weather warnings, NAVAREA navigational warnings, radionavigation warnings, ice reports and warnings generated by the USCG-conducted International Ice Patrol, and other similar information not provided by NAVTEX. SafetyNET works similarly to NAVTEX in areas outside NAVTEX coverage.*

Organisation	**Country**	**Areas Covered**	**Sectors Targeted**	**Dedicated Software/Equipment**
Applied Weather Technology	USA	Worldwide	Commercial Shipping	Software
C-Star	Norway	Worldwide	Commercial Shipping	Data compatibility with C-Map electronic charts
Fugro Geos *(Provides area and project specific weather forecasts rather than actual routeing*	Global	Worldwide	Offshore and coastal engineering applications	
SPOS	Netherlands	Worldwide	Commercial Shipping	Software
MetWorks	UK	Worldwide	Commercial Shipping and Yachts	
SMHI MetWorks	Sweden	Worldwide and European	Commercial Shipping	Software available.
Worldwide Weatherrouteing	Denmark	Worldwide	Commercial Shipping	
Kelvin Hughes *MetManager – Marine Weather Forecast Service*	UK			Shipboard route-planning software
Weather Routing, Inc.	USA	Worldwide	Commercial Shipping and Yachts	
Weathernews	Japan/Global	Worldwide	Commercial Shipping	
Nowcasting International	Ireland	Worldwide	Offshore Oil and Gas Industry, Superyacht, Recreation	
Wilkens Weather Technologies	USA	Worldwide	Offshore Oil and Gas	Web based forecasts
Oceanweather	USA	Worldwide	Commercial Shipping	VOSS - Vessel Optimization & Safety System
Argoss	Netherlands	Worldwide	Commercial Shipping	Web based route planning
Marincom	Canada	Worldwide	Commercial Shipping - Charterparty performance	

Table.1 Main weather routing services available with global coverage

With conventional weather-routing, high resolution weather data from a number of sources such as ECWMF (European Centre for Medium-Range Weather Forecasts) as well as ship specific parameters (performance curves, nature of cargo etc.) are used. The staff in a weather routing company is usually composed of meteorologists or ship's Masters who are knowledgeable and familiar with ships, seafarers and the seas. The vessel's route is monitored and the information is sent to the recipient in text format by email or telex. Typically, the service consists of advice as to when to sail and which route to take, a description of the main weather systems that are expected to affect the route and then a day by day forecast giving wind direction and strength, significant weather and visibility, significant sea height and swell direction and height.

Weather-routing can also be carried out on board the vessel by her own staff using data such as that from NOAA, which is freely available. In both scenarios the objectives of weather Routing are:

⇒ To minimise storm damage to ships and cargo;

⇒ To save time at sea, thereby saving money by reducing operating time;

⇒ To attain punctuality, essential for tidal terminals or to meet schedules;

⇒ Maintain conditions set by voyage constraints.

2.0 Use of Technology

Extended range forecasting and the development of selective climatologies, along with powerful computer modeling techniques and fast communications systems constitute the basis of ship routing systems. As technological developments in position fixing, communication systems, space-based observations, meteo-marine forecasting, integration of automated instruments, and intelligence management and monitoring systems are becoming more widely available, new applications are emerging to support the management and monitoring of maritime activities, particularly to improve safety at sea, in surveillance operations, assessments and in the enforcement of maritime laws and regulations. These applications include ship routing envisaged in its broader term to include a service to marine transportation in both the open and coastal seas.

The advent of powerful computing power has resulted in a quantum leap in weather forecasting accuracy. Organisations such as the European Centre for Medium-Range Weather Forecast, the Meteorological Office in the UK, JMA in Japan, the US National Centre for Environmental Prediction (NCEP) and the US Navy's Fleet Numerical Oceanographic Centre (FNMOC) routinely publish high-skill numerical global weather forecasts. Most of these services include sea state conditions such as information on wave height and direction. Some of these products are available on the public domain mainly through internet or broadcasting via marine weather fax to ships at sea. Long-range forecasts are available to show the general trend of storm tracks, and accuracy has improved to the limits of predictability.

The type of service offered to mariners depends in great part on the communication means and data flow capacity that can be handled. The technique used is to convert weather data encryption into ECDIS. ECDIS (Electronic Chart Display and Information System) integrates position data, normally from GPS (Global Positioning System) or DGPS (Differential GPS), with the inputs of other shipboard sensors on an electronic navigation chart (ENC). Inputs can be received from a variety of sensors, the most common of which are radar, displaying either or both overlay and ARPA (Automatic Radar Plotting Aids) targets, gyro, log speed, anemometer, and GPS derived course and speed over the ground.

ECDIS may also incorporate information or data elements that are available to the mariner on an 'as required' basis. These can include tide tables, light lists, port information, and weather data; i.e. prevailing wind and sea height information, and current data.

Future developments may include the inclusion of weather routing tools as part of the system. On the other hand, the implementation and uptake of ECDIS has not occurred as expected, the main factor being the lack of world-wide ENC coverage and its availability. We can thus expect that weather-routing software developed by organisations providing the service to be with us for some time yet.

The contribution of remote-sensed data to ship routing has also important implications. Active microwave sensors onboard satellite platforms to measure wind and wave height, period and direction (such as the advanced versions of ESA/ENVISAT ERS SAR (Synthetic Aperture Radar) and radar altimeter sensors, ASCAT on the EUMETSAT platform METOP, and NSCAT on the Japanese ADEOS platform) offer clear advantages for the study of marine winds and sea state. Firstly, they allow homogeneous, global and continuous coverage, at an improved resolution over conventional observations from ships and buoys. Due to frequent revisits, global wind fields from the scatterometer are likely to detect 3-4 of approximately 10 major cyclonic depressions which are over the Earth's surface at any one time, hence improving atmospheric forecasts and resultant wave fields. Wave height observations, and measures of the period of swells generated by a far-off storm can be used to improve wave forecasts - as the future sea state is dependent on accurate knowledge of the current situation. http://earth.esa.int/applications/data_util/hrisk/ssf/oliver.jpgSecondly, these data are of known quality and reliability, and are thoroughly validated before use. The assimilation of scatterometer data enables meteorological forecasts to give improved realizations of cyclonic features.

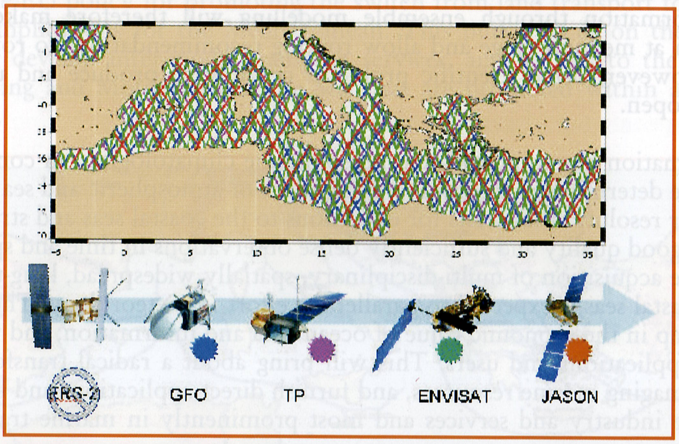

Fig.5 Ground tracks over the Mediterranean for altimetersfrom two operational missions JASON-1 (CNES/NASA) and ENVISAT (CNES/ESA) and two "best effort" missions TOPEX/POSEIDON interlaced (CNES/NASA) and Geosat Follow On (NOAA).

The efficiency of the assimilation of these data is improving and is enabling downscaling of forecast fields to higher resolution extending the forecasts from the open ocean to the coastal regions without the limitations of regional models. All these factors allow more accurate metocean and sea state forecasts to be produced, with a true representation of wind and wave fields by combining in situ and satellite sources.

Sea currents do not present a significant routing problem, but they can be a determining factor in route selection and diversion. Optimal ship routes are planned to avoid areas where currents will work against the ships progress. This is particularly important in areas where currents exceed a knot and in the crossing of straits. Commercial ship routing systems do incorporate some surface current data, and shipmasters do try to sway their routes to their best estimates of the locations of favourable currents. Direction and speed of sea currents are more predictable than wind and seas, but some variability can be expected. Satellites can also provide altimeter data that can be used for data assimilation on circulation models, as well as to provide geostrophic currents which constitute the non-tidal and non-wind component of currents. A better knowledge of actual surface currents in real-time could induce additional savings in the duration of the voyage and/or the fuel consumption.

Another important aspect concerns advances in naval architecture and hydrodynamics that allow an accurate prediction of ship responses to waves. Computer simulations of vessel motion and wave loads can be validated by model tests in towing tanks as well as full-scale hull monitoring systems. Coupled with accurate wind and wave forecasts, it is possible even by using personal computers to make accurate predictions of both voluntary and involuntary speed reduction for specific hull forms and loading conditions.

Advances in sensors technology and greater reliability on their performances furthermore permit ship's crew to obtain real-time information on motions and stresses experienced by the hull as well as in situ observations of the actual sea state, even in conditions with lack of visibility.

One of the areas in which the WERMED project will contribute is in the exploitation of probabilistic forecasts. Deterministic weater-routing such as that provided by current services (eg. Danish and Swedish) give precise information on the trip but lack precision after a few days due to the limit of predictability of deterministic forecasts. The exploitation of probabilistic information through ensemble modelling will therefore make it possible to increase precision at medium-range and allow routing recommendations to routes over longer time periods. However, some scientific problems on how to produce and use probabilistic forecasts are still open.

The use of information based on updated meteo-marine climatologies can compensate for the uncertainty in the deterministic medium-term forecasts of atmospheric and sea conditions. The reliance on higher resolution forecasts for extensions to the coastal seas and straits, will further need merging of good quality and sufficiently dense observations in time and space. In the near future the routine acquisition of multi-disciplinary, spatially widespread, long-term data sets of the ocean and coastal seas is expected to parallel the effort in meteorology. This will trigger an unprecedented leap in the economic value of ocean data and information, and will additionally target multiple applications and users. This will bring about a radical transformation in our perception of managing marine resources, and furnish direct applications and benefits to many sectors in marine industry and services and most prominently in marine transportation and ancillary activities.

3.0 Prospects for the Mediterranean Sea

The Mediterranean Sea does not lend itself easily to the concept of weather-routing as we know it in its traditional form for applications in trans-oceanic crossings. The limited extent and the semi-enclosed nature of the sea as well as relatively mild and climatic conditions in the Mediterranean Sea render the demand for weather routing in the region much less than that in other open oceans. Nonetheless, feedback from weather-routing organisations revealed that their services are nevertheless utilised in the Mediterranean Sea. Users of such services are mainly in the oil and gas industry such as pipe laying vessels as well as superyachts in the leisure sector. It was also stated in one of the replies that their clients included ferry and container companies operating in the region.

It would thus seem that, in the interest of greater efficiency in shipping, there are some of the criteria present in order to make weather-routing in the region viable, i.e. to save time at sea, avoid heavy weather and maintain schedules. As a minimum requirement, there would need to be a choice of routes that a vessel may follow. Since weather-routing is ship-specific, it would be ideal if a single particular ship-type (together with its corresponding performance curves) is chosen for a prototype system. Given that distances in the Mediterranean Sea are relatively small, vessels engaged on short-sea routes, such as ropax (ro-ro/passenger) or container feeder vessels would fit the criteria mentioned above.

The potential for weather-routing services in the Mediterranean must also be viewed within the context of current developments and trends within Europe. Maritime transport is indeed one of the key areas addressed by the EU Green Paper on Maritime Policy. The Green Paper sets the foundations to build a vision for Europe with a dynamic maritime economy in harmony with the marine environment and supported by excellence in the marine sciences. As the Green Paper puts it, "the EU is the leading maritime power in the world in particular with regard to shipping, shipbuilding technology, coastal tourism, offshore energy, including renewables, and ancillary services", and in the context of a competitive maritime industry......"shipping and ports are essential for international trade and commerce.....and maritime transport is a catalyst for other sectors."

More specifically for the Mediterranean, the geographical circumstances and the ever-increasing amounts of trade volumes crossing this sea, the dependence of a competitive and sustainable maritime industry on improved shipping and ports services is even more eloquent. This calls for better access and to improved connections both within and with the Mediterranean basin.

Furthermore, the EU policy for promoting the switch from land transport to water transport has important implications for the Mediterranean. This puts a focus on the need to extend ports to further develop inter-modal transport services, and has led to the development of Short Sea Shipping and Motorways of the Sea[5] that are promoted within an integrated EU transport policy.

Fig.6 Motorways of the Sea in the Mediterranean.

The corridors identified in the Motorways of the Sea project are useful to determine which routes would benefit the most from weather-routing, including the Mediterranean. The availability of weather-routing for vessels sailing on these routes concurs with the following statement: "Motorways of the Sea need to feature the best available quality throughout the chain in order to be attractive for users."

In such an evolving scenario the demand for weather-routing services is widening in its scope and scale, and is expected to become more wide-ranging, reaching closer to the coast and addressing the needs of short shipping activities and operations in the coastal sea areas. Traditionally weather-routing has targeted trans-oceanic shipping, and services have focused to

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[5] Motorways of the sea are key sea routes between EU Member States, offering regular, high-quality services that, combined with other transport modes, provide an efficient alternative to road-only transport. Through the trans-European transport networks (TEN-T), the EU is now supporting the development of motorways of the sea in four key corridors around our coasts: the Baltic Sea, western Europe (Atlantic Ocean – North Sea/Irish Sea), south-western Europe (western Mediterranean Sea), and south-eastern Europe (Adriatic, Ionian and eastern Mediterranean Seas).

deal with customer needs on this scale. Emerging needs are giving weather-routing services a new dimension; while retaining the open sea element, it also targets the coastal seas. The challenge for weather-routing is to diversify and integrate services to provide a tool and aid for the integrated management and optimal use of marine space including the coastal seas, especially the port areas, and to combine with needs for improved safety at sea and marine operations. The tendency to diversify land transportation of cargo and people with opportune marine highways and taxis, including intercity connections, is opening new opportunities for weather-routing that will demand excellence in state-of-the-art technology to downscale to the details at the resolution required by new applications.

Main Conclusions

1. Even though the Mediterranean Sea is relatively small compared to oceanic scales, its complex geographical configuration, large number of islands, presence of straits along key shipping routes, and the large volume of cargo, goods and passengers that go across it, offer specific conditions that render a high potential for dedicated ship and weather-routing services in the basin. Such services need to be customized to address the specific needs of the region, especially for what concerns applications that include the coastal seas.

2. Numerical modeling advances in meteorology and oceanography, supported by the continued application of more powerful computers, coupled to ensemble modeling and probabilistic forecasting, and higher skill to downscale forecasts to coastal scales with higher spatial resolution, will extend the time range, accuracy and spatial detail of the dynamic and statistical forecasts. This will improve and diversify the weather-routing services.

3. Increased flows of data deriving from satellite platforms, merged to in situ observations from routine and real time acquisition networks will offer greater skill, longer range predictability and higher resolution capabilities to forecasts. Integrated to data from ship-borne sensors, this will offer ship masters a more flexible and reliable handle on adjusting course and speed for actual conditions.

4. Progress in satellite and telecommunications technology, and more sophisticated onboard ship response systems will afford to handle larger flow and more diverse kinds of information to and from the ship with reduced delays. Two-way exchanges between the ship and the routing agency makes possible routing analysis to taking into account the actual ship's response, performance and overall state, and to proceed in real time, resulting in largely improved and effective routing procedures.

5. While current technologies are not perfect and refinements are needed to make use of available and new technologies, it is possible to utilize the advances in weather forecasting, satellite communications and computer technology to enhance the safety and efficiency of ship operations. The challenge lies in the effective integration of all these technologies and disciplines to provide a more reliable aid to ship masters in making better decisions.

II. WIND CLIMATOLOGY OF THE MEDITERRANEAN BASIN.

M. Burlando, L. Villa, K. Lagouvardos, A. Drago, S. Music and J. Azzopardi.

Meteorological and sea conditions have been affecting navigation since the very beginning of maritime sailing. In the past their effects were mainly felt upon the propulsion of the ship, the ability of governing the ship, and the security of navigation. Constant advancements of naval engineering have steadily reduced the effects of meteorological and marine conditions, however the resistance posed by swell or wind can still slow down or even stop ships of any size and all types of vessels are exposed to the risk of shipwreck in hazardous conditions.

The practice of defining an optimal route depending on atmosphere and sea state is called weather routing, i.e. ship routing by weather conditions. This practice focuses mainly on estimating the resistance posed by waves and wind against the motion of a specific vessel along its route. If particularly adverse meteorological and sea conditions are forecast, weather routing can define alternative routes also very different from the shortest one. However the latter would let vessels consume less fuel or would reduce their time of navigation.

In this context, WERMED (Weather routing dans la Méditerranée Occidentale) project has targeted to analyse the potential of modern weather routing techniques applied to navigation in the Mediterranean Basin. One of the purposes of the WERMED project is the estimation of risk scenarios for maritime transportation, by calculating the climatology of some meteorological and oceanographic quantities all over the Mediterranean. Within this framework, Action 2.1 has specifically studied, among the relevant meteorological quantities, the climatology of the surface wind. This activity has been carried out by a partnership of Italians, Greeks and Maltese (WERMED Action 2.1. Report, 2006).

It is worth noting that the information issued through this action goes far beyond its application in the framework of the WERMED Project. It might be either used in various ways and many different applications in ship design and operational planning, as well as in offshore and coastal engineering. We could mention, for example, the definition of margins of operationally acceptable environmental conditions along specific routes for existing ships, single ships or fleets, using the information of the surface wind climatology to assess probabilities in order to calculate operability indices, optimize the overall efficiency of ships, reorganise the geographical distribution of a fleet. The same information might be used to perform operational planning of offshore activities, both naval and civil, like defining the best seasonal window for hauling up, dredging, and construction. Finally, for assessing the operability of an activity or design in a specific sea environment it is recommended to study the efficiency of that activity or design in various sea states corresponding to average and extreme conditions, also provided by the present analysis.

Methodology

The climatology of the surface wind fields all over the Mediterranean Basin has been studied by means of statistical and numerical methods. In particular, all the analyses have been performed bearing in mind that one of the aims of the WERMED project is the estimation of the risk scenarios for maritime transportation due to some meteorological and oceanographic quantities, i.e. the surface wind speed and wave height and direction, evaluated on a climatological basis. Following this consideration, two types of statistical analyses have been performed:

1. The analysis of time-series of wind speed and direction from gridded data, both simulations and observations, to obtain a full characterisation of the single-point probabilistic distribution of the surface wind fields;

2. The cluster analysis of cross-correlated wind flow fields in order to identify the main wind climate regimes of the basin.

Two different spatial scales have been considered in the probabilistic analysis, as shown in Figure 1: a larger domain (left) comprehensive of the whole Mediterranean Basin, and a smaller domain (right) centred over the Strait of Sicily.

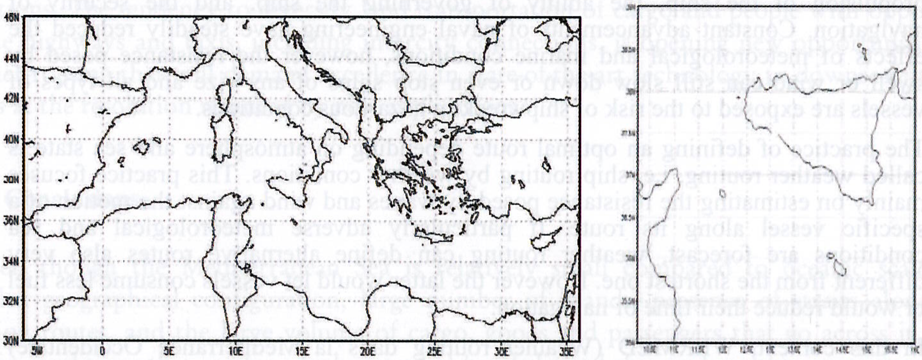

Figure 1: The domains corresponding to the spatial scales chosen for the statistical analysis: the whole Mediterranean Basin (left); the Central Mediterranean (right).

Probabilistic analysis of surface wind fields

The probabilistic analysis of surface wind fields sets out to describe the statistics of the wind blowing all over the Mediterranean Sea through the calculation of the first two raw moments of the single-point probability density functions, i.e. mean and variance, as well as minimum, maximum, and a few percentiles of the distribution functions, namely the 99th 90th 75th 50th and 25th percentile. From these results, a general outlook of those sub-basins of the Mediterranean, which are the most likely to present severe wind conditions or extreme anemological events, has been provided.

The analysis has been also performed on a monthly and seasonal basis, in order to achieve a deeper understanding of the different wind conditions as a function of the period of the year. Moreover, for July and August the analysis has been also performed by distinguishing night and day, in order to identify and quantify the effects of land and sea breeze regimes.

Finally, the joint frequency distribution of wind speed and direction has been calculated and represented by means of wind roses for 13 selected points covering the main sub-basins of the Mediterranean, listed in Table I.

Localisation	Longitude (°)	Latitude (°)	Localisation	Longitude (°)	Latitude (°)
Alboran Sea	-3.54	35.94	Adriatic Sea	15.84	42.78
Algerian Basin	3.08	37.92	Central Mediterranean	17.56	37.92
Strait of Sardinia	6.02	40.08	Ionian Sea	18.54	34.68
Channel of Sardinia	9.21	37.92	Aegean Sea	26.88	35.58
Ligurian Sea	9.21	43.68	Levantine Basin	30.07	33.96
Tyrrhenian Sea	12.16	40.08	Gulf of Lyon	4.06	42.42
Strait of Sicily	12.89	35.94			

Table I: the 13 points selected over the Mediterranean Basin where the joint frequency distribution of wind speed and direction has been calculated.

Cluster analysis of surface wind fields

The cluster analysis of surface wind fields has been used to identify, through an objective criterion of classification of wind patterns, the main wind climate regimes typical of the Mediterranean basin.

A great number of examples concern the use of cluster analysis to identify climate regimes by grouping recurrent time-series of contemporary meteorological observations or gridded data (e.g. Kalkstein et al. 1987; Davis and Walker 1992; Eder et al. 1994). More recently, cluster analysis has been used for the identification of sets of forecasts in ensemble prediction systems (see for example Stephenson and Doblas-Reyes 2000) and also to study climate dynamics (Smith et al. 1999; Cassou et al. 2004; Straus and Molteni 2004).

There also exists a branch of cluster analysis specifically developed for the classification of wind climate regimes. Weber and Kaufmann, in 1995, proposed an automated classification scheme for wind fields based on a hierarchical cluster analysis, and they tested this methodology to classify 744 different surface wind fields. In 1996, Kaufmann and Weber extended their automated classification to longer datasets, i.e. 8784 wind fields, introducing a further refinement of the clustering procedure through a two-stage classification: the hierarchical cluster analysis for detection and exclusion of outliers, which provides a first-guess classification into groups; the centroids of the first-guess clusters become initial seeds for the k-means partitional method. This automated wind field classification was applied again by Kastendeuch and Kaufmann in 1997, who improved the procedure to estimate the matrix of transition probabilities between wind fields, and by Kaufmann and Whitemann in 1999 for classification of wintertime wind patterns in the Grand Canyon Region.

In the present study, the two-stage clustering technique recently proposed by Burlando et al. (2007) has been applied to surface synoptic-scale wind fields. This procedure is mainly based on the two-stage clustering suggested by Kaufmann and Weber (1996), with some differences and refinements concerning, in particular, the aggregation method of the hierarchical clustering.

Data

There exist at least three main sources of marine wind data available to the user:

- direct measurements from buoys and platforms or observations from ships;
- indirect measurements by remote sensing instruments on board of high-altitude flying satellites or radar;
- numerical models operational at the various meteo-oceanographic centres.

These datasets have different characteristics in terms of quality, accuracy, errors, geographical distributions, number of data. In Action 2.1 of WERMED Project, buoys or platforms data have not been used directly, whereas most of the analyses have been performed on satellite data and numerical models output. In addition, the re-analyses over the Mediterranean Sea have been also used.

In particular, the wind climatology of the larger domain, i.e. the whole Mediterranean Sea, has been evaluated by means of the wind fields simulated by the meteorological model BOLAM. The reliability of these data has been verified through the comparison against observed wind fields from the satellite QuikSCAT, which belongs to the National Aeronautic and Space Administration (NASA). QuikSCAT data was chosen because the nature of these measurements makes them appropriate for a direct comparison with data obtained from mesoscale meteorological models, as both can be considered spatially-averaged values. Note that a direct calculation of the surface wind climatology from QuikSCAT data could not be performed because of their lack of spatial and temporal homogeneity.

The climatology of the smaller domain, corresponding to the Central Mediterranean, has been calculated by means of the HIPOCAS database, which consists of high-resolution, both in space and time, re-analyses. Finally, the cluster analysis, performed only over the larger domain, has been based on the ERA-40 re-analysis of the European Centre for Medium-range Weather Forecast (ECMWF).

In the following sections we report a short description of these data and of their use for the present application, focusing in particular on the limitations associated to each different source.

Satellite data

There are two main kinds of instruments on board of satellites used to measure the surface wind on the sea: altimeter and scatterometer.

Altimeters measure wind speed and wave height along the nadir ground track of the satellite. Typically data are provided at 7 km interval, however, the orbits followed by the satellites pass on the ground rather far from each other, so that large areas are often completely uncovered, or with too few data to derive a reliable statistics.

On the contrary, scatterometers measure wind speed and direction at the sea surface on a wide swath, typically 500 km, on one or both sides of its ground track. The data are provided at 25 or 50 km of resolution, depending on the instrument, and are representative of the average conditions in the corresponding area.

Both these instruments are accurate enough, particularly after correcting them for some bias, estimated through devoted sea campaigns and local measurements (buoys and platforms). However, some uncertainty exists in inner seas, as the Mediterranean Sea, because the calibration campaigns have been carried out mainly in the ocean. Moreover, scatterometer data are extremely sensitive to the environmental conditions, e.g. rain, which limits their operability in stormy areas.

QuikSCAT Level 3 data set

The QuikSCAT Level 3 data set consists of gridded values of the surface wind vector, represented through its meridional and zonal components. A rain probability index, determined using the Multidimensional Histogram (MUDH) Rain Flagging technique, is also included as an indicator of those wind values that may have degraded accuracy due to the presence of drops in the atmosphere echoing the instrument signal. Data are currently available from 19 July 1999 to present. The Level 3 data are given on a global grid of 1440 pixels in longitude by 720 pixels in latitude, corresponding to a 0.25° rectangular global map grid. The system measures winds between 3 and 30 m/s with an accuracy better than 2 m/s or 10% in speed, and 20° in direction (Ebuchi et al. 2002).

Meteorological model data

There are basically two kinds of available meteorological models suitable for wind simulation over the sea: general circulation models (GCMs), and limited area models (LAMs).

General circulation models are numerical codes that represent the atmosphere and its phenomena over the entire Earth using the equations of motion, and including radiation, photochemistry, and the transfer of heat, water vapor, and momentum. GCMs depict the atmosphere using a three-dimensional grid over the globe: for instance, the present version of GCM that runs operationally at the ECMWF to produce 10-day forecasts, has an average distance between grid points close to 25 km and 91 levels between the Earth's surface and 80 km.

Many different institutions run general circulation models, producing daily forecast and analysis worldwide. However, this resolution is still quite coarse relative to the scale typical of many physical processes, such as those related to clouds or other meteorological fields over inner basins, like the Mediterranean Sea, which occur at smaller scales and cannot be properly modelled. Instead, parameterisation schemes are necessary in order to describe the impact of subgrid-scale mechanisms on the large-scale flow of the atmosphere. This is one source of uncertainty in GCM-based simulations.

For this reason, some national meteorological centres, which have a particular interest in the Mediterranean Basin and/or in the surrounding areas, run locally their own meteorological models, forced by initial and boundary conditions from a general circulation model, in order to provide higher resolution forecasts. In this case, a so-called limited area model is usually used, which takes into account much more detailed information about the physics of the atmosphere as well as the geometry of the simulation domain. The output of a LAM is usually valid from several hours up to two or three days and within a limited spatial domain described through computational grids with horizontal resolution ranging between few tens of km up to a few km in the non-hydrostatic version of these codes.

In general, each kind of model has intrinsic errors that must be taken into account when using the data. The errors are mainly associated to the equations used to describe the atmosphere and their methods of resolution, as well as to the data that have been used to initialise the simulation.

As far as the surface wind fields directly produced by the model are concerned, there exist many different sources of error. The model outputs above the sea surface are not reliable at very low wind speeds because sub-grid processes dominate the wind dynamics, e.g. during prevailing land-sea breezes. In the coastal areas, however, surface winds are unreliable in all the conditions because of the dominant influence of topography, not properly represented in meteorological models. Offshore, surface winds are much more underestimated on average than off the coast. This problem is not yet completely understood, but dominant roles are likely to be played also by the modelling of the marine boundary layer (see Cavaleri and Bertotti, 1997; Cavaleri et al., 1997; Cavaleri and Bertotti, 2003). There is also the tendency to underestimate the peak wind speeds, probably connected to the proper parameterisation of the physical processes active in heavy storm conditions (Wilke et al., 1999; Tournadre, 1999). Finally, Chèruy et al. (2004) showed that the surface wind at smallest resolved horizontal scales is affected by systematic power deficits associated with the smoothing action of operators introduced in the numerical codes for numerical stabilization purposes.

BOLAM data sets

The following partners of WERMED project use the BOlogna Limited Area Model (BOLAM) (Buzzi et al. 1994; Buzzi and Foschini 2000), version 2001, for research and operational applications: the National Observatory of Athens (NOA), Greece, since 1999; the Department of Physics (DIFI) of the University of Genoa, Italy, since 1999; the Meteo-hydrological Centre of Civil Protection of Liguria (CFMI-PC), Italy, since 1999; the Agro-meteorological Service of Sardinia (SAR), Italy, since 2000; the Agency for Environmental Protection and Technical Services (APAT), Italy, since 2001.

Some of these versions of the model run over domains that do not cover the whole Mediterranean Sea. Other versions have fragmentary or partially incomplete data sets, so that they do not overlap each other. Finally, not all the available versions have comparable resolution. The only versions satisfying the requirements of similar computational domain and resolution, and whose data sets overlap for a period sufficiently long for a climatological study, resulted to be the NOA and SAR versions.

In particular, both the model runs were available for 3 years, from 1st April 2003 to 31st March 2006.

BOLAM-NOA operational runs are initialised every day with the 00 UTC GFS/NCEP analysis. The run produces +72 hours forecasts all over the Mediterranean Sea with 135 × 110 grid nodes at the horizontal resolution of 0.24° (~25 km), and 30 vertical levels. A recent evaluation of these operational forecasts in the Mediterranean region is given in Lagouvardos et al. (2003) with very encouraging results concerning, in particular, wind and precipitation forecasts.

BOLAM-SAR runs with the GCM/ECMWF forecast of +12 hours, initialised at 12 UTC, as initial conditions. This configuration satisfies two operational requirements: on one hand, the simulation starts every day at 00 UTC and produces +72 hours forecasts, analogously to BOLAM-NOA; on the other hand, the use of a forecast as initial analysis for the LAM allows BOLAM to start after the spin-up phase of the general circulation model is finished. Simulations are performed over the whole Mediterranean Basin with 254 × 187 grid nodes at the horizontal resolution of 0.18° (~20 km), and 32 vertical levels.

Provided that both the models store their output every 6 hours, at 00, 06, 12, and 18 UTC every day, the available data sets consisted of 4384 wind fields (3 years × 365 days/year × 4 wind fields/day plus 4 wind fields for the 2004 leap year).

Re-Analysis of the ECMWF

The Earth's climate has traditionally been studied by statistical analysis of observations of particular weather elements such as temperature, wind and rainfall. Climatological information is often presented in terms of long-term averages, and sequences of observations are examined for evidence of warming, more-frequent severe storms, and so on. A powerful new approach to climate analysis has emerged in recent years. It applies the tools and techniques of modern everyday weather forecasting to past analyses in a process called re-analysis. At the European Centre for Medium-range Weather Forecast this methodology was applied to create a 45-year long database of re-analyses, called ERA-40, comprehensive of all the main physical variables which describe the state of the atmosphere and oceans. A general account of ERA-40, with extensive references to the project, is given by Uppala et al. (2005).

The objective of ERA-40 were to create high-quality global analyses of atmosphere, land and ocean-wave conditions for the past four decades or more using an up-to-date data assimilation system and exploiting, at any time, the maximum information from the available observational sources. From this point of view, the quality of re-analysis products depends both on the quality of the observing system and on the quality of the assimilating numerical model and analysis system.

The ERA-40 atmospheric analyses were produced by three-dimensional variational data assimilation using six-hour cycling. The assimilating atmospheric model had T159 spectral truncation in the horizontal, with corresponding ~125 km grid spacing, and a 60-level resolution in the vertical, with variables represented up to a pressure of 0.1 hPa.

