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Co-ordinated Programme for Pollution Monitoring and Research

in the Mediterranean Sea (MED POL - PHASE I)

IOC/UNEP PILOT PROJECT ON PROBLEMS IN COASTAL TRANSPORT OF POLLUTANTS

MED POL VI

REPORT OF A DRIFTCARD EXPERIMENT IN THE MEDITERRANEAN SEA

D R I F T E X

In co-operation with:

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION

C O N T E N T S

BACKGROUND

At the UNEP Intergovernmental Meeting of Mediterranean Coastal States on the Protection of the Mediterranean, which was held in Barcelona, 28 January - 4 February 1975, the Co-ordinated Programme for Research and Monitoring of Pollution in the Mediterranean Sea (MED POL) was approved as the Environmental Assessment Component of the Mediterranean Action Plan.

The MED POL programme consisted of seven pilot projects and six related projects covering all the fields of marine pollution monitoring and research (UNEP, 1983).

One of the pilot projects (MED POL VI), Problems of Coastal Transport of Pollutants in the Mediterranean Sea, co-ordinated by the Intergovernmental Oceanographic Commission (IOC) in close consultation with UNEP, dealt mainly with the surface circulation of the Mediterranean Sea.

The main aim of the pilot project was to provide the necessary information on the main physical processes contributing to the coastal transport of pollutants in the Mediterranean Sea. Special attention was to be given to the movement of the surface layer since this contributes considerably to the rapid spread of certain pollutants, e.g. floating litter or petroleum hydrocarbons.

The project was supposed to assist in the assessment of all the aspects of marine pollution covered by the other six pilot projects particularly for the formulation and testing of models of the biogeochemical cycles of pollutants in the Mediterranean Sea.

A joint IOC/WMO/UNEP consultation was held in Malta, 8 - 13 September 1975, to develop the workplan of the MED POL VI pilot project. Experts from the countries bordering the Mediterranean Sea proper and several experts from outside the region were invited in order to discuss and prepare an operational document to serve as the framework for the co-operation of the Mediterranean research centres in its implementation (UNEP, 1983).

Since the gross features of the general current system in the Mediterranean are relatively well known, the pilot project was directed to the investigation of water circulation in coastal areas and exchange of water between the coastal and off-shore regions, especially areas where present or future pollutant discharge may be of importance, as for example at river mouths or near urban concentrations. Such investigations were to be carried out during all the seasons and especially under characteristic meteorological conditions of the areas, without neglecting small-scale fluctuations.

Guidelines to permit comparison of results and to facilitate broad participation had to be developed as part of the project. The choice of techniques and methods was such as to satisfy the minimum requirements in sensitivity and accuracy, consideration being given to ensuring simplicity in operational procedures and proper maintenance of instruments. The use of tracers, drogues and driftcards or drifters was suggested because of their simplicity. In particular, a driftcard experiment at the sub-regional scale was suggested in order to explore the usefulness of such an approach for the study of coastal and off-shore current systems in the various sub-basins of the Mediterranean.

INTRODUCTION

Sea surface transport in the Mediterranean is generally cyclonic (counter-clockwise) in both the eastern and western basins, but coastal currents are very complex and manifest a strong variability. Owing to the large ratio of coastline to sea surface in the Mediterranean Sea, the water circulation has an important longshore component. Therefore pollutants discharged into coastal waters often tend to be transported along the coasts.

Although the general nature of the mass transport of sea-water in the Mediterranean is reasonably well understood, the knowledge of local circulation patterns is still meagre. The majority of pollutants enter the sea in the upper layers. However, due to the vertical mixing, and to strong convective motions in some areas during the winter, they can be spread into the deep Mediterranean water, and flow slowly through the Strait. In order to understand their actual distribution and to predict the effect of potential sources of pollutants, a sound knowledge of the circulation and eddy diffusion is required.

Measurement of surface currents is one of the most difficult tasks in experimental physical oceanography. Direct measurements with currentmeters are unreliable at depths of less than 3 to 5 meter mostly because of the pumping effect of waves. Even vector averaging currentmeters do not allow precise measurements to be made in the surface layer.

Wind drift calculations, on the other hand, are usually made to quantify surface currents but there is evidence that changes in velocity shear may add difficulties to such computations.

Drogues, driftcards and drifters have been extensively used to determine surface currents in spite of the difficulties met when interpreting the results obtained. This is particularly true when they rely on accidental retrieval rather than on continuous tracking of their motions.

Accurate evaluation of the drifters' motion is complicated by several factors. First, there is always an uncertainty about its path and its recovery on a shore presuposes an onshore current component. Second, the recovery rate is highly dependent on the population density distribution along the coast as well as its habits and the type of coastline. Third, the time elapsed between the stranding of a drifter and its subsequent recovery is always uncertain.

The Driftcard Experiment (DRIFTEX) was intended to investigate the usefulness of driftcards as tracers for coastal surface currents, overcoming the well known drawbacks of such technique by releasing a large number of driftcards from an also large number of stations and using a computer model to process the information gathered rather than computing individual straight-line trajectories, as is often done (see Gerges, 1979 for a review).

In connection with the XXV Plenary Assembly of the International Commission for the Scientific Exploration of the Mediterranean Sea (ICSEM), Split 23 - 27 Octobre 1976, an ad hoc group of physical oceanographers laid down the details of such an experiment (IOC, 1977). It was agreed that it would consist of a series of driftcard launchings especially designed for the purpose in three areas:

- Rijeka Bay;

- Southeast Levantine basin, and

- Ligurian Sea

The IOC, in close consultation with UNEP, undertook the planning of such an experiment wich was initiated in winter 1976. Various institutes from the areas concerned participated in the project (see annex I). Of the three series of activities of which the DRIFTEX experiment was composed, only the Ligurian Sea exercise had indeed an international approach . The Egyptian and Yugoslavian exercises were planned and launched entirely with national resources.

THE RIJEKA BAY EXERCISE

A complex oceanographic and ecological study of the Rijeka Bay had been carried out since June 1976 (Jeftic et al., 1981). As part of this study, the Hydrographic Institute of the Navy (Split) and the Center for Marine Research of the "Rudjer Boskovic" Institute (Zagreb) undertook the investigation of surface currents by driftcards starting in December 1976. The main reason for this experiment was to acquire a better understanding of the characteristics of the surface layer movements in Rijeka Bay as well as of its flushing rate.

Numbered driftcards of 125 by 90 mm in size, sealed in transparent polythene envelopes of 135 by 95 mm were used in this exercise. The paper used for driftcards was of the 180 gram type, the weight of the cards was about 2 grams and that of the sealed envelope, including card and floater was 7.4 grams. A disc of foam was used to ensure the buoyancy of the card.

Concurrently with the driftcard experiment, currentmeter measurements were made (3 m depth) and surface drifters were tracked from a research vessel (Ilic et al., 1979). Meteorological observations were made from the research vessel every three hours during the launching period, and from the meteorological station at Rijeka continuously during the whole exercise. During this time, announcements were repeated several times a day through the local radio broadcasting stations.

The information required for the computations was recorded on specially designed logforms containing the following entries:

- number of the launching station
- date and time of launching
- meteorological observations
- colour of the card
- number of the card
- date and place of recovery

Ilic et al. (1979) discussed the results from some of the launchings in the Rijeka Bay between December 1976 and September 1977, though the exercise continued after that date. Table 1 shows the recoveries for these launchings in the weeks following them. The overall recoveries were above 21 % with a maximum in the first two weeks. This relatively high percentage in the recoveries was justified by the fact that the area is relatively closed. The hydrography of the region was described by Degobbis et al. (1979). Figure I shows the general circulation pattern as described by the driftcard exercise.

Table 1. Recovery dynamics for the Rijeka Bay exercise (from Ilic et al., 1979)

Launching date	Cards Launched	Retrieved		Recovery Dynamics (weeks) in % I	II	III	IV	after IV
Dec 1976	1200	224	19 %	24	4	3	7	62
Feb 1977	1200	320	27 %	36	19	8	10	27
Aug 1977	900	234	26 %	82	6	1	1	10
Sep 1977	900	113	12 %	31	12	7	28	22

THE SOUTHEAST LEVANTINE EXERCISE

A systematic investigation of the surface circulation of the Southeast Levantine basin had been carried out by scientists from the Institute of Oceanography and Fisheries in Alexandria (Egypt) for a period of two consecutive years. The purpose was to trace the spreading of polluted waters along the coast entrained by the nearshore surface currents before being mixed with offshore sea water. Understanding their seasonal variability in relation to wind action, and their role in the exchange of water between the coastal and offshore regions of the sea were thus essential.

The area covered by this exercise extended over most of the Egyptian continental shelf of the Mediterranean Sea, especially in an area extending from Sidi Krair (about 30 kms west of Alexandria) in the west, to Rosetta in the east. This area, covering about 80 kms of coast, contains almost all the main sources of pollution discharging into the Mediterranean from Egypt.

The prevailing wind conditions during the greatest part of the year are west-northwesterly, although north or north-east winds or even opposite southwest winds may blow for short periods.

Surface Woodhead-type drifters were used in the study. A card in a plastic envelope with a message to the finder in both Arabic and English, was carefully stapled and then fastened to the drifter's cap by a strong synthetic thread.

Batches of ten separate drifters serially numbered were released simultaneous but separately at each of the 57 coastal stations selected. Releases also took place at stations located outside the area. The sea state, wind speed and direction were recorded together with the geographical co-ordinates and drifters' numbers at the time of each release.

The results of the recoveries during this exercise are summarized in table 2 and figure II. The current system described by the trajectories drawn (Gerges, 1979) shows a very variable transport though generally flowing westwards nearshore and a more defined eastward flow further offshore (figure III).

Table 2. Driftcard recoveries in the southeast Levantine exercise (from Gerges, 1979)

Month	1976 released	1976 received		1977 released	1977 received	
January	80	0	0 %	183	24	13 %
February	-	-	-	220	45	21 %
March	48	10	21 %	189	47	25 %
April	-	-	-	109	2	20 %
May	138	48	35 %	254	30	12 %
June	227	64	28 %	254	30	12 %
July	90	14	16 %	-	-	-
August	199	66	33 %	65	6	9 %
September	-	-	-	93	31	33 %
October	-	-	-	40	6	15 %
November	234	44	19 %	187	46	25 %
December	230	16	7 %	-	-	-
Total	1246	262	21 %	1418	263	19 %

THE LIGURIAN SEA EXERCISE

The purpose of this exercise was not so much to investigate the current system in the northwest Mediterranean area, relatively well known, but to study the methodological approach consisting in launching a large number of driftcards at a large number of stations in a relatively small area and almost simultaneously. In this way, the redundancy would be large and the results could be processed in such a way that a coherent average current field could effectively be described.

The Ligurian Sea exercise began at the end of 1976 with the design and production at the IOC of the cards, written in four official UN languages (Arabic, English, French and Spanish), and sealed in plastic envelopes of 75 by 105 mm which had inside enough air to ensure buoyancy without being excessively exposed to the direct action of wind (figure IV).

On the 28 of April 1977, scientists from the Centre Scientifique de Monaco, the Station Marine de Villefranche sur Mer and the Gruppo di Ricerca Oceanologica di Genova launched the driftcards from the three ships involved in the exercise:

- KOROTNEFF (Villefranche sur Mer)
- RAMOGE (Monaco)
- PETRARCA (Genova)

Five thousand driftcards were released by groups of 100 cards (except the PETRARCA that launched 200 at a time) at 38 different locations (figure V). The cards recovered had to be mailed to the Centre Scientifique de Monaco where the information on the recovery sites was decoded (sometimes painfully) into geographical co-ordinates.

The IOC, with the assistance of the Institute for Oceanography and Fisheries in Alexandria (Egypt) acting as Regional Activity Centre for MED POL VI (RAC-VI) and in consultation with UNEP, responsible for the overall co-ordination of the whole Mediterranean Action Plan, was charged with the day-to-day co-ordination of the exercise.

More than one year after the launching of the driftcards (460 days), 534 cards had been recovered from all over the Western Basin of the Mediterranean Sea (figure VI). Of these 95 % were recovered within 4 months after the launching. A summary of the recovery statistics is shown in figure VII.

In view of the large amount of data and its complexity, from the very beginning it was clear that, unless a proper computer model was used in the processing, no further actions of this kind could be carried out within the framework of the MED POL programme.

After a number of attempts were made by the IOC, the Instituto de Investigaciones Pesqueras de Barcelona accepted to develop the computer system required. A preliminary overview of the processing technique was submitted to the IV ICSEM/UNEP Workshop on Pollution of the Mediterranean, Antalya 24 - 27 November 1978 (Cruzado, 1979) which called for comments on the proposal.

The problem was further analyzed and a DRIFTEX Processing System (DEPS) was developed allowing a comprehensive processing of the data that included a classical statistical approach with straight-line trajectory computations, graphic display of such trajectories and the computation, by means of a model, of multiple curved trajectories that allowed the establishment of a composite surface velocity field in the region covered by the experiment (Salat and Cruzado, 1981).

The effort required for the development of the system turned out to be much larger than it was first deemed necessary but the results obtained in the course of the project encouraged the scientists involved to study in depth many of the problems met. The result was a complex system of programmes only requiring a small computer although with a relatively large amount of disk storage and sophisticated (at the time) graphics output. In addition, the system opened new ways of dealing with surface-drift information which could be applied in the future to problems relevant to the transport of marine pollutants, especially hydrocarbons and other floating materials. It also achieved the digitization of the entire Western Mediterranean coastline and large parts of the Eastern Mediterranean.

THE DRIFTEX PROCESSING SYSTEM

The DRIFTEX Processing System (DEPS) was a set of programmes and data files intended for a thorough analysis of the information obtained through the release of a large number of driftcards at sea.

The basic objective of driftcard experiments is to estimate the surface velocity field in a region. Unlike what happens, for example, with drifting radio-buoys, driftcard experiments depend on the fortuitous recovery of cards, therefore there is a need for redundancy. This implies that a large number of individual driftcards, submitted to various forces and processes, are simultaneously moving around in a region, giving rise to a number of individual trajectories all of which must have a common component attributable to the water transport and a distinctive component attributable to random dispersion. What is really sought in this kind of experiments, rather than the individual driftcard behaviour, is the common part of the trajectories.

The main difficulty faced with experiments of this kind is that only release time and location are well known while no information is available on the path followed by individual driftcards (most of which are never recovered) and the time and location of the card recovery by sailors or sea-shore walkers have a large degree of uncertainty. This can only be overcome (at least in part) by using a relatively large number of driftcards, with the hope that averaging out redundant information will allow a reasonably good estimate of the actual velocity field in the area covered by the experiment.

The goal of the DEPS was to draw as much information as possible from the cards recovered, assuming all of them had been affected by the same velocity field. Therefore, it worked on a supposedly coherent set of driftcards.

The Experiment concept

The concept of driftcard Experiment used by the DEPS required that a coherent set of trajectories exists and that it can be represented by a collection of driftcards released at various times and locations with the aim of exploring the velocity field of a given area of the ocean. The primary choice of the area to be covered by the experiment should be made on the basis of previous oceanographic knowledge.

For the DEPS, the Experiment concept was substantiated by an open-ended file containing the recovery data sequentially organized according to the order in which the cards were received at the computer center. The information stored in this file was:

- driftcard identifier (usually a number)
- location of recovery (geographical co-ordinates)
- time of recovery (approximated to the day)

In this way, processing could be made at any time during the experiment with the information available. The results could thus be updated as new information was received.

The Launching Set concept

Since the reliability of the estimated velocity field depends on the redundancy of the information, a large number of driftcards must be released at a time at any given location and preferably at a large number of locations. The group of driftcards released at any one time constitutes a Launching Data Set (LDS). The LDS may cover one or more release sites provided the time difference and the distance between them are small compared to the time and distance from the release to the recovery sites.