ERA-40 data set

The ERA-40 database is a comprehensive set of physical quantities derived from the aforementioned process of re-analysis. This database is available to the scientific community to be used in any kind of research activity.

ECMWF ERA-40 data used in this project have been obtained from the ECMWF data server. These data have a global spatial coverage and are provided with 2.5° of spatial resolution both in longitude and latitude. We have used only the surface wind speed, i.e. the horizontal zonal, *u*, and meridional, *v*, components at 10 m a.s.l., over the Mediterranean Basin within the range 5°W - 35°E in longitude and 30°N - 45°N in latitude. The used data set consists of 4 fields per day, stored at 00, 06, 12, and 18 UTC, from September 1972 to August 2002.

High resolution re-analyses

Weather forecasting systems, spectral ocean wave predictions and ocean circulation models are now routinely adopted for storm detection, ship routing, offshore activities, and coastal protection, on a short-term prediction basis. The problem of handling climatological data is, in principle, overtaken since atmospheric data for several decades have recently become available from the global reanalysis projects, as described in the previous section. For coastal applications the spatial and temporal resolution of the re-analyses is, however, still relatively coarse. To improve this situation, the project "Hindcast of Dynamic Processes of the Ocean and Coastal Areas of Europe (HIPOCAS)", developed within the framework of the EU R&D projects, was initiated in 2000 aiming at generating high-resolution homogeneous 40-year hindcasts with horizontal resolutions that are adequate to represent at least the major features of the topography and bathymetry, i.e. about 5-10 km depending on the area, and temporal resolutions between 1 and 3 hours. The main advantage of the hindcasts is their high spatial and temporal resolution that makes them the most suitable source for the climatology study in this area. The models employed in the project were a state-of-the-art WAM wave model (WAMDI 1988) and the regional atmospheric model REMO (Jacob and Podzun 1997).

HIPOCAS data set

A data set of monthly values of wind intensity and direction, directly derived from the HIPOCAS database, was used for the statistical analysis of the spatial and temporal variability in the Central Mediterranean, between 10°E - 16°E and 35°N - 38°N, with horizontal resolution of 0.125° both in longitude and latitude. The used data set ranges from January 1958 to December 2001.

Wind climatology of the Mediterranean

The climatology of the surface wind over the Mediterranean Sea (Section 1.1) has been assessed using the data sets obtained from the two versions of model BOLAM, SAR and NOA, and the data extracted from the HIPOCAS archive. The main characteristics of the data sets are summarised in the following:

- The surface wind fields at 10 m a.s.l. of the meteorological model BOLAM have been used to study the wind climatology all over the entire Mediterranean Sea between 6°W - 36°E in longitude and 30°N - 46°N in latitude, i.e. the larger domain corresponding to the left picture of Figure 1, with spatial resolution around 20 km. The wind fields at 00, 06, 12, and 18 UTC of the second day forecast[6] from April 2003 to March 2006 have been used.
- The surface wind fields at 10 m a.s.l. of the HIPOCAS data set have been used to study the wind climatology of the Central Mediterranean between 10°E - 16°E in longitude and 35°N - 38°N in latitude, corresponding to the area of the Strait of Sicily and around Malta as shown in the right picture of Figure 1, with spatial resolution around 12.5 km. The monthly averaged wind fields from January 1958 to December 2001 have been used.

All these data sets consist of high-resolution data, but the HIPOCAS archive is a long-term data set, whereas the two BOLAM data sets have a pretty short time extension.

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[6] Model data from +24 to +48 hours have been chosen in order to avoid the spin-up phase of the model.

Moreover, re-analyses are usually considered pretty reliable data as they derive directly from observations. On the contrary, BOLAM wind fields require some kind of comparison with observations in order to check that data are not biased. Following this consideration, a comparison between BOLAM simulations and QuikSCAT observations has been performed, as reported in the following Section 3.1.

The most relevant results obtained in the context of the present analysis are collected in a CD-rom (AA. VV. 2007).

BOLAM data verification

BOLAM-NOA and BOLAM-SAR surface wind fields have been compared with QuikSCAT data in order to verify their reliability and the possible existence of systematic biases between simulations and measures. These two kinds of data can be considered homogeneous and their comparison is somewhat straightforward, in that both simulated and observed wind fields represent an average value over the corresponding pixels. However, some differences among the data sets exist which require further considerations.

QuikSCAT data corresponding to ascending and descending crossing of the Mediterranean Sea are about 12 hours shifted each other, as the satellite follows a sun-synchronous circular orbit around the Earth. Moreover, each orbit takes about 101 minutes to complete (14.25 orbits/day), so that, given the Earth's angular velocity and the longitudinal extension of the Mediterranean Basin, the satellite flies over the Mediterranean at most three subsequent ascending or descending crosses within a time window of about 3 hours. The position and time of crosses are slightly variable during the day, with a recurrent period of 4 days (57 orbits). As a consequence, QuikSCAT data corresponding to the ascending (descending) crosses are available at 3:00 ± 1:00 (16:00 ± 1:00) UTC in the Eastern Mediterranean, at 4:30 ± 1:00 (17:30 ± 1:00) UTC in the Central Mediterranean, and at 6:00 ± 1:00 (19:00 ± 1:00) UTC in the Western Mediterranean.

Following Ebuchi et al. (2002), satellite measurements taken at ± 30 minutes out of the model output time, i.e. at 00, 06, 12, and 18 UTC, can be compared with model data when they have similar spatial resolution. Unfortunately, satellite data are available neither at 0:00 ± 0:30 and 12:00 ± 0:30 UTC all over the Mediterranean, nor in the range 6:00 ± 0.30 and 18:00 ± 0:30 UTC over the Eastern Mediterranean. However, a great number of observations is available for comparison with model data when considering the time intervals 6:00 ± 0.30 and 18:00 ± 0:30 UTC over the Central and Western Mediterranean.

Figure 2 shows the scatter diagrams between BOLAM-NOA (left) and BOLAM-SAR (right) versus QuikSCAT wind speeds for all the pairs of data available in the period from April 2003 to March 2006. In the pictures, the green line represents the bisector, whereas the red lines correspond to the best fit of data through a linear relation forced to cross the origin. The angular coefficients of the best-fit functions worth 0.81 and 0.82 for BOLAM-NOA and BOLAM-SAR, respectively. The scatter plots do not show any evident data trend, curvature in the relationship, clustering of one or both variables, or changing of spread of one variable as a function of the other, and only a low percentage of outliers.

As a main result of this comparison, it is worth observing that both BOLAM models underestimate the wind fields over the Mediterranean Sea, but they perform almost the same way. However, it is well known that surface wind fields suffer for systematic errors associated with the numerical procedures adopted in computing them. For instance, Chèruy et al. (2004) showed that surface wind at smallest grid scales of numerical models is affected by systematic power deficits associated with the smoothing action of super-dissipation operators introduced in the numerical codes for numerical stabilization purposes.

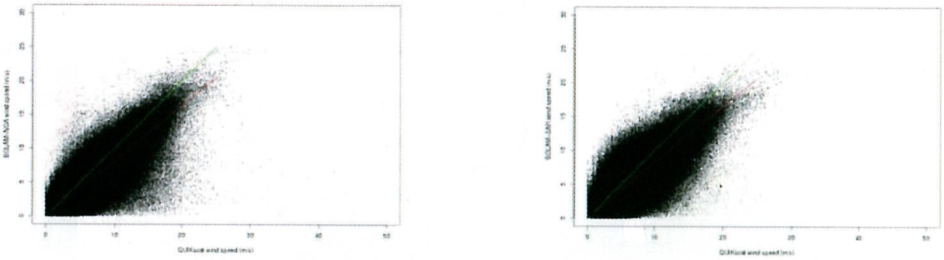


Figure 2: Scatter plot: BOLAM-NOA (left) and BOLAM-SAR (right) versus QuikSCAT. Red lines are the best-fits, green line is the bisector.

Statistical analysis of BOLAM data

In the following the main results concerning the statistical analysis of BOLAM data are reported. In particular, we will show those elaborations that point out where the most severe wind conditions and extreme anemological events occur within the Mediterranean Basin.

Note that, as already appeared from the comparison between the BOLAM-NOA, and BOLAM-SAR, data and QuikSCAT observations, the two versions of the meteorological model perform very similarly from the statistical point of view. Therefore, the following figures and considerations are valid for both BOLAM-NOA and BOLAM-SAR, if not explicitly stated differently. Finally, it is worth reminding that, as pointed out from the aforementioned comparison, the statistical results obtained from BOLAM data are likely expected to be somewhat lower than the actual values.

Figure 3 shows the mean surface wind speed calculated by the BOLAM data. The highest wind speeds, between 7 and 8 m/s, occur in the Gulf of Lion and in the Aegean Sea, which correspond to those areas influenced by Mistral and Etesian winds, respectively. This consideration is confirmed by the seasonal maps of mean surface wind speed (not shown), which present the main maximum within the range 9-10 m/s on the Gulf of Lion in winter, and the main maximum on the Aegean Sea in summer, up to more than 8 m/s in the eastern side of Crete. The wind roses calculated within these areas provide further details about the prevailing directions associated to Mistral and Etesian: in the Gulf of Lion the frequency of the wind coming from NW is greater than 30%, with relevant occurrences also for the wind speed higher than 15 m/s; in the Aegean Sea the overall frequency of the wind directions between WNW and NNW is slightly higher than 60% and most of the occurrences are lower than 10 m/s.

As far as extreme events are concerned, the map of maximum wind speed (not shown) points out that the windiest area all over the Mediterranean corresponds to the northern Adriatic Sea, where the Bora wind typically occurs with intensities up to 30 m/s. The Gulf of Lion and the Aegean Sea correspond to secondary maxima around 22 and 25 m/s, respectively. However, these secondary maxima persist also in the maps of the percentiles, while the absolute maximum along the Croatian coasts is evident only in the map of the 99th percentile, as Bora events are only associated to very strong winds. On a seasonal basis, extreme events appear much more frequent during winter, as the map of the 99th percentile in winter, reported in Figure 4, shows. In particular, this figure points out the real spatial extension that these phenomena can reach when extreme events occur: strong Mistral winds flow from the Gulf of Lion up to the Strait of Sardinia and also to the Strait of Sicily; the effect of Etesian winds can reach Cyprus eastward and the northeast part of the Gulf of Sirte southward; strong Bora events extend southward to the Ionian Sea through the Strait of Otranto.

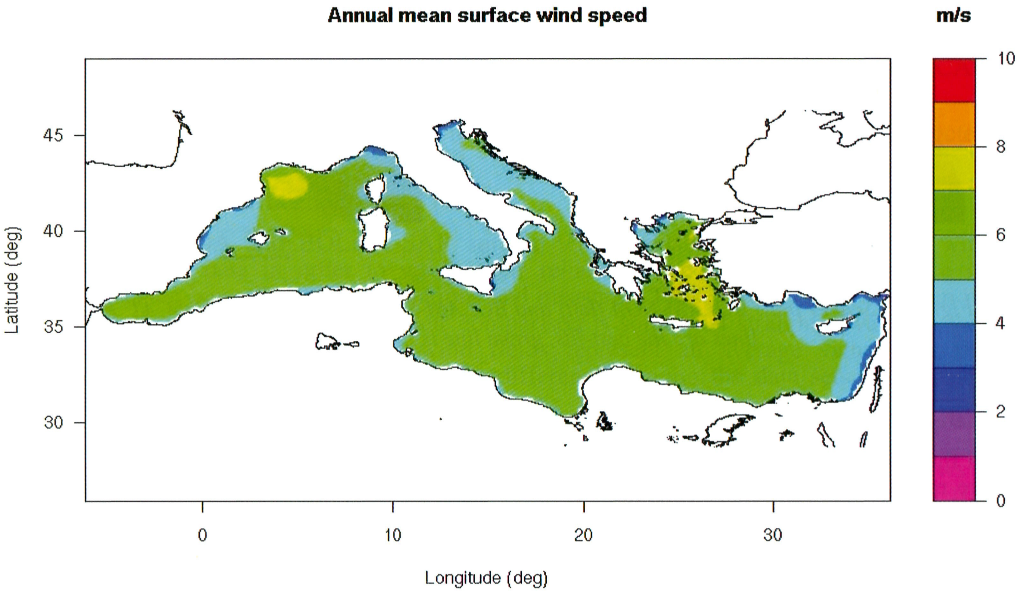


Figure 3: Annual mean surface wind speed calculated by means of BOLAM data.

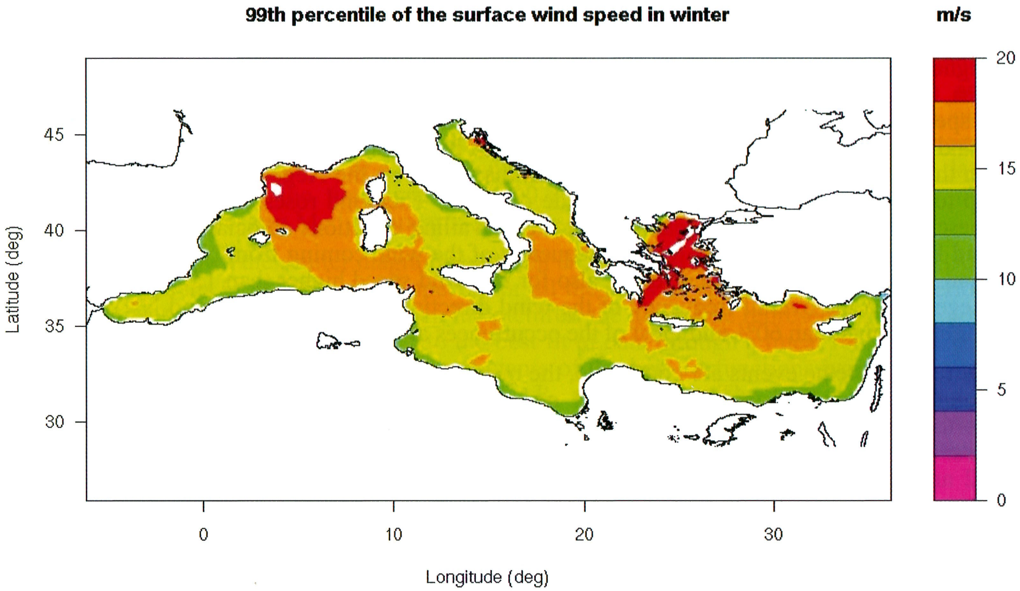


Figure 4: 99th percentile of the surface wind speed in winter, calculated by means of BOLAM data.

Statistical analysis of HIPOCAS data

The homogeneous, long-term and high-resolution wind hindcast HIPOCAS database has been used to evaluate the climatology for the Central Mediterranean area. This comprehensive and consistent data set is, at the moment, the most suitable source for the climatology study in this area because of its high spatial and temporal resolution.

Figure 5 shows the mean wind conditions in winter. During this season the dominant wind direction is from the northwest, similarly to a Mistral-like pattern. The wind speed is rather uniform with a main vein along the axis of the Sicilian Channel, but with considerable attenuation along the relatively sheltered Sicilian and Tunisian coastal seas. The strongest winds are experienced in the north-western approaches to Pantelleria Islands and in the Strait of Sicily, especially to the north of Cape Bon where values reach up to 18.8 m/s in December.

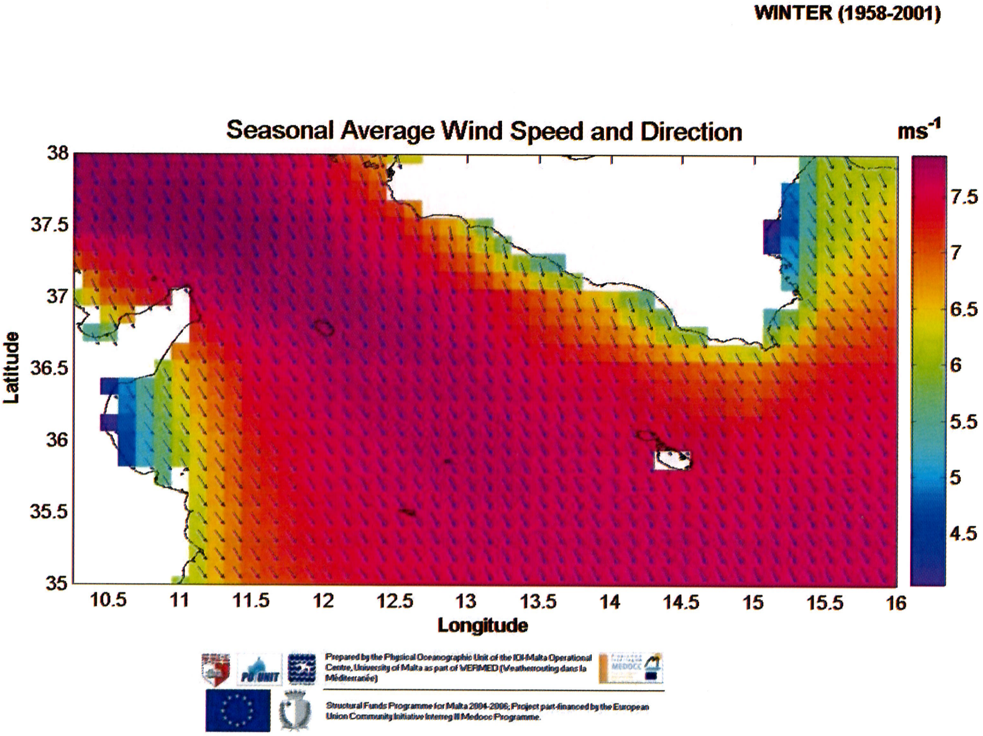
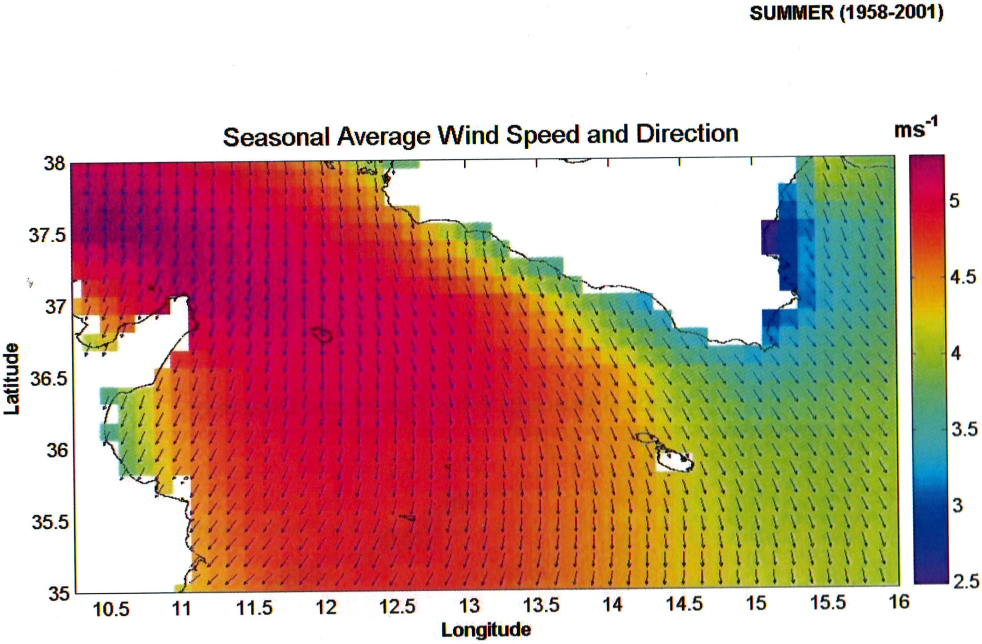


Figure 5: Mean surface wind speed in winter, calculated by means of HIPOCAS data.

In spring, the dominant wind direction is from the North in most of the area, and from the northeast on the Tunisian coast. The mean wind speed is around 80% of winter values. In space the tongue of strongest winds starts to become more confined to the area of the Strait of Sicily, and mean wind speeds are considerably weaker in the east and south of Malta. The weakest mean winds, below 4 m/s, are experienced on the eastern Sicilian coast.

Later on, in the summer months, the dominant wind direction varies in space with a predominant northerly direction west of the Strait of Sicily, blowing from the northwest in the area of Malta, but tending to steer from the northeast to the south of Pantelleria. The wind speeds experience a considerable decrease in the waters to the east of the Maltese Islands and southeast of Sicily. Figure 6 shows the mean wind conditions in summer.

During autumn the mean wind speed intensifies up to the winter values, while directions converge towards their winter pattern.



Prepared by the Physical Oceanographic Unit of the IOI-Malta Operational Centre, University of Malta as part of WERMED (Weatherrouting dans la Méditerranée)

Structural Funds Programme for Malta 2004-2006; Project part-financed by the European Union Community Initiative Interreg III Medocc Programme.

Figure 6: Mean surface wind speed in summer, calculated by means of HIPOCAS data.

The climatology can also be accessed from the Malta Page for WERMED residing on the CapeMalta website (www.capemalta.net/wermed). An online interface provides a facility for users to obtain climatological information at user-selected points, transects and zones anywhere in the area of study.

Wind climate regimes of the Mediterranean

The surface wind fields archived on the ERA-40 database have been used to evaluate the wind climate regimes of the Mediterranean Sea. This archive is a homogeneous and long-term database, and was expected to provide an accurate climatology of the Mediterranean Sea, even if the horizontal resolution is quite coarse. As already stated in Section 2.3, ERA-40 data are available from September 1957 to August 2002, four times per day at 00, 06, 12, and 18 UTC, all over the Earth. For the present study, however, only the surface wind fields at 10 m a.s.l. from September 1972 to August 2002, within the area between 5°W - 35°E in longitude and 30°N - 45°N in latitude, have been analysed. The reduction of the analysis to 30 years, despite the available 45 years, is required by the clustering procedure in order to avoid prohibitive computing times.

Cluster analysis of ERA-40 data

Cluster analysis is a numerical technique which seeks to allocate objects into groups, or clusters, following some kind of similarity criterion based on the definition of a distance metric measure between objects and an aggregation algorithm, such that a couple of objects in the same cluster can be considered more similar than a couple of objects belonging to distinct clusters (Everitt, 1977). In the present case, we wish to partition the ERA-40 surface wind fields into *k* groups. Unfortunately, the aforementioned criterion is usually not unique, and it strongly depends on the distance measure and aggregation algorithm chosen to perform the clustering. Since the present study focuses on the identification and classification of wind regimes, the methodology already applied in Burlando et al. (2007) to identify the climate regimes of the meso-scale wind patterns over Corsica has been applied.

The final result of the analysis was the identification of $k = 8$ distinct clusters, or wind climate regimes. Figure 7 shows the surface wind patterns corresponding to the wind climate regimes. The seasonal and daily distributions of each wind regime have been calculated in order to identify those patterns which correspond to summer or winter regimes, and those patterns that are typically diurnal or nocturnal. It turned out that clusters {1,2,3,4} are mainly summer wind regimes, whereas clusters {5,6,7,8} are winter regimes. Moreover, clusters {1,3} are typically diurnal, cluster {4} is nocturnal, and the other clusters do not show a pronounced difference of occurrences between night and day.

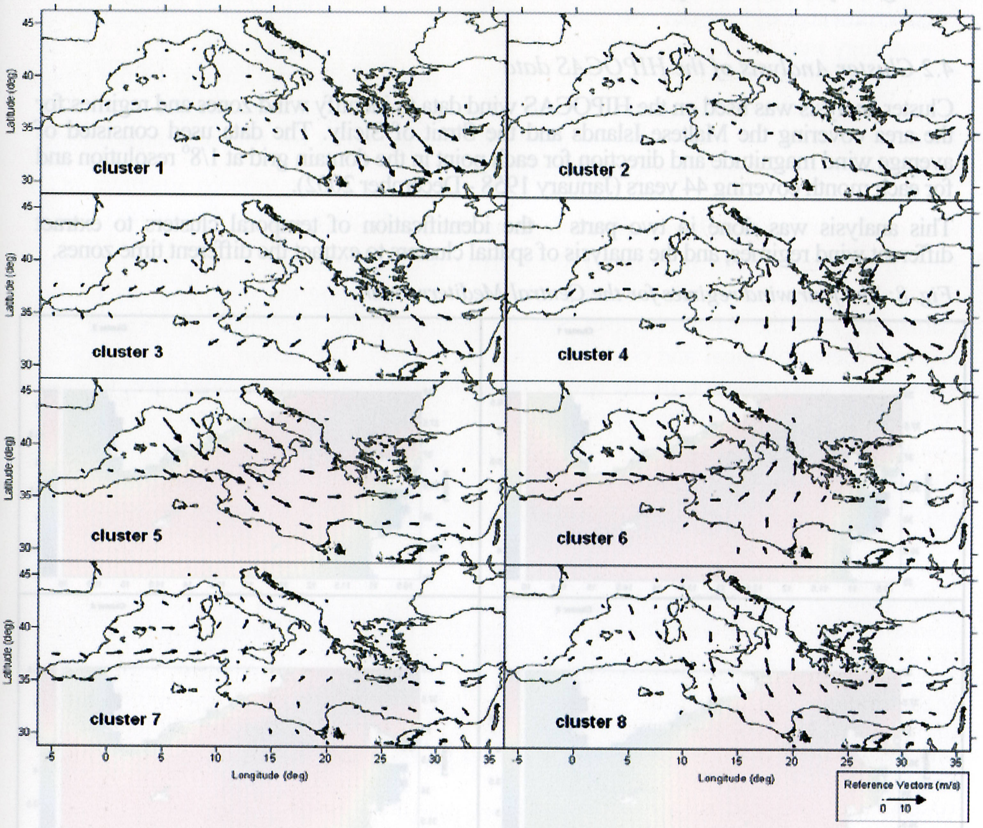


Figure 7: Mean wind vectors of the wind climate regimes.

The detailed description of all the clusters is far beyond the scope of the present chapter. The interested reader can refer to Burlando (2007), where an interpretation of the clusters in terms of the topographic and/or thermal forcing of the Mediterranean Basin, is also reported. In this context, it is just worth noting that the final classification has been able to identify both the surface circulation patterns already discussed in Section 3, which play an important role in defining the mean surface wind of the Mediterranean, as well as in determining extreme situations. These surface wind patterns, corresponding to Mistral events in the western Mediterranean sub-basin and Etesian winds in the eastern sub-basin, appear in cluster 5 and 1, respectively.

Cluster 1 is characterised by high mean wind speeds from northern quadrants, with a summer seasonality and a typical diurnal occurrence. This description corresponds to the definition of Etesian winds, which constitute one of the most relevant meteorological phenomena occurring over the Aegean Sea during summer. They originate like a part of the Asian monsoon system as they result from high pressure over the Balkans and the development of a thermal low over the Anatolian plateau. They are mainly north-easterly in the northern Aegean, northerly in the central and southern Aegean, and tend to become north-westerly near the south-western Turkish coasts (Kotroni et al., 2001).

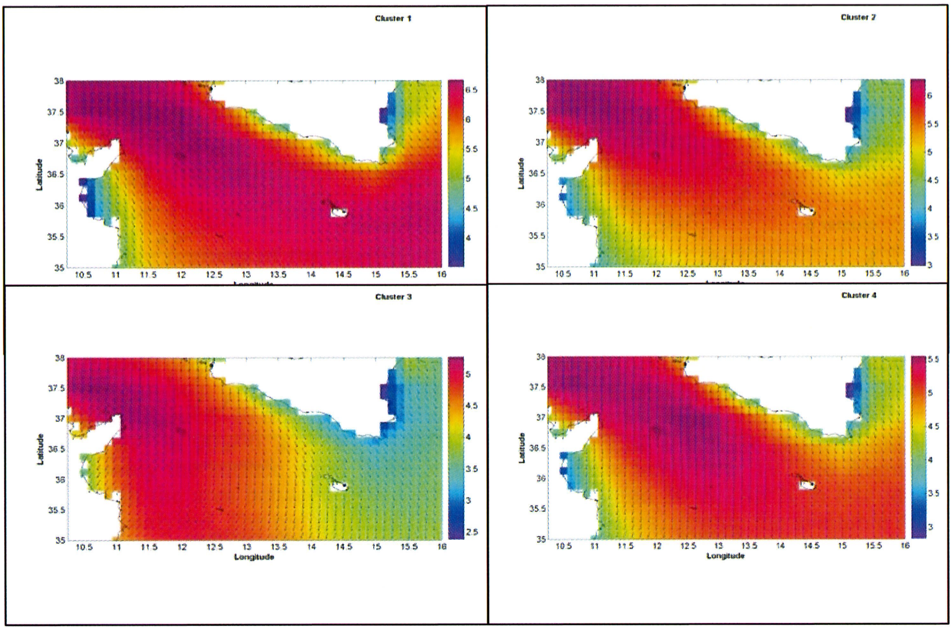
Cluster 5 belongs to the previously defined winter regimes, and does not show any daily distribution. It presents a strong northwesterly wind blowing from the Gulf of Lion to the Strait of Sicily. The pattern fits very well the classical description of Mistral (see for example Jiang et al. 2003), which is directly related to the effects of the mean westerly zonal flow, modulated by the advection of Atlantic lows, superposed on the topographic forcing of Pyrenees and Alps.

4.2 Cluster Analysis of the HIPOCAS data

Cluster analysis was used on the HIPOCAS wind data to identify wind zones and regimes for the area covering the Maltese Islands and the Strait of Sicily. The data used consisted of average wind magnitude and direction for each point in the domain grid at 1/8° resolution and for each month covering 44 years (January 1958 - December 2002).

This analysis was done in two parts – the identification of temporal clusters to extract different wind regimes, and the analysis of spatial clusters to extract the different time zones.

Fig. 8: The four wind regimes for the Central Mediterranean



For the sake of temporal cluster analysis, the `monthly' records are compared with each other. Each 'monthly' record consists of the snapshot of data at every point for a single month. The analysis to identify *k=8* unique temporal clusters was performed, and for each cluster those data records pertaining to that cluster were grouped, calculated and plotted as an average wind magnitude and direction. Note that cluster 1 corresponds to a wind regime which is typical of the winter months – it is characterised by strong winds, while cluster 3 corresponds to the wind regime typical of the summer months – hence the milder winds. The other two clusters depict regimes typical of the mid-seasons. Note that the northwesterly wind, which is the most prevalent wind for the Maltese Islands, is much more expressly defined in regime 1 and the least defined in regime 3.

The analysis by spatial clustering was used to extract the different wind zones. The data was considered to be composed of different time-series records -- one record for each grid point. Clustering was performed on these time-series to determine the different wind zones in the domain of interest. Figure 9 shows the domain divided into 4 separate clusters. Considering that the most prevalent wind is from the northwest, the analysis brings out the 'shadowing' effect of Sicily and Tunisia.

III. WAVE CLIMATOLOGY OF THE MEDITERRANEAN BASIN.

A. Orasi, S. Morucci, S. Corsini, C. Nieddu, P. Boi, A. Seoni, A. Drago, S. Music, A. Delitala

Introduction

The aim of the Interreg IIIB MEDOCC project entitled Weatherrouting dans la Méditerranée (WERMED) is to develop an experimental system for weather routing in the Mediterranean Sea and to analyse its potential in the region. The project is led by the Italian agency CINFAI (Consorzio Interuniversitario per la Fisica delle Atmosfere ed Idrosfere) and brings together partners from some of the main MEDOCC countries with clear maritime interests, namely Italy, Greece and Malta.

Weather routing follows the idea of optimize shipping routes depending on the evolution of the meteo-marine conditions. Unfavourable conditions at sea often cause considerable delay in marine transportation, higher operational costs and fuel consumption. Forecasts of wind, sea state and currents could allow in advance the assessment of optimal routes in terms of distances, costs, passengers comfort and safety, risks for the ship and the environment.

WERMED will estimate risk scenarios for maritime transportation in the Mediterranean, by means of the compilation and the use of high-resolution climatology maps of key meteorological and oceanographic parameters. Maps will be based on large databases of numerical analyses developed in the context of the most recent co-operative European projects. The potential risks associated with the Mediterranean main routes will be assessed, and the costs for running ships during different weather conditions will be evaluated.

Aim of the Action 2.2: Wave climatology on the Mediterranean

One of the purposes of the project WERMED is the estimation of risk scenarios for maritime transportation. This can be achieved by evaluating the main features of the climatology in the Mediterranean Sea by means of the statistical analysis of the relevant meteorological and oceanographic parameters. The action 2.2 of the project aims at the determination of the wave climatology and partners involved are: Region Sardinia and IOI-MOC (International Ocean Institute - Malta Operational Centre).

Sea wind-waves are the major factor affecting ship performance. Wave action causes ship motions that reduce engine efficiency and increases the drag due to the steering corrections. The relationship between ship speed and waves is similar to that of the wind. The ship speed is always reduced by head seas, while, up to a certain point in time, it is slightly increased by following seas and then it is again reduced. In heavy seas, exact performance may be difficult to predict because of the adjustments to course and speed in order to maintain a reasonable level of shiphandling and comfort.