For DEPS the Launching Data Sets were contained in an open-ended file. The information contained in this file was:

- LDS identifier
- number of driftcards released at that LDS
- driftcard identifiers for the LDS
- location of the release (geographical co-ordinates)
- time of release (approximated to the hour)

The Trajectory Concept

From the time of the release to the time of the recovery, the drift card is subject to a number of processes. On the one hand, there is a weathering process due to the action of the elements and attacks from sea-birds that may end up with the damage and loss of the card. However, not all the cards unrecovered are lost in this way. Many of them may be stranded on the shore at locations seldom frequented or may get trapped in convergent gyres away from populated coasts. On the other hand, the main cause of the drifter's trajectory, is supposed to be the uniform (or average) displacement, mostly under the effect of the wind stress, of surface water parcels in which the driftcards are trapped.

If the driftcard is recovered at sea, there is a large probability that it has not been stranded before but, for a great majority of cards, the probability that they have been lying on the shore for several hours, if not days, is large. Thus the distance between the points of release and recovery is always shorter than the length of the actual trajectory followed by the driftcard and the time elapsed between the release and recovery times is always greater than the actual time spend by the driftcard in its trajectory.

When a large number of driftcards have been released almost simultaneously, the trajectories described by the various driftcards recovered must be coherent and reflect the actual velocity field of the corresponding water layer. Taking away redundancy and computing trajectories that simultaneously fulfill all the constraints imposed by the group of cards selected should produce a non-synoptic velocity field close to reality.

Annex II gives a detailed description of the algorithm used for computing the trajectories. These trajectories could be displayed on real time and stored in disk memory for further processing and plotting. Problems created by eventual trapping of trajectories in coastline irregularities were in a few cases solved by manually establishing tangency points which would put the cards back into motion.

PROCESSING AN EXPERIMENT

The Experiment to be processed by the DRIFTEX Processing System (DEPS) may have a wide range of characteristics depending on the experiment planning mode. Two modes were considered:

1. Simultaneous launching at various locations of a large number of drift cards (for example the "Mare Ligur" experiment), and

2. Repeated launchings at a few locations of small numbers of drift cards (for example, the "Alexandria" experiment).

The DEPS was ready to accept both modes provided the problem was properly organized. This included two aspects:

- organizing the data files

- selecting the cards for velocity field computation

Organization of Data Files

A summary of the programmes and data files used by DEPS is given in Annex III. Two main files were organized:

1. Launching Data File (LDF) containing all the information relevant to the Launching Data Sets of an Experiment.

2. Recovery Data File (RDF) with all the information received with the recovered cards.

The LDF file was loaded according to the time of release. For example, all the releases made by the vessel PETRARCA in the "Mare Ligur" experiment were grouped under that name. All the releases made in the second week in January in the "Alexandria" experiment were gouped under JANUARY-II.

The RDF file was named according to the region covered, for example, "Mare Ligur" or "Alexandria", since all the data included in it were going to be used in the computation of a velocity field for that region. This file was progressively filled as the cards were received. Whether they corresponded to earlier or late recoveries made no difference. It was an open-ended file that allowed the data to be processed at any time after the launching, even though the number of available cards was only a fraction of the total number to be received on completion of the experiment.

Selection of the Cards

In the process of organizing the problem, the user had to study the characteristics of the Experiment, as well as the capacity of the DEPS in order to make a most profitable use of his computer resources. The Launching Data Set concept was to be followed in organizing the problem, since the process of card selection was to be made on the basis of simultaneity of the releases.

The basic unit, as far as selection of the cards was concerned, was the Launching Data Set (LDS). Various releases, even within a LDS, would give rise to different trajectories unless they were found to be redundant. Therefore, if cards were released by small groups in a large number of locations, the card selection procedure could turn out to be ineffective due to an excessive resolution.

Various criteria could be chosen for the selection of drift cards with which trajectories were to be computed and the velocity field estimated. After a first subjective overall study of the data allowed to distribute them in LDSs, the choice of a Selected Card Set (SCS) on which simultaneous trajectory computations could be achieved was made on the basis of the following criteria:

Redundancy	(R)	Working along two lines: when two or more release locations were within a square of side n miles they were considered as only one release. when various recoveries were made in a square of side n miles only the drift card recovered earlier was selected. All other driftcards were rejected.
Geographic Limits	(G)	All cards with recovery location outside the bondaries specified were rejected.
Time Limits	(T)	All cards with recovery times above or below the boundaries specified were rejected.
Distance Limits	(D)	All cards with recovery location more or less distant to the release site than the boundaries specified were rejected.
Velocity Limits	(V)	All cards with straight line velocities above or below the boundaries specified were rejected.

Figure VIII shows an example of selection for two redundant releases of the Launching Data Set PETRARCA in the Ligurian Sea exercise.

SAMPLE PROBLEMS

The DEPS was tested with four Sample Problems organised following the implementation of the DRIFTEX exercise. Three Launching Data Sets (PETRARCA, RAMOGE and KOROTNEFF), from the "Mare Ligur" experiment, and a fourth one (ALEXANDRIA) from the Southeast Levantine exercise were processed. For various reasons the data set from the Rijeka Bay exercise could not be processed.

The processing of these four data sets did not intend to make an assessment of the surface current field either in the Western Mediterranean or in the Southeast Levantine basins. It was only carried out in order to test the performance of DEPS. Therefore, no interpretation of the results was attempted (in spite of the modellers' temptations) and the intellectual property of the authors with regard to the results was respected.

Table 3 shows a scheme of the actions carried out for the complete processing of the "Mare Ligur" experiment.

Table 3. Actions carried out through DEPS for processing the data

1.	Punching of release and recovery data cards.
2.	Digitization of the coastline for the entire Western Mediterranean.
3.	Initialization of release, recovery and coastline data files.
4.	Loading of all data in the files.
5.	Plot of release and recovery points and coastline.
6.	Correction of obvious errors in the recovery data and iteration of 5.
7.	Indexing of the recoveries in IDSs.
8.	Computation of statistics.
9.	Selection of the four SCS: PETRARCA, RAMOGE, KOROTNEFF[1/] and ALEXANDRIA.
10.	Computation of the trajectories for subset PETRARCA.
11.	Iteration (5 times) of the previous step[2/].
12.	Indexing of the trajectory output file.
13.	Computation of the intensity/direction histogram for all spatial blocks affected by the computed trajectories and drawing of the current roses.
14.	Plotting of the computed trajectories.
15.	Steps 10 and 14 were repeated for subsets RAMOGE, KOROTNEFF and ALEXANDRIA.

1/ Since the RAMOGE subset of SCS was larger than 90 cards, the two releases closest to the KOROTNEFF subset were included in the latter.

2/ Some tangency points were manually corrected in order to solve some persistent card trappings.

"Mare Ligur"

After a selection of the cards was made following the techniques described above and the trajectories were computed (figures IX to XI), the overall current field was drawn (figures XII and XIII). Figure XIII is an example of how the current roses could be collated in order to make general charts of currents for the Western Mediterranean.

Several well known features of the general cyclonic circulation of the western Mediterranean basin were evidenced by the results:

1. The strong longshore current flowing along the northern shores between the French Riviera and the eastern Spanish coasts.

2. The pronounced cyclonic gyres of the Ligurian Sea and the central part of the basin.

3. The remarkable absence of recoveries in the Golfe du Lion indicating a highly divergent flow.

Another conclusion of the results was that coastal currents in the Provencal coastal zone are large (up to 1 knot and even more). A feature that may be inferred from comparing figures IX to XI is the fact of the increasing dispersion as the launchings were done more to the West.

A tentative explanation is the existence of a shift in wind direction from East to North in the days following the launching of the Experiment. Cards released by the PETRARCA took a path leading to the Ligurian coast under the eastern wind. Cards released by RAMOGE and especially by KOROTNEFF were subject to more northerly winds (Mistral). By the time the PETRARCA cards reached the Provencal coast, the Mistral may have been too weak to force them southwards. This hypothesis should have been checked with meteorological data for the days following the launching at present unavailable.

"Alexandria"

The original data for year 1977, as well as the complete results of the processing of the data obtained through Dr. M.A. Gerges for the Alexandria exercise are summarized in figures XIV and XV.

CONCLUSIONS

The Ligurian Sea exercise, a true international effort, was considered a trial experiment. Its success was a condition for future large-scale driftcard exercises to be launched over the entire Mediterranean Sea. Expectations were rather imprecise as far as geographic coverage and overall time scales were concerned. They turned out to be of over a year, covering the entire Western Mediterranean Sea. For such large scales the resolution defined by the releases was far too high in a far too small area with a large redundancy in the launchings.

The following conclusions and learnings can be drawn from the experience gained through both the organisation of the DRIFTEX exercise and the development of the computer model for the processing of the data:

1. A carefully organised exercise has many chances of being successful. However there are a large number of factors to be kept under control. Among others:

   Designing a proper driftcard with local languages for the area in which the driftcards are most likely to be recovered, is a major task, though the experience gained through DRIFTEX should allow a new exercise of the kind to progress in a better way.

   Organising the launching with various vessels working simultaneously in a given area should prove in general almost discouragingly difficult (in this case the DRIFTEX was a specially successful case due to the interest of the institutes involved).

   The mailing facilities given by the Government of Monaco (and for that case the Postal services of the countries involved (basically Italy, France and Spain) were remarkably effective. Experience elsewhere indicates that mailing among different countries is only subject to the good will of the person recovering the driftcard who properly stamps the card. Rewards offered may be in general difficult to fulfill.

   The manpower required for the decoding of the recovery information is very important (again only the patience of M. A. Vatrican who personnally decoded the Ligurian Sea information was crucial for the success).

   The computing power and dedication required in processing the data make one such exercise a one shot event which only a very well equipped and staffed computer centre can convert into a routine operation.

   The collection of meteorological data proved to be extremely difficult during the DRIFTEX Ligurian Sea experiment. Before embarking in one such exercise the sources of information should be perfectly clear.

2. With regard to the scientific value of such an exercise the following conclusions may be reached:

   In view of the uncertainty in determining the recovery time and to some extent location, the spatial resolution of the DRIFTEX was high. Taking into account that a velocity of 1 knot is quite an acceptable one in many areas of the Mediterranean, for every day one driftcard lays stranded on a beach, the error in the computed trajectory ranges from nil to eventually 10 miles or more.

   As a consequence, one may conclude that driftcard exercises may be extremely useful for meso and large scale studies and provide a general view of the velocity field (and its variation in time) quite reasonable for many purposes.

The existence of redundancy in the recoveries must be ensured for the current field to have any meaning. This means that large numbers of driftcards must be launched at once or in a small period of time. This increases the cost of such operations in terms of the cards and of the shiptime required. However, the example of the PETRARCA a ferry boat sailing from Genova to Corsica is a good example of low cost/benefit relationship.

Redundancy in the launchings should be avoided since it does not improve the resolution of the current field and, in any case, the precision of the launchings is always much greater than that of the recoveries.

3. For an international action of the kind of DRIFTEX a good co-ordination is required. This implies, particularly at the time of the launching, close contacts amongst scientists from neighbouring countries not always in a position to co-operate directly. Thus the role of the co-ordinating organization is crucial for the success of the exercise.

4. The following may be considered as the overall conclusions to be taken into account for further developments in the methodology and strategy of driftcard experiments:

Systematic launching of large-scale exercises, provided they are carefully planned according to the model with which the data are to be processed, should provide a sound knowledge of the general Mediterranean surface drift not given by any other method, whether direct measurements or purely theoretical computations are used alone.

Improvement of the model by changing it from purely dispersive to convergent/divergent with inclusion of the wind factor should provide a sound basis for prediction of the trajectories, something that may be considered basic for the preparation of real-time contingency plans for oil-combatting activities.

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UNEP, 1983. FAO/UNESCO/IOC/WHO/WMO/IAEA/UNEP: Co-ordinated Mediterranean Pollution Monitoring and Research Programme (MED POL - PHASE I): Programme Description. UNEP, Regional Seas Reports and Studies No. 23.

FIGURE LEGENDS

Figure I: Results of current measurements by driftcards, drifters and currentmeters in the Rijeka Bay exercise. Currentmeter measurements were made at 3 m depth for periods of 24 to 72 hours (from Ilic et al., 1979).

Figure II: Recoveries of driftcards launched during 1976 and 1977 in the Southeast Levantine exercise (from Gerges, 1979).

Figure III: Driftcard trajectories obtained during some of the launchings during the Southeast Levantine exercise (from Gerges, 1979).

Figure IV: Model of driftcard used in the Ligurian Sea exercise. The card was designed and produced at the IOC.

Figure V: Map of the Western Mediterranean basin showing the launching (▽) and recovery (x) sites for the Ligurian Sea exercise. Small squares indicate spatial resolution and digitized coastline. Large squares are spatial blocks for current roses.

Figure VI: Recovery of driftcards during the Ligurian Sea exercise. Notice that 95 % of the cards were recovered before 115 days (4 months) after the launching took place.

Figure VII: Summary statistics for the whole Ligurian Sea exercise.

Figure VIII: Example of detailed Statistics for two redundant releases of LDS PETRARCA in "Mare Ligur" Experiment. Cards marked (****) have been selected to build up a SCS. R n indicates this card is redundant with card n.

Figure IX: Plot of computed trajectories for the Launching Data Set PETRARCA (after 5 iterations).

Figure X: Plot of computed trajectories for the Launching Data Set RAMOGE (after 5 iterations).

Figure XI: Plot of computed trajectories for the Launching Data Set KOROTNEFF (after 5 iterations) showing also spatial blocks.

Figure XII: Spatial distribution of the velocity field in the Northern part of the Western Mediterranean Sea.

Figure XIII: Example of computed current roses for a number of spacial blocks in the Western Mediterranean basin.

Figure XIV: Summary Statistics for "Alexandria" Experiment.

Figure XV: Detailed Statistics for "Alexandria" Experiment with selection of cards.

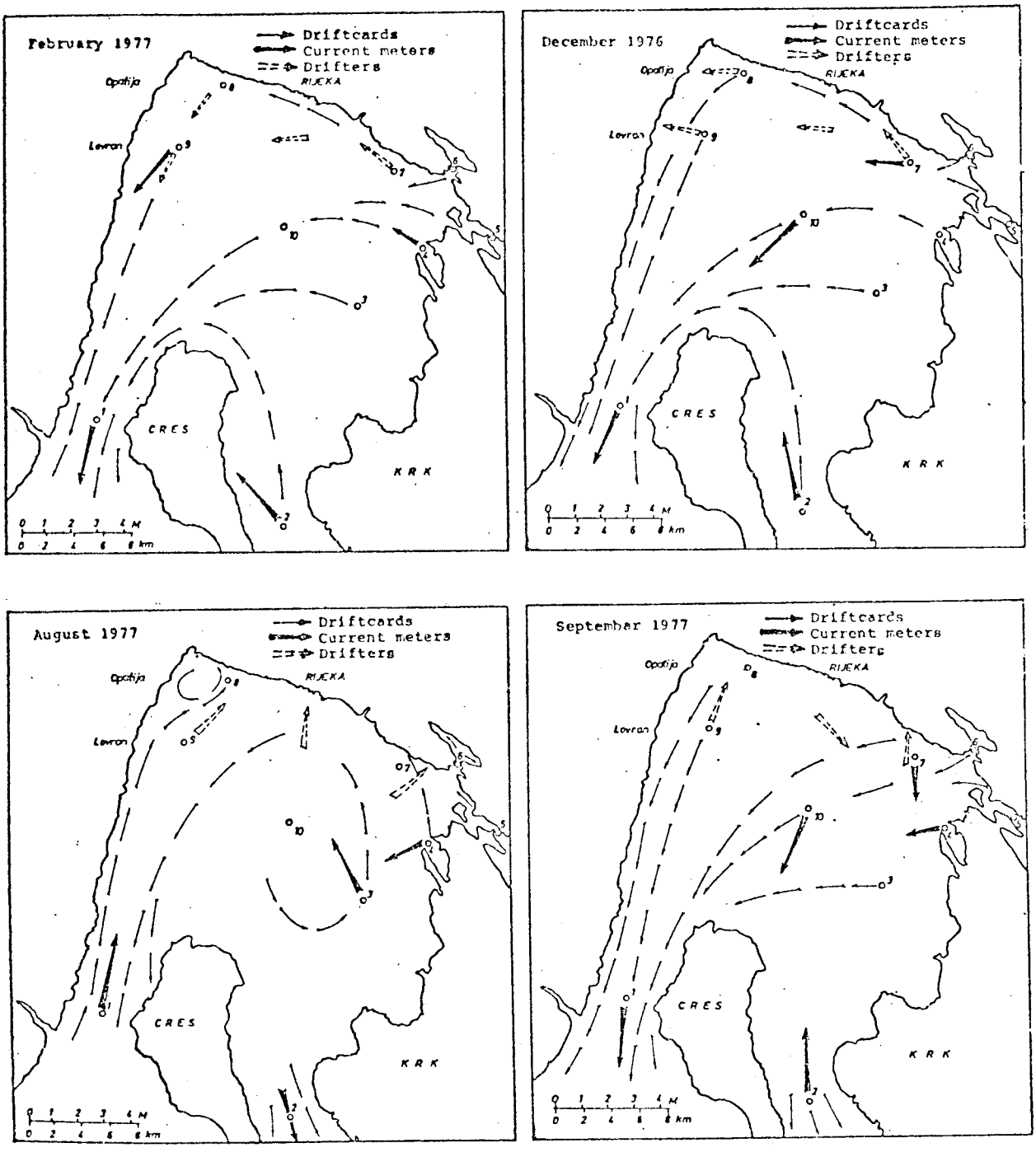


Figure I. Results of current measurements by driftcards, drifters and current-meters in the Rijeka Bay exercise. Currentmeter measurements were made at 3 m depth for periods of 24 to 27 hours (from Ilic et al., 1979)