Being weather-routing strongly influenced by the direction and the height of waves and by the direction and the intensity of surface wind at every instant, the determination of an optimal route among hundreds of alternative paths can be an hard task, and, furthermore, solutions could turn to be very sensitive to small errors in the forecasts.

Weatherouting can be made easier and more robust by narrowing the choice among the ensemble of possible routes on the basis of the general features of Mediterranean Sea climate.

This work aims to give a statistical description of the typical wave conditions in the Mediterranean Sea in terms of both space and time.

Data sources

Four are the main sources of data that have been used in this action:

- ☐ Wave observations from the APAT RON buoy network;
- ☐ WAM numerical analysis from the ECMWF Mediterranean operational model;
- ☐ WAM reanalysis from the ECMWF ERA 40 Project;
- ☐ WAM hindcasts from HYPOCAS database.

These data have very different origin and specific limitations. This heterogeneity involves quality and accuracy, geographical distributions and the amount of available data. In the following we give a brief description of the data and of their use in this work.

The Italian national wave measurement network has been working since July 1989. The RON (Rete Ondametrica Nazionale) was formed originally by eight directional pitch-roll buoys, displaced offshore of La Spezia, Alghero, Ortona, Ponza, Monopoli, Crotone, Catania and Mazara. Two translational buoys were added to the network in 1999 located near Cetraro and Ancona and at the beginning of 2002 the upgrade of the RON National wave measurement network started up.

The amount of stations was eventually brought up to 14, with the addition of 4 new buoys located in Capo Linaro (Civitavecchia, Central Tyrrhenian Sea), Capo Gallo (Palermo, Sicily), Punta della Maestra (Northern Adriatic) e Capo Comino (East Sardinia).

The synthetic spectral parameters (time series) recorded and collected are:

·Hs (m) significant wave height;
·Tp (s) peak period;
·Tm (s) mean period;
·Dm (N deg) mean direction.

And the spectral parameters for frequency band one are:

·Energy density;
·Mean direction;
·Directional spread;
·Skewness;
·Kurtosis.

WAM is a Wave model developed by the Wave Model Development and Implementation (WAMDI-Group, 1988). The WAM model has been extensively used for forecasting on global and regional scales in many weather prediction centres around the world (ECMWF, KNMI, FNMOC, NMC, NAVOCEANO, etc.), for special experimental programs and case studies.

Since July 1992 the European Centre for Medium-Range Weather Forecasts runs, in parallel with the meteorological model, its own WAM model. A complete discussion of the physics of wave evolution, wave generation and the actual details of the numerical implementation of the energy balance may be found in Komen et al. (1994).

Two different versions of the WAM model have been actually operational at ECMWF, one for the global ocean and one for the Mediterranean Sea. The global deterministic model currently uses the 0.5 degree irregular lat-long grid. The wave model for the Mediterranean Sea became operational in July 1992 including the area between 6° West and 36° East in longitude and 30° and 46° North in latitude. This model uses the 0.25 degree irregular lat-long grid

A general account of ERA-40 project, with extensive references to further documentation, is given by Uppala et al. (2005).

The data sets contain data at the resolution of the data assimilation and forecast system used by ERA-40 which is a 1.5° x 1.5° regular latitude /longitude grid.

In this work we have used the wave height over the Mediterranean basin for the entire ERA-40 database of 45 years, from September 1957 to August 2002.

The wave climatology study within the WERMED Project tasks 2.2 was supported also using the HIPOCAS database as a source of data. This is an extensive database, compiled from the EU R&D project HIPOCAS (*Hindcast of Dynamic Processes of the Ocean and Coastal Areas of Europe*). It includes homogeneous, long-term and high-resolution wave hindcasts. The WAM model was run over the Mediterranean with the grid resolution of 0.5° and with two grids used in a 2-way nesting mode: one over the Eastern Mediterranean with 0.25° resolution and another over the Central Mediterranean with 0.125° resolution.

The different data sources, in brief, have the following characteristics:

- ☐ the buoys data have generally a good quality and provide continuous local time series. However they are few and especially located close to the coasts;
- ☐ the WAM model data are continuous in space and time, hence ideal for the purpose of this work. The resolution is high (about 25 km) and the time series is quite long (about 13 years). However, the wave data show a marked tendency to underestimate the corresponding measured values;
- ☐ the ERA-40 database is continuous in space and time. Its data have a good quality but the spatial resolution is not as high as the WAM model one (about 110 km);
- ☐ the HIPOCAS data are continuous in space and time; the resolution is high (about 25 km and 15 km) there is a very large number of data available.

Wave Climatology over the Mediterranean Sea: data analysis

In order to build the climatology of the wave on the Mediterranean Sea starting from data described above, we decided to carry out three types of studies:

- ☐ time-series analysis;
- ☐ extreme events analysis;
- ☐ clustering.

The statistical analysis is carried out on both numerical simulation and buoy observation time-series of: significant wave height H_{m0}(m), peak period T_p (s), mean period T_m (s), mean wave direction Dir (°) and derived parameters as: energy flux $\bar{P}$ (W/m) and mean wave slope *mws* (%).

The analyses are on three different spatial scales: one over all the Mediterranean Sea, one along the Italian coastline and one in the Central Mediterranean.

The statistical analysis of extreme events is structured as follows: the statistical analysis of significant wave height time series coming from the ERA 40 Project is carried out on all the Mediterranean basin and in the Central Mediterranean selected points from HIPOCAS computational domain have been used.

Finally, the cluster analysis is carried out on the ECMWF WAM significant wave height fields over all the Mediterranean basin.

Climatology of wave time-series: all over the Mediterranean Basin

The three-scale analyses, all over Mediterranean basin, along Italian coastline and in the Central Mediterranean, were carried out using four different groups of data.

In order to study the wave climate over the entire Mediterranean, we have used the analysis field from ECMWF WAM numerical model simulations at horizontal 0.25 x 0.25 deg spatial resolution and for a time period of 13 years: from the 1st of July 1992 to the 31st of December 2005.

Every day ECMWF WAM model outputs for 0000 UTC, 0600 UTC, 1200 UTC and 1800 UTC are stored in a system called MARS. Each parameter is stored as a field of grid point values, in latitude rows starting at the north and working southwards; within each row values run from west to east.

Again overall the Mediterranean basin, in order to obtain the significant wave height return level at different years, we have used reanalysis of the WAM numerical model from the ERA-40 Project at the spatial resolution of 1.5 degree and for a 45-years long period: from June 1957 to June 2002.

In the second case, in order to assess the main features of wave climate on the whole Italian coastline we used RON buoys time series.

The Italian coastline has been subdivided in 13 coastal sectors on the basis of the availability of reliable time series of wave records and the geographic orientations of the coastlines. The sectors for which the general climatic features could reasonably be extrapolated are 11. The limits of each sector have been determined by the superposition of Coastal Sections in which at least a measurement buoy is present, are climatologically homogeneous and are well oriented with respect to the fetch. Due to the different orientation of the shores in Sardinia, 2 coastal sectors have been identified with the homogeneous coastal sections meeting the criteria described above.

In the third case, the comprehensive and consistent data set of hourly values of wave parameters produced by the HIPOCAS model was used for the analysis of spatial and temporal variability of waves in the Central Mediterranean. The wave climatology study area was the Central Mediterranean/Strait of Sicily between 35°N-39°N and 10.25°E-16°E. Horizontal resolution of the grid was 0.125°. A number of monthly time series of 44-year (1958-2001) of hourly wave parameters at every grid point in the area of interest were derived.

Data taken from HIPOCAS archive have been utilized for the detailed climatological study for the area centred on Malta Island, in the Strait of Sicily.

As said before, the statistical analysis is carried out on both numerical simulation and buoy observation time-series of: significant wave height H_{m0}(m), peak period T_p (s), mean period T_m (s), mean wave direction Dir (°) and derived parameters as: energy flux $\bar{P}$ (W/m) and mean wave slope mws (%). The wave energy flux (expressed in W/m) is calculated as $\bar{P} = \frac{\rho g^2}{32\pi} TH^2 \approx 0.982 H_{m0}{}^2 T_m$ and the total flux is the sum of the contribution of all the waves considered in the period of interest:

$\bar{P} = 0.982\sum(H_{m0}^{2}T_{m})$. The wave energy flux has been calculated starting from: $\bar{P} = \bar{E}c_{g}$ being $\bar{E}$ the energy density and c_{g} the group velocity defined in deep water respectively: $\bar{E} = \frac{\rho g H^{2}}{8}$ and $c_{g} = \frac{gT}{4\pi}$. The mean wave slope has been calculated as: $mws = \frac{2\pi H_{m0}}{gT_{p}^{2}}$ and has been represented in % values.

In particular, we have realized the following maps:

- maps for the four seasons and at annual level of:
  - mean of significant wave height;
  - mean of peak period;
  - mean of the mean period;
  - maximum of significant wave height;
  - 90th; 75th; 50th and 25th percentile of significant wave height;
  - mean of energy flux;
  - mean of wave slope;
  - joint distribution of mean significant wave height and direction.

In particular, we consider the joint frequency distributions of significant wave height and direction for 13 selected point in the Mediterranean basin. These points are shown in the following Table . With a comparative purpose we have chosen the same points (in the limit of the WAM resolution) already selected in action 2.1: Wind climatology.

	Sea name	**longitude**	**latitude**		**Sea name**	**longitude**	**latitude**
1	West Mediterranean	-3.50	36.00	8	Adriatico	15.75	42.75
2	Cabrera	3.00	38.00	9	Central Mediterranean	17.50	38.00
3	Sardaigne	6.00	40.00	10	Ionio	18.50	34.75
4	Tunisia	9.00	38.00	11	Aegean	27.00	35.50
5	Liguria	9.25	43.75	12	East Mediterranean	30.00	34.00
6	Tyrrhenian	12.00	40.00	13	Gulf of Lyon	4.00	42.50
7	Malta	12.75	36.00				

Table 1: 13 selected point over the Mediterranean basin.

In the following Figure 1 we show the position of the points:

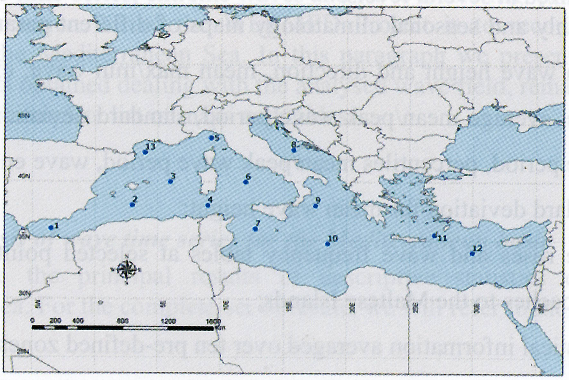


Figure 1: Selected points.

Climatology of wave time-series: along the Italian coast

In order to assess the wave climate in every coastal section along Italian coast, the longest available time series of parameters from the RON network in the period 1989-2003 have been analyzed.

A description of the buoys, of measurement and for more general information see Franco 2003.

Time series have been subjected to a standard L1 quality control analysis as described in the APAT: Atlante delle coste (available at APAT site: www.apat.it), inspected for missing data, the reliability of each single measurement, homogeneity of the set and controlled for systematic errors.

The parameters used in the present report are: Significant wave height: H_{m0} (m), Peak Period: T_p (s), Mean period: T_m (s), Mean wave direction: Dir (°)

In every Coastal Section the directional distribution of the wave heights has been evaluated in terms of Joint Frequency Distribution and represented by radar plots.

An archive of the sea storms has been compiled, leading to the evaluation of the independent maxima of each sea storm event in the section. Scatter plots of sea storms have been represented.

The common climatic features of the sections have been extrapolated, when possible to the sectors.

In order to obtain a seasonal representation of parameters we have assumed the following convention:

Winter: December, January, and February
Spring: March, April and May
Summer: June, July, and August
Autumn: September, October, and November.

Climatology of wave time-series: in the Central Mediterranean basin

The parameters used in the analysis were significant wave height H_s, wave direction $Wdir$ and mean wave period T_m and peak period T_p of total sea from HIPOCAS model. . Statistical analysis of these monthly time-series was done by calculation of maximum, minimum, mean values and standard deviation, as well as the 99th, 90th, 75th, 50th and 25th percentile for each parameter.

The full climatology was prepared in the form of 2D plots, and summary tables and charts and organized at several levels:

- (i) monthly and seasonal climatology maps of different parameters including mean wave height and direction, mean max/min wave, extreme min/max wave, average mean/peak wave period, standard deviation for peak/mean wave period, percentiles mean/peak wave period, wave energy density and standard deviation for mean wave height;
- (ii) wave roses and wave frequency tables at selected points, including the approaches to the Maltese Islands;
- (iii) statistical information averaged over ten pre-defined zones.

Statistical analysis of extreme waves

As already introduced, ERA-40 data are available from October 1957 to August 2002 at the resolution of 1.5° on the entire globe. For the scopes of this study, we have used from the ECMWF archives the significant wave height only for nodes inside the Mediterranean basin during all the 45-years period. After the determination of the annual significant wave height maximum, from June 1957 to June 2002, we obtain 44 values for each grid cell.

The aim is to estimate the wave height levels corresponding to assigned return periods. From all the methods available for the evaluation of extreme wave heights all over the Mediterranean basin, the method of annual maximum series (AMS) was found to be the most theoretically founded for the current application. We have used data from WAM numerical model simulations at the spatial resolution of about 25 km and during a period of 13-years: from the 1st of July 1992 to the 31st of December 2005. Based on the AMS method we produced:

- ➢ maps of wave heights with a return period of 5, 10 and 50 years

Extreme heights of surface waves in selected points in the Central Mediterranean were calculated for return periods of 2, 5 10, 15, 20, 25, 50 and 100 years. The annual extreme values of significant wave height were ranked by increasing Hs in order to calculate empirical values for the cumulative frequency, the exceedance and the return period for each wave height occurring in the series. A simple last squares regression was performed for each grid, using the Gumbel reduced variant as the dependent variable and the ranked wave height as the independent variable.

Wave clustering

In order to obtain the wave clustering of all the Mediterranean area we have used the wave fields archived on the WAM database. We are interested in measure the degree of *local* spatial association for each cell in which the wave height is obtained from the WAM model. This allows us to define spatial cluster of cells in which wave heights are strongly associated. The tool of G statistic has been used with this purpose. Through this method we produced:

- ➢ maps of cluster of wave heights superimposed to maps of maximum height values.

The wave clustering in the Mediterranean Sea has been achieved by means of the G statistic.

This statistic shows areas where higher-than-average values tend to be found near each other or where lower-than-average values tend to be found near each other. Analysis of wave time-series, extreme waves and wave clustering: principal results The aim of the action 2.2 of the WERMED Project is to reconstruct the wave climatology in the Mediterranean Sea. In this paragraph we present only the more interesting results obtained dealing with the analysed wave field, remanding to the CD produced for the complete list of maps and tables.

Main results

Statistical analysis of wave time series for the Mediterranean basin

We report here the principal results of descriptive statistics over the entire Mediterranean Sea. For the complete set of results we will refer to the CD produced.

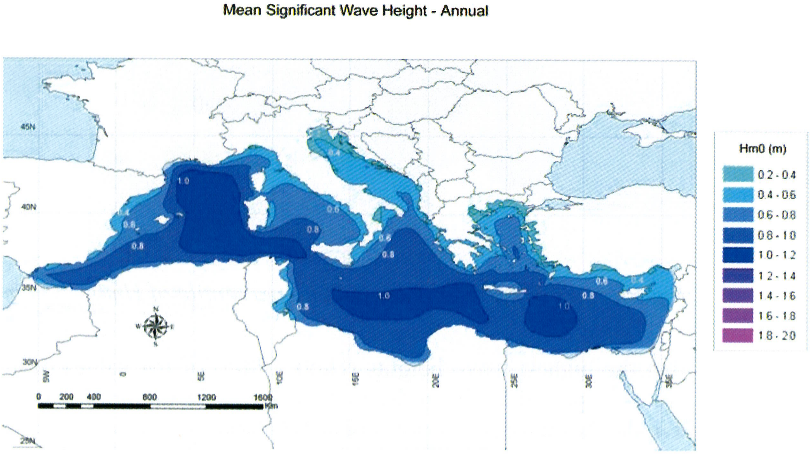

Mean Significant Wave Height - Annual

Figure 2 : Annual mean ECMWF WAM Hm0

This picture shows that the area with the highest mean Hs (about 1.2m) starts in correspondence with the Gulf of Lyon on the northern edge of the West Mediterranean Sea, extending all the way down to the African coasts. In the Central and Eastern part of the basin the region is placed in the middle of the basin, it follows the contours of the southern boundary being interrupted only by the geographical features of the major islands: Sicily and Creta. It ends just under the Aegean Sea. The lowest mean Hs areas are all along the northern boundary, in particular in the zones in front of the coasts of Liguria, in the North Adriatic Sea and in front of the North-Eastern coasts of the Mediterranean Sea; here the average Hs is about 0.3m. The spatial features seem not to change throughout the year, showing only lower mean values of Hs in spring and summer and higher mean Hs in winter and autumn.
As an indication of the distribution of the highest waves is interesting to study the percentiles. The following Figure 3 shows the annual 90th percentile of the Hm0 distribution.

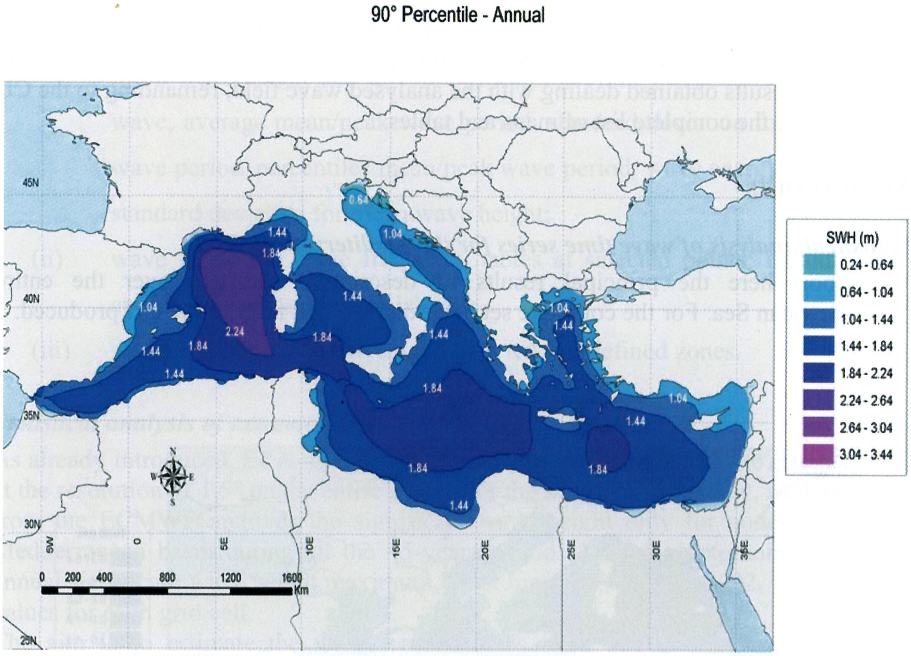


Figure 3: ECMWF WAM annual 90th percentile of Hm0

This map shows that the highest wave heights (Hm0 > 90% of the values of all the data considered) are as expected again in the Gulf of Lyon, in the north part of the African coasts and in the Aegean Sea and it is about 1.8-2.4m.

It can be of interest to compare the 90th percentiles obtained using the Hm0 RON buoy data distributions with the numerical simulations obtained from the ECMWF WAM analysis at the nearest grid points with respect to the buoys locations (Figure 4). The comparison shows that generally the observations are greater than the numerical simulations, the difference being more significant in the North part of the Mediterranean basin. We already outlined this fact making evident the need of a calibration procedure where data buoys are available.

The most apparent missing feature in the simulated climate map is an area of strong wave activity in the South part of the Tyrrhenian Sea. It is well known from the RON experience that the highest waves are found along the West coasts of Sardinia, the coast of Lazio and the coast of Calabria (Sections Sar-4, Laz-2 and Cal-1). Storms associated with strong North-Westerly winds in the central part of the Mediterranean Sea produces high waves typically exceeding 5 m Hm0 in all the mentioned sections. It would be reasonable to expect that pattern emerging from the map, but, instead, the Tyrrhenian Sea looks like to be sheltered from almost all the events that affect the western Sardinia.

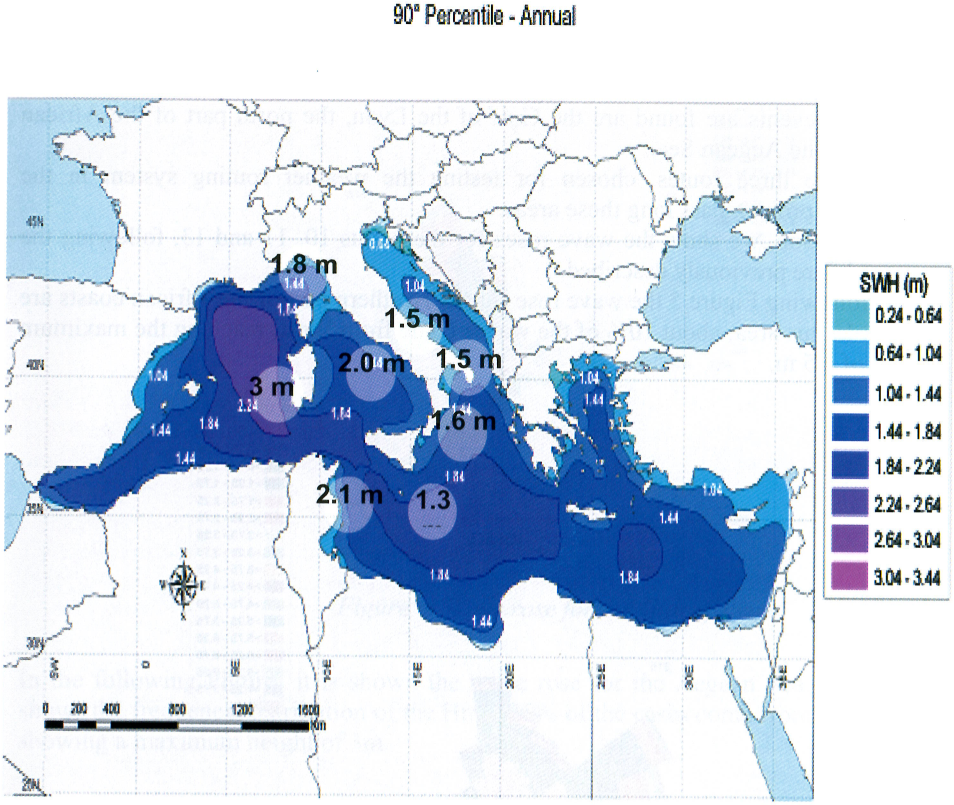

90° Percentile - Annual

Figure 4: Annual 90th percentile of the wave height calculated with ECMWF WAM model outputs. In the circle a comparison with RON buoys observations.

ECMWF_WAM: Wave roses

As said in the previous paragraphs, the zones of the Mediterranean where the more significant events are found are the Gulf of the Lyon, the north part of the African coasts and the Aegean Sea.

Two of the three routes, chosen for testing the weather routing system in the WERMED project, pass long these areas.

For this reason, we show the wave roses for the points 10, 11 and 13, following the nomenclature previously described.

In the following Figure 5 the wave rose for the Northern part of the African coasts are shown. In this area, about 10% of the waves come from West, reaching the maximum height of 4.5 m.

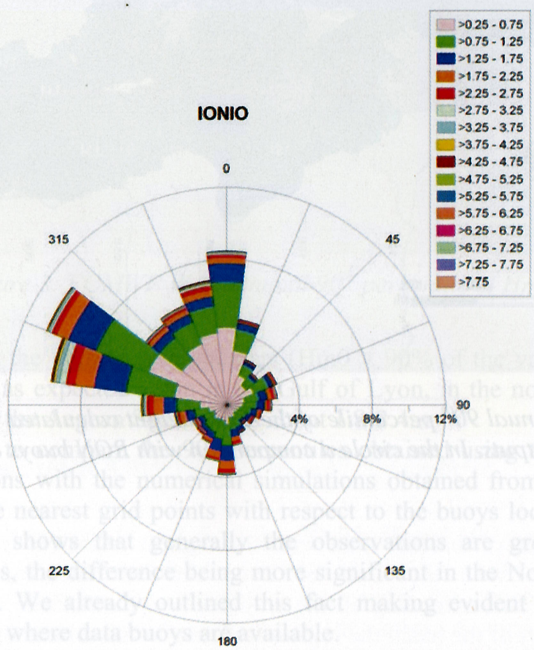


Figure 5: Wave rose for the north of the African coasts

In the following Figure the wave rose for the Gulf of Lyon is shown. In this area, about 16% of the cases come from north-west, largely exceeding the max height of 4.5 m.

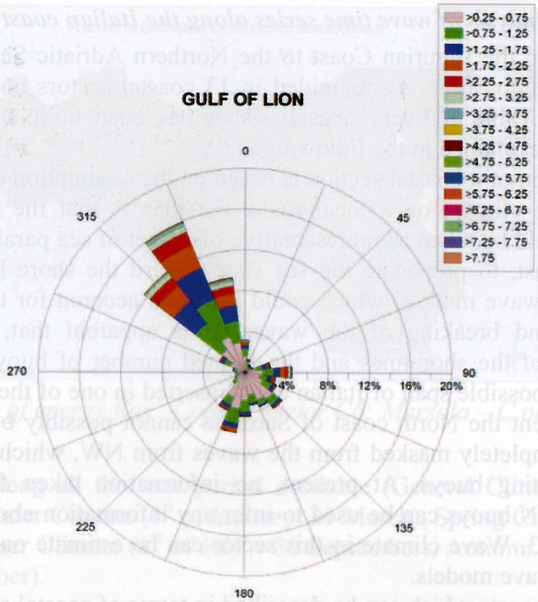


Figure 6: Wave rose for the Gulf of Lyon

In the following Figure it is shown the wave rose for the Aegean Sea. The figure shows the frequency distribution of the Hm0: 30% of the cases come from Northwest, showing a maximum height of 3m.

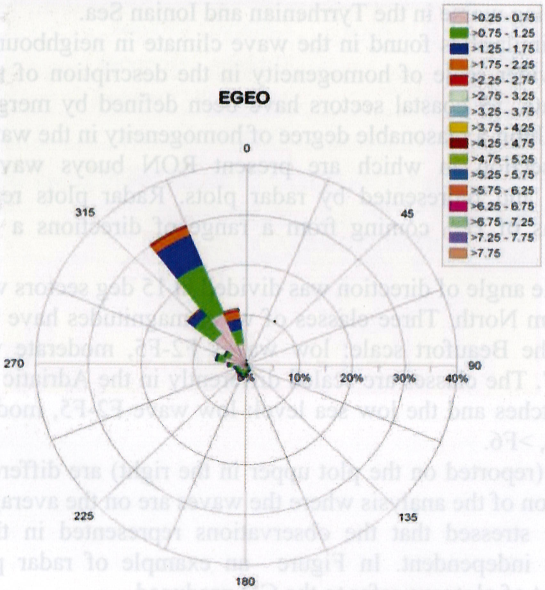


Figure 7: Wave rose for the Aegean Sea

Statistical analysis of wave time series along the Italian coast

Moving from the Ligurian Coast to the Northern Adriatic Sea and the Sardinia, the entire Italian coastline is subdivided in 13 coastal sectors codified from C1 to C13 (Figure 9 , Table). Every coastal sector has been built on two or more coastal sections, as explained in the following.

The definition of a coastal section is based on the assumption of relative homogeneity of the wave climate on a local scale, the idea is that the information of a buoy offshore could be taken as representative of a tract of sea parallel to the coast. This in order, at least, to propagate the sea state toward the shore by means of numerical small scale wave models, which could take into account for the shoaling, refraction, reflection and breaking of the waves. It is apparent that, given the geographic orientation of the shorelines and the limited number of buoys, it is not possible to have every possible span of Italian coast inserted in one of the sections. For example, at the moment the North coast of Sardinia cannot possibly be analysed in a section being it completely masked from the waves from NW, which are the only measured by the existing buoys. At present, no information taken from Alghero or Capo Comino RON buoys can be used to infer any information about what happens in the section Sar-3. Wave climate in this sector can be estimate only by mean of regional numerical wave models.

The Italian coasts which can be described in terms of coastal sectors (Figure 9 , Table) are:

Lig-2, Laz-21, Laz-2, sar-2, Sar-4, Cal-1, Sic-1, Sic-3, Sic-5, Cal-3, Pug-2,Abr-1, Mar-1, Emi-1

The remaining tracts, for which there is no available direct measurements of waves are: Lig-1,Tos-1, Cam-1, Cal-2, Sic-6, Sic-2, Pug-1, Ven-1.

It can be observed that sections cover almost all the Adriatic Sea western coasts, the situation being worse in the Tyrrhenian and Ionian Sea.

From the similarities found in the wave climate in neighbouring sections comes the idea of a wider scale of homogeneity in the description of the regional features of wave climate. 13 coastal sectors have been defined by merging those sections that seems to exhibit a reasonable degree of homogeneity in the wave climate distribution.

In every section in which are present RON buoys wave climates have been determined and represented by radar plots. Radar plots represent the number of observations of H_{m0} coming from a range of directions a in a selected range of heights.

The possible angle of direction was divided in 15 deg sectors with 0N denoting waves coming from North. Three classes of wave magnitudes have been used for the Hm0 based on the Beaufort scale: low waves F2-F5, moderate waves F6-F7 and high waves, >F7. The classes are scaled differently in the Adriatic Sea due to the reduced possible fetches and the low sea level: low wave F2-F5, moderate waves F5-F6 and high waves, >F6.

The scales (reported on the plot upper in the right) are different in order to improve the resolution of the analysis where the waves are on the average less energetic.

It must be stressed that the observations represented in the radar plots are not statistically independent. In Figure an example of radar plot is shown. For the complete set of plots we refer to the CD produced.

Figure 8 Radar plot of energy flux –Coastal sector C6: Marsala – C.po S. Alessio

Climates are defined along all the time period available (General Climate), and in every single season: Winter Climate (1st of January- 31 March), Spring Climate (1st of April – 30 June), Summer Climate (1st of July – 30 September), Autumn Climate (1st of October – 31 December).

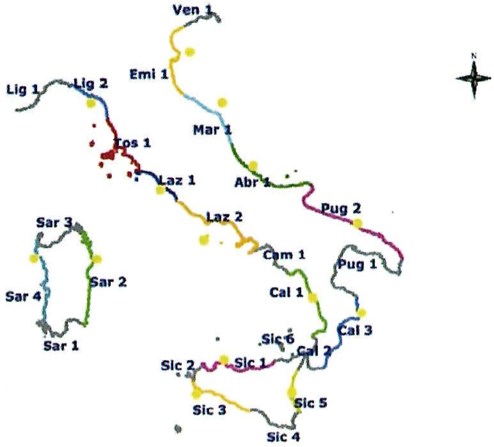


Figure 9 Coastal Sections

Coastal Sector	RON buoy	Id	Sections
Portofino - C.po Linaro	La Spezia - Civitavecchia	C1	Lig2-Tos1-Laz1
Capo d'Uomo - Acquamorta	Civitavecchia - Ponza	C2	Laz1-Laz2
Anzio - C.po Vaticano	Ponza - Cetraro	C3	Laz2-Cam1-Cal1
C.po Palinuro - C.po S.Vito	Cetraro - Palermo	C4	Cal1-Cal2-Sic1-Sic6
C.po Gallo - C.po Granitola	Palermo - Mazara del Vallo	C5	Sic1-Sic2-Sic3
Marsala - C.po S.Alessio	Mazara del Vallo - Catania	C6	Sic3-Sic4-Sic5
C.po Murro di Porco - P.ta Alice	Catania - Crotone	C7	Sic5-Sic6-Cal3
C.po Rizzuto - Bari	Crotone - Monopoli	C8	Cal3-Pug1-Pug2
Brindisi - Foce del Saline	Monopoli - Ortona	C9	Pug2-Abr1
P.ta Penna - Pesaro	Ortona - Ancona	C10	Abr1-Mar1
Numana - Grado	Ancona - Chioggia	C11	Mar1-Emi1-Ven1
C.po Carbonara - C.po Ferro	Siniscola	C12	Sar1-Sar2
C.po Ferro – C.po Spartivento Sardo	Alghero	C13	Sar3-Sar4-Sar5

Table 2 Coastal sectors

Statistical analysis of wave time series for the Central Mediterranean

HIPOCAS data, 44-years historical hourly series, have been used in order to study the sea basin of the Strait of Sicily.

Wave frequency distribution tables giving the percentage occurrence of wave height classes by wave directions were calculated for each month at 58 selected grid points over the study area in order to identify the dominant wave characteristics. The positions of these points are depicted in Figure .