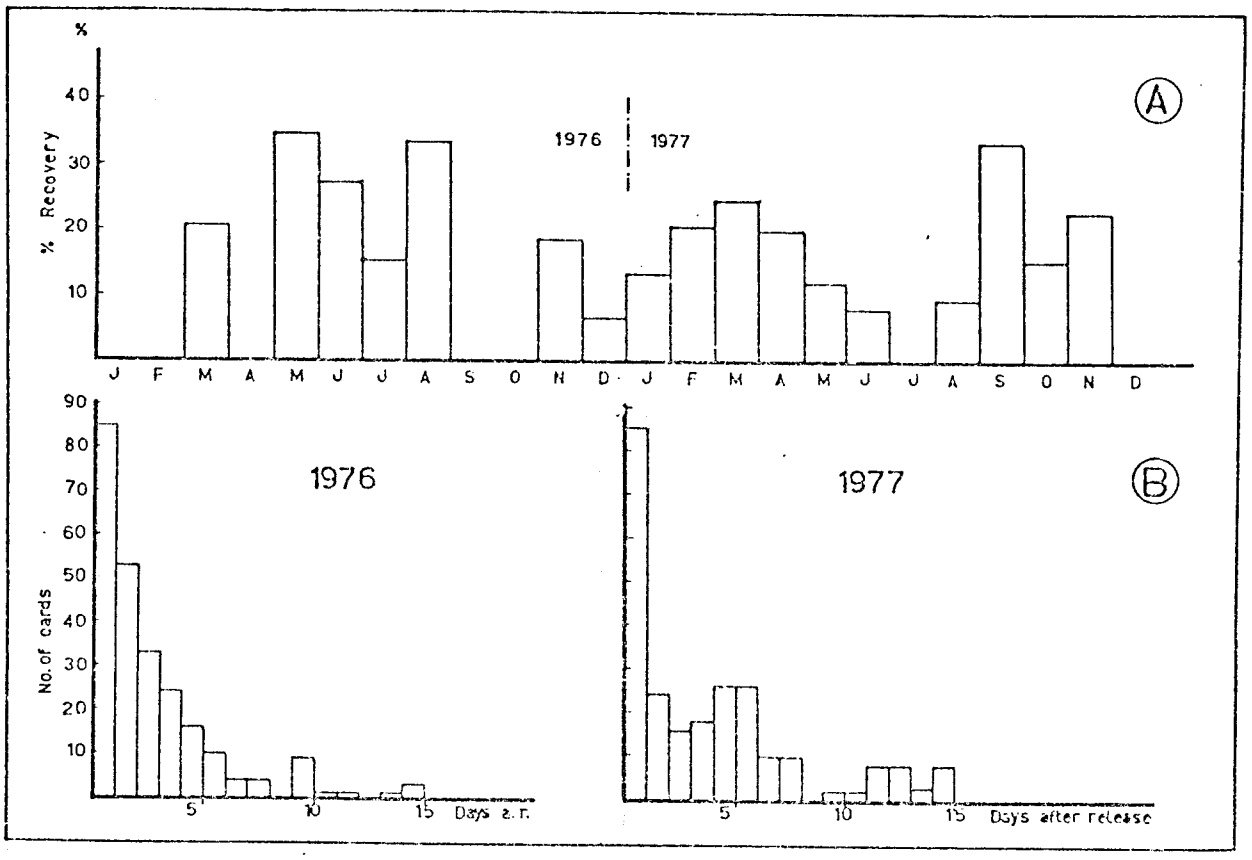


Figure II. Recoveries of driftcards launched during 1976 and 1977 in the Southeast Levantine exercise (from Gerges, 1979)