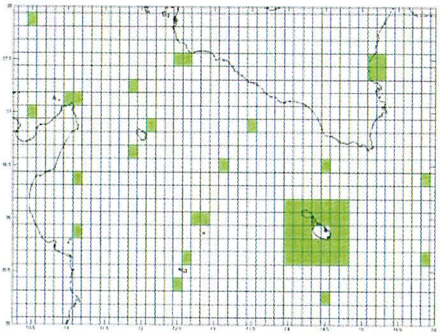
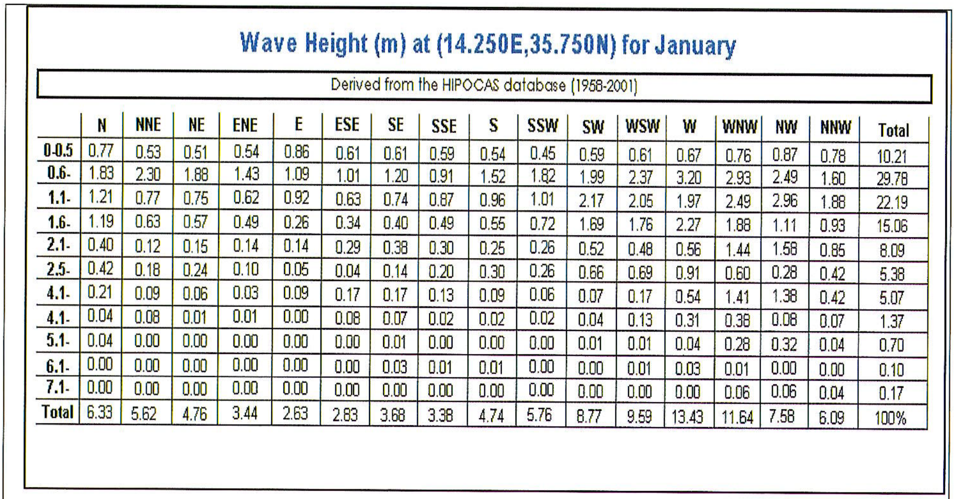


Figure 10 Selected grid points for wave rose and wave incidence analysis

These frequency distribution tables demonstrate the variability of wave conditions at each point on a monthly basis. Sixteen direction bins are considered. The % occurrence for each month is over the 44-year period, and for example 20% translates as roughly 6 days of the month. Results for the month of January (1958-2001) for the point 14.250ºE, 35.750ºN are given in Table as an example.

Each table is also summarized in two charts, the wave incidence plot that shows the prevailing wave directions, and the wave rose plot that gives the mean wave strength along each direction bin. Figure shows an example of wave incidence and rose plots in the case of the month of January at point 14.250ºE, 35.750ºN on the Southwest approaches to the Maltese Islands. The plots serve to demonstrate the dominant waves and their variability. An example of the wave incidence and wave rose graph for January (1958-2001) is given in Figure .



Wave Height (m) at (14.250E,35.750N) for January

Derived from the HIPOCAS database (1958-2001)

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
0-0.5	0.77	0.53	0.51	0.54	0.86	0.61	0.61	0.59	0.54	0.45	0.59	0.61	0.67	0.76	0.87	0.78	10.21
0.6-	1.83	2.30	1.88	1.43	1.09	1.01	1.20	0.91	1.52	1.82	1.99	2.37	3.20	2.93	2.49	1.60	29.78
1.1-	1.21	0.77	0.75	0.62	0.92	0.63	0.74	0.87	0.96	1.01	2.17	2.05	1.97	2.49	2.96	1.88	22.19
1.6-	1.19	0.63	0.57	0.49	0.26	0.34	0.40	0.49	0.55	0.72	1.69	1.76	2.27	1.88	1.11	0.93	15.06
2.1-	0.40	0.12	0.15	0.14	0.14	0.29	0.38	0.30	0.25	0.26	0.52	0.48	0.56	1.44	1.58	0.85	8.09
2.5-	0.42	0.18	0.24	0.10	0.05	0.04	0.14	0.20	0.30	0.26	0.66	0.69	0.91	0.60	0.28	0.42	5.38
4.1-	0.21	0.09	0.06	0.03	0.09	0.17	0.17	0.13	0.09	0.06	0.07	0.17	0.54	1.41	1.38	0.42	5.07
4.1-	0.04	0.08	0.01	0.01	0.00	0.08	0.07	0.02	0.02	0.02	0.04	0.13	0.31	0.38	0.08	0.07	1.37
5.1-	0.04	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.04	0.28	0.32	0.04	0.70
6.1-	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.01	0.00	0.00	0.01	0.03	0.01	0.00	0.00	0.10
7.1-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.04	0.17
Total	6.33	5.62	4.76	3.44	2.63	2.83	3.68	3.38	4.74	5.76	8.77	9.59	13.43	11.64	7.58	6.09	100%

Table 3 Frequency distribution by direction of wave height for January (1958-2001) at point 14.25ºE, 35.75ºN

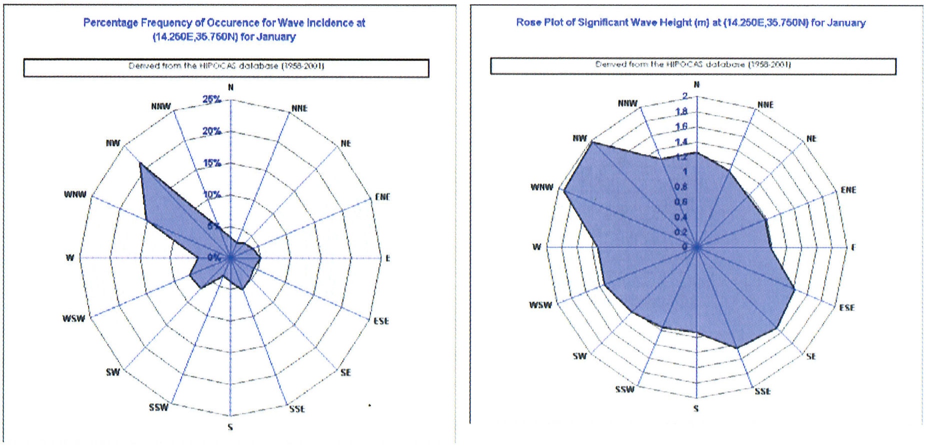


Figure 11 Wave incidence and wave rose plots for January (1958-2001) at point 14.250 E, 35.750 N

Statistical analysis of extreme waves in the Mediterranean basin

In this section are reported the results of extreme waves analysis. The expected significant wave height every 100 years in the Mediterranean Basin is illustrated in 12. In the Ionian Sea Hm0 return levels around 3.5m are expected every 100 years, which is clearly an underestimate. As was already done for the 90 percentile we show the expected 100 years return level of Hm0 map superimposed on RON observations at buoys locations (Figure). It is possible to note that the buoys results are much higher than the WAM ERA-40 analysis.

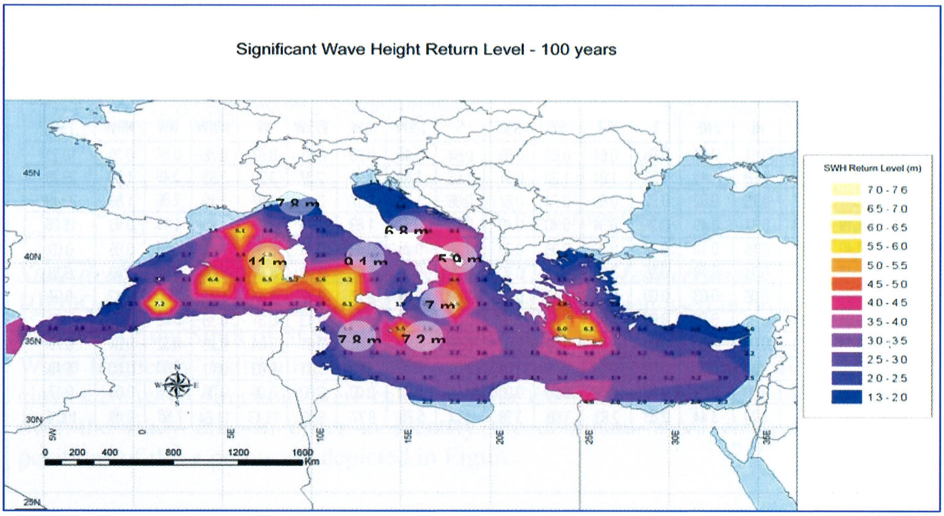


Figure 12 Map of wave height return level – 100 years
In the circle a comparison with RON buoys observations.

Statistical analysis of extreme waves in the Central Mediterranean basin

A Gumbel distribution (Gumbel, 1958) was fitted to each of the annual extreme values. This asymptotic distribution, also known as a Fisher-Tipett type I distribution, is commonly used with extreme values. The parameters of the Fisher-Tipett type I distribution of extreme values were estimated using two methods:

- The Graphic Method and
- The Method of Moments (Leder et al., 1998)

Results of the extreme value analysis at the point 14.5°E, 35.25°N are summarized in Table . The 100-year wave is the significant wave height likely to be exceeded only once in a century on average, and correspond to a cumulative probability of 0.99. Therefore the chance of having a Hs of 10.8m in any particular year is 1%. The 95% confidence interval gives upper and lower limits of 12.3m and 9.3m, respectively, within which one may expect to find a true value of the 100-year wave with 95% probability. On average, a significant wave height of 7.6m can be expected to occur in the study area every 5 years. There is a 95% probability that an extreme Hs of between 7.0m and 8.2m will occur in a 5-year interval.

Return period (years)	Significant wave height Hs (m)	Lower 95% confidence limit (m)	Upper 95% confidence limit (m)
2	6.2	5.8	6.5
5	7.6	7.0	8.2
10	8.4	7.6	9.2
15	8.8	7.9	9.8
20	9.1	8.1	10.1
25	9.3	8.2	10.4
50	10.1	8.8	11.4
100	10.8	9.3	12.3

Table 4: Extreme significant wave heights Hs for different return periods and their associated 95% confidence limits at the point 14.5°E, 35.25°N

The probability Po that an event with return period TR will be exceeded during a period of n years is Po=1-(1-Pa)^n, where Pa is the annual probability (Pa=1-P(x)). For a 10% probability of exceedance (Po) over a 5-year (n) interval, the corresponding return period is 48 years. In other words, a design Hs with a return period of 48 years only has 10% probability of being exceeded in a design life of 5 years. Table shows the Hs with a 10% probability of exceedance over different life spans (n=1, 2, 3, 4 and 5 years). A Hs of 8.3m (that occurs once in 10 years on average) has a probability of 90% that will not be exceeded during a period of one year.

Probability of exceedance Po	n (years)	TR (years)	Significant wave height (m)
0.10	1	10	8.3
0.10	2	19.5	9.1
0.10	3	29	9.5
0.10	4	38.5	9.8
0.10	5	48	10.0

Table 5: Significant wave heights with 10% of probability of exceedance (Po) over a different exposure period of n years.

Cluster analysis of wave clusters

Referring to the annual mean Hm0 map, we found a substantial agreement between the cluster detected with the G statistic, indicated in blue, with the region in which we detected the higher Hm0 (Figure).
When the season changes, the results keeps very similar, only in the summer (Figure) the zone of higher waves moves towards the Aegean Sea, due probably to the influence of the Meltemi wind.
In order to give a physical meaning to the spatial clusters (of ECMWF WAM Hm0) detected by means of the G tools, it can be clearly seen that the cluster is characterised by the homogeneous areas with the highest waves.

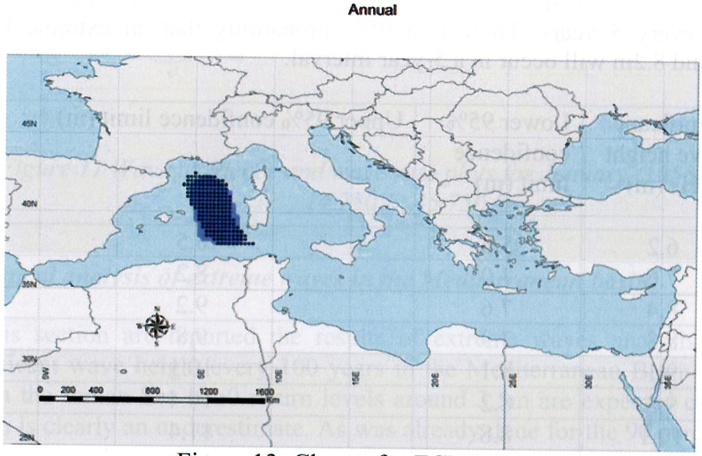

Annual

Figure 13: Cluster for ECMWF WAM Hm0

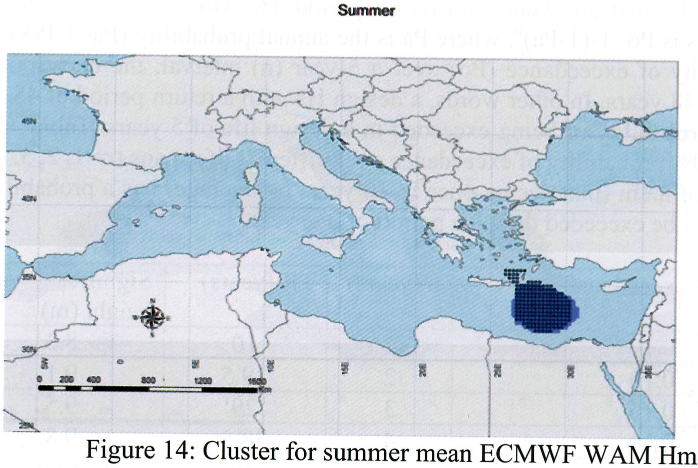

Summer

Figure 14: Cluster for summer mean ECMWF WAM Hm0

IV. WEATHER AND MEDITERRANEAN NAVIGATION.

K. Strataridakis, Capt. S. Vekkios, A. Drago, Capt. A. Gambina.

Introduction

Wermed action 2.3 requires the compilation of information relating to navigational risks that key ship routes in the Mediterranean can encounter. This document reports the findings relevant to vessels sailing Adriatic & Aegean sea (Greece and Italy) and the central Mediterranean trade routes (Malta).

Methodology

The questionnaire was prepared to the basis to extrapolate data from these records according to the Masters' experience, which are traveling several times in the same route.

Minoan Lines , operating ro-ro / passenger vessels on the routes of Adriatic sea Patras – Ancona & Patras – Venice, as well as on the route of Aegean Sea Piraeus – Heraklio.

The vessels' deck log book were examined for a period between March 2007 and November 2007. The results are given in the next paragraph.

For the Maltese shipping companies that were able to contribute to the compilation of the data that was acquired, the criteria utilised included:

- The trades served by the vessel to be in conformity with the Wermed routes established in the ARPAL report dated 26/07/2006;

- The ship type utilised on the route to be constant;

- Access to weather and ship records for a period of time spanning at least a minimum of 12 months.

Deviations

For the Aegean and Adriatic routes, from the reviewed documents resulted that not any voyages were cancelled due to bad weather as well as, no any deviation or alternative route was necessary to be done.

For the central Mediterranean routes the instances that the vessel routes where deviated are listed below. Through the perusal of records and interviews with ship's staff, it was ascertained that seeking an alternative route, (in the cases listed below, steaming on the western side of Corse and Sardegna) was not considered desirable or necessary.

1)
5 March 2006 Genova to Catania
Weather S to SW 8
Voyage distance increased by approx. 23 nm
Voyage time increased by 6.7 hours

2)
10 March 2006 Catania to Genova
Weather NW 8
Voyage time increased by 2.7 hours

3)
13/14 February 2007 Catania to Genova
Weather NW 8/9
Voyage time increased by 4.5 hours

Distance Catania/Genova 539 nm, typical steaming time 29 hours

Conclusion

The effect of wind and sea on our High Speed Ferries, in combination with the dimensions of the vessels on which are fitted fin stabilizers, during the period between March 2007 and November 2007, was absolutely normal for the vessels traveling around the Aegean and Adriatic.

During the period under review, for the central Mediterranean navigation (Malta), no voyages were cancelled due to bad weather. Great emphasis was taken, as it is the norm with a vessel providing a liner service, to keep to the published schedule of sailing times and ports. Any deviations experienced were compensated by other ways of making up the time lost i.e. increased speed at sea and a faster turn around in port. An important factor to be borne in mind is that the vessels are relatively large (approximately 200 metres) and of very good sea-keeping qualities. The fact that no passengers were carried by the ship under review, made the passenger comfort criterion redundant.

For the Aegean and Adriatic routing, the ships under review were two ships of MINOAN LINES:

H.S.F. OLYMPIA PALACE

MAIN PARTICULARS	
LENGTH OVER ALL	214.0 M
LENGTH BETWEEN PERP.	191.22M
BREADTH	26.40 M
FLAG	GREEK
PORT OF REGISTRY	HERAKLIO
Nr OF REGISTRY	35
CALL SIGN	SYHI
IMO Nr	9220330
DEPTH TO UPPER DECK	15.50 M
DEPTH TO MAIN DECK	10 M
NET TONNAGE	13560 T
GROSS TONNAGE	36825 T
DEADWEIGHT	7329,5 T
SERVICE SPEED	Apprx. 31,5 kn
CLASS	GL+100A5 E3 PASSENGER RO-RO SHIP, +MC AUT
PLACE & DATE OF BUILD	2001 – FINCANTIERI ITALY

MAIN MACHINERY	
MAIN ENGINE	WARTSILA NSD 16V46C 4SETSX 16,800KWX 500RPM
CONTROLLABLE-PITCH PROPELLER	4 BLADES X 2 SETS

RO/RO CAPACITIES	
TRAILER	1932 LANE MRS
PRIVATE CARS	110

RO/RO EQUIPMENTS	
STERN RAMP DOOR	2
FIXED RAMP	1
HOISTABLE RAMP	1

ACCOMMODATION	
Nr OF PASSENGERS ON SHORT INTERNATIONAL VOYAGES	1912 S 926 W

H.S.F. KNOSSOS PALACE

MAIN PARTICULARS	
LENGTH OVER ALL	214.0 M
LENGTH BETWEEN PERP.	191.22M
BREADTH	26.40 M
FLAG	GREEK
PORT OF REGISTRY	HERAKLIO
Nr OF REGISTRY	31
CALL SIGN	SYQO
IMO Nr.	9204063
DEPTH TO UPPER DECK	15.50 M
DEPTH TO MAIN DECK	10 M
NET TONNAGE	15.475 T
GROSS TONNAGE	24.003 T
DEADWEIGHT	7.422 T
SERVICE SPEED	Apprx. 31,5 kn
CLASS	GL +100A5 E3 PASSENGER RO-RO SHIP, + MC AUT
PLACE & DATE OF BUILT	2000 – FINCANTIERI ITALY

MAIN MACHINERY	
MAIN ENGINE	WARTSILA NSD 16V46C 4SETSX 16,800KWX 500RPM
CONTROLLABLE-PITCH PROPELLER	4 BLADES X 2 SETS
BOW THRUSTER	2 X 1,300 KW
STERN THRUSTER	2 X 1000 KW

RO/RO CAPACITIES	
TRAILER	1500 LANE MTRS
PRIVATE CARS	110

RO/RO EQUIPMENTS	
STERN RAMP DOOR	2
FIXED RAMP WITH COVER	1
HOISTABLE RAMP	1

ACCOMMODATION	
Nr OF PASSENGERS ON SHORT INTERNATIONAL VOYAGES	2190 S 1634 W

For Malta, a Maltese shipping agency, Malta Motorways of Sea Ltd. operating ro-ro and ropax and PCC vessels on the routes relevant to Wermed responded positively to a request for information. A series of visits to the vessel whilst at her berth in the port of Valletta ensued. The vessel's deck log books were examined for a period of time between March 2006 and March 2007, with a gap in the records for the months between end October 2006 and beginning December 2006. The results are given below:

Ship Data

Name of Vessel	Eurocargo Valencia
Gross Tonnage	20883t
Net Tonnage	6264t
Deadweight	14500t
Displacement	22260t
LOA	195.1m
Beam	25.2m
Summer Draught	7.4m
Main Engine	11250kW @ 90% MCR
Fuel Type	HFO 380 CSt
Max. Speed	19.7 knots

V. NUMERICAL MODELLING FOR WEATHERROUTING.

L. Villa, C. Nieddu, P. Marsiaj, S. Corsini, A. Orasi, S. Mariani, E. Trovatore, L. Pedemonte, S. Gallino, D. Sacchetti, C. Ratto, A. Drago, K. Lagouvardos, V. Kotroni, K. Mazi, A. Maragoudakis, V. Fragouli, A. Milesi, L. Folso.

Foreward

The aim of Action 3.1 of WERMED Project is to create the informatics tools in order to simulate the behaviour of ships sailing the Mediterranean sea. These tools are an ensemble of things like hardware, software, meteorological and wave numerical models and a certain number of informatics procedures. These thinks are managed by a personal computer server located in Cagliari, Italy.

In this report we briefly describe these informatics tools created in the contest of Action 3.1 in order to produce weatherrouting bulletins for a certain kind of real vessel and real Mediterranean routes.

In particular, in Chapter 2 we show the characteristics of the PC server where all the procedures work and where simulations take place. We here even describe the file system and the communication protocol.
In Chapter 3 we describe the way the simulations take place using CETENA cost function.
Finally, in Chapter 4 we present the operational weatherrouting simulations and how they work in order to produce the weatherrouting bulletin.

The following text is just an overview on the above mentioned topics. For every questions and for more detailed description of weatherrouting numerical models system please refer to others WERMED Action 3 sections or directly to the authors.

Weatherrouting numerical tools

In this chapter we will describe the instruments used in the Action 3.1 of WERMED Project with the aim to make the service of Weatherrouting operational for some routes of navigation over the Mediterranean Sea. "Numerical tools" are all those procedures developed in WERMED Project in order to generate daily bulletins of ship routing associate to particular routs in the Mediterranean and for specific goods or passengers ships. In particular, we here will describe the machine on which numerical procedures operate, the file systems and the communication protocols that allow to generate the basilar information of daily WERMED bulletins.

The RAS server

The infrastructure required for running the software has been provided by the Assessorato ai Trosporti of the Regione Autonoma della Sardegna - RAS at their "Centro di Calcolo" (CED). It consists of a server with:

- ☐ dual processor Intel(R) Xeon(TM) running at 2.40GHz;
- ☐ 2Gb of RAM;
- ☐ controller RAID with disk space of 100 GB;
- ☐ double network card with speed of 100 Mbit.

The operating system Linux (Centos 4.5 distribution) was installed on the server, together with applications, compilers and libraries required for the compilation and execution of the software. In particular, to maximize and optimise the execution of the software, the Intel Fortran compiler version 9.1.045 was installed.

The server is connected through a switch to the local network of CED and, by means of a static address, it can be accessed by other partners of the WERMED project.

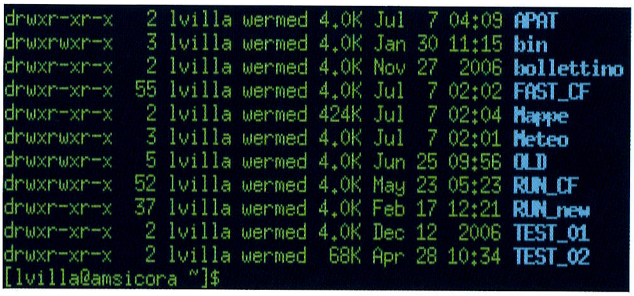
Transfers speed of about 470 kb/sec when connecting to the internet were easily achieved, thanks to the 4 Mbps connection provided by the Regione Autonoma della Sardegna.

The users had interactive access to the server through the secure protocol ssh. The encrypted traffic provided the required level of security and privacy.

The software has been continually updated by means of the native updating facilities of the Centos distribution, which allow for a remote maintenance.

The file system

Users can login into the RAS server by means of SSH comunication protocol. From any pc, anywhere an internet connection is available, it is possibile to enter the server and open a shell window giving user and password. At this time, users are in the home directory of server RAS.
Following Figure shows what a user see when reaches RAS server.



```
drwxr-xr-x   2 lvilla wermed 4.0K Jul  7 04:09 APAT
drwxrwxr-x   3 lvilla wermed 4.0K Jan 30 11:15 bin
drwxr-xr-x   2 lvilla wermed 4.0K Nov 27  2006 bollettino
drwxr-xr-x  55 lvilla wermed 4.0K Jul  7 02:02 FAST_CF
drwxr-xr-x   2 lvilla wermed 424K Jul  7 02:04 Mappe
drwxrwxr-x   3 lvilla wermed 4.0K Jul  7 02:01 Meteo
drwxrwxr-x   5 lvilla wermed 4.0K Jun 25 09:56 OLD
drwxrwxr-x  52 lvilla wermed 4.0K May 23 05:23 RUN_CF
drwxr-xr-x  37 lvilla wermed 4.0K Feb 17 12:21 RUN_new
drwxr-xr-x   2 lvilla wermed 4.0K Dec 12  2006 TEST_01
drwxr-xr-x   2 lvilla wermed  68K Apr 28 10:34 TEST_02
[lvilla@amsicora ~]$
```

Figure 0.1: Home directory of RAS server.

Among all the visibile directories, the following are used for the numerical simulations of WERMED Project:

1. APAT;
2. Meteo;
3. Mappe;
4. FAST_CF.

In *APAT* folder, files of meteorological and sea state forecast are stored. Those files are produced by numerical models in use at Agenzia per la Protezione dell'Ambiente e per i servizi Tecnici – APAT (http://www.apat.gov.it/pre_mare/).

Even in *Meteo* folder files of meteorological and sea state forecast are stored. Those files are produced by operational models at Dipartimento di Fisica dell'Università di Genova – DIFI (http://www.fisica.unige.it/atmosfera/previsioni.htm/).

In *Mappe* folder wind and wave maps are stored. In particular, those maps show wind fields and sea state for some specific areas, those areas for which weatherrouting bulletins are daily produced by WERMED Project.

FAST_CF folder is the core of the entire system of informatics tools. In this place all tools created for the Project and necessary for weatherrouting simulations are stored. In the following sections we briefly describe those folders.

Weather and sea state numerical models

As shown in previous paragraph, in order to perform weatherrouting simulation there are used two family of numerical models: weather and sea state forecast numerical models.

QBOLAM meteorological model and WAM sea state model are used by APAT in Rome, Italy.

QBOLAM is running since 2001 initialized by initial and boundary condition from General Circulation Model (European Centre for Medium Range Weather Forecasts – ECMWF) and it daily produces 42 hours forecast on 10 km resolution grid, all over Mediterranean Sea. Next Figure 0.2 shows an example of 10 m wind field produced by QBOLAM simulations.

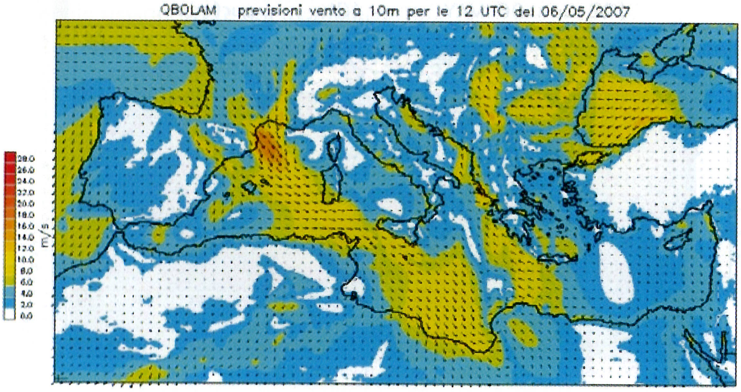


Figure 0.2: Wind field a 10 m produced by QBOLAM at APAT.

WAM sea state model recently start running at APAT and it daily produces 42 hours forecast on 10 km resolution grid, all over Mediterranean Sea. It is forced by means of 10 m winds field produced by QBOLAM. Next Figure 0.3 shows an example of significant wave height produced by WAM simulations

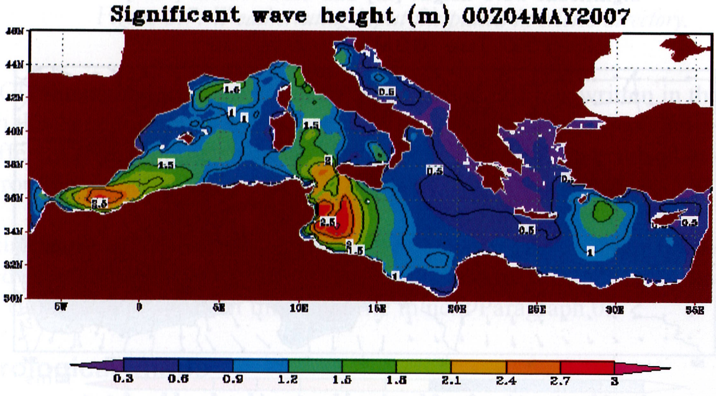


Figure 0.3: Significant wave height field produced by WAM at APAT.

BOLAM meteorological model and WAM sea state model are used by DIFI in Genoa, Italy.

The version of BOLAM used for the Project is running since 2004 and it is initialized by initial and boundary condition from Global Forecast System (National Centers for Environmental Prediction - NCEP) and it daily produces 72 hours forecast on 21 km resolution grid, all over Mediterranean Sea. Next Figure 0.4 shows an example of 10 m wind field and 2 m temperature produced by BOLAM simulations.

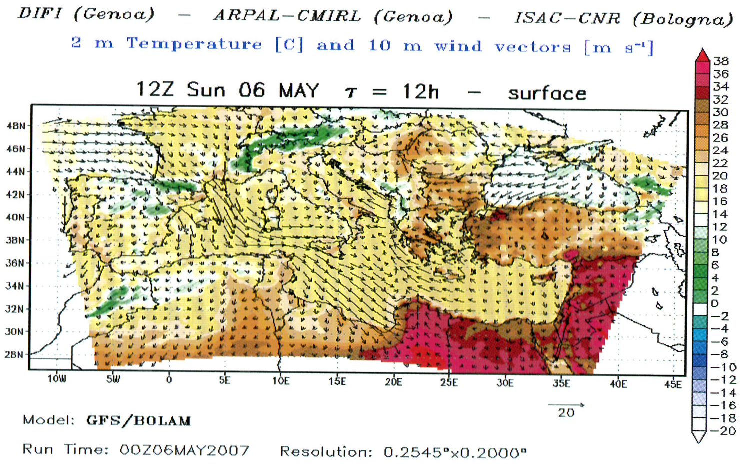


Figure 0.4: Wind field a 10 m and 2 m temperature produced by BOLAM at DIFI.

WAM sea state model is running since September 2006 at DIFI and it daily produces 69 hours forecast on 14 km resolution grid all over Mediterranean Sea. It is forced by means of 21 m winds field produced by BOLAM. Next Figure 0.5 shows an example of significant wave height produced by WAM simulations

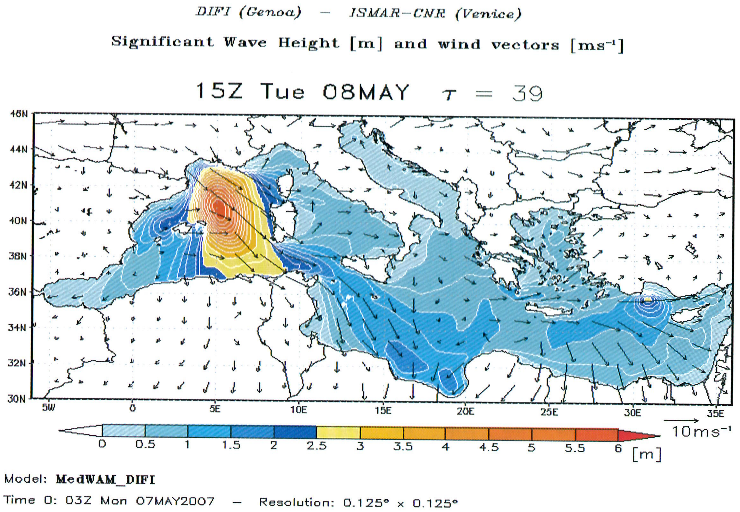
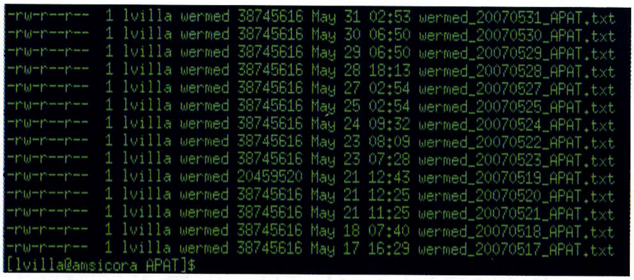


Figure 0.5: Significant wave height field produced by WAM at DIFI.

Input data from APAT and DIFI

In *APAT* folder files daily produced by APAT for WERMED Project are placed. As we can see in the following, those files can be used as initial condition to weatherrouting software, but, presently, they are not operatively used. They are just store in a database and they are use only in case of need, if analogous files from DIFI, for any possible reason, were not available.
Following Figure 0.6 shows weatherrouting input files placed in *APAT* directory.



```
-rw-r--r--  1 lvilla wermed 38745616 May 31 02:53 wermed_20070531_APAT.txt
-rw-r--r--  1 lvilla wermed 38745616 May 30 06:50 wermed_20070530_APAT.txt
-rw-r--r--  1 lvilla wermed 38745616 May 29 06:50 wermed_20070529_APAT.txt
-rw-r--r--  1 lvilla wermed 38745616 May 28 18:13 wermed_20070528_APAT.txt
-rw-r--r--  1 lvilla wermed 38745616 May 27 02:54 wermed_20070527_APAT.txt
-rw-r--r--  1 lvilla wermed 38745616 May 25 02:54 wermed_20070525_APAT.txt
-rw-r--r--  1 lvilla wermed 38745616 May 24 09:32 wermed_20070524_APAT.txt
-rw-r--r--  1 lvilla wermed 38745616 May 23 08:09 wermed_20070522_APAT.txt
-rw-r--r--  1 lvilla wermed 38745616 May 23 07:28 wermed_20070523_APAT.txt
-rw-r--r--  1 lvilla wermed 20459520 May 21 12:43 wermed_20070519_APAT.txt
-rw-r--r--  1 lvilla wermed 38745616 May 21 12:25 wermed_20070520_APAT.txt
-rw-r--r--  1 lvilla wermed 38745616 May 21 11:25 wermed_20070521_APAT.txt
-rw-r--r--  1 lvilla wermed 38745616 May 18 07:40 wermed_20070518_APAT.txt
-rw-r--r--  1 lvilla wermed 38745616 May 17 16:29 wermed_20070517_APAT.txt
[lvilla@amsicora APAT]$
```

Figure 0.6: Weatherruting input file placed in APAT directory.

In *Meteo* folder files daily produced by DIFI for WERMED Project are placed. Those files are operatively used as initial condition to weatherrouting software. Next Figure 0.7 shows weatherrouting input files placed in *Meteo* directory.

```
drwxrwxr-x  2 lvilla wermed 12K Jul  7 02:01 DATA
-rw-r--r--  1 lvilla wermed 42M Jul  7 01:43 wermed_input.txt
[lvilla@amsicora Meteo]$
```

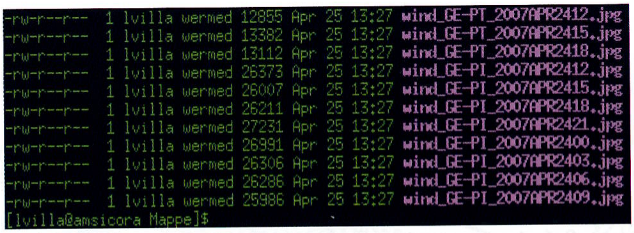
Figure 0.7: Weatherruting input file placed in Meteo directory.

The ASCII file named *wermed_input.txt*, produced at DIFI, is written in the same way and with the same format as APAT one. The only difference between those two files, apart different source of meteo and sea data, is that the DIFI one is used every day by weatherrouting numerical simulations.

DATA directory is the data base of all *wermed_input.txt* files that DIFI has been produced since the beginning of the operational phase of WERMED Action 3.1.
We will came back to speak of this input file in next Paragraph 0.

Meteorological maps

Mappe folder contains the image files that show the wind fields and the state of the sea for Mediterranean areas of interest for WERMED Project simulations. Such maps are daily produced by DIFI on the bases of the forecasts of the same weather and sea state models, described in the previous paragraph. In following Figure 0.8 *Mappe* folder is shown and there are visible some image files of wind and wave fields as above mentioned produced.



```
-rw-r--r--  1 lvilla wermed 12855 Apr 25 13:27 wind_GE-PT_2007APR2412.jpg
-rw-r--r--  1 lvilla wermed 13382 Apr 25 13:27 wind_GE-PT_2007APR2415.jpg
-rw-r--r--  1 lvilla wermed 13112 Apr 25 13:27 wind_GE-PT_2007APR2418.jpg
-rw-r--r--  1 lvilla wermed 26373 Apr 25 13:27 wind_GE-PI_2007APR2412.jpg
-rw-r--r--  1 lvilla wermed 26007 Apr 25 13:27 wind_GE-PI_2007APR2415.jpg
-rw-r--r--  1 lvilla wermed 26211 Apr 25 13:27 wind_GE-PI_2007APR2418.jpg
-rw-r--r--  1 lvilla wermed 27231 Apr 25 13:27 wind_GE-PI_2007APR2421.jpg
-rw-r--r--  1 lvilla wermed 26991 Apr 25 13:27 wind_GE-PI_2007APR2400.jpg
-rw-r--r--  1 lvilla wermed 26306 Apr 25 13:27 wind_GE-PI_2007APR2403.jpg
-rw-r--r--  1 lvilla wermed 26286 Apr 25 13:27 wind_GE-PI_2007APR2406.jpg
-rw-r--r--  1 lvilla wermed 25986 Apr 25 13:27 wind_GE-PI_2007APR2409.jpg
[lvilla@amsicora Mappe]$
```

Figure 0.8: Mappe folder.

Next Figure 0.9 shows two of above mentioned maps that were produced for Cagliari – Larnaca route: wind field, on the left, and wave field on the right.

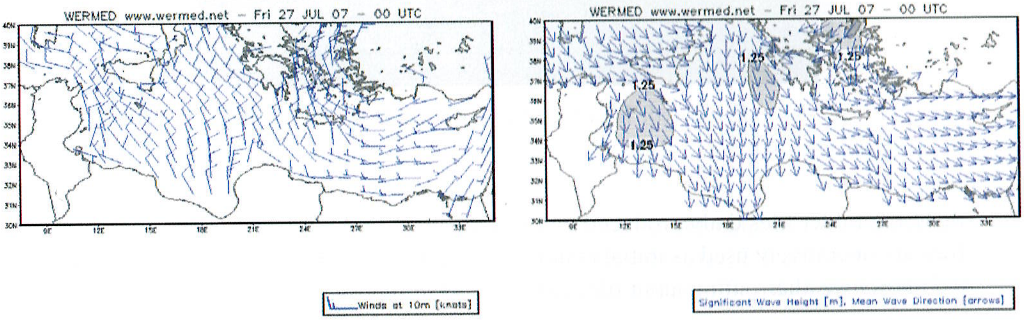
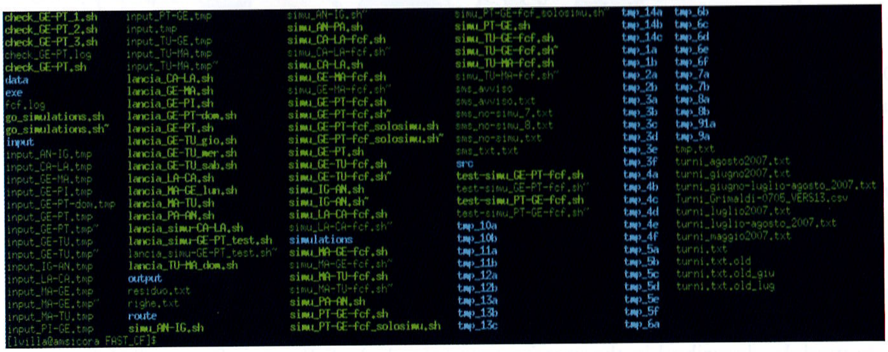


Figure 0.9: Cagliari – Larnaca route wind (left) and waves (right) maps.

Simulation objects

In *FAST_CF* folder all the file created in order to perform numerical simulations of weatherrouting, as it is planned for Action 3.1 of WERMED Project are placed. In the following Figure 0.10 it is shown the content of FAST_CF directory.



```
check_GE-PT_1.sh     input_PT-GE.tmp             simu_AN-IG.sh~               simu_PT-GE-fcf_solosimu.sh~  tmp_14a  tmp_6b
check_GE-PT_2.sh     input.tmp                   simu_AN-PA.sh                simu_PT-GE.sh                tmp_14b  tmp_6c
check_GE-PT_3.sh     input_TU-GE.tmp             simu_CA-LA-fcf.sh            simu_TU-GE-fcf.sh            tmp_14c  tmp_6d
check_GE-PT.log      input_TU-MA.tmp             simu_CA-LA-fcf.sh~           simu_TU-GE-fcf.sh~           tmp_1a   tmp_6e
check_GE-PT.sh       input_TU-MA.tmp~            simu_CA-LA.sh                simu_TU-MA-fcf.sh            tmp_1b   tmp_6f
data                 lancia_CA-LA.sh             simu_GE-MA-fcf.sh            simu_TU-MA-fcf.sh~           tmp_2a   tmp_7a
exe                  lancia_GE-MA.sh             simu_GE-MA-fcf.sh~           sms_avviso                   tmp_2b   tmp_7b
fcf.log              lancia_GE-PI.sh             simu_GE-PT-fcf.sh            sms_avviso.txt               tmp_3a   tmp_8a
go_simulations.sh    lancia_GE-PT-dom.sh         simu_GE-PT-fcf.sh~           sms_no-simu_7.txt            tmp_3b   tmp_8b
go_simulations.sh~   lancia_GE-PT.sh             simu_GE-PT-fcf_solosimu.sh   sms_no-simu_8.txt            tmp_3c   tmp_91a
input                lancia_GE-TU_gio.sh         simu_GE-PT-fcf_solosimu.sh~  sms_no-simu.txt              tmp_3d   tmp_9a
input_AN-IG.tmp      lancia_GE-TU_mer.sh         simu_GE-PT.sh                sms_txt.txt                  tmp_3e   tmp.txt
input_CA-LA.tmp      lancia_GE-TU_sab.sh         simu_GE-TU-fcf.sh            src                          tmp_3f   turni_agosto2007.txt
input_GE-MA.tmp      lancia_LA-CA.sh             simu_GE-TU-fcf.sh~           test-simu_GE-PT-fcf.sh       tmp_4a   turni_giugno2007.txt
input_GE-PI.tmp      lancia_MA-GE_lun.sh         simu_IG-AN.sh                test-simu_GE-PT-fcf.sh~      tmp_4b   turni_giugno-luglio-agosto_2007.txt
input_GE-PT-dom.tmp  lancia_MA-TU.sh             simu_IG-AN.sh~               test-simu_PT-GE-fcf.sh       tmp_4c   Turni_Grimaldi-0705_VERS13.csv
input_GE-PT.tmp      lancia_PA-AN.sh             simu_LA-CA-fcf.sh            test-simu_PT-GE-fcf.sh~      tmp_4d   turni_luglio2007.txt
input_GE-PT.tmp~     lancia_simu-CA-LA.sh        simu_LA-CA-fcf.sh~           tmp_10a                      tmp_4e   turni_luglio-agosto_2007.txt
input_GE-TU.tmp      lancia_simu-GE-PT_test.sh   simulations                  tmp_10b                      tmp_4f   turni_maggio2007.txt
input_GE-TU.tmp~     lancia_simu-GE-PT_test.sh~  simu_MA-GE-fcf.sh            tmp_11a                      tmp_5a   turni.txt
input_IG-AN.tmp      lancia_TU-MA_dom.sh         simu_MA-GE-fcf.sh~           tmp_11b                      tmp_5b   turni.txt.old
input_LA-CA.tmp      output                      simu_MA-TU-fcf.sh            tmp_12a                      tmp_5c   turni.txt.old_giu
input_MA-GE.tmp      residuo.txt                 simu_MA-TU-fcf.sh~           tmp_12b                      tmp_5d   turni.txt.old_lug
input_MA-GE.tmp~     righe.txt                   simu_PA-AN.sh                tmp_13a                      tmp_5e
input_MA-TU.tmp      route                       simu_PT-GE-fcf.sh            tmp_13b                      tmp_5f
input_PI-GE.tmp      simu_AN-IG.sh               simu_PT-GE-fcf_solosimu.sh   tmp_13c                      tmp_6a
[lvilla@amsicora FAST_CF]$
```

Figure 0.10: FAST_CF folder.

Many of the objects shown in this figure: folders, scripting language files, database, etc., are not used in numerical simulations. They become from tests and old model chains non yet used.
Files really used are those necessary to "cost function", a tool developed by CETENA S.p.A. for WERMED Project, described in following Paragraph 0, and all the procedures that drive weatherrouting simulations.

From the moment that a detailed description of such instruments goes beyond the purposes of the present text and in the next paragraphs it will be given a description of principle characteristics of those instruments. For further details about these files involved in simulations and about the scripting language of simulation procedures, it is possible to ask directly to the authors of this report.

RAS server connectivity

In order to execute the numerical simulations as planned on the Action 3.1 of WERMED Project, it is chosen to configure the server RAS in such way that could be used in remote through a SSH connection. Such system, that allows the PC to communicate via internet using safe protocols of transfer, it needs to enter user and password that are associates to a singular IP address.

Moreover, in this machine it is installed a software able to send e-mails by means of scripting languages. In particular, it is possible to send to one or more mail addresses the results of weatherrouting simulations, once they are produced by occasional or daily operational simulations.

The numerical simulations

Beginning from weather and wave data and fixed the time of departure, the cruise speed, the usable engine mean power and modifying three configuration parameters, every numerical simulation allows to know the forecast of the arrival time in the port of destination of the selected ship, beyond to various information like weather and wave parameters that the ship will encounter during its way. In following Figure 0.1 it is shown the flow chart of the weatherrouting simulations.

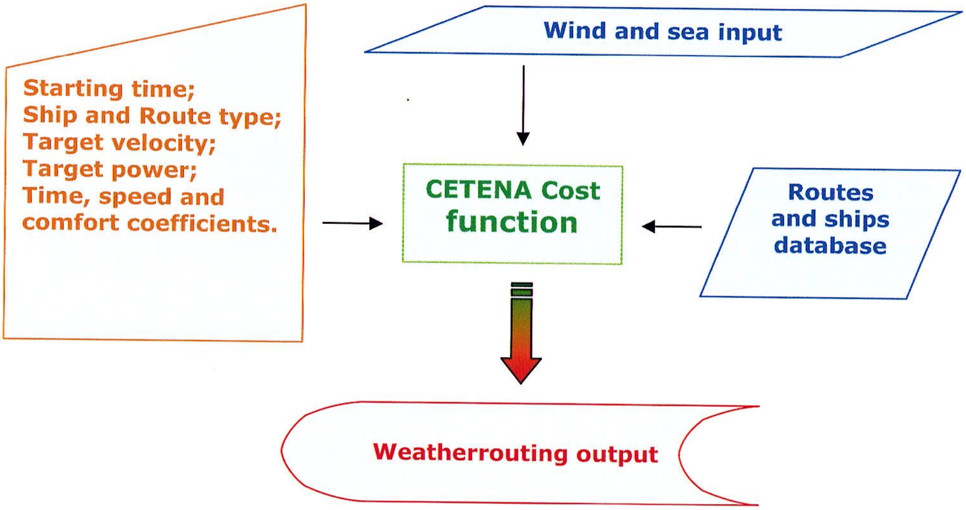


Figure 0.1: Flow chart of weatherrouting simulations.

CETENA cost function

This software has been designed to predict the behaviour of the ship course once suitable environmental conditions have been provided. Analyses are carried out evaluating the variations during ship route of the following three variables:

- power spent along the course;
- journey time duration;
- passenger comfort.

The core of the program is the so called "cost function", which calculates the optimal velocity pattern a ship would have to follow during her journey in order to meet the following specification requirements:

- keep the power as close as possible to the ship target power;
- arrive at destination in a target time;

- keep the passenger comfort onboard as high as possible. (Comfort coefficient as small as possible).

The above three requirements are however taken into consideration through a weighting factor which can be specified by the user prior to execute the calculation.

Once a route has been defined and the weather conditions have been forecasted for a suitable grid over the sea surface and for a time duration at least equal to the ship journey duration at her lowest speed, the calculation consists in the extensively evaluation of all possible velocity combinations for the ship to complete the assigned route. The best ship velocity combination is determined as the combination which minimize the cost function. This velocity pattern is given in output together with the ship power needed to sustain every ship velocity while sailing in the encountered sea states and together with the predicted comfort.

For a complete description we send back you to the CETENA Wermed Cost Function - user manual. In this technical report there are described:

- the scope of the application;
- the organization of input files;
- the ship data files;
- the route files;
- the ship seakeeping database.

Input data

Input data necessary to numerical simulations of weatherrouting are the weather and wave conditions for the entire Mediterranean basin. Such data, as already said, are produced by means of weather and waves numerical forecast models. These models daily supply wind and wave fields at the intervals of three hours for a period of 2 or 3 days ahead. CETENA cost function requires input files written in a very precise format. In following Figure 0.2 it is shown a draft of the meteorological input file necessary to the run of the cost function. Such file, as already said in previously Paragraph 0, is called *wermed_input.txt*.

Time	Long	Lat	Hsea	Tsea	Dsea	Hswell	Tswell	Dswell	Uwind	Dwin
2006100603	-5.5000	36.0000	0.41	2.81	81	0.16	3.51	36	5.16	95
2006100603	-5.3750	36.0000	0.43	2.89	77	0.21	3.55	45	4.08	97
2006100603	-5.3750	36.1250	0.41	2.89	84	0.18	3.65	54	4.02	92
2006100603	-5.2500	35.6250	0.34	2.86	61	0.26	3.38	44	3.47	110
2006100603	-5.2500	35.7500	0.38	2.89	67	0.26	3.49	45	3.88	103
2006100603	-5.2500	35.8750	0.41	2.94	71	0.26	3.59	50	3.88	103
2006100603	-5.2500	36.0000	0.44	2.98	76	0.25	3.64	53	4.08	97
2006100603	-5.2500	36.1250	0.44	2.99	80	0.27	3.65	63	4.02	92
2006100603	-5.2500	36.2500	0.42	2.97	85	0.25	3.63	69	4.02	92

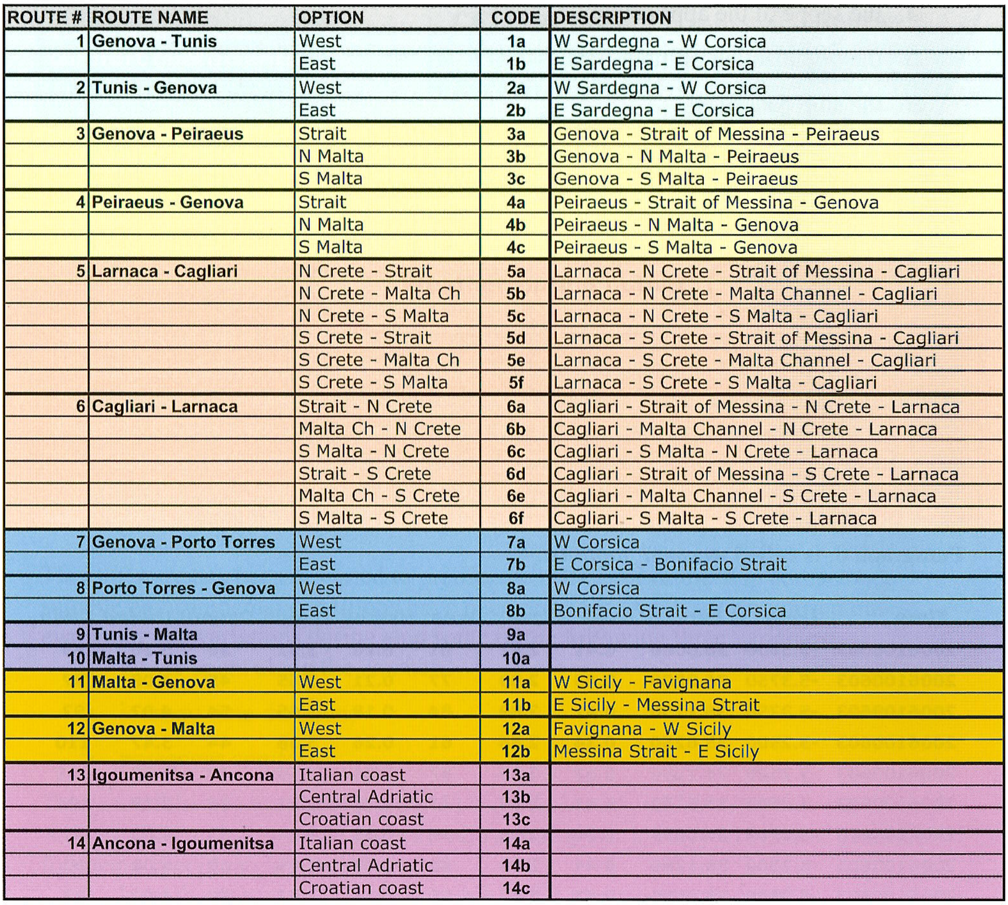
Figure 0.2: Part of wermed_input.txt file used by CETENA cost function.

In the previous figure there appear, for every line, the date (year, month, day and hour UTC), the coordinates in centesimal degrees of longitude and latitude, the significant height, mean period and direction of wind waves, the significant height, mean period and direction of swell waves and the velocity and direction of wind.

Such file is daily generated as weather and wave numerical models in use at APAT and DIFI has finished their simulations. Then it is renamed adding the running date (es. wermed_20070615.txt) and it is stored in respective folders *APAT* and *Meteo*, like already explained in previous Paragraph 0.

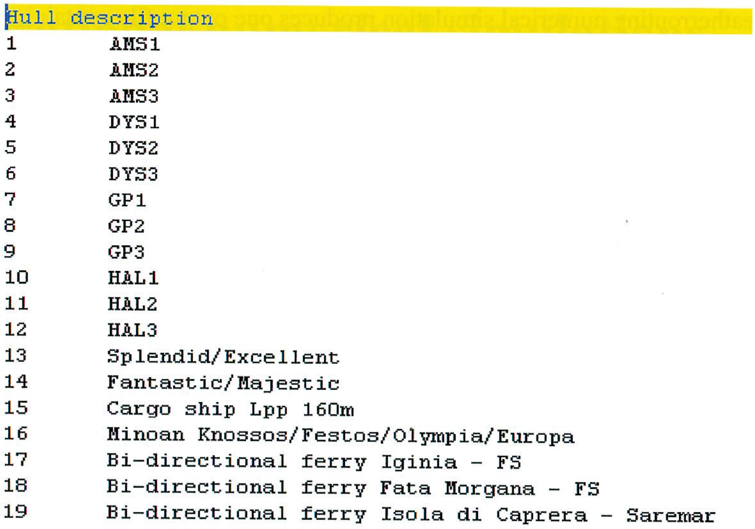
Routes and ships databases

CETENA cost function is able to perform almost infinite kind of simulations. For WERMED purposes it has been decided to simulate 14 marine routes for 19 different kind of ships. Next Figure 0.3 shows all possible routes and Figure 0.4 all ships presently available.



ROUTE #	ROUTE NAME	OPTION	CODE	DESCRIPTION
1	**Genova - Tunis**	West	**1a**	W Sardegna - W Corsica
		East	**1b**	E Sardegna - E Corsica
2	**Tunis - Genova**	West	**2a**	W Sardegna - W Corsica
		East	**2b**	E Sardegna - E Corsica
3	**Genova - Peiraeus**	Strait	**3a**	Genova - Strait of Messina - Peiraeus
		N Malta	**3b**	Genova - N Malta - Peiraeus
		S Malta	**3c**	Genova - S Malta - Peiraeus
4	**Peiraeus - Genova**	Strait	**4a**	Peiraeus - Strait of Messina - Genova
		N Malta	**4b**	Peiraeus - N Malta - Genova
		S Malta	**4c**	Peiraeus - S Malta - Genova
5	**Larnaca - Cagliari**	N Crete - Strait	**5a**	Larnaca - N Crete - Strait of Messina - Cagliari
		N Crete - Malta Ch	**5b**	Larnaca - N Crete - Malta Channel - Cagliari
		N Crete - S Malta	**5c**	Larnaca - N Crete - S Malta - Cagliari
		S Crete - Strait	**5d**	Larnaca - S Crete - Strait of Messina - Cagliari
		S Crete - Malta Ch	**5e**	Larnaca - S Crete - Malta Channel - Cagliari
		S Crete - S Malta	**5f**	Larnaca - S Crete - S Malta - Cagliari
6	**Cagliari - Larnaca**	Strait - N Crete	**6a**	Cagliari - Strait of Messina - N Crete - Larnaca
		Malta Ch - N Crete	**6b**	Cagliari - Malta Channel - N Crete - Larnaca
		S Malta - N Crete	**6c**	Cagliari - S Malta - N Crete - Larnaca
		Strait - S Crete	**6d**	Cagliari - Strait of Messina - S Crete - Larnaca
		Malta Ch - S Crete	**6e**	Cagliari - Malta Channel - S Crete - Larnaca
		S Malta - S Crete	**6f**	Cagliari - S Malta - S Crete - Larnaca
7	**Genova - Porto Torres**	West	**7a**	W Corsica
		East	**7b**	E Corsica - Bonifacio Strait
8	**Porto Torres - Genova**	West	**8a**	W Corsica
		East	**8b**	Bonifacio Strait - E Corsica
9	**Tunis - Malta**		**9a**	
10	**Malta - Tunis**		**10a**	
11	**Malta - Genova**	West	**11a**	W Sicily - Favignana
		East	**11b**	E Sicily - Messina Strait
12	**Genova - Malta**	West	**12a**	Favignana - W Sicily
		East	**12b**	Messina Strait - E Sicily
13	**Igoumenitsa - Ancona**	Italian coast	**13a**	
		Central Adriatic	**13b**	
		Croatian coast	**13c**	
14	**Ancona - Igoumenitsa**	Italian coast	**14a**	
		Central Adriatic	**14b**	
		Croatian coast	**14c**	

Figure 0.3: Available routes used by CETENA cost function.

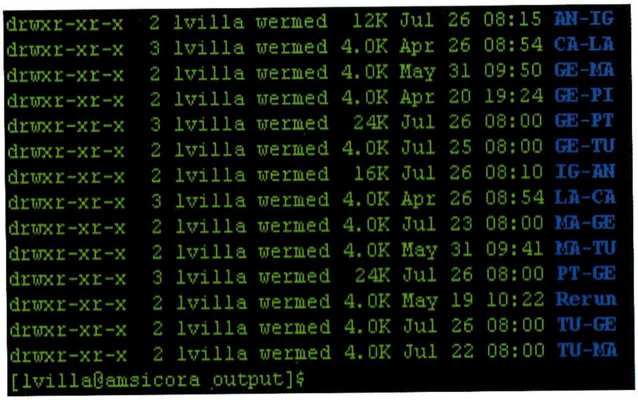


```
Hull description
1         AMS1
2         AMS2
3         AMS3
4         DYS1
5         DYS2
6         DYS3
7         GP1
8         GP2
9         GP3
10        HAL1
11        HAL2
12        HAL3
13        Splendid/Excellent
14        Fantastic/Majestic
15        Cargo ship Lpp 160m
16        Minoan Knossos/Festos/Olympia/Europa
17        Bi-directional ferry Iginia - FS
18        Bi-directional ferry Fata Morgana - FS
19        Bi-directional ferry Isola di Caprera - Saremar
```

Figure 0.4: Available ships used by CETENA cost function.

Storing and e-mail sending

Each weatherrouting numerical simulation produces one output file containing all the information generated by the elaboration of the cost function. In the present configuration of server RAS, file system is organized to put in order all these files taking into account the simulated routes. For example, for Genoa – Porto Torres route, passing westerly of Corsica, the output file is called GE-PT_fcf_200706251800_R_7a.txt, and it is stored in folder *GE-PT*. In following Figure 0.5 it is shown the *output* subfolder, in *FAST_CF* folder, containing all the possible outputs produced by weatherrouting numerical simulations.



```
drwxr-xr-x  2 lvilla wermed  12K Jul 26 08:15 AN-IG
drwxr-xr-x  3 lvilla wermed 4.0K Apr 26 08:54 CA-LA
drwxr-xr-x  2 lvilla wermed 4.0K May 31 09:50 GE-MA
drwxr-xr-x  2 lvilla wermed 4.0K Apr 20 19:24 GE-PI
drwxr-xr-x  3 lvilla wermed  24K Jul 26 08:00 GE-PT
drwxr-xr-x  2 lvilla wermed 4.0K Jul 25 08:00 GE-TU
drwxr-xr-x  2 lvilla wermed  16K Jul 26 08:10 IG-AN
drwxr-xr-x  3 lvilla wermed 4.0K Apr 26 08:54 LA-CA
drwxr-xr-x  2 lvilla wermed 4.0K Jul 23 08:00 MA-GE
drwxr-xr-x  2 lvilla wermed 4.0K May 31 09:41 MA-TU
drwxr-xr-x  3 lvilla wermed  24K Jul 26 08:00 PT-GE
drwxr-xr-x  2 lvilla wermed 4.0K May 19 10:22 Rerun
drwxr-xr-x  2 lvilla wermed 4.0K Jul 26 08:00 TU-GE
drwxr-xr-x  2 lvilla wermed 4.0K Jul 22 08:00 TU-MA
[lvilla@amsicora output]$
```

Figure 0.5: Output data base of cost function products.

Once output file has been stored, an automatic procedures sends this file (or a group of output from different simultaneous simulations), via e-mail, to a certain number of users, as already explained in previous Paragraph 0.

Operational numerical simulations

Each singular procedure involved in weatherrouting numerical simulations has been included in one *main procedure*, another scripting language file, with the aim to create a global tool that daily simulates a certain number of routes and sends the results to every interested users.
In the following Figure 0.1 it is shown how the main procedure works.

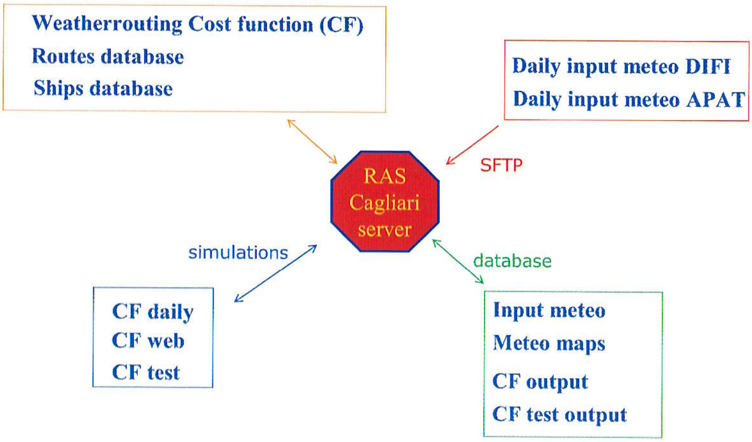
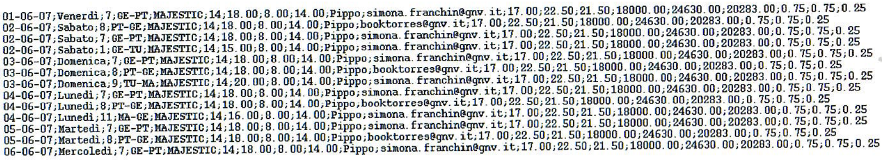


Figure 0.1: Main automatic procedure of weatherrouting cost function.

In the above figure it is shown how main procedure works in RAS server in Cagliari. This procedure is able to keep daily weather and wave input and support CETENA cost function. Moreover it perform every kind of simulations, like daily operational ones and web simulations, that are described in another section of this book, related to the Action 3.3. Then, it even can manage the storing activity and sending procedure of output files.