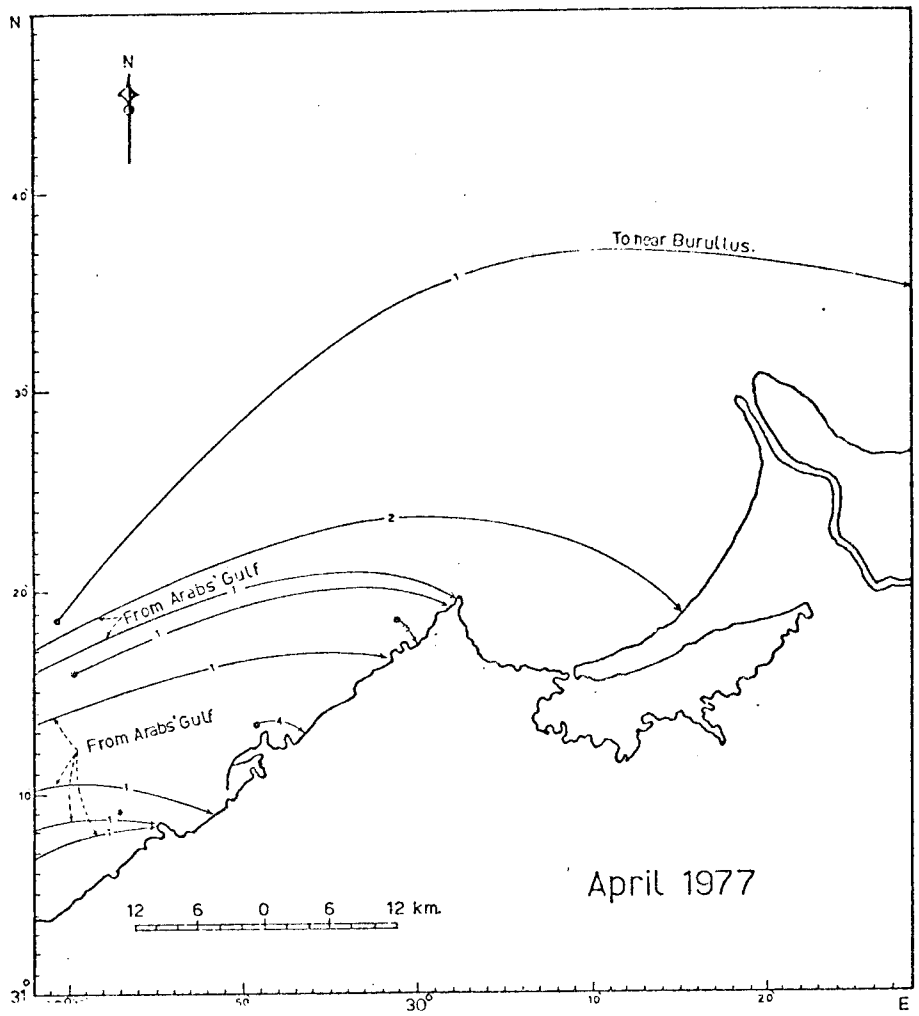


Figure III a

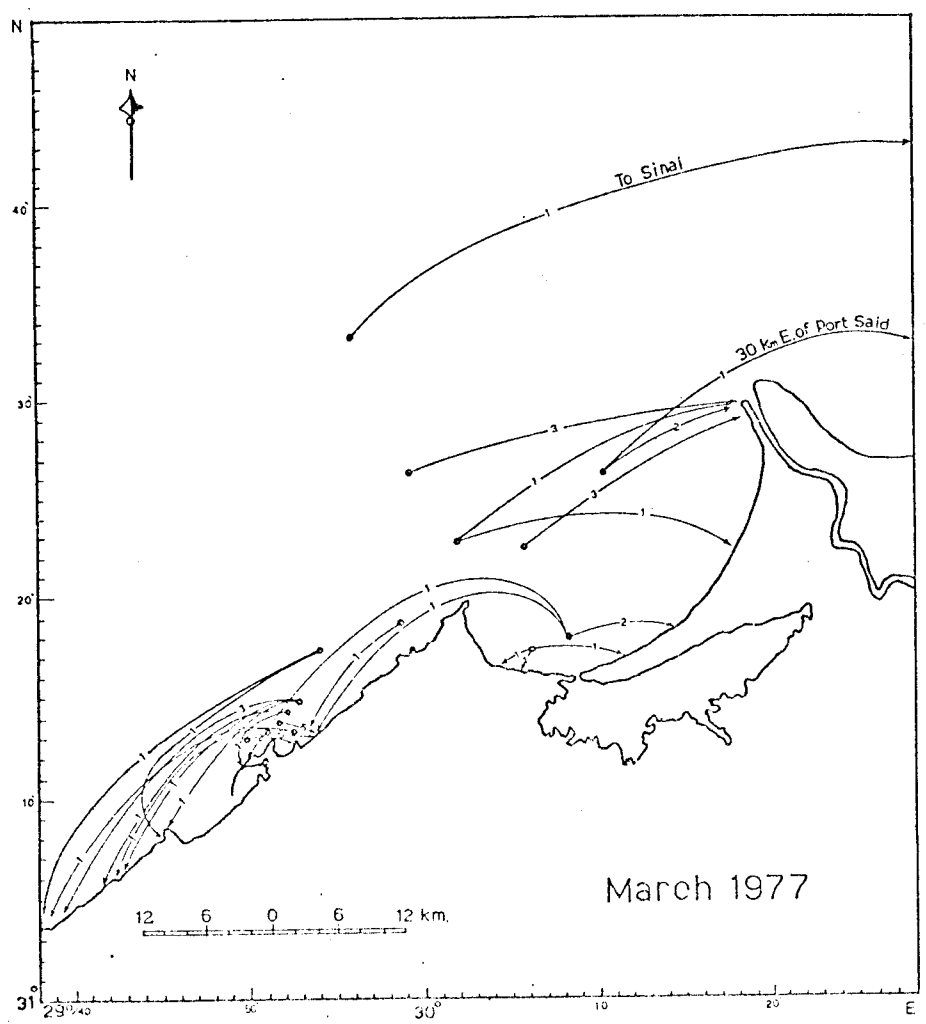


Figure III b

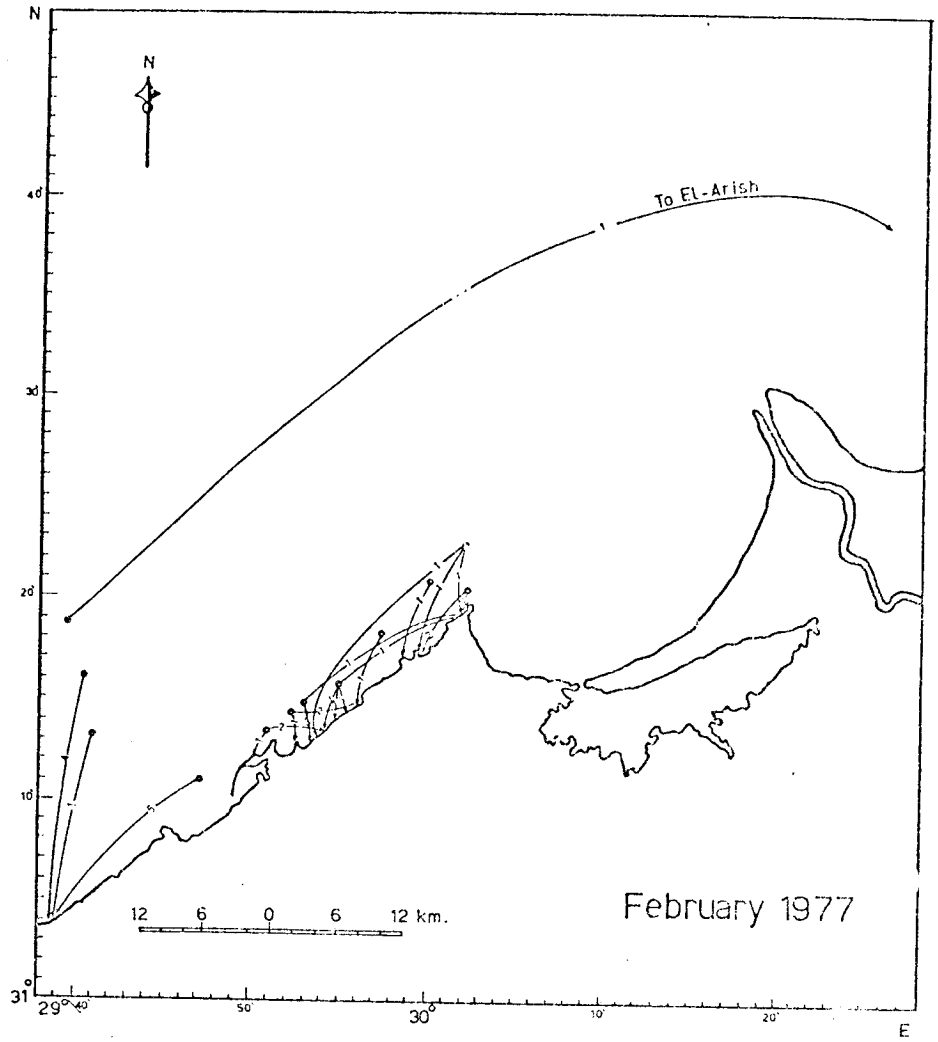


Figure III c

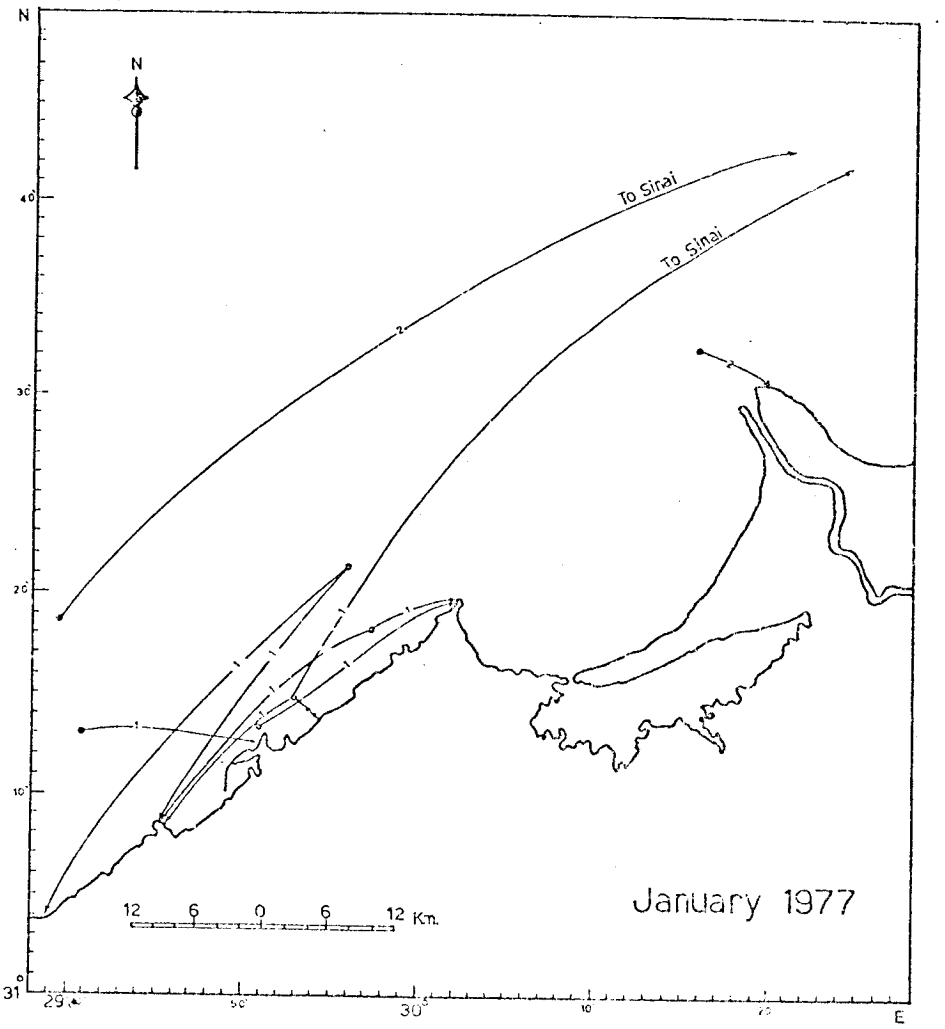
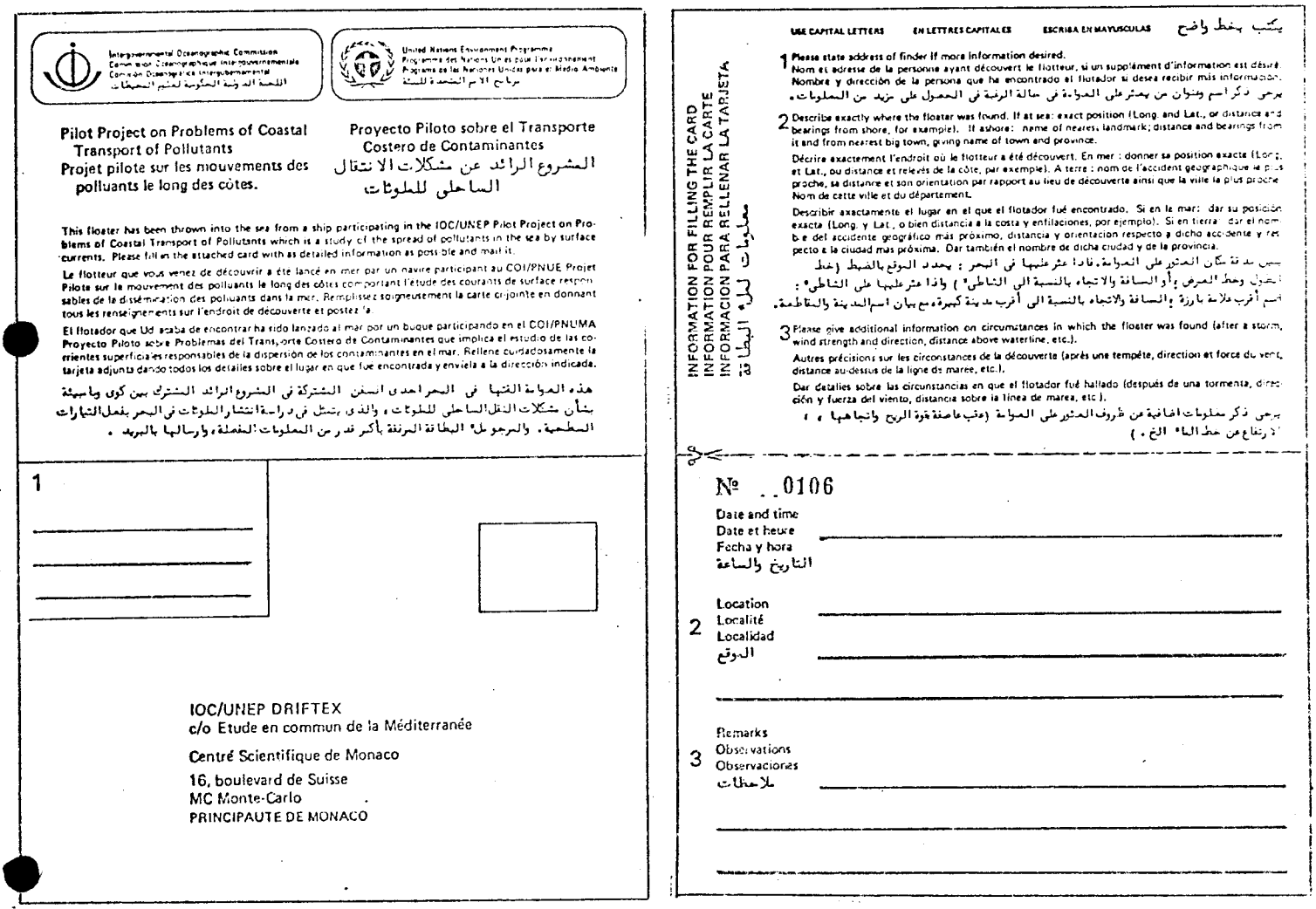


Figure III d

Figure III. Driftcard trajectories obtained during some of the launching of the Southeast Levantine exercise (from Gerges, 1979)



Intergovernmental Oceanographic Commission
Commission Océanographique Intergouvernementale
Comisión Oceanográfica Intergubernamental
اللجنة الدولية الحكومية لعلم المحيطات

United Nations Environment Programme
Programme des Nations Unies pour l'environnement
Programa de las Naciones Unidas para el Medio Ambiente
برنامج الأمم المتحدة للبيئة

Pilot Project on Problems of Coastal Transport of Pollutants
Projet pilote sur les mouvements des polluants le long des côtes.

Proyecto Piloto sobre el Transporte Costero de Contaminantes
المشروع الرائد عن مشكلات الانتقال الساحلي للملوثات

This floater has been thrown into the sea from a ship participating in the IOC/UNEP Pilot Project on Problems of Coastal Transport of Pollutants which is a study of the spread of pollutants in the sea by surface currents. Please fill in the attached card with as detailed information as possible and mail it.

Le flotteur que vous venez de découvrir a été lancé en mer par un navire participant au COI/PNUE Projet Pilote sur le mouvement des polluants le long des côtes comportant l'étude des courants de surface responsables de la dissémination des polluants dans la mer. Remplissez soigneusement la carte ci-jointe en donnant tous les renseignements sur l'endroit de découverte et postez la.

El flotador que Ud acaba de encontrar ha sido lanzado al mar por un buque participando en el COI/PNUMA Proyecto Piloto sobre Problemas del Transporte Costero de Contaminantes que implica el estudio de las corrientes superficiales responsables de la dispersión de los contaminantes en el mar. Rellene cuidadosamente la tarjeta adjunta dando todos los detalles sobre el lugar en que fue encontrada y envíela a la dirección indicada.

هذه العوامة القيها في البحر احدى السفن المشتركة في المشروع الرائد المشترك بين كوى وهيئة بشأن مشكلات النقل الساحلي للملوثات ، والذي يشتمل في دراسة انتشار الملوثات في البحر بفعل التيارات السطحية . والمرجو ملء البطاقة المرفقة بأكبر قدر من المعلومات المفصلة ، وارسالها بالبريد .

1

IOC/UNEP DRIFTEX
c/o Etude en commun de la Méditerranée
Centré Scientifique de Monaco
16, boulevard de Suisse
MC Monte-Carlo
PRINCIPAUTE DE MONACO

INFORMATION FOR FILLING THE CARD
INFORMATION POUR REMPLIR LA CARTE
INFORMACION PARA RELLENAR LA TARJETA
معلومات لملء البطاقة

USE CAPITAL LETTERS — EN LETTRES CAPITALES — ESCRIBA EN MAYUSCULAS — يكتب بخط واضح

1 **Please state address of finder if more information desired.**
Nom et adresse de la personne ayant découvert le flotteur, si un supplément d'information est désiré.
Nombre y dirección de la persona que ha encontrado el flotador si desea recibir más información.
يرجى ذكر اسم وعنوان من يعثر على العوامة في حالة الرغبة في الحصول على مزيد من المعلومات .

2 **Describe exactly where the floater was found. If at sea: exact position (Long. and Lat., or distance and bearings from shore, for example). If ashore: name of nearest landmark; distance and bearings from it and from nearest big town, giving name of town and province.**
Décrire exactement l'endroit où le flotteur a été découvert. En mer : donner sa position exacte (Long. et Lat., ou distance et relevés de la côte, par exemple). A terre : nom de l'accident géographique le plus proche, sa distance et son orientation par rapport au lieu de découverte ainsi que la ville la plus proche. Nom de cette ville et du département.
Describir exactamente el lugar en el que el flotador fué encontrado. Si en la mar: dar su posición exacta (Long. y Lat., o bien distancia a la costa y enfilaciones, por ejemplo). Si en tierra: dar el nombre del accidente geográfico más próximo, distancia y orientacion respecto a dicho accidente y respecto a la ciudad más próxima. Dar también el nombre de dicha ciudad y de la provincia.
يعين بدقة مكان العثور على العوامة . فاذا عثر عليها في البحر : يحدد الموقع بالضبط (خط الطول وخط العرض) أو المسافة والاتجاه بالنسبة الى الشاطئ . واذا عثر عليها على الشاطئ : اسم أقرب ملامة بارزة ، المسافة والاتجاه بالنسبة الى أقرب مدينة كبيرة مع بيان اسم المدينة والمقاطعة .

3 **Please give additional information on circumstances in which the floater was found (after a storm, wind strength and direction, distance above waterline, etc.).**
Autres précisions sur les circonstances de la découverte (après une tempête, direction et force du vent, distance au-dessus de la ligne de marée, etc.).
Dar detalles sobre las circunstancias en que el flotador fué hallado (después de una tormenta, dirección y fuerza del viento, distancia sobre la línea de marea, etc.).
يرجى ذكر معلومات اضافية عن ظروف العثور على العوامة (عقب عاصفة قوة الريح واتجاهها ، الارتفاع عن خط الماء الخ .)

№ 0106

Date and time
Date et heure
Fecha y hora
التاريخ والساعة

2 Location
Localité
Localidad
الموقع

3 Remarks
Observations
Observaciones
ملاحظات

Figure IV. Model of driftcard used in the Ligurian Sea exercise. The card was designed and produced at the IOC

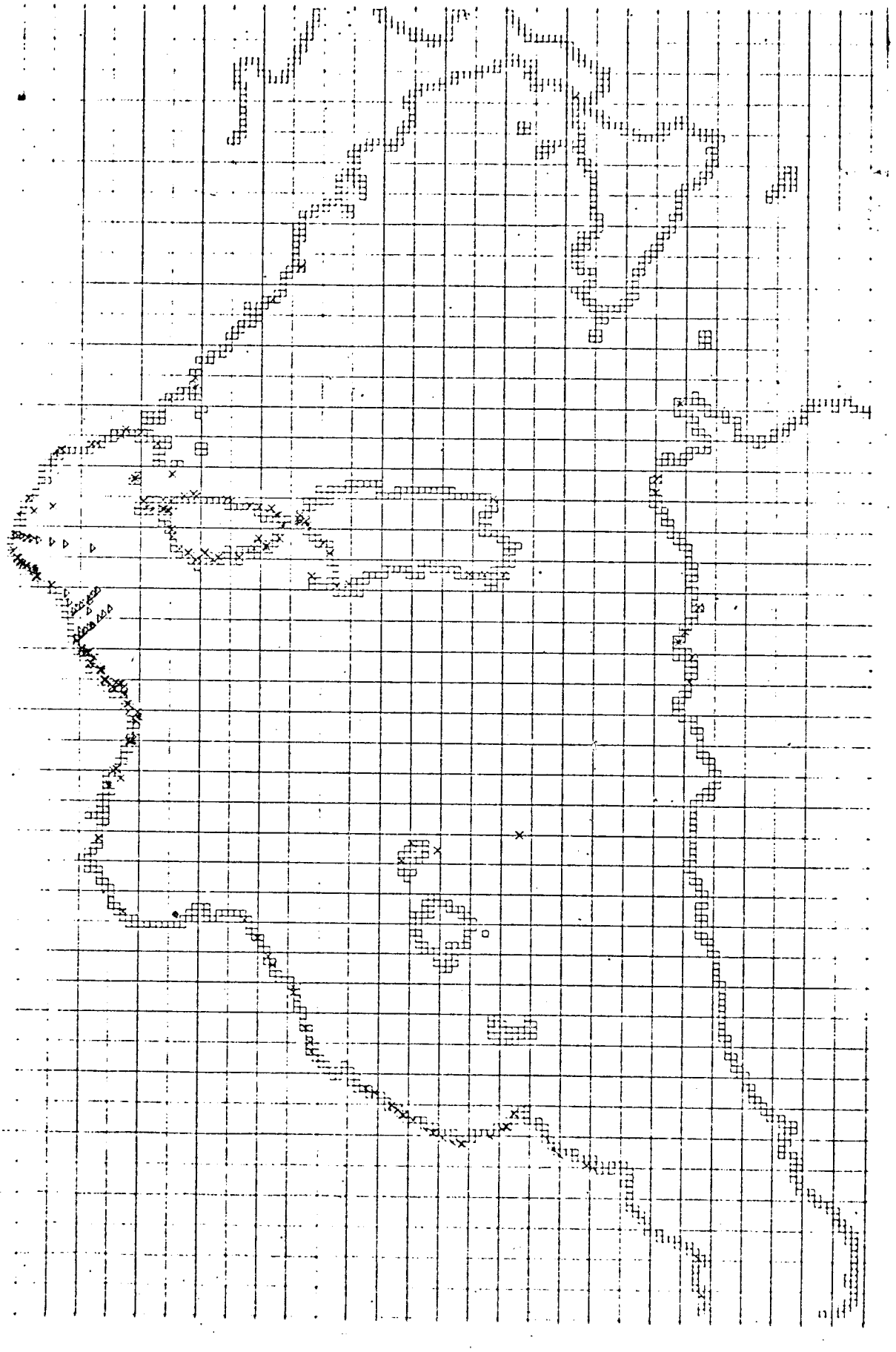
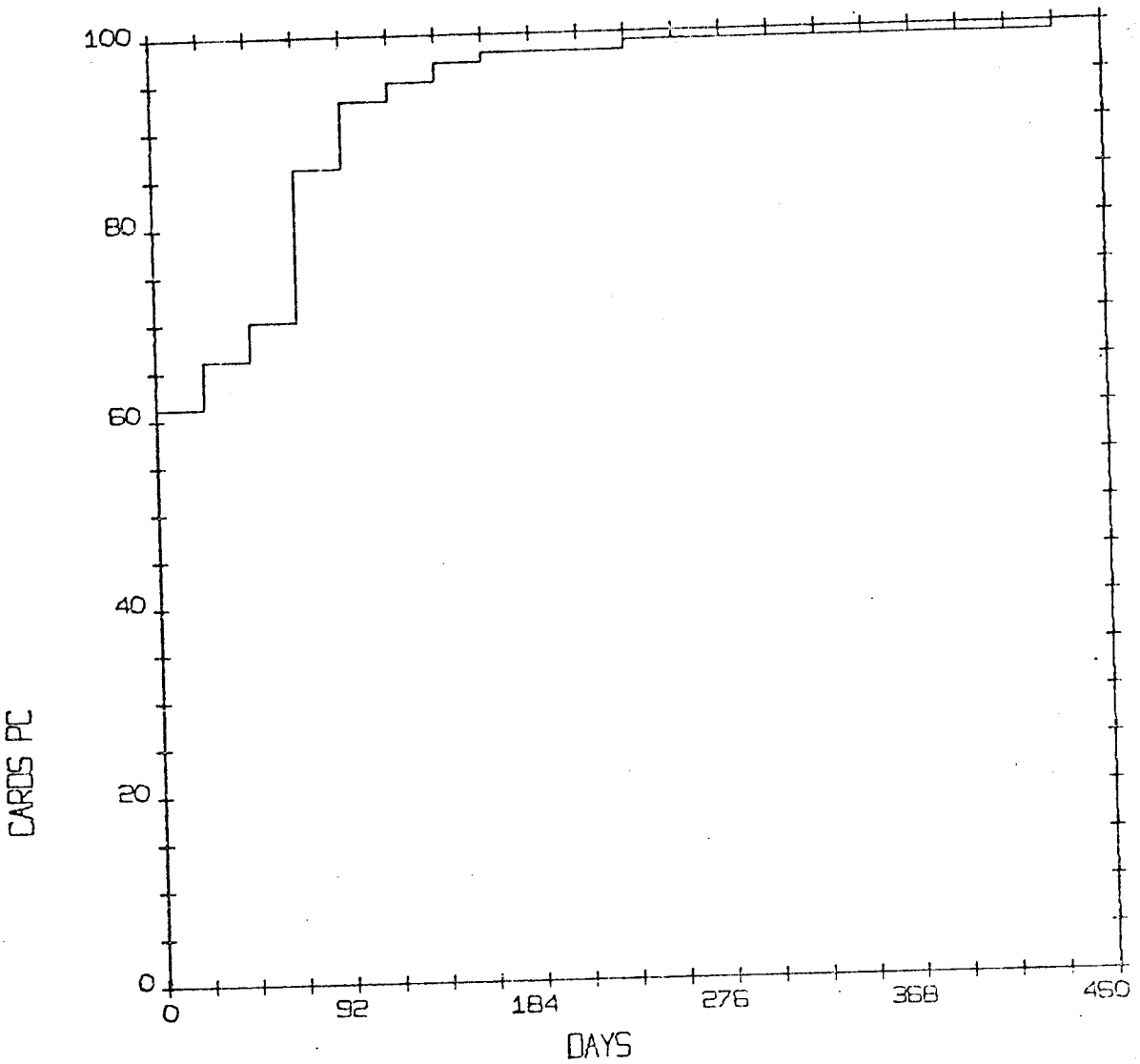