In particular, as far operational simulations are concerned, inside *FAST_CF* folder, and driven by the main procedure, it is placed a tool written in BASH scripting language that reads a file containing all information necessary to the simulation to execute. Following Figure 0.2 shows an extract of this latter file called *turni.txt*, that has to be written by the user and that allows to program future simulations that will be carried out day by day.
Using *turni.txt* file it is so possible to perform simulations by means of main procedure that starts running automatically every day.



```
01-06-07;Venerdì;7;GE-PT;MAJESTIC;14;18.00;8.00;14.00;Pippo;simona.franchin@gnv.it;17.00;22.50;21.50;18000.00;24630.00;20283.00;0.75;0.75;0.25
02-06-07;Sabato;8;PT-GE;MAJESTIC;14;18.00;8.00;14.00;Pippo;booktorres@gnv.it;17.00;22.50;21.50;18000.00;24630.00;20283.00;0.75;0.75;0.25
02-06-07;Sabato;7;GE-PT;MAJESTIC;14;18.00;8.00;14.00;Pippo;simona.franchin@gnv.it;17.00;22.50;21.50;18000.00;24630.00;20283.00;0.75;0.75;0.25
02-06-07;Sabato;1;GE-TU;MAJESTIC;14;15.00;8.00;14.00;Pippo;simona.franchin@gnv.it;17.00;22.50;21.50;18000.00;24630.00;20283.00;0.75;0.75;0.25
03-06-07;Domenica;7;GE-PT;MAJESTIC;14;18.00;8.00;14.00;Pippo;simona.franchin@gnv.it;17.00;22.50;21.50;18000.00;24630.00;20283.00;0.75;0.75;0.25
03-06-07;Domenica;8;PT-GE;MAJESTIC;14;18.00;8.00;14.00;Pippo;booktorres@gnv.it;17.00;22.50;21.50;18000.00;24630.00;20283.00;0.75;0.75;0.25
03-06-07;Domenica;9;TU-MA;MAJESTIC;14;20.00;8.00;14.00;Pippo;simona.franchin@gnv.it;17.00;22.50;21.50;18000.00;24630.00;20283.00;0.75;0.75;0.25
04-06-07;Lunedì;7;GE-PT;MAJESTIC;14;18.00;8.00;14.00;Pippo;simona.franchin@gnv.it;17.00;22.50;21.50;18000.00;24630.00;20283.00;0.75;0.75;0.25
04-06-07;Lunedì;8;PT-GE;MAJESTIC;14;18.00;8.00;14.00;Pippo;booktorres@gnv.it;17.00;22.50;21.50;18000.00;24630.00;20283.00;0.75;0.75;0.25
04-06-07;Lunedì;11;MA-GE;MAJESTIC;14;16.00;8.00;14.00;Pippo;simona.franchin@gnv.it;17.00;22.50;21.50;18000.00;24630.00;20283.00;0.75;0.75;0.25
05-06-07;Martedì;7;GE-PT;MAJESTIC;14;18.00;8.00;14.00;Pippo;simona.franchin@gnv.it;17.00;22.50;21.50;18000.00;24630.00;20283.00;0.75;0.75;0.25
05-06-07;Martedì;8;PT-GE;MAJESTIC;14;18.00;8.00;14.00;Pippo;booktorres@gnv.it;17.00;22.50;21.50;18000.00;24630.00;20283.00;0.75;0.75;0.25
06-06-07;Mercoledì;7;GE-PT;MAJESTIC;14;18.00;8.00;14.00;Pippo;simona.franchin@gnv.it;17.00;22.50;21.50;18000.00;24630.00;20283.00;0.75;0.75;0.25
```

Figure 0.2: Part of turni.txt file used by main automatic procedure for weatherrouting daily simulations.

As it can be noticed from the figure above, every line of *turni.txt* file represents one possible simulation of the cost function. Fields of every line are separated by "; " and they regard respectively the date, the day, the relative number and the abbreviation of the route, the name and the number of the ship, the time of departure, three fields presently not used by the procedure, main address email to which it will be sent the simulation output file, the three values of minimum, target and maximum velocity, the three values of minimum, target and maximum engine power and the three values of speed, power and comfort penalty coefficients.

Every day, at a prefixed hour, the main automatic procedure reads all rows written in *turni.txt* file and finds and isolates only the lines that begin with the running date. After that it prepare the input file for the cost function using the right elements inside the selected line, runs the simulation and stores the output file. Therefore, output file is sent to main e-mail address, again extracted from the line of *turni.txt* file, and to every other users who is interested in receiving the results of numerical simulations.

VI. HIGH RESOLUTION MODELLING FOR WEATHERROUTING.

K. Lagouvardos, V. Kotroni, A. Drago, S. Music, J. Azzopardi.

This chapter describes the meteo-marine high-resolution models used in the framework of the WERMED Project Action 3.2. Since higher spatial resolution is required in particular environments (such as straits, seas with many islands, etc), the project has made use and developed state-of-the-art fine grid models in selected areas, namely in three domains:

- the Aegean Sea
- the Adriatic Sea, and
- the Central Mediterranean

The following paragraphs describe the models used and the operational setup chosen by each partner. All models are running operationally and outputs are published in the forecast section of the WERMED web page (www.wermed.net)

The Aegean Sea

The National Observatory of Athens uses two models: Bologna limited area model (**BOLAM**, hereafter) and the Weather Research and Forecasting mode (**WRF**, hereafter).

The most recent version of **BOLAM** is based on previous versions of the model described in detail by Buzzi et al. (1994; 1997; 1998), Buzzi and Foschini (2000). The microphysical scheme implemented in BOLAM is coded mainly on the basis of the transformation process models described in Schultz (1995). The scheme includes five hydrometeor categories: cloud ice, cloud water, rain, snow, and graupel. The sub-grid scale precipitation is treated in BOLAM following the Kain-Fritsch convective parametrization scheme (Kain and Fritsch, 1993). In the version of Kain-Fritsch scheme implemented in BOLAM, an additional modification, regarding the delaying of downdraft occurrence (Spencer and Stensrud, 1998) has been introduced. Namely, the first downdraft is started not before 30 min of initiation of new convection. A recent evaluation of operational forecasts in the Mediterranean region is given in Lagouvardos et al (2003) with very encouraging results concerning mainly precipitation forecasts.

The operational model chain implemented in WERMED uses BOLAM capability to perform one-way nested simulations. A first simulation is performed with a coarse grid interval and then the outputs of this coarse simulation are used as initial and boundary conditions on a subsequent run with finer grid spacing. For both grids the same physical parameterisations have been used. For the operational use, two one-way nested grids are used:

- The coarse grid consists of 135x110 points with a 0.21 deg horizontal grid interval (~23 km), covering the area of Southern Europe and the Mediterranean Sea
- the fine grid consists of 160x148 points with a 0.06 deg horizontal grid interval (~6.5 km), covering Greece and the Aegean Sea (Fig. 1).

In the vertical, 30 levels are used in the coarse grid and 40 levels in the fine grid, while model top has been set at about 10 hPa on both nests. The vertical resolution is higher in the boundary layer and, to a lesser extent, at the average tropopause level. The 0000 UTC Global Forecast System (GFS, provided by the National Centers for Environmental Predictions-NCEP, USA) gridded analysis fields and 6-hour interval forecasts, at 1. degree lat/lon horizontal grid increment, are used to initialise the model and to nudge the boundaries of Grid 1 during the simulation period. These fields are interpolated on sigma levels from which they are then interpolated onto the model grid points. The orography fields are derived from a 30 arcsec resolution terrain data file provided by USGS. The operational runs are initialised every day with the 0000 UTC GFS analysis. The duration of the simulation is 72 hours for the coarse grid, and 66 hours for the inner grid starting at 0600 UTC of the same day.

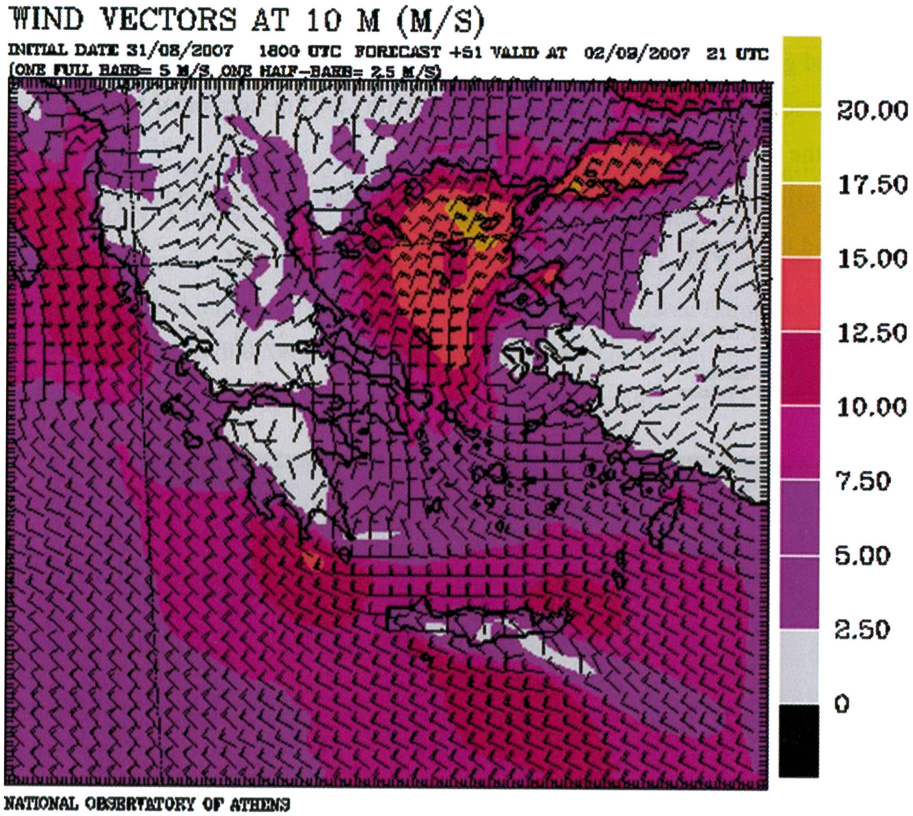


Figure 1: Horizontal extension of BOLAM fine grid

For comparison purposes, NOA also uses WRF model in the frame of WERMED project. WRF model is a next-generation mesocale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs. It features multiple dynamical cores, a 3-dimensional variational (3DVAR) data assimilation system, and a software architecture allowing for computational parallelism and system extensibility. WRF is suitable for a broad spectrum of applications across scales ranging from meters to thousands of kilometers.

The operational model chain implemented in WERMED uses WRF capability to perform two-way nested simulations. A first simulation is performed with a coarse grid interval and then the outputs of this coarse simulation are used as initial and boundary conditions on a subsequent run with finer grid spacing. For both grids the same physical parameterisations have been used. For the operational use, two one-way nested grids are used:

- The coarse grid consists of 220x140 points with 24 km horizontal grid interval, covering the area of Europe
- the fine grid consists of 180x165 points with 6 km horizontal grid interval, covering Greece and the Aegean Sea, (Fig. 2).

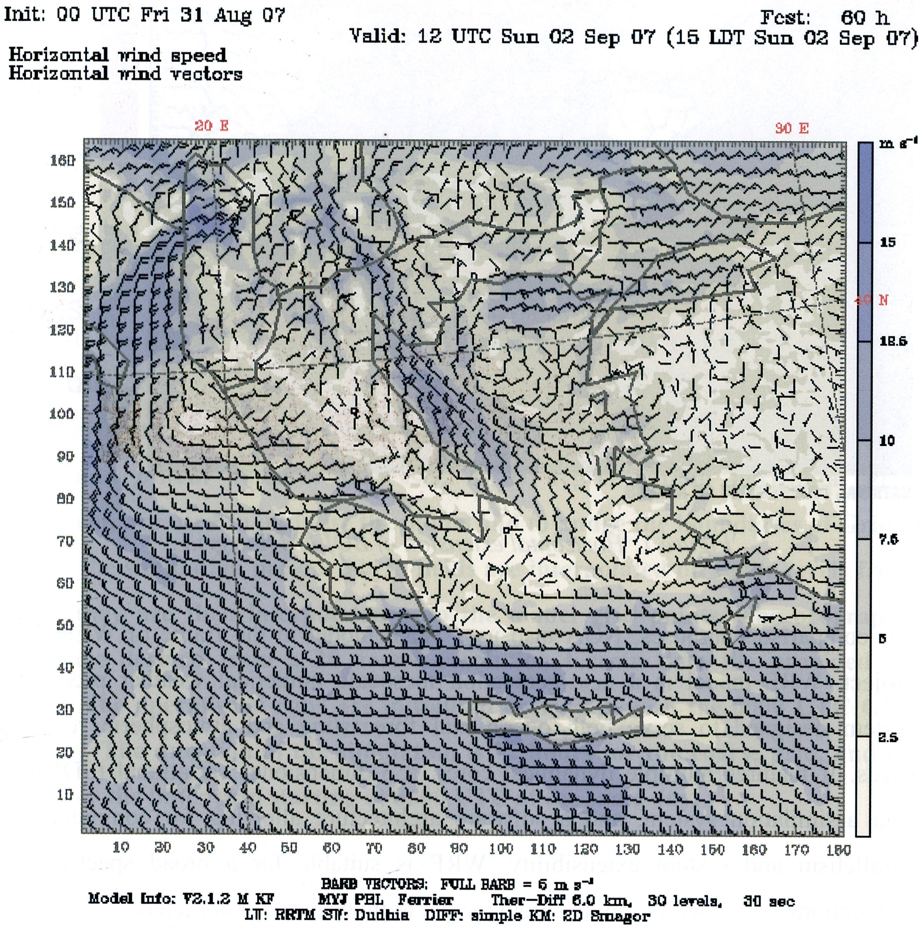


Figure 2: Horizontal extension of WRF fine grid

Adriatic Sea

For the need of weatherrouting in the Adriatic Sea and the provision of daily bulletins to MINOAN LINES, NOA implemented during the project, a fine resolution modelling chain for Italy and the Adriatic. The model used is BOLAM and the fine nest, with 6.5 km horizontal grid increment is nested in the same European domain as for the Aegean Sea fine resolution forecasts. All model configurations are the same as previously described. The horizontal extension of the domain is shown in Fig. 3.

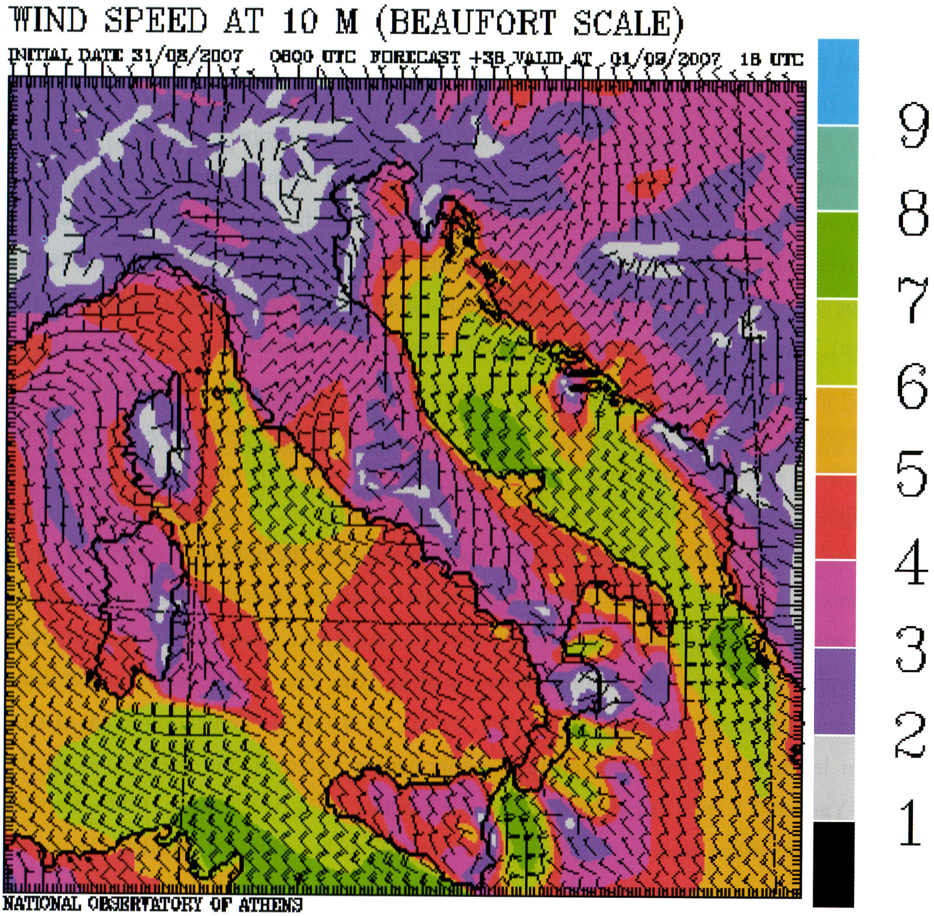


Figure 3: Horizontal extension of BOLAM fine grid

Central Mediterranean maritime area

The Physical Oceanography Unit at the IOI-Malta Operational Centre of the University of Malta has set up the MARIA Malta Atmospheric and Wave forecasting system which runs operationally to publish daily forecasts on the dedicated Malta Page for WERMED (www.CapeMalta.net/maria/pages/about.html).

Malta Page on WERMED

MARIA - Malta Atmospheric and Wave Forecasting System

Project managed by: Dr. Aldo. Drago - Director, IOI-MOC, University of Malta

Structural Funds Programme for Malta 2004-2006; Project part-financed by the European Union Community Initiative Interreg III Medocc Programme.

Figure 4: The dedicated WERMED page on the CapeMalta Website

For the atmospheric forecast the prognostic variables are temperature (T), wind (u,v components), specific humidity (q), surface pressure (ps) and turbulent kinetic energy (TKE). The key output parameters are geopotential, temperature, specific humidity, wind components on 10 vertical standard pressure levels together with a number of surface parameters including 2m temperature, 10m wind, 2m relative humidity, surface fluxes (latent, heat and radiative). The system is based on the Eta model which is a hydrostatic limited area grid point model with a "step-mountain" vertical coordinate system. The mountains in the Eta system are represented as grid-box mountain blocks. The non-slip bottom boundary condition used at the vertical sides of the model mountains provides an efficient simulation of the blocking/splitting/channeling effects due to mountain influence. A second-order nonlinear advection scheme is designed for the numerical expression of the horizontal advection terms in the model equations (Janjic, 1984). This scheme conserves several important parameters such as mass, energy and squared vorticity, and prevents a false generation of the numerical noise typical for many other atmospheric models. The Eta model uses explicit time differencing schemes (Mesinger, 1973, 1977; Janjic, 1974, 1979). Vertical turbulent mixing between levels in the free atmosphere is performed by using mixing coefficients of the Mellor-Yamada 2.5 level turbulence (Mellor and Yamada, 1974, 1982, Janjic, 1990). Vertical mixing in the surface layer is performed by a Monin-Obukhov similarity model. The model calculates the surface parameters using a viscous sub-layer scheme (Janjic, 1994).

Different viscous sub-layer approaches are applied over ground and over water surfaces in the model. Over the sea it is assumed that the viscous sub-layer operates in three regimes: smooth and transitional, rough, and rough with spray, depending on the Reynolds number. A nonlinear fourth-order lateral diffusion scheme, with the diffusion coefficient depending on the deformation and the turbulent kinetic energy, is introduced in order to control the level of small-scale noise. For the simulation of the radiative atmospheric effects, the GFDL radiation scheme is used; this includes interactive random overlap cloud effects. The revised Betts-Miller deep and shallow cumulus convection scheme is used to represent moisture processes responsible for excessive precipitation events (Betts, 1986; Betts and Miller, 1986, Janjic, 1994). The large-scale condensation scheme is implemented to simulate moist atmospheric processes of larger scales.

The downscaling of atmospheric conditions to the sub-regional scale is done by executing the model runs in two nesting steps with successively embedded model configurations. The first run is performed with the coarser resolution basin scale NCEP/Eta model (1/2 Deg ~ 32 Km) over the whole Mediterranean region. This in turn provides detailed initial and boundary conditions to the second model with the higher resolution (at 1/24 Deg ~ 5 Km) over the Central Mediterranean area. In the vertical, the basin scale model uses 32 levels from the ground up to 16 km.

For the initial and boundary conditions the NCEP/GFS objective analysis gridded data are used, on a 1.0 deg horizontal grid increment, for 10 standard pressure levels (from 1000-100hPa). The basin scale domain runs on a daily basis, starting from 12 UTC of the current day, and produces a 72-hour forecast with 6-hour outputs. The Central Mediterranean domain runs daily, starting from 12 UTC of the current daily and producing a 48-hour forecast with 3-hour outputs.

The Maria operational wave forecasting system uses the 3rd generation spectral wave model WAM Cycle 4 (Gunther et al, 1992). Originally developed by Hasselmann, the WAM model has been later extended by the WAMDI group (The WAM Development and Implementation Group). Within the WAM model, the basic equation is the wave action balance equation, with a wave field spectrum in the two-dimensional frequency and direction space.

The energy equation is forced by a source term related to the near-surface atmospheric wind. The model is forced by surface wind from the Eta atmospheric model, and runs once per day (at 12 UTC) for a 72 hour forecast. Subsequent model runs are initialized using the sea state at analysis time, calculated by the previous run as a 24 hour forecast. The model is set-up as a nested system with a coarse grid covering the whole Mediterranean region with grid resolution of 0.50° for both longitude and latitude direction. The finer grid nested within the coarse grid covers the Eastern Mediterranean region (east of 10° E) with grid resolution of 0.25°.The high-resolution grid (0.125°) over the Central Mediterranean is nested in the East Mediterranean grid. A summary on the geometry and resolution of the three domains is given in Table 1.

Grid	**South boundary**	**North boundary**	**East boundary**	**West boundary**	**Region**	**Res. (lat/long)**
Coarse	30°	46°	-7°	37°	Mediterranean	0.5°
Medium	30.5°	45.5°	10°	36.5°	Central and Eastern Mediterranean	0.25°
Fine	35°	39°	10.25°	16°	Central Mediterranean	0.125°

Table 1: WAM grid nesting for the Eastern and Central Mediterranean

The model set-up is based on the following run-time parameters: 30 frequencies (in the range from 0.041772 Hz to 0.66264); 24 directions (every 15 degree); 3 output grids; 4916 sea points; and 3-hour outputs. The time integration step is 1200 sec. The 2' resolution bathymetry of Smith and Sandwell (1997) is used for producing the bathymetries. The original bathymetry data set is interpolated onto the model grids for each of the 3 different output grids in the model set-up. The 6-hourly wind data used as input to the WAM model is generated by the ETA regional atmospheric model at the 0.5° resolution. The Mediterranean is treated as a closed basin, assuming no wave energy exchange with the Atlantic or the Black Sea. The main output parameters from the WAM wave model are: significant wave height; mean wave direction and frequency of total sea; wind sea and swell.

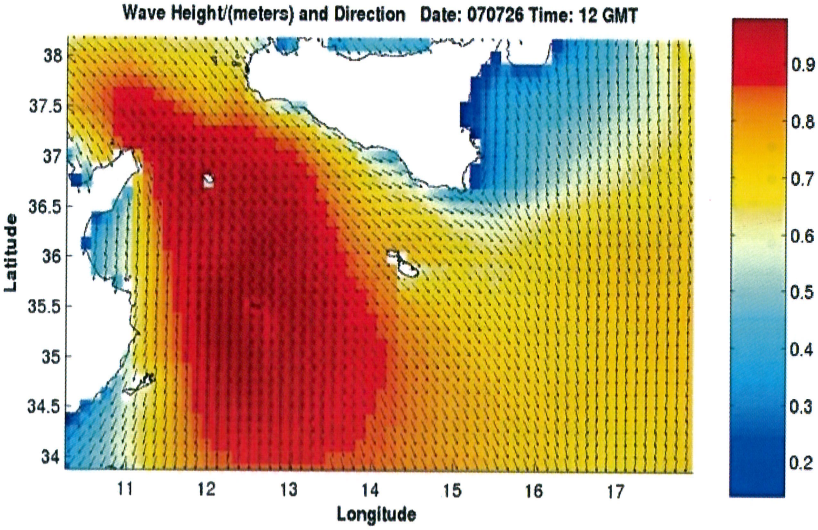


Figure 6: Forecasted significant wave height and wave direction in the Central Mediterranean

Both the atmospheric and wave forcasts are published through a user-friendly visual online interface which allows the flexibility for choice of parameters and forecast times. The interface gives access to maps of the selected parameters (www.capemalta.net/maria/pages/atmosforecast.html for meteo and www.capemalta.net/maria/pages/waveforecast.html for waves), and offer a 2D view of atmospheric/sea state conditions, either at basin scale for the full Mediterranean or more specifically for the Central Mediterranean Area.

VII. A PROTOTYPE OF OPERATIONAL SERVICE.

S. Gallino, P. Gemelli, P.F. Marsiaj, L. Pedemonte.

Introduction

The following is a report of the activities carried out in the framework of Action 3.3, i.e. the experimental weather-routing service of the WERMED Project.

The activities were carried out following the steps listed below:

- Identification of the routes on which the service could be tested;
- Creation of a prototype bulletin including both meteorological information and the reaction of vessels during navigation;
- Implementation of a web tool to use the service;
- Implementation of an experimental operational service on ships in navigation;
- Verification of the reliability of weather forecasts through the analysis of reports from vessels.

Routes

Mediterranean routes are relatively short (max. 2-3 days between the Suez Canal and Gibraltar). The main routes are fixed and selected to reduce distance to the minimum. While setting up the service, we consulted some captains of the ships to take into account all their operational needs. The first requirement for the main sailing routes is for ships to be able to choose among different route options, in order to counter bad meteorological or sea conditions.

We chose Mediterranean routes with the following characteristics:

- Routes long enough to make weather-routing calculation useful;
- Different route options with the relevant weather-routing data to assist captains in choosing the best route;
- Routes sailing through "sensitive" stretches of sea, where dominant winds in the Mediterranean Basin are particularly strong and frequent;
- Routes actually covered by vessels.

The criteria listed above were used to identify the following experimental routes (see *Figure 1*):

- Genoa – Tunis,
- Genoa – Piraeus,
- Larnaca –Cagliari,
- Genoa - Porto Torres,
- Tunis – Malta,
- Igoumenitza – Ancona.

The following routes were mapped out taking into account the current international cartography (British Admiralty and Istituto Idrografico Marina Italiana), as well as international provisions on sea transport (Ships' Routing).

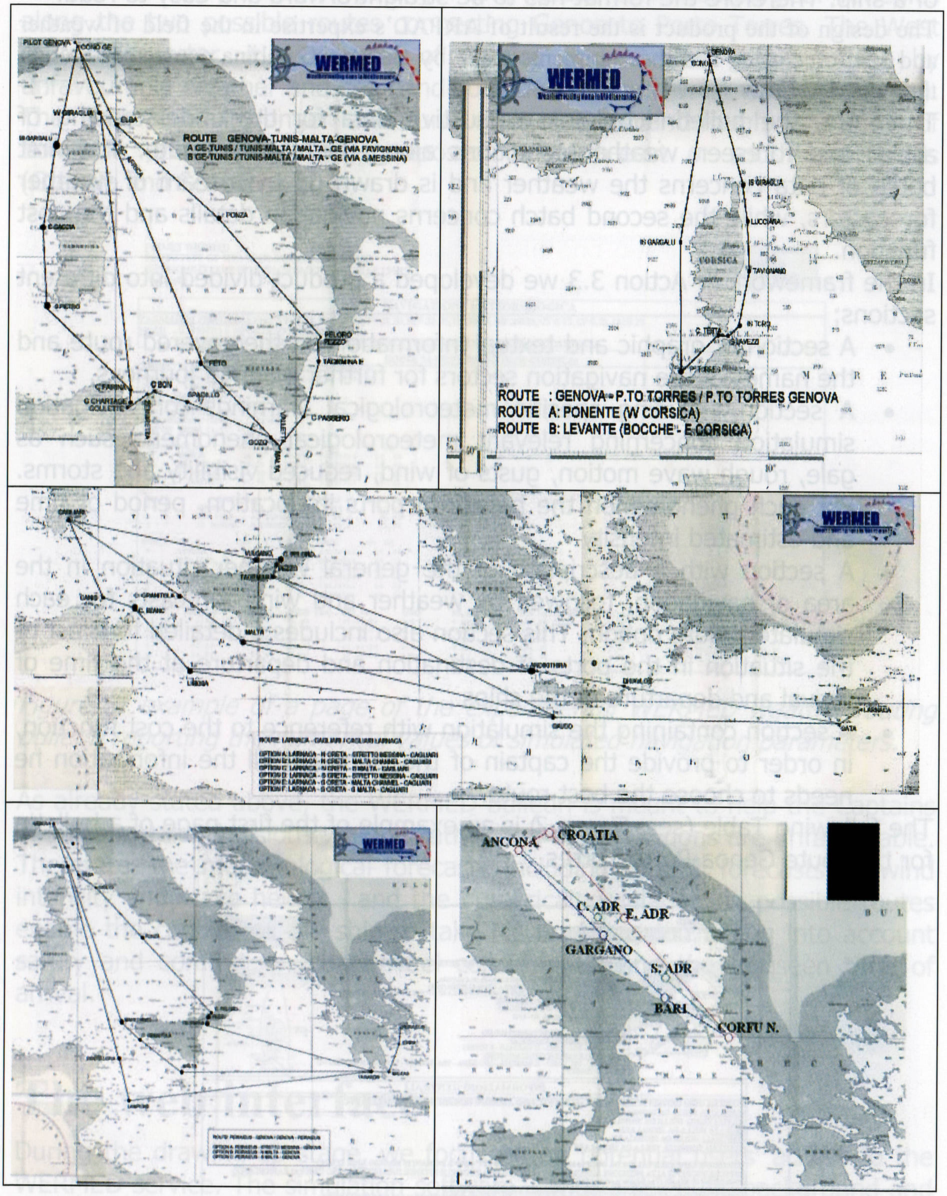


Figure 1: routes simulated by the WERMED service (top left: Genoa-Tunis and Genoa- Malta; top right: Genoa – Porto Torres; centre: Larnaca- Cagliari; bottom left: Genoa Piraeus; bottom right Igoumenitza Ancona).

The bulletin

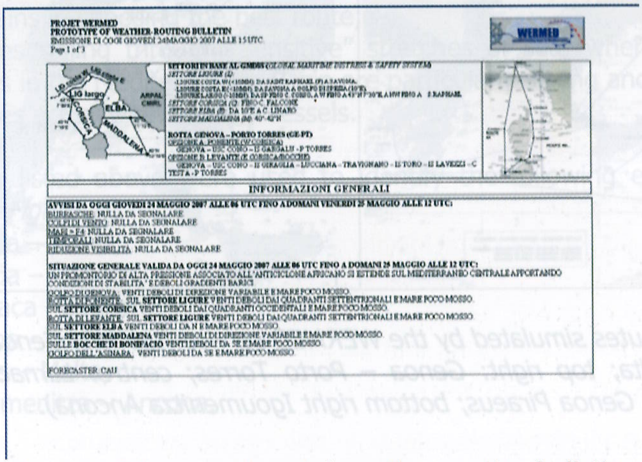
The weather-routing bulletin is a key tool to pass information to the captain of a ship. Therefore the format has to be straightforward and easy to read. The design of the product is the result of ARPAL's expertise in the field of weather and sea forecasting and the comments made by Captain Gambina contacted through the IOI-MALTA.

Therefore, the bulletin contains exhaustive data for the understanding of actual and foreseen weather conditions along the chosen route. The first batch of data concerns the weather and is drawn up by a team of weather forecasters, while the second batch concerns navigation details and the cost function.

In the framework of Action 3.3 we developed a product divided into different sections:

- A section of graphic and textual information on the covered route and the names of the navigation sectors for further planned journeys.
- A section including specific meteorological warnings for navigation simulation concerning relevant meteorological phenomena such as gale, rough wave motion, gusts of wind, reduced visibility and storms. For each phenomenon the bulletin reports its location, period of time and estimated intensity.
- A section with a description of the general weather situation in the area of navigation, followed by weather and wind forecasts for each simulated route option. This section also includes a detailed forecast of the situation in the ports of destination and departure at the time of arrival and departure of the ships.
- A section containing the simulation with reference to the cost function, in order to provide the captain of the ship with all the information he needs to choose the best route.

The following Table (see *Figure 2*) is an example of the first page of a bulletin for the route Genoa-Porto Torres.