Figure V. Map of the Western Mediterranean basin showing the launching (▽) and recovery (x) sites for the Ligurian Sea exercise. Small squares indicate spatial resolution and digitized coastline. Large squares are spatial blocks for current roses



3

GRAPHIC N. 3
****
SELECTED RELEASES
DATA SET PETRARCA
DATA SET RAMOGE
DATA SET KOROTNEFF

FRAME LIMITS

DAYS		CARDS PC	
0	460	0	100

GRID VALUE= 23 5 (0.3 INCHES PER GRID)

DATA LIMITS

DAYS		MILES	
0	447	10	634

COMPUTED CARDS IN MAP

CARDS	IN	OUT
534	534	0

Figure VI. Recovery of dirftcards during the Ligurian Sea exercise. Notice 95% of the cards were recovered before 115 days (4 months) after the launching took place

NAME OF EXPERIMENT MARE LIGUR

SUMMARY

LAUNCHING DATA SET	LOCATION LAT	LOCATION LON	TIME YR	MO	DA	HR	NUMBER OF CARDS LAUNCHED	NUMBER OF CARDS RECOVERED	PERCENT RECOVERY	GEOGRAPHICAL LIMITS LATITUDE		LONGITUDE		MAX TIME HOURS
PETRARCA	4422	855	77	4	28	19	200	3	1.5	4359	4424	810	841	2021
PETRARCA	4421	855	77	4	28	19	200	10	5.0	4318	4418	638	829	557
PETRARCA	4419	855	77	4	28	19	200	14	7.0	3944	4420	-10	831	2957
PETRARCA	4417	854	77	4	28	19	200	26	13.0	4421	4422	829	835	365
PETRARCA	4415	853	77	4	28	19	200	20	10.0	4302	4416	606	877	4397
PETRARCA	4414	853	77	4	28	19	200	25	12.5	4326	4416	652	827	2549
PETRARCA	4411	852	77	4	28	19	200	46	23.0	3900	4411	157	1014	4301
PETRARCA	4410	852	77	4	28	20	200	23	11.5	4335	4409	708	819	4300
PETRARCA	4406	851	77	4	28	20	200	38	19.0	4200	4330	615	928	7424
PETRARCA	4357	849	77	4	28	20	200	47	23.5	3907	4318	-19	932	2592
PETRARCA	4348	847	77	4	28	21	200	5	2.5	3704	4316	636	1101	6307
PETRARCA	4330	844	77	4	28	21	200	26	13.0	3646	4320	-236	924	5475
RAMOGE	4347	802	77	4	28	9	100	10	10.0	4335	4339	708	713	495
RAMOGE	4345	754	77	4	28	9	100	21	21.0	4310	4342	632	719	903
RAMOGE	4342	745	77	4	28	10	100	11	11.0	4326	4339	654	713	494
RAMOGE	4340	748	77	4	28	10	100	13	13.0	4335	4339	708	713	3902
RAMOGE	4339	749	77	4	28	10	100	9	9.0	4114	4336	555	1302	2846
RAMOGE	4337	751	77	4	28	10	100	6	6.0	4115	4424	609	912	2054
RAMOGE	4335	753	77	4	28	11	100	10	10.0	3704	4306	548	1539	5293
RAMOGE	4331	755	77	4	28	11	100	10	10.0	3912	4356	823	1012	4453
RAMOGE	4332	757	77	4	28	11	100	12	12.0	3655	4414	710	929	2533
RAMOGE	4330	759	77	4	28	11	100	17	17.0	3657	4358	-41	1027	3397
RAMOGE	4329	801	77	4	28	11	100	6	6.0	3719	4420	830	952	3445
RAMOGE	4327	803	77	4	28	12	100	13	13.0	3820	4329	-30	1019	3516
RAMOGE	4326	805	77	4	28	12	100	11	11.0	3855	4424	-4	941	1936
RAMOGE	4332	746	77	4	28	14	100	5	5.0	4315	4317	521	522	1138
RAMOGE	4338	728	77	4	28	15	100	14	14.0	3720	4328	25	939	5961
KOROTNEFF	4318	748	77	4	28	2	100	5	5.0	3651	4421	755	1020	2566
KOROTNEFF	4322	743	77	4	28	3	100	10	10.0	3824	4342	-24	948	10773
KOROTNEFF	4325	739	77	4	28	4	100	7	7.0	4114	4333	836	1018	3452
KOROTNEFF	4329	733	77	4	28	4	100	8	8.0	4109	4258	837	1100	3380
KOROTNEFF	4330	732	77	4	28	4	100	10	10.0	3648	4315	-203	1232	3332
KOROTNEFF	4332	731	77	4	28	5	100	2	2.0	4217	4310	638	841	2035
KOROTNEFF	4334	728	77	4	28	6	100	12	12.0	4308	4319	622	640	498
KOROTNEFF	4335	726	77	4	28	6	100	5	5.0	3942	4314	10	910	2754
KOROTNEFF	4337	724	77	4	28	6	100	8	8.0	4006	4421	400	914	3450
KOROTNEFF	4338	722	77	4	28	7	100	6	6.0	4252	4332	651	1030	2777
KOROTNEFF	4340	721	77	4	28	7	100	10	10.0	4110	4334	658	910	3977

NAME OF EXPERIMENT MARE LIGUR

SUMMARY

LAUNCHING DATA SET	LOCATION LAT	LOCATION LON	TIME YR	MO	DA	HR	NUMBER OF CARDS LAUNCHED	NUMBER OF CARDS RECOVERED	PERCENT RECOVERY	GEOGRAPHICAL LIMITS LATITUDE		LONGITUDE		MAX TIME HOURS
TOTAL							5000	53[illegible]	10.6	[illegible]		[illegible]		[illegible]

Figure VII. Summary statistics for the whole Ligurian Sea exercise

NAME OF EXPERIMENT MARE LIGUR

SUMMARY

LAUNCHING DATA SET	LOCATION LAT	LON	TIME YR	MO	DA	HR	NUMBER OF CARDS LAUNCHED	RECOVERED	PERCENT RECOVERY	GEOGRAPHICAL LIMITS LATITUDE		LONGITUDE		MAX TIME HOURS
PETRARCA	4422	855	77	4	28	19	200							
PETRARCA	4421	855	77	4	28	19	200	13	3.2	4318	4424	638	841	2021

STATISTICS

	CARD NUMBER	LOCATION LAT	LON	TIME YR	MO	DA	HR	RANGE (MILES)	BEARING (DEGRS)	TIME (HOURS)	SPEED (KNOTS)	
1	310	4418	829	77	4	29	24	18.9	260.8	29	0.65	****
2	286	4418	829	77	4	30	24	18.9	260.8	53	0.35	R 1
3	255	4418	828	77	4	30	24	19.6	261.2	53	0.37	R 1
4	181	4424	841	77	4	30	24	10.5	286.5	53	0.19	****
5	265	4418	828	77	5	1	24	19.6	261.2	77	0.25	R 1
6	392	4418	828	77	5	1	24	19.6	261.2	77	0.25	R 1
7	365	4418	829	77	5	1	24	18.9	260.8	77	0.24	R 1
8	229	4418	828	77	5	8	24	19.6	261.2	245	0.08	R 1
9	291	4418	828	77	5	8	24	19.6	261.2	245	0.08	R 1
10	356	4410	822	77	5	13	24	26.1	245.1	365	0.07	****
11	344	4318	638	77	5	21	24	116.9	237.3	557	0.20	****
12	51	4424	841	77	6	26	24	10.5	286.5	1421	0.00	R 4
13	68	4359	810	77	7	21	24	39.1	235.7	2021	0.01	****

SELECTED CARDS

	CARD NUMBER	LAUNCHING TIME	X	Y	RECOVERY TIME	X	Y	NUMBER OF CARDS
1	310	0.	384.	2661.	5.	365.	2658.	8
2	181	0.	384.	2661.	29.	374.	2664.	2
3	356	0.	384.	2661.	341.	360.	[illegible]	1
4	344	0.	384.	2661.	533.	[illegible]	[illegible]	1
5	68	0.	384.	2661.	1997.	[illegible]	[illegible]	1

Figure VIII. Example of detailed Statistics for two redundant releases of LDS PETRARCA in "Mare Ligur' Experiment. Cards marked (****) have been selected to build up a SCS. R n indicates this card is redundant with card n

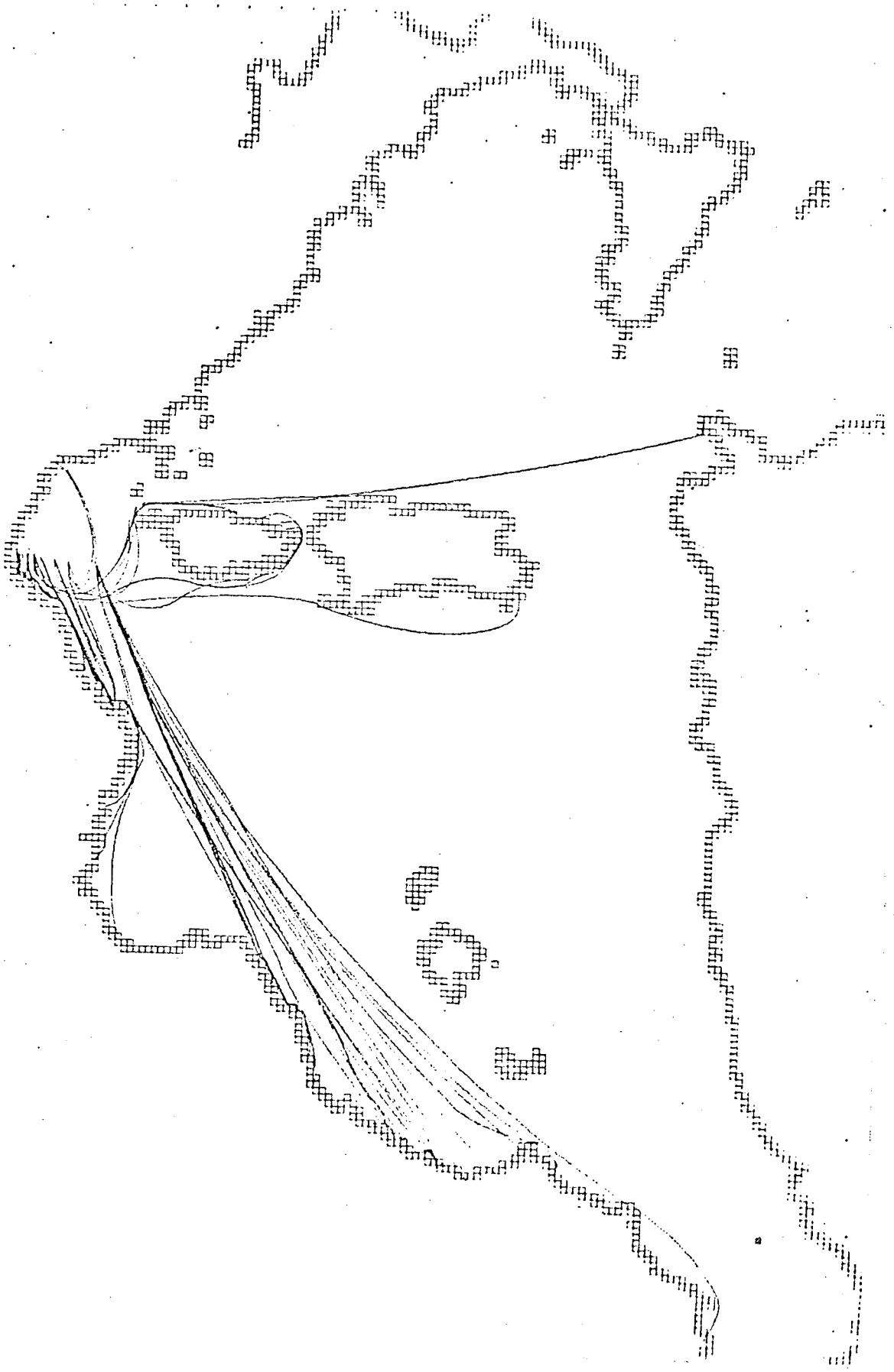


Figure IX. Plot of computed trajectories for the Launching Data Set PETRARCA (after 5 iterations)

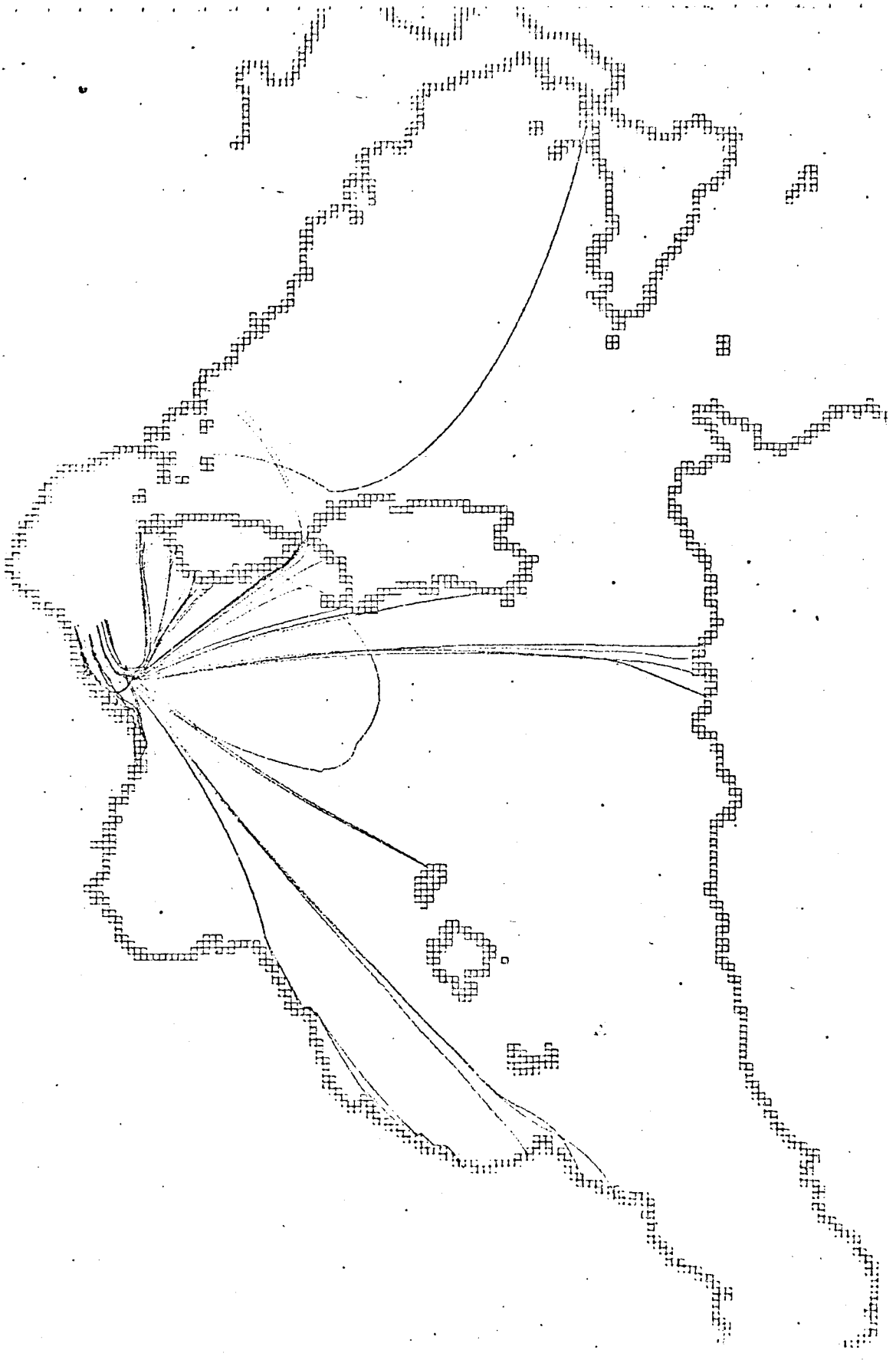


Figure X. Plot of computed trajectories for the Launching Data Set RAMOGE (after 5 iterations)

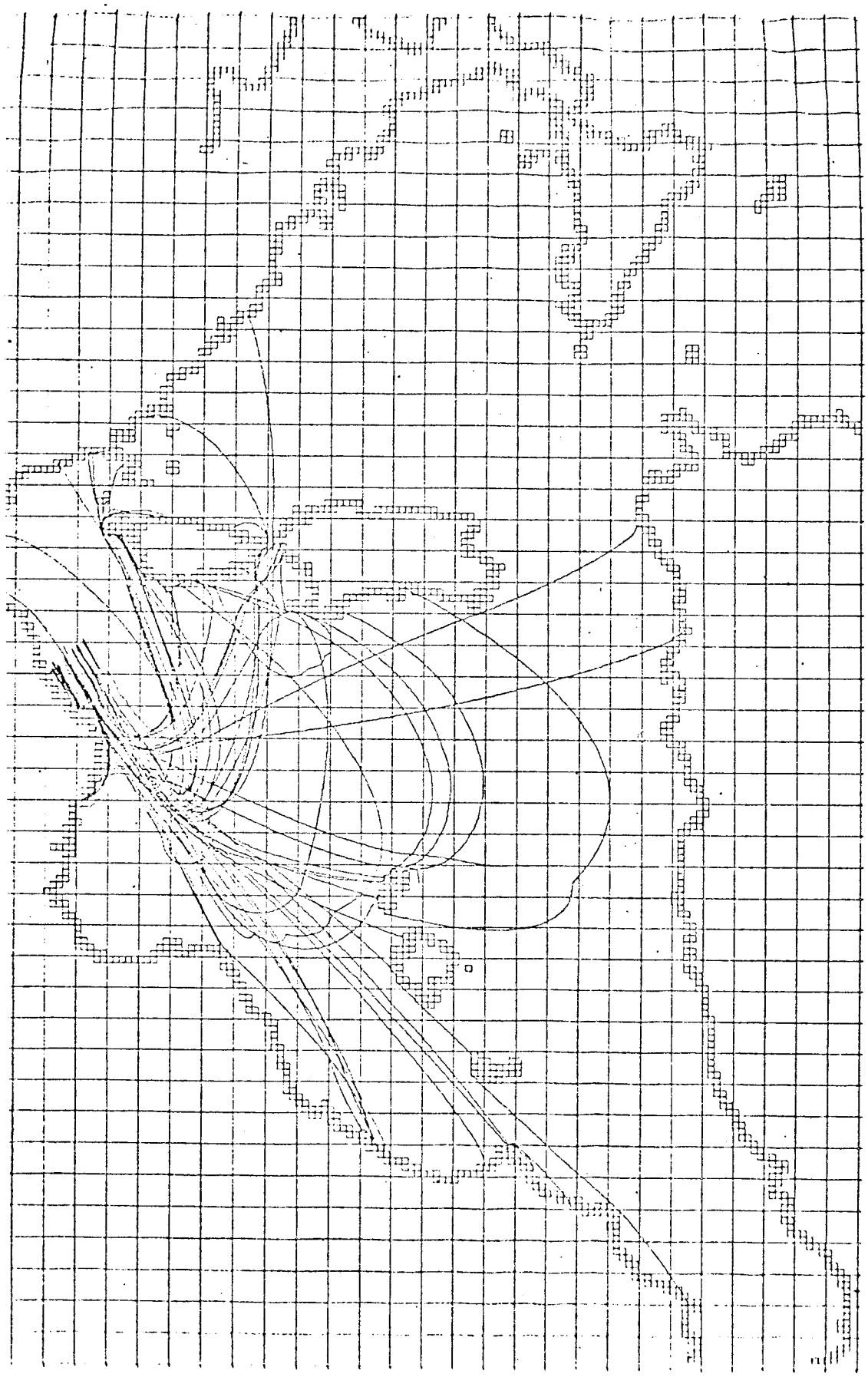


Figure XI. Plot of computed trajectories for the Launching Data Set KOROTNEFF (after 5 iterations) showing also spatial blocks

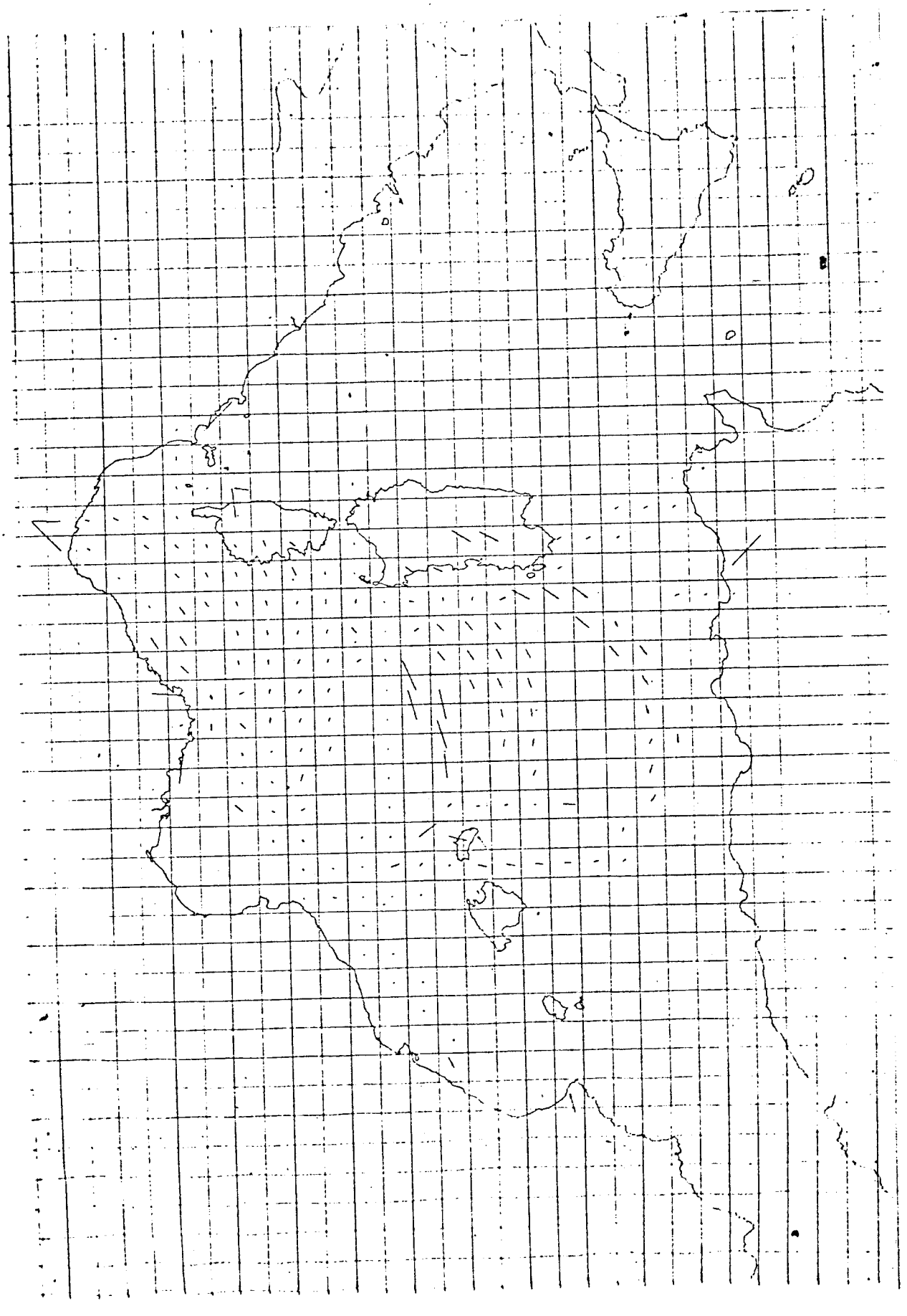


Figure XII. Spatial distribution of the velocity field in the Northern part of the Western Mediterranean Sea

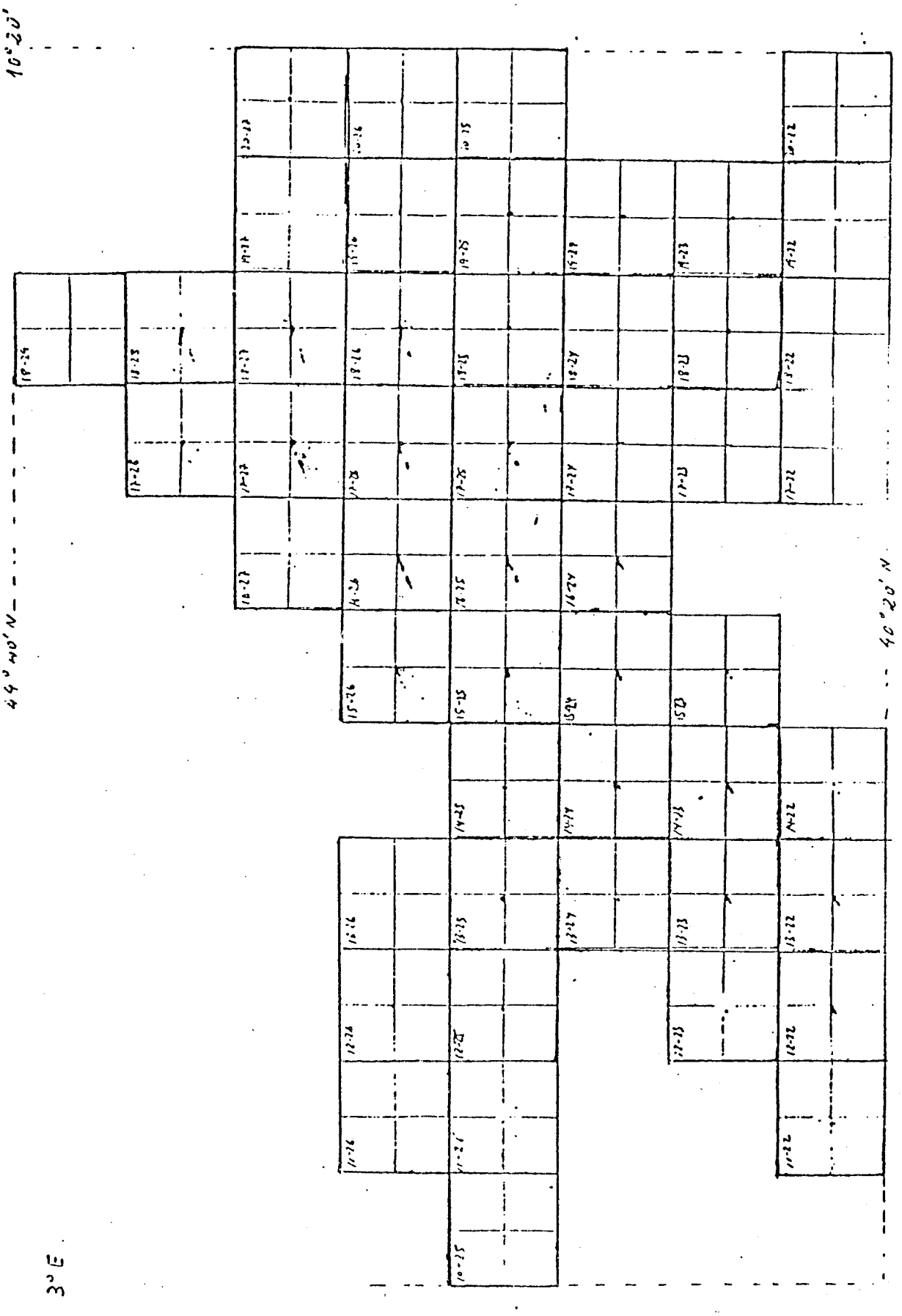


Figure XIII. Example of computed current roses for a number of spatial blocks in the Western Mediterranean basin