PROJET WERMED
PROTOTYPE OF WEATHER-ROUTING BULLETIN
EMISSIONE DI OGGI GIOVEDI 24MAGGIO 2007 ALLE 15UTC
Page 1 of 3

SETTORI IN BASE AL GMDSS (*GLOBAL MARITIME DISTRESS & SAFETY SYSTEM*)
SETTORE LIGURE (L)
-LIGURE COSTA W (<10MN) DA SAINT RAPHAEL (F) A SAVONA.
-LIGURE COSTA E (<10MN) DA SAVONA A GOLFO DI SPEZIA (10°E).
LIGURE LARGO (>10MN) DA SP FINO C. CORSO, A W FINO A [illegible] E A NW FINO A S.RAPHAEL.
SETTORE CORSICA (C): FINO C. FALCONE
SETTORE ELBA (E): DA 10°E A C. LINARO
SETTORE MADDALENA (M): 40°-42°N

ROTTA GENOVA – PORTO TORRES (GE-PT)
OPZIONE A: PONENTE (W CORSICA)
GENOVA – USC CONO – IS GARGALU – P TORRES
OPZIONE B: LEVANTE (E CORSICA/BOCCHE)
GENOVA – USC CONO – IS GIRAGLIA – LUCCIANA – TRAVIGNANO – IS TORO – IS LAVEZZI – C TESTA – P TORRES

INFORMAZIONI GENERALI

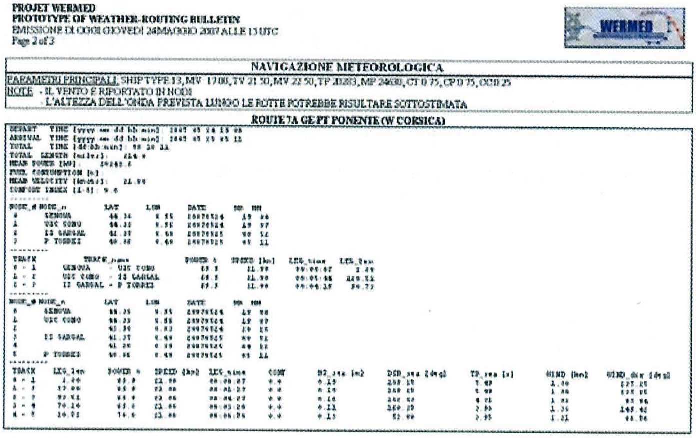
AVVISI DA OGGI GIOVEDI 24 MAGGIO 2007 ALLE 06 UTC FINO A DOMANI VENERDI 25 MAGGIO ALLE 12 UTC:
BURRASCHE: NULLA DA SEGNALARE
COLPI DI VENTO: NULLA DA SEGNALARE
MARE > F4: NULLA DA SEGNALARE
TEMPORALI: NULLA DA SEGNALARE
RIDUZIONE VISIBILITA': NULLA DA SEGNALARE

SITUAZIONE GENERALE VALIDA DA OGGI 24 MAGGIO 2007 ALLE 06 UTC FINO A DOMANI 25 MAGGIO ALLE 12 UTC:
UN PROMONTORIO DI ALTA PRESSIONE ASSOCIATO ALL'ANTICICLONE AFRICANO SI ESTENDE SUL MEDITERRANEO CENTRALE APPORTANDO CONDIZIONI DI STABILITA' E DEBOLI GRADIENTI BARICI
GOLFO DI GENOVA: VENTI DEBOLI DI DIREZIONE VARIABILE E MARE POCO MOSSO.
ROTTA DI PONENTE: SUL **SETTORE LIGURE** VENTI DEBOLI DAI QUADRANTI SETTENTRIONALI E MARE POCO MOSSO.
SUL **SETTORE CORSICA** VENTI DEBOLI DAI QUADRANTI OCCIDENTALI E MARE POCO MOSSO.
ROTTA DI LEVANTE: SUL **SETTORE LIGURE** VENTI DEBOLI DAI QUADRANTI SETTENTRIONALI E MARE POCO MOSSO.
SUL **SETTORE ELBA** VENTI DEBOLI DA N E MARE POCO MOSSO
SUL **SETTORE MADDALENA** VENTI DEBOLI DI DIREZIONE VARIABILE E MARE POCO MOSSO.
SULLE **BOCCHE DI BONIFACIO** VENTI DEBOLI DA SE E MARE POCO MOSSO.
GOLFO DELL'ASINARA: VENTI DEBOLI DA SE E MARE POCO MOSSO.

FORECASTER: CALI

Figure 2: first page of the experimental weather-routing bulletin of the Project WERMED - strictly meteorological information.

The bulletin is also accompanied by the results of the simulations of alternative routes. The WERMED weather-routing bulletin (see *Figure 3*) also includes data on duration, strength and values of meteorological variables along the two possible routes connecting Genoa to Porto Torres. The West route is shorter, it runs west of Corsica and is often characterised by unfavourable weather and sea conditions due to south-west winds (Libeccio). The East route is longer and runs east of Corsica through the Strait of Bonifacio and is sometimes exposed to north-east or south-east winds (Grecale and Scirocco).



PROJET WERMED
PROTOTYPE OF WEATHER-ROUTING BULLETIN
EMISSIONE DI OGGI GIOVEDI 24MAGGIO 2007 ALLE 13 UTC
Page 2 of 3

NAVIGAZIONE METEOROLOGICA

PARAMETRI PRINCIPALI SHIPTYPE 13,MV 17.00,TV 21.50,MV 22.50,TP 40283,MP 24630,CT 0.75,CP 0.75,OC 0.25
NOTE - IL VENTO E RIPORTATO IN NODI
- L'ALTEZZA DELL'ONDA PREVISTA LUNGO LE ROTTE POTREBBE RISULTARE SOTTOSTIMATA

ROUTE 7A GE PT PONENTE (W CORSICA)

Figure 3: example of a page of the experimental WERMED weather-routing bulletin reporting the numerical values of simulated navigation parameters.

As already stated above, the WERMED bulletin is meant to help the Captains of ships to take decisions when weather and sea conditions are unfavourable. Therefore, the meteorological forecast– including specific forecasts on wind intensity and wave height - and the numerical simulation on possible routes enable the captain of the ship to take his final decision taking into account safety and comfort on board, fuel consumption and the foreseen time of arrival.

The web interface

During the drawing-up stage, we focussed on potential users' access to the WERMED service. The simulation software – with a scientific background and developed in FORTRAN language – works with the data through input and output files on a typically remote server, therefore it cannot be operated by users lacking the necessary system knowledge.
Subsequently, we outsourced the development of a user-friendly interface on the net accessible through a browser. This provided both easy access to the service and user-friendliness (see *Figure 4*).

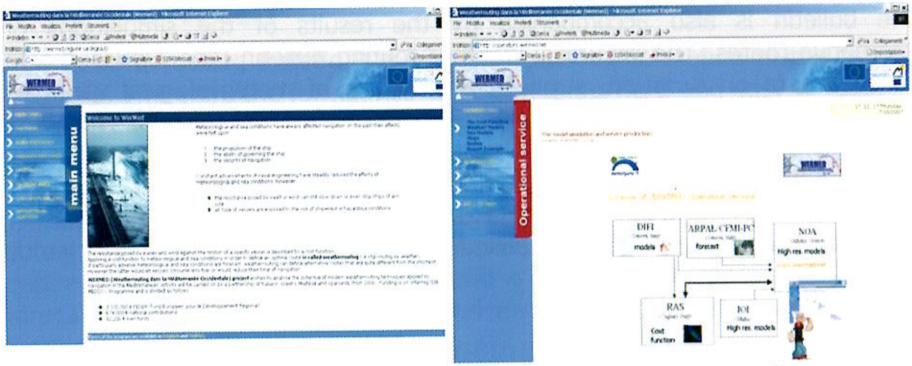
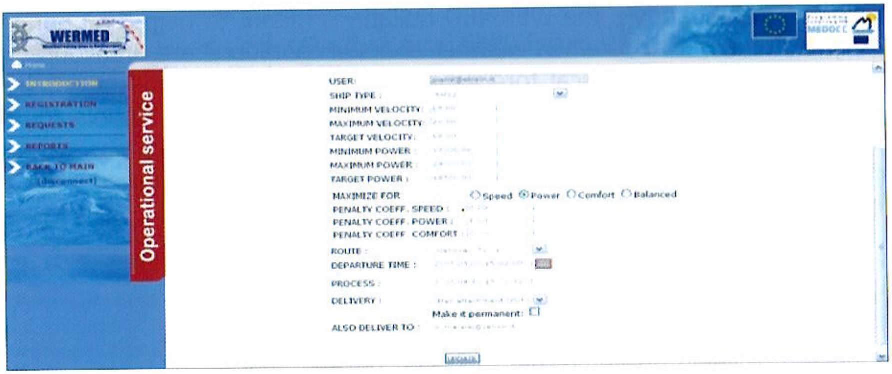


Figure 4: WERMED web pages: to the left the WERMED home page (www.wermed.net); to the right the first page of the web weather-routing operational service (operations.wermed.net)

The web WERMED service must meet the needs of different user groups:

- **Average users,** i.e. the end users of the service, like the captain of a ship who wants to plan his journey. He can choose the route among those available on the simulator and select the type of ship among medium-big passenger ships and a small merchant ship. Then he can enter navigation instructions (required power, target speed) and an optimisation profile favouring fast navigation (reducing the duration of the journey), low cost (reducing consumption) or the comfort of passengers (minimising vertical acceleration), or even a balanced combination of these three factors. All this is done on a data input page of the web site (see *Figure 5*).



USER:
SHIP TYPE :
MINIMUM VELOCITY:
MAXIMUM VELOCITY:
TARGET VELOCITY:
MINIMUM POWER :
MAXIMUM POWER :
TARGET POWER :
MAXIMIZE FOR ○ Speed ● Power ○ Comfort ○ Balanced
PENALTY COEFF. SPEED :
PENALTY COEFF. POWER :
PENALTY COEFF. COMFORT :
ROUTE :
DEPARTURE TIME :
PROCESS :
DELIVERY :
Make it permanent: ☐
ALSO DELIVER TO :

Figure 5: filling in simulation data

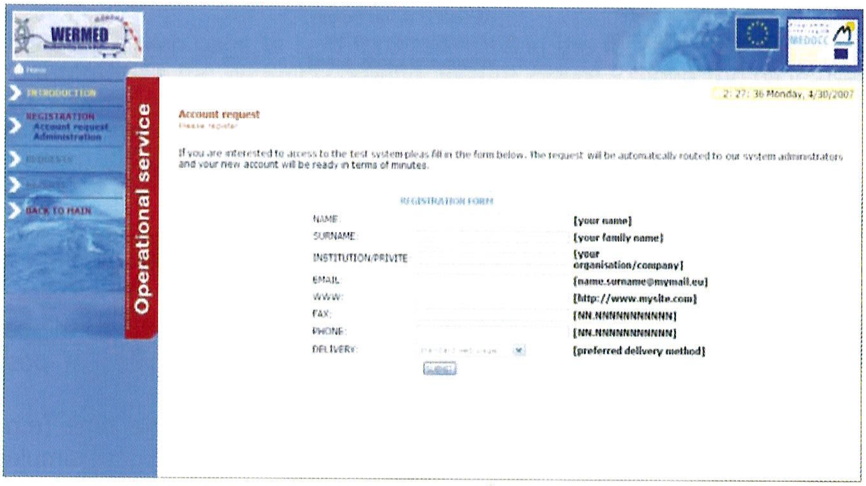
Once the simulation request has been completed - after the necessary processing time – the result is submitted to the users as a nautical bulletin with weather forecasts, maps of winds and wave height and direction along the foreseen route, as well as the speed profile to be adopted along the route.

- **WERMED "forecasters"** check pre-planned simulations and draw up specific bulletins (see picture 6) for end users, who receive their bulletins on a daily basis. These users have to upload batches of simulations as the forecast data for a certain time period become available in order to plan the journeys of liners travelling according to fixed time schedules (see picture 5).

- **Special users** have access to more functions than normal users; they can find their customised product on the web site at fixed times or receive bulletins by e-mail.

- **System administrators** can create and delete users and requests, change parameters, and carry out all the operations described above for other user groups.

To access the system, potential users have to register and upload some basic information. They then receive a welcome message by e-mail, while, at the same time, the system informs the administrator that there is a new registered user (see *Figure 6*).



Account request

Please register

If you are interested to access to the test system pleas fill in the form below. The request will be automatically routed to our system administrators and your new account will be ready in terms of minutes.

REGISTRATION FORM

NAME:	[your name]
SURNAME:	[your family name]
INSTITUTION/PRIVITE:	[your organisation/company]
EMAIL:	[name.surname@mymail.eu]
WWW:	[http://www.mysite.com]
FAX:	[NN.NNNNNNNNNNN]
PHONE:	[NN.NNNNNNNNNNN]
DELIVERY:	[preferred delivery method]

Figure 6: registration page of the WERMED system

Subsequently, the administrator provides the users with the credit necessary to access the system and sends them a standard message with access instructions.

The system operates in a simple way - as shown in *Figure 7* – and is completely automated. Requests submitted by users or uploaded in bulk by either forecasters or administrators are processed either following the order in which they have been uploaded or at the time required by the user. Only special users, forecasters and administrators can fix a starting time for simulations (e.g. not before 6 hours from the beginning of the journey, in order to have short-term, precise forecasts).

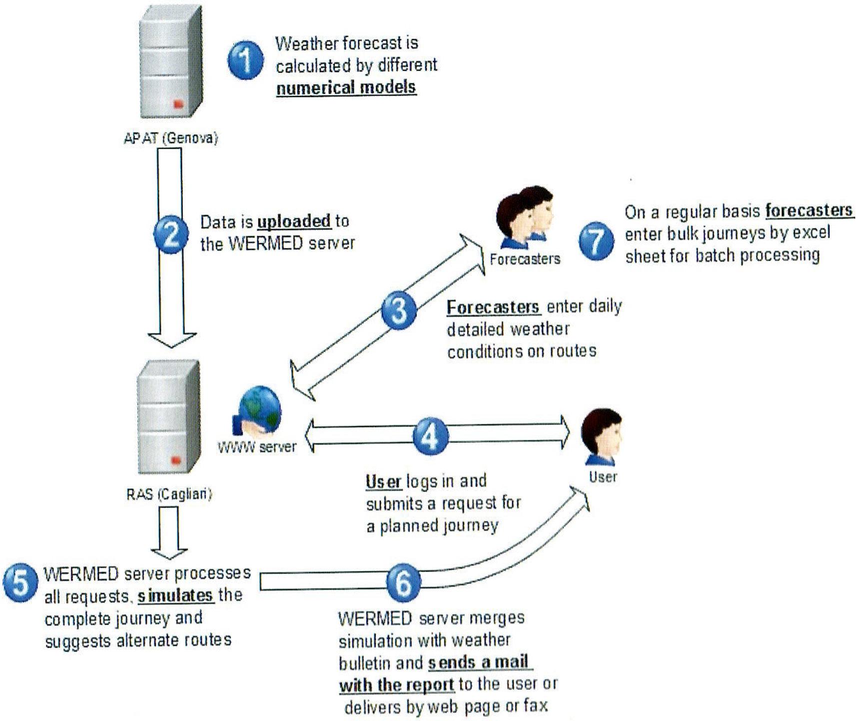


Figure 7: operational scheme of the WERMED web service

Simulations are processed one at a time. Then the system sends the simulation on to the scientific software, which produces the results.

- If the result is error-free the system sends the bulletin to the user.
- If the system detects an error the user is informed of possible causes.
- If the simulation is not completed in a reasonable time (e.g. 10 minutes) there probably is an error or a non-convergent simulation. The system then freezes the entire process and generates an error.

At any time, each user can view the list of completed simulations, those in progress and those still waiting to be processed (each user can view only his/her own simulations). Administrators and forecasters can view the list of all simulations.

According to the preference expressed by the user during the processing phase – possibly modified by the administrator in the activation phase – the bulletin resulting from the simulation can be either put on the web in the user's account or sent to the users as PDF file by electronic mail, or by fax trough an automatic system. This last option is planned but not aviable at the moment of writing this text (see *Figure 8*).

WERMED bullettin
Issued: 30/04/2007
By: Servizio Metereologico Wermed
For: piero@marsiaj.it

Route: 7 - Genova - Porto Torres

INFORMAZIONI GENERALI

AVVISI: BURRASCHE: NULLA DA SEGNALARE
COLPI DI VENTO: NULLA DA SEGNALARE
MARI > F4: NULLA DA SEGNALARE
TEMPORALI: PREVISTO SVILUPPO DI ATTIVITAâ€™ TEMPORALESCA SU TUTTI I SETTORI
RIDUZIONE VISIBILITÃ€: POSSIBILI RIDUZIONI DELLA VISIBILITAâ€™ ASSOCIATE A ROVESCI

SITUAZIONE GENERALE: SI MANTENGONO CONDIZIONI DI LIMITATO GRADIENTE BARICO SU TUTTI I SETTORI â€" PROGRESSIVA DIMINUZIONE DELLA PRESSIONE ATMOSFERICA
GOLFO DI GENOVA: VENTO DA SE 5/10 KT â€" MARE DA POCO MOSSO A QUASI CALMO
ROTTA DI PONENTE: SU TUTTI I SETTORI VENTI DOMINANTE DA SE CON INTENSITAâ€™ FINO A 10/15 KT â€" MARE POCO MOSSO
ROTTA DI LEVANTE: VENTO DA S/SW CON INTENSITAâ€™ FINO A 10/15 KT â€" MARE POCO MOSSO
GOLFO DELLâ€™ASINARA: VENTI DA SW 5/10 KT â€" MARE QUASI CALMO
FORECASTER: GEMELLI

NAVIGAZIONE METEREOLOGICA

General Settings:
SHIP TYPE: 14
MNV: 17.00; MXV: 22.50; TV: 21.60
MNP: 20283.00; MXP: 24030.00; TP: 18000.00
CT: 0.75; CP: 0.75; CC: 0.25

(Option: a - W Corsica)

Figure 8: first page of the PDF file of the WERMED bulletin that can be sent either by e-mail or fax

We designed a web page to help forecasters fill in the forecast reports on the different routes for the WERMED bulletin. Picture *Figure 9* shows the page used by forecasters to fill in the text for the different routes. Once he/she has chosen the forecast date and the route (from 1 to 14 or a general forecast for the Mediterranean Basin), the forecaster enters the warning text (WARNINGS field) and the text on the foreseen wind and sea conditions (SITUATION field).

BULLETTIN MANAGEMENT SECTION (for FORECASTERS)

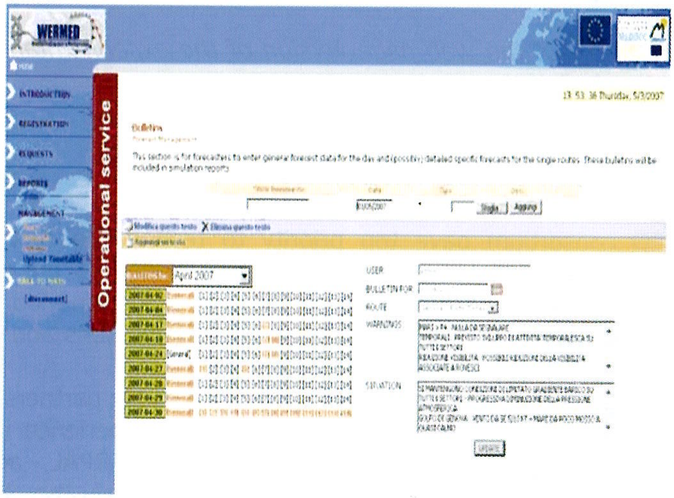


Figure 9: first web page of forecast text fields for the different routes of the bulletin

Once the forecaster has filled in the text fields and the simulation has produced the navigation parameters, the web service can either put the whole information on a web page, which the user can see on the web site, or in a PDF file to be sent either by fax or by e-mail. Picture *Figure 10* shows an example of a page in html format. Please note the maps with wind and wave forecasts during the journey in the area covering all alternative routes. Obviously the geographical area changes according to the selected route and the relevant options.

EXAMPLE OF REPORT VIA WEB (for USERS/FORECASTERS)

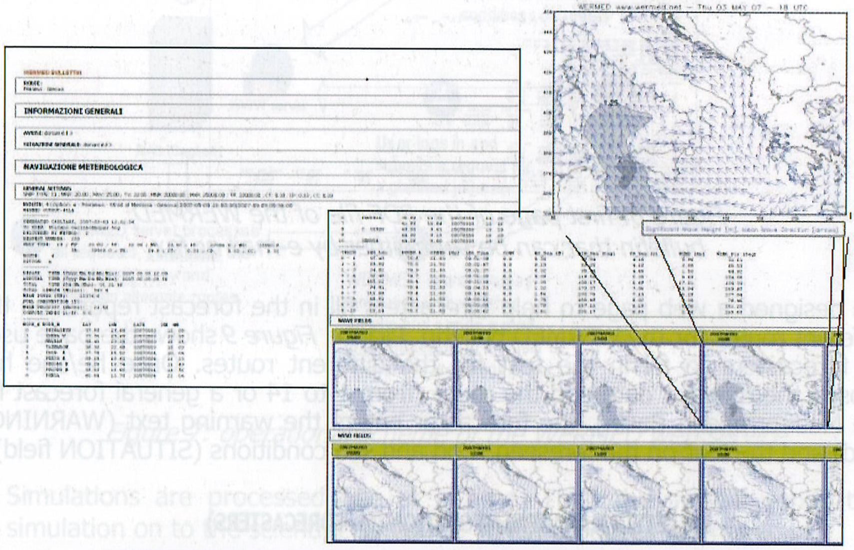


Figure 10: example of the web page version of the experimental WERMED weather-routing bulletin.

The operational service

The WERMED consortium gave top priority to testing the service, which should be carried out in a short time. We identified a pre-operational application of the service that could be created in a short period of time in order to identify possible problems, find the relevant solutions and create the final version as soon as possible.

We first organised a group of forecasters (from all project partners - ARPAL, IOI) and subcontractors (SAR, Himmel&Matter) with experience in sea and weather forecasting. In autumn 2006 the group – led by ARPAL - agreed on a common working strategy and working tools. It used mainly the model chain developed in Action 3.1 and the resources available to the centres at local level.

We chose electronic mail as means of communication, since the message can contain simulations of the cost function, the first version of the weather-routing bulletin and possible comments from other forecasters all at the same time. The same telemetric channel was chosen also by the shipping company to receive the messages.

We also decided that, in order to produce a useful service, we had to test it mainly on passenger ships sailing in the seas covered by the project. Therefore ARPAL contacted the company Gruppo Grimaldi – Grandi Navi Veloci (GNV) from Genoa, which gave its full cooperation.

Captain Renato Giannantonio authorised the company's two motor ships sailing along the Genoa – Porto Torres route to use the service daily. The captains of the ships and the navigation officers were briefed on the contents of the WERMED service and offered to draw up a report after each journey, providing an evaluation of the characteristics, performance, time and fuel consumption of navigation.

On November 21st 2006, with unfavourable weather and sea conditions, the service became operational on the above-mentioned GNV ships. The shipping company expressed its favourable opinion from the very beginning.

In January 2007 the Company asked for simulations also for the routes Genoa- Tunis and Tunis-Genoa.

To meet the demand for personnel – in order to provide daily forecasts the staff has to work also on week-ends and bank holidays - we adopted a monthly shift schedule (see Picture *Figura 11*), which all the structures involved made enormous efforts to adopt.

MOUNTHLY SHEDULE of SHIFTS and SIMULATION (for ADMIN)

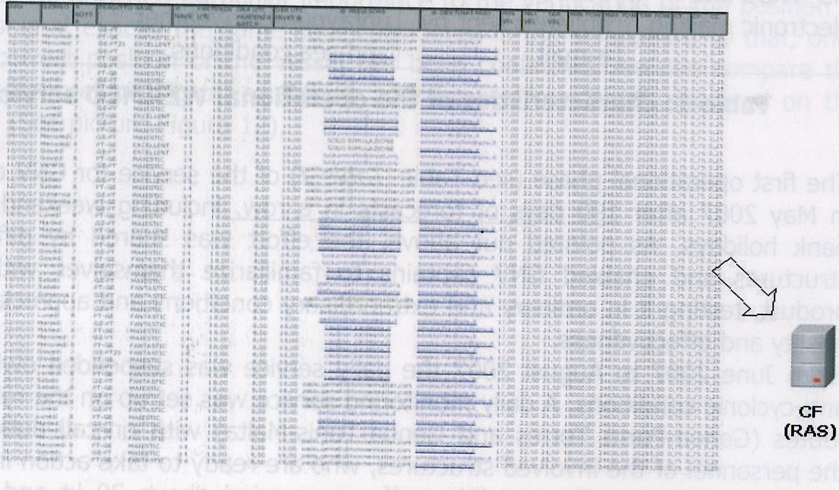


Figura 11: example of monthly forecast schedule listing the daily shifts of forecasters, the addressees of the product, the routes, the ships, the timetable and the parameters of the simulations taking the cost function into account.

Some of the captains were enthusiastic about the service, and, in some cases, when they received a particularly forecast of severe weather through the WERMED bulletin, they decided to change their sailing plans.

In the event of strong south-westly wind, the route normally taken by GNV ships sailing between Genoa and Porto Torres is exposed to gales and rough sea for a long period of time (8 to 14 hours). This track leads to an increase in consumption of fuel, discomfort for the passengers, a fall in the performance of the crew and a decrease in the purchase of food and drinks on board. Moreover, the unfavourable wind conditions entail a risk of structural damage for both the ship and the vehicles it transports.

Mooring is particularly difficult in case of unfavourable weather conditions, when strong wind makes manoeuvring risky for the ship. To reduce manoeuvring risks the company uses tugboats (only in the Genoa harbour) with the obvious consequences in terms of costs. In this situation the WERMED service can be of help, since, if the company can "book" the tugboat 12 hours in advance, it saves a substantial amount of money.

OPERATIONAL WEATHER-ROUTING SERVICE FOR GNV			
Pre-operational phase	I operational phase	Monitoring phase	II operational phase
October-November 2006	26/11/2006-31/05/2007	01/06/2007-31/08/2007	01/09/2007-31/10/2007
Testing simulations, drawing up the product in MS_Word and electronic mailing	Operational for 190 days, 19 bulletins a week, about 500 bulletins issued, bulletins sent by e-mail	13 weeks of operational simulations along all the routes, on-call shifts for the personnel, issuing bulletins on unfavourable weather and sea conditions	Not known at the time of writing

Table 1: characteristics of the operational WERMED service

The first operational phase (see Table *Table **1***) of the service for GNV ended in May 2007 after 190 days of forecasts in a row, including weekends and bank holidays. As pointed out above, the effort was shared by different structures and enabled GNV captains to familiarize themselves with the product, testing it in ordinary and extraordinary conditions and appreciate its quality and effectiveness.

From June 2007 to August 2007 the daily service was suspended owing to anti-cyclonic conditions. A daily monitoring service was set up on the relevant routes (Genoa-Porto Torres and Genoa-Tunis-Malta) with on-call duties for the personnel of the involved structures, who are ready to take action in case of unfavourable weather conditions (foreseen wind above 30 kt and wave height exceeding 2.5 metres).

The details of second phase of the operational service, forseen to start in September 2007, was not known at the time of writing.

The reports from the ships

The importance of reports from the ships becomes clear every time there is the need to verify the forecast issued for a "static" area, especially if the covered area changes at the same speed as the actual ship's sailing speed.

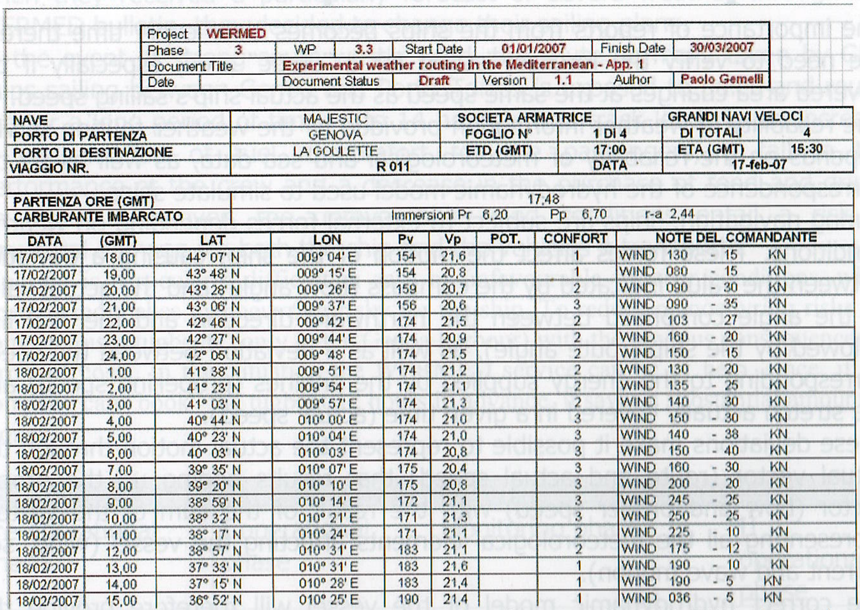
The reliability of weather information provided by the weather routing service depends on the reliability of meteorological and sea data, as well as on the correspondence of the hydrodynamic model used to simulate ships.

During navigation, ships are subject to external forces depending on weather conditions. These forces affect the motion of the ship, causing a deviation between the value indicated by the compass (bow angle) and the actual value of the angle comprised between the northward direction and the real line followed by the ship (route angle), as well as a deviation between the speed corresponding to the energy supplied by the engines (propelling speed) and the stretch actually covered in a given time (actual speed).

These deviations make it possible to represent the actual motion through the actual vector (route and actual speed) that results adding up the proper vector (bow and proper speed) with the result of the sum of the vectors representing all the meteorological elements affecting the vessel (wind, sea current and wave motion).

The correct hydrodynamic model of the vessel will therefore provide the parameters that characterise its motion when affected by external agents. In the case of the prototype created by WERMED this simulation also provides the estimated coordinates of the ship and the comfort factor on board.

In order to assess the forecasting value of the hydrodynamic simulation of the vessels and, as a consequence, of the meteo-marine model, we drew up a report format for the captains of the ships involved in the experiment. In the report we attached particular importance to the verification of the position of the ship at exactly the same hour considered in the simulation, so that, once the correct position of the vessel has been confirmed, we can compare the foreseen meteorological conditions and the real conditions observed on the ship. (See picture Figura 12).



Project	WERMED						
Phase	3	WP	3.3	Start Date	01/01/2007	Finish Date	30/03/2007
Document Title		Experimental weather routing in the Mediterranean - App. 1					
Date		Document Status	Draft	Version	1.1	Author	Paolo Gemelli

NAVE	MAJESTIC	SOCIETA ARMATRICE		GRANDI NAVI VELOCI	
PORTO DI PARTENZA	GENOVA	FOGLIO N°	1 DI 4	DI TOTALI	4
PORTO DI DESTINAZIONE	LA GOULETTE	ETD (GMT)	17:00	ETA (GMT)	15:30
VIAGGIO NR.	R 011		DATA	17-feb-07	

PARTENZA ORE (GMT)	17,48
CARBURANTE IMBARCATO	Immersioni Pr 6,20 Pp 6,70 r-a 2,44

DATA	(GMT)	LAT	LON	Pv	Vp	POT.	CONFORT	NOTE DEL COMANDANTE
17/02/2007	18,00	44° 07' N	009° 04' E	154	21,6		1	WIND 130 - 15 KN
17/02/2007	19,00	43° 48' N	009° 15' E	154	20,8		1	WIND 080 - 15 KN
17/02/2007	20,00	43° 28' N	009° 26' E	159	20,7		2	WIND 090 - 30 KN
17/02/2007	21,00	43° 06' N	009° 37' E	156	20,6		3	WIND 090 - 35 KN
17/02/2007	22,00	42° 46' N	009° 42' E	174	21,5		2	WIND 103 - 27 KN
17/02/2007	23,00	42° 27' N	009° 44' E	174	20,9		2	WIND 160 - 20 KN
17/02/2007	24,00	42° 05' N	009° 48' E	174	21,5		2	WIND 150 - 15 KN
18/02/2007	1,00	41° 38' N	009° 51' E	174	21,2		2	WIND 130 - 20 KN
18/02/2007	2,00	41° 23' N	009° 54' E	174	21,1		2	WIND 135 - 25 KN
18/02/2007	3,00	41° 03' N	009° 57' E	174	21,3		2	WIND 140 - 30 KN
18/02/2007	4,00	40° 44' N	010° 00' E	174	21,0		3	WIND 150 - 30 KN
18/02/2007	5,00	40° 23' N	010° 04' E	174	21,0		3	WIND 140 - 38 KN
18/02/2007	6,00	40° 03' N	010° 03' E	174	20,8		3	WIND 150 - 40 KN
18/02/2007	7,00	39° 35' N	010° 07' E	175	20,4		3	WIND 160 - 30 KN
18/02/2007	8,00	39° 20' N	010° 10' E	175	20,8		3	WIND 200 - 20 KN
18/02/2007	9,00	38° 59' N	010° 14' E	172	21,1		3	WIND 245 - 25 KN
18/02/2007	10,00	38° 32' N	010° 21' E	171	21,3		3	WIND 250 - 25 KN
18/02/2007	11,00	38° 17' N	010° 24' E	171	21,1		2	WIND 225 - 10 KN
18/02/2007	12,00	38° 57' N	010° 31' E	183	21,1		2	WIND 175 - 12 KN
18/02/2007	13,00	37° 33' N	010° 31' E	183	21,6		1	WIND 190 - 10 KN
18/02/2007	14,00	37° 15' N	010° 28' E	183	21,4		1	WIND 190 - 5 KN
18/02/2007	15,00	36° 52' N	010° 25' E	190	21,4		1	WIND 036 - 5 KN

Figura 12: example of a report drew up by the captains of GNV ships during and after each journey.

In the framework of the project we considered the following meteorological variables: wind (intensity and direction) and wave motion (significant wave height, direction, and period). These values were processed daily and submitted to the ships involved in the experiment. Then they were compared with the observations made during the experimental phase.

While evaluating the observations concerning the wind, we took into account the deviations caused by the difference between the forecast level (10 m) and the usually higher level at which the anemometer on board is positioned.

Without the adequate instruments the evaluation of the wave motion is not reliable. Therefore we decided not to ask for estimations in the report and to quantify only its tangible effects on the comfort of the passengers. Another important parameter to assess the forecasting capacity of the hydrodynamic model was the power supplied by the engines.

During the operational phase of the weather-routing system of the WERMED Project, we checked the reports submitted by ships from December 1st 2006 to March 31st 2007. 70% of the issued bulletins were followed by a report from the ship, which indicates an unexpected participation on the part of the captains, who generally tend to avoid any interference on how navigation is conducted.