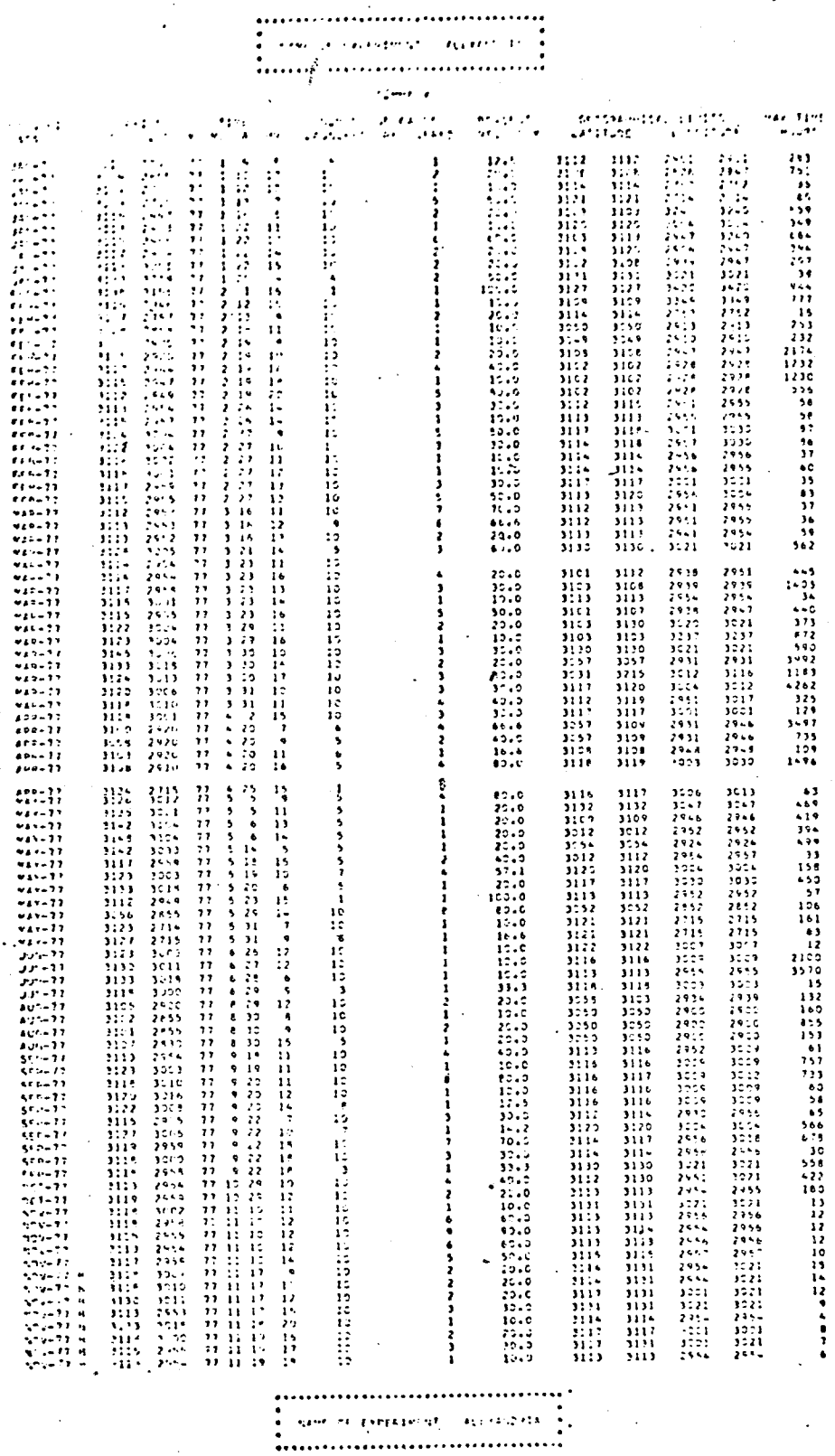


Figure XIV. Summary Statistics for "Alexandria" Experiment

****
* NAME OF EXPERIMENT . ALEXANDRIA *
****

SUMMARY

LAUNCHING DATA SET	LOCATION LAT	LON	TIME YR	MO	DA	HR	NUMBER OF CARDS LAUNCHED	RECOVERED	PERCENT RECOVERY	GEOGRAPHICAL LIMITS LATITUDE		LONGITUDE		MAX TIME HOURS
NOV-77	3118	3002	77	11	10	11	10							
NOV-77	3118	2958	77	11	10	12	10							
NOV-77	3117	2959	77	11	10	14	10	12	40.0	3113	3131	2956	3021	13

STATISTICS

	CARD NUMBER	LOCATION LAT	LON	TIME YR	MO	DA	HR	RANGE (MILES)	BEARING (DEGRS)	TIME (HOURS)	SPEED (KNOTS)	
1	3046	3115	2957	77	11	10	24	2.4	215.7	10	0.24	****
2	3045	3115	2957	77	11	10	24	2.4	215.7	10	0.24	R 1
3	3044	3115	2957	77	11	10	24	2.4	215.7	10	0.24	R 1
4	3040	3115	2957	77	11	10	24	2.4	215.7	10	0.24	R 1
5	3049	3115	2957	77	11	10	24	2.4	215.7	10	0.24	R 1
6	3099	3113	2956	77	11	10	24	4.5	208.3	10	0.45	****
7	3098	3113	2956	77	11	10	24	4.5	208.3	10	0.45	R 6
8	3097	3113	2956	77	11	10	24	4.5	208.3	10	0.45	R 6
9	3095	3113	2956	77	11	10	24	4.5	208.3	10	0.45	R 6
10	3094	3113	2956	77	11	10	24	4.5	208.3	10	0.45	R 6
11	3092	3113	2956	77	11	10	24	4.5	208.3	10	0.45	R 6
12	3166	3131	3021	77	11	10	24	21.1	48.4	10	2.11	****

SELECTED CARDS

	CARD NUMBER	LAUNCHING TIME	X	Y	RECOVERY TIME	X	Y	NUMBER OF CARDS
1	3046	0.	1293.	1877.	-14.	1292.	1875.	5
2	3099	0.	1293.	1877.	-14.	1291.	1873.	6
3	3166	0.	1293.	1877.	-14.	1309.	1891.	1

Figure XV. Detailed Statistics for "Alexandria" Experiment with selection of cards

ANNEX I

INSTITUTIONS AND SCIENTISTS PARTICIPATING IN DRIFTEX

CENTRE SCIENTIFIQUE DE MONACO 16, Bd. de Monte Carlo Principauté de Monaco	A. Vatrican
STATION ZOOLOGIQUE DE VILLEFRANCHE SUR MER La Darse Villefranche Sur Mer France	P. Bougis
GRUPO DI RICERCA OCEANOLOGICA DI GENOVA Via Balbi, Genova Italia	N. della Croce
CENTRE FOR MARINE RESEARCH ZAGREB "Rudjer Boskovic" Institute P.O.B. Zagreb Yugoslavia	Lj. Jeftic
HYDROGRAPHIC INSTITUTE Split Yugoslavia	D. Ilïc
INSTITUTE OF OCEANOGRAPHY AND FISHERIES Kayet Bey Alexandria Egypt	M.A. Gerges
INSTITUTO DE INVESTIGACIONES PESQUERAS Passeig Nacional s/n Barcelona 08003 Spain	A. Cruzado J. Salat Ll. Miralles
REGIONAL ACTIVITY CENTRE FOR MED POL VI (RAC VI) c/o Institute for Oceanography and Fisheries Kayet Bey Alexandria Egypt	
INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION 7, Pl. de Fontenoy 75700 Paris France	

ANNEX II

ALGORITHM FOR TRAJECTORY COMPUTATION

Trajectory computation is carried out by DEPS following a basically geometric and kinematic model that only takes into account the time and location of the release and recovery points of a Selected Card Set. Although it may be introduced at a later stage, wind action was not taken into account since at the time it was not considered to be crucial for the purely kinematic approach made of the problem. The model is basically thought to operate in a coast-free environment but it includes a mechanism that takes into account the existence of an irregular box-like coastline which is not crossed by the trajectories.

The model works on the basis of grouping the cards in blocks and the corresponding trajectories in pencils. All the cards forming a block remain in the corresponding pencil while there is no condition for deviation. When a card comes close to its recovery point or is trapped by the coastline it is discharged, even if there is time left over. At the initial step there is a single pencil corresponding to the first block formed by the whole SCS. At the first deviation a second block is formed and the pencil subdivides into two, then into three, four and so on until the last card is discharged, giving rise to an arborescent structure.

The velocity of each individual card is made up of two components that contribute with different weights:

block velocity, a common time-variant velocity corresponding to the pencil which is the main component representing the local current

residual velocity, computed from the straight-line distance to the point of recovery and the time remaining which is a secondary component representing a dispersion factor

In the computation of the individual trajectories, four mechanisms are playing:

1. The arrival points for each driftcard act as attraction poles for the entire block causing an acceleration of the block velocity. The effect of each pole is larger, the nearer the driftcard is to the pole and the shorter the time required to reach it. At every time step, let N be the number of cards in the block, XR(i), YR(i) and TR(i) the co-ordinates and time of recovery for card i (i=1,N) and X(i) and Y(i) the co-ordinates at the present time T. The residual velocity of card i is computed from the distance of its present position X(i), Y(i) to that of its recovery point XR(i), YR(i) and the time remaining before recovery:

$$U(i) = (XR(i) - X(i))/(TR(i) - T)$$

$$V(i) = (YR(i) - Y(i))/(TR(i) - T)$$

The attraction experienced by the block from the pole corresponding to card i is given by the difference between the block velocity and the residual velocity of this card. Thus the contribution of this card to the local acceleration of the block at time T is:

$$AX(i) = (U(i) - UB)/(TR(i) - T)$$

$$AY(i) = (V(i) - VB)/(TR(i) - T)$$

where AX(i) and AY(i) are the components of the acceleration in the X and Y directions due to pole i, and UB and VB the components of the block velocity, defined as the sum of all the individual accelerations. Therefore, the time change in the block velocity at this time step is:

$$(UB(T+dT) - UB(T))/dt = \text{sum } (AX(i),\ i=1,N)$$

$$(VB(T+dT) - VB(T))/dt = \text{sum } (AY(i),\ i=1,N)$$

2. The natural dispersion phenomenon is introduced in the model through a correction applied to each individual card. This correction consists in adding a small percentage of its own residual velocity and subtracting the same percentage from the block velocity. This percentage is given by a card binding factor FT (0.2 - 0.3). Thus, for each time step dT, the next position for each card is given by:

$$X(T+dT) = X(T) + FT*U(i)*dT + (1-FT)*UB*dT$$

$$Y(T+dT) = X(T) + FT*V(i)*dT + (1-FT)*VB*dT$$

3. As the pencil progresses, residual velocities from poles that lay in the direction of the pencil decrease or, at least, do not increase, but those from poles located in opposite directions increase. A deviation is produced when the ratio between the residual velocity of the fastest card and the block velocity exceeds the value of a parameter P (1 - 2). When this happens, if the difference between the angle of its residual velocity α and the angle of the block velocity β (see figure I) is smaller than a constant γ ($\geq 10^{\circ}$), the deviation makes no sense and is not consumated. If this difference is larger than γ, the circle is then divided into two semicircles by the bisectrix of the angle difference between α and β. Those cards located on the side of the deviated card define a new block and pencil and they, as well as the corresponding attraction poles, are considered as discharged from the old block.

This method may force cards to deviate when in fact, due to their small residual velocity, they have plenty of time to reach their poles and may as well follow the old pencil. Therefore, unless cards have a residual velocity of over 20% that of the fastest deviated card, they are not allowed to deviate and are forced to follow the old pencil.

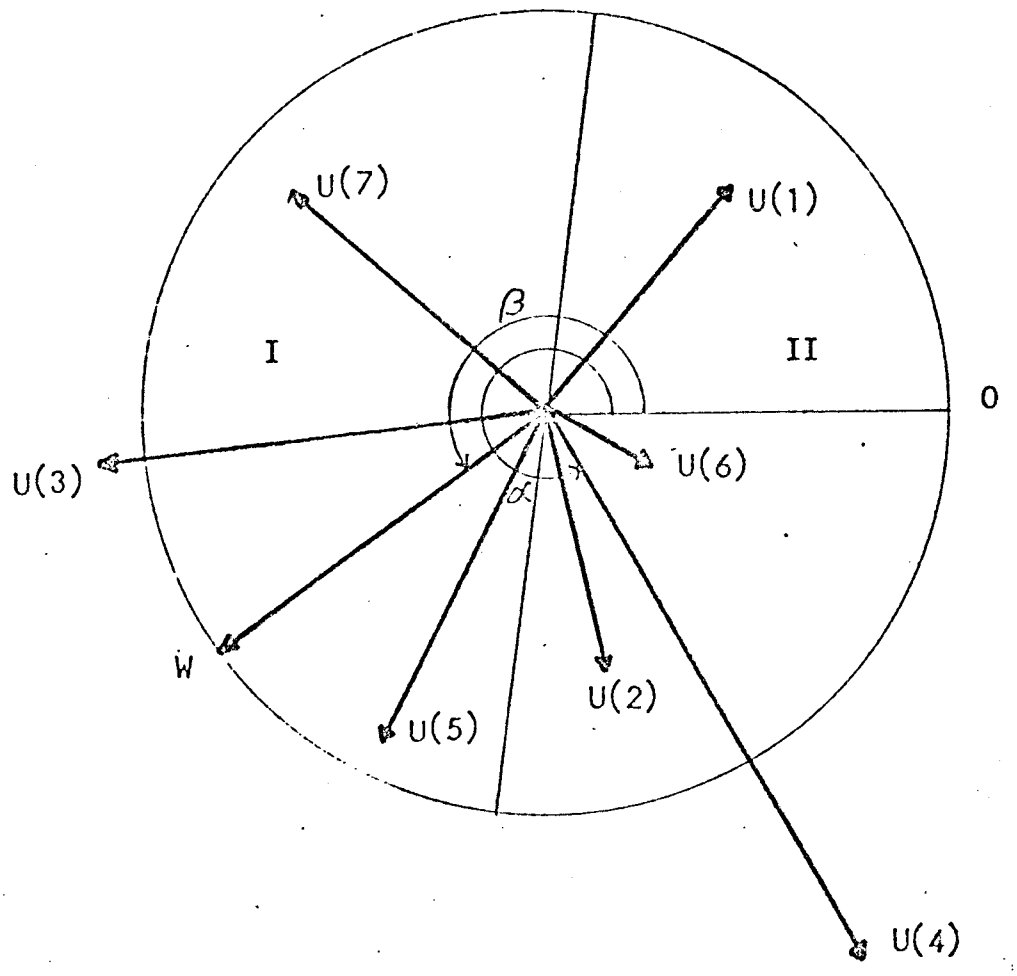


Figure I. Mechanism for deviation

Card 4 deviates because $U(4)W > P$, and $\alpha - \beta > \gamma$

Cards 3, 5, 6, 7 remain in the old block $(U(6)/U(4) < 0.2)$

Cards 1, 2 follow card 4 and start a new pencil.

W	block velocity
U(i)	residual velocity of card i
I	semicircle corresponding to old pencil
II	semicricle corresponding to new pencil
α	angle of fastest deviated card
β	angle of block velocity

4. When, in a time step, a newly computed position for a card lays inshore, it may be close to the recovery location in which case it is discharged by proximity but, if this is not the case, some other point at the same distance but in the sea is chosen such that is the nearest to the pole. It could happen that the difference of the angles between the computed point and the chosen one, relative to the last step's position, were more than 90°. This would imply a backwards displacement and the trajectory would most probably enter into an endless oscillating trap.

5. Trapping of cards occurs normally when the coast is locally concave in the direction normal to the trajectory. Trapped cards are processed separately from the pencil. First, they are discharged from the block and their trajectory finished at the trapping location. Second, the shortest way along the coast to reach its pole is computed, first to the left, then to the right. The point from where the card would be allowed to proceed is considered the last tangency point and saved, as well as the corresponding estimated time, for further iterations.

   This model has shown some instabilities due to inertia and peculiar situations. Among others:

   - When the ratio of the block velocity over the maximum residual velocity is larger than the value of a parameter Q (0.2 - 0.3), especially during the first time steps, a correction is made by substituting the largest residual velocity of the cards in the block for the block velocity.

   - Just after one card has been discharged at a recovery point or by getting trapped, a correction is artificially introduced by reducing the block velocity by a factor DE ($\leq$ 0.5). The same is done with the old and new block velocities when a deviation takes place.

   - If, in a deviation, all the cards are located on the side of the new pencil and the old block remains empty, the deviation is not consumated but the velocity is reduced as if it had occurred.

   - In computing the residual velocities for all the cards in a block, allowance is made for time lost in turnings around the coastline by increasing the velocities by a factor that is a function of Q.

   - Tangency points may be used in subsequent iterations of the model, using them as temporal attraction poles. This method gives more realistic values to the residual velocities than if computed as just straight-line velocities and in this way the overall behaviour of the model is closer to a coast-free environment for which the model was built.

ANNEX III

DEPS PROGRAMMES AND SYSTEMS CHARTS

An Integrated Set of Programmes

The DRIFTEX Processing System (DEPS) is an integrated set of programmes and data files that allows the thorough processing of the driftcard release and recovery information with a minimum of operator's intervention. The user of the DEPS, almost mechanically, can carry out the complete processing of his experiment, beginning with the loading of the release and recovery data and ending with a number of current roses covering the entire region. Statistics on the recovery/release ratio and straight-line velocities are computed and used as the basis for selecting a group of cards that will constitute a Selected Card Set (SCS) used for the computation of a number of trajectories coherent with the underlying velocity field. Programmes for graphic displays of the results and various intermediate steps are also included in the DEPS to allow for a close follow-up of the entire process.

Four groups of programmes deal with the various functions that the DEPS is capable of carrying out:

1. Service Programmes: Include initialization of files, loading of release, recovery and coastline data and modifying the data files to allow for correction.

2. Statistics Programmes: Include plotting of frequency histograms, distance vs. time diagrams, overall and detailed statistics as well as automatic selection of driftcards to be included in a SCS.

3. Trajectory Computation Programmes: Include computation of the trajectories, indexing of the output file for further use and drawing of the trajectories in real time on a screen.

4. Display Programmes: Include plotting of maps, release/recovery sites, computed trajectories, current roses and printing out of the current data for every spatial box considered by the experiment.

Three groups of data files contain the information required for the complete processing:

1. Input Files: Contain release data, recovery data and coastline data.

2. Working Files: They have been kept to a minimum but there are three files one containing the Selected Card Set and computed tangencies, a second containing block and pencil data and a third containing summary information of the computed trajectories.

3. Output Files: Contain data used for the display of the computed trajectories and velocity field. One contains the computed trajectories formatted according to the block and pencil system and the other is an index file that allows a synchronous scanning of the previous one.

Some of the programmes and files are optional, while others are required by the DEPS. However, the user should decide on which is the final structure of his system according to his particular needs. In order to use DEPS at its full capacity, all files and programmes should be implemented.

All programmes print messages when error conditions are found or when information is useful for further processing. They also support options for printing out the data contained in the files.

Service Programmes

This group includes programmes that deal with preparation of the various data files, loading of the information required by the other programmes and for modification of the data. Table 1 gives a summary description of each programme.

Table 1. Service programmes

Name	Description
CLIDF	Clears and initializes data files.
LDCST	Loads coastline data digitized.
LDLDS	Loads release data structured as LDSs.
LDREC	Loads recovery data unstructured.
MDREC	Modifies data in the recovery data file.
MDSCS	Modifies data in the SCS file.

Statistics Programmes

This group includes programmes that compute statistics, printing the results, plot the raw data in various ways and make the selection of the cards that constitute the SCS for further computations. Table 2 gives a summary of these programmes.

Table 2. Statistics programmes

Name	Description
INREC	Indexes the recovery file according to LDSs.
STTPL	Plots time histogram and distance vs. time diagram.
STTCS	Produces statistical computations and selection of drift cards.

Trajectory Programmes

This group includes three programmes that deal with the computation of the trajectories, beginning with the selection of a subset of the SCS, computation of the trajectories, analysis of the output file for further processing and indexing of the output file for synchronous work. The programme names and a summary description are given in table 3.

Table 3. Trajectory programmes

Name	Description
INDRI	Selects a subset of drift cards from the SCS, computes trajectories and saves output data.
ITRJF	Analyses the contents of the output file and summarizes it.
PSYNF	Prepares an index file for synchronous use of the output.

Table 4. Display programmes

Name	Description
PLOTR	Plots coastal boxes, release/recovery sites and computed trajectories.
ROSES	Computes and prints a direction/module velocity histogram and plots a current rose for each of the spatial boxes in which trajectories are defined.
FIELD	Plots the velocity field computed by averaging all the velocities computed in every spatial box.
SEQPL	Sequentially draws the trajectories on the screen.
SYNPL	Synchronously draws the trajectories on the screen.

Display Programmes

This group of programmes includes a variety of options mostly displaying on the printer, the plotter or the screen the output of either raw data or trajectories. They also compute the current roses for the various spatial boxes as well as the velocity field underlying the trajectories. A summary description is given in table 4.

General Systems Charts

Figure I shows a block diagram of all the programms and files that constitute the DEPS.

Programme Sequence Chart

Figure II shows a normal deck of computer control cards required to carry out a complete processing of a driftcard experiment.

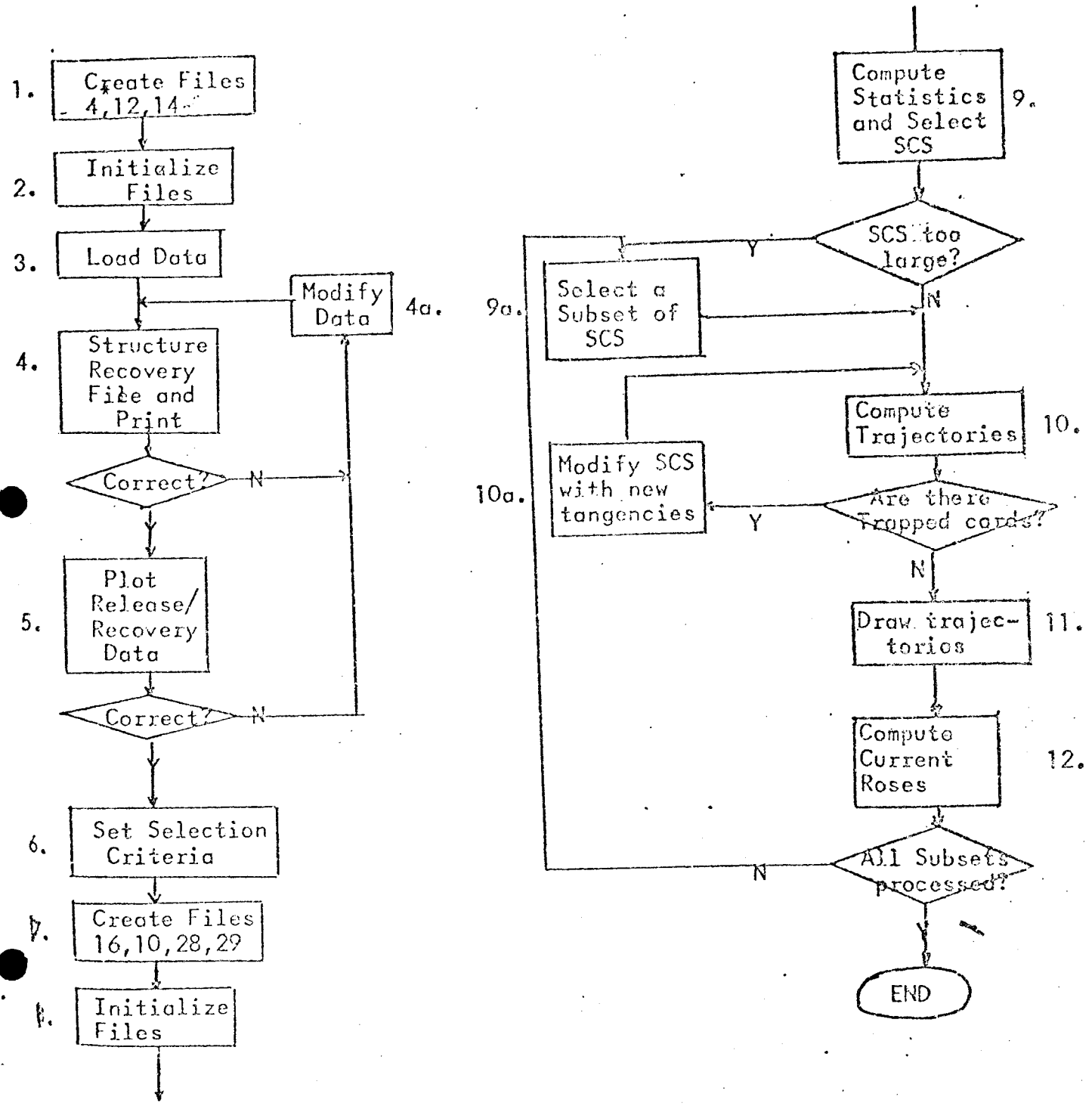


Figure II. Normal deck of computer control card required to carry out a complete processing of a driftcard experiment

```
// JOB LIGUR
// DUP
*DFILE          FX  CDF4   48   0022
*DFILE          UA  LDF12  14   0002
*DFILE          UA  RDF14  14   0002
*DFILE          FX  SCS16  30   0256
// XEQ CLIDF    1
*FILES(4,CDF4),(12,LDF12),(14,RDF14),(16,SCS16)
    4   12   14   16
MARE LIGUR
// XEQ LDCST    1
*FILES(4,CDF4)
      Coastline Data Cards
// XEQ LDLDS    1
*FILES(12,LDF12)
PETRARCA
      Release Data Cards
RAMOGE
      Release Data Cards
KOROTNEFF
      Release Data Cards
            1
// XEQ LDREC    1
*FILES(14,RDF14)
MARE LIGUR
      Recovery Data Cards
            1
// XEQ INPEC    1
*FILES(12,LDF12),(14,RDF14)
PETRARCA
RAMOGE
KOROTNEFF
            1
// XEQ SITCS    1
*FILES(12,LDF12),(14,RDF14),(16,SCS16)
PETRARCA      1    1
RAMOGE        1    1
KOROTNEFF     1    1

// JOB PETRA
// DUP
*DFILE          FX BLP10  100   0256
*DFILE          FX OUT28  400   0022
// XEQ INDRI    1
*FILES(4,CDF4),(10,BLP10),(16,SCS16),(28,OUT28)
-300.      1700.      3500.      4500.      4.        0.7190     5.
1.5        10.        0.3        2.         0.5       0.3        1.
          Drift-card Selection Cards
// DUP
*DFILE          UA IND29    2   0256
// XEQ ITRJF    1
*FILES(10,BLP10),(28,OUT28),(29,IND29)
// XEQ PLOTR    1
*FILES(4,CDF4),(12,LDF12),(14,RDF14),(28,OUT28),(29,IND29)
-300.      1700.      3500.      4500.      4.        0.7190     5.   FGCT
// XEQ ROSES    1
*FILES(28,OUT28),(29,IND29)
-300.      1700.      3500.      4500.      4.        0.7190     5.
// EOJ
// JOB RAMOG
     Same as for PETRA
// JOB KOROT
     Same as for PETRA
```

Figure III.

INPUT/OUTPUT AND FILES

General Format Characteristics

The DRIFTEX Processing System (DEPS) has been designed to make use of disk files whenever possible to keep the number of card reading actions to as low a level as possible. Besides, formats have been uniformized to the maximum allowed by the fact that use of data is sometimes more efficient in real form and sometimes in integer form. A description of the more common formats is given below:

1. Original data both for releases and recoveries are expressed normally in geographical units (latitude and longitude) and calendar units (year, month, day and hour). Driftcard identifiers are always a number between 1 and 9999. In the Original Data Format (ODF), all the variables are used in integer form. Latitude and longitude are expressed as degrees x 100 + minutes (resolution is 1 minute), positive being N and E, negative S and W. The year is expressed only with the lower two digits and the month is given by the order number of it. The hours are expressed from 0 to 23.

2. In all internal computations longitude, latitude and time are considered as real numbers. Longitude and latitude are expressed in miles with origin in a hypothetical point of longitude 0 and latitude 0 located in a plane tangent to the 45º parallel (cosine = 0.719). Time is expressed in hours. This format is called International Data Format (IDF).

3. A third type of format, used only in the output file and for screen drawing consists in a projection of the region considered by the DEPS to a square matrix of 3000 x 3000 integer points. This Screen Data Format (SDF) allows a more packed structure of the output file otherwise very large.

4. A common feature to many programmes is the reference to a geographic frame. This allows the conversion of the geographical co-ordinates to the various formats expressed above. The geographical frame of reference is normally entered via a punched card with the geographical limits (XMN, XMX, YMN, YMX), the spatial resolution (in miles), the cosine of the average latitude (0.719) and the number of spatial boxes for which the velocity field is to be defined (in resolution units). Other information may also be included in this card for the use of individual programmes. The punching format corresponds to FORTRAN (FORMAT(7F10.0)).

5. Finally, names for Experiments and for Launching Data Sets are formed by 10 characters (alphanumeric) of which the first two cannot be blank at once. These names are entered via a 5 element integer array read as (5A2).

Preparation of Input Data

The data corresponding to the release of drift cards at one or more location at a given time may be considered a LDS. Consecutive driftcard numbers should always be used, otherwise statistics will be erroneous. However, if cards are not consecutive every card may be considered a different release. This would give rise to a larger Launching Data File than the Recovery Data File and would be a waste of disk space. A better solution is to renumber the drift cards released and make an equivalence table. Releases that conform to the conditions expressed above (simultaneity and proximity) may be included in a single LDS. A careful check-out of the release data should be made before loading since there is no provision for modification of the LDF except by re-loading after initializing.

The data corresponding to the recovery of the driftcards may be loaded immediately after they are received at the co-ordinating centre and translated into geographical co-ordinates. Correction, deletion or addition of individual data is possible. However, a careful check should be made by plotting the release and recovery data together with the coastline data in order to pinpoint erroneous data always present in such large data sets.

The data corresponding to the coastline should be taken from a good nautical chart of the region. The cosinus of the projection is computed by dividing one degree of longitude by one degree of latitude. The resolution should be defined such that the main features (straits and channels) are not lost and then a grid may be drawn by the computer or manually. The grid will indicate the number of each box, beginning at the lower left corner (XMN, YMN). Grid numbers (column number, number of boxes in column, box numbers) should then be loaded into the Coastline Data File (CDF4).

Disk Storage Requirements

A total of eight disk files are used by the DEPS if it is to be used at its full capacity. They vary in size and record length. Some of them could, as well, be located on magnetic tape as their use is absolutely sequential, however, most of them are accessed randomly and they should be located on disk. Some of the files should be located in different disk drives than others to avoid read-write lags. Files used by the trajectory computation programme INDRI and the segments linked to it should be in fixed adress and/or variables. Table 5 shows the characteristics of the DEPS files .

Table 5. Disk files used by DEPS

File Number	File Length/ Record Length	Sectors (640 bytes)	UA/ FX	Disk Drive	Initialize
4	480/32*	48	FX	1	Yes
10	1600/20	100	FX	0	Yes
12	560/8*	14	UA	0,1,2	Yes
14	400/8*	10	UA	0,1,2	Yes
16	600/16	30	FX	0	Yes
28	32000/4**	400	FX	2	No
29	4/90	2	UA	0,1,2	No
30	32000/1**	100	UA	0,1	Yes

* File length should be adapted to the specific requirements

** File length is the maximum permissible in the IBM 1130 system

COMMENTS AND HINTS

A number of minor problems arose when using the DEPS, mostly in connection with the trapping of cards. Characteristics of the coastline, combined with peculiarities of some driftcards and pencils lead sometimes to cumbersome difficulties. However, the system was adapted to these kind of problems and the most that may happen is that a particular card has to be removed from the SCS or a manually derived tangency point entered via the MDSCS programme. In the course of working with the DEPS a number of hints have been found to help solving some of these problems. These are some of the hints that should be taken into account:

1. When digitizing the coastline, care should be taken in that boxes always have a continguous side. Boxes only connected through vertices may allow trajectories to proceed through the coastline.

2. When, after establishing the selection criteria, it is found that too many cards are selected, subsets may be chosen by grouping the nearest releases (see "Mare Ligur" problem).

3. It may happen that due to the peculiar structure of the coastline, cards are systematically trapped at some point. Two actions may be taken:

   (a) change the coastline by introducing some new box acting as a "stopper" or eliminating some box as in a "blind" island channel, or

   (b) introduce manually some tangency points. Estimation of the corresponding tangency time should be very careful.

   These corrections will reduce the overall running time by avoiding the cumbersome job of untrapping cards.

4. It may happen that due to a long distance existing between the trapping point and the recovery location a card can never attain its pole (a message is printed). In this case the recovery data should be checked because it may happen that the pole is inland. If this is not the case, then a manually introduced tangency point may solve the problem.

5. It is normally useful to pass the trajectory programme various times (4-5). Every iteration reduces the number of trapped trajectories and brings them closer to an error-free environment. Only after being sure of the computed trajectory set being correct should it be recorded on the output file.

6. It may be interesting to work with different space scales. In a first run, the overall behaviour may be interesting. Later on, a more detailed analysis may be made on the region around the launching area.

7. The same is true with time. After analyzing all the recoveries, a selection may be made on the basis of time. Recoveries with, say, more than 2 months may be neglected (programme STTPL may help).

8. Slow cards may introduce some difficulties if they have not been removed in the selection process. This is especially true with cards having a medium range. They may be excluded by using a velocity limit. In the sample problems 0.01 knot has been set as the minimum velocity (residual velocity).

9. It may be exciting to change the value of the parameters. Trajectories may drift into outer space!! If they are changed at all, care should be taken to do so at the beginning of the iterations and changes should be small.