The data set we used for checking includes the experimental phase, during which a total of 207 bulletins were issued. (See table
Table 2).

	December 2006	**January 2007**	**February 2007**	**March 2007**
Genoa – Torres	22	15	14	18
Torres – Genoa	25	18	14	18
Genoa – Tunis	6	6	6	8
Tunis – Genoa	3	2	4	5
Tunis – Malta	3	3	3	4
Malta – Genoa	0	3	3	4
MONTHLY TOT.	**59**	**47**	**44**	**57**
TOT. ISSUED BULLETINS			**207**	

Table 2: checking the reports issued by captains from December 1st 2006 to March 31st 2007. Monthly distribution of the bulletins issued during the experimental phase.

As an example we quote a case study on the line Porto Torres – Genoa of December 21st 2006, when meteorological conditions were particularly bad on the western coast of Corsica due to an intense western gale increased by a strong semi-zonal gradient in western Mediterranean (see picture Figure 13).

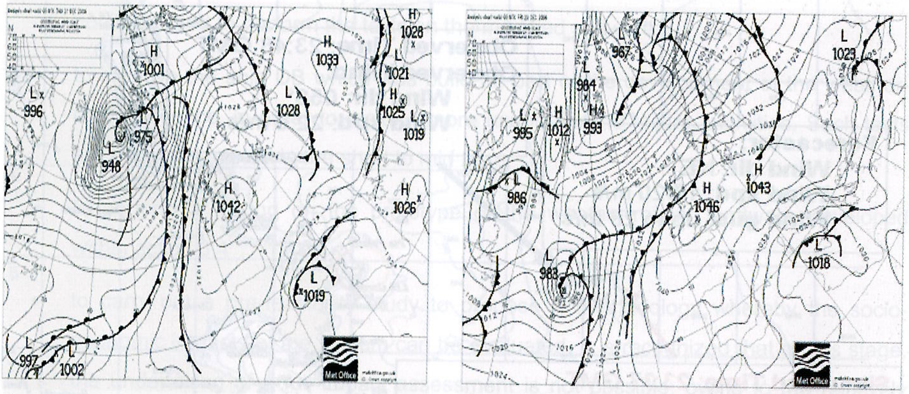


Figure 13: *Synoptic situation of the studied event: on the left analysis of the weather at 00OGMT of 21.12.2006, on the right at 00GMT of 22.12.2006.*

In this situation the captain of the ship chose the West route (the usual, shorter route). The case study is interesting because the ship sailed near the WERMED simulation point at approximately the same time of the day (see picture *Figura 14*).

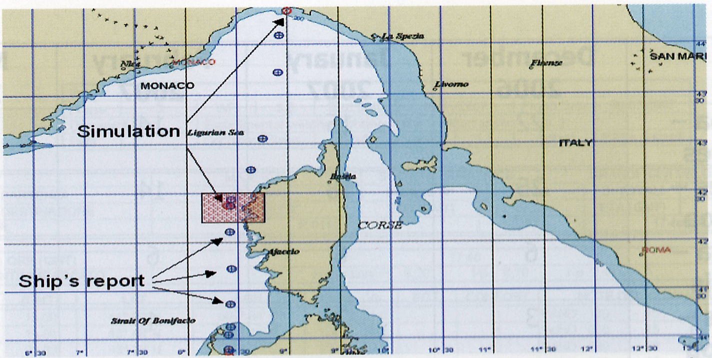


Figura 14: comparison between the points where the ship made a report and the points for which the WERMED simulation provided a sea and wind value (21/12/2006)

In this situation we could compare the forecast drawn uyp by the WERMED forecaster for this sea stretch and the values simulated by the WERMED system with the values reported by the Captain. The comparison between the simulated data (in red in the maps below) and the actual data resulting from the observation (in blue) concerning the position of the ship shows that the hydrodynamic model performed well, in that the simulated position of the ship is quite accurate (see picture Figura 15). The comparison between the weather conditions observed by the Captain (in blue in the map above), the data provided by the model (in red) and those of the bulletin (in green) proves the reliability of weather condition simulations also in a difficult sea area as the coastal area.

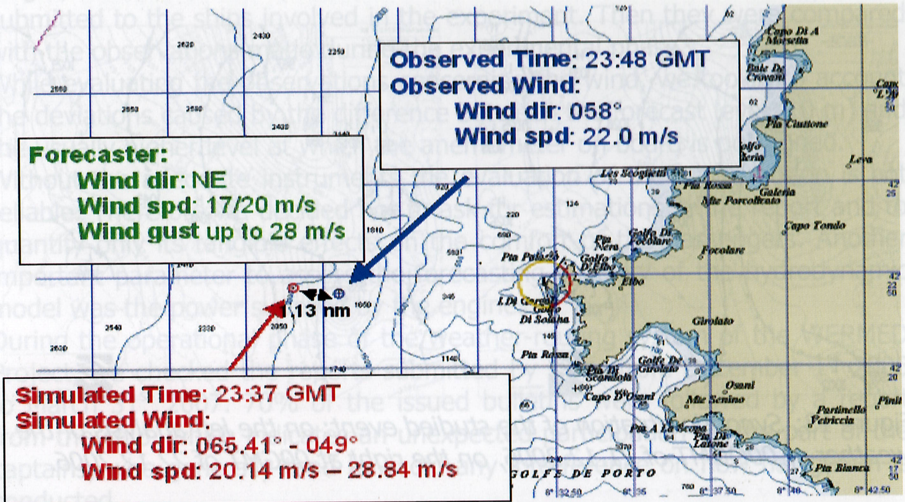


Figura 15: *Dettaglio relativo allo scostamento tra posizione stimata e posizione osservata alle 23.48 GMT (21/12/2006)*

For the verification of the entire operational period please see the REPORT ON ACTION 3.3 by P. Boi and P. Cau (SAR, Sardinia).

VIII. SOCIO-ECONOMICAL ASPECTS OF WEATHERROUTING.

K. Nieddu, *list of other participants.*

Introduction

The socio-economic impacts of a weather-routing system are referable to two key results, both of them fully achieved through the WERMED project:

- the implementation of an experimental service of weather-routing designed to optimize the navigation on specific routes, to be provided to private customers (shipowners, pleasure boaters, etc.) and, in the future, to institutional customers (e.g., institutions who are responsible for sea surveillance and security)
- to take advantage of the expertise acquired during the development of a weather routing service, in order to evaluate through a prototype of the service its potential for future planning.

To this end, action 3.4 has been divided into the following sub-activities:

- to modify the cost function in the software developed by CETENA on the implementation of a weather-routing service; with such modification, the software could be used to plan and evaluate future routes, thus helping the decision-making process.
- to create and maintain a DB of historical data on sea and weather conditions which could be used to perform the tests on the modified software;
- to improve the ship DB which was build as part of the development of the weather-routing service, in order to make it more usable for the testing activities. Such tests are expected to start in the short to mid term.
- to perform a testing on the prototype of the weather-routing software developed within action 3.4
- to carry out a pre-feasibility study to propose a methodology whereby the socio-economic impacts of the system can be evaluated. It is recognized that at this stage, the undertaking of a full impact assessment is not possible, owing to the relatively recent introduction of the system and the lack of data. At this early stage a methodology for impact assessment should be developed so as to enable the collation of data necessary to conduct an ex post socio-economic impact assessment in future. This would place an economic value on the activity serving as a basis to the marketing of the service to private operators and to the possible operation of the activity through the defrayment of public resources.

Description of the infrastructure

The infrastructure required for running the software has been provided by the Assessorato ai Trosporti of the Regione Autonoma della Sardegna at their "Centro di Calcolo" (CED). It consists of a server with

Dual processor Intel(R) Xeon(TM) running at 2.40GHz,

2Gb of RAM

controller RAID with disk space of 100 GB

double network card with speed of 100 Mbit

The operating system Linux (Centos 4.5 distribution) was installed on the server, together with applications, compilers and libraries required for the compilation and execution of the software. In particular, to maximize and optimise the execution of the software, the Intel Fortran compiler version 9.1.045 was installed.

The server is connected through a switch to the local network of CED and, by means of a static address, it can be accessed by other partners of the WERMED project.

Transfers speed of about 470 kb/sec when connecting to the internet were easily achieved, thanks to the 4 Mbps connection provided by the Regione Autonoma della Sardegna.

The users had interactive access to the server through the secure protocol ssh. The encrypted traffic provided the required level of security and privacy.

The software has been continually updated by means of the native updating facilities of the Centos distribution, which allow for a remote maintenance.

The server was also used for the operational phase of action 3.2, when the prototype of the WERMED weather-routing system was implemented. All the required software were insalled. In particular, a database service (MySQL), a web server (Apache 2.0), the required libraries for the scripting language PHP (version 5.0). In addition, many shell scripts were written in the language bash to automatize the maintenance and to organize the job queue. The job queue was generated through a web interface.

Modification of Cost Function

The WERMED cost function has been designed to predict the behaviour of the ship course once suitable environmental conditions have been provided. The cost function calculates the optimal velocity pattern in order to meet certain requirements established beforehand:

- Keep the power as close as possible to the ship target power
- Arrive at destination in a target time
- Keep the passenger comfort onboard as high as possible

Once a route has been defined and the weather conditions have been forecasted for a time duration at least equal to the ship journey duration at her lowest speed, the calculation consists in the extensively evaluation of all possible velocity combinations for the ship to complete the assigned route. The best ship velocity combination is determined as the combination which minimise the cost function.

The above mentioned cost function is based on daily weather forecasts on specific routes. It has been deemed interesting to extend the utility of the program to include the possibility to estimate the costs associated with long-term historical weather conditions on "average" ship routes. The objective is the possibility to perform feasibility studies of different routes related to the expected theoretic fuel consumptions and the possible time delays associated with the probable weather conditions and subsequently select the best suited vessel for a certain route.

Program description.

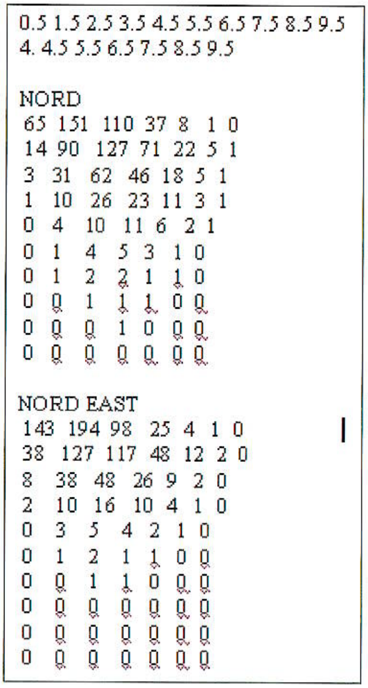
The software developed calculates the expected total fuel consumption in tons and the total added power due to weather condition in kW for a given vessel taking into account the probable sea conditions, that ship might encounter on an average annual basis for a given route. Essentially the program calculates the added power required to maintain a given speed in the presence of different wave conditions.

Weather conditions

The weather conditions used in the software is limited to the presence of waves. The wave environment is described using the JONSWAP sea spectrum, which mathematically represents a fetch limited sea as the Mediterranean Sea. The waves are assumed long crested.

The sea conditions are described through statistical data tabulated in a scatter diagram. The scatter diagram expresses the sea conditions in terms of the probability of a certain significant wave height/wave period (Zero crossing period) combination. The Global Wave Statistics (BMT, 1986) contains wave measurements of 104 ocean areas (Marsden areas) and covers all major ship trading routes. The scatter diagrams are given for the eight global directions and seasonal variations.

In the test case described subsequently the annually averaged wave information for area 26 is used. This scatter diagram covers the western part of the Mediterranean Sea. In the figure below a part of the input file scatter_diagram.dat is shown.



```
0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5
4. 4.5 5.5 6.5 7.5 8.5 9.5

NORD
 65 151  110 37 8   1  0
 14 90   127 71  22  5  1
 3   31   62   46  18  5  1
 1   10   26   23  11  3  1
 0   4    10   11  6    2  1
 0   1    4    5   3    1  0
 0   1    2    2   1    1  0
 0   0    1    1   1    0  0
 0   0    0    1   0    0  0
 0   0    0    0   0    0  0

NORD EAST
 143  194 98   25  4   1  0
 38   127 117  48  12  2  0
 8    38   48   26  9   2  0
 2    10   16   10  4   1  0
 0    3    5    4   2   1  0
 0    1    2    1   1   0  0
 0    0    1    1   0   0  0
 0    0    0    0   0   0  0
 0    0    0    0   0   0  0
 0    0    0    0   0   0  0
```

Figure 3 Example of a scatter diagram (Area 26)

In the first two lines the significant wave heights and the wave periods are given. Below the probability of a certain wave height/period for each global direction are tabulated as the number of occurrences. For the Area 26 the following probabilities of the global wave directions given in the Global Wave Statistics.

North	North-East	East	South-East	South	South-West	West	North-West
7.8 %	11.22 %	15.41 %	7.94 %	10.81 %	11.54 %	19.33 %	14.13 %

Table 2 Probability of given global wave direction for Area 26

Based on the ship geometry a seakeeping analysis is performed supplying information about the added power due to waves at different ship/wave encounter angles (headings) using as mentioned earlier the JONSWAP sea spectrum and long crested waves. The added power is calculated for a larger number of headings (24) but only the 8 global wave directions are used.

Calculation Procedure

In the following the calculation procedure and the main equations used in the software are explained.

- The first step in the calculation procedure is to determine the relative ship/wave encounters β given the route direction.
- For each encounter angle the average added power for journey 1, P_{1i} is calculated based on the added power (RAW) at a given wave height H_s and wave period T_z and the number of occurrences $n_{scatter}$ of this sea state.

$$P_{1i} = \sum_{i=1}^{8} \sum_{Hs=1}^{10} \sum_{Tz=1}^{7} RAW_{\beta} * (n_{scatter} / 1000)$$

- The total added power for journey 1 P_1 is calculated based on the probability of global wave direction in Area 26.

$$P_1 = \sum_{i=1}^{8} P_{1i} * probability\ of\ global\ wave\ direction$$

- Steps 2 and 3 are likewise performed for journey 2 (return journey)
- Finally the total annual fuel consumptions due to the presence of certain weather (wave) conditions can be determined for the outward and return journey.

$$T_1 = P_1 * \frac{365}{2} * \left(\frac{journey\ lenght / \gamma}{reference\ power} \right)$$

- Where γ is the specific fuel consumption in miles per tons given in Table 6
- The total annual fuel consumption T in tons is calculated as

$$T = T_1 + T_2$$

Integration of Ship Profiles in the Database

Three different ferries have been added to the ship database. The N/T Fata Morgana and N/T Isola di Caprera are bidirectional vessels whereas the N/T Iginia has been included in the data base assuming bidirectional hull form in the analyses in order to cover a wider range of ship lengths and sizes. In the following the main characteristics of the three vessels are described.

N/T Isola di Caprera

Figure 4 N/T Isola di Caprera

	N/T Isola di Caprera
Length [m]	70
Beam [m]	15.8
Draught [m]	3.2
Displacement [m^3]	1951
Still water power [kW]	1130
Still water velocity [kn]	12.5
Passengers capacity	591
Vehicle capacity	90 cars

Table 3 Main characteristics of N/T Isola di Caprera

N/T Fata Morgana

Figure 5 N/T Fata Morgana

	N/T Fata Morgana
Length [m]	101
Beam [m]	19
Draught [m]	5
Displacement [m^3]	5131
Still water power [kW]	2210
Still water velocity [kn]	14
Passengers capacity	500
Rail tracks	3
Capacity	12 rail cisterns or 12 trailer trucks or 79 cars

Table 4 Main characteristics of N/T Fata Morgana

N/T Iginia

	N/T Iginia
Length [m]	140
Beam [m]	19
Draught [m]	6.1
Displacement [m^3]	8585.3
Still water power [kW]	4369
Still water velocity [kn]	15
Passengers capacity	1660
Rail tracks	4
Capacity	43 trailers or 16 railway wagons and 95 cars

Table 5 Main characteristics of N/T Iginia

Integration of meteorological data

Significant height and period climatologies are considered in this study. They are obtained using data from the WAM model running at the ECMWF (Reading, UK) and cover a period of more than 13 years, between 1st July 1992 and 31st December 2002.

The climatologies are obtained for the two minor Sardinian islands of San Pietro and La Maddalena and for the route between Porto Torres and Genoa, considering in this last case both alternatives passing E or W of Corsica.

To determine the climatology in the two minor islands, the closest grid points have been considered. They are (39°N; 8,25°E) for Carloforte, the main harbor of San Pietro, and (41,25°N; 9,50°E) for La Maddalena.

		Latitude	Longitude
1	Golfo Ligure	43,50°N	9,00°E
2	Isola Gargalu	42,25°N	8,50°E
3	North of P. Torres	41,25°N	8,50°E
4	Tavignano	42,00°N	9,50°E
5	Isola Lavezzi	41,25°N	9,25°E

Table I. The five points used to determine the climatology of the route between Porto Torres and Genoa.

Significant height	Period (s)
(0; 0,25]	(0; 1,9]
(0,25; 0,75]	(1,9; 2,6]
(0,75; 1,25]	(2,6; 3,1]
(1,25; 1,75]	(3,1; 3,8]

(2,25; 2,75]	(4,6; 5]
(2,75; 3,25]	(5; 5,5]
(3,25; 3,75]	(5,5; 6,1]
(3,75; 4,25]	(6,1; 6,7]
(4,25; 4,75]	(6,7; 7,4]
(4,75; 5,25]	(7,4; 8,1]
(5,25; 5,75]	(8,1; 8,9]
(5,75; 6,25]	(8,9; 9,8]
(6,25; 6,75]	(9,8; 10,8]
(6,75; 7,25]	(10,8; 11,9]
(7,25; 7,75]	(11,9; 13]
(7,75; 8,25]	(13; 14,4]
(8,25; 8,75]	(14,4; 17,4]
(8,75; 9,25]	(17,4; ∞)
(9,25; 9,75]	
(9,75; ∞)	

Table II. Intervals in significant height and period used to build the climatology. The parentheses are used with their usual mathematical meaning.

To build the climatology of the route between Porto Torres and Genoa, five different grid points have been used. They are listed in Table I. They are chosen to represent the climatology along the full route, and correspond to the two sides of Corsica (2, 4 in Table I), to the open sea near Porto Torres (3) and Genoa (1) and to the peculiar region around the "Bocche di Bonifacio" (5) between Corsica and Sardinia.

In each of these points, 25 directions covering the full horizon were considered and for each interval of significant height the frequency of the sea being in that direction was determined. This is akin to building a wind rose to represent what the most frequent winds in a certain location are. The intervals of significant height used to do this are given in the first column of Table II.

Another parameter required to simulate the navigation is the period of the waves. For each significant height interval, a spectrum of periods was build, using the period intervals given in the second column of Table II.

Testing Of the implemented prototype

The modified cost function has been tested for the routes Genova – Porto Torres, Porto Torres – Genova. Average route length is set to 214 nautical miles and sailing time 10 hours at 21.5 kn. The route directions are assumed south for Genova – Porto Torres and north for Porto Torres – Genova.

In the present analysis the annually averaged wave information for area 26 is used. This scatter diagram covers the western part of the Mediterranean Sea.

Ship characteristics

The calculations have been performed using the GNV Splendid with the below given main characteristics.

Length [m]	190
Beam [m]	26.8
Draught [m]	6.5
Volume [m^3]	19124
Velocity [kn]	21.5
Reference power (85% of main motors) [kW]	19500
Specific fuel consumption [miles/t]	6

Table 6 Main ship input information for the GNV Splendid

Added fuel consumption

The annual added fuel consumption due to the presence of waves have been calculated for the Splendid on the route Genova-Porto Torres keeping a ship speed of 21.5 kn:

Total [t] = 560.7958

Added GE-PT [t] = 193.0153

Added PT-GE [t] = 367.7804

From the above numbers it is clear that the wave conditions the ship encounters on an average annual level from Porto Torres to Genova result in a significant larger fuel consumption than the same outward journey from Genova to Porto Torres. This confirms the importance of including the long-term weather conditions in a feasibility analysis in order to define the best suited vessel for a given route.

Pre-feasibility study of the weather routing

The pre-feasibility study of the economic impact established that weather routing in the Mediterranean is expected to yield substantial logistical advantages which would translate into socio-economic benefits. This is in good part because the Mediterranean basin is a significant contributor to maritime transport and is experiencing continued growth, particularly in the cruise tourism industry. This has important economic and environmental implications, and presents a strong need for the growth in the industry to be sustained through an enhanced focus on passenger comfort and safety with the context of a sustainable development approach aimed at safeguarding end enhancing environmental assets.

It is at this stage too early to derive concrete estimations regarding the socio-economic impacts of this project, mainly due to the lack of data. This study thus proposes a methodology in this regard based on three steps. The first is the estimation of route-specific impacts arising out of the adoption of the WERMED system on fuel consumption, cargo losses and comfort. The second concerns the resulting socio-economic impacts mainly in terms of the environmental effects emanating out of reduced emissions. The third relates to the possible benefits derived from better shipping activity by the wider economic segment that is dependent on marine space and resources.

It is proposed that the estimation of route-specific impacts be based on a regression approach between performance indicators and the degree of adherence to WERMED recommendations. The estimation of environmental effects can be based on available estimates of the environmental costs from emissions from shipping in the Mediterranean. The wider economic effects would require a case-by-case study to take account the dependence of the aggregate economy on the marine sector.

Future perspective

The products and activities carried out within action 3.4 of the WERMED project open several perspectives, stemming from:

- the implementation, within short time, of a fully working weather-routing service in the Mediterranean. The passage from the experimental phase to the operational one will require a feasibility study which will build on the one carried out as part of action 3.4.

- the implementation of a software designed to plan the routes; such software could be developed further and could be integrated with a wider system of modelisation and planning of maritime traffic, both passengers and goods .

- the building of a network of organizations and institutions to promote maritime traffic and to support the security of navigation. This would be in accordance with the recommendation of the EU on the development of short sea shipping, leading to a more efficient transport network in the Mediterranean area and to a reduction of pollution associated with transport. These are quite ambitious targets, and can only be achieved if there are appropriate tools to support the decision-making process. The Action 3.4 of the WERMED project has been a first step in the provision of such tools to institutions, making it possible to carry out more effectively the implementation of the policies set out in the planning documents.

REFERENCES.

AA. VV. 2007. *WERMED – Weatherrouting dans la Méditerranée. Action 2.1: Climatologie du vent superficiel.* Burlando M., Villa L., and C. F. Ratto (eds.), Technical Report

AA. VV. 2007. *WERMED – Weatherrouting dans la Méditerranée. Action 2.1: Climatologie du vent superficiel.* Burlando M., Villa L., and C. F. Ratto (eds.), CD-rom

Betts, A.K. and M. J. Miller, 1986: A new convective adjustment scheme. Part II: Single column tests using GATE wave, BOMEX, ATEX and Arctic Air mass data sets. Quart. J. Roy. Meteor. Soc., **112**, 693-709.

Betts, A.K., 1986: A new convective adjustment scheme. Part E. Observational and theoretical basis, Quart. J. R. Met. Soc., 112, 677-691.

Burlando M, Antonelli M, Ratto CF. 2007. Mesoscale wind climate analysis: identification of anemological regions and wind regimes. *Int. J. Climatol.* (in press)

Burlando M. 2007. Classification of surface wind climate regimes over the Mediterranean Sea through cluster analysis of synoptic-scale wind fields. *Theor. Appl. Climatol.* (submitted)

Buzzi, A., R. Cadelli, P. Malguzzi, 1997: Low level jet simulation over the Antarctic ocean. *Tellus*, **49 A**, 263-276.

Buzzi, A, Fantini M, Malguzzi P, Nerozzi F. 1994. Validation of a limited area model in cases of Mediterranean cyclogenesis: surface fields and precipitation scores. *Meteorol. Atmos. Phys.* **53**:137-153

Buzzi, A, Foschini L. 2000. Mesoscale meteorological features associated with heavy precipitation in the southern Alpine region. *Meteorol. Atmos. Phys.* **72**:131-146

Buzzi A., N. Tartaglione, P. Malguzzi, 1998: Numerical simulations of the 1994 Piedmont flood: role of orography and moist processes. *Mon. Wea. Rev.*, **126**, 2369-2383.

Cassou C, Terray L, Hurrell JW, Deser C. 2004. North Atlantic Winter Climate Regimes: Spatial Asymmetry, Stationarity with Time, and Ocean Forcing. *J. Climate* **17**:1055–1068

Cavaleri L, Bertotti L. 1997. In search of the correct wind and wave fields in a minor basin. *Mon. Wea. Rev.* **125**:1964-1975

Cavaleri L, Bertotti L, Hortal H, Miller M. 1997. Effect of reduced diffusion on surface wind fields. *Mon. Wea. Rev.* **125**:3024-3029

Cavaleri L, Bertotti L. 2003. The accuracy of modelled wind and wave fields in enclosed seas. *Tellus* **56A**:167-175

Chèruy F, Speranza A, Sutera A, Tartaglione N. 2004. Surface winds in the Euro-Mediterranean area: the real resolution of numerical grids. *Annales Geophysicae* **22**(*12*):4043-4048

Davis RE, Walker DR. 1992. An Upper-Air Synoptic Climatology of the Western United States. *J. Climate* **5**:1449–1467

Ebuchi N, Graber HC, Caruso MJ. 2002. Evaluation of wind vectors observed by QuikSCAT/SeaWinds using ocean buoy data. *J. Atmos. Oceanic Technol.* **19**:2049–2062

Eder BK, Davis JM, Bloomfield P. 1994. An Automated Classification Scheme Designed to Better Elucidate the Dependence of Ozone on Meteorology. *J. Applied Meteorol.* **33**:1182–1199

Everitt B. 1977. *Cluster Analysis*. HEB

Franco, L., Piscopia, R., Corsini, S., Inghilesi, R., 2003. Atlante delle onde nei mari italiani, AIPCN, Italia Navigando.

Getis, A. and Ord, J.K., 1992. The Analysis of Spatial Association by Use of Distance Statistics, Geographical Analysis, 24, 189-206.

Gumbel, E.J., 1958. Statistics of Extremes, Columbia University Press, New York.

Gunther, H., K. Hasselmann and P.A.E Janssen, 1992: Report No.4, The WAM Model Cycle 4, Edited by Modellberautungsgruppe, Hamburg

Jacob D, Podzun R. 1997. Sensitivity studies with the regional climate model REMO. *Meteorol. Atmos. Phys.* **63**:119-129

Janjic, Z.I., 1974: A stable centered difference scheme free of the two-grid-interval noise. *Mon. Wea. Rev.*, **102**, 319-323.

Janjic, Z.I., 1979: Forward-Backward scheme modified to prevent two-grid interval noise and its application in sigma coordinate models. *Contrib. Atmos. Phys.*, **52**, 69-84.

Janjic, Z.I., 1984: Non-linear advection schemes and energy cascade on semi-staggered grids. *Mon. Wea. Rev.*, **112**, 1234-1245.

Janjic, Z.I., 1990: The step-mountain coordinate: Physical package. *Mon. Wea. Rev.*, **118**, 1429-1443.

Janjic, Z.I., 1994: The step mountain eta coordinate model: Further developments of the convection, viscous sublayer, and turbulence closure schemes. *Mon. Wea. Rev.*, **122**, 927-945.

Janssen, P., 2004. The interaction of Ocean Waves and Wind, Cambridge University Press.

Jiang Q, Smith RB, Doyle J. 2003. The nature of the mistral: Observation and modelling of two MAP events. *Q. J. R. Meteorol. Soc.* **129**:857-875

Kain, J.S., and J.M. Fritsch, 1993: Convective parameterization for mesoscale models: The Kain-Fritsch scheme. *The Representation of Cumulus in numerical models, Meteor. Monogr.*, No **46**, Amer. Met., Soc., 165-177.

Kalkstein LS, Tan G, Skindlov JA. 1987. An evaluation of objective clustering procedures for use in synoptic climatological classification. *J. Climate Appl. Meteorol.* **26**:717–730

Kastendeuch PP, Kaufmann P. 1997. Classification of summer wind fields over complex terrain. *Int. J. Climatol.* **17**:521–534

Kaufmann P, Weber RO. 1996. Classification of Mesoscale Wind Fields in the MISTRAL Field Experiment. *J. Appl. Meteorol.* **35**:1963–1979

Kaufmann P, Whitemann CD. 1999. Cluster-Analysis Classification of Wintertime Wind Patterns in the Grand Canyon Region. *J. Applied Meteorol.* **38**:1131–1147

Komen, G.J., L. Cavaleri, M. Donelan, K. Hasselmann, S. Hasselmann, and P.A.E.M. Janssen, 1994. *Dynamics and Modelling of Ocean Waves*. Cambridge University Press, Cambridge.

Kotroni V, Lagouvardos K, Lalas D. 2001. The effect of Crete island on the Etesian winds over the Aegean Sea. *Q. J. R. Meteorol. Soc.* **127**:1917-1938

Lagouvardos K, Kotroni V, Koussis A, Feidas H, Buzzi A, Malguzzi P. 2003. The Meteorological Model BOLAM at the National Observatory of Athens: Assessment of Two-Year Operational Use. *J. Applied Meteorol.* **42**(*11*):1667–1678

Mellor, G.L. and T. Yamada, 1974: A hierarchy of turbulence closure models for planetary boundary layers. *J. Atmos, Sci.*, **31**, 1791-1806.

Mellor, G.L., and T. Yamada, 1982: Development of a turbulence closure model for geophysical fluid problems, *Rev. Geophys-Space Phys.*, **20**, 851-875.

Mesinger, F., 1973: A method of construction of second order accuracy difference schemes permitting no false two-grid interval wave in the height field. *Tellus*, **25**, 444-458.

Mesinger, F., 1977: Forward-backward scheme, and its use in a limited area model. *Contrib. Atmos. Phys.*, **50**, 200-210.

Schultz, P., 1995: An explicit cloud physics parameterization for operational numerical weather prediction. *Mon. Wea. Rev.*, **123**, 3331-3343.

Smith P, Ide K, Ghil M. 1999. Multiple Regimes in Northern Hemisphere Height Fields via Mixture Model Clustering. *J. Atmos: Sci.* **56**:3704–3723

Smith, W.H.F. and Sandwell, D.T. (1997). Global seafloor topography from satellite altimetry and ship depth soundings. Science, 277: 195-196

Spencer, P. L. and D. J. Stensrud, 1998: Flash flood events: importance of the subgrid representation of convection. *Mon. Wea. Rev.*, **126**, 2884-2912.

Stephenson DB, Doblas-Reyes FJ. 2000. Statistical methods for interpreting Monte Carlo ensemble forecasts. *Tellus A* **52**:300–322

Straus DM, Molteni F. 2004. Circulation Regimes and SST Forcing: Results from Large GCM Ensembles. *J. Climate* **17**:1641–1656

Tournadre J. 1999. Analysis of mesoscale variability of oceanic surface wind fields: contribution of active microwave sensors. In *Proceedings of IGARSS 99*, IEEE Press, **4**:1975-1977

Uppala SM, Kållberg PW, Simmons AJ, Andrae U, da Costa Bechtold V, Fiorino M, Gibson JK, Haseler J, Hernandez A, Kelly GA, Li X, Onogi K, Saarinen S, Sokka N, Allan RP, Andersson E, Arpe K, Balmaseda MA, Beljaars ACM, van de Berg L, Bidlot J, Bormann N, Caires S, Chevallier F, Dethof A, Dragosavac M, Fisher M, Fuentes M, Hagemann S, Hólm E, Hoskins BJ, Isaksen L, Janssen PAEM, Jenne R, McNally AP, Mahfouf J-F, Morcrette J-J, Rayner NA, Saunders RW, Simon P, Sterl A, Trenberth KE, Untch A, Vasiljevic D, Viterbo P, Woollen J. 2005. The ERA-40 Reanalysis. *Q.J.R. Meteorol. Soc.* **131**(*612*):2961-3012

Weber RO, Kaufmann P. 1995. Automated Classification Scheme for Wind Fields. *J. Appl. Meteor.* **34**:1133–1141

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Wilke CK, Milliff RF, Large WG. 1999. Surface wind variability on spatial scales from 1 to 1000 km observed during TOGA COARE. *J. Atmos. Sci.* **56**:2222-2231

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APAT - Agenzia Nazionale per la Protezione dell'Ambiente e per i Servizi Tecnici

ARPAL - Agenzia Regionale per la Protezione dell'Ambiente Ligure

Region of Sardinia - Assessorato dei Trasporti

NOA - National Observatory of Athens

Region of Crete

University of Malta - IOI - Malta Operational Centre

CTH : L'Organisme Nationale de Contrôle Technique des Ouvrages Hydrauliques, Algeria

Other Parties involved:

SAR - Servizio Agrometeorologico Regionale per la Sardegna

CETENA - Centro di Technologie Navali

Grandi Navi Veloci

Malta Maritime Authority

Himmel & Matter

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